STATE OF COLORADO
MINERAL RESOURCES BOARD

MINERAL RESOURCES OF COLORADO FIRST SEQUEL

1960

STATE OF COLORADO
MINERAL RESOURCES BOARD
204 State Office Building
Denver 2, Colorado

MINERAL RESOURCES OF COLORADO FIRST SEQUEL

Prepared under the supervision of
S. M. DEL RIO
Consulting Mining Engineer, Geologist
Golden, Colorado

1960

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To:

His Excellency, The Honorable Stephen L. R. McNichols,
Governor of the State of Colorado;

Dr. Edward L. Clark, Director,
Department of Natural Resources,

and

Members of the Forty-Third General Assembly:

The State Mineral Resources Board herewith transmits the second volume of the publication entitled, "Mineral Resources of Colorado," by S. M. del Rio and contributing authors.

It is hoped that this compilation will serve as a reference publication for those interested in the mineral resources of the Centennial State and through its use, the general mineral potential will be made apparent to the citizenry.

Colorado State Mineral Resources Board

Robert S. Palmer

204 State Office Building

1961

STATE OF COLORADO
MINERAL RESOURCES BOARD

FOREWORD

The Colorado State Mineral Resources Board was created by the passage of H. B. No. 1020 by the Thirty-first General Assembly of the State of Colorado (Chapter 217, Session Laws of 1937). The primary purpose of the Act was to create a state agency authorized to cooperate with the Federal Government "for the development and utilization of the mineral resources of the State through the construction and operation of" public works such as mine drainage tunnels, treatment plants and mills and projects for the proper disposal of mill-tailings such as reservoirs, dams, etc.

The Board is empowered to make such investigations as may be necessary to plan and carry out a comprehensive state-wide program for the development and utilization of the State's mineral resources as provided in the Statute.

The passage of Federal legislation designed to aid and assist depressed areas would enable the Board to carry on more extensive projects in mineralized areas largely dependent upon mining to bolster the economy.

The Board consists of nine members, appointed by the Governor of the State of Colorado, and an Executive Director who is also Executive Director of the Colorado State Board of Directors of the Metal Mining Fund. The Governor is Ex-Officio Chairman of the Board.

The Board's only official source of revenue is such moneys as are appropriated by the State Legislature from the general funds of the State. During the first few years of its existence no moneys were appropriated for the use of the Board by the State Legislature.

In 1938 the Board constructed an earth-filled dam at the town of Fairplay to take care of tailings from the mills and placer mines of the Alma-Fairplay District. Agreements were entered into with the water users below the dam and the miners of the area. To finance the dam construction, bonds were issued by the Board and the mine operators were assessed on a basis of tons milled and gravel washed. The project was highly satisfactory to all parties concerned and the Board paid all bonds in full, with interest.

In 1941 the State Legislature granted the Board $5,000.00, which was used to make a survey of the mining claims of the State. Claim owners were contacted to obtain all possible information in an effort to discover why many mining claims were not working, and to determine the principal minerals in each claim. The report was compiled and typed, but there were insufficient funds for printing.

The Board also received from the Nicholson Estate a legacy which enabled it to cooperate with the Federal Government in conducting a geophysical survey to determine the proper location and course of a deep drainage tunnel in the Leadville area.

The State Legislature, through the years since the creation of the Board, has made limited funds available for the compilation of information which was published under the supervision of Dr. John W Vanderwilt and entitled, "Mineral Resources of Colorado." This publication received wide distribution, being placed in numerous libraries throughout the United States and foreign countries. Distribution was also arranged through the Colorado School of Mines and various scientific and mining organizations, thus giving the publication the widest possible usage by the greatest number of people. A large topographic map was made in cooperation with the Reclamation Bureau and displayed at the State Fair, Annual Conventions of mineral-producing groups and other places at appropriate times.

Public demand caused later legislative action authorizing a second publication with more up-to-date information, including data compiled since publication of the first Mineral Resources Book and Mr. S. M. del Rio was selected for the purpose of compiling the data for the second publication and the results of his work and those cooperating with him are contained in this second publication.

It is the sincere hope of the Board that this new edition will be received with genuine enthusiasm and will be of real assistance to those who seek additional information regarding the mineral resources of the State of Colorado.

COLORADO STATE MINERAL RESOURCES BOARD

Arthur M. Lorenzon, Chairman

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PART II.

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MINERAL RESOURCES OF COLORADO

FIRST SEQUEL

The first comprehensive report on the minerals industry of Colorado, covering the years up to 1946, was prepared under the supervision and coauthorship of Dr. John W Vanderwilt, sponsored by the State of Colorado Mineral Resources Board. At the time of its publication in 1947, it was the intention of the Board, with the approval of the Legislature on each occasion, to supplement the original report by others to follow at ten year intervals. Thus a decennial series was established to serve as a source of information to those interested in the development of the mineral resources of the State.

This present volume, though somewhat belated from the decennial intention, is the first sequel in the series. It is also a centennial volume in that it is being published 100 years after the first effective discovery of gold in Colorado. In commemoration of this event we include herein a historical summary of developments in the industry from 1858 through 1958.

Aside from those pertinent instances in which data of a centennial character are presented, this sequent volume is principally dedicated to: summarizing events in the minerals industry since 1946; delving deeper into details in those phases of greater importance and more recent development and, in a number of cases, looking into the future.

Much has happened since publication of Dr. Vanderwilt's book in 1947, and even more since 1945, when in effect the coverage of that first volume ended. Petroleum and natural gas discoveries have multiplied many fold; the industrial minerals have attained unprecedented economic importance; scientific and technological advances, many of which germinated during the war, have created demands for minerals of comparatively little previous interest; the surge of the uranium boom in the fifties affected most segments of the minerals industry; the strong revival of interest in oil shale during recent years brought about the testing of new methods and processes in mining and retorting which yielded extremely encouraging results, helping to accelerate the day when a gigantic new industry will be established in Colorado. On the other hand, there has been a serious decline in base-metal markets in the last few years, and the depressed condition of gold at its pegged price has reached a critical point.

Thus this book is not a revision of Dr. Vanderwilt's volume, but takes up the years since the latter's publication. In certain cases, such as petroleum, data which was not available in the nineteen-forties is included herein to cover the full range of time. Otherwise, the original volume in this series and this first sequel are closely related in their contents. Much of the basic data, both geological and generally informative contained in the 1947 edition, are fundamental in nature and not repeated here. Frequent references to information in the original volume are made by page numbers in this book. For additional aid to the reader in this respect, the table of contents of the 1947 edition is appended to this report.

The context-format followed by Dr. Vanderwilt in preparing the original volume of the series has not been adhered to in the presentation of this report because the broader scope of statistical reporting adopted by the U. S. Bureau of Mines in 1952, enabled us to present much of our data under county headings. This was not possible to do in a satisfactory manner prior to that year. Special sections on the more important mineral items, whether actual or potential, are included in Parts II, III, and IV.

S. M. del Rio

Acknowledgements

The writer is extremely fortunate in having obtained the collaboration of a group of eminently competent individuals in the preparation of this report. All participants have given generously of their time, knowledge and experience without compensation and with some financial cost to themselves.

The cooperation of the companies and research organizations employing the non-consultant individuals who engaged in this work is gratefully acknowledged for granting our collaborators the time and facilities for preparation of their contributions.

We are particularly grateful to Dr. Francis M. Van Tuyl, Professor Emeritus of Geology, Colorado School of Mines, an inspiration and a friend to all who know him. Dr. Van Tuyl coordinated and supervised the petroleum section of this report.

Aside from the authors, whose names head their respective contributions, we express our appreciation to: Mr. Denman S. Galbraith, Geological Consultant, Denver, for his invaluable aid to the writer in the final phases of assembling this volume; Mr. G. A. (Bud) Franz, Commissioner, Colorado Bureau of Mines, who kindly reviewed the material in the by-county discussions; Mr. Arthur J. Jersin, Director, Colorado Oil and Gas Conservation Commission, and the Commission's Engineering Staff, for their unstinted cooperation; Mr. Alfred L. Ransome, Chief, Division of Mineral Industries, Region III, U. S. Bureau of Mines, for his kind review of the historical summary; and, Mr. Frank C. Bowman, well-known mining engineer, whose persuasion induced the writer to undertake this work.

S. M. del Rio

CHAPTER I

A Century Of Mineral Development

by

S. M. Del Rio

Chapter 1

A Century of Mineral Development

The finding of gold came first, the founding of Colorado followed.

A century ago the first positive indications of the existence of abundant gold in the "Pikes Peak Region" were discovered in the slimmer pickings of the plains in the outskirts of present Denver. Exaggerated news of the discoveries spread rapidly throughout the Nation, and the "Rush to the Rockies" was on.

No doubt the region that is now Colorado would have been settled in time, but at a rate immeasurably slower than that attained by the golden lure. The character of the State too would have been molded along entirely different lines. Had this been so, an appreciable percentage of the State's vast tourist industry—those who come not seeking, but bringing gold attracted by the glamor of its past — would not have developed.

Myriads of words have been written in a popular vein about the early and glamorous days of gold mining in Colorado, and many more have been written in a technical vein about the subsequent development of the State's well-rounded present mineral industry. So much has occurred and been recorded during Colorado's century of mineral production, that it is extremely difficult to compress it all into a few pages. However, because of the centennial nature of this report, we have made an effort to bring together into this volume the historical highlights of the development of Colorado's one-century-old mineral industry, even though fragmentarily.

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Gold was known to exist in what is now Colorado as far back as the early part of the 17th century. Throughout the years since those days vague but persistent rumors of gold's occurrence in the western mountains had filtered into the 'States'. But for the time, the information was too vague and indefinite and conditions not quite propitious to make a positive move about it. Many years were to elapse before the propor combination of circumstances set the stage for the proper men to dispel all uncertainty of its existence.

The gold strikes of California in '48 - '49 were still fresh in people's minds in 1857, although by the time of the financial panic of that year the bloom was off the California gold fields. Thus many experienced miners from California were available when again the cry of "gold!" was heard—this time from the "Pike's Peak Region".

The financial panic of 1857 was an important motivator in the rush to the Rockies, creating as it did numerous fortuneless and jobless individuals who had nothing to lose and much to gain by following the golden lure.

1858 — Despite the knowledge since earlier days of gold's existence in Colorado, it is fitting that credit for the discovery should go to the 'Georgia Argonauts' of William Green Russell's party, among whom were men with California gold experience. These pioneers, while camped on the Platte some two miles south of the present Capitol in Denver, made two encouraging strikes: one on the east bank of the Platte River some three and one-half miles above Cherry Creek; the other in a bar up Dry Creek about two miles from the Platte.

Greatly exaggerated news of Russell's discoveries promptly spread throughout the Nation deep in the throes of a depression, raising hopes in the hearts of many avid to recoup lost fortunes, or just eager to make a living. The migration was on—"Pike's Peak or Bust!".

Soon after the arrival of Russell's party, another one, organized in Lawrence, Kansas arrived on location and pitched camp on high ground on the eastward side of the South Platte about a mile north of Russell's Dry Creek diggings. These people seemed to be more interested in the real estate possibilities presented by the promise of a developing mining community than in the hard work of digging for gold. Thus it was that two dissenting groups within this party organized two town companies and proceeded to lay out respective cities in September of 1858: St. Charles on the east bank of Cherry Creek, and Montana City just south of Overland Park in present Denver.

Meantime, William Green Russell and some members of his party went back to Georgia for the purpose of refinancing and to return with an increased party and supplies. The remnant of his party then organized a town company and laid out Auraria City in October, on the west bank of Cherry Creek near its junction with the Platte in what is now West Denver.

In November and December, 1858, a party of officials sent out by Kansas Governor James W. Denver laid out Denver City, a name which was to outlive all the others, and by Christmas about 1,000 persons were on the South Platte many of whom knew absolutely nothing about mining.

1859 — Prospecting began in earnest with the Spring thaw in '59. Placering was started on Clear Creek just east of Table Mountain, and on Ralston Creek. Arapahoe City was laid out, and then Golden farther up the creek. "Boulder City" came into existence to the north early in the year with the coming of some 1,500 prospectors to the area. Discoveries now followed each other in rapid succession: gold was found on South Clear Creek at the mouth of Chicago Creek in what is now Idaho Springs; in the Boulder area at Deadwood Diggings near the mouth of North Beaver and South Boulder creeks, in Lump and Gamble gulches tributaries of South Boulder Creek; and also on the headwaters of the Arkansas River on Cache and Clear creeks in Chaffee County.

The most significant discovery was the one which brought to light what experienced miners hoped to find—the source of the placer gold. On May 7, 1859, John H. Gregory, an impoverished Georgia miner located the weathered and enriched outcrop of a vein on North Clear Creek near the present town of Black Hawk.

A month later William Green Russell recently returned from Georgia with an increased party, adequate financing and provisions, discovered good placer gravels and weathered lode outcrops in what became known as Russell Gulch.

In June a conclave of miners at the Gregory diggings roughly outlined and adopted the first pattern for mining districts and a miners' code of laws. One of the resolutions provided that lode claims were to be 100 feet long and 50 feet wide, and placer claims 100 feet long and from wall to wall of the gulch. These provisions remained in effect until enactment of the Federal mining act of May 10, 1872. Another meeting at Gregory's Diggings was held in July during which was established the first provisional government of any mining camp in the region. Here too, the first arrastra for gold extraction from hard rock was installed.

By this time prospectors were ranging far and wide and reports of discoveries were frequent in the settlements: placer gold was found at Buckskin, Mosquito, Hamilton, Tarryall, Montgomery and Fairplay, on branches of the South Fork of the South Platte in Park County; in Georgia and other gulches on the headwaters of the Blue and Swan rivers; at Georgetown; and the junction of California Gulch with the Arkansas. In September, the first steam quartz-mill was erected at the Gregory diggings just before a heavy snowfall started a stampede out of the hills to the settlements, but some 1,500 hardy souls remained in the gold camps.

1860 — Immigration continued unabated during this year which saw the first stage coach reach the Gregory diggings from the fast-growing town of Denver. It is estimated that between 100,000 and 150,000 people entered that year what was then known as the "Pike's Peak Country", now Colorado. A great many were disillusioned; not only were their dreams of quick and easy fortunes dispelled, but living conditions were primitive and crude, food extremely scant, and the only law a man's conscience and fear of retaliation. Thus began the backwash of malcontents who spared no diatribe in execrating the Pike's Peak Region as they stampeded their way back. Some 40,000 souls took part in this emigration. Others however, flocked to the rich California Gulch (Lake County) placers and to the new discoveries in McNulty Gulch, Summit County. —The lease system of mining was first used when the east half of Gregory's Discovery claim was leased to the American Mining Company.

1861-1865 — A scant three years after the Russell party first camped along the banks of Cherry Creek, and after many vicissitudes and postponements, the Territory of Colorado was established by Act of Congress on February 26, 1861, with William Gilpin as Governor. A few months later the War Between the States began following the secession of the southern states from the Union and their proclamation of a Confederacy.

In September of that year the Territorial Legislature proceeded to create 17 counties, designated their county seats, and upheld the mining codes then in existence in the various local districts.

By this time many of the enriched weathered zones of the lode deposits were rapidly becoming exhausted and recovery of gold from the underlying sulphides was almost impossible by the simple crushing and washing methods then in use. A great deal of money and effort was expended in experimenting with new processes but all unsuccessfully, so that by 1862-1863 mining at Gregory's had subsided to a trickle. The mills were losing as much as seventy-five per cent of the ore's gold content.

In the Spring of **1862**, about a year after Colorado Territory was formed, a Mr. Cassedy, pioneer in the Oil Creek development in Pennsylvania, drilled a 50-foot well near the live oil seep on Colorado's Oil Creek, a few miles north of present Canon City. This well was a producer as were also the next five or six drilled in the area. Thus Colorado became the second state in the Nation, after Pennsylvania, to produce oil from drilled wells.

The Civil War had its effect on the region, many miners leaving to enlist in their own states. Two regiments of militia were enlisted in Colorado. Members of the Russell party, attempting to return to Georgia, were made political prisoners.

At Georgetown the picture was brighter than at Gregory's camp due to excellent gold recovery by a small mill. In **1864**, a 40-stamp mill and a gold reverberatory furnace were installed, and the Belmont silver lode was discovered some 8 miles above the town. The first figures on coal production were recorded that year, 500 tons were mined in Calorado.

1866-1870 — During this period the placers of Gunnison County were discovered; the experimental Hill Smelter was built at Black Hawk; the Dives-Pelican silver lode at Silver Plume was discovered, and the first power drills operated in a mine in this country were used to drive the Burleigh adit at Silver Plume. Gold was discovered at Ward and silver at Caribou, Bolder County. Leaf gold in nests of lead carbonate was worked at Leadville, and the Hill smelter began shipping matte, thus encouraging the waning mining industry. In **1870** the Kansas Pacific railroad (now the Union Pacific) reached Denver in June, and the Colorado Central was completed to Golden in September. Also, the important Denver Pacific Railroad (Union Pacific) line to Cheyenne to connect with the transcontinental main line was completed. That year too, gold was discovered in Wightman's Gulch, Rio Grande County, and in Arrastra Gulch near Silverton. During this year 13,500 tons of coal were mined, all of it from Jefferson and Boulder counties.

The estimated value of the total mineral production (excluding fuels) of Colorado up through 1870 was $35,287,962 broken down as follows: gold $33,226,784; silver $1,962,289; copper $74,889; and lead $24,000.

1871-1880 — This decade was highlighted by the admission of Colorado into the Union as the 38th State on August 1, 1876. It is also marked by: the increased tempo of extraction plant construction; railroad advances; additional new mineral discoveries of importance; greater solidity in the industry; and the founding of the Colorado School of Mines at Golden.

The Ute and Ulay deposits at Lake City were discovered and the Homestake Mine near Tennessee Pass began producing; silver was found on Lincoln and Bross mountains in Park County, as well as in the Elk Mountains of Gunnison County; petzite (gold-silver telluride) was discovered at Gold Hill, Boulder County; the Golden Fleece deposits were staked in **1874** and the Smuggler lode above Telluride located in **1875**; Lake City, Hinsdale County, was founded in 1875. Virginia Canyon, north of Idaho Springs, drew attention upon opening of the Specie Payment mine, and a rush to California Gulch, Lake County, ensued when it was learned that the heavy sand which had fouled the sluices in earlier days was indeed silver-rich lead carbonate. This rush resulted in the founding of Leadville. In Ouray County, the Camp Bird's Una and Gertrude claims were staked. In Custer County, the Bassick gold deposit was discovered at Querida, the mines at Silver Cliff and the Bull Domingo mine opened, and the Terrible mine lode at Ilse discovered. In Fremont County, silver was found at Robinson and Kokomo, and the rich lodes in French Gulch near Breckenridge, which were the source of the placers first worked in 1859, were located. In Chaffee County the Great Monarch claim and the Madonna deposit were staked. The Bonanza area, Saguache County, was opened by the rush into Gunnison County. In Dolores County, the Rico deposits, known for several years, were developed, and in Eagle County, the Belden lode was discovered near Red Cliff. In Pitkin County, gold was found in the Independence district, and silver at Aspen.

The Colorado School of Mines, whose graduates and itself as an institution have played such a vital role in the scientific development of Colorado's and of the world's mineral resources, was founded by legislative act on February 9, 1874, and established at Golden, Jefferson County.

The Denver and Rio Grande railroad was completed to Colorado Springs; the South Park railroad was built from Denver to Morrison, and another line was begun up the North Fork of the South Platte toward the San Juan country by the same company. The Colorado Central reached Georgetown and the Denver and Rio Grande reached Leadville.

In **1876** Mr. Isaac Canfield drilled an 1187-foot well a short distance south of present-day Florence, Fremont County, and struck oil that occurred in joints and fissures of the Pierre shale. This was the discovery well of the Florence Field which is still producing a little oil to this day.

During this period there were smelters located at Dudley, Montezuma, Golden (3), Rico, Swansea near Empire, Alma, Denver, Silverton (2), Boulder (Boys), Halls Gulch, Crooke, California Gulch (Malta), Leadville (12), Crested Butte, Lake City (2), Tin Cup (2), Gothic, Garfield (5), Maysville, Poncha Springs, Chalk Creek. In all, there were at least 40 smelters to serve the State's mining industry of the 1870's.

Diversification in mineral production increased during this decade. In **1880** some 437,000 tons of coal were mined; 810,000 lbs. of plaster of Paris were produced at Colorado City from gypsum deposits located nearby; 10,200 tons of raw clay (first figures available) was mined, and $50,000 worth of stone, mostly granite, was quarried.

1881-1900 — These two decades are marked by further railroad extensions; the first recovery of zinc from Colorado ores; the driving of long access and drainage tunnels; the discovery of Cripple Creek's important gold deposits; the greater appreciation and increased importance of Colorado's fuel and non-metallic mineral deposits; the discovery of what a half-century later would become of great importance to the State and Nation, uranium and vanadium minerals in southwestern Colorado; the invention of the Wilfley Table at Kokomo; the establishment of the State Bureau of Mines on March 30, 1895; the development of serious labor troubles at Cripple Creek, Leadville, and in most of the Colorado smelters; the improvement in ore concentration and gold extraction processes and the building of adequate installations for the purpose; the advent of aerial cable transportation and extended use of electric power; the construction of large gold dredges at various placer locations; and the attainment of maturity by the industry.

The Yak drainage, haulage, and development tunnel, calculated to penetrate to a length of 23,800 feet, was started at Leadville in **1886**, but not completed until 1910. The Newhouse Tunnel (later known as the Argo) at Idaho Springs, started by hand in September, 1893, converted to power drill the following year and was completed to 22,000 feet six years later. This tunnel was driven for drainage, haulage, and development purposes. The Nelson Adit at Creede designed to drain the Amethyst and Last Chance mines, had penetrated to over 9000 feet by 1900.

By 1900 industrial minerals were in various stages of exploration and development, but most of their production was confined to localized markets due to difficulties in transportation and costs. Nevertheless, in **1889** ten granite quarries grossed $314,673; seventy-one sandstone quarries $1,224,000; and 15 limestone quarries $138,000, for a total of close to $1¾ million.

At Florence, the only oil producing field in the State until 1902, reached its peak production in **1892** with 824,000 barrels. From then, its decline was rapid and consistent, producing only 317,000 barrels in 1900. By 1887 two refineries, with a combined capacity of 2,000 bbls/day, and three oil companies were operating in the State.

During this period, the Greene Smelter was moved from Silverton to Durango; Mather and Giest, and also Guggenheim Brothers, built plants at Pueblo; the Globe smelter was built near Denver; a zinc oxide plant was erected at Canon City and ore from other states began to pour into the Colorado smelters in large quantities for treatment. However, at Golden, only one of its three smelters was in operation.

The new Colorado-Philadelphia chlorination plant at Colorado City began treating Cripple Creek ores in **1896**; some amalgamation mills were converted entirely to concentration, others to a combination of both treatments, and the cyanidation process was introduced. During this period, the first shipments of zinc concentrate were made to Kansas smelters, precursors of Colorado's coming importance as a zinc producer.

In **1897**, the Telluride Power Transmission Company installed what was said to be the longest transmission line in the United States, 17 miles to the Camp Bird mine, and by 1900, the Colorado Electric Power Company was supplying electricity to the Cripple Creek mines.

During this period, many coal deposits had been located throughout the State, but most of them remained relatively undeveloped due to lack of rail transportation and markets.

In **1898** two New Zealand type gold dredges were built on the Swan River, Summit County, but failed to do the required job. A year later, two orange-peel dredges were built on the Blue River, Summit County, and a Risdon and a Bucyrus on the Swan River.

The American Smelting & Refining Company was organized in **1899.**

In **1900** the production was as follows: gold 1,391,500 ounces; silver 20,337,000 ounces; copper 7.8 million pounds; lead 164.3 million pounds; zinc 16.3 million pounds; cement valued at $71,000; clay 33,000 tons; coal 5¼ million tons; stone valued at ¾ million dollars; iron ore 400,000 tons; manganese ore 231,000 tons; oil 317,000 barrels worth $323,400; uranium ore 306,655 pounds containing 20,000 pounds of uranium and 3 grams or radium; and tungsten, first mined in 1900, forty tons of 63% concentrate worth $3,216. Totally some 40,000 men were employed in Colorado's mineral industries during 1900.

1901-1920 — This 20-year period is marked by the separation of the City and County of Denver from Arapahoe County, one of the original 17 counties formed by the Territorial Assembly; by the scarcity of spectacular new ore discoveries; by severe fluctuations in the industry's fortunes; by marked advancements in the technology of ore dressing and smelting; by considerable increases in zinc production; by severe labor troubles; by the world-wide war of 1914-18, and by the decline of the metallic industry toward the end of the period.

Zinc production began to grow rapidly toward the turn of the century, rising from 16¼ million pounds in 1900, to 100 million pounds in 1911, and to an all-time peak of 134¼ million pounds in 1916, worth $18 million.

In **1902,** the Boulder and Rangely (shallow) oil fields were discovered. In **1903,** labor trouble became so serious that the militia had to be called out at Cripple Creek and Telluride. The 6,000-foot El Paso drainage adit at Cripple Creek was completed in **1904.** At this time, 578 mines were producing in Colorado. In **1905,** the following reduction plants were in operation: lead at Globe, Pueblo, Eilers, Arkansas Valley, Durango, and Salida; copper at Argo; zinc retorts at Pueblo; zinc oxide-copper matte at Canon City, and semi-pyritic plants at Silverton, Grand Junction and Pearl. By **1906** there were 33 metal producing counties in the State, and construction of the Golden Cycle roast-amalgamation-cyanidation mill at Colorado Springs was begun.

In **1907,** the Roosevelt drainage tunnel was started at Cripple Creek, and the Golden Cycle mill burned to the ground, but reconstruction was begun immediately. In **1909** the Eilers smelter at Pueblo was dismantled, and the former American Zinc-Lead Company smelter at Canon City shut down. The Burleigh Tunnel succeeded in draining the Seven-Thirty mine at Silver Plume; the Yak Tunnel at Leadville was in almost 3⅓ miles, and the Goldstone Camp on East Elk Creek Garfield County, was opened. Oil production exceeded 300,000 barrels worth $317,000, and vanadium ore containing some 20,000 pounds of metal was shipped from East Paradox Valley.

In **1911** only 5 lead and 1 zinc smelters were in operation in the State; the chlorination process at Cripple Creek and the chlorination and cyanide plants at Colorado City were permanently shut down; the 6,235-foot Rawley Tunnel near Bonanza, Saguache County, was driven in order to provide better haulage, drainage, and development facilities for the Rawley mine. This tunnel was completed in just under five months. Ores containing 6 grams of radium, 42,400 pounds of uranium, and 168,000 pounds of vanadium, were produced. By **1912,** the Roosevelt Tunnel at Cripple Creek was in over 17,000 feet but was not performing satisfactorily in draining the mines. Total metal production since 1859 amounted to $1¼ billion; total force employed in the industry during 1912, was some 23,000 men with 3,100 employed in clay mining alone, this industry produced $5,000,000 of clay during the year; the Colorado Fuel & Iron Company grossed $30,000,000 of which $27,000,000 represented proceeds from out of state sales. The company's payroll amounted to $3½ millions a year and used almost half-million tons of coal, in addition to 642,000 tons of coke. Also in 1912, almost a quarter-million dollars worth of carnotite ore, $660,000 worth of roscoelite ore, $315,000 of tungsten concentrates, and $830,000 of cement were produced. In **1913** the long-time producer Gold Links mine at Ohio City, Gunnison County, closed down, but a new silver district was discovered on Brush Creek, Eagle County.

The first World War broke out in Europe in July and August in **1914.** That same year the Cripple Creek district had its largest output since 1908, and four gold dredges were operating at Breckenridge. In **1915,** the Portland Gold Mining Company bought the Stratton Independence mine and mill, and the Vindicator Consolidated Gold Mining Company bought the Golden Cycle mill at Victor. Copper ore was shipped out of Parkdale, Fremont County, and Cripple Creek had its peak year; however, the number of producing mines in the State decreased by 45. Five smelters in the State were treating large tonnages of Oklahoma zinc residues, and Leadville had a boom year.

The blockade of Great Britain by German submarines was begun during 1915 and became the direct cause of drawing the United States into the world conflict.

In **1916** the Camp Bird mine shut down pending the driving of an 11,000-foot-long lower cross-cut adit to gain 1,600 feet of back; Aspen, Pitkin County, Creede, Mineral County, and Red Cliffs, Eagle County, had a banner year; the high copper prices prevailing at the time caused a renewal of activity in Fremont and Jackson counties and zinc production in the State soared to an all-time high. In **1917** five gold dredges operated at Breckenridge; the Roosevelt Tunnel at Cripple Creek connected with Portland's No. 2 shaft; the then prevalent and virulent influenza epidemic badly affected operations in the San Juan region mines; custom samplers were dismantled at Black Hawk, Georgetown, and Idaho Springs, but Climax Molybdenum Company began operating its 400-ton mill at Climax.

Germany's unrestricted submarine blockade of Great Britain finally drove the United States to declare war against the Central Powers on April 6, 1917, following the sinking of the American ship Lusitania. World War I ended by armistice November 11, 1918, following the Allied break of the Hindenburg Line in October.

The cessation of hostilities in Europe had an adverse effect on metal prices during **1919** as war stockpiles were released and began to compete in the open market with fresh production. This year the Graham Park mines at Leadville were shut down; the Globe smelter in Denver limited its activities to accepting only special ores, flue dusts, and other materials which would enable it to continue as an arsenic producer; the Wellington mill at Breckenridge, and the molybdenum mill at Climax shut down; the Pueblo, Durango, and Salida smelters curtailed operations, but the zinc oxide plants at Canon City and Leadville stepped up production treating zinc carbonate ores. The depressed condition of the industry continued into **1920**; three lead smelters were operating in the State: at Leadville, Durango, and Pueblo; a new oxide plant was built at Canon City, but not operated; Empire Zinc's magnetic separator at Canon City, successful since 1902, shut down, as well as the matting and fuming plant at Florence; Tomboy's new oil flotation mill, San Miguel County, began operating, but the Smuggler Union's new flotation mill at Telluride burned down —it was rebuilt in concrete; Colorado Central's Georgetown mill shut down. Metal mining in 1920 was at its lowest ebb since 1893. Silver was rescued for a few years by the Pittman Act, but gold—here's a familiar complaint—* ". . . the gold producers are struggling against . . . the fixed price of their product . . . "—while everything else went up!

1921-1930 — Colorado's mineral industry experienced a marked recovery during this decade which was accentuated in part by general national prosperity—a prosperity which

*State Bureau of Mines, Annual Report, 1920.

came to an abrupt halt toward the end of the period. A great variety of new and highly desirable heavy consumer goods had come into the market a few years after the War, based upon technological advances induced by the necessities of the conflict. Several years of national prosperity resulted, but lack of acumen in forecasting market saturation resulted in over-production which in turn caused industries' shutdowns and a collapse. Colorado's mining industry obtained its share in supplying the basic raw materials market during the boom and it, too, suffered when the market became sated. Also, during this decade, Colorado began to attract national attention as a potential important producer of oil.

The metal mining depression continued over into **1921**, but toward the end of the year, wage-scale reductions, decreasing costs of supplies and materials, and slight advances in metal prices, began to portend a healthy trend. In this year, 8,167 tons of carnotite ore containing 30.94 grams of radium, brought $640,320. Considerable activity developed in the oil shale areas of Garfield and Mesa counties where several companies erected experimental shale-oil extraction plants.

A bad flood in Pueblo together with lack of ore receipts caused the long-active lead smelter in that city to be shut down; it was later dismantled and sold. Only two gold dredges operated at Breckenridge, but a new 4,700-yard dredge began working near Fairplay. Empire Zinc began operating a large zinc oxide plant at Canon City. During **1922**, copper, lead, and zinc prices continued to improve and zinc production rose from 2,360,000 pounds in 1921, to 23,258,000 pounds in 1922.

Base metal prices continued their slow uptrend into **1923** but silver suffered a severe setback in May, when the Pittman Act, which had maintained the price at one dollar an ounce since 1920, expired. However, the industry in general responded enthusiastically to slight encouragement, lead production doubled, zinc more than doubled and gold production increased with the greater quantities of auriferous base-metal ores being mined. The straight gold producers however, were not happy, for their product's price had remained fixed at figures established many years before the War, while the cost of mining supplies and materials had risen 70 per cent over pre-War costs, taxation was much higher, and skilled labor very scarce.

In November, 1923, the Union Oil Company of California brought in the discovery well in the Wellington field, Larimer County. Metal prices dipped early in **1924**, but recovered during the second half of the year which saw general activity in most of the camps. Climax Molybdenum resumed operation with 50 men employed and in five months produced concentrates containing 157,000 pounds of molybdenum. The vanadium mill at Rifle began operating on dump ores; the marble companies were quarrying vigorously in Gunnison County;

the Golden Cycle mill treated 700 tons of ore per day valued at $400,000 a month; the Smuggler Union, San Miguel County, and the Sunnyside, San Juan County, each averaged 20,000 tons of ore per month, and the Wile Electric Smelter Company began installation of an experimental plant at Boulder for treating complex ores. Three important oil fields were discovered during 1924: Moffat in Moffat County, Ft. Collins in Larimer County, and Tow Creek in Routt County.

The mining industry continued to improve during **1925**, but silver continued to drop in price down to 69 cents an ounce. Important new ore bodies were found on the 2.900 and 3,000-foot levels of the Portland mine at Cripple Creek; large tonnages of lead and zinc concentrates were shipped from Gilman; the Rico district was reopened by four companies; Climax gradually increased its output to reach 10,000 tons for December; the small Berthoud oil and gas field was discovered in Larimer County, and the Thornburg gas field in Moffat County. Almost 1¼ million barrels of oil were produced, valued at $1¼ million. Clay production amounted to ¼-million tons worth $359,000; fluorspar, 11,800 tons with a value of $154,000; sand and gravel, almost 1¼ million tons worth $800,000 and 675,000 tons of stone valued at $882,000 was produced.

In **1926**, base metal prices dipped slightly, and silver went below 62½ cents an ounce. The Tomboy mine at Telluride shut down, but the Rawley mine and mill at Bonanza reopened at 350 tons of ore per day. The Camp Bird mine at Ouray, idle since 1916, opened some of its upper levels to lessees; Rico made heavy shipments of lead-zinc ores, and opened its new 250-ton flotation mill; Climax increased its output from 10,000 to 22,000 tons per month and produced 1,000,000 pounds of molybdenum in concentrates; the 25-ton vanadium plant at Rifle increased its capacity to 125 tons per day; in Jackson County the North McCallum oil and gas (carbon dioxide) field, and in Moffat County, the Hiawatha oil and gas field were discovered.

During **1927**, the Empire Zinc's magnetic mill ceased operations; base metal prices continued to dip, and silver dropped to 56.7 cents per ounce. The Colorado Gas Conservation Commission was established on April 1, 1927, mostly for the purpose of maintaining a log of the wells drilled in the State. Very little was done along the lines of actual conservation practices. However, conditions improved in **1928**, even silver registered a slight, though temporary, price gain; zinc production reached 71½ million pounds; the Rawley mill at Bonanza, Saguache County, continued treating 325 tons per day; the Sunnyside at Eureka produced a steady 900 tons of ore per day; the Climax mill treated 892 tons per day, and at the mine, over 50 million tons of ore was developed; the Rifle mill stepped up its throughput to 140 tons of vanadium ore per day, and the East Butte mill in the Silver Plume-Georgetown district, the Gold Dirt mill at Empire, and the Argo mill at Idaho Springs, were all in operation. Gilman made steady shipments of silver-pyrite and silver-chalcopyrite ores; Cripple Creek produced $3 million in gold; but the Smuggler Union mine which, during a period of 40 years had produced $75,000,000, shut down in December. Custom plants operating steadily during 1928 were: the lead bullion-leady copper matte smelters at Leadville and Durango; the zinc oxide plant at Canon City; the roast-amalgamation-cyanidation mill at Colorado Springs; the Argo selective flotation mill at Idaho Springs; the Portland non-roast cyanidation-concentration mill at Victor; the samplers at Victor, Idaho Springs, and Boulder; the old Globe smelter's arsenic-cadmium plant at Denver, and the zinc-lead flotation mill at Leadville. Some 352 mines were reportedly active during 1928, of which only one-third were in actual production, the remainder were either under development, being reconditioned, or were just simply prospects. In total 8,000 men were employed in the industry during the year.

Base metal prices continued to improve during **1929**, but silver dropped to 53.3 cents. At Gilman, Empire Zinc's new 600-ton underground mill went into operation; the Mayflower-Shenandoah, San Juan County, developed a large gold-copper-silver ore body 2,000 feet underground, and built a 600-ton flotation mill and an aerial tram to connect mine and mill; Climax continued to increase its capacity which enabled it to treat 40,000 tons in December. A sad note from San Miguel County, the famous old Smuggler Union mine and mill were sold for salvage value. However, in Gilpin County, the Chain-O-Mines on Quartz Hill began operating a half-mile aerial tram between mine and mill at 150 tons per day. Toward the end of the year the Wall Street crash affected the entire nation.

The year **1930** and subsequent years reflected the financial collapse of 1929. Prices dropped considerably, silver hitting a low of 38.5 cents. Less than 5,000 men were employed in the mineral industry in the State that year. Only two custom flotation mills operated, and only those mines with relatively high gold content in their ores were able to work at all. However the vanadium, molybdenum, and nonmetallic segments of the industry held their own. In 1930 were produced 8 million tons of coal worth $21½ million; 2½ million pounds of molybdenum; $600,000 worth of vanadium; $1 million in sand, stone, and gravel; $1 million in natural gas; and $1½ million in oil.

The Greenwood oil field in Weld County, and Piceance Creek and other gas fields in Rio Blanco and Moffat counties were discovered.

1931-1940 — This decade was marked by the continued depression until the mid-thirties when consumption, aided by some experimental, but effective, Government measures, checked it and brought about a gradual upswing. One of the measures of most benefit to Colorado mining was the raising of the price of gold in 1933 to the more realistic level of $35 per ounce.

By **1931,** silver had hit a low of 29 cents an ounce and for the first time in the State's history the total value of its annual production dropped far below one million dollars. Copper dipped to 9.1 cents, lead to 3.7 cents, and zinc to 3.8 cents. Many of the large mines, and most of the small operations shut down, but molybdenum and vanadium remained constant, as did many of the nonmetallics. The Powder Wash oil and gas field was discovered in Moffat County during this year. With the exception of gold, **1932** proved to be the worst year in Colorado's history for the mining of silver, copper, lead, and zinc. Silver was down to 28.2 cents, copper to 6.3 cents, lead to 3 cents, and zinc to 3 cents. The total value in dollars of silver production was just over one-half million, that of copper less than one-half million, lead $129,000 and zinc a scant $6,500! Gold production however, increased substantially due to the reduced cost of materials and supplies and an overabundance of labor at a reduced wage scale. Many idle citizens, non-miners and miners alike unable to find employment, took to the Colorado hills and streams in search of the yellow metal—the gold-panning prospector was back!—even though temporarily. Despite the dark clouds which prevailed during 1932 and well into **1933,** a rebirth of optimism became evident during the latter year. The price of gold was raised by the government from $20.67 which had prevailed for so many years, to $35 per ounce, and that of "new, domestically mined silver" to 64½ cents an ounce. At this time also, the required assessment work to be performed on mining claims was suspended temporarily. By the end of the year Climax had developed 80,000,000 tons of ore and was milling close to 4,000 tons per day with some 400 men on its payroll. There was a total of 6,000 men employed in the industry during 1933. Also during this year, the very important Weber sandstone producing horizon at Rangely field, Rio Blanco County, was discovered, 30 years after the first discovery at Rangely in the shallow Mancos shale.

By **1934,** the economic upswing, first suspected in 1933, was confirmed. The number of active lode mines in the State rose from 321 to 672, and the number of employed in the industry climbed to 12,000. Many of the dormant mining camps came to life, and once again the wisdom of utilizing the lean years for exploration and development paid off for those firms and individuals who had had the foresight and financial ability to have so occupied themselves during the depression. During **1935**, the price of silver rose above the official price of 64½ cents to 71.9 cents, that of copper to 8.3 cents, lead went to 4 cents and zinc to 4.4 cents. The corresponding value of production increased considerably over the low point in 1932. An unfortunate circumstance at this time of "mining revival" was the dearth of economically accessible custom milling and smelting facilities to many of the camps. A number of these facilities had been precipitately dismantled during previous bad years and thus several marginal districts, which given economically accessible milling and smelting facilities could possibly have revived, were unable to do so. In 1935, the Golden Cycle mill treated over a half-million tons of ore with a gross value of well over $5½ million; the new Cripple Creek Milling Company's 500-ton mill began operating; Empire Zinc, Eagle County, shipped 1,200 tons daily of complex ores; at Leadville, much of the good ore was in mines not yet dewatered after the general shut down; in Rio Grande County, the Summitville flotation and cyanide mill increased capacity from 150 to 300 tons per day; in the San Juan district there was a marked increase in exploration and development of gold veins; in Archuleta County the Price Gramps oil field was discovered.

Prices and value of production continued to rise during **1936**, gold hitting a 20-year high of $12,831,000. Climax ore production was up to almost 2 million tons per year; only 1 floating dredge operated in the State, and only the Leadville smelter handled some of Colorado's ores; the remainder was shipped to Kansas, Texas and Utah mills and smelters. The economic improvement in mining continued during the next three years, but with some price and production variations in some metals, which were mostly offset by counter-variations in others. In **1937** there were 562 working mines reported in the State, and a total industry employment of 16,400 men. Climax's mill capacity was doubled to over 10,000 tons per day and its production of molybdenum accounted for 78% of the world's, and 85% of the domestic molybdenum output; the value of tungsten production amounted to $83,000 and some 42 tons of carnotite ores was mined. Between the years 1923 and 1938, the petroleum industry made 21 oil and gas field discoveries, some of which were abandoned, but two of them, Rangely (Weber) and Wilson Creek, Rio Blanco County, were of major proportions. In **1939** the required assessment work on unpatented claims which had been suspended since 1933, was again put into effect. Over 1½ million tons of gold, silver, lead, copper and zinc ores were handled by Colorado mills; 21% of the ore produced was shipped directly to smelters; only the Leadville smelter and a small 25-ton Forks smelter operated in the State; capacity of the Climax mill was upped to 12,000 tons of mill-heads per day; the vanadium mill at Rifle treated 240 tons of ore per day and produced 1¾ million pounds of contained vanadium pentoxide; 600 tons of 46.6%

tungsten concentrate was produced. This year witnessed the start of the European phase of the second World War and its effects began to reflect in rising metal prices and production during **1940.** Silver averaged 71.1 cents for the year, copper 11.3 cents, lead 5 cents and zinc 6.3 cents. This relative firming of the market steadied operations in most of Colorado's principal mining camps. The Carlton Tunnel at Cripple Creek advanced 7,000 feet to a penetration of 26,634 feet; in Park County, a 10,000-cubic-yard per day dredge was being built; 2¾ million cubic yards of auriferous gravel averaging 22.8 cents per cubic yard was handled by one floating dredge and 27 land dredges. The total value of mineral production for 1940 was $63 million, the chief contributors being: molybdenum, coal, gold, silver, uranium-vanadium, copper, petroleum and lead. The end of this decade also marked the end of radium's primary importance in the mining of uranium ores, hereafter uranium itself would be the objective.

1941-1950—World-shaking events occurred during this decade: the European conflict which had begun in 1939 assumed worldwide proportions through Japan's devastating sneak raid on Pearl Harbor in December 1941; the jet and rocket ages began with Germany's development of the war-headed ram-jet robot plane, and that of the war-headed V-2 rocket, both of which created havoc in London; and the advent of the atomic age in July, 1945, when an atomic device was tested successfully in New Mexico—the precursor of the atomic bombs which blasted Hiroshima on August 6, and Nagasaki on August 9, 1945. No other war in history had seen so much science and technology utilized by both sides in order to gain advantage. These scientists and engineers, operating under the pressing demands of the conflict, made tremendous advances which in times of peace would serve to benefit mankind. Some of these advances and others still under development depend upon the greater utilization of formerly relatively little-used metals and minerals, many of which Colorado is helping to supply. Toward the end of the decade, and after only a few short years of peace, the Korean War broke out in 1950.

Through the Lend-Lease Act of March, **1941,** the United States began in earnest to supply England and France with armament and materiel requiring vast quantities of metals. Greater emphasis therefore was placed on the production of "war minerals" and less on that of "non-essential" minerals such as gold and silver. Nevertheless, gold production increased over that of 1940 due to the mining of higher grade ores at Cripple Creek which were made accessible in the lower levels by the draining effect of the completed Carlton Tunnel; zinc mining was resumed at Gilman at the expense of its copper mining, which accounted in a large measure for the heavy increase in zinc production and some of the drop in copper output. The gold mines closing order L-208 of October, **1942**, literally decimated all the gold camps, forcing the machine shops of those mines and mills, wherever possible, to keep busy by taking Government contracts. Copper rose to 12.1 cents, lead to 6.7 cents, and zinc to 9.3 cents; activity in vanadium exploration and development was redoubled; molybdenum production at Climax climbed to 48 million pounds for the year; zinc production more than doubled; labor shortage in the mining camps was becoming acute as men were drafted, volunteered, or left for more remunerative jobs in war industries.

Conditions in Colorado's mineral industry during the years **1943-44** were more or less a continuation of those prevailing during 1942: base metal prices continued their slow, upward trend; production of gold and silver dropped substantially; the scarcity of skilled labor became so pronounced that the Army had to release 4,500 soldier-miners for work in the industry. Colorado received a proportionate share of these men; premium payments were instituted for over-quota production of copper, zinc, and lead; there was a marked increase in activity in some nonmetallics such as feldspar and fluorspar, and in vanadium, tungsten, and beryl. The stockpiling of strategic and critical materials was revised down from a 3-year to a 3-month supply, and the Surplus Property Act was enacted in October, 1944, for the purpose of restricting the disposal of stockpiled materials at war's end which, if not properly controlled, could seriously disrupt the markets. In 1943, a combined effort by two oil companies brought in a small gas discovery well at Douglas Creek, Rio Blanco County, and the Amerada Petroleum Corporation completed a discovery well on the Clark Lake structure, Larimer County. During 1944, 33 successful wells were drilled into the Weber sandstone horizon of Rangely field. On July 1, **1945,** Order L-208 which had restricted the mining of gold and silver, was rescinded. However, an acute shortage of labor, materials and equipment persisted, which depressed production. The Premium Price Plan for copper, lead, and zinc was extended until June 30, 1946; Molybdenum Corporation of America's mine at Urad began producing molybdenum. The war in Europe terminated on May 8, 1945 and in Asia, September 2, 1945.

Metal prices rose appreciably during **1946:** silver to 80.8 cents, copper to 16.2 cents, lead to 10.9 cents, and zinc to 12.1 cents. Rescinding of Order L-208 the previous year was reflected in increased gold production; molybdenum reserves at Climax were determined at 260 million tons of "proved or probable" ore containing 1,600,000,000 pounds of metal. The labor situation improved appreciably during the year, but materials and supply costs remained high; the Premium Price Plan for copper, lead, and zinc was extended until June 30, 1947, at which time it was permanently discontinued. The value of production of nonmetallics during 1946 was $3.1 million, of which fluorspar alone accounted for $1.2 million. Further exploration for oil into the Weber sandstone in northwestern Colorado resulted in the discovery of the Elk Springs field.

During **1947**, the prices of silver, copper, and lead rose again, but zinc remained unchanged. At this time, there were 290 mines, 82 quarries and plants, and 22 custom mills operating in the State, with a total labor force of 8,400 men. After 23 years of being the leading molybdenum producing State, Colorado relinquished this position to Utah whose production of molybdenum came as a by-product of its considerable copper output; the Urad molybdenum mine shut down; base metal prices were decontrolled and permitted to rise in an attempt to keep up with rising production costs; gold became unprofitable to mine except in the richer mines; two oil fields were discovered, one at Chromo, Archuleta County, and another at Maudlin Gulch, Moffat County; coal production rose to a high of 6,360,000 tons valued at $29 million. Base metal prices and production continued to increase during **1948**; for the first time since 1891 lead's total value surpassed that of gold; domestic uranium ore production was stimulated by the AEC's announcement of a guaranteed minimum price; a natural gas discovery was made on the Pagoda structure, Routt County.

Early in **1949**, the AEC announced an upwardly revised price schedule for uranium ores; the famous Golden Cycle mill at Colorado Springs, built in 1906, closed in February, to be replaced by the new 1,000-ton Carlton custom mill then being built at Cripple Creek, meanwhile this district practically shut down awaiting start of the new mill; copper, lead, and zinc prices dropped sharply and many marginal operations were forced to close down, production however was maintained due to the larger firms' increased output in an effort to cut down per-unit costs of production; the value of non-metallics production increased to almost $5 million; 6,500 men were employed in the mineral industries exclusive of fuels. Cripple Creek's gold production in **1950**, was the district's smallest since its discovery in 1891, because of the lack of milling facilities; large production increases at the Upper San Miguel, Red Cliff, and Leadville districts, placed them at the forefront in the State, together they accounted for 79% of the zinc, 77% of the copper, 60% of the lead, 58% of the gold, and 48% of the silver produced that year; at Kokomo, the Victory-Lucky Strike-Wilson-MacKinley group of mines, among the State's leading producers, shut down.

The start of the Korean War resulting from the Communist attack on South Korea, caught the world by surprise in mid-**1950**, and the consequent rise in base metal prices permitted Rico Argentine and many other operations to reopen; the Bureau of Mines resumed driving the Leadville drainage adit which had been started during World War II. This was a year of successful oil exploration in the State: in Logan County, the Armstrong, the Mount Hope, the Walker, and the Yenter fields were discovered; in La Plata County, the Ignacio field; in Weld County, the Buckingham; in Morgan County, the Lee field; and in Larimer-Weld counties, the Loveland field, were discovered. Oil production for the year amounted to 23 million barrels valued at close to $60 million; 11 billion cubic feet of gas was produced, and in all, the petroleum industry contributed well over a third to the State's total income from production of mineral natural resources.

1951-1958—This 8-year period has been marked by the advent of the space age initiated by the Russian "sputniks" and United States satellites. These accomplishments by both countries have developed into an international race for the cosmos with the consequent demand and search for materials able to withstand the extreme conditions of operation associated with space rocketry. Many heretofore relatively little used metals are being reviewed for properties in their elemental, alloyed, or compound form which may make their use desirable in the missile field, or in the developing field of nuclear reactors. Some of these metals, such as beryllium, tantalum, zirconium, hafnium, yttrium, and thorium, are found in Colorado, and given the proper incentive for their exploration, could possibly become of importance to the State's mineral economy. The Colorado Oil and Gas Conservation Commission was set up in **1951** to supplant the Gas Conservation Commission established in 1927.

Conditions during **1951** were a continuation of those prevailing during the latter part of 1950. Further sharp rises in the price of base metals served to accentuate gold's depressed condition; copper rose to 24.2 cents per pound, lead to 17.3 cents, and zinc to 18.2 cents. At Cripple Creek, the new Carlton mill began purchasing ore and large-scale mining was resumed; a new Federal Government program to assist in financing exploration for reserves of strategic and critical materials, which had been authorized in 1950, was undertaken by the Defense Minerals Exploration Administration during 1951. A new uranium bonus payment plan was announced by the AEC which raised the guaranteed minimum price for ores, and stimulated the search for additional deposits on the Colorado Plateau. Fifteen oil and gas fields were discovered in Colorado during the year, 8 in Logan County, 2 in Morgan County, and one each in Rio Blanco, Mesa, Weld, Adams-Washington and Garfield Counties.

During **1952**, government emergency programs greatly stimulated exploration and mining of molybdenum, tungsten, and uranium. The greatest single advance in metallic ore production during the year was accomplished by the uranium mining industry, with new discoveries being reported frequently up and down the stratigraphic section and in the crystalline rocks; the demand for nonmetallics was firmly sustained by the continued high level of business, construction, and industrial activities; Cripple Creek was back to normal with the new Carlton mill fully operative, and regained its lead in gold production. However, due to a drop in lead and zinc prices, the Akron-Erie mines at Whitepine closed down and the operators confined activities to exploration and development; the large gold dredge at Fairplay shut down indefinitely; but oil and gas exploration continued apace and 18 new fields were discovered: 5 in Logan, 4 in Washington, 2 in La Plata, 2 in Adams, and 1 each in Sedgwick, Rio Blanco, Kiowa, Morgan, and Weld counties; the Colorado Oil and Gas Conservation Commission was organized in accordance with legislation of the previous year, for the purpose of administering the rules and regulations of Colorado regarding the drilling and production of oil and gas within the State. A capable engineering and office staff has enabled this Commission to render efficient and valuable service to the State and to the oil and gas industry.

The aggregate value of gold, silver, copper, lead, and zinc produced during **1953**, was the lowest since 1946. Lead's and zinc's price decline, begun in 1952, continued to the end of 1953; the average for the year was: lead 13.1 cents and zinc 11.5 cents per pound; silver remained firm at 90.5 cents per ounce, and copper rose to a new high of 28.7 cents per pound. Petroleum established a new high as several new fields in the Denver-Julesburg Basin became important producers, the major oil and gas fields of Little Beaver and Adena were discovered in Washington-Adams and Morgan counties in 1951 and 1953 respectively; fluorspar recorded the largest single increase among the nonmetallics; the AEC extended its purchasing program on uranium until March 31, 1962; during the year, 550 operators shipped uranium ore; the Climax mill treated an average of 21,000 tons of molybdenum ore per working day; the price on imported tungsten dropped to $32.40 per unit, but the domestic production price remained at $63 per unit under the government domestic purchasing program. Total value of mineral production for 1953, including fuels, but not uranium, was $211,586,000. Thirty-one new oil and/or gas fields were discovered during the year: 14 in Logan, 4 in Weld, 3 each in Adams and Moffat, 2 each in Morgan and Morgan-Weld, and 1 each in Washington, Sedgwick, and Mesa counties.

Due mostly to gains by the petroleum industry and nonmetallics, Colorado's mineral production in **1954** increased almost $45 million over that of the preceding year. There were

50 oil and/or gas field discoveries during the year: 17 in Logan, 11 in Washington, 9 in Morgan, 4 each in Adams and Weld, 2 in Moffat, and 1 each in Jackson, Baca, and Morgan-Weld counties. Oil production was 46¼ million barrels valued at $128 million. In Eagle County, the Eagle mine greatly increased its production of complex ores and accounted for much of the substantial increase in the State's copper production; gold, however, continued to decline due to high production costs and its fixed selling price; in June, the Federal Government started a lead-zinc stockpiling program, but it did not seem to improve Colorado's production of those metals; demand for molybdenum was at an all-time high, and Climax expanded its capacity to 28,000 tons per day, thus becoming the world's second largest underground mine. During this and the following two years, Colorado experienced a frantic rush in uranium prospecting by all types of people; during this period also, a great deal of fresh capital came into mining, most of it drawn by uranium's glamor, but substantial amounts of it also found their way into other branches of the industry, thus most segments of mining derived some benefits from the uranium boom. The petroleum industry, by now the most important economically of those dealing with mineral resources in the State, continued to gain stature in **1955**, with a production of 53 million barrels of oil and 50 billion cubic feet of gas, aggregately valued at close to $150 million; 62 oil and/or gas fields were discovered during the year; copper rose to 37.3 cents, lead went to 14.9 cents, and zinc increased to 12.3 cents per pound, but silver remained firm at 90.5 cents per ounce. Climax treated an average of 30,000 tons of molybdenum ore per day, but despite this unprecedented output, it was not sufficient to satisfy the demands of private industry and the Government had to relinquish some of its allocation in order to meet it; the value of tungsten production rose to $4 million, most of it coming from the Climax mill as a by-product of its molybdenum recovery; in the uranium field, 307 active properties were listed, although some of them were only in the exploration or development stage; five uranium mills were in operation in the State, in Garfield, Mesa, Montrose, and La Plata counties; vanadium production, a co-product of uranium mining, amounted to 4.6 million pounds; imports of cheaper foreign fluorspar caused domestic production to drop despite a strong market; nonmetallics were favorably affected by an upswing in building construction; for the first time in many years, salt in brine was produced from a well, to be used in processing uranium ores; production of coal increased due to greater demand for coking coal in Colorado, Utah, and California; at Haystack Mountain, the Sinclair laboratories expanded their experiments in the combustion and distillation of in-place oil shale. Some 15,000 men were employed in the State's mineral industries during 1955.

In a general way, **1956** was a prosperous year for the mineral industry: base metal prices continued to rise—copper to the unprecedented level of 42½ cents per pound, lead went up to 15.7 cents, zinc to 13.7 cents, and silver remained firm at 90.5 cents per ounce. The value of Colorado's total mineral production, including fuels and uranium, for the year, was $329,000,000, of which the petroleum industry contributed one-half with a record output of 58½ million barrels of oil and 54 billion cubic feet of natural gas, together valued at $168 million; uranium ore production contributed $12 million; coal $20 million; sand and gravel a record $11 million; lead $6.23 million; stone $5.22 million; copper $3.59 million; gold $3.42 million, and tungsten $3 million.

Forty-one new oil and/or gas fields were discovered in 16 counties in the State: 8 fields in Washington, 6 each in Logan and Weld, 4 each in Morgan and Rio Blance, 3 in Moffat, and 1 each in Jackson, Kiowa, Sedgwick, Mesa, Routt, Delta, Boulder, Bent, Garfield, and Adams counties. During this year, the American Gilsonite Company began construction of a refinery at Fruita, Mesa County, to produce gasoline and coke from Utah gilsonite for the use of the aluminum extraction plants of the Northwest; activity in the gas fields of western counties was stimulated by completion of the Pacific Northwest pipeline; in June the U. S. Bureau of Mines shut down its oil shale experimental plant at Rifle, but the Union Oil Company of California began erecting a pilot plant north of Grand Valley, Garfield County, and prepared to mine and retort 300 tons per day of oil shale; concurrently, Denver Research Institute began construction at Denver of a pilot plant to test and develop the Swedish "Aspeco" process for retorting oil shale; meanwhile, Sinclair continued its in-place retorting experiments at Haystack Mountain for the extraction of shale oil. During 1956, Climax mined and milled close to 10 million tons of molybdenum ore, a record in ore production for underground mines in North America; Jefferson and Park counties reported some shipments of gadolinite, samarskite, and yttrium-bearing fluorite; Colorado's share of the domestic uranium industry included 6.8% of the ore reserves, 18% of the mine production, and 25% of the milling capacity; at Florence, a $2½ million plant was completed to manufacture building materials from Fremont County gypsum deposits; the Federal domestic tungsten purchasing program ended but was renewed a few months later with a drop in price from $63 per unit to $55 per unit, but the funds allocated for the purpose became exhausted in December and most operations were forced to close down.

The decline in base metal prices during **1957** forced several of the large producers to shut down their operations during the last half of the year: Resurrection at Leadville, Rico Argentine at Rico, and the American Smelting & Refining Company's Keystone operations at Crested Butte. Five uranium mills operated during the year and four more were under construction at Rifle, Maybelle, Gunnison, and Slick Rock. Climax continued its expansion during 1957 and thereby attained an average production of 34,000 tons of ore per day; late in the year it was announced that Climax Molybdenum Company and American Metal Company, Ltd., would merge as of January 1, 1958, the combine to be known as American Metal Climax, Inc. The decline in industrial activity was reflected in a decreased production of feldspar, clays, gypsum, and perlite, but cement, stone, and sand and gravel experienced gains. At Bonanza, Saguache County, a new 100 ton per day mill was being completed for the treatment of complex ores. In Larimer County, near Masonville, a 50 ton per day flotation mill for recovering beryl from pegmatite ores was being tested, while at Loveland another 50 ton mill was being constructed in conjunction with a new beryllium hydroxide plant. During 1957, the 500-millionth ton of coal was produced in Colorado since the industry's beginning in 1864 and, totally, 2,500 men were employed in coal production during the year. Near Silverton, rhodonite deposits were being opened for the production of manganese by a new process being pilot-plant tested in New Jersey under contract with the General Services Administration. Exploration for petroleum and natural gas continued unabated with 33 new discoveries during the year: 8 in Washington; 7 each in Logan and Weld; 3 in Garfield; 2 each in Morgan and Rio Blanco; and 1 each in Adams, La Plata, Routt, and Mesa counties. At this time there were 197 oil fields in 18 counties with a total production of 55 million barrels of oil and 95 billion cubic feet of natural gas.

Operation of the gilsonite plant at Fruita was highly successful during 1958 and a planned expansion from 700 to 850 tons per day was begun; a decreased demand for steel reduced Colorado's 1958 coal production, a substantial amount of which goes for coke manufacture. New Jersey Zinc's Eagle mine at Gilman operated continuously despite the depressed price of zinc; Emperius Mining Company closed its Creede mine which had operated continuously for a record 25 years, but reopened it in November following a zinc price increase. At Silverton, the Central flotation-gravity custom mill, formerly the Mayflower or Shenandoah-Dives, was rehabilitated, this mill has a capacity of 750 tons per day; at Bonanza, the new flotation mill which had begun to operate early in the year shut down in the fall; two new uranium mills began operating and a third increased its capacity; at year's end the seven uranium mills operating in the State had a total capacity of 3,790 tons per day. Colorado's beryl industry was quite active during 1958: the 50 ton mill and hydroxide plant was completed at Loveland; the 50 ton concentrating mill near Masonville began treating pegmatite ores in test runs; the Mount Antero, Chaffee County, beryl deposits were under development; and the Boomer mine near Lake George, continued to lead the State in beryl production. Thorite mining was also active in Colorado during 1958, the Anna Lee and the Beardsley properties in Fremont County, and the Star in Custer County being the principal producers. Feldspar and mica mining suffered a severe blow by the withdrawal of International Minerals & Chemical Corporation from the Colorado market. Of importance to owners of mineral lands located in high-altitude areas of the State, was the measure passed by Congress changing the date for compliance with the required yearly assessment work from July 1, to September 1, effective beginning in 1959. Toward the end of 1958, the import of foreign lead and zinc ore as well as unfabricated metal, was restricted by the imposition of a quota based on 80% of the average yearly imports for the period of 1953-1957. Should the provisions of this quota be extended to cover the loop-hole left by the non-inclusion of fabricated lead and zinc materials, and should the quota (or any other equivalent measure which may supplant it) be retained for a sufficient number of years for its effect to become manifest, Colorado's lead and zinc mining industries can look forward to a period of greater stability.

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CHAPTER II

Colorado Minerals Production, 1946-1958

by

S. M. Del Rio

The primary motivator in the development of Colorado's mineral industry was gold, but soon after silver gained importance, and then lead and copper. Zinc followed when separation became possible in the mid-nineties. Fuels too, played an early role in the lateral growth of the industry which began to diversify soon after its inception, a natural consequence in a region abounding in a variety of minerals. In petroleum for instance, Colorado was the second state in the nation (1862) to produce oil from drilled wells after Pennsylvania; and coal was extracted on a small scale from outcrops and shallow pits to help fill the fuel needs of the early settlers.

With the passage of time other minerals, metallic and nonmetallic, have come into prominence and even surpassed in value of production those of the first-found precious and base metallics. In 1957 for example (the last year for which we have reliable figures), the order of production value was as follows:

1. Petroleum
2. Molybdenum
3. Coal
4. Uranium
5. Sand and gravel
6. Zinc
7. Natural gas
8. Natural gas liquids*
9. Lead
10. Stone
11. Fluorspar**
12. Copper
13. Gold
14. Silver

*1958 figure, 1957 figure withheld.

**State Bureau of Mines figure, U. S. B. of M. figure withheld.

The actual importance of gold to the wealth of the State is not properly reflected by its relatively low position as 13th on the list, and the same can be said for silver, lead, zinc, and copper. Practically the entire value of Colorado's gold production represents an inflow of new money for the State; this also holds true for the higher-placed molybdenum. On the other hand, an item such as sand and gravel, which is much higher on the list than gold and most of which is consumed within our boundaries, contributes relatively little to the total wealth of the State. Nevertheless, non-export production items such as sand and gravel, stone, and some of the coal, natural gas, natural gas liquids, and others to varying degrees, have a distinctively important place in the internal economy of Colorado, for by being produced here these materials retain funds within the State which would otherwise leave our boundaries for their purchase elsewhere.

Dr. John W Vanderwilt, in the first book of this series (1947), gives Colorado's major minerals production and values through the year 1945. In this sequent volume the following tables contain the figures for the period 1946 through 1958, although those of the last year are subject to later revision.

TABLE I

Value of Colorado's Mineral Production 1946-1958

Year	Value $1000
1946	77,573
1947	102,448
1948	128,861
1949	139,873
1950	154,898
1951	179,435
1952	187,539
1953	211,586
1954	255,852
1955	286,219
1956	321,914
1957	338,504
1958	305,284

TABLE II

Production and Values By Commodity

	Beryl		Clay	
Year	Short Tons	Value $	Short Tons	Value $
1946	---	----	301,107	367,686[2]
1947	[1]	[1]	274,596	427,027[3]
1948	[1]	[1]	299,000	488,000[3]
1949	144	43,000	254,691	499,294[3]
1950	97	30,000	310,130	618,814[3]
1951	97	32,339	443,000	958,000[3]
1952	54	24,588	568,730	1,087,154[4]
1953	75	39,515	777,969	1,429,780[4]
1954	60	27,130	854,791	1,002,873[4]
1955	46	22,950	464,231	1,117,901[4]
1956	179	93,748	522,573	1,215,305[1]
1957	182	91,000	403,000	978,000[4]
1958	134	58,000	449,000	1,111,000[4]

(Footnotes at end of tables)

	Coal		Copper (contained)	
Year	Short Tons	Value $	Pounds	Value $
1946	5,914,000	23,915,000	3,508,000	568,296
1947	6,358,000	28,772,000	4,300,000	903,000
1948	5,631,000	27,826,000	4,596,000	997,332
1949	4,636,000	23,735,000	4,806,000	946,782
1950	4,259,000	21,669,000	6,282,000	1,306,656
1951	4,103,000	21,165,000	6,424,000	1,554,608
1952	3,623,000	19,216,000	7,212,000	1,745,304
1953	3,575,000	19,198,000	5,882,000	1,688,134
1954	2,900,000	16,079,000	9,046,000	2,668,570
1955	3,568,000	20,100,000	8,646,000	3,224,958
1956	3,502,163	19,832,000	8,456,000	3,593,800
1957	3,594,000	21,831,000	10,230,000	3,079,000
1958	2,880,000	19,305,000	8,386,000	2,206,000

	Feldspar		Fluorspar	
Year	Long Tons	Value $	Short Tons	Value $
1946	37,312	145,975	32,539	925,867
1947	43,676	218,593	32,153	950,882
1948	62,497	253,227	27,698	831,218
1949	60,966	341,000	22,324	763,296
1950	59,457	329,000	18,489	654,089
1951	50,451	283,153	20,661	820,322
1952	38,268	224,385	29,185	1,505,968
1953	43,508	267,642	53,276	2,872,360
1954	[1]	[1]	59,197	3,197,252
1955	46,114	313,716	[1]	[1]
1956	47,014	327,276	[1]	[1]
1957	43,818	307,000	[1]	[1]
1958	34,648	237,000	[1]	[1]

Year	Gold (contained) Fine Ounces	Gold Value $	Gypsum Short Tons	Gypsum Value $
1946	142,613	4,991,455	1	1
1947	168,279	5,889,765	1	1
1948	154,802	5,418,070	1	1
1949	102,618	3,591,630	1	1
1950	130,390	4,563,650	62,150	184,000
1951	116,503	4,077,605	1	1
1952	124,594	4,360,790	1	1
1953	119,218	4,172,630	62,936	233,043
1954	96,146	3,365,110	64,650	252,910
1955	88,577	3,100,195	76,649	329,321
1956	97,668	3,418,380	88,026	352,761
1957	87,928	3,077,000	1	1
1958	79,539	2,784,000	103,000	341,000

Year	Lead (contained) Pounds	Lead Value $	Scrap Mica Short Tons	Scrap Mica Value $
1946	34,072,000	3,713,848	4,495	37,000
1947	37,392,000	5,384,448	1,341	13,246
1948	50,286,000	9,001,194	5,907	53,000
1949	53,706,000	8,845,548	4,168	60,000
1950	54,014,000	7,291,890	1,467	27,000
1951	60,672,000	10,496,256	1,882	32,901
1952	60,132,000	9,681,252	1	1
1953	43,508,000	5,699,548	1,599	19,455
1954	35,646,000	4,883,502	1	1
1955	31,610,000	4,709,890	699	12,596
1956	39,712,000	6,234,784	517	7,722
1957	42,006,000	6,007,000	312	6,000
1958	28,224,000	3,302,000	387	6,000

Year	Molybdenum (contained) Pounds	Molybdenum Value $ (est.)	Natural Gas MM Ft[3]	Natural Gas Value $
1946	8,670,855	8,112,320	6,728	314,000
1947	10,783,200	8,634,539	8,392	660,000
1948	12,630,000	9,879,071	8,967	539,000
1949	10,483,000	9,677,353	8,490	443,000
1950	24,090,000	10,831,769	11,168	436,000
1951	22,911,949	23,912,000	14,128	608,000
1952	24,557,149	24,557,000	34,260	1,184,000
1953	33,851,000	33,851,000	28,559	1,654,000
1954	42,545,000	44,672,000	45,705	3,976,000
1955	45,837,000	49,504,000	49,152	4,966,000
1956	37,489,000	43,112,000	54,205	5,312,000
1957	42,500,000	51,000,000	95,259	9,526,000
1958	25,100,000	31,375,000	82,464	8,659,000

Year	Natural Gas Liquids Barrels	Natural Gas Liquids Value $	Petroleum M-Barrels	Petroleum Price	Petroleum $1000
1946	20,000	50,000	11,941	1.32	15,762
1947	23,740	68,000	15,799	1,89	29,860
1948	33,480	132,000	17,988	2.56	46,048
1949	341,830	744,000	23,546	2.55	60,041
1950	386,000	873,000	23,266	2.55	59,329
1951	1	1	28,196	2.54	71,619
1952	1	1	30,572	2.55	70,960
1953	1	1	36,767	2.71	99,639
1954	1	1	46,530	2.77	128,887
1955	1	1	53,258	2.75	146,459
1956	1	1	58,565	2.78	162,809
1957	1	1	54,982	3.02	166,046
1958	2,798,381	6,753,000	48,309	2.99	144,444

Year	Pumice Short Tons	Pumice Value $	Sand & Gravel Short Tons	Sand & Gravel Value $
1946	600	1,200	2,532,946	1,796,396
1947	---	----	3,524,653	2,323,736
1948	---	----	4,906,299	2,657,610
1949	---	----	4,751,000	2,965,000
1950	---	----	5,154,000	3,940,000
1951	---	----	6,916,631	4,452,489
1952	1	1	8,461,039	6,268,367
1953	47,919	99,700	12,438,600	8,609,151
1954	1	1	13,552,406	9,026,993
1955	70,530	162,605	12,911,783	8,914,429
1956	50,015	109,206	15,152,000	11,081,625
1957	25,000	53,000	16,400,000	13,994,000
1958	34,000	65,000	20,626,000	17,842,000

Year	Silver (contained) Fine Ozs.	Silver (contained) Value $	Stone Short Tons	Stone Value $
1946	2,240,151	1,810,042	612,000	818,606
1947	2,557,653	2,314,676	1,069,250	1,406,989[5]
1948	3,011,011	2,725,117	2,195,250	2,490,449[5]
1949	2,894,886	2,620,018	1,816,790	2,803,538[6]
1950	3,492,278	3,160,688	1,679,960	2,776,331[5]
1951	2,787,882	2,523,174	1,470,123	2,334,376[5]
1952	2,813,643	2,546,489	1,708,872	2,566,401[5]
1953	2,200,317	1,991,398	884,104	1,750,726[5]
1954	3,417,072	3,092,623	1,804,004	2,112,093[7]
1955	2,772,073	2,508,866	2,149,019	3,508,053[7]
1956	2,284,701	2,067,770	2,250,168	5,216,641[7]
1957	2,788,000	2,523,000	2,438,000	4,168,000
1958	2,056,000	1,860,000	2,930,000	4,943,000

Year	Tin (contained) Long T	Tin (contained) Value $	Tungsten—60% WO_3 Short T	Tungsten—60% WO_3 Value $
1946	--	---	213	288,717
1947	--	---	68	108,241
1948	--	---	208	337,000
1949	17	37,000	222	351,148
1950	15	31,000	196	302,248
1951	18	54,033	336	1,092,780
1952	13	33,723	625	2,354,664
1953	[1]	[1]	817	2,902,490
1954	[1]	[1]	927	3,420,563
1955	[1]	[1]	1,152	4,079,341
1956	9	[1]	873	3,010,074
1957	15	[1]	45	55,000
1958	[1]	[1]	[1]	[1]

Year	Uranium Ore—Short T	Uranium Value $	Vanadium (contained) Pounds	Vanadium (contained) Value $
1946	Withheld	Withheld	1,036,050	584,135
1947	Withheld	Withheld	1,912,158	1,110,090
1948	Withheld	Withheld	Withheld	Withheld
1949	Withheld	Withheld	Withheld	Withheld
1950	Withheld	Withheld	Withheld	Withheld
1951	Withheld	Withheld	Withheld	Withheld
1952	Withheld	Withheld	Withheld	Withheld
1953	Withheld	Withheld	7,993,922	[1]
1954	Withheld	Withheld	4,528,472	[1]
1955	Withheld	Withheld	4,595,359	[1]
1956	496,517	12,410,000	5,582,484	[1]
1957	740,055	15,605,000	6,264,000	[1]
1958	939,706	22,486,000	4,791,000	[1]

Year	Zinc (contained) 1000 Pounds	Zinc (contained) Value $
1946	72,294	8,819,868
1947	77,490	9,376,290
1948	90,328	12,013,624
1949	95,406	11,830,344
1950	91,552	13,000,384
1951	111,428	20,279,896
1952	106,406	17,663,396
1953	75,618	8,696,070
1954	70,300	7,592,400
1955	70,700	8,696,100
1956	80,492	11,027,404
1957	94,000	10,904,000
1958	74,264	7,575,000

[1] Withheld, included in State total value.

[2] Value not included in State total.

[3] Excludes clay used for cement.

[4] Includes clay used for cement.

[5] Excludes limestone used for cement and lime.

[6] Excludes certain stone, value included in State total.

[7] Includes limestone used for cement.

Note: All figures are from U. S. Bureau of Mines Minerals Yearbooks with the exception of the petroleum production figures. The latter are from Colorado Oil and Gas Conservation Commission records.

Table III contains the average unit value of selected Colorado mineral commodities as compiled by the U. S. Bureau of Mines for the years 1953-1957. This table is included for convenience in making comparisons.

TABLE III

Average Unit Value of Selected Colorado Mineral Commodities (Minerals Yearbook 1957)

Commodity	Unit	1953	1954	1955	1956	1957
Beryl	$/short T	526.87	452.17	498.91	523.73	502.32
Clays	$/short T	1.84	1.17	2.41	2.33	2.43
Coal	$/short T	5.37	5.54	5.64	5.66	6.08
Nb-Ta	$/lb	1.70	1.99	1.68	0.62	0.50
Copper	c/lb	28.7	29.5	37.3	42.5	30.1
Feldspar	$/long T	6.15	6.54	6.80	6.96	7.01
Fluorspar	$/short T	53.91	54.01	52.28	52.26	52.71
Gold	$/Troy oz	35.00	35.00	35.00	35.00	35.00
Gypsum	$/short T	3.70	3.91	4.30	4.01	4.01
Iron ore	$/long T	4.25	---	---	5.92	6.81
Lead	c/lb	13.10	13.70	14.90	15.70	14.30
Mica (scrap)	$/short T	12.17	17.88	18.02	14.69	20.51
Molybdenum	$/lb	---	1.02	1.05	1.15	1.19
Natural gas	c/M-cu. ft.	5.80	8.70	9.90	9.80	10.00
Perlite	$/short T	9.00	9.98	10.00	10.71	10.55
Petroleum	$/barrel	2.71	2.77	2.75	2.78	3.02
Pumice	$/short T	2.08	2.13	2.30	2.18	2.14
Pyrite	$/long T	3.31	4.32	5.30	6.86	---
Salt	$/short T	---	---	4.72	4.66	4.50
Sand and Gravel	c/short T	69.2	66.6	69.00	73.1	85.30
Silver	c/Troy oz	90.5	90.5	90.5	90.5	90.5
Stone	$/short T	1.98	1.17	1.63	2.32	1.71
Tungsten	$/short T unit	59.19	61.47	59.00	57.47	20.45
Zinc	c/lb	11.5	10.8	12.30	13.7	11.6

A partial purpose of this centennial volume is to document, within certain limits, the activities of the State's mineral industry in statistical form. These data have been compiled from several sources and are presented herein under three headings. Table IV contains statistics on production and values of the precious and base metals, and the accompanying charts graph their oscillations in average unit price and yearly production. Activities of the coal industry in Colorado are presented entirely in graphic form in the coal section of this book; and, detailed statistics on petroleum production are contained in the petroleum chapter. Time, space, and the budget do not permit the statistical analysis of other commodities. Perhaps subsequent volumes of this series will supplement the data this one contains.

TABLE IV

Precious and Base Metal Production 1858-1958
(In Terms of Recovered Metals)

Year	GOLD Fine Ozs.	GOLD $ Value	SILVER Fine Ozs.	SILVER $ Value	COPPER Lbs.	COPPER $ Value	LEAD Lbs.	LEAD $ Value	ZINC Lbs.	ZINC $ Value
Year	GOLD Fine Ozs.	GOLD $ Value	SILVER Fine Ozs.	SILVER $ Value	COPPER Lbs.	COPPER $ Value	LEAD Lbs.	LEAD $ Value	ZINC Lbs.	ZINC $ Value
To 1867	1,210,536	25,021,784	302,829	406,139	----	----	----	----	----	----
1868	97,300	2,010,000	200,716	266,150	50,000	11,500	----	----	----	----
1869	153,800	3,180,000	475,472	630,000	102,000	24,735	150,000	9,000	----	----
1870	145,800	3,015,000	496,988	660,000	182,500	38,654	250,000	15,000	----	----
1871	175,700	3,633,951	776,648	1,029,059	183,000	44,140	555,000	33,300	----	----
1872	128,000	2,646,463	1,524,206	2,015,000	204,000	72,542	1,150,000	73,600	----	----
1873	97,500	2,018,931	1,543,047	2,001,331	379,493	106,258	1,236,400	74,184	----	----
1874	104,200	2,152,487	2,348,174	3,000,966	475,541	104,619	1,277,933	76,676	----	----
1875	107,700	2,224,568	2,330,291	2,889,560	280,815	63,745	1,636,000	94,888	----	----
1876	132,000	2,726,311	2,564,403	2,974,707	333,333	70,000	1,334,020	81,375	----	----
1877	152,300	3,148,708	2,882,121	3,458,546	493,664	93,796	4,286,364	235,750	----	----
1878	157,000	3,240,348	4,672,961	5,373,904	536,145	89,000	13,722,222	494,000	----	----
1879	154,700	3,193,500	11,899,335	13,327,257	704,301	131,000	47,348,000	1,941,268	----	----
1880	157,500	3,252,514	14,397,539	16,557,170	859,000	183,826	71,348,000	3,567,400	----	----
1881	159,800	3,300,000	13,272,188	14,997,572	884,000	160,888	81,094,000	3,892,512	----	----
1882	162,600	3,360,000	12,761,719	14,548,359	1,494,000	285,354	110,000,000	5,390,000	----	----
1883	198,600	4,100,000	13,434,610	14,912,417	1,152,652	190,188	141,114,000	6,067,902	----	----
1884	204,000	4,300,000	12,375,000	13,736,251	2,013,125	261,706	126,330,000	4,674,209	----	----
1885	203,600	4,203,425	12,220,892	13,076,451	1,146,460	123,818	106,692,000	4,160,989	100,000	4,300
1886	215,200	4,450,000	12,375,000	12,251,250	1,146,460	127,257	118,000,000	5,428,000	100,000	4,400
1887	193,600	4,000,000	11,601,563	11,369,534	2,012,027	277,660	126,000,000	5,670,000	100,000	4,600
1888	181,700	3,758,099	14,695,313	13,813,596	1,621,100	272,345	128,404,000	5,649,777	300,000	14,700
1889	187,900	3,883,859	18,375,136	17,272,629	1,170,053	157,956	133,940,000	5,223,660	300,000	15,000
1890	200,950	4,151,132	18,800,000	19,740,000	3,585,691	559,368	109,192,000	4,913,639	300,000	16,500
1891	222,500	4,600,000	21,160,000	20,948,401	6,336,878	811,121	126,256,000	5,429,009	300,000	15,000
1892	256,400	5,300,000	24,000,000	20,880,000	7,593,674	880,866	120,000,000	4,800,001	1,125,000	51,750
1893	364,151	7,527,000	25,838,600	20,154,107	7,695,826	831,149	110,000,000	4,070,000	1,650,000	66,000
1894	454,000	9,491,514	23,281,398	14,667,281	6,481,413	615,734	101,226,000	3,340,458	1,500,000	52,500
1895	644,000	13,305,100	23,398,500	15,209,024	6,079,243	650,479	93,968,000	3,006,976	1,671,000	60,156
1896	721,000	14,911,000	22,573,000	15,349,642	6,022,176	650,395	89,606,000	2,688,178	1,292,000	50,388
1897	947,249	19,579,433	21,278,202	12,766,919	9,149,967	1,097,995	80,794,286	2,908,592	2,683,989	110,044
1898	1,138,584	23,534,532	23,502,601	13,866,532	10,870,701	1,347,965	113,416,138	4,309,813	3,900,656	179,430
1899	1,282,471	26,508,675	23,114,688	13,866,811	7,356,970	1,258,041	138,048,446	6,212,178	11,300,656	655,438
1900	1,391,487	28,762,036	20,336,512	12,608,637	7,826,815	1,299,251	164,274,762	7,228,090	16,282,055	716,410
1901	1,339,112	27,679,445	18,492,563	11,095,538	7,872,529	1,314,712	148,111,020	6,368,772	26,843,731	1,100,593
1902	1,380,000	28,516,914	15,941,523	8,449,008	8,463,938	1,132,601	106,296,827	4,358,169	52,582,510	2,523,963
1903	1,045,252	21,605,357	13,245,438	7,152,536	7,809,920	1,069,958	101,513,414	4,263,566	80,616,000	4,353,263
1904	1,172,000	24,242,485	12,960,792	7,517,260	9,412,707	1,204,828	107,498,854	4,622,453	66,771,590	3,405,353
1905	1,224,000	25,295,222	12,339,435	7,527,056	9,661,546	1,507,201	115,746,777	5,440,098	83,561,396	4,930,123
1906	1,110,000	22,905,671	12,339,052	8,390,553	6,618,332	1,277,338	106,646,506	5,078,850	86,012,903	5,246,787
1907	982,500	20,307,648	11,599,514	7,655,679	8,826,254	1,765,251	89,065,232	4,720,457	85,048,564	5,017,865
1908	1,092,500	22,595,571	9,002,316	4,771,227	10,201,123	1,346,547	61,645,671	2,589,118	30,130,002	1,416,110
1909	1,063,000	21,984,008	8,904,701	4,630,444	10,916,191	1,419,105	72,162,326	3,102,980	51,210,260	2,765,354
1910	991,500	20,505,614	8,508,942	4,594,829	8,359,307	1,061,632	76,058,775	3,346,586	77,089,648	4,162,841

1911	920,000	19,001,975	7,330,168	3,884,989	8,024,488	1,003,061	69,679,289	3,135,568	94,607,456	5,392,625
1912	900,000	18,588,562	8,212,070	5,050,423	7,107,303	1,172,705	75,242,267	3,385,902	132,222,812	9,123,374
1913	878,000	18,146,916	9,325,255	5,632,454	7,227,826	1,120,313	87,897,774	3,867,502	119,346,429	6,683,400
1914	962,000	19,883,105	8,796,065	4,864,224	6,639,173	883,010	74,211,898	2,894,264	96,774,960	4,935,523
1915	1,084,323	22,414,944	7,027,972	3,563,182	7,112,537	1,244,694	68,810,597	3,234,098	104,594,994	12,969,779
1916	926,566	19,153,821	7,656,544	5,038,006	8,624,081	1,121,524	70,914,087	4,893,072	134,285,463	17,994,252
1917	760,901	15,729,224	7,304,353	6,018,787	8,122,004	2,217,307	67,990,012	5,847,141	120,315,775	12,272,209
1918	616,864	12,751,718	7,063,554	7,063,554	6,277,332	1,550,501	65,960,760	4,683,214	89,133,901	8,111,185
1919	478,265	9,886,627	5,758,010	6,448,971	3,560,207	662,198	37,070,241	1,964,722	37,220,493	2,717,096
1920	366,504	7,576,319	5,409,335	5,896,175	4,043,734	744,047	46,629,788	3,730,383	48,790,742	3,952,050
1921	330,659	6,835,328	5,631,657	5,631,657	4,153,442	535,794	19,660,466	884,721	2,360,000	118,000
1922	308,314	6,373,419	5,855,911	5,855,911	3,373,454	455,416	23,477,200	1,291,246	23,258,000	1,325,706
1923	318,870	6,591,629	5,334,488	4,374,280	4,248,109	624,472	45,698,185	3,198,873	54,152,000	3,682,336
1924	415,692	8,593,116	3,254,370	2,180,424	2,713,219	355,432	47,557,061	3,804,565	56,727,000	3,687,255
1925	349,607	7,227,022	4,506,940	3,127,816	2,360,500	335,191	62,966,000	5,478,042	61,621,000	4,683,196
1926	342,400	7,078,933	4,704,122	2,935,372	3,403,850	476,539	68,987,800	5,519,024	65,000,000	4,875,000
1927	255,400	5,279,118	3,784,605	2,145,871	5,670,581	742,846	66,772,557	4,206,671	71,729,000	4,590,656
1928	256,644	5,304,876	4,052,523	2,370,568	8,594,646	1,237,629	53,501,723	3,103,100	71,462,000	4,359,182
1929	213,708	4,417,358	4,397,377	2,343,802	8,905,074	1,567,293	48,889,906	3,080,064	58,861,000	3,884,826
1930	218,540	4,517,619	4,382,852	1,687,398	10,514,000	1,366,820	44,260,000	2,213,000	72,518,000	3,480,864
1931	233,300	4,822,734	2,195,914	636,815	8,165,000	743,015	13,768,000	509,416	32,373,000	1,230,174
1932	317,928	6,572,154	1,860,408	524,635	7,398,000	466,074	4,299,000	128,970	218,000	6,540
1933	242,828	6,206,676	2,186,140	765,149	9,667,000	618,688	4,803,000	177,711	2,569,000	107,898
1934	324,923	11,356,070	3,475,661	2,246,892	11,294,000	903,520	8,435,000	312,095	1,544,000	66,392
1935	349,281	12,224,828	4,696,064	3,375,296	14,654,000	1,216,282	11,345,000	453,800	2,403,000	105,732
1936	366,607	12,831,245	5,902,776	4,571,700	17,730,000	1,631,160	14,534,000	668,564	2,344,000	117,200
1937	368,905	12,911,675	6,260,693	4,842,646	21,868,000	2,646,028	19,572,000	1,154,748	8,494,000	552,110
1938	367,468	12,861,380	7,932,095	5,127,819	28,342,000	2,777,516	18,910,000	869,860	9,106,000	437,088
1939	366,852	12,839,820	8,496,488	5,767,313	26,430,000	2,748,720	16,444,000	772,868	3,660,000	190,320
1940	367,336	12,856,760	9,710,709	6,905,393	24,304,000	2,746,352	22,952,000	1,147,600	10,120,000	637,560
1941	380,029	13,301,015	7,301,697	5,192,318	13,496,000	1,592,528	25,148,000	1,433,436	31,444,000	2,358,300
1942	268,627	9,401,945	3,096,211	2,201,750	2,204,000	266,684	30,362,000	2,034,254	64,430,000	5,991,990
1943	137,558	4,814,530	2,664,142	1,894,501	2,056,000	267,280	36,064,000	2,704,800	88,188,000	9,524,304
1944	111,455	3,900,925	2,248,830	1,599,168	2,096,000	282,960	35,396,000	2,831,680	79,910,000	9,109,740
1945	100,935	3,532,725	2,226,780	1,583,488	2,970,000	400,950	34,088,000	2,931,568	71,546,000	8,227,790
1946	142,613	4,991,455	2,240,151	1,810,042	3,508,000	568,296	34,072,000	3,713,848	72,294,000	8,819,868
1947	168,279	5,889,765	2,557,653	2,314,676	4,300,000	903,000	37,392,000	5,384,448	77,490,000	9,376,290
1948	154,802	5,418,070	3,011,011	2,725,117	4,596,000	997,332	50,286,000	9,001,194	90,328,000	12,013,624
1949	102,618	3,591,630	2,894,886	2,620,018	4,806,000	946,782	53,706,000	8,485,548	95,406,000	11,830,344
1950	130,390	4,563,650	3,492,278	3,160,688	6,282,000	1,306,656	54,014,000	7,291,890	91,552,000	13,000,384
1951	116,503	4,077,605	2,787,882	2,523,174	6,424,000	1,554,608	60,672,000	10,496,256	111,428,000	20,279,896
1952	124,594	4,360,790	2,813,643	2,546,489	7,212,000	1,745,304	60,132,000	9,681,252	106,406,000	17,663,396
1953	119,218	4,172,630	2,200,317	1,991,398	5,882,000	1,688,134	43,508,000	5,699,548	75,618,000	8,696,070
1954	96,146	3,365,110	3,417,072	3,092,623	9,046,000	2,668,570	35,646,000	4,883,502	70,300,000	7,592,400
1955	88,577	3,100,195	2,772,073	2,508,866	8,646,000	3,224,958	31,610,000	4,709,890	70,700,000	8,696,100
1956	97,668	3,418,380	2,284,701	2,067,770	8,456,000	3,593,800	39,712,000	6,234,784	80,492,000	11,027,404
1957	88,000	3,077,000	2,788,000	2,523,000	10,000,000	3,079,000	42,000,000	6,007,000	94,000,000	10,904,000
*1958	78,000	2,730,000	1,974,000	1,787,000	8,000,000	2,173,000	28,000,000	3,332,000	72,000,000	7,457,000
TOTALS	40,422,738	908,670,000	763,420,000	597,431,000	585,072,000	90,167,000	5,460,442,000	320,119,000	3,714,116,000	341,797,000

*Preliminary figures.

Data from U. S. Geological Survey Prof. Paper 138, years 1858-1923;
U. S. Bureau of Mines "Mineral Resources of the United States" 1924-1931;
U. S. Bureau of Mines "Minerals Yearbook" 1932-1958.

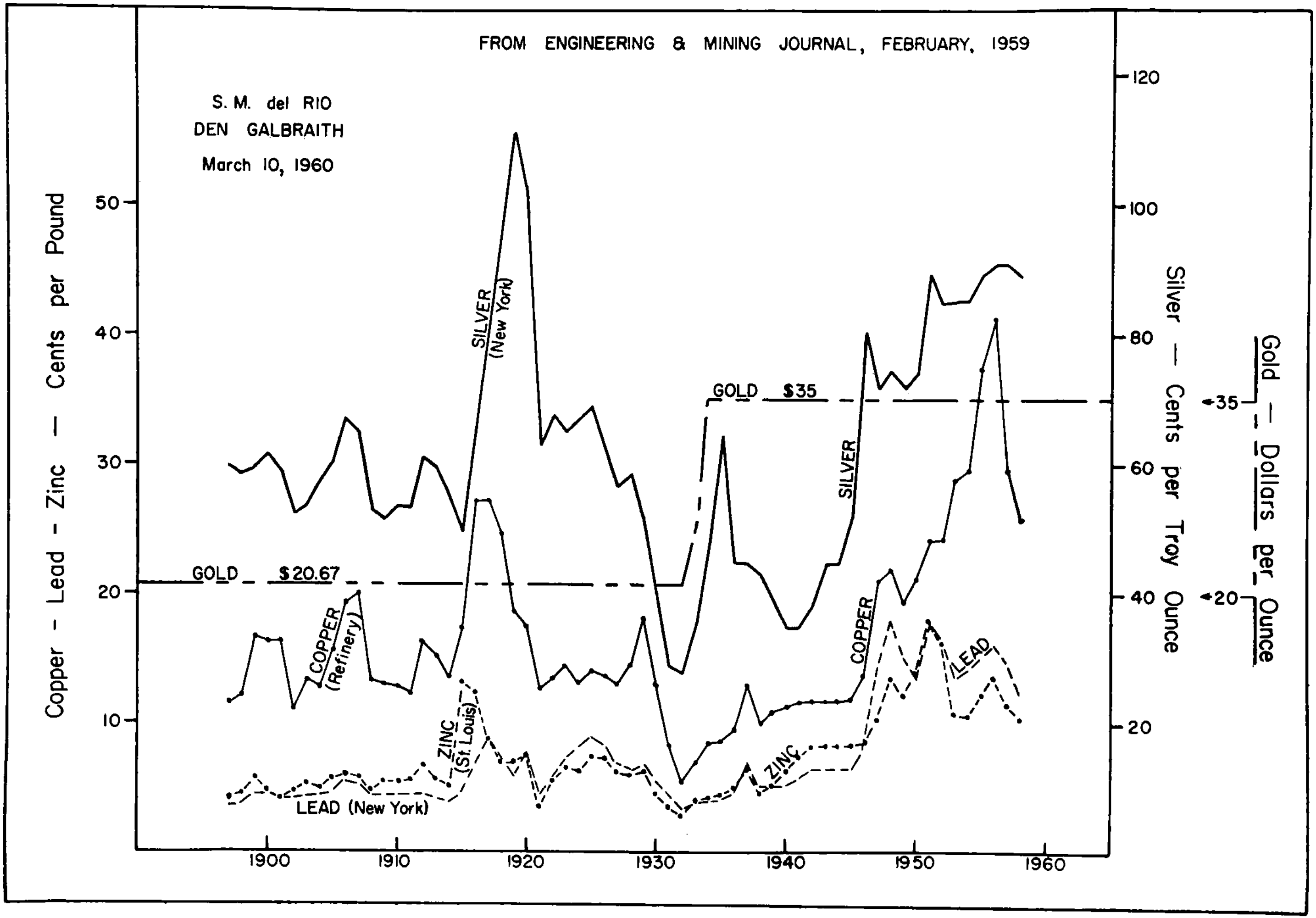

FIGURE I. AVERAGE ANNUAL PRICES — GOLD - SILVER - COPPER - LEAD - ZINC, 1897 - 1958

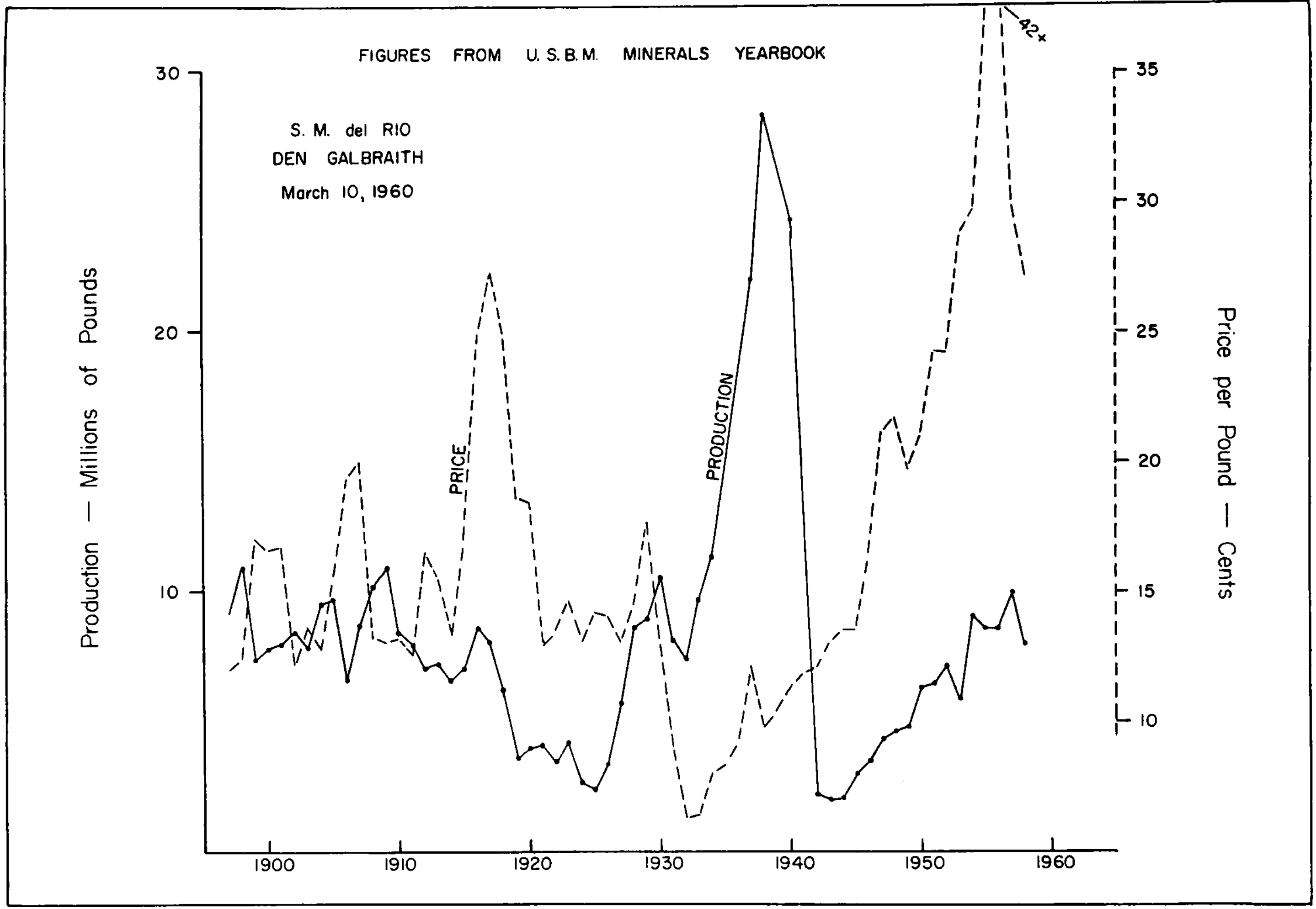

FIGURE 2. COPPER — PRODUCTION AND AVERAGE ANNUAL PRICE/LB., 1897–1958

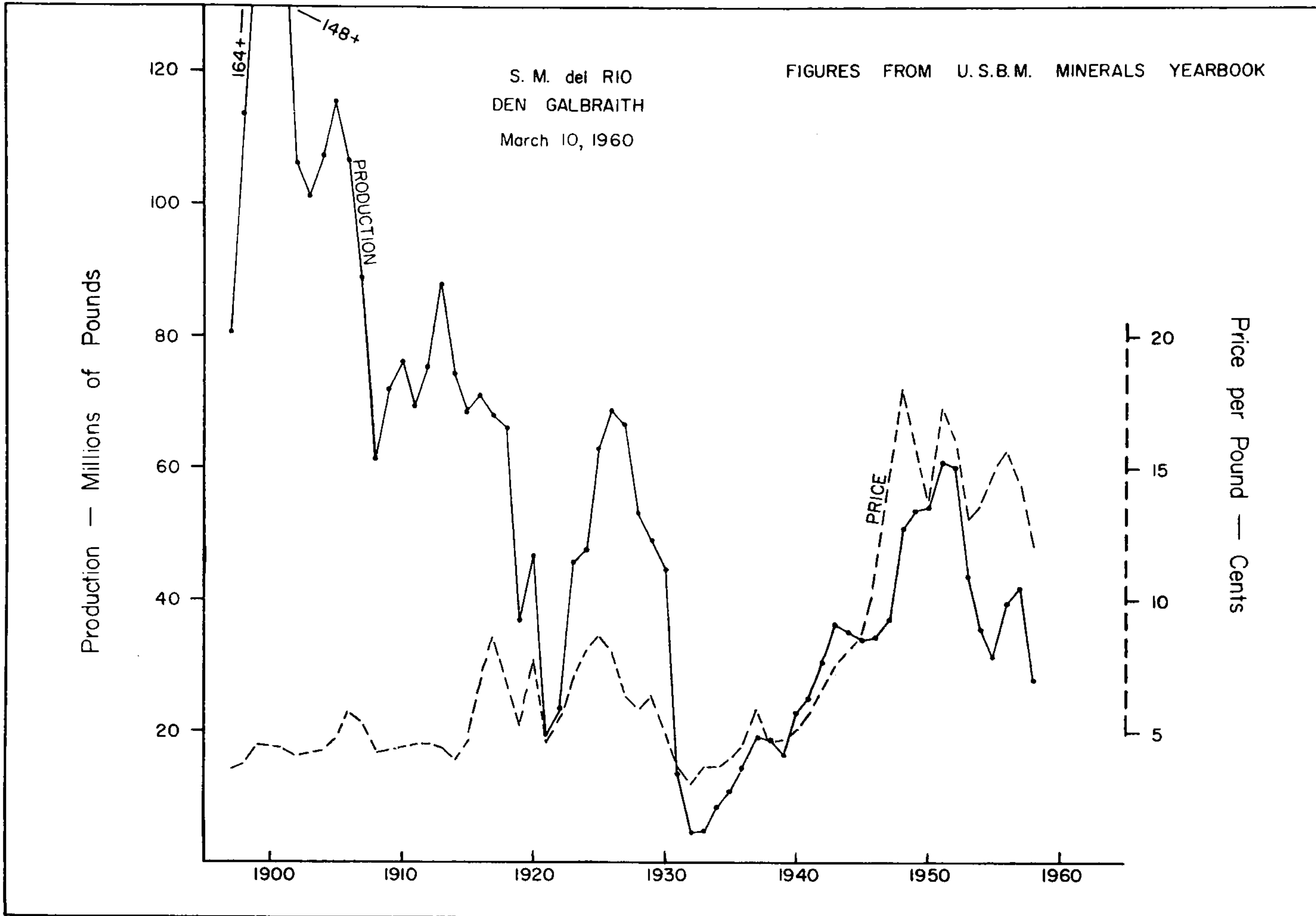

FIGURE 3. LEAD — PRODUCTION AND AVERAGE ANNUAL PRICE/LB., 1897-1958

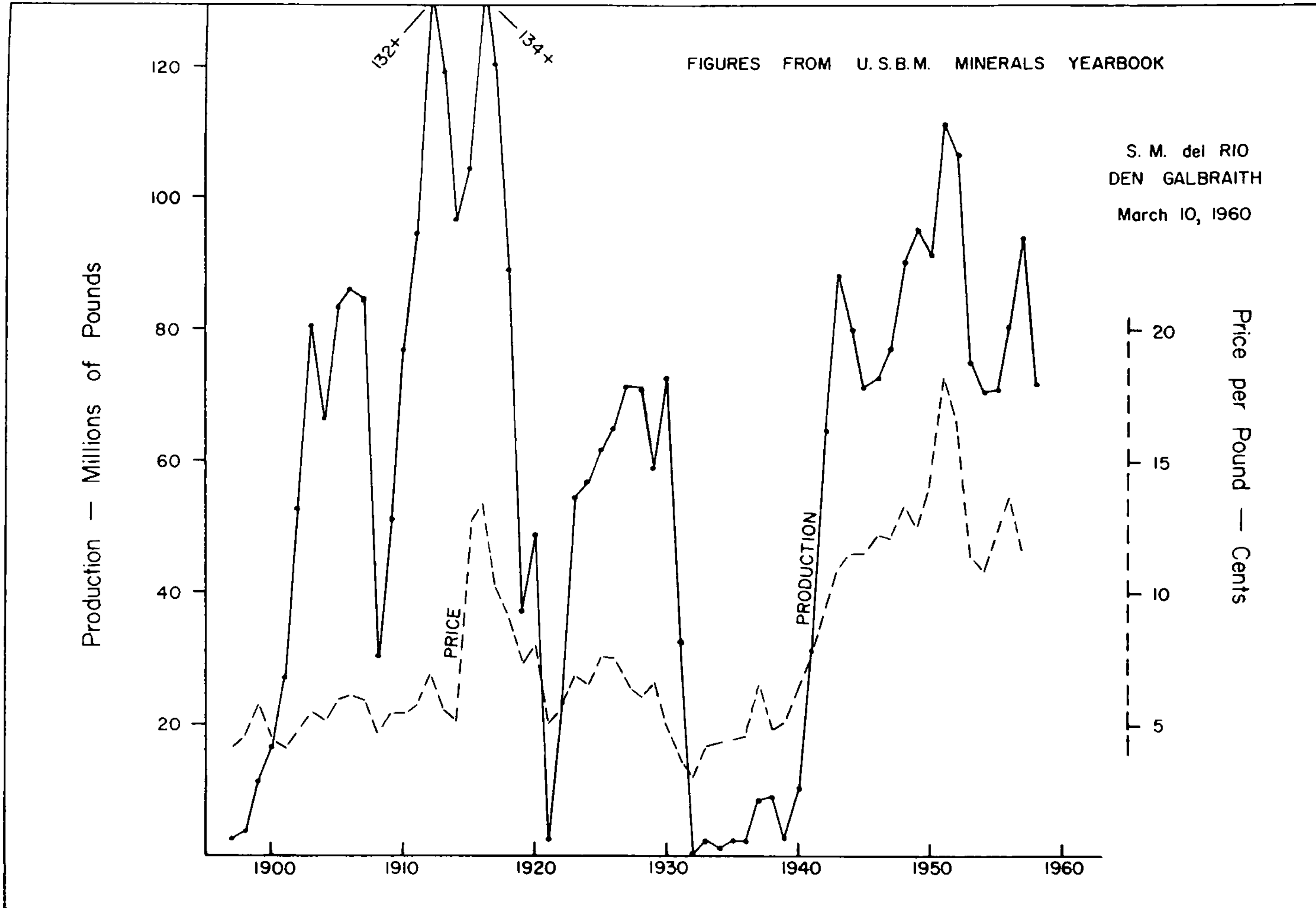

FIGURE 4. ZINC — PRODUCTION AND AVERAGE ANNUAL PRICE/LB., 1897-1958

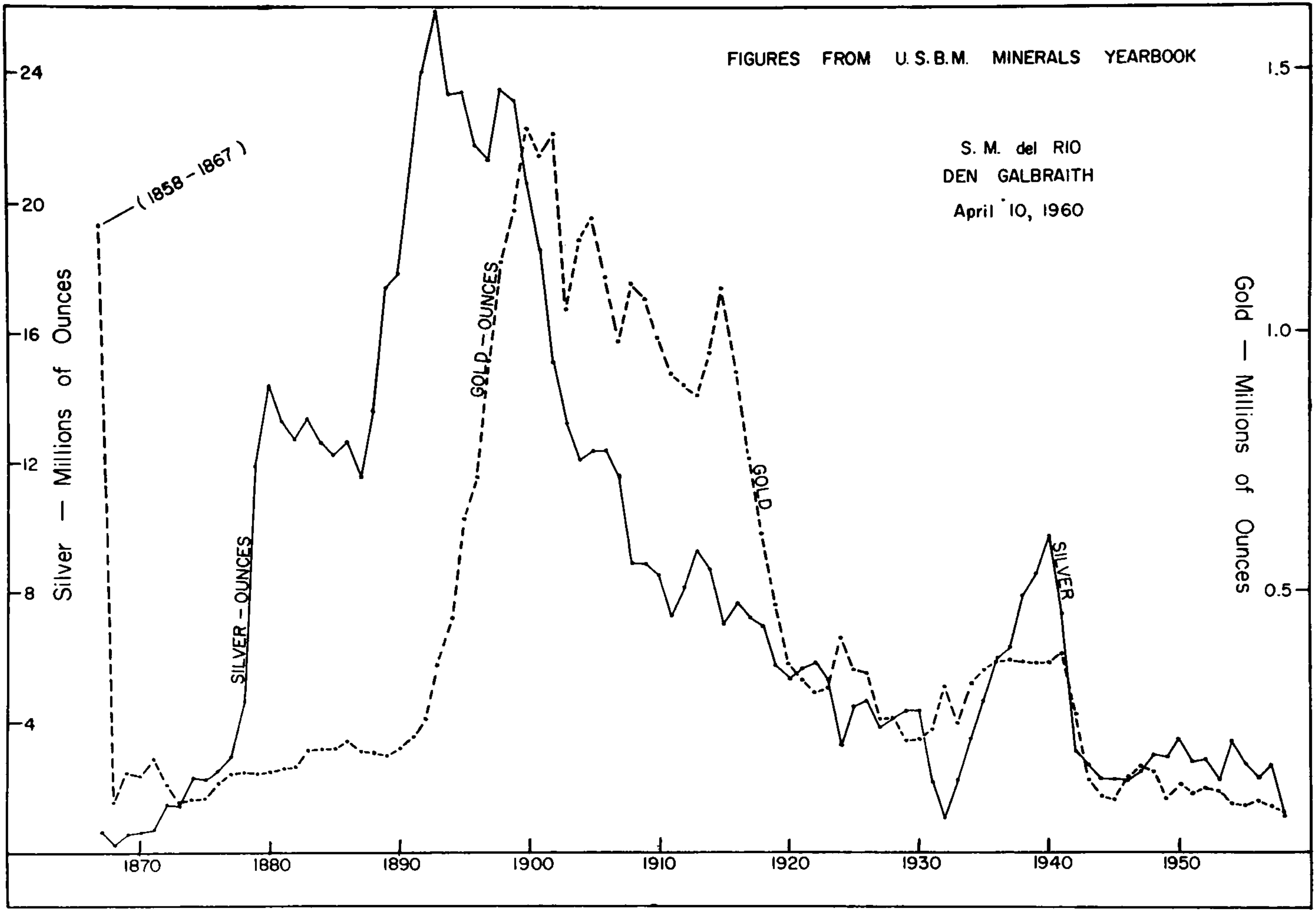

FIGURE 5. GOLD & SILVER PRODUCTION, 1858-1958

In the first volume of this series, Dr. Vanderwilt* comments authoritatively on the outlook for Colorado's mineral industry, and concludes that the State will continue to be an important producer of minerals far into the future.

Actually, despite 100 years of mining, we have yet to exhaust a single item of mineral production in Colorado. Gold, the first metal mined, is still being extracted vigorously, albeit with dimished enthusiasm due to fixed market price and soaring costs of production. Petroleum output and value have increased enormously with the passing years. Dr. Vanderwilt* gives the cumulative total production and value of petroleum since the first well was drilled in 1862, through 1949, at 50 million barrels valued at $51.84 million. The petroleum production for the year 1958 alone (not a peak year), totaled 49 million barrels valued at $144.44 million. Molybdenum production has grown through the years to become by far the most important metallic product in the State; at Climax, despite the current record-breaking rate of extraction for an underground operation of 34,000 tons per day, the present reserves are estimated at 640 million tons of ore containing one billion pounds of molybdenum; the Urad molybdenum deposit at Fremont Pass also contains important reserves. Uranium, as may be noted from the list on page 29, is fourth in value-rank of all minerals produced in Colorado; its co-product, vanadium, is being produced in greater quantities than ever before. Known ore reserves of these two metals are adequate and it is anticipated that numerous commercial deposits will be discovered in the future. Industrial minerals such as fluorspar, feldspar, scrap mica, clays, lightweight aggregates, limestone, granite, gypsum, sand and gravel, etc., are contained in abundance within the State. Zinc, lead, silver, copper, are still being mined despite adverse economic conditions in quantities which can be greatly increased given the proper incentives. Assuredly, some individual base-metal deposits have been mined out, but much ore still remains in virgin terrain, in inefficiently exploited old workings, and in insufficiently explored districts which can be located and mined profitably under adequate price and market conditions.

Dr. E. N. Goddard, U. S. Geological Survey, writing on the subject of "The Front Range Mineral Belt" on page 297 of the 1947 edition of MINERAL RESOURCES OF COLORADO (Vanderwilt), makes the following general comment.

> "The persistence of individual ore shoots in depth is seldom more than a few hundred feet; depths of 1,000 feet are unusual. However, there is no evidence that the bottom of mineralization has been reached in any locality, as ore has commonly been found from the tops of the highest hills to the bottoms of the valleys. Throughout the mineral belt, in districts that have

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*Vanderwilt, J. W, "Mineral Resources of Colorado," 1947, pp. 18-23.

been studied thoroughly, favorable structural locations are known that have not been explored; in other districts the detailed structural relations have not yet been worked out. It therefore seems likely that future prospecting on the basis of careful structural studies will uncover new ore bodies."

Occasionally, new ore bodies of importance are discovered in working mines, either laterally or at depth, by accident or by geologic concepts. It is economically desirable during the exploitation of a mine that every possibility be exhausted to discover all ore bodies which can be extracted by means of the costly facilities already available, such as adits, shafts, drifts, track, air, power, and surface installations. For this purpose, surface and underground geologic mapping should be conducted, a thorough understanding of the geologic conditions which emplaced the ore body gained, and ore controls, guides, and loci determined as far as possible. These data, accurately interpreted, should lead to the formulation of efficient programs of exploration designed to reveal other, hidden ore bodies which may exist accessible to the workings.

There still remain in Colorado many thousands of unexplored cubic miles of ground which is geologically favorable to ore occurrence. Many economic deposits undoubtedly exist in areas mantled by sediments or buried under extrusive igneous rocks. In this regard, Dr. Thomas B. Nolan* has said the following.

"Here in Colorado I believe there are areas in which major ore deposits may occur that have not yet been adequately studied or explored. We do not yet know whether the Leadville ore bodies end beneath the town or extend westward beneath the four-mile-wide covered area that lies between Leadville and the mining districts at the foot of the mountains to the west. We have not determined whether major ore bodies lie in or under the sedimentary rocks that adjoin the great Climax deposit and are separated from it by the Mosquito fault. In the San Juans, in district after district, survey geologists have found that the major known ore deposits are related directly to a late and rather brief stage in the volcanic activity that built up this great mountain mass. Is it not possible that major ore deposits lie buried by lavas that cover mineralized throats of older volcanoes that contributed to the development of the mountains? —At Gilman, surface manifestations of the largest single base-metal sulfide body known in Colorado are

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*Vanderwilt, J. W, "Mineral Resources of Colorado," 1947, pp 178-23.

*Director, U. S. Geological Survey, address before the National Western Mining Conference, February 6, 1959. Denver, Colorado.

> so weak that the deposit might still lie undetected, had not the Eagle River cut a canyon through it. Might not other deposits lie in the larger area of geologically similar terrane that has no such deep canyon cut through it?"

Search for deposits such as suspected by Dr. Nolan must be undertaken by scientific methods: extrapolation or projection of geologically determined guides; geochemistry; and geophysics.

There is nothing wrong with the minerals industry of Colorado that proper incentives in the form of good markets, adequate prices, and constructive tax treatment cannot cure. The mineral resources are here and capable technology is available. Exploration programs as they must be conducted today, with precision instruments, air and land carriers, and highly trained personnel, are costly. It is natural for the industry to hold back exploration programs of magnitude until the incentives to conduct them equal at least the financial risks taken. The two factors of prime consideration, markets and adequate prices, are beyond the power of a state's government to control, but the factor of taxes is within its power to alleviate. In some instances proper tax treatment may mean the difference between a healthy industry and a moribund one; between a steady and adequate tax revenue for the State from exploitation of its natural mineral resources, or none at all.

A subject which should be of interest to all who are concerned with the minerals industry of Colorado, including State authorities, is the matter of conservation. Not conservation through refrain in exploitation, but conservation through efficient exploitation. Upon analysis this subject is extremely complex, and a simple grasp of the problem is sufficient to show that no blanket remedies can be applied.

There are many instances in each segment of the extractive phase of the industry where far greater percentages of ultimate recovery should be attained. In coal mining, some operators leave as much as 50% of the coal underground, as pillars or lower-grade material; in metal mining, many operators are forced by low prices to mine only the richer-grade ores, in some cases with total loss of the remainder; in oil extraction, water-flooding and other measures of secondary recovery are often not resorted to until primary recovery has been almost completed and the oil has lost much of its natural gas—secondary measures are then not nearly as effective and ultimate recovery relatively low. The Adena field in the southern part of Morgan County is a good example of effective water-flooding recovery measures applied at a proper time in a field's development.

The over-all problem is definitely a complex one, but it is very worthy of attention, study, and if possible, determination.

CHAPTER III

Colorado Counties—
Mineral Resources

by

S. M. Del Rio

Prior to expansion of the U. S. Bureau of Mines yearly statistical publication MINERALS YEARBOOK from one to three volumes in 1952, figures on production by counties were limited principally to precious and base metals. For this reason the discussion by counties contained in the 1947 edition of MINERAL RESOURCES OF COLORADO (Vanderwilt) was limited to these metals. Other mineral resources in the State were discussed under item headings and not geographical subtitles.

In this volume we make a start at taking advantage of the more detailed reporting now possible under the broader scope of the MINERALS YEARBOOK to present all pertinent material under county subtitles; this includes mineral production, potential, and geology. With respect to the last named it is necessary to preface the by-county discussions with general information on the regional geology of the Front Range mineral belt which affects several counties.

The Front Range in Colorado, extending northerly from Canon City to the Wyoming border over a distance of roughly 190 miles, contains the largest mineralized area in the State. This area, known as the Front Range mineral belt, cuts diagonally across the range in a northeasterly direction extending from Breckenridge on the southwest, to south of Lyons on the northeast. The belt includes: the southeastern part of Summit County; a small portion of the northwestern part of Park County; virtually all of Clear Creek County; a small portion of the southeastern part of Grand County; virtually all of Gilpin County; a small portion of the northwestern part of Jefferson County; and, most of the western half of Boulder County.

The geology of the mining districts established within the above counties must be considered in the light of the regional geology of the mineral belt and of the Front Range which contains it. The 1947 edition of MINERAL RESOURCES OF COLORADO (Vanderwilt) includes an excellent summary discussion of the geology and ore deposits of the Front Range mineral belt by E. N. Goddard on pages 294-298, and the local geology of some of the individual mining districts on pages 299 through 327. Additional information on the geology of the mining districts is given in this volume under the counties in which they are located. Additional data on the general geology of the mineral belt, abstracted principally from reference No. 1 of the bibliography, is given below.

The Front Range Mineral Belt

The Front Range mineral belt is a narrow, long and sinuous band located in a transmountain area between the Breckenridge district in southern Summit County, and the Jamestown district to the northeast in Boulder County. The marked northeastern trend of a belt of porphyry stocks and the associated ore deposits reflects both, the direction of the Laramide mountain-building forces, and the regional and local distribution of the earlier rocks.

The mineral belt lies largely in an area of pre-Cambrian formations, but Mesozoic and Paleozoic sediments are also present in the southwestern part. The tortuous northeasterly course of the belt parallels closely the irregular area of relatively weak schists and gneisses which lie between large masses of granite. The chief rocks, in the order of their abundance, consist of pre-Cambrian metamorphics and intrusives, Laramide porphyries, and Mesozoic and Paleozoic sediments.

Pre-Cambrian Rocks of the Mineral Belt—[12]The pre-Cambrian rocks of the mineral belt include:

Idaho Springs Formation—Composed of highly metamorphosed sediments, constitutes the principal country rock in the area between the Geneva Gulch district, and the Ward district to the north. These metamorphics consist chiefly of quartz-biotite schist, quartz-biotite-sillimanite schist, biotite-sillimanite schist, and injection gneiss.

Swandyke Hornblende Gneiss—Prominent in the southwestern part of the belt in the Montezuma, Swandyke, and Hall Valley districts, but also occurs locally on the eastern side of the Continental Divide within the mineral belt.

Boulder Creek Granite—Occupies moderately large areas in the northern half of the belt. One batholith lies between Boulder and Nederland, and another south of Georgetown and Idaho Springs. Stocks and other bodies occur in the high country along the western side of the Central City quadrangle and in the southeastern part of the Rocky Mountain National Park quadrangle.

Granite Gneiss Group—Includes quartz monzonite gneiss and granite gneiss in the central and southwestern parts of the belt, and gneissic aplite in the northeastern part.

Pikes Peak Granite—Is represented in the mineral belt by only a few small stocks.

Silver Plume Granite—This granite, later than all the forementioned rocks, is found in batholiths, stocks, and dike-like masses. One batholith is located in the northern part of the Montezuma quadrangle, and another in the Jamestown district from where it continues northward.

Pegmatites—These occur throughout the mineral belt in all size variations.

Paleozoic and Mesozoic Rocks—[12]Paleozoic and Mesozoic sedimentary rocks, with Early Tertiary intrusives, predominate in the southwestern part of the mineral belt around the Breckenridge district. Pre-Cambrian schist, containing some injection gneiss and gneissic granite, underlies the sediments and is exposed in the southern and western parts of the district in small areas. The sedimentary rocks in the southwestern part of the mineral belt, include:

Permian-Pennsylvanian(?) Maroon Formation—Lies directly upon the pre-Cambrian basement but is overlapped by the overlying Morrison and Dakota formations to the east and west of the Breckenridge district. The Maroon rocks consist of 600 to 900 feet of red, gray, and black micaceous shale with some limestone and some red and gray micaceous grit and conglomerate.

Upper Jurassic Morrison Formation—Consists of about 200 feet of sandstone and variegated shales overlying the Maroon formation.

Upper Cretaceous Dakota Quartzite—From 20 to 225 feet in thickness, overlying the Morrison formation. Probably because of its rigidity and ability to retain open fractures, ore bodies are commonly localized in this quartzitic formation where crossed by veins.

In the western part of the Breckenridge district the Dakota and Morrison formations occur as a broad northwesterly band cut by porphyry intrusives, and much complicated by folding and faulting.

Upper Cretaceous Benton Shale—Overlies the Dakota quartzite and consists of approximately 360 feet of dark-gray shale.

Upper Cretaceous Niobrara Formation—Above the Benton, consists of about 350 feet of black or gray limy shales interbedded with thin-bedded dark-gray limestone.

Upper Cretaceous Pierre Shale—Overlying the Niobrara, exposes a thickness of approximately 2,500 feet some two miles northwest of Tiger. The Pierre consists principally of dark-olive and dark-brown clay shale much cut up by irregular intrusive stocks and sheets of porphyry which are cut off by the strong Williams Range thrust fault along the northeastern part of the Breckenridge district. To the east of the fault are pre-Cambrian hornblende gneiss, some schist, and granite.

Quaternary—Glacial and stream deposits occupy an extensive area along the Blue River valley. The town of Breckenridge is built upon the outwash gravels of the Wisconsin glacial stage just below a terminal moraine. Placer deposits have been found in the early and late glacial outwash gravels in the late glacial ground moraine south of the terminal moraine.

Laramide Intrusive Rocks[12]—Most of the Laramide intrusive rocks are limited to the narrow band of the Front Range mineral belt which extends from Boulder southwesterly to

Breckenridge. The northwest side of this main porphyry belt is marked by a line of stocks ranging in area from less than two, to somewhat more than 15 square miles. Dikes and small, irregular cross-breaking bodies are almost entirely limited to a strip ranging from two to ten miles in width just south of and paralleling the line of stocks. This series of dikes, which does not occur north of the stocks, indicates the presence of relatively shallow magmatic reservoirs below the surface along the line of dikes. It is in this strip containing the porphyry dikes and small irregular intrusive bodies that most of the Tertiary ore deposits of the Front Range occur.

On the western slope the composition of most of the porphyry belt intrusives lies between that of augite diorite and quartz-monzonite porphyry. In this area the mineral deposits contain chiefly complex lead-silver-zinc ores.

Northeast of Silver Plume, in addition to the intermediate rocks, more alkalic groups are found, such as alkalic syenite, alkalic trachyte, and bostonite. In the area of the more alkalic rocks pyritic gold ores, as well as the older complex sulfides, occur.

Scattered through the northeastern half of the mineral belt are short dikes and small irregular bodies of biotite latite, biotite monzonite, and latitic intrusion breccia. These rocks seem limited to the areas in which gold-telluride veins are found.

Rocks of extreme mafic character occur just west of the tungsten belt and also near its eastern edge.

With the exception of small areas of Tertiary (?) gravel in the Idaho Springs-Central City district and in the Nederland district, no Tertiary sediments have been recognized in the Front Range mineral belt in Boulder County.

Ore Deposits of the Mineral Belt[12]—The Front Range mineral belt is characterized throughout by base-metal mineralization containing appreciable silver and gold values. With the exception of the eastward-trending tungsten belt between Nederland and Boulder, the ores northwest of Idaho Springs have been chiefly valuable for their gold content. To the southwest, base metals and silver values predominate with the partial exception of the Breckenridge and Tiger districts where gold is more important.

Both residual and supergene sulfide enrichment are common in the mineral belt. The oxidized ores are generally richer in gold, silver, and lead than the primary ores, but contain less zinc and copper. Below the oxidized zone, and usually below the present level of ground water, there is a marked increase in the silver content of many veins due to the precipitation of secondary minerals from solutions which have leached silver from the oxidized zone. Secondary copper minerals are commonly associated with the silver minerals in this sulfide zone of secondary enrichment.

Ore deposits of the mineral belt have been classified according to geologic age into two main groups: pre-Cambrian, and Laramide (late Cretaceous—early Tertiary). Nearly all the mineral production of the Front Range, outside the Cripple Creek district, has come from deposits formed during the Laramide revolution.

Pre-Cambrian Deposits—The pre-Cambrian deposits of the Front Range mineral belt fall into four general classes: a) magmatic segregations, disseminations, and related depositions; b) hypothermal replacement bodies; c) pegmatitic quartz veins; d) pegmatites.

a) Magmatic segregations and disseminations have been relatively the most productive of the pre-Cambrian deposits. Chief representatives of this type of mineral body are: the Cotopaxi copper-zinc mine west of Canon City; the chalcopyrite ores in Jefferson County west of Golden; and, the gold-copper deposit near Empire.

b) The hypothermal deposits, possibly the most widespread of the pre-Cambrian deposits, have proven noncommercial nearly everywhere.

c) In many places pegmatitic dikes related to granite batholiths contain metallic mineralization consisting sometimes of minor vugs and stringers of chalcopyrite, and others of galena and sphalerite associated with calcite, fluorite, and barite. The gold content is usually less than one ounce per ton, and that of silver less than ten ounces per ton. Although deposits of this group are common, very few of them have been commercially productive. Some of the better known properties of this type are: The Nisley mine near Shawnee in Park County; the Happy Dream and Molly Grove mines near Kremmling; and the Masonville gold mine northwest of Loveland.

d) Pre-Cambrian pegmatites of the Front Range have a history of feldspar and some mica production with byproducts of beryl, columbite-tantalite, and rare earth minerals, (*) but they are mostly small operations subject to vagaries in the composition of the pegmatites, to high transportation costs in the face of a low-value principal product (feldspar), and to capricious markets. Very few Front Range pegmatites have been mined profitably with consistency.

Laramide Deposits—The mineral belt is an almost continuous band of mineralized Laramide fissures, extending northeastward from the Breckenridge district through the Montezuma, Silver Plume, Georgetown, Idaho Springs, Central

*Comments by the writer.

City, North Gilpin County, Boulder Tungsten, Caribou, Gold Hill, and Jamestown districts.

Southwest of Georgetown the belt is almost entirely confined to a northeastward-trending zone of metamorphic rocks bordered by batholiths and smaller masses of granite. North of Central City the mineral belt follows metamorphic rocks along the western and northwestern border of a Boulder Creek granite batholith. The Laramide faulting localized at the edge of the granite masses created fissures approximately parallel to the regional trend of the porphyry belt which were subsequently mineralized from many local sources.

A prominent structural feature during the Laramide revolution is the strong system of northwesterly faults known as "breccia reefs" which occur throughout the northern part of the Front Range but which are best developed in the Gold Hill District, Boulder County. These faults, though themselves mostly barren, exercised an important control on the localization of mineral deposition in the more open easterly and northeasterly fractures that intersect the "reefs". Most of the tungsten, gold, and gold-telluride ores of Boulder County have come from easterly and northeasterly fissures close to their intersection with the persistent, early, northeasterly faults. A similar control has been observed in other districts, notably the Central City-Idaho Springs district and the Silver Plume area to the southwest.

The general sequence of mineralization in the Laramide deposits was as follows: 1) pyrite, 2) sphalerite, 3) chalcopyrite, 4) galena and chalcopyrite, 5) silver-bearing sulfantimonides, sulfarsenides, and bismuthinides, 6) pyrite and subordinate chalcopyrite, 7) free gold, 8) minor amounts of sphalerite, galena, and silver minerals, 9) gold tellurides and sparse pyrite, gold, sphalerite, and galena, 10) ferberite and sparse sulfides.

Most of the ores between Breckenridge and Idaho Springs belong in groups 1 to 5, and most of the production north of Idaho Springs has come from groups 6 to 10.

Selected Bibliography and References

The technical literature on Colorado's mineral resources is extensive, but not all-encompassing. Certain items of mineral production and certain geological areas within the State are covered in satisfactory detail, but other items and other areas have been scantily investigated.

The publications given below have aided the writer in preparing the by-county discussions which follow the bibliography. Their sequence on the list is in close approximation to the alphabetical order of the counties with which they deal. In this manner, publications appertaining to areas within a certain county have been placed together on the list. A number of references contain data which are common to several counties; i.e., "Geology and Ore Deposits of the Front Range", "Industrial Minerals of Colorado", "Coal Resources of Colorado", etc. In such cases, the publication has been located somewhat arbitrarily on the list, but within a pertinent group.

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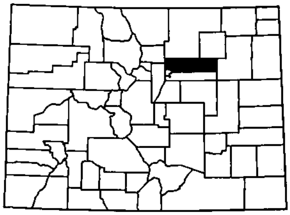


Courtesy Colorado Planning Division

Adams County

Adams County is located in the north-central part of the State, northeast of and adjacent to the City and County of Denver. It has an area of 1,250 square miles ranging in elevation from 4,500 to 5,300 feet above sea level with a population of about 85,000. The county seat is at Brighton, a farming, ranching, light industry, and business community of 6,500 inhabitants.

Available Maps of the County—

a. Adams County Map.

b. U. S. Army Map Service maps: 5063 I, IV; 5163 I, IV; 5263 I, IV.

c. U. S. Geological Survey topographic quadrangle maps cover all but the extreme eastern part of the county. See topographic quadrangle index in map in the pocket.

Mineral Production 1946-1958—Although Adams County is located on the plains well to the east of the mineral belt in the mountains, some gold and silver are produced. This production is a byproduct of sand and gravel operations along stream channels which derived their gold and silver content from weathering processes and stream action on lodes and veins in the hills.

Up to 1951, the only mineral production reported for the County by the U. S. Bureau of Mines was that of gold and silver, though obviously sand and gravel were extracted from which these metals were derived as byproducts. Petroleum was first produced in 1952, and has since become the most important single mineral product of the County. Complete information on the County's oil production, geology, and other pertinent data, is presented in the petroleum section of this book. The figures in the following table are from U. S. Bureau of Mines "Minerals Yearbooks".

Year	Placer Mines*	Gold Ounces	Silver Ounces	Petroleum Barrels[1]	Sand & Gravel Short Tons	Total $ Value
1946	3	576	94	----	----	20,236[2]
1947	2	387	64	----	----	13,603[2]
1948	3	480	75	----	----	16,868[2]
1949	4	775	116	----	----	27,230[2]
1950	3	909	137	----	----	31,939[2]
1951	6	1,279	179	----	----	968,921[3]
1952	6	1,097	158	74,365	----	1,114,555[4]
1953	5	1,218	175	616,743	1,148,839	2,822,030[5]
1954	7	1,089	154	1,253,997	1,400,000	4,936,143[5]
1955	5	1,290	186	1,089,094	Withheld	5,179,207[5]
1956	4	1,311	184	1,067,442	2,358,000	4,865,652[5]
1957	5	993	139	1,002,334	2,345,000	5,804,321[5]
1958**	6	1,053	146	779,612	1,648,000	4,600,957[5]

*Sand and gravel operations which produced gold and silver as a byproduct.

**Preliminary figures, subject to revision.

[1] Colorado Oil and Gas Conservation Commission figures, all others from U. S. Bureau of Mines Minerals Yearbooks.

[2] Gold and silver values only.

[3] Gold, silver, sand, gravel, and stone values.

[4] Value of all mineral production including some miscellaneous, but excluding natural gas, natural gas liquids, some sand, gravel, and stone.

[5] Value of total mineral production.

Hydrocarbons—Petroleum was discovered on the Noonan Ranch in 1951, and since then the County has become an important producer of oil and gas. As of the end of 1959, there were active in the County 17 oil-gas fields and 3 oil fields with a total production for the year of 676,505 barrels of oil and 1,784 million cubic feet of natural gas. The aggregate cumulative production up to that time amounted to 6,560,092 barrels of oil and 7,339 million cubic feet of gas.

*Adams County is located entirely within the Denver Basin. Production is from the 'D' and 'J' sands of the Dakota formation, Lower Cretaceous series. The eastern portion contributes most of the production; a small amount comes from the western part near Denver. At least two-thirds of the County has yet to be adequately tested by drilling. There are some possibilities for oil and gas production from the Hygiene sand of Upper Cretaceous age, the 'M' and 'O' Dakota sands, the Permian Lyons sands and, with decreased possibilities, the older Pennsylvanian formations.

Sand and Gravel—For a number of years Adams County led all Colorado counties in the production of sand and gravel. Most of it comes from the basins of the South Platte River, Bear Creek, and Clear Creek; fine sand, but no gravel, is produced from the Sand Creek and Cherry Creek areas. All of these deposits are near Denver and it is foreseen that the encroachment of industrial and suburban construction over the reserves will shorten their availability to a few years hence.

Gold and Silver—The County's production of gold and silver is derived as a byproduct of sand and gravel operations. These metals originated in weathered deposits on the eastern slope of the Front Range, and were washed down onto the

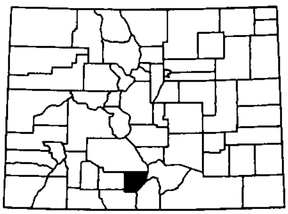
*Mr. George H. Fentress, Exeter Drilling Co., written communication.

plains by stream action and finally accumulated into low-grade placers.

Clays—Clays suitable for brick manufacture are widespread throughout much of the County.

Coal—With the exception of the eastern part, most of Adams County lies within the Denver Coal Region. Although no coal production is indicated in the table, at least 26 square miles of the County[6] are underlain by coal measures containing upward of 330 million tons of subbituminous coal under less than 1,000 feet of overburden in the Scranton district. In this area, the coal zone of the basal Laramie formation is apparently about 1,000 feet below the Denver formation coal zone on which the 330 million tons estimate is based. The coal is subbituminous in rank with a strong possibility of its being lignite.

Geological Note—Adams County lies in sedimentary terrane within the Denver Basin. The deepest part of the Basin is located in the extreme southwestern corner of the County. The surface rocks range in age from the Cretaceous Pierre shale, to the Tertiary Denver and Arapahoe formations, with Quaternary alluvium along some of the western creek and river valleys. The Denver and Arapahoe formations extend from the western end of the County through the east-central portion. Easterly in sequence beyond the Tertiary rocks, follow the Upper Cretaceous: Laramie, Fox Hills, and Pierre formations.



Courtesy Colorado Planning Division

Alamosa County

Alamosa County is located in the south-central part of the State in the heart of the fertile San Luis Valley. The county has an area of 723 square miles ranging in elevation from 7,300 to over 14,000 feet, and a population of 11,000. The county seat is at Alamosa, a farming and ranching center with 5,500 inhabitants.

Available Maps of the County—

a. Alamosa County Map.

b. U. S. Army Map Service maps: 4859 II, III; 4858 I, IV.

c. U. S. Forest Service maps: Rio Grande National Forest and San Isabel National Forest.

Mineral Production—The only mineral production credited to Alamosa County during the last several years consisted of sand and gravel. The statistics on this commodity are rather meager and begin only in 1953. The figures in the following table are from the U. S. Bureau of Mines Minerals Yearbooks.

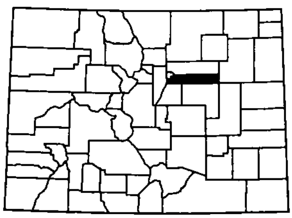
Year	Sand & Gravel Short Tons	$ Value
1953	--	71,300
1954	--	74,775
1955	180,000	56,526
1956	343,000	89,000
1957	----	
1958	11,000	5,100

Sand and Gravel—Considerable sand and gravel are produced in Alamosa County, particularly in the southwestern quadrant, as well as to the east of the city of Alamosa; along the course of the Rio Grande, the Empire Canal, creeks, and other drainage systems, both actual and ancient, whose waters reworked the sands and gravels of the Alamosa formation. The sands and gravels of the Alamosa formation represent considerable resources for the future.

Sodium Salts—Argall[9] reports the existence of sodium carbonate, sodium sulphate, and sodium chloride in San Luis Lake in the northern part of the County. Some shipments of soda were made from this deposit over 40 years ago.

Geological Note—Alamosa County is situated in the southern part of the San Luis Valley in sedimentary terrane of the Alamosa formation of Late Pliocene or Early Pleistocene age. In the extreme eastern part of the County are the Sierra Blanca Mountains, with Sierra Blanca Peak rising to 14,363 feet above sea level. Pre-Cambrian rocks are exposed along the mountains, fringed to the west by compound alluvial fans and torrential wash extending in a north-south band 2 to 5 miles in width. The remainder of the County, to the west, is surfaced chiefly by the Alamosa formation.

Arapahoe County



Courtesy Colorado Planning Division

Arapahoe County is located to the south and east of Denver County from where it extends eastward in a narrow band 12 miles wide and 72 miles long. The county has an area of 815 square miles ranging in elevation from 4,600 to 5,600 feet above sea level, and a population of 100,000. The county seat is at Littleton, an industrial and farming community a few miles to the south of the city of Denver, with a population of 9,000.

Available Maps of the County—

a. Arapahoe County Map.

b. U. S. Army Map Service maps: 5063 II, III; 5163 II, III; 5263 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover almost two-thirds of the County. See index map in the pocket.

Mineral Production—The only minerals reported produced in Arapahoe County during the past decade are sand, gravel, stone, and some clay. The statistics given in the following table are from the U. S. Bureau of Mines Minerals Yearbooks, and begin in 1951, when the Bureau expanded its reporting procedure.

Year	Sand & Gravel Short Tons	Total $ Value
1951	Withheld	123,862[1]
1952	Withheld	291,176[1]
1953	Withheld	864,190[2]
1954	564,000	485,025[2]
1955	763,000	714,582[2]
1956	1,430,000	1,468,750[2]
1957	1,640,000	1,503,300[2]
1958	1,693,000	1,646,000[3]

[1] Value of sand, gravel, and clays.

[2] Value of sand and gravel only.

[3] Same as [2] but includes 1,800 tons stone valued at $2,900.

Sand and Gravel—Sand and gravel production in Arapahoe County has increased considerably of recent years due to the intensification of highway and other construction in and around the Denver area. Most of the production has come from the courses of the South Platte River, Sand, Cherry, Coal, First, Boxelder, and Kiowa creeks. Similarly to the situation in Adams County, the deposits which lie in the vicinity of Denver and surrounding towns are being encroached upon by suburban and industrial construction and consequently may not be available a few years hence.

Coal—With the exception of the eastern part, most of Arapahoe County lies within the Denver Coal Region. Although no coal production is indicated in the preceding table, the County has appreciable reserves. [6]At least 40 square miles is underlain by measures under less than 1,000 feet of overburden, containing an estimated 272 million tons of lignite or subbituminous coal.

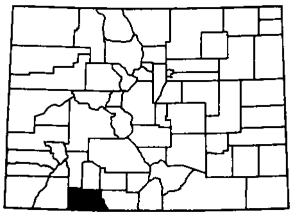
Hydrocarbons—*Arapahoe County lies entirely within the Denver Basin, but has yet to develop commercial production of oil or gas. The most promising area is the eastern portion along the southwestwardly-trending "fairway" of eastern Adams and southwestern Washington counties. The prospective

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

horizons for exploration are those which are currently productive in Adams County, that is the 'D' and 'J' sands of the Cretaceous Dakota formation, and those which are potentially productive: the Cretaceous Hygiene and 'M' and 'O' sands of the Dakota; the Permian Lyons sand and, with lesser probability, the underlying Pennsylvanian rocks.

Geological Note—Arapahoe County lies within sedimentary terrane of the Denver Depositional Basin, the deepest part of which is located in the extreme northwestern part of the County. The surface rocks range in age from the Denver and Arapahoe formations of Eocene age which cover the western four-fifths of the County, to the Upper Cretaceous rocks of the Laramie, Fox Hills, and Pierre formations which extend eastward in that sequence to the Washington County line.

Archuleta County



Courtesy Colorado Planning Division

Archuleta County is located in the southwestern part of the State just north of the Colorado-New Mexico line. It has an area of 1,364 square miles ranging in elevation from 6,000 to 13,272 feet, and a population of 3,000. The county seat is at Pagosa Springs, a farming, ranching, and lumber center with a population of 1,400.

Available Maps of the County—

a. Archuleta County Map.

b. U. S. Army Map Service maps: 4558 I, II, III, and IV; 4658 I, II, III, and IV.

c. U. S. Forestry Service maps, San Juan National Forest, and Rio Grande National Forest.

d. U. S. Geological Survey topographic quadrangle maps cover approximately three-fourths of the County. See index map in the pocket.

Mineral Production 1946-1958—For many years, since the discovery of the Price Gramps oil field, petroleum has been the County's principal mineral product. Some sand and gravel has been produced, but there are no reliable figures of its quantity. Small tonnages of coal have also been produced.

Year	Petroleum Barrels[1]	Total $ Value
1946	325,818	295,000[2]
1947	195,376	350,000[2]
1948	124,560	311,000[2]
1949	104,963	260,000[2]
1950	146,245	360,000[2]
1951	220,172	550,000[2]
1952	208,571	520,000[2]
1953	247,819	727,504[3]
1954	209,825	607,552[3]
1955	180,432	550,442[3]
1956	151,686	422,500[4]
1957	137,655	413,740[4]
1958	118,238	366,030[3]

[1] Colorado Oil and Gas Conservation Commission figures.
[2] Petroleum values only, estimated.
[3] Petroleum and sand and gravel values only. U.S.B.M. Minerals Yearbooks.
[4] Petroleum values only. U.S.B.M. Minerals Yearbooks.

Hydrocarbons — Petroleum was discovered in Archuleta County in 1935, when a well was completed on the Price Gramps structure in the southeastern part which struck oil in the Dakota sandstone at a depth of about 1,000 feet. The second, and last field of any consideration to be discovered, was the Chromo oil-gas field located a few miles southwest of Price Gramps. These two fields on the flank of the Chama Basin, had a total production during 1959, of 113,927 barrels of oil and 516,000 cubic feet of natural gas, and an aggregate cumulative production up to that time of 4,904,671 barrels of oil and 6.6 million cubic feet of gas.

*Archuleta County flanks the San Juan Dome and volcanic peaks of the San Juan Mountains, and incorporates the extreme northeastern segment of the San Juan Basin, the northwestern extension of the Archuleta Anticlinorium, and the northern portion of the Chama Basin. It is anticipated that additional production will be discovered in Cretaceous beds over much of the County, for there are numerous structural and stratigraphic areas which remain untested by the drill. Deeper prospects may be present also in rocks ranging in age from Jurassic to Mississippian, with emphasis on the Pennsylvanian and Mississippian.

Sand and Gravel—Sand and gravel are produced from the courses of the San Juan, Piedra, Navajo rivers, and their tributaries. There are adequate deposits of sand and gravel in the County, particularly along the courses of the forementioned drainages.

Coal[6]—At least 47 square miles in Archuleta County are underlain by bituminous coal deposits estimated to aggregate 455 million tons. Of this, 325 million tons are under less than 1,000 feet of overburden; 90 million lie between 1,000 and 2,000 feet below the surface; and the balance is under 2,000 to 3,000 feet of overburden. It is probable that much more coal exists than the estimate given, but no sufficient date is available for its inculsion herein.

*Mr. Enos J. Strawn, Pan American Petroleum Corp., written communication.

The coal in the Pagosa Springs district, northeast of Pagosa Junction and part of the San Juan River Coal Region, is in the Fruitland formation of Upper Cretaceous age. This coal is bituminous of high volatile A and B rank.

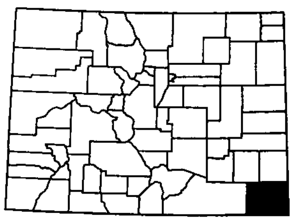
Clays—Clays suitable for brick manufacture are contained in the Pierre formation shales of Upper Cretaceous age, exposed west of the San Juan River in the north-central portion of the County.

Geological Note—Archuleta County lies in sedimentary terrane ranging in age from Pennsylvanian rocks exposed in the northwestern corner of the county, to Quaternary glacial, outwash, landslides, and mudflows in the eastern part. Triassic and Jurassic rocks are exposed along the Piedra River headwaters and tributaries bordering the valleys along the Carboniferous rock bottoms. Cretaceous rocks blanket the central portion of the County and consist of the Dakota sandstone, the Mancos shale, Lewis Shale, Mesa Verde group, McDermott formation, Kirtland shale, Fruitland formation, and Picture Cliffs sandstone.

Numerous northerly and northwesterly trending dikes and sills of Miocene Conejos andesite cut in a wide band across the eastern half of the County west of the Chalk Mountains.

The major structural features, from west to east are: the northwesterly trending San Juan Basin which cuts across the southwestern corner of the county; the Archuleta Anticlinorium which parallels the San Juan Basin 28 miles to the east; and the Chama Basin which in turn parallels the Anticlinorium some eight miles to the east just west of the Chalk Mountains. —Information on the petroleum geology of this county is contained in the petroleum section of this book.

Baca County



Courtesy Colorado Planning Division

Baca County, located in the southeastern corner of the State bordering Kansas and Oklahoma, has an area of 2,565 square miles ranging in elevation from 3,800 to 5,700 feet above sea level, and a population of 7,800. The county seat is at Springfield, a farming and ranching community with 2,200 population.

Available Maps of the County—

a. Baca County Map.

b. U. S. Army Map Service maps: 5358 I, II; 5359 II; 5458 I, II, III, IV; 5459 II, III; 5558 I, II, III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

Mineral Production—Natural gas was discovered in Baca County in 1954, but no reliable figures on its production or value are available. Sand and gravel are produced, but no tonnage figures are available for the past with the exception of 1957 and 1958 when 6,000 and 104,000 tons respectively were produced. The following values for sand and gravel production, beginning with 1953, are from U. S. Bureau of Mines Minerals Yearbooks.

1953	$43,769
1954	43,331
1955	33,166
1956	27,000
1957	12,500
1958	81,800*

*Includes 1,000 tons of stone valued at $8,800.

Oil and Gas—*In 1954, Amerada Petroleum Corporation extended the Greenwood gas field of Morton, Kansas, into eastern Baca County. In 1958, oil was first produced upon discovery of the Prairie Dog oil-gas field in the southern part. Baca County lies within the Hugoton Embayment, and production is derived from the Topeka limestone of Pennsylvanian age in the Greenwood gas field, and from the Marmaton sandstone of Pennsylvanian age in the Prairie Dog oil-gas field.

As of the end of 1959, the two forementioned fields were the only active ones in the County. Their combined production for the year amounted to 439 million cubic feet of gas, with a cumulative total production, up to that time, of 198 barrels of oil and 2,016 million cubic feet of natural gas.

*It is to be expected that other discoveries of greater commercial importance than the present fields will be made in the future. The most favorable formations for exploration are the sandstone and limestone beds of the entire Pennsylvanian section, plus possibly the carbonate rocks of Mississippian and Ordovician age.

Sand and Gravel—Sand and gravel have been produced from the courses of: Two Butte Creek and tributaries of Horse Creek in the northern part; Bear Creek and some of its tributaries east and west of Springfield to the County's boundaries, and from Sand Arroyo south and southwest of Springfield, south of Pritchett, and east of Utleyville.

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*Mr. Thaddeus R. Carpen, Continental Oil Co., written communication.

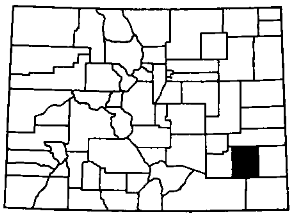
Copper—Baca County has one established mining district, Carrizo Creek (Estelene), in the southwestern corner. Dr. Vanderwilt discusses this district on page 32 of the 1947 edition of this book. *Although there has been no production from this area for a number of years, preparations are now (1958) underway to strip-mine this copper deposit. The ore consists of chalcocite (copper sulfide) partly altered to malachite and azurite, occurring in white sandstone.

Geological Note—The petroleum geology of Baca County is discussed in the petroleum section of this book.

Most of the rocks exposed in the County are of sedimentary origin and range in age from Permian to Quaternary. Some Tertiary dikes and lava flows occur in the southwestern quadrant. In this area, as well as in the northwestern portion, Triassic, Jurassic, and Cretaceous beds are exposed. Elsewhere in the County, the Ogallala formation of Tertiary age, and Quaternary sand dunes predominate.

The Permian rocks exposed in the northern part are part of the Taloga formation. The Triassic rocks include the Dockum group; the Jurassic rocks are represented by the Entrada and Morrison formations; the Cretaceous by the Purgatoire, Dakota, Graneros, Greenhorn, Carlile, and Niobrara formations; Tertiary rocks include the Ogallala formation and igneous rocks; and, Quaternary rocks, the Meade(?) formation and terrace deposits of Pleistocene age plus Recent alluvium and sand dunes.

Bent County



Courtesy Colorado Planning Division

Bent County is located in the Arkansas River Valley of southeastern Colorado. It lies in generally level and undulating terrain, with elevations ranging from 3,600 to 5,000 feet. The County has an area of 1,543 square miles with a population of 9,000. The county seat is at Las Animas, a farming and ranching community with some industrial development and a population of about 3,300.

Available Maps of the County—

a. Bent County Map.

b. U. S. Army Map Service maps: 5359 I, II, III, IV; 5360 II and III; 5459 III and IV; 5460 III.

*Mr. G. A. Franz, Jr., Colorado Bureau of Mines, personal communication.

Mineral Production—The only mineral production of consideration in this County has consisted of petroleum, natural gas, sand and gravel, and small quantities of bentonitic clays. The petroleum production figures have been well documented since the discovery of oil in 1955, but other production and value figures are fragmentary as may be seen from the table.

Year	Petroleum Barrels[1]	Sand & Gravel Short Tons	Clay Short Tons	Total $ Value
1953	----	----	---	7,230[2]
1954	----	----	244	5,459[3]
1955	4,249	----	207	28,574[4]
1956	4,783	211,000	---	101,700[5]
1957	5,784	7,000	20	21,400[5]
1958	1,132	70,000	---	39,490[4]

[1] Colorado Oil and Gas Conservation Commission figures. All others from the U. S. Bureau of Mines Minerals Yearbooks.

[2] Clay value only.

[3] Clay and sand and gravel values only.

[4] Petroleum and sand and gravel values only.

[5] Petroleum, clay, and sand and gravel values.

Hydrocarbons—Oil and gas were discovered in Bent County in 1955 at Bent's Fort in the north-central part when well No. 1 Cordes & Oberlander struck oil and considerable gas in the Atoka formation of Pennsylvanian age at a depth of 4,620 feet. Gas in commercial quantities was encountered at 5,215 feet in the Morrow formation of Pennsylvanian age. Bent's Fort oil-gas field is located about 10 miles northeast of Las Animas town.

The Lubers gas field was discovered in 1956 in the Cherokee sandstone of Pennsylvanian age. Both fields are in the southern end of the Las Animas Arch.

During the year 1959, the three active fields in the County produced a total of 627 barrels of oil and 9.6 million cubic feet of gas, and their total cumulative production up to that time amounted to 16,575 barrels of oil and 97.3 million cubic feet of natural gas.

*Undoubtedly new discoveries of greater commercial significance will be made in Bent County in the future. The most promising horizons for future exploration are the sandstone and limestone beds of the entire Pennsylvanian section, plus possibly the carbonate rocks of Mississippian and Ordovician age.

Sand and Gravel—Sand and gravel are produced from the course of the Arkansas River, which flows from west to east across the north-central part of the County, and from its north and northeasterly flowing tributaries. The County has adequate reserves of sand and gravel for its highway and construction requirements.

Clays—Deposits of bentonitic clay suitable for oil field use exist in the southwestern corner and have been mined sporadically for a number of years. These deposits, although ap-

*Mr. Thaddeus R. Carpen, Continental Oil Co., written communication.

parently not very extensive, must be considered among the State's bentonite resources.

Clays as raw materials for the manufacture of brick and tile occur in several geologic formations within the County. Several localities where these clays are exposed, were examined, sampled, and the samples tested, many years ago, and the results published[7]. The following data, taken from this publication, gives information on those deposits which appear to have the better potentialities.

1—[7]Twenty miles southeast of La Junta; 2 miles northeast of the J. J. Ranch house; half-mile west of the Purgatoire River.
A soft, greenish-gray, fine-grained, massive clay, exposed in many places along the Purgatoire River.
Morrison (Jurassic) formation; 35 feet below the top of the formation.
Should make good, reddish-brown pressed brick if burned to Cone 03, and will do for soft and stiff mud bricks if grogged.

2—[7]Four miles south of Las Animas on the Purgatoire River.
A medium-hard, gray, medium-fine, sandy, massive clay.
A shale member of the Dakota (Cretaceous), five feet from the top of the formation.
Excellent for a variety of purposes: soft-mud bricks, dry-pressed bricks, semi-dry pressed bricks, earthenware, virtrified bricks, virtrified floor tile, unvitrified floor tile, terracotta, hollow blocks, etc., conduits, unvitrified roofing tile, and sewer pipe. Some grogging may be required, but the tensile strength and plasticity are so high as to permit this without injuring the quality of the clay.

3—[7]Same location as No. 2 above, but from a horizon 15 feet below it.
A medium-hard, gray, medium-coarse, sandy, shaly clay, with some sandstone seams.
From the Dakota formation, possibly 20 feet below its top.
Should make fairly good, red, soft-mud bricks, if burned to Cone 05. The cohesion is probably too weak to permit the manufacture of other products.

4—[7]Northwest of Las Animas 8½ miles, and half-mile west of Adobe Creek, above the Fort Lyon Canal.
Near the top of the Carlile formation.
Medium-hard, gray to black, fine-grained shale and clay.
The clay has a number of possible uses, but the high absorption and air shrinkage and slightly deficient plasticity tend to lessen its probable value for anything but paving and flashed bricks.

***Uranium**—In Bent County there are sizable areas, particularly south of the Arkansas River and in the southwestern corner of the County, where geologic conditions are favorable to the occurrence of uranium. In those areas there are facies of the Dakota and Morrison formations in which some uranium occurrences are known.

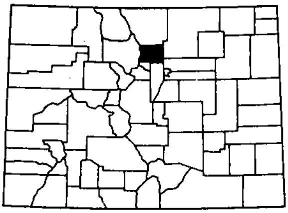
Geological Note—Bent County, in the southeastern plains of the State, is traversed from west to east across the northern half by the Arkansas River and, from its southern boundaries flowing northerly and northeasterly, by the river's tributaries. The John Martin Dam, 16 miles east of Las Animas, backs up

*Dr. Donald L. Everhart, U.S.A.E.C., personal communication.

the Arkansas River to within four miles of the town, forming the John Martin Reservoir.

Most of the Arkansas River, as well as its southern tributaries, flow over sediments of the Dakota (Upper Cretaceous) formation. North of the Arkansas are extensive exposures of Benton and Niobrara rocks, both Upper Cretaceous, while south of the river the highlands between the creek cuts are also formed by Benton beds. In the extreme southwestern corner occur Lower Cretaceous Purgatoire and Jurassic Morrison beds, while Niobrara and Tertiary Ogallala rocks underlie the extreme southeastern corner. A little Tertiary material (Ogallala) also occurs along the northern boundary.

The petroleum geology of Bent County is discussed in the petroleum section.



Courtesy Colorado Planning Division

Boulder County

Boulder County, in the north-central part of the State, has an area of 758 square miles ranging in elevation from 4,950 to 14,256 feet above sea level, with a population of 65,000. The County seat is at the city of Boulder, with a population of 35,000 and home of the University of Colorado.

Available Maps of the County—

a. Boulder County Map.

b. U. S. Army Map Service maps: 4863 I; 4864 II; 4963 I, IV; 4964 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

d. U. S. Forest Service maps: "Arapahoe National Forest" and "Roosevelt National Forest" include Boulder County.

Mineral Production 1946-1958—For a number of years the production of nonmetallic minerals and fuels has been of far greater economic importance to Boulder County than that of the metallic minerals. However, the production of fuels too has been declining considerably during the last 12 years as shown by the table. According to the U. S. Bureau of Mines Minerals Yearbook for 1958, the value of nonmetallic minerals represented 93% of the total value of all minerals produced during the year, with fluorspar leading in terms of sales.

MINERAL PRODUCTION 1946-1958

Year	*Active Lode	Mines Placer	Gold Ounces	Silver Ounces	Copper Pounds	Lead Pounds	Sand & Gravel Short Tons
1946	31	-	3,400	10,052	8,000	136,000	----
1947	27	1	2,059	14,360	11,000	161,700	----
1948	17		1,377	21,232	8,000	186,000	----
1949	12	1	2,195	78,245	16,000	240,000	----
1950	10	1	1,653	76,526	28,000	310,000	----
1951	9	1	749	120,306	26,000	416,000	----
1952	4	1	787	280,151	36,000	394,000	----
1953	7	1	131	24,332	16,000	200,000	----
1954	4	1	196	4,476	12,000	118,000	----
1955	5	1	232	45,680	16,000	178,000	----
1956	4	2	87	5,266	8,000	85,300	505,000
1957	5	2	88	804	1,300	30,800	399,000
1958**	6	1	123	8,282	----	16,000	619,000

Year	Stone Short Tons	Clays Short Tons	Petroleum Barrels[1]	Coal Short Tons	Total $ Value
1946	Withheld	Withheld	16,420	377,639	143,242[2]
1947	Withheld	Withheld	11,000	326,198	110,656[2]
1948	Withheld	Withheld	7,320	235,074	102,441[2]
1949	Withheld	Withheld	7,260	165,250	188,713[2]
1950	Withheld	Withheld	7,393	110,045	175,641[2]
1951	Withheld	28,138	4,956	113,923	1,745,955[3]
1952	Withheld	33,000	--	79,989	2,369,944[3]
1953	Withheld	36,958	2,524	49,821	3,171,686[4]
1954	Withheld	50,000	2,017	33,321	2,791,510[4]
1955	21,000	101,624	1,875	24,406	3,193,451[4]
1956	94,000	97,751	2,780	5,419	4,355,760[4]
1957	44,653	50,757	3,288	----	2,103,932[4]
1958**	8,391	50,000	2,510	----	2,183,910[5]

*Precious and base metal mines only.

**Preliminary figures, subject to revision.

[1] Figures from Colorado State Oil and Gas Conservation Commission, all others from U. S. Bureau of Mines Minerals Yearbooks.

[2] Includes only value of gold, silver, copper, and lead production.

[3] Includes only value of gold, silver, lead, copper, fluorspar, tungsten, and coal.

[4] Includes value of all products listed plus fluorspar, tungsten, peat, beryl, feldspar, mica, and gem stones.

[5] Same as [4] but includes uranium production.

The wide variety of geologic conditions existing in Boulder County permitted the accumulation of mineral deposits of varied types. The principal economic minerals produced from these deposits, as well as the possibilities for discovering additional economic concentrations, are discussed below.

Fluorspar—The principal fluorspar producing area is the Jamestown district where "Most of the Fluorspar deposits give promise of extending to considerable depth below the present workings" [15] —and— "In addition, several large nearly barren breccia zones that show small amounts of fluorspar at the surface are considered to be worthy of exploration at depths ranging from 100 to 200 feet" [15].

The County's fluorspar industry experienced some reverses during 1958. One of these was the cessation of government purchases at the end of the year, which had been a strong factor in maintaining domestic production. Another was the continued inroads made into the American market by cheaper foreign fluorspar, chiefly from Mexico, Italy, and Spain. By the middle of 1959, only one major operator was active in the County.

Fluorspar occurrences of the Jamestown district are discussed by Ralph E. Van Alstine and the general geology and metallic ore deposits by E. N. Goddard, both of the U. S. Geological Survey, on pages 459-460 and 323-327 respectively, of "Mineral Resources of Colorado" (Vanderwilt), 1947. Additional information is contained herein on pages 80-82 under Precious and Base Metals.

Tungsten—The Boulder Tungsten division has contributed most of the tungsten ore production derived from Boulder County. However, the history of production from these deposits reveals their noncompetitive nature, for they have proven to be economically workable only during periods of national emergency under heavy government subsidies. Nevertheless, there remain appreciable reserves of tungsten ore in the County which must be considered among the State's mineral resources.

Boulder Tungsten District—This district extends in a narrow southwesterly belt almost 10 miles long and from one to two miles wide, from Arkansas Mountain about 4 miles west of Boulder, to Sherwood Flats a mile northwest of Nederland. A general discussion of the geology of the district is contained on pages 328-326 of the 1947 edition of this book (Vanderwilt). Additional information is given below.

Geology[14]—The Boulder Tungsten district is located entirely within a terrane of pre-Cambrian rocks of which the most extensive is Boulder Creek granite. The only large mass of Idaho Springs formation schists and gneisses occurs in the western part of the area just west of the small Boulder Creek granite batholith northeast of Nederland. The contact between the granite and the Idaho Springs metamorphics extends north-northwestward from the east end of Barker Reservoir, just east of Nederland and west of Tungsten, through Hurricane Hill. Foliation of the schist is in general parallel to the bedding planes of the original sedimentary rocks which are intricately folded on a general trend parallel to the edge of the Boulder Creek granite batholith. Over wide areas, the apparent trend of the schistocity is remarkably uniform and, in the western part of the district, has an average strike north-northwesterly with a general dip of about 60 degrees northeasterly.

East of Hurricane Hill the country rock consists almost entirely of Boulder Creek granite and related rocks such as aplite and pegmatite. Many dikes of these latter rocks cut the granite in a direction mostly parallel to the platy structure of the granite, but a few of them cut across the structure. Although the rock of the Boulder Creek batholith is usually called a granite, it is technically a quartz monzonite and locally, a granodiorite. Strictly termed, the only granite in the batholith is found near Gold Hill, north of the Tungsten district.

The early(?) Tertiary porphyry rocks exposed within the district are all dikes and show considerable divergence from the northeastwardly trend of the porphyry belt as a whole, although their distribution conforms with that of the belt. Monzonite and hornblende monzonite porphyries are the most abundant, particularly in the western part of the district. Dikes of highly altered silicic felsite are found at the extreme east and west ends. Biotite latite porphyry and intrusion breccia occur in small dikes chiefly in the central and eastern areas. Gabbro occurs in the large and persistent Iron Dike in the eastern part of the district and in a few small dikes north of Nederland. The gabbro is black, or greenish-black, medium-grained, slightly diabasic, weathers to a brown color, and is typically more severely jointed than the adjoining rocks.

Deposits of coarse gravel of undetermined age and origin cap Tungsten Mountain to the southeast of Nederland, as well as high ridges and hills in a narrow belt which extends eastward for five miles. The Quaternary deposits comprise glacial moraine, glacial outwash gravels, and alluvium. Early glacial drift is scattered in moraine remnants along the valley sides and in the valley bottom near Nederland. A heavily timbered ridge which crosses the valley of Middle Boulder Creek about half-mile west of Nederland is a terminal moraine of Wisconsin age. The town of Nederland is built on outwash gravels of the Wisconsin glacier.

Structure[14]—The dominant structural feature of the tungsten district is the Boulder Creek batholith whose intrusion closely influenced the structure of the surrounding schist. Although no pre-Cambrian faults have been identified with certainty in the district, many doubtless exist. Some of the discontinuous dikes of Tertiary monzonite porphyry which are strung along an east-west line northeast of Nederland, mark a zone of weakness which possibly could be of pre-Cambrian age.

Most of the structural features which define the Front Range were formed during the Laramide revolution. The most prominent faults in the eastern part of the range have a northwesterly trend and extend diagonally from the border toward the middle, but on the western edge of the range, the main faults strike northeasterly. The northwestward trending faults of the eastern part of the Front Range are persistent for many miles in the pre-Cambrian terrane. The areas between the major faults are broken by many minor faults and vein fissures, most of which strike northeasterly nearly at right angles to the major faults.

The "breccia reefs" or "dikes", as they were known to the early miners, are silicified fault zones. In general they mark the major faults of the early northwestward-trending fracture system. In the Tungsten district the reefs are spaced 2 to 3 miles apart across the entire length of the district. From east to west they are known as: the Hoosier Reef, which marks the eastern end of the Tungsten district; the Livingston Reef; the Hurricane Hill Reef; and, the Maine Cross reef which marks the western end of the district.

The northwestward-trending fractures of the breccia-reef system are the oldest Laramide fractures recognized in the district and surrounding region. They are followed by the earliest dikes, such as the Iron Dike, and are cut and displaced by the northeastward-trending veins. Many of the fractures were mineralized with quartz and hematite before the tungsten vein fissures were formed. The Rogers Reef, where it crosses the ridge between North and Middle Boulder creeks, carries abundant hematite and quartz in a zone 20 to 30 feet wide and contains as much as 0.03-ounce of gold to the ton. Many of the veins with an easterly strike in the eastern part of the district show characteristics of the breccia reefs and are believed to be reef fractures that were partly reopened and mineralized during the tungsten deposition. Although many important ore bodies have been found in the northeastward-striking veins near the intersections with the reefs, the breccia reefs themselves are generally barren excepting where they were reopened at the time of vein formation and were mineralized with tungsten and gold, particularly near the margins of the district.

Ore Deposits[14]—The tungsten veins in the Boulder Tungsten district lie in a narrow belt extending from Arkansas Mountain, four miles west of the mountain front near Boulder, west-southwestwardly to the town of Nederland almost 10 miles distant. For the most part the belt is one to two miles in width, but at its western (Nederland) end it flares to a width of three miles. The belt, which covers an area of approximately 20 square miles, is readily accessible by automobile.

The principal tungsten production of the district has come from veins close to the northwestward-trending breccia reefs. The ore shoots are small and occur as fissure filling in veins. Ferberite ($FeWO_4$) is the principal ore mineral, but locally it grades into a low manganese wolframite [$(Fe, Mn) WO_4$]. Scheelite ($CaWO_4$) is found as a late mineral in many of the veins, but is only an accessory in many of the ore shoots. The predominant gangue mineral is a fine-grained quartz known locally as "horn" quartz, accompanied by sulfides, carbonates, and clay in small amounts. Silver ore formed during an earlier mineralization period than that of the tungsten, has been mined from several veins near the Hoosier breccia reef in the northeastern part of the district. Gold telluride is found in the central and northeastern part of the district and is probably earlier than the main tungsten mineralization. The structure, associations, mineralogy, and texture of the tungsten deposits indicate that they were formed under a relatively light load at moderate temperatures by hypogene solutions and that they should be classed as epithermal deposits formed near the magmatic source.

Although ferberite is found scattered throughout the Boulder Tungsten district, almost all the production has come from a few small areas which together comprise only a small fraction of the total; all of these are near breccia reefs. More than half of the total output of the district has come from two small areas which together cover an area of less than one square mile. One is in the vicinity of the Conger mine about half-mile northwest of Nederland, and the other along the east flank of Hurricane Hill north of Tungsten. The Conger mine is by far the largest in the district and has an output of over 400,000 units of WO3. As regards size and tenor of the tungsten ore shoots, an average of over 50 of these yielded a little over 350 tons as a mean total, assaying approximately 8% WO3. No progressive change in the ore has been noted with depth.

Prospective[14]—The general areas regarded as most favorable for prospecting in the Boulder Tungsten district, are those close to the major breccia reefs, although commercially valuable ore bodies are known to lie between them, and others will probably be found outside them in the future.

Experience through the district shows that different types of country rock are favorable to the ferberite ore shoots in different degrees. Within the metamorphic area, aplite, pegmatite, and granite, make excellent host rocks, but within the batholith of Boulder Creek granite, ore bodies, especially the smaller ore shoots, are likely to expand between walls of pegmatite and aplite, and to contract where granite forms both of the walls.

The character of the wall-rock alteration along the vein is significant. Strongly argillized wall rocks are unfavorable unless there is a well-developed silicified or sericitized casing along the vein itself. Branch veins in an argillized hanging wall are very likely places for ore if the walls are sericitized or fresh (away from the argillized zone) but unfavorable otherwise. The presence of minor quantities of lead, zinc, and silver sulfides, or of a small amount of barite, pyrite, or opal, suggests the possibility of ore nearby in the vein. Mineralization of this type has been noted at the top of Hurricane Hill in the Hurricane Hill breccia reef, and future work may prove the presence of ferberite ore bodies in branch veins beneath the heavy soil cover of this locality. If the direction of relative movements of the fissure walls is known, and changes in strike and dip of veins can be determined in advance of exploration, the most favorable localities for investigation can be forecast; however, it is much easier to locate the intersection of veins.

Petroleum—Petroleum was first discovered in 1902, when well McKenzie No. 1 was completed as a small producer just east of Boulder town in what became known as the Boulder field. *Present production is from the Hygiene sands and fractures of the Pierre shale, and from Lower Cretaceous sands.

As of the end of 1959 there were two oil fields in the County, the Boulder field, and the Highland field which extends into Larimer County. During that year, the two fields produced an aggregate of 1,682 barrels of oil, and had a cumulative production up to that time, of 751,842 barrels.

*Boulder County lies entirely on the western limb of the Denver Basin, but despite semi-continuous drilling in an effort to develop additional oil since the first discoveries, very little success has been encountered. Nevertheless, much of the County remains to be adequately tested. The more favorable horizons for future exploration are the sands of Lower Cretaceous age. The Mesozoic and Paleozoic rocks offer but minor possibilities for future development.

Coal[6]—Boulder County has extensive reserves of coal in the southeastern part within the Boulder-Weld field, part of the Denver Coal Region. The coal occurs in the Laramie formation of Upper Cretaceous age as lenticular beds of subbituminous rank. The County's reserves, considering only those deposits which are overlain by less than 1,000 feet of overburden, are estimated at about 425 million tons contained within an area of 58 square miles.

For a number of years the industrial, commercial, and domestic consumers of fuel have been steadily turning away from coal while increasing their demands for fluid fuels. This adverse trend in the market has caused the virtual cessation of coal mining operations in Boulder County.

Sand and Gravel—These materials are produced from main stream courses in the eastern half of the County, such as Boulder Creek, Coal Creek, Lefthand Creek, Little Thompson River, St. Vrain Creek, and some of their tributaries. Other sand and gravel deposits are scattered along many of the drainages, particularly in the eastern half.

Stone—Boulder County has a variety of stone suitable for use in the construction industries and for other purposes. Granitic rocks are widespread throughout the western half, but most of the commercial stone is derived from the Lyons sandstone of Permian age, which is used in the form of slabs for buildings, flagstones, terraces, fireplaces, etc. Many of the

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

beautiful buildings on the campus of the University of Colorado are faced with Lyons sandstone. The Lyons is a nearly pure, quartzose sandstone pinkish or reddish in color, built up of sheaves of thin laminae which permits easy separation. There are large resources of this material in Boulder County easily accessible along the eastern margin of the Front Range.

Clays—Boulder County has substantial deposits of clays in the eastern part, which occur in various sedimentary formations: Morrison (Jurassic); Dakota, Benton, Pierre, and Laramie (Cretaceous). The clays vary in characteristics, and dependent on these, deposits exist suitable for the manufacture of many varieties of construction materials, such as brick, tile, conduits, hollow blocks, etc.

Uranium*—The northern and eastern margins of the Jamestown mining district contain uranium-bearing vein structures in the Silver Plume granite and Boulder Creek granodiorite of pre-Cambrian age. At present there is one steadily producing uranium mine in the area and several prospects, with extensive areas exhibiting similarly favorable geologic environment for high-grade vein-type uranium deposits.

Barite[18]—A barite vein occurring in granite of pre-Cambrian age, is reported in the Sunshine Canyon area of Boulder County. Some barite was mined from this deposit in 1916. Siliceous barite has been found at the Buena Vista mine in a vein in pre-Cambrian granite on Lefthand Creek about three miles west of Millers Station.

Pegmatite Minerals — Feldspar, scrap mica, beryl, and columbite, have been produced from pegmatites occurring in a zone about seven miles north-northwest of Boulder, and south of Gold Hill. A small cerite (a hydrous cerium silicate) bearing pegmatite occurs about two miles northeast of Jamestown.

Nickel[19]—The Copper King mine, a small copper prospect three-quarter mile southwest of Gold Hill, contains a sufficient concentration of nickel, and some cobalt minerals, to represent a possible commerical deposit. The prospect is in an area of pre-Cambrian schists and gneisses of the Idaho Springs formation, about half-mile from the edge of a small batholith of pre-Cambrian Boulder Creek granite. The nickel occurs in the coarser-grained and more calcic layers of amphibolite. In these layers, pyrrhotite, pyrite, chalcopyrite, and several nickel minerals are irregularly disseminated or form a network and replace various of the amphibolite minerals. The recognized nickel and cobalt minerals are: polydymite (Ni_3S_4), bravoite (FeNi) S_2, violarite (NiFe) $_3S_4$, niccolite (NiAs), pentlandite (NiFeS), millerite (?) (NiS), and cobaltite (CoAsS).

*Dr. Donald L. Everhart, USAEC, personal communication.

The ore's grade varies widely. In the oxidized zone it may carry from 1 to 13% nickel, 0.2 to 6.2% cobalt and, from 0.05 to 31% copper. Samples taken from newly exposed sulfide ore assayed from 2.91 to 5.66% nickel, 0.13 to 0.21% colbalt and, from 0.32 to 1.15% copper. At the time of Dr. Goddard's last visit to the prospect in 1940, about 25,000 tons of ore containing 2% to 3% nickel had been blocked out, and diamond drilling indicated the probable existence of another 30,000 tons with about 0.5% nickel.

Precious and Base Metals—There are a number of metal mining districts established in Boulder County; these districts are discussed on the following pages of Mineral Resources of Colorado, John W Vanderwilt, 1947.

Boulder County (production statistics) — p. 33.

Central (Jamestown) — pp. 34-35, general data; pp. 323-27, geology.

Gold Hill (Rowena, Salina, Sunshine) — pp. 35-37, general data; p. 315, geology.

Grand Island (Cardinal, Caribou, Eldora, Nederland) — pp. 37 and 38, general data; p. 315, geology.

Magnolia — pp. 37 and 39, general data; p. 316, geology.

Sugarloaf — pp. 39 and 40, general data; p. 319, geology.

Ward — pp. 39 and 41, general data; p. 318, geology.

Additional information on some of the foregoing districts is contained below.

Gold Hill District[12]—Though most of the mines in this district are less than 600 feet deep, in nearly every one where exploration has extended to greater depths commercial ore has been uncovered and mined. Though the deepest workings are little more than 1,000 feet below the surface, ore has been mined in the district through a vertical range of about 2,500 feet and, where structural conditions are favorable, it seems likely that in many of the mines ore will extend to greater depths than the present workings. In most of the properties the depth of mining has commonly been determined by water and other operational difficulties rather than by pinching out of the veins.

Jamestown District—Similarly to the Gold Hill district, the mines in the Jamestown district are less than 600 feet deep. In none of the mines which were accessible to Goddard[16] during his examination had the veins been found to bottom with depth; in most of them the veins were as strong at the bottom level as at the surface. As ore has been mined over a vertical range of 2,300 feet, it seems probable that if structural conditions are favorable, ore bodies may be found at considerable depth below the present workings. At numerous places within the district there are structural conditions as yet unexplored that appear favorable for the localization of ore and it seems likely that many new ore bodies will be uncovered in the future comparable to those mined in the past.

Structure[12]—Five types of structure have played a part in determining the course of the veins and ore shoots in the district: that of the schist and gneiss; that of the pre-Cambrian granites; the primary structure of the Laramide intrusives; faulting during the Laramide revolution; and, post-intrusion faulting.

Throughout the Jamestown district the foliation of the Idaho Springs formation has a general northwesterly trend which ranges from north 10-degrees east to north 75-degrees east. The dip is moderately steep and generally to the east or southeast with local variations to west or northwest. In the north-central part of the district the Swandyke horn-blende gneiss forms part of a well-defined, shallow, structural basin or trough. Near the centre the gneissic structure is almost horizontal, but is modified by numerous small domes 100 to 200 feet across. The trough is broken on the south and southeast by the intrusion of Silver Plume granite.

In the Boulder Creek granite areas in the southern part of the district, the strike and dip of the foliation or platy structure conform generally with that of the surrounding schist. This may indicate that the granite was intruded at a moderately steep angle from the south and is therefore a part of the large batholithic mass of the Gold Hill-Boulder Canyon region. In the Overland Mountain stock, the platy structure dips in toward the center of the mass and the linear structure pitches toward a point near the north end of the mass. It is inferred that this body of Boulder Creek granite magma came up steeply from its north end and spread out to the south in a steeply-inclined somewhat funnel-shaped mass.

The Silver Plume granite's linear structure points to several widely separated centers of intrusion and suggests that there are four coalescing stocks of Silver Plume granite in the district. The granite west and northwest of Jamestown probably came from a center in the northwestern corner of the district. The granite body east and northeast of Jamestown apparently rose from a center 1¼-miles southeast of Jamestown and spread out fan-wise to the north. Another small stock rose from a point just north of Fairview Peak, and the granite in the extreme northern part of the district, east of Balarat, seems to have come up from under the horn-blende gneiss area three miles north of Jamestown.

In the Laramide granodiorite stock the platy structure indicates that the whole mass has a generally steep dip to the southwest and approximates the shape of an inclined cylinder. The structure of the small sodic granite-quartz monzonite stock is rather obscure but it may be that this mass came up under the granodiorite stock from about west-southwest at an angle of 45 to 60 degrees. This direction seems to have had an important bearing on the distribution of the ore.

Faulting on a large scale took place before the intrusion of the porphyries in the Jamestown district. These early faults are marked by persistent, silicified breccia zones that trend northwestward. The breccia "reefs" seem to end abruptly against large bodies of schist in which the fault movement was probably taken up by crumpling of the schist without the formation of clear-cut openings or fault zones.

The Maxwell is the strongest and most persistent of the breccia reefs in the district, and cuts across the central part in a northwesterly direction with a dip of from 75 to 85 degrees northeasterly. In the south-central part of the district the reef is cut by the large granodiorite stock. Near the John Jay mine in the southwestern part, there is another strong breccia reef which may be a continuation of the Hoosier reef of the Gold Hill district, but is separated from it by a broad area of schist. This reef strikes north-25 degrees-east for about a mile from near the John Jay mine to the top of Overland Mountain, where it veers to north-60 degrees-west. The Standard breccia reef in the eastern part of the district is much less extensive than the other two. The Standard vein and a porphyry dike follow the course of the breccia reef.

There are several other less extensive pre-ore faults which appear to belong to the breccia-reef period. At Gold Lake, in the extreme southwestern corner of the district, is a reef of strongly silicified granite and bull quartz which appears to be related to the Livingston Reef of the Gold Hill district. The Careless Boy vein in the northern part of the district, as well as the several short, steep-angle, northwesterly faults occurring southwest of the Smuggler mine, appear to be of the breccia-reef type.

The fault fissures occupied by the ore-bearing veins were formed after the intrusion of the porphyry stocks and dikes. Some veins cut the porphyry stocks, and others follow the walls of porphyry dikes. In the Jamestown district there is a system of mineralized fault fissures of an earlier age which trends northwesterly, and a younger system which has a northeasterly trend. The northwestward fissures were filled during the earlier stages of mineralization by the lead-silver and fluorspar deposits. The northwestward trending fissures were filled by the pyritic gold and telluride ores. Both sets of fissures show considerable shearing; brecciation and slickensided walls are common.

Magnolia District [16]The best ore bodies in the district have been found close to the intersection of cross veins or to the junctions of converging veins, but some have been localized by abrupt changes in strike and dip of the veins. The mines of the district are comparatively small, most of them being only a few hundred feet deep. Future exploration will probably uncover new ore bodies in the district, but the smallness of the deposits and lack of persistence of the vein fissures makes it seem unlikely that any large mines will be developed.

Ward District—This district is located in the west-central part of Boulder County about 19 miles by road west-northwest of Boulder town. It was discovered in 1861, one of the first and most productive in the County.

Geology[12]—The southern part of the district is chiefly in northward dipping schists and gneisses of the Idaho Springs formation, but in the northern half much of the country rock is Silver Plume granite. Several Laramide stocks of diorite and monzonite porphyry occur south and east of Ward. Porphyry dikes are common throughout the district but are more abundant in the northern half.

The most common rock of the Idaho Springs formation is a garnetiferous quartz-mica schist most abundant in the northeast. It contains some sillimanite and, in the southeastern part of the area, it grades into a facies which may be termed sillimanite schist. A fine-grained, dark, quartz-biotite schist is locally abundant in the northeastern part of the district. Southeast of Copper Rock the northwestern edge of the Boulder Creek granite batholith trends northeastward parallel to the foliation in the adjacent schist. The Silver Plume granite in the Ward district is the southern portion of a large stock that extends northward to the Thompson River. Associated with this stock are numerous dikes and irregular masses of pegmatite and aplite.

Fourteen varieties of Laramide intrusive rocks have been identified in the Ward district, most of which occur in dikes varying greatly in width, and ranging from a few hundred feet to over two miles in length. The White Raven quartz monzonite porphyry, locally known as "birdseye" porphyry, occurs in many dikes but is restricted to a belt less than two miles wide extending westward from Sunset to Sunnyside and northward to Ward. In many places the contact of this porphyry with the country rock is highly mineralized. Quartz latite has been noted in three localities in close association with quartz monzonite; at the White Raven mine it is found associated with White Raven porphyry where it has been impregnated with silver-bearing galena. There are several latite porphyry dikes scattered through the Ward district and nearly all are mineralized at their borders, and some of them are mineralized throughout. Abundant pyrite is present which locally contains appreciable values in gold.

Trachyte occurs near the village of Sunset about four miles southwest of Ward in an irregular stock and in several dikes. The main body of trachyte is on Bald Mountains about a mile and a half west of Sugar Loaf Mountain. The andesites, believed to be equivalent to the biotite monzonite of the tungsten belt, form dikes which attain a maximum length of a half-mile and are most common in the southeastern part of the district east of Bald Mountain and Copper Rock. Intrusion breccia, which has been found near Sunset, is a fine-grained, glassy rock containing fragments of schist, granite, pegmatite, and, locally, of earlier porphyries. In the upper tunnel of the Free Coinage mine, about half-mile south of Sunset, irregular stringers and seams of intrusion breccia are exposed in a strong northwesterly fault on the east side of a trachyte dike.

Ore Deposits[12]—Gold, silver, lead, copper, zinc, and tungsten, are the valuable constituents of the Ward district ores; the first three being responsible for most of the output. Nearly all of the ore occurs in tabular shoots or in chimneys roughly elliptical in cross section that appear to be local enlargements of the veins. The largest of these, in the White Raven mine, is about 30 feet wide and extends 200 feet along the vein.

The most productive veins have been found in granite or gneiss along dikes of quartz monzonite, quartz latite, and felsite, but some of the dikes are later than the ore. The veins in the Idaho Springs formation are much less continuous and generally of much lower grade. In many places, well defined veins in granite and gneiss feather out after entering the schist.

Although there are approximately 200 mines in the Ward district that have supplied ore, probably no more than 50 have produced ore valued at more than $5,000, and probably no more than 15 have produced ore valued at over $100,000.

Nearly all the gold mined in the district has been associated with pyrite and/or chalcopyrite in quartz veins. Generally, chalcopyrite gold is richer than that associated only with pyrite. Silver occurs with the gold and chalcopyrite, but is most abundant in galena ore. Enrichment of the pyritic gold ores in the oxidized zone above the water table has been responsible for all the rich free-milling gold ore in the region. The level of ground water in the district ranges from 50 to 250 feet below the surface, but generally it is less than 100 feet. Near the surface the vein minerals are oxidized and limonite is abundant. The iron-stained quartz is loose and honeycombed, containing drusy cavities lined with late quartz crystals. This "rotten quartz" is well known for its high values in gold.

The lead-silver ore is limited largely to the White Raven vein system. The gangue minerals are calcite and barite containing abundant galena in large well-formed crystals. Silver alloyed with gold occurs as a primary mineral included in the galena. Sphalerite is not abundant except locally. Galena, primary silver, and gold, are apparently contemporaneous with some calcite and are earlier than barite and a second generation of calcite. Later than all these is abundant supergene wire silver. In the oxidized zone the silver content is somewhat lower than immediately below the water table. Gold is not an important constitutent of the silver-lead ore, and zinc is commercially unimportant.

Copper-bearing ore in the Ward district has been valuable chiefly for its gold content, but both chalcopyrite and chalcocite are sufficiently abundant to be of commercial interest. From the Sunset area in the southeastern part of the district, chalcopyrite ore has been shipped which approximated 20% copper.

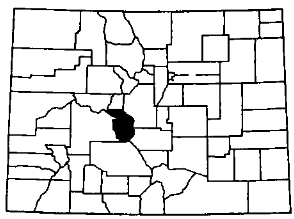
Gold telluride ore has been found locally in some mines. It is common in the eastern side of the district and has also been reported from the Morning Star mine in Spring Gulch.

Wolframite — $(Fe,Mn)WO_4$ — intimately associated with quartz and pyrite and with small amounts of chalcopyrite, is widely scattered through the veins of the district. It is most abundant north of Ward and in the eastern part of the district near Gold Lake.

Geological Note—Boulder County covers a wide variety of topographic relief and geologic terrane; from the mile-high elevation of the sedimentary plains in the east, to the 2½-mile elevation of some of the pre-Cambrian peaks of the Continental Divide to the west.

The western half lies within the confines of the northern extremity of the Front Range mineral belt in pre-Cambrian terrane. The eastern half is surfaced by sedimentary rocks which range in age from the Pennsylvanian Fountain arkoses and ferruginous shales, steeply tilted against the eastern margin of the mountains, to the Tertiary Denver formation in the southeastern corner of the County, and to the Recent alluvium along main streams and their tributaries. Moraines of Pleistocene age are found in the mountain areas in the western part. Eastwardly from the Fountain arkoses and shales are exposed in sequence: the Permian Lyons formation; the Permo-Triassic Lykins formation; the Jurassic Morrison formation; the Upper Cretaceous: Dakota, Benton, Niobrara, Pierre, and Laramie formations.

Chaffee County



Courtesy Colorado Planning Division

Chaffee County, in central Colorado, has an area of 1,040 square miles ranging in elevation from 7,000 to 14,420 feet, and a population of close to 7,500. The county seat is at Salida, a ranching, farming, mining and business center with a population of 4,800.

Available Maps of the County—

a. Chaffee County Map.
b. U. S. Army Map Service maps: 4662 II; 4760 I; 4761 I, II, III, IV; 4762 II, III; 4861 III, IV.
c. U. S. Geological Survey topographic quadrangle maps cover only a small portion of the County. See index map in the pocket.
d. U. S. Forest Service map "San Isabel National Forest" includes the County.

Mineral Production 1946-1958—Chaffee County produces relatively small quantities of a variety of minerals. Nonmetallics represent the most important group produced. The U. S. Bureau of Mines attributes fully 99% of the total value of the County's mineral production during 1959 to nonmetallics, of which limestone and sand and gravel were the leaders. Beside the items listed in the table, Chaffee County produced stone, sand and gravel, fluorspar, pegmatite minerals, tungsten concentrate, and gem stones. The figures in the table are from U. S. Bureau of Mines Minerals Yearbooks.

	Active Mines		Gold	Silver	Copper	Lead	Zinc	Total
Year	Lode[1]	Placer	Ozs.	Ounces	Pounds	Pounds	Pounds	$ Value
1946	5	1	412	17,196	78,000	47,000	722,000	134,157[1]
1947	5	2	300	49,001	262,600	47,500	141,800	133,990[1]
1948	6	1	275	1,243	----	100,000	2,000	28,916[1]
1949	8	2	103	3,572	----	96,000	24,000	24,982[1]
1950	7	-	217	2,801	2,000	158,000	4,000	32,444[1]
1951	4	-	40	558	----	32,000	38,000	877,427[2]
1952	3	-	33	569	4,000	42,000	54,000	1,269,708[2]
1953	2	-	284	664	2,000	22,000	32,000	1,763,672[2]
1954	5	-	20	750	----	32,000	24,000	1,380,763[2]
1955	4	-	1	979	----	12,000	----	988,339[2]
1956	6	-	18	1,972	2,800	37,300	11,600	977,425[2]
1957	1	-	4	2,188	1,700	144,300	----	970,629[2]
1958*	1	-	3	569	2,000	26,000	----	812,747[2]

*Preliminary, subject to revision.
[1] Precious and base metals only.
[2] Includes all mineral production.

The wide variety of geologic conditions existing in Chaffee County permitted the accumulation of mineral deposits of varied types, many of which have yielded commercial production. Some of these deposits are discussed below.

Stone — For a number of years limestone has been the predominant type of rock produced in the County. Virtually all of the output has come from the Monarch quarry in the southwestern part, and used chiefly in steel making at Pueblo. The material quarried occurs in a pure limestone bed about 100 feet thick, overlying a black dolomite near the base of the Leadville limestone of Mississippian age.

[9]A deposit of varicolored marble 398 feet thick is reported in Sec. 1, T-49-N, R-9-E, overlain by trachyte and sandstone

and underlain by quartzite. Another one[9] is located three miles northeast of Turret, in T-51-N, R-9-E.

[23]A small quantity of marble has been produced from a small quarry in Taylor Gulch of the Monarch district, but most of the marble is too coarse-grained and too remote from adequate transportation to be competitive.

Sand and Gravel—Sand and gravel are produced from deposits along the course of the Arkansas River between the towns of Salida and Buena Vista. A wide band of Quaternary terrace deposits extends from north to south across the County west of the Arkansas River.

Fluorspar — There are three main fluorspar producing areas in Chaffee County: the deposits at Poncha Springs; those near the top of Poncha Pass; and, those in the Brown's Canyon district.

Poncha Springs Area — [20]The deposit at the Poncha Springs fluorspar mine, about one mile southeast of Poncha Springs, is a north-south trending vein in a shear zone over 100 feet wide and several thousand feet long, with well defined walls, dipping steeply to the east. The wall rocks are pre-Cambrian granite, schist and amphibolite, which in the shear zone have brecciated into fragments of many sizes surrounded by gouge. Many small, independent faults within the shear zone separate blocks of fragmented granite with numerous open spaces. The spaces have been filled and the fragments partially replaced by fluorite, quartz, and calcite. The manner of deposition of the fluorite, and its texture, indicate epithermal conditions of accumulation. Other factors point to a Late Tertiary age for this deposit.

Poncha Pass Area —[20]Near the top of Poncha Pass, about one mile east of Highway 285, and about five miles south-southeast of the Poncha Springs mine, there is a fluorspar deposit in a shear and gouge zone cutting pre-Cambrian quartzites and muscovite schists. Fluorspar, calcite, quartz, opal, and chalcedony, occur in this shear zone which has roughly the same strike and attitude as the Poncha Springs vein. Rather than being a continuation of each other, these two zones appear to be in echelon. At least four mines have been established in the Poncha Pass area.

Brown's Canyon District—[21]The Brown's Canyon district, about 10 miles north of Poncha Springs, has been actively worked through the years by several companies. The country rocks are a complex of granite, gneiss, schist, and a porphyritic rhyolite flow. The longest vein in the southern part has been mined for a horizontal distance of 1,600 feet. The widest vein, 35 feet across at one point, occurs at the intersection of faults between the rhyolite and the granite gneiss. —Further data on this district is given on page 460 of the 1947 edition of this book (Vanderwilt).

Pegmatite Minerals — Feldspar, mica, and rare minerals have been produced from the Trout Creek Pass area in the eastern part of the County, and from the Turret district about 15 miles south of Trout Creek Pass. The rare earth minerals and beryl can be produced only as byproducts of feldspar and mica operations, but the low price of these materials and their high transportation costs prevent continuous mining of the pegmatites.

Chaffee County's most important deposits of beryllium minerals are located in the Mount Antero region in the south-central part, about 15 miles northwest of Salida. Various attempts have been made to mine these deposits but they have not been successful to date. As of this writing (July, 1959), a pilot plant to test a process for producing beryllium hydroxide is being operated at Salida, the report is that the process appears to be successful. New interest is being shown in the Mount Antero region which is discussed below.

Mount Antero Region —This area lies in very high and rugged terrain difficult of access.

[22]The following minerals occur in small pegmatites and in quartz veins, some of which were formerly mined for molybdenum: beryl—$Be_3Al_2(Si0_3)_6$; phenacite—Be_2Si0_4; and bertrandite—$H_2Be_4Si_20_9$.

The pegmatites have been described by Switzer (1939, p. 793), as being "uniformly small, seldom exceeding three feet in width, and extending laterally for only a few feet". Switzer classified them as follows:

1. Beryl pegmatites: beryl and smoky quartz.
2. Phenacite pegmatites: phenacite—colorless quartz; phenacite—smoky quartz.
3. Beryl-phenacite-bertrandite pegmatites: beryl-phenacite-bertrandite; beryl-phenacite-bertrandite-fluorite.
4. Topaz pegmatites.

The vein type deposits consist of quartz veins containing beryllium minerals. These veins differ from the pegmatites in that they are much richer in quartz, have little or no feldspar, and seem to be more continuous. In general, the veins' mineralogy is quite similar to that of the pegmatites, and it appears that a close relationship, if not a complete gradational sequence, exists between the veins and the pegmatites.

The California mine vein, located about 2 miles southwest of Mount Antero's crest, at about 12,500 feet elevation, is in country rock of Pomeroy quartz monzonite. Wall rock alteration is apparently related to intensity of vein mineralization, for where the vein is essentially barren of molybdenum or beryl, the quartz monzonite is unaltered, with the exception of 1-inch or less of silicious material along the contact. But where mineralization occurs, as noticed from the dump, it is associated with a sericite-quartz rock, probably altered country rock adjacent to highly mineralized parts of the vein. The sericite-quartz rock contains abundant molybdenum and molds of cubic pyrite crystals. Worcester (1919, p. 36), who saw the vein, said it varied from 18-inches to 3-feet in width, and that it had been followed on the surface by float for a mile or more.

The beryl varies in form, transparency, and color, and carries the relatively high beryllia content of 13½%. Molybdenum occurs in small veinlets in the massive quartz outcrop of the vein. Worcester, P.G. (1919, p. 36), described the richer parts of the vein as follows: "Molybdenite is everywhere that the vein has been opened. The richer ore is near the walls, but there are rich streaks and vugs scattered all through the vein. In these rich streaks, and along the walls, chunks of solid molybdenite from 1 to 2 inches thick and from 6 inches to 2 feet in length, are common occurrence. The molybdenite is entirely crystalline" . . . "Much of the richest ore is found with beautiful specimens of beryl . . ."

The material on the California mine dump suggests that as much as 10% beryl may have been present in the molybdenum-rich parts of the vein. As exposed on the surface near the mine workings, the vein shows little beryl or molybdenite and, in part, is apparently barren. A channel sample across an outcrop contained 0.016% Be0, or less than 0.1% beryl.

Iron — An iron deposit near the eastern margin of the Turret district, called the Calumet mine owned by the Colorado Fuel & Iron Co., was operated in the late 1800's.

Lightweight Aggregates—Bush[28] reports the occurrence of the following lightweight aggregates in Chaffee County.

Pumice—*Nathrop-Ruby Mountain Deposit*—This deposit is located on the east side of the Arkansas River along the north end and east flank of Ruby Mountain northeast of Nathrop, in Sections 11, 12, 13, T-15-S, R-78-W. At the north end the outcrop is 50 feet thick over a length of 75 feet, and along the east flank, about 300 feet south of the north outcrop, the exposure is 70 feet thick and 80 feet long. Both outcrops apparently belong to the same deposit whose attitude is more or less horizontal. The pumice is not traceable to the west or south, is of aeolian origin, has not been reworked since deposition, and is overlain by a perlite flow 10 to 15 feet thick. The deposit consists of fragmental pumice with many pieces up to 5 inches in size and some larger blocks up to 2 feet long and 1 foot in thickness, but the bulk of the material ranges from ¼ inch to 2 inches in size. The younger material which overlies the deposit and forms most of the bulk of Ruby Mtn. would limit mining the material by opencut methods to a short distance from the outcrop.

Other pumice and/or scoria deposits are listed by Bush as occurring in the SE¼ of T-50-N, R-9-E, and in the SW¼ of T-50-N, R-10-E.

Perlite—*Nathrop-Ruby Mtn. Deposit*—(See above). A thin perlite flow is traceable for about 300 feet along the east flank of Ruby Mtn., and for about 200 feet along the north end. The entire thickness does not crop out, but the deposit appears to exceed 15 feet. The material is partly granular, gray-black to black volcanic glass, most of it possessing the typical shelly perlitic texture.

Vermiculite—*Turret Deposit*—This deposit was not examined by Bush, but he reports from other sources as follows. The deposit is located in section 28, T-51-N, R-9-E, and consists of a 20-inch 'vein' in pre-Cambrian granites and amphibolites. About 8 carloads of this material are reported to have been extracted between 1910 and 1930.

Tung Ash Deposit—This deposit was not examined by Bush, but he reports from other sources.

Location: Section 29 (?), T-15-S, R-77-W.

Occurrence: In 'veins' between 'gray granite' and 'black schist'. The 'veins' are probably alteration zones and are described to be as much as 4 feet thick with 'shoots' of vermiculite up to 40 feet long.

Abe Lincoln No. 2 Deposit—This deposit is located in section 14, T-14-S, R-77-W, and is an alteration product of a hornblende schist associated with pre-Cambrian granite. The alteration zone is reported to be several hundred feet long and 10 to 12 feet wide. The material is said to break out in fairly hard, small fragments.

Graphite—An occurrence of graphite from which apparently some shipments have been made, is reported 2 miles northeast of Turret. The graphite occurs interbedded with limestone, quartzite, and schist. The main bed is from three to four feet thick, and a second bed is about one foot thick. The beds are one mile long, have a north-south strike, and dip about 35 degrees to the east. The graphite is amorphous, fine-grained, earthy, and over 50% of it is classified as "second grade". Two 50-ft. shafts have been sunk in the main bed about 100 feet apart, and a 125-foot adit has been driven in below the shaft collars.

Manganese—*Ten miles northwest of Salida at the Liberty Hill mine, a massive limestone of Carboniferous age near the pre-Cambrian contact, contains a soft, brownish-black ore composed of wad (a mixture of hydrous oxides of manganese) and pyrolusite (manganese dioxide), with a manganese content of close to 34 per cent.

Uranium—**There are several areas in Chaffee County where the pre-Cambrian complex, intruded by varied Tertiary igneous rocks, provides favorable geologic environment for

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*Mr. Edward D. Dickerman, personal communication.

**Dr. Donald L. Everhart, USAEC, personal communication.

uranium mineralization. These areas are generally favorable to prospecting for vein-type uranium deposits.

Precious and Base Metals—The metal mining districts established in Chaffee County are discussed on the following pages of the 1947 edition of this book (Vanderwilt). Additional information on the Chalk Creek and Monarch mining districts is contained herein following the list below.

Chalk Creek Mining District—[23]This district is located in the western part of Chaffee County a few miles to the east of the Continental Divide.

[23]The largest and most important area in the district is a belt ½-to-2 miles wide and about 10 miles long which extends from the Continental Divide northeast across Chrysolite Mountain to the northeast corner of the Garfield quadrangle. In this area is located the famous Mary Murphy group of mines with its extensive workings which has produced at least 75% of the district's total output.

The ores of the district contain gold, lead, zinc, silver, and a little copper. Most of the ore was mined from pyritic quartz veins in the Mount Princeton quartz monzonite, although veins in other rocks have been productive. The veins generally strike northeast and dip steeply, ranging from mere stringers a fraction of an inch thick and less than 50 feet in length, to lodes 50 feet thick and over a mile in length; most of them are separate veins one to three feet thick. Galena and sphalerite occur in variable amounts in the pyritic quartz, chiefly in streaks from 1 to 12 inches in width. Some chalcopyrite generally accompanies the pyrite. The gangue is chiefly white, vuggy quartz, although calcite, rhodonite, rhodochrosite, barite, and fluorite occur locally.

Strong oxidized ore and vein matter are largely confined to the veins on the west slope of Chrysolite Mountain, where complete, or nearly complete, oxidation extends to a depth of about 400 feet, and partial oxidation to about 900 feet. Elsewhere, the veins show little or no alteration of the sulfides. As in the Monarch district, the deeper oxidized zones are above the height of glaciation. The oxidized ore is typically brown, porous limonite or limonite quartz with variable amounts of cerussite, calamine, smithsonite, and patches or grains of galena. Free gold reportedly occurs in much of the ore.

Monarch Mining District.—[23]The Monarch mining district is located about 20 miles west of Salida and just east of the Continental Divide.

Most of the principal mines in the Monarch district are situated on Monarch Ridge, about ½-mile south of Monarch, in the area which extends from Taylor Gulch west to Columbus Gulch. Outlying groups of mines are situated high up in Middle Fork and North Fork valleys, in Hoffman Park, and near the source of Cree Creek.

The district has produced silver, lead, zinc, gold, and copper, listed in order of probable value. According to Crawford (1913, p. 139), ore produced before 1913 from Monarch Ridge yielded chiefly lead, silver, gold, and zinc; Columbus Gulch ores were silver, gold, and lead; and the North Fork mines produced mostly silver and lead ore.

The ore deposits of the Monarch district consist of replacement deposits in limestone and dolomite, and of veins. The replacement deposits, by far the most productive, occur in bedded and irregular forms and along faults. The bedded and irregular deposits occur locally in all of the formations which contain limy beds, but they are particularly characteristic of the basal 50 feet of the Manitou dolomite, and in many places rest on granite.

The largest ore bodies mined occur as replacements in limestone or dolomite beds along faults. In the Madonna mine some ore occurs in pre-Cambrian rocks on the southwest side of the Madonna fault, but most of it is in sedimentary rocks on the northeast or downthrow side of the fault in shoots that lie adjacent to the faults. The main ore body forms an irregular but practically continuous shoot with a pitch length of about 1,900 feet and a vertical height of nearly 1,500 feet.

The bedded replacement deposits are especially well developed on the east sides of Taylor Gulch and Cree Creek valley. The ore occurs chiefly in lower beds of the Manitou dolomite.

Most of the ore obtained from the replacement deposits has been oxidized, although primary sulfide minerals were reached at varying depths in the deeper mines. The oxidized ore is typically brown, soft, porous limonite, containing variable amounts of cerussite, calamine, smithsonite, and occasional patches or grains of galena. The common primary sulfides are pyrite, galena, sphalerite, and chalcopyrite.

Most of the veins in the Monarch district occur in the Mount Princeton quartz monzonite and in the Belden and Minturn formations, with a few in sedimentary rocks older than the Belden, in crystalline rocks of pre-Cambrian age, and in Tertiary intrusive rocks older than the Mount Princeton quartz monzonite. In length the veins range from a few feet to 4,000 feet in the Columbus vein, and the thickness varies from 1 to 4 feet, although the Columbus is reported to range from 6 to 20 feet.

The unoxidized parts of the vein consist of variable proportions of galena, sphalerite and pyrite, with lesser amounts of chalcopyrite, in a gangue of white vuggy quartz. Silver is present in nearly all the sulfide ores, and gold is present locally. Oxidation is not nearly as pronounced, or deep, in the veins as in the replacement deposits. The veins in the sedimentary rocks are more deeply altered than those in the crystalline rocks.

Several ore deposits in the Monarch district are associated with minerals characteristically developed by contact metamorphism. All these deposits are near the head of Taylor Gulch or in Cree Creek valley, near a large body of Mount Princeton quartz monzonite which has irregularly metamorphosed the bordering sedimentary rocks to the southeast for as much as ½-mile. Silver ore is reported to be associated with magnetite in the Mountain Chief mine, sphalerite is associated with diopside and andradite near the New York mine, and silver, copper, lead, and gold are associated with garnet in the Clinton mine.

Several localities within the district appear promising for discovery of additional ore deposits of the type previously found in the area, but these must be explored by purely scientific methods.

One of the areas in which substantial ore bodies may occur is just east of the southern extension of the Lake fault, from the Monarch Contact Tunnel, about 5 to 10 degrees southeasterly for some 2,000 feet toward the Madonna mine No. 6 portal. This area is covered by glacial debris, but is probably characterized by complex faulting where the Lake, Mayflower, and Madonna faults meet in a zone which could very well have been a locus of ore deposition. Obstacles to exploration at this point are the thickness of the glacial cover which may be from 50 to more than 100 feet, and the heavy flow of water which is likely to be encountered.

Another area favorable for exploration, but also mantled by glacial till, lies high in the Cree Creek valley near the Clinton mine. Here a northwest-trending fault is evidently concealed beneath the glacial deposits. Considering the known ore deposits on either side of the valley, and the tendency for large ore bodies to form where large faults cut limestone beds, the possibilities of ore existing in commercial quantities along the fault seem good. The most favorable stratigraphic zone is the Manitou dolomite, especially near, or at, its contact with the granite. This zone could probably be explored by drilling or bulldozing on the downthrow side of the fault at a point about 400 feet southwest of the Clinton mine, and on the upthrow side at a point between 800 and 1,000 feet west-northwest of the mine. The sharp folds in the beds adjacent to the fault would likely increase rather than diminish the possibilities for concentration of ore in this area by forming structural traps for the ore solutions, as occurred in folded beds east of the Star fault in the Akron mine. The depth of glacial debris and soil in this vicinity is not known, but it is probably not over 35 feet.

In Taylor Gulch, the upper 150 feet of the Leadville limestone, particularly at its contact with the overlying Belden shale has been insufficiently explored. This area, from the lower Garfield Tunnel northward for about a mile, is worthy of further exploration. The beds dip steeply west, and the contact of the Leadville and Belden lies on the west side of the valley where it is covered in large part by slope wash and talus.

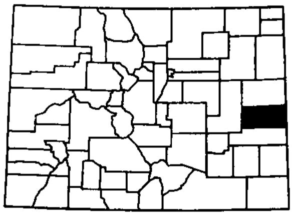
Gem Stones—There is no organized commercila production of gem stones in Chaffee County, but there are several localities where gem stones, mostly non-precious, occur. Below are listed some of the localities and the gem stones found therein.

[24]Locality	[24]Gem Stone
Calumet Iron Mine, Turret	Essonite (cinnamon stone), quartz crystal, sapphire, sagenite (transparent quartz with acicular crystals of rutile-TiO_2).
Calumet Mine, Salida	Ruby.
Chalk Creek, Buena Vista	Sapphire.
Dorothy Hill, Ruby Mountain area, Nathrop	Quartz crystal, almandite (a garnet type), spessartite (garnet type), topaz.
Mount Antero, Sawatch Range	Aquamarine, quartz crystal, smoky quartz, topaz.

Geological Note—Chaffee County lies in an area of vast relief, from the valley floor of the Arkansas River which runs in a southerly direction through the east-central part of the

County, to the more than 2½-mile elevations of some of the peaks along the Continental Divide to the west. Along the eastern border, and in sequence for a few miles toward the west, outcrop sedimentary rocks of Permian, Pennsylvanian, Devonian, Ordovician, and Cambrian age. Early Tertiary intrusive rocks in sills, dikes, stocks, and laccoliths, cover an appreciable portion of the County's area, particularly in the southwestern, southeastern, and northwestern parts. Quaternary terrace gravels form a wide band from north to south along the Arkansas River Valley. Tertiary extrusive rocks, consisting of basalt, andesite, latite, rhyolite, breccia, agglomerate, and tuffs, mostly Miocene, are found chiefly in the areas of the Tertiary intrusives. Pre-Cambrian granites extend easterly from the Arkansas River to the County's border; pre-Cambrian hornblende gneiss and greenstone are exposed in the south; and, pre-Cambrian schist and gneiss, mostly of sedimentary origin, are prevalent in the northwestern part of the County.

Cheyenne County



Courtesy Colorado Planning Division

Cheyenne County is located in the plains region of eastern Colorado bordering the State of Kansas. The County has an area of 1,772 square miles of undulating prairie land and level stream valleys ranging in elevation from 3,875 to 4,600 feet above sea level, and a population of 3,300. The county seat is at Cheyenne Wells, a farming community with 1,000 population.

Available Maps of the County—

Cheyenne County Map.

U. S. Army Map Service maps: 5361 I, II; 5461 I, II III, IV; 5561 I, II, III, IV.

U. S. Geological Survey topographic quadrangle maps cover most of the County. See index map in the pocket.

Mineral Production—Sand and gravel are the only minerals of consequence produced in the County. The U. S. Bureau of Mines gives the following values for sand and gravel production beginning with 1953.

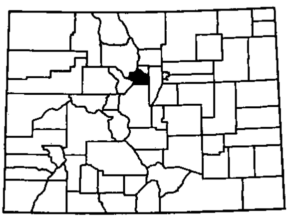
1953	$ 23,771
1954	13,725
1955	
1956	67,000
1957	101,000
1958	124,200*

*Includes 500 tons of stone valued at $3,800.

Sand and Gravel—Sand and gravel have been produced from the courses of Smoky Hill River and some of its tributaries in the vicinity of Cheyenne Wells and to the north and northeast of it. Also from Ladder Creek near First View. Other sand and gravel deposits occur along Big Timber Creek and Smoky Hill River in the northeast quadrant, and along the Big Sandy near Kit Carson and other localities.

Hydrocarbon Potential—There are no producing oil or gas fields in the County at present, and exploratory activity continues to be reduced due to the large areas of mineral ownership in the hands of a single entity. *However, because of the County's situation on favorable structure along the Las Animas Arch, the sandstone and limestone beds of the entire Pennsylvanian section, plus possibly the carbonate rocks of Mississippian and Ordovician age, are promising horizons for oil and gas exploration. In addition, the shallow Dakota sandstone of Cretaceous age, and the sandstones of Permian age, are secondarily prospective.

Geological Note—The western half of Cheyenne County is surfaced by upper Cretaceous rocks of the Pierre shale, and the eastern half by Late Miocene rocks of the Ogallala formation. Upper Cretaceous rocks of the Niobrara group, Apishapa shale and Timpas limestone, outcrop along the basins of Rush Creek and Big Sandy River.



Courtesy Colorado Planning Division

Clear Creek County

Clear Creek County is located in the north-central part of the State to the east of the Continental Divide. The terrain is typically mountainous, with elevations ranging from 6,880 feet, to 14,270 feet above sea level. The County has an area of 395 square miles, with a population of about 3,500. The County seat is at the historic mining town of Georgetown, with a population of about 400 people.

*Thaddeus R. Carpen, Continental Oil Co., written communication.

Available Maps of the County—

a. Clear Creek County Map.

b. U. S. Army Map Service maps: 4863 I, II, III, IV; 4963 III.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See topographic quadrangle index map in the pocket.

d. U. S. Forest Service maps: Roosevelt National Forest and Arapahoe National Forest, cover the County.

Mineral Production 1946-1958—Complex sulfide ores with varying content of gold and silver, and some placer gold, have been for many years the chief contributors to the value of Clear Creek County's mineral production. Besides these, the County produced some sand and gravel, uranium, stone, feldspar, mica, beryl, rare earths, columbium, tantalum, tungsten concentrate, peat, and gem stones. The following table lists Clear Creek County's major mineral products and total yearly values for the period 1946-1958. All figures are from U. S. Bureau of Mines Minerals Yearbooks.

Year	*Active Mines Lode	*Active Mines Placer	Gold Ounces	Silver Ounces	Copper Pounds
1946	21	1	3,696	82,792	38,000[1]
1947	34	–	2,911	167,830	40,500[1]
1948	32	1	3,646	127,162	26,000[1]
1949	33	2	3,071	86,289	34,000[1]
1950	30	–	3,298	84,245	26,000[1]
1951	22	–	1,802	85,793	18,000[1]
1952	19	–	1,049	30,013	18,000[1]
1953	16	1	2,306	51,853	48,000[2]
1954	9	–	1,035	34,955	26,000[3]
1955	15	–	691	23,191	14,000[4]
1956	18	1	5,091	76,401	109,000[4]
1957	22	..	4,589	49,459	88,700[5]
1958	9	1	1,401	27,051	52,000

Year	Lead Pounds	Zinc Pounds	Total $ Value
1946	941,000	780,000	400,141[1]
1947	933,800	336,600	437,471[1]
1948	1,498,000	566,000	591,760[1]
1949	1,492,000	832,000	531,183[1]
1950	628,000	304,000	325,032[1]
1951	782,000	954,000	456,653[1]
1952	590,000	462,000	244,811[1]
1953	880,000	186,000	319,156[2]
1954	214,000	10,000	108,802[3]
1955	198,000	12,000	109,980[4]
1956	1,151,000	----	481,836[4]
1957	861,300	9,000	370,797[5]
1958**	562,000	----	530,134[4]

*Precious and base metal mines only.

[1] Value of precious and base metals only.

[2] Same as [1], plus value of feldspar, beryl, mica, columbium and tantalum concentrate.

[3] Same as [2], but includes value of sand, gravel, and stone production.

[4] Same as [3], but includes value of some gem stone production.

[5] Same as [4], but includes value of uranium production.

Precious and Base Metals—Clear Creek County's production of precious and base metals originates in several of the mining districts which were established in the early days of the industry. General data on these districts, as well as geological information, are contained in the 1947 edition of "Mineral Resources of Colorado" (Vanderwilt) on the following pages.

Additional information on some of the districts is given below.

Central City-Idaho Springs District—Dr. E. N. Goddard, U. S. Geological Survey, discusses the geology of this area on pages 308-13 of the 1947 edition of this book (Vanderwilt). Supplementary information follows:

Geology[12]—Central City is on the axis of a northeasterly anticline whose core is one of the largest bodies of granite gneiss known in the Front Range. The rock is a fine-grained primary gneiss composed of white to pink feldspar, quartz, and biotite; it is light-gray on the fresh surface and weathers to a brown or buff color. Competency of this gneiss was an important factor in determining the position of the district's veins and ore shoots. Pegmatites in irregular lenses are abundant in the schist throughout the district and many of the ore shoots in veins within the schist are localized by walls of pegmatite.

Subsequent to the primary mineralization, faulting occurred in many parts of the district, much of it along veins, brecciating the ores. Other faults cut across the veins with minor displacements. In places this postmineralization fracturing was followed by the deposition of cherty quartz similar to the "horn quartz" of the Boulder County telluride veins, particularly in the region just southeast of Central City. It may be significant that this area coincides with the north end of the telluride zone of the district. Although the post-mineral fracturing along the veins was slight and local, it served to facilitate the descent of meteoric waters along parts of the veins thereby increasing the amount of downward enrichment.

Ore Deposits[12]—The bulk of the ore in the district occurs in veins which follow zones of minor faulting and in stockworks occurring within chimney-like zones of brecciation. The physical character of the rocks was the primary factor in determining the abundance and importance of the ore bodies in the various localities. North of Idaho Springs near Central City, distribution of the veins shows a close relationship to areas of granite gneiss, pegmatite, and porphyry dikes, while their absence in other areas appears due to the presence of the more plastic Idaho Springs formation. The more productive veins in the schist area south of Idaho Springs either break across the foliation of the schist, or cut or follow pegmatite or porphyry dikes.

Replacement of magnetite, and to a lesser extent quartz and silicates, was accompanied by the introduction of gold in some of the altered wallrock, and many of the pyritic gold ores and some of the gold telluride ores are due to replacement.

In most parts of the Central City quadrangle the water table appears to have been located between 50 and 150 feet in depth. In some mines secondarily enriched ore is limited mostly to the oxidized zone lying between the surface and the ground-water level. In others, the enriched zone extends downward 700 feet and more, and represents a secondary sulfide zone. Gold enrichment has occurred in the oxidized zone in all types of gold-silver ores; silver enrichment is limited mostly to the secondary sulfide zone of the galena-sphalerite veins; copper enrichment is generally of small magnitude and is chiefly limited to the pyritic ores; lead enrichment is inconsequential; and zinc enrichment has not been evident.

Outlook for the Future[16]—The future of the district is uncertain. Many of the smaller veins have been found to pinch out at moderate depths and in general the results of a deep exploration through the Argo Tunnel have been disappointing. However, some of the larger veins have been successfully mined to depths of 1,000 to 1,500 feet, and many of the mines in the district have not yet reached that depth. In many places there are structural conditions that have not yet been explored, and it seems probably that by careful scientific prospecting many new ore shoots will be uncovered.

Freeland-Lamartine District—The Freeland-Lamartine district is located about 3 miles west of Idaho Springs and occupies about 4 square miles of mountainous terrain within which are located the abandoned towns of Freeland and Lamartine. The district has yielded nearly $20 million in gold, silver, copper, lead, and zinc ores, from mesothermal veins of Tertiary age. The Freeland vein was discovered in 1861; the Lamartine vein in 1867; and the Great Western, in the northern part of the district, in 1878.

Geology[12, 29]—The rock through most of the district is gneiss and schist of the Idaho Springs formation, which has a general trend to the northeast and dips to the southeast. In the southern and southwestern parts of the area there are large irregular tongues of Boulder Creek granite which connect with the large mass to the south. Scattered throughout the area are irregular masses and lenses of gneissoid granite, Silver Plume granite, and pegmatite. Intruded into all these rocks, but chiefly into the Idaho Springs formation, are numerous porphyry dikes of general northeast trend, but in the southeastern part of the area there occur several with a northwest trend. These dikes include bostonites and alaskitic quartz monzonites. The veins of this region trend from east, to northeast.

The bedrock of the Freeland-Lamartine district is a generally conformable series of metamorphic and igneous rocks which were folded during pre-Cambrian time. The rocks are jointed and cut by numerous faults; some of the joins contain Tertiary intrusive porphyry, and many of the faults locally contain Tertiary gold-silver-lead-zinc ores. A general summary of the structural history of the bedrock in the district is as follows: 1. late pre-Cambrian northeasterly folding accompanied by intrusion of biotite-muscovite granite; 2. northwesterly warping and cataclistic deformation of biotite-muscovite, granite, granite gneiss, and pegmatite; 3. early Laramide (?) arching resulting in the formation of the regional joint pattern; and, 4. Tertiary fracturing and faulting followed by intrusion of dikes and deposition of hydrothermal veins.

Ore Deposits[12]—The veins of the district were formed as hydrothermal fissure fillings in faults in which replacement of the wallrocks by the ore minerals was not important to the formation of the ore deposits. Most of the veins have smooth walls and slickensides are abundant though inconsistent in bearing and plunge. The fissures are fairly regular in strike and dip and, where irregularities were present, they commonly provided favorable structures for mineralization.

The principal ore minerals are sulfides and sulfosalts of iron, copper, lead, and zinc, but locally, some free gold was found. Three types of veins have been mined in the district: pyrite gold veins; galena-sphalerite veins mined chiefly for silver, lead, and zinc; and, composite veins mined for gold, silver, and lead. Most of the veins in the district belong to the latter two types. Quartz is the most abundant gangue mineral, but carbonates locally form as much as 80% of the gangue.

It is probable that the belt of strong fractures which trend east-northeast from the head of Silver Creek to the valley of Clear Creek near the mouth of Fall River, of which the Lamartine and Freeland veins are a part, continues west-southwest of Lamartine to Georgetown. This intervening terrain has not yet been adequately studied and it is possible that blind ore bodies, as was the Lamartine lode, could be discovered in this area through proper scientific exploration.

Outlook[12]—The Lamartine and Freeland veins have had a substantial output, and the possibility of undiscovered ore shoots in an extension of this belt should be considered, especially as the Lamartine ore body did not outcrop and was apparently discovered by accident.

Alice (Lincoln, Yankee Hill)—General and geological data in this area are contained in "Mineral Resources of Colorado" (Vanderwilt), 1947, on pages 52-3, and 313-14. A brief statement on the potentialities of the district follows:

Outlook[12]—The many veins in the ridge south of Fall River were not being worked when Lovering and Goddard[12] mapped the area, and nothing could be learned concerning their output. Many of those veins had been extensively stoped near the surface, and the ore on the dumps suggested that they belong to the pyritic-gold type. However, the strike of the veins and their strength and number suggest that many similar blind veins exist under the extensive glacial cover that occupies the broad valley of Mill Creek just to the southwest.

Sand and Gravel—Sand and gravel are produced from the course of Clear Creek, virtually all of which has been worked for placer gold since the early days of Colorado mining.

Molybdenum — The Urad deposit, located about 5 miles southwest of Berthoud Pass, is the second largest deposit of molybdenite in Colorado after the one at Climax. The Urad deposit is discussed by Dr. Robert H. Carpenter in the molybdenum chapter of this book.

Uranium* — Numerous scattered prospects and small occurrences of uranium mineralization are known to exist in Clear Creek County, but it is expected that further discoveries will probably be small and scattered. Most of the known occurrences are in association with base and precious metal deposits in historic mining districts.

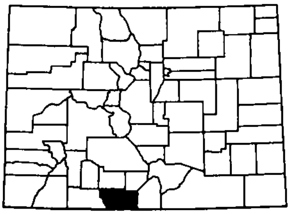
Gem Stones — Amethyst, a clear purple or bluish-violet variety of quartz whose color is possibly due to manganese impurities, is found at Red Elephant Mountain, Lawson, and Silver and Trail creeks in the Idaho Springs-Central City area[24].

Pegmatite Minerals — The pegmatite area within the metamosphic rocks of the Idaho Springs formation east and southeast of Idaho Springs, has produced sheet, punch, and

*Dr. Donald L. Everhart, USAEC, personal communication.

scrap mica, feldspar, some rare earth minerals, columbite, and beryl.

Geological Note—Clear Creek County is located within the Front Range mineral belt in pre-Cambrian terrane consisting chiefly of metamorphic rocks of the Idaho Springs formation, Boulder Creek granite, and Silver Plume granite. Numerous sills, dikes, and stocks of early Tertiary intrusive rocks occur throughout the County. Ore deposits which were formed during Laramide time are associated with the Tertiary intrusive porphyries.



Courtesy Colorado Planning Division

Conejos County

Conejos County is located in the southern part of the State, bordering New Mexico on the south; the Continental Divide is its western border, and the Rio Grande borders it to the east. The County has an area of 1,274 square miles ranging in elevation from 7,000 to 10,180 feet above sea level, and a population of about 10,000. The County seat is at the town of Conejos, on the Conejos River, with a population of about 200.

Available Maps of the County—

a. Conejos County Map.
b. U. S. Army Map Service maps: 4658 I, II; 4758 I, II, III, IV; 4858 III, IV.
c. U. S. Geological Survey topographic quadrangle maps cover the western three-fourths of the County. See topographic quadrangle index map in the pocket.

Mineral Production—Sand and gravel are the only mineral products reported from Conejos County during the last decade, although apparently some uranium was produced during 1956. The statistics on sand and gravel, as reported in the U. S. Bureau of Mines Minerals Yearbooks, begin in 1954 and do not contain tonnage figures. General data on Conejos County are contained on page 63 of the 1947 edition of "Mineral Resources of Colorado".

Sand and Gravel — Sand and gravel have been produced from deposits along the courses of Conejos River, Alamosa

Creek, and some of their tributaries, from Antonito north to Alamosa and Rio Grande counties. Appreciable areas of the County are mantled by Quaternary deposits some of which represent considerable resources of sand and gravel.

SAND AND GRAVEL PRODUCTION

Year	$ Value
1954	53,549
1955	21,474
1956	121,000
1957	
1958	18,000

Turquoise — The King mine, one of the most important turquoise mines in the United States, is located in Conejos County a few miles west of Manassa. This mine is credited with producing the largest single piece of turquoise found to date. It is at present on exhibition at the Colorado State Museum in Denver. The Colorado State Bureau of Mines "Annual Reports" credit Conejos County with turquoise production valued as follows:

1946	$30,000
1947	30,000
1949	500

The sporadic nature of turquoise production makes it very difficult to maintain proper statistics.

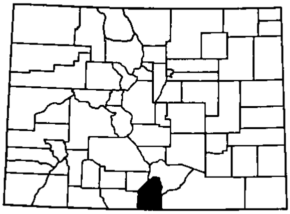
Pumice—Bush[28] reports on the Capulin deposit located in section 29, T-36-N, R-7-E, which is exposed for a distance of about 1,000 feet along the dip, in a steep bank on the south side of Alamosa Creek. The pumiceous beds are interbedded with numerous layers of gravelly conglomerate and represent a thickness of about 135 feet of the total exposed thickness of approximately 220 feet. Because of the 8 to 10 degree easterly dip of the beds, and the contaminating interbedding, it may prove difficult to work this deposit economically.

Geological Note—The surface rocks of Conejos County consist chiefly of Tertiary igneous rocks and of Quaternary deposits ranging in age from Recent alluvium to the Pleistocene Durango glacial wash.

Near the eastern border of the County, just west of a north-south band of Recent alluvium in the San Luis Valley, occurs a north-south band of Tertiary extrusive rocks belonging to the Potosi volcanic series of Miocene age. Among these rocks are exposures of stocks, sills and dikes of Tertiary intrusive rocks of Conejos andesite age. To the west occurs a broad band of Recent alluvium which stretches from the town of Antonito in the southern part of the County, northward into Alamosa and Rio Grande counties. West of Antonito and the County seat of Conejos, follows a series of extrusive igneous rocks: the Hinsdale formation of Pleistocene (?) age, consisting of widespread and local flows of andesite-basalt, rhyolite, and tuffs; and the Los Pinos member of the Hinsdale formation which in the northern part of the County consists of local flows of latite-andesite, and southward grades into sand, gravel, and tuff.

The extreme western part is surfaced chiefly by Conejos andesite of the Potosi volcanic series of Miocene age, consisting of complex flows and clastic sediments with some quartz latite. In the northwestern quarter of the County are exposures of Tertiary intrusive rocks of Conejos andesite age.

Quaternary deposits consisting of Recent alluvium, alluvial fans, torrential wash, landslides and mudflows, and Pleistocene Wisconsin glacial till and Durango glacial till and outwash, and Florida gravel, are found in various parts of the County.



Courtesy Colorado Planning Division

Costilla County

Costilla County is located in the central southern part of Colorado where it borders the State of New Mexico to the south; the Rio Grande borders it on the west, and the Sangre de Cristo Range borders on the north and east. Costilla County has an area of 1,220 square miles ranging in elevation from 7,500 to 14,317 feet above sea level, with a population of about 6,000. The County seat is at San Luis, the oldest town in Colorado, with a population of about 1,250.

Available Maps of the County—

a. Costilla County Map.

b. U. S. Army Map Service maps: 4858 I, II; 4958 I, II, III, IV; 4959 II, III.

c. U. S. Forest Service Map "Rio Grande National Forest" includes Costilla County.

Mineral Production—Sand and gravel and volcanic scoria are the only mineral products reported from Costilla County during the last decade. The U. S. Bureau of Mines Minerals Yearbooks give the total yearly value of these products beginning with 1953. It is estimated that the value of the volcanic scoria producton represents approximately two-thirds of the total values given in the table.

VALUE OF MINERAL PRODUCTION

Year	$ Value
1953	115,378
1954	93,201
1955	87,005
1956	85,691
1957	27,470
1958	108,650

Volcanic Scoria—The Mesita Hill deposit, 2 miles west of Mesita in an unsectionalized area, is mined by bulldozer and used mainly for the manufacture of cinder blocks and roofing. [28]Prior to processing, the material weighs 33 pounds per cubic foot. The deposit forms a low, roughly oval dome about 1,800 feet long, 1,400 to 1,500 feet wide, and up to 60 feet thick. The scoria is in the form of bomb fragments from 1 to 8 inches across, with some large masses approximately parallel to the surface being 12 feet across and 2½ feet thick. Many of the larger blocks have been brecciated and recemented. The scoria dome is the remnant of a cinder cone and it is probable that the vent lies beneath it.

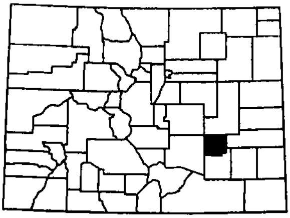
Sand and Gravel — Sand and gravel have been produced from the courses of Culebra Creek and some of its tributaries and from reworked material of the Quaternary Florida gravels occurring southwest of San Luis town. Extensive Quaternary Florida gravel deposits are located: north of Culebra Creek as far as Trinchera Creek; north of Fort Garland and west of Sangre de Cristo Creek to west of Ute Creek; south of Culebra Creek to south of Mesita; and, south and west of Fort Garland. Quaternary terrace deposits occur in the northeastern part of the County.

Uranium* — There are known occurrences of uranium bedded deposits in the high ranges of the northeastern part of the County. In this area, mildly metamorphosed asphatite-bearing sandstones and mudstones of Pennsylvanian and Permian age form favorable hosts for low-grade bedded uranium deposits, both oxidized and unoxidized.

Precious and Base Metals—Two mining districts have been active in Costilla County, the Plomo (Rito Seco) district, and the Russell (Grayback) district. These districts are discussed on pages 65 and 66 of the 1947 edition of "Mineral Resources of Colorado", Vanderwilt.

Geological Note—Along the crest of the Culebra Range at the eastern border of the County, sedimentary beds of Permian and Pennsylvanian age are exposed, the latter tilted against the pre-Cambrian metamorphic and igneous rocks of the major Sangre de Cristo Range. West of the crystalline rocks, parallel bands of the Los Pinos member of the Tertiary semi-volcanic Hinsdale formation, stretch south from Fort Garland into New Mexico. These are separated by a north-south band of Recent alluvium and torrential wash, and by another north-south band of Tertiary andesite-basalt, rhyolite, and tuffs of a volcanic member of the Hinsdale formation. Farther west, extensive deposits of Pleistocene Florida gravels and Recent alluvium, together with some exposures of Miocene Conejos andesite of the Potosi volcanic series, surface the rest of the County.

*D. L. Everhart, USAEC, personal communication.



Courtesy Colorado Planning Division

Crowley County

Crowley County, located in the southeastern part of central Colorado, has a population of 5,100 and an area of 812 square miles ranging in elevation from 4,100 to 4,500 feet above sea level. The County seat is at Ordway, a farming and ranching community with 1,400 population.

Available Maps of the County—

a. Crowley County Map.

b. U. S. Army Map Service maps: 5160 I, II; 5260 I, II, III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover most of the County. See index map in the pocket.

Mineral Production—Sand and gravel are the only minerals of consequence produced. The U. S. Bureau of Mines gives the values of this production for the following years:

1954	$ 7,898
1955	849
1956	
1957	22,900
1958	76,000*

*Includes 100 tons of stone valued at $400.

Sand and Gravel — Sand and gravel have been produced from the course of Bob Creek just north of Ordway, and from that of Horse Creek north-northeast of Ordway. Other sand and gravel deposits are located in the northeastern quadrant in north-trending elongate narrow bands of reworked Tertiary Ogallala gravels and Quaternary terrace deposits; also, in the southwestern corner along the course of the Arkansas River.

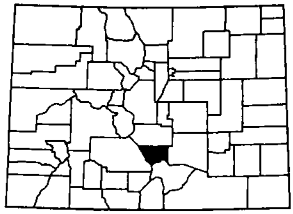
Hydrocarbon Potential*—The southeastern part of the Denver Basin and the extreme southwestern part of the Las Animas Arch are partly located in Crowley County. At the present time the County is considered moderately potential for hydrocarbon production from sandstones of Lower Cretaceous, Permian, and Pennsylvanian age, and carbonate rocks of Pennsylvanian, Mississippian, and Ordovician age.

Geological Note—Crowley County lies entirely in sedimentary terrane. The western part is mantled by Miocene-Pliocene rocks of the Ogallala formation; the southeastern corner, in the area of Lake Meredith, is surfaced by upper

*Mr. Thaddeus R. Carpen, Continental Oil Co., written communication.

Cretaceous rocks of the Niobrara group; and, the rest of the County, with the exception of some areas in the northeast, is overlain by upper Cretaceous rocks of the Pierre shale. In the northeast quadrant, paralleling the southerly-trending drainage system, are long, narrow bands of Quaternary terrace gravels, and a long, narrow remnant of Ogallala sediments which extends from northeast of Lolita northerly into Lincoln County.

Custer County



Courtesy Colorado Planning Division

Custer County is located in south-central Colorado, with the Sangre de Cristo Range forming its western boundary, and the Wet Mountains traversing the eastern part in a north-northwesterly direction near its eastern border. The level Wet Mountain Valley occupies the center portion.

Custer County has an area of 738 square miles, ranging in elevation from 6,700 feet in the Wet Mountain Valley to the north, to over 14,000 feet at some of the western peaks, and a population of about 1,500. The County seat is at Westcliffe, on Grape Creek, with a population of about 400 people.

Available Maps of the County—

a. Custer County Map.
b. U. S. Army Map Service maps: 4860 II; 4959 IV; 4960 II, III.
c. U. S. Geological Survey topographic quadrangle maps cover the eastern two-thirds of the County. See topographic quadrangle index map in the pocket.
d. U. S. Forest Service map "San Isabel National Forest" includes Custer County.

Mineral Production 1946-1958—Beside the mineral commodities listed in the table, Custer County produced sand and gravel, perlite, stone, gem stones, thorium, and rare earths. All figures are from U. S. Bureau of Mines Minerals Yearbooks.

Year	*Active Mines Lode	Placer	Gold Ozs.	Silver Ounces	Copper Pounds
1946	5		40	25,724	9,000
1947	6	----	35	27,472	4,100
1948	3	----	16	9,047	----
1949	4	----	19	16,061	----
1950	3		1	348	----
1951	1		6	1,011	----
1952	3	----	3	706	6,000
1953	3	----	3	337	----
1954	2	----	110	1,064	----
1955	3		73	1,927	8,000
1956	3		4	720	10,800
1957	5	----	47	1,350	2,500
1958	1	----	----	357	----

Year	Lead Pounds	Zinc Pounds	Total $ Value
1946	445,000	356,000	115,580[1]
1947	223,000	241,400	88,269[1]
1948	118,000	82,000	40,776[1]
1949	104,000	68,000	40,065[1]
1950	10,000		1,700[1]
1951	32,000	10,000	Withheld
1952	18,000	22,000	Withheld
1953	20,000	12,000	272,578[2]
1954	8,000		483,376[2]
1955	22,000	24,000	727,863[3]
1956	12,500	----	778,043[4]
1957	3,600	----	533,248[4]
1958	2,000	----	34,092[5]

*Precious and base metal mines only.

[1] Precious and base metal values only.

[2] Precious and base metal values plus those of perlite and sand and gravel production.

[3] Same as [2] above, but includes value of stone and gem stones production.

[4] Same as [3] above, but includes value of rare earth production.

[5] Same as [1] but includes rare earths, perlite, and manganese.

The Colorado State Bureau of Mines "Annual Reports" gives the following values for mineral production other than that listed in the foregoing table.

Year	$ Value — Perlite	Stone	Thorium
1949	91,300		
1950	101,000	----	----
1951	134,000	----	----
1952	242,000	----	----
1953	53,000	12,000	----
1954	43,000	11,000	----
1955	693,000	12,000	----
1956	725,000	----	
1957	755,000	----	4,000
1958	2,851	----	5,313

NOTE: The discrepancy in the State and Federal value figures for 1957 arises from the difference in the methods of reporting. The State figures are based on the value, at existing prices, of sold and unsold production, whereas the Federal Bureau of Mines bases its figures on the production which is actually sold.

Precious and Base Metals—The chief metallic ore production of the County has come from mines located in the Fairview, Hardscrabble, Oak Creek and Rosita Hills districts. General data on these districts are contained on the following pages of the 1947 edition of "Mineral Resources of Colorado", J. W Vanderwilt.

The aggregate output of these districts has been between seven and eight million dollars worth of ore containing gold, silver, and lead.

Sand and Gravel — Sand and gravel are produced from the courses of Grape Creek, Texas Creek, and their tributaries to the northeast and northwest of Silver Cliff.

Perlite—In recent years the production of perlite has led in value all other minerals produced in Custer County. Two substantial deposits are active: one west of Rosita has been worked intensively and is responsible for most of the output; the other one, in the vicinity of Silver Cliff, is now producing. The perlite from both of these operations is shipped to Florence, Fremont County, for processing.

[28]In the deposit west of Rosita, the perlite crops out along the gentle lower slopes of the Rosita Hills and extends over an area of approximately one square mile. The material is a relatively horizontal flow from 40 to 75 feet in thickness and overlies a bedded tuff described locally by the operators as 'pumiceous' material. In general the perlite is overlain by a rhyolite flow, but where not, it is covered by only ½ to 2 feet of overburden. The workings consist of bulldozed open cuts at right angles to the trend of the perlite outcrops.

Uranium*—A known bedded uranium deposit in the Crestone Needles area indicates the possibility that other similar deposits may be present. Mildly metamorphosed asphatite-bearing sandstones and mudstones of Pennsylvanian and Permian age in the Sangre de Cristo Mountains along the western border of the County form favorable hosts for low-grade, bedded uranium deposits, both oxydized and unoxydized.

Thorium[34, 36]—Thorium-bearing veins were discovered in the Wet Mountains of Custer County by the U. S. Geological Survey in 1950. The full extent of this thorium bearing district is not known as yet, but the deposits which had been found up to 1953 are within an area 20 miles long and about 10 miles wide. This area extends from Querida and Rosita, in Custer County, north-northwestward into Fremont County, with most of the deposits located in the southern half.

The thorium minerals occur in northwest-trending shear zones that contain barite-sulfide veins and cut a pre-Cambrian complex of amphibolite, biotite-granite, gneiss, metagabbro, migmatite, microcline granites, pegmatite and syenite (?). Pre-mineralization basic dikes are found along the shear zones.

The thorite ($ThSi0_4$) which has tentatively been identified as the principal radioactive mineral, is commonly associated with barite, quartz, galena, fluorite, limonite, pyrite, and rare-earth oxides. Some of the shear zones can be traced for over

*Dr. Donald L. Everhart, U. S. Atomic Energy Commission, personal communication.

a mile, but the largest known thorium-bearing ore body is 300 feet long, 26 feet wide, and 400 feet deep. Channel samples from the veins contain as much as 4.5% equivalent ThO_2. The uranium content is generally about .002%.

The Wet Mountains thorium area is a favorable locality for prospecting for thorium deposits. The most readily found radioactive localities are along shear zones on which many prospect pits were dug in the past searching for silver, gold, lead, or barite. In the absence of prospect pits, the zones can be located by the presence of (1) radioactivity, (2) siderite, quartz, and/or barite, (3) basic rocks, commonly completely altered to limonite, (4) a fetid odor of the altered rocks, (5) a characteristic red stain of the sheared rocks, or (6) green or blue amphibole(?) minerals coating the fractures of the country rock.

In some zones, the most abundant radioactive material is in areas that contain barite and/or smoky quartz; in others it is in areas containing only thorite minerals (as veinlets) and intensely red-stained country rock. All mineralized or altered rocks from this region should be tested with a radiation-detection counter. (See chapter on thorium.)

Alunite[9] ($K_2Al_6(OH)_{12}(SO_4)_4$) — Two large replacement-type deposits of alunite have been reported in the Rosita Hills east of Silver Cliff. The one at Mount Robinson was formed by the alteration of rhyolite and is associated with quartz and diaspore. This deposit is estimated to contain 1,200,000 tons of material averaging 6.5% alunite. The other is at Democrat Hill southeast of Mount Robinson, and is reputed to be the principal one in the Rosita Hills. This deposit is estimated to contain 800,000 tons averaging 16.6% alunite. Other concentrations of alunite are reported in several zones bisecting the mountains in a north-south direction.

Barite[9] ($BaSO_4$)—A barite-galena vein in pre-Cambrian gneiss and schist is found at the Feldspar mine on Oak Creek three miles north of Ilse. The vein, one to seven feet in width, crops out for a length of 1,000 feet, striking north 13-deg. west, and dipping 73-deg. to the east. This deposit was worked as early as 1916 and, in 1940, produced approximately 500 tons of ore. Barite has also been found as a gangue in the silver mines at Rosita, as well as in the thorium belt (see Thorium, above) where it occurs as white to red barite in association with thorite.

Clays[7]—In the northeastern corner of the County occur sedimentary formations which contain clays suitable for the manufacture of construction materials such as brick, unvitrified tile, pipe, etc.

Stone—Custer County has a variety of igneous (pre-Cambrian and Tertiary) and sedimentary rocks (from the Pennsylvanian Fountain formation to the Upper Cretaceous

Pierre shale) suitable for many applications in the construction industries.

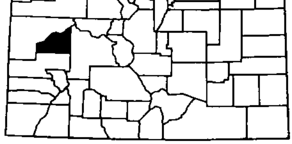
Fluorspar[9, 36]—Flourspar has been produced from the Antelope Creek district in the southeastern part of the County 7 miles southeast of Rosita. The area is one of pre-Cambrian granite and gneiss with Tertiary volcanic rocks which are not however, in close proximity to the vein. The fluorspar occurs as a shoot in a fissure vein which strikes N-41 deg-E, dips 80 degrees to the southeast, and cuts the granite. The ore shoot varies from 20 inches to 4 feet in width, and averages about 30 inches. The main vein widens and narrows, and finally disappears in a compact mass of siliceous vein matter. On either side of the fluorspar shoot is a band of brecciated siliceous material cemented by fluorspar.

Although the present condition of this deposit is not known to the writer (Ed.), it does not appear to have been worked intensively since 1920, and may possibly prove commercial in the future.

Geological Note—The Wet Mountain Valley extends from north to south across the center of the County, with the Sangre de Cristo Range on the west, and the Wet Mountains on the east.

Pre-Cambrian granite, schist, and gneiss form the exposed core of the Wet Mountains, with a broad band of Miocene volcanic and intrusive rocks along the western fringe of the mountains. To the west, in the Wet Mountain Valley, pre-Cambrian metamorphic rocks are exposed in the northern and central parts, with alluvial fans and torrential wash of Recent age forming a broad northwest-southeast band across the County. Farther west, to the County's boundary, sedimentary rocks of Pennsylvanian and Permian age are exposed along the slopes of the Sangre de Cristo Range, as well as dikes, sills, and stocks of early Tertiary intrusive rocks. In the northeastern corner are exposed sedimentary rocks ranging in age from the Pennsylvanian Fountain formation, to the Upper Cretaceous Pierre shale.

Delta County



Courtesy Colorado Planning Division

Delta County is located in the west-central part of the State and has an area of 1,161 square miles ranging in elevation from 4,750 feet in the Gunnison Valley, to over 9,000 feet on the Grand Mesa along the northern border. The County has a population of about 18,500; the County seat is at the small city of Delta, a fruit farming, mining, and light-industry center on the Gunnison River, with population of about 5,000.

Available Maps of the County—

a. Delta County Map.

b. U. S. Army Map Service maps: 4361 I, II, III, IV; 4461 I, II, III, IV; 4462 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover the south-central area and a small portion of the northern part of the County. See topographic quadrangle index map in the pocket at the back of the book.

d. U. S. Forest Service maps: Gunnison National Forest, Uncompahgre National Forest, and Grand Mesa National Forest, each cover portions of the County.

Mineral Production 1946-1958—Of recent years sand and gravel have been Delta County's leading mineral products, with coal a close second. The County also produces some clays, sulphur, and gypsum. The figures in the following table are from the U. S. Bureau of Mines Minerals Yearbooks.

	Short Tons			Total
Year	Coal	Clays	Sand & Gravel	$ Value
1946	98,899	[1]	[1]	[1]
1947	102,415	[1]	[1]	[1]
1948	97,554	[1]	[1]	[1]
1949	84,516	[1]	[1]	[1]
1950	71,797	[1]	[1]	[1]
1951	74,935	1,416	[1]	385,569[2]
1952	63,936	5,458	[1]	353,270[2]
1953	57,645	390	[1]	418,661[3]
1954	42,644	528	[1]	363,254[3]
1955	52,288	831	[1]	592,364[4]
1956	58,066	801	376,000	617,211[3]
1957	61,674	587	462,000	688,585[5]
1958	49,503	Withheld	217,000	474,138[5]

[1] No figures.

[2] Value of coal production only.

[3] Value of coal, sand and gravel, and clays.

[4] Same as [3] but includes value of gypsum production.

[5] Same as [4] but includes stone.

Sand and Gravel — Sand and gravel have been produced from various sections of the County: from the course of the North Fork, north and west of Paonia; in the vicinity of Hotchkiss from the North Fork and some of its tributaries, such as Cottonwood and Leroux Creeks; in the southeastern corner from the course of the South Fork; east of Eckert from Currant and other creeks; south, west, east, and northeast of Delta from the Gunnison River, Uncompahgre River, Tongue Creek, Doughspoon Creek, and other tributary creeks.

Coal[6]—Delta County is partly located within the southern portion of the vast Uinta Coal Region. The Grand Mesa coal field, part of the Uinta Coal Region, extends south from Mesa County into the northern half of Delta County. The County's portion of the Grand Mesa field comprises at least 86 square miles underlain by coal measures containing 1.66 billion tons of coal, of which 360 million tons is bituminous high-volatile C in rank, and the balance is largely subbituminous A in rank.

Of the bituminous coal, some 155 million tons lie under less than 1,000 feet of overburden; 198 million under between 1,000 and 2,000 feet; and the balance between 2,000 and 3,000 feet.

The coal field lies along the western and southern edges of the Grand Mesa, a high plateau in the southern part of the Piceance Creek Basin, and comprises part of the vast outcrop of the coal-bearing rocks of the Mesa Verde formation. The coal in the western edges of the field in the northwestern part of the County is bituminous, the remainder is mostly subbituminous.

Clays—Most of Delta County is mantled by sedimentary rocks of formations containing clays some of which are suitable for the manufacture of construction materials such as brick, tile, etc.

Oil Shale—The oil shale-bearing Green River formation of Middle Miocene age outcrops along the northern extremes of the County on the southern slopes of Grand Mesa, and covers approximately 30 square miles. Although the Grand Mesa oil shale deposit has not as yet been fully assessed, 25-ft-thick sections are known to occur. Delta County's resources of shale oil are substantial (see oil shale section).

Sulphur[9]—A sulphur deposit near the mouth of the Black Canyon of the Gunnison River, about 14 miles east of Delta, has been worked for years for agricultural purposes. The deposit is reported to constitute 10 to 15 per cent of a flat dipping sedimentary bed up to 8 feet thick. The shallow overburden is stripped and the ore is loaded by mechanical means.

Gypsum—Argall[9] reports gypsum beds averaging 110 feet in thickness exposed along the Gunnison River Valley and extending for 20 miles south from Smith Fork in Delta County, to Red Rock Canyon in Montrose County. Although no details have been published it is likely that the gypsum production referred to in footnote 4 under the production table above, came from these deposits near Smith Fork.

Hydrocarbons*—Delta County does not as yet produce oil or gas. The southern end of the Piceance Basin is located in the County, but it is questionable whether the many reservoir horizons found in the upper portion are present here due to thinning of the sedimentary cover against the Ancestral Un-

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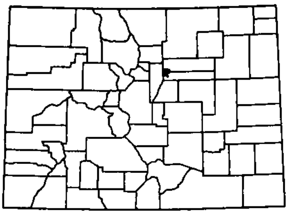
*Mr. Charles C. O'Boyle, Consulting Geologist, Denver, written communication.

compahgre highland. The sedimentary cover itself is of sufficient thickness to contain potential oil and gas horizons.

Geological Note—Delta County lies in sedimentary terrane indented by north-south drainage, part of the east-west flowing Gunnison River and its North Fork drainage basin.

In the extreme western portion, where the Gunnison River veers northwesterly, Jurassic rocks are exposed along its course, capped by the Upper Cretaceous Dakota quartzite. In the southern part of the County along the northern end of the Black Canyon and up to the Gunnison River's confluence with its North Fork, pre-Cambrian metamorphic rocks are exposed overlain by rocks of Triassic and Jurassic age capped by Cretaceous Dakota quartzite. The remainder of the southern two-thirds is mantled by Cretaceous Mancos shale. To the north the following are exposed in sequence: the Cretaceous Mesa Verde group; the Tertiary Wasatch formation; the Tertiary Green River formation; and, the Tertiary and Quaternary(?) volcanic rocks which cap Grand Mesa along the County's northern boundary.



Courtesy Colorado Planning Division

Denver County

Geographically, Denver County and the city of Denver are identical; consequently, the city of Denver is the seat of three governments, state, county, and municipal. The city-county has an area of 73 square miles and a population of about 600,000; its elevation is indicated by a bench mark on the Capitol steps at 5,280 feet above sea level. Denver, known as the "Mile High City", is the business, financial, and industrial hub of the Rocky Mountain West.

Available Maps of the County—

a. Denver City Maps.

b. Army Map Service maps: 4963 III, IV; 5063 I, II.

c. U. S. Topographic Quadrangle maps cover the County. See topographic quadrangle index map in the pocket.

Mineral Production—The only mineral production of any consequence in the County is that of sand and gravel, although some clays and gold have been produced, the latter as a byproduct of sand and gravel operations. The following table gives the value of mineral production beginning with 1951. All tonnage figures have been withheld with the exception of those for 1957; in that year the County was credited with producing 340,000 tons of sand and gravel. All figures are from the U. S. Bureau of Mines Minerals Yearbooks.

Year	$ Value
1951	428,464[1]
1952	707,356[1]
1953	670,597[1]
1954	1,119,083[2]
1955	111,611[2]
1956	382,500[2]
1957	250,800[2]
1958	----

[1] Value of sand, gravel, and clay production.
[2] Value of sand and gravel production only.

Sand and Gravel*—Sand and gravel deposits are located along the courses of the South Platte River, Bear Creek, and Clear Creek. The basins of Sand Creek and Cherry Creek contain fine sand but no gravel. All of this material is of igneous origin and makes excellent aggregate or concrete admixtures. The deposits vary in thickness from non-commercial to about 60 feet, with an average of 18 feet.

It is estimated that prior to the growth of Denver over much of the above areas, over 250 million tons of sand and gravel, plus an additional 60, million tons of fine sand were available within the Metropolitan district. This quantity of sand and gravel was contained within a radius of 10 miles from the confluence of Cherry Creek and the South Platte River, in deposits situated as follows: for 16 miles along the course of the South Platte River; 7 miles along Bear Creek; 12 miles along Clear Creek; 10 miles along Cherry Creek; and, for 10 miles along Sand Creek.

At present, partly because of past extraction, but mostly because of construction over the deposits, only a little over 80 million tons of sand and gravel remain available within the 10-mile circle mentioned above.

Geological Note—Exposures in the County consist mostly of unconsolidated alluvial and eolian deposits ranging in age from Pliocene to Recent, and outcrops of the Upper Cretaceous and Paleocene Denver formation, particularly in the western part.

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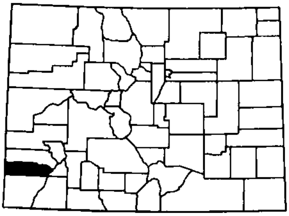
*Colorado Sand and Gravel Producers Association. Aerial Photo Map of Denver Metropolitan Area, showing sand and gravel deposits, with text.



Courtesy Colorado Planning Division

Dolores County

Dolores County, with a population of 2,200, is located in the southwestern part of the State bordering on Utah. The County has an area of 1,030 square miles ranging in elevation from 5,900 feet in the southwest, to the 13,000-ft. elevation of Dolores Peak to the northeast. The western part is a high plateau broken into mesas by deep narrow valleys; the central part is rugged and broken terrain; and along the eastern and northeastern boundaries are the San Miguel, Rico, and La Plata mountains. The County seat is at Dove Creek, a farming, ranching, and mining community with a population of 1,500.

Available Maps of the County—

a. Dolores County Map.
b. U. S. Army Map Service maps: 4259 I, II, III, IV; 4359 I, II, III, IV; 4459 III, IV.
c. U. S. Geological Survey topographic quadrangle maps cover a small area of the eastern end of the County. See topographic quadrangle index map in the pocket.
d. U. S. Forest Service map "San Juan National Forest" covers most of the county.

Mineral Production 1946-1958—By the end of 1958, Dolores County had produced gold, silver, copper, lead, and zinc, totally valued, since the beginning of mining in the county, at about $45 million. The Rico mining district in the southeastern part contributed most of the production. Beside the items listed in the following table, Dolores County produced pyrite, sand and gravel, uranium, and vanadium. The figures in the table are from the U. S. Bureau of Mines Minerals Yearbooks.

Year	Lode Mines	Gold Ozs.	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	3	136	173,297	223,000	4,351,000	6,870,000	1,493,309[1]
1947	5	104	124,199	217,100	4,084,500	6,866,800	1,580,682[1]
1948	5	108	132,312	148,000	4,860,000	6,360,000	1,871,465[1]
1949	6	79	80,032	66,000	2,776,000	2,708,000	862,600[1]
1950	5	71	72,735	70,000	2,276,000	2,730,000	777,794[1]
1951	4	220	131,912	102,000	4,462,000	5,054,000	1,843,525[1]
1952	2	128	127,446	146,000	4,460,000	5,468,000	1,787,258[1]
1953	1	95	103,908	36,000	3,742,000	5,268,000	1,337,454[2]
1954	3	147	118,621	22,000	4,354,000	5,792,000	1,358,309[3]
1955	3	156	114,392	10,000	4,404,000	5,142,000	1,507,772[3]
1956	2	179	97,181	12,400	3,716,000	3,336,600	1,580,607[4]
1957	1	13	8,829	600	402,200	318,600	509,539
1958	–	--	----	----	----	----	366,650[5]

[1] Precious and base metal values only.
[2] Same as [1] but includes pyrite and sand gravel values.
[3] Precious, base metals, and pyrite values only.
[4] Same as [2] but includes the value of uranium production.
[5] Pyrite, sand and gravel, stone, uranium ore.

Precious and Base Metals—There are two established mining districts in Dolores County: Lone Cone (Dunton), and Pioneer (Rico). These districts are discussed in the 1947 edition of Mineral Resources of Colorado (Vanderwilt), on the following pages.

Lone Star (Dunton)	General data p. 71
Pioneer (Rico)	General data pp. 73-74
Geology	pp. 414-416

J. D. Varnes, U. S. Geological Survey, in discussing the geology of the Rico mining district in the 1947 edition of this series, concludes on page 416 as follows:

> "Tracing of the ore-bearing beds in the Hermosa and Rico formations across faults which bound the main blocks within the dome calls for careful interpretation of all available geologic data. Unfortunately the geologic information is too often very meager because landslides and timber cover much of the ground surface. However, with further study, the prospects of discovering additional ore, now hidden by surface cover or lying in limestone beds not yet explored, are reasonably good in several parts of the district."

Pyrite—Pyrite, the most abundant ore mineral in the Rico district, became of particular economic importance with the establishment of uranium ore processing mills in western Colorado during the last decade. These mills consume considerable quantities of sulphuric acid, which can be produced from pyrite. The Rico Argentine Mining Company took advantage of this new outlet for its pyrite by constructing a $1½ million sulphuric acid plant which began operating in October, 1955. Since that time, the production of pyrite has become the most important nonmetal activity in Dolores County. The Colorado Bureau of Mines gives the following values for pyrite production since 1955.

1955	$ 55,000
1956	150,000
1957	380,000
1958	914,000

Sand and Gravel—Sand and gravel are produced from the basins of the Dolores River and some of its tributaries, and from some of the southwesterly flowing drainages in the vicinity of Dove Creek.

Uranium—Some uranium production has been credited to Dolores County for 1957 and 1958, originating from mines along the Dolores River and the Dunton area. No production figures are available. *Although the County lies to the southeast of the main uranium belt, the existence of scattered

*Dr. Donald L. Everhart, U. S. Atomic Energy Commission, personal communication.

carnotite deposits in favorable Morrison and Entrada formations indicate areas favorable for prospecting, particularly along the course of the Dolores River.

Oil and Gas*—No oil or gas has as yet been developed in Dolores County, although the western three-quarters of it lies within the confines of the Paradox Basin and the structural area of the Paradox Fold and Fault Belt. The balance of the County is more closely aligned with the San Juan Dome.

*Relatively few wells have been drilled, mostly salt tests in the Paradox formation of Pennsylvania age. However, the discovery of Mississippian gas at well Pure #1 Southeast Lisbon (Sec. 5, T. 44 N., R. 19 W.) in San Miguel County, and Devonian oil 25 miles to the northwest at well Pure #1 Northwest Lisbon (Sec. 10, T. 30 S., R. 24 E.) San Juan County, Utah, has stimulated interest in the Mississippian carbonates and the Devonian sands and carbonates. Increased exploratory drilling is anticipated in the near future. Prospective horizons include the Pennsylvanian Honaker Trail and Paradox formations, the Mississippian Leadville limestone, and the Devonian Ouray and Elbert formations.

Geological Note—Dolores County lies in typical Colorado Plateau sedimentary terrane. The western part comprises high table land broken into mesas separated by deep drainage indentations. The mesas are capped by Dakota sandstone of Upper Cretaceous age, and along the intervening canyons are exposed rocks of Jurassic, Triassic, Permian, and Pennsylvanian age. The center of the County is surfaced predominantly by Upper Cretaceous rocks of the Mancos shale and Mesaverde group, with Cretaceous Dakota sandstone and older formations exposed along the flanks of the drainage. The eastern part is rugged and mountainous. The Rico Mountains in the southeastern part of the County, are a domal uplift caused partly by laccolithic and sheet intrusion of magma into the bedded sediments, and also by vertical upthrust. The dome has been deeply dissected by the Dolores River. In this area, and along the northern part of the County, are exposed rocks of early and late Tertiary intrusives. The Dakota sandstone caps much of the terrain, but in the dissected portion of the Rico Uplift older rocks are exposed. Quaternary alluvium and landslides are common in the Rico and adjacent areas.

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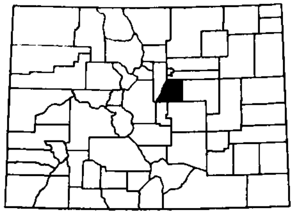
*Mr. Frank J. Adler, Phillips Petroleum Co., written communication.

Douglas County



Courtesy Colorado Planning Division

Douglas County is located in central Colorado a few miles to the south of Denver. The eastern two-thirds of the County comprises rolling prairie land suitable for grazing, and the western portion includes part of the Rampart Range of the Rocky Mountains. Elevations vary between 5,400 and 7,600 feet above sea level. The County has a population of 4,500, and the County seat is located at Castle Rock, a ranching and business community with a population of 1,400.

Available Maps of the County—

a. Douglas County Map.

b. U. S. Army Map Service maps: 4962 I, II, III; 5062 I, II, III, IV; 5063 II, IV.

c. U. S. Geological Survey topographic quadrangle maps cover most of the County. See topographic quadrangle index map in the pocket.

d. U. S. Forest Service map "Pike National Forest".

Mineral Production—Douglas County's mineral production during the period 1946-1958, consisted almost entirely of nonmetallics. Some gold production, presumably chiefly from Cherry Creek gravels, was reported for the last three years of the period. The following table shows the value of the County's mineral production beginning with 1951. Other items produced, not listed in the table, are coal, stone, feldspar, gemstones. All the figures in the table are from the U. S. Bureau of Mines Minerals Yearbooks.

Year	Sand & Gravel Short Tons	Clays Short Tons	Total $ Value
1951	Withheld	Withheld	165,958[1]
1952	Withheld	Withheld	120,819[1]
1953	Withheld	54,172	295,242[2]
1954	145,000	44,983	136,456[3]
1955	60,000	58,794	243,489[4]
1956	312,000	77,243	384,078[3]
1957	67,000	71,000	223,059[3]
1958	136,000	Withheld	267,561[3]

[1] Clay and sand and gravel values only.

[2] Same as [1] but includes stone and feldspar values.

[3] Clay, sand and gravel, stone, gem stone values only.

[4] Same as [2] but includes value of some gold production.

Sand and Gravel — Sand and gravel have been produced from Plum Creek, East Plum Creek, and West Plum Creek at Castle Rock and north and south of it to the County's boundaries; and from Cherry Creek and some of its tributaries east, northeast, and southeast of Castle Rock. Other deposits occur: northerly across the County along the courses of East Plum Creek and the South Platte River; along Cherry Creek and some of its tributaries in the eastern part in the vicinity of Parker, southeast of Franktown, and north and northwest of Cherry; in the central part southwest of Sedalia; and, in the south to the west of Larkspur.

Clays—Fire clay and other types of clay are produced in Douglas County from several pits and quarries in the Castle Rock area and to the southwest of Littleton. Along the eastern margin of the Rampart and Front Ranges are exposed clay bearing formations which provide raw materials for brick, tile, and other purposes.

Coal[6]—The plains portion of Douglas County east of the Rockies lies within the western confines of the Denver Coal Region. At least 12 square miles of the County are underlain by coal measures of subbituminous rank totalling no less than 187 million tons. Of this amount, 62 million tons are overlain by less than 1,000 feet of overburden, and 125 million tons lie between 1,000 and 2,000 feet below the surface. The coal occurs in several formations, but principally in the Laramie formation of Late Cretaceous age, in the middle of the Dawson arkose of Cretaceous-Paleocene age, and in the lower part of the Denver formation of Eocene age.

Uranium* — Scattered uranium occurrences of various mineralogic and structural types indicate favorable areas for prospecting. The pre-Cambrian complex in the western part of the County, the Dakota sandstone hogbacks along the Front and Rampart Ranges, and possibly the continental beds of Tertiary age in the eastern part, provide favorable environment for uranium deposition.

Feldspar—Douglas County has produced feldspar from a number of pegmatite zones within the pre-Cambrian terrane in the western part, principally from the Devil's Head-Dakan Mountain area.

Gem Stones — Amazonite, a beautiful green feldspar, smoky quartz, and quartz crystal, are found at Devil's Head in the mountains east of Deckers, and at Pine Creek Store near Sedalia. Topaz is found at Devil's Head.

Gypsum—Argall[9] reports a bed of gypsum 40 to 75 feet thick and about 8 miles long occurring near the top of the Lykins formation of Permo-Triassic age, at Perry Park. This deposit was apparently worked at the turn of the century.

Silica Sand—Silica sand has been produced in Douglas County principally from sandstone which was processed for foundry moulding sand. This material originated from several

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*Dr. Donald L. Everhart, U. S. Atomic Energy Commission, personal communication.

localities: near Larkspur; Waterton; near Palmer Lake; and near the abandoned station of Silica.

Stone—The western part of the County contains a variety of igneous, metamorphic, and sedimentary rocks, some of which are suitable for construction and monumental purposes. Rhyolite flows in the vicinity of Castle Rock have been quarried in the past. The following two deposits of welded tuff were examined by Bush[28].

Castle Rock Area—[28]This deposit, located in section 3, T-8-S, R-67-W, is a welded rhyolite tuff containing tridymite and biotite, and forms the cap rock of several buttes west and northwest of Castle Rock. The deposit has been quarried extensively and the material used as cut building stone. The horizontally bedded tuff is in the upper part of the Dawson arkose of Paleocene age and covers the entire top of the butte, an area of about 1,200 by 800 feet, with a thickness of at least 35 feet. Large tonnages of welded tuff are available at this locality and at other buttes in the vicinity. Tests by the U. S. Bureau of Reclamation indicate the tuff to be suitable for use as aggregate in medium-weight concrete. A cubic foot of such conrete weighs from 115 to 125 pounds.

Seller's Creek Area —[28]This welded rhyolite tuff deposit, located in section 13, T-8-S, R-67-W, correlates with the Castle Rock deposit. The tuff is exposed at the top of the section along the east bank of Seller's Creek. The bed is 12 feet thick in the rim outcrop where erosion may have removed a considerable portion. Available tonnages are very large, well over 1,000,000 tons.

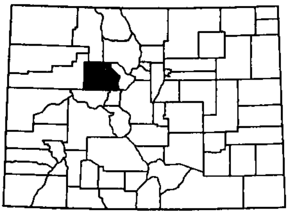
Other welded tuff deposits extend for several miles to the northeast, southeast, and southwest of the two discussed occurrences.

Hydrocarbons*—Douglas County has remained virtually untested for hydrocarbons because of the apparent absence of structures of sufficient size to warrant appreciable drilling. Generally, the Cretaceous sands along this Front Range belt are typically tight, but there are possibilities that commercial accumulations of hydrocarbons may occur in fracture systems of the more brittle limestones or shales, such as those of the Timpas and Pierre beds of Upper Cretaceous age.

Geological Note—The southwestern part of Douglas County lies athwart the Rampart Range, a pre-Cambrian complex with gneisses and schists, chiefly of sedimentary origin, west of Sedalia, and granite and related rocks south from there into Teller and El Paso counties. In the southwestern corner of the County, south of Devil's Head and east of West Creek, remnants of Cambrian and Ordovician rocks, with Pennsylvanian Fountain formation, are found along the course of Trout Creek.

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

East of the Rampart and Front ranges, tilted steeply against their slopes, are exposed: the Fountain formation of Pennsylvanian age; the Permian Lyons formation; the Permo-Triassic Lykins formation; the Jurassic Morrison formation; the Upper Cretaceous: Dakota sandstone, Benton shale, Niobrara formation, Pierre shale, and Laramie formation. Farther east and predominating in the rest of the County, are the Denver-Arapahoe formations and Dawson arkose (undiferentiated) of Eocene age. Scattered throughout the eastern part are remnants of the Lower Oligocene Castle Rock conglomerate capping higher ground, and Tertiary extrusive rocks consisting of rhyolite flows and tuffs interbedded in the upper part of the Dawson arkose. Quaternary terrace deposits are found along the eastern edge of the mountains, and Recent alluvium along the courses of streams and creeks.


Courtesy Colorado Planning Division

Eagle County

Eagle County, in the west-central part of the State, has an area of 1,686 square miles ranging in elevation from 6,150 feet in the Colorado River valley, to the 14,000 feet elevation of Mount of the Holy Cross. The County has a population of 5,000; the County seat is at Eagle, a ranching and commercial center with a population of 700.

Available Maps of the County—

a. Eagle County Map.

b. U. S. Army Map Service maps: 4562 I; 4563 I, II; 4662 I, IV; 4663 I, II, III, IV; 4762 I, IV; 4763 I, II, III, IV.

c. U. S. Forest Service map "White River National Forest" includes Eagle County.

Mineral Production 1946-1958—Eagle County is an important producer of precious and base metals, particularly zinc, of which it is one of the leading producers in the State. Beside the items listed in the following table, Eagle County produces pumice and scoria, sand, gravel, and stone.

Year	Lode Mines	Gold Ounces	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	4	164	57,364	17,000	1,380,000	32,873,000	4,215,770[1]
1947	1	936	233,351	481,500	1,847,000	34,750,000	4,815,776[1]
1948	3	3,298	416,032	444,000	2,240,000	32,710,000	5,339,698[1]
1949	4	766	216,589	404,000	3,200,000	34,900,000	5,135,622[1]
1950	3	5,636	669,461	652,000	4,220,000	29,912,000	7,175,976[1]
1951	1	2,793	412,788	556,000	8,548,000	58,400,000	12,745,943[1]
1952	1	1,700	348,090	390,000	7,960,000	52,000,000	10,383,527[1]
1953	1	3,750	581,100	880,000	5,000,000	33,700,000	5,467,787[2]
1954	4	10,121	2,111,786	4,710,000	5,176,000	37,208,000	8,406,234[2]
1955	2	8,416	1,613,096	4,494,000	6,342,000	42,644,000	9,651,425[3]
1956	2	2,053	581,901	1,395,100	7,258,200	39,532,100	7,752,034[4]
1957	1	3,201	931,850	2,385,800	8,953,400	48,209,400	8,583,711[5]
1958	2	3,903	1,103,857	3,170,000	8,182,000	49,770,000	8,166,132[6]

[1] Precious and base metal values only.
[2] Same as [1] but includes sand and gravel.
[3] Same as [1] but includes value of stone production.
[4] Same as [3] but includes value of pumice production.
[5] Same as [4] but includes the value of stone production.
[6] Same as [2] but includes pyrite, pumice and stone.

Precious and Base Metals—There are a number of mining districts established in Eagle County, but virtually all of its production has come from the Gilman district in the southeastern part. The 1947 edition of "Mineral Resources of Colorado" (Vanderwilt), contains a discussion of these districts on the following pages.

Brush Creek .... General Data p. 77
Burns and McCoy .... General Data p. 77
Fulford .... General Data p. 78
Gypsum .... General Data p. 78
Holy Cross (Eagle River) .... General Data p. 78
Homestake .... General Data p. 80
Mount Egley .... General Data p. 80
Red Cliff (Gilman, Battle Mountain, Belden) .... General Data p. 80

Ogden Tweto and T. S. Lovering, U. S. Geological Survey, discuss the history, geology, and ore deposits of the Gilman district on pages 378-387 of the 1947 edition of this book. See also reference No. 43 of the bibliography.

Sand and Gravel — Sand and gravel have been produced from the courses of the Eagle River, Brush Creek, and some of their tributaries near Eagle, and east and northeast of the town. Also from the Colorado River at State Bridge, and near Glenwood Springs. The Eagle and Colorado rivers, as well as some of their confluential streams, contain adequate deposits of sand and gravel.

Gypsum — Eagle County contains extensive deposits of gypsum and gypsiferous rocks of Pennsylvanian age, many of which are within easy access of U. S. Highways 6 and 24; east of Wolcott in the vicinity of Minturn, Avon, and Edwards; between Wolcott and Eagle; west of Eagle as far as Dotsero; south of Gypsum; north of Gypsum as far as the Colorado River. The gypsum occurs in shapeless masses, roughly lenticular, ranging in thickness from a few feet to more than 200 feet. On the surface these masses form softly rounded ashy-gray knolls.

Uranium*—Scattered uranium occurrences in the Permian sediments, particularly near Vail Pass, indicate favorable areas for prospecting. Much of the County is underlain by Permian sedimentary rocks which appear in places to be favorable for small uranium occurrences.

Manganese**—The Old Iron Mask mine in the Red Cliff district is reputed to contain an estimated half-million tons of manganese ore carrying 18.6% manganese. The ore was derived from the oxidation of manganiferous siderite in the limestone of Carboniferous age. No recent information as to remaining tonnage in this deposit is available.

Lightweight Aggregates—One perlite and two valcanic scoria deposits are reported in Eagle County:

Perlite—A perlite deposit is reported by Jaster[27] occurring on the southern and eastern flanks of Basalt Mountain north of the town of Basalt.

Scoria—*Dotsero Crater Deposit*—[28]This deposit, located in section 23, T-4-S, R-86-W, contains a large percentage of fines ranging in size from ¼ to ½-in. with some unexpanded bomb fragments. The scoria was ejected from a vent which developed in the bottom of a small tributary of the Eagle River. The crater remains well preserved. Lapilli and bomb fragments of scoria cover the surrounding hills of Triassic red sandstone. Some material from this deposit has been used as lightweight aggregate in nearby towns. The minable area, which lies east of the crater, is approximately 1,200 by 800 feet and has an average scoria thickness of from 3 to 4 feet with a maximum of 8 feet.

Mount Saunders Deposit—[28]This deposit, located in section 30, T-2-S, R-82-W, is not considered commercial at this time. Most of the scoria is in the form of bombs and bomb fragments many of which are unexpanded, and the useable scoria is intermixed with a number of dense boulders. The cost of separating the suitable material from that which is useless, and the comparative inaccessibility of the deposit to adequate markets, makes economic production from this deposit unfeasible at this time.

Stone—Eagle County has an abundance of igneous and sedimentary rocks of varied types: from pre-Cambrian granites and metamorphics to Tertiary volcanics, and sandstones, carbonate rocks, and shales, ranging in age from Cambrian to Upper Cretaceous.

Hydrocarbons***—Eagle County has as yet to produce oil or gas, but the possibilities of discovering accumulations in beds of Paleozoic age are encouraging. The County includes the

*Dr. Donald L. Everhart, USAEC, personal communication.

**Mr. Edward D. Dickerman, E.M., personal communication.

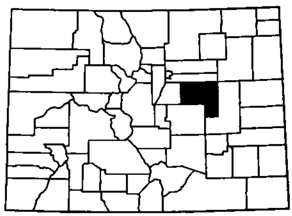
***Mr. Charles C. O'Boyle, Consulting Geologist, Denver, written communication.

Eagle basin and is underlain by a thick series of sedimentary beds which include many potential reservoir horizons. It is expected that exploratory drilling in the area will increase.

Geological Note—Eagle County is bisected in an east-west direction by Gore Creek which flows westward from its origin in the high-relief pre-Cambrian terrane of the Gore Range, and Eagle River, which is joined by Gore Creek in the vicinity of Minturn.

Along the western slopes of the Gore Range at the eastern end of the County Permian and Pennsylvanian beds are exposed locally and represent the eastern limb of a major synclinal area the western confine of which is the pre-Cambrian Sawatch Range. Westward from Minturn another broad synclinal area occurs exposing a thick section which comprises Pennsylvanian, Permian(?), Triassic, Jurassic, and Cretaceous rocks as high as the Mesaverde formation, which lies in the axis of the syncline near Wolcott. West from Wolcott older beds reappear, down to the gypsiferous shales of Pennsylvanian age east of Eagle. In the central and north-central parts of the County, particularly around State Bridge on the Colorado River, there are extensive flows of Late Tertiary or Quaternary(?) basalt and andesite. Tertiary intrusive stocks and dikes are found along the fringes of the Sawatch Range. Extensive Quaternary morainal and terrace deposits are found in the valleys indenting the Gore and Sawatch ranges, and in the area around Snowmass Mountain.

Elbert County



Courtesy Colorado Planning Division

Elbert County, located in the eastern part of central Colorado, has a population of 4,300 and an area of 1,864 square miles of undulating land indented by numerous streams and arroyos. Topographic relief is moderate, with elevations ranging from 4,700 to 6,500 feet above sea level. The County seat is at Kiowa, a small ranching community with about 100 population.

Available Maps of the County—

a. Elbert County Map.

b. U. S. Army Map Service maps: 5062 I, II; 5063 II; 5162 I, II, III, IV; 5163 II, III; 5261 I, IV; 5262 I, II, III, IV; 5263 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover the eastern part and a small portion of the western part of the County. See index map in the pocket.

Mineral Production—Elbert County has had some minor gold production in the past from placers along Boxelder Creek near Elizabeth, and from a drainage a mile or so west of the town (see pages 80-81 of the 1947 edition of this book). No gold production is credited to the County for the period 1946-1958. Petroleum was discovered in 1955, but the field was abandoned the same year. Sand and gravel are the only minerals of any consequence being extracted, although very minor quantities of stone and gem stones have been produced. The County has substantial reserves of coal, but none was produced during the 1946-1958 period. The U. S. Bureau of Mines Minerals Yearbooks give the values of sand and gravel production for the following years:

1953	$ 72,165
1954	13,708
1955	24,744
1956	85,020
1957	36,215
1958	160,000

Sand and Gravel — Sand and gravel have been produced from the courses of: Boxelder Creek near Elizabeth; Kiowa Creek south of Kiowa; Comanche and West Bijou creeks near the center of the County; and, Badger, Deer Trail, East Bijou, and Big Sandy creeks in the eastern and northeastern parts. Other sand and gravel deposits are located along both forks of Kiowa Creek south of Elbert town; along Boxelder Creek from south of Elizabeth north to the Arapahoe County line; along the course of Big Sandy Creek from River Bend southeast to the Lincoln County line, and from River Bend southwest to the El Paso County line.

Petroleum—Oil was discovered in 1955 on the Bradbury structure in the north-central part at a depth of 7,180 feet in the 'J' sand of the Dakota formation of Cretaceous age. The field proved noncommercial and was abandoned the same year after producing 374 barrels of oil and 48,000 cubic feet of gas.

*Elbert County is located along the southern flank of the Denver Basin and it may be anticipated that some commercial production will be developed in the future. The most prospective horizons are the Lower Cretaceous sands and the Hygiene sand of the Upper Cretaceous Pierre shale which has shown some gas in some of the test wells. The

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

Paleozoic section has not been sufficiently tested to permit speculation on its potentialities.

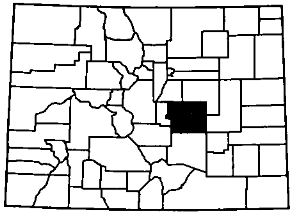
Coal[6]—The western nine-tenths of the County lie within the Denver Coal Region. At least 152 square miles are underlain by measures estimated to contain 790 million tons of coal, all of it under less than 1,000 feet of overburden. Coal has been mined from two areas: the Ramah-Fondis area in the southwestern part where the coal, lignitic to subbituminous in rank, occurs in the middle of the Dawson arkose of Paleocene age; and, the Buick-Mathieson area in the east-central part where coal for domestic use has been mined intermittently over many years. The coal measures, which crop out near the small towns of Buick and Mathieson, occur in lenses throughout the 300 to 350 foot thickness of the Laramie formation of Upper Cretaceous age.

Uranium*—Scattered uranium occurrences in the Laramie formation of Upper Cretaceous age, and in the Dawson arkose of Paleocene age, indicate the existence of areas favorable to prospecting.

Geological Note—Elbert County lies in the sedimentary terrane of the eastern plains of Colorado. Its surface rocks vary in age from the Upper Cretaceous Pierre shale exposed in the broad drainage basin of Big Sandy Creek in the eastern part, to the Pliocene Ogallala formation in the southeast.

Near the southwestern corner occur extensive remnants of Castle Rock conglomerate of Oligocene age capping beds of Upper Dawson arkose of Paleocene age. The arkose extends out from under the local conglomerate caps to cover the western third of the County. The Lower Dawson arkose, of Upper Cretaceous age, predominates in the rest of the County with the exception of the southeastern part where the Ogallala formation again forms the surface. Upper Cretaceous Fox Hills sandstone and Pierre shale are exposed in the northeastern part in the drainage basin of Big Sandy Creek. Quaternary alluvium occurs along the course of the Big Sandy, Kiowa, and Boxelder creeks.

El Paso County



Courtesy Colorado Planning Division

El Paso County, in east-central Colorado, has a population of 120,000 and an area of 2,159 square miles with elevations

*Dr. D. L. Everhart, USAEC, personal communication.

ranging from 5,000 feet in the southeastern plains, to the 14,110 feet elevation of Pikes Peak in the mountains to the west. The County seat is at Colorado Springs, a beautiful resort city, industrial and commercial center, and the official home of the new United States Air Force Academy. The population of Colorado Springs is about 80,000.

Available Maps of the County—

a. El Paso County Map.

b. U. S. Army Map Service maps: 5061 I, II, III, IV; 5062 II, III; 5161 I, II, III, IV; 5162 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover the County with the exception of a small area along the northeastern part.

d. U. S. Forest Service map "Pike National Forest" covers the western part of the County.

Mineral Production 1946-1958—Besides the items listed in the table, El Paso County produced stone, mica, feldspar, gem stones, uranium, rare earth minerals, and thorium. With the exception of the coal production figures all others are from the U. S. Bureau of Mines Minerals Yearbooks. Total value figures begin with 1951 when the U. S. Bureau of Mines changed its reporting procedure.

Year	Coal Short Tons	Clays Short Tons	Sand & Gravel Short Tons	Total $ Value
1946	191,186	----	----	----
1947	214,449	----	----	----
1948	192,788	----	----	----
1949	126,992	----	----	----
1950	112,984	----	----	----
1951	89,620	----	----	655,059[1]
1952	72,036	----	----	560,404[1]
1953	55,927	8,726	----	586,414[2]
1954	75,458	8,393	674,000	970,544[3]
1955	73,384	17,891	518,000	1,073,474[4]
1956	47,172	11,892	994,000	1,172,090[5]
1957	263,729**	6,810	1,317,000	1,537,084[6]
1958*	7,599	7,334	1,826,000	2,704,096[7]

*Preliminary figures.

**Pitkin County production included.

[1] Value of coal, clay, sand and gravel, and stone production.

[2] Same as [1] but includes value of mica and feldspar production.

[3] Same as [1] but includes value of gem stone production.

[4] Same as [3] but includes value of mica production.

[5] Same as [3] but includes value of uranium and rare earth production.

[6] Same as [5] but includes value of thorium production. Value of Pitkin County production included in the figure.

[7] Same as [5] but includes some manganese ore and gold and silver production.

Coal[6]—The northern part of El Paso County lies within the southern portion of the Denver Coal Region. At least 123 square miles are underlain by measures totalling no less than 560 million tons of coal. Of this, 350 million lie under less than 1,000 feet of overburden, 160 million are between 1,000 and 2,000 feet, and 50 million tons are between 2,000 and 3,000 feet below the surface.

The Colorado Springs coal field, north and northeast of that city, occupies the area of outcrop of the coal-bearing Laramie formation of Upper Cretaceous age. At the western edge of the field where the Laramie rocks approach the mountain front, the dips in the beds are steep to the east, as much as 50 degrees, but flatten out rapidly to 2 to 10 degrees a short distance to the east. The most important coal beds occur within the basal Laramie. The coal is subbituminous, chiefly C in rank.

Sand and Gravel—Sand and gravel are produced mostly from the courses of the north-south flowing Monument and Fountain creeks and their tributaries across the breadth of the County. Other deposits of importance are found through the southeastern quarter to the south of Colorado Springs; also northeast of this city, near Falcon, Peyton, Calhan, and Ramah.

Clays—Clay deposits occur along the Rampart Range to the northwest, west, and southwest of Colorado Springs, where are found upturned exposures of all formations from the Upper Cretaceous Niobrara to the Pennsylvanian Fountain. Some of these deposits have been worked for many years. Butler[7] sampled clay deposits in the vicinity of Calhan near the northeastern corner of the County with the following results.

Sample 168—

Location: 3 miles southeast of Calhan.

Occurrence: A hard, red and gray, medium coarse sandy clay. Sample from 8 feet of a horizontal material with 30 feet of overburden, on the north side of a ridge.

Economic Value: Should make first-class, light flesh-tinted pressed bricks, earthenware, terracotta, stoneware, refractory goods, etc.

Sample 169—

Location: ¾ mile southwest of Calhan.

Occurrence: A hard, light-brown, fine-grained, sandy clay. Sampled 5 feet of horizontal material with 10 feet of overburden occurring on the south side of a small knoll.

Economic Value: Very similar to No. 168, but not quite as good.

Sample 170—

Location: 1 mile south of Calhan.

Occurrence: A hard, grayish-red, fine grained sandy clay. Sampled 4 feet of horizontal material with 10 to 28 feet of overburden; in a cut on the northern side of a ridge.

Economic Value: Should make good vitrified floor tile and fine pressed bricks if burned to cone 5.

Sample 171—

Location: 1 mile southeast of Calhan.

Occurrence: Hard, grayish-red fine grained clay with a little sand. Sampled 9 feet of horizontal material with 10-25 feet of overburden on the north side of a long ridge.

Economic Value: Should make fine vitrified floor tile, refractory goods, wall tiles, and white earthenware.

Sample 172—

Location: 2½ miles southeast of Calhan, in a prospect hole.

Occurrence: Hard, gray, brown and red, fine grained sandy clay. Sampled 6 feet of horizontal material with 8 feet of overburden, on a prominent knoll.

Economic Value: One of the most valuable clays tested and may be used for a variety of products.

Sample 173—

Location: 3 miles east of Calhan.

Occurrence: A hard, white, brown, and red fine grained sandy clay. Sampled 6 feet of horizontal material with 10 feet of overburden on the side of a knoll.

Economic Value: Should make fine, nearly white pressed bricks, vitrified and unvitrified floor tile, wall tile, and refractory material.

Clay production for 1957 amounted to 6,810 tons valued at $18,689, and for 1958, 7,334 tons with a value of $21,387.

Stone—El Paso County has an abundance of a variety of igneous, metamorphic and sedimentary rocks many of which have applications in various phases of the construction industry. Pre-Cambrian granite has been quarried from near Cascade, northwest of Manitou, Permian Lyons sandstone from near Manitou and Colorado City, and Ordovician Manitou limestone from near Colorado Springs. Production in 1958 amounted to 574,557 tons valued at $1,230,620.

Feldspar, Mica — The Johny pegmatite, north of Bardeen and west of Fountain near the headwaters of Little Fountain Creek, has been worked for feldspar. According to Hanley[26] et al, scrap mica could be recovered as a by-product of feldspar production from the pegmatite.

Fluorspar—The St. Peters dome district, located near the eastern fringe of the Front Range about 8 miles southwest of Colorado Springs, has produced fluorspar intermittently since about 1910. [51]The last significant production apparently occurred during 1944-45 when 16,100 tons of ore were produced.

[51]Most of the district is on an arch-like joint structure in Pikes Peak granite of pre-Cambrian age. Three groups of joints are recognized, as well as a series of north-trending, (late Tertiary?) shear joints and minor faults which cut across all the earlier structures. Two periods of vein deposition are recognized within the sheared and faulted zones. Most of the fluorite in the district was deposited during the first stages of the second period of vein deposition. The fluorspar occurs in veins and as filling in irregular breccia bodies, intergrown with varying amounts of quartz. Some sulfides, mainly galena and sphalerite, were widely deposited late in the second stage of deposition, but in small concentrations. Some pyrite, chalcopyrite, and small amounts of gold and silver, are also found in the veins.

[51]The fluorspar deposits are known to occur over a vertical

length of over 600 feet, and as they are discontinuous vertically as well as horizontally, it is quite probable that some bodies exist which do not crop out at the surface.

[51]Conservative estimates of known ore bodies indicate reserves of at least 65,000 tons of ore containing 35% or more CaF_2 within 100 feet beneath the present workings, and 80,000 tons of additional, inferred ore.

Petroleum Potential*—The synclinal axis of the Denver Basin passes through El Paso County; for this reason the normal drilling objectives, the Lower Cretaceous sands and Paleozoic beds, are relatively deeper than in other, more favorably situated eastern Colorado counties. Possible prospective horizons are the sandstones of Lower Cretaceous, Permian, and Pennsylvanian age, and the carbonate rocks of Pennsylvanian, Mississippian, and Ordovician age.

Gem Stones—Schlegel[24] lists the following gem stone occurrences in El Paso County.

Locality	Gem Stone
Austin Bluffs, Colorado Springs	Carnelian, jasper.
Pikes Peak Area	Amethyst, tourmaline.
Crystal Park	Amazonite, topaz.
Manitou Springs	Smoky quartz.
St. Peters Dome	Amazinite, quartz crystal, smoky quartz, topaz.
Near Calumet	Sapphire.
El Paso County	Petrified wood.

Uranium**—A few occurrences in the Permian and Cretaceous hogbacks south of Colorado Springs indicate favorable areas for prospecting. Upturned continental sedimentary rocks along the front of the Rampart Range appear to be the most favorable host rocks. Radioactive anomalies and occurrences in granite and pegmatite of the pre-Cambrian complex appear to have little commercial significance.

Rare Earths, Thorium — Small quantities of rare earth minerals and thorium minerals have been reported produced from the St. Peters Dome area west of Colorado Springs (See rare earth and thorium sections).

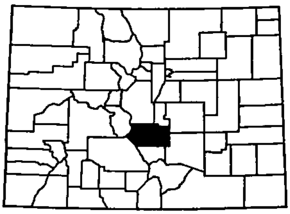
Geological Note—The western portion of El Paso County lies in pre-Cambrian terrane of the Rampart and Front ranges west of Colorado Springs. Steeply dipping sedimentary rocks ranging in age from pre-Pennsylvanian to Upper Cretaceous are exposed along the eastern margin of the range and represent the outcrop of the western limb of the Denver Structural Basin, with its trough located only a short distance to the east. The entire stratigraphic section of Paleozoic, Mesozoic, and Cenozoic rocks is exposed within a distance of four miles east

*Mr. Thaddeus R. Carpen, Continental Oil Co., written communication.

**Dr. Donald L. Everhart, U.S.A.E.C., personal communication.

of the Garden of the Gods. In the northwestern part of the County around the Palmer Lake area, nearly horizontal strata of the Dawson arkose of Early Tertiary age, directly overlay the pre-Cambrian crystalline rocks of the Front Range in a probable overlap of the older beds.

The southwestern part of the County east of the mountains is mantled by the Upper Cretaceous Niobrara group and Pierre shale, crossed by northerly-trending bands of Quaternary terrace deposits, particularly along Fountain and Monument creeks and some of their tributaries. North of the Pierre exposure, the Upper Cretaceous Fox Hills sandstone, the Upper Cretaceous Laramie formation and the Early Tertiary Dawson arkose are found in sequence. Remnants of Castle Rock conglomerate of Oligocene age, are found capping higher ground north of Eastonville and Peyton. To the east of Calhan and Yoder, the late Tertiary Ogallala formation extends to the eastern confines of the County.



Courtesy Colorado Planning Division

Fremont County

Fremont County, located in south-central Colorado, has a population of 20,000 and an area of 1,562 square miles ranging in elevation from 5,000 to 12,600 feet above sea level. The County seat is at Canon City, a regional business center with a population of 7,000.

Available Maps of the County—

a. Fremont County Map.

b. Army Map Service maps: 4860 I, IV; 4861 II, III; 4960 I, IV; 4961 II, III; 5060 IV; 5061 III.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See topographic quadrangle index map in the pocket.

d. U. S. Forest Service maps "San Isabel National Forest" and "Pike National Forest" include the County.

Mineral Production 1946-1958—The wide variety of geologic conditions existing in Fremont County permitted the accumulation of a diversification of economic mineral deposits. The following table gives yearly production and total value figures for the more important minerals. Besides those listed in the table, the following were produced: uranium, stone, pegmatite minerals, lightweight aggregates, and gem stones.

Year	Coal Short Tons	Petroleum Barrels*	Clay Short Tons	Sand & Gravel Short Tons	Stone Short Tons
1946	394,507	29,325	----	----	----
1947	429,600	25,348	----	----	----
1948	394,873	27,907	----	----	----
1949	339,651	33,425	----	----	----
1950	270,462	32,777	----	----	----
1951	279,466	21,869	5,849	----	----
1952	201,641	30,602	106,243	----	----
1953	175,307	29,702	192,390	62,000	----
1954	178,876	30,533	306,743	165,000	----
1955	216,119	31,204	18,807	----	----
1956	240,522	29,421	6,282	----	1,060,000
1957	224,503	25,033	4,813	28,000	1,168,000
1958	250,634	27,223	4,006	76,000	1,190,744

*State Oil and Gas Conservation Commission figures; all others from U. S. Bureau of Mines Minerals Yearbooks.

Year	Lode Mines	Gold Ozs.	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	4	19	2,182	30,000	36,000	226,000	38,784[1]
1947	2	8	592	22,300	8,800	118,800	21,141[1]
1948	3	11	1,074	36,000	14,000	126,000	28,483[1]
1949	1	20	31	----	----	----	728[1]
1950	1	1	21	----	----	8,000	1,190[1]
1951	-	--	21	----	2,000	2,000	(?)
1952	1	7	242	----	6,000	40,000	Withheld
1953	-	--	----	----	----	----	7,957,047[2]
1954	1	2	27	4,000	----	----	8,594,960[2]
1955	2	--	19	4,000	----	----	11,524,720[2]
1956	2	1	13	700	----	----	12,972,603[3]
1957	1	--	9	1,500	----	----	13,629,466[4]
1958	-	--	----	----	----	----	14,558,403[5]

[1] Precious and base metal values only.

[2] Includes values of cement, coal, stone, clay, gypsum, sand and gravel, oil, feldspar, mica, beryl, tungsten, columbium-tantalum concentrates.

[3] Same as [2] but includes values of uranium ore and gem stone production.

[4] Same as [3] but includes value of thorium production.

[5] Same as [3] but includes manganese ore and rare earths ore.

Precious and Base Metals—A number of mining districts have been established in the County. These districts are discussed in the 1947 edition of this book on the following pages:

Arkansas River Placers .... p. 83
Badger Creek .... p. 83
Canon City .... p. 83
Cotopaxi .... pp. 83-85
Currant Creek (Parkdale, Micanite) .... p. 85
Grape Creek (Greenhorn) .... p. 85
Hillside .... pp. 85-87
Red Gulch .... p. 87
Whitehorn .... p. 87

Production data are given on pages 82, 84, and 86.

Coal[6]—The Canon City field, just south of Canon City, comprises approximately 36 square miles underlain by 260,000,000 tons of coal all of it under less than 1,000 feet of overburden. The field is in the Colorado Piedmont section of the Great Plains physiographic province, and structurally is an asymmetric synclinal basin with steep to moderately dipping beds in the west and gently dipping beds in the east.

The coal occurs in the lower 600 to 700 feet of the Vermejo formation of Upper Cretaceous age which outcrops just east of the Wet Mountains. At the southwest end of the field the Vermejo formation is cut by a thrust fault and for a short distance the overturned beds of the formation are overlain by granite. As many as 16 coal beds have been reported in the coal bearing zone. Above it there is a persistent, massive sandstone about 250-ft. thick which forms resistant ridges and scarpments around the field.

Most of the coal is high volatile bituminous C rank, nonweathering nonagglomerating, and noncoking.

Petroleum*—The Florence-Canon City field, the first and oldest active field in the State, was discovered in 1862 when a shallow, 50-ft. well was drilled near a live oil seep on Oil Creek about 6 miles northeast of present-day Canon City. This well, and others drilled soon after, established Colorado as the second area in the United States, after Pennsylvania, to produce oil from drilled wells.

*In 1876, a well drilled a short distance south of where Florence now stands, struck oil at a depth of 1,187-ft. in joints and fissures of the Pierre shale of Upper Cretaceous age.

The Florence-Canon City field is the only active one in the County. During 1959, the field was credited with a production of 39,181 barrels of oil and, up to that time, with a total cumulative production of 14,301,550 barrels.

**Sporadic drilling for additional fractured shale production continues in the area and may result in more commercial production in the future. Lower prospective horizons include the Dakota sandstone of Lower Cretaceous age, and the carbonate rocks and sandstones of Mississippian, Ordovician, and Cambrian age. The Lyons sandstone of Permian age is present, but the remainder of the Permian and Pennsylvanian rocks are not considered favorable because they constitute the thick, arkosic, red Fountain formation.

Clays[52]—In the eastern part of the County important deposits of clay occur in formations of Cretaceous age in a roughly triangular area situated between the south end of the Front Range and the Wet Mountains, forming the Canon City Embayment. Clay-bearing strata crops out in hogbacks and cuestas which extend in an east-west direction along the north side of the Embayment, and in the hogbacks and foothills to the west of it. These clay deposits have been divided into various districts which are discussed below.

The Penrose District—This district is located along the north side of the Canon City Embayment north of the Arkansas River. Refractory clay outcrops along Beaver Creek and Red

*A. E. Brainerd and F. M. Van Tuyl in reference No. 1 of the bibliography.

**Mr. Thaddeus R. Carpen, Continental Oil Co., written communication.

Creek. The outcrop areas are coextensive with the broad cuestas lying from 4 to 10 miles north and northeast of the town of Penrose. The westernmost of the outcrop areas lies between Sixmile Creek and Beaver Creek, and the other between Beaver and Red Creeks. Little is known about these clay deposits as they have not been systematically prospected, and only a small quantity of clay has been mined from the Sixmile Creek and Beaver Creek exposures. The deposits are not near a railroad, and other types of roads leading into the region are at present inadequate. In the light of present information, the outlook for this district appears somewhat discouraging as the clay bodies of the Dry Canon member of the Dakota formation which have been found here to date are all small, locally confined, and persistently sandy.

The Canon City District—This district includes all the outcrop areàs of clay-bearing strata lying between Sixmile Creek on the east, to Parkdale on the west. The various areas comprising the district are discussed briefly below.

The Parkdale area includes two synclines which consist for the most part of Mesozoic strata isolated in a terrane of granitic rocks. The Dakota and Purgatoire formations are locally present around the edges of the synclines where they crop out in steep hogbacks. One of the synclines lies to the south of Parkdale, and the other northeast of it underlying the area known as Twelvemile Park. Clay has been mined from the Glencairn member of the Purgatoire formation and from the lower third of the Graneros shale.

The Grape Creek area includes the hogback which extends southwest of Canon City, south of the Arkansas River. In the hogback the Glencairn member of the Purgatoire formation is 80 to 90 feet thick and consists of dark-gray carbonaceous shale with interbeds of sandstone as much as 4 feet thick. Bodies of plastic clay occur locally in the upper 10 to 20 feet of the unit. This clay from the Glencairn member, a semi-refractory plastic clay, has been mined in the area since the early 1900's and practically all the accessible deposits removed.

The Skyline Hogback, just west of Canon City, extends north from the Arkansas River to Wilson Creek. The clay-bearing formations in the hogback are similar to those of the Grape Creek area, but in the Skyline Hogback, the Glencairn member of the Purgatoire formation becomes increasingly sandy toward the north, and the Dry Creek Canyon member of the Dakota sandstone, absent in the Grape Creek area, locally appears in the north end of the Skyline Hogback area. A plastic and semiplastic refractory clay bed, locally as much as 6 feet thick, has been mined from the Glencairn shale, and plastic clay taken from the Dry Creek Canyon member of the Dakota formation. Some clay shale at the base of the Graneros shale has been mined locally for low-grade clay, a large amount of which is still available.

The Oil Creek and Sixmile Creek area lies about four miles northeast of Canon City between the two streams named. Purgatoire and Dakota beds cap a southeastward-trending cuesta which locally takes the form of a hogback. In the east end of the area a 5-to-8-ft. bed of dark blue-gray plastic clay from the top of the Glencairn member of the Purgatoire formation has been mined intermittently.

The Wilson Creek area, 5 miles north of Canon City, includes cuestas capped by the Dakota and Purgatoire formations extending around the northwest end of a southeastward pitching syncline. The Dry Creek Canyon member of the Dakota formation commonly is present beneath about 3 square miles in the south-central part of the area in sections 3, 4, 5, 8, and 9 of T-18-S, R-70-W, and includes a minable flint clay bed in the south half of section 4, in the southwest corner of section 3, and in the northwest corner of section 9, T-18-S, R-70-W. Elsewhere in the Wilson Creek area this member is present locally but is not known to contain flint clay in minable grade or quantity.

Sand and Gravel—Sand and gravel deposits occur in various parts of the County. These materials have been produced from the course of the Arkansas River around Canon City, Florence, Portland, Concrete; and, to the west, from around Texas Creek, Cotopaxi and Howard. Other deposits occur around Texas Creek, Hardscrabble Creek, and other tributaries of the Arkansas River.

Stone—Fremont County contains an abundance of a wide variety of igneous metamorphic, and sedimentary rocks some of which have found wide acceptance in various applications. The "blue", "gray", "pink", and "red" monumental and building granites and monzonites of Cotopaxi are particularly well known. Travertine deposits southeast of Salida and northwest of Canon City have been worked for building stone and for industrial purposes. Dolomite for the steel furnaces at Pueblo is quarried west of Canon City; limestone is actively quarried from several locations within the Permian-Pennsylvanian terrane between Coaldale and Wellsville; and, gypsum from near Coaldale for the production of wallboard at Florence. Argall[9] reports a large gypsum deposit west of Coaldale being mined for use in cement manufacture. Other gypsum deposits occur 14 miles northeast of Canon City, 13 miles north of Florence, and west of Bardeen.

Uranium*—The production of uranium ores has become an important part of the mineral industry of the County. A wide variety of types of deposits are found. These include the

*Donald L. Everhart, U.S.A.E.C., personal communication.

Tallahassee Creek occurrences at the southeastern margin of the Thirty-Nine Mile volcanic field; those in the Dakota sandstone near Canon City; and, the mineralized shear zones in pre-Cambrian granite near Cotopaxi. In the Tallahassee Creek area pre-Cambrian rocks, mostly Pikes Peak granite, are overlain by arkose of Eocene age and a series of Tertiary volcanics; and, to the east, the Cretaceous continental sediments lap up against the mountain front. All of these environments appear favorable for uranium accumulation.

Pegmatite Minerals—Pegmatites are abundant in the pre-Cambrian terrane west of Canon City. A number of these pegmatites in the vicinity of Parkdale, Texas Creek, Cotopaxi, Howard, and Micanite, have been worked for feldspar and mica, the latter chiefly from those in the Micanite area which have been exploited for over 60 years. Beryl, columbium-tantalum, and rare earth minerals are coproducts of feldspar and mica operations.

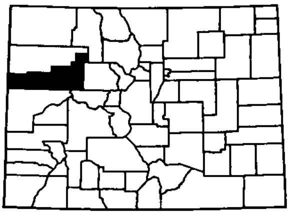
Lightweight Aggregates — Bush[28], in his maps showing the location of deposits of lightweight aggregates in Colorado, indicates the following reported deposits: pumice and scoria deposit about 1 mile south of Coaldale; one of pumice about 3 miles southeast of Howard; a perlite deposit in the northeast corner of T-50-N, R-12-E; a vermiculite deposit about 4 miles west of Texas Creek; and, another, 7 miles east of Howard.

Gem Stones—Schlegel[24] lists the following gem stone occurrences in Fremont County:

Chalk Creek Mountain, Fremont Pass	Spessarite (a variety of garnet), topaz, smoky quartz.
Canon City	Alamandite (a variety of garnet), amethyst, rose quartz.
Curio Hill, Wet Mountains	Agate.
Garden Park near Canon City	Aquamarine.
Parkdale	Jasperized bones, agate.
Royal Gorge	Aquamarine, tourmaline.

Thorium—The Wet Mountains thorium area extends north from Custer County into the south-central part of Fremont County. This area has been discussed under Custer County (See thorium section, this book).

Geological Note—Fremont County touches the fringe of the plains at its eastern extremity in the Canon City Embayment, west of the Denver Basin. Along the northern and western margins of the Embayment, abutting against the pre-Cambrian crystalline rocks of the Rampart Range and the Wet Mountains, sedimentary rocks are exposed varying in age from Cambrian to Upper Cretaceous. South and east of the crystalline rocks the sedimentaries are exposed in the following sequence: Cambrian and Ordovician rocks; locally, Williams Canyon limestone of Devonian (?) age; Mississippian Madison limestone; Pennsylvanian Fountain formation; Jurassic Morrison formation; and, Upper Cretaceous: Dakota sandstone, Benton formation, Niobrara formation, Pierre shale, Trinidad sandstone, and the Vermejo formation. The Sangre de Cristo Mountains along the western end of the county consist mainly of Paleozoic conglomerate, sandstone, shale, and limestone; pre-Cambrian gneiss and schist; and Tertiary intrusive and extrusive rocks.



Courtesy Colorado Planning Division

Garfield County

Garfield County borders on the state of Utah in western Colorado, and has a population of 13,000 in an area of 3,000 square miles ranging in elevation from 4,700 to 12,500. The County seat is at Glenwood Springs, a resort city and farming, ranching, and business center with a population of about 3,500.

Available Maps of the County—

a. Garfield County Map.

b. U. S. Army Map Service maps: 4262 I, IV; 4263 II, III; 4362 I, IV; 4363 II, III; 4462 I, IV; 4463 I, II, III, IV; 4562 I, IV; 4563 I, II, III, IV; 4564 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover most of the County. See topographic quadrangle index map in the pocket.

d. U. S. Forest Service maps "White River National Forest" and "Grand Mesa National Forest", include the County.

Mineral Production 1946-1958—Coal was the most important single mineral commodity produced during the period 1946-58. Besides the items listed in the table, natural gas, sand and gravel, stone, uranium, and some experimental oil shale were produced. All figures are from the U. S. Bureau of Mines Minerals Yearbooks.

Year	Coal Short Tons	Gold Ozs.	Silver Ounces	Lead Pounds	Zinc Pounds	Total $ Value
1946	49,342	1	1,756	35,000	110,000	18,689[1]
1947	51,956	129	1,841	26,500	70,800	18,564[1]
1948	46,906	--	----	----	----	----
1949	49,667	--	----	----	----	----
1950	44,672	--	----	----	----	----
1951	38,124	1	158	2,000	8,000	241,467[2]
1952	42,412	--	----	----	----	264,280[2]
1953	35,877	--	----	----	----	198,907[3]
1954	29,800	--	----	----	----	418,916[3]
1955	33,750	--	----	----	----	297,477[2]
1956	24,096	--	----	----	----	174,220[4]
1957	38,441	--	----	----	----	295,643[4]
1958	20,184	--	----	----	----	265,916[5]

[1] Value of precious and base metal production only.
[2] Value of coal and stone production.
[3] Value of coal, sand and gravel, and stone production.
[4] Same as [3] but includes value of uranium production.
[5] Same as [4] but includes value of limestone and gem stone production.

Coal[6]—Garfield County lies in the center of the Uinta Coal Region and possesses vast reserves of coal. At least 151 square miles are underlain by coal measures containing a minimum of 2,260 million tons of coal. There are two fields of importance in the County:

Book Cliffs Field—This field is located in the western part against the Utah state line. The coal-bearing rocks of the Mesaverde formation of Upper Cretaceous age crop out from the Utah border almost continuously around the edge of the Piceance Creek basin. The field crosses the western part of the County in a southwesterly direction, passing into Mesa County as far as the Colorado River. The coal is found in the Mount Garfield formation of the Mesaverde group of Upper Cretaceous age, and in the Anchor mine tongue of the underlying Mancos shale, which lies between the upper and lower members of the Sego sandstone of the Mesaverde group. The coal in the Mount Garfield formation occurs in lenticular beds within three coal-bearing zones: the Palisade, which lies immediately above the Sego sandstone; the Cameo, 200 to 450 feet above the top of the Sego; and, the Carbonera zone, about 260 feet above the Sego. The coal is mainly high volatile C bituminous, but some high volatile B is present.

Grand Hogback Field—A monoclinical fold on the east side of the Piceance Creek Basin forms the ridge called the Grand Hogback, consisting of steeply-dipping beds of the Mesaverde group. In this area, the group has been divided into the Iles below, and the Williams Fork above. The most persistent and thickest coal beds occur in the Williams Fork formation. The Iles contains the lower coal group which is of little importance in this field. The coal in the southern part of the field is mainly high volatile B bituminous rank, and is noncoking. The coal in the northern part is mainly high volatile C bituminous.

Oil Shale—Oil shale constitutes the single most important mineral reserve of the County. About 40% of the Piceance

Creek Basin and 60% of Battlement Mesa is located within its boundaries. The oil shale occurs in the lacustrine Green River formation of Middle Eocene age, which underlies both of the areas mentioned. The subject of oil shale is discussed by Dr. Charles H. Prien further on in this volume.

An interesting application of oil shale is the use of disintegrated material obtained from talus slopes at the foot of the cliffs, for surfacing roads in Garfield County. The oil shale makes a very smooth, very fast-drying road surface.

*Estimated shale oil reserves of the County, taking into consideration shale with a minimum content of 15 gallons of kerogen per ton, but not losses or consumption of oil in the extraction process, are as follows:

	Millions of Barrels	
45 gallons of Kerogen per ton of shale		
Indicated potential	6,321	
Inferred potential		369
30 gallons of kerogen per ton of shale		
Indicated potential	27,504	
Inferred potential		5,627
25 gallons of kerogen per ton of shale		
Indicated potential	40,674	
Inferred potential		9,342
15 gallons of kerogen per ton of shale		
Indicated potential	153,589	
Inferred potential		70,444
Total Indicated potential	228,088	
Total Inferred potential		85,782
Total Potential		313,870

Natural Gas** — The Garmesa gas field in the southwestern part of the County was discovered in 1925. Some of the wells drilled on the structure were estimated at an initial gas flow of 20 to 75 million cubic feet of gas per day, but with a very low B.T.U. content due to the high proportion of nitrogen and carbon dioxide gas.

[2]The Twin Buttes field in the northwestern part was discovered in 1951. Production was encountered in sandstone of the Morrison formation of Jurassic age.

During 1959 there were 8 gas fields active in the County which produced 781 million cubic feet of natural gas for the year, and had a cumulative production up to that time of 4,415 million cubic feet of gas.

***Garfield County includes the central portion of the Piceance Basin, the southern end of the Douglas Creek Arch, and the northern plunge of the Uncompahgre Uplift. There

*Reduced from reference No. 53 of the bibliography.

**A. E. Brainerd and F. M. Van Tuyl, in reference No. 1 of the bibliography.

***Mr. Charles C. O'Boyle, Consulting Geologist, Denver, written communication.

exist excellent possibilities for extension of the existing fields and for the development of new production from each of the structural features named.

Sand and Gravel — Sand and gravel have been produced from the course of the Colorado River near Glenwood Springs, and near Rifle on westward into Mesa County, and north of Rifle from Rifle Creek and some of its tributaries. Other substantial deposits occur along the Roaring Fork and Crystal rivers southeast of Glenwood Springs, and on East Salt Creek, West Salt Creek, and other tributaries of the Colorado River in the southwest corner of the County.

Precious and Base Metal Minerals—The production of precious and base metals has been of relatively small importance. The two mining districts established in the County are discussed on pages 88 to 90 of the 1940 edition of this book (Vanderwilt).

Uranium-Vanadium* — Uranium-vanadium ores occur in bedded deposits in the Morrison and Entrada formations of Jurassic age along the Grand Hogback north of Rifle. These occurrences have been known for many years. No significant quantities of commercial uranium are expectable.

Clays—Butler[7] sampled clay exposures along the Roaring Fork southeast of Glenwood Springs, and along the Colorado River as far west as Rifle. Some of these deposits contain clays suitable for the manufacture of construction materials. Three samples taken "1½ miles north of the railroad (at New Castle) . . . beyond the cement mill . . ." indicate clays good for first-class brick, buff earthenware, terra-cotta, and other purposes.

A mile north of Rifle, another deposit has been worked for making first-class brick. On the Roaring Fork, southeast of Glenwood Springs near the old Wheeler station, samples taken from the mouth of an adit and from its floor inside it, show the clay to be good for brick and tile.

Geological Note—Garfield County covers 110 miles in a comparatively narrow east-west band, and in this distance a wide variety of geologic formations and conditions are represented. The eastern part of the county is on the White River Plateau. At the southern fringe of the Plateau, north and northeast of Glenwood Springs, pre-Cambrian rocks are exposed along the Colorado River, Deer Creek, Grizzly Creek, and other deeply-indented drainages to the north. In the south-center of the Plateau are extensive, but irregularly-shaped areas of undifferentiated Early Paleozoic rocks surrounded by exposures of undivided Pennsylvanian rocks. Farther north, the Flat Tops are capped by extensive flows of andesite and basalt of Late Tertiary and Quaternary age.

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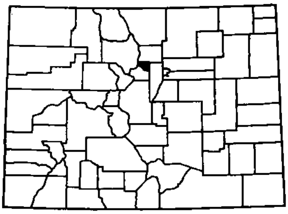
*Donald L. Everhart, U.S.A.E.C., personal communication.

Similar flows occur southeast and southwest of Glenwood Springs. Between Shoshone and Glenwood Springs, fringing the pre-Cambrian rock exposures along the Colorado River and some of its tributaries, are exposed undivided rocks of Cambrian-Ordovician age, and Devonian-Mississippian age including the Devonian Chaffee formation and the Mississippian Leadville limestone. West of Glenwood Springs along the eastern fringe of the Piceance Creek Basin, progressively younger rocks begin to appear against the uplift of the White River Plateau: undifferentiated Permian rocks; undivided Triassic rocks; Twin Creek limestone and Morrison formation of Jurassic age; Upper Cretaceous Dakota sandstone, Mancos shale, Iles formation, and Williams Fork formation. West of these, the Wasatch formation of Eocene age reaches almost to the center of the County where the oil-shale bearing Green River formation of Middle Eocene age predominates in the Piceance Creek Basin, and continues west into Utah. In the southwestern part of the County, Tertiary Wasatch and Mesaverde rocks, and Mancos shale of Upper Cretaceous age, outcrop along the Book Cliffs where coal measures of the Mesaverde formation are exposed and mined.



Courtesy Colorado Planning Division

Gilpin County

Gilpin County is located in north-central Colorado in mountainous terrain with the Continental Divide as its western boundary. The County has a population of 850 and an area of 149 square miles ranging in elevation from 6,880 to 13,260 feet above sea level. The County seat is at Central City, a famous mining community since the early days of mining in Colorado, with a population of 375.

Available Maps of the County—

a. Gilpin County Map.
b. U. S. Army Map Service maps: 4863 I; 4963 IV.
c. U. S. Geological Survey topographic quadrangle maps cover the County. See topographic quadrangle index map in the pocket.
d. U. S. Forest Service map "Arapahoe National Forest" includes the County.

Mineral Production 1946-1958—Gilpin County has been an active producer of precious and base metal ores since the beginning of Colorado mining. Besides the items listed in the table, the following were produced during the 1946-58 period: sand and gravel, peat moss, and minor quantities of tungsten ore and pegmatite minerals. All figures are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Active Mines Lode	Active Mines Placer	Gold Ozs.	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	9	8	348	3,334	5,000	118,000	57,000	35,500[1]
1947	9	7	302	4,470	5,100	140,000	60,000	43,106[1]
1948	6	5	83	716	----	22,000	2,000	7,757[1]
1949	9	6	135	610	----	18,000	----	8,121[1]
1950	7	12	84	315	----	6,000	----	4,035[1]
1951	3	4	171	1,240	----	16,000	----	161,625[2]
1952	4	5	30	78	----	2,000	----	50,139[2]
1953	6	4	158	975	2,000	4,000	----	7,510[3]
1954	7	2	319	4,498	8,000	74,000	34,000	31,783[3]
1955	6	1	485	18,501	8,000	268,000	34,000	81,453[4]
1957	5	4	89	1,680	5,900	16,500	----	19,782[5]
1958	6	2	238	714	2,000	4,000	----	25,467[6]

[1] Value of precious and base metals production only.
[2] Same as [1] but includes value of sand and gravel production.
[3] Same as [1] but includes value of some tungsten production.
[4] Same as [3] but includes value of sand and gravel production.
[5] Same as [1] but includes value of peat moss and rare earth production.
[6] Same as [2] but includes peat and stone.

The State Bureau of Mines gives the following figures for the values of peat, rare earths, and tungsten production beginning with 1953.

Year	Peat $	Tungsten $	Rare Earths $
1953	1,000	---	---
1954	6,500		---
1955	7,000	620	---
1956	10,000	500	---
1957	8,000	325	2,400
1958	6,260	---	---

Precious and Base Metals—The several mining districts established in Gilpin County have been grouped together into two general areas: The North Gilpin County District which includes the Perigo, Independence, Pine, Kingston, and Apex mining districts; and, the South Gilpin County District which includes the Central City, Nevada, Gregory, Russell, and Quartz Mountains mining districts. These two general areas are discussed on pages 90 to 94, and 314-15 of the 1947 edition of "Mineral Resources of Colorado" (Vanderwilt). Additional geologic information on the Central City district is found under Clear Creek County on pages 96-102 of this volume.

Regarding the North Gilpin County District, Lovering and Goddard[12] point out that the area has been very little studied and the structural features are imperfectly known, but that the work which has been done suggests that a detailed study of the relation of the veins to the northwesterly fracture system so prominent to the southeast may lead to the discovery of new ore bodies.

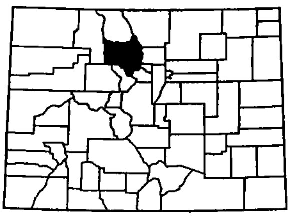
Sand and Gravel — Sand and gravel have been produced from the course of Clear Creek in the southeastern part of the County. Other sand and gravel deposits occur along the course of South Boulder Creek near Tolland and to the east of Tolland.

The sand and gravel production during 1958 amounted to 10,000 tons valued at $7,000.

Uranium—In the early days of uranium (radium) interest, the Quartz Hill area near Central City was the one locality of importance in the United States for the procurement of radium-yielding uranium ores. From the time that pitchblende was discovered on the dump of the Wood mine in 1871, to the present, the Quartz Hill area has yielded 324 tons of high-grade ore containing 110,575 pounds of $U_3 0_8$. None of these deposits appear to be of commercial significance today. The pitchblende occurs in small pods in metal-bearing veins in the Idaho Springs formation of pre-Cambrian age.

Peat Moss—Peat bogs of limited extent occur in shallow swales around the Missouri Lake area. The peat is extracted and sold chiefly as a soil conditioner.

Geological Note—Gilpin County lies in the central part of the Front Range mineral belt in a mountainous area of pre-Cambrian rocks. Schists and gneisses of the Idaho Springs formation predominate, with extensive bodies of pre-Cambrian granite, granite-gneiss, quartz monzonite gneiss, and granite pegmatite exposed in much of the area. Early Tertiary intrusive stocks and dikes are scattered throughout. Quaternary moraines are found in some of the valleys in the western part of the Country, particularly along South Boulder Creek.



Courtesy Colorado Planning Division

Grand County

Grand County is located in the northwestern part of Central Colorado. It is bounded on the north, east, and southeast by the Continental Divide; the Williams River Mountains of the Park Range system bound it on the southwest, and the main Park Range crosses from north to south-southeast near its western border. The center of the County is an elevated basin of fertile, rolling land called Middle Park. Grand County has a population of 4,200 in an area of 1,866 square miles ranging in elevation from 7,800 to 13,400 feet above sea level. The County seat is at Hot Sulphur Springs, a health-baths and resort town of 275 population.

Available Maps of the County—

a. Grand County Map.

b. U. S. Army Map Service maps: 4663 I; 4664 I, II; 4763 I, IV; 4764 I, II, III, IV; 4863 I, III, IV; 4864 I, II, III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover the southern and eastern portions of the County. See topographic quadrangle index map in the pocket.

d. U. S. Forest Service maps "Arapahoe National Forest" and "Routt National Forest" include the County.

Mineral Production—The only mineral production credited to Grand County during the last few years consisted of sand and gravel, stone, and uranium. No quantity figures are available, with the exception of that for sand and gravel for 1957 when 263,000 short tons were produced. The total yearly value of mineral production, beginning with 1953, is as follows:

1953	$416,442
1954	61,368
1955	94,063
1956	82,000
1957	350,887
1958	Withheld

Sand and Gravel — Sand and gravel have been produced from the courses of Muddy, Blacktail, and Rock creeks; from the Colorado, Blue, and Fraser rivers and some of their tributaries. Extensive Quaternary deposits, possible future sources of sand and gravel, occur east of the Williams River to the south of Parshall; east of the confluence of the Colorado and Fraser rivers; along the course of South Fork Creek west of Monarch; around the town of Stillwater, and north from there past Grand Lake to the northern tip of the County.

Stone—Grand County contains a variety of igneous, metamorphic, and sedimentary rocks some of which are suitable for application in the construction industries.

Uranium—Some uranium ore production has come from the Hot Sulphur Springs area. *Known occurrences in the Dakota sandstone of Upper Cretaceous age, in the Paleocene(?) Middle Park formation, and in a carbonaceous regolith zone of Eocene age at the contact of the pre-Cambrian rocks and the Middle Park formation, are indications of favorable environment for possible economic uranium occurrences. On either side of the Park are exposed tilted Mesozoic strata which include the favorable Dakota formation. The Park itself is generally underlain by Tertiary sediments which include the favorable Middle Park formation.

Grahamite—Argall[9] reports a deposit of grahamite, or of gilsonite, in veins of from a few inches to 6-ft. in width, in

*D. L. Everhart, U.S.A.E.C., personal communication.

section 24, T-4-N, R-77-W, about 20 miles north of Granby. This deposit was apparently worked before 1900 and the material hauled to Granby for shipment by rail.

Lightweight Aggregates—Bush[28] reports the existence of a scoria and (or) perlite deposit on the southwestern part of T-6-N, R-75-W, and that of an obsidian or perlite deposit in the north-central part of T-3-N, R-76-W.

Coal—The Middle Park Coal Field forms an irregular triangle with its apex south of the Colorado River just below the center of the County, and its broad base stretching east-west across about 2/3 of the north boundary of the County. [6]The presence of thin, impure, lenticular coal beds exposed in Middle Park has been known for many years. The coal occurs in the Middle Park formation of Paleocene age, which is correlative with the Coalmont formation of the North Park coal field, and is probably continuous with it. Due to the lack of detailed information the coal reserves of the Middle Park field have not been estimated. There have been no reports of workable coal beds in the basin.

Clays—Butler[7] sampled some clay exposures along the Colorado River, and reported two promising deposits:

1. Location: In the town of Hot Hulphur Springs on the south bank of the river.

   Occurrence: A 6-ft. exposure of soft, black, very fine-grained shale with white, plastic streaks under 4 feet of overburden, about 5-ft. above the water. Benton age. Should make good light-red pressed bricks.

2. Location: Hot Sulphur Springs, about ¼-mile north-east of above sample.

   Occurrence: Several hundred feet exposure of soft, brownish-gray fine-grained shales which are more or less gritty. This material was sampled at intervals, is of Pierre age, and occurs 800 feet above the black Benton shales under a sandstone capping.

Hydrocarbons* — Comparatively rugged topography, poor rock exposures, and more perceptible favorable areas elsewhere, have caused a relatively late start of exploration activities in Middle Park Basin of Grand County. These conditions will probably continue to restrict somewhat the intensity of future activities; but with the continuation of the limited exploration of the last few years, sufficient information should be developed to induce the drill-testing of some of the anomalies found.

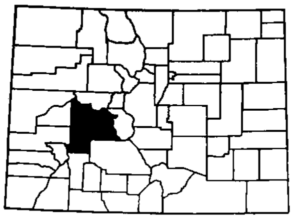
Favorable horizons for hydrocarbon exploration include the Cretaceous sandstones of the Pierre, Benton, and Dakota formations, and the Jurassic sandstones of the Morrison and Entrada(?) formations. There also exist possibilities of pro-

*Mr. A. W. Cullen, Consulting Geologist, Denver, written communication.

duction from fractures in the Pierre, Niobrara, and Benton shales.

Geological Note—About two-thirds of Grand County, in its central part, is occupied by Middle Park, an intermontaine structural basin surfaced chiefly by Tertiary rocks of the Middle Park and North Park formations. Extensive andesite and basalt flows of late Tertiary and Quaternary(?) age are widespread across the northern half of the County. Pre-Cambrian hornblende gneiss and greenstone fringe the southern boundary together with pre-Cambrian schist, gneiss, granite, and related rocks which also continue around the eastern border to the northeastern corner. Tilted against the western slopes of the Front Range, particularly around Granby, and along the eastern slopes of the Park Range to the west, are exposed sedimentary rocks ranging in age from Triassic to Upper Cretaceous. In the complex area between Granby and Troublesome are exposed pre-Cambrian metamorphic and igneous rocks, and sedimentary rocks ranging in age from the Jurassic Morrison formation to Quaternary terrace deposits. These latter, together with Quaternary moraines, extend northward from Granby to the northernmost extension of the County.

Gunnison County



Courtesy Colorado Planning Division

Gunnison County, located in west-central Colorado, has a population of 6,000, and an area of 3,243 square miles ranging in elevation from 6,875 to 14,259 feet above sea level. The County seat is at Gunnison, a ranching, mining, uranium-ore processing, and business center with a population of 3,000.

Available Maps of the County—

a. Gunnison County Map.

b. U. S. Army Map Service maps: 4461 I, II, III, IV; 4560 I, II, III, IV; 4561 I, II, III, IV; 4562 II, III; 4660 I, IV; 4760 IV; 4761 III, IV.

Mineral Production 1946-1958—Gunnison County is an important producer of a variety of minerals. The table below gives the production and yearly values of production of precious and base metals and coal as compiled from U. S. Bureau of Mines figures.

Year	Lode* Mines	Gold Ozs.	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Coal Short Tons	Total $ Value
1946	7	145	15,203	40,000	778,000	885,000	609,203	216,611[1]
1947	13	445	63,098	46,600	3,011,000	3,374,600	623,110	924,375[1]
1948	10	162	78,863	26,000	3,594,000	3,982,000	588,006	1,255,619[1]
1949	5	64	60,147	34,000	2,586,000	3,008,000	491,485	844,954[1]
1950	11	95	73,281	40,000	1,394,000	1,990,000	399,775	548,738[1]
1951	5	87	119,748	50,000	1,984,000	2,510,000	341,315	2,818,970[2]
1952	10	280	107,394	58,000	2,090,000	2,354,000	339,498	2,754,266[3]
1953	3	124	884	----	20,000	----	297,860	1,697,178[4]
1954	6	62	5,150	----	148,000	----	266,733	1,588,961[5]
1955	5	51	153,513	344,000	1,480,000	2,314,000	326,173	2,512,057[5]
1956	7	94	399,355	976,500	2,763,800	6,395,500	302,968	3,818,583[6]
1957	5	56	242,896	594,900	1,718,800	3,470,700	290,958	2,906,473[6]
1958	3	1	1,638	----	10,000	----	283,661	1,804,144[7]

*Precious and base metals mines only.

[1] Precious and base metal production values only.

[2] Same as [1] but includes coal.

[3] Same as [2] but includes sand and gravel and lepidolite.

[4] Same as [3] but includes mica, columbium-tantalum, and beryl.

[5] Same as [4] but includes feldspar and stone.

[6] Same as [5] but includes manganese.

[7] Same as [2] but includes sand and gravel, stone, and rare earths ore.

Precious and Base Metals—There are a number of mining districts established in Gunnison County, but only a few of them have been of importance. Vanderwilt discusses the various mining districts on the following pages of the 1947 edition of "Mineral Resources of Colorado".

District	Page
Box Canyon	98
Cebolla (Vulcan, Domingo, Powderhorn, White Earth)	98-99
Cochetopa (Green Mountain, Gold Basin)	100
Dorchester (Taylor River)	101
Elk Mountain	101-02
Gold Brick	103
Goose Creek (Madera)	104
Quartz Creek	104
Rock Creek (Marble)	105-06, and 446-51
Ruby	106
Spring Creek	106-07
Taylor Park	107-08
Tincup	107-10
Tomichi (Whitepine)	110-12

Additional information on some of the districts is given below.

Powderhorn District—The Powderhorn district occupies an area about 20 miles long and 6 miles wide extending from the vicinity of Iron Hill to the Lake Fork of the Gunnison River in the southwestern part of the County. Although the production from this district has been unimportant, renewed interest in the area has developed recently due to the variety of its mineral occurrences. These include some of the rarer metals for which new technological advances have created a demand.

[59]The Powderhorn district is underlain chiefly by pre-

Cambrian metamorphic and igneous rocks intruded by pre-Jurassic alkalic igneous rocks. Flat to gently-dipping strata of the Morrison formation of Jurassic age overlie the pre-Cambrian rock complex. Tertiary volcanic rocks were deposited on an early Tertiary erosion surface which locally nearly coincides with the late Paleozoic or early Mesozoic erosion surface on which the Morrison formation was deposited. Pre-Cambrian quartz veins containing pyrite, chalcopyrite, and sphalerite, were originally worked chiefly for their gold and silver content. Iron and manganese oxides, vermiculite, and minerals containing titanium, rare earths, thorium, and columbium, are found locally in veins or segregations in the alkalic igneous rocks and the carbonate rock (mostly dolomite and some calcite) of the Iron Hill stock. Small quantities of manganese and vermiculite have been produced.

Tincup District—Dr. Vanderwilt adequately discusses this district in the 1947 edition of this book on the pages indicated above. A portion of his text dealing with the possibilities of the district, in which Vanderwilt quotes Goddard[63], is of sufficient interest to repeat below.

". . . there is a distinct possibility of finding new ore bodies in the Tincup district comparable to those already exploited. In some of the larger mines, such as the Gold Cup and the Tincup group, there has apparently been no exploration of the lower potential ore horizons. It is possible that ore may have been formed at some of these lower horizons along the fault fissures that influenced the formation of ore bodies at the upper horizons. There is also the possibility of finding new ore bodies at favorable horizons along fault fissures that have remained uncovered or have not shown evidence of being associated with ore bodies. The West Gold Hill ore body apparently showed no surface indication of its existence and the faults with which it was associated were apparently inconspicious. It is probable that a careful survey of the district will uncover numerous pre-ore fault fissures which at present are unknown or little understood but which may be associated with ore bodies at favorable horizons beneath the surface. Thus future exploration in the Tincup district may be carried on along two lines: 1) exploration of lower favorable horizons along fault fissures known to be associated with ore bodies in upper horizons; 2) exploration for additional pre-ore fault fissures and along known fissures that show no surface indication of ore but may contain ore at favorable horizons at depth.

"The future possibilities of the molybdenum-tungsten veins depend largely on metallurgical treatment and on market conditions. The tungsten minerals in these veins seem to be scarce, but molybdenite is consistently present. There seem to be numerous molybdenum veins in the western part of the crest of Gold Hill that as yet have been little explored. Also these veins appear to occupy some of the most extensive fault fissures in the district."

Dings and Robinson[23] have the following to say on the subject.

In the Tincup district, the upper 175 feet of the Leadville limestone has been extensively explored and has yielded a large quantity of ore from the Gold Cup mine south to the Robert E. Lee No. 2 shaft, but from this point on south for about ½-mile, this formation has been inadequately explored although it warrants closer attention.

[23]It is said in the Tincup district that ore in quantity is not found at the contact of the porphyries and the sedimentary rocks, but the authors (Dings and Robinson) believe from their study of the area, that this is not necessarily true and that the contacts have not been adequately explored. The porphyries in general dip more steeply to the east than the sedimentary beds, and it is quite possible that undiscovered ore bodies might lie against both, the quartz doirite and the Tincup porphyries at their western margins in the area extending from an east-west line a little south of the Jimmy Mack mine north to the far end of Duncan Hill. Also in this general area, additional exploration should be conducted for possible bedded replacement deposits immediately beneath the Harding quartzite or the basal shaly beds of the Chaffee formation.

Tomichi (Whitepine) District—[23]The ore in the district occurs as replacement deposits and in veins. The former occur in limestones and dolomites of Paleozoic age in two distinct forms east of Whitepine. By far the more important of the two is replacement along fault zones. These deposits are confined generally to the northerly-striking easterly-dipping Star reverse fault which is of considerable displacement. Rhyolite porphyry dikes follow, and locally cut across the fault. The principal ore shoots occur on the western or footwall side of the fault in dolomite or limestone near the porphyry. Individual ore shoots range in length from a few feet to several hundred feet. The most favorable host rock is the Manitou dolomite of Ordovician age, although other carbonate rocks, particularly the Leadville limestone of Mississippian age, contain deposits along the fault zone. The oxidized zone generally terminates about 100 feet below the surface, and most of the ore mined at depth consists of a granular aggregate of sphalerite, galena, and variable amounts of pyrite and chalcopyrite. The galena is generally argentiferous and the pyrite locally auriferous.

[23]The vein deposits occur in the northern two-thirds of the district. Of these, only the pyritic quartz veins are economically significant. These veins range from irregular stringers a fraction of an inch wide, to well-defined veins 6 feet thick.

Some are less than 100 feet in length, but others reach a length of ½-mile. Most of the veins are in the Mount Princeton quartz monzonite. The vein filling is typically white, vuggy quartz with scant to abundant pyrite, some chalcopyrite, and local shoots of sphalerite, and commonly-argentiferous galena. Gold is carried by some of the pyrite, and occurs in the metallic state in some of the oxidized ores. The zone of oxidation is apparently quite shallow. Most of the mines do not appear to have gone down more than a few hundred feet.

[23]Near Whitepine in the Tomichi district there is an area which warrants additional exploration along the Morning Glim fault for a distance of about 1,000 feet northwest, and 3,000 feet southeast of the Parole mine.

Coal[6]—The southeastern end of the Uinta Coal Region is located in Gunnison County. About 162 square miles are underlain by measures containing 3,565 million tons of coal, of which 3,180 million tons are bituminous, 300 million subbituminous, and 85 million tons are anthracite or semi-anthracite coal. These reserves are contained in three fields within the county.

Carbondale Field—Structurally, this field is transitional between the highly faulted and folded south end of the Elk Mountains and the simple monoclinal fold of the Grand Hogback north of the Colorado River. The lower part of the Mesaverde formation of Upper Cretaceous age contains the thickest and most persistent coal beds. The coal ranges from high volatile C bituminous, to anthracite. In the northern part of the field the coal is mainly high volatile B bituminous, and in the southern part it is chiefly high volatile A and medium volatile bituminous. Most of this coal is noncoking.

Somerset Field—Coal in this field is high volatile C and high volatile B bituminous, and in the eastern half it is moderate to strongly coking. The coal occurs in the upper and lower coal zones of the Mesaverde formation of Upper Cretaceous age. In several places in the southeastern part of the field, igneous intrusions have metamorphosed the coal to semianthracite, but this tonnage is small.

Crested Butte Field—This field occupies the southeastern end of the Piceance Creek Basin. The coal beds have been folded, faulted, and intruded by igneous rocks and the area is one of considerable structural complexity. The coal, as expected under these conditions, ranges widely in rank, but in general, the coal north and west of the town of Crested Butte is semianthracite to anthracite, and that south of the town is high volatile B and C bituminous suitable for coking. The coal occurs throughout the field in the lower part of the Paonia shale member of the Mesaverde formation.

It is of interest that of the 3,180 million tons of estimated bituminous coal reserves in the County, 1,460 million are under less than 1,000 feet of overburden; 1,295 million between 1,000 and 2,000 feet; and, 425 million are between 2,000 and 3,000 feet below the surface.

Of the 85 million tons of anthracite and semianthracite coal reserves, 54 million are under less than 1,000 of overburden; 18 million between 1,000 and 2,000 feet; and, 13 million between 2,000 and 3,000 feet.

Sand and Gravel — Sand and gravel have been produced from the courses of the Slate River, Cement Creek, and other of the river's tributaries; from the Taylor River and some of its tributaries, such as Spring Creek; from the Gunnison River near the town of Gunnison, and westward to the western boundary of the County. Also from Lake Fork Creek and other streams. Extensive deposits are found in the vicinity of Gunnison; along Little Cimarron Creek; the Gunnison River; Lake Fork Creek; Tomichi Creek; and, Ohio Creek.

Sand and gravel production during 1958 amounted to 115,000 tons valued at $111,000.

Pegmatite Minerals and Rare Metals—The most important pegmatite area in the County is the Quartz Creek pegmatite district located on the western slope of the Sawatch Range about 17 miles east of Gunnison. The district occupies an area of approximately 10 square miles, underlain by pre-Cambrian and metamorphic igneous rocks. [64]A coarse-grained porphyritic granite intrudes the earlier pre-Cambrian rocks in the south-central part of the district, and a large quartz monzonite intrusive body occurs in the extreme northern part. These rocks are in turn intruded by many fine-grained, pink, granite dikes and by a large number of pegmatities. Flat-lying strata of the Jurassic Morrison formation, overlain by Cretaceous Dakota sandstone, lie unconformably on the pre-Cambrian rocks along the east and west sides of the area. The pegmatites have a general northeast trend across all the earlier structures which generally trend northwestward.

[64]The pegmatites range in size from short, narrow stringers, to over 2 miles in length and over 1 mile in width, and are variously shaped. Several types of pegmatites occur in the district, but the "homogeneous", or "one-unit" type are by far the most abundant. Of 1,803 pegmatites investigated in the area, 232 contain beryl. This mineral occurs in all types of pegmatites, and ranges from minute crystals to some 2 feet in diameter; the beryl generally appears in clusters.

[64]Columbite-tantalite has been found in 29 of the 1,803 pegmatites examined. It occurs in all types of pegmatites but in reduced amounts with the exception of two dikes. In one of these, the Brown Derby No. 1, a unit about 20 feet long and 1 foot wide, contains about 1.4% columbite-tantalite.

[64]Monazite, a phosphate of the cerium metals, is found in 24 of the pegmatites in very reduced quantities. The Brown Derby No. 1 dike is again the exception, for the same zone which carries the unusual tantalite-columbite concentration, contains about 2.2% monazite.

[64]Lepidolite is found in 17 of the pegmatites in the area, but its content within a pegmatite unit may range from a trace, to 95% of the unit's volume. Only the Brown Derby No. 1 has units containing lepidolite in excess of 10% of the rock.

[64]The pegmatite minerals reserves of the Quartz Creek district, although virtually impossible to calculate accurately, are estimated as follows:

[64]Hand-cobbable potash feldspar	796,000 tons
Hand-cobbable soda feldspar	9,700 tons
Milling-grade feldspar	251 million tons
Scrap mica reserves	14,000 tons
Cobbable beryl	325 tons
Lepidolite reserves	3,560 tons

[59]In the Powderhorn district titanium minerals are abundant in some of the pyroxenite of the Iron Hill stock. Titanium oxide averages 7.4% in the pyroxenite and exceeds 35% in some of the bodies of perovskite - magnetite rock (perovskite — calcium titanate — $CaTiO_3$). The bulk of the titanium occurs as perovskite, but some is present as sphene, a calcium-titanium silicate, and ilmenite, an iron-titanium oxide. Small amounts are contained in other minerals. Titanium-rich alkalic rocks commonly contain relatively high percentages of columbium.

[59]The Powderhorn district is a favorable area in which to prospect for thorium, rare earths, and columbium minerals. Because the known thorium deposits in the district are related spatially to the alkalic igneous rocks, those areas in or near such rocks are considered the most favorable for thorium prospecting. The most radioactive (due almost entirely to thorium and its derivatives) deposits in the district are in the mineralized shear zones which are from 1-foot to several feet wide, and occur in pre-Cambrian foliated rocks. In these shear zones the introduced material forms numerous closely-spaced films and veinlets in fractures in the country rock. Near the veinlets the wallrock is partly replaced and greatly altered. Masses of wallrock, generally iron-stained, are found in many places within the mineralized shear zones, which are commonly discontinuous and variable in width.

The occurrence of selenium, possibly in economic concentration, has been reported from the area just east of the small town of Powderhorn.

Uranium* — The most promising area for commercial uranium deposits is in the southeastern part of the County in faulted remnants of Paleozoic formations. One producing mine is located in this area. Faulted blocks of Harding quartzite of Ordovician age, Pennsylvanian Belden limestone and, to a lesser extent, shear zones cutting pre-Cambrian crystalline rocks, are generally favorable for the accumulation of primary uranium mineralization.

Molybdenum-Tungsten[23] — Some molybdenum and tungsten has been produced from the Quartz Creek district a few miles northeast of Pitkin. The ores of these metals are confined to the northern part of the district, and occur in fissure veins in pre-Cambrian rocks in association with sulfides, chiefly of iron, copper, and lead.

Stone—Gunnison County has a variety of igneous, metamorphic, and sedimentary rocks some of which are suitable for use in the construction industries. The "Yule Colorado Marble" quarry on Yule Creek, 3 miles from Marble, has shipped considerable material, but has been idle for a number of years. [9]Other marble deposits occur a few miles southeast of Powderhorn, and in the Tomichi mining district. Granite blocks have been quarried from a site on Beaver Creek about 7 miles south of Gunnison. Granite from this quarry was used on the State Capitol and on the State Museum in Denver.

During 1958, about 4,200 tons were produced valued at $23,200.

Iron—The iron deposits in the Taylor Peak and the Whitepine districts have been known for many years. [66]The Taylor Peak district lies in the eastern part of the Elk Mountains on the Pitkin-Gunnison counties boundary line. The ore deposits are located on the north, east, and south sides of Taylor Peak. The area consists of Paleozoic sediments resting on pre-Cambrian granite and intruded by fine-grained diorite of Tertiary age. The ore deposits are at or near the contact of the sediments with the intrusive diorite. The largest deposit is near the head of Copper Creek on the northwest slope of Taylor Peak south of Ashcroft. The ore is mainly magnetite, but pyrite is locally abundant. The Cooper Creek deposit has been estimated to contain between 3 and 4 million tons of low-grade ore. —No assays are given.

[23, 66]The Whitepine district lies on the west slope of the Sawatch Range about 10 miles north of Marshall Pass. The ore bearing area lies along the contact of pre-Cambrian granite with limestone, quartzite, and argillite of the Pennsylvanian Belden shale. The deposits are of two types, limonite bog ores, and magnetite-limonite replacement ores. The former occupy a small area within the granite. The latter form irregular

*Dr. Donald L. Everhart, USAEC, personal communication.

masses within the Belden rocks near the granite contact. These deposits have lain idle for many years, but several carloads of iron ore and two tons of cuprite were shipped from the Iron King mine during the early part of the century.

[59]In the Powderhorn district iron ore occurs in veins and irregular bodies of hematite and limonite in the carbonate rock of Iron Hill, and in lenticular bodies of magnetite and very fine grained perovskite in the pyroxenite which are commonly from 20 feet to as much as 75 feet wide. The iron-bearing veins in the carbonate rock are relatively small and contain abundant phosphorus in the form of apatite.

Graphite[23]—Several hundred tons of amorphous graphite have been produced by two mines in the Graphite Basin, about 1½ miles easterly from Cumberland Pass. The country rock is carbonaceous shale, dark limestone and some quartzite of the Belden shale. According to verbal reports, the graphite is amorphous and occurs in 3 seams of from 18 inches to 15 feet in thickness. The thickest seam averaged about 45% carbon, and the other two between 85% and 95% carbon. Above the portal of the caved main adit is a small exposure of slickensided, carbonaceous shale and graphite about 6 feet thick, lying between quartzite and gray recrystallized limestone.

Manganese*—A number of deposits of appreciable magnitude, consisting of manganese and manganiferous-iron ores, occur on Taylor Peak on the Pitkin County border, which assay between 10% and 20% manganese. Some of these deposits have been worked sporadically through the years and are credited with a total aggregate production of 8,000 tons. These ores have a high silica content.

*In the Cebolla district, near Powderhorn, manganese ore is associated with limonite, magnetite, and iron carbonate. The rocks of the district include granite, quartzite, and limestone, locally capped by trachyte. The ores occur chiefly in the limestone and follow the bedding. Assays from the richer manganiferous parts of the deposits showed 41% to 44% manganese. Other deposits occur in the pre-Cambrian rocks and intrusive granites. Some 15 miles to the northwest, deposits of manganese have been found near Sapinero.

Lightweight Aggregates—Bush[28] reports the existence of a perlite deposit just southeast of Whitepine; a pumice deposit 3 or 4 miles west of Gunnison, and a scoria deposit about 10 miles southwest of Gunnison at the northwestern corner of Saguache County.

[59]In the Powderhorn district vermiculite, an alteration product of biotite, has been mined in small quantities at several places from biotite-rich facies of the pyroxenite.

Bentonite—Argall[9] quotes a report of the existence of a

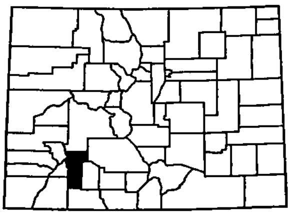
*Edward D. Dickerman, E.M., personal communication.

large deposit of excellent "northern type" bentonite in Lost Canyon, 10 miles north of Gunnison.

Gem Stones—Schlegel[24] reports the occurrence of lapix lazuli at Italian Mountain, and of Moonstone at Mount Beckwith.

Geological Note—Gunnison County covers a wide variety of geologic conditions too complex for more than a very generalized treatment in a geological note.

Along the eastern portion of the County, pre-Cambrian metamorphic and igneous rocks of the Sawatch Range and Taylor Park predominate, with stocks, sills, dikes, laccoliths and other bodies of Tertiary intrusives. In the eastern portion, between Taylor River and Monarch Pass, Paleozoic sediments occur in several areas as remnants of synclines or down-faulted blocks. Farther north, along the Elk Mountains and Taylor Park, pre-Cambrian granites, schists, and gneisses are exposed to the east. On the west of this area as far as the Slate River and the town of Gunnison, sedimentary rocks are exposed ranging in age from Cambrian-Ordovician to the Upper Cretaceous Mancos shale. West of the Slate River, along the Ruby Range north of Floresta, occur a series of north-trending Tertiary dikes. South of there, with West Elk Mountain at its near center, a large area reaching as far south as the Gunnison River, is mantled by latite and andesite agglomerate and breccia of Miocene(?) age. West and east of the Ruby Range are Wasatch rocks of Tertiary age and, beyone these, the Upper Cretaceous Mesaverde formation. Widespread throughout the northern half of the County, large bodies of Early Tertiary intrusive rocks are exposed. South of the Gunnison River, along its course and that of tributary drainage, pre-Cambrian rocks are exposed, with Pliocene(?) flows and tuffs of the Hinsdale formation; rocks of the Potosi volcanic series of Miocene age; and, volcanic flows and breccia beds of Lake Fork andesite of Miosene(?) age, capping the higher ground.



Courtesy Colorado Planning Division

Hinsdale County

Hinsdale County, located in the southwestern part of the State, has a population of 280 and an area of 1,062 square miles ranging in elevation from 8,500 to 14,306 feet above sea level. The County seat is at Lake City, a resort town and mining center with a population of 145.

Available Maps of the County—

a. Hinsdale County Map.

b. Army Map Service maps: 4558 I, IV; 4559 I, II, III, IV; 4560 II, III.

c. U. S. Geological Survey topograhpic quadrangle maps cover the County. See topographic quadrangle index map in the pocket.

d. U. S. Forest Service maps "Rio Grande National Forest", "San Juan National Forest", and "Uncompahgre National Forest" cover the County.

Mineral Production 1946-1958—Hinsdale County, in the San Juan mining region, has been in the past an important producer of gold, silver, and lead ores. With the exception of 1952, when ore production attained interesting figures, the mining industry of the County has been in a depressed condition for many years. Besides the items listed in the table, sand and gravel were the only other minerals of consequence produced.

Year	Lode Mines	Gold Ozs.	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	1	3	442	4,000	----	----	1,110[1]
1947	1	2	308	3,000	100	----	993[1]
1948	2	-	284	2,000	10,000	2,000	2,747[1]
1949	12	23	3,339	8,000	98,000	30,000	24,607[1]
1950	6	23	1,717	2,000	46,000	10,000	10,405[1]
1951	3	10	916	4,000	24,000	14,000	8,883[1]
1952	4	110	27,320	24,000	1,496,000	312,000	327,032[1]
1953	2	1	64	----	2,000	2,000	4,985[2]
1954	3	10	326	----	8,000	----	3,452[2]
1955	1	-	86	----	4,000	2,000	14,720[2]
1956	2	9	1,859	400	4,000	----	16,795[2]
1957	1	-	21	100	----	----	49[1]
1958	1	-	14	----	----	----	3,556[3]

[1] Precious and base metals production values only.

[2] Same as [1] but includes value of sand and gravel production.

[3] Same as [2] but includes value of uranium ore production.

Precious and Base Metals — The northern part of Hinsdale County contains the eastern end of a large mineralized area which extends westward from Lake City into Ouray, San Juan, and San Miguel counties. The mining districts are all clustered around the margin of the Lake City caldera, particularly around its northern and western perimeter. The Galena district, 5 miles west of Lake City, and the Lake District, 6 miles south of Lake City, have contributed most of the County's production. A summary discussion of the geology of the Lake City area by W. S. Burbank, USGS, is contained on pages 439-43 of the 1947 edition of this volume (Vanderwilt). General data on all the mining districts of the County are given on the following pages of that book:

Sand and Gravel—Sand and gravel deposits occur along the courses of Lake Fork Creek, north of Lake City, and along Clear Creek as far as Santa Maria Lake in Mineral County.

Uranium*—The finding of a few minor occurrences of uranium mineralization in the shear zones of pre-Cambrian granite has led to increased prospecting, but it is not anticipated that discoveries of importance will be made in such areas. The southern extreme of the County may be more favorable for prospecting where sedimentary rocks of Paleozoic, Triassic, and Jurassic age are exposed, and proper structural conditions may exist.

Pumice or Scoria—A deposit of pumice or scoria is reported by Bush[28] occurring about 6 miles northeast of Lake City, in the southwestern quarter of T-45-N, R-3-W.

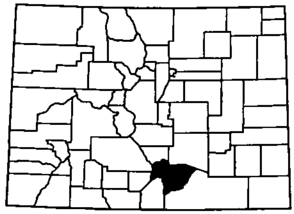
Geological Note—With the exception of its southern extremity, Hinsdale County is mantled predominantly by igneous rocks. In the northwestern corner along the Uncompahgre Mountains are exposed Miocene rocks consisting of: bedded tuff, agglomerate, and andesite and latite breccia of the San Juan tuff; Piedra rhyolite and related rocks of the Potosi volcanic series; Henson tuff, pyroxene-quartz latite, Burns quartz-latite, and other rocks of the Silverton volcanic series. North of Lake City, for several miles on either side of the Lake Fork of the Gunnison River, rocks of Lake Fork quartz-latite are exposed. East of this area, latite-basalt flows of the upper member of the Hinsdale formation of Pliocene(?) age cover the area known as Cannibal Plateau. Rocks of the lower member of the Hinsdale formation, consisting chiefly of rhyolite flows and tuff beds, are exposed around the Plateau's southern margin. The Hinsdale formation caps high ground in several localities farther to the south. East of Cannibal Plateau, and stretching into Saguache and Mineral counties to the east, and as far south as the Continental Divide, rocks of the Potosi volcanic series predominate. Southwest of Lake City, where the mining area is situated, there is a steep-walled basin or caldera created by a down-faulted block between Henson and Lake Fork creeks. These creeks flow around much of the caldera's oval-shaped perimeter. A large area in the center of the caldera is mantled by flows and intrusives of the Sunshine Park rhyolite of Miocene age. The rest of the caldera consists of rocks of the Silverton volcanic series and Fisher latite-andesite of Miocene(?) age. Pre-Cambrian granite is exposed south of the caldera, as well as in a large area along

*Donald L. Everhart, USAEC, personal communication.

the Continental Divide in the southern part of the county. Late Tertiary intrusive rocks in stocks and related bodies are exposed in the northwestern part of the County. In the south, fringing the pre-Cambrian granites on the west, are pre-Cambrian rocks of the Needle Mountains group consisting of schist, quartzite, and conglomerate. South of the pre-Cambrian rocks are sedimentary strata: Ouray limestone and Elbert formation of Upper Devonian age; Carbo-Permian rocks consisting of Leadville limestone, Molas, Hermosa, Cutler and Rico formations; Jurassic Morrison and Entrada formations; and, Cretaceous rocks from the Dakota sandstone to the McDermott formation.

Quaternary deposits are widespread throughout the County: torrential wash and alluvium are found along the stream courses; till and outwash of Durango and Wisconsin glacial ages; and, landslides are common.

Huerfano County



Courtesy Colorado Planning Division

Huerfano County is located in the south-central part of the State east of the Sangre de Cristo Range and the Culebra Mountains. It has a population of about 10,000, and an area of 1,580 square miles ranging in elevation from 5,690 to 14,317 feet above sea level. The County seat is at Walsenburg, a coal mining, light-industry, and business center of about 5,000 population.

Available Maps of the County—

a. Huerfano County Map.
b. U. S. Army Map Service maps: 4958 I; 4959 I, II, III, IV; 5058 I, IV; 5059 I, II, III, IV; 5159 III, IV.
c. U. S. Geological Survey topographic quadrangle maps cover much of the County. See topographic quadrangle index map in the pocket.
d. U. S. Forest Service map "San Isabel National Forest" includes the County.

Mineral Production 1946-1958—The mining of coal has always been the dominant mineral industry of Huerfano County. Of recent years this industry has become considerably depressed due to the increase of domestic and industrial use of gas and oil for fuel and power purposes at the expense of coal. Clays, sand, and gravel, are the only other minerals of consequence produced in the county. The following figures are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Coal Short Tons	Clay Short Tons	Sand & Gravel Short Tons	Total $ Value
1946	613,846	----	----	----
1947	585,181	----	----	----
1948	551,379	----	----	----
1949	439,130	----	----	----
1950	303,827	----	----	----
1951	309,760	Withheld	Withheld	1,774,925[1]
1952	246,149	Withheld	Withheld	1,627,045[2]
1953	135,719	Withheld	Withheld	851,121[3]
1954	55,979	6,270	Withheld	354,321[3]
1955	63,903	7,969	Withheld	413,535[4]
1956	61,892	9,501	321,000	573,821[4]
1957	69,297	5,597	153,000	558,074[4]
1958	63,269	6,516	389,000	674,232[5]

[1] Value of coal production only.
[2] Value of coal and sand and gravel production.
[3] Value of coal and clays.
[4] Value of coal, sand and gravel, and clays.
[5] Same as [4] but includes stone production.

Coal—The Walsenburg coal field, on the northern extension of the Raton Mesa Coal Region, extends to the northwest, west, and southwest of the town of Walsenburg. The field is divided into two approximately equal parts: the northwestern part adjacent to Walsenburg; and, the western part near the town of La Veta.

[6]About 172 square miles of the County are underlain by measures containing 1,110 million tons of coal. Of these, 550 million tons are between 0 and 1,000 feet below the surface; 290 million lie between 1,000 and 2,000 feet; and 270 million lie under two to three thousand feet of overburden. The coal, mostly high volatile bituminous B and C rank, occurs in the Vermejo formation of Upper Cretaceous age, and in the Raton formation of Paleocene age. The coal of the Vermejo formation is usually thicker and of higher rank than that of the Raton formation.

Sand and Gravel — Sand and gravel have been produced from some of the drainages to the north, south, and west of Walsenburg. Other deposits occur along the course of the Cucharas River southwest of Walsenburg, and in some of its tributaries as far west as Ojo. Extensive Quaternary terrace deposits occur at the headwaters of Muddy Creek in the northwestern corner of the County; also, east of this area between Muddy and Williams creeks. Another large terrace is situated southwest of the upper Muddy, a few miles to the north of Sharpsdale.

Clays—Huerfano County has a number of clay deposits suitable for a variety of purposes. Butler[7] sampled many clay exposures throughout the county and the results of his tests indicated the presence of useful deposits. Samples taken from uptilted sediments on the eastern fringe of the southern Wet

Mountains in the northern part of the County, give evidence of excellent clay in that area:

[7]**Location:** 5 miles northwest of St. Mary in an outlier of Dakota rock west of the main hogback.

Sample 1—
5-ft. bed striking N-10-E, dipping 25-E, at the top of the Purgatoire formation; exposed in walls of canyon cut into the hogback. Medium-hard, gray-to-black, fine-grained, thin-bedded clay with gritty streaks.
Should make fine brick, earthenware, etc.

Sample 2—
Same location as above sample, but taken near the base of the Dakota formation some 30 feet above the other. Very hard, light-gray, fine-grained clay and shale.
First class fire clay.

[7]**Location:** About 4 miles north of the location of the above two samples; about 1 mile north of Apache Creek and west of Huerfano station. In the second notch crossing the Dakota hogback.

Sample 1—
5-ft. bed striking N-10-E, dipping 85-E, exposed on the northern side of the hogback. Medium-hard, iron-stained sandy shale possibly of Purgatoire age.
Should make first class brick, earthenware, etc.

Sample 2—
Same location as No. 1, but a short distance below it; from a 5-ft. bed under 4-ft. of overburden. Medium-hard, black, fine-grained clays and shales, containing a white streak.
Should make first class refractory ware, etc.

Sample 3—
From 6-inch white streak mentioned above.
First class fire clay.

[7]**Location:** West of Huerfano station on the eastern side of Hayden Butte.

Sample 1—
75 to 80-ft. exposure of medium-hard, yellowish-gray, slightly gritty shales, with slight easterly dip, in arroyos half-way up the butte's side.
Should make good brick, earthenware, etc.

Other and more recent investigations on the clay deposits of eastern Huerfano County were made by Waage[52]. These deposits are divided into two areas. The following data is abstracted from Waage's work.

Capers Area—In T-25-S, R-65-W, straddling the Huerfano-Pueblo County line. Between 600,000 and 1-million tons of clay have come from this area since mining started in 1906. Most of this production has been derived from a 9-ft. to 20-ft. thick clay bed at the top of the Glencairn shale member of the Purgatoire formation. The clay is semiplastic and dark gray in color. A local clay body in the upper part of the Dakota formation has also been worked. This clay is light to dark blue-gray or black, is plastic, and occurs in a bed 4 to 6 feet thick under only 3 to 4 feet of overburden.

Cucharas Canyon Area—This area is in the northeastern corner of Huerfano County. Here, the Cucharas River crosses an outcrop area of Dakota sandstone at the crest of the Apishapa anticline. The Dry Creek Canyon member of the Dakota is present over local areas, and a minable body of clay is indicated in section 19, T-26-S, R-64-W. The clay is exposed on the north and south sides of a small canyon in the northwestern ¼ and the northwestern part of the northeastern ¼ of the section. The exposure on the south side of the canyon is too sandy for commercial purposes, but that on the north side contains two beds of plastic clay and two of flint clay. The upper plastic clay bed is 2 feet thick, and the other 3 to 7 feet in thickness, with an interbed of sandstone with ferruginous matrix up to 1-ft. thick, separating them. Another ferruginous sandstone interbed, 1-ft. thick and quite persistent, separates the lower of the plastic clay beds from the upper of the two flint clay strata. The uppermost of these is from 2 to 4 feet thick, and has sandy streaks about 6-inches thick at its basal part. This sandy portion separates the bed from the lower flint clay body which is about 4-ft. thick.

[52]Eastern Huerfano County is a promising area in which to prospect for clay deposits. The Dry Creek Canyon member of the Dakota formation, and the Glencairn member of the Purgatoire formation should be investigated.

Uranium*—Uranium occurrences are known in the upper Huerfano formation of Eocene age, and in the Dakota sandstone of Cretaceous age, near Badito Cone. Prospecting in these rocks appears favorable. Also favorable are the thick section of folded and faulted upper Paleozoic and Mesozoic rocks which crop out on either side of the Huerfano Basin.

Lightweight Aggregates — Bush[28] indicates the existence of a "perlite or volcanic ash" deposit in section 10, T-25-S, R-70-W and nearby areas. This could be the aeolian deposit reported by Argall[9] at the Polvo Blanco mine near Gardner, consisting of fine-grained material with an expanded weight of only 1 to 5 pounds per cubic foot.

Hydrocarbon Potential**—There is no hydrocarbon production in Huerfano County at present, but during the 1940's a small amount of oil was produced from the Trinidad sandstone of Upper Cretaceous age in the Ojo anticline in section 10, T-29-S, R-69-W; the wells were subsequently abandoned.

The County lies partly on the west flank of the Apishapa Uplift and in the Raton Basin geologic province. It is anticipated that exploration will be conducted periodically within the Huerfano portion of the Raton Basin where a number of structures, plus stratigraphic trap possibilities, are present. The prospective zones are:

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*Dr. Donald L. Everhart, USAEC, personal communication.

**Mr. Thaddeus R. Carpen, Continental Oil Co., written communication.

Tertiary: Poison Canyon.

Cretaceous: Trinidad sandstone, Pierre shale (and sandstone), Niobrara formation, Codell sandstone, Dakota sandstone.

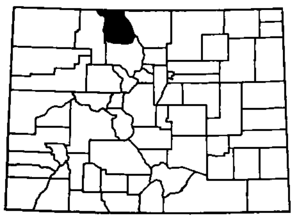
Jurrassic: Wannakah.

Permian: Lyons sandstone

Pennsylvanian: Sangre de Cristo sandstones, Madera limestones and sandstones.

Geological Note—The pre-Cambrian core of the Sangre de Cristo Range is exposed along the western border of the County. Pre-Cambrian schists of the southern Wet Mountains occur in the northwestern portion. Huerfano Basin lies between these two uplift regions which have brought the older sedimentary rocks to the surface along their margins. The north-central part of the Basin is mantled by rocks of the Huerfano formation of middle and lower Eocene age, grading south into Cuchara and Poison Canyon formations of Lower Eocene age. In this area at the southern boundary of the County, are the Early Tertiary instrusive rocks of the Spanish Peaks, with strong and persistent dikes radiating from these stocks. Similar stocks, related bodies, and northeasterly-trending strong dikes, some of later intrusions, are widespread northward as far as Gardner, and stretch eastward into the plains. Sedimentary rocks uplifted against the eastern margin of the Sangre de Cristos, range in age from Pennsylvanian to the Upper Cretaceous Pierre and Vermejo formations. On the eastern margin of Huerfano Basin another section of uplifted sediments is exposed against the pre-Cambrian crystalline rocks of the southern Wet Mountains, ranging in age from Permian to Upper Cretaceou Niobrara and Pierre formations. To the south, along the eastern margin of Park Plateau, a fringing band of Trinidad sandstone of Upper Cretaceous age is exposed and, to the east, the Upper Cretaceous: Pierre shale; Niobrara group; Benton group; and, Dakota sandstone predominate to the eastern boundaries of the County. Quarternary terrace deposits occur north of Huerfano Park, and in the vicinity of Mosca Pass.

Jackson County



Courtesy Colorado Planning Division

Jackson County, located in the north-central part of the State against the Wyoming border, has a population of 2,100, and an area of 1,628 square miles ranging in elevation from 7,800 to 12,935 feet above sea level. The County seat is at Walden, a ranching and business center with a population of 700 in the northern part of North Park.

Available Maps of the County—

a. Jackson County Map.

b. U. S. Army Map Service maps: 4664 I; 4665 I, II, IV; 4764 I, IV; 4765 I, II, III, IV; 4864 IV; 4865 III.

c. U. S. Geological Survey topographic quadrangle maps cover most of the County. See topographic quadrangle index map in the pocket.

d. U. S. Forest Service "Routt National Forest" map includes the County.

Mineral Production 1946-1958—Petroleum, natural gas, fluorspar, coal, sand and gravel, vermiculite, and a little copper and silver, comprise virtually all the minerals produced in the County during the 1946-1958 period. The petroleum production figures given in the following table are from records of the State Oil and Gas Conservation Commission; all others are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Coal Short Tons	Petroleum Barrels*	Total $ Value
1946	35,564	203,205	----
1947	42,755	192,435	----
1948	32,021	136,764	---
1949	8,538	120,909	----
1950	18,324	125,657	----
1951	3,354	119,072	----
1952	2,415	120,189	----
1953	2,833	117,052	1,443,726[1]
1954	2,267**	129,789	2,189,476[2]
1955	1,329	280,357	2,642,267[3]
1956	2,051	722,667	3,688,470[1]
1957***	1,448	888,103	Withheld[4]
1958	31,133	932,826	4,587,906[2]

*State Oil and Gas Conservation Commission figures.

**State Coal Mining Inspector's Report, 1954.

***Preliminary figures, subject to revision.

[1] Value of fluorspar, petroleum, sand and gravel, coal, and vermiculite.

[2] Same as [1], but excludes vermiculite and includes carbon dioxide.

[3] Same as [2], but excludes carbon dioxide and includes copper and silver.

[4] Value of petroleum, fluorspar, and coal.

Petroleum* — Petroleum was discovered in 1926 on the North McCallum structure in the east-central part of the County. Light oil was found in the Dakota formation of Upper Cretaceous age, associated with carbon dioxide gas. The McCallum field comprises two northwesterly-trending structures, North and South McCallum, separated by a low saddle.

As of the end of 1959 there were active in the County four oil and four oil-gas fields, with a total production for the year of 939,885 barrels of oil and 60,036 million cubic feet of gas. The total cumulative production for the county up to that

*A. E. Brainerd and F. M. Van Tuyl in reference No. 1 of the bibliography.

time was 5,329,780 barrels of oil and 333,336 million cubic feet of natural gas. *Present production is from the Cretaceous Frontier, Muddy, Dakota, and Lakota sandstones, and from the Jurassic Morrison and Sundance(?) sandstones. See the petroleum section in this book for greater details.

*Jackson County embraces all of the intermontaine basin known as North Park. The continued application of scientific exploration to the area should result in the discovery of additional reserves of oil and gas in structural and stratigraphic traps. Prospective areas for exploration include the periphery of the Park where the surface geology indicates favorable subsurface conditions for the existence of traps, particularly of the faulted or structural "nose" variety. Similar types of traps, or even anticlinal closures, may perhaps be defined by seismographic methods in the more inward parts of the basin. Prospective horizons include the producing zones given above, and the additional possibilities of accumulations in lenticular sandstones of the Coalmont and Pierre formations, and in fractured shales of the Pierre and Niobrara formations of Cretaceous age. The absence of Paleozoic rocks limits the prospective zones to post-Triassic sediments.

Fluorspar—The Northgate area in the northeastern part of the County, is an important producer of fluorspar. [21]The country rocks are pre-Cambrian granites and metamorphics with small areas of arkosic sandstone probably of Tertiary age. One deposit consists of two or more north-trending veins at least 1,600 feet long which at one place intersect and form an ore body 25 feet in width. Another group of veins occurs 1½ miles to the northeast and extends for over a mile. The largest vein in this group has a maximum width of 40 feet and has been mined by open pit methods.

There are several fluorspar mining operations in the Northgate area, but only one is active at this writing due to the depressed condition of the market brought about by excessive imports.

Ralph E. Van Alstine discusses the Northgate district on pages 463-64 of the 1947 edition of this book (Vanderwilt).

Coal—The North Park coal field comprises the large synclinal trough known as North Park which lies between the uplifted crystalline rocks of the Medicine Bow Mountains to the east, and those of the Park Range to the west.

[6]The 102 square miles of the area which have been evaluated, are underlain by measures containing 3,735 million tons of coal. Of this tonnage, 1,308 million are under 0-to-1,000 feet of overburden, 1,357 million tons are under 1,000-to-2,000 feet, and 1,070 million tons are between 2,000 and 3,000 feet below the surface.

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*A. W. Cullen, Consulting Geologist, Denver, written communication.

The coal, which is of subbituminous B rank, occurs in the Coalmont formation of Paleocene age. In the northeastern part of the field, coal-bearing strata outcrop on the flanks of the McCallum anticline where at least 3 beds are present. In the southwestern part of the field, 4 and possibly 5 coal beds are present.

Coal from the North Park field has been mined for domestic use for many years, but during the last few decades, coal has lost practically all its markets to natural gas and petroleum.

Sand and Gravel — Sand and gravel have been extracted from the course of the Michigan River north of Walden as far as the county line; from Camp Creek in the northeast corner; in the vicinity of Coalmont from Newcomb and Little Grizzly creeks; south of Hebron from Grizzly Creek; and, in the vicinity of Spicer, from Arapahoe Creek. Other possible sources are the Quaternary terrace deposits east and west of Spicer.

Vermiculite — Vermiculite deposits in northeastern Jackson County, near the Wyoming border have been known, prospected, and exploited to some extent for a number of years. [28]These occur in pre-Cambrian terrane consisting of granite, hornblende gneiss, granite gneiss, hornblende-biotite schist, and cross-cutting pegmatite dikes. The vermiculite developed from alteration of the hornblendic rocks. The three deposits in the area are all within the southeast ¼ of T-12-N, R-80-W. Only one of these, the Resort deposit, appears promising.

Precious and Base Metals—Production of these metals has been of very little consequence to the economy of the County. Mining districts have been established in the north and southeastern portions. Vanderwilt discusses these districts on the following pages of the 1947 edition of this book.

Indepence .... p. 120
Pearl .... p. 120-21
Rand .... p. 121
Teller .... p. 121

The occurrence of placer platinum, east of Owl near the Never Summer Mountains, has been known for several decades. Some activity was conducted in this area during 1957, but the results were inconclusive.

Geological Note—Most of Jackson County's area is contained within North Park. The Park itself is a large synclinal, north-south-trending trough confined on the east by the Medicine Bow Mountains uplift, and on the west by the parallel uplift of the Park Range.

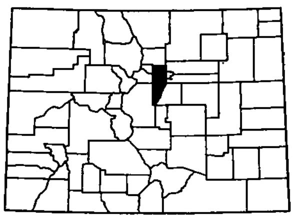
Along the eastern border of the County are the Medicine Bow Mountains and the Never Summer Mountains. The former extend north from Cameron Pass into Wyoming and consist chiefly of a core of crystalline rocks probably pre-Cambrian in age. Near the northern boundary, are exposures of pre-Cambrian granites and metamorphic rocks. At Cameron Pass, are andesite and basalt flows of Quaternary(?) and Late Tertiary age. South of the Pass, and for a few miles to the north, pre-Cambrian rocks consisting chiefly of hornblende gneiss and greenstone are exposed along the Never Summer Mountains. Much of the western side of these mountains consists of pre-Cambrian metamorphic rocks.

The Park Range, along the western border of North Park, is composed of rocks similar to those of the Medicine Bow and Never Summer Ranges. It is estimated from the thickness of the sedimentary sections exposed on either side of the Park, and the elevation of the crystalline peaks above the Park floor, that the amount of the uplift probably exceeded 20,000 feet.

The uptilted sedimentary rocks along the Park's lateral confines range in age from possibly Late Paleozoic, and Tertiary Chugwater formation, through Jurassic Morrison formation; Upper Cretaceous: Dakota sandstone, Benton shale, Niobrara formation, Pierre shale, and Coalmont formation.

The main area of the Park is mantled by Eocene rocks of the Middle Park formation. A long tongue of the Miocene North Park formation almost bisects the Park, stretching from Owl Mountain on the east, to the confluence of Roaring Fork and Grizzly creeks on the west. The base of this tongue on the east, is partly covered over by a large area of Quaternary talus and landslides which curves westerly along the southern boundary of the County and stops against a large flow of Quaternary(?) or Late Tertiary rocks.

Jefferson County



Courtesy Colorado Planning Division

Jefferson County is located directly to the west of the city of Denver. It has a population of 110,000, and an area of 791 square miles ranging in elevation from 5,300 to 10,623 feet above sea level. The County seat is at Golden, home of the Colorado School of Mines and an industrial and business center of 9,000 population.

Available Maps of the County—

a. Jefferson County Map.

b. U. S. Army Map Service maps: 4664 I; 4665 I, II, IV; 4764 I, IV; 4765 I, II, III, IV; 4864 IV; 4865 III.

Mineral Production 1946-1958—Jefferson County is an important producer of sand and gravel, clay and uranium. Other minerals produced during the 1946-1958 period were coal, stone, gold, silver, copper, pegmatite minerals, and petroleum.

Year	Sand & Gravel Short Tons	Clays Short T.	Coal Short T.	Gold Ounces	Silver Ounces	Copper Pounds	Total $ Value
1946	----	----	125,376	92	850	83,000	17,353[1]
1947	----	----	121,342	116	1,251	138,000	34,172[1]
1948	----	----	106,599	7	63	6,000	1,604[1]
1949	----	----	88,558	32	9	----	1,128[1]
1950	----	----	11,235	137	21	----	4,814[1]
1951	Withheld	164,854	21,119	263	42	----	1,125,601[2]
1952	Withheld	153,512	1,593	339	53	----	1,085,776[3]
1953	Withheld	197,454	----	319	132	6,000	1,133,524[3]
1954	658,000	221,440	----	290	42	----	1,137,214[4]
1955	660,000	168,419	----	394	70	----	1,131,279[4]
1956	987,000	236,605	----	488	81	----	2,274,039[5]
1957	2,037,000	183,658	----	575	94	----	3,588,560[5]
1958	1,534,000	237,611	----	504	81	----	3,286,762[5]

[1] Value of precious and base metal production only.
[2] Same as [1] but includes sand and gravel, clay, and stone production values.
[3] Same as [2] but includes pegmatite minerals.
[4] Same as [3] but includes value of oil production.
[5] Same as [4] but includes uranium production.
All figures from U. S. Bureau of Mines Minerals Yearbooks.

Sand and Gravel—Sand and gravel have been produced from: near Golden and east and west of it to the County's boundaries; north of Golden from easterly flowing streams, to the Boulder County line; and, south of Golden from Bear Creek, the North Fork of the Platte, and the Platte River.

Clays—For many years the sedimentary beds uplifted against the eastern margin of the Front Range to the north and south of Golden have been an important source of clays. [145]Commercial deposits of refractory clay are found in the top of the Glencairn member of the Purgatoire formation of Upper Cretaceous age directly under the Dakota sandstone. These deposits are now depleted and refractory clay must be shipped in from other counties to supply the raw materials requirements of established refractory products manufacturing plants.

Most of the clay used in the manufacture of construction materials, such as brick, tile, conduits, etc., is mined from the lower 4 or 5 clay beds of the Laramie formation of Cretaceous age. Small amounts of clay are also mined for this purpose from the Pennsylvanian Fountain formation, the Permo-Triassic Lykins formation, the Morrison formation of Jurassic age, the Lytle sandstone member and the Glencairn shale member of the Purgatoire formation, and from the Benton shale. The supply of raw clay for the manufacture of construction materials appears ample for many years into the future.

The Colorado State Bureau of Mines gives the following figures for the value of clay production during the years:

1946	$140,290
1947	201,300
1948	----
1949	254,400
1950	258,300
1951	323,400
1952	316,400
1953	401,100
1954	459,300
1955	661,000
1956	536,000
1957	580,000
1958	632,000

Uranium*—Jefferson County has some areas geologically favorable in which to prospect for high-grade pitchblende vein deposits similar to that of the important Schwartzwalder mine on Ralston Creek northwest of Golden. The pre-Cambrian Idaho Springs formation which predominates in the northern two-thirds of the county, is cut by large, through-going, tensional fracture patterns, and possibly breccia pipes in some areas. Geologic settings such as these are very favorable in which to prospect for commercial uranium deposits. Also, uranium mineralization is known to occur in the Dakota hogbacks along the Front Range. See uranium section for further details.

During 1958, the production amounted to 264,739 pounds of contained U_3O_8 valued at $1,219,897.

Coal—The northern two-thirds of the Foothills District of the Denver Coal Region is located in Jefferson County. [6]In this area, 78 square miles are underlain by measures containing 800 million tons of subbituminous coal ranging from B to C in rank with C predominating. Of this tonnage, 258 million tons lie between 0-to-1,000 feet below the surface, 508 million are between 1,000-to-2,000 feet, and 34 million lie under between 2,000 and 3,000 feet of overburden. The Foothills District has been a source of coal for local domestic use and sale in the Denver area for many years. But the increased availability of natural gas and oil and the consumers' preference for the cleaner fuels have virtually driven coal out of its former markets.

[6]The coal occurs in from 1 to 3 minable beds in the Laramie formation of Upper Cretaceous age, which crops out in steeply-dipping strata against the eastern margin of the Front Range. The coal beds are lenticular and discontinuous.

Stone—Jefferson County has a wide variety of igneous, metamorphic, and sedimentary rocks some of which are suitable for various applications. Several quarries have operated in the vicinity of Golden and produced concrete aggregate, surfacing material for streets and highways, and riprap. Dimension stone used in many buildings in Colorado, Wyo-

*Dr. Donald L. Everhart, USAEC, personal communication.

ming and Nebraska, has come from the Platte Canyon red granite quarry near Buffalo Creek.

The Colorado State Bureau of Mines gives the following figures for the value of stone production during the following years:

1946	$ 124,000
1947	195,300
1948	
1949	1,500,000
1950	625,000
1951	330,000
1952	503,000
1957	34,000
1958	8,000

Precious and Base Metals—The production of base and precious metals in Jefferson County has never attained very great importance. Most of the total gold and silver production has come from Clear Creek placers west of Golden. Some of the sand and gravel operations recover a little gold and silver as a byproduct. Copper has been produced from the Malachite mine on the divide between Clear Creek and Mount Vernon about three miles west of Morrison. Vanderwilt discusses the established mining districts of Jefferson County on the following pages of the 1947 edition of this book:

Evergreen .... Page 122
Golden Placers .... Page 122
Malachite .... Page 124

Pegmatite Minerals[26]—Hanley, et al., examined a number of pegmatites in the area of pre-Cambrian metamorphic rocks west and northwest of Golden, and others to the north of Deer Creek. The Bigger mine, in section 3, T-6-S, R-70-W, has produced several thousand tons of feldspar, some sheet and punch mica, beryl, columbium-tantalum and rare earth minerals. The Burroughs mine, 7½ miles southwest of Golden in the northeast quarter of section 27, T-4-S, R-71-W, has produced a considerable tonnage of feldspar and nothing else. Feldspar appears to be the only mineral of economic consequence in this dike. The Centennial Cone prospect, 7 miles west of Golden in section 32, T-3-S, R-71-W, contains a thin, intermediate zone not over 6-inches wide, of albite-quartz muscovite pegmatite with some beryl and monazite of interest only to mineral collectors. The Cresman Gulch prospect, about 2½ miles northwest of Golden in sections 17 and 18, T-3-S, R-70-W, has produced some potash feldspar and perhaps 1 ton or more of beryl. The latter occurs in the intermediate zone of quartz-albite pegmatite which is exposed along the footwall part of the dike for about 225 feet, with an average thickness of 3 feet. [26]Hanley, who examined the dike in 1943, gives a visual estimate of the beryl-bearing zone as containing 20,000 tons of rock with possibly 20 tons of beryl.

The Colorado State Bureau of Mines gives the values of pegmatite minerals production as follows:

Year	Feldspar $	Beryl $	Mica $	Rare Earths $
1947	5,200	---	---	---
1949	2,200	---	---	---
1950	1,000	---	---	---
1951	600	---	---	---
1952	800	2,000	60	---
1953	29,000	1,800	100	---
1954	25,000	11,200	150	---
1955	26,000[1]	12,000	[2]	---
1956	33,400[1]	2,000	[2]	---
1957	40,500[1]	2,000	[2]	800
1958	1,315[1]	---	[2]	---

[1] Includes value of mica production.
[2] Included with value of feldspar production.

Petroleum—Petroleum was first produced in the County through well Pallaoro No. 1, the discovery well of the Soda Lake field in the east-central part near Morrison town. A small quantity of oil is produced from fractures in the Codell sand and Timpas limestone of Upper Cretaceous age. The Soda Lake field, the only active one in the County, produced 482 barrels of oil during 1959, and had a total cumulative production up to the end of that year of 15,275 barrels.

The northeastern part of Jefferson County lies on the western limb of the Denver Basin in an area of structural complexity which has not been tested fully. *Lower Cretaceous sands hold the most promise for future production; the Mesozoic and Paleozoic horizons are considered only slightly potential.

Geological Note—The western three-quarters of Jefferson County is located within the Front Range of the Rocky Mountains, a north-south trending geanticline developed in pre-Cambrian and younger rocks, which extends from a few miles north of Canon City, northerly into Wyoming.

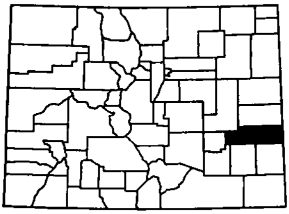
The northwestern part of the County contains the southern part of a large Boulder Creek pre-Cambrian granite batholith which continues northward across Boulder County. Just south of the granite body west of Plainview, a small body of Coal Creek pre-Cambrian quartzite and schist is exposed. To the south as far as Mount Morrison, pre-Cambrian metamorphic rocks chiefly of sedimentary origin predominate. South and west of Mount Morrison, following the western boundary of the County for a few miles and then widening to the east to fill the entire southern quarter, are granites and related rocks of pre-Cambrian age. The remainder of the area south and east of Mt. Morrison, east of Conifer, and north and east of South Platte as far as the eastern fringe of the mountains, consists of pre-Cambrian metamorphic rocks including the Idaho Springs formation.

Uptilted sedimentary strata, which represent structurally the eastern limb of the Front Range Anticline and the western limb of the Denver Basin, are exposed along the mountain front. Formations ranging in age from the Pennsylvanian

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

Fountain, through: the Permian Lyons; Permo-Triassic Lykins; Upper Jurassic Ralston and Morrison; Upper Cretaceous Dakota, Benton, Niobrara, Pierre, Fox Hills, and Laramie, are included in the section. In the area around Golden, a thrust fault has brought all the sedimentary formations, including Early Tertiary beds, into contact with the pre-Cambrian rocks of the mountains.

The plains east of the Front Range, within Jefferson County, are mantled chiefly by Tertiary sediments of the Denver-Arapahoe formation. In the area northwest of Stanley Lake, Cretaceous rocks of the Laramie formation are exposed.



Courtesy Colorado Planning Division

Kiowa County

Kiowa County, located on the prairies of eastern Colorado against the Kansas border, has a population of 2,800 and an area of 1,794 square miles ranging in elevation from 3,500 to 4,538 feet above sea level. The County seat is at Eads, a ranching, farming, and business center with 1,250 population.

Available Maps of the County—

a. Kiowa County Map.

b. U. S. Army Map Service maps: 5360 I, IV; 5361 II, III; 5460 I, IV; 5461 II, III; 5560 I, IV; 5561 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

Mineral Production—Sand and gravel, and petroleum are the only minerals of consequence produced in the County.

Sand and Gravel—Sand and gravel have been produced from: drainages in the vicinity of Eads; from the course of Big Sandy Creek near Chivington; and, from easterly-flowing drainages in the northeastern corner. Other sand and gravel deposits occur: east of Galatea; northwest of Arlington in the extreme western part of the County; in the southwest about 8 miles east of Adobe Creek Reservoir; and, along the southern boundary in the southeastern corner.

The U. S. Bureau of Mines gives the values of sand and gravel production for the following years:

1952	$ 8,126
1954	35,882
1955	59,252*
1956	17,000
1957	81,000
1958	40,700

*Includes the value of some gem stone production.

Hydrocarbons—Petroleum was first discovered in 1952 on the McClave Ranch about 12 miles south of Eads in the southern part of the County. Small production of oil and gas began in 1957 from the Morrow formation of Pennsylvanian age.

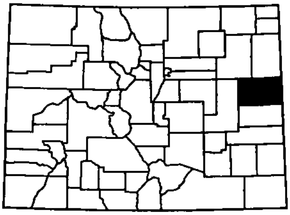
During 1959, there were 1 oil and 1 gas fields active in the County, which produced 1,860 barrels of oil and 4,000 cubic feet of natural gas. Total cumulative production up to that time amounted to 8,675 barrels of oil and 6 million cubic feet of natural gas.

*Kiowa County is on the Las Animas Arch and it is probable that new discoveries of greater commercial significance than the McClave field will be made in the future. The most prospective formations for future development are the sandstone and limestone beds of the entire Pennsylvanian section, plus possibly the carbonate rocks of Mississippian and Ordovician age.

The petroleum section of this book contains complete statistical data and geologic information on the area.

Geological Note—Kiowa County lies entirely in sedimentary terrane of the eastern Colorado prairie land. The eastern quarter of the county is mantled by the Miocene-Pliocene sediments of the Ogallala formation. West of these rocks, there is a broad north-south band of Upper Cretaceous rocks of the Niobrara group along the course of south-flowing Big Sandy Creek. In the south, the Niobrara exposures swing north around the Nee Noshe and Nee Sopah reservoir lakes to a point just south of Eads. Beyond the Niobrara exposures as far west as Haswell there is an extensive area of Ogallala sediments. South and west of Haswell Niobrara rocks appear again, surrounded on the north and west, and extending to the Lincoln and Crowley county lines, by Upper Cretaceous rocks of the Pierre shale.

*Mr. Thaddeus R. Carpen, Continental Oil Co., written communication.



Courtesy Colorado Planning Division

Kit Carson County

Kit Carson County, located on the plains of eastern Colorado bordering on Kansas, has a population of 8,300 and an area of 2,171 square miles ranging in elevation from 4,100 to 4,710 feet above sea level. The County seat is at Burlington, a farming, ranching, and business center with 2,250 population.

Available Maps of the County—

a. Kit Carson County Map.

b. U. S. Army Map Service maps: 5362 I, II; 5363 II; 5462 I, II, III, IV; 5463 II, III; 5562 I, II, III, IV; 5563 II, III.

Mineral Production—Sand and gravel are the only minerals of consequence produced in the County. A number of wells have been drilled for oil, but to date no commercial production has been encountered. Exploration for oil and gas continues and it is possible that commercial fields will be discovered in the future.

Sand and Gravel—Sand and gravel have been produced from deposits of reworked materials of the Ogallala and younger formations, from the courses of north-flowing drainages such as Lostmans Creek and other tributaries of the Republican River, both north and south of Burlington. Farther south, sand and gravel have been produced from the course of the Smoky Hill River and some of its tributaries; and, to the west, from the courses of other tributaries of the Republican River southwest of Seibert along the railroad as far as south of Flagler. Other sand and gravel deposits are scattered throughout the County along the northeasterly-flowing drainages, particularly in the eastern part, and east and west across the middle portion.

Petroleum*—In 1956, noncommercial oil production was discovered in the Lansing-Kansas City horizon of Pennsylvanian age in the Landsman field, but the discovery was abandoned soon after. No other production has been found in the County, possibly because of relatively little drilling.

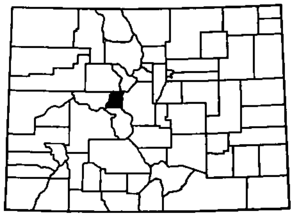
Kit Carson County lies along the southeasternmost margin of the Denver Basin, and the Las Animas Arch crosses its center. The Cretaceous section offers little probability of

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

economic production, but the Paleozoic section appears to be highly potential if judgment can be made from the discoveries in the Lansing-Kansas City horizon to the northeast along the same arching trend, and those in the Marmaton to the south.

Geological Note—With the exception of a relatively small area along the upper course of the Republican River to the west, the county is surfaced by the heterogeneous material of the Miocene-Pliocene Ogallala formation. Along the upper course of the Republican River are exposed Upper Cretaceous rocks of the Pierre shale northeast of Flagler for about 10 miles, and southwest of Flagler beyond the Lincoln County line.

Lake County



Courtesy Colorado Planning Division

Lake County occupies 384 square miles of a rugged mountain region at the crest of the Rockies in central Colorado, ranging in elevation from 8,935 to 14,431 feet above sea level. The County has a population of 7,700, and the County seat is at Leadville, population 4,500, one of the early mining boom towns of Colorado. Leadville, 80 years ago, was the second largest city in the State with 15,000 people; it is still the center of an important metal mining region.

Available Maps of the County—

a. Lake County Map.

b. U. S. Army Service maps: 4662 II; 4762 I, II, III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in pocket.

d. U. S. Forest Service maps "White River National Forest" and "San Isabel National Forest" include the County.

Mineral Production 1946-1958—Lake County has produced close to ¾ billion dollars worth of metallic ores during the 100 years of mining development in Colorado. The Leadville district has been the major contributor of precious and base metal ores in the County, and the Climax district the foremost producer of molybdenum ore in the world. Besides molybdenum concentrate, the Climax mill recovers tungsten, tin, and pyrite concentrate. The following production and total value figures are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Gold Ounces	Silver Ounces	Copper 1000-lbs.	Lead 1000-lbs.	Zinc 1000-lbs.	Molybdenum 1000-lbs.	Total $ Value
1946	10,780	332,472	195	8,883	11,992	9,600*	3,108,798[1]
1947	17,367	261,928	219	8,599	9,618	10,125*	3,292,914[1]
1948	20,881	214,450	208	9,506	11,452	13,077*	4,194,749[1]
1949	17,996	223,190	230	10,160	12,910	10,723*	4,083,288[1]
1950	21,008	280,633	304	12,784	14,784	11,903	4,877,667[1]
1951	19,323	272,355	310	11,992	16,288	22,539	Withheld
1952	18,405	322,034	326	11,248	16,974	23,874	Withheld
1953	9,345	196,263	118	6,144	7,890	37,306	37,547,577[2]
1954	5,438	137,557	80	3,870	4,874	42,545	50,346,551[2]
1955	5,165	98,155	52	2,808	3,242	43,043	52,323,801[3]
1956	3,556	156,628	208	3,319	4,255	37,489	46,010,817[2]
1957	5,675	374,002	539	7,388	13,137	42,500	50,344,051[2]
1958	207	16,246	2	362	----	25,100	32,947,213[4]

*Estimated.

[1] Precious and base metal values only.

[2] Same as [1] but includes tungsten, sand and gravel, stone, pyrite, tin, and molybdenum.

[3] Same as [2] but includes value of beryl production.

[4] Same as [1] but includes molybdenum, tungsten, and pyrite production values.

Molybdenum — For a number of years the production of molybdenite concentrate has been the most valuable of all the metallic products from Colorado mines. Because of its importance to the economy of the State and to the steel industry of the Nation, molybdenum is discussed by itself in a separate chapter of this book. A few additional remarks follow.

The Climax deposit, in the northeastern corner of the County, is the largest known economic accumulation of molybdenum in the world. Besides molybdenite (MoS_2) the ore carries small amounts of other economic minerals which, in a vast operation such as the one at Climax, become profitable to recover as byproducts.

A typical assay of Climax ore runs approximately: MoS_2—0.4%; WO_3—0.03%; tin—trace; and, pyrite (FeS_2)—1.25%. Although the assay does not include rare earths, a small amount of monazite (a phosphate of the cerium metals) is present in the ore. The molybdenite is first removed by flotation, and the tails, carrying the other minerals, are sent to the new (1958) 32,000 ton/day byproduct mill for their recovery. Besides molybdenite concentrate, Climax produces concentrates of tungsten, pyrite, monazite, and tin. The values of the tungsten and pyrite concentrates have reached appreciable proportions; the State Bureau of Mines gives figures for the following years:

Year	Tungsten	Pyrite
1955	$3,334,000	$153,000
1956	3,561,000	240,000
1957	2,578,000	59,000
1958	1,648,251	222,620

Precious and Base Metals — Practically all of the mining districts established in Lake County have contributed some production of one or more of the precious and base metals, but the most important contribution by far, has come from the Leadville district near the center of the County. Dr. Vanderwilt discusses these districts on the following pages of the 1947 edition of this book:

Leadville District—An excellent summary discussion of the geology and ore deposits of the Leadville mining district, by G. F. Loughlin and C. H. Behre, Jr., of the U. S. Geological Survey, is contained on pages 350-70 of the 1947 edition of this book (Vanderwilt). The comments of these two writers on additional exploration in this area, are worth repeating herein.

[16]Northeast of Leadville in Little Evans Gulch, siliceous silver ores reported to have been productive before the collapse of the silver price in 1893, remain for further consideration.

[16]Prospecting through the Yak tunnel of ground near the Mosquito fault east of the Resurrection mine is worthy of consideration as the surface along the west side of the fault shows distinct evidence of mineralization.

[16]The stimulation of gold mining from 1931 to 1941 proved that the eastern part of the district, despite the extensive work done in the Ibex mine, is entitled to further exploration. There are large tonnages of mineralized siliceous rock in the eastern part of the district that deserve thorough sampling to determine its value as milling ore.

[16]Similarly, the recent treatment of low-grade zinc-lead ore from dumps in the Iron Hill and Carbonate Hill areas gives some idea of the grade of ore left unmined. Large tonnages of this grade of ore no doubt remain as well as unknown quantities of higher-grade material which awaits exploration. The future of these two areas, as well as the Downtown and Fryer Hill areas, is obviously dependent upon unwatering. The same holds true for the little-explored area east and southeast of Breece Hill, all the way from Evans Gulch to Iowa Gulch. Drainage of this area could be brought about by driving a 4,500-ft. lateral from the Yak tunnel to the Sunday vein, which is in the same north-trending zone as the Hellena vein in Iowa Gulch. Drifting southward from such lateral would explore this zone and would probably unwater the Leadville dolomite in the vicinity of the Sunday vein. In the Hellena mine, however, this dolomite would still be below tunnel level, though the pumping lift would be substantially reduced.

[16]Beneath the eastern part of Rock Hill structural con-

ditions near the Mike fault may have been favorable to ore deposition, but the Leadville dolomite is so deeply buried there that it would remain at least 100 feet below any extension of the new tunnel (see paragraphs below on the Leadville drainage tunnel). This area is not far north of the small porphyry stock in Iowa Gulch where there is evidence of a minor center of mineral deposition. If the water in this vicinity were lowered to the level of the new tunnel, its surface would lie about 600 feet below the bottom of Iowa Gulch, and the ore bodies there, which have hitherto been accessible only by heavy pumping, might be mined.

[16]Far to the east of the main district and close to the crest of the Mosquito Range, three mines of impressive size, the Continental Chief, Hilltop, and Peerless, have been very productive in times past, and a few others are credited with appreciable production. The ore bodies have all been in the upper part of the Leadville dolomite. Structural conditions appear favorable for the occurrence of similar ore bodies, particularly beneath the crest of the range where the Leadville dolomite is cut by numerous mineralized fissures and is overlain by a thick sill of early White porphyry, locally separated from the dolomite by a thin bed of the basal shale of the Weber(?) formation. The extreme altitude of about 13,000 feet and the relative inaccessibility of the porphyry-dolomite contact along the steep slope are obstacles to exploration, especially as even the largest ore bodies thus far found are small in comparison with those of the main district.

The Leadville drainage tunnel, begun in December, 1943, on a World War II emergency basis, was driven southeasterly from the Arkansas River in two stages. The first one was terminated in August, 1945, after cessation of the hostilities in Europe. At this time, the tunnel had penetrated 6,600 feet to the outer edge of the district, about ½ the length originally planned. Reactivation of the work into the second stage was induced by the metals shortage developed by the Korean War. Actual driving on the tunnel began in September, 1950, and terminated in March, 1952, with the tunnel face 11,299 feet from the portal, in solid pre-Cambrian granite. This last circumstance indicated that the long, north-south-trending upthrust block between the Mikado fault and the Iron fault, which divides the district into an eastern and a western part, had a vertical rise of greater magnitude than was previously realized. The lower portion of this block, consisting of impermeable granite, makes an effective barrier to the movement of waters from the eastern part of the district to the drainage tunnel. Lead and zinc mineralization was found at several points along the course of the tunnel, but only two of them appear to be of sufficient consequence to merit investigation. These zones are between 8,225 and 8,600 feet in from the portal.

Sugar Loaf-St. Kevin District — [76]These two districts, frequently treated as one, are located a few miles to the west of Leadville around the shores of Lake Fork in the eastern foothills of the Sawatch Mountains. The area's total production has been estimated at between 10 and 15 million dollars. Lake Fork occupies a deep glacial valley in pre-Cambrian terrane consisting chiefly of schist, gneiss, granite, and pegmatite cut locally by dikes and irregular bodies of Tertiary intrusive rocks similar in appearance to Leadville's "white porphyry".

During Laramide time the Sawatch Mountains were uplifted into a broad, north-northwest trending anticlinal arch, and the Sugar Loaf-St. Kevin area was broken by numerous faults which are now disclosed as veins, chert dikes and sericitized rock. The veins have produced silver primarily, and a little gold. Zinc and lead occur in the northeastern part of the Sugar Loaf and in the central part of the St. Kevin districts, but generally not elsewhere. The veins occupy strong fissure zones normally less than 10 feet thick, with steep dips. The wallrocks are intensely shattered, and altered by hydrothermal action. Massive sulfides, as well as sulfide-free quartz, are found locally and, where sphalerite and galena occur, they may be either intergrown with pyrite, or entirely separate from it. Many of the ore shoots in the district bottomed at relatively shallow depths, between 100 and 200 feet.

Manganese — The Leadville area has been an important producer of manganese and manganiferous ores, particularly during the first World War. Very little of this material has been mined during recent years. Up to 1939[81] a total of 3,512,538 tons of ore had been extracted. Of this total, 936,024 tons were "metallurgical grade", assaying between 15 and 45% manganese, and 2,576,514 tons were "fluxing ore", running between 4 and 40% manganese, high in iron.

The Leadville manganese deposits are the most important in the State. *The ores are widely distributed, but possibly the largest deposits are those along the eastern edge of Poverty Flat, on Carbonate Hill, in Iowa Gulch, and on Iron Hill. They represent a concentration derived from manganiferous siderite which locally replaced the limestone, and are closely associated with base metal and silver ores. The most common host rock is the Blue limestone. Assays range from 2% to over 25% manganese, with 17% to 40% iron. Most of the ore shipped from the district has been used in local base metal smelters and in the steel works at Pueblo.

[85]DeHuff (1956) estimates the reserves of the Leadville district at 4 million tons of ore with an average manganese content of 15%. G. F. Loughlin** stated in 1940:

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*Edward D. Dickerman, personal communication.

**G. F. Loughlin, July, 1940. Report to the Public Works Administration.

"To summarize, it may be reasonable to assume that there are in the Leadville district 2,000,000 tons of oxidized manganese and manganiferous ores containing 10% to 25% mn., and 2,000,000 tons of manganosiderite ores containing 14% to 20% Mn".

Uranium*—Although no uranium occurrences of significance are known in Lake County, there are possibilities that some commercial uranium mineralization will be encountered in association with the precious and base metal deposits of the Leadville and surrounding districts.

Sand and Gravel — Sand and gravel have been produced from the course of the Arkansas River and some of its tributaries, southwest, northwest, and northeast of Leadville. Extensive Quaternary morainal and terrace deposits cover much of the center of the County.

The State Bureau of Mines gives the following values for sand and gravel production during the last two years:

1956	$134,000
1957	$200,000

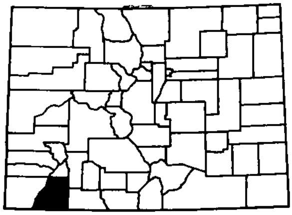
Geological Note—The Arkansas River has its origin in northern Lake County, south and east of the Continental Divide, on the eastern slopes of the Sawatch Range which borders the County to the west. The upper Arkansas River valley occupies the center in a north-south direction, confined on the east by the Mosquito Range, a sharp-crested ridge deeply indented by glacial cirques. Complex folding and faulting have been extensive in the region, particularly faulting within the Leadville area. East of the Leadville district, rocks of the pre-Cambrian basal complex are exposed, and include mica schist and gneiss into which batholithic pre-Cambrian rocks, chiefly Silver Plume and Pikes Peak granite, have intruded. Paleozoic sedimentary rocks ranging in age from Upper Cambrian to Pennsylvanian, are exposed along the eastern part of the County. These include: the Sawatch quartzite of Upper Cambrian age which rests upon an old erosion surface on the pre-Cambrian basement; the Upper Cambrian Peerless formation; the Ordovician Manitou dolomite; the Devonian Chaffee formation consisting of the Parting quartzite and the Dyer dolomite; the Mississippian Leadville limestone; and, the Weber formation of Pennsylvanian age. Late Cretaceous(?), Tertiary, and Pleistocene(?) igneous rocks intruded the pre-Cambrian and Paleozoic rocks forming sills, dikes, and plugs; which are the various "porphyries" of the district.

The western part of the County is located in the pre-Cambrian terrane of the Sawatch Mountains in which granites

*Dr. Donald L. Everhart, USAEC, personal communication.

and metamorphic rocks predominate. The center of the County, along the Arkansas River valley, is mantled by Quaternary morainal deposits, glacial outwash terraces, and glacial till.

La Plata County


Courtesy Colorado Planning Division

La Plata County, located in the southwestern part of the State bordering on New Mexico, has a population of 20,500 and an area of 1,691 square miles ranging in elevation from 5,900 to 14,091 feet at the summit of Windom Peak in the northeastern part. The County seat is at Durango, an oil, natural gas, and uranium-vanadium ore processing center with a population of 10,000.

Available Maps of the County—

a. La Plata County Map.

b. U. S. Army Map Service maps: 4358 I, II, III; 4458 I, II, III, IV; 4459 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

d. U. S. Forest Service maps "San Juan National Forest" and "Montezuma National Forest" cover the County.

Mineral Production 1946-1958—La Plata County is chiefly a producer of fossil fuels. Besides coal, natural gas, and oil, the County produced sand and gravel, precious metal minerals, and a small amount of copper. The following figures, with the exception of those for petroleum, are from U. S. Bureau of Mines Minerals Yearbooks. The petroleum figures are from records of the State Oil and Gas Conservation Commission.

Year	Gold Ounces	Silver Ounces	Petroleum Barrels	Coal Short Tons	Total $ Value
1946	548	360	---	56,147	19,471[1]
1947	892	968	---	48,977	Withheld
1948	176	537	---	48,923	7,004[1]
1949	217	2,286	---	45,091	9,664[1]
1950	61	1,443	5,658	43,206	3,441[1]
1951	---	---	12,100	38,776	162,181[2]
1952	33	147	21,301	37,853	161,281[2]
1953	202	163	11,938	43,800	422,039[3]
1954	558	428	10,788	40,446	447,683[3]
1955	426	1,167	8,868	54,728	534,080[4]
1956	1	2,580	9,879	51,447	348,124[3]
1957	113	95	12,491	38,737	485,183[3]
1958	--	898	19,201	33,058	447,316[3]

[1] Value of precious metal production only.
[2] Same as [1] but includes value of coal production.
[3] Same as [2] but includes sand and gravel, petroleum and stone.
[4] Same as [3] but includes copper.

Coal[6]—The southern half of La Plata County lies within the San Juan River Coal Region. The Durango coal field, the Red Mesa area, and the Bayfield-Yellow Jacket Pass district are included in the Region. About 608 square miles of the County are underlain by measures containing 7,906 million tons of coal. Of this tonnage, 1,796 million tons lie under 0-to-1,000 feet of overburden, 813 million between 1,000 and 2,000 feet, and 5,297 million tons lie between 2,000 and 3,000 feet underground.

The Durango Field—[6]Tihs field stretches southeasterly of Durango to the Bayfield-Yellow Jacket Pass coal district, and southwest of Durango to the Montezuma County line. The coal occurs in the Dakota sandstone, the Menefee formation of the Mesaverde group, and the Fruitland formation, all of Upper Cretaceous age. The Dakota coal is generally bituminous of high volatile rank, occurring in lenticular beds, thin and bony. The Menefee and Fruitland coal is generally bituminous of high volatile A and B rank. In general, the Menefee coal beds are thinner but of higher quality than those of the Fruitland measures. Most of the coals in the Durango area are cokable.

The Red Mesa Area—[6]The Red Mesa Area is located south of the western half of the Durango field, and stretches westerly to Montezuma County, and south to the New Mexico line. The Area is a canyon-cut plateau underlain by strata that dip predominantly to the southeast with local folding and faulting. The coal, which occurs in the Menefee and the Fruitland formations, is bituminous of high volatile A and B rank. The Menefee formation, exposed in the north and west, underlies most of the area at a depth of less than 3,000 feet. Three coal zones are recognized in the northwestern part, and two main zones are present farther south. The Fruitland formation outcrops in the southeastern part of the area where there are present from 1 to 4 coal beds.

Bayfield-Yellow Jacket Pass District—[6]This district is located northeast of Durango. The coal occurs in the Fruitland and Dakota formations. The Fruitland coal, which is high volatile bituminous, chiefly A in rank, is present in beds of minable thickness almost everywhere in the basal part of the formation.

Hydrocarbons—The Red Mesa oil-gas field, discovered in 1924 in the southwestern part, was the first productive field in the County. As of the end of 1959, there were active 4 gas, 4 oil-gas, and 1 oil field, with a total production for the year of 20,344 barrels of oil and 27,694 million cubic feet of natural gas, and an aggregate cumulative production up to that time of 118,579 barrels of oil and 126,432 million cubic feet of gas.

*La Plata County includes portions of the San Juan Basin and Four Corners Platform, both of which are productive. Within the Basin, gas is being produced from the Fruitland, Pictured Cliffs, Mesaverde, Dakota, and Burro Canyon formations of Cretaceous age, and from the Morrison formation of Jurassic age. Hydrocarbon accumulations are controlled by structural and stratigraphic traps.

*On the Four Corners Platform, shallow production of oil and gas is derived from the Mesaverde, Mancos, and Dakota formations of Cretaceous age. Deeper production is found at the Barker Dome gas field in the Ismay, Desert Creek, Barker Creek, and lower Hermosa zones of the Paradox formation of Pennsylvanian age. In the Alkali Gulch gas field, production is from the lower Hermosa zone of the Paradox.

*Continued shallow drilling in La Plata County will unquestionably locate additional oil and gas production in Cretaceous beds. Jurassic through Permian prospects are not encouraging, but deeper prospects are good in the Paradox, and may be augmented by eventual discoveries in the Mississippian and Devonian horizons.

Precious and Base Metals—The value of the county's production of base and precious metals to date is estimated to total between $6 and $7 million, with gold having contributed the major portion. Dr. Vanderwilt discusses the established mining districts of the County on the following pages of the 1947 edition of this book:

	Page
Animas River	133
La Plata (California, Oro Fino, May Day)	133-35
Cave Basin (Mount Runlett)	135
Needle Mountains (Tacoma, Florida River, Vallecito)	135-37

La Plata District—The La Plata (California) mining district, its geology and ore deposits, are discussed on pages 416-19 of the 1947 edition of this book. Additional information on ore deposits and prospects for further discoveries is given below.

[86]The greater part of the La Plata district's production has come from gold and silver tellurides occurring in veins and replacement deposits. In addition, the district contains a surprising variety of type of ore deposits within a small area. These include disseminated platinum-bearing chalcopyrite, gold contact-metamorphic deposits, deposits in which base-metal sulfides or pyrite and native gold predominate, and deposits characterized by the ruby silver minerals. They include disseminations and bed replacement bodies as well as veins. Some of these deposits are relatively unimportant economically, but scientifically form an interesting grouping; a few may, in the future, prove of economic value.

[86]Although the visible reserves of ore in the La Plata

*Mr. Enos J. Strawn, Pan Amer. Pet. Corp., written communication.

district appear to be negligible, the available facts seem to justify the hope that the district's future is relatively bright. The known vertical range of the ore deposits as a whole is far greater than that of the ore shoots developed in any one mine, and the lower limits of the productive zone are not yet known. Moreover, favorable conditions for ore shoots are produced by a large variety of geologic factors; it is also clear that many veins contain several ore shoots separated by nearly barren stretches, and that some ore shoots do not crop out at the surface. Therefore, the outlook for discovering new ore bodies along many of the known veins is promising, provided that the exploratory work is performed intelligently. It is also possible that new veins will be discovered in obscured areas, particularly in view of the poor exposures that characterize much of the district.

[86]Although determinable quantities of platinum and palladium occur in the disseminated copper ores from the Copper Hill mine, the tenor and quantity of the ore now showing does not encourage further mining. Nevertheless, it is possible that the ore body mined at the glory hole may dip in such way as to have been missed by the lower tunnel. Also, in the large area near the workings which is covered by glacial drift, talus, and soil, scattered exposures indicate that the geologic relations are similar to those near the known deposit. Exploration at or near the glory hole, possibly by drilling, may reveal additional ore.

[86]The contact-metamorphic deposits offer little hope of any important new discoveries, as probably most of the richer oxidized ore bodies have been discovered. Nevertheless, there is a possibility that some of them may have been overlooked or that workable primary ore may yet be found. They should be looked for along and just inside the borders of the central metamorphic area.

[86]Although most of the richer of the secondarily-enriched pyritic gold deposits presumably have been found, there is some possibility that small, rich, oxidized shoots, such as the one worked in the Century mine, may have been overlooked. The best hope for further production from these bodies appears to be in large-scale, low-cost operations on primary ores. Such methods would call for extensive prospecting and development of the deposits as well as careful research on metallurgical processes.

[86]The ruby silver veins of the Cumberland type offer little hope of important future production as compared with the telluride deposits and those of some of the other types. Comparatively small bodies of high-grade silver ore may yet be found by further development of known veins, or in new deposits. Search for them should be confined to the known ruby silver belt, particularly in the eastern part where, be-

cause exposures are poorest, deposits are more likely to have been overlooked in the past. More complete development of the Cumberland mine proper, either in depth or in partly developed ground, may prove the existence of a large body of low-grade silver ore which might be commercial under present mining and milling methods.

[86]Except for the vicinity of Diorite Peak, the distribution of telluride and mixed-sulfide gold ores, offers little encouragement to further exploration within the central metamorphic area. Outside this area, however, and especially near its borders, further exploration in many places would appear to be justified. Most of the veins that characterize the hinge fold encircling the central area have probably been found, but much of the exploration has been only superficial and many ore shoots may possibly remain undiscovered. The strong faults in the southern and northwestern parts of the district probably deserve more exploration than they have received, although they themselves are barren, but attention should be paid to the intersection of these faults with mineralized veins.

[86]Most of the eastern part of the district is heavily covered with vegetation and its rocks are poorly exposed, thus it is probable that this area has been less explored than any other part. The widespread distribution of telluride deposits within this zone, notably those in the Neglected and Mason mines and the Ohio-Indiana prospect, are indications of the possibility that other deposits may remain undiscovered.

[86]Any sign of mineralization in shale or other soft and incompetent rocks deserves investigation, for although commercial deposits are seldom found in rocks of that character, such signs may point to the existence of worthwhile deposits in more brittle rocks underneath.

[86]Many of the older dumps, if they have not been reworked already, warrant examination and sampling, for the mines from which they came were operated at a time when ores containing less than $50 to the ton could not be handled at a profit.

Sand and Gravel—Sand and gravel have been mined in the southern half of the County from: the course of the Animas River north and south of Durango; from Lightner Creek, La Plata River and some of its tributaries west of Durango; the Florida River and some of its tributaries to the east of Durango; and, Los Pinos River around Bayfield and Ignacio. Extensive Quaternary deposits of Florida gravel, Durango glacial wash, and Oxford gravel, are widely scattered throughout the southern half of the County, particularly south of Durango and in the Bayfield-Ignacio-La Boca area.

Pumicite—Argall[9] reports the existence of two deposits of pumicite (very fine-grained white ash) northwest of Animas City, which occur in lenses about 150 feet long and 40 feet wide. Another deposit is reported east of Durango on the eastern slope of Florida Mesa.

Uranium*—A few occurrences of "Colorado Plateau type" of bedded deposits are known west of Durango, but none of significant size. Nevertheless, favorable host rocks, the Triassic Chinle and the Jurassic Morrison and Entrada formations, are exposed in an east-west band across the County north of Durango, and represent a considerable area favorable for prospecting.

Geological Note—The Needles Mountains occupy the northern portion, forming an extremely rugged region with sharp peaks several of which rise to over 14,000 feet. The Animas River, rushing through deep canyons on a locally southwesterly course, separates the West Needles from the main group. The pre-Cambrian core of the Needles Mountains is exposed throughout the mountain area. South of the Needles Mountains, and separated from them by the deep valley of Needle Creek, is a plateau dissected by the Florida River and tributaries of the Animas River. The surface rocks of this area are of the same granite and schist as compose the main mass of the Needles, and are locally overlain by isolated erosion remnants of early Paleozoic rocks.

Around the southern perimeter of the exposed crystalline core of the Needles Mountains, the following sedimentary rocks are exposed: Ignacio quartzite of Cambrian age; Elbert formation and Ouray limestone of Devonian age; and, the Leadville limestone of Mississippian age. To the west and south of these exposures are Pennsylvanian rocks of the Molas and Hermosa formations.

The La Plata Mountains, in the central western part of the County and partly in Montezuma County, compose a rugged laccolithic type of mountain group. The most pronounced feature of these mountains is a domal uplift of sedimentary strata, about 15 miles in diameter, which blends somewhat into the southwestern flank of the broader San Juan Uplift. The mountains were carved from the uplifted sediments and intruded by numerous stocks, dikes, and sills of late Cretaceous or Tertiary igneous rocks. During the doming process, a large number of short, discontinuous faults were formed, some of which, after the emplacement of the nonporphyritic stocks, were reopened and new ones formed. These new faults became the loci of many of the La Plata district's ore deposits.

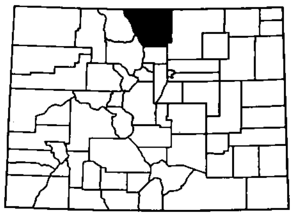
Sedimentary rocks ranging in age from Permian to Upper Cretaceous are exposed in a band 6 to 10 miles wide extending from just south of the La Plata mining district in the western part of the County, easterly across it, to the western boundary and beyond. From north to south across this band, the rocks

*Dr. Donald L. Everhart, USAEC, personal communication.

consist of: the Permian Rico and Cutler formations; the Jurassic(?)-Upper Triassic Dolores formation; the Jurassic Entrada sandstone, Wanakah formation, Junction Creek sandstone, and Morrison formation; the Upper Cretaceous Dakota sandstone, the Mesaverde group, and other undifferentiated Late Cretaceous rocks.

Southwest of Hesperus, along the County's western border, a broad band of Mesaverde rocks are exposed extending south to the New Mexico border and beyond. East of this band, another parallel band of Upper Cretaceous rocks of the Lewis shale is exposed, followed by other Upper Cretaceous rocks, including the McDermott formation, Kirtland shale, and Fruitland formation. Tertiary rocks are exposed in the southern part of the County within the northern portion of the San Juan Basin, these include: the Animas, Torrejon, Puerco, and Wasatch formations, and Pliocene(?) Bridgewater gravels. The center of this southern area is mantled by Quaternary Florida gravels, Durango glacial wash, and post-Durango deposits. The petroleum section contains information on the petroleum geology of this area.

Larimer County


Courtesy Colorado Planning Division

Larimer County is located in the central northern part of the State on the Wyoming border, has a population of 50,000 and an area of 2,640 square miles ranging in elevation from 4,800 to 13,562 feet above sea level. The County seat is at Fort Collins, home of Colorado State University and an agricultural, industrial, and business center with a population of 30,000.

Available Maps of the County—

a. Larimer County Map.

b. U. S. Army Map Service maps: 4765 I; 4864 I; 4865 I, II, III, IV; 4964 I, IV; 4965 I, II, III, IV; 5064 IV; 5065 III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

d. U. S. Forest Service maps "Roosevelt National Forest" and "Arapahoe National Forest" include the County.

Mineral Production 1946-1958—One of the important industries in the County is the manufacture of cement and the production of the raw materials required for its manufacture; these include limestone, clay, and gypsum. The production of petroleum and natural gas has been of appreciable importance for several decades. Besides these items, Larimer County produces stone, sand and gravel, pegmatite minerals, and some copper and silver. The petroleum figures in the following table are from records of the Colorado Oil and Gas Conservation Commission, and those for sand, gravel, and total values, are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Petroleum Barrels	Sand & Gravel Short Tons	Total $ Value
1946	164,313	----	----
1947	147,319	----	----
1948	141,212	----	----
1949	128,323	----	----
1950	129,618	----	----
1951	119,556	----	----
1952	108,293	----	----
1953	110,655	----	4,301,669[1]
1954	114,245	349,000	4,986,292[1]
1955	130,651	333,000	5,468,570[2]
1956	181,709	493,000	5,582,767[2]
1957	226,163	291,000	5,589,923[3]
1958	208,256	749,000	9,761,154[4]

[1] Includes the value of cement, stone, oil, sand and gravel, clay, feldspar, and beryl.

[2] Same as [1] but includes mica, copper, columbite-tantalite, and silver. Excludes value of cement.

[3] Includes value of cement, oil, stone, sand and gravel, gypsum, feldspar, beryl, mica, and columbite-tantalite concentrate.

[4] Same as [3] but excludes columbite-tantalite.

Hydrocarbons—*The Wellington oil and gas field in the northeastern part, about 14 miles north of Fort Collins, was the first active field in Larimer County. The discovery well, drilled in 1923, struck oil, and gas estimated at 82 million cubic feet per day, in the upper sandstone member of the Dakota formation of Upper Cretaceous age.

As of the end of 1959, there were in the County 7 oil-gas, 1 gas, and 2 oil fields, with an aggregate production for the year of 193,590 barrels of oil and 47 million cubic feet of natural gas, and a total cumulative production of 9,931,818 barrels of oil and 20,388 million cubic feet of gas.

**The eastern portion of Larimer County lies on the western limb of the Denver Basin and contains several productive, closed anticlinal structures. There are also good possibilities for the existence of potentially productive stratigraphic traps and fracture zones. The probabilities for the discovery of additional surface structures representing underlying hydrocarbon accumulations are rather dim, but correct subsurface interpretations may result in some commercial developments. Stratigraphic traps and fracture zones offer the best prospectives for exploration. The Hygiene sand of the Pierre formation of Upper Cretaceous age, while not known

*A. E. Brainerd and F. M. Van Tuyl in reference No. 1 of the bibliography.
**Mr. George H. Fentress, Exeter Drilling Co., written communication.

at present to be productive, offers interesting possibilities. The currently productive horizons are: the Permian Lyons sand; the Lower Cretaceous 'D' and 'J' sands of the Dakota formation; and, fracture zones in the Timpas limestone of Upper Cretaceous age.

Limestone—Limestone for cement manufacture is quarried about ½-mile north of La Porte, about 5 miles northwest of Fort Collins. The limestone occurs in the Niobrara formation of Upper Cretaceous age, interbedded with shales, and is mined in a manner designed to yield as close to the proper cement kiln feed as possible, thus minimizing the feed-blending operation. The calcium carbonate content of the kiln feed (cement rock) is maintained as close to 77% as possible. Most of the balance is a desirable amount of shale.

Limestone used in the refining of beet sugar is quarried from the Ingleside formation of Permian age, just to the north of Owl Canyon. The limestone required for this purpose must be of far greater purity than that used in cement manufacture.

Gypsum—Gypsum for use as a retarder in the manufacture of cement, is mined from the Lykins formation of Permo-Triassic age, some 17 miles north of La Porte, not far from the Wyoming border.

Gypsum for plaster and other purposes, is mined from the base of the Lykins formation a few miles west of Loveland.

Alabaster, the compact, fine-grained variety of gypsum, is mined for home ornamental articles near Livermore.

Sand and Gravel — Sand and gravel have been produced from the course of: Cache la Poudre River and some of its tributaries northwest and southeast of Fort Collins; from the North Fork of Cache la Poudre River and tributary streams near Livermore; Boxelder Creek and other minor streams near Wellington; from the Big Thompson River near Loveland; and, from Little Thompson River near Berthoud. Several other sand and gravel deposits are scattered throughout the eastern part of the County.

Stone—Larimer County contains unlimited quantities of igneous, metamorphic, and sedimentary rocks some of which are suitable for various applications in the construction and other industries. Dimension sandstone is produced from the Lyons formation of Permian age; crushed and dimension sandstone from the Dakota of upper Cretaceous age; and, crushed and dimension granite of pre-Cambrian age is produced in the vicinity of Masonville. Limestone and gypsum are discussed above.

Pegmatite Minerals[92]—The Crystal Mountain district, one of the important pegmatite areas in Colorado, is located in T-6. 7-N, R-71, 72-W, approximately 15 miles west of Fort Collins and Loveland, within the Front Range mountain uplift.

The Front Range is composed of pre-Cambrian metamorphic and igneous rock, cut locally by intrusive rocks of Tertiary age. Paleozoic and younger sediments are upturned along the flanks of the range. The oldest and most common metamorphic rocks in the Crystal Mountains district are quartz-mica schist of the Idaho Springs formation. These rocks have been intruded by Mount Olympus granite in irregular masses, large sheets, and sills, generally concordant with the schistocity. Numerous pegmatite dikes accompanied and followed the granite intrusions, forming concordant and discordant bodies in the granite and schist. The largest dikes in the area are discordant in the schist. Over 1,300 pegmatite dikes have been mapped north of Big Thompson River within an area less than four square miles.

[92]The shape of the pegmatites is controlled chiefly by the types of rocks they intruded. In competent rock, such as granite, the dikes are predominately tabular, with irregular bends, and relatively linear courses. In well-foliated rocks such as mica-schist, the concordant pegmatites are mostly lenticular with curving outlines. In these rocks, the discordant dikes have irregular and serrate margins. When a complexity of conditions exists in the country rocks intruded, the dikes may adopt a variety of irregular shapes. Most of the pegmatites in the area are unzoned or "homogeneous," of fairly uniform texture and mineral distribution.

[92]Perthite, plagioclase, and quartz are the essential minerals of the pegmatites, with muscovite a widespread but minor constituent. Tourmaline, garnet, beryl, and apatite are common accessory minerals, with uraninite, columbite-tantalite, chrysoberyl, and others, as rare constitutents. Beryl, perthite, scrap mica, and columbite-tantalite, are the principal economic minerals of the district.

At the present time none of the above minerals is being mined in appreciable quantity. The occurrence of beryl is widespread throughout the area; about 350 dikes, of the 1,300 mapped by the U. S. Geological Survey[92], were found to contain beryl, some of the pegmatites in appreciable amounts. A froth flotation mill for the separation and concentration of beryl, feldspar, and mica was installed near Masonville recently but was unable to operate commercially. Transportation costs prohibited the marketing of feldspar and mica, and no proper market could be found for the beryl concentrate. The U. S. General Services Administration purchases only "crystal beryl", not the finely ground flotation concentrate. Nevertheless, the Crystal Mountain area represents an important reserve of beryl for the future.

Precious and Base Metals — The production of precious and base metals has never attained importance in the County despite various scattered occurrences of gold, silver, copper, and some zinc. Several mining districts established in the area are discussed by Dr. Vanderwilt in the original edition of this book, published in 1947, on the following pages:

Uranium*—One mine in the Prairie Divide area has produced a few tons of pitchblende ore. This occurrence, and other scattered vein-type prospects in the pre-Cambrian rocks, plus occurrences in the Dakota sandstone hogback along the eastern flank of the Front Range, indicate favorable prospecting areas for similar deposits.

Clay—Butler[7] collected 75 samples from clay-bearing formations along the eastern margin of the Front Range, north-south across the County. Some of the formations he named, from which samples were taken, are: the Upper Cretaceous Fox Hills(?) in the northern part; the Upper Cretaceous Pierre, Carlile, and Dakota, north-to-south across the County; and, the Upper Cretaceous Graneros shale in the southern and northern parts. Butler did not identify the formations from which some of the samples were taken.

Only 15 out of the 75 samples represented worthless material. The remainder indicated the presence of clays suitable for various uses, including three localities which yielded samples of "first class" fire clay. These three sites are:

1. From a ditch, 700 feet north and 300 feet west of the southeast corner of section 24, T-8-N, R-70-W. Very hard, light bluish-green, fine-grained clay. First class fire clay.
2. 300 feet north and 900 feet west of the southeastern corner of section 20, T-11-N, R-69-W. "Material like this can be traced for 10 miles or more". Very hard, white, sandy clay in a 6 foot bed striking north-south, dipping 15-deg. east, and occurring near the top of the Lower Dakota(?) hogback. First class fire clay, but with low plasticity, cohesion, and tensile strength.
3. A 2-ft. bed striking N-30-E, dipping 5-deg. southeasterly; exposed in the bottom of a gully 600 feet north and 600 feet west of the southeast corner of section 31, T-12-N, R-69-W, about 3 miles south of the Wyoming line. Very hard, white and pinkish, gritty clay. A first class fire clay.

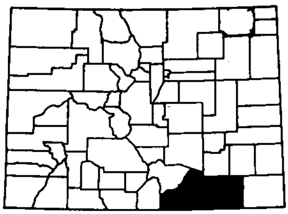
Gem Stones[24]—Schlegel lists the following gem stones and localities of their occurrence in Larimer County:

Locality	Gem Stone
Pennoyer amethyst mine, Red Feather Lake, Fort Collins.	Amethyst.
Specimen Mountain, Rocky Mountain National Park.	Agate, geodes, onyx, opal, jasper.

*Dr. Donald L. Everhart, USAEC, personal communication.

Coal[6]—The Wellington Coal Area, located chiefly in Weld County, stretches partly into the northeastern corner of Larimer County. In this locality, 12 square miles are underlain by measures containing 78 million tons of coal, all of it under 1,000 feet or less of overburden. There are two coal beds of subbituminous C rank in the Laramie formation of Upper Cretaceous age, northeast of the town of Wellington, where coal has been mined.

Geological Note—The western three-quarters of the County lies in the pre-Cambrian mountainous terrane of the Front Range. The Medicine Bow Mountains form the western boundary, with the Laramie Range farther east, separated from the Medicine Bows by the valley of the upper Laramie River. East of the Laramie Range is the main group of the Front Range. All this area, west of the eastern margin of the Front Range, is underlain predominantly by pre-Cambrian metamorphic rocks, largely of sedimentary origin, and pre-Cambrian granites and related rocks. Pre-Cambrian hornblende gneiss and greenstone are exposed in the Cameron Pass area, as are flows of Quaternary and Tertiary igneous rocks. East from the Margin of the Front Range, the following Paleozoic to Cretaceous rocks are exposed: the Pennsylvanian Fountain and Ingleside formations; the Permian Lyons sandstone, and the Permo-Triassic Lykins formation; the Jurassic Morrison formation; and, the Upper Cretaceous Dakota sandstone, Benton group, Niobrara group, and Pierre shale.



Courtesy Colorado Planning Division

Las Animas County

Las Animas County, located in the southern part of the State bordering on New Mexico, has a population of 24,500 and an area of 4,798 square miles, the largest in the State, ranging in elevation from 5,300 to 14,069 at the peaks of the Culebra Range. The County seat is at Trinidad, one of the oldest towns in Colorado and an important trading post on the old Santa Fe Trail. Trinidad is a coal mining, industrial, and business center with a population of 12,250.

Available Maps of the County—

a. Las Animas County Map.
b. U. S. Army Map Service maps: 4958 I, II; 5058 I, II, III, IV; 5059 II; 5158 I, II, III, IV; 5159 I, II, III, IV; 5258 I, II, III, IV; 5259 II, III; 5358 I, II, III, IV; 5359 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

d. U. S. Forest Service map "San Isabel National Forest" covers the Spanish Peaks area in the western part of the County.

Mineral Production 1946-1958—Las Animas County is a leading producer of coal, most of it cokable for consumption in the steel mill at Pueblo. Natural carbon dioxide gas, sand and gravel, stone, clay, uranium, and some gypsum, are also produced. The coal production figures in the following table are from reports of the State Coal Mine Inspectors; those for the total value of mineral production are from U. S. Bureau of Mines Minerals Yearbooks. Unfortunately, most of the figures on clay, sand and gravel, and other products are withheld by the U. S. Bureau of Mines in deference to the operators' wishes.

Year	Coal Short Tons	Total $ Value
1946	1,070,392	----
1947	1,289,582	----
1948	1,142,004	----
1949	889,306	----
1950	967,372	----
1951	991,419	6,438,763[1]
1952	857,589	5,601,956[1]
1953	1,172,771	7,991,361[2]
1954	875,298	6,475,547[3]
1955	1,317,403	9,415,036[4]
1956	1,232,916	8,950,802[5]
1957	1,318,124	11,059,872[5]
1958	768,275	8,526,026[6]

[1] Value of coal production only.

[2] Value of coal, sand and gravel, clays, and gypsum.

[3] Same as [2] but no gypsum production.

[4] Same as [3] but includes some gem stone production.

[5] Value of coal, uranium, sand and gravel, stone, clay, and CO_2 gas.

[6] Value of coal, sand and gravel, clays, and carbon dioxide.

Coal—The Trinidad coal field, part of the Raton Mesa Coal Region, is located in the western part of the County; the city of Trinidad lies on the eastern margin of the field. [6]At least 872 square miles of the County are underlain by measures containing no less than 11,330 million tons of coal. Of this tonnage, 2,613 million tons lie between 0-to-1,000 feet below the surface, 446 million are under between 1,000 and 2,000 feet of overburden, and 8,271 million tons are between 2,000 and 3,000 feet underground.

[6]The Vermejo formation of Late Cretaceous age is coal-bearing throughout the Trinidad field, and the Raton formation of Paleocene age, carries coal through almost its entire thickness of from 1,000 to 1,600 feet. The Vermejo coal beds are generally thicker, more persistent, and of better quality than the Raton beds, consequently, they are more extensively mined. Most of the coal is high volatile bituminous A in rank, but some is of high volatile B rank.

Oil and Natural Gas—The Garcia natural gas field in the southwestern-central part of the County was discovered in 1896. *Production was from the Codell sandstone at the top of the Carlile formation of Upper Cretaceous age. This field was not productive during 1959, but by that time had a cumulative production of 1,561 million cubic feet of dry natural gas.**

***In the late 1920's, several non-combustible gas wells were drilled into the Lyons (Permian) sandstone on the Model Dome in the western part, east of the settlement of Model. The gas was sought because of its relatively high helium content; the wells were subsequently shut in and held for future reserve by the Federal Government.

The Nina View Field, discovered in 1948 as a carbon dioxide producer, was the only active field during 1959. **That year it produced 82 million cubic feet, and had a cumulative production of 447 million cubic feet of carbon dioxide gas since its discovery. All gas from this field is piped to Ninaview in Bent County where it is processed into dry ice and liquid carbon dioxide and marketed as far as Montana and Texas.

***The western part of Las Animas County lies within the Raton Basin, the central part is on the Apishapa Uplift, and the eastern part on the Sierra Grande Uplift and there are a number of structures and various stratigraphic trap possibilities which will probably be explored in the future. The prospective zones for future development are:

Tertiary age—The Poison Canyon beds.

Cretaceous age—The Trinidad sandstone, Pierre formation, Niobrara formation, Codell sandstone, Dakota sandstone.

Jurassic age—Wannakah beds.

Permian age—The Lyons sandstone.

Pennsylvanian age—The Sangre de Cristo sandstones and the Madera limestones and sandstones.

The petroleum section of this book contains complete statistical data, and information on the petroleum geology of the County.

Sand and Gravel — Sand and gravel have been produced northeast, east, south, and southwest of Trinidad from the courses of the Trinidad River and some of its tributary streams such as Raton Creek; from the Apishapa River near Augusta and Aguilar; and, from the North, South, and Middle Forks of the Purgatoire River in the southwestern corner of the County. Other sand and gravel deposits are scattered widely throughout the western half of the County.

Clays—Waage[52] in his index map of refractory clay areas

*A. E. Brainerd and F. M. Van Tuyl in reference No. 1 of the bibliography.

**Colo. Oil & Gas Conservation Commission.

***Mr. Thaddeus R. Carpen, Continental Oil Co., written communication.

of south-central Colorado, indicates an extensive one in the northernmost part of Las Animas County. This area coincides with the Dakota sandstone exposure shown on the Geological Map of Colorado (U. S. Geological Survey, 1935), which extends into Pueblo and Huerfano Counties. Within Las Animas County this Dakota outcrop occupies all, or part, of the following: Ts-26, 27, 28-S, Rs-60, 61, 62, 63-W. The Dakota sandstone in this area is flat-lying, and imparts a plateau-like topography to the region. The Apishapa River and some of its tributaries have cut deep canyons through the Dakota, some exceeding 400 feet in depth, and exposed the clay-bearing beds. Apparently, the remoteness of this area and the possibly prohibitive cost of transporting any clay found and mined, has discouraged adequate prospecting. The inducements of future better economic conditions may lead to the discovery of economic deposits of refractory clay in this area.

Several decades ago, Butler[7] collected numerous samples of clay throughout the western half of Las Animas County, mostly along the railroad lines converging on Trinidad. Some of these samples indicate the existence of clay suitable for the manufacture of brick, tile, and other construction materials. He, however, did not investigate the area indicated by Waage as a possible source of refractory clay.

The State Bureau of Mines gives the following figures for the value of Las Animas County clay production beginning with 1950:

1950	$ 60,000
1951	75,000
1952	76,000
1953	31,000
1954	32,000
1955	32,000
1956	390,000
1957	300,000
1958	16,190*

*U. S. Bureau of Mines.

Uranium*—Several uranium occurrences are known in the County, especially near Trinchera Peak on the western border. The geologic environment is favorable for prospecting; favorable host rocks include the Permian continental sediments in the western part, and the Dakota and Morrison formations elsewhere throughout the County.

Geological Note—The southwestern boundary of the County lies along the western slopes of the Culebra and Sangre de Cristo ranges. Uptilted against this uplift are Pennsylvanian and Permian rocks in a north-south band up to 10 miles in width. East of this band, another narrower north-south band of exposures edges the western margin of the Park Plateau; here are exposed: Jurassic rocks of the Morrison formation; Cretaceous rocks of: the Purgatoire formation, Dakota sandstone, Benton group, Niobrara group,

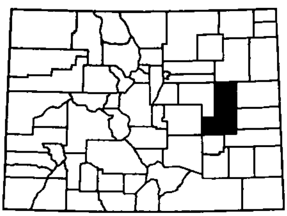
*Dr. Donald L. Everhart, USAEC, personal communication.

Pierre shale, and Vermejo formation. Farther east, on the Beaubien and Miranda Grant along the southwestern boundary, are Eocene rocks of the Raton formation. Park Plateau, to the north of the Grant, is surfaced predominantly by the Poison Canyon formation of Eocene age. In this area, particularly around the Spanish Peaks, are exposed Early Tertiary intrusive rocks consisting of stocks, dikes and sheets. The Peaks, the most prominent of these stocks, are in the center of numerous, persistent dikes which radiate from them. These dikes are from 2 to 100 feet in thickness and project above the ground in smooth, vertical, wall-like sheets some of which attain a height of over 100 feet.

Along the eastern margin of the Park Plateau is a fringe of Upper Cretaceous rocks of the Vermejo formation and the Trinidad sandstone. This is followed easterly by a broader north-south band of Upper Cretacious rocks of the Pierre shale and Niobrara group, the latter stretching as far east as Trinchera on the south and Wormington on the north. North of this band, Upper Cretacious rocks of the Benton group are exposed followed by Dakota rocks in the northernmost part of the County.

With the exception of a band of Benton and Niobrara rocks which crosses the middle of the County from north to south, the eastern half is surfaced chiefly by the Dakota sandstone of Upper Cretaceous age. In this area, waters of the main drainages and watersheds have eroded large areas of the Dakota and exposed rocks as old as those of the Permo-Triassic Lykins formation. In these localities are also exposed Jurassic rocks of the Morrison formation, and of the Lower Cretaceous Purgatoire formation.

Large-scale flows of Tertiary and Quaternary (?) igneous rocks cap Mesa de Maya, Chicorito Mesa, and Raton Mesa along the southern border of the County.



Courtesy Colorado Planning Division

Lincoln County

Lincoln County, located on the plains of eastern Colorado, has a population of 5,500 and an area of 2,593 square miles ranging in elevation from 4,500 to 5,400 feet above sea level. The County seat is at Hugo, a ranching and farming community with 1,000 population.

Available Maps of the County—

a. Lincoln County Map.

b. U. S. Army Map Service maps: 5261 I, II, III, IV; 5262 I, II; 5263 II; 5361 I, II, III, IV; 5362 I, II, III, IV; 5363 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover all but the northeastern part of the County. See index map in the pocket.

Mineral Production—Sand and gravel are the only minerals of consequence produced in the County. No hydrocarbons have as yet been produced, but there are possibilities for future development.

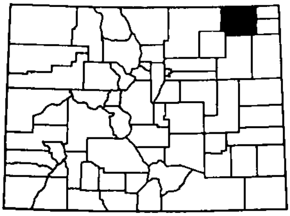
Sand and Gravel—Sand and gravel have been extracted from: the courses of Big Sandy Creek and some of its tributaries, near Hugo and southeast and northwest of it as well as in the vicinity of Limon; from some of the northerly and northeasterly trending drainages in the northern part; and, from North Rush Creek and other southeasterly-trending drainages in the southern and southwestern part. The U. S. Bureau of Mines gives the values of sand and gravel production for the following years:

1952	$ 5,220
1953	26,676
1954	338,131
1955	68,087
1956	368,000
1957	93,400
1958	208,000

Petroleum*—Lincoln County has not as yet developed any commercial production of hydrocarbons, and the results of limited drilling have not proven encouraging. The County lies on the Denver Basin, and the Las Animas Arch blends into the Basin in the extreme southeastern part; therefore, there exist probabilities for future commercial discoveries. Current exploration activities on the Las Animas Arch will probably lead to some wildcat drilling which will yield information as to the structure's potentialities within the County. The most favorable horizons are believed to be the Pennsylvanian and pre-Pennsylvanian formations.

Geological Note—Lincoln County lies on the rolling plains of eastern Colorado within the Piedmont section of the Great Plains Physiographic Province. Late Tertiary rocks of the Ogallala formation surface the County. The Ogallala formation, consisting of sand, gravel, silt, and clay, has been eroded in broad bands along the watersheds and stream courses, exposing considerable expanses of Upper Cretaceous rocks of the Pierre shale.

*Mr. George H. Fentress, Exeter Drilling Co., written communication.



Courtesy Colorado Planning Division

Logan County

Logan County, located in northeastern Colorado, has a population of 22,000 and an area of 1,849 square miles ranging in elevation from 3,600 to 4,100 feet above sea level. The terrain is generally level or gently undulating, with a few low-hill areas in the north. The County seat is at Sterling, a growing oil, ranching, farming, and business center with a population of 13,000.

Available Maps of the County—

a. Logan County Map.

b. U. S. Army Map Service maps: 5265 I, II; 5365 I, II, III, IV; 5364 I, IV; 5464 I, IV; 5465 I, II, III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover much of the County. See topographic quadrangle index map in the pocket.

Mineral Production—In the minerals field Logan County is principally a producer of oil and natural gas. During 1958, Logan was fourth in oil and fifth in natural gas production in the State. During recent years there has been an increase in the production of sand and gravel for paving and construction purposes; unfortunately, the figures do not go back beyond 1956. The petroleum production figures in the following table are from records of the Colorado Oil & Gas Conservation Commission, all others are from the U. S. Bureau of Mines Minerals Yearbooks.

Year	Petroleum Barrels	Sand & Gravel Short Tons	Total $ Value
1949	1,514	----	----
1950	92,509	----	----
1951	1,473,923	----	----
1952	3,007,526	----	2,000[1]
1953	5,404,186	----	14,605,585[2]
1954	8,102,687	----	22,619,826[2]
1955	9,115,024	----	24,926,473[2]
1956	7,971,445	335,000	22,378,500[2]
1957	6,517,112	457,000	20,004,440[2]
1958	5,746,294	324,000	17,216,740[2]

[1] Value of sand and gravel production only.

[2] Value of sand and gravel and petroleum production only.

Oil and Gas—The Armstrong oil-gas field, discovered in 1949 in the northwestern part, was the first producing field in the County and became the motivation for renewed activity in the Denver Basin.

Many fields have been discovered in Logan County since the Armstrong field was brought in. As of the end of 1959, there were active in the County 65 oil and gas fields, 9 oil fields, and 3 gas fields, with a total production for the year of 5,220,597 barrels of oil and 12,128 million cubic feet of natural gas. The total cumulative production up to the end of 1958, was 47,432,220 barrels of oil and 88,763 million cubic feet of gas.

*Western Logan County is one of the most prolific oil and gas areas in the Denver Basin. Most of the wells are producing from the 'D' and 'J' sands of the Dakota formation, but some production also originates in the 'M' and 'O' sands. Tests in the Upper Cretaceous beds and in the Paleozoic Lyons sand have not proved encouraging, but it is believed that many small pools remain to be discovered in the Lower Cretaceous horizons.

Sand and Gravel—Sand and gravel are produced from the courses of the South Platte River and some of its tributaries near Sterling and north, northeast, and southwest of it, also from the vicinity of Atwood, near Iliff, and north of Willard in the southwestern corner of the County. Deposits are also worked from easterly-trending drainages in the eastern part. Other sand and gravel deposits are scattered through the central and southern parts of the county.

Clay—Butler[7] sampled some of the clay formations in scattered parts of the County, with a few of them indicating the presence of useful clays. Two of these samples are discussed below.

1. Three miles southwest of Merino in a railroad cut on the river bluff. Sampled 15 feet of material lying under less than 8 feet of overburden. The bed strikes N-60-W and dips 5 degrees northeasterly. The clay is a gray to brown sandy shale and . . . "Should make attractive, pink pressed bricks and probably, if grogged, soft or stiff-mud bricks and earthenware".
   Butler does not name the formation from which the sample was taken.
2. Five miles southeast of Sterling . . . " . . . probably in the southeast quarter of section 6, T-7-N, R-51-W". Sampled a 15-ft. bed under 2 feet of overburden. The clay " . . . probably Laramie, but possibly of Brule age", is medium-hard, yellow and gray, fine to coarse-grained shale, more or less sandy. This clay has the same commercial applications as that of the previous sample.

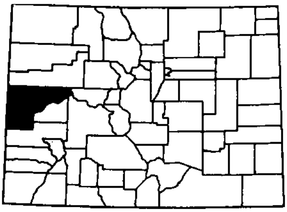
Geological Note—The petroleum geology of the Denver-Julesburg Basin, which includes Logan County, is discussed in the petroleum section of this book. A very generalized note on the surface rocks is given below.

The South Platte River, which provides the main drainage for the area, crosses the County from southwest to northeast. Its waters and those of tributary streams and intervening

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

watersheds, have eroded through the Tertiary formations which cover much of the County and exposed extensive and irregular areas of Upper Cretaceous rocks of the Pierre shale. These latter rocks predominate in the southwestern quarter, and are exposed in broad, irregular northwesterly trending bands in the northwestern quarter.

Along the northern border of the County, gravels, sands, and clays of the Pliocene Ogallala formation extend down from Wyoming and cover a small area to the northwest of Peetz. Surrounding these rocks and extending for 2 or 3 miles south of Peetz and to the east and west of it, are Miocene rocks of the Arikaree formation. These rocks also surface the southeastern quarter of the County. South of the Arikaree exposures on the northwest side of the river are exposed rocks of the Oligocene White River formation which also outcrop in a narrow band paralleling the South Platte to the south of it In the northeastern quarter, between the White River formation exposures on both sides of the South Platte and the river itself, Upper Cretaceous rocks of the Fox Hills formation are exposed.



Courtesy Colorado Planning Division

Mesa County

Mesa County, located in western Colorado on the Utah border, has a population of 55,000 and an area of 3,334 square miles ranging in elevation from 4,360 to 10,000 feet above sea level. The County seat is at Grand Junction, a uranium industry center and field headquarters of the Federal Atomic Energy Commission Raw Materials Branch. Grand Junction is a light industry, agricultural, and business community with a population of 21,000.

Available Maps of the County—

a. Mesa County Map.

b. U. S. Army Map Service maps: 4261 I, II, III, IV; 4262 I, II, III, IV; 4361 I, III, IV; 4362 1, II, III, IV; 4462 I, II, III, IV; 4562 III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover the northeastern and southwestern parts of the County. See index map in the pocket.

d. U. S. Forest Service maps "Grand Mesa National Forest" and "Uncompahgre National Forest" include Mesa County.

Mineral Production 1946-1958—Mesa County is a leading producer of vanadium-bearing uranium ores, and possesses one of the most modern and important processing plants in the world for the production of uranium and vanadium concentrates. Coal, natural gas, sand and gravel, clay, stone, and some precious and base metals were also produced during the 1946-58 period. Some of the production figures and values released by the U. S. Bureau of Mines are given below.

Year	Coal Short Tons	Clay Short Tons	Total $ Value
1946	91,846	--	--
1947	103,790	--	--
1948	97,651	--	--
1949	92,775	--	--
1950	84,771	--	--
1951	89,678	--	489,081[1]
1952	95,038	--	563,602[1]
1953	80,410	2,579	707,017[2]
1954	36,794	4,551	513,618[3]
1955	48,363	4,500	669,793[3]
1956	70,360	1,764	3,048,301[4]
1957	76,617	1,696	4,090,736[4]
1958	84,388	568	4,814,165[5]

[1] Value of coal and sand and gravel production only.

[2] Same as [1] but includes value of clay production.

[3] Same as [2] but includes value of stone and gem stone production.

[4] Same as [3] but includes value of uranium and some gold, silver, and lead.

[5] Same as [4] but no precious or base metals production.

Uranium-Vanadium—From the middle 1930's until the explosion of the first nuclear bomb on Hiroshima in August, 1945, the carnotite-type ores of the Colorado Plateau had been mined for their vanadium content. Since that time, uranium has become the primary economic constituent of the ores, and vanadium is recovered as a coproduct in the milling process. The uranium section of this book discusses the history, geology, ore deposits, and other related subjects of this industry. The minerals processing chapter describes the treatment of the ores.

*The southwestern portion of Mesa County is located within the famous Uravan Mineral Belt of the Colorado Plateau, in which the probabilities are excellent for continued discoveries of uranium-vanadium mineral deposits for a number of years to come. The ores occur predominantly in the Salt Wash member of the Morrison formation of Jurassic age.

Figures on the production of uranium and vanadium have not as yet been released in satisfactory detail. The U. S. Bureau of Mines gives the production of uranium in Mesa County for 1956, at 561,754 pounds of U_3O_8, contained in 88,597 tons of ore from 106 operations, at an average grade of 0.32% U_3O_8. For 1957, these figures are 704,784 pounds of U_3O_8 contained in 122,028 tons of ore from 109 operations, at an average grade of 0.29% U_3O_8.

*Dr. Donald L. Everhart, USAEC, personal communication. See also uranium section co-authored by Dr. Everhart.

The figures on vanadium production are not broken down by counties, but the State totals are given on page 32. Montrose, Mesa, and San Juan Counties were, in that order, the major producers of vanadium in Colorado during 1957.

Coal—The southwestern portion of the Uinta Coal Region designated as the Book Cliffs field and the Grand Mesa field, lies within Mesa County. Landis[6] calculates that 187 square miles are underlain by measures containing coal resources amounting to 1,295 million tons of bituminous, and 120 million tons of subbituminous coal. Of the bituminous coal, 560 million tons lie between the surface and 1,000 feet underground; 475 million are under from 1,000 to 2,000 feet of overburden; and, 260 million tons between 2,000 and 3,000 feet below the surface.

The Book Cliffs Field, discussed under Garfield County on page 139, enters northern Mesa County from Garfield in a southeasterly direction and extends as far as the Colorado River. The coal in this field is mainly high volatile bituminous C in rank, but there are also present some high volatile B as well as some subbituminous coal.

The Grand Mesa Field — This field is discussed under Delta County on page 113. It begins at the Colorado River, which separates it geographically from the southeastern extremity of the Book Cliffs field, and continues southeasterly into Delta County. The coal in this field is mainly bituminous high volatile C in rank, but there is some subbituminous coal present.

Natural Gas—Natural gas was first produced from the Asbury field, discovered in 1949 in the northwestern part of the County. Production is from the lower unit of the Dakota sandstone of Lower Cretaceous age. As of the end of 1959, there were four active gas fields: Asbury Creek, Highline Canal discovered in 1951, the Bar X discovered in 1953, and Divide Creek in 1956. During 1959, the four fields produced a total of 786 million cubic feet of natural gas, and had an aggregate cumulative production up to that time of 4,070 million cubic feet.

*Mesa County includes much of the southern portion of the Piceance Creek Basin, and the northeast flank of the Uncompahgre Uplift. The possibility of extending the existing fields and of developing new producing areas within each of the major structural features named is excellent.

**The southwestern part of the county lies within the Paradox Fold and Fault Belt portion of the Paradox Basin, but the excessive depths to pre-Pennsylvanian formations in the Paradox Basin have been deterrents to exploratory drilling in the past. However, the discovery of Mississippian gas at well Pure No. 1 Southeast Lisbon, Sec. 5, T. 44 N., R. 19 W., and

*Mr. Charles C. O'Boyle, Consulting Geologist, Denver, personal communication.
**Mr. Frank J. Adler, Phillips Petroleum Co., written communication.

of Devonian oil at well Pure No. 1 Northeast Lisbon, Sec. 10, T. 30 S., R. 24 S., San Juan County, Utah, 25 miles to the south, has stimulated interest in the northern portion of the Paradox Basin and should result in an increase in exploratory drilling.

*Prospective zones include the Pennsylvanian Honaker Trail and Paradox formations, the Mississippian Leadville limestone, and the Devonian Ouray and Elbert formations.

Sand and Gravel — Sand and gravel have been produced from the course of the Colorado River at Grand Junction, to the northeast of it as far as the Garfield County line, and to the west of it in the vicinity of Fruita. Also from the Gunnison River near Whitewater, and from the Dolores River and some of its tributary streams, such as North and West creeks, in the southwestern part of the County. Other sand and gravel deposits exist west of Collbran and Molina along Plateau Creek; to the north and to the west of Mack; near Loma; and, to the south of Book Cliff, and northwest of it to the Garfield County line.

The State Bureau of Mines gives the values of sand and gravel production for the following years:

1954	$ 125,000
1955	130,000
1956	131,000
1957	500,000
1958	1,188,869

Oil Shale—Oil shale constitutes an important mineral resource of the County. The shale occurs in the lacustrine Green River formation of Middle Eocene age, on Battlement Mesa and Grand Mesa. Another exposure lies some 10 miles west of De Beque. Dr. Charles H. Prien discusses oil shale in another section of this book.

Clay—Butler[7] sampled several clay localities in the north-central part of the County, and two of the samples indicated the existence of useful clays. Butler covered only a small area and undoubtedly there are other deposits of clay useful for the manufacture of construction materials. His two samples are discussed below.

1. Sampled a 20-ft. horizontal bed on the side of a hill forming a bank of the Gunnison River, about 2 miles south of Grand Junction.
   The material is a medium-hard, very fine-grained shale which " . . . should make good red pressed bricks . . . "
2. Sampled a 15-ft. bed under 1-to-10 feet of overburden on the side of a hill forming a bank of the Gunnison River, 1 mile southwest of Grand Junction, in the northeast quarter of the southwest quarter of section 22, T-1-S, R-1-W.
   The material is a medium-hard, red, very fine-grained shale which " . . . should make good, red, soft-mud bricks, and possibly pressed bricks . . . "

Butler does not name the formations from which the above samples were obtained.

*Mr. Frank J. Adler, Phillips Petroleum Co., written communication.

Precious and Base Metals—Mesa County has not been an important producer of these metals, but some gold, mostly placer, and copper, silver, and lead have been produced. The several mining districts established in the county are discussed by Dr. Vanderwilt on the following pages of the 1947 edition of this book:

	Page
Gateway (Calamity, Maverick, others)	141
Sinbad	141-42
Unaweep	142

Stone—Pink sandstone has been quarried for local building purposes from the Morrison formation of Jurassic age southwest of Fruita. Sandstones of Jurassic and Cretaceous age are exposed over much of the county and some of them, as well as the andesites and basalts of Grand Mesa, may be expected to find some applications in the construction industry.

Gem Stones—Schlegel[24] lists the following gem stone occurrences in Mesa County:

Glade Park	Opalized wood.
Opal Hill, Fruita	Opalized wood.
Pinon Mesa	Banded and moss agate, chalcedony.

Heavy Minerals—Murphy and Houston* report a deposit of titanium-bearing black sandstone occurring on the flank of Grand Mesa, about 20 miles east of Grand Junction. Although the formation in which the sandstone occurs was not named, it is probably of Late Cretaceous age.

*In Wyoming, quite similar deposits contain up to 16½% TiO_2 as an average in some individual deposits, with some samples assaying up to 35%. The titanium occurs chiefly as ilmenite (an iron titanate), and anatase (titanium dioxide) free from magnetite intergrowths. Associated with the titanium minerals, are monazite, columbium-bearing opaque minerals, and uranium ranging up to 0.02% U_3O_8. The radioactivity present in such deposits aids greatly in their discovery and delineation by radioactivity counters, and the high specific gravity of the economic minerals permits prospecting by panning.

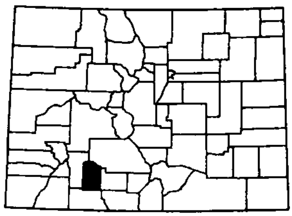
Geological Note—The geology of the Uravan Mineral Belt, and that of the petroliferous areas of the County, are discussed in the uranium and petroleum sections respectively.

The northeastern third of the County is surfaced by Eocene rocks of the Wasatch and of the oil shale-bearing Green River formations. The latter is exposed on Battlement Mesa and is overlain near the center by lava flows of Quaternary(?) or Tertiary age. The Green River formation is also exposed over a large area on Grand Mesa north of the Delta

*J. F. Murphy and R. S. Houston in reference No. 93 of the bibliography.

County line and south of Plateau Creek. The southern portion of Grand Mesa is overlain by an irregularly shaped, extensive lava flow of Quaternary(?) or Tertiary age. The Book Cliffs, an arcuate, southeasterly-trending series of southwesterly facing scarpments, enter the County at the northeast corner and extend to the Colorado River. Northeast of the Cliffs, and along the river, Upper Cretaceous rocks of the Mesaverde formation are exposed. Grand Valley, parallelling the Book Cliffs to the southwest, is surfaced by Mancos shale of Upper Cretaceous age. Southwest of the northwesterly-flowing Gunnison River, and the Colorado River beyond Grand Junction, and parallelling these water courses, are a series of extensive mesas and broken ground known collectively as the Uncompahgre Plateau. In this and the surrounding areas are exposed rocks from Pennsylvanian to Upper Cretaceous age. The Uravan Mineral Belt, the geology of which is discussed in the uranium section of this book, crosses this area.

Mineral County


Courtesy Colorado Planning Division

Mineral County, located in the San Juan Mountains west of the San Luis Valley in southwestern Colorado, has a population of 650 and an area of 923 square miles ranging in elevation from 8,250 to 13,722 feet above sea level. The County seat is at Creede, a picturesque and important mining community since the early 1890's, with a population of 600.

Available Maps of the County—

a. Mineral County Map.

b. U. S. Army Map Service maps: 4559 I, II; 4658 I, IV; 4659 I, II, III, IV; 5558 I.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

d. U. S. Forest Service map "Rio Grande National Forest" includes the County.

Mineral Production 1946-1958—Mineral County is an important producer of precious and base metals, especially silver; sand and gravel, fluorspar, and some gem stones, are also produced. The figures in the following table are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Lode Mines	Gold Ozs.	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	7	175	335,110	61,000	492,000	6,000	357,296[1]
1947	6	245	317,712	46,600	658,400	14,000	402,394[1]
1948	6	247	297,926	36,000	902,000	176,000	470,961[1]
1949	6	779	263,867	74,000	2,324,000	1,342,000	814,256[1]
1950	2	803	345,247	68,000	2,844,000	1,746,000	968,587[1]
1951	3	804	236,652	50,000	2,334,000	1,784,000	1,040,742[1]
1952	3	1,122	174,219	48,000	3,026,000	2,048,000	1,037,257[1]
1953	2	1,257	173,996	24,000	3,392,000	1,716,000	861,643[2]
1954	7	1,964	238,685	50,000	4,356,000	2,220,000	1,156,181[3]
1955	7	1,025	135,640	36,000	2,384,000	1,490,000	722,940[3]
1956	2	802	111,731	47,200	2,531,100	1,853,400	805,501[3]
1957	4	1,662	279,249	136,200	4,462,200	3,638,800	1,417,646[3]
1958	3	785	92,841	80,000	2,466,000	2,038,000	640,099[3]

[1] Value of precious and base metals only.

[2] Same as [1] but includes sand and gravel.

[3] Same as [2] but includes gemstone production.

Precious and Base Metals—The Creede mining district, the only one established in the County, is discussed by Vanderwilt on pages 142-44 of the 1947 edition of this book. It is estimated that by the end of 1958, the area had produced minerals valued at approximately $60 million.

The rocks of the Creede area are part of the great volcanic field of the San Juan Mountains and consist of rhyolites and quartz latites of Miocene age. The chief deformation has been complex faulting with some tilting near the faults. Nearly all the faults show some mineralization and almost all of the ore has been mined from veins along the faults. The chief production has come from the Amethyst vein along the major fault area. Other producing faults are the Alpha, the Solomon-Ridge, and the Equity. The veins strike a little west of north, or northwesterly, and dip to the west or southwest. The ore minerals include zinc blende, silver-bearing galena, gold, pyrite, and chalcopyrite, in a gangue of quartz, much of it violet or pink hued, chlorite, barite, and fluorite. In some deposits secondary enrichment is pronounced and vertically extensive.

Sand and Gravel — Sand and gravel have been produced from the courses of: the Rio Grande at Wagonwheel Gap and to the southeast of it as far as the Rio Grande County line; the South Fork of the Rio Grande and other tributaries of the river in the southeastern part of the county; and, from the West Fork of the San Juan River in the south. Other sand and gravel deposits are located along the upper Rio Grande near Creede and to the south and southwest of it, and along Goose Creek south of Wagonwheel Gap.

Fluorspar—The Wagonwheel Gap deposit near the southeastern corner of T-41-N, R-1-E, on the east side of Goose Creek, has produced an appreciable quantity of fluorspar to date. The deposit is in a vein zone that cuts the Tertiary several more or less parallel fluorspar veins. The zone is rhyolitic tuff and breccia country rock, and is made up of traceable for over ½ mile, with a maximum fluorspar width of 35 feet. In addition to barite, the deposit contains more sulfides than most such occurrences. The zone is persistent in its strike, varying only 10-degrees, from due east, to N-80-E, and dipping from 70 to 80 degrees south.

The State Bureau of Mines gives the following values of fluorspar production for the late 1940's:

1946	$254,000
1947	254,000
1949	59,000
1950	107,000

Gem Stones—Schlegel[24] lists the following gem stones and localities of their occurrence in Mineral County:

Amethyst mine, Bachelor Mountain, Creede	Amethyst.
West Willow Creek, North Creede	Amethyst, turquoise matrix.
Wolf Creek Pass, San Juan Mountains	Agate, moonstone.

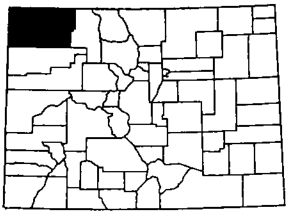
Clay—Nutting[71] briefly describes the adsorbent clay which occurs in a large deposit near Creede and assigns it to the fuller's earth group. [102]The material occurs in the lower member of the Creede volcanic formation of Miocene age and represents more or less altered beds of rhyolite tuff. Other beds of similar material outcrop along the southern borders of the low hills between Sunnyside Creek and Willow Creek. Tuff beds of the type which might yield adsorbent clays are common in the lower part of the Creede formation.

Sulphur—Larsen and Hunter[103] report two sulphur deposits in the County: the Trout Creek deposit 25 miles southwest of Creede, and the Middle Fork deposit 5 miles south of the Trout Creek workings on the south side of the Continental Divide. Both deposits are in rocks of the Miocene Potosi volcanic series in the andesitic breccia division which overlies thick flows of pink quartz and latite and underlies flows of rhyolite and latite. Both the deposits are of sulphur springs origin.

Geological Note—Mineral County lies almost entirely within the San Juan Mountains region. These mountains are a dissected dome made up chiefly of Tertiary volcanic rocks with pre-Cambrian, Paleozoic, Messozoic, and Tertiary sedimentary rocks exposed in the western and northern parts and, locally in other areas.

The central part of the County, in the Fisher Mtn. and Beautiful Mtn. area, is surfaced by flows, tuff beds, and coarsely porphyritic rocks of Fisher latite. To the north, rocks of quartz-hornblende rhyolite and tuff beds of the Alboroto rhyolite of the Potosi volcanic series, blanket a circular area of about 50 square miles on Snowshoe Mountain and surroundings. The upper Rio Grande circles about two-thirds of this area from the southwest around to the north and east.

Along the river local sand, gravel, shaly tuff, and some rhyolite flows of the Miocene Creede formation are exposed. In the northeastern part of the County southwest of La Garita Mountains, and in the northwestern corner, uniform and widespread flows of quartz latite, underlain by quartz-latite tuff and thick rhyolite flows of Piedra rhyolite of the Potosi volcanic series, are exposed. East and south of the Fisher Mountain and Beautiful Mountain area, are extensive flows of Alboroto rhyolite, with Piedra rhyolite to the southeast. In the southern part are complex flows and clastic beds of quartz-latite of the Conejos component of the Potosi volcanic series. Fringing the Conejos exposures on the north, are narrow bands of Sheep Mountain quartz latite of the Potosi series, while on the south, the Conejos is fringed by narrow bands of red and white sands and pebbles of the Blanco Basin formation of Oligocene(?) age.



Courtesy Colorado Planning Division

Moffat County

Moffat County, located in the northwestern corner of the State, has a population of 7,000 and an area of 4,761 square miles ranging in elevation from 5,400 to 7,600 feet above sea level. The County seat is at Craig, a stock raising and business center with a population of about 4,000.

Available Maps of the County—

a. Moffat County Map.

b. U. S. Army Map Service maps: 4264 I, II, III, IV; 4265 I, II, III, IV; 4364 I, II, III, IV; 4365 I, II, III, IV; 4464 I, II, III, IV; 4465 I, II, III, IV; 4564 III, IV; 4565 III, IV.

c. U.S.G.S. topographic quadrangle maps cover most of the County. See index map in the pocket.

d. U. S. Forest Service maps "Routt National Forest" includes a small portion of the County.

Mineral Production 1946-1958—Moffat County is an important producer of mineral fuels, both fossil and radioactive; its uranium deposits are reputed to be the largest in Colorado. Sand and gravel and some precious base metals are also produced. The petroleum figures in the following tables are from records of the State Oil and Gas Conservation Commission, all others are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Coal Short Tons	Petroleum Barrels	Total $ Value
1946	142,923	639,518	
1947	146,494	752,368	-
1948	144,288	833,350	-
1949	130,404	857,803	-
1950	124,408	988,845	-
1951	110,096	1,046,832	543,172[1]
1952	90,532	989,441	479,209[2]
1953	89,940	949,149	3,456,591[3]
1954	85,683	1,018,423	3,252,952[3]
1955	100,554	958,331	3,241,996[4]
1956	96,460	1,278,779	4,498,830[4]
1957	108,024	1,374,902	4,946,303[4]
1958	388,661*	1,170,207	6,992,318[5]

[1] Value of coal production only.

[2] Value of coal and sand and gravel only.

[3] Same as [2] but includes value of oil production.

[4] Same as [3] but includes base and precious metal production.

[5] Same as [3] but includes value of uranium ore and stone production.

*Pitkin Co. coal production included with that of Moffat Co. for 1953.

Hydrocarbons—The first producing well in the county was completed on the Moffat Dome in the southeastern part in February, 1924. *Production was encountered in the Dakota sandstones of Cretaceous age. **The well came in originally at a rate of 4,580 barrels per day, but was eventually abandoned due to water encroachment, after producing a total of 429,000 barrels. The field produces currently from the Cretaceous Mancos shale, the Jurassic Morrison and Entrada formations, and the Triassic Shinarump formation.

As of the end of 1959, there were 13 oil-gas, and 1 oil fields in the County which were active, and produced a total for the year of 1,300,315 barrels of oil and 10,477 million cubic feet of natural gas. The aggregate cumulative production up to that time, including that of a few now shut-in fields, totaled 32,642,862 barrels of oil, and 160,793 million cubic feet of gas. Complete production statistics by field and year are contained in the petroleum section of this book.

***Moffat County includes most of the Sand Wash Basin and the Axial Basin Uplift, therefore the possibilities for the extension of the existing fields, and the developing of new producing areas in each of the major structural features named, are excellent.

Coal—The Green River Coal Region, and the northern part of the Uinta Coal Region, extend into Moffat County. The former underlies the northeastern half, and the latter a part of the southern portion of the County.

[6]Landis calculates that at least 511 square miles are underlain by measures containing a minimum of 18,275 million tons of coal. Of this tonnage, 10,700 million tons lie between 0-to-

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*A. E. Brainerd and F. M. Van Tuyl in reference No. 1 of the bibliography.

**Don Vieaux and E. R. Haymaker in reference No. 106 of the bibliography.

***Mr. Charles C. O'Boyle, Consulting Geologist, written communication.

1,000 feet below the surface, 5,450 million under between 1,000 and 2,000 feet of overburden, and 2,125 million tons between 2,000 and 3,000 feet underground. There are three fields within the County:

Lower White River Field — This field, part of the Uinta Coal Region, is located in the central southern part of the County. In his estimate of reserves, Landis[6] took into calculation only that coal in this field which occurs in the Williams Fork formation of the Cretaceous Mesaverde group, although coal probably also occurs in the Iles formation, as it does in the adjoining field. The coal is bituminous of high volatile C rank and noncoking, but complete information on this field is lacking.

Danforth Hills Field — This field is just east of the Lower White River Field, and part of the Uinta Coal Region[6]. The regional dip in this area is southwestward, but the structure is locally interrupted by several anticlinal and synclinal folds. The Mesaverde group here consists of the basal Iles formation and the overlying Williams Fork formation, both of Upper Cretaceous age. The Trout Creek sandstone, uppermost member of the Iles formation, furnishes a conspicuous marker bed. The Williams Fork formation contains three coal groups, and the Iles formation two, but the coal beds are generally discontinuous. The coal is mainly high volatile C bituminous, but some beds in the northern part may be subbituminous.

Yampa Field—This field lies to the north of the Danforth Hills Field, in the southern extremity of the Green River Coal Region. [6]The coal occurs in the Iles and Williams Fork formations of the Upper Cretaceous Mesaverde group, in the Lance formation also of Upper Cretaceous age, and in the Paleocene Fort Union formation. Coal of the Mesaverde group outcrops in steep hogbacks along the edges of the regional syncline, and ranges in rank from subbituminous to anthracite. Most of this coal is bituminous of high volatile C rank, locally anthracitic, and metamorphosed locally near basalt sills. The subbituminous coal occurs in the upper part of the Williams Fork formation, and in the Lance and Fort Union formations.

Uranium—The uranium deposits of Moffat County occur in the Browns Park formation of Miocene(?) age and are reputed to be the largest in the State. *They consist chiefly of uraninite bodies which parallel the ground-water table, and their host rocks are exposed along the northern limb of the Axial basin near Maybell. The chances for discovering additional ore bodies in this area are excellent. The uranium section of this book contains a description of these deposits, general geology, and other pertinent data.

Sand and Gravel — Sand and gravel have been produced

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*Dr. D. L. Everhart, USAEC, personal communication. Co-author uranium section.

from the courses of the Yampa River and some of its tributary streams: at Craig; east of Craig to the Routt County line; west and southwest of Craig. East and west of Hamilton from the courses of the Williams Fork, Deer, and Morapos creeks. Also from Daniels, Willow, Fourmile, and Timberlake creeks in the northeastern part of the County. Other sand and gravel deposits are scattered in various parts; an extensive one exists about 5 miles west of the Snake River some 20 miles north-northwest of Maybell.

Precious and Base Metals—The several mining districts established in the County are discussed by Dr. Vanderwilt in the 1947 edition of this book on the following pages:

Most of the production has come from placers. Very recently (1959), a renewal of interest has been in evidence in the Fourmile-Fortification creeks area between Craig and the Wyoming line.

Geological Note—The geology of the petroleum and uranium areas of Moffat County are discussed respectively in the petroleum and uranium sections of this book.

With the exception of the extreme northeastern corner, and parts of the northwestern area, the northern half of the County is mantled chiefly by Miocene rocks of the Wasatch and Green River formations. In the northeastern corner, Upper Cretaceous rocks of the Mesaverde group are exposed in the area east and south of Slater and Battle Creek. *In this area, the Elkhead Mountains represent erosion remnants of an isolated Tertiary volcanic field and associated Tertiary sediments. The volcanic field extends as far south as Cedar Mountain near Craig, and as far west as Fortification dike. The eastern extension of the Uinta Mountains, with the related Cold Spring Mountain Uplift to the north, enter the northwestern part of the County from Utah, bearing locally to the southeast. The southeast plunge of the Uinta arch, which terminates at Cross Mountain, is followed by the Axial basin anticline to the southeast. The pre-Cambrian core of the Uinta Mountains is exposed along both sides of the Green River beyond a band of Tertiary rocks of the Browns Park formation which continues easterly from the mountains to near Craig.

South of the Uinta Mountains, a fringe of Devonian to Upper Cambrian rocks are exposed, followed by Carboniferous rocks which include the Weber quartzite along the Yampa River. South of the river, the section repeats in inverse order

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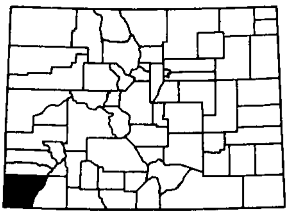
*Byrl D. Craig, Jr., in reference No. 106 of the bibliography.

to the Yampa Plateau where Triassic rocks are exposed, followed by the Jurassic Nugget sandstone, Twin Creek limestone and Morrison formation, overlain by the Upper Cretaceous Dakota sandstone and Mancos shale. East of Craig, along Elkhead Creek, and northwest of Craig, are Tertiary rocks of the Lance formation, followed by a band of Eocene rocks of the Fort Union formation. South of Craig are the Williams Fork Mountains, surfaced by Upper Cretaceous rocks of the Iles and Williams Fork formations, and Lewis shale. South of Maybell, the Axial Basin is floored by Tertiary rocks of the Browns Park formation, followed southeasterly, to the southeastern corner of the County, by rocks of the Mancos shale. South and southeast of Cross Mountain, Coyote basin and the Danforth Hills are surfaced by Tertiary rocks of the Wasatch and Green River formations.


Courtesy Colorado Planning Division

Montezuma County

Montezuma County is located in the southwestern corner of the State in the Four Corners area, the only point in the Nation where four states come together, Arizona, Colorado, New Mexico, and Utah. The County has an area of 2,097 square miles ranging in elevation from 5,600 to 13,225 feet above sea level, and a population of 13,000. The County seat is at Cortez, an oil, natural gas, and business center with a population of about 5,000.

Available Maps of the County—

a. Montezuma County map.
b. U. S. Army Map Service maps: 4258 I, II, III, IV; 4259 II, III; 4358 I, III, IV; 4359 II, III.
c. U. S. Geological Survey topographic quadrangle maps cover part of the eastern portion of the County. See index map in the pocket.
d. U. S. Forest Service map "San Juan National Forest" includes most of the County.

Mineral Production 1946-1958—Montezuma County has not been a substantial producer of raw minerals, but their variety has been noteworthy. The County produces oil, combustible gas, carbon dioxide gas, coal, sand and gravel, gold, silver, copper, uranium, and stone. The petroleum figures in the following table are from records of the State Oil and Gas Conservation Commission, all others are from the U. S. Bureau of Mines Minerals Yearbooks.

Year	Lode Mines	Gold Ounces	Silver Ounces	Coal Tons	Petroleum Barrels	Total $ Value
1946	1	142	344	1,251	---	5,248[1]
1947	---	---	---	---	---	---
1948	---	---	---	---	---	---
1949	1	16	73	1,295	11,214	626[1]
1950	1	215	1,180	1,105	7,200	9,009[1]
1951	---	---	---	---	1,841	---
1952	---	---	---	---	1,799	---
1953	---	---	---	---		2,293[2]
1954	---	---	---	---	11,953	27,699[3]
1955	1	19	94	1,108	7,053	245,231[4]
1956	1	34	70	---	5,678	51,888[5]
1957	1	59	69	1,035	4,910	286,133[4]
1958	1	82	969	---	3,684	442,855[6]

[1] Value of precious and base metals only.

[2] Value of some coal production not shown in table.

[3] Value of petroleum production only.

[4] Value of all products including sand and gravel whose production figure is not given in the table; withheld by USBM as requested by operator.

[5] Value of oil, carbon dioxide gas, coal, gold, and silver only. Excludes value of sand and gravel production.

[6] Same as [5] but excludes coal, and includes sand and gravel, stone, copper, uranium ore, and lead.

Coal—The northwestern extremity of the San Juan Coal Region is located in Montezuma County, where it is subdivided into 2 fields, the Cortez area east of the town of Cortez, and the Mesa Verde area in the southeastern part south of Cortez.

According to Landis[6], 293 square miles of the County are underlain by measures containing 1,150 million tons of coal. Of this tonnage, 50 million lie between 0-to-1,000 feet below the surface, and 1,100 million tons are between 1,000 and 2,000 feet underground.

Cortez Coal Area—[5]East of Cortez there are several small areas in which reserves of bituminous coal have been estimated to be present in the Dakota formation of Upper Cretaceous age. The overall area is located within the Canyon Lands section of the Colorado Plateau physiographic province, which consists of a plateau of moderate to strong relief, dissected by canyons. One bed of minable thickness is present which contains noncoking bituminous coal of high volatile B or C rank.

Mesa Verde Area—[6]Coal mining, mostly for local use, has been conducted in this area for many years. The coal occurs throughout the Menefee formation of the Upper Cretaceous Mesaverde group, and is mostly bituminous of high volatile B or C rank, essentially noncoking.

Sand and Gravel—Sand and gravel have been produced from: the courses of McElmo Creek, the Dolores River, and some of the tributaries near Cortez, north, south, and east of it; in the vicinity of the town of Dolores; and, near Yellowjacket. In the Mancos area, from Mud Creek, and East and West Mancos rivers, and near Stoner, from Stoner Creek.

The U. S. Bureau of Mines credits Montezuma County with a production of sand and gravel for 1957 of 356,000 short tons valued at $259,000.

Uranium*—Colorado Plateau-type ore bodies occur in the Morrison formation of Jurassic age, which is exposed along canyon walls over much of the western part of the County. Scattered uranium occurrences in Cross Canyon, south of Dove Creek, may lead to the continued finding of other small deposits in that part of the County.

Precious and Base Metals—The mining districts of Montezuma County are discussed by Vanderwilt in the 1947 edition of this book on the following pages:

Bear Creek ....Page 149
East Mancos River (Red Arrow Mine)........................ 150
Stoner 151

The East Mancos district, about 10 miles northeast of the town of Mancos, is the most interesting one in the County. This area may be considered the western extension of La Plata district in La Plata County. Dr. Vanderwilt comments on the East Mancos River district as follows: "The area in which the veins are found is in sedimentary formations, a large part of which is Mancos shale. Outcrops are few. Access to many areas is very difficult so that the discovery of the small isolated rich veins is largely a matter of chance. It is more likely that additional veins will be discovered from time to time in this area by the prospector who has the courage to devote the necessary time, which may require several seasons."

Sulphur — Aurand[126] reports the occurrence of a "large deposit" of low-grade sulphur about 20 miles east of Dolores. The writer has not visited the area, but others who have state that it consists of several small, poor grade deposits of fumarole or spring origin, and not large.

Oil and Gas—Petroleum was first produced in 1931 from the Mancos River oil field which was discovered in 1927 in the southwestern part of the County. As of the end of 1959, there were 9 oil and gas fields, of which the following 8 were active: 4 oil-gas, 1 oil, and 3 gas fields. During 1959 these fields produced a total of 106,878 barrels of oil and 246 million cubic feet of natural gas, including 94 million cubic feet of carbon dioxide gas from the McElmo field. Up to the end of 1959, the County had a total cumulative production of 167,520 barrels of oil and 1,120 million cubic feet of gas, of which 489 million cubic feet consisted of carbon dioxide gas from the McElmo Dome. This field is located about 13 miles west of Cortez in the southern part of the Paradox Basin. Gas production is from the Leadville formation of Mississippian age, and from the Shinarump formation of Triassic age. The carbon dioxide gas

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*Dr. D. L. Everhart, USAEC, personal communication.

is processed at a plant on McElmo Creek and shipped as dry ice and liquid carbon dioxide to markets in the surrounding States.

*Montezuma County lies in the southern portion of the Paradox Basin. Structurally, this area is part of the Four Corners Platform. Present producing horizons are:

Cretaceous: Dakota sandstone—marginal oil and gas.

Pennsylvanian: Paradox formation
Ismay Zone—oil
Desert Creek Zone—gas distillate

Mississippian: Leadville limestones—carbon dioxide gas at McElmo.

*The southern part of Montezuma County is located within the Mountain Ute Indian Reservation. Up to the present (1959), little exploratory drilling has been undertaken on the eastern half of this land, but the interest shown by the oil industry in the sale of Mountain Ute Indian lands on September 2, 1959, together with recent oil discoveries on the western half of the Reservation, are indications that the area is being seriously studied for testing in the near future. It is probable that drilling below the top of the Paradox salt will be undertaken soon in order to explore the oil and gas potential of the Mississippian and Devonian formations.

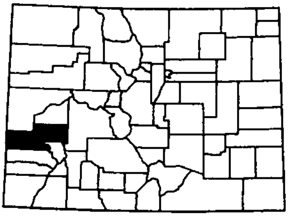
*The prospective zones include the Cretaceous Mancos shale and Dakota sandstone, the Pennsylvanian Honaker Trail and Paradox formations, the Mississippian Leadville limestone, and the Devonian Ouray and Elbert formations.

Geological Note—The petroleum geology of this County is discussed elsewhere in the petroleum section of this book.

The topography is mainly broken table land, capped by Upper Cretaceous rocks which include the Dakota sandstone and Mancos shale. The rugged La Plata Mountains straddle the La Plata County line in the center of the eastern part of Montezuma County. The mountains are carved from a domal uplift of sedimentary rocks intruded by numerous stocks, dikes, and sills of Tertiary age. In the Montezuma portion of La Plata Mountains are exposed: Triassic rocks of the Dolores formation; Jurassic rocks of the Entrada and Morrison formations, and Upper Cretaceous rocks of the Dakota sandstone and Mancos shale. The Tertiary outcrops consist of the diorites, monzonites, and porphyries of the intrusive igneous rocks. The area of Mesa Verde National Park, and the eastern half of the Mesa Verde Southern Ute Indian Reservation, is surfaced by Upper Cretaceous rocks of the Mesaverde formation; the western half of this area is mantled by Dakota sandstone and Mancos shale. Morrison formation and older Jurassic rocks are exposed in the deep drainages and eroded lands in the

*Mr. Frank J. Adler, Phillips Petroleum Co., written communication.

western part of the County. The area of Yucca House National Monument contains an exposure of early Tertiary intrusive igneous rocks which occupy approximately 30 square miles in extent.



Courtesy Colorado Planning Division

Montrose County

Montrose County, located in the plateau region of southwestern Colorado, bordering on Utah, has an area of 2,240 square miles ranging in elevation from 5,150 to 9,600 feet above sea level, and a population of 17,000. The County seat is at Montrose, a business center with a population of 6,500.

Available Maps of the County—

a. Montrose County Map.

b. U. S. Army Map Service maps: 4260 I, II, III, IV; 4360 I, II, III, IV; 4361 II, III; 4460 I, IV; 4461 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

d. U. S. Forest Service maps "Uncompahgre National Forest" and "Gunnison National Forest" include most of the County.

Mineral Production 1946-1958—Montrose County leads the State in uranium ore production. During 1957, it accounted for 57% of Colorado's total output, and represented 97% of the value of the County's total mineral production. Besides uranium ore, Montrose produced coal, sand and gravel, copper, gold, silver, gem stones, and salt. The salt is produced as brine from a drilled well and used solely in processing uranium ores. The figures in the following table are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Silver Ounces	Copper Pounds	Coal Short Tons	Sand & Gravel Short Tons	Total $ Value
1946	23,307	292,000	1,459	----	66,766[1]
1947	7,781	119,200	8,949	----	32,424[1]
1948	2	----	13,749	----	142[1]
1949	----	----	15,143	----	35[1]
1950	----	----	32,252	----	----
1951	----	----	2,419	----	12,434[2]
1952	----	----	3,083	----	16,463[2]
1953	----	----	3,205	Withheld	323,002[3]
1954	213	10,000	2,689	111,000	108,857[4]
1955	----	----	3,220	154,000	115,106[5]
1956	----	----	2,707	Withheld	6,871,144[6]
1957	886	1,600	1,974	294,000	9,327,512[6]
1958	5,302	16,000	1,991	139,000	9,614,034[7]

[1] Value of silver and copper only. Production too small for some years to include in the table.

[2] Value of coal production only.

[3] Value of sand and gravel and coal production only. Production of sand and gravel withheld by USBM in deference to operator's wishes.

[4] Same as [3] but includes some precious and base metal production.

[5] Same as [3] but includes salt and gem stone production values.

[6] Includes the value of uranium-vanadium production, sand and gravel, coal, salt, and some silver and copper production.

[7] Same as [6] but includes some stone and gem stone production.

Uranium—The uranium section of this book contains a discussion of the geology, ore deposits, mineralogy, and other pertinent information on the Uravan Mineral Belt. This belt extends over three Colorado Counties: starting in San Miguel, it enters Montrose west of Naturita and continues north through the town of Uravan and on into Mesa County. The most prolific part of the belt has been the portion located in Montrose County.

*The uranium occurs in the Salt Wash member of the Jurassic Morrison formation in small but numerous deposits of the typical Colorado Plateau "carnotite ore bodies." It is anticipated that with continued incentive of a stable and adequate uranium market, many more small bodies of ore will continue to be developed in this County in the future.

In 1958, the County produced 2,275,618 pounds contained U_3O_8 valued at $9,427,008.

Precious and Base Metals—Montrose County has not been a substantial producer of precious and base metal ores. The total value of this production since 1886 amounts to approximately $550,000. The La Sal Creek district in the western part, a few miles south of Paradox, has been the largest contributor. This district, as well as the others established in Montrose County, are discussed by Vanderwilt on the following pages of the 1947 edition of this book:

La Sal Creek	Page 151
Naturita	154
Sinbad	155
Tabequatche Basin	155

Coal—Landis[6] calculates that about 40 square miles of the County is underlain by measures containing 1,140 million tons

*Dr. D. L. Everhart, USAEC, personal communication.

of coal, all of it lying between 0-to-1000 feet below the surface. Of this tonnage, about 1,027 million are of subbituminous grade, and 113 million tons are bituminous. There are two unrelated coal fields in the County.

Nucla-Naturita Field —[6]This field ,located around the towns of Nucla and Naturita, is part of the Canyon Lands section of the Colorado Plateau physiographic province. The area is a dissected plateau of moderate to pronounced relief. The coal occurs in the Dakota sandstone of Upper Cretaceous age, in an almost horizontal attitude, but with some local folds and faults probably present. There are at least three coal beds present within a stratigraphic distance of 45 feet, with the middle occurrence being the thickest and most exploited.

Tongue Mesa Field —[6]This field is located in the southeastern part of the County at the north end of the Uncompahgre Mountains, and extends into Ouray and Gunnison Counties. The area is underlain by coal-bearing strata of the Upper Cretaceous Mesaverde formation, which apparently represent an erosional outlier with no connection to Mesaverde beds in surrounding areas. Heavy vegetation, and landslides and talus from overlying Tertiary volcanic rocks, and Quaternary glacial deposits, conceal the coal-bearing strata. Two, and possibly three, coal beds are present with thickness ranging to 40 feet, and dipping from 2 to 25 degrees. The coal is subbituminous in rank.

Sand and Gravel — Sand and gravel have been produced from the courses of the Uncompahgre River and some of its tributaries, such as Cedar Creek, in the vicinity of Montrose, southeast of it, and from near the town of Cedar Creek east of Montrose. Numerous deposits have been worked in the western part of the County from the courses of the Dolores River, the San Miguel River, and some of their tributaries such as Anderson and Naturita creeks. Other deposits are located: south of Cimarron town; between Cimarron and Cedar Creek towns; along the Uncompahgre River from the Delta County line to the Ouray County line, and near Redvale.

During 1958, the County produced 139,000 tons of sand and gravel valued at $117,000.

Fluorspar—Aurand[36] reports a small deposit of fluorspar on Vernal Mesa, 14 miles northeast of Montrose, along the Gunnison River in an area of pre-Cambrian granites and gneisses. The vein cuts through a granite complex and is easily traced down the walls of the canyon. Some work has been done on this deposit, but the CaF_2 content is too low (less than 35%) and the ore shoot too narrow (8 inches) for economic development at present.

Mica—Mica-bearing pegmatities are found in the eastern part in the area of pre-Cambrian rocks northwest and east of Cimarron town in the canyons of the Gunnison River and its tributaries. Most of these dikes are of the unzoned type and contain as accessory minerals muscovite, garnet, biotite, and black tourmaline; minor accessory minerals are beryl, magnetite, and pyrite. The feldspar in these pegmatites is of good quality but occurs in small masses. Practically all of the mica is of the scrap variety and very little, if any, is of sheet or punch quality.

Gypsum—Substantial deposits of gypsum are exposed along the valley of the Gunnison River in the eastern part of the County, and in the Paradox Basin. These deposits are discussed by Vanderwilt on pages 242-43 of the 1947 edition of this book.

Gem Stones—Schlegel[24] lists the occurrence of heliotrope (a green variety of cryptocrystalline quartz containing specks of red jasper) in the vicinity of Uncompahgre town.

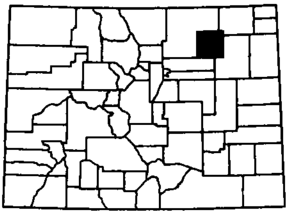
Oil and Gas*—No oil or gas production has as yet been developed in Montrose County, although the western part lies within the Paradox Fold and Fault division of the Paradox Basin. The eastern part is on the Uncompahgre Uplift.

*The County remains relatively untested excepting for a few wells on the Paradox Valley salt anticline, and along the southwest flank of the Uncompahgre Uplift. Drilling depths in excess of 10,000 feet necessary to test the pre-Pennsylvanian horizons in the salt area, and complex structure along the Uncompahgre Fault, have been deterrents to past exploration of the deeper formations. However, the discovery of Mississippian gas at well Pure #1 Southeast Lisbon (Sec. 5, T. 44 N., R. 19 W.), and Devonian oil at Pure #1 Northwest Lisbon well (Sec. 10, T. 30 S., R. 24 E., San Juan County, Utah), 12 miles to the west, should result in increased exploratory drilling to test these horizons. The prospective zones include the Pennsylvanian Honaker Trail and Paradox formations, the Mississippian Leadville formation, and the Devonian Ouray and Elbert formations.

Geological Note—With the exception of relatively small areas along the Gunnison River in the northeast, and in the Uncompahgre Plateau, north of Nucla, Montrose County lies almost entirely in sedimentary terrane. The topography is typical of that of a dissected plateau: essentially level over large areas, with folding and faulting modifying the surface and streams cutting deep and frequently steep canyons. The Uncompahgre Plateau uplift is the largest fold in the area, but a strong anticline underlies Paradox Valley. In this, and Sinbad Valley in the northwestern part, as well as elsewhere along the deeper drainages, rocks ranging in age from Carboniferous through Triassic are exposed. Beyond these older rocks, and covering most of the County, are Cretaceous rocks of the Dakota sandstone, eroded in places to expose Jurassic

*Mr. Frank J. Adler, Phillips Petroleum Co., written communication.

beds of the Morrison and Entrada formations. Some 20 miles east of Sinbad, a southeasterly-trending band of pre-Cambrian granite outcrops, representing an exposure of the crystalline core of the ancient Uncompahgre Mountains. In the northeastern part of the County, in the area of the Black Canyon of the Gunnison, pre-Cambrian schists and gneisses with pre-Cambrian granite intrusions are exposed on either side of the river in a northwesterly band. Quaternary material, consisting of Florida gravel, Durango till, Durango glacial outwash, post-Durango deposits, Wisconsin glacial outwash, and Recent alluvium, occur throughout the eastern part. Recent alluvium mantles most of the floor in Paradox Valley, and much of it in Sinbad Valley.


Courtesy Colorado Planning Division

Morgan County

Morgan County, located in the northeastern quadrant of the State, has a population of 24,000 and an area of 1,300 square miles ranging in elevation from 4,100 to 4,600 feet above sea level. The County seat is at Fort Morgan, an oil, ranching, sugar-beet farming, and business center with a population of 8,000.

Available Maps of the County—

a. Morgan County Map.

b. U. S. Army Map Service maps: 5164 I, II; 5264 I, II, III, IV; 5364 III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover the northern half of the County. See index map in the pocket.

Mineral Production 1946-1958—Morgan County is an important producer of petroleum and natural gas. It was second in the State in petroleum production during 1958, and fourth in natural gas. Sand and gravel are the only other mineral products of consequence produced. The figures on petroleum given below are from records of the Colorado Oil and Gas Conservation Commission and begin with 1950, the year petroleum was first produced. The value figures are from U. S. Bureau of Mines Minerals Yearbooks and begin in 1952, when the Bureau modified its method of reporting.

*Mr. Frank J. Adler, Phillips Petroleum Co., written communication.

Year	Barrels Petroleum	Sand & Gravel Short Tons	Total $ Value
1950	5,650	--	[1]
1951	74,416	-	[1]
1952	99,587	-	2,809[2]
1953	294,342	-	654,316[2]
1954	5,088,825	-	14,223,951[3]
1955	7,476,348	-	20,361,957[3]
1956	7,378,408	223,000	20,651,300[3]
1957	6,838,319	312,000	20,883,960[3]
1958	7,305,334	178,000	21,744,850

[1] No value given.

[2] Sand and gravel value only.

[3] Value of petroleum and sand and gravel production.

Petroleum — Petroleum was first produced in 1950, with the discovery of the Lee field in the southern part, south of Fort Morgan. 'Production is from the 'D' sand of the Dakota formation, Lower Cretaceous series. The 'J' sand produces gas in dual-completion wells.

Morgan County is one of the leading producers in the "fairway" portion of the Denver Basin. By the end of 1959, there were 38 oil-gas, 1 oil, and 1 gas fields in the County, among them the major Adena field, the second largest in the State. The total production for 1959 amounted to 8,610,282 barrels of oil and 14,303 million cubic feet of natural gas, and the cumulated aggregate production totalled 43,171,940 barrels of oil and 57,523 million cubic feet of gas.

*Most of the production is derived from the Cretaceous 'D' and 'J' sands of the Dakota formation, but a few wells have been completed in the Greenhorn limestone of Upper Cretaceous age. Both the Greenhorn and the Niobrara formations have given indications of productive potentialities in a number of wells and it is expected that some commercial production will be developed from these horizons. A few tests have penetrated the Lyons sand of Permian age, and older rocks, but the expectation of commercial production from these older beds is not great. The Upper Cretaceous beds have shown shaly sands with some oil and gas content, indicating latent potentialities. Morgan County still possesses substantial areas of untested lands and the probabilities for continued discoveries are good.

Sand and Gravel — Sand and gravel have been produced from the courses of the South Platte River and some of its tributaries: in the vicinity of Orchard and Goodrich in the western part; near Weldona; from various drainages north of Fort Morgan; in the vicinity of Snyder to the east; north and northwest of Adena from Bijou Creek and other north-flowing drainages in the southwestern quadrant, and from Beaver Creek in the southeastern quadrant. Other sand and gravel deposits are located in various parts of the County. A considerable one reaches from several miles west of Fort Morgan, east to Brush and Hillrose, having an average north-south width of about seven miles.

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

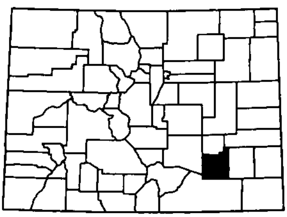
Clay—Butler[7] sampled a number of clay beds in scattered central part of the County and some of them proved upon testing to be suitable for the manufacture of construction materials. These occurrences are listed below.

1. Location: ½ mile west of Fort Morgan in an abandoned brickyard south of the tracks.
   Occurrence: Sampled a 10-ft. bed of soft, greenish-brown, sandy clay.
   Should make good, red, soft-mud bricks.
2. Location: Northwest of Fort Morgan at the Platte Narrows, in a ravine north of the dam at the head of the Platte and Beaver ditch.
   Occurrence: Sampled a 20-ft. bed with 4 feet of overburden, consisting of medium-hard, yellowish-green, somewhat gritty shale. Bed strikes N-20-E and dips 5-E.
   Should make good flesh-colored pressed bricks.
3. Location: South bank of a creek in the SE¼ of the NE¼ of section 11, T-5-N, R-58-W.
   Occurrence: Sampled a 20-ft. bed of medium-hard, yellowish-green, fine-grained gritty shale, with a slight easterly dip.
   Should make good pink, pressed bricks.

Butler does not mention the formations from which the samples were obtained.

Geological Note—Morgan County lies in prairie country in the sedimentary terrane of the eastern limb of the Denver Depositional Basin. The petroleum geology of the County is discussed in the petroleum section of this book.

The South Platte River crosses the County near its center in a meandering easterly direction. Its valley is mantled by Quaternary alluvium, and with Quaternary terrace deposits in the Fort Morgan-Brush area. Along the northern part of the northwest quadrant, and in the southwest corner of the County, Upper Cretaceous rocks of the Fox Hills sandstone are exposed, overlain by Cretaceous Laramie sandstone beds. The remainder is surfaced chiefly by Upper Cretaceous rocks of the Pierre shale.



Courtesy Colorado Planning Division

Otero County

Otero County, located in the southeast quadrant of the State, has a population of 26,000 and an area of 1,276 square miles ranging in elevation from 4,000 to 5,100 feet above sea level. The County seat is at La Junta, a ranching, farming and business center with a population of 8,500.

Available Maps of the County—

a. Otero County Map.

b. U. S. Army Map Service maps: 5159 I, II; 5160 II; 5259 I, II, III, IV; 5260 II, III; 5359 III, IV; 5360 III.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

Mineral Production—The only mineral production of any consequence in the County consists of sand and gravel. In La Junta, alabaster ornaments are manufactured on a small scale from material which Argall[9] reports occurs as "surface float." Some rose agate is produced in the area, but the source of the raw material is not reported. The value of the County's mineral production, beginning with 1953, is given below and represents almost entirely the value of sand and gravel production.

1953	$237,610
1954	27,591
1955	38,248
1956	
1957	95,650
1958	9,600

Sand and Gravel — Sand and gravel have been produced from the courses of the Arkansas River and some of its tributary streams in the vicinity of La Junta and to the northeast, west, and northwest of it, and also from Timpas Creek in the southwest quadrant. Other sand and gravel deposits are found on both sides of the Apishapa River in the western part, as well as along the Arkansas River, extending from the towns of Swink to Fowler in the northwest corner.

Clay—Butler[7] sampled a number of clay beds in scattered parts of the County, some of which represent deposits suitable for the manufacture of construction materials. Three of his findings are given below:

1. Location: "On the Bloom Land and Cattle Company's ranch, in the canyon of Timpas Creek"—apparently in section 28, T-27-S, R-59-W.

   Occurrence: Sampled a 5-ft. horizontal bed of hard, gray-to-black, medium fine-grained sandy clay, exposed in an adit driven into the canyon wall. (Name of formation not given.)

   Tests indicated the material to be "First-class fire-clay."

2. Location: "On the Bloom Land and Cattle Company's ranch" ¾-mile north of the Santa Fe R.R. and north of Timpas Creek—apparently in either section 15 or 22, T-27-S, R-59-W.

   Occurrence: Sampled an 8-ft. bed of horizontal material with less than 3-ft. of overburden near the top of the Carlile formation, exposed in an abandoned tunnel on the side of a knoll. The material consists of medium-soft, black-to-brown, fine-grained shale and clay.

This material ". . . was formerly mined and shipped to Pueblo." Should make nearly white soft-mud bricks, pressed bricks, probably stiff-mud bricks, and vitrified and unvitrified floor and wall tile.

3. Location: "Five miles northwest of the J.J. ranch, on the public road." Apparently in the SW¼ of section 3, T-26-S, R-54-W.

   Occurrence: Sampled 15 feet of horizonal material with 2 feet of overburden near the top of the Carlile formation, along the banks of an arroyo at the side of the road. The material consists of medium-hard, black, medium-fine to fine-grained shale and clay.

   Should make fairly good pressed red bricks.

Hydrocarbons Potential*—There are no oil or gas fields currently active in the County, but it does possess moderate potentialities for future development of production. The southern tip of the Denver Basin and the northern flank of the Sierra Grande Uplift enter the County, and it is possible that commercial production may be encountered in one or more of the sandstones of Lower Cretaceous, Permian, and Pennsylvanian age, and/or in the carbonate rocks of Mississippian and Ordovician age.

Geological Note—Otero County lies entirely in sedimentary terrane of typical prairie land, incised by drainages tributary to the Arkansas River. The latter cuts across the northern part in a meandering easterly course. Upper Cretaceous rocks are exposed over most of the County: the Niobrara formation covers much of it, with exposures of Dakota sandstone in the southeastern corner and some isolated ones to the southwest; a narrow band of Benton shale separates the Niobrara from the Dakota in the southeastern quadrant and in the southwestern corner. Older Cretaceous rocks of the Purgatoire formation, and Jurassic rocks of the Morrison formation, are exposed along the Purgatoire River and some of its tributaries in the southeastern part. Recent alluvium surfaces much of the Arkansas River valley floor.

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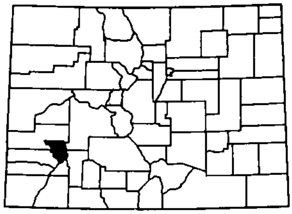
*Mr. Thaddeus R. Carpen, Continental Oil Co., written communication.

Ouray County



Courtesy Colorado Planning Division

Ouray County, located in the southwest quadrant of the State, has a population of 2,200 and an area of 504 square miles ranging in elevation from 6,300 in the north, to 14,150 feet in the rugged southern portion. The County seat is at Ouray, a mining and business center with a population of 1,100.

Available Maps of the County—

a. Ouray County Map.

b. U. S. Army Map Service maps: 4360 I; 4459 I, IV; 4460 I, II, III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

d. U. S. Forest Service map "Uncompahgre National Forest" covers the County.

Mineral Production 1946-1958—Ouray County has been an important producer of precious and base metals since 1878. The value of this production totals close to $100 million. Sand and gravel and gem stones are also produced. The figures in the following table are from Bureau of Mines Minerals Yearbooks.

Year	Lode Mines	Gold Ounces	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	9	8,504	194,297	199,000	1,743,000	1,247,000	828,991[1]
1947	18	4,536	150,886	269,800	2,184,300	1,285,000	821,994[1]
1948	18	2,466	172,713	334,000	2,944,000	2,520,000	1,177,238[1]
1949	19	2,824	206,667	346,000	3,042,000	2,748,000	1,175,434[1]
1950	18	5,000	238,021	380,000	2,200,000	1,918,000	1,024,617[1]
1951	17	2,168	129,216	512,000	2,422,000	2,202,000	1,135,501[1]
1952	9	2,443	95,871	394,000	2,322,000	1,914,000	959,187[1]
1953	4	3,224	91,975	508,000	2,720,000	1,728,000	929,907[1]
1954	5	2,688	68,249	500,000	2,262,000	1,424,000	767,035[1]
1955	2	3,266	48,450	342,000	1,278,000	930,000	658,218[2]
1956	3	2,647	55,903	251,000	1,054,700	1,175,900	577,119[2]
1957		----	----	----	----	----	355[3]
1958	2	201	1,866	1,000	18,000	----	11,456[2]

[1] Value of precious and base metal production only.

[2] Same as [1] but includes sand and gravel.

[3] Operations shut down. Small metal sale from mill cleanup.

Precious and Base Metals—The various established mining districts in Ouray County are discussed by Dr. Vanderwilt, and the geology of the mining areas summarized by W. S. Burbank* on the following pages of the 1947 edition of this book.

*U. S. Geological Survey.

Red Mountain District—Burbank[16] comments as follows regarding the potentialities of this district:

"The future of this district appears to be dependent upon economical methods of developing and treating fairly large bodies of rock that contain irregularly distributed ore and also in devising some method of prospecting for hidden ore chimneys of which a considerable number may remain. The discovery of the Lark pipe on the Cement Creek side of Red Mountain within the last few years (written 1947) has served to focus attention on the weakness of surface indications above some ore bodies. Because of the small diameter of many higher-grade ore bodies, some scarcely more than few tens of feet across, and because of the widespread general alteration of the rocks, some geochemical methods of prospecting may possibly prove applicable."

Sneffels District (also Telluride, San Miguel Co.)—[16]Burbank's observations on the potentialities of this area merit repeating herein:

". . . as less than 20% of the total vein length of the stronger veins is actually developed at all and as some ore shoots are known to extend below the Telluride erosion surface, there remains also some opportunity of discovery of ore shoots not indicated either by underground or surface developments. The tonnages in undepleted favorable ground would amount to 20 or 30 million tons, not allowing for selective mining. While these figures do not by any means represent an exhaustive consideration of individual ore deposits and the economic factors involved in their development, they give from the geologic viewpoint a rough estimate of the future of the district as compared to its past."

Uncompahgre District—The geology of this extensive district, located at the western margin of the San Juan Mountains, is excellently summarized by Burbank[16] on the pages listed above. Opposite page 410 of the 1947 volume, Dr. Burbank presents a generalized structure map of the district, and opposite page 412, a series of sketches illustrate the types of structural control of ore deposition. In this volume we limit ourselves to commenting on additional possibilities of the district, and include the table of sedimentary rocks which was unaccountably left out of the 1947 book.

BEDDED FORMATIONS OF THE UNCOMPAHGRE DISTRICT*

Era	Age	Name	Thickness (ft.)	Character
Tertiary	Miocene(?)	San Juan tuff	1800-3000	Chiefly andesitic and latitic volcanic debris. Well stratified tuff near base, conglomeratic in part. Tuff-breccia in upper part.
Tertiary	Oligocene(?)	Telluride Conglomerate	0-50	Mostly coarse conglomerate with pebbles and boulders of granite, schist, quartzite, porphyritic igneous rocks, and Paleozoic and Mesozoic sedimentary rocks. Locally thin limestones and shales.
Mesozoic	Upper Cretaceous	Mancos Shale	0-1200	Dark-gray marine shale with thin limestone beds. Basal beds, a foot or less thick, of pebbly texture, phosphatic, with chert and sandstone pebbles and shark teeth.
Mesozoic	Upper Cretaceous	Dakota Sandstone	135-150	Gray or rusty quartzose sandstone with shale partings, and locally carbonaceous shales in middle and upper part. Chert pebbles in basal sandstone. Beds altered to quartzite in areas of strong mineralization.
Mesozoic	Upper Jurassic	Shale member Morrison	350-400	Mostly variegated shales, green predominant except where altered; also red and brown shales and yellowish to gray sandstone. Near top sandstone beds contain chert pebbles like those in Dakota(?) sandstone.
Mesozoic	Upper Jurassic	Sandstone member Morrison	250-300	White or gray sandstones interbedded with red-brown and green shales, and thin limestones. Basal sandstone 25-30 ft. thick, locally altered to quartzite.
Mesozoic	Upper Jurassic	Wanakah member Morrison	85-125	Basal unit a dark bituminous shaly limestone, overlain by limestone breccia. Middle unit a soft, friable sandstone with clayey layers near top; mostly even-bedded. Upper unit mostly green and brown shales with green sandstone locally at base; thin limestone beds and lenses; widespread layers of chert beds near the top.
Mesozoic	Upper Jurassic	Lower LaPlata Sandstone	45-80	Very massive friable white sandstone, crossbedded in upper part; cliff-forming; more evenly bedded in lower part, with layers of coarse and fine grains.
Mesozoic	Jurassic(?) and Upper Triassic	Dolores formation	40-100	Fine-grained bright-red sandstone, sandy marls, and shales. Contains beds of limestone pebbles or pebble conglomerate. Locally quartzose pebble beds near base.
Paleozoic	Permian	Cutler formation	0-2100	Series of bright-red sandstones, pinkish grits and conglomerates, alternating with sandy shales and earthy reddish limestones.
Paleozoic	Pennsylvanian	Hermosa formation	1400-1600	Near base greenish sandstone and dark marine shales interbedded with thin fossiliferous limestones. Middle and upper parts contain thick beds of arkosic grits interbedded with shale and limestone.
Paleozoic	Pennsylvanian	Molas formation	40-60	Red calcareous shale and sandstone with quartzite pebbles and chert and interbedded conglomerate layers with many chert pebbles. Also pebbles of underlying Mississippian limestone.
Paleozoic	Mississippian	Leadville limestone	180-230	Basal part mostly dark-blue-gray or brownish-gray limestone, with sandy layers near base. Upper part mostly coarser-textured clastic limestone with interbeds of reddish shale. Locally, thin-bedded cherty and ferruginous limestone at top.
Paleozoic	Upper Devonian	Ouray limestone (dolomite)	65-70	Mostly gray, buff, white, fine-textured dolomite or dolomitic limestone; layers of pinkish clastic limestone with Upper Devonian fossils locally.
Paleozoic	Upper Devonian	Elbert formation	35-50	Thin-bedded buff dolomitic limestones, with interbedded sandstone and calcareous shale.
	Pre-Cambrian	Uncompahgre formation	5000-8000	Massive to thin-bedded quartzite with minor shale partings; in wide bands alternating with slate or shale bands. Quartzites white, pink and brownish to dark-gray; slates and shales or schist layers, rusty-brown or black.

*USGS Bul. 906-E, "Structural Control of Ore Deposition in the Uncompahgre District, Ouray County, Colorado," by W. S. Burbank—1940.

W. S. Burbank[112] divides this district into four areas based on major and minor structural features. The outstanding structural feature is the crossing of the northeastward-trending intrusive axis just north of Ouray, with the northwestward-trending axis of uplift with its parallel lines of rupturing which extends along the Uncompahgre Valley. These two axes divide the area roughly into quarters whose potentialities are discussed below.

Northern Division[112]—The narrow gold-bearing veins and the contact metamorphic deposits in this area are not too promising for future major discoveries. Further prospecting in the veins should be confined mainly to the coarser grained and more massive sandstone beds for most favorable exploration. Disseminated copper deposits may exist at depth in porphyritic rocks in the Uncompahgre center.

[112]In the American Nettie mine, if exploration east of the Jonathan dike is attempted, it should be extended from near the intersections of the dike with the Nettie No. 1 porphyry dike, and Nettie No. 2 (clastic) dike. If the Pony Express breccia does not increase in thickness or permeability, there is little justification for extending drifts much beyond the northeast end of the main ore shoot above. It is also possible that a narrow, favorable zone may exist in leached beds along the west side of the Jonathan dike. A drift northward parallel to the dike along this side would determine shortly the possibilities that sulfide pockets there might contain higher-grade ore than the small ones already found several hundred feet west of the dike. In the upper workings below the quartzite the more favorable places for prospecting in depth would be those near or within the Jonathan dike at cross-fissures or cross-dikes.

[112]Beneath the Calliope and other veins, lying within 1,200 feet of the Bachelor, the lower or Pony Express zone has not been prospected by any of the development tunnels. There is reason to believe that the ground may be mineralized but the grade of ore is likely to be low, and the better mineralized ground may lie farther east than that along the Pony Express vein.

[112]All the outcropping mineralized fissures of the northern group have been prospected or mined, but there may be a blind ore shoot along the eastern part of the dike that lies from 1,200 to 1,400 feet south of the Newsboy vein and dike. Although the exposed part of this dike is barren at the surface, ore is present to the east along one of the northwestward-trending fissures in the Dakota (?) sandstone about in line with the dike. If the two intersect below in the Pony Express or lower zone, structural conditions would be favorable for an ore shoot.

Western Division[112]—Generally, structural conditions in this area have not been favorable for the formation of ore shoots of consequential size.

Southern Division[112]—The mineral stages and zoning in the western ore shoot of the Mineral Farm mine, suggest that the ore may change below the zinc zone into a higher-grade copper zone possibly containing some gold, and finally, into a low-grade pyrite body. Conditions appear to warrant further prospecting of the channel's downward extension.

[112]The area along the northwest side of Canyon Creek between the Ouray fault and the subsurface contact between the quartzite and slate probably deserves further prospecting, as the upper ore horizon at the base of the Molas formation has not been thoroughly tested there. This horizon is partly concealed beneath talus and morainal debris on the hillslope north of Canyon Creek. Fissure channels such as are exposed in and near the Columbine mine illustrate the possibilities in this area.

Eastern Division[112]—This division is less favorably situated for the formation of ore bodies of large size than the northern area because there are no direct circulation channels between the intrusive axis and the Uncompahgre break.

Upper Uncompahgre, Mineral Point, and Poughkeepsie Districts (Ouray and San Miguel Counties—The geology of these districts, which adjoin one another at the headwaters of the Animas and Uncompahgre rivers, is summarized by Burbank in the 1947 edition of this book (Vanderwilt) on the pages listed previously. Dur. Burbank concludes as follows regarding the potentiality of this area:

"Because of relatively poor access to parts of the area there has been little large-scale exploration that would permit an accurate estimate of the average value and continuity of the ore shoots. Mine workings are relatively shallow so that the area is essentially virgin for deep development to the base of the volcanic series. Throughout much of the high country adjacent to the Mineral Point and Engineer Mountain area, the depth to the base of the volcanic series is estimated to be as much as 3,000 feet. Also, since the volcanic rocks are probably underlain by pre-Cambrian rocks favorable to fissuring and mineralization, potentially productive ground is not necessarily limited to rocks above the Telluride erosion surface."

Sand and Gravel — Sand and gravel have been produced from the course of the Uncompahgre River in the vicinity of Ouray and near Ridgway. Other deposits occur along the course of the Uncompahgre River, from Ridgway north to Colona; also along Cow Creek and to the east of it, and along Dallas Creek.

Gem Stones—Rose-red rhombohedrons of rhodonite (manganese metasilicate) are found in a number of mines in the vicinity of the Silverton caldera. These include those south of Ouray such as the Mountain Monarch, the Grizzly Bear, and others. Rock crystal (colorless, transparent quartz) and crystals of "sugar" quartz are found on the dump of the Treasury tunnel 6 miles south of Ouray. Andradite (common garnet) and topazolite (topaz-colored transparent garnet) are found in the Mount Sneffels area southwest of Ouray.

Coal—The Tongue Mesa field, which extends into Montrose and Gunnison Counties, is partly located within the northeastern portion of Ouray County. Landis[6] calculates that 22 square miles are underlain by measures containing 1,015 million tons of subbituminous coal, all of it lying between 0-to-1000 feet below the surface.

The geology and manner of occurrence of the coal in the Tongue Mesa field is discussed under Montrose County on page 218 of this volume.

Uranium*—The northern part of the County is surfaced by a sequence of Jurassic and Cretaceous continental sediments which, in the southern part are overlain by thick flows of Tertiary volcanic rocks with a few Tertiary intrusives exposed.

Small uranium occurrences in the Entrada formation of Jurassic age, and a few others in the Tertiary igneous rocks, are indications of the small probability of discovering deposits of substantial size.

Geological Note—Ouray County is located in the northwestern part of the San Juan Mountains physiographic province; the mountains form an outlying group of the southern Rocky Mountains.

The northern half of the County lies in sedimentary terrane of Upper Cretaceous age. Rocks of the Dakota sandstone predominate in the northwest quadrant, and the Mancos shale predominates in the northeast quadrant east of the Uncompahgre River valley.

The Uncompahgre River bisects the County flowing from south to north, and along its course are exposed sedimentary rocks ranging in age from Devonian to Upper Cretaceous: the Elbert formation and Ouray limestone of Devonian age south of Ouray; Leadville limestone, Molas, Hermosa, Cutler, and Rico formations of Carboniferous and Permian age at Ouray and north and south of it; the upper Triassic Dolores formation north and south of Ouray; the upper Jurassic Entrada and Morrison formations, and Upper Cretaceous rocks of the Dakota sandstone, Mancos shale, Mesaverde group, and other undifferentiated Upper Cretaceous rocks.

Quaternary alluvium, landslides, mudflows, and glacial deposits occupy much of the Uncompahgre River valley floor, and some areas in the western and southwestern parts of the County.

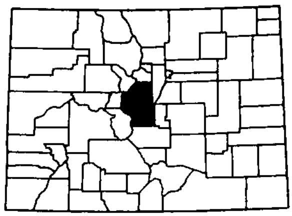
Tertiary volcanic rocks of bedded tuff-conglomerate and quartz-latite breccia of the San Juan tuff predominate in the

*Dr. Donald L. Everhart, USAEC, personal communication.

southern half overlying Cretaceous sediments. Much of this material is not highly indurated and in many places weathers to a badlands topography. The San Juan tuff is very favorable for landslides, particularly where it overlies soft strata such as the Mancos shale. A long narrow segment of San Juan tuff extends northward along the County's northeastern boundary, capping the coal region of the Tongue Mesa field.

East of Ouray, near the southeastern border, are exposed dikes, sills, and other intrusive bodies of quartz latite and granodiorite of Tertiary (Miocene?) age. In the Eldredge area south of Colona, as well as in the western part of the headwaters of Leopard Creek, and south in the Mount Sneffels area, are exposed stocks, laccoliths, and sheets of granite-to-gabbro rocks of Tertiary (Miocene?) age. In the extreme southern part of the County, in the Red Mountain area, are flows of igneous rocks of the Silverton volcanic series of Miocene age.

Park County



Courtesy Colorado Planning Division

Park County, located in the exact center of the State, has a population of 1,800 and an area of 2,178 square miles ranging in elevation from 7,200 to 14,284 feet above sea level at the top of Mount Lincoln. The County seat is at Fairplay, an old mining community, and a ranching, tourist, and regional business center with a population of 600.

Available Maps of the County—

a. Park County Map.

b. Army Map Service maps: 4761 I; 4762 I, II; 4861 I, II, III, IV; 4862 1, II, III, IV; 4863 II, III; 4961 III, IV; 4962 III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover most of the County. See index map in the pocket.

d. U. S. Forest Service maps "Pike National Forest" and "San Isabel National Forest" include most of the County.

Mineral Production 1946-1958—Park County has been a substantial producer of precious and base metals since 1859. The value of this production totals close to $50 million. In recent years the County has become the most important producer of beryl in the State. Sand and gravel, pegmatite minerals, and gem stones were also produced during the 1946-58 period. The figures in the following table are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Active Mines Lode	Placer	Gold Ounces	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	8	7	20,088	15,995	17,000	122,000	683,000	815,382[1]
1947	12	7	15,123	20,890	20,800	160,300	764,600	668,178[1]
1948	11	5	9,120	7,867	2,000	104,000	280,000	382,610[1]
1949	7	4	10,205	14,829	6,000	238,000	506,000	472,126[1]
1950	6	3	16,321	11,363	28,000	116,000	510,000	675,423[1]
1951	8	2	13,266	10,121	30,000	124,000	520,000	596,822[1]
1952	5	3	2,019	6,193	30,000	64,000	456,000	169,530[1]
1953	2	3	1,470	7,659	26,000	66,000	550,000	193,255[1]
1954	4	1	509	3,927	10,000	36,000	198,000	74,340[2]
1955	4	1	30	647	6,000	6,000	4,000	97,081[2]
1956	5	1	70	895	6,500	9,600	19,700	109,282[3]
1957	4	2	264	13,547	8,900	433,300	117,800	190,985[4]
1958	5	-	58	37,886	12,000	1,354,000	----	197,867[5]

[1] Value of precious and base metals production only.
[2] Same as [1] but includes value of sand and gravel production.
[3] Same as [1] but includes feldspar, tungsten, and fluorspar production value.
[4] Same as [1] but includes value of pegmatite minerals and gem stones.
[5] Same as [4] but includes value of sand, gravel, and uranium ore production.

Precious and Base Metals—The various mining districts established in Park County are discussed by Dr. Vanderwilt, and the geology of the mining areas summarized by Dr. Singewald*, on the following pages of the 1947 edition of this book.

Park County (general)	Pages 161, 162
Alma placers	161, 163
Geology	348
Beaver Creek	163-64
Geology	341-42
Buckskin	165, 166
Geology	336-41
Consolidated Montgomery	165, 167-68
Geology	336-41
Fairplay	168, 169
Geology	348
Guffey (Freshwater)	168, 170
Halls Gulch	170
Horseshoe	171
Geology	336-41
Mosquito	171-73
Geology	336-41
Sacramento	173
Geology	336-41
Pulver	173
Tarryall Creek	174, 175
Geology	347-49
Tarryall Springs	174
Weston Pass	176

In this volume we limit ourselves to presenting additional

*United States Geological Survey.

geological data on the placers of northwestern Park County, and to discussing the potentiality of this area and also that of the Alma, Horseshoe, and Weston Pass mining districts.

Alma, Horseshoe Districts — Singewald includes the Buckskin, Consolidated, Montgomery, and Mosquito districts in his geologic discussion of this general area on pages 336-41 of the 1947 edition of this volume. His comments on the outlook of this region are repeated herein in abstract form (see also 119 of the bibliography).

The London veins apparently have been nearly mined out from the northern part of Pennsylvania Mountain to the northernmost limits of gold mineralization south of New York Mountain. However, there are possibilities that the vein system continues southeastward across the central and southern parts of Pennsylvania Mountain, and also that gold deposits may exist in the Cambrian Sawatch quartzite, or even in pre-Cambrian rocks below the productive zone at London Mountain. South of the London-Butte workings, the London ore horizons continue, raking steeply southeastward, at depths of 1,000 to 2,800 feet below the surface where they remain wholly unprospected. No mineralogic evidence suggests that the southern limit of gold mineralization has yet been reached.

Gold veins and replacement deposits in the Sawatch quartzite occur in both the Loveland and the North Star areas. All deposits readily found along the outcrop of the formation have been practically mined out, but small areas near abandoned mines may contain additional deposits concealed by strata above the Sawatch quartzite.

Beneath parts of the areas capped by Pennsylvanian strata and porphyries on both Bross and Lincoln mountains, the Leadville dolomite remains unprospected, though it may contain ore bodies worth as much as one million dollars in gross value. Unprospected ground within the upper part of the Leadville dolomite, where it is concealed beneath younger rocks between the Hilltop and Continental Chief mines, and east of the Peerless mine, may contain additional deposits worth up to a million dollars.

Small silver-lead deposits may be found in dolomites, particularly in the upper part of the Leadville dolomite, concealed by Pennsylvanian strata and porphyries: east of the Loveland area; east of the Sacramento area, and adjacent to the hanging wall of the London fault within the Sacramento area.

Prospecting in areas other than those mentioned above is not likely to produce satisfactory results, but the most promising of such areas would be: between the London fault and the crest of the Mosquito Range within the transverse belt of profuse minor faults northeast of Mount Evans, and along the footwall zone of the London fault opposite the Sacramento area. In both of these localities the favorable pre-Pennsylvanian rocks lie unprospected beneath a thick cover of unfavorable Pennsylvanian strata. There is also a possibility of finding deposits in concealed pre-Pennsylvanian rocks along the Sherman fault, or in a zone of reverse dips which extends from Mosquito Creek north-northeastward on the west side of the South Platte River, but there are no clues for prospecting.

Placers of Northwestern Park County—Dr. Quentin D. Singewald discusses the gold placers of northwestern Park County on the previously-listed pages of the 1947 edition of this book, and includes a glacial map of the Beaver-Tarryall area opposite page 346. In this volume we submit below additional geological data and a discussion of the potentialities of the area, abstracted from a later publication by Dr. Singewald[120].

Source of the Gold—All the lode deposits from which placer gold could be derived are located within the mountains, and nearly all are concentrated within definite areas of belts of mineralization.

The only mineralized area east of South Platte valley lies at the heads of Montgomery and Deadwood gulches, and its outline coincides with that of the green contact-metamorphosed rocks. The deposits, which are of a high-temperature type, surround the apex of a small stock. In the absence of master channels, the ore-forming solutions spread into innumerable small fissures depositing lodes containing small quantities of gold and almost no copper, lead, zinc, or silver. Though not of commercial value individually, these lodes in aggregate have supplied large amounts of placer gold.

In the Mosquito Range the greatest ore deposition as well as the greatest igneous intrusion, took place within a belt that is approximately 3 miles wide and trends northwestward from Leadville to North Star Mountain. Scattered lodes occur throughout the belt, but the vast majority are concentrated within the four mineralized areas discussed below.

The North Star Mountain area has supplied chiefly gold and minor amounts of silver and other metals. In this area there are many veins in both the pre-Cambrian metamorphic and the overlying pre-Pennsylvanian sedimentary rocks, but most of them are too small to be mined. Nevertheless, the distribution of placers in South Platte valley indicates that the North Star Mountain area, and perhaps scattered lodes to the west, was a major contributor of placer gold.

A fairly large mineralized area which surrounds Mount Bross and Mount Lincoln includes three major silver mines as well as many small mines and prospects that have silver and only insignificant amounts of gold. What little gold has been found occurs chiefly in the northern part of the area which doubtless contributed a small amount of gold to the placers.

An area which extends from the north side of Buckskin

Gulch across lower Loveland Mountain to the south of Mosquito Gulch includes several medium-sized gold mines. Small placers located in Buckskin Gulch prove that some of this placer gold derived from that area. Also, it is possible that the fairly numerous lodes farther up Buckskin Gulch also contributed gold to the placers.

The fourth mineralized area of the belt is located in the vicinity of London Mountain and includes the London group of mines whose chief output has been gold with small amounts of silver, lead, zinc, and copper, and has been the largest producer in the entire district. However, despite the large yield from the lode mines, this area does not seem to have contributed appreciable amounts of gold to the placers, for the lode veins and replacement bodies do not outcrop at all, or have been only slightly eroded. Nevertheless, it is quite possible that veins formerly existed within the eroded area of South Mosquito Gulch, and therefore the London Mountain area must be regarded as a possible, though not certain, source of placer gold.

Gold Placers—Placer gold was first discovered in Park County in 1859. Since then the area has produced about $9 million in placer gold and silver, of which about 85% was gold.

In general, placers which are located within the maximum limits of glaciers of the last or Wisconsin stage are associated with moraines deposited by ice, whereas those farther down stream are associated with water-laid deposits.

By far the most productive localities have been the outer parts of terminal moraines marking maximum ice advance during the Wisconsin glaciation. Those in South Platte and Tarryall valleys have been extensively worked and account for a large share of the region's output. Smaller and moderately productive placers have been found locally upstream. Some are in secondary terminal moraines deposited during major ice stands or readvances. Those associated with the Alma substage rank second in output. In Deadwood Gulch minor placers are associated with the Briscoe substage. Still other placers have been worked in lateral moraines, the most productive of which have been those deposited between the time of maximum advance and the Briscoe substage. Where bedrock depressions underlie the surface, the gold content is likely to be higher than elsewhere.

The bulk of the gold contained in moraines lies adjacent to bedrock. Commonly, two other pay streaks, each about one foot thick, are found above the bedrock, but are less rich and much more lenticular than that of the bedrock.

Pre-Wisconsin moraines, which doubtless contained as much gold as the later ones, have not been worked, presumably because only the lateral debris is now exposed. The far more favorable terminal lobes have either been completely eroded or else partly eroded and covered by later outwash.

Outwash aprons are composed of the same materials as the moraines immediately upstream, but they are slightly flatter, more rounded, and extremely large ones are absent. There is a gradual diminution in the size of boulders and in gold content away from the moraine. Gold is not uniformly distributed over the bedrock but occurs in definite channels which must be located by prospecting. Commonly they are associated with channels in the bedrock surface.

Outlook—In the South Platte and Tarryall valleys, the gold occurs at the base of the outwash materials, adjacent either to bedrock or to older gravels, where it could not have been appreciably affected by post-glacial erosion. Consequently there is no good reason to believe that the present stream channels are richer than other parts of the apron. By contrast, the entire apron in Beaver Creek has been worked within the limit of productive sediments.

The pre-Wisconsin outwash apron of Tarryall Gulch has yielded considerable gold at the Cline Bench placer 3 miles downstream from the Wisconsin moraine. An outlier of the same apron, to the north, is therefore worthy of prospecting.

Although no large output from Buckskin Gulch is to be anticipated, the digging of a few prospect pits to bedrock near the stream and just inside the margin of the moraine of the Alma substage is perhaps warranted.

In Mosquito Gulch, the presence of even small amounts of gold at the Orphan Boy placer southeast of Park City, and on the eastern spur of Bald Hill at the Dyer placer, suggests that the terminal moraine of the Alma substage merits prospecting.

In the area of the Alma placer on the South Platte River, there has not been adequate prospecting either in the river channel nor along the west bank, although both merit investigation. The river bed, particularly the area adjacent to the lower part of the Alma placer, may contain gold washed down the slopes or reconcentrated from eroded portions of the moraine during post-glacial time. Location, or depth of any bedrock channels beneath the floodplain of the river is unknown, but can be determined readily by geophysical work.

The east side of the valley, between the Fairplay moraine and the main Snowstorm cuts, shows widespread traces of gold in moraine east of the South Platte River, and of commercial production in cuts near the McConnell ranch. Nevertheless, there is no record of adequate prospecting in ground between the main Snowstorm placer and the outer margin of the Fairplay moraine. The surface is covered with lateral moraine which warrants testing immediately above bedrock. The considerable surface relief doubtless reflects bedrock relief, and consequently surface depressions and channels would seem to be the most favorable localities in which to look first.

Only two small placers exist west of the South Platte River between Sacramento and Mosquito Creeks, but the absence of other placers does not condemn the ground; on the contrary, the presence of gold at these two localities suggests that the lateral moraine may be gold-bearing elsewhere. However, the chances of finding commercial deposits should be regarded as fortuitous, and it should be kept in mind that gold east of the river has no relation whatever to possibilities west of the river. The most favorable places to begin prospecting would be in the iceborder channel adjacent to the terminal part of the Briscoe moraine and at the mouths of other ravines in lateral moraine to the south.

On the river bed between Sacramento and Mosquito creeks, the stream and floodplain channel of the South Platte River above Sacramento Creek has not been tested to bedrock. Therefore the depth to bedrock and the possibilities for commercial placers are not known, but the most favorable places for prospecting appear to be just down stream from commercial placers in the bank.

The Fairplay placer extends approximately from Sacramento Creek to more than a mile southeast of Fairplay, crossing several properties. A great deal of the gold in this placer came from the Fairplay moraine, but considerably more came from outwash materials beyond. There are still good possibilities of locating additional gold pockets or channels which are directly associated with the Fairplay moraine. Along the northeast side of the South Platte River, prospecting immediately above the bedrock is warranted, both in the outermost 1,000 feet of the moraine itself, and in the adjoining iceborder channel continuously from the river to or beyond the point where the terminal arc curves to become a lateral moraine. Whether or not additional productive channels may be discovered along the southwest side of the stream, close to the moraine border in section 32, T-9-S, R-77-W, involves the question of the quantity of gold deposited west of the present stream, but prospecting is certainly warranted. On both sides of the present workings search should be made immediately above bedrock, which may be over 100 feet below the surface.

South of Fairplay and east of the river there is a plain which extends to beyond the Purcell ranch, composed of outwash material that stands about 9 feet topographically lower than the apron west of the river. This difference in altitude is due to post-glacial erosion which has not affected in any way the occurrence of placer deposits, as the gold would have been originally deposited mainly at the base of the gravel. This ground warrants prospecting, and if commercial quantities of gold are found there, prospecting should be continued southward to the Crooked Creek confluence. Because the surface gravel derived from glacial outwash of the South Platte River may possibly overlie a layer of preglacial gravel derived from Crooked Creek, the maximum gold content in this area will not necessary be found immediately above bedrock.

The Wilson placer is the most important producer in Park Gulch, extending from the middle of section 17, T-9-S, R-75-W, to Tarryall Creek. By far the most probable immediate source of the Wilson placer gold and its associated gravels, other than granite, is the eroded part of Terrace No. 2. Extensive dissection of this terrace in the lower reaches of Park Gulch doubtless reconcentrated much of the gold against the barrier of granite hills. According to this interpretation, the richest ground has already been worked, but the North Branch would be highly favorable for prospecting and the main branch, east of the ridge of Laramie (?) age rocks, somewhat less so.

Within the drainage area of Tarryall and Michigan creeks there remain large areas which have at least some possibility for production. Aside from the Ames prospects, which are just east of where Tarryall Creek emerges from the mountains, the most favorable ground consists of an extensive area north of the Ames land, covered by outwash from Wisconsin glacier, and also a large island of earlier outwash correlated with the Cline bench. Eastward and northeastward, the Cline bench terrace merges topographically with the later outwash apron. Thus, all of the ground east of the mountains as far as the southernmost tributary of Michigan Creek may be regarded as having commercial potentialities. As the gold content may be expected to decrease eastward from the mountains, the western part should be prospected first. Outwash from the last glaciers may not be expected to contain gold in commercial quantities for more than a few miles beyond the ice terminus. However, gold disseminated over Terrace No. 2, and even No. 1, may have been reconcentrated into commercial deposits in any of the places where the terrace has been sufficiently dissected. Therefore, gold placers could conceivably be found anywhere along Tarryall Creek. Should commercial gold be found while exploring upstream along Tarryall Creek from the Wilson placer, and should it continue for any considerable distance away from the eastern granite hills, then all of Tarryall valley may be regarded as potentially favorable ground. In summary, the entire outwash apron for several miles east of the Peabody placer, as well as the Cline Bench and its outlier, are favorable for prospecting; in the southern part of this terrain several promising channels have already been found. Less favorable, but well worthy of consideration, is the entire valley of Tarryall Creek between the Fairplay-Denver highway and the eastern granite hills.

Although less promising than the Tarryall Creek valley, the South Branch of Park Gulch valley must be regarded as possible placer ground. The area northwest of the Fairplay-

Denver highway, or at the western base of the ridge of rocks of Laramie (?) age, are probably the richest.

*Pennsylvania Mountain Placer**—High up the slopes of Pennsylvania Mountain, there is a roughly triangular, gravel-covered area which has been worked intermittently for a number of years. It lies at about 12,250 feet elevation above the timberline, and extends to the broad, sloping crest of the mountain. This deposit has been noted for the coarseness of its gold, one nugget which was found within one foot of the surface, weighed just one pennyweight less than 1 Troy pound. The production has been small, due chiefly to the lack of locally available water, but these gravels merit proper investigation. Mr. Prommel states from personal experience in the area, that exploration should be attempted by drilling and not by pitting. The immediate subsurface at that altitude consists of permafrost which thaws rapidly along the walls of a pit dug in the warm season, and the material slumps readily into the hole. Several lakes exist at lower elevations in the area, from which water could be pumped to the workings for hydraulic mining in the event the results of a drilling program disclosed the existence of a commercial placer.

Weston Pass District—[121]This district lies on the crest of the Mosquito Range, 10 miles south-southeast of Leadville, and extends into Lake County.

Mineralization occurs in a single, discontinuous stratigraphic horizon of appreciable extent, which lies about 170 feet above sandy shale beds at the base of the Leadville limestone. This ore bed has been traced for 6,800 feet along the strike, but does not appar to exceed 10 feet in vertical thickness, although some stopes are said to have risen to 25 feet.

The Weston fault, located about 1,400 feet east of Weston Pass summit, trends northwesterly, and could have been the main channel of mineralization. The ore apparently does not occur along any well-developed fissures, but impregnates the limestone. It also deposited in and around small vuggy cavities which locally may be massed so as to constitute a cellular replacement body in the densely crystalline limestone.

The ore minerals in the Ruby mine occur as disseminated masses of galena and minor amounts of sphalerite, with the oxidized minerals cerussite (lead carbonate), iron oxide, calamine (zinc hydroxide silicate), and smithsonite (zinc carbonate), forming a casing around the sulfides. The ore formed in more or less continuous bodies following a definite stratigraphic horizon.

The quantity and tenor of the ore visible at the surface, although discouraging, is not representative, for it is simply the lean remnant of the outcrop after the richer portion was

*H. W. C. Prommel, consulting geologist and mining engineer; written communication.

mined. With due consideration for the topography and the depth of the ore bed below the surface, a blanket deposit is ideal for exploration by coredrilling.

Weston Pass-Sherman Mountain Area—Mr. H. W. C. Prommel*, who is familiar with the area, is of the opinion that the terrain lying along the Mosquito Range to the north of Weston Pass, as far as Sherman Mountain, is worthy of detailed exploration. Proper geologic mapping of the area may reveal the existence of fissure veins and limestone replacement bodies of commercial magnitude.

Sand and Gravel — Sand and gravel have been produced from the course of the South Platte River southeast of Fairplay, near Garco and Hartsel, and north of Alma; from Salt Creek, and from South Fork. Also from the courses of North Fork and Elk Creek in the vicinity of Bailey, and from tributaries of the South Platte west of Lake George. Other sand and gravel deposits are located on both sides of the South Platte River and its southern tributaries, such as High Creek, Fourmile Creek, and South Fork, and in an area from Como north to Jefferson.

Pegmatite Minerals—The most important pegmatite zones are the Guffey-Micanite area, which straddles the Park-Fremont County line, and the Lake George area in the eastern part of the County.

The Guffey area within Park County lies chiefly in pre-Cambrian metamorphic terrane. Some of these pegmatites have produced appreciable quantities of mica, feldspar, beryl, and columbite; notably the Meyer's Ranch pegmatite (in granite gneiss), and the Famous Lode pegmatite (in schist).

The Lake George area forms part of the Pikes Peak-Florissant pegmatite province and lies in pre-Cambrian terrane of Pikes Peak granite. A number of these dikes have been mined intermittently for a number of years, chiefly for feldspar, with some mica, beryl, and columbite recovered in the operation.

Beryl—In the Lake George area there are non-pegmatitic beryl occurrences of importance. The most noteworthy is the Boomer lode, 7 miles west of Lake George town, which in 1957 accounted for 91% of the total beryl output in Colorado. During 1958, this mine produced 227,248 pounds of material assaying 9.17% BeO, and 84,630 pounds containing 2.84% BeO.

Messrs. C. C. Hawley and W. N. Sharp of the U. S. Geological Survey, who have examined the area, have kindly sent us the following written communication**.

"The Lake George beryllium district constitutes about 6 square miles centered about 8 miles northwest of the village of

*H. W. C. Prommel, consulting geologist and mining engineer; written communication.

**Publication authorized by the Director, U. S. Geological Survey.

Lake George. The district is underlain by schists, gneisses, and pegmatites of pre-Cambrian age which have been intruded by small and large masses of granite, most of which also are known to be of pre-Cambrian age. The east part of the district is underlain by one of these pre-Cambrian masses, the Pikes Peak (granite) batholith.

"The important beryllium deposits are not the pegmatites, but are, rather, replacement deposits of hydrothermal origin. They occur in veins, pipes, and more irregular masses which are localized by fractures and rock contacts. The deposits are associated with intrusive granite bodies and with quartz-mucovite-topaz greisens. The deposit at the Boomer mine, the most important in the district, is associated with a small stock that intrudes metamorphic rocks; other deposits are found within the Pikes Peak batholith or near its contact. The beryllium minerals of the deposits, beryl and bertrandite, are accompanied by one or more of the greisen minerals and small amounts of galena, sphalerite, chalcopyrite, fluorite, and, less commonly, wolframite and arsenopyrite.

"Although the known deposits are confined to a small area, greisenized rocks are known to occur locally in a larger but as yet undefined area; the larger greisenized area is believed favorable for prospecting."

Gem Stones—Schlegel[24] lists the following gem stones and localities of their occurrence in Park County.

Locality	Gem Stone
Agate Plateau, Guffey	Agate
Mount Antero Summit	Smoky quartz, amazonite, beryl
Old Salt Works, Antero Junction	Chalcedony, Bloodstone, Moss agate
South Park, near Grand River	Almandite, heliotrope
Tarryall Mountains	Amazonite, smoky quartz, topaz

Coal—The South Park coal field comprises a north-south elongated exposure of Upper Cretaceous rocks of the Laramie formation which crop out around the northern end and northern flanks of the Michigan syncline, and to a lesser extent around the south end. The east flank of the syncline has been cut by a thrust fault and the Laramie is not exposed there, but three coal beds are reported present on the west side from where coal has been mined in the past. A few miles south of the Michigan syncline, the Laramie crops out around the edge of a small syncline, and there is evidence of the presence of two coal beds.

Landis[6] calculates that 8 square miles of the County are underlain by coal measures containing 92 million tons of coal. Of this tonnage, 32 million lie between 0-to-1,000 feet below the surface, 33 million between 1,000 and 2,000, and 27 million tons between 2,000 and 3,000 feet underground. The results on one modern analysis of the coal indicates that it is subbituminous

B in rank, but because of its physical properties, Landis classifies it as bituminous.

Uranium*—The general geology of the County is complex, involving folded and faulted rocks of pre-Cambrian, Paleozoic, and Mesozoic age, intruded and covered in the southern portion by Tertiary volcanics. The few known, scattered uranium deposits of any significance are associated with sedimentary features within the volcanics. The deposits of most interest in the county are those in the Tertiary lake beds in South Park.

Barite—Argall[9] reports the existence of a barite deposit 2 miles southwest of Hartsel which occurs in vertical veins 1 to 2 feet wide, and in irregular layers 6 inches to 3 feet thick in a flat-lying Permian limestone bed of the Maroon formation. This material averages about 64% BaO.

Fluorspar — Argall[9] lists five fluorspar deposits in the County: two in the Jefferson-Kenosha Pass area in the northwest; one 3 miles east of Lake George; one in the Tarryall district, and another one 24 miles northwest of Lake George.

The Jefferson-Kenosha Pass deposits are briefly discussed by Cox[21] as follows:

"In the Jefferson district near Kenosha Pass are some sizable deposits which were worked in 1913-14, but neglected thereafter until the autumn of 1943. The fluorspar is light green to deep purple and is generally associated with large quantities of quartz. Aurand[38] described one vein as being 3 to 15 feet wide but containing only 15 to 18 inches of commercial fluorspar. A deposit which is now receiving attention and which may be part of the same vein, is reported to be about 30 feet wide in one place. In addition to the quartz, a considerable amount of barite is associated with the fluorspar."

Argall[9] very briefly describes the other three deposits in tabular form. The following comments are from this source.

Kyner Property—3 Miles East of Lake George: The fluorspar occurs in fissure veins and replacement in granite, with a maximum width of 20 inches. The fluorspar is coarse and runs between 92-97% CaF_2.

Parker Property—In the Tarryall district: The fluorspar occurs in a 15 inch vein in granite, and runs 75% CaF_2.

Tarryall Property—This property is reputedly "24 miles northwest of Lake George": The fluorspar occurs in a vein at least 900 feet long, and from a few inches to over 1 foot in thickness.

All the foregoing properties have shipped some ore.

Lightweight Aggregates—Bush[28] reports the existence of a large deposit of pumice in sections 28, 32, and adjoining areas of T-14-S, R-75-W. This deposit, which is 18 feet thick at the

*Dr. Donald L. Everhart, USAEC, personal communication.

exposure, possibly could be the largest in Colorado. The pumice is associated with pumicite and pumice sand, and is locally altered to a non-swelling type bentonite. The deposit is relatively horizontal and overlies a bed of unconsolidated sand and gravel. The origin of this and other deposits located north and west of Black Mountain is presumed to be this composite volcano of probably Tertiary age.

Bush[28] also reports the occurrence of a deposit of vermiculite about 5 miles west of Lake George northeast of Wilkerson Pass, in section 11, T-12-S, R-72-W. Present exposures are not sufficient to outline the extent of the deposit, but the general area merits investigation as it is not difficult of access. The country rocks are pre-Cambrian granite, schist, and hornblende gneiss with some later pegmatite. The vermiculite is in steeply-dipping alteration zones in the hornblende gneiss.

Hydrocarbons* — Park County embraces all of the intermontane basin known as South Park, but no production of oil or gas has as yet been discovered. The complex, faulted nature of the basin requires more detailed geologic and geophysical data, supplemented by test-well control, than is currently available to the operators for a successful approach to a comprehensive program of exploration. Prospective objectives for possible hydrocarbon accumulations include: the Lower Cretaceous Pierre formation, approximately 250 to 300 feet above its base; fractured zones in the Pierre, Niobrara, and Benton shales; the Carlile and Codell sandstones at the top of the Benton group; the Dakota sandstone, and the Jurassic sandstones of the Morrison and Entrada formations. Of secondary importance are beds in the Paleozoic sequence, starting with the basal section of the Weber (Pennsylvanian) and including limestones and dolomites of the Leadville (Mississippian) and Manitou (Ordovician) formations, and the Harding sandstone of Ordovician age.

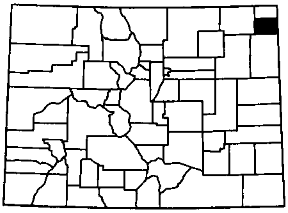
Geological Note—Approximately three-quarters of the County's area lies in igneous terrane. The northeastern part is occupied by a series of northwesterly trending mountains belonging to the Front Range complex; these include the Platte River Mountains, the Kenosha Mountains, and the Tarryall Mountains. The pre-Cambrian crystalline core of these uplifts, consisting of metamorphic rocks, granites, and related rocks, is exposed as far south as the South Platte River in the southeastern part of the County. The southern portion is covered by Miocene extrusive rocks consisting of basalt, andesite, latite, rhyolite, and other related volcanic rocks.

West of the pre-Cambrian area is the north-south trending intermontaine basin known as South Park which lies in sedimentary terrane extending laterally to the western confines of the County. The western boundary of the County runs along

*Mr. A. W. Cullen, Consulting Geologist, Denver, written communication.

the crest of the Mosquito Range, part of the major Park Range. From South Park westward are exposed sedimentary rocks in the following sequence: Eocene rocks of the Middle Park formation; Upper Cretaceous rocks of: the Laramie formation around the Michigan syncline, Pierre shale, Niobrara group, Benton group, and Dakota sandstone; Jurassic rocks, including the Morrison formation; Permian, Pennsylvanian, Mississippian, Devonian, Ordovician, and Cambrian rocks.

In the southwestern part of the County, along Agate Creek, there is an exposure of Miocene rocks, possibly of Florissant Lake beds age. Quaternary morainal and terrace deposits occur in the valley of the South Platte River and some of its tributary streams, from Howbert to Breckenridge.



Courtesy Colorado Planning Division

Phillips County

Phillips County, located near the northeastern corner of the State, has a population of 4,800 and an area of 680 square miles ranging in elevation from 3,600 to 3,900 feet above sea level. The County seat is at Holyoke, a farming and business community of 1,500 population.

Available Maps of the County—

a. Phillips County Map.

b. U. S. Army Map Service maps: 5464 I; 5465 II; 5564 I, IV; 5565 II, III.

Mineral Production—The only minerals produced in Phillips County are small quantities of sand and gravel. Natural gas was discovered several years ago, but the lack of developed markets prevented production.

Sand and Gravel—Sand and gravel have been produced from the courses of Frenchman Creek and some of its tributaries in the vicinity of Holyoke and to the west of it. The U. S. Bureau of Mines gives the following values for sand and gravel production beginning with 1953.

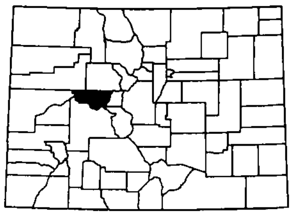
1953	$18,114
1954	3,967
1955	----
1956	8,000
1957	3,700
1958	4,000

Oil and Natural Gas—No production of natural gas has as yet been established from Phillips County, although gas in apparently commercial quantity was discovered in the Huxton field, section 31, T-9-N, R-47-W, in 1955. The discovery well has remained shut in since completion, but activities now going forward in the area may bring about a development of markets and the beginning of production. The gas horizon is in the 'J' sand, Dakota formation, of Cretaceous age.

*Phillips County is located on the extreme eastern flank of the Denver Basin. It is expected that other gas fields will be discovered in the Dakota rocks, but possibilities of petroleum production from this source are not considered good. The hydrocarbon potential of the older beds has not been explored, but westward expansion of Paleozoic oil production from central Nebraska eventually will provide information on these lower horizons.

Geological Note—The topography of Phillips County consists of low-relief undulating prairie land, with a few minor buttes to the south. The County is surfaced predominantly by Miocene rocks of the Arikaree formation.

Pitkin County



Courtesy Colorado Planning Division

Pitkin County, located in the west-central part of the State, has a population of 2,500 and an area of 975 square miles ranging in elevation from 6,625 to 14,259 at the crest of Castle Peak. The County seat is at Aspen, a progressive winter and summer sports and cultural center with a population of 950.

Available Maps of the County—

a. Pitkin County Map.
b. U. S. Geological Survey maps cover the eastern two-thirds of the County. See index map in the pocket.
c. U. S. Army Map Service maps: 4562 I, II, III, IV; 4662 I, II, III, IV.
d. U. S. Forest Service maps "White River National Forest" and "Grand Mesa National Forest" include the County.

Mineral Production 1946-1958—Pitkin County has been an important producer of precious and base metals, being particu-

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

larly noted for its silver production. Of recent years, this once extremely active mining County has experienced a considerable decline in this industry. Coal and sand and gravel were the only other minerals of any consequence produced since 1950. The following figures are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Lode Mines	Gold Ozs.	Silver Ounces	Lead Pounds	Zinc Pounds	Coal Short Tons	Total $ Value
1946	2	1	41,630	215,000	18,000	----	59,303[1]
1947	2	4	27,757	220,000	23,000	563	59,940[1]
1948	5	9	35,618	218,000	60,000	890	79,553[1]
1949	3	-	32,692	164,000	98,000	4,327	67,652[1]
1950	4	14	30,869	134,000	42,000	6,798	52,482[1]
1951	5	17	10,142	114,000	58,000	7,730	75,610[1]
1952	4	8	1,043	38,000	----	7,328	42,516[2]
1953	3	1	4,392	18,000	4,000	35,928	181,797[2]
1954	2	1	110	4,000	----	88,606	Withheld
1955	1	-	128	2,000	----	91,909	703,517[2]
1956	1	-	497	71,900	----	153,979	1,141,846[2]
1957	1	-	48	200	----	Withheld	Withheld
1958	-	-	----	----	----	Withheld	Withheld

[1] Precious and base metal production value only.
[2] Value of precious and base metals and coal production.

Precious and Base Metals—Pitkin County has produced to date approximately $110 million in precious and base metals; the Aspen district has contributed the major portion of this production. Ute City, now Aspen, was at one time the leading silver producing camp in the world. The largest single mass of native silver ever discovered was found at the Smuggler mine in this district, and weighed over one ton.

Dr. Vanderwilt discusses the established districts of Pitkin County on the following pages of the 1947 edition of this book.

Ashcroft	Pages 176 and 178
Avalanche	178
Frying Pan (Homestake)	178-79
Independence	179
Lincoln Gulch	179-80
Roaring Fork (Aspen, Richmond Hill, Lenado)	180-82
Snowmass	182

Coal—The Carbondale coal field, part of the southeastern portion of the Uinta Coal Region, crosses the western part of Pitkin County, and extends into Garfield County to the north, and into Gunnison County to the south. The Carbondale field is discussed under Gunnison County, on page 151 of this book.

Landis[6] calculates that 17 square miles are underlain by measures containing 404 million short tons of bituminous coal. Of this tonnage, 133 million underlie between 0-to-1,000 feet of overburden, 133 million lie between 1,000 and 2,000 feet below the surface, and 138 million tons are located between 2,000 and 3,000 feet underground.

Uranium* — Small quantities of uranium ore have been mined in the Aspen area. The geology is complex, involving folded and faulted rocks of pre-Cambrian, Paleozoic, and Mesozoic age, with extensive Tertiary intrusives. It is not anticipated that deposits of appreciable importance will be discovered in this area.

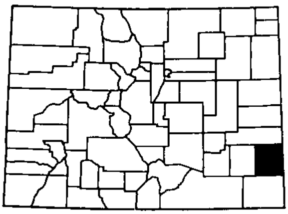
Sand and Gravel — Sand and gravel have been produced from the valley of the Roaring Fork northwest of Aspen. Other sand and gravel deposits occur along the course of the Roaring Fork from Aspen northwestwardly as far as Basalt on the Eagle County line; also along Crystal Creek south of Carbondale; along East Sopris Creek south of Basalt; along the courses of Capitol and Snowmass creeks south of Snowmass, and along Maroon and Castle creeks near Aspen.

Stone—Pitkin County contains a variety of igneous, metamorphic, and sedimentary rocks, some of which have found application in the construction industries: a beautiful gray marble of coarse to fine texture is found near Aspen; granite has been produced in a quarry 10 miles south of Aspen; gypsum occurs in the Pennsylvanian rocks north of Aspen to the County line; lime kilns have operated in the past at Meredith and Thomasville, probably obtaining their limestone requirements from Mississippian rocks along the northwestern flank of the Sawatch Range, and sandstones are found in the central area of the County.

Geological Note—A portion of the northwestern part of the Sawatch Range, a north-south trending, broad, domal uplift, occupies the eastern third of the County. Here are exposed pre-Cambrian granites, schists and related rocks which form the core of the range. To the southeast, in the Grizzly Mountain-Independence Pass area, the pre-Cambrian rocks are overlain by Tertiary igneous flows of basalt, andesite, and related rocks, with Tertiary intrusive rocks in the center of the area. Westward from the mountains are exposed sedimentary rocks in the following sequence: strata of Cambrian and Ordovician age; Devonian and Mississippian rocks including those of the Chaffee formation and Leadville limestone, and Pennsylvanian and Permian rocks. The central area, south of Basalt, is surfaced by Upper Cretaceous rocks of the Dakota sandstone overlain in part by the Mancos shale which is overlain in a small area south of Woody Creek by a remnant of the Mesaverde formation. Around much of the periphery of these Cretaceous exposures, outcrop rocks of Triassic and Jurassic age which include the Entrada and Morrison formations. West of the Cretaceous exposures is the northern extension of the Elk Mountains uplift where Pennsylvanian and Permian rocks

*Dr. Donald L. Everhart, USAEC, personal communication.

are exposed. These are followed to the west by a stratigraphic ascention through a narrow, northerly trending band of Triassic, Jurassic, and Upper Cretaceous rocks. These last include the Dakota sandstone, Mancos shale, and Mesaverde formation. West of these exposures, the surface is predominantly Eocene of the Wasatch formation, and extends westward into other counties. Early Tertiary intrusive rocks occupy the area around Snowmass Mountain and to the north and west of it. Similar intrusives outcrop in a narrow band trending southwesterly from Sopris Mountain, and another, roughly circular body of these intrusives, crops out west and southwest of Ashcroft in the southern part of the County. Quaternary terrace and morainal deposits occur in the valley of the Roaring Fork and those of a number of its tributary streams throughout the County.



Courtesy Colorado Planning Division

Prowers County

Prowers County, located in southeastern Colorado against the Kansas border, has a population of 14,800 and an area of 1,636 square miles ranging in elevation from 3,200 to 4,000 feet above sea level. The County seat is at Lamar, a farming, light industry, and business center with a population of 7,700.

Available Maps of the County—

a. Prowers County Map.
b. U. S. Army Map Service maps: 5459 I, II; 5460 II; 5559 I, II, III, IV; 5560 II, III.
c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

Mineral Production—The only minerals of consequence produced in the County have been sand and gravel. Activity in oil exploration is on the increase with about 90% of the County under lease.

U. S. Bureau of Mines Minerals Yearbooks give the following values for the County's minerals production beginning with 1953.

1953	$ 66,697—Sand and gravel only
1954	137,319—Sand and gravel only
1955	55,255—Sand and gravel only
1956	87,000—Sand and gravel only
1957	62,900—Sand and gravel only
1958	112,400—Sand and gravel and some stone

Sand and Gravel — Sand and gravel have been produced from the course of the Arkansas River, east and west across the northern half of the County, and from the valleys of its northern tributaries. Other deposits occur in the eastern part between Granada and Plum creeks, between Plum and Two Buttes creeks, and east of the latter to the Kansas border. In the northeastern corner of the County there is an area of reworked sands and gravels of the Ogallala formation of Tertiary age. Another sand and gravel deposit occurs about 5 miles north of Kornman.

Clay—Butler[7] sampled a number of clay strata in various parts of the County, and the results of his tests on these samples disclosed the existence of two deposits of useful clay:

1. Location: On Clay Creek ". . . near a schoolhouse," 8 miles south of Lamar.

   Occurrence: Sampled 6 feet of horizontal material occurring under a sandstone ledge near the top of the Dakota formation along the creek bank.

   The material is a medium-hard, gray to black clay and shale—should make good pink soft-mud bricks and earthenware.

2. Location: On Clay Creek, 5½ miles south of Lamar.

   Occurrence: Sampled 6 feet of horizontal material occurring under a sandstone ledge (near the top of the Dakota?), on the eastern bank of the creek.

   The material is hard, gray to brown, fine-grained clay and shale, burns pink or buff according to the burning temperature, and can be used to manufacture a wide variety of products.

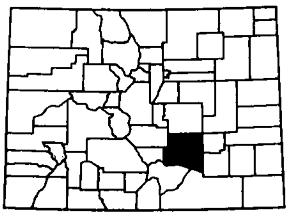
Stone — Some white sandstone has been quarried near Lamar for local construction and flagstone use. The sandstone is probably obtained from the Dakota sandstone which is common near Lamar.

Hydrocarbons—The first discovery in the County occurred in 1958 when a well on the Barrel Springs field, which had been abandoned the previous year, was reworked and brought in at 2.3 million cubic feet of gas per day from the Atoka sandstone of Pennsylvanian age. Total production to the end of 1959 amounted to 1,164 barrels of oil and 2 million cubic feet of gas. About 90% of the County is under lease.

*Prowers County lies on the southern flank of the Las Animas Arch and in the Hugoton Embayment. It is anticipated that other discoveries will be made in the future. The most favorable horizons for future exploration are the sandstones and limestones of the entire Pennsylvanian section, plus possibly the underlying carbonate rocks of Mississippian and Ordovician age.

*Mr. Thaddeus R. Carpen, Continental Oil Co., written communication.

Geological Note—Prowers County lies in sedimentary terrane typical of Colorado's southeastern plains. The Arkansas River crosses the northern half of the County, flowing from west to east, and provides the principal drainage to the area. North of the river, Upper Cretaceous rocks of the Niobrara group predominate, with Benton group rocks exposed over large areas adjoining the river from Bristol west to Wiley, and from Amity east to the Kansas line. South of Lamar, a wide band of Upper Cretaceous rocks of the Dakota sandstone extends southward to the headwaters of North Butte Creek. On either side of this band of Dakota rocks are Upper Cretaceous rocks of the Benton group. The southeastern quadrant, and along the southern border to the west, is surfaced by Tertiary rocks of the Ogallala formation, indented deeply enough by the larger drainages to expose Benton and Dakota beds beneath. A relatively broad band of Recent alluvium has been deposited along the course of the Arkansas River. On the southern border of the County, in the Two Butte area, are several small exposures of Early Tertiary intrusive igneous rocks. The Uplifting effect of these intrusives is indicated by the exposure of older rocks in this area: the Permian Lykins formation; the Jurassic Morrison formation, and Upper Cretaceous rocks of the Purgatoire formation and Dakota sandstone.



Courtesy Colorado Planning Division

Pueblo County

Pueblo County, located in the south-central part of the State, has a population of 120,000 and an area of 2,414 square miles ranging in elevation from 4,350 feet in the east to over 8,000 in the southwestern portion. The County seat is at Pueblo, a steel industry, commerce and business center with a population of about 100,000.

Available Maps of the County—

a. Pueblo County Map.

b. U. S. Army Map Service maps: 4960 II; 5059 I, IV; 5060 I, II, III, IV; 5159 I, IV; 5160 I, II, III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

d. U. S. Forest Service map "San Isabel National Forest" covers a small portion of the County.

Mineral Production—Pueblo County produces principally nonmetallic minerals for the construction industries. Sand and gravel, clays, and stone accounted for 98% of the total value of the County's mineral production during 1958. The U. S. Bureau of Mines has released the following figures on mineral production beginning with 1951.

Year	Sand & Gravel Short Tons	Clay Short Tons	Total $ Value
1951	Withheld	86,033	505,942[1]
1952	Withheld	81,716	573,311[1]
1953	Withheld	86,240	848,012[1]
1954	940,000	67,993	793,880[1]
1955	986,000	78,107	949,396[1]
1956	985,500	73,191	1,004,732[1]
1957	992,000	67,840	1,183,273[1]
1958	2,454,000	70,067	2,026,975[2]

[1] Value of sand and gravel and clay production only.

[2] Same as [1] but includes value of uranium ore production and some stone.

Sand and Gravel—An accelerated State Highway construction program raised Pueblo County to the lead in the production of sand and gravel during 1958.

Sand and gravel have been extracted from the courses of: the Arkansas River east and west across the County; Fountain Creek from Pueblo north to the El Paso County line; the Saint Charles River, Graneros Creek, and other tributaries of the Saint Charles to the south and southwest of Pueblo. Other extensive sand and gravel deposits are abundant throughout the County: to the south, east, and north of Whiterock; along Mustang Creek; north of Waremart; along Chicosa Creek, the Cucharas River, Sixmile Creek, Chico Creek; northwest of Pinyon; along Dry Creek, and other areas.

Clays[52]—Refractory clay and semirefractory clay production began in Pueblo County during the ending decade of the last century. Flint clay high in alumina (average 35% Al_2O_3) is restricted to the Dry Creek Canyon member of the Dakota sandstone of Upper Cretaceous age. Low grade refractory and semirefractory plastic clay are associated with the flint clay and also occur in lenses at the top of the Glencairn shale member of the Purgatoire formation of Lower Cretaceous age, and in at least one locality, in the top of the Dakota sandstone. The various clay producing districts are discussed below.

Turkey Creek District[52]—This district is located in the northwest corner of the County where the Dakota and Purgatoire formations crop out over an area of about 18 square miles. The clay mining community of Stone City is located on the southwestern fringe of the area, with Turkey Creek flowing southwardly along its eastern margin.

[52]The Turkey Creek district lies along the crest of the Turkey Creek anticline which plunges southeastward away from the south end of the Front Range. Over most of the district the anticline has been stripped to the Purgatoire and

Dakota beds. Only the clay of the Dry Creek Canyon member of the Dakota formation is known to be of minable thickness and grade in this district. The Glencairn shale member of the Purgatoire formation is poorly exposed, but where its upper clay-bearing part is observable, it consists predominantly of sandy clay and shale with considerable intercalated sandstone.

[52]The district's active mining area is located around Stone City and occupies about 2½ square miles of the Dakota-Purgatoire outcrop along the southwest limb of the Turkey Creek anticline. Another area, called the Hell Canyon area, contains undeveloped minable deposits of refractory clay in the Dry Creek Canyon member of the Dakota sandstone; it lies north of the Stone City area along Turkey Creek on the east side of the district.

[52]Structurally, the Hell Canyon area lies chiefly on the northward striking east limb of the anticline. The dips seldom exceed 5 degrees, and average 3 degrees. Flint clay is the principal type of clay in this area, but plastic clay is locally developed to a considerable thickness.

Several tracts of relatively large extent within the Hell Canyon area are known to contain the Dry Creek Canyon member of the Dakota sandstone. Even though little or no clay may be evident at the outcrop of this member, such tracts merit exploration by core drilling. The average depth of the holes would be about 40 feet, and the spacing of the holes for exploration purposes could be up to a maximum of 800-ft. centers. Waage delineates in detail on page 69, reference No. 52 of the bibliography, some of the more favorable tracts for exploration in the Hell Canyon area of the Turkey Creek district.

The estimated (1953) reserves of refractory clay in the Turkey Creek district are, in short tons:

	Indicated	Inferred	Total
Flint Clay			
Stone City Area	656,000	326,000	982,000
Hell Canyon Area	800,000	725,000	1,525,000
Totals	1,456,000	1,051,000	2,507,000
Plastic Clay			
Stone City Area	246,000	180,000	426,000
Hell Canyon Area	----	762,500	762,500
Totals	246,000	942,500	1,188,500

Beulah District—This district, located in the southwestern part of the County, consists of a broad flat developed on the Dakota sandstone. The entire area is broken by numerous northwest-trending faults which seldom exceed 100 feet in displacement. The eastern margin of the district is marked by a strike fault that brings the Dakota to the surface. The basal beds of the Graneros shale crop out over limited areas in the eastern part of the district, and the Purgatoire is exposed in many canyons which cut through the Dakota in the western part of the flat.

The clay-bearing Dry Creek Canyon member of the

Dakota sandstone is locally present in the southeastern part of the district along Rock Creek, where it is known to contain flint and plastic clay in commercial quantities, but it is not known to contain flint clay in economic deposits elsewhere in the district.

The Rock Creek area is traversed by the northwestward-trending Rock Creek fault, which is a zone of discontinuous strike-faults downthrown to the east, with maximum displacements in the center of the area from 60 to 90 feet. Outcrops of the clay-bearing zone of the Dry Creek Canyon member of the Dakota are scarce, but the clay beds in the mines range in thickness from 3 to 15 feet, with an average of 6 to 7 feet.

Capers Area—This clay area is located in the southwestern part of the County and extends into Huerfano County. See page 161 under Huerfano County for a discussion of this area.

Rye Area—South of Beulah, and just north of the settlement of Rye in the southwestern corner of the County, there is an area of Dakota exposures which Waage considers worthy of exploration:

"Among the more important areas in this category . . ." (deserving of careful re-examination for clay deposits) ". . . are the outcrop areas of the Dakota in southwestern Pueblo County around the settlement of Rye."

Butler[7] took two samples from the western extremity of these exposures with the following results:

1. Location: About 3 miles west-southwest of Graneros in a canyon tributary to Graneros Creek; about ¾ mile east of the hill which deflects the stream at its mouth.

   Occurrence: Sampled a 4-ft bed striking N-60-W and dipping 45 degrees northerly, in the south bank of the arroyo. "May be of Purgatoire age."

   Material: Very hard, dark-gray sandy shale with a 4″ coaly streak at the base. A "first-class fire clay."

2. Location: In the same arroyo as the previous sample but ¼-mile farther east from the hill which deflects the stream at its mouth.

   Occurrence: Sampled a 4-ft. bed striking N-60-W and dipping 40 degrees northerly, occurring in the bed of the arroyo.

   Material: Very hard, gray, somewhat sandy clay interbedded with thin sandstone layers not included in the sample. A "first-class fire clay."

Stone—Limestone for use as riprap and road and street construction has been quarried west of Pueblo. A large deposit at lime has been quarried extensively since 1877 for use in the steel furnaces at Pueblo. Other quarries have produced limestone for various purposes, including beet sugar refining, from a high-calcium limestone deposit 1 mile west of Beulah. Coarse-grained white marble with red and chocolate concentric markings has also been quarried from the Beulah area.

Sandstone for use in construction has come from the Turkey Creek area in the northwestern part of the County. Silica rock has also been quarried in this area for use in the Pueblo steel furnaces.

[9]Gypsum has been mined by open-pit methods just south of Stone City, and another mine produced an appreciable tonnage from an 8-foot thick bed five miles northwest of Stone City.

Lightweight Aggregates — Bush[28] reports the existence of a vermiculite deposit in either section 5 or 8, of T-24-S, R-68-W, about 2 miles east of San Isabel. The country rock is a medium-to-coarse-grained pink granite with some gneissic structure, which is cut by altered peridotite dikes and aplitic pegmatites. The vermiculite occurs in thin, roughly vertical alteration zones in the peridotite, up to 6″ in thickness, and generally, over the entire length of the peridotite. The thinness of the altered zones would probably result in an uneconomical operation at this time.

Uranium*—The only uranium occurrences of interest in the County are the "bedded-type" deposits in a sandstone unit of the Cretaceous Dakota formation, on the eastern flank of the Turkey Creek anticline in the northwest corner of the County. Indications are that only small, scattered ore bodies occur in the area. The U. S. Bureau of Mines credits the County with two active mines during 1958, which produced 9,917 lbs. of contained U_3O_8, valued at $40,418.

Hydrocarbons Potential**—Pueblo County is located on portions of several major structures: the northeastern part is on the southwest flank of the Denver Basin; the southern and southwestern parts are on the Apishapa Uplift, and the northwestern part on the Red Creek arch and the Canyon City Embayment. Numerous wells, many of them located on well-defined structures, have been drilled, but with negative results. Nevertheless, it is expected that periodical exploratory drilling on a moderate scale will continue because of the possible presence of structural and stratigraphic traps. The favorable propsective zones for exploration include: the Cretaceous beds of the Pierre shale, Niobrara formation, Codell sandstone, and Dakota sandstones; the Permian Lyons sandstone, and the carbonate rocks of Mississippian and Ordovician age.

Geological Note—Only a small portion of the County, along the southwestern boundary, lies in pre-Cambrian crystalline terrane. In this area, west of Beulah and of Rye, are exposed schists and gneisses, core of the southern extremity of

*Dr. Donald L. Everhart, USAEC, personal communication.

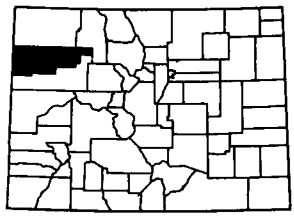
**Mr. Thaddeus R. Carpen, Continental Oil Co., written communication.

the Wet Mountains. Along the eastern fringe of this area west of Beulah are small isolated exposures of Cambrian and Ordovician rocks, followed easterly by Pennsylvanian, Permian, Jurassic, and Cretaceous rocks. In the northwestern corner north of Stone City, are: Permian rocks of the Lykins formation, undivided Triassic rocks, Jurassic Morrison beds, and Cretaceous rocks of the Purgatoire and Dakota formations. Beyond this area in the northwest quadrant, Upper Cretaceous rocks of the Niobrara group predominate, with Dakota sandstone in the northwest fringed by Upper Cretaceous rocks of the Benton group. A 15-mile wide band of Upper Cretaceous rocks of the Pierre shale extends from Undercliffe, south of the Arkansas River, northward beyond the Arkansas and along Fountain Creek into El Paso County. To the east of these Pierre rocks north of the Arkansas, the surface is formed by Miocene-Pliocene rocks of the Ogallala formation. Small remnants of this Ogallala material are found scattered over other portions of the County.

The southern half of the County, south of the Arkansas, is surfaced predominantly by Niobrara rocks, with an irregular, northwesterly-trending band of Benton exposures separating the Niobrara from Dakota rocks exposed along the southern border.

Pliocene rocks of the Nussbaum formation cover several irregular areas northeast of Pueblo. A few northeastward-trending Tertiary intrusive dikes, possibly the northeasternmost exposures of the Spanish Peaks system, outcrop to the southwest of Whiterock. Quaternary terrace deposits cover several irregularly shaped areas from Pueblo northward on both sides of Fountain Creek, and also the area along the Arkansas River valley from west of Pueblo to east of Avondale. Recent alluvium occupies much of the valley floors of the Arkansas River and several of its tributaries.

Rio Blanco County



Courtesy Colorado Planning Division

Rio Blanco County, located in the western corner of the State bordering on Utah, has a population of 5,000 and an area of 3,264 square miles ranging in elevation from 5,800 to 12,190 feet above sea level. The County seat is at Meeker, an oil, farming, ranching and business center with 1,660 population.

Available Maps of the County—

a. Rio Blanco County Map.

b. U. S. Army Map Service maps: 4263 I, II, III, IV; 4264 II, III; 4363 I, II, III, IV; 4364 II, III; 4463 I, IV; 4464 II, III; 4563 IV; 4564 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover all but the extreme eastern and southwestern parts of the County. See index map in the pocket.

d. U. S. Forest Service map "White River National Forest" includes the eastern portion of the County.

Mineral Production 1946-1958—Rio Blanco County is the leading producer of petroleum in the State. Coal, uranium ore, sand and gravel, and some stone were also produced during the period. The petroleum production figures in the following table are from records of the Colorado Oil and Gas Conservation Commission; all others are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Petroleum Barrels	Coal Short Tons	Total $ Value
1946	10,606,372	10,468	--
1947	14,427,930	14,623	--
1948	16,671,757	21,393	--
1949	22,221,143	32,907	--
1950	21,640,331	38,783	--
1951	24,994,121	35,661	--
1952	25,354,852	40,174	177,749[1]
1953	25,759,486	22,960	243,936[1]
1954	25,737,101	18,538	69,602,681[2]
1955	26,413,865	20,046	72,135,825[3]
1956	30,651,844	18,630	85,280,520[4]
1957	28,471,587	12,901	86,151,998[4]
1958	23,280,029	12,653	69,341,011[5]

[1] Value of coal, sand, and gravel production only.
[2] Same as [1] but includes value of oil production.
[3] Same as [2] but includes the value of stone production.
[4] Same as [2] but includes value of uranium ore production.
[5] Same as [4] but includes the value of stone production.

Hydrocarbons—Petroleum and natural gas are by far the principal mineral products of Rio Blanco County. The value of the petroleum produced has for a number of years contributed all but a small portion of the total value of the County's mineral production.

*The State's largest oil field was discovered in 1902 when light oil was struck in the porous part of calcite veins in the Mancos shale (Cretaceous) at depths varying from 500 to 1,700 feet. This was the beginning of the large Rangely oil field in the northwestern corner. In 1933, a "deep" test was made in the Rangely structure which struck oil in the Weber formation at 5,700 feet and became the first well in the State to develop oil in Pennsylvanian beds.

As of the end of 1959, there were active in the County three oil-gas fields, one oil field, and three gas fields, with an

*A. E. Brainerd and F. M. Van Tuyl in reference No. 1 of the bibliography.

aggregate production for the year of 20,554,897 barrels of oil and 59,856 million cubic feet of natural gas. The cumulative aggregate production, up to that time, totaled 325,983,948 barrels of oil and 395,275 million cubic feet of gas. The petroleum section in this book contains detailed statistics.

*Rio Blanco County includes the northern portion of the Piceance Creek Basin, the Douglas Creek Arch, and a very small portion of the Uinta Basin. The possibilities for the extension of existing fields and for the development of new producing areas are excellent.

Coal—Much of the northern part of the Uinta Coal Region is located in Rio Blanco County.

Landis[6] calculates that 711 square miles are underlain by measures containing 9,852 million tons of bituminous coal. Of this tonnage, 1,786 million tons lie between 0-to-1,000 feet underground, 1,218 million tons are between 1,000 to 2,000 feet below the surface, and 6,848 million lie under 2,000 to 3,000 feet of overburden.

The following three coal fields extend into Rio Blanco County from Moffat and Garfield and have been discussed in preceding pages under those counties.

1. Lower White River Field—Moffat County, page 210.
2. Danforth Hills Field—Moffat County, page 210.
3. Grand Hogback Field—Garfield County, page 139.

Uranium**—Uranium ore bodies occur in the Morrison formation of Jurassic age and in Upper Triassic formations on the northwest flank of the White River Uplift northeast of Meeker. The uranium-vanadium deposits are scattered and of modest size, and the probabilities of discovering ore bodies of substantial tonnages are reduced.

The Atomic Energy Commission has released the following uranium production and value figures beginning with 1955:

Year	Operations	U_3O_8-lbs.	$ Value
1955 (Jul-Dec)	11	3,777	16,585
1956	12	12,845	55,983
1957	8	Withheld	Withheld
1958	13	40,417	174,773

Sand and Gravel — Sand and gravel have been produced from the course of the White River in the vicinity of Meeker and southwest of it, and along State Highway 64 to west of Rangely; from Curtis and Good Spring creeks north of Meeker along State Highway 73-789; from Flag Creek south of Meeker, and from Piceance Creek and some of its tributaries in the vicinity of the settlement of Rio Blanco. Other sand and gravel deposits occur along the course of the White River and some of its tributaries in scattered areas of the County.

Oil Shale—Rio Blanco County contains a large portion of the Piceance Creek Basin oil shale reserves. In the oil shale

*Charles C. O'Boyle, Consulting Geologist, Denver, written communication.
**Dr. Donald L. Everhart, USAEC, personal communication.

section of this book are discussed the potentialities of this future industry and its importance to Colorado and the Nation.

*Estimated shale oil reserves in Rio Blanco County, based on the total oil content of the shale within its boundaries, are as follows:

Indicated potential	162,997	million barrels
Inferred potential	735,727	million barrels
Total	898,724	million barrels

The above figure includes only what may be considered potentially economic shale, with a minimum kerogen content of 15 gallons per ton of shale; it does not take into consideration retorting and other losses and consumption in extraction.

The following figures represent a breakdown of the total "economic" reserves by category of kerogen content in the shale.

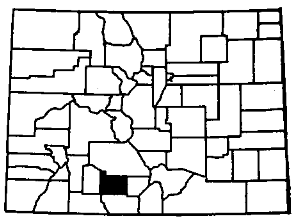
45 gallons of kerogen per ton of shale		
Indicated potential	489	million barrels
Inferred potential	333	million barrels
30 gallons of kerogen per ton of shale		
Indicated potential	9,337	million barrels
Inferred potential	49,036	million barrels
25 gallons of kerogen per ton of shale		
Indicated potential	14,577	million barrels
Inferred potential	89.891	million barrels
15 gallons of kerogen per ton of shale		
Indicated potential	138,594	million barrels
Inferred potential	596,467	million barrels
TOTAL	898,724	million barrels

Geological Note—In the eastern part of the County, the Flat Tops and other isolated areas are capped by flows of andesite and basalt of Tertiary and possibly Early Quaternary age which overlie Cretaceous rocks. The remainder of the County lies in sedimentary terrane. In the northeastern portion, Upper Cretaceous Mancos shale predominates, with Upper Cretaceous Mesaverde rocks exposed from under the protective volcanic caps in some of the areas. In the southeastern corner, in the area of the Flat Tops volcanic cap, the White River uplift has brought older rocks to the surface; these include pre-Cambrian rocks exposed where drainage has incised deeply. In this area, near the center of the White River Plateau, are exposed undivided rocks of Lower Paleozoic and Pennsylvanian age surrounded by Permian rocks. Around the fringes of the Plateau, to the north and west, are exposed: undifferentiated Permian and Triassic rocks; Jurassic rocks including the Morrison formation; the Upper Cretaceous Dakota sandstone, and, along the Grand Hogback and the Danforth Hills to the north, Upper Cretaceous rocks of the Mancos shale, Lewis shale, and Williams Fork formation. West of the Cretaceous exposures, a narrow, north-trending band of Tertiary rocks of the Wasatch formation (Lower Eocene) marks the eastern boundary of the Piceance Creek basin.

*Reduced from data in reference No. 53 of the bibliography.

The Piceance Creek Basin is an elongated northwesterly-trending structural and topographic basin, with a northerly extension projecting from its northeastern part known as the Gray Hills. The erosion resistant lacustrine Green River formation of Middle Eocene age occupies the central portion of the Basin and forms conspicuous highlands. The Roan Plateau, along the southern boundary of the County, is an east-west trending ridge which forms a drainage divide. Thus, the Rio Blanco County portion of the Basin is incised by numerous northerly flowing streams tributary of the northwesterly-to-northerly flowing Piceance Creek which crosses near the center of the area. In the central part of the Rio Blanco portion of the Basin, the Green River formation is overlain by Eocene rocks of the Bridger formation. The Cathedral Bluffs, rising 2,500 feet above Douglas Creek to the west, mark the western extremity of the Plateau. Here, a fringing exposure of Lower Eocene Wasatch formation, underlying the Green River formation, crops out, followed to the west, along the valley of north-flowing Douglas Creek, by Upper Cretaceous rocks of the Williams Fork formation. The creek itself has cut through the Williams Fork beds to expose the underlying Iles formation of Upper Cretaceous age. Ravena Park, in the northwestern corner, is surfaced in the center by Mancos shale surrounded by the younger rocks of the Iles and Williams Fork formations. The extreme western and southwestern parts of the County are mantled by rocks of the Wasatch formation with local remnants of Green River beds capping occasional buttes or mesas.

Rio Grande County



Courtesy Colorado Planning Division

Rio Grande County, located in south-central Colorado, has a population of 13,000 and an area of 916 square miles ranging in elevation from 7,600 to 13,189 feet above sea level. The County seat is at Del Norte, a farming, sheep raising, and business community with 2,250 population.

Available Maps of the County—

a. Rio Grande County Map.

b. U. S. Army Map Service maps: 4658 I; 4659 I, II; 4758 I, IV; 4759 II, III.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

d. U. S. Forest Service map "Rio Grande National Forest" covers most of the County.

Mineral Production 1946-1958—Rio Grande County has been a desultory producer of metallic minerals. The value of metallic ores produced since 1870 to date totals approximately $7½ million. Some gold, silver, copper, gems, and sand and gravel were produced during the period. The following figures are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Lode Mines	Gold Ounces	Silver Ounces	Copper Pounds	Total $ Value
1946	1	1,834	2,334	14,000	68,347[1]
1947	1	2,129	2,442	18,500	80,956[1]
1948		--	--		--
1949	1	82	201	4,000	3,840[1]
1950	-	--	--	--	--
1951	-	--	--	--	--
1952	-	--	--	--	--
1953	-	--	--	--	132,240[2]
1954	1	19	7	--	671[1]
1955	1	28	4	--	994[3]
1956	-	--		--	235,150[1]
1957	-	--	--	--	93,600[4]
1958	1	6	14	2,814	3,037[5]

[1] Value of precious and base metals production.

[2] Value of sand and gravel production only.

[3] Value of precious metals mineral production and gem stones.

[4] Value of sand and gravel and gem stone production.

[5] Same as [1] but includes sand and gravel production.

Precious and Base Metals—The mining districts established in this County are discussed by Dr. John W Vanderwilt on the following pages of the 1947 edition of this book.

Rio Grande County Production	Page 183
Embargo-Jasper District	182
Summitville	184-86

Since the late 1940's, activity in metal mining has been confined mostly to exploration and development work.

Sand and Gravel — Sand and gravel have been produced from the course of the Rio Grande north and northwest of Monte Vista, in the vicinity of Del Norte and between it and the settlement of South Fork; from South Creek south of South Fork town, and from several tributaries of the Rio Grande in the southeastern corner and also from near the Rio Grande canal northeast of Del Norte. Other sand and gravel deposits occur on both sides of the Rio Grande, as well as between Rock Creek and Monte Vista, and between Rock Creek and Gato Creek in the south.

Gem Stones—Schlegel[24] reports the ocurrence of plume agate, chalcedony, opal, and quartz crystal in the vicinity of Del Norte.

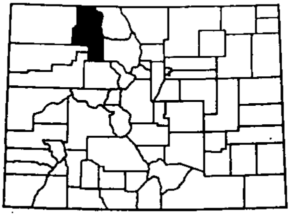
Alunite (hydrous aluminum and potassium sulphate; possible source of potash and alumina)—Argall[9] reports the existence of large deposits of alunitic rocks in sections 8 and 17, T-37-N, R-5-E, on Marble Mountain. The material was formed as replacement of andesitic tuff and breccia over an area of 50 acres to a depth of 8 feet. The rock contains 18.80% Al_2O_3 and 2.22% K_2O, and shows 12.52% loss on ignition.

Stone—Cross and Larsen[146] report that volcanic tuff was regularly quarried and shipped to Denver and other points from beds a few miles southeast of Del Norte. Large quantities of this light-pink to nearly white rock are available. It is easily quarried and is sufficiently indurated to make a fairly strong, durable, and attractive building stone. The tuffs belong to the Potosi volcanic series of Miocene age, and are in general of Treasure Mountain latite, with some of Alboroto quartz latite.

Geological Note—The eastern extremity of the County, from Monte Vista eastward, and along the valley of the Rio Grande from Monte Vista northward to Del Norte and thence westward across the northern part, is surfaced by Quaternary alluvium. Monte Vista, the largest town in the County, is located on the western margin of the San Luis Valley. The valley is a structural basin bordered on the east by the Sangre de Cristo Range, and on the west by the San Juan Mountains. West of Monte Vista there is a narrow north-south band of Quaternary alluvial fan and torrential deposits which at the latitude of Del Norte broaden westward beyond the town. These alluvial sediments border the eastern margin of the San Juan Mountains.

The San Juan Mountains are a dissected dome composed mostly of Tertiary volcanic rocks which in Rio Grande County belong chiefly to the Potosi volcanic series, and younger flows along the eastern front. The Potosi eruptives covered an area 10,000 square miles and have an estimated volume of about 4,000 cubic miles. The succession of rocks from bottom to top is: dark quartz latite; (erosion of canyons); rhyolite, dark quartz latite; (erosion of canyons); rhyolite, dark quartz latite; (erosion of canyons); rhyolite; (erosion of canyons); quartz latite.

The eastern front of the mountains in the southern part is composed of Pliocene(?) latite-basalt flows of the upper member of the Hinsdale formation, and of Miocene-Pliocene (?) quartz latite flows and clastic beds of Los Pinos gravel. To the north, along the eastern front of the mountains, are quartz latite rocks of the Piedra rhyolite, Huerto latite, and quartz-hornblende rhyolite, all of them upper members of the Potosi volcanic series. West of these rocks, north and south of the Rio Grande, are extensive flows of Conejos quartz latite, the lowest member of the Potosi volcanic series. The westernmost part of the county is mantled by a repetition of the younger rocks exposed along the eastern front of the mountains. Quaternary land slides and mud flows occur locally in scattered parts of the mountains.



Courtesy Colorado Planning Division

Routt County

Routt County, located in northwestern Colorado bordering on Wyoming, has a population of 8,900 and an area of 2,231 square miles ranging in elevation from 6,230 to 12,065 feet above sea level. The County seat is at Steamboat Springs, a ranching, resort, petroleum, and business center with 2,200 population.

Available Maps of the County—

a. Routt County Map.

b. U. S. Army Map Service maps: 4564 I, IV; 4565 I, II, III, IV; 4663 I, IV; 4664 I, II, III, IV; 4665 I, II, III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover the northern three-fourths of the County. See index map in the pocket.

d. U. S. Forest Service maps "Routt National Forest" and "White River National Forest" cover the County.

Mineral Production 1946-1958—Coal and petroleum are Routt County's principal mineral products. Pumice, sand, gravel, and some precious and base metals were also produced during the period. The petroleum figures in the following table are from records of the State Oil and Gas Conservation Commission, all others are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Coal Short Tons	Petroleum Barrels	Total $ Value
1946	896,303	39,967	1,759[1]
1947	1,016,823	40,354	----
1948	939,875	41,290	----
1949	807,289	50,185	----
1950	832,854	62,824	
1951	676,021	40,055	3,197,579[2]
1952	686,970	35,548	3,320,813[2]
1953	614,500	38,675	2,922,807[3]
1954	444,233	45,204	2,216,632[4]
1955	525,039	42,691	2,721,929[5]
1956	489,938	65,197	2,461,122[6]
1957	465,065	94,498	2,280,623[6]
1958	399,169	161,000	2,082,125[7]

[1] Value of some precious and base metal production only.

[2] Value of coal production only.

[3] Value of coal, pumice, and sand and gravel production.

[4] Same as [3] but includes value of petroleum, copper, and silver.

[5] Same as [4] but excludes copper and silver.

[6] Same as [4] but includes some gold production.

[7] Same as [6] but excludes copper and gold, and includes zinc.

Coal — The Yampa coal field, which Routt shares with Moffat County to the west, is located within the southeastern extremity of the Green River Coal Region in the western half. The Yampa coal field has been discussed in foregoing pages under Moffat County.

Landis[6] estimates that 415 square miles of the County are underlain by measures containing 8,485 million tons of coal, of which 1,310 million tons are subbituminous and 7,175 are bituminous. Of the total tonnage, 5,000 million tons are estimated to underlie from 0-to-1,000 feet of overburden, 3,130 million tons are between 1,000 and 2,000 underground, and 355 million lie between 2,000 and 3,000 feet below the surface.

Hydrocarbons—Oil was first discovered in 1924 on the Tow Creek structure in the central part about 14 miles west of Steamboat Springs. The production came from fractures in the Mancos shale of Upper Cretaceous age.

As of the end of 1959, there were four oil-gas fields and one oil field active in the County, with an aggregate production for the year of 113,813 barrels of oil and 45 million cubic feet of natural gas. The cumulative aggregate production for the County, up to that time, totaled 2,776,498 barrels of oil, and 554 million cubic feet of gas.

*Routt County includes the eastern flank of the Sand Wash basin and the northern plunge of the White River Uplift. The oil and gas future of the County is bright, as the prospects for extension of the present type of production, and the discovery of other accumulations in younger and in older reservoir beds, are excellent.

Precious and Base Metals—Production of precious and base metals in Routt County has been of limited economic consequence. The total aggregate value of their production since 1873 to date does not exceed $500,000.

Dr. John W Vanderwilt discusses the mining districts established in Routt County on the following pages of the 1947 edition of this book:

Copper Ridge	Page 186
Hahns Peak (Columbine)	186-88-89
Routt County Production	187
Oak Creek	189
Rock Creek (Gore Range)	189
Slater (or Three Forks)	189-90
Slavonia	190
Spring Creek (Steamboat Springs)	190
Yarmony	190-91

Scoria—Scoria is produced a few miles north of McCoy in the southernmost part of the County. The material has been

*Mr. Charles C. O'Boyle, Consulting Geologist, Denver, written communication.

used as concrete aggregate and railroad ballast. Bush[28] lists two deposits in the McCoy area:

Crater Deposit[28]—This deposit is located in section 16, T-1-S, R-83-W, six miles by dirt road from McCoy. Scoria comprises the bulk of a rounded volcanic cone which lies upon the flat surface of Conger Mesa. The cone is approximately 225 feet high and about 2,000 feet in diameter at the top. The scoria bed is about 200 feet thick and overlies dense basalt flows. Most of the material is in the form of bombs or bomb fragments, many of them unexpanded or only partly expanded.

Volcano Deposit[28]—This deposit is 1½ miles northwest of the Crater deposit in section 17 of the same township, and about 7½ miles by dirt road from McCoy. The scoria occurs on a volcanic cone on the west side of Rock Creek which has eroded a large part of the cone, but the remainder has been well exposed by large-scale quarrying operations. In 1951, the workings consisted of two adjacent open cuts which together extended over a length of about 1,100 feet. The working face along the entire length was from 175 to 200 feet high and entirely in scoria. Large tonnages of this material are available. The scoria occurs as bombs and bomb fragments ranging in size from 1 inch to 14 feet long and 2 to 4 feet thick. Varying degrees of expansion have caused a diversity of densities in the material so that it must be graded after crushing. The cone overlies pre-Cambrian granite and Sawatch quartzite.

Sand and Gravel—Sand and gravel have been produced from the course of the Yampa River to the east and west of Hayden. Other sand and gravel deposits occur in a north-northwesterly belt extending from the confluence of Elk River and Willow Creek, through the Hahns Peak-Columbine area, to the confluence of Little Snake River and South Fork on up into Wyoming; also southwest of Steamboat Springs south of the Yampa River, in a roughly triangular area which extends westward from Steamboat Springs to Milner, and south for about 8 miles. Other smaller deposits are scattered in various parts of the County.

Routt County's production of sand and gravel in 1958 amounted to 15,000 short tons valued at $12,000.

Clay—Butler[7] sampled clay beds in the vicinity of Steamboat Springs and to the west of it, and located two deposits of possible utility:

1. Location: On the eastern side of Saddle Mountain 12 miles west of Steamboat Springs, on Bear River half-mile above its junction with Trout Creek.

   Occurrence: Sampled a 50-ft. exposure of medium-hard, light-gray, fine-grained clay containing more or less gritty material, striking S-60-W, dipping 5 degrees southeasterly, which occurs 100 feet above the river, in a bluff.

Remarks: "Should make good, red pressed bricks with rather high absorption."

2. Location: "On the Harvey Woolery Ranch 1¼ miles northwest of Steamboat Springs."

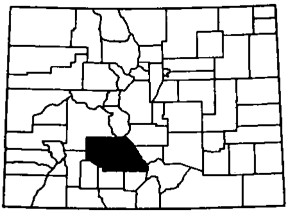
   Occurrence: Sampled a 100-ft. exposure of hard, gray, fine-grained shale with several sandstone streaks at the base which strikes due north and dips 7 degrees westerly, and occurs at the top of a bluff on the west side of Bear River; "in the lower Benton division of the Mancos formation."

   Remarks: "It is reported that tests have been made on this clay and that good light, flesh-tinted pressed bricks were made from it, but the absorption is too high for a good grade of face bricks."

Stone—Routt County has a variety of igneous, metamorphic, and sedimentary rocks, some of which are suitable for use in the construction industries. Aurand[128] reports a deposit of onyx marble on the south side of the Yampa River southwest of Steamboat Springs. The blocks are somewhat limited in size, but the marble is well suited for ornamental purposes and has been used as such. Argall[9] reports that "Good slabs, some as large as five by twelve feet, have been quarried" from this locality.

Geological Note—The extreme eastern part of Routt County lies in pre-Cambrian terrane of the Park Range, with the northern half of its eastern boundary coinciding with the Continental Divide. It is estimated that the amount of uplift represented by the Park Range probably exceeds 20,000 feet. The exposed pre-Cambrian crystalline core of the range comprises hornblende gneiss and greenstone, granite and related rocks, and schists and gneisses of sedimentary and igneous origin. Quaternary terrace and morainal deposits of varying extent are numerous in the area. On the eastern end of the Elkhead Mountains, in the Hahns Peak-Columbine area, are exposed Early Tertiary intrusive rocks, and folded and faulted sediments ranging in age from Permian to Upper Cretaceous: undifferentiated Permian rocks; undivided Triassic beds; Jurassic rocks including the Morrison formation, and Upper Cretaceous rocks of the Dakota sandstone, and Benton and Mancos shales. A narrow, southerly-trending section of the foregoing sediments extends tilted against the western front of the Park Range from Hahns Peak to south of Steamboat Springs where it is obscured by alluvium of Quaternary age. South of the alluvium, in the Sidney area, and still along the western front of the range, rocks of the Mancos shale surround an extensive remnant of Upper Cretaceous Mesaverde rocks which are capped at their southern end by Late Tertiary volcanic extrusives. Complex geologic conditions exist in the McCoy-Pershing area in the southeastern part of the County.

Here, folding and faulting have brought to the surface pre-Cambrian metamorphic rocks, and sediments of Cambrian and Ordovician age, Pennsylvanian, Permian and Triassic rocks, Jurassic rocks of the Morrison formation, and Upper Cretaceous rocks of the Dakota sandstone. From Steamboat Springs westward, the County lies in sedimentary terrane; the sequence is as follows: Upper Cretaceous rocks of the Mancos shale, Iles formation, Williams Fork formation, Lewis shale, and Tertiary rocks of the Lance and Wasatch formations. The foregoing Upper Cretaceous rocks also occupy the southwestern part of the County which includes the eastern portion of the Williams Fork Mountains. Early and Late Tertiary intrusive rocks in the form of laccoliths, sills, and persistent dikes are abundant in the northern half; Late Tertiary-early Quaternary(?) volcanic flows occur in the southern part.



Courtesy Colorado Planning Division

Saguache County

Saguache County, located in south-central Colorado, has a population of 5,200 and an area of 3,146 square miles ranging in elevation from 7,500 to 14,291 feet above sea level. The County seat is at Saguache, a farming, ranching, and trading community with 1,250 population.

Available Maps of the County—

a. Saguache County Map.

b. U. S. Army Map Service maps: 4659 I, IV; 4660 I, II, III, IV; 4759 I, IV; 4760 I, II, III, IV; 4859 I, IV; 4860 II, III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover a portion of the southern half of the County. See index map in the pocket.

d. U. S. Forest Service maps "Rio Grande National Forest" and "Gunnison National Forest" cover the County.

Mineral Production 1946-1958—Saguache County's production of precious and base metals has been of moderate importance. The value of this production, since 1880 to date, totals approximately $11 million. Of recent years the mining of uranium ore has become the most important single aspect of the mineral industry. Turquoise, sand and gravel, and manganese ore were also produced during the period 1946-58. The figures in the following table are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Lode Mines	Gold Ozs.	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	7	57	28,396	86,000	478,000	480,000	149,533[1]
1947	10	47	21,445	24,200	793,900	236,400	169,061[1]
1948	10	60	19,473	18,000	662,000	482,000	206,234[1]
1949	11	98	21,970	42,000	638,000	738,000	223,904[1]
1950	6	689	30,342	48,000	808,000	464,000	236,528[1]
1951	7	119	24,623	74,000	784,000	538,000	277,906[1]
1952	8	106	14,745	48,000	556,000	364,000	178,611[1]
1953	2	136	4,666	12,000	72,000	----	89,484[2]
1954	5	4	2,938	2,000	140,000	18,000	99,211[3]
1955	3	12	3,101	6,000	112,000	54,000	91,580[2]
1956	5	--	2,958	8,000	111,000	14,100	148,054[4]
1957	3	--	1,339	1,700	26,600	13,500	75,984[4]
1958	6	34	16,866	40,000	522,000	462,000	2,057,193[5]

[1] Value of precious and base metal production only.
[2] Same as [1] but includes production of sand, gravel, and turquoise.
[3] Same as [2] but no turquoise production.
[4] Same as [2] but includes uranium ore production.
[5] Same as [4] but includes manganese ore production. No sand and gravel production.

Uranium—The value of uranium production during 1958 accounted for 90% of the total value of minerals produced in Saguache County. The U. S. Bureau of Mines gives the following production and value figures beginning with 1956.

Year	Number of Operations	Contained U_3O_8-lbs.	$ Value
1956	4	16,916	75,478
1957	5	12,224	52,730
1958	6	465,932	1,894,911

The uranium section of this book contains information on the geology and ore deposits of the uranium occurrences in Saguache County. Dr. Everhart, U. S. Atomic Energy Commission, briefly comments on the potentialities as follows:

"*Outlook*: Varied types of uranium deposits, including two important producing districts in the Cochetopa Creek and Marshall Pass areas, together with favorable geologic settings for extensions or repetitions of ore bodies, indicate high favorability for significant ore reserves in Saguache County.

"*Geology*: In the Marshall Pass and Kerber Creek districts, highly folded and faulted pre-Cambrian rocks and Paleozoic formations ranging in age from Ordovician through Pennsylvanian are surrounded by Tertiary volcanics and Quaternary sediments. In the Cochetopa district, pre-Cambrian rocks are overlain by the Morrison formation, both being transected and mineralized by the prominent Los Ocho fault."

Precious and Base Metals—The various mining districts established in Saguache County are discussed by Dr. Vanderwilt on the following pages of the 1947 edition of this book:

In regard to the Kerber Creek (Bonanza) district, it may be added that appreciable quantities of ore remain unmined. But as pointed out by W. S. Burbank (USGS) on page 446 of the 1947 edition of this book (Vanderwilt), ". . . the comparative shortness of most ore shoots are unfavorable . . . to sustained large-scale production from many of the mineralized fissures in the volcanic rocks." This area is well suited to small operations of the 2 to 4 man type. A modern 100 ton per day froth flotation mill has been installed in the district, so that transportation costs are cut to a minimum. But dearth of leasers to undertake ore extraction, and the depressed condition of the base metals market, has prevented the mill from operating. (See also reference No. 129 of the bibliography.)

Turquoise — The Hall mine, located in the northeastern part 8 miles northwest of Villa Grove, is an important though desultory producer of turquoise. In 1957, the sale of 420 pounds of the gem stone grossed $15,600, or approximately $37 per pound, and ranked turquoise as the second mineral in importance, value wise, produced in the County.

[130]The Hall mine was originally a copper prospect almost 75 years ago. Turquoise was first recognized in the mine in 1893, but was not produced commercially until 1936. The turquoise occurs in veins and nodules filling openings in weathered felsite porphyry. The porphyry is mostly light in color and contrasts vividly with the blues and greens of the turquoise. The country rock is apparently part of the volcanic flows of late Tertiary age which cover most of the Bonanza district 5 miles to the west. Field evidence points to the turquoise as having been formed by meteoric waters that leached the essential constituents from surficial rocks and reprecipitated them under favorable conditions in fracture and shear zones.

The State Bureau of Mines gives the following values of turquoise production beginning with 1952:

1952	$ 8,338
1953	4,500—estimated
1954	8,227
1955	8,100
1956	33,000
1957	15,600

Sand and Gravel — Sand and gravel have been produced from the courses of Saguache Creek west of Saguache town, and some of its tributaries such as Middle, Jacks, and Sheep creeks; also from Cochetopa Creek in the northwestern corner; from the area of the Rio Grande Canal south of Saguache; from the Mineral Hot Springs area east-northeast of Saguache, and from the areas of other canals southwest of the Luis Maria Baca Grant No. 4. Other sand and gravel deposits are located: 5 miles south of La Garita; along the railroad south of Alder, and between Sargents and Doyleville on the northern border of the County.

The State Bureau of Mines gives the value of sand and gravel produced in the County during 1957 at $30,000, and none for 1958.

Manganese* — Practically all the mines and prospects in the "Manganese Belt" of the Bonanza district contain manganese in varying amounts. The Pershing, or Headlight, mine in the upper end of Manganese Gulch contains pyrolusite (MnO_2) associated with psilomelane (H_4MnO_5), siliceous material, and minor amounts of iron oxides. Some of the manganese ore locally carries appreciable amounts of gold and silver. The manganese oxides are presumed to have been derived from rhodochrosite ($MnCO_3$).

[131]Muilenburg states that the manganiferous ore of the Bonanza district is valuable only as a flux in smelting and that no deposits of manganese ore as such are known to occur in the district.

Lightweight Aggregates—Bush[28] reports the following deposits in Saguache County:

Perlite:

1. *Prosser's Rock Deposit*—Located in the northwestern part, within sections 6 and 7, T-47-N, R-3-E. Perlite is exposed on the east flank of a long, high ridge known as Prosser's Rock, 300 to 350 feet above Razor Creek. Further prospecting must be performed before the areal extent of the deposit can be delineated. A 60 to 70-foot layer of perlite with some interbedded obsidian is indicated. The perlite is mostly grayish-black and has the perlitic texture. A part of the deposit is suitable for opencut mining operations, but increasing depth of cover to the west limits the depth of penetration by opencut methods.
2. *Cathedral Deposit*—Located in the SW¼ of T-45-N, R-1-W, at an altitude of 10,500 feet. The perlite crops out in a 300-ft. cliff which is reported to be almost all perlite. The areal extent of the deposit is not known, but tonnages appear to be very large.
3. *Cochetopa Dome Deposit*—Located in section 36, T-46-N,

*Edward D. Dickerman, E.M., personal communication.

R-2-E, at an altitude of 9,700 feet. The perlite exposures are in the south-facing cliffs that form the southern and southwestern edges of Cochetopa Dome. The cliffs are 1½ miles long and are breached by the present drainage. The average thickness of the perlite flow is 40 to 50 feet, and is overlain by a great thickness of rhyolite and other volcanic rocks. The perlitic material is not homogeneous. Certain zones have a concentration of material with typical perlitic texture, and in other zones this texture may be almost entirely lacking. Zones which contain both kinds of material are common and are characterized either by pearly globes intermingled with blebs of red obsidian or by rounded masses of reddish-brown nonperlitic volcanic glass in a perlite ground mass. The expansibility of the material decreases with increase of nonperlitic glass.

Besides the foregoing, Bush lists the following locations of other perlite deposits in the County:

4. T-44-N, R-2-E and nearby areas.
5. T-47-N, R-2-E, the E½.
6. T-47-N, R-3-E, the W½.
7. T-46-N, R-2-E, the SE¼.
8. T-46-N, R-3-E, the SW¼.
9. T-47-N, R-4-E, the NW¼.
10. T-47-N, R-7-E, the NE¼ and adjoining areas.

Pumice:

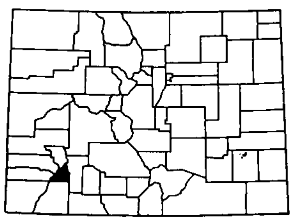
1. *Cochetopa Dome Deposit*—Bush[28] writes that both pumice and perlite (see No. 3 above) are present near the south edge of Cochetopa Dome, and that these deposits are among the largest in the State. The pumice deposit is located in the NW¼ of T-45-N, R-3-E and adjoining areas, about 5½ miles west of Cochetopa Pass. Up to 10 feet of pumice is exposed in road cuts along State Highway 114. The deposit is mostly horizontal in attitude, between 1 and 2 miles long, and possibly as much as 1 mile in width. Very large tonnages appear to be available, although of somewhat varied quality. The pumice lies on the valley floor about 1½ miles south of Cochetopa Dome which is marked at this point by cliffs of perlite 80 to 100 feet high. Volcanic ash is associated with the pumice which is covered in places by as much as 2 feet of overburden. The deposit is amenable to open pit or open cut methods of mining.

Marble—Argall[9] reports a deposit of marble located in the beds of Mississippian age which are exposed along the western front of the Sangre de Cristo Range northeast of Villa Grove. The marble, which is red, yellow, black, blue, and pea-green, has widely spaced joints which permit quarrying in blocks as large as 15 feet.

Geological Note—The western two-thirds of Saguache County is surfaced chiefly by rocks of the Potosi volcanic series of Miocene age. The eastern third lies within the northern part of the San Luis Valley and along the western slope of the Sangre de Cristo Range, its backbone marking the eastern boundary of the County.

The Sangre de Cristo Range is characterized by its relatively narrow width of from less than 10 miles to 20 miles. Pre-Cambrian rocks consisting of granites and related rocks, extend north from Mosca in a narrow band along the western slope of the range to the northeastern corner of the County where pre-Cambrian metamorphics are exposed. Ordovician rocks which are exposed overlying the pre-Cambrian rocks to the east, include the Manitou limestone, Harding sandstone, and the Fremont limestone, followed to the east by another narrow band of outcrops which include the Upper Devonian Chaffee formation and the Mississippian Leadville limestone. Pennsylvanian and Permian rocks, varying in thickness from 2,000 to 13,000 feet, compose the bulk of the sediments which form the Sangre de Cristo Range. The San Luis Valley, which is confined on the east by the Sangre de Cristos and on the west by the San Juans, is floored by coalesced alluvial fans and fringed by torrential wash from the surrounding mountains. In the area immediately west of Villa Grove are exposed pre-Cambrian granites and folded and faulted Paleozoic sediments. The remainder of the County, with the exception of a few local areas, is mantled by complex igneous flows of the Potosi volcanic series. Immediately to the northeast of these flows, there occurs an extensive flow of younger volcanic rocks of Late Tertiary age occupying the Bonanza-Sargents area. Another but smaller area of similar rocks is found west of Russell Lake, and yet smaller areas occur widely scattered in the southwestern part of the County. In the northwestern corner, for 15 miles east and west of Cochetopa Creek, are exposed undivided pre-Cambrian rocks and sediments of Jurassic and Cretaceous age, including the Morrison formation and the Dakota sandstone.

San Juan County



Courtesy Colorado Planning Division

San Juan County, located in southwestern Colorado within the rugged San Juan Mountain region, has a population of 1,300 and an area of 392 square miles ranging in elevation from 8,500 to 13,870 feet above sea level. The County seat is at Silverton, an early-day mining community with a population of 850.

Available Maps of the County—

a. San Juan County Map.

b. U. S. Army Map Service maps: 4459 I, II, III, IV; 4559 III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

d. U. S. Forest Service map "San Juan National Forest" covers the County.

Mineral Production 1946-1958—San Juan County is an important producer of metallic minerals. The value of its metals production since 1873, to date, totals close to $140 million. Sand and gravel, tungsten, uranium and gem stones were also produced during the 1946-1958 period. The figures in the following table are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Lode Mines	Gold Ounces	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	15	17,396	361,328	757,000	7,084,000	3,757,000	2,253,957[1]
1947	20	20,123	417,451	789,900	5,797,100	3,607,600	2,519,279[1]
1948	30	16,471	542,490	654,000	6,004,000	3,332,000	2,727,256[1]
1949	31	11,549	584,068	608,000	7,026,000	3,198,000	2,559,262[1]
1950	25	13,902	596,149	690,000	6,784,000	2,590,000	2,453,255[1]
1951	28	9,998	453,327	1,102,000	9,064,000	3,684,000	3,265,458[1]
1952	20	10,203	363,530	1,190,000	8,446,000	2,942,000	2,839,970[1]
1953	12	2,696	122,462	272,000	2,958,000	1,264,000	840,937[1]
1954	7	491	20,395	24,000	458,000	166,000	151,272[2]
1955	8	455	35,829	78,000	938,000	492,000	281,751[3]
1956	8	841	37,283	85,600	1,665,800	1,287,400	597,763[1]
1957	8	2,180	54,753	131,700	1,124,800	624,100	469,242[1]
1958	7	1,205	33,336	96,000	782,000	548,000	245,473[5]

[1] Value of precious and base metals only.
[2] Same as [1] but includes some tungsten production.
[3] Same as [2] but includes value of some gem stone production.
[4] Same as [1] but includes value of sand and gravel production.
[5] Same as [1] but includes value of uranium and gem stone production.

Precious and Base Metals—Most of the northern part of San Juan County lies within the mineralized area of the Silverton caldera. W. S. Burbank, U. S. Geological Survey, discusses the general features of the San Juan Mountains region, which includes the caldera, on pages 396-408 of the 1947 edition of this book. His text is illustrated with a generalized geologic and structural map of the region, and another of the Silverton volcanic center. In the same book, John W Vanderwilt discusses the mining districts of the County on the following pages:

Eureka District—In the geological discussion of the Eureka district on pages 435-37 of the 1947 edition of this book (Vanderwilt), Varnes and Burbank conclude as follows:

"Chimney deposits similar to those of the Red Mountain district" (see Red Mountain district, Ouray County, pp 428-31, 1947 edition) "are found in the area immediately northwest of Silverton on the ridge between Mineral and Cement creeks known as Anvil Mountains." . . . "Other isolated and small ore bodies of this kind have been mined in this area, and probably many undiscovered ones remain in the large area of altered rocks on the mountain.

"Those chimney deposits of the Red Mountain type which have had a large production in the past, generally have a prominent outcrop composed of silicified and kaolinized breccia. Recently (1947?) the Lark mine east of the Red Mountain divide in the Cement Creek drainage area has developed a body of base metal sulfide ore in a chimney deposit which has no prominent outcrop. This find has created considerable interest because of the strong possibility that similar deposits with no pronounced surface expression have been overlooked. Such deposits will be difficult to find, but detailed surface mapping supplemented by modern geophysical and geochemical techniques appears to be a promising way to approach the problem."

Burbank, writing in a more recent publication[132] discusses the effect of major structural features on ore deposition in the Eureka district and submits information helpful in exploration and development; the following is from this reference.

[132]The Sunnyside, Ross Basin, and Bonita fault systems lie in the northeastern part of the Silverton volcanic area and form part of the northeastern border zone of the Silverton caldera.

[132]The Ross Basin fault at the head of Cement Creek trends east-southeast, dips steeply southward, and has an over-all displacement of combined tilting of the beds and faulting, which amounts locally to as much as 2,000 feet.

[132]The Sunnyside fault, dipping steeply southeastward, begins essentially at its junction with the Ross Basin fault northeast of Lake Emma and extends northeastward across the

northern part of Treasure Mountain to the Animas Valley. At Treasure Mountain one branch of the fault forms the strong Cinnamon fault which continues east-northeasterly into Hinsdale County. The displacement of the Sunnyside fault is estimated at 1,500 feet at its western end, and about 800 feet to 1,000 feet at Treasure Mountain. Most of the ore bodies of the Sunnyside mine occur along the legs of the two faults and in their fractured common footwall not far from their intersection.

Viewed on a map, the Ross Basin fault and the Sunnyside fault form the rough outline of the front part of a boot tilted back on its heel. The Ross Basin fault which comes down from Ross Basin in a southeasterly direction to Lake Emma forms the instep, and the Sunnyside fault which trends northeastward from Lake Emma forms the front of the leg-part of the boot. The back line of the boot leg is formed by the Toltec fault which starts near Emery Peak and trends northeasterly across the northern part of Eureka Mountain to Picayune Gulch. Finally, the sole line, or bottom of the boot, is represented by the Bonita fault which trends northwesterly from its junction with the Toltec fault at Emery Peak, to Ross Basin where it joins the Ross Basin fault.

[132]The center area of the boot is a structural trough or graben 1½ to 2 miles wide and 8 to 10 miles long which projects northeastward from the downfaulted central block of the Silverton caldera. The most productive ore deposits of the area lie near some of the junctions of the main faults which bound the bootshaped graben, or in transverse fissures contiguous to the faults.

[132]All the faults dip steeply toward the center of the graben, while the surrounding volcanic formations are tilted away from it on all sides. These attitudes indicate alternate periods of tension and compression, with the central block subsiding during periods of tensional stress, and tending to squeeze out during compressional periods with consequential upward tilting of the volcanic formations. This action is believed to be mainly responsible for localization of the better ore bodies in transverse fissures within a belt 1,000 to 1,500 feet wide along the southwest border of the Bonita fault. A somewhat similar dilation of the veins is noticeable in the footwall of the Ross Basin fault.

[132]The Bonita and Toltec faults possess a common hanging wall at their intersection and in this they differ from the common footwall of the Ross Basin-Sunnyside faults intersection. Also, an intrusive rhyolite body is present in the Bonita-Toltec intersection, and these differences could have influenced the localization of the ore shoots. One of the strong east-southeast trending veins of the area joins the Bonita-Toltec junction just to the west of Emery Peak and it is possible that this vein

could be strongly mineralized at depth. The ground beneath the Peak is relatively remote from present (1951) workings.

[132]The Bonita fault and the Ross Basin fault join near the head of Cement Creek in a network of faults and fissures. The branches and offsets of the faults form a broken block of highly mineralized but not very productive ground which occurs in a relatively narrow wedge between the main faults.

[132]The footwall belt of the Ross Basin fault contains a number of productive veins that join the fault at nearly right angles. A few thousand feet from the fault, many of these veins take a sharp turn eastward at their intersection with a system of strong east-trending, steep-dipping fissures and minor faults which are downthrown toward the south, the same as the Ross Basin fault. The more conspicuous ore shoots occurring in this belt, north of the Ross Basin fault, commonly are located at the above-mentioned bends of the northeast-trending veins. This belt of stuctural controls and mineralization in the footwall of the Ross Basin fault, is about 1 mile wide and extends into the headwaters of Poughkeepsie Gulch, at least as far as the vicinity of Lake Como. The George Washington ore shoot of the Sunnyside mine, one of the most important ore shoots in the district, is located in the Ross Basin fault zone near its intersection with the Sunnyside fault. It is about 1,000 feet long, and had been mined to 1,400 feet when operations ceased. The ore shoot lies between walls of pyroxene quartz latite and Burns quartz latite.

[132]Judging from past production and from surface expression of faulting and mineralization, the most favorable areas for major development lie near the various major faults and their junctions at the boot end of the graben. Most of the past production has come from between walls of pyroxene quartz latite, or between walls of this rock and Burns quartz latite. Ores at the Sunnyside-Ross Basin fault junction "probably extend to a depth of 10,000 feet or more." However, each ore shoot and area involves special problems to be considered in relation to regional and local structural controls, fracturing characteristics and other effects of the host rocks, and the strength of the mineralizing processes.

[132]The general relations of the more productive ore bodies to the several fault systems and the lack of systematic exploration in some parts of the fault systems and contiguous belts of mineralized ground indicate that the productive potentialities of the area are not exhausted. The more favorable ground includes the footwall belt of the Bonita fault, and probably some ground contiguous to the junction of the Sunnyside-Ross Basin faults at greater depths or in the hanging walls and footwalls of the major faults that have not already been thoroughly prospected.

[132]If the Gold King and Lead Carbonate ore shoots can be

considered representative of structural localization of shoots close to the footwall of the Bonita fault zone, they afford clues to the most effective exploration of the Bonita fault belt as a whole. As the Bonita fault lies high on the upper slopes of the 13,000-foot ridge between Bonita and Emery peaks, the footwall of the fault zone has been approached at depth in only one place, the heading of the American tunnel of the Gold King mine. This tunnel was never connected with the mine workings which are more than 800 feet above and therefore little information is available as to possible vertical changes in the character of fissuring and mineralization with depth. Several other transverse veins along the length of the fault belt bear relations to the fault similar to those of the Gold King and Lead Carbonate vein systems. Further studies of the potentialities of these veins as well as the west-dipping cross veins of this belt appear worthy of particular consideration in long-range development of the area. The possibility that some shoots may tend to shorten at higher altitudes may be an important consideration. It is evident that the potential importance of some shoots of ore cropping out at high altitudes may be difficult to evaluate. While all these features are relatively favorable to the existence of undeveloped potentialities, there is a possibility of unfavorable rock characteristics and other changes at depth which cannot be entirely evaluated from surface studies.

[132]Further exploration and development of known, and potentially productive, ground near the Ross Basin-Sunnyside junction is justified by past production. The exploration of ground at depth outward from this productive center is a logical way to expand the area of development along and near both the Sunnyside and the Ross Basin fault systems and their contiguous veins. The footwall area of the Ross Basin fault and the footwall and hanging wall of the Sunnyside fault include examples of shallow ore shoots that may have counterparts at greater depths.

[132]Gold was introduced mostly during the late stages of mineralization. It seems, therefore, that the ore-forming solutions have a common source beneath the downfaulted keystone blocks and rose along active belts of fissuring chiefly in the main faults and their footwalls. Nearer the surface the solutions also became dispersed into subsidiary fissures formed and kept open by the wedging and dilating action of the keystone blocks. Concentrations of gold which may locally enhance the value of base-metal ore appear likely to be found in much more restricted parts of the vein systems which have been dilated by late-stage settling of the fault blocks. Vein intersections and transverse fissures in the immediate footwalls of major faults are among the more favorable places. In other situations, transverse hanging-wall fissures may have provided channels through which the gold-bearing solutions could have leaked

more readily than through the highly compressed walls of major fault systems.

Sand and Gravel — Sand and gravel have been produced from the course of the Animas River in the vicinity of Silverton and west, southwest, and south of it; also from Cascade Creek in the southwestern part of the County. Other sand and gravel deposits are located along the courses of the more level drainages.

Tungsten—Hubnerite (manganese tungstate) bearing quartz veins occur in the Cement Creek-Mineral Creek areas of the Eureka district north of Silverton. The ore occurs erratically within large masses of quartz vein matter and silicified rock. Aurand[128] reports that the tungsten occurrences in Dry Gulch, a tributary of Cement Creek, proved to be of considerable extent. However, judging from the sporadic production which has come from the area, mostly during periods of sustained high prices, the mineralization is erratic and of an average low grade.

Gem Stones—The Eureka area north of Silverton is well known for the abundance of its rhodonite (manganese silicate) mineralization. Excellently colored crystals of rhodonite have come from the Sunnyside and other mines in the area.

Uranium*—The Elk Park area prospect is the only active uranium property. In general, high temperature metallogenic provinces, such as underlie San Juan County, are not favorable to the accumulation of large uranium deposits. For this reason it appears that the probabilities of discovering other ore bodies of appreciable size are not great.

The geology consists of complexly folded and faulted pre-Cambrian and Paleozoic rocks which have been intruded and overlain by a wide variety of Tertiary intrusives and extrusives.

Stone—San Juan County has a wide variety of igneous, metamorphic, and sedimentary rocks, some of which have possible application in the construction and other industries. A few of these rock types have found use in the past: Aurand[128] reports the former quarrying of a granitic rock from Anvil and Kendall mountains which was used for building purposes in Silverton; Argall[9] reports that a limestone quarry operated in the past on the east bank of the Animas River, 1½ miles south of Silverton. The limestone was probably obtained from Mississippian or Devonian beds exposed at the site and was used as flux in the then-existing lead blast-furnace at Silverton. Sandstone was also quarried from this area of sedimentary formations south of Silverton, and used in the construction of the town's City Hall.

Iron—Aurand[128] reports the existence of bog iron deposits in the swampy ground along Mineral Creek and in Ironton

*Dr. Donald L. Everhart, USAEC, personal communication.

Park. Some of this material was shipped to Silverton for use as flux in the defunct Silverton smelter.

Geological Note—The principal structural feature within San Juan County is the Silverton caldera which occupies the northern half. Structurally, the caldera is located near the edges of two ancestral uplifts of the San Juan Mountains, and appears to be one of the eruptive centers of the Silverton volcanic series. The downfaulted, or collapsed block of volcanic rocks which forms the caldera is of remarkable symmetry, about 8 miles in diameter, and surrounded by radial fissures, dikes, and by radial and concentric intrusive axes.

The domal uplift of the Needle Mountains occupies the south-southeastern part of the County and forms an extremely rugged region of sharp peaks, many of which rise over 13,000 feet. The San Juan Mountains proper, which cross the County in a southeasterly direction, are a dissected dome over 100 miles across.

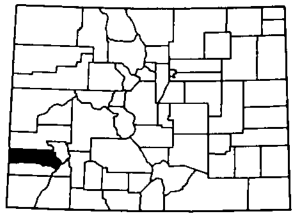
The oldest rocks in the region are a complex of ancient, highly metamorphosed schists and gneisses much intruded by granite and granodiorite of pre-Cambrian age. These rocks are exposed south and southeast of Silverton, from the Hinsdale County line westward to beyond the Animas River, and in the Needle Mountains on either side of the Animas River between pre-Cambrian granite exposures. Separating these two areas of ancient pre-Cambrian rocks, between the San Juans proper and the Needle Mountains, there is a broad, southwesterly curving band of pre-Cambrian rocks of the Irving greenstone, Vallecito conglomerate, and quartzite and schist of the Uncompahgre formation.

West of the pre-Cambrian rocks and southwest of Silverton to the southwestern corner of the County, Paleozoic rocks are exposed: a narrow north-northeasterly band of Ignacio quartzite of Cambrian age; an adjoining (overlying) narrow band to the west of Upper Devonian rocks of the Elbert and Chaffee formations and Ouray limestone; Mississippian Leadville limestone; Pennsylvanian shales of the Molas formation; complex Pennsylvanian sediments of the Hermosa formation, and Permian (?) red beds of the Cutler and Rico formations. The above sequence repeats itself in inverse order on the western side of the area, and continues higher into the stratigraphic sequence where younger sediments are exposed in irregularly-shaped areas and bands when not obscured by caps of volcanic rocks. Here are exposed upper Triassic rocks of the Dolores formation; Jurassic rocks of the Entrada and Morrison formations, and Upper Cretaceous rocks of the Dakota sandstone, Mancos shale, and Mesaverde group.

The northern part of the County, including the Silverton caldera, is mantled by a complexity of lavas, tuffs, and agglomerates of the Silverton volcanic series of Miocene age, with scattered exposures of Tertiary intrusive rhyolite and granite porphyry from south of Eureka, within the caldera, to the northern tip of the County. Earlier Tertiary rocks of the San Juan tuff extend in an irregular, discontinuous east-west band just south of Silverton.

Quaternary deposits consisting of landslides, alluvium, rockstreams, mudflows, and glacial deposits, are scattered throughout the County. Torrential wash and alluvium predominate in the drainage valleys.

San Miguel County



Courtesy Colorado Planning Division

San Miguel County, located in southwestern Colorado bordering on Utah, has a population of 3,000 and an area of 1,284 square miles ranging in elevation from 5,000 to 13,900 feet above sea level. The County seat is at Telluride, a mining and business community with a population of 1,200.

Available Maps of the County—

a. San Miguel County Map.
b. U. S. Army Map Service maps: 4259 I, IV; 4260 II, III; 4359 I, IV; 4360 II, III; 4459 IV; 4460 III.
c. U. S. Geological Survey topographic quadrangle maps cover the eastern and western thirds of the County. See index map in the pocket.
d. U. S. Forest Service maps "Uncompahgre National Forest" and "San Juan National Forest" include much of the County.

Mineral Production 1946-1958—San Miguel County is one of the most important producers of precious and base metals in the State. As of the end of 1958, the cumulative value of these metals since 1875 totalled $206 million, exceded only by Lake and Teller Counties. San Miguel is also an important producer of uranium ores, ranking third in the State for 1958 behind Montrose and Mesa Counties. Sand and gravel, bog iron, manganese ore, and gem stones were also produced during the 1946-58 period. The following figures are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Mines	Gold Ounces	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	11	24,730	358,443	1,321,000	4,762,000	3,925,000	2,367,082[1]
1947	10	39,567	440,676	1,490,200	5,271,300	4,135,000	3,356,001[1]
1948	8*	39,669	582,266	3,538,000	7,784,000	6,972,000	4,786,753[1]
1949	7*	35,789	655,646	2,800,000	10,828,000	12,008,000	5,597,424[1]
1950	9*	53,618	820,132	3,906,000	15,874,000	17,762,000	8,096,533[1]
1951	9*	35,320	706,007	3,580,000	16,298,000	18,456,000	8,920,078[1]
1952	12*	35,868	868,167	4,488,000	15,894,000	19,682,000	8,953,357[1]
1953	6	40,416	776,486	3,900,000	15,848,000	20,866,000	7,837,566[1]
1954	4*	21,694	611,808	3,554,000	12,206,000	15,932,000	5,836,227
1955	4	18,987	453,745	3,214,000	10,196,000	13,064,000	5,425,082
1956	3	27,150	694,655	5,262,600	14,399,000	20,335,800	10,857,580[1]
1957	4	22,840	782,376	6,249,200	15,442,900	23,142,000	10,219,988[1]
1958	3	26,626	696,166	4,896,000	13,748,000	21,186,000	10,020,355[5]

*From 1 to 2 placer operations not included in the figure.

[1] Value of precious and base metal production only.

[2] Same as [1] but includes sand and gravel and bog iron production.

[3] Same as [2] but includes gem stone production.

[4] Same as [3] but includes value of uranium production.

[5] Same as [2] but includes value of uranium production.

Precious and Base Metals—The Upper San Miguel, or Telluride district, within the volcanic area of the San Juan Mountains in the eastern part of the County, has been the most prolific of San Miguel's metal mining areas. This district and the others established in the County are discussed by Vanderwilt, and the geology summarized by Varnes or Burbank, on the following pages of the 1947 edition of this book:

Klondyke	Page 202
San Juan County Production	203
Lower San Miguel (Placerville, Sawpit, Newmire)	202 and 204-5
Mount Wilson	205 and 206
Geology (D. J. Varnes, USGS)	428
Ophir (Iron Springs, Ames)	205, 207 and 209
Geology (D. J. Varnes, USGS)	425-27
Upper San Miguel (Telluride)	208-9
Geology (W. S. Burbank, USGS)	421-25

The potentialities of some of the areas, pointed out in the geological summaries in the 1947 edition, merit repeating below.

Mount Wilson District—(D. J. Varnes, USGS, page 428)—Difficulty of access to this very rugged group of mountains has done much to discourage mining on all but the most prominent veins. Except for the few large explorations in the vicinity of the Silver Pick mine, the mineralized area still remains one of undetermined value.

Iron Springs District—The U. S. Geological Survey has completed a study of this area which is at present being prepared for publication. (D. J. Varnes, USGS)—Several factors have contributed to the decline of this camp, one of the more important being that prospecting has not been actively pursued during a period of several decades in which the technology of milling and the demand for base metals have changed greatly. Although the area is one of great relief, timber, grass, and landslides obscure many veins so that a geological interpretation of the vein system is here a very necessary guide to effective prospecting.

Telluride District — The Telluride (San Miguel County), and Sneffels (Ouray County) districts are discussed as one area by W. S. Burbank on pages 421-25 of "Mineral Resources of Colorado," 1947 edition (Vanderwilt). The outlook for this area, taken from page 424, is repeated on page 226 of this book under Ouray County.

Uranium—San Miguel County is the third ranking producer of uranium ores in the State. The U. S. Atomic Energy Commission has released the following figures of its production.

Year	Operations	Contained U_3O_8-lbs.	$ Value at Mine
1955 (last 6 mos.)	69	205,440	864,180
1956	106	471,392	1,968,554
1957	119	454,037	1,858,275
1958	140	790,617	3,311,440

The uranium producing area is located within the southern part of the prolific Uravan Mineral Belt. *Typical "Plateau-type carnotite ore" bodies occur in the Salt Wash member of the Jurassic Morrison formation, and to a lesser extent in the Triassic Chinle formation. It is anticipated that numerous other small ore bodies will be discovered in the area.

The uranium section of this book discusses the geology, ore deposits, and the mineralogy of the Uravan Mineral Belt.

Sand and Gravel — Sand and gravel have been produced from the courses of the Dolores River and some of its tributary streams in the western part of the County, such as Disappointment Creek, McIntyre Creek, and others; also from Basin Creek in the central part; from the headwaters of the San Miguel River near Telluride, and farther west, near Vance, Sawpit, and Placerville. Other sand and gravel deposits are located: between Placerville and Leonard; in the extreme northeastern corner of the County; north of the confluence of McKenzie Creek with the San Miguel River; northeast of Norwood, and seven miles northwest of Cedar.

Bog Iron**—A deposit of bog iron is being exploited about 2 miles east of Ophir in the eastern extremity of the County. The known portion of the deposit covers about 10 acres and ranges in thickness from 2 to 14 feet. The bog iron is mined during the snow-free part of the year at a rate of about 50 tons per day and shipped east for use as pigment. Another deposit is worked occasionally to produce similar material for use as a soil conditioner. The State Bureau of Mines gives the follow-

*Dr. Donald L. Everhart, USAEC, personal communication.

**G. A. Franz, Jr., Deputy Commissioner, State Bureau of Mines, personal communication.

ing value figures for the production of bog iron from this County:

1954	$54,100
1955	52,000
1956	17,000
1957	27,000
1958	30,000

Manganese[131]—Some manganese ore has been taken from a deposit at the head of Gypsum Valley near the top of the divide which separates it from Dry Creek Basin. This blanket deposit overlies a sandstone bed and underlies a red sandy shale, possibly in Jurassic rocks, but it has also been described as occurring in the Dolores formation of Triassic age. The ore is composed almost wholly of soft, crystalline to granular pyrolusite (manganese dioxide) with associated manganite (manganese sesquioxide), psilomelane (hydrous manganese manganate) and some barite and calcite. Samples of "average" ore assayed 43.38% manganese, and an average of analyses on cobbed ore assayed 54.75% manganese. Muilenburg states ". . . very few impurities which would be detrimental to the chemical trade are present."

Coal—The Dakota sandstone, which underlies about three-quarters of the County with much of it overlain by Mancos shale and later rocks, probably contains appreciable resources of coal. Available information indicates that most of the beds may be thin, impure, and discontinuous, but it is probable that minable beds may be found locally under less than 3,000 feet of overburden.

Oil and Gas—*No oil or gas has as yet been produced in the County, although well Pure #1 Southeast Lisbon (Sec. 5, T. 44 N., R. 19 W.) now being completed (Jan., 1960), is an apparent gas discovery in the Leadville limestone of Mississippian age.

*The western three-quarters of San Miguel County lies within the confines of the Paradox Basin, and the eastern half covers portions of the San Juan Dome. Relatively few wells have been drilled to date, the majority Pennsylvanian Paradox salt tests, but the discovery of Mississippian gas in the well cited above, and Devonian oil 14 to the west at well Pure #1 northwest Lisbon (Sec. 10, T. 30 S., R. 24 E., San Juan County, Utah), have stimulated interest in the Mississippian carbonates and Devonian sands and carbonates. It is therefore anticipated that increased exploratory drilling will be conducted in the future.

*The prospective horizons include the Pennsylvanian Honaker Trail and Paradox formations, the Mississippian Leadville limestone, and the Devonian Ouray and Elbert formations.

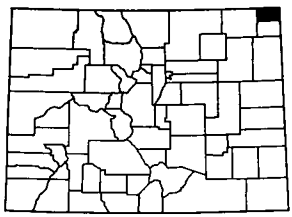
Geological Note—The extreme eastern part of the County lies within the rugged terrain of the northwestern San Juan

*Mr. Frank J. Adler, Phillips Petroleum Co., written communication.

Mountains, a dissected domal uplift over 100 miles in width. The predominant rocks in the area, around the County's eastern border, consist of complex lava flows belonging to the Miocene(?) San Juan tuff, and the Miocene Silverton and Potosi volcanic series. West of the mountains the volcanic rocks give place to lower country of plateaus and canyons cut in relatively flat sedimentary rocks. This plateau area, comprising the balance of the County, is surfaced chiefly by Upper Cretaceous rocks: Mancos shale from Noel in the northeast, to the San Miguel Mountains in the southeast, and west to Gypsum Valley, and Dakota sandstone along the northern quarter and west of Gypsum Valley to the western boundary. Triassic and Jurassic rocks, including the Chinle, Entrada, and Morrison formations, are exposed along the course of the upper San Miguel River. Jurassic rocks have been exposed by many other drainages such as, McKenzie, Beaver, Naturita, and Basin creeks. In Gypsum Valley, to the west, are exposed Pennsylvanian rocks of the Paradox and Hermosa formations, and in the canyon of the Dolores River, as well as in Gypsum Valley, are exposed a series of Permian, Triassic, and Jurassic rocks which include the Cutler, Chinle, Entrada, and Morrison formations. The Jurassic rocks are exposed for varying distances away from the canyons and valleys. Upper Cretaceous rocks of the Mesaverde formation overlie the Mancos shale in an irregular area southeast of Gypsum Valley. Quaternary deposits of glacial till, landslides, and torrential wash occur in the mountain area to the east, and alluvium in some of the drainages and valleys to the west.

The southern portion of the Uravan Mineral Belt is located in the western part of San Miguel County. The belt, a narrow, elongate, uranium mineralized area, begins in the vicinity of Egnar and crosses the County in a north-northeasterly direction. The geology and ore deposits of this prolific uranium belt are discussed by Drs. Wright and Everhart in the uranium section of this book.

Sedgwick County



Courtesy Colorado Planning Division

Sedgwick County, located in the extreme northeastern corner of the State bordering Nebraska, has a population of 4,900 and an area of 554 square miles ranging in elevation from

3,400 to 3,675 feet above sea level. The County seat is at Julesburg, a farming, livestock raising, light industry, and business community with 2,000 population.

Available Maps of the County—

a. Sedgwick County Map.

b. U. S. Army Map Service maps: 5465 I; 5565 I, II.

c. U. S. Geological Survey topographic quadrangle maps cover most of the County. See index map in the pocket.

Mineral Production—Sand and gravel are the only minerals of consequence produced in the County. Occasionally, some stone and gem stones are produced. Natural gas was discovered as far back as 1952, but due to the lack of developed markets, no production had been established as of the end of 1958. The U. S. Bureau of Mines gives the following values for the County's mineral production beginning with 1952; virtually all of the values represent sand and gravel production.

1952	$ 1,930
1953	12,800
1954	1,074
1955	1,636
1956	29,060
1957	30,200
1958	47,560

Sand and Gravel — Sand and gravel have been produced from the course of the South Platte River in the vicinity of Julesburg and from some of its tributaries; also from drainages flowing southeasterly, south of Julesburg to the Phillips County line. Other sand and gravel deposits are located along the course of the South Platte River from the Logan County line to the Nebraska State line.

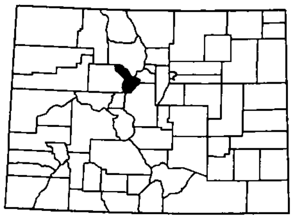
Natural Gas*—Sedgwick County is located on the extreme eastern flank of the Denver Basin. Commercial accumulations of gas of limited size have been developed in the 'D' and 'J' sands of the Dakota formation of Cretaceous age along the Phillips County line. It is expected that additional gas fields will be discovered in the Dakota rocks, but possibilities for petroleum production from this source are not considered good. The hydrocarbon potential of the older beds has not been explored, but westward expansion of Paleozoic oil production from central Nebraska eventually will provide information on these lower horizons.

The Chappell gas field near Julesburg was discovered in May, 1952, when drilling well Franklin No. 1 encountered gas in the 'D' sand of the Dakota formation of Cretaceous age in the interval 3,181-3,217 feet in depth. The well was shut in for lack of markets until 1959. During that year, the Chappell field was credited with producing 2 million cubic feet of dry natural gas.

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

Geological Note—Sedgwick County lies entirely in sedimentary terrane of northeastern Colorado. The topography is that of low-relief, flat or undulating plains, with a few low hills along the South Platte River. The river crosses the northwestern quadrant of the County, flowing in an east-northeasterly direction. The surface in that quadrant is composed chiefly of Oligocene rocks of the White River formation, with a broad band of Recent alluvium along the valley floor of the river. The remainder of the County is surfaced predominantly by Miocene rocks of the Arikaree formation.

Summit County



Courtesy Colorado Planning Division

Summit County, located in the west-central part of the State, has a population of 1,200 and an area of 616 square miles ranging in elevation from 8,500 to 14,267 feet above sea level at the crest of Torrey's Peak. The County seat is at Breckenridge, an early day mining community with a population of 300.

Available Maps of the County—

a. Summit County Map.

b. U. S. Army Map Service maps: 4762 I, IV; 4763 I, II, III, IV; 4862 IV; 4863 III.

c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.

d. U. S. Forest Service maps "Arapahoe National Forest," "Pike National Forest," and "White River National Forest," cover the County.

Mineral Production 1946-1958—Summit County's income from the production of mineral resources has derived almost totally from precious and base metals. Sand and gravel are the only other minerals of consequence produced in the County. The U. S. Bureau of Mines Minerals Yearbooks give the following figures of the County's production and total yearly values.

Year	Operations Lode	Operations Placer	Gold Ounces	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Total $ Value
1946	23	2	1,667	128,246	31,000	2,026,000	7,293,000	1,277,570[1]
1947	31	4	2,340	192,999	66,500	3,210,600	11,837,600	2,165,205[1]
1948	31	1	2,664	344,427	110,000	9,518,000	21,222,000	4,955,082[1]
1949	32	1	2,320	341,368	134,000	8,676,000	20,288,000	4,303,073[1]
1950	23	3	844	153,334	36,000	3,422,000	6,872,000	1,613,597[1]
1951	29	–	367	66,120	10,000	1,240,000	892,000	454,071[1]
1952	22	1	294	36,313	6,000	1,478,000	1,314,000	504,469[1]
1953	15	–	523	47,826	32,000	2,400,000	2,400,000	702,158[2]
1954	11	2	436	43,847	32,000	2,182,000	2,398,000	686,472[2]
1955	14	2	204	16,387	14,000	978,000	1,252,000	328,911[2]
1956	10	1	436	41,602	29,900	1,348,100	2,227,000	583,871[2]
1957	9	–	105	35,149	14,900	936,300	1,319,400	326,913[1]
1958	5	2	36	3,560	2,000	17,000	258,000	51,336[3]

[1] Value of precious and base metals production.

[2] Same as [1] but includes sand and gravel production.

[3] Same as [1] but includes some manganese concentrate production.

Precious and Base Metals—The importance of Summit County as a producer of precious and base metals is reflected in the cumulative value of its production. Since 1859, to the end of 1958, the county had produced a total of $74 million in contained value of these metals.

The established mining districts and the geology, ore deposits, and potentials of some of the districts are discussed on the following pages of the 1947 edition of this book. Additional data is given herein.

Breckenridge (Bevan, Union, Minnesota, Blue R., Swan R., Illinois Gulch, French Gulch, etc.)	Pages 209 and 211
Geology (E. N. Goddard, USGS)	299-300
Summit County Production	210
Frisco	212
Green Mountain (Wilkinson)	212-13
Montezuma (Snake River, Peru)	214-15
Geology (E. N. Goddard, USGS)	300-02
Tenmile (Robinson, Kokomo)	215 and 216
Geology (A. H. Koschmann, USGS)	370-78
Upper Blue River	215-16
Geology (Q. D. Singewald, USGS)	343-46

Breckenridge District—A summary of the principal geological features of the Breckenridge district as well as its history of production are discussed by E. N. Goddard on the pages listed above in the 1947 edition of this book (Vanderwilt), and a map of the area showing some of the major mine workings and known faults and veins is contained opposite page 300.

Summary information regarding the character of the sedimentary rocks in the district is given in this volume on page 48, under the subheading Paleozoic and Mesozoic Rocks under the heading The Front Range Mineral Belt. Additional information on the district is given below.

[12]The main part of the Breckenridge district lies on the

western limb of a regional structural trough about 10 miles wide which extends from South Park north-northwestward to Middle Park.

[12]Southeast of Breckenridge the prevailing northeasterly dip is broken by an open anticline and a compressed syncline, both of which trend northwestward. Two broken, downfaulted belts cross these folds and intersect near the Wellington mine 2 miles east of Breckenridge. One belt trends north-northeastward, and the other east-northeastward, and in both of them normal and reverse faults are common. The most productive mines of the district, the Wellington, Washington, Golddust, Dumkin, and Puzzle-Ouray, follow premineral faults of small throw in the north-northeasterly downfaulted belt. Nearly all the productive veins strike between 40 and 80 degrees northeast, and the fissures they occupy are generally older than the faults which strike 10 to 20 degrees to the northeast.

[12]The bulk of the district's porphyry was intruded after folding was completed and part of it is later than the initial easterly and northeasterly faults which were mineralized later. The large Williams Range thrust fault along the eastern side of the district is earlier than the coarsely porphyritic Laramide quartz monzonite common throughout the district, but much of the northeasterly and north-northeasterly faulting is later than the latest porphyry masses. Most of the monzonite in the central part of the area is part of one large intrusive sheet, and in it are found most of the productive veins. Its base is irregular, but commonly occurs a short distance above or below the Dakota quartzite horizon.

[12]Although a wide variety of ore minerals have been found in the Breckenridge district, the only commercial ones have been gold, various silver minerals, sphalerite, galena, and pyrite. Contact-metamorphic ores, stockworks, veins, blanket deposits, and placers, have been exploited but most of the production has come from veins and placers. The primary mineralization is believed to have been related to the solidification of the deeper parts of the quartz-monzonite porphyry and to have occurred later than any of the porphyry intrusions. Supergene enrichment has modified many of the deposits.

[12]*Contact Metamorphic Deposits*—Contact metamorphic bodies have been of little consequence in the Breckenridge district due to their small size, disappointing tenor of the ore, and spotty mineralization.

[12]*Stockworks*—Stockworks are found chiefly in the northeastern quarter of the district in a narrow zone trending east-northeast through Tiger toward the south end of the Williams Range thrust fault. Most of the mineralization was deposited in small open fissures with little replacement of the country rock and produced low-grade pyritic gold ore with some content of galena and sphalerite. Secondary enrichment entered

into the commercial aspects of the exploitation of some of these deposits, and it is unlikely that the primary ores can be mined profitably unless costs are greatly reduced or market prices improve sufficiently. There is a distinct possibility that other, yet undiscovered stockworks will be found in this general zone.

[12]*Intrusive Breccia Deposits*—These deposits are found in the southwestern part of the district and, although similar in appearance to the stockworks, are different in origin. The aggressive intrusion of the quartz-monzonite porphyry brecciated the baked upper Cretaceous shale adjacent to it and incorporated the fragments in the upward moving magma. Continued movement of the freezing porphyry caused a network of small fissures to break through the porphyry matrix, the fragments, and the adjacent wallrock. The subsequent mineralization of the fissures developed mineral deposits intermediate in character between the stockworks and the lodes in broad shear zones.

[12]*Hypogene Deposits*—Hypogene deposits are largely confined to northeasterly premineral faults, but many of the veins are related to channels of mineralization that trend more nearly northward than the veins themselves.

Most of the productive veins lie in a short, narrow, northeasterly belt extending from Little Mountain to Mineral Hill, and with the exception of the rich, narrow gold veins of Farncomb Hill, very few veins outside this belt have produced any appreciable amounts. Most of the ore has been found where the vein walls are composed of porphyry or Dakota quartzite. The ore shoots were localized in the more open parts of faults of moderate movement which formed where the faults broke through the more rigid wall rocks.

The primary ores of the productive veins consist largely of lead, zinc, and iron sulfides, with some native gold and some silver. High-grade galena and gold ore appear to be limited to a depth of 200 to 300 feet from the present topography and is residual from the leaching of the more soluble sphalerite and pyrite from the primary ores. The latter have a greater depth range, reaching more than 800 feet in the Wellington mine.

[12]*Gold Veins of Farncomb Hill*—The important veins are limited to an area about 2,500 feet long and less than 1,500 feet wide on the western side of Farncomb Hill. In this location the Pierre shale is invaded by an irregular quartz-monzonite porphyry stock which appears to occupy one of the minor conduits which supplied magma for the porphyry intrusion. The rich gold veins lie near the porphyry mass on its north side and are faulted by numerous bedding plane slips or along the contact of the shale with the porphyry sills. In some of the veins the chief sulfide mineral is chalcopyrite,

while in others it is sphalerite. The pockets of native gold found in the veins are closely related to the small bedding faults which dislocate the veins near the porphyry sills. Here and there in the veins are found narrow pockets of crystalline gold ramifying through a matrix of limonite, may be 2 to 3 feet in diameter and as much as 1 inch in thickness. Some of these small pockets have yielded up to $4,000 in gold. The gold of the Farncomb Hill veins occurs as leaf and wire gold and is very spectacular in appearance.

[12]*Blanket Deposits*—These are replacement deposits which lie along bedding planes and are mostly limited to Gibson Hill, Shock Hill, and Little Mountain. They occur in replaceable beds of the Dakota and Maroon formations. The most favorable situation for these deposits seems to be in the sandy shale of the upper Dakota quartzite where cut by bedding-plane faults near minor veins.

[12]*Placer Deposits*—The placer deposits of the Breckenridge district may be divided into: 1. gulch deposits; 2. bench or high-level placers (merge with 1); 3. deep or low-level placers occupying the main valley bottoms.

1. Gulch deposits are relatively small and steeply-sloping gravels in the bottoms of minor gulches, but they include some of the most productive properties in the district. Those clustering around Farncomb Hill have yielded aggregately over $5 million, and their gold shows the wiry and flaky texture of the Farncomb veins, which undoubtedly were the source of the gold.
2. The bench placers occur well above the present valley bottom, in gravel which is probably the outwash from one of the stages of glaciation preceding the Wisconsin stage. They are found mostly along both sides of the valley of the Blue River, from the Wisconsin moraine a mile south of Breckenridge, northward at least as far as Dillon. The bench placers have been worked by hydraulic methods and have yielded substantial amounts of gold. The most successful areas have been along French Gulch, Swan River, and Gold Run Gulch; the last named having been the most productive with an output of about $750,000.
3. The low-level placers are largely in outwash gravels accumulated during the Wisconsin glacial stage. The related moraines themselves are practically barren, and the upstream gravels above the terminal moraine contain gold in concentrations influenced by the effects of discharges from tributary streams. The most productive ground has been in the outwash gravels below the terminal moraine.

Montezuma District—The Montezuma and Argentine districts in Summit and Clear Creek Counties are discussed collectively by E. N. Goddard (USGS) on pages 300-02 of the 1947 edition of "Mineral Resources of Colorado" (Vanderwilt). The present volume follows Lovering and Goddard's[12] presentation by including in the discussion of the Montezuma district the closely related Swan River, Geneva Creek and Hall Valley districts. This area comprises that part of the Front Range mineral belt which lies between the Breckenridge district, 5 miles southwest of Montezuma, and the Argentine district about 4 miles to the northeast.

[12]The first silver lode found in Colorado was discovered in 1864 on Glacier Mountain, about 1 mile south of Montezuma. This discovery intensified prospecting in the region and resulted in the development of the Montezuma, Argentine, and Silver Plume-Georgetown districts. The baritic lead and silver ores of Hall Valley and Geneva Gulch were discovered about 1871.

[12]The amount of ore mined from the Montezuma district has been rather disappointing and activity in the area has fluctuated greatly from year to year. The ore deposits are mesothermal veins containing gold and silver, sulfides of lead, zinc, arsenic, antimony, copper, and bismuth. Baritic copper ores containing galena, sphalerite, pyrite, and commonly associated with rich silver minerals are abundant in a southeastern branch of the mineral belt which extends from Glacier Mountain to Hall Valley. In the Hall Valley and Geneva Gulch areas veins containing bismuth and silver in association with chalcopyrite in a quartz gangue are common. Southeast of the Montezuma stock substantial quantities of gold and silver are present in the chalcopyrite-galena-sphalerite ores which are associated chiefly with quartz and ankerite as the gangue minerals.

[12]Galena is usually more abundant in the upper part of the veins, while the copper content increases slightly with depth, chalcopyrite being relatively more abundant than gray copper in the lower levels. Generally, the silver content of the veins shows very little relation with depth from the surface, although the Glacier Mountain ores are commonly richer in silver in the deeper parts of the ore shoots. There has been relatively little supergene enrichment of the silver content of the veins in the district, most of the silver occurring as primary mineralization.

[12]The vertical range of ore deposition in the district is at least 2,000 feet, and could be more than 3,000 feet. Commonly, the walls enclosing the persistent ore shoots are composed of competent rocks such as pegmatite, granite, porphyry, and gneiss. Ore bodies which occur in schist are generally found in veins which cut across the schistocity. As is common in the Front Range, most of the ore shoots occur near the junctions of branching veins; at the intersections of veins with barren premineral faults, and where changes in dip or strike of the

veins created open fissures or spaces during the movement of the walls.

[12]Reserves of high-grade ore in the Montezuma district are probably small, but many of the veins may yield profitable amounts of ore when mined on a small scale. Reserves of baritic lead-zinc ores are larger than those of any other class and can now be concentrated by flotation. The presence of ore in the Ida Belle, Rainbow, and Copenhaguen mines indicates the possibilities of finding ore bodies in the brecciated zone of the Williams Range thrust fault where it is crossed by mineralized fissures. Exploration of possible intersections between northeasterly veins and some of the strong northwesterly premineral faults, such as the Jones Gulch fault, has been neglected.

Argentine District (Summitt and Clear Creek Counties)—E. N. Goddard, as mentioned above, discusses the Argentine district collectively with the Montezuma district on pages 300-02 of the 1947 edition of this book (Vanderwilt). Additional information from a later publication[12] is given herein.

[12]The Argentine district straddles the Continental Divide between the Montezuma district and the Silver Plume-Georgetown district. Despite the handicaps of rugged terrain and lingering snows at high altitudes, the area has a good record of gold, silver, lead, and copper production.

The eastern border of the Montezuma quartz monzonite stock is just to the west of the Argentine district, and quartz monzonite dikes are numerous throughout the surrounding Idaho Springs formation which is the predominant rock in the southern half of the district. Farther north along McClellan Mountain, an irregular mass of Silver Plume granite extends northward into the Silver Plume-Georgetown district. Pegmatites and aplites are abundant throughout both the schist and the granite areas.

[12]Within that portion of the district which lies to the west of the Continental Divide, known as the West Argentine district, the mineral belt is very narrow and all the veins occur in a zone less than 1 mile in width. The belt trends north-northeasterly and its eastern side is marked by a series of strong veins that extend almost continuously north-northeasterly for 8 miles, from the Snake River 2 miles southeast of Montezuma, into the headwaters of Leavenworth Creek. Within the Argentine district the Pennsylvania, Delaware, Peruvian, Santiago, and Independence veins occur in this zone and are the source of the bulk of the district's production. The Baker, Josephine, and Stevens mines on the northwestern edge of the mineralized belt, although less important than those on the forementioned veins, have been productive.

[12]The ores of the district are valuable chiefly for their lead, silver, and gold contents, but some zinc and copper are also

present. As in the region to the west of the district, quartz and ankerite are the common gangue minerals, but on Mount McClellan many of the veins contain fluorite. The predominant ore minerals are galena, pyrite, sphalerite, chalcopyrite with some gray copper, silver sulfantimonides (chiefly dark ruby silver), and gold. The gold is generally associated with chalcopyrite or sphalerite, and the silver minerals with galena and gray copper. The most productive ore shoots have been located where the wall rocks are competent, such as granite or granite gneiss. The appearance of schist has usually coincided with a decrease in ore. The ore in many of the productive veins, including the Santiago, Commonwealth, Stevens, Baker, Josephine, and Kelso mines, is close to a persistent northwesterly fault which is itself ore-bearing locally.

Kokomo District (Tenmile)—A. H. Koschmann, U. S. Geological Survey, discusses the history, geology, and ore deposits of this area on pages 370-78 of the 1947 edition of this book (Vanderwilt). In conclusion, Dr. Koschmann comments as follows on the future of the district:

"Reserves of known ore in the district are fairly large; furthermore, geologic conditions are favorable for the extension of known ore bodies to great depths and for the discovery of new ore bodies in unexplored or inadequately explored ground. As ore has been mined in the Robinson mine down the dip for 2,000 feet with no indication of restriction of mineralization in depth, deep exploration of other known ore bodies is warranted. The most productive ore bodies in the district are the replacement deposits in the limestone beds and future prospecting should be chiefly concentrated on these beds wherever there is evidence of mineralization. Vein deposits have been relatively unimportant; they offer opportunities to the small lessee, but are too small to justify a plan of extensive development."

Upper Blue River Area—The Upper Blue River area comprises about 85 square miles of rugged topography just to the south of Breckenridge and less than 2 miles to the east of Kokomo. Great relief makes much of the area difficult of access and permits the snow to linger into the summer.

Dr. Quentin D. Singewald discusses the Upper Blue River area on pages 343-46 of the 1947 edition of "Mineral Resources of Colorado" (Vanderwilt), and includes a generalized geological map of the area opposite page 344. Additional information is given herein.

Rocks of the Area[130]—Pre-Cambrian rocks crop out over a vast area along the crest and both slopes of the Tenmile Range and in a much smaller area northeast of Breckenridge. The prevailing pre-Cambrian rocks are gneisses of the Idaho Springs formation with which are associated relatively insignificant amounts of nearly pure schist.

[139]Three masses of pre-Cambrian granite are exposed in Monte Cristo Gulch. In addition, granite is widely distributed in films, bands, lenses, and irregular layers too small to map. The granite bodies have been correlated with the Silver Plume granite.

[139]Pegmatites are widespread in the Idaho Springs formation and in the granite. In the gneiss they occur both as conformable and as crosscutting bodies which range from paper-thin dikes to many feet in width.

[139]The pre-Pennsylvanian sedimentary rocks are the principal ore-bearing formations of central Colorado and are therefore of particular interest. These rocks crop out continuously from North Star Mountain to the north side of McCullough Gulch, along the south side of Spruce Creek, and at several isolated localities between the north bank of Spruce Creek and the head of Sawmill Gulch. From their outcrops between North Star Mountain and Spruce Creek, these strata slope beneath the surface at increasing depths eastward as far as a zone of westerly dips in the Blue River Valley.

[139]Pennsylvanian and Permian sedimentary rocks differ greatly in thickness on opposite sides of the Boreas Pass fault which is west of Bald Mountain on the eastern edge of the area. On the southwestern side of the fault they total over 9,000 feet in thickness, while on the northeastern side they are less than 1,500 feet thick. The thick section crops out in an easterly and northeasterly direction along the Continental Divide between North Star Mountain on the southwestern part of the area, and Boreas Pass, thence north to Carter Gulch beyond which they are concealed by morain and terrace gravels. To the southwest of the fault these rocks continue uninterrupted into the Beaver-Tarryall district and therefore, the three-fold division proposed for the series south of the Continental Divide is used for the Blue River area.

Upper Division—5,000 feet—Redbeds. Clastic: boulder and pebble conglomerates; sandstones, siltstones, and shales.

Middle Division—2,800 feet—Predominantly clastic with intercalated dolomites in the nonred lower third, and limestones in the red upper two-thirds.

Lower Division—2,000 (?)—Mostly gray micaceous strata ranging from coarse arkosic conglomerate to shales.

[139]Northeast of the Boreas Pass fault the Pennsylvanian and Permian rocks crop out continuously along the lower slope of Bald Mountain, and at several places north of Breckenridge. Their thickness on this side of the fault ranges from 600 to possibly 1,500 feet, and they have been mapped as a single unit.

Mesozoic sedimentary rocks crop out along the slope of Bald Mountain in two nearly parallel belts separated by the Boreas Pass fault, and also northwest of Breckenridge. These strata consist of upper Cretaceous Benton shale (1,000 feet), and Dakota quartzite (160 feet); the Jurassic Morrison formation (300 feet), and Entrada sandstone (100 feet), and 200 feet of Triassic (?) red shales, conglomerates, and limestone breccia.

[139]Late Cretaceous or Early Tertiary "porphyries" are widely distributed. In the sedimentary rocks they occur as sills; as sill zones composed of sills separated by sedimentary layers; laccolithic sills, and crosscutting bodies, but in the pre-Cambrian rocks they occur as numerous dikes.

[139]*Structure*—Intense deformation of the rocks occurred at least twice, once during the pre-Cambrian era, and again during Laramide time. The pre-Cambrian structure shows greater deformation in some areas in which the strikes and dips of the foliation vary greatly, drag folds abound, and granite and pegmatite are more profuse, and less deformation in others in which the attitude of the foliation is fairly constant.

[139]The Laramide orogeny in central Colorado included igneous activity and crustal compression which folded the rocks and broke them along major and minor faults. Ore deposition followed soon after the magma's intrusion. Major faults reaching deeply tapped the source of the mineralizers, served as the main channels of ascent for these solutions, and influenced the general distribution of the mineralization; but minor faults localized most of the ore bodies.

Suggestions for Prospecting[16]—Mineralization in this district has been concentrated in two general areas to which prospecting should be confined, but the possibilities of locating deposits much larger than those already worked are admittedly small. Within the western area new ore bodies in excess of several hundred thousand dollars gross value should not be anticipated, therefore exploration costs should be regulated by this reasonable limit of possible gross returns. Away from the known deposits, undiscovered ore bodies are most likely to be found in pre-Pennsylvanian strata, and also in the pre-Cambrian rocks below, immediately to the east of their outcrop belt between North Star Mountain and McCullough Gulch. There, the favorable horizons lie concealed at increasingly greater depth eastward beneath the barren lower division of Pennsylvanian and Permian strata as well as beneath a mantle of unconsolidated deposits at many places. Somewhat less likely to conceal undiscovered ore bodies are calcareous zones of the middle division of Pennsylvanian and Permian strata. One prominent zone at the base of this division includes the ore-bearing bed in the Bemrose and Governor mines; it is concealed by unconsolidated material at most places between the Bemrose mine and McCullough Gulch, but is almost continuously exposed by placer workings and road cuts between the Bemrose mine and Hoosier Pass. Another prominent zone, some 1,500 feet stratigraphically higher, includes the ore-bearing bed at the Fredonia mine; it is intermittently exposed for ½-mile northward from the mine and very well exposed for two miles southward, but affords no indications of new ore bodies. Gold deposits, and perhaps minor deposits of tungsten, iron and molybdenum, may be anticipated in the central parts of the mineralized areas, and silver-lead-zinc deposits in the outer parts.

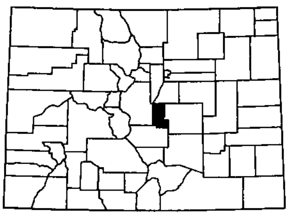
[16]Although chances of finding ore within the eastern mineralized area are difficult to evaluate, the likelihood of discovering new ore bodies larger than in the western area does not appear good. Empirically, the most promising ground is in the immediate vicinity of mines that have had relatively large outputs. Concealed ore in Dakota quartzite may possibly exist beneath alluvium east of Shock Hill, beneath alluvium and Benton shale north of Shock Hill, and beneath moraine both to the north and to the south of the Germania mine. South-southeast of Breckenridge, close to the Boreas Pass fault, ore bodies may lie concealed beneath unconsolidated materials that cover most of the terrain for a distance of ¾-mile northward from the Twin Sisters mine, and also at a few other places. Undiscovered deposits near the Germania, and possibly near the Sultana mine (a mine north of Breckenridge), may contain noteworthy quantities of gold, but elsewhere in the eastern area silver-lead-zinc deposits are to be anticipated.

Sand and Gravel—Sand and gravel have been produced from the course of the Blue River in the vicinity of Dillon and north to the Grand County line; from the Snake River near Dillon, and from Tenmile Creek near Kokomo. Other sand and gravel deposits are located: along the course of the Blue River; in the Breckenridge area; south of Tiger; along the course of Straight Creek northeast of Dillon; along the Snake River east of Dillon, and in the Montezuma area from Tiger to the Snake River along the drainages.

Geological Note—The southeastern bulge of Summit County is located within the southern part of the Front Range mineral belt. A summary of part of the general geology of the belt is contained on pages 47-52 of this book. The geology appertaining to the mining districts has been discussed above, or referred to pertinent pages of the 1947 edition of this book.

In general, Summit County lies within pre-Cambrian terrane with numerous isolated remnants of sedimentary rocks, chiefly of Cretaceous age, occurring in a north-northwesterly belt from Dickey to the Grand County line. An intermontaine structural trough extends from south of Breckenridge and crosses the County in a north-northwesterly direction. The Williams Range confines this trough on the northeast, and the Gore Range along the southwest. Upper Cretaceous rocks of the Pierre shale fringe the eastern margin of the trough. East of the Pierre exposures, separating them from the pre-

Cambrian complex to the east, is the Williams Range thrust fault which has caused the pre-Cambrian formations to overlie as much as 4,000 feet of sediments. The pre-Cambrian rocks within the County, occurring along the Williams, Gore, and Tenmile ranges, consist of gneisses and schists, greenstone, granite, and related rocks. West of the Pierre exposures, Upper Cretaceous rocks of the Benton shale and Niobrara formation occur locally. Upper Cretaceous rocks of the Dakota sandstone occur in the Dillon area and north from there along the belt previously mentioned. South of Breckenridge and in the Kokomo area are sedimentary rocks ranging in age from the Pennsylvanian Maroon formation, to the Upper Cretaceous Pierre shale. Quaternary glacial and stream deposits occupy an extensive area along the Blue River Valley. Early and Late Tertiary intrusive rocks are common in large areas of the southern part of the County.



Courtesy Colorado Planning Division

Teller County

Teller County, located in the central part of the State, has a population of 2,800 and an area of 555 square miles ranging in elevation from 7,600 to 12,500 feet above sea level. The County seat is at Cripple Creek, a historic early-day mining community with a population of 850.

Available Maps of the County—

a. Teller County Map.
b. U. S. Army Map Service maps: 4961 I, II, III, IV; 4962 II, III; 5061 III, IV.
c. U. S. Geological Survey topographic quadrangle maps cover the County. See index map in the pocket.
d. U. S. Forest Service map "Pike National Forest."

Mineral Production 1946-1958—Teller County has always been primarily a producer of gold. In this category it leads the State with a total cumulative production value, since the discovery of the Cripple Creek deposits in 1891, to the end of 1958, of $422 million. In fact, the County's considerable gold production places it second only to Lake County in total cumulative value of metallic minerals produced. Lake County, because of its huge molybdenite operation at Climax, leads the

State with $855 million. Silver, sand and gravel, feldspar, scrap mica, stone, and gem stones were also produced during the period 1946-1958. The figures in the following table are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Lode Mines	Gold Ounces	Silver Ounces	Total $ Value
1946	25	47,640	7,536	1,673,489[1]
1947	37	58,158	6,860	2,041,738[1]
1948	28	53,569	5,139	1,879,566[1]
1949	13	13,460	2,989	473,805[1]
1950	4	5,779	1,938	204,019[1]
1951	26*	27,699	4,636	977,021[1]
1952	22	48,527	9,133	1,738,176[2]
1953	19	51,559	10,035	1,845,962[3]
1954	22	48,935	7,035	1,760,659[4]
1955	13	47,171	7,086	1,667,599[5]
1956	11	52,544	6,652	1,904,372[6]
1957	17	45,323	6,396	1,630,020[6]
1958	19	43,057	6,845	1,535,847[7]

*In addition one placer mine operated.

[1] Value of precious metal production only.

[2] Same as [1] but includes value of some feldspar production.

[3] Same as [2] but includes sand and gravel production.

[4] Same as [3] but includes some stone production.

[5] Same as [1] but includes stone and gem stone production.

[6] Same as [4] but includes gem stone production.

[7] Same as [5] but includes feldspar and scrap mica.

Precious Metals—Virtually all of the precious metal output of the County has come from the Cripple Creek area. General data on the two mining districts in Teller County are given on pages 217-19, and the history, geology, and ore deposits of the Cripple Creek district are discussed on pages 387-95 of "Mineral Resources of Colorado" (Vanderwilt), 1947 edition. Supplementary information on the Cripple Creek district is given below.

Ore Deposits [142]—The ore deposits of the Cripple Creek district occur chiefly within the fragmental rocks and igneous intrusions that occupy the steep-walled basin, but a few extend into the adjacent pre-Cambrian rocks. All the ore bodies, whatever their shape, are causally related to fissures and their localization is principally structural. In this respect, the ore deposits of the district may be divided into three groups: veins or fissure fillings, some of which are single fissure veins, but more commonly consist of mineralized sheeted zones sometimes 10 feet or more in width, each of which comprises a series of approximately parallel closely spaced narrow fissures; irregular deposits in shattered rock which have formed by the mineralization of the broken rock at the intersections of two or more fissures or fissure zones; mineralized "collapsed breccia" deposits, which consist of rubble-like masses of pipe-like form where shattered ground has been corroded and the rounded fragments coated with vein minerals.

[142]The localization of the vein fissures is related primarily to the major structural features and configuration of the basin, and only secondarily to the physical character of the rocks. One of the outstanding features of the vein fissures is their

arrangement in relatively long narrow zones separated one from another by broad, relatively barren areas. Most of the vein zones are close to the contact between the breccia and the pre-Cambrian rocks, some are wholly within the breccia masses, but some extend into the pre-Cambrian wall rocks. Many of the vein fissure zones that are close to the contact occur at abrupt bends or recessions along the contact, other fissure zones coincide with or parallel the dominant local trends of the contact between the granite and breccia, and others coincide with or parallel the major subsurface structural features of the basin, such as buried granite ridges and spurs. Some fissure zones, though not directly related to known structural features, parallel them and thus suggest a probable genetic relationship to buried parallel structural features.

[142]Although the localization of the vein fissures and fissure zones was primarily controlled by the major structural features of the basin, factors such as the physical character of the host rocks locally influenced their distribution, arrangement, and extent. The most favorable host rocks are those most susceptible to fissuring. Vein fissures occur in all types of rock, but along any one fissure zone they are most abundant in the breccia. Many vein fissures follow dikes, especially phonolite and basaltic dikes. These dikes have a tendency to develop platy parting parallel to their walls and are sheeted where they lie in, and parallel, the zone of fissuring. Where the veins intersect dikes, sills, or the larger irregular intrusive bodies at right angles or nearly so, the fissures are either tight within such rocks, or terminate at the contact.

[142]The conformity between many of the vein fissure zones and the corresponding local structural features of the basin, which indicates their genetic relations, implies post-basin movement along many of the pre-existing master fissures that bound the basin and favors exploration along analogous structural features along the basin walls as yet unexplored or inadequately explored. On the basis of the relation between the structure of the basin and the known vein zones, the following localities, which either have not been prospected or are inadequately explored, have been recommended by Dr. Koschmann[16] for further study and exploration.

1. The south end of the Vindicator vein system, south of the Teresa mine.
2. The area to the south of the Queen mine, especially along the extension of the southerly-trending contact.
3. The northeast extension of the Gold Dollar-Mabel M zone.
4. The northwest-trending contact west of the Anaconda tunnel and along its extension in the breccia and granite.
5. The northwest-trending contact between the Index

shaft and the Goodwill tunnel and its extension in the granite and breccia.

6. The west wall of the North basin which is marked by a series of step-like recessions of the contact.
7. Both walls of the Galena Hill embayment, especially along the projected course in the breccia.
8. The contact east of the Patti Rosa mine and northwest of the Cameron mine.
9. Both walls of the Cameron embayment, especially along the projected course in the breccia.
10. The irregular contact north of the Masterpiece tunnel where stretches of contact of northerly trend alternate with stretches of northeasterly trend.

Sand and Gravel — Sand and gravel have been produced from Rule Creek north of Divide; from Twin Creek west of Divide and near Florissant, and from one of the streams in the vicinity of Cripple Creek. Sand and gravel are produced generally in accordance with the State Department of Highways needs in the area. The U. S. Bureau of Mines reports a production of 28,000 tons during 1957, valued at $17,000.

Stone—Virtually all of Teller County's surface is composed of granitic rocks with Pikes Peak granite predominating. The rock is a pink, coarse-grained granite, poor in ferromagnesian minerals. In the southwestern part of the County Silver Plume granite and Tertiary extrusive and intrusive rocks are found. Some of these rocks are suitable for use in the construction industries. The Colorado Bureau of Mines gives the following values for stone production:

1953	$23,000
1954	23,000
1955	22,000
1956	12,000
1957	11,000
1958	----

Pegmatite Minerals[143] — The Pikes Peak-Florissant pegmatite province, and the Cripple Creek pegmatite province lie partly within Teller County. Pegmatites in the area east of Florissant occur in Pikes Peak granite and are typically small. Generally, the only economic minerals they contain are gem stones, such as topaz, quartz, and amazonite. The Cripple Creek province pegmatities occur both in the granite along the margins of the Pikes Peak granite batholith and in the metamorphic rocks in the area. Muscovite is a major accessory mineral in many of these pegmatites. Minor accessories include beryl and columbite.* Some scrap mica has been shipped from this area, and feldspar valued as follows:

*Colorado Bureau of Mines, Annual Reports.

1952	$109,000
1953	10,000
1954	9,000
1955	9,000
1956	----
1957	5,000
1958	----

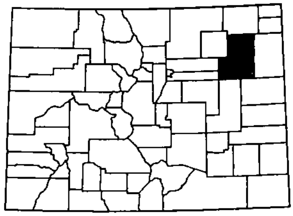
Gem Stones—In the Crystal Peak area north of Florissant are found excellent amazonite, topaz, phenocite, amethyst, smoky quartz, rutilated quartz, quartz crystals, and garnet. Turquoise is found in the Cripple Creek area.

Uranium—*All known uranium prospects of significance have been found in the Miocene Florissant lake beds in three separate basins within the High Park and Lake George areas. Newly discovered (1958), these deposits may prove to be the precursors of others of considerable extent which may be discovered in similar environments. The host Florissant lake beds consist of interbedded arkosic sandstone and conglomerate, shaly siltstone, and tuffaceous sediments, which are, at least in part, lacustrine.

Geological Note—The most interesting and economically important geological feature in Teller County is the Cripple Creek basin, or caldera, discussed by A. H. Koschmann (USGS) in the 1947 edition of "Mineral Resources of Colorado" (Vanderwilt).

Teller County lies in the pre-Cambrian terrane of the southeastern extremity of the Front Range. Pikes Peak granite is the predominant rock in the County with the exception of a few areas. Trout Creek cuts across the northeastern quadrant, flowing in a northerly direction, and in this area are exposed Pennsylvanian rocks of the Fountain formation overlying still earlier sediments. From Lake George south to the west of Midland are Miocene lake beds of the Florissant sediments, which also occur at the confluence of Fourmile and East Oil creeks, and at High Park west of Cripple Creek. Silver Plume granite occupies much of the southwestern corner of the County west of Midland, Gillett, and Victor. Late Tertiary intrusives are exposed in the Cripple Creek area and also near the headwaters of Trail Creek in the northwest. Tertiary volcanic rocks cap pre-Cambrian rocks in the Cripple Creek area, and metamorphic rocks of the pre-Cambrian Idaho Springs formation are exposed at Cripple Creek and the immediate surroundings.

*Dr. Donald L. Everhart, USAEC, personal communication.



Courtesy Colorado Planning Division

Washington County

Washington County, located on the plains of northeastern Colorado, has a population of 7,300 and an area of 2,530 square miles ranging in elevation from 4,000 to 4,800 feet above sea level. The County seat is at Akron, a ranching, farming, oil and gas community with a population of 1,650.

Available Maps of the County—

a. Washington County Map.

b. U. S. Army Map Service maps: 5263 I, II; 5363 I, II, III, IV; 5364 I, II, III, IV; 5463 III, IV; 5464 III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover only the northwestern corner of the County. See index map in the pocket.

Mineral Production 1952-1958—Petroleum, natural gas, and sand and gravel are the only minerals of consequence produced in the County. The petroleum production figures in the following table are from records of the Colorado Oil and Gas Conservation Commission; the total value figures are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Petroleum Barrels	Total $ Value
1952	39,655	----
1953	2,572,234	6,848,532[1]
1954	3,410,811	9,489,912[1]
1955	5,899,299	16,032,243[1]
1956	7,214,095	20,197,000[1]
1957	7,027,222	21,395,738[1]
1958	6,852,619	20,477,770[1]

[1] Value of petroleum and sand and gravel.

Hydrocarbons — Petroleum was first discovered in 1952, a year in which several fields were discovered. The first field to come into production was the Abbott, in the western part. Production was encountered in the 'J' sand of the Dakota sandstone, Lower Cretaceous series. The other fields which were discovered the same year are: the Akron gas field, a few miles northwest of Akron town; the Rush-Willadel oil and gas field in the southeastern quadrant of the County, and the Woodrow-East oil and gas field in the west-central part.

Despite the relatively short time since it became a petroleum producer, Washington County has become one of the most important in this category in the State. As of the end of 1959, there were four oil fields, 52 oil-gas fields, and one gas field in the County, with a total cumulative production since 1952 of 39,784,653 barrels of oil, and 24,465 million cubic feet of natural gas. The County's 1959 production placed it third in the State in oil, and seventh in natural gas with 3,768 million cubic feet for the year.

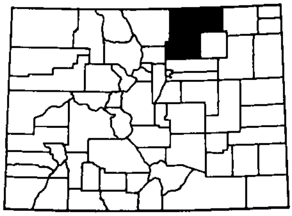
*Some of the thickest oil and gas pay sands of the Denver Basin are found in Washington County. The only producing zones are the Dakota 'D' and 'J' sands of lower Cretaceous age. Large areas still remain untested and it is anticipated that an appreciable number of new fields will be discovered in these sands in the future. In the light of our present knowledge, other beds above or below the current producing horizons appear to lack good reservoir characteristics and therefore their productive potential is questionable.

Sand and Gravel — Sand and gravel have been produced from reworked deposits of the Ogallala formation and Quaternary sediments: in the drainages near Akron and 10 miles to the south; near Platner; near Otis; north of Hyde; east of Pinneo; near Lindon and east and west of it from scattered locations along the route of U. S. Highway 36, and from the course of Arikaree Creek around Cope in the southeastern corner of the County. Other sand and gravel deposits are located north of Akron to Waitley; south of Pinneo; northeast of Platner; east of Otis and south of Hyde. The Ogallala formation and later sediments which cover most of the County are composed in part of sands and gravels which under natural conditions of reworking and classification have formed usable deposits of sand and gravel.

Geological Note—Washington County is located entirely in sedimentary terrane. The northeastern corner, in the area around Burdett and the headwaters of Willow Creek, is surfaced by Miocene rocks of the Arikaree formation. The westernmost part, as far east as Waitley in the north, Rago in the middle, and Lindon in the south, is mantled by Upper Cretaceous rocks of the Pierre shale. Fringing the eastern margin of the Pierre exposures, there is a narrow, irregular band of Oligocene rocks of the White River formation which extends northerly from Lindon, to east of Waitley and north into Logan County. The remaining three eastern quarters of the County are surfaced chiefly by the heterogenous materials of the Pliocene Ogallala formation and Quaternary sediments.

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

Weld County



Courtesy Colorado Planning Division

Weld County, located in the northern part of the State, bordering Wyoming and Nebraska, has an area of 4,033 square miles ranging in elevation from 4,400 to 5,000 feet above sea level, and a population of 80,000. The County seat is at Greeley, a farming, livestock raising, light industry, educational, and business community with 28,000 population.

Available Maps of the County—

a. Weld County Map.
b. U. S. Army Map Service maps: 4964 I, II; 5064 I, II, III, IV; 5065 I, II, III, IV; 5164 I, II, III, IV; 5165 I, II, III, IV; 5265 I, II, III, IV.
c. U. S. Geological Survey topographic quadrangle maps cover the southern half of the County. See index map in the pocket.

Mineral Production 1946-1958—Fossil fuels are the most important mineral products of the County. Within the last few years the value of petroleum production has surpassed that of coal. Sand and gravel, stone, and some rare earth concentrate, were also produced during the 1946-58 period. The petroleum production figures in the following table are from records of the Colorado Oil and Gas Conservation Commission, all others are from U. S. Bureau of Mines Minerals Yearbooks.

Year	Petroleum Barrels	Coal Short Tons	Total $ Value
1946	6,220	1,145,968	
1947	7,063	1,230,683	
1948	3,351	976,532	
1949	8,875	823,013	
1950	21,375	782,811	
1951	67,478	879,223	3,596,330[1]
1952	480,700	754,779	3,128,605[1]
1953	612,515	700,347	4,804,509[2]
1954	1,363,320	626,904	6,653,541[3]
1955	1,609,784	614,208	7,279,865[4]
1956	1,825,924	643,540	8,321,641[5]
1957	2,347,818	621,102	10,171,415[5]
1958	2,123,545	580,011	9,534,362[4]

[1] Value of coal production only.
[2] Value of coal and sand and gravel production.
[3] Same as [2] but includes petroleum.
[4] Same as [3] but includes some stone production.
[5] Same as [4] but includes some rare earth production and no stone production.

Hydrocarbons—Petroleum was first discovered in 1930 on the Greasewood structure near the northwest corner of Morgan County. *The field, which is approximately 60 miles east of the Rocky Mountain front, was the first commercial development far removed from the foothills structure. Production was found in the upper sandstone member of the Dakota group (Cretaceous), at 6,661-ft. in what was considered to be a stratigraphic trap. This discovery pointed up the possibilities for the existence of other stratigraphic pools on the eastern flank of the Denver Basin.

As of the end of 1959, there were in the County four oil, 27 oil-gas, and one gas fields. The gas production for the year amounted to 2,015 million cubic feet, and that of oil to 1,778,953 barrels. The total cumulative production to the end of 1959 amounted to 12,746,423 barrels of oil and 11,189 million cubic feet of gas.

**Weld is the largest of the counties located within the Denver Basin. It extends from the productive belt of the Front Range in the west, eastwardly across the Basin to well up on its eastern flank. Weld is one of the most promising counties in Colorado for future development, as it contains favorable horizons from the Upper Cretaceous Pierre to the Pennsylvanian Fountain formation. Present producing zones include the Cretaceous Hygiene sand of the Pierre shale, the 'D' and 'J' sands of the Dakota, and the Permian sand of the Lyons formation. There has also been some production from the Greenhorn formation of Upper Cretaceous age. There exist good possibilities for developing additional production from the Niobrara and Greenhorn formations in the eastern part of the County.

Coal—Most of Weld County lies within the Denver Coal Region, but only certain areas have been adequately investigated. In these areas, Landis[6] estimates that 335 square miles of the County are underlain by measures containing 1,700 million tons of subbituminous coal, all of it lying under between 0 to 1,000 feet of overburden. There are four coal fields and coal areas in the County:

[6]**Briggsdale Area**—This area is located a few miles to the northwest of the northwestern corner of Morgan County. At least one mine has produced coal in the past from this area near the settlement of Briggsdale. The coal occurs in the Laramie formation of Upper Cretaceous age. Although no analysis of the coal is available, it is assumed to be subbituminous C in rank.

[6]**Boulder Field**—This field is located in the southwestern part and extends into Boulder County. The coal beds, which are lenticular, occur in the Laramie formation of Upper Cretaceous age. Six beds are recognized in the field, all of them within the lower 225 feet of the Laramie. Three of the beds

*A. E. Brainerd and F. M. Van Tuyl, in reference No. 1 of the bibliography

**Mr. George H. Fentress, Exeter Drilling Co., written communication.

are particularly lenticular and exhibit extreme thickness variations laterally. In general, the coal beds seldom exceed 10 feet in thickness, but may reach 14 feet locally. Regional inclination of the strata is from ½ to 2 degrees, but there have been recorded steep to vertical dips in localities affected by faulting. The coal is mainly subbituminous B in rank and, in most of the field, lies under less than 1,000 feet of overburden.

[6]**Eaton Area**—This area is located in the west-central part of the County north of the city of Greeley. The coal occurs in the Laramie formation of Upper Cretaceous age, and is subbituminous C in rank.

[6]**Wellington Area**—Coal has been mined in the past from this area which extends westward into Larimer County to the north of Fort Collins. There are indications that two coal beds are present in the area, with thickness ranging between 4 and 6 feet. The coal is subbituminous C in rank, and the beds dip 6 degrees easterly.

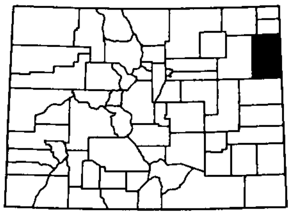
Sand and Gravel—Sand and gravel have been produced in the vicinity of Greeley from the course of the South Platte River, and from the area to the east and west of the city; also from near Black Hollow settlement and Black Hollow reservoir; from near Pierce and south of it; from northeast of Carr; from a stream southwest of Briggsdale; from west of Keota; from several tributaries of Pawnee Creek in the northeastern part of the County; from east of Buckingham; from the course of the South Platte River south of Greeley as far as Brighton; from St. Vrain Creek and other streams in the southwest, and from several northerly-flowing drainages in the southern part. Other sand and gravel deposits are located: north of Kuner to Fosston; east of Kuner along the South Platte to Morgan County; west, southwest and south of Kuner along the South Platte to Adams County; north of Greeley to Nunn in a wide band; west of Greeley to Larimer County; southeast of Crest, and north of Nunn to the Wyoming border.

Gem Stones—The finest jasper in Colorado is found near Kalouse in the northwestern part of Weld County, associated with agate and petrified wood.

Clay—Butler[7] sampled a number of clay beds in various localities of the County and the results of his tests indicated the presence of useful clays: in the vicinity of Eric in the southwestern part; at a coal prospect in T-5-N, R-66-W about 1,500 feet northwest from the southeast corner of section 30; about 8 miles due west of Greeley; in the vicinity of Peckham along the railroad; in the Black Prince coal mine 12 miles south-southeast of Greeley; in the vicinity of Evans south of Greeley, and about 8 miles due east of Grover.

Geological Note—The petroleum geology of Weld County is discussed in the petroleum section of this book. A brief note on the general surface geology is given below.

Weld County lies entirely within the sedimentary terrane to the east of the Rocky Mountain front. Pliocene rocks of the Ogallala formation surface a small area north of Kauffman in the northeastern part, surrounded by an irregular band of Miocene rocks of the Arikaree formation. The remainder of the "panhandle" in the northeast is surfaced chiefly by Oligocene rocks of the White River formation with the exception of areas where drainages have cut through to expose Upper Cretaceous rocks of the Laramie, Fox Hills, and Pierre formations. The western margin of the White River rocks extends northwestwardly from New Raymer in the south-central part of the panhandle to Carr in the northwestern corner of the County. Southwest of the White River exposures are rocks of the Laramie formation which blanket most of the balance of the County. In the southern part, however, two tongues of Eocene rocks of the Denver-Arapahoe group come up from Adams County, one in the Keenesburg area, and another south and west of Hudson. In the extreme western part, west of Greeley, and also along the course of the Platte River, a narrow band of Fox Hills rocks fringes the western margin of the Laramie exposures. West of this band, Upper Cretaceous rocks of the Pierre shale predominate as far as the western boundary of the County. The valley floors of the major drainages, such as the South Platte River, Cache la Poudre, Boulder, Lone Tree, Crow, and other creeks, are mantled by extensive Quaternary terrace and alluvial deposits.



Courtesy Colorado Planning Division

Yuma County

Yuma County, located in the northeastern part of the State bordering on Nebraska and Kansas, has a population of 10,500 and an area of 2,383 square miles ranging in elevation from 3,500 to 4,200 feet above sea level. The County seat is Wray, a farming, ranching, and business community of 2,500 population.

Available Maps of the County—

a. Yuma County Map.

b. U. S. Army Map Service maps: 5463 I, II, III, IV; 5464 I, II, III, IV; 5563 I, II, III, IV; 5564 I, II, III, IV.

c. U. S. Geological Survey topographic quadrangle maps cover a small portion of the southeastern quadrant of the County. See index map in the pocket.

Mineral Production—The only minerals of consequence reported produced by the County are sand and gravel. Occasionally, a small quantity of stone is quarried. The following figures are from U. S. Bureau of Mines Minerals Yearbooks.

1952	$ 3,043
1953	10,650
1954	80,629
1955	162,212
1956	164,500
1957	341,600
1958	294,200

NOTE: The values for 1952 through 1957 represent sand and gravel production only. The 1958 figure includes 1,600 tons of stone valued at $11,200, and 440,000 tons of sand and gravel valued at $283,000.

Sand and Gravel — Sand and gravel have been produced from the North Fork of the Republican River in the vicinity of Wray; from drainages and reworked gravels of the Ogallala and younger formations north and south of Wray; from the courses of the Arikaree River and some of its tributaries in the southeast-central part of the County, and in the southwestern part north and northwest of Joes; from the courses of the South Fork of the Republican River and some of its tributaries in the south and southeastern parts, and from Willow Creek and some of its tributaries in the northwest. Other sand and gravel deposits are located in scattered parts of the County: at Eckley and southeast of it; south of Robb; south of Laird; a few miles north of Idalia, and on the same line, north of the Arikaree River, and south of the South Fork and south of Lostmans Creek a few miles west of their confluence.

Clay and Volcanic Ash—Butler[7] sampled a few clay beds not far from Wray, some of which were being used at the time for the manufacture of bricks. One of the deposits sampled, located about 4 miles south-southwest of Wray, apparently consisted chiefly of volcanic ash, which occurs in the Ogallala formation in that vicinity. The material did not prove adequate for clay products, but some shipments had been sent east for the manufacture of polishing powders. One other of Butler's samples indicated a deposit of usable clay not being worked at the time ". . . on the Wray side of Flirtation Peak . . ." The material consisted of a 15-foot horizontal bed of medium-hard, yellow, somewhat gritty shale which occurred along the side of a high bluff. Butler's tests on the sample indicated the material to be suitable for the manufacture of bricks.

Hydrocarbons—There has been no hydrocarbon production of consequence in the County. The Arikaree field, in the southeastern part, was discovered in 1919. The discovery well, Midfields Oil Company's No. 1 State, developed a little gas production from the Niobrara formation which was marketed to neighboring farms prior to its abandonment.

*Yuma County is located on the extreme southeast flank of the Denver Basin and the northern portion of the Las Animas Arch. Except for shows of gas in the Niobrara group (Upper Cretaceous), limited test drilling has not as yet discovered economic hydrocarbon accumulations. The most favorable horizons for exploration are the Cretaceous sands of the Dakota and Niobrara formations, and the sandstones and limestones of the Pennsylvanian system. It is highly possible that future discoveries will consist mostly of natural gas.

Geological Note—Yuma County lies entirely in the sedimentary terrane of the High Plains section of the Great Plains province. The extreme northern part, north and south of easterly-flowing Willow Creek, is surfaced by Miocene rocks of the Arikaree formation. The remainder of the County is mantled by Pliocene rocks of the Ogallala formation and Quaternary sediments, chiefly aeolian sands of the Sandy Hills formation and unconsolidated silts and clays. The major and deeper drainages, such as the North Fork of the Republican River and the Arikaree River, have cut through these formations to expose Upper Cretaceous rocks of the Pierre shale.

*Mr. George H. Fentress, Exeter Drilling Co., written communication.

Part II

Special Section On Metals

Prepared Under the Supervision of

S. M. del Rio

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PART II

Special Section On Metals

Molybdenum *Uranium* *Rare Earths*
Thorium *Beryllium* *Minerals Processing*

The preceding by-county discussions deal with virtually every mineral item produced in Colorado, although perforce, in a brief and localized manner.

In this section, those metals which merit special attention because of their actual or potential importance to the mining industry of the State, are treated in greater detail.

World War II had an energizing impact on every field of research and scientific development. Termination of the War permitted science and technology to direct their efforts to peaceful applications of the progress made under duress. In the field of nuclear energy, the atom is being harnessed to propel sea-going vessels and to generate electricity; radioactive isotopes are being used ever more widely in the fields of medicine, agronomics, metallurgy, and many others. The rocket, which was brought to an effectives degree of development during the war, has been turned to the conquest of the cosmos. These, and other war-germinated events, have created a demand for metals and materials capable of withstanding the previously abnormal conditions of operation now common in nuclear reactors and space rocketry.

Today, many hitherto relatively little used metals are being reviewed for properties in their elemental, alloyed, and compound forms which may make their use desirable in the new fields. It is envisioned that consequential to this research many new applications, some of them perhaps unsuspected, will come to light.

The use of molybdenum in steels, cast iron, and malleable castings, has long been established. Its use in the pure metallic form in electronics and in high-temperature applications is growing and the demand for it in these and other fields can be expected to increase. Dr. Robert H. Carpenter* discusses in this section the geology of the two known major molybdenum deposits in Colorado, Climax and Urad. The mine at Climax has become the largest underground mining operation in the world, as well as the largest molybdenite producer. The related ore-processing plant at Climax is by far the largest in the State, and the value of its principal product, molybdenite concentrate, leads all other metallic products in the State.

The production of uranium ores and concentrates in Colorado has attained an importance surpassed only by molybdenum among the metals. Utilization of uranium's nuclear

*Professor of Geology, Colorado School of Mines.

properties are almost inconceivable in their potential. This metal will increase in importance as more is learned about its control, applicability, and the neutralization—or reutilization to the point of neutrality—of resulting radioactive wastes. Colorado will continue to be an important producer of uranium ores and concentrates for many years into the future. Dr. Robert J. Wright* and Dr. Donald L. Everhart**, both formerly with the U. S. Atomic Energy Commission, discuss in this section the history, geology, and related subjects pertinent to the uranium industry in Colorado.

The rare earths, thorium, and beryllium are among those comparatively little used elements which are at present under study by research scientists. Colorado has known deposits of these materials and no doubt others will be discovered under the stimulus of adequate markets whenever they develop.

The rare earths are at present used principally in the glass industry, in carbon-arc-electrode cores, as misch metal, ferrocerium, and other applications. These elements are extremely difficult to separate from one another and the process for doing so is quite costly. Research is being conducted to develop lower cost reduction methods that will permit production of the individual elements in sufficient quantities at prices that will encourage their use. Mr. Vance Haynes, Jr.***, discusses the rare earth elements and the manner of their occurrence in Colorado.

A few years ago, the potential use of thorium in the so-called "breeder" reactor created a stir in the mining industry, but interest subsided rapidly when in 1955 the Atomic Energy Commission reiterated its statement of 1948 indicating that no purchasing program was to be established for thorium. Nevertheless, because of its convertibility to fissionable U-233 under neutron bombardment, thorium has strong potentialities in the nuclear field. The principal nonenergy uses for thorium and its compounds are in the manufacture of gas mantles, as a catalyst in the petrolum industry, in refractories, in the electrical industry, in magnesium alloys, and in some pharmaceutical and other applications. Mr. J. H. Heinicke**** discusses in this section the thorium occurrences in Colorado.

Beryllium is a metal of potentially strong demand. Actually, United States requirements far exceed domestic production, and this is one of the strong deterrents, some of which are listed below, to its wider use in industry at the present time:

a) high cost of production;
b) manner of its principal occurrence in this country, in pegmatites which makes it economically difficult to mine and therefore scarce;

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**Chief Geologist, International Minerals & Chemical Corp., Skokie, Ill.
***Senior Project Engineer, American Institute of Research, Golden, Colo
****Senior Project Engineer, American Institute of Research.

c) difficulty of producing the pure metal;

d) toxicity of beryllium compounds.

The chief difficulties are, of course, its high cost, and the scarcity of occurrences in sufficient concentration for economic exploitation. Colorado contains numerous beryl-bearing pegmatites and some vein-type deposits, representing substantial resources of beryllium. It can be expected that as the West increases in population and industrialization, other of the more abundant pegmatite minerals, such as feldspar and mica, will be economically extractable and beryl will then be produced as a coproduct. Prior to that time very few pegmatites will prove commercial for beryl production alone. In this section Mr. Denman S. Galbraith* discusses beryllium in Colorado.

Also included in this special section on metals, is a chapter on minerals processing. The economic and technical necessity of concentration and separation of the valuable minerals in an ore is axiomatic. It is well in keeping with the facts to state that without effective methods of ore treatment the mining industry would have expired with the exhaustion of the rich shipping ores. Mr. Arthur P. Wichmann**, for many years an educator on the subject of minerals processing, discusses this topic as it appertains to Colorado.

S. M. del Rio

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Chapter IV

Molybdenum

by

DR. ROBERT H. CARPENTER

Professor of Geology

Colorado School of Mines

CHAPTER IV

Molybdenum

by

DR. ROBERT H. CARPENTER*

Molybdenite, the most common ore mineral of molybdenum, occurs in many of the mining areas of Colorado as a constituent of Precambrian pegmatite and quartz veins, and also in association with younger porphyry intrusive bodies. Occurrences of molybdenite throughout the State are listed and briefly described in Bulletin 14, of the Colorado Geological Survey.

The majority of the known molybdenite deposits of Colorado have been found along the northeast-southwest trending Colorado Mineral Belt which extends diagonally across the State from Boulder through Central City, Idaho Springs, Georgetown, Montezuma, Breckenridge, to Leadville and beyond. Climax and Urad, the two major developed deposits, as well as many of the more favorable molybdenite prospects, are located along this mineral belt.

Geology of the Mineral Belt

As a result of erosion of younger rocks, the ancient Precambrian gneisses, schists, and granites are exposed along the Mineral Belt in the Front Range, the Ten Mile Arch (Park Range), and in the Sawatch Range. In the intervening basins, strata of Paleozoic, Mesozoic, and Cenozoic age, outcrop. Tertiary intrusives transect these rocks as stocks, dikes, and possibly even as volcanic necks, the upper portions of which have been removed by erosion. These intrusives, believed to be Eocene in age, range in composition from diorite to granite, and texturally may be classified as porphyries for the most part. The lead, zinc, and silver mineralization of the Mineral Belt, as well as the molybdenite, often occur in close association with the porphyries, and may be genetically related to them.

Productive Deposits

Molybdenite reserves at Climax class it as one of the major mineral resources of the entire nation. A second deposit, located at the Urad mine, although not in production, is an important low-grade reserve. Other known deposits which so far have been developed only to the prospect stage, may become important with additional exploration and favorable economic conditions.

Climax Deposit

The famous Climax molybdenite deposit is situated at

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Fremont Pass near the crest of the Park Range, one of the major ridges of the Colorado Rockies some 100 miles southwest of Denver, and 13 miles north of Leadville. Geologically, it is located in the central part of the Colorado Mineral Belt.

Ore was first produced from the deposit in 1918 and 1919, but the operation did not prove economical because of limited demand and low price. In 1924, production was increased to 400 tons per day from the initial 250 tons. Intensive exploration was carried out under the guidance of B. S. Butler, John W Vanderwilt, and other leading geologists and, by 1929, over 100 million tons of ore had been blocked out. Today, the production rate is 35,000 tons per day with reserves reported to be approximately 640 million tons of ore containing one billion pounds of molybdenum.

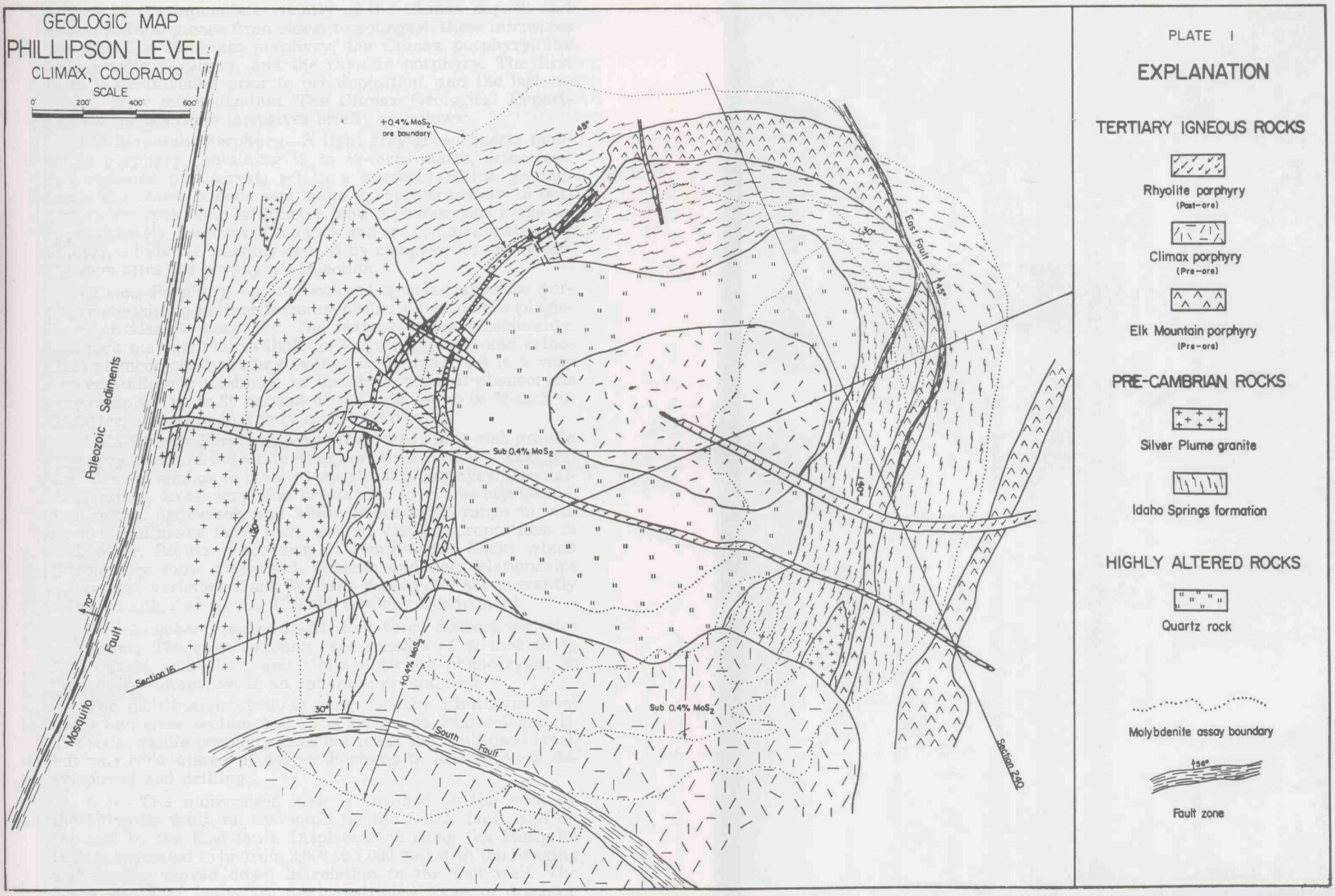
Geologic Relationships—The Climax deposit is located in Tertiary intrusive rocks and Precambrian granites, schists and gneisses immediately east of the westerly dipping Mosquito fault which flanks the western fringe of the Park Range. Paleozoic sediments, consisting of gray sandstone, gray to black shales, and an occasional thin limestone bed, have been downfaulted on the overlying or hanging wall side. Tertiary igneous rocks have intruded the Precambrian rocks. Mineralization occurs in highly fractured rocks within, and adjacent to, the prophyry intrusives.

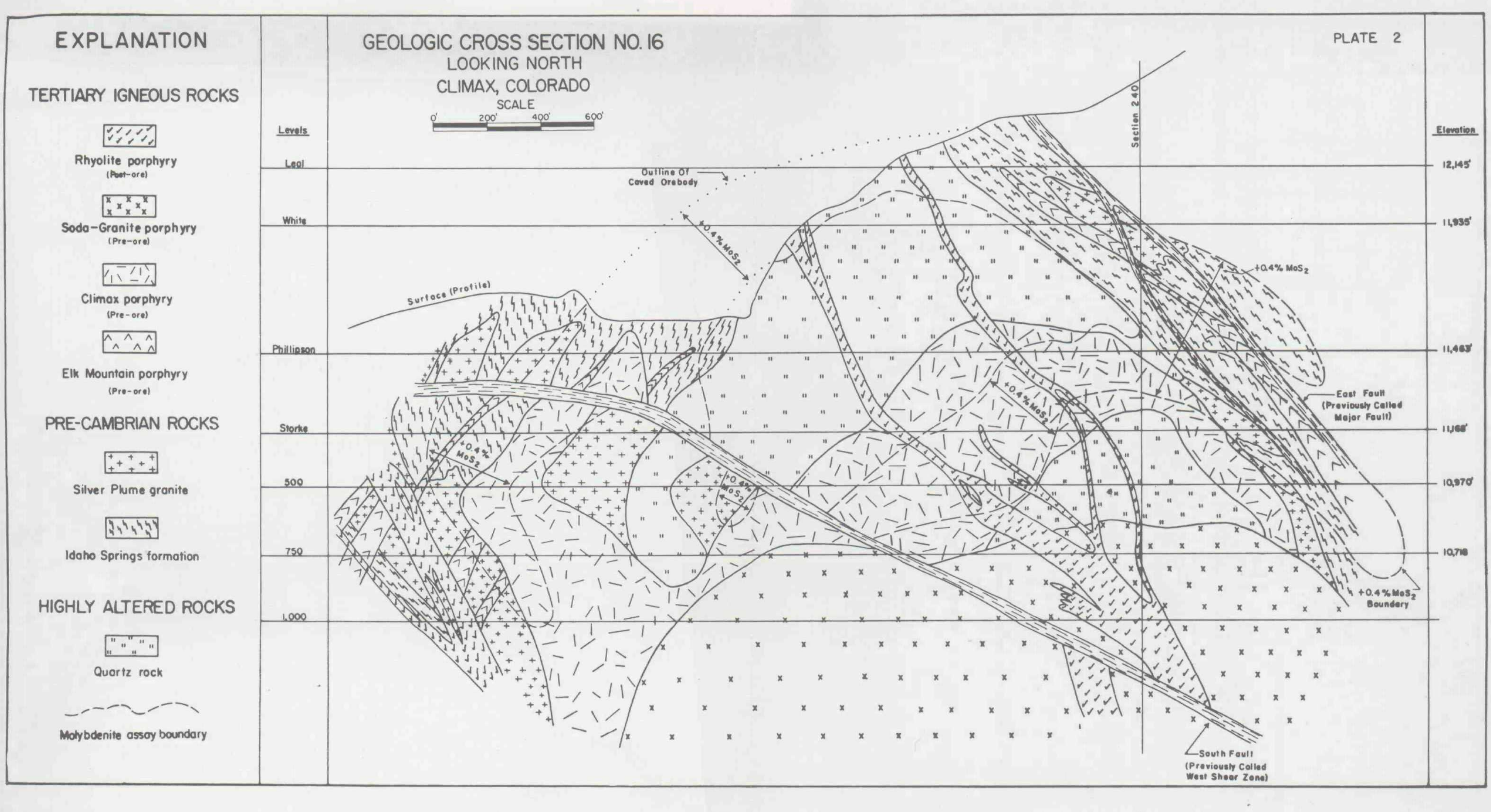
Geology—The Climax porphyry stock appears to have acted as a center of mineralization in the upper levels of the mine even though no clear cut genetic relationships have been established between the mineralization and the intrusive body. Ore occurs within this porphyry, around its fringes, and above its upper extremities. Its domal crest is situated about 100 feet above the Phillipson level. The geologic plan map, Plate I, and the cross section, Plate II, illustrate these relationships.

The geologic staff at Climax is of the opinion that the ore bodies have been formed as a result of fracturing in a ring-like manner around and within the central core of Climax porphyry. In the third dimension, the ore is arcuate over the domal top of the Climax porphyry intrusive body, occurring within it, and in the adjacent highly altered rocks.

Quartz, molybdenite, and associated minerals have filled the fracture network to form the ore; this mineralization has developed in all rock types with the exception of the rhyolite porphyry. The area of intense silicification immediately adjacent to the Climax porphyry body on the Phillipson level appears to have resulted from flooding of shattered rocks. The cause of this fracturing may have been vertical stresses which resulted from intermittent intrusive activity at depth; there is some evidence that suggests doming of the Precambrian terrain by Tertiary intrusive forces.

Tertiary Intrusive Rocks—Four separate igneous rock types of


GEOLOGIC MAP
PHILLIPSON LEVEL
CLIMAX, COLORADO
SCALE
0' 200' 400' 600'
+0.4% MoS_2 ore boundary
Paleozoic Sediments
Mosquito Fault
Section 16
Sub 0.4% MoS_2
+0.4% MoS_2
South Fault
East Fault
Section 240
PLATE 1
EXPLANATION
TERTIARY IGNEOUS ROCKS
Rhyolite porphyry (Post-ore)
Climax porphyry (Pre-ore)
Elk Mountain porphyry (Pre-ore)
PRE-CAMBRIAN ROCKS
Silver Plume granite
Idaho Springs formation
HIGHLY ALTERED ROCKS
Quartz rock
Molybdenite assay boundary
Fault zone


EXPLANATION
TERTIARY IGNEOUS ROCKS
Rhyolite porphyry (Post-ore)
Soda-Granite porphyry (Pre-ore)
Climax porphyry (Pre-ore)
Elk Mountain porphyry (Pre-ore)
PRE-CAMBRIAN ROCKS
Silver Plume granite
Idaho Springs formation
HIGHLY ALTERED ROCKS
Quartz rock
Molybdenite assay boundary
GEOLOGIC CROSS SECTION NO. 16
LOOKING NORTH
CLIMAX, COLORADO
SCALE
0' 200' 400' 600'
PLATE 2
Levels
Leal
White
Phillipson
Storke
500
750
1,000
Elevation
12,145'
11,935'
11,463'
11,168'
10,970'
10,718'
Outline Of Caved Orebody
Surface (Profile)
Section 240
+0.4% MoS_2
East Fault (Previously Called Major Fault)
+0.4% MoS_2 Boundary
South Fault (Previously Called West Shear Zone)

presumed early Tertiary age are recognized by Climax geologists in the immediate vicinity of the Climax deposit and within it. In sequence from oldest to youngest, these intrusives are: the Elk Mountain porphyry, the Climax porphyry, the soda granite porphyry, and the rhyolite porphyry. The first three were intruded prior to ore deposition, and the last intruded after mineralization. The Climax Geological Department describes these intrusives briefly as follows:

Elk Mountain Porphyry—A light gray-green quartz monzonite porphyry containing ⅛ to ¼-inch quartz, orthoclase, and andesine phenocrysts set in a microcrystalline groundmass. The above phenocrysts make up approximately 15 percent of the rock. One millimeter biotite phenocrysts make up approximately 3 percent of the rock and are commonly strongly aligned, a foliation possibly caused by compression and shearing soon after the porphyry's injection.

Climax Porphyry—A buff-colored quartz-orthoclase porphyry containing neither ferromagnesian minerals nor plagioclase; an alaskite porphyry. The texture varies considerably. The rock may contain as little as 2 percent quartz and orthoclase phenocrysts averaging ⅛-inch in diameter set in a very fine crystalline groundmass, or the above mineral phenocrysts may comprise up to 30 percent of the rock, be up to ¾-inch in diameter, and occur in a very coarse matrix.

Soda-Granite Porphyry—A buff colored albite-rich granite porphyry. Much of the albite is apparently secondary. Textural varieties are similar to those of the Climax porphyry. Groundmass ranges from very fine crystalline to coarse-crystalline, and quartz, orthoclase, and albite phenocrysts range in size from 1 millimeter to ½ inch, and in varying proportions to each other. Biotite is common in 1 millimeter flecks which occasionally show alignment. Genetic and age relationships of textural varieties of all Tertiary porphyries are currently being investigated by the Climax Geology Department.

Late Rhyolite Porphyry—At least three distinct varieties are known. The most common type consists of ¼ inch to ½ inch quartz, orthoclase, and albite-oligoclase phenocrysts, 20 percent by volume, set in an aphanitic groundmass.

The distribution of these rocks on the Phillipson level and along cross section No. 16 is shown on Plates I and II. The soda granite porphyry does not reach the Phillipson level, but was encountered at deeper horizons in underground development and drilling.

Faults—The mineralized area is outlined on the west by the Mosquito fault, on the south by the South fault, and on the east by the East fault. Displacement along the Mosquito fault is estimated to be from 2,000 to 7,000 feet with the hanging wall having moved down in relation to the foot wall. The South and East faults are more restricted zones of crushing and adjustment and may be in part pre-mineral, although neither appears to have acted as a channelway for mineralizing solutions, but may have served to establish a structural framework for the intrusion of the Climax porphyry stock.

The entire area is fractured and jointed, and within the mineralized zone, the individual fractures are spaced on the average of one inch apart. This spacing interval increases outwardly from the main mineralization to one foot or more in the unaltered Precambrian rocks. The majority of these fractures trend N 15°-20° E and N 10°-15° W on an average, with the greatest number striking northeasterly.

Hydrothermal Alteration and Mineralization—Hydrothermal alteration in the mineralized area grades from strong to extreme, which makes it difficult to identify the original rock types in many of the underground and surface exposures.

In the broader sense, alteration zoning at Climax consists of the quartz rock in the center of the mineralized area, forming a cap over the top of the Climax porphyry intrusive body; the somewhat less intense alteration of the ore zone which lies adjacent to it; and a decreasing hydrothermal effect outward into the country rock.

The massive quartz rock cap, some 600 feet thick, consists of 98 percent quartz in equidimensional grains about 1-millimeter in diameter, and the remainder of orthoclase, scattered flakes of molybdenite, hubnerite, fluorite, sericite, and topaz. The molybdenite content ranges from 0.01 to 0.30 percent.

The ore zone which surrounds the body of quartz rock consists of hydrothermally formed orthoclase and quartz which decreases outwardly from the quartz rock, and three distinct types of veinlets: molybdenite-quartz, pyrite-topaz-quartz, and sericite-quartz. The intervening rock between the veinlets has been replaced by the constituents of these veinlets. The close spacing, or frequency, of the molybdenite-quartz veinlets in this zone has resulted in an over-all molybdenite content in excess of 0.4 percent. The boundaries of this zone are gradational into the quartz rock on one side, and into the less altered country rock on the other. Outward from the ore zone there is a gradual decrease in the amount of hydrothermal alteration until the only obvious alteration is the clay and sericite replacement of plagioclase and the bleaching of biotite and its replacement by sericite. The dispersed pyrite weathers to limonite stain.

The molybdenite-quartz veinlets consist of quartz with varying amounts of molybdenite, orthoclase, fluorite, pyrite, and sericite. The grain size within these veinlets is 1-millimeter or less and their molybdenite content is variable.

The pyrite-topaz-quartz veinlets range from ¼ to ½ inch in width and may contain small amounts of hubnerite, chalcopyrite, galena, sphalerite, rhodochrosite, sericite, and fluorite. These veinlets cut across the quartz-molybdenite ones.

The third type, which consists largely of sericite and topaz, transects both of the above types. The sericite and topaz may occur separately or together, either in veinlets or on joint surfaces, often with scattered grains of pyrite. Kaolinite and montmorillonite are common associates.

In their comprehensive publication on hydrothermal alteration at Climax, Vanderwilt and King[3] conclude that the various types of hydrothermal alteration, progressing from the quartz rock core outwardly through the ore zone and into the fringes, developed simultaneously; that the quartz rock replaced earlier-formed lower-temperature alteration types; that the molybdenite-quartz phase replaced the sericite-kaolin, and that this finally formed on the fringes as higher temperature types developed in the central part. The quartz replacement of the domal cap over the Climax porphyry intrusive body is believed to have sealed off the fractures and to have forced the molybdenite mineralization to form around this mass of silica rather than within it.

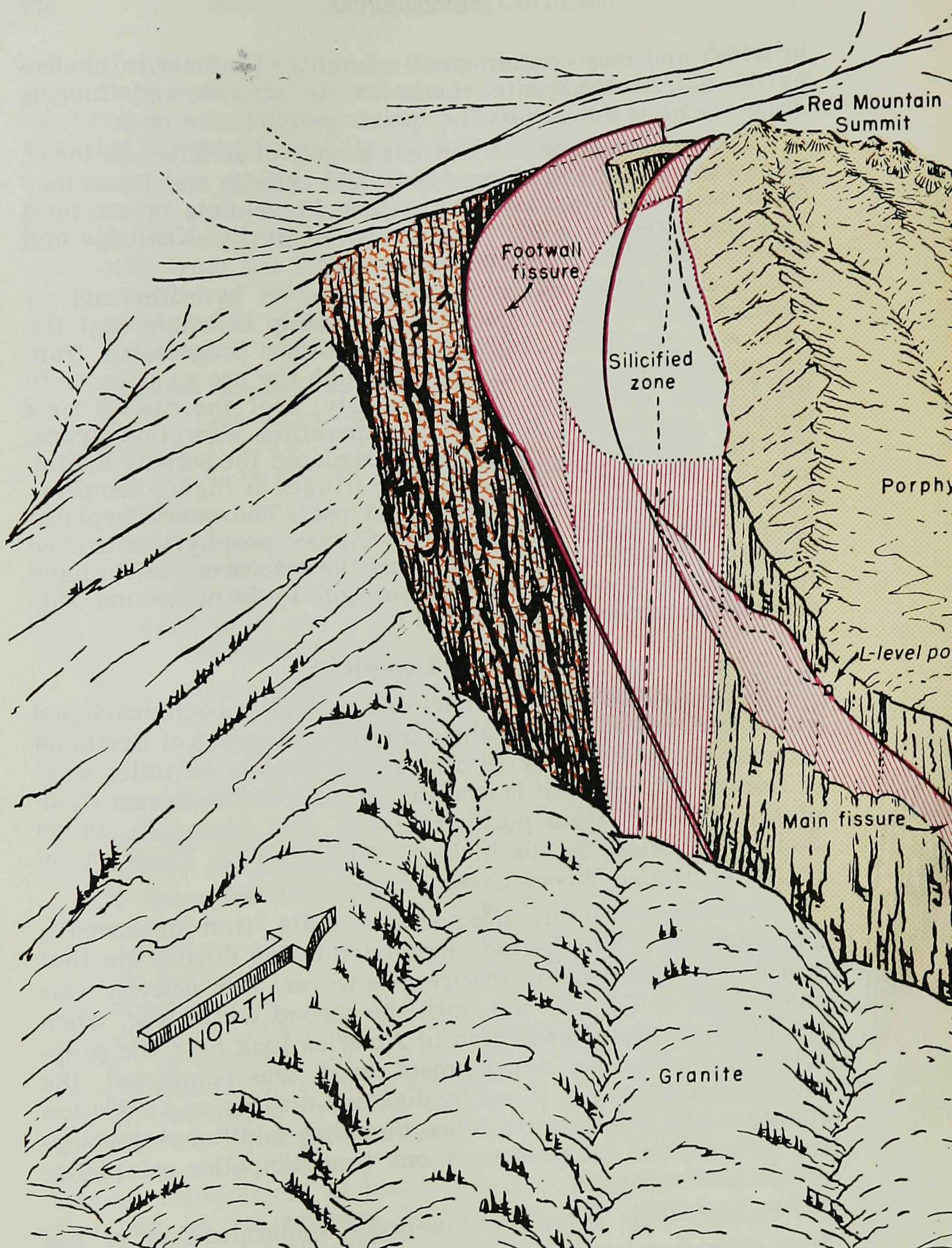
Urad Deposit

A large low-grade molybdenite deposit has been developed at the Urad mine situated about 5 miles southwest of Berthoud Pass on U. S. Highway 40 and approximately 55 miles west of Denver. This deposit is localized around the southwest flank of the Red Mountain porphyry stock. Red Mountain, 12,129 feet in elevation, stands in high relief between Clear Creek on the north and Woods Creek on the southeast.

The Urad deposit, discovered in 1914, first produced a small tonnage of high-grade molybdenite ore during the first world war from major fissures. However, this activity was short lived and it was not until the second world war, when the Molybdenum Corporation of America took over the property, that extensive development work was completed, the low-grade ore body outlined by diamond drilling, and a 200-ton flotation mill constructed. Since that time additional development work has been carried out in anticipation of higher molybdenite prices.

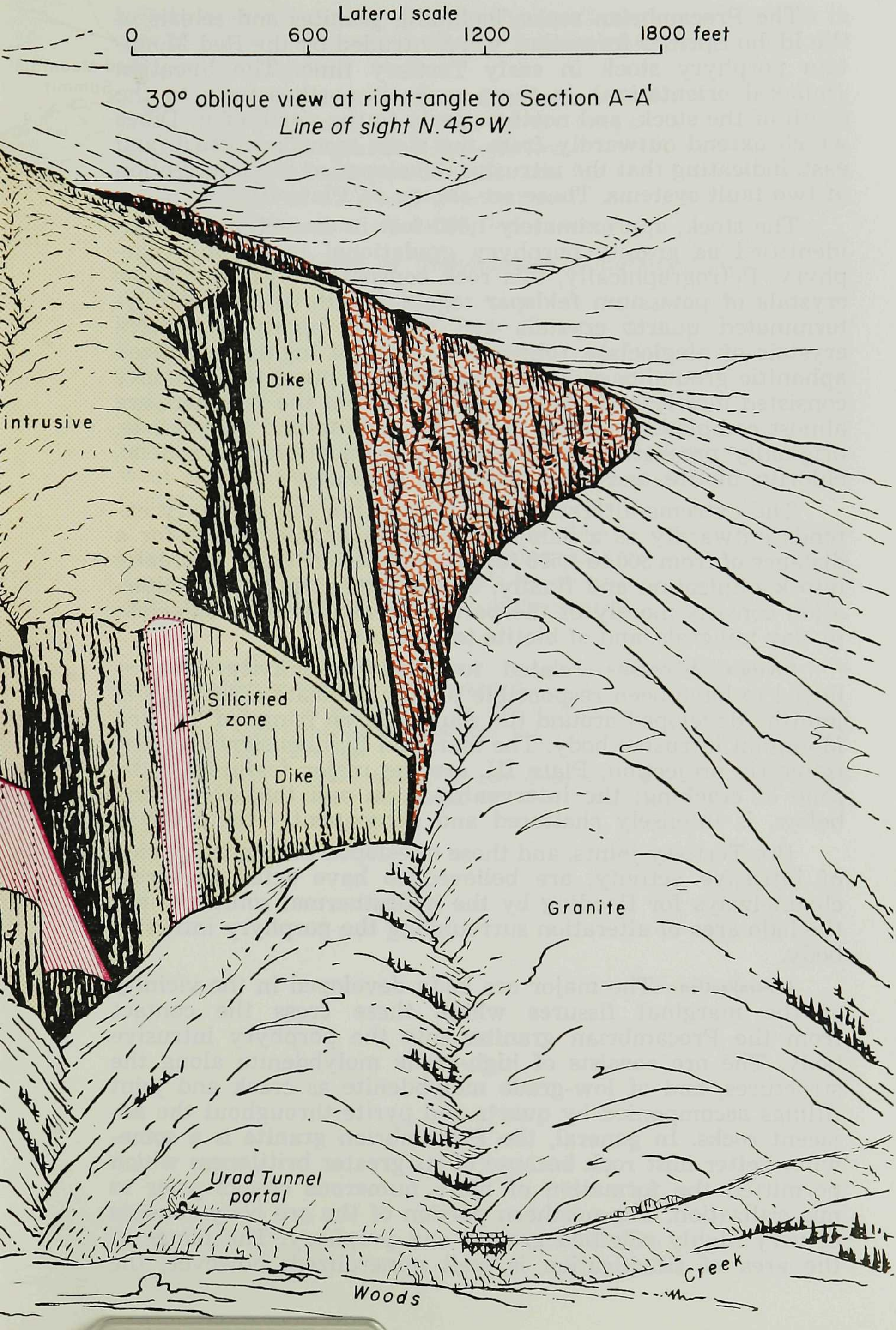
Geology—The extensive low-grade mineralization at the Urad mine has developed on the southwestern flank of the Red Mountain porphyry intrusive in close proximity to the contact between the porphyry and the adjacent Precambrian granites where strong fissures which dip inward into the intrusive, cross the contact. Plate III, an isometric projection of Red Mountain, illustrates these relationships in three dimensions.

PLATE 3


Red Mountain Summit
Footwall fissure
Silicified zone
Porphy
L-level po
Main fissure
NORTH
Granite
JOHN R. STACY

METRIC PROJECTION OF RED MOUNTAIN

(alteration halo removed)



The Precambrian rocks, including granites and schists of the Idaho Springs formation, were intruded by the Red Mountain porphyry stock in early Tertiary time. The lineation (mineral orientation) in these rocks is northeasterly to the south of the stock, and northwesterly to the north of it. Dikes which extend outwardly from the stock trend northeast, and east, indicating that the intrusive developed at the intersection of two fault systems. These are shown on Plate III.

The stock, approximately 1,800 feet in diameter, has been identified as granite porphyry gradational to rhyolite porphyry. Petrographically, this rock consists of ⅓-inch tabular crystals of potassium feldspar together with ¼-inch doubly-terminated quartz crystals and smaller, highly sericitized crystals of plagioclase (oligoclase) set in a highly sericitized aphanitic groundmass. This groundmass appears to have once consisted mostly of feldspar and quartz, but the feldspars are almost completely altered to sericite. Biotite and hornblende, originally present in the rock, have been altered to sphene, chlorite, biotite, and other alteration products.

The extreme alteration effective within the porphyry extends outwardly as a halo into the Precambrian rocks for a distance of from 500 to 1,500 feet. Sericitation changes gradually into kaolinization and finally, on the outer fringes, the alteration consists merely of the partial breakdown of plagioclase to clay minerals, and of biotite to chlorite.

Structure—Stresses related to intrusive activity are believed to have been responsible for the intricate cracking and jointing developed around the southwestern fringe of the Red Mountain intrusive body. The marginal fissures shown on the isometric projection, Plate III, are the major features in the zone of cracking; the intervening rock, and that above and below, is intensely shattered and subsequently mineralized.

Pre-Tertiary joints, and those developed during the period of intrusive activity, are believed to have acted as access channelways for flooding by the hydrothermal solutions into the halo area of alteration surrounding the porphyry intrusive body.

Mineralization—The major ore body developed in the vicinity of the marginal fissures where these cross the contact from the Precambrian granites into the porphyry intrusive body. The ore consists of high-grade molybdenite along the structures, and of low-grade molybdenite as crack and joint fillings accompanied by quartz and pyrite throughout the adjacent rocks. In general, the Precambrian granite is a somewhat better host rock because of its greater brittleness which permitted the formation of more numerous cracks prior to mineralization. The northern portion of the ore body consists of very highly silicified granite and porphyry. The fringe of the area of silicification is well mineralized; however, the values drop off rapidly toward the north due to a decrease in the frequency of spacing of the mineralized fractures in the area of silicification.

The molybdenite content decreases rapidly from the ore body inward toward the center of the porphyry intrusive and outward into the granite. Nonetheless, the values remain appreciably above background within the more intense alteration areas within the halo and it is believed that mineralization is one stage of the over-all alteration process.

Other Areas of Molybdenite Mineralization

Appreciable molybdenite mineralization has been found in other areas along the Colorado Mineral Belt, such as northeast of Apex, in the region northeast of Montezuma on the fringe of porphyry intrusives, in the Mt. Antero-Twin Lakes area south of Independence Pass, and along the western flanks of the Sawatch range to the south of Aspen. It also has been found in appreciable quantities in the Tincup district northwest of Monarch Pass, near Cumberland Pass in Gunnison County, and in many other parts of the State.

Exploration for large low-grade deposits throughout the Colorado Mineral Belt and other favorable areas in the State is in progress and doubtless will be continued in view of the favorable long range future for molybdenum.

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Chapter V

Uranium

by

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Manager, Western Exploration

American Metal Climax, Inc.

and

DR. DONALD L. EVERHART

Chief Geologist

International Minerals and Chemical Corp.

CHAPTER V

Uranium

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Table of Contents

*Manager, Western Exploration, American Metal Climax, Inc., Denver, Colo.
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Illustrations

History

A large portion of the uranium produced in the United States has come from the mines and mills of Colorado and the State has played an important role in the free world's development of atomic energy. Most of the uranium has been taken from carnotite deposits of the southwestern part of the State, but part has come from uraninite deposits near Craig and Gunnison and from pitchblende ores of the Front Range.

All uranium ores also contain the element radium; carnotite, in addition to uranium and radium, also carries vanadium. Because of shifts in price and demand for these three metals—uranium, radium, and vanadium—the uranium ores of the State have been exploited at different times for these different metals. The mining history has gone through four stages:

1. 1898-1923 Radium was produced from carnotite and pitchblende with minor by-product uranium and vanadium.
2. 1923-1935 World price for radium collapsed, and most Colorado mines closed.
3. 1935-1945 Vanadium was produced from carnotite.
4. 1945-1959 Uranium was extracted from all ores and by-product vanadium was obtained from carnotite.

Pitchblende was first found in the United States on the dump of the Wood mine, Central City, Colorado, in 1871. At about the same time carnotite deposits in southwest Colorado had been noted by prospectors, who staked them for copper. In 1881, samples of carnotite ore taken from Roc Creek, Montrose County, were sent to an assayer in Leadville who reported trace amounts of gold and silver. First production of carnotite ore appears to have come from Roc Creek in 1898 when Gordon Kimball mined ten tons, mostly from one ore pocket, sacked the ore and packed it 12 miles by burro to Paradox Valley, then 80 miles by wagon to Placerville, and from there by rail to Denver. The shipment was delivered to a French chemist, Charles Poulot, for transfer to France. The ore assayed 21.5 percent U_3O_8, 15 percent V_2O_5, and Kimball received $2,600 for the lot. In 1899 the mineral carnotite was described by French scientists, M. M. C. Friedel and E. Cumenge, from samples of Roc Creek ore supplied by Poulot, presumably the material mined by Kimball.

Meanwhile, radium had been discovered in 1898 by Pierre and Mme. Curie, and G. Bemont, in Paris, France. Its usefulness soon established a market for radium-bearing ores, which then became of interest to prospector and miner. A rush to the carnotite districts of San Miguel, Montrose, and Mesa Counties began about 1910, and mining was active until 1923. By 1913 half the world's radium, produced to that time, had come from mines in these three counties of Colorado and adjoining Grand and San Juan Counties in Utah. Standard Chemical Company, the main producer, opened a radium mill in 1910 on the Dolores River in Paradox Valley. The mill was moved to Uravan about 1915. Two other mills are known to have operated nearby, in at least an experimental way—the National Radium Institute plant in Long Park (about 1915) and a mill at Saucer Basin (about 1920).

During the same period pitchblende was hand-picked from gold-silver ores in the Central City district and more than 100,000 pounds of uranium oxide were shipped from the region, mostly before 1917.

Carnotite ore production declined abruptly in 1923 when radium from ores in the high grade pitchblende deposit at Shinkolobwe, Belgian Congo, entered world trade. This influx of high-grade material so depressed the price for radium ores that carnotite production in Colorado became uneconomic and most of the mines were closed. During the period of carnotite mining from 1913 to 1923, the ores are estimated to have yielded 202 grams of radium. By-products included about 2,000,000 pounds of uranium produced between 1913 and 1923 and 1,116,000 pounds of vanadium produced between 1915 and 1923. In 1914 the price at Placerville of ore containing 2 percent U_3O_8 was $82 per ton.

There followed after 1923 a period of quiescence in the carnotite field. Radium production was not profitable at then current prices. Vanadium for domestic users was supplied by the Minasragra mine in Peru and the United States Vanadium Company operation at Rifle, Colorado, which was active from 1922 to 1931. There was as yet no market for uranium. By the middle 1930's, however, the growing need for vanadium products rekindled interest in carnotite. About 1935 many of the mines were reopened and the search for ore extended into new areas. Because of the strategic importance of vanadium during World War II, production was stimulated by government aid, particularly through ore purchase by Metals Reserve Corporation.

On August 6, 1945, at Hiroshima, Japan, the era of atomic energy began, and with it a major, exciting new chapter in the history of the mineral industry of Colorado. Actually, the atomic energy program of the United States had begun in 1942 with the decision to develop the atomic bomb, and immediately uranium, the basic raw material for atomic energy, was intensively sought by the Federal government. Colorado assumed tremendous importance because within its borders lay the only two domestic sources of uranium known at the time—the carnotite (vanadium- and uranium-bearing) ores of the Uravan district and the pitchblende veins associated with the precious- and base-metal ores of the fabulous Central City district.

Due to the necessity for secrecy in the atomic energy program, the search for new sources of uranium during the latter part of World War II was carried out exclusively by officers and civilian employees of the now-famous Manhattan District Project of the U. S. Army Engineers and by a very limited number of geologists and mining engineers recruited by selected mining companies under contract with the Government. Chief among these was Union Mines Development Corporation, a subsidiary of Union Carbide Corporation. Much of this activity was centered in Colorado in the vicinity of the known deposits. By the enactment of the Atomic Energy Act of 1946, the U. S. Atomic Energy Commission was established, one of its major responsibilities being the development of uranium resources. In 1947, the A.E.C., in cooperation with the U. S. Geological Survey, inaugurated diamond drilling projects and geological surveys for uranium on certain public lands, largely in western Colorado. In order to aid this official exploration program, the Department of the Interior, under the public land laws, withdrew from mineral entry and appropriated approximately 150 square miles of public lands in southwestern Colorado and southeastern Utah. Lands covered by such Public Land Orders, which were subsequently found to contain uranium ore, were made available to mining companies for development and mining, through leasing arrangements with the A.E.C. The remainder of such lands were later released from the withdrawal orders and again became open for mineral entry.

With the gradual lifting of secrecy after the end of the war, the Atomic Energy Commission in 1948 inaugurated a major uranium exploration and development program based upon the full-scale participation of the mining industry and the prospector. The key points of this program were 1) the establishment of guaranteed minimum prices for uranium ores and refined products, 2) the establishment of a bonus for the discovery and development of new deposits of uranium ores, and 3) the expansion of the A.E.C.'s direct exploration program. Under this stimulation and beginning in early 1950 the now-fabled uranium boom skyrocketed throughout the western United States. Colorado has continued to be prominent in the fast-developing and now important uranium industry.

During the pre-war period of vanadium interest, a number of processing mills had been established. Five of these—at Naturita, Uravan, Durango and Rifle, all in Colorado, and Monticello, Utah—were later modified to recover uranium for atomic energy uses. The Uravan, Durango, Rifle and Monticello plants are still in operation, but it is reported that the Monticello mill is to be shut down by 1960. The other vanadium mills outlived their usefulness and are now in ruins but new uranium-producing plants were established to satisfy the needs of a new era.

The location of the mills and approximate dates of operation are as follows:

Approximate Date of Operation	Location	Company
1922-Present	Rifle, Garfield Co., Colo.	United States Vanadium Corp.
1930-1932	Dry Valley, San Juan Co., Utah	International Vanadium Corp.
1935-1943	Slick Rock, San Miguel Co.	North Continent Mines, Inc.
1937-1944	Blanding, San Juan Co., Utah	Blanding Mines Co.
1939-1945	Gateway, Mesa Co.	Gateway Alloys
1940	Loma, Mesa Co.	
1940-1957	Naturita, Montrose Co.	Vanadium Corp. of America
1942-1945	Durango, La Plata Co.	U. S. Vanadium Corp. for Metals Reserve Corp.
1949-Present	Same Plant	Vanadium Corp. of America
1942-1946	Monticello, San Juan Co., Utah	Vanadium Corp. of America for Metals Reserve Corp.
1949-Present	Same Plant	Atomic Energy Commission
1951-Present	Grand Junction, Mesa Co.	Climax Uranium Co.
1958-Present	Gunnison, Gunnison Co.	Gunnison Mining Co.
1958-Present	Maybell, Moffat Co.	Union Carbide Nuclear
1958-Present	Canon City, Fremont Co.	Cotter Corporation

Colorado's uranium resources to date have been largely developed in six major districts:

1. The Uravan district, Mesa, Montrose, and San Miguel Counties;
2. The Front Range district, Boulder, Clear Creek, Gilpin, Jefferson, and Larimer Counties;
3. The Maybell district, Moffat County;
4. The Cochetopa district, Saguache County;
5. The Marshall Pass district, Chaffee, Gunnison and Saguache Counties; and
6. The Tallahassee district, Fremont County.

Uravan District

Most of the uranium produced in Colorado has been mined from a region in Mesa, Montrose, and San Miguel Counties, in the southwest portion of the state (Fig. 1). The orebodies

FIGURE 1. INDEX TO FIG. 2 — LOCATION OF URANIUM MILLS

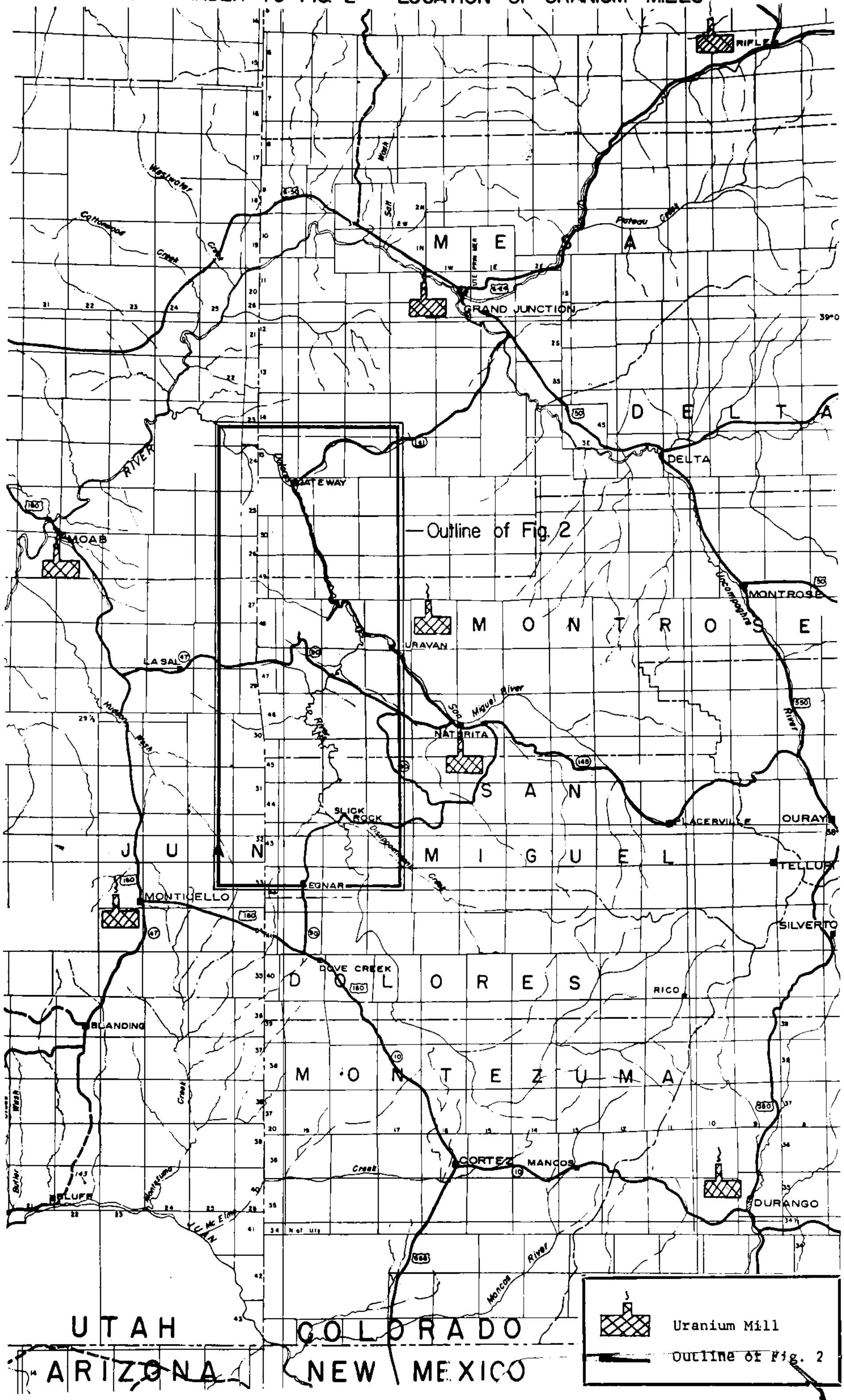


FIGURE 2. URANIUM-VANADIUM DEPOSITS, URAVAN MINERAL BELT

are generally referred to as "carnotite deposits," although many minerals other than carnotite are present.

Uravan Mineral Belt

The deposits occur mainly in the Uravan Mineral Belt, a narrow slightly curving zone extending from the Gateway area southeastward to the Uravan region and thence south through Paradox Valley and Slick Rock (Fig. 2). The concept of the Uravan belt was developed by the U. S. Geological Survey in 1943. The belt consists of a zone from one to several miles wide in which deposits are larger and more closely spaced than elsewhere. Margins of the belt cannot everywhere be clearly defined but are recognized where ground generally favorable for ore is bordered by generally unfavorable ground. All area within the belt is not necessarily favorable; rather the deposits are found in patches of favorable ground which alternate with zones of unfavorability. These patches range from several hundreds to several thousands of feet in length and in width. Many of the favorable zones, as well as the deposits within them, are elongate at right angles to the trend of the Uravan belt.

General Geology

Stratigraphy — Most deposits are found in horizontal or slightly dipping beds of Mesozoic age. Production has been largely from the Morrison formation of Jurassic age. Sandstones of the Chinle formation of Triassic age, which contain large uranium deposits in the Big Indian district near Moab, Utah, are less favorable in Colorado and are largely non-productive. A generalized geologic section is as follows:

Age	Formation Name	Thickness in feet	Description
Cretaceous	Mancos shale	50+	Gray shale; only lower part exposed.
	Dakota sandstone	100+	Gray, yellow, and brown sandstone with some shale and coal; forms cliffs.
	Unconformity		
	Burro Canyon formation	65-100	White, gray and red sandstone with minor mudstone; forms cliffs.
Jurassic	Morrison formation		
	Brushy Basin member	360-590	Varicolored bentonitic shale with minor sandstone and conglomerate; forms smooth slopes.
	Salt Wash member	245-365	Light-gray to light-brown sandstone interbedded with red and gray mudstone; forms a series of cliffs and ledges.
	Summerville formation	80-110	Red, gray, and green mudstone and thin red sandstone.
	Entrada sandstone and Carmel formation	55-170	Red to tan sandstone; forms smooth rounded cliffs, overlying red to tan mudstone.
	Unconformity		
	Navajo sandstone	0-40	Light-gray, crossbedded sandstone.
	Kayenta formation	0-255	Red to dark-red sandstone; forms a series of ledges.

Age	Formation Name	Thickness in feet	Description
Triassic	Wingate sandstone	240-275	Light-red to light-brown sandstone; forms vertical cliffs.
	Chinle formation	200-465	Light-red to red mudstone interbedded with thin beds of sandstone, shale and conglomerate.
	Moenkopi formation	420-500	Red and brown sandstone, shale, and conglomerate.
	Unconformity		
Permian	Cutler formation	470+	Light- to dark-red arkose and arkosic conglomerate.
Pennsylvania	Hermosa formation		
	Limestone member	Unknown	Gray limestone; partly exposed.
	Paradox member	Unknown	Salt and gypsum with minor limestone, black shale, and sandstone; only upper portion exposed.

(Modified after U. S. Geol. Surv. TEI-700, Dec. 1957)

The Morrison formation is divided into two units. The upper part consists of the Brushy Basin shale member, characterized largely by vari-colored mudstones with lesser bentonitic beds and minor amounts of sandstone, marl, and conglomerate. The Brushy Basin shale ranges from 300 to more than 500 feet in thickness. In places lower sandstones of the member contain uranium deposits, but most production has been realized from sandstones in the Salt Wash member.

The Salt Wash unit is 245 to 365 feet thick. It was deposited by a system of braided streams which originated in a source area located generally in southwest Utah. Crossbedded gray, tan and white sandstones alternate with red, brown, and greenish gray mudstones. Three to eight sandstone units are usually present in the section and these form cliffs and ledges separated by slopes of mudstone. The sandstone ledges are referred to by many miners as "rims," but some confusion exists in this designation: in some areas the term "first rim" means the uppermost sandstone layer; in other localities "first rim" refers to the lowest sandstone. Most mines are in the uppermost sandstone which ranges from 15 to 80 feet in thickness, but lesser production has also been realized from lower sandstone units.

Structure—Most of the structural features in the Uravan district are directly or indirectly related to five salt-cored anticlines which trend northwesterly along the Colorado-Utah line. Four of these are in Colorado. From north to south these are the Sinbad Valley, Paradox Valley (Fig. 3), Gypsum Valley, and Dolores anticlines. All but Dolores anticline have been unroofed by erosion so that the structures are now expressed by elongate northwest-trending valleys developed on weak rocks of the Pennsylvanian Paradox formation. Where exposed in the floors of the valleys, the Paradox consists of salt, gypsum and intermixed clastic sediments. The original thickness of the saline section, when deposited, is thought to have been on the order of 5,000 feet, but wells have been drilled in some of the anticlines to depths of more than 10,000 feet in these

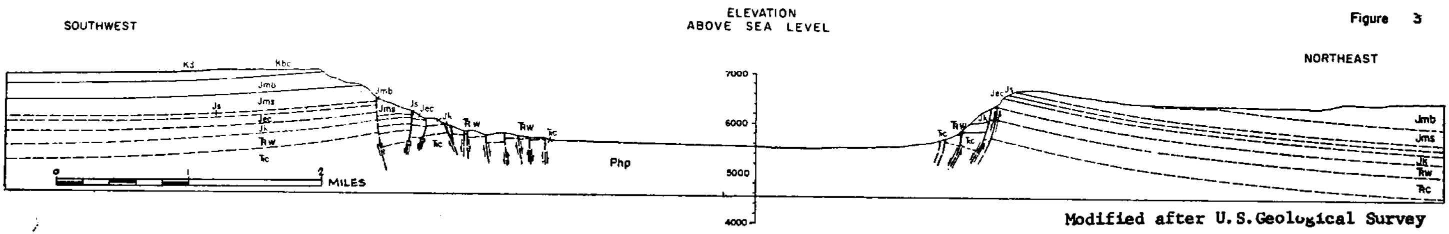


FIGURE 3. CROSS SECTION – PARADOX VALLEY SALT ANTICLINE

rocks. This indicates that the saline section has been thickened along axes of the anticlines by flowage toward the crests from nearby structural lows. The salt anticlines were structurally active from Permian through early Cretaceous time. In early Tertiary time two additional uplifts developed, which affect present structure in the north end of the Uravan belt. These are the domal structures of the La Sal Mountain mass and the elongate Uncompahgre uplift. At the present time the sedimentary beds dip generally away from the salt anticlines and the La Sal and Uncompahgre uplifts. Dips are low, on the order of several degrees, except in areas of structural complexity.

Faults, especially those of the high angle normal type, are common near salt anticlines due to collapse of the roof and limbs following erosion and salt removal. With rare exceptions, faults and joints in most mines are post-ore in age. Offset of the ore by faults presents a problem in following the ore in some workings. In places, uranium values have been depleted along faults due to leaching by circulating ground water.

On the other hand, the ore in a few deposits is localized along faults. As an example, rich veinlike pods of carnotite occur in a fault zone at the Rajah mine, Roc Creek, Montrose County. It probably was one of these pods that yielded the ore produced by Kimball in 1898.

Mineralogy—For many years the typical ore produced in the Uravan district was characterized by canary yellow carnotite with minor amounts of yellowish tyuyamunite. Occasionally small concretionary masses of blue-black ore, called corvusite, were found. With the stimulation of World War II demands for uranium, exploration and mining reached greater depths and more blue-black and black ores were found. Since 1950, mineralogic study has demonstrated the presence of several primary uranium and vanadium minerals in the deeper ores.

It is now recognized that these ores contain a series of uranium and vanadium compounds—from primary, unoxidized minerals, through partly oxidized, to secondary, completely oxidized minerals. Three types have been defined:

1. Oxidized ore. Ore minerals are yellow, red and brown. Dominant minerals are:
   carnotite $K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2O$
   hewettite $CaV_6O_{16} \cdot 9H_2O$
   vanadium clay

   The gangue is composed largely of iron oxide and, in places, gypsum.
2. Partly oxidized ore. Ore minerals are bluish black, greenish black, black green. Dominant minerals are:
   corvusite $V_2O_4\ 6V_2O_5 \cdot n\ H_2O$
   rauvite $CaO.2UO_3 \cdot 5V_2O_5 \cdot 16\ H_2O$ (?)

hewettite $CaV_6O_{16}.9H_2O$
vanadium clay

Calcite is largely leached from the gangue and the gangue sulphides are changed, at least in part, to oxides and sulphates.

3. Unoxidized ore. Most ore minerals are black. Dominant minerals are:
   coffinite $U(SiO_4)$ 1-x (OH)4-x
   montroseite VO(OH)
   uraninite UO_2 $.UO_3$

Gangue minerals include calcite and small but persistent amounts of pyrite, marcasite, galena and chalcopyrite.

The unoxidized and partly oxidized ores have certain peculiarities of practical importance. Because both ore and gangue minerals may be black, it is difficult to estimate the grade of unoxidized ore by visual inspection. Also, the ratio between vanadium and uranium varies widely. Some samples contain high vanadium values but little uranium; in others the reverse is true. For the most part unoxidized ores are thinner and higher grade than oxidized ores. Apparently during oxidization metals migrate from their primary position into surrounding rock, and blending of uranium and vanadium values takes place.

Secondary enrichment is not of economic importance.

Description of Deposits

Ore consists of sandstone which is impregnated with vanadium and uranium minerals. Orebodies are roughly tabular in form and generally parallel the attitude of the enclosing rock. In places the edges of ore cut sharply across bedding of the sandstone, especially in "rolls." Where a roll forms the edge of an orebody, the boundary between ore and waste is sharp. More commonly, the margin of a deposit is gradational and is determined by economic considerations: the ore narrows to the point where it is too thin to mine or mineral content decreases from commercial ore through mineralized sandstone to barren rock.

Ore normally forms a single main layer but splits or lenses may be present at several levels above or below the main zone, separated from it by barren or slightly mineralized sandstone. Here mining at several levels is necessary.

In plan, the deposits assume many forms and are typically irregular in outline. However, experience has shown that many of the orebodies in a particular area are elongate in a common direction and in places the direction of elongation is normal to the trend of the Uravan belt at that point.

Size of deposits ranges widely from a few tons to more than 100,000 tons. A typical orebody consists of a group of lenses and pods of ore, separated by mineralized rock or waste, and mined from an integrated set of workings. Size distribution in one group of 666 deposits is as follows:

Size of deposit (tons)	Percent of total
0- 100	29
100- 3,000	41
3,000- 10,000	16
10,000- 25,000	8
25,000- 50,000	3
50,000-150,000	3

Average grade of ore produced is 0.28 percent U_3O_8 and 1.62 percent V_2O_5. Because of the reduced value of a pound of uranium in ores containing less than 0.20 percent U_3O_8, according to the Atomic Energy Commission Circular V buying schedule, most mines attempt to maintain grade above 0.20 percent U_3O_8.

Thickness of ore varies from a knife edge to as much as 30 feet or more, with an average of a few feet. Grade largely determines the thickness of ore that can be economically mined.

Among the peculiarities of carnotite deposits is the occurrence of ore in "rolls" and in fossilized trees or other plant matter. In a roll the ore cuts sharply across the bedding in a smooth curve. Ore may be present on either the concave or convex side of the roll but the boundary between ore and waste is sharp. In mining, the ore commonly breaks cleanly against the roll surface so that an impression of the roll may remain on the mine wall. Rolls are narrow elongate features in plan, and some have been mined for lengths of hundreds of feet. The long axis is commonly parallel to the direction of deposition of the host rock. In places a rough parallelism has been noted between the long axes of rolls, the axes of fossilized logs, and the elongation of ore bodies.

The Salt Wash sandstone contains fairly abundant plant fossils. These are largely tree trunks and fragments and seams of compressed leaves and fine-grained organic matter. Some trees are partly replaced with dolomite, gypsum, or silica; some are coalified; and some are mineralized by ore. Trees are recumbent, not upright in an attitude of growth, and they either fell or were carried by streams into present position. Fossil plant material is present in sandstones both within and outside the Uravan belt, but an abundance of this material is regarded as a favorable criterion for ore. Some of the richest ore pockets found in the carnotite region are associated with fossil trees. For example Hess in 1933 noted "On the Cracker Jack claim on Calamity Gulch, a log 80 feet long and about 2 feet thick, a smaller log 18 inches thick, 30 feet away, and the sandstone between yielded 180 tons averaging 5.65 percent U_3O_8 . . . and 8 percent V_2O_5."

Ore Guides

A number of geologic features have been shown by experience to be associated with uranium deposits. In places these relationships are sufficiently consistent to aid the search for ore. Ore guides may be considered as being of two general types: Large scale and small scale.

Large Scale Guides. These serve in a gross way to define large areas within which favorable ground may reasonably be expected. Large scale guides include the following:

1. Most deposits are in areas where the Salt Wash sandstone is more than 240 feet thick.
2. Most deposits are in areas where the Salt Wash contains about 50 percent sandstone and 50 percent mudstone.
3. A higher proportion of favorable ground and more ore is found within the Uravan belt than in most similar areas outside the belt. Some important deposits, however, are outside the belt—for example, those along La Sal Creek, Grand County, Utah.

Small Scale Guides. These help to outline the patches of favorable ground, measuring several hundreds to several thousands of feet in length and width, which are apt to contain ore. Small scale guides include the following:

1. More ore is found in the upper Salt Wash sandstone than in any other stratigraphic unit.
2. Most ore bodies are in sandstone between 20 and 80 feet thick, and the major deposits are in sandstone more than 40 feet thick. This does not mean, however, that the thickest sandstones always contain the most ore. For example, on Calamity Mesa, Mesa County, sandstone thickness of 20 to 25 feet appears optimum for ore, and few deposits are found where the sandstone is more than 30 feet thick.
3. Tan, brown, and gray sandstones are more favorable than red sandstones.
4. Scour-and-fill bedding within the ore sandstone is favorable. This is typified by abrupt small-scale crossbedding, thin, discontinuous mudstone layers, fossil wood, and conglomerate consisting of mudstone, pebbles and cobbles.
5. Presence of greenish-gray mudstone immediately below the ore-bearing sandstone is favorable, and red sandstone here is unfavorable. In some areas, ore is found only where the green-gray mudstone is more than 1 foot thick.
6. Abundant fossil wood is favorable for ore.

Mining Methods

Because of the wide range in size, thickness, shape, and form of carnotite deposits, varied methods of mining are used. A few orebodies are so situated as to permit open cut opera-

Figure 4

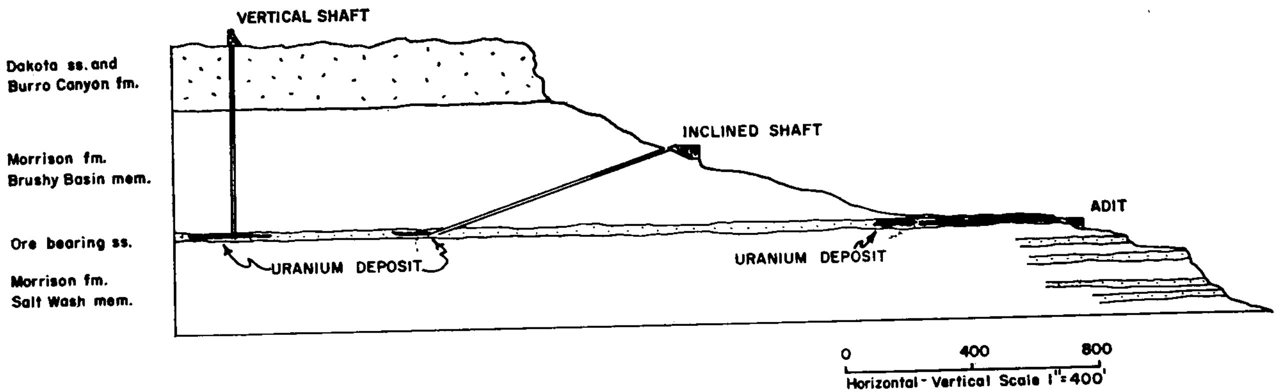


FIGURE 4. MINING METHODS — URAVAN DISTRICT

tions but most workings are underground. Selection of mining method must take into consideration the fact that many properties are in remote areas where the supply problem is great. Power is commonly not available and water may require considerable transportation.

Mine entry is by adit, incline, or vertical shaft (Fig. 4). If the ore body is relatively near the outcrop, an adit is preferred for reasons of economy. Cost is in the range of $20 to $35 per foot. In addition to economy, an adit offers the advantages of ease in handling mine water and gravity transportation from orebody to portal. Inclines are used where the deposit is at fairly shallow depth (up to 250 feet) but distance from ore to the outcrop is prohibitive for an adit. Inclines are driven at angles of 10 to 25 degrees, with an average of about 20 degrees. Costs are on the order of $25 to $50 per foot. In addition to costing less, per foot, than a vertical shaft, an incline requires smaller hoisting equipment and less elaborate surface installation. Vertical shafts are appropriate for deep ore bodies at some distance from the outcrop. Costs are in the range of $75 to $150 per foot.

Entries are normally driven to the lowest portions of a deposit to faciiltate handling of ore and waste. Most stopes are open with pillars of waste or leaner ore left for ground support. Little timber is used except to support isolated slabs or shattered zones. Roof bolts are used, but not extensively. Ore is taken from the face to transfer chutes in a variety of ways—slushing, hand tramming, and through use of small trackless equipment.

Close attention must be paid to ventilation because of the radioactivity associated with uranium ores. It has been found that radiation is controlled by the same methods as are normally used for dust control.

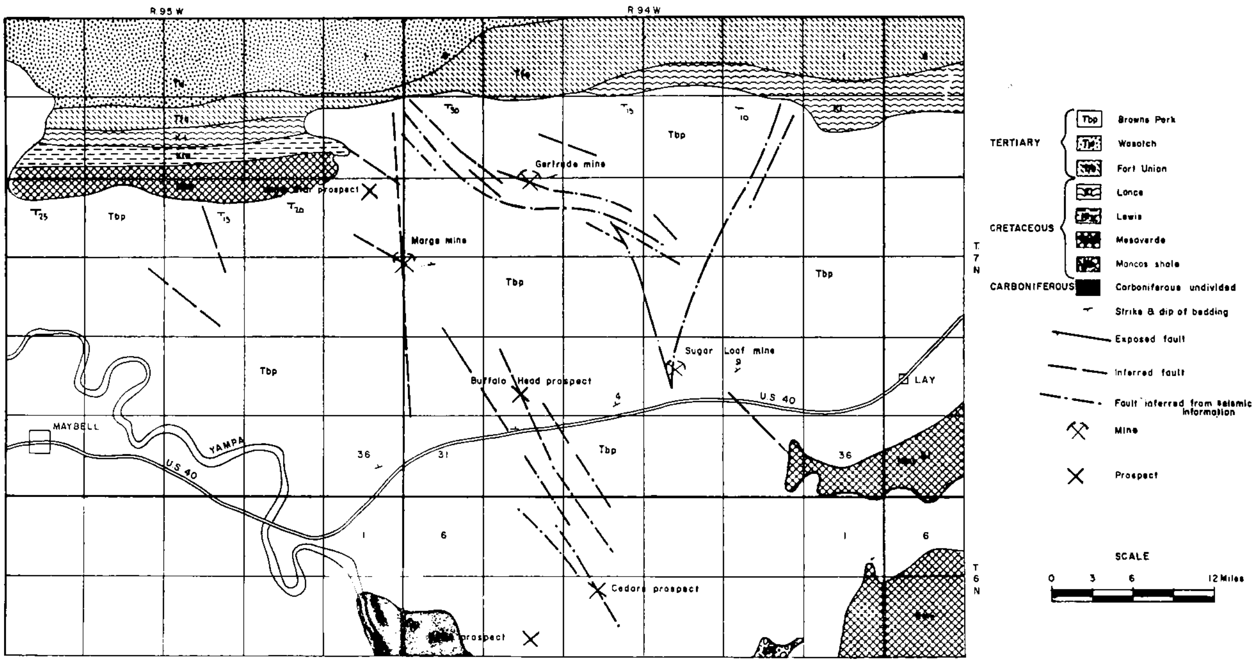
Maybell District

Uranium deposits near Maybell, Moffat County, were discovered in 1954 by prospecting with a light plane carrying radioactivity detection equipment. Most of the orebodies are north of U. S. 40 between Lay and Maybell, but a few prospects are located south of the highway and as far east as Craig.

General Geology

Browns Park Formation—The ore is contained in tuffaceous sandstones of the Browns Park formation of Miocene(?) age (Fig. 5). This unit is of continental origin and was deposited on a land surface of considerable relief, on which rocks ranging from Precambrian to Eocene in age were exposed. The Browns Park now unconformably overlies these older rocks. At one time the formation occupied a large area of northwestern Colorado but it since has been partly removed by erosion, leaving remnants only in the low parts of the predepositional erosion surface.

FIGURE 5



GEOLOGICAL MAP OF THE MAYBELL AREA, MOFFAT CO., COLORADO

MODIFIED AFTER A. ORMAND

In places, the thickness of the Browns Park is as much as 2,000 feet, and at Maybell a thickness of 500 to over 1,200 feet has been indicated by drilling. At the base is a conglomerate, which ranges from 0 to 150 feet in thickness and contains pebbles and cobbles of igneous and metamorphic rock types in a fine grained pyroclastic matrix. This unit has widespread anomalous radioactivity and numerous minor uranium deposits. The rest of the section consists mostly of gray-white to buff, partly limonite-stained massive, arkosic, fine to medium grained sandstone which is commonly cemented by clay and calcium carbonate and less commonly by silica. The sandstone is tuffaceous in places. In places the sandstone contains black chert grains which impart a "salt and pepper" appearance to the beds. Separating beds of sandstone, which are 5 to 30 feet thick, are intercalated tuff and clay layers which range from 1 to 5 feet in thickness.

A striking color contrast is noted between unoxidized and oxidized sandstone. Unoxidized rock is blue or gray due to unoxidized clays and/or fine-grained pyrite. Oxidized rock is buff or brown due to iron oxides formed by oxidation of the pyrite. The color change marking the contact between oxidized and unoxidized rock is found at depths ranging from 10 to 440 feet. It has been noted that the depth of oxidation is greater in arkosic than in tuffaceous sandstone, possibly due to the lack of cementing agents which permits a faster rate of oxidation in arkosic rock.

Structure—The major deposits are on the flanks of the Lay syncline, a large, shallow, east-trending structure which passes across the northern edge of the Browns Park outcrop belt. The two largest developed deposits, Gertrude and Marge, are located on the north flank of the syncline, where the beds dip 6 to 10 degrees south. The Johnson orebody, which is a minor deposit, is located on the south flank of the syncline, which dips 2 to 6 degrees north.

Faults are common and appear to play a greater role in ore localization than in the Uravan district. Some orebodies are elongate along faults and in several of the smaller deposits, such as Sugar Loaf, the ore is found along a fault zone.

Most faults trend between N 5° E and west. Many of these structures are evident in the Marge and Gertrude open pits, mostly with displacements of only a few feet. Seismic surveys by the U. S. Geological Survey have established the presence of many northwest-trending faults that are not visible in outcrop. Inferred displacement on some of these structures is as much as 250 feet.

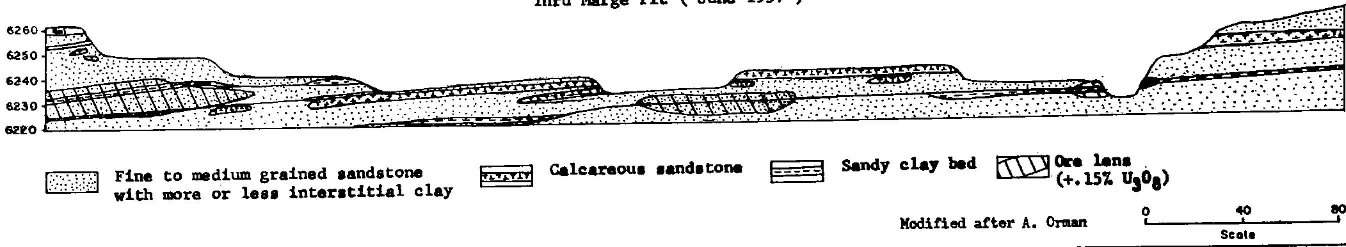
Ore Deposits

The ore consists of uranium minerals disseminated in tuffaceous sandstone.

With the exception of a few small deposits found along

Figure 6

Generalized Geologic Cross Section
Thru Marge Pit (June 1957)



Modified after A. Orman

faults, the orebodies occur in partly overlapping, lenticular deposits with lateral dimensions much greater than the thickness (Fig. 6). Horizontal measurements are as much as 1,000 feet and the thickness ranges from 2 to 30 feet. The ore is more or less concordant with the enclosing beds.

One unusual feature is the occurrence of ore in separate, partly overlapping layers, at different elevations. For example, the Gertrude contains ore at five levels.

Mineralogy

In oxidized rocks the ore is yellow and in unoxidized rocks the ore is blue or dark gray. The two ore types reflect differences in mineralogy and correspond to the color contrast between oxidized and unoxidized sandstone.

Dominant uranium minerals in oxidized yellow ore are meta-autunite and uranophane. These minerals may be visible as yellow stains and smears, particularly associated with limonite stains and around concretions of limonite or calcite. Gangue minerals include quartz, calcite, limonite, jarosite, gypsum, and clay.

Dominant uranium minerals in unoxidized blue ore are uraninite and coffinite. These minerals are not visible megascopically and for this reason visual estimation of uranium grade is difficult. Gangue minerals include quartz, calcite, gypsum, clay, and fine grained pyrite.

Mining Methods

Most mining is done from two open pits which are expected to exceed 200 feet in depth. The soft overburden is easily and cheaply removed with standard equipment. Careful selective mining is required to maintain ore grade and high recovery. Deeper ore will be mined by underground methods.

Front Range District

The occurrence of pitchblende in association with precious- and base-metal veins in a number of the famous deposits of the Front Range Mineral Belt has been known for at least 80 years. Perhaps the best-known of these occurrences are in the Central City area and localities relatively nearby, including Russell Gulch, Fall River, and Idaho Springs. A few hundred pounds of high-grade, hand-sorted pitchblende ore were shipped from these deposits to several chemical firms shortly after the discovery of radium. Some of the first uranium exploration activities of the Union Mines Development Co. and of the A.E.C. were concentrated on various deposits of the Central City district. These included, among others, the Kirk, Wood-Calhoun, and Cherokee mines, and the Jo Reynolds mine near Idaho Springs (Fig. 7). Early exploration was also undertaken at the Caribou silver mine near Nederland, Boulder County, and the Copper King mine, Larimer County.

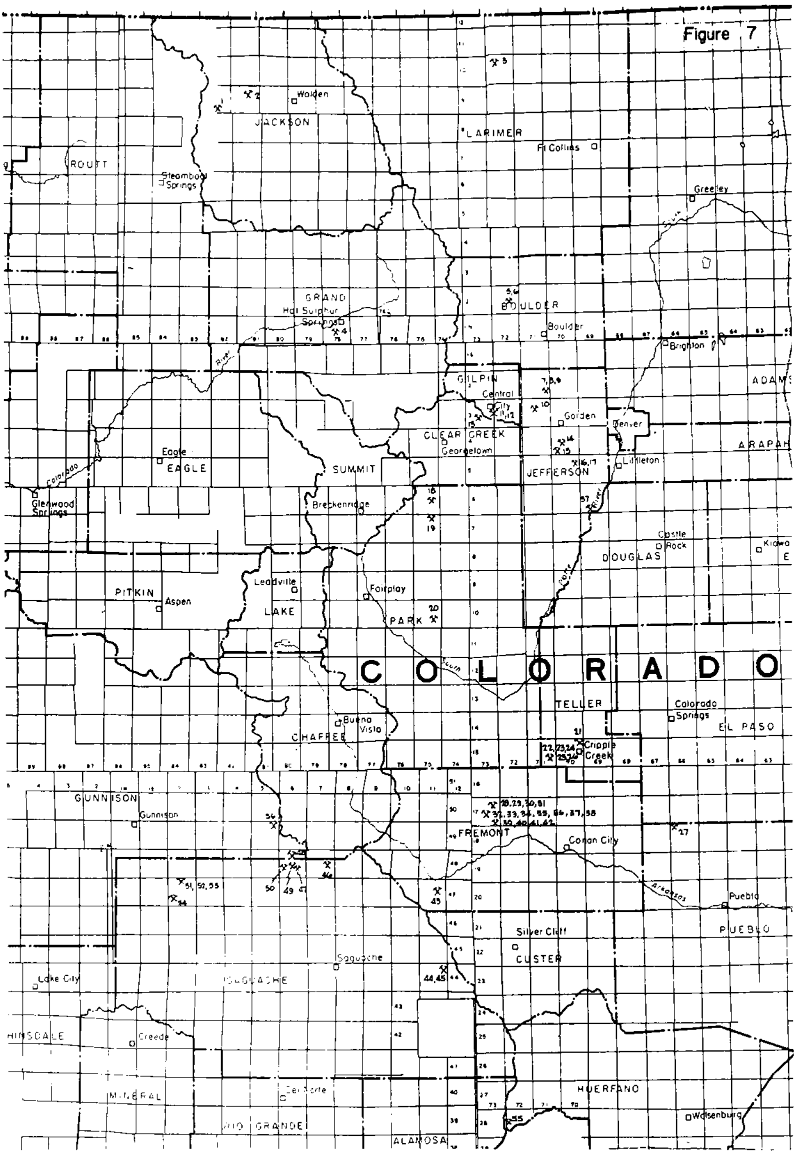


Figure 7
Walden
JACKSON
LARIMER
Ft Collins
ROUTT
Steamboat Springs
Greeley
GRAND
Hot Sulphur Springs
BOULDER
Boulder
Brighton
GILPIN
Central City
ADAMS
Golden
CLEAR CREEK
Georgetown
Denver
Eagle
EAGLE
SUMMIT
Littleton
ARAPAHOE
JEFFERSON
Glenwood Springs
Breckenridge
Castle Rock
DOUGLAS
Kiowa
Leadville
PITKIN
Aspen
Fairplay
LAKE
PARK
C O L O R A D O
TELLER
Colorado Springs
Buena Vista
EL PASO
CHAFFEE
Cripple Creek
GUNNISON
Gunnison
FREMONT
Canon City
Pueblo
PUEBLO
Silver Cliff
CUSTER
Saguache
Lake City
HINSDALE
Creede
HUERFANO
Walsenburg
ALAMOSA

FIGURE 7

None of these pitchblende occurrences in old mines or prospects which had exploited other metals has developed into a consistent uranium producer, however, and the present uranium reserves of the Front Range district are all contained in newly discovered deposits lying outside, but closely adjacent to, the Front Range Mineral Belt. Mines of current productive and reserve significance include the mines: 1) Schwartzwalder, 2) Fairday A. M., and 3) Wright Lease.

Schwartzwalder Mine

The Schwartzwalder mine is located in the southeast quarter of Sec. 25, T. 2 S., R. 71 W., Jefferson County, about 8 miles northwest of the town of Golden. In 1949, Mr. Fred Schwartzwalder of Golden discovered secondary uranium minerals—largely torbernite—in the vicinity of an old copper prospect. In November 1953, the first shipment of 53 tons of ore was made. Schwartzwalder worked the mine until February 1956, when the property was sold to Denver-Golden Oil and Uranium Co., the present owners. Since that time, the mine has been in continuous production, averaging 1,500 to 2,000 tons of ore per month at average grades of about 0.7 percent U_3O_8.

The mine is in Precambrian(?) rocks, about a half mile west of the contact with steeply eastward dipping sedimentary rocks of Paleozoic and Mesozoic age. The vicinity of the mine is underlain by the Idaho Springs formation, which consists of the following rock types:

←

Figure 7. Uranium Deposits in Colorado, Exclusive of the Uravan District Having Significant Ore Production and/or Reserves

Number on map	Property	Number on map	Property
1	Pedad Claims	31	Mary L No. 1 Claim
2	Spring Claims	32	Picnic Tree-Hall Homestead Deposit
3	Copper King Mine		
4	Beaver Claims	33	Dickson-Snooper Mine
5	Fairday A.M. Mine	34	Rainbow Deposit
6	Goldleaf Claims Group	35	Knob Hill Deposit
7	Schwartzwalder Mine	36	Ponderosa Deposit
8	Mena Mine	37	East Big Wash Deposit
9	U.P. Shaft	38	Thorn 9 and 10 Claims
10	Ascension Mine	39	NE¼, Sec. 36 Deposit
11	Cherokee Mine	40	NW¼, Sec. 36
12	Carroll Mine	41	Last Chance No. 1 Claim
13	Blazing Star Mine	42	Hurd-Canon Development Company Lease
14	Grapevine Mine		
15	Wright Lease Mine	43	Lightning Claims
16	Mann Ranch Lease Mine	44	Bobcat Claims
17	Pallaoro Lease	45	Mocking Bird Claim
18	Gem Dandy Claims	46	Bonita No. 1 Claim
19	Mac George Claims	47	Lookout Claims
20	Lucky Jim Claims	48	Little Indian No. 36 Claim
21	Genevieve Claims	49	Erie No. 38 Claim (Pitch Mine)
22	McVey Lease	50	Apache No. 4 Claim
23	Abril Nos. 2, 6 and 8 Claims	51	T1 Mine (Los Ochos Claim)
24	Sand Creek No. 4 Claim	52	T2 Mine
25	NE¼, NE¼, Sec. 36—Park City No. 1 Lease and Claims	53	West Mine
		54	LaRue Claims
26	SW¼, NE¼, Sec. 36 Lease	55	Trinchera Peak Prospect
27	Avery Ranch Lease	56	Big Red Claims
28	Joan No. 1 Claim	57	Seven Devils Prospect
29	Sunrise-Smaller Lease	58	Placerville Deposits
30	Southport No. 3 Claim		

1. Quartz-mica-feldspar gneiss and schist;
2. Amphibolite;
3. Quartz-biotite gneiss and quartz mica schist; and
4. Granite and biotite granite gneiss.

Granite and pegmatite, comprising the youngest of the Precambrian rocks in the region, intrude the Idaho Springs formation.

The major structural features of the region are northerly-trending asymetrical folds and northwest-trending breccia faults. Significant among the latter are the steeply dipping Rogers and Hurricane Hill breccia "reefs," which can be traced northwesterly along strike for about 30 miles.

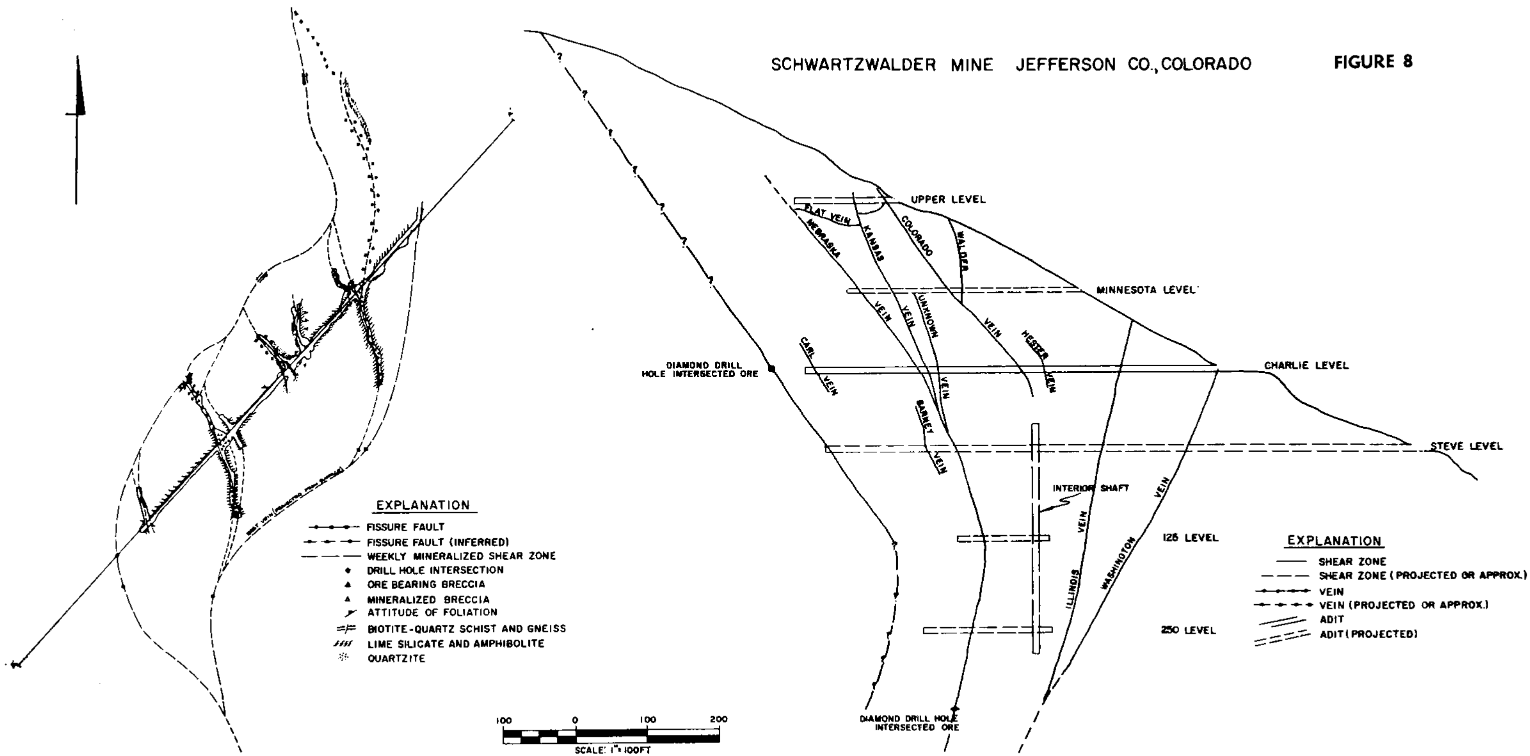
North to northwest-trending uranium-bearing fault zones are found along the west limb of a synclinal fold, in a transition zone between quartz-rich mica schist south of the mine and lime-silicate amphibolite, gneiss, and schist north of the mine. The uranium deposits are confined to both flat and steeply dipping fissure veins of Tertiary age.

Four vein systems have been identified at the Schwartzwalder mine (Fig. 8). The initial discovery of uranium was made in a northwesterly-trending, flatly dipping (up to 45°) thrust known as the Flat vein, which represents the earliest stage of faulting in the mine area. It is cut and displaced by later steeply dipping reverse faults. A second system of veins strikes north to northwesterly and dips 35 to 85° northeast. Included within this group are the Nebraska, Kansas, Colorado, Unknown, and Walder veins. Repeated movement along these faults produced intense brecciation and the brecciated zones near vein intersections have been particularly favorable for the localization of ore bodies. A third system of veins strikes N. 40° W. and dips 65 to 70° southwest. Included within this group are the Washington and Illinois veins, in which ore shoots are found where the veins cut across foliation in competent rocks. The fourth system of veins, considered to represent the latest period of fracturing, parallels the general foliation and schistosity of the rocks and in many places cuts and displaces the other vein systems. Only secondary uranium mineralization has been found along this set and only the East vein of this group, which is of minor economic importance, has been named.

The mineral assemblage in the Schwartzwalder veins includes pitchblende, the secondary uranium minerals torbernite, autunite and uranophane (in the supergene zone), hematite, pyrite, marcasite, chalcopyrite, tennantite and emplectite, and minor chalcocite, bornite, covellite, sphalerite, and galena. Gangue minerals include quartz, ankerite, calcite, adularia, and minor garnet. The quartz, pyrite, and marcasite were deposited before pitchblende and the other sulfides. Abundant ankerite was introduced at the same time, and appears to have

SCHWARTZWALDER MINE JEFFERSON CO., COLORADO

FIGURE 8



GEOLOGIC PLAN OF CHARLIE TUNNEL LEVEL

VERTICAL SECTION A - A'

GEOLOGY BY J.D. SCHLOTTMAN

persisted throughout most of the formation of the veins. Pitchblende was deposited after pyrite, during ankerite and quartz deposition, and before other sulfides. Calcite followed in the closing phase of hydrothermal activity.

Denver-Golden Oil & Uranium Company commenced mining above the Minnesota level in March, 1956. During the following year, the Nebraska, Kansas, Colorado, Walder, and Flat veins were mined out above this level. In August, 1956, the Charlie level, 100 feet below the Minnesota level, was started. By February, 1957, all of the veins had been developed from this level. Production continued on the Charlie level, chiefly from the Nebraska and Illinois veins, until January, 1958. In January, 1957, the lowermost Steve adit was driven and is under development and production.

In January, 1958, the sinking of the interior Parker shaft was commenced below the Steve level. This shaft is being sunk to a depth of about 380 feet. Levels off the Parker shaft have been driven at 125 to 225 feet. Mining by shrinkage stoping has been at a rate of 100 to 200 tons per day. Production is limited by marketing allocations to 1,500 to 2,000 tons per month. Grade averages about 0.70 percent U_3O_8. Ore haulage is by truck to the Cotter Corporation mill at Canon City, a distance of 140 miles.

Fairday A. M. Mine

The Fairday A. M. mine, also known as the Coliowa mine, lies 5 miles west of Jamestown, Colorado, on the northwest edge of the Jamestown mining district. The mine is operated by La Salle Mining Company of Grand Junction, Colorado. Pitchblende-bearing veins follow a conjugate fault system of north- and northeast-striking strike-slip faults in Precambrian Boulder Creek granite and Idaho Springs schist and gneiss. Ore is concentrated in intersections of the conjugate faults and in refracted portions of the veins. Granitic wall rock is generally unfavorable because its argillization along fractures formed abundant gouge which apparently provided poor conduits for mineralizing solutions. Minerals associated with pitchblende are chiefly pyrite and quartz, which were introduced into the quartz-biotite schist and gneiss. Pitchblende is believed to have been deposited early in the paragenetic sequence, following quartz and overlapping pyrite mineralization.

The Fairday A. M. mine was discovered by surface radiometric traversing in 1955. To date, about 5,000 tons of high-grade ore (averaging more than 0.5 percent U_3O_8) have been produced from stopes along several drifts on one level.

Wright Lease Mine

The Wright Lease mine is located in Section 32, T. 4 S., R. 70 W., Jefferson County, Colorado, less than a mile west of

Idledale in Bear Creek Canyon. The original discovery, in the summer of 1954, consisted of a series of radiometric anomalies oriented along a northeasterly trend. Diamond core drilling subsequently disclosed commercial-grade uranium ore at depth, and underground exploratory drifting was initiated. Operated by Foothills Mining Company, the mine has been intermittently active over about a four-year period, and monthly production has varied from 50 to 300 tons of ore, averaging nearly 0.3 percent U_3O_8.

The Wright Lease deposits are about 14 airline miles southeasterly from the margin of the Front Range Mineral Belt and occur in a breccia vein trending N. 50° W. and dipping at an average of 70° northeast, in schist, gneiss, and granite pegmatite of the Idaho Springs formation. The ore shoots contain both sooty and hard pitchblende, associated with chalcopyrite, pyrite, marcasite, and copious calcite, some of which is iron-bearing. The ore shoots are concentrated in those local segments of the vein that trend northerly, and the wall rock along ore shoots is generally quartz-feldspar pegmatite.

The mine workings consist of an adit level and two sublevels serviced by an interior two-compartment shaft. Since about 25 percent of the material within the ore shoots is waste, resuing mining methods are used. Thickness and grade of ore is greatest on the lowermost (186-foot) level, where the main ore shoot is about 100 feet long and averages 6 feet in thickness.

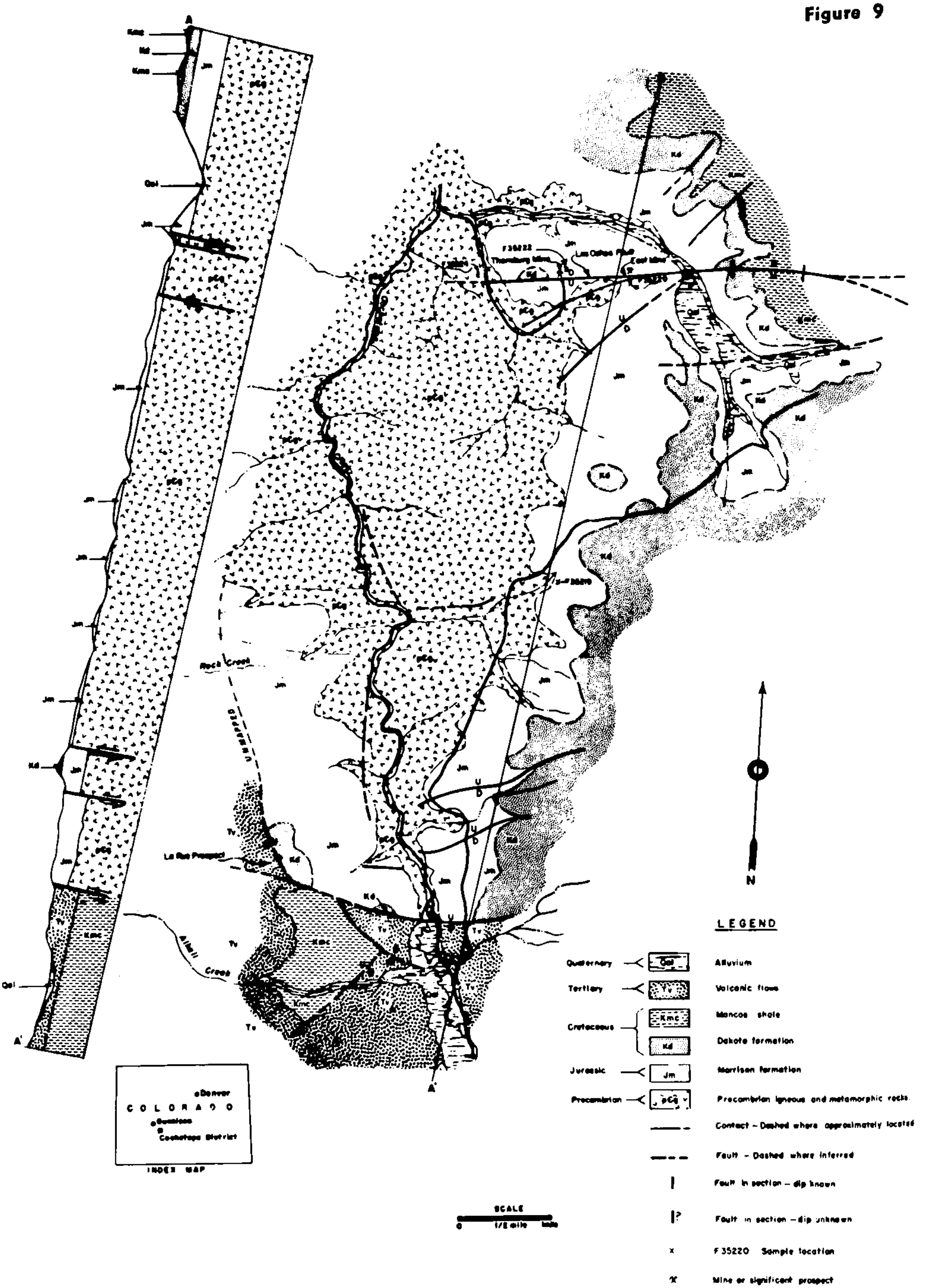
Cochetopa District

The Cochetopa district is located in northwest Saguache and southern Gunnison Counties, about 20 miles southeast of Gunnison. That part of the district in which significant uranium occurrences are known is approximately 10 miles in length from north to south, and 5 miles wide (Fig. 9).

Rocks in the district range in age from Precambrian through Miocene. In the northern part of the district, the Precambrian metamorphic complex consists of quartz-biotite schist, hornblende gneiss and minor ultrabasic rocks; in the southern part of the district, the basement rocks were intruded by later Precambrian coarse-grained, pink, biotite granite and granite gneiss. Pegmatite stringers and dikes cut the granitic rocks. The contact between granite and schist is gradational; there are unassimilated schist remnants in the granite and lit-par-lit intrusions in the schist.

The Morrison formation, approximately 300 feet thick, lies directly on the Precambrian rocks. The lower 40 feet is fine-grained, buff to cream-colored, crossbedded sandstone with some siltstone and mudstone tentatively correlated with the Salt Wash sandstone member. The upper 256 feet, the Brushy Basin shale member, is an alternating series of variegated mud-

Figure 9



GEOLOGIC MAP AND SECTION OF A PORTION OF THE COCHETOPA MINING DISTRICT stones, siltstones, and shales containing lenticular sandstone beds.

Unconformably above the Morrison formation is conglomerate and sandstone of the Dakota formation up to 115 feet thick, and the Mancos shale, up to 300 feet in thickness, conformably overlies the Dakota. Both formations are Upper Cretaceous in age. Erosional remnants of Miocene volcanic rocks totalling at least 800 feet in thickness overlie the sedimentary rocks, and the youngest rocks in the district are Miocene intrusives, occurring about 3½ miles southeast of the T-1 (formerly Thornburg) mine. They are intermediate in composition, and intrude the volcanic rocks.

Except for Precambrian foliation, folding or warping of the rocks in the Cochetopa district has been minor. Faulting and shearing dominate the structural pattern. The most persistent and abundant faults trend either easterly or northeasterly, with nearly vertical dips (Fig. 9). Many of these faults are post-Cretaceous and pre-Miocene in age, but a few in the southern part of the district transect and displace the Miocene volcanic rocks. The most important fault in the district, from the standpoint of ore reserves, is the east-trending, nearly vertical Los Ochos fault, traceable for 3½ miles. It cuts, and displaces, the Mancos shale, but cannot be dated relative to the Miocene volcanics, since erosion has removed them along the fault.

The initial uranium discovery in the district was on the Los Ochos claims where visible uranium minerals and abnormal radioactivity were noted in several outcrops. Core drilling by Gunnison Mining Company, lessee of the claims, indicated ore bodies at depth, and an inclined shaft, the first working of the Thornburg mine, was started in the fall of 1954. Subsequent development has blocked out substantial ore reserves in a number of ore bodies in the T-1 mine (formerly the Thornburg mine) and the West mine, along the Los Ochos fault—sufficient to supply feed to the Gunnison uranium mill, which began operations in the spring of 1958.

Exploration at Gunnison Mining Company's East mine on the Kathy Jo claims has revealed only one small ore body adjacent to the Los Ochos fault. There are no other underground uranium mining operations in the district.

Ore mined from an open cut has been stockpiled at the La Rue claims in the southern part of the district. To date, other exploration in the district has proven non-productive.

Los Ochos Claims

Gunnison Mining Company's T-1 mine is located on the Los Ochos claims in the north-central portion of the district in Sec. 4, T. 47 N., R. 2 E., N.M.P.M. Sedimentary rocks along the Los Ochos fault are silicified and brecciated. The fault is marked by abnormal radioactivity in a number of places, and visible secondary uranium minerals locally mark the presence of commercial ore.

At the Los Ochos claims, the fault splits into two subparallel components over a distance of about 800 feet. The No. 1 orebody is controlled by the eastern juncture of this split and is a pipe-like ore shoot, roughly triangular in plan, raking approximately 80° east. It extends from the surface tc some 35 feet below the haulage level, a length of about 175 feet. The sequence of events in the deposition of the ore appears to have been as follows: 1) initial displacement on the Los Ochos fault; 2) invasion of the fault and wall rocks by solutions resulting in intense silicification of the sedimentary rocks along the fault; 3) renewed movement along the fault in which a linear zone of silicified rocks adjacent to the fault was extensively brecciated and fractured; 4) introduction of marcasite and pitchblende.

The No. 2 orebody is 380 feet west of the No. 1 orebody. A fractured and brecciated zone of Morrison sandstone and mudstone lies north of, and adjacent to, the north segment of the Los Ochos fault. This brecciated zone is believed to have been developed during the second stage of movement on the Los Ochos fault. Orebody No. 2 is limited on the south by the north segment of the Los Ochos fault. Subsequent workings have revealed a series of ore bodies more or less adjacent to each other, largely in the sandstone of the Morrison formation. Ore in the T-1 mine is now considered to be generally in one contiguous body.

The mineralogy of the Los Ochos ores is relatively simple. Silicified and brecciated sandstone and mudstone and altered metamorphic rocks contain both sooty and hard, fine-grained pitchblende in veinlets with marcasite and unidentified hydrothermal clay minerals. Oxidized uranium minerals throughout the deposit include autunite and uranophane and postmine uranopilite, zippeite, and johannite. Chalcedony, barite, and crystalline white quartz, together with the hydrothermal clay minerals, comprise the gangue minerals of the deposit. The paragenetic sequence appears to have been as follows:

1. Silicification;
2. Fracturing and marcasite;
3. Early marcasite and clay minerals;
4. Fracturing;
5. Later marcasite;
6. Pitchblende;
7. Kaolinite.

The orebodies of the T-1 mine are situated principally at intersections, splits, and changes in strike or dip of faults, especially where accompanied by brecciation of sedimentary rocks. The Morrison and Dakota formations contain the most favorable host rock, although the Precambrian schist is also widely mineralized and contains a portion of the No. 1 ore shoot. Silicified zones are associated generally with the mineralized structures.

Room and pillar and top-slicing mining methods have been used in the development of T-1 mine, in stopes above the main adit haulage level. A few winzes have been sunk below the level. The first production in 1958 averaged about 6,000 tons of ore per month, with an approximate average grade of 0.27 percent U_3O_8. Present production averages 10,000 to 12,000 tons of ore per month with an approximate average grade of 0.16 percent U_3O_8.

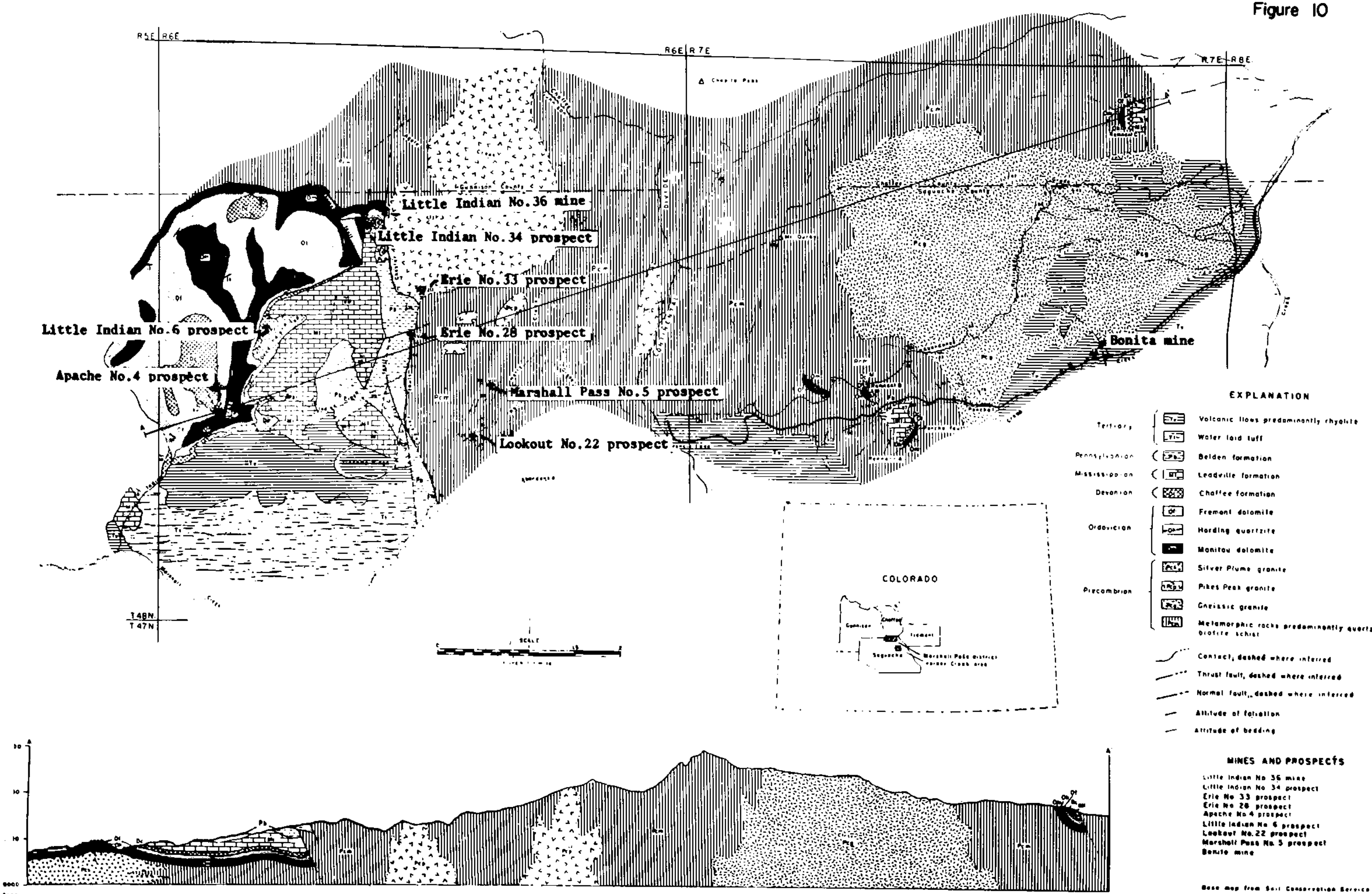
Marshall Pass District

The Marshall Pass mining district is in the southern part of the Sawatch Range, of south central Colorado, near the pass for which it is named, in Saguache County, and small parts of Gunnison and Chaffee Counties, some 6 miles, airline, east of the village of Sargents. Here, in 1955, the initial discoveries of uranium were made in quartzite beds of the Harding formation (Ordovician age) in the western part of the district, and in "fossil" (Eocene?) soil lying on Precambrian rocks, in the eastern part of the district. These occurrences have not proved to be commercial, but substantial reserves of high grade ore were subsequently developed along the Chester thrust fault in the western part of the district.

The geology of the Marshall Pass district is characterized by a variety of Precambrian rocks with scattered faulted remnants of folded Paleozoic sedimentary rocks (Fig. 10). Three of these remnants in the Marshall Pass area range in size from less than one to nearly 10 square miles in area. The largest, in the western part of the district, is bounded on the east by the Chester thrust fault, of Laramide age, along which there has been more than 2,000 feet of displacement. The Precambrian rocks consist of metasediments (chiefly quartz biotite schist), Pikes Peak granite, and gneissic granite. The Paleozoic rocks range from the Manitou dolomite of Ordovician age to the Belden formation of Pennsylvania age. In the southwestern part of the district, Miocene volcanics overlie the older rocks.

The four major orebodies in the district lie principally on, or near, the Chester fault. The most important deposit of the district is exploited by the Erie No. 28 (or Pitch) mine, owned and operated by Pinnacle Exploration Company of Gunnison. This deposit is in the fractured limestone, arkosic sandstone, and shale of the Belden formation. The largest orebody lies along the intersection of the steeply east-dipping Chester thrust fault and the later, gently east-dipping normal Todd fault, which offsets the Chester fault some 130 feet vertically. Ore varies in thickness from a few feet to at least 50 feet and appears from drilling to be continuous for at least 1,300 feet along the fault intersection. The mineralized limestone in the footwall of the Chester fault is dark gray to black in color and

Figure 10



Geologic Map And Section Of The Marshall Pass District, Gunnison, Saguache and Chaffee Counties, Colorado

Geology by R.C.Malan

contains numerous white dolomite veinlets as fracture fillings. In places, the dolomite in the veinlets has been replaced by pyrite. Later fracturing of the rock has offset these original veinlets and new ones were formed. Following this second period of fracturing, pyrite and pitchblende were introduced into both sets of veinlets. Some pyrite and pitchblende has replaced the limestone immediately adjacent to the Chester fault. Uranophane occurs in crushed Precambrian pegmatite on the hanging wall of the fault, near the surface.

At the Little Indian No. 36 mine, near the northern extremity of the exposed portion of the Chester fault, several thousand tons of intermediate to high grade ore have been mined from two orebodies in the Harding quartzite. Tension fractures have formed in the quartzite as a result of drag along the Chester fault. Most of the ore is confined to these tension fractures. This ore is of intermediate grade and is localized along a small southeast plunging fold along the steeply dipping contact of the Harding and Fremont formations. Minor amounts of ore have been found in the Fremont dolomite immediately adjacent to the Harding contact. Autunite and uranophane are associated with minor to moderate amounts of clay minerals.

Other occurrences or prospects along splits of the Chester fault include Little Indian No. 34 prospect, at the contact of the Chaffee (Devonian) and Leadville (Mississippian) formations, and the Erie No. 33 prospect in jasperized Belden limestone. Apache No. 4 and Little Indian No. 6 prospects lie 2 and 1½ miles, respectively, west of the Chester fault, the former in Harding quartzite, and the latter in the Chaffee formation. Less than a mile east of the Chester fault, two other prospects—Lookout No. 22 and Marshall Pass No. 5—occur in colluvium overlying Precambrian quartz-mica schist and have yielded high grade pitchblende ore. In part, the pitchblende, which oxidizes to "gummite" (largely becquerelite), is associated with chalcocite, covellite, galena, pyrite, and hematite.

Exploration is presently restricted to underground longhole drilling and drifting. Considerable additional drilling is underway along unexplored portions of the Chester fault which is potentially the most favorable zone of the district.

Underground mining methods include top slicing, square setting, and cut and fill. Access is by adit. At two properties, several hundred tons were mined from open cuts prior to underground development. Production averaged less than 60 tons per day, of ore averaging more than 0.4 percent U_3O_8.

Tallahassee Creek District

The Tallahassee Creek uranium mining district is centered around T. 17 S., R. 73 W., in Fremont County (Fig. 7). Here, in 1954, uranium discoveries were made on the basis of two strong radiometric anomalies. Since then, 15 ore bodies, of which most have no surface expression, have been discovered by exploratory drilling. Eight of these are in various stages of stripping and mining and two are being developed and mined by underground methods.

This district is located on the southeastern fringe of the Thirty-nine Mile volcanic field, an extensive area of Miocene volcanic flows in central Colorado. Precambrian metamorphic rocks are overlain by a discontinuous section of Eocene(?) arkosic sandstone, conglomerate, and siltstone apparently occupying depressions in the pre-volcanic erosional surface. A series of volcanic flows at least 800 feet in thickness overlies the Precambrian rocks and Eocene sediments. Within the lower half of this flow series, there is a section of sediments consisting primarily of conglomerate, with discontinuous lenses of sandstone and siltstone. Within this sedimentary section, there is at least one relatively persistent bed of altered tuff and fine clastics with generally minor amounts of cobbles and boulders. These sediments accumulated in lowlands developed during an inter-volcanic period and are the products of erosion of the older flow units. Subsequently, younger flows blanketed this dissected terrain. Within the district, erosion since extrusion of the youngest flows has cut through to the Precambrian rocks. Erosional remnants of the flows are preserved in the drainage divides. The present drainage pattern appears to be crudely superimposed on the drainages in which the volcanic conglomerate was deposited.

Uranium deposits occur in the Eocene(?) arkose and in the sedimentary section within the volcanic flows. Fifteen orebodies ranging in size from 700 to 25,000 tons average 0.26 percent U_3O_8. Total reserves exceed 100,000 tons. Average ore thickness ranges from 2½ to 8 feet.

Three closely spaced, bedded deposits in the Eocene(?) arkose are situated in the northern part of the district. These bodies are lenticular in outline and are concordant with sedimentary features. They are located on or near a reverse fault along which Precambrian rocks on the east are in contact with arkose on the west. One the bodies occupies a scour cut into the Precambrian rocks; the others are irregular in outline and are stratigraphically higher in the arkose section.

The other 12 orebodies are bedded deposits in sedimentary rocks in the lower part of the section of volcanic flows. These deposits occur along a two-mile sector of Middle Tallahassee Creek in the central part of the district and in the vicinity of the confluence of South and North Tallahassee Creeks in the southeastern portion of the district. The host generally consists of lenses of finer-grained clastic sediments commonly enclosed by boulder conglomerate, all derived from erosion of volcanic flows. At least three of the deposits are restricted to a uniformly bedded, altered tuff containing variable amounts of fine clastics, cobbles and boulders.

Most of the orebodies are localized at or near the gradational contact of oxidized and unoxidized sediments. The principal ore mineral, uraninite, is associated with variable amounts of carbonaceous material, pyrite and calcium carbonate. Two small oxidized deposits containing autunite have been mined out.

All the deposits in the district occur within a vertical range of 350 feet and those in the volcanic sediments are within a range of 265 feet.

The two major deposits of the district are mined by open pit methods. Production rates are highly variable, ranging from 400 to 1,000 tons of ore per month at Gunnison Mining Company's NE¼, Section 36 mine, and 300 to 3,000 tons per month at Seacol, Inc.'s Joan No. 2 mine.

Miscellaneous Mines and Prospects

In addition to the established uranium mining districts, there are a number of other areas within Colorado which contain significant occurrences of uranium. Generally these consist of: 1) relatively small mines or prospects which have contributed only modest, sporadic shipments of ore to date, or 2) groups of occurrences which, if taken together, may indicate areas of potential uranium production, provided that aggressive exploration is carried out in the future.

Elk Mountain Area, Gunnison County

The Elk Mountain fault zone follows the crest of an irregular asymmetric anticlinal fold of the Elk Mountain uplift. The fault zone is characterized by strong reverse faulting and over-thrusting toward the southwest. Rocks exposed in the fault zone include the Precambrian complex of granites and schists overlain by a thick section of Paleozoic and Mesozoic sediments and locally intruded by Tertiary granodiorite stocks. A number of small low-grade uranium deposits, in the form of disseminations in carbonaceous sediments and in mineralized shear zones in the Precambrian rocks, occur in the thrust fault. These are located 8 to 12 miles east and southeast of Crested Butte.

Henson Creek Area, Hinsdale County

The Henson Creek area is located along the north margin of the Lake City caldera, an oval-shaped downfaulted block of Miocene volcanics. Within the area a thick series of rhyolite, latite and andesite tuffs, breccias and flows overlie the Precambrian complex and are intruded and locally domed by a number of rhyolite porphyry plugs which parallel the caldera rim, located 4 to 5 miles to the south. The plugs and some volcanic rocks contain anomalous amounts of uranium. Uranophane coating fractures occur in several small erratic pods near the contact of three of the rhyolite porphyry plugs. The deposits are located about 3 miles northwest of Capitol City, an abandoned mining town.

Huerfano Park Area, Huerfano County

In the Huerfano Park area, a downwarped elongate basin is underlain by Tertiary sediments. A thick section of folded and faulted upper Paleozoic and Mesozoic sedimentary rocks crop out along the east and west margins of the basin and underlie the Tertiary section within the basin.

Uranium occurrences are in the upper part of the Huerfano formation of Eocene age and in the Dakota formation of Cretaceous age near Badito Cone. In the Tertiary beds uranium is associated with carbon trash and discontinuous carbonaceous shale lenses interbedded with coarse-grained to conglomeratic arkosic sandstone in fluvial scours. Known mineralized zones are as much as 100 feet in length but are spotty, and ore-grade concentrations are restricted in size. In the Dakota formation, uranium is disseminated in small patches in fine- to medium-grained sandstone and in places is associated with concentrations of fluorite, iron oxide, and carbonaceous material.

In the Tertiary host rocks, minor amounts of autunite are present, but most of the uranium is in the form of a black urano-organic complex material associated with carbon trash. At Badito Cone, the deposits are chiefly of the carnotite-tyuyamunite type, but in one occurrence, uraninite is disseminated in silicified sandstone.

Physical exploration in the area has been largely superficial, not exceeding 25 feet in depth. Several prospects have been opened by trenching and shallow open-pitting, and a few holes have been drilled. In the Badito Cone area, several test shafts have been sunk on mineralized outcrops.

Middle Park Area, Jackson County

Several uranium prospects are distributed throughout Middle Park, an intermontane structural basin in Jackson County bounded on the east and west by tilted Mesozoic sedimentary rocks and older crystalline rocks of the Front and Park Ranges (Fig. 7). The basin is formed almost entirely on sedimentary and volcanic rocks of Tertiary age. Known uranium occurrences in Middle Park are in the following three geologic settings: 1) a buried carbonaceous regolith zone of Eocene(?) age at the contact of Precambrian rocks and the Middle Park formation of Eocene(?) age in the Beaver Creek area, 2) small lenses within the Middle Park formation in the Troublesome Creek area, and 3) bedded deposits in sandstone of the Dakota formation near Rabbit Ears Pass.

In the Troublesome Creek area, carnotite, autunite, and schroeckingerite and several vanadium minerals are associated with marcasite and jarosite. In the Rabbit Ears pass locality, carnotite is the dominant uranium mineral, with subordinate amounts of autunite.

No mining is presently in progress in the area.

Morrison Area, Jefferson County

Uranium-bearing asphaltite has been mined from two deposits, the Mann No. 1 lease and Pallaoro lease, located about two miles southeast of Morrison, where Turkey Creek cuts the hogback formed by the upturned edge of the Dakota formation. The deposits are in the NE¼ of Sec. 12, T 5 S, R 70 W.

Host rock is the Upper Dakota sandstone, which strikes about N 45° W and dips 25° east. The ore is found in fractures along the footwall of a fault which strikes parallel to the enclosing beds but dips westerly at an angle of about 70°. The ore-controlling fault crosses both properties. The ore consists of asphaltite, which carries uraninite(?), and is associated with pyrite. Several thousand tons of ore have been mined.

These are the most important of a group of uranium occurrences in Dakota sandstone along the Front Range from Morrison north to the Wyoming state line.

Turkey Creek Area, Pueblo and El Paso Counties

Ore containing coffinite and possibly minor uraninite has been found in a sandstone unit of the upper Dakota formation of Cretaceous age on the east flank of the Turkey Creek anticline in the northwest corner of Pueblo County and the southwest corner of El Paso County (Fig. 7). Ore is concentrated along and below the present water table at approximately 80 feet of depth. Ore-grade concentrations range up to a few hundred tons in size, are irregular in shape, and are concordant with the bedding of the sandstone. The host sandstone is moderately permeable, contains carbonaceous material, and is probably fluviatile or deltaic in origin. At the Avery Ranch mine of the Cliff and Creek Mining Company (the only mine in the area), a modified, pillar-supported open stope mining method is used and access is by inclined shaft.

Meeker District, Rio Blanco and Moffat Counties

A small uranium-producing locality is centered around Coal Creek, about 15 miles northeast of Meeker in Rio Blanco County. The area is on the nose of the Coal Creek anticline at the north end of Grand Hogback. Carnotite-type deposits occur in the Morrison formation in a favorable belt less than a mile wide and about 6 miles in length, forming an arcuate pattern around the nose of the anticline. Ore bodies are commonly less than 500 tons in size and are sparsely distributed. Mining has been by small stripping operations near the outcrop and underground workings.

Small copper-uranium-vanadium deposits also occur in the Weber sandstone of Pennsylvanian age and in the Curtis formation of Jurassic age, in the Skull Creek area of southwestern Moffat County, to the northwest of Meeker.

Kerber Creek Area, Saguache County

The Kerber Creek area, near the northwestern end of the San Luis Valley, includes about 40 square miles of folded and faulted Precambrian metamorphic rocks, and Paleozoic formations ranging in age from Ordovician through Pennsylvanian. The upper part of the Harding quartzite of Ordovician age is irregularly mineralized by uranium, and locally is of ore grade. Minor amounts of autunite and uranophane and trace amounts of vanadium minerals characterize the mineralized zone.

Sangre de Cristo Range Prospects, Saguache and Custer Counties

Several significant uranium occurrences lie in the Sangre de Cristo Range in a northwesterly trending belt, about 25 miles in length and less than a quarter of a mile in width, between Crestone, Saguache County, and Westcliffe, Custer County, in the central part of the range. The belt follows the strike of Paleozoic beds, and the uranium occurrences are restricted to a stratigraphic section 800 to 900 feet thick in the upper Sangre de Cristo formation of late Pennsylvanian or Permian age. Nine separate fine-grained arkosic sandstone and siltstone members within this section are locally mineralized. These beds are characterized by abundant asphaltic organic material.

At La Veta Pass and in other localities in the southern part of the range, oxidized uranium, vanadium, and copper minerals occur in moderately to steeply-dipping arkosic and asphaltic sandstone, shale, and coarse-grained sandstone lenses containing carbon trash. In the Westcliffe-Crestone belt, mixtures of uraninite and urano-organic complex material predominate, with trace amounts of autunite. In the southern localities, volberthite, carnotite, and secondary copper minerals are present.

Needle Mountains Area, San Juan and La Plata Counties

The Needle Mountains fault zone consists of steeply dipping Precambrian slates and quartzites. Precambrian granites and older metamorphic rocks in the Needle Mountains dome are overlain by Tertiary volcanic rocks to the north. The area is strongly faulted by high angle normal and reverse faults commonly trending east-west paralleling and forming many of the major formational contacts. Fractures in shattered quartzite contain uraninite with minor sulphides in several prospect pits along a half mile section of a fault zone on the west end of the range.

High Park-Lake George Area, Teller County

Several uranium prospects are being developed, largely by Cotter Corporation, in the Florissant "lake beds" of Miocene age in Teller County (Fig. 7). Interbedded arkosic sandstone and conglomerate, shaly siltstone, and tuffaceous sediments are, at least in part, lacustrine in origin. The sediments occupy three separate basins, ranging in size from 4 to 20 square miles, in westernmost Teller County. Several bedded uranium deposits, each containing several thousands of tons of ore, range from 4 to 13 feet in thickness at 4 to 80 feet of depth. The principal ore mineral is uraninite, but in the oxidized zones, autunite is present. Carbonate and vanadium content appear to be negligible. Average grade of the ore is slightly less than 0.2 percent U_3O_8. No mining has, as yet, been done in these deposits.

Acknowledgements

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Chapter VI

The Rare Earths

by

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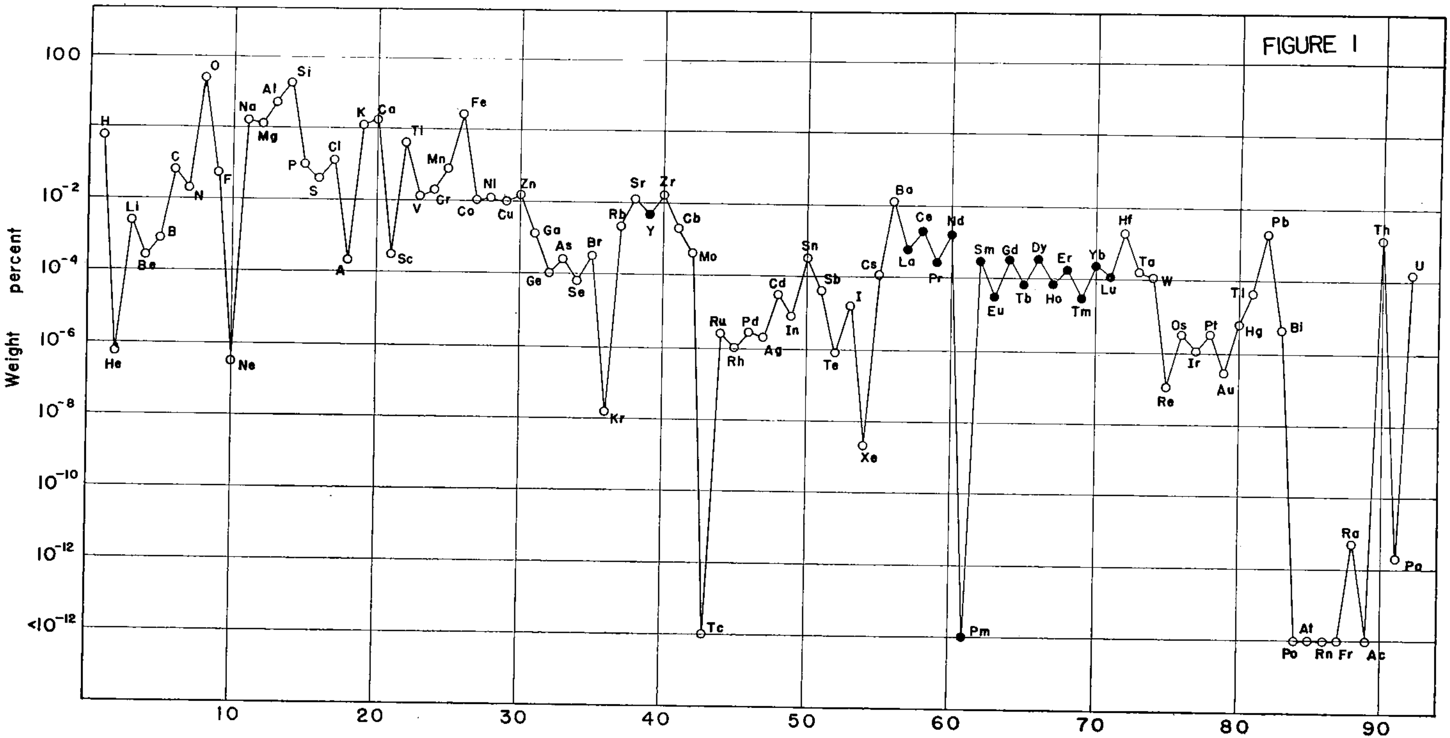

CRUSTAL ABUNDANCE OF THE ELEMENTS

CHAPTER VI

The Rare Earths

by

VANCE HAYNES, JR.*

By strict definition, the rare earth elements are those which, in atomic number, follow lanthanum and precede hafnium; that is, they include the atomic numbers from cerium (58) through lutetium (71). These elements are designated as the lanthanides. In the mineral industries it is still permissible to include among the rare earths not only the lanthanides, but also lanthanum itself, scandium, and yttrium. The rare earth elements, as discussed herein, are as follows:

	Element	Atomic Number	
	Scandium	21	
	Lanthanum	57	
	Cerium	58	Cerium
	Praseodymium	59	
	Neodymium	60	(Light Group)
	Promethium	61	
	Samarium	62	Group
	Europium	63	
Lanthanides	Gadolinium	64	
	Terbium	65	
	Dysprosium	66	Yttrium
	Holmium	67	
	Erbium	68	(Heavy Group)
	Thulium	69	
	Ytterbium	70	Group
	Lutetium	71	
	Yttrium	39	

The rare earth elements, excluding scandium in this instance, are commonly classified into two groups as may be seen above on the right: the cerium, or light group, and the yttrium, or heavy group. Chemically, the rare earth elements behave very similarly due to the very small difference in the structure of their atoms, particularly among the lanthanides where variations in the number of electrons occur in an inner electron shell (4f) and not in the outermost shell as with other elements. Coupled with an additional close similarity in ionic radii, the rare earths display similar geochemical habits. Scandium is the exception, for it has a considerably smaller ionic radius and hence behaves more independently in nature. The cerium and yttrium groups can be separated from each

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other fairly easily by normal chemical methods—a similar separation occurs in nature—but a further separation into individual elements is considerably more difficult.

According to Rankama and Sahama (1950) europium occupies a unique position among the lanthanides because of its usual occurrence in the bivalent state in nature instead of the trivalent state of the other lanthanides. Therefore, it has a tendency to separate from the others during magmatic differentiation, leaving the normal rare earth minerals relatively impoverished in europium. Because of its ionic radius, europium tends to follow strontium in nature, but only as a minor constituent in its minerals.

Treatment

Many rare earth minerals can be taken into solution by strong acid treatment, others require fusion. Until the development of ion exchange methods by the U. S. Atomic Energy Commission (Spedding, 1947, 1950), the individual rare earth elements had to be separated by a very lengthy and tedious process of fractional precipitation. Ion exchange methods are very expensive and time consuming, but they remain the principal commercial methods in use today. The products derived from the ion exchange reaction are high purity rare earth oxides, which are the fundamental compounds from which most other rare earth products are made. In order to produce relatively pure rare earth metals, the principal method is to convert the oxides into fluorides and to reduce them with metallic calcium or lanthanum in a thermite-type reaction.

Uses

The rare earths lend themselves to a widespread number of uses. Prior to World War II, a mixture of the cerium group was the principal commercial product, its chief application being in the manufacture of gas mantles, lighter flints, and low melting-point alloys. Cerium oxide has long been used as a grinding and polishing medium for certain types of glass. Since the War, other uses have been developed, particularly for individual rare earth elements. Cerium group elements are used in ferrous metallurgy to impart desirable properties to some steels and to act as "getters" in removing harmful elements. Increasing importance is being placed upon the use of certain yttrium group elements in the atomic energy field: gadolinium is the best known absorber of thermal neutrons; the rarer europium is also an excellent neutron absorber; yttrium has a high neutron transparency; isotopes of thulium and yttrium can be used as source material for producing useful x-rays. Scandium, too, has atomic energy applications.

Research for new uses, as well as better separation techniques, are being conducted by both the government and private industry; no doubt some very useful and desirable applications will be discovered. The future economic condition of the rare earths will depend upon the success of the research now in progress, and the availability of rare earth ores.

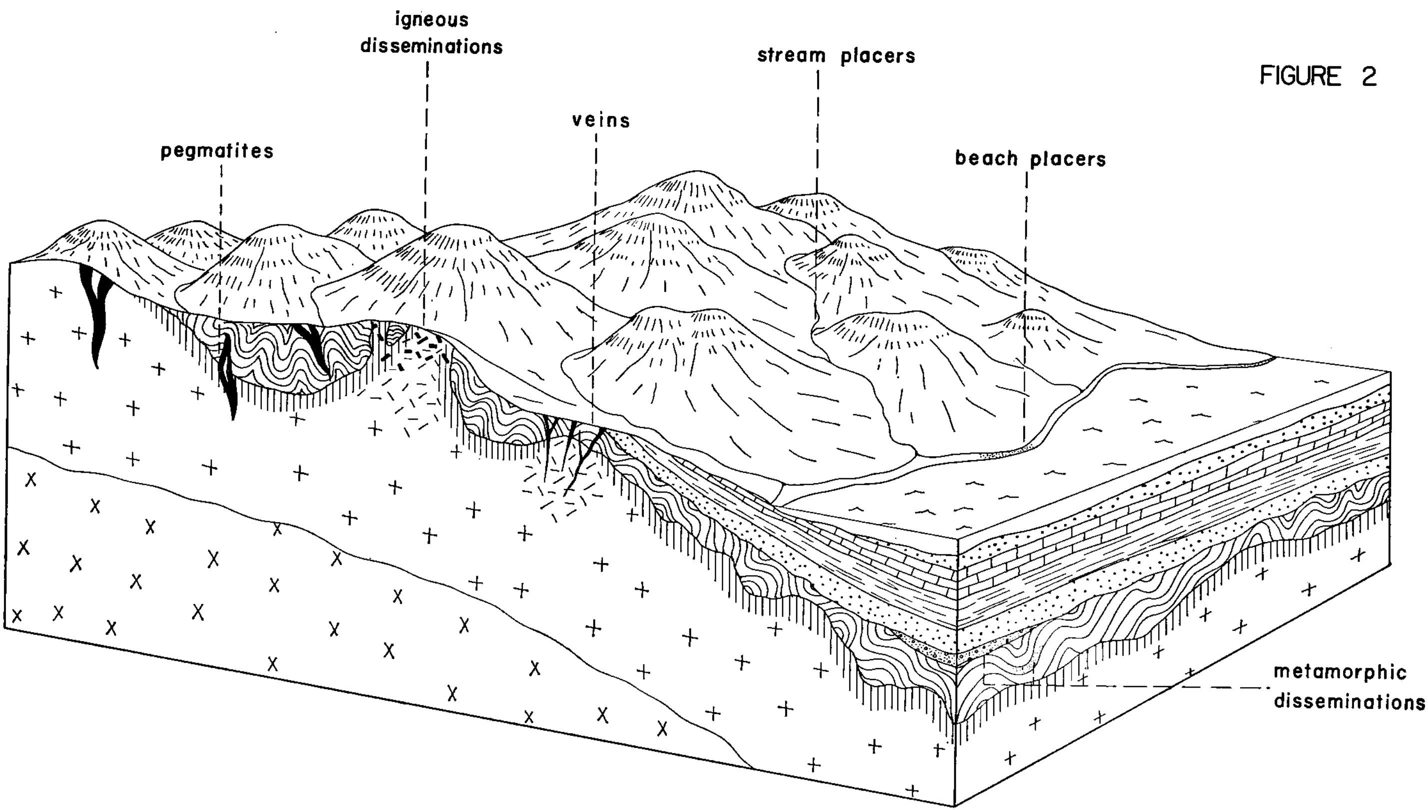
Geology

There are over 100 mineral species containing rare earths as essential constituents, and many more containing them as minor constituents, but only a few minerals are relatively common. These latter include the multiple oxides euxenite, samarskite, and fergusonite; the phosphates monazite and xenotime; the silicates allanite and gadolinite, and the fluocarbonate basnaesite. Generally, other minerals are rare and for the most part of scientific interest only. This does not imply, however, that they may never be found in sufficient concentration and quantity to represent ore. Bastnaesite used to be considered one of the rare minerals, but the discovery of two deposits of considerable size has placed it as one of the more important ore minerals of the cerium group of elements. Bastnaesite has also been found as an accessory mineral in granite (Smith and Cisney, 1956). Some 25 rare earth minerals have been identified in Colorado (Table 1, page 383).

In the lanthanide assemblages found in minerals, the odd atomic-numbered elements are less abundant than the adjacent even-numbered ones. Significantly, this condition also holds true for their presence in meteorites. Rare earth minerals have been divided into two main categories based upon their rare earth assemblages (Goldschmidt and Tomassen, 1924). One is the complete assemblage in which all the lanthanides, plus yttrium, are represented. Minerals of this category are usually richer in either the cerium group or the yttrium group elements. The other category is the selective assemblage in which only one group is present and the other essentially absent. The relative abundance of individual lanthanides within a mineral assemblage has been found to vary, and recent investigations (Butler, 1958) indicate that certain assemblages may be diagnostic of certain mineral species. These matters are of interest to the exploration geologist because an estimate of the elements available in a deposit can often be made if the rare earth minerals can be identified.

Ore deposits of the rare earths may be divided into five types based upon genesis and form (Fig. 2). These are, a) igneous disseminations; b) pegmatites; c) veins; d) metamorphic

FIGURE 2



PRINCIPAL TYPES OF RARE EARTH DEPOSITS

disseminations, and e) placers. Carbonatites may be considered special cases of igneous disseminations, and veins. The foregoing classification is of necessity somewhat arbitrary, for some deposits are a combination of genetically related types.

Igneous Disseminations

Granites and some alkalic rocks are the primary igneous sources for most rare earth minerals. In granitic rocks, the rare earth minerals are usually accessory constituents that occur as disseminated small grains. Such occurrences are usually of too low a tenor to represent ore. The same holds generally true for some alkalic rocks, although in some alkalic complexes certain rocks contain rare earth minerals in sufficient concentration to constitute ore. Deposits of this type may be called igneous disseminations. In the Pikes Peak granite near South Platte (loc. 20), there are disseminated crystals of allanite as an accessory mineral which represent less than 1 per cent of the total rock composition, but in places there are schlieren, or veinlike concentrations, which make up 10 per cent or more of the rock. These particular occurrences are noncommercial at the present time.

The Olhio prospect (location 8 on map), northwest of Canon City, is an igneous dissemination of xenotime and monazite in rock tentatively identified as a quartz diorite. The ore is confined to a dikelike body in granite and several tons have been shipped from it for chemical and oredressing tests. One gravity separation test produced a concentrate of xenotime, with some monazite, which represented better than 2 per cent of the original rock.

For many years Climax Molybdenum Company recovered small quantities of monazite from its ore in the Climax deposit. The monazite is only a very minor accessory mineral in the Climax porphyry stock, but the large tonnages being treated made it profitable in the past to recover the monazite. Undoubtedly there exist many other igneous masses in Colorado that contain similar minor accessory rare earth minerals which could possibly be produced profitably as byproducts of high-tonnage operations such as the one at Climax.

There are other occurrences in Colorado which could be called igneous disseminations, but these are more closely related to pegmatites and are discussed under that heading. Carbonatites may also contain rare earth minerals as igneous disseminations, but these, too, are discussed separately.

Pegmatites

Pegmatites related to both granitic and alkalic rocks have long been known for their diversified rare earth mineral content. Actually, the rare earth elements were originally discovered in pegmatite minerals.

Pegmatites are thought to be late-stage fluid differentiates

FIGURE 3

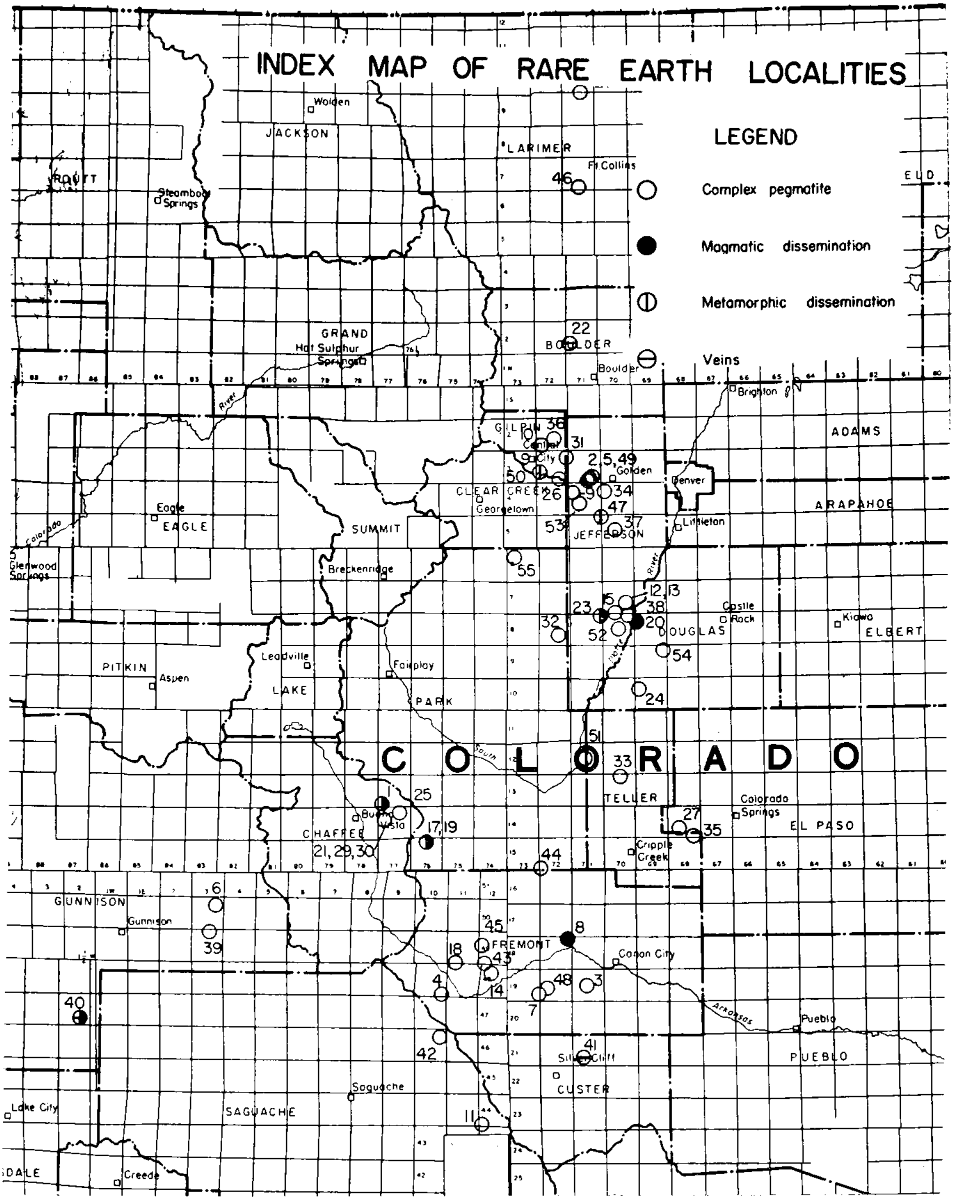


FIGURE 3

remaining after crystallization of the parent magma. Rare earths, especially those of the yttrium group, and scandium, are concentrated in these fluids, which may solidify within the parent rock, or may migrate into neighboring rocks. Pegmatites commonly crystallize in concentric zones from the walls inward. The rare earth minerals are sometimes restricted to one or more zones, and in such cases, if the rare earth-bearing zone can be determined, it can be mined selectively. Pegmatites, however, are not generally the best deposits for economic production of rare earth minerals, for even though these minerals be restricted to zones, they are generally too sparingly present or too erratically distributed. Some rare earth masses weighing several hundred pounds have been found, but it is most frustrating to the miner to learn the costly lesson that that pocket was the only one present in many tons of rock. In most cases, particularly in the United States, rare earths are obtained from pegmatites profitably only as by-products of mining for other minerals, such as feldspar, mica; and beryl and lithium minerals as associated byproducts. A few pegmatites, such as the Baringer Hill locality in Texas (Hess, 1908; Landes, 1932), and some in Madagascar, Scandinavia, and Brazil, have been mined primarily for rare earths, but such dikes are uncommon. Up to the present, pegmatites in Norway and Madagascar have supplied the only ores for scandium. This element occurs in the mineral thortveitite, a very rare complex silicate.

Up to the present, all rare earth production in Colorado has come from pegmatities and probably has not exceeded a few hundred pounds per year, mostly in pound lots of hand-picked minerals from feldspar and mica mining. Euxenite, samarskite, and gadolinite, the most common produced, are usually found as individual crystals or masses ranging in size from less than one inch to over one foot. There are in Colorado a few pegmatites which could conceivably be mined selectively for rare earth minerals, but it is significant that during the period 1956-1958, several mining companies investigated Colorado pegmatites for rare earths and concluded that they could not be regarded as reliable sources.

There are no less than 100 pegmatites in Colorado which are known to contain rare earth minerals. Some of them contain unusual assemblages of different minerals, others contain rare species, and still others have provided masses or crystals of exceptional size. Roscoe Dike (loc. 2 on map) on Clear Creek west of Golden, has long been known to mineralogists and collectors for its rare earth crystals. Gadolinite, fergusonite, xenotime, monazite, allanite, tengerite (?), uraninite, and fluocerite (?) (Adams, J. W., personal communication) have been collected here. Bastnaesite and tysonite occur in the Black Cloud pegmatite (loc. 33) near Lake George, and in St. Peter's Dome (loc. 27). Some pegmatites in the South Platte area (loc.

38) contain doverite (Haynes, 1958) and crystal aggregates of cyrtolite and thorite of unusual size. A euxenite crystal weighing approximately 300 pounds was mined from a pegmatite (loc. 34) west of Lookout Mountain. Robert Benton has obtained gadolinite crystal masses of a hundred and more pounds from his prospect near Cotopaxi (loc. 4). Pegmatites in Silver Plume granite near Jamestown (loc. 22) contain fine-grained cerite with small amounts of bastnaesite and tornebohmite (Goddard and Glass, 1940).

The White Cloud pegmatite (loc. 38) near South Platte, has produced about 20 tons of complex rare earth ore containing yttrofluorite, yttrocerite, doverite, gadolinite, fergusonite, cyrtolite, and allanite (Haynes, 1958). A shipment of 14.7 tons tested by Wah Chang Corporation, indicated a rare earth content of 1.73 per cent RE_2O_3, of which 30.2 per cent was Y_2O_3, and 25.6 per cent was Ce_2O_3. Pilot shipments of yttrofluorite have been made by Edwin Over from his Teller pegmatite (loc. 51) near Lake George. According to Mr. Hal Miller (personal communication, 1958) of Wah Chang Corporation, this yttrofluorite contains a higher percentage of rare earths than any other as yet tested by his organization. Of the total 29.3 per cent rare earth oxides reported, 65 per cent is Y_2O_3.

Mr. Henry Kruger, of Canon City, has formed the Rare Earth-Uranium Mining and Development Company for the purpose of extracting individual rare earth salts from minerals handpicked from the Henry pegmatite (loc. 43), 6 miles north of Cotopaxi. This company has installed several ion-exchange columns, and offers to purchase selected rare earth minerals from other sources.

There are a few pegmatites in Colorado which contain euxenite disseminated in small grains throughout certain parts, usually the wall zone. These occurrences could be called igneous disseminations, but actually they are part of the pegmatitic stage of crystallization. Commonly, the disseminated portions are rich enough to represent milling-grade ore, but tonnages have been limited; two prospects of this type occur southeast of Texas Creek (locs. 7 and 48). Recent work at the Yard mine (loc. 1) (Heinrichs, 1948) has revealed disseminations of small grains of euxenite beneath the main pegmatite. In western Park County, west of Badger Creek, several pegmatites reveal pronounced zones containing disseminated euxenite (locs. 17, 19). One hand specimen of this rock shows a concentration of over 50 per cent euxenite. Another unusual occurrence is the Seerie prospect (loc. 23) northwest of Foxton, which contains a zone with a mixture of disseminated cyrtolite and uranothorite-thorogummite crystals.

Many of the pegmatites in Colorado demonstrate the mineralization sequence observed by Bjørlykke (1937) in Norway. His statement to the effect that the presence of fergusonite indicates an excess of yttrium earths, so that it is unlikely that either columbite or tantalite would be found in the same pegmatite, has so far held true for Colorado.

Veins

As indicated previously, the occurrence of bivalent europium as an accessory element in some hydrothermal minerals is to be expected, but occurrences of rare earth minerals in veins are rare. Monazite has been reported in hydrothermal veins such as the hypothermal occurrences at Shinkolobwe, Belgian Congo (Derricks and Vaes, 1956), and parisite is reported in a vein at Irish Creek, Va. (Glass, Koschmann, and Vhay, 1958). There are numerous veins genetically related to and associated with carbonatites that contain rare earth minerals. Rare earths also occur in vein thorite deposits as an accessory in thorite. Examples are: the Lehmi Pass district of Idaho (Trites and Trooker, 1953, pp. 191-205); the Powderhorn district of Colorado (loc. 40) (Olson and Wallace, 1956), and the Wet Mountain area of Colorado (loc. 41) (Singewald and Brock, 1956). The veins in the Bear Lodge district of Wyoming are reported to contain up to 12.68 per cent RE_2O_3 (Heinrich, 1958, p. 162). The two Colorado occurrences are associated with alkalic rock complexes and with intrusive carbonates; in essence, they are carbonatites. According to Mr. Hal Miller, of Wah Chang Corporation Boulder Laboratories, thorite ores from the Wet Mountain area have a rare earth content which approximates one-tenth of the thoria content. Complete assemblages of the rare earths are reported, but with the yttrium group more prevalent than the cerium group. It is geochemically significant that these hydrothermal thorite rare earth assemblages from the Wet Mountains are relatively rich in europium (greater than 1 per cent total RE_2O_3). Mr. Miller is of the opinion that full-scale production from the Wet Mountains thorium deposits could result in a substantial coproduction of rare earths.

Carbonatites

Associated with some alkalic rock complexes there are intrusive carbonates, in which calcite and sometimes dolomite are the chief rock minerals, in the form of stocks and veins; such occurrences are called carbonatites. There is substantial evidence to support a magmatic origin for these intrusive carbonates, but the source of the magna is not generally agreed upon (Turner and Verhoogen, 1951). In recent years a characteristic association of certain rare earth minerals with some intrusive carbonates has been recognized, and the discoveries of large quantities of bastnaesite and carbonatites at Mountain Pass, California (Olson and others, 1954), and in the Gallinas Mountains of New Mexico (Soulé, 1946), have made this previously rare mineral an important ore for cerium earths. Other, but rarer lanthanide minerals sometimes associated with bastnaesite, are parisite, lanthanite, sahamalite, and synchisite. These occur as disseminations in calcium carbonate intrusive rocks and as crystals in late-stage veins associated with carbonatites.

There are two carbonatites in Colorado: the Iron Hill carbonate stock in the Powderhorn district (Olson and Wallace, 1956), and the other in the northwestern extremity of the Wet Mountains area. The principal rare earth mineral at Iron Hill is a cerium-earth apatite. Veins outside the carbonate intrusive contain yttrium minerals, such as xenotime. The commercial aspects of the Powderhorn district for rare earths have yet to be determined.

Northwestern extensions of the thorite veins in the Wet Mountains reveal intrusive carbonates, whereas only replacement and vein carbonates are reported to occur within the main thorite district (Heinrich, 1958). These carbonatite associations in the northwestern extensions of the district had not been reported previously, but are now attracting the attention of local prospectors. Beside calcium carbonate, the associated minerals include barite, fluorite, hematite, and vermiculite. Base metals, plus silver, have appeared in some assays. Xenotime is reported in some veins, but ferrothorite with accessory rare earths, is the chief ore mineral. Mr. Miller, of Wah Chang, states that Dr. Laszlo Dudas, at Anaconda, Montana, has detected small amounts of another mineral in the thorite which could be the rare phosphate, abukumalite.

The area between Texas Creek and Silver Cliff could bear additional prospecting for carbonatite occurrences.

Placers

Many of the rare earth minerals are more resistant to erosion by weathering processes than the common minerals composing the rock which contains them. As the rock weathers and decomposes, the rare earth minerals are liberated and may concentrate in beach and stream placers, forming important deposits. Rare earths from dissolved minerals may find their way to the seas, where they are deposited with the other sediments. The rare earth content of sediments has generally been neglected by geochemists, but phosphorites are known to contain rare earths in above-average concentrations.

For many years the principal commercial source of rare earths was the monazite beach placers along the coasts of India and Brazil. But of recent years numerous other monazite placers have been reported throughout the world and in the United States (Ninninger, 1954; Heinrich, 1958). Stream and beach placers in the Carolinas and in Georgia have been known for years and have produced rare earths. Most of the thorium group elements, and thorium, produced by the Lindsay Chemical Company, have come from placer minerals, both foreign and domestic; smaller quantities of yttrium earths were also separated from these minerals as byproducts. A prime source in this country for yttrium group elements is the placer euxenite from Bear Valley, Idaho, where 1 pound or more per cubic yard occurs in the gravels with several other heavy minerals, including monazite and columbite.

In Colorado, Heinrich (1958, p. 505) reports 0.15 per cent monazite in stream placers in the San Luis Valley, and as much as 25 per cent in heavy-mineral concentrates from Routt County. Actually, the potential of rare earths in placers is virtually unassessed in Colorado. Xenotime and euxenite are likely placer minerals in Colorado streams which drain granitic highlands and some biotite schist areas.

Metamorphic Disseminations

Rare earth minerals in metamorphic rocks are derived from several sources: some form as a result of differentiation during metamorphism of sediments or partial fusion of metamorphic rocks; some are the result of metamorphism of primary rocks containing accessory rare earth minerals, and others result from metamorphism of ancient placers. In all metamorphic deposits the rare earth minerals occur as small grains.

In Colorado, there are four known metamorphic dissemination deposits. Three of them, located between Central City and Idaho Springs (loc. 50) consist of disseminated, randomly oriented grains of xenotime and monazite in biotite gneiss and migmatite consisting of biotite and pegmatite (Young and Sims, 1958). These are believed to represent metamorphosed placers and are a potential source of yttrium-group elements. Ore from the McKay property averaged 0.84 per cent Y_2O_3, according to Wah Chang Corporation, and while this is low-grade, the tonnages available are relatively large, and concentration is relatively simple. A previously unreported metamorphic dissemination has been discovered by Dwight Songer of Kittridge (loc. 47) but the rare earth mineral in the deposit has not been identified. The deposit is a migmatite on the contact between gneiss and granite.

Metamorphic disseminations could become an important source of rare earths. The above deposits have been discovered because of their radioactivity, but others could exist without possessing radioactive indicators.

In the Central City deposits the xenotime occurs in direct association with biotite; in Songer's deposit the rare earth values are confined to biotite. Therefore, it is well to examine the heavy mineral concentrates from biotite gneisses and schists as well as migmatites, whether or not the rock is anomalously radioactive.

Economic Aspects

At the present time the rare earths occupy a rather unsettled economic position in industry. The demands for individual elements are sporadic because present and future usage depends principally upon research. Basic scientific investigations may possibly indicate a potential application for one of the elements, and thus a certain limited demand may be created for research purposes on that element. The result of the research may in turn reveal that the envisioned application is not feasible, and the demand drops.

In the past, most of the rare earth applications utilized the cerium-group elements, usually as a mixture, and the market remained relatively stable due to a steady source, monazite. At the same time, uses for the yttrium group were few, and byproducts from monazite processing were able to satisfy the small demand of researchers working with the heavy group. Two factors which have brought the yttrium-group elements stronger into the picture in this country are the advent of atomic energy and the discovery of the previously-mentioned large bastnaesite deposits. Whitman (1958) brings out additional factors which tend to change the picture.

When rare earth elements were detected in the products of atomic fission, the Atomic Energy Commission initiated a detailed study of these elements. This led to the ion-exchange method of separation and, for the first time, individual elements could be produced in pure form and at much lesser expense than the conventional method of fractional precipitation. Then, at long last, study of the physical and chemical properties of the rare earths as individual elements could be undertaken. As a result, many new uses have been found for these metals in the field of atomic energy, particularly for the yttrium group of elements.

The discovery of an estimated 10 billion pounds of cerium-group oxides in the bastnaesite deposit at Mountain Pass, California, exerts a profound effect upon the market for these elements. Now the potential supply is considerably greater than the demand, and organizations, such as Molybdenum Corporation of America, which owns most of the Mountain Pass reserves, are working diligently to develop new uses requiring a substantial production of bastnaesite ore.

The present economic situation is approximately as follows: The cerium-group elements are in more than sufficient supply in the form of ore reserves to satisfy all foreseeable demand in their particular markets. As for the yttrium group, there are no deposits of this heavy group which could in any way compare in size with those at Mountain Pass, or with the large monazite placers. This circumstance, which is not reassuring of reliable sources of supply, deters industry from accepted use of the yttrium group in its processes where it could become applicable, or to undertake research for other applicabilities. As it stands now, the demand for yttrium-group elements is sporadic and its present applications are highly specialized, although mention has been made of their applicability to the nuclear field. In addition, the yttrium group industry, if it can be called such, has been plagued by unsound promotional schemes which have been of no benefit. Another important economic factor for the future is that there are indications that a moderate supply of yttrium group earths can be obtained as byproduct of thorium production from thorite and brannerite.

The outlook for Colorado is uncertain. It is unlikely that cerium earths will be produced except as a byproduct and even this does not seem warranted. The only past production of cerium-group minerals has been a small output of monazite concentrates from the Climax molybdenum deposit. Pound lots of handpicked yttrium minerals have been produced from Colorado pegmatites for many years. These small quantities were sold for the most part to mineral dealers, scientific institutions, and chemical companies for about $2 per pound. Limited production of this type will probably continue indefinitely.

In 1956, several small companies were formed for the purpose of producing purified rare earth salts from Colorado minerals. Most of these went out of business because of insufficient markets, poor management, lack of technical knowledge, or unreliability of ore sources. The first real stimulus to rare earth exploration in Colorado resulted from contracts for purified yttrium granted by the Federal Government to Michigan Chemical Company and Dow Chemical Company in 1957. The resulting activity, though intense, was shortlived.

Fixed prices for rare earth ores have never been established in Colorado. During the shortlived, forementioned interest in yttrium, prices were based upon the yttrium oxide content, and ranged from $0.50 to $7.50 per pound of contained Y_2O_3. Wah Chang paid $1.00 per pound Y_2O_3 for ore containing 1 per cent or better, but preferred a 2 per cent cutoff, and paid $2.00 per pound Y_2O_3 for xenotime concentrates containing 10 per cent or better from Mr. Van McKay's Central City deposit.

If an adequate demand for yttrium-group earths ever develops, Colorado can be expected to supply a substantial portion of this market, particularly if a concordant demand for thorium also develops, for a considerable quantity of rare earths would be byproduced from the thorium operations. The metamorphic dissemination deposits in Colorado have already produced several thousand pounds of yttrium oxide even though only recently recognized. Deposits of this type are promising, and there undoubtedly exist other undiscovered ones in the Idaho Springs formation.

Table 1. Colorado Rare-Earth Minerals Indexed by Locality on Figure 3, Page 375

Mineral	Locality number (refer to Plate 1)
allanite	2, 3, 4, 12, 14, 18, 20, 26, 38, 44, 49, 51, 55
bastnaesite	22, 27, 33
brannerite	36
cerite	22
cyrtolite	4, 6, 11, 12, 14, 15, 18, 23, 27, 38, 42
doverite	38, 52
euxenite	1, 4, 7, 11, 14, 16, 17, 18, 19, 21, 25, 29, 30, 42, 44, 48, 53
fergusonite	2, 27, 38
fluocerite (tysonite)	33
gadolinite	2, 4, 5, 26, 38, 49, 51, 54
microlite	27, 39
monazite	1, 2, 4, 5, 6, 8, 13, 14, 32, 39, 44, 49, 51
pyrochlore	35
samarskite	11, 33, 34, 42, 54
samiresite	6
tengerite	2, 4
thorite	15, 23, 40, 41
thorogummite	23, 52
tornebohmite	22
uranothorite	23, 44
xenotime	2, 4, 8, 11, 17, 21, 26, 27, 31, 38, 40, 42, 50, 51, 52
yttrocerite	38
yttrofluorite	32, 38, 51, 52
yttrotantalite	locality unknown
yttrotitanite	9
unidentified fluocarbonate	38
unidentified multiple oxide	13, 14, 24, 37, 49

Table 2, Index of Colorado Rare-Earth Mineral Localities, Figure 3

Number	Locality
1	Yard pegmatite (Pink Lady feldspar mine), Trout Creek Pass area.
2	Rosco dike, Clear Creek Canyon, Jefferson County.
3	Wilson prospect, Copper Gulch, Fremont County.
4	Benton prospect, Cotopaxi, Fremont County.
5	Centennial Cone, Jefferson County.
6	Bucky mine, Quartz Creek district, Gunnison County.
7	Addey mine, Lookout Mountain, Fremont County.
8	Olhio prospect, Current Creek, Fremont County.
9	Bergen Park mine, Jefferson County.
10	Dory Hill, Gilpin County.
11	Crestone pegmatites, Saguache County.
12	Vermillion pegmatite, South Platte, Jefferson County.
13	Mugford mine, South Platte, Jefferson County.
14	Henry Lode, Cotopaxi, Fremont County.
15	Patsy mine, South Platte, Jefferson County.
16	Noga prospect, Buena Vista, Chaffee County.
17	Lucky Beck prospect, Badger Creek, Park County.
18	Zabresky prospect, Howard, Fremont County.
19	New Discovery prospect, Badger Creek, Park County.
20	Allanite schlieren, 3 miles south of South Platte.
21	Lower Surry quarry, Trout Creek Pass, Chaffee County.
22	Jamestown cerite locality, Boulder County.
23	Seerie prospect, Buffalo Creek, Jefferson County.
24	Prospect near Westcreek.
25	May Day lode, Trout Creek Pass, Chaffee County.
26	Floyd Hill, Clear Creek County.
27	St. Peters Dome area, El Paso County.
28	Pegmatite prospect near Livermore, Larimer County.
29	Luella pegmatite, Trout Creek Pass, Chaffee County.
30	Clara May pegmatite, Trout Creek Pass, Chaffee County.
31	Ohlman xenotime prospect, Golden Gate Canyon, Jefferson County.
32	Wellington Lake area, Jefferson County.
33	Black Cloud mine, Divide, Teller County.
34	Branch pegmatite, Lookout Mountain, Jefferson County.
35	Hilburn prospect, St. Peters Dome, El Paso County.
36	West prospect, near Dory Hill, Gilpin County.
37	Hinman mine, Indian Hills, Jefferson County.
38	White Cloud mine, South Platte, Jefferson County.
39	Brown Derby mine, Quartz Creek district, Gunnison County.
40	Powderhorn district, Gunnison County.
41	Wet Mountains area, Custer and Fremont Counties.
42	Mocking Bird claims, Villa Grove, Saguache County.
43	Colorado Feldspar mine, Cotopaxi, Fremont County.
44	Guffey area, Park and Fremont Counties.

Number	Locality
45	Pine Ridge prospect, 7 miles north of Cotopaxi, Fremont County.
46	Crystal Mountain area, Larimer County.
47	Songer prospect, Kittredge, Jefferson County.
48	Lamp prospect, Lookout Mountain, Fremont County.
49	Pegmatites between Centennial Cone and Rosco Dike, Jefferson County.
50	Russel Gulch-Idaho Springs area, Gilpin and Clear Creek Counties.
51	Teller Lode, Park County.
52	Bertha mine, South Platte, Jefferson County.
53	Bergen Park area, Jefferson County.
54	Devil's Head area, Douglas County.
55	Rosalie Peak area, Park County.

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Chapter VII

Thorium

by

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CHAPTER VII

Thorium

by

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Thorium was discovered by Berzelius in 1828 and was named for the mythological Scandinavian god of war, Thor. Economic interest in thorium began in 1884, when Auer von Welsbach patented the incandescent mantle. Gas mantle manufacture remained the predominant use of thorium until the latter part of the 1940's, when undisclosed quantities were put to use in atomic energy programs, but in the latter part of the 1950's it is probable that the use of thorium in alloys became predominant.

The greatest source mineral for thorium the world over has been monazite, which is a phosphate of the light-group rare earth elements and thorium. The United States was a significant producer of monazite from about 1890 through 1910, and began increasing production again in 1948, chiefly from the Carolinas and Florida. In 1953 Idaho accounted for the major domestic supply.

Interest in thorium began to quicken in Colorado in 1949-1950 when the U. S. Geological Survey began investigations for thorium in the Wet Mountain and Powderhorn districts. Colorado thorium ores occur mainly in vein deposits containing thorite (thorium silicate), or varieties grading from ferrothorite (iron-containing) to hydrothorite (hydrated thorite).

Colorado production reached a peak in 1958 under the stimulus of ore purchases by the Marion Mill, operated by the Wah Chang corporation near Boulder. The mill was especially adapted to the problematical ores of this State and provided the mines with a solution to otherwise costly transportation and concentration problems. However, the Marion Mill discontinued operations toward the end of 1958, and as a result practically all mining activities ceased.

The construction of the Rio Tinto Dow Ltd. thorium mill in the Blind River-Algoma area in Canada was a factor that also influenced the thorium market. The production of thorium sulfate and oxide as a by-product of uranium was expected to reach a rate of 100 to 200 tons annually by mid 1959[8]. This rate exceeds the total estimated consumption in the United States for the year 1958.

Despite the slump in Colorado production at the end of 1958, the interest in the ore reserves of this State has not lessened. The Cotter Corporation in the early part of 1960 was planning the construction of a new pilot plant in the Canon City area. The Colorado reserves enjoy an enviable inland

*Senior Project Engineer, American Institute of Research position which will continue to increase in value as industry continues to move westward. Perhaps it will even be a thorium breeder-reactor which will some day supply the necessary power for thorium metal reduction and fabrication in the area.

Uses and Consumption of Thorium

The skyrocketing consumption of thorium following 1953 was due mainly to the development of thorium-magnesium alloys, used as structural members and airframes in missile and aircraft manufacture. These alloys are lightweight and strong, and have exceptional retention of mechanical properties at elevated temperatures. Other non-energy uses are gas mantle manufacture, as a catalyst in the petroleum and chemical industries, as a constituent of lamp filaments, electrodes, special optical glass, and polishing compounds. Thorium is also used in certain medical preparations, and as a refractory oxide for high temperature crucibles.

The following table gives the thorium consumption for the various non-energy classifications as used in the United States (lbs. contained ThO_2)[8].

Year	Gas Mantle Manufacture	Magnesium Alloys	Refractories & Polishing	Chemical & Medic.	Elect.	Total
1947	26,658		3,110	1,176	1,283	32,227
1948	36,697		1,634	1,767	427	40,525
1949	44,621		1,847	596	237	47,301
1950	48,471		1,889	2,097	314	52,771
1951	31,132		3,382	6,246	1,457	42,217
1952	25,247		1,157	11,064	277	39,925
1953	8,707	3,600	236	5,179	1,222	18,944
1954	9,765	4,647	24	3,738	2,016	20,190
1955	44,566	23,944	105	3,898	926	73,439
1956*	40,000	50,000	200	4,000	1,000	95,200
1957*	40,000	100,000	----	4,000	1,000	145,000
1958*	40,000	120,000	5,000	6,000	1,000	172,000

*Estimate.

Statistical compilation by the AEC of reports of company purchases and sales of material have been discontinued. Production of thorium is no longer made public because of the limited number of producers[9].

Official data has not yet been released on the consumption of thorium for energy purposes, but it is estimated that 10 tons, chiefly in oxide form, were used in 1958[8]. It was estimated by the AEC that for several years following 1960, the energy demand by domestic and foreign users will be about 10 tons of metal annually[9].

Thorium is a potential source of nuclear fuel, as it can be mutated to a fissionable isotope of uranium (U233) through breeding in a reactor. In 1958, nuclear uses were limited to breeder reactors either as a fuel constituent or as a blanket, and seven experimental and full-scale reactors were being planned or under construction.

Mineralogy and Geology

In the earth's crust, thorium is about as plentiful as lead or molybdenum, and is about three times as plentiful as uranium—which is another reason for the interest in thorium for energy applications. But in spite of the relative abundance of thorium, known economic concentrations are at present limited to a few specific areas.

There are only five minerals that contain thorium as an essential constituent:

Thorianite, ThO_2, series to UO_2.

Thorite, $ThSiO_4$, 81.5 per cent ThO_2, ideal.

Huttonite (dimorph of thorite), 81.5 per cent ThO_2, ideal.

Thorogummite, hydrated thorite, 24-58 per cent ThO_2, var.

Cheralite (Th, Ca, Ce) (PO_4, SiO_4), 30 per cent ThO_2, var.

Until the discovery of thorite-thorogummite ore deposits in Colorado, these minerals were considered rare, and were of little or no economic interest. Varieties and synonyms of the "essential constituent" minerals are the following:

Thorianite—aldanite (high Pb, U); uranothorite (high U).

Thorite or Thorogummite—auerlite (high PO_4); calciothorite (Ca); enalite (U, RE, PO_4?); eucrasite (Ca, RE); ferrothorite, ferrithorite (Fe); freyalite (very high Ce); uranothorite (high U); orangite (orange metamict thorite).

Thorogummite—hyblite (with sulfate?); hydrothorite; mackintoshite (U^4); maitlandite (U^4, Pb); nicolayite.

There are also about 65 other distinct minerals which are frequently reported to contain thorium as a minor constituent. Among these are two that are important ore minerals: monazite and brannerite.

Monazite, (Ce, Y, La, Th)PO_4, is widespread as small accessory grains and crystals in granitic and intermediate rocks. Its concentration in placers has allowed easy mining and separation from co-products the world over. Monazite is also an undetermined potential source of thorium in Colorado placer deposits. The thorium content of monazite ranges from 0 to 30 per cent. Five to six per cent may perhaps be considered average.

Brannerite, (U, Ca, Fe^2, Y, Th)$_3$(Ti, Si)$_5$$O_{16}$, until the development of the Blind River-Algoma deposits, was a commercially unimportant mineral. No important occurrences of this mineral have been reported in Colorado. Thorium content ranges from 0 to 12 per cent ThO_2.

General Relationships

During the crystallization stages of an igneous rock, the relatively large size and the high quadrivalent charge of the thorium ion does not permit its entrance into normal rock minerals, and therefore thorium is usually concentrated in residual solutions as crystallization proceeds. The residual solutions may later give rise to pegmatites and to hydrothermal vein deposits.

Other elements also tend to concentrate in the residual solutions—Zr, the rare earths, and Nb, Ta, Ti, U, Be, as well as others. Dependent upon the relative concentrations of these elements in a given system, a wide variety of complex minerals may result, and frequently a related series of complex minerals may be found in a deposit (refer to chapter on rare earths, by C. V. Haynes). In the presence of divalent calcium and the rare earth elements, especially those of the yttrium group, thorium is captured in magmatic calcium minerals. Thorium replaces elements of the light, or cerium-group rare earths in monazite, and the excess positive charge often causes a partial replacement of pentavalent phosphorus by tetravalent silicon. $ThSiO_4$ is isomorphous with $LaPO_4$, and the thorium is carried in the crystal lattice of monazite as thorite.

Ultimately, the relative concentrations of the "residual" elements are largely governed by the source-rock type. In the world picture, thorium is generally present in greater abundance in pegmatites associated with alkalic rocks.

Of special interest to Colorado are the carbonatite types of thorium occurrence. Carbonatites are carbonate-silicate rocks genetically related to complexes of feldspathoidal or quartz-free intrusive igneous rocks, commonly forming the lower part of the necks of some explosive-type volcanoes and also as cone sheets, dikes, and breccia zones[2]. Mesothermal and epithermal vein deposits may also contain thorium, and in some instances are related to carbonatite deposits.

Because of the insolubility of thorium, no supergene enrichment can take place which involves its transportation in solution. Occasionally, however, hypogene thorium-bearing minerals show enrichment of thorium as a result of the supergene solution and extraction of more soluble constituents. Thorium minerals further resist mechanical abrasion and thus may be transported to new sites of deposition as a result of weathering. They accumulate in the resulting placer deposits because of their density in concentrations much greater than existed in the rocks in which they were originally present. The importance of Colorado thorium-containing placer deposits remains to be determined.

Thorium Deposits In the Wet Mountains

The Wet Mountain thorium province covers an area of about 10 by 25 miles which lies in Custer and Fremont Counties, Colorado, between Canon City and Silver Cliff. The Wet Mountains are an en echelon continuation of the Colorado Front Range. The prevailing bedrock in the province is a pre-Cambrian crystalline complex.

The crystalline complex is composed of products of high-grade metamorphism and is represented by many varieties and gradations of hornblende, plagioclase, pyroxene, and biotite gneisses; associated with other normal metamorphic-mineral constituents such as garnet, sillimanite, etc. Pegmatites, migmatite, and their attendant effects are also widespread.

A nonfoliated, 600 million year old albite stock, covering about three square miles, transects the northeasterly-striking foliation of the crystalline complex. Syenite dikes, many of which are brick red in color, are fairly common and continuous. These are considered to be essentially contemporaneous with early facies of the stock. The syenite dikes are both preceded and postdated by altered, dark colored aphanitic to medium-grained basic dikes which may in part be Tertiary in age. Both the syenite and the basic dikes vary in trend from N50W to S70W.

The prevailing trend of the thorium veins ranges from N30W to N80W. The veins are generally less than 10 feet wide, but a few range up to 50 feet in width; they may be traced on the surface for distances up to a mile.

Outcropping vein material is normally decomposed, friable, and heavily impregnated with yellow, brown, and red oxide minerals. The thorium vein minerals are reddish-brown, resembling thorite, and are variously referred to as ferrothorite, thorite, or hydrothorite. These minerals are irregularly distributed constituents occurring as blebs and veinlets and lens-shaped pods, frequently located at fissure intersections. By 1958, there were some 800 prospects in the province. The largest known thorium-bearing zone has been reported to be about 300 feet long, 26 feet wide, and over 400 feet deep.

The thorium-bearing minerals for the greater part are impure, admixed, and intergrown with hematite, limonite, and other vein materials. Typical vein minerals such as quartz, barite, carbonates, and minor amounts of fluorite, sulfides, manganese and copper stain may or may not be present. Frequently, surface limonite will give way to a greater abundance of carbonate minerals at depth.

The most widespread product of hypogene alteration in the veins and their walls is pink feldspar, which is commonly accompanied by quartz. A somewhat less widespread hypogene alteration may have been dominantly carbonatization. It is possible that the Wet Mountain thorium deposits are also related to a carbonatite type of occurrence.

Thorium Deposits In the Powderhorn District

The Powderhorn district is located in Gunnison County, approximately 10 to 20 miles southwest of Gunnison. The area is about six miles wide and 20 miles long, trending northwestward from the vicinity of Iron Hill to the Lake Fork of the Gunnison River.

The Powderhorn District is underlain chiefly by the pre-Cambrian metamorphic Black Canyon (biotite) Schist, and Dubois Greenstone, and the somewhat younger pre-Cambrian Powderhorn granite. These rocks are cut by foliated amphibolite dikes and by small stocks, dikes, and irregular bodies of a variety of alkalic igneous rocks of pre-Jurassic age. The pre-Cambrian rocks are overlain by flat to gently dipping strata of the Morrison formation (Jurassic) which are in turn overlain unconformably by volcanic rocks of Tertiary age.

The Iron Hill complex is a composite stock that occupies an area of about 12 square miles in the southeastern part of the district. The dominant rock type of the stock is pyroxenite, and the second most abundant rock type is a dolomitic carbonate, which outcrops over an area of about two square miles. Other rocks occurring in the complex include jiolite, uncompahgrite, and quartz gabbro. Associated small igneous intrusive bodies which cut the pre-Cambrian bedrock include diorite, quartz diorite, gabbro, syenite, augite syenite, and shonkinite. These rocks all have common chemical and structural features and probably are genetically related.

The foliation and layers of the pre-Cambrian rocks strike generally from N-S to N45E and dip steeply; they appear to have controlled the emplacement of many dikes and veins.

Three distinct ages of mineralization occur in the Powderhorn district: 1) pre-Cambrian sulfides, 2) minerals containing titanium, rare earths, thorium, columbium, together with iron and manganese oxides, associated with the alkalic rocks, and 3) narrow, discontinuous veins, fissures, and joint fillings containing manganese oxides in the volcanic rocks of Tertiary age.

The thorium deposits of the second group, above, occur in weakly radioactive zones within the carbonate rock, in layered carbonate-rich veins filling fissures in and near the Iron Hill stock; and in mineralized shear zones in pre-Cambrian metamorphic rock.

The shear zones include the most highly radioactive deposits in the district, and range in width from less than a foot to as much as 18 feet. The shear zones may extend in length to several hundred feet; the Little Johnie vein has been traced intermittently for more than 3,500 feet.

The deposits consist of closely spaced veinlets of quartz, iron oxides, alkali feldspar, thorium in the form of thorite or hydrothorite, and other minerals; sometimes including barite or carbonate, and minor amounts of pyrite, galena, and sphalerite.

Other Colorado Thorium Deposits

Vein thorium mineralization occurs also in stringers and lenses in pre-Cambrian rock in the vicinity of St. Peters Dome, El Paso County. Thorium occurrences in pegmatite have also been reported in this area. The mineral is of the ferrothorite type and is very similar in appearance to the Wet Mountain material. An altered zircon is sometimes associated with the thorium mineralization.

Most Colorado rare earth-containing pegmatites also carry some thorium and uranium, but such deposits are of considerably lesser potential than the vein-type occurrences. Placer deposits in various mountain and intermountain valleys may also prove to be a thorium source, most probably on a by-product basis.

Colorado Production

Lake County is reported to have produced somewhat over $3,000 in monazite in 1953. In 1954, uranium and thorium were produced from the Uranium Queen Mine, Durango, La Plata County. In 1957 almost $4,000 was produced from Snyder Gulch in Custer County. Some production was also obtained from the Trail Mines, near Colorado Springs, El Paso County.

The 1958 production of thorium ores in Colorado is reported to have reached 1,008 tons, from approximately 16 properties in five counties*[11].

The Zabel-Beardsley lease in the Hardscrabble District of Custer County, operated by Calico Minerals, led the thorite ore production of the State with 440 tons. Cotter Corporation's Star Claims followed with 332 tons, and the Anna Lee Mine is reported to have supplied 67 tons.

In recent years there has been a considerable increase in the handling of thorium-containing minerals and ores for purposes other than their thorium content. Many pegmatite minerals, notably those containing the yttrium-group rare earth elements, temporarily acquired new importance and were mined chiefly for their rare earth content. The contained thorium, or the thorium minerals associated in the ores, were generally not valued. Whether the thorium content of such materials was eventually extracted and utilized has not been ascertained. There is also a small traffic of thorium containing mineral specimens.

Thorium Ore Prices

In 1957 two thorium mills were operated in Colorado: the Florence Mill at Florence, Fremont County, operated by the Missouri Metal Reduction Co.; and the Marion Mill near Boulder, operated by the Wah Chang Corporation. Only the Marion Mill was in operation during 1958, but discontinued by the end of the year due to high operating costs and transportation costs to east coast markets[11].

Payments for thorite-type *ores* were negotiated between

*Personal communication, representatives of U. S. Bureau of Mines.

buyer and seller[8]; however, some producers quoted prices ranging from 70 cents a pound as contained ThO_2 for ore averaging 2 per cent ThO_2, up to about $1.25 for 10 per cent ore. The price for 10 per cent thorium *concentrate* from thorite ores remained about $1.75 per pound ThO_2 content.

During 1958, the Wah Chang Corporation purchased ore at a base price of $1.06 per pound ThO_2 contained, less a charge of $2.45 per each 1 per cent thoria in the ore, and a $10.00 per ton mill charge. A ton of 5 per cent ore thus had a net value of $83.75*.

Prices on large-tonnage contracts of monazite averaged about $250 per short ton (12½¢/lb.) of concentrate containing 51 per cent total rare earth oxides, including thorium. Nominal quotations in 1958 were as follows:

Per lb., c.i.f. U. S. ports, 55 per cent total rare earth oxides including thorium, massive, 14c;[4]
sand—55% grade—15¢
66% grade—18¢
68% grade—20¢

Thorium Ore Treatment**

On the basis of the thorium ore prices, it might be expected that an arbitrary cut-off value could be established for any given mining property, taking into consideration from the mine operator's point of view the various costs involved, including the cost of transportation of the ore to the mill—which in the past involved perhaps 200 miles of travel. But this is only partially true. Every thorium deposit must be considered a separate problem, because of the variable nature of the Colorado deposits.

Many low-grade ores prove to be amenable to upgrading processes but are of too low a tenor to pay the operator's costs. Other higher-grade ores often cannot be concentrated economically because of treatment costs or poor recovery.

Generally, it is very difficult to up-grade Wet Mountain ores by physical processes such as gravity or flotation. The principal reason is that most ores are finely disseminated in, or admixed with, problematical gangue minerals. Particular problems are: a tendency of the "thorite" to slime; intimate admixture and attachment to limonite and hematite; and admixture with other heavy minerals such as barite. Because of upgrading and recovery problems of this nature, chemical concentration methods were employed by the Wah Chang Corporation.

Ores from the Powderhorn District have not been commercially recovered.

*Personal communication, Hal Miller, Wah Chang Corp.

**Personal communication, representatives of the Wah Chang Corporation, and of the Cotter Corporation.

But chemical processing of some ores is difficult, too. Methods involving leaching and extraction by the use of acid may become prohibitively expensive in the treatment of high-carbonate ores. Fluorite and phosphate minerals may also produce undesirable reactions, as well as some alteration products such as iron and alumina in various forms.

Thus it is apparent that every thorium deposit of the Colorado vein type involves a separate, individual set of problems. The 1958 production of 1,008 tons attests to the fact that such problems can, and have been, overcome. As technology advances, better and cheaper methods of ore treatment will be developed.

It is probable that placer deposits containing heavy minerals with thorium as a constituent will be discovered and mined in Colorado. Normally, placer sands are readily concentrated by gravity methods, and do not present as great a variety of problems as encountered in hard rock deposits. In this country, larger placer operations favor the use of spiral concentrators, which are simpler and require less power than tables. Final cleaning of the concentrate is accomplished with magnetic and electrostatic separators.

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Chapter VIII

Beryllium

by

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CHAPTER VIII

Beryllium

by

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Beryllium is a metal of very desirable properties, able to impart to its alloys characteristics for specific applications which substitutes can only approximate. The potential demand for this element is much greater than the actual consumption due to reluctance on the part of precision machinery designers and many other possible users to specify beryllium or beryllium alloys. This reluctance is a natural consequence of the lack of adequately reliable sources of beryllium in this country, and of its high cost.

Beryl is the principal economic mineral of beryllium. The table given below, of its production, imports, and consumption, reveals the following:

a. The United States is the largest beryllium consumer in the world;
b. the beryl industry in this country is at present of almost inconsequential magnitude;
c. the United States depends substantially on imports for its supply of beryl.

The tonnage figures in the table, obtained from U. S. Bureau of Mines Minerals Yearbook, Vol. 1, 1958, represent short tons of ore containing 10 per cent to 12 per cent BeO.

Production

	1949-53 Ave.	1954	1955	1956	1957	1958
Colorado	93[1]	59[2]	46[3]	163[4]	182[5]	134[6]
U. S. Total	557[7]	669[8]	500[9]	445[10]	521[11]	463[12]
Total Value	$214,545	$303,649	$267,927	$231,126	$275,855	$238,017
World—Tons	6,800	7,700	8,900	12,900	11,900	7,000

U. S. Consumption

	1949-53 Ave.	1954	1955	1956	1957	1958
	2,712	1,948	3,860	4,341	4,309	6,002

U. S. Imports

	1949-53 Ave.	1954	1955	1956	1957	1958
	5,393	5,816	6,037	12,371	7,290	4,599

[1] 16.7% of U. S. production.
[2] 8.3% of U. S. production.
[3] 9.2% of U. S. production.
[4] 36.8% of U. S. production.
[5] 35.0% of U. S. production.
[6] 28.9% of U. S. production.
[7] 20.6% of U. S. consumption.
[8] 34.4% of U. S. consumption.
[9] 13.0% of U. S. consumption.
[10] 10.2% of U. S. consumption.
[11] 12.1% of U. S. consumption.
[12] 7.7% of U. S. consumption.

Beryllium is a grayish to steel-gray metal with a bright, metallic luster and properties somewhat similar to those of aluminum and magnesium. It is a light metal, one-third lighter than aluminum, has considerable stability, and a high melting point, but is quite brittle at ordinary temperatures. Con-

*Geological Consultant, Denver, Colorado.

siderable difficulties are encountered in producing pure beryllium metal.

Currently, the only commercial source of beryllium is the mineral beryl. This mineral occurs in pegmatites and granites, and rarely in other igneous and metamorphic rocks. Pegmatites have accounted for nearly all the beryl produced, but at present some nonpegmatite occurrences are coming into prominence. The important known reserves in commercial deposits are in foreign countries.

Beryllium is utilized largely in alloying, chiefly with copper, and is used in the nuclear field and x-ray equipment. Beryllia, the oxide, also finds uses in the nuclear field, and in high temperature refractories.

Mineralogy

More than 30 minerals contain beryllium as a constituent, but the only important source of beryllium is the mineral beryl, a beryllium-aluminum-silicate, which theoretically can contain as much as 14 per cent BeO.

Beryl occurs in elongated, prismatic, hexagonal crystals which are subhedral to euhedral in form, commonly tapered, and occasionally exhibit vertical striations. It may also be found in columnar, granular, disseminated, or compact masses. It has a greasy, vitreous luster, and can be transparent to translucent to opaque. It has a hardness of 7.5 to 8.0, a specific gravity of 2.63 to 2.80 (normally 2.70), a white streak, a conchoidal or uneven fracture, and is insoluble in acids. Crystals of beryl range from microscopic to several feet in circumference and length, and, in weight, may range from negligible to tens of tons.

Five important varieties of beryl exist, which, when transparent, are valued as gems. These are listed below in the order of their desirability:

Emerald—Precious. Emerald-green to grass-green. Minor variations.

Aquamarine—Semi-precious. Pale-blue to blue to bluish-green to sea-green.

Heliodor—Semi-precious. Also known as yellow or golden beryl. Yellow to golden-yellow to brownish-yellow.

Morganite—Semi-precious. Pale pink to watermelon red.

Common beryl—Only rarely a gem. Colorless, white, pale blue, dull blue, bluish-green, emerald green, green, yellowish-green, greenish-yellow, yellow, light brown, pink, and black.

Specimens of black beryl have been noted from Africa. This mineral is normally translucent, exhibits nice chatoyancy (iridescence), and might be considered a semi-precious gem. Black beryl will occur banded in clear beryl or as rims and centers with green beryl and aquamarines.

Colorless and white beryl is often confused with quartz or feldspar but hardness and luster aid in visual inspection. Fragments of blue-green beryl might be mistaken for feldspar, especially microcline. Since beryl has nearly the identical specific gravity of quartz, it can readily be distinguished from many of the heavier minerals. Beryl is harder than green tourmaline and, also, apatite, which can be scratched with a knife.

Most other beryllium minerals are rare to uncommon. The helvite group, $3BeO_3 \cdot (Mn, Fe, Zn) O_3SiO_2 \cdot (Mn, Fe, Zn) S$, ranks second to beryl in abundance (Norton and others, p. 23) and the individual minerals are distinguished as helvite, danalite, and genthelvite, when they are manganese-rich, iron-rich, or zinc-rich, respectively. Minerals of the helvite group have been noted in the Silverton district, Colorado. They are found in contact metamorphic deposits, chiefly tactites, but are known in some manganese-bearing veins. Helvite may be mistaken for garnet, with which it is a common associate.

Bertrandite, $Be_4Si_2O_7(OH)_2$, and chrysoberyl, $BeAl_2O_4$, have been marketed along with beryl but seldom occur in any quantity. They straddle beryl in hardness, bertrandite generally below quartz, chrysoberyl above topaz. In Colorado, bertrandite occurs in granitic pegmatites and in greisenized areas of the Lake George beryllium district, where the notable Boomer mine is located. Chrysoberyl has been found at the Drew Hill and Ramstetter Ranch prospects and other localities in Jefferson County. Chrysoberyl may exhibit chatoyancy, and certain varieties are considered gem quality.

Several rare earth minerals, such as gadolinite, $Be_2Y_2FeSi_2O_{10}$, contain beryllium. Phenacite, Be_2SiO_4, occurs in high temperature veins. Idocrase (vesuvianite), $Ca_{19}(Al, Mg)_{13}Si_{18}(O, OH, F)_{76}$, contains beryllium as an accessory constituent, where beryllium has replaced magnesium.

The other minerals in which beryllium occurs as an essential constituent are quite rare and have no value, other than collectors' items or as gems.

Properties

The physical properties of beryllium metal cannot be given with certainty because of the difficulties encountered in the preparation of the chemically-pure form: it has a melting point of 2,345° F. and a boiling point of 5,400° F.; a specific gravity of around 1.84 to 1.85 which approaches that of magnesium; its hardness can be compared to that of mild steel; it is three times stronger than steel on a strength-to-weight basis. At ordinary temperatures, beryllium is quite brittle; at temperatures around 750° C. the metal oxidizes noticeably; it combines readily with the halogens. The fact that it is chemically close to aluminum makes a complete separation of the two rather difficult.

Beryllium possesses a low cross-section of thermal neutron absorption and slows down high energy neutrons to thermal speeds, thus saving fuel and increasing the efficiency of nuclear reactors in which it is used as a shield around the core. Also, it has the virtue of being highly permeable to x-rays and, in this respect, it is 17 times more permeable than aluminum.

As an additive to certain metals beryllium forms alloys of vastly enhanced physical and chemical properties, most prominent of these alloys being beryllium-copper.

The oxide, beryllia, is a refractory material of unique properties. Beryllia has a melting point of 4,685° F., strength, purity, hardness, high electrical resistivity, and, unlike most ceramics, high thermal conductivity in the crystalline state, stability at high temperatures, and general thermal chemical inertness. Beryllia has attraction for the nuclear physicist because it possesses a low-neutron cross-section and high moderating ability.

Uses

Some of the uses for beryllium and its oxide have been mentioned or implied from its properties. Alloying, especially with copper, accounts for the major consumption. Other uses, such as: in nuclear reactors as a neutron moderator to slow down neutrons to thermal speeds; in nuclear reactors as a neutron reflector to minimize loss of neutrons from the core; in airplane construction where beryllium's high strength-to-weight ratio is a great advantage; in alloys with zinc, nickel, cobalt, chromium, molybdenum, platinum, iron, gold, magnesium, and combinations of some of these metals, and many others, would be greatly increased were commercial deposits more abundant and the problems of its metallurgy and high cost solved. The same is true of the oxide which has many desirable properties and applications.

Beryllium is therefore in the peculiar position of being in potentially high, but actually extremely cautious, demand. Many applications have been developed for this metal and its oxide, but it cannot be extensively used under the present status of scarcity of commercial beryl deposits, high costs, and as yet undeveloped metallurgy.

Mining and Separation

Most of the domestic beryl has been produced as a by-product or coproduct of mining for mica, feldspar, and lithium minerals from pegmatites. Pegmatites are mined by either open pit or underground methods, depending upon the terrain. The costs of mining are generally high due to the unpredictable nature of pegmatites with their abrupt changes in mineralization and consequent inability of the operator to foretell grade of ore. Selective mining is necessarily recoursed to, and beryl recovery is accomplished by hand-sorting and cobbing. This method entails a substantial loss of beryl, for there is a limit to the minimum size of crystal which can be sorted or cobbed economically. In some foreign countries where cheaper labor is abundant, beryl is extracted profitably by these means. In Colorado there is one notable commercial nonpegmatite beryl operation, the Boomer lode near the town of Lake George, Park County. During 1958, this underground mine was the major beryl producer in the United States. (See Chapter III, Park County, page 240.)

The increased interest in beryllium which developed during the middle 1950's, created a flurry of activity in the pegmatite areas of Colorado, particularly in those where beryl was known to occur. In most such areas, the other commercial pegmatite minerals such as feldspar and mica, were of very minor interest because of the distance of the deposits to ready markets and uneconomical transportation costs. Some attempts were therefore made to mine pegmatites for recovery of their beryl content alone, but none of the operations proved successful. The over-all average beryl content of pegmatites is too low to warrant mining the entire body for recovery of this mineral. Economic exploitation of pegmatites must continue to depend upon the production of a variety of economic minerals, with feldspar and mica, the most abundant, bearing the brunt of the operation. Rare instances to the contrary are mere exceptions. At some future time, the Rocky Mountain West will become sufficiently industrialized to create local markets for increased feldspar and mica production; beryl then will be recovered in quantity as a coproduct. Meantime, beryl production from pegmatites in Colorado will remain of inconsequential importance and greater attention will be devoted to exploration for vein-type occurrences such as the Boomer lode, and other nonpegmatite sources.

Froth flotation methods for concentrating and separating mica, feldspar, and beryl have been developed to an effective degree. This makes it possible to minimize the selectivity of mining a pegmatite by avoiding only the quartz units; everything else could possibly go into the mill. Two factors militate against the immediate use of flotation for the recovery of pegmatite beryl in Colorado, the lack of adequate markets for feldspar and mica, and the exclusion of flotation beryl concentrate from the government's beryl purchasing program. Paragraph (c), Section 4 of the program specifies:

> "Beryl ores acceptable under this program shall be in the form of clean crystals cobbed free of waste."

Geology

Beryl Deposits in Pegmatites

Most of the commercial beryl mined to date has come from pegmatites. Pegmatites are thought to form by deposition in the presence of liquid and mineralizer-rich solutions following the crystallization of the main mass of the parent magma. Occurrences of pegmatite bodies are essentially restricted to regions covered by igneous and/or metamorphic rocks, particularly in younger mountain ranges and in granitic shields in which metamorphic rocks exist.

The composition of pegmatites is closely akin to granite, but, because of extended periods of fluidity and the greater content of hyperfusible constituents, they are coarse-grained, with individual crystals often growing to tens of feet in width and length. The essential minerals are quartz, orthoclase, microcline, plagioclase, and muscovite. Most of the bodies are sodium-rich, and contain minor amounts of accessory minerals, such as biotite, magnetite, garnet, and occasionally black tourmaline. A large percentage of the beryl-rich pegmatites contain lithium minerals.

Many attempts have been made to classify pegmatites on the basis of either genesis or structure or composition, or any combination of these points, but even the most detailed system fails to satisfy all conditions. Pegmatites are best understood after they have been worked out and all the data has been accumulated, but, invariably, the question of genesis remains hypothetical.

Pegmatites may be divided into three main types:

1. *Simple.* Homogeneous, or grossly so. Often composed of essentially one mineral, such as quartz.
2. *Zoned.* Heterogeneous. Minerals arranged in shells or zones, varying from symmetrical to discontinuous, in a concentric fashion around a core. Essential and accessory minerals may be concentrated in economic abundance.
3. *Complex.* Heterogeneous. Similar to zoned type, except that secondary features, such as fracture fillings, or veins, and replacement bodies, have been superimposed upon the original body. Often contain assemblages of rare minerals.

The simple or homogeneous types of pegmatite bodies predominate in Colorado. Thurston (1955, p. 30) notes that 94 per cent of the more than 1,300 pegmatites covered in his report on the Crystal Mountain area can be classed as homogeneous. Although the majority of pegmatites can readily be distinguished, where sufficiently exposed, as to whether they are homogeneous or heterogeneous, many masses are found in various stages of development, grading from simple dikes or sills to simple pegmatites containing occasional clots of minerals, to zoned bodies which may have irregular zones and/or discontinuous cores.

The various zones in the heterogeneous types have been classified by Cameron and others (1949, p. 20) as border zone, wall zone, intermediate zone (or zones), and core. The internally-zoned types of pegmatite bodies often become quite complex and much of the original texture and structure may be destroyed when secondary features are superimposed. According to Sheridan (1957, p. 6), the Peerless pegmatite of Pennington County, South Dakota, has a sequence of 7 zones, 2 replacement units, and 2 types of fracture-filling units.

The size of a pegmatite body may vary from pencil-like proportions to widths up to hundreds of feet and lengths up to thousands of feet. The shape of pegmatites is commonly tabular to lenticular to pipe-like masses but can assume very irregular outlines. The general shape of the mass may be reasonably predicted, even where poorly exposed, since there are normally certain relations between those bodies and the enclosing host rock which will indicate such distinctions as to whether it is concordant (guided by the foliation of the invaded rocks) or discordant (across the foliation), and which will offer clues as to irregularities in size, shape, attitude, and deformation.

Complex pegmatite bodies will usually contain the rarer mineral suites and, almost without exception, the giant-size crystals grow in pegmatites that are internally zoned. Important concentrations of beryl may occur in one or more zones. In the zoned Hyatt pegmatite of the Crystal Mountain district (Thurston, 1955, pp. 73, 81) beryl is found in both the wall and an intermediate zone. The beryl in the wall zone is generally fine-grained and must be recovered by milling. In intermediate zones beryl crystals are seldom disseminated in a consistent or logical manner but are generally localized in shoots or streaks, in either predictable or random fashion, in pod-like masses, in rolls, along areas reflecting changes in strike and dip, and may conceal themselves in isolated positions, such as cupolas, where these features have escaped detection from drilling or where they cannot be predicted from the internal structural knowledge of the pegmatite body.

Variations in position, composition, and properties of beryl are difficult to predict within individual bodies of pegmatite, but certain diagnostic characterstics have been noted by Jahns (1955, p. 1094-95) as follows: "As traced in its occurrence from the walls of a given pegmatite body inward to the center, this mineral (speaking of beryl) characteristically shows progressive changes as follows: increase in content of total alkalies, decrease in content of beryllium, increase in specific gravity and indices of refraction, and maximum changes in habit from irregular anhedral to prismatic, to equant, and thence to tabular parallel to the base."

The known occurrences or deposits of beryl in Colorado are shown on Table 1 and Figure 1. Table 2 contains a summary of the so-called pegmatite districts(?) with an emphasis on beryllium mineralization.

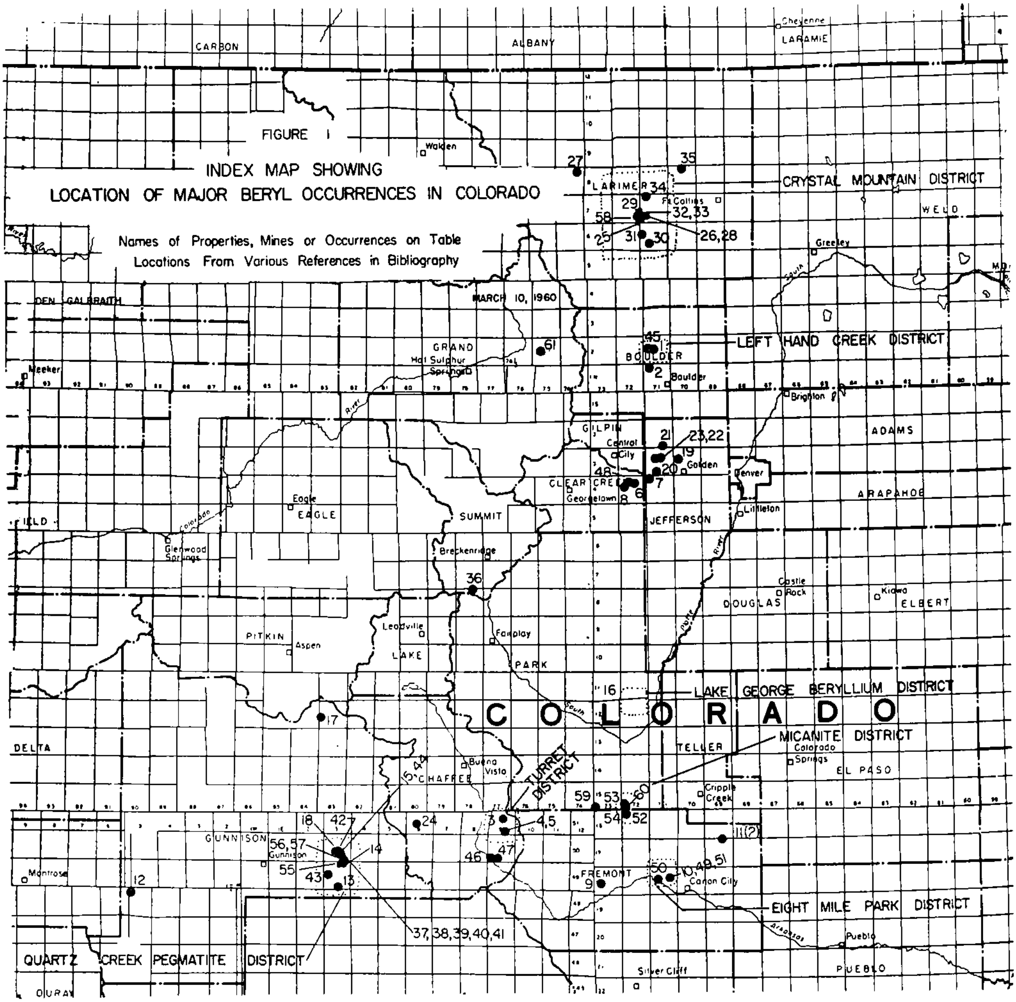

FIGURE 1

See tables of locations, pages 411-412.

Beryllium in Non-Pegmatite Rocks

Beryllium has been found in deposits other than zoned pegmatites but the production has been minor and seldom commercial. Warner and others (1959, pp. 1, 22, 23, 59-61) have shown that, as an accessory constituent in rock minerals, beryllium is more common in feldspathoidal and granitic rocks than other types of igneous rocks, and other than pegmatite deposits beryllium minerals occur in greatest abundance in quartz-tungsten veins and in pyrometasomatic (metamorphic) deposits.

The best example of a non-pegmatitic deposit in the United States is the Boomer mine (see Park County, p. 240) for reference and more complete description) of the Lake George beryllium district. Beryllium is found in replacement deposits of hydrothermal origin, occurring in veins, pipes, and irregular masses which have been localized by fractures and rock contacts. The Boomer mine, which was the leading producer of beryllium in 1958 (Eilerton, 1958, p. 230), is associated with a small stock which has intruded metamorphic rocks. The chief beryllium minerals are beryl and bertrandite.

At the California mine, 2 miles southwest of Mount Antero, Adams (1953) describes a quartz vein in a quartz monzonite stock which contained beryl (some gem quality) and molybdenite. Low-grade berylliferous granite exists in this area.

Areas in other states of the Rocky Mountain region have occurrences of beryllium in contact metamorphic deposits and pneumatolytic veins. These conditions could well exist in Colorado.

Reserves

Production of beryl in Colorado has been small and an estimate of reserves is not much better than an educated guess. U. S. Bureau of Mines statistics (Reno, 1956, p. 97) would give Colorado an estimated 2,500 tons containing 1.0 per cent or more beryl, and approximately 6,100 tons containing about 0.1 per cent beryl. Exploration and mining conducted since 1956 does not indicate that any appreciable alteration of the above figures is warranted.

Problems

The most serious problem facing the beryllium industry is the uncertainty as to future availability of an adequate supply, either in a stockpile or in reasonably certain reserves. This problem could be substantially corrected by a realistic, long-range Government program. Methods for seeking, appraising, and developing new deposits must be found and improved by application of the techniques presently applied to other mineral concentrations or by as yet unanticipated approaches. Such problems as cost of products, effects of toxicity, inefficient methods of mining, and dependency on foreign sources of supply could largely be eliminated with increased technology.

Rising costs of labor looms as an uncertain threat, and Colorado operators are faced with inconsistent and low-demand markets for minerals which are associated with beryl.

Suggestions for Prospecting

At the present time, beryllium exploration in Colorado should be pinpointed at the internally-zoned type of pegmatite body, especially those existing in berylliferous provinces, since metallurgical research has been directed at the handling of beryl ores from pegmatites. As metallurgical concentration becomes a reality in its application to low-grade, fine-grained beryl, non-pegmatitic occurrences of beryllium will increase in interest. Any program should be integrated to include such considerations as: economic studies, regional geologic setting and structure, and mineralogical research, particularly with microscopic and spectographic analyses.

Geophysical and geochemical surveys and trace element studies should be initiated to develop systematic techniques. Ground geophysical surveys might prove useful in detecting hidden or obscure structural zones. Geochemical surveys and trace element studies might isolate certain elements which could prove useful in localizing targets, and, further, the type and quantity of trace elements within partially exposed masses could aid in anticipating concentrations of various minerals within hidden portions of the mass. Warner and others (1959, p. 40) have noted geochemical relations between beryllium and tin, tungsten, fluorine, and other elements, in vein-type and pyrometasomatic deposits. W. R. Griffitts* (personal communication), as well as Norton and others (not dated, p. 28), has observed the wide distribution of bismuth minerals and fluorite in beryl-bearing quartz veins. Detailed mineralogy and spectographic studies may offer other possibilities for indicator elements or minerals.

Certain regions in Colorado appear favorable for further study in the search for non-pegmatitic occurrences of beryllium. The area with the most potential appears to be the greisenized rocks in the vicinity of Lake George in Park County. The fluorite region of the southern Rocky Mountains is another area of interest. Marginal areas should be examined closely as the beryllium emplacement may be situated in a fringe position surrounding fluorite-rich deposits. Pneumatolytic-type deposits merit consideration, since fluorite is often a typical constituent in this type of mineralization. Phenacite or bertrandite are the likely beryllium minerals in pneumatolytic or high-temperature veins.

*U. S. Geological Survey, Denver Federal Center.

Semi-portable beryllium analyzers are now available to assist the prospector. Beryllium is detected by counting neutrons emitted during an alpha bombardment. The detecting device utilizes an isotope of antimony, Sb^{124}, as a source. The half-life of Sb^{124} is about 60 days and the useful period of this supply might reasonably extend from 3 to 4 half-lives. Thus, it will be expensive to maintain the source of the instrument. These analyzers are limited in scope as an exploration tool since (1) the heavy lead shielding necessary to protect the operator makes the instrument cumbersome to handle, even with two men, (2) the instrument must be held very close to the surface, and (3) the source must be kept at a consistent interval above the surface, making it difficult to operate in rough terrain, in order that a correct count is obtained. Beryllium analyzers will probably best serve the prospector in field-checking samples as they give fast results and will report beryllium accurately even though it occurs in the form of an accessory constituent.

Outlook

The outlook for beryllium in Colorado fluctuates from uncertain to optimistic. A study of the pegmatite districts suggests that pegmatites will not account for substantial reserves of beryl. With the anticipated growth of Colorado and the adjacent Rocky Mountain states there is a potential for extended markets for beryl and associated industrial minerals. Metallurgical advances and a long-range program would give the so-called small miner and small companies some incentive to continue active exploration and development programs.

Acknowledgements

The author is indebted to Mr. L. C. Rove, Longyear Company, Mr. W. R. Griffitts, U. S. Geological Survey, Mr. Ernest Wilson, Electronics Laboratory, U. S. Geological Survey, and to many others, including Mr. S. M. del Rio, supervising author of this book, for their time, suggestions, and critical comment.

D. G.

Table 1. Index of Colorado Beryllium Mineral Localities Shown on Figure 1, Page 408

Number	Locality
1	Beryl Lode mine, Left Hand Creek, Boulder County.
2	Beryl Nos. 1 & 2 mine, Sunshine(?) district, Boulder County.
3	Combination mine, Turret, Chaffee County.
4	Mica-Beryl mine, Railroad Gulch, Chaffee County.
5	Rock King prospect, Railroad Gulch, Chaffee County.
6	Brant beryl-topaz prospect (Beaver Brook pegmatite), Clear Creek County.
7	Roscoe beryl prospect, Jefferson County.
8	Santa Fe Mountain beryl prospect, Santa Fe Mountain, Clear Creek County.
9	Devils Hole beryl mine, Micanite district, Fremont County.
10	Mica Lode mine, Eight Mile Park district, Fremont County.
11	Phantom Canyon beryl prospect, Eight Mile Park district, Fremont County
12	Black Canyon beryl prospect, Black Canyon, Fremont County.
13	Brown Derby No. 4 prospect, Quartz Creek district, Gunnison County.
14	Brown Derby Ridge prospect, Quartz Creek district, Gunnison County.
15	Buck Horn prospect, Quartz Creek district, Gunnison County.

Number	Locality
16	Boomer mine, Lake George beryllium district, Park County.
17	Comet prospects, Quartz Creek district, Gunnison County.
18	New Anniversary prospect, Quartz Creek district, Gunnison County.
19	Cresman Gulch prospect, Jefferson County.
20	Centennial Cone beryl-monazite prospect, Jefferson County.
21	Drew Hill prospect, Jefferson County.
22	Ramstetter Ranch prospect, Jefferson County.
23	Robinson Gulch prospect, Jefferson County.
24	California mine, Mount Antero, Chaffee County.
25	Big Boulder prospect, Crystal Mountain district, Larimer County.
26	Buckhorn mica mine, Crystal Mountain district, Larimer County.
27	Chaney-Sims beryl prospects, Crystal Mountain district, Larimer County.
28	Double Opening mine, Crystal Mountain district, Larimer County.
29	Humphrey beryl prospect, Crystal Mountain district, Larimer County.
30	Hyatt pegmatite, Crystal Mountain district, Larimer County.
31	Lewis beryl prospect, Crystal Mountain district, Larimer County.
32	Mica-Beryl prospect, Crystal Mountain district, Larimer County.
33	Tantalum prospect, Crystal Mountain district, Larimer County.
34	Wisdom Ranch mine, Crystal Mountain district, Larimer County.
35	Holden mine, Larimer County.
36	Monte Cristo prospect, Quandary Peak, Summit County.
37	Pegmatite 417, Quartz Creek district, Gunnison County.
38	Brown Derby No. 5, Quartz Creek district, Gunnison County.
39	Pegmatite 537, Quartz Creek district, Gunnison County.
40	Pegmatite 538, Quartz Creek district, Gunnison County.
41	Beryl Claim prospect, Quartz Creek district, Gunnison County.
42	Bucky pegmatite, Quartz Creek district, Gunnison County.
43	Opportunity No. 1 prospect, Quartz Creek district, Gunnison County.
44	New Anniversary prospect, Quartz Creek district, Gunnison County.
45	New Girl prospect, Left Hand Creek district, Boulder County.
46	Combination prospect, Turret district, Chaffee County.
47	Last Chance Spar-Mica Dyke prospect, Turret district, Chaffee County.
48	Grover mine, Beaver Brook Valley, Clear Creek County.
49	Meyer's mine, Eight Mile Park district, Fremont County.
50	School Section mine, Eight Mile Park district, Fremont County.
51	R. H. Magnuson prospect, Eight Mile Park district, Fremont County.
52	Rowe's prospect, Micanite district, Park County.
53	Beryllium Lode prospect, Micanite district, Park County.
54	Lower South mine, Micanite district, Fremont County.
55	Brown Derby mine, Quartz Creek district, Gunnison County.
56	White Spar No. 1 prospect, Quartz Creek district, Gunnison County.
57	White Spar No. 2 prospect, Quartz Creek district, Gunnison County.
58	Crystal Silica mine, Crystal Mountain district, Larimer County.
59	Myer's Ranch mine, Park County.
60	Rose Dawn mine, Micanite district, Park County.
61	Green Ridge and Highlonesome pegmatites, Grand County.

Table 2. Colorado Pegmatite Districts.

The information on the following pegmatite districts is largely after Heinrich (1957), Hanley and others (1950), Landes (1935), and Lovering and Goddard (1950), with some revisions and additions by the author and other authors listed in the bibliography. Beryllium minerals are in bold face for prompt recognition.

1. Crystal Mountain District:

Location—South-central Larimer County. Largely in T. 6 & 7 N., R. 71 & 72 W.

Description of Pegmatites—Related to the Mount Olympus granite, a satellitic intrusive of the Longs Peak batholith, both being a facies of the Silver Plume granite. Majority unzoned. Zoned types well developed. No mappable secondary replacement units. Most pegmatites feldspar-rich, some quartz-rich, few tourmaline-rich.

Dominant Minerals—Perthite, plagioclase, quartz.

Economic Minerals—**Beryl,** scrap mica, perthite, columbite-tantalite.

Major Accessories—**Beryl,** muscovite, black tourmaline, garnet, apatite.

Minor Accessories—Spodumene, uraninite, gummite, metatorbernite, autunite, lithiophilite-triphylite, purpurite, amblygonite, cleavelandite, columbite-tantalite.

Rare Accessories—**Chrysoberyl,** hematite, bismuthinite, sillimanite, biotite, magnetite, molybdenite, rose quartz.

Remarks on Beryl Occurrences—In homogeneous and banded as well as zoned pegmatites. In discordant bodies more commonly than concordant in the Hyatt area. In only minor quantities in quartz-rich or tourmaline-quartz-rich pegmatites. Least abundant in pegmatites immediately adjacent to granite masses. Often occurs in more than one zone, such as wall zone and an intermediate zone. Beryl in wall zone is fine grained.

2. **Left Hand Creek District:**

Location—Central Boulder County; along Left Hand Creek; includes Ward and Gold Hill areas; parts of T. 1 & 2 N., R. 71-73 W.

Description of Pegmatites—Related to Silver Plume and Boulder Creek granites near Gold Hill. Related to Silver Plume granite near Ward. Occur in schist of Idaho Springs formation and Boulder Creek granite. Most bodies are parallel to the foliation of the schist and the platy structure of the granite. Majority of dikes or masses in the granite are marginal, but a few are interior. Mainly concordant and simple; zoning not commonly developed.

Dominant Minerals—Quartz, potash feldspar, plagioclase.

Economic Minerals—**Beryl,** feldspar, scrap mica.

Major Accessories—**Beryl,** muscovite.

Minor Accessories—Garnet, columbite, black tourmaline, biotite, cleavelandite.

Remarks—Poorly developed internal structure of the majority of pegmatites and mineral association doesn't suggest much potential for important quantities of beryl.

3. **Jamestown District:**

Location—Near Jamestown in Boulder County, but mainly to the north; directly north of Left Hand Creek district.

Description of Pegmatites—Related to Silver Plume and Boulder Creek granites, primarily the former. Occur in Silver Plume and Boulder Creek granites and in Idaho Springs formation. Irregular masses in Silver Plume granite are gradational with granite or are well-defined dikes that cut granite, schist and gneiss. Well-defined dikes of Boulder Creek granite association parallel gneissic structure. Minor zoning. Banded textures.

Dominant Minerals—Quartz, potash feldspar, plagioclase.

Economic Minerals—Cerite(?).

Major Accessories—Cerite, epidote, fluorite, allanite, muscovite, black tourmaline (last three are most abundant in pegmatites related to the Boulder Creek granite).

Minor Accessories—Monazite, bastnasite, törnebohnite, uraninite, pyrite, chalcopyrite.

Rare Accessories—**Beryl,** biotite.

Remarks—Not a favorable district for beryl prospecting.

4. **Nederland District:**

Location—Near Nederland, southwestern and south-central Boulder County.

Description of Pegmatites—Related mainly to Boulder Creek granite. Occur in Idaho Springs formation and as marginal bodies in the Boulder Creek batholith. Along west edge of batholith, masses are generally parallel to foliation of gneiss and schist, as well as the Idaho Springs-Boulder Creek contact. Few bodies related to Silver Plume granite, particularly to the north. Zoned and unzoned.

Dominant Minerals—Quartz, potash feldspar, plagioclase.

Economic Minerals—None.

Major Accessories—Muscovite, biotite.

Minor Accessories—Black tourmaline, pyrite, fluorite, molybdenite.

Remarks—No occurrences of beryl noted in the literature.

5. **Granby District:**

Location—Grand County, generally from Frazer to Grand Lake.

Description of Pegmatites—Two age groups; Boulder Creek and Silver Plume granites, the former predominate. Many simple and concordant. Minor zoning. Best zoning found in the bodies related to Silver Plume granite.

Dominant Minerals—Quartz, orthoclase, oligoclase, microcline(?).

Economic Minerals—None.

Major Accessories—Biotite (predominate mica), muscovite, garnet, black tourmaline.

Minor Accessories—**Beryl,** magnetite.

Remarks—A generally unfavorable district for beryl.

6. **Clear Creek District:**

Location—Northwestern Jefferson County, southeastern Gilpin County, northeastern Clear Creek County; generally from Evergreen to Central City.

Description of Pegmatites—To the south, most bodies are related to the Boulder Creek and Pikes Peak granites; to the north, the Boulder Creek and Silver Plume granites. Some pegmatites near Central City and Idaho Springs are genetically related to granite gneiss, are abundant in schist, and are normally parallel to prevailing structure in schist. Also, in the Idaho Springs-Central City area many ore shoots in veins have been localized by walls of pegmatite. Zoned types common. Secondary units known. Many muscovite-rich, numerous tourmaline-rich.

Dominant Minerals—Quartz, albite, microcline, occasionally muscovite.

Economic Minerals—Scrap mica, feldspar, rarely **beryl.**

Major Accessories—**Beryl,** muscovite, biotite, black tourmaline, garnet.

Minor Accessories—**Chrysoberyl,** monazite, apatite, magnetite.

Rare Accessories—**Bertrandite,** columbite, samarskite, molybdenite, topaz, fluorite, rose quartz, amazonstone.

Remarks on Beryl Occurrences—Numerous pegmatites contain minor beryl. Often crystals up to 1,000 pounds have been discovered but an entire pegmatite body may contain only one or two crystals which can be sorted out. Large chrysoberyl crystals have been found associated with the beryl.

7. **South Platte District:**

Location—Essentially from Evergreen in Jefferson County to Dekkers in Douglas County.

Description of Pegmatites—Mainly of Pikes Peak granite age but a few in the north may be genetically related to Silver Plume granite. Mainly homogeneous but many with well-developed zoning. Some are muscovite-rich, few tourmaline-rich.

Dominant Minerals—Quartz, albite, microcline.

Economic Minerals—Feldspar, scrap mica.

Major Accessories—Muscovite, biotite, fluorite(?).

Minor Accessories—Bismuthinite, bismutite, pyrite, black tourmaline.

Rare Accessories—**Beryl,** columbite, monazite.

Remarks—No appreciable beryl has been found.

8. Georgetown-Silver Plume District:

Location—Central Clear Creek County.

Description of Pegmatites—Related to both Boulder Creek and Silver Plume granites, the two being difficult to distinguish between. Occur as dikes and irregular masses, generally quite small. Normally coarse intergrowths of orthoclase or microcline, quartz, and biotite, with or without muscovite. The bodies which contain allanite are generally restricted to rocks of Boulder Creek granite. This group also contains oligoclase more commonly than orthoclase. Mainly homogeneous. Few with good zoning. Good host rock for mineralized solutions or wall rock for localizing ore shoots.

Dominant Minerals—Quartz, orthoclase, oligoclase, albite, microcline.

Economic Minerals—None, excepting base metals.

Major Accessories—Muscovite (occasionally a dominant mineral), biotite, black tourmaline, magnetite, garnet.

Minor Accessories—**Beryl,** apatite, zircon, allanite, hornblende, scapolite.

Rare Accessories—**Bertrandite,** columbite, monazite, corundum.

Remarks—Unfavorable area for beryl.

9. Montezuma District:

Location—Eastern Summit County, western Clear Creek County, northwestern Park County, southern Grand County.

Description of Pegmatites—Three age groups; Silver Plume, Boulder Creek, and Pikes Peak granites, with the first named predominate, the second least predominate. Occur as short dikes and small irregular masses. Mineral composition often quite simple: quartz, orthoclase, microcline, muscovite, and biotite. Geneva Gulch pegmatites more closely related to Pikes Peak granite than to Silver Plume granite, with magnetite, sillimanite, garnet, and tourmaline as conspicuous minerals. Near Montezuma two age groups; Silver Plume and Pikes Peak granites. The Silver Plume group contains considerable biotite and muscovite. Good zoning is uncommon in the Pikes Peak group, but the pegmatites of Silver Plume age commonly display some zoning.

Dominant Minerals—Quartz, orthoclase, oligoclase, microcline, albite.

Economic Minerals—None, excepting base metals.

Major Accessories—Muscovite, biotite, black tourmaline, magnetite, garnet.

Minor Accessories—**Beryl,** apatite, zircon, allanite, hornblende, scapolite.

Rare Accessories—**Bertrandite,** columbite, monazite, corundum.

Remarks—Very minor potential for beryl.

10. Pikes Peak-Florissant District:

Location—Northwestern El Paso County, northern Teller County, southwestern Douglas County, northeastern Park County.

Description of Pegmatites—Related to Pikes Peak granite and are generally interior to the batholith. Small with poor zoning. Commonly contain a central vug with crystals and an outer zone of graphic granite that grades into granite wall rock.

Dominant Minerals—Quartz, orthoclase, microcline.

Economic Minerals—Gem topaz, gem quartz, gem amazonstone.

Major Accessories—Microcline crystals, quartz crystals, topaz, kaolinite.

Minor Accessories—**Phenacite crystals,** fluorite crystals, zircon crystals, biotite, muscovite, cleavelandite, goethite, hematite, limonite, cassiterite crystals.

Rare Accessories—Columbite, allanite, fayalite, rutile, samarskite, xenotime, **danalite**, pyrochlore, bastnasite, **bertrandite,** fluorcerite, cryolite, pachnolite, gearksutite, thomsenolite, ralstonite, galena, elpasolite, prospopite, astrophyllite, arferedsonite, chalcedony, fergusonite, sphalerite, anatase, apatite, sphene.

Remarks on Beryl Occurrences—No beryl reported. Beryllium minerals are in no great quantity.

11. Cripple Creek District:

Location—Southern portion of Pikes Peak batholith in southern Teller County, northeastern Fremont County, western El Paso County.

Description of Pegmatites—Mainly related to Pikes Peak granite but some probably related to Cripple Creek granite, a satellitic facies of the Silver Plume granite. Dikes and irregular masses occur in both granites, those in Pikes Peak commonly following gneissic structure or at right angles to it. Probably both marginal and exterior pegmatites of the batholith. Mainly simple types. Zoning not common.

Dominant Minerals—Quartz, oligoclase, microcline.

Economic Minerals—Feldspar.

Major Accessories—Muscovite.

Minor Accessories—Biotite, apatite, triphite, **beryl,** pyrite, columbite, garnet, magnetite.

Remarks—Beryl quite minor.

12. Guffey-Micanite District:

Location—Northern Fremont County, southeastern Park County.

Description of Pegmatites—May be related to both Cripple Creek and Pikes Peak granites. Zoning common. Some replacement structural units and fracture-controlled muscovite veins.

Dominant Minerals—Quartz, microcline, plagioclase.

Economic Minerals—Feldspar, scrap mica, sheet mica, **beryl,** columbite.

Major Accessories—Muscovite, biotite, **beryl** (some golden but not gem variety), garnet, apatite.

Minor Accessories—Columbite, black tourmaline, iron-manganese phosphates, magnetite, beyerite, bismutite.

Rare Accessories—Sillimanite, cordierite, pinite, monazite, rose quartz.

Remarks—Beryl production has been slight.

13. Eight Mile Park District:

Location—Fremont County, from west of Canon City to Texas Creek.

Description of Pegmatites—Most related to Pikes Peak granite but a few to the north of Cripple Creek granite age. Masses fall into three groups with respect to the batholith: interior, marginal, and exterior. Interior—small tabular bodies in swarms, generally with some zonal arrangement. Marginal—large, flat-flying, sheet-like masses which transect granite flow structure, generally with zonal structure poorly developed. Exterior—occur in schist near batholith contact in tabular or lens-like bodies, generally conformable and concordant, and with well-defined zonal structure, and secondary units strongly developed along footwall contacts of core. Replacement units are common but small. Fracture-controlled replacement bodies of muscovite are conspicuous. Occasionally wall zones characterized by large crystals of microcline with graphic granite.

Dominant Minerals—Quartz, microcline, oligoclase.

Economic Minerals—Feldspar, scrap mica, **beryl,** columbite, rose quartz.

Major Accessories—Muscovite, biotite, black tourmaline, **beryl,** garnet.

Minor Accessories—Apatite, columbite, magnetite, triplite, bismutite, beyerite.

Rare Accessories—Cleavelandite, lepidolite, red and green tourmaline (in bodies which have lepidolite), montebrasite (fremontite), chalcocite, hematite, corundum, dumortierite, sillimanite, zircon.

Remarks on Beryl Occurrences—Beryl generally occurs in an intermediate zone. Fairly good internal structure and good mineral association make this a favorable area for beryl. Columbite or columbite-tantalite may be an indicator mineral. Exterior pegmatites (those occurring in schist or gneiss outside of the batholith) are generally the most favorable for prospecting. Beryl production has been small but in comparison with other districts has been appreciable.

14. Alma District:

Location—West of Alma in northwestern Park County.

Description of Pegmatites—Very little data on these pegmatites. Possibly of Silver Plume age. Commonly associated with aplites. Generally simple dike-like masses with uninteresting mineralogy.

Dominant Minerals—Quartz, potash feldspar, plagioclase.

Economic Minerals—None.

Major Accessories—Muscovite, biotite.

Minor Accessories—**Beryl,** molybdenite.

Remarks—Beryl has been reported in float by many prospectors but the area has little potential.

15. Climax District:

Location—Northeastern Lake County.

Description of Pegmatites—Related to Silver Plume granite. Simple dikes and irregular masses. Mostly unzoned.

Dominant Minerals—Quartz, potash feldspar, plagioclase.

Economic Minerals—None.

Major Accessories—Muscovite.

Minor Accessories—Magnetite, biotite, garnet, black tourmaline(?).

Remarks—Often these pegmatites are simple quartz bodies. Very limited potential.

16. Cotopaxi District:

Location—Western Fremont County, running generally north to the Park County line.

Description of Pegmatites—Related to Pikes Peak granite and occurring in that granite. Interior and marginal bodies. Zoning uncommon and poorly developed. Small secondary vugs occasionally present.

Dominant Minerals—Quartz, potash feldspar, plagioclase.

Economic Minerals—Feldspar.

Major Accessories—Biotite, magnetite, fluorite, muscovite.

Minor Accessories—Apatite, monazite, allanite, garnet, bismutite.

Rare Accessories—Hornblende, epidote, chlorite, calcite.

Remarks—Poorly developed pegmatites and no occurrence of beryl or beryllium minerals noted.

17. Turret District:

Location—Southeastern Chaffee County, around Turret.

Description of Pegmatites—Related to Pikes Peak granite. Occur in granite and occasionally hornblende gneiss. Mainly unzoned. Zoning very poorly developed.

Dominant Minerals—Quartz, potash feldspar, plagioclase.

Economic Minerals—Feldspar (plus sodic plagioclase).

Major Accessories—Muscovite, **beryl**, garnet.

Minor Accessories—Biotite, apatite, columbite, quartz crystals.

Rare Accessories—Allanite, magnetite.

Remarks on Beryl Occurrences—A generally unfavorable district.

18. Trout Creek District:

Location—Eastern Chaffee County, around Trout Creek.

Description of Pegmatites—Related to Pikes Peak(?) granite. Occur in granite. Sediments encroach on east and west sides of the district. Mainly simple. Zoning poorly developed.

Dominant Minerals—Quartz, potash feldspar, plagioclase.

Economic Minerals—Feldspar, euxenite(?).

Major Accessories—Biotite, magnetite, fluorite, muscovite, euxenite, ilmenite, specular hematite.

Minor Accessories—Apatite, monazite, **gadolinite**, allanite, garnet, bismutite.

Rare Accessories—Hornblende, epidote, chlorite, calcite.

Remarks—Gadolinite is the only mineral present which might contain beryllium. Generally unfavorable district.

19. Mount Antero District:

Location—South-central Chaffee County, around Mount Antero.

Description of Pegmatites—Early Tertiary age. Related to the Princeton batholith. Associated with quartz veins of similar mineralogy. Small bodies in granite with outer zones of graphic granite. Occasional central, crystal-filled vugs. Small lensoid bodies with gradational contacts with granite. Rarely over a few feet long. Poorly zoned.

Dominant Minerals—Quartz, microcline, albite.

Economic Minerals—**Gem beryl (aquamarines)**.

Major Accessories—Quartz crystals, microcline crystals, fluorite crystals, **phenacite crystals, beryl crystals,** muscovite.

Minor Accessories—**Bertrandite crystals**, garnet crystals, albite crystals.

Rare Accessories—Topaz, molybdenite, ferrimolybdite, magnetite, native sulfur, calcite, tourmaline, biotite, apatite, columbite(?).

Remarks on Beryl Occurrences—Considerable of the beryl in this district is non-pegmatitic, primarily in the associated quartz veins. Berylliferous granite occurs in this area.

20. Quartz Creek District:

Location—Southeastern Gunnison County, around Quartz Creek.

Description of Pegmatites—About 14 percent zoned. Zonal structure not well defined. Many without intermediate zones. Zoned bodies usually contain a large wall zone and small discontinuous cores. Often the zonal structure may be cut by fracture fillings and replacement bodies, the latter not mappable. Many banded pegmatites. Plagioclase (albite) is the dominant mineral in many. Many bodies lithium-rich.

Dominant Minerals—Albite, perthite, quartz.

Economic Minerals—**Beryl,** lepidolite, microlite, topaz, feldspar.

Major Accessories—**Beryl,** muscovite, garnet, magnetite, biotite (see lepidolite below).

Minor Accessories—Black tourmaline (also dark green, light green, blue, pink, in lepidolite-bearing pegmatites), columbite-tantalite, monazite, lepidolite (ranges from a trace to 95 percent by volume of individual pegmatite unit), microlite, chlorite, topaz, gahnite, samarskite, epidote, apatite, fluorite.

Rare Accessories—Spodumene, amblygonite, allanite, lithiophilite-triphylite, betafite, chrysocolla.

Remarks on Beryl Occurrences—Beryl is irregularly distributed and occurs in clusters, or groups of crystals. It is associated with albite, cleavelandite, quartz, perthite, muscovite, garnet, lepidolite, tourmaline, topaz, microlite, tantalite, monazite, gahnite, and biotite, but is not restricted in its associations. Most bodies with cleavelandite also contain lepidolite. Possible significant association between beryl and lepidolite, as well as beryl and cleavelandite. Beryl most common in albite-rich pegmatities, but is fine-grained. It is less common in perthite-rich bodies but can be hand-sorted in cleavelandite-rich bodies. Beryl does not occur in graphic-granite pegmatites. Granite and quartz monzonite are unfavorable host rocks for beryl-bearing pegmatites. Beryl-bearing pegmatites occur most abundantly in hornblende gneiss.

21. Gunnison River District:

Location—Along the Gunnison River and its tributaries. Western Gunnison County and eastern Montrose County.

Description of Pegmatites—Simple dikes and irregular masses. Mostly unzoned. Zoned bodies have poor internal structure.

Dominant Minerals—Quartz, potash feldspar, plagioclase.

Economic Minerals—Feldspar.

Major Accessories—Muscovite, garnet, biotite, black tourmaline.

Minor Accessories—**Beryl,** magnetite, pyrite.

Rare Accessories—Hornblende, sphene, specular hematite, molybdenite.

Remarks—Pegmatites with poor internal zoning and uninteresting mineralogy. Generally an unfavorable district for prospecting.

22. Monarch Pass District:

Location—Along line between Fremont and Gunnison Counties.

Description of Pegmatites—Those in granite generally homogeneous. The bodies in schist and gneiss to the southeast and east show poorly developed zoning.

Dominant Minerals—Quartz, microcline, albite(?).

Economic Minerals—None. Feldspar a possibility.

Major Accessories—Muscovite, biotite, black tourmaline.

Minor Accessories—Garnet, magnetite, apatite.

Remarks—Very minor data on this district.

Summary of Colorado Pegmatites

The pegmatites of the known districts listed in Colorado are granitic in composition although there are a few exceptions. Thus, they contain the essential minerals quartz, feldspar, and muscovite. Some simple types may be composed essentially of one mineral, as quartz pegmatite. In many districts, feldspar is the dominant mineral, generally microcline or perthite, occasionally orthoclase. In the Quartz Creek district plagioclase is the dominant mineral in many bodies. Albite and oligoclase are the most common plagioclase minerals. The usual accessories are: muscovite, biotite, magnetite, apatite, garnet, and black tourmaline.

The age of the pegmatites along the Front Range and in outlying districts is pre-Cambrian, except for early Tertiary pegmatites in the Mount Antero district.

Pegmatites are related to each of the three major types and ages of pre-Cambrian granite: Boulder Creek, Pikes Peak, and Silver Plume. Some of the characteristics of the pegmatites of these age groups are summarized below:

Boulder Creek Pegmatites—Usually parallel gneissic and platy granite structure. May have oligoclase in excess of orthoclase or microcline. Internal structure not well developed. Allanite is a common accessory mineral.

Pikes Peak Pegmatites—Probably the greatest number. Often contain microcline in excess of oligoclase or albite. Occasionally zoned but not well developed and often discontinuous. Sillimanite may be an accessory.

Silver Plume Pegmatites—Often simpler in mineral composition than the two above. Often cut across host-rock structure. Orthoclase and microcline are more abundant than quartz in some areas. May contain feldspar in excess of quartz or plagioclase. Perthite may be the dominant mineral. Muscovite, biotite, and magnetite are often abundant accessories. Generally better zoning in this age group.

Summary of Beryl Occurrences in Colorado

Most all commercial pegmatites have been the internally-zones or complex types. Pegmatites which display well-developed internal structure and an economic concentration of minerals are most commonly found in metamorphic rocks, away from or near the contact of granite batholiths. Almost all commercial beryl, columbite-tantalite, and mica deposits have been found in pegmatites hosted by metamorphics.

Beryl is commonly associated with many minerals but often is not restricted to any definite group. Beryl-rich pegmatites often contain lithium minerals and this generalization holds true for many areas throughout the United States. Beryl occurs with albite, muscovite, and quartz, but in certain cases prefers microcline to albite. In lithia-bearing pegmatites, beryl is normally found with lepidolite, cleavelandite (a variety of albite), and quartz. Disregarding the common accessory minerals, beryl most commonly appears with columbite, or columbite-tantalite. After columbite, the most insistent associates of beryl are molybdenite and bismuth minerals (bismuthinite, bismutite, beyerite). Fluorite is noted in some beryl-bearing pegmatites, but not in others. When fluorite is an accessory, the beryllium minerals are normally phenacite and bertrandite.

Thus, in Colorado pegmatites, beryl is most commonly associated with albite, muscovite, quartz, microcline, lithium-bearing minerals, cleavelandite, columbite, molybdenite, and certain bismuth minerals.

The most productive pegmatite districts in Colorado (excluding the Lake George beryllium district) have been the Crystal Mountain, Eight Mile Park, Micanite, and Quartz Creek districts, along with certain areas in Jefferson County.

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Chapter IX

Minerals Processing

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Mineral processing is to mining what mining is to an ore deposit. An ore deposit in the ground is useless; it must be mined to be useful. Likewise, most of the non-nuclear ore mined in Colorado is useless, in an economic sense, as it comes out of the ground; it must be concentrated and separated to be prepared for usefulness. Mineral processing is therefore an inseparable part of the mining industry in Colorado which could not have developed without the application of effective means of concentrating and separating the minerals.

Following the trends in industrial developments taking place in the world in general, the emphasis in mining has had to shift periodically from the predominance of one metal or mineral to another. In the earliest days of Colorado mining, the emphasis was on the precious metals, first gold, and later silver. Then came the development of treatment plants and the interest in lead, zinc, and copper. Later, in the nineteen-twenties and thirties, the production of radium and vanadium flourished. Later yet, due to the delineation of a large body of molybdenum ore at Climax whose vast proportions justified intensive research into the metal's properties and uses, the production of molybdenum concentrate became of primary importance to the State's economy during the late thirties, World War II, and to the present. More recently, since the late forties, the mining and concentration of uranium ores has come into prominence following the development of nuclear energy.

The demands of general industrial development, of increasing population, of the advent of the jet, rocket, and space age, of the progressive use of nuclear energy in military and in a multitude of peaceful fields; all these are resulting in an increased consumption of many metals, including some heretofore little used ones. Colorado has the resources to enable it to contribute to the supply of many of these metals.

World economic conditions, greatly expanded production facilities resulting in overproduction, and competition of imported minerals and nonferrous metals and ores (especially fluorspar, tungsten, lead, zinc, and copper) have had a depressing effect on the production of these commodities. Gold mining, too, because of inflationary conditions which raise its cost of production beyond its 25-year-old pegged price, has never really recovered from the shutdown of the mines during World War II. On the other hand, present day emphasis is in

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the less known and more glamorous metals such as uranium, molybdenum, beryllium, columbium, tantalum, thorium, tungsten, lithium, and others, many of which occur within the State's boundaries. The Climax mine, for example, is the largest producer of molybdenum in the world and, as by-products, recovers appreciable quantities of tungsten and small amounts of tin.

Development of Mineral Processing

The evolution of milling and mineral dressing plants in Colorado progressed gradually from the early miner's gold pan, rocker, arrastra, stampmill, etc., to the present highly specialized gravity separation, froth-flotation, and hydrometallurgical plants.

The early prospectors were primarily interested in gold to be found in the sands and gravels of mountain streams, and their principal tools, both for prospecting and for gold recovery, were the gold pan and small handrockers. As large deposits were discovered in localities where sufficient water was available, sluice boxes and wooden-riffled launders were installed and flume lines and ditches built to carry the water to the workings. In some areas these devices were followed by large land and floating dredges, some of which are operative to this day, but none of which operated during 1958.

Here and there in scattered localities, the search for placer gold, as well as the exhaustion of some of the deposits, led to the discovery of ore in place and thus began the era of lode mining. In a few places, particularly in the vicinity of Leadville, mining of the rich oxidized lead ores resulted in the building of numerous small lead-smelting plants. Charcoal from native timber was the prevailing fuel and, to this day, remnants of the early beehive charcoal ovens, as well as slag dumps of the smelters, still remain in some of those areas. The high cost of operation attending these smelter units and the exhaustion of the rich oxidized surficial deposits of lead minerals were the primary causes for the rather temporary existence of these small smelting operations. A few of the larger smelters which were more strategically located survived for a period of time, notably the one at Denver, and others at Pueblo, Salida, Durango, and Leadville. Today, the only surviving nonferrous smelter in Colorado is the Arkansas Valley Smelter at Leadville. Another, but specialized reducing operation in the State, limits itself to the manufacture of electrolytic cadmium from flue dusts and residues originating at various other smelters and shipped into Denver for treatment at this plant, the old Globe smelter of the American Smelting and Refining Company.

At the beginning of the lode mining period, the majority of the mills used stamps and amalgamation as the principal means for recovering the gold content; ores which were amenable to this process were called free-milling ores. When the shallow, oxidized, enriched portions of the ore bodies were exhausted and the unaltered sulfides were encountered, this type of treatment failed to recover the values, and losses as great as 75 percent were experienced. Also, most of the non-ferrous metallic ores of Colorado are of the complex sulfide type, and other methods of concentration, such as jigs, vanners, and shaking tables, began to replace or supplement amalgamation in the recovery processes for the heavy sulfide minerals. The Wilfley shaking table, invented by A. R. Wilfley at Kokomo, Colorado, at the turn of the century, contributed a great deal to the improved concentration and separation of the complex sulfide ores. Many of the complex ores require comminution to minus 65, and some to minus 200 mesh before liberation of the mineral particles from the gangue is accomplished. This fine material plus the much finer "slimes" created as the result of such fine grinding, cannot be properly handled in jigs or shaking tables. Another consideration is that gravity methods fail to make a clean separation of the zinc minerals, sphalerite and marmatite, from galena, the lead sulfide.

Fortunately, just prior to 1920, a revolutionary process was introduced into Colorado which has proven to be one of the most progressive accomplishments in the field of mineral beneficiation, froth flotation. To this process Colorado's base-metal mining industry owes its continued existence. Today, by careful selection of flotation reagents, proper control of acidity in the pulp, and control of other variables, the different minerals in a complex sulfide ore can be separated into individual concentrates. A complex sulfide ore may contain pyrite, galena, marmatite, and chalcopyrite, plus minor quantities of gold and silver; from it, through the application of froth flotation, may be produced a lead concentrate which will usually contain most of the gold and silver values, a zinc concentrate, a copper concentrate, and a siliceous waste (tailings).

The cyanidation process for extracting gold from its ores was introduced in the early nineteen hundreds and is still in successful use today, with some improvements. Ores of low sulfide content prove quite amenable to cyanidation. The gold in these ores occurs primarily as tellurides and must first be roasted to drive off the tellurium, thus freeing the gold to make it leachable by cyanide.

Uranium metallurgy has developed considerably during the last decade or so. Uranium and vanadium ores are not generally amenable to upgrading by conventional ore dressing methods, and are treated directly by hydrometallurgical means for extraction of their metallic content. The vanadium ores are generally roasted with salt, or some other sodium compound, and the resulting calcines are leached with water. Uranium ore treatment involves leaching with acid (sulphuric generally), or alkaline (sodium carbonate), and extraction of the values from solution is accomplished by chemical means, and, more recently, by ion exchange or solvent extraction methods, with the subsequent precipitation of the uranium as an oxide; the form in which, as "yellow cake," it is sold to the Atomic Energy Commission.

Typical Mineral Processes

The mineral treatment processes being used in Colorado are discussed briefly below as applied by typical operations.

Molybdenum

The Climax Molybdenum Company's mine near Fremont Pass, at Climax, Colorado, is the largest underground mine in the world today. In conjunction with this vast ore-producing operation, the company has installed a 34,000 ton per-day mill on location which far exceeds any other milling operation in the State. This mill, treating ore containing approximately one-half percent molybdenite (molybdenum sulfide), is an outstanding example of modern large-scale milling practice, and serves to illustrate the economic feasibility of recovering minerals present in only minor amounts in the original rock. Besides molybdenite, the ore contains small quantities of pyrite, wolframite (tungsten mineral), and cassiterite (tin mineral).

At the mill, the mine ore undergoes a series of crushing stages, grinding, and sizing in order to reduce it to proper fineness for liberation of values and treatment by froth flotation. The molybdenite is recovered as a relatively pure concentrate in the form of filter cake which is dried, barreled, and shipped east for further treatment and production of metallic molybdenum and molybdenum compounds.

The tailings from the molybdenum flotation are treated in the byproducts plant where Humphrey Spirals (gravity concentration devices) separate the remaining heavy minerals from the worthless gangue. The resulting bulk gravity concentrate is then treated by froth flotation, tabling, and magnetic separation and the three byproduct minerals, pyrite, cassiterite, and wolframite are thus separated into salable products.

Gold

The ores from the Cripple Creek district, and those from a small area in the foothills northwest of Boulder, differ from the ordinary type of complex sulfide ores found in other Colorado mining areas. The values in these ores consist chiefly of gold tellurides and contain only minor amounts of sulfides. The Carlton mill of the Golden Cyle Corporation at Cripple Creek is the only mill operating at present in the State which treats this type of ore. This mill was placed in operation in 1950, and incorporates the most modern improvements for processing this type of ore. It is a custom mill and serves the entire Cripple Creek district.

Briefly described, the process at Golden Cycle consists of crushing, grinding, and sizing the ore to liberation and flotation fineness, then making a froth flotation separation of the tellurides and pyrite contained in the ore, which results in a relatively high-grade bulk concentrate carrying the major amounts of these minerals. The concentrate is then roasted in a Fluo-Solids reactor in order to drive off the tellurium and sulphur and to free the gold. The resulting calcines are then quenched and cyanided in a separate circuit to leach out the gold, and the latter precipitated from this solution by means of zinc dust.

The tailings from the froth flotation separation, which contain some gold values, are sent through the "low-grade" circuit where they are subjected to cyanidation by a weak solution, and to the unique activated-charcoal absorption process. The activated charcoal is introduced into the weak cyanide circuit and extracts the gold from solution almost as fast as it enters it. The "loaded" charcoal is then screened out of the pulp and its gold load leached out in the "desorber" by a concentrated cyanide solution. This gold-pregnant solution goes to electrolytic tanks where the gold is precipitated. After this step, the gold from both the primary and the secondary circuits come together in the melting furnaces where it is melted with suitable fluxes, fire-refined, cast into ingots, and sold to the United States Mint.

Complex Sulfides

The most prevalent type of nonferrous metallic ores which occur in Colorado is composed of a mixture of base-metal sulfides containing minor amounts of gold and silver. The predominant sulfide minerals are pyrite, galena, marmatite, and chalcopyrite. These minerals occur in different proportions in the ores of different localities, although, generally, the lead and zinc minerals predominate. The pyrite may or may not carry gold and silver in sufficient quantities to warrant recovery and, if barren, may either be discarded or, in rare cases, used to manufacture sulphuric acid. If the pyrite is present in minor amounts but contains some gold and silver values, it is recovered along with the galena, which is the mineral which usually carries most of the precious-metal values in the ore.

Although in some areas copper minerals are sufficiently abundant in the complex ores to be of economic consideration, the majority of the mills are primarily concerned with the recovery of lead and zinc minerals. Two typical Colorado mills which treat complex sulfide ores are discussed briefly below.

Empire Zinc Mill—The 1,250-ton per-day mill, situated at Gilman, Colorado, and contained entirely underground, is the largest producer of zinc concentrates in the State. The ore fed to the mill carries pyrite, marmatite, galena, and some copper minerals, chiefly chalcopyrite, as well as minor values in gold and silver.

The ore is conventionally crushed, ground to flotation fineness, and treated by selective flotation. In the first step, the galena and the chalcopyrite are floated while the pyrite and marmatite remain depressed. The resulting galena-chalcopyrite concentrate, which carries the precious-metal values, is then collected in thickeners, filtered, and shipped to the smelter at Leadville. The tails from the galena-chalcopyrite float, containing the pyrite and marmatite, are sent to another flotation circuit where the marmatite is reactivated and floated while the pyrite remains depressed. The marmatite concentrate is then thickened, filtered, dried, and shipped to an Illinois smelter. The pyrite is discarded along with the tails from the zinc flotation.

Pandora Mill—This 1,800-ton per-day mill of the Idarado Mining Company near Telluride, Colorado, treats ores mainly from the Black Bear vein with minor quantities from other veins. The ore contains galena, pyrite, marmatite, chalcopyrite, and carries some values in gold and silver.

The process at Pandora is quite similar to that used at Gilman, but the ore contains a greater concentration of chalcopyrite than Gilman's, enough to justify the making of a separate copper concentrate. This requires an extra flotation step in which, after the galena-chalcopyrite concentrate is made, the galena is floated while the chalcopyrite remains depressed. The tails from this step comprise the copper concentrate which is shipped to the El Paso smelter. The zinc concentrate is sent to the Texas Zinc smelter at Amarillo, and the lead concentrate goes to the smelter at Leadville.

Uranium and Vanadium

Up to the middle forties, vanadium was the principal element sought in the sedimentary ores of the Colorado Plateau. Since then, uranium has superseded vanadium as the objective and at present most of the vanadium output results as a byproduct of the uranium production from Colorado Plateau ores. There are other sources of uranium ores in Colorado which do not contain vanadium, such as the "primary" ores from some areas of the Front Range.

Because of emergency ore-purchasing conditions and the circumstance that uranium and vanadium ores are not as a rule amenable to upgrading by conventional ore beneficiation methods, specialized hydrometallurgical processes are used.

Ores which contain both uranium and vanadium are first roasted with a sodium salt to produce a soluble vanadium compound which is leached out with water. After separation from the uranium-containing solids, the vanadium water solution is adjusted to a proper pH, at which point the vanadium precipitates out in the form of sodium hexavanadate. In some processes which use ammonia as a precipitant, the result is an ammonium vanadate. In either case, the precipitate is separated by filtration, dried, and fused. When the product is ammonium vanadate, the ammonia is driven off during the fusing operation, and this results in a higher grade vanadium product. The fused material is poured out onto cooling plates where it forms thin, brittle slabs which break up easily into small chunks and grains upon removal from the cooling plates. This granular material is then packaged and shipped.

The uranium, which remained in the solids after separation from the vanadium water solution, is leached out by an acid solution from which it is in turn extracted through the ion exchange, or solvent process. The uranium is then stripped from the resins used in ion exchange, or from the organic solvent used in solvent extraction, and again obtained in a purified and more concentrated aqueous solution from which it is finally precipitated in the form of yellow cake.

Recently, several uranium extraction plants using alkaline (sodium carbonate) leaching instead of acid, have been placed in operation. The alkaline process is particularly applicable to ores which contain too much acid-consuming lime (in excess of seven percent). Precipitation is accomplished after removal of carbon dioxide, by control of the alkalinity. The sodium diurinate, yellow cake, obtained is filtered, dried, and shipped to the Atomic Energy Commission.

A summary description of the process used in a typical modern mill is given below.

Gunnison Mining Company Mill—This 400-ton per-day mill near the town of Gunnison, Colorado, is typical of a modern uranium extraction plant using acid leaching and solvent extraction.

Feed for this mill consists mainly of ores containing primary uranium minerals, pitchblende and its derivatives. The ore is crushed, ground to proper fineness, and treated with a sulphuric acid leach in agitator tanks. The acid solution, which then contains approximately 0.8 gram of uranium per liter, is separated from the remaining solids in classifiers and thickeners, and thoroughly mixed in stages with Di(2 ethylhexyl) phosphoric acid and iso decanol dispersed in kerosene. This organic solvent extracts the uranium from the aqueous (acid) solution, thereby purifying it, for many of the impurities dissolved in the acid solution are not transferable to the organic solvent. This step is also one of concentration, for the uranium is transferred from the large volume of the aqueous solution (0.8-gram U308/liter) to the much smaller one of the organic solvent (5-grams U308/liter); in some instances, a concentration ratio of as much as 10 to 1 may be achieved by the solvent extraction step.

After transfer of the uranium from the aqueous to the organic phase has been accomplished, the uranium is transferred back into an alkaline solution from which it may be easily precipitated. This "stripping" operation is performed by agitating the uranium-laden organic solvent together with a strong carbonate solution. Here again, an additional concentration of the uranium content takes place. The stripping solution now contains 40 grams U308 per liter as against 5 grams for the organic solvent, and 0.8 gram in the original acid leach. After separation of the two phases, precipitation of the uranium is accomplished in agitator tanks through the addition of sulphuric acid, expulsion of the carbon dioxide formed (uranium will not precipitate quantitatively in the presence of CO_2), and the addition of magnesium dioxide. The precipitate is then filtered, heat-dried, crushed, and packaged into 55-gallon drums ready for shipment.

Tungsten

Tungsten, in the form of wolframite—$(Fe, Mn)WO_4$—is produced by Climax Molybdenum Company as a byproduct of its molybdenum ore treatment. Recovery of this product by Climax has been discussed on a previous page under Molybdenum.

An important tungsten-producing area in Colorado is the Boulder tungsten mining district in Boulder County, where the principal mineral is ferberite, an iron tungstate. The ore occurs in narrow veins commonly composed of fine-grained quartz locally known as "horn" which carries varying amounts of ferberite.

The horn-quartz is extremely hard, and the ferberite is present as a coating—almost a stain—on crack surfaces and within the horn. These conditions present an extremely difficult milling problem, and in many instances physical liberation or separation of the tungsten content from the rock is impossible.

In the Boulder area concentration is performed by gravity processes only. Shaking tables are used, as well as a variety of slimes-catching devices such as vanners, round tables, blanket tables, and cloth-covered sluice boxes.

At this writing (1959), there is no tungsten production per se in the State of Colorado due to the depressed condition of the market and competition from cheaper foreign imports. The history of the Boulder tungsten district indicates that it has prospered only during periods of national emergency, such as the two world wars, when tungsten was scarce and in exceptionally urgent demand.

Mineral Processing Research and Testing Facilities

Ore dressing methods are based on economically proved processes and equipment. Because of variations in the composition of ores from locality to locality, mine to mine, and even within the same vein, a method which may work successfully on a given ore, may require modification for successful application to another ore, even though the latter may be of the same general metallic type as the former.

The mining districts of Colorado are dotted with idle mills designed by individuals with a generalized knowledge of milling who based their designs upon experience gained elsewhere with similar ore types. In most instances the mills failed because of economic conditions or lack of ore, but in some others they failed because the mills were not specifically designed to treat the particular ores they were meant to handle.

Installation of an ore dressing plant represents a major financial undertaking deserving of every prior assurance for its success. Aside from the all-important considerations of availability of sufficient ore reserves accessible to the mill, and of an adequate market for the products, the selection of the process best adapted to the ore, and proper design of the mill for efficient accomplishment of its purpose, are of vital importance. Certainly the expenditure of a few hundred, or even a few thousand, dollars to assure the best possible recovery of values and grade of concentrate from the ore to be treated, is not only justified but must be considered an indispensable part of the total cost of the installation.

We are fortunate to have in Colorado a number of excellent research and testing facilities for minerals beneficiation and extractive metallurgy. Foremost of these is the internationally known Colorado School of Mines Research Foundation, Inc., located at Golden. This institution is a Colorado nonprofit corporation employing a large staff of competent mineral research engineers. Ore concentration and metal extraction projects and studies at the Research Foundation have included a large variety of metallic ores as well as industrial minerals and represent problems arising in many parts of the world. Many other facilities for research in chemistry, physics, mining, fuels, explosives, and other activities related to the mineral industries are available at the Research Foundation, as well as a variety of equipment for various sizes and types of pilot plants.

Beside the foregoing facilities at Golden, several of the larger mining companies maintain private research laboratories and pilot plants. Climax Molybdenum Company, and the mining division of Kerr-McGee Oil Industries maintain such establishments near Golden. Union Carbide Nuclear Company has an excellent laboratory near Grand Junction. Denver Equipment Company maintains an excellent ore testing service in Denver in connection with mill design problems and the sale of its mineral dressing equipment.

Denver is the center of an important mining and milling machinery manufacturing industry which has served mining in Colorado and the entire Rocky Mountain area since the early days of mining in the State. Machinery of this type made in Colorado is known and used throughout the world.

Marketing of Concentrates

Mineral processing plants in Colorado are handicapped to the degree that most of the concentrates produced must be marketed outside the State. These products sometimes must be shipped as far as the industrial part of the nation east of the Mississippi River.

In the case of lead, we are fortunate in having in Colorado at Leadville, the Arkansas Valley smelter of American Smelting and Refining Company where such concentrates may be sold. Copper concentrates may be marketed at the smelters in the Salt Lake City, Utah, area. Zinc concentrates present a difficult economic problem to their producers. Depressed market conditions due to competition by cheaper foreign imports, stiff smelter schedules which absorb much of the value of the concentrate, plus expensive freighting distances to the smelters, all have contributed to reduce zinc production in Colorado to an undertaking fraught with the probability of loss.

Actually, conditions in the future may warrant the installation of a zinc reduction plant within the State, an event which would reduce the cost of shipping the concentrates. Zinc smelters are large consumers of natural gas and must be located near a source of this fuel. Within recent years large reserves of natural gas have been developed in Colorado with new fields being added continually. Zinc ore reserves in the State appear to be adequate to supply a smelter beyond its period of amortization. If the present rate of industrial development in the western and Pacific Coast states continues, the installation of a zinc smelter in Colorado should be considered seriously.

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Colorado Mineral Processing Plants

In former years it was customary when referring to the location of a mill, to give the mining district in which it was situated. Originally, mining districts were officially designated areas related to mineral monuments to which mining claims were referred for location. Since accurate mapping by the U. S. Geological Survey and the Forest Service, and the accurate location of township and section corners has become widespread, most mining claims are now referred to these corners and not to the original monuments. For this reason, many of the names of the old mining districts have fallen into disuse or have been changed. Today, actual geographic designations, such as nearest towns and counties, are far more descriptive of location. We adhere to the more modern trend in giving the location of the mills in the following list.

Molybdenum

1. Climax Molybdenum Corporation
   500 5th Avenue, New York, N. Y.
   34,000 t.p.d. flotation mill; company ores only, Climax, Col.
   Products: molybdenite concentrate.
   Byproducts: pyrite, tungsten concentrate, tin concentrate.
   1958: 6,363,620 tons milled (10 weeks on strike, shut down).
2. Molybdenum Corporation of America
   Empire, Clear Creek County, Colorado
   Mill at Urad, near Empire.
   No recent operation.

Gold

1. The Golden Cyle Corporation
   P.O. Box 86, Colorado Springs, Colorado
   Carlton Mill at Cripple Creek, Colorado
   500 to 1,000 t.p.d. flotation, cyanidation mill.
   Products: gold bullion.
   1958: 100,970 tons treated.

Complex Sulfides

1. Idarado Mining Company
   Ouray, Colorado
   Pandora Mill at Telluride, San Miguel County.
   1,800 t.p.d. selective flotation mill.
   Products: copper, lead, and zinc concentrates.
   1958: 382,100 tons processed.
2. Empire Zinc Division, New Jersey Zinc Company
   160 Front Street, New York 38, N .Y.
   Mill completely underground at Gilman, Eagle County.
   1,250 t.p.d. selective flotation mill.
   Products: zinc concentrates, lead concentrates.
   1958: 263,600 tons treated.
3. Marcy-Shenandoah Corporation
   Jarvis Building, Durango, Colorado
   Silverton Central Mill, Silverton, San Juan County.
   750 t.p.d. selective flotation mill.
   Products: lead concentrates, zinc concentrates.
   1958: did not operate; last activity, 1953, treated 158,000 tons. Mill is in operative condition.
4. Emperius Mining Company
   Emperius Building, Creede, Mineral County.

150 t.p.d. mill, flotation, at Creede.
Products: high-silver lead concentrates and zinc concentrates.
1958: 26,500 tons treated (mill shut down 5 months of the year).

5. Resurrection Mining Company, of Newmont Mining Company.
P.O. Box 939, Leadville, Lake County.
450 t.p.d. selective flotation mill.
Products: lead concentrates and zinc concentrates.
1958: did not operate.

6. Park City Consolidated Mines Company
438 South Main Street, Salt Lake City, Utah
Keystone Unit (ASARCO operator), Crested Butte, Gunnison County.
250 t.p.d. selective flotation mill.
Products: Lead concentrates, zinc concentrates.
1958: did not operate. Treated 40,780 tons during half of 1957.

7. Rico Argentine Mining Company
217 Kearns Building, Salt Lake City, Utah
150 t.p.d. flotation mill at Rico, Dolores County.
Products: lead concentrates, zinc concentrates, pyrite.
1958: idle; reopened early in 1959. Company operates a sulphuric acid plant from pyrite roasted in a Fluo-solids reactor. Acid sold to neighboring uranium mills.

8. Argyle Mining & Milling Company
Silverton, Colorado
125 t.p.d. flotation mill near Silverton, San Juan County.
Products: lead concentrates, zinc concentrates.
1958: operated; has operated almost continuously since 1943.

9. Front Range Mines, Incorporated
405 Burns Vault Building, 1536 Welton Street, Denver
200 t.p.d. flotation mill at Dumont, Clear Creek County.
Products: sulfide concentrates containing lead, copper, gold, and silver.
1958: treated 6,680 tons; 64,000 tons since 1949.

10. National Minerals Corporation
2242 South Grove Street, Chicago 16, Illinois
150 t.p.d. selective flotation mill near Bonanza, Colorado.
Products: lead concentrates, zinc concentrates.
1958: new mill; started up early in year but shut down in the fall.

11. Crested Butte Mining & Milling Company
Crested Butte, Gunnison County
200 t.p.d. being built (1959).

12. Camp Bird Colorado, Inc.
Home Office, London, England

200 t.p.d. flotation mill 6 miles south of Ouray, Ouray Co.
Products: lead concentrate with gold and silver, zinc concentrate.
1958: idle; last year of operation 1956; mill operative. Development program going on in the mine.

13. Belisle & Reed, partnership.
Ophir, Colorado
25 t.p.d. trial mill near Ophir, San Miguel County.
Products: lead concentrate by gravity separation.
1958: operated.

14. British Western America Uranium Corp.
821 Security Bank Building, Salt Lake City, Utah
Mill at Georgetown, Clear Creek Co.; formerly Lupton mill.
110 t.p.d. gravity and flotation mill.
Products: lead concentrates, zinc concentrates.
1958: idle.

15. Consolidated Copper Development & Mining Company
3221 33rd Street, Denver, Colorado
150 t.p.d. flotation mill in Silver Lake area, Custer County.
1958: idle; not operative without reconditioning.

16. Glory Hole, Inc.
228 South Wabash Ave., Chicago, Illinois
100 t.p.d. flotation, gravity mill, Central City, Gilpin Co.
Products: sulfide concentrates containing lead, silver, and gold.
1958: operated in the summer only.

17. Nederland Mines, Inc.
991 Avenue of the Americas, New York, N. Y.
100 t.p.d. mill 6 miles east of Nederland, Boulder County.
1958: idle.

18. Kostelic, Louis
203 West 3rd Street, Leadville, Colorado
25 t.p.d. gravity mill.
Products: sulfide concentrates.
1958: some operation during the year.

In addition to the above 18 mills, there is a considerable number of small mills scattered throughout the older mining districts of Colorado. Most of these are shut down or operate only occasionally, but if circumstances warranted, such as discovery of new ore bodies or improvement of metal markets, could be readily rehabilitated and placed in full operation.

Uranium and Vanadium

1. Union Carbide Nuclear Company
Post Office Box 1049, Grand Junction, Mesa County
800 t.p.d. acid leaching and ion exchange mill, Uravan, Montrose Co.
Captive 75%; custom 25%.

Products: uranium concentrate, vanadium concentrate.
1958: treated 300,000 tons.

2. Union Carbide Nuclear Company
Address as above.
1,100 t.p.d. acid leach, solvent extraction mill at Rifle, Garfield Co.
Captive 75%; custom 25%.
Products: uranium concentrate, vanadium concentrate.
1958: treated 310,000 tons.

3. Trace Elements Corporation
Division of Union Carbide Nuclear Company, address as No. 1 above.
300 t.p.d. acid and continuous ion exchange mill at Maybell, Moffat Co.
Captive 75%; custom 25%.
Products: uranium concentrates.
1958: treated 105,000 tons.

4. Vanadium Corporation of America
420 Lexington Avenue, New York, N. Y.
Acid and alkaline leach mill at Durango, La Plata County.
Products: uranium concentrate, vanadium concentrate.
1958: treated 190,400 tons.

5. Gunnison Mining Company
Gunnison County
400 t.p.d. acid leach and solvent extraction mill near Gunnison, Gunnison County.
Captive 80%; custom 20%.
Products: uranium concentrate.
1958: treated 104,750 tons.

6. Climax Uranium Company
Post Office Box 1901, Grand Junction, Mesa County.
500 t.p.d. acid leach and solvent extraction mill at Grand Junction.
Products: uranium concentrate, vanadium concentrate.

7. Cotter Corporation
Santa Fe, New Mexico
72 t.p.d. carbonate leach custom mill near Canon City, Fremont Co.
Products: uranium concentrate.
1958: started operation, treated 7,685 tons.

Tungsten

1. Cold Springs Tungsten, Inc.
First National Bank Building, Denver, Colorado
Gravity mill at Nederland, Boulder County.
1958: idle, no recent operation.

2. Wah Chang Corporation
Post Office Box 441, Boulder, Boulder County.
50 t.p.d. gravity mill near Boulder.

Product: tungsten concentrate (ferberite).

Tungsten is also produced by Climax Molybdenum Company as a byproduct of its molybdenum milling operation; this has been discussed elsewhere in this chapter. A small number of other tungsten mills, not listed above, exists in the Boulder tungsten district which could probably be rehabilitated readily in the event economics justified it.

Beryllium

1. American Beryl Corporation
   13685 Braun Road, Golden, Jefferson County.
   100 t.p.d. flotation mill in Storm Mountain area, Larimer County.
   Products: beryl concentrate, mica concentrate.
   1958: a few test runs; shut down since.
2. Beryl Ores Company
   Arvada, Colorado
   3 t.p.d. mill in Rocky Flats area, Jefferson County.
   Products: ground beryl and ground mica, dry.
   1958: 400 tons.
3. Mineral Concentrates and Chemical Company
   Denver, Colorado
   2 t.p.d. Mincon Pilot mill, Loveland, Larimer County.
   1958: trial operation Dec., 1958. Sintering and leaching beryl.

Feldspar

1. The Western Feldspar Milling Company
   Post Office Box 671, Salida, Chaffee County.
   250 t.p.d. grinding plant at Salida.
   Product: ground feldspar for glass manufacture.
   1958: treated 28,375 tons.

Fluorspar

1. Ozark-Mahoning Company
   310 West 6th Street, Tulsa, Oklahoma
   350 t.p.d. flotation mill at Northgate district, Jackson Co.
   Product: acid grade fluorspar concentrate.
   1958: 51,380 tons treated.
2. Ozark-Mahoning Company
   Address same as above.
   150 t.p.d. mill at Jamestown, Boulder County.
   Product: acid grade fluorspar concentrate.
   1958: milled 51,380 tons.
3. Allied Chemical Company
   40 Rector Street, New York 6, N. Y.
   150 t.p.d. flotation mill at Valmont, Boulder County, ores from Jamestown district.
   Product: acid grade fluorspar concentrate.

1958: milled 35,000 tons.

4. Reynolds Mining Co.
Poncha Springs, Chaffee County.
200 t.p.d. flotation mill at Poncha Springs.
Product: acid grade fluorspar concentrate.
1958: idle.
5. Colorado Tri-State Mining Company
332 Colorado National Bank Bldg., Denver, Colorado
500 t.p.d. heavy media separation mill at Dillon, Summit County.
Product: gravel spar.
1958: idle; no recent operation.

Gypsum

1. Pabco Building Materials Division of Fibreboard Products Corp.
San Francisco, California
500 t.p.d. mill at Florence, Fremont County.
Products: plaster, wallboard, and other building products.

Mica

1. Beryl Ores Company
Arvada, Jefferson County.
3 t.p.d. mill at Rocky Flats area.
Product: dry-ground scrap mica.
1958: 100 tons produced.

Perlite

1. Persolite Products, Inc.
Box 3056, Denver 18, Colorado.
Mill at Florence, Fremont County.
4,800 cubic feet of expanded perlite per day capacity.
Raw material custom-milled by Flexore, Inc., at Silver Cliff.
1958: moved from Denver to Florence; treated 348 tons.

PART III

Oil Shale—Coal

Prepared Under The Supervision Of

S. M. del Rio

OIL SHALE — DR. CHARLES H. PRIEN

COAL — DR. PARKE O. YINGST

PART III

Oil Shale - Coal

Oil shale and coal are the most abundant known mineral resources of Colorado. The potential value of these materials in terms of dollars is not conceivable at present because of the multitude of products which can be derived from them. The progressive future growth of population and industrialization in the West, water supply, and other considerations will determine the number, type, quantity, and value of the derivatives to be produced locally, as well as the value of the raw product at the mine.

In this section Dr. Charles H. Prien*, an authority on oil-shale retorting and shale-oil chemistry, discusses the present status of the potentially gigantic shale-oil industry and looks into its imminent future.

Dr. Parke O. Yingst**, engaged in coal research for a number of years, discusses the reasons for the decline of coal, describes research being conducted to increase demand, and delves into future trends of coal preparation and utilization.

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Chapter X

Oil Shale

by

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CHAPTER X

Oil Shale

by

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Few areas in the world contain greater resources than those portions of Colorado, Utah, and Wyoming in which the oil shales of the Green River formation are located. This area contains the free world's largest proved oil shale deposits of economic significance. If the oil which is here entrapped were expressed in dollars, it would amount in value to more than seven times the 275 billion dollar national debt of the United States. The major portion of these oil shale reserves, and the most amenable to commercial development, is located in the State of Colorado.

As a source of oil, the significance of the Green River formation can best be realized by a comparison with known crude petroleum reserves. The Green River deposits (see Fig. 1) contain almost five times the world's, and 29 times the United States', known crude reserves. This is equivalent to a 300 years' supply of petroleum for the United States at present consumption rates.

About one-tenth of this enormous reserve, it is believed, will become economically recoverable within the next few years. This portion lies wholly within Colorado and is part of the richest section, the "mahogany ledge." The remainder will become financially attractive as technology continues to improve. A 100-billion barrel proven oil reserve is ready to be exploited (no exploration necessary), without the market development problems usually associated with new industries. Oil shale products would move into established petroleum market channels.

It was not until World War I that interest was aroused in the important oil shale deposits of the western United States. Between 1916 and 1920, some 20,000 placer-mining claims were filed on nearly all the oil shale land in Colorado, Wyoming, and Utah.

The Leasing Act of 1920 withdrew public deposits of oil shale from further locations and placed them under the general land-leasing law with oil and gas. Although vacant public land is, under certain conditions, still available under this act, companies planning to produce shale oil find it desirable to own their land and avoid the difficulties of the leasing act.

The placer-mining claims which were valid when the Leasing Act was passed are still valid. Some 200,000 acres of these oil-shale claims have gone to patent in the last five years.

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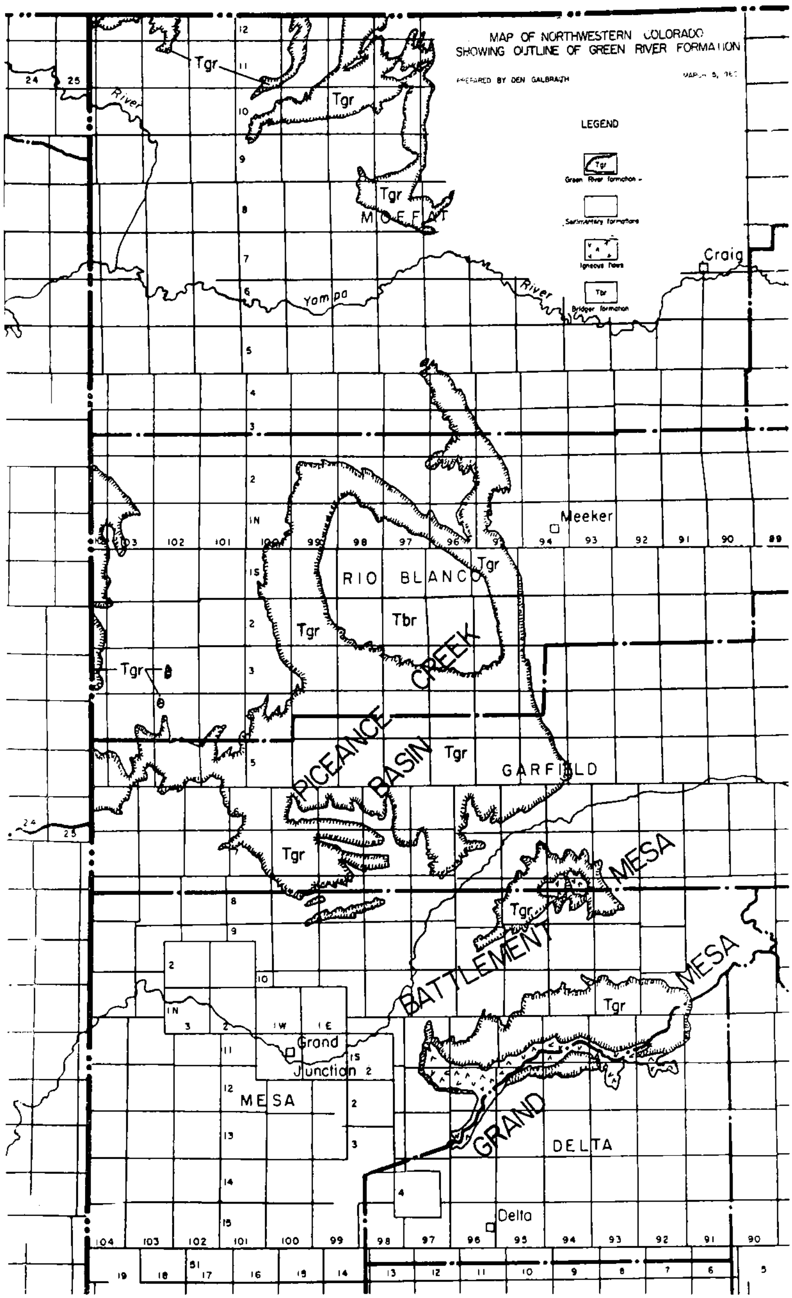
MAP OF NORTHWESTERN COLORADO
SHOWING OUTLINE OF GREEN RIVER FORMATION
PREPARED BY DEN GALBRAITH
LEGEND
Green River formation
Sedimentary formations
Igneous flows
Bridger formation
Tgr
Tbr
MOFFAT
RIO BLANCO
GARFIELD
MESA
DELTA
Craig
Meeker
Grand Junction
Delta
Yampa River
PICEANCE CREEK BASIN
BATTLEMENT MESA
GRAND MESA

FIGURE 1

It is pertinent here to review briefly the activities of some major petroleum companies and their shale land purchases (patenting)[8].

The Union Oil Company of California started buying oil-shale land in 1921. In the next few years Pure, Continental, Standard Oil of New Jersey, Prairie Oil and Gas Company, Ventura Oil Company, and Honolulu Oil Company bought blocks of shale land. During the 1930's, Standard Oil Company of New Jersey sold its shale land. (It was later bought by Standard Oil Company of California.) The Texas Company acquired 10,000 acres of shale when it bought the Ventura Oil Company, and Sinclair Oil and Gas Company acquired 7,000 acres when it absorbed the Prairie Oil and Gas Company.

The end of World War II found only four large oil companies owning substantial blocks of shale property. In 1946, Standard Oil Company of California leased 12,000 acres of shale land from a private group. The difficulties of lease terms made it more desirable later to purchase this land outright. Soon Union Oil Company of California began to add to its 20,000-acre block on Parachute Creek. In 1948, Pacific Western Oil Corporation of Los Angeles contracted for 22,000 acres of choice land. These cost about $30/acre, about the same as Union had paid in 1921.

During the next two years Union added more than 10,000 acres to its holdings at costs up to $50/acre. Cities Service and Shell began to build blocks of land in 1951 and paid $50 to $60/acre. In 1952, Gulf Oil Corporation contracted for 4,000 acres, and The Texas Company added 7,000 acres to its 10,000-acre block. Some 60,000 acres of land were patented in 1952 alone. Union Oil Company has continued to maintain a dominant position, building its holdings in recent years to nearly 50,000 acres, at prices up to $100/acre. Standard Oil of California has purchased additional land in several areas, sometimes paying more than $100/acre. With recent acquisitions, Standard's holdings, now well over 50,000 acres, place the company in an equally dominant position with Union Oil. Within the past two years, Dow Chemical acquired control of Columbia Oil Shale and Refining Company, which owns 8,000 acres of the best shale land. Dow is thus the first major chemical company to acquire shale land.

It is obvious from the above that interest in oil shale has increased markedly during the past ten years. The price of land has correspondingly increased. Some land is known to have been sold for more than $300/acre. However, this is still equivalent to a little more than 500 bbl. of reserve for each dollar paid, certainly a reasonable investment.

In 1954 Standard Oil (California) completed a $100,000 survey and mapping project of its widespread holdings. Other companies have acquired water rights and plant space, and have engaged in planning for access roads and mining sites.

The Union Oil Company has recently purchased 3,000 acres of ranch land near Grand Valley for plant working space. Eaton Shale Company, now owned by Standard Oil of California, has similarly acquired 2,000 acres, and Standard of California and Pacific Western each have about 1,500 acres near Debeque, Colorado. The Texas Company has nearly 2,500 acres of ranch land with its property.

The map (Fig. 2) and table (table on p. 452) accompanying this section show the location and reserves of most of the major holdings in the active oil shale area of Colorado. Patented and unpatented land as well as ranch lands are included. Holdings by individuals and subsidiary companies have been grouped under names which are most familiar.

The area shown, in Garfield County, Colorado, lies 200 miles west of Denver and 30 miles east of Grand Junction. The rich oil shale outcrops in 30 miles of bold escarpment 3,000 ft. above the Colorado River. Much of the exposure is plainly visible from the Denver & Rio Grande Railroad and transcontinental highways. The tributaries to the Colorado River add an additional 600 miles of escarpment as potential working faces.

At one time during the early 1920's over 80 experimental retorts were in operation in the oil shale region. However, the plentiful supply of crude oil which began to appear after 1925 as new oil fields were found, caused interest in shale to dwindle, and substantial activity was not renewed until World War II.

In the 1940's, the Bureau of Mines set up a sizable pilot plant operation near Rifle, Colorado, and engaged in development work until the plant was closed in 1955. During this period, Union Oil Company of California was actively engaged in research and development on shale retorting. In May, 1957, the company dedicated a 300-tons-per-day pilot plant near Grand Valley, Colorado. This plant was operated until July, 1958. In 1955, Sinclair Oil & Gas Company conducted tests on underground retorting of oil shale on its lands at Haystack Mountain in the shale area.

The Oil Shale Corporation of Beverly Hills, Calif., began investigation of the Swedish Aspeco process in 1956. This work is still in progress (1958).

Occurrence

Oil shales are widely distributed over the face of the earth, over one million million tons of reserves already being known. The deposits vary greatly in their oil-yielding properties, texture, specific gravity, in fracture, and in color. The more extensive known world deposits occur in Scotland, France, Germany, Sweden, Estonia, Great Britain, the USSR, Burma, Australia, Manchuria, Brazil, Canada, and the United States.

Because of its size the Oil Shale Area Map planned for this page has been placed in the pocket.

Lesser deposits are found in Italy, Spain, Bulgaria, Servia, Turkey, Yugoslavia, Norway, South Africa, Syria, Mongolia, Argentina, Chile, and Uruguay.

It would appear that only the deposits of Brazil and of the United States are sufficiently large to be of significance to the world petroleum picture in the immediate future. *Recoverable* reserves elsewhere are unlikely to exceed 5 to 10 billion barrels as now known. However, local situations in individual areas and particularly the intense national desire for a country to produce its own oil makes even the smaller deposits significant.

Brazil's recoverable reserves have been estimated at 300 billion barrels. The most extensive are the Iraty black shales, which extend over a distance of 250 miles, in beds 100 to 300 ft. thick.

In the United States oil shales have been found in at least one-half of the 49 states, including Alaska. The two areas of greatest extent are the black Chattanooga Formation shales of Indiana, Kentucky, Tennessee, West Virginia, and Pennsylvania; and the Green River Formation shales of Colorado, Utah, and Wyoming. Because the Chattanooga shales occur in lean beds less than 15 ft. in thickness they are not believed commercially attractive at the present time.

The western shales of the Green River Formation are immediately commercially attractive. Recent estimates place total reserves of contained oil in these shales at well over one trillion barrels. The Green River Formation encompasses large areas in the Piceance Basin, in northwestern Colorado; the Uinta Basin in southeastern Utah; and the Great Divide, Washakie, and Green River Basins in Wyoming[12].

Oil shale in the 1,400 square miles of the Piceance Basin of northwestern Colorado is probably the largest single deposit in the United States. This area (Fig. 1) is bounded by the Colorado River on the south, the White River on the north, Douglas Creek on the west, and Government Creek on the east.

Geology

John R. Donnell, U. S. Geological Survey, has given the following geologic description of the area[2]:

"The oil shales are found in the lacustrine (marlstone of the) Green River Formation of middle Eocene age, which attains a maximum thickness of about 3,500 ft. Underlying the Green River formation are variegated shales and lenticular sandstone of the Wasatch formation of Paleocene and early Eocene age. . . . Underlying the Wasatch formation is the Mesaverde formation of Late Cretaceous age.

"That part of the area which is underlain by the Green River formation is a high plateau rising about 4,400 ft. above the valley of the Colorado River near Rifle, and attaining an altitude of 9,400 ft. The whitish and light-blue cliffs of the resistant oil shale are in sharp contrast to the low-relief badland topography of the Wasatch formation bordering the plateau.

"The Green River formation consists of four members which are, in ascending order, Douglas Creek, Garden Gulch, Parachute Creek, and Evacuation Creek. The richer shales which are (of immediate) economic interest are mostly confined to the Parachute Creek member, which in turn is divided into the upper and lower oil shale zones. These rich oil shale zones are extremely resistant to weathering and form sheer cliffs or steep slopes. They are separated by a thin sequence of lean oil shale that weathers to a gentle slope or recess. In the lower part of the upper oil shale zone is the Mahogany ledge, a unit that contains the principal oil shale beds in the sequence. Everywhere that the ledge crops out it forms a sheer cliff delimited above and below by lean shales that form slopes. The subsurface counterpart of the Mahogany ledge is referred to . . . as the Mahogany zone. The ledge, or zone, is about 110 ft. thick at the axis of the basin, and thins toward the margins. Undoubtedly, the first segment of the oil shale sequence to be worked commercially will include part or all of the Mahogany Zone. . . . The richest oil shale bed within the Mahogany ledge, or zone, is called the Mahogany bed, which is used as a stratigraphic reference bed."

The following brief comments as to the geologic origin of the Green River Formation are offered: Under climatic influences relatively stable, shallow, fresh-water lakes gradually changed to lakes that periodically filled and evaporated, but that supported luxuriant microflora. Strongly alkaline, playa-like ponds eventually resulted, in which glauberite crystallized out and in which organic ooze consisting almost wholly of microscopic algae accumulated. Bacteria caused putrefaction, and evaporation reduction to a syrupy consistency and occasionally to dryness. The macerated organic matter was covered by the deposits of the next cycle and subsequently lithified into oil shale.

The lakes were chemically and thermally stratified during evaporation into regions of varying concentration and composition, in accordance with modern concepts of limnology. The nitrogen in the resulting oil shale was probably derived, originally as nitrates, from the lush vegetation, animal and marine life on the lake and its margins, and by fixation of atmospheric nitrogen by certain algae. The presence of various species of marine, animal, and bird skeletons in the formation, together with the remains of insects and the spores of fungus and higher plant life, has been noted.

The theory that rock flowage resulted in oil migration, with subsequent adsorption and inspissation, appears to have been unlikely in the Green River formation.

Colorado Reserves

The Green River formation of the western United States covers an area of nearly 16,500 sq. miles, including 2,600 sq. miles in Colorado, 4,700 sq. miles in Utah, and 9,200 sq. miles in Wyoming. The Colorado deposits, while the least extensive in area, are not only the richest but also the most accessible and the most amenable to commercial development[10, 11].

Utah and Wyoming deposits have been explored by very few core holes. Those that have been drilled suggest that Utah may have approximately 160 billion barrels of oil in reserves, and Wyoming about 12 billion barrels. The deposits in both cases vary from surface outcrops to more than 5,000 ft. below the surface, and are intermittent.

By contrast, the combined resources of oil shale in the Piceance Creek Basin of Colorado alone, north of the Colorado River, underlies about 1,380 sq. miles, varies from 15 to 2,000 ft. in thickness, and contains about 3 trillion tons of oil shale with an oil content of more than one trillion barrels. The oil yield is 15 gallons or more per ton. Oil shale in the Battlement Mesa and Grand Mesa areas just south of the river in the same region have not been mapped in detail, but are known to contain some deposits over 25 ft. in thickness.

More than 100 test core holes and 35 oil and gas test well rotary drillings have been made in the Piceance Creek deposits. According to Duncan[3] and Donnell[2] the 25 gallon/ton deposits alone of the Piceance Creek Basin total more than 700 billion tons, or 400 billion barrels. Including both the rich upper and leaner lower zones, these 25 gallon/ton deposits are up to 1,500 ft. in thickness.

At present only the upper rich Mahogany zone of the Piceance Creek Basin is considered commercially minable by current known technology. Even restricting thinking to this zone, the known deposits of oil shale are considerable. Donnell estimates[2] that the upper Mahogany Zone includes 1,130 sq. miles of shale, varying from 15 to 130 ft. in thickness, and containing 90 billion barrels of oil in beds averaging 30 gallons per ton in richness.

If the reserves are considered to include all beds averaging 25 gallons of oil per ton, it is found that 1,200 sq. miles of shale are present, ranging from 15 to 220 ft. in thickness, and containing 260 billion tons, or 155 billion barrels of oil. This 25 gallon/ton reserve alone is approximately equal to the total petroleum reserves of the Middle East.

The Mahogany Zone lies at depths ranging from a few hundred feet to about 1,700 feet below the surface[3], and is usually less than 1,000 ft. beneath the drainage level of the streams in the Basin.

Over 200,000 acres of the Piceance Creek reserves are under private ownership, and another 31,000 acres are in Naval

Reserves 1 and 3. The principal ownerships, their size, and the extent of their reserves, is shown in the accompanying table.

Area and Reserves of Major Colorado Oil Shale Properties

(Revised from ROCKY MOUNTAIN OIL REPORTER, March, 1959, Vol. XVI, No. 3, p. 18)

Owner	Total area* (acres)	Shale bearing area (acres)	Shale oil reserves** thousands of barrels
Cities Service	10,000	7,100	1,480,000
Continental Oil	10,800	3,600	270,000
Dow Chemical	8,500	7,900	2,312,000
Doyle, et al.	4,400	3,400	761,000
Dutton	2,560	2,560	563,000
Energy Resources Technology Land, Inc.	15,040	15,040	5,400,000
Gabbs Exploration	5,000	5,000	550,000
Gulf Oil	3,700	1,600	133,000
Honolulu Oil	3,300	1,500	205,000
Kerogen Oil	2,300	1,400	196,000
Massive Group	4,500	2,400	118,000
Getty Oil	21,900	17,800	4,186,000
Oil Shale Corp.	1,291	1,124	105,000
Parachute Oil Shale	5,600	4,900	830,000
Pure Oil	3,800	1,000	20,000
Savage Oil Shale Development	26,600	17,600	2,223,000
Shell Oil	5,500	3,000	473,000
Skyline Oil	5,900	5,400	406,000
Sinclair Oil & Gas	7,300	4,700	867,000
Std. Oil Co. (Calif.) (including Eaton Shale Co.)	69,200	50,600	9,248,000
Texas Company	18,700	14,000	1,626,000
Texas National Pet. Co.	4,683	1,400	74,000
Union Oil Co. of Calif.	50,400	40,100	8,856,000
Wasatch Development Co.	6,400	6,400	1,280,000
Weber Oil (General Petroleum)	24,600	23,000	4,000,000
U. S. Naval Reserve	38,700	31,700	5,000,000

*From the minable section yielding 25 gallons of oil per ton of shale. Recoverable reserves may be 35% less from losses in mining, crushing, and retorting.

**Approximately 20,000 acres are in litigation due to conflicting ownership. Such areas have been omitted from the above list and from the map.

(John Savage)

Chemical Constitution of Oil Shale[8]

Organic matter is present in Colorado oil shale, in quantities varying from a trace to 30 percent by weight (usual average is 6 to 12 percent), corresponding to up to 80 gallons of derived shale oil per ton, in a laminated calcareous, inorganic matrix. This matrix, or marlstone-like rock, has an approximate analysis of 48 percent silica, 17 percent alumina and iron oxides, 28 percent calcium and magnesium oxides, and consists principally of calcite, dolomite, and clay, with quartz, feldspar, and pyrite as minor minerals.

The organic matter in Colorado oil shale, sometimes called kerogen, is a high-molecular weight substance of largely unknown chemical structure. In semipure form it is a brown amorphous powder, with a carbon/hydrogen weight ratio of approximately 7.3, and resembles powdered, decayed leaf mold in appearance. It contains roughly 2.6 percent nitrogen, 1.3 percent sulfur, and 9.5 percent oxygen. Chemically it is probably a nonbenzenoid, polycyclic substance loosely interconnected through hetero side chains. An approximate empirical formula might be given as $C_{158}H_{265}O_{15}N_{4.6}S$. It is noted that there are 1.66 hydrogen atoms for each carbon atom present.

This organic substance is essentially insoluble in common petroleum solvents at room temperature.

The chemical relationship between the organic and inorganic matter is unknown although some evidence of coordinated porphyrin iron and nickel complexes between the two has recently been found by the Denver Research Institute, University of Denver. The role of the nitrogen, sulfur, and oxygen hetero atoms in the structure is also incompletely understood. Evidence of at least two forms of kerogen has been discovered, each with its own rate of decomposition, and each varying in relative proportions of C, H, N, S, and O present.

Nitrogen is apparently present in both the inorganic and organic portions of Colorado oil shale. The inorganic portion probably consists of cyanides, cyanamides, or nitrides which resist the high temperatures and essentially reducing atmospheres of subsequent pyrolysis, and appear in the spent shales therefrom. The forms in which the organic nitrogen occur are not known, but they are probably present as a byproduct of the degraded plant residues from which the organic matter originated. Upon pyrolysis, these organic nitrogen compounds are stabilized to pyrroles, pyridines, and quinolines, with the liberation of ammonia. These organic nitrogen derivatives appear in the resultant shale oil.

Sulfur is also present in approximately equal quantities in both the inorganic and organic portions of oil shale. The inorganic sulfur consists mainly of sulfides and sulfates of iron. The forms of the organic sulfur are not known, but like the organic nitrogen, are probably degradation products of plant remains. Upon pyrolysis of oil shale, hydrogen sulfide is produced. Sulfur compounds appear in the spent shale as sulfides and sulfates, and in the resulting shale oil as organic disulfides and thiophene derivatives.

Oxygen is present in the inorganic portion of oil shale as sulfates, aluminates, carbonates, and phosphates, and in the organic portion as fatty acid, carbonyl, and ether linkages. Upon retorting, phenol, cresol, and xylenol homologues and other tar acid residues appear in the resulting shale oil.

It is from this complex organic substance that the liquid hydrocarbon mixture, called "shale oil," is formed. The process employed and the only successful one to date, is that of destructive pyrolysis of the dry, crushed oil shale at temperatures in the order of 900° F. The resulting shale oil, with a C/H ratio of approximately 7.2 to 7.5, a nitrogen content of 1.8 percent and a sulfur content of 0.8 percent, consists of 39 percent hydrocarbons (many highly unsaturated) and 61 percent carbon-hydrogen compounds containing oxygen, nitrogen, or sulfur. It contains less than 3 percent straight-run gasoline fraction. Only one-half of the total oil is distillable below 300° C. (572° F.) at 40-mm. pressure. It is thus intermediate between petroleum crude (C/H of 6 to 7) and coal pyrolytic products (C/H of 10 to 16) in character.

Recent Advances In Oil Shale Technology

Over 3,000 retort designs have been patented to carry out the pyrolysis of oil shale[5]. Heat, in these designs, is furnished either externally through the retort wall, or internally by contact with hot gases, liquids, or solids. Combustion of residual carbon on the retored shale (so-called "shale coke") is most often used to furnish the temperatures required.

Only three of these retorting processes are known to be of interest in the United States at the present time. These are (a) the vertical-retort rock-pump process of the Union Oil Co.[4]; (b) the gas-combustion process of the U. S. Bureau of Mines[1]; and (c) the Aspeco rotating-kiln, heated-balls process of The Oil Shale Corporation, under development at Denver Research Institute, University of Denver[6]. Several others, apparently under less intensive investigation, are also mentioned below.

The Union Oil process has been developed on the largest scale to date. A large pilot plant and associated mine was operated in western Colorado near Grand Valley from March, 1957, until July, 1958. Dr. Fred Hartley, Vice President of the company, stated that the vertical upward-flow retort utilized in these studies has attained capacities of "up to 1,200 tons of rock per day . . . on fully automatic control for continuous periods of up to six weeks"; and that "a single retort (of this same design) with a capacity of 3,000 tons/day is a reasonable extrapolation" for a commercial plant.

The second principal U. S. process is the gas-combustion process developed by the U. S. Bureau of Mines. This is also a vertical retort, but with downward flow of the raw shale. At the time that the Rifle, Colorado, operations of the Bureau were discontinued in 1955 this retort had been operated at a 200-ton-per-day capacity intermittently over a nine-month period, and with sustained operation of two months.

The firm of Cameron and Jones, Denver, Colorado, has since constructed a modified and improved form of this retort, of 13 tons/day capacity, near Sao Paulo, Brazil, for use on the Paraiba Valley shales of Brazil. It is stated that this latter retort has met all design specifications to date, in extended runs of over 1,000 hours. A large-scale prototype unit using this modified gas combustion process is now under construction in Brazil.

The most recent new shale process is the modified Aspeco process of The Oil Shale Corporation, under investigation here at the University of Denver. This process differs from the two previously mentioned, in that it employs a rotating kiln to which heated thermospheres and crushed shale are fed. The resulting shale coke is burned separately in a fluidized bed to reheat the thermospheres. In both the Union and Bureau processes the combustion zone furnishing heat for the process is located in the same vessel as the retorting zone.

The Aspeco process has been operated at a 24 ton/day pilot plant in Denver for a period of nearly one year. This pilot plant is now being modified to provide improved operation.

The patent literature of the past several years indicates activity by other companies in oil shale retorting—The Texas Company, Standard Oil of California, Sinclair, Atlantic Refining, to name only a few. The more important of these patents, along with the over-all status of oil shale technology in all its aspects, are discussed each year in the September issue of Industrial and Engineering Chemistry, as part of an annual research review on this subject[7].

Retorting of oil shale "in situ," i.e., underground, has been receiving attention in the U. S., primarily as a result of the efforts of Sinclair Oil and Gas Company (see U. S. Patent No. 2,780,449). This process was studied at Sinclair's oil shale property on Haystack Mountain in western Colorado several years ago.

A gas is introduced into an input well under pressure to produce parting of the oil shale and increase permeability. A hot zone is then established by injecting fuel gas and air. The hot zone so produced underground is moved toward an output well some 300 ft. away, distilling the shale oil vapors before it. The resulting shale oil is withdrawn from the output well.

To date it would appear that the Sinclair underground retorting process will still require considerable further investigation before evaluation of its future potential can be made. It is interesting to note in this regard that the U. S. Bureau of Mines, in conjunction with Project Plowshare at Livermore, California, which is devoted to a study of underground nuclear explosions, has proposed the testing of such an explosion in oil shale to obtain data as to its applicability in breaking up the shale and retorting it in situ. Much research is still necessary, however, before nuclear explosive techniques can be pursued further for oil shale, either underground or even as a means of removing the overburden.

It would appear at present that practical, economical recovery of shale oil must continue for the foreseeable future to depend on mining, to be followed by retorting the shale above ground. This appears particularly true when one considers the new economies being effected in both mining and aboveground retorting.

The use of ammonium nitrate as an explosive, and rotary drilling to replace percussion drilling, are reducing mining costs considerably below 50¢ per ton. Similarly, retorting costs have been decreased to where 50¢/barrel now appears to be attainable. These economies argue well for a commercial oil shale industry based upon above-ground retorting in the near future.

One further development in oil shale technology deserves mention; this is the hydrogasification process of the Institute of Gas Technology. In this process the organic matter in the shale is converted to a fuel gas by reaction with hydrogen at 1,200-5,700 lbs./square inch pressure and 1,300° F. From the preliminary economic data obtained, it would appear that this process must await considerably higher natural gas prices than those anticipated in the reasonable future, before becoming commercially feasible. At today's prices, the organic matter in oil shale is worth twice as much per pound in the liquid form as shale oil, than as a fuel gas.

For the present, complete refining in Colorado of shale oil to end-fuels is neither economically nor technically feasible. From an economic viewpoint, there is no sufficient market nearby for the products, and from a technical point of view, there is no sufficient water available. Since the oil is not suitable in its raw state as a pipeline crude (too viscous to pump), the approach is therefore to refine the material partially so as to produce a suitable pipeline crude, transport it to the marketing area (e.g., Los Angeles), and complete its refining near the ultimate market.

Two series of partial refining operations have been proposed for performance at the mining area for preparation of the shale oil for transportation to the west coast by pipeline. One of these, proposed in part by the Union Oil Company and used in the National Petroleum Council's study, entails the following operations which would be conducted in Colorado.

The shale oil is coked, and the resulting gasoline fraction catalytically reformed. The higher boiling point coke distillate is hydrogenated to remove sulfur and nitrogen and to saturate partially the olefins present. The hydrogen sulfide and ammonia produced are recovered. The gasoline fractions obtained by hydrocracking are sent to the above-mentioned catalytic reforming unit. The remaining liquid product is hydrogenated diesel fuel. Hydrogen for the process is obtained by steam-methane reaction through the use of refinery gas from the coking unit. The raw, catalytic reformed gasoline and the hydrogenated diesel stocks are sent via pipeline to Los Angeles for finishing by conventional refinery processing.

The second proposal consists of the Bureau of Mines process in which the raw shale oil is submitted to a visbreaking treatment (gas loss 2-6 percent), and thence sent to Los Angeles for refining by conventional recycle thermal cracking, catalytic reforming, and acid treatment of gasoline stock, to produce gasoline and heavy fuel oil as the main products.

Economics of An Oil Shale Industry

Past efforts to create an oil shale industry have all failed as a result of unfavorable political, economic, or technical factors. It appears, however, that the appropriate time has arrived for development and utilization of U. S. oil shale deposits. Six reasons may be given for this conclusion[6].

(1) Nuclear energy, although a competitor for other energy sources, is not expected to alter appreciably the demand curve for petroleum and its products in the next 25 years;

(2) In order to meet its increasing requirements for petroleum, the U. S. must add over 5 million barrels/day of *new* oil to its present requirements by approximately 1965, at which time its total consumption will be in the order of an astounding 14 million barrels/day. Certainly, therefore, a market will exist in the immediate future for at least one million barrels/day of oil from shale. Even 1 million barrels of shale oil per day would be only 7 percent of the daily U. S. demand in 1965;

(3) Capital outlays for an oil shale industry, while enormous (in the order of $7,500/daily barrel), are no greater than those required for new petroleum if exploration costs are included. These capital outlays, *per se*, therefore cannot be considered an important factor in deciding between shale oil and crude petroleum, for they are required whether shale oil is to substitute for a portion of the increased petroleum demand or not. There is every reason to believe, of course, that improvements in shale technology have already reduced the capital outlays required, and will continue to do so as research continues;

(4) Petroleum drilling costs are constantly increasing, as a result of greater drilling depths and the decline in new reserves per foot of well drilled. Shale processing costs, on the other hand, are continually declining as technology improves. It follows, therefore, that shale oil will inevitably become cheaper to produce than domestic crude petroleum;

(5) Anticipated U. S. demand for added fuels in the near future will be sufficiently large to provide an adequate market for a million barrel/day industry by 1970. Tar sands, if competitive by this time, can also hope to secure an adequate share of this total market without particularly disturbing shale oil's growth;

(6) The only significant competition for shale oil in the future is foreign oil. But it is doubtful that U. S. defense policy will permit a major dependence upon foreign crude. In addition, foreign crude prices are likely to increase as a result of further nationalization and increased demand outside the U. S. As a result, shale oil prices and foreign crude prices will tend constantly to converge.

It is pertinent to review briefly the order-of-magnitude costs involved in producing shale oil. These costs are based on the Mahogany Ledge, in which the shale averages 25 gallons/ton. It would appear that it costs somewhere between $1.40 and $1.65 per barrel to mine, crush, and retort this 25 gallon/ton oil shale to shale oil at the present time. This might be thought of as the price at the "well-head," except that the resulting shale oil, as usually obtained, is not pumpable. A coking or visbreaking step is therefore usually necessary and this will add approximately $0.35/bbl., so that the cost now becomes $1.75 to $2.00 per bbl. at the intake end of the pipeline in Colorado. If $0.50/bbl. is a reasonable pipeline tariff the cost of oil laid down in California (which is the most likely market) becomes $2.25 to $2.50 per barrel.

Of the $1.40 to $1.65 required to mine, crush, and retort the shale, approximately $0.90/bbl. is required for mining and crushing alone. The balance of $0.50 to $0.70 per barrel is required for retorting. Of course, if a pipeline crude could be produced directly from the retort, most of the $0.35/bbl. required for upgrading the shale oil could be saved. This would therefore appear to be a most fruitful area for research.

Impact of An Oil Shale Industry In Colorado

It is interesting to examine the economic effect of a one-million barrel per day shale oil industry upon Colorado and the nation. This figure is chosen as being consistent with future U. S. demand for petroleum, and with water availability in western Colorado[9].

Shale will be mined initially solely from that portion of the Green River Formation lying in northwestern Colorado. The retorts to extract the oil from the shale will be located near the mouth of the mines. Since the resulting fluid is too viscous to be pumped any distance through pipelines, partial refining must take place near the retorts. It is contemplated that the partially refined product will then be pipelined to California or to an equidistant midwestern market for final refining. Due to the large quantities of process water required for final refining, this production phase must be located where water supplies are more plentiful than they are in western Colorado.

Urban Development

To support the shale oil industry under this pattern will require the development of a new metropolitan area of 340,000 people on the western slope, stretching east and west along the Colorado River near Grand Valley, Colorado (50 miles northeast of Grand Junction, Colorado). This is a city larger than either Omaha or Salt Lake City, and is equivalent to 25 per cent of Colorado's 1950 population. Some 59,130 residents of the new city will be employed directly in the shale oil industry, and an additional 80,300 will be employed in local service jobs. Some 100,000 new homes must be built to house the new population. The city will require the production of 180,000 acres of farmland to feed its inhabitants.

At present, the lower-lying areas along the Colorado River suitable for urban development have fewer than 3,000 residents. The opportunity afforded to create a planned community of the size suggested, free of many of the ills of our older cities, is indeed a challenge of the first magnitude. Certain officials of Colorado are aware of this opportunity, and it is to be hoped that steps will be taken in the near future to insure planned urban development of the area.

The cliff faces and plateaus of the shale country, stretching for 50 miles along the north bank of the Colorado River, will be the location for the oil shale industry itself. The canyons of tributary Parachute Creek, Clear Creek, Roan Creek, Brush Creek, etc., will be the access routes to this industry. The retorts through which will pass 1.5 million tons of crushed shale rock each day, and from which daily will flow 1 million barrels of crude shale oil, will be placed high up on the escarpment of the shale cliffs. Most of the retorts will not be visible from U. S. Highway 6, which runs along the Colorado River, due to the complex pattern of canyon formations.

Visible from the highway will be certain of the refineries which will process the shale oil, reducing its viscosity and increasing its flow properties sufficiently to place it in the 750-mile pipeline, which will begin near Grand Valley and terminate in Los Angeles. These refineries will not be the enormous complexes which can be seen in the petroleum centers of the nation today, but rather much simpler versions designed to carry out only the minimum operations necessary to prepare a "pipeline crude."

Capital Requirements

To build this industrial complex, including the mines, plants, pipelines, refineries and employee housing, will require an enormous amount of capital—$7.8 billion, with almost $7 billion of this amount being required for the Colorado facilities. By way of comparison, the total assets of the Standard Oil Company of New Jersey, the world's largest oil company and the second-largest industrial corporation in the world, are $7.9 billion.

The Colorado payroll of the industry will be $387 million each year. Operating and maintenance supplies, much of which will be purchased in the mountain states area, will require the outlay of $236 million annually.

Some 2,289,920 tons of steel and 486,860 tons of other metals will be consumed over a period of years in the construction phase of the industry. In addition, when production of 1 million barrels per day is reached, 135,000 tons of metals will be required annually for maintenance of the facilities.

Each day the pipelines to California will carry sufficient partially refined shale oil to produce 502,600 barrels of gasoline and 249,440 barrels of diesel oil. The California refineries will also produce 35,680 barrels of liquefied petroleum gas and 12,000 barrels of residual fuel.

By-Products

The Colorado facilities will yield daily 1,840 tons of ammonia (for fertilizer), 860 tons of sulfur (for sulfuric acid), 23,600 tons of petroleum coke, and 496,600,000 cubic feet of fuel gas (1,000 BTU/cubic foot).

The by-product fuel gas is in itself a sizable source of energy. If converted into electrical energy terms, it is equivalent to 31 million KWHR's of power per day. This is three times the total average daily production of electrical power in Colorado in 1956. The fuel gas could be placed in pipelines for market (the Pacific Northwest pipeline passes within 50 miles of the area), or used in part to generate cheap by-product electrical power.

The ammonia, sulfur and coke by-products of the Colorado operations will total 9,599,500 tons annually. These products, to say nothing of a possible shale petro-chemical industry, could form the bases for additional satellite industries on the western slope of Colorado. These possibilities have not been fully explored, and it is assumed for the purposes of this writing that the bulk of the by-products would be shipped to markets outside the area.

Tax Implications

From the standpoint of the new city, Colorado and the nation, the amount of taxes that will be collected as a result of the development of a shale oil industry is important. Community facilities, schools, highways, and a multitude of additional government services would have to be provided.

It is estimated that Federal, State, and local taxes totaling $629,648,000 will be generated by the Colorado shale oil industry, its employees, supporting employees and their property.

Local city and county taxes will total $27 million. Colorado will collect $43 million, which amounts to 32 percent of the total 1956 Colorado State income tax. Finally, the U. S. Treasury will be paid some $560 million annually. This latter figure is approximately three-quarters of one percent of the total 1956 Federal tax receipts.

The capital requirement per worker in the shale oil industry is extraordinarily high—about $124,000 per employee. In contrast, the ratio of assets to employees in the General Motors Corporation is about $12,400 per employee or one-tenth as great. Since profits are a function of return on capital, and since taxes in turn are based on profits, it follows that the shale oil industry will produce taxes disproportionately high to its total number of employees. The industry will be a large taxpayer, making it especially important to the finances of Colorado.

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Chapter XI

Coal

by

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Because of its size the Index Map of Coal Bearing Areas planned for this page has been placed in the pocket.

CHAPTER XI

Coal

by

DR. PARKER O. YINGST*

Coal is one of Colorado's most important and plentiful natural resources. The total reserves of coal in the State have been estimated at 500 billion tons, considering all workable seams to a depth of 6,000 feet. Much of this coal is not extractable by current methods and equipment, but it represents a resource for the future when commercially applicable methods and equipment may be developed.

The estimate of currently minable coal reserves as of January 1, 1953, was 99,440 million tons, or sufficient to supply the national requirements, based on 50 percent coal recovery and present rate of consumption, for 125 years. A later estimate made by Landis (see 10 of the bibliography) as of January 1, 1956, placed the minable reserves at 80,779 million tons. Landis did not wish to include in his calculations large areas of coal bearing lands on which there is as yet little information. As more data is developed through geological studies and drilling, there is every possibility that economic coal deposits will be found in those areas and that the true reserves figure may approximate 100 billion tons.

About one-third of Colorado's area (Fig. A) is underlain by coal-bearing beds which extend, wholly or partly, over 32 counties. All of the coals in the State are of Cretaceous age or younger and were deposited in the area of the old Rocky Mountain Geosyncline. Colorado has the unique distinction of having coal deposits of a multiplicity of ranks, from subbituminous, through the various grades of bituminous, to anthracite.

History

Coal was mined early in the history of Colorado, at first by individuals for their own domestic use, but gradually, commercial production developed. The U. S. Geological Survey made the first official report on Colorado coal production in 1864; that year 500 tons were marketed.

The State Coal Mine Inspection Department began its official tally on coal production in 1873 with a figure of 69,977 tons for the year. Output continued to increase up to the peak of 1918 when 12,655,055 tons of coal were mined. Since then there has been a steady decline in production to a low of less than 3 million tons in 1954.

Nationally, the trend in coal extraction has more or less

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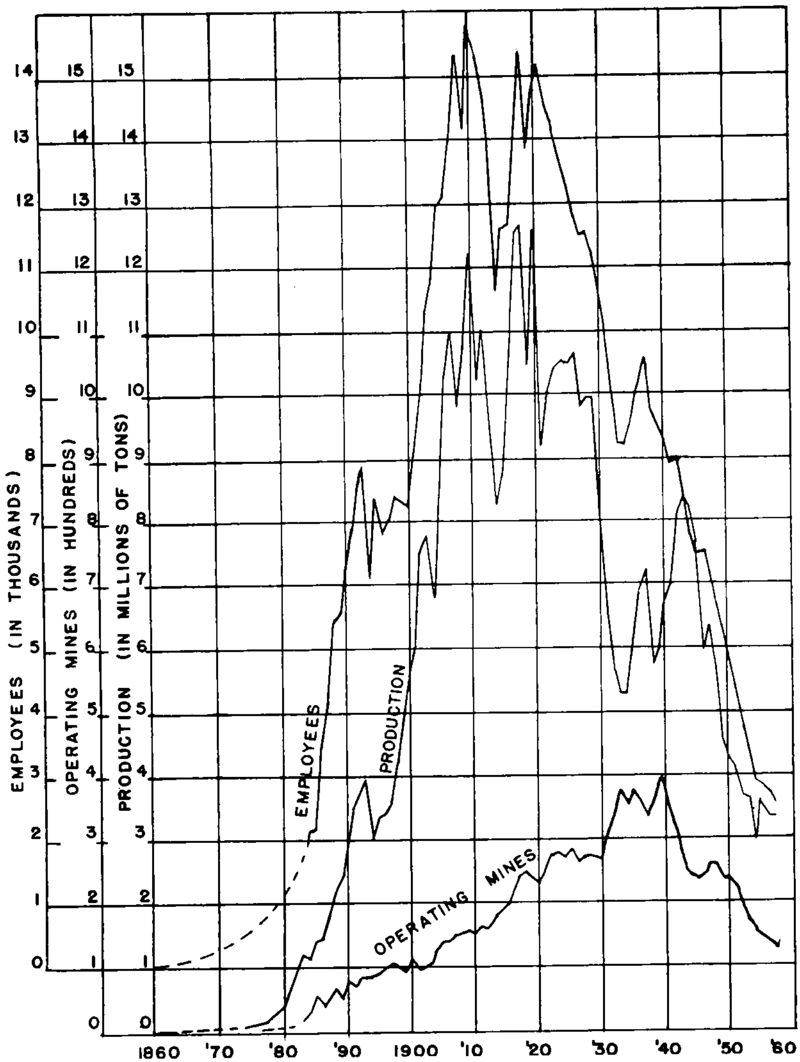
COLORADO
COAL MINING RECORD

Figure I

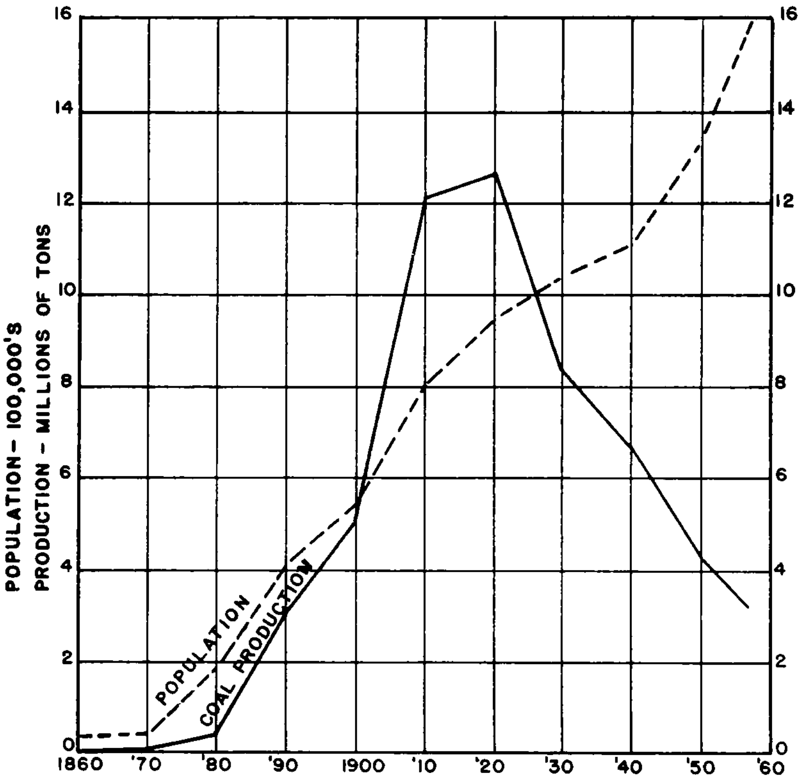


paralleled Colorado's pattern, or vice versa, but a gradual, healthy expansion of the industry is now predicted and it is forecast that by 1975 the national production will reach an all-time high of 700 million to 1 billion tons. The decline in coal consumption can be attributed chiefly to two major causes: competition from oil and gas which captured the domestic, railroad, and much of the industrial market, and the slowness of the coal industry to progress to advantage. Today, the principal consumers of coal are the steel smelters and the electric power generating plants.

Production and Markets

Up to 1918, coal production in Colorado roughly paralleled

Figure 2



COAL PRODUCTION — POPULATION

IN

COLORADO

(BASED ON CENSUS YEARS)

the industrial expansion and population growth of the State (see Fig. 2). Fortunately the coal deposits of eastern Colorado were located advantageously close to the population and industrial centers such as Denver, Colorado Springs, and Pueblo.

The adoption of improvements in coal mining methods was particularly slow in Colorado. Although mechanical loading was introduced in the State as early as 1925, the tonnage of mechanically loaded coal had increased to only 50 percent by 1944. In 1957 there was still as much as 10.5 percent of all coal extracted, and 14 percent of all underground production, being loaded by hand. Nevertheless, the changes which have taken place in mining methods and improvements in equipment have resulted in greater per-man yield; although not in total production which is dependent on demand. In 1890, the average per-man rate of production was 2.56 tons per day, as against 9 tons in 1958. The increase in per-man productivity is even more pronounced when the decrease in working hours per day since 1890 is considered.

A healthy trend in the utilization of coal which may bring about greater consumption-production, is one which has actually tended to reduce it—the more efficient use of coal as a fuel. This trend is quite marked in power generation. At the turn of the century as much as 10 pounds of coal were required to produce 1 kilowatt-hour of electricity. The national average today is 1.1 pounds per kilowatt-hour, and there are at present under construction plants designed to operate at supercritical pressures which are expected to reduce coal consumption to from 0.5 to 0.7 pounds per kilowatt-hour. Such reduction in per-unit consumption of coal may create a further decrease in production, but only until the more competitive position of coal thus attained makes itself felt.

The demand for electricity in the United States is increasing at a rate of about 7 percent per year, or doubling every 13 to 14 years. Steam power-generating plants are the least costly to build on a unit capacity basis, and it is expected that with increased efficiency in the utilization of coal as a fuel, the coal industry should capture a sizable share of this developing market.

In Colorado the demand for electric power has been increasing at a rate above the national average. This increase has so far been met almost entirely by steam plants and much of the future expansion should use coal as a fuel. Many of the plants now in operation, and most of the ones being designed or constructed, are equipped to convert readily to whatever fossil fuel the economics of the moment may favor.

Coal consumed by the steel industry as coke represents a very large portion of the present coal market, but here, too, technological advances have decreased the demand. Modification in blast furnace practice has reduced the amount of coke necessary to produce the same amount of steel. Then, too, larger blast furnaces require more rigid specifications on the type of coke used, so that some cokes which were formerly acceptable are no longer so.

Producing Fields

The individual coal fields of Colorado have been discussed in detail in various publications of the U. S. Geological Survey and the U. S. Bureau of Mines. Summary discussions of these fields are contained in this book under the respective county in which each is located. A selected bibliography of pertinent publications is given at the end of this chapter. Here we confine ourselves to submitting information on the past and current activities of the fields, and include production graphs for illustration purposes. These graphs emphasize the decline of Colorado's coal industry.

A. South Park Field

This field had a small production during a relatively short period of activity from 1880 to 1897. No production has been recorded from this field since 1897 (Fig. 3).

B. North Park Field

This field, opened in 1909, has achieved a moderate production, but has been relatively inactive since 1953. Its greatest activity occurred during World War I when a production peak of close to 100,000 tons per year was reached. Since then a few small "wagon mines" have operated sporadically for local consumption. However, in 1958 a new strip mine started operations and ended the year with a production of 30,103 tons. See graph, Figure 3.

C. Canon City Field

The Canon City field has been one of the most consistent producers in the State. Its peak came during World War I when production reached almost 900,000 tons per year. Today the field produces about 300,000 tons annually. In 1958, there were 21 active mines in the field, only one of which employed more than 10 men (Fig. 3).

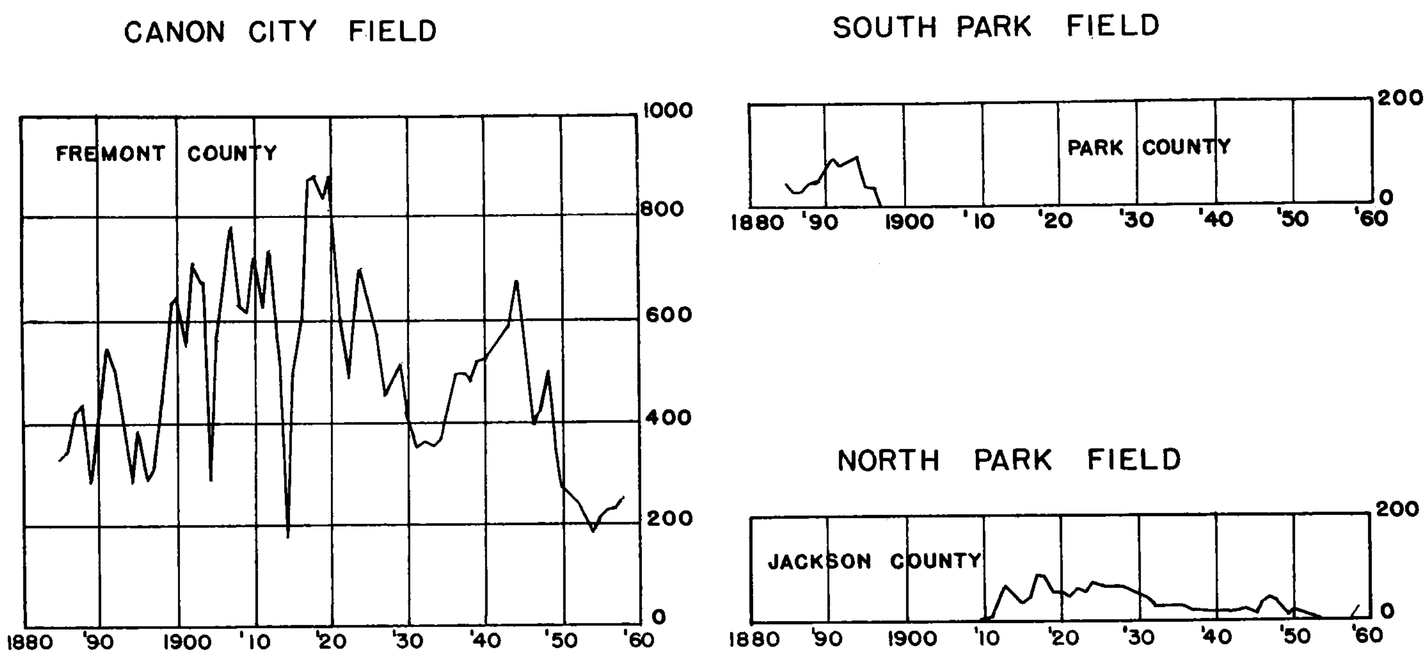
D. Denver Coal Region

The Denver Coal Region extends into Adams, Arapahoe, Douglas, Elbert, El Paso, Larimer, Jefferson, and Weld Counties. Compared to other areas, this coal region has enjoyed a long period of high productivity, chiefly because of its proximity to the Denver area markets. Current production is approximately the same as it was at the turn of the century; most of it originates in Weld and El Paso Counties (Figs. 4 and 5).

E. Trinidad Field

Production in this field has decreased considerably since its peak in 1910. Huerfano County contributed most of the loss, having dropped from over 2 million tons in 1920, to 63,350

Figure 3



ANNUAL PRODUCTION - 1000'S TONS

in 1958. Almost all of Huerfano County's coal is of the non-coking type. Las Animas County also experienced a decrease, but its production became more or less stabilized at about one million tons per year since the middle 1930's, but in 1958 it dropped again, to 774,000 tons. Most of Las Animas coal is of the coking type and the major part of the production is shipped to the steel mill at Pueblo. The most notable development in this field in recent years has been the opening of Colorado Fuel & Iron new Allen mine. This operation is an outstanding example of modernity in equipment and planning. There were 36 mines active in the Trinidad field during 1958, of which only five employed more than six men (Fig. 6).

F. Uinta Region

This coal region comprises a number of fields and districts. The coals include subbituminous, bituminous coking and non-coking, and anthracite. Generally, and in spite of considerable yearly variations, production in this region has held up quite well by comparison. Pitkin County, which had almost no coal production during 30 previous years, has been mining coal at a steadily increasing rate since 1950. The reason has been the growing demand for high-grade coking coals of the Carbondale and Redstone districts type (Fig. 7).

G. Green River Field

The graph on Fig. 8 illustrates the severe fluctuations in this field's production. The coals range in grade from sub-bituminous, bituminous, semianthracite, to anthracite, depending upon the proximity of the deposit to later igneous intrusions; the closer to the intrusion, the higher the rank of the coal. The most prominent development in this field in recent years is the stripping operations in the Edna and Osage mines. These pits contributed 84 percent of the field's 1958 total production of 386,635 tons. Fourteen mines in all were active during that year, most of them small operations (Fig. 8).

H. San Juan Region

Lack of transportation facilities and distant potential markets have prevented this region from comparable development. The coals are of the coking and noncoking varieties (Fig. 9).

Mining

In the early days of the industry in Colorado, all coal produced was either "pick" coal or was shot on the solid. The black powder used as explosive was ignited by fuse or squib. Later, the powder was replaced by dynamite, and later still, "airdox," "cardox," and permissible explosives came into use. These changes were necessary in order to reduce the large number of fatal accidents resulting directly and indirectly from blasting. Today, the use of explosives for breaking coal

Figure 4

DENVER REGION

ANNUAL PRODUCTION

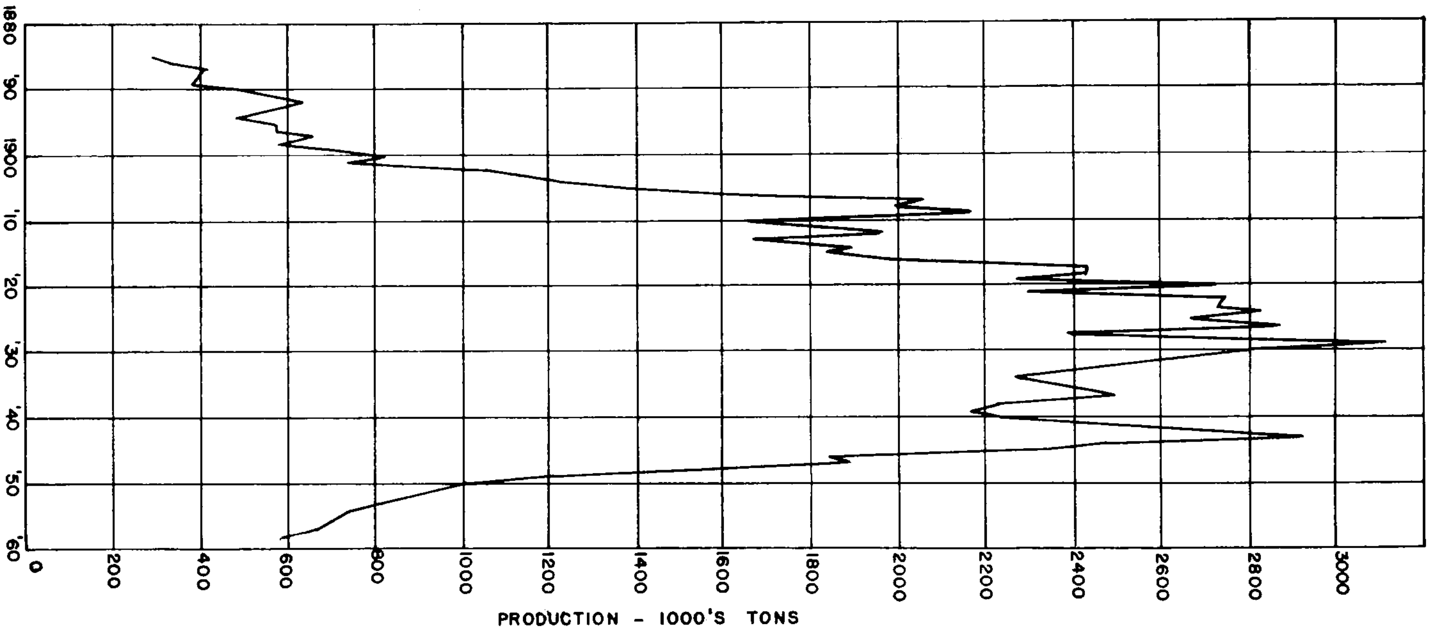
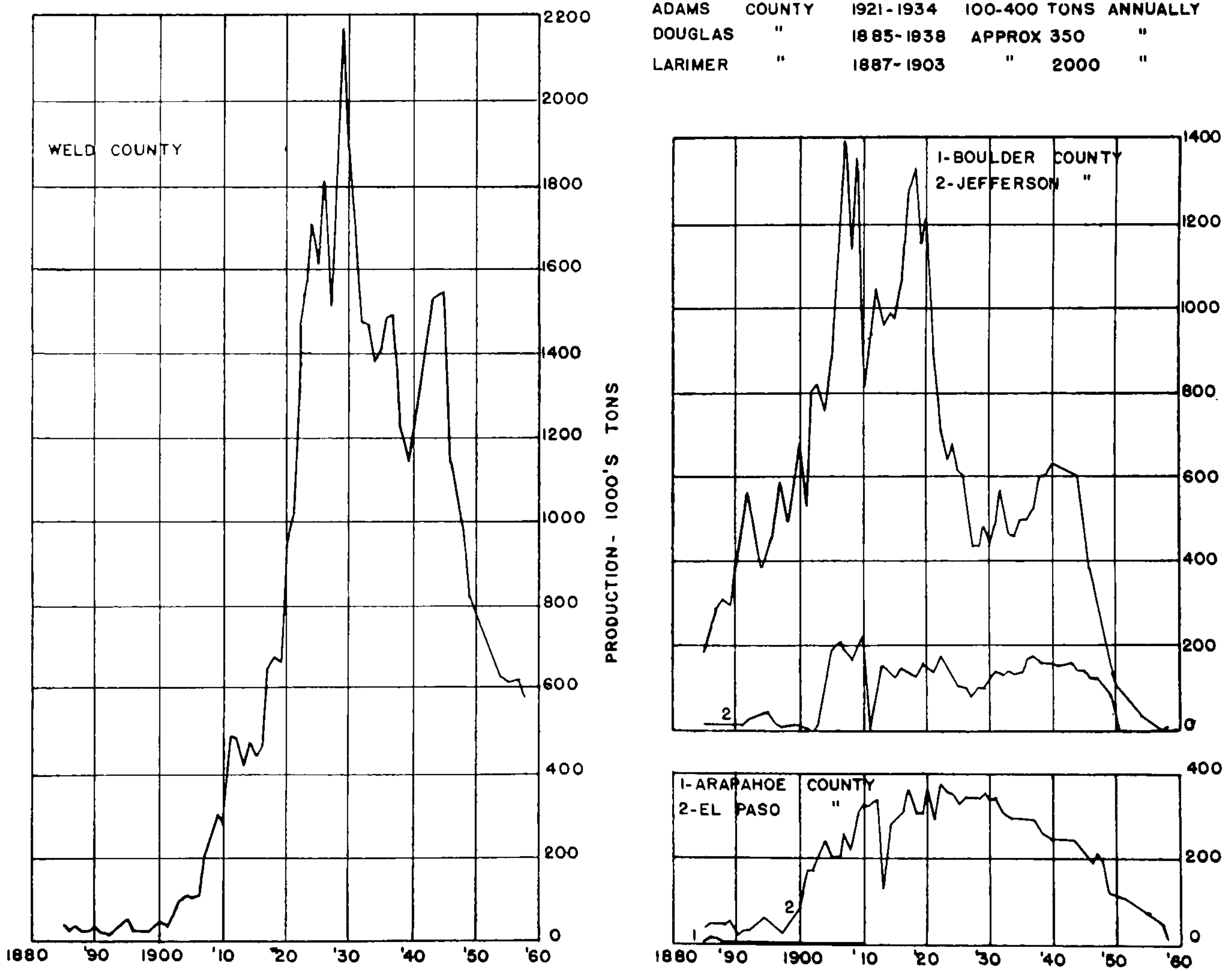


Figure 5

ADAMS COUNTY	1921-1934	100-400 TONS ANNUALLY	
DOUGLAS "	1885-1938	APPROX 350 "	
LARIMER "	1887-1903	" 2000 "	



DENVER REGION — ANNUAL PRODUCTION BY COUNTIES

Figure 6

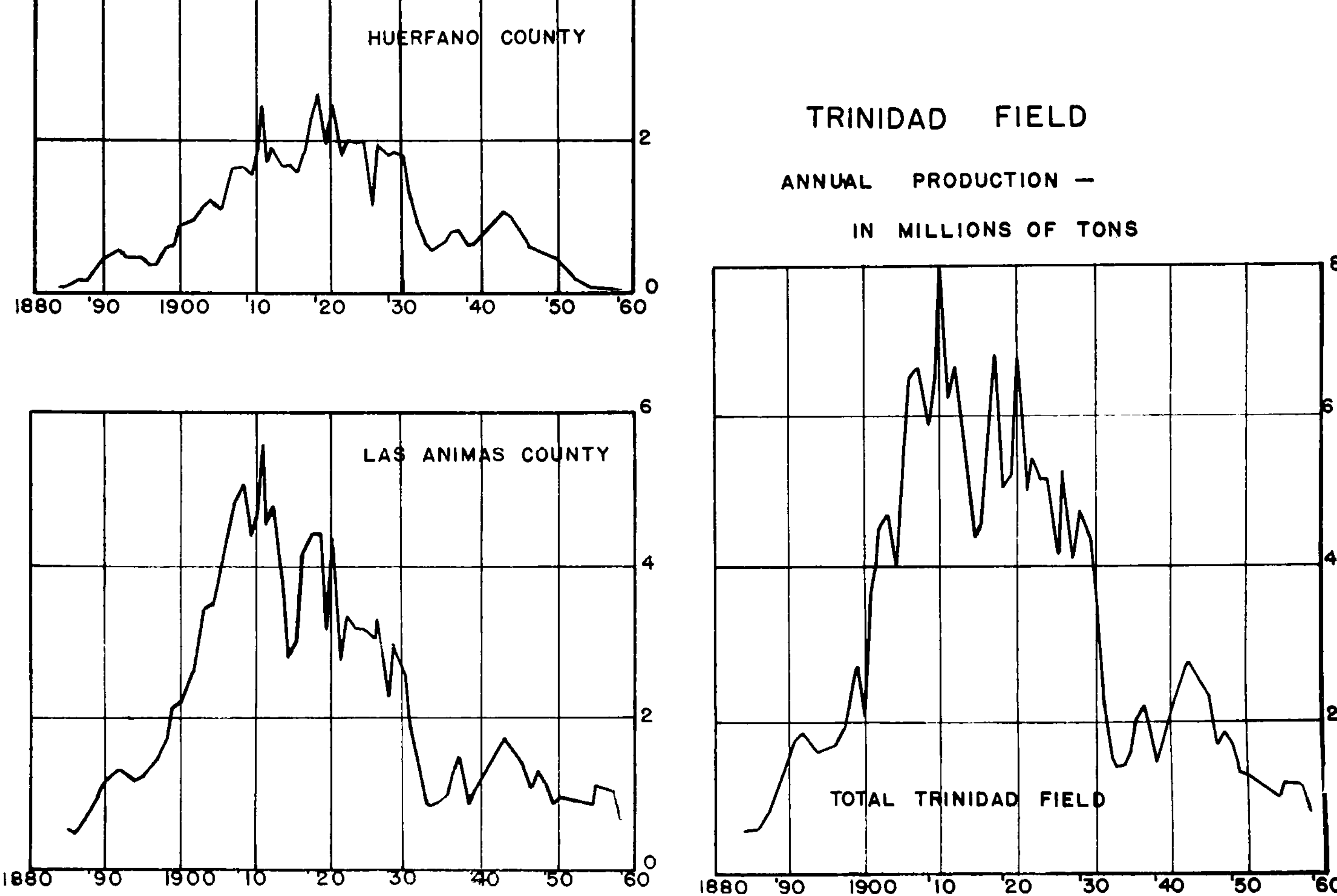
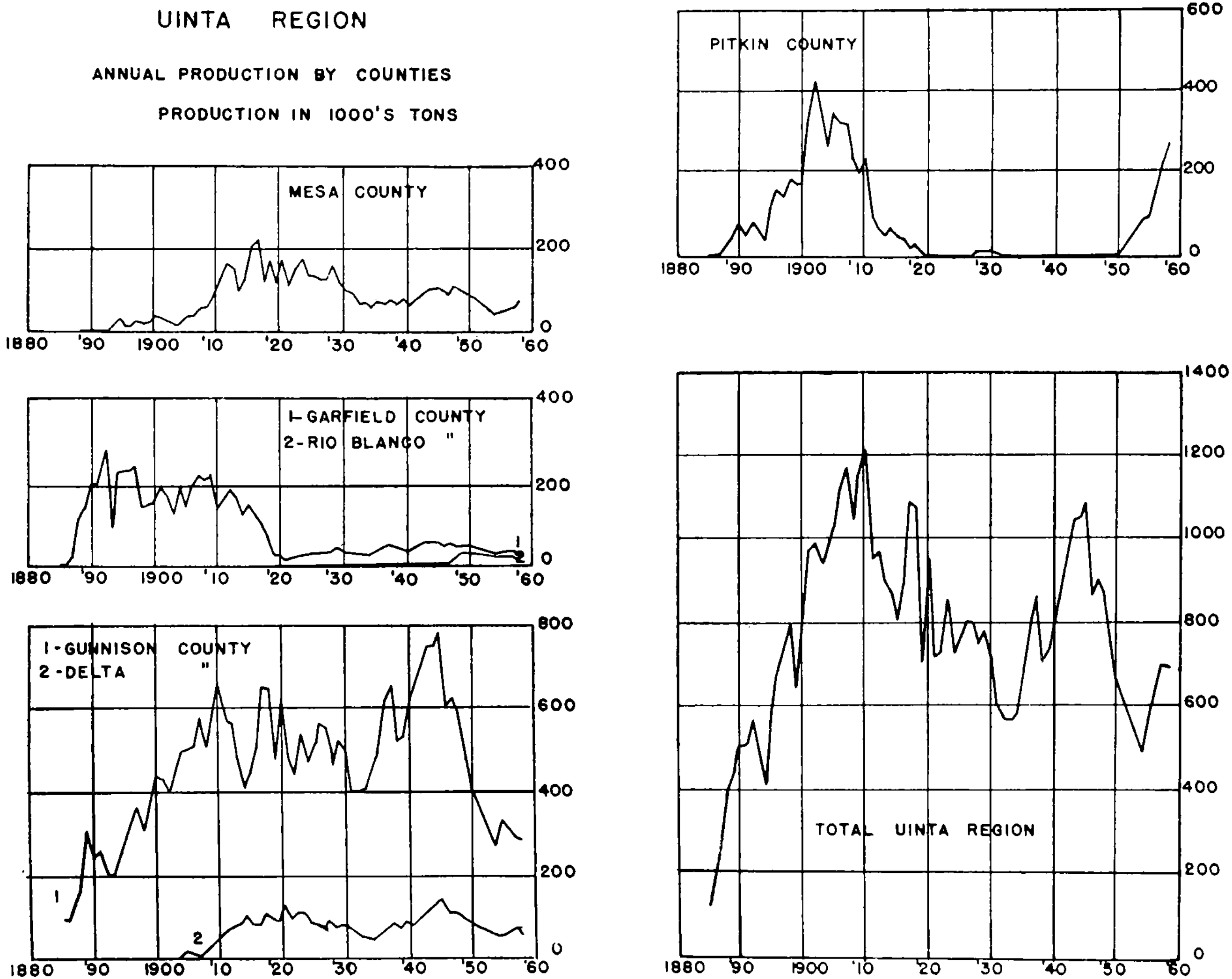

TRINIDAD FIELD
ANNUAL PRODUCTION —
IN MILLIONS OF TONS
HUERFANO COUNTY
LAS ANIMAS COUNTY
TOTAL TRINIDAD FIELD
1880
'90
1900
'10
'20
'30
'40
'50
'60
0
2
4
6
8

Figure 7


UINTA REGION
ANNUAL PRODUCTION BY COUNTIES
PRODUCTION IN 1000'S TONS
MESA COUNTY
1-GARFIELD COUNTY
2-RIO BLANCO "
1-GUNNISON COUNTY
2-DELTA "
PITKIN COUNTY
TOTAL UINTA REGION
1880
'90
1900
'10
'20
'30
'40
'50
'60
0
200
400
600
800
1000
1200
1400

GREEN RIVER FIELD

ANNUAL PRODUCTION —

1000'S TONS

Figure 8

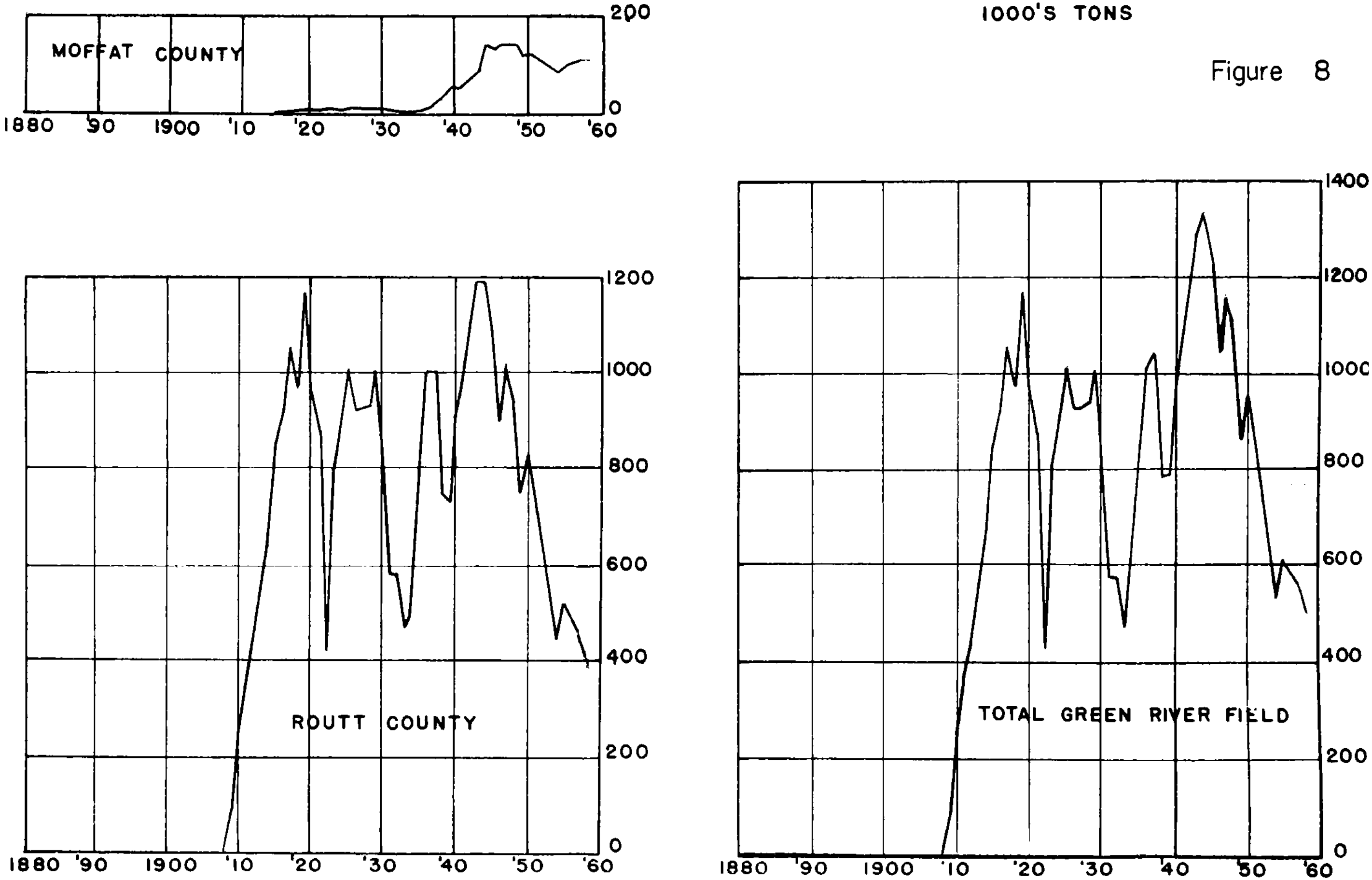
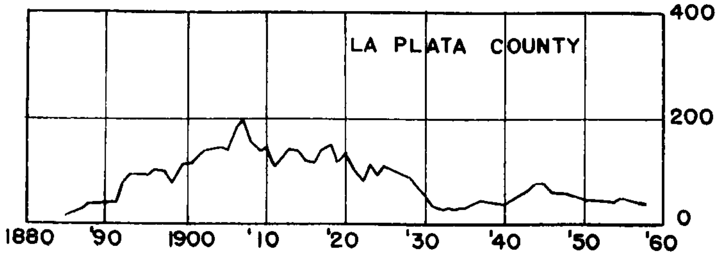


Figure 9



ARCHULETA COUNTY
1913–1955 200 TO 3700 TONS ANNUALLY

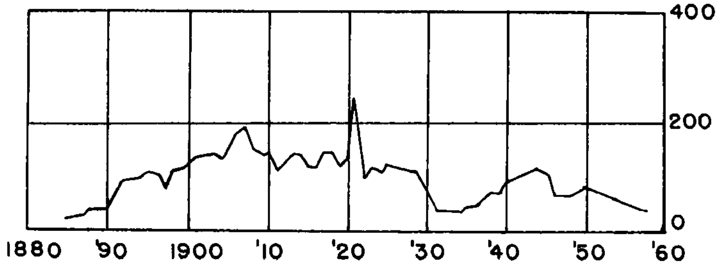
DOLORES COUNTY
1885–1930 SPORADICALLY TO 11000 TONS

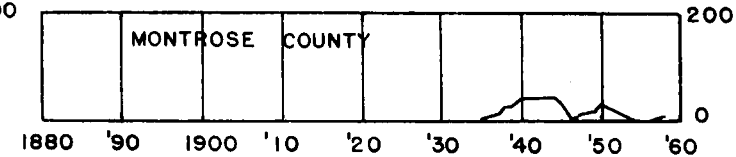
MONTEZUMA COUNTY
1885–1915 150 TO 8000 TONS ANNUALLY

SAN MIGUEL COUNTY
1919–1955 25 TO 1550 TONS ANNUALLY

SAN JUAN REGION

ANNUAL PRODUCTION - 1000'S TONS





is on the decline due to the increasing use of continuous mining machines which break and extract their own coal.

The undercutting machine, which preceded the continuous miner, was designed to cut a groove, or "kerf," under the coal, thus leaving it unsupported and permitting easy breaking with a minimum of explosive. This type of mining produced a maximum of lump coal which was the size most in demand at the time. However, as the utiliziation of coal progressed, the demand for lump coal dropped while it grew for fine coal. This circumstance permitted the development of the continuous mining machine. It is worthy of note that the first of these machines, precursor of the present Joy "Continuous Miner," was built in Denver and tested in the coal fields of Weld County.

The introduction of continuous mining machines has required considerable change in the development plan of coal mines. The vast capacity of these machines permits a decrease in the number of working faces while increasing daily production. Modern mine layouts provide for rapid depletion of working places, thus eliminating to a large extent the maintenance of large areas until the pillars can be extracted. Continuous mining machines involve a very sizable capital investment and it is essential that they be kept working as constantly as possible. Proper upkeep, time studies, and forward planning of the work cycles help to solve this problem.

In the early days of the industry, haulage was performed by manpower or draught animals. The first major change in this phase of the operation was the introduction of trolley and battery locomotives, the latter most particularly in gassy mines. However, any form of locomotive haulage is intermittent and not as desirable as a continuous system; for this reason many mines today use conveyors.

One phase of coal mining in which no notable change had taken place for many years is that of roof support. Timber was used almost entirely for this purpose until the introduction of the roofbolt. The adoption of the roofbolt has been rapid, although it is still undergoing improvements. Its employment has not only reduced the number of accidents from roof falls but has made it possible to maintain entries free of obstructions and provides increased headroom. A new form of roof support similar to the old fashioned cement grouting is at present under investigation. Various types of thermo-setting plastics are used instead of cement. Experiments of this nature with epoxy resins and polystyrene esters indicate that their bonding strength is sufficient to hold the heaviest ground that can be supported by roof bolts or conventional timber. However, there are still a number of problems which must be solved before this system can be generally adopted.

In the old days, mines using shafts for surfacing the coal always hoisted it in the cars in which it had been loaded. This made it possible to weigh the coal, less the car tare, and credit it to the miner who had loaded it. Today, with the changeover to mechanized mining and the elimination of individual tonnage accounts, many shaft mines are installing underground loading pockets and equipping the hoists with automatic, self-dumping skips.

Improvements have also been made in such equipment as drills, lighting, ventilation, and electrical installations. The hand-operated augers have been replaced by electric post-mounted or jumbo-mounted drills which have much greater capacity in both depth and rate of drilling. For drilling roof-bolt holes, small, specially designed air hammers are employed. Tungsten carbide cutting tips on cutter chains and on drills have almost eliminated the problem of steel sharpening.

Formerly, electric power was brought into the mine at the low voltage required by the equipment. Today, power is brought in at high voltage and reduced to requirements at underground substations. In many cases, diamond drill holes are used to let the main cables into the mine, thus eliminating the normal hazards which develop when the cables are strung along the haulageways. Illumination, too, has been improved through the use of floodlights, and experimentation has shown that fluorescent lighting is feasible underground.

Communications have also come a long ways in coal mining. Block signals, telephone, radio, and even closed-circuit television have been brought into play. Where locomotive haulage is in use, block signals may be used for traffic control, or the locomotive man may be in direct communication with the dispatcher by radio. Telephones are located in all sections of the mine. A recent development, especially in mines using belt haulage, is the use of closed-circuit television cameras located at strategic points such as transfer points. The operator at the control panel can thus "see" any failure or developing trouble and stop the equipment before major damage, or any damage, is done.

Ventilation has undergone numerous changes as operators learned more about the problem and realized that it represents one of the large items on the cost sheet. Today, air courses are maintained as free of sharp curves and obstructions as possible. Regulators and airlocks are used to a great extent to prevent shortcircuiting of the air and to insure its maximum distribution in the mine. A big step forward was the development of the axial flow fan which provides more air at greater pressures than ordinary fans. The higher pressure obtained with these fans permits the elimination of many auxiliary booster fans.

Very few changes have been made in the methods used for mining steep-dipping beds. The most difficult seams to mine are those which dip over 15 degrees and less than 35 degrees. These dips are too steep to permit the use of conventional mining and loading equipment, and too flat to permit loading the coal by gravity. Scrapers and conveyors are used under these conditions to move the coal to the entry below and to the cars. The coal plane, which is widely used in the European coal fields on longwall faces, is also being used there in modified form to mine steep seams. The "plane" can be likened to a scraper able to work on a vertical face. It takes a cut along the seam, and as it cuts it moves the coal away from the face onto a conveyor belt alongside. The modified coal plane may find favor in some of the coal mining districts in Colorado.

Probably the most notable changes in coal mining are those which have been brought about by the adoption of strict safety codes. The numerous mine explosions and fires which caused the deaths of many coal miners and heavy financial losses to the operators, necessitated and brought about the adoption of a uniform and strict set of regulations. This code is enforced by the U. S. Bureau of Mines and by the proper authorities within the individual States. The resulting changes have been so pronounced that a miner of 40 years ago would hardly recognize the coal mine of today. Formerly, waste material and spillage was "gobbed" on the sides of a room and along the haulageways; trolley wires and power lines were strung along entries in a haphazard manner; men carried open-flame carbide lights; clothing was torn and baggy; every foot of the underground, and much of the surface, was covered with coal dust; electric switches were often of the open, knife type; motors were not enclosed or guarded; air courses barely permitted passage of personnel; and the air at the working faces was very poor.

Today, it is required that all entries and passageways be clear of debris; trolley wires, where used, are hung from rigid insulators at fixed heights above the floor and guarded in those places where men must pass under them; magnetically locked battery cap-lamps of over 50 candlepower have replaced the old carbide lamps; clothing must be snug fitting and hard hats and hard-toed shoes are mandatory; all working places and entries must be rock dusted at regular intervals to reduce coal dust to less than critical concentrations; electrical equipment underground must be completely sealed in dust and gas-proof jackets or covers; air courses must be maintained clear, and free of obstructions, and ventilation at the working faces must be maintained well above the needs. The practice of rock dusting alone has completely changed the "face" of the coal mine. Whereas before, everything was black and light-absorbing, now it is white to gray, and light-reflecting, so that even with the same amount of illumination, the working places are better lighted and therefore much safer. Another safety measure is the use of water sprays on all dust-creating equipment such as cutting machines and continuous miners, and in localities where dangerous coal dust might be raised, such as loading points, and conveyor transfers.

Large mines have constructed elaborate repair shops underground. These shops are quite complete and only the largest of equipment need be taken outside for overhaul. The ease of accessibility to these shops makes it possible to make repairs as the need arises and thus to keep down-time at a minimum.

Open pit, or strip mining, has not changed a great deal in procedure, but has changed a great deal in the equipment used. Thirty to forty years ago, a five-yard dipper on a shovel was about the largest, but today that size would probably be relegated to clean-up work only. The size of equipment used has gradually grown until at present 50-yard dippers are common. The coal is loaded into trucks of 50-ton capacity and hauled to central cleaning plants. Drilling has also improved to where it is possible to work much higher faces than previously.

A new and intriguing development in coal mining that is becoming more common under certain conditions is "auger mining." Small, isolated coal deposits which may not warrant underground mining, or may have too much overburden for strip mining, may possibly be mined economically by auger. Augers 4 to 5 feet in diameter bore into the coal and lift it to the surface as they progress. Auger sections are added as needed. Holes 1,000 feet deep have been mined out by this method. The units are powered by electric motors or diesel engines, and are semiportable in that they can be moved readily from hole to hole; the holes are spaced as closely as possible.

Most developments in coal mining have been directed toward improving the competitive position of coal through increased production without a corresponding increase in its unit cost. Progress in these aims has been reflected over the years in the gradual increase in man-shift productivity. In 1908, the national average amount of coal produced per man-shift was 3.34 tons, by 1953, the figure had risen to 8.17 tons. In Colorado, the 1955 figure was 5.84 tons in underground mines, and 24.41 tons in strip mines.

Preparation

Coal preparation methods have undergone many changes which parallel the progress achieved in the mining phase of the industry. In the early days, the miner would simply sort out a certain amount of waste underground and that would represent the full extent of coal preparation, but gradually the market became more demanding, and the "breaker" came into use. Breakers were actually screening plants arranged in such way as to permit ready handsorting of the various coarse sizes. This crude improvement in coal preparation was the only one introduced for a number of years. Later, water sprays were used to clean the coal of the fine dust, and still later, the coal was sprayed with various coatings, generally oil, to allay dust in transportation and to prevent freezing together. As competion became stronger, the operators searched for ways of improving their product and of recovering more of the coal which was going to waste in the high-ash discard material. One of the first developments was that of crushing the coarse waste material and treating it on tables and jigs. This procedure helped to recover some of the coal which had previously gone to waste, but nothing was done to improve generally the run-of-the-mine coal until the heavy duty jig, long in use in treating metallic ores, was introduced in coal preparation. The jigs, which are still in use, produce a fairly clean coal and a high-ash reject. The reject is frequently retreated for additional recovery of coal by crushing it finer and running it through secondary jigs. The jigs have made it possible to produce coal to certain ash specifications within certain limits.

The next development in coal preparation was the sink-float method of gravity separation, now more commonly known as the heavy, or dense media, process. This method involves the preparation of a synthetic heavy liquid of a desired specific gravity through the addition to water of finely ground magnetite or other heavy material which is cheap and plentiful. Through proper control of the specific gravity of the dense media it is possible to obtain a float product (coal) of the desired ash content within reasonable limits. The changeover from dry preparation plants to wet plants has necessitated the addition of filtering and drying equipment for fine-sized coal. For this purpose, the centrifugal drying unit has found much favor, but thermal drying is also used and preferred by some.

Coal preparation plants of today are a far cry from the "breakers" of the early days. Generally they are very clean, well lighted, and the equipment is arranged efficiently. Many of the plants are operated from master control panels and, in some cases, include closed circuit television cameras located at strategic points. Automatic electronic controls are used on many of the operations within the plants.

The Future and Research

It is generally believed that the coal industry has reached its low point and that the future will demand increased production. There are factors, however, which will affect future market trends, and others which will bring about additional changes in coal mining, preparation, and utilization.

It must be recognized that certain markets have been lost as far as raw coal is concerned, but these markets will be regained in some degree in the future by coal but as a processed fuel, i.e., as a gas, liquid, or carbonized char. This refers specifically to the railroad, domestic, and industrial markets.

The railroads of the United States consumed about 132 million tons of coal in 1944 at the peak of wartime activity.

Since then they have almost totally converted to diesel-electric power with the result that coal consumption in 1956 by the railroads amounted to only 12 million tons. This market may be regained gradually at some future date by coal processed into diesel fuel. Also, some raw coal may be used as fuel in direct-burning turbines for driving locomotives.

Various methods of converting coal into gaseous and liquid fuels have been developed. These methods generally fall into the main classes of hydrogenation, carbonization, and oxygenation, and each is capable of producing a number of products, such as oils, gases, heavy tars, gasoline, and chemicals. Large capacity plants of these types require very high capital investments. It is very probable that coal for use in these plants will have very stringent specifications as to ash content, sulfur, moisture, trace elements, etc., which will in turn require more elaborate coal preparation.

In markets other than those previously mentioned, coal will be confronted by stronger competition from other sources. The steel industry consumes large quantities of coking coal in the manufacture of pig iron and steel. In recent years various processes have been developed which, if successful, may eliminate, or drastically reduce, the amount of coke required for iron and steel production .The most notable of these developments is the Krupp-Renn process. To meet this competition the coal industry will need to improve coke quality and learn to upgrade many of the low-grade coking coals in order to produce premium quality coke.

Coal for electric power generation will face competition from nuclear power plants, but at present the initial cost of a nuclear power plant is much higher per unit capacity than a conventional coal burning, steam-generating power plant, so that the economics for the immediate future favor the coal industry. The electric power requirements of the United States are doubling every 13 to 14 years, and this circumstance appears to hold the best opportunity for the coal industry.

Much research work is underway in electric power generation, especially in the "supercritical" steam pressure ranges. No doubt the coal which would be used in such plants would need to have strict specifications as to ash content and ash fusion temperatures.

It is envisioned that the coal mine of the not-too-distant future will probably form part of an integrated over-all plant involving the mine proper, a preparation plant, a byproducts plant, a power plant, and either a refinery or chemical plant. Naturally, such installation requires a very heavy capital investment and the proper assurances to justify it. Aside from capital, the primary consideration is a large reserve of coal capable of lasting at least 50 years at peak operating capacity.

The type of byproducts plant planned as part of the over-all installation would depend upon the types of byproducts desired, limited, of course, by the types for which the particular coal to be used is best suited. Availability of water at the site chosen for the complex may influence the selection of byproducts to be made, or the degree of completion to which they will be carried in the manufacturing process.

Availability of a plentiful supply of water must also be considered if the electric power plant part of the integration is to utilize steam. Research is at present being conducted in the adaptation of the gas-fired turbine to burn coal. If the work now in progress attains success, the water requirements for power generation would drop to a minimum.

Increasing use of pipelines for the transportation of solids in liquid slurries will certainly come in for much consideration in selecting a site for the integrated installation. This is a development whose applicability to the problem would require careful weighing. Through the use of pipelines for transportation, the coal may be piped to the byproducts plant and all the products in turn pumped to the areas of consumption. At the present time a pipeline is being used to transport coal 108 miles in the State of Ohio. Gilsonite mined at Bonanza, Utah, is transported 70 miles by pipeline to a refinery near Grand Junction, Colorado.

A possible source of potential profit of interest to the coal industry is the presence of trace elements in coal. Small amounts of uranium, germanium, and other elements are contained in coals from certain areas. Effective research will some day be conducted for the development of economic methods for the extraction of these trace elements which concentrate in the ash, or go off with the products of combustion.

Waste products of the coal industry are being subjected to appreciable research for possible applications in commerce or industry. The material which is now going to waste dumps could possibly be converted into millions of dollars of additional income. It has been determined that shale and slate, when subjected to shock heat treatment, expand to form a very desirable lightweight aggregate. Fly-ash from boilers using pulverized coal is used in various ways by the construction industry, such as in building blocks and in substituting for some of the sand and cement in concrete. At a mine near Aachen, Germany, four products are made in the preparation plant: coal with an ash content of 5 to 6 percent goes to the coking ovens; another product, containing nearly 40 percent ash, is used as power plant fuel; a third product with from 70 to 80 percent ash is gasified, and the fourth and final product is used for road ballast—no waste.

Much research has been performed on coal and much more still remains to be conducted. Basic research is underway at a number of educational and governmental institutions, and at some of the laboratories of the larger companies, but the amount of money being spent on coal research as compared to other industries of comparable importance is not sufficient. Some of the projects currently active at various institutions throughout the country are briefly discussed below.

Research to use coal tar as road surfacing material is now advanced to the testing point; several states have put in, or are putting in sections of test roads. The amount of coal used directly or indirectly for this purpose amounts to between 2,000 and 2,200 tons per mile of pavement. If this process is perfected to utilize the high volatile coals of Colorado, it would represent a potential additional market of 600,000 tons of coal for annual new road construction in the State.

Research is also underway on the problems of fine grinding of coal and the associated problem of ash removal. The use of irradiation for improving the fine-grinding characteristics of coal is at present under investigation. Several projects are being conducted to develop means of removing the ash content to percentages permissible for use of the fine-ground coal as fuel in direct-burning turbines and diesels.

In mining, much research and planning is going into automation. One plan is being studied which would permit mining to a depth of 1,000 feet entirely by remote control. Much money and time is also being spent on the improvement of present equipment in all phases of the mining operation.

In the byproducts field, high-temperature carbonization has been well proven and the liquid products are well known. In the low-temperature field, the process is also well proved, but much remains to be learned respecting the refining and use of the low-temperature products derived.

The future will probably see much work performed on coal petrography and in attempting to correlate the different physical, chemical, and petrographic characteristics of the constituents in this fossil fuel. These things must be investigated and learned in order to have a better understanding of coal which will enable the industry to place its product in the best competitive position possible.

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PART IV

Petroleum and Natural Gas

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HISTORICAL SUMMARY—DR. ARTHUR E. BRAINERD,
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OIL AND GAS CONSERVATION IN COLORADO—
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PART IV

Petroleum and Natural Gas

The last decade has witnessed a tremendous growth in importance of the petroleum and related industries in the economy of Colorado.

The aggregate value of production of petroleum, natural gas, and natural gas liquids, has grown from $16 million in 1946, second only to that of coal at $24 million for the year, to a peak of $178 million in 1957, $160 million in 1958, and $154 million in 1959. The over-all petroleum industry became the leader in 1947 in value of production of all minerals produced in the State, a position which has not been challenged since. In 1958, the industry contributed 52½ percent of the total value of Colorado's mineral output, and 49½ percent in 1959.

Because of the economic importance to the State of the petroleum industry, we have endeavored to present in this section a discussion of its history, the geology of the various producing and potential areas, conservation, and other pertinent data in as complete a manner as is compatible with the space available. Other data appertaining to hydrocarbon possibilities within individual counties, are presented in the preceding county by county mineral resources discussions in Chapter III of this book.

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Chapter XII

Historical Summary

by

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CHAPTER XII

Historical Summary

by

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Despite the circumstances of Colorado having been the second state in the Nation to produce oil from drilled wells, and the considerable amount of wildcat drilling which continued throughout the early years, the State did not become an important producer of hydrocarbons until the middle of the 1940's. The reasons for this are entirely economical; up to that time: local markets were of modest proportions; transportation facilities to out-of-State markets were inadequate; a discouragingly small amount of oil was developed considering the considerable footage drilled on favorable structures; and drilling depths required to test adequately many of the most promising structures were then almost prohibitive.

The vastly increased demand for oil created in the 1940's by World War II encouraged the development of the deeper pay zone (Weber) at Rangely, which had been discovered in 1933. The success encountered by this deeper drilling stimulated interest in oil exploration throughout the State and thus the latest era in the development of Colorado's petroleum industry began.

Early Years

In the Spring of 1862, about a year after Colorado Territory was formed, Mr. A. M. Cassedy, a pioneer in the Oil Creek development in Pennsylvania, came to Colorado and drilled a well to a depth of 50 feet near the live oil seep which is located in the Morrison formation on Oil Creek about six miles north of the present site of Canon City. The discovery was located in the south-central part of what is now T. 17 S., R. 70 W., Fremont County.

Oil in small quantities was found in the first well, and also in the next five or six subsequent wells which ranged in depth from 50 to 90 feet. The oil was refined by a primitive method and the products, mainly kerosene and fuel oil, were sold in Denver and in the mining camps to the west until about 1870. The gasoline cut was burned or discharged into the creek as a waste product.

The Cassedy discovery well was completed about two and one-half years after the Drake well in Pennsylvania, the first drilled oil well in the world, and thus Colorado became the second state in the Nation to produce oil from drilled wells.

In 1876, Mr. Isaac Canfield drilled a discovery well south-

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east of the Cassedy discovery, a short distance south of the town of Florence, Colorado. Oil was encountered at a depth of 1,187 feet in joints and fissures of the Pierre (Cretaceous) shale on a monocline forming the east flank of the Canon City embayment. This was the discovery well of the Florence field which is located chiefly in Ts. 19-20 S., R. 69 W., Fremont County, Colorado.

From 1876 to 1902 the Florence field was the only producing oil field in the State. Two companies were formed early in the life of the field, the Florence Oil Company, and the United Oil Company. These two companies, taken over later by the Continental Oil Company, carried on the development in the field which at that time was fairly rapid, as indicated in a letter received recently by Thos. S. Harrison from Martin Rathvon of Casper, Wyoming. Mr. Rathvon advised that he came to Florence in 1894 with his father, Mr. William R. Rathvon, later General Manager, Land Department, United Oil Company, and at that time he drove the stake for well No. 75. Well No. 42, which was drilled in April, 1889, is still producing some oil to this day and is probably the oldest producing well in the country, if not in the world. The timing on the above wells would indicate that six or seven were being drilled each year in the period around 1890. It is interesting to note that because of the unusual nature of the reservoir (fissured shale), the ratio of dry holes to producers was exceptionally high for a proven area.

The peak of production at Florence was reached in 1892 with about 824,000 barrels listed for that year (Colorado Year Book, 1931). The decline was rapid and consistent. In 1900 the field produced 317,000 barrels; in 1923, production was 86,000, and in 1953, with the Canon City extension included, only 29,500 barrels were produced. Nearly 1,300 wells have been drilled to date and the field has produced approximately 14,500,000 barrels of 32-degree API oil.

In 1890, a well drilled on the White River anticline of northwestern Colorado, Ts. 2-3 N., Rs. 96-97 W., Rio Blanco County, found a small amount of sweet gas in the Wasatch formation of Tertiary age. In later years other wells drilled on the structure have obtained gas with initial flows listed from 2 million to 15 million cubic feet daily. In 1944, the Frontier Refining Company drilled a well on the crest of the anticline to a depth of 7,005 feet, ending in the Mesaverde formation. Some shows of gas and oil were encountered but no commercial production was obtained.

A small amount of wet gas was found in a well drilled in southeastern Colorado near Garcia, Ts. 33-34 S., R. 62 W., Las Animas County, in 1898. Gas occurs in the Apishapa shale of Cretaceous age. The occurrence encouraged some later drilling in the area, but to date, nothing of commercial importance has been found.

In 1902, the Boulder Oil Company completed a small discovery well, McKenzie No. 1, T. 1 N., R. 70 W., Boulder County, which opened the Boulder oil field. This represents the earliest commercial production in the Denver Basin. The Inland Oil Company followed the completion of the discovery well with several commercial wells a few miles to the north. The oil occurs in sandy and fractured zones in the Pierre (Cretaceous) shale. The oil has a 43-degree API gravity. Mr. Martin Rathvon, in a recent letter, stated that the Inland Oil Company well No. 13 had an initial flowing potential of 60 barrels per hour, and was the first flowing well in the State.

The Boulder field was quite active for several years, reaching a peak of production in 1909 of 85,700 barrels. The decline was rapid, and by 1914 production had dropped to 7,000 barrels. In 1959, the production was only 1,700 barrels. The Inland Oil Company had a pipeline from its wells to a small refinery built by the Company to the east of Boulder. It is estimated that the total production for the field at depletion will be under 800,000 barrels.

Another Colorado discovery was made in 1902, on the Rangely anticline, Rio Blanco County, Ts. 1-2 N., Rs. 101-102 W. Oil of 43-degree API gravity is found in the porous parts of calcite veins in the Mancos (Cretaceous) shale at depth of from 500 to 1,700 feet. The veins follow fracture lines running nearly at right angles to the axis of the Rangely anticline on which prolific production was later found in the Weber (Pennsylvanian) sand. The reason for drilling was probably the existence of oil seeps along the valley of the White River where it crosses the anticline. It is reported that some oil staining was found in some of the calcite veins along the valley.

For many years the Raven Oil Company maintained a small topping plant in the field and the products were sold in northwestern Colorado and northeastern Utah, the Continental Oil Company being the main marketer. Operations at the plant were discontinued in the middle forties.

The production of shallow Rangely oil, as late as 1920, was only 16,000 barrels. The 1953 production was approximately 210,000 barrels. For 1959, it had increased to 621,000 barrels.

Following the shallow Rangely discovery there were other interesting but noncommercial developments, such as the finding of carbon dioxide gas in a wildcat well at Black Canyon in Delta County; small showings of oil in wells at Debeque, Mesa County; a small gas discovery at Beecher Island in Yuma County. All of these developments were prior to 1923. In each case the real importance was to indicate a need for future exploration and study of the general area.

During the years 1876 to 1923, the three commercial oil fields discovered are estimated to have added a total of 20 million barrels to the State's proved oil reserves.

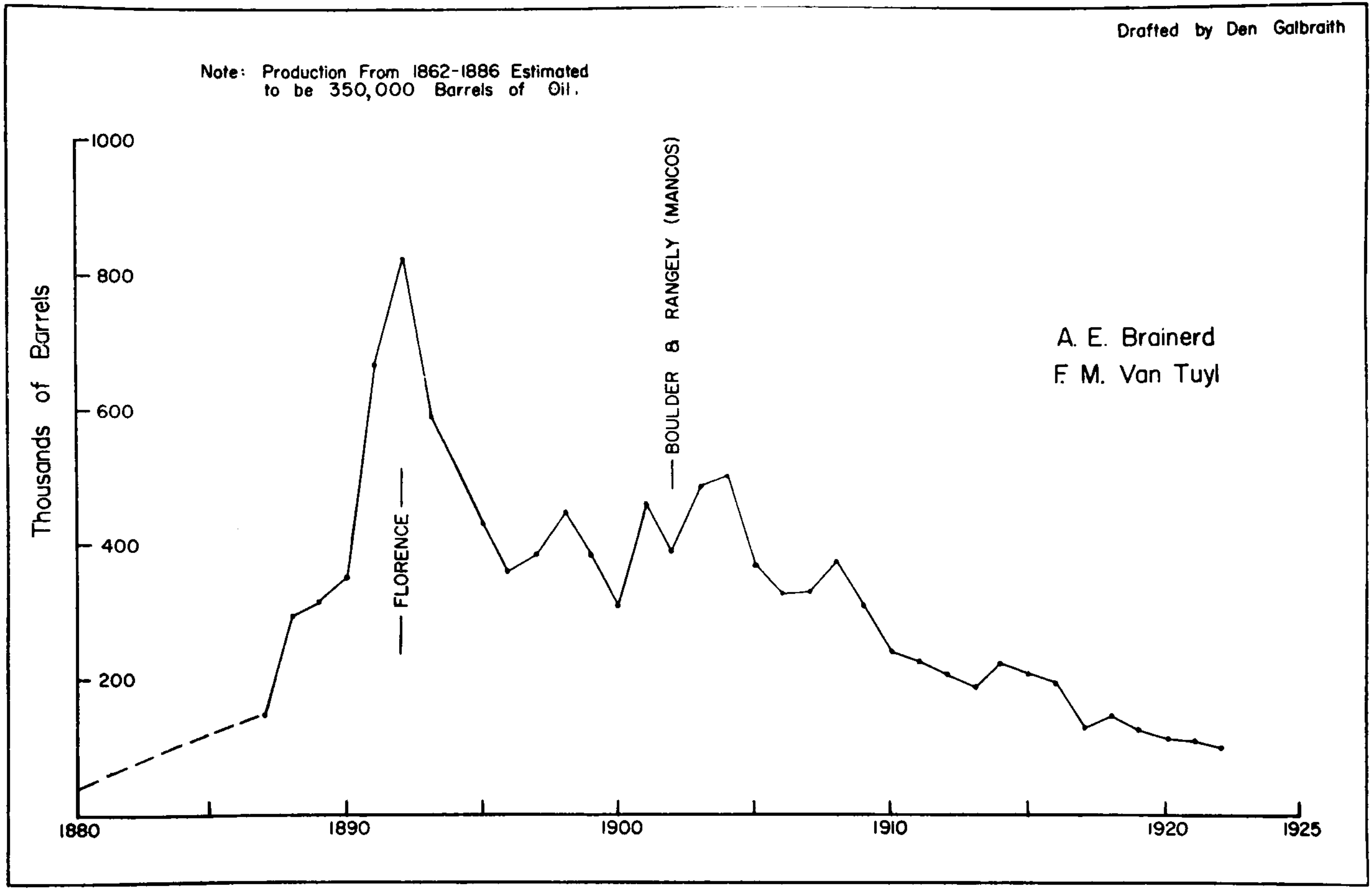

FIG. I. COLORADO OIL PRODUCTION CURVE — EARLY YEARS — 1862-1922

The year 1922 may be considered as closing the first cycle in the exploratory development of Colorado's petroleum industry. Between 1862 and early 1923 only three producing oil fields had been found. These were discovered by random wildcat wells. Two of these fields, Florence and Rangely, had evidence of oil in nearby seeps. No discoveries were made from 1902 until late 1923, a period of about 21 years. Production had declined in the State to 86,000 barrels for the year 1923. Colorado's population had increased to just under one million people, and the demand for petroleum and for petroleum products had increased apace. Petroleum products from the Midcontinent area, and from Wyoming, were being brought into the State in ever larger quantities. The need for increased exploration and development of new fields had become imperative.

The accompanying production curve (Fig. 1) shows graphically the results of oil development in the State from 1887 through 1922.

Intermediate Years (1923-1943)

For a number of years prior to 1925, several publications, issued as quarterlies by the Colorado School of Mines, and as bulletins by the Colorado Geological Survey and by the U. S. Geological Survey, contributed useful information on the stratigraphy, structure, and oil and gas possibilities of certain areas of the State which was very helpful in petroleum exploration.

Just before, and through the 1920's, many oil companies were represented in Colorado with exploratory groups. Some of the more active ones were, Carter Oil Company, Continental Oil Company, Gulf Oil Company, Marland Oil Company (now Continental), Midwest Refining Company (Stanolind), Ohio Oil Company, Producers and Refiners Corporation (Sinclair), California Company, Roxanna (Shell), Sun Oil Company, Texas Company, Union Oil Co. of California, and others. There were also several independent groups in Denver in the early 20's which were very active in geological exploration throughout the State. Early exploration was directed to the search for anticlines and domes with substantial closure, together with detailed stratigraphic studies.

As result of the geological work carried on by the State and Federal surveys, the oil companies, and individuals, and subsequent test drilling, several new fields were discovered and Colorado entered a second cycle of development. The industry was badly crippled during the depression years from 1929 to 1933, but recovered somewhat in the next three years. This is shown on the accompanying production curve (Fig. 2).

On November 11, 1923, the Union Oil Company of California brought in a large oil and gas well on the Wellington anticline, T. 9 N., R. 68 W., about 13 miles north of Fort Collins, Larimer County. The discovery was in the upper sandstone (Muddy) member of the Dakota group of Cretaceous age. This was the first important sandstone production in the State. The discovery well, estimated at 82 million cubic feet of wet gas daily, got out of control and blew wild for 49 days. Before it was brought under control, the gas cap was substantially depleted and there was a considerable spray of oil. The Wellington structure had been determined to be a closed anticline by detailed geological surface work in earlier years and the well was located on the strength of this mapping. To the end of 1959, the field had produced a little more than 6 million barrels of oil.

Only a short time later, on March 3, 1924, the Texas Company brought in the discovery well on the Moffat (Hamilton) dome, Ts. 4-5 N., R. 91 W., Moffat County, about 14 miles south of Craig. The structure had been detailed by surface methods before the location was made. Production was found in the Dakota sandstone of Cretaceous age, and the initial flow was rated at 4,560 barrels of 41-degree API oil daily.

The discoveries at Wellington and Moffat attracted nationwide interest to Colorado. Geological field work was increased greatly, and late in 1924, there were about 100 drilling operations in the State, the greater number of which were exploratory. All the discoveries during the next 15 years, with possibly one exception, were made as a result of geological exploration and advice.

Two additional oil fields were discovered in 1924. The Union Oil Company of California brought in a discovery well on the Fort Collins anticline, T. 8 N., R. 68 W., in Larimer County; production was from the upper (Muddy) member of the Dakota sandstone. The second discovery was made by the Texas Company on the Tow Creek anticline, T. 6 N., R. 86 W., about 14 miles west of Steamboat Springs in Routt County. The Tow Creek production was found in fractured shales of the Mancos formation several hundred feet above the Dakota sandstone.

In 1926, the Continental Oil Company made a discovery on the North McCallum anticline in North Park, T. 9 N., R. 78 W., Jackson County. Light oil was found in the Dakota associated with carbon dioxide gas under high pressure. It took several years to overcome the production difficulties brought about by the carbon dioxide-oil mixture.

The Mountain Fuel Supply Company discovered gas and oil in commercial quantities in the same year on the Hiawatha anticline of northwestern Colorado, T. 12 N., R. 100 W. Production was found in the Continental Wasatch and Ft. Union formations of Tertiary age.

During 1927, the Midwest Refining Company made a discovery on the Iles structure, T. 4 N., R. 92 W., Moffat County.

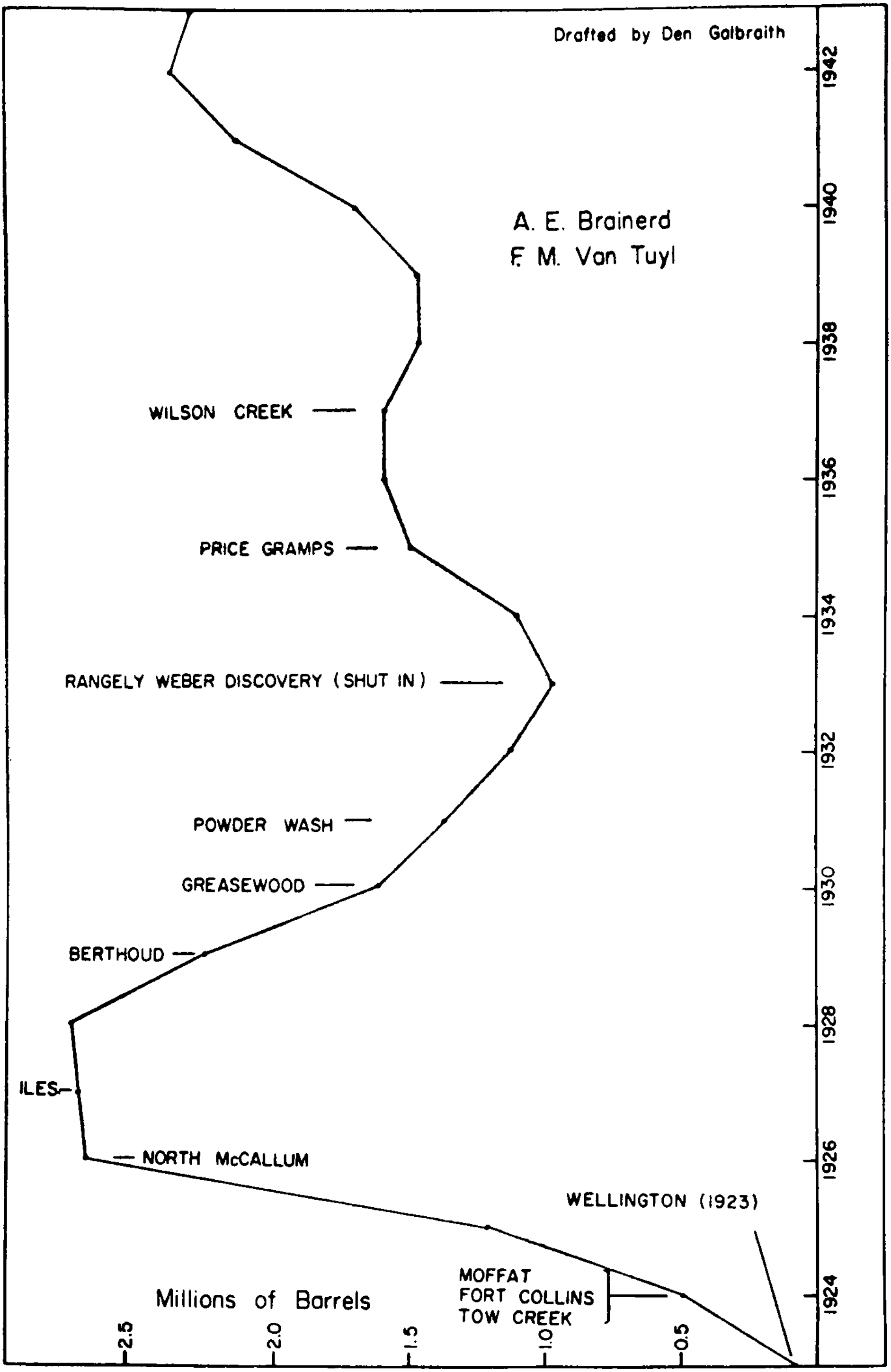

FIG. 2. COLORADO OIL PRODUCTION CURVE
INTERMEDIATE YEARS — 1923-1943

Oil was encountered in the Morrison formation of Jurassic age, the first production in Colorado in important quantity from below the Dakota group.

In 1929, the Girdler Corporation discovered gas on the Model dome in T. 29 S., R. 60 W., Las Animas County. The gas was inert, consisting mainly of nitrogen and carbon dioxide, but when analyzed, it was found to contain 8 percent helium. This was the first gas pool in the State to show a high helium content and the field was taken over by the Federal government and shut in for later needs.

In 1930, the Platte Valley Petroleum Corporation completed a discovery oil well in the Greasewood field, T. 6 N., R. 61 W., in eastern Weld County. This is about 60 miles east of the Rocky Mountain front and represented the first commercial development on the east flank of the Denver Basin.

Production at Greasewood was found in the upper ("D") sand member of the Dakota group, at a depth of 6,661 feet. The structure, a northwest plunging anticline, has very small if any closure. The trap which brought about the accumulation is considered to be of the stratigraphic type. The possibility of similar accumulations in the general area was the incentive for directing exploration into northeastern Colorado in the early 1930's. Surface geology was the chief method of exploration; this was supplemented with some of the earliest geophysical work done in the State.

Early development at Greasewood was not too encouraging as there were only three producing wells, offset by five dry holes. Its importance was in indicating the potentialities of commercial oil and gas fields in a new and large undeveloped area.

A second discovery in 1930 was the Piceance Creek gas field in T. 2 S., R. 95-96 W., Rio Blanco County. Gas is from the continental Wasatch and Green River formations of Tertiary age, at depths of about 3,000 feet. The Piceance Creek structure shows 250 to 300 feet of closure. In more recent years this structure was tested to a depth of 12,019 feet by General Petroleum Company without developing deeper pays.

During 1931, the Mountain Fuel Supply Company discovered gas in the Powder Wash field in T. 11 N., R. 97 W., northwestern Colorado. A sandstone in the continental Wasatch formation, encountered at a depth of 2,152 feet, carried gas. In 1936, oil was found in deeper sand lenses at 3,037 and 5,014 feet.

In 1930 and 1932, gas discoveries were made in northwestern Colorado on the Bell Rock structure, T. 6 N., R. 92 W., and the Craig structure, T. 6 N., R. 91 W., Moffat County. Gas was found in the basal Mesaverde at about 2,800 feet. Although these fields have been abandoned in the Mesaverde and both have been drilled deeper without finding commercial production, the occurrence of gas indicated that the Mesaverde was to be considered prospective in future exploration activities.

The most important oil and gas discovery in Colorado up to the present time, was made by the California Company on the Rangely anticline in 1933, when deeper drilling revealed the existence of a large oil and gas pool in the Weber sandstone of Pennsylvanian age below the partially developed shallow Mancos (Cretaceous) fissure production. The discovery well showed an initial productive capacity of 300 barrels of 31-degree API gravity oil; its depth was about 5,700 feet. Owing to depressed market conditions and the lack of a pipeline outlet, the well remained shut in until 1943. As will be pointed out later, the Weber pool at Rangely constitutes one of the three richest oil pools of the Rocky Mountain region.

No additional discoveries were made until 1935, when the Hughes Estate drilled a well on the Price Gramps structure in T. 33 N., R. 2 E., in Archuleta County of southcentral Colorado. Production was encountered in the Dakota sandstone at a depth of about 1,000 feet. This field appears to have been discovered as a result of random wildcat drilling. The operator owns the land in fee and produces, transports, and refines and markets its oil—a unique setup.

The Texas Company and the California Company drilled a joint well in 1937, on the Wilson Creek structure, Sec. 35, T. 3 N., R. 94 W., Rio Blanco County, and discovered oil in a sandstone in the basal part of the Morrison formation of Jurassic age. In 1941, a well, carried through the Morrison, found oil in the Entrada sandstone of Jurassic age. This Entrada discovery marked the first oil found in this formation in the State.

The Wilson Creek structure has about 900 feet of closure and some 15,000 acres within the closed area. However, production is found only on the higher portions of the anticline. This structure had been drilled in 1926 through the Dakota group, finding only water. The discovery of oil in the Morrison sandstone at Iles and in the Weber sandstone at Rangely gave the incentive to drill deeper on the Wilson Creek structure.

Oil production in Colorado reached a low ebb in the middle of the depression in 1933, then increased slightly through 1936, due mainly to field development. Following 1936, there was a decline through 1938, and from that time, there was a steady increase each year through 1957—the peak year up to the end of this decade.

In the years from 1923 through 1938, surface and subsurface geology played a major role in the discovery of oil and gas in Colorado. However, geophysical surveys played an increasingly important role from the late 20's on. Fourteen oil and six gas pools were opened during this period. Two of the oil fields, Rangely and Wilson Creek, may be classed as major pools. It is estimated that in the years between 1928 and

1938, the industry discovered a total of more than 425 million barrels of oil in the State.

During the late 20's and early 30's, a large part of eastern Colorado was covered by magnetometer surveys. This type of work decreased in the late 30's, and very little magnetometer work has been done since 1940. Some gravity surveys were carried on locally with the torsion balance during the late 20's and early 30's. These surveys were slow and costly, and the results obtained often open to question. The use of the torsion balance was discontinued in the middle 30's, later to be supplanted by the gravitymeter.

Experimental seismograph work was started as early as 1932, and by 1940, this instrument was in active use by many oil companies in various parts of the State. The earlier work was done in the summer months and was confined to local areas. With the development of new techniques and better equipment, large areas have been covered in the State and surveys have been, and are now, conducted throughout the entire year.

Increased drilling in the State, and in bordering States, since the 1920's, furnished more and more subsurface data. The value of this information as an exploratory aid was given full recognition along with the surface information, and subsurface studies played an increasingly important role in exploratory thinking.

The Boom Years (1944-1960)

From the beginning of 1938 to the middle of 1943, there were no new oil or gas fields discovered in Colorado. However, production increased a little each year due to the development of fields already discovered.

With the accumulation of a large amount of geological data afforded by earlier exploration efforts in Colorado and bordering states, and the additional data supplied by geophysical surveys, especially seismic work, Colorado was now at the threshhold of a great expansion of wildcat and development activity. Commercial discoveries of oil and gas had been made in all the more promising oil and gas potential sections of the State except southeastern and southwestern Colorado, where drilling had revealed shows or small production sufficiently encouraging to justify further exploration efforts.

So much information was supplied by exploration activities of all kinds and by the discovery of many new fields during the next 20 years, that only general statements may be made regarding these developments.

With the assurance of a pipeline outlet in 1945, development of the Weber standstone pool at Rangely, discovered in 1933, became intensive in 1944 with 33 successful wells completed in that zone during the year. During the next three years, drilling was very active, and by 1949 the development of the Weber was nearly completed. In 1953, Rangely production reached 22.6 million barrels, and the reserve estimate places the field in a class with Salt Creek and Elk Basin in Wyoming.

The Weber development at Rangely brought about an extensive search for additional oil and gas fields in the Weber sandstone and other prospective horizons in northwestern Colorado. However, no additional prolific oil and/or gas pools have been discovered up to this time.

In 1948, attention was directed to the southwestern part of the State due to a north extension of the Barker Creek gas pool from New Mexico into Colorado, and to a discovery by Western Natural and Byrd-Frost on the Dove Creek structure T. 38 N., R. 19 W., Montezuma County. The Dove Creek well developed small oil and gas production in the Paradox formation of Pennsylvanian age, at 5,934 feet in depth.

As a result of the development in recent years of important reserves of oil and gas in the Paradox formation, and very promising prospects in the Mississippian and Devonian systems across the State line in southeastern Utah, extensive leasing and exploration activities have spread into southwestern Colorado. As indicated in Mr. Adler's contribution to this volume, several Paradox discoveries have already been made. Devonian and Mississippian formations also offer possibilities of oil and gas production. A considerable expansion of exploration activities in the extension of the Paradox Basin into Colorado is anticipated.

The discovery of gas in large quantities in the Mesaverde sandstones on the Ignacio anticline by the Stanolind Oil and Gas Company in 1950 indicated Cretaceous possibilities over a substantial area in the Colorado portion of the San Juan Basin in southwestern Colorado also. Later developments indicate that stratigraphic trap-type of gas accumulations are also important in the Mesaverde formation. There are also believed to be similar type traps in the earlier Cretaceous, Jurassic, Triassic, and possibly still older formations.

In the park areas, commercial production is still confined to North Park where the productive area at the North McCallum field has been extended and stepped up. A productive area has also been discovered at the northwest end of the South McCallum anticline. Two fault-sealed oil fields, Battleship and Canadian River, have been developed to the north and east of the North McCallum field.

Middle and South Parks are not yet commercially productive.

Although commercial oil production has been developed for many years on the west limb of the Denver Basin and the small Greasewood pool had been discovered in Weld County on the east limb in 1930, the potentialities of the eastern portion of the Basin were not fully appreciated until 1949.

A new wave of leasing, seismic surveying, and drilling, was set off by the discovery of oil in commercial quantities in the Dakota (Cretaceous) sands on a seismograph high by the Ohio Oil Company near Gurley in Cheyenne County, Nebraska, in the summer of 1949. In a matter of months, millions of acres were leased on the east flank of the Denver Basin, and both seismograph surveying and wildcat drilling assumed boom proportions in southwestern Nebraska and northeastern Colorado.

The first discovery of oil and gas in northeastern Colorado during this phase was by the British American Oil Company and the Plains Exploration Company on a seismic high in March, 1950, in the Armstrong area of Logan County, just south of Cheyenne County, Nebraska. Gas was encountered in the first Dakota, or "D" sand, light oil in the third Dakota, or "J" sand, and small amounts of low-grade oil (17-degrees API) in the Lakota sand. Oil production at the present time is from the "J" sand.

The interest of oil men in northeastern Colorado was heightened considerably in 1950 by the discovery of oil in commercial quantities in what is now known as the Merino field in extreme southwestern Logan County. The southwesterly trend was thus established from the Gurley and other newly-discovered pools of southwestern Nebraska into Colorado along the strike of the gently dipping Cretaceous and older formations through Logan County and into Morgan County, and the exploratory drilling was concentrated largely along a belt, or "fairway," following this trend.

Numerous important "D" and "J" sand discoveries along the trend to the southwest during 1951, 1952, and 1953, such as the prolific Adena field in southern Morgan County and the Little Beaver field in western Washington and eastern Adams Counties; the extensive widening of the fairway; and the finding of oil in commercial quantities in the Lyons sandstone (Permian) in the Big Hollow field in western Weld County on the west limb of the Denver Basin, led to a great expansion of wildcat and development drilling in eastern Colorado during the succeeding three years. The peak of activity was reached in 1955, when a total of 1,273 wells were drilled in the Colorado portion of the Basin. Of this number, 638 were wildcats which resulted in 45 oil and 14 gas discoveries, for a success ratio of about 1 to 11. Activity has been declining since that year.

The peak production for the Basin up to this time was attained in 1956, when it amounted to 25,607,649 barrels.

The most important production to date in southeastern Colorado is in the Canon City Embayment where the Florence-Canon City field has been continuously productive, though on

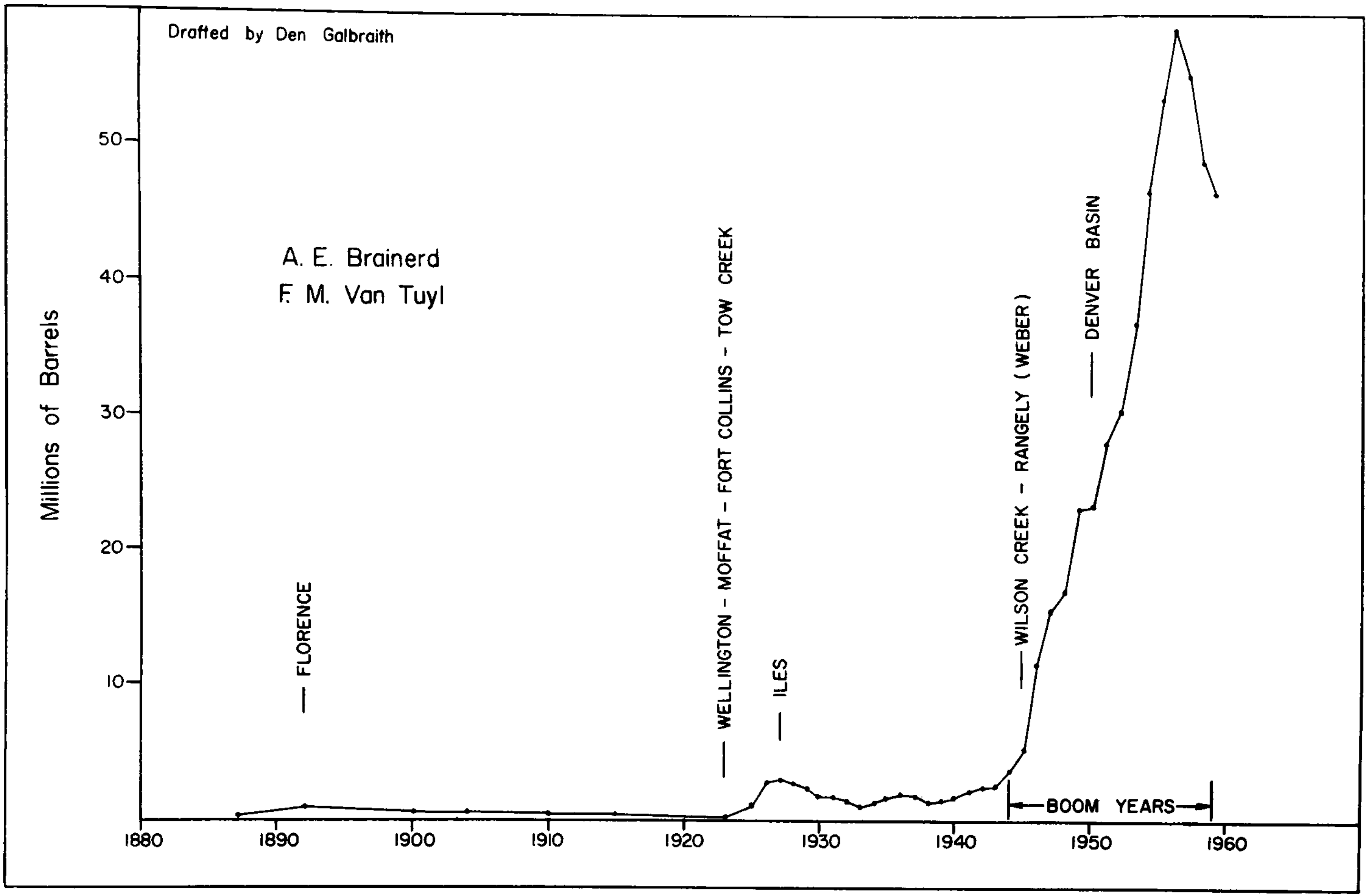

FIG 3. COLORADO OIL PRODUCTION CURVE — 1887-1959

a small scale, from fractures in the Pierre (Cretaceous) shale since 1876.

Numerous uplifts and basins elsewhere in southeastern Colorado, including the south extension of the Denver Basin, have received the attention of individuals and oil companies for many years, preference being shown to domes and closed anticlines revealed by surface geological surveys, subsurface geology, and seismograph surveys. In general, the testing of such structures has been disappointing since commercial accumulations of hydrocarbons such as the extension of the Greenwood gas field of Kansas into Baca County, Colorado, and of the McClave gas field of Kiowa County, Colorado, are essentially stratigraphic trap pools in Pennsylvanian limestones and sandstones. These discoveries, together with several apparent smaller finds of oil and/or gas, all since 1950, have laid the foundation for much more extensive exploration and development in this portion of Colorado.

The accompanying production curve (Fig. 3) shows the Colorado production of petroleum from 1880 through 1959. The phenomenal increase from 1944 through 1957 is due largely to the development at Rangely and Wilson Creek on the western slope, and the amazing development in the Denver Basin of northeastern Colorado.

The State has produced approximately 552 million barrels of oil and about 947,000 million cubic feet of hydrocarbon gas up to January 1, 1960. Based upon present methods of recovery, the proved reserves of oil, as of the end of 1959, were estimated to be 381 million barrels; and of hydrocarbon gas, about 2,296,159 million cubic feet.

The writers have obtained information for this report from many published sources and from personal experience of themselves and associates in the development of Colorado's oil and gas industry.

Figure 4 is an index map subdivided to illustrate the portions of the State covered by the texts and maps in subsequent chapters of this section. The last chapter, appertaining to oil and gas conservation in Colorado, concerns itself with the entire State.

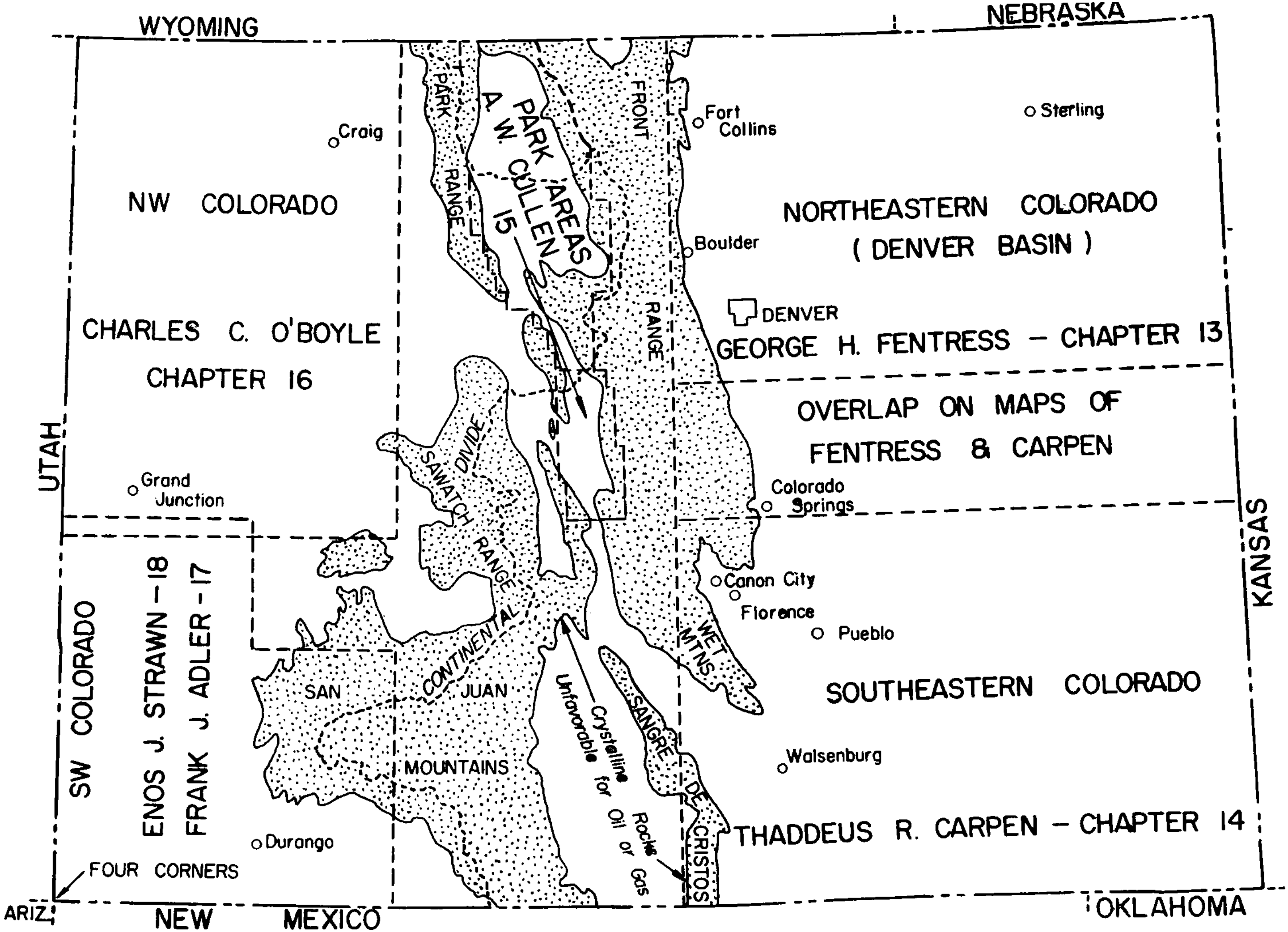

FIG. 4. INDEX MAP—PART IV—PETROLEUM AND NATURAL GAS

Chapter XIII

The Denver Basin of Colorado

by

George H. Fentress

Exeter Drilling Company

Denver, Colorado

CHAPTER XIII

The Denver Basin of Colorado

by

GEORGE H. FENTRESS*

The Colorado portion of the Denver Basin comprises some 30,000 square miles, covering nearly all of northeastern Colorado. The Basin has often been called Denver-Julesburg, Denver-Cheyenne, or Julesburg; yet Emmons used the term "Denver Basin" in the earliest reference to the structure. This name is commonly preferred even though an additional 30,000 square miles or more of it extends into western Nebraska and portions of southeastern Wyoming and northwestern Kansas.

Geologically, the Denver Basin is bounded on the west by the Front and Laramie ranges of the Rocky Mountains; on the northwest by the Hartville Uplift in Platte, Goshen, and Niobrara Counties, Wyoming; on the north by the Black Hills Uplift in southwestern South Dakota; on the northeast and east by the Chadron Arch, an extension of the Central Kansas Uplift, which reaches from central Kansas through Harlan County, Nebraska, northwestward through Sheridan County; on the southeast by the Las Animas Arch, which extends northeast from east-central Las Animas County, Colorado, through eastern Kit Carson County; and on the southwest by the Apishapa Uplift of southern Pueblo and northern Las Animas Counties, Colorado (see index maps, Fig. 4, p. 505, Fig. 7, p. 534, and Plate 1 in pocket).

The northern portion of the Basin is drained by the North Platte River system, the central part by the South Platte River system, and the southernmost portion by the Arkansas River system. The highest elevation in the Basin, about 7,500 feet above sea level, is in the Black Forest area along the divide which separates the South Platte and Arkansas Rivers of El Paso County.

The Denver Basin is located in the western portion of the Great Plains physiographic province. Except along the Front Range foothills, the surface of northeastern Colorado is largely covered with Quaternary sands and gravels and outwash Tertiary Arapahoe-Denver, Fort Union, Dawson, Green Mountain, Castle Rock, White River, Arikaree, and Ogallala formations of arkoses, sands, clays, gravels, and conglomerates. The Upper Cretaceous Pierre shales, Fox Hill clays and sandstones, Laramie sandstones and clays are found outcropping in many places on the eastern plains. Except along major streams and irrigated areas, the principal economic activity is wheat farming and cattle grazing.

*Exeter Drilling Company, Denver, Colorado.

History of Oil and Gas Development

Following the discovery of oil in 1876 near Florence, Colorado, in the Canon City embayment, not now considered a part of the Denver Basin, wildcat activity to the north, on the west rim of the basin, finally resulted in the discovery of several additional oil and gas fields. The test drilling was mainly at or near oil seepages, and on obvious surface structures. The Boulder field, discovered in 1902, has produced about 747,708 barrels of oil from Hygiene sandstone lenses and adjacent fractures of the Pierre shale. A few non-commercial shows of gas had been found prior to 1923, but during that year the Wellington oil field of Larimer County was discovered on the basis of surface geology. Up to May, 1959, this field had produced a total of 6,202,722 barrels of oil. In 1924, the Fort Collins field was discovered on a surface structure and had produced, by the same date, approximately 3,177,000 barrels of oil. These two fields produce from Cretaceous sandstones of the Dakota series, with additional production from the Lyons sandstone of Permian age, recently developed in the Fort Collins field. In 1925, the Berthoud field was discovered with production encountered in the basal Hygiene sandstone, and subsequently from Niobrara marls and Dakota sandstones. Cumulative production through May, 1959, was 101,810 barrels of oil and considerable gas.

The first commercial oil on the eastern flank of the Basin, discovered at the Greasewood field in 1930, was the result of surface geological studies which supposedly delineated a faulted structure. However, later developments along the eastern flank of the Basin showed that the field was not structural or faulted, but like most eastern Colorado fields, was of the stratigraphic type. To the end of May, 1959, the Greasewood field has produced 916,540 barrels of oil from the "D" sand of the Dakota formation. Its discovery stimulated considerable interest in this portion of the Basin, but economic conditions of the period precluded extensive activity.

Geophysical exploration began in the Basin as early as 1928 and culminated in the first seismic discovery, just over the Colorado line, in 1942 on the Horse Creek structure, Laramie County, Wyoming. Clark Lake field in Larimer County, Colorado, was a seismic discovery in 1944, and has produced approximately 572,000 barrels of oil from Cretaceous sandstone of the Dakota group. These discoveries instigated extensive seismograph, magnetometer, and gravitymeter work throughout the Basin which led ultimately to an intensified drilling campaign upon discovery of oil in Cheyenne County, Nebraska, in 1949, as a direct result of seismic work.

In 1943, the Ohio Oil Company inaugurated a geophysical program in southwestern Nebraska and northeastern Colorado which resulted in the drilling of well No. 1 Egging in the

Gurley area of Cheyenne County, Nebraska. The well was completed in August, 1949, at 4,401 feet with an initial potential of 225 barrels of oil per day from Cretaceous Dakota sandstone. This discovery led to intensified activity in eastern Colorado. The first discovery in the State during this recent period occurred in 1950 when British American Oil Company completed well No. 1 Segelke as an oil producer in the "D" sand in Section 26, T. 11 N., R. 53 W., Logan County, and thereby opened the Armstrong field. Also during this year the following fields were discovered: Merino, Mount Hope, Walker, and Yenter, all in Logan County; Buckingham field in Weld County; Lee field in Morgan County, and Loveland field in Larimer County.

There has been fairly sustained activity in the Basin since 1950. The accompanying table (see Appendix at end of this chapter) of producing, formerly producing, and shut in oil and gas fields, lists 263, of which 250 were discovered since 1950. The numbers on the table correspond to those on the map of the Denver Basin contained in the pocket at the back of this book.

General Stratigraphy

The stratigraphy of the pre-Cretaceous rocks in the Denver Basin is not well known, partly because of the lack of wells, but chiefly because of extreme facies changes which make correlation and nomenclature difficult. For this reason the pre-Cretaceous systems are mentioned only briefly to indicate general interpretations.

The pre-Cambrian of the Front Range and of the subsurface is composed chiefly of granite, schist, gneiss, and quartzite, with an abrupt unconformity between it and the overlying sedimentary Fountain (Pennsylvanian) at the foot of the Front Range, with Upper Cambrian to pre-Fountain, to Pennsylvanian beds resting progressively eastward on the pre-Cambrian through the Basin in the subsurface.

Cambrian strata (Sawatch sandstone) are absent in the central portion, but are present in the southeastern part of the Basin and in the Canon City embayment area.

Correlation of the Ordovician is difficult. Manitou, Harding, Simpson, Fremont, Arbuckle, Viola, and Roubidoux, are names applied variously to Ordovician formations in various parts of the eastern, southeastern, and southwestern portions of the Basin. Generally, the Ordovician is composed of siliceous dolomite and oolitic chert, with some limestone and sandstone. The lower part is often called Cambro-Ordovician. No Ordovician is known to exist in the northern part of the Basin.

The Silurian and Devonian systems are not believed to be present in the Denver Basin.

The Mississippian Kinderhook, Osage, Spergen, and Meramac series of beds are identified in the southeast portion of the Basin with transgressively younger beds being found to the northwest into the central part. The youngest, or Chester series, is found only in far southeastern Colorado, indicating rapid withdrawal of Mississippian seas late in that period. Formations are very difficult to distinguish, but the rocks are composed of sandstones, limestones, siltstones, and shales. Some of the strata are noted for their oolites. Names of formations variously identified are Beulah, St. Genevieve, Hardscrabble, St. Louis, Williams Canyon, Spergen-Warsaw, Burlington, Keokuk and Gilmore City.

The Ancestral Rockies were formed shortly after the beginning of Pennsylvanian time. The sediments of this period in the Basin are complicated by on-lap conditions and numerous and extreme facies changes. The Ancestral Rockies provided the source for the upward to 4,000 feet thick Fountain formation arkosic sandstones, which is everywhere present along the Front Range and which grades rapidly, in the central part of the basin, into all the various facies of a normal Kansas type stratigraphy. The Pennsylvanian is more easily divided into series of Virgil, Missouri, Des Moines, Marmaton, Cherokee, Atoka and Morrow ages. The formations within these series are variously identified through the eastern and southern part of the Basin, from younger to older, as Waubaunsee, Shawnee, Douglas-Pedee, Lansing-Kansas City, Bronson-Marmaton, Cherokee, Atoka and Morrow. The Fountain apparently encompasses all of these formations and series through time. The Pennsylvanian is predominately limestone to the south, interbedding with some dolomites to the north. The upper beds are usually difficult to distinguish from the overlying Permian. The Lansing-Kansas City and Marmaton have become important oil and gas bearing formations beyond the eastern and southern limits of the Basin, but not in the Basin proper.

The Permian Lyons sandstone has become an important oil producing horizon in the Denver Basin. The formational names often applied to the Permian beds of anhydrites, dolomites, shales, limestones, and sandstones of the area are, Freezeout-Glendo, Day Creek, Forelle, Minnekahta, Opeche, Blaine, Lykins (Harrison, Falcon, Bergen, Glennon, Strain), Lyons, Stone Corral, Wolfcamp, and Ingleside. The Wolfcampian series interfingers in part with the Fountain, making it difficult to distinguish from underlying Pennsylvanian beds. The uppermost Permian is almost indistinguishable from the overlying Triassic-Jurassic, because of the many interbedded colored shales. Its upper beds of the "Lykins" are often termed Permo-Triassic because of this apparently conformable condition. The Lyons sandstone changes facies eastward into the sediments of the lower part of the Blaine evaporitic basin where salt, anhydrite, and shale were deposited during the retreat of the Anadarko sea.

The Triassic-Jurassic Lykins, Spearfish, Jelm, Ralston, and Morrison formations are composed of varicolored shales, siltstones, some anhydrites, gypsum, sandstones, clays, and marly limestones. Its boundary with the overlying, unconformable Cretaceous is generally easily distinguishable grading into conglomeratic sandstones of the Lower Cretaceous.

The Cretaceous system is composed, in descending order, of the Arapahoe-Denver, Laramie, Fox Hills, Pierre shale (with its Sussex, Shannon, Parkman, and Hygiene sandy zones), Niobrara shales and marls, Timpas (Fort Hays) limestone, Codell sandstone, Carlile shale, Greenhorn limestone and Graneros shale, and the Dakota or "alphabet" series of sandstone beds ("D," "G," "J," "M," and "O") with intervening

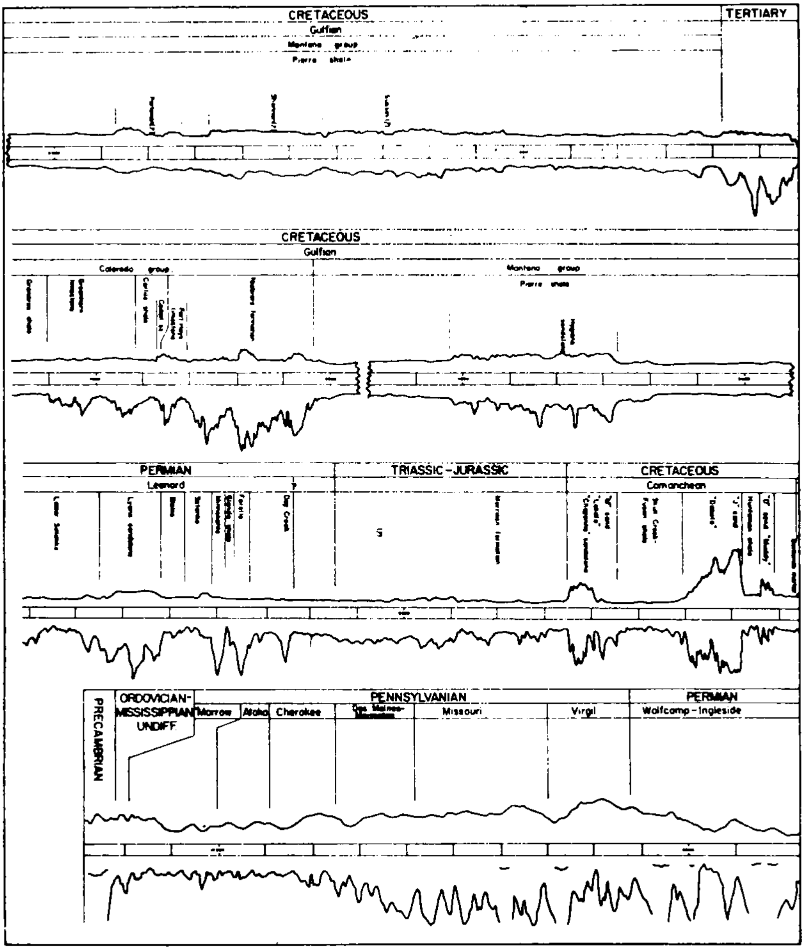

Figure 5- Type electric log, Denver Basin, T. 9 N., R. 61 W., Weld County, Colorado.

shales and the basal Lakota or Cheyenne conglomeratic sandstone. Nearly every Cretaceous sandstone or marly limestone bed has yielded production somewhere within the Denver Basin, making the Cretaceous the most important oil and gas productive system. The sedimentation of Cretaceous sands is discussed more fully further on in this chapter.

The continental Tertiary deposits have had no oil or gas significance in the Denver Basin to date.

Figure 5 shows a type electric log for the central part of the Denver Basin, together with accompanying nomenclature of series and some formational names. Further breakdown of formational names is not feasible in pre-Cretaceous beds because of the extreme facies changes that take place throughout the greater portion of the Basin. Reference is made to Figure 8 of Chapter XIV (T. R. Carpen) in this book, page 539, for an excellent breakdown of formational names.

Structure

The Denver Basin is a typical asymmetrical structural and depositional basin. The basinal axis trends north-south through Denver, Colorado, and Cheyenne, Wyoming, parallel to, and 10 to 25 miles east of the Front Range. The structural configuration in the Colorado portion of the Basin, as revealed by contours drawn on the top of the Dakota sandstone, is shown in Plate 1 (in the pocket). The contours are not too clearly defined along the central and far western portions of the Basin because of the general lack of subsurface control and because the sandstone outcrops at the surface on the west flank in very steeply-dipping beds requiring a congestion of the contours. The sediments in the trough are approximately 13,000 feet thick at the deepest point. The gently dipping eastern limb of the syncline exhibits no major structural feature either on the surface or in the subsurface. There are, however, numerous small structures, both open and closed, on the eastern limb, many of which contain oil or gas accumulations. The pronounced flattening of the contours east of the main producing trend is believed to be an area where continental Dakota beds, with some possible marine interbedding, were deposited.

Most of the larger anticlines of the Basin are along or near the foothills of the Front Range. The Wellington, Berthoud, Fort Collins, Black Hollow, Loveland, and other structures are characteristic. Many other structures in the area which have been tested have not proven productive. This area is essentially the east limb of a geanticline complicated by numerous thrust and normal faults formed by extreme movement in the pre-Cambrian mountain front areas during the Cretaceous Laramide Revolution.

The structural features on the eastern limb of the Basin seldom have more than 100 feet of closure, being usually associated with broad terraces and structural noses which often can be traced for several miles. These terraces and noses are not everywhere productive of oil and gas and may be complicated by stratigraphic lensing of the Dakota sands. No production has been obtained on the eastern limb from any beds below the Cretaceous excepting for the questionably commercial Lyons at the Keota field; yet only a few wells have been drilled to the Lyons horizon, much less to the deeper Pennsylvanian beds.

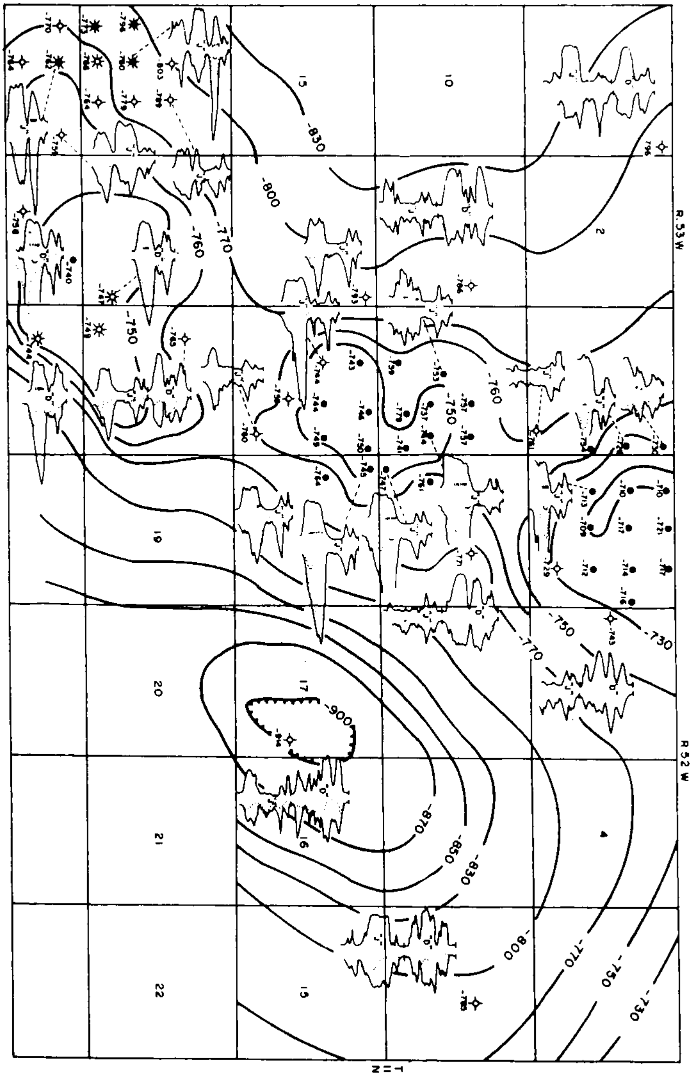

Figure 6 - West Peetz-Lewis Creek-Armstrong fields, Logan County, Colorado. Contoured on top of the "J" sand (7-1-58).

Thus far no important oil or gas production has been obtained on the east flank of the Basin from fractured shales, marlstones, or limestones of Cretaceous age, such as produce on several structures on the west flank of the Basin where more extensive deformation is apparent. The features that do exist on the eastern limb are variously thought to have been caused by: (1) very minor shifting of the beds from adjacent movements, (2) sand build up along an uneven early Cretaceous sea floor as influenced by shifting sands in a shallow sea being rapidly loaded with sediments and, (3) from differential compaction of the beds during deposition. A study of the map (Fig. 6) of the West Peetz-Lewis Creek-Armstrong fields indicates a structural feature with about 40 feet of closure where clean productive sands are found predominantly on the feature, while shaly, tight sands appear on its flanks, indicating that ordinary folding was not a direct cause of the structure.

Sedimentation

Only the Lyons, Lakota, the "alphabet" sands, and Pierre sands sedimentation will be discussed, although there are other horizons that are potentially productive but which are not economically important at present.

The Lyons sandstone seems to have been derived from highlands to the west and northwest, being deposited along a Permian strand line (beach formed by waves and currents). The sand is generally red, somewhat arkosic and clean. At the Black Hollow and Keota fields it is white to medium gray in color. The sandstone interfingers eastward into a Permian evaporitic basin, and southward is interstratified with the Fountain. It is strongly cross-bedded and interstratified with siltstones. Where productive, the sand seems to be complicated by permeability and facies barriers, even though structure is important for hydrocarbon accumulation.

The Lakota sandstone consists of conglomeratic and cherty sandstone derived substantially from the Morrison formation on marginal flood plains, showing the first evidence of an invading Cretaceous sea. The uppermost member of this formation is commonly called "M" sand. Small amounts of heavy oil have been produced from the "M" sand in central Logan County, Colorado. Generally, the depositional history of this upper sand is similar to that of the subsequently deposited "D" and "J" sands.

The source of the "D" and "J" sands seems to have been northeast of the producing trend in Nebraska. These sands are apparently continental in the region to the northeast, east, and southeast of the producing area. A line can generally be drawn surrounding the producing area, outside of which there appear to exist continental deposits. This can be observed on the structure map, where the westward-dipping beds seem to flatten on the east side of the Basin. This line, then, would represent the farthest eastward extent of truly marine sedimentation. Various transgressive shorelines can easily be traced with trends northeast-southwest on the southeastern and eastern part of the producing trend, and east-west on the northern part in Nebraska. Coincidentally, these trends somewhat parallel the Chadron and Las Animas arches, as well as the North Platte and South Platte Rivers.

The "J" sand is white or light gray to tan, generally clean, very fine to medium-grained, and angular to subangular. There are often carbonaceous streaks and fragments in the sand which generally becomes "reworked" with shaly material in the areas of the clean sand trends. This sand is productive in all parts of the Basin, where it is marine. In a large area trending north from Morgan and Weld Counties, Colorado, into western Kimball and Banner Counties, Nebraska, and southeastern Wyoming, the sand is typically filled with kaolinite or illite. This clay-filled sandstone grades into quartzitic sandstone westward. The Adena field is on the western or down-dip side and the producing zone pinches out eastward against this massive sand. East of the clayey area there is some interfingering of this clay-filled sandstone into the more extensively productive "J" areas. Distinct sand trends can be established in western Washington County, eastern Adams County and southwestern Logan County, Colorado. In the area of massive sand the oil fields are very small, many only one-well fields, except for the Keota field of Weld County, Colorado, which is not believed to be a shore-line deposit.

The "D" sand may be described as being lithologically like the "J" except that it may be finer grained and more carbonaceous. Unlike the "J," it is not found throughout the entire Basin but pinches out or disappears in most parts to the west. The "D" sand merges eastward and southward with the "J" sand in the area of continental deposition; the black shale bed that separates the two sands in the producing areas wedges out and the two sands become indistinguishable. The west edge of the "D" marks the deeper part of the marine waters. In what is now the producing area, the sea was very shallow and the sands were affected by fluctuations in sea-level, sea currents and wave action, which resulted in washing and reworking of sand, shale and carbonaceous material. The clean productive sands were formed as spits, offshore and onshore bars, subsea channels, deltaic deposits and beaches. Some of the sands were probably wind-blown sand dunes, but it is obvious that the major sand bodies were deposited as bars and beaches paralleling the transgressing shoreline.

The Sussex, Shannon, Parkman and Hygiene sands of the Pierre shale are composed of light to dark gray slightly calcareous and carbonaceous, fine-grained sandstones and siltstones. The sands grade into silts and shales eastward, indicating a transgressing-regressing sea. The sands are apparently derived from the west. Permeability and facies traps are presently responsible for the small amount of oil presently being found in some of these zones.

Production

The tabulation of oil and gas fields in the Denver Basin proper shows that 263 fields have, through May, 1959, produced an accumulated 166,017,733 barrels of oil and 179,353 MM cubic feet of gas. Nearly 30 of these fields have had no production of oil or gas because of being classified as shut in gas fields for lack of sufficient reserves to warrant long extension of gas lines. Nearly 30 fields have already been abandoned for lack of sufficient economic production. Therefore, approximately 200 fields produced during the month of May, 1959, almost two million barrels of oil and nearly 200 billion cubic feet of gas. It should be noted, however, that the Adena field produced about one-fourth of all the oil in the Colorado portion of the Denver Basin and, together with the Rangely field in western Colorado, produced about one-half of the oil from the entire State.

Exclusive of all wildcat dry holes drilled, there have been 3,216 total field wells drilled, of which 2,049 were productive of oil or gas, and of which 1,491 wells are producing as of May, 1959. These figures are not completely representative since data was not available as to total field wells, productive and dry, on fields discovered prior to 1950. The flush period of drilling and production came during the years 1950 through 1955. The fields discovered during this period have had an average of 13.5 producing wells per field per year, with accumulated production through May, 1959, which averages over 20 million barrels of oil and over 27 billion cubic feet of gas per annum.

The fields discovered during the last three years have not been completely developed so that the average of three field wells per field per year is not an accurate average for this period. Yet, the data indicates the stabilization of drilling and discovery since the 1950-1955 boom years, with drilling being more established along the fairway trend of production. There has been relatively little drilling outside of the producing areas, so that newly discovered fields have been and will be generally smaller in areal extent. Even so, production is excellent from the large majority of these fields, regardless of size. It is difficult to analyse the productive capacities of fields for the last three years because of insufficient producing time. Yet, there appears to be a rising rate of producing wells drilled per field, even though it may appear that production is falling. Certainly the barrels recovered per well will be as great as most of the wells that were discovered prior to this period.

Since 1953, numerous oil and gas pipelines have been constructed throughout a large number of the producing fields on the eastern flank of the Basin. Rotary drilling methods have improved considerably since that year so that wells are normally being drilled within five to ten days. Although oil is commonly used in the drilling mud today, there is room for considerable improvement in muds to prevent contamination of the producing horizons with what is commonly called "mud blocks." The mud and water mixture, even with oil, penetrates the sandstone and forms a surface tension block which hampers completions, often quite seriously. Most of the oil and gas wells completed require heavy pumping equipment. Comparatively few wells are capable of flowing, and if so for only a few months, except where secondary recovery methods are installed early in the life of a field. Most wells are perforated through cemented casing, acidized to help clean out invaded mud and sandfraced for more permanent completions. Most of the fields are of a gas solution drive which will recover more than 200 barrels per acre foot by natural means. A few fields have some amount of water drive, but generally not sufficiently effective to recover large amounts of oil without secondary recovery. Gas fields have become increasingly more important because of active interest of gas pipeline companies that now have a greater demand for the product.

Activity has generally been excellent in the Denver Basin in spite of low reserve capacity of the fields. Drilling costs are lower than in most other Rocky Mountain areas and there is a general absence of proration. The Colorado Oil and Gas Conservation Commission does regulate the waste of gas which sometimes effects a proration on oil. Completion costs are generally about twice the cost of drilling.

Outlook

It appears at present that the oil and gas industry of eastern Colorado should enjoy fairly stabilized activity for the next few years. The major oil and gas companies have large blocks of acreage and a few of the large companies have been quite active, though mainly in a supporting way. Largely, the independent operator has been the most active because of the low cost of the initial drilling and early returns from production. Although productive capacities of wells are good and pay-out of money invested is fairly rapid, numerous dry holes are necessary to find production, and most operators budget their activities by market and other favorable conditions in order to foresee a guaranteed return on money invested. Considerable attention is now being given to water flooding and gas injection in fields which have four or more wells. Most fields have proven to be floodable and thus, in most cases, will yield twice the amount of oil which would be obtained by purely conventional means. Secondary recovery projects are considered at present as the greatest future of the Basin.

The fairway area of production will account for most of the new oil in the next three to five years. The majority of the fields discovered in this area will be small, although at least one to two fields per year will be found that cover an area greater than one section of land. Production will be profitable with outlets for oil and gas nearby.

Additional fields, largely gas fields, will be discovered and developed from the "D" and "J" sands to the east of the fairway, but testing will be retarded because of the lack of currently proved fields of substantial size and the long distance from pipelines. There has been relatively little drilling in the area as compared to the fairway itself, and it is expected that water, in varying proportions, will be produced with any oil or gas developed. Production from Pennsylvanian beds can be expected eventually, since it has already been established in southeastern Colorado, and a short distance into Nebraska and Kansas on the Las Animas and Chadron arches.

Several "D" sand fields will be found in channel sands or offshore bars in eastern Weld County, and possibly south of Weld County. Drilling and completion costs here are more expensive and consequently prospects are not so desirable at the present time, although a few wells are drilled each year. In this area the "J" sand is not quite so inviting because of its extensive clayfill and quartzitic characteristics. Yet there may possibly exist other features the size of Keota where clean sands have been winnowed. In this area and in western Morgan County, Niobrara and Greenhorn limes and shales have yielded small amounts of oil, although the commercial qualities of these formations have not been definitely proven. Better methods of drilling and completing these fractured limes and shales must be found, and even then, substantial production from these formations will depend upon the extent of good fracture systems.

In Boulder and Weld Counties small oil production has been found in sandstones of the Pierre shale and it is possible that similar oil or gas production will be developed from similar zones in Adams, Arapahoe, Elbert, and Douglas Counties. Several wells have been drilled already for the specific purpose of searching for oil and gas in these reservoirs. The shallow depth of the sands is appealing, but previously, no careful study of samples from these sands had been made until the New Windsor field was discovered.

The Pierre, Niobara, Greenhorn, Dakota, Lakota, and Lyons formations are productive in the Basin at the present time. Fracture systems, stratigraphic traps, fault traps, and closed structures, are all known to be present in the area.

The area of greatest uncertainty as regards future potentialities for oil and gas is the west flank of the Denver Basin, including the foothills of the Front Range and a fringing belt to the eastward ranging from about 10 to 27 miles in width. Several oil seepages, and a few oil and gas fields, appear in this portion of the Basin. However, the sands in the more closely folded and thrust-faulted belt of the foothills are typically tight in the subsurface, and production has been in part from fractures in most of the known accumulations such as those in the Pierre shale.

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APPENDIX

Oil and Gas Fields of The Denver Basin

(May 31, 1959)

Number	Field Name	County	General Location	Gravity	Year Discovered	Total Producing Wells	Total Dry Wells	Presently (May, 1959) Producing	Oil Production May, 1959	Gas-MCF Production May, 1959	Oil Accum. Production, May 1959	Gas-MCF Accum. Production, May 1959	Pay Zone and Remarks
1	Abbott	Washington	3-2S-54W	26	1952	2	3	2	1,124	281	75,339	9,313	"J"
2	Abbott-N	Washington	28-1S-54W	36	1955	1	2	-	--	--	6,293	--	"J" (aban)
3	Adena	Morgan	20-1N-57W	40	1953	223	38	174	546,309	478,523	29,149,097	32,396,504	"D" & "J"
4	Adena—S	Morgan	35-1N-58W	43	1954	3	5	3	3,562	5,725	423,201	419,736	"J"
5	Adobe	Logan	9-8N-54W	43	1956	1	1	-	--	--	3,352	10,750	"J"
6	Agate	Washington	24-1S-56W	38	1956	1	2	1	334	67	13,370	2,673	"D"
7	Akron	Washington	23-3N-53W	--	1952	2	3	-	--	--	629	132,527	"J"
8	Akron-E	Washington	25-3N-52W	41	1955	24	7	20	9,693	8,292	615,672	551,769	"D"
9	Allen	Morgan	9-2N-56W	40	1955	5	6	4	3,271	1,367	177,931	97,476	"D"
10	Amber	Logan	25-11N-54W	38	1956	3	4	3	2,633	2,447	205,658	226,282	"D" & "J"
11	Antelope	Weld	18-6N-66W	42	1957	1	1	-	--	--	2,589	--	Sussex
12	Anton	Washington	15-4S-52W		1958	1	3	-	--	--	587	--	"J"
13	Arford	Logan	28-9N-54W	31	1951	1	4	-	--	--	3,492	81,300	"J"
14	Arikaree	Yuma	21-2S-43W		1919	?		-	--				
15	Armstrong	Logan	26-11N-53W	38&17	1950	5	5	4	630	21,706	86,637	2,765,881	"D" & "J" & "O"
16	Ashley	Morgan	1-2N-59W	53	1955	2	3	1	418	2,725	29,761	467,466	"J"
17	Atwood	Logan	20-7N-53W	37	1951	7	2	4	1,530	549	349,814	109,584	"J"
18	Atwood-E	Logan	25-7N-53W	35	1955	32	12	25	27,322	88,339	999,749	2,211,720	"D"
19	Azure	Washington	14-1S-55W	37	1957	8	4	8	4,926	761	207,861	30,731	"D" & "J"
20	Badger Cr.	Adams	23-2S-57W	39	1953	47	13	34	27,707	14,093	3,475,449	1,901,475	"D" & "J"
21	Badger Cr.-W	Adams	15-2S-57W	35	1953	4	2	2	180	--	253,053	122,093	"D" & "J"
22	Barrow	Washington	5-2N-53W	41	1957	2	1	-	--	--	23,931	456,070	"D" (aban)
23	Battle Canyon	Weld	22-11N-56W	36	1953	23	10	19	2,994	13,838	746,986	2,300,567	"J"
24	Beacon	Adams	12-1S-58W	39	1955	17	5	15	4,868	72,953	633,329	1,722,005	"D"
25	Beall Cr.	Logan	26-10N-53W	37	1955	7	7	7	18,286	11,948	1,047,378	896,331	"J"
26	Becker	Washington	10-2S-55W	40	1957	1	4	1	207	83	24,097	13,649	"J"
27	Berthoud	Larimer	16-4N-69W	39	1925			1	113	--	101,810	1,223,506	"D"
28	Big Beaver	Washington	16-3S-56W	41	1954	25	11	15	76,139	4,651	4,527,304	313,014	"J"
29	Big Sandy	Logan	2-8N-55W	43	1953	5	3	4	6,221	12,740	380,756	1,062,520	"J"
30	Bijou	Morgan	6-4N-59W		1957	14	10	11	23,731	69,988	449,039	610,716	"D" & Green
31	Bijou-W	Morgan	12-4N-60W		1958	14	13	11	12,878	47,916	504,063	1,009,855	"D"
32	Black Hollow	Weld	6-7N-66W	36	1953	-	-	18	44,630	1,209	3,462,959	81,317	Lyons
33	Bobcat	Washington	5-1S-56W	40	1954	34	13	30	45,174	39,115	4,098,710	2,357,460	"D"

34	Bobcat-W	Washington	8-1S-56W	52	1956	1	3	1	258	374	26,297	25,568	"J"
35	Bonham	Logan	27-8N-55W	40	1953	3	5	2	1,174	441	215,620	45,010	"J"
36	Boots Hill	Morgan	13-1N-56W	40	1954	1	4	-		--	8,517	27,126	"D"
37	Boulder	Boulder	9-1N-70W	39	1901			3	79	--	747,708	...	Hyg.
38	Bradbury	Elbert	28-6S-61W		1955	1	0				374	48	"J" (aban)
39	Buckingham	Weld	34-8N-59W	38	1950	9	10	9	4,347	21,788	612,943	912,506	"D"
40	Buckingham-W	Weld	25-9N-60W	41	1955	4	6	-	--	--		--	"D"
41	Buffalo	Washington	9-2N-54W		1954	1	3		--	--	5,148	151	"J" (aban)
42	Buffalo Slough	Washington	23-2N-54W		1957	1	5	1	157	63	8,341	3,293	"J"
43	Burr	Morgan	29-2N-56W	39	1956	5	3	5	4,707	2,423	198,250	95,638	"D"
44	Busy Bee	Adams	9-3S-60W		1955	4	9	3	3,540	10,843	79,802	183,254	"J"
45	Cabin Cr.	Adams	16-3S-59W	41	1955	2	2				1,339	2,355	"J" (aban)
46	Camp Cr.	Logan	3-1N-53W	36	1955	4	4	1	315	39	48,200	4,095	"J"
47	Casement	Washington	6-11N-54W		1953	1	0	-	--	--	--	10,607	"D"
48	Cedar Cr.	Logan	12-9N-54W	38	1954	9	7	9	10,082	19,539	260,303	462,825	"D"
49	Cedar Cr.-N	Logan	1-9N-54W	39	1955	4	4	4	5,042	20,388	388,813	1,281,539	"D"
50	Centennial	Washington	9-2S-55W		1959	1	3	1	994	390	7,493	1,560	"J"
51	Chappel	Sedgwick	35-12N-44W		1952	1	0			--		--	"D"
52	Clark Lake	Larimer	15-9N-68W	38	1944			4	1,832	271	571,804	367,636	"D"
53	Cliff	Logan	32-12N-54W	39	1955	33	8	30	46,834	93,960	3,214,209	6,096,488	"D"
54	Columbine	Logan	5-7N-52W		1956	1	6	-	--	--	--	--	"D"
55	Cone	Washington	3-3S-56W		1958	2	3	1			6,165	560	"J"
56	Cotton Valley	Weld	17-9N-56W	38	1955	4	6	2	454	100	98,570	21,700	"D"
57	Cottonwood	Logan	12-9N-55W	39	1954	1	4	1	266	106	15,590	6,334	"J"
58	Cottonwood-S	Logan	24-9N-55W		1954	2	6	1	579	--	46,272	3,163	"D"
59	Coyote	Logan	12-6N-53W		1955	1	1	1	--	3,795	--	40,854	"D"
60	Crist	Sedgwick	14-9N-46W		1956	1	1	-	--				"D"
61	Crow	Weld	27-8N-60W	40	1956	1	3	1	228	114	12,952	1,091	"D"
62	Dailey	Logan	3-8N-48W		1957	1	0		--	--	--	--	
63	Dale	Logan	14-8N-53W	39	1952	15	11	9	2,006	8,709	604,326	2,314,883	"D" & "J"
64	Dale-N	Logan	11-8N-53W	39	1955	4	4	3	929	942	141,383	183,808	"J"
65	Darby Cr.	Logan	17-10N-53W	38	1955	14	6	11	12,009	24,004	925,208	1,559,517	"D"
66	De Nova	Washington	16-2S-49W	20	1956	2	3	2	741	250	22,415	500	"J"
67	Dike	Morgan	32-5N-60W		1959	2	6	1	3,979	7,489	10,346	13,856	"D"
68	Divide	Logan	10-8N-53W	39	1954	24	6	19	5,557	5,038	1,744,076	2,227,763	"D"
69	Doherty	Adams	16-2S-65W	42	1957	1	2	1	373	10,774	2,896	11,274	"J"
70	Dune Ridge	Logan	32-7N-52W	38	1954	14	4	9	20,041	16,202	922,961	1,615,317	"D"
71	Elm Grove	Logan	16-6N-53W	40	1957	10	5	9	14,586	30,877	407,100	1,108,529	"D"
72	Empire	Morgan	1-3N-61W		1953	3	2	-	--	--	1,878	--	"D"&"J"&Green (aban)
73	Flag	Weld	35-7N-58W		1958	2	3	1	2,625	2,888	28,889	20,873	"D"
74	Fleming	Logan	16-8N-50W		1953	1	1	-					(aban)
75	Fort Collins	Larimer	30-8N-68W	35	1923			14	7,779	1,015	3,177,000	373,934	"D"&"J"&Lyons
76	Fort Morgan	Morgan	19-3N-57W	40	1954	9	6	1	3,682	192,430	66,401	2,303,114	"D"
77	Frasco	Logan	4-7N-55W	37	1954	5	9	3	6,072	2,222	204,564	112,728	"J"
78	Fremont Butte	Washington	12-3N-53W	33	1957	1	2	-	--	--	8,787	45,050	"D"
79	Frenchman Cr.	Logan	31-8N-50W		1952	4	11	-	--	--	107	346,972	"J"

Number	Field Name	County	General Location	Gravity	Year Discovered	Total Producing Wells	Total Dry Wells	Presently (May, 1959) Producing	Oil Production May, 1959	Gas-MCF Production May, 1959	Oil Accum. Production, May 1959	Gas-MCF Accum. Production, May 1959	Pay Zone and Remarks
80	Fringe	Weld	32-12N-57W	39	1957	2	3	2	1,260	5,538	82,713	130,829	"D"
81	Garnet	Logan	30-10N-53W		1959	1	1	1	2,718	1,712	7,625	13,610	"D"
82	Gary	Morgan	16-1N-56W	40	1953	1	2	1	85	25	15,740	4,816	"D"
83	Gary-N	Morgan	22-2N-56W	31	1954	7	4	4	1,287	1,030	203,219	155,900	"D"
84	Gary-S	Morgan	29-1N-56W		1955	1	2	--		--	--	--	"D" (aban)
85	Goat Hill	Logan	22-11N-53W		1956	5	7	4	2,435	7,243	300,243	1,093,550	"J"
86	Goodrich	Morgan	25-5N-60W	38	1951	1	0				5,688	1,770	"J"
87	Grail	Weld	14-7N-53W	39	1957	7	3	6	2,062	9,329	90,180	71,136	"D"
88	Graylin	Logan	5-8N-53W	37	1951	14	3	12	5,913	15,266	1,232,415	1,756,905	"D" & "J"
89	Graylin-NW	Logan	1-8N-54W	40	1953	58	8	33	45,645	40,941	5,443,971	7,637,044	"D" & "J"
90	Greasewood	Weld	24-6N-61W	42	1930	7	13	1	254	76	916,540	177,015	"D"
91	Greasewood-S	Weld	35-6N-61W	40	1954	4	3	2	563	--	91,246	81,791	"D"
92	Hardway	Washington	17-3N-51W	38	1955	3	3	3	1,180	3,038	65,077	189,068	"J"
93	Hatfield	Logan	7-7N-52W		1959	2	2	2	--	--	--	--	"D" & "J"
94	Haxtun	Phillips	31-9N-47W		1955	1	1	--	--	--	--	--	"J"
95	Hector	Washington	18-1S-56W	38	1955	3	4	3	608	444	100,047	67,131	"J"
96	Highland	Boulder	4-3N-69W	31	1956			1	17		995	11	Cret.
97	Hirst	Washington	15-3S-58W		1958	1	3	1	833	83	10,642	2,522	"J"
98	Hone	Washington	16-2S-55W		1958	4	6	4	8,621	1,857	171,102	44,460	"J"
99	Horsetail	Logan	2-9N-54W	39	1954	5	2	5	888	30,109	184,961	962,372	"D"
100	Hyde	Washington	10-2N-49W	26	1955	7	4	6	8,955	1,470	404,697	64,394	"D"
101	Igo Cr.	Weld	35-10N-59W		1956	1	2	--					
102	Jackpot	Morgan	35-7N-59W	40	1955	36	5	27	5,555	31,581	974,106	1,806,227	"D"
103	Jackpot-S	Morgan	14-6N-59W	40	1955	3	4	1	147	753	79,439	151,633	"D"
104	Jackson	Morgan	25-5N-60W	39	1954	3	1		--	--	2,449	125	"D" & "J"
105	Johnson Hill	Logan	18-8N-54W		1953	1	2		--	--	106	8,634	"J"
106	Johnson Hill-E	Logan	21-8N-54W	40	1954	4	1		--	--	35,684	385,695	"J"
107	Johnson Hill-N	Logan	7-8N-54W	40	1953	25	5	10	7,223	17,556	1,231,275	2,318,851	"J"
108	Kejr	Washington	2-2S-56W	38	1955	36	11	31	54,030	12,058	2,030,909	659,420	"D" & "J"
109	Kejr-S	Washington	14-2S-56W		1956	2	4	2	1,543	600	156,460	99,474	"J"
110	Keota	Weld	9-9N-61W	40	1951	21	13	9	1,403	5,012	1,060,885	397,450	"J"
111	Key	Logan	25-8N-54W	40	1957	4	5	3	2,993	1,311	95,586	56,009	"J"
112	Kiowa Cr.	Weld	28-2N-61W		1955	1	2		--	--	--	82,303	"J"

113	Knoll	Logan	35-8N-51W		1956	1	4		--	--	--	13,831	"J"
114	Knox	Adams	2-2S-59W	38	1954	2	3	1	199	96	31,741	23,522	"J"
115	Lamb	Morgan	16-3N-58W		1956	5	5	2	1,145	2,002	16,726	43,862	"D"
116	Lance	Washington	23-3S-56W	38	1956	1	4	1	264	52	38,763	11,498	"J"
117	Landsman	Kit Carson	20-10S-47W		1956				--	--	--	--	(aban) Lan-KC
118	Lark	Morgan	15-1N-59W	42	1955	1	6	1	319	--	39,112	27,110	"J"
119	Last Chance	Washington	25-3S-56W	43	1955	2	6	2	2,753	83	282,431	19,264	"J"
120	Leader	Adams	17-2S-59W	40	1954	7	1	7	1,344	22,759	126,991	706,659	"J"
121	Lee	Morgan	2-2N-57W	38	1950	5	6	1	174	150	49,794	287,183	"D" & "J"
122	Levee	Morgan	22-5N-55W	48	1956	1	3		--	--	16,045	13,714	"J"
123	Lewis Cr.	Logan	12-11N-53W	38	1953	18	7	13	20,299	24,415	2,832,321	2,470,346	"J"
124	Liberty	Logan	5-8N-54W	39	1954	12	4	11	7,257	22,729	678,938	1,547,966	"J"
125	Liberty-S	Logan	16-8N-54W	44	1953	1	4		--	--	140,868	109,868	"J"
126	Liberty-W	Logan	6-8N-54W	42	1953	6	3	2	1,243	2,909	409,976	695,711	"J"
127	Little Beaver	Washington	5-2S-56W	40	1951	95	25	62	65,322	94,012	10,428,976	12,196,318	"D" & "J"
128	Little Beaver-E	Washington	34-1S-56W	40	1954	28	14	20	23,528	10,737	2,152,393	1,953,381	"D" & "J"
129	Little Hoot	Logan	11-10N-54W		1953	12	7	7	5,482	9,356	28,270	1,224,651	"D" & "J"
130	Loam	Weld	31-7N-58W		1957	1	1		--	--	--	--	"D"
131	Logan	Logan	22-8N-54W	39	1951	4	8	1	302	30	109,292	101,745	"J"
132	Logan-N	Logan	15-8N-54W	38	1954	2	3	1	397	2,922	20,780	64,793	"J"
133	Lone Valley	Washington	28-1N-54W	42	1957	5	5	5	7,484	2,707	150,626	60,489	"J"
134	Long-S	Weld	23-12N-56W	39	1953	7	3		--	--	153,033	184,478	"D" (aban)
135	Lost Cr.	Weld	3-2N-62W	38	1957	2	5	2	2,221	1,131	62,830	57,636	"D"
136	Loula	Logan	12-7N-54W	38	1956	1	5		--		3,703	3,050	"J" (aban)
137	Loveland	Larimer	29-5N-68W	37	1950	6	6 est.	4	1,771	1,651	83,281	61,060	Hyg-Timpas
138	Luft	Logan	18-8N-53W	40	1952	36	2	20	4,832	7,307	1,775,595	2,843,659	"D" & "J"
139	Luster	Morgan	34-1N-55W		1958	9	9	7	14,518	37,962	179,017	175,110	"J"
140	Malpais	Weld	2-8N-57W		1959	1	2		--	--	--	--	"D"
141	Marks Butte	Sedgwick	26-10N-47W		1953	1	0						
142	Masters	Weld	25-5N-61W	39	1953	10	5	4	897	2,802	318,083	1,301,302	"D"
143	May	Weld	30-12N-56W	39	1956	11	5	8	3,682	4,817	225,000	212,364	"J"
144	Merino	Logan	29-6N-54W	39	1950	22	6	15	16,751	4,654	2,796,133	1,083,727	"J"
145	Merino-NE	Logan	12-6N-54W	40	1953	1	3	1	740	199	47,242	13,150	"J"
146	Messer	Morgan	6-5N-56W		1952	1	3		--		3,639	--	"J" (aban)
147	Messex	Morgan	1-5N-55W	39	1951	2	8	1	219	580	304,506	682,733	"J"
148	Messex-W	Morgan	35-6N-55W	38	1955	3	3	2	714	545	60,893	43,673	"D" & "J"
149	Middlemist	Adams	29-2S-57W	40	1952	18	6	16	13,537	14,045	1,203,356	536,589	"J"
150	Midjay	Adams	19-1S-57W		1959	1	2	1	--	--	--	--	"J"
151	Minto	Logan	6-8N-53W	39	1953	3	7	1	3,832	2,285	282,668	153,756	"J"
152	Minto-W	Logan	34-9N-53W	39	1954	20	6	12	6,790	13,814	844,453	1,428,442	"D" & "J"
153	Minto-N	Logan	25-9N-53W	40	1954	3	7	2	2,010	1,205	203,499	139,121	"J"
154	McKenzie	Weld	13-9N-57W	65	1955	2	3	1	135		6,266	149,793	"D" & "J"
155	McRae	Morgan	23-1N-55W	42	1953	10	7	7	9,655	5,260	1,082,903	528,744	"J"
156	Mosley	Morgan	9-3N-57W		1955	1	3						
157	Mount Hope	Logan	24-9N-54W	38	1950	59	7	29	16,258	20,606	4,144,343	5,996,878	"D" & "J"
158	Mount Hope-E	Logan	32-9N-53W	39	1954	18	12	14	11,231	31,891	1,289,485	3,924,481	"D" & "J"
159	Mount Hope-N	Logan	18-9N-53W	40	1952	13	5	6	8,262	21,344	481,395	666,371	"D" & "J"

Number	Field Name	County	General Location	Gravity	Year Discovered	Total Producing Wells	Total Dry Wells	Presently (May, 1959) Producing	Oil Production May, 1959	Gas-MCF Production May, 1959	Oil Accum. Production, May 1959	Gas-MCF Accum. Production, May 1959	Pay Zone and Remarks
160	Mountain View-E	Adams	21-1S-57W	40	1953	2	4		--	--	9,890	3,392	"D" & "J" (aban)
161	Muddy Cr.	Adams	27-1S-59W	34	1955	3	2				25,417	34,668	"D"
162	New Windsor	Weld	26-7N-67W	41	1956			6	8,093	286	239,068	9,718	Sus & Lyons
163	Noonen Ranch	Adams	15&24-3S-59W	40	1952	1	4	1	66	40	19,649	5,774	"J"
164	Nugget	Washington	20-1S-56W		1959	10	4	11	61,845	12,755	362,856	128,712	"D"
165	Onyx	Morgan	24-4N-60W		1959	1	0	1	64	256	2,710	175,362	"J"
166	Opal	Morgan	9-4N-58W		1959	4	1	1	595	3,231	4,035	17,092	"D"
167	Orchard	Morgan	3-4N-60W	36	1955	14	9	7	2,927	14,735	361,006	614,819	"D" & "J"
168	Otis	Washington	25-3N-50W		1954	2	3	1		1,577		182,642	"D"
169	Padroni	Logan	20-9N-52W	36&66	1951	11	9	11	282	11,851	99,902	3,163,372	"D" & "J"
170	Patroni-W	Logan	6-9N-52W	39	1952	10	2	9	7,166	1,619	612,154	188,238	"D," "J" & "M"
171	Park	Morgan	35-1N-59W	38	1954	12	11	7	4,876	4,219	607,897	505,592	"J"
172	Pawnee Cr.	Logan	2-7N-54W	40	1951	29	16	8	4,801	2,664	882,340	609,637	"J"
173	Pawnee Cr.-N	Logan	26-8N-54W		1955	1	2			--	7,171	57,322	"J"
174	Pawnee Hills	Logan	11-7N-55W		1954	1	3	1	77	2,845	9,403	434,400	"D"
175	Peavy	Logan	20-12N-55W	50	1955	3	4	1	1,008	437	67,184	165,276	"D," "J" & "M"
176	Pebble	Logan	21-12N-52W	38	1957	3	2	3	8,039	2,832	97,305	12,882	"J"
177	Peetz-W	Logan	6-11N-52W	37	1952	18	8	13	4,133	44,731	1,119,175	3,061,682	"D" & "J"
178	Peetz-NW	Logan	29-12N-52W						--	--	--		See W. Peetz
179	Peterson	Morgan	21-2N-56W	40	1955	5	5	4	4,266	2,568	222,299	145,377	"D"
180	Phegley	Washington	29-1S-55W	38	1955	18	7	14	10,241	5,462	700,270	164,063	"D"
181	Pinneo-N	Morgan	4-2N-55W	38	1956	1	1		--	--	241	--	"D"
182	Pinneo-SW	Morgan	20-2N-55W						--	--	--		See Zorichak
183	Pierce	Weld	22-8N-66W	36	1955			20	64,224	1,512	2,092,126	50,270	Lyons
184	Platner	Washington	18-2N-51W		1955	1	1	1					
185	Pleasant Valley	Washington	34-3N-53W	46	1955	1	2	1	1,115	446	35,704	10,826	"J"
186	Plum Bush Cr.	Washington	30-2S-55W	41	1954	42	14	40	80,680	33,117	4,406,238	733,355	"J" (unit)
187	Prairie View	Logan	29-10N-53W	38	1956	3	3	1	141	352	21,592	29,361	"D"
188	Prewitt	Logan	36-6N-54W	38	1956	2	5	2	589	80	69,967	10,627	"J"
189	Prong-E	Washington	21-1S-55W		1957	1	3	1	254	390	16,402	7,410	"D" & "J"
190	Purdy	Washington	1-2N-52W	32	1955	1	3	1			4,992	1,268	"D"
191	Rago	Washington	12-1S-55W	37	1953	2	4	2	1,396	522	97,119	39,239	"D"
192	Rago-N&S	Washington	14&23-1N-53W	42	1954	5	4	4	3,409	727	215,656	50,599	"D" & "J"

193	Rake	Morgan	26-4N-60W		1958	4	5	4	7,731	22,259	31,756	41,317	"D"
194	Ramp	Washington	8-3S-55W		1958	5	5	5	4,223	886	113,190	19,471	"J"
195	Raymer Cr.	Logan	15-8N-55W	35	1953	2	3	2	998	2,515	54,848	137,370	"D"
196	Regent	Morgan	6-2N-57W		1957	1	3	1	111	676	7,101	46,973	"D"
197	Ridge	Morgan	7-5N-58W	38	1956	1	2	1	155	124	10,990	17,518	"D"
198	Rift	Logan	14-8N-48W		1957	1	0						
199	Rill	Washington	4-2S-56W		1958	2	6	2	3,813	800	31,907	7,000	"J"
200	Riverside	Weld	19-5N-61W		1955	2	1						
201	Roderick	Washington	15-3S-54W	29	1956	12	7	12	24,671	1,698	573,408	85,742	"J"
202	Roggen	Weld	11-2N-63W	40	1953	3	5	2	669	607	254,935	391,855	"J"
203	Roggen-SW	Weld	23-2N-63W	40	1953	9	10	4	4,571	10,237	518,677	940,426	"D"
204	Rosener	Adams	12-1S-59W	37	1954	5	2	3	1,447	2,085	121,816	115,588	"D" & "J"
205	Ruby	Washington	28-2N-54W		1959	1	0	1	2,319	300	6,213	750	"D"
206	Rufus Run	Morgan	23-1N-56W	40	1955	2	0	1	125	13	17,391	902,141	"D"
207	Rush Cr.	Weld	1-11N-56W	54	1954	4	4	4	975	6,443	14,781	1,133,583	"D"
208	Rush Willadel	Washington	25-3S-51W	22	1952	1	4	1	1,219	79	88,690	5,843	"D"
209	Sam	Morgan	7-1N-56W		1955	1	2		--	--	--	--	"J"
210	San Arroyo	Adams	11-1S-58W		1954	1	1				--	--	"J"
211	Sand River	Morgan	27-1N-56W	40	1954	25	11	20	20,785	19,469	1,926,272	1,177,450	"D"
212	Sandy Hill	Logan	20-7N-52W		1958	2	4	2	2,325	1,771	20,313	15,713	"D"
213	Scarp	Logan	8-11N-54W		1958	1	3	1	2,598	1,559	18,846	11,309	"J"
214	Second Cr.	Adams	8-3S-65W		1956	3	1	2	267	750	28,910	78,916	"D" & "J"
215	Shears Draw	Washington	15-1N-54W	48	1955	3	3	2	1,566	190	99,539	12,208	"J"
216	Soda Lake	Jefferson	7-5S-69W	37	1955	1					14,793	3,231	Timpas
217	Spar	Washington	34-1N-54W		1958	1	2	1	3,284	--	41,846	--	
218	Spring Cr.	Logan	30-9N-55W		1958	3	6		--	--	2,177	840	"J"
219	Springdale	Logan	16-8N-53W	38	1951	6	1	4	34	33,497	12,292	2,710,053	"J"
220	Springdale-S	Logan	28-8N-53W	41	1952	8	6	5	1,790	2,016	417,864	285,499	"J"
221	Spruce	Weld	2-8N-56W		1956	2	3	1	1,902	--	157	30,177	"J"
222	Spurgin	Weld	13-11N-57W	37	1954	1	3		--	--	14,824	9,588	"D"
223	Spurgin-N	Weld	12-11N-57W	40	1957	1	1		--	--	4,918	826	"J"
224	Sterling	Logan	2-7N-52W		1955	1	3		--	--	--	--	"D" & "J"
225	Stoneham	Weld	29-9N-56W	40	1952	3	6		--	--	2,164	220,579	"J"
226	Stoneham-S	Weld	17-8N-56W	40	1952	4	3	2	752	870	89,990	162,557	"J"
227	Stony Buttes	Logan	24-11N-55W		1955	1	3	1	--	1,061	--	18,990	"J"
228	Stony Point	Washington	20-2N-54W		1954	2	3	1	54		9,387	4,511	"D"
229	Surveyor Cr.	Washington	15-2N-52W		1955	9	5	6	3,456	38,079	92,206	217,649	"D"
230	Swan	Washington	21-2S-56W	41	1955	10	5	5	4,941	3,778	381,290	149,375	"J"
231	Terrace	Weld	12-10N-59W		1958	1	1		--	--	2,807		"D"
232	Timpe	Morgan	6-1N-56W	39	1955	3	2	2	615	179	68,010	21,207	"D" & "J"
233	Topaz	Washington	15-1N-54W	45	1957	2	3	2	1,287	614	37,284	19,114	"J"
234	Tower	Weld	6-11N-56W		1958	1	1	1	445	267	8,796	5,277	"J"
235	Trend	Morgan	34-5N-60W		1958	8	4	6	5,349	10,766	107,052	201,557	"D"
236	Turner	Weld	1-7N-59W		1955	1	2		--	--	454	--	"D" (aban)
237	Twin Mills	Logan	18-7N-51W		1957	1	3		--	--	--	--	
238	Two Mile	Weld	4-10N-56W		1956	2	1	1	1,945	--	9,364	304,071	"J"
239	Vallery	Morgan	13-3N-59W		1954	12	9	5	--	68,893	29,933	1,326,720	"D" & "J"

Number	Field Name	County	General Location	Gravity	Year Discovered	Total Producing Wells	Total Dry Wells	Presently (May, 1959) Producing	Oil Production May, 1959	Gas-MCF Production May, 1959	Oil Accum. Production, May 1959	Gas-MCF Accum. Production, May 1959	Pay Zone and Remarks
240	Vigor	Weld	31-12N-57W		1958	1	1	1	632	1,447	6,220	12,496	"J"
241	Vim	Weld	16-11N-58W	40	1957	1	1	1	1,387	6,473	47,303	243,087	"D"
242	Vista	Logan	9-11N-54W	39	1955	1	4	1	460	1,002	80,796	44,881	"J"
243	Walker	Logan	21-9N-53W	39	1950	23	7	11	6,922	6,659	1,404,388	4,081,966	"D," "J" & "O"
244	Wellington	Larimer	31-10N-68W	37	1923			13	6,620	1,120	6,202,722	38,531	"D"
245	Westfork	Washington	19-3S-55W	45	1956	16	6	16	40,044	14,412	886,193	160,717	"J"
246	W. Plains	Logan	31-10N-54W	39	1954	2	3	2	737	2,389	114,520	149,925	"D"
247	W. Plains-N	Logan	19-10N-54W	42	1955	2	4	1	23	1,578	19,028	338,898	"D" & "J"
248	Wetzel Cr.	Washington	19-2S-56W	45	1955	5	7	4	4,734	1,700	255,475	72,315	"J"
249	White	Logan	2-10N-55W		1957	2	2	1	--	1,230	1,168	131,939	"J"
250	White Butte	Weld	26-8N-56W	42	1954	1	4	1	473	--	47,320	19,652	"J"
251	Willard	Logan	19-7N-54W	38	1951	4	5	3	1,747	218	137,857	152,416	"D"
252	Windy Hill	Adams	5-3S-57W	41	1955	3	4	3	2,039	--	94,253	27,569	"J"
253	Winston	Logan	6-10N-52W	39	1955	5	5	3	1,789	179	387,957	59,254	"J"
254	Woodrow	Washington	8-1S-55W		1955	1	1	1	--	--	--	--	"D" (gas)
255	Woodrow-E	Washington	26-1S-55W	60	1952	6	2	2	880	75	51,555	42,010	"D"
256	Woodrow-S	Washington	19-1S-55W	54	1954	4	7	3	2,939	1,259	185,722	66,579	"D" & "J"
257	Woodrow-W	Adams	2-1S-57W	36	1953	1	3		--	--	13,259	3,034	"D" (aban)
258	Xenia	Washington	13-2N-54W	39	1954	3	5	2	1,197	1,784	70,585	210,527	"D" & "J"
259	Xenia-N	Washington	7&5-2N-53W	38	1955	5	4	2	910	765	47,252	112,141	"D" & "J"
260	Xenia-W	Washington	2&11-2N-54W	43	1954	17	10	13	8,936	19,052	1,005,677	668,303	"J"
261	Yenter	Logan	2-8N-54W	38	1950	66	7	26	39,349	113,210	7,167,353	16,449,236	"J"
262	Young	Morgan	14&11-4N-58W		1957	3	5	2	388	67,195	842	101,492	"D"
263	Zorichak (Pinneo)	Morgan	16-2N-55W	38	1954	29	14	29	26,114	48,237	894,767	1,088,788	"D" & "J"
	TOTALS					2,049	1,167	1,491	1,962,961	3,512,742	151,767,680	179,353,183	

Statistics from Petroleum Information, Colorado Oil & Gas Conservation Commission, AIME, and personal files.

Chapter XIV

Southeastern Colorado

by

THADDEUS R. CARPEN

Continental Oil Company

Denver, Colorado

CHAPTER XIV

Southeastern Colorado

by

THADDEUS R. CARPEN*

Southeastern Colorado in this paper refers to approximately the entire southeastern quarter of the State (Plate 2 in the pocket and Fig. 4). The southern and eastern boundaries of the area are Colorado's borders with the States of New Mexico, Oklahoma and Kansas. Westwardly, the province extends to the front of the first principal north-south mountain ranges; namely, the Sangre De Cristo Range, Wet Mountains and southern Front Range. The northern limit of the province might be considered as approximating a line projected southwestwardly from the town of Burlington, Colorado, to Canon City, Colorado. This northern boundary overlaps into the southern end of the Denver-Julesburg Basin province, which is discussed separately in this publication. Conversely, the northern end of a major southeastern Colorado subprovince, the Las Animas Arch, extends in the subsurface for a considerable distance north of the town of Burlington.

Southeastern Colorado consists of a number of separate but adjoining geological subprovinces. They are the Las Animas Arch, Apishapa Uplift, Red Creek Arch, Canon City Embayment, Raton Basin, Sierra Grande Uplift and Hugoton Embayment. The first three of these subprovinces are the large positive tectonic features which cause the southeastern and southwestern termination of the Denver Basin. The latter three are large tectonic features which extend into Colorado from the bordering states to the south and southeast. Figure 7 shows the generalized outlines of the subprovinces and their relationship to each other. Later, the subprovinces will be discussed individually as regional structural features.

Southeastern Colorado cannot be considered a true Rocky Mountain province geologically or geomorphologically. In many respects it is more similar to the typical Mid-Continent geological provinces, of broad gentle basins and buried Paleozoic positive areas. Even though all the tectonic features in southeastern Colorado were either upwarped or downwarped during the Laramide orogeny, the earth movements were gentle compared to the mountain building and formation of intermontain basins in the more typical Rocky Mountain provinces. Southeastern Colorado might best be regarded as transitional between the strong tectonics of the Rocky Mountains and the mild warping of the Mid-Continent.

Southeastern Colorado, when compared to areas in adja-

*Continental Oil Company, Denver, Colorado.

FIGURE 7

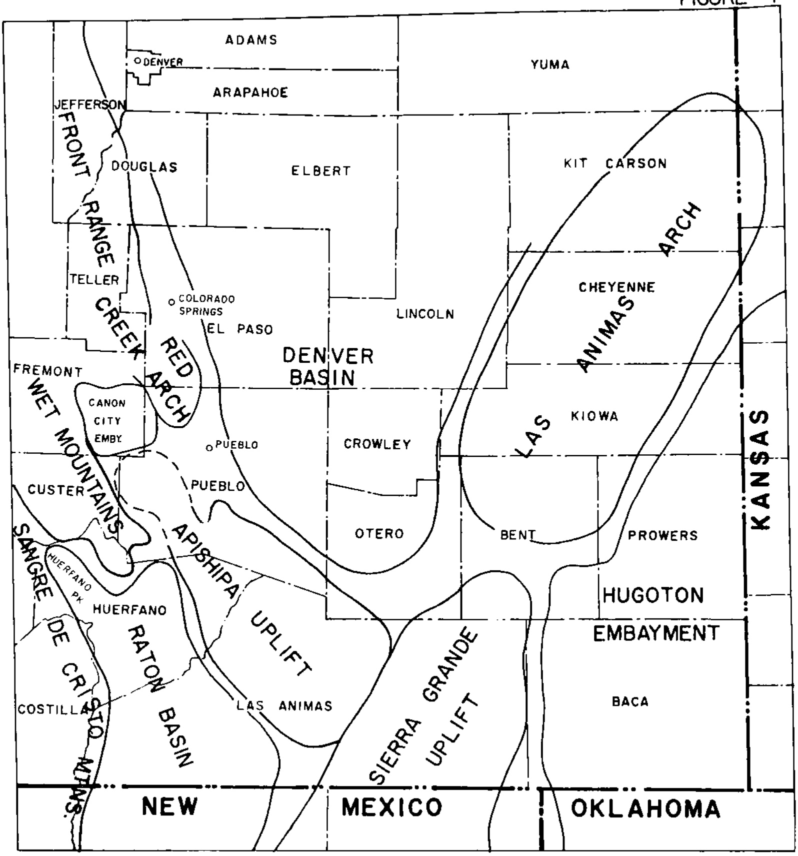

Figure 7 By: T. R. Carpen

INDEX MAP OF SOUTHEASTERN COLORADO
Showing Major Geological Subprovinces

20 10 0 20 40 50
Scale

cent states or even to other parts of Colorado, cannot be considered an important oil and gas producing province at this date. However, this has not been the case in the past nor is it necessarily expected to remain true for the future.

The Canon City Embayment was the second area in the United States to produce oil from drilled wells. Colonel Drake's famous oil discovery at Titusville, Pennsylvania, in 1859 was the first. The discovery in Colorado was in 1862, by an oil pioneer named A. M. Cassedy, approximately six miles north of the town of Canon City.

Later, in 1876, the much more important Florence oil field was discovered by Isaac Canfield near Florence, Colorado. This field became one of the early large oil producing areas, reaching its peak around 1892 when as much as 824,000 barrels of oil were produced in one year. Since that year, there has been a steady decline of production from the Florence-Canon City field. However, there are still several old wells producing in the area and cumulative production has surpassed 14,000,000 barrels. Limited drilling has been revived in the Florence area recently and it is probable that additional commercial wells will be developed.

Since the early 1900's, there have been periodic flurries of exploratory drilling in various parts of southeastern Colorado, but very little in the way of lasting commercial oil or gas has been found. However, there has always been enough encouragement in the way of oil shows and small production to stimulate the oil industry into additional searching, which is going on today. One of the important encouragements was the discovery of gas from rocks of Pennsylvanian age by Continental Oil Company, in 1952, at the McClave Field in Kiowa County.

At the present time (June, 1959) the only commercial production from southeastern Colorado is about 26,000 barrels of oil a year from the Florence field, 14 gas wells producing from the Colorado side of the Greenwood Gas field in Baca County, plus several more small or undeveloped gas fields in Bent, Baca, or Kiowa Counties which are shut-in.

More significant than the present producing status is the future potential of the area which even from a conservative standpoint is very promising. For a considerable length of time now it has been recognized that the province meets all the requirements of an excellent petroleum producing province. The sedimentary section is of adequate thickness and contains sufficient marine sediments to provide a source for hydrocarbons. There are also various potential sandstone and limestone reservoir rocks dispersed through the section, local structural and stratigraphic trapping conditions exist, rejuvenated regional structures provide unconformities, and lastly, numerous oil and gas shows have been encountered in the area. Yet, except for the Florence-Canon City field, substantial oil and gas accumulations have been difficult to locate. It is now realized that this difficulty stems from the fact that the area's hydrocarbons have been accumulated primarily in obscure stratigraphic traps. This problem is further complicated by the fact that in many cases the deeper Paleozoic structure does not coincide directly with the younger surface structure.

Today's oil operators are aware of these variations and with the addition of new well control each year, they are rapidly approaching the time when the optimum subsurface conditions required for large oil accumulations can be recognized.

The current cycle of exploratory drilling may be considered as having started in about 1952. In the last three years, this drilling activity has been steadily accelerating, especially on the Las Animas Arch and in the Hugoton Embayment (sometimes also referred to as the Dodge City Embayment). At the present pace of activity, 1959 will probably establish a new record for the number of tests drilled and may result in the discovery of some new large oil or gas accumulations.

Regional Physiography

The surface physiographic features of southeastern Colorado, like the tectonic features of the province, are transitional from the flat high plains of the Mid-Continent to the high peaks of the Rocky Mountains. However, over most of the area, it is the intermediate forms that predominate.

A description of the physiography and related geomorphology of an area with so much variation and of such a large size can only be accomplished by dividing it into subdivisions. For the sake of simplicity, rather than dividing the area into truly physiographic subdivisions, it is easier to use the same geological subprovinces, as previously described. The primary aspects of each subprovince will be described in abbreviated form.

In the east along the Colorado-Kansas border which is part of the Hugoton Embayment, the surface is essentially a flat alluvial plain of Tertiary sediments sloping gently to the southeast. Occasional creeks cut through the Tertiary Ogallala formation, exposing steeper banks of Dakota sandstone along a portion of the drainage pattern. The only exception to this pattern is an isolated volcanic plug in southern Prowers County which causes the prominence called Two Buttes.

West of the Hugoton Embayment is the broad gentle regional arching of the Las Animas Arch and Sierra Grande Uplift. On the surface, the Las Animas Arch does not appear as a definable physiographic unit except as it is indicated by the outcrop pattern of Cretaceous rocks and gentle dip slopes. Only slight variations of relief occur except where creeks have incised steep banks into the Dakota-Purgatoire sandstones south of the towns of Las Animas and La Junta. This condition is most strongly exhibited in central Las Animas County, where the Las Animas Arch has risen enough to be considered part of the Sierra Grande Uplift. Here at the junction of the Purgatoire River and Chauaco Creek, the streams have cut down through the complete Dakota, Jurassic and Triassic section and into the Permian red beds, creating a miniature Grand Canyon approximately 900 feet deep.

The Sierra Grande Uplift keeps rising to the south until at the New Mexico border it culminates in the high lava capped Mesa De Maya. Remnants of these lava flows continue to the west, mainly in New Mexico, and steadily increase in elevation. South of the city of Trinidad, the lava caps prominent Fisher Peak, highest point of Raton Mesa.

The lava flows are more resistant to erosion than the gravels and consolidated sedimentary rocks which they overlie, and thereby have preserved much of the slope on which they were extruded. In this case the slope dips gently to the southeast, as is evident by the fact that the mesas range from an elevation of around 9,000 feet on the west to only 5,000 feet in Cimarron County, Oklahoma. This old erosional surface is considered to be a pediment correlated by Levings, 1951, to a gravel strewn surface on the Spanish Peaks at an elevation of nearly 10,000 feet.

West and northwest of Trinidad, Colorado, is the Raton Basin. Although this is a structural basin, topographically it is a roughly dissected highland increasing in elevation towards the Spanish Peaks and the Sangre De Cristo Mountains.

The Raton Basin, especially the northern portion, has a considerable number of igneous features. The most outstanding are the Spanish Peaks, which are igneous stocks that have resisted erosion more than the surrounding sedimentary rocks, and have maintained an altitude of more than 13,000 feet. A spectacular system of dikes radiate from the peaks, some of which extend for miles as sharp ridges reminiscent of the Great Wall of China.

Other scattered smaller igneous stocks and plugs remain as isolated high buttes on low mountains surrounded by sedimentary rocks.

The western boundary of the Raton Basin is defined by the sudden appearance of steeply dipping sedimentary rocks along the east side of the Sangre De Cristo Mountain Range.

A prominent surface feature along the eastern side of the Raton Basin is the long erosional scarp of Trinidad sandstone.

The Apishapa Uplift, which trends northwest-southeast, separates the Raton Basin from the Denver Basin. This broad gentle upwarp is typified by erosional cuestas of Upper Cretaceous limestones on its flanks and dip slopes of Dakota sandstone over its crest.

The Canon City Embayment is in alignment with the northwest tip of the Apishapa Uplift. It is a small sedimentary, structural, and topographic basin, surrounded on all but the east side by mountains. In its center is preserved an erosional remnant of Tertiary rocks forming a mesa. On the west and north flanks sedimentary rocks ranging in age from Lower Cretaceous to Ordovician outcrop around the surrounding mountain flanks.

On the east, the Canon City Embayment appears to open into the broad vast expanses of the Denver Basin. Actually, though, it is separated from the Denver Basin by a series of gentle northwest-southeast trending anticlinal folds extending from the Red Creek Arch to the Apishapa Uplift.

Stratigraphy

Southeastern Colorado has a rather complete section of sedimentary rocks, ranging in age from Cambrian through the Recent. The only system not represented in the section is the Silurian. There is also still some question as to whether the Williams Canyon formation in the Canon City Embayment is of Devonian or Mississippian age. Since southeastern Colorado is such a large area, consisting of numerous subprovinces, each with a somewhat different geologic history, the entire section of rocks is never found at any one particular place. Certain subprovinces have a rather complete sequence of Paleozoic rocks while other areas lack many of the Paleozoic formations but have a more complete section of the younger rocks.

The most widespread sequence of rocks over southeastern Colorado is that consisting of the Jurassic Morrison formation and the Cretaceous Dakota sandstone group. In fact, these rocks are fairly widespread over the whole State.

A problem that arises from the large number of subprovinces in southeastern Colorado is that of stratigraphic nomenclature. Rock units that could not be continually traced between subprovinces at the time they were originally studied usually were given different names. Subsequent studies and long range correlations proved that many of the rock formations with different names and in separated subprovinces were equivalent and correlative, even though common usage has preserved the original names. The usual method of solving this common geologic problem is exhibited in Figure 8, which is a correlation chart of the generalized stratigraphic section for southeastern Colorado.

Brief descriptions of the individual rock units and a discussion of their areal distribution is presented in the following text. The sequence of description is from the oldest to the youngest.

Paleozoic Rocks

The oldest sedimentary rocks in southeastern Colorado are of Upper Cambrian and Ordovician age and exist in two separated areas. They are present in the subsurface in the Hugoton Embayment along the Colorado-Kansas border and on the Las Animas Arch, and as surface outcrops in the Canon City Embayment and along the east flank of the southern Front Range. These rocks at both places, although differently named, are correlative and are believed to have been deposited continuously. Post Ordovician erosion of ancient Paleozoic positive areas subsequently stripped them away except in the present areas of preservation.

The Arbuckle or its equivalent on outcrop, the Manitou,

FIGURE 8

CORRELATION CHART OF THE GENERALIZED STRATIGRAPHIC SECTION FOR SOUTHEASTERN COLORADO

GEOLOGIC TIME		RATON BASIN	CANON CITY EMBAYMENT	LAS ANIMAS ARCH HUGOTON EMBAYMENT
QUATERNARY	RECENT	ALLUVIUM	ALLUVIUM	DUNE SAND-ALLUVIUM
QUATERNARY	PLIESTOCENE		TERRACE DEPOSITS	TERRACE DEPOSITS MEADE (?) FM.
TERTIARY	PLIOCENE		NUSSBAUM FM.	OGALLALA FM.
TERTIARY	MIOCENE	DEVILS HOLE FM.		
TERTIARY	OLIGOCENE	FARISITA CGL.		
TERTIARY	EOCENE	HUERFANO		
TERTIARY	EOCENE	CUCHARA		
TERTIARY	PALEOCENE	POISON CANYON FM.		
TERTIARY	PALEOCENE	RATON FM.	ARAPAHOE FM.	
CRETACEOUS	UPPER	VERMEJO FM.	VERMEJO FM.	
CRETACEOUS	UPPER	TRINIDAD SS.	TRINIDAD SS	
CRETACEOUS	UPPER	PIERRE SHALE; APACHE CR. SS. MEM.	PIERRE SHALE	
CRETACEOUS	UPPER	NIOBRARA: APISHIPA SH.; TIMPAS LS.; SMOKY HILL M.; FT. HAYS	NIOBRARA: APISHIPA SH. MEM.; TIMPAS LS. MEM.	NIOBRARA: SMOKY HILL M.; TIMPAS LS. FM.
CRETACEOUS	UPPER	CARLILE SH.	CARLILE SH.	CARLILE SH.
CRETACEOUS	UPPER	GREENHORN LS.	GREENHORN LS.	GREENHORN LS.
CRETACEOUS	UPPER	GRANEROS LS.	GRANEROS LS.	GRANEROS LS.
CRETACEOUS	UPPER	DAKOTA SS.	DAKOTA SS.	DAKOTA SS.
CRETACEOUS	LOWER	PURGATOIRE FM.: SH. MEM.; SS. MEM.	PURGATOIRE FM.: GLENCAIRN SH.; LYTLE SS. MEM.	PURGATOIRE FM.: KIOWA SH. MEM.; CHEYENNE SS. M.
JURASSIC	UPPER	MORRISON FM.	MORRISON FM.	MORRISON FM.
JURASSIC	UPPER	TODILTO	RALSTON CR. FM.	MIDDLE UNIT JURRASS.
JURASSIC	UPPER	ENTRADA (OCATE) SS.		ENTRADA SS.
TRIASSIC	UPPER	DOCKUM GROUP: CHINLE FM.		DOCKUM GROUP: SLOAN CANYON
TRIASSIC	UPPER	DOCKUM GROUP: SANTA ROSA SS.		DOCKUM GROUP: DOKUM SS.
PERMIAN	OCHOA			TOLOGA
PERMIAN	GUADALUPE	UNNAMED	LYKINS: UP. "CRINKLY" LS.	DAY CREEK
PERMIAN	LEONARD	UNNAMED	LYKINS: L. "CRINKLY" LS.	BLAINE
PERMIAN	LEONARD	GLORIETA SS.	LYONS SS.	NIPPEWALA GRP.
PERMIAN	LEONARD	YESSO FM.	FOUNTAIN FM.	SUMNER GRP. STONE CO.
PERMIAN	WOLFCAMP	SANGRE DE CRISTO FM.	FOUNTAIN FM.	WOLFCAMPIAN
PENNSYLVANIAN	VIRGIL	SANGRE DE CRISTO FM.; ARK. LS. MEM.	FOUNTAIN FM.	VIRGILLIAN
PENNSYLVANIAN	MISSOURI	ARK. LS. MEM.	FOUNTAIN FM.	LANSING-KANSAS CITY
PENNSYLVANIAN	DES MOINES	MADERA FM. GRAY LS.	FOUNTAIN FM.	MARMATON-CHEROKEE
PENNSYLVANIAN	ATOKA	SANDIA CLASTIC M.	FOUNTAIN FM.	ATOKAN
PENNSYLVANIAN	MORROW	?	GLEN EYRIE FM.	MORROWAN; KEYES SS
MISSISSIPPIAN	CHESTER			CHESTER
MISSISSIPPIAN	MERAMEC		BEULAH LS.	ST. GENEVIEVE LS.
MISSISSIPPIAN	MERAMEC		HARDSCRABBLE LS.	ST LOUIS LS.
MISSISSIPPIAN	MERAMEC			SPERGEN LS.; WARSAW LS
MISSISSIPPIAN	OSAGE			OSAGE
MISSISSIPPIAN	KINDERHOOK			KINDERHOOK
DEVONIAN			WILLIAMS CANYON LS.	
ORDOVICIAN	UPPER		FREMONT FM.	VIOLA LS.
ORDOVICIAN	MIDDLE		HARDING SS.	SIMPSON SS.
ORDOVICIAN	LOWER		MANITOU LS.	ARBUCKLE DOLO.
CAMBRIAN	UPPER		UTE PASS DOLO.	BONNETERRE DOLO.
CAMBRIAN	UPPER		SAWATCH SS.	REAGAN or LAMOTTE SS.
PRE-CAMBRIAN		IGNEOUS AND METAMORPHIC		

By: *T. R. Carpen*

FIGURE 8

are the most widespread of this group. They overlap the basal Upper Cambrian, Reagan or Sawatch sandstone, and in places directly overlie the pre-Cambrian basement rocks. The Ordovician rocks above the Arbuckle are of more limited distribution than the Arbuckle, especially in southeasternmost Colorado. They were probably originally deposited more thinly, and then further greatly reduced by the long period of erosion that followed Ordovician time and lasted until Mississippian deposition commenced.

There are no rocks of Silurian age recognized in Colorado, indicating that the whole area was above sea level and undergoing erosion.

During Devonian time thick carbonate sections were being deposited in western Colorado; however, in southeastern Colorado the only questionable remnant of Devonian rocks is the Williams Canyon formation in the Canon City Embayment area. Further east, rocks of Devonian age are completely absent, suggesting non-deposition due to the area being above sea level rather than by erosion following Devonian deposition.

Cambrian System

Reagan or Lamotte Sandstone—Sawatch Sandstone

The Reagan or Lamotte sandstone is Oklahoma and Kansas nomenclature for the basal sandstone in southeasternmost Colorado subsurface. It ranges from 0 to 70 feet in thickness and is predominantly white, fine to coarse grained, glauconitic, and in places dolomitic.

The Sawatch sandstone is equivalent where it outcrops on the east flank of the southern Front Range. It ranges from 0 to 76 feet in thickness and is white to pink to red in color. At the top it is fine-grained, ranging to coarse-grained at the bottom where it may be somewhat feldspathic and may contain quartz pebbles up to three inches in diameter near its contact with the pre-Cambrian. Glauconite is common in the upper part.

Bonneterre Dolomite—Ute Pass Dolomite

The Bonneterre dolomite of the Hugoton Embayment-Las Animas Arch subsurface section, is a light gray to buff, medium to coarsely crystalline, sandy dolomite ranging up to 100 feet in thickness. Its Front Range equivalent is a thin sequence of coarsely crystalline pink dolomite.

Ordovician System

Arbuckle Group—Manitou Limestone

The Arbuckle group with a maximum thickness of 550 feet in southeasternmost Colorado is primarily a light buff, crystalline, frequently sandy dolomite, commonly oolitic and cherty. It is truncated on the Sierra Grande Uplift where it is overlain by rocks ranging in age from Ordovician to Permian.

The Front Range equivalent is the Manitou limestone with a surface outcrop thickness ranging to more than 150 feet north of the Canon City Embayment. It varies from a pink, cherty, finely crystalline dolomite to an oolitic, finely crystalline, buff limestone.

Simpson-Harding Sandstone

The Simpson group is a thin, gray to buff, dolomitic sandstone overlying the Arbuckle in southeasternmost Colorado. It contains blue-green shale and glauconite, and is not as widespread as the Arbuckle.

In the Canon City Embayment, its equivalent is the Harding sandstone which ranges up to 144 feet in thickness. At the base it is coarsely grained and white, grading upwards to a very fine-grained, white, yellow or pink sandstone. The upper two-thirds contain many fish remains, both in the sand, and in dark, varicolored shale beds.

Viola-Fremont Limestone

The Viola of southeasternmost Colorado is preserved only as thin remnants of rather local distribution because of extensive pre-Mississippian erosion. It consists of gray to buff, cherty, finely to sometimes coarsely crystalline dolomite.

The Fremont limestone, as the outcrop section is called, is as much as 280 feet thick in the Canon City Embayment. It is a gray to buff, fine to medium crystalline dolomite with purplish-to-pinkish mottling in part. Only small amounts of reddish brown chert are present. The lower 15-20 feet are rather distinctive, being composed of red to pink, medium to coarsely crystalline fossiliferous dolomite.

Devonian (or Mississippian?) System

Williams Canyon Limestone

This formation consists of a sequence of thin, purple mottled, gray to buff, finely crystalline limestone, dolomitic limestone and dolomite, and a few layers of pink to lavender sandstone. No fossils have been recovered to definitely establish its age. It is present only in the Canon City Embayment area; however, some geologists believe it may be equivalent to Mississippian rocks of Lower Meramec age.

Mississippian System

At the beginning of Mississippian time, the seas in which the Mississippian beds were deposited encroached from the Anadarko Basin in Oklahoma. By the middle of Mississippian time all of southeastern Colorado was inundated. Towards the end of the Mississippian, the sea again withdrew to the southeast, after which the Mississippian rocks were left exposed to subaerial erosion.

This sequence of events accounts for the oldest Mississippian rocks, and then again, the youngest Mississippian rocks being present only in the Hugoton Embayment, while middle

Mississippian rocks are present over a large area of southeastern Colorado.

As in the case of the Cambrian and Ordovician rocks, the entire Mississippian section was truncated on the Sierra Grande and Apishapa Uplifts during periods of former uplift.

Kinderhook Group

Up to 125 feet of rocks in the subsurface is assigned to the Kinderhook Group near the Kansas border. They wedge out rapidly to the west. They consist primarily of buff to brown dolomite with some thin limestone streaks. The "Misener sandstone," the basal poorly sorted sand of this group, is also recognized in many wells.

Osage Group

Up to 100 feet of Osage rocks exist along the Kansas border again wedging out wetsward. They are made up of the Burlington-Keokuk limestones which consist of very cherty, glauconitic, buff to gray, finely granular dolomite and dolomitic limestone.

Meramec Group

This is the most widespread group of Mississippian rocks. The thickness ranges from 450 feet in the Hugoton Embayment to about 125 feet in the outcrops along the southern Front Range. The group is made up as follows:

Warsaw and Spergen Limestones

There are about 100 feet of these beds in southeasternmost Colorado consisting of an upper gray to buff, finely granular, slightly cherty dolomite and a lower finely to coarsely crystalline limestone and dolomitic limestone which is glauconitic and oolitic.

St. Louis Limestone—Hardscrabble Limestone

The St. Louis limestone extends from western Kansas to the Front Range where its equivalent, the Hardscrabble, outcrops on the surface. In both vicinities it has a maximum thickness of about 125 feet. Along the Colorado-Kansas border it consists of buff, oolitic, finely crystalline limestone and dolomitic limestone. It is cherty near its top and base.

The Hardscrabble is a buff to dark brown, finely crystalline limestone, cherty and oolitic at its top. Some of the beds toward the base are dolomitic.

Ste. Genevieve Limestone—Beulah Limestone

The Ste. Genevieve limestone also extends from Kansas to the Front Range where its equivalent is the Beulah limestone. In the Hugoton Embayment, where its thickness ranges up to 180 feet, it is a buff, oolitic, sandy limestone with some orange to tan chert near its base.

The Beulah limestone along the Front Range reaches a maximum thickness of only about 50 feet. It is a pink-stained, sandy and oolitic limestone with some yellow-red chert.

Chester Group

A thin section of Chester rocks overlies the Ste. Genevieve limestone in and around Baca County. It consists of thin beds of buff limestone, sandstone and green and maroon shale.

Pennsylvanian System

Pennsylvanian rocks are present throughout southeastern Colorado except on the crests of the Sierra Grande and Apishapa Uplifts, where they are absent by both truncation and non-deposition. The Pennsylvanian rocks demonstrate a profound facies change over the province. Along the Colorado-Kansas border and in the eastern part of the Denver Basin they are a marine sequence of limestones with interbedded dark shales. Along the flanks of the Sierra Grande-Apishapa Uplift, and the Front Range, they change rapidly into a thick, undifferentiated, red arkosic unit named the Fountain formation. The Fountain formation was derived from erosion of abruptly uplifted granite mountains during Pennsylvanian and Lower Permian time along the present day Sierra Grande-Apishapa Uplift and the Front Range. This system of ancient mountains is commonly referred to as the "Ancestral Rockies."

During the same geologic time, the Raton Basin and Sangre De Cristo Mountains were part of a narrow northwest-southeast trending depositional trough which was located west of the Ancestral Rockies. Here the Pennsylvanian sequence was mostly marine at its beginning, but as time progressed, more and more coarse arkosic clastics were introduced from the rising mountains on either side. By the middle of Pennsylvanian time, the red arkoses of the Sangre De Cristo formation were being deposited in great thicknesses. The Sangre De Cristo formation is equivalent to the upper two-thirds of the Fountain formation and likewise extends into Lower Permian time.

Morrow Rocks—Glen Eyrie Shale

Up to 550 feet of Morrow sediments exist in the Hugoton Embayment. The upper part is black and green shales while the lower part includes thin sandstones and limestones. A basal sandstone ranging up to 200 feet thick, named the "Keyes sandstone," exists in southeasternmost Colorado. This sandstone is composed of coarse to medium quartz grains, commonly with considerable interstitial feldspathic clay. It thins northward and westward in which directions it is frequently represented by a basal calcareous detrital conglomerate.

The black and purple Glen Eyrie shale is the Morrow equivalent along the Front Range.

Atoka Rocks—Sandia Formation

In southeasternmost Colorado there are up to 700 feet of Atoka deposits in a band north and east of the Sierra Grande Uplift. The marine facies of these rocks is dark shales with thin interbedded dark siliceous limestones. Approaching the

Sierra Grande Uplift they grade into arkosic tongues interbedded with gray, purple and brown shales. Along the Front Range the basal part of the Fountain formation is considered to be Atokan.

In the Sangre De Cristo Mountains and probably in the subsurface of the Raton Basin the Sandia formation is considered, at least in part, to be of Atokan age. Sandia is a name brought up from New Mexico and the rocks consist of dark limestones, black shales and light gray sandstones.

Des Moines Rocks—Madera Formation

In southeasternmost Colorado, the marine facies of Des Moines rocks is represented by the Cherokee and Marmaton groups. The Cherokee consists of dark gray and black bituminous shale interbedded with brown to gray, argillaceous limestone. The Marmaton is composed of buff to brown, dense to finely crystalline limestone with subordinate black and gray shale interbeds. Towards the Sierra Grande-Apishapa Uplift and Front Range, the Cherokee and Marmaton beds become more arkosic until they are part of the Fountain formation.

In the Raton Basin the Madera formation is mostly of Des Moines age. It is divided into a "lower gray limestone member" and an "arkosic limestone member." The former is dominately a gray limestone with dark gray limey shale and light gray sandstone interbeds. The "arkosic limestone member" consists of an interbedded red to gray sandstone, red to gray shales and red to gray limestones. It is transitional from the rocks below to the Sangre De Cristo formation above.

Missouri Rocks

In southeasternmost Colorado these rocks are represented by about 350 feet of Lansing-Kansas City limestones and thin interbedded dark marine shales. The limestones are cream to buff to brownish gray, finely crystalline, frequently with numerous oolitic and/or oocastic zones up to 25 feet thick. The Lansing-Kansas City, like all other Pennsylvanian rocks, becomes part of the Fountain formation on approaching the uplifts.

Virgilian Rocks

Up to 650 feet of Virgil sediments exist in southeastern Colorado as parts of the Douglas, Shawnee and Wabunsee Groups. They are light colored limestones, usually less oolitic than the Lansing-Kansas City, with thin gray, black to green and red shale interbeds. Towards the west and south they become more sandy until they lose their identity as part of the Fountain formation.

Fountain Formation—Sangre de Cristo Formation

Along the Front Range, the Fountain formation ranges up to at least 4,400 feet in thickness, consisting of coarse, reddish, arkosic sandstones and conglomerates with interbedded red silty micaceous shales. Its age ranges from Atokan to lower

Permian, during which times it was being shed from the uprising granitic Ancestral Rockies. Further from its source it thins and becomes intertongued with normal marine sediments.

The Sangre De Cristo formation is the Raton Basin equivalent of the approximate upper two-thirds of the Fountain formation. The lithology is essentially the same, but in places its thickness exceeds more than 10,000 feet.

Permian System

Permian rocks, which are primarily red beds, cover most of southeastern Colorado. By upper Permian time, even the former strongly positive ancestral Sierra Grande and Apishapa uplifts were beveled and buried by continuous deposition.

Several widespread anhydrite beds exist in the upper Permian beds which constitute excellent regional correlation markers.

Wolfcamp Rocks

In western Kansas the Wolfcamp rocks are predominately limestones and dolomites which grade westward into fine-grained, red sandstones and red, silty shales and then finally into the red arkoses and shales of the upper part of the Fountain formation and Sangre De Cristo formation. The subdivisions of Admire, Council Grove (with the Foraker limestone) and Chase groups can only be separated along the Colorado-Kansas border. Elsewhere, these rocks cannot even be readily separated from the Sumner group above them.

Leonard Rocks

Rocks of Leonard age are divided into the Sumner group and Nippewalla group which contain some widespread identifiable formations.

Sumner Group—Stone Corral—Yeso Formation

The base of the Sumner group is difficult to differentiate from the underlying Wolfcamp. However, the top is marked by the widespread Stone Corral anhydrite. The Stone Corral ranges from 60 feet in thickness along the Kansas border to only a few feet in Pueblo County. It is composed of white, finely granular anhydrite and some buff to red finely granular dolomite. The rocks beneath it are primarily red, fine-grained sandstones, siltstones or shales which thin westward and then lose their identity in the Fountain formation.

In the Raton Basin, the Yeso formation, consisting of orange-red dolomitic sandstone and silty sandstone with thin stringers of red dolomite, is considered to be equivalent to the Sumner group.

Nippewalla Group—Blaine Formation—
Lyons Sandstone—Glorieta Sandstone

The Nippewalla group includes all of the rocks from the top of the widespread Blaine anhydrite to the top of the Stone

Corral. Along the Colorado-Kansas border this section is about 800 feet thick, consisting of the white to pink Blaine anhydrite at the top, then a sequence of red to orange sandstones, siltstones and shales. The Nippewalla thins to about 200 feet along the Front Range with the Blaine anhydrite correlating with one of the "crinkly" limestones in the lower part of the Lykins formation.

The clastic sediments beneath the Blaine anhydrite grade westward into the thick Lyons sandstone and its Raton Basin equivalent, the Glorieta sandstone. The Lyons and Glorieta are fairly homogeneous, orange to pink to cream colored, medium-grained, frosted, subrounded quartz sandstones.

Guadalupe Rocks—Day Creek—Lykins Formation

In the Hugoton Embayment there are up to 600 feet of Guadalupe rocks including the Whitehorse, Day Creek anhydrite and Taloga formation. The Day Creek anhydrite is a good marker bed while the rest are fine-grained red clastics.

Westward towards the Front Range the Guadalupe rocks thin to about 200 feet and make up the upper part of the Lykins formation which is a red sandstone and siltstone; the Day Creek anhydrite is correlated with one of the upper "crinkly" limestone members.

In the Raton Basin the red sandstones, siltstones and shales with anhydrite inclusions above the Glorieta sandstone are considered equivalent to Guadalupe rocks.

Mesozoic Rocks

Triassic System

Triassic rocks are more widespread in southeastern Colorado than generally recognized. They range up to more than 500 feet of thickness along the east flank of the Sierra Grande Uplift. However, since they are primarily reddish colored clastics of non-marine origin, they are difficult to differentiate from the Permian rocks below.

Dockum Group

All of the Triassic rocks in southeastern Colorado are part of the Dockum Group of late Triassic age. This includes the Dockum sandstone which is orange-pink-white, fine to coarse grain to conglomeratic, with lenses of limestone and variegated shale interbeds. The Sloan Canyon formation is primarily a variegated mudstone with interbedded limestone, dolomite and sandstone.

The Santa Rosa sandstone and Chinle formation are equivalents of the Dockum sandstone and Sloan Canyon formations respectively, in the Raton Basin.

Jurassic System

Jurassic rocks are widespread in southeastern Colorado and represent various phases of continental type deposition.

The system is represented by three formations or their equivalents.

Entrada Sandstone—Ocate Sandstone

This white to buff sandstone with eolian cross bedding overlies the Dockum group. It thins northward and eastward from a maximum thickness of about 100 feet. However, it is locally absent by erosion.

Middle Unit—Todilto

This formation ranges from 50 to 150 feet in southeastern Colorado. It consists of gypsum, anhydrite, limestone and varicolored mudstone, but is most recognizable by a thin interval of nodular red to orange chalcedony. These beds are approximately equivalent to Todilto, Wanakah, Ralston or Curtis Summerville in adjacent areas.

Morrison Formation

The Morrison formation is widespread throughout most of the Rocky Mountain region, but is not well understood. It is usually considered to mark the boundary between the Jurassic and Cretaceous systems; however, in some places it appears to be transitional with the overlying Purgatoire. It is a continental deposit consisting of variegated mudstone, claystone, siltstone and marlstone, but includes lenses of limestone, sandstone and conglomerate. It ranges up to 400 feet thick along the Front Range and Sangre De Cristo Mountains and thins irregularly to the east.

Cretaceous System

Most of southeastern Colorado is covered by some part of the Cretaceous system. The thickest Cretaceous section preserved in the area is in the Canon City Embayment where up to 5,500 feet is present. In the remainder of the area much of the section has been removed by erosion. About 80 percent of these rocks are marine sediments with clay shale being the predominant lithologic type.

At the close of Jurassic time, the Cretaceous seas encroached over southeastern Colorado, causing the deposition of the basal Purgatoire sandstone. A temporary regression and renewed transgression of the seas resulted in the deposition of the Dakota sandstone. Afterwards, the sea continued to deepen and spread, causing marine shales and thin limestones to be deposited over the entire area. Another shortlived but widespread cycle of sea level regression occurred during the time that the Codell sandstone was deposited. Inundation then continued for a long time, allowing the marine Niobrara formation and Pierre shale to accumulate to considerable thickness. Towards the end of Cretaceous time, the sea started withdrawing and allowed the Trinidad sandstone to be deposited. In the late stage of Cretaceous time, a period of instability marked the beginning of the Laramide Orogeny, during which time the coal-bearing Vermejo formation was deposited.

Purgatoire Formation

Averaging about 200 feet thick, this formation consists of a lower sandstone and conglomerate member and an upper shaly member.

The sandstone member, called Lytle or Cheyenne, is about 150 feet thick and is of non-marine origin. It is a white to light gray, massive sandstone containing conglomerate lenses in its lower part.

The shale member, Glencairn or Kiowa, is a gray to black, sometimes sandy or carbonaceous marine shale.

Dakota Sandstone

The Dakota, which averages about 100 feet in thickness, is a brown-weathering, hard, cross bedded, cliff former. Shale interbeds are common, especially to the east. It is considered to be transitional from non-marine to marine.

In some parts of southeastern Colorado, the Purgatoire formation and the Dakota sandstone cannot be differentiated, in which case they are combined and designated as the Dakota.

Graneros Shale

This formation is about 100 feet thick and is a dark gray to black marine shale with thin layers of bentonite.

Greenhorn Limestone

This formation consists of a series of alternating thin, light colored, densely crystalline limestones and dark gray, limey shales.

Carlile Shale

The Carlile consists of a gray calcareous shale and a dark gray non-calcareous shale overlain by the Codell sandstone member. The Codell is a light brown to cream, medium-grained sandstone with some interbedded dark gray limestone. In the Raton Basin it attains a thickness of up to 40 feet.

Niobrara Formation

The Niobrara consists of the Timpas limestone member at its base overlain by more than 500 feet of gray, speckled calcareous shale called the Smoky Hill or Apishapa member. The Timpas limestone is white and dense with thin beds of interbedded shale.

Pierre Shale

The Pierre shale consists of a dark gray, non-calcareous shale with gray calcareous concretions or ferruginous concretions. Its thickness exceeds 3,500 feet in the Canon City Embayment. The top few hundred feet is sandy and transitional with the Trinidad sandstone.

Trinidad Sandstone

The Trinidad sandstone is a buff to gray fine-grained micaceous sandstone with thin interbeds of silty shale. It contains weathered feldspar and ferromagnesian minerals. Its maximum thickness is about 300 feet northwest of Walsenburg, Colorado.

Vermejo Formation

These beds rest conformably on the Trinidad sandstone with which they intertongue. Vermejo rocks consist of buff, gray and dark gray siltstones and feldspathic sandstones and black carbonaceous silty shale and numerous coal beds.

Cretaceous-Tertiary Systme

Raton Formation—Arapahoe Formation

It is still questionable as to which system these rocks belong. However, they do represent the beginning of the nonmarine clastic deposition resulting from the strong orogenic uplifting of the Laramide Revolution.

At the base of the Raton formation there frequently is a thin granule to pebble conglomerate. Then a sequence of buff to gray, fine to coarse-grained arkoses, graywackes or sandstones with gray to dark gray silty shale beds and some coal seams. The feldspar grains are weathered and generally white or light gray in color.

In the Raton Basin up to 1,700 feet of these rocks are present.

The name Arapahoe formation is applied to correlative strata in the Canon City Embayment.

Cenozoic Rocks

Tertiary System

The mountain building of the Laramide Orogeny commenced in late Cretaceous time and disturbances continued sporadically in southeastern Colorado through at least the first half of Tertiary time.

The Front Range and Sangre De Cristo Mountains were uplifted strongly, providing the source for new surges of coarse-grained clastic sediments. Great thicknesses of such coarse rocks filled the Raton Basin, where they are preserved today. Eastward, however, rejuvenated uplifting of the Las Animas Arch and Sierra Grande-Apishapa Uplifts prevented much deposition and allowed erosion to remove much of the Cretaceous section.

From Miocene time through Quaternary (?) time, vulcanism spread igneous rocks over a large portion of the terrain in the southern part of the area under consideration. Final broad uplifting of the area since the vulcanism has caused dissection and removal of much of the pediment surfaces and lava flows.

Poison Canyon Formation

The lower part of the Poison Canyon formation appears to grade into the Raton formation from which it is differentiated by the pink color of its feldspar grains. It contains massive, buff to red arkosic sandstones and conglomerates with thin, yellow shale beds. It is as much as 2,500 feet thick south of the Spanish Peaks.

Cuchara Formation

The Cuchara formation is restricted to the Raton Basin. It ranges in thickness from 5,000 feet near the Spanish Peaks to a thin edge further north in Huerfano Park. It is composed of massive, red, pink and white sandstones interbedded with red, gray and tan claystone. The basal sandstone beds are frequently conglomeratic.

Huerfano Formation

This formation is as much as 2,000 feet thick in Huerfano Park, where it is in an unconformable overlap relationship with beds below it. It consists of variegated shales and red, tan and white sandstones. The formation is poorly consolidated except at its base where it is conglomeratic.

Farasita Conglomerate

The Farasita is a mass of boulders, cobbles and pebbles deposited during Oligocene time in Huerfano Park. It overlaps unconformably the younger sediments and laps onto the pre-Cambrian along the west flank of the Wet Mountains.

Devils Hole Formation

The Devils Hole formation is a sequence of rocks ranging from 25 to 1,300 feet thick in northern Huerfano Park and extending northward into the Wet Mountains Valley. It consists primarily of water-laid conglomeratic tuff, composed of a matrix of fragments of volcanic glass, pumice, perlite and quartz. The coarse material is a mixture of pebbles of pumice, perlite and pre-Cambrian gneiss and schist.

The Devils Hole formation unconformably overlaps the underlying sedimentary sequence.

Ogallala Formation—Nussbaum Formation

These rocks of Pliocene age were deposited at the end of Tertiary time as alluvium over the plains east of the mountains. In many parts of southeastern Colorado they have already been removed by erosion. However, they are still present on the surface in the Hugoton Embayment as the Ogallala formation and as a remnant of Nussbaum Formation in the Canon City Embayment.

The formations consist of poorly sorted, light colored, clayey sandstones and gravels, usually unconsolidated at the top.

Late Tertiary & Quaternary (?) Igneous Rocks

In the Raton Basin, igneous intrusions in the form of stocks, dikes, sills and laccoliths may have occurred as early as Eocene time. This group of intrusions is composed primarily of felsite, monzonite and quartz monzonite type rocks.

Intrusions in the form of stocks, dikes, and sills again occurred during Miocene time. This stage involved primarily hornblende andesite and olivine basalt rocks.

Finally a period of sporadic vulcanism occurred which lasted from late Tertiary time into Quaternary time. The extruded lava flow rocks ranged from rhyolite to andesite to basalt.

The variability in texture and composition of the rocks making up the Spanish Peaks igneous stocks suggest at least seven pulses of injection (and probably extrusion) throughout Tertiary and Quaternary time.

Quaternary System

Alluvium and Terrace Deposits

From Pleistocene time into Recent (or present) time, gravel or sand terraces, river alluvium and some glacial moraine debris on mountain sides have been accumulating in various local areas in southeastern Colorado.

Structural Geology

The structural geology of southeastern Colorado (see Plate 2 in pocket) can again best be described by subdividing the area into its major geological subprovinces (see Fig. 7). The subprovinces as used in this paper are, in actuality, the major regional structural features of the area. Because of their large size, long geologic history and their effect on stratigraphy, it is proper to consider them regional tectonic elements in addition to present day structural features.

In any case, each of the major structural features with its multitude of smaller superimposed local structures will be described.

Hugoton Embayment

The Hugoton Embayment extends into Kiowa, Prowers, Bent and Baca Counties, Colorado, from southwestern Kansas and the Oklahoma Panhandle, as the most northwesterly extension of the Anadarko Basin of Oklahoma. It is sometimes also referred to as the Dodge City Embayment.

There is gentle easterly dip into the embayment from the east flanks of the Sierra Grande Uplift and Las Animas Arch. This easterly monoclinal dip is interrupted by numerous smaller structures in the subsurface rocks which are not evident on the surface. The local structures are mostly of Paleozoic origin, they are buried by variable thicknesses of Permian and Mesozoic rock with many intervening unconformities, and lastly they are concealed by the Tertiary Ogallala formation overlap. However, buried structures in the Hugoton Embayment are being located by seismograph exploration and currently by subsurface mapping techniques where the increased well control allows.

The largest of the subsurface structures recognized to date is the Keyes Dome, the crest of which is in Cimarron County, Oklahoma, just south of the southeastern tip of Colorado. The structure is somewhat circular in shape, with a diameter of about 14 miles and proven closure of at least 250 feet. A large part of the structure is productive of gas and some oil from the Keyes sandstone.

Approximately 25 miles north of Keyes dome there is weak subsurface structural closure which is a westward extension of the Greenwood gas field structure of Morton County, Kansas. Fourteen gas wells produce from this feature on the Colorado side, from Virgilian and Missourian limestones. The accumulation is partly due to a stratigraphic change causing a loss of porosity in the reservoir rocks.

The final well known local structure in the Hugoton Embayment is the Two Buttes igneous plug. It is a Tertiary igneous intrusion which when it penetrated to the surface caused a sharp circular upheaval around it, in all rocks that it penetrated. The flanks of this dome have been drilled several times without any success in finding hydrocarbons.

Sierra Grande Uplift

The Sierra Grande Uplift on the surface is a broad northeast-southwest trending anticlinal structure extending into eastern Las Animas County, Colorado, from New Mexico. Its east side is delineated by the Hugoton Embayment, while the west side is defined by the Raton Basin. The north end abutts at right angles with the Apishapa Uplift which extends from the northwest.

In the subsurface, the Sierra Grande Uplift is a strongly upthrown fault block, which from Atoka time until possibly as late as Wolfcamp time was part of the Ancestral Rockies, shedding great quantities of coarse arkosic clastic sediments into the adjacent depositional troughs. The east flank of the uplift, located at about the Las Animas-Baca County line, is bound by a north-south fault zone sometimes referred to as the "Freeze Out Creek Fault." Vertical displacement along this fault zone is between 1,000 to 2,000 feet. It probably extends a long distance southward into New Mexico and Oklahoma. However, the faults do not extend vertically above Wolfcamp rocks and therefore are not indicated on the surface.

The northern flank of the Sierra Grande Uplift is likewise terminated by a 1,000 to 1,500-foot fault in the subsurface. This fault extends westwardly and probably joins the fault along the north side of the Apishapa Uplift. This fault likewise does not cut rocks younger than Wolfcamp in age and, therefore, is not visible on the surface.

The presence of the strong faults in the subsurface is interpreted from well data, by abrupt and very strong changes in subsurface elevations of Morrow and pre-Pennsylvanian strata, and because of the abrupt absence of Pennsylvanian sediments on top of the Sierra Grande Uplift.

On the crest of the Sierra Grande Uplift, there are superimposed various low relief structures discernible in the Cretaceous surface rocks. Several of these have been drilled without encountering any hydrocarbons.

Las Animas Arch

The Las Animas Arch on the surface is a northeastward plunging anticlinal extension of the Sierra Grande Uplift. It can be identified from the outcrop pattern as far north as Cheyenne County. In the subsurface, however, the Las Animas Arch is separated from the Sierra Grande Uplift by an east-west trough in central Bent County. The subsurface Las Animas Arch, which has previously also been referred to as the "Kiowa Dome," rises structurally until its crest in Cheyenne County. North of Cheyenne County, the subsurface structure plunges northeastwardly as far as the southeastern corner of Yuma County, Colorado. The west flank of the Las Animas Arch dips off into the Denver Basin while its east flank dips into the Hugoton Embayment.

Local, low relief structural closures and probably some fault closures exist along the crest and flanks of the Las Animas Arch. Although some such features have been identified by surface geological methods, they are much more common in the subsurface. The subsurface structures have more structural relief with depth because of their Paleozoic origin and fewer concealing unconformities. As of this time, none of the local structures on the Las Animas Arch is oil or gas productive. However, this should not preclude such a possibility for the future.

Apishapa Uplift

This wide anticlinal arch trends northwestward from its junction with the Sierra Grande Uplift in north-central Las Animas County, until it merges with the Wet Mountains in southwestern Pueblo County. To the southwest it is limited by the Raton Basin while on the northeast it dips into the Denver Basin.

In the subsurface, the Apishapa Uplift is similar to the Sierra Grande Uplift in that it is a buried granite ridge which formed part of the Ancestral Rockies during Pennsylvanian and Lower Permian time. Likewise, its northeast flank is bound by strong faulting which probably connects to the faulting on the north side of the Sierra Grande Uplift, and to the Wet Mountain fault system on the west.

The surface crest of the over-all Apishapa Uplift is slightly north of Rattlesnake Butte along the Pueblo-Huerfano County line. Peripheral faults varying from only a few feet to several hundred feet modify the configuration of the structure. Nearly all such faults are downthrown towards the crest of the uplift, suggesting it is a collapsed dome.

Local closed surface structures with varying outlines and trends are superimposed on the major feature. Most of these structures have been drilled at one time or another, some all the way to pre-Cambrian granite. Oil or gas shows have been encountered in various tests, but there presently is no commercial production.

The Model anticline, a north-south arcuate structure, approximately 7 miles long, with at least 300 feet of closure, is located south of the town of Thatcher in Ts. 29, 30 S., R. 60 W., Las Animas County. In 1929, non-hydrocarbon gas was discovered in the Lyons sandstone. The gas was produced because of its 8 percent helium content, and the United States Government subsequently took over the property and shut it in as a possible future helium reserve.

Raton Basin

The Raton Basin is a north-south trending assymetrical basin with its steep flank on the west along the Sangre De Cristo Mountains, and its gentle flank on the northeast rising toward the Apishapa Uplift and on the southeast sloping up the Sierra Grande Uplift in New Mexico. Approximately half of the basin is in New Mexico. At the north end, the basin is bifurcated by the Greenhorn Mountain anticline. There the northeast segment trends north of Walsenburg, Colorado, and is referred to as the Del Carbon syncline. The northwest segment, known as Huerfano Park, extends narrowly to the northwest between the Wet Mountains and the Sangre De Cristo Mountains.

The maximum depth of the Raton Basin, as estimated from the known rock thicknesses and projected in the vicinity of the Spanish Peaks, must be at least 25,000 feet.

Numerous local structures of various sizes and types are scattered throughout the basin. A large percent of these structures, especially in the northwest part of the basin, are intruded by igneous rocks. There is still considerable question as to whether the structures existed prior to igneous intrusion, or are the result of igneous intrusion. Probably structures of both types are present. In the first case, the anticlinal features would have originated in the early phases of the Laramide Orogeny, thrust faulting then occurred in and along the Sangre De Cristo Range which provided avenues along which the igneous rocks subsequently intruded into the structures in the form of laccoliths or sills.

Under the alternate explanation, faulting and the intrusion of igneous rocks along the fault planes occurred early in the Laramide Orogeny. The igneous rocks were injected between the sedimentary beds to form laccoliths which swelled up all the sedimentary rocks above them in the form of structures. *Morley dome,* south of Trinidad, Colorado, is an example of such an igneous structure. The surface structure with about 450 feet of closure is next to an igneous plug. When drilled on its crest, the well penetrated 450 feet of igneous rock between the Dakota and Purgatoire formations which approximately equals the amount of surface closure.

There are quite a few other local structures in Raton Basin, some of which are intruded and others not. Three such structures have been chosen as representatives of petroliferous prospects in various parts of the basin and are described briefly.

The *Ojo anticline* is a local structure on U. S. Highway 160 in southwestern Huerfano County along the east side of the Sangre De Cristo Mountains. It is a narrow northwest trending, south plunging, overturned nose, cut by transverse faults. It probably represents the south end of the Sheep Mountain fold system. Thrust faults exist to the west and east of the nose. The structure has been drilled numerous times since 1926, with oil and gas shows frequently encountered in the Upper Cretaceous beds. One old well even produced oil from the Trinidad sandstone for a short period, but it never resulted in commercial production.

The *Tercio anticline* is a strong closed anticlinal structure in southwestern Las Animas County, just north of the Colorado-New Mexico border, on the west flank of the Raton Basin. Its axis trends northwestward, it is 5½ miles long, and has 1,700 feet of surface closure. The only evidence of igneous activity is several small igneous sills intruded into the Pierre Shale in the center of the structure on the surface. The structure has been drilled to 7,457 feet, the last 5,300 feet being in the Sangre De Cristo formation. Only dead oil shows in the Dakota and Morrison were encountered.

The *Garcia anticline* is a gentle surface anticlinal nose on the east flank of the Raton Basin located about 10 miles southeast of Trinidad, Colorado. The nose plunges southwestward with two possible small closures along its crest and has basalt dikes cutting across its axis. Wells were drilled on the structure as early as 1892, producing gas from the Apishapa shale which was used to heat and light ranches in the area. For several years after 1934, a small plant to extract natural gasoline from several gas wells operated until it was discontinued as nonprofitable. The gas is probably associated with fractures in the Apishapa shale. The structure has since been drilled dry into the Pennsylvanian Madera formation with some oil shows being encountered in this lowermost formation.

Canon City Embayment

The Canon City Embayment is a small structural basin located in western Pueblo and eastern Fremont Counties, Colorado. It is limited on the southwest by the Wet Mountains, on the southeast by the Apishapa Uplift and on the north and northeast by the Front Range and the Red Creek Arch. The west flank of the basin is steeply dipping or overturned and is bound by the northwest-southeast trending Wet Mountains fault which thrust pre-Cambrian granite against the younger sedimentary rocks of the basin. The eastern flank has a gentle dip, rising slowly to a broad ridge or platform which separates this basin from the Denver Basin. The platform consists of a series of low relief northwest trending surface anticlines connecting the Red Creek Arch with the structural crest of the Apishapa Uplift. In the subsurface, the platform separating the Canon City Embayment and Denver Basin represents a buried granite ridge like the ancestral Apishapa. All the pre-Pennsylvanian rocks are absent and only a thinned section of Fountain overlies the pre-Cambrian.

Although there are several local structures in the Canon City Embayment, two of the best known are the small Chandler anticline on the west flank and the Brush Hollow anticline on the east flank. Both of these structures have been drilled for oil, but found dry.

The Florence-Canon City oil field occurs on the east monoclinal flank of the embayment. Steep surface dips along the east side of the producing area, along with other data, suggest the possibility of a fault limiting the producing area. The accumulation is restricted to a zone of fracture porosity in the Pierre shale.

Red Creek Arch

This feature is represented by a large anticlinal nose plunging southeastward from the south end of the Front Range in northwestern Pueblo County. Numerous local anticlines trending parallel to the axis of the main arch are superimposed on the crest and flanks of the major structure.

The structural trend continues southeastward towards the crest of the Apishapa Uplift in the form of a series of low relief anticlines. The anticlines on this trend are the Rock Canyon, Columbian Heights and San Carlos, some of which have been drilled as deep as pre-Cambrian granite without significant oil or gas shows.

Present Oil and Gas Productive Areas

Florence-Canon City Field

This oil field, located in Ts. 18, 21 S., Rs. 68, 70 W., was discovered in 1876, and reached its peak production in 1892 with 824,000 barrels. The old producing area, as much as four miles in width, extends over 13 miles in a north-south direction.

The oil is produced from fractured zones in the Pierre shale and possibly the top of the Niobrara formation, from depths of 1,600 to about 4,000 feet. The structure is monoclinal dip to the west. A fault, downthrown to the west, is suggested along the east side of the producing area by steep surface dips and other data.

Many of the wells drilled in the producing area were dry holes as they did not encounter adequate fracturing in the reservoir rock. In other parts of the field, fracturing must be extensive and interconnected, as demonstrated by the fact that one well produced more than one million barrels of oil before abandonment. Another producer, well No. 42, has produced oil continually since April, 1889, to the present. This is probably the oldest producing well in the country, if not in the world.

Currently, there are about 30 old wells scattered through the field, each still producing a few barrels of oil per day. Production for the year 1958 was 26,340 barrels, with the cumulative production for the field through December 31, 1958, totalling 14,262,558 barrels. The oil is 30.9 degrees API gravity.

New drilling in the field is carried on periodically by small companies searching for as yet untapped pools within the reservoir.

McClave Gas Field

Located in T. 19 S., Rs. 48, 49 W., Kiowa County, this gas discovery was made by Continental Oil Company in 1952, from a stray Morrow sand at a depth of approximately 4,900 feet. The sand was named the McClave sand. The discovery well was rated at 2,705 MCFGPD after fracture treatment. Since the discovery, four additional gas wells, up to six miles away from the discovery, have been completed. Calculated open flow potentials range up to 5,500 MCFGPD. However, all the gas wells are still shut-in. Additional development drilling is being conducted at the present time.

The McClave gas field is a stratigraphic entrapment on the south flank of the Las Animas Arch. From its area of best development in T. 20 S., R. 49 W., the producing sand pinches out in all directions except to the southwest. It is a tight coarse-grained sand with a known maximum thickness of 25 feet in the productive area.

In 1956, an extension to the original McClave gas discovery well was temporarily completed as an oil well from a thin porosity zone in the Marmaton limestone. This well was short lived and produced only 6,800 barrels of oil before being depleted and reverted into a shut-in McClave sand gas well.

Greenwood Gas Field

This gas field was discovered during 1951 in T. 33 S., R. 42 W., of Morton County, Kansas, from a Morrow sandstone. Subsequent development proved the Upper Pennsylvanian limestones of Virgilian and Missourian age to be the main reservoir, extending over an area of about 300 square miles. The controlling factor for gas entrapment in the limestones appears to be a pinchout of porosity in the reservoir rocks from east to west, as the strata ascend on to the weak northward nosing off of Keyes Dome.

In 1954 and 1955, Amerada Petroleum extended the Greenwood gas production into Ts. 32, 33, 34 S., Rs. 41, 42 W., of Baca County, Colorado. Since then, 14 gas wells have been completed on the Colorado side, from the lower Topeka zone at depths of about 3,000 to 3,500 feet. The wells test very little gas until after acid treatment, which enables them to be completed for open flow potentials of from 2 to more than 15 MMCFGPD.

Subsurface mapping of the wells in Baca County, Colorado, suggest the possibility of about 50 feet of local structural closure on the westward extension of the Greenwood Field.

Bents Fort Field

Located in section 21, T. 21 S., R. 51 W., Bent County. This field was discovered in 1955 with Stansbury No. 1 Cordes-Oberlander, the discovery well, being dually completed for 50 barrels per day of 40 gravity oil from an Atoka sand at 4,619 feet, plus 3,700 MCFGPD from a Morrow sand at 5,203 feet. A second well was completed similarly and a mile northwest stepout well was completed for 887 MCFGPD from the Morrow sand. The gas production remains shut-in while cumulative oil production through the end of 1958 was 16,016 barrels.

The accumulation at Bents Fort is a stratigraphic trap caused by an updip pinchout on the south flank of the Las Animas Arch of lenticular Lower Pennsylvanian sands. Such sands represent the sea-ward termination of the arkosic tongues derived from the Sierra Grande Uplift during Pennsylvanian time.

Lubers Field

This field, located in section 15, T. 22 S., R. 49 W., Bent County, was discovered in 1956 by the D. D. Harrington No. 1 Earl well. It was completed for 10,000 MCFGPD from a Cherokee sandstone at a depth of 4,331 feet, and is presently shut-in. A well two miles south failed to find the Cherokee pay sand developed but was completed for 560 MCFGPD from a Morrow sand. This latter well is providing gas to the town of McClave.

Colt Field

Located in Section 7, T. 20 S., R. 52 W., Kiowa County, the

Colt field consists of one shut-in gas well completed by Armell & Stanolind in 1956, for 554 MCFGPD from a Morrow sandstone at a depth of 5,300 feet.

Prairie Dog Field

At a location in section 31, T. 34 S., R. 44 W., Baca County, Shell Oil Company discovered gas and oil in 1958 from Marmaton sandstones at a depth of 4,113 feet. The well was completed for 23 barrels of oil per day plus 140 barrels of water per day plus 1,770 MCFGPD from two 12-foot sandstones, one directly above the other. A second well with a similar producing capacity has been completed. The wells are presently shut-in.

This accumulation is a combination structural and stratigraphic trap caused by a pinching out of the Marmaton sand on a local closure or structural nose.

Barrel Springs Field

Located in section 27, T. 25 S., R. 45 W., Prowers County, this single gas well resulted during 1958 from Excelsior's reworking of a well drilled and abandoned during 1957. The well's final potential after perforating and acidizing an Atoka sand at the depth of 4,912 feet was 2,288 MCFGPD. It is shut-in.

The well is another example of a stratigraphic pinchout of Lower Pennsylvanian sands.

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Chapter XV

North, Middle, and South Parks

by

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CHAPTER XV

North, Middle and South Parks

by

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The term "park" has been appropriately applied to each of three natural, intermontane, topographic depressions with a north-south alignment in north-central Colorado. North, Middle and South Parks, as these depressions are now commonly known, have played an important part in the economic life of the State, including the exploration for and development of oil and/or gas properties (see Figs. 4 and 9).

All three areas are readily accessible by paved highways extending westward from Denver and can be easily traversed by numerous, well-graded, County and ranch roads. However, in Middle Park the accessibility is somewhat restricted by the rugged terrain of parts of the basin. Walden in North Park, Hot Sulphur Springs in Middle Park, and Fairplay in South Park are the County seats of Jackson, Grand and Park Counties, respectively. Other towns of comparable size, such as Fraser, Tabernash, Granby and Kremmling, exist entirely in Grand County along the routes of U. S. Highway No. 40 and the Denver & Rio Grande Western Railroad.

The headwaters of some of the major drainages of Colorado and the western United States are located in the three parks. Most important of these is the Colorado River, which rises in Middle Park and flows westward, eventually reaching the Gulf of California. The North Platte River rises in North Park and the South Platte in South Park; both rivers flow northward and eastward to join the Missouri Valley drainage system and eventually their waters find their way to the Gulf of Mexico via the Mississippi River.

North, Middle and South Parks are open areas surrounded by mountain ranges of the Colorado Rockies. Considerable topographic similarity exists between North and South Parks in that the floors of each are comparatively flat and broken only by minor ridges, hills, or mesas. Middle Park, in contrast, has much more relief and is not so easily recognized as a basin. The Front Range, beginning at Canon City, Colorado, and extending northward as a single anticlinal unit to a point close to the Wyoming State line, forms the eastern boundaries of the three parks. The Front Range is rugged with elevations ranging from 8,000 feet in the valleys to 11,000 and 12,000 feet in the intermediate areas and to elevations of over 14,000 feet along the Continental Divide. Likewise, the western borders of the parks are formed by the Park Range, beginning at a point southwest of Fairplay and extending northward into

*Geological consultant, Denver, Colorado.

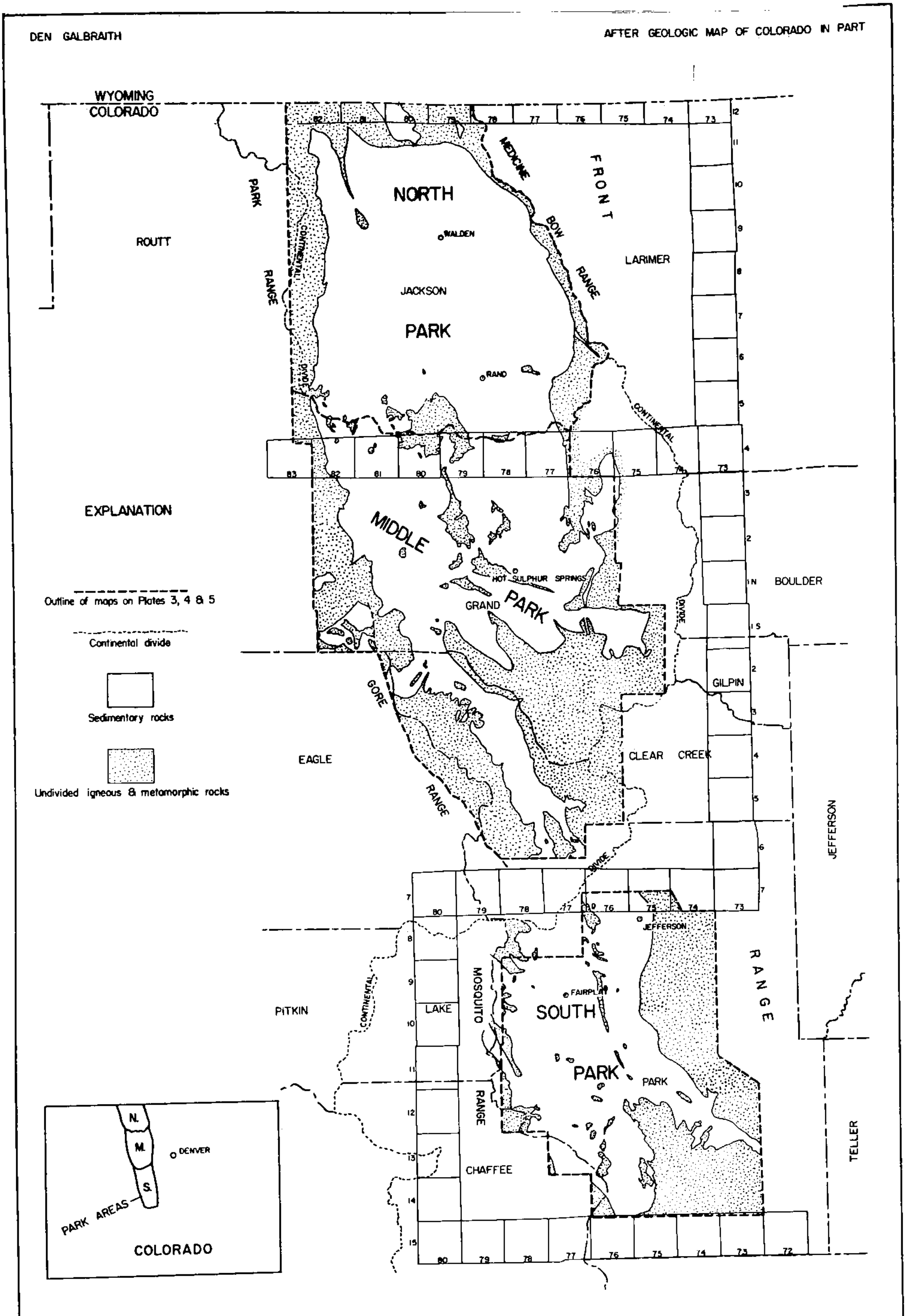


FIGURE 9

INDEX MAP SHOWING
LOCATION OF NORTH, MIDDLE AND SOUTH PARK

Wyoming. The average elevation of the more rounded portions of the Park Range is approximately 10,800 feet; above this altitude a number of more or less prominent peaks rise to elevations ranging from 11,000 to over 12,000 feet. Each of the parks is surficially separated from the other by spurs or subsidiary connections to these two major ranges. The Continental Divide separates Middle Park from North and South Parks.

There is variation in the total stratigraphic column between the park areas, particularly between North and Middle Parks, as one unit, and South Park. From the north end of North Park southward, progressively younger sediments overlie the basement complex, beginning with rocks of Permian age and extending into the Cretaceous. The Morrison formation of Jurassic age overlies the pre-Cambrian in most of Middle Park; along the northern and eastern edge of South Park, the Morrison is missing and the Dakota quartzite of Cretaceous age rests directly on the pre-Cambrian basement. However, within the areas of western South Park sediments of pre-Permian age occur that are not known to be present in North or Middle Parks. Except for local differences, the Mesozoic beds of the three parks, insofar as the Cretaceous and Jurassic are concerned, have some common characteristics. At the north end of North Park there are Triassic sediments correlative with the Chugwater formation of southern Wyoming; on the other hand, beds of this age are not known southward beyond the limits of northwestern Middle Park.

The east and west boundaries of the parks are structurally controlled by the north-south anticlinal uplifts of the Front Range on the east and the Park Range on the west. The long, synclinal, downwarped trough between these two regional positive elements is interrupted by a highland extending diagonally across these ranges and coinciding with the mineral belt of central Colorado. This highland separates the composite North and Middle Park basin from South Park while other mountain range spurs form the north and south limits of the two-basin structural complex.

The Early Paleozoic sediments in the western South Park area show considerable variation in thicknesses and show other evidences of long periods of erosion caused by different stages of uplift and exposure which probably followed patterns of structural movements established during pre-Cambrian time. In addition, structural movements of Pennsylvanian age assumed the trend of earlier established patterns and contributed much as a strong influence to the folding and faulting of the Laramide orogeny. The west side of the Front Range and the eastern flank of the Park Range are characterized by a series of rather long overthrust, high-angle reverse and high-angle normal faults, some of considerable horizontal or vertical displacement. In some areas there has been extensive squeezing and deformation of the sediments into sharp, narrow local folds brought about by a horizontal component of movement of the Front Range in a westerly direction; this structural condition is particularly true for the southern portion of Middle Park.

In general, the comparatively confined intermontane park areas have been subjected to several stages of structural adjustments, most important of which occurred during the Laramide revolution. Each stage must have had a bearing on the end result of the complexly folded and faulted basins. The structural history involving Laramide time suggests the commencement of regional uplift as early as the late Cretaceous with accompanying downwarp of the parks followed by an early Paleocene stage of relatively rapid uplift, erosion and volcanism within the Front Range and sedimentation within the parks. The final stage of structural history involved the tangential movement of the Front Range mass in a westerly direction, creating folds and thrust faults younger than the Paleocene.

Middle and South Parks and adjacent mountainous areas show evidences of Pleistocene alpine glaciation.

North Park

The floor of North Park varies in elevation from 7,900 to 8,100 feet and in connection with Middle Park it occupies the northern part of one synclinal basin from 40 to 50 miles wide and about 100 miles long. The Rabbit Ears Range, forming a portion of the Continental Divide, separates North Park topographically from Middle Park while Independence Mountain, a spur of the Medicine Bow segment of the Front Range, limits it on the north. The comparatively level floor of the park occupies an area of about 1,000 square miles (Plate 3 in pocket).

Stratigraphy

The oldest known rocks of the sedimentary column of North Park have been described in the Northgate district and are questionably correlated with the Satanka shale of Permian age. The youngest sediments, other than gravels and silts, make up the North Park formation of Tertiary (Miocene) age.

Permian

Satanka(?) Shale

At the north end of North Park in the Northgate district from 0 to 50 feet of red silty shale overlying pre-Cambrian rocks have been questionably correlated with the Satanka shale, a stratigraphic unit common to the Laramie Basin of southern Wyoming.

Forelle Limestone

Overlying the Satanka (?) shale and in some cases the pre-Cambrian, occurs thin laminated beds of dove-gray, pink and purplish limestone correlated with the Forelle limestone of the Laramie Basin. This horizon varies in thickness from 8 to

15 feet and underlies the Chugwater formation without a noticeable break in sedimentation in the northeastern sector of North Park.

Triassic

Chugwater Formation

The Chugwater formation is characterized by fine- to medium-grained red sandstones, shales, and sandy shales. At some localities the sandstones show varying degrees of coarseness and the shales include some vari-colored zones. On the east and west flanks of North Park this formation rests unconformably on pre-Cambrian and is in disconformable contact with the overlying Entrada sandstone. Surface exposures of the formation have been assigned an average thickness of 1,350 feet although one deep test well within the North Park basin encountered only 500 feet of Chugwater.

Jurassic

Entrada Sandstone

The Entrada sandstone of Upper Jurassic age is a buff to pink and light-brown, medium- to fine-grained sandstone with local coarseness approaching a conglomeratic facies at its base. This sandstone is approximately 240 feet thick.

Sundance(?) Formation

Although there seems to be no definite correlation of Jurassic sediments in North Park with the Sundance formation in Wyoming, it should be noted that a 100-foot subsurface section between the Entrada sandstone and the Morrison formation and consisting of thin, light colored, slightly glauconitic sandstone beds with interbedded green and red shales might logically be placed in the upper Sundance.

Morrison Formation

The Morrison formation of Upper Jurassic age shows common lithologic characteristics over a widespread area. This stratigraphic unit consists predominantly of vari-colored shales and sandy shales with thin beds of irregular, drab, gray limestones and some lenses of sandstone and conglomerate. Its thickness varies from 230 to 470 feet, depending somewhat on the placement of the lower limit of the formation.

Cretaceous

Dakota Group

Unconformably overlying the Morrison is the Dakota sandstone series, of Cretaceous age, with three noticeable subdivisions. The base of the Dakota is generally marked by a quartz and chert-pebble conglomerate grading upward into a white to light-gray, massive, usually crossbedded sandstone with a variable thickness from 20 to 220 feet. The basal sandstone is overlain by 10 to 50 feet of grey, green and red sandy clay-shale and gray to black sandy shale. The upper member of the Dakota group is a buff to brown, fine-grained ripple marked sandstone varying in thickness from 12 to 108 feet.

The upper member of this group would include the sandstone often referred to as the "Muddy," and assigned to the upper limit of the Thermopolis shale, the next younger formation above the Dakota in many areas of Wyoming.

Some preference has been shown in descriptive treatment of the Dakota group to the name Cloverly; others have preferred the name Lakota for the basal sandstone, Fuson for the middle shale member and Dakota sandstone for the upper member.

Benton Group

The term Benton is used herein for simplicity. Beds formerly called Benton in eastern Colorado are now divided into the Carlile shale, Greenhorn limestone and Graneros shale in descending order. In central-southern Wyoming, the rocks formerly called Benton are divided into the Carlile shale, Frontier formation, Mowry shale, and Thermopolis shale—nomenclature often used in describing the formations of North Park.

The Benton shale is a dark gray to black fissile shale unit with a sandy zone at its top and some thin beds of limestone within the shale. As much as 635 feet of Benton have been measured in North Park; this measured interval includes all of the stratigraphic section between the Niobrara formation and the Dakota group. The sandy zone at the top is probably the facies equivalent of the Codell sandstone of the Carlile shale of eastern Colorado, while the thin limestone 15 to 25 feet thick beneath approximately 200 feet of upper Benton (Carlile) shales is the equivalent of the Greenhorn limestone. It has been suggested that the Codell sandstone might be equivalent to a member of the Frontier formation of southern Wyoming; subsurface correlations based on lithology have also placed a calcareous, light-gray, fine-grained, glauconitic sandstone beneath the Greenhorn within the Frontier zone of North Park.

Niobrara Formation

The Niobrara formation of eastern Colorado is divided into two members, a lower light-gray, chalky, dense limestone and an upper section of dark-gray, calcareous, shale speckled with minute brownish-white particles of limestone. The lower member, or Timpas limestone, is very poorly developed in North Park as an impure limestone which in most places contains so much shale as to resemble calcareous shale more closely than limestone. The upper shale member is transitional with the overlying Pierre shale and the contact between formations is indefinite. The Niobrara has been assigned thicknesses ranging from 400 to 650 feet.

Pierre Shale

The Pierre shale is a rather homogenous interval composed mainly of gray to dark-gray, brownish and black marine shales with some sandy shales and thin sandstones occurring close to the top and in the lower part of the formation. In North Park, the unconformable relationship of the Pierre with the overlying Coalmont formation governs observed thicknesses which range upward from 2,950 feet and may be as much as 4,000 feet.

Tertiary

Coalmont Formation

The Coalmont formation of Eocene age contains two more or less distinct members of fresh-water origin. The lower member resting on marine Cretaceous consists of a maximum of 3,500 feet of gray, buff, fine-grained sandstones, some pebble conglomerates, and brown, dark, sandy, carbonaceous shales. This member is coal-bearing. The upper zone, approximately 2,000 feet thick, consists of light yellow and drab shale with many interbedded layers of light gray and buff sandstone. An unconformity separates the upper and lower members of the Coalmont.

White River Formation

The White River formation of Oligocene age, along with the overlying North Park formation, occupies a comparatively narrow belt coincident with the North Park syncline in the south-central part of the park. This formation, consisting of a lower unit of alternating white sandstone, grit, conglomerate, and reddish brown and green shale and an upper unit of tuffaceous, siltstone and claystone, has been recognized in North Park only for a short time. The White River is about 400 feet thick. Its relationship with the underlying Coalmont is obscure but an unconformity is strongly suggested.

North Park Formation

Like the underlying White River, the North Park formation is also confined to the position of the North Park syncline and is of late Miocene and possibly early Pliocene age. The formation varies in thickness from 400 feet at the west end of the syncline to 1,800 feet at the eastern extremity adjacent to the Medicine Bow Range. In ascending order, it consists of calcareous, medium- to coarse-grained sandstones; buff to pink, calcareous, tuffaceous siltstone and fine-grained sandstone; and a unit of volcanic conglomerate composed of boulders, cobbles, and pebbles of basalt in a matrix of buff sand and silt.

Structure

The sedimentary rocks of North Park form a synclinal trough which is a complete topographic and nearly-complete structural basin. Along the west flank beds dip away from the Park Range at angles varying from 15 degrees to vertical, and on the east, adjacent to the Medicine Bow Range, sediments exhibit westward dips ranging between 20 degrees and 50 degrees. The north end of the basin is terminated by the large east-west Independence Mountain thrust fault which cuts the strata at almost right angles to the basin axis and places a hanging wall block of pre-Cambrian granite against the Coalmont formation. The Rabbit Ears Range forms the divide on the south between North and Middle Parks and may be considered a topographic ridge due partly to differential erosion, partly to volcanics, and partly to anticlinal uplift. However, the structural attitude of the North Park basin adjacent to the Rabbit Ears Range is well hidden by timber, debris, and volcanic rocks (see Plate 3 in pocket).

The axis of the North Park basin begins at a point against the Independent Mountain thrust southeast of the center of T. 11 N., R. 80 W., and extends south-southeastward to the center of the south line of T. 5 N., R. 78 W. Transverse to the basin axis is the North Park syncline, a superimposed structural depression, extending from Owl Mountain on the southeast to Delaney Butte on the northwest.

Compressional activity exerted on the basin area by movements of the Park and Medicine Bow Ranges have resulted in regional peripheral thrust faults, normal faults and associated sharp folding. On the northwest side of the Park and in Ts. 9, 11 N., R. 81 W., a narrow faulted ridge about 20 miles long and 2 to 4 miles wide with a pre-Cambrian core is separated from the Park Range to the west by a narrow valley of sedimentary rocks. This ridge, faulted on the west, forms the Boettcher Ridge, Sheep Mountain, Delaney Butte complex which appears to have some structural alignment to the southeast with the North Park syncline.

Minor folds throughout the basin have been mapped with particular emphasis being placed on the northeast flank where surface anticlinal anomalies parallel to the strike of the Medicine Bow Range have been found productive of oil and/or gas.

Oil and Gas

Recognition of the McCallum anticline by A. L. Beekley in his study of the geology and coal resources of North Park during 1911 for the United States Geological Survey paved the way for later private surveys and the eventual discovery of oil and gas on two highs of the anticline during 1926 and 1927. Exploration activity in the basin was dormant for many years following these discoveries but in early 1953 considerable new interest was created, resulting in two additional important commercial discoveries.

McCallum Domes

The McCallum anticline is located in Ts. 8, 9 N., Rs. 78, 79 W., and is a sinuous, surface anomaly with two areas of structural closure designated as the North and South "domes." The two features are slightly en echelon to each other. The anticline is asymmetric with the steep limb being on the northeast or mountainward side. Pierre shale is the oldest sedimentary rock outcropping on the surface of this fold.

The North McCallum closure is approximately 8 miles long and from 1 to 2 miles wide (see Fig. 10). Dips on the east flank range from 50 degrees to 75 degrees while on the west flank they are from 20 degrees to 40 degrees. Surface closure is estimated at 1,400 feet but subsurface data are indicative of as much as 2,000 feet of closure. However, the productive closure is limited to about 1,200 feet. There is evidence of minor transverse normal surface faulting at the north end of the structure and evidence of a substantial, longitudinal, subsurface, normal fault on the east limb, down-dropped to the east and with a maximum stratigraphic displacement of approximately 2,000 feet. The discovery well, Sherman "A" No. 1, was completed by Continental Oil Company in the NW¼ NW¼ Section 12, T. 9 N., R. 79 W., during December, 1926, for an initial production of an estimated 30,000,000 cubic feet of carbon dioxide gas and 500 barrels of 47.8 API gravity condensate daily from the Dakota sandstone at a total depth of 5,113 feet.

In 1930, a small plant was built at North McCallum to process the carbon dioxide into dry ice. It was found impractical to separate the oil vapors from the ice, and the project was abandoned. Later, small amounts of the carbon dioxide were used by Cardox Corporation as a coal mining explosive but a decrease of the market demand for this product eliminated its use. Production of oil was also difficult because of the freezing action of the expanding carbon dioxide.

Following the discovery, development drilling did not take place until 1945 when nine additional Dakota wells were completed and a gas recycling program was initiated. In September, 1952, Pollock A-6 near the crest of the structure in the NW¼ SW¼ Section 2, T. 9 N., R. 79 W., was drilled into granite at a total depth of 6,180 feet and was plugged back and completed in Jurassic (Morrison and Sundance?) sands between 5,376 and 5,504 feet for an initial daily production of 10,800,000 cubic feet of carbon dioxide gas and 224 barrels of 47.6 API gravity condensate. During December, 1957, Sherman B-1 was completed in the NW¼ SE¼ Section 13, T. 9 N., R. 79 W., at a plugged-back interval of 6,184 to 6,214 feet for 47 barrels of oil per day from the "Muddy" sandstone as a new-pay discovery; the small amount of gas associated with this production is a hydrocarbon gas.

At the present time, there is one producing well in the "Muddy" sand, nine producing wells and one shut-in well in the Dakota, and five producing wells in the Morrison horizon. As of January 1, 1959, the cumulative oil production for the Muddy was 4,195 barrels, for the Dakota 2,270,624 barrels, and for the Morrison 744,530 barrels. The daily production for the

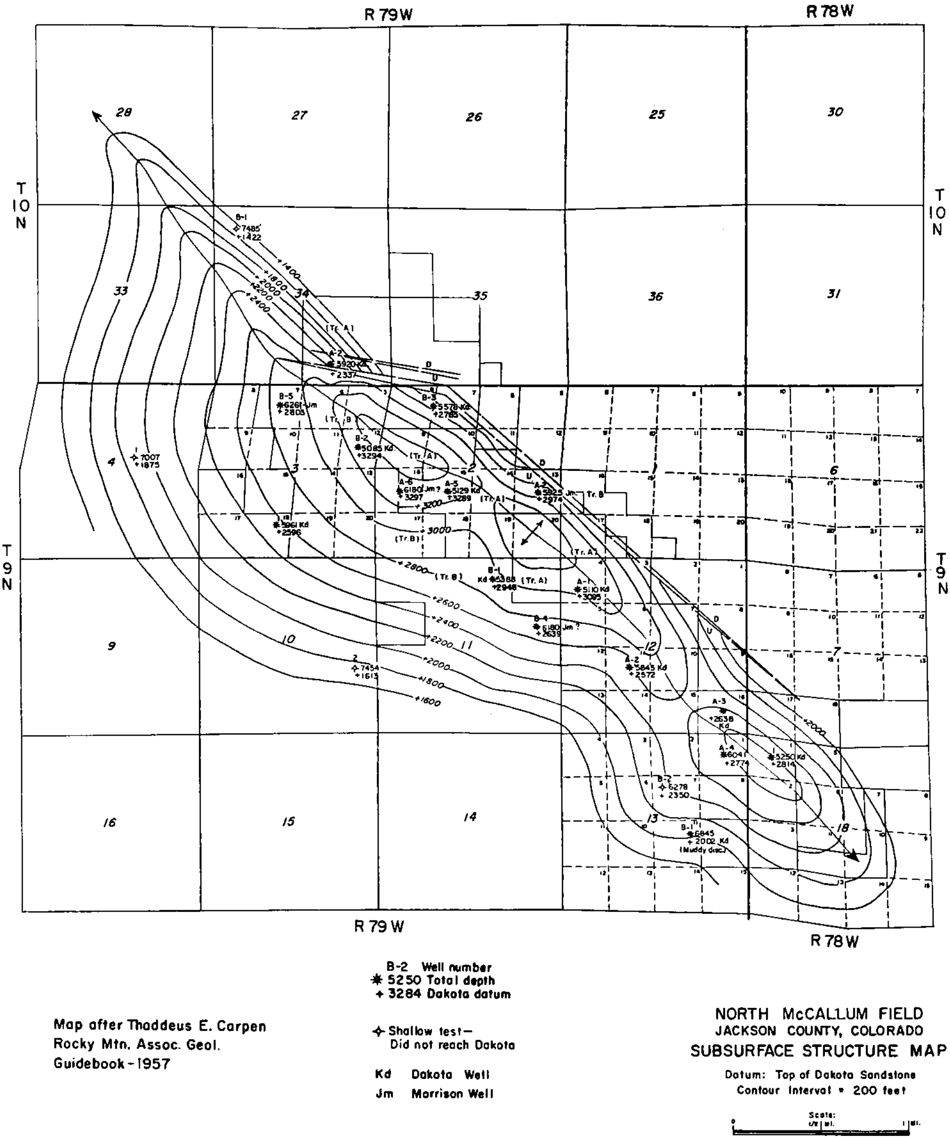

R 79W
R 78W
T 10 N
T 9 N
28
27
26
25
30
33
34
35
36
31
4
3
2
1
6
9
10
11
12
7
16
15
14
13
18
B-2 Well number
5250 Total depth
+ 3284 Dakota datum
Map after Thaddeus E. Carpen
Rocky Mtn. Assoc. Geol.
Guidebook - 1957
Shallow test—
Did not reach Dakota
Kd Dakota Well
Jm Morrison Well
NORTH McCALLUM FIELD
JACKSON COUNTY, COLORADO
SUBSURFACE STRUCTURE MAP
Datum: Top of Dakota Sandstone
Contour Interval = 200 feet

FIGURE 10

field on April 18, 1959, was 1,234 barrels of oil. Cumulative carbon dioxide gas production as of January 1, 1959, for the Dakota was 205,425,377 MCF and for the Morrison 33,150,261 MCF. The gas-oil ratio for the Dakota based on March, 1959, production of 14,245 barrels of oil and 2,468,417 MCF of gas is 173,280 cubic feet of gas per barrel of oil and for the Morrison based on March, 1959, production of 1,204,157 MCF and 23,658 barrels of oil is 50,900 cubic feet of gas per barrel of oil.

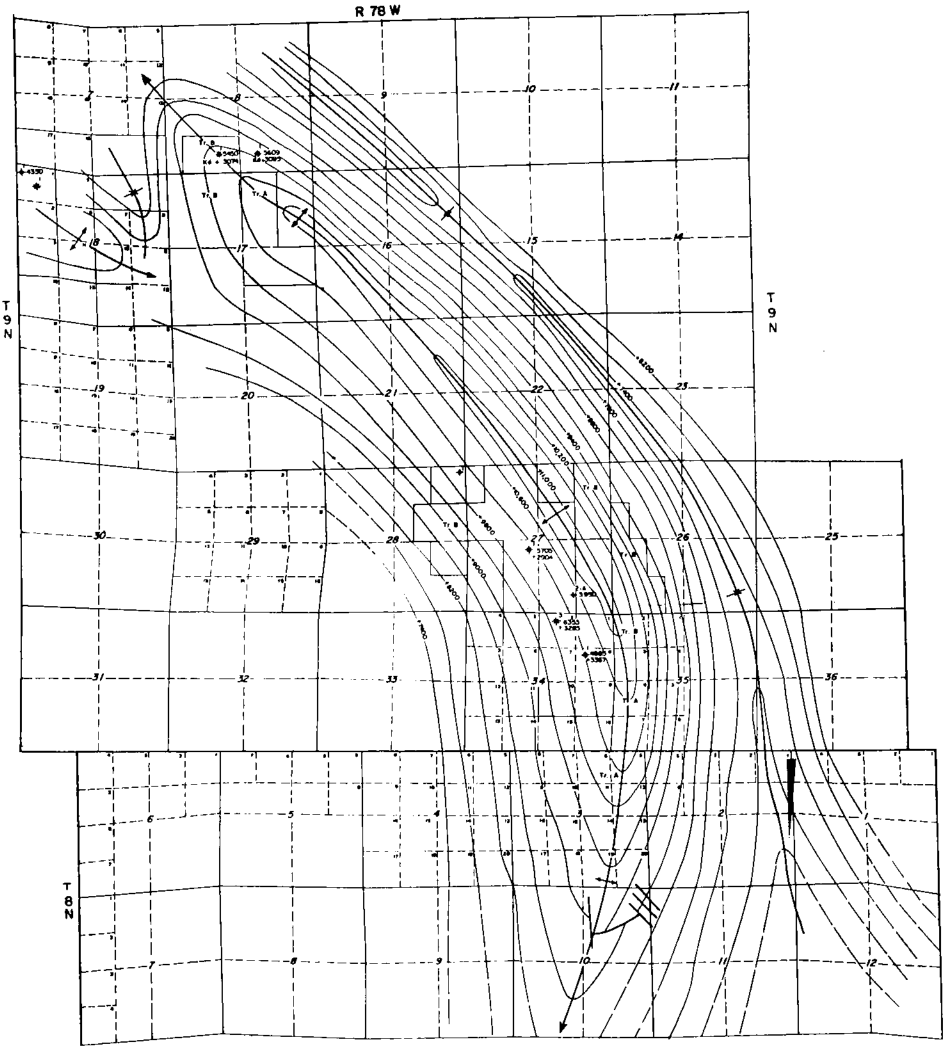
The Dakota and Morrison producing horizons are gas expansion reservoirs. The average pay thickness of the Dakota is 79 feet; the average porosity is 16.2 percent, and the permeability ranges between 0 to 400 millidarcies with an average of 70 millidarcies. The average net pay thickness of the Morrison is 90 feet; the average porosity is 15.7 percent, and the permeability average is 31 millidarcies. The net pay for the "Muddy" producer is 14 feet of sand and since this interval was not cored other pertinent data are not available.

The API gravity of the Dakota oil is 47.8° and the Morrison oil 48.8°; both are nearly colorless. Analysis of the Dakota gas, with very close similarity for the Morrison, is as follows: carbon dioxide, 92.1 percent; methane 0.5 percent; ethane 3.9 percent; nitrogen 3.4 percent.

The original reservoir pressure for the Dakota has been estimated at 2,350 psi, while that of the Morrison was measured at 2,424 psi.

South McCallum is approximately 6½ miles long and 2 miles wide with its crest located in Sections 22 and 27, T. 9 N., R. 78 W. (see Fig. 11). Dips on the east flank range from 30 degrees to vertical and in some places are slightly overturned while on the west flank they range from 25 degrees to 40 degrees. Surface mapping indicates a structural closure of 1,800 feet. The crest of South McCallum on the Dakota horizon is not any higher than comparable beds in North McCallum; the first Dakota sandstone of South McCallum is probably the "Muddy" sandstone of North McCallum.

In 1927, Continental Oil Company completed Hoye No. 1 in the SE¼ NE¼ Section 34, T. 9 N., R. 78 W., at a total depth of 5,410 feet and for an estimated initial production of 50,000,000 cubic feet of carbon dioxide gas with a small amount of condensate from the top 10 feet of the Dakota sandstone. This hole was subsequently abandoned because of mechanical difficulties. Drilling of a second well was attempted in 1927, but was abandoned at 1,300 feet. In November, 1935, Hoye No. 3 drilled in the NW¼ NE¼ Section 34, T. 9 N., R. 78 W., was completed as a shut-in noncommercial well of 15,000,000 cubic feet of carbon dioxide gas and 10 barrels of condensate per day. In March, 1953, this well was deepened to granite at a total depth of 6,358 feet; the Jurassic sandstones had slight shows, but drillstem tested water. Continental's Hoye No. 4 in the NE¼ SW¼ Section 27, T. 9 N., R. 78 W., was completed in



Map after Thaddeus E. Carpen
Rocky Mtn. Assoc. Geol.
Guidebook – 1957

R-7 Well number
5250 Total depth
3284 Dakota datum

Shallow test – Did not reach Dakota

Non-Commercial well

SOUTH McCALLUM ANTICLINE
JACKSON COUNTY, COLORADO
SURFACE STRUCTURE MAP

Datum: Marker bed in Pierre shale
Contour Interval = 400 feet

Scale: 0 1/2 mi. 1 mi.

FIGURE 11

1943 in the Dakota series for 5,560,000 cubic feet of carbon dioxide gas and 13½ barrels of condensate per day; this hole was subsequently plugged and abandoned.

During November, 1958, Gulf Oil Corporation completed Ballinger No. 1 in the SW¼ SE¼ Section 8, T. 9 N., R. 78 W., at the northwest end of the South McCallum structure for an initial production of 14,659,000 cubic feet of carbon dioxide gas and 181 barrels of condensate from the Dakota between 5,302 and 5,330 feet; the hole was drilled into the Morrison at a total depth of 5,609 feet.

There are two Dakota wells presently producing at the north end of South McCallum. As of January 1, 1959, these wells had a cumulative production of 13,515 barrels of oil; during February, 1959, the production was 8,448 barrels of oil and the present daily average is 421 barrels. The gas: oil ratio is approximately 62,725 cubic feet of carbon dioxide gas to one barrel of oil.

The reservoir and crude oil characteristics for the Dakota producing horizon in South McCallum are very similar to those of the Dakota in North McCallum.

Battleship Field

The Battleship field is located on the east side of North Park in sections 22 and 23, T. 10 N., R. 79 W. (see Fig. 12). The

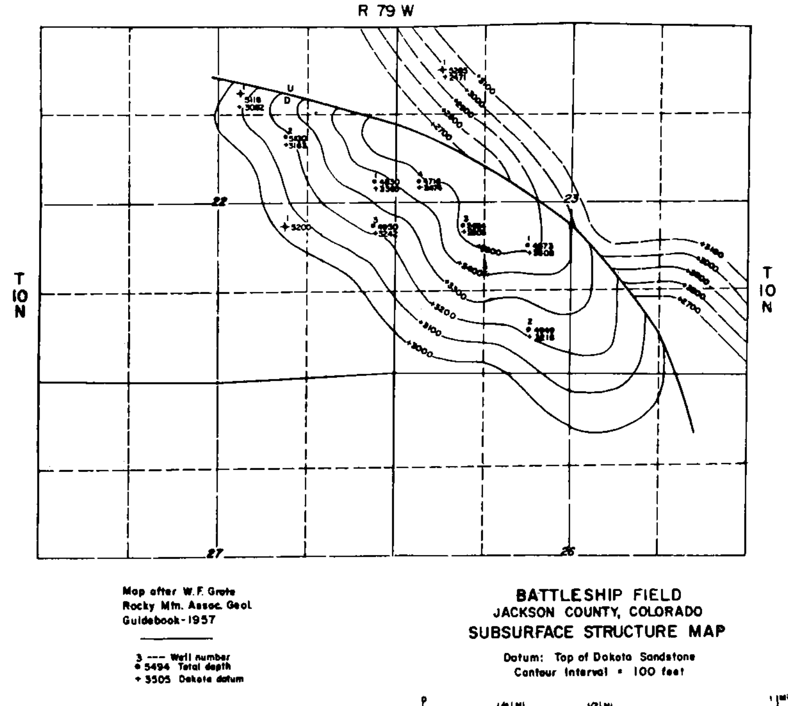


FIGURE 12

structure is expressed in beds of the Coalmont formation surrounding a small inlier of Pierre shale. The surface structure shows approximately 200 feet of closure with a north-south trend; however, later seismic work delineated an anomaly with a northwest-southeast axis, and closure against a longitudinal high-angle reverse fault downthrown on the northeast. Subsurface mapping on the Dakota horizon indicates a structural closure of about 500 feet.

The discovery well on Battleship was drilled by Lion Oil Company in its Dwinell No. 1 NE¼ SW¼ section 23, T. 10 N., R. 79 W., to the Frontier zone topped at 3,866 feet where completion was made during October, 1954, for 50 barrels of 41° API gravity oil per day. The Frontier production which was obtained from a very tight, fractured sandstone subsequently underwent a very rapid decline. Dwinell No. 1 was deepened to a total depth of 4,673 feet during February, 1955, and recompleted in the Lakota sandstone for an initial production of 181 barrels of 33.2° API gravity, dark green oil. The discovery well also tested commercial quantities of oil in the upper or first sandstone of the Dakota series between 4,562 and 4,580 feet. Dwinell No. 3, NW¼ SW¼ section 23, T. 10 N., R. 79 W., was drilled into the Triassic red beds at a total depth of 5,496 feet with no commercial shows of oil and/or gas indicated for the stratigraphic section below the Lakota sandstone.

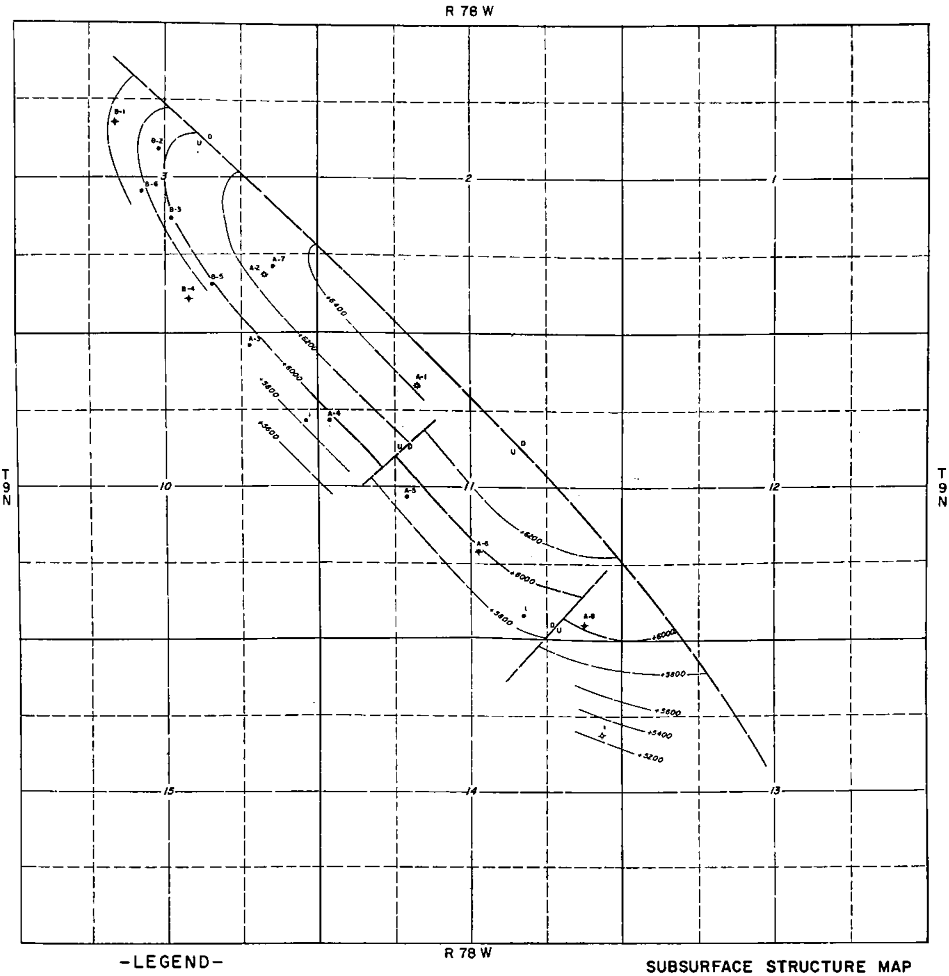
There are seven producing wells in the field, one of which has been completed in the Dakota and six in the Lakota. As of January 1, 1959, the cumulative production for the Dakota was 64,786 barrels of oil and during the month of February, 1959, this horizon yielded a total of 313 barrels of oil. The cumulative production for the Lakota at the first of the year was 1,048,331 barrels while the February, 1959, production amounted to 22,732 barrels of oil. The present daily production (April 18, 1959) is 778 barrels of oil.

The Dakota sandstone shows a thickness of about 30 feet but only the top 10 feet is considered permeable enough for oil production. The effective pay thickness is limited to 7 feet; the average porosity within this interval is 18.4 percent and the average permeability is 65 millidarcies. The Lakota pay section averages 45 feet, has an average porosity of 18.5 percent and an average permeability of 145 millidarcies.

The field has an active water drive and has no measurable gas accompanying the oil production from either zone.

Canadian River Field

The Canadian River field is located in Sections 3, 10 and 11, T. 9 N., R. 78 W., on the eastern rim of the North Park basin (see Fig. 13). The Elk Mountain anticline in the western foothills of the Medicine Bow Range provided the geologic lead for surface examination of the projection of this anticline



-LEGEND-

- Oil Well
- Gas Well
- Dry Hole

SUBSURFACE STRUCTURE MAP
CANADIAN RIVER FIELD
JACKSON COUNTY, COLORADO

Datum - Top Lakota sandstone
Contour Interval = 200 feet

FIGURE 13

Map revised after A. Saterdal
Rocky Mountain Association of Geologists
Guidebook - 1957

into the Pierre shale to the northwest. The width of outcrop pattern for the Pierre shale in the northeastern sector of T. 9 N., R. 78 W., along with some relatively steep dips at the Pierre-Coalmont contact southwest of the present limits of the field, strongly suggested an area which could suitably accommodate anticlinal folding. However, even with the aid of aerial photographs the surface geologic data was not sufficient to properly define the Canadian River structure. Consequently, a seismic survey was conducted in the critical areas and the resultant structural interpretation shows a northwest to southeast reverse fault downthrown on the northeast with a vertical displacement in excess of 2,000 feet against which seismic reflection dip-strike data on subsurface beds define closure. Subsurface structural control from well information tied to the seismic survey indicates a rather steep southwest dip, away from the reverse fault, of about 30 degrees. At least 1,600 feet of subsurface fault closure has been defined for an area approximately one-half mile wide and two miles long, northwest to southeast.

The Canadian River field was discovered by Cabeen Exploration Corporation's Blevins A-1, NE¼ SW¼ section 11, T. 9 N., R. 78 W., during March, 1956. This well was completed in the "Muddy" sandstone encountered at 1,483 feet for 2,500,000 cubic feet of hydrocarbon gas. New pay discoveries were made in Blevins A-2, SE¼ SE¼ section 3, T. 9 N., R. 78 W., in the Dakota sandstone between 1,704 and 1,724 feet and the Lakota sandstone between 1,768 and 1,828 feet. Initial production from the Dakota was 15,540,000 cubic feet of hydrocarbon gas and from the Lakota 5,500,000 cubic feet of hydrocarbon gas.

In addition to gas, the Dakota and Lakota horizons are oil bearing. Blevins A-3, NE¼ NE¼ section 10, T. 9 N., R. 78 W., was completed in the Lakota between 2,038 and 2,068 feet for a flowing initial potential of 240 barrels of oil per day; Texas-Government No. 1, SE¼ NE¼ section 10, T. 9 N., R. 78 W., was completed in the Dakota between 2,070 and 2,084 feet for 43 barrels of oil per day flowing. Blevins A-9, SE¼ SE¼ section 11, T. 9 N., R. 78 W., was abandoned as a dry hole at total depth of 2,470 feet after encountering the Entrada sandstone at 2,384 feet.

There are seven Lakota oil wells, one Dakota oil well, one Dakota marginal shut-in oil well (at the gas-oil contact) and one Dakota-Lakota gas well. The discovery gas well in the Muddy is shut-in. Gas from the Dakota-Lakota well is being used for gas injection into the Lakota sandstone. The Dakota and Lakota oil rings are of very limited lateral extent.

The cumulative production as of January 1, 1959, was 237,025 barrels of oil and during the month of February the field produced a total of 5,240 barrels. The daily production for April 18, 1959, was 224 barrels. The cumulative gas production as of January 1, 1959, was 709,959,000 cubic feet of gas; the gas production for the month of February, 1959, was 39,000,000 cubic feet. Based on February figures, the gas: oil ratio is approximately 7,500 cubic feet of gas per barrel of oil.

The oil in the Lakota is a brownish-green sweet crude of 21° API gravity. Initial bottom-hole pressures were 720 psi in the Muddy and 900 psi in the Dakota and Lakota. The gas is nearly pure methane with a B.T.U. rating of approximately 1,000.

The Muddy sandstone has a net pay thickness of 30 feet; an average porosity of 23 percent and an average permeability of 180 millidarcies. The Dakota sandstone has a net pay of 20 feet with excellent porosities and permeabilities indicated by initial gas recoveries from 12 feet of this sand. The Lakota sandstone has a net pay thickness of up to 80 feet with porosities ranging up to 27 percent and with permeabilities as high as 1,500 millidarcies.

Miscellaneous Development

M. E. Davis' State No. 1, NW¼ NW¼ section 36, T. 7 N., R. 81 W., in the Coalmont area, encountered oil shows in the basal Pierre sands and in highly fractured Frontier sand. A drillstem test of the Frontier from 6,892 to 6,913 feet, open 40 minutes, recovered gas to the surface in 18 minutes, mud to the surface in 40 minutes, and 5,250 feet of heavily oil and gas cut mud, 1,450 feet of slightly mud-cut, green oil; the bottom-hole flowing pressure was 2,950 psi and the bottom-hole shut-in pressure 3,550 psi. A subsequent test, open 4½ hours, flowed gas, mud, and oil to the pits at an estimated rate of 35 barrels of oil per hour. Efforts to complete this well commercially were unsuccessful. The north offset, Hiawatha Oil & Gas Company's Government No. 1-25 was also a failure and was drilled to granitic basement rocks, underlying Chugwater red beds at a total depth of 8,244 feet. Formation thicknesses encountered in this hole are Coalmont 3,300 feet, Pierre 2,950 feet, Niobrara 400 feet, Carlile 200 feet, Greenhorn 15 feet, Frontier 25 feet, Mowry 400 feet, Dakota 100 feet, Fuson 40 feet, Lakota 25 feet, Morrison 480 feet, and Chugwater 230 feet.

Middle Park

Middle Park covers an area of about 750 square miles occupying the southern portion of the North Park-Middle Park synclinal basin, which ranges up to 36 miles wide and approximately 70 miles long (see Plate 4 in the pocket). The park is bounded on the east by the Front Range, on the south by the Vasquez and Williams River Mountains, on the west by the Park Range, and on the north by the less rugged Rabbit Ears Range. The general level of this park is broken by many minor peaks, mountain ranges, high divides and deep gulches so that surface elevations range from 7,000 feet to over 10,000 feet. Middle Park is less evident as a single topographic unit than North Park; however, there is similarity in shape except for the long, narrow Blue River Valley extending southeastward between the Williams River Mountains and the Park Range.

Stratigraphy

In the northwestern part of Middle Park the oldest sedimentary rocks overlying the pre-Cambrian are of Triassic age and extend into the area from the north. However, over much of the park a thin series of Jurassic beds, absent in some places, overlies the basement rocks. At the town of Dillon, in the southeastern extremity of the Blue River Valley, red beds of the Pennsylvanian begin to appear beneath the Jurassic. These red beds thicken southward and will be described as part of the stratigraphy of South Park. The youngest sediments occur in the southern portions of the park and are classed as "lake beds" of late Tertiary age.

Triassic

Chugwater Formation

The Chugwater formation is characterized by red, fine- to medium-grained sandstones, red shales, and red sandy shales. The shales include some vari-colored zones. No measured thicknesses are available for the surface exposures but the unconformable relationship of the formation to the underlying pre-Cambrian would induce considerable variation. A test well within the Middle Park basin logged Jurassic beds above the pre-Cambrian, suggesting a rather limited occurrence of the Chugwater.

Jurassic

Morrison Formation

The Morrison formation consists primarily of vari-colored clay-shale and mudstone with sandstones at the base and top. The lower sandstone is 10 to 25 feet thick and may be absent locally; it is very probable that this basal, yellow-white, relatively coarse, quartz sandstone represents a thin edge of the Entrada sandstone of adjacent areas. The shaly section of the Morrison is about 100 feet thick and the upper light-buff to white, massive, cross-bedded sandstone is 20 to 25 feet thick, separated from the overlying conglomerate at the base of the Dakota by 1 to 5 feet of gray, micaceous shale. The contact between the Morrison and Dakota is disconformable.

Cretaceous

Dakota Sandstone

The Dakota horizon is divisible into three distinct units. A bed of chert-pebble conglomerate and light-gray to white, fine-to-medium-grained sandstone 20 to 73 feet thick lies at the base of the Dakota at most places but is absent locally. The middle unit consists of dark argillaceous sandstone and interbedded dark-gray shale; in some places of the park the lower beds of the middle unit are arkosic. The upper unit is a clean, white quartzite or light-gray sandstone with a thickness of at least 75 feet. The Dakota section varies in thickness from 152 to 400 feet and is conformable with the overlying Benton shale.

Benton Shale

A complete section of the Benton shale is not known in Middle Park but the formation appears to have a thickness of about 300 feet. The Benton consists largely of dark-gray fissile shale but a sandy zone 30 to 60 feet thick of interbedded dark-gray, sandy shale and thin-bedded sandstones is present at the top. This sandy zone is probably the facies equivalent to a sandstone within the Frontier formation of Wyoming and to the Codell sandstone member of the Carlile shale of eastern Colorado.

Niobrara Formation

The Benton shale is overlain by a prominent thick-bedded dark-to-light gray, or buff, fine-grained limestone 10 to 25 feet thick and often called the Timpas limestone member of the Niobrara formation. Overlying this basal limestone is the Niobrara shale member which consists of three units; a lower, dark-gray, calcareous shale 140 to 150 feet thick, a middle zone of interbedded thin-bedded limestone and dark-gray shale about 100 feet thick, and an upper dark-gray, calcareous shale which is transitional with the overlying Pierre shale. The Niobrara section varies in thickness from 400 to 500 feet.

Pierre Shale

The outcrops of Pierre shale in Middle Park are limited in thickness by the unconformable contact with the overlying Middle Park formation although there may be as much as 5,000 feet of the Pierre remaining in some areas. The Pierre consists principally of dark-gray to brown or greenish-brown shales with some sandstone and a few beds of sandy and argillaceous limestone. Some of the sandstones are arkosic.

Tertiary

Middle Park Formation

The Middle Park formation overlies the Pierre shale unconformably and consists of a lower volcanic member composed of a mixture of dark-colored andesitic breccia, agglomerate, flows, irregular dikes, conglomerate, and an upper member of grit, sandstone, conglomerate, and shale. The formation varies in thickness from about 2,500 feet to as much as 5,500 feet, with the thicker measurement occurring in the northern portion of the park. Although it is very possible that a Cretaceous age may be applicable to the lowermost portion of the Middle Park formation, it is generally conceded to be Paleocene in age and can be traced northward into North Park where it is known as the Coalmont formation.

White River Group(?)

A series of grayish-white clay and brown conglomerate lies unconformably upon all formations in Middle Park. These sediments are largely confined to a topographic basin near Granby and lie between the Middle Park formation and beds of Miocene age and are separated from both by pronounced unconformities.

Late Tertiary (Browns Park)

Large areas of southern Middle Park are covered by poorly exposed andesite, light-colored tuffaceous clay, conglomerate, and chocolate-colored shales interbedded with basalt flows. These beds probably include deposits ranging from late Miocene to Pliocene age.

Structure

Middle Park is confined by four major structural units, the Front Range on the east, the Park Range on the west, the Rabbit Ears Range on the north, and the fractured central Colorado mineral belt with the associated Vasquez and Williams River Mountains on the south.

The west side of the Front Range, including the Vasquez and Williams River Mountains, is characterized by a series of northwest-trending overthrust faults crudely in echelon to each other with their depressed side on the southwest. The largest of the thrusts is the Williams Range fault which begins on the southwestern side of the mountains and extends northwestward for a distance of about 50 miles to a point near the east flank of the Park Range; the fault has a horizontal displacement of about 4½ miles. There are similar thrust faults on the west side of the Park Range and on its east flank for a relatively short distance between Green Mountain and Dillon. There are no bordering faults on the east flank of the Park Range northwest of Green Mountain where the sedimentary beds turn up anticlinally against the flank of the Range.

The structural axis of the Middle Park basin begins at a point of control close to the center of T. 1 N., R. 77 W., and extends northwestward to join the North Park axis at the center of the south line of T. 5 N., R. 78 W.

In the southeastern portion of the park and in the vicinity of Fraser, the Middle Park formation rests unconformably on folded Cretaceous rocks and overlaps onto the pre-Cambrian. About midway between the towns of Hot Sulphur Springs and Granby is a northerly trending narrow anticline about 15 miles long which has been named the Granby anticline. In the central part of the basin close to Corral Peaks another anticline is suggested in outcrops of the Middle Park formation beneath rocks of volcanic origin.

The rough terrain, topography, volcanic rocks, and heavily wooded areas of Middle Park have been the primary cause of only a very limited amount of geologic coverage with very sketchy references to the structural attitude of the basin.

Oil and Gas

The Cretaceous and Jurassic oil and/or gas producing sedimentary rocks of the North Park basin also occur in Middle Park but up to the present, there have been no commercial discoveries drilled. Exploration activity in the area has been hampered considerably by accessibility with only room for a limited application of the scientific tools used in developing drillable prospects. It has only been within the last three years that concerted efforts have been made to develop the petroleum possibilities of Middle Park.

Corral Peak Structure

The Corral Peak structure is located in the west half of Ts. 2, 3 N., R. 78 W., Grand County, Colorado. The mean surface elevation is approximately 10,000 feet and the suggestion of anticlinal structural closure is evident in beds of the Middle Park formation underlying rocks of volcanic origin. The axis of the anomaly trends north-south and is about 15 miles long. Because of volcanic rocks and heavy vegetation, detailed mapping of Corral Peaks is near impossible, but it is apparent that the structure is asymmetric with a steep to overturned west limb and a southward plunging axis, which terminates in a complexity of faulting.

During December, 1957, Murphy Corporation et al. abandoned their Corral Peak Unit No. 1, NW¼ NW¼ section 4, T. 2 N., R. 78 W., at a total depth of 7,471 feet; the ground elevation at the location is 10,040 feet. The Pierre shale was contacted at 2,675, the Niobrara shale at 6,475 feet, the Timpas limestone at 6,876 feet, the Muddy(?) sandstone at 7,264 feet, and the Dakota at 7,345 feet. At the total depth, it is estimated that the hole is bottomed a very short interval above the Morrison formation. Igneous intrusive rocks were cored between 7,142 and 7,178 feet. No important shows of oil and/or gas were logged in this test well.

Granby Anticline

The Granby anticline is located in Ts. 1, 2, 3 N., R. 77 W., with an axis extending northward from Section 26, T. 1 N., R. 77 W., into Section 13, T. 3 N., R. 77 W. The surface stratigraphic section exposed on the anticline includes sandy beds of the upper Pierre shale, volcanic breccia of the basal member of the Middle Park formation, a series of grayish-white clay and brown conglomerate which may be of the White River group, and some beds of light-colored, tuffaceous clay, conglomerate, and chocolate-colored shale, interbedded with basalt flows which are of lower Miocene age.

The anticline is narrow, elongated, and asymmetric with a steep west flank exhibiting dips between 30 and 80 degrees while dips on the more gentle east flank vary between 10 and 50 degrees. The east flank is complicated by numerous surface faults, and the magnitude of dips on the west flank strongly suggests a similar condition. Folding in subsurface rocks was substantiated by a seismic survey.

There have been several test wells drilled on or adjacent to the Granby anticline including the following:

Operaotr	Location	Total Depth	Deepest Formation Penetrated	Remarks
Brit-Am. Oil	NE¼ 3-2N-77W	4629′	pre-Cambrian	Morrison or pre-Cambrian
Lewis Mack	SE¼ 2-2N-77W	2000′		Junked hole
Lewis Mack	SE¼ 2-2N-77W	3114′	Morrison	Show of gas
Great Lakes	NE¼ 31-2N-76W	5077′	Red beds	
Glasscock	NW¼ 31-2N-76W	5606′	Morrison	
Lion Oil	NW¼ 16-1N-77W	5366′	Lakota	Show of gas
Mack Petr.	SE¼ 6-1N-76W	1770′	Dakota (?)	

South Park

South Park is approximately 50 miles long from north to south and about 35 miles wide measured from the encircling divides; the flat land area of the park is nearly 900 square miles and varies in surface elevations from 8,500 to 10,000 feet. The Front Range borders South Park on the east, the Continental Divide on the north, the south end of the Park Range or Mosquito Range on the west, and a low divide of volcanic rocks on the south (see Plate 5 in the pocket, and Fig. 9).

Stratigraphy

Almost a complete section of Paleozoic, Mesozoic, and Cenozoic rocks is represented in the South Park area with notable absence of the Silurian and Triassic. However, within the park itself only post-Mississippian rocks are exposed. The mountains immediately to the west contain outcropping sections of pre-Pennsylvanian beds. Along the northern and eastern edge of South Park, the Morrison is missing and the Dakota quartzite of Cretaceous age rests directly on the pre-Cambrian basement. Exploration drilling within parts of the South Park basin has revealed the Entrada sandstone overlying pre-Cambrian.

Cambrian

Sawatch Quartzite

The Sawatch of Upper Cambrian age has been identified and separated in the Mosquito Range into two parts; a lower member varying in thickness from 0 to 190 feet composed of hard, massively bedded, gray to white quartzite with a basal conglomerate locally, and an upper member, 40 to 60 feet thick, of gray, greenish-gray, and reddish shale, thin limestone, and shaly limestone. The upper member is called the Peerless shale.

The contact of the Sawatch with the underlying pre-Cambrian is unconformable whereas the relationship of the Peerless shale member with the overlying Manitou limestone appears to be a gradual transition.

Ordovician

Manitou Limestone

The Manitou limestone of Lower Ordovician age in the Mosquito Range and adjacent areas west of South Park consists of highly crystalline, thin-bedded, light-gray, dolomitic limestone, very siliceous in places and containing thin, dark-green to black interbedded shales. Within the Manitou there are zones of white to cream-colored chert or chalcedony. The thickness of this formation varies from 80 to 250 feet with pre-Upper Devonian erosion accounting for considerable variation in thickness over short distances.

At the north end of the Mosquito Range and in the Leadville district, Devonian sediments unconformably overlie the Manitou; however, at the south end of the range younger Ordovician sediments are in contact with the limestone.

Harding Sandstone

The Harding sandstone of Middle Ordovician age consists of light greenish-gray to dark reddish-brown alternating beds of shale and calcareous sandstone with a few beds of impure limestone and quartzitic sandstone. The sandstone is absent in the northern sector of the Mosquito Range and has been observed in thickness of from 50 to 75 feet at the southern end of the range.

Fremont Limestone

The Fremont limestone of Upper Ordovician age is a light-gray or light-brown, massively bedded dolomitic limestone approximately 75 feet thick at the southwestern limit of South Park.

Devonian

Chaffee Formation

The Devonian rocks of this part of Central Colorado have been designated the Chaffee formation with two members, the Parting quartzite below and the Dyer dolomite above. The Chaffee is Upper Devonian in age and unconformably overlies the Ordovician.

The Parting member is a pink, thick-bedded quartzite with some coarse sandstone and conglomeratic layers. Locally, beds of greenish and reddish shales occur with minor alterations to shaly limestone. The Parting quartzite appears as a very persistent outcrop in some areas and shows a range in thickness of from 10 to 70 feet.

The Dyer dolomite member consists of a gray to bluish-gray, dense, dolomitic limestone becoming somewhat shaly or sandy toward the base. The Dyer averages 75 feet in thickness, which varies as the result of pre-Mississippian erosion.

Mississippian

Leadville Limestone

Dense, blue to blue-gray dolomites with numerous streaks of black chert characterize the Leadville limestone of Mississippian age. The thickness of this horizon varies from 50 to 160 feet with differences being the result of erosion preceding Pennsylvanian deposition.

Permo-Pennsylvanian

Unconformably overlying the Leadville limestone is a lower series of shale, sandy shale, limestone, sandstone, conglomerate and grits which range upward into a thick upper series of red beds. The lower series has been questionably placed at a stratigraphic position equivalent to the Weber quartzite of northern Utah while the upper red bed sequence has been designated as the Maroon formation.

Weber(?) Formation

The Weber (?) formation consists of three zones of variable lithology. The basal portion, about 300 feet thick, is made up of dark-gray to black shale with interbedded limestone and locally thin sandstones; the middle zone consists of grit, sandstone, sandy shale, shale, and limestone between 700 and 1,000 feet thick with the sandstones being white to light-gray in color; and the upper zone consists mainly of coarse-grained sandstone, grits, and coarse, arkosic conglomerates with a thickness ranging between 1,200 and 1,600 feet. The Weber (?) of the Leadville district is unquestionably of Pennsylvanian age.

Maroon Formation

The Maroon formation covers the surface over a wide area in the western part of South Park. At least the greater part of the Maroon is of Permian age and consists of fine-grained, red sandstone and sandy shale with thin beds of limestone locally. In a northerly direction the deposits tend to become coarser in character although a basal arkosic conglomerate member is recognized over much of the southwestern part of the park. Maximum thicknesses of measured sections of members of the Maroon formation aggreate in excess of 9,400 feet.

Jurassic

Entrada Sandstone

The basal unit of the Jurassic sequence in South Park is the Entrada, sometimes referred to as the Garo sandstone. The Entrada is a pink, red, white, and gray, cross-bedded, locally conglomeratic sandstone showing considerable variation in thickness from 0 to 409 feet. An unconformity separates this sandstone from the overlying Morrison formation.

Morrison Formation

The Morrison formation is of Upper Jurassic age and consists of vari-colored shales; thin, vari-colored, irregular limestones; and lenticular, cross-bedded sandstones with some conglomerates. The thickness of the Morrison varies between 250 and 360 feet and the formation is unconformably overlain by the Dakota sandstone.

Cretaceous

Dakota Sandstone

The Dakota sandstone consists primarily of white to light-gray, quartz grains with some slightly arkosic beds and streaks of pebble conglomerates. At about the middle of the formation there are a few layers of black to dark-gray shale and sandy shale which vary to light-gray and pink sandy shales. The Dakota section averages about 225 feet in thickness and is conformable with the overlying Benton shale.

Benton Shale

Good outcrops of the Benton shale in South Park are rare but where observed the formation consists primarily of dark-gray to black papery shales with minor amounts of sandstone, limestone and bentonite. The most conspicuous sandy layer is at the top where from 11 to 20 feet of calcareous sandstone is present. The limestones of the Benton are generally dark-gray, to black, very shaly, and fine-grained and occur in a zone about 40 feet thick approximately 90 feet below the top of the formation. The upper sandstone probably corresponds to the Carlile sandstone and the limestone interval to the Greenhorn limestone of the plains area east of the Front Range. The Benton shale varies in thickness from 410 to 460 feet.

Niobrara Formation

The Niobrara formation consists of two divisions which can be easily recognized in this and other areas of east-central Colorado. The lower or Timpas member of the Niobrara is a thin, light-gray, slightly chalky limestone from 40 to 70 feet thick and the upper or Apishapa member is a dark-gray to black, calcareous shale making up the bulk of the average formation thickness of 540 feet. The presence of pebbles, phosphate nodules, and abundant fish teeth at the contact between the Benton and Niobrara indicates an unconformity; the contact of the Niobrara with the overlying Pierre shale is transitional.

Pierre Shale

The outcrops of the Pierre consist essentially of dark-gray to black, fissile shale, carbonaceous and calcareous in part. Approximately 250 to 300 feet above the base of the Pierre there are some dark gray, sandy shales and brownish-gray, slabby sandstones occupying an interval of about 150 feet. At the top of the formation there appears to be a gradual transition from shale through sandy shale to the sandstone of the Fox Hills. The thickness of the Pierre shale is estimated to be from 2,300 to 2,700 feet.

Fox Hills Sandstone

The Fox Hills is a white to light-gray and yellow, poorly cemented, fine-grained sandstone, commonly cross-bedded and with numerous large concretions locally. The maximum thickness of the sandstone is 350 feet.

Laramie Formation

Conformably overlying the Fox Hills sandstone is the Laramie formation from which sub-bituminous coal was once mined. The formation consists of sandstone, shale, volcanic tuff, and coal. The sandstones are generally white to dark-gray, fine- to medium-grained, highly arkosic, and in many places highly carbonaceous. The shaly beds are brown, gray, black and sandy. In the upper half of the formation occur beds of water-laid volcanic material. Three prominent coal beds occur in the Laramie beginning with a seam averaging 8 feet thick immediately above the basal sandstone of the formation. The Laramie reaches a maximum of 300 feet in thickness and is unconformably overlain by the Denver formation.

Denver Formation

The coarse continental deposits unconformably overlying the Laramie formation and consisting of conglomerate, gravel, grit and sandstone with interbedded volcanic tuff and agglomerate have been placed in the Denver formation of Upper Cretaceous and Paleocene age. The thickness of the Denver formation in South Park is in excess of 7,000 feet.

Tertiary

The Tertiary sediments of South Park occur in the southern portion of the basin and although not pertinent to oil and/or gas possibilities they may be briefly described as follows:

Balfour Formation

The Balfour formation of probable Oligocene age is made up of clay, volcanic ash, fine clayey sandstones, trachytric lava flows, and conglomerates.

Antero Formation

The Antero formation is of Oligocene age and consists of an upper member of thin limestone beds, tuff, sandstone, conglomerate, and minor shale; a middle member of fine-grained tuff, shaly beds and limestone lenses; and an upper member of poorly consolidated conglomerate with sandy interbeds.

Wagontongue Formation

This formation occurs only at the southern end of the park and consists of poorly consolidated conglomerate, sandstone, and sandy clay with an abundance of fragmental volcanic material. The Wagontongue formation is probably of Miocene and Pliocene age.

Structure

The structure of South Park is complex and resolves itself around the geologic history of the closely confining mountain ranges. The major structural features are the syncline of the Park occupied by sediments of the Denver formation, the Front Range highland on the east and north, and the Mosquito Range on the west. These structural features are complicated by several lesser folds and by at least three major reverse or thrust faults, trending northwest, and by a number of transverse faults of lesser magnitude. The southern one-third of the basin is covered by lavas and late Tertiary sediments which conceal the details of structure.

An important structural adjustment for this area occurred during Late Cretaceous and Early Tertiary time when tangential westward movement of the Front Range created the bordering low-angle Elkhorn thrust fault and other paralleling thrusts to the west. The eastern limits of South Park are defined by the Elkhorn fault which places an upthrown block of pre-Cambrian granite against the Tertiary and older sediments on the west. The Elkhorn thrust can be traced for a distance of 41 miles and is most probably related to the Williams Range thrust of Middle Park with a comparable horizontal displacement of about 4½ miles.

In the western area of the park and on the Mosquito Range there is a large reverse fault upthrown on the northeast with displacements ranging between 3,000 and 5,000 feet. The Mosquito fault and its branch, the London fault, trend approximately S. 35° E. through Ts. 10-13 S., Rs. 77-78 W.

Within the park and beginning at the town of Hartsel in outcrops of the Maroon, Morrison, and Dakota, the South Park reverse fault extends north-northwestward and is traced with some uncertainty through beds of the Pierre shale to a point close to the southeast corner of section 26, T. 8 S., R. 77 W., approximately 3½ miles west of the abandoned townsite of Como where the older formations are again exposed.

The Elkhorn, Mosquito, and South Park faults form a prominent tectonic fault block limited on the east by the Elkhorn thrust and on the west by the Mosquito fault with the intervening South Park fault separating the block into two segments. The easternmost segment contains the synclinal area of the park while the western block shows the monoclinal rising of sedimentary beds westward to the summit of the Mosquito Range.

When aligned with the Middle Park-North Park basin to the north, the South Park syncline can be likened to the small end of a horn. The syncline is quite narrow, sharp, and tapers to non-existence at its southeastern extremity; it is outlined chiefly by beds of the Pierre, Fox Hills, and Denver formations. On the west limb of the syncline beds of the Denver show east dips varying from 25 to 40 degrees whereas the same beds approach the vertical and are overturned against the

Elkhorn thrust block on the east. Much of the eastern flank of the syncline has been overridden by the thrust block. The narrowness of the syncline can be illustrated by the fact that the west limb, between the hogback of Dakota sandstone and the synclinal axis, shows its greatest width of only 8 miles across T. 9 S., Rs. 76-77 W.

Oil and Gas

There have been no successful discoveries of oil and/or gas in South Park and although spasmodic exploration has been carried out ever since the drilling of the first test well about 1893, it has only been during the past three years that a systematic effort was made to locate commercial accumulations of oil or gas. Exploration drilling activity has been confined to the synclinal area of the park and within the region of Pierre shale outcrops with sandstone beds of the Dakota, Morrison, and Entrada being the principal objectives. As a result of these recent efforts, it is very apparent that the South Park syncline is a more complexly folded and faulted feature than is evident from surface geologic data.

At the south end of the park, several small domes have been mapped with Dakota, Morrison, or pre-Cambrian rocks occupying the centers of the structures. In the west central part of the syncline and on its west limb an anticlinal feature has been noted in T. 9 S., R. 76 W., with an axial trend of N. 20° W. The anomaly which has received the most exploratory attention is the Hartsel anticline formed mainly in beds of the Pierre shale and extending N. 30° W. through sections 19 and 20, T. 12 S., R. 74 W., sections 1 and 12, T. 12 S., R. 75 W., and section 16, T. 11 S., R. 75 W. Most of the seismograph geophysical surveying conducted in South Park has been confined to the area of the Hartsel anticline.

Several shows of oil and gas have been recorded in logs of the test wells drilled, the most important show being in the South Park Oil Company's test in SE¼ SE¼ section 16, T. 11 S., R. 75 W., drilled in 1935 to a total depth of 5,705 feet in the Pierre shale. Oil of 33.5° API gravity was encountered in an igneous sill at 4,161 feet and flowed 75 barrels of oil natural in 18 hours; after being shut-in for storage the well failed to produce again and was abandoned.

A notable effort was made by McDannald Oil Company to contact sediments of the sub-thrust plate of the Elkhorn fault in the test well drilled in section 28, T. 11 S., R. 73 W. This hole was spudded in pre-Cambrian granite and was bottomed in the same material at a total depth of 2,087 feet.

Other important test wells drilled in South Park to date are as follows:

Operator	Location		Total Depth	Deepest Formation Penetrated	Remarks
South Park	NE¼ SE¼	13- 8S-76W	3228′	Pierre	Shows gas & oil
South Park	NE¼ NW¼	5- 9S-76W	2465′	Dakota	
South Park	NE¼ SE¼	34-11S-75W	7725′	Pierre	
South Park	NE¼ NW¼	21-11S-75W	810′	Pierre	Show gas
McDannald	SE¼ NW¼	20-12S-74W	6182′	Maroon	Thrust faulted
McDannald	SW¼ SE¼	1-12S-75W	7098′	Dakota	Thrust faulted
Wycomo	NW¼ SE¼	16-11S-75W	5924′	Niobrara (?)	Shows gas & oil
Shell	NE¼ NE¼	28-11S-75W	8490′	Morrison	No shows
Shell	SE¼ SE¼	4-12S-74W	571′	pre-Cambrian	Entrada on granite
Shell	NW¼ SW¼	4-12S-74W	5349′	pre-Cambrian	Morrison on granite (?)
Shell	NW¼ NW¼	32-11S-75W	3560′	pre-Cambrian	Entrada on granite
Shell	NW¼ NE¼	7-12S-74W	3905′	Morrison	
Shell	SW¼ NE¼	34-12S-74W	4443′	Morrison	
Tennessee	SE¼ NW¼	11- 8S-76W	7475′	Pierre	

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Chapter XVI

Northwestern Colorado

by

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Northeastern Colorado

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CHARLES C. O'BOYLE*

The area of northwestern Colorado treated in this report is delineated by the Wyoming-Colorado boundary to the north, the Rocky Mountain uplift to the east, the Gunnison River uplift on the south, the Uncompahgre Plateau on the southwest and the Colorado-Utah line on the west, comprising approximately 17,000 square miles. The region can be divided into a number of subprovinces, both geologically and geographically. As shown on Fig. 14, the Sand Wash Basin to the north is separated from the central and southern Piceance Basin by the Uinta Mountain, Axial Basin and White River uplifts. Just east of the Colorado-Utah line, the Douglas Creek arch separates the Piceance Basin from the Uinta Basin of Utah.

Although numerous oil seeps and tar sands had been known in the area since the days of the early explorers, it was not until 1902 that commercial production was established on the Rangely anticline from fractures in the Mancos shale. Since that time the region has had only sporadic exploration, due to its remoteness from established markets, the great thickness of sedimentary cover and the complicated stratigraphy of the sediments. It is a region of geologic paradoxes and the key has yet to be discovered in an oil and gas sense. However, the area is now more active than at any time in its history and this activity will furnish not only additional reserves, but an increase in geologic knowledge, which will help in the solution of the many problems which face those now attempting the development of the area.

Northwestern Colorado is a land of high plateaus, drained by the Colorado River and its principal tributary, the Green River. These rivers, through the eroding action of their tributaries, have dissected the land into innumerable valleys and rugged hills. The general altitude of the region is from 6,000 to 7,500 feet, while the more prominent mountains within and surrounding the area exceed 10,000 feet. Much of the region is timbered by juniper and scrub oak, with conifers covering most of the lands at elevations of 7,000 feet and above. Precipitation varies from 10 inches in the lower altitudes to 40 inches in the higher regions. Temperatures range from over 90 degrees in the summer to occasional days in the winter when the temperature drops well below zero. On the whole, the climate is mild and dry.

The sedimentary cover of the region has an aggregate

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FIGURE 14

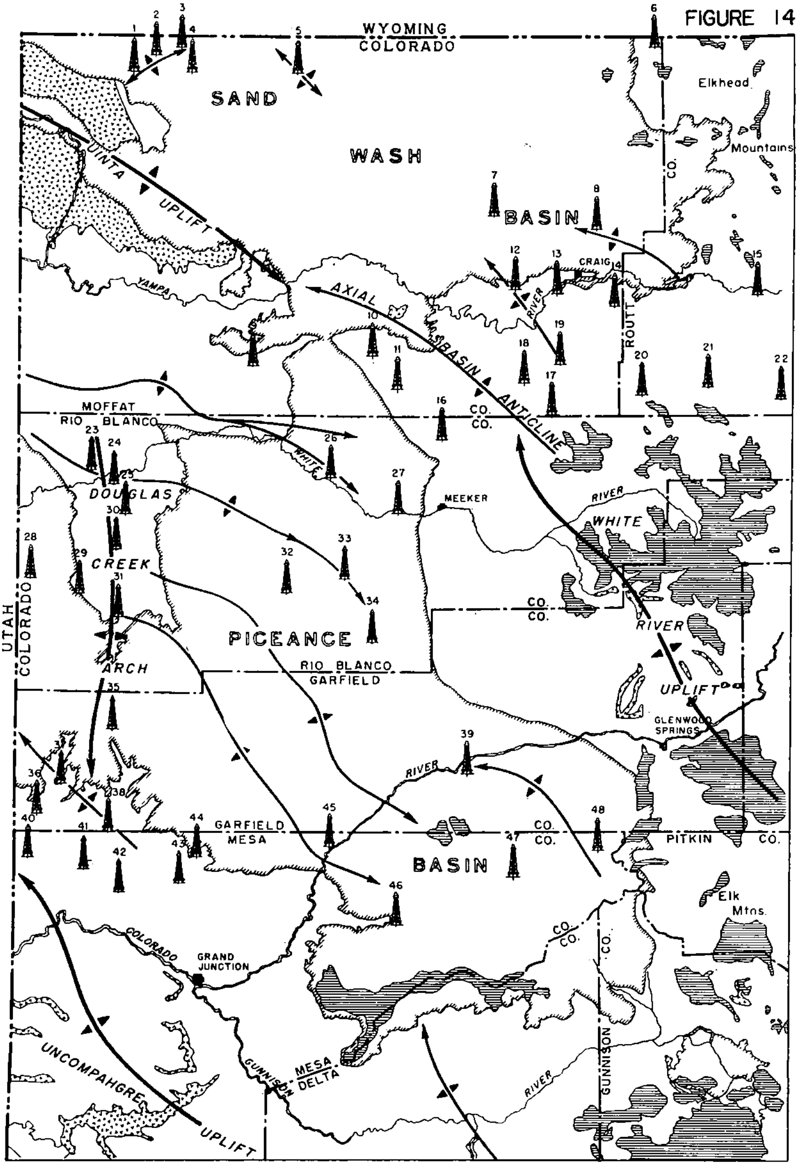
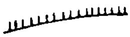


Figure 14 Charles C. O'Boyle

AERIAL SKETCH MAP OF NORTHWESTERN COLORADO

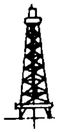

Major anticlinal features


Subordinate anticlinal trends


Base of Tertiary


Volcanics


Precambrian


Oil and/or gas fields

1—Sugar Loaf
2—West Hiawatha
3—Hiawatha
4—Shell Creek
5—Powder Wash
6—Slater
7—North Lay Creek
8—North Craig
9—Elk Springs
10—Danforth Hills
11—Maudlin Gulch
12—Bell Springs
13—Craig
14—Buck Peak
15—Tow Creek
16—Wilson Creek
17—Thornburg
18—Iles
19—Moffat
20—Pagoda
21—Williams Park
22—Oak Creek
23—Rangely
24—South Rangely
25—Gillam Draw
26—White River
27—Powell Park
28—Hells Hole
29—West Douglas
30—North Douglas
31—Douglas
32—Sulfur Creek
33—Piceance Creek
34—South Piceance Creek
35—Douglas Pass
36—Carbonera
37—South Canyon
38—Garmesa
39—Rulison
40—Bar X
41—Highline
42—Mack Creek
43—Asbury Creek
44—Hunters Canyon
45—Coon Hollow
46—Plateau
47—Sheep Creek
48—Divide Creek

thickness of over 20,000 feet. As a consequence, no exploratory wells have penetrated the entire sedimentary section. Outcrops on the rims of the basins are not continuous and where present are often complicated by local structure or covered by the luxuriant vegetation of the higher altitudes. As a result, only portions of this tremendous thickness of sedimentary beds are exposed in any locality. Variations within these sediments themselves and the interfingering of one formation with another make correlation of these isolated partial exposures difficult. Thus, a rather localized and confusing nomenclature has developed for the various sedimentary rocks.

The original oil fields of the region were mapped on the surface and this method is still applicable to the Cretaceous and older beds, but even here unconformities between formations and local structural complexities make the extension of surface data to the subsurface hazardous. Surface mapping of the Tertiary beds has proved to be only faintly indicative of the structure in depth. Seismic methods are also limited by structural complexity, as well as by the attenuation of energy within many of the formations, and by the lack of sufficient precise stratigraphic data to correctly interpret the seismic results. This same lack of precise stratigraphic data makes the correlation of electric logs difficult and often open to question. As a consequence, northwestern Colorado is considered a region where exploration for oil and gas is difficult and expensive. This fact has hindered the development of the area; however, it presents a challenge by its very complexity, which can be found in few other regions within the Rocky Mountain province.

Geologic History

Paleozoic

Middle Cambrian time marks the earliest presently interpretable record of the geologic history of northwestern Colorado. At that time the area stood above sea level and lay on the west flank of the great transcontinental arch, the backbone of the North American Continent. The area to the west, in what is now Utah and Nevada, was submerged beneath the great Paleozoic seas, and northwestern Colorado lay on the eastern shore. During this period the area was at times emergent and at other times slightly below sea level, when the comparatively thin Paleozoic section of the region was deposited. Local features adjacent to the area were the Rocky Mountain arch to the east, a northwesterly trending anticlinal feature superimposed across the northeasterly trending transcontinental arch, and the Uncompahgre-San Luis highland to the south, another northwesterly trending uplift. Separating these two uplifted areas was a downwarp of the earth's crust to which the name Colorado trough, or sag, has been given.

By Upper Cambrian time, the Paleozoic seas to the west had slowly invaded and covered northwestern Colorado and in these shallow waters the Sawatch quartzite was deposited. These beds are thickest in the area of the Colorado trough, thin to the east on the flanks of the Rocky Mountain arch, and probably were never deposited on the Uncompahgre-San Luis arch to the south. Northwestern Colorado remained beneath the seas during the remainder of Cambrian time and well into the Lower Ordovician, the sedimentary sequence changing from the sandstones of the Sawatch to the sandy, thin-bedded limestones and dolomites of the Ordovician Manitou formation. Northwestern Colorado and adjacent areas were then uplifted and subjected to erosion throughout the remainder of Ordovician time, all of Silurian time, and much of the Devonian. Near the end of Devonian time the seas again invaded the area and the sands, limestones and sandy dolomites of the Chaffee formation were deposited. These beds, though having essentially the same sedimentary sequence as those of the Cambro-Ordovician, are much thinner and represent a shorter period of deposition. Although an unconformity marks the top of this sequence, sedimentation in the region was closely followed by the deposition of the Leadville limestone. This formation, correlative with the Madison limestone of Lower Mississippian age in other regions, is comparatively thin over northwestern Colorado, as the Rocky Mountain arch and the Uncompahgre-San Luis highland, though beneath the great Madison seas, still remained positive elements. In late Mississippian and earliest Pennsylvanian time, the area rose above sea level and the extensive, predominantly red residual soil of the Molas formation was developed on the exposed Leadville limestone. Throughout this long period, the tectonic events which affected northwestern Colorado were continental in nature and evidence suggesting local folding or faulting during early Paleozoic time is meager. It is probable, however, that some local structures developed which are now masked by later tectonic events.

This relatively quiescent history of sedimentation was brought to a close in Lower Pennsylvanian time, when the Colorado arch was accentuated, forming the Ancestral Colorado Rockies, and the great horst of the Uncompahgre highland was elevated. Rapid subaerial erosion stripped both the sedimentary and pre-Cambrian rocks from these flanking highlands and streams spread the debris across northwestern Colorado to form the Belden, Minturn and Maroon formations. Deposition reached its maximum thickness in the Colorado trough, which lay between these two active tectonic elements. Subsidence was more rapid in the eastern portion of this trough and formed the barred Central Colorado Basin. Not only were subaerial and subaqueous red beds deposited in this depression, but in the center a thick sequence of marine shales and evaporites accumulated. The Central Colorado Basin shoaled rapidly in what is now the northern and western portions of northwestern Colorado and on this restriction between the Central Colorado Basin and the great Pennsylvanian basins to the west, the sandy limestone, red siltstone and shale sequence of the Morgan formation was deposited. Near the close of Pennsylvanian time, the western seas slowly but persistently encroached over much of the area, depositing a thick sequence of marine sandstones, the Weber formation, in the western portion. This sequence thins eastward and southward until in the southeastern portion of the area a thin tongue of the formation lies on the pre-Cambrian. In Permian time the western seas withdrew from the area, leaving as a record of their withdrawal the South Canyon Creek dolomite and the Phosphoria formation, a relatively thin sequence of calcareous marine beds.

Mesozoic

During all of Triassic and Jurassic time, northwestern Colorado lay at or above sea level and the still active Ancestral Rockies were furnishing sediments to the eastern portion of the area, though in decreasing amounts. The entire Triassic period was a time of extensive red bed deposition in the area and it was during this time that the Moenkopi, Shinarump and Chinle formations were deposited.

During the Jurassic, the great eolian sand deposits, which had already formed to the west at the end of Triassic time, spread across northwestern Colorado. These sandstones are first represented by the basal Navajo formation, which, though it attains considerable thickness in the western portion of the area, thins rapidly to the east against the flanks of the then still active central Colorado highlands. In the western portion of the area the Navajo sandstone is separated from the similar eolian Entrada sandstone by a very thin red siltstone sequence, the Carmel formation. The Entrada sandstone thins to the east in a much more gradual manner than the underlying Carmel and Navajo formations. In fact, the Entrada sandstone was probably the first formation to transgress across the Rocky Mountain arch from west to east since the deposition of the Mississippian Leadville limestone. Over this arid and comparatively smooth surface the western seas again spread, depositing the marine Curtis formation, a thin sequence of glauconitic sandy limestone and gray marine shale. The Jurassic seas again withdrew to the west and on the exposed low, almost featureless, surface accumulated the extensive floodplain deposits of the Morrison formation.

Throughout the Paleozoic era and the Triassic and Jurassic periods, the tectonic framework of northwestern Colorado included positive areas to the east and south and great depositional basins to the west and north. Throughout that time northwestern Colorado maintained a general westerly and northwesterly regional structural dip. With the opening of the

Cretaceous period, however, the tectonic conditions which controlled sedimentation in the area were reversed. The great epicontinental seas were now to the east and the mountain uplifts to the west, and the regional dip of the area became easterly. The new source areas to the west supplied the sandy detrital material which forms the thin, but widely distributed, sediments of the Dakota formation. Chert pebbles and conglomeratic lenses within this formation are evidence of the close proximity of the uplifted areas which supplied the sedimentary material. The Rocky Mountain arch, upon which were superimposed the Ancestral Rocky Mountains, was still a positive feature during Lower Cretaceous time, for in certain areas along the present Rocky Mountain Front, the Dakota sandstone lies on pre-Cambrian. A period of relative tectonic quiescence followed the deposition of the Dakota, and during this period the dark-gray, carbonaceous and siliceous shales of the Mowry formation accumulated. Volcanic activity and crustal unrest in the area to the west is evidenced by thin, but persistent, bentonite beds which cap this formation. Renewed erosion from these newly uplifted source areas supplied the sandy sediments which form the sequence of near-shore and lagunal sandstone beds of the Frontier formation. Again a relatively long period of stable tectonic conditions followed, and approximately 1,000 feet of calcareous shales and limestones of the Niobrara formation accumulated. This sequence is overlain by several thousand feet of only slightly calcareous marine shales of the Mancos formation. However, pulses of tectonic activity in the land masses to the west are evidenced within this sequence by several zones in which the marine shales become extremely sandy.

The Cretaceous seas of northwestern Colorado, wherein the Mancos shale was deposited, were now forced from the area, not by regional uplift, but by the shear mass and bulk of sedimentary debris carried from the west across the area, to form the essentially sandy sequence of the Mesaverde group. The basal beds of this group are composed primarily of marine sandstones laid down beneath the surface of the seas. However, the succeeding beds which comprise the great bulk of this sequence grow progressively more subaerial, until the upper beds are fluvial in character. As this great mass of sediment spread across northwestern Colorado, the shores of the Cretaceous seas retreated in a progressive fashion to the east, and in the swamps and lagoons which comprise its ephemeral shoreline, the carbonaceous shales and coals which make up the present great coal deposits of the region accumulated. When the contact between the Mancos shale and the Mesaverde group is considered in the light of time equivalents, this contact climbs in the sedimentary column essentially from west to east. However, if this contact is based on the tops of formations which underlie the Mancos shale in northwestern

Colorado, such as the Frontier or Dakota, the Mancos-Mesaverde contact would appear to lie at the same stratigraphic interval across the area. This is due to the fact that the Rocky Mountain arch to the east, though still beneath the sea, was slowly being uplifted at the same rate as the facies line between the Mancos shales and the sandstones of the Mesaverde group was climbing in the stratigraphic column. This similarity between the depositional rate of the Mesaverde and the uplift of the Rocky Mountain arch to the east has led to great confusion in correlations of the sedimentary sequence of the Upper Cretaceous of northwestern Colorado. A decrease in source sediments and a structural barrier formed by the Axial Basin uplift prevented the filling of the Cretaceous sea in the northern portion of northwestern Colorado and in this embayment the sandy, but essentially marine, shales of the Lewis formation were deposited. At the close of Cretaceous time, the slow but persistent rise of the Rocky Mountain arch, superimposed on a more widespread and general continental uplift, caused the withdrawal of the Cretaceous seas from the area. This renewed uplift, or tectonic activity, supplied new source material which spread a blanket of sands and shales over most of the area. In fact, these new sediments, being derived from the same source area as the underlying Mesaverde group, are so similar in lithology that where the Lewis shale is absent, these sediments are essentially indistinguishable from the underlying Mesaverde. However, where these sediments are separated from the underlying Mesaverde by the Lewis formation, they have been differentiated and given the name Lance formation. The Cretaceous period was brought to a close by the start of the great Laramide revolution, which saw the beginning of the uplift of the present Rocky Mountain System and its attendant structural adjustments, which gave rise to new sedimentary source areas in northwestern Colorado and the entire Rocky Mountain region.

Cenozoic

At the close of Cretaceous time and during very earliest Paleocene time, northwestern Colorado was subjected to erosion. However, the rising Rocky Mountains to the east soon furnished sufficient debris in the form of conglomerates, sands and minor amounts of sandy shales to spread a sedimentary cover over the entire area. These fluvial deposits constitute the present Fort Union formation. Following this first great pulse of the Laramide revolution, the sediments supplied to northwestern Colorado became progressively finer and the varicolored mudstones and shales, accumulated under fluvial conditions, comprise the Wasatch formation. These sediments were insufficient in amount to fill the rapidly subsiding structural basins of northwestern Colorado, and in these basins great inland seas or lakes were formed. The lacustrine deposits which accumulated were composed of oil shales (highly organic shales and marlstones), minor amounts of evaporites and a considerable thickness of fine, sandy to silty sediments, which constitute the Green River formation. On the margin of the basins, these lacustrine sediments interfinger with fluvial sediments of Wasatch lithology. Because of this interfingering and the structural adjustments contemporaneous with deposition, the Tertiary section contains no recognizable lithologic unit which can be used as a time equivalent over the entire region; this makes correlation difficult.

The last extensive sedimentary sequence to be deposited in northwestern Colorado is a series of conglomerates, poorly indurated sandstones and volcanic tuffs of Miocene age. These beds are the depositional product of renewed uplift of the present Rocky Mountains. Locally, in the vicinity of the Uinta Mountain uplift, a basal conglomerate of this series, separated from the overlying beds by an angular unconformity, has been given the name Bishop conglomerate. The remainder of these beds are known as the Browns Park formation. Throughout the area where they occur, these beds lie with angular unconformity on all older beds and mask underlying structural conditions over many hundreds of square miles. Remnants of extensive volcanic flows and intrusions which took place at this time are to be found within these beds and extend over much of the eastern portion of northwestern Colorado. The Browns Park formation presently exhibits folding and faulting which took place in post-Browns Park time.

Structure

The structural geology of northwestern Colorado is complex, more so perhaps than any other oil- and-gas-producing region of comparable size within the Rocky Mountain region. The area contains two major structural and sedimentary basins, the Sand Wash Basin on the north and the Piceance Basin on the south. The uplifts, complementary to these basins, expose pre-Tertiary rocks and display the complex structural history of the region. Three major structural trends are evident in northwestern Colorado: a northwest-southeast trend; a north-south trend; and an east-west trend. It is the superposition of these various lines of folding, one upon the other, which accounts for the structural complexity of the area. The oldest line of folding, the northwest-southeast, had its inception in Pennsylvanian time. This trend parallels the Uncompahgre uplift, the oldest and most persistent major anticlinal feature in the area. While this northwest alignment has been greatly modified by subsequent folding, it still remains the major axial trend of most of the oil- and gas-producing structures of the region. The north-south trend of folding, of which the Douglas Creek arch is the largest structural feature, had its inception at the close of Cretaceous time. Downwarping of the Uinta Basin on the west and the Piceance Basin on the east during Paleocene and Eocene time further accentuated this positive feature. This line of folding on the west, the Uncompahgre uplift to the south, and the rising Rocky Mountain arch to the east first defined the Ancestral Sand Wash-Piceance Basin. This older basin covered a much greater area of northwestern Colorado than the present Sand Wash and Piceance basins, which are but remnants of the older basin. The east-west line of folding, represented by the Uinta Mountains of northern Utah, also began in late Cretaceous time. However, this disturbance, while of considerable intensity in central Utah, became progressively milder toward the east, until in northwestern Colorado this uplift gave rise to only a broad and relatively gentle anticlinal feature. At the end of Cretaceous time, the great Rocky Mountain arch, which had been slowly rising since the mid-Cretaceous, was uplifted with renewed intensity. This event, the Laramide revolution, was the greatest tectonic disturbance to affect the region of northwestern Colorado since Pennsylvanian time. As part of this great structural unrest, the northwest-southeast trend of folding was reactivated and many of the present producing structures of the region were strongly redefined. In late Eocene time the east-west line of folding, only weakly developed near the close of the Cretaceous, elevated the present Uinta Mountains and its associated structures with such intensity as to affect the then existing structures of the Sand Wash Basin and the adjacent Axial Basin uplift. This east-west folding extended as far south as the present White River drainage where it was relieved by a zone of major faulting in which the valley of the present river is developed. The last major structural deformation of northwestern Colorado occurred in early Miocene time. The White River uplift, which up to this time had existed as a relatively gentle anticlinal nose extending northwestward into northwestern Colorado from the Sawatch Range to the southeast, was elevated to a considerable height. This uplift severely restricted the areal extent of the Piceance Basin, which prior to this time had extended from the Douglas Creek arch on the west as far east as the Gore and Sawatch Ranges. Contemporaneously with the development of the White River uplift, the eastern portion of the Uinta Mountain anticline collapsed along the great marginal faults which had bounded this uplift. The great graben thus formed was later filled by the Browns Park formation, which masks much of the detail of local structural elements. This period of deformation was brought to a close by intense volcanic activity. The centers of this activity extended in a line from the San Juan Mountains to the south, along the western flank of the Rocky Mountain uplift to beyond the Colorado-Wyoming line.

Except for broad regional uplifts, northwestern Colorado has been relatively stable since Miocene time, though subject to extensive erosion. With each period of folding, associated faulting took place in the area. The normal faults related to local anticlinal features generally have a northwesterly-southeasterly trend; however, this trend becomes northeasterly on the crest and western flank of the Douglas Creek arch. The major thrust faults of the area have an east-west trend; however, this trend can be modified locally by differential movement of the thrust blocks along previously existing normal faults. In general, faulting of both local and regional nature is more common in northwestern Colorado than present areal geologic maps would indicate. Not only is pre-Tertiary faulting hidden by the extensive cover of Tertiary deposits, but faulting which took place during the intense tectonic activity of Tertiary time is all but concealed by similar lithologies, repetitive over many hundreds of feet within the deposits themselves, which makes mapping or tracing of existing faults extremely difficult. This condition also prevails in much of the Cretaceous Mesaverde-Mancos section. It is the superposition of these various lines of folding, one upon the other, which gives the sinuous trends to the anticlinal and synclinal features of the area, as shown on Fig. 14, pages 596-7.

Stratigraphy

Rocks representative of all post-Proterozoic geologic periods, except the Silurian, are present in various parts of northwestern Colorado. Non-deposition and erosional unconformities limit the present areal extent of many of the formations. This area has always been remote from centers of population; and as a consequence, correlations have been carried into the region from the better-known areas of Colorado, Wyoming and Utah. Hence, because of the complexity of the sediments themselves and the correlations carried from west, north and east, the nomenclature used for the various formations and members of formations in the literature is confusing. Even at the present time, the correlation of beds of formational rank is controversial, and further study is necessary before correlation of members and facies can be made with any scientific assurance.

The older Paleozoic formations are known principally from exposures marginal to the basins and their distribution in the deeper portions can only be inferred at present. The extent of formations of Pennsylvanian age or younger are better known, but facies changes and unconformities within these younger beds have made correlations with marginal exposures difficult.

Cambrian

Sedimentation during Cambrian time is represented in northwestern Colorado by beds of Upper Cambrian quartzite, quartzitic sandstones and dolomites. The individual beds are generally only a few feet thick and are interbedded with thin beds of light, greenish-gray shale. A sandy dolomite near the top of these Cambrian beds is very glauconitic and can be found in all surface exposures and in the subsurface, where it forms an excellent marker horizon. The Cambrian beds are called the Sawatch quartzite in Colorado, while beds of similar age and quite similar lithologies have been named the Lodore formation at their outcrop along the eastern end of the Uinta Mountain anticline. Resting conformably on the lower quartzites in the vicinity of the White River uplift and in much of the subsurface are a series of thin-bedded dolomites which are often conglomeratic in nature. These beds are capped by an algal biostrome from three to five feet thick. The present thickness of the Cambrian beds in northwestern Colorado ranges from zero to over 600 feet.

Ordovician

The Manitou limestone of Lower Ordovician age conformably overlies the Cambrian in this region. Approximately the lower half of this formation is composed of flat-pebble limestone conglomerates, interbedded with greenish-gray limey shales. The flat pebbles, composed of dense gray limestone, lie at varying angles with the bedding planes. They are contained in a matrix of dolomitic limestone, which weathers buff-colored on the outcrop. The upper half of the Manitou limestone is composed of thin-bedded, fossiliferous, dolomitic limestones. Locally, arenaceous and glauconitic zones are contained within these dolomitic beds. In this area the thickness of the Manitou formation ranges from zero to nearly 200 feet.

Silurian

No beds of Silurian age have been identified in northwestern Colorado.

Devonian

The Chaffee formation of Upper Devonian age unconformably overlies the Manitou limestones. The unconformity separating these two formations is represented by an erosional surface of minor irregularity and the beds of the Chaffee and Manitou are essentially parallel. The Chaffee formation has been divided into two members, the Parting member at the base, overlain by the Dyer member. Because of unconformities, both at the base and the top of this formation, the thickness of both members varies considerably from place to place. The lower, or Parting member, consists of quartzites and quartzitic sandstones, with subangular to rounded grains coarse in size, separated by light-green dolomitic shale. The overlying Dyer member consists of thick-bedded limestone and dolomites, which contain stringers and lenses of silt and sand. Chert and pyrite are found in limited amounts in this upper member. On the outcrop the Chaffee formation weathers varicolored, from browns which are almost black, through buffs, to various shades of gray. The thickness of the Chaffee formation varies considerably, due to nondeposition, or to uplift and erosion in post-Devonian time. The more complete sections of the Devonian Chaffee formation attain thicknesses of between 200 and 250 feet.

Mississippian

Leadville Limestone

The epicontinental seas of Lower Mississippian time covered all of northwestern Colorado and the Leadville limestone was deposited during this time. Except for a very thin sequence of sandy limestone beds at the base, the Leadville consists of nearly pure, bluish-gray limestones, massively bedded, and containing irregular stringers and nodules of blue-gray to black chert throughout the section. The upper portion of the Leadville limestone is highly oolitic in northwestern Colorado. Irregular dolomitization occurs within the beds. The Leadville is porous and cavernous, both on the outcrop and in the subsurface, and should make an excellent reservoir. Due to unconformities, both at the base and at the top of this formation, the thickness of the Leadville limestone varies considerably. In a broad sense it may be considered to thin easterly toward the Rocky Mountain Front. The thickest sections of the Leadville limestone have been encountered in the subsurface, where beds of typical Leadville lithology attain a thickness of between 550 and 700 feet, whereas outcrop sections rarely exceed 400 feet and thin eastward to less than 200 feet in the vicinity of Eagle. This increased thickness in the subsurface may be due to beds of similar lithology, but of younger age, overlying the typical Leadville limestone. These beds could be an eastward extension of the Deseret limestone of Utah. The Leadville is correlative with the Madison limestone of other areas.

Molas Formation

Toward the end of Mississippian time, the surface of the Leadville limestone was subject to prolonged weathering. The red and yellow clay, containing angular fragments of the underlying limestone and chert, now forms a fossil regolith, to which the name Molas has been applied, as it is similar to and occurs at the same stratigraphic horizon as the type Molas in the San Juan Mountains.

Pennsylvanian

The Pennsylvanian stratigraphy of northwestern Colorado is complex, and although extremely challenging from a purely scientific point of view, its economic importance as the principal producing horizon in the Rangely oil field has given most of the impetus to the study of the beds of this system.

Belden Shale

The earliest Pennsylvanian formation in northwestern

Colorado is the Belden shale. At its type section on the eastern edge of the Eagle Basin, the Belden formation is about 125 feet thick, and is composed of beds of dark shale and impure coals, with some interbedded limestones near the top. Northwesterly from this section, the number of limestones increases until in the extreme western portion of northwestern Colorado the lithology changes to predominantly shaley and arenaceous limestones, bearing little resemblance to the dark shales and coals of the type section to the east. However, recent work has shown that these two dissimilar lithologies are correlative and the basal beds of Pennsylvanian age throughout northwestern Colorado are now called Belden.

Minturn-Morgan Formations

With the rise of the Ancestral Rockies and the Uncompahgre highlands, the Colorado sag, lying between these two positive elements, was greatly accentuated to form the so-called Colorado trough, a barred depositional basin. Conglomerates, arkosic grits and lenticularly bedded micaceous shales and mudstones were deposited on the margins of this basin. Subsidence, however, was dominant over deposition and in the center of the basin a thick sequence of anhydrites, dolomitic limestones and associates shales accumulated. The name Minturn has been assigned to both these subaerial and subaqueous beds. Over the shallow constriction which existed on the northwestern portion of the Colorado trough, the Pennsylvanian seas deposited a sequence of marine limestones and interbedded sandstones and shales, called the Morgan formation. These marine beds interfinger with the predominantly clastic Minturn formation. Periods of quiescence during the uplift of the surrounding mountains allowed the waters of the Pennsylvanian seas to deposit a sequence of marine limestones over the entire basin and it is the uppermost of these, the Jacque Mountain limestone, which forms the most consistent marker bed or time line within the sequence.

Maroon-Weber Formations

Following the deposition of the Jacque Mountain limestone, arkoses and conglomerates continued to accumulate within the basin and spread farther and farther toward its center until the basin was completely filled. These red bed deposits are known as the Maroon formation. The great Pennsylvanian seas from the west lapped against and interfingered with this growing mass of arkose and red sands. Along this ever encroaching shoreline, the near-shore and reworked dune deposits of the Weber formation were laid down, attaining a thickness of over a thousand feet in the extreme northwestern part of the area. This sequence is composed of well-sorted, angular to subrounded sand grains, with occasional siltstone and limestone lenses. It is this sandstone which serves as the reservoir in the major Rangely oil field of northwestern Colorado. Another period of relative quiescence marked the end of the Pennsylvanian in the area and a tongue of the Weber sandstone spread eastward along the axis of the Colorado trough almost to the southeastern end of the basin.

Permian

In the eastern and southeastern portions of northwestern Colorado, the Pennsylvanian-Permian contact lies within the Maroon formation, for the red arkoses and sands which compose this sequence continued to be deposited well into Permian time. In the northwestern, or seaward, portion of the area, the Pennsylvanian-Permian contact lies near the top of the Weber sandstone, or at the contact between it and the overlying phosphoria formation.

Phosphoria-Park City Formation

The Phosphoria, or Park City, formation, marine in character, marks the final retreat of the Pennsylvanian-Permian seas from the area. This sequence is made up of limy sandstone, fossiliferous, thin-bedded light-gray limestone and gray and red shale. Phosphate nodules, so typical of this formation in other parts of the Rocky Mountain province, are found to a minor extent in the basal portion of these beds. In the extreme western and northern portions of the area under discussion, the Park City has a thickness of between 100 and 150 feet and thins rapidly eastward and southeastward to where it pinches out somewhere within the Maroon formation.

Triassic

Moenkopi Formation

During Lower Triassic time, northwestern Colorado lay near or very slightly above sea level. The red shales and sandstones of the Moenkopi formation were laid down disconformably on the underlying Permian beds. The brick-red calcareous shales and sandstones contain abundant mud cracks and ripple marks typical of shoreline deposits. This formation has a maximum thickness of 800 feet in the northwestern corner of the area and thins to the east and south where it interfingers with and loses its identity within the arkosic red beds which were still being deposited on the flanks of the Ancestral Colorado Front Range and the Uncompahgre highland.

Shinarump Conglomerate

Unconformably overlying the Moenkopi red beds is a sequence of gray and buff sandstones and pebble conglomerates of the Shinarump formation. This sequence is highly irregular in thickness, representing a stream deposit on a widespread alluvial plain, dipping westerly and northwesterly toward the still synclinal areas to the west. The thickness ranges from over 50 feet in some areas to total absence in others, due to non-deposition.

Chinle Formation

Conformably overlying the Shinarump conglomerate is a series of bright-red siltstone, shale and marlstone beds of Upper Triassic age. These beds mark the close of widespread red bed deposition in northwestern Colorado. Where recognizable, the Chinle formation varies in thickness from over 300 feet in the western portion of the area to a feather edge to the east and southeast. This great variation in thickness is due to both irregular deposition and erosion.

Wingate-Kayenta Formations

In the extreme southwestern portion of northwestern Colorado on the north end of the present Uncompahgre uplift, the light-brown to white, fine-grained, massive sandstone of the Wingate formation of Upper Triassic age is found. This relatively thick sandstone unit represents the wedge-edge of the thick Wingate sandstone formation of east central Utah. Overlying the Wingate is a relatively thin group of beds composed of irregularly bedded, brownish-red, limey shales and medium-grained sandstones of the Kayenta formation. While these beds are spectacularly exposed in the vicinity of Colorado National Monument, they must wedge out rapidly in the subsurface beneath the Douglas Creek arch and the adjacent Piceance Basin, as they have not been identified in the subsurface in these localities.

Jurassic

An unconformity separates the Triassic and Jurassic systems in northwestern Colorado. This unconformity becomes more pronounced to the east along the western portion of the Colorado Rockies where Jurassic beds overlap all older formations until they lie on the pre-Cambrian in many places.

Navajo Sandstone

The earliest Jurassic formation in northwestern Colorado, the Navajo sandstone, consists of massively bedded light-gray to cream and light-brown sandstone beds. The sand grains which make up practically all of this formation vary from subangular to rounded and are fine in size, so typical of eolian deposits. Again, like so many other formations of northwestern Colorado, the Navajo sandstone forms a broad sedimentary wedge from west to east. At its outcrop in the vicinity of Dinosaur National Monument at the east end of the Uinta Mountains and in the subsurface at Rangely, the Navajo sandstone attains a thickness of over 600 feet. It thins rapidly, however, to the east and loses its identity in the subsurface near the east flank of the Piceance and Sand Wash Basins.

Carmel Formation

The Carmel formation, consisting of irregularly bedded bright-red siltstones, separates the Navajo from the Entrada sandstone in the western portion of the area, where it attains a thickness of over 100 feet. However, the Carmel thins rapidly eastward and is not present in the eastern portion of the area. Where the Carmel is absent, a differentiation of the Navajo and Entrada sandstones is difficult and, as a consequence, in petrographic descriptions these basal Jurassic sands are often termed Entrada-Navajo.

Entrada Sandstone

The Entrada, eolian in origin, is present everywhere in the region and is an excellent marker bed where exposed on the surface and also in the subsurface. It is one of the few "blanket" sands of the area. Good sorting of the constituent grains, which are predominantly quartz, only moderate cementation, and cross-bedding are characteristics of this sandstone. Thinning within this formation, from a maximum thickness of 200 feet, is rather uniform from west to east.

Curtis Formation

An invasion of the Upper Jurassic seas from the west and northwest into northwestern Colorado is marked by the marine Curtis formation. This sequence grades from glauconitic, sandy limestone at the base into medial gray shales to oolitic limestone beds at the top. While having a maximum thickness of only 150 feet in northwestern Colorado, this formation is present in much of the western portion of the area and is recognized in the subsurface in most of the oil fields of the region.

Morrison Formation

Near the end of Jurassic time, all of northwestern Colorado was covered by the Morrison formation. Lenticular sandstones, varicolored siltstones and marlstones, fossil wood and dinosaur remains indicate that this formation was deposited on an extensive flood plain. The basal portion of this sequence contains a considerable number of well-developed lenticular sandstone lenses, which form excellent stratigraphic traps. The Morrison attains a thickness of over 700 feet in the western portion of the area and thins to the east and southeast to less than 300 feet in the vicinity of Steamboat Springs and along its outcrop on the west flank of the present Rocky Mountain uplift.

Cretaceous

Northwestern Colorado, from Cambrian through Jurassic time, lay on the east limb of a great continental syncline, or seaway, to the west. The regional dip during much of this time was to the west, as most of the pre-Cretaceous sediments thin in an easterly direction. At the close of the Jurassic, this synclinal area to the west was elevated and the positive area to the east, the Rocky Mountain arch, slowly sank beneath the sea. As a result, the regional dip became easterly.

Dakota Sandstone

The rapidly rising lands to the west spread a relatively thin veneer of conglomeratic sandstones, greenish mudstones and varicolored shales across the region. These beds, the Dakota formation of Lower Cretaceous age, are continuous with similar deposits which extend over most of the present Rocky Mountain region. The contact between these earliest Cretaceous beds and the underlying Jurassic sandstones and shales is difficult to recognize in the subsurface and in certain areas of northwestern Colorado is difficult to place on the outcrop. Because of this, the thickness of the Dakota in northwestern Colorado varies widely, but in those places where the upper and lower contact can be drawn with some assurance, the Dakota is found to have a thickness of 100 to 150 feet.

Mowry Formation

Overlying the Dakota formation in gradational contact is a series of dark-gray, slightly carbonaceous and siliceous shales of the Mowry formation. Over the greater part of the area, a bentonite bed, recognizable on the outcrop and on electric logs, marks the top of this formation. This bentonite bed is the best time and lithologic marker in the Lower Cretaceous sequence of northwestern Colorado. The Mowry shale has a rather uniform thickness of 150 to 200 feet.

Frontier Formation

The contact of the Frontier formation with the underlying Mowry shale marks the division between Lower and Upper Cretaceous time. Acceleration in the rate of uplift of the lands in central and western Utah and a consequent increase in the amount of erosional detritus to the east caused an easterly retreat of the shoreline of the epicontinental Cretaceous seas, and the near-shore and lagunal beds of the Frontier formation were laid down. These beds consist of alternate sandy siltstones, grading in places to rather well-developed sandstones, and gray, calcareous sandy shales. On the surface the Frontier formation generally forms a fairly well-developed cuesta or hogback behind the more resistant Dakota outcrop. These beds are best developed in the western and northwestern portions of the region, where they attain a thickness of approximately 250 feet. However, because of depositional thinning, this formation is represented by a sandy zone less than 100 feet thick near the top of the Benton shale along the flank of the present Rocky Mountain uplift.

Mancos Formation

Following the deposition of the Frontier, the Cretaceous seas again invaded northwestern Colorado from the east and deposited several thousand feet of gray marine shales over the area. Approximately the basal 1,000 feet of this shale sequence is highly calcareous, consisting of impure limestones and foraminiferal shales. While containing no reservoir beds, as generally conceived, fracture zones in this interval constitute important oil-producing horizons in northwestern Colorado. These beds can be correlated with the Niobrara formation of eastern Colorado and should be given formational rank in northwestern Colorado. The overlying marine shales, which compose the upper portion of the Mancos formation, contain a number of very sandy zones which are recognizable, both on the surface and in the subsurface, over the greater part of the area. It is only recently that these sandy zones could be correlated with some degree of certainty. The most prominent of these intervals, which crops out on the crest of the Rangely anticline and in the vicinity of Meeker, Colorado, has been given the name "Meeker zone" by geologists working in the area. Throughout northwestern Colorado the upper Mancos shale interfingers with the overlying Mesaverde group. This interfingering relationship has led to anomalous thickness figures for the marine Mancos shale. If the base of the Mancos is taken at the top of the Frontier formation and the top is considered to be the base of the first continuous sequence of interbedded sandstones, then an average thickness of 4,500 feet can be assigned to the Mancos in northwestern Colorado.

Iles Formation

This formation, the lower member of the Mesaverde group, consists of a series of well-bedded massive sandstones and interbedded light-gray sandy shales, with some coals occurring near the middle of the formation in the eastern part of the region. These beds were deposited in a near-shore environment, at various times slightly beneath and slightly above sea level. The sandstone beds within this formation are generally thicker and more continuous than those of the overlying Williams Fork. If only those beds stratigraphically equivalent to the type section of the Iles formation are considered, then this sequence has a rather uniform thickness of between 1,200 and 1,500 feet throughout northwestern Colorado. However, if all interbedded sandstones and shales above the marine Mancos are included in the basal portion of this formation, the thickness of the Iles will increase westward until, in the vicinity of the Utah-Colorado line, it approaches 2,000 feet. The similar lithologies of the various sandstone beds making up this sequence and the monotonous similarity of the interbedded shales make correlation of individual units nearly impossible. However, in certain areas where wells are spaced sufficiently close and structural complications are well understood, it is possible to at least zone this formation. The sandstones of the Iles are uniformly composed of angular to subangular grains, predominantly fine in size, and are low in porosity and permeability, due to interstitial filling of authigenic clays.

Williams Fork Formation

Conformably overlying the Iles formation in all of northwestern Colorado is a thick series of lenticular sandstones, interbedded shales and coals of the Williams Fork formation, the upper member of the Mesaverde group. The great bulk of this sequence was deposited in a littoral and lagunal environment. Though zonation is possible in much of the outcrop, the division of the Williams Fork in the subsurface is extremely difficult. Many hundreds of feet of interbedded sands, shales and coals of varying thickness and stratigraphic position characterize this unit. The sandstone beds are extremely lenticular and cannot be distinguished from one another, either macroscopically or microscopically. The interbedded shales are uniform throughout the section, both in appearance and composition. For this reason, structural complications of great scientific and economic interest go unrecognized where they occur in the subsurface, and cause considerable difficulty in structural and lithologic interpretations.

Lewis Shale

In the northern and eastern portions of the area the marine Lewis shale overlies the Williams Fork formation. The shales of the Lewis are quite similar to those of the Mancos, though generally more sandy and lighter gray on the outcrop. These marine shales are not present south of the Axial Basin uplift. On the eastern side of the present Piceance Basin, the sequence of sandstone beds of high interstitial clay content is equivalent to the marine Lewis to the north and east, and can be considered a continental and lagunal sandstone facies of the Lewis formation. This interfingering of subaerial and littoral sands with typical marine shales took place in northwestern Colorado throughout most of Upper Cretaceous time. Hence, as the name Mancos has been applied solely to the thick sequence of Cretaceous marine shales and not to the contemporaneously deposited sandstone sequence of the Mesaverde, it would seem logical and proper that the term Lewis be restricted to the sequence of marine shales which overlies the Williams Fork, and is in turn overlain by the Lance formation. South of the Axial Basin uplift, the zone which is the time equivalent of the Lewis shale should be included in the Williams Fork formation, as typical Mesaverde sedimentation took place in the southern part of northwestern Colorado prior to, during and subseqent to Lewis time. The Lewis shale thins rapidly to the west and south from over 2,000 feet in the eastern part of the area to a few hundred feet in exposures on the northeast flank of the Axial Basin uplift.

Lance Formation

In those portions of northwestern Colorado where the marine Lewis shale is distinguishable as a separate lithologic unit, the succession of discontinuous cross-bedded sandstones, gray to yellow shales and thin coal beds of Upper Cretaceous age which overlies the Lewis is called the Lance formation. Again, south of the Axial Basin uplift, equivalent beds cannot be distinguished with certainty from underlying beds of the Mesaverde group. At the base the Lance formation lies in gradational contact with the underlying Lewis, but a pronounced unconformity is found at the top of these beds. Because this unconformity is angular, the thickness of the Lance varies widely in northwestern Colorado. A maximum thickness of approximately 1,500 feet can be assigned to this formation in the area.

Tertiary

The Cretaceous Lewis sea was the last marine invasion of northwestern Colorado. By the end of Cretaceous time all deposition in the area was subaerial and fluvial in nature. During the Paleocene, the Laramide orogeny, which had begun in late Cretaceous time, was greatly accelerated over most of the Rocky Mountain region. The uplifts which constitute the present Rocky Mountain chain were forming with renewed intensity.

Fort Union Formation

Much of the debris eroded from the new highlands was deposited in western Colorado and adjacent areas and today is called the Fort Union formation. A pronounced unconformity separates the Paleocene from the underlying Cretaceous. The basal beds of the Fort Union are conglomeratic in nature over much of the region, with the size of the conglomeratic material increasing strongly from west to east and north to south. While the Fort Union formation has long been recognized on the outcrop and in the subsurface in the Sand Wash Basin to the north, equivalent beds in the Piceance Basin have been included within the Wasatch formation. Here, only the basal Paleocene conglomerate has been separated from the overlying formations and given the name Ohio Creek conglomerate. Recent work, however, both on the surface and in the subsurface, has shown that beds of Fort Union age and typical of the lithologies of the beds called Fort Union in the Sand Wash Basin can be recognized in the Piceance Basin proper. Above the basal conglomerate, or conglomeratic sandstone, a series of light-gray, rather poorly indurated, massive sandstone, with interbedded greenish-gray shales, are found over much of the region. The Fort Union formation becomes progressively more shaley toward the top and the enclosed sandstones are finer grained, much more lenticular and erratic in their distribution. While the base of the Fort Union is easily recognized over most of northwestern Colorado, the top of this formation is more difficult to place. In certain areas the base of the overlying Wasatch formation is conglomeratic and the top of the Fort Union is placed at the base of this conglomerate. In other parts of the area the top of the Fort Union is drawn at the base of the soft variegated clays so typical of the overlying Wasatch, which differs so markedly from the greenish-gray shales of the Fort Union. Because of the fluvial nature of its deposition, and contemporaneous tectonics, the thickness of the Fort Union varies considerably. Over 1,500 feet of beds of this age have been recorded within the Sand Wash Basin. In the southwestern portion of the area beds of Fort Union age attain a thickness of only a few hundred feet. While this great difference in thickness would suggest an erosional unconformity between the Fort Union and the overlying Wasatch, in most of northwestern Colorado the contact between these two formations appears to be gradational. Hence, this great variation in thickness is believed to be largely depositional in character.

Wasatch Formation

The fluvial red bed deposits of Eocene age which once covered all of northwestern Colorado are called the Wasatch formation. This sequence consists essentially of a great thickness of maroon, green and gray shales. Irregularly distributed within this mass of varicolored shales are lenses and beds of fine-grained sandstones. Thin, fresh-water limestones and local beds of conglomerate are also common. This formation reaches its maximum development in the center of the present basins, where beds of typical Wasatch lithology attain thicknesses of over 5,000 feet.

Green River Formation

While the surrounding highlands were contributing tremendous amounts of sediments to the Piceance and Sand Wash basins during Eocene time, the rate of subsidence was greater than the rate of deposition. Great inland lakes were formed in the basins and the lacustrine deposits of the Green River formation were laid down. As mentioned on p. 603, these lake sediments interfinger with the fluviatile deposits of the Wasatch facies on the margins of the basins. In the Piceance Basin the beds have an aggregate thickness of 3,500, and have been separated into a number of distinct lithologic units. At the base is the Douglas Creek member, with a variable thickness of from 200 to 800 feet. This member consists of cross-bedded, ripple-marked, and well sorted sandstone beds separated by thin light-gray calacareous shales. Conformably overlying the Douglas Creek member is the Garden Gulch member, composed of predominately gray, paper-thin shales. These beds form long topographic slopes on the outcrop, in contrast to the overlying and underlying cliff-forming members. While the Douglas Creek contains some low-grade oil-shale beds, it is the overlying Parachute Creek member that is noted for its rich oil-shale deposits, near the top of which occurs an extremely rich oil-shale zone known as the Mahogany ledge. Within this ledge is a persistent bed known as the "Mahogany marker," which is an excellent reference datum, both on the surface and in the subsurface. The Parachute Creek member varies in thickness from less than 200 feet to a little more than

1,000 feet at its type section on Parachute Creek. Overlying the Parachute Creek member of such great economic interest is the Evacuation Creek member, consisting of barren gray shale and marlstones, with some interbedded sandstones. Due to depositional thinning and subsequent erosion, the thickness of the Evacuation Creek member is extremely erratic, varying from zero to over 900 feet.

Bishop Conglomerate

In the northwestern part of the area, principally on the flanks of the Uinta Mountain uplift, occurs a conglomerate made up of a heterogeneous collection of well-rounded boulders of varying size, which cap relict erosion surfaces. This deposit has been given the name Bishop conglomerate. While extremely variable in disposition and thickness, due to subsequent erosion, the Bishop conglomerate attains a thickness of 200 feet in parts of northwestern Colorado.

Browns Park Formation

Another terrestial deposit of Miocene age overlies the Bishop conglomerate and all older beds in the northern portion of northwestern Colorado. The term Browns Park formation has been given to this series of beds, which consists of a basal conglomerate with overlying white to gray or grayish-pink, poorly sorted sandstones. Irregularly bedded within the sandstone sequence are thin bentonites and volcanic tuffs. These beds were laid down with pronounced unconformity on a land surface which reflected considerable structural relief. These deposits filled grabens, breached anticlinal folds, and other depressions of the Miocene topography of the region. The Browns Park formation attained a thickness of at least 2,000 feet, and by the end of mid-Miocene time had transformed a great part of the northern portion of northwestern Colorado into a featureless plain. Renewed uplift and subsequent erosion has removed these deposits from much of the area; however, this formation still effectively masks much of the pre-Browns Park structure in the Sand Wash Basin and other parts of northwestern Colorado.

Quaternary

Quaternary deposits are not common in northwestern Colorado. The area is being actively eroded and the few Quaternary deposits present are confined principally to the channels of existing rivers and streams.

Occurrence of Gas and Oil

Types of Traps

Most of the oil and gas production from northwestern Colorado is from anticlinal traps, due primarily to the fact that most exploratory drilling has been on anticlinal features expressed on the surface. The stratigraphy of the region has not been sufficiently well understood in the past to allow subsurface exploration for stratigraphic pinch-outs. However, stratigraphy and in a sense stratigraphic traps have a profound influence on oil and gas accumulation in the area. Production from the few blanket-type sands which are found in northwestern Colorado is the exception rather than the rule, most production being obtained from lens-type sand bodies and permeability pinch-outs on the crest or flanks of anticlinal structures. Faulting also plays an important part in structural accumulations within the area; however, the relatively complex stratigraphy and the wide spacing of exploratory wells have prevented the gathering of sufficient detail to allow the delineation of many of these faults.

Reservoir Horizons

Oil and gas occur in beds of Paleozoic, Mesozoic and Cenozoic age in northwestern Colorado. At the present time, commercial quantities of oil or gas are produced from eleven distinct formations, which are discussed below.

Weber Sandstone

The Weber sandstone of Pennsylvanian age is the most important producing horizon in northwestern Colorado. The Rangely field, one of the great oil fields of North America, yields most of its oil from this horizon. Two other fields, Elk Springs and Thornburg, lying to the north and east of Rangely, are the only other fields which produce oil in commercial amounts from the Weber. However, this sandstone has been oil-stained in cores and has yielded free oil on drillstem test in a great percentage of the wells in other parts of the area which have encountered this formation.

The porosities and permeabilities of the Weber are generally very low. This sandstone is relatively fine-grained and well-cemented with calcareous and some silicious cements where encountered in the subsurface. The very characteristic, though, of a highly indurated sandstone has led to extensive fracturing within the formation under the stress of folding. As a consequence, this secondary permeability and the increase in over-all porosity yield a considerably higher reservoir capacity than routine porosity and permeability determinations would indicate. While the high degree of fracturing is beneficial in this way, it is detrimental in that the vertical fractures give a high vertical permeability to producing reservoirs and water influx and coning present production hazards.

Shinarump Formation

The Triassic Shinarump, where well-developed, has produced commercial quantities of oil and gas in the area. This formation, however, due to its extreme lenticularity does not form extensive reservoirs, and as a consequence, known reserves of oil in the Shinarump are small. The sandstones and interbedded conglomerates which form the reservoirs within this formation have high interstitial clay content, which leads to extreme variability in porosity and permeability.

Entrada Sandstone

The Entrada sandstone of Jurassic age yields oil from a number of fields located on the Axial Basin uplift and gas in a number of wells on the Douglas Creek arch. This sandstone, of excellent porosity and permeability, has nearly ideal reservoir characteristics. However, the oil column encountered within this formation is generally only a small fraction of its total thickness, even on anticlinal structures of considerable closure. Because of the high horizontal and vertical permeabilities inherent in this sand and the relatively thin oil column, water invasion through coning is a common production hazard. However, when properly completed, wells which produce from this sandstone have excellent production records, and the fields which produce from the Entrada and the overlying Morrison are, with the exception of Rangely, the most important oil fields of northwestern Colorado.

Morrison Formation

Near the base of the Morrison is a series of highly lenticular sands correlative with the Sand Wash member of the Morrison formation of the Colorado Plateau. These lenticular sands are sufficiently well-developed to carry commercial quantities of oil and gas in a number of fields in northwestern Colorado. However, permeability and porosity of these sands vary considerably, both horizontally and vertically within each sand lens, as would be expected from their mode of deposition. Though these basal Morrison sands are separated from the Entrada sandstone by the thin Curtis formation, the coincidence of occurrence of oil in both the Morrison and Entrada and similarity of the oil in each formation would suggest a common source, and thus the Morrison and Entrada, in a broad sense, could be considered a common reservoir. This is illustrated by the fact that when oil saturation is found in the Morrison formation, the underlying Entrada may also be saturated, but if the overlying Morrison is barren, it is extremely unlikely that oil or gas will be found in the underlying Entrada sandstone.

Dakota Sandstone

This widespread sandstone and shale sequence, which is such an excellent marker horizon over most of the Rocky Mountain region, should be an excellent oil reservoir over most of northwestern Colorado. This is not the case, however, and commercial production from the Dakota sandstone is not common in the area. While residual staining is commonly encountered in drilling in the sands of this formation, commercial accumulation of oil has only been found in the Moffat field. Accumulations of gas, however, are more common, but still not numerous, and represent rather recent accumulations which have migrated locally from underlying and overlying formations along faults.

Mancos Shale

The Mancos shale of Upper Cretaceous age produced the first oil from northwestern Colorado at Rangely near the turn of the century. While this formation contains no true reservoir beds, open fractures containing secondary calcite accumulations have proved to be a reservoir of importance. From early in this century to the present, fracture production in the Mancos shale has amounted to over six million barrels of oil, and while this is the oldest producing formation in northwestern Colorado, exploration for additional reserves lagged badly over the intervening years due to the unusual occurrence or type of reservoir. It is only in the last few years that such accumulations have been found to occur in localities other than the producing fields of Rangely and Tow Creek. While oil can be produced from all horizons of the Mancos shale, it is within the basal calcareous portion, equivalent to the Niobrara formation of the eastern slope, that the best production is found. This is due to the better competency of these calcareous shales, which approach true limestones in composition. Under tangential stress, these beds break readily and have sufficient strength to hold open the incipient fractures thus formed. The Mancos shale is and will continue to be an important oil-producing formation in northwestern Colorado.

Mesaverde Group

The Mesaverde group, containing many hundreds of feet of massively bedded sandstones, would normally be considered an excellent reservoir horizon. Though a large number of wells have tested these sandstones in northwestern Colorado, no commercial accumulations of oil have been found. However, accumulations of gas in both commercial and non-commercial amounts are quite common. Commercial production of gas is dependent on finding sufficient porosity and permeability within a sand body to form a reservoir of economic importance. Such sands, with sufficient cleanliness and sorting, are more common to the basal portion of this group, especially the marine sandstone tongues in the transition zone between this formation and the contemporaneously deposited Mancos shale. The typical sandstone beds which make up the great bulk of this group are composed of relatively fine sands, well-cemented with secondary silica, the porosity of which is greatly reduced by a clay filling of the interstitial voids. As a consequence, these sandstones have extremely low permeabilities and poor porosities.

Lewis Shale

In the Sand Wash Basin, where the Upper Cretaceous marine Lewis shale is recognized, a number of discontinuous sandstone lenses near the top of this sequence produce gas. These sandstones are relict offshore bars formed on the edge of the retreating Lewis sea. The porosity and permeability of these marine sandstone bodies vary from poor to good, being dependent on the thickness of the sand lens and directly proportional to the degree of sorting of the constituent grains.

Fort Union Formation

The Fort Union, the basal Tertiary deposit of northwestern Colorado, yields both oil and gas in a number of fields in the Sand Wash Basin. Lenticular sand bodies of varying size constitute the reservoir beds. The constituent grains composing these sand bodies are poorly sorted and considerably coarser on the average than the sands of the underlying Lance. These sands are also highly carbonaceous and are interbedded with lignitic to sub-bituminous coals. The degree of cementation is extremely variable and production is best from the coarser and softer sands. Oil of high-gravity paraffin base and high pour point requires special production techniques. In the Piceance Basin the Fort Union formation was, for many years, considered the basal portion of the overlying Wasatch, and production from Fort Union beds or beds of Fort Union age has often been assigned to the Wasatch formation. However, a rather appreciable production of gas can be assigned to beds of Fort Union age in the Piceance Basin proper. While some staining has been observed in cores from the Fort Union in this basin, no commercial quantities of oil have been found.

Wasatch Formation

Lenticular sand bodies within the Eocene Wasatch formation produce gas in northwestern Colorado. These sand bodies, at varying horizons within the great mass of variegated shales which comprise this formation, are extremely variable in configuration and constituents. While resembling the sands of the underlying Fort Union, they have a more heterogeneous mineral assemblage, are less well-cemented and more poorly sorted, with constituent grain size ranging from silts to conglomerates. As a consequence, porosities and permeabilities are extremely variable and commercial production is dependent on finding interstitital porosity and permeability sufficiently well-developed.

Green River Formation

The youngest producing beds in northwestern Colorado are the basal (Douglas Creek) sandstones of the Eocene Green River formation, which yield variable quantities of gas and small amounts of oil. The fine- to medium-grained sandstones which constitute the reservoir beds are rather tightly cemented with interstitial calcite. As a consequence, average porosities and permeabilities are low; however, an interconnected series of fractures give secondary porosity and permeability to these reservoirs.

New Producing Horizons

In northwestern Colorado production has been established from most of the potential reservoir horizons of Pennsylvanian or younger age. The two exceptions are the Navajo sandstone of Jurassic age and the Frontier sandstone of Upper Cretaceous age. The Navajo sandstone, well-developed in the western part of the area, becomes thinner and finer grained toward the east. Porosity and permeability are very well-developed in the main body of this sandstone and under the proper combination of structural and stratigraphic conditions, the Navajo could become a reservoir of importance. However, no shows of oil or gas of any consequence have been encountered in this formation and its excellent porosity and permeability make it a regional aquifer. Because of the complex structural history of the area, bianket sands have for the most part been flushed free of oil or gas. For this reason, the Navajo sandstone cannot be considered a future reservoir of promise.

The Frontier sandstone, while present in the subsurface throughout northwestern Colorado, represents a littoral or near-shore deposit whose sandy beds are, in reality, a suspension of sand grains in a clay matrix, and the formation as a whole can be considered a highly sandy shale. Hence, porosity and permeability cannot be expected to be extensively developed within this formation, and though shows of oil and gas have been encountered in its more sandy portions, it is doubtful that this formation will ever be an important reservoir.

Extension of Producing Areas

Like all oil and gas provinces, deeper drilling and the testing of more complex structural features will greatly extend the producing areas of northwestern Colorado. It is only at the present time that the search for stratigraphic traps can be undertaken with any degree of confidence. The basal sandstone tongues of the Mancos-Mesaverde transition zone will first receive most of this type of exploratory effort. The Weber-Maroon transition zone, while more limited in extent, will also add measurable reserves to the region.

The Triassic Shinarump conglomerate, while long established as a producing reservoir horizon, has received little study in the past; however, when its complex lithology and depositional history have been deciphered, a structural-stratigraphic reservoir within this formation is extremely probable.

The number of wells which have penetrated the Mississippian Leadville limestone and older beds are relatively few in the area. Those that have, encountered little encouragement and difficult drilling. The Leadville limestone has shown excellent vugular porosity, where cored, and this porosity, combined with appreciable thickness, could make this formation the most outstanding reservoir of the area. Exploration for Mississippian and older production must wait for a better understanding of pre-Pennsylvanian stratigraphy and structure.

SELECTED REFERENCES

The geologic literature of northwestern Colorado is rather extensive because of the many sedimentary and structural problems of the area. For introductory reading, the following recent publications are suggested. Many additional references will be found in these publications.

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Chapter XVII

The Paradox Basin of Colorado

by

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The Paradox Basin of Colorado

by

FRANK J. ADLER*

Recent oil discoveries in southwestern Montezuma County, Colorado, by Monsanto Chemical Company (Lion Oil Company), the Texas Company, and the California Company, are the latest developments in the exploration for hydrocarbons in the Colorado portion of the Paradox Basin.

The evolution of this Pennsylvanian evaporite basin into an oil province has been a long and arduous process. Complex stratigraphy and general inaccessibility of the more favorable areas, coupled with a lack of pipeline and other transportation facilities were, until recently, deterrents to exploration. As the Colorado portion of the Paradox Basin is an integral part of the entire basin (see Index Map, Fig. 15), a brief summary of the latter's development is given below.

1908—Oil was discovered in shallow wells at Mexican Hat oil field near the San Juan River, San Juan County, Utah. Accumulation was synclinal in sands of Permian and Pennsylvanian age. The field was not commercial, as indicated by a total production of only 54,000 barrels of oil although 119 wells were drilled.

1927—Oil was discovered in the Paradox formation at Cane Creek, San Juan County, Utah, located on the Colorado River about 15 miles south of Moab. The well blew out, caught fire, and was abandoned. An offset well was also abandoned after failing to find the same porous interval.

1930—Gas was discovered at Boundary Butte on the Arizona-Utah state line. Although the discovery well indicated the presence of commercial gas, it was not produced due to lack of pipeline facilities.

1945—Gas was discovered in the Paradox formation at Barker dome, New Mexico, on a prominent surface anticline on which gas had been discovered in the Dakota formation in 1925.

1948—Gas distillate was discovered at Dove Creek in Montezuma County, Colorado. No active development followed because of a thin pay section, complex stratigraphy, and lack of market outlet. In the same year a second well on the Boundary Butte structure in Utah confirmed the presence of gas, but the field remained shut in.

1954—Commercial oil was discovered at the Desert Creek

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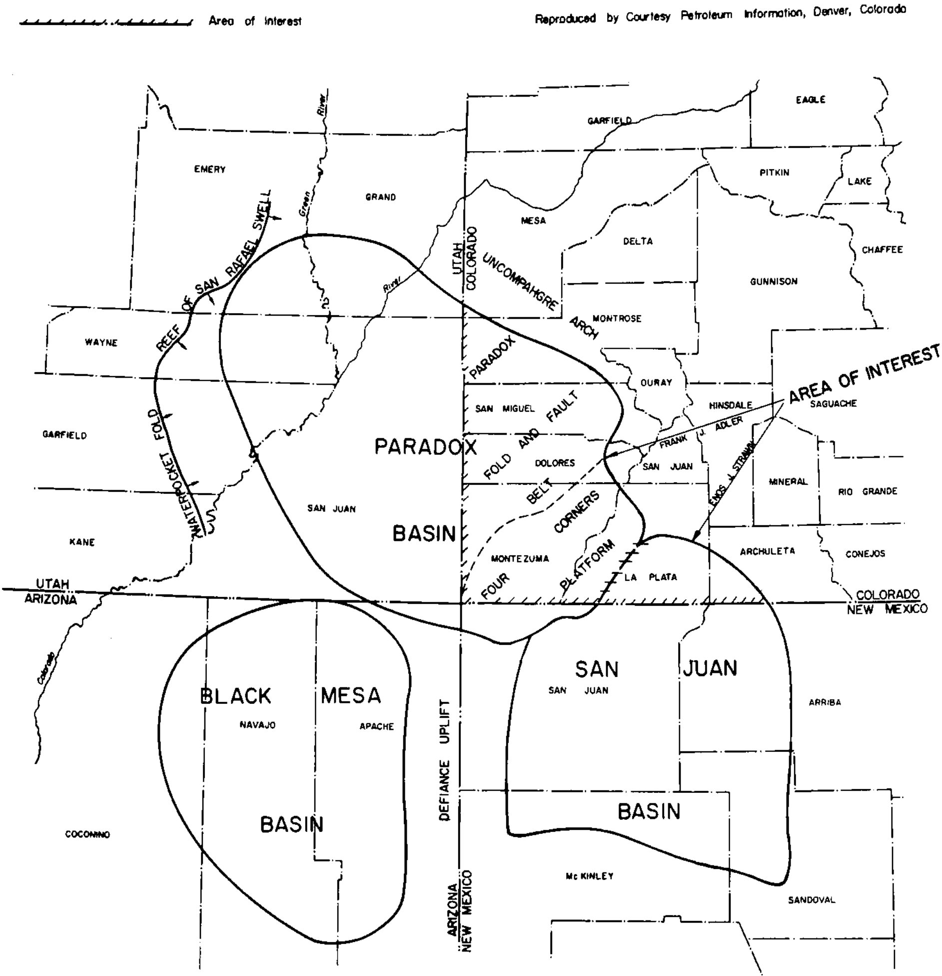

FIGURE 15

INDEX MAP OF FOUR CORNERS AREA SHOWING LOCATION OF PARADOX - SAN JUAN - BLACK MESA BASINS

Drafted by Den Galbraith AREA OF INTEREST COVERED IN REPORT BY ADLER & STRAWN March 20, 1960 field on the Navajo Indian Reservation, San Juan County, Utah. It is from this field that the principal oil reservoir found to date in the Paradox formation of Pennsylvanian age derives its name.

1956—The Aneth oil field, San Juan County, Utah, was discovered and gave impetus to active development elsewhere in the Paradox of Utah and Colorado. As of May 1, 1959, approximately 425 oil wells drilled in the greater Aneth area have produced 11,042,798 barrels of oil, seven billion cubic feet of natural gas, and 160,262 barrels of water.

1958—The Four Corners Pipeline to California, and the Tex-Mex Pipeline to Jal, New Mexico, with connections to the Gulf Coast, were completed. Paradox oil and gas production to May 1, 1959, from a total of 500 wells, was approximately 11.6 million barrels of oil and 183.5 billion cubic feet of gas. These figures include all producing wells in the Paradox Basin as of May 1, 1959. Virtually all the gas and gas-distillate production is from the Barker dome field of Colorado and New Mexico, and practically all the oil production originates in Utah.

The new discoveries in Colorado are the first indications of commercial oil in this portion of the Paradox Basin and indicate that future exploration in the State will be accelerated.

Location

The Colorado portion of the Paradox Basin is located in the southwestern part of the State and covers all or parts of La Plata, Montezuma, Dolores, San Miguel, Montrose, and Mesa Counties.

Physiographic changes from deep canyons to high mesas to broad plateaus and high laccolithic mountains make this one of the most scenic areas in the United States. It is also a land of ancient culture as evidenced by the Pueblo Indian ruins at Mesa Verde National Park.

Major highways, County roads and jeep trails now crisscross the area, thus overcoming the old problem of accessibility. In the mountain region along the eastern border of the area the Denver and Rio Grande railroad operates a narrow gauge railroad between Durango and Silverton.

General Geology

The Paradox Basin is a northwest-southeast trending evaporite basin of Pennsylvanian age approximately 300 miles long and 150 miles wide. The Colorado portion is about 120 miles long and 70 miles wide. It is an asymmetrical basin with the axis paralleling the Uncompahgre Uplift. Thicknesses of Pennsylvanian sediments within the basin range from 1,500 feet along the margins to 5,500 feet in the area south of the salt anticlines. In the salt-flow area, thicknesses up to 13,000 feet may be present. The thick sedimentary section adjacent to the Uncompahgre Uplift and the rapid thinning to the margins indicate periodic uplift of the highlands and depression of the basin along ancient hinge lines which advanced or retreated during various stages of the basin's development.

The simplest explanation which would apply for any one stage in the basin's growth is as follows: Consider a broad, relatively shallow sea, bounded on the northeast by the Uncompahgre Mountains and on the south, southwest and northwest by large islands (Zuni-Defiance, Grand Canyon and Emery respectively). This was essentially a closed system, within which evaporation, concentration and chemical precipitation of sediments was rapid. Seaways along the mountain front and between the islands replenished the water in the sea and prevented the basin from drying up. Deposition within the basin was cyclic and proceeded upward from a basal limestone or dolomite to anhydrite to salt. This sequence, depending upon local environment conditions, may be reversed or incomplete. There are also rapid lateral gradations from salt towards areas of less restricted conditions with anhydrite, then dolomite and limestone. Dense, black, organically rich shales, characteristic of the euxinic environment of deposition, and probably the source beds for Paradox oil and gas, are interbedded with the evaporites and restricted carbonates (Herman and Sharps, 1958, p. 79). Reasonable stratigraphic correlations can be made by using mechanical logs (principally gamma ray-neutron and sonic logs) but the sample log made from a careful study of the samples and cores is by far the best guide. In general, dense marine limestones were deposited along the margins of the basin, porous limestones and dolomites along the hinge lines (called reefs by some geologists) and anhydrite and salt in the center and deeper portions of the basin. Arkosic material was shed from the Uncompahgre Uplift and deposited along the mountain front.

Periodic rejuvenation of the Uncompahgre Uplift and subsequent basin adjustment resulted in a shift of the hinge lines as the sea transgressed or regressed over the area. The location of new hinge lines is therefore of the utmost importance in the search for new oil fields.

The structural configuration of the Paradox Basin was altered during the Triassic and again at the close of the Cretaceous. Former low areas which had been the site of Pennsylvanian anhydrite and salt deposition were elevated and the anhydrite frequently became the updip permeability barrier for oil entrapment. Thus to the normal complications involving an evaporite basin may be added later structural deformation which destroyed or masked Pennsylvanian structure. Structure maps used in conjunction with isopach and facies maps of specific zones are the principal exploration tools.

The present structural boundaries of the Paradox Basin are the Uncompahgre Uplift to the northeast and east, the San Juan Dome to the east, the San Juan Basin to the southeast, the Defiance Uplift to the south, and the San Rafael Swell to the northwest. The western limit lies between the Circle-Cliffs-Water Pocket fold and the Monument Upwarp.

Stratigraphy

Rocks ranging in age from pre-Cambrian to Recent (except for Ordovician and Silurian) are exposed within southwestern Colorado. As this report is concerned principally with the Paradox Basin of Colorado, discussion of the stratigraphic column will be limited to the pre-Cambrian and Paleozoic formations with the greatest emphasis on the Pennsylvanian sediments. Excepting for the eastern portion of the Mountain Ute Indian Reservation, most of the Colorado portion of the Paradox Basin contains a relatively thin, often exposed Cretaceous section which does not have the gas potential present in it in the San Juan Basin. The Jurassic and Triassic sections likewise appear to offer little oil or gas potential anywhere in this area. Because of these conditions, the Mesozoic formations are not discussed in this chapter. The reader is referred to page 661, Chapter XVIII, on which Mr. Enos J. Strawn describes the Mesozoic rocks of the San Juan Basin which, while not entirely applicable, is indicative. The reader is also referred to an excellent discussion of Mesozoic stratigraphy along the southwestern flank of the San Juan Mountains by Dr. Frank E. Kottlowski (see bibliography at the end of this chapter).

The general stratigraphic features of the Paleozoic formations are summarized in the following table.

Table of Paleozoic Formations of the Paradox Basin

System	Series	Group or Formation and Member	Character	Feet Thickness
Permian		Cutler	Red beds (sands, shales, arkose)	1500-7000
Pennsylvanian		Hermosa		
		Honaker Trail	Upper part clastics (sands, shale, arkose and thin bedded limestone); lower portion, cherty limestone.	1000-3500
		Paradox		
		Upper Member	Biostromal and biohermal limestone, penesaline and saline deposits of evaporitic carbonates, anhydrite, salt, and black euxinic shale.	Av. 300′ south of Dolores-Glade Anticline. Thins and grades into salt to north.
		Middle Member	Salt anhydrite, gypsum, black siltstone and euxinic black shale.	300-4000
		Lower Member	Lithologically similar to upper unit.	50-600
		Pinkerton Trail	Fossiliferous gray limestone, gray silty shales.	84-type section
		Molas	Residual deposit of red calcareous shales and sandstones with chert, limestone, and quartz pebbles; thin fossiliferous limestone lenses.	50-150
Mississippian	L. Mississippian	Leadville Limestone		
		Upper Limestone	Massive limestone, top badly weathered.	Generally less than 150′
		Lower Dolomite	Dolomite and limestone containing chert beds.	0-400
Devonian	U. Devonian	Ouray Limestone	Massive limestone.	0-50
		Elbert		
		Upper Member	Sucrosic dolomite, green waxy shale, floating frosted sand grains.	0-150
		McCracken Sandstone	Fine- to medium-grained sandstone, glauconitic.	0-150
		Aneth	Resinous limestone, dolomite, and shale.	Less than 100′
Cambrian	U. Cambrian	Ignacio (restricted)	Quartzitic sandstone.	0-200
Pre-Cambrian				

Pre-Pennsylvanian Stratigraphy of Southwestern Colorado

Cambrian, Devonian and Mississippian sediments lying unconformably on pre-Cambrian rocks comprise the pre-Pennsylvanian strata in southwestern Colorado. All except the Mississippian have type sections in the western portion of the San Juan Mountains. Ordovician and Silurian sediments are not recognized in this area due to lack of faunal evidence. Stratigraphic terminology was established by Cross, et. al., in U. S. Geological Survey folios 120, 131, 153 and 171 (Larsen and Cross, 1956) and except for modification by Barnes in 1954, Cooper in 1955 and Baars and Knight in 1957 is still in use.

Cambrian rocks are represented by the Ignacio quartzite of late Cambrian age. Devonian formations are all Upper Devonian in age and include, in ascending order, the Aneth formation, the Elbert formation which is divided into the lower McCracken sandstone and an upper member (Knight and Cooper, 1955, pp. 56-58) and the Ouray limestone. Mississippian sediments are represented by the Leadville formation which is divided into a lower dolomite and upper limestone (Baars and Knight, 1957, pp. 110, 121, 125). The Pennsylvanian Molas shale generally overlies the ancient karst topographic surface of the upper limestone member.

Pre-Cambrian Rocks

Pre-Cambrian rocks are exposed in the San Juan Mountains where they are divided into three types. The oldest, consisting of gneisses and schists, outcrop along the Animas River Canyon between Rockwood and Silverton and include highly metamorphosed amphibolite, granite gneiss and mica-quartz schist, all of which are mainly metamorphosed intrusive rocks (Larsen and Cross, 1956, p. 18).

A younger section consisting of quartzites, slates and conglomerates was named the Needle Mountains group for exposures in the Needle Mountain quadrangle (Cross, Howe, Irving and Emmons, 1905). This group is divided into the Vallecito conglomerate and the overlying Uncompahgre formation. The Vallecito conglomerate is exposed in Vallecito Canyon and along Pine River where it is at least 3,000 feet thick (Larsen and Cross, 1956). The Uncompahgre formation is at least 8,500 feet thick in the Grenadier Range and Uncompahgre Canyon. Because of the nature of the outcrop, complete thicknesses are unknown (Larsen and Cross, 1956).

A complex group of intrusive igneous rocks that intrude the other pre-Cambrian rocks constitute the third type of pre-Cambrian rocks (Larsen and Cross, 1956).

Excellent exposures of each of the three types of pre-Cambrian rocks can be seen in contact with Paleozoic sediments. The older gneisses and schists are overlain unconformably by the Ignacio quartzite at Coalbank Pass. At the head of Box Canyon near Ouray the nearby vertical Uncompahgre strata are overlain by the Devonian Elbert formation. "Good exposures of pre-Cambrian granites underlying Paleozoic sediments occur in only a few places such as along Mountain View Crest immediately south of Needle Creek, where the Ignacio quartzite overlies a 3-6 foot zone of deeply weathered granite which grades downward into the Eolus granite" (Baars and Knight, 1957, p. 113).

Cambrian Rocks

The Ignacio quartzite was named for exposures near Electra Lake (formerly called Ignacio Reservoir). It consists of a lower pink or reddish colored massive quartzite which is overlain by white quartzites, both of which have distinct bedding. Above this are friable sandstones with shale partings which are in turn overlain by massive quartzite layers (Cross, Howe and Ransome, 1905). Basal conglomerates are present at Coalbank Pass and along the railroad between Rockwood and Rockwood quarry. An Upper Cambrian age determination was based upon one single complete fossil (Cross, Howe and Ransome, 1905). It is possible that the Ignacio represents an eastward extension of a major transgression of Cambrian seas from the west (Lochman-Balk, 1956, p. 63).

A Devonian age for the Ignacio was suggested by Barnes because of the gradational contact with the overlying Elbert, the inconclusive faunal evidence and belief that the Ignacio was intruded by a granite porphyry of Devonian or younger age (Barnes, 1954, pp. 1780-91). Subsequent studies by Baars and Knight indicate that the Ignacio is both Devonian and Cambrian in age and contains previously unrecognized sandstones. This is based upon the section penetrated in the Gulf No. 1 Fulks well (Sec. 27, T. 37 N., R. 17 W.) in Colorado wherein the Devonian Aneth formation, which normally overlies the Ignacio, is absent, resulting in the Devonian McCracken quartzite resting directly on the Ignacio. The lithologies of both formations are very similar and both can be correlated into the outcrop section at Coalbank Pass (Baars and Knight, 1957, p. 117). Baars and Knight concluded that the Upper Ignacio should "be referred to the Upper Devonian McCracken sandstone member of the Elbert formation of Knight and Cooper and the lower sandstone, where present, be considered the Ignacio formation of late Cambrian age" (Baars and Knight, 1958, p. 97). Based upon this concept, the Ignacio is absent in the Pure No. 1 unit (Sec. 15, T. 15 S., R. 104 W.) in Colorado and at Ouray near the mouth of Canyon Creek and only 0-10 feet thick at Rockwood quarry (Sec. 12, T. 37 N., R. 9 W.). An isopachous map of the thus restricted Ignacio quartzite indicates an arcuate pattern of deposition to the east between the Uncompahgre Uplift to the north and the Zuni Uplift to the south. Within southwestern Colorado the Ignacio thickens to the west, being in excess of 200 feet at the Utah State line (Baars and Knight, 1958, fig. 11).

Devonian Rocks

Upper Devonian sediments in southwestern Colorado attain a thickness in excess of 400 feet and are typical of marine transgressions and regressions from the Cordilleran geosyncline eastward into Colorado. The shaley dolomites of the Aneth formation represent an early marine invasion which did not reach the San Juan Mountains. The overlying quartzites of the "Upper Ignacio" and Lower McCracken, which are unconformable with the Aneth formation, are indicative of littoral deposits (Knight and Cooper, 1955, p. 65). These are overlain by a transitional facies followed by a near shore sequence of thin interbedded shales, limestones, dolomites and quartzites of the Elbert formation (Larsen and Cross, 1956) or of the upper member of the Elbert formation (Knight and Cooper, 1955, pp. 56-58). Quiet water marine sediments are represented by the overlying Ouray limestone which grades transitionally into the Mississippian.

Aneth Formation

The type section for the Aneth formation is the 170 feet of dark colored, resinous limestone, dolomite and shale encountered in the Shell No. 1 Bluff well (Sec. 32, T. 39 S., R. 22 E.) in Utah. Age assignment is made on the basis of fish plates and fish scales which were identified as Upper Devonian (Knight and Cooper, 1955, p. 58).

The Aneth formation thins in all directions from its type locality in Utah. It is absent at Coalbank Pass, and in the Gulf No. 1 Fulks well where the McCracken rests on the Ignacio (Baars and Knight, 1957, p. 117) and is also missing in the Animas River Valley section. An unconformity is postulated at the top of the Aneth because of the abrupt lithologic change from the marine section comprising the Aneth, to the clean sandstones of the McCracken sandstone member of the Elbert (Knight and Cooper, 1955, p. 58). In southwestern Colorado the Aneth is less than 100 feet thick (Baars and Knight, 1957, fig. 6).

Elbert Formation

The name Elbert was applied by Cross to a 54-foot sequence of argillaceous limestone and calcareous shale overlying the Ignacio quartzite and underlying the Ouray limestone. This section is located just above Rockwood on Elbert Creek, a western tributary of the Animas River (Cross, 1904).

In 1955 it was redefined to include two members based upon core data from the Shell No. 1 Bluff well in Utah, referred to above. These members are the Lower McCracken sandstone and an upper member composed of interbedded sandstone and dolomite containing thin gray green shale partings (Knight and Cooper).

McCracken Sandstone Member of the Elbert Formation

The McCracken sandstone is essentially white, light gray to red, fine- to medium-grained, occasionally coarse, generally poorly sorted, commonly glauconitic and contains a few streaks of sandy dolomite. It rests unconformably on the Aneth where that formation is present and has a transitional contact with the upper member of the Elbert formation (Cooper, 1955, p. 63). As previously stated, where the Aneth formation is absent the McCracken rests directly upon the Ignacio. The maximum development of the McCracken is attained in southwestern Montezuma County near the Four Corners where it is more than 150 feet thick. From there it thins to the north and east and is absent in northern Montrose and southern Archuleta Counties (Baars and Knight, 1957, fig. 7).

Upper Member of the Elbert Formation

The upper member of the Elbert formation consists of thin bedded, dense to finely sucrosic dolomite, locally anhydritic with occasional floating, frosted sand grains. Thin, gray-green, waxy shales and sandy, red, clayey shales are associated with the dolomite. Thin sandstone beds in the lower portion of this unit are transitional with the underlying McCracken sandstone (Cooper, 1955, p. 63). This member ranges in thickness from 0-150 feet in southwestern Colorado.

Ouray Limestone

A. C. Spencer proposed the name Ouray limestone for a 100-300 foot section of massive limestone, containing Devonian fossils, underlying Mississippian strata near Ouray at the junction of Canyon Creek with the Uncompahgre River (Spencer, 1900, p. 125-129). This definition was later changed by W. S. Burbank who noted that the Ouray was chiefly Mississippian in age, the Devonian portion being 65-70 feet thick while the Mississippian varied in thickness from 180-235 feet (Burbank, 1930). Kirk restricted the name Ouray to the Devonian and called the Mississippian portion Leadville with the understanding that the name Ouray would not be used outside of southwestern Colorado (Kirk, 1931, p. 224).

Baars and Knight effected a positive correlation of the Ouray over the Four Corners area based upon faunal evidence in deep wells. This characteristic fauna is present in the Dyer member of the Chaffee formation of central Colorado; the lower Ouray formation of Arizona and the Percha shale of New Mexico. In southwestern Colorado the Ouray varies in thickness from 0 to 50 feet (Baars and Knight, 1957, p. 121, fig. 11).

Mississippian Rocks

In southwestern Colorado the name Leadville has been applied to the Mississippian carbonate rocks on the basis of faunal and lithologic similarity to the type Leadville section of Lower Mississippian age in the Crested Butte Quadrangle, Colorado. At this locality it is a 400 to 525 foot limestone section, the lower portion of which is slightly dolomitic, and contains chert beds separated by bands of calcareous shale (Emmons, Cross and Eldridge, 1894). In southwestern Colorado it is unconformable with the overlying Pennsylvanian and has a transitional contact with the Devonian Ouray limestone (Baars and Knight, p. 121).

The Leadville is tentatively divided into a lower dolomite and an upper limestone member. The lower dolomite, in southwestern Colorado, thickens to the northwest, from zero in eastern La Plata County to over 400 feet in southwestern Mesa County (Baars and Knight, 1957, p. 121, fig. 12).

The upper limestone member varies in thickness due to the effects of pre-Molas erosion. Regional uplift in Upper Mississippian time and sustained weathering produced a thick residual red soil on the badly weathered upper limestone beds. Molas debris filled the resulting karst topography (Johnson, 1945). In general, the upper limestone member is less than 150 feet thick in southwestern Colorado (Baars and Knight, 1957, fig. 13).

Pennsylvanian Rocks

Pennsylvanian nomenclature has been considerably altered and changed since 1899, when Spencer first applied the name Hermosa formation to the series of beds lying between the top of the Rico member of the Cutler formation and the top of the Ouray limestone, which Spencer considered to be Devonian in age. The type locality is somewhere in the vicinity of Hermosa Creek where the formation includes an 1,800 foot section. The upper portion contains shales and some limestone beds, the middle part includes bands of dark gray fossiliferous limestone which are interbedded with sandstones and conglomerates and the lower portion contains greenish gray sandstone and gray to black shales (Cross and Spencer, 1900, p. 48). No specific location was given for this section.

The name Molas formation was applied by Cross and Howe in 1905 to exposures at Molas Lake, south of Silverton, Colorado. This 75-foot section includes a sequence between the Hermosa formation and the Ouray limestone, which was not present in the area described by Spencer (Cross and Howe, 1905).

Roth measured and described a 2,146-foot section of Hermosa strata in Secs. 26 and 35, T. 37 N., R. 9 W., La Plata County, Colorado, and suggested that this be considered the type locality (Roth, 1934, p. 945). Studies by Baker, Dane and Reeside indicated that the black shale and anhydrite of the Hermosa formation at the type locality were correlative with the thick evaporite deposits called the Paradox formation in Paradox Valley, Colorado (Baker, Dane and Reeside, 1933, p. 963). In 1944 Bass re-examined the type section and correlated it with strata to the west by subsurface control. As a result of this study he reduced the Paradox formation to the status of a member of the Hermosa formation and proposed the names Upper and Lower Hermosa for the overlying and underlying strata (Bass, 1944, pp. 6-9).

Wengerd and Strickland proposed, as a result of stratigraphic studies of outcrop sections and well control, formational status for the Upper Hermosa and Paradox members and also suggested that the name Pinkerton Trail be substituted for the Lower Hermosa member and it also be raised to formational status (Wengerd and Strickland, 1954, p. 2166). In 1958, Wengerd and Matheny substituted the name Honaker Trail formation for the name Upper Hermosa. They proposed that the name Hermosa be reserved for group status to include the Honaker Trail, Paradox and Pinkerton Trail formations (Wengerd and Matheny, 1958, p. 2075).

In addition to the above changes it also became necessary to assign names to the various producing horizons within the Paradox formation. Thus in late 1958 the Four Corners Geological Society and the Intermountain Association of Petroleum Geologists, in cooperation with geologists working in the Four Corners area, proposed the following nomenclature which is now in general use.

- Pennsylvanian System
  - Hermosa Group
    - Honaker Trail Formation
    - Paradox Formation
      - *Ismay Zone
      - *Desert Creek Zone
      - *Akah Zone
      - *Barker Creek Zone
    - Pinkerton Trail Formation
  - Molas Formation

Molas Formation

At its type locality at Molas Lake this formation is 75 feet thick and consists of red, calcareous shales and sandstones with chert, limestone and quartz pebbles and thin fossiliferous limestone lenses. Mississippian fossils are found in the chert and limestone pebbles near the base of the unit and Pennsylvanian fossils occur in the thin fossiliferous limestone lenses (Cross, Howe, Irving and Emmons, 1905). It rests unconformably on the Leadville limestone (formerly called Ouray) and is considered to be early Pennsylvanian in age (Girty, 1903, p. 246).

The Molas formation is essentially a residual deposit which formed on the underlying Leadville and older rocks. Debris from this formation has been found as much as 100 feet into the underlying Leadville. In southwestern Colorado it ranges

*Denotes producing horizons.

from 50 to 150 feet in thickness and is correlative with the lower part of the Pennsylvanian Sandia formation in New Mexico. Fossils found in the upper part of the formation indicate a middle Atokan to early Desmoinesian age. Recent studies by Merrill and Winer indicate that the Molas formation can be divided into three recognizable members which they have designated as the Coalbank Hill, Middle Member and Upper Member. At the Molas type locality the Coalbank Hill member is missing, the Middle Member lies disconformably on the Leadville limestone while the Upper Member grades into the overlying Pinkerton Trail formation (Merrill and Winer, 1958, p. 2116).

Pinkerton Trail Formation

At the type locality approximately 12 miles north of Durango, Colorado, on the west side of U. S. Highway 50, the Pinkerton Trail formation is 84 feet thick and consists of gray siliceous limestone, dark gray silty shale, very dark gray clay shale and clayey limestone with abundant fossils which range in age from Atokan to earliest Desmoinesian. It is correlative with the Belden shale in northwest Colorado, the middle part of the Sandia in north-central New Mexico and is present in most deep wells drilled in the Four Corners area (Wengerd and Matheny, 1958, p. 2065).

This formation is important as it represents the last phase of Pennsylvanian deposition prior to the formation of the Paradox evaporite basin.

Paradox Formation

The Paradox formation which is of Cherokee (early Desmoinesian) age includes the entire evaporitic sequence from the base of the evaporitic carbonates overlying the Pinkerton Trail formation to the top of the Horn Point limestone.

Thickness of the Paradox formation increases from zero along the margins to about 5,000 feet in the deeper part of the basin. On the Paradox Valley anticline in the center of the basin (where there has been salt flowage) a section in excess of 12,000 feet was encountered in the Continental No. 1 Scorup-Summerville (Sec. 8, T. 47 N., R. 18 W.) in Montrose County, Colorado. Deposition within the basin followed a cyclic pattern of limestone or dolomite, anhydrite and salt. Depending on the location within the basin, this sequence could be incomplete or reversed. In addition to vertical transitions there are also lateral gradation with the result that within any one cycle normal marine limestones grade basinward into biostromal and biohermal limestones, then into evaporitic dolomites, anhydrite and salt. Black, euxinic shales are interbedded with the limestones, dolomites and evaporites.

The Paradox formation contains three separate members. The lower unit varies in character from arkose and siltstone overlain by gypsum along the Uncompahgre Uplift to interbedded black shale, siltstone, gypsum and dolomite in the central part and along the southwest margin of the Paradox Basin. Dark gray shales, gray porous dolomite, and gray cherty limestone are found still further southwest along the edge of the Paradox Basin (Wengerd and Matheny, 1958, pp. 2065-75). In southwestern Colorado this unit varies in thickness from 600 feet immediately north of Barker Dome to 50 feet at the north end of Glade Anticline. This member is divided into the Akah and Barker Creek producing zones. Production at Alkali Gulch in Colorado, Barker Dome in Colorado and New Mexico, North Dinne Mesa in Arizona and Akah and Boundary Butte in Utah is from these zones.

The middle unit is the salt member and contains interbedded salt, anhydrite, gypsum, black siltstones and euxinic black shales. It grades laterally towards the shelf into penesaline gypsum, anhydrite and dolomite. Recognition of this unit outside the limits of the Paradox salt basin is difficult due to the absence of reliable marker beds such as the distinct black, euxinic shales and anhydrites, which in these areas have become gray shales and normal marine limestones. In southwestern Colorado the middle member of the Paradox is about 300 feet thick near the New Mexico state line and increases northward to 4,000 feet on the Dolores-Glade Anticline (Wengerd and Matheny, 1958, fig. 16). At Paradox Valley, where it has been intruded upward into the overlying strata, it is about 12,000 feet thick. The top of this unit is generally picked at the top of the black shale overlying the salt. This point is also a good correlative marker on mechanical logs.

The upper unit is lithologically similar to the lower member and represents the last stages in the development of the Paradox evaporite basin prior to the deposition of the Honaker Trail formation. This unit grades basinward from biostromal-biohermal, dolomitic limestone and black shales into evaporites, evaporitic carbonate and black silty shales. The upper unit which is the main producing interval in the Paradox formation is divided into the Ismay and Desert Creek producing zones. Production in the Greater Aneth area is from these zones. In southwestern Colorado, south of the Dolores-Glade anticline, this unit averages about 300 feet in thickness. North of this area it is difficult to recognize as the lower portion grades laterally into salt. The top of this unit is generally picked at the first black shale in the section. This is also an easily identifiable point on mechanical logs.

Honaker Trail Formation

The type section of the Honaker Trail formation is located at Honaker Trail (Sec. 29, T. 41 S., R. 18 E.) in San Juan County, Utah, and includes the Pennsylvanian sediments overlying the black shales, evaporitic carbonates and evaporites of the Paradox formation (Wengerd and Matheny, 1958, p. 2075). At the type section of the Hermosa group in the Animas

Canyon, it is represented by the upper 600 feet of the section (Wengerd, 1957, p. 136). In southwestern Colorado it ranges in thickness from 1,000 feet at the Four Corners to 3,500 feet adjacent to the Uncompahgre-San Luis Uplift. Lithologically the formation normally consists of a lower cherty limestone section and an upper, chiefly clastic, interval containing sands, shales, arkose and thin-bedded limestone.

Near the Uncompahgre Uplift the entire formation is essentially arkosic, the source being the ancient highland to the northeast. The lower portion of this arkosic interval grades into cherty marine carbonates to the south, southwest and northwest. The upper arkosic section grades into sands, shales and thin bedded limestone towards the edges of the basin away from the uplift.

The base of the Honaker Trail is picked at the base of a cherty limestone section which at the type locality overlies the Horn Point limestone. The top of the formation is placed at the top of the first good marine limestone in the section, which at Honaker Trail is designated the Shafer limestone. As the Shafer limestone lies at the top of the Rico formation this correlation necessitates the elimination of the name Rico and the inclusion of these rocks in the upper part of the Honaker Trail.

The Honaker Trail ranges in age from late Cherokee in the southern portion to Virgillian in the northern portion of the Paradox Basin while the Rico ranges in age from Missourian to Wolfcampian. Wengerd and Strickland (1954, pp. 2174-75) believed the Rico to be transitional and considered it the basal member of the Cutler. Correlation by Turnbow (1955, p. 69) indicated the Rico to have a late Pennsylvanian age. Herman and Barkell (1957, p. 872) agreed with Turnbow and discarded the name Rico entirely.

The Honaker Trail formation correlates with parts of the Maroon and Minturn formations of Colorado, Lower Supai in Arizona and Madera, and the Pennsylvanian part of the Abo in north-central New Mexico.

Permian Rocks

Overlying and grading transitionally upward from the essentially marine sediments of the Honaker Trail formation are the predominately non-marine sediments of the Cutler formation. In southwestern Colorado, this formation consists of red to brown limy sandstone, micaceous siltstone, feldspathic sandstone, arkose, nodular shale and thin knarly fresh water limestone of fluviatile origin (Wengerd 1957, p. 136). The Cutler thickens from 1,500 feet near the Four Corners to more than 7,000 feet in the Pure No. 1 Gateway Unit (Sec. 15, T. 15 S., R. 104 W.) in Mesa County, Colorado. At the type locality near Ouray it is overlain unconformably by the Triassic Dolores formation (Cross and Howe, 1905). In southeast

Utah it is overlain by the Moenkopi (Baker and Reeside, 1929, pp. 1413-48).

The Cutler is of Wolfcampian age and is correlative with the Upper Maroon of central Colorado, Upper Weber sandstone of the Rangely area, the Lower Chupadera and Abo formations of north central New Mexico and the Toroweap, Coconino, Hermit and Upper Supai of the Grand Canyon region (Wengerd, 1957, p. 136).

Geologic History

During pre-Pennsylvanian time the Four Corners area was a relatively stable shelf situated east of the Cordilleran geosyncline and as such did not receive the thickness of sediments present in central Utah.

In southwestern Colorado the oldest Paleozoic rocks are represented by the Ignacio quartzite (restricted) of Upper Cambrian age. These sands mark the easternmost extent of a transgressing sea from the west and are correlated with the Tapeats sandstone in southern Utah and Arizona.

Ordovician and Silurian seas either did not penetrate into this area or deposits of this age were eroded as a result of pre-Devonian epirogenic uplift. In any event, these sediments are absent and the area was apparently a low lying land mass until Upper Devonian time.

Upper Devonian time was a period of transgressing and regressing seas from the Cordilleran geosyncline to the west. The Aneth formation probably represents the first marine invasion. This invasion did not reach the San Juan Mountains. The unconformity at the top of the Aneth indicates a retreat of the seas prior to a second transgression which deposited the littoral sediments comprising the McCracken sandstone. The transition from near shore to quiet water marine deposition is evidenced by the upper member of the Elbert formation and the overlying Ouray limestone.

Deposition of limestone continued through early Mississippian time as indicated by the Leadville limestone, which has a transitional contact with the underlying Ouray. During late Mississippian time regional uplift resulted in a karst topography developing on the Leadville surface and the formation of thick residual deposits which comprise the lower portion of the Molas formation.

Marine invasion during late Molas time resulted in the deposition of the upper part of the Molas formation and the overlying Pinkerton Trail formation.

Subsidence of the Paradox geosyncline and emergence of the Uncompahgre highland began after deposition of the Pinkerton Trail limestone. The Paradox geosyncline appears to have been connected with the Oquirrh basin in central

Utah to the northwest and the Sonoran geosyncline to the southeast. Clastics shed from the highlands to the northeast interfingered with the evaporites of the Paradox formation. A thick wedge of arkose was deposited along the mountain front. Transgressions and regressions of the Paradox seas resulted in the deposition of clean limestones and dolomites along the margins of the basin while evaporites in the form of anhydrite and salt were deposited in the deeper portion.

During middle and late Pennsylvanian time the seas began to withdraw to the northwest into the Oquirrh basin and southeast into the Sonoran geosyncline. This is evidenced by the lower carbonate and upper clastic sections of the Honaker trail formation.

The overlying Cutler formation, which is a continental deposit, indicates a complete withdrawal of the seas in the Four Corners area during most of Permian time. The sources for these sediments were the Uncompahgre Highland in Colorado and the Naciemento and Zuni-Defiance Uplifts in New Mexico. Towards the end of the Permian marine seas again advanced on the Four Corners area from the west, southwest and southeast. However, this area remained above sea level and continued to receive clastics from the highlands to the southeast and northeast.

The Uncompahgre Uplift was slightly rejuvenated and continued to shed arkose during early Triassic time as evidenced by the character of the Moenkopi formation. However, by late Triassic time only siltstone was being deposited as indicated by the Chinle formation.

During Jurassic time the seas began encroaching on the Uncompahgre Uplift until it was completely covered by the Morrison formation. Succeeding Cretaceous sediments do not reflect the presence of this old highland. Towards the close of the Cretaceous the Uncompahgre was again rejuvenated and began to be eroded.

The intrusion of the Paradox salt into the overlying formation, which had begun in either late Permian or mid-Triassic time and continued into the Jurassic had virtually ceased by early Morrison time although there is some evidence of slight growth of the Gypsum Valley and Dolores salt cores in Dakota time. Towards the end of the Cretaceous broad anticlines were formed over these structures. The subsequent solution and collapse of the crestal areas began during the period of Laramide deformation and has continued until the present.

Igneous activity, which may have begun in late Cretaceous time and was repeated during the Tertiary, resulted in the intrusions and extrusions which form the San Juan, La Plata, Rico and Ute Domes.

Structure

The major tectonic elements of the Paradox Basin in southwestern Colorado as described by Kelley are the Uncompahgre Uplift to the north, the Paradox Fold and Fault Belt in the center and the Four Corners Platform on the south. Adjoining these features to the east is the San Juan Dome (Kelley, 1955, p. 23, fig. 5). These tectonic elements (see Plate 6 in pocket) are described as follows:

Uncompahgre Uplift

The Uncompahgre Uplift which forms the northeast limit of the Paradox Basin is expressed on the surface as a northwest-southeast trending structurally high area bounded on the steep southwest flank by a series of curved, unconnected faults which are located high on the uplift (Kelley, 1955, p. 47). Near Gateway, Colorado, Cutler sediments may be seen in sedimentary contact with the pre-Cambrian.

Paradox Fold and Fault Belt

This tectonic unit parallels the Uncompahgre and includes the northwesterly trending salt anticlines and faults. The southeastern boundary is the San Juan Dome and the southern limit is the Four Corners Platform.

The salt anticlines have an en echelon pattern. The northernmost structures are set to the northwest while those to the south extend to the southeast. These structures were all formed by the upward flowage of Paradox salt. Subsequent erosion of the Paradox beds and collapse of the anticlinal crests has resulted in what might be called "horst grabens." Intrusive Paradox beds within the graben are frequently in contact with Upper Cretaceous sediments which were also downfaulted as much as 3,000 feet with respect to the graben rims (Kelley, 1958, p. 31).

Intrusion of the Paradox salt began in either late Permian or mid-Triassic time, continued into the Jurassic and perhaps locally into the Cretaceous. This is evidenced by "stratigraphic thinning and pinchout of formations ranging from Chinle (Upper Triassic) to Morrison (Upper Jurassic) across the axial part of the salt structures." Ultimately broad anticlines were formed over these structures in Cretaceous time (Shoemaker, et al., 1958, pp. 39-59). Subsequent solution and collapse of the crestal areas began during the period of Laramide deformation and has continued until the present. Kelley has suggested that on the basis of gravity studies, down-folding as well as upward flowage may have occurred. This would result in some of the salt structures being synclines at depth.

The prominent salt anticlines of Colorado are long, relatively narrow, features with crestal graben areas and sharply upturned beds on the flanks. From north to south these include the Sinbad, Paradox Valley, Gypsum Valley and Dolores anticlines. With the exception of the Dolores structure, Paradox beds are exposed on the surface within the crestal area. At the present time these structures have all been tested into the Paradox salt by one or more wells. The entire Pennsylvanian section has been penetrated on Paradox Valley, Gypsum Valley and Dolores. No production or encouraging oil shows were encountered.

Four Corners Platform

This northeasterly trending tectonic feature is situated behind the Hogback monocline which delineates the northwestern limit of the San Juan Basin. It connects with the San Juan Dome to the northeast and the Blanding Basin to the west. The Four Corners Platform is therefore essentially a structurally high, relatively stable area bounded by the San Juan Basin to the southeast, the Blanding Basin to the west and the mobile Paradox Fold and Fault Belt to the north.

Within the Four Corners Platform there are a number of anticlines, the most important of which is Barker Dome, located athwart the Colorado-New Mexico line with the main part of the structure in New Mexico. This is a large northeastward trending structure approximately seven miles long and four miles wide with about 375 feet of surface closure. Gas-distillate with a high sulfur content is produced from this anticline.

Except for Barker Dome, Pennsylvanian Paradox oil production in southwestern Colorado is only indirectly related to structural development. Stratigraphic controls in the form of updip facies changes from porous limestone and dolomite to impermeable limestone and anhydrite are the primary factors in determining areas of oil accumulation. Seismic mapping and detailed subsurface mapping of the producing horizons is used in conjunction with stratigraphic studies to isolate specific prospects.

San Juan Dome

The San Juan Dome may be a multiple igneous dome whose origin is due to igneous uplift rather than to compression (Kelley, 1955, p. 28). Igneous activity probably began in late Cretaceous time and was repeated during Tertiary time. Dikes are numerous, and plugs, stocks, associated laccoliths and sills of diverse ages and types also occur. Monzonite porphyry stocks and laccolithic types of Laramide age occur at Ouray. It is probable that many of the intrusives in the La Plata and Rico domes are of the same age. Other central-type intrusives in the form of stocks or plugs found in the San Juan Mountains range from rhyolite or granite porphyry to andesite or diorite. These are more numerous in the western part where some of them may be early Miocene, or younger. The eastern intrusives are late Miocene or Pliocene in age (Kelley, 1955, p. 55).

The accompanying structure map (in pocket) contoured on top of the Dakota formation shows the regional relationship of the tectonic features discussed above. Igneous uplifts such as the Ute Mountains, La Plata Mountains and the San Juan Dome are large domal areas around which are subsidiary small folds.

One of the subsidiary folds is McElmo Dome located on the north flank of the Ute Mountains. It is a surface and subsurface structure covering an area of about two townships. Approximately 300 feet of closure is present on the surface but this decreases below the Paradox salt section. Minor structural complications in the form of east-west faults are present on the west side of the crestal area. Another group of minor normal and reverse faults trending northeast-southwest are present to the south and southeast. A dike fault on the south has the same general trend. At the present time eight wells have been drilled on McElmo Dome. Three of these were flank tests located on the northeast, east and south flanks. Flammable gas has been produced from one well from the Triassic Shinarump sandstone and carbon dioxide is produced from the Mississippian Leadville formation (Zabel, 1955, pp. 132-136).

Producing Zones

At the present time there are four principal reservoirs within the Pennsylvanian Paradox formation. These are, in descending order, the Ismay, Desert Creek, Akah and Barker Creek zones. Each is situated within a separate depositional cycle of the Paradox formation. With the exception of the Barker Creek zone which produces at Barker Dome, accumulation is controlled essentially by stratigraphy and only localized by structural development.

Ismay Zone

Within the Colorado portion of the Paradox Basin all commercial Pennsylvanian production, except for Barker Dome and Alkali Gulch, is from the Ismay zone. This zone, which is at the top of the Paradox formation, is best developed in the extreme southwestern portion of Montezuma County near the Four Corners. It thins and grades to the northeast into a nonporous anhydritic limestone and thence into massive anhydrite. Isopachs of the Ismay limestone show it to have a general northwest trend, ranging from about 160 feet at the Four Corners to 30 feet about five miles to the northeast where it grades into the updip anhydrite permeability barrier. This barrier is very irregular, indicating a delicate balance must have existed between environment conditions favorable for limestone and anhydrite deposition. It is possible that the deposition of limestone in the form of bars or reefs sealed off local bodies of water basinward which became highly saline, resulting in the concentration and deposition of anhydrite. This would help to explain the irregular shape indicated by isopachs of the Ismay anhydrite. These isopachs indicate a narrow band of anhydrite deposition which attains a maximum thickness of about 115 feet paralleling the Ismay limestone trend.

To the north of the anhydrite, relatively clean limestone is again encountered which varies in thickness from 50 to 100 feet. At the present time this area is non-productive, but as additional stratigraphic control becomes available it will perhaps become important for exploration.

Desert Creek Zone

The Desert Creek zone, which is the most important reservoir in the Paradox Basin to date, is not well developed in southwestern Colorado. Isopachs of this zone show thicknesses varying from about 50 to 130 feet in this portion of the Paradox Basin with most of the section consisting of anhydrite and shale. In the northern portion of the area the carbonates in the Desert Creek zone are replaced by salt. Marginal gas-distillate production was obtained from this zone in the Dove Creek field located in the northwestern portion of Montezuma County.

Akah Zone

At the present time there is no production in Colorado from the Akah zone. This zone is best developed outside the margins of the salt basin and occupies a stratigraphic position immediately below the Desert Creek zone. Thus the only area offering any potential from this zone is located within the two southern tiers of townships between Barker Dome and the Four Corners.

Barker Creek Zone

This is essentially a limestone-dolomite zone and derives its name from the producing section in the Barker Dome gas field where it occupies a stratigraphic position immediately overlying the Pinkerton Trail formation. It is about 400 feet thick in the Alkali Gulch area north of Barker Dome and thins, becoming evaporitic northward into the basin and is absent at the Dolores-Glade anticline. Similarly to the Akah zone, it is best developed along the margins of the Paradox Basin.

Typical Oil Pools

Ismay Zone

The Lion Oil Company's discovery of Flodine Park on April 4, 1959 (Sec. 15, T. 35 N., R. 20 W.) in Montezuma County, Colorado, which was completed for an IP of 400 BOPD (45°)

on a 25/64" choke now appears to be a southeastward extension of the Ismay pool two miles to the west in San Juan County, Utah. As field development will undoubtedly bridge this gap, a discussion of the Ismay field is pertinent.

The Ismay field was discovered in October, 1956, by the Texas Company. The discovery well (No. 1 J) located in Sec. 20, T. 40 S., R. 26 E., San Juan County, Utah, was completed in a 40-foot limestone section in the basal portion of the Ismay zone for a flowing gauge of 1,410 BOPD (43°). Within the field the pay section varies in thickness from 9 to 62 feet and contains pinpoint and vugular porosity averaging 6 to 9 percent. Accumulation is essentially controlled by stratigraphy along a small westward plunging structural nose. Isopachs of the Ismay limestone indicate a local limestone development along this nose. The field is bordered on the north by an updip anhydrite permeability barrier which replaces the porosity in the Ismay limestone.

Subsequent field development encountered production in a 10 to 36-foot limestone section in the upper portion of the Ismay limestone. The Lion Oil Company discovery in Colorado was completed in this portion of the Ismay zone. Production in the Lion well is from a 43-foot limestone-dolomite interval with an average porosity of 8.5 percent and average permeability of 5 md. Formation pressure is 2,150-2,200 psi.

At the present time 14 wells have been completed in the Ismay field. Total production since its discovery in 1956 to May 1, 1959, is 156,016 barrels of oil, 175 million cubic feet of gas and 24,836 barrels of water. Recoverable reserves are estimated to be approximately seven and one-half million barrels of oil.

Desert Creek Zone

The Byrd Frost-West National Gas No. 1 Driscoll located in Sec. 3, T. 38 N., R. 19 W., Montezuma County, Colorado, the discovery well of the Dove Creek gas-distillate field, was completed from a 25-foot limestone interval for a flowing gauge of 254 BOPD (48°) plus 1.7 million cubic feet of gas per day. Accumulation is stratigraphic, being dependent upon a local limestone development on the west plunging Dove Creek structural nose. Two additional wells have since been completed but the field is capable of only marginal production. In the Reynolds No. 1 Federal the porosity averages 11 percent, permeability 63 md. and the pay thickness is 8 feet. Average porosity in the three wells comprising this field is about 10 percent, permeabilities range from 20-110 md. and the average thickness of the producing interval is 14 feet.

At the present time the Driscoll well is shut in. Cumulative production from the field to May 1, 1959, is about 55,280 barrels of oil and 490 million cubic feet of gas.

Barker Dome

Barker Dome has a long production history which commenced in 1925 with the discovery of natural gas in the Dakota formation. The discovery well was drilled by the Gypsy Oil Company (now Gulf Oil Corporation) in Sec. 16, T. 32 N., R. 14 W., San Juan County, New Mexico. The well reached a total depth of 3,365 feet in the Dakota sandstone and reportedly was capable of producing 30 million cubic feet of gas per day. No development followed due to lack of pipeline facilities. The well was abandoned and the leases reverted back to the Ute Indians. Southern Union Gas Company leased acreage on Barker Dome in 1930 but did not drill any wells and eventually turned the acreage back to the Ute Indians (Bates, 1942, p. 92).

In 1941 Southern Union again obtained leases on Barker Dome and immediately began development of the gas field. The Southern Union No. 1 Barker (Sec. 21, T. 32 N., R. 14 W., San Juan County, New Mexico) was completed in January, 1942, at a total depth of 2,495 feet in the Dakota formation for an initial open flow gauge of 7.6 million cubic feet with a rock pressure of 557 psi (Barnes, 1952, p. 119). The Dakota gas is now depleted, having produced about 16 billion cubic feet to January 1, 1959, from 14 wells, all located in New Mexico.

Pennsylvanian gas production from the Lower Paradox member of the Hermosa group was established in 1945 by the Aztec Oil and Gas Company. The discovery well, the Barker No. 9 located in Sec. 21, T. 32 N., R. 14 W., was completed at a total depth of 9,466 feet for an initial open flow gauge of 42 million cubic feet of gas per day with a rock pressure of 2,975 psi. Subsequent development of the field was conducted by El Paso Natural Gas Company. As the gas is sour, it is passed through a scrubbing plant before entering the El Paso Natural Gas transmission line. At the present time the Dakota formation is used for reservoir storage of processed Paradox gas. Cumulative production to May 1, 1959, from 13 wells (four of which are in Colorado) amounted to approximately 176 billion cubic feet of gas and 77,000 barrels of distillate.

Gas production is essentially from three limestone sections and a fourth section which is not present in all wells. Porosity varies from 1.5 to 3.5 percent and in the various sections and permeability ranges from 0.1 to 30 md. Porosity is both primary and secondary with secondary voids being the most important. Solution openings such as vugs and stylolites combined with joints and fractures comprise the best producing intervals. This suggests that the reservoirs on Barker Dome are essentially fracture reservoirs (Barnes, 1952, p. 119).

The Barker Dome gas field is a structural accumulation located along the southeastern margin of the Paradox Basin.

Conclusions

At the present time (1959) 114 Pennsylvanian or deeper tests have been drilled within the Colorado portion of the Paradox Basin. These offer some evaluation of the oil and gas potential.

Based upon present stratigraphic and structural knowledge of the Paradox fold and fault belt and the results of the 31 wells drilled to date in this area, the potential for Paradox production is poor. Mississippian and Devonian formations appear to offer more encouragement but drilling depths of 10,000 feet or more will probably retard much exploratory drilling in the near future.

The Four Corners Platform is a more favorable area. Gas production has been found at Barker Dome and Alkali Gulch, gas-distillate at Dove Creek and oil production at Flodine Park, Towaoc and Marble Wash, all from Paradox zones. These areas will continue to stimulate exploration in the rest of the Four Corners Platform. Mississippian and Devonian sediments are not so deeply buried in the western portion of this area and can be tested at reasonable costs. These, perhaps more than the Paradox formation, offer the greatest potential for oil and gas production. Encouraging shows of oil and gas have been encountered in Mississippian and Devonian rocks in Utah, Arizona and New Mexico. Discovery of commercial oil and gas production from these formations in any portion of the Four Corners Area will result in renewed exploratory drilling in southwestern Colorado.

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Chapter XVIII

The San Juan Basin of Colorado

by

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by

ENOS J. STRAWN*

In the San Juan Basin of southwestern Colorado there exists a sedimentary section which exceeds 14,000 feet in thickness. Several important petroleum pay horizons have been discovered within the Cretaceous portion of this thick section, and from stratigraphic evidence and oil and gas shows in wells drilled for petroleum, there will be other pays discovered as drilling progresses.

The problem of delineating the confines of the San Juan Basin is difficult and controversial. For the purpose of convenience, the author uses the base of the Pictured Cliffs hogback as the maximum northern extent of the basin as far east as the junction of the outcrop of the Pictured Cliffs formation with U. S. Highway 160. Here, the limit of the basin is difficult to define due to the rapid change in dip, but the author has arbitrarily chosen an imaginary line of demarcation which follows approximately eastward along U. S. Highway 160 to the Archuleta anticlinorium. The Archuleta anticlinorium separates the San Juan Basin from the Chama Basin (Kelly, 1955, p. 112). An accompanying index map (Fig. 15, p. 628, and Plate 6 in the pocket) illustrates the geographic relationship of the Paradox Basin to the San Juan Basin. The Paradox Basin was a basin of deposition in Paradox time (lower and middle Pennsylvanian) while the San Juan Basin, for the most part, is considered to be a structural basin.

Although oil and gas had been noted by early settlers in seeps, in water wells, and in early wells drilled for petroleum, it was not until 1950 that substantial quantities of hydrocarbon gas was discovered by Pan American Petroleum Corporation (Stanolind) on Ignacio anticline from the shallow Fruitland formation. Only one basement test has been drilled in this area, the Pan American No. B-6 Ute (Sec. 17, T. 33 N., R. 7 W.) which was spudded in on December 15, 1955, and bottomed in pre-Cambrian granite at a depth of 13,127 feet. The test was drilled near the crest of Ignacio anticline, a surface, subsurface and seismic structure, which has a surface closure of approximately 200 feet (Ferebee, 1955, p. 174). The Animas (?) formation of Paleocene age crops out on the surface in the area of the Ignacio anticline (Barnes, 1953, map). Elevation of the Pan American, No. B-6 Ute, is 6,510 feet (derrick floor). Formation tops are as follows:

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	Gas Shows (S.G.) and Production in Basin ⊙	Depth in Feet	Thickness in Feet
Upper Cretaceous			
Kirtland	S.G.	2115	
Fruitland	⊙	2270	274
Pictured Cliffs	⊙	2544	152
Lewis	S.G.	2696	1824
Mesaverde	⊙	4520	662
Mancos		5182	2213
Dakota	⊙	7395	206
Jurassic			
Morrison	⊙	7601	753
Todilto		8354	31
Entrada	S.G. (?)	8385	278
Triassic			
Chinle		8663	477
Shinarump (?)		9140	60
Moenkopi		9200	40
Permian			
Cutler		9240	1568
Rico (?)		10808	135
Pennsylvanian			
Honaker Trail	S.G.	10943	1250
Paradox	S.G.	12193	710
Molas	S.G.	12903	81
Devonian			
Elbert (?)		12984	30
Cambrian			
Ignacio(?)		13014	33
Pre-Cambrian			
Granite		13047	

Deeper gas zones have been discovered in the area since the initial discovery of significant quantities of gas in the Fruitland formation. Current drilling, for example, reflects the importance of the Mesaverde and Dakota as important gas reservoir beds. To date, no large oil discoveries have been found in the San Juan Basin in southwestern Colorado. This is easily explained when it is realized that only a very small portion of the area has been adequately tested by the drill. The stratigraphic column present in this area contains each of the geologic requisites necessary for the accumulation of oil.

It is very interesting to note the importance of the stratigraphic development of Cretaceous gas pays in the area. Initially, wells were drilled on structure such as at Ignacio anticline (T. 33 N., Rs. 7, 8 W.) and Bondad anticline (T. 33 N., R. 9 W.). Later, it was discovered that low flank wells and wells drilled on regional dip were equally good, and in some cases better, than wells located on structure. Thus, stratigraphic development is an important factor in hydrocarbon accumulation in this area. Coincident with the factor of accumulation in stratigraphic traps is the occurrence of both connate and meteoric waters. Each of these types of water has caused considerable trouble in the drilling of wells, especially when drilling with gas. In the event that too much water is encountered while drilling with gas, the bit balls up with mud in the hole and the operator is forced to "mud up" before drilling ahead.

Surface indications of oil and gas are not common in the area. This may be due in large part to the thick cover of continental Tertiary sediments that blanket all of the area except the upturned edges of Cretaceous rocks which form the basin's limits along the hogback. Gas in particular has been noted to be escaping from Cretaceous sands and coals along the upturned edges of the hogback.

Geomorphology and General Geology

The San Juan Basin in southwestern Colorado is located within the Navajo section of the Colorado Plateau province (Fenneman, 1951, map). The general physiography of the area is best described as canyon and mesa type topography, ranging in elevation from approximately 5,500 to 8,000 feet. Two major rivers incise the area. These are the San Juan and the Animas, which are in turn fed by many streams draining the San Juan mountains from the north. The city of Durango is located just outside the basin's structural limits, but is the largest centrally located city, supplying the needs of the northern part of the basin.

Tertiary and Cretaceous rocks form the surface cover except for a few minor instances where Tertiary flows or intrusive igneous rocks appear. These occur in the southeastern portion of the area, in Archuleta County (Wood, et al., 1948, map). Beneath the surface cover, sediments range in age from Quaternary through the Cambrian (Rhodes and Fisher, 1957, p. 2508).

The total sedimentary section represented in the basin can be observed cropping out along hogbacks flanking the mountain areas to the north. The Animas River section is especially spectacular to the north of the city of Durango, and is aptly illustrated and discussed by Kilgore (1955).

Surface-mapping methods in the area have delineated numerous anticlinal structures, both closed and open types. Published maps of the U. S. Geological Survey reveal the locations of most of the important structural features of the area as they were mapped by: Wood, et al. (1948); Zapp (1949); Barnes (1953 and Barnes, et al. (1954). Prior to government mapping, many petroleum companies mapped the entire area both by reconnaissance and detail methods.

Subsurface investigations have proven helpful in locating prospective areas, but to date the most successful method for locating production in the basin has been through the drilling of random wildcat wells.

Stratigraphy

The approximately 14,000 feet of sediments underlying the surface profile of the San Juan Basin of southwestern Colorado are composed of both continental and marine strata representing nearly all geologic ages (see Fig. 16). Several hiatuses, both major and minor, are noted in the geologic column.

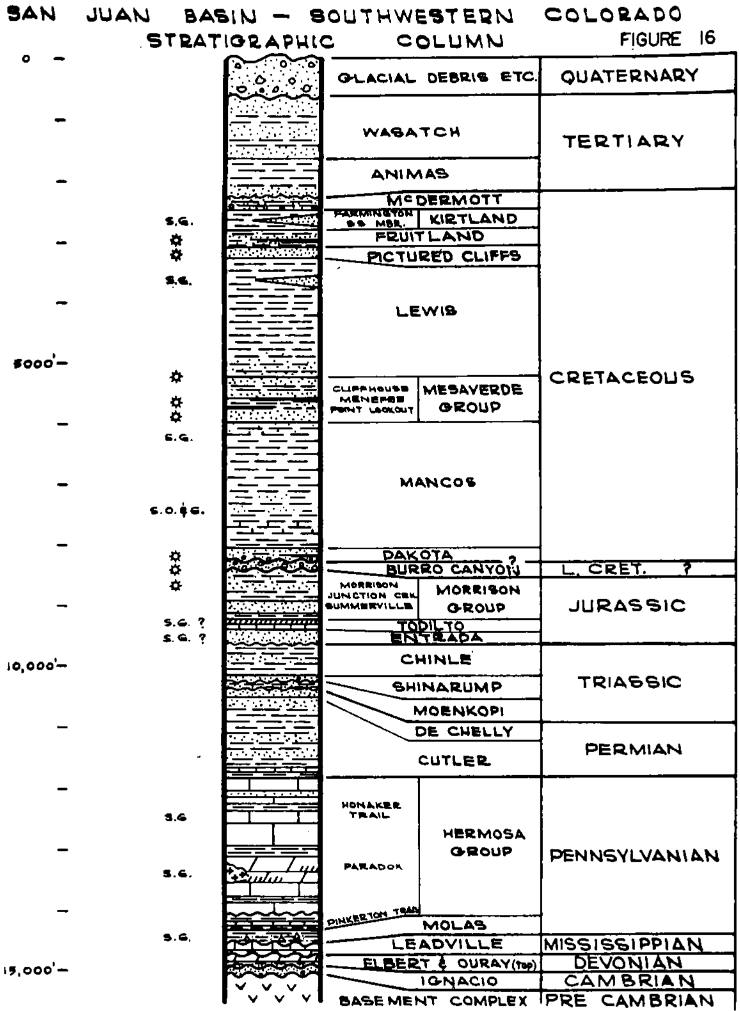

FIGURE 16

Cambrian System

Ignacio Quartzite

The Ignacio quartzite was named from exposures which overlie granite near Electra Lake. These exposures vary in thickness but at Baker's bridge this unit is about 75 feet thick. Baars and Knight (1957) discuss conflicts in age and terminology of the Ignacio and point out some of the difficulties in correlations connected with this erratic unit. Dead oil has been noted in the Ignacio quartzite in well cuttings and in some wells it contains irregular porosity.

Devonian System

Upper Devonian strata are representative of a typical transgressive phase encroaching into Colorado from the west-lying Cordilleran geosyncline. The Aneth formation, composed generally of limestone, dolomite and shale, may be present in the western part of the basin, but is not present in Animas Canyon either because of non-deposition or of erosion. This unit has shown promise in some deep wells of the Four Corners area, and because of its thinning into the basin from the west, may contain stratigraphic changes conducive to oil or gas accumulation.

Elbert Formation

This unit comprises two members: the underlying McCracken sandstone and the upper member which is composed of light-colored dolomite with thin seams of green and purple shale at the top. Baars and Knight (1957, p. 119) indicate that the undifferentiated Elbert reaches thicknesses up to 200 feet in the western part of the basin. Although shows of oil and gas have been noted in both members elsewhere, the McCracken sandstone is believed to be the most promising prospective horizon.

Ouray Limestone

The Ouray limestone thins eastward in the basin with the zero isopach lines approximately on the La Plata-Archuleta County line. As much as 25 to 30 feet may be present in the basin (Baars and Knight, 1957, p. 122). Like the Aneth formation, the Ouray has possibilities for petroleum and natural gas in the basin due to its eastward thinning.

Mississippian System

Leadville Limestone

Karst topography characterizes the upper surface of the Leadville, often spectacularly illustrating the unconformity between this unit and the overlying Molas shale of Lower Pennsylvanian age. It is usually a light gray, coarsely crystalline, fossiliferous limestone, grading downward in most instances to dolomite and ranges in thickness from 0 to 150 feet or more in the area. Good porosity is locally developed in the middle and lower Leadville where oil, gas (usually nonflammable) and water are present. CO_2 gas, helium and oil have been produced west and southwest of the area of study. The Leadville is considered to be a prospective horizon, particularly when drilled on a closed structure, from which erosion did not remove it during growth of the structure. Leadville truncation possibly occurred on Ignacio anticline since the Pan American No. B-6 Ute, a basement test in Section 17, T. 33 N., R. 7 W., did not encounter Mississippian Leadville but drilled from Pennsylvanian Molas into Devonian rocks. Where Mississippian is missing on structure, the possibilities of structure-stratigraphic traps may be present on the flanks.

Pennsylvanian System

Mallory (1958) aptly illustrates and explains the positive mass north and east of Durango, Colorado, named Uncompahgria. This continental area supplied clastics into the northern San Juan Basin, probably throughout Pennsylvanian time. The results of the intermingling of marine and continental sediments in Desmoinesian rocks may eventually be found to be very significant from the standpoint of the occurrence of hydrocarbons in the San Juan Basin of southwestern Colorado.

Molas Formation

The basal Pennsylvanian Molas formation which ranges from 40 to 120 feet in thickness, is composed generally of shales, siltstones and thin carbonates, and represents a pause in marine carbonate sedimentation between the Mississippian and Pennsylvanian systems.

The Hermosa Group

This group comprises the Pinkerton Trail formation at its base, the Paradox formation, and the Honaker Trail formation at its top (Wengerd and Matheny, 1958, p. 2075).

Pinkerton Trail Formation

Shelf limestone with interbedded shales comprise typical Pinkerton Trail strata deposited prior to the strong subsidence of the Paradox autogeosyncline (Wengerd and Matheny, 1958, p. 2085). Their isopach map (1958, p. 2087) indicates that the Pinkerton Trail may exceed 200 feet in the basin near the New Mexico state line. Hydrocarbon prospects from these strata have to date been considered to be negligible, principally because of facies changes occurring in the eastern part of the basin, as indicated on the aforementioned map.

Paradox Formation

In the San Juan Basin of southwestern Colorado, the Paradox is considered to be the most prospective formation for petroleum and natural gas below the Cretaceous. Wengerd and Matheny (1958, p. 2088) have pointed out the probable extension of Paradox sediments into the San Juan Basin indicating the overlap of the two basins. This is borne out in part by the discovery of minor amounts of anhydrite in samples in the Pan American No. B-6 Ute (Section 17, T. 33 N., R. 7 W.). When one considers the valuable petroleum deposits discovered in southeastern Utah producing from traps related to the development of carbonate barriers and reefs, one ponders the potential of the northern part of the San Juan Basin where similar stratigraphic conditions may exist. Scruton (1953) has made it easier to understand more thoroughly the evaporite deposits by explaining and illustrating the mechanics and physiography of evaporite areas through study of modern restricted marine estuaries. He has reached certain important conclusions concerning the deposition of evaporites from the standpoint of static versus dynamic processes.

Paradox sediments range through a heterogeneous assortment of marine strata including limestones, dolomites, anhydrites, salts, shales, sandstones, etc. Black euxinic Paradox shales are source beds as well as the carbonates themselves. Thickness of the Paradox in the San Juan Basin of southwestern Colorado ranges from approximately 500 to 1,700 feet.

Honaker Trail Formation

Deposited in marine seas ranging from late Desmoines through Virgil, the Honaker Trail comprises gray to reddish gray, fine to coarse crystalline limestone with chert and interbedded shales, siltstones and sandstones (Wengerd and Matheny, 1958, p. 2075). A rapid facies change occurs the narrow extension of the San Juan Basin in southwestern Colorado. This change is apparent as the San Juan mountains are approached, when thin sandstones become thicker arkoses due to the proximity of the San Luis-Uncompahgre positive area—an extremely active element in post-Cherokee time. Recent shows from the Honaker Trail, outside the western edge of the basin at Alkali Gulch, make this horizon another prospect when deep wells are to be drilled in the basin. The Honaker Trail ranges from 300 to 1,200 feet from east to west (Wengerd and Matheny, 1958, p. 2093).

Permian System

Cutler Formation

After withdrawal of the Pennsylvanian sea (Rico sediments represent the transitional phase), great thicknesses of continental red beds resulting from tectonic uplift of the numerous positive elements comprising the Ancestral Rockies, were deposited. The Cutler, approximately 2,000 feet thick, is one of these redbed formations. It consists mostly of sandstone and shale with relatively thin limestones usually near the base. Minor shows have been noted in wells in northwestern New Mexico, but production in the Cutler, if established, would be an oddity.

DE CHELLY FORMATION

Present only in the western edge of the basin, where it is but a few tens of feet thick, the De Chelly is composed of buff to light red quartz sand and is usually water bearing. At Boundary Butte anticline near the four corners, the De Chelly carries oil.

Triassic System

Moenkopi Formation

The Moenkopi red beds thin from west to east in the area of interest and may be as much as 40 feet thick in the Pan American No. B-6 Ute. The writer is unaware of any significant shows in this formation.

Shinarump Formation

The Shinarump is composed mostly of sandstone in the

San Juan Basin but is an irregular unit which Momper (1957, p. 92) recommends reducing to less than formation status. Minor shows noted in the Shinarump to the west of the basin make this unit a weak possibility for hydrocarbons in the basin. North of Durango this unit is less than 50 feet thick (Kilgore, 1955, p. 119).

Chinle Formation

Approximately 500 feet of red shales and sandstones comprise this sequence in the basin. These strata, because of their continental origin, have, so far, shown no evidence of being commercially prospective.

Jurassic System

Entrada Formation

The Entrada is about 300 feet thick in the center of the basin in southwestern Colorado. It is a white to gray sandstone and often one of the most permeable horizons in the entire section. Unfortunately, it is usually water bearing. Unconformably overlying older rocks in the eastern portion of the basin (Wood, et al., 1948), it has been considered a likely hydrocarbon prospect, especially where structurally controlled.

Todilto Formation

The Todilto formation, composed of limestone and gypsum, ranges from 0 to 130 feet in the basin in Colorado. The greater thickness is usually accounted for by deposits of gypsum which are thick along the eastern San Juan Basin as a whole. Despite the fact that oil has been noted in the Todilto in the basin in New Mexico, and asphaltic residue noted on the outcrop, the formation is considered a poor prospect for production. There is good evidence to indicate that the Todilto has been the source bed for minor accumulations of oil in the Entrada.

Morrison Group(?)

Three prominent continental formations comprise the Morrison group(?) in the area of interest. These are: the Summerville, at the base, composed of pink to brown shale with interbedded sandstones approximately 80 feet thick; the Junction Creek sandstone ranging up to 200 feet thick; and the Morrison mudstones, shales and sandstones at the top, which range up to 650 feet in thickness. Only the Morrison rocks have been productive, yielding gas from fractured quartzitic sandstones in the Ignacio area.

Cretaceous System

Burro Canyon Formation

The Burro Canyon formation of Lower Cretaceous age, attaining a possible thickness of 100 feet, is a relatively thin conglomeratic sandstone which extends into the western portion of the basin in Colorado, unless it has been confused with basal Dakota conglomerates in the area. This horizon is gas productive in the Ignacio-Bondad area.

Dakota Formation

In earlier days, the Dakota was one of the targets on structure most sought by drillers in the basin. Recently, this formation has given indications of potential for extensive gas reserves in stratigraphic traps in the deeper parts of the basin; near its borders, the formation carries water. The Dakota is largely a sandstone unit, but also contains shales and coal, usually in the lower middle section. The total section of the formation averages about 200 feet in thickness.

Important Dakota oil production has been obtained at the Price Gramps oil field (Sec. 24, T. 33 N., R. 2 E.) in the Chama Basin, which is adjacent to the San Juan Basin on the east. The cumulative production, from 1935 through 1958, totalled 4,711,578 barrels of 31.6 API gravity oil. The occurrence of oil in important quantities at Price Gramps (Waldschmidt, 1948, p. 124), although outside the confines of the San Juan Basin, is significant in regard to the possibilities of other oil production in the northeastern portion of the basin.

Mancos Formation

This marine shale formation, approximately 2,200 feet thick, has a few minor shaly sands at the transitional phase near the top and in the Gallup section above its Greenhorn member. Interesting shows have been noted in wells drilled through the Mancos in several locations. If one considers the Chromo field production to the east in the Chama embayment, in Ts. 32, 33 N., R. 1 E. (Wengerd and Gill, 1952, p. 107), and to the west in the Red Mesa area, T. 33 N., R. 12 W., it is difficult to understand why the Mancos will not produce in the San Juan Basin of southwestern Colorado.

Mesaverde Group

Three important formations comprise this group; the basal Point Lookout sandstone, the Menefee formation and the Cliff House sandstone. These regressive-transgressive units total about 700 feet in the basin and account for the largest gas production to date. Interestingly enough, production is related more to favorable stratigraphic conditions than to structural position. For example, gas wells in the syncline north of Bondad anticline, T. 33 N., R. 9 W., have indicated a higher potential production than wells located on the anticline itself.

Lewis Shale

Over 1,800 feet of gray marine Lewis shale is found in the basin. Near the top, lenticular sands are sometimes discovered, such as at Bondad, that have indicated the possibilities of gas production. Though the Lewis may never become an economic producer, it is always a threat, or more aptly described as a challenge to the driller.

Pictured Cliffs Formation

Almost entirely a salt and pepper sandstone unit, about

150 feet thick, the Pictured Cliffs can nearly everywhere be shown to contain some gas. At the Ignacio field where it produces, a halo of water (Ferebee, 1955) has limited gas production to a considerable degree. Toward the basin's rim, the Pictured Cliffs yield flowing wells of fresh warm water.

Fruitland Formation

Fruitland gas production has been rather profuse at Ignacio and Bondad anticlines since 1950. However, it is the writer's understanding that many of the wells, particularly flank wells, have gone to water. Recently, other Fruitland wells have indicated production in the area, thus upholding the Fruitland's reputation as a prospective horizon for the drill, stratigraphic as well as structural. The Fruitland is a continental sand, shale and coal sequence that totals approximately 275 feet thick.

Kirtland Shale

The continental shale of the Kirtland contains numerous lenticular sandstones which comprise its Farmington sandstone member. This member thickens and becomes more arkosic toward the mountains, thus indicating the effects of mountain building during Kirtland time. Farmington sands have contained interesting gas shows in the area, but to date have been uneconomic. The over-all thickness of the Kirtland in the Animas valley is about 1,200 feet.

McDermott Formation

This purple colored unit is best exposed four miles south of Durango where it is about 300 feet thick. Here, it consists of unweathered andesitic debris, but southward grades to sands and shales and pinches out south of Farmington, New Mexico. Few or no indications of the existence of hydrocarbons have been found in the McDermott.

Tertiary System

The underlying Animas and overlying Wasatch formations comprise the Tertiary system. These units form a thick layer of continental sediments measuring up to 2,700 feet in the area of interest. The Animas contains mostly shale and forms smooth valley slopes, but becomes sandier near the top. The Wasatch forms prominent cliffs, towering and picturesque, along U. S. Highway 550 south of Durango, near the New Mexico state line. Neither formation is considered a likely economic prospect for hydrocarbons.

Quatetrnary System

Retreating Pleistocene glaciers deposited terminal moraines on the terraces above the Animas River and glaciofluvial debris was spread over a considerable portion of the basin. These boulder beds are a constant problem to the driller who must set surface casing through the rubble, especially when a location is made near a major drainage area. In addition to the boulder beds, soil-fill on the smooth slopes, down-dip from the sharp hogbacks and along river terraces, is suitable for farming operations.

Structure

The regional structure of the San Juan Basin in southwestern Colorado (Plate 6 in pocket) is represented for the most part by steeply dipping beds of the Hogback monocline, sharply bending into gentle regional attitudes which dip toward the center of the Basin, located just south of the Colorado-New Mexico State line. Average hogback dips approximate 35°, while gentle regional dips are about 1°. The age of the monoclinal folding which forms the rim of the San Juan Basin is placed as Laramide or, more specifically, in late Cretaceous and early Tertiary times. The eastern part of the basin is characterized by an abrupt lack of steep dips at the Piedra River, where the normal structure is complicated by the northwest-trending Archuleta anticlinorium. Here, numerous structures, faults and basaltic dikes appear. Several prominent anticlinal features have been drilled in this area but have yielded no commercial production.

The Bondad and the Ignacio anticlines are the most prominent anticlinal features in the western part of the basin. The location and position of the productive horizons on these structures have been discussed previously.

Drilling and Completion Methods

Until about 1953, mud drilling was the prevailing method for drilling wells in the San Juan Basin of southwestern Colorado. This system proved improper for completing producers in the Cretaceous section, with the exception of the Fruitland formation.

After gas drilling and frac methods of completion were tested and proven, successful Mesaverde and Dakota gas wells began to be commonplace, especially the Mesaverde because of its shallower depth.

Approximately 200 Fruitland, Pictured Cliffs, Mesaverde and Dakota-Morrison gas wells are productive in the subject area. The accompanying map (in pocket) illustrates the location of producing wells and their proximity to the hogback monocline.

Spacing to date is 320 acres for the Fruitland and Pictured Cliffs, 320 acres for Mesaverde and 640 acres for Dakota-Morrison wells. No secondary recovery operations have yet been attempted.

Compilation of Production and Reserves

Cumulative production to January 1, 1959, from the San Juan Basin of southwestern Colorado was compiled in round figures and supplied to the writer through the kindness of Robert Patterson and A. M. Derrick of the El Paso Natural Gas Company. They are as follows:

Fruitland	26,000,000 MCF gas
Mesaverde	33,000,000 MCF gas
Dakota-Morrison	11,000,000 MCF gas

Generalized estimates of recoverable reserves originally in place in the Colorado portion of the San Juan Basin were supplied through the cooperation of Lewis C. Jameson from the files of Val R. Reese and Associates, Inc., of Albuquerque, New Mexico. They are as follows:

	Approximate Proved Acres	Estimated Recoverable Reserves Per Acre (MCF)	Estimated Reserves (MCF)
Fruitland	19,000	8,000	152,000,000
Mesaverde	150,000	12,500	1,875,000,000
Dakota	20,000	14,500	290,000,000

These very rough reserve estimates are based on average recoverable reserves which have been calculated in different portions of the area. The productive area was estimated from a count of the sections within the area proved by drilling.

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Chapter XIX

Oil and Gas Conservation In Colorado

by

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Denver, Colorado

CHAPTER XIX

Oil and Gas Conservation of Colorado

by

ARTHUR J. JERSIN

An analysis of the conservation phase of the Colorado oil and gas industry reveals that: (1) the law makers of the State have kept pace with oil and gas activity by passing legislation as various problems arose; (2) a survey made in April, 1959, revealed that only 6.3 percent of all casinghead gas was being flared; and (3) as a result of pressure maintenance and secondary recovery projects now in operation, over 543,000,000 additional barrels of oil will be produced over and above primary reserve estimates.

Summary of Colorado Oil History and Highlights of Oil Laws Adopted

Oil was first discovered in Colorado in 1862, when A. M. Cassedy completed a small producer on Oil Creek, six miles north of Canon City in the south-central part of the State. Since that date, there has been continued exploration and development of oil and gas in Colorado, with the greatest boom period occurring from 1945 through 1956. In January, 1960. this state ranked tenth in the nation, with a rate of production of 130,000 barrels of oil per day. The growth of Colorado's petroleum industry is illustrated graphically in Figure 3, page 503, and in the tables of production by county, field, and year contained at the end of this chapter.

The first petroleum law in Colorado, adopted March 7, 1889, prohibited the emptying of oil into any creek, stream, river, or lake in the State, and imposed a penalty for such an offense.

With continued drilling in the State, eight separate fields were discovered and were producing oil at a rate of about 7,000 barrels per day by the end of 1926. This increased activity caused the legislators to pass additional laws, and on April 1, 1927, an Act was adopted which created a regulatory body known as the Gas Conservation Commission. This Commission consisted of three men appointed by the Governor, and the State Oil Inspector as an ex-officio member. The office of the State Oil Inspector was charged with the duty of enforcing any regulations which the Commission adopted.

Additional legislation was adopted on April 5, 1929, which basically provided for proper abandoning and plugging meth-

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ods for wells drilled for oil and gas. During the next 22 years, no major statutory changes were made which affected oil and gas conservation.

The daily average production of oil was approximately 8,000 barrels at the end of 1944. Then came the development of the Weber reservoir of the Rangely field and, soon after, the Colorado portion of the Denver-Julesburg Basin. By the end of 1950, the State was producing in excess of 65,000 barrels of oil per day. This quickened pace of oil and gas activity continued until the middle of the year 1956, when the peak rate of 170,000 barrels of oil per day was reached.

On March 22, 1951, a major change in oil and gas law was adopted. The 1951 law, with subsequent amendments, sets forth the foundation for the now existing rules and regulations in Colorado. This new Act created an Oil and Gas Conservation Commission as successor to the Gas Conservation Commission. This new Commission now consists of five members, who are appointed by the Governor with the consent of the Senate.

Among other things, the law under which the State now operates defines the word "waste" as follows:

1. "The term 'waste' as applied to oil shall include underground waste, inefficient, excessive or improper use or dissipation of reservoir energy, including gas energy and water drive, surface waste, open pit storage and waste incident to the production of oil in excess of the producer's above-ground storage facilities and lease and contractual requirements, but excluding storage, other than open-pit storage reasonably necessary for building up or maintaining crude stocks and products thereof for consumption, use and sale.

2. "The term 'waste' as applied to gas shall include the escape, blowing or releasing, directly or indirectly, into the open air of gas from wells productive of gas only, or gas in an excessive or unreasonable amount from wells producing oil or both oil and gas; and the production of gas in quantities or in such manner as will unreasonably reduce reservoir pressure or unreasonably diminish the quantity of oil or gas that might ultimately be produced; excepting gas that is reasonably necessary in the drilling, completing, testing and in furnishing power for the production of wells.

3. "The term 'waste' means and includes (a) physical waste as that term is generally understood in the oil and gas industry; (b) the locating, spacing, drilling, equipping, operating or producing of any oil or gas well or wells in a manner which causes or tends to cause reduction in quantity of oil or gas ultimately recoverable from a pool under prudent and proper operations or which causes or tends to cause unnecessary or excessive surface loss or destruction of oil or gas; (c) abuse of the correlative rights of any owner in a pool due to non-uniform, disproportionate, unratable, or excessive withdrawals of oil or gas therefrom, causing reasonably avoidable drainage between tracts of land or resulting in one or more producers or owners in such pool producing more than his just and equitable share of the oil or gas from such pool."

With the above definition of "waste" as the objective, a set of rules and regulations was adopted and made available to persons engaged in the Colorado oil and gas industry.

As to limiting production of oil and gas, the law provides that the Commission, "when necessary, shall limit the production of oil and gas in any field or pool" to exercise its authority to prevent waste and protect correlative rights.

The Commission is now equipped with a staff of twelve employees, which consists of five clerks, six petroleum engineers, and a director. This staff is charged with the duty of enforcing Commission regulations, and, by so doing, the office of the Commission has become extremely beneficial to the industry as a means of obtaining records of drilling activity and oil and gas well histories.

A complete tabulation of Colorado oil production is presented at the end of this section, showing the number of barrels of oil produced from each oil field for each year of production. The table includes cumulative figures for both oil and gas production to January 1, 1960, and gas production figures for the year 1959.

Gas Flaring

One major problem which exists in all oil-producing provinces is the venting, or flaring, of casinghead gas. Casinghead gas is natural gas which is produced at the surface from an oil well. Natural gas is almost always associated with oil in underground reservoirs; therefore, because of this association, gas production is unavoidable with the production of oil.

With a few exceptions, most Colorado oil fields are relatively small. At the time the Commission was created, oil was being produced from approximately 60 fields, and 75.1 percent of all casinghead gas was being vented, or flared. The major factors which caused this large percent of gas flare were (a) many of our small oil fields contained insignificant gas reserves scattered over relatively large areas; (b) the price of the gas at the well-head could not justify the expenses of gathering and cleaning for market; and (c) no State agency had authority to issue effective orders for preventing unreasonable volumes of casinghead gas production.

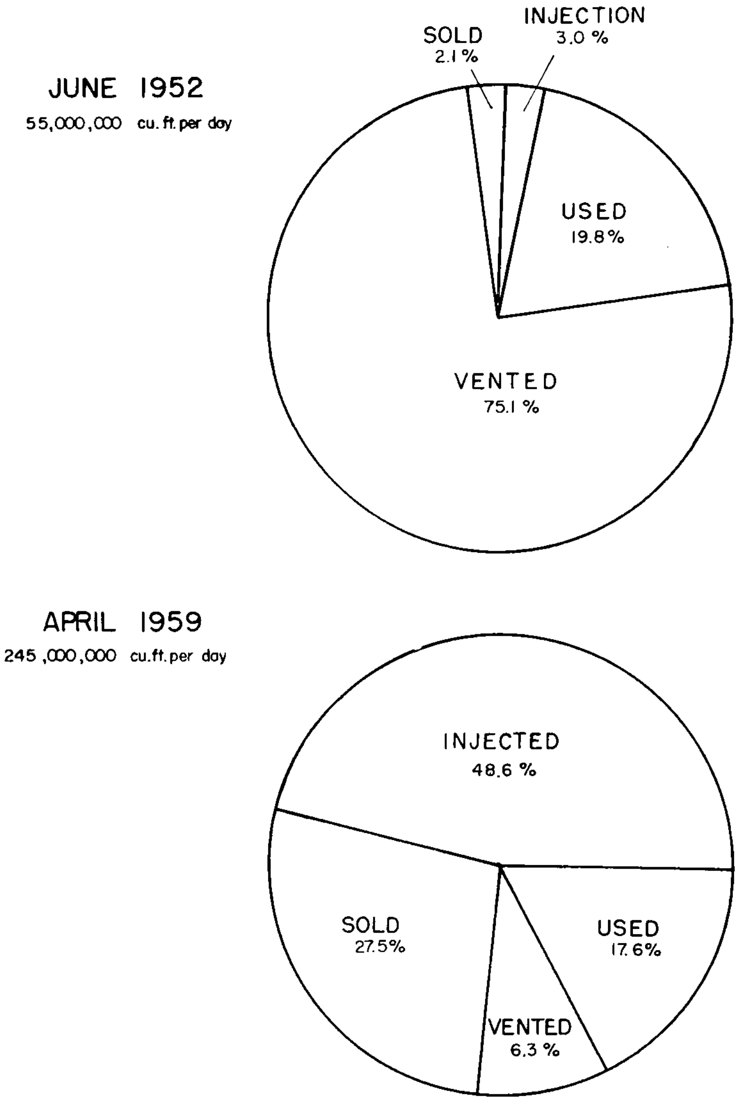
It is encouraging to realize that during the month of April, 1959, only 6.3 percent of all casinghead gas produced in Colorado was vented or flared, while the volume of oil production was approximately 130,000 barrels per day. A breakdown of the disposition of Colorado casinghead gas is shown diagrammatically for the months of June, 1952, and April, 1959, on Fig. 17.

Summary of Commission Oil Field Orders

As of September, 1959, the Commission had issued approximately 400 orders on various phases of industry practices. A majority of these orders pertain to matters such as unitization, spacing, and maximum efficient rates of production. As

FIGURE 17

COLORADO
CASINGHEAD GAS PRODUCTION
and
DISPOSITION



a result of these orders which affect 96 different fields, 86.6 percent of all Colorado oil production comes from fields in which some type of Commission order has been issued, or in which there is some type of field-wide operating agreement. The following table shows the situation.

Colorado Oil Fields—April 1959

	Number	Pct.	Oil Production Bbls./day	Pct.
Fields with operating agreements and restrictive orders	40	15.6	94,874	74.5
Fields with other orders	56	21.9	15,388	12.1
Fields with no orders	160	62.5	17,116	13.4
TOTAL	256	100.0	127,378	100.0
Fields producing 1000 or more barrels daily	15	5.9	94,584	74.3
Fields producing less than 1000 barrels daily	241	94.1	32,794	25.7
TOTAL	256	100.0	127,378	100.0

Of the remaining 160 oil fields in the State which operate under general rules and regulations, rather than under special field rules, there are only 38 which produce over 100 barrels of oil per day. These 38 fields are developed with 664 wells which produce an average of 19 barrels of oil and 5 MCF of gas per well per day.

Fluid Injection Projects and Unit Operations

As of January, 1960, the oil industry discovered an estimated total of 3,217,000,000 barrels of oil in place in the State of Colorado. Of this volume of oil in place, 552,000,000 barrels have already been produced, with an estimated remaining primary reserve of 214,000,000 barrels. As a result of fluid injection projects now in operation, an estimated volume of 543,000,000 additional barrels of oil will be recovered over and above primary reserves, for a total State oil reserve of 757,000,000 barrels. These figures represent a recovery of about 41 per cent, which will be larger with the commencement of new fluid injection systems now in the formulative stage, and it is very likely that improved methods of recovery such as in situ combustion and use of miscible fluids will yield an even greater percent of recovery than can now be predicted with conventional methods.

The first fluid injection project to function in the State was started in the Wilson Creek field, Rio Blanco County, on May 14, 1946, when gas was first injected into the Morrison formation. Our second fluid injection project began November, 1950, in the form of a pilot gas injection system for the Weber reservoir of the Rangely field, also in Rio Blanco County. The first fluid injection system to use water started September 18, 1956, when water was initially injected into the "D" sand of the Willard field, Logan County.

As of January, 1960, 23 different fluid injection programs were in operation, and plans were well under way in six other fields for installation of some type of fluid injection equipment. Of these 23 active programs, over 80 percent were started since January, 1957, and are located in 21 different oil fields. Sixteen of the programs utilize water injection systems; four utilize gas injection systems, and three utilize both water and gas injection systems.

Generally, none of these injection projects have been in operation long enough to allow a concrete determination of the degree of effectiveness of the various programs; however, performance data accumulated thus far are generally very favorable. A brief discussion of each fluid injection project now in operation follows.

Colorado has 12 fields which operate under unit agreements, with no type of fluid injection program. A list of these fields with respective data appears in the form of a tabulation in the latter part of this section.

Adena ("J" Sand) Field

On May 26, 1953, the Falcon Seaboard Drilling Company completed the No. 1 Snodgrass, located in the NW NE NW, section 20, township 1 north, range 57 west, Morgan County, as the discovery well of the "J" sand reservoir of the Adena field. This field is the largest oil field discovered to date in the Denver Basin, and was completely defined by 170 oil wells on 40-acre spacing, and 15 gas wells on 160-acre spacing. The areal extent of the oil zone is about 8,450 acres, and the gas cap covers about 4,650 acres. The average net sand thickness is 30 feet, with an average porosity of 19.7 percent and average permeability of 356 millidarcys. The field is basically a stratigraphic trap which dips to the west at a rate of only 48 feet per mile.

Prior to unitization of the field, emergency restrictive orders were issued by the Commission from April 1, 1954, until July 1, 1954, which limited the production of gas to 150 MCF per well per day. Thereafter, following a full hearing on the maximum efficient rate of production, a limitation of 125 barrels of oil per well per day with a penalty GOR of 1200 to 1 was entered and in effect until August 1, 1956.

One of the most significant phases of the history of this field is the unique method of restriction and allocation of production set forth in Order No. 26-30, which became effective August 1, 1956. Based on detailed engineering and geologic data accumulated at several lengthy hearings, the order provided that the maximum efficient rate of production of the "J" sand was 14,000 barrels of oil and 25,173 MCF of gas, daily. This field allowable was then allocated between the separately owned tracts of land on the basis of oil and gas originally in place underlying each tract. Order No. 26-30 has proved itself to be very successful in preventing waste and protecting correlative rights.

A unit agreement for the "J" sand was approved by the Commission on December 22, 1955, with The Pure Oil Company designated as the unit operator. The productive acreage committed to the unit represented 93 percent of the oil originally in place, and 100 percent of the gas originally in place. On October 1, 1956, additional tracts were included in the unit, which increased the amount of oil originally in place under unit operations to 99.94 percent. The 0.06 percent of non-unitized oil-in-place is located on the edge of the "J" sand reservoir, with only three producing wells.

Very exhaustive studies of the "J" sand reservoir were devoted to evaluating various production methods and fluid injection patterns in order to determine the most efficient pressure maintenance program. After many months of work, the study revealed that a water injection program should be utilized, and that it should be a line type flood at either the water-oil contact zone or the gas-oil contact zone. The gas-oil contact zone was selected for the following reasons:

1. There would be a difference of from 2 to 4 million bbl. in oil recovery between the two programs, primarily due to loss of oil to the dry gas cap during oil-water contact injection. Performance calculations and Hele-Shaw model studies established that these losses could not be prevented in such a shallow dipping formation.

2. During the oil-water contact program the production of low ratio oil and areally maintaining balanced withdrawals ahead of the flood front would be difficult, if not impossible, since the gas cap had unevenly invaded the oil zone and could never be separated from the producing area.

3. During the gas-oil contact injection program, channeling of injected water through highly gas-saturated streaks would not occur. This was determined by theoretical calculations using data from tests which determined the effective permeability to water in the presence of oil and a trapped gas saturation and further confirmed by laboratory model studies.

4. Early in the gas-oil contact program an effective water barrier could be formed. Model studies showed that interference would occur although a small volume of gas would continually stream from the gas cap to the oil zone between injection wells at the interference radius. These studies also indicated that by reducing the spacing between injection wells, the streaming between these wells would be lessened.

5. The gas-oil contact program would require a shorter operating life than the oil-water contact program.

6. A fewer number of injection wells would be required along the gas-oil contact. Sand conditions are far superior along this contact.

7. An initially straighter and more easily controlled flood front would exist during the gas-oil contact program.

8. Fewer producing wells and less related production equipment would be required by the gas-oil contact program.

9. The gas-oil contact program would offer more flexibility with regard to the timing of gas cap production.

10. The injection water distribution system could be installed at less expense for the gas-oil contact injection program.

Primary recovery of oil by competitive production methods with a limitation of 125 barrels of oil per day and a penalty GOR of 1,200 to 1, was estimated to be 40,365,000 barrels, or approximately 30 percent of the original oil-in-place. With unitization and the gas-oil contact water injection program, the most recent estimate reveals that an additional 30,635,000 barrels of oil will be recovered, for a total oil recovery of 71,000,000 barrels, which is in excess of 50 percent of the volume of oil-in-place.

The pressure maintenance program was started February 25, 1957. As of January 1, 1960, 65,016,637 barrels of water had been injected into the reservoir through 38 water injection wells, with a cumulative volume of production of 31,137,936 barrels of oil, and 30,917,500 MCF of gas.

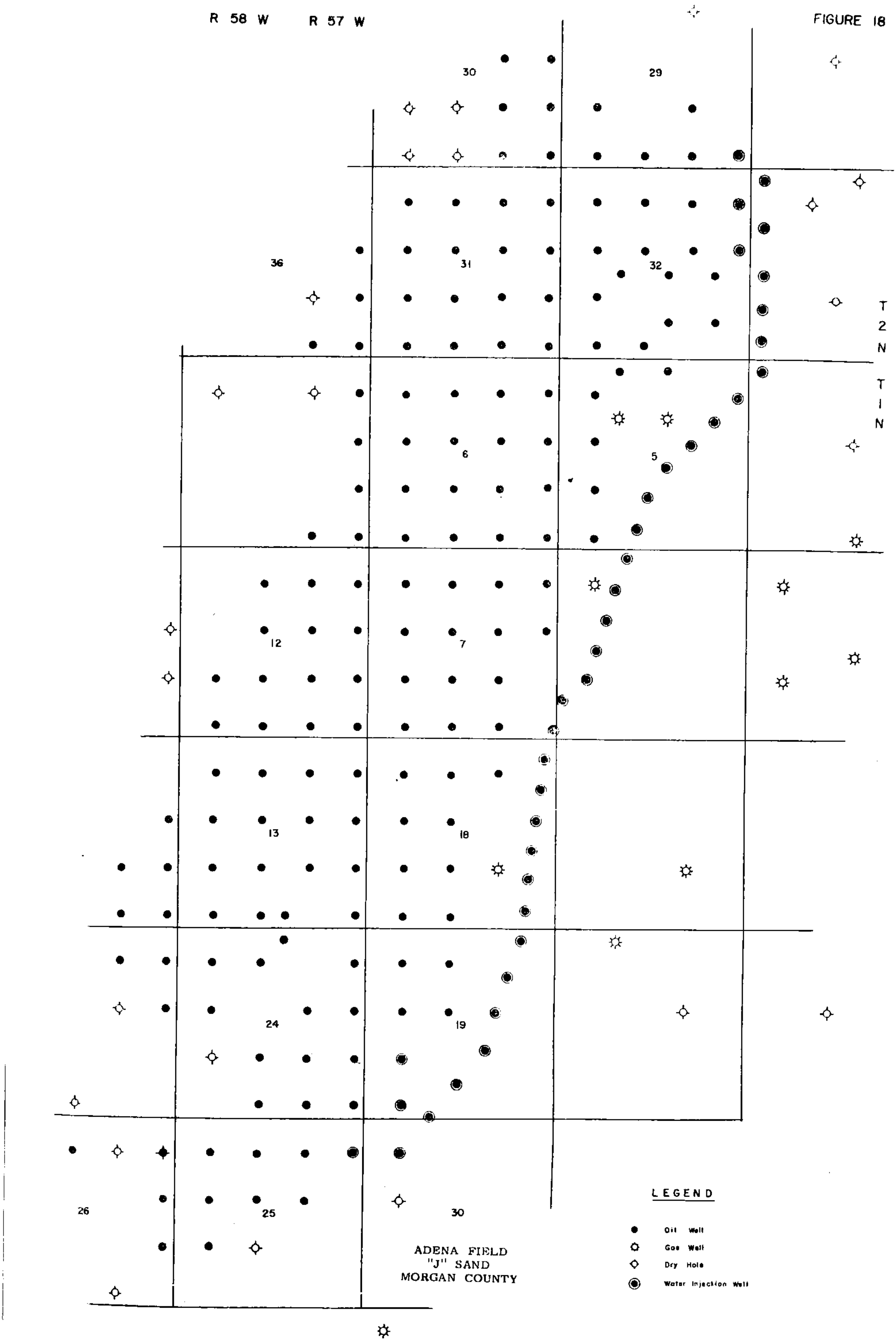
Since water injection commenced, the operator has requested an increase of the "J" sand reservoir oil allowable from time to time because of performance characteristics. The most recent change has increased the oil allowable to 20,000 barrels of oil per day, which allowable became effective March 1, 1960. This last change in the field oil allowable was granted by the Commission because the maximum efficient rate of production increased as a result of a wide oil bank created by pressure maintenance operations. This oil bank is approximately one and one-half locations wide, with 40 wells producing oil from said bank. A decline in the field gas-oil ratio has accompanied the widening of the oil bank, since more of the reservoir is affected by the relatively large volume of water injected. With this increased oil allowable, there will be no loss of bottom hole pressure, since the reservoir is now experiencing lower withdrawals on a per barrel basis. Also, it is interesting to realize that the no-flare status of the field will be maintained.

Following is a map (Fig. 18) showing wells completed in the "J" sand reservoir, with the current line of water injection wells indicated.

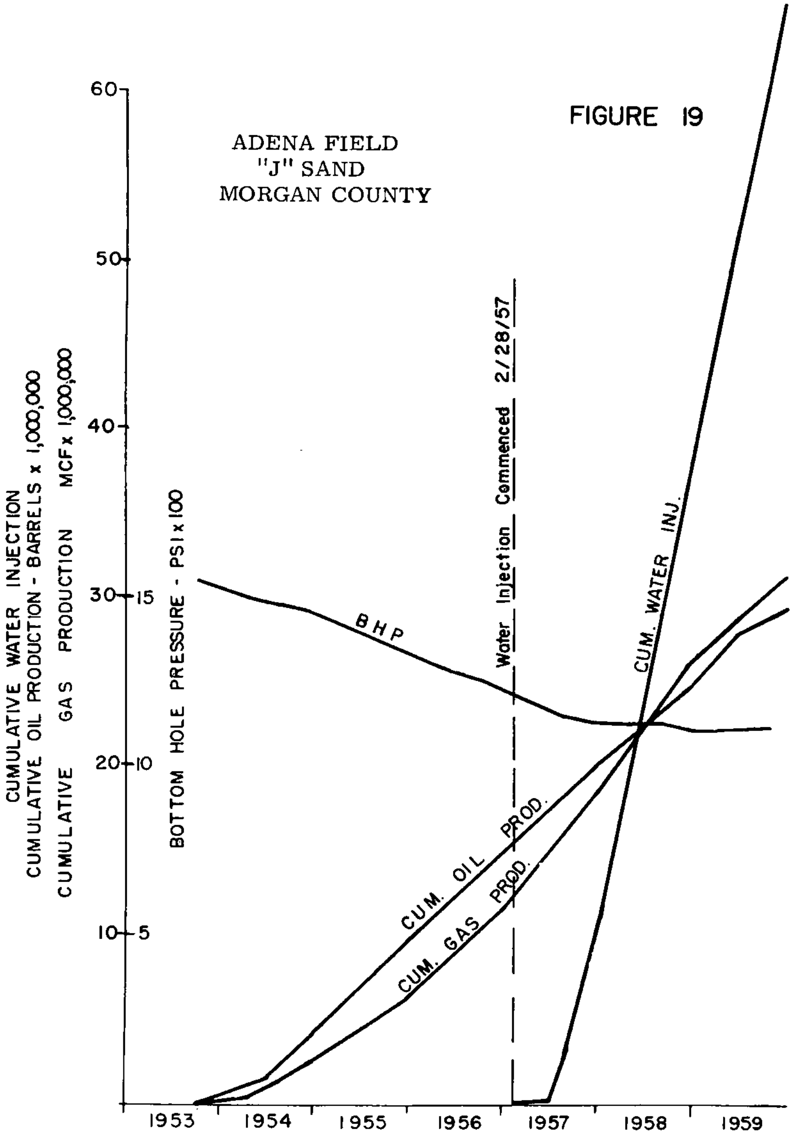
Also presented is a graph (Fig. 19) showing performance characteristics of the reservoir.

Badger Creek "D" Field

The original discovery of oil in the "D" sand reservoir of the Badger Creek field was made in April, 1953, when commercial production was encountered in the Forest Oil Corporation's No. 1 C. D. Causey well located in the NE SW NW,



ADENA FIELD
"J" SAND
MORGAN COUNTY



section 23, township 2 south, range 57 west, Adams County, Colorado.

The reservoir is a stratigraphic trap with a pinch-out to the east and a water table on the west, north and south. The pay sand covers an area of approximately 1,430 acres, with an average effective pay thickness of 13 feet, an average porosity of 20.05 percent, and an average saturation of 22.0 percent.

The oil is 38° API, with a solution gas-oil ratio of 235 cubic feet per barrel and a formation volume factor of 1.185, both at the saturation pressure of 715 psi. The original solution pressure was 1,300 psi.

On June 17, 1958, the Commission issued its Order No. 21-4, which approved a pressure maintenance program by water injection. The plan calls for conversion of certain producing wells into injection wells in a pattern which can best be described as a diagonal alternating line drive in which wells in every other row in a NE-SW direction become injection wells. There are 17 injection wells now in operation (Fig. 20). Initial injection commenced on September 8, 1958, and as of January 1, 1960, 2,159,435 barrels of water had been injected.

Primary reserves have been estimated at 4,000,000 stock tank barrels, or 21.1 percent of the original oil-in-place. It is estimated that an additional 4,292,148 stock tank barrels of oil will be recovered by water injection, for a total of 43.7 percent of the original oil-in-place.

Cumulative production has been from 36 wells, with a total, as of January 1, 1960, being 2,671,407 barrels of oil, and 1,543,103 MCF of gas.

Black Hollow Field

On July 30, 1953, The California Company completed the No. 1 Biamonte well located in the NE NW, section 6, township 7 north, range 66 west, Weld County, Colorado, as the Lyons discovery of the Black Hollow field. The trap is a dome.

With this discovery, a new trend of exploration on the western flank of the Denver Basin commenced. Prior to this time, minor production in the Lyons sand of Permian age had been discovered in the Keota field, but no significant reserves had been encountered. Besides being the initial significant Lyons discovery in the State, Black Hollow had the distinction, for some time, of being the deepest producing field in the State, with production from a depth of approximately 8,950 feet.

On July 22, 1958, after some 17 producing wells had been completed, the Oil and Gas Conservation Commission approved a unit agreement and a water flood plan for the Lyons reservoir, which designated The California Company as operator of the unit comprising 2,016 acres.

On August 16, 1958, initial injection of water commenced, and as of January 1, 1960, 266,628 barrels of water had been injected into the one injection well located on the northeast edge of the field (Fig. 21).

Cumulative production from the field, as of January 1, 1960, was 3,762,773 barrels of oil, and 90,003 MCF of gas.

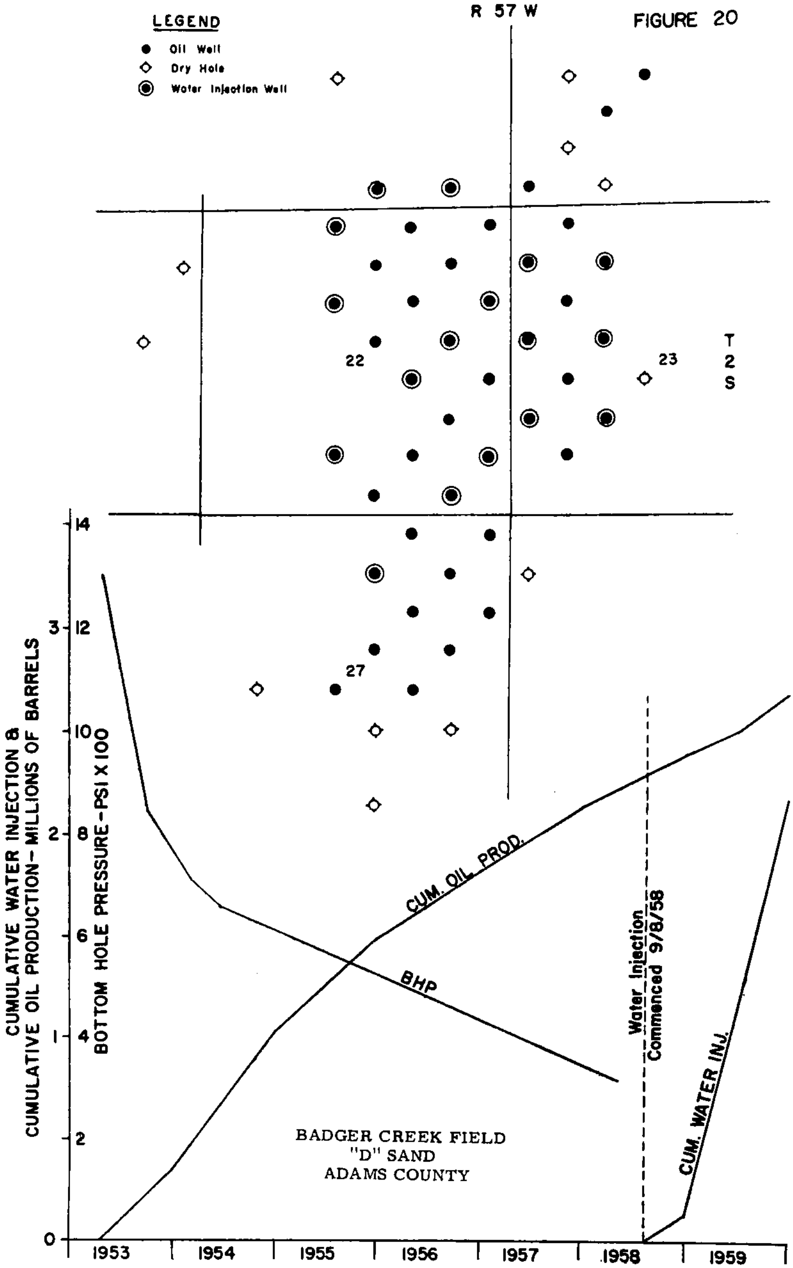
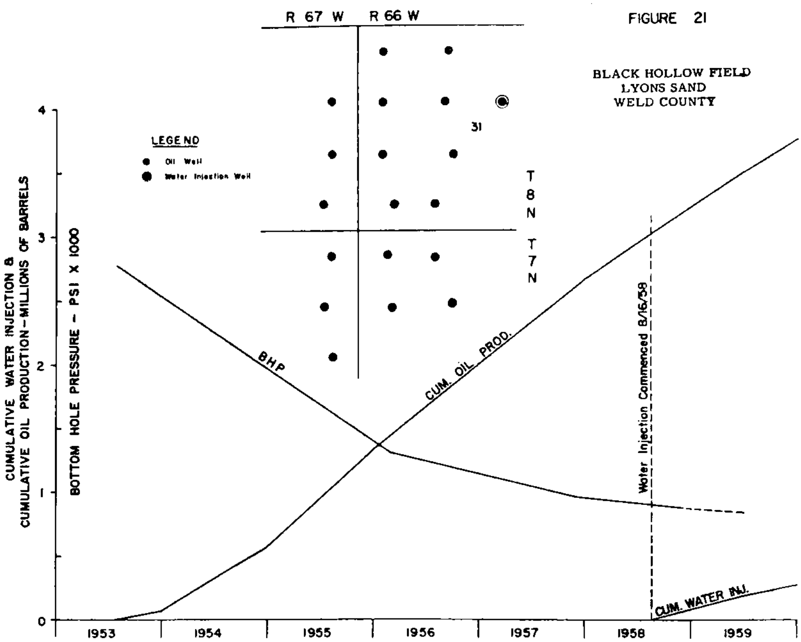


FIGURE 20
LEGEND
Oil Well
Dry Hole
Water Injection Well
R 57 W
T 2 S
22
23
27
CUMULATIVE WATER INJECTION & CUMULATIVE OIL PRODUCTION—MILLIONS OF BARRELS
BOTTOM HOLE PRESSURE—PSI X 100
CUM. OIL PROD.
BHP
Water Injection Commenced 9/8/58
CUM. WATER INJ.
BADGER CREEK FIELD
"D" SAND
ADAMS COUNTY
1953
1954
1955
1956
1957
1958
1959



Canadian River Field

On April 7, 1956, the Cabeen Exploration Company completed the discovery well for the Canadian River field. This well is the No. 1 Blevins, completed in the Dakota-Lakota formation, and located in the SW NW NW, section 11, township 9 north, range 78 west, of North Park, Jackson County, Colorado. Subsequently, ten oil wells and two gas wells were completed in this reservoir.

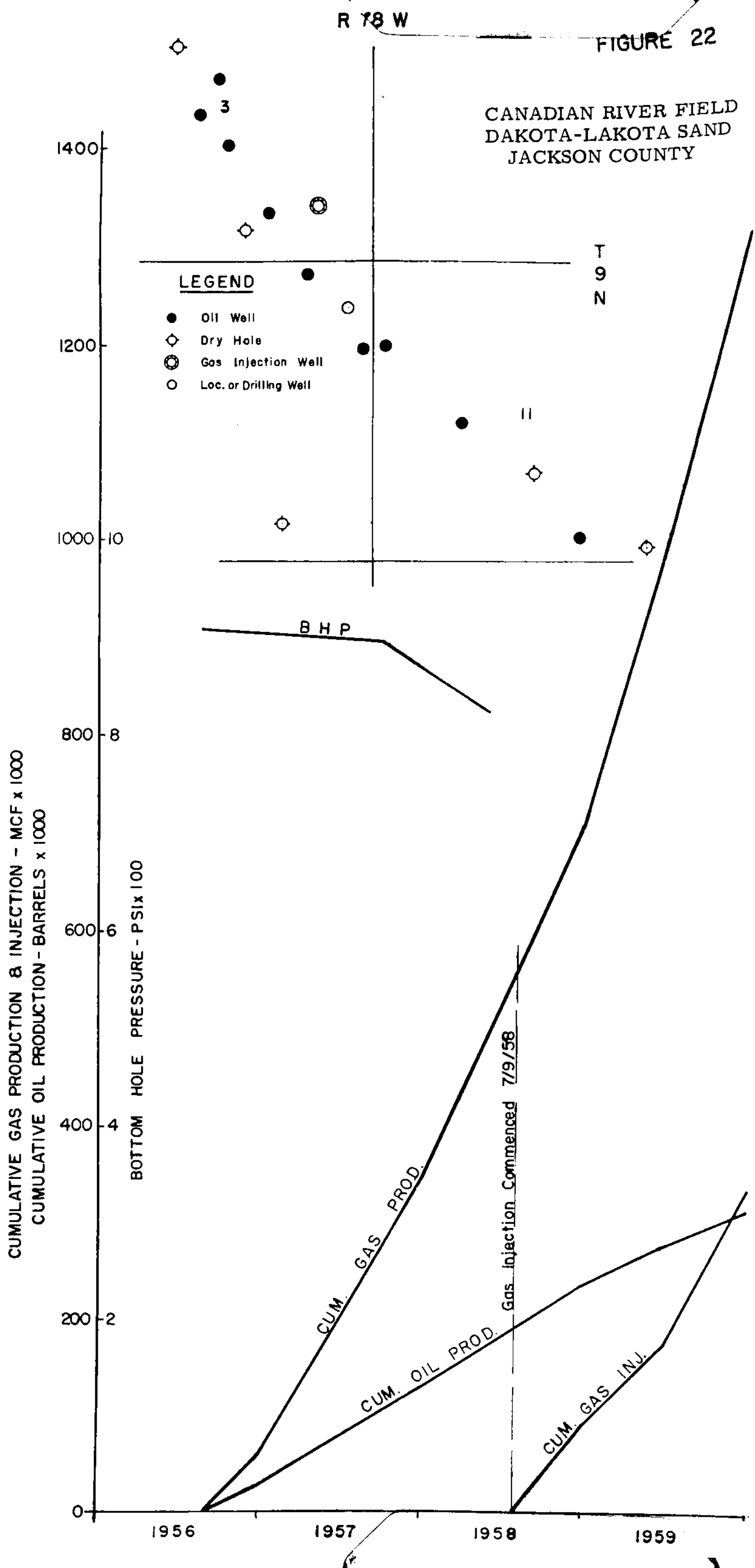
Order No. 96-1, issued November 5, 1956, by the Oil and Gas Conservation Commission, prohibited the producing of any well that had a gas-oil ratio in excess of 20,000 to 1. On January 28, 1958, Order No. 96-2 was issued, approving a plan of gas injection into the reservoir and using one well as the gas injection well. The pressure maintenance by gas injection will tend to keep the gas-oil interface from moving into the gas cap section of the reservoir, which movement could result in a loss of ultimate recovery of oil. The Cabeen Exploration Company is the operator of the injection project, and of the entire field.

The initial injection of gas began on July 9, 1958, and as of January 1, 1960, there had been 331,232 MCF of gas injected into this reservoir (Fig. 22).

The cumulative production figures as of January 1, 1960, were 313,107 barrels of oil, and 1,374,259 MCF of gas.

FIGURE 22

CANADIAN RIVER FIELD
DAKOTA-LAKOTA SAND
JACKSON COUNTY



Dune Ridge Fied

On June 20, 1954, the discovery well for the "D" sand reservoir of the Dune Ridge field was completed. This well was Shell Oil Company's State No. 1 in the NW SE, section 32, township 7 north, range 52 west, Logan County, Colorado. To date, there have been 13 producing oil wells completed in the field producing from a common stratigraphic trap.

On March 18, 1955, a pressure maintenance program was approved by the Oil and Gas Conservation Commission. This program called for gas to be injected into the reservoir through the discovery well in the extreme eastern part of the field. It was estimated that the ultimate oil recovery would be approximately 700,000 barrels by primary methods, and that an additional 200,000 barrels of oil would be recovered as a result of gas injection. Gas injection commenced in August of 1955, and was continued until February 4, 1959, at which time a total of 1,167,813 MCF of gas had been injected into the reservoir, and gas injection was discontinued.

On December 10, 1957, the Commission issued Order No. 54-4, which approved a unit agreement and a water injection plan for the Dune Ridge field, with Shell Oil Company designated as the operator of this unit comprised of some 560 acres of land. Initial injection of water commenced in February, 1958, and as of January 1, 1960, there had been 1,366,495 barrels of water injected into the reservoir, utilizing five injection wells (Fig. 23).

Recovery of oil by supplementing primary recovery with gas injection was estimated at 900,000 barrels, which represents 32 percent of the oil-in-place. An additional 475,000 barrels of oil will be recovered by water flooding the reservoir, which will bring the total ultimate recovery to 1,375,000 barrels of oil, or 49 percent of the original oil-in-place.

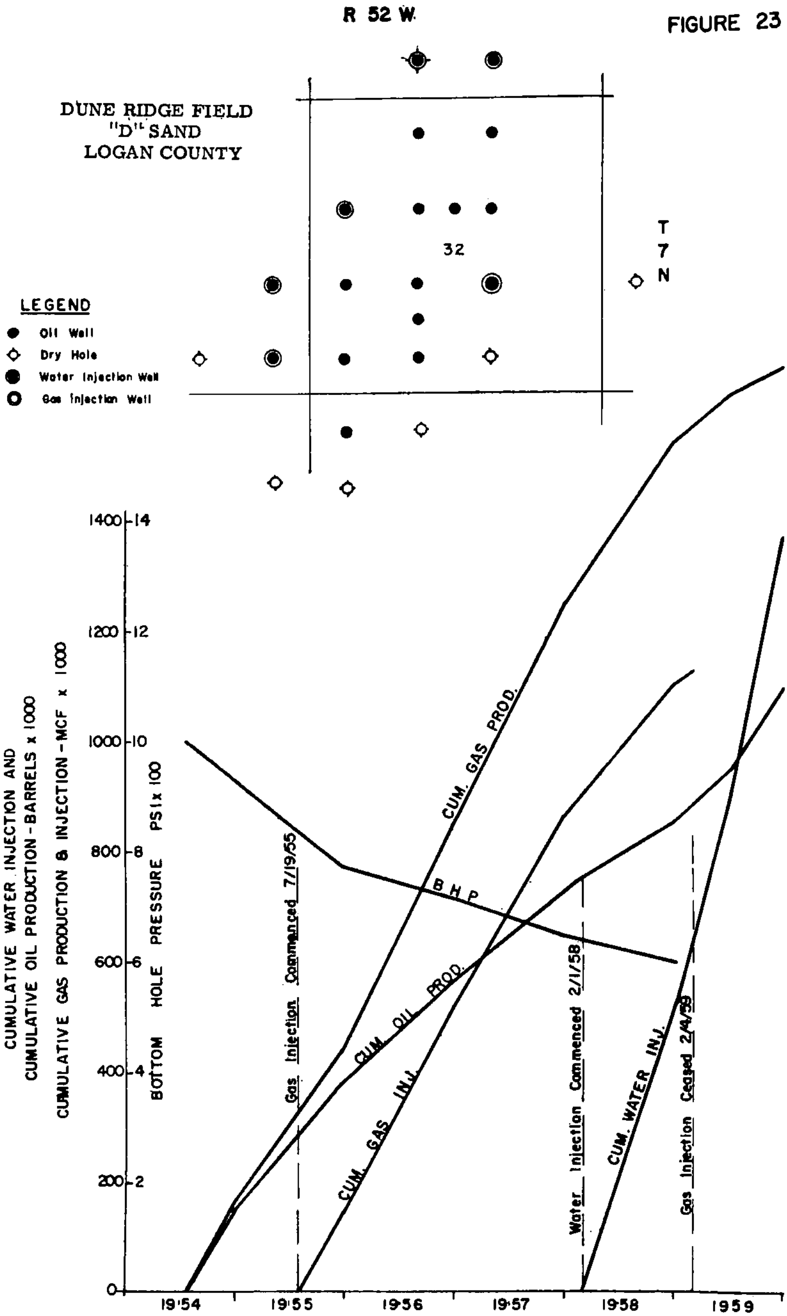
As of January 1, 1960, 1,094,783 barrels of oil, and 1,674,871 MCF of gas had been produced from this reservoir.

Fort Morgan Field

The Fort Morgan field was discovered in May, 1954, with the completion of S. D. Johnson's Lind-Bacon No. 1 well in the SW SW, section 19, township 3 north, range 57 west, Morgan County, Colorado, in the "D" sand formation. Following this discovery, drilling continued at a slow rate until the ten wells capable of producing from this formation were completed in April of 1955.

This "D" sand pool is encountered at a depth of approximately 5,550 feet, with accumulation resulting from a stratigraphic trap with the productive sand shaling out up-dip to form the eastern limits of production. Water has been in evidence at the down-structural locations. Pressure history to date indicates that some water influx is probably occurring

FIGURE 23


R 52 W.
DUNE RIDGE FIELD
"D" SAND
LOGAN COUNTY
LEGEND
Oil Well
Dry Hole
Water Injection Well
Gas Injection Well
32
T
7
N
CUMULATIVE WATER INJECTION AND
CUMULATIVE OIL PRODUCTION - BARRELS x 1000
CUMULATIVE GAS PRODUCTION & INJECTION - MCF x 1000
BOTTOM HOLE PRESSURE PSI x 100
1400 14
1200 12
1000 10
800 8
600 6
400 4
200 2
0
1954
1955
1956
1957
1958
1959
CUM. GAS PROD.
B H P
CUM. OIL PROD.
CUM. GAS INJ.
CUM. WATER INJ.
Gas Injection Commenced 7/19/55
Water Injection Commenced 2/1/58
Gas Injection Ceased 2/4/59

at the present time; however, field history is not sufficient at this time to indicate the magnitude of influx. Present geological and engineering data indicates that the reservoir contains primarily gas with small but significant oil band on the down-dip side.

Initial gas-oil ratios of the first five wells completed ranged from a reported 6,000 cubic feet per barrel to 97,500 cubic feet per barrel, and on November 26, 1954, the Commission issued its first orders in the field. These orders established 160-acre drilling and spacing units for gas, and 40-acre drilling and spacing units for oil, and provided that no gas from any well be produced unless the gas so produced was marketed, returned to the reservoir, or required for lease development, operations and fuel.

Following the above orders, production from the field was curtailed, since only two wells were connected to a market. This situation continued through 1955, after which time the field was essentially shut in until February, 1958, at which time a gasoline extraction plant was erected, and a market again became available for gas.

On September 26, 1958, the Commission held a hearing to consider approval of a plan of unit operations. Following the above hearing, the Commission issued an order, effective September 26, 1958, approving a unit agreement and providing for the pressure maintenance program of gas injection and re-cycling.

The field consists of approximately 2,202 productive acres; however, no reserve figures are available at the present time, since production history is insufficient to verify any volumetric calculations, and could be subject to considerable error due to the complex nature of producing mechanisms.

Cumulative production figures as of January 1, 1960, were 107,582 barrels of oil, and 3,336,558 MCF of gas.

Injection, as indicated on the graph (Fig. 24), is taking place through one well located in the SW, section 30, township 3 north, range 57 west, and, as of January 1, 1960, there had been 729,086 MCF of gas injected into the reservoir.

Graylin-Northwest "D" Field

On May 2, 1951, The British-American Oil Producing Company completed the "D" sand discovery well in the Graylin-Northwest field. This well, the Monroe No. 1, is located in the NE NE SW of section 7, township 8 north, range 53 west, Logan County, Colorado. There were 41 producing wells drilled to the "D" sand in this field.

The structure is a combined stratigraphic trap and anticline, and there are 3,808 productive acres in the field. The producing mechanism in the reservoir is solution gas with a weak water drive. The original bottom-hole pressure was

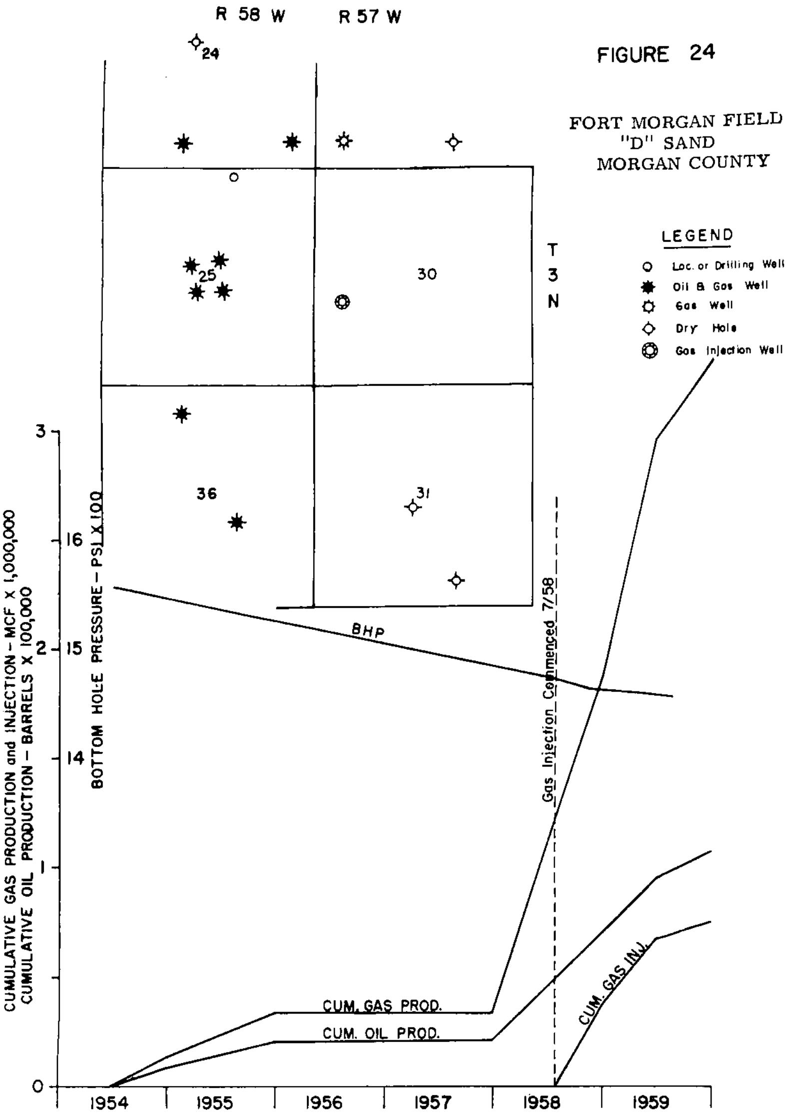


FIGURE 24

1,320 psi, and the bottom-hole pressure, as of January 1, 1959, was 202 psi. The average net pay thickness is 8.7 feet. Average porosity for the "D" sand reservoir has been calculated at 21.2 percent, and the average permeability is 344 millidarcys.

The original oil-in-place has been calculated at 27,295,000 barrels of stock tank oil. The primary reserves were estimated to be 7,435,422 barrels of oil, with an additional 3,535,000 barrels estimated as recoverable by the approved fluid injection system, for a total reserve of 10,970,422 barrels, which represents 40 percent of the original oil-in-place.

On December 15, 1959, the Oil and Gas Conservation Commission issued Order No. 25-9, which approved a unit agreement and a plan for the injection of water into the "D" sand. The British-American Oil Producing Company has been designated as the unit operator. There are 19 wells selected to become water injection wells in a semi-peripheral flood pattern. As of January 1, 1960, the injection of water had not yet begun, but the unit operator estimates that injection should begin early this summer. The unit operator is presently completing wells to provide the source water for the flood, and making other necessary installations.

The cumulative production, as of January 1, 1960, was 6,807,534 barrels of oil, and 9,345,881 MCF of gas (Fig. 25).

Jackpot Field

On January 7, 1955, J. L. Nelson completed the discovery well in the "D" sand of the Jackpot field. This well is located in the NW SW of section 1, township 6 north, range 59 west, Morgan County, Colorado. This "D" sand stratigraphic trap reservoir was completely defined by 36 commercial wells.

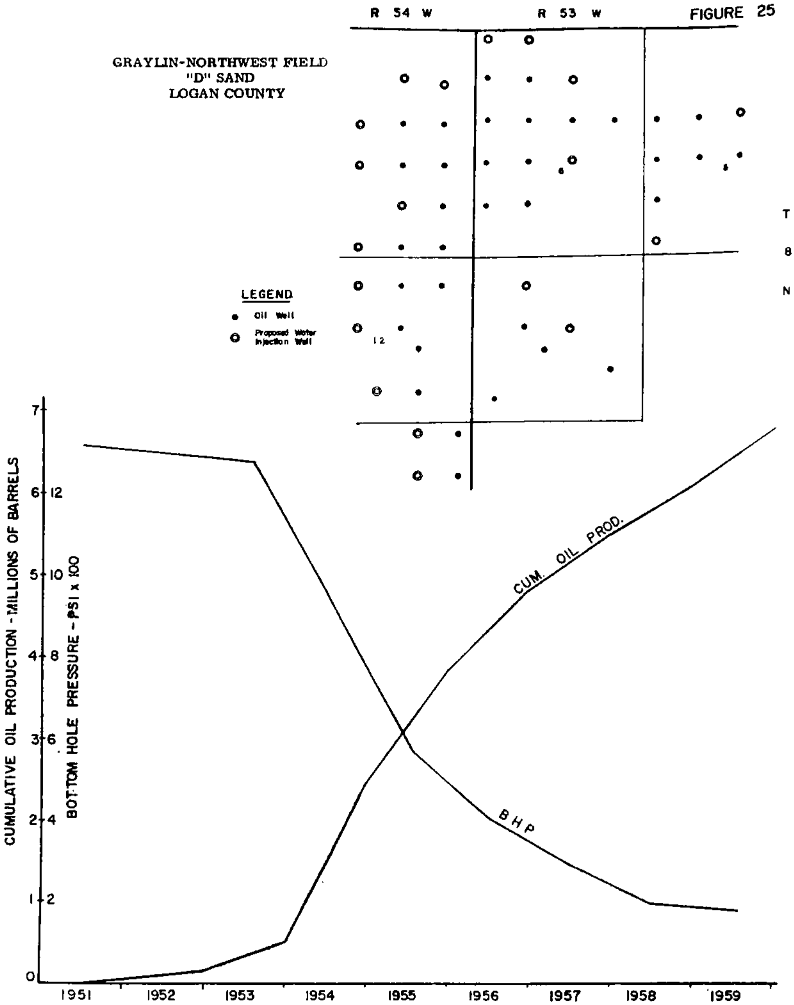
On November 19, 1959, Order No. 56-3 was issued by the Oil and Gas Conservation Commission, approving a unit agreement for the "D" sand reservoir and a plan for water injection. The Monsanto Chemical Company was designated as operator of the unit. The unit area consists of 2,320 acres. The flood program, as approved, will utilize 16 water injection wells, initially. The injection of water has not yet begun; however, the unit operator is now completing injection wells and making other necessary installations to begin the flood program.

The estimated oil recovery by primary means is 1,064,000 barrels, or about 19 percent of the original oil-in-place. An additional 1,142,000 barrels of oil is estimated as recoverable by water injection, for a total of 2,206,000 barrels, or about 40 percent of the original oil-in-place.

The cumulative production from the "D" sand, as of January 1, 1960, is 995,702 barrels of oil, and 1,737,745 MCF of gas (Fig. 26).

Kejr Field (North Unit)

On April 18, 1955, the Sohio Oil Company completed the discovery well in the north portion of the Kejr field. This well, the No. 1 Kejr "A," is located in the SE SE, section 2, township 2 south, range 56 west, Washington County, Colorado. Subsequently, there were 17 producing wells drilled to the "D" sand, primarily a stratigraphic trap. Prior to unitization, there

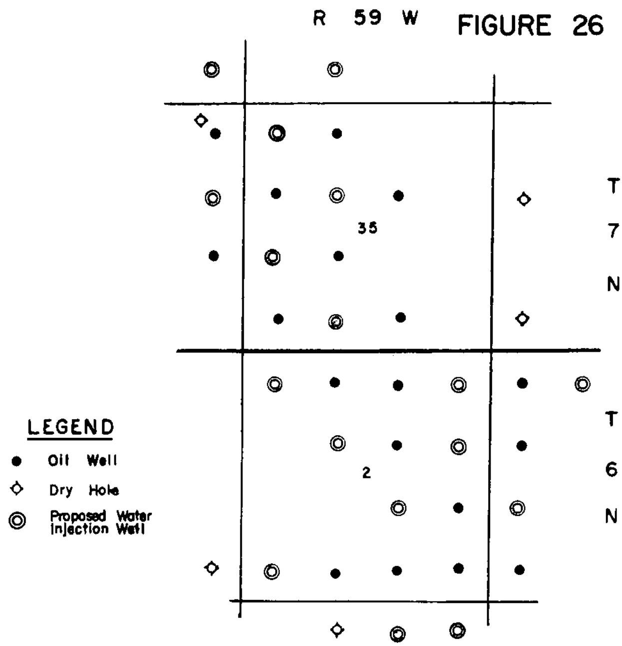


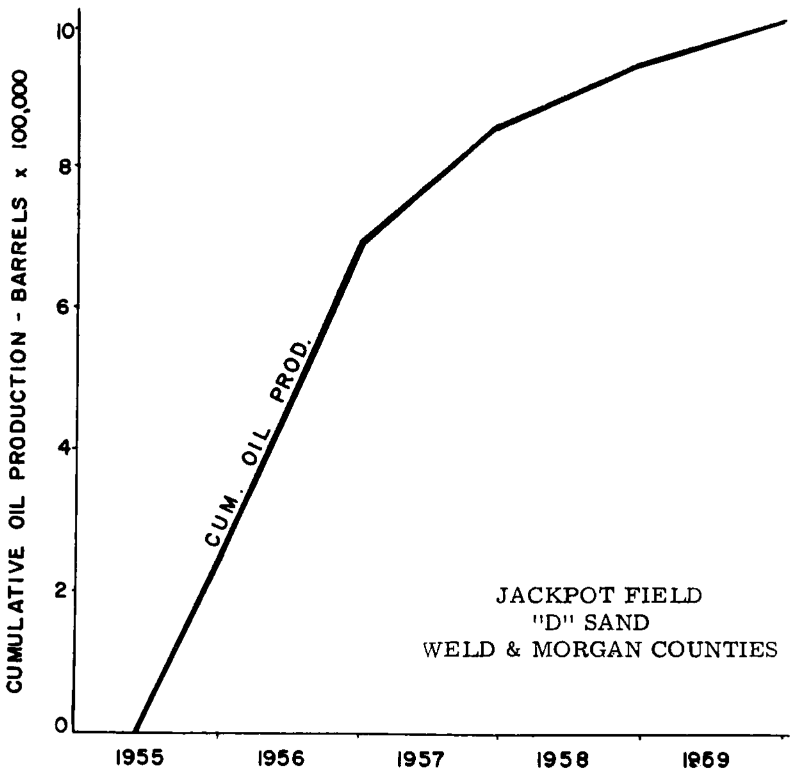
were no restrictive orders governing the production from this reservoir.

On September 26, 1958, Order No. 95-3 was issued by the Oil and Gas Conservation Commission, approving a unit agreement for the "D" sand reservoir, and a plan for water injection. The Sohio Oil Company was designated as operator of the unit, which consists of 840 acres of land. The flood pattern is of a peripheral type, and utilizes eight wells for the injection of water.

The ultimate recovery of oil by primary means is esti-

FIGURE 26


R 59 W
T 7 N
T 6 N
35
2
LEGEND
Oil Well
Dry Hole
Proposed Water Injection Well

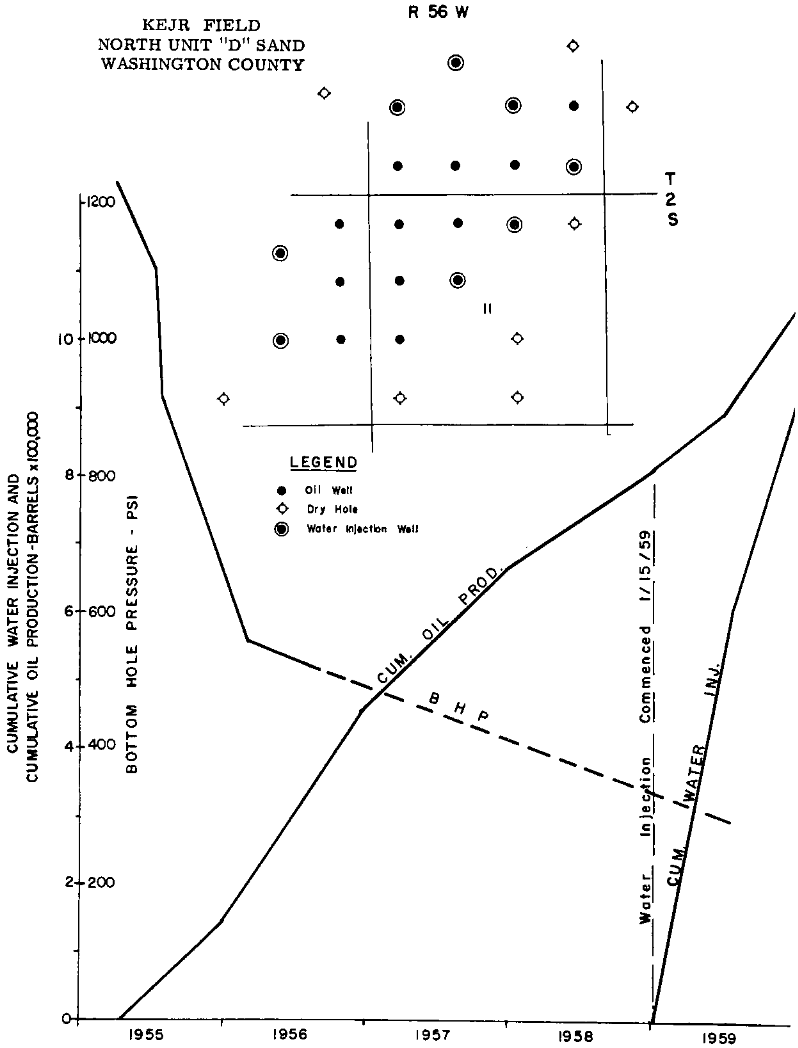

CUMULATIVE OIL PRODUCTION - BARRELS x 100,000
CUM. OIL PROD.
JACKPOT FIELD
"D" SAND
WELD & MORGAN COUNTIES
0
2
4
6
8
10
1955
1956
1957
1958
1959

mated to be 1,167,000 barrels, and an additional 1,500,000 barrels of oil will probably be recovered due to water flooding.

The initial injection of water into the "D" sand of the North Kejr Unit began on January 15, 1959, and as of January 1, 1960, 905,206 barrels of water were injected.

Cumulative production figures as of January 1, 1960, were 1,044,723 barrels of oil, and 403,239 MCF of gas (Fig. 27).

FIGURE 27



Kejr Field (South Unit)

On December 3, 1955, the discovery well for the south portion of the Kejr field was completed by the Dawson-Cramer Oil Company. The well is the No. 1 Kejr, located in the NE NW, section 14, township 2 south, range 56 west, Washington County, Colorado. There were 14 producing "D" sand wells completed in this area.

On May 27, 1958, the Oil and Gas Conservation Commission issued Order No. 95-2, which approved a unit agreement for the "D" sand of the South Kejr unit and a plan of water injection. The Sinclair Oil and Gas Company was designated as operator of this unit comprising 960 acres of land. There are presently five wells being used for the injection of water.

The estimated primary recovery of oil is 721,550 barrels, or 15.8 percent of the original oil-in-place. The additional oil to be recovered, due to water flooding, is estimated at 1,184,610 barrels, for a total of 41.7 percent of the original oil-in-place.

The initial injection of water began on September 18, 1958, and as of January 1, 1960, there had been 643,239 barrels of water injected into this reservoir.

As of January 1, 1960, there had been 721,829 barrels of oil, and 213,137 MCF of gas produced from this reservoir (Fig. 28).

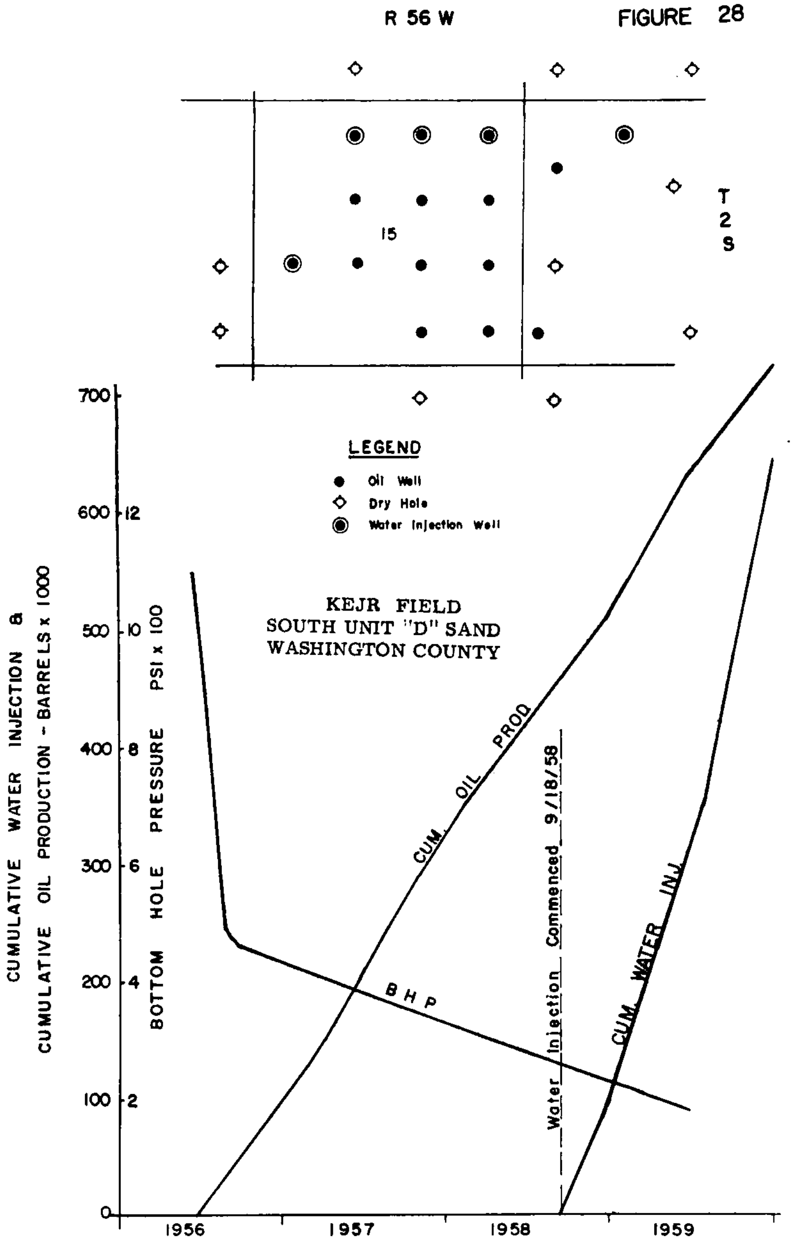
Leader Field

On May 23, 1954, Ginther, Warren & Ginther completed the discovery well in the "J" sand of the Leader field. This well was the No. 1 G. H. Leasure, located in the SE SE SW, section 17, township 2 south, range 59 west, Adams County, Colorado. There were seven wells drilled in this field, one gas well and six oil wells, all of them producing from a common stratigraphic trap.

During the first year of production, a rapid decline in oil production and an extremely rapid increase in gas-oil ratio took place, due to the gas cap moving into the oil zone of the reservoir. In the interests of conservation, the field was shut-in on March 8, 1955, and remained shut-in until July 9, 1956, at which time Order No. 59-6 was issued, which allowed the operators to begin producing their wells, provided that there would be no flaring or waste of reservoir energy.

On February 18, 1958, the Oil and Gas Conservation Commission approved a unit agreement and a pressure maintenance program by the injection of gas into the reservoir through the discovery well. The injection of gas commenced in April, 1957, and as of January 1, 1960, there had been 715,677 MCF of gas injected into the reservoir.

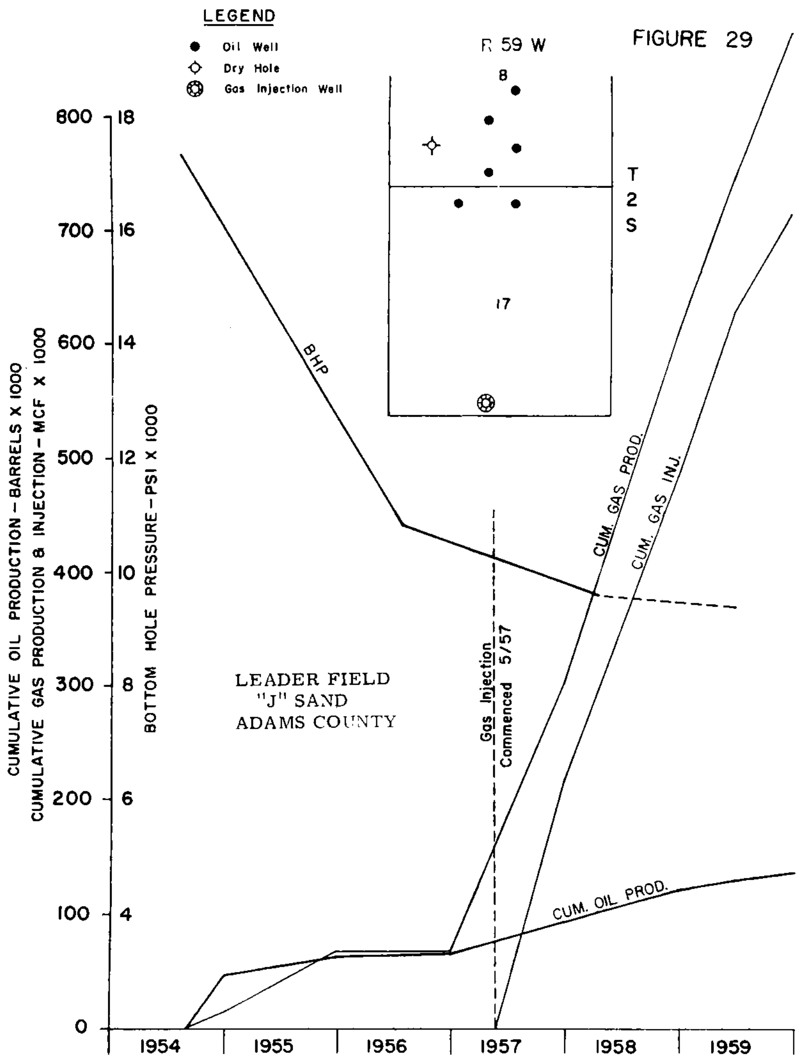
On April 30, 1959, Order No. 59-8 was issued by the Commission, approving a water flood program for the Leader field unit area. The initial injection of water began into one well,


R 56 W
FIGURE 28
T 2 S
15
LEGEND
Oil Well
Dry Hole
Water Injection Well
KEJR FIELD
SOUTH UNIT "D" SAND
WASHINGTON COUNTY
CUMULATIVE WATER INJECTION &
CUMULATIVE OIL PRODUCTION - BARRELS x 1000
BOTTOM HOLE PRESSURE PSI x 100
CUM. OIL PROD.
CUM. WATER INJ.
B H P
Water Injection Commenced 9/18/58
700
600
500
400
300
200
100
0
12
10
8
6
4
2
1956
1957
1958
1959

the Ryan No. 1, on September 11, 1959, and as of January 1, 1960, 18,051 barrels of water were injected into the reservoir (Fig. 29).

The unit area includes 1,040 acres of land, which covers the entire field. Total ultimate recovery of oil is estimated to be 766,000 barrels.

As of January 1, 1960, there had been 135,389 barrels of oil, and 872,641 MCF of gas produced from this field.



Lewis Creek Field

On July 30, 1953, The British-American Oil Producing Company completed the No. 1 Jorritsma well located in the NE SW SE, section 12, township 11 north, range 53 west, Logan County, Colorado, the discovery well for the "J" sand in the Lewis Creek field. The trap is a combination permeability barrier and closed structure.

On October 31, 1958, the Oil and Gas Conservation Commission approved a unit agreement and a plan for a water injection program. The British-American Oil Producing Company was designated as the operator of this unit consisting of 1,450 acres of land. The flood program is a property line type which utilizes five injection wells.

Engineering approximations indicate that there were 17,300,000 barrels of oil originally in place in this reservoir, and that 4,500,000 barrels, or 26 percent, would have been recovered by primary methods; however, by use of the water flood project now in operation, an estimated additional 2,500,000 barrels of oil will be recovered. The ultimate total recovery is estimated at over 40 percent of the original oil-in-place.

The initial injection of water began on May 13, 1959, and as of January 1, 1960, 1,346,455 barrels of water were injected into the reservoir.

Cumulative production figures, as of January 1, 1960, were 3,019,158 barrels of oil and 2,596,805 MCF of gas (Fig. 30).

Little Beaver ("D" Sand) Field

The "D" sand pool of the Little Beaver field was discovered on May 12, 1952, by the Goodall Oil Company's Wheatlake No. 1 well located in the SW SW SW, section 5, township 2 south, range 56 west, Washington County, Colorado. Immediately following the completion of this discovery well, the "D" sand reservoir was developed with 69 more oil wells.

The reservoir is a stratigraphic trap on monoclinal structure with porosity pinchout on the east and southeast, and an aquifer on the down-dip portion. The "D" sand has an average porosity of about 20 percent, and an average permeability of approximately 300 millidarcys.

Prior to unitization, the field was operating under a maximum efficient rate of production of 125 barrels of oil per well per day, with a penalty GOR of 800 to 1.

On August 20, 1957, the Oil and Gas Conservation Commission approved a unit agreement for the "D" sand. The Continental Oil Company was designated as operator of the unit consisting of 2,680 acres of land.

It is estimated that 9,401,000 barrels of oil would be recovered by primary methods, or 24.1 percent of the original oil-in-place. Based on engineering calculations, it is indicated

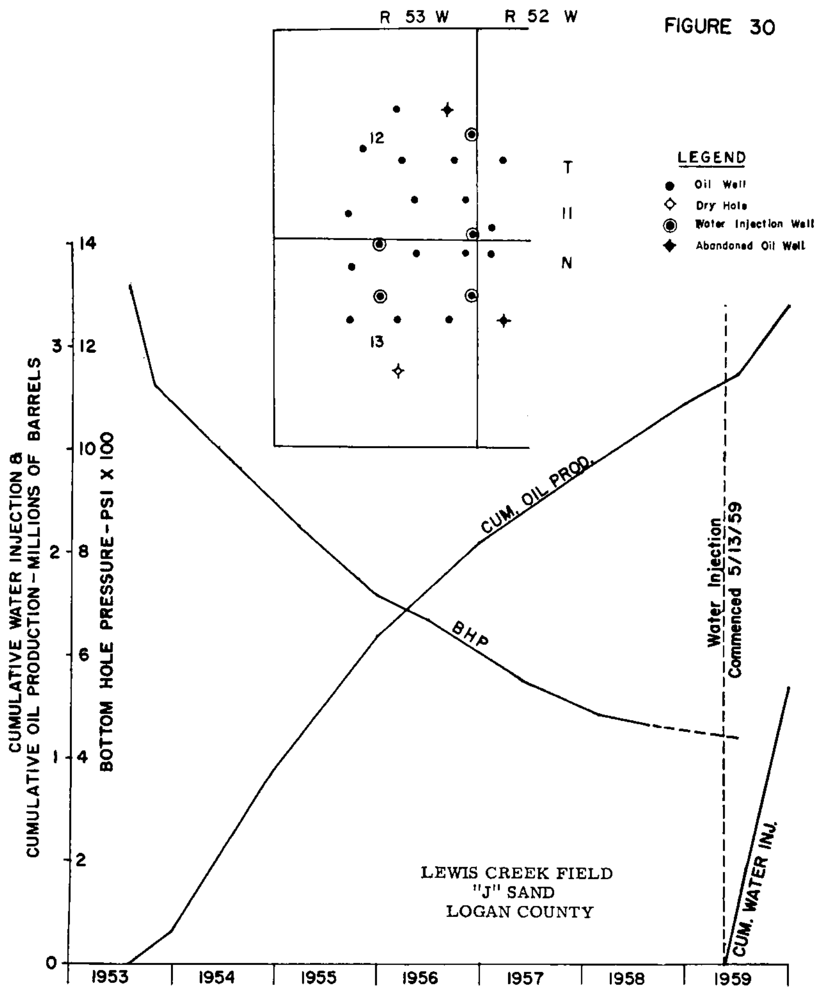
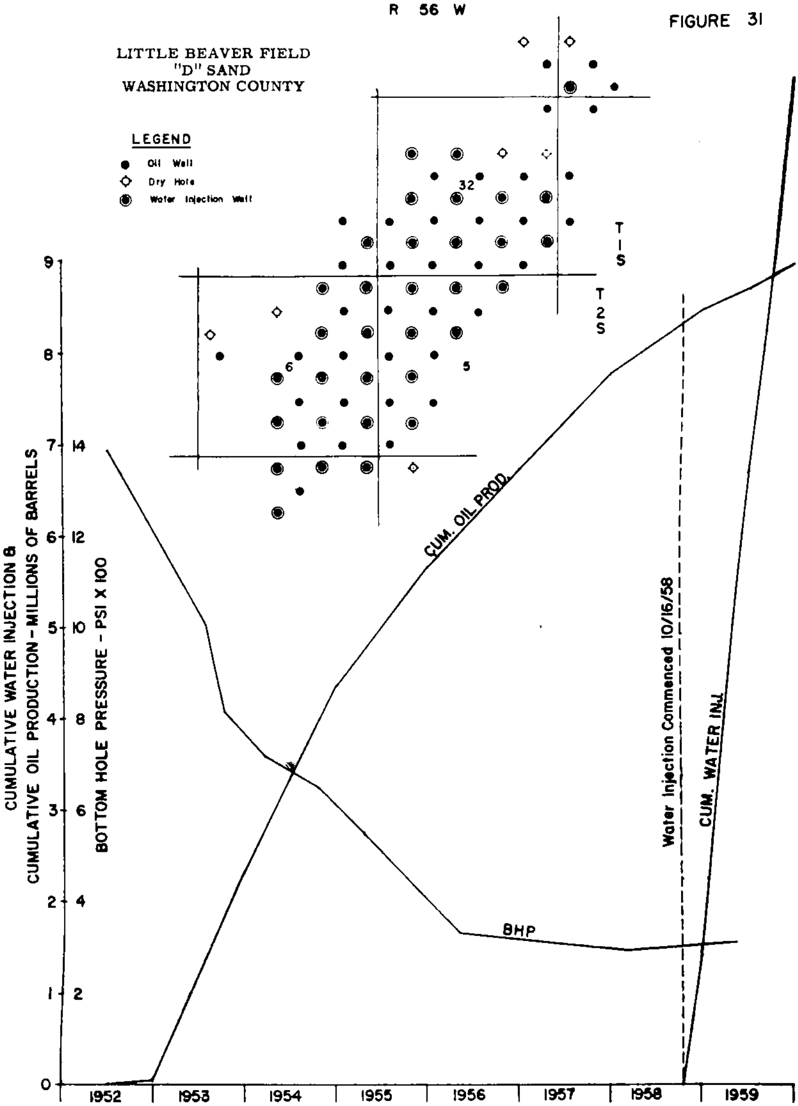


FIGURE 30

that ultimate recovery by water flooding will be 48 percent of the original oil-in-place, with the estimated ultimate recovery of oil from the Little Beaver "D" sand reservoir being 17,550,600 barrels.

The injection of water into this reservoir began on October 16, 1958, and as of January 1, 1960, 10,958,827 barrels of water had been injected. A "five-spot" plan is being used, and there are currently 33 water injection wells.

Cumulative production figures, as of January 1, 1960, were 8,927,052 barrels of oil, and 7,407,732 MCF of gas (Fig. 31).



Little Beaver-East Field

On November 24, 1954, the discovery well for the "D" sand reservoir of the Little Beaver-East field was completed. This well was Vaughey & Vaughey's No. 1 Downing, located in the NE NE NE, section 34, township 1 south, range 56 west, Washington County, Colorado. There were 23 producing wells drilled in the "D" sand of this field, all of which were oil wells. The reservoir is primarily a stratigraphic trap.

On March 18, 1958, the Oil and Gas Conservation Commission approved a unit agreement for the "D" sand reservoir. The Monsanto Chemical Company was designated as operator of this unit comprising 1,280 acres of land.

Subsequently, on April 22, 1958, the Commission approved a plan of water injection into the "D" sand reservoir. Primary recovery of oil has been estimated at 2,314,000 barrels, or 24.7 percent of the oil-in-place. With water flooding, it is estimated that an additional 2,386,000 barrels of oil, or 50.1 percent of the oil-in-place, should be recovered. The flooding plan will be a line-type flood, water being injected into the western or down-dip edge of the reservoir and flooding to the east. There are five injection wells in operation at the present time (Fig. 32).

The initial injection of water began on September 19, 1958, and as of January 1, 1960, 2,650,842 barrels of water had been injected into this reservoir.

The cumulative production figures as of January 1, 1960, were 1,825,255 barrels of oil, and 1,870,947 MCF of gas.

Luft Field

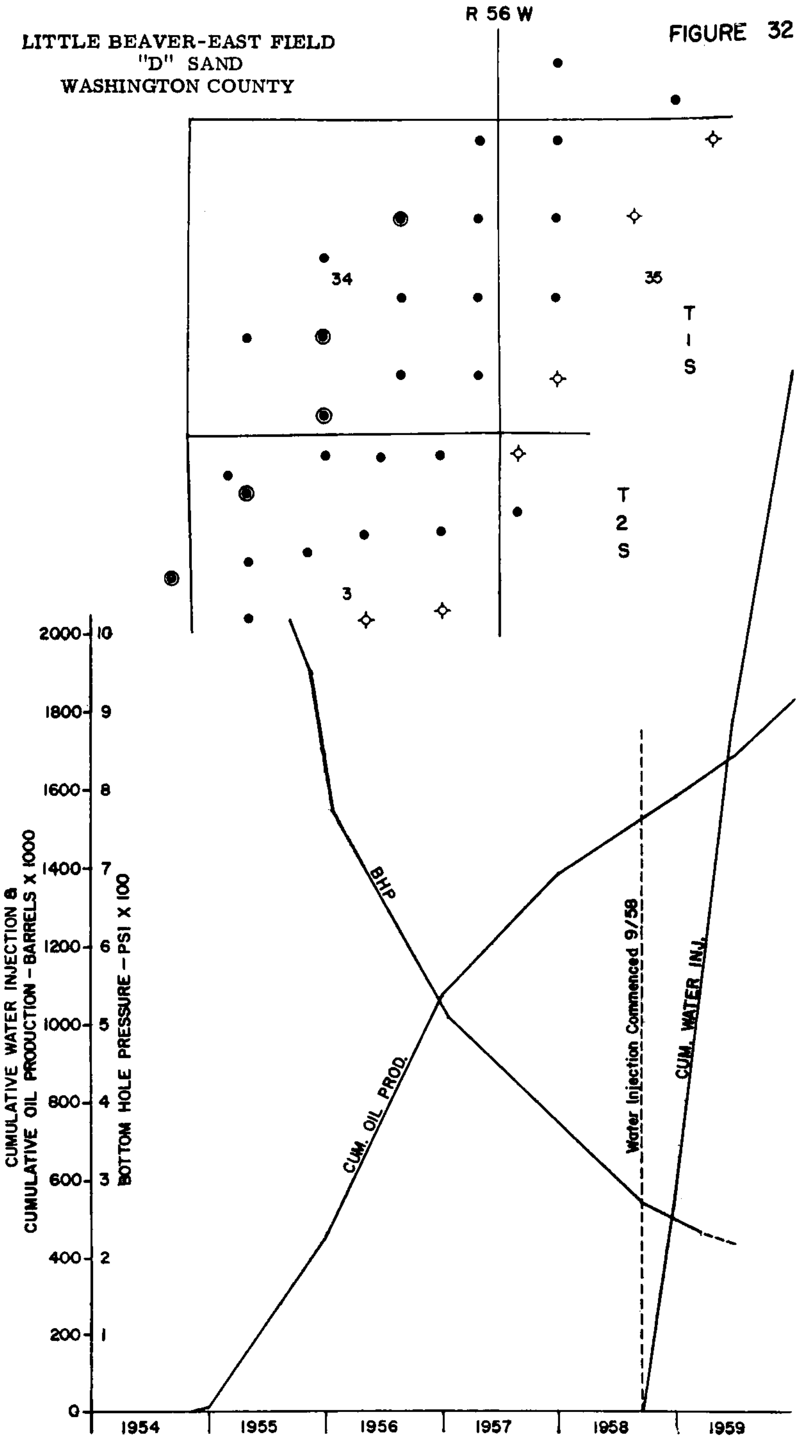
On April 20, 1952, the Plains Exploration Company completed the discovery well for the Luft field. This well, the No. 1 Conrad Luft, Jr., was located in the SW NE SW, section 17, township 8 north, range 53 west, Logan County, Colorado, and completed in the "D" sand. There were 35 producing wells completed in this field. The trap is due to a permeability pinchout on a structural nose.

On July 22, 1958, the Oil and Gas Conservation Commission issued Order No. 14-2, which approved a unit agreement for the "D" sand reservoir in the Luft field, and a plan for water flooding the reservoir. The Shell Oil Company was designated as operator of the unit comprising 1,080 acres of land. The operator is using 13 wells located around the edge of the reservoir for injection wells. This peripheral type flood plan will result in an estimated additional recovery of 1,175,000 barrels of oil. Total recovery of oil from this reservoir will be about 2,825,000 barrels.

The initial injection of water into the reservoir began on January 23, 1959, and as of January 1, 1960, 1,367,654 barrels of water had been injected into the reservoir.

FIGURE 32

LITTLE BEAVER-EAST FIELD
"D" SAND
WASHINGTON COUNTY



Cumulative production figures, as of January 1, 1960, were 1,714,176 barrels of oil, and 2,615,440 MCF of gas (Fig. 33).

Phegley Field

On June 6, 1955, the discovery well was completed by the Dawson-Cramer Oil Company in the "D" sand of the Phegley field. This well is the No. 1 Mintie Morgan, located in the SE SE, section 30, township 1 south, range 55 west, Washington County, Colorado. Subsequent development led to the completion of 14 producing wells in the "D" sand reservoir, a combined stratigraphic and structural trap.

On the 30th of April, 1959, the Oil and Gas Conservation Commission approved a unit agreement for operation of the "D" sand reservoir of the Phegley field. The Champlin Oil and Refining Company was designated as operator of this unit, comprising 1,600 acres of land. As a result of engineering studies, primary recovery for the "D" sand reservoir was estimated to be 1,195,000 barrels of oil, or 20.9 percent of the

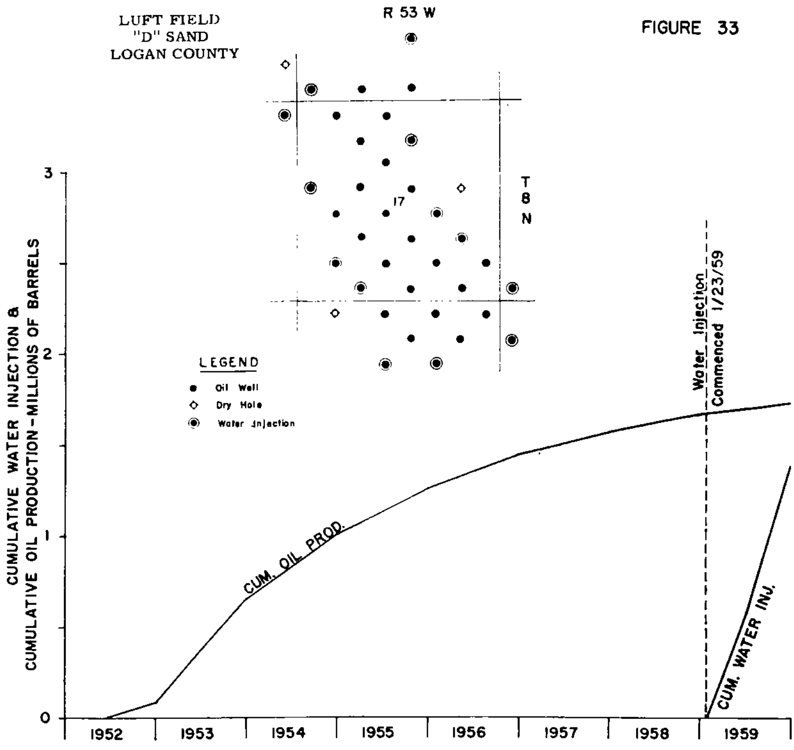


FIGURE 33

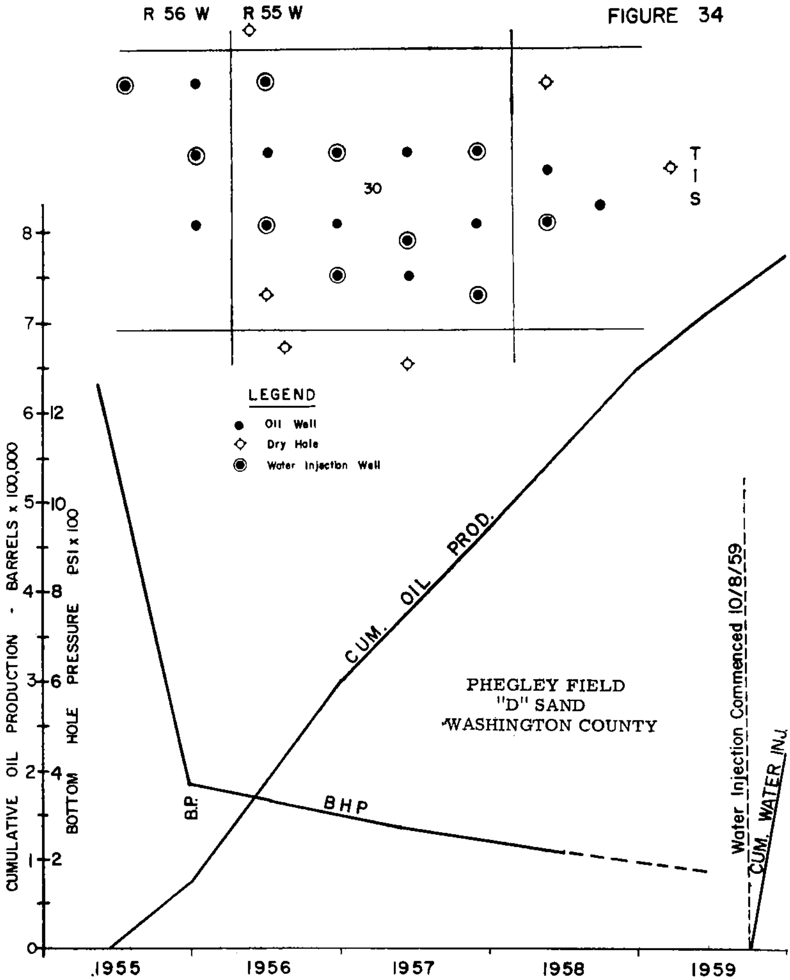
original oil-in-place. The additional oil that will be recovered due to water flooding is estimated to be 1,109,430 barrels, or 19.5 percent of the oil-in-place, with the total recovery being 40.4 percent of the oil-in-place, or 2,304,430 barrels.

A five-spot flood program has been approved that will eventually utilize 11 injection wells. Ten of these wells have been drilled and completed for water injection.

Cumulative production figures as of January 1, 1960, were 766,012 barrels of oil, and 212,674 MCF of gas (Fig. 34).

Plum Bush Creek Field

On December 7, 1954, the Kimbark Company completed



the discovery well in the "J" sand of the Plum Bush Creek field. This well was the No. 1 Porter, located in the SW SW, section 30, township 2 south, range 55 west, Washington County, Colorado. Subsequently, 40 producing wells were completed in this field. Prior to unitization, there had been no restrictive orders governing production from this reservoir, which is a combined stratigraphic and structural trap.

On July 22, 1958, the Oil and Gas Conservation Commission issued Order No. 57-6, which approved a unit agreement for operation of the "J" sand in the Plum Bush Creek field. The Continental Oil Company was designated as operator of the unit comprising 2,640 acres of land. On March 26, 1959, Order No. 57-7 was issued, which approved a water flood plan for the "J" sand reservoir of this field. The operator estimates that 8,975,600 barrels of oil, or 23 percent of the original oil-in-place, would be recovered by primary methods. An additional estimated recovery of 8,582,300 barrels of oil, or a total of 45.2 percent of the original oil-in-place, will be recovered by water flooding. A five-spot injection program is in use at the field, and 21 wells are being used for the injection of water. The initial injection of water began on June 15, 1959, and as of January 1, 1960, there had been 2,237,350 barrels of water injected into the reservoir.

The cumulative production figures, as of January 1, 1960, are 2,983,681 barrels of oil, and 974,207 MCF of gas (Fig. 35).

Rangely Field (Weber Reservoir)

Location and Characteristics

The Rangely field is located in northwestern Colorado on the northeastern edge of the Uintah Basin. The structure is an asymetrical anticline trending northwest-southeast, with 1,900 feet of surface closure. Dips range from 15° to 35° on the southwest flank, and from 4° to 6° on the northeast side. Major production in the field is from the Weber sandstone of Pennsylvanian age.

Due to the size and structural extent of the reservoir, fluid characteristics vary with structural position, as reported by the U. S. Bureau of Mines in its "Report of Investigations 4761." The gravity of the crude varies from 32° to 34° API. The original saturation pressure varied, by virtue of structural position, from 2,560 psia to 1,960 psia, and the original solution gas-oil ratio ranged from 440 cubic feet per barrel at the gas-oil contact to 230 cubic feet per barrel at the oil-water contact. One of the outstanding characteristics of the reservoir fluids is the high nitrogen content of the gas, which varies between 14.6 and 23.7 mol percent.

The top of the Weber sandstone lies at depths ranging from 5,500 to 6,500 feet, and is considered to be about 1,200

FIGURE 35

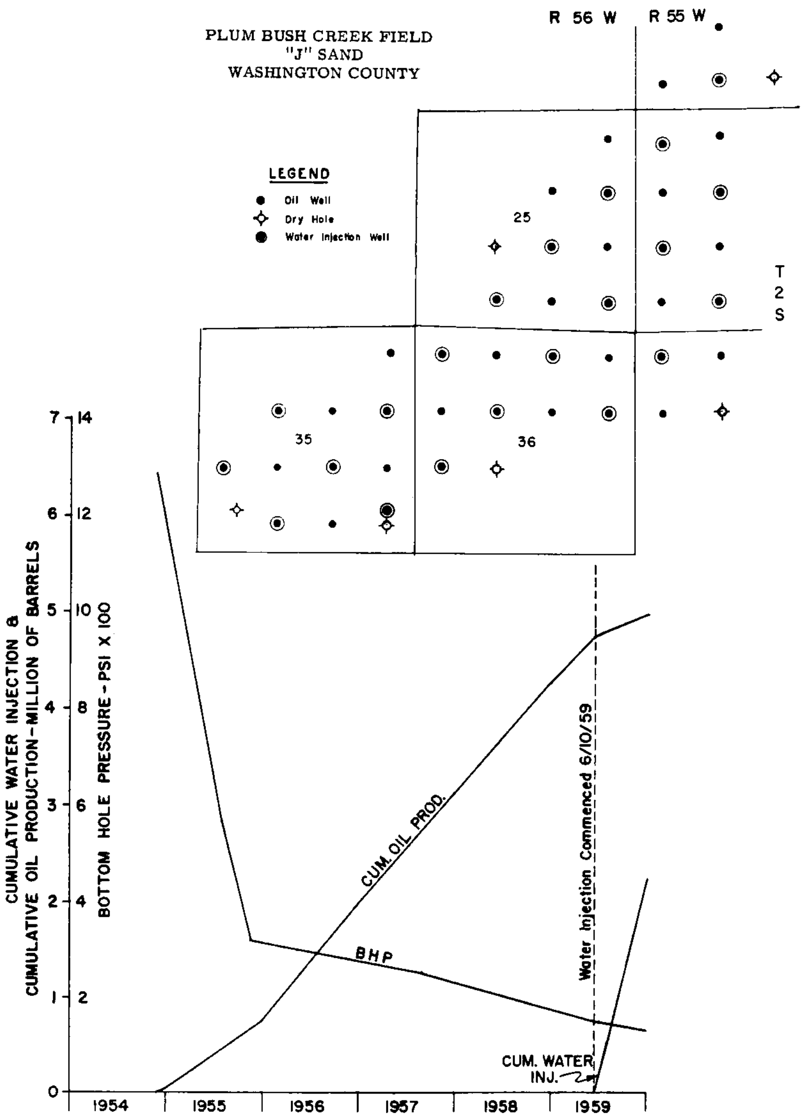


FIGURE 35

feet thick, with the oil-pay interval distributed through the uppermost 550 to 600 feet. The pay zone is a very fine-grained, calcareous sand, light-colored and grading to reddish in the bottom. Permeabilities in the pay section of several hundred millidarcys have been observed; however, the over-all average is reported to be 10 to 15 millidarcys, with distribution being from good on the west end to very poor on the east. The average porosity has been calculated at approximately 12 percent. Productive limits of the field cover an area of approximately 19,000 acres. In the central area, there is an overlying gas cap of 75 to 100 feet thick, defined by the original gas-oil contact at an elevation of 320 feet below sea level. The original oil-water contact was established at an elevation of 1,160 feet below sea level.

History of Production Practices

1. Development and Production—The original discovery of oil in the Weber reservoir was made in August, 1933, by The California Company in the drilling of its Raven No. 1-A well, located in the NW SE, section 30, township 2 north, range 102 west. A total of 8,138 barrels of oil were produced from this well while testing in 1933, after which it was shut in. Development of the reservoir was deferred approximately ten years, due mainly to the cost of transportation to markets. With petroleum demands increased by World War II, full-scale development commenced in 1943.

From 1943 to 1945, the major portion of the oil produced was trucked to refineries in Salt Lake City, Utah, and to the railroad terminal at Craig, Colorado. In September, 1945, a 10-inch pipeline was completed between Rangely and Wamsutter, Wyoming, with a daily capacity of about 30,000 barrels. With this pipeline and continued trucking, the daily average production from the field climbed to approximately 37,000 barrels. In November, 1948, a second 10-inch pipeline was completed from Rangely to Salt Lake City, Utah, and the rate of oil production was approximately doubled. Production from the Weber reservoir gradually increased until the highest rate occurred during the month of May, 1956, when a daily average of 81,500 barrels of oil was produced. After this peak month, the rate of production commenced to decline until now approximately 45,000 barrels of oil are being produced daily. It is anticipated that, as a result of secondary recovery methods now being employed, the rate of production will begin to increase during the year 1960.

The operators formed a Rangely Engineering Committee in 1946, for the purpose of furthering orderly development and maintaining cooperative operations of the field. The committee, headed by a resident engineer, was composed of key field personnel—usually engineers or geologists. It was charged with planning and recommending field-wide coring programs, executing reservoir pressure and gas-oil ratio surveys, and other duties coordinating activities of the various operators on a field-wide basis. This committee laid the foundation for unitization, which was later accomplished.

2. **Orders of the Oil and Gas Conservation Commission**— The first action of the Commission in the Rangely field was on December 6, 1951, at which time it issued its Orders No. 2-1 which, among other things, established 40-acre drilling and spacing units; shut in high gas-oil ratio wells; requested periodic gas-oil ratio and bottom-hole pressure surveys, and production reports on an individual well basis. The order also provided for a per well gas limitation of 150 MCF per day, which restriction was temporarily suspended pending further hearing.

As a result of a series of hearings, the Commission issued its Order No. 2-8, which, among other things, provided that during the interval July 1, 1952, to December 31, 1952, no gas should be produced from any well in excess of 150 MCF per day unless such excess gas be reinjected into the Weber reservoir. This order further provided that after January 1, 1953, no gas should be produced unless it be used for field operations, sold, or returned to the reservoir.

The validity of the no-flare ruling of the Commission was tested in the District Court in and for the City and County of Denver, and the Court sustained the Commission ruling.

Following the Court's decision, a series of lengthy hearings was held, and, as a result of various Commission actions, full-scale injection into the Weber reservoir commenced on September 15, 1953, and flaring was essentially eliminated. The initial injection plan, which was modified from time to time, included the following wells for injection:

Operator	Well
The California Company	Fee 54
	Fee 65
	Emerald 34
	McLaughlin 38
Phillips	Levison 16
Sharples	McLaughlin 5-33
Stanolind	Hagood 6
	Rector 4
	F. V. Larson B-11
Texas	Carney 12-5
	U.P. 57-21
	U.P. 34-31

The decision of the District Court was appealed to the Supreme Court of Colorado, and on May 16, 1955, the Supreme Court rendered its decision which invalidated the "no-flare" ruling in the Rangely field, and put an end to the Commission's power to require the injection of all produced gas into the Weber horizon. Among other things, the Court stated, "It . . . is apparent that delegation of authority by the Legislature to the Oil and Gas Conservation Commission has been stintingly, sparingly, and almost grudgingly granted."

As a result of the Court's decision, the Commission issued an order which limited production to previous daily averages and allowed a "hardship flare" over and above the gas required for operations. This order was issued with the expectation that the operators would utilize gas injection equipment installed.

On July 17, 1956, the Commission, after holding additional hearings, issued its Order No. 2-28, effective July 23, 1956, which, among other things, set a maximum daily oil allowable of 300 barrels per well per day, and established a penalty gas-oil ratio for all producing wells at 600 cubic feet of gas per barrel of oil produced. The order also provided credit for gas injection, and a shut-in clause for wells with ratios in excess of 20,000 cubic feet per barrel.

The final climax to restrictive orders and years of unit negotiations came on August 21, 1957, when the Commission issued its Order No. 2-31 approving the unit agreement for operation of the Weber reservoir of the Rangely field. Subsequently, on October 1, 1957, the Commission's Order No. 2-32 became effective, which basically approved a fluid injection program and plan of operations.

3. Fluid Injection History—Injection into the Weber reservoir of the Rangely field commenced on November 26, 1950, when The California Company started gas into its Fee No. 65 well. The Texas Company started injecting gas into its U.P. No. 57-21 on December 4, 1950. These two wells constituted the initial pilot injection system, and until November, 1952, were the only wells in which gas was being injected. Cumulative injection through October, 1952, amounted to 1,904,552 MCF.

A dispersed type program of gas injection was commenced in November, 1952, which involved the conversion of the following 18 oil wells to gas injection wells:

Company	Well	Date of Conversion
California	Emerald 34	11/ 6/52
Texas	U.P. 34-31	7/15/53
Texas	Carney 12-5	7/15/53
Sharples	McLaughlin 5-33	7/28/53
Stanolind	L. N. Hagood "A"-6	8/24/53
Stanolind	F. V. Larson "B"-11	8/24/53
Stanolind	E. Rector 4	8/30/53
California	McLaughlin 38	9/11/53
California	Fee 54	9/12/53
Phillips	Levison 16	9/15/53
Phillips	M. B. Larson D 2-26E	11/ 53

Company	Well	Date of Conversion
Texas	U.P. 32-27	3/ 54
California	Emerald 6	3/12/54
Phillips	Levison 12	5/ 54
Texas	U.P. 56-21	11/ 3/54
Texas	U.P. 67-32	11/ 5/54
California	Fee 4	1/ 55
California	Gray B-10	4/20/55

The next change in the Weber reservoir fluid injection history came about as a result of unitization. As of January 1, 1960, 34 oil wells were converted to inject water, and 20 wells were injecting gas (Figs. 37 and 38). The dispersed gas injection system is slowly being changed to a crestal type injection plan.

4. Entrada Gas Storage—On November 22, 1955, the Oil and Gas Conservation Commission approved a pilot operation for the purpose of determining the feasibility of injecting gas into the Entrada formation for storage purposes. Following this approval, The Texas Company commenced injection into the Entrada formation through its U.P. 70-32 well on March 8, 1956. During 1956, a total of 944,765 MCF of dry gas, and 2,272,879 MCF of wet gas were injected. During 1957, an additional 26,791 MCF of dry gas, and 1,089,199 MCF of wet gas were injected, with the cumulative injected volume of gas being 4,333,634 MCF during this operation. Current plans call for determining the productivity of this gas.

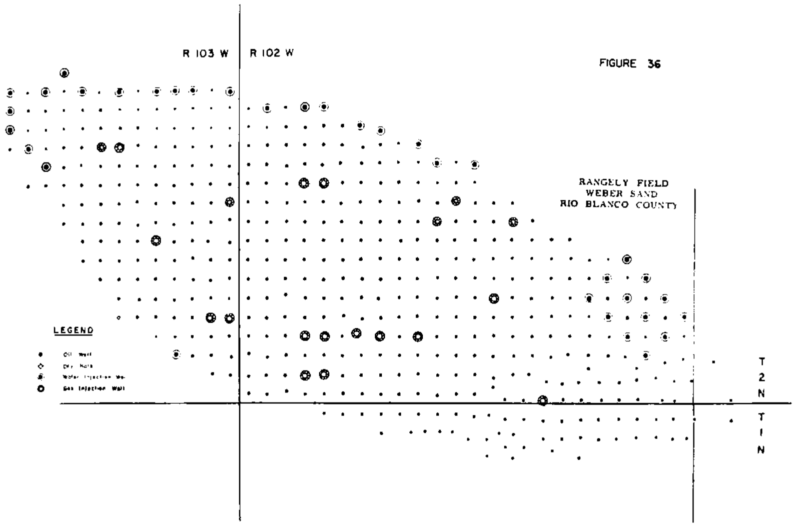
5. Reserves—As previously mentioned, the Weber reservoir of the Rangely field was originally discovered in 1933; however, full-scale development and production did not commence until 1944. With continuous operation after 1944, a cumulative total of 276,426,933 barrels of oil, and 349,965,784 MCF of gas had been produced as of January 1, 1960.

As of January 1, 1960, the total volume of gas injected (commenced in November, 1950) was 193,173,430 MCF. The total volume of water injected as of January 1, 1960 (commenced December, 1957) was 8,760,514 barrels.

Primary oil reserves have been estimated at 350,000,000 barrels, with an estimated additional 438,000,000 barrels to be recovered as a result of unit operations and pressure maintenance programs, for a total recovery of 788,000,000 barrels of oil.

Roggen-Southwest Field

On November 5, 1953, the discovery well for the Roggen-Southwest field was completed in the "D" sand. This well was the Spears Free Clinic No. 1 J. Zimbleman, Jr., in the SE NE, section 22, township 2 north, range 63 west, Weld County, Colorado. There were nine producing oil wells completed in two separate reservoirs of the "D" sand of this field.



On October 22, 1957, the Oil and Gas Conservation Commission issued its Order No. 111-1, approving a unit agreement and a water flood plan for the northwest sand lens, only. This unit consists of 400 acres of land. No injection is taking place in the southeast lens.

As of January 1, 1960, there were 549,042 barrels of oil, and 1,037,506 MCF of gas produced from the field, with 233,144 barrels of oil and 274,217 MCF of gas produced from the unitized reservoir. It is estimated that 570,000 barrels of oil will be recovered under primary production, and that an additional 220,000 barrels will be recovered as a result of fluid injection, for a total recovery of 790,000 barrels.

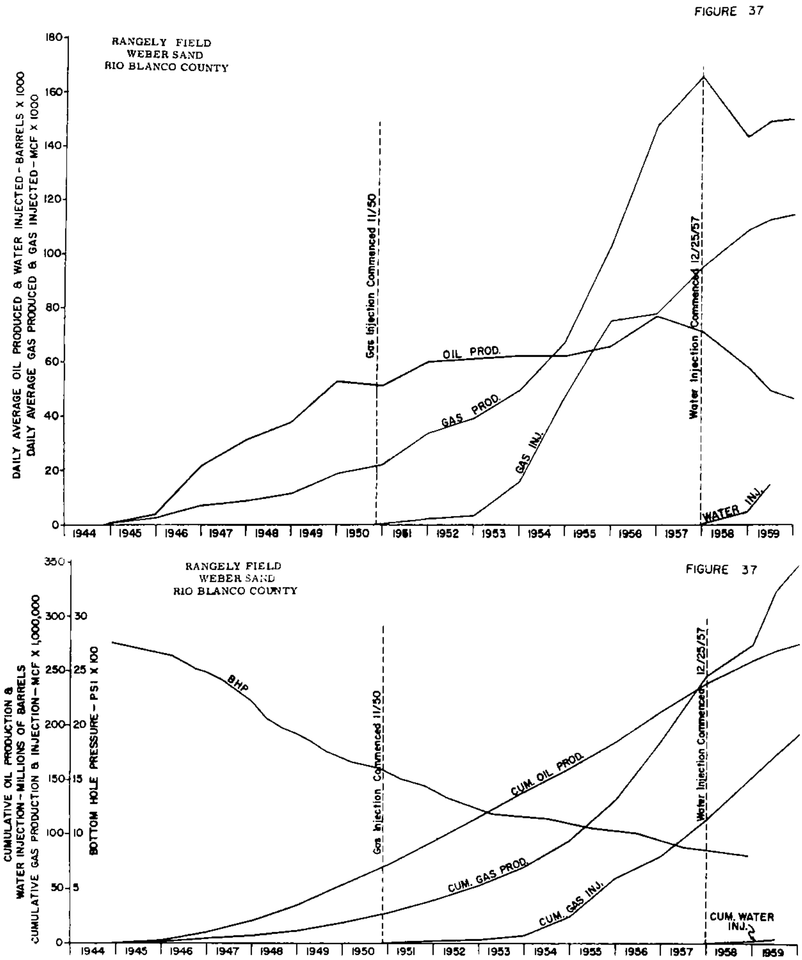
The injection of water began on November 14, 1957, and as of January 1, 1960, 624,846 barrels of water had been injected into the reservoir through one well located at the western edge of the field (Fig. 38).

Willard Field

The Willard field, located in section 19, township 7 north, range 54 west, Logan County, Colorado, was discovered by the Sinclair Oil Company on October 23, 1951, by the drilling of its W. M. Phillips No. 1 well. Production is from the "D" sand at a depth of approximately 5,100 feet.

The reservoir is a stratigraphic trap with no significant structure, typical of most "D" sand reservoirs of the Denver-Julesburg Basin. The average net pay of the field is approximately 13 feet.

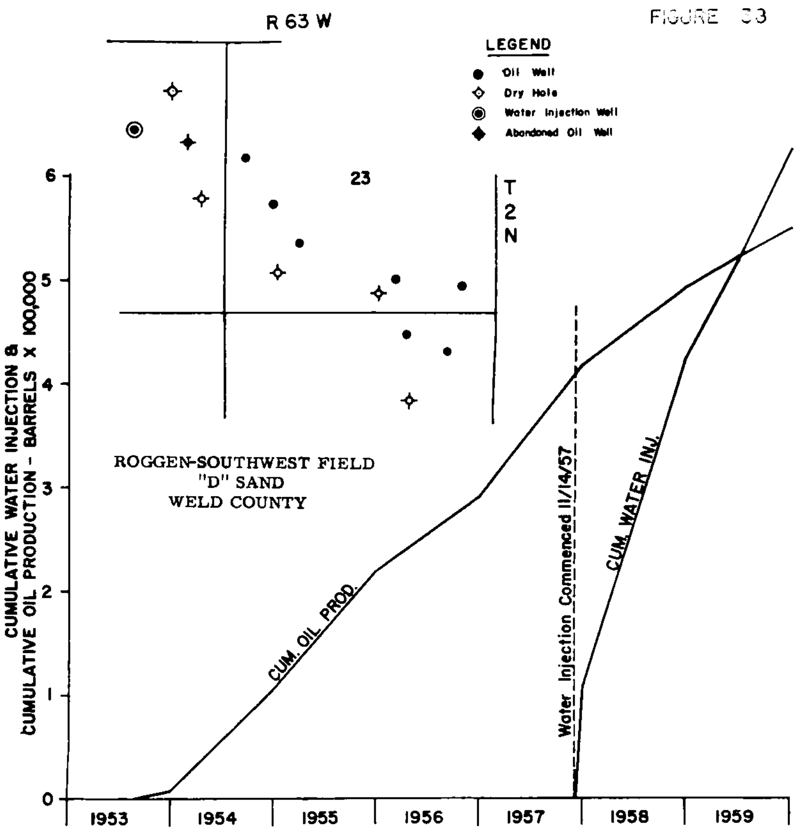
Four wells were completed in this field on 20-acre loca-



tions. The initial production varied from 230 barrels to 98 barrels per day of 38° gravity oil. Early in the life of the field, one well began producing a considerable volume of water and was shut in.

On August 7, 1956, the Oil and Gas Conservation Commission issued its order permitting water injection into the "D" sand reservoir. The W. M. Phillips No. 3 well was recompleted as a water source and injection well. The water is obtained from a sand at a depth of 960 feet, pumped to the surface, metered, returned through a closed system, and injected by gravity into the "D" sand through perforations from 5,111 to 5,127 feet.

No unit agreement exists in this field, since the operator,



the Sinclair Oil and Gas Company, is the only lease owner in the field. The recovery estimates for this small reservoir are 92,000 barrels of oil by primary methods, and 73,000 barrels of oil by secondary methods. The total estimated recovery of oil from this reservoir is 165,000 barrels.

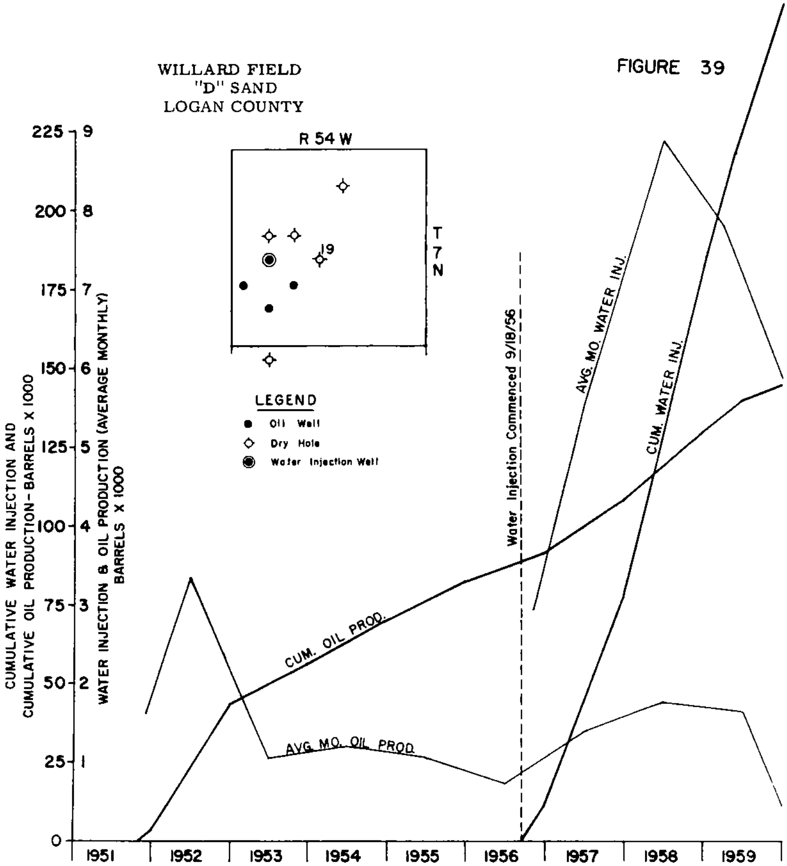
The initial injection of water began on September 18, 1956, and as of January 1, 1960, there had been 264,523 barrels of water injected.

Cumulative production figures as of January 1, 1960, were 143,738 barrels of oil, and 153,269 MCF of gas (Fig. 39).

Wilson Creek Field

General

The Wilson Creek field is in the northern part of Rio Blanco County in western Colorado, near the town of Meeker. The original discovery, drilled jointly by The Texas Company and The California Company on a closed anti-cline in 1938, encountered oil in the basal Morrison. This well, Unit No. 1,



is located in the SW NW, section 35, township 3 north, range 94 west. The Entrada sand, the second producing oil reservoir in the field, was discovered by the Unit No. 5 well, located in the NE NE, section 34, township 3 north, range 94 west.

A federal unit was formed for the field and was approved November 24, 1936. The unit covers 31,541 acres, with participating areas of 3,194.26 acres in the Morrison and 950.12 acres in the Sundance.

Twenty-one commercial oil wells were completed in the Morrison formation, and 18 wells in the Entrada formation.

One of the most outstanding features of the field is its location in rugged mountain terrain. Surface elevations of the wells vary from about 7,600 to 8,600 feet, and for many years it had the reputation of having the highest producing well in the world. Locations were extremely costly because of the difficult terrain, and it is not unusual to drive a considerable distance in going from offsetting wells.

The field is entered from the north near the town of Axial on State Highway 13, and from the south at a junction approximately five miles west of Meeker on State Highway 64. The south entry has affectionately been referred to as the "Little Burma Road," as a result of a comparison made by returning veterans from the Burma theatre after World War II.

Water which is produced from both the Morrison and Entrada is disposed of by injection into zones in the Mancos.

Although some 12 years old, the field is one of the outstanding oil producers in the State, and still ranks third in daily average oil production. Production from the two individual zones is considered below.

Morrison Formation

As previously mentioned, the original discovery of oil in the Wilson Creek field was made in basal sands of the Morrison formation of Jurassic age, with the effective pay section ranging from 20 to 35 feet throughout the field. On initial test, the discovery well flowed 492 barrels of 47° API, paraffin base crude oil a day. The original shut-in bottom-hole pressure was 2,100 psi. The productive limits of the Morrison reservoir extend over approximately 3,890 acres.

Following discovery, joint engineering committee meetings were set up by the only two operators in the field (Texas Company and The California Company), and the reservoir has been produced throughout its entire life at a maximum efficient rate of production, as determined by this engineering committee. A pressure maintenance program by gas injection was commenced May 14, 1946, when gas was initially injected into the Morrison pay through Unit well No. 20, located in the SW NE, section 34, township 3 north, range 94 west. As indicated in the graph (Fig. 40), bottom-hole pressure decline has been materially affected as a result of production practices and gas injection. In order to further increase the ultimate recovery from this reservoir, a water injection project was commenced in January, 1959. The water is injected into the flank of the pay zone, and it appears that the water is successfully moving oil from the flanks into the productive area without the necessity of drilling additional costly wells.

As of January 1, 1960, the cumulative production from the reservoir was 25,828,405 barrels of oil and 13,505,777 MCF of gas. The cumulative volume of gas injected to the above date was 7,094,838 MCF, and the cumulative injected water was 642,523 barrels.

Entrada Sand

Discovery of oil in the Entrada occurred in March of 1941, some three years after the field discovery. This reservoir covers an area of approximately 1,298 acres, and has a very active

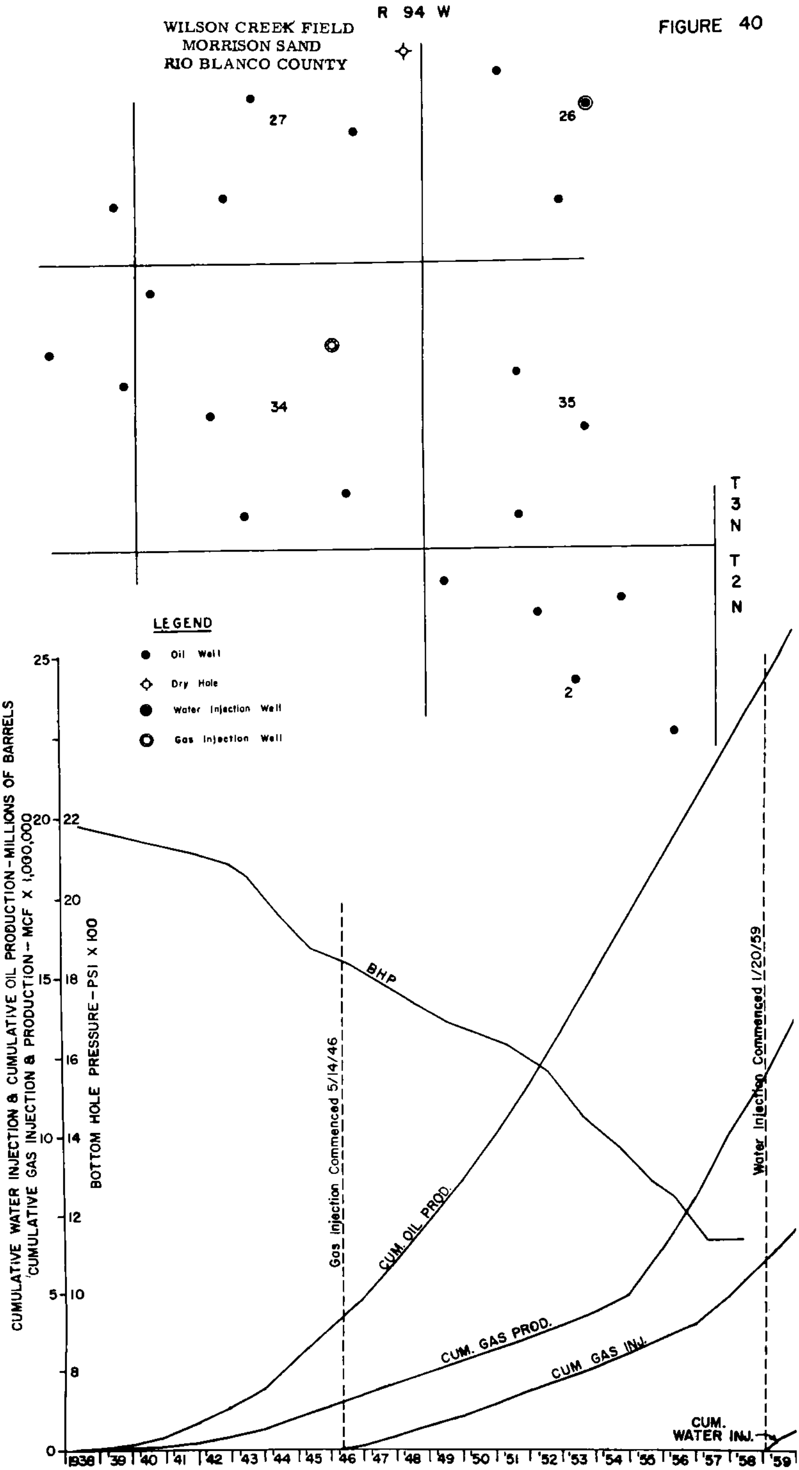


FIGURE 40
WILSON CREEK FIELD
MORRISON SAND
RIO BLANCO COUNTY
R 94 W
27
26
34
35
2
T 3 N
T 2 N
LEGEND
Oil Well
Dry Hole
Water Injection Well
Gas Injection Well
CUMULATIVE WATER INJECTION & CUMULATIVE OIL PRODUCTION - MILLIONS OF BARRELS
CUMULATIVE GAS INJECTION & PRODUCTION - MCF X 1,000,000
BOTTOM HOLE PRESSURE - PSI X 100
BHP
CUM. OIL PROD.
CUM. GAS PROD.
CUM GAS INJ.
CUM. WATER INJ.
Gas Injection Commenced 5/14/46
Water Injection Commenced 1/20/59
0 5 10 15 20 25
8 10 12 14 16 18 20 22
1938 '39 '40 '41 '42 '43 '44 '45 '46 '47 '48 '49 '50 '51 '52 '53 '54 '55 '56 '57 '58 '59

water drive, as shown by water production and the fact that the bottom-hole pressure declined only 123 psi from 1953 to 1958, during which time some 3,500,000 barrels of oil and 19,000,000 barrels of water were produced. The oil gravity is essentially the same as in the Morrison, 48° API; however, the oil was considerably more undersaturated with an original gas-oil ratio of only 75 to 80 cubic feet of gas per barrel of oil produced.

As in the Morrison, the rate of production from this reservoir has been on an engineering basis, consistent with production and pressure information obtained and studied. To supplement the natural water drive, gas injection was commenced in October, 1956, and has been continuous since that time, with the cumulative gas injection, as of January 1, 1960, being 1,160,304 MCF (Fig. 41).

As of January 1, 1960, cumulative production from this reservoir has amounted to 16,680,553 barrels of oil, and 4,242,579 MCF of gas.

Xenia-West ("J" Sand) Field

The original discovery of oil in the "J" sand reservoir of the Xenia-West field, a combined stratigraphic and structural trap, was made on December 23, 1954, when the Kingwood Oil Company completed the No. 2 Snyder well located in the SW SE, section 2, township 2 north, range 54 west, Washington County, Colorado. On October 20, 1959, the Commission issued Order No. 55-3, which approved a unit agreement and a secondary recovery program utilizing water injection.

The water flood plan provided for the conversion of three oil wells to water injection wells as the initial injection system. These three wells are located on the northern edge of the field. Four additional wells were selected and approved as future water injection wells. The Kingwood Oil Company is the designated unit operator. The three initial injection wells commenced injection of water on November 6, 1959, and as of January 1, 1960, 43,727 barrels of water had been injected (Fig. 42).

Primary reserves have been estimated at 380,000 barrels of oil. It is estimated that an additional volume of 950,000 barrels of oil will be recovered by water flooding.

The cumulative production, as of January 1, 1960, is 1,063,260 barrels of oil, and 813,871 MCF of gas.

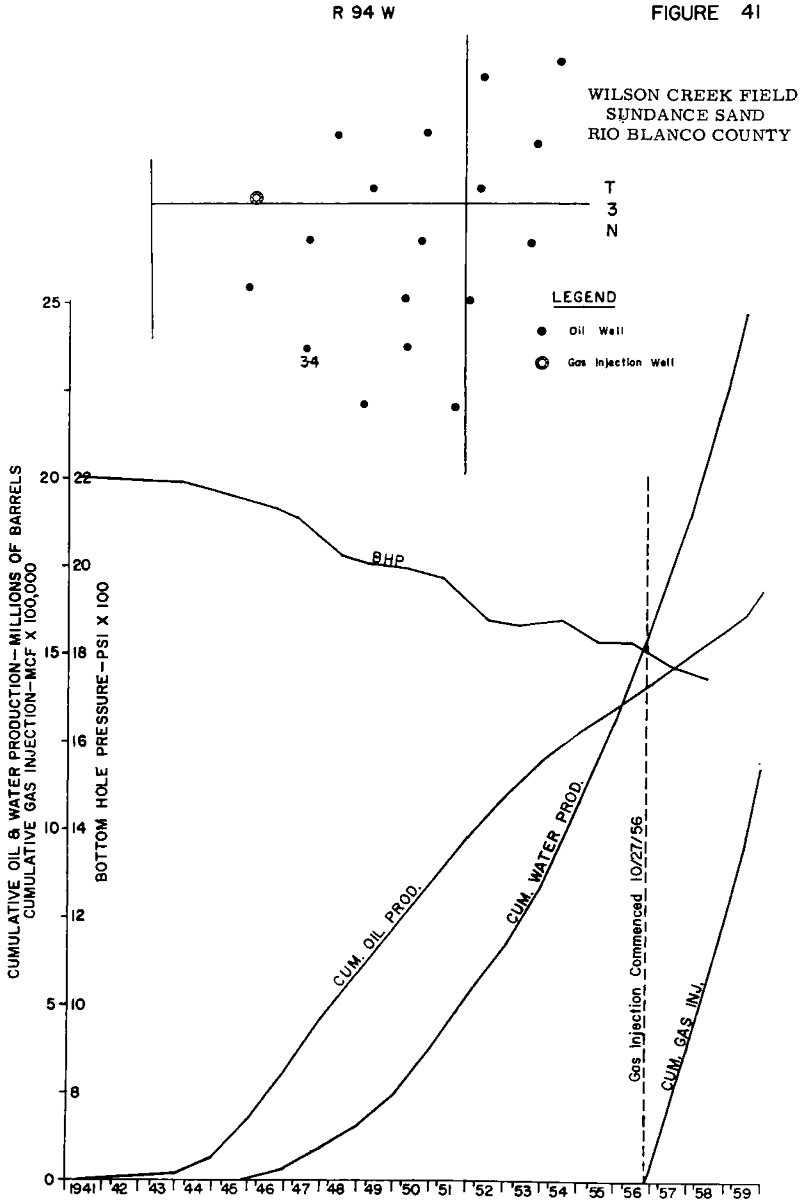
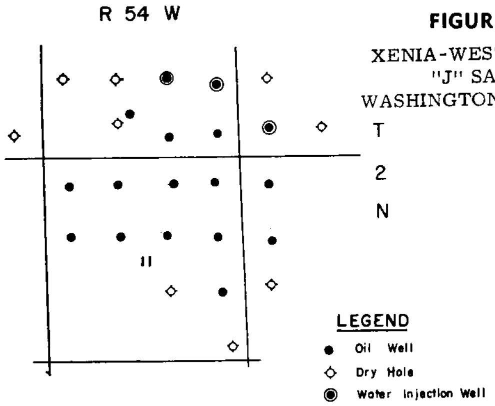
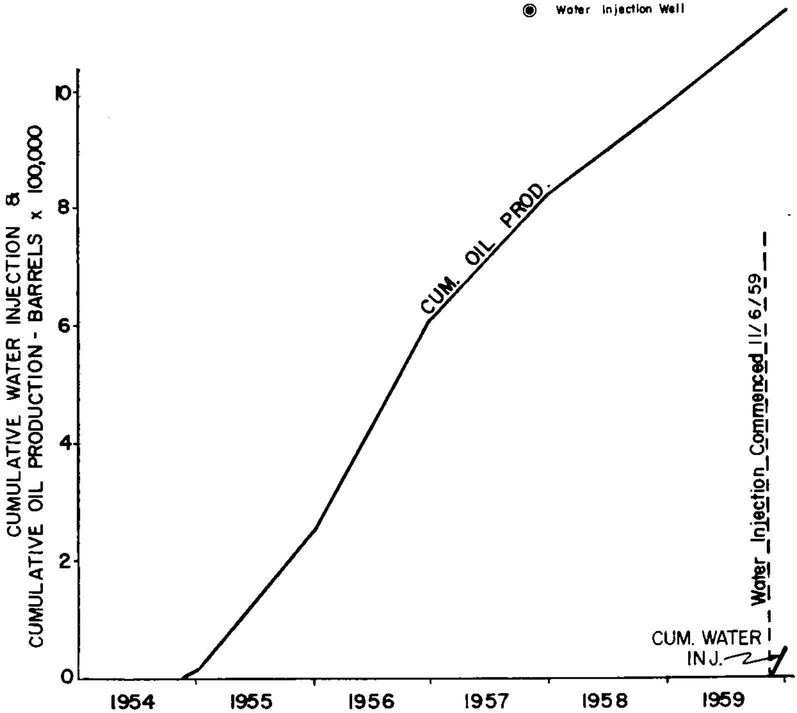

R 94 W
FIGURE 41
WILSON CREEK FIELD
SUNDANCE SAND
RIO BLANCO COUNTY
T
3
N
34
LEGEND
Oil Well
Gas Injection Well
CUMULATIVE OIL & WATER PRODUCTION—MILLIONS OF BARRELS
CUMULATIVE GAS INJECTION—MCF X 100,000
BOTTOM HOLE PRESSURE—PSI X 100
BHP
CUM. OIL PROD.
CUM. WATER PROD.
Gas Injection Commenced 10/27/56
CUM. GAS INJ.
0
5
10
15
20
25
8
10
12
14
16
18
20
22
1941
'42
'43
'44
'45
'46
'47
'48
'49
'50
'51
'52
'53
'54
'55
'56
'57
'58
'59

FIGURE 42

XENIA-WEST FIELD
"J" SAND
WASHINGTON COUNTY





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Producing Federal Units

Field	County	Date Unitized	Reservoir	Acreage	Discovery Well Name	Discovery Well Location	Discovery Date	To: 1-1-1959 Cumulative Oil (Bbls.)	To: 1-1-1959 Production Gas (Mcf.)
Douglas Creek	Rio Blanco	2/1/38	Dakota	4.411	Superior Oil Co. No. 1 Unit	NW SW 5-3S-101W	7/1/43	0	6,092,719
Powder Wash	Moffat	7/1/39	Ft. Union-Wasatch	9,018	Mt. Fuel Supply B. W. Musser No. 1	SE NW NE 5-11N-97W	4/9/31	2,698,774	47,406,207
Piceance Creek	Rio Blanco	1/1/40	Green River	62,477	White Eagle Oil Co. No. 1 Fordham	SW SW 9-2S-96W	8/28/30	0	13,405,921
Maudlin Gulch	Moffat	7/1/45	Morrison-Sundance	7,235	Texas Co.-Frontier Ref. No. 1 Unit	NW NW 35-4N-95W	Nov. 1947	1,149,720	226,787
Iles Dome	Moffat	11/23/45	Morrison-Sundance	3,007	Midwest Oil Corp. Parkinson No. 4	SW SE 22-4N-92W	4/1/27	15,792,271	1,735,841
Asbury Creek	Mesa	8/31/49	Dakota	720	Amerada Pet. Co. Asbury Creek Unit No. 1	C SE NE 14-9S-101W	12/16/49	0	1,619,399
Highline Canal	Mesa	8/10/51	Dakota	10,267	Amerada Pet. Co. Unit No. 1	NW SE NE 2-9S-103W	12/20/51	0	129,919
Bar X Anticline*	Mesa	9/30/52	Dakota-Morrison	1,971	Frontier Ref. Co. Bar X Unit No. 1	NW 31-8S-104W	4/30/53	0	1,534,554
McCallum	Jackson	12/29/52	Dakota-Lakota	8,292	Continental Oil Co. No. 1 Sherman	NW NW 12-9N-79W	Dec. 1926	3,019,349	238,578,003
Twin Buttes	Garfield	6/26/53	Morrison	3,762	Greenbrier Oil Co. No. 1 Gov't	C NW NW 24-5S-102W	10/10/51	0	2,300,508
Ace	Moffat	6/25/54	Ft. Union-Wasatch	6,400	Mt. Fuel Supply B. W. Musser No. 1	SE NW NE 5-11N-97W	4/9/31	79,887	3,282,877
Thornburg	Moffat-Rio Blanco	4/13/55	Weber-Sundance	3,760	Marland Oil Co. Wymore No. 1	SW NW 16-3N-91W	3/27/25	712,900	7,548,158
Douglas Creek-No.	Rio Blanco	1/18/56	Weber	32,356	Phillips Pet. Co. No. 1-"A" Douglas	NW NE 19-1S-101W	4/23/56	8,401	798,721

*Unit extends into Utah. Prod. Colo. portion only.

Colorado Oil and Gas Production, 1887-1959

County and Field	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896
FREMONT										
Florence-Canon City	76,295	297,612	316,476	368,842	665,482	824,000	694,390	515,746	438,232	361,450
BOULDER	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906
Boulder						11,800	36,722	18,167	10,502	48,952
FREMONT										
Florence-Canon City	384,934	444,383	390,728	317,385	460,520	385,101	447,203	483,596	365,736	278,630
STATE TOTAL	384,934	444,383	390,728	317,385	460,520	396,901	483,925	501,763	376,238	327,582
BOULDER	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916
Boulder	68,353	84,174	85,709	42,186	37,973	15,304	11,796	6,515	6,376	5,479
FREMONT										
Florence-Canon City	263,498	295,469	225,062	193,482	187,341	190,498	176,693	215,548	202,069	191,486
STATE TOTAL	331,851	379,643	310,771	235,668	225,314	205,802	188,489	222,063	208,445	196,965
County and Field	**1917**	**1918**	**1919**	**1920**	**1921**	**1922**	**1923**	**1924**	**1925**	**1926**
FREMONT										
Florence-Canon City	114,664	134,895	102,000	88,000	83,000	72,000	64,000	59,000	99,912	147,567
BOULDER										
Boulder	5,847	4,646	5,000	7,000	5,000	4,000	3,800	7,200	7,200	10,529
LARIMER										
Fort Collins								86,123	358,178	462,908
Wellington								1,135	70,167	759,680
COUNTY TOTAL								87,258	428,345	1,222,588
MOFFAT										
Iles									17,968	26,568
Moffat								325,722	339,806	1,269,528
COUNTY TOTAL								325,722	357,774	1,296,096
RIO BLANCO										
Rangely (Shale)			14,000	16,000	20,000	23,000	20,000	29,000	21,820	29,993
ROUTT										
Tow Creek									42,287	140,832
STATE TOTAL	120,511	139,541	121,000	111,000	108,000	99,000	87,800	508,180	957,338	2,847,605
County and Field	**1927**	**1928**	**1929**	**1930**	**1931**	**1932**	**1933**	**1934**	**1935**	**1936**
FREMONT										
Florence-Canon City	294,152	429,489	336,805	199,418	134,373	116,989	91,343	82,151	69,955	67,961
BOULDER										
Boulder	9,720	9,075	8,325	6,935	7,258	6,832	5,840	6,391	6,357	5,951
JACKSON										
McCallum			1,362	254	8,675	SI	SI	19,580	SI	SI

Colorado Oil and Gas Production, 1887-1959 (Cont.)

County and Field	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936
LARIMER										
Berthoud				5,110	12,105	6,716	5,163	4,760	4,017	3,446
Fort Collins	323,390	241,428	159,225	112,135	91,279	69,099	49,870	38,132	25,544	23,391
Wellington	865,301	789,567	663,001	376,595	273,365	223,737	176,223	148,412	110,566	95,218
COUNTY TOTAL	1,188,691	1,030,995	822,226	493,840	376,749	299,552	231,256	191,304	140,127	122,055
MOFFAT										
Hiawatha				335	380	692	3,639	5,406	6,195	6,143
Iles	257,071	621,960	503,349	368,861	391,187	241,803	210,032	514,947	1,027,901	1,164,540
Moffat	736,463	463,648	464,272	419,681	326,717	247,916	209,251	168,824	158,097	161,229
COUNTY TOTAL	993,534	1,085,608	967,621	788,877	718,284	490,411	422,922	689,177	1,192,193	1,331,912
MONTEZUMA										
Mancos River					950	603	715	606	724	218
RIO BLANCO										
Rangely (Shale)	23,725	23,620	29,145	32,850	10,368	28,595	29,962	31,270	29,746	28,774
Rangely (Weber)							8,138	SI	SI	SI
COUNTY TOTAL	23,725	23,620	29,145	32,850	10,368	28,595	38,100	31,270	29,746	28,774
ROUTT										
Tow Creek	260,877	187,264	172,874	144,151	121,158	100,219	86,249	73,313	66,383	64,813
WELD										
Greasewood				13,782	177,920	107,467	52,198	36,487	26,981	18,924
STATE TOTAL	2,770,699	2,766,051	2,338,358	1,680,107	1,555,735	1,150,668	928,623	1,130,279	1,532,466	1,640,608

County and Field	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946
ARCHULETA										
Price Gramps	161,020	176,173	217,344	304,877	330,017	439,860	251,918	278,575	349,600	235,818
BOULDER										
Boulder	9,125	7,023	6,317	4,405	4,893	4,200	7,320	7,320	7,300	16,420
FREMONT										
Florence-Canon City	57,694	62,843	57,770	55,458	53,546	49,165	20,971	44,262	40,730	29,325
JACKSON										
McCallum	SI	SI	SI	SI	SI	10,422	11,684	63,112	179,633	203,205
McCallum-South		5,655	SI	SI	SI	493	Abd.			
COUNTY TOTAL		5,655				10,915	11,684	63,112	179,633	203,205
LA PLATA										
Red Mesa							4,095	1,260	1,000	SI
LARIMER										
Berthoud	4,825	4,200	3,840	3,060	3,090	3,097	2,707	2,501	2,463	2,210
Clark Lake								80,786	85,872	55,124
Fort Collins	15,432	33,105	40,178	56,395	45,235	29,145	28,537	33,542	15,477	5,902
Wellington	73,464	76,416	75,234	71,533	71,532	80,007	66,831	63,784	120,605	101,077
COUNTY TOTAL	93,721	113,721	119,252	130,988	119,857	112,249	98,075	180,613	224,417	164,313
MOFFAT										
Hiawatha	5,841	10,314	25,711	98,984	195,215	188,825	155,996	102,940	69,234	52,336

Iles	1,036,108	818,822	736,524	580,262	555,946	543,745	483,037	456,326	426,717	453,422
Moffat	149,210	125,940	112,456	116,725	120,014	125,796	117,508	113,797	104,233	92,967
Powder Wash	1,013	SI	SI	SI	40,154	37,890	45,178	51,958	70,319	40,793
COUNTY TOTAL	1,192,172	955,076	874,691	795,971	911,329	896,256	801,719	725,021	670,503	639,518
MONTEZUMA										
Mancos River	Abd.									
RIO BLANCO										
Rangely (Shale)	30,723	26,084	132,021	118,258	221,258	307,958	305,902	289,733	212,803	326,285
Rangely (Shinarump)										39,078
Rangely (Weber)	SI	SI	SI	SI	SI	SI	15,050	99,163	1,367,776	7,859,435
Wilson Creek		52,984	129,526	239,797	451,818	533,693	759,738	1,400,271	2,053,822	2,381,574
COUNTY TOTAL	30,723	79,068	261,547	358,055	673,076	841,651	1,080,690	1,789,167	3,634,401	10,606,372
ROUTT										
Tow Creek	56,625	56,034	52,903	50,752	49,291	47,290	46,883	43,433	39,632	39,967
WELD										
Greasewood	5,878	8,691	6,505	8,857	7,104	4,518	3,665	3,808	6,717	6,220
STATE TOTAL	1,606,958	1,464,284	1,596,329	1,709,363	2,149,113	2,406,104	2,327,020	3,136,571	5,153,933	11,941,153

County and Field	**1947**	**1948**	**1949**	**1950**	**1951**	**1952**	**1953**	**1954**	**1955**	**1956**
ADAMS										
Badger Creek							435,083	947,820	665,670	468,923
Badger Creek-W							34,369	84,960	59,516	39,371
Beacon									57,028	261,321
Busy Bee									9,642	20,450
Cabin Creek									1,339	Abd.
Knox								2,122	17,945	5,149
Leader								43,817	19,894	225
Little Beaver							10,873	11,650	6,206	4,561
Middlemist						71,795	127,842	149,115	173,490	201,657
Mountain View-E							3,050	4,195	1,041	1,344
Muddy Creek									9,729	10,469
Noonen Ranch						2,570	4,173	4,680	2,735	280
Rosener								1,903	42,318	28,275
Second Creek										3,763
Windy Hill									20,211	20,268
Woodrow-West							1,353	3,735	2,330	1,386
COUNTY TOTAL						74,365	616,743	1,253,997	1,089,094	1,067,442
ARCHULETA										
Chromo			3,800	16,062	28,238	15,905	14,531	10,595	7,767	7,435
Price Gramps	195,376	124,560	101,163	130,183	191,934	192,666	233,288	199,230	172,665	144,251
COUNTY TOTAL	195,376	124,560	104,963	146,245	220,172	208,571	247,819	209,825	180,432	151,686
BENT										
Bent's Fort									4,249	4,783
BOULDER										
Boulder	11,000	7,320	7,260	7,393	4,956	0	2,524	2,017	1,875	2,740

Colorado Oil and Gas Production, 1887-1959 (Cont.)

County and Field	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956
Highland										40
COUNTY TOTAL	11,000	7,320	7,260	7,393	4,956	0	2,524	2,017	1,875	2,780
ELBERT										
Bradbury									374	Abd.
FREMONT										
Florence-Canon City	25,348	27,907	33,425	32,777	21,869	30,602	29,702	30,533	31,204	29,421
JACKSON										
Battleship								9,486	128,471	316,699
Canadian River										27,248
McCallum	192,435	136,764	120,909	125,657	119,072	120,189	117,052	120,303	151,886	378,720
McCallum-So.										
COUNTY TOTAL	192,435	136,764	120,909	125,657	119,072	120,189	117,052	129,789	280,357	722,667
JEFFERSON										
Soda Lake									8,457	2,825
LA PLATA										
Barker Dome					4,208	18,415	10,179	8,067	6,159	4,477
Red Mesa	SI	SI	SI	5,658	7,892	2,886	1,759	2,721	2,709	5,402
COUNTY TOTAL				5,658	12,100	21,301	11,938	10,788	8,868	9,879
LARIMER										
Berthoud	1,911	1,675	2,368	3,490	2,541	2,280	2,518	2,463	2,499	1,551
Clark Lake	39,646	35,987	29,410	26,870	28,326	25,910	32,568	30,873	27,747	23,331
Fort Collins	5,150	33,508	30,970	36,839	27,049	22,237	20,516	25,706	43,183	89,926
Loveland									1,683	12,896
Wellington	100,612	70,042	65,638	62,419	61,640	57,866	55,053	55,203	55,539	54,005
COUNTY TOTAL	147,319	141,212	128,386	129,618	119,556	108,293	110,655	114,245	130,651	181,709
LOGAN										
Adobe										2,672
Amber										35,802
Arford					2,034	1,430	28	Abd.		
Armstrong			1,514	5,956	7,118	7,164	7,660	14,460	14,585	8,171
Atwood					8,678	66,278	51,029	43,032	58,903	53,829
Atwood-East									87,249	141,030
Beall Creek										283,628
Big Sandy							2,753	37,442	119,545	67,986
Bonham							25,937	76,937	33,013	28,740
Cedar Creek								15,992	25,089	29,589
Cedar Creek-N									95,223	133,688
Cliff									923,205	962,668
Cottonwood								6,758	1,274	3,088
Cottonwood-S										16,148
Dale						32,281	136,375	146,771	78,928	60,214
Dale-North								19,258	53,144	30,322
Darby Creek									26,246	329,194
Divide						16,589	23,038	415,530	631,323	375,821

Dune Ridge						158,413	227,131	186,176
Frasco						5,596	7,350	47,334
Frenchman Creek					107	Abd.		
Goat Hill								28,244
Graylin			60,585	113,976	106,518	218,943	274,880	208,970
Graylin-NW					265,850	1,757,176	1,271,734	827,121
Horsetail							86,384	42,452
Johnson Hill						106	(Gas)	
Johnson Hill-E						25,569	10,275	5,533
Johnson Hill-N					89,023	463,829	257,646	140,499
Lewis Creek					158,422	786,817	655,283	441,117
Liberty						93,622	173,769	162,297
Liberty-S					67,641	29,223	19,262	9,010
Liberty-W					57,046	84,304	108,268	77,528
Little Hoot						68	140	42
Logan			14,147	26,061	27,935	17,538	7,620	4,758
Logan-North						1,102	4,888	4,256
Loula								3,703
Luft				86,159	566,745	366,788	281,968	221,160
Merino		72,573	461,504	390,574	413,585	337,313	359,638	288,284
Merino-NE						15,875	9,915	6,177
Minto					1,894	61,811	81,303	94,916
Minto-No.						54,547	44,170	36,588
Minto-West						90,265	192,715	217,800
Mount Hope		8,349	296,492	602,218	1,083,767	686,986	517,376	418,850
Mount Hope-E						175,244	434,797	283,408
Mount Hope-N					6,778	29,975	75,181	118,919
Padroni					1,778	14,187	14,915	27,109
Padroni-W				70,360	102,076	86,770	59,503	51,195
Pawnee Creek			1,145	56,270	74,674	64,630	290,935	212,350
Pawnee Creek-N								5,694
Peavy							8,781	21,010
Peetz-NW						4,631	13,363	8,304
Peetz-W				129,674	268,957	238,233	164,307	126,375
Prairie View								9,407
Prewitt								25,061
Raymer Creek					4,620	5,543	10,102	8,894
Springdale			1,838	250	249	878	2,076	1,080
Springdale-So.				47,538	113,511	82,003	55,586	46,131
Vista							9,077	36,578
Walker		329	139,628	245,062	243,001	201,355	207,917	142,652
Westplains						32,308	33,410	14,777
Westplains-No.							7,560	3,118
Willard			3,354	40,279	12,404	14,371	12,469	8,703
Winston							108,457	137,290
Yenter		5,302	477,400	1,075,363	1,490,785	1,120,488	867,146	647,985
COUNTY TOTAL	1,514	92,509	1,473,923	3,007,526	5,404,186	8,102,687	9,115,024	7,971,445

Colorado Oil and Gas Production, 1887-1959 (Cont.)

County and Field	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956
MOFFAT										
Ace								16,295	15,467	17,024
Danforth Hills								15,151	47,053	73,768
Elk Springs	20,194	78,559	57,128	42,017	40,352	33,596	29,458	28,739	24,772	25,336
Hiawatha	53,165	66,300	63,269	66,331	121,693	108,863	138,203	155,501	148,938	208,134
Iles	542,789	534,840	522,837	498,465	440,747	376,336	333,669	301,658	220,450	186,900
Maudlin Gulch	1,726	2,463	54,707	177,214	222,645	137,760	96,038	135,910	119,359	88,271
Moffat	92,523	107,424	84,767	81,160	74,658	60,567	61,391	56,491	58,340	65,034
Powder Wash	41,971	43,764	75,095	123,658	146,737	272,319	289,074	297,135	299,168	321,977
Shell Creek									903	770
Sugar Loaf								1,059	6,039	18,927
Temple Canyon							3,046	10,484	10,526	3,207
Thornburg									7,316	269,431
COUNTY TOTAL	752,368	833,350	857,803	988,845	1,046,832	989,441	950,879	1,018,423	958,331	1,278,779
MONTEZUMA										
Dove Creek			11,214	7,200	1,841	1,799	SI	11,953	7,053	5,678
Mancos River	SI	SI	SI	SI	SI	SI	SI	SI	SI	SI
COUNTY TOTAL			11,214	7,200	1,841	1,799	0	11,953	7,053	5,678
MORGAN										
Adena							32,155	4,520,714	5,924,610	5,631,946
Adena-So.								126,809	80,473	73,877
Allen									837	49,721
Ashley									6,564	4,293
Boots Hill									764	2,531
Burr										24,428
Empire (See Weld Co.)							1,787	Abd.		
Fort Morgan								8,802	12,219	169
Gary							892	6,252	3,929	1,978
Gary-North								7,055	110,424	29,513
Goodrich					127	2,170	944	674	1,137	384
Jackpot									222,501	199,279
Jackpot-So.									36,557	29,562
Jackson								2,141	308	Abd.
Lark									6,000	15,240
Lee				5,650	8,665	10,017	7,112	4,476	1,745	412
Levee										7,694
Masters (See Weld Co.)								3,489	5,711	8,427
McRae							194,671	193,660	163,707	154,843
Messer						3,639	Abd.			
Messex					65,624	83,761	56,781	37,545	28,402	18,379
Messex-West									13,051	21,628
Orchard										214,731
Park								19,131	216,091	150,700

Peterson									12,179	54,308
Poe										352
Ridge										4,589
Rufus Run									4,372	6,790
Sand River								158,077	553,623	486,294
Timpe									22,791	21,980
Vallery									3,737	8,655
Zorichak									44,616	155,705
COUNTY TOTAL				5,650	74,416	99,587	294,342	5,088,825	7,476,348	7,378,408
RIO BLANCO										
Douglas Ck.-No.										3,954
Rangely (Morrison)										2,121
Rangely (Shale)	350,038	365,891	354,759	313,907	328,625	297,625	293,698	315,109	245,340	212,245
Rangely (Shinarump)	37,177	25,346	20,260	15,291	10,607	12,289	11,114	9,509	6,164	6,083
Rangely (Weber)	11,333,431	13,676,832	19,258,803	18,506,766	21,859,773	22,194,168	22,600,814	22,772,222	23,717,099	27,920,613
Wilson Ck.	2,707,284	2,603,688	2,587,321	2,804,367	2,795,116	2,850,770	2,853,860	2,640,261	2,445,262	2,507,087
COUNTY TOTAL	14,427,930	16,671,757	22,221,143	21,640,331	24,994,121	25,354,852	25,759,486	25,737,101	26,413,865	30,652,103
ROUTT										
Oak Creek			11,389	25,154	3,608	SI	SI	4,005	1,321	SI
Tow Creek	40,354	41,290	38,796	37,670	36,447	35,548	38,675	41,199	41,370	65,197
COUNTY TOTAL	40,354	41,290	50,185	62,824	40,055	35,548	38,675	45,204	42,691	65,197
WASHINGTON										
Abbott						4,216	3,399	7,696	10,773	17,283
Abbott-No.									6,293	Abd.
Agate										5,128
Akron-East									169,594	159,396
Barrow										489
Big Beaver								188,990	862,016	873,948
Bobcat								494,145	1,147,072	890,363
Bobcat-West										11,132
Buffalo								3,816	1,332	Abd.
Camp Creek									19,974	12,440
De Nova										5,457
Hardway									1,890	22,019
Hector									18,118	45,257
Hinge								1,939	26,526	9,170
Hyde									76,676	92,037
Kejr									146,658	580,841
Kejr-South									4,698	59,793
Lance										19,318
Last Chance									9,016	120,528
Little Beaver (See Adams Co.)						30,378	2,542,805	2,670,923	1,600,962	1,233,057
Little Beaver-East								4,583	488,536	700,949
Nugget									28,400	75,131
Phegley									78,469	221,808

Colorado Oil and Gas Production, 1887-1959 (Cont.)

County and Field	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956
Pleasant Valley									2,404	10,887
Plum Bush Creek								1,949	769,771	1,226,583
Purdy									617	2,560
Rago							6,120	13,288	25,779	21,948
Rago-North								4,227	49,380	39,815
Roderick										12,808
Rush-Willadel						4,594	18,094	13,928	10,717	10,442
Shears Draw									8,367	29,744
Stony Point									257	3,794
Swan									3,525	112,067
Westfork										90,305
Wetzel Creek									7,143	61,534
Woodrow-East						467	1,816	3,005	9,697	16,884
Woodrow-South								1,518	53,753	41,707
Xenia									13,625	19,355
Xenia-North									1,330	10,453
Xenia-West								804	245,931	347,665
COUNTY TOTAL						39,655	2,572,234	3,410,811	5,899,299	7,214,095
WELD										
Battle Canyon							28,262	162,694	239,688	172,195
Black Hollow							66,947	499,730	788,781	657,514
Buckingham				1,856	28,624	20,050	12,302	40,545	69,162	64,307
Buckingham-West									24,309	115,751
Cotton Valley									1,940	55,035
Crow										2,079
Empire (See Morgan Co.)							662	Abd.		
Greasewood	7,063	3,351	8,875	19,519	37,579	249,274	38,475	14,010	1,766	2,756
Greasewood-So.								45,937	12,586	4,495
Jackpot									34,032	239,184
Keota					1,275	210,366	365,959	215,860	101,458	75,171
Long-South							40,158	97,936	14,929	Abd.
Loveland										55
Masters (See Morgan Co.)							13,858	150,055	50,184	24,520
May										95,315
McKenzie										295
New Windsor										1,443
Pierce									29,724	162,961
Roggen							22,543	20,593	86,631	46,889
Roggen-SW							8,883	96,779	113,881	73,597
Rush Creek										1,521
Spurgin								1,182	7,324	4,551
Stoneham								958	SI	438
Stoneham-South						1,010	14,466	12,875	13,317	17,615

Turner									454	Abd.
White Butte								4,166	19,618	8,237
COUNTY TOTAL	7,063	3,351	8,875	21,375	67,478	480,700	612,515	1,363,320	1,609,784	1,825,924
COLORADO TOTAL	15,799,193	17,987,511	23,545,677	23,266,082	28,196,391	30,572,429	36,768,750	46,529,518	53,257,956	58,564,821

County and Field	1957	1958	1959	Gas-MCF 1959	Cumulative to Jan. 1, 1960 Oil-Barrels	Cumulative to Jan. 1, 1960 Gas-MCF
ADAMS						
Badger Creek	466,677	359,927	332,497	140,228	3,676,597	1,961,878
Badger Creek-West	26,616	7,084	1,746	39	253,662	122,069
Beacon	179,620	102,653	60,397	794,365	661,019	2,221,288
Busy Bee	12,455	17,641	52,853	145,903	113,041	263,948
Cabin Creek	----	----	----	----	1,339	2,355
Doherty	2,282	241	2,927	87,125	5,450	87,625
Flint	----	----	1,186	1,780	1,186	1,780
Knox	2,889	2,173	2,143	1,066	32,421	24,114
Leader	30,089	25,925	15,439	263,213	135,389	872,641
Little Beaver (See Washington Co.)	3,764	4,054	1,359	124,646	42,467	848,157
Middlemist	216,430	195,439	151,745	188,498	1,287,513	664,852
Moore	----	----	1,963	----	1,963	----
Mountain View-East	283	----	----	----	9,913	3,392
Muddy Creek	2,779	1,844	----	----	24,821	32,143
Noonen Ranch	3,318	2,682	3,915	1,023	24,353	6,862
Poison Spring	----	----	5,985	693	5,985	693
Rosener	21,781	20,345	15,209	29,105	129,831	134,024
Second Creek	12,790	8,957	4,050	5,624	29,560	65,772
Simpson	----	----	3,492	1,135	3,492	1,135
Windy Hill	18,216	27,505	20,820	1,141	107,020	22,482
Woodrow-West	2,345	3,142	2,271	----	16,562	3,030
COUNTY TOTAL	1,002,334	779,612	679,997	1,785,584	6,563,584	7,340,240
ARCHULETA						
Chromo	5,521	5,218	4,633	516	119,705	6,342
Ignacio	----	----	----	----	----	223*
Price Gramps	132,134	113,020	109,294	----	4,784,966	----
COUNTY TOTAL	137,655	118,238	113,927	516	4,909,671	6,565
BACA						
Greenwood	----	----	----	439,436	----	2,002,082*
Prairie Dog	----	198	----	----	198	13,662
COUNTY TOTAL	----	198	----	439,436	198	2,015,744

Colorado Oil and Gas Production, 1887-1959 (Cont.)

County and Field	1957	1958	1959	Gas-MCF 1959	Cumulative to Jan. 1, 1960 Oil-Barrels	Cumulative to Jan. 1, 1960 Gas-MCF
BENT						
Bent's Fort	5,784	1,132	204	3,300	16,152	45,940
Lubers	----	----	----	6,280	----	51,407*
McClave	----	----	423	----	423	----
COUNTY TOTAL	5,784	1,132	627	9,580	16,575	97,347
BOULDER						
Boulder	3,007	2,473	1,682	----	751,484	----
Highland (See Larimer Co.)	281	37	----	----	358	----
COUNTY TOTAL	3,288	2,510	1,682	----	751,842	----
ELBERT						
Bradbury	----	----	----	----	374	48
FREMONT						
Florence-Canon City	25,033	27,223	39,181	----	14,301,550	----
GARFIELD						
Baldy Creek	----	----	----	5,922	----	5,922*
Carbonera	----	----	----	84,246	----	84,246*
Garmesa	----	----	----	303,423	----	1,637,320*
Prairie Canyon	----	----	----	59,259	----	59,259*
Rulison	----	----	----	41,700	----	41,700*
South Canyon	----	----	----	86,558	----	86,558*
Twin Buttes	----	----	----	199,585	----	2,500,093*
COUNTY TOTAL	----	----	----	780,693	----	4,415,098
JACKSON						
Battleship	352,290	306,171	257,615	----	1,370,732	----
Canadian River	102,088	108,430	76,426	664,300	314,192	1,374,259
McCallum	433,725	504,710	439,620	46,549,070	3,458,969	285,127,073‡
McCallum-South	----	13,515	166,224	12,822,294	185,887	46,834,190‡
COUNTY TOTAL	888,103	932,826	939,885	60,035,664	5,329,780	333,335,522
JEFFERSON						
Soda Lake	1,093	2,418	482	----	15,275	3,820
KIOWA						
Brandon	----	----	1,860	----	1,860	----
McClave	6,708	107	----	4,340	6,815	6,105*
COUNTY TOTAL	6,708	107	1,860	4,340	8,675	6,105
LA PLATA						
Alkali Gulch	----	----	----	2,897,576	----	2,915,570*

Barker Dome	4,917	4,433	4,287	3,761,676	65,142	59,552,086*
Blanco	----	----	----	----	----	----
Ignacio	----	----	----	----	----	----
Ignacio-Blanco	877	284	357	20,966,362	1,518	91,463,375*
Red Mesa	6,697	14,484	15,700	40,902	72,263	167,519*
COUNTY TOTAL	12,491	19,201	20,344	27,666,516	138,923	154,098,550
LARIMER						
Berthoud	1,431	1,558	1,420	58	101,015	1,223,506*
Clark Lake	20,828	20,401	19,183	3,084	582,862	369,400
Fort Collins	111,911	104,490	92,051	10,827	2,987,186	352,107
Highland (See Boulder Co.)	233	333	215	----	781	----
La Porte	----	----	118	----	118	----
Loveland	36,344	25,808	22,035	22,014	98,766	299,512*
Wellington	55,389	55,666	58,568	10,680	6,161,090	18,143,180
COUNTY TOTAL	226,136	208,256	193,590	46,663	9,931,818	20,387,705
LAS ANIMAS						
Garcia	----	----	----	----	----	1,561,000*
Model	----	----	----	----	----	53,000§
Nina View	----	----	----	81,713	----	446,860‡
COUNTY TOTAL	----	----	----	81,713	----	2,060,860
LOGAN						
Adobe	680	----	----	----	3,352	10,750
Amber	105,850	52,533	29,228	35,143	223,413	247,907
Arford	----	----	----	----	3,492	81,300
Armstrong	8,615	7,910	8,731	518,331	91,884	3,087,580*
Atwood	33,574	25,948	21,962	8,049	363,233	114,523
Atwood-East	232,125	391,736	304,300	1,207,262	1,156,440	2,983,821
Beall Creek	421,415	259,963	180,996	139,324	1,146,002	960,008
Big Sandy	62,690	65,434	64,018	98,726	419,868	1,124,458
Bonham	25,074	17,956	16,274	4,718	223,931	47,467
Casement	----	----	----	----	----	10,607*
Cedar Creek	21,521	102,809	122,129	245,961	317,129	582,450
Cedar Creek-North	61,075	73,400	56,730	232,622	420,116	1,414,888
Cliff	583,234	529,258	564,099	1,168,681	3,562,464	5,825,861
Cottonwood	1,456	2,280	2,161	863	17,017	6,909
Cottonwood-South	15,545	11,433	6,237	----	49,363	2,899
Coyote	----	----	----	53,087	----	75,623*
Dale	36,215	24,971	26,170	98,214	541,925	2,400,264
Dale-North	24,463	15,113	9,955	9,990	152,255	222,644
Darby Creek	302,407	213,232	144,559	281,782	1,015,638	1,772,037
Divide	155,809	91,110	63,850	58,420	1,773,070	2,257,334
Dune Ridge	159,490	121,699	241,874	129,845	1,094,783	1,674,871
Elm Grove	103,626	224,313	163,355	344,338	491,294	1,298,021

Colorado Oil and Gas Production, 1887-1959 (Cont.)

County and Field	1957	1958	1959	Gas-MCF 1959	Cumulative to Jan. 1, 1960 Oil-Barrels	Cumulative to Jan. 1, 1960 Gas-MCF
Frasco	66,677	54,772	85,553	37,939	267,282	140,338
Frenchman Creek	----	----	----	----	107	346,972*
Garnet	----	----	19,494	37,359	19,494	37,359
Goat Hill	186,174	73,569	25,998	73,388	313,985	1,134,502
Graylin	140,773	79,488	67,976	174,297	1,272,109	1,860,356
Graylin-NW	573,206	546,980	495,676	487,258	5,737,743	7,940,645
Hadfield	----	----	1,984	11,649	1,984	11,649
Horsetail	28,342	21,082	16,335	515,362	194,595	1,239,560
Johnson Hill	----	----	----	----	106	8,634*
Johnson Hill-East	670	27	----	----	42,074	400,348
Johnson Hill-North	115,711	113,442	80,245	192,174	1,260,395	2,373,921
Key	2,981	78,828	30,265	20,671	112,074	68,391
Knoll	----	----	----	----	----	13,831*
Lewis Creek	346,710	326,887	303,922	243,460	3,019,158	2,596,805
Liberty	115,300	97,930	76,383	211,992	719,301	1,659,013
Liberty-South	6,176	3,560	----	--	134,872	97,539
Liberty-West	45,480	31,184	16,473	42,802	420,283	724,596
Little Hoot	----	957	106,001	719,167	107,208	1,642,028*
Logan	3,808	5,497	1,632	164	108,996	101,247*
Logan-North	4,427	3,994	4,954	36,766	23,621	94,112
Loula	----	----	----	----	3,703	3,050
Luft	139,614	89,131	69,640	67,405	1,821,205	2,862,184
Merino	219,001	176,194	179,919	50,063	2,898,585	1,113,827
Merino-Northeast	5,306	6,483	8,749	2,362	52,505	14,561
Minto	67,374	45,820	43,581	23,748	396,699	195,023
Minto-North	35,243	32,031	21,364	12,497	223,943	166,727
Minto-West	121,392	94,265	64,234	141,496	780,671	1,532,565
Mount Hope	282,379	175,859	205,175	239,361	4,277,451	6,132,546
Mount Hope-East	189,092	144,579	124,059	348,516	1,351,179	4,098,196
Mount Hope-North	104,140	118,470	76,774	280,878	530,237	853,462
Padroni	26,577	12,795	13,423	284,099	110,784	3,391,560*
Padroni-West	102,848	104,372	90,096	21,130	667,220	201,206
Pawnee Creek	136,731	71,835	61,455	30,993	970,025	581,108
Pawnee Creek-North	1,372	105	----	----	7,171	57,322
Pawnee Hills	3,487	4,146	3,777	135,934	11,410	507,672*
Peavy	17,949	14,686	10,918	4,620	73,344	248,434
Pebble	15,814	38,351	87,772	42,276	141,937	43,037
Peetz-Northwest	1,837	5	----	48,613	28,140	250,923
Peetz-West	86,464	59,017	45,536	267,458	1,118,563	2,896,906
Prairie View	16,769	5,929	3,190	2,943	35,285	28,870
Prewitt	29,254	12,652	6,737	904	73,704	11,115
Raymer Creek	9,263	11,204	11,925	30,195	61,551	156,222
Sandy Hill	----	10,222	22,822	17,404	33,044	25,375

Scarp	----	3,266	30,191	25,098	33,457	27,058
Shield	----	----	3,792	----	3,792	----
Spring Creek	----	1,777	22,793	5,682	24,570	6,372
Springdale	1,795	2,192	4,191	736,490	14,549	3,058,827*
Springdale-South	34,920	28,560	21,774	14,948	430,023	293,982
Sterling	----	----	----	32,990	----	32,990*
Stony Buttes	----	----	2,173	21,054	2,173	21,054*
Vista	21,741	10,537	5,415	13,336	83,348	51,863
Walker	104,764	90,221	73,868	78,419	1,448,797	4,119,894*
Westplains	16,224	13,515	11,593	22,900	121,827	160,394
Westplains-North	3,610	2,533	2,597	194,860	19,418	433,938*
White	----	363	854	95,158	1,217	148,007*
Willard	16,546	21,081	14,531	1,658	143,738	153,269
Winston	90,077	41,477	26,370	2,637	403,671	60,825
Yenter	624,240	634,766	489,820	1,390,357	7,433,295	17,260,331
COUNTY TOTAL	6,517,112	5,747,734	5,220,627	12,128,286	52,654,287	100,894,763
MESA						
Asbury Creek	----	----	----	175,513	----	1,794,912*
Bar X	----	----	----	401,765	----	1,936,319*
Divide Creek	----	----	----	110,830	----	110,830*
Highline Canal	----	----	--	97,824	-	227,743*
COUNTY TOTAL	----	----	----	785,932	----	4,069,804
MOFFAT						
Ace	16,962	14,139	16,209	368,143	96,096	3,651,020*
Buck Peak	34,498	124,860	172,011	137,661	331,369	232,558
Craig	----	----	----	----	----	213,873*
Danforth Hills	113,886	184,295	257,847	19,509	692,000	78,222
Danforth Hills-North	----	9,973	26,298	14,426	36,271	24,322
Elk Springs	21,489	23,024	19,003	629	443,667	9,160
Hiawatha	186,446	176,962	132,457	2,136,637	2,554,448	62,033,583*
Hiawatha-West	----	340	5,572	2,453,475	5,912	25,571,848*
Iles	206,317	190,167	208,992	65,952	16,001,263	1,801,793
Maudlin Gulch	57,119	56,508	45,776	32,297	1,195,496	259,084
Moffat	81,115	81,361	174,684	----	7,549,315	5,100
Powder Wash	275,466	225,105	187,249	2,594,816	2,886,023	50,001,023*
Shell Creek	352	687	328	75,982	3,040	557,348*
Sugar Loaf	14,111	13,774	13,191	1,628,456	67,101	8,522,862*
Temple Canyon	----	----	----	----	27,263	17,500
Thornburg (See Rio Blanco County)	367,141	69,012	40,698	949,318	753,598	7,813,265*
COUNTY TOTAL	1,374,902	1,170,207	1,300,315	10,477,301	32,642,862	160,792,561
MONTEZUMA						
Desert Canyon	----	----	3,725	5,585	3,725	5,585
Dove Creek	4,747	2,883	2,400	22,763	56,768	474,776

Colorado Oil and Gas Production, 1887-1959 (Cont.)

County and Field	1957	1958	1959	Gas-MCF 1959	Cumulative to Jan. 1, 1960 Oil-Barrels	Gas-MCF
Florine Park	----	----	30,558	59,747	30,558	59,747
Mancos River	163	801	207	----	4,987	
Marble Wash	----	1,494	----	----	1,494	3,332
McElmo	----	----	----	93,510	----	489,000‡
Point Lookout	----	----	----	----	----	23,000*
Towaoc	----	----	69,988	50,798	69,988	50,798
COUNTY TOTAL	4,910	5,178	106,878	232,403	167,520	1,106,238
MONTROSE						
Montrose Dome	----	----	----	13,830	----	13,830*
MORGAN						
Adena	5,457,125	5,031,650	6,589,087	6,374,418	33,187,287	37,307,787*
Adena-South	72,823	52,472	33,494	53,471	439,948	443,119
Allen	74,825	52,211	32,002	12,333	209,596	112,700
Ashley	8,443	7,905	4,198	26,985	31,403	511,506
Bijou	----	307,906	403,367	978,430	711,273	1,307,027
Bijou-West	----	439,927	188,664	616,669	628,591	1,433,060
Boots Hill	2,527	2,148	547	1,647	8,517	29,760
Bow	----	----	----	77,271	----	77,271
Burr	64,852	85,403	49,576	25,344	224,259	105,592
Dike	----	----	25,006	50,845	25,006	50,845
Empire (See Weld Co.)	----	----	----	----	1,787	----
Fort Morgan	----	47,749	38,643	1,456,641	107,582	3,336,558
Gary	1,207	1,135	1,014	420	16,427	5,206
Gary-North	27,303	21,602	16,592	11,220	212,489	172,007
Goodrich	----	----	----	----	5,436	1,770
Jackpot (See Weld Co.)	58,548	35,242	21,772	133,271	537,342	1,354,212
Jackpot-South	8,214	4,314	2,409	17,503	81,056	179,730
Jackson	----	----	27,091	2,291	29,540	2,416
Lamb	----	7,939	21,375	194,253	29,314	212,609
Lark	7,652	7,696	3,461	----	40,049	16,400
Lee	6,051	4,124	2,170	1,660	50,422	287,733*
Levee	6,152	2,007	----	----	15,853	13,522
Luster	----	98,987	147,335	394,711	246,322	421,085
Masters (See Weld Co.)	4,201	2,211	351	2,168	24,390	348,417
McRae	184,959	142,966	101,504	57,693	1,136,310	562,658
Messer	----	----	----	----	3,639	----
Messex	9,395	4,275	540	1,440	304,702	679,383
Messex-West	12,063	11,193	9,019	6,524	66,954	48,595
Onyx	----	----	696	5,107	696	5,107
Opal	----	----	28,190	182,142	28,190	182,142
Orchard	86,822	37,578	37,823	151,353	376,954	921,225*

Park	105,380	88,098	66,668	61,573	646,068	543,223
Peterson	77,637	57,738	48,726	29,908	250,588	158,479
Poe	----	----	4,808	55,278	5,411	119,783
Rake	----	9,336	109,975	268,965	119,311	275,369
Regent	4,923	1,505	2,271	7,772	8,699	50,647
Ridge	2,931	2,639	1,513	1,203	11,672	18,059
Rufus Run	3,183	2,318	1,569	155	18,232	2,851
Sand River	336,412	289,016	219,337	206,907	2,042,759	1,257,913
Timpe	11,096	9,068	8,118	2,000	73,053	22,768
Trend	----	64,590	75,342	537,507	139,932	659,644*
Vallery	1,423	429	72	868,344	14,065	1,723,490*
Young	----	479	11,389	883,441	11,868	930,220*
Zorichak	202,152	371,957	274,668	540,047	1,049,098	1,627,664
COUNTY TOTAL	6,838,319	7,305,813	8,610,382	14,298,910	43,172,090	57,519,552
PROWERS						
Barrel Springs	----	----	1,164	1,980	1,164	1,980
RIO BLANCO						
Douglas Creek	----	----	----	787,701	----	6,880,420*
Douglas Creek-North	2,463	1,984	1,923	1,264,538	10,324	2,059,108*
Gilliam Draw	----	----	----	56,303	----	66,093*
Piceance Creek	----	----	----	3,887,656	----	17,293,577*
Pinnacle	991	----	3,837	----	4,828	----
Rangely (Mancos)	326,479	386,600	620,775	----	6,823,984	----
Rangely (Morrison)	350	----	----	----	2,471	----
Rangely (Shinarump)	6,039	4,108	3,568	340	206,633	51,937
Rangely (Weber)	25,610,802	20,454,286	17,171,762	51,739,444	276,426,933	349,965,784
Thornburg (See Moffat)	----	----	----	----	----	684,211*
White River	----	----	----	----	----	526,000*
Wilson Creek	2,524,463	2,433,041	2,753,275	2,119,887	42,509,018	17,748,356
COUNTY TOTAL	28,471,587	23,280,019	20,555,140	59,855,869	325,984,191	395,275,486
ROUTT						
Curtis	440	53,640	45,298	27,666	99,378	40,616
Grassy Creek	----	----	4,503	1,670	4,503	1,670
Hidden Valley	2,437	12,703	2,495	1,450	17,635	5,200
Oak Creek	----	----	----	----	45,477	----
Pagoda	----	----	----	----	----	21,706*
Sage Creek	----	----	6,108	----	6,108	----
Tow Creek	91,621	96,591	55,555	13,867	2,603,543	284,527
COUNTY TOTAL	94,498	162,934	113,959	44,653	2,776,644	353,719
SEDGWICK						
Chappel	----	----	----	2,083	----	2,083*
WASHINGTON						
Abbott	13,683	12,862	13,106	3,276	83,018	11,327

Colorado Oil and Gas Production, 1887-1959 (Cont.)

County and Field	1957	1958	1959	Gas-MCF 1959	Cumulative to Jan. 1, 1960 Oil-Barrels	Cumulative to Jan. 1, 1960 Gas-MCF
Abbott-North	----	----	----	----	6,293	----
Agate	5,389	3,749	3,561	705	17,827	3,600
Akron	----	----	----	----	----	133,156*
Akron-East	141,167	102,783	107,428	97,633	680,368	609,582
Anton	----	540	47	----	587	----
Azure	50,511	126,119	60,747	9,921	237,377	35,226
Barrow	20,497	3,396	----	----	24,382	476,353
Becker	14,958	8,107	1,284	513	24,349	11,822
Big Beaver	1,177,946	1,052,575	1,037,797	97,079	5,193,272	381,181
Bobcat	631,671	651,971	522,928	460,214	4,338,150	2,610,839
Bobcat-West	8,987	4,816	2,891	4,032	27,826	27,603
Buffalo	----	----	----	----	5,148	151
Buffalo Slough	3,672	3,604	18,696	28,007	25,972	30,915
Camp Creek	7,873	5,783	7,528	663	53,598	4,496
Centennial	----	----	10,716	3,418	10,716	3,418
Cone	----	5,859	1,634	----	7,493	530
Coral	----	----	2,027	482	2,027	482
De Nova	----	9,466	14,298	1,106	29,221	1,106
East Prong	1,955	10,772	4,076	3,785	16,803	8,855
Fremont Butte	6,020	2,518	----	----	8,538	44,450
Hardway	19,971	15,282	13,021	35,747	72,183	210,740
Hector	21,119	11,469	7,946	6,800	103,909	70,732
Hinge	11,926	8,142	48,903	31,387	106,606	46,238
Hirst	----	5,405	9,445	1,367	14,850	3,518
Hone	----	125,391	102,540	15,826	227,931	52,145
Hyde	92,120	101,082	98,378	16,903	460,293	74,111
Kejr	609,562	470,736	573,985	124,881	2,381,782	729,480
Kejr-South	50,808	32,435	18,669	3,845	166,403	99,489
Lance	11,591	6,150	4,221	843	41,280	12,501
Last Chance	81,061	57,534	32,625	1,016	300,764	21,073
Lindon	----	----	2,847	34	2,847	34
Little Beaver (See Adams Co.)	1,200,023	850,912	971,421	932,796	11,100,481	12,205,020
Little Beaver-East	400,753	277,080	304,993	137,552	2,176,894	1,977,450
Lone Valley	32,833	87,227	64,369	28,436	184,429	75,981
Nugget	77,809	60,491	485,120	287,279	726,951	379,694
Otis	----	----	----	50,576	----	221,027*
Phegley	174,964	174,044	116,727	76,288	766,012	212,674
Pleasant Valley	9,346	9,344	10,899	4,359	42,880	14,092
Plum Bush Creek	1,134,458	1,127,412	723,508	257,575	4,983,681	974,207
Purdy	1,416	433	----	----	5,026	2,306
Rago	15,883	10,595	14,621	5,723	108,234	42,518
Rago-North	51,193	50,988	46,802	9,553	242,405	56,623
Ramp	----	91,105	48,841	5,949	139,946	22,788

Rill	----	9,406	39,403	6,425	48,809	8,525
Roderick	87,682	353,203	276,753	18,787	730,446	92,048
Ruby	----	----	50,221	108,617	50,221	108,617
Rush-Willadel	12,018	12,689	14,510	934	96,992	6,381
Shears Draw	29,292	24,047	17,543	2,227	108,993	13,488
Spar	----	27,306	35,773	----	63,079	----
Stony Point	4,007	1,688	235	----	9,981	4,511
Strand	----	----	2,723	817	2,723	817
Surveyor Creek	22,880	51,002	39,935	488,168	113,817	553,530*
Swan	129,196	102,027	84,096	51,715	430,911	204,117
Topaz	9,795	20,991	14,003	6,643	44,789	22,661
Westfork	274,319	368,196	406,285	134,100	1,139,105	256,902
Wetzel Creek	82,587	79,223	54,874	12,890	285,361	76,405
Woodrow-East	9,124	5,495	8,168	708	54,656	40,189
Woodrow-South	34,883	38,680	32,731	14,483	203,272	78,897
Xenia	17,570	14,148	12,475	13,368	77,173	215,672*
Xenia-North	16,242	14,703	10,140	8,865	52,868	117,286
Xenia-West	216,462	150,916	161,455	203,115	1,123,233	813,871
COUNTY TOTAL	7,027,222	6,851,897	6,769,968	3,817,431	39,785,181	24,514,450
WELD						
Antelope	661	1,880	----	----	2,541	----
Battle Canyon	83,359	52,315	33,506	165,658	772,019	2,402,852
Black Hollow	675,225	547,294	527,282	14,855	3,762,773	90,003
Buckingham	48,161	30,036	28,087	193,461	343,130	777,855
Buckingham-West	100,449	36,731	16,599	41,801	293,839	258,182
Cotton Valley	25,554	14,064	4,787	1,115	101,380	24,815
Crow	5,673	4,186	3,131	1,786	15,069	2,366
Empire (See Morgan Co.)	----	----	----	----	662	----
Flag	----	20,684	21,664	23,087	42,348	35,682
Fringe	40,246	35,960	14,959	73,454	91,165	174,002
Grail	11,284	65,532	19,930	57,248	96,746	99,056
Greasewood	12,014	9,006	3,329	271	902,739	169,603
Greasewood-South	9,438	14,981	8,361	----	95,798	81,191
Jackpot (See Morgan Co.)	107,811	56,442	39,059	150,345	476,528	531,487
Jasper	----	----	----	48,849	----	48,849*
Keota	48,338	33,912	21,756	58,318	1,074,095	435,213
Kiowa Creek	----	----	----	----	----	82,303*
Loam	----	----	1,132	27,638	1,132	27,638
Long-South	----	----	----	----	153,023	184,478
Lost Creek	13,728	38,087	25,082	39,466	76,897	104,756
Loveland (See Larimer)	164	861	331	----	1,411	----
Masters (See Morgan)	28,351	20,043	11,772	61,351	298,783	982,646
May	71,294	41,004	36,328	44,340	243,941	242,794
McKenzie	2,212	3,314	849	----	6,670	221,693*
New Windsor	85,234	111,568	96,098	3,230	294,343	11,574
Pierce	742,666	829,997	750,702	17,724	2,516,050	60,216

Colorado Oil and Gas Production, 1887-1959 (Cont.)

County and Field	1957	1958	1959	Gas-MCF 1959	Cumulative to Jan. 1, 1960 Oil-Barrels	Cumulative to Jan. 1, 1960 Gas-MCF
Roggen	54,608	21,746	4,548	5,122	257,558	399,168
Roggen-Southwest	125,997	74,918	54,987	102,438	549,042	1,037,506
Rush Creek	5,610	5,220	6,795	546,909	19,146	1,506,028*
Spruce	----	----	240	47,444	240	53,307*
Spurgin	1,767	----	----	----	14,824	9,588
Spurgin-North	3,117	1,801	----	----	4,918	826
Stoneham	765	3	----	----	2,164	220,579*
Stoneham-South	15,136	11,782	9,369	10,440	95,570	168,759
Terrace	----	1,797	----	----	1,797	-- -
Tower	----	5,000	6,801	3,752	11,801	6,751
Turner	----	----	----	----	454	----
Two Mile	956	5,691	6,104	187,537	12,751	413,147*
Vigor	----	2,490	5,701	14,722	8,191	18,100
Vim	21,089	19,215	13,409	70,810	53,713	284,382
White Butte	6,911	5,985	5,440	----	50,357	19,792
COUNTY TOTAL	2,347,818	2,123,545	1,778,138	2,013,171	12,745,608	11,187,187
STATE TOTAL	54,984,993	48,739,048	46,448,146	194,522,554	551,892,812	1,279,499,257

*Dry Gas

‡Carbon Dioxide

§Helium

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APPENDIX

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by John W Vanderwilt
1947

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Prepared by the United States Geological Survey, under the general supervision of W. S. Burbank

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PART III. INVESTIGATIONS OF STRATEGIC MINERAL RESOURCES

By W. M. Traver, Jr.

ILLUSTRATIONS

Rill	----	9,406	39,403	6,425	48,809	8,525
Roderick	87,682	353,203	276,753	18,787	730,446	92,048
Ruby	----	----	50,221	108,617	50,221	108,617
Rush-Willadel	12,018	12,689	14,510	934	96,992	6,381
Shears Draw	29,292	24,047	17,543	2,227	108,993	13,488
Spar	----	27,306	35,773	----	63,079	----
Stony Point	4,007	1,688	235	----	9,981	4,511
Strand	----	----	2,723	817	2,723	817
Surveyor Creek	22,880	51,002	39,935	488,168	113,817	553,530*
Swan	129,196	102,027	84,096	51,715	430,911	204,117
Topaz	9,795	20,991	14,003	6,643	44,789	22,661
Westfork	274,319	368,196	406,285	134,100	1,139,105	256,902
Wetzel Creek	82,587	79,223	54,874	12,890	285,361	76,405
Woodrow-East	9,124	5,495	8,168	708	54,656	40,189
Woodrow-South	34,883	38,680	32,731	14,483	203,272	78,897
Xenia	17,570	14,148	12,475	13,368	77,173	215,672*
Xenia-North	16,242	14,703	10,140	8,865	52,868	117,286
Xenia-West	216,462	150,916	161,455	203,115	1,123,233	813,871
COUNTY TOTAL	7,027,222	6,851,897	6,769,968	3,817,431	39,785,181	24,514,450
WELD						
Antelope	661	1,880	----	----	2,541	----
Battle Canyon	83,359	52,315	33,506	165,658	772,019	2,402,852
Black Hollow	675,225	547,294	527,282	14,855	3,762,773	90,003
Buckingham	48,161	30,036	28,087	193,461	343,130	777,855
Buckingham-West	100,449	36,731	16,599	41,801	293,839	258,182
Cotton Valley	25,554	14,064	4,787	1,115	101,380	24,815
Crow	5,673	4,186	3,131	1,786	15,069	2,366
Empire (See Morgan Co.)	----	----	----	----	662	----
Flag	----	20,684	21,664	23,087	42,348	35,682
Fringe	40,246	35,960	14,959	73,454	91,165	174,002
Grail	11,284	65,532	19,930	57,248	96,746	99,056
Greasewood	12,014	9,006	3,329	271	902,739	169,603
Greasewood-South	9,438	14,981	8,361	----	95,798	81,191
Jackpot (See Morgan Co.)	107,811	56,442	39,059	150,345	476,528	531,487
Jasper	----	----	----	48,849	----	48,849*
Keota	48,338	33,912	21,756	58,318	1,074,095	435,213
Kiowa Creek	----	----	----	----	----	82,303*
Loam	----	----	1,132	27,638	1,132	27,638
Long-South	----	----	----	----	153,023	184,478
Lost Creek	13,728	38,087	25,082	39,466	76,897	104,756
Loveland (See Larimer)	164	861	331	----	1,411	----
Masters (See Morgan)	28,351	20,043	11,772	61,351	298,783	982,646
May	71,294	41,004	36,328	44,340	243,941	242,794
McKenzie	2,212	3,314	849	----	6,670	221,693*
New Windsor	85,234	111,568	96,098	3,230	294,343	11,574
Pierce	742,666	829,997	750,702	17,724	2,516,050	60,216

Colorado Oil and Gas Production, 1887-1959 (Cont.)

County and Field	1957	1958	1959	Gas-MCF 1959	Cumulative to Jan. 1, 1960 Oil-Barrels	Gas-MCF
Roggen	54,608	21,746	4,548	5,122	257,558	399,168
Roggen-Southwest	125,997	74,918	54,987	102,438	549,042	1,037,506
Rush Creek	5,610	5,220	6,795	546,909	19,146	1,506,028*
Spruce	----	----	240	47,444	240	53,307*
Spurgin	1,767	----	----	----	14,824	9,588
Spurgin-North	3,117	1,801	----	----	4,918	826
Stoneham	765	3	----	----	2,164	220,579*
Stoneham-South	15,136	11,782	9,369	10,440	95,570	168,759
Terrace	----	1,797	----	----	1,797	----
Tower	----	5,000	6,801	3,752	11,801	6,751
Turner	----	----	----	----	454	----
Two Mile	956	5,691	6,104	187,537	12,751	413,147*
Vigor	----	2,490	5,701	14,722	8,191	18,100
Vim	21,089	19,215	13,409	70,810	53,713	284,382
White Butte	6,911	5,985	5,440	----	50,357	19,792
COUNTY TOTAL	2,347,818	2,123,545	1,778,138	2,013,171	12,745,608	11,187,187
STATE TOTAL	54,984,993	48,739,048	46,448,146	194,522,554	551,892,812	1,279,499,257

*Dry Gas

‡Carbon Dioxide

§Helium

Table of Contents
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MINERAL RESOURCES OF COLORADO
by John W Vanderwilt
1947

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Prepared by the United States Geological Survey, under the general supervision of W. S. Burbank

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By W. M. Traver, Jr.

ILLUSTRATIONS

INDEX

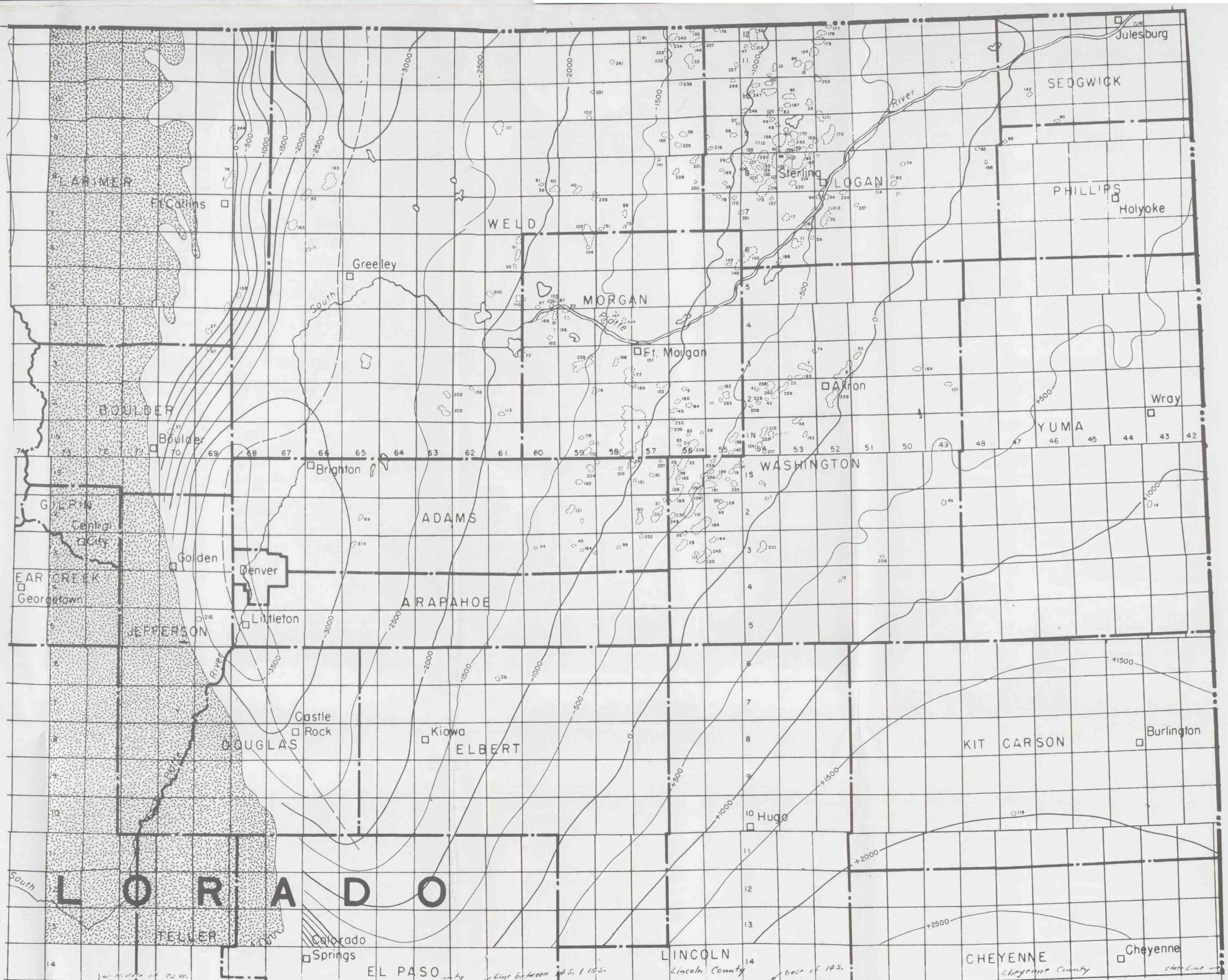
Topographic quadrangle index map, Colorado

(Courtesy of U. S. Geological Survey)

TRANSFERRED FROM TEXT TO POCKET

Plate 1

Structure contour map, northeastern Colorado



List of Fields to be Placed Along the West Edge of Plate 1

LIST OF FIELDS

Number	Name	Number	Name
1	Abbott	49	Cedar Creek-N
2	Abbott-N	50	Centennial
3	Adena	51	Chappel
4	Adena-So.	52	Clark Lake
5	Adobe	53	Cliff
6	Agate	54	Columbine
7	Akron	55	Cone
8	Akron-E	56	Cotton Valley
9	Allen	57	Cottonwood
10	Amber	58	Cottonwood-S
11	Antelope	59	Coyote
12	Anton	60	Crist
13	Arford	61	Crow
14	Arikaree	62	Dailey
15	Armstrong	63	Dale
16	Ashley	64	Dale-N
17	Atwood	65	Darby Creek
18	Atwood-E	66	De Nova
19	Azure	67	Dike
20	Badger Creek	68	Divide
21	Badger Creek-W	69	Doherty
22	Barrow	70	Dune Ridge
23	Battle Canyon	71	Elm Grove
24	Beacon	72	Empire
25	Beall Creek	73	Flag
26	Becker	74	Fleming
27	Berthoud	76	Fort Collins
28	Big Beaver	77	Fort Morgan
29	Big Sandy	78	Frasco
30	Bijou	79	Fremont Butte
31	Bijou-W	80	Frenchman Creek
32	Black Hollow	81	Fringe
33	Bobcat	82	Garnet
34	Bobcat-W	83	Gary
35	Bonham	84	Gary-N
36	Boots Hill	85	Gary-S
37	Boulder	86	Goat Hill
38	Bradbury	87	Goodrich
39	Buckingham	88	Grail
40	Buckingham-W	89	Graylin
41	Buffalo	90	Graylin-NW
42	Buffalo Slough	91	Greasewood
43	Burr	92	Greasewood-S
44	Busy Bee	93	Hardway
45	Cabin Creek	94	Hatfield
46	Camp Creek	95	Haxtun
47	Casement	96	Hector
48	Cedar Creek	97	Highland

List of Fields, Con't, Page 2

Number	Name	Number	Name
98	Hirst	151	Midjay
99	Home	152	Minto
100	Horsetail	153	Minto-W
101	Hyde	154	Minto-N
102	Igo Creek	155	McKenzie
103	Jackpot	156	McGhe
104	Jackpot-S	157	Mosley
105	Jackson	158	Mount Hope
106	Johnson Hill	159	Mount Hope-E
107	Johnson Hill-E	160	Mount Hope-N
108	Johnson Hill-N	161	Mountain View-S
109	Kejr	162	Muddy Creek
110	Kejr-S	163	New Windsor
111	Keota	164	Noonen Ranch
112	Key	165	Nugget
113	Kiowa Creek	166	Onyx
114	Knoll	167	Opal
115	Knox	168	Orchard
116	Lamb	169	Otis
117	Lance	170	Padroni
118	Landsman	171	Padroni-W
119	Lark	172	Park
120	Last Chance	173	Pawnee Creek
121	Leader	174	Pawnee Creek-N
122	Lee	175	Pawnee Hills
123	Levee	176	Peavy
124	Lewis Creek	177	Pebble
125	Liberty	178	Peetz-W
126	Liberty-S	179	Peetz-NW
127	Liberty-W	180	Peterson
128	Little Beaver	181	Phegley
129	Little Beaver-E	182	Pinneo-N
130	Little Hoot	183	Pierce
131	Loam	184	Platner
132	Logan	185	Pleasant Valley
133	Logan-N	186	Plum Bush Creek
134	Lone Valley	187	Prairie View
135	Long-S	188	Prewitt
136	Lost Creek	189	Prong-S
137	Loula	190	Purdy
138	Loveland	191	Rago
139	Luft	192	Rago-N & S
140	Luster	193	Rake
141	Malpais	194	Ramp
142	Marks Butte	195	Rayner Creek
143	Masters	196	Regent
144	May	197	Ridge
145	Merino	198	Rift
146	Merino-NE	199	Rill
147	Messer	200	Riverside
148	Messex	201	Roderick
149	Messex-W	202	Roggen
150	Middlemist	203	Roggen-SW

List of Fields, Con't, Page 3

Number	Name	Number	Name
204	Rosener	256	Woodrow-S
205	Ruby	257	Woodrow-W
206	Rufus Run	258	Xenia
207	Rush Creek	259	Xenia-N
208	Rush Willadel	260	Xenia-W
209	Sam	261	Yenter
210	San Arroyo	262	Young
211	Sand River	263	Zorichak (Pinneo)
212	Sandy Hill		
213	Scarp		
214	Second Creek		
215	Shears Draw		
216	Soda Lake		
217	Spar		
218	Spring Creek		
219	Springdale		
220	Springdale-S		
221	Spruce		
222	Spurgin		
223	Spurgin-N		
224	Sterling		
225	Stoneham		
226	Stoneham-S		
227	Stony Buttes		
228	Stony Point		
229	Surveyor Creek		
230	Swan		
231	Terrace		
232	Timpe		
233	Topaz		
234	Tower		
235	Trend		
236	Turner		
237	Twin Mills		
238	Two Mile		
239	Vallery		
240	Vigor		
241	Vim		
242	Vista		
243	Walker		
244	Wellington		
245	Westfork		
246	W. Plains		
247	W. Plains-N		
248	Wetzel Creek		
249	White		
250	White Butte		
251	Willard		
252	Windy Hill		
253	Winston		
254	Woodrow		
255	Woodrow-E		

PLATE I

STRUCTURE CONTOUR MAP OF NORTHEASTERN COLORADO

SHOWING MAJOR PORTION OF THE DENVER BASIN WITH LAS ANIMAS ARCH TO THE SOUTHEAST

CONTOURED ON TOP OF DAKOTA SANDSTONE

By George H. Fentress

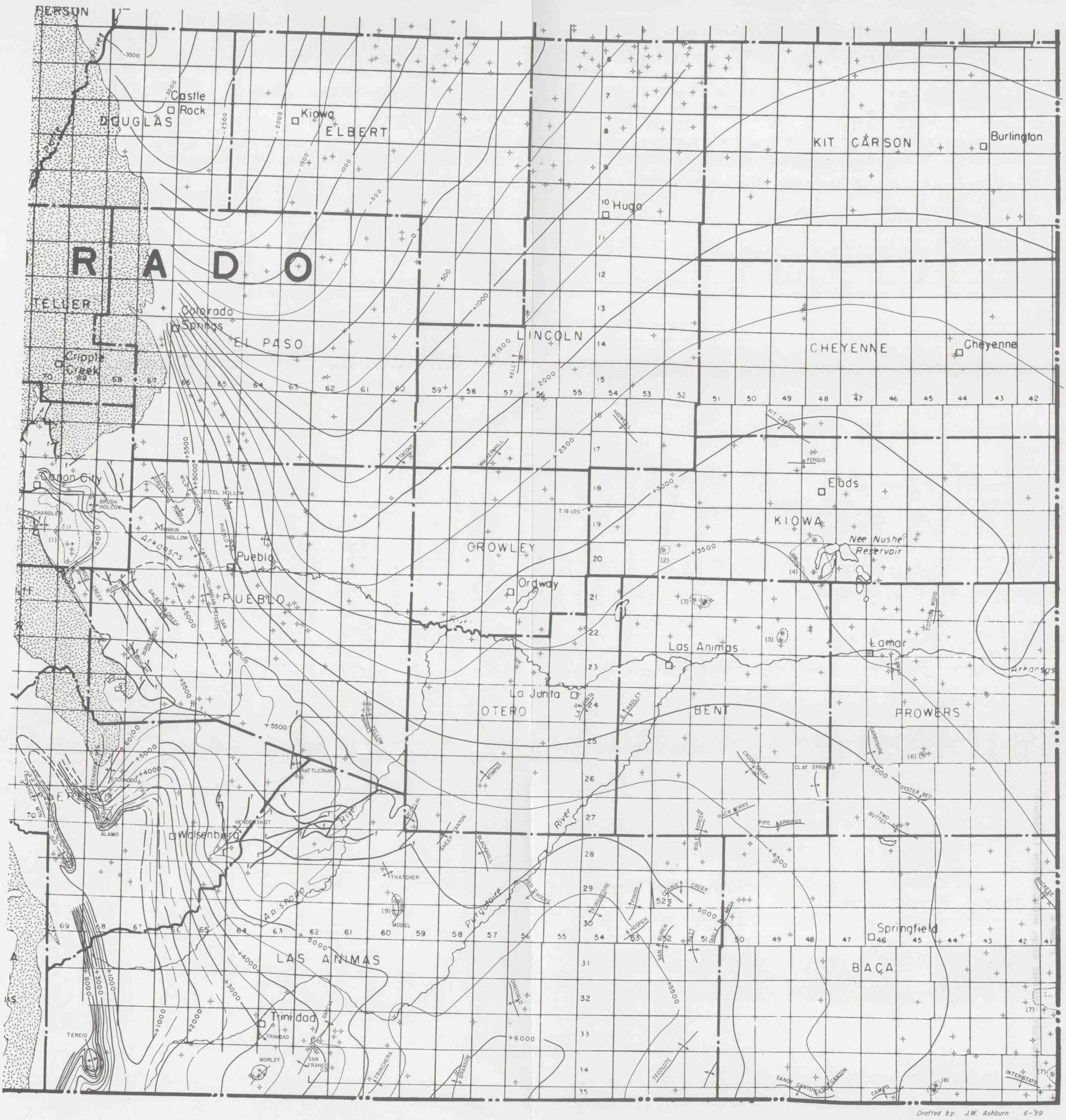
May 31, 1959

CONTOUR INTERVAL 500 FEET

OVERLAPS PLATE 2 TO THE SOUTH

Plate 2

Structure contour map, southeastern Colorado



SEE FIG. 5 FOR LOCATION OF MAJOR GEOLOGICAL SUBPROVINCES

Contour control partly from U.S.G.S. Oil & Gas Investigation Map 176: "Preliminary structure contour map of the Colorado plains" by E.A. Finley, C.E. Dobbin and E.E. Richardson — 1955.

INDEX OF OIL OR GAS FIELDS

1. Florence – Canon City
2. Colt
3. Bents Fort
4. McClave
5. Lubers
6. Barrel Springs
7. Greenwood
8. Prairie Dog
9. Model

PLATE 2

EXPLANATION

Precambrian rocks

Fault

Axis of anticline

(2) Oil or gas field

Dry hole

Oil & gas well

Gas well

STRUCTURE CONTOUR MAP OF SOUTHEASTERN COLORADO ON TOP OF DAKOTA SANDSTONE

SHOWING LOCAL STRUCTURAL AXES, OIL OR GAS PRODUCING AREAS AND DRY HOLES

By Thad R. Carpen

May 31, 1959

OVERLAPS PLATE 1 TO THE NORTH

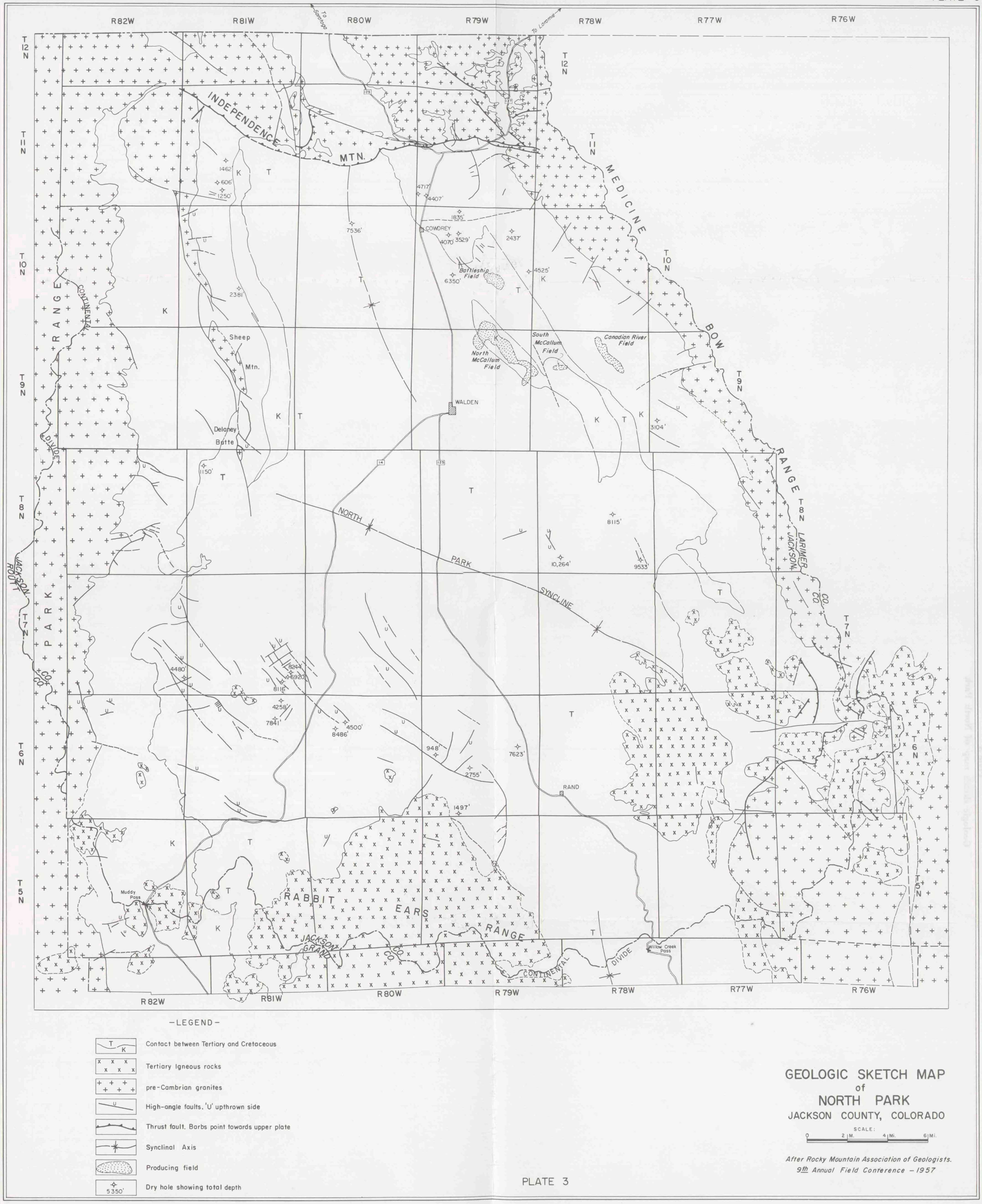
Contour Interval – 500 Feet

Scale 1:500,000

Drafted by J. W. Ashburn & Den Galbraith

Plate 3

Geologic sketch map of North Park



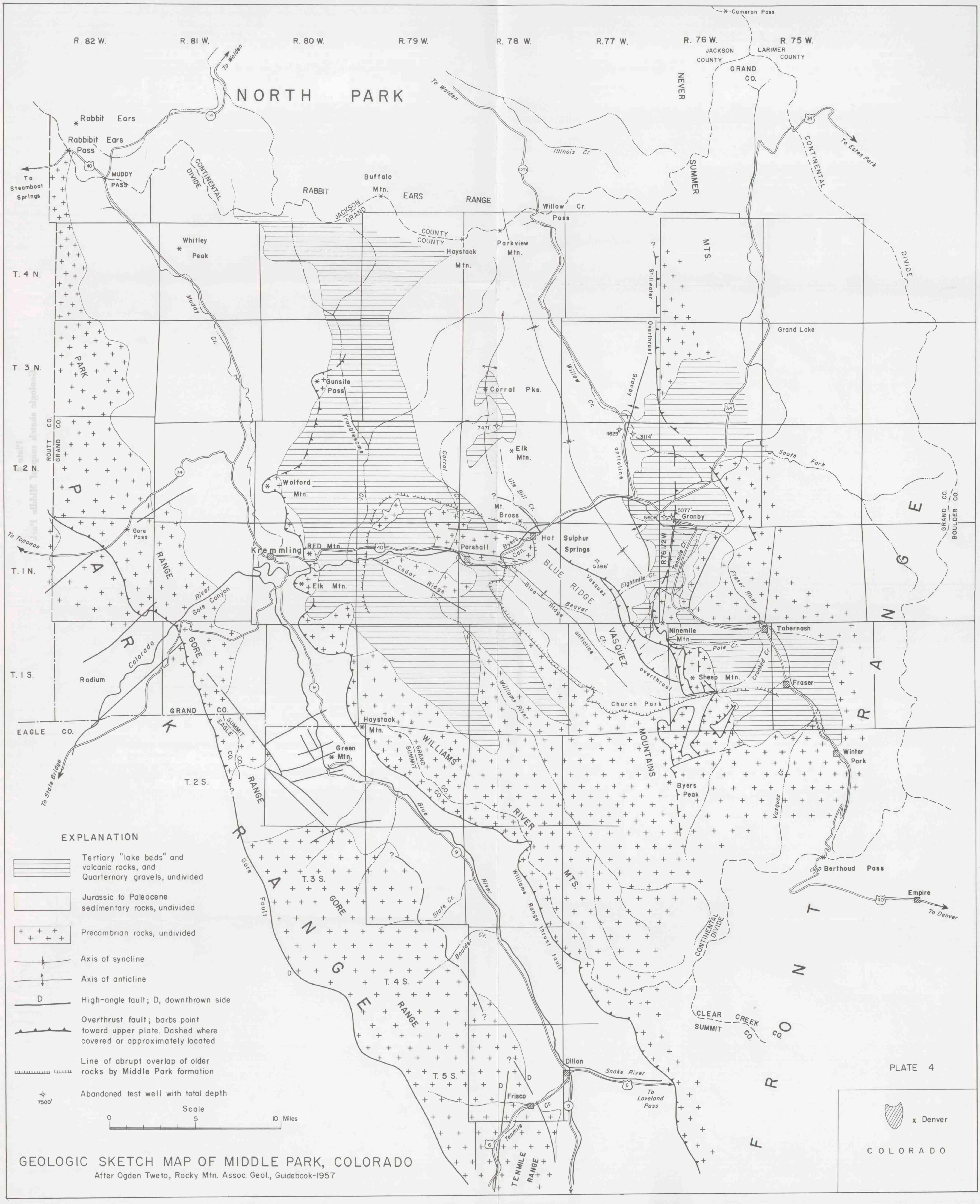
GEOLOGIC SKETCH MAP
of
NORTH PARK
JACKSON COUNTY, COLORADO

SCALE: 0 2 MI. 4 MI. 6 MI.

After Rocky Mountain Association of Geologists. 9th Annual Field Conference – 1957

Plate 4

Geologic sketch map of Middle Park

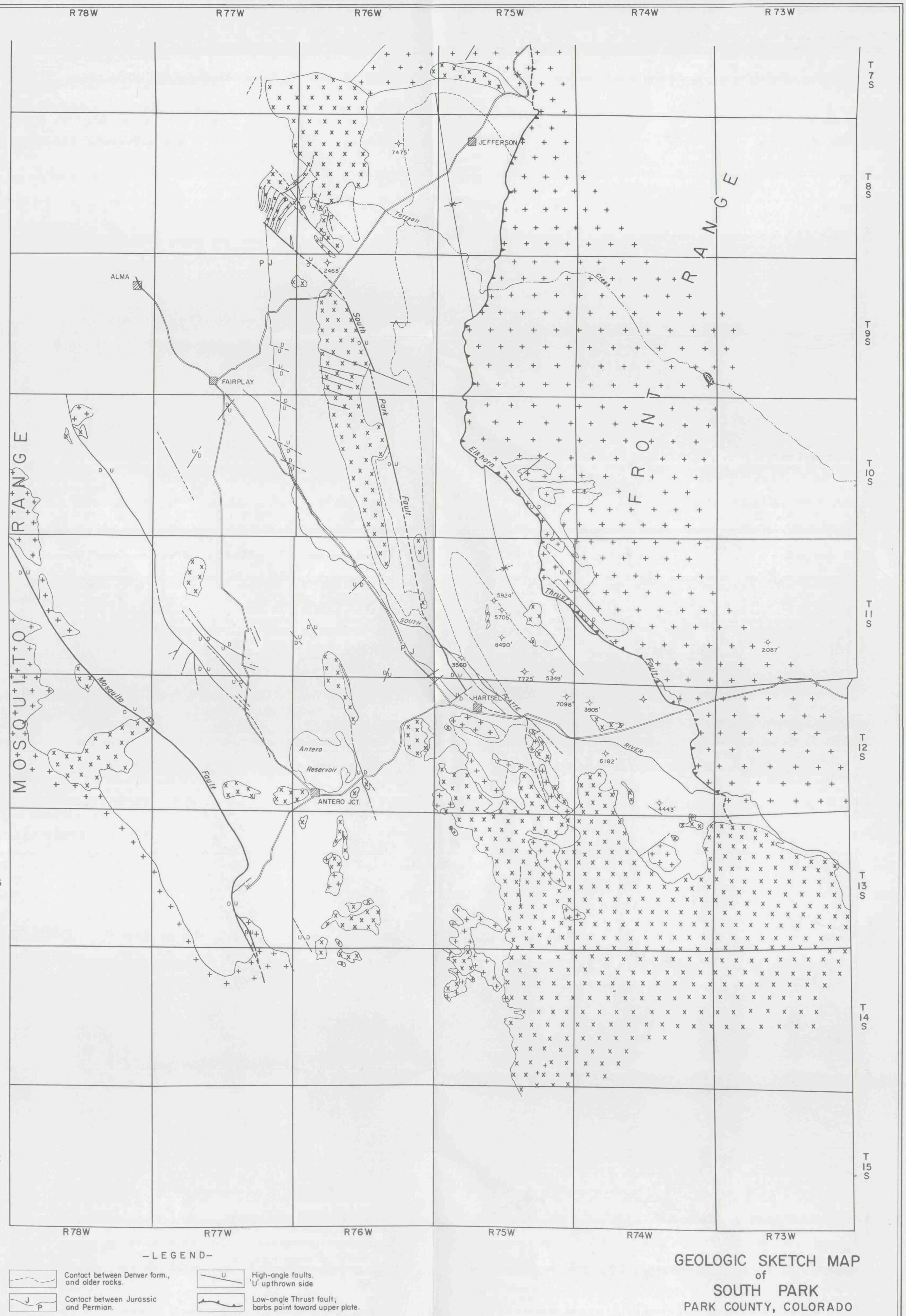


GEOLOGIC SKETCH MAP OF MIDDLE PARK, COLORADO

After Ogden Tweto, Rocky Mtn. Assoc. Geol., Guidebook-1957

Plate 5

Geologic sketch map of South Park



GEOLOGIC SKETCH MAP of SOUTH PARK

PARK COUNTY, COLORADO

After Geological Society of America Memoir No.33, Plate I and U.S. Geological Survey Bull., No.381, Plate XVI

Plate 6

Structure contour map of southwestern Colorado

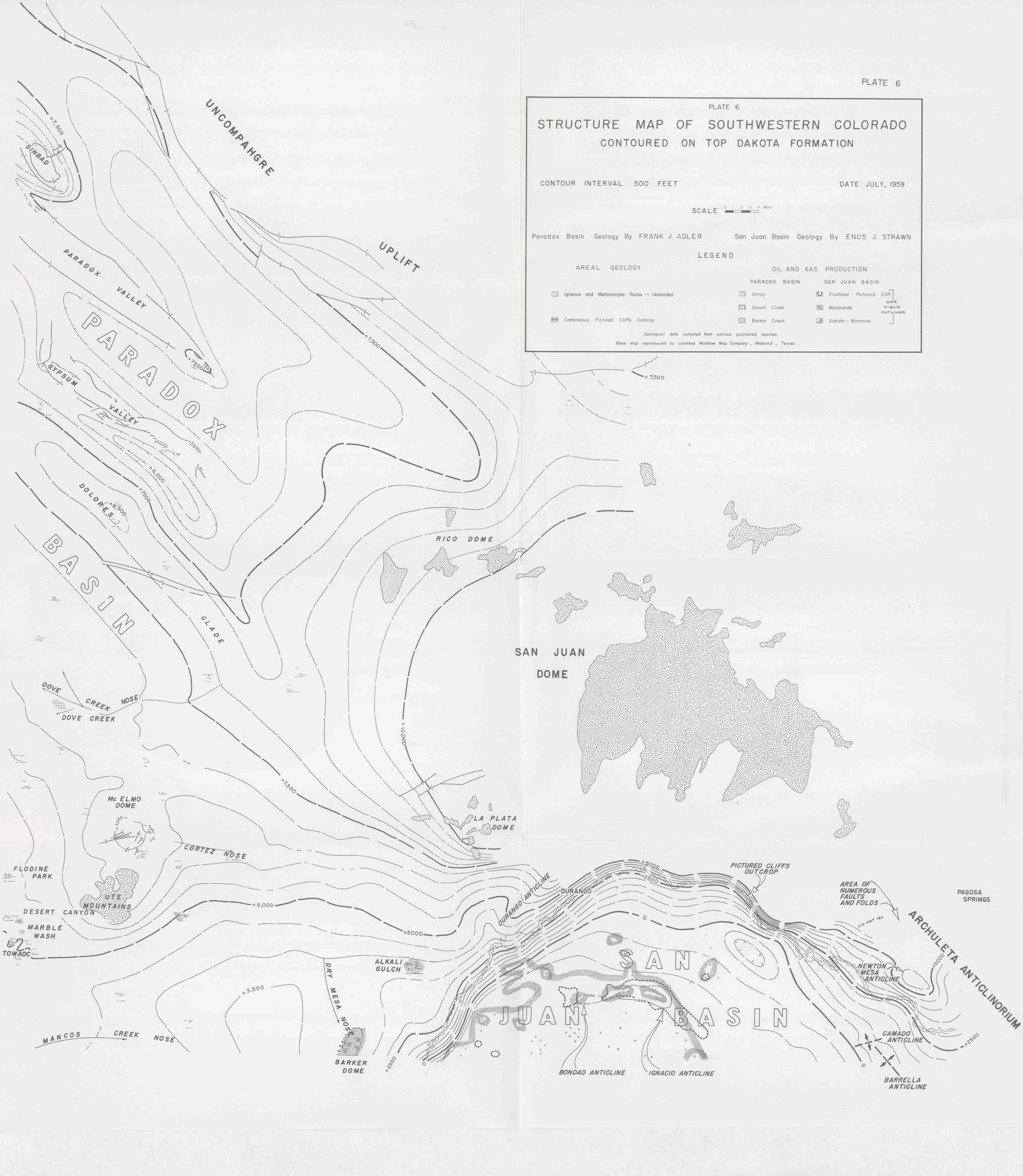


PLATE 6
STRUCTURE MAP OF SOUTHWESTERN COLORADO
CONTOURED ON TOP DAKOTA FORMATION
CONTOUR INTERVAL 500 FEET
DATE: JULY, 1959
SCALE: 0 1 2 3 4 Miles
Paradox Basin Geology By FRANK J. ADLER
San Juan Basin Geology By ENOS J. STRAWN
LEGEND
AREAL GEOLOGY
Igneous and Metamorphic Rocks — Undivided
Cretaceous Pictured Cliffs Outcrop
OIL AND GAS PRODUCTION
PARADOX BASIN
Ismay
Desert Creek
Barker Creek
SAN JUAN BASIN
Fruitland – Pictured Cliff
Mesaverde
Dakota – Morrison
GAS FIELD OUTLINES
Geological data compiled from various published sources.
Base map reproduced by courtesy Muldrow Map Company, Midland, Texas.
UNCOMPAHGRE
UPLIFT
SINBAD
PARADOX VALLEY
PARADOX
GYPSUM VALLEY
DOLORES
BASIN
GLADE
DOVE CREEK NOSE
DOVE CREEK
Mc ELMO DOME
CORTEZ NOSE
FLODINE PARK
UTE MOUNTAINS
DESERT CANYON
MARBLE WASH
TOWAOC
MANCOS CREEK NOSE
DRY MESA NOSE
BARKER DOME
ALKALI GULCH
RICO DOME
SAN JUAN DOME
LA PLATA DOME
DURANGO ANTICLINE
DURANGO
PICTURED CLIFFS OUTCROP
AREA OF NUMEROUS FAULTS AND FOLDS
PAGOSA SPRINGS
ARCHULETA ANTICLINORIUM
NEWTON MESA ANTICLINE
CAMADO ANTICLINE
BARRELLA ANTICLINE
SAN JUAN BASIN
BONDAD ANTICLINE
IGNACIO ANTICLINE
U.S. HWY 160
+7,500
+10,000
+5,000
+5000
+2500
+3,500
+6,000
+8,500
+1000
0

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

COLORADO

INDEX TO TOPOGRAPHIC MAPPING IN COLORADO

The Geological Survey is making a series of standard topographic maps to cover the United States, Puerto Rico, and the Virgin Islands. Under the general plan adopted, the unit of survey is a quadrangle bounded by parallels of latitude and meridians of longitude. Quadrangles covering 7½ minutes of latitude and longitude are published at the scale of either 1:24,000 (1 inch=2,000 feet) or 1:31,680 (1 inch=½ mile). Quadrangles covering 15 minutes of latitude and longitude are published at the scale of 1:62,500 (1 inch=approximately 1 mile), and quadrangles covering 30 minutes of latitude and longitude are published at the scale of 1:125,000 (1 inch=approximately 2 miles). In certain western States, a few quadrangles covering one degree of latitude and longitude have been published at the scale of 1:250,000 (1 inch=approximately 4 miles). A few special maps are published at other scales. Each quadrangle is designated by the name of a city, town, or prominent natural feature within it, and on the margins of the map are printed the names of adjoining quadrangle maps that have been published. The maps are printed in three colors. The cultural features, such as roads, railroads, cities, and towns, as well as the lettering, are in black; the water features are in blue; and the features of relief, such as hills, mountains, and valleys, are shown by brown contour lines. The contour interval differs according to the scale of the map and the relief of the country. On maps that contain supplemental information additional colors are used, such as green for woodland areas and red for highway classification, urban areas, and United States land lines. A folder describing topographic maps and symbols is available free upon request.

Prior to August 1951 the green tint denoting woodland areas was overprinted on only a small portion of the first edition of a quadrangle map. Due to the increasing demand for woodland coverage, however, the greater part of the edition of each map published after that date has carried the green overprint. Therefore, in ordering maps, it is requested that it be specified whether copies with or without woodland coverage are desired.

In many instances, an area is covered by 2 or more maps which carry the same name, but are published at different scales. Wherever this occurs, the map order should also include the map series designation, such as 7½-minute series, 15-minute series, or 30-minute series.

The extent of map coverage is shown on the index map, on which the mapped areas are outlined in black. Quadrangles for which published maps are available have the quadrangle name, publishing agency (if other than the Geological Survey), and the date of survey also printed in black. A list of special maps and sheets is given on the following pages.

HOW TO ORDER MAPS

The price of the standard quadrangle map is 30 cents per copy, but a discount of 20 percent is allowed on orders of $10 or more, and 40 percent on orders of $60 or more, based on the retail price. All maps published by the Geological Survey are subject to the discount rates. Prices for maps other than standard quadrangle maps are given on the following pages of this text. Prepayment is required and may be made by money order or check, payable to the Geological Survey, or in cash—the exact amount—at the sender's risk. Postage stamps are not accepted.

Maps covering areas in the States west of the Mississippi River (including all of Louisiana and Minnesota) should be ordered directly from the Geological Survey, Federal Center, Denver 25, Colorado, where a distribution center for these States is maintained. Maps for areas east of the Mississippi River should be ordered from the Geological Survey, Washington 25, D. C.

Sendings of approximately six maps or less are folded and mailed in envelopes unless unfolded copies are requested in the original order. Larger quantities of maps are rolled and forwarded in tubes.

The Geological Survey does not supply mounted maps.

Further information concerning maps may be obtained from the Map Information Office, Geological Survey, Washington 25, D. C.

Revised July 1960
7-7,000

SPECIAL MAPS AND SHEETS

[Measurements are approximate]

Alta Basin and vicinity, Colo. This map shows part of the Chattanooga mining area in San Miguel County. Limiting parallels, 37°52′ and 37°57′. Limiting meridians, 107°48′ and 107°52′. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval, 25 feet. Size, 25 by 35 inches. 1936. Price, 30 cents.

Arkansas River, Colo. Plan and profile and dam site of Arkansas River, vicinity of Bear Creek to vicinity of Clear Creek. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval on land, 20 feet; on river surface, 5, 10, and 20 feet. Vertical scale of profiles, 200 feet to 1 inch. Size, 22 by 29 inches. 10 sheets (7 plans, 2 profiles, 1 sheet showing dam sites). Price, 30 cents a sheet.

Aspen and vicinity, Colo. This map shows Aspen and the adjacent area in Pitkin County. Limiting parallels, 39°10′26″ and 39°12′46″. Limiting meridians, 106°48′ and 106°50′20″. Scale, 1:9,600, or 800 feet to 1 inch. Contour interval, 25 feet. Size, 16½ by 20 inches. 1891. Price, 30 cents.

Black Canyon of the Gunnison National Monument, Colo. This map shows the Black Canyon of the Gunnison River and the adjacent area in Montrose County. Limiting parallels, 38°31′ and 38°37′30″. Limiting meridians, 107°37′30″ and 107°48′15″. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval, 40 feet. Size, 23 by 30 inches. 1934–50. Also published in a shaded relief edition. Price, either contour or relief edition, 50 cents.

Bonanza and vicinity, Colo. This map shows Bonanza and the adjacent area in Saguache County. Limiting parallels, 38°17′ and 38°20′30″. Limiting meridians, 106°06′ and 106°09′. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval, 20 feet. Size, 17½ by 26 inches. 1920. Price, 30 cents.

Breckenridge special, Colo. This map shows Breckenridge and the adjacent area in Summit County. Limiting parallels, 39°27′ and 39°33′. Limiting meridians, 105°56′53″ and 106°04′. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval, 50 feet. Size, 19 by 22 inches. 1908. Price, 30 cents.

Cattle Creek, Colo. Plan and profile of Cattle Creek from a point 1 mile above mouth to mile 10, and dam sites. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval, 20 feet. Vertical scale of profile, 80 feet to 1 inch. Size, 22 by 28 inches. 1 sheet. Price, 30 cents.

Central City special, Colo. This map shows Central City and the adjacent area in Gilpin County. Limiting parallels, 39°46′23″ and 39°49′06″. Limiting meridians, 105°29′15″ and 105°32′46″. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval, 50 feet. Size, 19 by 21 inches. 1904. Price, 30 cents.

Cheyenne sheet (NK-13), 1:1,000,000 series. This map shows parts of Colorado, Nebraska, South Dakota, and Wyoming. Limiting parallels, 40° and 44°. Limiting meridians, 102° and 108°. The altitude of the land is shown by contour lines and tints. Scale, 1:1,000,000, or about 16 miles to 1 inch. Size, 23 by 26 inches. 1957. Price, $1.

Colorado (State). This map shows counties, location and names of all cities and towns and most of the smaller settlements, and railroads (in black); rivers, many of the smaller streams, and other water features (in blue). It does not show contours. Scale, 1:500,000, or about 8 miles to 1 inch. Size, 44 by 53 inches. 1956. Price, $1. Also published in black and white at the scale of 1:1,000,000, or about 16 miles to 1 inch; size, 21 by 27 inches; price, 20 cents.

Colorado (Topographic). This map is an overprint of the 1:500,000-scale base map described directly above, and in addition, shows highways in purple and contours in brown. It also shows national forests and parks, Indian reservations, and urban areas in different color patterns, and accentuates county boundaries in green. Contour interval, 500 feet. Size, 44 by 53 inches. 1956. Price, $2.

Colorado (Relief). This map is overprinted on a modified base map which shows only county boundaries and the larger cities (in black), and the water features (in blue). The physical features of this map are brought out by shaded relief in color, on the conventional plan of assumed diagonal illumination from the northwest. It does not show contours. Scale, 1:500,000, or about 8 miles to 1 inch. Size, 44 by 53 inches. 1956. Price, $2.

Colorado National Monument, Colo. This map shows the Colorado National Monument and the adjacent area in Mesa County. Limiting parallels, 39° and 39°07′30″. Limiting meridians, 108°37′30″ and 108°45′. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval, 20 feet. Size, 17 by 21 inches. 1934. Also published in a shaded relief edition. Price, either contour or relief edition, 30 cents.

Colorado River, Colo. Plan of Colorado River from Rifle to Glenwood Springs, and dam site. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval on land, 20 feet; on river surface, 5 feet. Size, 22 by 28 inches. 2 sheets. Price, 30 cents a sheet.

Colorado River, Utah-Colo. Plan and profile of Colorado River from mile 987 to mile 1076, Utah and Colorado, and Dolores River to mile 22, Utah, and dam sites. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval on land, 20 feet; on river surface, 5 feet. Vertical scale of profiles, 20 feet to 1 inch. Size, 22 by 28 inches. 14 sheets (11 plans, 3 profiles). Price, 30 cents a sheet.

Creede and vicinity, Colo. This map shows the mining district adjacent to Creede in Mineral County. Limiting parallels, 37°50′ and 37°55′. Limiting meridians, 106°54′ and 106°59′. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval, 50 feet. Size, 16½ by 21 inches. 1910. Price, 30 cents.

Crystal River, Colo. Plan and profile of Crystal River from Carbondale to Marble, and dam site. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval on land, 20 feet; on river surface, 5 feet. Vertical scale of profile, 80 feet to 1 inch. Size, 22 by 28 inches. 2 sheets (1 plan, 1 profile). Price, 30 cents a sheet.

Denver and vicinity, Colo. This map was compiled from the Arvada, Derby, Englewood, Fitzsimons, Fort Logan, Highlands Ranch, Littleton, Parker, and Sable quadrangle maps. Limiting parallels, 39°32′30″ and 39°52′30″. Limiting meridians, 104°48′ and 105°07′30″. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval, 10 feet. Size, 50 by 69 inches. 1957. Price, $1.50.

Denver Mountain Area, Colo. Map of about 5,700 square miles north and west of Denver, including Rocky Mountain National Park and the Denver Mountain Parks. Text on the reverse side of the map discusses the geology and history of the region. Limiting parallels, 39°30′ and 40°45′. Limiting meridians, 104°45′ and 106°. Scale, 1:190,080, or 3 miles to 1 inch. Contour interval, 500 feet. Size, 26 by 38 inches. 1938-48. Also published in a shaded relief edition. Price, either contour or relief edition, flat or folded, 50 cents.

Denver Mountain Parks, Colo. This map shows the mountain playground west of Denver. Limiting parallels, 39°30′ and 39°45′. Limiting meridians, 105°10′ and 105°40′. Scale, 1:62,500, or about 1 mile to 1 inch. Contour interval, 100 feet. Size, 22 by 30 inches. 1903–23. Price, 50 cents.

Dinosaur National Monument, Utah-Colo. This map shows the Dinosaur National Monument and the adjacent area in Uintah County, Utah, and Moffat County, Colo. Text on the reverse side of the map discusses the history of exploration and mapping of the area and describes the topography, rock formations, and ancient and present-day flora and fauna, with illustrations. Limiting parallels, 40°24′ and 40°45′. Limiting meridians, 108°30′ and 109°21′. Scale, 1:62,500, or about 1 mile to 1 inch. Contour interval, 50 feet. Size, 30 by 51 inches. 1941. Also published in a shaded relief edition. Price, either contour or relief edition, $1.

Dunton mining area, Colo. This map shows Dunton and the adjacent area in Dolores County. Limiting parallels, 37°44′30″ and 37°47′. Limiting meridians, 108°04′30″ and 108°08′30″. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval, 50 feet. Size, 19½ by 22 inches. 1937. Price, 30 cents.

Eagle River, Colo. Plan and profile of Eagle River, Brush Creek to Mitchell Creek, Homestake Creek to mile 13, and tributaries. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval on land, 20 feet; on river surface, 5 feet. Vertical scale of profile, 200 feet to 1 inch. Size, 22 by 28 inches. 7 sheets (6 plans, 1 profile). Price, 30 cents a sheet.

Fryingpan Creek, Colo. Plan and profile of Fryingpan Creek from a point 2 miles above mouth to Chapman Gulch, and dam site. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval on land, 20 feet; on river surface, 5 feet. Vertical scale of profile, 80 feet to 1 inch. Size, 22 by 28 inches. 2 sheets (1 plan, 1 profile). Price, 30 cents a sheet.

Gold Hill mining area, Colo. This map shows the mining area adjacent to Gold Hill in Boulder County. Limiting parallels, 40°01′ and 40°05′. Limiting meridians, 105°19′ and 105°25′. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval, 25 feet. Size, 30 by 33 inches. 1938. Price, 30 cents.

Great Salt Lake sheet (NK-12), 1:1,000,000 series. This map shows parts of Colorado, Idaho, Utah, and Wyoming. The altitude of the land is shown by contour lines and tints. Limiting parallels, 40° and 44°. Limiting meridians, 108° and 114°. Scale, 1:1,000,000, or about 16 miles to 1 inch. Size, 23 by 26 inches. 1957. Price, $1.

Great Sand Dunes National Monument, Colo. This map shows the Great Sand Dunes National Monument and the adjacent area in Saguache and Alamosa Counties. Limiting parallels, 37°40′ and 37°50′. Limiting meridians, 105°30′ and 105°40′. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval, 10 feet. Size, 28 by 36 inches. 1938. Price, 50 cents.

Green River, Wyo.-Colo.-Utah. Plan and profile of Green River from Green River, Utah, to Green River, Wyo. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval on land, 20 feet; on river surface, 5 feet. Vertical scale of profiles, 20 feet to 1 inch. Size, 21 by 27 inches. 16 sheets (10 plans, 6 profiles). Price, 30 cents a sheet.

Henson Creek, Colo. Plan of Henson Creek from a point near the mouth to mile 11, and dam sites. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval, 20 feet. Size, 22 by 28 inches. 1 sheet. Price, 30 cents.

Idaho Springs special, Colo. This map shows Idaho Springs and the adjacent area in Clear Creek and Gilpin Counties. Limiting parallels, 39°44′30″ and 39°46′23″. Limiting meridians, 105°29′50″ and 105°33′30″. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval, 50 feet. Size, 16½ by 20 inches. 1904. Price, 30 cents.

Independence Pass and vicinity, Colo. This map shows the area along the Continental Divide from Independence Pass to Grizzly Mountain in Pitkin, Lake, and Chaffee Counties. Limiting parallels, 39°02′30″ and 39°07′30″. Limiting meridians, 106°32′ and 106°40′. Scale, 1:48,000, or 4,000 feet to 1 inch. Contour interval, 50 feet. Size, 16 by 20 inches. 1932. Price, 30 cents.

Leadville mining district, Colo. This map shows the Leadville ore belt in Lake County. Limiting parallels, 39°13′50″ and 39°16′. Limiting meridians, 106°13′ and 106°19′47″. Scale, 1:9,600, or 800 feet to 1 inch. Contour interval, 25 feet. Size, 20½ by 48 inches. 1911. Price, 50 cents.

Leadville No. 4, Colo. This map shows Fairplay and the area west of it in Park County. Limiting parallels, 39°10′ and 39°15′. Limiting meridians, 106° and 106°15′. Scale, 1:48,000, or 4,000 feet to 1 inch. Contour interval, 50 feet. Size, 16 by 20 inches. 1927–34. Price, 30 cents.

Little Snake River, Colo.-Wyo. Plan of Little Snake River from Baggs, Wyo. to Middle Fork mile 3, Slater Fork to mile 30, South Fork to mile 12, and dam sites. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval on land, 10 feet; on river surface, 5 feet. Size, 22 by 28 inches. 6 sheets. Price, 30 cents a sheet.

Mesa Verde National Park, Colo. This map shows the Mesa Verde National Park and the adjacent area in Montezuma County. Limiting parallels, 37°09′18″ and 37°21′. Limiting meridians, 108°15′ and 108°37′30″. Scale, 1:31,250, or about ½ mile to 1 inch. Contour interval, 25 feet. Size, 31 by 46 inches. 1911. Price, 50 cents.

Owens Creek reservoir site, Colo. Plan of Owens Creek reservoir site in T. 9 S., R. 92 W. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval on land, 10 feet; on river surface, 5 feet. Size, 20 by 22 inches. 1 sheet. Price, 30 cents.

Pikes Peak and vicinity, Colo. This map covers an area of about 660 square miles, and was compiled from 1:24,000 scale quadrangle maps. Text on the reverse side of the map discusses the geologic story of Pikes Peak and the adjacent area. Limiting parallels, 38°42′ and 39°03′. Limiting meridians, 104°41′ and 105°12′. Scale, 1:62,500, or about 1 mile to 1 inch. Contour interval, 100 feet. Size, 32 by 32 inches. 1948–56. Also published in a shaded relief edition. Price, either contour or relief edition, flat or folded, 75 cents.

Platoro mining area, Colo. This map shows Platoro and the adjacent area in Conejos County. Limiting parallels, 37°20′15″ and 37°22′. Limiting meridians, 106°31′ and 106°33′. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval, 25 feet. Size, 18 by 22 inches. 1936. Price, 30 cents.

Rico district, Colo. This map shows Rico and the adjacent area in Dolores County. Limiting parallels, 37°40′ and 37°44′39″. Limiting meridians, 107°58′37″ and 108°05′39″. Scale, 1:23,600, or about 2,000 feet to 1 inch. Contour interval, 50 feet. Size, 17 by 22 inches. 1898. Price, 30 cents.

Rico mining district, Colo. This map shows the mining area adjacent to Rico in Dolores County. Limiting parallels, 37°40′ and 37°44′. Limiting meridians, 107°59′ and 108°03′. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval, 25 feet. Size, 20 by 25 inches. 1930. Price, 30 cents.

Roaring Fork, Colo. Plan and profile of Roaring Fork from Colorado River to mile 55. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval on land, 20 feet; on river surface, 5 feet. Vertical scale of profiles, 80 feet to 1 inch. Size, 22 by 28 inches. 5 sheets (3 plans, 2 profiles). Price, 30 cents a sheet.

Rocky Mountain National Park, Colo. This map shows the Rocky Mountain National Park and the adjacent area in Boulder, Grand, Jackson, and Larimer Counties. Limiting parallels, 40° and 40°33′. Limiting meridians, 105°30′ and 106°. Scale, 1:125,000, or about 2 miles to 1 inch. Contour interval, 100 feet. Size, 16½ by 22 inches. 1915. Price, 30 cents.

San Juan River, Colo. Plan and profile of San Juan River from Montezuma Creek to West Fork, and dam sites. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval on land, 20 feet; on river surface, 5 feet. Vertical scale of profile, 40 feet to 1 inch. Size, 22 by 28 inches. 3 sheets (2 plans, 1 profile). Price, 30 cents a sheet.

Set of one hundred topographic maps illustrating specified physiographic features. This set of maps has been selected to illustrate a wide variety of well-portrayed physiographic features. The set generally follows the Physical Divisions Map of the United States, and illustrates most of its 86 subdivisions. 1955. Price, $30 a set.

Set of twenty-five topographic maps illustrating specified physiographic features. A smaller set arranged for those interested in a less-detailed study than that of the one-hundred map set. 1955. Price, $7.50 a set.

Shaded relief maps. Besides the regular topographic maps, maps of the Anvil Points, Holy Cross, Juanita Arch, and Kassler quadrangles have been published in an edition on which the relief is shown both by brown contour lines, as on the regular topographic map, and by shading in brown, which gives the map the appearance of a model of the surface, with the light striking it from the northwest. The shading makes the inequalities of the surface more readily apparent to the inexperienced map reader than do the contour lines alone. Price, 30 cents.

Silver Plume special, Colo. This map shows Silver Plume and the adjacent area in Clear Creek County. Limiting parallels, 39°41′33″ and 39°42′26″. Limiting meridians, 105°42′35″ and 105°45′. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval, 50 feet. Size, 8½ by 14 inches. 1904. Price, 30 cents.

Snowmass Mountain and vicinity, Colo. This map shows the area east of Marble in Pitkin and Gunnison Counties. Limiting parallels, 39° and 39°07′30″. Limiting meridians, 107° and 107°15′. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval, 50 feet. Size, 22 by 32 inches. 1930. Price, 30 cents.

Sugarloaf-St. Kevin mining districts, Colo. This map shows part of Lake County. Limiting parallels, 39°14′ and 39°17′30″. Limiting meridians, 106°22′ and 106°24′. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval, 50 feet. Size, 16 by 20 inches. 1930. Price, 30 cents.

Summitville mining area, Colo. This map shows Summitville and the adjacent area in Rio Grande and Conejos Counties. Limiting parallels, 37°24′ and 37°27′. Limiting meridians, 106°34′20″ and 106°38′20″. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval, 25 feet. Size, 22 by 27 inches. 1936. Price, 30 cents.

Tenmile district, Colo. This map shows Kokomo and the adjacent area in Summit and Eagle Counties. Limiting parallels, 39°22′57″ and 39°30′25″. Limiting meridians, 106°08′ and 106°16′08″. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval, 100 feet. Size, 18½ by 21½ inches. 1882. Price, 30 cents.

Tenmile mining district (north half), Colo. This map shows parts of Summit and Eagle Counties. Limiting parallels, 39°25′30″ and 39°30′. Limiting meridians, 106°07′30″ and 106°14′. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval, 25 feet. Size, 33 by 40 inches. 1927–40. Price, 50 cents.

Tenmile mining district (south half), Colo. This map shows parts of Summit, Lake, and Park Counties. Limiting parallels, 39°21′ and 39°25′30″. Limiting meridians, 106°07′ and 106°14′. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval, 25 feet. Size, 31 by 40 inches. 1927–39. Price, 50 cents.

Troublesome Creek, Colo. Plan and profile of Rabbit Ear and East Fork reservoir sites on Troublesome Creek. Scale, 1:12,000, or 1,000 feet to 1 inch. Contour interval on land, 10 feet; on river surface, 5 feet. Vertical scale of profile, 40 feet to 1 inch. Size, 22 by 28 inches. 2 sheets (1 plan, 1 profile). Price, 30 cents a sheet.

United States Series of Topographic Maps, Scale 1:250,000. This is a series of topographic maps produced by the Army Map Service and published and distributed for civilian use by the Geological Survey. Size, 24 by 34 inches. Price, 50 cents each. Woodland shown by green overprint, unless otherwise noted. The following maps cover areas in Colorado:

Aztec. Limiting parallels, 36° and 37°. Limiting meridians, 106° and 108°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1954.

Cheyenne. Limiting parallels, 41° and 42°. Limiting meridians, 104° and 106°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1954.

Cortez. Limiting parallels, 37° and 38°. Limiting meridians, 108° and 110°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1956.

Craig. Limiting parallels, 40° and 41°. Limiting meridians, 106° and 108°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1954.

Dalhart. Limiting parallels, 36° and 37°. Limiting meridians, 102° and 104°. Contour interval, 100 feet, with supplementary contours at 50-foot intervals. 1954.

Denver. Limiting parallels, 39° and 40°. Limiting meridians, 104° and 106°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1953.

Durango. Limiting parallels, 37° and 38°. Limiting meridians, 106° and 108°. Contour interval, 200 feet. Overprinted with shaded relief. 1945.

Greeley. Limiting parallels, 40° and 41°. Limiting meridians, 104° and 106°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1954.

La Junta. Limiting parallels, 37° and 38°. Limiting meridians, 102° and 104°. Contour interval, 100 feet, with supplementary contours at 50-foot intervals. 1955.

Lamar. Limiting parallels, 38° and 39°. Limiting meridians, 102° and 104°. Contour interval, 100 feet, with supplementary contours at 50-foot intervals. 1954.

Leadville. Limiting parallels, 39° and 40°. Limiting meridians, 106° and 108°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1956.

Limon. Limiting parallels, 39° and 40°. Limiting meridians, 102° and 104°. Contour interval, 100 feet, with supplementary contours at 50-foot intervals. 1954.

Moab. Limiting parallels, 38° and 39°. Limiting meridians, 108° and 110°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1956.

Pueblo. Limiting parallels, 38° and 39°. Limiting meridians, 104° and 106°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1954.

Raton. Limiting parallels, 36° and 37°. Limiting meridians, 104° and 106°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1954.

Rawlins. Limiting parallels, 41° and 42°. Limiting meridians, 106° and 108°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1954.

Rock Springs. Limiting parallels, 41° and 42°. Limiting meridians, 108° and 110°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1954.

Scottsbluff. Limiting parallels, 41° and 42°. Limiting meridians, 102° and 104°. Contour interval, 100 feet, with supplementary contours at 50-foot intervals. 1954.

Shiprock. Limiting parallels, 36° and 37°. Limiting meridians, 108° and 110°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1954.

Sterling. Limiting parallels, 40° and 41°. Limiting meridians, 102° and 104°. Contour interval, 100 feet, with supplementary contours at 50-foot intervals. 1954.

Trinidad. Limiting parallels, 37° and 38°. Limiting meridians, 104° and 106°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1954.

Vernal. Limiting parallels, 40° and 41°. Limiting meridians, 108° and 110°. Contour interval, 200 feet, with supplementary contours at 100-foot intervals. 1954.

Whitewater Reservoir site, Colo. Plan of Whitewater Reservoir site, Lower Gunnison River, from vicinity of Grand Junction to Escalante. Scale, 1:24,000, or 2,000 feet to 1 inch. Contour interval on land, 20 feet; on river surface, 5 feet. Size, 22 by 28 inches. 2 sheets. Price, 30 cents a sheet.

Yampa River, Colo. Plan of Yampa River from mouth of Elk River to mile 73, Morrison Creek to mile 10, and dam sites. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval on land, 20 feet; on river surface, 5 feet. Size, 22 by 27 inches. 5 sheets. Price, 30 cents a sheet.

Yampa River, Colo. Plan and profile of Yampa River from Green River to Morgan Gulch. Scale, 1:31,680, or ½ mile to 1 inch. Contour interval on land, 20 feet; on river surface, 5 feet. Vertical scale of profiles, 20 feet to 1 inch. Size, 21 by 27 inches. 5 sheets (3 plans, 2 profiles). Price, 30 cents a sheet.

MAPS SHOWING NATIONAL PARKS AND MONUMENTS

[Additional information can be obtained from the National Park Service, Department of the Interior, Washington 25, D. C.]

Black Canyon of the Gunnison National Monument, Colo. See "Special maps and sheets," page 2.
Colorado National Monument, Colo. See "Special maps and sheets," page 2.
Dinosaur National Monument, Utah-Colo. See "Special maps and sheets," page 2.
Great Sand Dunes National Monument, Colo. See "Special maps and sheets," page 3.
Hovenweep National Monument, Utah-Colo. This monument is shown on the 1:250,000-scale map of the Cortez quadrangle.
Mesa Verde National Park, Colo. See "Special maps and sheets," page 3.
Rocky Mountain National Park, Colo. See "Special maps and sheets," page 3.

MAP REFERENCE LIBRARIES

Many libraries maintain map reference facilities where the published maps of the Geological Survey may be consulted. These maps are also on file in the field offices of the Geological Survey. In this State, maps are deposited in the libraries listed below.

BOULDER:
Library, University of Colorado.
COLORADO SPRINGS:
Library, Colorado College.
DENVER:
Denver Public Library.
Library, U. S. Geological Survey, Federal Center.
FORT COLLINS:
Library, Colorado State University.
GOLDEN:
Library, Government Documents Division, Colorado School of Mines.
GUNNISON:
Division of Natural Sciences and Mathematics, Geology Dept., Western State College of Colorado.

MAPS OF THE UNITED STATES

BASE MAPS:

A wall map, showing State and county boundaries and names, State capitals, and county seats (in black); and water features (in blue). State boundaries are accentuated by green overprint. A buff background distinguishes the United States from adjoining countries. Insets show Alaska and Hawaii, and the Canal Zone, Puerto Rico, and the Virgin Islands. Scale, 1:2,500,000, or about 40 miles to 1 inch. 2 sheets, each 41 by 54 inches (when trimmed and assembled to make a single sheet, 54 by 80 inches). 1959. Price, $1.50.

Shows State and county boundaries and names, and water features (in black). Scale, 1:5,000,000, or about 80 miles to 1 inch. Size, 27 by 41 inches. 1933. Price, 50 cents.

Shows State and county boundaries and names (in black), and water features (in blue). Scale, 1:5,000,000, or about 80 miles to 1 inch. Size, 27 by 41 inches. 1933. Price, 50 cents.

Shows State boundaries and names (in black), county boundaries and names, and water features (in blue). Scale, 1:5,000,000, or about 80 miles to 1 inch. Size, 27 by 41 inches. 1933. Price, 50 cents.

Shows State boundaries and principal cities (in black); and water features (in blue). Scale, 1:7,000,000, or about 110 miles to 1 inch. Size, 20 by 30 inches. 1916. Price, 30 cents.

Shows State boundaries and principal cities (in black); and water features (in blue). Scale, 1:11,875,000, or about 190 miles to 1 inch. Size, 13½ by 20 inches. 1906. Price, 20 cents.

Shows State boundaries and principal cities (in black); and water features (in blue). Scale, 1:16,500,000, or about 260 miles to 1 inch. Size, 9½ by 13 inches. 1911. Price, 10 cents.

CONTOUR MAP:

Shows State boundaries and principal cities (in black); water features (in blue); and contours (in brown). Scale, 1:7,000,000, or about 110 miles to 1 inch. Size, 20 by 30 inches. 1916. Price, 30 cents.

OUTLINE MAP:

Shows State boundaries and names only. Scale, 1:5,000,000, or about 80 miles to 1 inch. Size, 27 by 41 inches. 1940. Price, 50 cents.

PHYSICAL DIVISIONS:

Shows physical divisions outlined in red on a base map 20 by 30 inches. Subdivisions and characteristics of each are listed on the margin. Scale, 1:7,000,000, or about 110 miles to 1 inch. Size, 28 by 32 inches. 1946. Price, 30 cents.

STATUS INDEX MAPS:

A series of maps showing the status of various phases of mapping in the United States. Each map is accompanied by a text which gives a detailed explanation. Scale, 1:5,000,000, or about 80 miles to 1 inch. Size, 27 by 41 inches. Free on application to the Geological Survey, Washington 25, D. C. The following maps are available:

Aerial Mosaics of the United States. Shows all areas in the United States for which mosaics or photo maps have been prepared from aerial photographs, scale of negatives, dates of photography, and agencies from which copies may be obtained. Color patterns indicate the holdings of the various Federal and state agencies and commercial firms that have reported their coverage to date. 1959.

Aerial Photography of the United States. Shows the status of aerial photography, areas that have been photographed, and agencies holding the film. Coverage of aerial photography is shown to the extent known only if reproductions are generally available for purchase. 1959.

Topographic Mapping in the United States. Map 1. Shows the status of topographic mapping in the conterminous United States, by the Geological Survey and other Federal agencies. A general appraisal of the adequacy of these maps is indicated by color patterns. 1960.

Topographic Mapping in the United States. Map 2. Shows the status of topographic mapping in Alaska, Hawaii, Puerto Rico and the Virgin Islands, American Samoa, Guam, and the Panama Canal Zone, by the Geological Survey and other Federal agencies. A general appraisal of the adequacy of these maps is indicated by color patterns. 1960.

AGENTS FOR TOPOGRAPHIC MAPS

Purchasers may save delay incident to ordering through the mails by buying from the following agents, who carry in stock some or all of the maps described in this index and sell them at prices usually in advance of rates herein mentioned.

COLORADO

ASPEN:
Carpenter's Book Shop.
BOULDER:
University Book Store, University of Colorado.
COLORADO SPRINGS:
The Chinook Bookshop, 208½ North Tejon Street.
Out West Printing & Stationery Co.,
11 East Pikes Peak Avenue.
CORTEZ:
Montezuma Blue Print Co., P.O. Box 816.
CREEDE:
Ramble House.
DENVER:
Kendrick-Bellamy Stationery Co., 1641 California Street.
Kistler's, 1636–46 Champa Street.
GRAND JUNCTION:
Dunkin Blue Print & Supply Co., 236 Main Street, P. O. Box 1400.
SALIDA:
Robert F. Harrison, Consulting Engineering Service, 124 East Second Street.

CALIFORNIA

BAKERSFIELD:
Earl M. Price & Co., 1600 G Street.
LOS ANGELES:
Westwide Maps Co., 114 West Third Street.
SAN FRANCISCO:
Thomas Bros., 2308 Market Street.

NEW MEXICO

ALBUQUERQUE:
Holman Homesteads, 401 Wyoming Boulevard, NE.
R. M. Metcalfe, Inc., 706 Second Street, NW.

NEW YORK

NEW YORK CITY:
International Map Co., Inc., 140 Liberty Street.

PENNSYLVANIA

PHILADELPHIA:
J. L. Smith Co., 27 South Eighteenth Street.

UTAH

SALT LAKE CITY:
Photo-Blue Co., 123 East Second South, P.O. Box 626.

WASHINGTON

SEATTLE:
Max Kuner Co., 1324 Second Avenue.

WYOMING

CASPER:
Kintzel Blue Print Co., 134 North Center Street,
P.O. 741.

GEOLOGICAL SURVEY OFFICES

(over-the-counter map sales only)

Some or all of the maps described in this index may be purchased over-the-counter only at the following Geological Survey offices:

COLORADO

DENVER:
468 New Custom House.

DISTRICT OF COLUMBIA

WASHINGTON:
1028 GSA Bldg., 19th & F Streets, NW.

UTAH

SALT LAKE CITY:
504 Federal Bldg.

Topographic quadrangle index map, Colorado
(Courtesy of U.S. Geological Survey)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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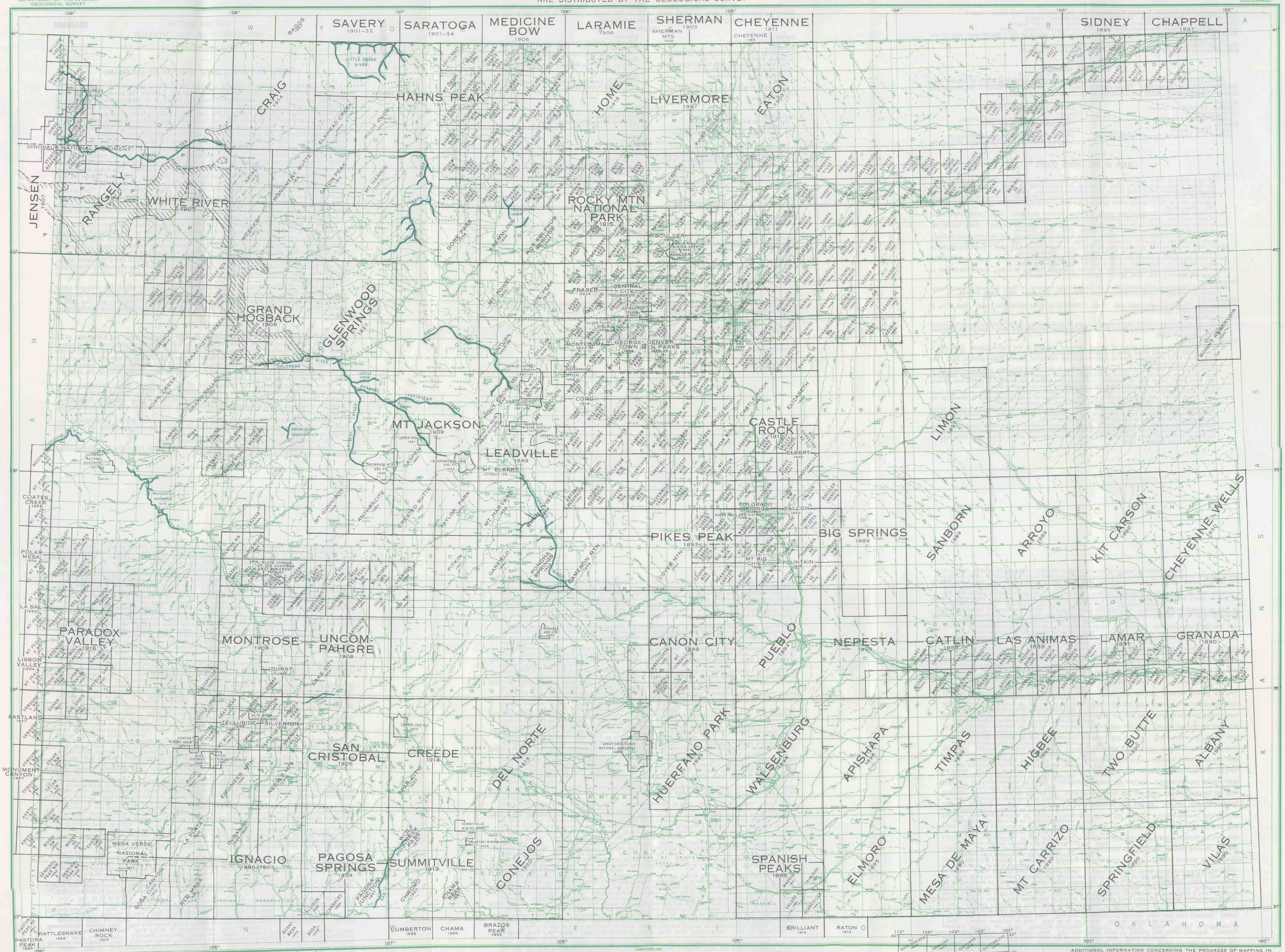
ORDER MAPS BY NAMES PRINTED IN BLACK AND BY SERIES DESIGNATION

ALL MAPS SHOWN ON THIS INDEX
ARE DISTRIBUTED BY THE GEOLOGICAL SURVEY

COLORADO



INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1960

SURVEYED AREA. WHERE QUADRANGLE IS NOT COMPLETELY COVERED, THE AREA ACTUALLY MAPPED IS ENCLOSED WITH A DASHED LINE WITH HACHURES

TOPOGRAPHIC MAPS PUBLISHED WITH DATE OF SURVEY. MAPS PRIOR TO 1896 MAPPED BY RECONNAISSANCE METHODS

GARFIELD 1940

MAPS OF THE SAME AREA ON 2 SCALES. WHEREVER THE SAME NAME APPLIES TO 2 OR MORE MAPS COVERING THE SAME AREA, AN ORDER SHOULD ALSO INCLUDE THE SERIES DESIGNATION (7½' FOUNTAIN, 15' FOUNTAIN).

FOUNTAIN 1948

THE NUMBER OF PUBLISHED MAPS SHOWN ON THIS INDEX IS 579

JULY 1960

RIVER SURVEYS (SEE TEXT)

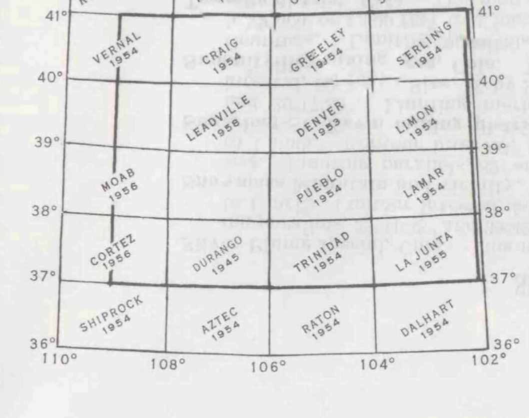
MAPS PUBLISHED

ALL 7½' QUADRANGLE MAPS ARE PUBLISHED AT THE SCALE OF 1:24,000

P INDICATES AREA MAPPED WITHOUT CONTOURS

† ADVANCE SHEETS (AVAILABLE IN BLACK AND WHITE EDITION ONLY)

(S) FOLLOWING QUADRANGLE NAME INDICATES MAP IS ALSO AVAILABLE IN A SHADED RELIEF EDITION



MAPS PUBLISHED AT THE SCALE OF 1:250,000, WITH DATE OF SURVEY (SEE TEXT)

NOTE: ONLY THOSE MAPS INDICATED BY NAME ARE AVAILABLE

ADDITIONAL INFORMATION CONCERNING THE PROGRESS OF MAPPING IN COLORADO MAY BE OBTAINED FROM THE TOPOGRAPHIC DIVISION, U. S. GEOLOGICAL SURVEY, DENVER 25, COLORADO, OR THE MAP INFORMATION OFFICE, U. S. GEOLOGICAL SURVEY, WASHINGTON 25, D. C

TRANSFERRED FROM TEXT TO POCKET

Figure 2. Map of the Oil Shale Area (Garfield, Rio Blanco and Mesa Counties), from page 449

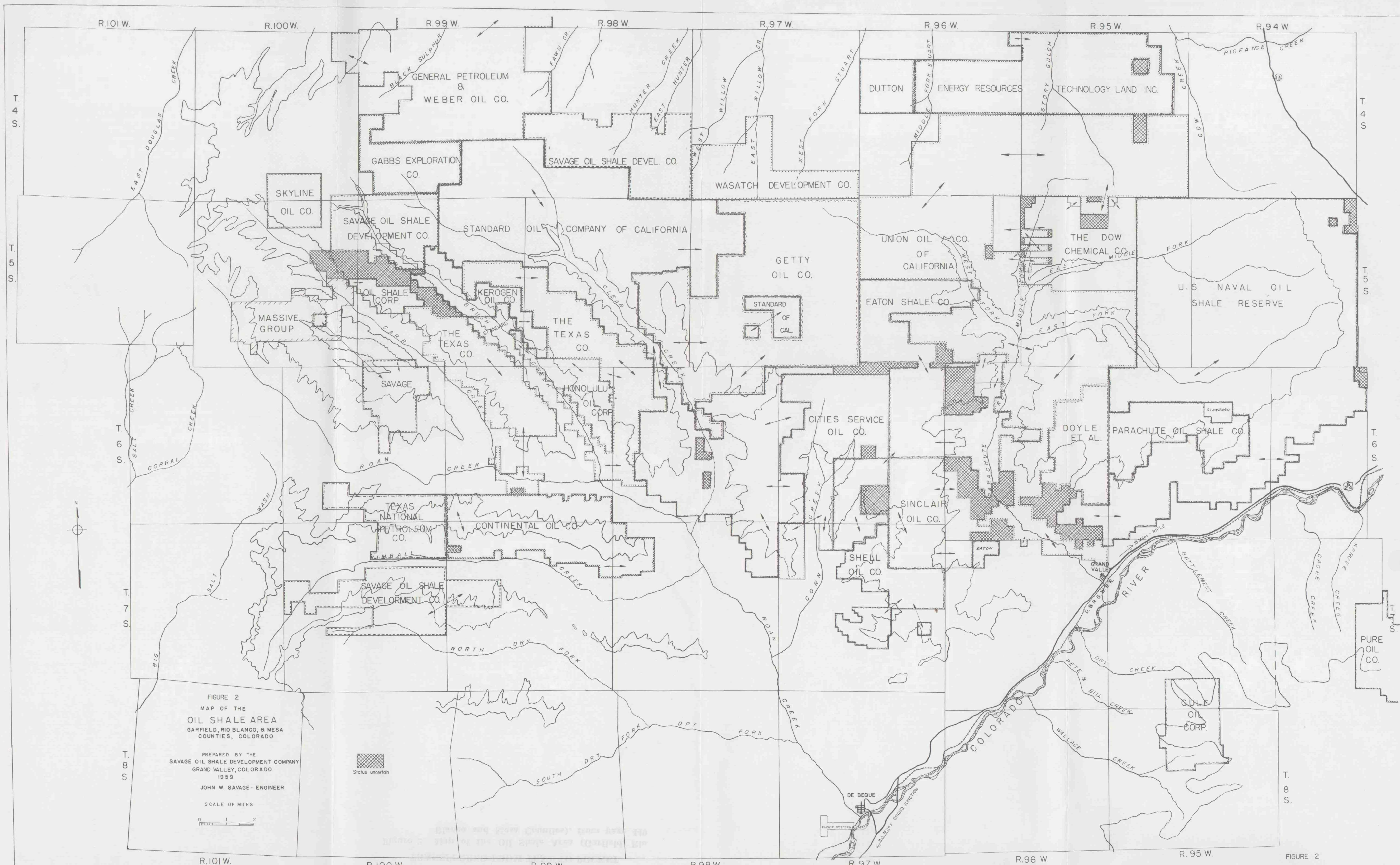


FIGURE 2
MAP OF THE
OIL SHALE AREA
GARFIELD, RIO BLANCO, & MESA COUNTIES, COLORADO

PREPARED BY THE
SAVAGE OIL SHALE DEVELOPMENT COMPANY
GRAND VALLEY, COLORADO
1959
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SCALE OF MILES

FIGURE 2

TRANSFERRED FROM TEXT TO POCKET

Figure A. Index Map of Coal Bearing areas, from page 465

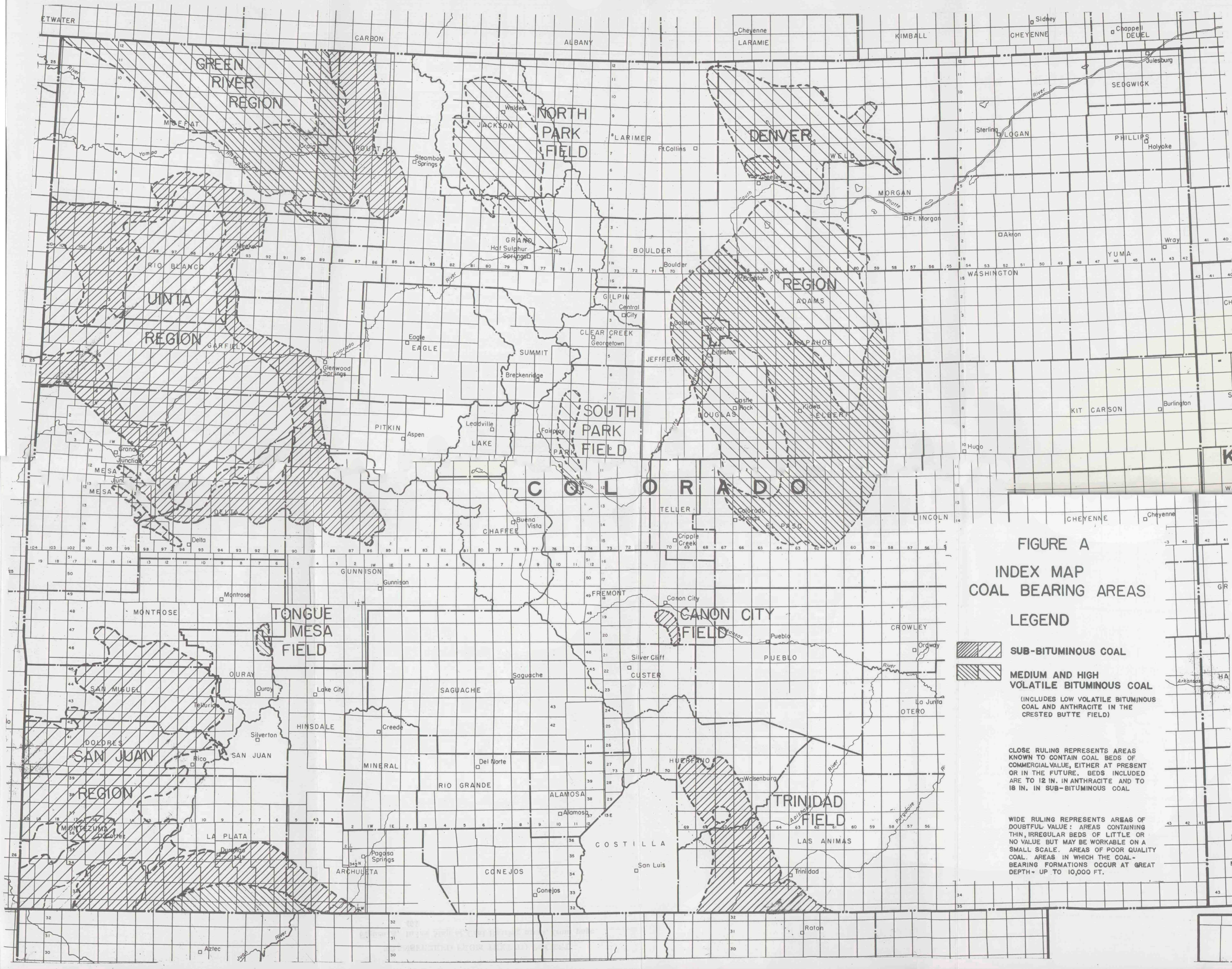

FIGURE A

INDEX MAP COAL BEARING AREAS

LEGEND

SUB-BITUMINOUS COAL

MEDIUM AND HIGH VOLATILE BITUMINOUS COAL (INCLUDES LOW VOLATILE BITUMINOUS COAL AND ANTHRACITE IN THE CRESTED BUTTE FIELD)

CLOSE RULING REPRESENTS AREAS KNOWN TO CONTAIN COAL BEDS OF COMMERCIAL VALUE, EITHER AT PRESENT OR IN THE FUTURE. BEDS INCLUDED ARE TO 12 IN. IN ANTHRACITE AND TO 18 IN. IN SUB-BITUMINOUS COAL

WIDE RULING REPRESENTS AREAS OF DOUBTFUL VALUE: AREAS CONTAINING THIN, IRREGULAR BEDS OF LITTLE OR NO VALUE BUT MAY BE WORKABLE ON A SMALL SCALE. AREAS OF POOR QUALITY COAL. AREAS IN WHICH THE COAL-BEARING FORMATIONS OCCUR AT GREAT DEPTH - UP TO 10,000 FT.