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R. D. GEORGE, State Geologist

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SOME ANTICLINES OF ROUTT COUNTY, COLORADO

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GEOLOGICAL BOARD

LETTER OF TRANSMITTAL

STATE GEOLOGICAL SURVEY,

UNIVERSITY OF COLORADO, June 23, 1920.

Governor Oliver H. Shoup, Chairman, and Members of the Advisory Board of the State Geological Survey.

GENTLEMEN: I have the honor to transmit herewith Bulletin 23 of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,
State Geologist.

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Some Anticlines of Routt County Colorado

INTRODUCTION

BY R. D. CRAWFORD

PURPOSE OF THE REPORT

Oil seeps in Routt County have long been known, and two or three test wells were drilled many years ago. In the summer of 1919 a party of the Colorado Geological Survey studied the local geologic features that might have a bearing on oil formation and accumulation. The result of examination of two structures seemed to be deserving of an early notice which was issued as a one-page statement on "Two Anticlines in Routt County, Colorado," under date of September 30, 1919. The geologic work will be continued in Routt and Moffat counties, but the present report is being published in the hope that it will be of use to operators in 1920.

FIELD AND OFFICE WORK

The field work on which this report is based was done in the summer of 1919 by K. M. Willson, V. C. Perini, J. C. Myers, J. R. Murphy, and the writer. The first three named were in the field nearly three months; the last two were in the field about six weeks. Considerable time was spent by the writer in reconnaissance in the mapped area and in nearby areas; the remainder of the time was employed in detailed work, chiefly in Williams Park. The greater part of the mapping was done by the other members of the party. That part of the Tow Creek anticline north of Yampa River was mapped by Messrs. Willson and Myers. Mr. Willson's report will be found in later pages of this bulletin. That part of the Tow Creek anticline south of Yampa River, the Curtis anticline, and areas near the east border of the region surveyed were mapped by Messrs. Perini, Murphy, and Myers. Mr. Perini's report appears in the last pages of this bulletin.

Part of the drafting in connection with this work was done by R. M. Carr who also made tracings of drawings for the zinc etchings used here.

MAPPING METHODS

In mapping the geology different instruments and methods were used in various parts of the field. In areas for which no base map was available and in which it seemed essential to determine elevations as well as locations on the ground, a traverse plane-table and telescopic alidade were used; locations were made by intersections and by stadia measurements. These instruments and methods were employed in Williams Park, on the Tow Creek anticline, and near the east side of the area mapped.

In Williams Park a base line about 1½ miles long was measured with stadia. From the bases a system of triangulation was carried over the park, while short distances were platted from stadia measurements. The whole was later tied to section corners near the west side of the park on the east line of T. 4 N., R. 88 W.

The two parties that mapped the Tow Creek anticline used a common base line about five miles long, running from the southeast corner of section 1 to the southeast corner of section 36 in T. 6 N., R. 88 W. Distances and bearings along this township line were kindly supplied by United States Surveyor General John B. McGauran of Denver. From this base line a system of triangulation was carried over the Tow Creek anticline and Curtis anticline and tied to the United States Geological Survey triangulation stations on Elk Mountain and Pilot Knob. Short distances were determined by stadia measurements.

For much of the area base maps, traced from township plats in the United States Surveyor General's office in Denver, were used. The geologic mapping was done by making paced traverses and using Brunton compasses. An enlargement of a small part of the United States Geological Survey topographic map of the Hahns Peak quadrangle served as a base map for the northeast part of the area, and a similar map of the Daton Peak quadrangle was used for a small area southwest of Hayden. Nearly all the mapping was done on the scale of two inches to the mile.

POSITION AND TOWNS

Routt County, with an area of about 2,340 square miles, lies in northwestern Colorado immediately west of the Continental Divide. It is reached by the Denver and Salt Lake railroad ("Moffat Road") which enters the county near the southeast corner, runs northward to Steamboat Springs, the county seat, and thence west to Craig, the present terminus, six miles west of the Routt County line. The towns within the county include Yampa, Phippsburg, Oak Creek, Steamboat Springs, Milner, McGregor, Bear River, Mount Harris, and Hayden on the railroad, besides Hahns Peak and Columbine near the north end of the county.

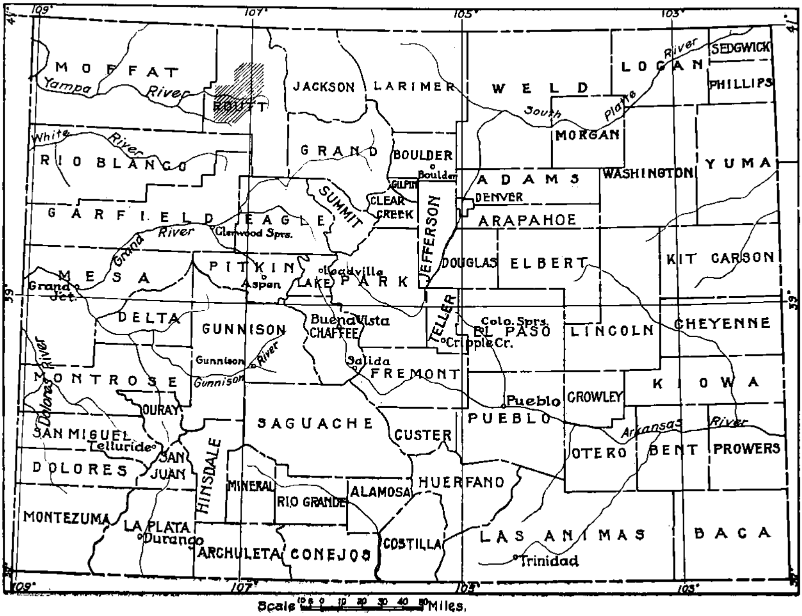

Fig. 1. Index map of Colorado showing area covered by this report

INDUSTRIES

Farming, stock raising, metal mining, and coal mining are the principal industries of the county. In 1919 Routt County, with an output of 1,168,310 tons[1] of coal, held third place among the counties of Colorado in coal production.

GENERAL GEOLOGIC AND PHYSIOGRAPHIC FEATURES

A strip several miles wide along the east border of the county is high on the slope of the Park Range—part of the Continental Divide—whose crest is the east boundary of the county. Here the country rock is composed chiefly of ancient gneisses and granites. By far the greater part of the county is an area of sedimentary rocks. In several localities are basaltic dikes and intrusive sheets and fewer intrusions of acidic rock. Near the south end of the county are a few volcanic necks and craters.

Routt County is drained by Yampa River and its tributaries of which the largest is Elk River. Along these and other streams

[1]See Seventh Annual Report of the State Inspector of Coal Mines for 1919, by James Dalrymple, p. 44.

alluvial flats furnish fertile soil for the heavy crops of hay and oats that are grown on numerous ranches, or farms. Productive soil overlies the Mancos and Lewis shale of the parks and valleys, and much of it is under cultivation.

With the exception of Yampa River[2] and its relationships there is a close connection between the broader topographic and structural features. Where the more resistant beds of the Mesaverde sandstone have been weakened by folding streams have cut gulches or canyons that may reach a depth of several hundred feet; Sage Creek canyon is a good example of an anticlinal valley. Williams Park owes its origin to the folding that led to the easy removal of the Mesaverde formation. Twentymile Park, on the other hand, is a topographic basin that occupies a structural basin, or broad synclinal fold. In places, as mentioned on page 17, there is no close relation between the details of structure and topography. Generally the Mesaverde formation, with its numerous sandstone beds, forms ridges and cliffs. The softer Mancos and Lewis shales are easily eroded, and occupy valleys and parks. The latter are commonly hilly or rolling.

WATER AND FUEL

There is little probability of serious difficulty in obtaining sufficient water for drilling purposes from streams and wells. No part of the area mapped is far removed from good coal seams. Two wells in Williams Park are reported to furnish sufficient gas for drilling operations.

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[2]See "The history of Yampa River, Colorado, and its possible bearing on that of Green River," by E. T. Hancock: U. S. Geol. Survey Prof. Paper 90, pp. 183-189, 1915.

SEDIMENTARY ROCKS AND SURFICIAL DEPOSITS

BY R. D. CRAWFORD

Little time was spent by the Survey party in detailed stratigraphic study, and no attempt was made to collect fossils systematically. Aside from the observations on the Mancos shale, what is said in this section is largely summarized from the work of others. The principal formations are of Upper Cretaceous age.

"DAKOTA" FORMATION

The formation that has heretofore been called Dakota by geologists working in northwestern Colorado is exposed about three miles east of Elk Mountain. The same formation outcrops near Hahns Peak, at Steamboat Springs, and near Poose Creek about six miles southwest of Williams Park. The "Dakota" sandstone is not exposed in the mapped area south of Yampa River, but it has evidently been encountered in three wells drilled near the south border of Williams Park by the Twentymile Oil Company.

No detailed examination of this formation was made for the present report, but where seen it seems to have its usual character. It is composed principally of gray to white sandstone and quartzite which, near the top of the formation, alternate with beds of shale; conglomerate is often found at the base. The thickness of the formation probably does not exceed 200 feet in this region.

MANCOS SHALE

In mapping the Yampa coal field Fenneman and Gale[3] included within the Mancos shale all the beds that overlie the "Dakota" sandstone and underlie the Mesaverde formation. The same procedure is followed here. For the present report the top of the Mancos formation is taken at the plane of the first pronounced lithologic change where a shaly sandstone member several feet thick overlies the great mass of shale. This shale-sandstone contact was exposed in a number of places and accurately located, but for the most part it is covered by soil and talus; hence the boundary between the Mancos and Mesaverde formations is generalized on the accompanying maps.

Although the Mancos shale is found over wide areas, continuous exposures from base to top suitable for measurement of

[3]Fenneman, N. M., and Gale, H. S., The Yampa coal fields, Routt County, Colorado: U. S. Geol. Survey Bull. 297, 1906.

the thickness of the formation are absent from the region surveyed. Fenneman and Gale in their report (p. 20) cited above, give the thickness as 2,000 to 2,500± feet. K. M. Willson has determined the Mancos shale north of Yampa River to be about 2,100 feet. Gale[4] gives a general thickness of approximately 5,000 feet for this formation in northwestern Colorado. Lee[5] gives a section of the Mancos shale 5,800± feet in thickness as measured by E. T. Hancock at Axial (Mt. Streeter). Professor R. D. George informs the writer that he found the Mancos shale to be about 4,100 feet thick near the head of Milk Creek in T. 3 N., R. 92 W.

In Williams Park the Mancos shale is cut by erosion to within 300 feet of the base as shown by two wells drilled by the Twentymile Oil Company. By using the well logs for the lower part of the formation, calculating the thickness of the upper part from the scaled map distance in the southeastern part of T. 4 N., R. 88 W., where the exposed beds have an average northwestward dip of about 22°, and estimating the thickness of unexposed beds near the crest of the anticline the aggregate thickness is found not to exceed 4,400 feet. Obviously this rough determination is unsatisfactory from the standpoint of prospective drilling, but it is the best that can be done with data at hand. The thickness of the Mancos formation on the west limb of this fold can probably be determined with a fair degree of accuracy when the drill reported to be at work at the time of writing encounters the Mancos sandstone. As mentioned beyond there may be local thickening here. (See page 22.)

The lower part of the Mancos formation is composed mainly of black carbonaceous shale. This is overlain by a sandstone member that was seen by the writer in only three exposures. Near the south border of Williams Park the exposed part of this member is composed of alternating sandstones, shales, and limestones. The beds are dominantly sandstone with some limestone and numerous shale partings. Individual layers range in thickness from less than an inch to five inches. The limestone is fossiliferous and on breaking, gives a distinct though not strong bituminous odor. The sandstone is of medium grain and only moderately porous. The zone as a whole is a fair water carrier as shown by the spring at one outcrop. Both sandstone and limestone weather to brownish gray. From surface indications the thickness of the sandy member was

[4]Gale, H. S. Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 45 and 62, 1910.

[5]Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 53-55, 1916.

estimated at 20 to 40 feet. The log of the first well drilled by the Twentymile Oil Company shows "sand and shale" at depth 1,266 to 1,309 feet with an estimated dip of 29°. These figures give an actual thickness of 38 feet. Near Poose Creek, about 6 miles southwest of Williams Park, the sandy member is 25 feet thick. The well log mentioned gives 450 feet as the distance from the top of the Mancos sandstone to the top of the "Dakota" sandstone. Using the same dip as before, which the writer thinks is a little too high, the thickness of the Mancos sandstone and underlying shale is about 390 feet. On Poose Creek where measurements were taken the sandstone and underlying shale have a thickness of about 425 feet. Owing to difficulty in accurately locating the boundary between the "Dakota" and Mancos formations, on account of mantle rock, the figure given may be in error 10 to 20 feet.

On Poose Creek 30 feet above the sandstone member is a limestone stratum 15 inches thick. Another limestone stratum 12.5 feet thick lies 217 feet above the sandstone. The same limestone strata are found near the south border of Williams Park.

The remainder of the Mancos formation is nearly all shale. For some distance above the limestone the shale is at intervals very calcareous and weathers to thin plates. At least one thin limestone layer an inch or two in thickness and composed principally of Ostrea fossils is found in the shale. Much of the shale higher in the formation is dark and carbonaceous, but near the top, for several hundred feet, it is lighter in color and weathers to a light gray clay. A few hundred feet below the top of the Mancos is a limestone bed at least 18 inches thick. Outcrops of this may be seen near the northwest part of Williams Park.

The Mancos shale was long ago shown by its fossils to be of marine origin. No systematic search for fossils was made for the present report.

MESAVERDE FORMATION

The Mesaverde formation, which conformably overlies the Mancos, is a series of marine and fresh-water deposits having a thickness in this region between 3,000 and 4,000 feet. It contains many beds of soft to fairly hard sandstone of which the most prominent reaches a thickness of more than 100 feet. There are present many beds of sandy shale and fewer beds of carbonaceous shale. Workable seams of good coal are plentiful. No detailed examination of the Mesaverde formation has been made by the writer; but descriptions are given on later pages by Messrs. Perini and Willson.

Fuller descriptions[6] are given by Gale and by Fenneman and Gale in their reports on the coal fields.

LEWIS SHALE

The Lewis shale conformably overlies the Mesaverde formation and has a thickness of probably not more than one-third of the Mesaverde. It is a dark clay shale, but is less carbonaceous than the bulk of the Mancos shale. A few outcrops of limestone beds 3 to 5 inches thick are to be seen. Other workers have found marine fossils in the Lewis formation.[7]

LARAMIE FORMATION

Along the Yampa River in the vicinity of Hayden the Laramie formation, as determined by previous workers, overlies the Lewis shale with apparent conformity. It is composed for the most part of friable sandstone that commonly is cross bedded. The sandstone locally carries bands of concretions several feet in diameter. In a few gullies may be seen outcrops of gray shale. At least one coal seam has been opened in the Laramie near Hayden.

TERTIARY (?) SANDSTONE

South of Williams Park soft, friable cross-bedded sandstone, protected by a basalt flow or sheet, stands in a nearly vertical cliff 300 or 400 feet high. The white to gray rock above the green timber of the lower elevations and below the green timber of the basalt-capped table-land makes a conspicuous landmark visible for many miles. The thickness of the sandstone is not readily determined since sandhills from the disintegration of the sandstone that breaks from the cliff are piled up near the cliff as well as throughout an area about half a mile wide. Small remnants of sandstone in place and near the base of the formation are found farther west.

Inasmuch as the sandstone lies nearly level while the underlying Mancos shale has a pronounced dip in its nearest exposure, it is evident that the unconformity at the contact between shale and overlying sandstone is angular. Since no fossils were collected from these beds their age has not been determined. In appearance the sandstone cliff resembles the cliff of Green River sandstone west of the Grand Hogback, in Garfield and Rio Blanco counties, Colorado. Lithologically and structurally the sandstone south of Williams Park resembles the Laramie sandstone north of Hayden; but the unconformity below the former, representing a

[6]U. S. Geol. Survey Bull. 415, pp. 63-71.
[6]U. S. Geol. Survey Bull. 297, pp. 22-28.
[7]U. S. Geol. Survey Bull. 415, p. 72.

long erosion period, points to an age younger than Laramie for the beds under consideration.

SURFICIAL DEPOSITS

Within the region are numerous areas of variable extent in which unconsolidated talus, gravel, alluvium or soil overlies the bedrock. Locally, particularly near the south side of Williams Park, the unconsolidated mantle rock is deep enough to prevent the working out of details of structure from the surface geology.

FOLDS[8]

BY R. D. CRAWFORD

GENERAL FEATURES

In Routt County and adjacent parts of Moffat County are a number of anticlinal folds whose axes are roughly parallel to the Park Range on the east. The axial trend of other anticlines is toward the west. Fenneman and Gale[9] have shown that these anticlines are minor folds near the border of a general synclinal basin that pitches northwestward with its axis passing through Yampa and Hayden and to the northwest of Hayden many miles. Figure 2 shows the positions of the most important folds.

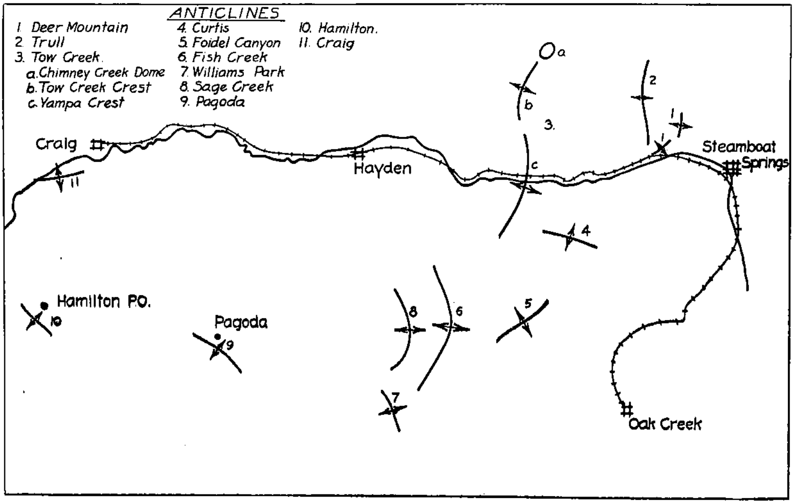

Fig. 2. Index map showing positions of some anticlines of Routt and Moffat counties. Compiled from maps of the United States Geological Survey and the Colorado Geological Survey

Williams Park is a topographic basin that has been eroded down into the Mancos shale in an area where two strong anticlines approach each other or possibly intersect. These anticlines—the Sage Creek on the west and the Fish Creek on the east—diverge

[8]The structural features of the northern and eastern parts of area mapped are discussed in later pages by Messrs. Perini and Willson, who, assisted by J. C. Myers and J. R. Murphy, mapped those parts of the field. Here will be considered chiefly the structures of Williams Park, in the mapping of which the writer was assisted by the four men named. The work within the park was done principally by Mr. Perini and the writer, while the Mesaverde formation north and west of the park was mapped by Messrs. Willson and Myers.

[9]Fenneman, N. M., and Gale, H. S., The Yampa coal field, Routt County, Colorado: U. S. Geol. Survey Bull. 297, p. 12, 1906.

northward. For some distance the intervening synclinal area is likewise deeply eroded and forms part of the park. Toward the south erosion has been retarded by basalt sheets or flows which at one time probably extended a considerable distance northward over the south part of the park site. The Mesaverde beds form the rim of the park on the east, north and west.

While the main topographic features have been controlled by the broader structural conditions there is very little sympathy between the minor details of structure and of topography. In places what appear to be dip slopes are underlain by shale whose bedding planes strike in the direction of the surface slope, and what appear to be escarpments may have no evident relation to the structure of underlying beds. It is not improbable that many minor features of relief are controlled by the vegetation which in turn may depend on the relation between dip of the shale and circulation of the groundwater and consequent seepage.

Under the conditions described it has been impracticable to work out the details of structure in all parts of the park. The dip and strike symbols on the accompanying maps (Plates I and II in pocket) show the areas in which accurate determinations are possible. In places these determinations were made only after considerable digging with pick and shovel. In the course of the work a great amount of detail was accumulated, and most of this, where dependable, is shown on the maps in order to give all the available evidence for favorable and for unfavorable structural conditions from the standpoint of oil storage. Locally, on escarpment slopes, the platy Mancos shale has very high dip—much higher than at the bottom of nearby gullies. This may be due to the spreading of the shale layers into a fanlike structure as the result of freezing of infiltered water. Most of these abnormally high dips, as well as those where there has been evident creep on the slopes, have been rejected.

WILLIAMS PARK ANTICLINE

This name is here applied to the highest structure in the park—that lying southeast of Willow Creek. The structure might be considered a bulge on an extension of the Sage Creek anticline, but it is separated by at least one synclinal fold from a closed structure several miles north on the anticline named. Whether or not it opens directly into the Fish Creek anticline without intervening synclinal folding has not been determined because of the absence of outcrops from a considerable area.

The thickness of Mancos shale remaining along the axial plane of this fold is less than 300 feet. Erosion has removed the Mancos sandstone from the crest and exposed this member for short distances along both limbs of the fold. The limestone bed that lies a little higher in the formation outcrops on the east limb, but is covered with mantle rock on the west limb. These lowest exposed beds have a dip of 35° to 60° on the east limb and a fairly uniform northward strike throughout the area of limited exposure. The sandstone on the west limb of the fold has a dip of 5° to 10° where it is exposed, and the direction of dip changes greatly and frequently along the short line of outcrop. Several of the determined dips are shown on Plate II. It is evident that there are local wrinkles on the main fold; this is brought out more clearly when the strike of the lower beds is compared with the strike of the shale beds higher in the formation. Although the southernmost determined dip on the west limb indicates a northward pitching anticline, it is obvious that the southward convergence of the strike directions of the higher beds on opposite limbs of the fold tends to close the structure. (See Pl. II.) Further, the presence of gas in the "Dakota" sandstone, as shown by the flow in two wells, points to the possibility of a closed structure. Owing to the scarcity of outcrops the structurally highest point on the anticline has not been located.

FISH CREEK ANTICLINE

A prominent anticline with curving axis can be followed along the east side of Williams Park, thence west of north to a point two miles or more northwest of Grassy Gap. Near the south border of the park the axis of this fold trends southwest. This anticline was mentioned as part of the Tow Creek anticline by Fenneman and Gale,[10] but since it is separated from the main Tow Creek anticline by a deep synclinal fold while the axis near its north end trends in a direction greatly different from that of the Tow Creek anticlinal axis it seems advisable to treat this structure separately. Owing to the fact that Fish Creek runs near its axis for several miles it is here called the Fish Creek anticline.

Like most of the anticlines in this general region this fold shows a higher dip on the east limb than on the west. The dip on the the west limb is 15° or less throughout the length of the fold excepting at the north part where it increases to more than 20°. For the most part the dip of the east limb is between 15° and 50°. The

[10] U. S. Geol. Survey Bull. 297, p. 14.

anticline pitches northward throughout its known length. Toward the south side of Williams Park the axis bends sharply toward the west, and the anticline probably merges with the Williams Park structure previously described. There is, however, an area of about a square mile in which no outcrop appears and which may possibly contain a structural terrace or even a shallow syncline.

SAGE CREEK ANTICLINE

The Sage Creek anticline was mapped by Fenneman and Gale[11] from Williams Park to a point about four miles south of Hayden where it disappears under the Lewis shale. These geologists, who were concerned chiefly with the coal-bearing Mesaverde formation, did not work out the structural details in the Mancos shale in Williams Park. This anticline also is asymmetric with the east limb dipping more steeply than the west. One prominent nose on the west limb in section 15, T. 5 N., R. 88 W., is the only notable minor feature where the Mesaverde beds are exposed.

The Sage Creek anticline, pitching northward, can be easily followed from section 35, T. 6 N., R. 88 W., southward for seven

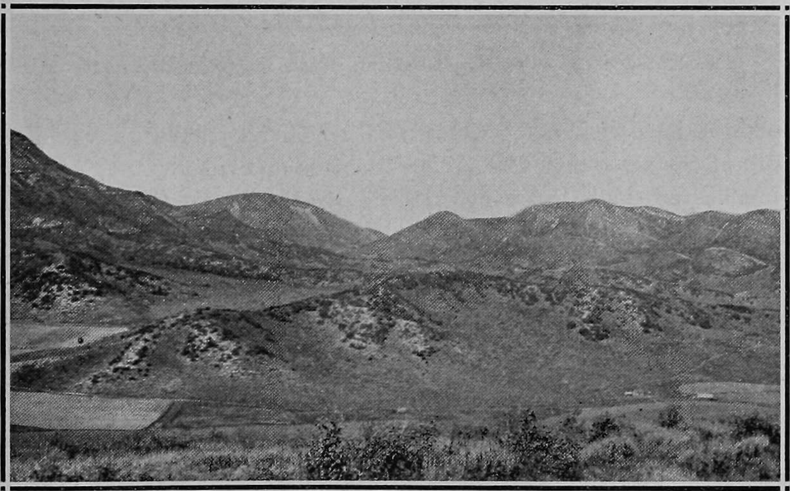

Fig. 3. Sage Creek anticline looking north from Williams Park

miles or more to Williams Park. In the park the most evident broader structural and topographic features seem to combine to obscure the details of structure, and in a rapid reconnaissance one might easily receive the impression that this anticline passes without interruption into the Williams Park structure previously de-

[11] Op cit., pp. 15, 54.

scribed. It was only by close attention to details and after much digging with pick and shovel that a closure about half a mile north of the Dunkley schoolhouse was proved. Dependable readings of southeastward dips of 3° to 40° were taken. While some of these

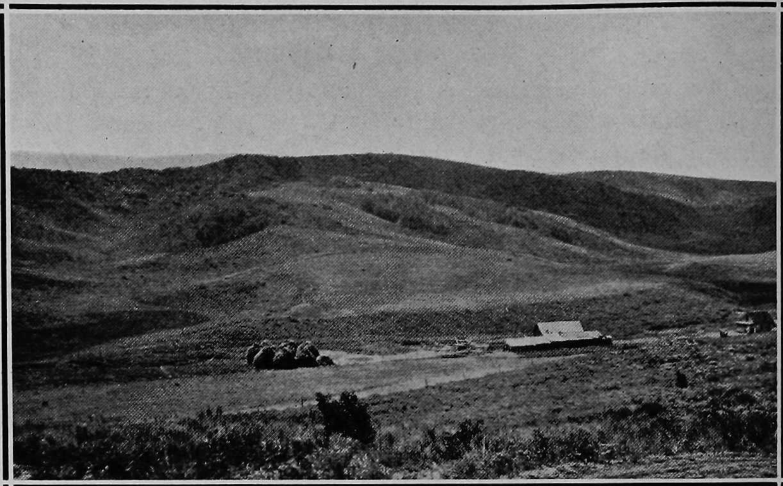

Fig. 4. Sage Creek anticline looking south toward structurally highest part

observations were made where weathering may have increased the dip of the shale near the surface there is no evidence that weathering has affected the strike. It will readily be seen from the convergence of the strike directions on the opposite limbs of the fold that there is a good closure between the schoolhouse and B. A. Long's farm house. (See Pl. II.) It is further evident from the approximate parallelism of strike of the beds on the opposite limbs that the intersection of the axial plans with any bedding plane is nearly horizontal for about a mile.

MINOR FOLDS

One prominent nose in the Mesaverde formation on the west limb of the Sage Creek anticline has been mentioned. South and southwest of Hayden in a few localities the general north to northwestward dip of the Lewis shale is very low and even approaches zero. About three miles south of Hayden a southeastward dip was noted, which indicates a small anticline; but, owing to the scarcity of good outcrops of the Lewis shale and the unreliability of dips taken at the surface, it has not been practicable to work out details of structure in this formation.

OIL AND GAS POSSIBILITIES OF THE STRUCTURES DESCRIBED

The chief factors to be considered in connection with the oil and gas possibilities of the region are: (1) the capacity of the sedimentary rocks for the formation of oil and gas; (2) the presence or absence of suitable reservoirs for the reception and storage of oil and gas; (3) the depth of such possible reservoirs from the surface; (4) the ground-water conditions; and (5) the degree of regional alteration to which the beds have been subjected.

The lower beds of the Mancos shale are highly carbonaceous, and there is no apparent reason to doubt their capacity for the generation of oil and gas. In Wyoming, sandstones in similar shales of approximately the same age have in recent years yielded much petroleum. In the Rangely, Colorado, field, near the Colorado-Utah line, oil has been found in the Mancos formation. Formations below the Mancos in the region under consideration contain a relatively small amount of shale. In the Mesaverde formation overlying the Mancos there are, in addition to the coal seams, many shale beds that carry considerable carbonaceous material.

The "Dakota" sandstone, though in places quartzitic and nearly tight, is usually open enough for the free circulation of ground water. In the Williams Park anticline a considerable flow of gas is reported from two wells that have been drilled into this sandstone since the Survey party was in the field.

About 400 feet above the "Dakota" sandstone is a persistent sandstone member of the Mancos shale. (See p. 12.) This member, which is 25 feet or more in thickness, is composed chiefly of sandstone with intercalated beds of shale and limestone. The sandstone is only moderately porous, but these beds have openings enough for the circulation of ground water as evidenced by at least one spring at the outcrop in the Williams Park anticline. It is believed that the porosity is sufficient for the reception and circulation of oil and gas. The overlying shale furnishes a compact cover that would prevent the escape of petroleum where structural conditions are favorable to accumulation.

Several anticlines of this region are open at one end and have a fairly constant angle of pitch. Owing to the probability of leakage at the open end such anticlines are generally not suited to the accumulation of oil and gas. Only those will be considered here which are closed or which do not furnish conclusive evidence of being open.

Conditions indicating the southward closure of the Williams Park anticline were mentioned on page 18. Even if the change in dip and strike of the beds should not be sufficient to effect a closure, leakage might be prevented by basalt dikes. A dike, or sheet, dipping 20° southward, may be seen a mile or two southwest of the exposed crest of the fold. This rock is in part nearly compact and similar to the basalt that overlies the sandstone of the cliff farther east; it is in part vesicular, with cavities that have a maximum diameter of about two inches. It is obvious that the basalt might form either an impervious cover or a good reservoir, depending on the degree of compactness and the dip of the dike or sheet.

The removal of part of the sandstone member of the Mancos shale and consequent outcropping of the sandy beds afford opportunity for the leakage of any oil that may have found its way to these beds. The chances of finding oil or gas in commercial quantity in the remaining Mancos beds in this anticline are slight. However, the remaining Mancos shale is 200 feet in thickness, or more, and is probably ample to form an impervious cover for the "Dakota" sandstone. The gas already found in this sandstone may have been generated in underlying beds or, possibly, in the overlying Mancos shale.

From the crest of the Sage Creek anticline there has been removed by erosion perhaps 700 or 800 feet of Mancos shale. If the thickness of this formation has not been materially affected by folding it may have been originally about 4,400 feet in all, or about 4,000 feet from the top down to the first prominent sandstone. (See p. 12). The sandstone would accordingly be about 3,200 or 3,300 feet below the present surface. But accurate determination of the thickness of the formation and depth to the sandstone must await the drill. It is not improbable that local thickening has accompanied folding and that the thickness of the shale in the anticline a few miles south may be different from the thickness here. Uniformity of thickness is hardly to be expected in a heavy shale formation between competent sandstone strata in a region of much folding. Hewett and Lupton[12] have found that the shale on opposite limbs of a single anticline may differ several hundred feet in thickness, being thicker on the steeper side.

The same factors that could produce local thickening might cause a bulge on an anticline and show a closed structure at the sur-

[12]Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Big Horn Basin, Wyoming: United States Geol. Survey Bull. 656, 1917.

face where none exists at depth. There is, however, no observed indication that the closure of the Sage Creek structure does not hold through the Mancos shale. Of those mentioned in previous pages it should be the first to be tested. Fully to test the structure to and including the "Dakota" sandstone the driller should be prepared to bore 4,000 feet, but it is possible that the Mancos sandstone would be reached within 3,000 feet. Whether or not sandstone lenses or other possible reservoirs exist above the main sandstone member can only be determined by drilling. Jointing, fracturing, or solution might make the limestone or calcareous platy shale sufficiently open to receive oil or gas. Though the highest part of the anticline is limited in width by the syncline on the east, the most promising drilling area extends much farther in a general north-south direction where the axis of the folded sandstone is evidently nearly level for about a mile. A further advantage is found in the wide area of possible drainage which extends far north of Yampa River and includes much of the general synclinal basin mentioned on page 16.

Should the Sage Creek anticline prove to be productive a careful examination of other hitherto untested areas within the region would be advisable. Among these may be mentioned the Fish Creek anticline northeast of the Williams Park anticline and sections 11 and 15, T. 5 N., R. 88 W. Though the writer has not examined in detail the area in the two sections named the dip and strike of the beds, as mapped by other members of the party, are significant.

GROUND WATER

Very little is known about ground-water conditions at depth within the area under consideration. Shallow wells in the Lewis and Mancos shales furnish sufficient water for stock and household use. In all probability any sandstone within the region is sufficiently porous to carry water. Mr. W. A. Dawson, of the Twentymile Oil Company, states that when the first well of his company reached the "Dakota" sandstone water rose in the well 1,000 feet, that is, to within 725 feet of the surface.

DEGREE OF CARBONIZATION OF MESAVERDE COAL

David White[13] has pointed out the close relationship that exists in oil fields between the character of oil and the degree of carbonization of coal in the same or overlying formations. He says:[14]

[13]White, David, Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, pp. 189-212, 1915.

———, Late theories regarding the origin of oil; Geol. Soc. Am. Bull., vol. 28, pp. 727-734, 1917.

———, Genetic problems affecting search for new oil regions: Mining and Metallurgy, No. 158, pp. 1-20, 1920.

[14]Geol. Soc. Am. Bull., vol. 28, p. 732.

Noting the gradual elimination of the volatile hydrocarbons—the so-called volatile matter—from the oil shale simultaneously with the devolatilization of the associated coals in the course of the progressive regional alteration of the organic deposits, I have called attention to several other points which seem to indicate a mutual relationship between coal and petroleum in the second or **geochemical stage** of development, and that both react to the same geophysical influence, as follows: (1) That in regions where the coals and other carbonaceous debris in the strata are of the rank of brown lignites, the oils in the same or closely associated geological formations are also of low rank, averaging 20° to 26° Baumé; (2) that where the organic debris (coals, etcetera) has advanced to the sub-bituminous rank, the oils of the same or of nearly contemporaneous underlying formations are of higher rank, averaging 28° to 35°; (3) that when the deposits of organic debris have been regionally transformed (by elimination of volatile matter) until they have reached the bituminous rank, the oils have in general attained a rank of 35° or more, the highest grade of petroleum being found in the areas where the regional alteration of the organic debris has progressed farthest; **except** (4) that in those regions where the organic debris, whether it be represented by beds of coals, by bogheads, or by carbonaceous matter in shales, has passed the point corresponding to a content of 65 per cent of fixed carbon, pure coal basis, the oils which may formerly have been present in the same or in the underlying formations have mostly disappeared; and (5) that wherever the devolatilization of the coals, etcetera—that is, the solid residues in the strata—has progressed so far that they have a fixed carbon content of 70 per cent or more, **oils**, if present, will be "freak" oils, and in pockets or amounts too small to be of commercial importance, though gas pools may persist. I know of no commercial oil pools in the world that are found in or beneath formations in which the regional carbonization of the organic debris has passed 75 per cent fixed carbon, pure coal basis; in fact, I have not yet been able to learn of an oil pool in or beneath a formation in which the fixed carbon percentage of the organic debris exceeds 70, and it is most improbable that oil pools exist under such conditions.

It will at once be seen that these conditions seem to define a law restricting the distribution of productive oil pools, and to afford a basis on which to eliminate many areas of great extent in which fruitless and costly exploration by the drill is now going forward.

In Doctor White's third paper cited, page 5, he states:

More observations and tests are necessary to fix more exactly the stage of regional alteration beyond which commercial oil pools, though formerly present, will not have survived, but it is probable that the limit falls, in general, slightly lower than the point at which coals of the ordinary bituminous type show a fuel ratio of 2.2, or 68 per cent of fixed carbon in the pure coal; it may approach nearer the ratio of 2.0, or 66 per cent fixed carbon. Coals verging toward the sapropolic type, such as are believed by many to approach more closely the typical mother substance of oil, are more fatty and accordingly richer in hydrogen and lower in fixed carbon (pure coal basis) than the other types, until, in the course of alteration by geologic processes, they approach the above limit, when the volatile matter seems to disappear rapidly. At the semi-bituminous stage (fuel ratio 3.0, fixed carbon 75 per cent), their carbonization is approximately on a parity with typical bituminous coal.

Gale[15] gives analyses of 43 samples of Mesaverde coal from mines and prospects over a wide area extending from Pilot Knob north of Yampa River to Meeker on White River. Of these 43 analyses 39 show fixed carbon between 52 and 62 per cent on a pure coal basis—that is, after eliminating moisture and ash. Only 2 of the 39 contain over 60 per cent fixed carbon. Two others, from Pilot Knob, where the coal has been locally affected by basalt intrusion, show respectively 71.6 and 95.6 per cent fixed carbon. The remaining 2 of the 43 fall considerably below the general lower limit of 52 per cent, having 46.4 and 48.6 per cent fixed carbon, respectively. Gale states that these two analyses were made from weathered samples.

Insofar as the Mesaverde beds are concerned, excepting the areas of local metamorphism, alteration, as shown by coal analyses. has been sufficient, yet not too much for the production of oil, acording to the limits set by White. It is to be expected that the regional alteration of the older Mancos beds would be somewhat more than that of the Mesaverde, yet well within the limits mentioned.

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[15]Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 248-249.

TOW CREEK ANTICLINE (NORTHERN PART)[16]

BY K. M. WILLSON

PHYSIOGRAPHY

DRAINAGE

The chief drainages of the area are Yampa River, Elk River, and their tributaries, Deep, Wolf, Trull, Chimney, and Butcherknife creeks. Of these streams, which are named above in order of their importance, all are perennial but upper Wolf Creek. The Yampa and Elk rivers are very large streams which drain a considerable part of the area to the east, which includes a large portion of the west slope of the Park Range. The small tributaries mentioned all have their sources in this area. Deep Creek, of about equal length with Wolf Creek, carries the largest amount of water of any of these small tributaries.

TOPOGRAPHY

The greater part of the area, the surface of which is formed by the Mesaverde formation, consists of rough hilly country with long ridges running northward to the divide between the heads of Tow Creek and Wolf Creek, which flow south, and Deep Creek and Chimney Creek which flow northeastward. This divide is formed by a large dike cutting across in a southeasterly direction from the north crest of Wolf Mountain. Northeast of this divide where the Mancos shales come to the surface, there is a physiographic basin with low rolling hills and valleys, which is inclosed on all sides by mountainous ridges and hills. Along the eastern boundary of this basin the Elk River flows southward to join the Yampa River. The river valleys of this area show youth, maturity, and in places old age. Where the Yampa River cuts the Tow Creek fold it has carved a canyon to keep pace with the upbowing of the beds. The remainder of its course in this area is through an open valley. The same antecedent conditions are true for the canyon cut by the Elk River east of Elk Mountain where the upbowing was accompanied by dislocation. It is characteristic of this district that the tops of the anticlines have been eroded away deeply by the streams, and physiographic valleys now occupy the structural hills. In professional paper 90 of the United States Geological Survey on page 184 Mr. Hancock, speaking of the Yampa River, says:

[16]The report that follows is an abridgment of a thesis submitted by Mr. Willson, in June, 1920, to the Graduate Faculty of the University of Colorado in partial fulfilment of the requirements for the degree M. S.—R. D. C.

Emerging from the foothills of the Park Range it enters a more or less open country and traverses the formations involved in the Axial Basin anticline, and the Juniper unlift with apparent disregard for rock structure.

This statement is very true of the canyon cut by the Yampa River in this district and clearly shows antecedent conditions. The channels of Tow Creek and Chimney Creek are, however, developed along the crest of this anticline and follow what must represent the more or less fractured zone along the top of the fold. Their valleys are clearly subsequent.

There are several prominent peaks in this area, the most noticeable of which are Wolf Mountain, Pilot Knob, Elk Mountain, and Chimney Peak, and many unnamed points between the forks of Tow Creek.

Sand Mountain is a large intrusive body at the northern end of the area which presents a triangular-shaped crest formed by the the union of three sharp ridges. One of these ridges trends southwest in a knifelike ridge of almost the same height as the mountain, to the crest of Wolf Mountain. This ridge forms the divide between Morgan and Deep Creeks. The second ridge is formed by a dike with several interrupted crests which extend southeastward almost to the junction of Elk River and Deep Creek where it ends abruptly in a sharp point four or five hundred feet above the valley floor. The third ridge extends northward toward Hahns Peak and disappears in a high slope after about three miles of prominent points.

Wolf Mountain has two crests, each about 9,000 feet in elevation, and connected by a high ridge of nearly equal height. Running off from the north crest in a southeasterly direction is a high ridge formed by a dike which ends abruptly on the north side of Chimney Creek gap. From the south crest there are three ridges, one of which extends southward formed by the outcropping edges of the Twentymile sandstone, and two which trend southeastward about a mile apart and formed by dikes. Both of the latter ridges end at Wolf Creek, but the first slopes away gradually to the south, and is finally lost in Twentymile Park.

Pilot Knob is a very prominent point 9,200 feet in elevation on the ridge about midway between Sand Mountain and Wolf Mountain. Its western end is sharp, and on it is a secondary triangulation station of the United States Geological Survey. It can be seen from all parts of the surrounding country. Elk Mountain is a somewhat circular body having a very steep slope on the east rising about 3,500 feet above the valley to a ridgelike crest which extends for nearly half a mile in a north and south direction and which slopes westward at an angle of about 30°. This mountain is probably an igneous stock, and its character causes it to stand out abruptly in an area of soft shale. It can be seen for long distances north and south, but is hidden to the west by the higher ridges of Mesaverde sandstone. It can be seen almost as far east as Steamboat Springs.

The other really prominent high point is Chimney Peak. It is not known locally by any name so far as the writer was able to find out, and this has been given it here because Chimney Creek derives the greater part of its water from drainages on the north and west slopes. It is formed by a dike having several sharp points in a line extending southward, the highest of which was very useful in our triangulation work on account of its prominence from all directions. It is located about four miles west of Elk Mountain and about four miles southeast of Wolf Mountain.

Between the forks of Tow Creek are many sharp-pointed hills, but they do not form landmarks that may be seen from any considerable distance because they are surrounded by the higher ridges of Mesaverde sandstone. West of Chimney Peak there is a group of three having an average elevation of 8,000 feet. Their east slope drains into the east branch of Tow Creek and their west slope drains into the west branch of the same creek. South of these hills are two or three lesser ones, one of which is seen quite prominently from the Tow Creek valley. These hills are all of igneous rock, and represent erosion remnants of an intrusive body. These points and the country immediately adjacent to them are heavily wooded and present a decidedly mountainous aspect.

VEGETATION

Much of this area is good farming land, especially along the Yampa and Elk River valleys, and Deep Creek. In these valleys the principal crop is timothy and alfalfa hay, while in the rough country large truck gardens and small fields of oats, rye and wheat are raised. Throughout the hilly parts of the area scrub oak is abundant with frequent groves of aspen and pines, and occasional spruces. Some cottonwoods and willows and small brush grow along the main stream channels. No use is made of the scrub oak, and large tracts are cleared for agricultural purposes by burning. The pines furnish logs for buildings, for timbering mines, and some is used for firewood. Few of the evergreens in this area are of sufficient size to be used for lumber. Sagebrush grows along the valley slopes and the area covered by the Mesaverde sandstone, and with the scrub oak forms a part of the food for the herds of cattle and horses which range through the country. The basin which drains into Elk River is covered with a sparse growth of spear grass, except where it has been cultivated.

SOILS

In this district the soils vary according to the character of the rocks from which they are derived. The sandstones as a rule produce sandy clay; the shales weather out to a fine dark gray silt of a somewhat sandy character; and the igneous rocks produce a dark, rich soil of fine to coarse texture. All are productive.

CLIMATE

The winds of this district are varied but during the summer months blow mostly from the north down the parallel ridges and valleys. Their work is very noticeable in the soft sandstones where pinnacles, balanced rocks, and various similar forms have been produced. On the north slopes some polishing and, in a few places grooving of rock surfaces were seen in the district of igneous rocks. Rapid changes in temperature and frost action are evident by the slide-rock and talus on most of the high points. On the whole the climate is semiarid. Precipitation is about the same as at Denver, coming at irregular intervals with long periods of drought. The winters are long and severe, and the summers are short and generally dry with heavy showers. The following table was made from data obtained from the summaries of the United States Weather Bureau showing the maximum, minimum, and mean monthly, and annual temperatures, and the precipitation for the year 1918, at Steamboat Springs.

Weather record at Steamboat Springs

	Temperature in degrees Fahrenheit						Precipitation in inches
	1918			1919			
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	1918
January	43	—24	15.2	43	—24	11.9	5.00
February	45	—36	17.3	53	—16	19.4	2.70
March	61	—13	28.8	60	—20	27.4	2.12
April	61	—15	36.8	74	12	41.0	1.86
May	76	21	48.0	79	20	48.6	.46
June	94	19	59.3	89	19	55.6	.79
July	88	27	60.1	92	30	63.4	3.07
August	89	25	57.6	92	28	60.0	1.02
September	87	20	52.8	90	14	55.2	2.70
October	81	10	45.3	76	—16	34.6	2.81
November	65	—12	26.0	—	—	...	1.31
December	44	—26	15.6	42	—32	6.9	1.16
Annual	94	—36	38.6	92	—32	...	25.00

GROUND WATERS

The work of the ground waters must be considerable as there are about ten large perennial springs in the area, and a great many boggy places and intermittent springs. Some of these seem to be connected with the oil-bearing sandstones as they contain oily matter in small quantities. Others are of the finest, clear, cold and tasteless water. The solvent action of these waters is not noticeable in the formation of sinks or caves, but good water wells are easily obtained in the areas where the Mesaverde sandstones are near the surface. In the shale areas the water contains much saline matter in solution which makes it undrinkable. The largest of these is the one which comes up near the center of the body of Tow Creek intrusive. This makes a fair-sized stream which flows into the east fork of Tow Creek.

STRATIGRAPHY

The stratigraphy of the region has to deal with sedimentary and igneous rocks. The sediments consist of sandstone and shale, and the igneous rocks, which are all intrusive, are both acidic and basic in character. The rocks in this district range in age from the pre-Carboniferous gneisses and granites which form the basal complex to later Tertiary in the form of dikes, sheets, and laccolithic, and stocklike bodies, and to Quaternary alluvium. The sedimentary strata were laid down when this part of the continent was largely submerged. The submergence likely ranged from deep-water to shallow-water and swampy conditions, as well as from salt-water or marine to brackish-water and fresh-water stages. These strata were deposited in an approximately horizontal position but subsequent movements of the earth's crust have folded and even broken the originally continuous strata. Their position in the stratigraphic section indicates their relative geologic ages. Their exact equivalents are known but partly. Some are transitional while between others there are small unconformities due to erosion or non-deposition.

These sediments are for the most part of Cretaceous age. There is a thin layer of "Red Beds" lying on the basal complex of which little information was obtained. There are thin beds of alluvium in the river valleys. The rocks adjacent to the eastern boundary of the area are gneisses and granites of pre-Carboniferous or probably pre-Cambrian age which form the masses of the Park Range and the basal complex of this area.

Since the chief interest is limited to that part of the stratigraphic column which may be oil bearing, namely, the Cretaceous, only a brief summary of the older rocks is given here. The following summarized description of the Cretaceous strata is given in tabular form for convenience of reference and comparison.

Summarized description of the strata

Geologic Age	Formation name	Description	Topographic Forms	Thickness Feet
Cretaceous	Lewis	Composed largely of dark gray to black, calcareous, marine, clay shale containing lenticular beds of limestone.	Slopes, valleys and rolling plains.	1200-1800
	Mesaverde	Includes a succession of alternating sandstone, shale and clay, and coal seams. Three very prominent ledges of massive sandstone. The shale and clay form valleys and slopes covered with debris and waste. The coal seams are generally hidden by debris.	Steep, rough ridges with narrow valleys between the sandstone ledges.	3000-3700
	Mancos	A thick mass of dark shale containing lenticular beds of sandstone and several hard calcareous layers near the base.	Slopes, valleys and rolling plains.	2000-2500
	Dakota	Two heavy sandstones with a thin layer of interbedded black shale.	Hogbacks.	160±
Undetermined	"Red Beds"	Red sandy clay and shale with a thick, massive red sandstone bed near the middle.	Slopes and valleys.	?
	Basal complex	Gneisses and granitic rocks.	Mountainous masses.	...

PRE-CRETACEOUS ROCKS

Basal complex.—The igneous and metamorphic rocks like those of similar areas in the Rocky Mountains form a vast complex of schist, gneiss, granite, and quartzite, each with various phases of development. A fairly detailed description of these beds is given on pages 200-202 of the first report of the Colorado Geological Survey of 1908, which, according to the present limited information applies also to this region.

"Red Beds."—These rocks consist of red sandstone and shale lying on gneisses and granitic rocks. These red beds can be traced to the Hahns Peak district where, in the report cited above, they were referred to as Carboniferous to Jurassic. They consist of sandy red shale with a thick cross-bedded sandstone near the middle of the group. No outcrop was found which would serve as a place for the determination of their thickness.

CRETACEOUS ROCKS

These rocks consist of four important formations; the ages are matters which as yet have not been settled completely, but lithologic similarities and other characters are so similar to related districts that this is not at present important.

"Dakota" formation.—The oldest of these formations is the "Dakota," the basal part of which is a conglomerate layer about ten feet thick composed of fragments from the older beds of the mountain district. This layer lies unconformably on the "Red Beds." Above this is a layer of dark sandy shale a few inches thick which is overlain by a hard, massive, sandstone white to brown in color, and from 30 to 40 feet thick, which in places has been changed to a quartzite. Lying on this is a bed about 70 feet thick which is composed of thin beds of sandstone and interbedded sandy shale. Above this is a forty-foot bed of hard massive sandstone much jointed and cross-bedded.

This is directly overlain by the dark Mancos shales. A maximum thickness for the "Dakota" in the section measured on Elk River near the mouth of Salt Creek is thus 160 feet. Due to the dislocation and probable compression at this point, this figure may be somewhat low. The lower sandstones are generally somewhat prominent as ridge makers and form the highest part of the hogbacks in which the whole formation is exposed, owing to the highly tilted condition of the strata along the mountain border. No fossils were obtained from this formation and none have been reported from the Hahns Peak district or in nearby fields, and its assignment to Dakota Cretaceous is based on its stratigraphic position and lithologic similarity to "Dakota" east of the range.

Mancos formation.—Above the Dakota is the Mancos shale, a thick mass of dark clay shale with a calcareous sandstone member about 460 feet above the base, and containing some very calcareous shales in the 600 feet above the sandstone. The layers above the calcareous shales are very dark colored. The formation is considered as a single unit, but has been subdivided in other places on paleontological grounds. As taken here it includes the dark shales of the Benton and the limy layers of the Niobrara of other fields. The term Mancos is here applied to all the dark-colored shaly strata conformably overlying the Dakota and apparently conformably underlying the soft, yellow, thin-bedded sandstone at the base of the Mesaverde formation. A very exact determination of the thickness of this formation is impossible in this area because nowhere is a section of constant dip and definitely exposed contacts to be found. Measurements taken give it a total thickness of 2,127 feet. These measurements were made from the exposures on the Chimney Creek dome and from exposures along Elk River in section 4, T. 7 N., R. 85 W. Some fossils were found in the Mancos and the following is a list of those identified by Professor Junius Henderson from the collection:

Inoceramus dimidus
Inoceramus sp.
Inoceramus sp.
Inoceramus probably fragilis
Inoceramus fragilis
Scaphites warreni

Fish scales were identified by Professor T. D. A. Cockerell, as follows:

Hypsodon sp.
Ichthyodectes sp.

On page 207 of the Colorado Geological Survey, First Report of 1908, the following fossils are recorded from the Mancos:

Baculites gracilis
Inoceramus dimidus
Ostrea congesta
Prionocyclus wyomingensis
Scaphites warreni

The sandstone which lies about 460 feet above the top of the Dakota formation was examined in cross section on Poose Creek about half a mile from its junction with the Williams Fork River, and also along the Elk River east of Elk Mountain. In both cases it was found to be a porous sandstone with numerous thin shale partings. The measurement on Poose Creek gave its thickness as 25 feet. The exact determination of its thickness as exposed in the north end of the Trull anticline was not possible on account of the intense folding which had taken place there, but further south near Trull it was found to be about 35 feet thick. From these measurements it seems safe to assume that it would provide an ample reservoir for the storage of commercial quantities of oil.

Mesaverde formation.—The thick series of sandstones and shales overlying the Mancos shales and overlain by the conformable Lewis shales are called the Mesaverde. On page 23 of Bulletin 297 of the United States Geological Survey the following is reported concerning the correlation of the Mesaverde. "In the Yampa field the formation is apparently analogous to that of the type locality both in character of its constituent members, in its position between two great clay shale groups, and in the fossils that it contains." It corresponds approximately to what is called Pierre-Fox Hills on the east side of the range. It consists of thick-bedded and thin-bedded sandstones with interbedded shale and coal seams. This formation has been described in detail in the bulletin mentioned above and also in the United States Geological Survey Bulletin 415, pages 63-71. The formation may be divided into two, three, or more groups but is here considered in three groups—an upper, middle, and lower.

The lower contact with the top of the Mancos is marked by a soft yellowish to white sandstone showing discontinuous and irregular bedding, and in some places cross bedding. This contact is not often plainly marked, as it occurs on the lower part of the slope between the heavy basal sandstones and the shale flats. It is nearly always covered with debris and wash from above, and generally overgrown with brush. In mapping the boundaries the exact contact was therefore found only at intervals, and it is to be considered as generalized.

The upper boundary was taken as the top part of the highest sandstone in the upper group. This sandstone does not outcrop continuously but is covered with waste and wash from the slope above it. When found it is a soft, iron-stained layer, seven or eight feet thick, lying on a bed of interstratified white calcareous sandstone and dark shale, and is overlain by light brown clay shale of the Lewis formation.

For purposes of mapping the structural contours, the ledges of sandstones making prominent scarps were taken as horizons. Three such ledges were used in the work on this area, they are the Twentymile and Trout Creek, described in Bulletin 297 of the United States Geological Survey on pages 26-27, and a heavy brown sandstone forming the top of the ridges of both sides of Tow Creek and lying 890 feet above the base of the formation. The last will be referred to as the Tow Creek sandstone member; it has a total

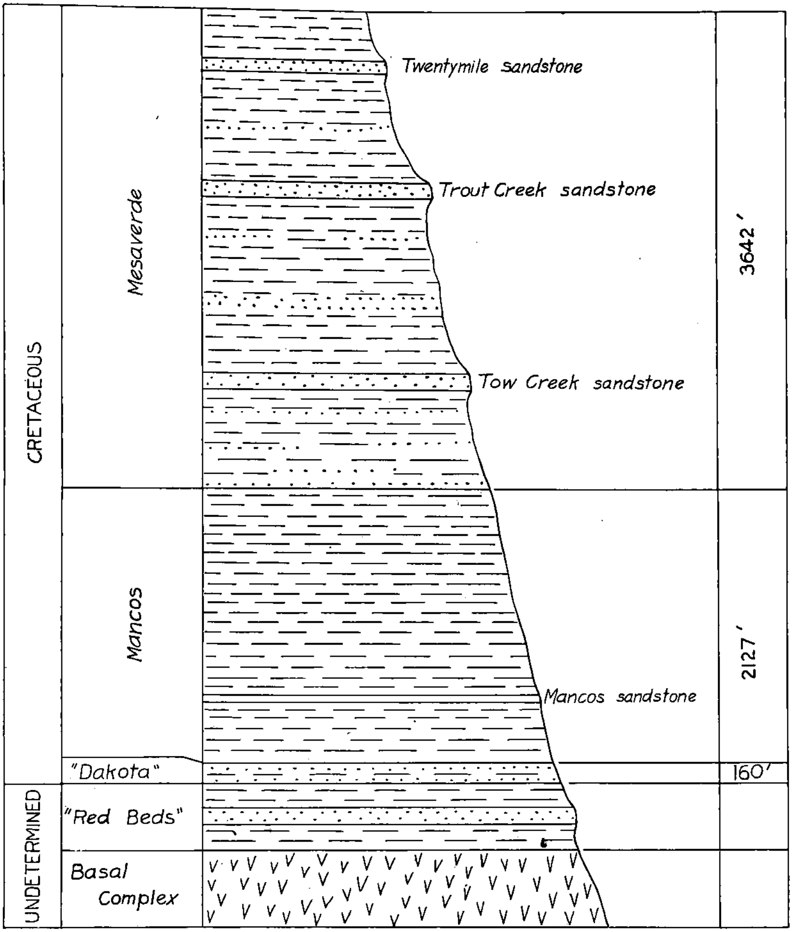

Fig. 5. Vertical section of sedimentary rocks of the Tow Creek anticline

thickness of 100 to 112 feet, and though massive throughout it has two or three more or less prominent divisions, due to erosion of streaks of softer material.

Descriptions of the Mesaverde formation given in the bulletin referred to above apply very well to this area, and as it is eroded too deeply to allow oil accumulation in this area it was not studied in detail beyond the location of horizons within the formation. The following shows the position and character of the strata used in mapping this structure, as obtained from the cross section measured along the Yampa River. (1) The Twentymile is a massive white sandstone, averaging 75 feet thick and occupying a stratigraphic position 2,307 feet above the Tow Creek sandstone. (2) The Trout

Creek is a similar layer of equal thickness which occupies a position 1,470 feet above the Tow Creek member. (3) The Tow Creek is a massive brown sandstone averaging 100 feet thick. The figures given above are from the top of the Tow Creek to the top of the bed mentioned. The total thickness of the Mesaverde as calculated from the measurements made along the north side of the Yampa River where it cuts this fold, is 3,642 feet.

IGNEOUS ROCKS

The main part of this paper is not to consider the petrography of the area, and what is reported here is of a limited nature. Specimens and slides were made and examined only from the main bodies of igneous rocks. No specimens were taken and no slides examined from Pilot Knob or Sand Mountain, but a description of them is given on pages 32-33 of Bulletin 297, United States Geological Survey. The rocks of related districts are described on pages 45-55, Bulletin 5, pt. 1, Colorado Geological Survey, and also in the First Report (1908) of the Colorado Geological Survey on pages 211-219. The igneous rocks of this district are all intrusive in character, and consist of two general types. The laccolithic and stocklike bodies are of acidic porphyry, with attendant phases, and the dikes and sheets are of basalt. There are two varieties of basalt; one contains quartz and the other does not.

RHYOLITE PORPHYRY

The rocks of acidic type were studied in less detail than the basalts. They occur in the laccolithic body in the Tow Creek crest and on Elk Mountain; on page 32 of Bulletin 297 of the United States Geological Survey they are reported to be present on Sand Mountain. The Tow Creek intrusive, the only body strictly within the area, when seen from a distance was so light colored and apparently stratified, that it was thought to be sandstone. It was found that this apparently bedded part of the intrusion near the north central part of the body changes quite rapidly into a finer-grained and structureless rock toward the borders of the intrusion.

The hand specimen of the most acidic part shows frequent quartz phenocrysts about one-fourth of an inch in maximum diameter, numerous colorless feldspar phenocrysts of about equal size, and many small but quite perfect hexagonal crystals of biotite embedded in a fine, light groundmass. The quartz phenocrysts can be distinguished by their lack of cleavage which is very noticeable in the feldspars. The rock presented a chalky appearance except where it was stained by alteration of the iron-bearing minerals.

Under the microscope quartz is not very abundant and is found to consist mainly of large corroded phenocrysts containing numerous bays which contain portions of the groundmass. Orthoclase and andesine feldspars are present in much more abundance than the quartz and generally in somewhat larger phenocrysts. The latter is the more common feldspar and it often shows albite and Carlsbad twins. Biotite is very sparingly present and very occasional small subhedrons of hornblende can be seen. The groundmass which makes up approximately half of the rock is microgranular, and appears to be composed largely of feldspar which is much kaolinized, with some quartz. The phenocrysts of both feldspar and quartz contain many inclusions of glass, apatite, and some titanite. Many small cavities are distributed through the rock.

This rock is here designated a rhyolite porphyry though it is almost coarse enough to be a granite porphyry, and might be so named without being far wrong. It grades into felsitic phases where there are only a few small phenocrysts and the amount of femic minerals is considerably more.

OLIVINE BASALT

The quartzless variety of basalt is the most basic of these igneous rocks. It is found in the dikes extending from the south crest of Wolf Mountain into the Tow Creek laccolithic body. It is a very dark, compact rock with frequent small phenocrysts of olivine.

The microscope shows this rock to be composed principally of Olivine and feldspar in nearly equal amounts with some pyroxene and iron ore. The olivine is less altered than in the finer-grained quartz-bearing variety, and is present as subhedral and anhedral grains of various sizes up to 1 mm. The feldspar is present in medium-sized lathlike microlites oriented in every direction. It was found by measuring the extinction angles to consist principally of labradorite. The feldspar has suffered more or less alteration in some places and a cloudy appearance is presented by the resulting products. The pyroxene is chiefly augite in subhedral grains of small size. The iron ores consist chiefly of magnetite or ilmenite in numerous small irregular grains widely distributed through the rock. Biotite is present in occasional small anhedral flakes.

QUARTZ BASALT

The variety of basalt containing quartz is found in Chimney Peak and in sheets around the Chimney Creek dome. It is a heavy rock of bluish-gray color containing numerous imperfect crystals of bright green olivine about 3 mm. in diameter, and less numerous grains of quartz of about the same size embedded in a dark bluish-gray groundmass.

Under the microscope this rock shows olivine, pyroxene, feldspar, iron ores, and quartz.

Olivine is the most abundant mineral present. It is present in the larger grains as phenocrysts of small size and also as fine crystals in the groundmass. These grains have the typical cracks along some of which iron ore has developed. In some instances the olivine seems to have altered to fine grains of iron ore and the original outline of the olivine retained. All gradations between the fresh grains and the iron ore replacements are present. A reddish, pleochroic aggregate of irregular outline occurs in small amounts. This may be iddingsite, an alteration product of olivine. The pyroxene is chiefly augite in small euhedral and subhedral grains. The feldspar is present in lathlike microlites, probably of labradorite or anorthite, but this is a little doubtful on account of the small size and imperfect definition of the twinning. In the uneven groundmass, considerable iron ore, chiefly magnetite and ilmenite, is present in small irregular grains. One of the noticeable features of this rock is the fairly frequent number of corroded grains of quartz. They average about 3 mm. in diameter and have very irregular outlines with numerous bays. A fringe of mineral surrounds each grain. This fringe is composed of a fibrous aggregate, probably serpentine, produced from the partial absorption of these grains, and the surrounding minerals. These grains are probably not true phenocrysts as they appear to have been picked up by the magma before it cooled. Occasional rods and specks are found as inclusions in the grains. These may be rutile or some similar mineral.

AGE

The age of these rocks is post-Mesaverde and probably Tertiary, since they came approximately into their present position subsequent to the deposition and solidification of the Mesaverde formation, and accompanying or subsequent to the folding. There seem to have been two periods of igneous activity. The earlier rocks were acidic in type, for the heavy olivine basalt which extends from the south crest of Wolf Mountain cuts the acidic porphyry in the Tow Creek crest. The dikes and sheets may be of the same age, as their close resemblance in composition suggests. Nowhere was a dike found cutting a sheet. The rocks of this area so closely resemble those in the Hahns Peak and Rabbit Ears district that it seems quite probable that they are of nearly the same age, and came from the same general reservoir.

METAMORPHISM

The metamorphism of this area is chiefly confined to very narrow contact zones of intruded igneous rocks in the form of dikes, sheets, and laccolithic bodies.

In the case of dikes very little effect could be noticed. Nowhere was there a well exposed contact of sedimentary beds and dike rocks, but examination a very few feet away from the contact shows nothing beyond a slight hardening, and not always that. The beds into which the dikes were intruded have not been perceptibly tilted, or otherwise changed by the intruded rock. It seems probable that they were fissure fillings in part, with some absorption and minor fracturing.

The sheets intruded into the Mancos shale and showing in nearly circular outcrop in three successive beds around the Chimney Creek dome have caused very little metamorphism. On the upper and under sides the effects seem to be about equal. The effects extend from a foot to 10 feet with a fairly constant average of 18 inches. The shale at the contact has for an inch or two been baked to a material resembling porcellanite, and the succeeding layers vary in hardness from that rock to ordinary shale in about a foot and a half. The effect is most noticeable on the innermost and outermost sheets. The middle sheet is thinner and less continuous than the others, and has caused less metamorphism. The contact metamorphism as seen along the borders of the Tow Creek laccolithic mass is very slight. Though the mass is largely acidic porphyry and must have been intruded at a higher temperature than that of the dikes and sheets, its effect is apparently no more pronounced. No good exposure of this contact with shale was found, but a sandstone at the south end and near the forks of Tow Creek showed only a slight hardening of the rock. None of the intrusions seems to have been accompanied by any appreciable amount of water and this likely accounts for the very slight effects thus produced.

STRUCTURE

GENERAL

The structure in this district is an asymmetrical anticline having three crests located along an axis of northward trend which bends northeast at its northern extremity and slightly southeast at its southern extremity. This axis plunges to the south and hence the northern crest is the highest. These three crests are separated from each other by synclines crossing the anticline almost at right angles to the axis. The fold produced lies approximately parallel with the mountain uplift with the steep side facing toward it. The general trend of the axis of this fold is roughly parallel with the major folds in bordering districts, such as the Trull anticline, and the Sage Creek anticline. The west limb of this anticline has a rather constant dip of about 12° westward and the east limb a steep dip of from 40° to 50° eastward in the Yampa River valley and lessening considerably to the north. (See Pl. III., in pocket.)

YAMPA CREST

The southern and lowest crest occupies the area along Tow Creek below its forks and along the Yampa River in sections 7, 8, and 17, T. 6 N., R. 86 W. The anticline has been tested by two wells, neither of which gave favorable results. The logs are not reliable and there is no certainty of the depth attained. The well along the Moffat Highway in section 7, T. 6 N., R. 87 W., is a dry hole, and from reports concerning its depth went down a consid-

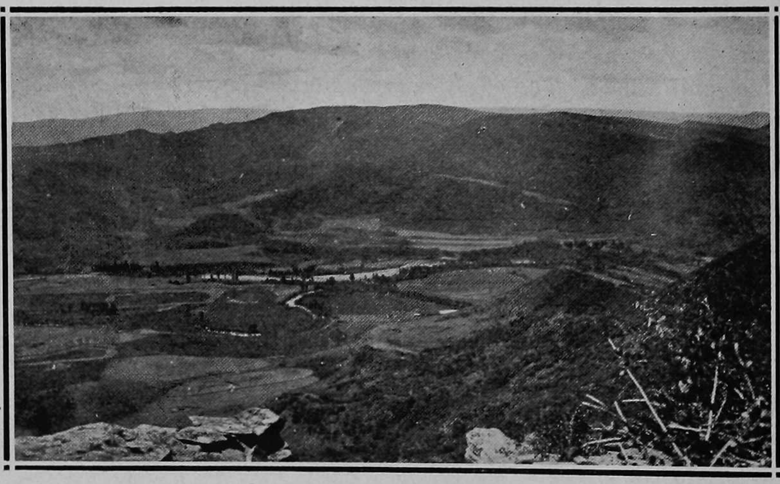

Fig. 6. Yampa crest of the Tow Creek anticline from the Tow Creek sandstone ledge

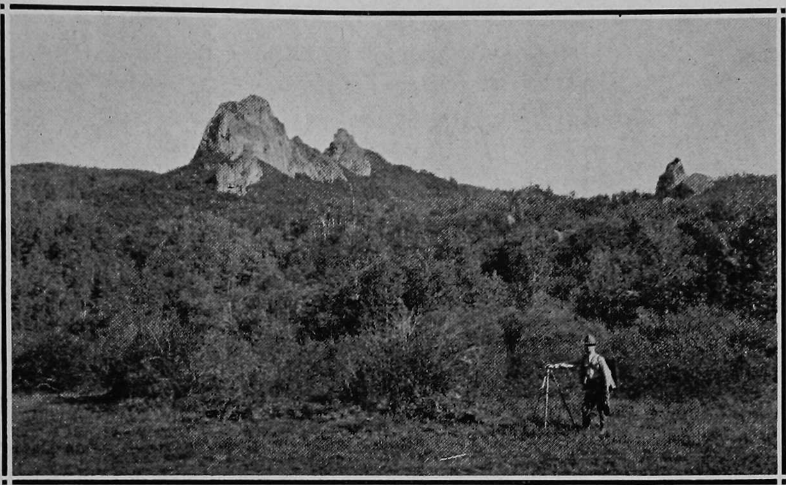

Fig. 7. Dike in the Tow Creek anticline

erable distance into the Mancos shale without obtaining any oil. The other well located in section 32, T. 7 N., R. 87 W., is on the east side of Tow Creek about a quarter of a mile below the forks. It flows a small amount of water steadily. This well begins near the base of the Mesaverde and probably went some distance into the Mancos. This well is seemingly fairly well located to test the structure, but perhaps is a little too far to the east and may have gone principally into the Mesaverde beds, which have a very strong dip to the east at this place. This seems to be indicated by the fact that artesian water was obtained. A more favorable and decided test would be about a half mile farther south and on the west side of Tow Creek. The possibility that the intrusion resembling a laccolith, to the north of the well, but separated from it by a syncline, has caused leakage in this dome, cannot be overlooked. Its nearness suggests that it may have fractured or replaced a part of the possible oil reservoir south of the syncline and thus rendered this crest unproductive. From the contact slopes of the intrusion it seems quite probable that downward it breaks into and fractures the possible reservoir rocks of this district.

In case future developments should secure good quantities of oil in the Chimney Creek crest a more extended exploration of this dome might be warranted. Plentiful fuel from the coal mines of MacGregor and Mount Harris could be easily obtained, and the Yampa River and Tow Creek would furnish a plentiful supply of water for drilling needs.

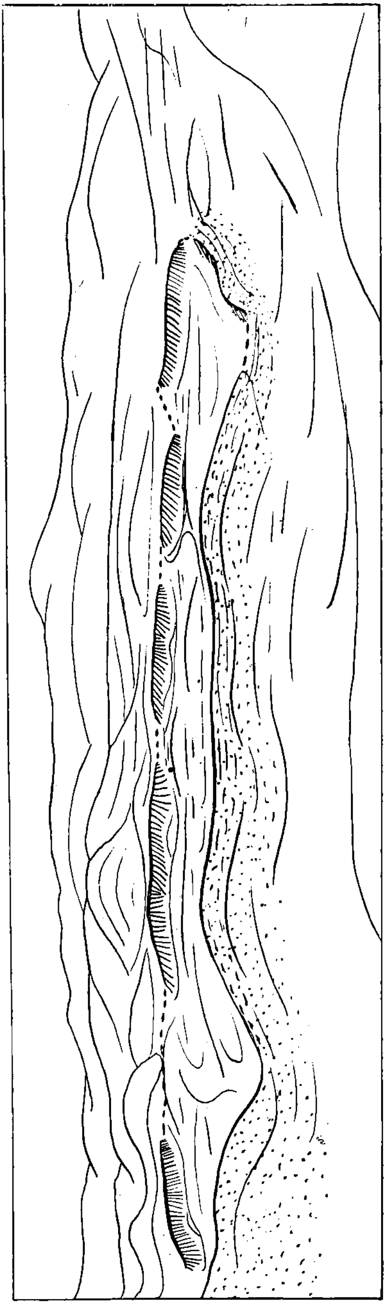

Fig. 8. Chimney Creek dome looking north; sketched from a photograph

CHIMNEY CREEK DOME

The northern crest is a quaquaversal structure in Mancos shale on Chimney Creek with its center in section 4, T. 7. N., R. 86 W. This structure is nearly a perfect dome as shown by the almost circular outcrop of calcareous layers and the rather equal dip of about 25° in every direction. These dips flatten out in every direction quite rapidly. The results of operation of forces necessary to produce such a fold can be seen in other parts of the area, but it is possible that an intrusion of igneous rock, laccolithic in type, may underlie this fold. (See fig. 9.) It may also have been formed by a combination of these forces. The possibilities of igneous intrusion beneath this crest are strengthened by the presence of three dikes or sheets which show in irregular and interrupted outcrop around the dome. These sheetlike bodies do not follow the bedding planes of the shale exactly, but are intruded at practically the same angle and cut across the bedding only for short distances. The rock of these intrusions is basalt and is about the same in all, and very much like that of the dike in Chimney Peak. The nearest body is a dike about three miles to the northwest. That these sheetlike bodies around the dome carry corroded grains of quartz seems to indicate that they have picked up this material not far away, and it is quite possible that they are really dikes and the included quartz was taken up in passing through the sandstones. That dikes would be intruded in a circular form at such nearly equal distances from the center of the fold seems rather improbable unless connected to a laccolithic body underlying the dome. Assuming this to be the case, oil may still be found in the dome, as their metamorphic effect on the shale is very slight. If the oil had accumulated previous to intrusion there would likely be some seeps around the intrusions. No such seeps were found nor was there anything along the contact to indicate that oily matter had been passed through. In case the accumulation is taking place at present the dikes would not materially injure the chances of obtaining oil from this structure, but it might restrict the district in which it could be obtained to that part of the dome lying outside of the area inclosed by them. The metamorphism of the possible oil reservoirs is probably not much greater than that seen in the shales.

The possibility suggested above that the crest is underlain by a laccolithic body deserves much consideration, but nothing more than hypothetical conjectures can be advanced until data obtained

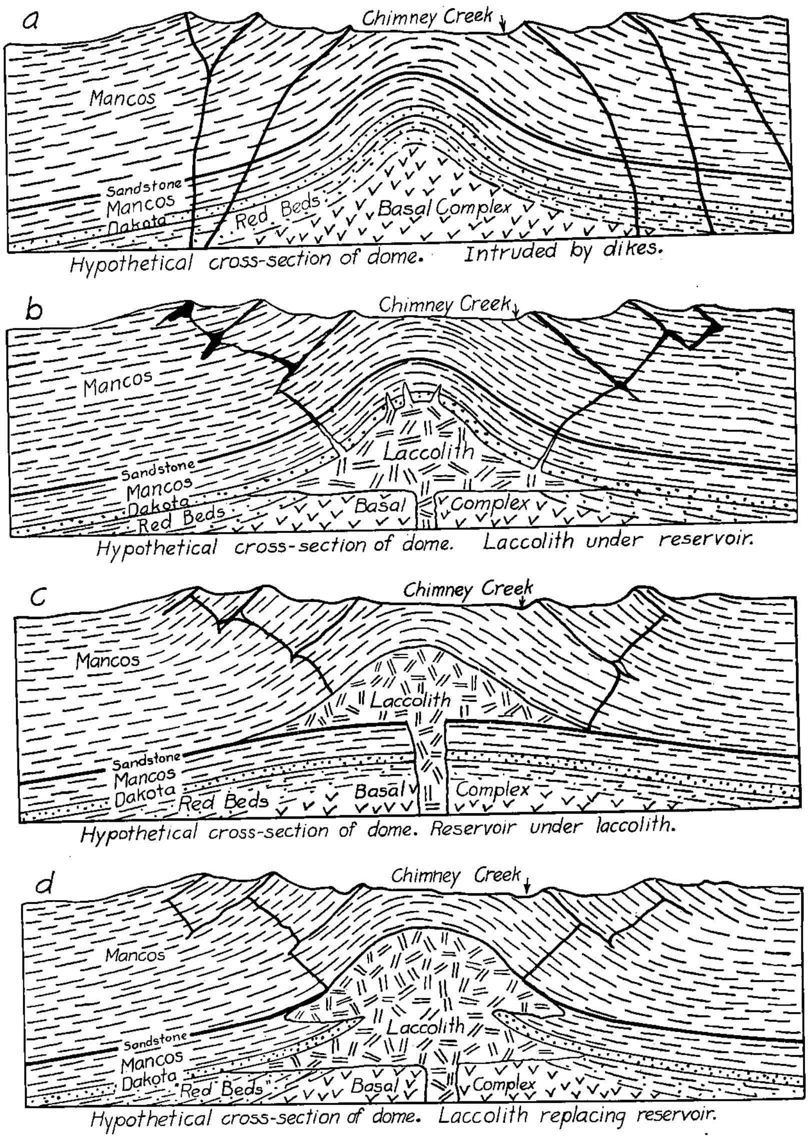

Fig. 9. Possible relationships of rocks in the Chimney Creek dome

from drill holes are available. If a laccolith or thick sill has caused or accentuated the arching and doming of this structure it would still be possible for oil to accumulate under certain conditions as follows:

(a) If an oil reservoir lies above the laccolithic body and it is not materially changed by the intrusion, the possibilities of obtaining any oil which may have accumulated are not affected by the presence of the intrusion. (See fig. 9b.)

(b) If a reservoir lies underneath the laccolith and has not been too much altered it probably has sufficient arching for the accumulation of a commercial quantity of oil. (See. fig. 9c.)

(c) If the possible reservoir has been displaced or broken up by the igneous intrusion it would probably be necessary to go beyond the borders of such disturbed area to find an oil reservoir. (See fig. 9d.)

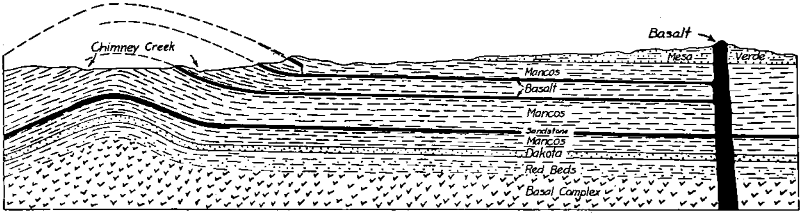

Fig. 10. Possible relationships of sedimentary and igneous rocks in the Chimney Creek dome

Evidence of channels which would allow the movement of magma upwards is seen in the thickened bodies at four or five places in the line of these intrusions. That these channels seem to diverge upwards from a point near the center of the dome may indicate that arching movement took place subsequent to their opening. That these thickened places probably represent channels which probably connect the sheetlike intrusions seems likely. If such is the case they would not materially affect the foregoing discussion as they may or may not indicate a laccolithic intrusion. The size of one such body appearing in a hill on the south side of Chimney Creek at the southwest side of the dome is such as to give evidence of outlet sufficient to almost, if not quite, prevent the formation of a laccolith.

So far as the present knowledge permits, based on data obtained at the surface, these intrusions may be regarded as sheets (fig. 10) with occasional thickenings, or possible channel connections. As to the possibility of there being other sheets below the known bodies very little can be said. If there are others it is likely that they are quite similar to those exposed and would thus have a small effect on any oil which may have accumulated or may be accumulating. Regarding these bodies as sheets, they were probably intruded either at a time previous to the folding which, followed by erosion, has caused them to be exposed, or perhaps subsequent to folding and previous to erosion. The metamorphic effects of these intrusions is described elsewhere.

Drilling needs.—Water sufficient for drilling needs could probably be obtained from Chimney Creek with little trouble. In case the water there was found to be insufficient it could be easily obtained by pumping from Deep Creek. Coal for fuel can very likely be obtained in good quality and quantity from mines and prospects, within four or five miles.

TOW CREEK CREST

The middle crest of this anticline, of which the structure contours are shown on the map, is filled with an igneous intrusion which resembles a laccolith. No deeply eroded channel has been cut by which such a hypothesis can be substantiated but certain evidence is available. The shape of the igneous body as presented on the surface is roughly elliptical with its long direction lying north and south. On all sides the Mesaverde sandstones dip away at angles varying from 10 to 45 degrees. The borders of the igneous intrusion are of a finer-textured rock than that composing the central parts. This central part which grades insensibly into the finer-grained rock of the fairly wide border is porphyritic, and is described elsewhere. On the igneous rock near the central part of the southern half is a small patch of basal Mesaverde sandstone, the lower part of which contains a layer of bituminous sandstone very similar to that from which oil seeps to the east along the creek. Near the border at the south end of the igneous rock is another small patch of Mesaverde sandstone similar to the one above and also to those connected with the oil seeps. The significance of these patches of sandstone seems to be that the Mesaverde formation once covered at least the greater part of the intrusion. That a considerable cover was present on the intrusion is indicated by the porphyritic texture of the central part of the mass. Provided the intrusion was stocklike in character the rock would likely be porphyritic in character to within a very short distance of the contact. The particular position of this intrusion with the adjacent folding is suggestive of the fact that the strata were affected by some such force as would be exerted by an intrusion of laccolithic shape.

From impressions gained in the field and substantiated in making the structural contour map, the normal results of folding, without intrusion, would have produced a fairly broad syncline, of low dip northward away from the Yampa crest. Instead, this syncline dips sharply away from the north end of the Yampa crest, and flattens out abruptly for a short distance. From the contact on the south end of the intrusion the sediments dip southward to the flat part of this syncline. The syncline thus produced instead of being broad is narrow, and instead of making a smooth downward curve, is irregular. The shape of this syncline between the Yampa and Tow Creek crests is not strictly characteristic of the forces which seem to have operated in the formation of the other parts of the anticline, but seems to indicate a force acting at an angle upwards, such as would be exerted by a laccolithic intrusion. To sum up the evidence the intrusion closely resembles a laccolith, and no oil can be expected from drillings in the igneous rock.

OIL POSSIBILITIES OF THE TOW CREEK ANTICLINE

There are various indications of the presence of oil within the strata of this area. At three points along the Moffat Highway water seeps carry small amounts of oil which have accumulated as a residue in the earth around these seeps. That saline matter is also present is shown by the thin crust of alkali around the borders of these seeps. These seeps come from the sandstones lying just above the Tow Creek sandstone. The saturated earth gives a decided oily smell when heated with a match, and in some places where it has been hardened and concentrated by the sun's rays will almost ignite. An oily scum is also present on the small puddles around these seeps.

About three hundred feet above the forks of Tow Creek on the east bank of the east branch is a ledge of sandstone very close to the base of the Mesaverde formation which is saturated with a dark tarry oil. The surface of this ledge has been opened up for about 4 feet vertically and 10 feet horizontally, the top and bottom of the layers are shale contacts toward which the oil decreases in amount. There are occasional shale partings at intervals of from 2 to 10 inches. This layer of sandstone is just full enough of oil so that it does not ooze from the surface, which is of a dark brown color. In each direction this ledge is covered with debris from the slope above, and about a half mile up the creek the surface has been uncovered again and here a short tunnel was being driven into the ledge to drain the oil from the rock. The oily rock taken from the tunnel was, in August, 1919, being heated in a small crude still to extract the oil. Some of the oil thus obtained was examined and found to be very similar to crude petroleum from oil wells.

In a sandstone ledge the thickness of which was undetermined on account of the debris covering it, and which is about a hundred feet above the still, is an oil spring described in bulletin 297 of the United States Geological Survey, page 79. A small pool has been formed where it issued from the rock. When examined the surface of this pool was covered with a scum of dark, tarry oil which was very slowly trickling over the edge with some water. The water seemed to be just enough to keep the pool at a constant level and trickle over the side for a few feet where it was absorbed and dried up. The slope below was covered with waste from above, but a considerable amount of brea, presumable overflow from the pool above, had accumulated on the surface from which the earth and brush had been removed over an area about fifty feet wide and two hundred feet down the slope. This layer was not uniform in thickness, and in most places did not exceed three inches. The prospectors had uncovered some chunks six or seven inches thick without reaching bottom. This patch, including the spring, was fenced in to keep out the stock, for which these seeps, probably on account of their salt, have great attraction. One of the prospectors working on the little tunnel below, said that he had skimmed about a bucket of oil each evening for the past seven years from this pool.

Past experience has been largely against the possibilities of obtaining oil in districts into which igneous rocks have been intruded, but in certain Mexican fields their presence has been shown to be favorable to very productive areas. A district in which the structure, rocks, and conditions are quite similar to this is that between Tuxpam and Tampico where very productive wells have been obtained around the igneous intrusions. For a fairly complete discussion of these occurrences consult "The Mexican Oil Fields," by L. G. Huntley, in the Transactions of the American Institute of Mining Engineers, Volume 52, pages 281-321. It is not at all certain that the conditions in Mexico are reproduced exactly enough in this district to warrant drilling on the limbs of the fold adjacent to the intrusion, but provided that the Chimney Creek crest was found to be productive, and other nearby fields show good quantities of oil in the strata below the Trout Creek sandstone, the west limb of this fold would be worth prospecting. In any event the dike running northward from this intrusion to the south crest of Wolf Mountain may trap oil coming up the strata from the south and west, and if such is the case, wells could be drilled to tap the reservoir along a line roughly parallel to this dike and at no great distance from it. On the east side of the structure the seeps indicate a leakage of oil from some reservoir or else the accumulation of very small amounts close to the surface due to the action of circulating waters. The conditions on this side of the structure seem far less favorable to the accumulation of oil in strata than on the west side.

The Mancos shale forms broad valleys, rolling hills and plains between the Dakota ridges or hogbacks and the harder basal ledges of the Mesaverde formation. This shale formation has numerous fossils, especially in the basal and upper parts, and contains considerable carbonaceous material. These carbonaceous beds of shale are directly overlain by a thick cover of sediments which also carry large amounts of material such as seems to be productive of oil. That oil is actually contained in the strata can be seen by the various seeps of the district. Granting that the substances from which oil could be produced are contained in the strata it is only necessary to have the proper forces acting and it will form. The forces generally considered necessary are heat or pressure, or both. That such forces have been at work is quite certain. The accumulation of any oil formed will generally be accompanied and aided by ground waters. That sufficient ground waters have been present seems highly probable, and that they have been in more or less constant motion, especially since deformation began, is almost certain. Since the essential conditions necessary to produce, accumulate, and store oil have probably been represented here, it seems from this standpoint that the field is favorable to the production of oil.

This anticline is as yet unproved. The conditions seem to be favorable to careful tests, and of these the first should be made on the Chimney Creek crest where the sandstone in the Mancos might be reached near the center of the dome at a depth of about 600 feet, and the Dakota sandstone at about 1,100 feet. In drilling, both of these possible reservoirs should be tested. In the southern crest, which seems to have conditions second in favor to the one above, the Mancos sandstones should be about 1,800 to 2,000 feet, and the Dakota sandstone 2,300 to 2,500 feet below the surface, but thickening of the Mancos formation would increase these figures. The conditions in the Tow Creek or middle crest are the least favorable of the three, and prospective drilling should follow the conditions previously discussed.

ANTICLINES NEAR STEAMBOAT SPRINGS[17]

BY V. C. PERINI

SEDIMENTARY ROCKS

The stratigraphic column is made up of rocks mostly of the Upper Cretaceous age. There are some unconsolidated gravels and boulders that lie unconformably upon the Cretaceous rocks that probably belong to the Tertiary or Quaternary system.

In studying the formations the report by Fenneman and Gale[18] was used almost entirely. A generalized section of the rocks was taken from this report and studied and followed wherever possible. A check was made of the thickness of the Mesaverde formation in Yampa canyon. A complete section of the Mancos formation could not be found in this vicinity, but a part was obtained on Poose Creek, southwest of Williams Park.

"DAKOTA" FORMATION

This formation is approximately 150 feet in thickness and is made up of sandstones, shales and conglomerates. The lower part at some places contains a conglomerate composed of gray flint and feldspar pebbles. The upper part is characterized by a grayish-white, even-grained, massive sandstone and beds of sandy shales and slabby sandstones.

At Steamboat Springs, this formation forms a prominent ridge and the beds are clearly shown where a railroad cut has been made through part of the formation. The strata dip about 35° to the west at this place, and are found overturned to the north of the Yampa River.

The characteristic cross bedding, ripple marks and flow and plunge structures, that are usually found in this formation of other regions, were not found to any great extent.

MANCOS FORMATION

The shales of the lower part contain sand, and where weathered are very brittle and light colored. Some of the shales found near

[17]What follows is an abridgment of a thesis submitted by Mr. Perini in June, 1920, to the Graduate Faculty of the University of Colorado in partial fulfilment of the requirements for the degree M. S. To publish the entire paper would necessarily nearly duplicate part of what appears in previous pages of this bulletin. Accordingly only the statements that apply more particularly to the area mapped by Mr. Perini appear here. This area includes the southern part of the Tow Creek anticline, the Curtis anticline and the Trull anticline.—R. D. C.

[18]Fenneman, N. M., and Gale, Hoyt S., The Yampa coal field, Routt County, Colorado. U. S. Geol. Survey Bull. 297, 1906.

Steamboat Springs in the vicinity of Deer Mountain, are platy and exceedingly hard. When dug into they separate into large, regular, smooth-surfaced sheets. They are usually thick bedded with regular bedding planes. The shales of the upper part are dark, calcareous, and thin bedded. In some places, however, the beds are thicker and rather hard with very definite bedding planes.

A 38-foot bed of sandstones and sandy shales was found south of the Elk River near the Trull schoolhouse, section 28, T. 7 N., R. 85 W. The section of this bed is as follows:

Fine-grained, fossiliferous sandstone	7 feet
Alternating sandstones and shales	16 feet 8 inches
Thin-bedded sandstones	14 feet 7 inches
	38 feet 3 inches

It was impossible to determine how far this bed occurred above the base of the Mancos. It probably lies approximately 400 feet above the base as a similar bed found on Poose Creek southwest of Williams Park, and the bed shown in the columnar section in Bulletin 297, United States Geological Survey, are about this distance from the base.

MESAVERDE FORMATION

This is the most conspicuous formation in the field, and it is approximately 3,500 feet in thickness.

The more prominent sandstones and coal beds form rather definite horizons which are the basis of this formation, being divided into lower, middle, and upper coal groups. From the base of the Mesaverde to the lower coal group, alternating beds of sandy shales and sandstones are found. The sandstones are massive at some places, the beds being from 80 to 100 feet thick. There are also thin sandstones which alternate with the sandy shales. The sandstones are usually hard and fine grained. They differ in color from a cream to a grayish white and in some places have weathered to a dark yellow.

The Tow Creek sandstone is the most outstanding rock of this group. It is very massive and at some places is 100 feet thick. The freshly broken surfaces are cream-colored which weather to a distinctive yellow. The texture differs at the various outcrops, but in general it may be classified as a medium-grained sandstone. The most prominent exposures of these sandstones and shales are found on the eastern limb of the Tow Creek anticline where the Yampa River has cut its channel through them.

The Trout Creek sandstone is the most important stratum between the lower and middle coal groups. It is a massive white rock, and usually forms ledges wherever it is exposed. These ledges are 50 to 100 feet high which are weathered in part into pinnacles. Wherever the slightly dipping sandstone has been exposed to any great extent, cracks appear at the surface making odd-shaped outlines. These cracks form an easy place for erosive agents to work, and the surface is usually roughly and irregularly marked by five-sided and six-sided figures. The cracks are probably formed by expansion and contraction due to the differences in daily temperatures.

The beds between the Trout Creek sandstone and the top of the lower coal group consist of alternating shales and thin sandstones.

Between the top of the middle coal group and the top of the Mesaverde, sandstones and shales are found. The lower part consists of alternating beds of sandy shale and thin sandstones with an occasional stronger bed of sandstone.

The Twentymile sandstone is very similar to the Trout Creek sandstone. It is also white and massive and forms prominent ledges. The most prominent ledge found was on the western limb of the Tow Creek anticline where the dip averages 9° to the west. Here the sandstone forms a vertical ledge about 75 feet high which is almost continuous around the southern end of the anticline. This sandstone is generally softer than the Trout Creek sandstone and usually weathers into more prominent pinnacles. These pinnacles stand from 4 to 10 feet high at the southern exposure around Twentymile Park. Some have small diameters and their pitted markings indicate that they were probably formed partly by wind erosion. They are in places capped by a harder sandstone layer.

On the eastern flank of the Tow Creek anticline where the dip averages about 25°, this sandstone has been eroded to a greater extent. It forms a series of white humps which are separated by shallow depressions. This condition probably is due to the atmospheric agents, which have more erosional effect on the upturned edges.

Above the Twentymile sandstone, shales, thin sandstones and a prominent white sandstone are found. This white sandstone is massive with an average thickness of about 50 feet.

LEWIS FORMATION

The main outcrops of Lewis shale are found on the western flank of the Tow Creek anticline, and in Twentymile Park.

TERTIARY OR QUATERNARY BEDS

The hills east of Trout Creek and south of the Yampa River towards Steamboat Springs are, in part, covered by a mantle of recent gravel and boulders. This mantle lies unconformably on the Mancos shales and is conspicuous on the rounded hill tops to the east of Trout Creek.

The gravel is unconsolidated and made up of a mass of coarse igneous material. Pegmatites, granites, gneisses and basic rocks were found which were probably washed from the crystalline rock area to the east.

There is also a mantle of the same material covering the top of Deer Mountain. The material found here is coarser and more angular than the material east of Trout Creek. When Deer Mountain is viewed from a distance, the top of the mountain and the crystalline area to the east appear to have been a continuous slope at one time. This indicates that the gravels were probably washed from the area to the east. Deer Creek has cut a deep valley through this material and the shales beneath, and now separates Deer Mountain from the main range.

STRUCTURE

GENERAL FEATURES

Sedimentary rocks are usually laid down by water in an approximately horizontal position. At a later period, by the processes of mountain-making movements, these rocks are sometimes lifted many thousands of feet. Anticlines, domes, synclines, and other structural features are the result of these movements. Structure means the attitude which the rocks have acquired since they were formed. Faulting usually accompanies these movements, especially in the sandstones.

Owing to the fact that there has been such intense folding in this region, there are probably many faults and fractures that do not express themselves at the surface. It can not be determined as to how much faulting has occurred in the underlying Mancos formation, and in the lower sandstone members of the Mesaverde formation. If there has been any considerable amount of faulting in the Mesaverde formation, the accumulation of gas and oil would be seriously hindered, and the greater part that may have accumulated would probably escape through the fissures and other openings caused by the faulting. If the faults do not extend beyond the lower sandstone members of the Mesaverde formation, the oil and gas, if accumulated in the Mancos formation, may find a way to the sandstones of the Mesaverde formation, and there be sealed, making a large reservoir.

Throughout this region the basal complex is overlain by thousands of feet of sedimentary rocks. These rocks were probably horizontal at earlier times, and there were minor movements that resulted in the advance and retreat of the sea. This is indicated by the presence of sandstones, shales, and conglomerates. These sediments were uplifted during Tertiary (?) times, and the main folds now present were formed as a result of the forces originated. The folds that were formed at this period were probably those having axes roughly parallel to the Front Range. These folds are: the Tow Creek anticline, the Trull anticline, the Sage Creek anticline, and the fold passing through Williams Park.

There are also anticlines and synclines whose axes are almost at right angles to the above folds. These are: the Curtis anticline, the Twentymile Park syncline, and the syncline roughly parallel to the Yampa River. These folds were probably formed at a later time, and might have been formed in a long, wide syncline that existed between the Tow Creek anticline and the Trull anticline, by forces from the north or south. Mr. Willson states that the evidence found indicates that the intrusion of igneous rocks forming Elk Mountain, and the many dikes and other igneous bodies north of the river, were intruded after the main folding had taken place. The forces generated by the intrusion of Elk Mountain might have been sufficient to form the Curtis anticline.

RELATION TO TOPOGRAPHY

The topography depends to a considerable extent on the structure and hardness of the underlying beds. Throughout this region wherever the strong resistant sandstones of the Mesaverde are the underlying beds, the slopes follow the structure of these rocks. When the field is observed from the higher points this feature is well demonstrated. Twentymile Park, which lies to the east of the Tow Creek anticline, is a structural basin about 4 miles wide and 9 miles long, the strata dip towards the center on all sides. The central part is a low-rolling plain in the easily eroded Lewis shales. As the edges are reached the relief increases where the sandstones of the Mesaverde come to the surface and form escarpments to the south. This makes an abrupt slope on one side and a long gentle slope toward the plain within, which follows the general dip of the formation.

The Tow Creek anticline is another example where the slopes on each limb follow the structure of the underlying beds. Where the sandstone beds are upturned to any great extent, and are of unequal hardness, erosion acts more rapidly on the softer beds and leaves the harder layers as long, narrow, sharp-crested, parallel ridges. The lower part of the Mesaverde develops this kind of topography on the east limb of the Tow Creek anticline near the Yampa River, and also in Dunkley Canyon.

Where the Mancos or Lewis shales are the underlying beds, which are practically of equal hardness throughout, rolling or gently undulating plains usually result. The topographic features are seldom controlled by the shales. In comparison with the sandstone areas, when the shale areas are observed from the higher points, the general structural features can not usually be determined by the slopes of the hills. The slopes are very deceiving at times, and indicate promising reverse dips. Closer examination, however, shows that the dip of the sediments is, at some places, opposite to the slope of the ground. This is especially true near Steamboat Springs.

TOW CREEK ANTICLINE

The Tow Creek anticline is roughly oval in outline with minor modifications to the northwest and northeast where a syncline crosses the axis of the anticline. Mr. Willson, who was in charge of the mapping of this anticline, north of the river, reports that it has a closure of about 600 feet at the northern limit of the axis. The crest is in sections 5, 6, 7, and 8, T. 6. N., R. 86 W. (See Plate II.) This fold, south of the Yampa River, pitches to the southwest. The dips to the east are very steep, especially in the northern part where they average about 40°. The dips to the southeast and south are more gentle and average 20°. The dips to the west and to the southwest average 9°.

The gathering area for this fold, from which the gas and oil, if present, are accumulated, is limited on the east by a steep syncline that separates it from the Curtis anticline, the syncline parallel to the Yampa River, and the Twentymile Park syncline. It is limited on the southeast and on the southwest by synclines that separate it from the Foidel Canyon fold, and the fold that passes through Williams Park. The main area from which oil or gas may have been gathered is, therefore, the broad low area to the west. Smaller quantities may have accumulated from the Twentymile Park syncline, the syncline parallel to the Yampa River, and from the syncline to the south.

This anticline was partly tested by a well that was drilled in 1902 (?) in the southeast corner of section 7, T. 6 N., R. 86 W. The well at the present time is inactive, and no reliable information could be obtained as to its depth or sands encountered. The information obtained indicates that it was a dry well. It appears that this well was drilled slightly too far to the east. The axial plane of the anticline, as estimated from the structural map, dips 85° to the west. This would place the crest of the possible Mancos oil-bearing sandstone almost immediately beneath the well. If this anticline produces gas, as the Williams Park anticline from the "Dakota," the well would more probably encounter the oil, if present, if drilled farther to the west on the western limb of the anticline, and farther to the north, nearer to the crest.

The Mancos sandstone at the crest is approximately 1,700 feet below the level of the Yampa River. The "Dakota" sandstone at the crest is approximately 2,200 feet below the level of the Yampa River. This approximation is fairly accurate if there has been no local thinning or thickening of the Mancos formation at this place.

The Tow Creek anticline is structurally favorable for the accumulation of oil and gas. If the petroleum is present in any of the underlying rocks, and is associated with water under pressure, it will probably migrate up the dip. The oil would then be expected to accumulate near the crest of the anticline. The writer did not examine the area to the north to determine the influence of the igneous rocks present on the accumulation of the oil or gas, hence he does not feel justified in recommending or condemning this anticline.

CURTIS ANTICLINE

The Curtis anticline lies in the central and southwestern part of T. 6 N., R. 86 W. (See Plate I.) Its axis, which trends northwest and southeast, is almost at right angles to the Tow Creek anticline. This anticline plunges to the west and is separated from the Tow Creek anticline by a steep syncline. The dips to the northwest and southwest average 15°. The dips to the north average 20°. The dips to the south average 10°. The dips taken on the massive sandstones west of Trout Creek are not reliable, as these sandstones were almost level and no definite bedding planes could be found. There also appeared to be some slumping caused by weathering. The average dips taken on these sandstones were 2° to the southwest, and 2° to the northwest, which places this fold in the terrace type of folds rather than the true anticlinal type. These dips were probably away from the axis of the fold where the anticline has its broadest limit. The narrowest part is to the west where it closes.

Sufficient time was not available to examine the eastern boundaries of this fold as closely and carefully as was desired. The dips recorded, however, along the eastern side of Trout Creek indicate that the fold opens to the southeast and therefore would allow the escape of any gas or oil.

Bulletin 297 of United States Geological Survey, referred to before, shows a probable fault near Trout Creek. This fault was not definitely found by the writer, but the appearance of a massive white sandstone east of Trout Creek below the general level of the Trout Creek sandstone, indicates that there was a displacement of some kind. If this fault is present, and the displacement is of any great extent, there is a probability that it has sealed any gas or oil accumulated to the west of the fault.

The gathering ground for this fold is limited on the west by the Tow Creek anticline, on the north by a narrow syncline parallel to the Yampa River, and on the south by the Twentymile Park syncline.

It is suggested that this fold be studied and investigated more carefully, in order that more definite conclusions may be deduced as to its oil and gas possibilities.

TRULL ANTICLINE

The Trull anticline extends from section 4, T. 7 N., R. 85 W., to section 9, T. 6 N., R. 85 W., where it disappears under the alluvium south of the Yampa River. Mr. Willson mapped this anticline north of the Trull schoolhouse, which is on Elk River.

The dips recorded on the western limb between the Yampa River and the Elk River average 50°. Those north of Elk River, where the anticline becomes broader, average 42°. The dip of the shales on the eastern limb at the Yampa River is 42°. Between this dip and Elk River no reliable dips were recorded on the eastern limb, as the shales are covered by a gravel and boulder deposit, and slumping hindered the obtaining of accurate dips near the Elk River. The dips taken on the eastern limb north of the Elk River average 50°.

This anticline is in the lower part of the Mancos formation, as shown by the outcrops of the Mancos sandstone in sections 28 and 4, T. 7 N., R. 85 W. It closes at the northern end where the dips are 60° to the northeast and 50° to the northwest. These dips were taken on the Mancos sandstone where the Elk River cuts its channel through the fold. The elevations of the two sandstone outcrops were approximately determined, and it was found that the anticline plunges slightly to the south towards the Yampa River syncline, where it then probably opens again to the south. The general dip of the strata south of the river is to the northwest.

The outcrops found along both banks of the Yampa River do not indicate that the anticline closes or plunges to the south. The dip of the shales south of the river could not be obtained as they are covered by a mantle of alluvium.

It was noticed that there is an abrupt change in the trend of the axis where it crosses the Yampa River. This change may be due to a bend in the fold, or it may be due to a fault which crosses the fold. If it is a fault, the displacement, according to the bend of the axis, must be approximately 1,500 feet. There is no expression of such a fault on the surface to the east or west.

The gathering area is limited on the west by the intrusion of igneous rocks which form Elk Mountain, to the south by the syncline parallel to the Yampa River, and to the north by a sharp syncline. The greatest gathering area is to the east, and to the south of Elk Mountain.

If there is a fault present at the Yampa River, it would also limit the gathering area. It might also seal any gas or oil accumulated south of the river. The syncline parallel to the Yampa River is about two miles from the Yampa River, so if the fault did seal any oil or gas, the gathering area would not be sufficient to allow the accumulation of any commercial quantities of gas or oil.

The gentle plunge of the anticline to the south may change before it reaches the Yampa River. There is also a possibility of the presence of minor folds or wrinkles that do not appear at the surface. If these are present they would reduce the amount of accumulation at the highest point of the anticline to the north. The folding is sharp at the crest.

With such folding there was undoubtedly a great deal of fracturing within the sandstones. Any fractures present might allow the escape of gas or oil. The Mancos sandstone is open at two places which would permit the escape of gas and oil. If the "Dakota" sandstone contains gas and oil there is a probability of its being accumulated at the highest point of the anticline in section 4, T. 7 N., R. 85 W.

It does not seem justifiable to recommend a test of the Dakota sandstone as the structural conditions are not pronouncedly favorable, and because this sandstone is the only possible reservoir. The best location for a test well would be about 600 feet south of Elk River near the axis of the fold, in section 4, T. 7 N., R. 85 W. Wells drilled here should encounter the ''Dakota'' sandstone at a depth of about 600 feet.

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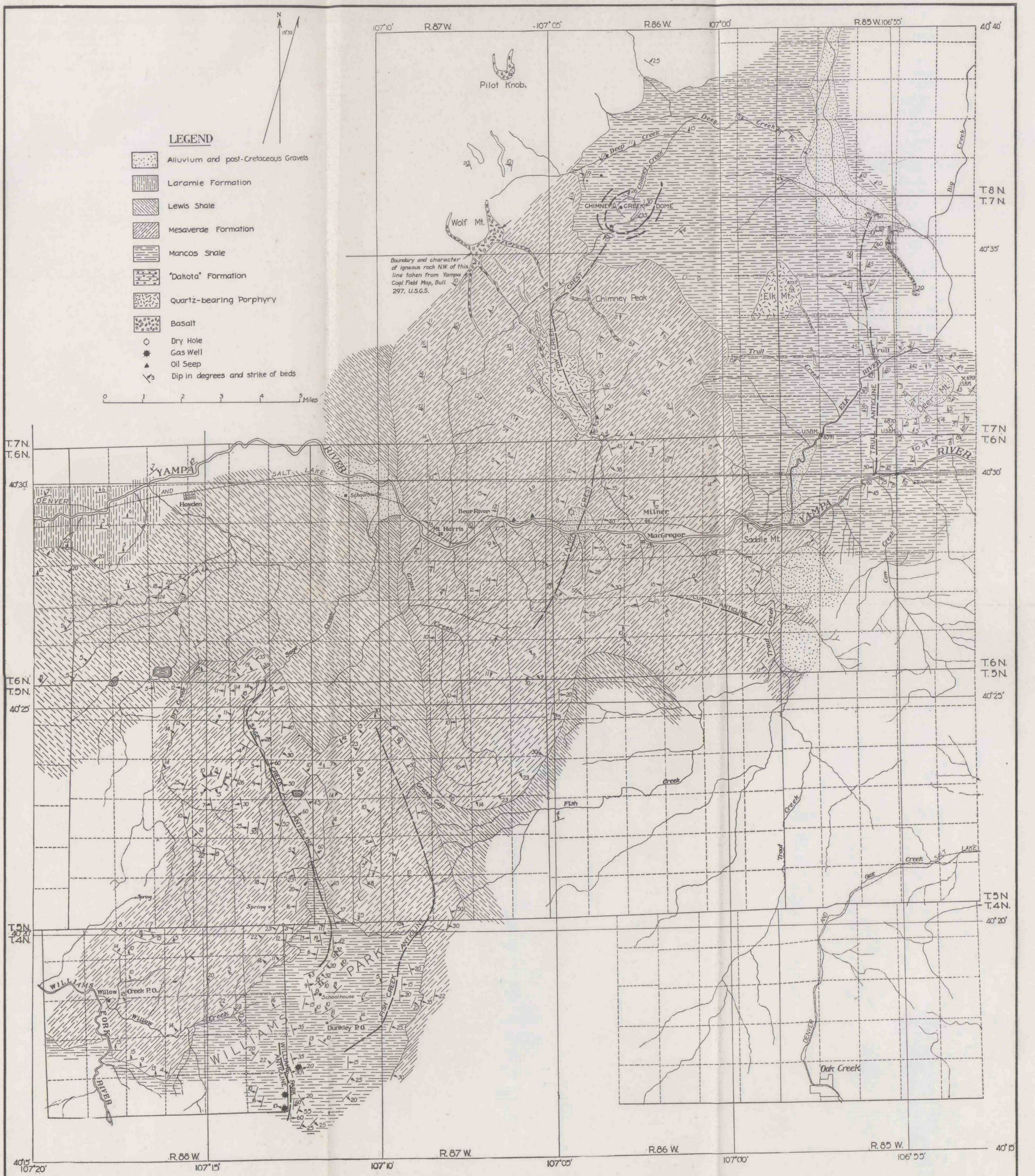
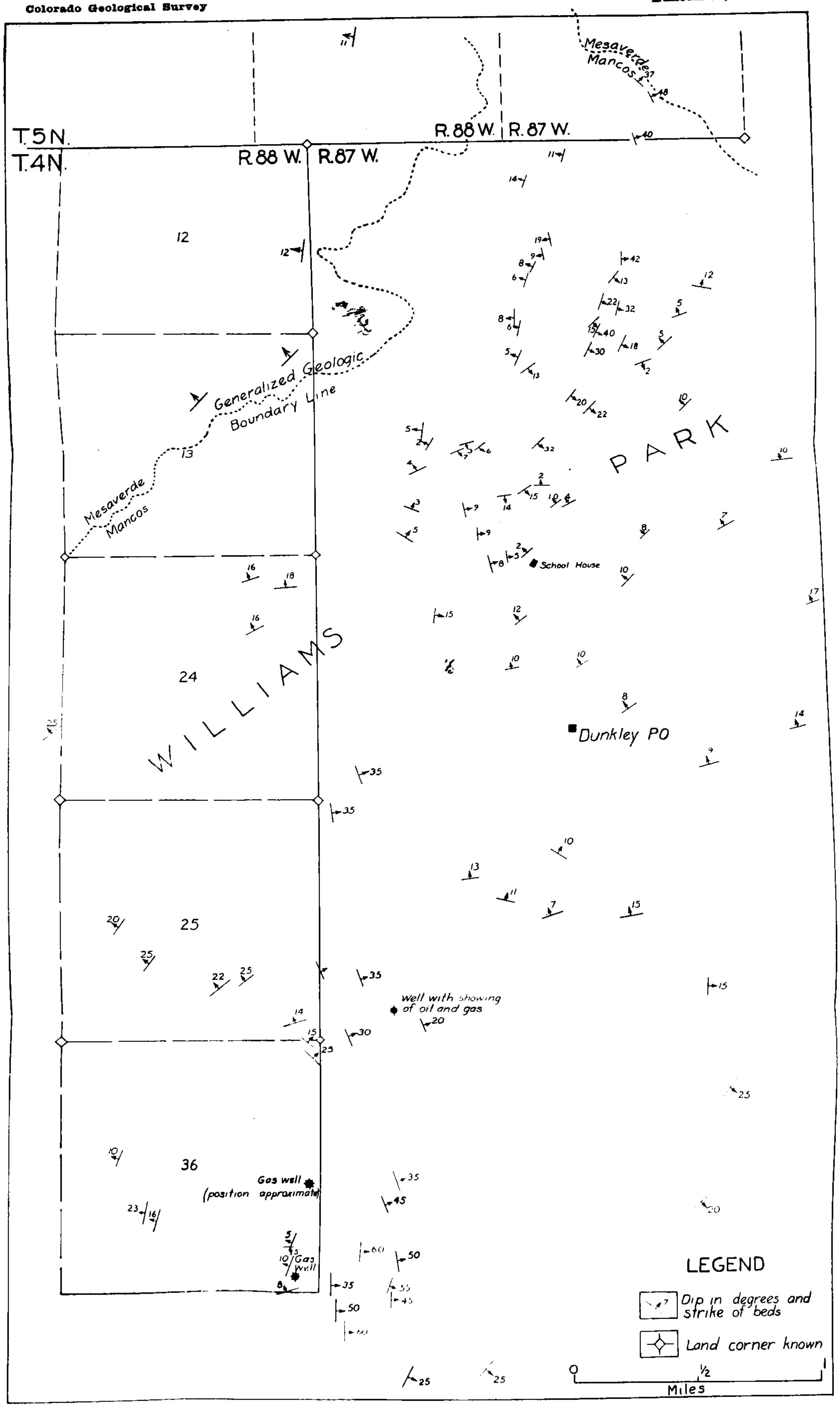


SOME ANTICLINES OF ROUTT COUNTY, COLORADO

Geology by R. D. Crawford, K. M. Willson, V. C. Perini, J. C. Myers and J. R. Murphy. Land lines and drainage taken from United States Geological Survey topographic maps of the Hahns Peak and Daton Peak quadrangles and United States Surveyor General's township plats



ANTICLINES OF WILLIAMS PARK
Geology by R. D. Crawford, V. C. Perini, K. M. Willson and J. C. Myers

TOW CREEK ANTICLINE
Geology north of Yampa River by K. M. Willson and J. C. Myers; geology south of Yampa River by V. C. Perini and J. R. Murphy