

2008–09—Years of Science and Service for Colorado

Colorado Geological Survey—2008/2009 Summary

Director's Message

In looking back over my previous Director's messages, that old adage strikes me as being true as ever: The more things change, the more they stay the same.

The Colorado Geological Survey continues to conduct ground-breaking research and churn out award-winning products courtesy of a dedicated staff whose excellence has not been dimmed by perennial budget challenges. During the second half of 2009, CGS scientists won national recognition for their work from the American Association of Petroleum Geologists, the Geothermal Research Council, the Geological Society of America, and the Association of American State Geologists.

At the start of the 2009 legislative session, Gov. Ritter asked all state agencies to reduce their spending by 10 percent. To meet this goal, every member of our agency participated in a top-to-bottom review of expenses to determine how we could reduce our budget without impacting staff. Through a mix of cost-containment and attrition, we have been able to meet the Governor's target.

This is the second time in 10 years CGS has had to change the way we



CGS Director and State Geologist Vince Matthews welcomes all to Colorado's geology.

do business to adapt to fiscal reality. And that reality is we have been flat-funded for the past 10 years. Despite the constant pressure to do more with less, CGS continues to produce on a daily basis because we have been able to reprioritize our workload to get things done.

Our geologic mapping program, unfortunately, has become a casualty in this process. Where CGS would normally produce seven geologic maps, in 2010 we will produce only four.

Looking to the future, we continue to work on a variety of important

issues facing the citizens of Colorado: groundwater, carbon sequestration, geologic hazards, avalanche safety, and energy & mineral resources.

As this edition of *RockTalk* goes to print, we want to welcome Mike King as DNR's new Executive Director. Mike was a strong supporter of CGS and its programs during his four years as Deputy Director and we look forward to working with him in his new role.

And I can say to him without equivocation it is my privilege to oversee the best state geological agency in the country.

Jim Martin, DNR Executive Director



From the start of the Ritter administration James Martin has been one of the Governor's most trusted advisors. As the Executive Director

of the Colorado Department of Public Health and Environment, Martin managed Colorado's diverse public health and environmental protection programs while serving as a member of the Governor's cabinet and on the Colorado Oil and Gas Conservation Commission.

In October 2009, Ritter tapped Jim to succeed Harris Sherman, who was named to a top Agriculture Department Post by the Obama administration.

As Executive Director of the Department of Natural Resources, Jim's responsibilities included Colorado's energy, water, wildlife, parks, and state lands programs.

Before joining the Ritter administration, Jim was the executive director of Western Resource Advocates, a Boulder-based environmental law and policy organization. In 2003, Jim accepted an appointment to the Colorado Air Quality Control Commission by Gov. Bill Owens.

Prior to that, Jim served as director of the Natural Resources Law Center at the University of Colorado School of Law. From 1986 to 1992, Jim worked for former U.S. Senator Tim Wirth, including four years as state director and counsel. He has also worked with Environmental Defense as a senior attorney and director of the group's energy program.

Jim earned his undergraduate degree in biology from Knox College in Illinois and his law degree from Northwestern School of Law, Lewis and Clark College, in Oregon.

As *RockTalk* went to publication, Jim found himself with a new challenge, as he was asked by the Obama administration to take the helm of the Environmental Protection Agency's Region 8 office. His time at DNR was short but memorable. Congrats Jim!

2008/2009 Highlights

Colorado Geological Survey's water science work addresses the interaction of geology with water. This encompasses investigations into groundwater resources, geologic controls on surface water and groundwater quality, environmental site assessments, and contaminant remediation. Much

of our recent work has focused on groundwater aquifers, which are often important sources of drinking water. Staff members involved in water science work include Peter Barkmann, Ralf Topper, Nick Watterson, and Erik Oerter. These geologists have been involved in numerous projects.



CGS hydrogeologist Peter Barkmann has been the key actor in the Denver Basin project, and instrumental in the Sand Wash Basin study as well as the oil shale oversight. Peter puts his expertise in the regional and structural geology of Colorado to use with other activities in the CGS.



CGS hydrogeologist Ralf Topper has applied his expertise to numerous projects dealing with groundwater in Colorado, including Arkansas River, the Black Squirrel and Lost Creek Basin projects and stormwater recharge.

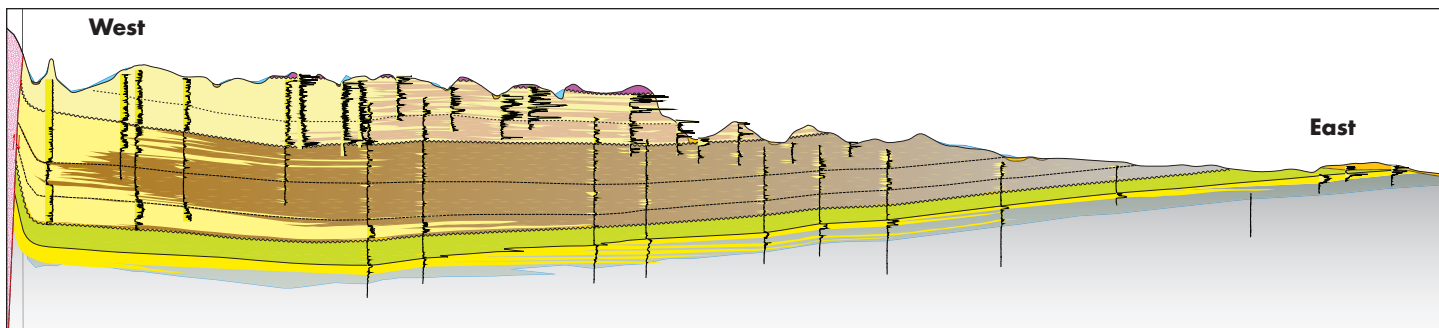


Erik Oerter provides expertise to the CGS in low-temperature geochemistry, geochemical modeling and environmental geology fields. Among his activities, Erik has worked the DRASTIC and Rico project, CDOT underground storage tanks, Lost Creek aquifer recharge and the Clear Creek recharge projects.



Nick Watterson, whose interest lies in groundwater hydrogeology, and fluvial geomorphology. Nick was key in the DRASTIC project, in the CGS's geothermal work, the BLM mineral assessment, and numerous other activities.





One of the east–west cross sections across the Denver Basin hydrologic province, extending east from Palmer Lake across northern El Paso County, illustrates heterogeneity in the Late Cretaceous to Early Tertiary sediments comprising the Denver Basin bedrock aquifers from one side of the basin to the other. Coarse-grained sandstone deposits, shown in shades of yellow, concentrate on the west side of the basin where they originated as large alluvial fan systems emerging from the rising Laramide Front Range to the west.

Denver Basin Cross-Sections

CGS hydrogeologists are in the final stages of preparing a series of 15 geologic cross-sections transecting the Denver Basin hydrologic province. This effort utilizes computer-based technology, up-to-date water well and petroleum industry well data, combined with surface geologic mapping to depict the three-dimensional relationships of the vital bedrock aquifers which supply water to hundreds of thousands of citizens along the Front Range Corridor. The product will help water-resource managers, planners, and individual landowners understand and visualize the variable distribution of the groundwater resource within this region.

In conjunction with this effort, the CGS is collaborating with the Denver Museum of Nature and Science to prepare a series of maps of the Denver Basin. This series will include a geologic compilation map, a variety of structural and isopach maps of the Upper Cretaceous through Eocene formations and paleogeographic maps. The product will be in both paper and digital format aimed at both the general public and technical audiences.

The Denver Basin bedrock aquifers lie in a broad asymmetrical structural basin of late Cretaceous to Early Tertiary sedimentary rocks, which extends from Greeley south to Colorado Springs and from Golden east to Limon. Conventional portrayals show the aquifers in a simplistic layer-cake view which suggests relative uniformity in aquifer quality across the region. The new cross-section clearly illustrate the lack of uniformity in the sediments, and hence the

aquifers, from one location to the other. Most notably, the preserved alluvial fan systems that comprise the Arapahoe, Denver, and Dawson Aquifers are thickest and best developed along the west edge of the basin and thin dramatically to the east as illustrated in the cross-section above. Because of this morphology, the best aquifer characteristics are found on the west side of the basin, fortuitously where the greater demand has historically developed. Recognizing the heterogeneity in the aquifers will help water planners maximize this critical resource as well as aid in educating the public about its limitations.

Sand Wash Basin Groundwater

In response to concerns raised by Moffat County and the Yampa/White/ Green River Basin Roundtable, the CGS is conducting an assessment of surface-water depletions and impacts to ground-water resources caused by the production of coalbed methane (CBM) in the Sand Wash Basin in northwest Colorado. This study follows on the heels of similar studies recently conducted in the Piceance, Raton and San Juan Basins that have demonstrated varying degrees of impact water resources by caused by development of a much needed energy resource. Production of CBM involves the pumping of ground water from coal seams in order to release methane gas bound in the coal structure. Pumping this ground water has the potential to deplete surface water and injure ground water users, thereby injuring existing water rights. This study aims to evaluate the magnitude of the potential depletive effects with the current and

anticipated future CBM production levels. The results of the study will provide the regulating community a background for better managing these basic resource activities. CGS hydrogeologists are developing the geological framework to be used in evaluating the depletive effects and analytical modeling may eventually be performed to assess impacts according to the geological framework.

Oil Shale Development Oversight Support

The CGS continues to monitor developments in the oil shale industry with reference to utilization of this potentially vast energy resource as well as the environmental impacts which may arise from its exploitation. CGS staff have been called in to participate in multi-agency reviews of specific oil shale pilot study permit applications as well as the U.S. Bureau of Land Management (BLM) Draft Programmatic Environmental Impact Statement on the development of oil shale and tar sands in Colorado, Utah, and Wyoming. CGS personnel also participate in quarterly BLM Oil Shale Research and Development Program Multi-Regulatory Agency meetings. These meetings are a forum convened to coordinate regulatory efforts by the many state and federal agencies that will have jurisdiction over various aspects of oil shale permitting and to keep all parties informed about current developments in the industry. State Geologist Vince Matthews represented Colorado on the review panel for the BLM's first round proposals and will represent the State for the second round proposals.

Technical Liaison Support to the *Water for the 21st Century* Process

CGS hydrogeologists support the *Water for the 21st Century* process as technical liaisons to the nine river basin roundtables. *Water for the 21st Century* is also known as the Interbasin Compact Committee forum and was established to convene the many stakeholders in the water user community to identify water needs and identify water supply options that will mutually benefit as many stakeholders as possible. CGS provides groundwater expertise to the individual basins, some of which have been almost exclusively dependent on surface water resources and have much to gain by understanding the vast potential of ground water resources that can complement their historic surface water supplies. The activity also allows CGS staff to familiarize itself with growing needs for hydrogeological investigations in regions away from the Front Range environment. Based on observations from the roundtable meetings, CGS staff formulate scopes of work and prepare grant applications to fund hydrogeological activities to benefit citizens within the basins as needed.

East River DRASTIC Project

CGS recently completed a groundwater resource evaluation for the East River watershed in the Grand Mesa–Uncompahgre–Gunnison National Forests. The East River watershed is in Gunnison County and encompasses the town of Crested Butte. The focus of the study was to evaluate the vulnerability of groundwater resources to surface contamination by applying the Environmental Protection Agency’s “DRASTIC” method. DRASTIC is an acronym for the seven hydrogeologic input parameters used in the approach: *Depth* to groundwater, net *Recharge* of groundwater, *Aquifer* media, *Soil* media, *Topography*, *Impact* of the vadose zone, and hydraulic *Conductivity* of the aquifer. DRASTIC is a Geographic Information Systems-based approach by which the user classifies and assigns ratings for each hydrogeologic parameter and weighs each parameter according to its importance with regard to the pollution potential of groundwater. The results of the study will be useful for Forest Service and other land managers in understanding potential impacts to groundwater resources when making land use decisions.

Geothermometry of Rico Area Warm Springs

Recent work by the CGS to assess the statewide heat flow and geothermal gradient present in Colorado (Map Series 45 and 46) indicates that there is an area of high heat flow and high geothermal gradient centered around the town of Rico in southwest Colorado. In the Rico area there are several hot springs and wells that are surface expressions of geothermal heat at some depth. In order to evaluate the temperature of the geothermal heat source at depth, a variety of geothermometry methods were used to examine water chemistry data from these springs.



Warm spring north of the Town of Rico along the Dolores River. The colorful deposits around the spring pool are formed when dissolved minerals in the water precipitate out of solution over time.

Aquifer Studies in the Arkansas River Basin—A Digital, Geographic Bibliography

In November 2007, the CGS published Information Series 74 as a digital and geo-referenced bibliography of publicly available studies and data related to the alluvial aquifer system of the lower Arkansas River mainstem below Pueblo Reservoir in Colorado. The spatial bibliographic database was created within a GIS platform providing an “interactive” digital product that can be used by ground-water professionals, water managers, and the public for researching information related to the alluvial ground-water resources of the lower Arkansas River basin.

The Colorado Water Conservation Board recognized the utility of the work and requested and funded the Colorado Geological Survey to expand the focus area to include the entire Arkansas River basin watershed and compile references for both the alluvial and bedrock aquifers. A review and understanding of the available literature provides a foundational basis for a future decision support system in the Arkansas River basin. As with the previous study, the study areas and content for the bibliographic database were geo-referenced within a GIS platform to provide a searchable mapping tool. This tool allows the end-user to identify studies and data by geographic reference and specific content for either the alluvial aquifers, bedrock aquifers, or both. The content includes aquifer configuration, aquifer hydraulic properties, water level data, or water quality information. This new work product includes 334 citations and is inclusive of all the citations and information contained in IS-74.



Upper Black Squirrel Creek Basin—Aquifer Recharge and Storage Evaluation

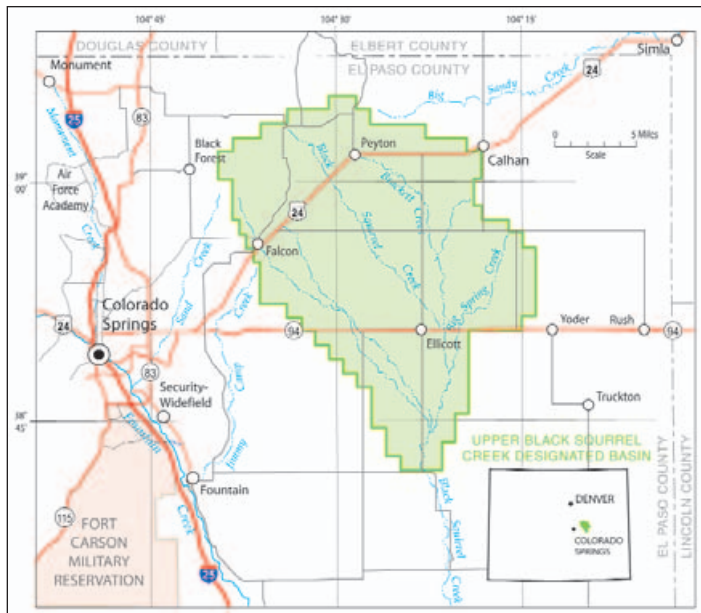
In June 2007, the CGS initiated a project for the El Paso County Water Authority to evaluate and refine the existing knowledge of the hydrogeology of the alluvial aquifer system in the Upper Black Squirrel Creek basin for the purpose of assessing the potential for aquifer recharge and storage implementation.

The study area encompasses the entire Upper Black Squirrel Creek drainage in east-central El Paso County and coincides with the designated groundwater basin boundary of approximately 350 square miles. All the streams in the basin are ephemeral and flow only in direct response to thunderstorms, spring snowmelt, or prolonged periods of rainfall. Groundwater from the alluvial aquifer has been the dominant water source since the late 1800s for domestic, agricultural and municipal uses. This study integrates new field data with information from previous studies and cooperating partners. The analysis and display of data collected or acquired for this study was accomplished through application of GIS software. The results and findings of this study were conveyed through production of a series of map plates and a final report, dated December 2008, which is available for download in pdf (<http://ibcc.state.co.us/Basins/Arkansas/WaterActivitiesWaterSupplyReserveAccount/>).

Our work produced a new geologic map of the basin, a bedrock structure map, and defined the geometry and thickness of the alluvial deposits. GIS analysis was used to quantify the available storage capacity in the alluvium. Up to 200,000 acre-feet of additional storage capacity in the unsaturated portion of the alluvial aquifer was identified. Land use, land ownership and proximity to existing infrastructure were evaluated and displayed with the available storage areas to demonstrate that water conveyance infrastructure currently exists and more is proposed that could be used to convey water to the potential recharge areas identified in this study.

Funding for this project was made available through two grants, a Severance Tax Trust Fund grant from the CWCB and a Water Supply Reserve Account grant sponsored by the Arkansas River Basin Roundtable. Individual project cooperators including: Cherokee Metro District, Colorado Springs Utilities, Meridian Ranch Metro District, Paintbrush Hills Metro District, Sunset Metro District, Upper Black Squirrel Creek Ground Water Management District, and Woodmen Hills Metro District provided the balance of the project funding.

The information provided in this report significantly enhances our knowledge of the hydrogeology of the Upper Black Squirrel Creek basin, establishes a framework of the aquifer's physical characteristics, and provides specific locations for future implementation of aquifer recharge/storage projects.



Location of the Upper Black Squirrel Creek Designated Ground Water Basin and Study Area.



Photo of Upper Black Squirrel Creek in the center of the basin a few miles north of Ellicott. All the streams in the basin are ephemeral, with dry sandy streambeds, and flow only in direct response to thunderstorms, spring snowmelt, or prolonged periods of rainfall.

Managing Stormwater in Mountainous Regions of Colorado

CGS worked with Clear Creek County to produce a manual (July 2009) to introduce, educate, and provide general guidance for implementing green stormwater management practices at the watershed, community, and individual lot level. Funding for this project was provided through a CWCB Severance Tax grant awarded to the county. While the manual was developed for Clear Creek County, the concepts, guidelines, and best management practices are applicable throughout the mountain regions of Colorado and surrounding states. It is designed to assist planners, developers, architects, landscape professionals, city and county community development

and public works staff, and the public with the selection and design of practices and techniques that facilitate runoff reduction and infiltration. The manual focuses on use of land use planning tools, engineering design and construction techniques that help maintain predevelopment hydrology instead of emphasizing techniques that drain precipitation from the watershed. Maintaining an area's predevelopment hydrology is particularly important to those rural mountain communities in Colorado which rely predominantly on groundwater for their water supplies. Stormwater infiltration and absorption techniques provide a way to maintain predevelopment hydrology and reduce the loss of water resources from the local watershed that occurs with land development and disturbance.

This manual discusses the water resource impacts of development, the regulatory environment, and both structural and nonstructural controls and best management practices. The hydrogeology of Clear Creek County is presented as a separate chapter in the context of natural recharge. Summary fact sheets for filtration, infiltration, detention, and flow control best management practices are included as appendices. Users are referred to a wide range of publically available stormwater BMP design manuals for detailed engineering and application information. The project included development of outreach materials for residential, commercial, and roadway applications that the county has incorporated.



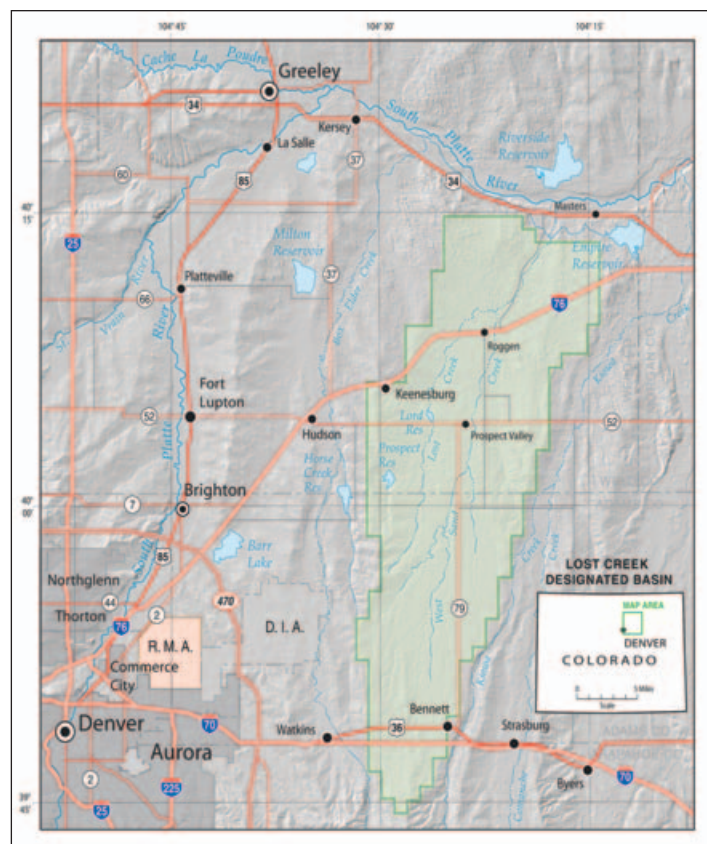
Subsurface infiltration techniques reduce runoff, erosion, and evaporative losses while maintaining predevelopment hydrology.

Lost Creek Basin—Aquifer Recharge and Storage Study

The CGS assisted the Lost Creek Groundwater Management District with a Water Supply Reserve Account grant for the Lost Creek Designated Ground Water Basin. The project involves collecting, compiling, and analyzing hydrologic, aquifer property and water quality data for the ground water resources in the alluvial aquifer. Geographic, infrastructure, and land ownership and use information will be analyzed to assess the potential for aquifer recharge and storage. The procedure includes the following steps:

1. Characterize the configuration and extent of the alluvial aquifer within the Lost Creek basin;
2. Compile and present current and historic ground-water levels and water level trends;
3. Characterize the amount of natural recharge and estimate the available storage capacity in the alluvial aquifer;
4. Determine hydraulic and storage properties of the alluvial aquifer;
5. Present the spatial relationship with the underlying Denver Basin bedrock aquifers;
6. Characterize the land use and ownership; and
7. Identify the existing water delivery infrastructure.

CGS initiated work on this project in June 2009 with anticipated completion in December 2010. The scope of work is tailored to identify select sites or sub-basin areas for potential pilot project implementation.



Location map of the Lost Creek Basin. The Basin is on the eastern plains, serving a predominantly agricultural area.



STATEMAP

The CGS received the nation's fourth-largest geologic-mapping award in 2008 from the STATEMAP grant program. This grant is supported by the National Cooperative Geologic Mapping Program through USGS. In 2008, the CGS mapped seven 1:24,000-scale quadrangles in the state—Divide, Elizabeth, Fruita, Leadville South, Milner, Minturn, and North Delta.

The program is accomplished using in-house staff, consultants, field assistants, and volunteers. Permanent staff members mapping in the program include Dave Noe, Matt Morgan, and Jonathan White. Consultants during the 2008 season include Bob Kirkham, Karen Houck, Jonathan Funk, Jim McCalpin, Alan Busacca, Jay Temple, and Rick Livaccari. Field assistants and volunteers included David Mendel, Karri Sicard, John Hodge, Shelly Nelson, Mike Zawaski, Steve Keller, and Jeremy McCreary.



STATEMAP Project Manager Dr. David Noe maps in the badlands-like terrain in the Mancos shale in Delta County, locally known as “the ‘dobes.” David manages the STATEMAP program and was the key researcher in the Anton paleoseismic work. Dave is also an accomplished paleontologist.



Close-up of a coiled ammonite *Hopluscaphtes* sp found in an ironstone concretion in the Milner quadrangle. Some ammonite species are used as biostratigraphic markers; they indicate the age of the strata. This particular species was found in the lower part of the Lewis Shale and is Late Cretaceous in age.

In western Colorado, mapping of the **North Delta** and **Fruita** quadrangles involved subdividing the thick Mancos Shale into mappable subunits to aid in the evaluation of expansive bedrock and selenium hazards. In the **Milner** quadrangle, near Steamboat Springs, we mapped surficial deposits to evaluate gravel resources, as well as the outcrops of the coal-rich Mesaverde Group. Our mapping in the **Minturn** and **Leadville South** quadrangles in central Colorado focused on areas of complicated structure and stratigraphy, large landslides, and Pleistocene glacial and lacustrine deposits. In the **Divide** quadrangle, west of Colorado Springs, we mapped the Pikes Peak Granite and the Divide gravels. Mapping in the **Elizabeth** quadrangle extended our multi-year mapping effort along the Front Range urban corridor, with emphasis on the stratigraphy of the Dawson Group and Tertiary conglomeratic gravels.



Matt Morgan, mapper for the STATEMAP program, is our in-house expert on surficial geology, meteoritics, and seismic risk.



Hogbacks of the Mesaverde Group are characteristic of the Milner Quadrangle, mapped in the summer of 2008. Visible in this photo are deltaic sandstone cliffs of the Trout Creek Sandstone (middleground) and Twentymile Sandstone (background).

Paleoseismic Investigations

CGS concluded field investigations at a trenching site along a 95-mile long, 100-foot high escarpment that passes near the town of Anton in Washington County. Over 2,000 feet of trenches were dug and described at this site from 2004 through 2008 as part of a program to identify Quaternary (recent age) faults in eastern Colorado. The trenches, dug along a transect from the escarpment crest, down the slope and across a playa at the base, revealed unbroken Holocene to Pliocene strata with no evidence of fault rupture.

Results of the study will be submitted to the USGS National Earthquake Hazard Reduction Program. Evidence indicates that this feature formed during the past 20,000 years from simultaneous wind erosion and loess deposition. The results indicate there is no reason to elevate the earthquake hazard in this part of Colorado, which is the way we like to see these studies turn out.

The Anton trenches revealed a wealth of new information about the Colorado High plains during the ice ages. Numerous types of deposits are present, including sand dune, sand sheet, loess, playa, gully fill, and older braided stream deposits, as well as buried soil layers and erosion surfaces. One notable discovery is the identification of sand-filled wedges indicating permafrost conditions during three major glacial episodes. Such features are known from basins in Wyoming and locations further north, but this is the first evidence of widespread permafrost conditions on Colorado's plains. Other notable discoveries involve Paleo-Indian archaeology. Working with Dr. Steve Holen, Curator of Archaeology at the Denver Museum of Nature and Science, we found stone artifacts that may be of Clovis age—approximately 12,500 years ago (dated by carbon-14.) A camel limb bone was recovered (approximately 16,500 years old) that shows percussion and green-bone fracturing—possible evidence of pre-Clovis hunters. Unfortunately no other major bone fragments or tools were found, leaving this discovery an intriguing mystery.

Colorado Avalanche Information Center (CAIC)

The Colorado Avalanche Information Center continues to distinguish itself as the authority for timely, accurate avalanche information. CAIC is a program within the CGS that promotes avalanche safety through forecasting, education and research. The program provides current information on snow, weather and avalanche conditions for backcountry recreation and other avalanche safety operations including the Colorado Department of Transportation. During the 2008–2009 and 2009–2010 operating seasons the CAIC produced daily weather and avalanche products for ten backcountry zones and twenty seven portions of Colorado's state and federal highways. The Center also provided avalanche safety training to 10,000 people.

The CAIC operates eight offices with fifteen staff members. The main office is co-located with the National Weather Service's Boulder Weather Forecast Office. This

office provides weather forecasting for all of the CAIC's operations. Forecasters in the CAIC—Boulder office also produce backcountry avalanche forecasts for any backcountry zone not covered by one of the field offices. The CAIC works directly with CDOT on highway maintenance operations from offices in the Eisenhower Tunnel and the towns of Marble, Silverton, and Pagosa Springs. Field offices in Breckenridge, Aspen, and Telluride work on backcountry products. The forecaster in the Telluride office produces both backcountry products for the Northern San Juan zone and highway products for State Highway 145 over Lizard Head Pass. The CAIC also employs a statewide Avalanche Education Coordinator based in Crested Butte Colorado.

Led by Director Ethan Greene, the CAIC staff is comprised of both permanent and seasonal state workers. There is a very low turnover in the Center's seasonal staff. Two staff changes during the 2008–2009 and 2009–2010 included Simon Trautman joining in the fall of 2008 as a forecaster in the CAIC—Boulder office and Mark Gober working as a Avalanche Forecaster in the CAIC—Silverton office in the fall of 2009.



Mark Gober stands next to a pile of avalanche debris on US550 after a large cycle in February 2010.

CAIC Program Developments 2008–2010

The CAIC's products are available through the Center's Web site, email service, and seven phone hotlines. In addition the Center began providing daily information on avalanche conditions through ten Twitter accounts in the fall of 2009. This conduit for avalanche information proved quite popular with between ten and two hundred Followers for each of the ten backcountry zones during the 2009–2010 operating season. For the 2010–2011 we will use Twitter for information exchange.

The CAIC is the official repository of avalanche accident information within the United States. The Center houses and maintains avalanche accident information dating back to 1900. In order to maintain accident information during the operating season, the CAIC launched an online accident database in December of 2009. The platform contains three online





CAIC Director Dr. Ethan Greene provides leadership to the 15 professionals in the organization who provide a range of services to state agencies and citizens.

forms to allow recreationalists, residents and avalanche professionals to submit incident reports to the database. These forms cover minor avalanche involvements to investigations of fatal avalanche accidents. It also creates online reports and summaries of accidents and current statistics. The database was designed both as an archive and operational tool. It stores important information on accidents for future researchers and also alerts avalanche centers around the country whenever an accident is reported.

In the fall of 2006 the CAIC launched a new tiered scheme of avalanche safety products. Tier I includes an avalanche danger rating and a very simple message on how to approach avalanche terrain during the next 24 hours. Tier II contains a detailed weather forecast as well as an analysis of current snowpack and avalanche conditions. Tier III contains raw data that advanced users can apply to their specific avalanche problem. During the 2009–2010 we added features to both our Tier II and III products. In the Tier II product we added a Highlights section that contains a brief summary of current conditions and news items such as accidents both within Colorado and the United States. For the Tier III products, we added an online database and visualization of automated weather stations. The CAIC operates twelve high-elevation weather stations. The Center provides these data to the National

Oceanographic and Atmospheric Administration's Meteorological Assimilation and Ingest System (MADIS) program. MADIS then provides us with hourly data from approximately 600 automated weather stations that could be used for avalanche forecasting. Data from these stations are available through the CAIC's Web site. The CAIC also continues to make progress providing direct observations, in the form of reports and images, of snowpack conditions and avalanche occurrence.

As part of its mission to promote avalanche safety education, the CAIC continues to develop avalanche education programs. During the 2008–2009 and 2009–2010 operating seasons the CAIC began providing avalanche education programs within the Larimer, Summit, Eagle, San Miguel and San Juan county school systems. Our goal is that all public school students in Colorado will know the basics of avalanche safety before they graduate from high school.

The CAIC also began a Professional Development workshop series with the Colorado Mountain College and American Institute for Avalanche Research and Education (AIARE), a Crested Butte based non-profit organization. These workshops provide continuing educa-

tion and small group discussion for avalanche professionals on current topics that affect their industry. From the fall of 2008 through the spring of 2010 the CAIC sponsored two workshops on mountain weather forecasting and one on wet snow and avalanche hazard mitigation. The CAIC also continues to host the Colorado Snow and Avalanche Workshop (CSAW), which is a one-day workshop for avalanche professionals. There were 375 and 450 participants in CSAW08 and CSAW09 respectively.

The CAIC continues to work on national and international projects in the avalanche forecasting and education communities. In the fall of 2009, the second edition of *Snow, Weather, and Avalanches: Observation Guidelines for Avalanche Forecasting in the United States* was published by the American Avalanche Association. This manual is used throughout the United States by professional avalanche operations and describes how to observe and record snow and avalanche observations. It is also used by several colleges (including Colorado State University, University of Utah, Montana State University, University of Alaska, and Lake Tahoe Community College) as a textbook. Ethan Greene (CAIC Director) has served as editor of both the first and second editions.



CAIC forecasters John Snook and Scott Toepfer examine the site of an avalanche accident in January 2010 near Battle Mountain in Eagle County.

The new *International Classification for Season Snow on the Ground*, published by UNESCO, was one of several publications produced with participation from Colorado's CAIC.

In 2009 the United Nations Education, Scientific and Cultural Organization (UNESCO) published a revision of *The International Classification for Seasonal Snow on the Ground*. Ethan Greene served as a member of the committee that produced the revision.

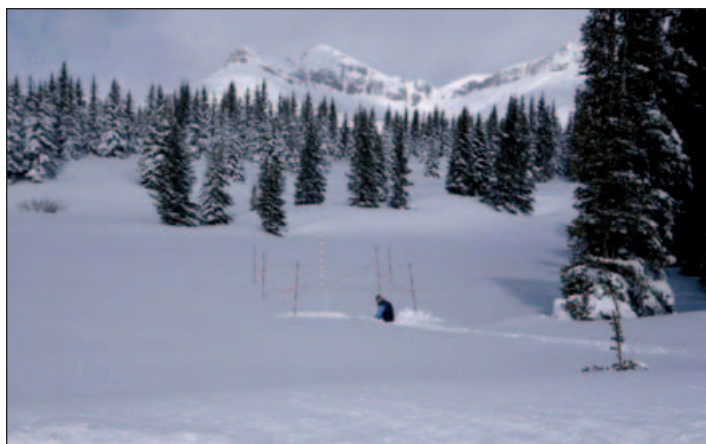


In the spring of 2010 a new North American Avalanche Danger Scale was released. This product will help backcountry users make better risk-decisions when entering avalanche terrain. The improved scale improves the clarity and utility of how avalanche danger and risk is communicated to the public. The project, led by Parks Canada with the participation of the Canadian Avalanche Centre, the National Search and Rescue Secretariat, United State Forest Service and the Colorado Avalanche Information Center, establishes a single North American standard for an avalanche warning system and provides the first international standard for the use of icons in avalanche warnings.

Snow Property Monitoring Activities

The CAIC manages a series of snow study sites to monitor snow properties where state or federal highways cross Colorado's mountain passes. Each day CAIC forecasters measure the depth of new and old snow layers as well as water content and other snowpack parameters. They use these data to track the evolution of the snowpack and estimate the stability in nearby avalanche start zones. Several sites are monitored by CDOT personnel. The following sites are visited daily by CAIC staff:

- Berthoud Pass
- Loveland West
- Loveland East
- Vail Pass Summit
- Vail Pass Narrows
- Lizard Head Pass
- Red Mountain Pass Summit
- Molas Pass
- Coal Bank Pass
- Wolf Creek Pass.



Susan Hale investigates the snow structure at the CAIC's study plot on Molas Pass.

Geologic Hazards

The geologic hazard mapping program of the greater Uncompahgre River corridor of Montrose County was completed in 2008. Project Manager Jon White presented the results of this mapping program to Montrose county commissioners and county staff on August 27, 2008. The report and accompanying hazard maps of landslides, rockfall, debris flow, collapsible soil, swelling soil, flooding, avalanche, earthquake and faults, corrosive soils, and salt precipitate and selenium impairment in Mancos Shale terrain. The publication will be available to the public as an open-file report in 2010.

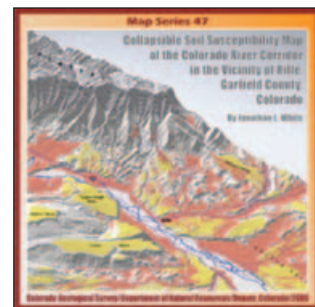
Engineering geology bulletin 14, *Collapsible Soils in Colorado*, by Jon White and Celia Greenman, was published in 2008 and is now available at the CGS publication desk. This comprehensive 108-page publication describes the geologic setting and geomorphic processes in the formation of collapse-prone soil, the occurrence of collapsible soil in the state, the engineering properties of collapsible soil, the published record, and mitigation and suggested level of investigation. Collapsible soil is a significant geologic hazard in Colorado that is responsible for settlement-related damage to structures in the semi-arid to arid terrains of Colorado. The report, including a statewide map plate, won a national award from the Association of State Geologists and the Geological Society of America.



Publication EG-14, *Collapsible Soils in Colorado* by White and Greenman is an award-winning contribution from the CGS discussing this common geologic hazard.

Jon White reported on the status of the statewide landslide inventory program at the 2008 GSA national meeting in Houston on November 5, 2008.

At the request of county officials, Chris Carroll investigated a large slope failure in Archuleta County in May, 2008. The East Fork landslide occurred in a remote area 12 miles from Pagosa Springs, along the East Fork of the San Juan River. The toe of the landslide impinges upon and constricts the flow of the river in a box canyon, creating a potential hazard to the area downstream from the slide and to a buried Xcel Energy natural gas pipeline. The landslide involves the reactivation of an area of historic slides. The CGS investigation initiated a series of monitoring efforts by the U.S. Forest Service, the U.S. Geological Survey and Archuleta County Office of Emergency Services. The landslide



Map Series 47, *Collapsible soil susceptibility map of the Colorado River corridor in the vicinity of Rifle, Garfield County, Colorado*, was completed by Jon White in 2008. This 2-plate map series is available from the CGS publication desk.



covers 350 acres, 650 feet wide and has moved several hundred feet downhill. Xcel will continue to monitor the slope landslide for additional movement.

On December 2, 2008 a large rock slide approximately 600 feet high and 1,200 feet wide closed the Pike View Quarry in Colorado Springs. The quarry is located in a geologically complex area on the Rampart Range fault zone in the Cascade Quadrangle that lies along the Front Range, where the geology was recently mapped by CGS geologists (Morgan and others, 2003). The Colorado Division of Reclamation, Mines, and Safety requested that CGS engineering geologists perform a forensic evaluation of the site and cause of the rockslide. Jon White and TC Wait investigated the rockslide and provided a technical report to DRMS on January 7, 2009.

Landslides, unstable soil, subsidence, and earthquakes are all geologic phenomena that can quickly turn into “disasters” when people and property are affected. To minimize the risk from geologic hazards, communities must plan and develop with those dangers in mind. The goal of Land Use Review Program is to create disaster-resistant communities by getting geologic hazards considered in all land use decisions.



CGS Landslide expert Jon White walks the walk at the Pikeview quarry. Jon works extensively with the CDOT in rockfall and slope stability issues and is a regular mapper in the STATEMAP program.



The Pikeview Quarry is located just north of Colorado Springs, and is easily visible from I-25. The landslide occurred in early December 2008, severely impacting the quarry's operation. Fortunately no injuries resulted from the event.

Land use planning

Land use planning is the process communities use to identify and permit appropriate and compatible uses for land within their jurisdictions. The Colorado Geological Survey (CGS) plays an important role in this process.

Cities, counties, and school districts across the state ask CGS to review hazard-related aspects of master plans, zoning, subdivision, school construction, and other land use decisions. Some reviews are required by state planning laws; while many local communities voluntarily ask for our assistance. Regardless of the type of review, CGS works cooperatively with citizens, development professionals, and local governments. Striving for an effective link between geologic hazard mitigation and land use, key objectives include:

Protecting Public and Private Investment

Most development heavily depends on the extension of public and private infrastructure. In geologic hazard areas, maintenance of facilities can be expensive. CGS tries to identify infrastructure which may require an excessive degree of main-

tenance and repair costs, and when possible, redirect development away from hazardous areas. This can be a powerful tool in redirecting development to more appropriate areas.

Protecting Public Safety

Communities must know about potential hazards before they plan for wise development. CGS evaluates each site for hazard vulnerability and how human activity impacts potential risks. A typical land use review includes a field investigation, a review of geologic, geotechnical, and engineering studies done for a proposed development, and a review of other studies and maps. For instance, survey scientists publish studies on geologic hazards across the state.

When potential hazards are identified, CGS evaluates how human life and property may be impacted. Typical recommendations might include requiring additional hazard studies as part of a proposed site plan or building permit. Such studies must show how to mitigate the potential hazard to an acceptable level and demonstrate the feasibility of mitigation. Proper upfront mitigation is nearly always more economic than after-the-fact damage repair.

Finding Compatible Land Uses

Where total avoidance of the risk is not an option, a land use reviewer may make recommendations to limit types or densities of development or both as a means of minimizing or reducing risk. For example, clustering homes on flatter slopes, away from landslide hazard areas, will reduce dangers to life and property, as well as reduce overall development costs. Grading, cutting, and filling, each of which entails some risk of undermining natural support, are reduced. Minimizing alteration of the land reduces the risk of erosion, landslides, and construction costs.

Geologic Hazard	Number of Development Sites
Swelling Soil or Bedrock	274
Flooding	100
Unstable Slopes	61
Landslides	44
Rockfall	40
Subsidence from Historic Mining	10
Avalanche	4

CGS developed plans and recommendations for mitigation of these hazards in the 2008–2009 period.



The Geological Hazards crew—(left to right) TC Wait, Jon White, Karen Berry and Jill Carlson. The staff handles land-use reviews, geologic hazard investigations, and other emergency response within the Survey.

Subsidence Center

The CGS staff operates the Mine Subsidence Information Center out of its main office at 1313 Sherman Street, Room 715, in Denver. The MSIC is a resource and reference library that contains historic coal mine maps, mine subsidence research studies and maps, technical reports and investigations, reference books, and a work space. Many of the maps are now available digitally, and a work station is available for viewing these maps.



A sinkhole caused by subsidence of an old coal mine east of Erie in 2009. The MSIC maintains a database to assist landowners and developers identify areas where subsidence could present a problem.

The operation of the MSIC primarily involves responding to requests for general subsidence information from the public. This includes assisting home owners, consultants, other agency groups, local governments and many other people who are interested in subsidence associated with historic coal mining in Colorado, and arranging for and providing copies of selected maps to requestors (who are charged for the cost of reproduction). The CGS staff also manages the reference library, adds reference material, organizes materials for efficient retrieval, maintains access and usage control of reference materials, and is in the process of having the materials converted to digital format. Official professional opinions on the type and risk of subsidence related to underground coal mines rendered for or on behalf of real estate development, sale, or transfer are beyond the scope of the grant.

During 2008–2010, additional Federal grant monies have enabled the MSIC to do outreach programs to local communities affected by mine subsidence, including hosting a workshop for planners, realtors, and local decision makers scheduled for March 31, 2010. CGS is also undertaking several GIS projects to better correlate areas where historic coal mining has occurred and areas where known subsidence events have been reported. These tools will help Colorado communities with land use decisions for proposed development in potentially undermined areas.

The MSIC is funded by a Federal grant from the Office of Surface Mining, passed through the Colorado Division of Reclamation Mining and Safety as part of its annual Abandoned Mine Land Grant. Its operating budget estimate reflects the actual costs of running the Center, plus CGS administrative costs, mandatory DNR—EDO indirect costs for grants, and leased space.



Coal

In 2008 the Colorado Oil and Gas Conservation Commission funded a study entitled "Fruitland Formation Coal Mapping in Archuleta County, Colorado." This funding provided for geologic mapping of the Pictured Cliffs Sandstone, Fruitland Formation, and Kirtland Shale along 23 miles of the San Juan Basin Rim in western Archuleta County. The Fruitland had never been mapped as a separate formation on any publication in this area before. In addition, coal bed outcrops were mapped along with coal cleat, fractures, distressed vegetation, clinker, and fault information. COGCC will display the map on their MapGuide web-based map server.

In 2009, Chris Carroll and Brenda Hannu concentrated on the CGS's cooperative agreement with the U.S. Geological Survey's National Coal Resource Data System (NCRDS) program. This national database is a compilation of stratigraphic code for all coal bearing intervals in the US. The CGS maintains the Colorado portion of this data system for the eight coal basins in our state. The CGS has compiled this data cooperatively with the USGS for 35 years, with cumulative annual grants totaling over \$852,000. The database contains information on coal bed occurrences with regard to depth, thickness, and coal quality.



Chris Carroll, CGS Coal Geologist, is the CGS expert on coal resources in Colorado. Chris is a skilled field geologist who has worked with the STATEMAP program and performed numerous field mapping activities.

Dr. Jim Burnell, CGS Minerals Geologist, is the CGS expert on mineral resources and the mineral industries in Colorado.

As new data becomes available, the CGS continually updates the NCRDS database using the 'real-time' login available at the CGS office. The CGS will continue correcting and supplementing stratigraphic data in the STRAT database, particularly in areas relevant to coalbed methane development in Colorado. Our emphasis in 2009 was to correlate subsurface coal beds in the Fruitland Formation in the San Juan Basin, with regard to our recent project in Archuleta County. The subsurface coal correlations to outcrop measured sections there will help determine which coal beds at the outcrop are being utilized for coalbed methane depletion, and the detection of gas seeps in the area. The goal is to make useful analytical and stratigraphic data available to coal and energy industries, government researchers and regulators, and the general public.

Oil and Gas

The CGS oil and gas program has as its primary goal the responsibility of monitoring petroleum industry activities within the State of Colorado and making that information available to all interested stakeholders. An updated summary report was prepared in the fall of 2008 for the *Colorado Business Economic Outlook for 2009* published by the Leeds School of Business at the University of Colorado at Boulder. CGS continued to work with COGCC in maintaining the *Oil and Gas Wells Map of Colorado* (CGS Map Series 44). This publication is routinely updated each quarter and during 2008, land ownership status was added to further increase its utility. CGS is also collaborating with COGCC to develop a new *Oil and Gas Fields Map of Colorado*, a publication that has not been updated since CGS Map Series 33 was released in 2002. When completed, the new fields map will be fully GIS-based to facilitate frequent, on-demand updating.



Minerals

Activities in the Colorado Geological Survey minerals program in 2008 covered the separate fields of metals, uranium and industrial minerals. A goal of the program is to retain and maintain familiarity with the active and historic mining operations of the State and to communicate that information to the citizens of the Colorado.

To that end, in 2008, Minerals Program personnel toured active operations at the Fairburn Mine (Gilpin County), the Henderson Mine and mill (Clear Creek and Grand Counties), Cripple Creek and Victor's Cresson Mine (Teller County), the Cash Mine (Boulder County), the site of a proposed uranium mill in the Paradox Valley of Montrose County and a visit underground at the Commodore #5 in Creede.

Jim Burnell represented the CGS at the Energy and Minerals Field Institute, operated by the Colorado School of Mines, visiting natural resource extraction and utilization facilities around the State where he provided commentary to the attendees about Colorado's geology and minerals industries.

The Minerals Program was active in disseminating information in 2008. The Mineral and Energy Resources annual report and the natural resources section of the annual Business and Economic Outlook Forecast of the University of Colorado were produced in 2008 within the State. The annual review of the Colorado

mining industry was provided to the journal "Mining Engineering" and to the U.S. Geological Survey's Commodities Information review. Jim Burnell, the Minerals Geologist, provided numerous talks around the State in 2008 on mineral resources necessary for alternative energy technologies, uranium deposits and mining in Colorado, molybdenum, and the Colorado mining industry in 2008.

BLM Mineral Potential Report

The CGS staff researched and wrote the *Mineral Potential Report* for the Grand Junction Field Office of the Bureau of Land Management. This report provides information on the mineral resources in the area, which includes Mesa, Garfield and a portion of Montrose Counties. It is a key component of that agency's planning process.

CO₂ Sequestration Project—Developing Protocols for Carbon Management

The Southwest Regional Partnership on Carbon Sequestration is one of seven partnerships established by the U.S. Department of Energy's National Energy Technology Laboratory (NETL) in 2003. These partnerships form a nationwide network to evaluate optimum strategies for minimizing greenhouse gas intensity via suitable carbon sequestration methods. The Southwest Partnership is led by the New Mexico Institute of Mining and Technology and comprises a large, diverse group of expert organizations and individuals specializing in carbon sequestration science and engineering, as well as public policy and outreach.

At the conclusion of a two-year regional characterization effort (Phase I, 2003–2005), the Southwest Partnership identified three specific sites where the technical feasibility of carbon storage in geologic environments could be evaluated. Each of these four-year pilot demonstrations are currently underway (Phase II, 2005–2009) and include injecting carbon dioxide (CO₂) into: (1) the Aneth oil field in the Paradox Basin of southeastern Utah, (2) a deep, unmineable coalbed at Pump Canyon near the Colorado–New Mexico state line in the northern San Juan Basin, and (3) an oil and gas field at the SACROC Unit in the Permian Basin of west Texas.

The Colorado Geological Survey participated in the Pump Canyon CO₂-Enhanced Coalbed Methane/Sequestration Demonstration, to evaluate the efficacy of using CO₂ to enhance coalbed methane recovery while also evaluating the suitability of coal seams for longer-term carbon storage. Successful demonstration results will be directly scalable to a large portion of the San Juan Basin for significant, low-cost CO₂ sequestration.

CO₂ Sequestration Project—New Study

The University of Utah and CGS were recipients of a DOE grant of \$3.8 million to study the potential for sequestering CO₂ in three strata in the Colorado Plateau. Other partners in the project are Tri-State Transmission and Generation, Shell Exploration and Production Company, Schlumberger

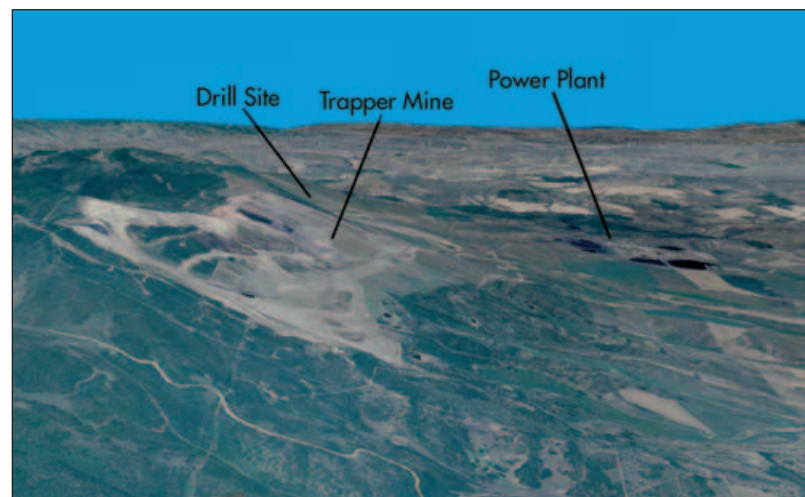
Carbon Services, Utah Geological Survey, Arizona Geological Survey, and New Mexico Bureau of Mining and Geology.

Since 2003, CGS has participated in the Southwest Partnership for Carbon Sequestration (SWP). In its regional capacity analyses for the Carbon Sequestration Atlas of the United States and Canada (NETL, 2009), the SWP identified the Cretaceous Dakota Sandstone, the Jurassic Entrada Sandstone, and the Pennsylvanian Weber Sandstone as three of the most promising geologic sequestration formations for the southwestern U.S. The primary goal of this project is to characterize these three promising carbon sequestration formations. The Dakota and Entrada formations are ubiquitous throughout the Colorado Plateau and Rocky Mountain region, and thus represent common sequestration candidates for most point sources in the region.

We will focus on rock core and geophysical data of these formations from all areas of the region. However, we will focus new data collection and model simulation analyses on a representative case-study area in northwest Colorado where we will drill and core an 8,500 foot deep well. Specifically, we will focus our analysis on the sequestration potential of these three, deep-saline formations within a large, Laramide-age structure south of the town of Craig. The proposed study includes detailed structural analysis of the large forced fold, as well as the characterization within the structure of the Dakota, Entrada, and Weber saline aquifers and their overlying seals.

The characterization project not only is important locally, but also has regional implications because the formations are widespread and because the structure is only 50 miles northeast of the heart of the Piceance Basin. Given the structure's size, it conceivably could serve as a regional sequestration sink for future power plants, natural gas processing plants, cement plants, and oil shale development.

The state geological surveys in the other three Colorado Plateau states will extend the information gleaned at the Craig site to their parts of the Plateau. The four-state region has emissions of more than 170 million tons of CO₂ per year from power plants and has an estimated 89 billion to 320 billion tons of storage capacity.



Location of the activities for new CO₂ Sequestration research.



Geothermal Energy

CGS has re-ignited its geothermal resources program over the past few years as alternative energy resources are being encouraged to meet the State's energy and environmental goals. This year marks a milestone in that CGS hired a full-time geothermal resources senior scientist. That person is Paul Morgan (see article below.) Paul brings a strong résumé to this post and will serve as the project manager on new geothermal investigations.

CGS is starting new grant-funded work with the Governors Energy Office to increase the knowledge and use of our geothermal resources (DOE Award DE-EE0000082). This work includes

- field data collection,
- geothermometric characterization of groundwater data,
- detailed geothermal gradient mapping of Colorado's warm sedimentary basins using oil and gas well bottom-hole temperatures,
- developing geologic models for Colorado-based geothermal resource occurrences, and
- providing a "roadmap" of state and federal regulations for prospective developers in Colorado.

We are also in contract negotiations with the Dept of Energy and the Arizona Geological Survey to capture past geothermal data for Colorado, convert it to digital format, and upload it to the newly created National Geothermal Data System. This data system will make geothermal data in Colorado web-accessible to citizens, industry, consultants, academia, government agencies, and all interested parties.

Colorado Geothermal Bibliography

This year's updated *Colorado Geothermal Bibliography* (Information Series 76) contains all known published and unpublished documents pertaining to the geothermal resources of Colorado. This publication supersedes our previous geothermal bibliography for Colorado (Bulletin 44, 1981) and contains 360 reference citations. The work was created in an effort to promote the exploration, development, and use of geothermal resources within Colorado. The document will assist

people in finding relevant geothermal resource information for Colorado. The complete bibliography is available on the geothermal page of the CGS Web site.

CGS Adds Geothermal Specialist

Paul Morgan—Will Work for Free Heat

Although all my formal education was in Great Britain, I learned all I ever needed to know in the US. There was nothing wrong with my formal education, but I was not ready to put the pieces together until later. I came to Southern Methodist University in Dallas in 1974 at the height of the first energy crisis as a freshly graduated Ph.D. in geophysics: I came from measuring temperatures in the Earth in Cyprus and Kenya to work as a post-doc under the number one expert in the field who immediately expected me to participate in finding geothermal energy in the western US. I couldn't even speak Texan! That number one expert, David Blackwell, is still very active and I still consider it an honor to work with him sometimes. And I still cannot speak Texan!

Before the first energy crisis, my goal was to start a career in mineral exploration, but I graduated at a time when mineral prices were low and the job market even lower. My interest was in combining the components of my first degree in Geology and Physics and being able to use geophysics to explore geology and understanding the physical processes of geology. The thermal studies of my doctoral studies were an ideal combination of these interests, and perfectly timed with studying emerging mechanisms of plate tectonics; to me, geothermal energy is the same combination, but at a shallower depth.

As the price of oil cycles up and down, interest in geothermal energy cycles down and up, but as heat makes the world go round, or at least the internal mechanisms, I have spent a career studying heat in all layers of the lithosphere, and even other planets. I have spent most of my career, over 25 years of the time, in universities in the US and Australia, and have had the pleasure of mentoring many students in geothermal and other studies. As of the beginning of 2010 I have measured heat on 5 of the 7 continents and 3 of the 8 (or 9) planets. I am



Geothermal specialist Dr. Paul Morgan is the newest addition to the staff. Paul is an internationally recognized geophysicist and expert in geothermal energy. He also actively participates with NASA agencies on planetary geology topics.

currently associated with a project to remeasure heat flow on the Moon, which will add to my planetary body count. I am learning to speak Moon. However, I am most excited that I am now back intellectually where I started in the US, working full-time studying geothermal resources. Colorado probably has a record of a millennium or more of use of its thermal springs by Native Americans, and more than a century of more conventional direct uses. I plan to see the first economic geothermal electricity generation in Colorado.



Matt Sares—Geothermal Program Head and Deputy Director of CGS

Behind the Scenes—Admin Staff

As with most state agencies this fiscal year, the Administration and Business Services section has been doing more with fewer resources. Nick Watterson (former GIS superman) filled a vacant hydrogeologist position in the Science Section. Dori Vigil (former accounting technician) transferred to a new position with the Colorado Water Conservation Board. These changes have required the remaining four staff members to expand their skill sets to keep CGS running smoothly.

Larry Scott, Graphics Designer, continues to create wonderful graphics for CGS publications and also assists with front desk coverage on an as-needed basis. Rachael Nickless, Publications Program Assistant, has learned the art of balancing family and work in the past two years with the addition of her son, Brayden, in 2008. Along with her regular duties, she has taken on the CAIC cash receipt and Friends database updates so that the CAIC supporters continue to receive valuable forecasts from the Avalanche Center.

Brenda Hannu, LUR Program Assistant and Director's Assistant, continues to provide first-level computer troubleshooting while keeping the LUR Program and the Division Director in line. In addition to this, she has taken on the additional work of payment processing for CGS. Her hard work has been very much appreciated by staff as the accounting tech vacancy has not caused any payment delays.

Pat Schindler, Admin Manager, continues to ride herd on the wonderful CGS staff, making sure they behave fiscally along with her normal purchasing, HR liaison, and other management duties. Pat picked up the monthly invoicing responsibilities along with the other accounting tasks that arise that aren't being handled by Brenda or Rachael.

All in all, the Admin section continues to perform an outstanding job at its current staffing level!



Rachael Nickless, Brenda Hannu, Larry Scott, and Pat Schindler are key components of CGS operation on the administrative and support staff. Rachael handles our publications, Brenda the IT function, Larry the graphics and Pat the budget and financial matters.

2008/09 Colorado Geological Survey Publications

The CGS released some landmark publications in the 2-year time period. The highlight is the 2nd edition of the award-winning *Messages in Stone*. This introduction to the rocks, geologic structure and geologic history of Colorado contains 125 new or improved pages and a new section on mountain building. This book is appropriate for geologists and non-geologists alike. The first edition was used as a text at a dozen institutions of higher education in the state.

The Tourist Guide to Colorado Geology is a foldable, waterproof, map-format guide to geologic features of the State, including maps of the geology, various geologic features and descriptions of geologic phenomena of Colorado.

Sixteen new geologic maps of 7.5 minute quadrangles were published in 2008/2009, representing work in four different areas of the state. Eight maps were updated and reissued from the Glenwood Springs area, for a total of 12 maps currently from that area of Garfield, Eagle and Pitkin Counties, mostly south of the Colorado River. Three more maps were published from the Uncompahgre River–Lower Gunnison area of Montrose and Delta Counties. One of the most thoroughly mapped areas is the Front Range corridor. Four new maps have been published from the corridor south of Denver, with recent work moving out onto the plains. Finally, a map from the Central Mountains added to the total of 16 down the core of the Rockies. These maps are all listed below and are available through the Colorado Geological Survey Office, as are all the publications.

Publications List

- Messages in Stone: Colorado's Colorful Geology*, Matthews, V. ed. 2nd edition.
- Tourist Guide to Colorado Geology*, Matthews, Vince.
- Geologic Map of the Shoshone Quadrangle, Garfield County, Colorado* by Kirkham, R., Streufert, R.K., and Cappa, J.A. MS-35
- Geologic Map of the Carbondale Quadrangle, Garfield County, Colorado* by Kirkham, R. and Widmann, B.L. MS-36.
- Geologic Map of the Cottonwood Pass Quadrangle, Garfield and Eagle Counties, Colorado* by Streufert, R.K.; Kirkham, R.; Widmann, B.L.; and Schroeder, T.J. II. MS-37.
- Geologic Map of the Glenwood Springs Quadrangle, Garfield County, Colorado* by Streufert, R.K.; Cappa, J.A.; Shaw, C.A., Allen, J.C.; and Schroeder, T.J. II. MS-38.
- Geologic Map of the Basalt Quadrangle, Garfield and Pitkin Counties, Colorado* by Streufert, R.K.; Widmann, B.L.; Kirkham, R.. MS-39
- Geologic Map of the Leon Quadrangle, Garfield and Eagle Counties, Colorado* by Kirkham, R.; Widmann, B.L.; and Streufert, R.K. MS-40.
- Geologic Map of the Mount Sopris Quadrangle, Garfield and Pitkin Counties, Colorado* by Streufert, R.K. MS-41
- Geologic Map of the Dotsero Quadrangle, Garfield and Eagle Counties, Colorado* by Streufert, R.K.; Kirkham, R.; Schroeder, T.J. II & Widmann, B.L. OF08-14.
- Geologic Map of the Hoovers Corner Quadrangle, Montrose County, Colorado* by White, J.L.; Williams, F.J.; Morgan, M.L.; and Townley, S.H. OF08-03.



Geologic Map of the Delta Quadrangle, Montrose County, Colorado by White, J.L.; Williams, F.J.; Morgan, M.L.; and Townley, S.H. OF08-03.

Geologic Map of the Montrose East Quadrangle, Montrose and Delta County, Colorado by Morgan, M.L. OF07-02

Geologic Map of the Elizabeth Quadrangle, Elbert County, Colorado by Morgan, M.L. OF09-03.

Geologic Map of the Ponderosa Park Quadrangle, Douglas and Elbert Counties, Colorado by Temple, J.; Madole, R., Keller, J.W. & Martin, D. OF07-04.

Geologic Map of the Mount Deception Quadrangle, Teller and El Paso Counties, Colorado by Temple, J.; Madole, R., Keller, J.W. & Martin, D. OF07-07.

Geologic Map of the Dakan Mountain Quadrangle, Douglas, Teller and El Paso Counties, Colorado by Temple, J.; Busacca, A., Mendel, D., and Sicard, K. OF08-16

Geologic Map of the Cameron Mountain Quadrangle, Chaffee, Park and Fremont Counties, Colorado by Wallace, C.A. and Lawson, A.D. OF08-12.

Collapsible Soils in Colorado by White, Jonathan and Greenman, Celia; EG-14.

Interpretive Geothermal Heat Flow Map of Colorado by Carroll, Chris; MS-45.

Geologic Map of the Montrose East Quadrangle, Montrose County, Colorado, by Morgan, Matthew; OF 07-02.

Lower Arkansas River Alluvial Aquifer: Geographic, Digital Bibliography, by Watterson, N.A. and Topper, R.; IS-74.

Collapsible Soil Susceptibility Map of the Colorado River Corridor in the Vicinity of Rifle, Garfield County, Colorado; White, J.L., MS-47.

Proceedings of the 43rd Forum on the Geology of Industrial Minerals by Cappa, J.A., RS-46.

Outside Publications by CGS Staff

CGS scientists published numerous contributions to their field in the 2008–2009 years, including presentations at scientific meetings (abstracts and poster sessions) listed below.

Burnell, James R., 2008, *Resource Constraints on Alternative Energy Development* (abst), American Institute of Professional Geologists Annual Meeting, September 2008, and at the 111th National Western Mining Conference and Exhibition also in 2008.

Burnell, James R., *The Colorado Mining Industry in 2007–2008* (abst), Northwest Mining Association Annual Meeting Proceedings.

Burnell, James R., 2008, *You Say Alternatives are the Answer ... Let's Talk—Resource Constraints on Alternative Energy Development*, *The Professional Geologist*, Mar/Apr 2009, pp. 34–38.

Carroll, C.J.; Gianniny, G.L.; Gonzales, D.; Skyles, E; Stetson-Lee, T; Lindblom, S.; Houck, K. 2009 (abst) : *Coal Bed Stratigraphy and Surface Mapping of the Fruitland Formation in Archuleta County, Colorado*; American Association of Petroleum Geologists Annual Conference.

Carroll, C.J., 2009, *The coal geology and mining resources of the Boulder–Weld coal field*, Rocky Mountain Association of Geologists (RMAG), *The Mountain Geologist*, v. 46, pp. 13–25.

Coulter, D.W., Hauff, P.L., Sares, M.A., Bird, D.A., Peters, D.C., and Henderson F.B. III, 2009, Chapter 10—*Hyper-spectral remote sensing of a mineralized system in the Grizzly Peak Caldera, Colorado: Implications for exploration and acid drainage baselines*, in Bedell, Richard and others, eds., *Remote Sensing and Spectral Geology, Reviews in Economic Geology*, v. 16: Littleton, Colorado, Society of Economic Geologists, p. 123–134.

Deardorff, J.; McCray, J. and Young, G., 2008, (poster) *The Carbon Sequestration Potential of Oil and Gas Fields in the Denver–Julesburg Basin of Colorado*; Colorado Oil and Gas Association Conference, Denver.

Deardorff, J., Nummedal, D., McCray, J. and Young, G., 2008, (poster) *A Methodology for Assessing the Carbon Sequestration Potential of Deep Saline Aquifers Beneath an Industrial CO₂ Source*; Colorado Oil and Gas Association, Denver.

Gianniny, G.L.; Skyles, E.; Stetson-Lee, T.; Carroll, C.J. ; Houck, K.: *Strike-Parallel Facies Heterogeneity and Base-Level Change in the Campanian Fruitland Formation Coal System, North Eastern San Juan Basin* (poster); American Association of Petroleum Geologists Annual Conference, 2009.

Greene, Ethan (editor), 2009, *Snow, Weather, and Avalanches: Observation Guidelines for Avalanche Forecasting in the United States*, American Avalanche Association.

Greene, Ethan (Committee Member), 2009: *The International Classification for Seasonal Snow on the Ground*; United Nations Education, Scientific and Cultural Organization.

Mahan, S.A., Noe, D.C., and McCalpin, J.P., 2009, *Use of OSL dating to establish the stratigraphic framework of Quaternary eolian sediments, Anton scarp upper trench,*

northeastern Colorado High Plains, USA: Quaternary International, v. 199, p. 92–103.

Morgan, M.L., Matthews, V., Gutiérrez, F., Thorson, J.P., Madole, R.F., and Hanson, P.R., 2007, *From buttes to bowls: Repeated relief inversion in the landscape of the Colorado Piedmont*, in Reynolds, R.G., ed., *Roaming the Rocky Mountains and Environs: Geological Field Trips: Geological Society of America Field Guide 10*.

Morgan, M.L., 2008, Review of the book *The History of Meteorites and Key Meteorite Collections—Fireballs, Falls, and Finds*: PALAIOS, <http://paleo.ku.edu/palaios/reviews/mccall.pdf>.

Morgan, Paul, 2009, *Geothermal energy on Mars*, in Badescu, V. (ed) *MARS: Prospective Energy and Material Resources*, Springer-Verlag, Ch. 11, pp 331–349.

Morgan, Paul, 2009, *A Preliminary Analysis of Geothermal Resources in the Central Raton Basin, Colorado, from Bottom-Hole Temperature Data*, *GRC Transactions*, Vol. 33, 509–513.

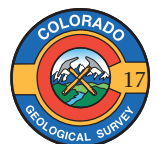
Morgan, Paul, 2009, *A Preliminary Analysis of Geothermal Resources in the Central Raton Basin, Colorado, from Bottom-Hole Temperature Data* (abstract): American Association of Petroleum Geologists, Annual Convention.

Morgan, Paul, Sares, Matt, and Dechesne, Marieke, 2009, *Stratigraphic Control of Temperatures in the Wattenberg Field, Denver Basin, Colorado*, (abs.): in Proceedings, AAPG 2009 Annual Convention and Exhibition, June 7–10, 2009 Denver, Colorado. http://www.searchanddiscovery.net/documents/2009/80066morgan/ndx_morgan.pdf

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Sessions Chaired

Matt Sares chaired sessions at the Oil Shale Symposium in Golden, CO, in both 2008 and 2009. At the AAPG Annual Meeting in Denver, 2009, **Matt Sares** was the session chairman of *Geothermal Energy Systems—Their Structure, Stratigraphy, and Rock Mechanics*.

Jim Burnell chaired several sessions at the AIPG annual meeting in Grand Junction in October, 2009.

Vince Matthews chaired a session at the 111th National Western Mining Conference and Exhibition, 2008.

Field Trips Led

Jim Burnell led a trip for the American Institute of Professional Geologists annual national meeting to Moffat County—Coal Mining and Reclamation in Northwest Colorado.

Vince Matthews led field trips for the Vail Symposium, the Rocky Mountain Association of Geologists, the joint AASG/USGS regional meeting and the Pueblo Nature and Raptor Center.

Matt Morgan led a field trip for Rocky Mountain Field Institute in Colorado Springs on surficial geology of the Manitou Springs quad.

Paul Morgan led a trip for *Geothermal features in the Chalk Creek Valley, Upper Arkansas Valley, CO*: Special field trip for staff of the BLM, DNR, and State Attorney's Office, January 14, 2009

Matt Morgan and Jon White led a field trip (w/ J. White) for UC-Colo. Springs on the geologic hazards of the Colorado Springs area. Worked at the Dinosaur Discovery Day 2008

Dave Noe co-led an "On the Rocks" field trip in northwestern Colorado for Rocky Mountain Association of Geologists in July 2009. The trip included an underground tour of the Twen-

tymile Coal Mine (led by Rocky Thompson, Peabody Coal), followed by stops at outcrops of Mesaverde rocks that were mapped by CGS under the STATEMAP program.

Dave Noe led a one-day field trip for a geomorphology class from Mesa State College in August 2009.

TC Wait led a field trip for Missouri university students viewing geologic hazards along the Front Range in May 08.

Jon White led a field trip to the DeBeque Canyon landslide for registrants of the AIPG national conference in Grand Junction in 2009.

HONORS and AWARDS

Paul Morgan received the GRC Best Poster Award "In recognition of quality of content and presentation at the poster session" at the 2009 Geothermal Resources Council Annual Meeting in Reno Nevada, October 24–27, 2009. The title of the poster was *A Preliminary Analysis of Geothermal Resources in the Central Raton Basin, Colorado, from Bottom-Hole Temperature Data*.

From the same meeting, CGS's **Matt Sares** received the GRC Best Presentation award, in recognition of quality of content and presentation at the Resource Assessment Session for his talk *Statewide Geothermal Resource Mapping in Colorado*.

Matt Sares won the AAPG-EMD President's Certificate for Excellence in Presentation Award at the AAPG Annual Convention and Exhibition in Denver for the presentation *Geothermal Resources of Colorado and the Potential for Electrical Power Generation*.

Jonathan White, and former CGS employee Celia Greenman, received the John C. Frye Memorial Award at the 2009 Geological Society of America meeting for their publication *Collapsible Soils in Colorado*. The Frye award is presented by the American Association of State Geologists (AASG) for a publication in the field of environmental geology.

The John C. Frye Memorial Award is given each year to a nominated environmental geology publication released in one of the three preceding calendar years, either by GSA or by a state geological survey. From the award presentation, "The nominated publications identify a geologically based environmental issue, provide sound and substantive information pertinent to the problem, relate geology to the issue, and present information directly usable by geologists, other professionals such as land-use planners and engineers, and ideally also by informed laypersons. The selection committee assesses uniqueness, significance as a model, and overall worthiness."



Celia Greenman and Jon White receiving the Frye Award from David Wunsch, President of AASG.



This is the 2nd Frye Award in four years for the Colorado Geological Survey.

Jim Burnell was named the winner of the Service to Geology award from the Colorado Section of the American Institute of Professional Geologists at the annual December banquet.

Service to the Profession and the Community

Peter Barkmann served as member American Society of Civil Engineering (ASCE) Managed Recharge Standards Committee.

Jim Burnell is on the Executive Board of the Colorado Section, American Institute of Professional Geologists (AIPG) and serves as a Councilor for the Colorado Scientific Society. Jim served as Field Trip Coordinator for the AIPG national meeting in Grand Junction.

Jill Carlson is serving as Web site Editor and Treasurer of the Rocky Mountain Section of Association of Engineering Geologists (AEG).

Chris Carroll was President of the Friends of Dinosaur Ridge and Board Member and on the Denver Coal Club Board of Directors.

Vince Matthews serves as Chair of the Natural Resources Committee for the *Business and Economic Outlook Forum* of the University of Colorado's Leeds School of Business. **Jim Burnell** also serves on that committee.

Vince Matthews also served on the Executive Committees of the Western States Seismic Policy Council and the Association of American State Geologists; the Geologic Advisory Committee at Colorado State University; the National Steering Committee of the Advanced National Seismic System (ANSS) of the U.S. Geological Survey.

Matt Morgan served as President of the Colorado Scientific Society and Secretary of the Colorado Earthquake Hazards Mitigation Council.

Erik Oerter serves on the Advisory Board for the University of Colorado-Boulder Department of Geological Sciences and the Database Manager for the Colorado Scientific Society.

Matt Sares served on the Oil Shale Symposium Organizing Committee (Colorado School of Mines) in both 2008 and 2009; the 2008 Remediation of Abandoned Mine Lands Conference Organizing Committee for the National Ground Water Association, and serves on the Colorado Inactive Mine Reclamation Program Advisory Committee.

Ralf Topper served the Colorado Ground-Water Association as President, Legislative Committee Chairman is a member of the South Platte Decision Support System technical review committee and was Advisory Council member for the National Ground-Water Association's Mine Waste Conference, Sept 2008.

TC Wait is a participating member of the Colorado Flood Task Force.

Genevieve Young started a 2-year term as Rocky Mountain Councilor of the Energy Minerals Division of the American Association of Petroleum Geologists. She was also elected as 1st Vice President of the Rocky Mountain Association of Geologists.

Meetings Hosted

In 2008, **Matt Sares** hosted meetings on groundwater depletion in January 2008: Raton Basin Coalbed Methane Groundwater Depletion Study Public Meeting, Trinidad; Piceance Basin Coalbed Methane Groundwater Depletion Study Public Meeting, Rifle.

Outreach CGS Booth

CGS provided a booth for outreach at numerous events during 2008.

- Encana Energy Expo in Rifle.
- National Science Teachers Conference.
- Colorado Oil and Gas Association annual meeting.
- Colorado Oil and Gas Prospect Fair.
- Denver Gem and Mineral Show.
- Geological Society of America Annual Meeting.
- Colorado Mining Association Annual Meeting.
- San Miguel County Energy Fair in Norwood.
- In 2009, the events attended were as follows:
- Society of Mining Engineering Annual Meeting.
- Colorado Geothermal Working Group.
- American Association of Petroleum Geologists annual meeting.
- Denver Gem and Mineral Show.
- American Institute of Professional Geologists Annual Meeting.
- Colorado Oil and Gas Prospect Fair, Nov. 2009

CGS was a sponsor for "GEO-velopment," part of a biannual seminar series hosted by the American Association of Civil Engineers and the GEO Institute.

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Mike King, Executive Director

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Division Director

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THIS ISSUE

Editor: Jim Burnell

Production: R. Ciminelli

The CGS hosted a delegation of Malaysian scientists in the U.S. to learn about how to form programs addressing geologic hazards, from both scientific and emergency management perspectives. TC Wait presented information on our identification of the most significant or "critical" landslides affecting infrastructure and population centers. She also explained how we are currently inventorying all identified landslide terrain in the state and capturing these in a digital GIS framework.

CGS scientists hosted a delegation from South Korea seeking information on how Colorado manages development of aggregate mining in a mountainous environment near urban centers. Talks were provided by Matt Sares, Matt Morgan and Jim Burnell of CGS, along with Bill Langer, aggregate expert from the U.S. Geological Survey and Tony Waldron of the Colorado Division of Reclamation, Mining and Safety. A field trip was provided the delegation to several aggregate facilities in Jefferson County.

Talks

CGS scientists spent a lot of time on the dais in the 2008–2009 time period, presenting talks to Colorado citizens and organizations. **Vince Matthews**, our State Geologist, has given his talk on resource competition from China and India to more than 20,000 Coloradans over the

(See *Talks* on page 20)





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(Talks from page 19)

last several years, as well as the keynote presentation at a number of professional organizations. He has also given numerous presentations on "Colorado's Colorful Geology" to a variety of audiences in the state.

TC Wait spoke about *Colorado's Landslides* and CGS's role to Malaysian delegates in June, presented case histories to advanced engineering geology students at the Colorado School of Mines (CSM), and made presentations to the CSM Student chapter of the Association of Engineering Geologists and the Chaffee County Optimist Club. **Matt Morgan** spoke at the Denver Mining Club on *Crash, Boom, Bang: A Look at Recent Meteorite Encounters with Humans; Non-Terminal Meteorite Impacts: The Case for Studying Small Cratering Events* to the Colorado Scientific Society, and *Geology of the Denver Basin* to the Boy Scouts of America.

Our hydrogeologists met the public in 2008 as **Peter Barkmann** presented a lecture at the AGWT Teachers' Institute in Ft. Collins in July on the *Geology of Ground Water Resources in Colorado*. **Ralf Topper** spoke to the El Paso County Water Authority on the *Upper Black Squirrel Creek project*, to the Lost Creek Ground Water Management District on *Aquifer Recharge and Storage*, and to the Colorado Water Workshop and the Colorado Ground-Water Association on *Coalbed Methane Produced Water*.

Geothermal energy was a hot topic in Colorado, and the CGS has ramped up emphasis on the issue. **Matt Sares** presented numerous talks on geothermal

resources and development to professional organizations along with **Paul Morgan**, including the American Association of Petroleum Geologists, the Colorado Geothermal Working Group in Salida, and a visiting energy mission from Iceland. **Matt** spoke on geothermal energy to a series of working groups, including Tri-County Group (Ouray, Montrose, and San Miguel Counties), Salida/Chaffee County, and Poncha Springs. Additional talks were delivered by our Deputy Director to the Colorado Scientific Society, Electric Utilities' Roles in Promoting Geothermal Technologies Workshop, Colorado Association of Geotechnical Engineers, Colorado Mountain College in Steamboat Springs, Sand Dunes National Park, the Chaffee County Sustainability Summit, Four Corners Geological Society, and the Delta Alternative Energy Expo.

Ethan Greene of the CAIC presented an invited talk at the fall meeting of the American Geophysical Union entitled *Three-Dimensional Reconstruction of Snow from Serial Surface Sections*. Another invited presentation by Dr Greene was *Avalanche Impacts* in a special session on *2008 Weather Impacts* at the American Meteorological Society annual meeting in 2008.

From the Mineral and Energy Resources area, **Chris Carroll** presented a talk entitled *Fruitland Coal Mapping in Archuleta County*, an update presentation to Colorado Oil and Gas Conservation Commission, Gas and Oil Regulatory Team (GORT) in Durango, La Plata County in Dec 2008 and at the Colorado Mining Association's Education Foundation "Total Concept in Mining" on CGS's mineral fuel publica-

tions. Chris also gave a presentation at the ESRI International User's Conference in San Diego, CA, entitled "Geologic Map and Coal Bed Stratigraphy of the Fruitland Formation, Archuleta Co"

In 2008, **Jim Burnell** delivered a talk on *Resource Constraints on Alternative Energy Development* to the American Institute of Professional Geologists, the Denver Coal Club, the Colorado Association of Conservation Districts annual meeting, the North Fork Coal Working Group, the Ouray Geology Society, the Colorado Scientific Society, the Denver Global Warming Study Group, and as part of the Energy and Minerals Field Institute of the Colorado School of Mines. In 2009, the evolving resources talk was presented to the American Institute of Chemical Engineers, the Northern Colorado Alternative Energy Society, the SE Denver Rotary Club, to Hazen Research in Golden, the Denver Bar Association Continuing Legal Education, the Rocky Mountain Association of Geologists, the NW Colorado Energy Producers Association, the Delta Energy Fair and in webinar format to the Western Business Roundtable. **Dr. Burnell** presented *Uranium in Colorado* at the American Institute of Professional Geologists, the Western Museum of Mining and Industry, the Friends of Mineralogy, the Petroleum Pioneers and at a break-out session of the Leeds School of Business annual Business and Economic Outlook Forum and talked on the *Colorado Mining Industry in 2007 and Critical and Strategic Minerals—Does Colorado Have a Role?* to the Denver Mining Club and as the Van Tuyl Lecturer at the Colorado School of Mines.