UTAH GEOLOGICAL SURVEY

SURVEY NOTES

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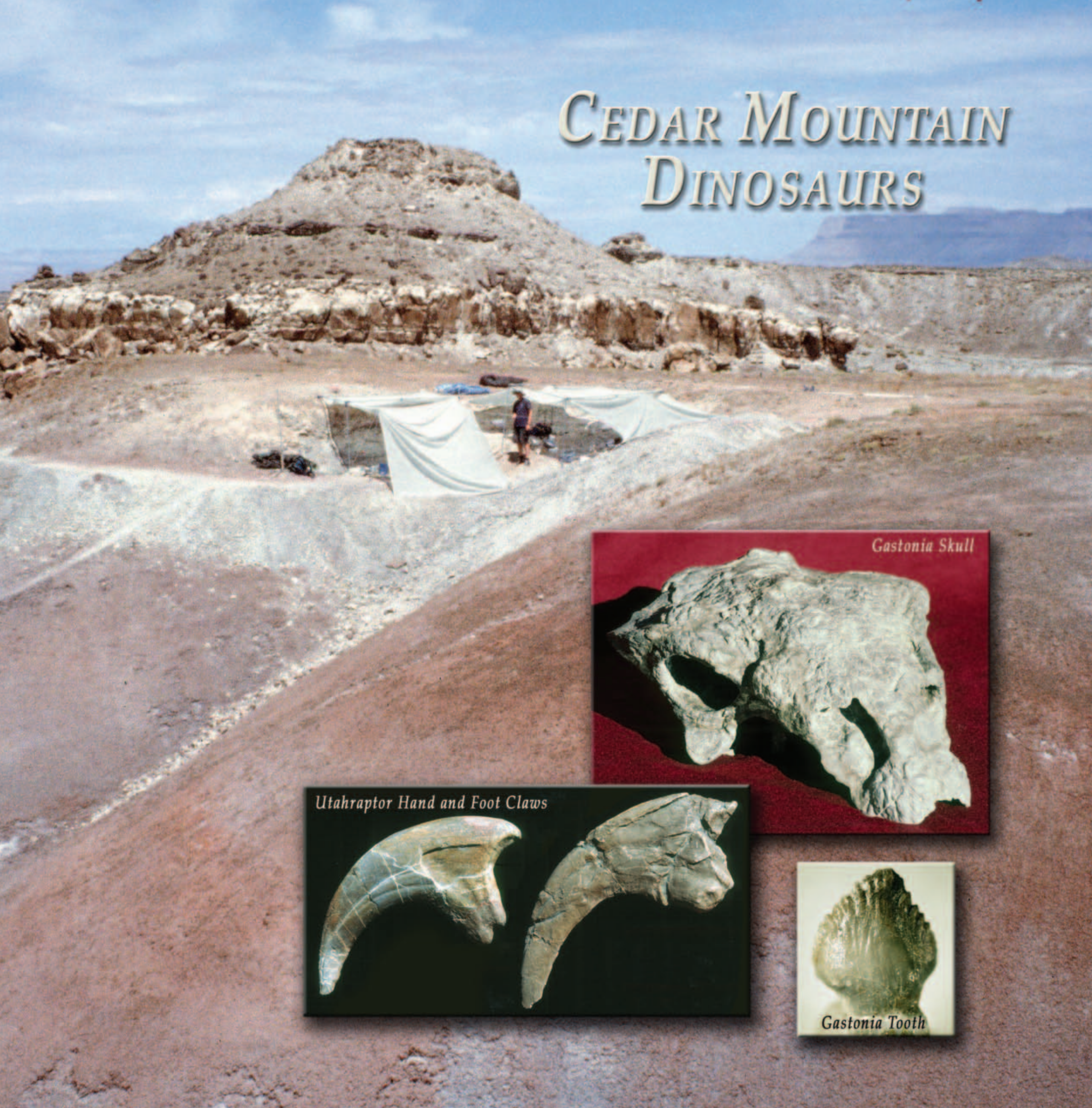
Cedar Mountain Dinosaurs



Gastonia Skull

Utahraptor Hand and Foot Claws

Gastonia Tooth

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Design by Vicky Clarke

Cover*: A new UGS dinosaur quarry at base of Cedar Mountain Formation (see page 1). Other captions, p. 5.*

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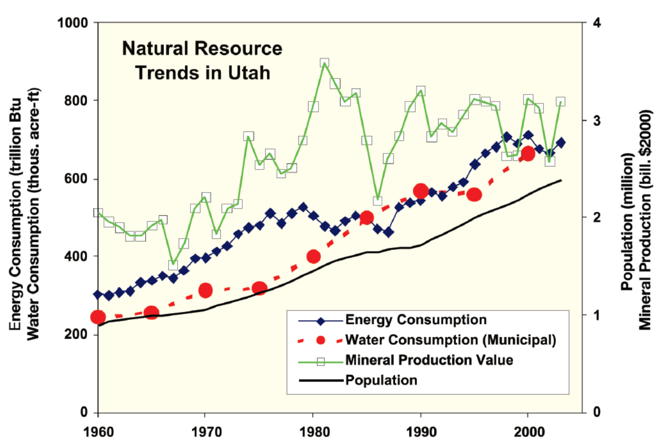
The Director's Perspective

by Richard G. Allis

The Utah Geological Survey (UGS) has just completed a five-year planning document to coincide with the transition to a new governor and executive administration. The document points out that the need for geological information and advice is becoming increasingly important due to Utah's ongoing economic and population growth, which are stressing its geologic resources (minerals, energy, ground water), increasing vulnerability to natural hazards, and increasing conflict over wise use of land. Examples of issues confronting Utahns over the next decade for which geological information from the UGS will be critical include the following:

- Utah has considerable energy and mineral wealth (annual production value of $3 billion) but there are increasing challenges to extracting that wealth in an acceptable and environmentally sustainable way.
- Utah's demand for electricity continues to grow, and will likely require new coal-fired power plant capacity.
- Natural gas has become Utah's most important energy commodity in recent years, replacing copper (1960s) and oil (1980s), but normal production decline rates in existing wells will require new exploration to sustain this trend through the 2000s.
- The continued growth in urban areas is filling available land on the valley floors and causing development in more hazardous areas along the mountain-front regions.
- Utah has been lucky that a very damaging earthquake has not yet occurred along the Wasatch Front in historical times; old, unreinforced masonry buildings vulnerable to collapse that were built until the 1970s are abundant in most downtown city areas.
- Utah is the second-driest state, and this is compounded by the ongoing drought; ground-water resources are finite, and in some areas of the state they may have been over-appropriated

Clearly the UGS has an important role to play in state government in the coming years.



Utah's use of its natural resources such as oil, gas, minerals, and ground water has grown as the population has grown. These trends are expected to continue, requiring additional geologic advice and information to help with challenging land-use decisions that balance development versus preservation needs. Mineral production value has been adjusted to year-2000 dollars.

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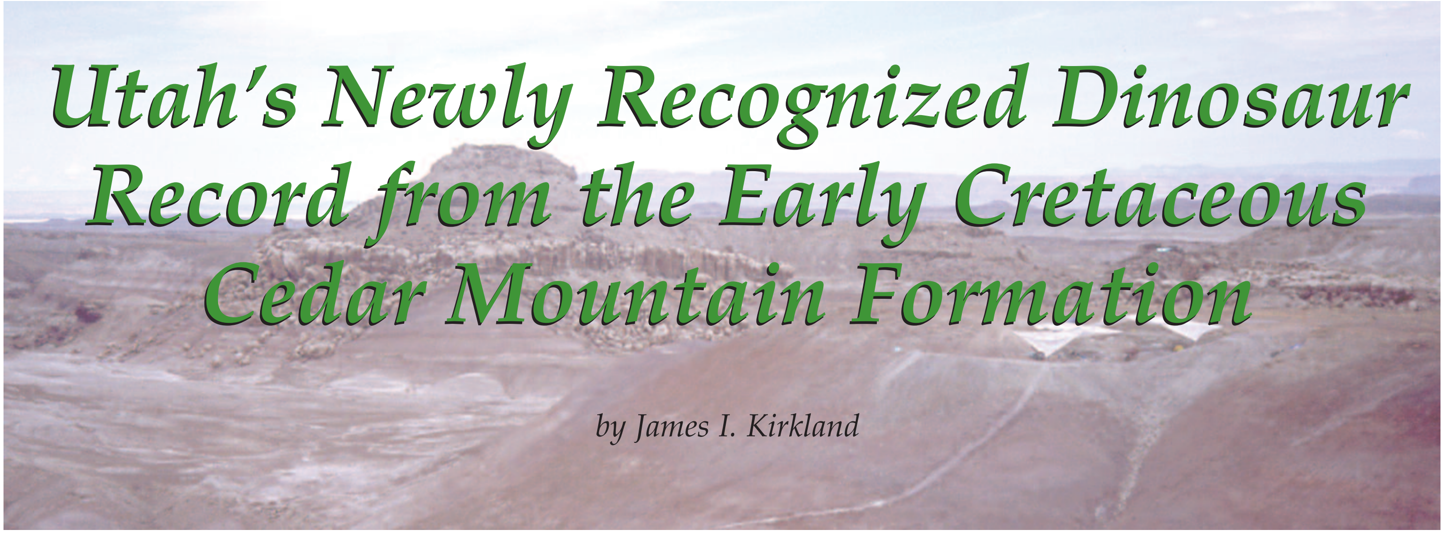


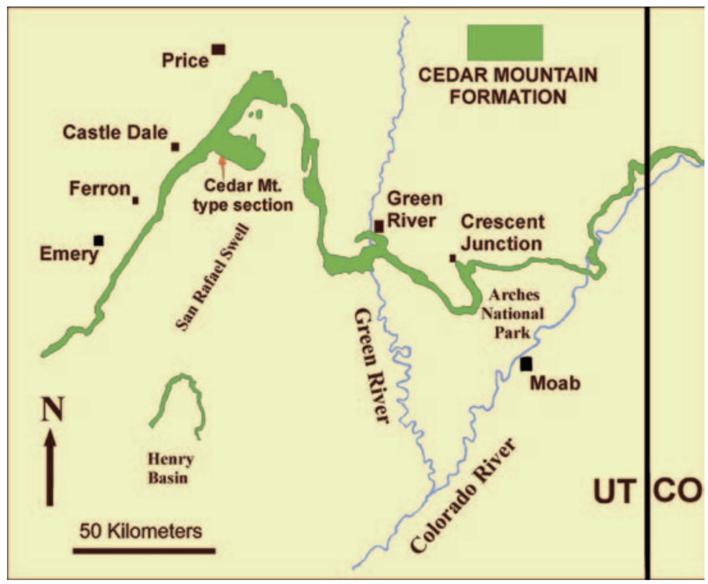
Utah's Newly Recognized Dinosaur Record from the Early Cretaceous Cedar Mountain Formation

by James I. Kirkland

Introduction

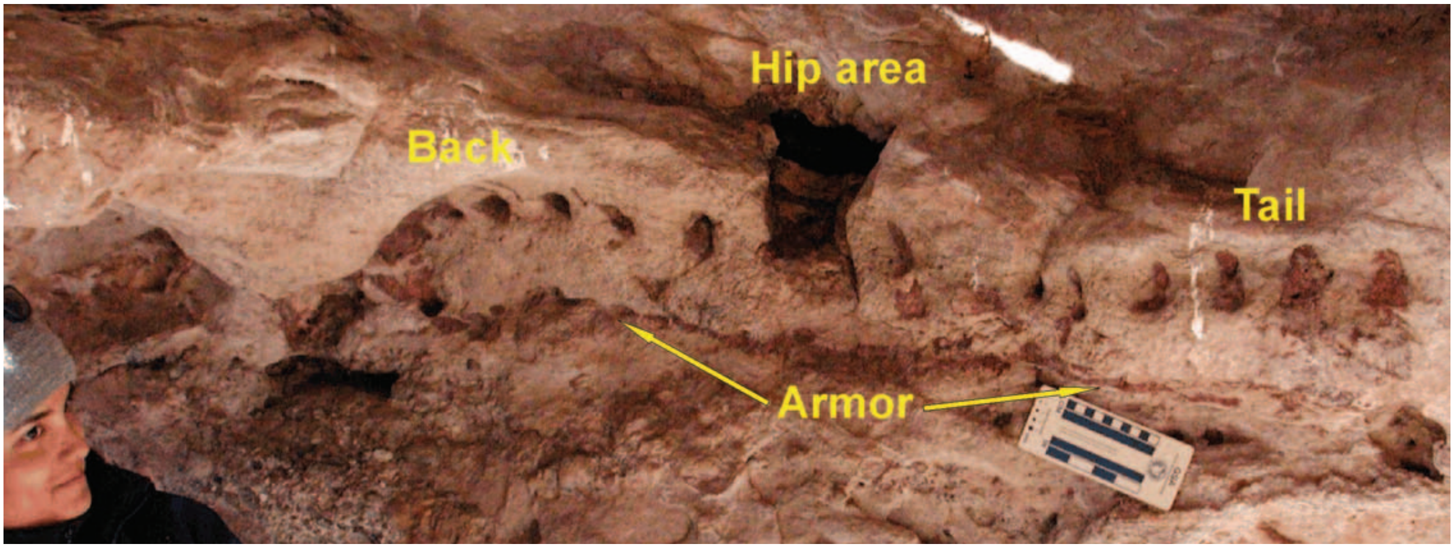
Many of Utah's sedimentary rock layers contain abundant fossils and other features that have given us a wealth of information about dinosaurs and the environmental conditions under which they lived. With sites such as the Carnegie Quarry at Dinosaur National Monument in northeastern Utah, and the Cleveland-Lloyd Quarry southwest of Price, Utah is justifiably famous for its dinosaurs from the Late Jurassic Morrison Formation. Likewise, Utah's Late Cretaceous dinosaur record is well known as the most complete in the world, owing to the extraordinary fossil record preserved in southern Utah. However, rocks from the Early Cretaceous period had until recently yielded little information about the dinosaurs that lived here during that time. Only over the past decade have new discoveries revealed the importance of dinosaurs preserved in Utah's Early Cretaceous Cedar Mountain Formation. This recently recognized dinosaur record permits for the first time a detailed reconstruction of Utah's Early Cretaceous geology, biology, geography, and climate.

In 1944 the University of Utah's William Lee Stokes applied the name Cedar Mountain Shale to drab, slope-forming rocks lying between the Buckhorn Conglomerate and Dakota Formation, based on a type-section defined on the southwest flank of Cedar Mountain at the north end of the San Rafael Swell in Emery Co., Utah. In 1952, he renamed it the Cedar Mountain Formation and included the Buckhorn Conglomerate as its basal member. Back then, where the cliff-forming Buckhorn is not present, the rule of thumb for distinguishing the Cedar Mountain from the underlying Morrison Formation included (1) its more drably variegated color, (2) its more abundant carbonate nodules often with a thick carbonate paleosol (ancient soil) at the base, (3) the presence of common polished chert pebbles identified as gastroliths (dinosaur stomach stones), and (4) the absence of dinosaur bones.



Outcrop of Cedar Mountain Formation in east-central Utah.

The reported absence of dinosaur bones in the Cedar Mountain Formation limited the number of paleontologists investigating these rocks for many years. Because geologists lacked any accepted means of subdividing these rocks, they were long considered to be a rather monotonous sequence of Early Cretaceous strata that generally thicken to the west. Then, new dinosaur species reported in the mid-1990s led to a rush of institutions searching for the dinosaurs in the Cedar Mountain Formation. Brigham Young University, College of Eastern Utah Prehistoric Museum, Denver Museum of Nature and Science, Dinosaur National Monument, Oklahoma Museum of Natural History, and the Utah Geological Survey are just some of the many research groups presently looking for fossils. A wealth of new fossil sites, and some radiometric dates, have established that the relatively thin layer (normally less than 100 meters) of Early Cretaceous Cedar Mountain Formation, which separates thousands of



Ankylosaur preserved lying on its back in Buckhorn Conglomerate near Buckhorn Wash, near Cedar Mountain type section southwest of Cedar Mountain.

meters of Jurassic rocks and thousands of meters of Late Cretaceous rocks, is more complex than previously thought. Additionally, it preserves nearly 30 million years of what may be the most interesting episode of dinosaur history apart from their origin and extinction.

In 1997, using the distribution of specific dinosaur faunas (groups of dinosaurs living together) and their relationship to distinct rock types, I defined four additional members of the Cedar Mountain Formation. In ascending order, these are the Yellow Cat Member, Poison Strip Sandstone, Ruby Ranch Member, and Mussentuchit Member. Together with the Buckhorn Conglomerate, these rock units and the fossils they contain are shedding light on the previously obscure Early Cretaceous history of Utah.

Stratigraphy and Dinosaurs of the Cedar Mountain Formation

Buckhorn Conglomerate

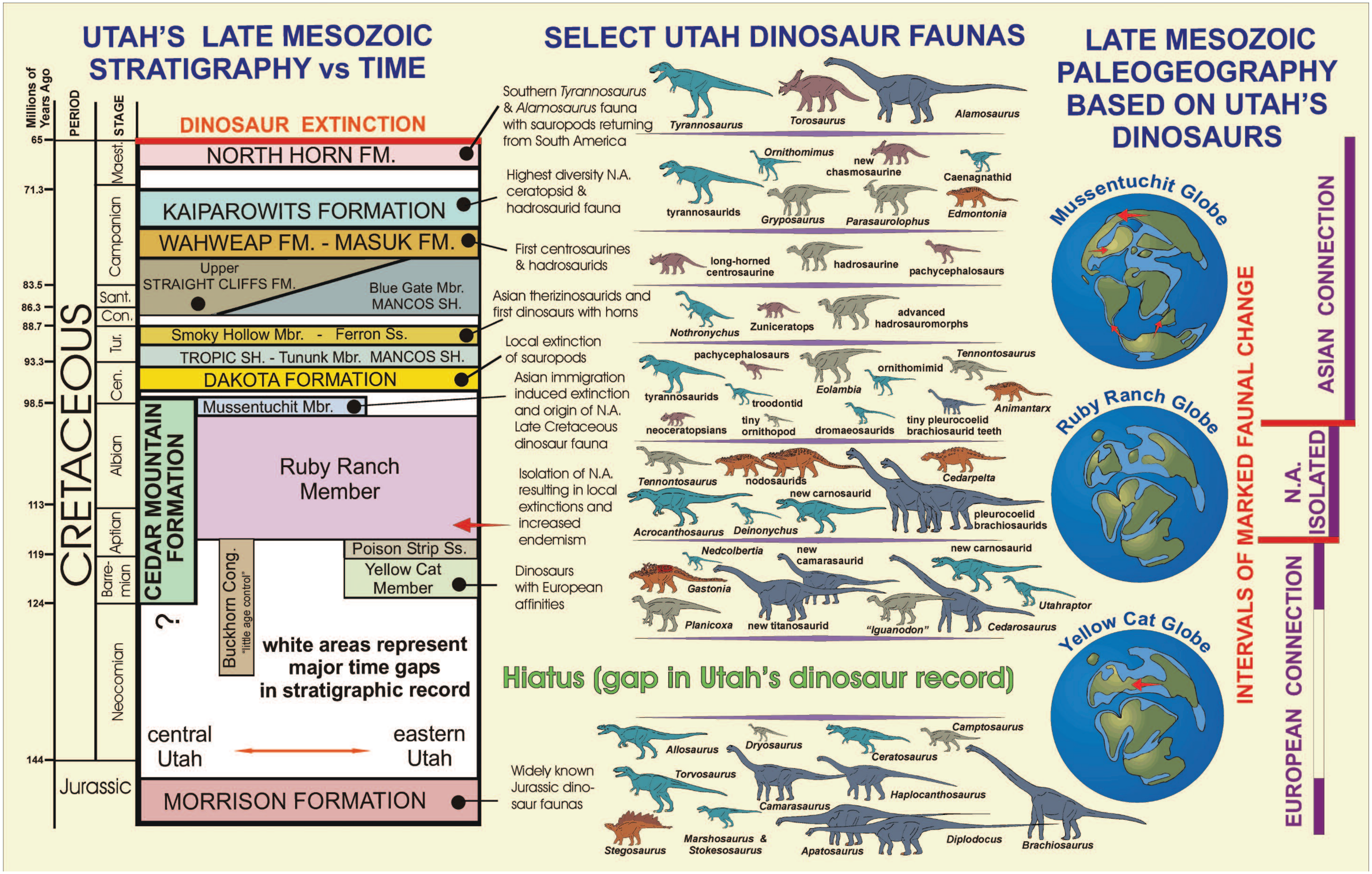
The basal Buckhorn Conglomerate consists largely of a chert-pebble to cobble conglomerate up to 25 meters thick that defines a northeast-flowing river system extending along the west flank of the San Rafael Swell. The chert pebbles preserve Late Paleozoic marine fossils reworked from ancient mountains in northwest Arizona and Nevada. In recent years, a controversy has arisen over the age of the Buckhorn Conglomerate, as a thick carbonate paleosol locally overlies the Buckhorn and a similar paleosol has been used to define the base of the Cretaceous elsewhere. However, well-developed paleosols may occur at a number of stratigraphic positions within the Cedar Mountain Formation. Additionally, the recent discovery of a possible ankylosaur (armored dinosaur) skeleton suggests a Cretaceous age as these dinosaurs are rare in the Jurassic and are abundant in the Early Cretaceous.

Yellow Cat Member

The Yellow Cat Member consists of drab variegated mudstone, limestone, and paleosols, with some sandstone lenses. It is recognized in the area between the Green and Colorado Rivers, where it is thought to reflect the last effects of salt diapirism (upward flow of buried salt) in the region around Arches National Park. This member is typically underlain by a massive carbonate paleosol, reflecting an approximately 25-million-year gap in sediment accumulation between the Late Jurassic and middle Early Cretaceous. It is overlain conformably by the Poison Strip Sandstone and pinches out under it to the east and west. These rocks reflect a complex of floodplain and lake environments in a semiarid setting. Dinosaurs identified in these rocks include the polacanthine ankylosaur, *Gastonia burgei*; advanced iguanodonts (bipedal plant eaters with thumb spikes), *"Iguanodon" ottingeri*, and perhaps other species; and several sauropod (long-necked dinosaurs) families, represented by the brachiosaurid *Cedarosaurus weiskopfae*, a new titanosaurid, and a possible camarasaurid. Meat-eating or theropod dinosaurs are represented by the small coelurosaur, *Nedcolbertia justinhoffmani*, the giant "raptor" *Utahraptor ostrommaysorum*, and a large carnosaurid perhaps related to Utah's state fossil, the Late Jurassic *Allosaurus*. The dinosaurs, together with pollen and charophytes (green algae), indicate that these rocks are approximately 125-120 million years old. Similar types of dinosaurs are also known from rocks of this age in Europe when the northernmost Atlantic Ocean had not yet opened up.

Poison Strip Sandstone

The Poison Strip Sandstone is actually a complex of well-cemented sandstones that indicate a complex of beaches and low-sinuosity and meandering river systems. These hard sandstones form the most continuous marker bed in the Cedar Mountain Formation and hold up an extensive cliff of lower Cedar Mountain and



A generalized column of Utah's Late Mesozoic strata plotted against the geological time scale with a summary of Utah's preserved dinosaur faunas and resulting continental paleogeographic patterns these dinosaurs indicate.

upper Morrison Formation extending across much of east-central Utah. Petrified logs and cycads are common in these beds. Dinosaurs are less commonly preserved and include *Gastonia*, the iguanodont *Planicoxa venenica*, and the titanosaurimorph sauropod *Venenosaurus dicrocei*. Overall the fossils suggest persistence of the Yellow Cat fauna.

Ruby Ranch Member

The Ruby Ranch Member is present everywhere the Cedar Mountain Formation is recognized and thickens to the northwest, perhaps indicating the earliest development of a foreland basin caused by initial Cretaceous thrust faulting in central Utah. Its appearance is much like the Yellow Cat Member, except that carbonate nodules are much more common and cover the ground. These represent paleosols and ephemeral ponds formed under semiarid conditions. Ribbon sandstones representing low-sinuosity rivers are common in this member. Dinosaurs from these rocks are completely distinct from those identified in the underlying rocks. The armored ankylosaurs are particularly diverse and include a nodosaurid similar to *Sauropelta*, as well as a giant nodosaurid and the huge ankylosaurid, *Cedarpelta bilbyhallorum*, in the uppermost part of the member. Other plant-eaters include the primitive, large ornithopod *Tenontosaurus*, with sauropods represented by slender-toothed brachiosaurs that may represent several species and are often referred to as *Astrodon* or *Pleurocoelus*. Meat-eating theropods are represented by small raptors similar to *Deinonychus*, a large undescribed carnosaurid, and the huge, high-spined *Acrocanthosaurus*. Similar dinosaur faunas are known across much of North America and suggest that these rocks were formed 115-105 million years ago when flowering plants first radiated and came to dominate the world's floras. However, this particular dinosaur assemblage is known only from North America, suggesting isolation from the rest of the world as the result of rising sea levels flooding Europe and western Canada prior to the development of Alaska. The rather low diversity of dinosaurs across all of North America for this interval lends further support to the concept of North America as an island continent during this time.

Mussentuchit Member

The uppermost Mussentuchit Member is well developed only along the west side of the San Rafael Swell. It is separated from the underlying Ruby Ranch Member by a black chert-pebble lag except in the thick outcrops of Cedar Mountain Formation on the north end of the San Rafael Swell, where the contact appears gradational. The top of the Mussentuchit, and laterally the Ruby Ranch, is overlain by the Dakota Formation and, where removed by Late Cretaceous erosion, the Tununk Member of the Mancos Shale. The Mussentuchit is most readily distinguished by the abundance of smectite (altered volcanic ash) mixed into its mudstones, a near absence of carbonate nodules, and the local presence of lignite (low-grade coal) beds. Locally, the smectite is so pure that the swelling clays are mined for this industrial material. A radiometric age of 98.37 ± 0.07 million years, obtained by the Oklahoma Museum of Natural History from volcanic ash within the Mussentuchit Member, coincides with the Early Cretaceous/Late Cretaceous boundary.

The Oklahoma Museum of Natural History has been using wet screen-washing techniques to recover tiny fossil mammal remains from microvertebrate sites in the Mussentuchit Member. By sorting the bone residues generated in this way, they have recognized about 80 species including a diversity of fish, frogs, salamanders, turtles, lizards, the oldest North American snake, crocodilians, birds, and mammals (including the oldest North American marsupial, *Kokopelia*). A wealth of dinosaur teeth have also been recovered representing ankylosaurid and nodosaurid ankylosaurs, several ornithopod taxa (a new small species, *Tenontosaurus*, and *Eolambia*), tiny slender brachiosaurid sauropod teeth (the last known in North America until the titanosaurid *Alamosaurus* appears more than 30 million years later in the North Horn Formation), dome-headed pachycephalosaurs, and primitive horned dinosaurs. Meat-eating dinosaur teeth are diverse and abundant, including primitive coelurosaurs, troodontids, dromaeosaurine and velociraptorine dromaeosaurids, and North America's earliest known tyrannosaurids. A partial skeleton of what may be a toothless ornithomimid (ostrich-mimic) has also been recovered.

So far only two dinosaur species, now housed in the collections of the College of Eastern Utah Prehistoric Museum in Price, Utah, have been described from relatively complete skeletal remains from these rocks. They are named for a husband/wife team of amateur paleontologists living in Castle Dale, Utah. The advanced ornithopod *Eolambia caroljonesa* was named for Carol Jones, who discovered the site. Retired University of Utah radiological technician Ramal Jones discovered the skeleton of the primitive nodosaurid ankylosaur, *Animantarx ramaljonesi*, as part of a highly refined radiological survey of the Carol site. This is the only dinosaur ever discovered thus far by technology alone.

The Mussentuchit fauna is particularly interesting in that it is the first time we find dinosaurs representing all the families that are so characteristic of the remainder of the Late Cretaceous in North America, in addition to preserving a few last examples of Early Cretaceous dinosaurs. As the direct ancestors of the tyrannosaurids, the derived iguanodont *Eolambia,* and the marsupial *Kokopelia* are Asian animals; this suggests that these rocks document the first immigration event of animals across the "Alaska Land Bridge." This event is reported to have led to the extinction of many of North America's "homegrown" (endemic) dinosaur groups. The

Alaskan Land Bridge has remained an important migration corridor for life on land in the northern hemisphere to the present day. As the Mussentuchit Member appears to preserve a mixture of Early and Late Cretaceous dinosaurs, it can be said that Utah's dinosaurs are dating the origin of Alaska, having caught the immigration-induced extinction in the act.

Conclusions

Utah's Cedar Mountain dinosaurs are contributing critical information about an important period of time in the history of terrestrial life in the northern hemisphere. Globally, this was a time of changing climatic conditions during a period of exceptionally high carbon dioxide causing "super-greenhousing" (a world with no polar icecaps and a sluggish, poorly oxygenated ocean), major restructuring of biogeographic migration corridors, and a complete restructuring of plant communities with the origin and rapid rise to dominance of flowering plants. The UGS continues to discover and integrate new data from the Cedar Mountain Formation into an increasingly robust history of Utah during the Early Cretaceous and its relationship with the rest of the world. Continued new dinosaur discoveries only serve to show that Utah has the most complete dinosaur record in all of North America, and that there is still a great deal to learn from it.

Cover: Skull is holotype for armored dinosaur *Gastonia burgei,* as is tooth; claws are from hind foot of *Utahraptor ostrommaysorum.*

Inventory and Management of Utah's Fossil Resources

by Martha Hayden

Paleontological resources are managed mainly for their scientific value, but also for their educational and recreational values. In this context, Utah's fossils are among the state's unique and valuable natural resources. Different types of fossils require different resource-management strategies. So how are these resources managed, and who is responsible for their management?

Elaine and Earl Gowin look on while UGS paleontologist Don DeBlieux and his wife Jane jacket a mammoth tusk discovered in a gravel pit on the Gowin's farm near Fillmore, Utah. Fossils like this tusk are common in the shoreline gravels of Lake Bonneville, an Ice Age lake that covered much of western Utah. The addition of significant new localities like this to our paleontological locality database adds to our understanding of prehistoric life in Utah.

Cooperation among various types of property owners and land-management agencies is one key to effective paleontological resource management. Fossils are found on private, state, and federal lands. Laws protecting fossils on private land do not exist, so we must rely on education as a resource-management strategy. Government land-management agencies each have their own rules and responsibilities for managing fossils and other resources on lands under their jurisdiction. At times, management of other types of resources takes precedence over management of paleontological resources. However, the value of fossils on public lands is recognized by most, if not all, land-management agencies. A report released by the Department of the Interior in 2000, "Assessment of Fossil Management on Federal and Indian Lands," was developed with the cooperation of eight federal agencies: Bureau of Indian Affairs, Bureau of Land Management, Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Forest Service, National Park Service, Smithsonian Institution, and U.S. Geological Survey. That report lists seven "basic principles" for development of future legislation governing the treatment of fossils on public lands. The basic principles are:

- Fossils on federal land are a part of America's heritage.
- Most vertebrate fossils are rare.
- Some invertebrate and plant fossils are rare.
- Penalties for fossil theft should be strengthened.
- Effective stewardship requires accurate information.
- Federal fossil collections should be preserved and available for research and public education.
- Federal fossil management should emphasize opportunities for public involvement.

The UGS is not a land-management agency. However, Utah State Code, which provides legal authority to the UGS, establishes the state's "interest in the preservation and protection of the state's paleontological resources and a right to the knowledge derived and gained from the scientific study of these resources." Utah State Code also assigns authority to the UGS to "collect and distribute information regarding the …paleontology… of the state; … stimulate research, study and activities in the field of paleontology; … mark, protect, and preserve critical paleontological sites;" and "collect, maintain, and preserve data and information in order to accomplish the purposes of this section and act as a repository of information concerning the geology of this state." The UGS is also charged with the authority to issue permits for qualified paleontologists to excavate critical paleontological resources from state lands. In other words, the UGS is charged with the responsibility for the preservation and protection of Utah's paleontological resources from state lands, and has a mandate to collect information about fossils.

Effective data management is another key to successful management of paleontological resources; to this end the UGS Paleontology Section maintains a paleontological locality database for the state of Utah. This database includes 9,699 localities from all lands in Utah. Our authority to compile and maintain locality data is derived from partnerships and cooperative agreements with state and federal land-management agencies. In particular, the UGS has had a cooperative agreement since 2002 with the Utah State Office of the Bureau of Land Management (BLM) for the management of paleontological resource data for BLM lands within the state. The BLM manages 23 million acres of land in Utah (42% of the state's land area), the largest area of any single land-management agency in the state. Under our agreement with the BLM, the main focus of work has been to convert existing paleontological locality data into a format that can be used in a Geographic Information System (GIS).

To protect critical fossil resources from vandalism and unauthorized collecting, information in the locality database is released only to land managers and qualified paleontologists engaged in paleontological mitigation and research. The only specific locality data released to the general public are for those sites that are open to public visitation. For example, information about the St. George Dinosaur Tracksite can be found on our website at http://geology.utah.gov/online/pdf/pi-78.pdf, including a locality map for visitors as well as a summary of the ongoing paleontological research.

We also have, or have had, various cooperative agreements for specific paleontological resource-management projects with many agencies, including Zion National Park, the Bureau of Reclamation, and the U.S. Forest Service at Flaming Gorge National Monument, and Grand Staircase-Escalante National Monument. These projects involve using our locality database and GIS analysis to produce paleontological sensitivity maps and address specific research and management issues.

Welcome aboard to lots of new faces: Our temporary geophysicist is **Jake Umbriaco**, a recent graduate of the University of Utah, working with the Ground-water Section. **Mike Kirschbaum** comes back as a temporary geologist with the Hazards Program, **Garrett Vice** has been hired as a temporary geologist with our Cedar City office, **Stefan Kirby** is working with the Ground-water Section, and **Carole McCalla** will be helping out in GIO, in particular, increasing the number of school kits that we have available. **Justin Johnson** replaces **Matt Butler** as GIS person for the Environmental Sciences. Matt is leaving for the private sector, and Justin worked with us previously.

Carolyn Olsen leaves us after 25 years with UGS, the last 17 as Curator of the Core Research Center. The new manager is **Mike Laine**, who managed the predecessor of the Center in 1986-88, then spent four years with Oil Gas, & Mining. He has since been a consulting geologist and petroleum geologist working in the Uinta Basin with Questar, and as a subcontractor with the UGS on the Ferron project.

Robert W. (Bob) Gloyn

November 19, 1942 – September 6, 2004

Bob Gloyn, long-time metallic minerals geologist at the Utah Geological Survey, passed away recently following surgery. For those who knew him, he was affectionately known as Gloynnie.

Bob was born in Portland, Oregon and raised in South Pasadena, California. Bob's sister Eleanor still resides in the Pasadena area. Bob met his life-long sweetheart and companion Ellen while attending high school. Bob and Ellen were married in Eagle Rock, California in 1966. Bob graduated from Occidental College in 1964, and from Princeton University with an M.A. in geology in 1967. Bob's career in mining and exploration took him all over the western U.S., northern Mexico, and much of Australia.

Bob joined Getty Oil Company's mineral group in 1967 and worked for a short time on an exploration project in Sonora, Mexico before transferring to Getty's Petrotomics uranium mine in the Shirley Basin, Wyoming. Bob worked in ore control for most of his two and a half years at the mine and was responsible for mapping the mine's roll-front geology and compiling a complex stratigraphic cross section of the minable ore body. Bob's research and mapping gave him a unique understanding of uranium deposition and roll-front geology in the Shirley Basin. Bob's work was applauded by Getty personnel at the mine and at the corporate office in Los Angeles, and his work led to a much more efficient mining technique.

Bob transferred to Getty's exploration office in Salt Lake City in 1971, and for the following eight years explored the western U.S. gaining an in-depth knowledge of mineral deposits and prospects. It was during this time that Bob became familiar with the mining districts in Utah and eastern Nevada. During one of his excursions in eastern Nevada in 1974, Bob fell down a blind winze while investigating an abandoned mine and was trapped for several days before being rescued. As a result, Bob suffered an injury to his left arm that plagued him for several years. Years later, he would muse that the accident may have shortened his arm, but it certainly didn't dampen his curiosity.

Bob was selected to go to Australia in September 1979, and worked in Getty's Australian office in Sydney where he spent two and a half years as senior geologic advisor conducting base- and precious-metals exploration in Queensland and eastern Australia, and in the Perth office as senior exploration geologist managing precious-metals exploration programs in Western Australia.

Bob and his family returned to Getty's Salt Lake office in late 1983 and once again Bob returned to his roots in western metals exploration. Following Getty's takeover by Texaco in 1985 and the disbanding of the minerals program, Bob consulted for several companies before joining the Utah Geological Survey in June 1988.

In his early years at the Survey, Bob managed the Energy and Minerals Program as it is now called. He relinquished his managerial duties in 1997 to become senior geologist so he could concentrate his efforts on numerous mineral investigations involving state-owned lands and compiling geological and mineral production summaries on Utah's mining districts. During his 16 years at the Utah Geological Survey, Bob was senior contributor to the U.S. Geological Survey's annual mineral summary for Utah. His interest and knowledge about mineral emplacement and mineralogy of Utah's mining districts was unsurpassed. Bob's attention to detail was officially recognized in June 2004 when he and his co-authors received the UGS' Arthur L. Crawford Award in recognition of their outstanding geologic publication on the energy and mineral resources of Carbon and Emery Counties.

Bob was a long-time member of the Society of Economic Geologists; Society of Mining, Metallurgy and Exploration; Northwest Mining Association; and the Utah Geological Association. Bob was a caring person and generous in his professional and charitable contributions. He was always recognized as a "top giver" in the State's Employees' Charitable Fund. Bob was well known and highly regarded in Utah's mining community and he leaves a legacy of unbridled inquiry and a penchant for detail for all of those he worked with and those who are to follow. Bob's quick wit and affable demeanor will be sorely missed by all who knew him. Bob leaves behind his wife Ellen and children Sarah Miralles, Jason Gloyn, Elizabeth (Lizzie) Gloyn, and Meredith (Merry) Ashton.

Pilot Project Shows Promise for Aquifer Storage and Recovery

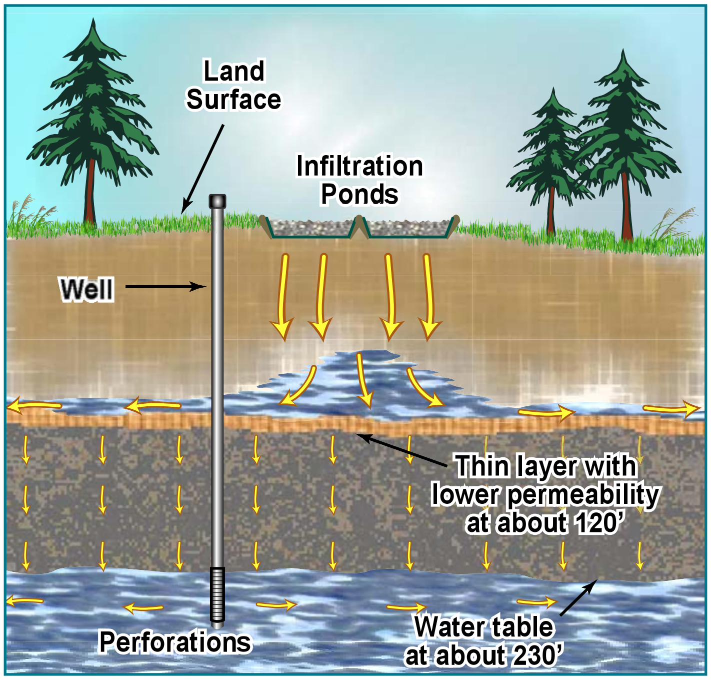
by Mike Lowe and Hugh Hurlow

The pilot project for the Ogden-area aquifer storage and recovery project described in the August 2003 issue of Survey Notes is well underway. Aquifer storage and recovery projects involve the storage of water in an aquifer via artificial ground-water recharge when water is available, and recovery of the stored water from the aquifer when water is needed. Pre-experiment work included establishing a monitoring well at the site, measuring water levels in the monitoring well and other nearby wells, analyzing water quality from nearby wells and the Weber River, and performing microgravity surveys. In March 2004, water from the Weber River was diverted into four shallow infiltration ponds on coarse-grained river deposits at the pilot-project site. The 1- to 2-foot-deep ponds have a total area of about 3.7 acres.

Two of the four shallow infiltration ponds at Ogden-area aquifer storage and recovery project site.

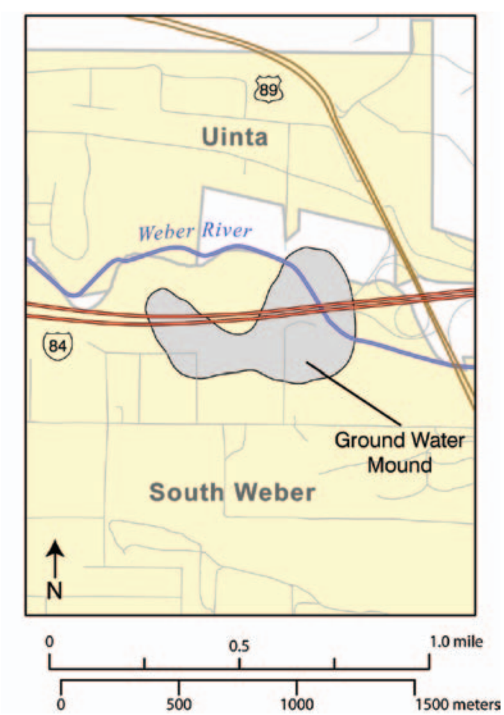
When the diversion of water from the Weber River was completed in July 2004, the aquifer beneath the project site had received about 800 acre-feet of ground-water recharge, resulting in a water-level rise of about one foot in the monitoring well at the site. A low-permeability layer (a sediment layer that allows water to move through it less readily than adjacent layers) about 120 feet below the land surface at the project site caused the infiltrating ground water to spread laterally, resulting in lower water-level increases at the monitoring well than were anticipated prior to the experiment. During the same time period, water levels in other nearby wells declined 4 to 10 feet; this indicates water levels at the monitoring well would have actually declined at least a few feet in the absence of the recharge experiment, so the net water-level rise at the monitoring well was at least 4 feet.

Microgravity surveys conducted before, during, and after the time of infiltration clearly show the building, migration, and dispersal of the newly created ground-water mound below and adjacent to the recharge ponds. Microgravity has proven to be an invaluable tool to monitor the subsurface movement of ground water infiltrated from the recharge ponds, given the insufficient number of suitable monitoring wells adjacent to the recharge site.



Schematic diagram showing low-permeability layer and water levels at Ogden-area aquifer storage and recovery project site. Arrows indicate ground-water movement.

Marek Matyjasek (Weber State University), Mike Lowe (Utah Geological Survey), and Ben Everitt (Utah Division of Water Resources) measure ground-water levels in monitoring well at Ogden-area aquifer storage and recovery project site.



Schematic map showing area of ground-water mound associated with infiltration ponds at Ogden-area aquifer storage and recovery project site.

A digital ground-water flow model is currently being constructed to improve our understanding of the aquifer system and the effects of the ground-water recharge experiment. Post-experiment water-level, water-quality, and microgravity data will continue to be collected until May 2005.

Although the recharge rate at the pilot-project site is lower than anticipated, the project has been enough of a success that the Weber Basin Water Conservancy District has purchased the site property, and plans are being considered for implementing aquifer storage and recovery at the site on a permanent basis beginning next spring. The preliminary results of this pilot project, combined with recharge experiments conducted near the mouth of Weber Canyon in the 1950s, indicate a strong likelihood for the success of similar aquifer storage and recovery projects in the greater east shore area of Great Salt Lake, where ground-water levels have declined up to 50 feet since the late 1930s. Active gravel pits in the area may be potential sites for future infiltration ponds when the gravel resources become depleted.

This project highlights the ability of many entities to successfully work toward a common goal. Project participants include the Weber Basin Water Conservancy District, U.S. Bureau of Reclamation, Weber State University Department of Geosciences, University of Utah Department of Geology and Geophysics, Utah Division of Water Resources, and Utah Geological Survey. Additional information regarding the Ogden-area pilot project is at http://weberbasin.com/aquifer.

Energy News

Deep Utah coal deposits-repositories for greenhouse gas emissions?

by David E. Tabet

Concern about potential global warming caused by greenhouse gas emissions from the burning of fossil fuels has prompted the Utah Geological Survey to join a consortium of researchers from several western states (Arizona, Colorado, New Mexico, and Oklahoma) to investigate geologic reservoirs that could possibly be used to permanently store such emissions. Coal is known for its ability to hold significant amounts of carbon dioxide, a greenhouse gas, within its molecular structure. Coal beds at depths greater than 2000 feet are logistically and economically difficult to mine because of the high pressures and stresses that occur at these depths. Such less-likely-to-be-mined coal deposits are present in east-central Utah, in the Book Cliffs, Emery, Sego, and Wasatch Plateau coalfields (see figure). Any of those coal deposits located within about 20 miles of the various Utah coal-fired power plants are logical targets to store greenhouse gas emissions because they are close enough to the source to make an emission-storage project potentially economic. Target coal deposits at depths ranging from 2000 to 6000 feet are present in Utah in the Blackhawk and Neslen Formations of the Mesaverde Group, and the underlying Ferron and Emery Sandstone Members of the Mancos Shale.

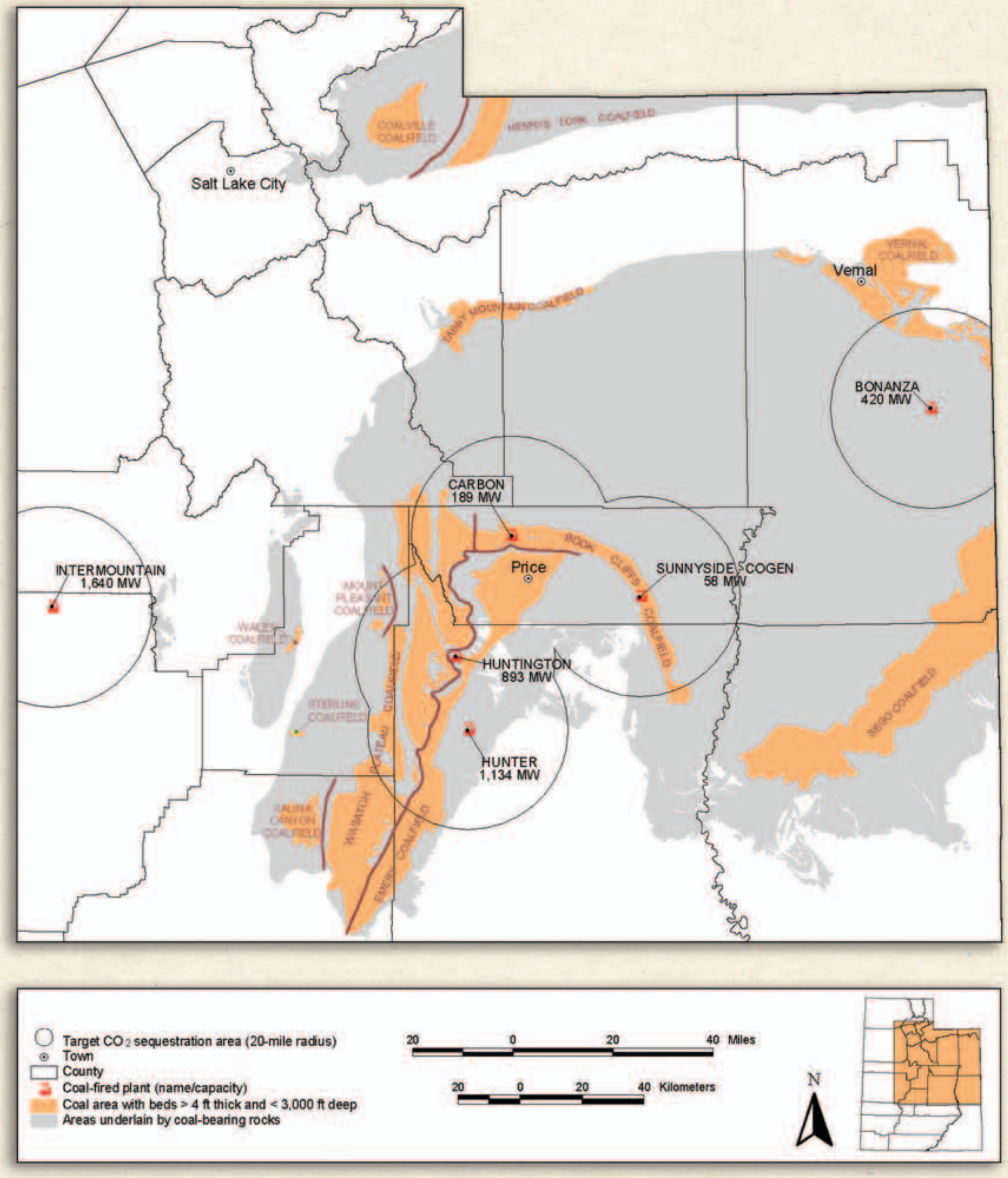
The Utah Energy Office has inventoried the amount of carbon dioxide emitted annually by Utah's coal-fired electric power plants and found that the amount varies up to 12.5 million tons depending on the size of the plant. Although no deep coal deposits occur within 20 miles of the Intermountain Power Plant in western Utah, several power plants near the Book Cliffs and Wasatch Plateau coalfields are well situated to take advantage of deep coal beds for sequestering greenhouse gas emissions. Comparison of the annual carbon dioxide emission rates for these power plants with the coal reservoir storage capacities, shows that most of the central Utah coal-fired power plants could have their carbon dioxide emissions stored in deep coal reservoirs for a good portion of their expected useful lifetimes. The deep coal deposits in the Emery coalfield near Price are currently being tapped for their stored economic methane gas reserves, and a network of pipelines and wells is currently in place that could also be used for carbon dioxide sequestration efforts. As methane reserves in that area decline, pumping greenhouse gases into the coal reservoirs might have the added benefit of enhancing methane production by flushing out additional recoverable coalbed methane.

Based on this quick inventory, it appears that deep coal resources near existing coal-fired power plants in central Utah could theoretically provide adequate reservoirs to store carbon dioxide emissions for at least 35 years, or the expected life of at least several of the power plants. Whether it is technically and economically feasible to sequester greenhouse gas emissions of coal-fired power plants in deep coal beds remains the subject of future research.

Power Plant Name	Annual Coal Usage (millions tons)	Annual Carbon Dioxide Emissions (million tons)	Retirement Schedule
Bonanza	2.0	4.0	2025?
Carbon	0.6	1.5	2010
Hunter	4.3	9.8	2025
Huntington	3.0	6.6	2019
Intermountain	5.3	12.5	2035?
Sunnyside Cogen	0.5*	0.3	2033?

*burns waste coal, not run-of-mine coal

Utah's coal-fired electric generating plants, their average annual coal consumption, and carbon dioxide emissions. Retirement schedule is based on assumed 40-year power plant design life (source: Utah Energy Office).



Coalfield name	Geologic unit name	Acres within 20 miles	Average coal thickness (ft)	Coal reservoir size (tons)	CO_2 storage capacity(tons)
Book Cliffs	Blackhawk	70,000	35	4,410	44.1
Wasatch Plat.	Blackhawk	40,000	20	1,440	14.4
Wasatch Plat.	Emery	150,000	40	10,800	108.0
Emery	Ferron	96,000	24	4,147	41.5
Sego	Neslen	45,000	14	1,134	11.3
TOTAL		401,000	31	21,931	219.3

Estimates for Utah coalfields of the area, average thickness, reservoir size, and carbon dioxide storage capacity of deep coal deposits that lie within 20 miles of coal-fired power plants (tonnages are millions of short tons).

GeoSights

The amazing monoliths and "mountain" of gypsum at Lower Cathedral Valley, Capitol Reef National Park, Wayne County, Utah

by Carl Ege

Lower Cathedral Valley, located in the northeast corner of Capitol Reef National Park, is one of the park's most photogenic areas and is a popular destination for photographers and sightseers. A gravel road just west of Caineville takes you to the base of the cathedrals (high clearance and/or four-wheel-drive vehicle is recommended).

Geologic Information:

Lower Cathedral Valley contains numerous, large stands of massive rock called monoliths or cathedrals. Two of the largest cathedrals are Temple of the Sun and Temple of the Moon. The cathedrals consist of fine-grained sandstone and siltstone in shades of red to reddish-orange. The color is the result of tiny amounts of hematite (an iron oxide) and other iron-bearing minerals. The sandstone and siltstone belong to the Jurassic-age (approximately 160 million years old) formation called the Entrada Sandstone, the same rock formation that makes up the hoodoos or goblins of Goblin Valley State Park and the arches, fins, and spires of Arches National Park. During the Middle Jurassic, extensive tidal flats covered the present area of Capitol Reef National Park, where a large amount of sandy mud was deposited.

The Entrada Sandstone contains areas of fractured and unfractured rock.

Temple of the Sun, seen from the base of Temple of the Moon. Each of the temples is composed of the Jurassic Entrada Sandstone.

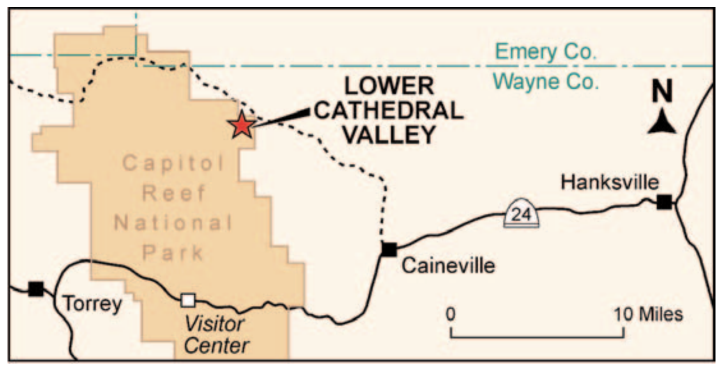
The fractured, jointed, rock is partly responsible for monolith development by creating zones of weakness where surface water penetrates the sandstone, which slowly weathers and erodes the rock. Over time, continued erosion leaves areas of unfractured, free-standing masses of rock called monoliths or cathedrals. In other areas of Capitol Reef National Park, many cathedrals are still protected from large-scale erosion by overlying, weather-resistant cap rock of the Curtis Formation. However, in Lower Cathedral Valley, the Curtis Formation has been removed, resulting in the steeple-shaped appearance of the monoliths.

Northeast of Temple of the Sun is Glass Mountain, a geological curiosity composed of large gypsum (selenite) crystals. The gypsum was deposited from evaporating seawater approximately 165 million years ago (upper part of the Middle Jurassic Carmel Formation). After deposition and burial under subsequent layers of sediment, the low-density gypsum moved slowly upward along faults or fractures, and in some cases formed

Glass Mountain, located northeast of Temple of the Sun. Hat for scale.

Close-up view of a selenite crystal at Glass Mountain.

small domes. Glass Mountain is one of these gypsum domes, rising 15 feet above the floor of Lower Cathedral Valley. Gypsum is a slightly soluble mineral; precipitation over an extended period of time will most likely dissolve Glass Mountain and create a sinkhole.



How to get there:

From the town of Torrey in Wayne County, travel east on Utah Highway 24 approximately 25 miles to the turnoff for Lower Cathedral Valley, located just west of Caineville. If your approach is from the east from Hanksville, travel west on Utah Highway 24 for about 18 miles to the turnoff. The turnoff is not well marked, so proceed with caution. Travel north approximately 18 miles to Lower Cathedral Valley (road junction). Turn left (west) and proceed about 0.5 miles until the road splits in two directions. If you turn right (northeast), your destination is Glass Mountain. If you turn left (west), Temple of the Sun is less than 0.5 miles away.

Doelling receives Lehi Hintze Award – 2004

Special congratulations go to Hellmut Doelling for being selected as the second recipient of the Lehi Hintze Award for outstanding contributions to Utah geology. Hellmut has had a long, varied, and productive career with the UGS, and is still active today mapping in the Salina-Loa area. The award is most deserved.

The Utah Geological Association (UGA) and Utah Geological Survey (UGS) presented Dr. Doelling the 2004 Lehi Hintze Award for outstanding contributions to the geology of Utah on November 15, 2004. Dr. Doelling's many contributions come from a career of over 40 years studying the geology of Utah. His work includes exploring and describing most of the uranium mines in Utah, co-authoring the Utah Coal Monograph Series, and authoring a number of county geology bulletins. He was instrumental in establishing the Geologic Mapping Program in Utah, and produced geologic maps covering over one-quarter of the State. Dr. Doelling's numerous geologic maps include Arches National Park and Grand Staircase-Escalante National Monument. Dr. Doelling's publications are a great source of geologic information for students and researchers of Utah geology.

Dr. Lehi Hintze and Dr. Hellmut Doelling

The Lehi Hintze Award was established in 2003; the first recipient was Dr. Lehi F. Hintze. Lehi Hintze has spent a lifetime dedicated to studying, mapping, writing, and teaching about the geology of Utah. Dr. Hintze is professor emeritus at Brigham Young University, and also spent almost 10 years mapping for the Utah Geological Survey. The Lehi Hintze Award was established through efforts of the Utah Geological Survey and Utah Geological Association to recognize outstanding contributions to the understanding of Utah geology. Recipients can be from academia, government, the private sector, or the general public.

"Glad You Asked"

by Carl Ege

What are fulgurites and where can they be found?

Most people have never seen a fulgurite, and many that have probably did not realize what it was at the time. Fulgurites are natural tubes or crusts of glass formed by the fusion of silica (quartz) sand or rock from a lightning strike. Their shape mimics the path of the lightning bolt as it disperses into the ground. All lightning strikes that hit the ground are capable of forming fulgurites. A temperature of 1800 degrees Celsius is required to instantaneously melt sand and form a fulgurite (most lightning strikes have a temperature of 2500 degrees Celsius). Fulgurites have been found worldwide, but are relatively rare.

Two types of fulgurites have been recognized: sand and rock fulgurites. Sand fulgurites are the most common and are generally found in beach or desert regions containing clean (free of fine-grained silt or clay), dry sand. They resemble roots or branching tube-like structures that have a rough surface, covered with partially melted sand grains. Sand fulgurite tubes have a glassy interior, due to rapid cooling and solidification of the sand after the lightning strike. The size and length of a fulgurite depends on the strength of the lightning strike and the thickness of the sand bed. Many sand fulgurites average 1 or 2 inches in diameter and can be up to 30 inches long. Sand fulgurites have been found in Utah's deserts and on top of some of the higher summits of the Wasatch Range.

Coatings or crusts of glass formed on rocks from a lightning strike are called rock fulgurites. These fulgurites are found as veins or branching channels on a rock surface or lining preexisting fractures within the host rock. Rock fulgurites are primarily found on the top or within several feet of mountain summits. Mountain peaks are natural lightning rods that are repeatedly blasted by lightning strikes during severe weather. Rock fulgurites can be found throughout many of the mountain ranges of the world, including the French Alps (Mont Blanc), Pyrenees Range, and western U.S. mountains such as the Sierra Nevada, volcanic peaks of the Cascade Range, Rocky Mountains, and Utah's Wasatch Range.

While hiking in the summer of 2003, I discovered both sand and rock fulgurites on some of the higher summits of the Wasatch Range. I observed very small sand fulgurites (an inch or less) in some of the surface float on top of Mount Raymond (10,241 feet) and Broads Fork West Twin (11,328 feet). I also found rock fulgurites on top of Mount Raymond, Broads Fork West Twin, Mount Baldy (11,068 feet), and Mount Timpanogos (11,749 feet). Some of the rock fulgurites, such as those found on Mount Timpanogos, are the result of human activity (a steel shelter placed on top of the peak attracts lightning). In the Wasatch Range, rock fulgurites appear to be confined to mountaintops composed chiefly of quartzite, but summits consisting of other rock types could have them as well.

So, the next time you go hiking or exploring be on the lookout for fulgurites! It is very possible new fulgurite discoveries await the adventurer on many of the higher summits and desert areas of Utah.

Rock fulgurite (circled in white) found on quartzite at the summit of Mount Raymond in the Wasatch Range, Salt Lake County, Utah. Hammer for scale.

Sand fulgurites found on the top of Mount Raymond. U.S. quarter for scale.

Teacher's Corner

by Mark Milligan

Earth Science Week 2004 - A Rocking Success

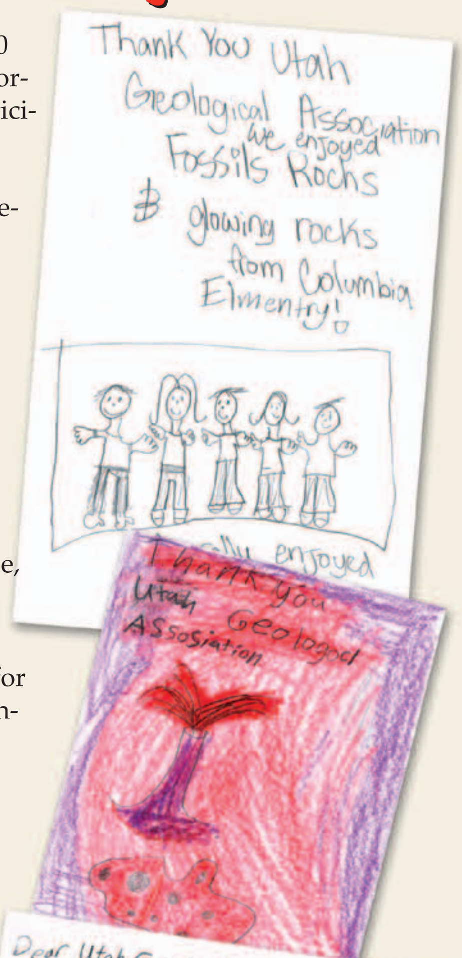
What happens when you put a humble geologist face-to-face with 10, 20, or even 90 grade-school students? Mayhem, chaos, and panic akin to a '70s disaster movie? Fortunately not, based on comments we received from teachers and students who participated in this year's Earth Science Week activities:

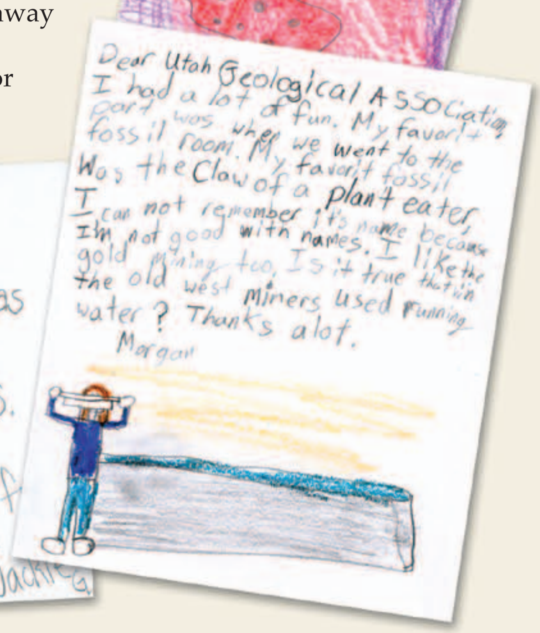
> "We LOVE coming here! We will offer bribes to keep coming back!" (Granite Elementary teacher)
>
> "Outstanding! Best field trip I've been on. The presenters did an excellent job." (Carl Sandburg Elementary teacher)
>
> "Excellent hands-on exhibits and activities." (Timpanogos Elementary teacher)
>
> "My favorite rock was all of them." (Sara, Columbia Elementary 4th grader)
>
> "I'm so happy you let us come it was wonderful. I've been very interested in rocks. When I grow up I want to be a geologist… You really inspired me." (Chloe, Columbia Elementary 4th grader)

The week of October 18th to the 22nd, the UGS and 51 volunteers hosted 950 students and 117 teachers and parents. During 1½-hour sessions participants panned for "gold," observed erosion and deposition on a stream table, identified rocks and minerals, and toured the paleontology lab.

In 1998 the American Geological Institute launched Earth Science Week with the goal of increasing public understanding and appreciation of Earth sciences. What better way to fulfill this goal than reaching out to the next generation of citizens?

Earth Science Week has become such a success that we had to turn schools away this year. Next year we hope to award Earth Science Week reservations to entrants of a poster contest. Lucky schools may also win bus fare. Watch for more details in this summer's issue of *Survey Notes*.





New Publications

Earthquake fault map of a portion of Cache County, Utah, 2 p., PI-83 . . . . FREE

Earthquake fault map of a portion of Tooele County, Utah, 2 p., PI-84 . . . . FREE

Earthquake fault map of a portion of Washington County, Utah, 2 p., PI-85 . . . . FREE

Geologic map of the Ogden 7.5-minute quadrangle, Weber and Davis Counties, Utah, by Adolph Yonkee and Mike Lowe, 42 p., 2 pl. 1:24,000, M-200 . . . . $12.00

Geologic map of the Little Creek Mountain quadrangle, Washington County, Utah, by Janice M. Hayden, 2 pl., 1:24,000, M-204 . . . . $9.95

Geologic map of the La Sal 30' x 60' quadrangle, San Juan, Wayne, and Garfield Counties, Utah, and Montrose and San Miguel Counties, Colorado, by Hellmut H. Doelling, 2 pl. scale 1:100,000, M-205 . . . . $10.50

Geologic map of the Wah Wah Mountains North 30' x 60' quadrangle and part of the Garrison 30' x 60' quadrangle, southwest Millard County and part of Beaver County, Utah, by Lehi F. Hintze and Fitzhugh D. Davis, CD (2 pl., scale 1:100,000)[contains GIS data], M-207DM $19.95

Ground-water sensitivity and vulnerability to pesticides, Tooele Valley, Tooele County, Utah, by Mike Lowe, Janae Wallace, Matt Butler, Rich Riding, and Anne Johnson, CD (23 p., 2 pl., 1: 65,000), MP-04-3 . . . . $19.95

Ground-water sensitivity and vulnerability to pesticides, Morgan Valley, Morgan County, Utah, by Mike Lowe, Janae Wallace, Neil Burk, Matt Butler, Anne Johnson, Rich Riding, CD (23 p., 2 pl. 1:87,000), MP-04-4 . . . . $19.95

Reconnaissance investigation of ground cracks along the western margin of Parowan Valley, Iron County, Utah, by Christopher B. DuRoss and Stefan M. Kirby, CD (17 p.), RI-253 . . . . $14.95

Utah Geology, CD (reprint of 4 years of the journal, 1170 p., 14 pl.) $14.95

Oil and gas field studies, compiled by Craig D. Morgan, CD (80 p., 29 plates) (reprints of 11 oil and gas reports), OFR-430 . . . . $14.95

Geothermal resources of Utah - 2004: A digital atlas of Utah's geothermal resources, compiled by Robert E. Blackett and Sharon Wakefield, CD [contains GIS data], OFR-431 . . $14.95

Progress report: Geologic map of the Vernal 30' x 60' quadrangle, Utah and Colorado, Year 2 of 3, compiled by Douglas A. Sprinkel, 2 pl., 1:100,000, OFR-432 . . . . $9.95

Liquefaction potential maps for Utah, CD (463 p., 81 plates) (reprints of Liquefaction potential maps for: northern Wasatch Front, central Utah, and for Davis, Salt Lake, and Utah Counties), OFR-433 . . . . $14.95

Interim geologic maps of the Copperton, Magna, and Tickville Spring quadrangles, Salt Lake and Utah Counties, Utah, by Robert F. Biek, Barry J. Solomon, Jeffrey D. Keith, and Tracy W. Smith, 4 pl., 1:24,000, OFR-434 . . . . $24.95

Progress report: geologic map of the south half of the Beaver 30' x 60' quadrangle, Beaver, Piute, Iron, and Garfield Counties, Utah, by P. D. Rowley, G. S. Vice, J. J. Anderson, R. E. McDonald, D. J. Maxwell, B. R. Wardlaw, C. G. Cunningham, T. A. Steven, and M. N. Machette, 19 p., 1 pl., 1:100,000, OFR-435 . . . . $9.95

Interim geologic map of the Curlew Valley drainage basin, Box Elder County, Utah, and Cassia and Oneida Counties, Idaho, by Hugh A. Hurlow, 34 p., 1 pl. 1:100,000, OFR-436 . . . . $9.95

Field guides to southwest Utah, 2004, CD (742 p., 12 pl.), 10/04, OFR-437 . . . . $14.95

Interim geologic map of the east half of the Salina 30' x 60' quadrangle, Emery, Sevier, and Wayne Counties, Utah, by Hellmut H. Doelling, 12 p., 1 pl. 1:62,500, OFR-438 . . . . $7.95

Interim geologic map of the lower San Juan River area, eastern Glen Canyon National Recreation Area and vicinity, San Juan County, Utah, by Grant C. Willis, scale 1:50,000, OFR-443DM, [contains GIS data] $14.95

Geologic map of the Huntington 30' x 60' quadrangle, Carbon, Emery, Grand and Uintah Counties, Utah, by Irving J. Witkind, (digitized from U.S. Geological Survey Miscellaneous Investigations Series Map I-1764 [1988]), scale 1:100,000, OFR-440DM, [contains GIS data] $14.95

Utah Geological Survey
1594 W. North Temple, Suite 3110
Box 146100
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