U T A H G E O L O G I C A L S U R V E Y

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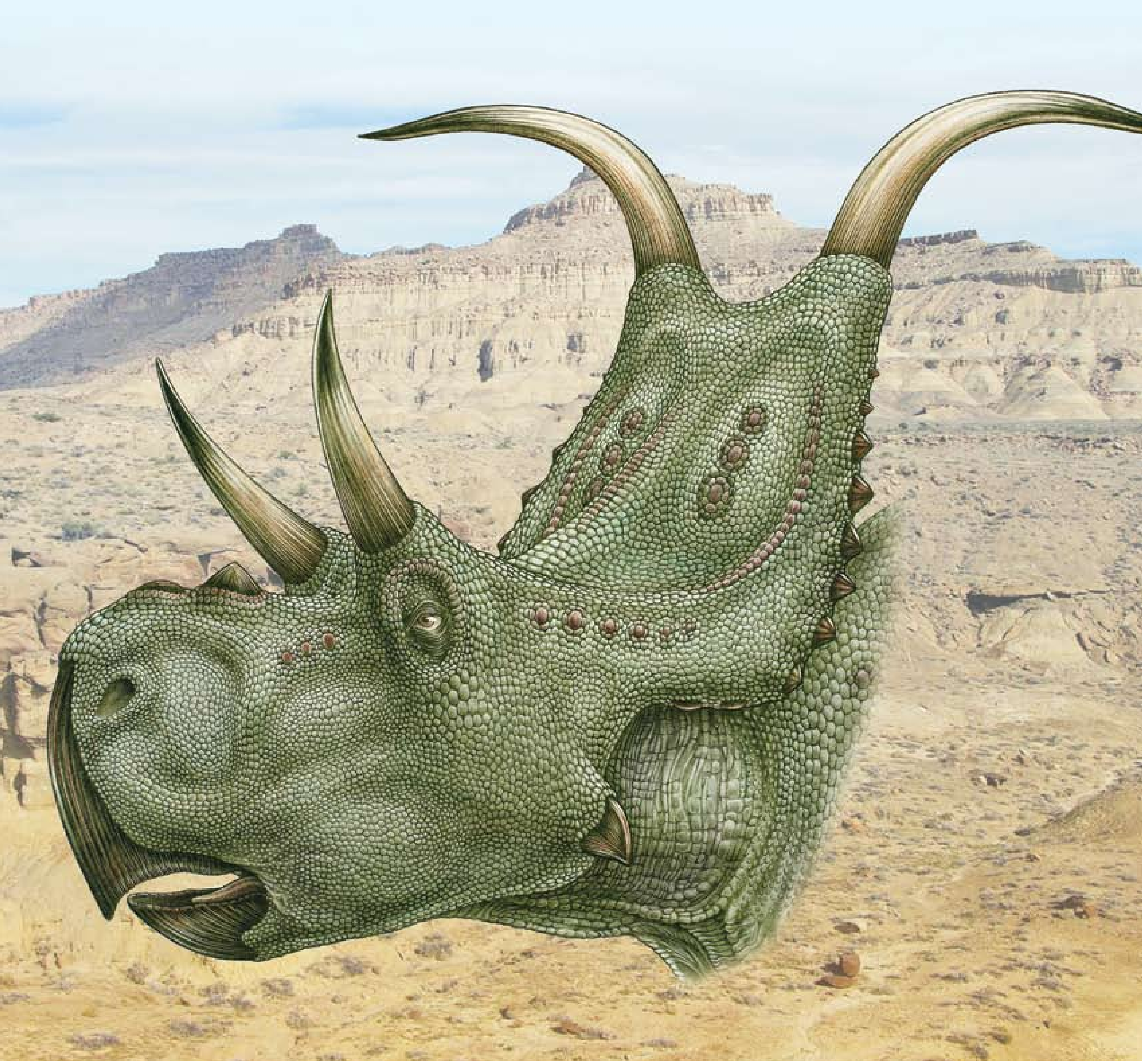

New Horned Dinosaurs from the Wahweap Formation

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Design: Liz Paton
Cover: Life reconstruction of Last Chance ceratopsian, illustrated by Brad Wolverton. Background photo: Rocks of the Wahweap Formation in Wesses Canyon, Grand Staircase-Escalante National Monument. Photo by Don DeBlieux.

THE DIRECTOR'S PERSPECTIVE

by Richard G. Allis

This summer the Utah Geological Survey began its largest project ever—the drilling of 15 to 20 ground-water monitoring wells in Utah's west desert. The 2007 State Legislature expressed concern about potential impacts of ground-water withdrawal in neighboring valleys of Nevada by the Southern Nevada Water Authority (SNWA), and appropriated over $2 million for a network of monitoring wells (see article on p. 8). The Paleozoic carbonate rocks that underlie a large part of the Basin and Range Province of western Utah and eastern Nevada may form a regional aquifer that allows ground water to flow between various basins and more localized basin-fill aquifers. However, its characteristics are not well understood and no wells in the major valley on the Utah side of the state line (Snake Valley, mostly Millard County) penetrate the aquifer. The U.S. Geological Survey (USGS) recently released a draft report of its two-year study of the water resources of this region (reference in above-mentioned article). According to the USGS, a relatively large head difference (about 1000 feet) exists between the south and north ends of Snake Valley (a distance of about 100 miles), and between Spring Valley to the west in Nevada and Snake Valley (a distance of about 25 miles). The head gradients imply ground-water flow from the south towards the north in Snake Valley, and from the west. Chemical and isotopic data support these flow paths, with most recharge occurring in the Snake Range between Snake Valley and Spring Valley, and perhaps also in the Schell Creek Range on the west side of Spring Valley. Carbon-14 dating indicates ground-water ages of less than 1000 years to 6000 years with age increasing downgradient, suggesting ground-water flow velocities on the order of 100 feet/year.

The USGS reassessment of the ground-water system indicates ground-water inflows from the west of 29,000 acre-feet/year into the south end of Snake Valley, and 14,000 acre-feet/year into the north end of the valley. The estimated ground-water outflow from Snake Valley towards the northeast is 29,000 acre-feet/year (pre-irrigation development), and Fish Springs (20,000–27,000 acre-feet/year) in Juab County may represent a large part of this. Although the ground-water flows appear to be precise numbers, the USGS points out they are derived from the difference between two large numbers with significant uncertainties: the proportion of total precipitation that infiltrates the ground, and total evapotranspiration. In the case of Snake Valley, evapotranspiration is estimated to be 130,000 ± 30,000 acre-feet/year. The uncertainties are therefore comparable to the magnitude of the inferred interbasin flows, so caution is needed when interpreting the ground-water flow system in any basin.

The USGS estimates the present rate of ground-water extraction in Snake Valley is 24,000 acre-feet/year (mostly for crop irrigation), which approaches their estimate of the magnitude of the ground-water outflow from the valley. Utah's Division of Water Rights reports that about 60,000 acre-feet/year of ground-water depletion is committed (either approved or perfected water rights) on the Utah side of Snake Valley, and on the Nevada side about 15,000 acre-feet/year is committed. This includes about 32,000 acre-feet/year of spring flow (Big Springs, Gandy Warm Springs, Twin Springs, and Fish Springs) which is used in Utah and is reflected in Utah's water rights but not included in the USGS ground-water use (extraction) estimate. Applications for ad-

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THE CASE FOR FISHING DINOSAURS AT THE ST.GEORGE DINOSAUR DISCOVERY SITE AT JOHNSON FARM

by Andrew R. C. Milner and James I. Kirkland

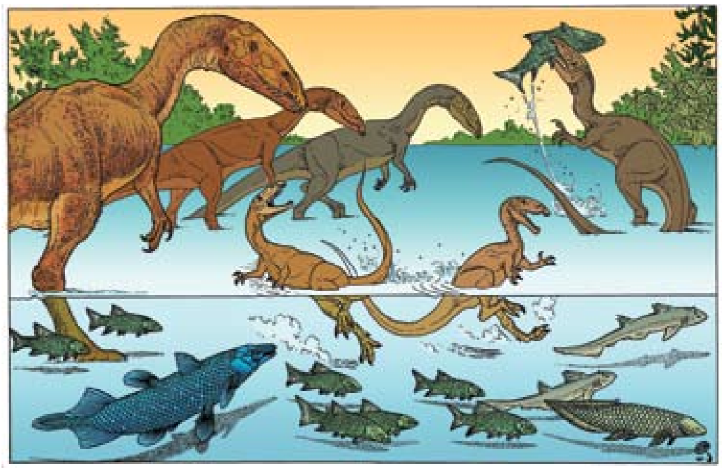


Illustration by Russell Hawley

The St. George Dinosaur Discovery Site at Johnson Farm (SGDS) preserves a world-class collection of dinosaur tracks and associated features. The initial discovery and preliminary scientific interpretation of the site were reported in previous issues of *Survey Notes* (2000, v. 32, no. 3; 2002, v. 34, no. 3). This article summarizes evidence suggesting that dinosaurs at SGDS were feeding on fish.

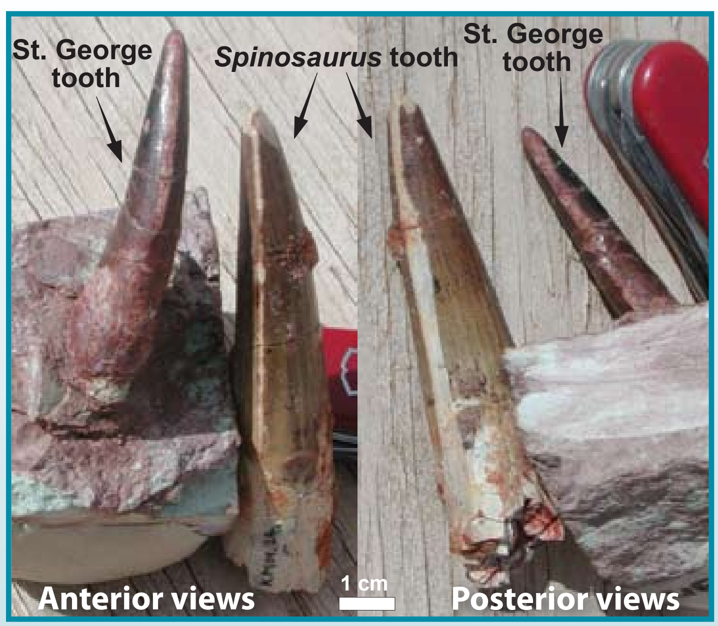
The SGDS preserves not only thousands of dinosaur tracks on at least 25 track-bearing horizons in the basal Jurassic Moenave Formation, but also abundant fish, plant, and invertebrate fossils as well as rare dinosaur teeth and bone. The Moenave Formation at the SGDS provides a window into the earliest Jurassic (about 200–198 million years ago) ecosystem near the margin of a large prehistoric lake—Lake Dixie.

The main track-bearing sandstone near the base of the Whitmore Point Member of the Moenave Formation ("Johnson Farm sandstone bed") preserves casts of dinosaur tracks at its base. This sandstone bed was deposited rapidly on a bed of clay, preserving the fine detail of the clay's surface. Southeast of Riverside Drive at the SGDS museum, the base of this sandstone exposes casts of mud cracks and dinosaur tracks (mostly large *Eubrontes* with smaller, nearly identical *Grallator* type tracks) with isolated scours (flute casts) and diamond-shaped salt casts, suggesting an exposed lake-shore mud flat. Northwest of Riverside Drive, this same surface preserves tool marks, small flute casts, and crescent marks (scratch circles) on an extensively scoured surface; these features indicate relatively strong longshore currents that paralleled the lake shore and exposed mud flat, forming a subaqueous channel. Like in the ocean, longshore currents are created in large lakes by waves obliquely striking the shore.

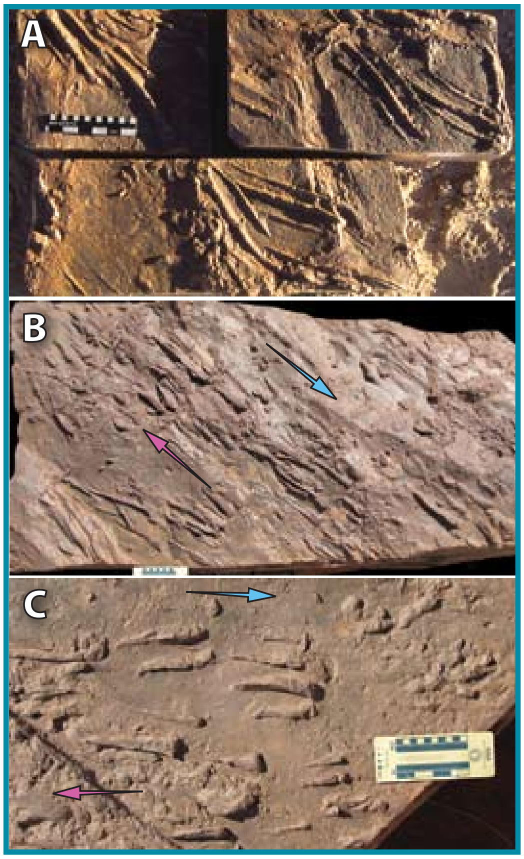
Thanks to the landowners, volunteers, the City of St. George, and critical funding from the State of Utah and the federal government, a museum opened in April 2005 over Shelden Johnson's initial discovery site south of Riverside Drive.

Among the most exciting discoveries at SGDS is an abundance of dinosaur swim tracks (known by the name *Characichnos*) at the base of the thickened "Johnson Farm sandstone bed" northwest of Riverside Drive representing the subaqueous channel. Here, the SGDS has the world's largest and best-preserved collection of dinosaur swim tracks, which resolves a long-standing controversy among paleontologists about the very existence of swim tracks. Part of the controversy revolved around the simple fact that if a dinosaur were swimming fully buoyed up in the water, it would not leave marks on the bottom. Swim tracks of meat-eating dinosaurs are typically arranged in sets of three parallel scrape marks that taper at each end, with the longer middle toe leaving a longer and deeper scrape mark compared to the shorter outer toes.

Most, but not all, of the swim tracks are comparable in size to the smaller walking track *Grallator*, which here is indistinguishable from small-scale versions of *Eubrontes*. The vast majority of these



Large theropod teeth from SGDS vs. Spinosaurus *from North Africa.*



(A) Initial swim track blocks discovered by A.R.C. Milner in 2001. (B and C) Examples of swim tracks from Washington County School District Quarry #1. Red arrows indicate swim direction, blue arrows indicate current direction.

swim tracks are oriented in the opposite direction from the current indicators in the channel. The most likely scenario is that numerous meat-eating dinosaurs were wading in the shallows of the lake and stepped off into the deeper subaqueous channel, where the smaller dinosaurs were swept off their feet, resulting in the dinosaurs floundering in the water against the strong current.

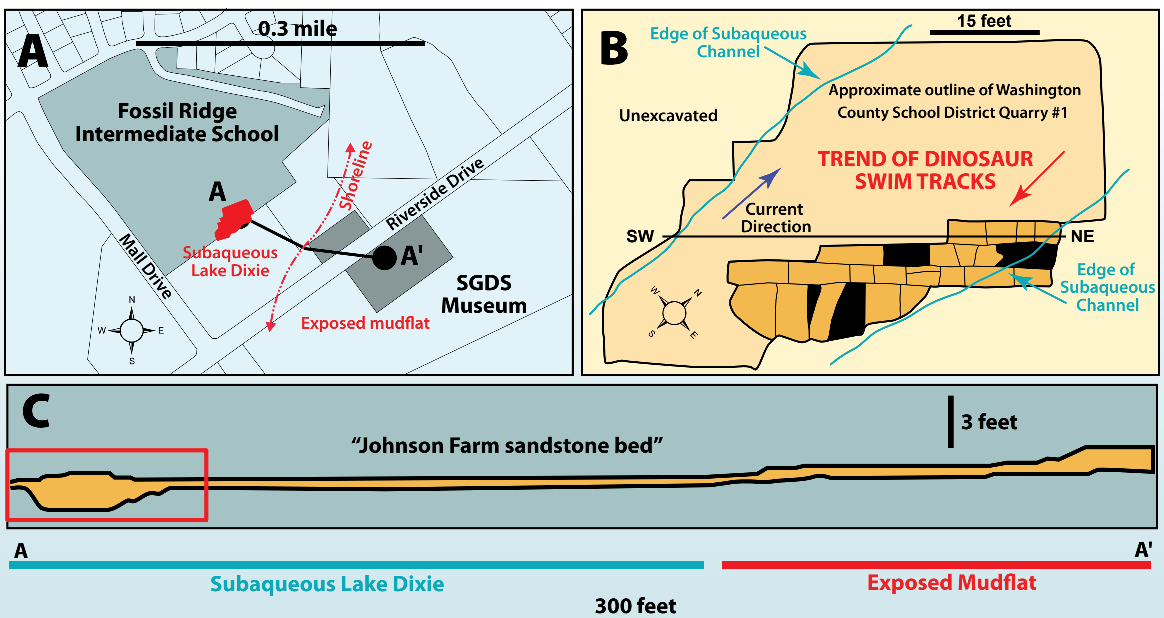
The abundance of swim tracks leads to the obvious question: Why were so many dinosaurs wading hip deep in the lake? It is certainly a lot harder to walk through water than to walk along a beach.

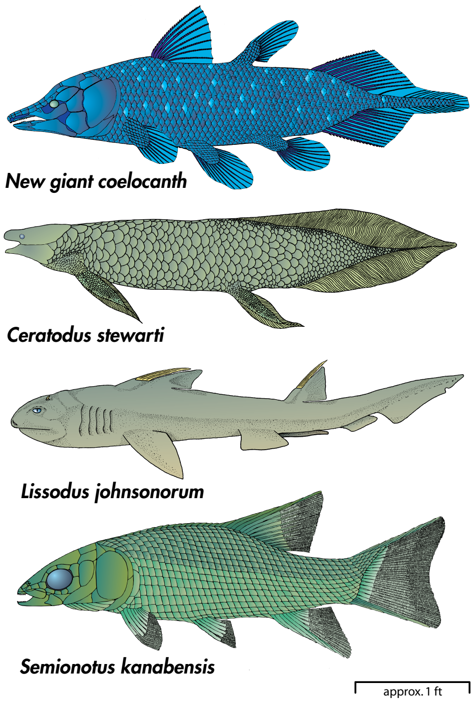
Many fish remains have been recovered at the SGDS from higher in the Whitmore Point Member. This, along with sedimentological data, indicates that after the top of the "Johnson Farm sandstone bed" was deposited, Lake Dixie deepened and expanded across the area to an eventual maximum extent north of Cedar City and Zion National Park and east to Kanab. How far Lake Dixie extended south into Arizona and west into Nevada is unknown.

Many of the fish preserved in the Whitmore Point Member are large and include two new species we named in 2006: the hybodont (spiny, freshwater) shark *Lissodus johnsonorum* and the lungfish *Ceratodus stewarti*, both about 3-4 feet long. Other fish include a large coelacanth (lobe-fined fish) similar to *Chinlea* (about 6 feet long) and abundant semionotid fish as much as 4 feet long, probably all belonging to the genus *Semionotus*. *Semionotus* was shaped like a modern carp, but completely covered in a "chain mail" armor of heavy, enamel-covered, diamond-shaped scales (ganoid scales) like the modern gar of the southeastern United States. The abundance of large fish lends additional support to the hypothesis that Lake Dixie was a very large lake.

The larger dinosaur teeth recovered from the SGDS are almost certainly from the theropod dinosaur that made the *Eubrontes* tracks. A well-preserved thoracic vertebra from the SGDS suggests the dinosaur may have been a relative of the double-crested theropod *Dilophosaurus*, which is known from several specimens in the overlying Kayenta Formation, where hundreds of *Eubrontes* tracksites are documented. The large SGDS teeth are tall, slender, and typically cylindrical, exhibiting a distinct wear pattern in which the serrated ridges (carinae) along the front and back margins of the teeth are worn from the tip down to the base. We hypothesized this may be from the enamel-on-enamel wear produced by these dinosaurs biting through the "chain mail"-covered semionotids. Spinosaurid teeth from the

(A) Area of the SGDS showing location of Lake Dixie shoreline just prior to deposition of the "Johnson Farm sandstone bed." Red area indicates location of Washington County School District Quarry #1, where the swim track blocks were excavated. Cross section A–A' shown in C. (B) Map of area of Washington County School District Quarry with orange indicating mapped blocks and black areas representing missing blocks. Line labeled SW–NE indicates cross section within red box in C. (C) Cross section showing relative change in thickness of "Johnson Farm sandstone bed." Red box indicates area shown in B.





Reconstructions of larger fossil fish from SGDS.

Andrew R.C. Milner (right) is the City Paleontologist and Curator at the St. George Dinosaur Discovery Site at Johnson Farm in St. George, Utah. His research primarily includes vertebrate tracks and fossil fishes of the Mesozoic, particularly the Late Triassic and Early Jurassic. Andrew studied late Pleistocene Champlain Sea fossils in eastern Canada for the Canadian Museum of Nature in Ottawa, and spent five seasons working on the Middle Cambrian Burgess Shale in Yoho National Park, British Columbia, Canada, for the Royal Ontario Museum (Toronto, Ontario).

Dr. Jim Kirkland (left) is the Utah State Paleontologist with the Utah Geological Survey. An expert on the Mesozoic, he has spent more than 30 years excavating fossils across the southwestern U.S. and Mexico, and has authored and co-authored more than 75 professional papers. The reconstruction of ancient marine and terrestrial environments, biostratigraphy, paleoecology, and mass extinctions are some of his interests. He has discovered and described numerous new dinosaurs including several armored and horned dinosaurs, and several meat-eating dinosaurs of which the giant dromaeosaur *Utahraptor* is the best known. He has also described and named many fossil mollusks and fish.

Early Cretaceous of North Africa are similar and display the same sort of distinctive wear pattern. Spinosaurids are thought to have fed to a significant degree on fish, as indicated by their crocodile-like skulls. The huge semionotid *Lepidotes* is commonly preserved in the same environments with spinosaurid remains, suggesting that this type of tooth wear is a result of eating fish covered in heavy, enamel-covered scales.

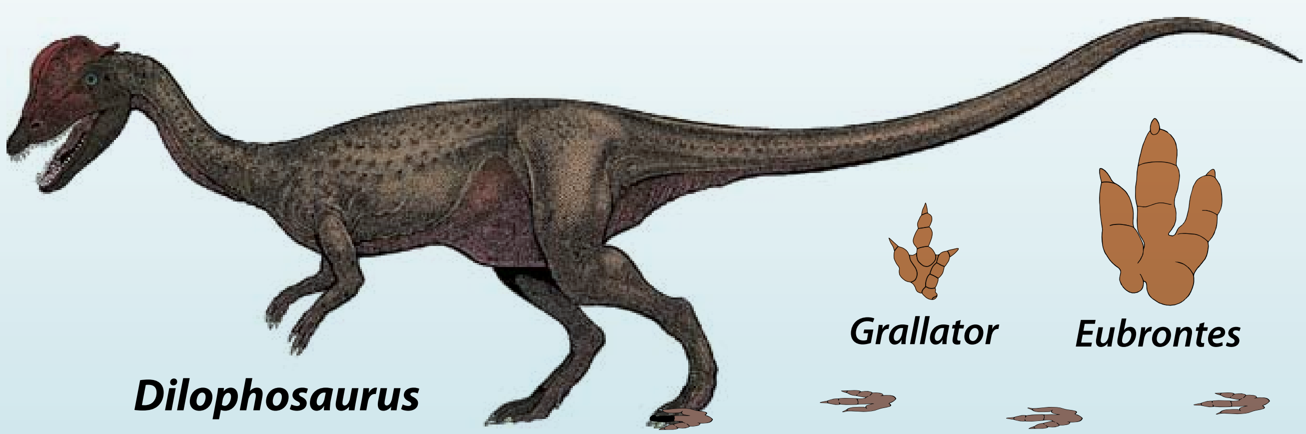
Dilophosaurus exhibits a few features that suggest fish-eating behavior:

1) The ends of the jaws are expanded laterally to form an interlocking rosette of long teeth at the front of the jaws. Spinosaurids have a similar feature, which is well developed in the Indian gharial—the most fish-eating of all modern crocodilians.

2) Unlike other meat-eating dinosaurs, *Dilophosaurus'* nasal openings are retracted back from the front of the jaws. Spinosaurid nasal openings are even more extremely retracted. This characteristic may have limited the splashing of water into their nostrils while fishing.

3) Both *Dilophosaurus* and spinosaurids have relatively long arms, which, with their well-developed claws, may have helped them catch fish.

Finally, the Triassic-Jurassic boundary has been proposed to fall within the Moenave Formation. Dramatic faunal turnover has been proposed for the Late Triassic and, whether as a period of more rapid faunal loss than normal or a mass extinction, the subsequent earliest Jurassic was a very different and apparently more impoverished world biologically. The abundance of large fish in Lake Dixie would have provided an important source of protein in this post-cataclysmic world.



Reconstruction of Dilophosaurus *from the Kayenta Formation with the Eubrontes and Grallator track types. Illustration by Brad Wolverton.*

NEW HORNED DINOSAURS FROM THE WAHWEAP FORMATION

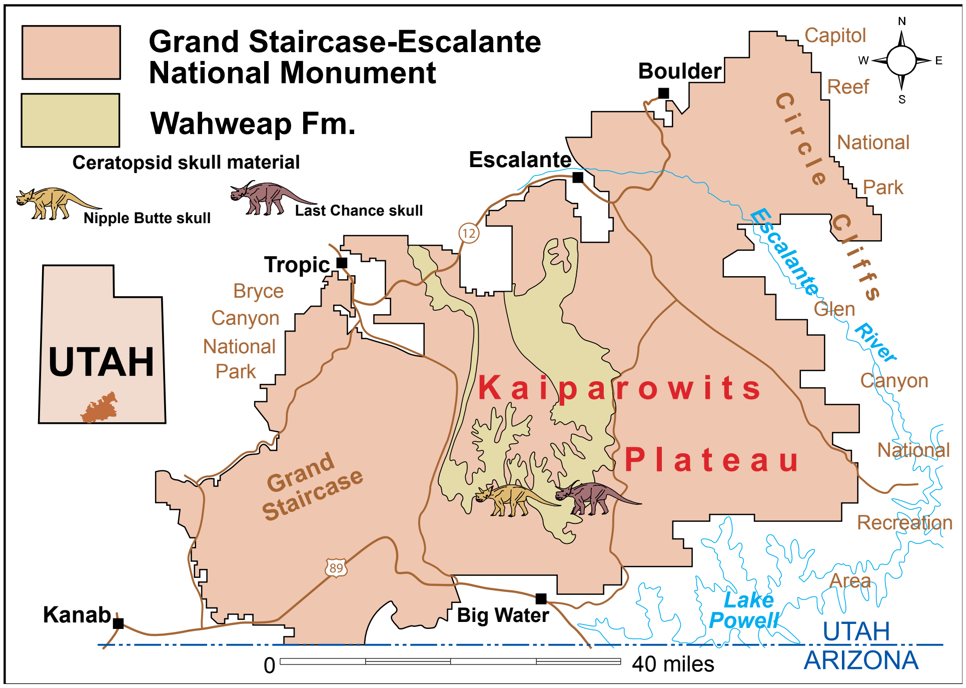
Grand Staircase–Escalante National Monument, Southern Utah

by James I. Kirkland and Donald D. DeBlieux

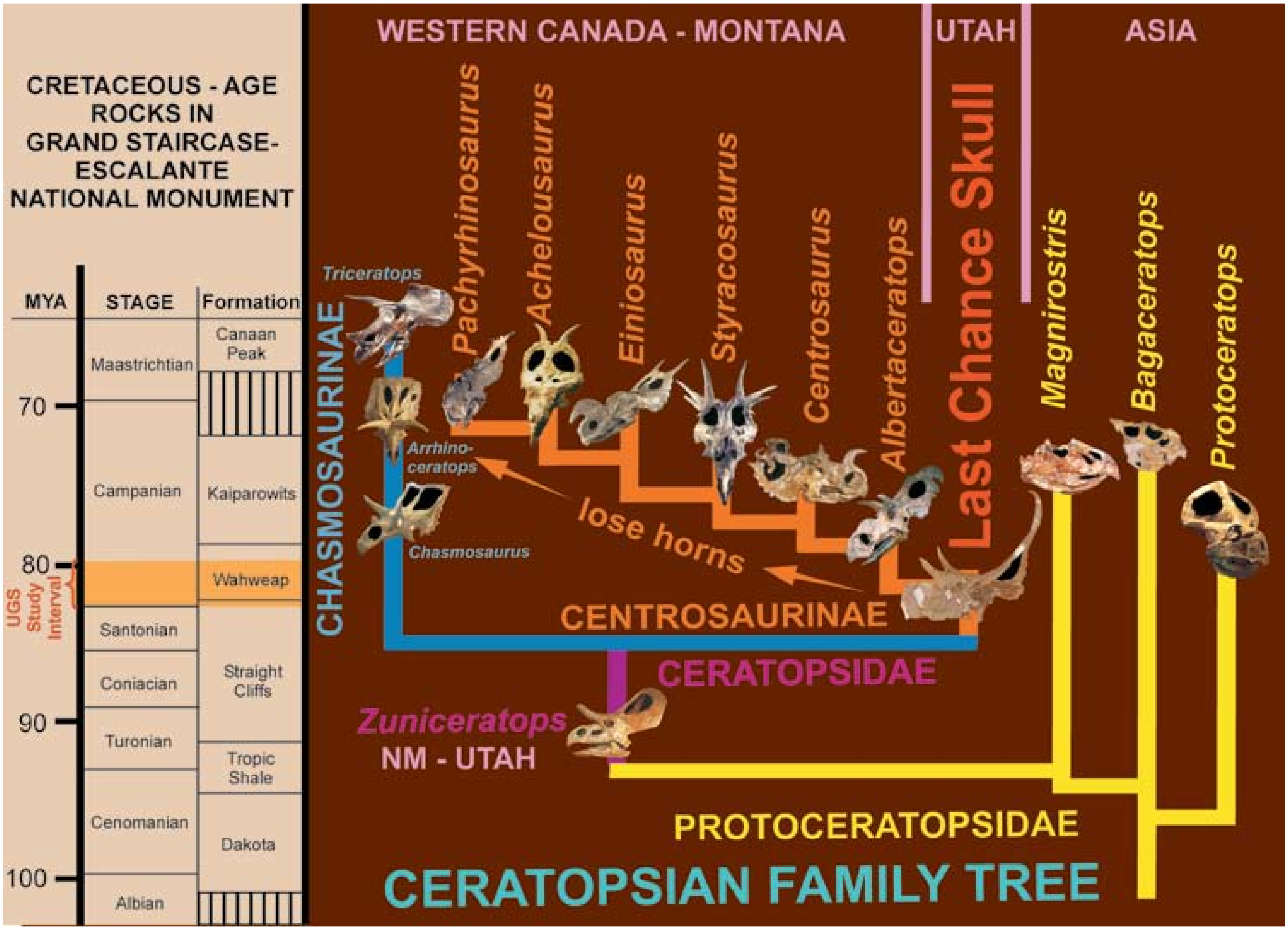
The Utah Geological Survey has been funded by the Bureau of Land Management to conduct paleontological site inventories in the lower Campanian (84–80 million years ago) Wahweap Formation in Grand Staircase-Escalante National Monument. Our work has resulted in the discovery of two undescribed species of ceratopsid (horned) dinosaurs. The ceratopsid family of dinosaurs is restricted to western North America and is best known from the latest Cretaceous (75–65 million years ago) as typified by the well-known *Triceratops*. They are quadrapedal plant-eating dinosaurs characterized by narrow beaks, large facial horns, and large, variously ornamented frills of bone extending off the back of their skulls. They are derived from the generally hornless and simply frilled protoceratopsids known from Asia and North America from 110–65 million years ago. The transition from protoceratopsids to ceratopsids is shown by *Zuniceratops* from New Mexico and Utah (92 million years ago), which has two horns above the eyes, no horn on the nose, and a simple frill. The ceratopsids are in turn divided into two subfamilies: the chasmosaurines with longer skull, large horns over eyes, and moderately ornamented frills; and centrosaurines with short, deep skulls, large nasal horns (lost in later taxa), and highly ornate frills.

The collection of the first partial skull from Nipple Butte was reported in *Survey Notes* (v. 33, no. 1) in 2001. It was collected from low in the Wahweap Formation on the south side of the Wahweap outcrop belt. Unfortunately, although a new species, the skull was not complete enough to distinguish it from other similar skulls because the frill at the back of the skull was not completely preserved. Frills exhibit many critical features used to distinguish the various species of horned dinosaurs from each other—a useful fact for both other ceratopsians and paleontologists. However, the skull was complete enough to establish this specimen as the first centrosaurine discovered that has large horns over its eyes. Thus, it provided a link between the centrosaurines and the more primitive *Zuniceratops*.

In 2002, co-author Don DeBlieux discovered a skull weathering out of sandstone near the middle of the Wahweap Formation near Last Chance Creek on the east side of the Wahweap outcrop belt. Collection of bone on the surface and cleaning of the block revealed a nearly complete skull lying on its left side; part of the right side had eroded away, with much of the skull still imbedded in the rock. We spent eight days using a gas-powered cutoff saw to separate the block containing the skull from the surrounding ledge. Finally, in September 2005, the block was transported by helicopter to a truck waiting on a nearby road and driven to the UGS preparation lab in Salt Lake City. Since then, more than 700 hours of preparation has exposed a beautifully preserved skull with all the features needed to fully characterize this new dinosaur.



Grand Staircase-Escalante National Monument with outcrop of lower Campanian Wahweap Formation and general locations of Nipple Butte and Last Chance ceratopsian skulls indicated.



Hypothesized ceratopsian family tree plotted against a linear time scale in millions of years ago (MYA) and Cretaceous rocks in Grand Staircase-Escalante National Monument. Note that frill is not preserved on skull of Magnirostris. *Francois Gohier provided many of the ceratopsian skull photographs.*

The Last Chance skull is the oldest, and the first diagnosable, centrosaurine recovered south of Montana. The skull is about one meter (3 ft) long from the beak to the back of the frill, where a pair of curved spines add another 0.5 meter (1.5 ft) to the total length. The front of the skull is shorter and deeper than other centrosaurines, and is unique in bearing two low horns in a line above the large nasal opening. The erect horns over the eyes are 25 cm (10 in) long and extend over the nasal horns. Of all known centrosaurines, the Last Chance skull is unusual in having large blade-like spines extending laterally from its cheeks and a frill that narrows away from the skull toward the spines. With the many low spines along the sides of the frill, this new ceratopsid would have been impressive in life with 24 horn-covered spines of various sizes sticking out from the skull.

The long horns over the eyes and small nasal horn are primitive characters as indicated by the ceratopsid sister taxon *Zuniceratops.* Additionally, in all other centrosaurines (including the Nipple Butte skull) and in all chasmosaurines, the lower bone making up the frill (squamosal) expands laterally so there is a notch between the back of the skull and frill that housed the external ear. In the Last Chance skull, *Zuniceratops*, and the protoceratopsids, the notch (perhaps to protect the ear) is not developed. Taken together, these observations indicate that the Last Chance ceratopsian is the most primitive of all the known centrosaurines.

A final feature of considerable importance is the presence of an extra hole in the side of the skull behind the nasal opening. This opening is not present in the more advanced centrosaurines and chasmosaurines, but is present in *Zuniceratops* and two closely related species of protoceratopsids: *Bagaceratops* and the larger *Magnirostris*. *Magnirostris* also possesses tiny horns over its eyes. Thus, the Last Chance ceratopsian, together with *Zuniceratops*, provides substantial evidence that among all the known Asian protoceratopsians, *Magnirostris* is the closest relative of the large horned ceratopsids of North America.

The illustration on the cover of this issue is a life reconstruction of the Last Chance ceratopsian, illustrated by Brad Wolverton.

Colorful Coal "Clinker" Close to Castle Gate, Carbon County

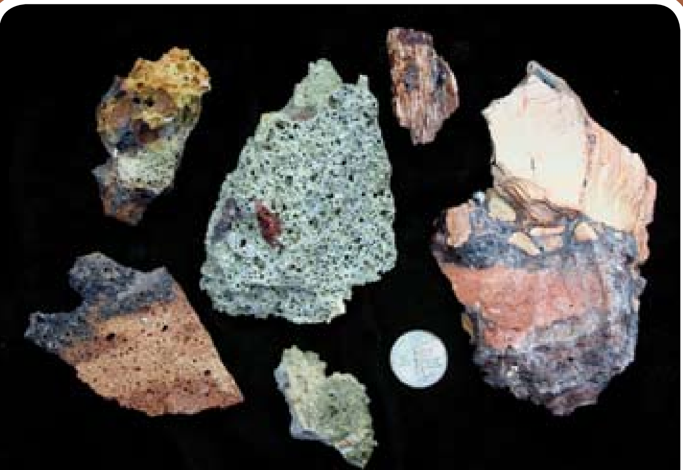
By Mark Milligan

Geologic Information: You do not need a volcano for fire and molten rock—a coal seam will suffice. This GeoSights article highlights "clinker," an odd assortment of rock heated, baked, and melted by burning coal seams.

Coal seam fires burn throughout the world. The fires can be ignited by human activities or naturally by lightning strikes, wildfires, and spontaneous combustion. In the case of spontaneous combustion, heat is generated when coal chemically reacts with oxygen (oxidation) and moisture (the "heat of wetting"). These chemical reactions can take place at the surface with atmospheric oxygen and precipitation or in the shallow subsurface with seasonal fluctuations of the water table.

Once ignited, the coal is reduced to ash, and its volume can decrease by more than 90 percent. Overlying rocks can then collapse into the resultant void space. Cracks formed by collapse can propagate to the surface, which allows more oxygen to reach additional coal below the surface and keeps the fires going.

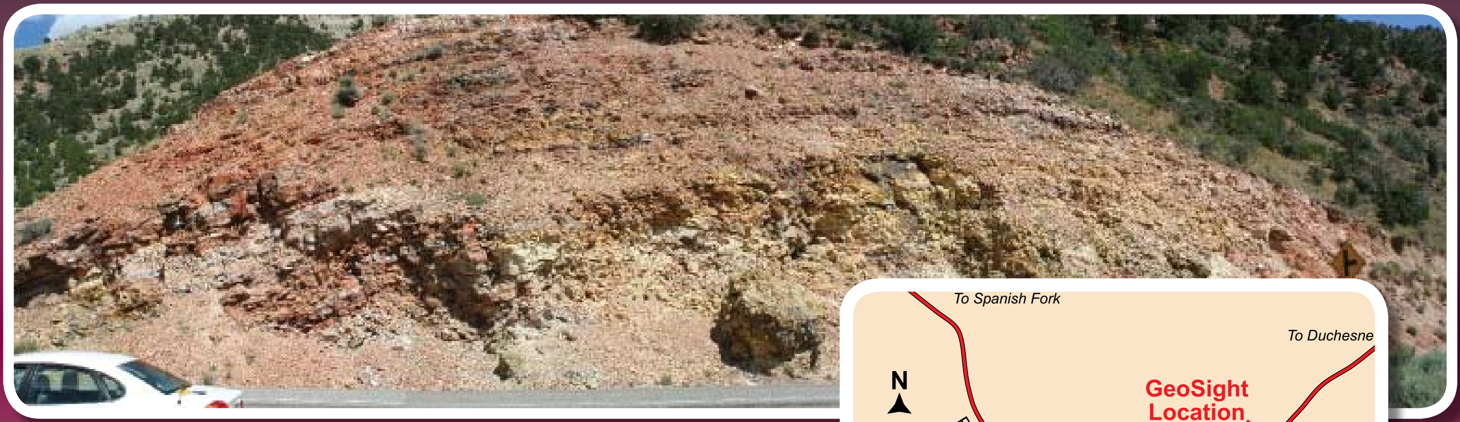
A troubling result of uncontrolled coal fires is the release of carbon dioxide (CO_2), the greenhouse gas that has the biggest impact on global warming. Some researchers estimate that coal fires in China alone release as much CO_2 as all cars and light trucks in the United States, or roughly 2 to 3 percent of the annual worldwide emissions of CO_2 from fossil fuels.



"Clinker"—a colorful assortment of rock heated, baked, and melted by burning coal seams. Quarter for scale.

Clinker is derived from shale, siltstone, and sandstone beds surrounding the burned coal seams. The term "clinker" comes from the "clink" sound made when the baked rocks are walked on or struck by a rock hammer. Taken out of the context of its outcrop, clinker eludes identification. At this GeoSight location, some of the clinker looks like vesicular basalt in hues of red, orange, and brown, or even pistachio green. Some is nearly glassy like obsidian but with colors akin to Neapolitan ice cream. Much of the coloration comes

GEOSIGHTS



"Clinker" outcrop on southeast side of U.S. Route 191.

from iron impurities. The red hues form under oxidizing conditions (iron oxides), while the greens form under reducing (oxygen-depleted) conditions. Fused breccias can form when overlying rock collapses into the void left by the burned coal seams.

In Utah, the Burning Hills and Smoky Mountain of Kane County get their names from naturally burning, deep underground coal seams. But Carbon County is the place to see the clinker described above. The clinker of this outcrop is within a mudstone-dominated section of the Late Cretaceous (about 84 million years old) Blackhawk Formation, an important coal-producing geologic unit of central Utah.

As a somber side note, on March 8, 1924, an explosion resulted in the deaths of 172 men in the nearby Number Two Mine of the Utah Fuel Company, located at Castle Gate. This was the third-deadliest coal mine disaster in the United States at the time, and remains the tenth deadliest. Some victims of the explosion are buried in the historic Castle Gate Cemetery directly across the highway from the outcrop.

How to get there: This clinker outcrop is located roughly 90 miles southeast of Salt Lake City and 10 miles northwest of Price, near the former town site of Castle Gate. The town of Castle Gate was dismantled in 1974 to make way for the current coal-loading facility that can be seen from U.S. Route 6. To get to the outcrop from Route 6, turn northeast onto U.S. Route 191 and travel approximately 1.3 miles to the small pullout on the left (just past the entrance to the Castle Gate Cemetery). The clinker outcrop is across the highway from this pullout. Please use caution near the highway, as the Castle Gate Cemetery is full.

UGS CHAIRS THE GOVERNOR'S GEOLOGIC HAZARDS WORKING GROUP

By Gary E. Christenson and Francis X. Ashland

Landslides in 2005 and 2006 that damaged houses in approved, permitted subdivisions highlighted a need to evaluate the land-use-regulation process in Utah and identify possible improvements to prevent future damage. To perform this evaluation, Utah Governor Jon M. Huntsman, Jr., approved establishing the Geologic Hazards Working Group (GHWG), chaired by the Utah Geological Survey, to develop recommendations to improve the subdivision-approval process, identify responsible parties and resources needed, and determine how state agencies, including the UGS, can help.

Members of the GHWG include local government officials representing cities and counties that have experienced losses from geologic hazards; representatives of the American Planning Association, Utah City Engineers Association, Utah League of Cities and Towns, and Utah Association of Counties; and state government officials from agencies that provide assistance to local governments. The group held a series of meetings between September 2006 and August 2007 and developed 11 draft recommendations. Public comments on draft recommendations, chiefly from developers, consultants, and homeowners affected by landslides, were sought at a public meeting in June 2007.

In summary, the GHWG recommends that (1) local governments adopt, implement, and enforce ordinances that effectively address geologic hazards, (2) pre-development geologic-hazards reports by developers' consultants objectively assess geologic hazards, recommend prudent actions to reduce risks, and be reviewed by professionals acting on behalf of local governments, and (3) developer's consultants inspect, monitor, and provide final documentation, with local government oversight, that site grading and develop-

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The Utah Geological Survey's Ground-Water Monitoring Project in Utah's West Desert

by Hugh A. Hurlow and Stefan Kirby

During its 2007 session, the Utah State Legislature charged the Utah Geological Survey (UGS) with establishing a ground-water monitoring network in Utah's west desert. The project is in response to proposed large-scale ground-water pumping in Spring and Snake Valleys, eastern White Pine and Lincoln Counties, Nevada, by the Southern Nevada Water Authority (SNWA), the principal water supplier for the Las Vegas area. Ground-water withdrawal by the proposed SNWA wells may cause long-term, large-scale declines in ground-water levels in Utah in western Millard, Juab, and Beaver Counties, and perhaps areas farther east including Fish Springs National Wildlife Refuge. Significant ground-water-level declines could have serious detrimental economic and environmental effects in Utah. For additional background on the proposed ground-water withdrawal, refer to the article in the May 2006 issue of *Survey Notes* (v. 38, no. 2).

The UGS ground-water monitoring network will include wells of various depths in various hydrogeologic settings (see accompanying map). Drilling began in early July 2007 and will continue sporadically over as much as three years. The objectives of the monitoring network are to define background water-level and geochemical conditions prior to SNWA pumping, and to quantify any changes in these conditions after pumping begins. The wells will be for monitoring purposes only, for at least the next 50 years.

Five classes of wells are planned: (1) paired wells screened in the carbonate-rock and basin-fill aquifers, 100 to 1500 feet deep; (2) wells in the basin-fill aquifer adjacent to areas of current agricultural use, 250 to 400 feet deep; (3) water-quality monitoring wells designed to track movement of saline ground water in the Great Salt Lake Desert near areas of current agricultural use; (4) spring-gradient wells designed to measure the hydraulic gradients contributing to spring discharge; and (5) shallow wells (piezometers) in Wetlands of Conservation Concern (i.e., wetlands occupied by Species of Conservation Concern) as defined by the Utah Division of

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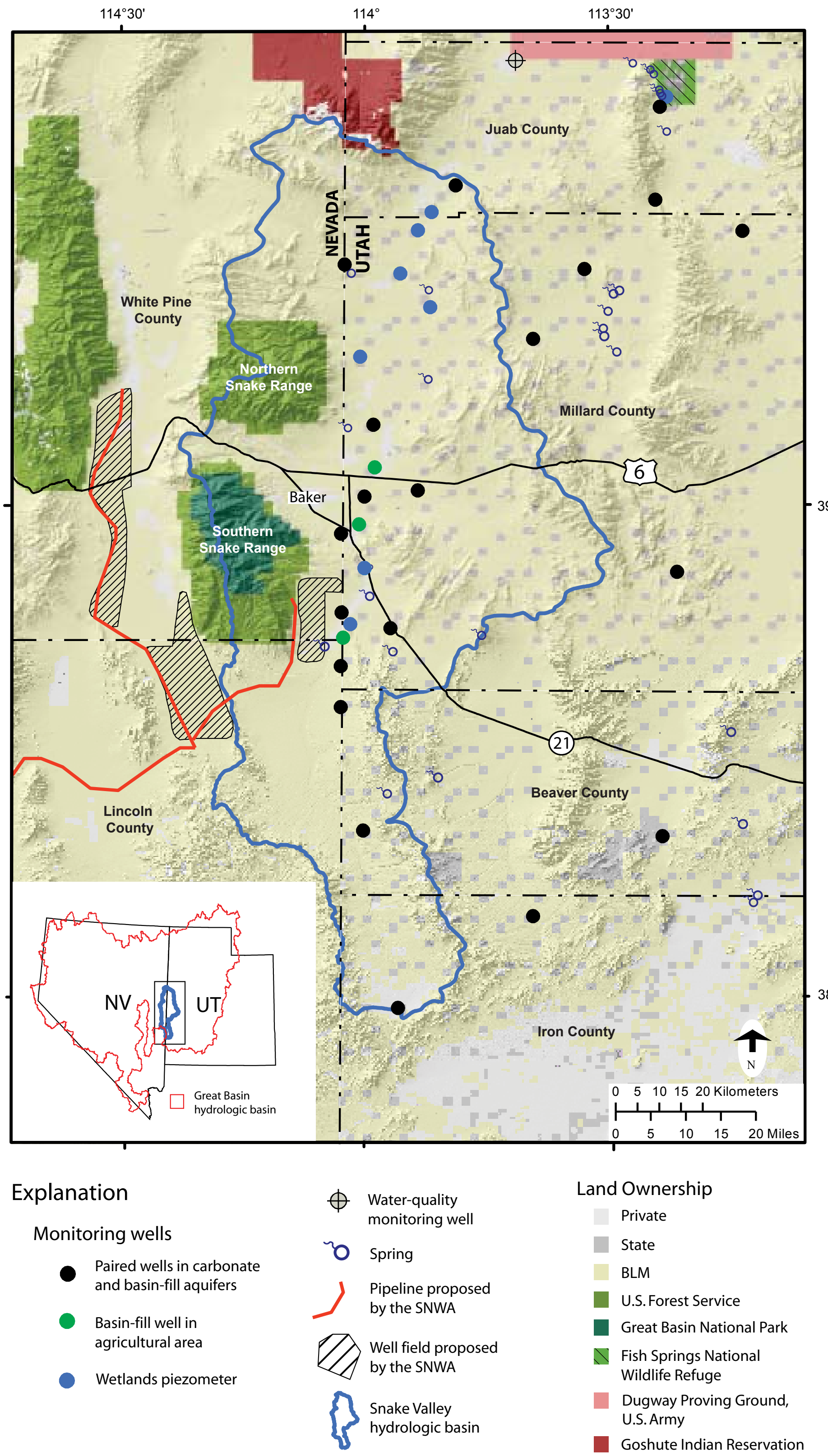

Project area showing proposed new ground-water monitoring wells.

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Wildlife Resources. A pumping well and two additional observation wells will be installed at two of the sites to accommodate aquifer testing. The UGS will perform aquifer tests and initial water-quality sampling and analysis, including major ions, stable and radiogenic isotopes, and dissolved gasses. The wells will be equipped with down-hole water-level data loggers.

Data from this project will improve our understanding of the regional ground-water flow systems in the carbonate and basin-fill aquifers in the west desert. The data may be used in a wide variety of applications, including constructing a regional ground-water flow model, geochemical modeling of the ground-water flow systems, hydrologic and biologic monitoring programs similar to those currently under design for Spring Valley, and establishing possible limits on future withdrawals.

The SNWA project has generated much activity in addition to the UGS ground-water monitoring project. In April 2007, the Nevada State Engineer ruled that SNWA may withdraw 40,000 acre-feet per year from Spring Valley for 10 years and an additional 20,000 acre-feet per year thereafter, subject to possible restrictions or cutbacks depending on the results of ground-water and biological monitoring during the first five years of pumping (http://water.nv.gov/scans/rulings/5726r.pdf.). During the Spring Valley hearing process, the U.S. Department of the Interior (DOI) agreed to withdraw its protests of SNWA's water-right applications in exchange for the establishment of a hydrologic and biologic monitoring program, to be cooperatively planned by SNWA and several divisions within the DOI (http://water.nv.gov/hearings/spring%20valley%20hearings/stipulation%20for%20withdrawal%20of%20protests.pdf). The Nevada State Engineer has not yet scheduled hearings on the Snake Valley applications. Negotiations between the Utah and Nevada State Engineers on an interstate water-use agreement for Snake Valley are currently in progress. The U.S. Geological Survey's Basin and Range Carbonate Aquifer System Study (BARCASS) report was released for public comment on June 1, 2007 (http://nevada.usgs.gov/barcass/index.htm) (see Director's Perspective in this volume). The Bureau of Land Management's (BLM) Environmental Impact Statement (EIS) for the proposed well and pipeline system is also underway (http://www.blm.gov/nv/st/en/prog/planning/groundwater_projects.html).

In addition to implementing the ground-water monitoring program, the UGS will continue its active role in the Snake Valley ground-water issue by monitoring developments on all of the projects mentioned above, reviewing the BARCASS report, maintaining its present network of six down-well transducers in Snake Valley, providing hydrogeologic review of the BLM's EIS process, and participating in a biologic working group initiated by the Utah Division of Wildlife Resources.

(continued from page 7)

ment conform to specifications. Other recommendations include possible geologic-hazards disclosure in real estate transactions, and post-disaster technical investigations to determine causes and identify where the subdivision-approval process failed.

The GHWG determined that state agencies can help local governments principally by providing technical resources and funding to assist in writing ordinances, prepare and update geologic-hazards maps, and assist with other technical aspects of the development-approval process. Many of the GHWG's recommendations can be completed with existing resources, but some involve a significant increase in workload to expand programs. The GHWG final report is planned for presentation to Governor Huntsman in late fall 2007.

(continued from inside cover)

ditional ground-water appropriation in the area have been filed with the respective State Engineers in Nevada and Utah and are awaiting consideration in each state. Included in the pending applications are those by the SNWA in Nevada to export 25,000 acre-feet/year to the Las Vegas area, 10,000 acre-feet/year by the Central Iron County Water Conservancy District in Utah to be exported for use in Iron County, and approximately 9000 acre-feet/year by SITLA for irrigation of Utah Trust Lands located in Snake Valley. Local water users have reported declining springs but little decline in ground-water levels has been noted to date.

The new ground-water monitoring wells in Utah's west desert come at an opportune time. Although they may not provide immediate scientific insight to the sustainable yield of the ground water in the region, the new knowledge that these wells will produce will be immense and will help with the long-term management of this precious resource. The wells will provide important baseline information concerning ground-water flow paths, relative amounts and sources of recharge and discharge, and water-quality data for the Snake Valley ground-water flow system. In particular, a better constrained estimate of recharge of the shallow, unconsolidated aquifer (which represents most of the accessible water storage) from the deep carbonate aquifer will be very important. The UGS welcomes input from researchers and the public on how to maximize the scientific value derived from this investment.

Does Your Shale Have Gas? Utah Shales Do!

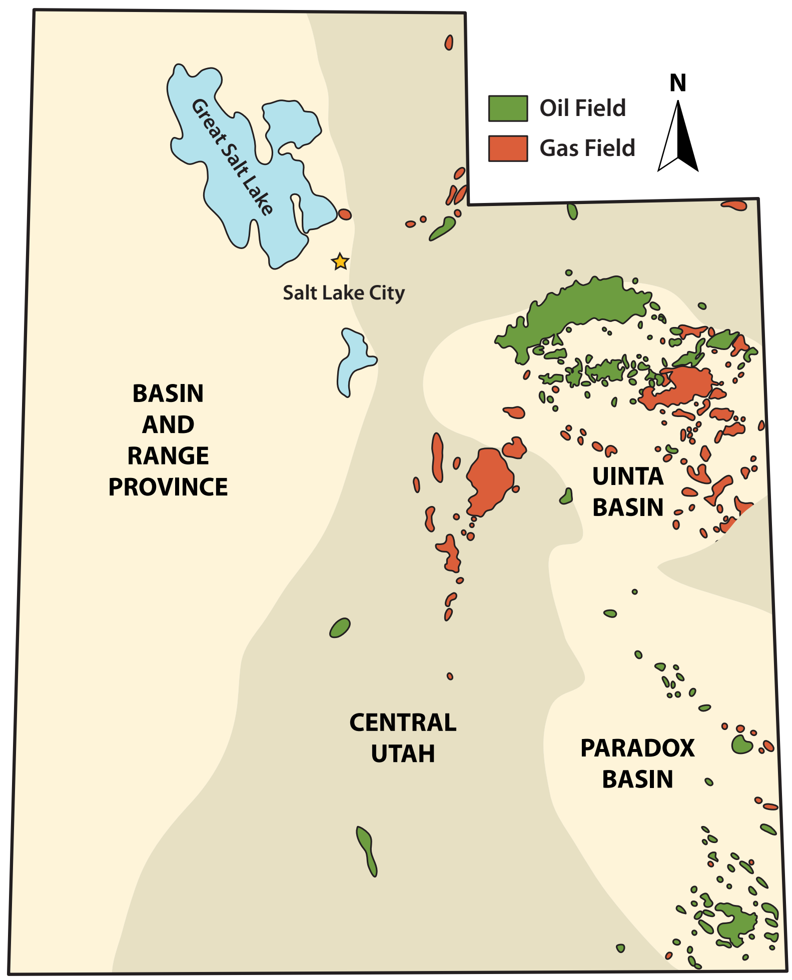
by Craig D. Morgan

In the quest to meet the ever-increasing demand for energy, companies are exploring for rocks such as shale that not many years ago were considered incapable of producing economic quantities of natural gas. A well-known success story is the Barnett Shale in Texas, which contains trillions of cubic feet of gas and has become an economic success as a result of higher gas prices as well as improved drilling and completion techniques. Recently, exploration for "shale gas" has become a major focus in Utah. Numerous wells have been completed in the Cretaceous Mancos Shale in the Uinta Basin, two wells have recently been completed in the Pennsylvanian Paradox Formation shales in the Paradox Basin, and a well has been drilled and others are planned to test for gas in shales within the Mississippian Doughnut Formation in central Utah.

Shale is considered an unconventional reservoir by the oil and gas industry. Most natural gas is produced from conventional reservoirs consisting of porous (open space within a rock) and permeable (the capacity to transmit gas or liquid) sandstone or limestone where geologic structure or depositional changes in the rock have trapped the hydrocarbons. Shale, a fine-grained sedimentary rock consisting mostly of clay and having very low permeability, starts as mud deposited on the floor of a sea or lake, and contains organic remains of the plants and animals that lived in the water. If the mud is eventually buried deep enough, elevated pressures and temperatures turn it into shale and the organic matter is converted into hydrocarbons. The pressures that develop with deep burial cause some of the hydrocarbons to be pushed out of the shale into porous sandstone or limestone beds, but much of it remains trapped within the shale. Although shale beds are commonly the source of hydrocarbons, they are generally considered poor reservoir rock and have rarely been targets of exploration for natural gas because the very low permeability makes production difficult. New well treatments, however, can induce a significant number of fractures, which serve as pathways for the gas to migrate from the shale to the wellbore. Many shale gas wells produce low volumes of gas on a daily basis but will produce for many years. Higher gas prices make these low-volume gas wells economical.

Since a shale bed can be present throughout a large area, and does not require a structural or depositional trap to form a gas reservoir, it could potentially become a major resource play—a large area with low geologic risk but a significant amount of recoverable natural gas. To be a good gas target a shale bed needs to (1) be widespread, (2) contain sufficient organic material, (3) have been buried deep enough to generate dry gas (dry gas means the well does not produce water or oil with the gas), and (4) be thick enough (typically 100 feet or more) or have sufficient natural fractures to contain significant recoverable reserves.

To encourage exploration and development of shale gas in Utah, the Utah Geological Survey recently funded three shale gas studies that are available on CD-ROM from the Natural Resources Map and Bookstore: (1) *Shale Gas Reservoirs of Utah: Survey of an Unexploited Potential Energy Resource*, by Steven Schamel, Open-File Report 461; (2) *Shale Gas Resources of Utah: Assessment of Previously Undeveloped Gas Discoveries*, by Steven Schamel, Open-File Report 499; and (3) *Integrated Sequence Stratigraphic and Geochemical Resource Characterization of the Lower Mancos Shale, Uinta Basin, Utah*, by Donna Anderson and Nicholas Harris, Open-File Report 483.



Oil (green) and gas (red) fields of Utah. Most of the current drilling is occurring in the Paradox and Uinta Basins. Several shale gas wildcat tests are scheduled to be drilled in central Utah in the near future. Some areas within the Basin and Range Province may have shale gas potential.

What are "Potholes" and how are organisms able to live in them?

By Jim Davis

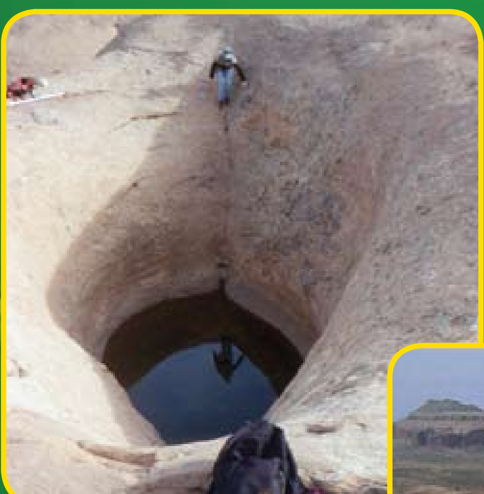
Potholes, which are depressions eroded in bedrock, are common in southern Utah. Also referred to as weathering pits, tanks, tinajas, and waterpockets, some of Utah's best examples are in aptly named places like the Waterpocket Fold at Capitol Reef National Park; Pothole Point in Canyonlands National Park; Swiss Cheese Ridge near Moab; and Cookie Jar Butte, a peninsula on Lake Powell. Potholes are usually not a part of an active drainage; rather, they often form on flat or slightly dipping bedrock, typically sandstone surfaces, and huge potholes can form atop knolls, domes, and fins, and along the edges of mesas. Acting as rain gauges, they capture water directly from precipitation. Potholes range in size from a few inches across to large cavities more than 50 feet deep that contain hundreds of gallons of water. Their enlargement is slow on the human timescale, but over longer periods of time the complex interactions of rock, water, and life gradually increase the dimensions of these hollows.

Weathering and erosion of potholes results, at least in part, from biological activity. Quartz sandstone is ordinarily resistant to moisture-induced chemical changes but can be more rapidly altered through "geomicrobiologic" processes. Some species of bacteria are capable of "consuming" siliceous minerals, and plants such as diatoms then sequester the silicon and other elements put into solution. When pools dry up, diatom skeletons, organics, and other fine particles are subsequently carried out of the pothole by winds. The sandstone basins are also "sealed" by mats of cyanobacteria, fungi, algae, and fine sediment. This surface "biofilm," along with subsurface "endolithic" cyanobacteria (within-rock organisms), prevents water from soaking into the otherwise porous sandstone. Organisms on and within the rock represent a "weathering front" wherein water is retained, and along which the pothole is enlarged by a combination of biological and physical means.

There is an amazing diversity of life in pothole pools. Although some species are geographically widespread, many are rare, narrowly endemic to certain locations, or unique only to these rock pools. Transitory or ephemeral waters like potholes are ancient environments inhabited by ancient organisms. Many species have survived to the modern day only because these rain-filled pools are available. The pools are free of many predators such as fish and some aquatic insects found in permanent waters like oceans, lakes, ponds, or tidal pools. Animals of pothole pools appear to have remained basically unchanged over the course of hundreds of millions of years, having fossil records dating from the Mesozoic Era and earlier. Accordingly, they are described as "Mesozoic lifeboat niches" for organisms that have not survived in other habitats, but who have found continuing sanctuary in potholes through geologic time.

The trade-off of using pothole pools as a refuge is that organisms must be able to endure great and rapid changes in water temperature, pH, oxygen and carbon dioxide concentration, and ion concentration. Perhaps most significantly, they must endure the periodic drying of the pool. Additionally, pools can freeze solid in winter, effectively eliminating the availability of liquid water. Species must also overcome such ecological dynamics as overcrowding, predation, and competition for resources. Yet it is these extreme conditions that have allowed for unusual biological niches to open, niches that are occupied by strange creatures that posses extraordinary capabilities for survival in such a severe aquatic environment.

Background: Microscopic views of diatoms from pothole pools in the vicinity of Moab, Utah.



A person descends along a fracture into a gigantic pothole in the Jurassic Navajo Sandstone near the Slickrock Trail, Moab, Utah. Pothole location is commonly related to the presence of fractures or joints in the bedrock.

Small, circular potholes occur along the edge of a mesa above Bartlett Wash, Grand County, Utah. These pools are in the Jurassic Moab Member of the Curtis Formation.

"GLAD YOU ASKED"

SURVEY NEWS

Crawford Award recipients Bill Case, Chris Wilkerson, Mark Milligan, and Sandy Eldredge.

EMPLOYEE NEWS

Welcome to **Jim Davis**, the new geologist in the Geologic Information and Outreach Program. Jim has his M.S. in geography from New Mexico State University. **Rich Emerson** has filled the geologist position in the Ground Water and Paleontology Program and comes to us from Weber State University where he received his B.S. in geology. **Emily Chapman** joins the bookstore team, replacing **Jeff Campbell** who left in June. Emily has a B.S. in geology and will be a great asset to the bookstore. **Matt Affolter** has joined the Ground Water and Paleontology Program to assist with the drilling project in Utah's west desert.

CRAWFORD AWARD

The Utah Geological Survey awarded its prestigious Crawford Award to UGS geologists Sandy Eldredge, Bill Case, Mark Milligan, and Chris Wilkerson in recognition of the outstanding geologic publication, "Geologic Guide to the Central Wasatch Front Canyons, Salt Lake County, Utah." The presentation was made at the annual UGS awards picnic on June 29.

The publication is a comprehensive geologic guide to six major Wasatch Range canyons and includes background information on the regional geologic history, plus a geologic map of each canyon that highlights points of interest with photos and other illustrations. The publication has been a top seller in the Natural Resources Map & Bookstore; more than 100 copies were sold within the first two days of its release.

The Crawford Award was established in 1999 to commemorate the 50-year anniversary of the Utah Geological Survey. The award recognizes outstanding achievement, accomplishments, or contributions by a current UGS scientist to the understanding of some aspect of Utah geology or Earth science. The award is named in honor of Arthur L. Crawford, first director of the UGS.

CORRECTION

In the last *Survey Notes* (May 2007, page 9), the article on expanded deep, tight gas development in the Uinta Basin had an error on the graph of gas production. The vertical axis should have been labeled "Annual Gas Production (Bcf/year)."

NEW PUBLICATIONS

Geologic map of the Copperton quadrangle, Salt Lake County, Utah, by Robert F. Biek, Barry J. Solomon, Tracy W. Smith, and Jeffrey D. Keith, 2 pl., 1:24,000, ISBN 1-55791-738-8, M-219 .... $11.95

Geologic map of the Kolob Arch quadrangle and part of the Kanarraville quadrangle, Washington and Iron Counties, Utah, by Robert F. Biek, 3 pl., 1:24,000, ISBN 1-55791-749-3, M-217 .... $13.95

Geologic map of the Kolob Reservoir quadrangle, Washington and Iron Counties, Utah, by Robert F. Biek, 2 pl., 1:24,000, ISBN 1-55791-739-6, M-220 .... $11.95

Geologic map of the Cogswell Point quadrangle, Washington, Kane, and Iron Counties, Utah, by Robert F. Biek and Michael D. Hylland, CD (2 pl., 1:24,000), ISBN 1-55791-740-X, M-221 .... $14.95

The hydrogeology of Moab-Spanish Valley, Grand and San Juan Counties, Utah, with emphasis on maps for water-resource management and land-use planning, by Mike Lowe, Janae Wallace, Stefan M. Kirby, and Charles E. Bishop, CD (40 p. + 83 p. appendices, 12 pl.), ISBN 1-55791-764-7, SS-120 .... $24.95

Interim geologic map of the east half of the Loa 30' x 60' quadrangle, Wayne, Garfield, and Emery Counties, Utah, by Hellmut H. Doelling and Paul Kuehne, 28 p., 1 pl., scale 1:62,500, OFR-489 .... $8.00

Whole-rock major- and trace-element geochemical data for basaltic rocks in the St. George 30' x 60' quadrangle and adjacent areas, Washington, Iron, and Kane Counties, Utah, by Robert F. Biek and J. Buck Ehler, 1 pl., 1:100,000, OFR-500 .... *Web only*

Geologic map of the Twin Rocks quadrangle, Wayne County, Utah, by Samuel C. Sorber, Thomas H. Morris, and Jeremy M. Gillespie, 2 pl., 1:24,000, ISBN 1-55791-775-2, MP-07-3 .... $11.95

Geologic map of the Fruita quadrangle, Wayne County, Utah, by Briana T. McLelland, Thomas H. Morris, Daniel H. Martin, and Samuel C. Sorber, 2 pl., 1:24,000, ISBN 1-55791-773-6, MP-07-2 .... $11.95

Geologic map of the Golden Throne quadrangle, Wayne and Garfield Counties, Utah, by Daniel H. Martin, Thomas H. Morris, Samuel C. Sorber, and James L. Eddleman, 2 pl., 1:24,000, ISBN 1-55791-768-X, MP-07-1 .... $11.95

Recharge and discharge areas for the principal basin-fill aquifer, Beryl-Enterprise area, Iron, Washington, and Beaver Counties, Utah, by Kevin Thomas and Mike Lowe, CD (14 p. + 10 p. appendices, 1 pl., 1:125,000), ISBN 1-55791-770-1, M-225 .... $14.95

Recommended septic tank soil-absorption-system densities for the shallow unconfined aquifer in Cache Valley, Cache County, Utah, by Charles E. Bishop, Janae Wallace, and Mike Lowe, 35 p., ISBN 1-5579-771-X, RI-257 .... $14.95

Wildfires and debris flows in northern Utah, by Ashley Elliott, 4 p. flyer, PI-90 .... Free

Teacher's Corner

4th & 5th Grade Teachers!

Sign up now for two events in October

Earth Science Week

October 15–17, 2007 (Monday–Wednesday)

Come celebrate Earth Science Week at the Utah Geological Survey with your class.

Earth Science Week is observed in October throughout the nation as well as in other countries. The purpose is to increase public understanding and appreciation of the Earth sciences. Launched in 1998 by the American Geological Institute (AGI), efforts have grown on local, national, and international levels to highlight the vital role Earth sciences play in society's use of resources and interaction with the environment.

The Utah Geological Survey will host hands-on activities for 4th- and 5th-grade school groups October 15–17 (Monday–Wednesday), 2007. Groups are scheduled for 1½-hour sessions, during which they will pan for "gold," see how fossils are excavated, learn about rocks and minerals, and observe stream erosion and deposition.

For more information, please visit http://geology.utah.gov/teacher/esweek.htm

To make reservations, please call 801-537-3300.

"More! Rocks in Your Head" Workshop

Saturday, October 6, 2007

Generous funding from the American Association of Petroleum Geologists (AAPG) Foundation allows us to offer greatly reduced fees for this nationally acclaimed workshop. Held in conjunction with AAPG's Rocky Mountain Section meeting in the Salt Lake City area, October 7–9, 2007. Science core curriculum topics include rocks, minerals, fossils, and soil (4th grade); weathering and erosion (4th & 5th grades); geologic processes affecting Earth's surface (5th grade); and deposition of rock layers (5th grade). Teachers are guaranteed to walk away excited to share what they have learned with their students. Activities are hands-on and require little or no teacher preparation time. Teachers will receive:

- Teaching manual with activities
- Rock and mineral kit
- Classroom-ready materials
- 7 Re-Licensure Points

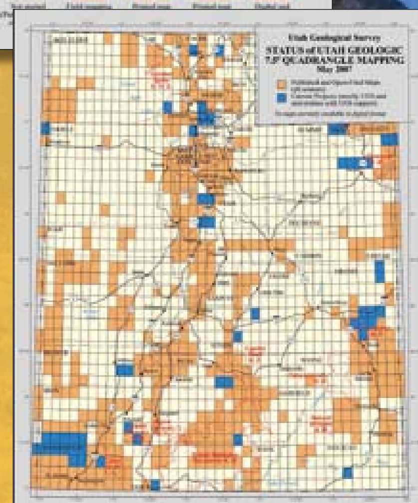
Hours: 8:30 a.m. – 4:00 p.m.
Fee: $40.00
Location: Department of Natural Resources
1594 W. North Temple
Salt Lake City, Utah

For further information, please contact Sandy Eldredge at 801-537-3325, sandyeldredge@utah.gov

Registration deadline: Sept. 20, 2007

UGS Geologic Mapping Program Requests Your Input on Future Mapping Priorities

We want your input on future mapping priorities!
Do you have a particular area where you would like to see new geologic mapping take place? Let us know by completing a user poll on the Utah Geological Survey website. You will find interactive maps showing areas of completed mapping and areas left to map. Simply click on a 30′x60′ or 7.5′ map or maps of interest and submit. Completing this poll will assist us in prioritizing future geologic mapping projects in Utah.



The Utah Geological Survey's Geologic Mapping Program maps Utah's geology at scales of 1:24,000 (7.5′) to 1:100,000 (30′x60′). These maps provide information on stratigraphy, structure, Quaternary geology, geologic hazards, economic geology, ground-water resources, paleontologic resources, and scenic geologic resources. UGS geologic maps are used by geologists, government officials, industry representatives, and the public to better understand Utah's geology, delineate the economic value and potential of property, and assess geologic hazards. Currently in the 30′x60′ quadrangle series, geologic maps of 17 of the 46 quadrangles have been released as GIS files (digital geographic databases) and 25 as printed maps (UGS, USGS, and university sources). In the 7.5′ quadrangle series, geologic maps of 422 of the 1512 quadrangles have been released as color or black-and-white printed maps.

To complete the mapping user poll, please go to the following website:
http://geology.utah.gov/databases/map_poll/

We thank you for your input and interest. For questions or comments, please contact grantwillis@utah.gov or donclark@utah.gov.

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