

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

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WETLAND MONITORING IN SNAKE VALLEY

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Design: Elizabeth Firmage

Cover: Springhead and associated wet meadow at an unnamed cluster of springs north of Big Springs in southern Snake Valley. Photo by Jennifer Jones.

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The Director's Perspective

by Richard G. Allis



The 2014 legislative session has just ended, and it included an important building block of ongoing general funds for the Utah Geological Survey. Our original source of funding for monitoring and maintaining groundwater wells in Snake Valley of Utah's west desert, as well as preserving the data and serving it to the public on our website, had dried up. The building block constitutes replacement funding that is essential for sustaining the valuable time series of hourly water-level and spring-flow changes that have now been collected for at least six years (see article by Hurlow and Jordan, page 4; also, the article by Menuz and others, page 1, discusses wetlands research being done in Snake Valley). The groundwater network includes 67 newly drilled wells, 11 previously drilled wells, and surface-flow gauges at six springs. Monitoring shows that in southern Snake Valley there are significant irrigation effects having an annual cycle, as well as effects from longer term groundwater pumping and variations in precipitation (and consequently recharge) to the groundwater. However, farther north and at greater distance from the main recharge source assumed to be in the Snake Range, these precipitation signals are much attenuated.

Modeling of the impacts of large-scale groundwater extraction by the Southern Nevada Water Authority (SNWA) for a water rights hearing several years ago consisted of a relatively simple model, and showed many tens of feet of drawdown over decades in southern Snake Valley. The UGS monitoring program now provides sufficient data for a more accurate and detailed model that can be calibrated against ongoing irrigation effects and natural recharge changes. The value of this continuous dataset steadily increases with time, and will allow Utah to more quantitatively predict future effects if SNWA decides to continue its plan for large-scale extraction of groundwater in southern Snake Valley.

Later this year, the UGS anticipates publishing a compilation of scientific findings from its studies in Snake Valley as a result of the groundwater monitoring program. This will be a Bulletin (*Hydrogeologic Studies and Groundwater Monitoring in Snake Valley and Adjacent Hydrographic Areas, West-Central Utah and East-Central Nevada*, compiled by Hugh A. Hurlow) containing 10 chapters and over 100 illustrations. Like the water-level data that are now accumulating, this Bulletin will be valuable for protecting Utah's groundwater resource in Snake Valley.

Former UGS Board Member Richard Kennedy Passes Away

Richard Kennedy, former UGS Board member (1993–2001) and university professor, passed away on February 9, 2014, in Henderson, Nevada. He was 84 years old. Dr. Kennedy had a distinguished teaching career and was recognized as the "Outstanding Science Educator" by the State of Utah

in 1994. He was a certified gemologist and appraiser and consulted in geology and mining for several companies. According to his family, he was "involved in his love of the wonders of geology throughout his life."





Utah Geological Survey researcher Ryhan Sempler collects water quality data at Clay Springs in Snake Valley while curious horses look on. In addition to supporting domestic and wild horses, wetlands in Snake Valley are home to two habitat-restricted species of concern, least chub and Columbia spotted frog, and over 20 species of snail found nowhere else in the world.

WETLAND MONITORING IN SNAKE VALLEY, UTAH

DEVELOPING A METHOD TO UNDERSTAND WETLAND CONDITION

by Diane Menuz, Jennifer Jones, Ryhan Sempler, and Richard Emerson

Although wetlands make up only one percent of Utah's landscape, they provide a large number of important benefits, including water quality enhancement, flood abatement, and critical habitat for a rich diversity of birds, frogs, and other animal species. In addition to these often indirect economic benefits, wetlands also generate revenue from hunting and bird watching opportunities, and by serving as pasture or watering grounds for livestock. Wetlands include everything from predominantly dry and barren saline playas to wet meadows at the edge of springs and cattail marshes filled with nesting birds. Water is the common factor that unites these systems; all wetlands experience periods where water levels are at or above the surface of the soil. Saturation limits oxygen availability in the soil so that only plants with special adaptations can grow in the flooded, low-oxygen conditions.

The Utah Geological Survey (UGS) is developing a field method to evaluate the condition of wetlands in the state using a variety of plant, hydrologic, soil, and landscape data. The method is intended to be used by a variety of practitioners, including restoration specialists, land managers, researchers, and private consultants, and will allow for comparison

between similar wetland types as well as documenting change at a site over time. Development of a Utah-specific condition assessment method will make it easier to support management decisions and effective conservation efforts at the state scale.

One of the focal areas for initial method development is Snake Valley, home to numerous spring-fed wetlands in Utah's west desert. The water in Snake Valley is predominantly used locally for growing alfalfa and hay and enhancing habitat for livestock and wildlife. Increasing concerns about additional groundwater-development pressures have been the impetus for numerous recent hydrogeology, groundwater, and wildlife resource studies in the region (see article by Hurlow and Jordan in this issue of *Survey Notes*). Adequate water to supply the valley's wetlands is important to provide habitat for snail species found nowhere else on earth and wildlife species having limited habitat range (least chub and Columbia spotted frog), as well as to allow the ranching way of life to continue as it has for over 100 years. Obtaining data on current conditions of wetlands in Snake Valley and their associated water regimes is paramount to addressing and mitigating potential changes from current and future threats.



The most common disturbances seen at wetland study sites included soil disturbance from grazing (left) and manipulation of hydrology to create or enhance pasture (above). Other important disturbances, notably changes in groundwater levels, are not easy to detect during field surveys but will be monitored through a network of shallow wetland and deep groundwater wells.

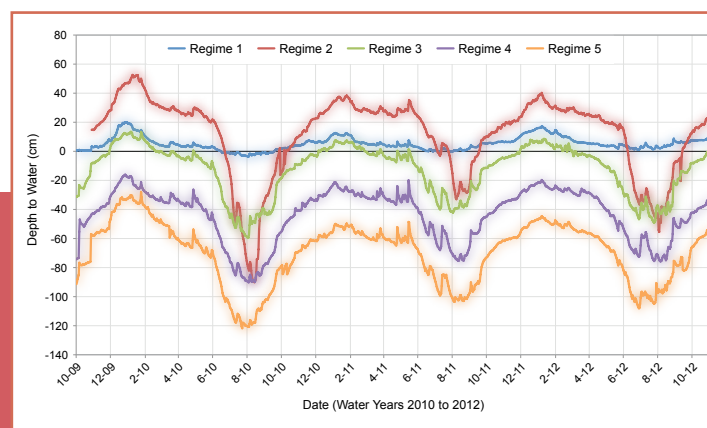
Wetland condition is evaluated through examination of a site's hydrology, plant community, soil, and surrounding landscape and comparing the status to that of natural, undisturbed sites. Some information on wetland condition is readily apparent during brief site visits. For example, it may be easy to detect whether the hydrology has been manipulated to create unnatural flow patterns or whether a site has been overgrazed to the point where the soil is compacted and completely bare. Other indicators require substantially more time and expertise to be useful. Plant species can be powerful indicators of recent and current conditions, but using plant data to determine condition generally requires more field time during surveys, specialized knowledge to properly identify species, and an understanding of how different species respond to disturbance.

The UGS began testing wetland condition assessment methods in 2010. Six out of the seven surveyed sites were in northern Snake Valley because these sites provide most of the critical wildlife habitat in the region. The sites were generally found to be in excellent condition, with only a few sites having any elements that were regarded as very disturbed. While it was important to note the relative health of the surveyed wetlands, the lack of variability in survey results hampered development of field protocols. Additional surveys were conducted in summer 2013 to expand the range of conditions captured (see map in article by Hurlow and Jordan in this issue of *Survey Notes*). We surveyed a total of 18 sites, including 8 sites in northern and 10 sites in southern Snake Valley. Common stressors near sites included overgrazed vegetation and soil trampling, altered hydrology due to ditching, and heavy algae formation (which sometimes indicates issues with water quality). Cover of non-native plant species and native species known to be invasive was generally

low, indicating overall good site condition. A final method for assessing wetland condition in Utah and final scores for each site in Snake Valley are currently being developed and should be available by the end of the year.

In addition to field surveys, the UGS has been collecting and managing data from 80 shallow wetland wells, or piezometers, that provide hourly water-level data. Sixty wells 5 to 10 feet deep were installed between October 2009 and March 2010 by the UGS and a Utah Division of Wildlife Resources (DWR) consultant, and an additional 20 wells were added in 2012 and 2013 by the DWR and UGS. Data from all wells are now downloaded biannually and managed by the UGS (<http://geology.utah.gov/databases/groundwater/projects.php>). Well data will allow us to determine the relationship between the timing and duration of flooding and associated plant species. We can also use the data to map water levels across wetlands, allowing us to better understand critical relationships between water levels, vegetation, and sensitive animal species. Together, this information helps us identify wetland areas that are vulnerable to changes and anticipate how those changes may affect the plants and animals that depend on them. ■

Five water regimes, or patterns of the timing and duration of flooding, observed in wetlands in Snake Valley based on data from wetland wells. Plant species are closely associated with each regime, with, for example, bulrush and other species adapted to extreme inundation found in regime 1 and saltgrass dominant in the drier regimes 4 and 5. Understanding the relationship between plant species and water regimes allows predictions of expected vegetation changes with changes in water levels in the area.





Utah Geological Survey researchers Rich Emerson and Diane Menuz download data from an automatic recording probe in a shallow wetland well on the edge of Pruess Lake in southern Snake Valley. Water level data are recorded every hour year-round and can be used to determine natural seasonal and annual fluctuations and responsiveness to groundwater manipulations.



Data collected by the Utah Geological Survey researchers on water quality, soil composition, plant community, and stressors present can be used to determine how close this wetland is to a natural, undisturbed state.

ABOUT *the* AUTHORS



conducting rare plant surveys in southern California.

DIANE MENUZ joined the UGS in 2013 as the Assistant State Wetland Coordinator. Her work focuses on developing the wetland condition assessment method for the state and implementing associated fieldwork. Prior to joining the UGS, Diane worked on projects modeling flow in Wisconsin streams, modeling the distribution of invasive riparian plant species in the Columbia River Basin, and



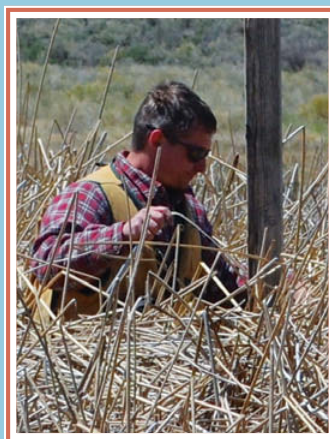
of wetland scientists in the state. Before coming to Utah, Jennifer worked in wetlands in the western U.S. for eight years on projects in the Southern Rockies of Colorado and the Sierra Nevada.

JENNIFER JONES has been the State Wetland Coordinator since 2012, leading various projects for the UGS Wetland Section that target a variety of wetland needs for the state. In addition to coordinating development of the condition assessment tool for Utah wetlands, she facilitates collaboration among other state, local, and interest groups to develop wetland program planning that serves the broader group



flow paths around Great Salt Lake. Before moving to Utah, Ryhan worked on habitat management projects for the New York State Bureau of Wildlife, helped study zoonotic diseases in Montana, and worked on various other wildlife research projects throughout the country.

RYHAN SEMPLER was hired by the UGS in 2013 as a Wetland Specialist Technician. He is helping develop the wetland condition assessment method specific to Utah wetlands, and is involved with modeling surface water



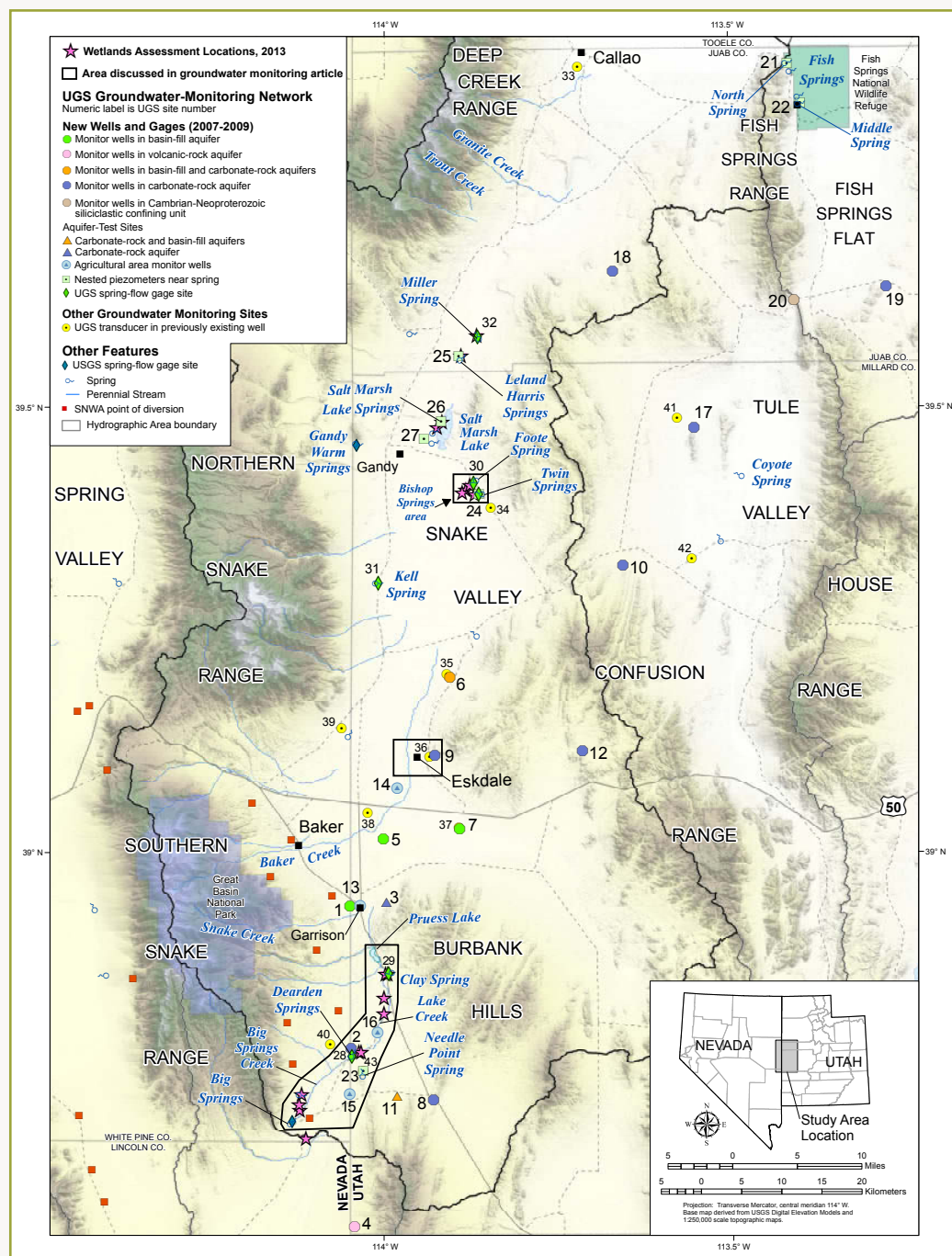
RICH EMERSON is a geologist in the UGS Groundwater and Paleontology Program, where he has worked since 2007. His work focuses on geographic information system (GIS) analysis, remote sensing, wetland mapping, and collection and analysis of shallow-groundwater data throughout the state.

UGS GROUNDWATER & SPRING FLOW MONITORING IN SNAKE VALLEY

by Hugh Hurlow and Lucy Jordan

In March 2007 the Utah State Legislature requested the UGS to establish a groundwater-monitoring network in Snake Valley and adjacent areas, in response to concerns over potential drawdown of the water table and reduced spring flow from proposed large-

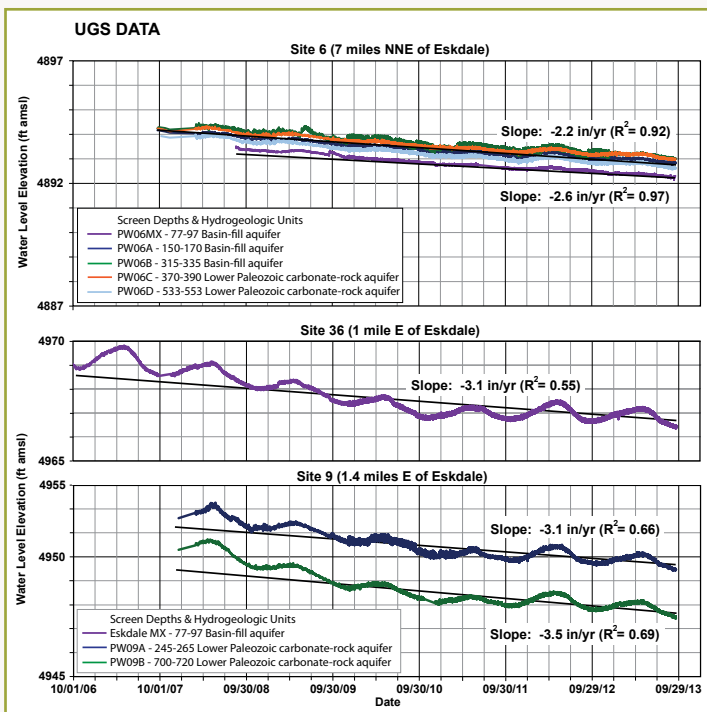
scale groundwater development projects in east-central Nevada and west-central Utah. The UGS groundwater-monitoring network was completed in spring 2009, and includes 67 newly constructed wells, 11 previously existing wells, and surface-flow gages at six springs.



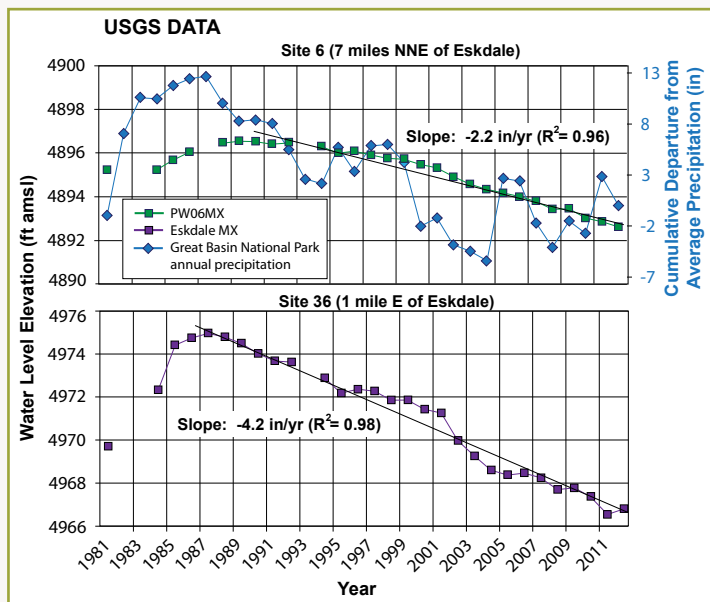
The objectives of the UGS groundwater-monitoring network are to (1) determine baseline temporal and spatial groundwater-level and chemical trends, (2) establish groundwater monitoring near the planned pumping wells and areas of current groundwater use to assess their impacts on groundwater resources, (3) monitor discharge from selected springs that host environmentally sensitive aquatic species, (4) conduct aquifer tests to measure the hydraulic properties of, and hydraulic connectivity between, the basin-fill and carbonate-rock aquifers, and (5) evaluate groundwater-flow systems within Snake Valley and from Snake Valley to Fish Springs National Wildlife Refuge.

This article focuses on our preliminary findings from monitoring groundwater levels and spring flow. The UGS monitoring wells have five to seven years of high-frequency (hourly) data. The U.S. Geological Survey (USGS) has collected water-level data annually for some of these wells for at least 30 years, providing a long-term context. Groundwater-level trends can be compared to precipitation data from the Great Basin National Park climate station, in a principal area of groundwater recharge for the Snake Valley basin-fill and carbonate-rock aquifers.

Near the Eskdale agricultural area in southern Snake Valley, data from UGS sites 9 and 36 show that groundwater levels vary seasonally due to local pumping for crop irrigation, and



Groundwater levels near and north of Eskdale from UGS data. Site 6 shows little or no effects of groundwater pumping, and a gradual decline of groundwater levels of about 2.4 inches per year. Sites 9 and 36 show seasonal variations in groundwater levels resulting from groundwater pumping, superposed on a gradual decline of about 3.1 to 3.5 inches per year.



Long-term groundwater levels near and north of Eskdale, and annual precipitation at Great Basin National Park. The decline at site 6 may result primarily from decreased annual precipitation after the mid-1980s, whereas the greater rate of decline at site 36 may represent the combined effects of groundwater pumping and decreased precipitation.

Snake Valley surface-flow and water-level data, lithologic and geophysical logs, and well-construction information can be accessed through the UGS web-based groundwater-data server at http://geology.utah.gov/databases/groundwater/map.php?proj_id=1.

that this cyclical variation is superposed on a trend of steadily declining groundwater levels of 3.1 to 3.5 inches per year in the basin-fill and bedrock aquifers from 2007 to 2013. Long-term data from the USGS show that groundwater levels in the basin-fill aquifer have declined by about 4.2 inches per year since 1987. Data from UGS site 6, seven miles northeast of Eskdale, may help distinguish groundwater-level trends related to climate from those related to pumping. Groundwater levels at site 6 lack the cyclical fluctuations characteristic of groundwater pumping, so long-term groundwater-level trends here likely show little or no effect from pumping and result primarily from overall decreased annual precipitation after a period of far greater-than-normal precipitation (and, presumably, recharge to the aquifers) during the early 1980s. Groundwater levels at site 6 have declined by 2.2 inches per year since 1989, which can be interpreted as the long-term climatic signal in the Eskdale area. Groundwater pumping, therefore, may account for at least 1 inch per year of the decline at sites 9 and 36 observed in the UGS data, and for about 2 inches per year of the decline observed in the long-term data.

Groundwater levels in UGS monitor wells near other agricultural sites in Snake Valley also respond cyclically due to groundwater pumping, and show similar or greater rates of long-term decline. Groundwater levels in wells far from current agricultural pumping have declined at substantially lower rates than those near agricultural areas. Collectively the data show that in Snake Valley agricultural areas, groundwater is currently being withdrawn at rates slightly greater than it can flow to the discharge areas. Proposed large-scale groundwater-development projects would greatly expand the area and magnitude of groundwater withdrawal and discharge capture, resulting in lower groundwater levels and reduced spring flow throughout southern and central Snake Valley.

Snake Valley has numerous springs that support agriculture and provide habitat for environmentally sensitive species. At the Bishop Springs area in east-central Snake Valley, the average discharge from Foote Reservoir Spring is 5.9 ± 0.1 acre-feet per day. Utah Division of Wildlife personnel removed Russian olive (*Eleagnus angustifolia*) trees around the reservoir and outlet stream in early 2012. Prior to tree removal, the spring discharge shows a slight downward trend, whereas the discharge after the trees were removed trends up. Non-native Russian olive and saltcedar trees have been implicated in increased water loss from riparian systems through evapotranspiration in the West since the 1980s. Our data suggest more water is flowing in the stream channel since the removal of the trees. If verified, this result could provide an approach for the Division of Wildlife Resources to preserve in-stream flow that provides habitat for several aquatic species of concern in west desert spring-fed wetlands, in support of a conservation agreement that decreases the likelihood that the species will be listed by the U.S. Fish and Wildlife Service as threatened.

In the southern part of the Snake Valley hydrographic area, flow from Dearden Springs supports much of the in-stream flow and shallow groundwater (i.e., underflow) in Lake Creek, which extends from the springs 9 miles downstream to Pruess Lake. The Dearden Springs–Lake Creek reach, together with the upstream Big Springs–Big Springs Creek reach in Nevada, forms a 17-mile-long surface water-groundwater system, the largest and most continuous in Snake Valley. The creek and associated wet meadows are used for grazing and provide wildlife

continued on page 9

when **SHARKS, RAYS, & SAWFISH** ruled Utah's rivers

BY JAMES KIRKLAND

The recently published 637-page tome, *At the Top of the Grand Staircase: The Late Cretaceous of Southern Utah* (Indiana University Press: edited by Alan Titus and Mark Loewen) is filled with papers summarizing the geological and paleontological research on these rocks since the 1996 establishment of Grand Staircase–Escalante National Monument (GSENM). While I am a coauthor on several papers in this volume relating to new dinosaur discoveries, I also took the opportunity to finally publish my research on Utah's freshwater elasmobranchs (sharks and rays) that I had begun as a graduate student 35 years ago. This *Survey Notes* article briefly summarizes the results of this research.

The first extensive research on the vertebrate fossils in southern Utah was not on the dinosaurs, but was in the quest for the tiny fossil mammals that had lived in the shadow of the dinosaurs. The process of recovering these fossils involves breaking down fossiliferous rock by gently washing the rock, preferably soft shales, mudstones, or poorly consolidated sandstones, through fine screens and picking out the small identifiable bones and teeth from the residues under a microscope. In this way, collections of the entire fauna can be made—not just the mammals, but the fish, salamanders, frogs, lizards, turtles, crocodiles, and even dinosaur teeth. This research, begun during the early 1980s, revealed not only that southern Utah preserved the most complete record of Late Cretaceous life on land, but that throughout the Cretaceous, Utah's rivers hosted a variety of freshwater sharks and rays. As an aspiring young paleontologist, I was assigned the job of researching these teeth, as the “more interesting” groups of animals were already spoken for by more established scientists. As with the Cretaceous mammals, isolated teeth from the sharks and rays are useful for identifying species, and I realized that these collections contained new species that documented the entire evolutionary history for several lineages of freshwater elasmobranchs. Unfortunately, the taxonomy of these fish was a mess, and it took many years of research to get a handle on this group of slippery organisms.

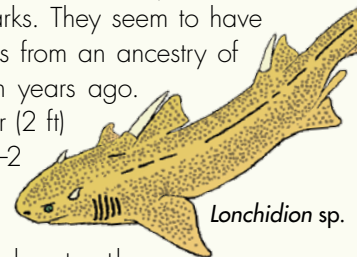
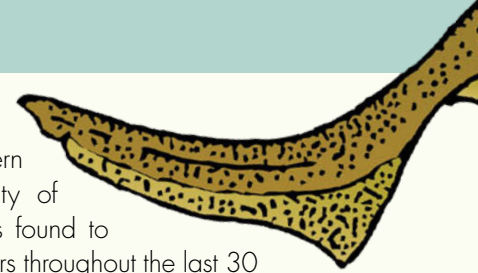
Today, most people would not expect to catch a shark or ray while fishing in one of North America's rivers. However, in the tropics and in the southern hemisphere, freshwater sharks and rays are characteristic of many large river systems. The Fitzroy River in eastern Australia, for example, includes a variety of sharks, sawfish, and stingrays and can be thought of as a

modern analogue for the Late Cretaceous rivers of southern Utah. A comparable diversity of freshwater elasmobranchs is found to have been living in Utah's rivers throughout the last 30 million years of the Cretaceous.

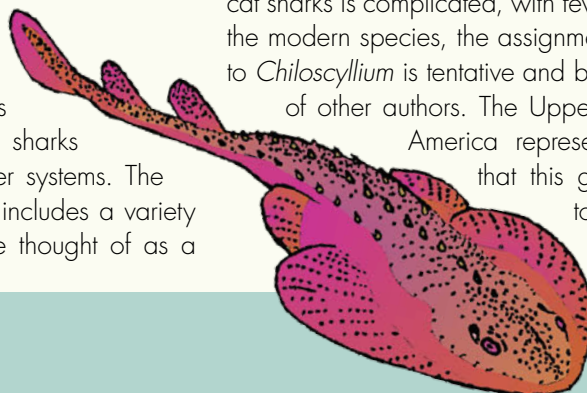
Hybodonts are an extinct group of sharks that were the dominant sharks for much of the Mesozoic Era following the near-extinction of sharks at the end of the Paleozoic Era. They are characterized by dorsal fin spines and small spines on their heads. There are two lineages of hybodont sharks. *Hybodus* is a moderately large species with a maximum length of 3 meters (10 ft), with teeth well adapted to grabbing fish. This is the only spined shark found in these rocks that was just as much at home in the ocean as it was in Utah's rivers. *Lonchidion* is a smaller shark, usually less than 1 meter (3 ft) long, with long, low blade-like teeth better adapted to cutting up soft-prey animals.

Among the more advanced sharks, or neoselachians, were a number of orectoloboid species that probably can be divided into two evolutionary lineages. Orectoloboid sharks are represented today by the nurse, carpet, and cat sharks. They seem to have entered into the Cretaceous river systems from an ancestry of shallow coastal sharks about 90 million years ago.

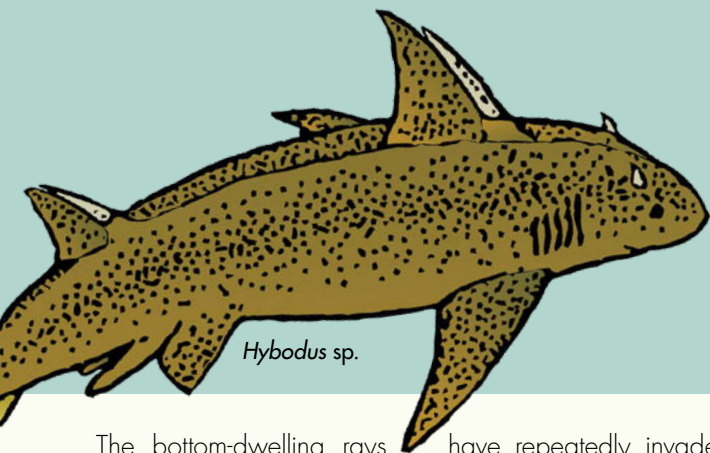
They were small sharks less than 1 meter (2 ft) long with a mouth packed with tiny 1–2 millimeter (0.1 in) teeth useful for grasping and shredding small prey. One lineage, *Cantioscyllium*, was characterized by teeth whose primary cusp is ridged and there are lateral cusps. Through time, species of *Cantioscyllium* have progressively subdued the ridges on their teeth. The other lineage has been referred to the modern cat shark *Chiloscyllium* and is characterized by teeth lacking lateral cusps, and whose primary cusp may have shoulders that are incipiently serrated. Because the taxonomy of the modern cat sharks is complicated, with few differences in the teeth among the modern species, the assignment of these Cretaceous species to *Chiloscyllium* is tentative and based primarily on the taxonomy of other authors. The Upper Cretaceous of western North America represents the only time and place that this group of sharks is documented to have populated freshwater environments.



Lonchidion sp.



Mylephus bipartitus



Hybodus sp.

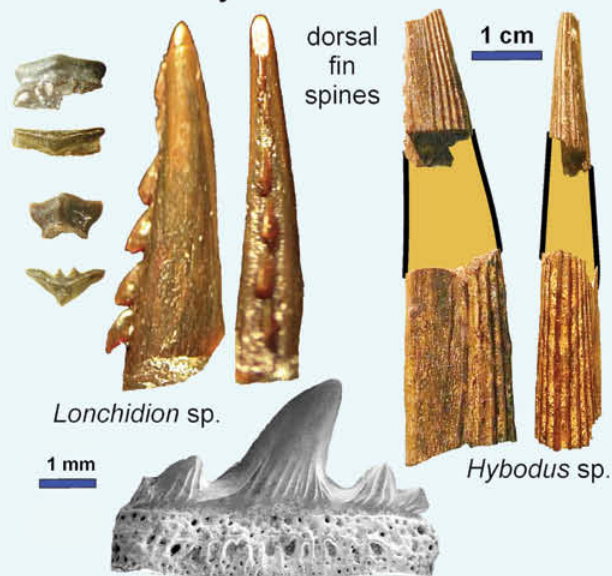
The bottom-dwelling rays have repeatedly invaded freshwater habitats throughout geological history since their origins in the Jurassic. The genus *Myledaphus* ("mill stone of the earth"), first recognized in the 1870s, reached the relatively large size of around 3 meters (10 ft) long prior to their extinction at the end of the Cretaceous. Initially, the large grinding teeth of this ray were thought to be the teeth of a large stingray. However, the discovery of a *Myledaphus* mummy at Dinosaur Provincial Park in Alberta, reported in 2005, proved that these were not freshwater stingrays, but a specialized group of the more primitive guitarfish. The abundance of fossil teeth from Utah document a lineage of primitive rays linked by having crushing teeth with a distinct mid-line crest. They originated more than 100 million years ago at the end of the Early Cretaceous with small species (*Cristomylus*) that got progressively larger and developed more efficiently packed teeth (*Pseudomyledaphus*) with more complex grinding surfaces (*Myledaphus*) through the Late Cretaceous.

The last group is represented by two lineages of extinct Scelerorhynchiform sawfish. While looking superficially like modern sawfish, differences in the skulls and pectoral fins indicate that this group originated from guitarfish in the Early Cretaceous. They reached a greater diversity than modern sawfish and included very large species, prior to their extinction at the end of the Cretaceous. Modern sawfish (pristids) do not appear until the Eocene, about 45 million years ago. The most common Utah species are found throughout the Upper Cretaceous and have small teeth on their saw (or rostrum) and ridged, diamond-shaped teeth in their mouths. We assigned these species to the ptychotygonid *Texatrygon*, which appears to be related to *Lebanopristis* and *Micropristis*, which are known from complete specimens in the Middle East. Another taxon, the scelerorhynchid *Columbusia*, is only known from its oral teeth and may have had a toothless rostrum more like that of a swordfish. These fish used their rostrums to grub for invertebrates in the sediment and to slash at small fish in more open water.

After being so characteristic of Utah's Cretaceous river systems, all of these lines of freshwater elasmobranchs went extinct with the dinosaurs at the end of the Cretaceous. Perhaps the continued success of the bony fish was a result of their much higher reproductive rates. ■

Cretaceous Fossil Teeth From Utah

Hybodont sharks



Orectolobiform sharks



Scelerorhynchiform sawfish



The illustrations are recreations of some of the freshwater sharks and rays characteristic of Utah's Late Cretaceous river systems, by Russell Hawley.



Texatrygon avonicola

ENERGY NEWS

UGS Set to Publish Major Study on Potential Paleozoic Shale-Gas Resources

by Thomas C. Chidsey, Jr.

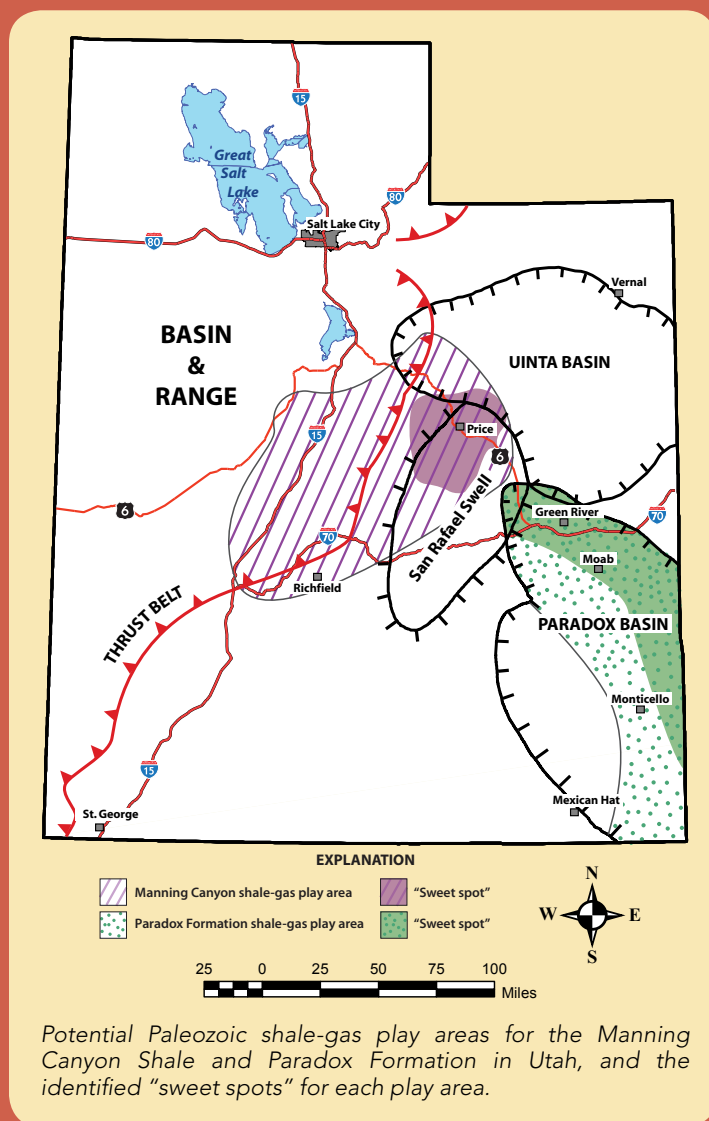
Over the past decade shale-gas plays in Texas, Arkansas, Louisiana, Oklahoma, and the northern Appalachian states have been the sites of extensive drilling programs using horizontal drilling and new hydraulic fracturing (or “fracking”) techniques (see related 2012 *Survey Notes* article, v. 44, no. 2, p. 8–9). Shale, a fine-grained sedimentary rock composed mainly of clay or mud, contains numerous pores (open spaces) that are very small but can store significant quantities of gas (or oil), thus serving as a hydrocarbon reservoir. The permeability (the connectivity of those pores that allows gas or liquids to flow) of shale is extremely low unless natural fracture systems are present. Horizontal wells are directed to encounter multiple natural fractures over thousands of feet, and fracking significantly increases the number of fractures and their permeability. The result of this drilling activity has been the discovery of an estimated 129 trillion cubic feet (tcf) of commercial, recoverable gas from shale in these established plays. Although Utah produces 0.4 tcf of natural gas per year, and has proven reserves of 7.0 tcf, all of this is in conventional (i.e., non-shale) reservoirs.

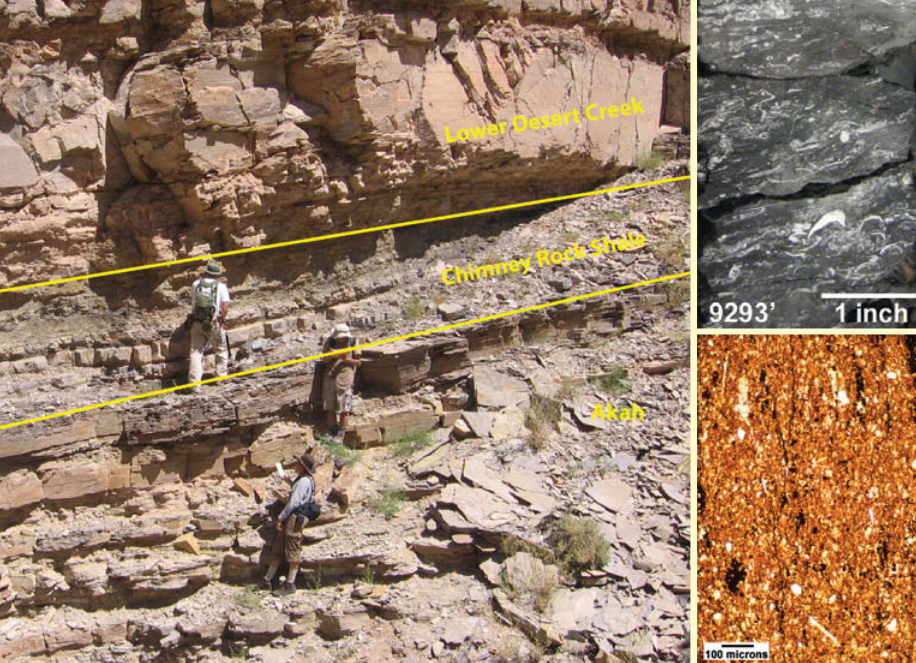
For the past four years, the Utah Geological Survey (UGS) has been conducting a major study of potential Paleozoic-age shale-gas plays in Utah, specifically the Mississippian Manning Canyon Shale in central Utah and the Pennsylvanian Paradox Formation in southeastern Utah (see related 2011 *Survey Notes* article, v. 43, no. 2, p. 3–5). These approximately 300-million-year-old shale beds are widespread, thick, organic rich, naturally fractured, and buried deep enough in many areas to generate, store, and produce natural gas and oil. The study was funded in part by the Research Partnership to Secure Energy for America (RPSEA) and represents the work of UGS staff, outside geologic consultants and engineers having expertise specifically with shale reservoirs, and various petroleum service companies and labs. The objectives of the study were to (1) identify and map the major trends for target shale intervals and identify areas having the greatest gas potential, (2) characterize the geologic, geochemical, and petrophysical rock properties of those shale beds, (3) reduce exploration costs and drilling risk, especially in environmentally sensitive areas, and (4) recommend the best practices to complete and stimulate these shales to reduce development costs and maximize gas recovery.

The UGS Paleozoic shale-gas study produced a number of key findings. The Manning Canyon Shale was deposited in a

shallow restricted-marine, brackish, and freshwater setting like the modern Everglades and Florida Bay. Total organic carbon in the shale varies from 1 to 15 percent. Over time, the Manning Canyon was buried deeply enough to generate natural gas. The greatest Manning Canyon potential is a 600-square-mile area surrounding Price, including the northwest end of the San Rafael Swell. Several exploration wells in the area have reported gas tests and hydrocarbon shows. Potential shale-gas reservoirs in the Paradox Formation are estimated to contain about 6.5 tcf of gas, mainly in the northeastern part of the play area (the southwestern part is more oil prone with a potential for over 250 million barrels of oil). In addition, the study shows that overlying limestone beds, such as the lower Desert Creek zone of the Paradox, may also contain significant gas reserves.

The resulting UGS publication, currently in the final stages of review, is titled *Paleozoic Shale-Gas Resources of the Colorado Plateau and Eastern Great Basin, Utah: Multiple Frontier Exploration Opportunities*. The publication will be in digital format and is anticipated to contain 11 chapters with over 180 figures and 30 tables. These chapters include (1) a geologic overview of Utah’s potential shale-gas reservoirs, (2) the geologic setting of the Manning Canyon Shale and Paradox Formation, (3) recent drilling activity (several wells





(Left) UGS geologists describing and measuring an outcrop of the Chimney Rock shale (Paradox Formation) east of Mexican Hat, southeastern Utah. The organic-rich Chimney Rock is a potential shale-gas reservoir deep in the subsurface. The lower Desert Creek, which may also have gas potential, and Akah are also zones in the Paradox Formation.

(Top right) Well core (slabbed) of black, organic-rich, shelly Manning Canyon Shale from a recent well south of Price, Utah. The well initially tested 468,000 cubic feet of gas per day from the Manning Canyon.

(Bottom right) Microscopic view (thin section) of the Hovenweep shale (Paradox Formation) showing quartz silt (numerous white angular grains), which creates brittleness and fractures, within a muddy matrix.

have tested gas from shale in these formations), (4) visual descriptions of shale cores obtained from both new and old wells, (5) petrographic (microscopic) descriptions of the rocks from wells and outcrops, (6) geochemical analyses to establish organic content and maturity (capacity to generate gas) of the shales, (7) petrophysics and rock mechanics to determine porosity, permeability, and fracture potential, (8) identification of outcrop analogs, (9) a variety of thickness and top of shale (structure) maps, (10) recommendations for the best well completion practices, and (11) identification of play “sweet spots” that have the greatest shale-gas potential. Raw data, core photographs, laboratory analyses, microscopic images, etc., will be included in 21 appendices.

Successful development of shale-gas plays requires integrating accurate geologic characterization and reservoir-specific engineering practices—a major goal of the UGS study. Our study results can be used by geologists, petroleum engineers, pipeline companies, landowners and other stakeholders, and local, state, and federal government officials and decision makers for the prudent exploration and development of these potential Utah shale-gas resources.

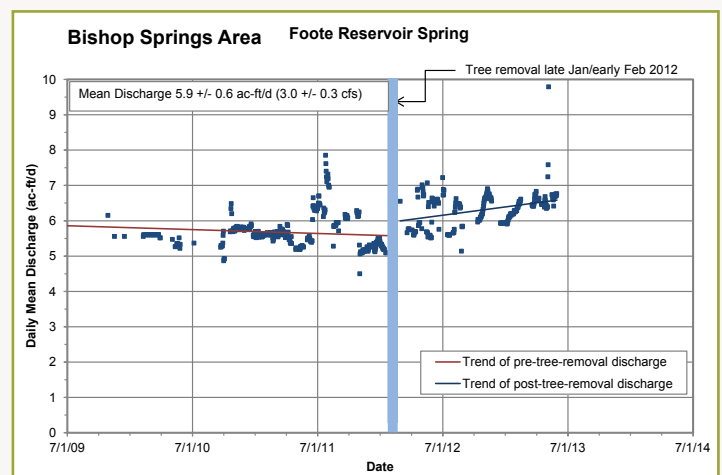
For more information on the UGS Paleozoic shale-gas study, visit our web page at geology.utah.gov/emp/shalegas/index.htm. 📄

UGS GROUNDWATER & SPRING FLOW MONITORING IN SNAKE VALLEY

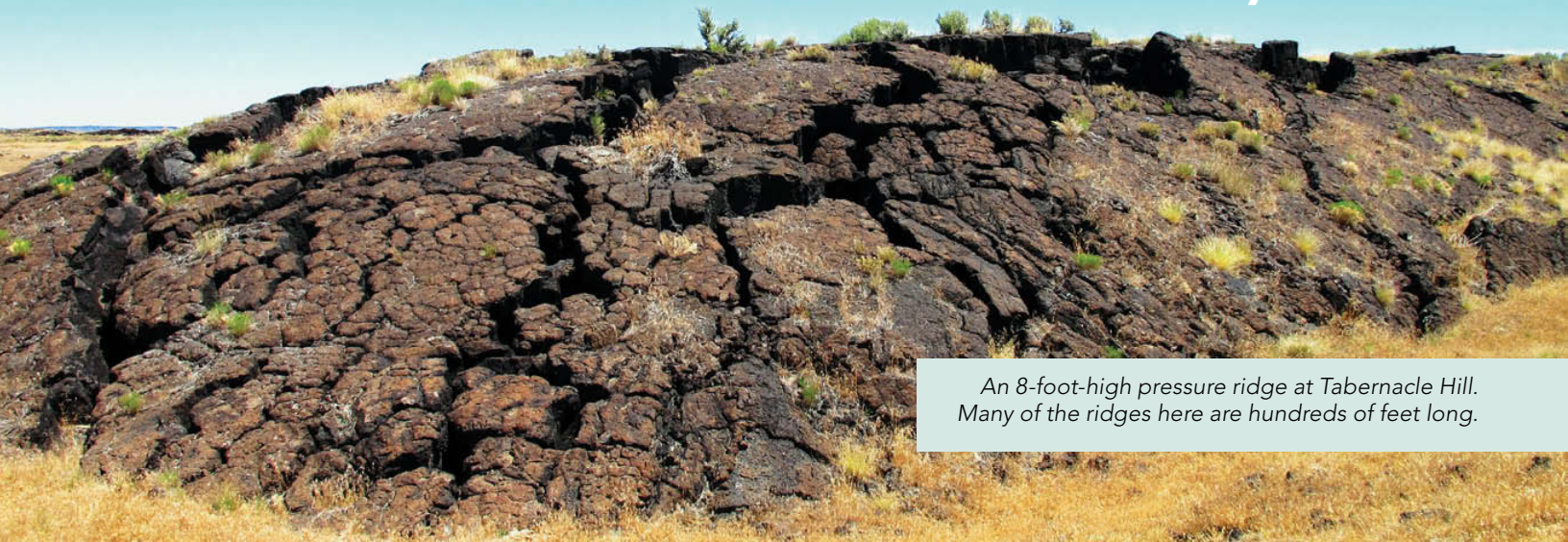
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habitat. Recent groundwater-flow models constructed by the Southern Nevada Water Authority (SNWA) and the USGS suggest that groundwater pumping along the eastern flank of the southern Snake Range west of Lake Creek would severely reduce groundwater levels and spring flow in the Big Springs–Dearden Springs–Lake Creek–Pruess Lake hydrologic/ecologic system. UGS monitoring of spring flow at Dearden Springs and Clay Spring, and groundwater levels in many wells in this area, will help quantify the impact if development occurs.

UGS flow data for Dearden Springs are an essential part of an in-progress study of surface flow and groundwater-surface water interaction along Big Springs Creek–Lake Creek, associated with a monitoring agreement between the Department of the Interior and SNWA. The Dearden Springs data are also part of a monitoring and mitigation plan in the Nevada State Engineer’s decision to grant water rights to SNWA in Spring Valley, and will likely be incorporated into any future monitoring and mitigation plan associated with large-scale groundwater development in southern Snake Valley. Separating climatic and groundwater pumping signals in the data will be the main use, and challenge, of the UGS monitoring. 📄



Hydrograph for Foote Reservoir Spring. Flow increased after removal of Russian olive trees surrounding the impoundment and outflow stream.



An 8-foot-high pressure ridge at Tabernacle Hill. Many of the ridges here are hundreds of feet long.

The Black Rock Desert is a volcanic area, or volcanic *field*, covering more than 700 square miles in eastern Millard County. Episodic volcanic activity has occurred here from a couple million years ago up to a few centuries ago, leaving intriguing landforms and features including volcanic cones, lava tubes, pressure ridges, and craters. This article focuses on the northeastern part of the field, which includes Black Rock Volcano, Tabernacle Hill, White Mountain, the Ice Springs lava flows, Devils Kitchen, and Pahvant Butte, all easily identifiable from Interstate 15.

The Black Rock Desert lies within the Basin and Range physiographic province, which has been shaped over the past 17 million years by stretching and uplift of the Earth's crust. Extension resulted in development of faults in the thinning crust, creating a recurrent pattern of linear north-south trending mountain ranges and valleys. Some of the faults have been conduits for magma (and water) to reach the surface; many of the volcanic cones, vents, and hot springs in the Black Rock Desert align with the faults. Currently, the Black Rock Desert may be the largest geothermal prospect in Utah.

The Black Rock Desert is the youngest volcanic field in Utah and contains both Utah's youngest known rhyolite dome, White Mountain, and its most recent eruptive event, the basalt flows at Ice Springs. Two major eruptions—at Pahvant Butte and Tabernacle Hill—occurred when Ice Age Lake Bonneville covered the area, forming volcanic islands in the lake.

About 15 miles south of Fillmore, the Black Rock Volcano—a horseshoe-shaped volcanic cone—rises more than 300 feet above the valley floor between I-15 and the town of Kanosh. Volcanic cones are built of material ejected and piled up around a central volcanic vent, forming a steep, conical hill. They are called “cinder” cones when made of loose particles of volcanic rock, and “spatter” cones when gobs of ejected molten lava partially fuse the particles together. The Black Rock Volcano is one of many cones of the Black Rock Desert that are a

combination of the two, known as “cinder-and-spatter” cones.

Tabernacle Hill is reached by way of Lava Tubes Road, named for the caves in the area. The lava tubes, which extend for hundreds of yards, formed as the surface of lava streams cooled, solidified, and crusted over. The subterranean lava then vacated the tubes as the supply of lava diminished, leaving behind empty conduits. The central tuff ring, from which Tabernacle Hill gets its name, is a type of volcanic cone made of ash and grittier fragments (lapilli) created by explosive eruptions caused by the interaction of basaltic magma and shallow water. Only two-thirds of Tabernacle Hill's original 3,000-foot-diameter cone remains; the northwest side has been obliterated by eruptions. The central caldera within the tuff ring is surfaced with pressure ridges and domes, which are elliptical mounds that commonly split lengthwise along their crest as molten lava pushes upward on the solidified crust of the flow.

At about 400,000 years old, White Mountain is the youngest known rhyolite dome in Utah. The dome gets its name from the bright-white wind-blown gypsiferous Bonneville sands draped across the volcanic protrusion. The 160-foot-high hill consists of rhyolite, which is more viscous than basalt and tends to pile up to form domes rather than spreading out in flows. At the dome's base is glassy-black obsidian formed by the rapid cooling of lava, with frothy, bubble-filled pumice at the top of the hill.

The Ice Springs lava flows, also called “The Cinders,” were named for the natural icehouse conditions within the lava flows where ice and icicles can be found throughout the year beneath the blocky aa lava. Aa (pronounced *ah ah*) is characterized by its rough-textured, loosely piled and jagged appearance, and is notoriously difficult to travel across—sturdy hiking boots are recommended. Pahoe-hoe lava flows have an entirely different form, with a smooth, “ropey” texture. Lava flows can begin as pahoe-hoe and change to aa, as seen at Tabernacle Hill. The Ice



(Above left) Entrance to a lava tube at Tabernacle Hill.

(Above right) Inside a lava tube with skylights at Tabernacle Hill. Skylights may be original to the lava flow, or the cave ceiling could have collapsed after formation of the cave.

Springs lava flows cover 17 square miles—dark volcanic rock so recently extruded that little to no soil or vegetation has yet taken hold. The flows originated from a cluster of four spatter-and-cinder cones. These cones, along with several others, churned out 700 million cubic yards of lava, one flow as recently as around 600 years ago, earning the Ice Springs basalt the designation of “newest rock in Utah.” People living in the area at the time were undoubtedly mesmerized by the advance of glowing, molten rock, and people may yet again see lava erupt here in the future.

North of the Ice Springs flows is Devils Kitchen, named for the hollow sound associated with its lava flow. In the days of horse and wagon when travelers traversed the flow, hoofs and wagon wheels vibrated the lava and the sound resonated through it, like tapping on a drumhead or on the flat tin roof of the devil’s kitchen. The Devils Kitchen fault forms a prominent escarpment for most of its length from the Ice Springs flows toward Pahvant Butte. The fault scarp is up to 60 feet high and exposes columnar basalt, characterized by vertically jointed columns, typically hexagonal and about two feet across, that form from the cooling and contracting of thick lava. Numerous boulders along the fault scarp have petroglyphs etched into the dark patina.

Pahvant Butte, also known as “Sugarloaf,” is a major landmark in the northern Black Rock Desert. A volcanic island in Ice Age Lake Bonneville that emerged from beneath the lake surface, Pahvant Butte has a wave-cut shoreline terrace surrounding most of the tuff cone that rises almost 700 feet above this ancient beach level. The upper part of the cone consists of palagonite, a yellowish-colored rock created from the contact of basalt lava flows with water. The northwest side of Pahvant Butte is draped in the peculiar cavity-filled “lace curtain” rock that resembles dripped wax (see article by W.F. Case in *Survey Notes*, v. 34, no. 1). The southernmost part of the Pahvant Butte lava field disappears under the younger Ice Springs basalt flows. ■

how to get there

There are many ways to access the Black Rock Desert volcanic field, most of which involve travel over unpaved but graded dirt roads. This selected route starts in Fillmore and goes west to Ice Springs, from where you can go north to Devils Kitchen and Pahvant Butte, or south to Tabernacle Hill and White Mountain.

From I-15, take either Fillmore exit, then go down Main Street and turn west on 400 North (State Route 100). Cross the I-15 overpass (where 400 N turns into 500 N to Flowell) and go 5.9 miles to 4600 West (Pahvant Heritage Trail). At this intersection you can access the northern Ice Springs flows, Devils Kitchen, and Pahvant Butte by turning right and going north and west to Clear Lake Road, or you can access the southern Ice Springs flows, Tabernacle Hill, and White Mountain by turning left and going south and west along the perimeter of the Ice Springs flows to 2300 South.

Tabernacle Hill and Pahvant Butte are classified by the Bureau of Land Management (BLM) as Areas of Critical Environmental Concern (ACEC) because they are unusual volcanic features and because of their important historic, wildlife, and scenic values. A visit to the BLM office in Fillmore is a good way to get information, directions, maps, and current conditions: 95 East 500 North, Fillmore, UT, 84631, (435) 743-3100.



GLAD YOU ASKED

by Mark Milligan

Coal became Utah's official state rock in 1991. In 2013 Utah mines produced roughly 17 million tons of coal valued at \$579 million, ranking us 15th among 25 U.S. coal producing states. Photo by Michael Vanden Berg.

IS UTAH'S STATE ROCK GOOD, BAD, OR UGLY?

Utah may be famous for its red rock, but the official state rock is coal. I was recently asked by a child, "Do you like coal?" "Yes." But, it can leave a black mess on your hands and clothes, and if you are naughty at Christmas you might find a lump of it in your stocking. And there are worse associations: "anthrax" is derived from the Greek word for coal (the skin disease causes lesions that are as black as coal), burning high-sulfur coal contributes to acid rain (note that Utah's coals are low in sulfur), and coal is a major source of mercury pollution (again, Utah's coals contain relatively low amounts of mercury). So, what are the positive aspects of coal that led it to be designated as Utah's state rock?

Coal has historical importance in Utah and was mined in the territory as early as the 1850s. By the 1860s mines at Coalville in Summit County supplied coal to Salt Lake City. Historically, coal was used to heat houses and power trains, contributing in a substantial way to Utah's early growth. The Utah State Legislature designated coal as Utah's state rock in 1991, long after such uses were commonplace. Despite no longer being commonly used for trains or heating, in 1991 Utah coal mines produced almost 44 BILLION pounds of coal (22 million tons), valued at \$795 million (inflation-adjusted). More recently (2013), Utah mines produced roughly 34 billion pounds (17 million tons) of coal, valued at \$579 million.

When I talk to groups of school kids, I often find that neither they nor their parents know what coal is used for today. I tell them to look up, because the lights above their heads are likely powered by coal-fired power plants. In Utah, approximately 81 percent of our electricity generation is derived from coal; the rest of Utah's generation comes from natural gas (15 percent), hydroelectric (1.5 percent), and other sources (2.5 percent). Beyond Utah, coal accounts for 43 percent of U.S. and 41 percent of global electrical production. Another way to look at it, approximately 96 percent of coal mined in Utah is burned to generate electricity. The remaining 4 percent is mainly used by industrial plants, in kilns and furnaces.

The historical significance, usefulness, and economic contributions of coal justified its designation as Utah's official state rock, but how

is it formed and why does this rock burn? Coal is formed of ancient plant matter. Plants (and some algae and bacteria) use the energy of sunlight to convert carbon dioxide in the atmosphere to carbon-based sugars through photosynthesis. Plants then use these sugars to build cellulose or other complex carbon molecules that comprise plant's leafy and woody matter. When high concentrations of plants die and accumulate in bogs and wetlands with low-oxygen conditions, burial, heat, and pressure can convert plant matter to coal. Coal is the long-term storage vessel of the carbon-based energy of plants. When coal is burned the stored energy is converted to heat, which can be used to turn turbines that create the electrical energy used in our homes and industries.



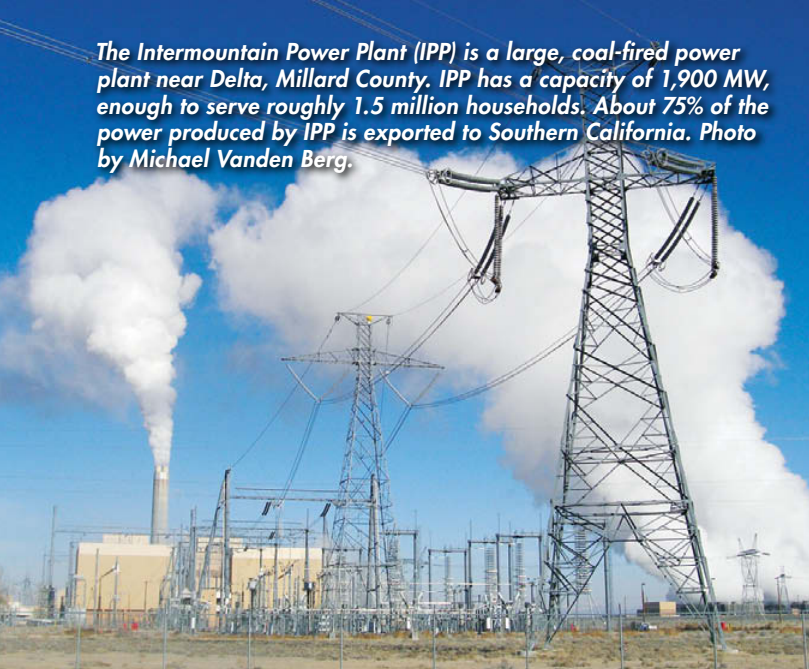
Is coal beautiful? Victorian England apparently thought so. Jet, a variety of coal that can be carved and polished, was popular mourning jewelry from the 1860s to the 1880s. Pictured is a pendant that is dedicated, "DWS Fell Asleep June 27th 1870 Aged 17." Photo courtesy of Barbara Robbins, www.artofmourning.com.

When not turned to coal, the carbon-based energy of plants can be consumed by animals and become part of the food chain, and either released back to the atmosphere through burning or decomposition, or stored in soil as detritus. This cycling of carbon, from the atmosphere to plants to animals, soil, or coal and back to the atmosphere, is part of the Earth's larger carbon cycle (oceans are a major part of complex carbon cycling). When we mine and burn coal and other fossil fuels such as oil and gas, we are removing carbon from long-term storage within the Earth and releasing it to the atmosphere as carbon dioxide.

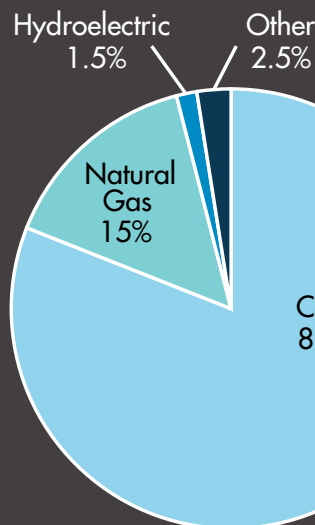
In addition to being vital for photosynthesis, atmospheric carbon dioxide is also an important greenhouse gas. When carbon dioxide is maintained at a relatively constant level in our atmosphere, it helps moderate our planet's temperature. However, since the Industrial Revolution, we have been removing large quantities of carbon from storage and transferring it to the atmosphere (Utah's coal only accounts for 0.2 percent of the nearly 16 TRILLION pounds [8 billion tons] of coal mined globally in 2012). The vast majority of scientists agree that this increasing carbon dioxide in the atmosphere is the largest driver of global warming.

So is Utah's state rock good, bad, or ugly? The answer certainly depends on who you ask, for coal has elements of good and elements of bad. As for beauty, that is in the eye of the beholder. ■

The Intermountain Power Plant (IPP) is a large, coal-fired power plant near Delta, Millard County. IPP has a capacity of 1,900 MW, enough to serve roughly 1.5 million households. About 75% of the power produced by IPP is exported to Southern California. Photo by Michael Vanden Berg.



UTAH'S ELECTRICITY BY SOURCE



The majority of Utah's electricity generation is produced by coal-fired power plants. This percentage is likely to drop as power plants such as the Intermountain Power Plant convert to cleaner burning natural gas. Data from the U.S. Energy Information Administration.

NEW PUBLICATIONS

Geologic hazards of the State Route 9 Corridor, La Verkin City to Town of Springdale, Washington County, Utah, by Tyler R. Knudsen and William R. Lund, DVD (13 p., 9 pl. [contains GIS data]), ISBN 978-1-55791-880-2, Special Study 148.....\$24.95

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Utah's extractive resource industries 2012, by Taylor Boden, Michael Vanden Berg, Ken Krahulec, and Dave Tabet, 29 p., ISBN 978-1-55791-884-0, Circular 116.....\$9.95

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Interim geologic map of the Cedar City 7.5-minute quadrangle, Iron County, Utah, by Tyler R. Knudsen, CD (20 p., 2 pl.), scale 1:24,000, Open-File Report 626.....\$14.95

Interim geologic map of the Cedar City NW quadrangle, Iron County, Utah, by Tyler R. Knudsen and Robert F. Biek, CD (18 p., 2 pl.), scale 1:24,000, Open-File Report 627.....\$14.95

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SURVEY NEWS

2013 UGS EMPLOYEE OF THE YEAR

Congratulations to **Tom Chidsey** who was named the 2013 UGS Employee of the Year. Tom is a senior scientist with the Energy and Minerals Program and has worked at the UGS for 25 years. For 23 of those years, Tom served as Petroleum Section chief. Tom never settles for the minimum required, but always goes above and beyond. He has consistently produced a high volume of superb quality work, having published over 100 technical papers. He has impeccable character and integrity, and has brought praise to the UGS from organizations such as the American Association of Petroleum Geologists and Brigham Young University. Tom is a role-model employee, carrying a heavy workload capably and cheerfully, and is a deserving recipient of the UGS Employee of the Year Award.

EMPLOYEE NEWS

The Groundwater and Paleontology Program welcomes **Nathan Payne** as the new GIS analyst. He comes to us from Utah State University where he recently graduated with a Bachelor of Science in Geography.



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