UTAH GEOLOGICAL SURVEY

SURVEY NOTES

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NORTHWEST UTAH
UTAH'S NEWEST ENERGY HOTSPOT?

THE DIRECTOR'S PERSPECTIVE

by Richard G. Allis

The Utah Geological Survey has recently produced two important reports that will help inform discussions about Utah's economic directions. One is a second edition of "Utah's Energy Landscape" (UGS Circular 113, by Michael Vanden Berg), which shows energy production and consumption trends updated with 2010 data. The second is "Utah Mining 2010" (UGS Circular 114, by Mark Gwynn, Ken Krahulec, and Michael Vanden Berg), which highlights recent trends in the mining of all geologic commodities in Utah. The take-away message from both reports is that despite volatility in commodity prices in recent years, and a pattern of declining consumption of some key commodities since about 2008 due to the economic downturn, the contribution of local energy and mineral production to Utah's economy remains strong. The total value of energy and mineral production in 2010 was $8.4 billion, the second-highest value in Utah's history (after 2008). Strong metals prices during 2010 enabled copper, molybdenum, magnesium, and gold production to contribute $3.3 billion to this figure. In addition, Utah continues to be a strong net exporter of energy in the form of natural gas and electricity, largely generated from coal. Utah produces about 30 percent more energy than it consumes, a trend that has continued since the early 1980s (see graphs of production and consumption of energy in Utah). Declining coal production since 2001 has largely been compensated for by increases in natural gas and oil production.

Utah's overall energy consumption has grown at an average of 2.1 percent per year since 1960, a figure very close to the state's average population growth over that time (2.3 percent per year). Although electricity demand growth along the Wasatch Front has been almost twice that rate, energy efficiency savings elsewhere have compensated for this. A closer look at geological commodity trends in Utah shows significant changes during the past decade, and especially since the economic downturn that began in late 2008. The downturn has significantly affected the consumption of industrial minerals such as aggregate (sand, gravel, crushed stone) and cement, which are down by over 30 percent since they peaked in 2007 (for a historical review, see "Director's Perspective" in the September 2009 issue of *Survey Notes*). Similarly, the consumption of petroleum products in Utah has decreased by about 10 percent during this time, largely due to a decrease in diesel fuel use, with motor gasoline demand remaining relatively steady. As a result of this decline and

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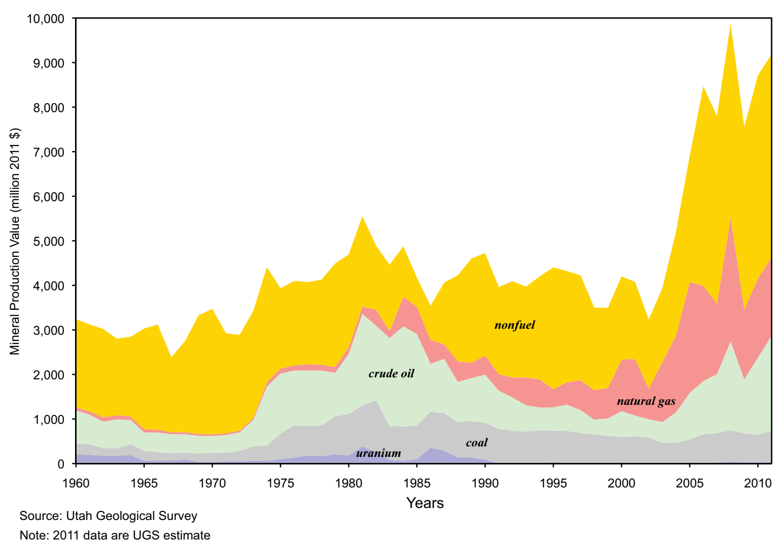

Total annual value of Utah's energy and mineral production, inflation-adjusted to 2010 dollars.

Contents

Design: *Jeremy Gleason*

Cover: *Exposure of glassy Snake River Plain-type rhyolite near Goose Creek, Box Elder County. Photograph by Donald Clark.*

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NORTHWEST UTAH
COULD IT BE UTAH'S NEWEST ENERGY HOTSPOT?

by Grant Willis and Donald Clark

Few people visit there, fewer people live there, and other than a dry strip along I-84, few people have even seen most of northwest Utah, yet this area may prove to be an important player in Utah's energy future. The roughly 7000-square-mile area that extends from the Wasatch Front, across Great Salt Lake to the Nevada and Idaho border, is remote and desolate, but it holds a rugged beauty of its own. It hosts some of Utah's most complex, poorly exposed, and least understood geology; however, a few intriguing clues suggest that vast geothermal resources may lie beneath these desert basins. This potential, coupled with largely unknown potential for fresh water, a rapidly growing building-stone and flagstone trade, a scarcity of accurate geologic maps, and a lack of knowledge about earthquakes and others hazards, induced UGS geologists to team up with USGS and university colleagues to improve surface maps and subsurface knowledge of the four 30' x 60' quadrangles that cover this huge area.

Over the past few years, the drive to develop alternative (non-hydrocarbon) energy resources has focused much attention on Utah. Deep-seated faults, abundant warm and hot springs, high temperatures encountered in some drill holes, three operating geothermal power plants, and much success passively heating greenhouses and buildings all hint at large untapped geothermal resources beneath parts of western Utah. The northwest part of the state may have significant potential. It has very young volcanic rocks (some less than 500,000 years old), and the Indian Cove well in Great Salt Lake encountered temperatures of 430° Fahrenheit at 12,400 feet depth. This high temperature—about as hot as the highest setting on your kitchen oven—makes it very attractive for traditional-style geothermal power plants. But this is only one good data point in a vast area. If we want to accurately assess the resource, we need a better understanding of which sedimentary basins have the best potential for high temperatures, and which host rocks have the best permeability and porosity. Exploration efforts are handicapped by the lack of detailed geologic maps and limited subsurface data. Before spending millions of dollars to drill exploratory holes, we first need to complete better geologic maps of the faults and rock exposures around the basins, and to collect less expensive geophysical data to get a better handle on the depth, shape, and rock composition of the basins. Over the past four years we have ramped up geologic mapping and geophysical data acquisition in the area.

The Need for Better Geologic Maps

The northwest part of the state has long stood out as an area in need of better geologic maps. It has some of the most complicated geology of any similar-size area in Utah. Key geologic and logistical challenges include: (1) it is cored by a large metamorphic complex and as a result has the most highly deformed and altered strata of any part of the state (see sidebar), (2) due to generally poor exposures, formations in the region are not well defined, making the highly deformed sections even more difficult to decipher, (3) much of the area is masked by Lake Bonneville deposits, (4) structural basins are abundant, but they are not demarcated by the well-defined normal faults that bound most basins in the Basin and Range

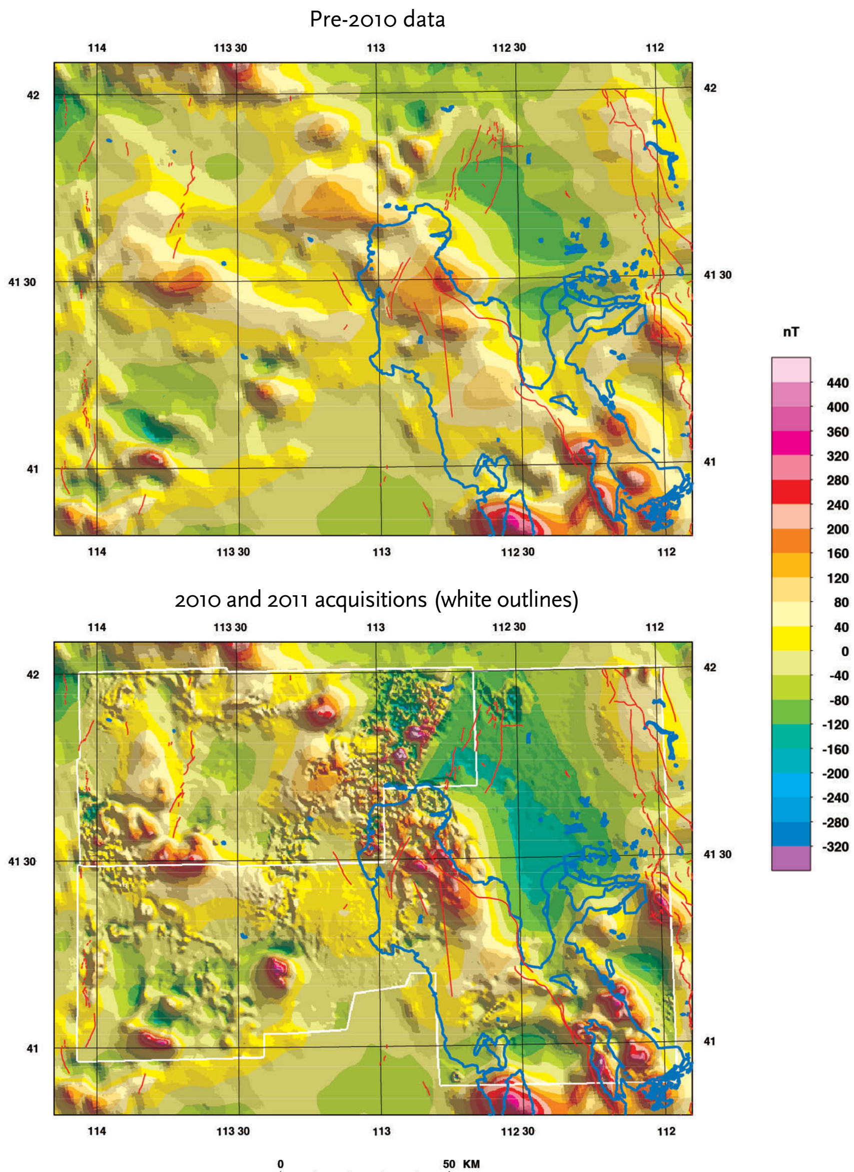
USGS geologist Dave Miller (right) discusses the complicated geology of the Dove Creek Hills with UGS geologists Don Clark (left) and Grant Willis (middle). Raft River Mountains in background. Photo by Bob Biek.

Track hoe perched atop an exposure of the Vipont granodiorite-phase intrusion (about 28 million years old). The hoe is used to remove slabs of the Neoproterozoic Quartzite of Clarks Basin from an active quarry operation just out of sight. Intense deformation from the metamorphic core complex created strong foliation that causes the quartzite to break into flat slabs that are used in buildings, to face walls, and in landscaping all over the world.

Province, (5) very little geophysical data and very few drill holes limit subsurface control, and (6) rugged terrain, few roads, and large tracts of military and private land make mapping and data acquisition slow and expensive.

This is not the type of area that a new geologist can drop into "cold turkey" and expect to immediately start mapping. We need specialists who have devoted many years, even decades, to working out the complicated geologic puzzle. Three years ago the "stars were aligned!" Through the late 1970s to mid 1990s, USGS geologist David Miller was busy mapping 7.5' quadrangles in western Utah preparatory to completing four 30' x 60' quadrangles. But his plans were waylaid in 1994 by budget cuts. We were able to publish several of his 7.5' quadrangle maps in the UGS map series. But several other unfinished maps, including three partially completed 30' x 60' maps, were relegated to file cabinets. We recognized that his accumulated knowledge was more valuable than the lines on paper, and for over a decade we lobbied the USGS to fund Dave to finish the job.

Finally, in 2006 the USGS was able to dovetail this "high desert" project into his other work. Dave was only given enough time to work on the Newfoundland Mountains and Tremonton 30' x 60' quadrangles, the two with the most completed mapping, but he was determined to finish the work. After seeing Dave's early results, the USGS agreed to extend the project if the UGS could contribute a significant portion of the effort. The Utah State Geologic Mapping Advisory Committee recognized this unique opportunity and helped us secure National Cooperative Geologic Mapping Program federal/state cost-share funding. We added Mike Wells (structural geologist at University of Nevada, Las Vegas), who did his dissertation followed by 20 years of guiding student projects on the Albion (Idaho)/Raft River/Grouse Creek metamorphic core complex; Jack Oviatt (geomorphologist at Kansas State University), who is the leading expert on Lake Bonneville deposits; Mike Perkins (University of Utah), who spent his career studying volcanic ashes (tephras) from eruptions in the Yellowstone hotspot that blanketed the area in the late Tertiary; and Donald Clark (UGS), who has established himself as our lead mapper of northwest Utah geology. Dave added Tracey Felger, an experienced USGS mapper, and Vicki Langenheim, a USGS geophysicist.



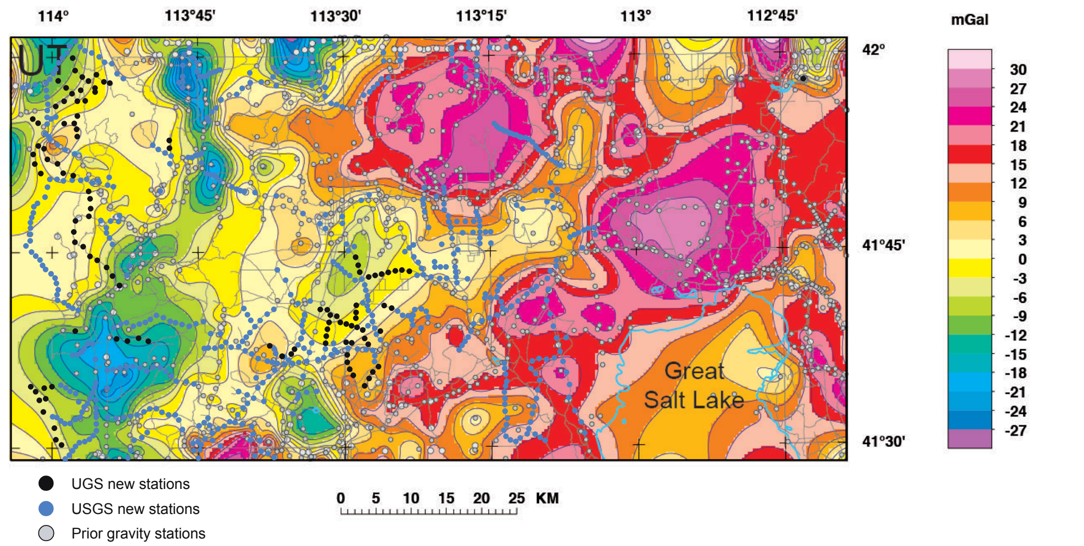
Aeromagnetic maps of northwest Utah. Over the past two summers, the UGS and USGS have cooperated to improve the detail of aeromagnetic mapping. The data are collected by instruments mounted on airplanes. Warmer colors show areas with exposed or buried rocks that have higher concentrations of magnetic minerals. For example, the low "bumpy" terrain indicates that basalt flows are probably buried in the shallow subsurface. When used in conjunction with gravity data and new field mapping, these data help define deep basins and major faults, and locate buried igneous intrusions.

We are now well into the third year of this four-year project. This team has been able to combine many older maps with extensive new mapping to accurately depict the complicated geology of the area. We will be ready to release the first open-file version of the Grouse Creek map in less than a year. In time, this new mapping and research may pave the way for development of a large, environmentally clean, renewable energy resource in Utah.

Geophysics Reveals Basin Structure

While the Basin and Range Province from central Idaho to southern Nevada is characterized in part by deep valleys, northwest Utah stands out for having unusually broad basins with irregular, poorly defined margins. In addition, complex intervening bedrock ranges, broad salt and mud flats, large military bombing ranges, and limited surface evidence of petroleum potential have resulted in few exploration drill holes or seismic lines in the area. The one exception, thick tar-like oil seeps at Rozel Point in Great Salt Lake near Promontory Point, generated some drilling and seismic studies in the 1980s. The heavy, low-grade oil, logistical problems, and unknown size of the oil reservoir doomed the enterprise, but this project did give us a glimpse of the subsurface geology on the east side of the area. And one drill hole, the Indian Cove, yielded high subsurface temperatures that triggered the recent interest in geothermal resources.

Map depicting existing isostatic gravity data for the northwest corner of Utah. The blue and black dots show where the UGS and USGS have collected new data to improve the resolution of the map. Cooler colors depict lower gravity values (typically less dense basin-fill materials), while warmer colors depict higher gravity values (typically higher density bedrock); sharp changes typically denote buried faults.

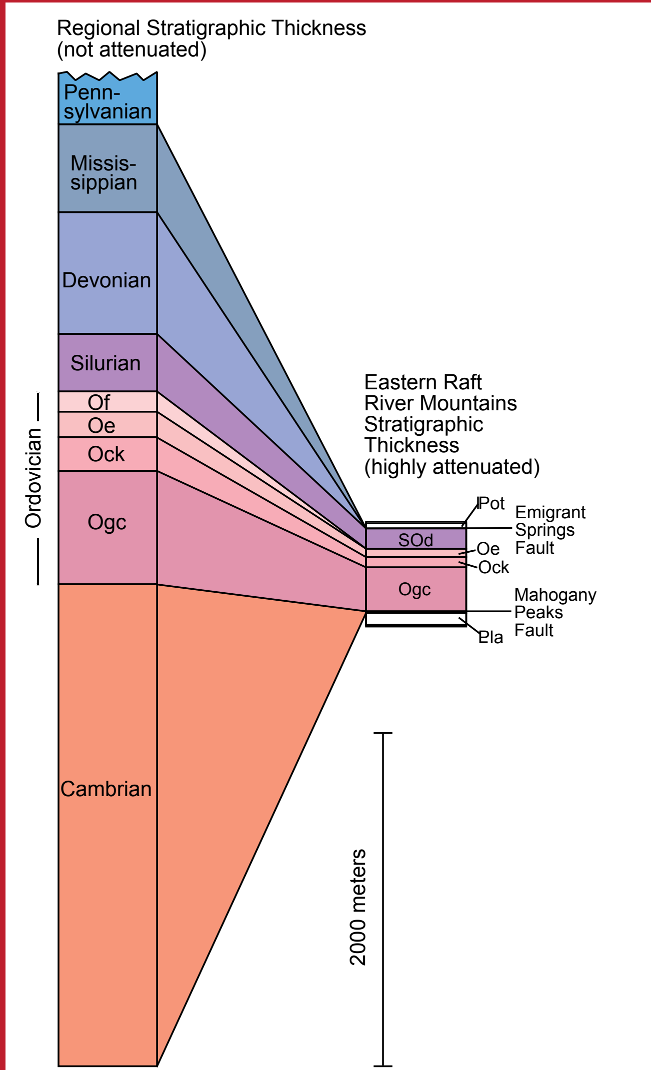


Additional drill holes are badly needed, but drilling is expensive. Before spending millions of dollars on a drilling program, we need better understanding of the shape, composition, and depth of the basins. For that need, we turn to geophysics. Over the past two years, the UGS, in cooperation with the USGS, has been conducting detailed aeromagnetic and gravity surveys of northwest Utah. Aeromagnetic surveys consist of mounting on an aircraft a highly sensitive instrument that detects very subtle changes in the earth's magnetic field. These changes reveal shallowly and deeply buried iron-bearing minerals, thereby allowing us to distinguish shallowly buried basalt flows, deep-seated granitic intrusions, and thick, buried sedimentary (generally iron-poor) formations. Gravity surveys, conducted from trucks and ATVs and on foot, use a highly sensitive gravimeter to measure subtle changes in the earth's gravity caused by rock density differences (yes, you actually do weigh a few micrograms less in some places than in others, but sorry dieters, the difference is less than when you trim your fingernails!). These subtle differences reflect density variations of underlying basin fill and bedrock, and can reveal the geometry of covered basins. When these two tools are used in conjunction with improved geologic maps and better geologic models, we can identify sites with the highest potential for geothermal resources, and prioritize targets for future exploratory drilling.

WHAT IS A METAMORPHIC CORE COMPLEX?

The Albion (Idaho), Grouse Creek, and Raft River Mountains host one of the major metamorphic core complexes in the western U.S. A metamorphic core complex is an area from a few miles to over 50 miles across characterized by a core of high-grade metamorphic rock, several miles of vertical uplift, and capping "shells" of highly sheared, attenuated, and variably metamorphosed sedimentary rock. They are common in areas of localized extension within otherwise thickened hinterlands of fold/thrust belts. Crustal extension (probably driven by temperature differences in the earth's upper mantle) leads to the rise of a deeply buried welt of hot rock and magma. The resultant doming leads to gravitational collapse on low-angle faults, causing overlying rock to shear and metamorphose, separate into distinctive structural zones (somewhat like layers of an onion), and thin down to a few percent of its original thickness (making it nearly unrecognizable). Rocks at the surface commonly slide away from the uplift.

The Albion/Raft River/Grouse Creek metamorphic core complex has evidence of over 10 miles of vertical uplift that occurred in episodic pulses over about 100 million years of geologic time. Each pulse produced a unique structural fabric that overprinted each previous fabric. Through careful field mapping and research over the past few decades, geologists have painstakingly teased this story out of the rock record. We are fortunate to have one of these geologists, Mike Wells, structural geologist at UNLV, on the Grouse Creek mapping team.



These two stratigraphic columns show a typical section of Paleozoic rock in northwest Utah (left), and the same section of rock where it has been highly attenuated to less than 1/8 its original thickness as part of the Albion–Raft River–Grouse Creek metamorphic core complex (right). Modified from Wells (2009).

Every Record Must Fall

An Update on the Largest Arches in the World

by Grant Willis

In the May 2009 issue of *Survey Notes*, we reported that Landscape Arch in Arches National Park was the natural arch with the largest measured span in the world. This was based on the work of the Natural Arch and Bridge Society (NABS), a small group dedicated to finding, measuring, and classifying natural arches (www.naturalarches.org). However, there are always obscure parts of the world where a larger arch could hide. Only about a year after NABS posted official measurements of Utah's Landscape and Kolob Arches, a NABS group traveled into an area of rugged karst topography in southeast China. There, they measured two exceptionally large bridges formed by the dissolution and undercutting of limestone (karsting). Both of these are massive structures deep in the rugged Guangxi Province of southeast China. Fairy Bridge has an incredible span of 400 feet. Jiangzhou Immortal Bridge is less accurately measured at 280 to 340 feet, relegating Landscape Arch to 2nd or 3rd place—for now. Other behemoths could remain hidden in some side canyon of this rugged terrain.

Though Landscape Arch doesn't have the longest measured span of any type of natural arch, it holds the record for sandstone arches and for "arc-type" arches, and with its thin ribbon of gravity-defying sandstone, many would agree that it is the most awe-inspiring arch in the world.

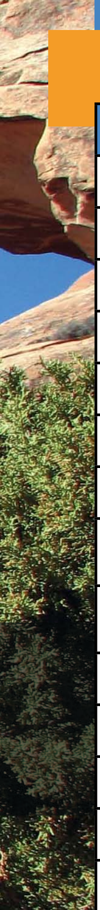
The May 2009 article generated questions regarding the definitions of "arch" and "bridge." Some people view "arches" and "bridges" as two separate kinds of features. However, NABS, the only organization that I know of that deals with such matters in a scientifically rigorous way, states that a natural bridge is a type of natural arch, and that when comparing span length, bridges are included with all other types of natural arches.

Landscape Arch, Arches National Park. Photo by Jeremy Gleason

ABOUT THE AUTHORS

Grant Willis has been a mapping geologist with the UGS for 28 years, including 17 years as manager of the Geologic Mapping Program. He has authored or coauthored over 40 geologic maps, and is currently mapping Glen Canyon National Recreation Area.

Donald Clark has been a mapping geologist with the UGS for eight years, and previously was a UGS contract and student mapper. He has authored or coauthored 12 geologic maps in northwest and central Utah, and is currently working on the Rush Valley and Grouse Creek 30' x 60' quadrangle maps.



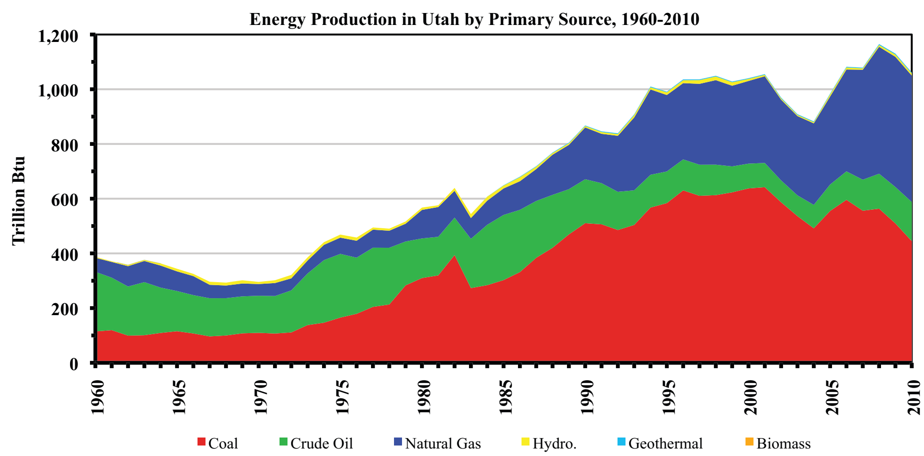
Top Fourteen Arches in the World (from Natural Arch and Bridge Society website at www.naturalarches.org). NABS now recognizes 14 arches with spans over 200 feet. Expect this list to change again as searches continue. (Utah arches in bold)

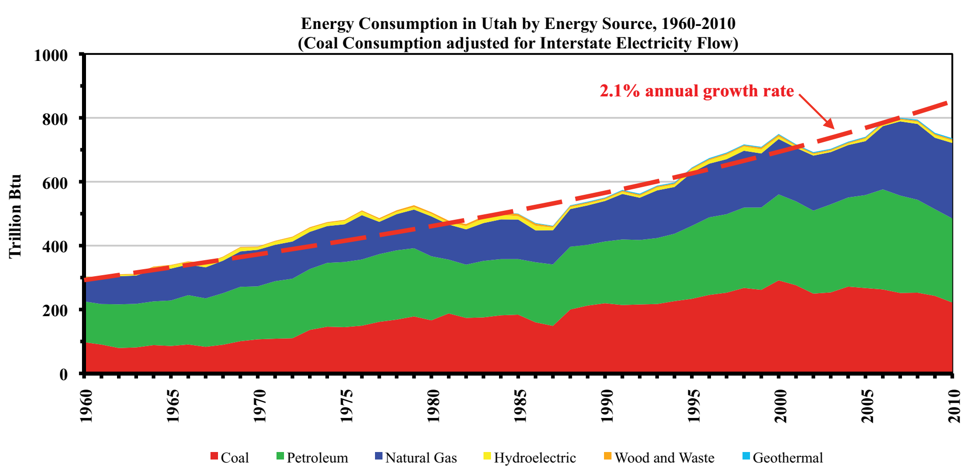
Rank	Name	Type/Lithology	Location	Span Length
1	Fairy Bridge	meander natural bridge in karsted limestone	Buliu River, Guangxi, China	400 ft
2, 3, or 4	Jiangzhou Immortal Bridge	meander natural bridge in karsted limestone	Jiangzhou, Guangxi, China	280–340 ft
2 or 3	**Landscape Arch**	**arc natural arch in sandstone**	**Arches National Park, Utah**	**290 ft**
3 or 4	**Kolob Arch**	**alcove natural arch in sandstone**	**Zion National Park, Utah**	**287 ft**
5	Aloba Arch	buttress arch and meander natural bridge in sandstone	Ennedi Range, Chad (Sahara Desert)	250 ft
6	**Morning Glory Natural Bridge**	**alcove natural arch in sandstone**	**Negro Bill Canyon, near Moab, Utah**	**243 ft**
7	Gaotun Natural Bridge	waterfall natural bridge in karsted limestone	Bazhou He Scenic Area, Guizhou, China	240 ft
8	**Rainbow Bridge**	**meander natural bridge in sandstone**	**Rainbow Bridge National Monument, Utah**	**234 ft**
9	**Sipapu Natural Bridge**	**meander natural bridge in sandstone**	**Natural Bridges National Monument, Utah**	**225 ft**
10	**Stevens Arch**	**shelter arch in sandstone**	**Escalante River, Utah**	**220 ft**
11	Shiptons Arch (Tushuk Tash)	? in conglomerate	Near Kashgar, Xinjiang, China	214 ft
12	Hazarchishma Natural Bridge	meander natural bridge in karsted limestone	Bamyan Province, Afghanistan	211 ft
13	Outlaw Arch	alcove arch in sandstone	Dinosaur National Monument, Colorado	206 ft
14	Snake Bridge	meander natural bridge or alcove arch in sandstone	Sanostee, New Mexico	204 ft

The Director's Perspective *continued*

increased oil production within Utah, the need for imported oil has decreased, especially from Canada. Natural gas production and consumption have leveled off since 2008, although 1300 megawatts of new natural gas-fired electricity has come on line since 2005 and caused the share of coal-fired electricity to drop from 96 percent to 81 percent. Natural gas is now the dominant energy source produced in Utah, surpassing coal in 2010. The growth in electricity demand that has dominated the last 50 years ceased in 2007, and may have temporarily delayed plans for new generation.

The production of geological commodities is dependent on many factors such as price and external supply variations that are often impossible to predict. Although we have seen a recent decline in energy consumption in Utah, the signs of economic recovery during 2011 and continued population growth are both drivers that will ensure that energy consumption resumes a growth trend. It will be interesting to see whether the growth rate is similar to the past 50 years, or if recent patterns of energy savings will lower that rate.





Figures modified from Utah Energy Statistics web data, http://geology.utah.gov/emp/energydata/overviewdata.htm.

Utah's Gordon Creek Field to Test Commercial-Scale Storage of Carbon Dioxide

by Craig Morgan

View of the Gordon Creek Unit 1 well site, currently producing methane gas from the Ferron Sandstone. The well, which was originally drilled and cased much deeper, will be used for the demonstration to inject CO_2 into the deeper Navajo Sandstone.

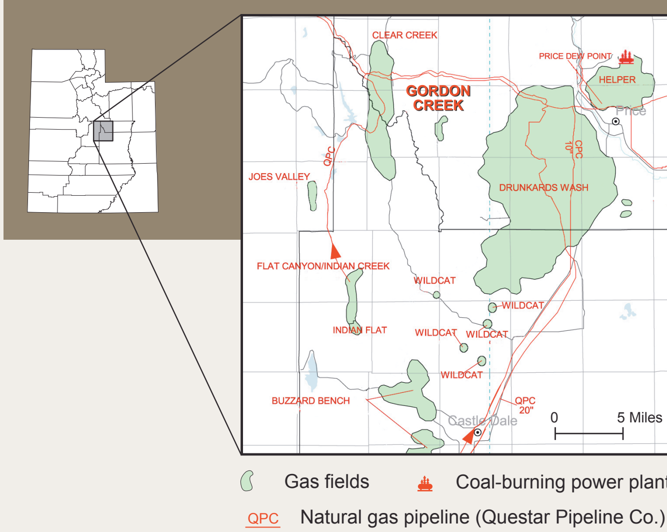
Energy News

Over the next decade, Gordon Creek gas field in central Utah will be the site of a significant demonstration of technologies for the potential commercialization of carbon dioxide storage in deep, saline (brine-filled) reservoirs. The demonstration, which is attracting international attention, will be conducted by the Southwest Partnership for Carbon Sequestration (SWP), one of seven government/industry partnerships managed by the U.S. Department of Energy's National Energy Technology Laboratory (NETL). The principal investigators for the SWP are the New Mexico Institute of Mining & Technology and the University of Utah; the Utah Geological Survey is a partner.

Recent climate change is attributed to carbon dioxide (CO_2), the most common greenhouse gas. The U.S. emits over 6 billion tons of CO_2 each year primarily due to the combustion of fossil fuels; 40 percent of this is for the generation of electricity. Utah, a major coal-producing state, depends on several coal-fired power plants within the state for over 80 percent of its electricity. Demonstrating the ability to safely store CO_2 deep underground may lead to development of commercial capture and long-term storage of greenhouse gases from large industrial plants, greatly reducing the volume of anthropogenic CO_2 released into the atmosphere. Fortunately, Utah's geology provides abundant potential for long-term storage of CO_2 in deep, saline reservoirs and depleted to nearly depleted oil and gas fields.

The SWP has successfully demonstrated smaller-scale methods of storing CO_2 elsewhere in the southwestern United States. Two demonstrations were conducted in New Mexico's San Juan Basin. CO_2 was injected into coalbeds demonstrating the potential for long-term storage and enhancing the recovery of coalbed methane. Water produced by the enhanced coalbed methane process was desalinated and used to irrigate grasslands and increase terrestrial sequestration (natural absorption of CO_2 by plants). CO_2 has also been injected into producing fields to enhance oil recovery. The SWP demonstrated CO_2 storage with enhanced oil recovery at SACROC oil field near Snyder, Texas, and Greater Aneth field near Montezuma Creek, Utah, on the Navajo Nation.

Location of the Gordon Creek gas field, where the SWP will demonstrate technologies necessary for commercial-scale storage of CO_2 in a deep saline reservoir.



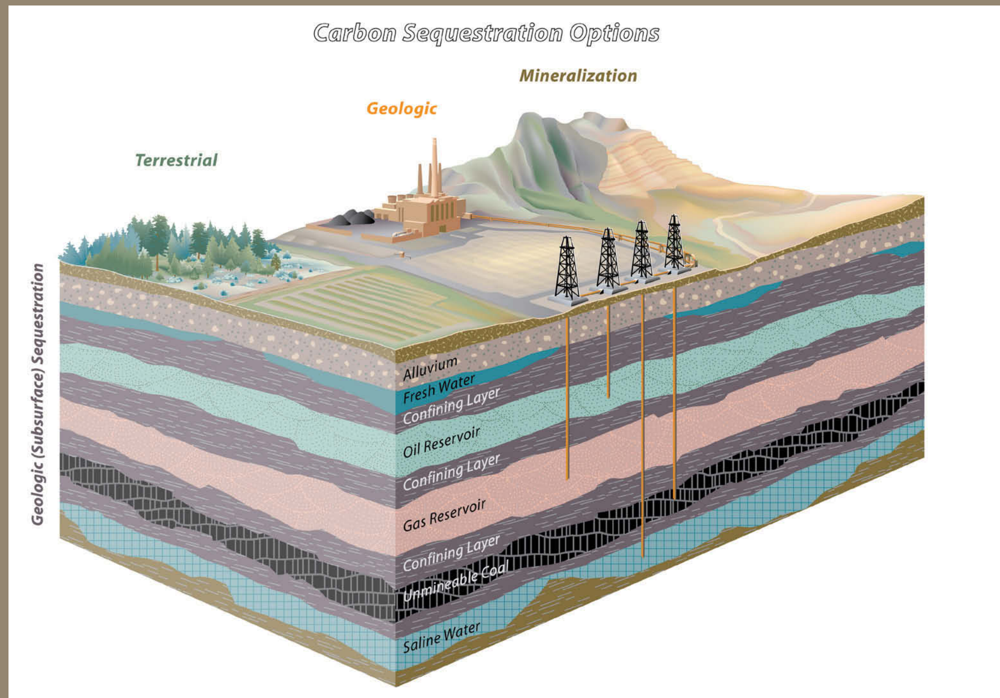
Gordon Creek field produces natural gas from the Cretaceous Ferron Sandstone about 3300 feet below the surface. Gordon Creek LLC, a wholly-owned subsidiary of Thunderbird Energy Corporation, is the field operator/owner and a member of the SWP. Gordon Creek LLC will drill a

Period	Formation/Member		Depth (feet)
CRETACEOUS	Mancos Shale	Blue Gate Sh Mbr	0
		Ferron Ss Mbr	3250
		Tununk Sh Mbr	3668
	Dakota Sandstone		4025
	Cedar Mountain Formation		4120
JURASSIC	Morrison Formation		4460
	Summerville Formation		5895
	Curtis Formation		6275
	Entrada Formation		6585
	Carmel Formation		7582
	Temple Cap Formation		8437
	Navajo Sandstone		8542
	Kayenta Formation		8793
	Wingate Sandstone		8916
TRIASSIC	Chinle Formation		9267
	Moenkopi Formation		9520
PERM.	Kaibab Formation		10,890
	White Rim Sandstone		11,135

Methane Producer — Seal

CO_2 Source — Potential CO_2 Storage Reservoir

Geologic formations at Gordon Creek gas field. For the demonstration, CO_2 will be produced from the White Rim Sandstone and the gas will be injected into the Navajo Sandstone. Seals prevent the gas from migrating upward. Gordon Creek field produces methane gas from the Ferron Sandstone. The Kaibab Formation may contain CO_2 in some areas of the field but is a seal in other areas. Depths (formations tops) are from the Gordon Creek Unit 1 well.



Block diagram showing terrestrial and geologic sequestration. Geologic sequestration can be in old oil and gas fields, unmineable coal beds, and saline aquifers such as the Navajo Sandstone. From Colorado Geological Survey, 2007, Resource Series 45.

12,000-foot production well to produce CO_2 from the Permian White Rim Sandstone for the commercial-scale demonstration. CO_2 from the production well will be transported by pipeline to an injection well where the gas will be compressed into a high-density liquid and injected down an existing cased well into the Jurassic Navajo Sandstone reservoir, a saline aquifer about 8500 feet below the surface. A third well will be used to help monitor the pressure and gas saturation in the deep formation; seismic data will be used to monitor the growth and distribution of the resulting CO_2 plume. A maximum of 1 million tons of CO_2 per year will be injected for up to four years, followed by several years of monitoring.

The UGS has been a member of the SWP since its inception in 2003. In an earlier project, we identified and characterized naturally occurring CO_2 deposits throughout Utah to better understand the seal and reservoir properties needed for a potential storage site. Next, we characterized reservoirs throughout the state, identifying saline aquifers having CO_2 storage potential as well as several specific sites for possible commercial development for the NETL Carbon Sequestration Atlas of the U.S. We were also a major contributor to the reservoir characterization for the CO_2-enhanced oil recovery project at Greater Aneth field. For the current study, we will be leading the geologic characterization of the Navajo and White Rim Sandstone reservoirs and overlying seal formations at Gordon Creek field and throughout Carbon and Emery Counties.

The Gordon Creek demonstration will be watched closely throughout the world by scientists and policy makers involved in climate issues. A successful commercial-scale demonstration at Gordon Creek field could provide long-term benefit to Utah's coal and power generation industries and possibly lead to the development of a new carbon sequestration industry in Utah.

A full list of the SWP partners and additional information about SWP activities can be found at http://southwestcarbonpartnership.org.

Brigham Young University student Walter Harston (left) and the author examining the White Rim Sandstone in Black Box Canyon, San Rafael Swell. At Gordon Creek field, the White Rim contains CO_2 that will be produced for the demonstration.

GLAD YOU ASKED

IS THERE CORAL IN GREAT SALT LAKE?

By Jim Davis

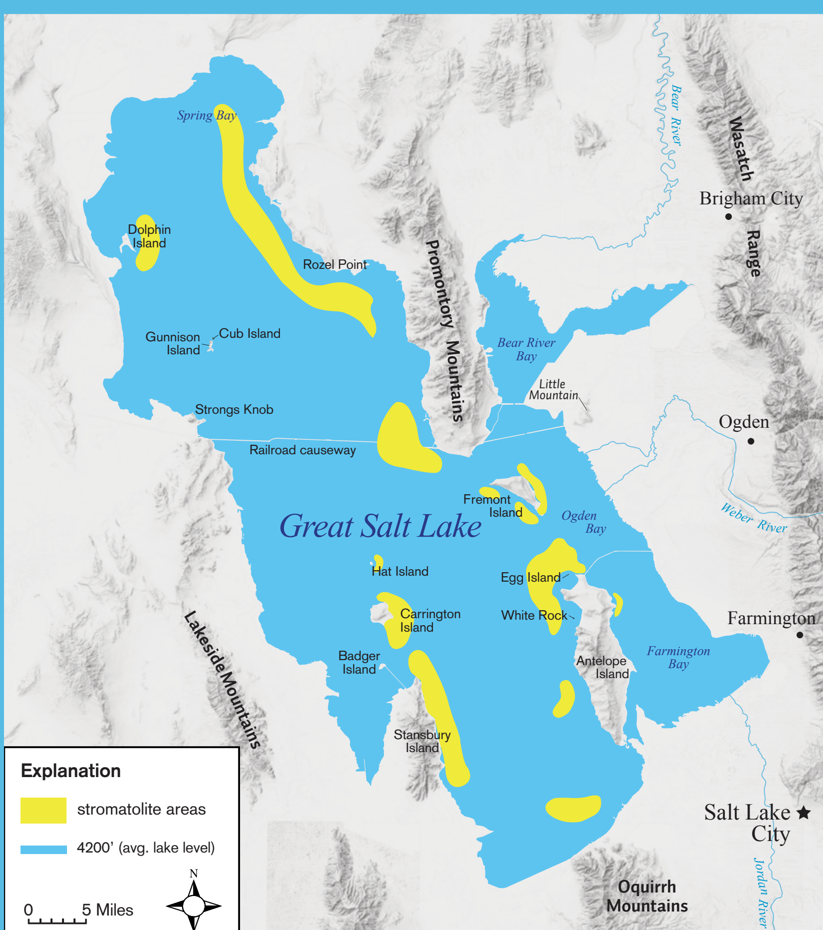
Great Salt Lake has reef-like structures that resemble coral and are often called coral, yet they are not true coral. While true coral is an animal, Great Salt Lake "coral" is blue-green algae (cyanobacteria). These algae build bulbous sedimentary rock structures known by various names: algal bioherms and stromatolites are two of the most common.

Stromatolites, which are among the oldest fossil evidence of life on Earth, dominated the shallow seas for billions of years. Still forming today, stromatolites (pronounced strō · MAT · o · lites) are limited to a few locations around the world that are inhospitable to other organisms that might otherwise outcompete or consume them. These locations are typically shallow, warm, hypersaline waters such as closed-basin lakes where there is no outflow, warm springs, or restricted marine embayments.

Stromatolites are composed of limestone (calcium carbonate) and dolomite (calcium magnesium carbonate). Other types of stromatolites, depending on the organisms that create them and the environment in which they live, can be rich in silica, iron, or manganese. Although various algae are cited worldwide as contributors to stromatolite formation, the dominant algae in Great Salt Lake is a cyanobacteria of the genus *Aphanothece*.

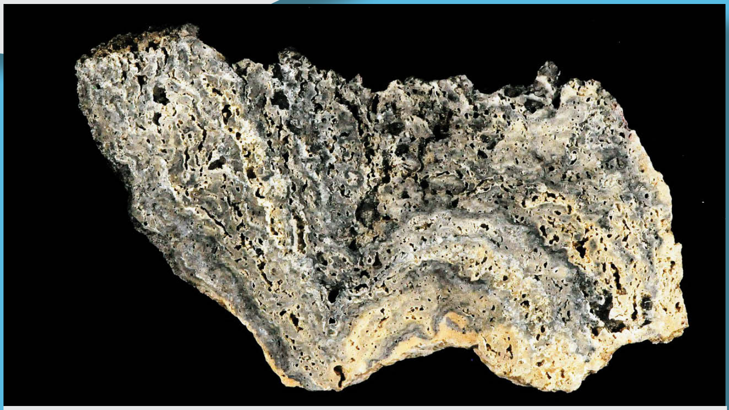
Great Salt Lake is ideal for stromatolites, and is home to some of the most extensive reefs of living stromatolites on Earth. The lake's briny environment precludes organisms that would ordinarily graze or browse on nutritious stromatolites or burrow and bore into them. Additionally, a lack of animals minimizes stirring of sediments from the lake bed that would otherwise blanket stromatolites from sunlight. The absence of plants and scarcity of other algae on the lake floor also reduce competition for nutrients and space.

Most Great Salt Lake stromatolites are broad, circular, and domal in shape, measuring around one to three feet across and four to eight inches high. The largest was measured at 12 feet in diameter and 3.5 feet tall. Because stromatolites are photosynthetic, their distribution is limited to shallow, sunlit waters of which Great Salt Lake possesses vast tracts adjacent to its shoreline and numerous islands. They are most observable when lake level is near average (4200 feet) or lower and after planktonic algae have been grazed out by brine shrimp, making the water more transparent.



Stromatolite areas in Great Salt Lake. Although stromatolites in the north arm of the lake can be seen, their cyanobacteria colonies no longer exist due to salinities that are about double or triple that of the south arm, a condition created when the railroad causeway was constructed in 1959. Map modified from Eardley, 1938; Gwynn and Murphy, 1980.

UGS geologist Tom Chidsey holds a small, bleached-out (no living organisms) stromatolite near Stansbury Island, Great Salt Lake. Photo by Michael Vanden Berg.



A sliced stromatolite from Rozel Point, Great Salt Lake, measuring about seven inches across, shows a porous structure and contorted laminations. Voids such as these hold hydrocarbons in massive deposits off the coast of Brazil. Photo by Michael Vanden Berg

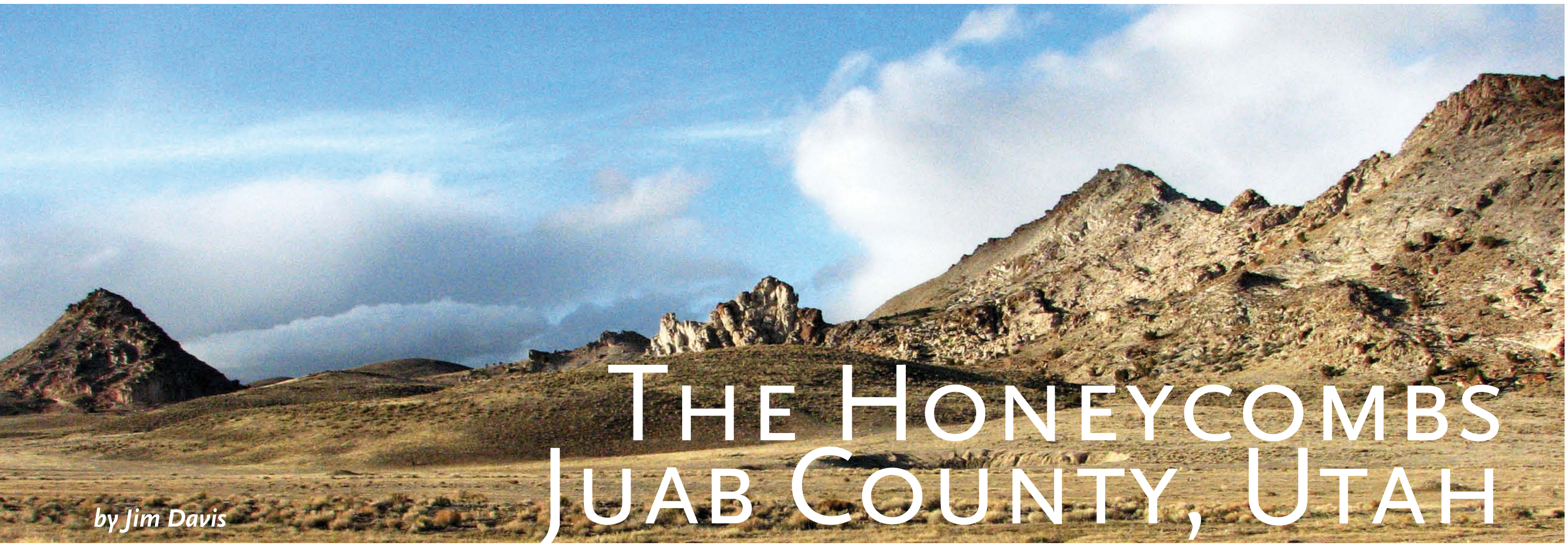
Stromatolites grow by accretion from chemical precipitates, particularly calcium carbonate, and by the inclusion of sediments that settle out of the water column. Great Salt Lake provides plenty of calcium carbonate because it is a closed-basin lake that concentrates elements through evaporation, and the lake has considerable areas of calcium-laden limestone and dolomite in its drainage basin.

The process of stromatolite formation begins with mat-like accumulations of gelatinous, mucous-covered filamentous strands of algae—proficient trappers of sediment. Metabolism of algae and other microorganisms, such as bacterial decomposers, along with water agitation and temperature fluctuations, drive carbon dioxide out of the water. Removal of carbon dioxide raises the pH, which triggers the precipitation of calcium carbonate. The calcium carbonate is then integrated with the algal mats and cements the sediments. These physical and biological processes work to enlarge the stromatolite in laminar fashion—the rock grows in fine-banded layers.

Since the 2006 discovery of a substantial oil play off the coast of Brazil, stromatolites have created a buzz in the petroleum industry. In the Brazilian play, petroleum occupies the voids within the porous, stromatolitic rock formed in an ancient lake at the time Africa and South America were beginning to break apart, some 150 million years ago. Geologists are looking to modern Great Salt Lake stromatolites as an analogy for the ancient ones that now hold oil. One of the largest oil fields in the Uinta Basin, so far producing nearly a million barrels of oil, is sourced from an ancient reef of stromatolites that resided in a large lake.

A Great Salt Lake stromatolite was donated to the UGS in the 1990s and is housed at the Utah Core Research Center. Periodic saline spray keeps it healthy, green, and vibrant. The stromatolite measures 16 inches in diameter and weighs almost 40 pounds.

A stromatolite reef emerges from Great Salt Lake near Hat Island in September, 2007, when lake levels were nearly five feet below the average of 4200 feet. Photo by Jim Van Leeuwen, courtesy of the Utah Division of Wildlife Resources, Great Salt Lake Ecosystem Program.



The Honeycombs
Juab County, Utah

by Jim Davis

Far out in Utah's west desert, 25 miles from the Nevada border, is a solitary cluster of hills called The Honeycombs, also known as the Honeycomb Hills. Rising just a few hundred feet above the surrounding landscape, the humble Honeycombs are overshadowed by neighboring Great Basin mountain ranges. The hills barely draw notice, until examined up close. Their rough and craggy rocks—mostly gray but also red, orange, lavender, and pink—are permeated with hollows ranging from pea-sized pits to alcoves large enough to shelter a horse and rider. The pattern of the hollows and the thin walls that separate them resemble the hexagonal cellular structures of beehives that give The Honeycombs their name.

An outcrop of lace rock; orange lichen covers the rocks at left. Outcrop is about 40 feet high.

Geologic Information

The distinctive appearance of the rocks at The Honeycombs results from a process known as honeycomb weathering, also called cavernous or alveolar weathering. This type of weathering produces rock riddled with cavities known as tafoni, giving the rock a texture described as lace rock, stone fretwork, or stone lattice. Pitting in the stone can be nested—smaller cavities within larger ones that are themselves within larger ones. This type of weathering is typically found on inclined or vertical rock faces and occurs worldwide at all latitudes. Honeycomb weathering is an especially common feature on cliff faces in deserts and along seacoasts.

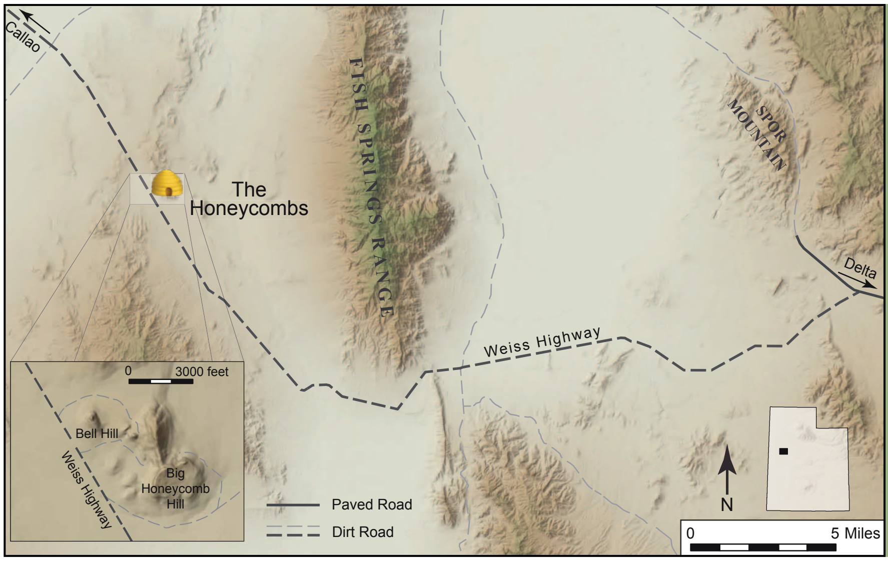
Honeycomb weathering is likely a combination of physical and biological factors. "Salt weathering" is often cited—accounting for the prevalence of the weathering features at ocean and desert locales—by way of pressurization in rock pores from salt crystal growth, hydration, or decay through chemical processes from salts such as halite, gypsum, epsomite, sylvite, and mirabilite. Other mechanisms that contribute to honeycomb features include internal characteristics of the rock such as bedding planes and rock heterogeneity, and external factors

View of The Honeycombs from the Weiss Highway looking to the north-northwest. The Honeycombs include one large elongate and irregularly shaped hill (right) and one small, circular hill (far left), unofficially named "Big Honeycomb Hill" and "Bell Hill," respectively. The hills are the erosional remnant of a single lava dome.

such as microclimate (wind and air pressure, humidity, solar radiation, frost action, and thermal stress). Microorganisms such as algae and fungi on the rock and within rock pores protect the thin walls between the cavities and preserve the seemingly delicate tafoni. Honeycomb weathering can develop within a human time frame, emerging and enlarging on rock walls and stone monuments in less than a century. Tafoni features form in a wide variety of rock types, including rhyolite at The Honeycombs, but typically is seen on sandstone and granite.

The Honeycombs were created by a volcanic episode 4.7 million years ago. During the eruption, magma oozed upward through limestone and older volcanic rocks, culminating in an explosive eruption of ash and rock fragments followed by lava flows. Forty feet of tuff (consolidated ash and other volcanic debris) underlies a lava dome of 200 million cubic yards of topaz-rich rhyolitic lava. The lava dome has since been eroded to form the hills, and the central magma conduit is exposed within The Honeycombs. The Honeycombs are a

How to get there



From U.S. Highway 6 between Delta and Lynndyl, go west on State Route 174 (Brush Highway). After about 41 miles, and about 3½ miles after passing the sign for the Topaz Mountain turnoff, turn left onto a well-graded dirt road (Weiss Highway), which is marked by a sign for Trout Creek, Callao, Gold Hill, and Ibapah. After about 30 miles you will see The Honeycombs, a few hundred feet off to the right (east) of the Weiss Highway. Several dirt roads lead to the hills: the southern road goes around to the back of the hills (east side) and then continues on a few hundred yards as a four-wheel-drive high-clearance road, the middle road goes to the southern side of the hills, and the northern road begins just after passing Bell Hill and ends on the north side of the hills. Be sure to have a full tank of gasoline, food and water, a spare tire, and emergency supplies, as services are distant from The Honeycombs. Contact the Fillmore Bureau of Land Management Field Office for more information and current conditions at (435) 743-3100.

young component of a swath of volcanism stretching eastward from Nevada through Juab County and into southern Tooele County. This zone is referred to as the *beryllium belt of western Utah* (also the *Deep Creek–Tintic belt*) because of numerous occurrences of beryllium mineralization.

The Honeycombs have enticed geologists because of the rock's distinctive geochemical signature—enriched in elements such as beryllium, fluorine, uranium, tin, rubidium, thorium, cesium, yttrium, and lithium. Since the discovery of beryllium here in the early 1960s, various companies have explored for this metal as well as uranium. In 2010, all mineral claims at The Honeycombs were acquired by the Canada-based gold and rare earth metal company Redhill Resources Corporation. The Honeycombs have been dubbed a "miniature Spor Mountain," in reference to a mountain of similar origin 20 miles to the east. At Spor Mountain, the majority of the world's beryllium is produced from Earth's largest known deposit. Currently, The Honeycombs are a Bureau of Land Management public community pit for collecting the sought-after lace rock that is desirable for display in aquariums.

Honeycomb weathering on a rhyolite boulder in the northern part of The Honeycombs.

Erosion has exposed the central magma conduit with its vertical, concentric, and contorted layering or flow-banding of rhyolite.

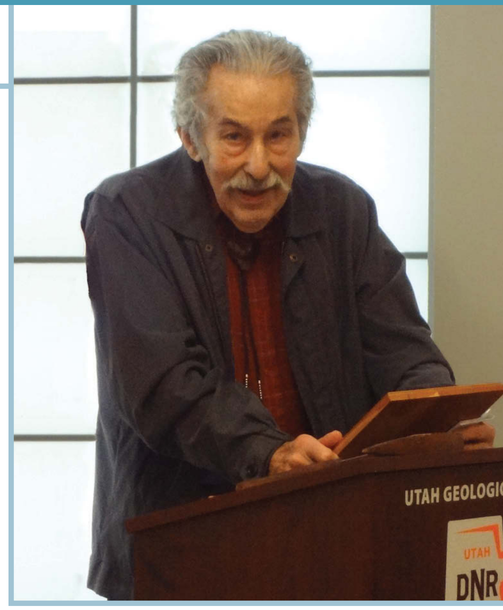
Useful Maps: Fish Springs 30' x 60' quadrangle (1:100,000 scale), Middle Range North 7.5' quadrangle (1:24,000 scale)

Location: N 39° 42.47' W 113° 34.73' W

Elevation: approximately 5100 to 5686 feet

SURVEY NEWS

2011 Lehi Hintze Award

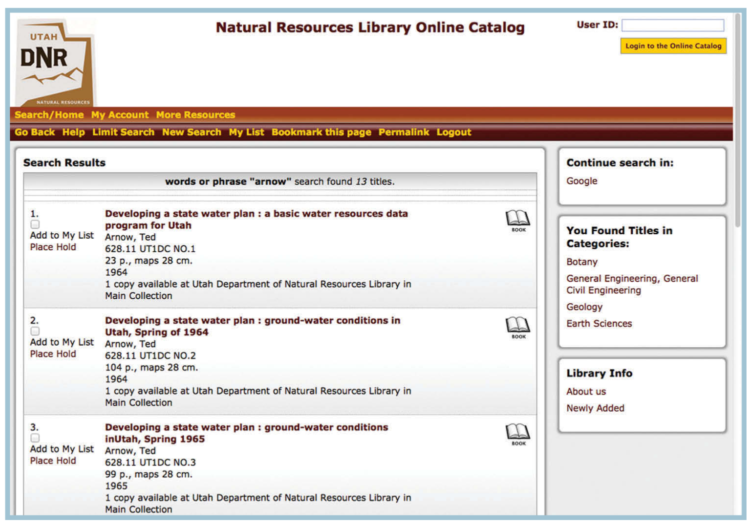


The UGS congratulates **Ted Arnow** (retired, USGS), this year's recipient of the Lehi F. Hintze Award! Ted had a distinguished professional career in the groundwater and hydrology disciplines in Utah. One of Ted's most significant achievements was the extraordinary increase in productivity of the USGS water-resource program, which collaborated with the State Department of Natural Resources in the publication of 21 major technical reports. Now 90, Ted has also been a life-long supporter of the geologic community; he was one of the founding members of the Utah Geological Association and the author of its Constitution. Ted is a well-deserving winner of the Lehi Hintze award.

Named for the first recipient, Dr. Lehi F. Hintze of Brigham Young University, the Lehi Hintze Award was established in 2003 by the Utah Geological Association and the UGS to recognize outstanding contributions to the understanding of Utah geology.

New Online Library Catalog

A new online catalog is now available for the Utah Department of Natural Resources Library. The new system will allow for greater searching capabilities and provide access to some of the libraries's collection online. Use Quick Search to find items by title, author, subject, or series, or use the Advanced Search function to search using multiple fields at once. Contact the Utah DNR Librarian with questions about how to use the new system at 801-537-3333 or stephanieearls@utah.gov.



Employee News

The Energy and Minerals Program welcomes **Peter Nielsen** as a geologist. He has an M.S. in Geology from Brigham Young University, and previously worked as a consultant in hydrology and geochemistry, a computer modeler, and a resource evaluator for coal mines.

In September, the Energy and Minerals Program bid farewell to **Valerie Davis**, who retired. **Lisa Brown** resigned as secretary for the Mapping and Geologic Hazards Programs after eight years of service. **Jim Ollerton**, a geologist with the Geologic Hazards Program, left in November to pursue other interests.

UGS Board News

UGS Board Chair **Don Harris** resigned in September when he accepted a new job and moved out of state. The Governor appointed **Marc Eckels** as his replacement. Marc is chief operating officer, vice president, and a director of Wind River Resources Corporation and Wind River II Corporation. He has considerable oil and gas experience from the Uinta Basin, as well as diverse minerals exploration and engineering geophysics experience.

Teacher's Corner

Earth Science Week 2011 A 10 Year Milestone

by Mark Milligan

Last October the UGS celebrated its 10th year of hosting students for Earth Science Week (ESW).* In these 10 years nearly 7,000 students have attended! The 4th graders we wowed in 2001 may now be sophomores in college.

In 2011, 680 students from seven schools rotated through five 15-minute activity stations where they observed erosion and deposition on a stream table; learned about the properties of rocks and minerals in the mineral identification room, in the rock talk room, and at the "gold" panning troughs; and studied dinosaurs in our paleontology prep lab. Thanks to numerous volunteers from various agencies, universities, corporations, and organizations, this year was another resounding success, as evidenced by the following comments taken from thank-you notes:

"**Best field trip EVER.**" (Hawthorne Elementary student)

"My favorite activity was the [stream table] model. **Sadly, my Range Rover and beach house were washed away.**" (J.E. Cosgriff student)

"Thank you for sharing the wonders of the world. I never knew that there would be so much **fun and learning in science.**" (Hawthorne Elementary student)

**ESW activities at the UGS started in 2001 but were canceled in 2008 due to construction at the Utah Core Research Center, making this the 10th ESW.*

"It was a VERY, and I mean **very, cool trip.**" (J.E. Cosgriff student)

"My students had an **AMAZING** experience participating in all of the Earth Science Week learning activities yesterday. The staff's enthusiasm and the spectacular specimens were the foundation of solid science learning. Thanks for making the activities so interactive and for helping to **challenge student thinking.** The Rock Cycle poster is the best I've seen...." (Hawthorne Elementary teacher)

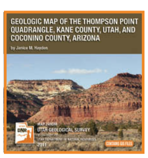
"**I cannot wait to come again.** I loved it." (J.E. Cosgriff student).

"It is the **very best field trip in the valley,** and we were so lucky to go." (Sunrise Elementary teacher)

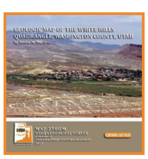
As a final note, for students such as these who are anxious to return, UGS will host the 11th annual ESW on **October 9–12, 2012.**

NEW PUBLICATIONS

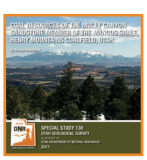
Landslide hazards in Utah, by Gregg Beukelman, 4 p., **PI-98** .... **FREE**



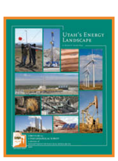
Geologic map of the Thompson Point quadrangle, Kane County, Utah, and Coconino County, Arizona, by Janice M. Hayden, CD (2 pl. [contains GIS data]), scale 1:24,000, ISBN 978-55791-830-7, **M-249DM** **$24.95**



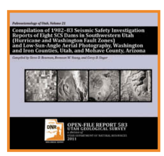
Geologic map of the White Hills quadrangle, Washington County, Utah, by Janice M. Hayden, CD (11 p., 2 pl. [contains GIS data]), scale 1:24,000, ISBN 978-1-55791-847-5, **M-250DM** **$24.95**



Coal resources of the Muley Canyon Sandstone Member of the Mancos Shale, Henry Mountains coalfield, Utah, by Sonja Heuscher, CD (18 p.), ISBN 978-1-55791-852-9, **SS-138** **$14.95**

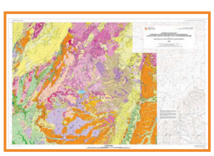


Utah's Energy Landscape—2010 update, by Michael D. Vanden Berg, 45 p., ISBN 1-978-1-55791-851-2, **C-113** **$5.95**



Paleoseismology of Utah, Volume 21—Compilation of 1982–83 seismic safety investigation reports of eight SCS dams in southwestern Utah (Hurricane and Washington fault zones) and low-sun-angle aerial photography, Washington and Iron Counties, Utah, and Mohave County, Arizona, compiled by Steve D. Bowman, Brennan W. Young, and Corey D. Unger, 6 DVD set (4 p., 2 pl., 789 photographs [contains GIS data]), **OFR-583** **$49.95**

Interim geologic map of the Johnson Lakes quadrangle, Kane County, Utah, and Coconino County, Arizona, by Janice M. Hayden, 13 p., 1 pl., 1:24,00 scale, **OFR-584** **$13.95**



Interim geologic map of the west part of the Panguitch 30' x 60' quadrangle, Garfield, Iron, and Kane Counties, Utah—Year 3 progress report, by Robert F. Biek, John J. Anderson, Peter D. Rowley, and Florian Maldonado, CD (107 p., 1 pl.), 1:65,000 scale, **OFR-585** **$17.95**

Interim geologic map of the Provo 30' x 60' quadrangle, Salt Lake, Utah, and Wasatch Counties, by Kurt N. Constenius, Donald L. Clark, and J. Buck Ehler, DVD (42 p., 2 pl. [contains GIS data]), scale 1:62,500, **OFR-586DM** **$24.95**

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Interim Geologic Map of the Provo 30' x 60' Quadrangle, Salt Lake, Utah, and Wasatch Counties, Utah

The Utah Geological Survey recently released an interim geologic map covering ~1800 square miles of north-central Utah, from Strawberry Reservoir on the east, through the Provo area and Utah Valley, to Utah Lake and the Lake Mountains on the west, and from Point of the Mountain and Deer Creek Reservoir south to Payson.

The map covers the populated Wasatch Front and Interstate 15 corridor, as well as the less populated backvalley area to the east. This new map depicts the regional geology in unprecedented detail, and is the first release in color of the backvalley part of the map. The open-file report contains explanatory information, including a 40-page booklet describing map units and providing geologic references, and a second plate with lithologic columns, correlation diagrams, age-data tables, an index to geologic mapping, and geologic symbols. This DVD release also includes digital geologic data in PDF format and GIS (Geographic Information Systems) format.

Open-File Report 586DM
$24.95

Available at the Natural Resources Map & Bookstore

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