UTAH GEOLOGICAL SURVEY

SURVEY NOTES

Volume 46, Number 1

January 2014

Utah's Microbial Carbonates

& Modern Ancient

Contents

Design: *Nikki Simon*
Cover: *Image on the left shows living and growing microbial mats exposed during low lake level in Bridger Bay, Great Salt Lake, along the northwest part of Antelope Island. Image on the right shows ancient (54 million years old) microbial heads, several feet in diameter, in the Green River Formation, Uinta Basin, south of Vernal. Photos by Michael D. Vanden Berg.*

State of Utah
Gary R. Herbert, *Governor*

Department of Natural Resources
Michael Styler, *Executive Director*

UGS Board
Mark Bunnell, *Chair*
William Loughlin, Tom Tripp,
Sunny Dent, Kenneth Puchlik,
Marc Eckels, Pete Kilbourne,
Kevin Carter *(Trust Lands Administration-ex officio)*

UGS Staff

Administration
Richard G. Allis, *Director*
Kimm Harty, *Deputy Director*
Starr Soliz, *Secretary/Receptionist*
Dianne Davis, *Administrative Secretary*
Jodi Patterson, *Financial Manager*
Linda Bennett, *Accounting Technician*
Michael Hylland, *Technical Reviewer*
Robert Ressetar, *Technical Reviewer*

Editorial Staff *Vicky Clarke*
Lori Steadman, Jay Hill, Nikki Simon,
Elizabeth Firmage

Geologic Hazards *Steve Bowman*
Richard Giraud, William Lund, Greg McDonald,
Jessica Castleton, Gregg Beukelman, Chris DuRoss,
Tyler Knudsen, Corey Unger, Adam McKean,
Ben Erickson, Pam Perri, Adam Hiscock

Geologic Information and Outreach *Sandra Eldredge*
Christine Wilkerson, Patricia Stokes, Mark Milligan,
Lance Weaver, Gentry Hammerschmid, Jim Davis,
Marshall Robinson, Bryan Butler, Robyn Keeling

Geologic Mapping *Grant Willis*
Jon King, Douglas Sprinkel, Kent Brown, Basia Matyjasik,
Donald Clark, Bob Biek, Paul Kuehne, Zach Anderson

Energy and Minerals *David Tabet*
Robert Blackett, Craig Morgan, Jeff Quick, Taylor Boden,
Thomas Chidsey, Cheryl Gustin, Tom Dempster,
Brigitte Hucka, Stephanie Carney, Ken Krahulec,
Brad Wolverton, Sonja Heuscher, Mike Vanden Berg,
Andrew Rupke, Mark Gwynn, Christian Hardwick,
Peter Nielsen, Hobie Willis, Rebekah Wood

Groundwater and Paleontology *Mike Lowe*
James Kirkland, Janae Wallace, Martha Hayden,
Hugh Hurlow, Don DeBlieux, Kim Nay,
Paul Inkenbrandt, Lucy Jordan, Kevin Thomas,
Walid Sabbah, Rich Emerson, Stefan Kirby,
Scott Madsen, Jennifer Jones, Diane Menuz,
Galvan Haun

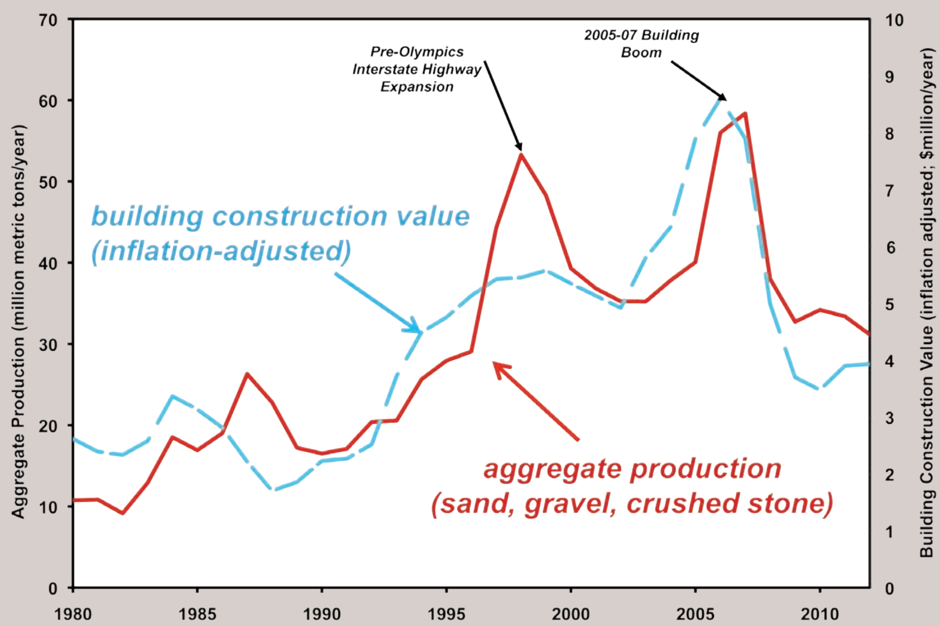
The Director's Perspective

by Richard G. Allis

This issue of *Survey Notes* has an Energy and Mineral theme. Included is the annual UGS tracking of the total value of Utah's energy and mineral production (see sidebar, page 13), which for 2012 is $8.2 billion. Although this is a 12% decline compared to 2011, it is still in the $8–10 billion range that has occurred since 2004, and represents an important part of Utah's economy. Oil is Utah's most valuable single natural commodity, and the $2.5 billion value in 2012 is a record for Utah. The decline in total commodity value in 2012 reflects generally lower prices for base metals and natural gas.

An often-overlooked sector of Utah's extractive commodities is the industrial minerals. These contributed a total value of $1.2 billion; saline minerals (potash, salt, and magnesium chloride) represent 35% of the total, aggregate (sand, gravel, and crushed stone) represents 17%, and cement and lime products 16%. This issue of *Survey Notes* also highlights two industrial minerals in Utah that are gaining increasing attention from the petroleum exploration industry: gilsonite, which is unique to the Uinta Basin and is now used as an additive to drilling fluid; and frack sand, which is used as a proppant during hydraulic fracturing. Utah may have deposits of suitable sand or soft sandstone that can complement the traditional frack sand sources in the Midwest. A challenge will be finding a source close to a rail line so it can be economically transported to the areas of greatest demand.

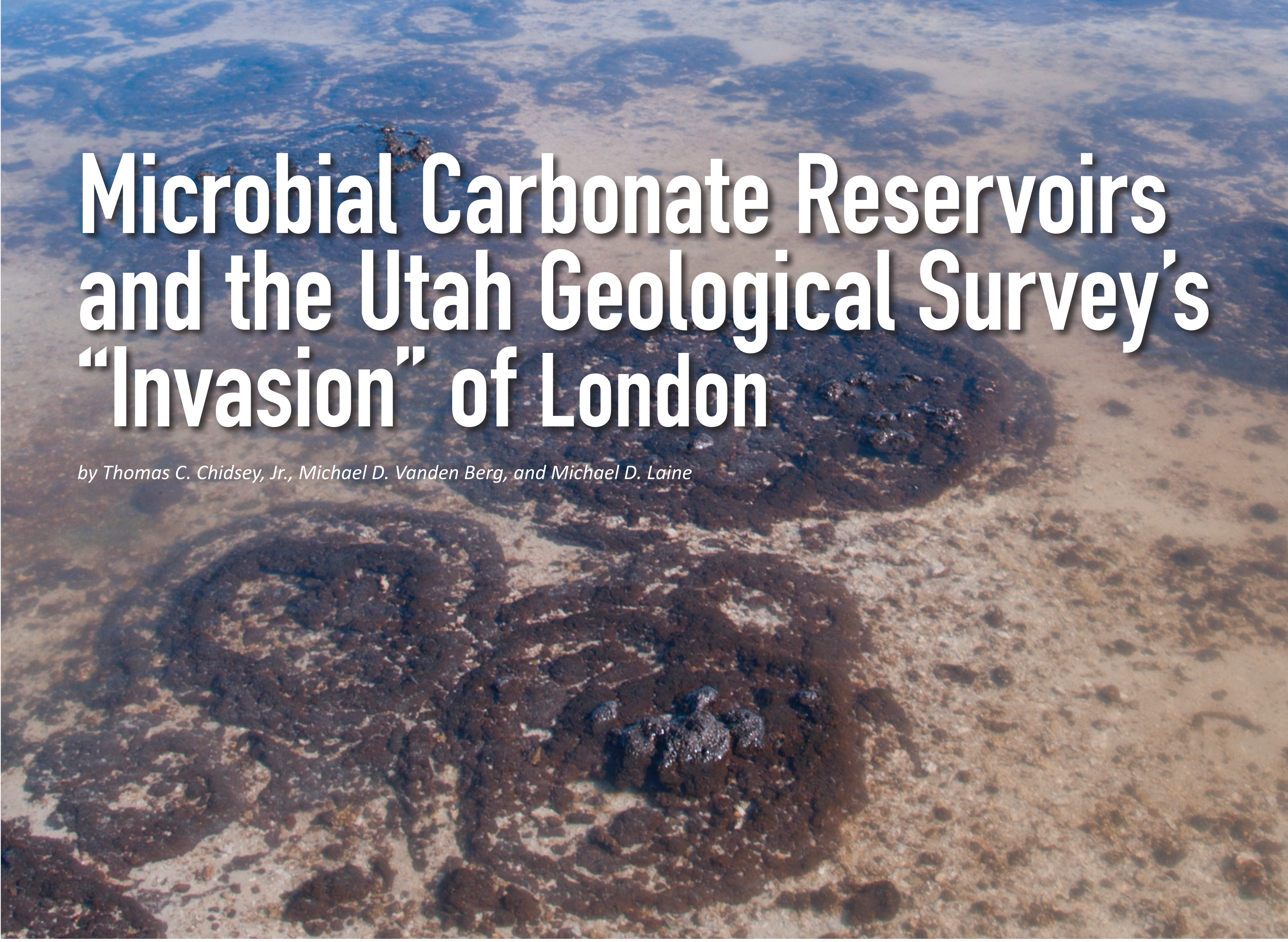
In contrast to energy and metal commodities, the production of industrial minerals often reflects economic activity. This is particularly true of aggregate, which underpins most building and infrastructure construction. It is interesting to compare the value of buildings constructed in Utah with the amount of aggregate produced from quarries each year. The graph of trends since 1980 shows an overall upward trend in both building value and aggregate production due to increasing population and demand. However, there are two prominent spikes in the aggregate trend, one in the late 1990s, and another between 2005 and 2007, although the building value trend has only one spike during 2005 to 2007. The aggregate spike during the late 1990s is likely due to the I-15 reconstruction project prior to the 2002 Winter Olympics when there was not a coincident housing boom. Between 2005 and 2007 Utah's economy was growing at an annual rate of more than 5%. The national financial collapse in 2008 caused Utah's annual growth rate to decline to -1% in 2009, although it had recovered to more than 3% by 2012. So far, we have not seen a corresponding recovery in either aggregate demand or new building construction.



Survey Notes is published three times yearly by Utah Geological Survey, 1594 W. North Temple, Suite 3110, Salt Lake City, Utah 84116; (801) 537-3300. The Utah Geological Survey provides timely scientific information about Utah's geologic environment, resources, and hazards. The UGS is a division of the Department of Natural Resources. Single copies of *Survey Notes* are distributed free of charge within the United States and reproduction is encouraged with recognition of source. Copies are available at *geology.utah.gov/surveynotes.* ISSN 1061-7930 Printed on recycled paper

Microbial Carbonate Reservoirs and the Utah Geological Survey's "Invasion" of London

by Thomas C. Chidsey, Jr., Michael D. Vanden Berg, and Michael D. Laine



Modern, living microbial mats in Bridger Bay, Antelope Island, Great Salt Lake, in October 2013 when the lake was nearly 5.5 feet below its historical average of 4200 feet.

When British rock and roll bands, such as the Beatles and Rolling Stones, first came to America in the 1960s, it was referred to as the "British Invasion." Last year it was our turn in a different type of "rock" invasion, on mini-scale, as we "invaded" London to represent Utah at a special symposium on microbial carbonates, sponsored by The Geological Society (of London). Microbial carbonates are a distinctive type of oil reservoir rock that until recently was unrecognized in terms of oil potential and economic importance on the global scale. New billion-barrel, microbial-carbonate oil fields have been discovered offshore of Brazil, in the Caspian Sea region of Kazakhstan, and in other areas of the world. Research by the Utah Geological Survey (UGS) along with our colleague and carbonate expert, David Eby (Eby Petrography & Consulting, Inc., Denver, Colorado), revealed the presence of microbial rocks in Utah too, particularly in the Uinta Basin. We studied outcrops in the field, well cores stored at UGS's Core Research Center (UCRC), and a modern example of microbial carbonates forming today—Great Salt Lake. Evaluation of the various microbial fabrics, environments of deposition (facies), petrophysical properties (porosity, permeability, etc.), changes to the rock over time (diagenesis), and bounding surfaces is critical to understanding these unusual reservoirs.

Microbial Carbonates 101 and Modern and Ancient Examples from Utah

Microbial carbonates are organic sedimentary deposits that form when microbial communities trap and bind sediment (mud and silt) and/or form the locus of mineral precipitation, principally calcium carbonate ($CaCO_3$). They develop in microbial mats, typically composed of bacteria, fungi, protozoans, or algae, and are found in fresh to hypersaline lake (lacustrine), brackish water (bay), or marine environments. Microbial carbonates take several forms: thinly layered (stromatolites), clotted (thrombolites), spherical (oncolites), and precipitated from mineral-rich springs (tufa or travertine).

Great Salt Lake

All of the deposits described above are forming today in and around Great Salt Lake. In fact, the lake is a microbial carbonate factory—the slimy muds, the rounded mounds (stromatolite heads and microbial mats several feet in diameter) exposed at low water levels best observed at Rozel Point in the lake's north arm and in Bridger Bay at the northwest end of Antelope Island, and associated carbonate grains such as the oolites (small, smooth rounded sand) that form beaches and dunes near the lake, are all microbially related carbonates.

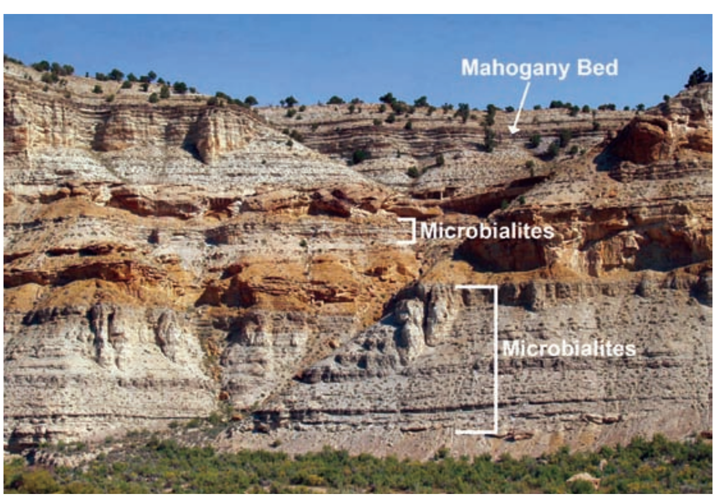
Branching microbial carbonates (stromatolites) in the Green River Formation from the Skyline 16 research core.

Green River Formation, Uinta Basin and Other Potential Targets

Now imagine these deposits buried at depths of thousands of feet for millions of years. If they are thick, contain interconnected pores capable of storing oil (reservoir rock), are sealed by impermeable layers of rock above and below, and are located near organic-rich deposits that generated hydrocarbons at the right time, then all the major ingredients would be present for significant oil accumulations.

The Green River Formation in the Uinta Basin of eastern Utah was also deposited in a fresh to hypersaline lake—54 million years ago (Ma) during the Eocene Epoch. Outcrops and cores of the Green River display many of the features, vertically and horizontally as well as microscopically, observed in and around Great Salt Lake, as well as in highly productive non-marine microbial reservoirs worldwide—stromatolites, thrombolites, oncolites, tufa, and associated grains such as oolites. One small oil field in the Uinta Basin, West Willow Creek, produces from a microbial carbonate buildup. Others may possibly be discovered now that there is a better understanding of these reservoir types.

In addition, microbial carbonates are abundantly represented in cores of marine reservoirs in various fields from the (1) Mississippian (340 Ma) and Pennsylvanian (307 Ma) of the Paradox Basin, (2) Permian (260 Ma) and Triassic (250 Ma) of the Kaiparowits Basin, and (3) Jurassic (175 Ma) of the thrust belt, in southeastern, south-central, and northern Utah, respectively. In light of our work, these areas can now be explored for new potential microbial reservoirs and drilling targets.



The Green River Formation and stratigraphic section of microbial carbonates exposed in the eastern Uinta Basin. Note the Mahogany bed, well known for oil shale, near the top of the outcrop.

Large microbial (thrombolite) head within the Green River Formation.

The Symposium "Across the Pond"

Based on our work with Utah's microbial carbonates, The Geological Society invited us to present papers at their 2013 symposium—*Microbial Carbonates in Space and Time: Implications for Global Exploration and Production*. The Geological Society was created in 1807 by the founders of modern geological thought and headquartered at Burlington House near Piccadilly Circus in downtown London since 1870. It is the oldest and most prestigious geological society in the world. Past distinguished members include William Smith, who made the first geologic map published in 1815 (prominently displayed near the entrance hall in Burlington House); Charles Lyell, author of *The Principles of Geology* in 1830; Charles Darwin, most famous, of course, for his groundbreaking concept of organic evolution published in 1859, *The Origin of Species by Means of Natural Selection*; and Utah's own James E. Talmage (1862–1933)—geologist, professor, Mormon (Church of Jesus Christ of Latter-day Saints) scholar, and church general authority. The 2013 symposium was attended by over 200 leading experts on microbial carbonates and representatives of oil companies exploring and developing these reservoirs around the world.

Our participation in the microbial carbonate symposium afforded us a great opportunity to learn and exchange ideas with the attendees. Our papers were poster-type presentations where we had one-on-one discussions about the research we conducted, specifically on the microbial carbonates in Great Salt Lake and the Green River Formation. Unique from past Geological Society meetings and very different from the other papers were our displays of representative cores and outcrop specimens of Utah microbial carbonates (carried to London in a suitcase!). In addition, we had slices of reservoir-quality Green River microbial outcrop samples and bags of Great Salt Lake oolitic sand for the attendees to take with them. However, the primary goal (and we hope, the result) of our presentations was to make the attendees and the oil companies they represent aware of the: (1) vast new oil potential of Utah microbial carbonates, and (2) opportunity to come to Utah where they can examine microbial carbonates in cores at the UCRC, and visit ancient and modern analogs represented by outcrops and the environment in Great Salt Lake, respectively, as part of UGS-sponsored training core workshops and field trips. Thus, our "UGS invasion" of London may lead to the exploration and development of new discoveries of microbial carbonate oil resources in Utah. In addition, revenue to the UGS and geotourism in the state may increase as geologists come for training and study to apply Utah examples to microbial oil fields they operate elsewhere in the world.

Tom Chidsey and Mike Vanden Berg in front of the "map that changed the world," William Smith's geologic map of Great Britain, published in 1815. Displayed at the Geological Society (of London), this was the first geologic map ever created.

About the Authors

Tom Chidsey has been a geologist with the UGS since 1989, and serves as the Petroleum Section Chief in the Energy and Minerals Program. Besides microbial carbonates, other recent projects include evaluation of potential Paleozoic shale-gas reservoirs, a compilation of Utah's major oil plays, analysis of the Mississippian Chainman Shale of western Utah, and determination of best management tools for produced water in the Uinta Basin. He also conducts numerous industry and university workshops using the UGS core collection and leads field trips to areas studied as parts of various projects.

Michael Vanden Berg has been a geologist with the UGS Energy and Minerals Program since 2003. Michael's research focuses primarily on the petroleum-bearing units of the Uinta Basin, in particular the Green River Formation. Current research includes a detailed analysis of the unconventional Uteland Butte reservoir, characterization of the immature shales from the upper Green River, and examination of the microbial carbonate units with comparisons to modern microbialites found in Great Salt Lake.

Mike Laine was the UGS's UCRC curator/geologist from 2004 to 2012 before leaving to join his family in California. As curator, Mike managed general UCRC operations, oversaw two major UCRC expansions, obtained many additional cores from wells drilled in Utah, hosted numerous industry and university core workshops annually, and assisted with geologic research using the core collection.

UTAH STILL SUPPLYING GILSONITE TO THE WORLD AFTER 125 YEARS OF MINING

by Taylor Boden

Gilsonite, one of Utah's earliest mined industrial minerals, is currently experiencing increased interest by the oil and gas industry, which has resulted in a significant increase in development of the resource. The Uinta Basin of eastern Utah hosts the world's largest deposits of gilsonite, and is the only place where gilsonite is economically produced in large quantities. Gilsonite has a wide variety of industrial applications and is used by companies worldwide. Major uses for gilsonite include ink and paint, and as a performance additive for the foundry and asphalt industries, but the oil and gas industry has developed as a growth market for gilsonite due to the expansion of various applications in well drilling.

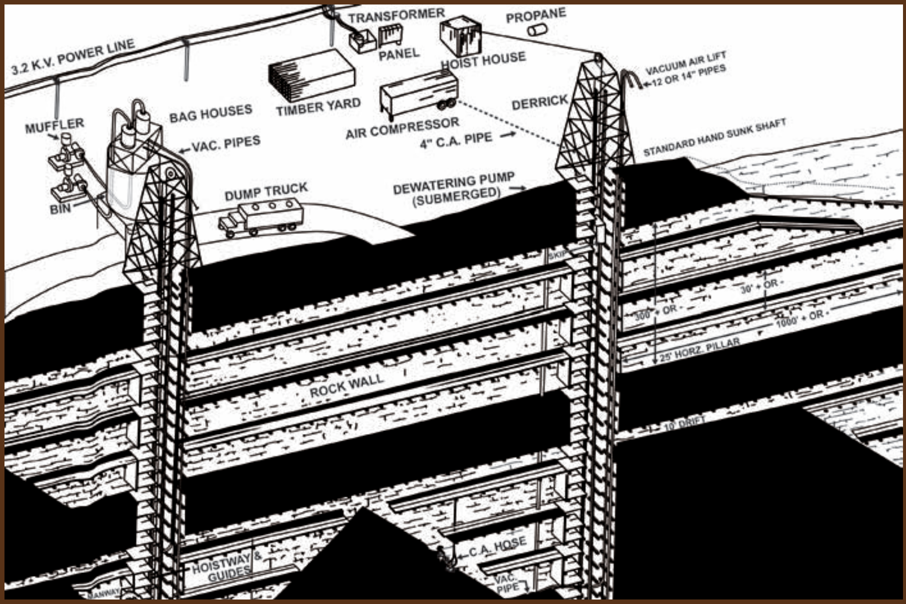
Gilsonite is a geologically interesting and economically significant resource, and its wide range of uses has changed over time with new technology and industrial needs. Gilsonite's unique properties make it important for many oilfield drilling fluid products and the recent boom in oil and gas development has increased demand. When gilsonite is added to oil- and water-based drilling fluids, it partially melts or deforms, plugging off micro-fractures in the rock and smearing the inside of the well bore to make a tight, tough filter cake that prevents fluid loss. The dissolved gilsonite also increases drilling fluid viscosity, providing lubrication, and together with the sealing off and stabilization of problem rock around the well bore, helps prevent the drill pipe from getting stuck in the well. Gilsonite is also used in cementing fluids as a lost-circulation material due to its plugging and binding properties, and as a slurry density reducer in some specialty cementing fluids.

Gilsonite is a member of the asphaltite group of hydrocarbon bitumens, and forms a swarm of subparallel, northwest-trending, near-vertical, laterally and vertically extensive veins in the Uinta Basin of Utah and Colorado. Gilsonite was generated from the Mahogany oil shale zone in the Parachute Creek Member of the Eocene Green River Formation, and is hosted in the Tertiary-aged (about 57 to 36 million years old) Wasatch, Green River, Uinta, and Duchesne River Formations. The veins range from sub inch to as much as 22 feet wide, and formed in two stages associated with thermal maturation of the Mahogany oil shale. High pressures deep in the Uinta Basin led to expulsion of large quantities of hot water from the oil shale rocks, which hydrofractured the overlying and underlying strata. Subsequently, thick, liquid gilsonite was expelled from the oil shale source beds, forcing open the existing fractures in the overlying and underlying strata. The gilsonite later solidified in these fractures, probably primarily through cooling. The gilsonite veins are widespread across the Uinta Basin, extending from Rio Blanco County in western Colorado to Duchesne County in eastern Utah.

Historical open-cut mining on the southeast end of the Cowboy vein.

Gilsonite has a long, colorful mining history dating back to the late 1800s. Gilsonite, named after Samuel H. Gilson, was discovered in the 1860s in Utah. Gilson was not one of the original discoverers, but his enthusiastic development and promotional efforts linked the material to him, and the name gilsonite further solidified in common usage when an early mining company adopted and trademarked the name. The first regular shipments of gilsonite began in 1888, from veins in the Fort Duchesne area. Early gilsonite mining was predominantly by open-cut mining with picks, shovels, and horse-powered hoists (for more background see Survey Notes v. 36, no. 3, July 2004).

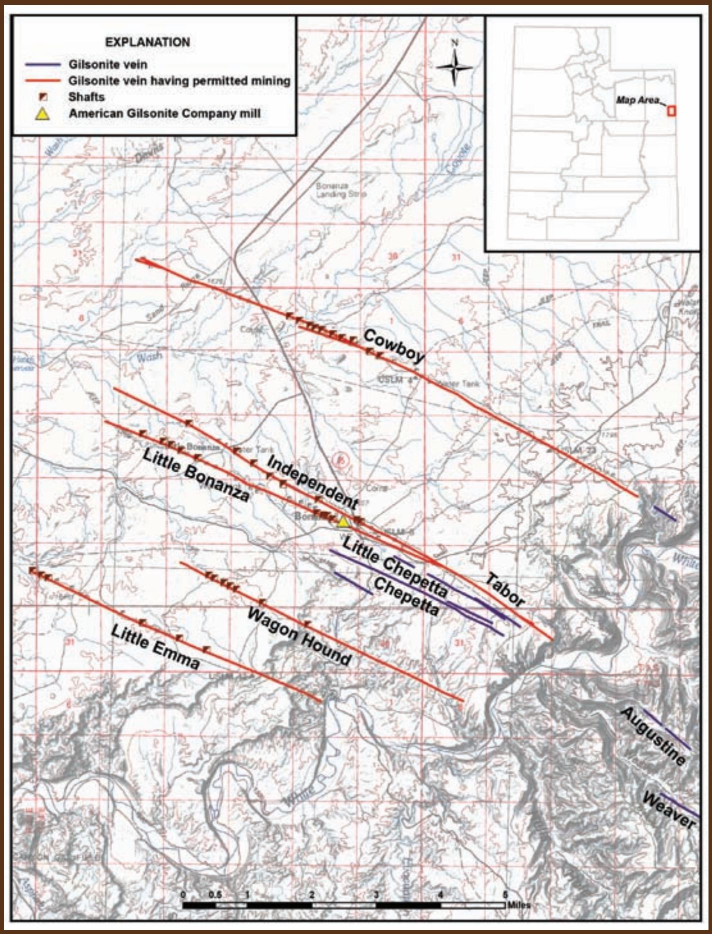
Historically, mining occurred at various veins and locations in the gilsonite field, but it is currently concentrated on the widest known veins around Bonanza, Utah. Permitted mining in this area occurs on the Cowboy, Independent, Little Bonanza, Wagon Hound, and Little Emma veins. All the gilsonite produced today from the Uinta Basin is by underground mining methods. Current mining consists of two major phases: (1) shafts are sunk at regular intervals along the veins, and (2) drifts and slopes are then extended laterally from the shafts. The top 30 feet of the gilsonite is not mined for safety and reclamation reasons. Gilsonite mining is labor intensive, because of its unusual mode of occurrence in narrow (down to 18 inches wide), deep, vertical veins; and the explosive hazards associated with gilsonite dust. The mining of the ore is still done by hand, using air-powered chipping hammers to carefully break the gilsonite while avoiding contaminating the ore with broken wall rock, since product purity is important to customers. The broken ore enters a vacuum tube at the bottom of the underground mined area and is air lifted to the surface, where it is deposited into a bag house next to the shaft headframe and then trucked to a plant for processing.



Gilsonite underground mining methods (from American Gilsonite Company).

American Gilsonite Company (AGC) and Ziegler Chemical and Mineral Company are the only companies that mine and process gilsonite at their operations in southeastern Uintah County. Gilsonite production in 2012 was about 82,000 short-tons, with AGC responsible for most of that production. Gilsonite production in 2012 is valued at approximately $89 million, at an average price of about $1085 per short-ton (as reported by the U.S. Office of Natural Resources Revenue). Gilsonite value has significantly increased from oilfield demand, and gilsonite sales to the oilfield market have increased over 150% since 2009. In response to increased demand, AGC has initiated an approximately $20 million investment program to open new mines, explore new mine development methods, develop strategic long term reserves, and continue investment in health and safety. AGC expects to double its current production capacity in the near future to satisfy customer demand, and has opened three new mines in the last 18 months, with five more under active development.

Even though significant amounts of the approximately 45-million-short-ton original gilsonite resource have been mined, millions of tons of the valuable resource still remain. This resource tends to be in the deeper parts of the veins and in thinner, more remote veins that will likely be more expensive to mine than veins mined in the past. Recent mapping by the Utah Geological Survey (Special Study 141) of the gilsonite deposits in the Uinta Basin has located and described many of the more remote veins, which were previously only vaguely know. At the planned increased production rate, gilsonite could continue to be mined in the Uinta Basin for decades, ensuring a steady supply to world markets of this unique and valuable Utah resource.



Location of gilsonite veins with permitted mining and shaft locations, and American Gilsonite Company's mill.

American Gilsonite Company mine site shaft headframe and bag house.

Frack Sand in Utah?

By Andrew Rupke

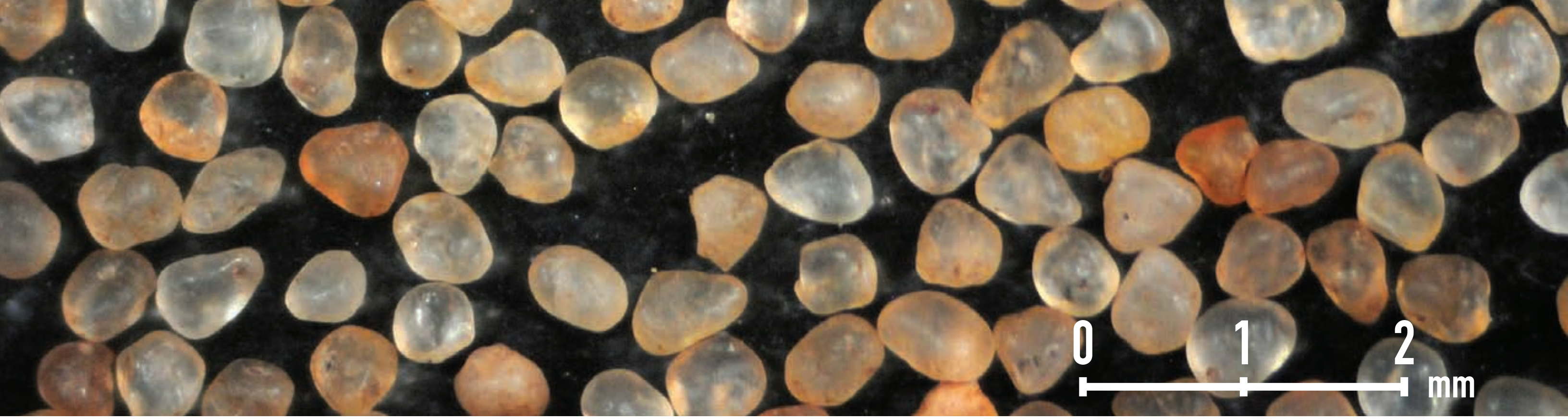
In recent years, hydraulic fracturing (or “fracking”) has become a widespread technique for extracting previously unrecoverable oil and gas from low-permeability rock formations. During hydraulic fracturing, fluid is pumped into a well at high pressure in order to fracture the rocks containing oil or gas, thereby releasing the hydrocarbons. An important component of the fracturing fluid is proppant, a material that “props” open the fractures allowing the oil or gas to be pumped out. Frack sand (or ”frac sand,” as it is known in industry) is the most common proppant used in the oil and gas industry. The U.S. Geological Survey estimates that about 28 million metric tons of sand, valued at about $1.3 billion, was produced domestically in 2012 for use as proppant and related applications.

Not just any sand or sandstone deposit is suitable for use as proppant. Frack sand must meet stringent specifications: it should be nearly all quartz; grains must be round, equidimensional (spherical), and the right size; and the sand must be able to withstand very high pressures without breaking. One reason frack sand must be nearly pure quartz is because mineral impurities, such as feldspar, are commonly weaker and more prone to breaking. Spherical and round sand grains provide good porosity and permeability, which allows the oil and gas to migrate through them; angular grains tend to pack together, which reduces permeability. The size of frack sand grains is also important, and frack sand is generally marketed and sold by size. Larger sand grains provide better permeability, but smaller sand grains are typically stronger. Therefore, the size of the proppant is generally chosen to meet conditions in a specific well. The industry term for strength of a proppant is “crush resistance.” Sand needs to have a high crush resistance because if grains break and produce smaller fragments, those fragments can plug pore space and reduce permeability. The American Petroleum Institute and the International Standards Organization provide standardized test procedures for evaluating frack sand.

The vast majority of domestically produced frack sand comes from the Midwest (Illinois, Wisconsin, and Minnesota) and the South (Texas and Oklahoma) because those areas have large deposits of sand and sandstone that meet the recommended specifications. Frack sand miners in those areas ship their product to oilfields around the country, which can result in high shipping costs (often 50% or more of the total proppant cost) for oil field operators located long distances from the sources. A local source of frack sand for western oil and gas fields would obviously reduce costs and be more efficient than shipping frack sand across the country. For these reasons the Utah Geological Survey (UGS), with funding from the Utah School and Institutional Trust Lands Administration, produced a preliminary study of potential frac sand sources in Utah. We took numerous samples from sand and sandstone deposits throughout the state to test their suitability. The primary characteristics we evaluated were purity, grain size distribution, and sphericity and roundness. To evaluate the purity we ran semi-quantitative chemical analyses on each sample using the UGS’s x-ray fluorescence device. We sieved each sample using sieve sizes that correspond to marketed frack sand sizes, and sphericity and roundness were visually estimated using a Krumbein-Sloss chart. We also qualitatively took note of

An outcrop of Jurassic White Throne Member of the Temple Cap Formation, a sandstone found in southwest Utah.

A potential source of frack sand—dune sand in Kane County.



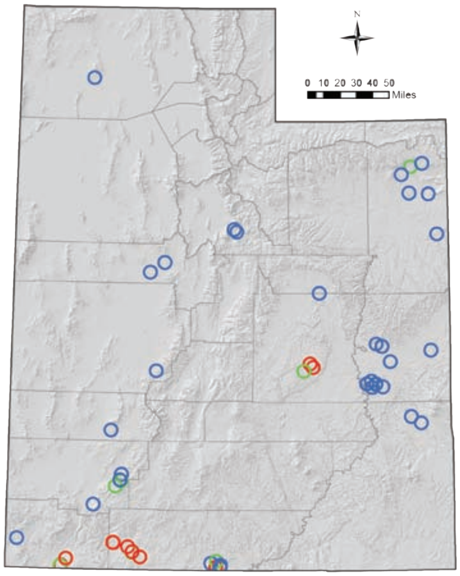
Magnified grains from dune sand in Kane County. The scale bar is in millimeters.

friability of sandstone samples—a “friable” sandstone will easily crumble, which is a good thing if you want to produce sand.

Overall, our results indicate some potential for frack sand deposits in Utah. A number of samples have high quartz content, but some washing may be required to upgrade the sand to meet specifications. All the samples met sphericity recommendations and many met roundness recommendations. Sieve results indicated that the most widely utilized frack sand size distribution could not be produced, but some of the other common, smaller sizes probably could. Based on results from the tests, we assigned an overall suitability ranking for each sample. These rankings suggest that the three geologic units with the highest potential for frack sand are the Permian White Rim/Cedar Mesa Sandstones, Jurassic White Throne Member of the Temple Cap Formation, and Quaternary eolian dune sands in southwest Utah. Although the White Rim/Cedar Mesa Sandstones of Emery County had the best size characteristics, most of the samples had marginal roundness, and much of the unit is located in the San Rafael Swell, a popular recreational area that could complicate permitting. Both the White Throne Member and eolian dune sands, which were sampled in Kane and Washington Counties, showed potentially suitable size distributions, but the Quaternary dune sands may have the highest potential because they are unconsolidated, which would require less processing.

Although our preliminary results suggest geologic units with frack sand potential may be present, additional work is required to determine ultimate suitability of any of the deposits. Due to cost constraints, our study did not include crush resistance testing—a key aspect of frack sand suitability. More detailed study of sandstones with potential, the White Throne Member and White Rim/Cedar Mesa, would be necessary to determine if they are sufficiently friable—friability of fresh exposures may differ from the weathered exposures that we sampled. Also, for all potential units, adequate mine sites with sufficient resources to maintain production would need to be delineated. As domestic frack sand production increases, a variety of possible environmental and health concerns have arisen in many communities near major frack sand producing areas. Some of the concerns are not necessarily frack-sand specific, such as increased truck traffic due to mining, but others are, such as potential exposure to respirable crystalline silica, which has an exposure level regulated by the U.S. Occupational Safety and Health Administration. While operators have worked to mitigate these concerns, they have been prominent in the Midwest.

If additional work shows that some of Utah’s sand and sandstone is acceptable for frack sand, and an appropriate site is located, Utah could become one of the few frack sand producers in the west. However, if the sand is unsuitable, Utah has another potential source for proppant: aluminum-rich mineral deposits that can be used to produce high-quality synthetic proppant. Aluminum-rich minerals such as kaolinite, alunite, and halloysite are found in a number of areas, primarily in the western half of the state.



Frack sand sample locations. Red indicates samples that are most suitable for frack sand, green indicates some suitability, and blue indicates the least suitability.

Energy News

by Robert Ressetar & Michael Vanden Berg

Utah Hosts Petroleum Geology Convention

Salt Lake City was the site for the 2013 convention of the Rocky Mountain Section of the American Association of Petroleum Geologists (RMS-AAPG), held September 22–24. Hosted by the Utah Geological Association, the convention drew nearly 500 professional geologists, geophysicists, and engineers, mostly from the Intermountain West, but from as far away as Canada, Europe, and Asia. In addition, 117 university students participated in the event, significantly more than at previous conventions, and many gave presentations on their graduate or undergraduate research. Several Utah Geological Survey (UGS) personnel were active on the convention's organizing committee, including Craig Morgan as conference general chairman, Michael Vanden Berg as RMS-AAPG president, and the following chairs: Thomas Chidsey, technical program; Robert Ressetar, exhibits; Stephanie Carney, registration; Paul Inkenbrandt, social events; and Sandy Eldredge, teacher activities (see related article in "Teacher's Corner," page 12 of this issue of *Survey Notes*). Additional committee members included local university faculty members, consulting geologists, and staff from Utah oil companies.

The highlight of the convention was the extensive technical program—participants presented nearly 130 talks and posters featuring the latest in petroleum geology research, geothermal resources, and policy issues related to energy development in the Rocky Mountain region. A common theme in the presentations was the profound recent changes in the petroleum industry, including innovative well completion techniques that are moving historically unconventional hydrocarbon resources into the realm of conventional. However, as petroleum production expands in both new and established areas, peripheral concerns arise involving topics such as air quality, groundwater protection, wildlife conservation, and economic development. These concerns were the subject of a half-day Energy Policy Forum that focused on the potential impacts of expanding hydrocarbon production, particularly in the Uinta Basin of eastern Utah.

Unconventional energy sources were prominent in many of the geological presentations. For example, nine presentations, several from UGS geologists, addressed geothermal resources in western states, including newly discovered geothermal potential in Utah's Black Rock Desert. Nationally, production of natural gas and oil from shale has brought the most significant changes to the energy industry in decades, and this new hydrocarbon source was the topic of several sessions. Researchers from the University of Utah and the UGS gave seven presentations on their joint assessment of the hydrocarbon potential of the Mancos Shale in the Uinta Basin. UGS geologists and their collaborators also described the hydrocarbon potential of Paleozoic shales in the Paradox Basin, the northern San Rafael Swell, and the Basin and Range Province. Another recent development in petroleum geology is the recognition of the significance of microbial carbonate reservoirs. Utah is special in having both modern (in Great Salt Lake) and ancient (in the Uinta Basin's Green River Formation) examples of this rock, which was the topic of seven presentations as well as a post-meeting core workshop and field trip (see related article on page 1 of this issue of *Survey Notes*).

The All-Convention Luncheon provided a step away from petroleum geology as the featured speaker, Dr. Rebecca Williams of the Planetary Science Institute, presented the latest findings from the Mars rover *Curiosity*. Even this event maintained a local flavor as many Utah landscapes have served as analogs to geologic features on Mars—see *Survey Notes*, v. 40, no. 3, p. 1–4.

Overall, the conference was a resounding success. Attendees offered many compliments on the technical program, short courses, and field trips, in addition to remarking on the beauty of Salt Lake City and Utah.

Top: *Genevieve Atwood (of Earth Science Education and former director of the UGS) points out features to geology students and young professionals on a pre-convention field trip to Antelope Island.* ***Middle Left:*** *Bob Bereskin (Bereskin and Associates) and Tom Chidsey (UGS) in front of their award-winning poster on the hydrocarbon potential of the Chainman Shale of western Utah.* ***Middle Right:*** *Michael Vanden Berg, UGS geologist and RMS-AAPG President, giving opening remarks at the conference.* ***Bottom:*** *Julie LeFever, North Dakota Geological Survey, showing meeting attendees core from the Bakken Formation, the target of much drilling activity in North Dakota.*

GeoSights

St. George Dinosaur Discovery Site at Johnson's Farm, Washington County

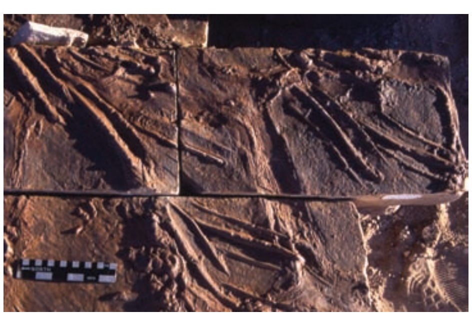
by Christine Wilkerson

Two hundred million years before humans flocked to southwestern Utah, dinosaurs were hanging out and enjoying this area. Thousands of dinosaur tracks and other fossils found here tell the story of dinosaurs walking, running, crouching, swimming, wading, and fishing while living near the shores of a large ancient lake, named Lake Dixie.

Discovery and Preservation: While leveling land on his property in February 2000, Dr. Sheldon Johnson discovered bumps on the underside of a large block of sandstone he was moving. Instead of the usual indented dinosaur tracks (impressions), these looked like the actual dinosaur feet, and were in fact, well-preserved 3-D casts of dinosaur footprints. Many of the casts at the site show detailed skin impressions, foot pads, claw marks, and dew claws.

After this initial discovery, abundant fish, plant, trace, and invertebrate fossils, rare dinosaur teeth and bones, and thousands of additional tracks made by a number of different track makers were identified.

This natural cast of a Eubrontes *dinosaur track was discovered at the St. George Dinosaur Discovery Site.*



These Grallator*-type swim tracks display three parallel scrape marks with the longer middle toe leaving a longer and deeper scape mark compared to the shorter outer toes.*

To preserve these world-class dinosaur trackways for scientific and educational purposes, Dr. Johnson and his wife, LaVerna, donated the tracksite to St. George and worked with the city, local businesses, federal and state governments, and paleontologists to create the on-site museum. Hundreds of thousands of visitors and paleontologists from all over the world have visited this remarkable site to learn how dinosaurs walked and behaved.

Geologic History and Information: Nearly 200 million years ago (Early Jurassic time), Lake Dixie was a large, freshwater oasis attracting dinosaurs to its water's edge with its abundance of large fish and shores of edible plants.

Ripple marks and mud cracks found in the sandstones and mudstones of the Moenave Formation indicate that the beaches and mudflats along the shoreline of Lake Dixie were periodically submerged. As dinosaurs and other creatures walked in the mud, they left footprints, which were then quickly filled in with silt and sand, preserving the fine details of the impressions. These later hardened into stone and became track casts.

Just offshore, dinosaurs swam and fished. The dinosaur swim tracks at this site are currently the world's largest and best-preserved assemblage, and helped end the controversy among paleontologists over what these kinds of marks represent. Large serrated dinosaur teeth have been found at the site with a distinct wear pattern, indicating dinosaurs may have eaten large fish covered in heavy, enamel-covered scales.

Trackways, footprints, tail drags, and burrows are all examples of trace fossils or ichnofossils (fossils without any physical body parts) that provide evidence of an animal's actions and behaviors. The majority of dinosaur tracks from the 25 track-bearing layers within the Moenave Formation are from two types of tracks, *Grallator* and *Eubrontes*.

The more common track, *Grallator*, is a 4- to 8-inch-long, three-toed print, probably belonging to a slender, meat-eating dinosaur such as the 10-foot-long *Megapnosaurus*. *Eubrontes*, a larger 13- to 18-inch-long, three-toed print, is thought to be made by a large meat-eating dinosaur such as the crested *Dilophosaurus*, which grew up to 6½ feet tall and 19 feet long, and weighed 900 pounds. Many, small non-dinosaur tracks have also been found, including those of ancient crocodilians and horseshoe crabs.

One important discovery is a *Eubrontes* trackway displaying extremely rare crouching and tail drag traces. It shows the dinosaur first sitting on the ground, then lumbering forward and sitting down again. Later as the dinosaur continued on its way, climbing up a sand bar, its tail scraped the ground as it walked leaving drag marks along the trackway.

How to get there: If traveling on I-15 from the north, take exit 10 (Green Springs Drive) toward Washington City and continue south (left) onto Green Springs Drive. Soon Green Springs Drive becomes 3050 East and about one mile later the road curves to the southwest and becomes Riverside Drive. Continue after the curve for about one mile; the museum is located on the south (left) side of the road at 2180 East Riverside Drive.

If traveling on I-15 from the south, take exit 6 (Bluff Street) in St. George, then turn east (right) onto Riverside Drive. Continue on Riverside Drive for about 3.5 miles until you reach the museum located on the south (right) side of the road at 2180 East Riverside Drive.

For current exhibit and other information, visit the St. George Dinosaur Discovery Site at Johnson's Farm website at www.dinosite.org.

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

Glad You Asked

by Robyn Keeling

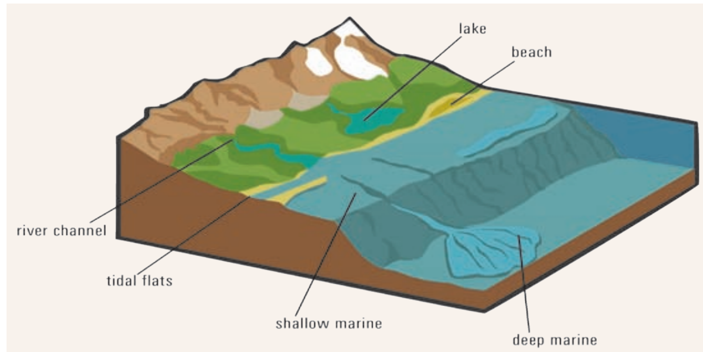
How can sedimentary rocks tell you about Utah's history?

Every rock has a unique story to tell. Just as a detective pieces together clues from a crime scene to determine what may have happened, a geologist uses clues within sedimentary rocks to determine what type of environment the rock formed in. Sedimentary rocks form through the deposition and cementation of material (sediments). The original sediment can be composed of various substances:

1. Fragments of other rocks that are transported by water (streams, ocean currents, etc.), wind, or glaciers, and deposited in another environment, such as sand on a beach that solidified into sandstone or mud on the ocean floor that formed shale.
2. Organic materials, such as plants in a swamp, which can form coal.
3. Minerals that precipitate out of water, such as salt from saline lakes like Great Salt Lake, forming rock salt, or calcium carbonate from marine animal shells, forming limestone.

Sedimentary rocks have many characteristics that provide important information about past climates, past life forms, and the ancient geography.

> The grain size, shape, and sorting within the rocks that are composed of rock fragments indicate the energy of the water, wind, or glaciers transporting the sediments, as well as the length of time or distance the sediment was carried. High-energy environments such as (a) large, fast rivers or (b) steep mountain streams form rocks with the largest grain sizes (sometimes as large as boulders) that are also mixed in with varied smaller sizes. When these mixtures are deposited and cemented after relatively short transport, the grains retain angular shapes and are called breccia. Longer transport across greater distances allows abrasion to smooth the grains into rounder shapes, and the resultant rock is called conglomerate. As the energy within the system decreases, the grain sizes being transported



Depositional Environment	Sediment	Sedimentary Structures	Sedimentary Rocks
river channel	*boulders, sand, mud; variable sorting and rounding*	*cross-bedding, ripple marks, mudcracks*	*conglomerate, sandstone, shale*
lake	*mud, sand*	*mudcracks, ripple marks, bedding, fossils*	*shale, sandstone, salt (saline lakes)*
beach	*boulders, sand, mud; well-sorted and well-rounded*	*cross-bedding, ripple marks*	*conglomerate, sandstone, shale*
tidal flats	*sand, mud*	*ripple marks, mudcracks*	*sandstone, shale*
shallow marine	*sand, mud, carbonate sediment, well-sorted and well-rounded*	*bedding, cross-bedding, ripple marks, marine fossils*	*sandstone, shale, limestone*
deep marine	*mud, carbonate sediment*	*marine fossils*	*shale, limestone*

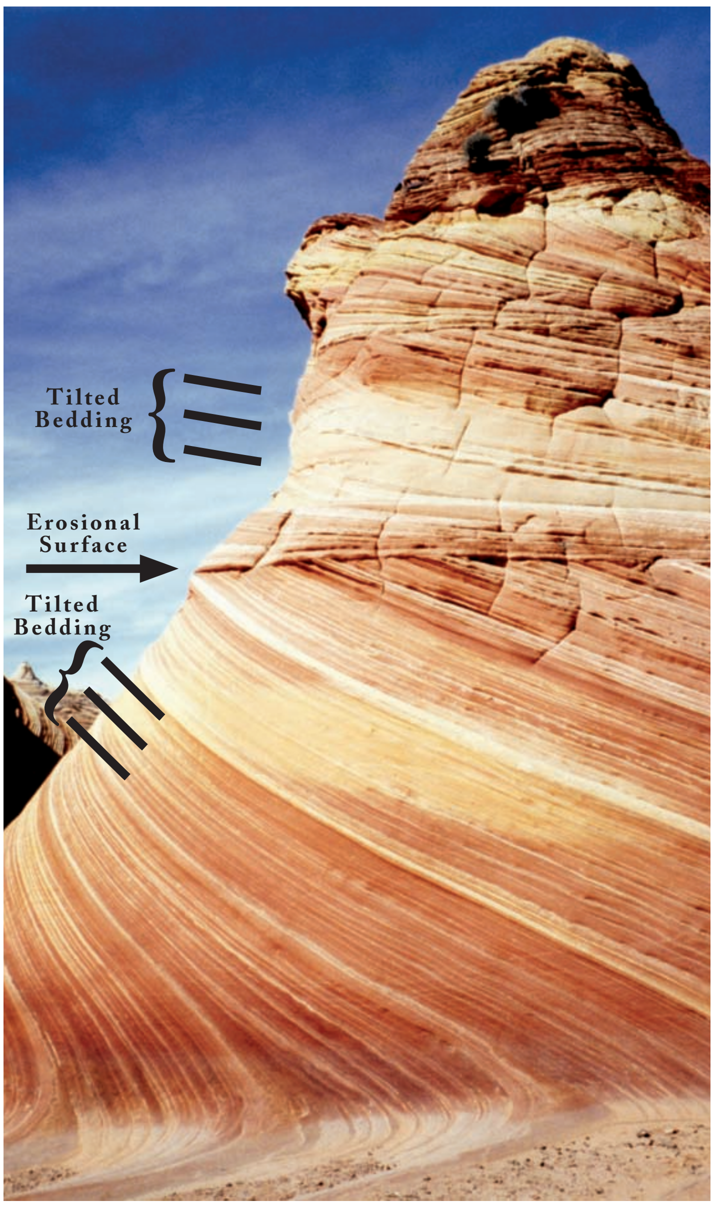
also decrease, as is the case with some rivers or deltas carrying coarse to fine grains of sand, which are cemented together to become sandstone. The very lowest energy environments, such as lagoons and deep, standing water bodies, can only carry the smallest particles such as mud and clay, which can become mudstone and/or shale.

Mudcracks form when wet clay is temporarily exposed to the air and dries.

Ripple marks indicate which direction the water currents were moving and are typical of rivers, beach deposits, and tidal action.

Fossils, tracks, and burrow marks indicate specific life forms and climate conditions, as well as pinpoint the age of the rock.

Sediment is often deposited in layers, and each layer (bed) can reveal details such as slight changes in water conditions or even seasonal changes. One variation, cross-bedding, contains multiple sets of layers with different orientations; like ripple marks, these indicate current directions.



Ancient sand dune deposit, now cross-bedded Navajo Sandstone in southern Utah.

Ripple marks and mudcracks in Big Cottonwood Canyon, Salt Lake City

The canyon walls along the first six miles up the road from the mouth of Big Cottonwood Canyon are composed of tilted layers of reddish-brown quartzite and black to purple to green shale. These rocks are remnants of a tidal-flat environment and formed from deposition of alternating layers of sand (now quartzite) and clay (now shale).

The same depositional environments that existed in ancient times also exist today (just in different places). By using the geologists' motto, "the present is the key to the past," geologists can determine what the area might have looked like at various times in the past.

Ripple marks preserved in the quartzite about 1½ miles up Big Cottonwood Canyon.

Mudcracks five to seven inches in diameter in the shale about 6½ miles up Big Cottonwood Canyon.

Little Sahara sand dunes in western Utah.

Teacher's Corner

Earth Science Week

Another successful Earth Science Week (ESW) was held at the UGS's Utah Core Research Center with over 860 students attending, along with about 60 parents and 35 teachers. This year was a smashing success with the help of numerous volunteers—in addition to UGS staff—from other Department of Natural Resources divisions, and various organizations. We also extend our appreciation to Utah Kennecott Copper, CML Metals Corporation, and U.S. Magnesium for donations of several minerals.

More! Rocks in Your Head

Thirty Utah teachers attended this nationally acclaimed teacher workshop, which was held September 21, 2013 in conjunction with the Rocky Mountain Section (RMS) of the American Association of Petroleum Geologists (AAPG) annual meeting. The workshop was attended mostly by 4th-grade teachers (who teach their students about rocks and minerals, per the Utah science curriculum mandate), who walked away with a better understanding of the subject matter as well as with much appreciated numerous and valuable resources. The workshop was paid for by the RMS-AAPG and National AAPG foundations.

Survey News

Kathi Galusha was Financial Manager for the UGS and had worked here for eight years. Sadly, Kathi passed away in August. Everyone at the UGS will miss her keen financial advice and admirable work ethic.

Jodi Patterson joined the UGS as the new Financial Manager. Jodi has an MBA from Weber State University and has worked for the state for 20 years. Welcome to the UGS!

The Groundwater and Paleontology Program welcomes **Galvan Haun** as the new secretary. He comes to us from Atlanta, Georgia, where he worked in state and federal government positions. Galvan replaces **Rebecca Medina** who resigned after nine years of service.

The Editorial Section bids farewell to **Stevie Emerson** who accepted a position at Weber State University. Thanks, Stevie, for doing great work for the UGS for the past six years. **Elizabeth Firmage** is our new graphic designer. She has a Bachelor of Fine Arts in Graphic Design from the University of Utah. Welcome to Elizabeth, and best of luck to Stevie.

2013 Lehi Hintze Award

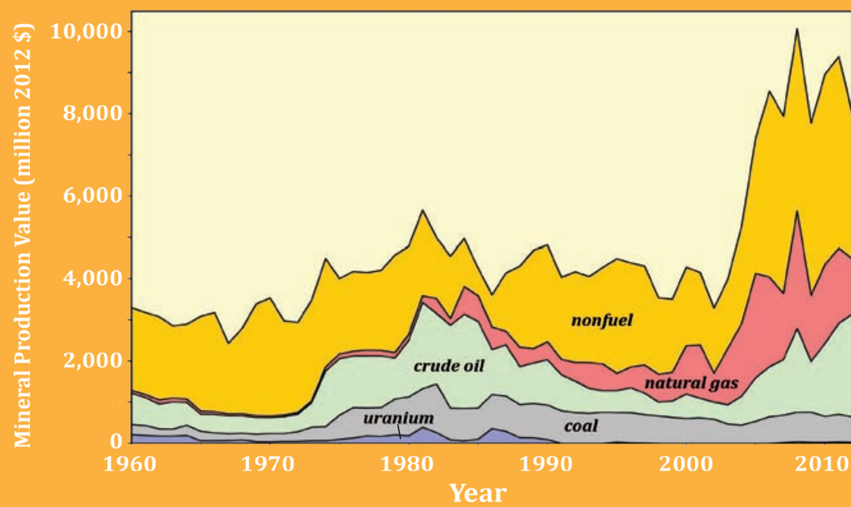
The Utah Geological Association and the Utah Geological Survey (UGS) presented the 2013 Lehi Hintze Award to Robert Q. "Bob" Oaks, professor emeritus at Utah State University Geology Department, for a lifetime devoted to serving students, researching the geology of northern Utah and southern Idaho, and using his seemingly endless wealth of knowledge to benefit communities in those areas. As Susanne Janecke, geology professor at USU noted in her nomination letter, "Bob has contributed through his research in and near the state, his long career as a caring and conscientious mentor and educator of geology students, and his tireless work for local communities, community groups, and service work. Bob is like a top-notch library of knowledge and has been a wonderful source of information for many of us working in the northern Utah region. Since retiring from teaching, Bob became the valley's favorite consulting groundwater geologist and he has invested a huge amount of time and effort helping Cache Valley communities find water." Bob 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.

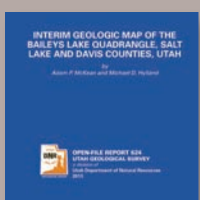
UGS Publishes Resource Industry Report

The annual report on the value of Utah's extractive resource industries shows that the gross value of all energy and mineral commodities produced in Utah during 2012 was $8 billion. This represents a 15% decrease from the 2011 inflation-adjusted value of $9.4 billion (see graph), which is attributable to low prices for copper, molybdenum, precious metals, coal, and natural gas. The report, UGS Circular 116, *Utah's Extractive Resource Industries 2012*, is available at the Department of Natural Resources Bookstore and on the UGS website at http://geology.utah.gov/utahgeo/rockmineral/index.htm#minactivity.

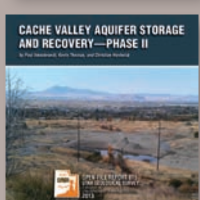
Total annual value of Utah's energy and mineral production, inflation adjusted to 2012 dollars, 1960–2012



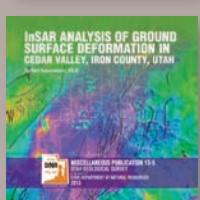
New Publications



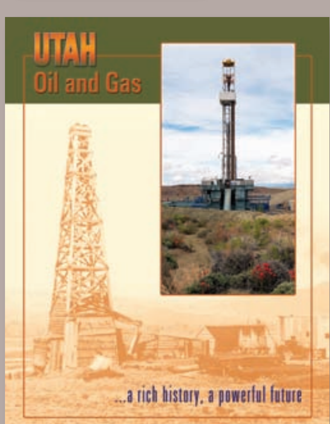
Interim geologic map of the Baileys Lake quadrangle, Salt Lake and Davis Counties, Utah, by Adam P. McKean and Michael D. Hylland, CD (18 p., 1 pl.), scale 1:24,000, **OFR-624............$14.95**



Cache Valley aquifer storage and recovery—Phase II, by Paul Inkenbrandt, Kevin Thomas, and Christian Hardwick, CD (33 p., 1 pl.), **OFR-615...............$14.95**



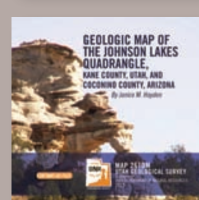
InSAR analysis of ground surface deformation in Cedar Valley, Iron County, Utah, by Kurt Katzenstein, CD (43 p.), ISBN 978-1-55791-882-6, **MP-13-5.................................$14.95**



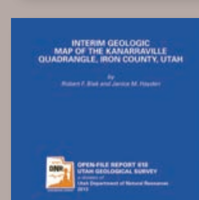
Utah oil and gas—a rich history, a powerful future, 24 p., ISBN 1-55791-655-1, **PI-71** updated 2013**.....$1.50**

Interim geologic map of the easternmost part of the Duchesne 30' x 60' quadrangle, Duchesne and Wasatch Counties, Utah—Year 1 of 6, by Douglas A. Sprinkel, CD (19 p., 1 pl.), scale 1:24,000, **OFR-625....$14.95**

Hydrogeochemistry, geothermometry, and structural setting of thermal springs in northern Utah and southeastern Idaho, by Brennan Young, Katherine Shervais, Moises Ponce-Zepeda, Sari Rosove, and James Evans, CD (9 p. + 20 p. appendices [contains GIS data]), **OFR-605......................$14.95**



Geologic map of the Johnson Lakes quadrangle, Kane County, Utah, and Coconino County, Arizona, by Janice M. Hayden, CD (2 pl. [contains GIS data]), scale 1:24,000, ISBN 978-1-55791-873-4, **M-261DM...........$24.95**



Interim geologic map of the Kanarraville quadrangle, Iron County, Utah, by Robert F. Biek and Janice M. Hayden, CD (31 p., 1 pl.), **OFR-618......$14.95**

Geologic map of the Yellowjacket Canyon quadrangle, Kane County, Utah, and Mohave County, Arizona, by Janice M. Hayden, CD (2 pl. [contains GIS data]), scale 1:24,000, ISBN 978-1-55791-865-9, **M-256DM...........$24.95**

UTAH GEOLOGICAL SURVEY
1594 W North Temple, Suite 3110
Box 146100
Salt Lake City, UT 84114-6100

Address service requested
Survey Notes

PRSRT STD
U.S. Postage
PAID
Salt Lake City, UT
Permit No. 4728

Did you know that the Utah Geological Survey has a PHYSICAL STORE LOCATION where you can browse and purchase items pertaining to all aspects of Utah geology and mapping?

We carry a wide variety of books and maps for all Utah outdoor enthusiasts as well as printed topographic maps for the entire United States. You can also find us online at mapstore.utah.gov.

Natural Resources Map & Bookstore | 1594 W North Temple Salt Lake City, UT 84116

Mon–Fri 8:00 a.m.–5:00 p.m. | 801-537-3320 OR 1-888-UTAHMAP | geostore@utah.gov

Follow Us!

UGS Blog
geology.utah.gov/blog

UGS Facebook

UGS Twitter