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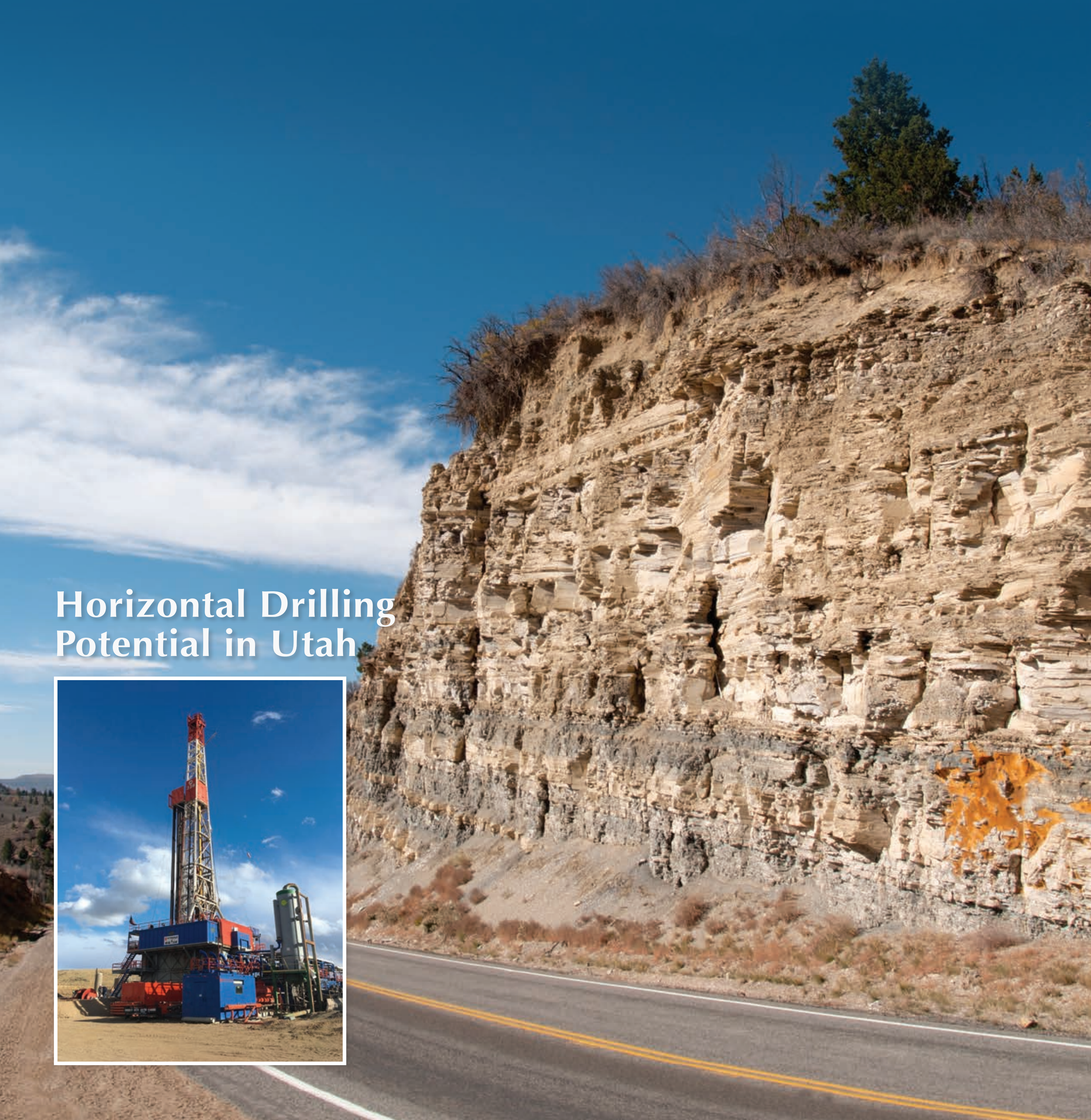

Horizontal Drilling Potential in Utah

Contents

Design | *Jennifer Miller*
Cover | Outcrop of the Carbonate Marker Unit (Black Shale facies), lower Green River Formation, in Willow Creek Canyon, western Uinta Basin, Utah.
INSET PHOTO Drill rig in the Uinta Basin drilling horizontal wells for Newfield Exploration Company.

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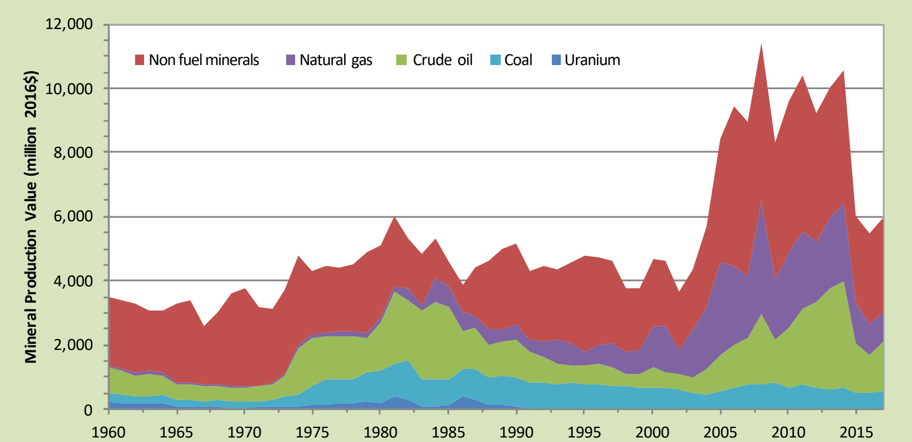
THE DIRECTOR'S PERSPECTIVE

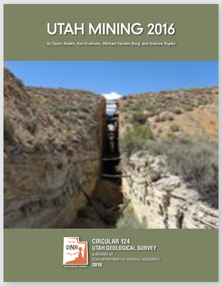
by Richard G. Allis

Probably the two most widely referred-to publications produced by the Utah Geological Survey (UGS) are the annual *Utah Mining* and the less frequent *Utah's Energy Landscape*. Both provide reviews of trends in Utah's energy and mineral commodities, and they contain numerous graphs and tables. The latest *Utah Mining* report has just been published, covering data to the end of 2016 (UGS Circular 124; https://ugspub.nr.utah.gov/publications/circular/c-124.pdf). The total value produced by Utah's extractive industries in 2016 was $5.5 billion and is estimated to be $5.9 billion for 2017 (see graph below). The 2014 crash in commodity prices, especially oil and natural gas, caused the total value to fall from the $9–$10 billion level characteristic of the previous decade, and bottom out in 2016. Industry examples of the effects of external economic factors are the petroleum drilling rig count in Utah which decreased from more than 30 in 2013 to zero for a while in 2016, and well completions which decreased from around 1000 to between 100 and 110 in 2016 and 2017 (Utah Oil, Gas and Mining data; the rig count is now at nine). Another example is aggregate mining (sand, gravel and crushed stone), which the local construction industry depends on. There have been two booms in aggregate production in Utah in recent years: leading up to the 2002 Winter Olympics with massive interstate construction, and the building boom from 2005 until the financial collapse in 2008. During both booms, aggregate production in Utah exceeded 50 metric tons per year (55 million short tons/year) compared to 10–20 million metric tons per year typical of the previous 50 years. Aggregate production sank to a low of 30–32 metric tons per year in 2012–13. The latest estimates for aggregate production in 2016 and 2017 are once again approaching the 50 million metric tons per year mark, confirming recent statements from the governor and the legislature that our economy is booming. Local extractive commodities are playing their part in this latest boom.



Source: Utah Geological Survey; U.S. Geological Survey; Utah Division of Oil, Gas, and Mining; U.S. Energy Information Administration; Utah Tax Commission. Note: 2017 data are estimated.

NEW PUBLICATION Utah Mining 2016



This report summarizes 2016 energy and mineral resource production statistics and values for Utah. Discussions cover energy resources including oil, natural gas, coal, and uranium, and nonfuel mineral resources including base and precious metals as well as industrial minerals. The report also updates exploration projects and development of new resources. By Taylor Boden, Ken Krahulec, Michael Vanden Berg, and Andrew Rupke, 27 pages, ISBN 978-1-55791-944-1, Circular 124.

UGS publications are available for download at geology.utah.gov or for purchase at utahmapstore.com.

HORIZONTAL DRILLING IN UTAH:

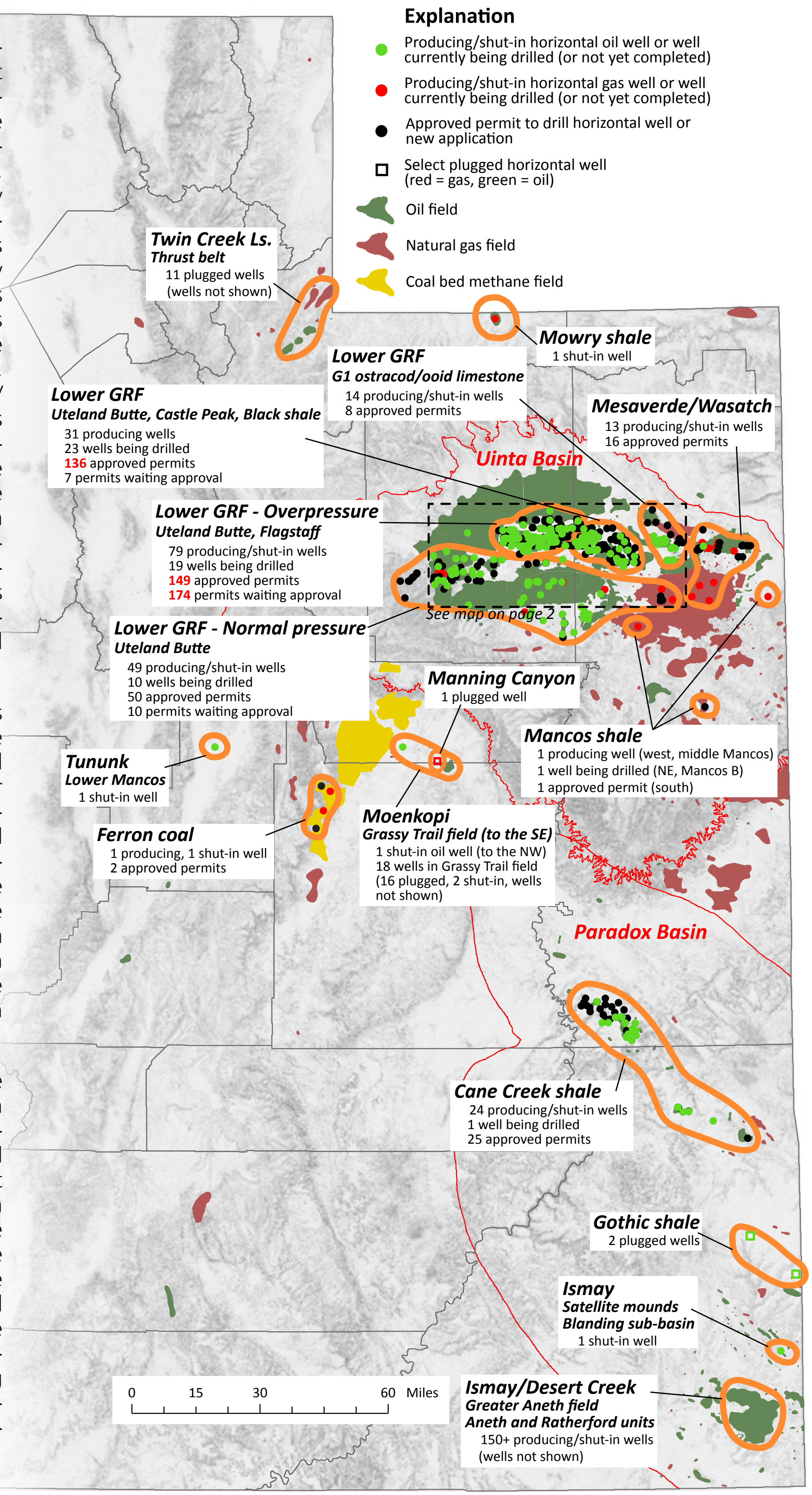
Can Utah Compete with Surrounding States?

BY Michael Vanden Berg

Advancements in horizontal drilling and associated hydraulic fracturing have garnered significant attention in the past several years. In the past decade, the petroleum industry has combined these well-established technologies into a formidable system for exploiting domestic shale reservoirs. In fact, U.S. oil production broke 10 million barrels per day in November 2017 for the first time since production peaked in 1970. Furthermore, U.S. net imports of oil were 60 percent of total demand as recently as 12 years ago, now they are only 20 percent. This massive resurgence in oil production mostly comes from onshore unconventional shale plays such as the Permian of West Texas, the Bakken of North Dakota, the Niobrara of Colorado and Wyoming, the STACK/SCOOP play of the Anadarko basin in Oklahoma, as well as several others. As surrounding states experience a surge in horizontal drilling, can Utah join the bandwagon? In general, the geology of Utah's shale formations is not conducive to massive petroleum development at today's prices and with current technology, but potential exists for smaller-scale horizontal development in regional shale play areas. Utah's largest potential lies in the development of established conventional reservoirs using new horizontal drilling technology.

There are nearly 15,000 producing or shut-in wells in Utah; surprisingly, only about 350 target a single reservoir with a true horizontal wellbore. Directional wells are much more common, accounting for over 4000 producing wells in Utah. In contrast to horizontal wells, directional wells start out vertical, bend until they get to a desired location, then turn vertical (or nearly vertical) again when penetrating the reservoir (see illustration on page 3). Most of the producing horizontal wells in Utah are in the Uinta Basin (about 185 wells) or southern Paradox Basin (over 150 wells in the Greater Aneth field), with the remainder scattered around the central and eastern part of the state.

The first horizontal drilling in Utah occurred at the Grassy Trail field near the town of Price. Between 1982 and 1984, 18 wells with multiple short horizontal laterals (average of only 332 feet) were drilled in the Triassic Moenkopi Formation. The best eight wells were completed for an average production rate of 128 barrels (bbls) of oil per day, double the production from the vertical wells in the field (the Moenkopi in this area is still considered prospective for oil, and Whiting Petroleum drilled a horizontal test in 2012 near the town of Wellington). In the 1990s, Utah experienced a significant surge in horizontal development with extensive drilling targeting conventional carbonate reservoirs in the Greater Aneth field in southeastern Utah and more minor drilling in the Twin Creek Limestone in northern Utah.



Horizontal well data from the Utah Division of Oil, Gas and Mining. Data accurate as of February 2018; well status and permit counts, especially in the Uinta Basin, are constantly changing. Oil and gas fields from UGS.

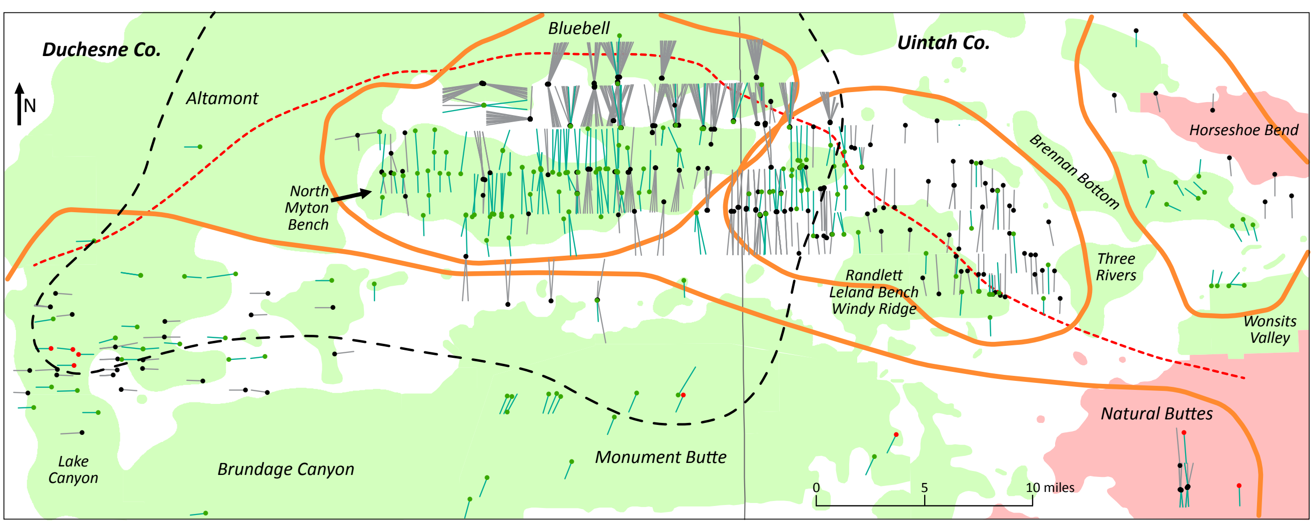
High oil and natural gas prices in the mid-2000s and high oil prices between 2011 and 2014 spurred significant exploration in Utah's shale deposits. During this time, the Utah Geological Survey (UGS) researched the hydrocarbon potential of various shale resource plays including the Mississippian Manning Canyon Shale, several Pennsylvanian Paradox Formation shales (Gothic, Hovenweep, and Chimney Rock), and the Cretaceous Mancos Shale, the thickest, most extensive shale unit in Utah. Despite substantial geologic research, only a handful of horizontal wells have been drilled targeting these shale formations.

In pursuit of a shale gas play in 2008, Whiting Petroleum re-entered an old vertical well and drilled a 5000-foot horizontal lateral in the Cretaceous Mowry Shale (lower Mancos equivalent) near the Utah-Wyoming border north of the Uinta Mountains. This horizontal well never produced and is currently shut-in. In 2010, Bill Barrett Corporation drilled a 4200-foot horizontal well targeting gas in the Manning Canyon Shale south of Price, Utah. Despite a significant gas "show," this well never produced and is now plugged. Also in 2010, XTO Energy drilled a 6000-foot lateral in the middle Mancos in the central Uinta Basin. This well has produced just over 1 billion cubic feet (cf) of gas and lots of water (over 440,000 bbls), which is expensive to dispose of properly. While the well is still producing, there is currently no plan for XTO or any other company to drill other Mancos gas wells in the area.

After oil and natural gas prices crashed in 2008, the price of oil quickly rebounded but natural gas prices remained low. This caused companies to abandon most of their shale gas interest, targeting instead shale oil (or tight oil) plays. In 2013, Anadarko Petroleum drilled two horizontal wells in the suspected liquid-rich area of the Gothic shale in the south-central Paradox Basin (a third vertical well was drilled, but the planned horizontal was never completed, and two additional proposed horizontal wells were never drilled). Unfortunately, both wells (and the vertical well) are now plugged after producing only negligible volumes of oil and gas. In 2015, Whiting drilled a 4000-foot lateral in central Sanpete County targeting the Tununk Member of the lower Mancos Shale. This well produced about 24,000 bbls of oil and 74 million cf of gas before it was shut-in in mid-2017. Also, in the pursuit of a liquids shale play, KGH Operating has recently completed drilling a 12,000-foot lateral in the Mancos B (otherwise called the Prairie Canyon Member of the upper Mancos Shale) near Bonanza, Utah, in Uintah County. While results for this well are not yet available, the Mancos B has been drilled just over the border in Colorado with significant success. In addition, in early 2017, Del Rio Resources received approval for a horizontal Mancos B well in the southern part of the basin. The hope is that the Mancos B on the eastern side of the Uinta Basin could become a significant oil target as more exploratory wells are drilled to define this play.

Despite the limited success of the few exploratory wells within Utah's shale formations, UGS research concluded that although significant potential exists, continued exploration and possibly new technologies (and higher prices) will be needed before these resource plays can significantly contribute to the state's petroleum production.

In contrast to Utah's shale plays, the Uinta Basin is poised for a significant increase in horizontal well drilling, as evidenced by the nearly 550 new horizontal well permits already approved or in the works (as of February 2018). Currently, the most important horizontal target in the basin, and all of Utah, is the lower Green River Formation. These well-known lacustrine rocks exhibit subsurface conditions especially conducive for successful horizontal development. Organic-rich petroleum source rocks are interbedded with packages of more conventional reservoir units (dolomite, sandstone), many of which are laterally continuous. Starting in 2010, operators began drilling 5000-foot laterals in these thin reservoir units in the southern part of the basin, most notably the highly porous dolomites of the Uteland Butte member (subject of a recently completed UGS research project on tight-oil potential in Utah: https://geology.utah.gov/resources/energy/oil-gas/shale-oil/). Initial production (first month) from these wells ranged from 20 to 275 bbls of oil equivalent per day (which includes natural gas), with an average of 150 bbls per day. It soon became clear that horizontal wells drilled farther north in the basin, where the beds deepen into the subsurface and the reservoir is overpressured, were more successful. Most of these lateral wells were drilled by Newfield Exploration and some by Bill Barrett, with initial production ranging from 300 to 1100 bbls per day, with an average of about 630 bbls per day. Starting in 2014, Newfield began to drill 11,000-foot horizontal laterals (over 2 miles!) in the Uteland Butte (now targeting the moderately porous organic-rich,



Approximate area of overpressure within the basin (>0.5 psi/ft)
Northern extent of Uteland Butte dolomites
Highlighted areas from state-wide map
Oil field
Natural gas field
Horizontal oil well - producing, shut-in, or currently being drilled/completed
Horizontal gas well - producing or shut-in
Lateral track for producing and shut-in wells, or wells that are currently being drilled/completed
Horizontal well with approved or yet-to-be approved permit
Proposed lateral track for planned well

Well data from the Utah Division of Oil, Gas and Mining. Data accurate as of February 2018; well status and permit counts are constantly changing.

clay-rich limestones) and in the overpressure zone, mostly in the North Myton Bench oil field. These new "super-extended laterals" experienced initial production rates of 800 to 2000 bbls per day with an average of 1285 bbls and quickly became the lateral length of preference for this part of the basin. In fact, Axia Energy has submitted plans for an extensive drilling campaign in the narrow swath of land between North Myton Bench and Bluebell fields, with multiple horizontal wells proposed to be drilled from single well pads. As the map on page 2 shows, these new super-extended laterals are clustered in an area bounded to the south by the extent of higher overpressure and constrained to the north by the pinch-out of the dolomitic reservoir units.

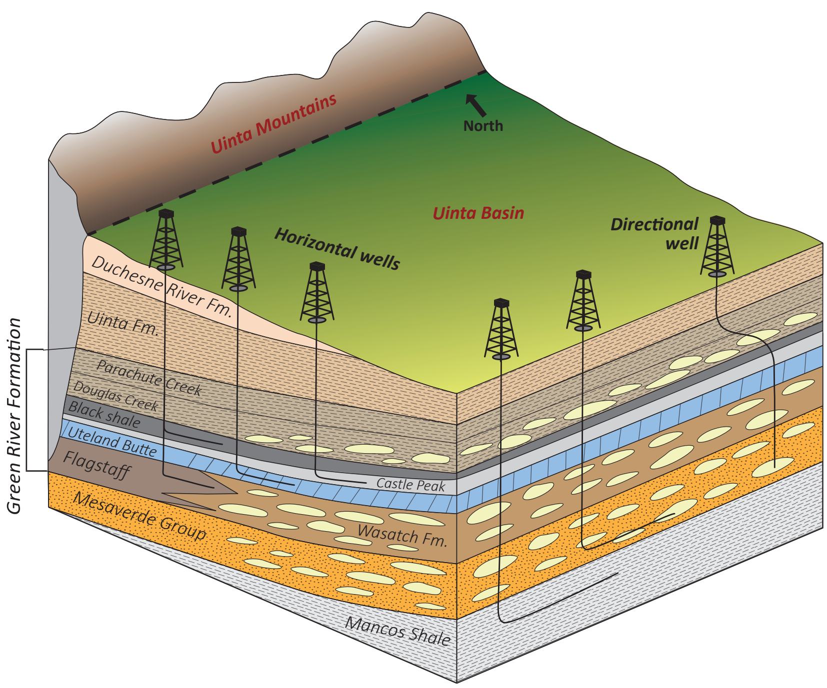
In addition to the Uteland Butte play, companies like Newfield, Axia, Crescent Point Energy, and QEP Resources have drilled laterals in several other units of the Green River Formation. Additional targets include the underlying Flagstaff Member carbonates, and the overlying Castle Peak siliciclastic interval, Black Shale facies, and lower Douglas Creek Member, including the informally named G1 ostracod/ooid limestone (subject of a soon-to-be-published UGS research paper). Numerous layered targets make the Green River Formation a true "stacked" horizontal play. Soon, several horizontal laterals could be drilled into multiple Green River zones in a single wellbore.

An additional horizontal target has emerged in the northeastern corner of the Uinta Basin and focuses on a conventional sandstone reservoir as opposed to a shale formation—the Cretaceous Mesaverde Group. The Mesaverde is composed of interbedded fluvial sands, overbank mudrocks, and coal beds and has traditionally been targeted for its gas resources with vertical and directional wells. Similarly, the overlying fluvial Wasatch Formation also contains significant gas resources. In fact, the largest natural gas field in Utah, Natural Buttes, produces gas from the Wasatch and Mesaverde. In 2008 and 2009, EOG Resources drilled three 4000-foot laterals, two in the Wasatch and one in the Mesaverde in the northern Natural Buttes field. To date, these three wells have produced over 4 billion cf of gas and are still producing. Then in late 2017, EOG drilled two 7000-foot laterals in the Mesaverde in the same area. Between 2014 and 2015, QEP Resources drilled two 5000-foot laterals, one 7500-foot lateral and four 10,000-foot laterals in Red Wash field targeting the Neslen unit within the Mesaverde Group. These wells have already produced a combined 24 billion cf of gas and a minor 115,000 bbls of oil. This reconnaissance horizontal drilling in the Wasatch and Mesaverde could set the stage for massive new development should natural gas prices return to higher levels.

The second hottest horizontal play in Utah, but small compared to the Green River Formation, is in the northern part of the Paradox Basin, targeting the Pennsylvanian Paradox Formation's Cane Creek shale (also included in the recently completed tight-oil project). The first vertical wells targeting the Cane Creek were drilled in the 1960s, but real commercial success started in the 1990s with the drilling of the first horizontal wells, and then greatly increased in the early 2010s when Fidelity Petroleum drilled several more horizontal wells. Currently, 24 horizontal wells are producing from the Cane Creek, most from the Big Flat field near Dead Horse Point State Park and a few minor producers farther to the southeast. The most successful well, Cane Creek Unit 12-1, was drilled in 2012 with an initial production rate of about 1700 bbls of oil per day and to date has produced just over 1 million bbls. Fidelity has since sold their Cane Creek acreage to Kirkwood/WESCO Operating, who currently have 25 approved horizontal well permits on file.

Horizontal well drilling is not new to Utah; it has been an established technology since the early 1980s. With high natural gas prices in the mid-2000s, several companies drilled exploratory horizontal wells in Utah's potential shale gas plays, but as the price of gas crashed in 2008, these targets were no longer pursued. As the price of crude oil rose in the early 2010s, companies refocused their efforts on liquid-rich plays in established basins but with new horizontal drilling targets and techniques (e.g., longer laterals). By far the most successful of these plays is within the Green River Formation in the Uinta Basin, and to a lesser extent, the Cane Creek play in the northern Paradox Basin. Other shale plays (Manning Canyon, Gothic, Mowry, Mancos) and horizontally-targeted conventional reservoirs (Wasatch, Mesaverde, Moenkopi) will need further research and possibly technological advances (and higher prices) before Utah can compete with the Bakken of North Dakota or the Permian of West Texas.

For more information on recently completed UGS shale research, visit the Oil and Gas section of our website: https://geology.utah.gov/resources/energy/oil-gas/.



Schematic of Uinta Basin stratigraphy and possible horizontal drilling targets.

ABOUT THE AUTHOR

Michael Vanden Berg has worked at the Utah Geological Survey for 15 years and is currently the Energy and Minerals Program Manager. In addition to his managerial duties, Michael researches the lacustrine deposits of the Green River Formation, including their hydrocarbon potential, as well as modern lacustrine systems such as Great Salt Lake. Michael is also the General Chair for the upcoming AAPG Annual Convention in Salt Lake City, May 20–23.

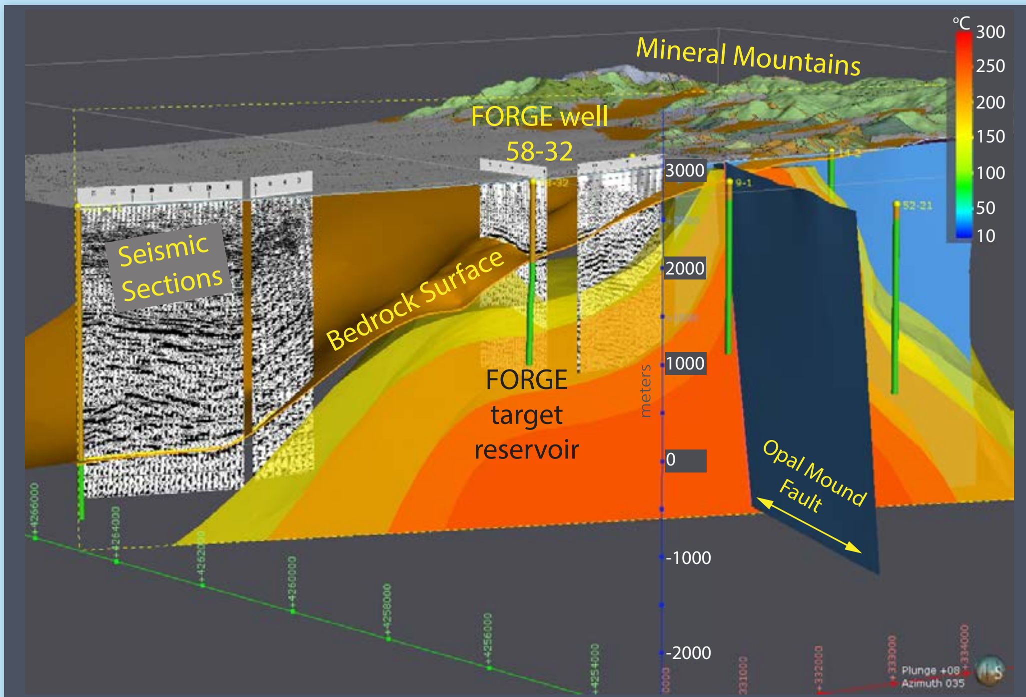
Using Gravity

in a Multidisciplinary Approach to Better Understand the Subsurface

BY Christian L. Hardwick

The Utah Frontier Observatory for Research in Geothermal Energy (FORGE) site near Milford, Utah, is one of two remaining sites in the competitive U.S. Department of Energy (DOE) initiative to locate and create a dedicated research laboratory where scientists and engineers will be able to develop and test enhanced geothermal system (EGS) technologies and techniques (see *Survey Notes*, v. 48, no. 3; v. 50, no. 1). The first objective of this project was locating a reservoir that fits all the critical parameters required by DOE (tight crystalline rock, 175°–225°C, 1.5 to 4 kilometers depth). We achieved this objective by using a multidisciplinary approach, combining different scientific survey techniques and data types, which gives us higher confidence on what we cannot see from the ground surface. While information from a wellbore is an excellent source for directly determining subsurface parameters, it is very expensive to drill a well, and it only provides data for the immediate area surrounding the well (within a few meters [tens of feet]). For better understanding of a study area, we can augment wellbore information with geologic, hydrologic, geophysical, geochemical, and other types of data.

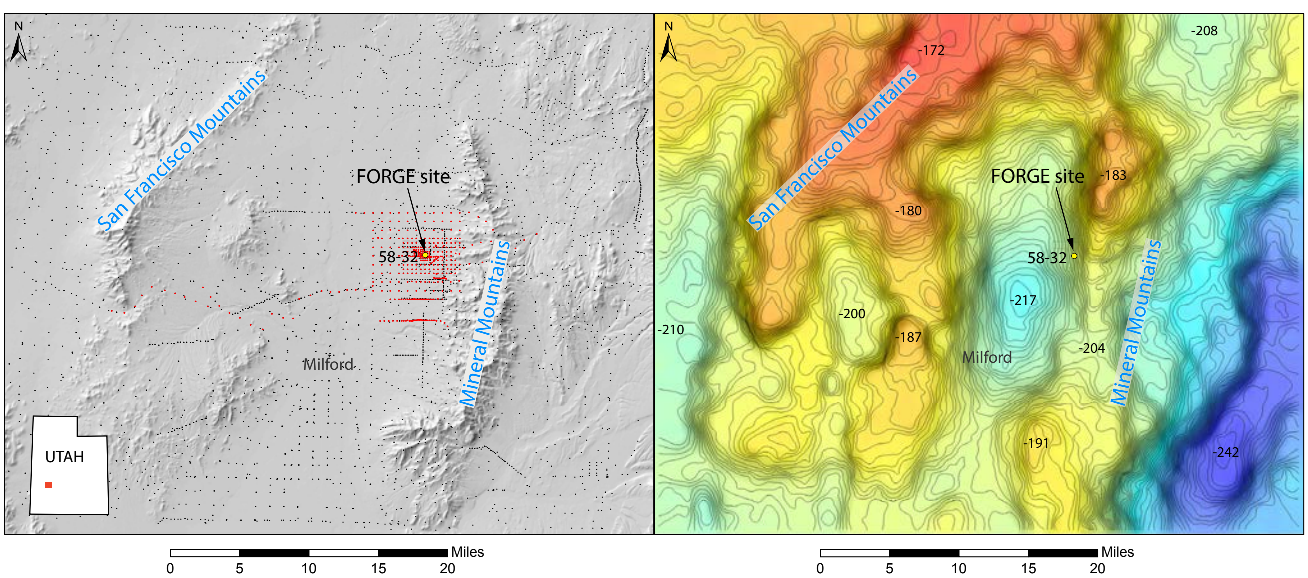
The most cost-efficient way to characterize subsurface bedrock geometry is by using geophysical surveys. At the Utah FORGE site, gravity surveying is one of the main geophysical survey types used because it is low-impact, non-invasive, and only requires 15 minutes per measurement for high-quality data. Earth's gravity field, simply put, is primarily the result of the mass distribution beneath our feet.



A composite model of the Utah FORGE site integrating multiple data types (geologic, thermal, gravity, seismic, hydrologic) depicts the subsurface bedrock geometry and temperature field which are key parameters to the FORGE project. The earth model output was generated using Leapfrog software (copyright © Aranz Geo Limited).

As the density and mass of a material increases, so does the gravity field. Within valleys filled with sediments, such as the one containing Milford, when density decreases the gravity field also decreases. These changes in the gravity field are called anomalies when they differ from expected gravity field values, and we in turn use these gravity anomalies to create models of the subsurface. These models help us identify underground structures and, in the case of the Utah FORGE study, estimate how deep the bedrock is in a valley filled with sediment.

Gravity models also give insight into the structural controls of basins, groundwater flow/aquifers, seismic risk/hazards, and geothermal reservoirs. At first glance, prominent features are drawn from abrupt changes in the gravity field, known as high gradients, that indicate steeply dipping interfaces and/



Maps of the Utah FORGE study area. Left panel: shaded elevation map showing the locations of the gravity survey stations, red dots are new stations, black dots are legacy data, FORGE well 58-32 indicated by yellow dot. Right panel: gravity anomaly field (same extent as left panel) with 1 mGal contours. Warm colors indicate gravity highs (typically mountain ranges) and cool colors are gravity lows (typically basin-fill sediments).

at the Utah FORGE Site

or faults hidden below the surface. High gravity gradients to the north and west of the FORGE site are inferred to be major fault offsets. Near the FORGE site, however, there are no notable gravity gradients that would indicate significant fault offsets hidden in the subsurface.

In geothermal studies, the better we understand the thermal properties of rock and subsurface geometries, the better we can characterize the thermal regime and setting. The Utah Geological Survey operates a thermal laboratory where thermal conductivity, density, and specific heat are measured on samples obtained from well cuttings, core, and outcrop. These measured properties are crucial parameters in understanding thermal regimes. When we integrate known thermal properties of the local geology with subsurface geometry, we can generate a thermal regime of the subsurface and estimate the temperature at a given depth. Initial calculations estimated the minimum FORGE temperature of 175°C would be reached between 1900 and 2400 meters (6234 and 7874 feet) depth, and the newly drilled FORGE well later confirmed this temperature at 2000 meters (6562 feet) depth. Results of the FORGE gravity surveys are consistent with independent 3D seismic interpretations for FORGE, which improves our confidence in the survey methods.

When we combine multiple methods and data types, we can better characterize and ultimately improve our understanding of a study area. We look forward to integrating subsequent FORGE data with current data sets to paint a more complete picture of the geothermal resource as the project advances.

Gravity surveying near the Utah FORGE site, (Mineral Mountains in the background) using a Scintrex CG-5 autograv to measure the local gravity field.

TEACHER'S CORNER

EARTH SCIENCE WEEK October 1–4, 2018
Hands-on Activities for School Groups

Come celebrate Earth Science Week with the Utah Geological Survey! This popular annual event features educational activities that are particularly suited for the 4th and 5th grades, where earth science concepts are taught as outlined in the Utah Science Core Curriculum standards. Earth Science Week activities take place at the Utah Core Research Center in Salt Lake City and include panning for "gold," identifying rocks and minerals, experimenting with erosion and deposition on a stream table, and examining dinosaur bones and other fossils.

Groups are scheduled for 1½-hour sessions. Reservations typically fill early; to inquire about an available time slot for your group, contact Jim Davis at 801-537-3300.

Launched by the American Geosciences Institute (AGI) in 1998, Earth Science Week is an international event highlighting the vital role earth sciences play in society's use of natural resources and interaction with the environment.

For more information, please visit our web page at https://geology.utah.gov/teachers/earth-science-week/.

UTAH TEACHER WINS ACCLAIMED TEACHER OF THE YEAR AWARDS

The UGS is pleased to announce that Deborah Morgan, who currently teaches 9th grade Earth Systems at South Sevier High School in Monroe, Utah, was awarded the 2017 Utah Geological Association's Earth Science Teacher of the Year, followed by the 2018 Teacher of the Year award given by the Rocky Mountain Section (RMS) of the American Association of Petroleum Geologists (AAPG), and the 2018 Teacher of the Year (K–12) given by the AAPG Foundation for demonstrating outstanding leadership in the field of geoscience education. Ms. Morgan will accept her awards at the AAPG Annual Convention and Exhibition, May 20–23, 2018. Congratulations Deborah!

Call for Nominations for the
2018 UTAH EARTH SCIENCE TEACHER OF THE YEAR AWARD
For Excellence in the Teaching of Natural Resources* in the Earth Sciences

The Utah Geological Association (UGA) is seeking nominations for the 2018 Utah Earth Science Teacher of the Year Award. The UGA awards $1,200 to the winning teacher plus $300 reimbursement for procuring resources related to earth science education (e.g., materials, field trip expenses, etc.). All K–12 teachers of natural resources* in the earth sciences are eligible.

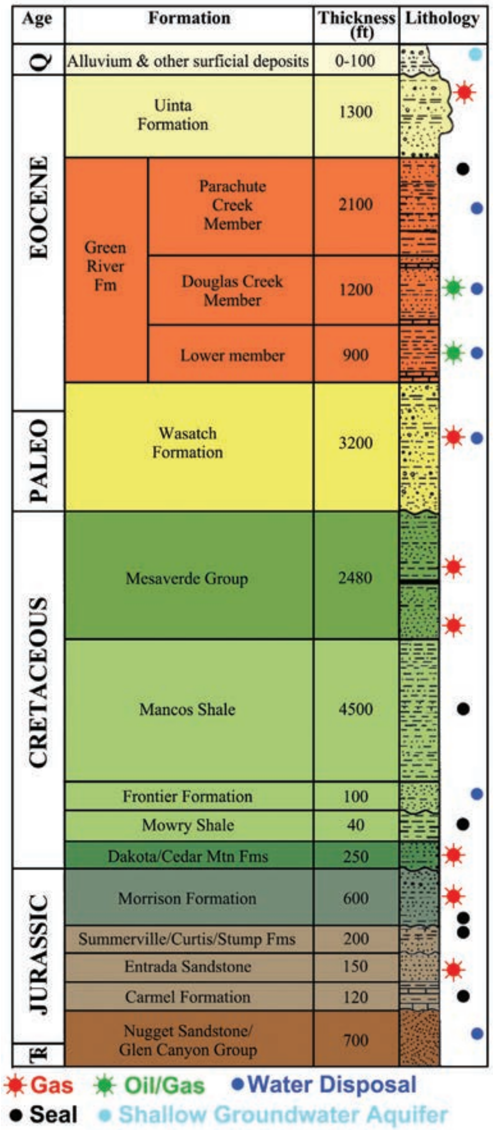
Application deadline is June 1, 2018. Additional information, requirements, and entry forms are available on the UGA website (www.utahgeology.org) under the Education tab.

**Natural resources are defined as earth materials used by civilization past and present, such as natural gas, petroleum, coal, oil shale, mineral ores, building stone, and energy resources from the earth such as geothermal energy.*

Oil and Gas in the Uinta Basin, Utah

What to Do With the Produced Water

BY Thomas C. Chidsey, Jr.



Above: Stratigraphic column from the surface down through the Upper Triassic-Lower Jurassic-age Nugget Sandstone in the Uinta Basin showing major oil- and gas-producing reservoirs, seals, water disposal zones, and shallow groundwater aquifers. Modified from Hintze and Kowallis (2009), Geologic History of Utah.

Below: Produced water evaporation pond and spray evaporation system, Altamont oil field, Duchesne County. Photo by Richard Powell, Utah Division of Oil, Gas & Mining.

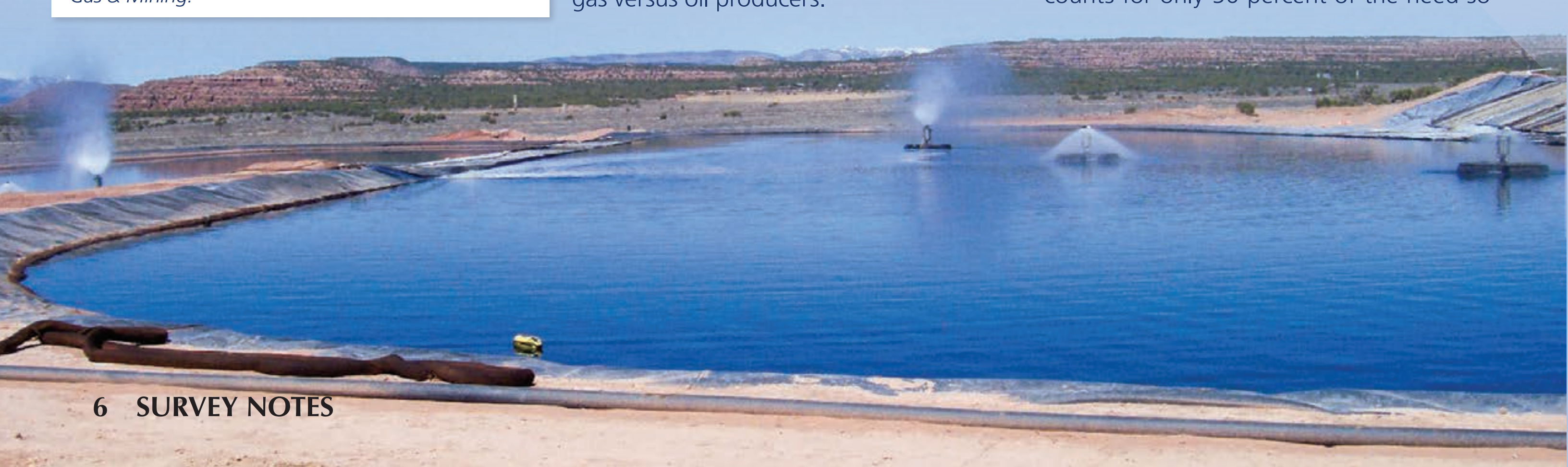
Oil and gas fields in the Uinta Basin of eastern Utah produced over 24 million barrels of oil and 306 billion cubic feet of gas in 2016 from the 56 to 44 million-year-old Tertiary Wasatch and Green River Formations and the 73 to 66 million-year-old Upper Cretaceous Mesaverde Group. Pores in the reservoir rocks that contain oil and gas also include water. This water has resided in the rocks for thousands and perhaps millions of years. Over time, the water naturally dissolves minerals in the surrounding rock, adding chemical constituents such as chlorides or bicarbonate to the water, which is produced along with the oil and gas. The hydrocarbon production generates over 70 million barrels of saline (briny) non-potable water that requires disposal. To put this in perspective, Utahns use an average of 3.6 billion barrels of water per year or 5,200 barrels per household.

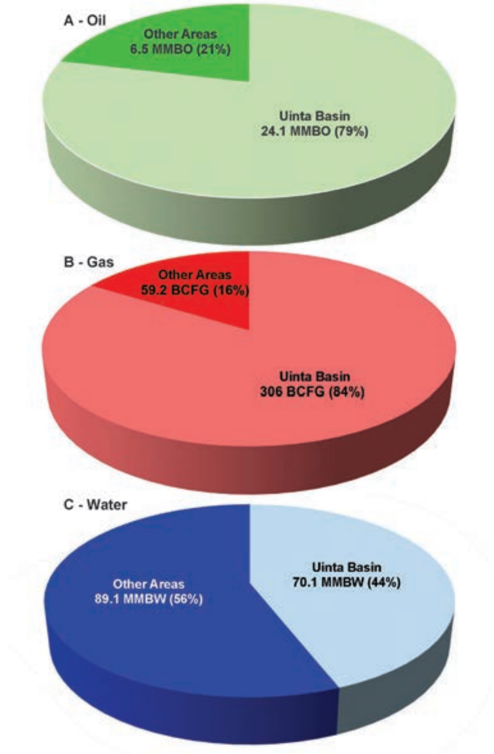
Although drilling activity is currently low in Utah and elsewhere due to depressed oil and gas prices, existing fields continue to produce. As wells mature, water production increases while oil and gas production decreases. However, oil and gas prices change depending on the economics of global market supply and demand. As prices increase, which we are seeing currently, oil and gas drilling and production respond accordingly; more wells will mean more water.

The environmentally sound disposal of produced water affects the economics of the hydrocarbon resource development in the basin. Thus, there is an economic incentive to minimize the amount of water produced and/or generate revenue by treating and reusing produced water, particularly in arid regions of the West. Specific Uinta Basin water issues include water use/reuse for well drilling and completion (e.g., hydraulic fracturing [HF or "fracking"]; see *Survey Notes*, v. 44, no. 2, p. 8–9), appropriate sites for disposal/reuse of water, development of systems to manage the produced water streams, and differing challenges for gas versus oil producers.

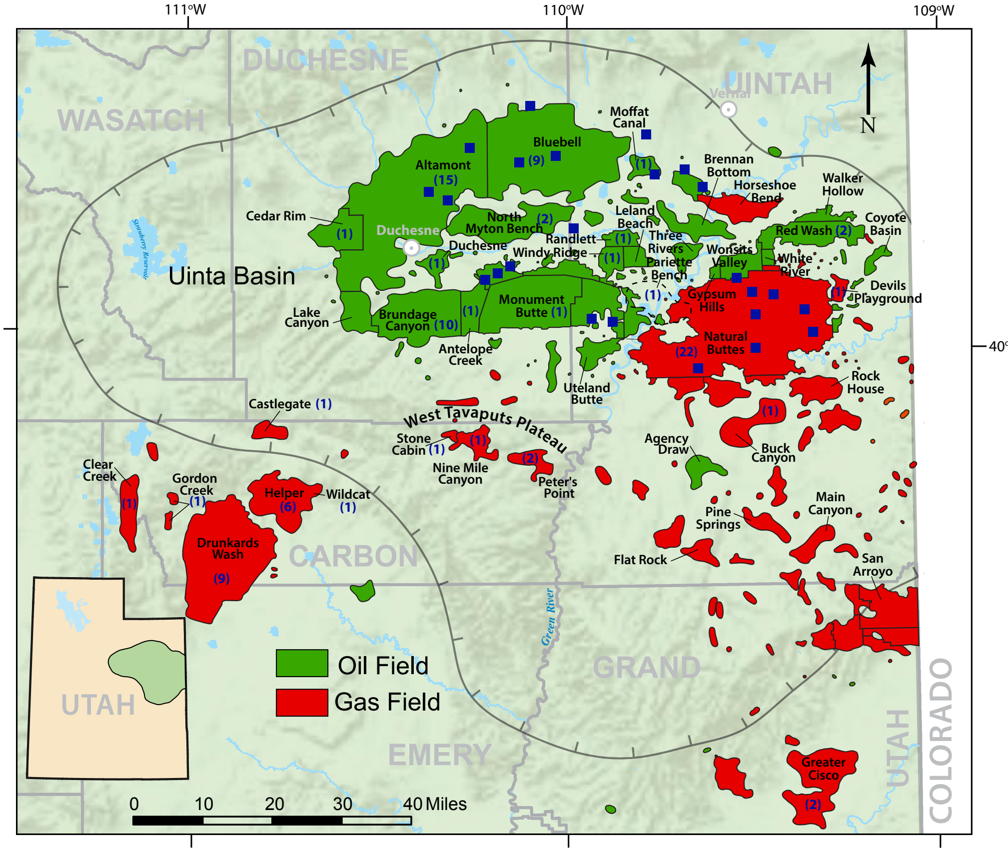
In late 2012, the Utah Geological Survey (UGS) was funded by the Research Partnership to Secure Energy for America (RPSEA) to address all these issues and conduct a study detailing what to do with the produced water in the Uinta Basin (see *Survey Notes*, v. 45, no. 1, p. 10–11). This now-completed study included (1) describing and mapping the major oil and gas reservoirs and aquifers in the basin, (2) characterizing the quantity and quality of water produced, and (3) helping define best management tools and options to dispose of the produced water economically and safely. Our study evaluated the thickness, structure, porosity, permeability, water quality, and temperature of all aquifer/reservoir units in the basin from the Eocene-age Green River Formation through the Jurassic-age Glen Canyon Group.

Large volumes of produced saline water are typically disposed of by several techniques. Less than 3 percent of the produced water is used for HF. If natural gas prices rebound and gas exploration and drilling increase, more produced water could be used in HF of "tight" (low-permeability) sandstones, and possibly more prospective shale reservoirs (see *Survey Notes*, v. 43, no. 2, p. 3–5 and 8–9). About 11 percent of produced water is hauled from the well site to specially designed, lined storage ponds where it evaporates; evaporation rates are often increased by huge water sprayers (about 8 percent of the water evaporates annually from these ponds, allowing continued delivery of new water). Extensive drilling for gas in tight sandstones in the eastern part of the basin (e.g., Natural Buttes field) generates significant quantities of water, while in the central basin (e.g., Monument Buttes field) expanding enhanced oil recovery (EOR) programs, called waterflooding recovery (injecting oil-bearing sandstone reservoirs with water to push remaining oil towards producing wells to increase recovery), creates a need for water. Waterflooding projects use 18 percent of the total produced water, but this accounts for only 50 percent of the need so





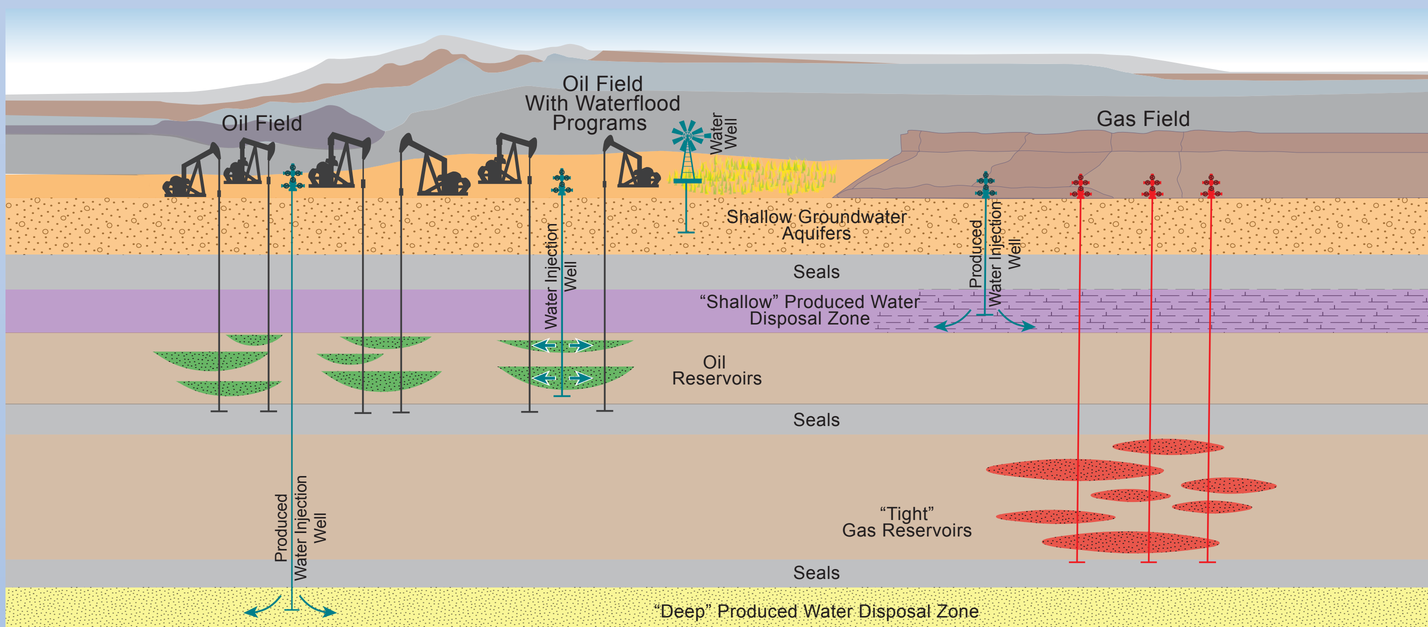
Production in the Uinta Basin in comparison to the rest of the state during 2016 (2017 data unavailable). MMBO = million barrels of oil, BCFG = billion cubic feet of gas, MMBW = million barrels of water. Data source: Utah Division of Oil, Gas & Mining, December 2016.



The Uinta Basin of eastern Utah showing oil and gas fields. The number of produced-water disposal wells is shown in parentheses near field names, those fields with enhanced-oil-recovery (waterflood) projects are labeled in blue, and locations of evaporation ponds are represented by blue squares.

the shortage is made up with freshwater supplies. Thus, excess compatible produced water from gas wells could increasingly be transported to oil fields undergoing EOR. Finally, about 60 percent of the produced water in the Uinta Basin is injected via wells into porous rock at a sufficient depth as to not cause contamination of shallow freshwater aquifers. The natural groundwater in deep aquifers is characterized as saline because it contains total dissolved solids (TDS) concentrations greater than 10,000 milligrams per liter (mg/L) (Class IV groundwater by the Utah Department of Environmental Quality). Most produced water also has TDS concentrations greater than 10,000 mg/L and therefore can be stored in deep Class IV aquifers. Injection is the preferred method of disposal over evaporation ponds. Injection of high volumes of produced water near fault zones is known to cause significant earthquakes in Oklahoma and other states. However, no such seismic events have been recorded in Utah from water injection because the aquifers are low pressure and faulting in the areas is limited; most injection sites are remote and away from populated areas.

The results of our study were published in November 2017 as UGS Bulletin 138, *Produced Water in the Uinta Basin, Utah: Evaluation of Reservoirs, Water Storage Aquifers, and Management Options*. The study provides a framework to address the varied water uses and disposal interests of various stakeholders and is helping industry, particularly small producers and regulators, make informed management decisions.



Schematic diagram showing oil and gas wells and hypothetical zones to dispose of the produced water.

“core center news”

BY Michael Vanden Berg

CORE LIKE NEVER BEFORE:

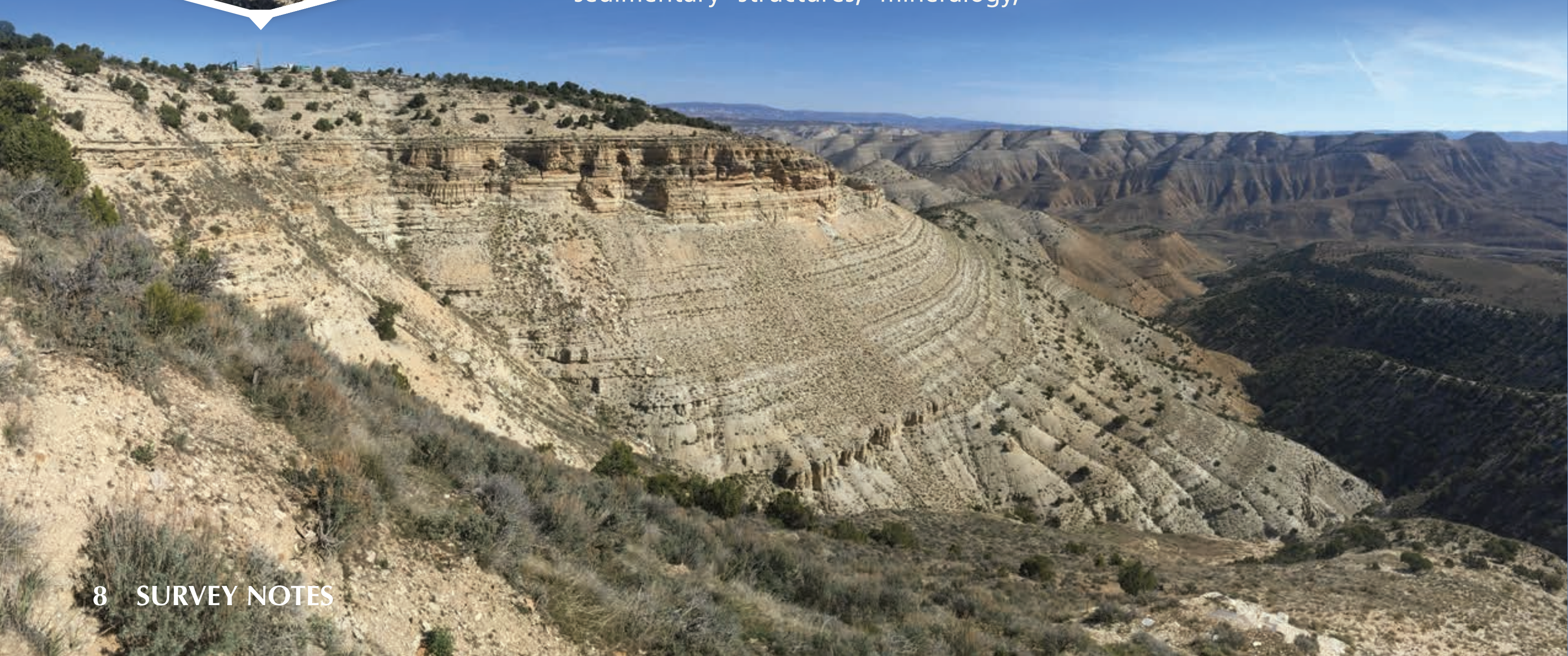
An Unprecedented 1600-Foot Core from the Green River Formation in the Uinta Basin

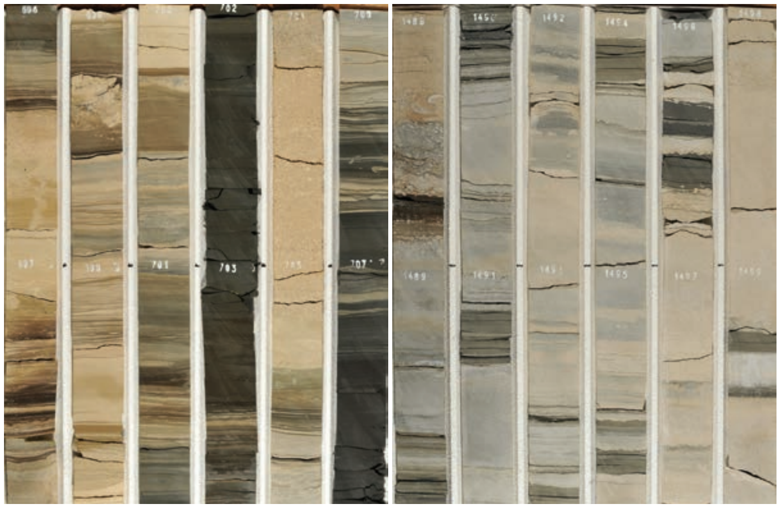
In May 2015, the Utah Geological Survey (UGS) had a unique opportunity to team up with French oil company Total SA and the University of Utah to drill a 1600-foot continuous core from the Eocene-age Green River Formation. Drilling 1600 feet of core is a rare treat and has provided an unprecedented window into the evolution of ancient (55- to 43-million-year-old) Lake Uinta. Drilled on the far east side of the Uinta Basin, just over the border in Colorado, the PR-15-7c core is destined to become one of the Utah Core Research Center’s (UCRC) prized and most studied acquisitions.

For several years, the UGS-Total-University of Utah partnership has researched the evolution of Lake Uinta, from initial formation to eventual demise, to better understand how paleoclimate relates to sediment deposition in a lacustrine setting. Also of interest is the potential for these different sedimentary layers to generate (organic-rich zones) or store (porous reservoirs) hydrocarbons. Not only is this research important for understanding the Uinta Basin’s petroleum system (the most productive in Utah), but it is also applicable to the study of lacustrine systems around the world.

The PR-15-7c core captured nearly the entire Green River Formation. The well was spudded in the upper Parachute Creek Member and coring began only a couple feet below the surface. The core is missing the very top of the formation due to limitations on drilling location. Coring proceeded through the famous Mahogany “oil shale” zone, several organic-rich and organic-lean intervals, into the Douglas Creek Member, through the Carbonate Marker unit, the Wasatch tongue, the Uteland Butte, and finally into the underlying Wasatch Formation. After transport to the UCRC, the core was slabbed (cut length-wise) for improved viewing of the depositional features. The next step was to describe the core inch-by-inch in fine detail, making notes on lithology, sedimentary structures, mineralogy, fossils, depositional cycles, etc. This tedious exercise was performed by University of Utah graduate student Jennifer Morris under the direction of Dr. Lauren Birgenheier. In addition to the description, we collected over 200 samples spaced evenly down the entire core that were analyzed for total organic carbon (TOC), elemental abundances, mineralogy, and thermal properties. This important analytical work was performed in partnership with the U.S. Geological Survey in Denver, Colorado.

The first transgression of ancient Lake Uinta, recorded in the Uteland Butte interval at the base of the core, occurred after an extensive period of fluvial deposition (Wasatch Formation). The Uteland Butte displays evidence that Lake Uinta, at its formation, was a freshwater lake with abundant gastropods and bivalves. These nearshore deposits also record several shallowing-upward lake level cycles and contain evidence of full or partial exposure (preserved mud cracks and thin coal deposits). After Uteland Butte deposition, the lake regressed, and the core captures a return to fluvial deposition, recorded in the Wasatch tongue interval. Shortly thereafter, Lake Uinta experienced another dramatic increase in water depth termed the Long Point transgression, marked in the core by an organic-rich, gastropod-rich, limestone bed. This transition into a





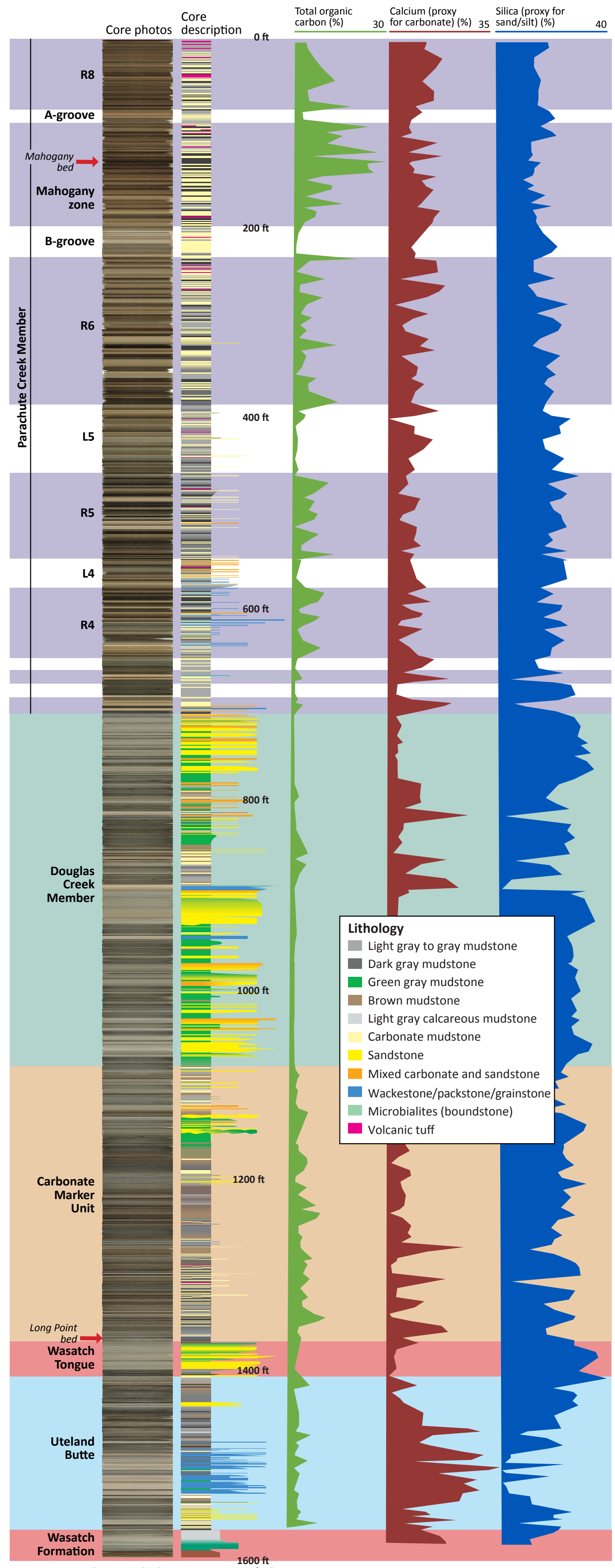
Select photos from the PR-15-7c core.

larger, deeper lake continued through the entire 278-foot-thick Carbonate Marker unit, which is composed mostly of organic-rich carbonate mudstone. Interestingly, the gastropods in the Long Point bed are the last freshwater mollusks found throughout the rest of the existence of Lake Uinta, suggesting that from this point on, the lake was moderately to strongly saline.

Starting at about 1080 feet in core depth, there is a dramatic change in lithology. The Douglas Creek Member marks a transition to a more siliciclastic-dominated system with preserved delta channels and distal mouth bar deposits from an expanded influx of sand into the lake brought by significant river systems. Lake level was fluctuating at this time but is thought to be relatively lower than previous intervals. In addition, during this time microbialites start to appear, most likely growing in the off-channel lagoons of the deltas. At about 710 feet in core depth, the lake again returned to a more carbonate-dominated system represented by the Parachute Creek Member. This upper Green River Formation interval is well known for its alternating organic-rich (R-zones) and organic-lean (L-zones) intervals, the former prized for its "oil shale" development potential. Overall the lake was growing in size and depth up through deposition of the Mahogany bed, within the Mahogany zone, located at 115 feet in the core. This bed represents Lake Uinta's highest level and largest regional extent (and is the most organic-rich), before retreating again during upper Parachute Creek time (only partially captured in this core).

For researchers interested in studying lacustrine sedimentation, Eocene hothouse climate, lacustrine-hosted hydrocarbon systems, and basic basin evolution, the PR-15-7c core is a unique and invaluable resource. Rarely do geologists get to see a continuous section of rock from the subsurface. Researchers at the UGS have already used this core several times for core workshops, particularly for Uinta Basin oil and gas operators, to help them understand the different intervals of the Green River Formation and how they relate to hydrocarbon production. We are only at the very beginning of understanding everything this core has to offer. We look forward to continued research and collaborations, and to discovering all the secrets hidden within these wonderful rocks.

If you are interested in seeing or studying the PR-15-7c core, or are interested in using the core for a workshop, please contact Michael Vanden Berg at michaelvandenberg@utah.gov or Peter Nielsen, UCRC curator, at peternielsen@utah.gov or 801-537-3359.



Stratigraphy and description of the PR-15-7c core.

GEOSIGHTS Parowan Gap, Iron County

BY Christine Wilkerson

Located in Iron County northwest of the town of Parowan, Parowan Gap is a three-mile-long pass transecting the Red Hills between Parowan Valley on the east and northern Cedar Valley on the west. A world-class gallery of Native American rock carvings is displayed at The Narrows on Parowan Gap's west end and a trail of Cretaceous-age dinosaur tracks can be explored near the east end.

GEOLOGIC SETTING AND FORMATION OF PAROWAN GAP

The rock strata exposed within Parowan Gap underwent low-angle thrust faulting and folding between 45 and 100 million years ago during the Sevier orogeny, a mountain-building period caused by dense oceanic crust in the Pacific Ocean colliding with and moving beneath the lighter continental crust of North America. These rock formations include the Jurassic-age Navajo Sandstone and Carmel Formation (on the west side of the Gap), the Late Cretaceous-age Iron Springs and Grand Castle Formations, and the early Tertiary-age pink member of the Claron Formation.

A long-gone stream carved Parowan Gap. This stream existed before the hills were here and may have been the ancestral, western part of Parowan Creek, a present-day stream draining Parowan Canyon near Parowan. Bounded by normal faults, the Red Hills began to rise relative to the adjacent Parowan and Cedar Valleys due to fault movement initiated during Basin and Range extension (beginning about 20 million years ago). Keeping to its established course, the stream continued to erode through the uplifting hills for millions of years until either the hills rose too quickly for the stream to keep cutting down, or the region's climate became drier and the stream dried up, or perhaps both. Today, only during exceptional flood years does a small stream occupy the Gap.

A petroglyph is an image that has been carved or engraved into a rock surface. The meanings of many petroglyphs at Parowan Gap have been lost over time. Multiple contemporary interpretations of the Zipper Glyph include a travel map, symbolizing the journey path and time taken, or perhaps a solar calendar with an outline that conforms to the contours of the Gap at The Narrows. Photographer: Bob Biek

PETROGLYPHS

The Parowan Gap Petroglyphs site, managed by the Bureau of Land Management (BLM), is listed on the National Register of Historic Places for its importance as a cultural treasure and is widely recognized for the number and quality of its petroglyphs, with over 90 panels showcasing over 1,500 carvings. In 2014, the site was improved with interpretive signs, trail upgrades, and new restrooms.

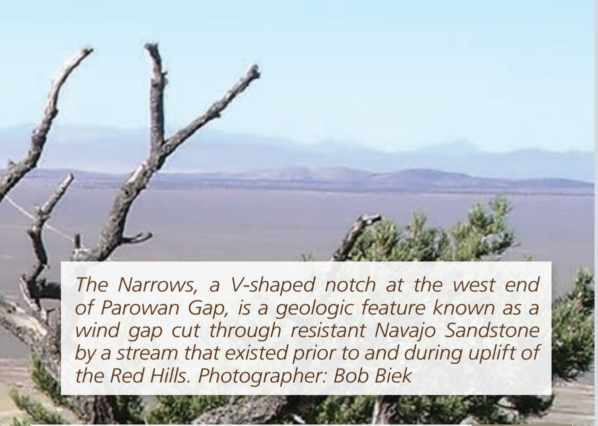
The carvings, cut into Navajo Sandstone at The Narrows, are thought to be the creations of multiple cultural groups over a lengthy period of time. Although some glyphs are possibly almost 5,000 years old, most researchers believe that people of the Fremont culture, who lived in the area approximately 700 to 1,500 years ago, carved the majority of them. To the modern-day Paiute and Hopi Tribes, this is an important historical, cultural, and spiritual site.

Typical petroglyphs here are of geometric designs, embellished with dots and dashes, but there are also carvings of lizards, snakes, bear claws, mountain sheep, and human figures. The true meaning of many of the petroglyphs remains unknown. Do they represent concepts, ideas, or actual happenings; hunting, communal, or religious rituals; lunar and solar calendars or other astronomical events?

A double track of hadrosaur (plant-eating duck-billed dinosaur) footprints preserved as natural casts in an Iron Springs Formation boulder along the trail at the Parowan Gap Dinosaur Track Site. Scale bar on left is 6.5 inches long. Photographer: James Kirkland

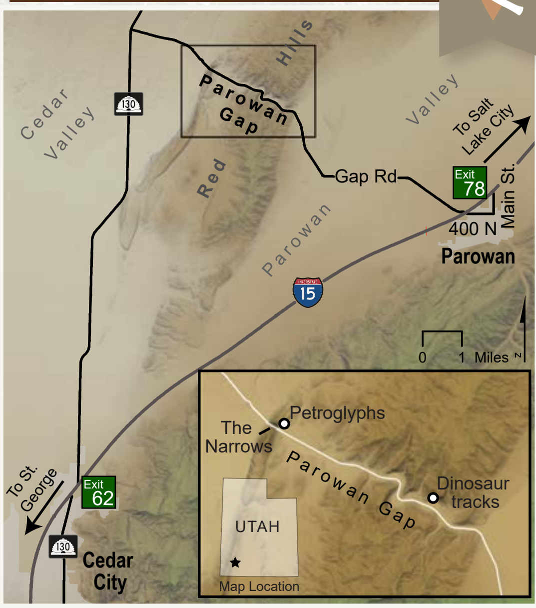
DINOSAUR TRACKS

The Parowan Gap Dinosaur Track Site, also managed by the BLM, has a trail that winds through dinosaur tracks exposed as natural casts on fallen sandstone blocks of the Iron Springs Formation. Such casts form when sediment fills the original dinosaur footprint and hardens into stone; it then becomes a three-dimensional replica of the dinosaur's footprint. These tracks were left behind from dinosaurs walking in an area of muddy and sandy braided streams about 75 to 85 million years ago. Most of this area's tracks were produced by ornithopods—very likely hadrosaurs (plant-eating duck-billed dinosaurs)—and a small number of tracks are from theropods (meat-eating dinosaurs) and ceratopsians (plant-eating horned dinosaurs).



The Narrows, a V-shaped notch at the west end of Parowan Gap, is a geologic feature known as a wind gap cut through resistant Navajo Sandstone by a stream that existed prior to and during uplift of the Red Hills. Photographer: Bob Biek

HOW TO GET THERE



From southern Utah, travel on I-15 North, take exit 62 (State Route 130), just north of Cedar City. Turn left onto State Route 130 toward Enoch and continue for approximately 13 miles before turning right onto the road going to the Parowan Gap Petroglyphs. The petroglyph site is on the left just after traveling through The Narrows. Continue driving on Gap Road for about 2 more miles to reach the Parowan Gap Dinosaur Track Site.

From northern Utah, travel on I-15 South, take exit 78 (Parowan), and turn left at the stop sign toward the town of Parowan. Drive into Parowan on Main Street for about ¾ mile until you reach the cross street of 400 North. Turn right onto 400 North; this street will become Gap Road soon after you cross under the interstate highway. Continue on Gap Road for approximately 7 miles until you reach the east end of Parowan Gap. Continue for about ¾ mile to the Parowan Gap Dinosaur Track Site and then another 2 miles to the Parowan Gap Petroglyphs.

GLAD YOU ASKED

Does Utah Really Use More Water Than Any Other State?

BY Mark Milligan

A TRICKY QUESTION

Water in the U.S. and especially in the American West is a complex matter, and even a question as seemingly simple as how much water a state uses can be confusing. A different answer can be reached depending on caveats such as total versus per capita use; consideration of salt water use; surface water versus groundwater use; intended use of the water such as domestic, mining, or power generation; and if the water is delivered by a public supplier. So, what about claims that Utah uses more water than any other state?

To investigate various claims and caveats of water use, one must rely on reports published by the U.S. Geological Survey (USGS). In compiling water use reports, the USGS utilizes data derived from different sources and methods and thus has varying levels of accuracy from state to state. For example, as part of continuing efforts to improve their data for Utah, the Utah Division of Water Resources recently released a report which stated they may be underestimating unmetered irrigation (secondary water) water use by as much as 34 percent for large water districts (for details see https://water.utah.gov/WaterUseCollectionReportFINAL1_29.pdf). So when ranking states, the margin of error could be greater than the reported differences in water use. Nevertheless, the USGS reports are the best and most reliable source for comparing states' water use.

Since the 1950s the USGS has published water use reports for years ending in "0" and "5." Unfortunately, although limited data are currently available, the full 2015 report is not expected to be released until fall of 2019. This article uses the most recent data available whether from 2010 or 2015. Since 2000 the USGS has categorized water use as public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, or power generation (see next page for details).

SOME ANSWERS

Which state uses the most **total water**? California.

In 2010, when considering all sources and uses of water, California led the nation in water use with an average of 38 billion gallons per day! Utah's 4.46 billion gallons per day pales in comparison and ranks us 30th on this list. California may have consumed the most total water, but it had an enormous population of 37.3 million while Utah had only 2.76 million people, which is why it may be preferable to compare per capita use.

Which state uses the most **total water per capita**? Idaho.

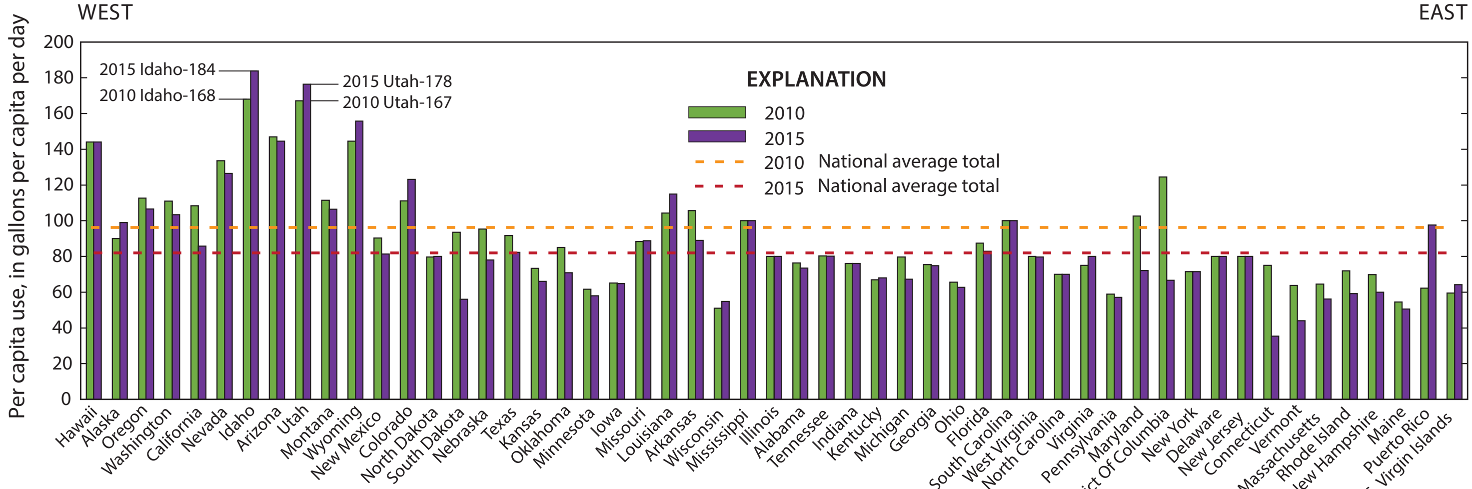
In 2010 Idaho's 1.57 million people used 10,955 gallons per capita per day (GPCD) (82 percent was used for irrigation)! Utah used 1,616 GPCD day ranking us 12th on this list. Total water includes categories of commodities that may use water in one state for a product that is consumed or utilized in another state. For example, if Utah water is used to generate electricity sold to California, should the water be legered against the producing state or consuming state? Conversely, California grows many crops that are shipped to Utah, and in this case some of California's water is shipped to Utah in fruits and vegetables. This may be a reason the USGS does not highlight per capita total use in its report. It does, however, highlight the use of domestic water per capita, water which is locally produced and consumed.

Which state uses the most **domestic water per capita**? Idaho.

In 2015, when considering per capita use of domestic water (both public supply and self-supplied), Idaho topped the nation by using 184 GPCD. Utah was a close second using 178 GPCD. The national average was 82 GPCD. While national domestic water use continues to drop, Idaho and Utah continue to use more. In 2010 the national average was 88 GPCD, while Idaho and Utah used a reported 168 and 167 GPCD, respectively.

Which state's **public supply customers** use the most water per capita? Utah.

In 2010 Utah's public supply customers used 248 GPCD, ranking us number 1 on this list. Nevada ranked second, using 229 GPCD. How did Utah surpass Idaho which used 210 GPCD and is ranked 5th on this list, behind Wyoming and Hawaii? Although Idahoans' water use tops the two previous lists, only one percent of the state's use is categorized as public supply. The very small number of public supply customers apparently do not use as much water as the vast majority of Idahoans who supply their own water through private wells or surface diversions.



Total domestic (public supply and self-supplied) water use per capita. Adapted from USGS Open-File Report 2017-1131, Public Supply and Domestic Water Use in the United States, 2015.

WHAT DOES IT ALL MEAN?

An internet search will yield many articles from mainstream, reputable media that have some form of the claim that at 248 GPCD, Utah has the highest per capita water use in the nation. While correct, the claim is only true for public supply customers, a consideration generally not addressed by the media. Interestingly, the 2010 USGS report does not explicitly give any per capita public supply use numbers or rankings, in spite of having the data to do so.

Although state rankings are good for creating attention-grabbing headlines that inspire water-use awareness, they have little to no scientific merit. Arid states typically use more water for landscape and crop irrigation. Farmers usually grow crops that yield higher profit margins and those crops, especially the abundant grass hay and alfalfa hay grown in Utah and Idaho, use a lot of irrigation water. Indeed, irrigation (not including irrigation water delivered from a public supply) accounts for 72 and 82 percent of Utah's and Idaho's 2010 water use, respectively.

Utah has historically used copious amounts of water to irrigate valley crops and for landscaping during our dry summer growing seasons. This has largely been possible because adjacent mountains receive ample precipitation. For example, the town of Alta, in the Wasatch Range above Salt Lake Valley, averages over 54 inches of precipitation a year, slightly more than Seattle and Salt Lake City combined. Despite elevated mountain precipitation, many areas in Utah have been supplementing surface water supplies by pumping groundwater at rates that exceed recharge, and some are starting to be impacted. For instance, the need to deepen or replace old shallow wells is a common occurrence in some aquifers. Also, ground-subsidence cracks attributed to land subsidence caused by decreasing groundwater levels have damaged infrastructure and houses in Cedar Valley, Iron County (for more information, see *Survey Notes*, v. 43, no. 1, p. 1–3).

Increasing per capita water use coupled with rapid population growth and projected reductions in both snowpack and streamflow due to changing climate is not sustainable. Nearly 3 million people currently live in Utah and that number is expected to swell to roughly 5.5 million by 2050. To sustain such growth Utah will soon need to make big decisions about conservation measures, water management, and the potential development of costly new supply projects.

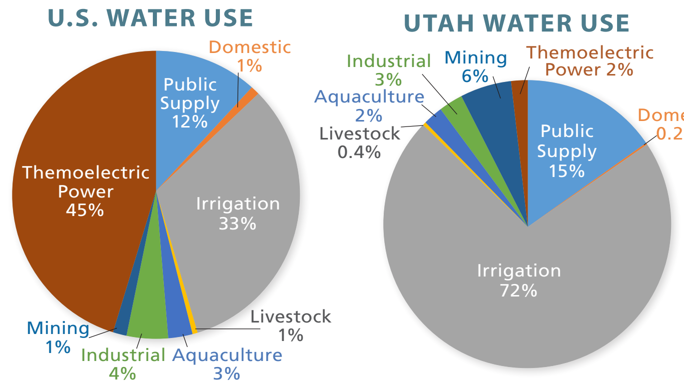
FOR MORE INFORMATION

USGS *Estimated Use of Water* publications can be found at https://water.usgs.gov/watuse/50years.html.

Information on future water supplies can be found at the Utah Division of Water Resources, https://water.utah.gov and in a report by the Utah Foundation, a non-partisan and non-profit, public policy research group: https://cicwcdorg.files.wordpress.com/2018/01/2014-09-flowing-toward-2050-utah-foundation-rpt-723-2014-09-2.pdf.

CURRENT USGS WATER USE REPORTING CATEGORIES AND TOTAL GALLONS USED PER DAY IN 2010

(the most recent year of available data)



- Public Supply–**42 Billion** U.S. / **673 Million** Utah.
Water withdrawn by public and private water suppliers that furnish water to at least 25 people or have a minimum of 15 connections. Public suppliers provide water for a variety of uses, such as domestic, commercial, industrial, thermoelectric-power, and public water use.

- Domestic–**3.6 Billion** U.S. / **8.44 Million** Utah (self-supplied only).
Water used for indoor and outdoor household purposes such as drinking, food preparation, flushing toilets, and watering lawns. As a reporting category it includes water provided by public water suppliers and self-supplied water such as private wells. Reported uses may only include self-supplied water to avoid double counting with the Public Supply category.

- Irrigation –**115 Billion** U.S. / **3.22 Billion** Utah.
Water used for crop production and recreational lands such as parks and golf courses.

- Livestock –**2 Billion** U.S. / **16.5 Million** Utah.
Water used for livestock watering, feedlots, dairy operations, and other on-farm needs.

- Aquaculture –**9.42 Billion** U.S. / **97.1 Million** Utah.
Water used for offstream fish hatcheries and the farming of finfish, shellfish, and other organisms that live in water.

- Industrial–**16 Billion** U.S. / **118.2 Million** Utah.
Water used for fabrication, processing, washing, and cooling. Includes industries such as chemical, food, mining, paper, petroleum refining, and steel.

- Mining–**5.32 Billion** U.S. / **250.19 Million** Utah.
Water used for extracting commodities such as minerals, coal, oil, gas, sand, gravel, and stone.

- Power–**160 Billion** U.S. / **80.9 Million** Utah.
Water used in the process of generating electricity with steam-driven turbine generators (thermoelectric power). This includes almost all coal, nuclear, and geothermal power plants as well as some solar and many natural gas power plants. Thermoelectric power generation accounted for 45 percent of total (fresh and saline) and 38 percent of fresh water use nationally in 2010.

SURVEY NEWS

A New State Dinosaur

The 2018 Utah State Legislature passed a bill naming the *Utahraptor* the official state dinosaur. *Utahraptor* was dicovered in 1990 by State Paleontologist Jim Kirkland in Grand County, Utah.

Photo courtesy of Gaston Design Inc.

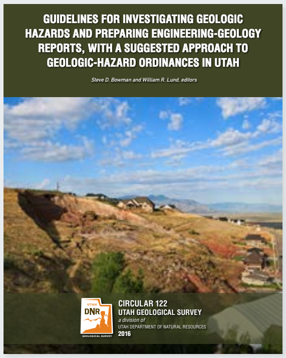
Photo courtesy of Utah Division of Emergency Management

Utah Geological Survey Participates in Inaugural *Preparedness Day on the Hill* Event

UGS Geologic Hazards Program staff Steve Bowman, Gordon Douglass, and Ben Erickson were at the Utah Capitol on March 6, 2018, participating in the inaugural Preparedness Day on the Hill event organized by the Utah Division of Emergency Management. The event highlighted a variety of emergency preparedness issues, including geologic hazards such as earthquakes and landslides. The new earthquake and fault map of Utah (UGS Map 277; https://ugspub.nr.utah.gov/publications/maps/m-277.pdf) even caught the attention of Governor Gary Herbert, who stopped by to talk about the earthquake hazard along the Wasatch Front.

EMPLOYEE NEWS

The Association of Environmental & Engineering Geologists (AEG) presented the 2017, Holdredge Award to **Steve D. Bowman** and **William R. Lund** for their work as editors on the outstanding publication *Guidelines for Investigating Geologic Hazards and Preparing Engineering-Geology Reports, With a Suggested Approach to Geologic-Hazard Ordinances in Utah,* published as Utah Geological Survey Circular 122. The prestigious award, first established in 1962 by AEG, is named in honor of Claire P. Holdredge, a founding member and the first AEG president. The award is presented for a publication by an AEG member(s), released within the five previous years that is judged to be an outstanding contribution to the engineering geology profession.



Craig Morgan retired in March after 28 years of service with the UGS. Craig came to the UGS in 1990 with a strong background in petroleum having worked for UV Industries and Wexpro/Celsius (Questar) as an exploration geologist. As a Senior Geologist in the UGS Energy and Minerals Program, Craig managed several U.S. Department of Energy-funded projects including the Bluebell field and Green River Formation studies in the Uinta Basin, and carbon capture and sequestration throughout Utah. He conducted the early work on the Cane Creek shale horizontal drilling play in southeastern Utah and was a major contributor to many other petroleum studies during his UGS career. Craig has left a legacy of outstanding publications for the petroleum industry and others to use now and well into the future. Outside the UGS, Craig served as president of the Utah Geological Association (UGA), was co-editor of UGA's 2009 Uinta Basin guidebook, led many field trips, and was UGA's delegate to the American Association of Petroleum Geologists (AAPG); he was also the General Chair for the 2013 AAPG Rocky Mountain Section meeting in Salt Lake City. Craig's knowledge and expertise will be greatly missed, and we wish him well as he retires to the clear skies, mild winters, and multitude of golf courses of St. George, Utah!

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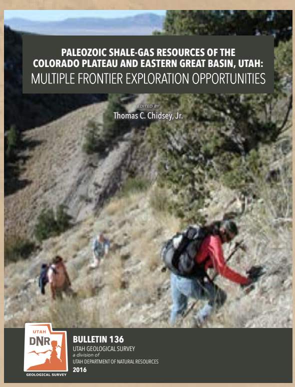
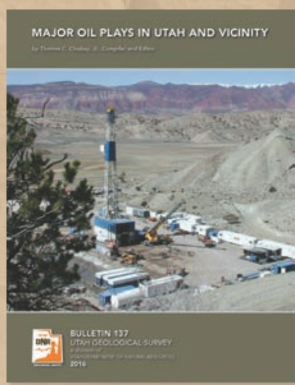
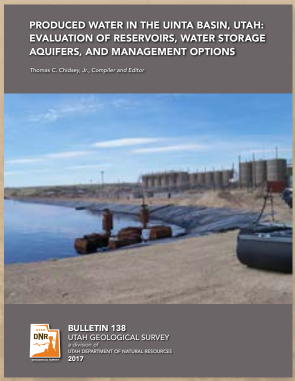
RECENT OIL AND GAS PUBLICATIONS



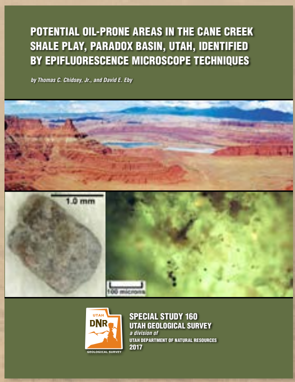
Paleozoic shale-gas resources of the Colorado Plateau and eastern Great Basin, Utah–multiple frontier exploration opportunities, edited by Thomas C. Chidsey, Jr., 241 p. + appendices, ISBN 978-1-55791-909-0, **Bulletin 136**



Major oil plays in Utah and vicinity, edited and compiled by Thomas C. Chidsey, Jr., 294 p., ISBN 978-1-55791-922-9, **Bulletin 137**



Produced water in the Uinta Basin, Utah–evaluation of reservoirs, water storage aquifers, and management options, compiled and edited by Thomas C. Chidsey, Jr., 279 p., 3 pl., + 7 appendices, ISBN 978-55791-939-7, **Bulletin 138**



Potential oil-prone areas in the Cane Creek shale play, Paradox Basin, Utah, identified by epifluorescence microscope techniques, by Thomas C. Chidsey, Jr., and David E. Eby, 44 p. + 126 p. appendices, ISBN 978-1-55791-937-3, **Special Study 160**