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

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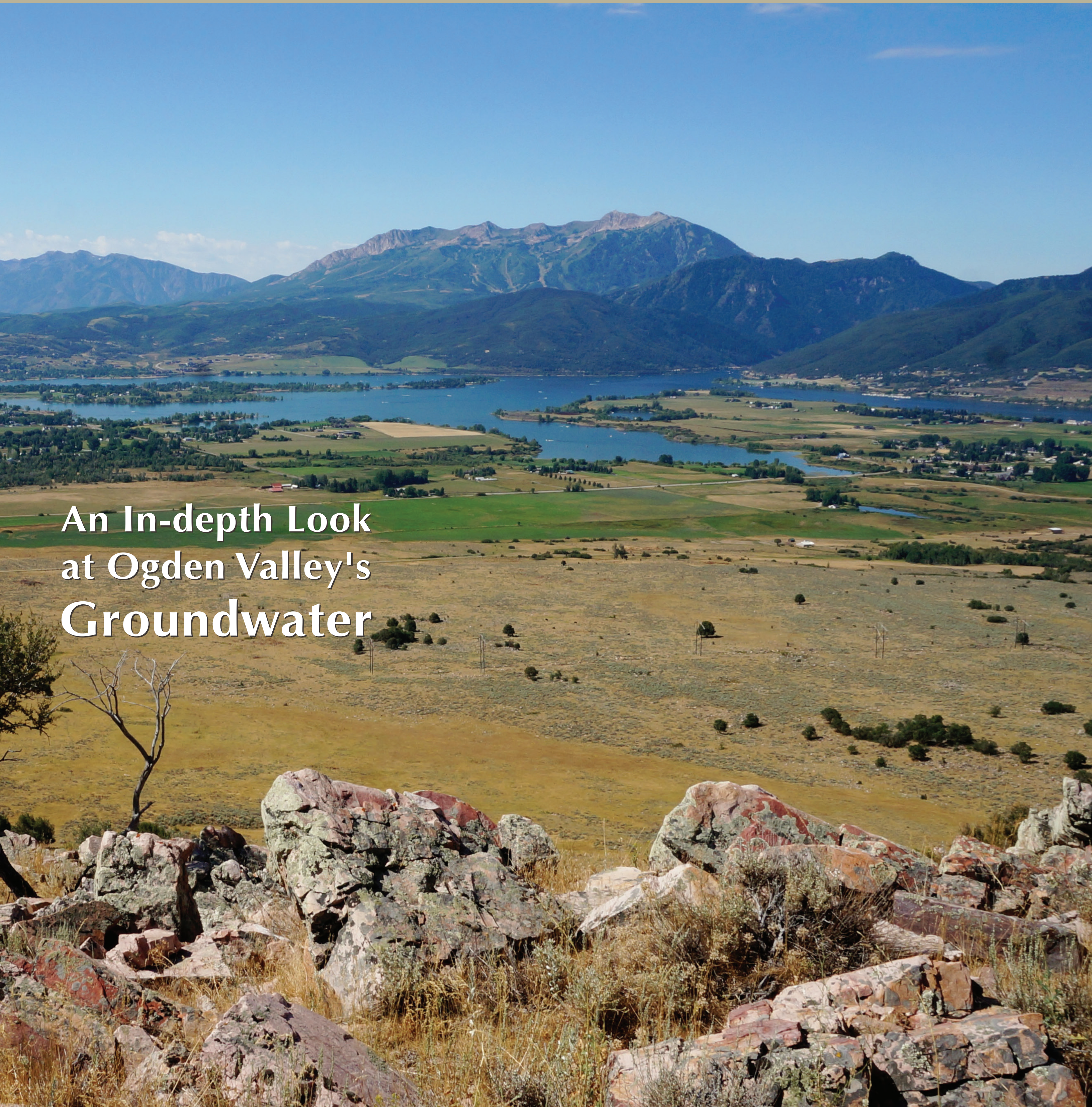

An In-depth Look at Ogden Valley's Groundwater

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Design | *John Good*
Cover | Ogden Valley and Pineview Reservoir viewed to the southwest. Wasatch Range in the background. Photo credit: J. Lucy Jordan

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DIRECTOR'S PERSPECTIVE

by Bill Keach

I have been thinking lately about how technology has affected science and how science has affected technology. As a new geophysicist coming out of university in 1986, my first assignment was to interpret all the 2D seismic data in the San Joaquin Basin. The basic tools for my first year of oil and gas exploration were the same as those I received in kindergarten—colored pencils and instructions to color between the lines. Today we use sophisticated computers to not only facilitate the interpretation process but to more fully analyze the rock properties from the seismic data. More interestingly, today's computers require unique minerals and elements to make them both powerful and efficient. For example, lithium is a key component in rechargeable batteries that just about every mobile device uses, and gallium is used in light-emitting diodes or LEDs.

In May 2018 the U.S. Department of the Interior released a list of 35 critical minerals, which are defined as "critical to the economic and national security of the United States." In 2010 only 14 minerals were on the list. The expansion represents the world's ever-growing demand for high-performance products and technology and the U.S.'s growing reliance on imports of these minerals, which are important to everything from curbing automotive air pollution (platinum group minerals) to computer technology (platinum, beryllium, and tantalum among others) to batteries (lithium, cobalt, and graphite).

Many critical minerals are known to exist in Utah, and a few are in production now. Currently, Utah is the world's largest producer of beryllium and is the primary producer of magnesium metal in the U.S. Our state is also one of two in the U.S. that produces potash and the only domestic producer of a specialty potash (potassium sulfate) which has a higher value than the more common variety of potash (potassium chloride). Historically, Utah has produced gallium, germanium, manganese, uranium, and vanadium along with minor production of antimony, arsenic, barite, bismuth, scandium, and tungsten.

Some critical minerals are poised for development given the right regulatory approvals and economic conditions, and others may have potential given more research and exploration. For example, recent activity by operators is focusing on a new potash development at Sevier Lake and possible production of lithium from Great Salt Lake and the Paradox Basin. Also, helium has significant potential for increased production in Utah. Given the recent lack of supply this should make balloon enthusiasts happy.

The UGS is playing a significant role in identifying the critical minerals in Utah. We anticipate delivering a comprehensive report to the U.S. Geological Survey in mid-2020 that will be an important report for the State of Utah, operators, and planners.

The "Glad you Asked" article in this issue discusses the use of interactive maps as a teaching tool. These maps are a tremendous resource for anyone wanting to know where to find minerals, fossils, and fault lines. The technology behind them is, in part, powered by some of these critical minerals. Of course, the greater power is the ingenuity of those developing the tools.

In the coming years expect Utah's contribution to understanding critical minerals to increase. If not, I may need to return to using my colored pencils.

An In-depth Look at Ogden Valley's Groundwater

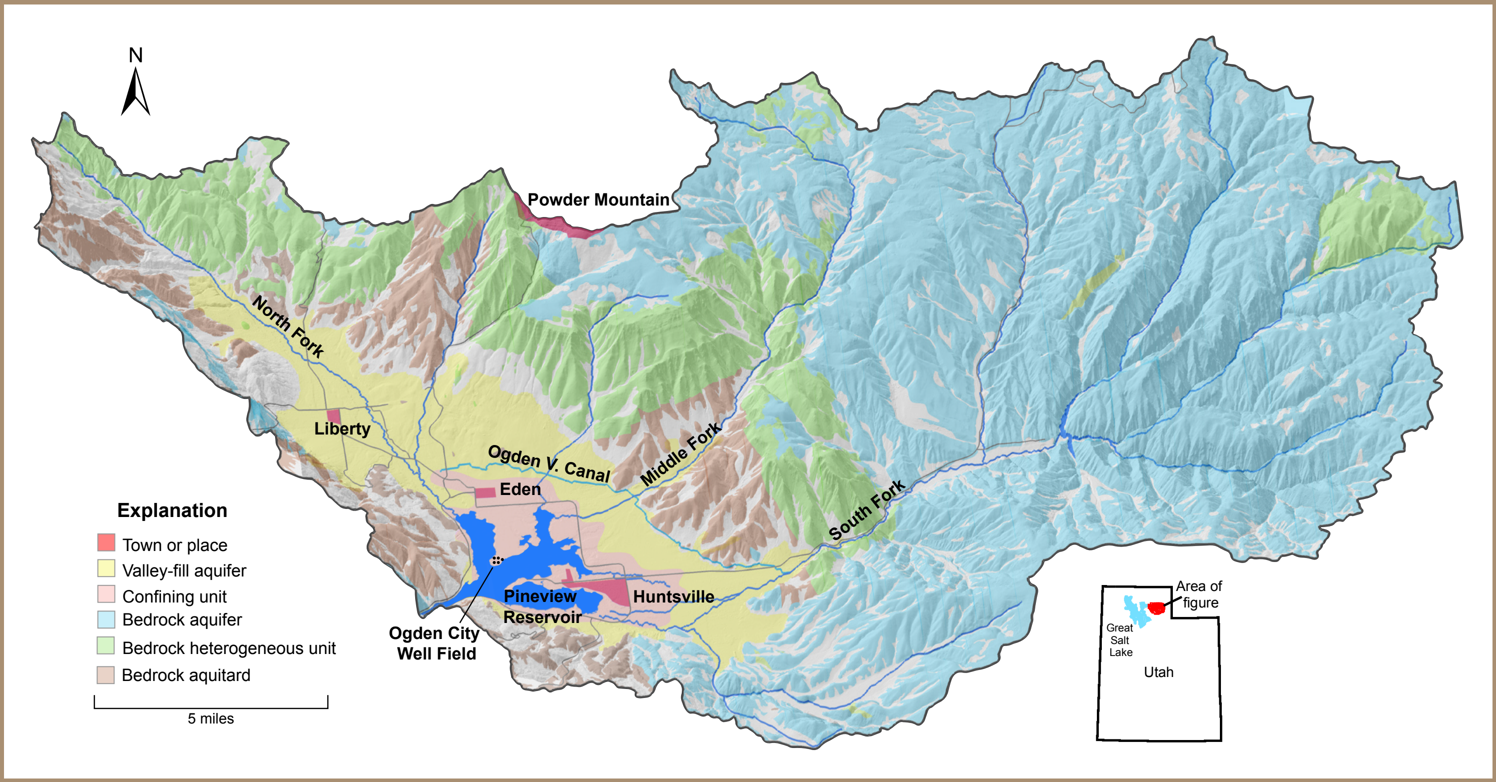
by J. Lucy Jordan

Groundwater—water that flows in the spaces between rock and soil particles—is vitally important as a pristine drinking-water source for Ogden Valley and Ogden City residents. Surface water—water in Ogden Valley's streams and reservoirs—is equally important to the valley's residents for irrigation and to Ogden City to supplement its water supply. The two systems are intimately connected in Ogden Valley, as a new study by the Utah Geological Survey (UGS Special Study 165) has revealed.

This new research brought up several important questions about the Ogden Valley groundwater–surface-water system, such as: When a 3-mile reach of stream loses the volume of an Olympic-sized swimming pool every 90 minutes, where does that water go? How can young groundwater be found under a mostly impenetrable clay layer? Should septic tanks continue to be installed for sewage waste disposal in Ogden Valley? This article touches on the answers presented in the new report.

Compared to many watersheds in Utah, Ogden Valley has plentiful water resources. Several large streams drain to Pineview Reservoir, providing most of the valley with adequate irrigation water. The mountains surrounding the valley are composed largely of carbonate and conglomerate rocks that make adequate aquifers, and the principal valley-fill aquifer is thick and productive. However, urban and residential development of agricultural land is causing concern about interference with existing water rights and impacts to water quality. The UGS used state-of-the-art tools to better define the quantity and quality of the groundwater in Ogden Valley and understand the connection between surface water and groundwater.

Scientists use stable isotopes of hydrogen and oxygen in water to determine the source of groundwater and how groundwater interacts with surface water. In our study, we analyzed these isotopes in hundreds of well and surface water samples collected at various times throughout the year, which provided enough data to be able to tease out small differences in the stable isotope ratios of waters across the valley. The results show that, on average, roughly half the water in the upper part of the principal aquifer is recharged by precipitation or streams on the valley floor and half comes from recharge high in adjoining mountains. We could see even more detail between sub-watersheds—groundwater underlying the South Fork drainage gets 60 percent of its recharge from surface water, whereas the North Fork drainage gets only about 30 percent from surface water. This quantification will help water managers foresee



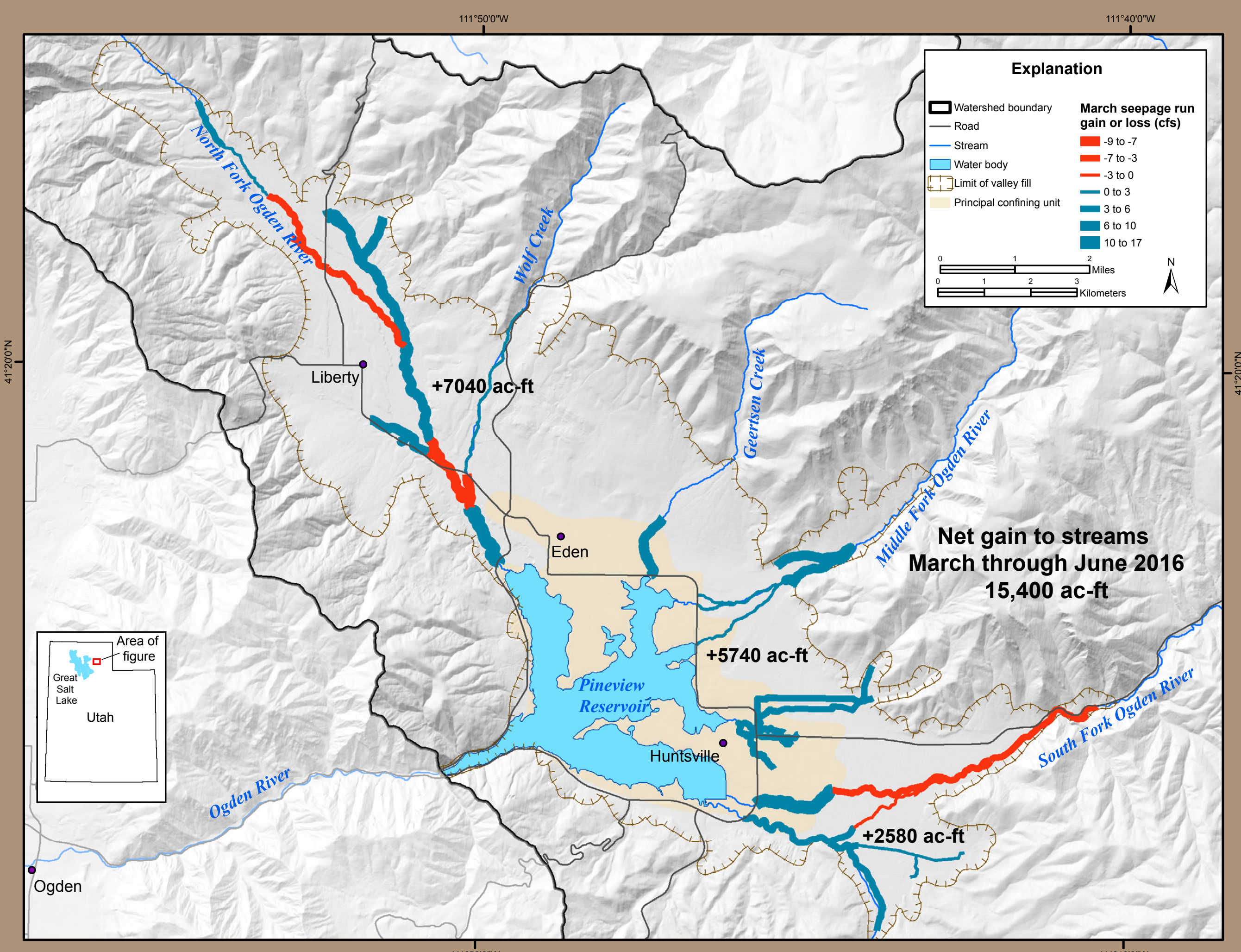
Oblique aerial view of Ogden Valley showing outcrop of aquifer and confining units.

potential impacts to existing water users if points of water use are moved from one location to another and highlights the need to protect groundwater from contamination that may be present at or near the surface.

The results of seepage runs, in which we measured streamflow at many points along streams and canals to discern where water seeps from the ground into the stream or vice versa, corroborate the findings from the stable isotope research. The boulder and cobble streambed of the South Fork Ogden River is where we measured a volume of water equivalent to an Olympic-sized pool seeping into the aquifer every 90 minutes (17 cubic feet per second or cfs). Aggregating our seepage run data throughout Ogden Valley, we estimate that streams lost on average 12,000 acre-feet of water during baseflow conditions (July through February) and gained 15,000 acre-feet during spring runoff. The Ogden Valley Canal loses about half its flow during the height of the irrigation season, and that water recharges the principal aquifer. This dynamic interplay between streams and groundwater is possible because the water table fluctuates near the base of the stream channels. A lowered water table resulting from increased pumping or reduced streamflow could have negative impacts to the system, shunting water that currently flows to the shallow unconfined aquifer and Pineview Reservoir to deeper parts of the confined aquifer.

Understanding the amount of groundwater flow into Pineview Reservoir is important to evaluating reservoir water quality and quantifying groundwater in Ogden Valley. We used a simple mass balance approach in which we quantified known flows into and out of the reservoir and solved for net groundwater flow to or from the reservoir. By integrating our stable isotope analyses into the mass balance model (a new technique for us), we were able to refine the estimate of net groundwater flow through the reservoir. Net groundwater input to Pineview Reservoir in 2016 was likely 34,000 acre-feet of water. Groundwater flowing into the reservoir helps balance years having less streamflow input, which helps stabilize water supply for downstream users and recreation.

The Ogden City well field, located on a peninsula surrounded by Pineview Reservoir, has reliably produced water for a century. The wells are completed in a confined aquifer separated from the overlying reservoir and shallow aquifer by a silt and clay unit that is as much as 120 feet thick. The silt and clay confining unit would



Gaining (blue) and losing (red) reaches of major streams during a March 2016 seepage run and estimated net gain or loss from March through June (runoff season) from three sub-basins. During baseflow, nearly all the gains estimated during the runoff season, shown here, are lost back to the aquifer. The streams and aquifers are actively exchanging water but are generally in balance each year.

typically be expected to isolate the well field from surface water and shallow groundwater, but our samples revealed concentrations of an environmental tracer that indicate a good fraction of the well water was recharged to the aquifer less than 50 years ago. Also, the stable isotope ratio in the well water is more like that of shallow wells in the unconfined part of the aquifer than expected given the well field's depth and location, corroborating a near-surface recharge source. Recharge could travel relatively quickly through leaking abandoned well casings in the bottom of the reservoir, leakage through thinner parts of the confining unit, or from the west where the distance from the edge of the confining unit to the well field is shortest. This finding illustrates that water in the confined aquifer could be vulnerable to surface contamination.

Hydrogeologists quantify the amount of groundwater in an aquifer system using groundwater budgets. Because directly measuring groundwater flow under the earth's surface is impossible, we make budgets using atmospheric, streamflow, and pumping data, usually entered into a computer model that can help us quantify the volumes of water moving through different parts of the aquifer. Our water budget calculations show that the watershed receives about 540,000 acre-feet of water from precipitation on an average year. Much of that is lost to evaporation before it enters the groundwater system, leaving about 160,000 acre-feet of water to interact with streams and aquifers. The South Fork sub-basin, because it is the largest in area, has the largest percentage of the total budget. Groundwater in the valley-fill aquifer system is a fraction of the total budget. Roughly 67,000 acre-feet of water recharges the valley-fill aquifers each year. Recharge to the valley-fill aquifers is roughly one-third each from precipitation, seepage, and mountain block recharge. Roughly half of the discharge from the valley-fill aquifers flows to Pineview Reservoir, a quarter discharges as baseflow to the streams as they cross the valley fill, and most of the remaining discharge is pumped from the confined aquifer at the Ogden City well field. Recharge and discharge are generally in balance in Ogden Valley.

A UGS scientist measures streamflow during the March 2016 seepage study.

Most homes and businesses in Ogden Valley use septic tank soil absorption systems for indoor wastewater disposal, which add nitrogen and other waste products to the environment. The UGS evaluated the impact of septic tanks on Ogden Valley's groundwater in 1998 and recommended that lot sizes be at least 3 acres to limit the increase in mean nitrate concentration to 1 milligram per liter (mg/L) over the then-mean concentration of 0.74 mg/L. In our current study, we found that the geometric mean nitrate concentration in the unconfined valley-fill aquifers (the aquifers that receive the bulk of septic-tank leachate) was 1.43 mg/L, still well below the allowable drinking water maximum limit of 10 mg/L, but clearly higher than in 1998. Our updated recommendation, using a smaller groundwater flow volume than was used in the 1998 study, is 4.4 to 5.8 acres minimum per system. Advanced removal septic tank systems, lagoon systems, or sewage treatment plants are options that could be used to protect Ogden Valley's water quality if planners want to allow higher density housing development.

These are just a few of the new details we learned about the watershed and groundwater of Ogden Valley. The new 222-page report will be a useful tool for policy makers and water users to understand the potential effects of current and future water use on water supply and the environment of Ogden Valley.

ABOUT THE AUTHOR

J. Lucy Jordan is a senior geologist in the Utah Geological Survey's Groundwater and Wetlands Program. Lucy's work with UGS over the past 15 years has focused on water-resource assessments in Utah, including water-quality studies, aquifer testing, well drilling, spring and wetland inventories, and nitrate- and salinity-compromised groundwater systems. She is currently managing a real-time surface-water flow monitoring program in western Utah and is involved in quantifying hydrological changes in small watersheds undergoing wildlife habitat restoration projects in Utah.

Is There a Wetland on Your Property? Identification and Next Steps

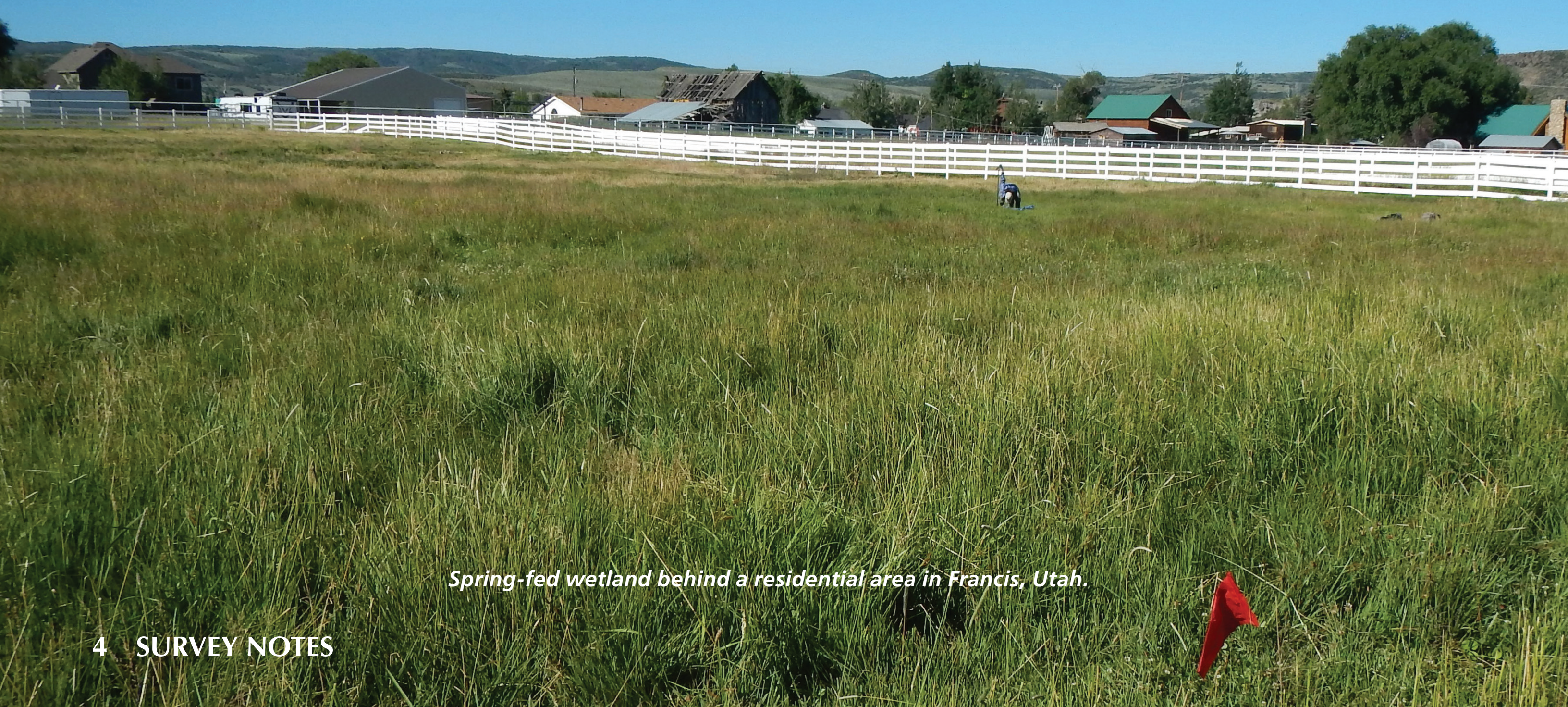
by Diane Menuz

The most common question we are asked in the Groundwater Program's Wetlands Section is, "I'm thinking of buying a property but it may have wetlands on it. How do I know and what will this mean for me?" Wetlands and other aquatic features like streams and lakes are protected under the federal Clean Water Act, legislation passed in 1972 to address the rampant dumping of sewage, industrial chemicals, and other pollutants into our nation's waters. Wetlands are integral to water quality protection because they can detain or transform pollutants that come from upland areas, thus preventing the runoff from reaching our streams and lakes. Wetlands provide a broad range of other important functions as well, including flood storage, erosion control, natural groundwater recharge areas, and wildlife habitat, as well as economic and recreational values.

Wetlands are areas that are flooded or saturated for at least part of the growing season, the period between spring and fall when plants and soil microbes are most active. Some areas are obviously wetlands — marshes with standing water or waterlogged meadows that feel squishy with each step. However, many wetlands in Utah are only wet for a short period of time in the spring and might not even be wet every year, especially during periods of drought. The U.S. Army Corps of Engineers (Army Corps), the lead regulatory agency for wetland permits in Utah, looks at three factors to determine whether an area is a wetland: (1) evidence of wetland hydrology (e.g., water or signs of water such as sediment deposits, dry algae, soil cracking, flow patterns), (2) abundance of wetland-associated vegetation (obvious species such as cattail and bulrush, but also many grasses, sedges, and other plants), and (3) hydric soil indicators (distinct soil textures and colors that form in soils that are frequently saturated). Many wetlands are tough for non-experts to identify, particularly during a drought year or in the middle of the summer.

Two good online resources can aid your investigation — the U.S. Fish and Wildlife Service's (USFWS) National Wetland Inventory (NWI) and the Natural Resources Conservation Service's (NRCS) National Cooperative Soil Survey. NWI data show the distribution of wetlands and other aquatic resources and the soil survey data indicate whether map units have hydric soils (e.g., soils that form in wetland conditions). However, both sets of data have their limitations. NWI data are mapped using aerial imagery with minimal field verification and may miss some wetlands entirely, and soil survey data provide information on the percent of a map unit that has hydric soil, not the exact location of areas with hydric soils. Furthermore, both sets of data are out-of-date in much of Utah and show approximate rather than exact boundaries.

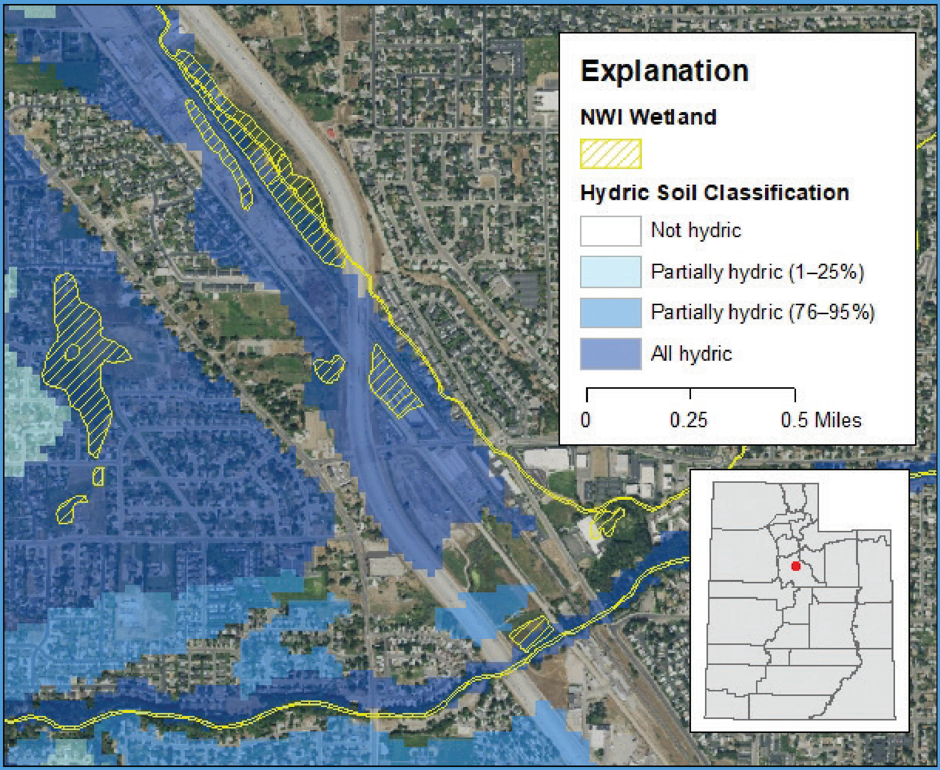
If you have any reason to believe there may be wetlands on a property you are considering developing, you may want to consult with the local office of the Army Corps to discuss your plans, possible impacts to wetlands and other aquatic resources, and if those resources fall within the regulatory jurisdiction of the Army Corps. They may recommend hiring a consultant to conduct a delineation to determine exact wetland boundaries and identify other aquatic resources that might be regulated under the Clean Water Act. If a permit is required, the Army Corps can walk you through what the permitting process will look like for your project. Nationwide, the Army Corps denies only 3 percent of requests for permits, but obtaining a permit will add time and cost to a project, including consulting fees for aquatic resource delineation and permit preparation and mitigation costs to compensate for impacted resources. You also may want to find out if your local planning department has any restrictions, such as setback requirements between development and aquatic resources. If you are concerned about wetlands on agricultural land, the NRCS can conduct



Spring-fed wetland behind a residential area in Francis, Utah.

a delineation on the property and help you understand the applicable regulations for agricultural use.

While the UGS does not have a regulatory role in the wetland permitting process, we are working to update NWI data to provide the public with more current and spatially accurate information on the location and extent of wetlands in Utah. We have completed mapping projects in the Upper Bear River (see *Survey Notes*, v. 49, no. 1), on the east shore of Great Salt Lake, and around Bear Lake and have ongoing projects in the Uinta Basin and Cache County. We also maintain a web application that displays NWI data for the state with other supporting data layers to make it easier for people to find out what is mapped on their property. While the mapping work we do will never replace the need for precise field delineations, it is an important tool for conducting preliminary screenings of areas to determine whether potential wetland issues might exist.



NWI wetlands data and NRCS hydric soils data in Provo, Utah. Note that many areas mapped as having hydric soils are developed, and not all areas mapped as wetlands are also mapped as having hydric soils.

Helpful links and contact information for regulatory agencies

Resources for Spatial Data

UGS Utah Wetlands Mapper: https://geology.utah.gov/apps/wetlands
USFWS National Wetlands Inventory Mapper: https://www.fws.gov/wetlands/data/mapper.html
NRCS Soil Web Survey: https://websoilsurvey.sc.egov.usda.gov
California Soil Research Lab SoilWeb: https://casoilresource.lawr.ucdavis.edu/gmap/

Helpful Contacts

Army Corps Regulatory Office Contacts: https://www.spk.usace.army.mil/Missions/Regulatory/Contacts/Contact-Your-Local-Office/
NRCS Utah Service Centers: https://www.nrcs.usda.gov/wps/portal/nrcs/main/ut/contact/local/

Earth Science Week

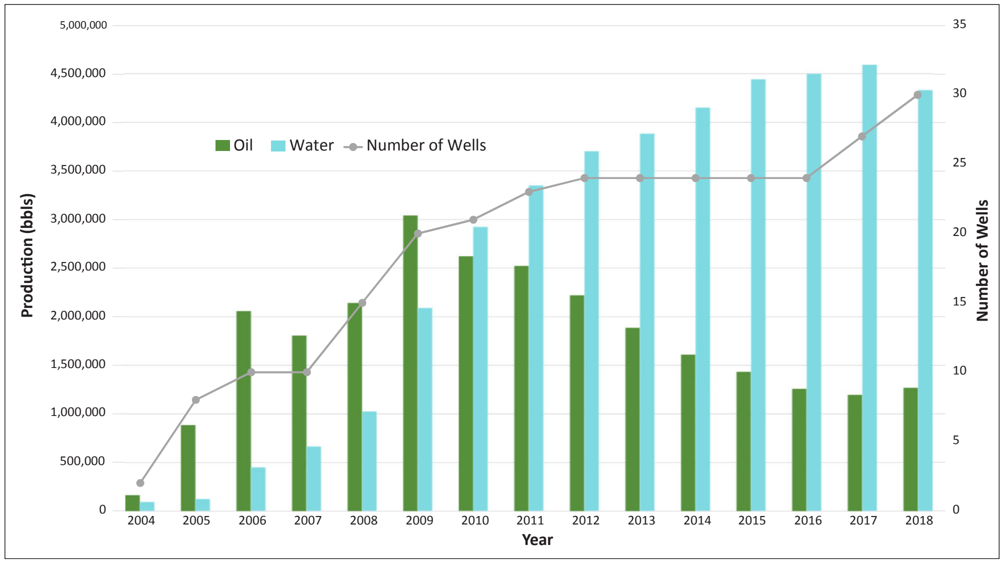
This past October, nearly 600 students from elementary schools along the Wasatch Front participated in the Utah Geological Survey's 18th annual Earth Science Week (ESW) activities held at the Utah Core Research Center. Students explored geology and paleontology through fun, hands-on activities like "gold" panning for colorful minerals, learning the processes of erosion and deposition in a stream trailer, and getting up-close and personal with real dinosaur bones. Many thanks to our volunteers from professional associations, public- and private-sector institutions, other divisions within the Utah Department of Natural Resources, and individual geology enthusiasts who helped make ESW 2019 possible.

Since its creation in 1998 by the American Geosciences Institute (AGI), ESW has encouraged people everywhere to explore the natural world; promote Earth science understanding, application, and relevance in our daily lives; and encourage stewardship of the planet. For more information on ESW, see the AGI web page at www.earthsciweek.org; for information on next year's ESW activities at the Utah Geological Survey, see our web page at geology.utah.gov/teachers/earth-science-week.

Energy News

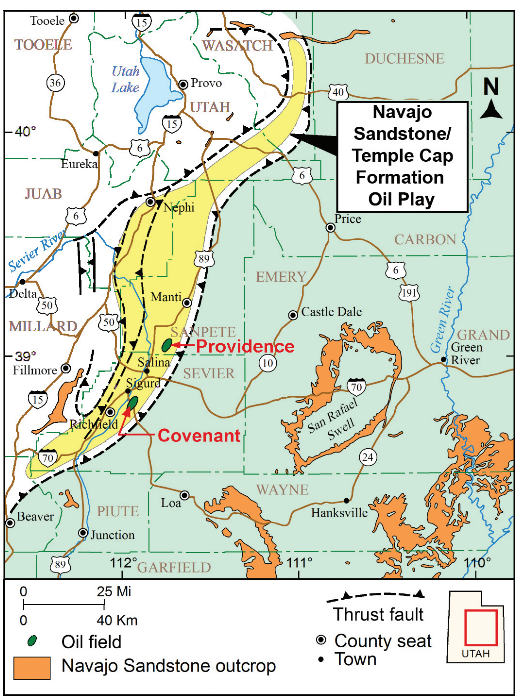
Covenant Oil Field in the Central Utah Thrust Belt Turns 15 Years Old

by Thomas C. Chidsey, Jr.



Oil and water production, as well as number of wells, from Covenant field, 2004-2018. Source: Utah Division of Oil, Gas and Mining.

Fifteen years ago Michigan-based Wolverine Gas & Oil Corporation discovered Covenant oil field about 8 miles east-northeast of Richfield, Sevier County, in a region known as the central Utah thrust belt (see *Survey Notes*, v. 37, no. 2). Over 100 wells had been drilled in the region with no success until the Kings Meadow Ranches No. 17-1 well tested over 700 barrels of oil per day (BOPD) making Covenant the biggest Utah discovery since 1979, when the 129-million-barrel Anschutz Ranch East field was discovered on the Utah-Wyoming border east of Coalville. Although Wolverine attempted to keep the new discovery and oil production rates confidential, it was the worst-kept secret in central Utah. Covenant field is located adjacent to State Highway 24 just a few miles from the small town of Sigurd. The drill rigs, pump jack, oil tank batteries, and assorted oil field equipment were in plain site. Tanker trucks capable of carrying 800 barrels of oil could be observed leaving the field area—and were counted by locals. It was not long before word spread of the new and very significant oil find in a region that had only frustrated geologists for decades. Farmers and ranchers in the area received large cash offers from oil companies to lease subsurface mineral rights (see *Survey Notes*, v. 51, no. 2). Seismic crews used helicopters, large vibroseis trucks, and dynamite charges set in shallow drill holes to determine the subsurface structural picture by bouncing induced vibrations off the deep layers of rocks. Geologists studied the rock outcrops, re-examined old well data, and generated new maps and cross sections to identify potential traps for oil and gas. Everyone was excited at the prospect of finding similar large oil fields throughout central Utah, including local citizens, Sevier and Sanpete county commissioners, Utah legislators, geologists and oil companies, speculators, and the news media. The Covenant discovery even made the cover of the American Association of Petroleum Geologists (AAPG) monthly news magazine, the *Explorer*, which is distributed to over 30,000 geologists worldwide.



Location of Covenant oil field, play area, and selected thrust systems in the central Utah thrust belt.

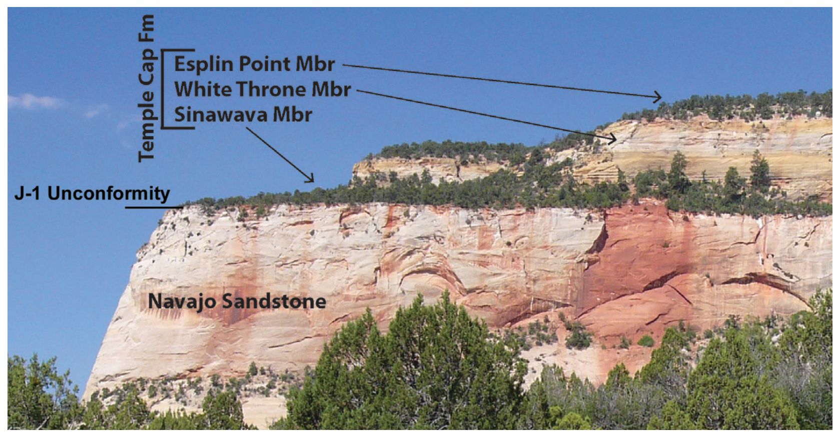
Over the years, Covenant field has met all expectations. The field has produced nearly 27 million barrels of oil! Thirty-four production wells were drilled in the field, and although Covenant now produces more water than oil (a natural occurrence as oil fields mature), the field still flows over 3,400 BOPD. Oddly, no gas, usually associated with oil, has ever been produced from Covenant.

Unfortunately, the search for another Covenant field in the central Utah thrust belt has been unsuccessful with about 30 wells drilled since 2004 attempting to penetrate similar traps of oil; one small field, Providence, about 15 miles northeast of Covenant in Sanpete County, was discovered in 2008 and has produced only about 445,000 barrels of oil from one well. There are several reasons for these disappointing results: (1) the structural targets (traps) were different or more complex than predicted (shallow, contorted layers of Jurassic-age mudstone and evaporite [anhydrite, gypsum, and salt] in the region often make interpretation of the deeper rock configuration extremely difficult), (2) additional potential reservoir rocks outside of the producing formations had low porosity and permeability and thus were unable to store or flow oil, (3) oil migrated from organic-rich source rocks prior to the formation of most traps, and (4) geologists still do not fully understand the petroleum system of the region. The lack of drilling success, the collapse of oil prices in late 2014, and the proliferation of lower risk yet economically viable shale-oil plays (e.g., the Permian Basin of West Texas) has halted almost all exploration in the central Utah thrust belt.

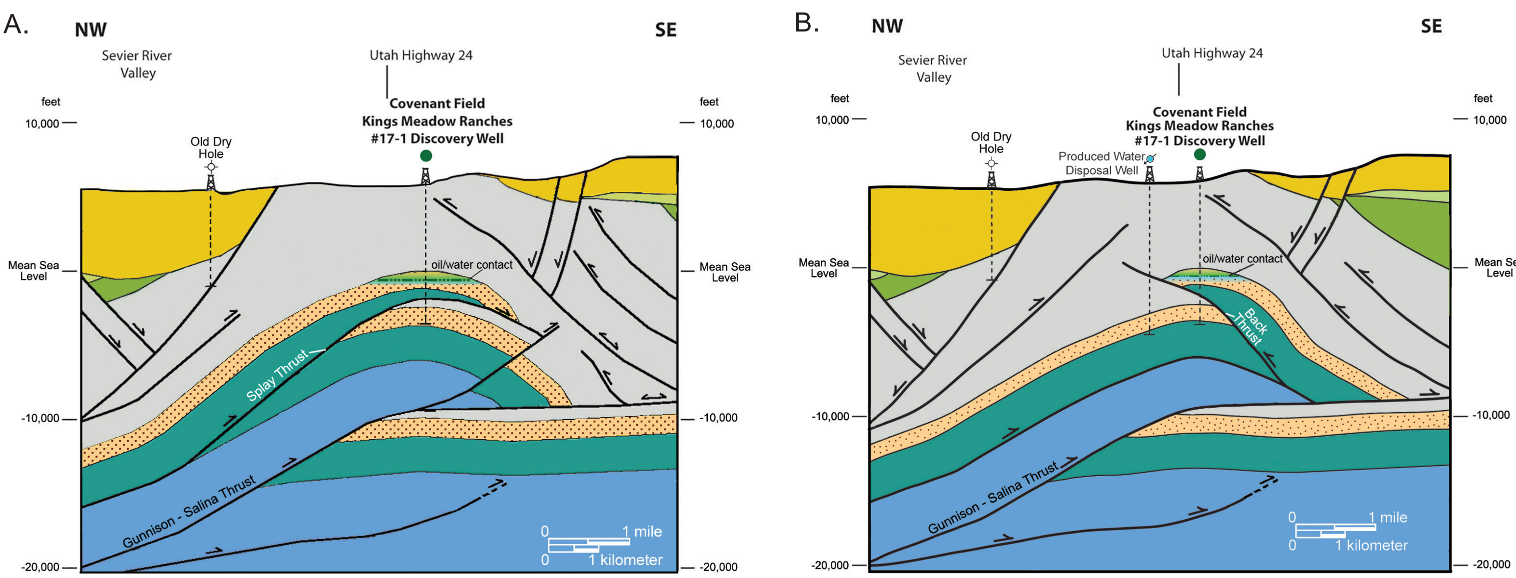
On the positive side, geologists have learned a great deal since the discovery of Covenant field that can be used in future exploration efforts. Initially, oil production was interpreted to be from the Early Jurassic-age (about 190 to 183 million years ago [Ma]) Navajo Sandstone that was deposited in a great sand "sea" or erg, similar to the Sahara (see *Survey Notes*, v. 48, no. 2). New outcrop work, regional well correlations, and age dating were used to determine that the upper section of what was thought to be Navajo is actually the Middle Jurassic-age (173 to 170 Ma) Temple Cap Formation. The Temple Cap was deposited as coastal dunes (White Throne Member) and associated tidal flats (Sinawava Member) analogous to the modern coast of Namibia of southwestern Africa. The Temple Cap Formation is separated from the underlying Navajo Sandstone by the J-1 unconformity—a time gap of over 10 million years (see *Survey Notes*, v. 50, no. 1). These units are best observed in outcrops in Zion National Park. To date, Covenant is the only field in Utah that produces from the Temple Cap Formation. Both the Navajo Sandstone and White Throne Member of the Temple Cap Formation have excellent reservoir properties (porosity and permeability) in the field that result in high oil storage and flow capacity. The producing wells in Covenant field are about equally divided between the Navajo and White Throne. Impermeable mudstone beds in the overlying Sinawava Member and anhydrite, gypsum, salt (halite), shale, and mudstone in the Arapien Formation (also Middle Jurassic in age) provide the seals for the underlying reservoir rocks.

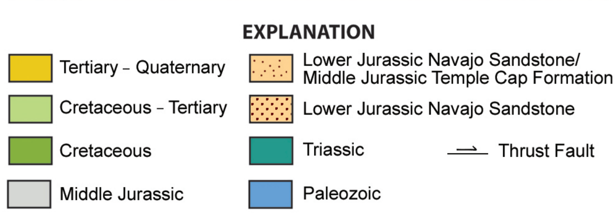
The interpretation of the Covenant trap also changed since the field was discovered. The original drilling objective, a "rollover" anticline, was thought to have formed on a typical east-directed thrust splay off a larger, deeper thrust fault (a low-angle fault where older rocks have been displaced by compressional forces over younger rocks). However, when Wolverine drilled an injection well into the Navajo Sandstone to dispose produced water from the field, they encountered the Navajo only once instead of twice as was expected based on the presence of the thrust splay as shown on their cross section. This discovery indicated that the producing anticline was actually created by a west-directed back thrust, a type of structural feature along the regional-scale Sanpete–Sevier Valley anticline and extensively mapped by Utah Geological Survey geologists and others. Furthermore, the back thrust likely developed after an initial anticlinal "paleotrap" and in the process of reconfiguring the structure, any gas associated with the oil leaked to the surface as seeps or migrated to other potential reservoir rocks where it remains to be discovered.

The 2004 discovery of Covenant field proved that the central Utah thrust belt has all the right components for major accumulations of oil: (1) nearby organic-rich source rocks, (2) large but complex traps, (3) high-quality reservoir rocks sealed by overlying impermeable beds, and (4) a complex yet ultimately favorable oil migration history. Although much has been learned over the past 15 years based on the Covenant discovery, it will require higher oil prices, companies and investors willing to take big risks, continued good science, and a bit of luck to find another large field in the central Utah thrust belt. Otherwise, Covenant may remain a "one-field wonder" for years to come.



Jurassic-age Navajo Sandstone and Temple Cap Formation (view west) near the east entrance of Zion National Park. Photo by Doug Sprinkel.





*Structural cross sections through Covenant oil field. **A.** Initial interpretation following the discovery showing a "rollover" anticlinal trap created by a splay thrust off a large, deeper thrust fault. **B.** Reinterpretation after a produced-water disposal well was drilled showing the anticlinal trap created by a back thrust. Modified from Wolverine Gas & Oil Corporation.*

Glad You Asked

TEACHER'S CORNER

Needing A Great Resource for Teaching Your Students About Utah Fossils?

by Marshall Robinson

The UGS has many resources and tools for teachers including teaching kits, geologic guides, geology-related videos, and maps. Additionally, our interactive web maps are a great resource to start with as they provide a wide variety of geologic information in one spot that teachers from across the world can access. Over the past several years, the UGS has created these user-friendly, information-rich interactive maps to enable map users to explore and understand geology in a more immersive way.

The Geologic Map Portal was the first interactive map created for the UGS website, and it displays a collection of over 800 of Utah's best geologic maps. Every geologic map is available for download in various formats, with some of the more recent maps (and all 30' x 60' quadrangles) available in a GIS (geographic information system) format. Each colored polygon (which represents a closely related group of rocks, i.e., formations) is clickable, which opens a pop-up showing detailed rock unit descriptions. An improvement to this application came a couple years ago when the 2-dimensional base map was converted to a more true-to-life 3-dimensional base map. This improvement allows the user to tilt and rotate the map to see the rock units in a way that helps them better understand the relationship between geology and landscape. Elementary school teachers and college professors alike can take advantage of this new visual aid to help them teach their students geology in both the classroom and field. Although experiencing geology in person and in the field is probably the best way to understand difficult geologic concepts, our interactive map can certainly add to the experience as it allows you to see the geology of any given location in Utah whenever you want.

In the past 10 years, the UGS has built over 20 interactive maps focused on many aspects of geology. Some of the more useful applications for teachers are centered around popular geology, geologic hazards, and energy and mineral resources. Every interactive map we have created is on the UGS Interactive Maps web page, but a brief summary of some of our more helpful interactive maps follows.

Popular Geology
(click on "Popular Geology" filter on Interactive Maps web page):

This option is for those looking for more "general information" interactive maps. These maps give detailed information about rockhounding, fossil sites, pretty landscaping rocks, and fascinating geologic sites throughout the state (called GeoSights). These interactive maps are a great resource for finding and understanding some of Utah's more *fun* geologic resources.

Geologic Hazards
(click on "Hazards" filter on Interactive Maps web page):

The Utah Quaternary Fault & Fold Database map shows all of Utah's active faults. On this interactive map one can find if their home or prospective home is near a fault line. The lines on this map represent faults generally considered to be likely sources of large earthquakes (about magnitude 6.5 or greater). Additionally, a more all-inclusive hazards application is being developed that will display all available geologic hazard data in one interactive map.

Though it is not a true interactive map, we also provide an interactive "story map" of Large Earthquakes on the Wasatch Fault. This teaching tool is great for anyone looking to gain a general understanding of Utah's most hazardous fault system as you can scroll through and learn when large earthquakes have occurred on the Wasatch fault over time in addition to how we have gathered this information.

Energy Resources
(click on "Energy Resources" filter on Interactive Maps web page):

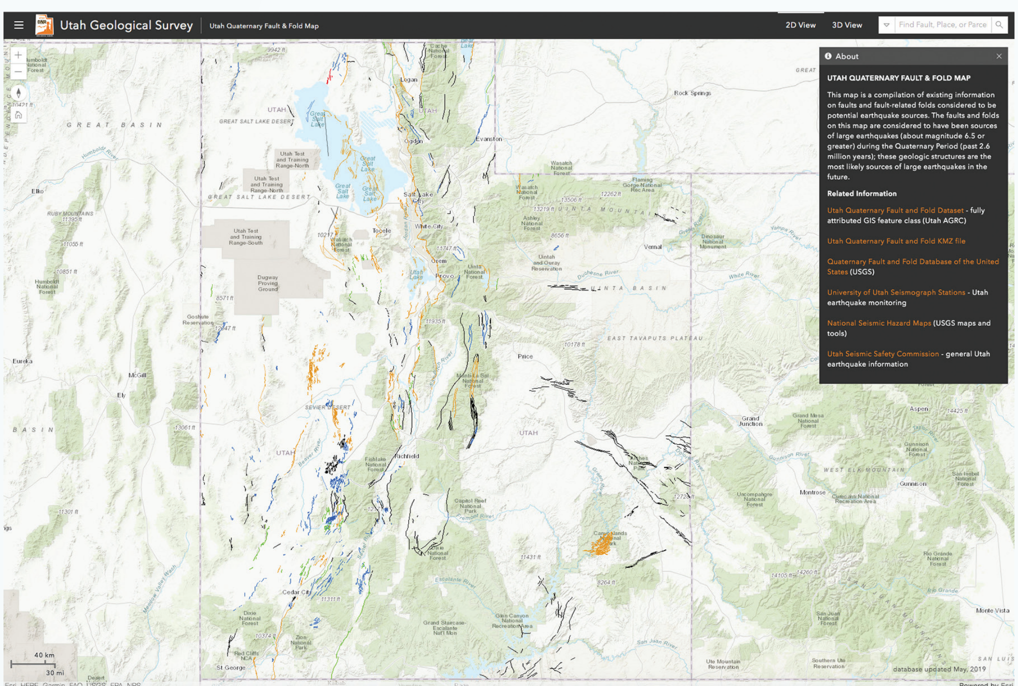
Many teachers may not know that the UGS houses rock core samples and cuttings from thousands of oil and gas wells in a large warehouse building known as the Utah Core Research Center. We created an interactive map to display all of the data

Screenshot of the Geologic Map Portal showing an oblique view of Mt. Timpanogos and Provo Canyon from the south. The 3-dimensional base map allows the user to see the relationship between the landscape and geologic formations (colored polygons), faults (heavy black lines), and ancient shorelines of Lake Bonneville (blue lines).

from each well in a user-friendly format. These data include information about well location and depth, rock type, and, in some cases, high-resolution photos of the core. Another useful resource map is about Utah's mining and industrial resources. This new interactive map shows where all of Utah's mining districts are located as well as where limestone, gypsum, dolomite, and bentonite resource potential is best in Utah. Seeing the location of these mineral resources is an important step in learning the geologic history of Utah because specific minerals are found in specific geologic environments (for more information on this topic, see the "Glad You Asked/Teacher's Corner" article in the September 2018 issue of *Survey Notes*).

The UGS website has interactive maps for a broad audience. Everyone from amateur rock-hounders to teachers to researchers and consultants will find valuable data in our interactive maps. Other UGS interactive maps cover topics ranging from geothermal and wetlands data to groundwater and mineral resources. We continue to work hard on providing the most up-to-date and accurate data in the most user-friendly way possible.

Screenshot of the GeoSights interactive map. Here, people can find many of Utah's very unique geologic wonders.



Screenshot of the Utah Quaternary Fault & Fold Database interactive map. The different line colors correspond to how recently the fault last moved and ruptured the ground surface, generating a large earthquake.

Interactive maps available on the UGS website:

Abandoned Coal Mines

Aerial Imagery Collection

Building Stones of Downtown Salt Lake City

Earthquakes on the Wasatch Fault

G.K. Gilbert Geologic View Park

Geochronology Database

Geologic Canyon Tour

Geologic Map Portal

GeoSights

Geothermal Wells and Springs

Groundwater Monitoring Portal

Guide to Fossils & Dinosaurs

Landscape Rock Collecting

Non-Petroleum Well Data

Quaternary Faults & Folds

Rock & Mineral Collecting

Utah Core Research Center Inventory

Utah Mineral Occurrence System

Utah Mineral Resource Reports

Utah Mineral Resources

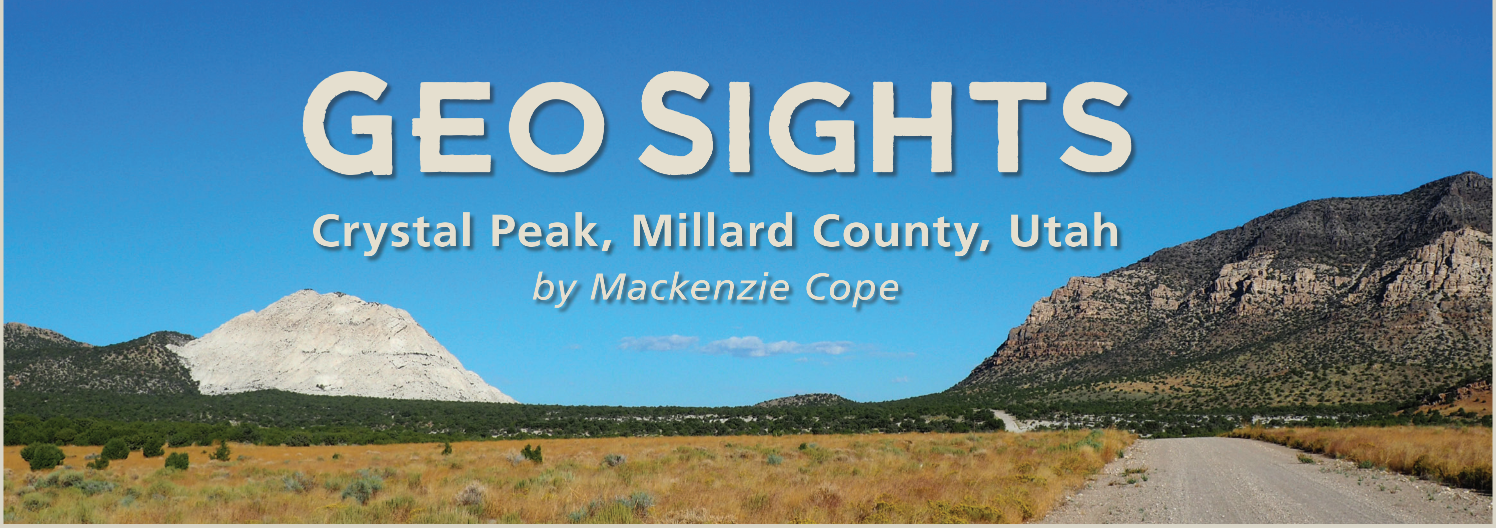
Utah Wetlands

Virtual Field Guides

GEO SIGHTS

Crystal Peak, Millard County, Utah

by Mackenzie Cope



View to the east of Crystal Peak. The glowing quality of the peak is due to the high concentration of quartz crystals in the Tunnel Spring Tuff. The peak is more resistant to erosion than the surrounding areas making it prominent.

Traveling through the seemingly endless Great Basin Desert in western Utah, an unusual sight suddenly appears as you pass yet another mountain range. As if teleported from another dimension, the other side of the expansive valley holds a bright white, glowing mountain nestled between brown, red, and gray cliffs. How does such a striking, isolated dome form in the middle of the desert? Clues to the geologic story of Crystal Peak come from the volcanic rocks of the Tunnel Spring Tuff, major tectonic events of the region, and the cavernous structures called tafoni that cover the mountain from top to bottom.

Tunnel Spring Tuff

The white, sparkly rock of Crystal Peak is called the Tunnel Spring Tuff. It is a rhyolitic ash-flow tuff made of pyroclastic debris from an explosive volcanic eruption. The composition of the tuff is a mixture of ash, pumice, glass shards, minerals, and abundant rock fragments of limestone, sandstone, shale, and dolomite. The white color of the rock comes from its concentration of ash and pumice. The mountain's name derives from the abundance of crystals—mainly quartz, sanidine, plagioclase, and minor biotite—that cause the mountain to sparkle. The quartz crystals in the Tunnel Spring Tuff have well-formed points on both ends—referred to as double terminated—making this formation easily identifiable. These 3-millimeter-long (1/8 inch) crystals are best seen with a hand lens or magnifying glass and are clear or smoky gray in color.

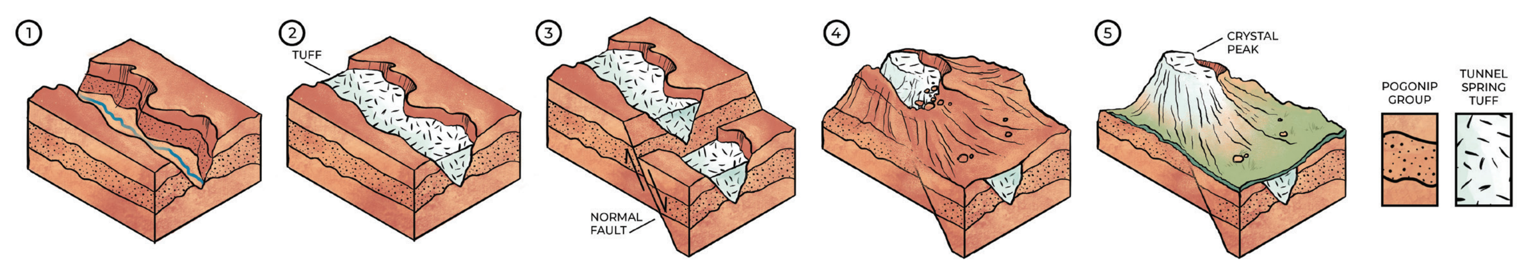
Geologic History

The geologic story of Crystal Peak starts with the erosion of Paleozoic-age sedimentary rock layers called the Pogonip Group. The formations in the Pogonip Group consist of limestone, sandstone, shale, and dolomite. They range from 382 to 485 million years old and collectively are about 1,000 meters (3,300 feet) thick. These formations are the source of the sedimentary rock fragments in the Tunnel Spring Tuff; the fragments are known as xenoliths, literally "foreign stone," from the Greek "xenos" (foreign) and "lithos" (stone). The Pogonip Group was eroded when a river system carved a deep stream valley over a span of millions of years (*block 1*).

During the Oligocene Epoch, about 33 million years ago, an explosive volcanic eruption threw large amounts of ash, pumice, and rock into the air that rained down covering large areas of land. The volcanic ash and other material settled in topographic low areas like the stream valley eroded into the Pogonip Group, eventually forming the Tunnel Spring Tuff (*block 2*). The rock fragments in the Tunnel Spring Tuff are likely derived from the caldera walls from which the volcano erupted.

After the deposition of the tuff, north-south trending normal faults, associated with Basin and Range extension, cut the landscape. As the crust was extending, uplifted fault blocks (horsts) and down-dropped fault blocks (grabens) broke apart the former Pogonip stream valley now filled with the Tunnel Spring Tuff (*block 3*). Sections of the former stream valley were uplifted while neighboring areas were dropped down.

Over time, erosion started to affect the horsts, filling the grabens with sediment. The Pogonip Group, made up of softer sedimentary rocks, eroded more quickly than the resistant ash-flow tuff. A ridge of Tunnel Spring Tuff thus formed, while the adjacent Pogonip Group rocks eroded down to a lower elevation. An inverted valley was created whereby the original topographic lows became the topographic highs and vice versa



The formation of Crystal Peak. (1) A stream valley is carved into the sedimentary rocks of the Pogonip Group. (2) A volcanic eruption fills the stream valley with ash, pumice, and Pogonip Group rock fragments as a rhyolitic ash-flow tuff where it lithifies into the Tunnel Spring Tuff. (3) Basin and Range extension causes normal faulting in the Tunnel Spring Tuff and Pogonip Group. (4) A ridge of Tunnel Spring Tuff forms while the sedimentary rocks of the Pogonip Group are eroded. (5) The slightly-welded rhyolitic ash-flow tuff erodes more slowly until only a single dome-like peak—Crystal Peak—is left. (Modified from Bushman, A.V., 1973, Pre-Needles Range Silicic Volcanism, Tunnel Spring Tuff [Oligocene], West-Central Utah) (*block 4*). Today, most of the Tunnel Spring Tuff has been eroded away and only occurs in a handful of locations in southwestern Utah. Crystal Peak is the thickest remaining section of the Tunnel Spring Tuff (*block 5*).

Tafoni

Tafoni (also called honeycombs, alveoli, and stonelace) cover the surface of Crystal Peak. They are characterized by clusters of holes and recesses formed from cavernous weathering. The tafoni on Crystal Peak completely cover the steep sides, creating a "swiss cheese" texture on the surface. They are actively forming today as the Tunnel Spring Tuff continues to weather and erode.

Tafoni form in a variety of environments and rock types but are most common in salt-rich desert environments and coastal areas. The composition of the rock plays the most important role in tafoni creation. The Tunnel Spring Tuff is poorly welded and thus somewhat porous and permeable. As weathering occurs, rainwater containing carbonic acid (H_2CO_3) infiltrates the tuff and travels through the pore spaces.

The absorbed water moves via capillary action. In this case, it means using the walls of the small spaces to propel the water horizontally through the rock body. The acidic water in the pore space dissolves limestone and dolomite rock fragments as it moves through the rock. The water eventually evaporates, leaving calcite ($CaCO_3$) behind.

This dissolution starts a process called salt weathering. Although usually facilitated by the minerals gypsum or halite, the salt weathering that initiates tafoni formation at Crystal Peak is driven by the crystallization of calcite ($CaCO_3$) precipitated from water. Calcite crystallization can generate a pressure of 10 atmospheres, a pressure strong enough to break rock grains and walls of the pore spaces, expanding the open area in the rock. The process feeds on itself as larger tafoni help regulate humidity and temperature, promoting more crystallization and subsequent weathering. The pore spaces grow into cavities and continue to increase in size.

Research shows that the cavities are spherical until they reach about 20 centimeters (8 inches) in diameter. The width then increases faster than the height and depth and they become elongated cavities. The average width of the tafoni at Crystal Peak is 2 meters (6 feet) but varies considerably. The spacing of the tafoni is a mystery as they do not follow any significant pattern or condition for their placement on steep rock faces.

Researchers will doubtless learn more about Crystal Peak and its tafoni, but time is not unlimited. In another million years, Crystal Peak, the Tunnel Spring Tuff, and the cave-like tafoni may be completely eroded away and replaced with a new geologic mystery, erasing the last piece of evidence for the ancient stream valley and violent volcanic events that occurred in this remote western desert of Utah.

Tafoni vary in size, with some of the largest cavities being over 2 meters (6 feet) wide. The tafoni cover most of the steep sides on Crystal Peak.

HOW TO GET THERE

The roads leading out to Crystal Peak are well-maintained gravel and dirt. A four-wheel-drive vehicle is not necessary but may reduce travel time. Travel is not recommended in winter or in bad weather conditions. There are no parking areas or facilities at Crystal Peak so use caution when parking on the shoulder and be prepared with plenty of water, food, sun protection, and fuel. GPS Coordinates: 38.7965° N, 113.5962° W

From Delta:

- Head west on Main Street/U.S. Route 6/50 for about 5 miles.
- Turn left onto Utah State Route 257 and travel south for 47 miles.
- Turn right at Black Rock Road/Crystal Peak Road and continue for 3 miles.
- Keep left, then stay on the main road for 9.5 miles.
- At the fork, go left and continue straight for 5.5 miles.
- At the fork, go right and stay on the main road for 17 miles to arrive at Crystal Peak.

From Milford:

- Travel north on Main Street/Utah State Route 257 for 22 miles.
- Turn left at Black Rock Road/Crystal Peak Road and continue for 3 miles.
- Keep left, then stay on the main road for 9.5 miles.
- At the fork, go left and continue straight for 5.5 miles.
- At the fork, go right and stay on the main road for 17 miles to arrive at Crystal Peak.

2019 Lehi Hintze Award | GRANT WILLIS

The Utah Geological Association (UGA) and the Utah Geological Survey (UGS) presented the 2019 Lehi Hintze Award to **Grant Willis** for his contributions to Utah geology. Over his 30-plus-year career Grant has been an author or co-author on more than 50 geologic maps throughout Utah. For the past 25 years, Grant has managed the Geologic Mapping Program at the UGS and supervised the publication of more than 320 geologic maps and dozens of geologic reports. During that time Grant managed the development and advancement of digital geologic mapping at the UGS, a program that is now recognized by state geological surveys nationwide as one of the most advanced and innovative programs in the nation. Grant also secured nearly $4.3 million in grants from the U.S. Geological Survey's STATEMAP Program and significant funding through the National Park Service, Department of Defense, and other sources. Two of his proposals were ranked by the U.S. Geological Survey as the best proposals submitted among the 50 state geological surveys for their respective years.

Grant has given back to his profession and to society in many ways. He is a Charter Life Member of the UGA and served as its President in 2013–14 and as Program Chair in 2000–01, and was the lead editor of UGA Publication 36 in 2007. During his tenure as UGA President, Grant created the UGA's Earthquake Safety Committee, working with local officials and engineers to address the impending disaster posed by Utah's unreinforced masonry building stock. Over the years, Grant has led or contributed to numerous geologic field trips for the UGA, UGS, and other organizations, including multiple trips for GSA, AAPG, ExxonMobil, AASG, and the UGS Board. He has been the driving force behind annual field reviews of new geologic mapping, helping to expose new maps to a broad audience.

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

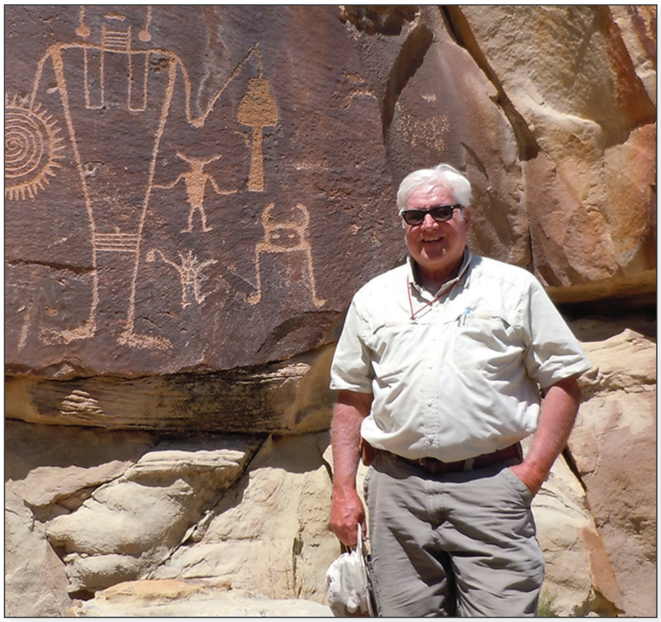
2019 Employee of the Year | STEPHANIE CARNEY

Congratulations to **Stephanie Carney**, who was selected by her peers as the 2019 UGS Employee of the Year. Stephanie has been with the UGS since 2006; she is currently a Senior Geologist in the Geologic Information and Outreach Program and serves as the UGS Technical Reviewer. Stephanie is at the front line of technical writing and reviewing and is a key component to every UGS publication. Stephanie goes beyond basic editing to help authors improve the flow of text, and she uses her impressive geology background to help ensure that the science is sound. Stephanie goes above and beyond to produce the highest quality publications, providing a level of consistency that helps the entire survey maintain its professionalism and inspires public confidence in our science. She is respectful, accountable, trustworthy, accommodating, meticulous, and has unending patience. She never wavers in her dedication, remaining relentlessly positive and engaged with her work. Stephanie exceeds all expectations, and she is also a genuinely kind and caring person that makes the entire office a more positive place to be. Stephanie is an outstanding employee and deserving recipient of this special award and recognition.

The American Association of Petroleum Geologists (AAPG) Rocky Mountain Section presented the 2019 John D. Haun Landmark Publication Award to **Douglas A. Sprinkel, Thomas C. Chidsey, Jr.**, and Paul B. Anderson (not pictured), in recognition of their work on the outstanding Utah Geological Association (UGA) Publication 28, *Geology of Utah's Parks and Monuments*. This volume includes geologic overview papers for Utah's national parks and several state parks. Since the printing of the first edition in 2000, this book has sold about 500 copies each year, nearly 10,000 copies total. The book is by far the number one selling UGA publication. The third edition was published in 2010 and a fourth edition is being planned that will include updated geology and the addition of new monuments.

The John D. Haun Landmark Publication Award recognizes the authors or editors of a book, guidebook, or other publication that over the past decade has had exceptional influence on developing new hydrocarbon plays or deeper understanding of fundamental geology within the Rocky Mountain region.

Douglas Sprinkel retired from the Utah Geological Survey (UGS) after 33 years of service. Doug began his career at the UGS as manager of the Applied Geology Program following a 10-year stint in the petroleum industry exploring much of central Utah. Doug later served as UGS deputy director between 1987 and 1990, before joining the Geologic Mapping Program where he took on the major task of mapping much of the Uinta Basin and Uinta Mountains. In addition, he specialized in the Lower and Middle Jurassic strata of Utah. Doug served as president of the Utah Geological Association (UGA) and was senior or co-editor of four UGA guidebooks on Utah geology including the award-winning *Geology of Utah's Parks and Monuments*. He has authored or co-authored 15 geologic maps and about 100 professional papers and abstracts, and received the Lehi Hintze Award in 2015 for his outstanding contributions to the geology of Utah. Doug's expertise and institutional knowledge of Utah's geology will be greatly missed, and we wish him well in his retirement!



The Editorial Section welcomes **Rosemary Fasselin** as the new cartographer/GIS analyst. Rosemary has a B.A. degree from the University of Utah and over 10 years of experience in GIS applications. The Editorial Section also bids farewell to **Jenny Erickson** who has accepted a position in the private sector. A warm welcome to Rosemary and best wishes to Jenny.

In Memoriam

Dianne Nielson, former geologist with the Utah Geological and Mineral Survey in 1983, passed away unexpectedly on November 7, 2019. Over 27 years, and until her retirement in 2011, Dianne served the State of Utah in a number of energy and environmental policy positions including appointments as director of the Division of Oil, Gas and Mining by Governor Scott Matheson, executive director of the Department of Environmental Quality by Governor Mike Leavitt, and as energy advisor to Governor Jon Huntsman. She was always a geologist, but one with excellent management and regulatory skills who brought her technical smarts to bear on every decision she made.

RECENT OUTSIDE PUBLICATIONS BY UGS AUTHORS

Climatic impact on fluvial-lake system evolution, Eocene Green River formation, Uinta Basin, Utah, USA, by L.P. Birgenheier, M.D. Vanden Berg, P. Plink-Bjorklund, E. Rosencrans, **R.D. Gall**, M. Rosenberg, L. Toms, and J. Morris: Geological Society of America Bulletin, https://doi.org/10.1130/B31808.1.

A mid-Cretaceous tyrannosauroid and the origin of North American end-Cretaceous dinosaur assemblages, by S.J. Nesbitt, R.K. Denton Jr., M.A. Loewen, S.L. Brusatte, N.D. Smith, A.H. Turner, **J.I. Kirkland**, A.T. McDonald, and D.G. Wolfe: Nature Ecology & Evolution, v. 3, p. 892–899.

Chronostratigraphy and terrestrial palaeoclimatology of Berriasian-Hauterivian strata of the Cedar Mountain Formation, Utah, USA, by R.M. Joeckel, G.A. Ludvigson, A. Moller, C.L. Hotton, M.B. Saurez, C.A. Suarez, B. Sames, **J.I. Kirkland**, and B. Hendrix: Geological Society of London Special Publications, v. 483, https://doi.org/10.1144/SP498-2018-133.

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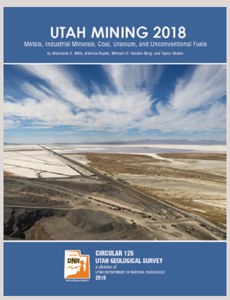
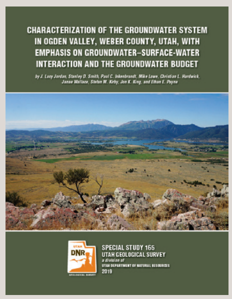
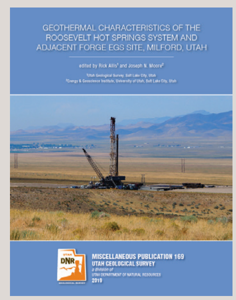


Utah Mining 2018: Metals, Industrial Minerals, Coal, Uranium, and Unconventional Fuels, by Stephanie E. Mills, Andrew Rupke, Michael D. Vanden Berg, and Taylor Boden, 34 p., **C-126**, https:// doi.org/10.34191/C-126.

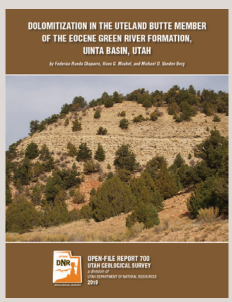


Characterization of the Groundwater System in Ogden Valley, Weber County, Utah, with Emphasis on Groundwater–Surface-Water Interaction and the Groundwater Budget, by J. Lucy Jordan, Stanley D. Smith, Paul C. Inkenbrandt, Mike Lowe, Christian L. Hardwick, Janae Wallace, Stefan M. Kirby, Jon K. King, and Ethan E. Payne, 222 p., 3 pl., 5 appendices, **SS-165**, https:// doi.org/10.34191/SS-165.

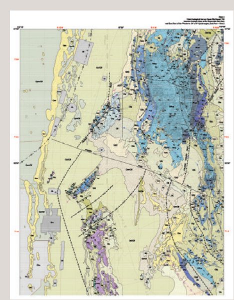


Geothermal Characteristics of the Roosevelt Hot Springs System and Adjacent FORGE EGS Site, Milford, Utah, edited by Rick Allis and Joseph N. Moore, 245 p., 8 appendices, 2 plates, scale 1:24,000, **MP-169**, https://doi. org/10.34191/ MP-169.

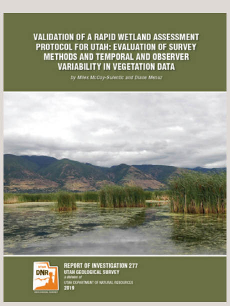
Proceedings Volume, 2018 Lake Bonneville Geologic Conference and Short Course, October 3–6, 2018, edited by William R. Lund, Adam P. McKean, and Steve D. Bowman, (8 technical sessions [35 presentations], 7 posters), **MP-170**, https:// doi.org/10.34191/MP-170.



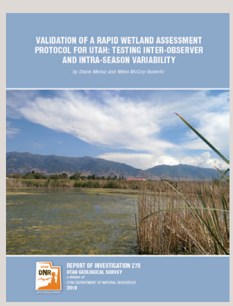
Dolomitization in the Uteland Butte Member of the Eocene Green River Formation, Uinta Basin, Utah, by Federico Rueda Chaparro, Hans G. Machel, and Michael D. Vanden Berg, 99 p., 8 appendices, **OFR-700**, https:// doi. org/10.34191/OFR-700.



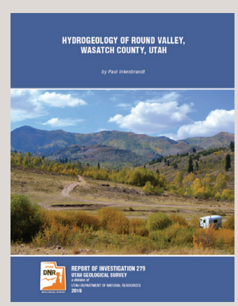
Interim Geologic Map of the Bonneville Salt Flats and East Part of the Wendover 30' x 60' Quadrangles, Tooele County, Utah, East Part–Year 2, by Donald L. Clark and Charles G. Oviatt, 24 p., 2 pl., scale 1:62,500, **OFR-702**, https:// doi. org/10.34191/OFR-702.



Validation of a Rapid Wetland Assessment Protocol for Utah: Evaluation of Survey Methods and Temporal and Observer Variability in Vegetation Data, by Miles McCoy-Sulentic and Diane Menuz, 14 p., 2 appendices, **RI-277**, https://doi. org/10.34191/RI-277.



Validation of a Rapid Wetland Assessment Protocol for Utah: Testing Inter-observer and Intra-season Variability, by Diane Menuz and Miles McCoy-Sulentic, 9 p., 4 appendices, **RI-278**, https:// doi.org/10.34191/RI-278.



Hydrogeology of Round Valley, Wasatch County, Utah, by Paul Inkenbrandt 45 p., 1 plate, scale 1:24,000, **RI-279**, https:// doi.org/10.34191/RI-279.