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

SURVEY NOTES

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The UGS Response to the March 18, 2020, Magnitude 5.7 Magna, Utah, Earthquake and Aftershock Sequence

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Cover • Subsidence features on the mud flats behind the Saltair building likely caused by liquefaction from the 2020 M 5.7 Magna, Utah, earthquake. Photo by Adam Hiscock. Inset: Damage to commercial buildings in Magna from the 2020 M 5.7 Magna, Utah, earthquake. Photo by Emily Kleber and Jessica Castleton.

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DIRECTOR'S PERSPECTIVE

by Bill Keach

Such an interesting time to live and work. A pandemic has been with us since March. Local, state, and national economies have been severely impacted. Social issues have stirred many emotions in many people. Through it all the UGS continues to exemplify compassion and professionalism. Lives are being lived and work is being done. For the past four plus months the majority of UGS staff have been working from home and in the field. Work continues to progress, and we continue to look for ways to increase productivity AND maintain a sense of community.

For the Utah Geological Association's July meeting, I spoke about curiosity, patterns, and discovery. Many great discoveries come from being curious first, and then recognizing patterns in the data. A favorite line of mine, by Mark Twain, is as true today as it was when written in 1889: "You cannot depend on your eyes when your imagination is out of focus[1]." For me, our science is about focusing our imagination to make more sense of the world around us. Technology plays a role in focusing our eyes and mind on what can be newly seen. One of the questions posed after the talk asked, "What do you see in the future for the UGS and technology?" One aspect is finding new ways to derive new insights from our historical archives. Nearly every report, research paper, and map are now digitally archived. Digitally available data can provide the basis for new avenues of research. The imagination can be turned loose on "What if?" and "How?" questions. Which in turn lead to better insights on public needs such as understanding groundwater supplies, building safety, natural hazards, critical minerals, etc.

Over the past few years, the UGS Web Services team, working closely with the various programs, has been busy developing new online applications which improve access to UGS digital data. The Utah Geologic Hazards Portal was released in May of this year (www.geology.utah.gov/apps/hazards). Here, one can access available hazard data for any location in the state. Information on faults, landslides, problem soils, flooding, etc., can be researched, and a report can be generated for the location. We continue to work on new web applications to increase accessibility to UGS data.

Each year the UGS Board selects the winner(s) of the Arthur L. Crawford Award, which "recognizes outstanding achievement, accomplishments, or contributions by a current UGS scientist(s) to the understanding of some aspect of Utah geology or earth science." The winning nomination is highlighted in this issue's "Survey News" column and below are comments from the Board on all three of this year's nominees. From the Board Chair, Elissa Richards, "*… this was a difficult task because all three nominations were excellent, and the finalists' achievements and contributions are impressive.*"

"*The Wasatch Fault Zone research* [by Greg McDonald and co-authors] *lays the geologic foundation needed for further study and reduction of risks as development increases along the Wasatch Front. It could literally be a life saver and the methodology sets a standard.*"

"*The Roosevelt Geothermal compilation of papers* [by Rick Allis and Joseph Moore, editors, with multiple co-authors] *both clearly and completely describes the geothermal resource and provides a better understanding of the geology of this part of Utah.*"

"*The Ogden Valley Groundwater paper* [by Lucy Jordan and co-authors] *provides a complete and clear geologic context, provides critical information about current and future groundwater use, and sets a standard and methodology that could be applied to Utah's developing back valleys and other areas.*"

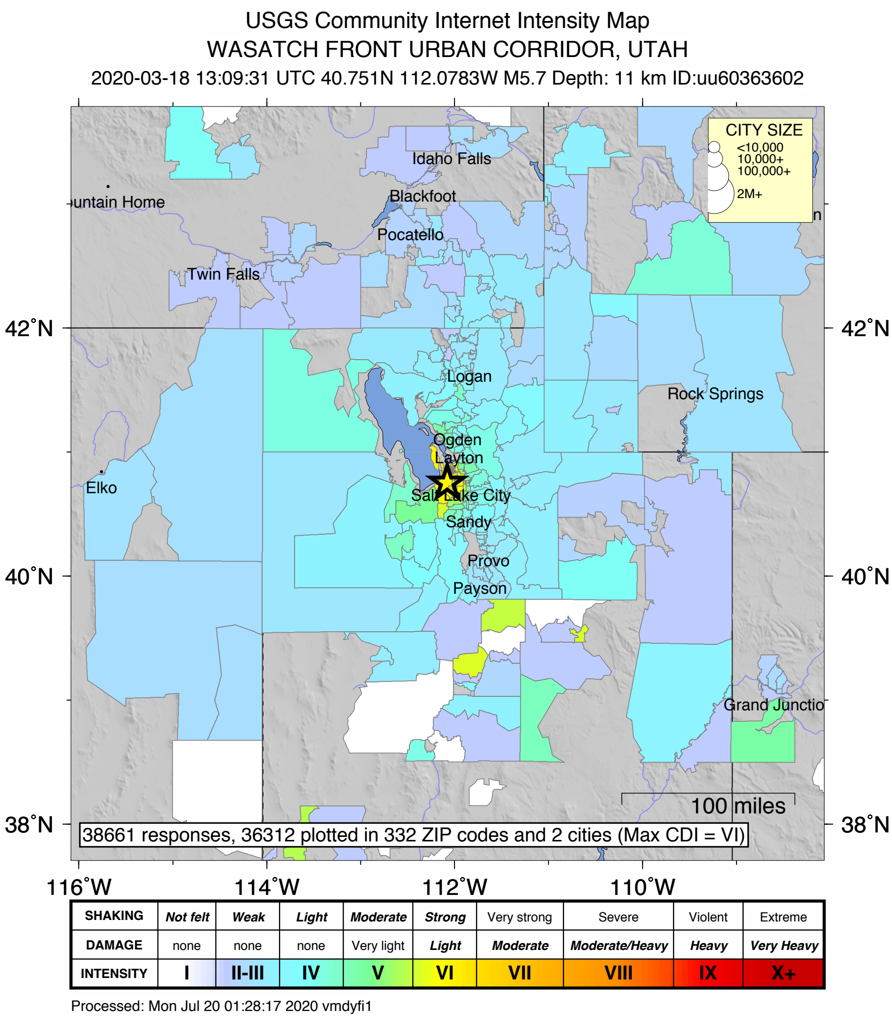
[1] *A Connecticut Yankee in King Arthur's Court*, Mark Twain, 1889

The UGS Response to the March 18, 2020, Magnitude 5.7 Magna, Utah, Earthquake and Aftershock Sequence

by the UGS Geologic Hazards Program

Early on the morning of March 18, 2020, a magnitude (M) 5.7 earthquake shook the Wasatch Front. The earthquake was centered about 8 miles below Magna, Utah, and about 10 miles west of downtown Salt Lake City. The earthquake was widely felt along the Wasatch Front and into Idaho, Wyoming, and Colorado as shown by the *Did You Feel It* reports to the U.S. Geological Survey (USGS). Fortunately, there were no deaths from the earthquake; however, multiple injuries were reported as well as damage to buildings and homes.

The Magna earthquake was the largest along the Wasatch Front since pioneer settlement in 1847 and serves as a reminder that Utah is seismically active and that damaging earthquakes do occur. In fact, the epicenter of the 2020 Magna earthquake is very near the epicenter of the 1962 M 5.2 Magna earthquake, which caused structural damage to buildings in the area. The Wasatch fault zone is expected to produce an earthquake around M 7.0 in the future and has the potential to produce a M 7.6 based on knowledge of past, prehistoric earthquakes and specific fault lengths. In terms of energy, a M 7.0 earthquake would release 90 times more energy than the M 5.7 Magna earthquake and would be much more damaging.



USGS Did You Feel It *public responses to the Magna earthquake (shown as a star on the map). Colored county footprints represent the intensity of earthquake ground shaking reported by the public. Warmer colors represent more extreme shaking and cooler colors represent less intense shaking. https://earthquake.usgs.gov/archive/product/dyfi/uu60363602/us/1595208519431/uu60363602_ciim.jpg*

To assist emergency managers and first responders to the earthquake, the Utah Geological Survey (UGS) immediately activated its Emergency Operations Center (EOC), where scientific information collected on the earthquake could be coordinated and managed. Initial response included deployment of two field-reconnaissance teams to investigate geologic effects from the earthquake and to provide scientific assistance to first responders as needed. The scientific information we collected was shared with the Utah Division of Emergency Management's (UDEM) State EOC and the University of Utah Seismograph Stations (UUSS). In addition, the UGS worked extensively with the UUSS to determine which fault(s) were involved with the earthquake and subsequent aftershocks.

Digital Clearinghouse

Within two hours of the earthquake, the UGS established a digital web-based clearinghouse (https://geodata.geology.utah.gov/pages/search.php?search=!collection609) to collect, distribute, and archive important data and other information on the earthquake. The clearinghouse provides timely information to the public and media and provides future researchers with the necessary data to investigate earthquake effects. Clearinghouse data are also critical to the performance evaluation of infrastructure during earthquakes, including the effectiveness of building codes, material types, and construction methods. These evaluations can reduce the impact and effects from future earthquakes.

Various organizations contributed to the Magna earthquake clearinghouse, including the UGS, Salt Lake County, the UUSS, the USGS, the Utah Department of Transportation (UDOT), the Earthquake Engineering Research Institute (EERI), UNAVCO, the Utah State Historic Preservation Office, UDEM, Utah State University, Utah Valley University, the Natural History Museum of Utah, Stanford Research Computing Center, the Utah Geological Association, Granite School District, StrongMotions Inc., Geohazards TEP, Poll Sound, and Salt Lake City. Additionally, we began a public outreach campaign through social media to encourage impacted citizens to share their photographs and videos. Seventeen people responded and contributed 50 photographs and 15 videos.

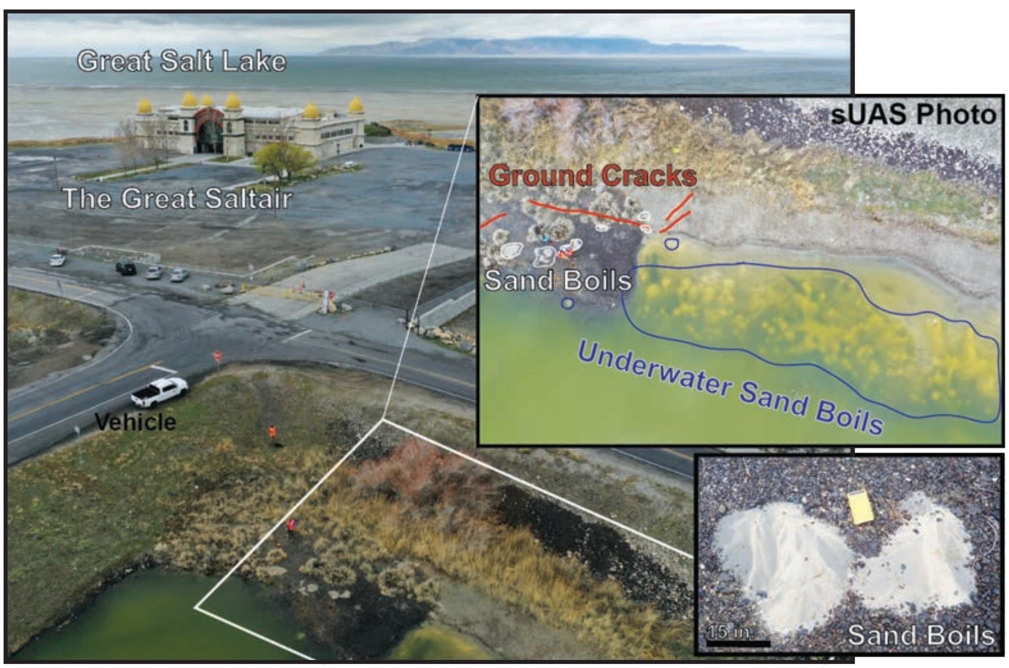
The majority of submitted items were photographs documenting damage to structures and ground deformation caused by earthquake shaking. Numerous maps and diagrams from scientists were submitted to contextualize the main shock and subsequent aftershocks. Submitted videos documented the varied intensity of shaking experienced in Salt Lake Valley. The contributions, nearly 800 submissions, to the clearinghouse have provided great insight to the impacts of the M 5.7 Magna, Utah, earthquake and will be a valuable resource for future researchers.

Field Reconnaissance

In the hours following the earthquake, the UGS deployed field teams to document geologic effects in areas determined to be susceptible. A M 5.7 earthquake is too small for fault movement to rupture the ground and offset the ground surface in the Intermountain West. However, the field teams observed surface cracking, liquefaction, and lateral spread features which were mostly a result of ground shaking.

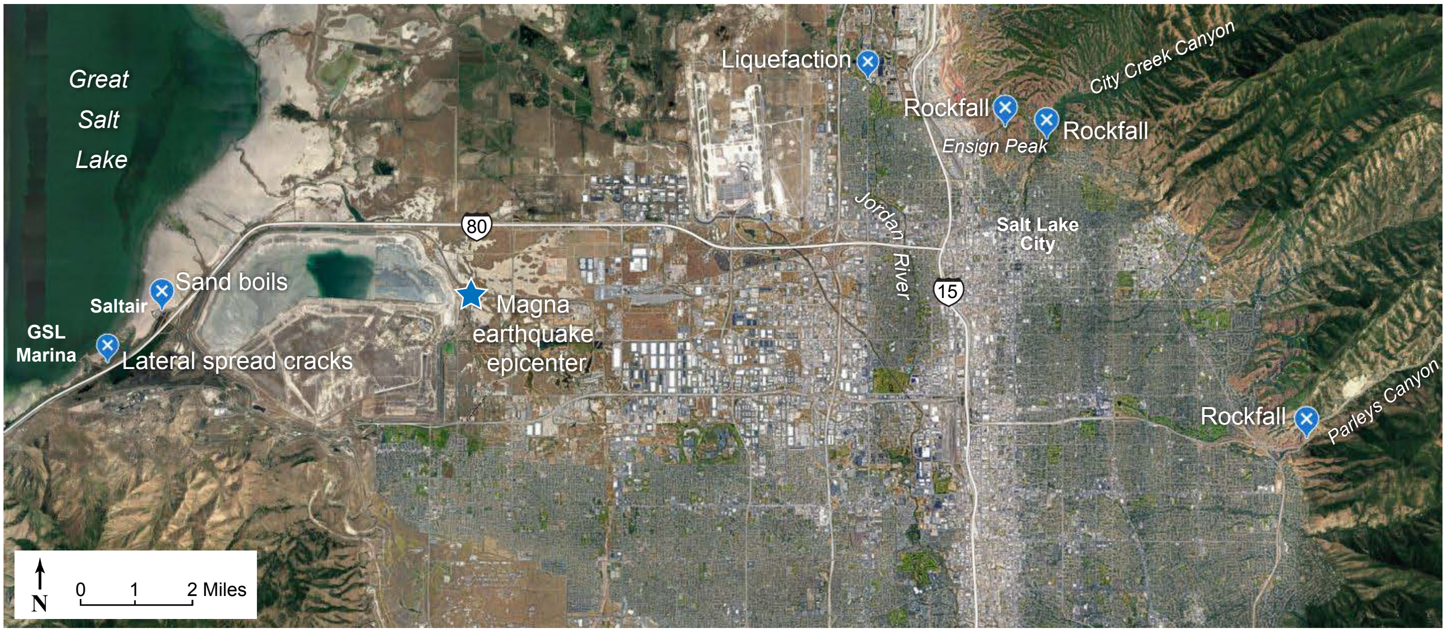
Liquefaction was the most widely observed geologic effect due to ground shaking from the earthquake. Liquefaction is a phenomenon where sandy, water-saturated soil temporarily loses strength due to strong ground shaking from an earthquake. The ground may behave like a fluid, causing damage to infrastructure like buildings, roads, and pipelines. Liquefaction from the Magna earthquake was observed along the Jordan River and near Great Salt Lake, where groundwater levels are high. The UGS field reconnaissance teams observed several types of liquefaction, including sand boils, ground cracking, and lateral spreading.

The day after the main shock, UGS field teams were notified by UDOT of possible liquefaction features near the Interstate 80/State Route 202 interchange near Saltair. Upon investigation, our field teams observed sand boils on land and below water, as well as ground cracking within the engineered fill at the interchange. Using a UGS small unmanned aircraft system (sUAS), field teams were able to observe the extent of underwater sand boils, which were much more numerous than those on land. Underwater sand boils were observed in other ponds at the interchange, as well as along the access road to the nearby Great Salt Lake Marina State Park.



The area around The Great Saltair concert venue had numerous liquefaction features within fills associated with the Interstate 80/State Route 202 interchange and The Great Saltair parking area. Aerial reconnaissance via sUAS showed liquefaction features including numerous underwater sand boils.

Beyond the deformation observed near Saltair, UGS geologists looked for ground shaking-related damage within a several mile radius from the epicenter, including sites along the Jordan River, marshy areas, and the foothills and canyons of the Wasatch Range where rockfall-prone outcrops are known. Two places along the Jordan River had minor lateral spreading that consisted of several-foot-long zones of fresh, transverse cracking of riverbank deposits, and we discovered a relatively recent rockfall at the mouth of Parleys Canyon that upon further inspection likely predates the earthquake. We also documented two rockfalls sourced from a Tertiary-age conglomerate: one just west of Ensign Peak and the other several miles up City Creek Canyon. Both rockfalls had fresh exposures on the source outcrops, impact craters, furrows, and downed and broken scrub oak through the runout zones and rock debris and boulders from the detached blocks as they broke apart while traveling downslope. Overall, however, we observed no major or widespread ground shaking-related features that could be directly attributed to the earthquake.



Location of ground shaking-related damage documented by field reconnaissance teams.

Which Fault Caused the Main Earthquake?

Immediately following the Magna earthquake, the UGS and the UUSS began working to identify and understand the fault or faults that moved and caused the earthquake and subsequent aftershocks. Since the earthquake-producing fault(s) did not rupture the ground surface, the UGS analyzed available geologic mapping and gravity data, comparing it with available seismicity data from the UUSS, to identify suspected faults.

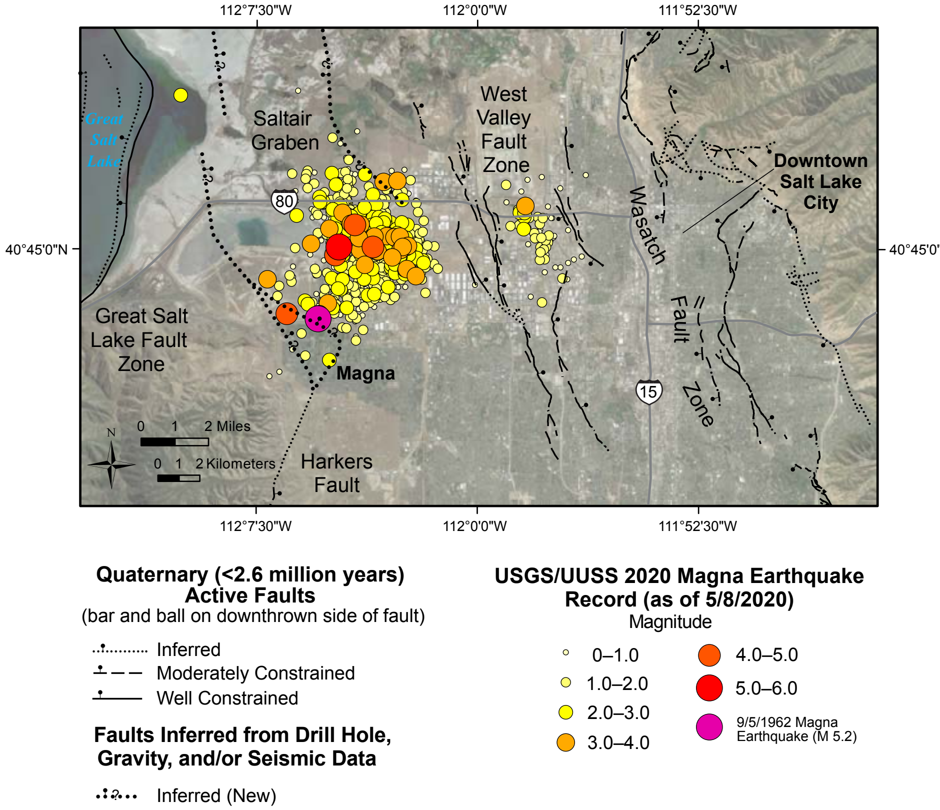
Based on preliminary data available for the Magna main shock and larger aftershocks, the UGS identified several possible source faults. One area of interest is called the Saltair graben—an inferred basin fault structure—which may be influencing some of the Magna aftershock locations. However, this area was probably not responsible for the main shock. After receiving and analyzing more data, it seems likely that the main shock resulted from movement of a previously unidentified fault potentially related to the Wasatch fault zone deep in the subsurface.

Minor ground shaking-related lateral spreading observed along the Jordan River.

Aftershocks

Thousands of aftershocks followed the main earthquake. As of July 9, 2020, the UUSS had recorded 2,343 aftershocks. Most of the aftershocks occurred in two main areas: (1) a western grouping near the mainshock location and (2) an eastern grouping near the West Valley fault zone. Many of the western grouping of aftershocks occurred along a west-dipping trend that highlights a hypothetical west-dipping fault. Both areas of aftershocks have geologists and seismologists asking many questions about what the structure of the Salt Lake Valley subsurface geology looks like and how the faults connect miles down below the surface. These and many other questions will be studied by geologists and seismologists for some time.

Generalized Map of Northern Salt Lake Valley Showing Normal Faults and Their Relation to the Magna M 5.7 Earthquake and Aftershocks of March 18–May 8, 2020



Map showing Magna earthquakes and aftershocks with mapped Quaternary (<2.6 million years) faults and the Saltair graben, a potentially related inferred basin fault structure. Current research suggests that the main shock resulted from movement of a fault potentially related to the Wasatch fault zone at depth. Numerous aftershocks appear to be related to the West Valley fault zone as well.

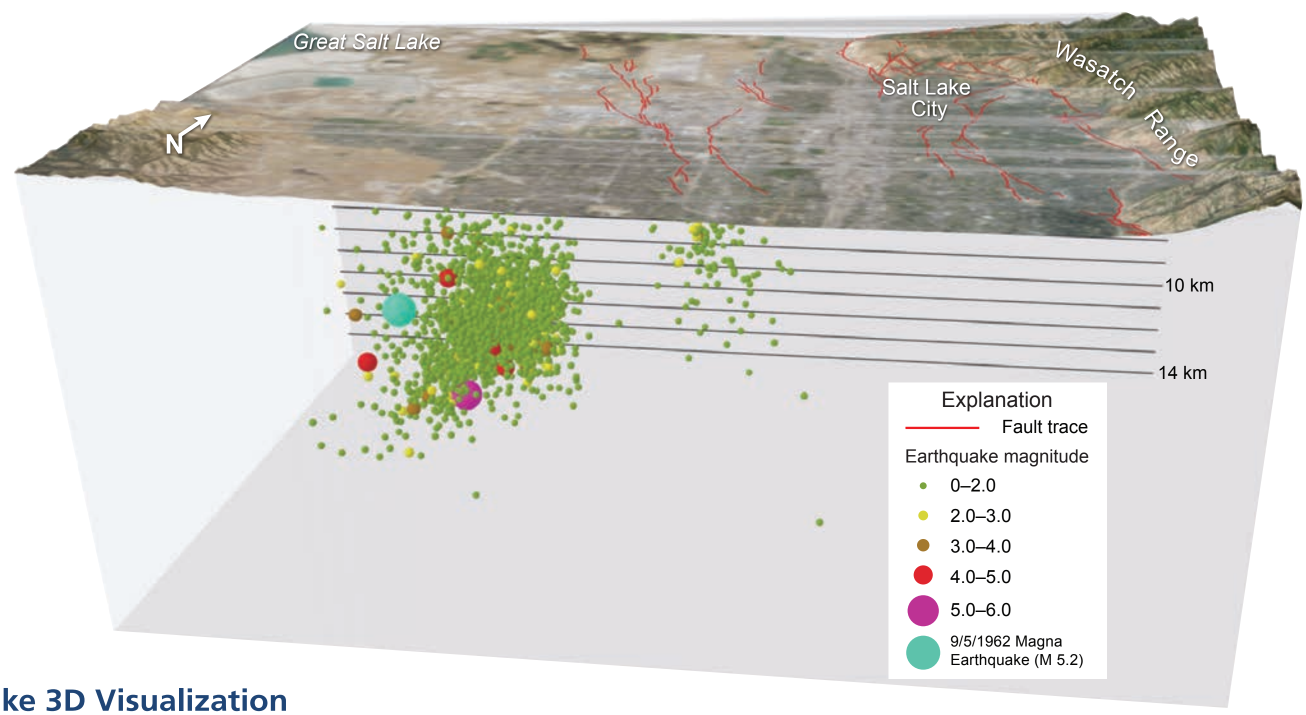


Image from three-dimensional web scene showing the location of the Magna earthquake and aftershocks below the Salt Lake Valley floor.

Earthquake 3D Visualization

On the day of the earthquake, the UGS created an interactive three-dimensional (3D) web scene using a geographic information system (GIS) data set that represented the main shock and subsequent aftershocks. The web scene models the earthquake locations in three-dimensional space using ArcScene GIS software with data provided by the UUSS. The initial scene was created using the GIS earthquake locations, imagery, hazardous (Quaternary) fault lines, and a digital elevation model. It was then converted into a web scene and used to create an interactive ArcGIS Online web application (https://utahdnr.maps.arcgis.com/apps/CEWebViewer/viewer.html?3dWebScene=8df0f2ead6e74ab1969f7f49686f8875). The last update was on July 9, 2020, that displayed over 2,300 locations. As additional aftershocks are detected, the 3D web scene will be periodically updated.

Although no deaths occurred and damage was moderate, the recent Magna earthquake is a reminder that Utah is seismically active and that damaging earthquakes do occur. Even with the recent stress relief of the Magna earthquake, enough seismic energy has built up along the Wasatch fault zone that an earthquake up to about M 7.6 could occur at any time, most likely in the Salt Lake Valley or Brigham City areas. You can prepare for future earthquakes by following the recommendations of the UGS and the Utah Seismic Safety Commission that are outlined in the *Putting Down Roots in Earthquake Country Handbook* available online at https://ussc.utah.gov/pages/view.php?ref=1 or a printed copy may be obtained from the Natural Resources Map & Bookstore (https://www.utahmapstore.com/).

ABOUT THE AUTHORS

The mission of the **Geologic Hazards Program** is to: 1) respond to geologic hazard emergencies and provide unbiased, scientific advice to local governments and incident commanders, 2) investigate and map geologic hazards in urban and other areas (to publish and distribute maps and GIS spatial data), and 3) provide geologic hazard-related technical and educational outreach and information to inform Utahns about hazards. The focus of the Program is to reduce Utah's life-safety, property, and economic risk from geologic hazards. https://geology.utah.gov/about-us/geologic-hazards-program/

Additional Information

Utah Earthquakes (1850 to 2018) and Quaternary Faults Map [https://doi.org/10.34191/M-277]

Utah Quaternary Fault and Fold Database online map [https://geology.utah.gov/apps/qfaults/]

UGS Earthquake Hazards web page [https://geology.utah.gov/hazards/earthquakes/]

Utah Geologic Hazards Portal [https://geology.utah.gov/apps/hazards/]

State of Utah Earthquakes website [https://earthquakes.utah.gov/]

Utah Seismic Safety Commission [https://ussc.utah.gov/]

UGS Earthquake Probabilities for the Wasatch Front Region in Utah, Idaho, and Wyoming publication [https://doi.org/10.34191/MP-16-3] and fact sheet [https://pubs.usgs.gov/fs/2016/3019/fs20163019.pdf]

ENERGY NEWS

Impacts of the COVID-19 Pandemic on Utah's Energy Industry

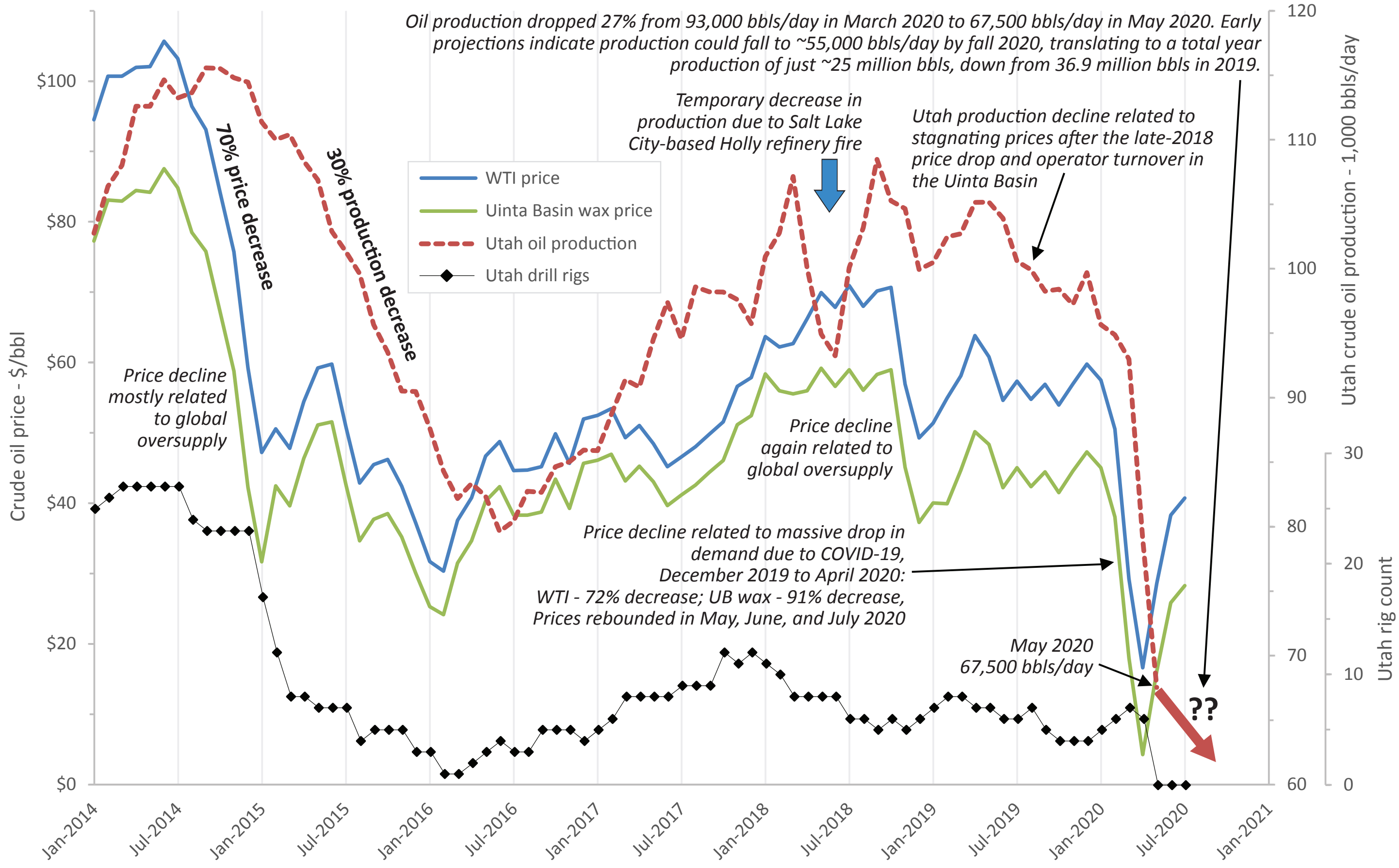
by Michael D. Vanden Berg

The COVID-19 pandemic has significantly changed everyday life around the world and in Utah. Starting in mid-March 2020, state leaders issued stay-at-home directives to try and limit the spread of the coronavirus. This lockdown had major consequences on all aspects of life, including the energy economy in Utah. At the time of this writing (late July), the economy has started to reopen, but new COVID-19 cases continue to surge, leaving doubts about the immediate and long-term economic impact of this pandemic. This article highlights some of the more important and interesting energy metrics from spring 2020 that showed dramatic changes due to COVID-19 responses.

The most significant impact on the energy economy of the COVID-19-related shutdown was the massive drop in oil prices. Two events occurred in March 2020 that dramatically changed oil prices worldwide—Russia and Saudi Arabia entered into an oil price war, flooding the market with new supply, and at the same time the world experienced a massive drop in petroleum product demand linked to COVID-19-related travel restrictions. These two events culminated on April 20, when May futures prices for West Texas Intermediate (WTI—U.S. oil price benchmark) went negative (-$37 per barrel) for the first time in history. Similarly, the price for Uinta Basin wax (UB wax) dropped to an unprecedented -$50 per barrel. Prices rebounded in late April and early May as Russia, Saudi Arabia, and other OPEC+ countries agreed to massive oil production cuts, combined with a more economically driven production decline in the United States due to reduced drilling activity.

The graph on page 6 displays monthly average oil prices for WTI and UB wax, coupled with monthly Utah oil production in thousand barrels per day (bbl/day) over the past six years. UB wax sells at a discount due to the limited Salt Lake City refinery market and the challenges of handling the waxy crude. The price crash experienced in late 2014 can help inform how the current price crash will impact oil production over the next several months. Average monthly oil prices bottomed out in April 2020 before rebounding in May, June, and July. Unfortunately, despite this price rebound, Utah's drill rig count fell from eight rigs in early April to zero rigs in early May. Recent drilling mostly focused on horizontal wells in the unconventional Green River/Wasatch play in the Uinta Basin, Utah's major oil producing area. These unconventional wells experience steep production declines in the first several months and without constant new drilling, overall production declines will be significant.

Monthly crude oil prices and monthly Utah oil production, January 2014 to July 2020



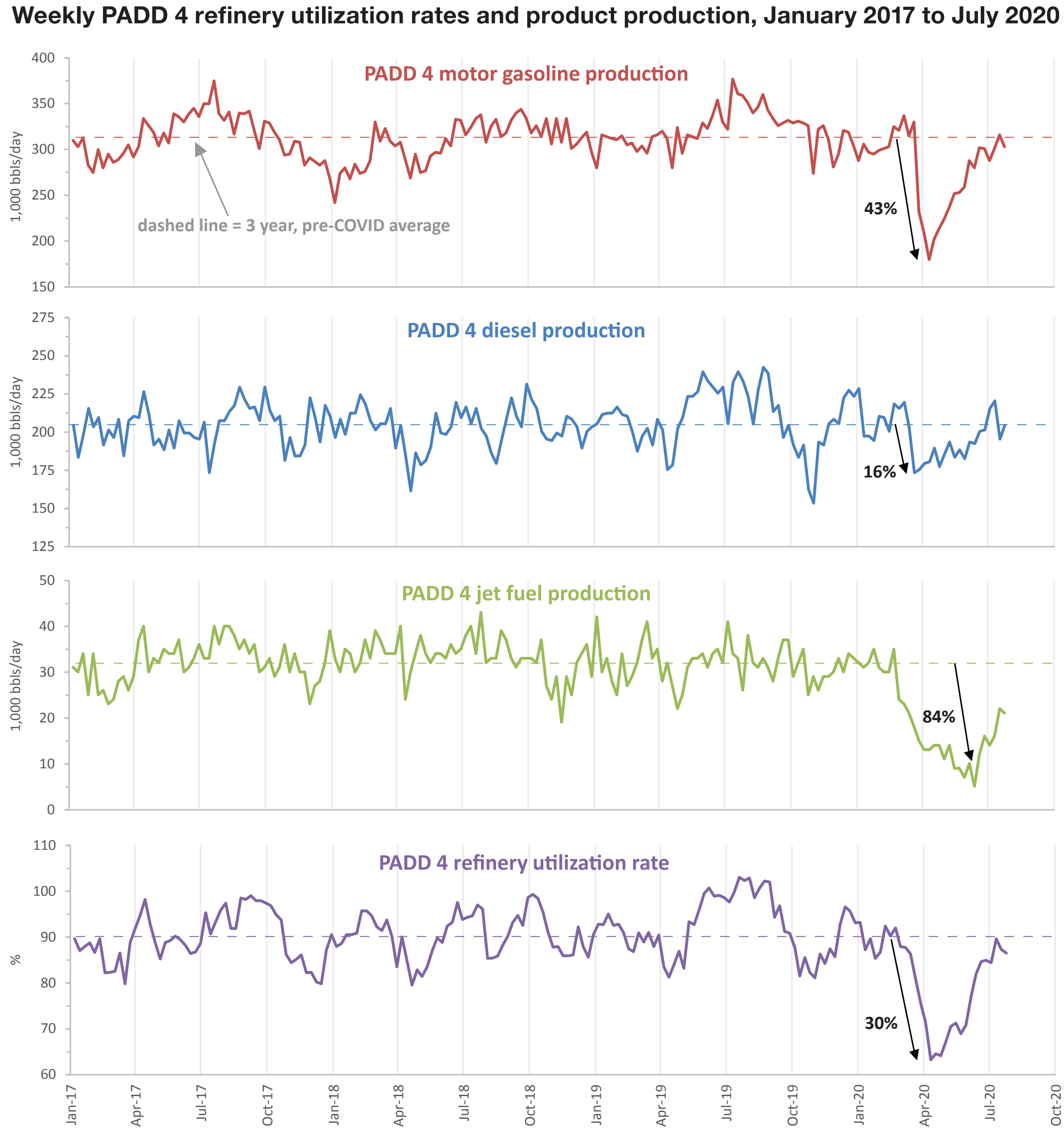
Data sources: U.S. Energy Information Administration; Utah Division of Oil, Gas and Mining; Big West Oil price bulletin

After a sustained decrease in oil production over the past 12 months, mostly related to stagnating prices and operator turnover in the Uinta Basin, production plummeted by 27 percent from 93,000 bbls/day in March 2020 to 67,500 bbls/day in May, due to COVID-19-related price reductions—by far the largest two-month decrease in decades. Unfortunately, production will continue to drop, albeit at a lower rate, well into the fall. Early projections indicate that production could drop to about 55,000 bbls/day by fall 2020, the lowest rate in over ten years. These projections would translate to a total 2020 Utah production of about 25 million barrels, down 32 percent from the 2019 total of 37 million barrels.

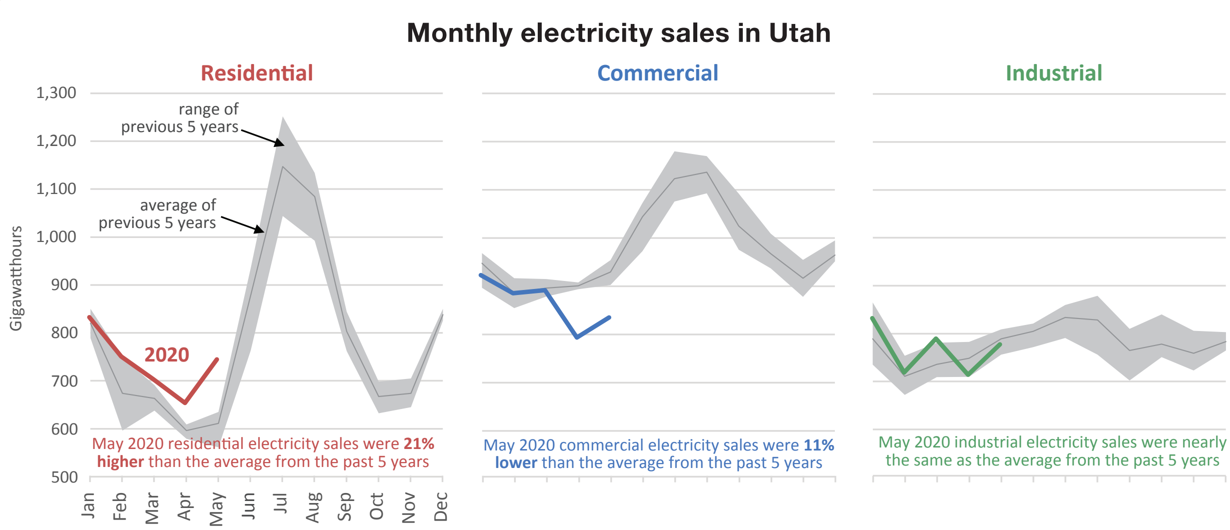
As previously mentioned, the COVID-19-related travel restrictions and stay-at-home orders created an unprecedented drop in petroleum production demand. This dramatic decrease can be evaluated by looking at the drop in PADD 4 (Petroleum Administration for Defense Districts; PADD 4 includes Utah, Colorado, Wyoming, Idaho, and Montana) refinery utilization rates and refinery production of motor gasoline, diesel, and jet fuel. Refinery utilization rate refers to the proportion of time a refinery operates in relation to its full capacity. Typically, refineries operate at about 90 percent of their full capacity; however, this rate dropped to 63 percent in April 2020 due to reductions in demand. As states reopened their economies in May and June, demand for products returned and rates bounced back to nearly 90 percent. Motor gasoline produced at PADD 4 refineries displays a similar trend. A massive 43 percent decrease occurred in early April, followed by a sharp rebound as production returned to normal by the end of July. Diesel fuel demand only dropped 16 percent in late March and quickly rebounded to pre-COVID-19 averages, since commercial trucking never really stopped during the shutdown. Jet fuel demand dropped the most (84 percent) and has yet to fully recover as commercial air travel continues to suffer from mandated travel restrictions.

The petroleum industry was not the only energy sector affected by the COVID-19 stay-at-home guidelines; electricity demand in Utah was also impacted. Residential electricity usage increased by 9 percent in April 2020 and 21 percent in May, compared with the average of the past five years. This increase was expected as many Utahns transitioned to working from home and schools shut down. In contrast, commercial electricity usage dropped 13 percent in April and 11 percent in May as most businesses had to shut down, at least temporarily. Industrial electricity demand remained steady as factories and other industrial complexes mostly continued to operate. Electricity demand should generally return to normal in summer 2020 (data only currently available through May) as the economy begins to reopen, but a resurgence in COVID-19 infections could change this scenario.

The COVID-19 pandemic has dramatically impacted all aspects of life in Utah and beyond. These impacts have rippled through our economy, affecting some industries more than others. Utah's upstream petroleum industry was severely impacted, and the effects of reductions in price, production, and related jobs to Utah's rural economy will be difficult to manage for many months, if not years. In contrast, demand for petroleum products in Utah has already mostly rebounded and impacts to electricity demand have been minimal and short lived. As new virus infections continue to surge in July, impacts and restrictions might endure well into the fall, further impacting Utah's energy economy. The Utah Geological Survey will continue to monitor the effects of COVID-19 on Utah's energy industry; for the latest updates, visit our website at geology.utah.gov.



Source: U.S. Energy Information Administration



Source: U.S. Energy Information Administration

What Gives Utah's "Red Rock Country" its Color?

by Lance Weaver

Glad You Asked!

Utah's Colorado Plateau is famous for its striking vistas and dazzling colors. Hues of red, pink, maroon, yellow, brown, and white create an array of stunning rock colors that attract visitors from all over the globe. From the red rocks of the Navajo Sandstone to the Vermilion Cliffs of the Moenave and Kayenta Formations to the pink, crimson, and chocolate cliffs of the upper Grand Staircase, many who visit the Colorado Plateau wonder what gives the rocks their brilliant colors. This question has spurred much research by geologists, involving chemical and physical analysis. The answers can be complicated, as many different minerals can cause coloration in rocks; however, for the most part, the red, pink, yellow, and brown colors of Utah's "Red Rock Country" simply comes down to one element—iron.

Coloration of the Navajo Sandstone caused by post-depositional movement of the iron mineral hematite. (Photo credit Peter Fitzgerald, GNU Free Documentation License)

Since minerals form the basis for many pigments and dyes, it should be no surprise that they are also responsible for the coloration of rocks. Of all the common colorful minerals found in Earth's crust, few are as abundant, dynamic, and multi-colored as iron. Depending on how it combines with other elements, iron can form a veritable rainbow of colors. When iron combines with oxygen it becomes iron oxide, and its degree of oxidation largely determines its color. Ochre, a mixture of clay, sand, and iron oxide, has been one of the most commonly mined mineral pigments for tens of thousands of years and is composed of the same minerals that often color rocks. Obtained from iron-bearing clays, ochre can produce several colors and hues that are used as natural coloring agents. Red ochre comes from hematite (Fe_2O_3), a mineral named for the same Greek root word for blood, and has long been used as a red pigment. Some iron oxides, when hydrated (combined with hydrogen and oxygen), can form bright yellows such as yellow ochre which comes from the mineral limonite ($FeO(OH)+H_2O$). Brown ochre comes from the mineral goethite ($FeO(OH)$) and is a partially hydrated iron oxide. Iron can also form black pigments from minerals such as magnetite (Fe_3O_4), or even blue and green hues from minerals such as glauconite and illite. For the most part, these iron minerals, and particularly hematite, are responsible for coloring the Colorado Plateau's sedimentary rock layers.

Researchers have questioned how the pigment-bearing iron minerals get into rocks like sandstone and shale as well as how the minerals are dispersed within the rock. One might suspect that the brightly colored minerals might be sprinkled throughout the sand and clays or cements that composed the sandstone and shale units—something like chili powder, evenly mixed within salt. However, by looking at thinly cut sections of rock under a microscope, it becomes clear that this is typically not the case in Utah's Color Country rock. Instead, the very sand grains that form the matrix of the rock units are actually "frosted" or coated with a layer of iron-rich mineralization. These grains are then cemented together with a pale to white calcite or silicate glue. In the case of sandstone units like the prominent Navajo or Wingate Sandstone, the sand is composed almost entirely of translucent or white quartz grains that are coated with a thin veneer of red hematite mineralization. Although the exact timing is debated among geologists, this "coating" of iron-bearing minerals likely began forming as the grains were transported from their place of erosion to their respective areas of deposition. The same process can be seen today as mineral-rich waters of semi-arid to tropical rivers mineralize large amounts of sediment as it is transported and deposited into adjoining basins.

The Amazon River's "meeting of waters" is a fantastic example of the different water chemistries likely responsible for the coloration of ancient sediments. The Rio Negro, a tributary of the Amazon, is a "blackwater"" river which is clear, slightly acidic, and contains high concentrations of reduced iron. The Amazon, however, has lower concentrations of iron and dissolved solids, but a higher sediment load and oxidized iron giving it its reddish-brown color. (Photo credit Gabriel Heusi, Wikimedia, Creative Commons license.)

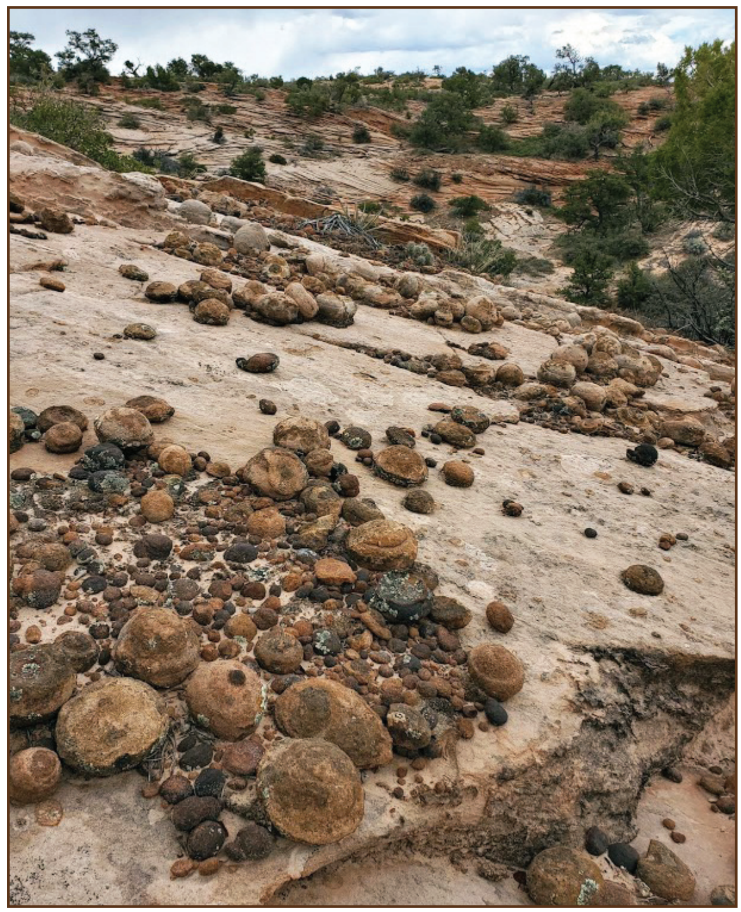
Multicolored sections of the Navajo Sandstone in the Zion National Park area.

After the sediment is buried, moving groundwater can further mineralize and alter the red rock to change it to varying shades of pink, vermilion, maroon, or even white. In southern Utah the upper parts of the Navajo and Entrada Sandstones often exhibit areas referred to as "bleached zones." This term refers to areas where reducing groundwaters have partially removed the iron oxide coating from the sand grains. A reducing agent is a solvent that can remove oxygen from a compound. So in the case of the iron pigments that colored the Navajo Sandstone, groundwater that was slightly acidic or contained other reducing agents seems to have dissolved large amounts of iron mineralization from the upper sections, often redepositing the iron in cracks, joints, or different sections of the sandstone that possess irregularities in grain size. Areas that have lost iron oxide become lighter shades of pink and white, whereas areas that gained additional iron oxide from groundwater movement become darker shades of maroon and even black. In most cases, these color alterations likely happened while the units were deeply buried beneath the surface. However, because these units are so permeable, allowing water to flow easily through them, water has continued migrating, dissolving bits of iron and other minerals even after they have been exposed by erosion. The dissolved minerals often get left behind on canyon walls and surfaces as the water evaporates, contributing to the creation of the well-known "desert varnish" on the rock face.

Another interesting feature of post-depositional iron-oxide movement within southern Utah's sandstones are Moqui marbles (see "Glad You Asked" article in the September 2017 issue of *Survey Notes*). Moqui marbles are spherical concretions or nodules of hematite and sandstone that are formed as large amounts of reducing water dissolve hematite and illite minerals from one part of the sandstone and redeposit them around a point of nucleation. It is unclear what creates the nucleation spot for these iron concretions, but once the hematite begins to bind to some type of ionized nucleus, a chemical reaction begins causing more dissolved hematite to precipitate out of solution around existing nodules.

The amount of iron-oxide mineralization that gives Utah's sandstones their color is typically very small. One in-depth analysis of rock coloration in the Navajo Sandstone found that minuscule differences in iron-oxide mineralization can mean the difference between red, pink, and white sandstone. For instance, red sandstone contained an average of 0.7 percent of iron oxide within the samples, whereas a sample of "bleached" white sandstone contained 0.2 percent. Pink samples seem to have nearly the same amount of iron minerals as the deep red samples; however, the iron in the pink sections of rock is largely stripped from the original grain coatings and redeposited in voids between the sand grains.

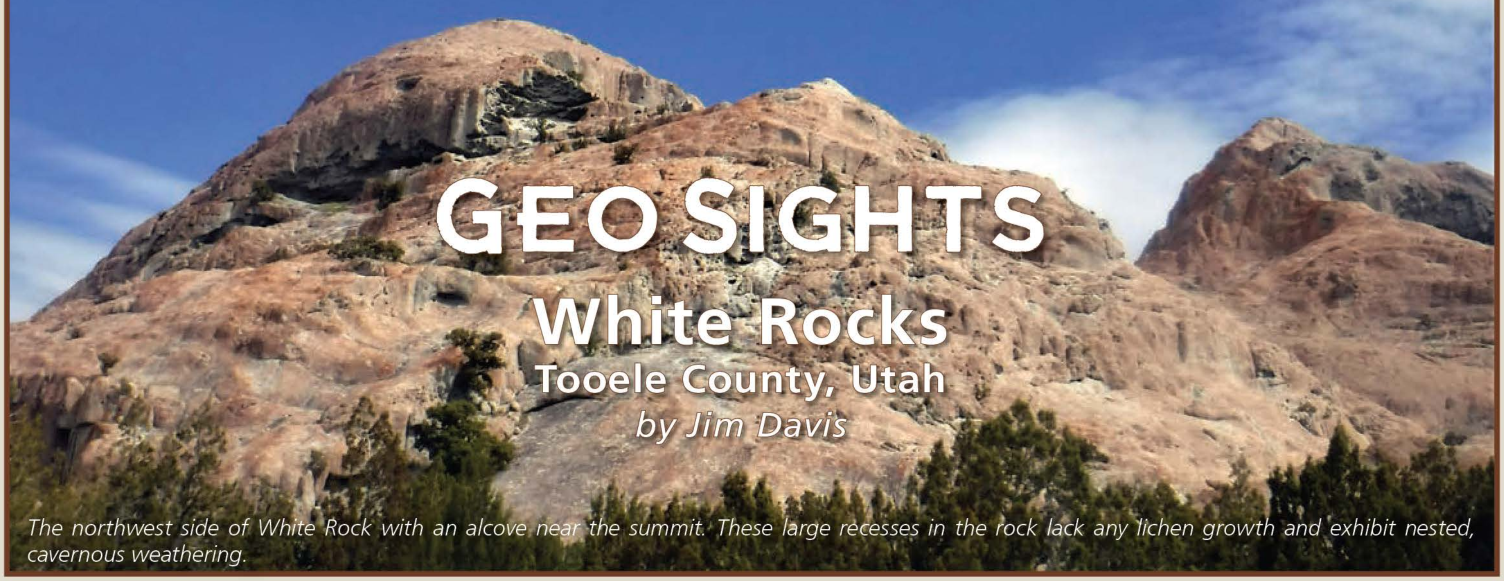
Although geologists are confident about the minerals involved in coloring Utah's red rocks, many questions remain. Some of these involve the extent to which ancient folding, petroleum migration, or even deep geothermal waters might have played a role in the mineralization and coloring of the rocks. Regardless of the answers, all can agree that the colors of the rocks in Utah's Colorado Plateau region make for some of the most spectacular scenery on Earth.



Iron nodules, often called "Moqui marbles," weathering out of the Navajo Sandstone. The nodules here range from about 1 to 4 inches in diameter.

For more information see:

Nielson, G. B., Chan, M. A., and Petersen, E.U., 2009, Diagenetic coloration facies and alteration history of the Jurassic Navajo Sandstone, Zion National Park and vicinity, southwestern Utah, *in* Tripp, B.T., Krahulec, K., and Jordan, J.L., editors, Geology and geologic resources and issues of western Utah: Utah Geological Association Publication 38, p. 67–96.



GEO SIGHTS
White Rocks
Tooele County, Utah
by Jim Davis

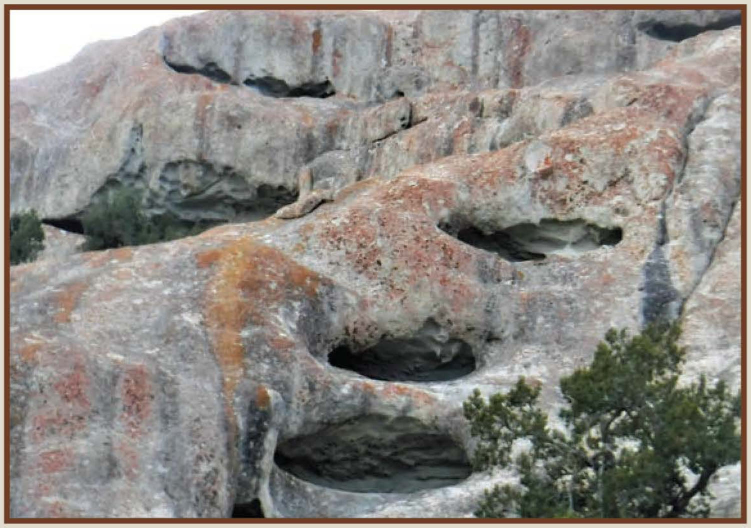
The northwest side of White Rock with an alcove near the summit. These large recesses in the rock lack any lichen growth and exhibit nested, cavernous weathering.

White Rocks is a collection of three light gray, dome-shaped hills of igneous rock in the southern Cedar Mountains in northwestern Utah. People come to White Rocks to hike, climb, camp, seek seclusion, take in the panoramic mountain and valley scenery, and to explore the numerous and diverse weathering features scored into their bald, steep-sided surfaces.

The names White Rocks and White Rock Complex are used to refer to the three largest isolated outcrops that rise starkly above the floor of a sandy, gently sloping 2-square-mile amphitheater. The amphitheater is bounded by various types of faults and encircled by the southern Cedar Mountains. The main outcrop, known officially as White Rock, is considerably larger than the other two outcrops combined, which are informally known as “south rock” and “west rock” and are nearly the same size. Several small, low-lying outcrops or knolls, all less than an acre in size and of the same igneous rock, are scattered across the amphitheater. A bubbling spring and pool, White Rock Spring, is at the west-edge of White Rock.

Collectively, White Rocks is composed of intrusive igneous rock, meaning the rock crystalized from molten magma as it slowly cooled beneath the surface of the Earth. The southern Cedar Mountains are situated in the Uinta-Tooele structural zone (see *Survey Notes*, v. 52, no. 2, p. 4–5), an ancient east-west-trending zone across northern Utah and eastern Nevada, where two blocks of continental crust likely converged around 1.7 billion years ago. Much later this zone of weakness was exploited by igneous activity that swept through Utah between 40 and 23 million years ago. This igneous episode is responsible for White Rocks, dated at nearly 39 million years ago, as well as other volcanic rocks in the southern Cedar Mountains.

A miniature arch, or window, with an opening about one foot high, at the base of the west side of White Rock.

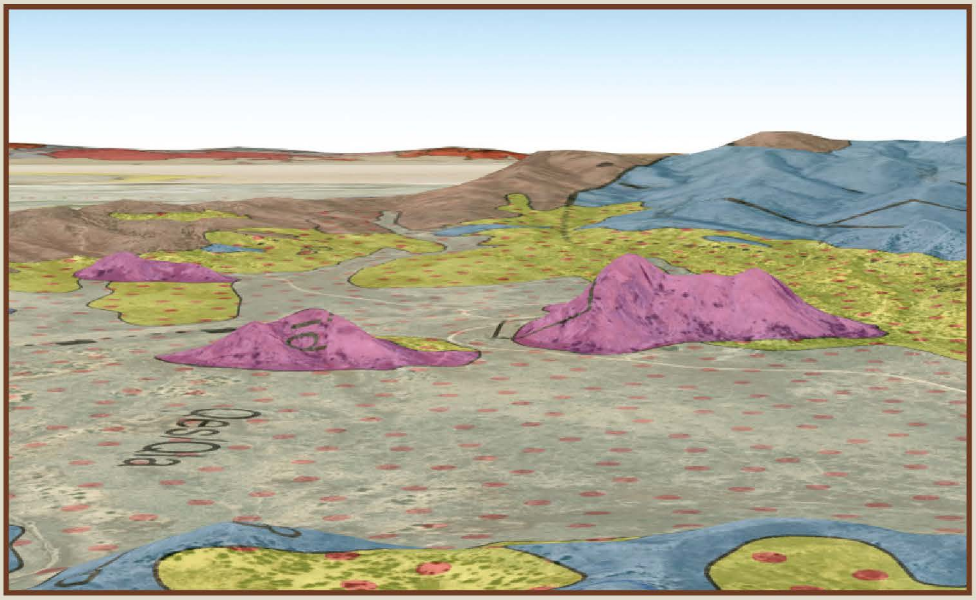


Stacked oblong-shaped caverns on a northwest-facing slope, east side of White Rock. Cavern at bottom is 6 feet high at entrance.

The White Rocks outcrops are peppered with large- to small-sized alcoves and cavities, honeycomb-type, and other weathering features on recesses, vertical walls, and below overhangs. Excellent and larger-scale rock weathering forms occur all over the main White Rock and on the north-facing sides of the south rock. Light gray in color, the rock is patterned with blotches and expanses of primarily orange and lesser yellow, black, and tea-green lichen, preferential to north-facing slopes and absent from caverns. Streaks of iron and manganese stain the rock where storm water is channeled off the domes. Vegetation is sparse; junipers, grass, and cacti grow out of scattered pockets of soil and fractures in the rock. Sweeping views from the top of White Rock include Skull Valley to the north and the Stansbury Mountains to the east.

The rock of White Rocks is an attractive *porphyritic dacite*. Common to volcanic domes such as the Mt. St. Helens lava dome in Washington State, *dacite* is intermediate in composition between andesite and rhyolite. *Porphyritic* rock has large, visible crystals called phenocrysts in a finer-grained groundmass. The easily observable phenocrysts of White Rocks constitute about one-quarter of the rock. White plagioclase feldspar forms the largest crystals, accompanied by fractured, gemmy quartz, and flecked with blackish-brown biotite and amphibole. The grayish groundmass is an intergrowth of plagioclase, potassium feldspar, and quartz. A similar and much larger dacitic intrusion called Little Granite Mountain is located south of White Rocks on the Dugway Proving Ground military installation.

American geologist Clarence King visited White Rocks during the Fortieth Parallel Survey (1867–72) and wrote, "The limestone body of Cedar Mountains . . . is accompanied by outbursts of volcanic rock." King characterized the rock as a quartziferous trachyte, having " . . . a crystalline aggregation of sanidin[e] . . . reach an inch in length . . . brilliant black prisms of hornblende, flakes of biotite, and cracked, rounded grains of quartz." The expedition petrographer called the rock "a very peculiar rhyolite," observing that the quartz grains contain ". . . little glass inclusions, each with a dark bubble . . . the most extraordinary surcharging of them ever seen in this mineral." The rock has another distinctive attribute—fine-grained, spheroidal to oblong inclusions that are linked to the development of some of the weathering cavities. King's petrographer noted, "The crystalline groundmass contains locally some roundish, microfelsitic spots . . . which cannot be resolved into individual crystals."



Virtual view of White Rocks using the Rush Valley 30' x 60' quadrangle geologic map from the UGS interactive Geologic Map Portal; https://geology.utah.gov/apps/intgeomap/. Oblique view to the west with satellite base map. The pink hills are the three main outcrops at White Rocks and are surrounded by a plain of sand and silt—yellow and white with red dots. Limestone (blue) and lava flows (brown) encircle the White Rocks amphitheater. White Rock, at right, is about 44 acres and rises some 375 feet from the amphitheater floor. The nearby second white rock (south rock) rises 185 feet in height and is 12 acres in size, and in the distance, at left, the third white rock (west rock) rises 145 feet in height and covers 10 acres.

HOW TO GET THERE

From Salt Lake City go west on I-80 for 42 miles and take Exit 77 (Rowley, Dugway). Turn left and continue south on Highway 196 for 29.5 miles. A Bureau of Land Management (BLM) sign for "White Rocks" marks the turnoff. Turn right onto the gravel road (White Rock Road) and go west for 5.5 miles where the road splits. Take the left (southwest) fork onto a curvy road for 3.8 miles to reach the most visited part of the White Rocks area (west side of main White Rock). From here the road continues to loop around the main White Rock but shortly after passing White Rock Spring, a pond adjacent to the road about 60 feet in diameter (mostly dry in summer), the road degrades and is not recommended for low-clearance vehicles.

Notes:

There are no services in Skull Valley, including the nearby "closed city" of Dugway (on a military installation). Go with sufficient fuel and supplies. The Dugway Proving Ground is near the edge of the White Rocks amphitheater to the west and south; trespassing here is prohibited. White Rock has tall cliffs, steep slopes, and loose and crumbling rock surfaces; use caution when traversing the rock. The White Rocks area is frequented by climbers, scouts, horse riders and target shooters. Autumn and spring are the most pleasant times of year to visit and weekends can be more crowded. Approximately a dozen primitive, dispersed, first-come-first-served campsites are around the bases of the White Rocks, most at the main rock. There are no developed facilities, water, or restrooms. No fees are required. Dogs are allowed.

Land Ownership:

Nearly the entire amphitheater containing the White Rocks is Bureau of Land Management. Within a one-mile radius of White Rock is private, state, national forest, and military land.

Location:

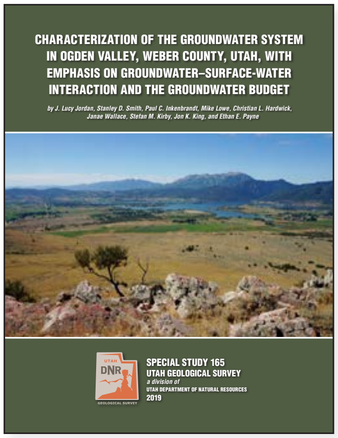
Latitude 40.32244°N, Longitude 112.90191°W

Elevation:

Approximately 5,280 to 5,693 feet

SURVEY NEWS

2020 Crawford Award

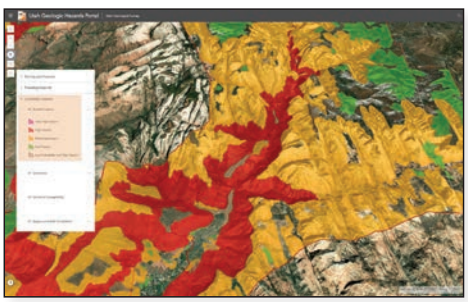


The Utah Geological Survey's prestigious Crawford Award was presented to **Lucy Jordan**, Stan Smith (formerly UGS), **Paul Inkenbrandt**, Mike Lowe (UGS, retired), **Christian Hardwick**, **Janae Wallace**, **Stefan Kirby**, **Jon King**, and Ethan Payne (formerly UGS) in recognition of their work on the outstanding publication, *Characterization of the Groundwater System in Ogden Valley, Weber County, Utah, with Emphasis on Groundwater–Surface-Water Interaction and the Groundwater Budget* (UGS Special Study 165).

The work summarized in Special Study 165 has had a major influence on the understanding of groundwater conditions in Ogden Valley. The project's cutting-edge science contributed to a comprehensive assessment and model of Ogden Valley's groundwater system that will likely guide sustainable development in this area for decades to come. Special Study 165 provides a complete and clear geologic context, provides critical information about current and future groundwater use, and sets a standard and methodology that could be applied to Utah's developing back valleys and other areas.

The Crawford Award recognizes outstanding achievement, accomplishments, or contributions by current UGS scientists to the understanding of some aspect of Utah geology or earth science. The award is named in honor of Arthur L. Crawford, first director of the UGS.

New Online Geologic Hazards Resource



The UGS recently released the Utah Geologic Hazards Portal, an online mapping application that provides information on the type, location, and relative susceptibility of geologic hazards. Users of the new app can zoom in to their location or search by address to find geologically active faults, landslides, and a host of other geologic hazards in selected areas. The app also includes a report generator designed to provide a summary of information for specific sites. The Utah Geologic Hazards Portal can be accessed from the UGS website at https://geology.utah.gov/apps/hazards/.

UGS Board Update

We are pleased to announce a transition of leadership roles among our UGS Board members. **Elissa Richards** has accepted the nomination of chair and **Ken Fleck** has accepted the nomination of vice chair. Elissa and Ken are taking on the leadership roles previously held by **Marc Eckels** and **Pete Kilbourne**, respectively. Congratulations to Elissa and Ken and thank you to Marc and Pete for your many years of UGS Board leadership.

Employee News

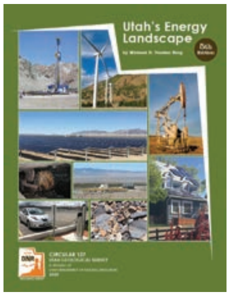
Congratulations to **Rosemary Fasselin** who accepted a Senior GIS Analyst position with the UGS Geologic Mapping Program. Best wishes to **Andy Cvar** who left the UGS after 5 years of service with the Natural Resources Map & Bookstore.

In Memoriam

Harold (Hal) E. Gill, former geologist with the Utah Geological (and Mineral) Survey from 1980 to 1986, passed away at his home in Arizona on April 16, 2020. Hal worked in the (then) Applied Geology Program Site Investigations Section where he was well known for his hard work and good humor. In particular, he worked on landslides and in identifying groundwater resources for municipalities throughout the state, and did the original engineering geologic work for the Park City area.

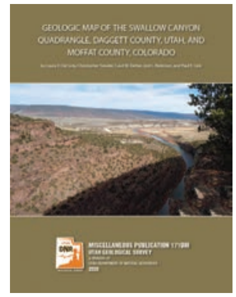
NEW PUBLICATIONS

Available for download at **geology.utah.gov** *or for purchase at* **utahmapstore.com**.

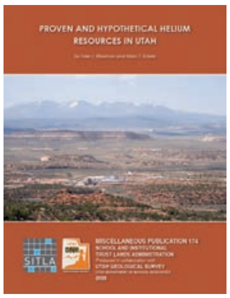


Utah's Energy Landscape–5th Edition, by Michael D. Vanden Berg, 45 p., **C-127**, https://doi.org/10.34191/C-127.

Critical Minerals of Utah, by Stephanie E. Mills and Andrew Rupke, 49 p., **C-129,** https://doi.org/10.34191/C-129.

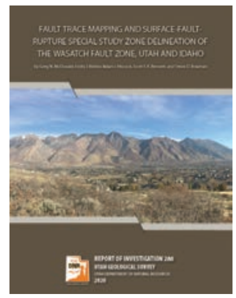


Geologic Map of the Swallow Canyon Quadrangle, Daggett County, Utah, and Moffat County, Colorado, by Laura D. De Grey, Christopher Tressler, Carol M. Dehler, Joel Pederson, and Paul K. Link, 11 p., 2 plates, scale 1:24,000, **MP-171DM**, https://doi.org/10.34191/MP-171DM.



Proven and Hypothetical Helium Resources in Utah, by Tyler J. Wiseman and Marc T. Eckels, 44 p., 1 plate, scale 1:850,000, **MP-174**, https://doi.org/10.34191/MP-174.

Geologic Hazards of the Bullfrog and Wahweap High-Use Areas of Glen Canyon National Recreation Area, San Juan, Kane, and Garfield Counties, Utah, and Coconino County, Arizona, by Tyler R. Knudsen, Adam I. Hiscock, William R. Lund, and Steve D. Bowman, 66 p., **SS-166**, https://doi.org/10.34191/SS-166.



Fault Trace Mapping and Surface-Fault-Rupture Special Study Zone Delineation of the Wasatch Fault Zone, Utah and Idaho, by Greg N. McDonald, Emily J. Kleber, Adam I. Hiscock, Scott E.K. Bennett, and Steve D. Bowman, 23 p., **RI-280**, https://doi.org/10.34191/RI-280.

Time Series Analyses of a Great Basin Groundwater-Fed Wetland Complex, Juab County, Utah: Climate Effects on Groundwater-Dependent Wetlands, by Paul Inkenbrandt, 26 p., **RI-282**, https://doi.org/10.34191/RI-282.

Carbonate (Limestone and Dolomite) Analytical Database of Utah, by Andrew Rupke, 2 p., **OFR-715,** https://doi.org/10.34191/OFR-715.

Interim Geologic Map of the Grouse Creek and Utah Part of the Jackpot 30' x 60' Quadrangles, Box Elder County, Utah, and Cassia County, Idaho, by David M. Miller, Donald L. Clark, Michael L. Wells, Charles G. Oviatt, Tracey J. Felger, and Victoria R. Todd, 29 p., 1 plate, scale 1:62.500, supercedes OFR-598, **OFR-716DM,** https://doi.org/10.34191/OFR-716DM.

Geologic Map of the Deep Creek Mountains Wilderness Study Area, Tooele and Juab Counties, Utah (GIS Reproduction of USGS MF-2099 [1989]), by David W. Rogers, 1 plate, scale 1:50,000, **OFR-717DR**, https://doi.org/10.34191/OFR-717DR.

RECENT OUTSIDE PUBLICATIONS BY UGS AUTHORS

Unexpected Abundance and Diversity of Phototrophs in Mats from Morphologically Diverse Microbialites in Great Salt Lake, Utah, by M. Kanik, M. Munro-Ehrlich, M. Fernances-Martins, D. Payne, K. Gianoulias, L. Keller, A. Kubacki, M. Lindsay, B. Baxter, **M. Vanden Berg**, D. Colman, and E. Boyd: Applied and Environmental Microbiology, v. 86, no. 10, https://doi.org/10.1128/AEM.00165-20.

Lacustrine Cyclicity in the Early Eocene Green River Formation, Uinta Basin, Utah–Evidence from X-ray Fluorescence Core Scanning, by A.P. Walters, S.R. Meyers, A.R. Carroll, T.R. Hill, and **M.D. Vanden Berg**: Journal of Sedimentary Research, v. 90, p. 429–447, https://doi.org/10.2110/jsr.2020.24.

TEACHER'S CORNER

2020 Earth Science Week

Since its creation in 1998 by the American Geosciences Institute (AGI), Earth Science Week (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.

Normally, the UGS hosts ESW activities for school groups annually in October. Due to the COVID-19 pandemic, on-site activities for ESW 2020 at the UGS are canceled. However, we are planning to provide online virtual activities as an alternative. For updates and more information on ESW, see our web page at geology.utah.gov/teachers/earth-science-week.

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