UTAH GEOLOGICAL SURVEY

SURVEY NOTES

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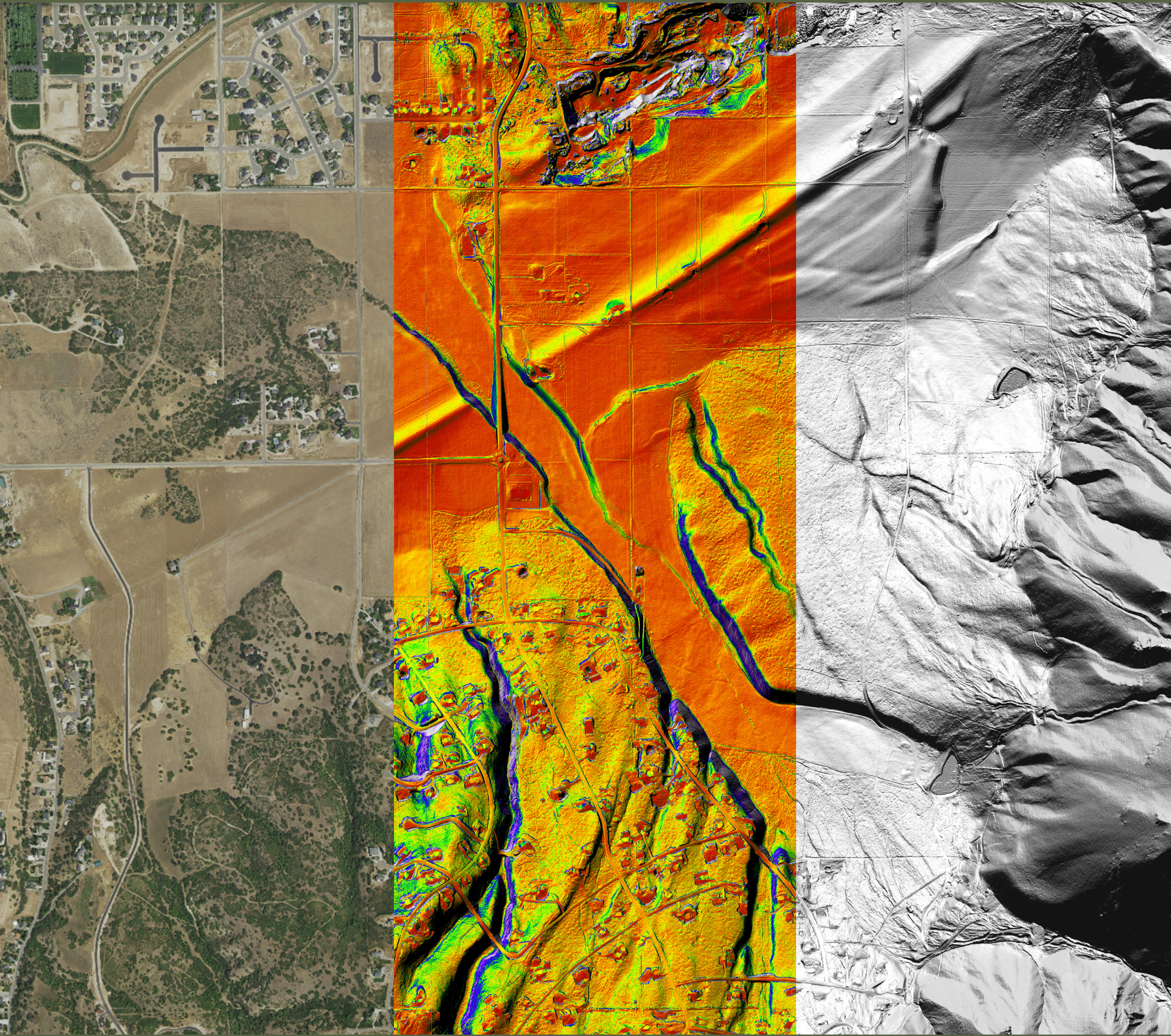

Mapping Geologic Hazards In Utah

Contents

Design | *Jennifer Miller*
Cover | Modern aerial imagery on the left shows recent development in Salem, Utah, and the surface-slope image (center) and hill-shaded image (right) highlight how geologic processes affect topography.

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THE DIRECTOR'S PERSPECTIVE

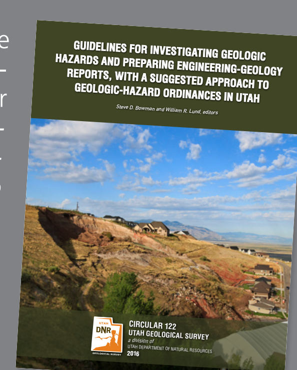
by Richard G. Allis

Earthquakes, and the faults that trigger them, are a main research focus of the UGS Geologic Hazards Program. This issue of *Survey Notes* highlights new mapping of the Wasatch fault zone, and announces the publication of a new map of Utah's historical earthquakes and hazardous faults. UGS Map 277, *Utah Earthquakes (1850–2016) and Quaternary Faults* (https://ugspub.nr.utah.gov/publications/maps/m-277.pdf), is another visually powerful reminder that we live in earthquake country. The last destructive earthquake in Utah occurred 25 years ago near St. George and had a magnitude of 5.5 (moment magnitude). The historical record shows that earthquakes of at least magnitude 5.5 occur on average once every 10 years in Utah. In the central part of the Wasatch fault between Nephi and Brigham City, it has been over 100 years since several damaging earthquakes estimated to be about magnitude 5.5 occurred. However, we know from trenching across the Wasatch fault that more than 20 earthquakes of at least magnitude 6.5 have occurred in the past 6000 years on this central part of the fault zone. These studies also indicate that the characteristic magnitude of earthquakes here is between 7.1 and 7.3, which is large enough to cause major loss of life and large-scale damage to the most populous area of the state. Last year, the UGS published a report by the Working Group on Utah Earthquake Probabilities quantifying the earthquake risk. This group estimated a 57 percent probability of at least one earthquake of magnitude 6.0 or greater occurring in the next 50 years in the Wasatch Front region (https://ugspub.nr.utah.gov/publications/misc_pubs/mp-16-3/mp-16-3.pdf). The probability of at least one earthquake of magnitude 6.75 or greater occurring in the next 50 years is 43 percent. The report concludes that there is a "realistic chance that many current residents of the Wasatch Front region will experience a large earthquake in their lifetimes."

Are you prepared for a large earthquake? Does your family have a plan if an earthquake occurred right now? If you are at work and your children are at school, how will you get back together? Have you prepared a disaster supply kit (water, food, first aid supplies, medications) in case you are without vital services for days following an earthquake? Is your hot water heater strapped and could tall furniture and objects fall and cause injury? An excellent handbook on the threat posed by earthquakes in Utah, and preparing for, surviving, and recovering from these inevitable events, is *Putting Down Roots in Earthquake Country—Your Handbook for Earthquakes in Utah* (http://files.geology.utah.gov/online/pdf/eq_handbook.pdf).

Claire P. Holdredge Award

Steve Bowman and **William Lund** were selected as the recipients of the Association of Environmental & Engineering Geologists (AEG) Claire P. Holdredge Award for their publication UGS Circular 122: ***Guidelines for Investigating Geologic Hazards and Preparing Engineering-Geology Reports, with a Suggested Approach to Geologic-Hazard Ordinances in Utah***. While Steve and Bill were co-editors of the publication, the entire Geologic Hazards Program contributed individual chapters, sections of text, figures, and/or technical review, and the award should be considered as applying to all program staff and others who supported the project.



Publication available at https://ugspub.nr.utah.gov/publications/circular/c-122.pdf.

The Wasatch Fault from Above:

Re-mapping the Wasatch Fault Zone Using Airborne High-Resolution Topographic Data

BY Emily Kleber

In 1883, the celebrated pioneer of Utah geology, G.K. Gilbert, wrote a letter to the *Salt Lake Daily Tribune* warning residents of Utah's shaky past. In this letter, he indicated the massive elevation difference between Salt Lake Valley and the peaks in the Wasatch Range as evidence for a prolonged history of geologic uplift of the mountains and down-dropping of the valley floor from earthquakes. He noted that this is a regional pattern throughout the Great Basin, where mountain ranges are flanked on either side by valley floors and often have evidence of recent earthquake activity. "When an earthquake occurs, a part of the foot-slope goes up with the mountain, and another part goes down (relatively) with the valley. It is thus divided, and a little cliff marks the line of division. This little cliff is...a 'fault scarp' and the earth fracture which has permitted the mountain to be uplifted is a 'fault'." Gilbert warned that fault scarps along the western base of the Wasatch Range in Salt Lake Valley were evidence of large surface-faulting earthquakes that had occurred before pioneers settled in Utah in 1847, and more would occur in the future.

Gilbert was observing the central segments of what we now call the Wasatch fault zone. This zone consists of a series of normal faults in ten active segments along a 250-mile-long stretch from north of Malad City, Idaho, to south of Fayette in central Utah. The Wasatch fault zone is one of the best studied continental normal-fault zones on Earth. Although the Wasatch fault has been previously mapped, much of the mapping is spatially coarse and not at the accuracy needed for effective land-use and geologic-hazard ordinances. A recent cooperative grant between the Utah Geological Survey (UGS) and the U.S. Geological Survey's National Earthquake Hazards Reduction Program is providing funding to re-map the Wasatch fault zone in greater detail using recently acquired lidar (light detection and ranging) data and historical aerial photographs. This higher resolution mapping better fits the demand of modern GIS analysis and mapping, as well as current and future development along the Wasatch Front.

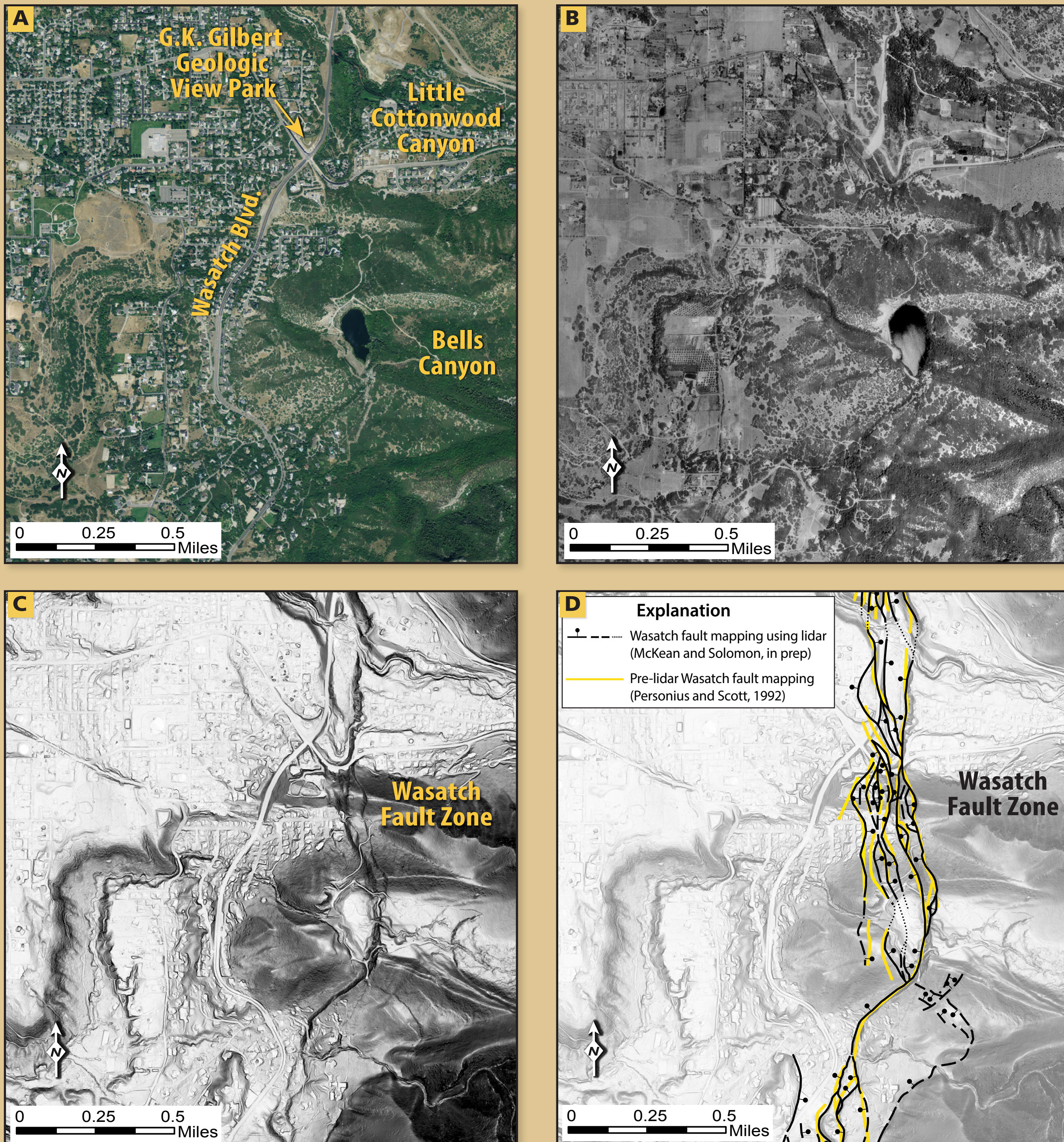
Mapping from Above

Lidar is a remote sensing technique that has recently revolutionized how earth scientists study the interaction of earthquakes and surface processes over time. Lidar is similar to radar or sonar, but instead of radio or sound waves measuring distance, pulses of laser light are emitted from a sensor and reflected off various things on the Earth's surface. The amount of reflected light and timing of the laser pulse return to the sensor can be calculated to represent what the laser pulse hit, for example vegetation or buildings, and gives a precise location of that point, with less than half-inch accuracy. These data are commonly collected from an aircraft that flies in a lawn mower-type pattern to completely cover an area of interest. The result of this airborne survey is millions to billions of elevation points that can be classified based on the reflection of the laser light pulse from the aircraft-mounted sensor. This classification enables geologists to remove points classified as buildings, vegetation, or infrastructure, and focus on the shape of the land surface that has been modified by geologic processes.

Map showing urban areas along the Wasatch Front. The 10 segments of the Wasatch fault zone (WFZ) are labeled, as is the extent of currently available airborne lidar data coverage.

From 2011 to 2014, a partnership with local, state, and federal agencies funded the collection of over 3000 square miles of airborne lidar data along the entire active Wasatch fault zone including Salt Lake and Utah Valleys. This dataset has more than 40 billion lidar points! These data are being used for several local, state, and federal projects to better characterize the Wasatch fault zone and improve seismic hazard analysis in the Wasatch urban corridor. These data are available online for free through the National Science Foundation-funded OpenTopography data portal or through the Utah Automated Geographic Reference Center (AGRC).

The mapping for this project includes about thirty 7.5-minute quadrangles along the Wasatch Front in Idaho and Utah as well as the northern part of Salt Lake Valley that includes the West Valley fault zone. The lidar data are used to create three-dimensional models of the ground surface by stripping off vegetation and infrastructure. Once this surface is created, the data can be digitally manipulated to view the surface in meaningful ways to observe the surface geology of the Wasatch fault. Two of the most useful models for these surfaces are a hillshade model, where the sun is modeled at a certain height and direction, and a slope model, where subtle changes in the surface slope angle can be detected.



Airborne data for mapping the Wasatch fault zone at the mouth of Little Cottonwood Canyon, Utah. (A) Recent aerial photography, (B) historical aerial photography showing undeveloped areas, (C) slope-shade model that combines hillshade and slope models, and (D) a comparison of mapping done with lidar (black lines) and without lidar (yellow lines).

In addition to modern data techniques, an incredibly valuable tool for urban fault mapping is historical aerial photographs. The UGS has an extensive online collection of photographs of Utah from the 1930s to 2014. These photos are critical for urban mapping because they may show the ground shape before being modified by development activities. Additionally, many of these photos were taken in an overlapping pattern called stereo-pairs, allowing them to be viewed in 3D using a special set of glasses. This technique has been used for decades and remains relevant today. Within the *UGS Aerial Imagery Collection* is a set of historical low-sun-angle stereo aerial photos taken of the Wasatch fault before major development occurred in many areas. Like the hillshading technique used with lidar data, the low sun angle generally illuminates fault scarps clearly, allowing for more accurate mapping of fault traces.

Once the new fault mapping is completed, surface-fault-rupture-hazard special study areas will be delineated along the Wasatch and West Valley fault zones. These buffered zones around the fault traces define areas requiring additional geological and geotechnical investigation to evaluate the hazard from surface faulting prior to development. For well-defined faults that are mapped with certainty, the special study areas will extend 500 feet on the downthrown side and 250 feet on the upthrown side of each fault trace. For buried or inferred faults, the special-study areas will extend 1000 feet on each side of the suspected trace of the fault. These special-study areas are critical to the success of municipal and county geologic-hazard ordinances dealing with hazardous faults, as well as understanding surface-faulting hazard and associated risk.

For more information:

- Lidar elevation data: https://geology.utah.gov/resources/data-databases/lidar-elevation-data/
- OpenTopography: http://www.opentopography.org
- AGRC: http://gis.utah.gov/data/elevation-terrain-data
- UGS Aerial Imagery Collection: http://geodata.geology.utah.gov/imagery
- UGS Geological Hazards Investigation Guidelines: https://ugspub.nr.utah.gov/publications/circular/c-122.pdf
- LiDAR: Valuable Tool in the Field Geologist's Toolbox, *Survey Notes*, January 2015: https://ugspub.nr.utah.gov/publications/survey_notes/snt47-1.pdf

ABOUT THE AUTHOR

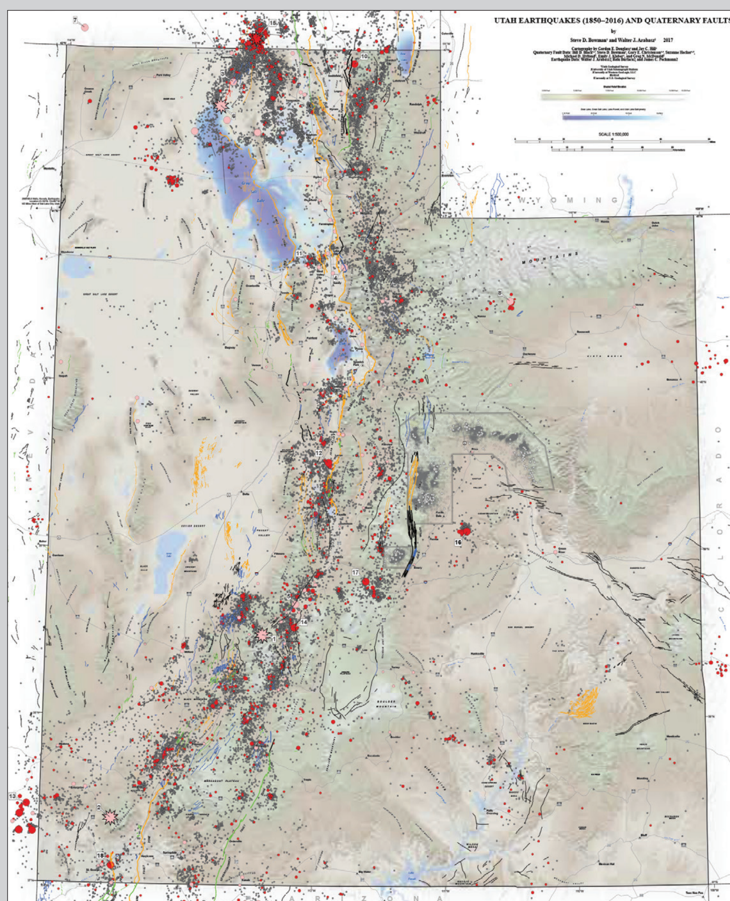
Emily Kleber is a Hazards Mapping Geologist for the UGS where she has worked since 2016. She has degrees in geology from University of California–Davis and Arizona State University. Emily has expertise with high-resolution topographic data from her work with the National Science Foundation-funded lidar project OpenTopography. She is passionate about helping people understand geologic hazards in Utah through her work with the UGS as well as adjunct teaching at Salt Lake Community College and Westminster College.

NEW MAP

Highlights Utah's Earthquakes and Hazardous Faults

The Utah Geological Survey, the University of Utah Seismograph Stations, and the Utah Division of Emergency Management recently published the *Utah Earthquakes (1850 to 2016) and Quaternary Faults* map that shows earthquakes known to have occurred within and surrounding Utah and mapped Quaternary faults considered to be earthquake sources. This map is based on the most recently available earthquake and fault data. The three-agency Utah Earthquake Program developed the map so the public could more fully understand the hazard from earthquakes and faults, as well as the resulting risk to property, infrastructure, and life safety in Utah. Additional information on the hazard and resulting risk from earthquakes is available at https://geology.utah.gov/hazards/earthquakes-faults/ and from the Utah Seismic Safety Commission (https://ussc.utah.gov).

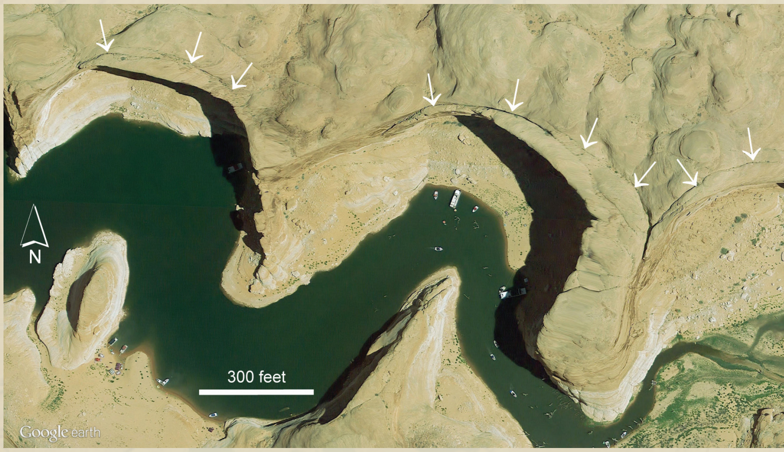
The map is available as a PDF download (https://ugspub.nr.utah.gov/publications/maps/m-277.pdf, 44 by 62 inches in size) that can be printed on a wide-format printer, and is being professionally printed for purchase at the Utah Department of Natural Resources Map & Bookstore (http://mapstore.utah.gov/). Printed copies are anticipated to be available in September 2017.



Geologic Hazard Mapping
in Glen Canyon National Recreation Area

BY Tyler Knudsen, Adam Hiscock, William Lund, and Steve Bowman

Stunning landscapes and a variety of recreational opportunities centered on Lake Powell attract nearly 2.5 million visitors annually to Glen Canyon National Recreation Area (GCNRA). Geologic processes that shaped this rugged landscape are still active today, and can be hazardous to visitors, employees, and infrastructure. To provide the National Park Service (NPS) with necessary geologic-hazard information for future park management, the Utah Geological Survey (UGS) has nearly completed a geologic-hazard investigation of two high-use sections of the recreation area: a 297-square-mile area near the Bullfrog and Halls Crossing Marinas, and a 117-square-mile area centered on Wahweap and Antelope Point Marinas near the Utah-Arizona border.



Curvilinear joints (marked by white arrows) above alcoves in Forgotten Canyon increase the rockfall hazard for boaters moored below. Google Earth image.

Erosional geologic processes dominate the Glen Canyon region. Canyon entrenchment and widening via stream erosion (primarily floods) and mass wasting (primarily landslides and rockfall) create the principal geologic hazards with which tourists and NPS staff must contend. Both flooding and rockfall have caused multiple fatalities and many additional injuries.

On an annual basis, the most widespread and dangerous geologic hazard in GCNRA is flooding. Flash floods are sudden, intense, localized events that occur in response to heavy rainfall that often accompanies summertime monsoonal thunderstorms. Viscous, sediment-laden floods (debris flows) have repeatedly destroyed or damaged roads near Lees Ferry, where several short, steep drainages have headwaters in the easily eroded, clay-rich Chinle Formation. Narrow, bedrock-floored canyons (slot canyons) are particularly prone to the effects of flash floods because they commonly lack escape routes, are remotely located, are subject to periodic logjams that present troublesome obstacles, and many can hold cold floodwater for weeks that can contribute to hypothermic conditions. Since 1961, 15 people have died in GCNRA due to canyon floods. Eleven deaths occurred on August 12, 1997, when a severe thunderstorm caused a flash flood that swept 11 tourists and a tour guide down Antelope Canyon near Page, Arizona—the tour guide alone survived. The increasing popularity of canyoneering—hiking, climbing, and swimming through slot canyons with the aid of technical climbing equipment—will likely cause an increase in flood-related incidents within GCNRA.

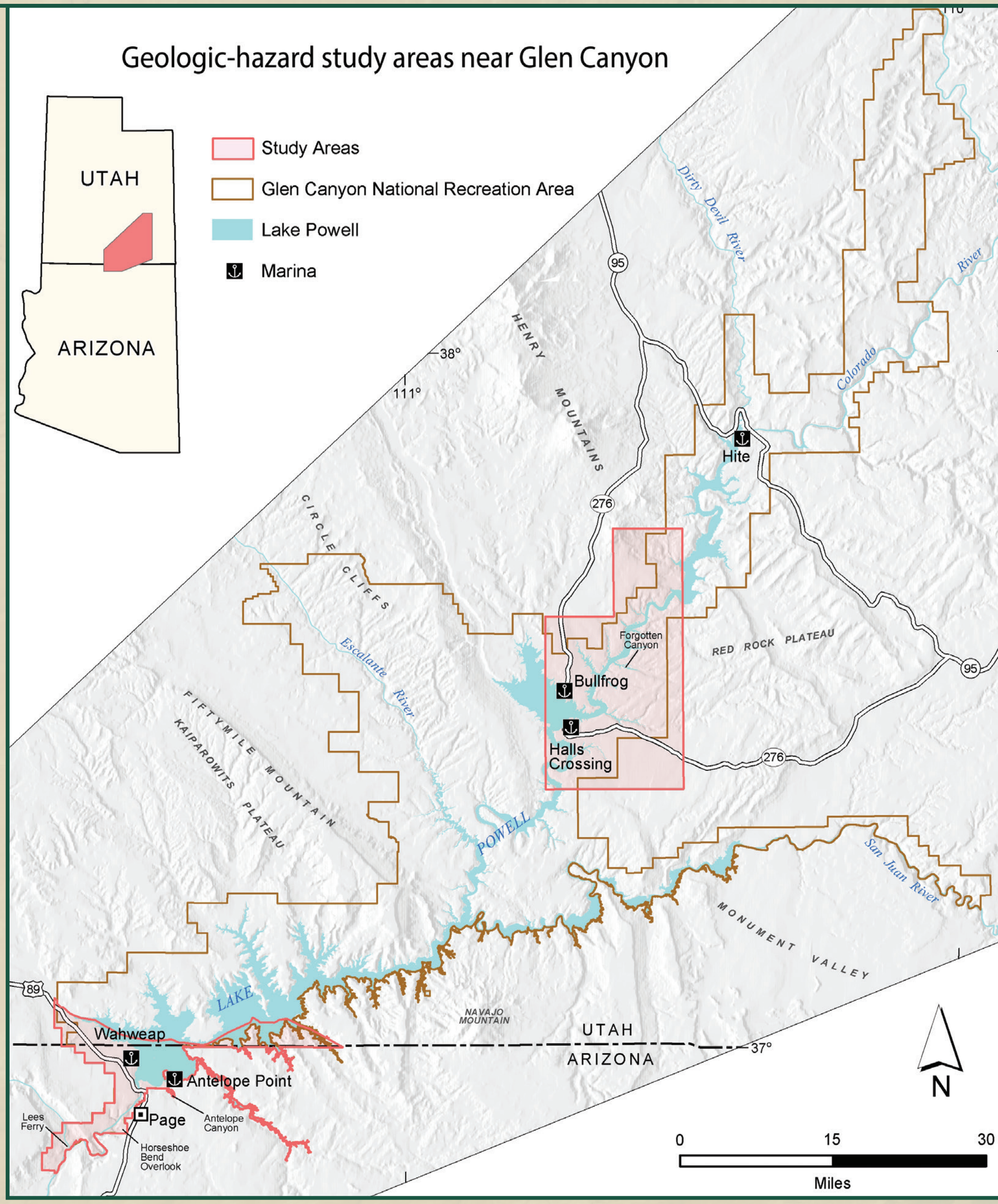
Flood damage in 2013 to road near Lees Ferry. Photo courtesy of the National Park Service.

The geology of GCNRA is conducive to widespread rockfall hazard. Rockfalls are particularly prevalent and hazardous where easily eroded bedrock units create slopes below more resistant bedrock formations. Four resistant-over-easily-eroded bedrock pairs are particularly susceptible to rockfall in the study area: Shinarump Conglomerate over the Moenkopi Formation, Wingate Sandstone over the upper Chinle Formation, Navajo Sandstone over the Kayenta Formation, and Entrada Sandstone over the Carmel Formation. Erosion of the "weak" underlying units and subsequent undercutting of the more resistant bedrock formations leads to many rockfalls. Natural breaks or joints in sandstone are prominent features in the Glen Canyon region and, depending on their orientations and frequency, can significantly increase the rockfall hazard. Alcoves and other overhanging rock masses along the Lake Powell shoreline make attractive mooring spots and campsites for boaters, particularly in the summer when alcoves provide shade, cooler temperatures, and shelter from thunderstorms. Unfortunately, alcoves also generate frequent rockfalls. Fatal incidents in 1975 and 2007 were both attributed to falling rock from alcove ceilings that destroyed boats moored below. At least

An open joint (indicated by white arrows) has partially detached a Navajo Sandstone block and creates a high hazard for visitors to the popular Horseshoe Bend Overlook.

two additional fatalities in GCNRA occurred when small rock masses upon which people were standing broke loose causing both the rock and the person to fall down near-vertical slopes. This most recently occurred at the Horseshoe Bend Overlook in July 2010.

Our geologic-hazard mapping is based primarily on geologic mapping previously completed by the UGS Geologic Mapping Program. Soils mapping by the Natural Resources Conservation Service, incident reports from the NPS, aerial photograph interpretation, a limited number of geotechnical reports, and both ground- and boat-based field reconnaissance were also key data sources used to evaluate and map geologic hazards. We compiled and mapped geologic-hazard data at a scale of 1:24,000 in a geographic information system (GIS) database. Geologic hazards mapped in the Glen Canyon study area are (1) flooding and debris flows, (2) rockfall, (3) landslides, (4) soils susceptible to erosion, (5) gypsiferous soil and rock, (6) expansive soil and rock, (7) collapsible soil, (8) surface faulting, and (9) liquefaction. An accompanying report will describe each geologic hazard and provide background information on data sources, the nature and distribution of the hazards, and possible hazard-reduction measures.



For more information:

- Geologic Hazard Maps: https://geology.utah.gov/map-pub/maps/geologic-hazard-maps
- Fatalities and Costs of Geologic Hazards, see chapter 1 in UGS Circular 122: https://ugspub.nr.utah.gov/publications/circular/c-122.pdf
- GCNRA: https://www.nps.gov/glca

TEACHER'S CORNER

Utah Geological Association Teacher of the Year Award

Deborah Morgan of South Sevier High School is this year's recipient of the Utah Geological Association's Utah Earth Science Teacher of the Year Award. Deborah developed her "Out of the Earth" lesson plan "to help students start an educated and thoughtful discussion about the importance of our natural resources and the management of them."

Deborah was awarded $1,200 plus $300 reimbursement for procuring resources related to earth science education. Additionally, her name will be entered in the regional contest sponsored by the Rocky Mountain Section of the American Association of Petroleum Geologists. Congratulations Deborah!

2017 FLOODING AND LANDSLIDES
in Box Elder County, Utah

BY **Richard Giraud and Greg McDonald**

In the Tremonton area of Box Elder County, an abrupt change in winter weather caused overland flooding, riverine flooding along the Bear River, and landslides. Beginning on February 7 and lasting through February 27, 2017, weather systems moving through northern Utah brought over 4 inches of rain and warm temperatures up to 20 degrees above normal. The combination of rain and above-normal temperatures quickly melted the deep, low-elevation snowpack causing flooding and landslides. Overland flooding and a rise in shallow groundwater levels flooded fields, roads, and basements, and caused septic drain systems to malfunction. The area experienced similar problems during the record wet year of 1983. Flooding and resulting damage overwhelmed the capabilities of local jurisdictions and on February 14, 2017, Box Elder County declared a local emergency. On February 17, Box Elder County Emergency Management invited the Utah Geological Survey (UGS) to assist in evaluating landslide problems. On March 31, Governor Herbert declared a State of Emergency and on April 6, requested a Presidential Disaster Declaration. On April 21, President Trump signed a Disaster Declaration for Public Assistance for $5.98 million (for both Box Elder and Cache Counties).

The February 2017 weather event triggered numerous landslides and Box Elder County officials were concerned about potential threats to houses and roads. All the landslides of concern lie in the bluffs above the Bear River. The river bluffs originally formed as the water level of ancient Lake Bonneville declined to modern Great Salt Lake levels and the Bear River incised into the lake bed sediments. River erosion formed large meander bends and river bluffs 50 to 120 feet high. All of the landslides observed in 2017 are reactivations of preexisting landslides with historical movement. The snowmelt and rain event appears to have raised shallow groundwater levels, saturating landslides and triggering movement that lasted from mid-winter into early spring.

The UGS monitored landslide movement and advised local officials on landslide risk and associated hazards on three landslides located at 10800 North 4400 West, 9050 North River Road, and 7200 North 4600 West. The 10800 North 4400 West landslide damaged a county road. During the snowmelt and rain event, water from overland flooding was flowing across the road and onto the landslide head, keeping the landslide saturated and causing the landslide to step closer to the road. On May 2, 2017, the landslide main scarp was 9.5 feet from the road at its closest point. The landslide has removed lateral support for the roadway embankment and the road will likely fail due to this lack of support. **The 9050 North River Road landslide** threatens a road in Elwood City. The landslide is only 50 to 70 feet high, but extends for about 1700 feet along the river bluff. Landslide movement adjacent to River Road caused the landslide head to drop 3 to 5 feet and step closer to the road. The landslide main scarp is 6.5 feet from the road at its closest point and parts of the road will likely fail due to lack of lateral support. The landslide also threatens the access road to Hansen Park and has exposed an underground telephone cable. **The 7200 North 4600 West landslide** directly threatens a house. The landslide advanced a few feet closer to the house in 2017. The landslide is now 14 feet from the house at its closest point and the house was abandoned as a safety precaution. The lower landslide is at river level and under water when the Bear River is at flood stage. Flood conditions in February likely played a role in triggering landslide movement here in 2017. **A fourth landslide at Bear Hollow Lakes,** a private water recreation and residential development, nearly impacted a house. A concrete block barrier was subsequently placed below the landslide in an attempt to protect the house.

Wet years with rapid snowmelt and rain events continue to show Box Elder County's vulnerability to overland flooding, riverine flooding, and landslides. Communities that have developed in areas where flooding and landslides damage houses and infrastructure face difficult challenges on how to manage these areas in the future. The 1983 and 2017 flooding and landslide events provide important lessons on where to build safely and how to manage these hazards when they occur. Because these landslides have shown historical movement prior to 2017, they will likely move again in the future. The recently published UGS *Guidelines for Investigating Geologic Hazards and Preparing Engineering-Geology Reports* (https://ugspub.nr.utah.gov/publications/circular/c-122.pdf) will be useful for planning and managing redevelopment and mitigation of existing hazards. The UGS continues to map landslides, document historical landslide events, and monitor groundwater and landslide movement in select areas to aid in reducing landslide hazards in Utah.

For more information:

- For information on the UGS Geologic Hazards Program: https://geology.utah.gov/hazards/
- For information on landslides: https://geology.utah.gov/hazards/landslides-rockfalls/
- For photographs from the UGS geologic emergency response to the Box Elder County flooding and landslide event: https://geodata.geology.utah.gov/pages/search.php?search=!colection181

Photo taken March 15, 2017.

Photo taken March 29, 2017.

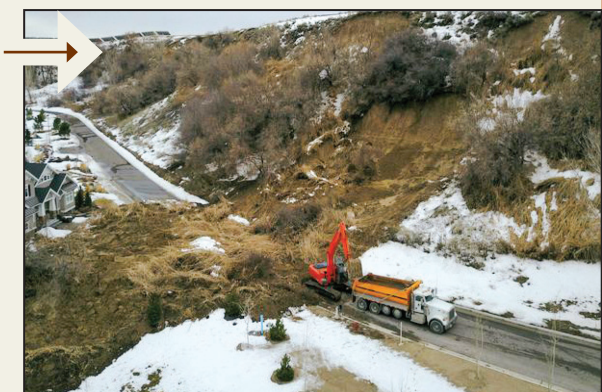
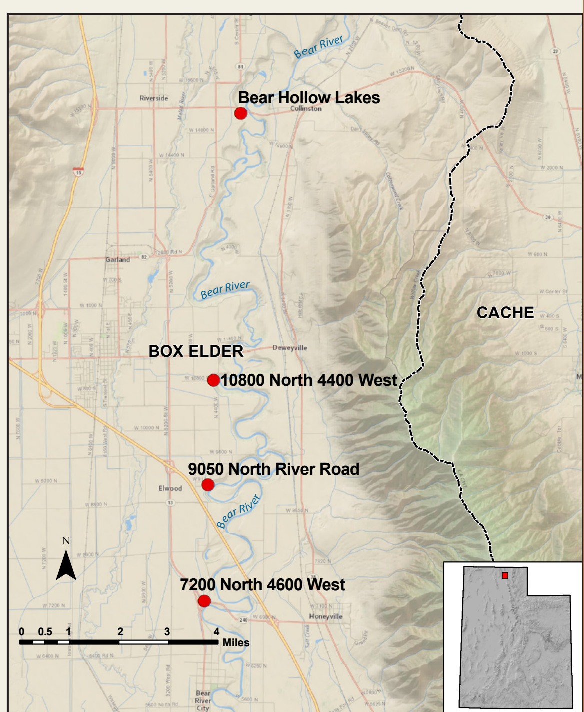


Photo taken February 19, 2017, courtesy of Pete Clark.



Location of Box Elder County landslides.

GLAD YOU ASKED

What are Moqui Marbles?

BY Christine Wilkerson

Moqui marbles are small, brownish-black balls composed of iron oxide and sandstone that formed underground when iron minerals precipitated from flowing groundwater. They occur in many places in southern Utah either embedded in or gathered loosely into "puddles" on the ground near outcrops of Jurassic-age Navajo Sandstone.

The word Moqui comes from the Hopi Tribe. The Hopi were previously known as the Moqui Indians, named so by the early Spaniards, until their name was officially changed to Hopi in the early 1900s. According to some Internet sources, there is a Hopi legend that the Hopi ancestors' spirits return to Earth in the evenings to play marble games with these iron balls, and that in the mornings the spirits leave the marbles behind to reassure their relatives that they are happy and content.

Moqui marbles (sometimes spelled Moki) are also known by collectors by many other names—Navajo cherries, Navajo berries, Kayenta berries, Entrada berries, Hopi marbles, Moqui balls, or Shaman stones. Geologists call them iron concretions.

These spherical iron concretions commonly range in size from a fraction of an inch (pea size) to several inches in diameter, although some can be as large as grapefruits. In addition to marbles or balls, iron concretions can be shaped like buttons, pipes, corrugated sheets, UFO "flying saucers," plates, or doublets and triplets (two or three conjoined balls).

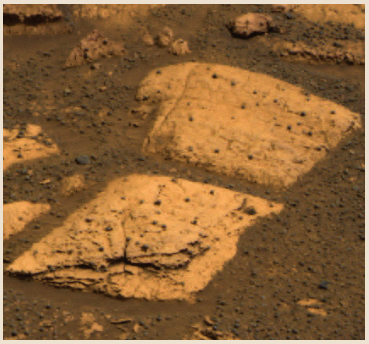
The host rock for the marbles, the Navajo Sandstone, was originally deposited around 180 to 190 million years ago as a huge sand dune field, similar to the modern Sahara, that covered parts of Utah, Arizona, Colorado, Wyoming, Idaho, Nevada, and New Mexico. A very thin, microscopic layer of hematite (an iron oxide mineral) coated the sand grains, giving the sand its red color. The sand was later buried by other sediments and eventually compacted into sandstone, during which time the hematite coatings continued to spread over the grains, ultimately giving us some of the most spectacular red sandstones visible in southern Utah.

But not all Navajo Sandstone is red; some Navajo Sandstone is white. While still buried, water containing reducing agents like hydrocarbons (petroleum) or weak acids traveled slowly through parts of the permeable sandstone, bleaching the red rock by dissolving the iron into the water. This iron-laden water eventually flowed to a place where the groundwater chemistry changed and caused the iron to precipitate. This precipitated iron surrounded and cemented the sand grains and in time formed iron concretions consisting of concentric layers of hard iron minerals enclosing loosely to well-cemented sand. Some recent studies have also proposed that microorganisms later helped convert the precipitated iron into iron oxide.

Once the overlying rock layers were eroded and the Navajo Sandstone revealed, weathering of the sandstone exposed the hard, weather-resistant iron concretions, many of which are amassed in large groups on the surface. Many concretions are located in State Parks, National Parks and Monuments, and Native American reservations where collecting is prohibited.

Martian Blueberries

Discovered on Mars by NASA's Mars Exploration Rover Opportunity in 2004, the Martian blueberries are thought to have formed in a similar manner to the Moqui marbles on Earth, therefore providing some of the first evidence for water in Mars' ancient past. And just like on Earth, these hematite concretions were found scattered on the ground and embedded in rock outcrops, "like blueberries in a muffin" according to one rover scientist. Martian blueberries are gray not blue, and are much smaller than most marbles in Utah, usually about BB pellet-size. By continuing to study iron concretions in Utah, geologists can make analogies as to how these blueberries formed on Mars.



Spherical iron concretions or "blueberries" litter the ground within Mars' Eagle Crater in this image taken by the Opportunity rover in 2004. Image credit: NASA/JPL/Cornell

Eroded from Navajo Sandstone, split iron concretions expose a loosely cemented sand interior surrounded by a hard, layered outer rind of hematite. Photographer: Michael Vanden Berg

Although Moqui marbles are spherical, iron concretions can develop into a variety of shapes. Photographer: Michael Vanden Berg

Iron concretions eroded from Navajo Sandstone scattered on the ground in Grand Staircase–Escalante National Monument in south-central Utah. Photographer: Michael Vanden Berg

ENERGY NEWS

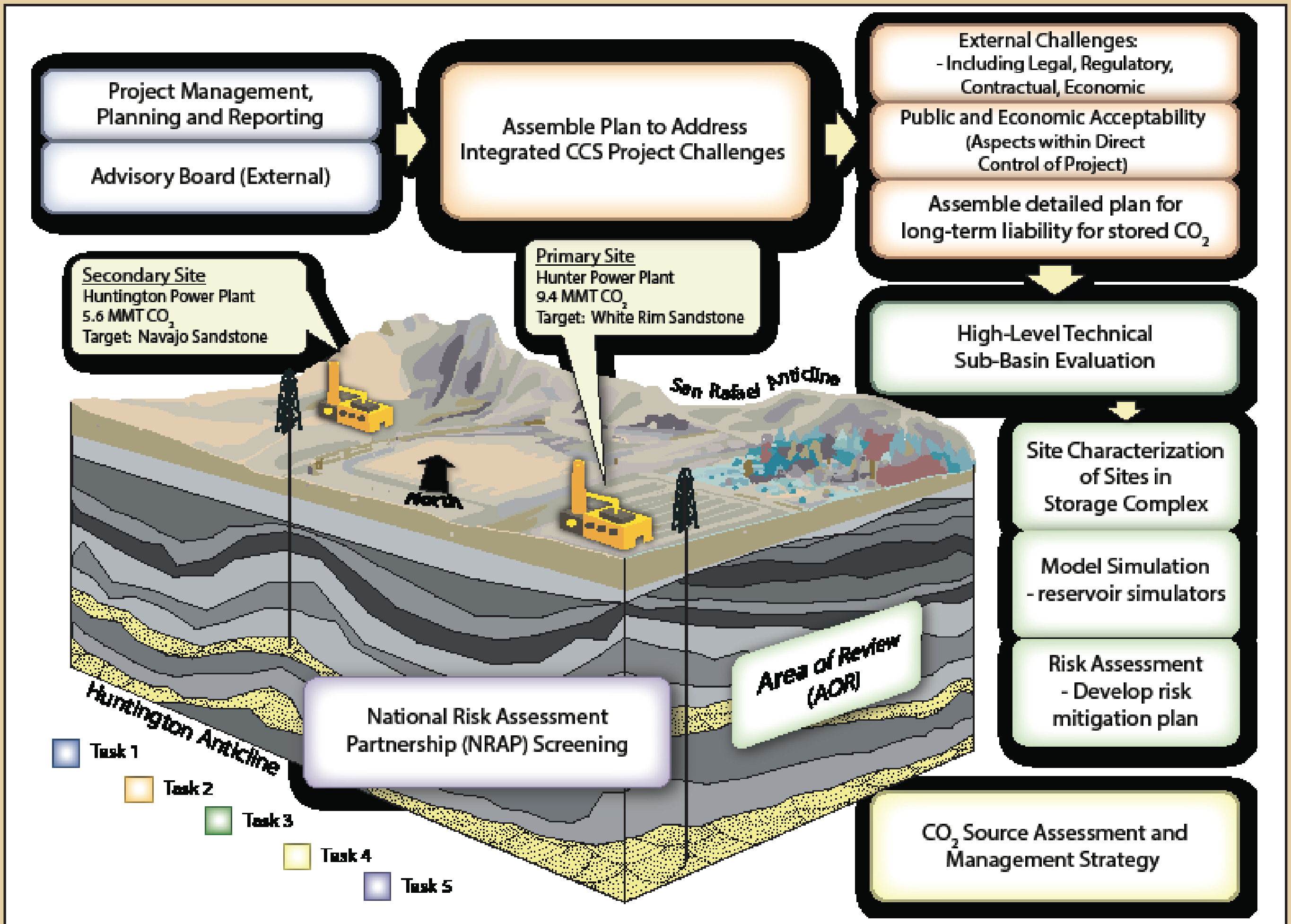
BY
Mark Milligan

The Utah Geological Survey
A Partner in the CarbonSAFE Rocky Mountains Project

CarbonSAFE Rocky Mountains is a research and development project with the goal of planning and ultimately developing a system to effectively capture and safely store carbon dioxide (CO_2) emitted from a coal-fired power plant in central Utah. The project is coordinated by the Energy & Geoscience Institute at the University of Utah in partnership with the Utah Geological Survey (UGS), Utah Department of Environmental Quality, Sandia National Laboratories, New Mexico Institute of Mining and Technology, Schlumberger Carbon Services, Los Alamos National Laboratory, and PacifiCorp. The UGS is leading all geological efforts for the project.

Temperature records show Utah's climate is changing. Our snowpack melts earlier each year and heat waves are more common. Over the last century the state's average annual temperature rose by about two degrees Fahrenheit (seasonal and annual average temperature data for all states can be found at https://www.ncdc.noaa.gov/temp-and-precip/state-temps/). Utah's elevated temperatures are reflective of average worldwide temperature increases, which are chiefly attributed to elevated levels of greenhouse gases in the atmosphere, principally CO_2. The harnessing of fossil fuels such as oil, natural gas, and coal built modern civilization, but in doing so transferred carbon that had been stored in underground geologic formations for millions to hundreds of millions of years into the atmosphere as CO_2. Since the industrial revolution began in the 1700s, CO_2 in the atmosphere has increased by approximately 40 percent to levels higher than any documented in the past 800,000 years of historical and ice core records.

For several reasons, Utah has started to reduce its reliance on coal-generated electricity. In particular, coal-fired power plants produce more CO_2 per unit of electricity than other fossil fuels. A decade ago coal-fired power plants generated approximately 90 percent of the electricity Utahns used. Today that has fallen to approximately 75 percent. However, Utah is still a major coal-producing state with substantial reserves, and the state continues to depend on several large coal-fired power plants. Despite the continued reduction in reliance, coal power will not soon be entirely replaced. An emerging technology, carbon capture and storage (CCS) holds the potential to reduce CO_2 emissions from coal-fired plants, thereby bridging the gap until newer alternative forms of power generation are available. CCS is the separation and capture of CO_2 from the exhaust gases of fossil fuel power plants or other industrial processes, and long-term storage of the CO_2 in deep underground geologic formations (deep ocean storage is another



Conceptual diagram of the CarbonSAFE Rocky Mountains project illustrating tasks necessary to ensure a successful outcome; courtesy of the Energy & Geoscience Institute at the University of Utah.

potential option). This technology allows for continued power plant operation but with reduced CO_2 emissions. The process involves separating the CO_2 from other exhaust gases, compressing it to a dense liquid state, piping it to an injection site, and injecting it through a deep well (at least 800 meters [2,600 feet]) into a suitable geologic reservoir for long-term storage. During and after injection the storage reservoir is continuously monitored to track CO_2 migration and any potential impacts such as induced seismic activity, while the overlying land surface and shallow subsurface is monitored for any signs of leakage. Conservative estimates indicate that geologic formations in Utah and the greater Rocky Mountain area can safely and permanently store many hundreds of millions of tons of CO_2, enough for dozens of years of emissions from the many coal-fired power plants in the region.

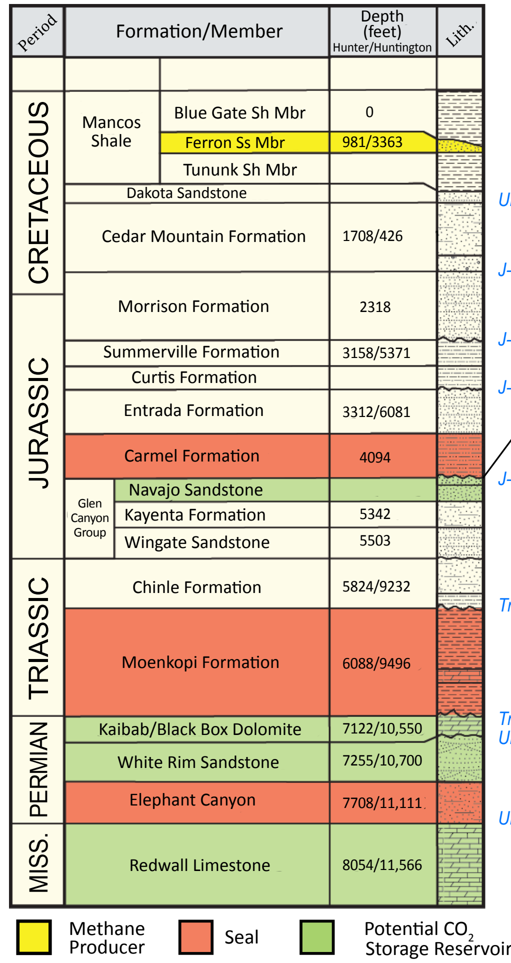
The CarbonSAFE Rocky Mountains project is one of 16 projects across the nation funded by the U.S. Department of Energy's (DOE) CarbonSAFE initiative. Past CCS projects funded by the DOE have focused on pilot or short-term injection tests. The CarbonSAFE initiative is designed to foster the development, permitting, and construction of long-term commercial-scale (50+ million metric tons of CO_2) CCS systems targeted to be operational by the year 2025.

The CarbonSAFE Rocky Mountains project is in the initial phase of a potential four-phase, nine-year program with the goal of permitting and constructing a commercial-scale CCS system at PacifiCorp's Hunter Plant, with the Huntington Plant as a secondary option. Phase I is an 18-month pre-feasibility study of technical and regulatory requirements. Multiple surface injection sites and deep-storage reservoirs are being evaluated with an emphasis on storage capacity, efficiency, and costs associated with CO_2 capture, compression, transport, injection, and monitoring.

The UGS is leading the geological characterization of potential storage reservoirs and seals, such as the Navajo Sandstone and overlying Carmel Formation. The UGS has worked on CCS studies since 2003 as an original partner when the DOE established the Southwest Regional Partnership on Carbon Sequestration.

CarbonSAFE Rocky Mountains —Ensuring Safe Subsurface Storage of Carbon Dioxide in the Intermountain West

Two PacifiCorp coal-fired power plants in Emery County are being considered for the CarbonSAFE Rocky Mountains project: the Hunter Plant south of Castle Dale (top photo) and the Huntington Plant northwest of Huntington (bottom photo). Photos courtesy of Ian Andrews, PacificCorp.



Geologic formations near the Hunter and Huntington Power Plants in the southern Castle Valley area, Emery County, Utah. Depths for the Hunter Plant (first number, depth) are drill depths from the Lawrence 15-1 well (SW1/4SE1/4 section 1, T. 18 S., R. 8 E., Salt Lake Base Line and Meridian) drilled in 1984 about 8 miles north and approximately along structural strike with the plant. Depths for the Huntington Plant (second number, depth column) are projected downdip from the Government 1 well (SE1/4NW1/4 section 15, T. 17 S., R. 8 E., Salt Lake Base Line and Meridian) drilled in 1954 about 4 miles southeast (updip) from the plant. Drill depths are preliminary and may change with more detailed mapping. Stratigraphy based on Hintze and Kowallis, 2009, Geologic History of Utah.

For more information on CCS work by the UGS, see the following:

- UGS web page on carbon sequestration (https://geology.utah.gov/resources/energy/carbon-sequestration/)
- "Energy News: Utah's Gordon Creek Field to Test Commercial-Scale Storage Of Carbon Dioxide" in *Survey Notes*, v. 44, no. 1, January 2012
- "Energy News: Carbon Dioxide Sequestration Demonstration Project Underway in Utah!" in *Survey Notes*, v. 41, no. 3, September 2009
- "Geological Sequestration of Carbon Dioxide and Enhanced Oil Recovery: The Utah Geological Survey's Efforts to Reduce Global Warming While Increasing Oil Production" in *Survey Notes*, v. 39, no. 2, May 2007
- "Energy News: Storing Carbon Dioxide Emissions Underground—New Projects" in *Survey Notes*, v. 36, no. 2, August 2004
- "Storing Carbon Dioxide Beneath the Colorado Plateau" in *Survey Notes*, v. 35, no. 3, August 2003

GEOSIGHTS

BY Marshall Robinson

Wolverine Petrified Forest, Garfield County

Nestled off the beaten path south of the Burr Trail between Boulder and Capitol Reef National Park, Wolverine Petrified Forest provides an awesome display of petrified wood. Don't expect to find a flourishing forest of towering trees though, as this forest hasn't been standing for millions of years. A sizable number of petrified wood-chunks are scattered among the rocks, but one area in particular has an impressive collection of in-place petrified wood. Tempting as it may be, don't walk off with anything you find here though, as the area lies within Grand Staircase–Escalante National Monument (GSENM), which makes it illegal to collect rocks of any kind. Commonly known as Wolverine Petrified Forest, this area's official name is Wolverine Petrified Wood Natural Environmental Area. This name was given in 1996 when the area earned its "Special Management Designation" as a part of the conception of GSENM by then-President Bill Clinton. The official name is a bit of a mouthful, so for the sake of this article it is referred to as Wolverine Petrified Forest.

Geologic Information

So, why is there so much petrified wood here? There isn't a tree for miles, especially one that resembles the petrified wood found here. Around 225 million years ago, during the Triassic Period, Utah was much closer to the equator and coastline, and the climate was also much warmer. At this point in Utah's ancient history, the topography was much flatter, so the waterways were sluggish, yet prevalent due to the rain-saturated, volcanic mountains to the south. Northwest-flowing rivers and streams transported nutrient-rich volcanic ash and soil throughout Utah, and blanketed the surrounding plains as they flooded often. Large conifer trees grew in this fertile soil, but ironically, the same mountains that provided these lush tree-growing conditions probably led to their demise as well. Violent eruptions of ash overwhelmed the region and its waterways with too much silica, killing the trees, and subsequently burying them in the surrounding ash-laden mud and water that protected and preserved them for later discovery.

These prehistoric conditions are evident in the petrified wood-rich mudstone layers known today as the Petrified Forest Member of the Chinle Formation. In addition to an abundance of petrified wood, this 150- to 300-foot-thick layer of rock is found sporadically throughout the Colorado Plateau and is distinguished by its dull-pink layers, "popcorn" weathering texture, and resemblance to badlands. At Wolverine Petrified Forest, the highest concentration of petrified wood is contained within an approximately 10- to 30-foot-thick deposit. This rock layer is easily erodible and forms an easily-distinguishable slope beneath the brown-red cliffs of the Wingate Sandstone.

What is Petrified Wood?

Petrified wood is the result of trees being buried by either sediment or water, and cut off from the decomposition processes found in oxygen-rich conditions. While buried for millions of years, the organic tissues and voids in the wood are replaced by quartz via a process called permineralization. Unlike trace or compression fossils that are merely impressions of the original organism, petrified wood's original plant structure remains preserved, allowing observers in the present day to see what the wood looked like millions of years ago. It is a fascinating opportunity to look at the remains of a 225-million-year-old fossilized tree and still tell how old it was when it died by counting its rings. Much of the petrified wood at Wolverine Petrified Forest came from the now-extinct conifer tree species *Araucarioxylon arizonicum*, an ancestor of the modern-day monkey puzzle tree (see *Survey Notes*, v. 35, no. 3, August 2003, p. 3-6 for more information on the wood of Wolverine Petrified Forest; http://ow.ly/VQvQ30dHsEl).

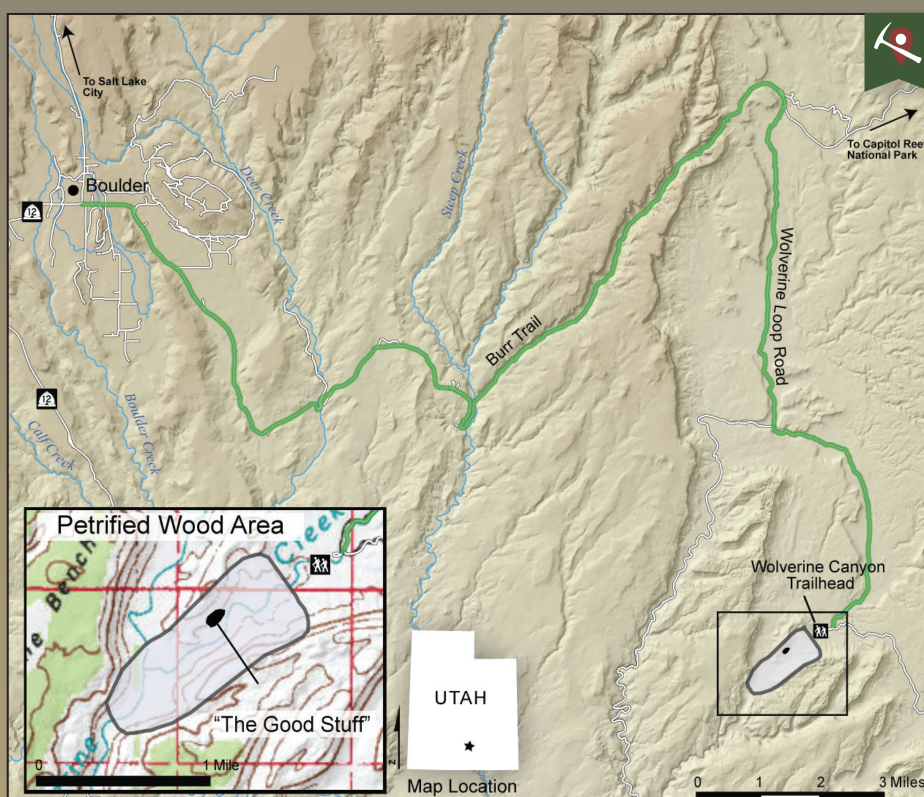
Relief map of western United States showing Utah's flat, river-dominated topography. Image from Ron Blakey's website, "Paleogeography of the Southwestern US." http://ow.ly/IDj930cKjb1

Where is the good stuff?

There's no need to hike very far from the trailhead to start finding petrified wood as it can be found scattered along the trail; however, the best in-place petrified wood is just under a mile from the trailhead. The walk isn't strenuous, but be prepared with plenty of water, sturdy shoes, a hat, sunscreen, and first aid kit. There is also no cell-phone service in the area, so make sure to let someone else know your plans (a signal mirror may help in emergencies as well). If you stay on the main trail, you'll see gorgeous scenery, but miss out on seeing the full tree trunks, stumps, and branches of petrified wood. At roughly the ¾-mile-mark (there is no actual marker), begin looking to your right (north) for dark black rocks. There are a few locations where petrified wood is preserved as a stump in the ground, and other locations where the wood is laid out on the ground just as it fell 225 million years ago, half-buried by the dirt and rock surrounding it. The best and most intact pieces are tens of feet long, upwards of 3 feet in diameter, and are found at the following coordinates: latitude 37.7979611017° N, longitude 111.2200917° W and latitude 37.797071° N, longitude 111.220973° W. Remember, it is illegal to remove the petrified wood.

HOW TO GET THERE

From Salt Lake City, travel south on I-15 to exit 188 (Scipio – U.S. Highway 50). Continue south on U.S. 50 for 25 miles and turn right (south) onto Utah State Highway 260. After 4.2 miles, turn right onto Utah State Highway 24 and continue for 64 miles to Torrey. Turn right (south) onto Utah State Highway 12 and continue for 36.6 miles and turn left (east) onto the Burr Trail Scenic Backway in Boulder. Travel eastbound on the Burr Trail for 18.4 miles and turn right (south) onto Wolverine Loop Road (also known as Bureau of Land Management [BLM] Road 110). Pavement ends at this junction, so please continue with caution for 10 miles along the sometimes washboarded dirt road, across numerous washes (try to plan around dry weather), and turn right into the parking lot for the Wolverine Petrified Forest (a sign for Wolverine Petrified Wood Natural Environmental Area marks the entrance).



Note: Wolverine Loop Road (BLM 110) is generally impassible during and shortly after wet weather conditions and crosses numerous washes that can be subject to flash floods. Please research weather and road conditions when planning a trip. A helpful website that provides road conditions for Grand Staircase–Escalante National Monument is http://ow.ly/SCYRH.

SURVEY NEWS

2017 CRAWFORD AWARD

The prestigious 2017 Crawford Award was presented to **James I. Kirkland** in recognition for his work on the outstanding paper "The Lower Cretaceous in East-Central Utah—The Cedar Mountain Formation and Its Bounding Strata," from *Geology of the Intermountain West*, Volume 3, Utah Geological Association.

Most think of Utah as the "real Jurassic Park" because of the important dinosaur collections excavated from the Late Jurassic Morrison Formation. However, the number of new and existing dinosaurs that Jim has discovered, excavated, and described from the Cedar Mountain Formation rivals the Morrison. His contributions demonstrate that the Early Cretaceous Cedar Mountain Formation is as productive and important to understanding dinosaur diversity and evolution. He has put Utah on the map for Early Cretaceous dinosaur research. Because of his work, Jim is recognized throughout the world as the expert on the Cedar Mountain Formation, its stratigraphy, and dinosaur fauna. This paper is the culmination of a career of studying this formation and the vertebrate fossils it contains; it is the quintessential reference on the Cedar Mountain. It solidifies the regional understanding of the Cedar Mountain lithostratigraphy, biostratigraphy, and environments of deposition. It also formalizes the member names, which he and a co-worker first applied a decade ago. It is well written and well organized with many annotated photographs and detailed illustrations.

The Crawford Award recognizes outstanding achievement, accomplishments, or contributions by a current UGS scientist 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.

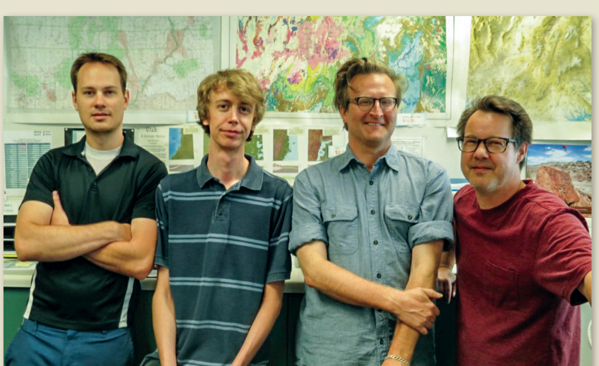
NEW UGS BOARD MEMBERS

We are pleased to welcome two new UGS Board members. They were appointed by Governor Herbert and confirmed by the Senate during this year's legislative session. The new members are **Dave Garbrecht**, representing industrial minerals, and **Rick Chesnut**, representing engineering geology. Terms have expired for **Tom Tripp** and **William Loughlin** who have served us well as members of the UGS Board, and we thank them for their efforts.

EMPLOYEE NEWS

The Editorial Section welcomes **Martha Jensen** as the new cartographer/GIS analyst. Martha has a Master of Science degree in Ecology, with an emphasis in GIS techniques, from Utah State University. She replaces **Jay Hill** who accepted the position as Web GIS Specialist with UGS Web Services. Welcome to Martha and congratulations to Jay.

UGS BOOKSTORE Leader of the Pack in Publication Sales



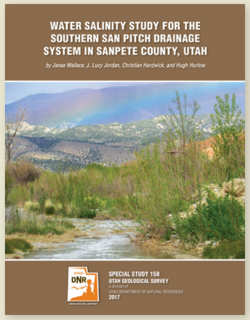
Bookstore staff (left to right): Gentry Hammerschmid, Brian Butler (manager), Andy Cvar, Jim Davis.

The Association of American State Geologists recently compiled information on state geological survey publication sales, and the Natural Resources Map & Bookstore—operated by the Utah Geological Survey—ranks 1st in the country for annual sales revenue. State geological survey bookstores face a substantial challenge in maintaining economic viability in the digital age, when so much of the geologic information produced by the surveys is available for free on the web. The success of the UGS bookstore can be attributed to a wide selection of maps (demand still exists for paper maps!), creative and careful decisions regarding inventory and pricing, effective use of social media for marketing, and excellent customer service. Be sure to stop in next time you're in the neighborhood!

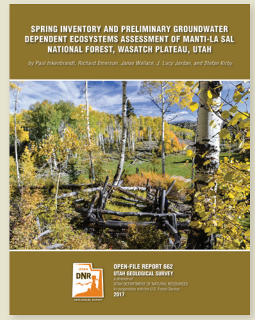
NEW PUBLICATIONS

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

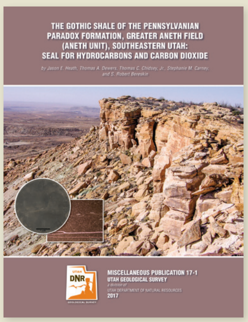
Utah earthquakes (1850 to 2016) and Quaternary faults, by Steve D. Bowman and Walter J. Arabasz, 1 plate, ISBN 978-55791-938-0, **Map 277**



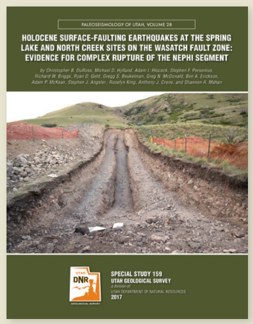
Water salinity study for the southern San Pitch drainage system in Sanpete County, Utah, by Janae Wallace, J. Lucy Jordan, Christian Hardwick, and Hugh Hurlow, 37 p., 2 pl., ISBN 978-1-55791-935-9, **Special Study 158**



Spring inventory and preliminary groundwater dependent ecosystems assessment of Manti-La Sal National Forest, Wasatch Plateau, Utah, by Paul Inkenbrandt, Richard Emerson, Janae Wallace, J. Lucy Jordan, and Stefan Kirby, 15 p. + 67 p. appendices, 3 pl., **Open-File Report 662**



The gothic shale of the Pennsylvanian Paradox Formation, Greater Aneth field (Aneth unit), southeastern Utah–seal for hydrocarbons and carbon dioxide, by Jason E. Heath, Thomas A. Dewers, Thomas C. Chidsey, Jr., Stephanie M. Carney, and S. Robert Bereskin, 31 p., ISBN 978-55791-940-3, **Miscellaneous Publication 17-1**



Paleoseismology of Utah, Volume 28—Holocene surface-faulting earthquakes at the Spring Lake and North Creek sites on the Nephi segment of the Wasatch fault zone: evidence for complex rupture of the Nephi segment, by Christopher B. DuRoss, Michael D. Hylland, Adam Hiscock, Stephen F. Personius, Rich Briggs, Ryan Gold, Gregg Beukelman, Greg N. McDonald, Ben Erickson, Adam McKean, Steve Angster, Roselyn King, Anthony J. Crone, and Shannon A. Mahan, 44 p. + 75 p. appendices, 4 pl., ISBN 978-1-55791-936-6, **Special Study 159**

RECENT OUTSIDE PUBLICATIONS BY UGS AUTHORS

The adverse impact to canals from landslide activity in California and Utah, by J.V. De Graff, **R.E Giraud**, and **G.N. McDonald**: Landslides—Putting experience, knowledge and emerging technologies into practice, AEG Special Publication no. 27, p. 340–351.

Terrestrial carbon isotope chemostratigraphy in the Yellow Cat Member of the Cedar Mountain Formation—complications and pitfalls, by M.B. Suarez, C.A. Suarez, A.H. Al-Suwaidi, G. Hatzell, **J.I. Kirkland**, J. Salazar-Verdin, G.A. Ludvigson, and R.M. Joeckel: Terrestrial Depositional Systems—Deciphering complexities through multiple stratigraphic methods, p. 303–335.

An examination of the hypersaline phases of Eocene Lake Uinta, upper Green River Formation, Uinta Basin, Utah, by **M.D. Vanden Berg** and L.P. Birgenheier: Journal of Paleolimnology, p. 1–19. doi: 10.1007/s10933-017-9983-x.

Quantification of organic content in shales via near-infrared imaging—Green River Formation, by Y. Mehmani, A.K. Burnham, **M.D. Vanden Berg**, and H. Tchelepi: Fuel 208, p. 337–352.

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