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Using Drones for Geologic Characterization and Emergency Response in Zion National Park

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Design | *John Good*
Cover | Drone photo of Zion National Park oversized parking area. Flood damage to the area was caused by heavy rain on The Watchman and surrounding mountains in the background. Photo date: July 13, 2021.

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DIRECTOR'S PERSPECTIVE

by Bill Keach

"What is your favorite place?" My answer is always, "Where I am!"

The world is an amazing place with great people everywhere. I can say so with some conviction as I have wandered through more than forty countries and walked on six of the seven continents. I am often asked, "What is your favorite place?" My answer is always, "Where I am!" I once met a woman in Ecuador who shared with me that "every place has its enchantment, you just have to find it." She was right of course, and that includes the people you meet. For me, to know a place, you have to walk the streets, hear the sounds, smell the aromas in the air, AND meet the people. Some years back I had the opportunity to visit Libya. Late one evening I was sitting on an ancient wall in a park in Benghazi. For three hours I sat and visited with my "escorts" learning about their country, their history, and their families. On a different occasion I spent an afternoon on the steps of a cathedral in Quito, Ecuador, whose construction started in the 1500s. A local priest regaled me with stories of its rich history, of earthquakes, revolutions, and faith.

In Utah I have had many similar experiences. I love rural Utah. It offers plentiful opportunities to explore the rocks, visit small cafes, and to hear the sounds of nature. Over the past 16 years I've had the opportunity to lead many geology field trips across Utah, and I make it a point to frequent local establishments and vendors. The Cottonwood Steakhouse (Bluff), Cowboy Corral (Elsinore), Georgies (great Mexican food in Escalante), the Parowan Cafe, the Burr Trail Grill (Boulder) and the Antica Forma (try the wide selection of pizza) are just a few that come to mind. In places like these you can sit for a spell, and be fed in more ways than one.

A recent trip to Escalante Petrified Forest State Park on Veterans Day this past November is a great example of a new favorite place. My wife and I were attracted to the park to see petrified wood (her) and the geology (me). Definitely worth the visit for both! The petrified wood in this small park in central Utah is around 150 million years old (Morrison Formation). To see much of it you must hike up the hill behind the campground. I took my drone with me, after obtaining permission from the park staff, to get some great views of the country. While pulling out my drone a mountain biker stopped to take a short rest. It was then I realized I had forgotten my phone, which I needed to fly the drone. Not having even learned his name yet, he offered to let me use his phone (which had the needed app). While flying the drone I learned his name and that he was an avid drone pilot from southern California. Eventually we met his mother who was hiking the same trail. What a wonderful place, in the midst of nature and surrounded by petrified wood, to meet these amazing folks. They were willing to share without even knowing me. The world is truly full of enchantment, just waiting to be found. On that day I found it in the rocks, in nature, and in people.

P.S. Drone usage has become an integral part of work at the UGS. This month's article *"Incorporating Small Unmanned Aircraft System (sUAS) Technology in Geologic Hazard Characterization and Emergency Response: Zion National Park"* is a great example.

Drone image from Escalante Petrified Forest State Park.

Incorporating Small Unmanned Aircraft System (sUAS) Technology in Geologic Hazard Characterization and Emergency Response: Zion National Park

by Ben A. Erickson, Jessica J. Castleton, and Adam I. Hiscock

The Utah Geological Survey (UGS) often uses small unmanned aircraft system (sUAS) technology (including unmanned aerial vehicle [UAV] or drone, pilot, and observer) in geologic hazard characterization and emergency response in ongoing hazard identification and mapping. sUAS surveys can be used to create valuable three-dimensional (3D) data and high-resolution images, as well as decrease the response time and costs while increasing the level of safety for scientists responding to geologic hazards.

ZNP flood-damaged overflow parking area. Park guest vehicle trapped in the flood deposit. Photo date: July 1, 2021.

The UGS recently had the opportunity to conduct an sUAS survey for the National Park Service at Zion National Park (ZNP). With annual visitation at ZNP exceeding 4 million in recent years and only dropping to over 3.6 million in 2020, the likelihood of geologic hazards affecting park visitors and infrastructure continues to rise. In the summer of 2021, and at the request of ZNP, the UGS conducted multiple sUAS investigations to evaluate the extent of severe flooding that occurred during that summer. This investigation followed a similar one we conducted for ZNP in the summer of 2019 for the Cable Mountain rockfall. The use of the sUAS can provide data for future flood mitigation designs and determine the measures needed to mitigate the risk associated with the remaining material from the rockfall event, as well as determine future safety. Drone use is currently restricted within all U.S. national parks (and always prohibited for private citizens without proper permitting). However, the UGS and ZNP were granted emergency authorization allowing the drone flights.

sUAS Flash Flood Investigation

On June 29, 2021, an intense monsoonal rainstorm occurred in the early afternoon, resulting in sheet flooding, channel flow, canyon debris flows, and flash flooding of the Virgin River. A weather station located within ZNP recorded 1.16 inches of rain within a two-hour time span with 0.7 inches recorded in the final hour. The total rainfall recorded for the day was 1.18 inches. The ZNP South Gate, part of Utah State Route 9, and the Park Transportation, Inc. (PTI) areas, including shuttle and oversized parking areas, experienced an intense, ten-year flooding event, resulting in the closure of their respective services. Cleanup and repair lasted several weeks after the event. Fortunately, no injuries were reported, but the park and the nearby community of Springdale, Utah, had extensive flood damage.

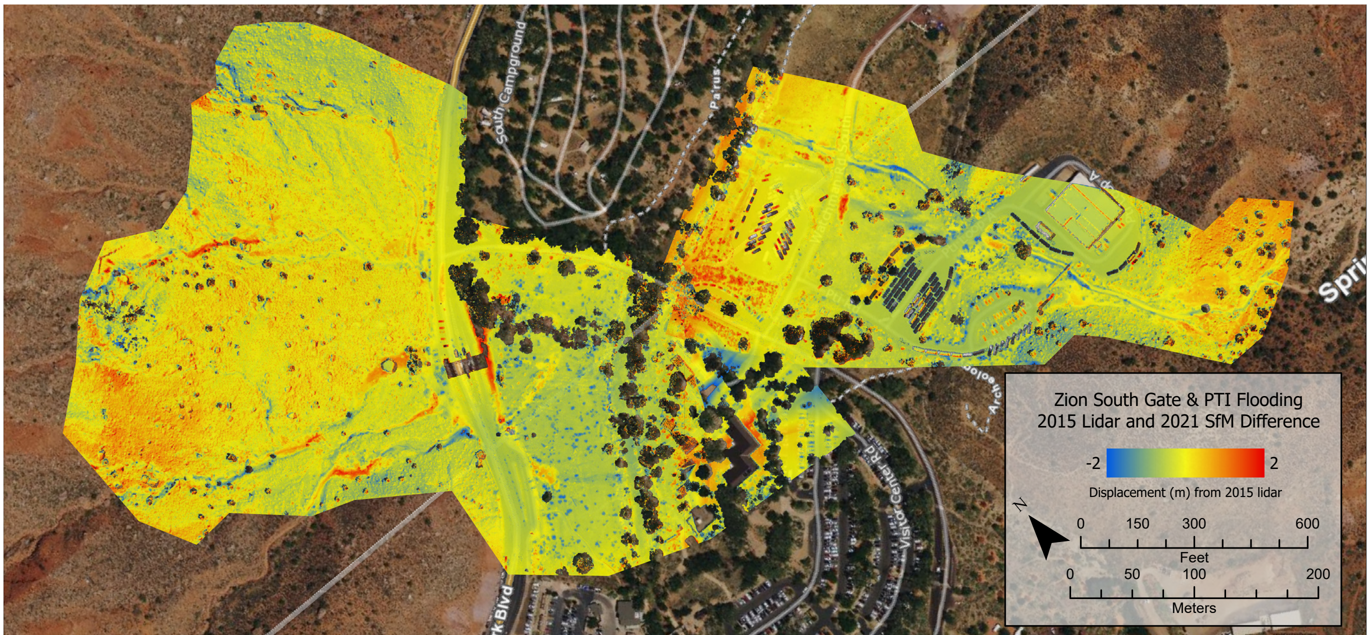
The UGS evaluated the impacted areas and created a flight plan for optimal coverage of the area. The drone is equipped with a 1-inch CMOS Hasselblad camera and Global Navigation Satellite System (GNSS). The imagery data gathered by the sUAS flights and GNSS points were combined to generate a structure-from-motion (SfM) three-dimensional model using Agisoft Metashape software, on which digital measurements and mapping were performed. The SfM model also includes point cloud data, similar to lidar elevation data. Using CloudCompare and ESRI's ArcGIS Pro software, we compared our model to 0.5-meter lidar

Drone flight paths (yellow lines) used to collect imagery data for SfM modeling and lidar data comparison.

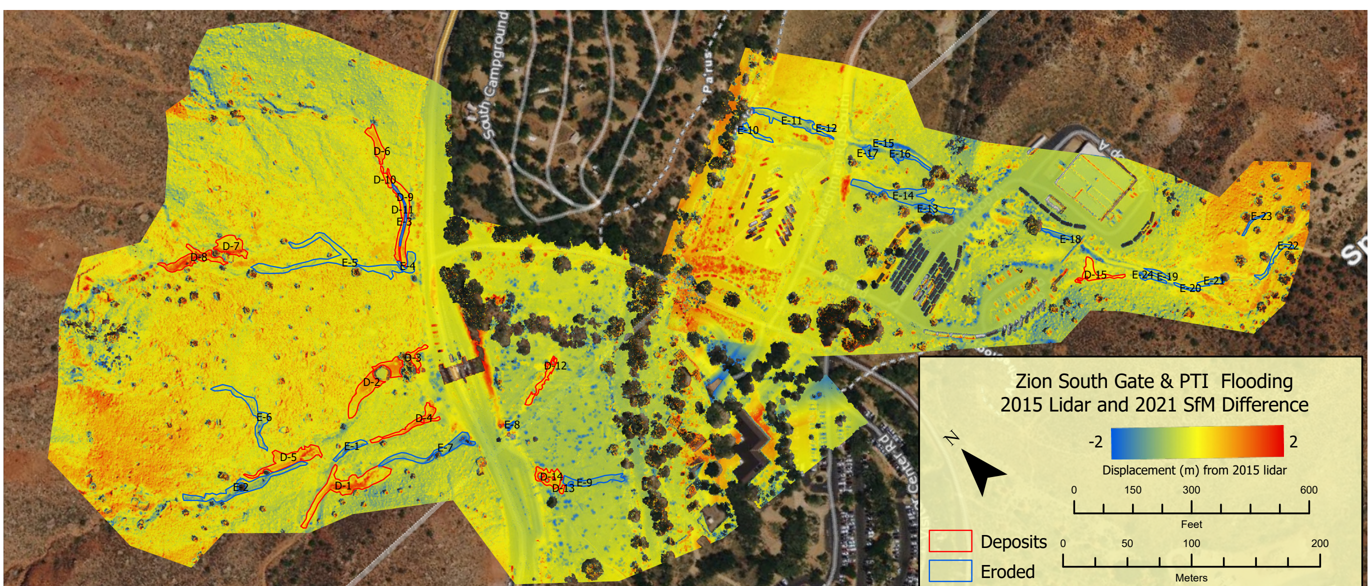
elevation data acquired by ZNP in 2015. By comparing the model and lidar, we were able to detect changes in erosion and deposition of sediments in the area between 2015 and 2021.

The differencing results of the 2021 SfM model and 2015 lidar data show where erosion from water flow channels occurred and the areas where sediments carried by the flood water were deposited. In the figures below, blue indicates where erosion has occurred and red indicates where deposition has occurred since 2015, whereas yellow indicates no change since 2015. Some areas near the PTI maintenance building and shuttle parking area appear to have unexpected, widespread erosion since 2015, perhaps due to a registration error with the lidar data; however, additional analysis would be necessary to evaluate the erosion anomaly.

Volume calculations also can be performed on areas of interest to determine the amount of material that was removed or added (see bottom figure). Based on the volume calculations, more deposition took place within the area where the drone was flown, compared to erosion, with about 47,816 cubic feet of material added and 35,491 cubic feet of material removed. Much of the deposition occurred in drainages and on floodplains leading to the North Fork of the Virgin River. Road culverts and parking lots were also inundated with deposition of mud and debris. The prevalence of deposition within the flight path indicates much of the erosional process took place at higher elevations outside of the imaged area. Areas that experience erosional scouring are also hazardous and can impact infrastructure, such as exposing buried pipelines, undermining foundations, and causing pavement to move.



Resulting differencing comparison from the 2015 0.5-m lidar and the 2021 SfM sUAS data. Areas in yellow show little to no change. Blue areas show areas of removal or erosion, down to –6.5 feet (2 meters). Red areas show addition or deposition, up to 6.5 feet (2 meters).



ZNP South Gate and PTI identified areas of interest for volume calculations comparing 2015 lidar and 2021 SfM model. The model includes a total of 24 erosional polygons and 15 depositional polygons.

Cable Mountain rock avalanche source area outlined in yellow; the scar measures approximately 133 feet wide, between the white lines, based on the SfM orthomosaic image. The volume of the rock avalanche was calculated to be 435,712 cubic feet, with a corresponding mass of approximately 31,292 tons. Photo date: October 24, 2019.

sUAS Cable Mountain Rockfall Investigation

On August 24, 2019, around 5:30 p.m., an approximately 31,292-ton (calculated with sUAS data obtained by the UGS) slab of Navajo Sandstone detached from the vertical northwestern face of Cable Mountain and broke apart, sending about 435,712 cubic feet (calculated with sUAS data obtained by the UGS) of debris flowing downslope toward the Weeping Rock Trailhead parking lot. The granular debris damaged the East Rim and Weeping Rock Trails, deposited sediment on the Hidden Canyon Trail, and flowed across Zion Canyon Scenic Drive to the Virgin River.

The popular Weeping Rock Trail is still closed due to this large-scale rock avalanche. Another large rock slab having void space behind it, like the slab that fell, is located to the northeast on the Cable Mountain cliff face. This slab was investigated due to its proximity to the failed slab's scar; however, fractured rock slabs that pose a rockfall hazard are located all along the cliff face. The acquired sUAS imagery data show these large rock slabs are highly fractured and semi-detached, bulging away from the cliff face. Using differencing between the 2015 lidar elevation data digital terrain model (DTM), point cloud data, and our sUAS model, we were able to estimate deposition depths to assist ZNP in developing a mitigation plan. We later returned in July 2021 and performed an additional flight to compare with the 2019 sUAS data. The results provided change information showing areas that have experienced erosion and deposition in the two-year timeframe.

***A.** Drone photo showing the void space between the rock bulge (white arrows) and the main cliff face of Cable Mountain. **B.** Photo from the top of Cable Mountain showing significant rock bulging (white arrows) and fractures filled with vegetation. (Photo credit: Tyler Knudsen) Date of photos: October 24, 2019.*

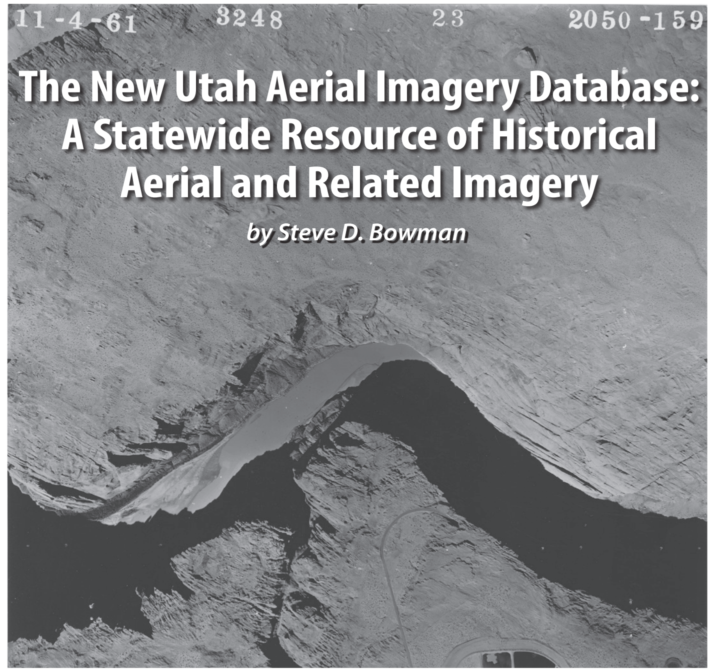
The use of sUAS within the UGS Geologic Hazards Program has become a vital tool in the assessment of geologic hazards. It has provided a means of increasing the evaluation of hazards and improving detail, while increasing the safety of our geologists at minimal expense. The utilization of sUAS has been incorporated in multiple types of geologic hazard responses, including landslides, flooding, fire-related debris flows and rockfalls, rock avalanches, fault mapping, sinkholes, fissures, subsidence, earthquakes, and the clarification of general hazard mapping. Future deployment of sUAS within the UGS is anticipated to increase. The addition of other sensing tools like thermal cameras, multi-spectral cameras, and lidar sensors would increase the capabilities, demand, and quality of the resulting analysis products the UGS provides. The UGS has just started enabling the capabilities of using sUAS and looks forward to future applications to help us better understand Utah's geology and hazards.

ABOUT THE AUTHORS

Ben Erickson is a Project Geologist with the Geologic Hazards Program who joined the Utah Geological Survey in 2011. He is a Utah native and has a B.S. degree in earth science from Utah Valley University and an M.S. degree in geological engineering from the University of Utah. Ben works to share knowledge of geologic hazards through mapping and working with communities. His role in emergency response ranges from logging digital data to explaining geological hazard conditions to local communities, civic leaders, and the media.

Jessica Castleton is a Senior Geologist with the Geologic Hazards Program. She earned a B.S. degree in applied environmental geoscience from Weber State University in 2005 and an M.S. degree in engineering geology from the University of Utah in 2015. In addition to mapping hazards, Jessica responds to debris flows, floods, and other geologic hazard events, and provides outreach for communities to inform about local geologic hazards.

Adam Hiscock is a Project Geologist with the Geologic Hazards Program. He earned a B.S. degree in geology from the University of Utah and a Professional Geologist license in 2016 while working at the UGS. Adam specializes in paleoseismology and active fault mapping, has co-led multiple UGS paleoseismic research projects on the Wasatch fault zone, and re-mapped many active faults in Utah. He has extensive experience using sUAS platforms to study geologic hazards. He serves as staff to the Utah Seismic Safety Commission, providing outreach and education on Utah's earthquake hazards.



The New Utah Aerial Imagery Database: A Statewide Resource of Historical Aerial and Related Imagery

by Steve D. Bowman

Vertical black and white (panchromatic) air photo view of the Colorado River just south of Glen Canyon Dam from the 1961 3248 collection.

The Utah Geological Survey (UGS) recently released the new online Utah Aerial Imagery Database (https://imagery.geology.utah.gov) containing aerial photography (air photos) and related imagery dating from 1935 to 2020; about one-half of the collection dates before 1960. As of December 2021, the database contains over 1,200 imagery projects totaling over 277,000 air photos and 4,300 aerial project index sheets. The database is the most comprehensive publicly accessible online aerial imagery system at a state level in the United States.

Imagery and Related Items in the Utah Aerial Imagery Database as of October 2021

Database Category	Totals
Air Photos	48,332
Externally Linked Air Photos	228,682
Index Sheets	4,378
Camera and Lens Reports	1,705
Aerial Project and Other Documents	116
Total Items:	**283,218**
Imagery Collections:	**1,231**

Historical aerial imagery is critical in the investigation of infrastructure hazard vulnerability; watershed and land management; engineering, environmental, and geologic projects; and past land uses to understand how the landscape and man-made features have changed over time and how they may affect current and future infrastructure. Nearly every infrastructure planning and design project uses aerial imagery to help understand the land surface, its features, and how they have changed over time. The imagery is also used by the public exploring Utah's backcountry, seeing what their property looks like in an aerial view, and dealing with property boundary location issues. The UGS also uses aerial imagery in nearly all its applied geologic research projects.

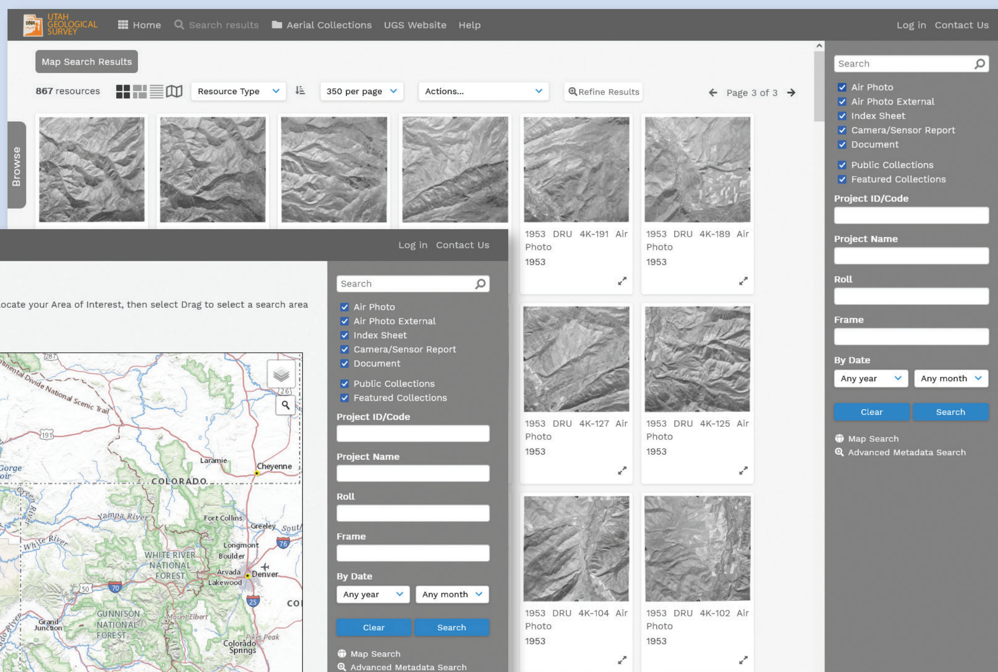
Most of the frames in the database were acquired in stereoscopic mode, meaning successive frames overlap and create stereo pairs that provide a three-dimensional (3D) image when viewed with a stereoscope. Other related imagery includes frames that are low-sun-angle photographs acquired during the morning or afternoon when shadows highlight certain topographic features, such as fault scarps, or oblique photographs taken at a non-vertical angle to the ground, like a panorama.

Various federal government agencies originally acquired most of these frames for agricultural and/or forest management purposes. The database also includes all UGS-acquired imagery. Aerial and related imagery is separated in the database by acquisition agency and the project code or name the agency assigned to the project as a collection. The project code consists of the year or year range the images were acquired and the specific project coding.

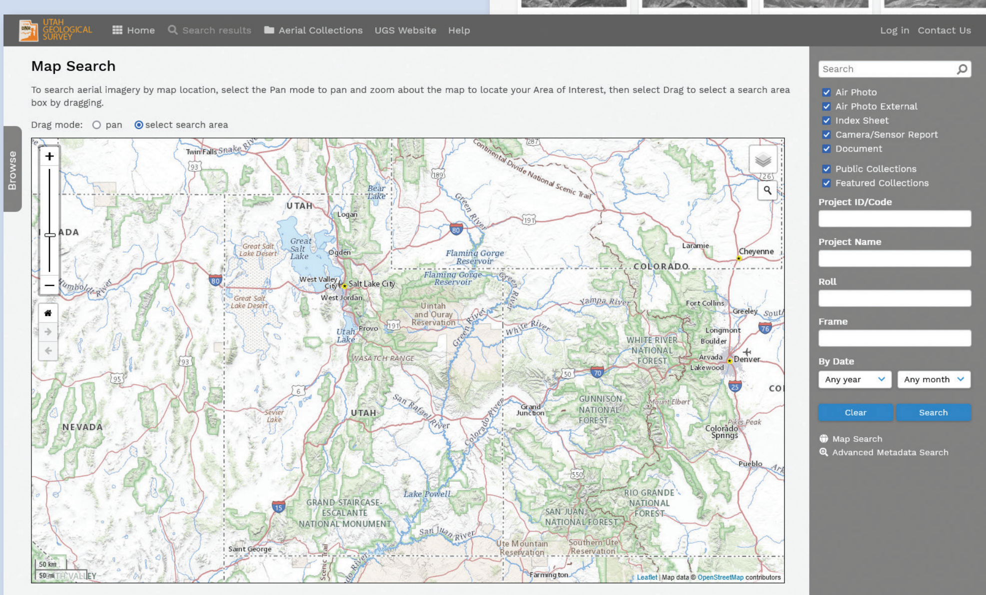
The externally linked air photos are contained in the U.S. Geological Survey (USGS) Earth Resources Observation and Science Center (EROS) EarthExplorer system (https://earthexplorer.usgs.gov/). Upon searching and discovering these photos in the Utah Aerial Imagery Database, the user clicks the Download button and is redirected to the EarthExplorer website to complete the download where a free EarthExplorer user login is required.

Oblique color air photo view of the Gunnison River looking north from the 1988 P8867 collection and acquired by the UGS.

Imagery in the database can be easily searched for using the Map Search feature. The user simply draws a search box and all imagery within the search box will be shown as thumbnail images, a text list, or as markers on a map. Markers on the map are color coded based on year ranges of the imagery. When markers overprint other markers in a search area, a green dot is displayed showing the number of clustered markers. Clicking on the green dot or zooming further into the map will show the clustered markers. In addition, imagery may be searched for using metadata that individually describes the images, such as the Project Code, Project Name or individual roll and frame numbers, among other metadata.



Search results showing image thumbnails, captions, and dates.



Map Search feature of the Utah Aerial Imagery Database.

Additional imagery and related items are being routinely added to the database. Donations of imagery are much appreciated, so the database may be more complete and serve as an easily accessible public archive.

Critical Minerals: Reshaping the Minerals Industry

by Stephanie E. Mills

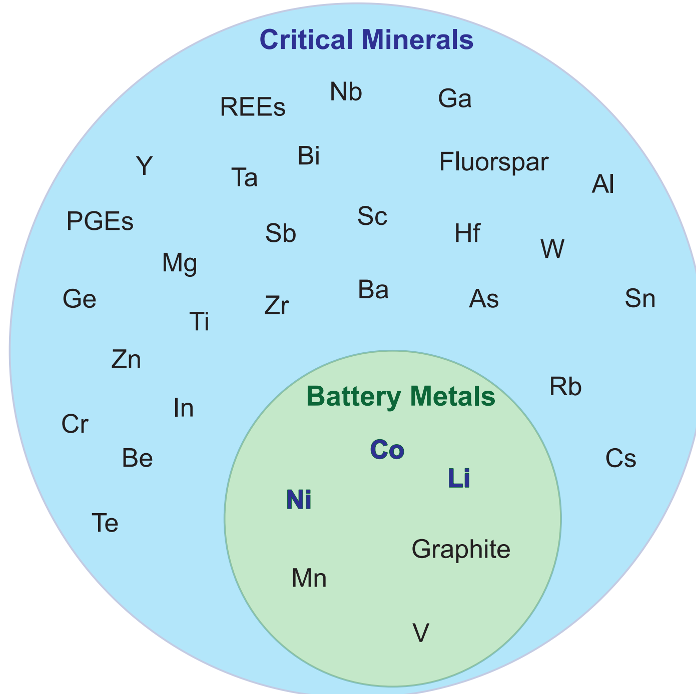
Anyone who has been paying attention to the mining industry over the past few years will have noticed a shift in the language around commodities. Gone are the simple days of precious versus base metals (with a few bulk commodities thrown in). In the modern market conversation, commodity groups now run the gamut from critical minerals and battery metals to specialty metals, future minerals, energy metals, green metals, and beyond. This complexity of language comes from the realization that modern economies and a shift to carbon neutral energy production are dependent on high-tech devices and new battery technology, which require a wider variety of materials than at any other point in history.

In general, the term "critical minerals" encompasses the commodities in most other mineral groups. Critical minerals refers to a formalized group of mineral commodities defined and published by governmental organizations. Most governments use the same basic definition, that critical minerals are those essential to domestic economy and/or security and that have a supply chain vulnerable to disruption. In the United States, the most recent iteration of critical minerals created by the U.S. Geological Survey (USGS) was published in 2018. However, the list of critical minerals is not static. The USGS reviews the critical mineral list every three years, and the 2021 review identified five commodities that no longer meet the definition of critical mineral (helium [He], potash [KCl and K_2SO_4], rhenium [Re], strontium [Sr], and uranium [U]), and two new ones that do (nickel [Ni] and zinc [Zn]), for a total of 33 commodities or commodity groups, such as rare-earth elements (REEs) and platinum-group elements (PGEs).

Can we just use the term critical minerals and call it a day? In general, yes. But critical minerals cover a wide range of commodities with very different economic and mining implications, hence the complicated language around commodity subgroups. Below are three of the most common questions about critical minerals.

What about battery metals?

One of the most commonly discussed subgroups of critical minerals are the battery metals, referring to the mineral commodities used in the production of batteries for everything from electric vehicles to renewable energy storage. Battery metals and critical minerals have always had a significant overlap, and in the 2021 critical mineral list update all the commonly cited battery metals (lithium [Li], cobalt [Co], graphite [C], and manganese [Mn]) are now considered critical minerals. Is there any point to singling out the battery metals? Yes! Just because a mineral commodity is considered critical does not mean there is potential for substantial market expansion. Beryllium, for example, is a critical mineral essential to aerospace and defense, but demand is projected to continue at current rates. Battery metals, however, are expected to go through substantial market growth in the near future given the focus on shifting to a carbon neutral economy, and this demand has and will continue to have major impacts on allocation of exploration and development expenditure.



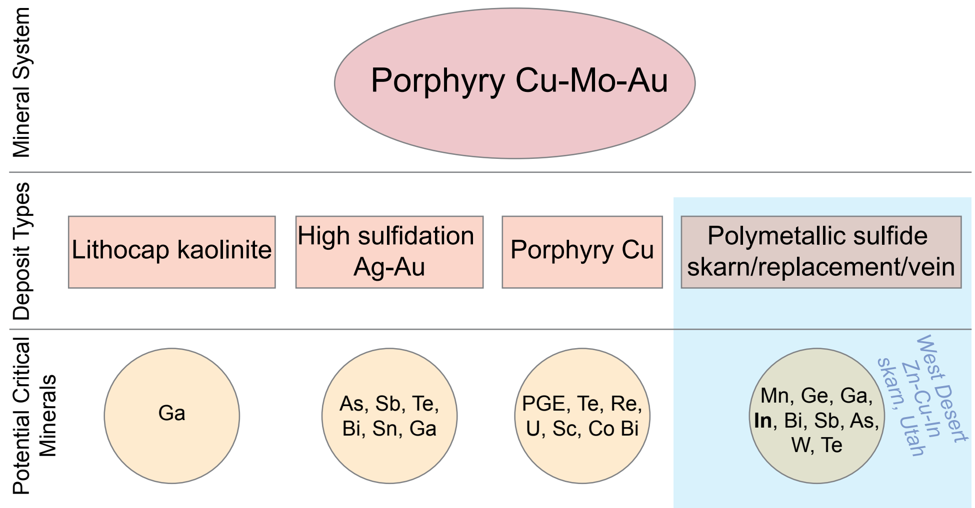
Classification of critical minerals and battery metals. Bold typeface indicates the most commonly cited battery metals.

Do critical minerals have any blindspots?

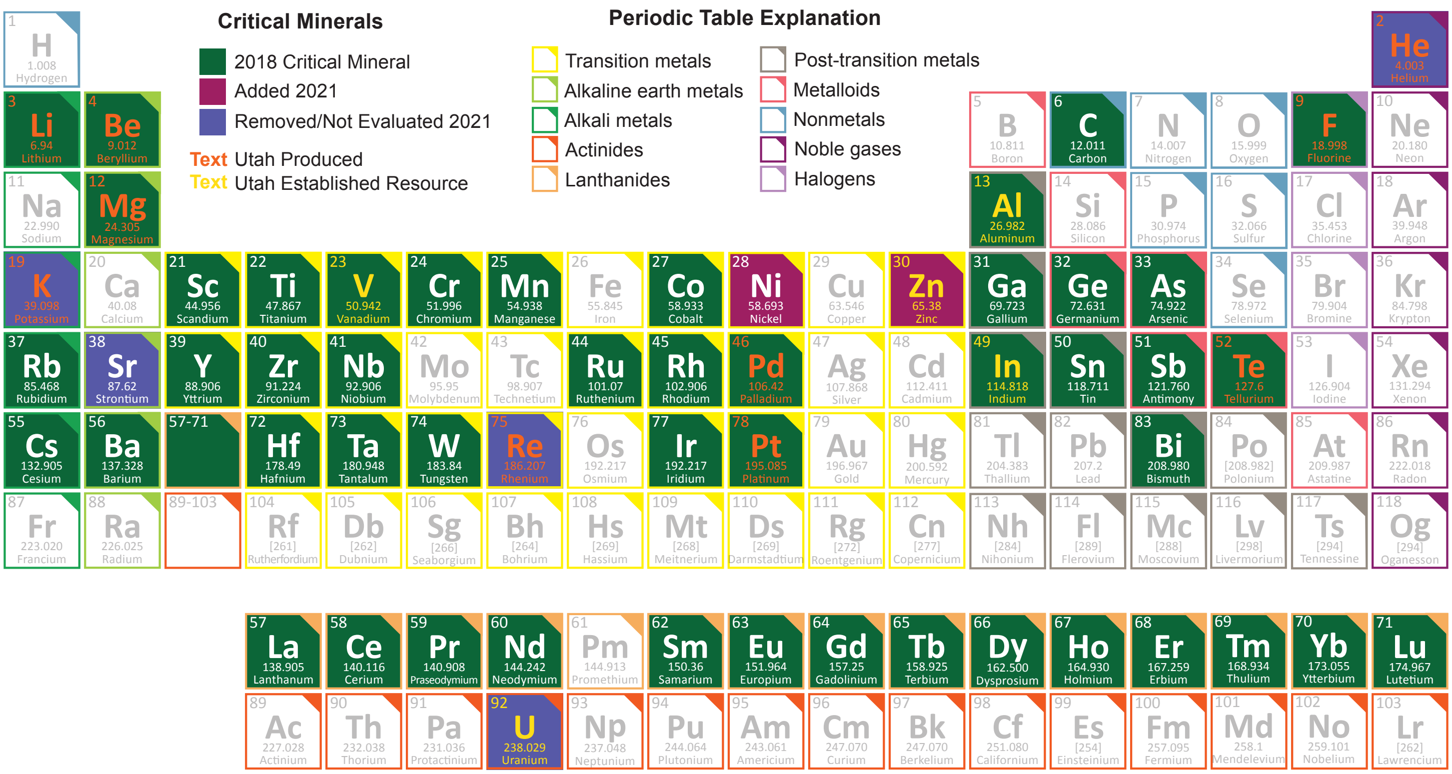
Given that the 2021 critical mineral update contains 33 mineral commodities, it would seem that everything of importance for future economies is covered. However, Utah's most significant produced mineral commodity, essential to current and future economies across the world, is copper, and copper is not a critical mineral. Other major infrastructure metals like iron (also mined in Utah, with the restart of the Black Iron mine in 2020) and aggregate are also not considered critical minerals. So although critical minerals tell a big part of the story about the future of the minerals industry, many of the traditional mineral commodities will continue to be essential. It is important that government and industry long-term planning continues to include these commodities.

How do we explore for critical minerals?

Critical minerals span every known geologic terrane, and many may not have strong enough economics to support stand-alone mining, such as gallium. How then do we approach critical minerals from an exploration standpoint? The USGS recently published a "mineral systems" approach to critical minerals. The mineral systems approach helps explorationists understand the critical mineral potential of known types of mineral deposits and encourages a holistic view of deposit economics, including consideration of critical mineral byproduct production along with core commodities. A good example of this in Utah is the West Desert skarn deposit in Juab County. Under the mineral systems approach, West Desert can be classified as a skarn deposit in a porphyry mineral system. The mineral systems approach suggests possible enrichment of nine critical minerals in a skarn deposit, one of which is indium. As it turns out, West Desert hosts an established resource of indium, the only known indium resource in the United States and enough indium to cover U.S. indium consumption for more than 15 years, based on 2020 imports. This demonstration of the mineral systems model shows how important it can be to remove blinders, especially in an exploration phase, and consider all the mineral potential in a deposit.



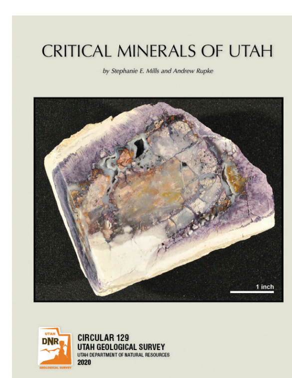
An example of the mineral systems approach to critical minerals exploration, with the West Desert skarn deposit type and critical mineral potential highlighted.



Periodic table showing the critical minerals from the original 2018 list, those that were not included in the 2021 update, and those that were added in the 2021 update. Critical minerals produced or having established resources in Utah are highlighted.

The UGS and critical minerals

As the minerals landscape evolves, the Utah Geological Survey (UGS) remains at the forefront of understanding emerging and traditional commodity trends. The UGS has been leading the way with understanding Utah's critical mineral landscape and published a summary of knowledge to date in 2020 (*Critical Minerals of Utah*, UGS Circular 129). Currently the UGS is carrying out a mapping and critical mineral assessment of the Gold Hill mining district, and a critical mineral web map will be available later this year. As always, look for updates on projects and publications at geology.utah.gov.



Glad You Asked!

What Movies Feature Utah Geology?

by Mackenzie Cope

Utah's legacy of movies is quite different from the average movie-making experience. Instead of artificial backgrounds and sets, Utah's impressive geologic landscapes have served as the backdrop for hundreds of movies since the early 1920s where the state's natural scenery has come to represent "the Wild West." One of the first movies filmed in Utah, ***The Deadwood Coach*** (1924), used an array of filming locations in southern Utah such as Zion National Park, Springdale, Bryce Canyon National Park, and Cedar Breaks. Partially due to *The Deadwood Coach*'s success, the natural wonders of Utah's geologic scenery became one of the driving reasons Hollywood studios came to Utah to film their movies. Westerns filmed in central and southern Utah were especially popular in the early days, but a change in popular movie genres in more recent years has brought with it a preference for filming in northern Utah as well. This article highlights the geology of six of the most used Utah backdrops for Hollywood films.

Bonneville Salt Flats

The Bonneville Salt Flats, an evaporative remnant of ancient Lake Bonneville, is an unparalleled place in northern Utah. When the lake was at its largest extent around 18,000 years ago, it was about 1,000 feet deeper than today's Great Salt Lake. As this massive freshwater lake evaporated, it left behind a hard salt crust due to the concentration of salts and other minerals in the lake. In films, the Bonneville Salt Flats has served as the backdrop for many fictional settings such as Davy Jones' Locker, the afterlife, Area 51, and as itself in the true-story film ***The World's Fastest Indian*** (2005).

Some films that highlight the Bonneville Salt Flats:

- Independence Day (1996, PG-13) - science fiction
- The World's Fastest Indian (2005, PG-13) - biography
- Pirates of the Caribbean: At World's End (2007, PG-13) - adventure
- Brigsby Bear (2017, PG-13) - drama

Wasatch Range and Uinta Mountains

The Precambrian to Cretaceous-age rocks (>540 million to around 66 million years old) of the Wasatch Range were initially uplifted by compressional folds and faults of the Sevier orogeny between 160 and 50 million years ago. Beginning around 13 million years ago, the rocks were uplifted again by extensional forces that caused Basin and Range normal faulting, which continues today. The Precambrian- and Paleozoic-age rocks (>540 million to 250 million years old) of the Uinta Mountains were uplifted during the Laramide orogeny around 60 to 30 million years ago. After millions of years of erosion, magma intrusions in the Wasatch Range, faulting, and glaciation, these mountain ranges have become some of the most impressive geologic features Utah has to offer. Hollywood studios and independent filmmakers have sought out the Wasatch and Uinta Mountains for their jagged snowy peaks and lush green forests to create all kinds of wilderness settings. Additionally, Park City in the Wasatch Range is home to the Sundance Film Festival. This festival, which began in 1978 and celebrates independent movie making, has significantly increased the number of movies and TV series that have been filmed in the region.

Some films that highlight the Wasatch and Uinta Mountains:

- Jeremiah Johnson (1972, PG) - adventure
- Better Off Dead (1985, PG) - romantic comedy
- Wind River (2017, R) - mystery
- Yellowstone (2018-, TV-MA) - western

Moab

The Moab area is home to red rock cliffs, winding canyons, and iconic geologic formations like arches, fins, and petrified sand dunes. Most of these features were formed from a diverse geologic history beginning more than 300 million years ago when salt and sediments were deposited in the Paradox Basin. Sedimentary layers were deposited on top and make up the steep red cliffs that dominate Moab's scenery. After uplift of the Colorado Plateau about 5 million years ago, the less dense salt layers shifted and formed an anticline that fractured the overlying sandstone. Wind and water took advantage of those fractures to form the arches and fins in Arches National Park. Dead Horse Point State Park towers over the Colorado River that has cut through and exposed rock layers ranging in age from 184 million to slightly older than 285 million years. ***Wagon Master*** (1949), the first movie filmed in the Moab area and directed by John Ford, opened the gates for Moab as a filming location for westerns. That film made Hollywood realize the desert scenery there was just as grandiose as Monument Valley. Dead Horse Point became a popular filming location in the 1950s and was often used as a stand-in for the Grand Canyon.

Some films that highlight the Moab area:

- The Comancheros (1961, PG) - western
- Thelma and Louise (1991, R) - drama
- 127 Hours (2010, R) - biography
- Westworld (2016-20, TV-MA) - science fiction

Southwestern Utah

Southwestern Utah, home to Zion National Park, St. George, and Snow Canyon State Park, is known for its massive cliffs and colorful exposed rocks. The Navajo Sandstone, which makes up the towering cliffs of Zion National Park and Snow Canyon, is a geologic formation that formed from an ancient Sahara-like desert 185 to 180 million years ago. St. George and Snow Canyon also have basalt bluffs and lava tubes from volcanic eruptions and flows as old as 2.5 million years. Filmmakers started using these sage-brushy, red-cliff deserts to film westerns in the late 1920s during the silent film era starting with *The Deadwood Coach*. ***The Conqueror*** (1956), another early movie filmed there, was filmed during U.S. Government above-ground nuclear testing in Nevada. The film crew, along with the locals, are members of a group referred to as the "Downwinders" and were exposed to radiation as it blew over parts of Utah. About 40 percent of the film crew contracted cancer in their lifetimes and it is believed the nuclear testing was partly to blame.

Some films that highlight southwestern Utah:

- Butch Cassidy and the Sundance Kid (1969, PG) - western
- The Car (1977, PG) - horror
- The Electric Horseman (1979, PG) - western

Lake Powell

The 186-mile-long, man-made Lake Powell is a popular tourist destination because of its striking geologic features and diverse water recreation activities. Glen Canyon Dam, completed in 1963, enabled the Colorado River to fill Glen Canyon and create Lake Powell. Glen Canyon was formed by the Colorado River carving deep channels into the rock layers for over 5 million years. These erosional forces exposed many geologic formations that were deposited from about 300 to 90 million years ago. Filming in the Glen Canyon/Lake Powell area began in the 1960s and was a popular location for historical and science fiction films. The mix of red rock desert and open water created realistic otherworldly backdrops. Some of the movies filmed there are living time capsules of the landscape before the dam was finished. ***The Greatest Story Ever Told*** (1965) filmed one of its iconic baptism scenes in the Colorado River days before the dam closed and Lake Powell started filling. That scene's filming location is now covered by water in today's Padre Bay.

Some films that highlight Lake Powell:

- Planet of the Apes (1968, G) - science fiction
- Doctor Who: The Impossible Astronaut (2011, TV-PG) - science fiction
- John Carter (2012, PG-13) - science fiction

Monument Valley

Monument Valley, located on the Navajo Nation straddling the Utah and Arizona border, is known for its flat desert plains and towering stand-alone buttes. The buttes were formed from extensive regional weathering and erosion that removed hundreds of feet of bedrock from the valley floor, leaving behind only pockets of shale, sandstone, and conglomerate which form the buttes or "monuments" we see today. John Ford, legendary director of westerns, was one of the first to use this landscape as a backdrop for his movies. His first Monument Valley film, ***Stagecoach*** (1939), showed this desert wonder to the world and inspired many other filmmakers to utilize this unique area. After countless classic western movies and memorable cameos like in ***Back to the Future Part III*** (1990) and ***Forrest Gump*** (1994), Monument Valley's landscape has become as famous as the names in the movie credits.

Some films that highlight Monument Valley:

- My Darling Clementine (1946, PG) - western
- Fort Apache (1948, PG) - western
- The Searchers (1956, PG) - western
- The Lone Ranger (2013, PG-13) - western

To learn more about movies filmed in Utah, check out these resources:

- Utah Film Commission: film.utah.gov
- Filmed in Utah interactive map: visitutah.com/things-to-do/film-tourism
- When Hollywood Came to Utah by James V. D'Arc
- Little Hollywood Museum in Kanab, Utah
- Moab Museum of Film and Western Heritage

Simplified map of Utah showing six popular filming locations: (1) Bonneville Salt Flats, (2) Big Cottonwood Canyon, Wasatch Range, (3) Double Arch, Arches National Park, Moab, (4) Observation Point, Zion National Park, southwestern Utah, (5) Lone Rock Beach, Lake Powell, and (6) The Mittens, Monument Valley Navajo Tribal Park.

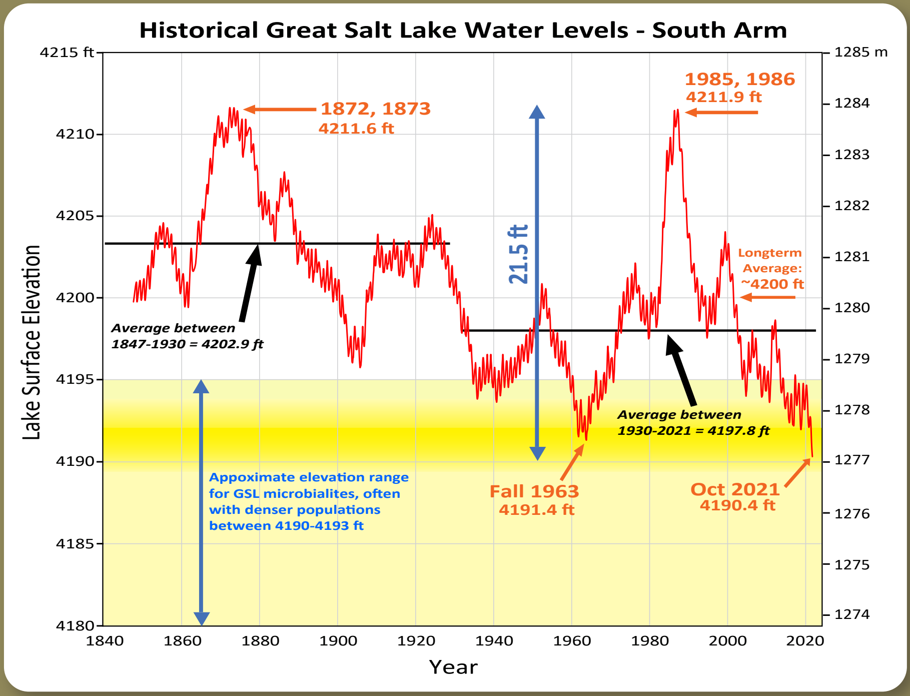
GEO SIGHTS

Microbialites of Bridger Bay, Antelope Island, Great Salt Lake

by Stephanie Carney and Michael D. Vanden Berg

Great Salt Lake (GSL) in northern Utah has a perception problem. Visitors often comment on the stinking "gross" lake that should be avoided, unless you enjoy swarms of biting gnats and being surrounded by millions of brine flies. However, those of us that live in Salt Lake City know the truth; GSL is an unsung gem, full of life and beauty. But our secret is getting out, especially over the past few months as historic low lake level has brought renewed attention to the lake. GSL is one of the most important habitats for migratory birds in western North America, supporting upwards of 5 million shorebirds, almost 2 million eared grebes, and hundreds of thousands of waterfowl during spring and fall migrations. The migratory birds take advantage of GSL's unique ecosystem and extensively feed on the lake's brine shrimp and brine flies. However, none of this biodiversity would be possible without the vastly underappreciated base of the GSL ecosystem—the abundant and diverse algae and bacteria. The bacterial community is particularly intriguing, forming remarkable microbial mats that cover and help create unique, organic sedimentary rocks called microbialites. And Bridger Bay on the northwest corner of Antelope Island is the perfect place to view them.

Microbialites mostly form in saline lakes or restricted ocean settings but can also form in specific freshwater conditions. They form as a result of microbial mats trapping and binding sediments, like ooids, pellets, and carbonate grains. The



Long-term water level of Great Salt Lake. Source USGS gage data.

mats also facilitate the precipitation of minerals, most commonly calcium carbonate (limestone), through photosynthetic processes that introduce oxygen to the water. The microbialites grow slowly as more sediment and precipitated calcium carbonate accumulate. Microbialites have been forming on Earth for billions of years and can be found worldwide in the fossil record. Australia boasts the oldest fossilized microbialites (3.5 billion years old), which are the first evidence of life on Earth. In fact, researchers believe that microbial communities that built the first microbialites likely contributed much of the oxygen to Earth's early developing atmosphere. "Modern" microbialites, those that formed during the Holocene Epoch (between about 12,000 years ago and the present), are rarer than the abundant examples found in the fossil record. The most famous recent examples are stromatolites, an internally layered type of microbialite, found in Hamelin Pool of Shark Bay in the shallow coastal waters of western Australia. However, to the surprise of many, our very own GSL hosts the largest population of Holocene microbialites in the world.

The shallow, saline, nearshore environment around GSL is an ideal place for the development of microbialites. Cyanobacteria are the main microbes responsible for microbialite growth in GSL and form thin, dark green-brown mats that cover the domal structures. However, this microbial mat is only active on microbialites found in the south arm of GSL. After the construction of the earthen railroad causeway in 1959, the north arm water turned hypersaline and the microbial mat communities could not survive, leaving behind only remnant, desiccated, salt-encrusted mounds. If microbialites are still "growing" today, this growth is only occurring in the south arm and would be directly associated with the living microbial mats. One of the most accessible places to see these amazing structures covered with a healthy microbial mat is at Bridger Bay.

However, at the time of this writing, the living microbialites in the south arm of GSL are in danger. Because microbialites thrive in an extensive shallow-shelf environment, they are at the mercy of the ever-changing lake level. Drought and the ever-increasing demands of water along the Wasatch Front have caused GSL to drop to its lowest level in more than 150 years of recorded lake history. In October 2021, the lake elevation reached a low of 4,190.2 feet (compared to the long-term, historically recorded average of about 4,200 feet), well below the previous historic low of 4,191.4 feet recorded in 1963. The GSL microbialites occupy elevations ranging from about 4,195 to roughly 4,180 feet, but the densest populations often occur between 4,192 and 4,191 feet. Therefore, the recent extreme low lake levels have exposed a significant proportion of the microbialite population in the south arm. Studies have shown that it only takes a short period of exposure time, maybe weeks, for the microbial mat to die and erode off the top of the microbialite structures, but it takes several years of higher lake level before the microbial mat can potentially recover. The exposure during fall 2021 will likely have lasting, unpredictable consequences for the microbialite population and the base of GSL's ecological pyramid for years to come, even if lake levels return to higher levels in subsequent years.

Top: Submerged microbialites covered with a living microbial mat in Bridger Bay, July 1, 2021, when lake elevation was at 4,191.8 feet. View to the southwest.

Bottom: The same view on November 4, 2021, when lake level was at 4,190.6 feet. The exposed microbialites have lost their living microbial mat and have experienced heavy damage most likely from people trying to walk on them. Field notebook for scale.

The recent exposure of these unique structures has highlighted the distressful situation at GSL. The Utah Geological Survey (UGS) along with several other dedicated researchers will continue to monitor and study the microbialites and their relationship to the greater GSL ecosystem. If you would like to see these amazing microbialite structures firsthand (without having to swim in 10 feet of water), Bridger Bay on Antelope Island offers the most convenient location. We ask that visitors **DO NOT** walk on these delicate structures. They easily break apart under the weight of a person, and what took hundreds of years to build can be ruined with one errant step. We hope that if lake levels return to more normal elevations, the microbial mat can recolonize these structures and the GSL ecosystem can be renewed. For more information, please see our web page at https://geology.utah.gov/resources/energy/oil-gas/#tab-id-3.

HOW TO GET THERE

Drive north from Salt Lake City on Interstate 15 approximately 40 miles. Take exit 332 and turn left onto Antelope Island Drive. Travel west until you reach the Antelope Island State Park entrance gate. There is a fee to enter the park (for information, go to https://stateparks.utah.gov/parks/antelope-island). After passing the gate, continue traveling west for 7 miles across the Davis County Causeway. Once on the island, veer right, past the marina, and travel for about 0.5 miles. Bridger Bay will be on your right (northwest corner of island). Park at Ladyfinger point. Because the lake level is so low, nearly all the microbialites are exposed along the shore. GPS coordinates: 41° 03′ 29″ N, 112° 14′ 58″ W

New UGS Board Members

We are pleased to welcome two new UGS Board members who were appointed by Governor Cox and were confirmed by the Utah Senate in October. The new members are **Riley Brinkerhoff**, representing the petroleum industry, and **Becky Hammond**, representing minerals and scientific interests. Terms have expired for **Marc Eckels** and **Pete Kilbourne** who have served us well as members of the UGS Board, and we thank them for their efforts.

2021 Hintze Award

The Utah Geological Association (UGA) and the Utah Geological Survey (UGS) presented the 2021 Lehi Hintze Award to **Dr. Thomas H. Morris**, retired Professor of Geology from the Brigham Young University (BYU) Department of Geological Sciences, for his outstanding contributions to Utah geology. Tom earned a B.S. in geology from BYU and an M.S. and Ph.D. from the University of Wisconsin-Madison, then worked as a petroleum geologist for Exxon in Louisiana. After four years he returned to BYU to teach and conduct research in geology, instilling his incredible enthusiasm for Utah's geology in hundreds of students. Tom's research has been devoted to the geology of Utah and he published over 40 technical papers, 80 abstracts, and the beautifully illustrated Geology Unfolded guides that culminated in a series of books outlining the geology of Utah and its national parks.

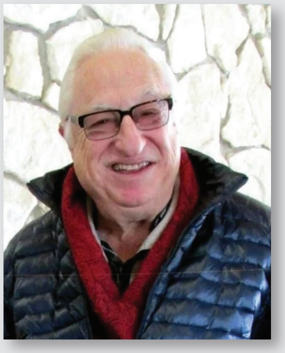
Tom served as president of the UGA (2007), co-edited the 2013 UGA guidebook, and contributed, along with many of his students, numerous papers to UGA guidebooks over the years. In addition, he co-edited the 2004 American Association of Petroleum Geologists (AAPG) guidebook and has chaired or co-chaired many committees for AAPG, the Geological Society of America (GSA), and the Society for Sedimentary Geology (SEPM) at both the regional and national level. Tom has led or co-led dozens of field trips for the UGA, AAPG, GSA, universities, industry, and the UGS using Utah geology to educate both the current and future generation of geologists.

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

2021 Employee of the Year

Congratulations to **Rosemary Fasselin** who was selected by her peers as the 2021 UGS Employee of the Year. Rosemary brings technical expertise and creative problem solving to her job as Senior GIS Analyst with the Geologic Mapping & Paleontology Program. A tremendous load was placed on her shoulders to not only become our GeMS expert (now a U.S. Geological Survey requirement), but she was also essential in preparing many of our record number of STATEMAP deliverables. She hired, trained, and managed new staff, and provided support to mapping geologists and GIS analysts across all programs at the UGS. Her work is highly organized and efficient, she brings a fresh perspective and finds new and innovative ways to complete tasks, and she is always available to share her knowledge. Her positive influence, productivity, enthusiasm, and commitment to making the UGS better through teamwork and communication make her a role model and deserving recipient of the employee of the year award.

In Memoriam



Bruce Norman Kaliser, former hazards geologist with the Utah Geological Survey, passed away on December 8, 2020, at the age of 78. Bruce worked at the UGS for over 20 years before moving into private consulting. He authored or co-authored more than 85 reports and publications on geologic hazards in Utah. He had an occasion to be interviewed by the National Geographic magazine and traveled extensively, including to some of the most exotic locations on the globe.

Introducing the new Data Management Program at the Utah Geological Survey

The UGS collects a significant amount of data and strives to make it available to the public as quickly as possible. To address the projected future growth of our data repositories, the UGS created this program to work with UGS staff to ensure that their data are collected, stored, and delivered in a secure, highly compatible, and efficient way. The program also manages the UGS website, the predominant venue for sharing UGS data, and develops web applications and interactive databases available on the website. The program is staffed by the previous Web Services Section of the Geologic Information & Outreach Program and is managed by **Marshall Robinson**. Find out more about the Data Management Program and its projects at https://geology.utah.gov/about-us/data-management-program/.

Employee News

The Data Management Program welcomes **Cyndi Andersen** as the new GIS Manager. Cyndi earned an A.A.S. in civil engineering from Idaho State University and a B.A.S in technology and management with a minor in GIS from the Oregon Institute of Technology. Cyndi is a certified GIS Professional and comes to us with over 20 years of GIS experience during which she led GIS, GPS, and asset management programs for several local government agencies in both Idaho and Oregon.

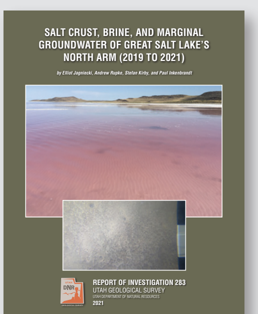
Jessie Pierson has accepted the position of Senior GIS Analyst and cartographer with the Editorial Section. Jessie earned an M.S. in geography from Oregon State University, with additional certifications in geographic information science and water conflict management. She attended Prescott College for her undergraduate degree, earning a B.A. in environmental studies and visual arts. She comes to us from the Utah Division of Water Resources where she worked as a GIS analyst.

Becka Downard joins the Groundwater & Wetlands Program as the new wetland ecologist. Becka has a Ph.D. in ecology from Utah State University and comes to us from the Utah Division of Water Quality where she worked as a wetland coordinator.

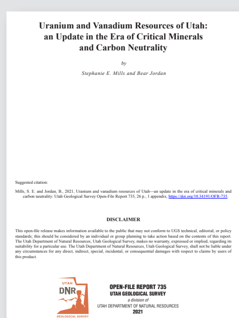
The Energy & Minerals Program welcomes **Katie Cummings** as the new curator of the Utah Core Research Center. Katie has a B.S. in geology from East Carolina University and an M.S. in geology from the University of West Georgia. She previously worked for the North Carolina Geological Survey for a year, followed by the Vulcan Materials Company where she was a geologist for five years.

NEW PUBLICATIONS

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



Salt Crust, Brine, and Marginal Groundwater of Great Salt Lake's North Arm (2019 To 2021), by Elliot Jagniecki, Andrew Rupke, Stefan Kirby, and Paul Inkenbrandt, 40 p., 4 appendices, **RI-283**, https://doi.org/10.34191/RI-283

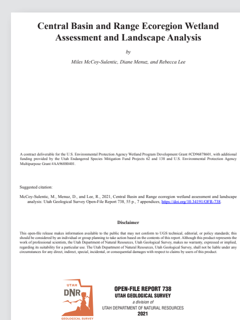

Uranium and Vanadium Resources of Utah: an Update in the Era of Critical Minerals and Carbon Neutrality

by

Stephanie E. Mills and Bear Jordan

OPEN-FILE REPORT 735
UTAH GEOLOGICAL SURVEY
2021

Uranium and Vanadium Resources of Utah: An Update in the Era of Critical Minerals and Carbon Neutrality, by Stephanie E. Mills and Bear Jordan, 26 p., 1 appendix, **OFR-735**, https://doi.org/10.34191/OFR-735


Central Basin and Range Ecoregion Wetland Assessment and Landscape Analysis

OPEN-FILE REPORT 738
UTAH GEOLOGICAL SURVEY
2021

Central Basin and Range Ecoregion Wetland Assessment and Landscape Analysis, by Miles McCoy-Sulentic, Diane Menuz, and Rebecca Lee, 55 p., 7 appendices, **OFR-738**, https://doi.org/10.34191/OFR-738

RECENT OUTSIDE PUBLICATIONS

BY UGS AUTHORS

Interpretation of hydrothermal conditions, production-injection induced effects, and evidence for enhanced geothermal system-type heat exchange in response to >30 years of production at Roosevelt Hot Springs, Utah, USA, by S.F. Simmons, R.G. Allis, **S.M. Kirby**, J.N. Moore, and T.P. Fischer: Geosphere, https://doi.org/10.1130/GES02348.1

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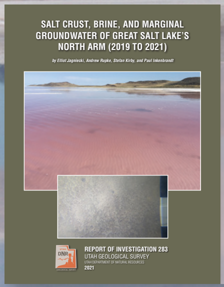
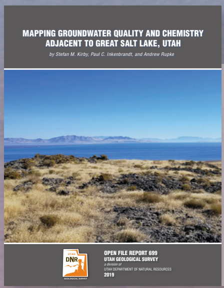
Great Salt Lake North Arm Salt Crust Monitoring, Spring 2017 Update, by Andrew Rupke and Taylor Boden, 13 p., **OFR-714**, https://doi.org/10.34191/OFR-714

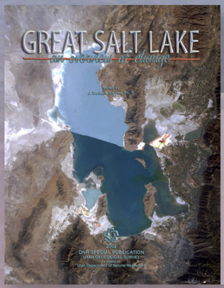


Salt Crust, Brine, and Marginal Groundwater of Great Salt Lake's North Arm (2019 To 2021), by Elliot Jagniecki, Andrew Rupke, Stefan Kirby, and Paul Inkenbrandt, 40 p., 4 appendices, **RI-283**, https://doi.org/10.34191/RI-283

Great Salt Lake's North Arm Salt Crust, by Andrew Rupke, Taylor Boden, and Peter Nielsen, 22 p., 4 appendices, 1 plate, **RI-276**, https://doi.org/10.34191/RI-276



Mapping Groundwater Quality and Chemistry Adjacent to Great Salt Lake, Utah, by Stefan M. Kirby, Paul C. Inkenbrandt, and Andrew Rupke, 19 p., GIS database, **OFR-699,** https://doi.org/10.34191/OFR-699



Great Salt Lake: An Overview of Change, J. Wallace Gwynn, editor, 584 p., Utah Department of Natural Resources Special Publication, https://ugspub.nr.utah.gov/publications/dnr/GSL2002.pdf

For more information, see our Great Salt Lake, Lake Bonneville, and Bear Lake web page at geology.utah.gov/great-salt-lake.

Publications are available for download at geology.utah.gov *OR for purchase at* utahmapstore.com.