UTAH GEOLOGICAL SURVEY

SURVEY NOTES

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Geologic Diagnostic: An "MRI" for the Earth

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Design | *John Good*
Cover | View to the northwest from West Desert site showing exposed Silurian-age (about 430 million years old) dolomite contrasting with the more recent alluvial and lacustrine deposits of the Great Salt Lake Desert. Photo by Jake Alexander.

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DIRECTOR'S PERSPECTIVE

by Bill Keach

"Raindrops keep falling on my head..."

As I sat down to write this edition's musings, it started to rain heavily, very heavily. The lyrics to an old song (1969) came immediately to mind: *"Raindrops keep falling on my head…"* It reminded me of all the precipitation we had this past spring. In a drought parched state, rain is a welcome addition, bringing "the greatest snow on Earth" to the mountains, replenishing reservoirs, and revitalizing parts of Great Salt Lake. Alta ski resort recorded 903 inches and Snowbird had 805 inches of snow; both significantly above their annual averages of 500 plus inches. Many reservoirs which had been nearly empty in recent years reached 100% capacity. The south arm of Great Salt Lake was up 5.5 feet from historic lows reached over the past several years. Still not near its historical average, but enough to bring hope to those concerned about the wellbeing of the lake.

With all the good that rain brings to a land starved of moisture, it also brings hazards such as landslides, rockfalls, and flooding. As with any geologic event, the UGS received many requests from landowners, cities, counties, and even national parks to visit, assess, and document landslides. UGS staff gave countless interviews to the media and the Utah State Legislature invited us to two interim sessions to share our knowledge. Some statistics we shared include:

- UGS staff responded to at least 25 emergencies,
- we received over 200 reports of active landslides across the state, and we assume many more were not reported,
- UGS staff clocked more than 500 hours of time for investigations,
- we produced eight drone videos (including two from a news station helicopter), and
- more than 1,500 photos were uploaded to our website, and a separate webpage was made for each event.

The runoff also led to numerous reports of groundwater flooding in various parts of the state. UGS staff responded to a number of these events as well. We collaborated with the Division of Emergency Management to update their website with current information about groundwater flooding.

Furthermore, the UGS website had a surge in public interest with more than 24,000 views and nearly 600 downloads of landslide-related content. UGS social media posts about landslides were read by over 100,000 people.

In addition to timely landslide information, our social media pages have become a valuable venue for the UGS to share a variety of geologic information with the public. Our posts aim to give the reader a greater understanding of the geologic world around them and the impact it has on their daily lives. A couple of examples include information about how certain minerals are used to make solar panels and where and how geothermal energy is created and used in the state. Each a very different geologic resource, but both create the electricity Utah citizens consume.

When you have a moment, search your favorite social media site for the Utah Geological Survey to learn more about the geology in our state and the impact it has in your life. You are likely to find something of interest, such as landslides, minerals, and geothermal resources.

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Geologic Diagnostic: An "MRI" for the Earth

by Jake Alexander, Andrew Rupke, and Stephanie E. Mills

Critical minerals, as defined by the U.S. Geological Survey (USGS), refers to commodities that are important to the country's economy or national defense, but have a supply chain that faces potential risk for various reasons. The most recent critical mineral list generated by the USGS includes 50 commodities such as lithium, rare earth elements (REEs), beryllium, vanadium, and aluminum, to name just a few. In many cases, the United States produces little or none of these important minerals. In 2019, the USGS kicked off the Earth Mapping Resources Initiative (Earth MRI) with the goal of identifying new domestic critical mineral deposits. This initiative facilitates the collection of the basic geological information necessary for mineral exploration, such as modern geological mapping, geophysical surveys, lidar data, and geochemical data. The USGS recognized that in many areas of the country these basic data are unavailable, outdated, or incomplete and slows the exploration efforts of companies seeking to identify new deposits. Another key part of the USGS's strategy is to tap into the mineral resource expertise of state geological surveys across the country. Over the past several years, the USGS and many state surveys, including the Utah Geological Survey (UGS), have been collaborating to identify the most important areas in each state that have or may have critical mineral deposits. To further investigate a few of these promising areas and deposits, the UGS has been working on several Earth MRI projects, two of which are highlighted below.

An example of mineralized skarn from drill core at the West Desert site. Core sample is approximately 2.5" in diameter. Photo courtesy of Kayla Smith (UGS).

WEST DESERT SKARN

One of these Earth MRI projects is studying the critical minerals indium and zinc at the West Desert zinc-copper-indium skarn deposit in Juab County at the southern end of the Great Salt Lake Desert. The importance of indium in modern society is wide-ranging as it is commonly used in touch-screen technology. Indium is chemically similar to its neighbor on the periodic table, tin, and the compound indium-tin oxide is an electrically conductive, optically transparent coating used in televisions, smartphones, and laptops that enables us to interact with our daily devices, order food at a restaurant kiosk, and navigate with ease on our vehicle's GPS system. The West Desert skarn is the only established domestic resource of indium, and the deposit could meet the domestic indium demand for several years if it was produced today.

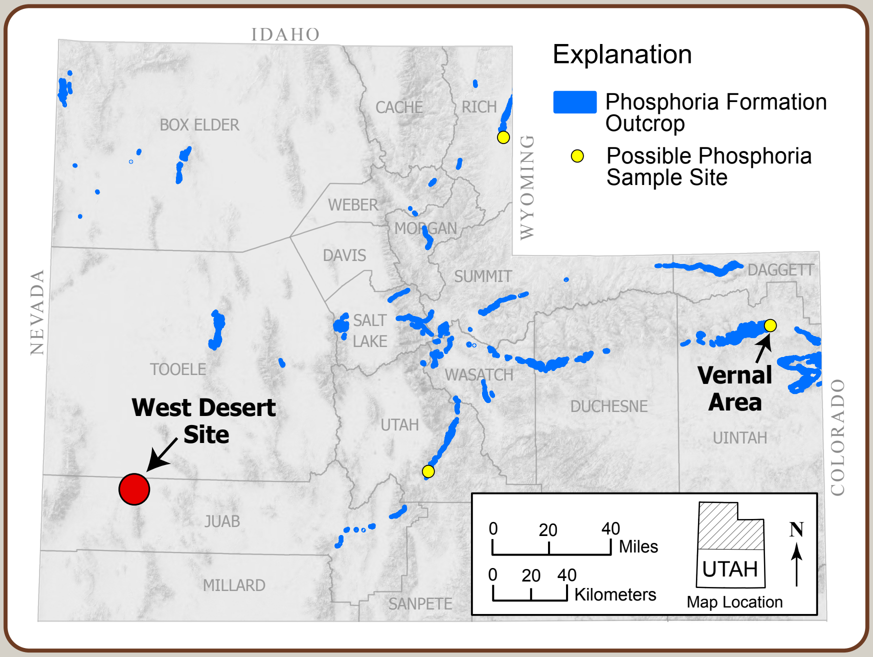
At the West Desert site, indium and zinc are identified in the porphyry-related skarn zones, and historical working of the area produced minor amounts of lead, silver, zinc, and gold from 1890 to 1953. Geologically, indium and zinc are commonly related since indium is found in the zinc ore mineral sphalerite, and as a result most indium is produced as a by-product of zinc mining. The mineralization at West Desert is the result of skarn alteration caused by Eocene-age (about 40 million years ago) magmatism. A skarn is formed when fluids, transporting metals in solution such as indium, leave hot igneous rock and move through the existing host rock. At West Desert, the fluids altered shales interbedded within massive limestone and dolomite rocks of the Ordovician-age (about 460 million years ago) Wah Wah Limestone and Kanosh Shale, and members of the Cambrian-age (about 520 million years ago) Orr Formation. To understand why and how critical minerals are concentrated in this deposit, we are collecting samples for geochemical analysis which will allow comparison of altered and unaltered rocks exposed at the surface above the deposit.

Additionally, the West Desert deposit is not exposed at the surface, and our investigation provides an opportunity to understand the subtle expression of this mineralizing system at a distance from the deeper resource. This "blind deposit" approach to our geochemical sampling program will provide data that future exploration geologists can use to identify deposits elsewhere that are not exposed at the earth's surface. We are also collecting high-resolution photogrammetry of key areas via small Unmanned Aerial Systems. Our drones will be flown low to the ground since this field site is extremely close to the southern edge of the U.S. Department of Defense Utah Testing and Training Range. We aim to integrate these two datasets (geochemistry and high-resolution photography) to document and evaluate the surficial alteration in three dimensions.

PHOSPHORIA FORMATION

A second Earth MRI project will seek to determine if significant concentrations of critical minerals are hosted in the Permian-age Phosphoria Formation, which was deposited over 250 million years ago. The Phosphoria Formation is a current source of phosphate in both Utah and Idaho, and several million tons of phosphate rock is mined from the formation each year near Vernal, Utah. Lesser amounts of phosphate rock are produced near Diamond Fork in Utah County. The phosphate rock from these mines is primarily used in manufacturing phosphate-bearing fertilizers. The marine conditions that were favorable for depositing phosphate minerals such as fluorapatite are also known to concentrate and deposit anomalous amounts of certain critical minerals such as REEs, vanadium, and fluorine (or fluorspar), all of which the U.S. currently imports. REEs are used in many high-tech devices such as smartphones, electric vehicles, and flat-screen televisions; vanadium is a key component in producing certain types of strong steel alloys; and fluorine is important for producing refrigerants and aluminum, to name a few applications of these critical minerals. Some potential may exist to produce these minerals as by-products from active or future phosphate mines. For example, some by-product fluorosilicic acid (a fluorine compound that offsets the need for fluorspar) is already being produced from domestic phosphate rock. However, any potential is mostly speculative at this point because we have little information on the actual critical mineral content of phosphate rock in Utah.

Backed by funding from Earth MRI, the UGS is working cooperatively with the Idaho, Montana, and Wyoming Geological Surveys to characterize the geochemistry of the Phosphoria Formation and fill this data gap. Each geological survey is selecting sites in their respective states to measure, describe, and sample the Phosphoria Formation where it crops out or from drill core. The samples collected from the formation will be analyzed for a long list of elements that will include REEs, vanadium, and fluorine. These data will provide some basis for assessing the potential for future production of critical minerals from Utah's phosphate rock. This project presents a great opportunity for the UGS to use federal funding to study and analyze Phosphoria Formation drill cores that were donated in recent years to



The UGS's Earth MRI project sites.

Peloidal nodules rich in the phosphatic mineral fluorapatite may contain anomalous amounts of critical minerals. The sample shown here is a peloidal phosphorite from the Phosphoria Formation, Crawford Mountains, Rich County, Utah.

Steeply dipping beds of limestone and phosphorite in the Phosphoria Formation, Crawford Mountains, Rich County, Utah.

Core Research Center. Currently, we are selecting other strategic sites in Utah where information on the Phosphoria Formation, particularly geochemistry, would be beneficial.

As the Utah Geological Survey takes advantage of current interest and funding in critical mineral research, we hope to provide timely information on the state's critical mineral resources to support responsible and sustainable management of those assets into the future.

For more information see:

The USGS Earth MRI website:
https://www.usgs.gov/special-topics/earth-mri

Critical Minerals of Utah, Second Edition publication:
https://ugspub.nr.utah.gov/publications/circular/c-135.pdf

ABOUT THE AUTHORS

Jake Alexander is a geologist in the Energy & Minerals Program who joined the UGS in 2022. He has a B.S. degree in geology from Texas A&M University–Corpus Christi and an M.S. degree in geology from the University of Tennessee. Jake investigates Utah's metal and industrial mineral potential across the state and currently focuses on critical minerals.

Andrew Rupke is a senior geologist in the Energy & Minerals Program who joined the UGS in 2010. He has a B.S. degree in geology from Calvin College in Grand Rapids, Michigan, and an M.S. degree in geology from the University of Utah. Andrew's work and research at the UGS focuses on Utah's diverse industrial mineral resources including potash, phosphate, salt, high-calcium limestone, aggregate, gypsum, and others.

Stephanie Mills is a senior geologist in the Energy & Minerals Program who joined the UGS in 2019. She has a B.S. Hons degree from the University of Texas at Austin and a Ph.D. from Monash University. Stephanie is an economic geologist with over a decade of experience researching and working in minerals exploration across the globe. Her specialization is in magmatic-hydrothermal systems with a focus on porphyry, skarn, epithermal, and Carlin-style deposits.

The Development of Field Spectroscopy for Minerals Exploration: Utah, Fieldwork, and Family

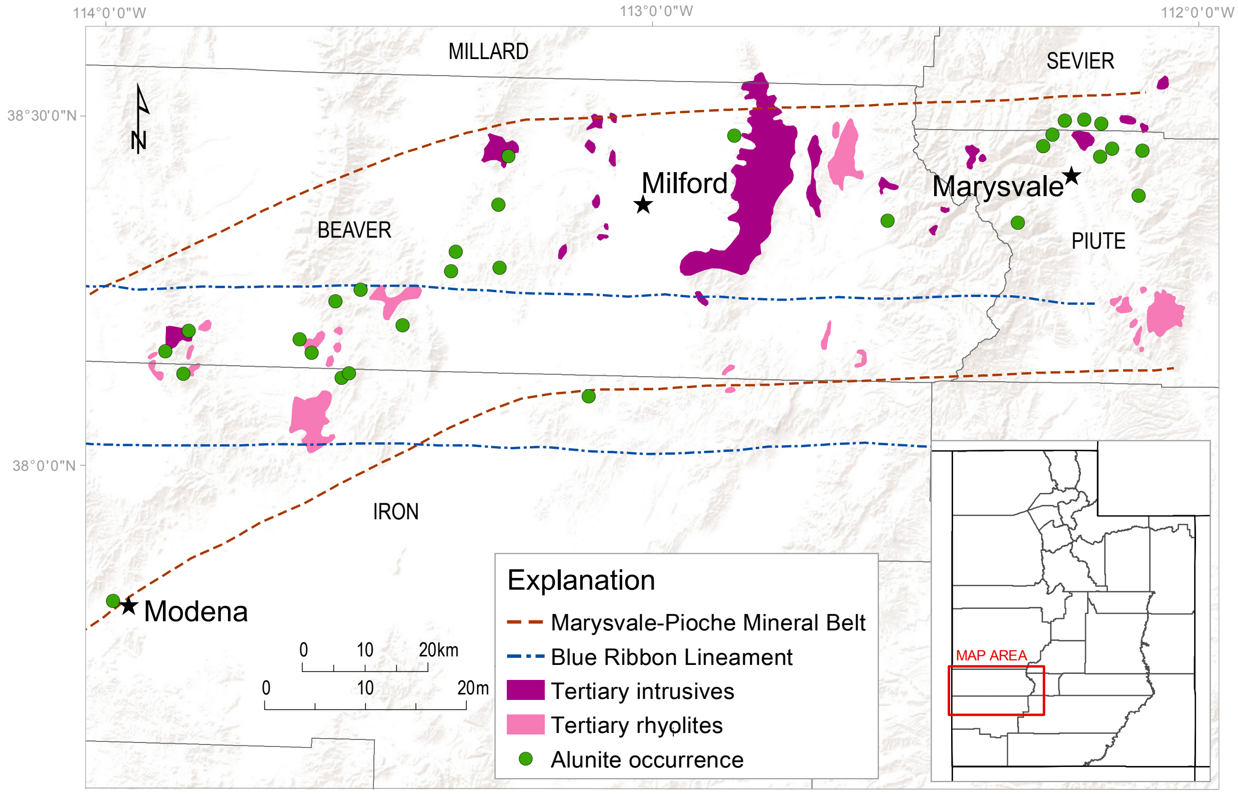
by Stephanie E. Mills

Spectroscopy has been an important analytical method in the geosciences over the past century, and in more recent decades has become an essential tool in minerals exploration across the globe. Spectroscopy can help identify key mineral assemblages that point exploration geologists towards different types of mineral deposits. However, to use the method effectively, an exploration geologist must first understand mineral formation, distribution, and characteristics of different alteration and deposit types. One of the mineral industry's leading researchers in alteration mineralogy and an early adopter of short-wave spectroscopy is geologist Anne Thompson. Using Utah's unique geological landscape, the mineral alunite (hydroxylated aluminum potassium sulfate, $KAl_3[SO_4]_2[OH]_6$), and with a nanny and baby in tow, Anne spearheaded using spectroscopy in the field for minerals exploration.

What is spectroscopy?

Spectral identification of minerals utilizes a non-destructive analytical technique known as reflectance spectroscopy, which has been used by mineralogists since the early 1900s. Reflectance spectroscopy measures the unique absorption spectra (how electromagnetic radiation is absorbed) of different minerals and focuses on the visible and near infrared (VNIR), shortwave infrared (SWIR), and longwave infrared (LWIR) parts of the electromagnetic spectrum. Early uses of spectroscopy were mainly for mineral identification and defining new mineral species, whereas modern uses include everything from paleoecology to asteroid surface mineralogy. The technology to support the application of spectroscopy continues to develop, moving from early handheld field-based instruments to stationary scanners that integrate traditional photography with spectral readings to satellite-based spectral mapping of entire landscapes.

Fine-grained bladed alunite crystals from Blawn Wash, Beaver County. Image courtesy of Ken Krahulec.



Adaptation of overview map in Thompson (1991) showing the extent of alunite occurrences in the Marysvale-Pioche belt.

How is spectroscopy used in modern geosciences and minerals exploration?

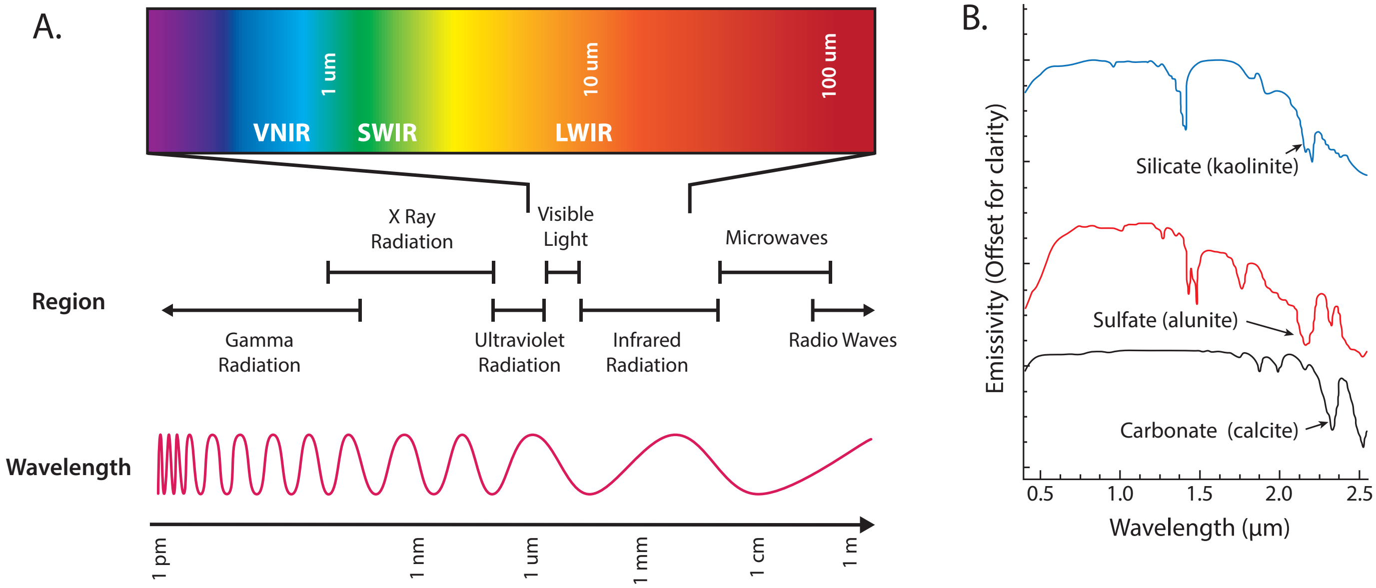
Spectroscopy is an ideal method for identifying hydrated minerals due to their strong and unique spectral response, so the use in identification and characterization of clays and micas caught the attention of geologists in the minerals industry in the late 1980s and early 1990s. Clays and micas are of particular interest in minerals exploration because they occur in the alteration zones around mineral deposits, which means they often have a systematic spatial distribution around economic areas of an ore deposit. Characterization of spectrally responsive minerals in alteration zones has become a major field of innovation and a standard method in the minerals explorationist's toolbox.

In the 1980s the development of models for precious metal deposits that occur in the shallow subsurface, known as epithermal deposits, meant that the mineral alunite, which occurs with these deposits, also became an important indicator of mineralization. At the time there were no formal studies on the formation of alunite, even as exploration geologists needed guidelines to help understand how the alunite they identified might be related to potential ore.

How does Utah fit in?

Southern Utah hosts a unique range of alunite occurrences, some of which were exploited as a source of aluminum and potash throughout the early to mid-1900s. In fact, Blawn Mountain, the largest known alunite deposit in the United States, is located in the Wah Wah Mountains of Beaver County. The presence of such diverse species of alunite made a perfect natural laboratory for geologist Anne Thompson, who is today a global leader on alteration mineralogy and the application of spectroscopy in minerals exploration. Back in the 1980s, as industry geologists were scrambling to understand how alunite could help them find epithermal deposits, Thompson was a geological researcher in Utah. At the time, the Utah Geological Survey (UGS) gave small research grants funded by Mineral Lease revenue to non-UGS researchers, and Thompson was one such recipient. Her research in the Marysvale-Pioche mineral belt focused on characterizing alunite associated with argillic alteration, the type of clay- and alunite-rich alteration commonly found around epithermal deposits.

Thompson's alunite research culminated in UGS Miscellaneous Publication (MP) 91-2 and focused on parsing field relationships, mineralogy, and geochemistry of alunite in argillic alteration with respect to gold mineralization. Thompson recognized that at least three different environments of formation for alunite were present in the Marysvale-Pioche mineral belt. Building on the knowledge she had developed in Utah, Thompson began more detailed comparisons of alunite compositions, including comparisons to known epithermal deposits in Chile. Soon after Thompson completed the Utah research, she met Phoebe Hauff at a conference in Denver. Hauff had one of the earliest handheld spectrometers (a PIMA: portable infrared mineral analyzer) and was developing a mineral database that would become the backbone of spectroscopy in mineral exploration for the next three decades.



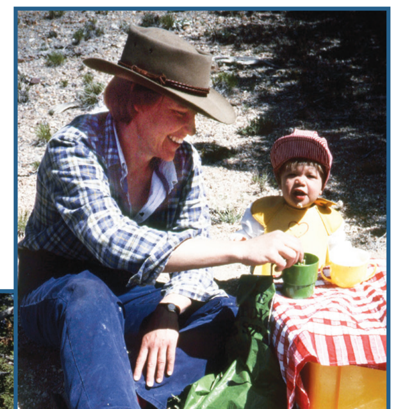
***(A)** Overview of the electromagnetic spectrum and **(B)** example of the spectral response of different minerals (after Ni and others, 2020).*

The pair met in a hotel room during the conference to run Thompson's alunite samples, and Hauff immediately recognized that the differences Thompson had found in the composition of alunite could be recognized using the much simpler and faster spectrometer. They went on to collaborate for many years, continuing to develop a variety of case studies and applications for field spectroscopy in minerals exploration. Not only did Thompson's work continue through her career and lead to field-defining publications such as the *Atlas of Alteration*, it propagated through the Utah geology community. Erich Petersen, Professor of Economic Geology at the University of Utah, worked with Thompson during her time in Utah and noted, "Anne introduced us to VNIR and we took off with it….[her] legacy continues."

Thompson's work on argillic alteration in the Marysvale-Pioche belt is impressive on its own. What many people do not realize is that Thompson carried out this extensive field-based research with her infant daughter in tow. Between her husband working full-time and no family support in the area there were few options for childcare – not that Thompson let this be an obstacle. Thompson started fieldwork when her daughter was three months old and continued to do a week or two at a time until her daughter was 18 months old. She had help from her parents who traveled out west from Florida for one field session and then met a young woman at an outdoors store who became a part-time field nanny. Her daughter and the nanny often spent their days nearby in the field while Thompson mapped and sampled. They patched together a variety of field vehicles, from a Subaru Outback family wagon to rental trucks and then finally Thompson bought a second-hand SUV to get them all around. A mountain bike allowed Thompson to expedite some field visits, while the others stayed closer to the vehicle.

Thompson's work not only highlights the start of a career-spanning step change in the understanding and detection of alteration mineralogy, but also highlights the importance of flexible work arrangements that allow geoscientists in different family and life phases to continue growing and developing their expertise, especially in the early career phase. To celebrate Thompson's early work through the UGS, a modern format version of her publication MP 91-2 is planned for release later this year.

...with a nanny and baby in tow, Anne spearheaded using spectroscopy in the field for minerals exploration.



(Top) Thompson having lunch with her 13 month old daughter in May 1990 and (bottom) Thompson's parents as field assistants in 1989 with her then-4-month old daughter. Thompson cites help from her parents as a critical part of her early fieldwork as a mother.

For more information see:

Thompson, A.J.B., 1991, Characteristics of acid-sulfate alteration in the Marysvale-Pioche mineral belt—A guide to gold mineralization: Utah Geological and Mineral Survey Miscellaneous Publication 91-2, 29 p., https://doi.org/10.34191/MP-91-2.

Thompson, A.J.B., Hauff, P.L., and Robitaille, A.J., 1999, Alteration mapping in exploration—Application of short-wave infrared (SWIR) spectroscopy: Society of Economic Geology Newsletter, no. 39, 14 p.

HAZARD NEWS

An Update on Utah's Very Active Spring 2023 Landslide Season

by Greg McDonald and Ben Erickson

Utah's 2023 spring landslide season was the most active since 2011, which the Utah Geological Survey (UGS) geologic hazards team anticipated given the record snowpack of the winter of 2022–23 across the state. Fortunately, landslide and flood-related damage was localized, partly due to infrastructure and development improvements that are increasingly being put in place as awareness of geologic hazards grows. Notable landslide damage included a house that was impacted by a landslide but was not structurally damaged, a hotel that was damaged by landslide debris breaking through part of a back wall, a cabin impacted by a debris flow, a shed that was demolished, two condominium units with damaged decks, and several roadways that were either covered by debris or were cracked/displaced by ground movement.

Landslide in Duchesne County that initiated as a debris slide and mobilized into a debris flow traveling about 1,200 feet. Photo taken May 30, 2023.

Much of the UGS Geologic Hazards Program's response included fulfilling requests for landslide evaluations from county and city officials and emergency managers in addition to field checking known landslides, which we visit every spring to document their yearly activity. All spring 2023 landslides were a result of elevated groundwater levels from melting of the record snowpack. Interestingly, many of the landslides we monitor annually, and that have been active in past wet years, showed no significant movement this year. Whether the lack of activity is a result of several previous years of drought, a transient or delayed response to groundwater recharge, or other factors is not clear at this time. Another factor may be that this year's snowmelt occurred at a relatively moderate rate, in contrast to 1983 when temperatures rose dramatically causing rapid snowmelt that resulted in numerous debris slides and flows.

Fill embankment failure along Trappers Loop Road in Morgan County. Photo taken April 28, 2023.

Our team documented several different types of landslides having a wide range of sizes, from small debris slides to debris flows with several-hundred-foot runouts, to large complexes having partial or global reactivation. One of the first landslides we responded to was a relatively small earth slide in Fruit Heights that occurred on April 8th. The landslide was about 15 feet wide with a 200-foot runout and occurred on a scarp formed by the Wasatch fault displacing Lake Bonneville sands and silts. Although considered small, the landslide impacted a shed, injuring two occupants. A somewhat unusual landslide in downtown Park City resulted in damage to a several-story hotel. The base of the slope had been excavated, exposing in-place bedrock composed of Permian-age (about 250 to 300 million years old) Park City and Phosphoria Formations. The slide initiated as a bedrock dip-slope failure that moved a relatively large, intact block of rock nearly 10 feet high along with loose soil and sediment that impacted the hotel. One of the

Landslide in Mountain Green. Photo taken April 20, 2023.

larger landslides we documented occurred in a remote part of Duchesne County. The landslide involved the partial reactivation of a landslide associated with the Eocene-age (about 34 to 56 million years old) Green River Formation. Our field observations indicated the landslide began as a debris slide from a roughly 450-foot-wide section of snowmelt-saturated soils that quickly mobilized into a debris flow having a runout of over 1,200 feet. A human-caused wildfire, the Church Camp fire, burned the forested area in 2013 and numerous fire-killed trees were incorporated into the debris flow.

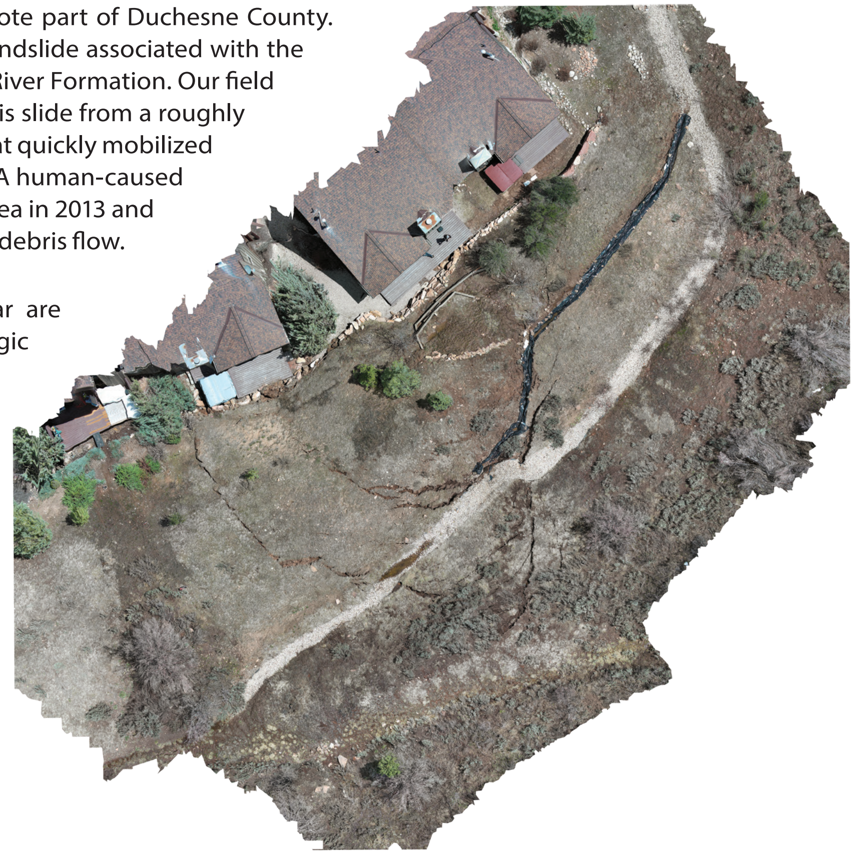


Image from a 3D model created using UAV-acquired photos of a landslide in the Cove Canyon subdivision, northwest of Park City. Photo taken May 8, 2023.

Several of the landslides we documented this year are new slides that occurred in landslide-prone geologic materials and/or on slopes that have been modified. Some of the larger, damaging landslides involved landslide-prone slopes that had toes excavated or grading that did not account for proper drainage. We also documented numerous roadcut failures across the state. Many were relatively shallow, leaving thin debris deposits covering roads.

The UGS uses several different modern tools and techniques to monitor and gather data on landslides. To collect data on-site, including field observations and photos, we use a GIS (geographic information system) app on a cell phone or tablet. This method allows us to synchronize data to a working project, usually on the same day a landslide is visited, allowing other UGS geologists to see where landslides have been recently investigated and view information for any particular site. The data are then uploaded to the UGS website and an archive, making the information accessible to the public within a few days following an event (https://geodata.geology.utah.gov/pages/collections_featured.php?parent=184933). Another tool we use that has been extremely useful is a UAV (unmanned aerial vehicle, commonly called a "drone"). UGS geologists can deploy a UAV within minutes to assess the greater landslide area and collect videos and photos for documentation in a safe and effective manner. A UAV does not negate the need for on-the-ground field observations, but rather helps guide site visits and enhance our data collection capabilities. For example, images obtained from a UAV flight can be used to generate 3D models using structure-from-motion techniques to compare to models made from earlier years or to lidar (light detection and ranging) data to quantify landslide movement.

Landslide along a joint plane within a bedrock dip-slope block failure in Park City. Photo taken May 8, 2023.

Investigating and documenting landslide activity, especially for wet, active years, plays an important part in better understanding landslide hazards in Utah. This information, in part, is used to determine and map landslide hazards and susceptibilities as part of the UGS's hazards mapping initiative. Identifying and mapping geologic hazards is important for land-use planning and management and enables safer and more cost-effective development.

For more information and updates on the spring 2023 landslides, visit our Landslide Current Events page:
https://geology.utah.gov/hazards/landslides/current-events/

Cinder Cones of Southwest Utah:
What Exactly Are They and How Did They Get There?

by Jackson Smith

Glad You Asked!

Utah boasts stunning natural beauty, characterized by an array of spectacular geological features. One of these striking features is the cinder cone volcanoes that stand out as towering landmarks. Utah claims more than 150 cinder cone volcanoes, found throughout the southwestern quadrant of the state.

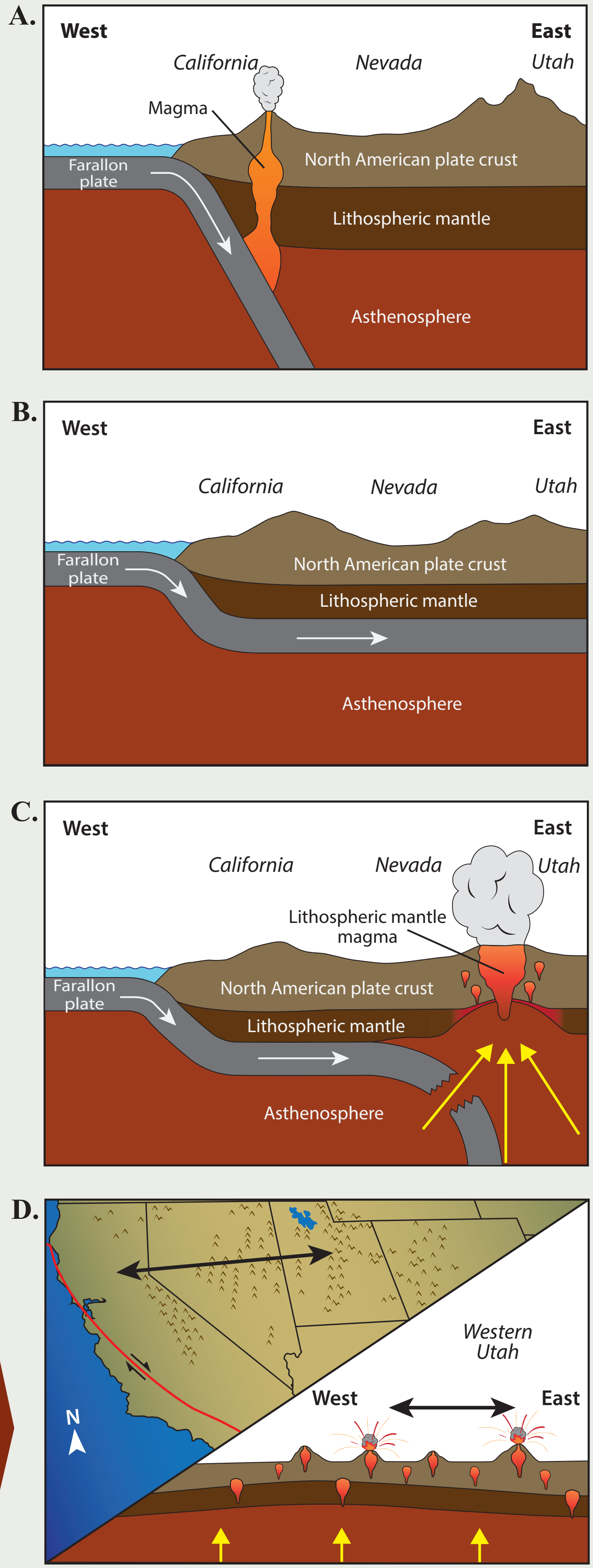
Cinder cone volcanoes, also known as scoria or pyroclastic cones, are relatively small and symmetrical volcanoes, and as their name suggests, conical in shape. They form through explosive eruptions caused by the release of gas-rich magma from a volcanic vent. Expanding gas drives magma vertically to the surface where it violently erupts into the air and solidifies as fragmented volcanic material called cinders or scoria, which then fall to accumulate around the vent. The cinders gradually build up to form a cone-shaped structure. If there is a persistent wind blowing during the eruption, the cones can take on a more asymmetrical shape as they form. One of the most well-known cinder cones in the world is the Parícutin cinder cone that erupted suddenly out of a corn field in Mexico in 1943 and within a decade, grew to 1,391 feet high.

Many Utahns are familiar with at least a few of the cinder cones found in southwest Utah. Their presence and prevalence stems from the dynamic and complex forces of plate tectonics and geologic events set in motion millions of years ago, even though some of the cinder cones are only thousands of years old.

The Earth's crust is broken up into sections called tectonic plates, which steadily move slowly around the planet over millions of years, in many cases smashing into and overriding each other. Starting more than 150 million years ago, an ancient oceanic plate called the Farallon plate was forced under the western side of the continental North American plate in a process called subduction. Most of the time, subducted plates take a steep dive into the Earth's interior. Instead, the more-buoyant-than-normal Farallon plate, with a little extra push-back from the North American plate, leveled out and advanced far eastward underneath the crust in Utah and much of western North America.

Over time as it progressed farther east, the Farallon plate could not remain flat and its trajectory steepened downward again, and even rolled back toward itself. As subduction slowed, a section of the Farallon plate broke off and sank deeper down into the planet's interior. The sinking of the detached section and the initial rollback motion facilitated the migration and flow of hot material upward from a deeper zone called the asthenosphere, which in turn helped to melt the lowest layer, called the lithospheric mantle, of the overriding North American plate. This magma rose through the crust of the North American plate towards the Earth's surface and caused extremely explosive and enormous volcanic activity throughout Utah—but did not form small cinder cone volcanoes at first.

Sequence of events in the subduction of the Farallon plate and its effect on volcanism in Utah.



__A)__ The Farallon oceanic plate subducts under the North American continental plate. __B)__ The subducted part of the Farallon plate levels out and pushes its way to the east, causing the uplift of mountain ranges like the Uintas. __C)__ Subduction slows and the distal end of the Farallon plate detaches and sinks, allowing the hot inflow of the asthenosphere to push upwards, melting the lithospheric mantle, and creating magma that causes extraordinary volcanic eruptions. __D)__ After the Farallon plate is fully subducted, a transform boundary forms (red line) between the North American plate and the laterally moving Pacific plate. As the two plates grind past each other, the hot and soft North American plate stretches and extends toward the west and the crust thins allowing basaltic and less viscous magma from the asthenosphere to erupt and create cinder cone volcanoes.

Hancock Peak cinder cone on the Markagunt Plateau, east of Cedar Breaks National Monument, Garfield County. Photo courtesy of Robert Biek, 2012.

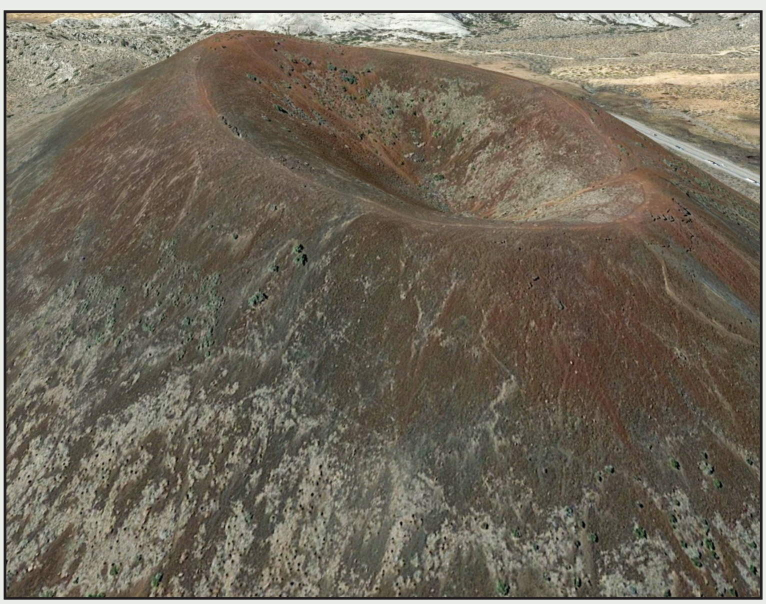
View of the Ice Springs cinder cone volcanoes from the southwest looking northeast. Photo courtesy of Jim Davis, 2013.

The hot material of the asthenosphere that did not erupt continued to push upwards against the crust of the North American plate for millions of years (even to this day) making the crust hotter and softer.

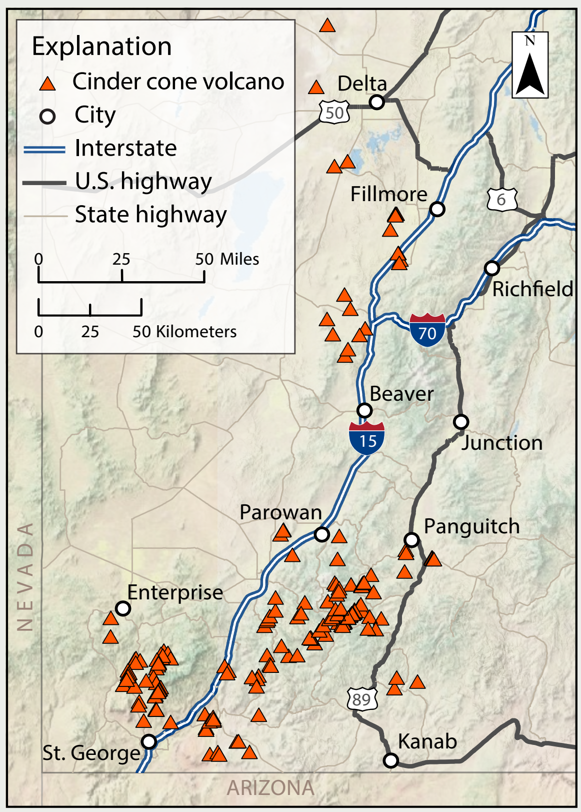
By about 17 million years ago the bulk of the Farallon plate was subducted and the North American plate encountered, and is still in contact with, the Pacific plate. Unlike the subducted Farallon plate, the Pacific plate laterally grinds past the North American plate at a transform boundary commonly known as the San Andreas fault. This oblique tectonic motion coupled with the previous long period of heating and softening from the hot asthenosphere is stretching, elevating, and thinning the continental crust across the Basin and Range Province from western Utah to eastern California. In turn, this stretching and thinning facilitated a transition from enormous explosive volcanoes, such as the Tushar Mountains (which are part of the Marysvale volcanic field) to the many small cinder cones found today across southwest Utah. The magma that fed these cinder cones was mainly composed of the upwelling asthenosphere and is therefore less viscous (basaltic composition, instead of andesitic composition)—generating far smaller and less violent eruptions.

Some cinder cones are relatively large, like the "E" Hill cinder cone (Utah's tallest) that rises around 1,000 feet above the city of Enterprise, but they are still the smallest volcano type. Accordingly, there are many basaltic lava flows in Utah where the source vent or cone has entirely eroded away, such as Utah's oldest basalt, the 19-million-year-old Mosida Basalt, west of Utah Lake. The oldest basalt flow tied to an existing cinder cone comes from the dual Dickinson Hill cinder cones southeast of Panguitch, dated to be about 5.3 million years old. The Markagunt Plateau boasts over thirty cinder cones, most less than 1 million years old. The youngest basalt in Utah comes from the Ice Springs cinder cone in the Black Rock Desert of Millard County, which likely erupted about 10,000 years ago (previously reported ages of 600 to 720 years have recently come into question).

Utah's cinder cones stand as a testament to the geological processes that have unfolded for more than 150 million years, capping an ongoing narrative of incredible volcanic and tectonic forces.



Cinder cone north of St. George near Diamond Valley, in Snow Canyon State Park, Washington County. Photo courtesy of Google Earth Imagery.



Location map of cinder cone volcanoes in southwest Utah.

For more information see:

Judge and others, editors, 2019, Young volcanism in Millard County: Utah Geological Association Publication 48, p. 1–13, doi: 10.31711/ugap.v1i1.88.

Palisade State Park in Sanpete County, Utah

by Peter J Nielsen

Visiting Palisade State Park provides a grand view of ancient landscapes and geologic processes that formed the hills and valleys that encompass the park. The park is at the junction of the linear and narrow mountains of the Basin and Range Province and the flat-lying, layer-cake geology of the Colorado Plateau.

Palisade Lake

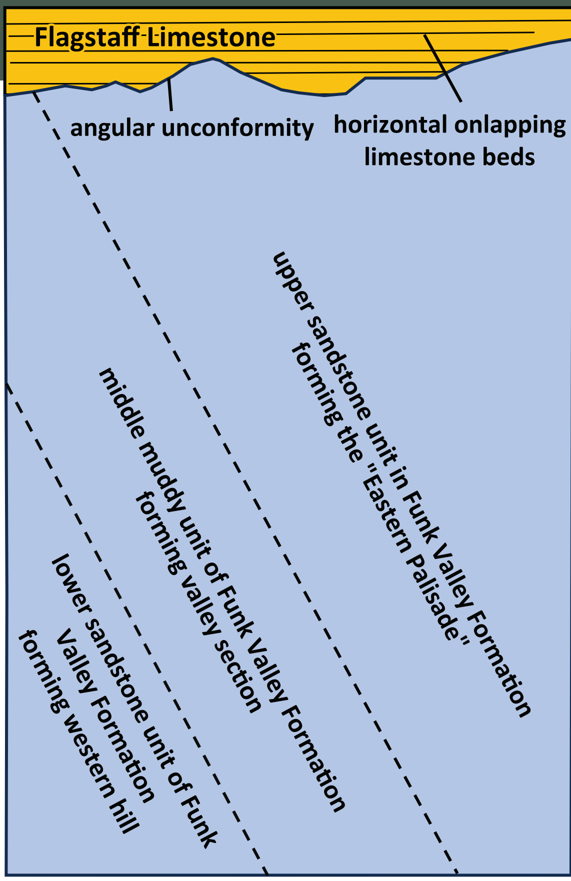
Daniel Funk and family helped settle Sanpete County in 1857. A surveyor by trade, he became familiar with the valleys and mountains in Sanpete County, and observed a small cove at the mouth of Sixmile Canyon could be dammed and filled to make a lake. Funk, with the help of Brigham Young—second president of the Church of Jesus Christ of Latter-day Saints—acquired the land from the local San Pitch band of the Ute Indian Tribe that wintered in the valley. They built an earthen dam in the small drainage, dug a nearly three-fourths-mile-long canal to the stream channel in Sixmile Canyon, and began to divert water to fill the lake in the 1870s.

Funk Lake became a well-known recreational site for residents in central Utah. It was renamed to Palisade Lake by the second owner, who came from the Hudson River Palisades area in New York. The lake and facilities have had many owners, with attendance waxing and waning over the years until it became a state park in 1962. A nine-hole golf course was added in the 1970s and expanded to 18 holes in the 1980s. The state park is a great place to camp, fish, boat (non-motorized only), hike, bike, and just relax. The park makes a great hub for several hundred miles of designated OHV (off-highway vehicle) trails accessed by Sixmile Canyon to Skyline Drive to the east.

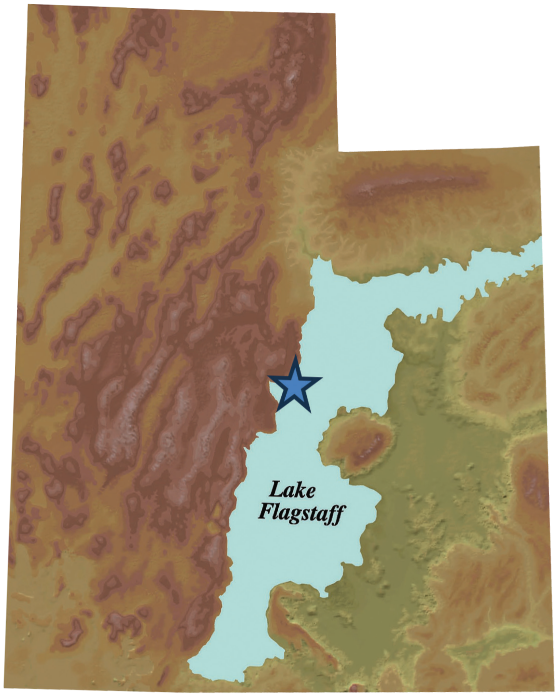
The Palisade

When driving into the state park or while playing golf on the spectacular course, you cannot help but notice on the east side of the park a prominent wall of rocks, called a “palisade.” The nearly vertical beds that form the palisade are part of the Funk Valley Formation, which locally has three different sections that help form the small cove that holds the park. The hill west of the park and golf course is made up of the lower unit and consists of interbedded layers of resistant sandstone and more erodible shale. The middle section is an easily weathered, muddy sandstone that readily erodes, making a “strike valley” or a valley that forms between two resistant, inclined rock layers. Resistant sandstone beds form the eastern cliff or palisade. The Funk Valley rocks were deposited between 97 and 76 million years ago by rivers flowing from the west that deposited sand and mud into a nearby eastern seaway. The Funk Valley Formation is mostly unfossiliferous, but the ancient landscape would have been filled with vegetation and dinosaurs that are not preserved.

The light-yellow, horizontal rock layers that cap the Funk Valley rocks on the eastern palisade are named the Flagstaff Limestone. These rocks were deposited in a freshwater lake called Lake Flagstaff that covered most of central and northeastern Utah about 61 to 58 million years ago. Freshwater fossils are found in these limestone beds.



Relationship between tilted Funk Valley Formation layers and horizontal Flagstaff Limestone beds. The contact is an onlapping angular unconformity with a 22-million-year time gap.



Paleogeographic map showing the ancient landscape during the time that Lake Flagstaff covered the Funk Valley Formation rocks at the park, approximately 61 to 58 million years ago. Blue star is location of Palisade State Park (modified from Reading and others, 1998, UGS Public Information Series 54).

View looking south at Palisade State Park with the lake and golf course. The light-colored hills to the left and right of the golf course are the upper and lower sandstone units of the Funk Valley Formation. They are more resistant to weathering and erosion. The golf course and lake are in the middle sand and mud unit that is more easily weathered. Geologically recent mudflows from Forbush Cove, south of the lake, filled up the entrance to the small strike valley where the state park is located. Flagstaff Limestone lies on top of the Funk Valley sandstone beds on the left side of the photograph.

View looking northeast from hole 4 tee showing the "palisade" cliff of tilted Funk Valley Formation beds with horizontal Flagstaff Limestone layers on top. Flagstaff Limestone beds onlap from left to right on the ancient erosional surface. Basin and Range normal faults have dropped the rocks down to the left.

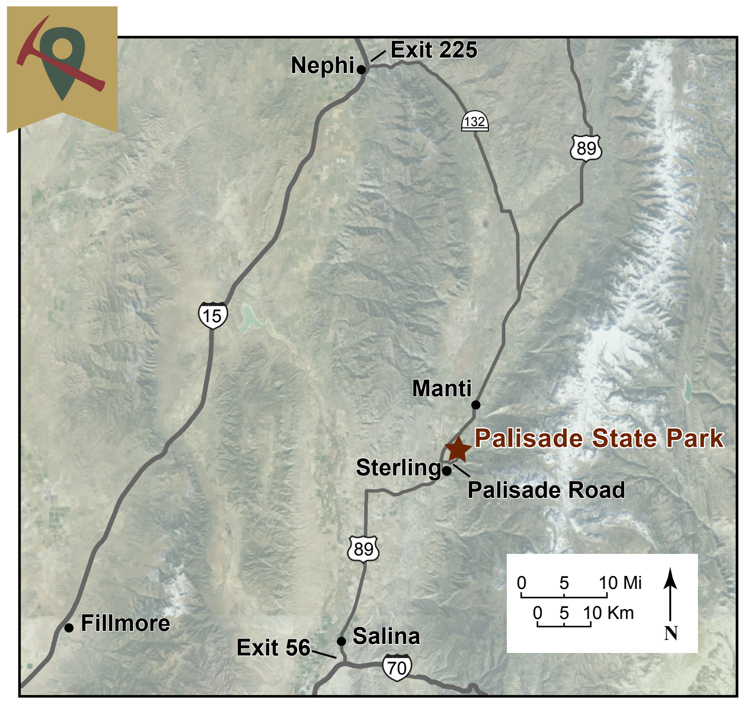
The Unconformity

Make your camp at the lake and head up to the golf course. Take a minute before hitting your best drive of the day at the hole 4 tee and look east at the large display of rocks on the palisade. Several geologic events are recorded in that wall of rocks. The nearly vertical rock layers of the Funk Valley Formation were folded and tilted by the Sevier orogeny, a mountain building event that impacted the rocks in this area about 60 million years ago. The contact between the vertical Funk Valley rocks and the mostly horizontal Flagstaff Limestone beds represents approximately 22 million years of erosion that formed an ancient landscape in this area. This contact is called an "angular unconformity." Angular because the rocks above and below the contact are at different angles, and unconformable because a time gap exists between deposition of the two rock formations. If you look at the horizontal beds from north to south, you can see that they "onlap" or intercept the ancient topography at different heights. This onlap records progressively higher lake levels and deposition of the Flagstaff Limestone until the lake covered the ancient topography.

The last thing of note are three offset and down-dropped blocks of Funk Valley Formation and Flagstaff Limestone. These blocks were moved by high-angle normal faults (faults that dip greater than 45 degrees) within the last 10 to 20 million years, well after the ancient lake was gone, during Basin and Range extension that has been slowly stretching the crust in an east-west direction. The results of this crustal extension and associated faulting are the repeated valley and mountain landforms which begin with the Sanpete Valley and San Pitch Mountains immediately west of the state park and continue west to the Sierra Nevada mountain range.

Thus, over the course of nearly 100 million years, deposition, tilting, and erosion of the Funk Valley Formation followed by Lake Flagstaff, Basin and Range extension, and differential erosion of a strike valley, all coalesced to write the geologic story of Palisade State Park.

How to Get There



Palisade State Park GPS Coordinates: 39.2092° N, 111.6667° W

From the north

Travel north or south on I-15 to Nephi, Utah. Take Exit 225 east onto Highway 132 and proceed 30 miles to the intersection with Highway 89. Turn south (right) and travel 17 miles to Palisade Road, turn east (left) and go 2 miles to the state park.

From the south

Travel east or west on I-70 to Salina. Take Exit 56 north onto Highway 89 and proceed approximately 24 miles to Palisade Road, turn east (right) and go 2 miles to the state park.

SURVEY NEWS

2023 Crawford Award

The Utah Geological Survey's prestigious Crawford Award was presented to **Ryan D. Gall** in recognition of his geologic research on the lower Green River Formation, culminating in the outstanding publication, "Geologic Characterization and Depositional History of the Uteland Butte Member, Green River Formation, Southwestern Uinta Basin, Utah," published in the 2022 Utah Geological Association Publication 50. This research has significantly furthered understanding of the Uteland Butte petroleum play and the general geologic evolution of ancient Lake Uinta. The research has been a vital source of information for several Uinta Basin oil companies, as the Uteland Butte is the most prolific horizontal well target in the basin. The work contributes substantially to the effort to designate the Uteland Butte as a formal member of the Green River Formation, a major step forward for Uinta Basin geology.

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

Mesozoic Terrestrial Ecosystems Conference Brings Ancient Worlds to Salt Lake City

The 14th Mesozoic Terrestrial Ecosystems Conference took place June 7–10 in Salt Lake City. Held in the U.S. for the first time and organized by the UGS, Dinosaur National Monument, and in partnership with Utah Friends of Paleontology, the internationally acclaimed conference delivered a rich program of scientific presentations, discussions, and workshops to nearly 180 participants representing nine different countries from around the world. During the event **Jim Kirkland** received special recognition from the National Park Service for his 50 years of fossil discoveries on the Colorado Plateau. Congratulations to Jim and thanks to all that participated!

Employee News

The Geologic Information & Outreach Program welcomes **Patrick Engberson** to the Editorial Section as the new media production specialist and welcomes back **Peter Nielsen** as a geologist with the Natural Resources Map & Bookstore. Patrick has a B.A. in film and media studies from the University of Utah. **Josh Dustin** has accepted the position of GIS analyst with the Geologic Mapping Program. Josh earned a B.S. in interdisciplinary studies from Southern Utah University and is pursuing an M.S. in GIS from the University of Wyoming. **Sofia Agopian** has accepted the position of project geologist with the Geologic Hazards Program. Sofia has a B.S. in geology from the University of Southern Maine. Congratulations to Patrick, Josh and Sofia, and welcome back Peter.

The Energy & Minerals Program welcomes **Gabriela St. Pierre** as a new project geologist focusing on carbon sequestration projects and **Ammon McDonald** as the new curator of the Utah Core Research Center. Gabriela has a Ph.D. in geology from the University of Utah and has worked in the oil and gas industry for three years. Ammon has a B.S. in geology and a B.S. in chemistry from the University of Utah and previously worked for the Utah Division of Oil, Gas and Mining as a field operations manager. Ammon replaces **Katie Cummings** who left to pursue other career opportunities. Congratulations to Gabriela and Ammon and best wishes to Katie.

The Groundwater & Wetlands Program welcomes **Emily Jainarain**, **Erin Brinkman**, and **Kate Baustian** who have accepted positions as hydrogeologists and **Kiersten Winwood** who is a GIS analyst. Emily has a B.S. in geology from Southern Florida University and recently graduated from Utah State University with an M.S. in watershed science. Erin has a B.S. in geology from Georgia Southern University and recently received her M.S. from the University of Utah in contaminant transport. Kate has a B.S. in geology from the University of North Carolina at Chapel Hill and an M.S. in geography from the University of Utah. Kiersten has a B.S. in watershed and earth systems and GIS and previously worked for the Utah Division of Water Rights as a GIS analyst. The program bids farewell to **Hector Zamora** who left to work for the City of Tucson, and **Jeremiah Bernau** who left to pursue a career with Chevron Corporation. Congratulations to Emily, Erin, Kate, and Kiersten and best wishes to Hector and Jeremiah.

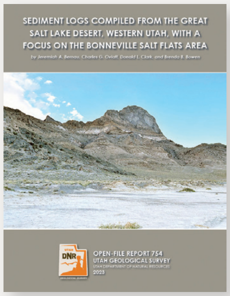
In Memoriam

Former UGS employee **Roselyn Dechart** passed away on May 10, 2023. Roselyn worked as an executive secretary with the UGS from 1984 until her retirement in 1996. She had a passion for gardening, travel, and activism, and was a former President of the Bountiful Chapter League of Women Voters. We express our sincere condolences to Roselyn's family.

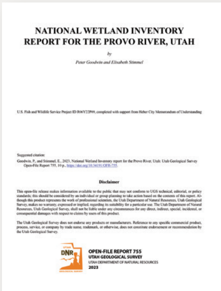
New Publications

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

Cobalt Database of Utah, by Jake Alexander, 5 p., 1 plate, **OFR-749**, https://doi.org/10.34191/OFR-749



Sediment Logs Compiled From the Great Salt Lake Desert, Western Utah, With a Focus on the Bonneville Salt Flats Area, by Jeremiah A. Bernau, Charles G. Oviatt, Donald L. Clark, and Brenda B. Bowen, 24 p., 3 appendices, **OFR-754**, https://doi.org/10.34191/OFR-754



National Wetland Inventory Report for the Provo River, Utah, by Peter Goodwin and Elisabeth Stimmel, 10 p., **OFR-755**, https://doi.org/10.34191/OFR-755

Recent Outside Publications *by UGS Authors*

Holocene Water Balance Variations in Great Salt Lake, Utah—Application of GDGT Indices and the ACE Salinity Proxy, by R.T. So, T.K. Lowenstein, **E. Jagniecki**, J.E. Tierney, and S.J. Feakins: Paleoceanography and Paleoclimatology, v. 38, no. 6, https://doi.org/10.1029/2022PA004558

The March 2020, MW 5.7 Magna, Utah, Earthquake—Documentation of Geologic Effects and Summary of New Research, by **A.I. Hiscock, E.J. Kleber, A.P. McKean, B.A. Erickson, G.N. McDonald, R.E. Giraud, J.J. Castleton, and S.D. Bowman**: Geology of the Intermountain West, v. 10, 19 p.

Discrete Measurements of the Least Horizontal Principle Stress From Core Data—An Application of Viscoelastic Stress Relaxation, by K.L. McCormack, J.D. McLennan, **E.A. Jagniecki**, and B.J. McPherson: SPE Reservoir Evaluation and Engineering, https://doi.org/10.2118/214669-PA

A Mars-Analog Sulfate Mineral, Mirabilite, Preserves Biosignitures, by K.K. Gill, **E.A. Jagniecki**, K.C. Benison, and M.E. Gibson: Geology, https://doi.org/10.1130/G51256.1

Teacher's Corner

A New Addition to the Natural Resources Map & Bookstore!

An entire shelf has been dedicated to showcase popular geology materials for teachers. The Utah Geological Survey offers teaching kits, field trip itineraries, multimedia for the classroom, and more! These resources are available to Utah teachers and are grade-specific when possible, matching the current Utah State Science Core Curriculum standards. The bookstore is the only place to check out these resources in person, speak with a geologist, and rent one of our specialized teaching kits!

Bookstore hours are Monday through Friday 10:00 a.m. to 5:00 p.m.

CALL FOR VOLUNTEERS

Earth Science Week

October 2–5 and 10–12

Do you have an interest in promoting the future of geological sciences? Come celebrate Earth Science Week with the Utah Geological Survey by volunteering to help with hands-on activities that are particularly suited for 4th and 5th grade elementary school students. Earth Science Week activities take place at the Utah Core Research Center in Salt Lake City and include panning for "gold," identifying rocks and minerals, experimenting with erosion and deposition on a stream table, examining dinosaur bones and other fossils, and learning about earthquakes.

No experience is needed and anyone with an interest in geology can help. For more information, please visit our website at https://geology.utah.gov/teachers/earth-science-week/.

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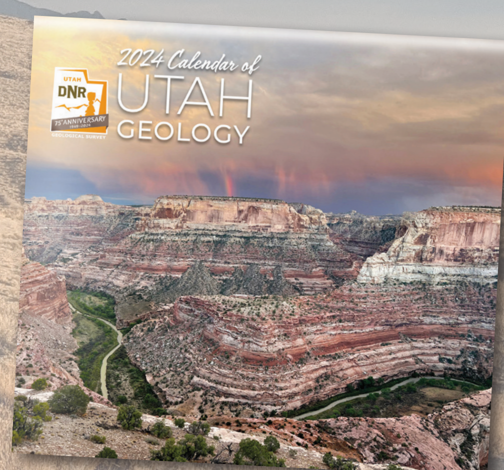
2024 CALENDAR OF UTAH GEOLOGY

Learn more about Utah's geologic diversity through scenic photographs taken by UGS employees who are often on assignment in some of the state's most interesting and unique locations.



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