UTAH GEOLOGICAL SURVEY

SURVEY NOTES

Volume 55, Number 2 May 2023

MAPPING GEOLOGIC HAZARDS IN AND NEAR BRYCE CANYON NATIONAL PARK

Contents

Design | *John Good*
Cover | Northeast-directed view of Bryce Canyon National Park's Navajo Loop Trail descending into the stunning colors and textures of the Pink Cliffs—composed of the Tertiary-age Claron Formation. Photo by Tyler Knudsen.

State of Utah
Spencer J. Cox, *Governor*

Department of Natural Resources
Joel Ferry, *Executive Director*

UGS Board
Elissa Richards, *Chair*
Ken Fleck, *Vice Chair*
Dave Garbrecht, Sam Quigley, Rick Chesnut, Riley Brinkerhoff, Becky Hammond, Michelle McConkie (Trust Lands Administration-ex officio)

UGS STAFF

Administration
Bill Keach, *Director*
Michael Hylland, *Deputy Director*
Jodi Patterson, *Financial Manager*
Winnie Pan, *Accounting Technician*
Starr Soliz, *Secretary/Receptionist*
Cheryl Wing, *Secretary/Receptionist*

Editorial Staff | *Jennifer Miller*
Lori Steadman, John Good, Jackie Dewolfe

Geologic Hazards | *Steve Bowman*
Jessica Castleton, Tyler Knudsen, Greg McDonald, Adam McKean, Ben Erickson, Adam Hiscock, Emily Kleber

Geologic Information & Outreach | *Mark Milligan*
Stephanie Carney, Jim Davis, Suzanne Sawyer, Jackson Smith, Torri Duncan

Data Management | *Marshall Robinson*
Lance Weaver, Jay Hill, Mackenzie Cope, Nathan Payne

Geologic Mapping & Paleontology | *Stefan Kirby*
Basia Matyjasik, Donald Clark, Zach Anderson, James Kirkland, Martha Hayden, Don DeBlieux, Rosemary Fasselin, Matthew Morriss, Lauren Reeher

Energy & Minerals | *Michael Vanden Berg*
Jeff Quick, Taylor Boden, Tom Dempster, Andrew Rupke, Christian Hardwick, Elliot Jagniecki, Ryan Gall, Stephanie Mills, Eugene Szymanski, Katie Cummings, Kayla Smith, Jake Alexander

Groundwater & Wetlands | *Hugh Hurlow*
Janae Wallace, Paul Inkenbrandt, Lucy Jordan, Diane Menuz, Trevor Schlossnagle, Pete Goodwin, Kathryn Ladig, Claire Kellner, Becka Downard, Greg Gavin, Hector Zamora, Jeremiah Bernau

Survey Notes is published three times yearly by the Utah Geological Survey, 1594 W. North Temple, Suite 3110, Salt Lake City, Utah 84116; (801) 537-3300. The UGS provides timely scientific information about Utah's geologic environment, resources, and hazards. The UGS is a division of the Department of Natural Resources. Single copies of *Survey Notes* are distributed free of charge within the United States and reproduction is encouraged with recognition of source. Copies are available at https://geology.utah.gov/map-pub/survey-notes/.
ISSN 1061-7930 Printed on recycled paper

DIRECTOR'S PERSPECTIVE

by Bill Keach

A couple of items were considered in this year's General Legislative Session that will impact Utah for a long time.

Aqueduct Resilience Funding

Utah's main water aqueducts provide water to most of our residents from reservoirs east of the Wasatch Front. What many do not realize is that all of the aqueducts cross the Wasatch fault zone at least once, some multiple times. In 2016, the Working Group on Utah Earthquake Probabilities forecasted that Utah has a 57% chance of experiencing one or more magnitude 6.0 or greater earthquakes in the next 50 years, and a 43% chance of an earthquake with a magnitude 6.75 or greater. We are seven years into that forecast. To put that in perspective, you may remember the magnitude 5.7 earthquake Utah experienced March 18, 2020. A magnitude 6.0 earthquake would be nearly 3 times stronger than a 5.7 earthquake. A 6.75 earthquake would be nearly 38 times stronger. In the event of a large earthquake, our main aqueducts would be at serious risk. Depending on the location and magnitude we could see large parts of our population without water for two to six months. All the water districts along the Wasatch Front have formulated plans to enhance the resiliency of the aqueducts to survive a large earthquake. The challenges are money and time. Where do you get the funding? And how fast can improvements be made? Partial funding is available through grants from the Federal Emergency Management Agency (FEMA). How fast depends on when full funding can be obtained.

Last year the UGS partnered with Envision Utah, the water districts, and the Utah Seismic Safety Commission to lead three field trips to educate legislators on the critical nature and urgency of the problem. We then asked the Governor to support improving the resiliency of our aqueducts. He proposed, and the legislature approved, $50 million to help the water districts accelerate the process. All of the funding will go to other agencies. However, it underscores the role of the UGS to "provide timely scientific information about Utah's geologic environment, resources, and ***hazards***."

Paleontology

HB396 enacted changes that allow cities to retain fossils found in their jurisdictions. Under current statute the state has full oversight for all fossils on state-owned lands, which includes lands owned by cities and counties. The new law provides certain conditions: the cities must be of a sufficient size (>65,000 population), have a full-time paleontologist, and have a museum that meets federal standards (or a plan to meet those standards). The immediate impact of HB396 will enable the city of St. George to provide active oversight for fossils found on city lands, including those on display at the St. George Dinosaur Discovery Site at Johnson Farm. The new law will give them greater oversight for new discoveries that may be found in the future.

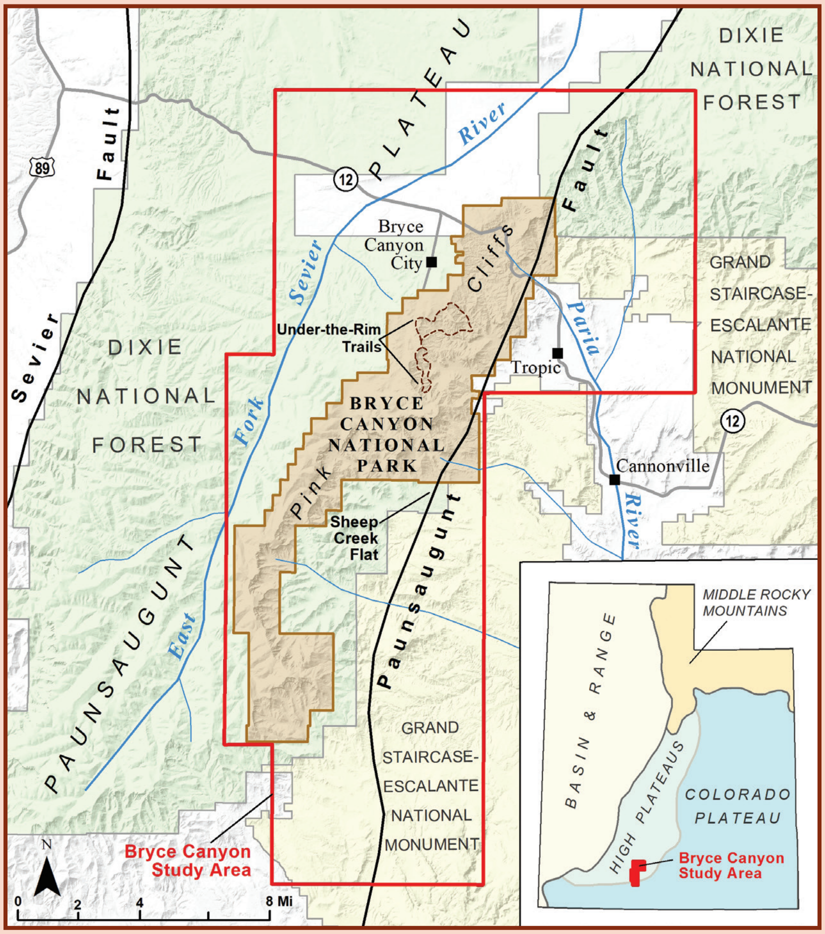
Critical Minerals

On the last day of the legislative session, though unrelated, the UGS hosted a visit by Tanya Trujillo, Assistant Secretary of the Department of the Interior, Water and Science. We spent a half-day visiting the Great Salt Lake Marina where we discussed water issues and potential solutions. Her visit also underscored the role Utah will play in the energy future and independence of our country. The U.S. Geological Survey (USGS), at the direction of the U.S. Congress, has embarked on a mission to identify and map critical mineral resources across the country. The UGS and USGS have partnered on several projects to locate and quantify resources available in Utah. Two projects funded by the USGS are underway now. The first is to obtain airborne lidar imaging for all areas in Utah that have incomplete coverage. The second is to acquire airborne geophysical data over most of western Utah. These two datasets will empower the UGS to better identify and map our natural resources.

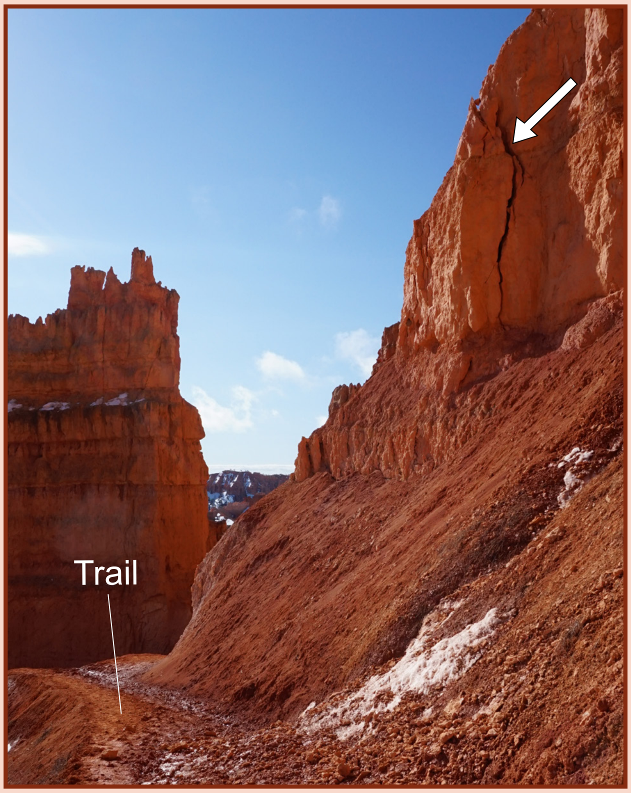
Mapping Geologic Hazards in and Near Bryce Canyon National Park

by Tyler Knudsen

Known for its colorful and intricately eroded landscape, Bryce Canyon National Park (BCNP) has attracted several millions of visitors since its establishment as a National Monument in 1923. From the 1990s through the mid-2000s, BCNP averaged about 1 million visitors annually. Visitation has more than doubled over the past two decades, peaking at nearly 2.7 million visitors in 2018. Geologic processes that shaped BCNP's dramatic landscape are still active today and can be hazardous to visitors, park employees, and infrastructure. To help reduce negative impacts from geologic hazards, the Utah Geological Survey (UGS), with support from the Bryce Canyon Natural History Association and the National Park Service (NPS), conducted a geologic-hazard investigation of a 270 square-mile area centered on the park. The study area encompasses BCNP, the communities of Tropic and Bryce Canyon City, and recreational areas within the adjoining Dixie National Forest and Grand Staircase–Escalante National Monument. Available geologic, hydrologic, topographic, soil, and geotechnical information was used to identify the location and severity of mapped geologic hazards that may impact safety and existing and future development. Early recognition and mitigation of geologic hazards can reduce risk to life, property, and the local economy. Our study provides descriptions and maps for 14 geologic hazards: rockfall, landslides, flooding/debris flow, shallow groundwater, surface faulting, liquefaction, collapsible soil, piping and erosion, wind-blown sand, soluble rock, corrosive soil and rock, expansive soil and rock, shallow bedrock, and radon gas.



Overview of the Bryce Canyon geologic-hazards study area.



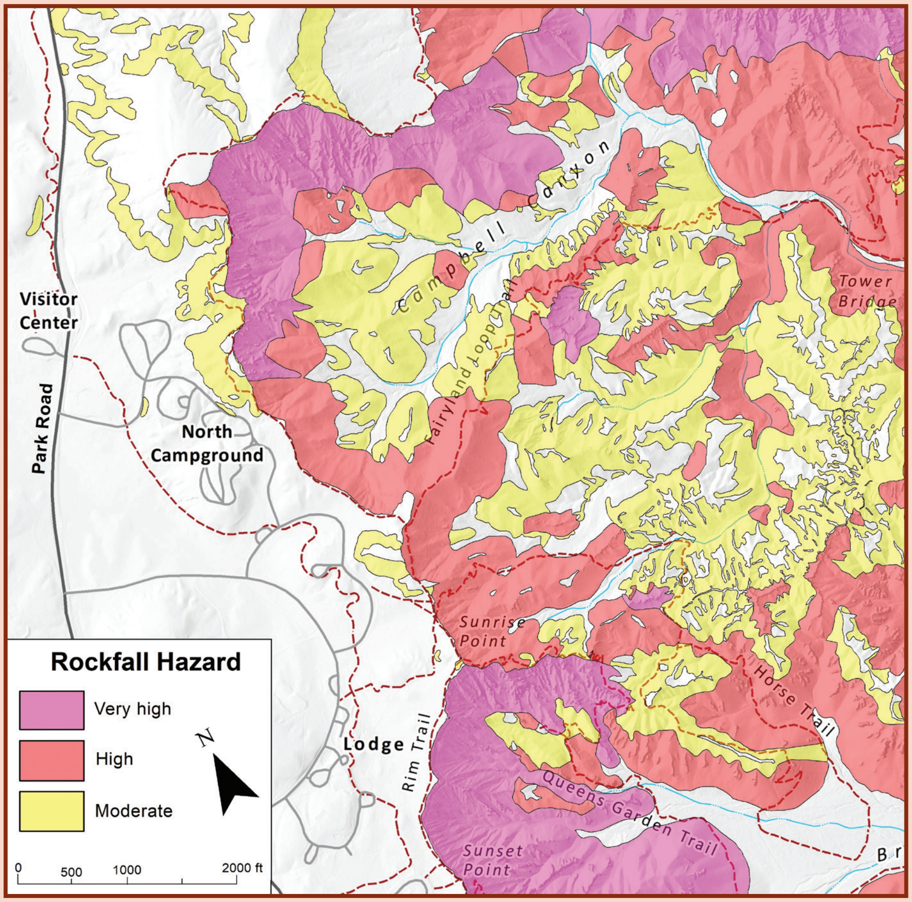
Periodic slope monitoring can detect signs of imminent slope failure such as this detached block of Claron Formation (noted with white arrow) above the Navajo Loop Trail.

BCNP is centered on the eastern rim of the Paunsaugunt Plateau that is part of the High Plateaus subsection of the Colorado Plateau province. The eastern plateau rim marks a major drainage divide that separates the relatively low-gradient Sevier River system and the much steeper Paria River system that is a tributary to the Colorado River. The Paria River's steeper gradient induces greater erosional downcutting than the gentle Sevier River system. Much of BCNP, including its high-use areas, is dominated by the iconic, brightly colored limestone, sandstone, mudstone, and conglomerate of the Paleocene to Eocene (about 65 to 35 million years ago) Claron Formation. On the surface of the Paunsaugunt Plateau that is drained by the Sevier River system, Claron strata typically weather to gently rolling hollows and hills. However, along the plateau's eastern rim aggressive erosion by the Paria River system into the Claron Formation has sculpted steep-walled amphitheaters adorned with vertical spires, hoodoos, and slot canyons—collectively known as the Pink Cliffs. Mass wasting (rockfalls, landslides, and debris flows) and flash floods along the Pink Cliffs create the principal geologic hazards with which visitors, park employees, planners, and public safety personnel must contend.

Rockfall hazard is particularly acute along BCNP's increasingly popular Under-the-Rim Trails that descend into and traverse the actively eroding Pink Cliffs. The sharp increase in park visitation over the past decade has further increased the likelihood of a hazardous rockfall-visitor encounter. Since 2010, the NPS routinely closes Wall Street—part of the Under-the-Rim Trail network that passes through a photogenic and precarious vertical-walled canyon—in winter months when increased moisture and freezing temperatures combine (frost wedging) to produce frequent rockfalls. Starting in 2016, the NPS began using on-trail Preventative Search and Rescue (PSAR) volunteers to alert visitors to risks that may be encountered while hiking the Under-the-Rim Trails. These volunteers can instruct hikers to reduce their risk to rockfall by limiting their time spent in extremely high-hazard sections of trail, such as Wall Street. Weather-triggered closures, PSAR volunteers, informational signage, and periodic slope monitoring that can detect signs of failure are the most effective tools the NPS can use to improve visitor safety in this vulnerable area.

South-directed view of Bryce Canyon National Park's Queens Garden Trail descending into the stunning colors and textures of the Pink Cliffs—composed of the Tertiary-age Claron Formation.

May 23, 2006, Wall Street rockfall that blocked part of the Under-the-Rim Navajo Loop Trail for 14 months. Photo courtesy of Kristin Legg (NPS).

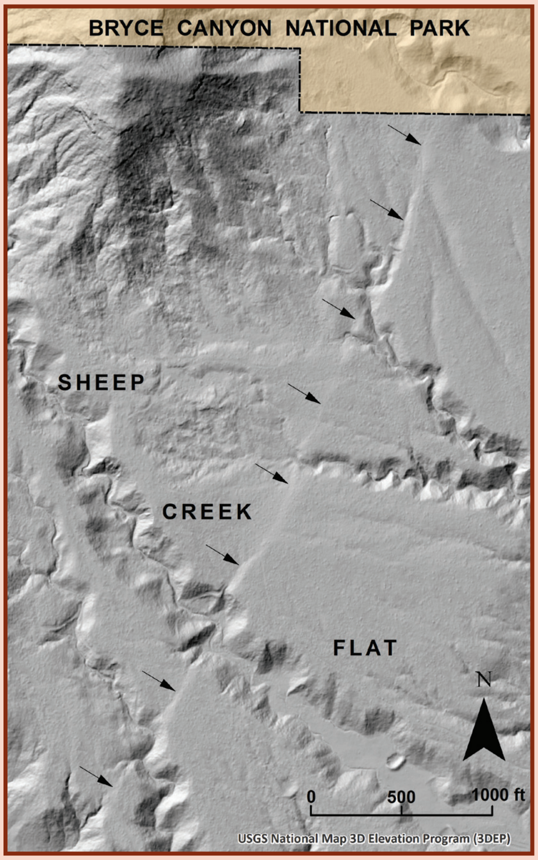


Sample of the rockfall hazard map that covers part of BCNP's Under-the-Rim trails.

Although large earthquakes are rare in the Bryce Canyon area, strong ground shaking, surface faulting, and liquefaction are still possible. Potential sources of strong earthquakes near BCNP include the Sevier fault, 12 miles to the west, and the Paunsaugunt fault that traverses directly through the study area. Currently, most of the Paunsaugunt fault in Utah, including all fault sections in the study area, is not included in the UGS database of hazardous faults (faults that have ruptured the ground surface within the Quaternary time period or the past 2.6 million years). However, mapping completed for this study shows that Quaternary-age deposits are locally displaced by the Paunsaugunt fault in the Bryce Canyon area and that the fault should be considered hazardous. Results from this study will be used to improve the UGS hazardous fault database.

Although large earthquakes are rare in the Bryce Canyon area, strong ground shaking, surface faulting, and liquefaction are still possible.

Most of the remaining geologic hazards considered in this study are localized, and though potentially costly when not recognized and properly mitigated, the problems associated with them are rarely life threatening. Upon publication later this year, this geologic-hazards investigation and mapping will be available for viewing and download from the UGS Geologic Hazards Portal (https://geology.utah.gov/apps/hazards).



The Paunsaugunt fault (indicated by arrows) has vertically displaced the surface of Sheep Creek Flat up to 6 feet.

ABOUT THE AUTHOR

Tyler Knudsen is a Senior Geologist in the UGS Geologic Hazards Program where he has worked since 2006. Based out of the Cedar City office, he has authored or co-authored several maps and studies on the geology and geologic hazards of southwest Utah. Tyler holds degrees from the University of Utah (2002, B.S. geology) and the University of Nevada, Las Vegas (2005, M.S. geoscience), and is a Utah licensed Professional Geologist.

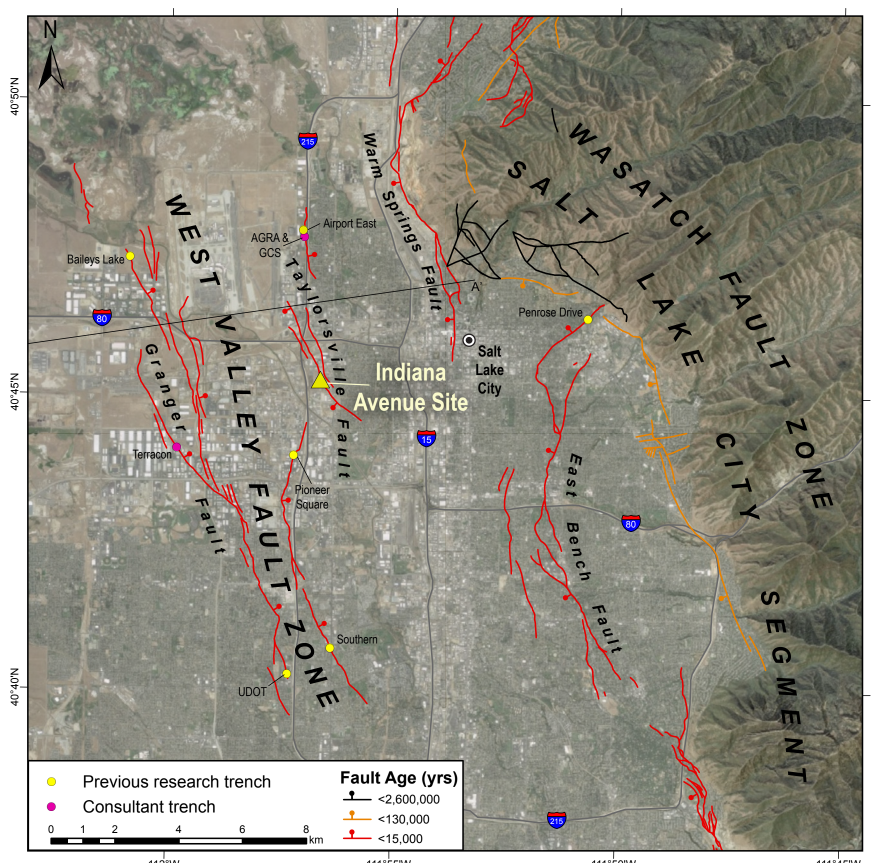
Digging Up Evidence of Past Earthquakes in Salt Lake Valley

by

Adam I. Hiscock, Emily J. Kleber, Michael D. Hylland, and Greg N. McDonald

In the late 1800s, geologist Grove Karl Gilbert recognized the large elevation difference between the spectacular and rugged Wasatch Range and the Salt Lake Valley as being created by episodic fault movement associated with large earthquakes, each time raising the mountains and dropping the valley floor. Gilbert was the first geologist to identify the Wasatch fault zone and the seismic hazard it presents to residents along the Wasatch Front. What he did not recognize at the time was the presence of a second fault system running through the middle of Salt Lake Valley—the West Valley fault zone.

The West Valley fault zone is antithetic to the Salt Lake City segment of the Wasatch fault zone; i.e., the fault plane of the Salt Lake City segment dips westward underneath the Salt Lake Valley, whereas the fault plane of the West Valley fault zone dips eastward and towards the Salt Lake City segment. The West Valley fault zone consists of two separate faults: the Taylorsville (eastern strand) and Granger (western strand) faults. These faults connect with the Salt Lake City segment several miles below the valley surface to form a V-shaped, downthrown crustal block known as a graben. Fault scarps (i.e., slopes formed from ground movement during past surface-rupturing earthquakes) that define the Taylorsville and Granger faults are generally much smaller than scarps

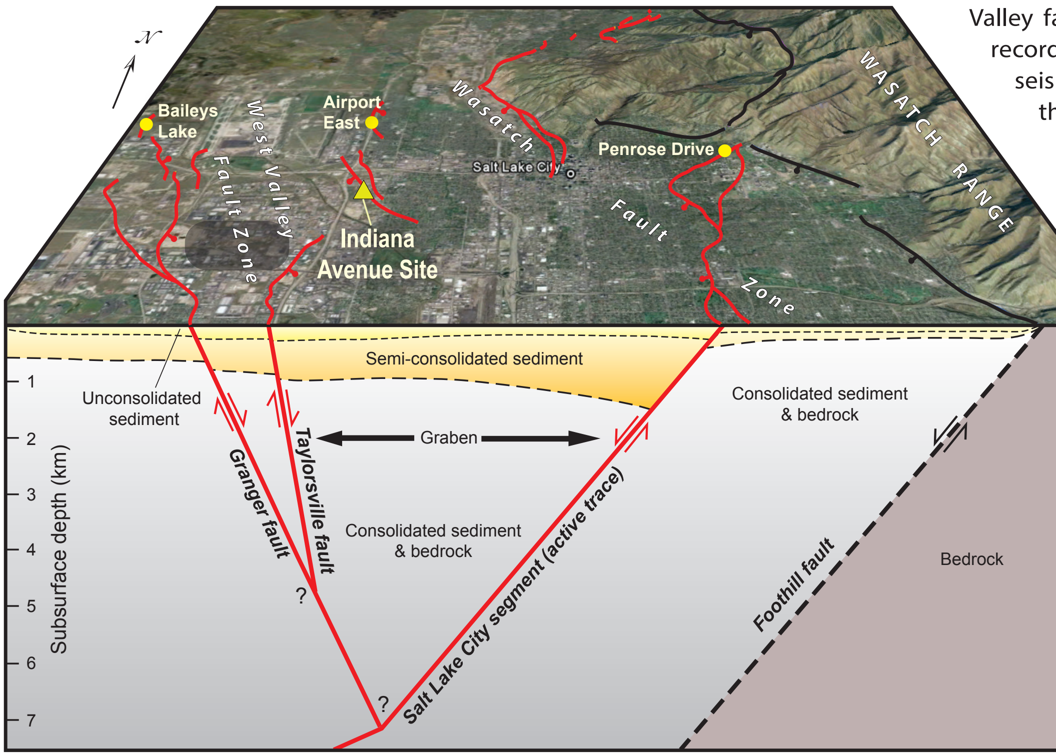


The West Valley fault zone and the Salt Lake City segment of the Wasatch fault zone. Yellow dots indicate previous research trenches; pink dots indicate previous consultant trenches that yielded earthquake timing data. Indiana Avenue trench site shown as yellow triangle. Red, orange, and black lines show mapped faults; bar-and-ball symbols along lines indicate downthrown side of fault.

along the Wasatch fault zone. Many of these fault scarps have been disturbed or destroyed by human activity in the Salt Lake Valley. Unlike the Wasatch fault zone, which has been the subject of dozens of detailed scientific studies, the West Valley fault zone has had comparatively little scientific study despite the fact that it is still capable of generating large, damaging earthquakes.

To study past earthquakes, geologists conduct paleoseismic (ancient earthquake) studies by excavating trenches across fault scarps and studying and dating the geologic deposits in the excavation to determine past earthquake timing. Ideally, sites for paleoseismic studies have fault scarps that have not been disturbed by human activity. Since the West Valley fault zone runs through the heavily urbanized Salt Lake Valley, sites suitable for paleoseismic trenching studies are very sparse, and the few sites that do exist are disappearing rapidly due to urban growth and development.

Previous paleoseismic investigations have identified evidence that earthquakes have occurred at roughly the same time on both the West Valley and Wasatch fault zones (see *Survey Notes*, v. 44 no. 2, May 2012, and *Survey Notes*, v. 48, no. 2, May 2016). Data from these studies suggest that fault movement on the Wasatch fault zone can trigger earthquakes on the antithetic West Valley fault zone. Seismological data from the March 2020 Magna earthquake sequence indicate the magnitude 5.7 mainshock occurred on the Salt Lake City segment several miles beneath the Salt Lake Valley, and the aftershocks included a sequence of small earthquakes in the vicinity of the West Valley fault zone. Data from the Magna earthquake sequence as well as from previous paleoseismic studies have improved our understanding of how these major faults interact beneath Salt Lake Valley; however, significant uncertainties remain. Detailed paleoseismic studies have only been conducted on a few strands of the West Valley fault zone; thus, the current earthquake record is far from complete. Additional paleoseismic research is needed to help fill gaps in the earthquake record for the West Valley fault zone.



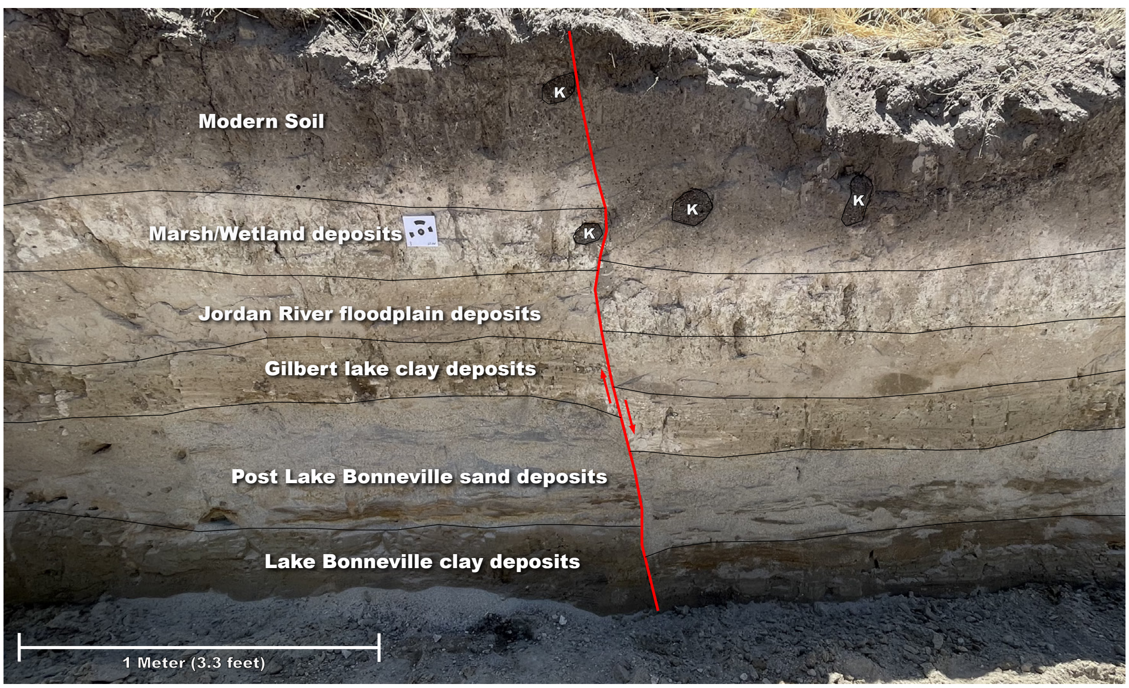
The inferred relationship between the Salt Lake City segment of the Wasatch fault zone and the West Valley fault zone (specifically, the Taylorsville and Granger faults). Vertical motion on the west-dipping Wasatch fault zone has uplifted the Wasatch Range and down dropped Salt Lake Valley. The West Valley fault zone is antithetic to the Wasatch fault zone to the east, forming a V-shaped graben. Modified from UGS Special Study 149 (Hylland and others, 2014).

In the summer of 2022, the Utah Geological Survey (UGS) set out to collect additional data from the Taylorsville fault of the West Valley fault zone to help fill these gaps in the earthquake record. We excavated two paleoseismic fault trenches at the Indiana Avenue trench site across a 3- to 5-foot-high scarp on one of the last undeveloped parcels of land along the West Valley fault zone. We estimate the oldest sediments exposed in the trenches were deposited about 15,000 years ago, when Salt Lake Valley was submerged under Lake Bonneville. Younger sediments exposed in the trench excavations were likely deposited after Lake Bonneville had receded, when the modern-day Jordan River and Great Salt Lake were depositing sediments across parts of Salt Lake Valley. Evidence for potentially two surface-rupturing earthquakes was observed in the trenches. Unfortunately, due to a shallow groundwater table at the site, we were unable to trench deeper to search for evidence of additional, older earthquakes.

Samples were collected to determine ages of exposed geologic units and to determine the timing of fault movement at the site. Two dating methods are typically used in paleoseismic studies: radiocarbon and optically stimulated luminescence (OSL) dating. Radiocarbon dating measures the concentrations of the radioactive isotope carbon-14 and OSL dating measures trapped electrons that accumulate over time in quartz-bearing minerals in buried sediments. The samples collected are currently being processed, but when the results are received, they will be used to develop a model for the timing of past earthquakes at the Indiana Avenue site. This model will be compared to models from other trench sites on the West Valley fault zone and the Salt Lake City segment of the Wasatch fault zone to fill gaps in the earthquake record, improve earthquake probability estimates, and further our understanding of the relationship between these two active fault systems.

The fault scarp at the Indiana Avenue trench site (view looking northeast). Red line denotes the base of the scarp and the mapped fault line with bar-and-ball symbols indicating the direction of fault movement (i.e., downthrown side of fault). Yellow box shows the approximate location of the south trench.

The south trench at the Indiana Avenue trench site (view looking southwest). Both the south and north trenches were approximately 5 feet deep and 140 feet long. Due to shallow groundwater at the site, we were unable to dig deeper, which would have allowed us to possibly find evidence of additional, older, surface-rupturing earthquakes.



Annotated photo showing the easternmost fault trace in the Indiana Avenue south trench (view looking south). Fault shown in red with arrows indicating fault movement. Approximate stratigraphic unit contacts shown in black with preliminary unit interpretations. K symbols indicate krotovina, or animal burrows. As shown by the offset stratigraphic contacts, this fault has approximately 10 inches of vertical displacement.

Scan QR code to view a 3D model of the south trench at the Indiana Avenue trench site generated using an iPad Pro lidar scanner. Alternatively, visit https://skfb.ly/owNQM to view the model.

This research is part of a broader effort to improve our understanding of earthquake hazards and risk in Utah's most populous region. Results from this and other paleoseismic studies are eventually incorporated into the U.S. Geological Survey National Seismic Hazard Maps, which are used in updating building codes and helping drive more earthquake resilient building design. Studying past earthquakes on any of Utah's many active fault systems serves as a reminder that Utah is earthquake country, and we should always be prepared for earthquakes to occur. To learn more about earthquakes and how to prepare for them visit earthquakes.utah.gov.

This research was funded in part by the U.S. Geological Survey Earthquake Hazards Program - External Research Grants.

IN-LIEU FEE WETLAND MITIGATION: A Boring Name For an Exciting Idea

by Becka Downard and Diane Menuz

The goal of the 1972 Clean Water Act is to restore and protect the health of all waterbodies in the United States. Though people do not often think of wetlands when they go fishing and swimming, healthy wetlands improve the water quality of nearby lakes and streams. Water becomes cleaner as it slowly flows through wetlands because pollutants settle out in the mud or are taken up by plants. Wetlands are also nursery and nesting grounds for fish and wildlife and can decrease the impact of drought and floods by storing floodwaters like a sponge and releasing water slowly. Wetlands in good health can support many ecosystem functions like improving water quality, providing habitat, and hydrologic buffering. However, it has taken Americans a long time to recognize how important wetland functions are. Before the 1970s more than one-half of the nation's wetlands were destroyed to make room for farms, homes, and roads.

One part of the Clean Water Act—the Section 404 Dredge and Fill Permit referred to here as a wetland permit—protects wetland functions by requiring anyone who negatively impacts wetlands to make up for those impacts through wetland mitigation. Wetland mitigation is the term for creating, restoring, or preserving wetlands to replace wetland functions that have been lost. The U.S. Army Corps of Engineers (USACE) approves wetland permits only after permit applicants show how they will offset their impacts. Mitigation projects that create high functioning wetlands are challenging because they require a lot of specific scientific knowledge, time, and money. Permittee-responsible mitigation—when a permit applicant is responsible for mitigation rather than a wetland bank or fee program—slows down the wetland permit process as applicants wrestle with layers of red tape, which is especially costly with high inflation. Even worse, many permittee-responsible mitigation projects are small and isolated "postage-stamp" wetlands that do not support many wetland functions because they do not have enough water or because weed species like cattails and Phragmites invade the mitigation wetlands.

An In-lieu Fee (ILF) mitigation program, an alternative to permittee-responsible mitigation, has the potential to streamline wetland permitting and increase the quality of wetlands in Utah. ILF programs collect fees from permit-seekers based on how much they impact wetlands instead of (i.e., in-lieu of) permittee-responsible mitigation. The ILF collects fees from multiple permits and then can combine the fees to fund large wetland projects in places where they are more likely to succeed. USACE and a team of scientists provide feedback on and approve the ILF program's mitigation plan and all the projects they build, which saves time for permit-seekers (who do not have to get those approvals themselves) and leads to better projects. An ILF also takes responsibility for monitoring the progress of wetland projects and long-term site management.

*Narrow-leaf cattail (*Typha latifolia*) is common in poor-quality wetland mitigation projects. Cattails thrive where natural hydrology has been disrupted and do not provide the same level of ecosystem functions that more desirable plants support.*

During the 2022 Utah Legislative Session, Representative Casey Snider proposed House Bill 118—Wetland Amendments— which asked the Utah Geological Survey to study how an ILF might work in Utah. To answer that question, we spoke with people who run ILF programs in other states as well as scientists and managers in Utah that could play a role in wetland mitigation. The first concern we addressed was whether such a program could work financially in a very dry state that does not have a lot of wetlands to impact. ILF programs in other states highlighted the opportunities for a state with a lot of public lands and the possible flexibility if fees are designed with arid lands in mind.

Two themes emerged from interviews with Utah stakeholders. First, no one is happy with the current wetland permit process. Permit-seekers are frustrated with the lengthy approval process while they develop mitigation projects and with how uncertain they are about the outcome of their applications. Despite their best efforts, stakeholders are often disappointed when mitigation projects result in small, weed-choked wetlands that do not provide many ecosystem functions. The second important issue is that Utah's land and wildlife managers believe an ILF program would give them a great opportunity to learn more about wetland restoration. A single program responsible for wetland mitigation would provide a venue for experts on wildlife, hydrology, and local watershed needs to share their knowledge and develop new skills to enhance wetland restoration across Utah.

A beaver dam analog installed on a stream near Strawberry Reservoir. This is a common stream and wetland restoration technique that could be pursued by an ILF.

Riparian wetlands of Moab's Mill Creek, where invasive species removal and cattle fencing has allowed native willows to grow again.

We recommend that the State of Utah create an ILF program because it would be good for both permit-seekers and for Utah's wetlands. An ILF would benefit the environment by creating better wetland mitigation projects and would also benefit the economy by speeding up permitting and preventing project delays. For an ILF to become a self-sustaining program it will need a program administrator who can focus on planning the program structure and getting approval from USACE. Representative Snider submitted a request for funding during the 2023 legislative general session for such a position that ultimately wasn't funded. A final report on the ILF for Utah is due during this spring's interim legislative session after which more support may be generated for funding for an ILF administrator through either the legislative or executive branch.

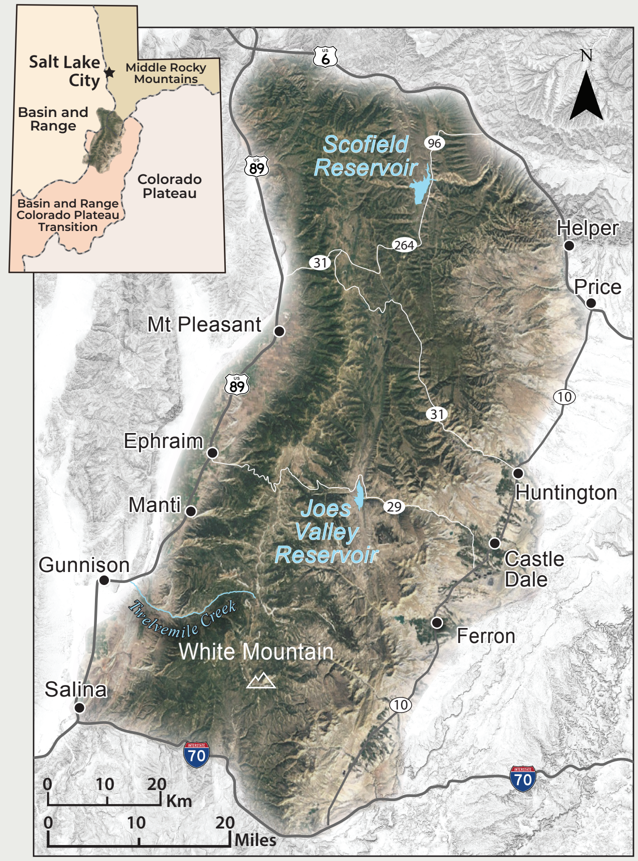
Wetlands are rare in Utah, covering less than one percent of the state, but they provide so many more services than their small area would suggest. Healthy wetlands that support many wetland functions are critical, especially because wetlands are so scarce in the West. An ILF program for Utah could make a big difference in replacing lost functions through high-quality mitigation and by improving general knowledge and collaboration regarding wetland restoration.

What do landslides, glaciers and faults have to do with the lakes on the Wasatch Plateau?

by Lance Weaver

Glad You Asked!

The Wasatch Plateau is located south and east of the southernmost part of the Wasatch Range in central Utah and is in the transition zone between the Colorado Plateau and the Basin and Range physiographic provinces. The plateau is a table-like mountain range with an abundance of lakes and reservoirs along its axis. These many lakes and reservoirs are the result of three very different geological processes that continue to shape the area. These include landslides, which are responsible for most of the plateau's smaller lakes; extensional faulting, which created valleys (or grabens) that accommodate the plateau's largest modern reservoirs as well as a few mid-size lakes; and Pleistocene-age (about 2.6 million to 12,000 years ago) glaciation, which created many of the plateau's smaller high-elevation lakes.

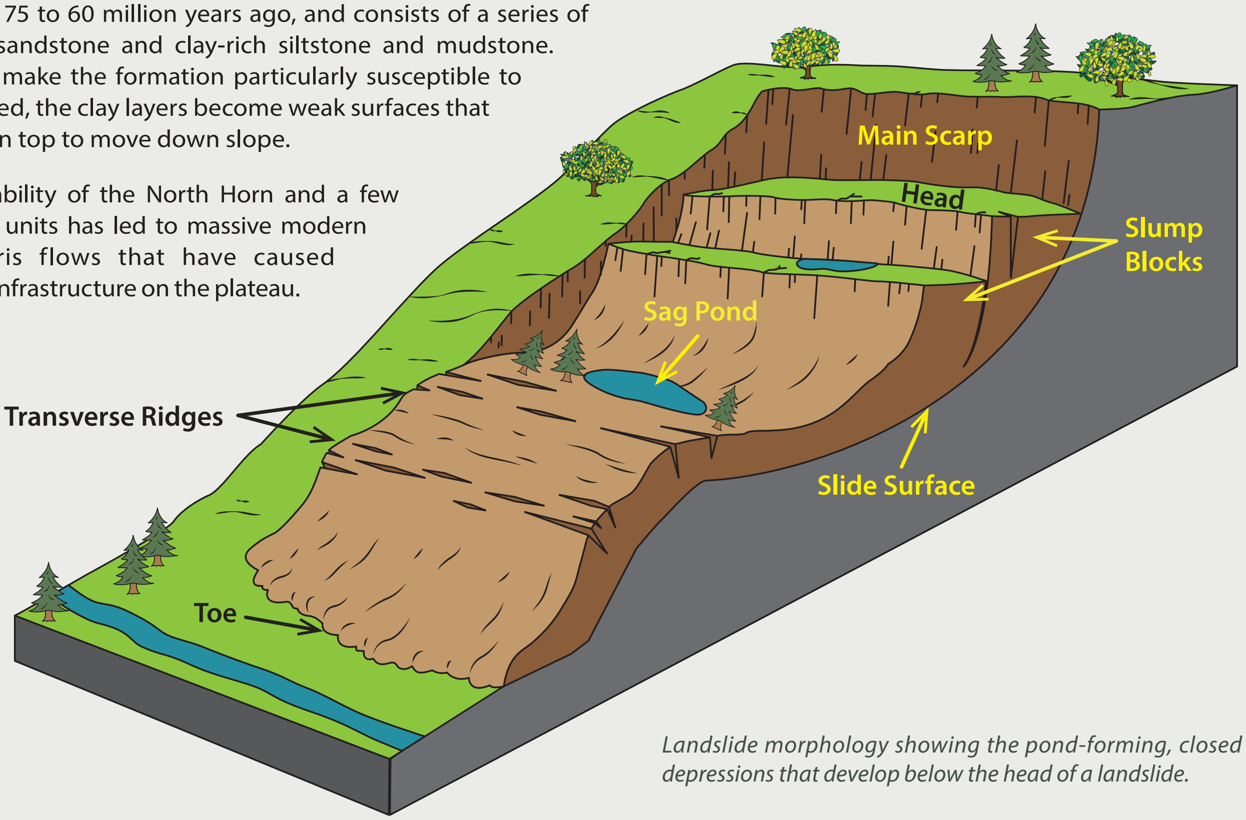


Location of the Wasatch Plateau in Utah.

The Wasatch Plateau is home to many mid- to high-elevation wooded shallow ponds and lakes that create amazing opportunities for camping, fishing, and recreating. However, most do not realize that the small, relatively flat basins that house many of these lakes are actually closed depressions that form near the uppermost part, or *head* of large ancient landslides. Although the bottom, or toe, of landslides can often form lakes as they dam stream drainages, few of these types of lakes last because they are prone to overtopping and erosion. However, the top part of landslides commonly form what is known as a *sag pond* or closed depression just below the head. The Wasatch Plateau contains many of these with classic examples existing in areas such as Mayfield Canyon's Twin Lake or the many ponds in the Spring Hill area and other headwaters of Twelvemile Creek. Ponds can also form between the toe and head of the landslide due to the uneven, jumbled, or hummocky topography, such as Slide Lake west of Joes Valley Reservoir.

The abundance of ancient landslides that created these lakes and ponds is largely the result of the composition of the North Horn Formation. This formation formed during the Late Cretaceous Period and Early Paleocene Epoch, approximately 75 to 60 million years ago, and consists of a series of alternating layers of sandstone and clay-rich siltstone and mudstone. These clay-rich layers make the formation particularly susceptible to landslides. When wetted, the clay layers become weak surfaces that allow the rock layers on top to move down slope.

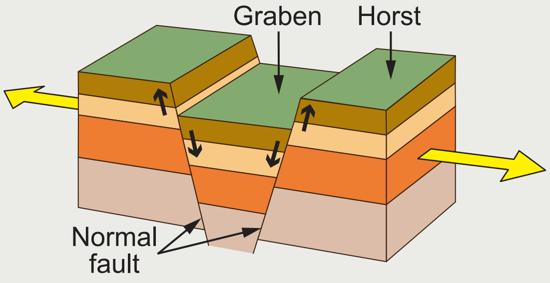
Occasionally, the instability of the North Horn and a few other similar geologic units has led to massive modern landslides and debris flows that have caused significant damage to infrastructure on the plateau.



Landslide morphology showing the pond-forming, closed depressions that develop below the head of a landslide.

One such example occurred in Twelvemile Canyon, which has a long history of damaging landslides. In the spring of 1983, a massive landslide in the canyon temporarily blocked the creek, which soon overtopped the natural dam and created a debris flow. The debris flow traveled 2.4 miles down the South Fork of Twelvemile Creek before burying part of Pinchot Campground. Another 1983 landslide, below nearby Twin Lake, closed the road and threatened to block Twelvemile Creek entirely. Less than two decades later, in 1998, another large landslide from the North Fork of Cooley Creek traveled 1.8 miles down the South Fork of Twelvemile Creek, depositing large amounts of landslide material in the creek. In addition to these historical landslides, prehistoric landslides are common in the canyon, and evidence shows that some have blocked and deflected creeks.

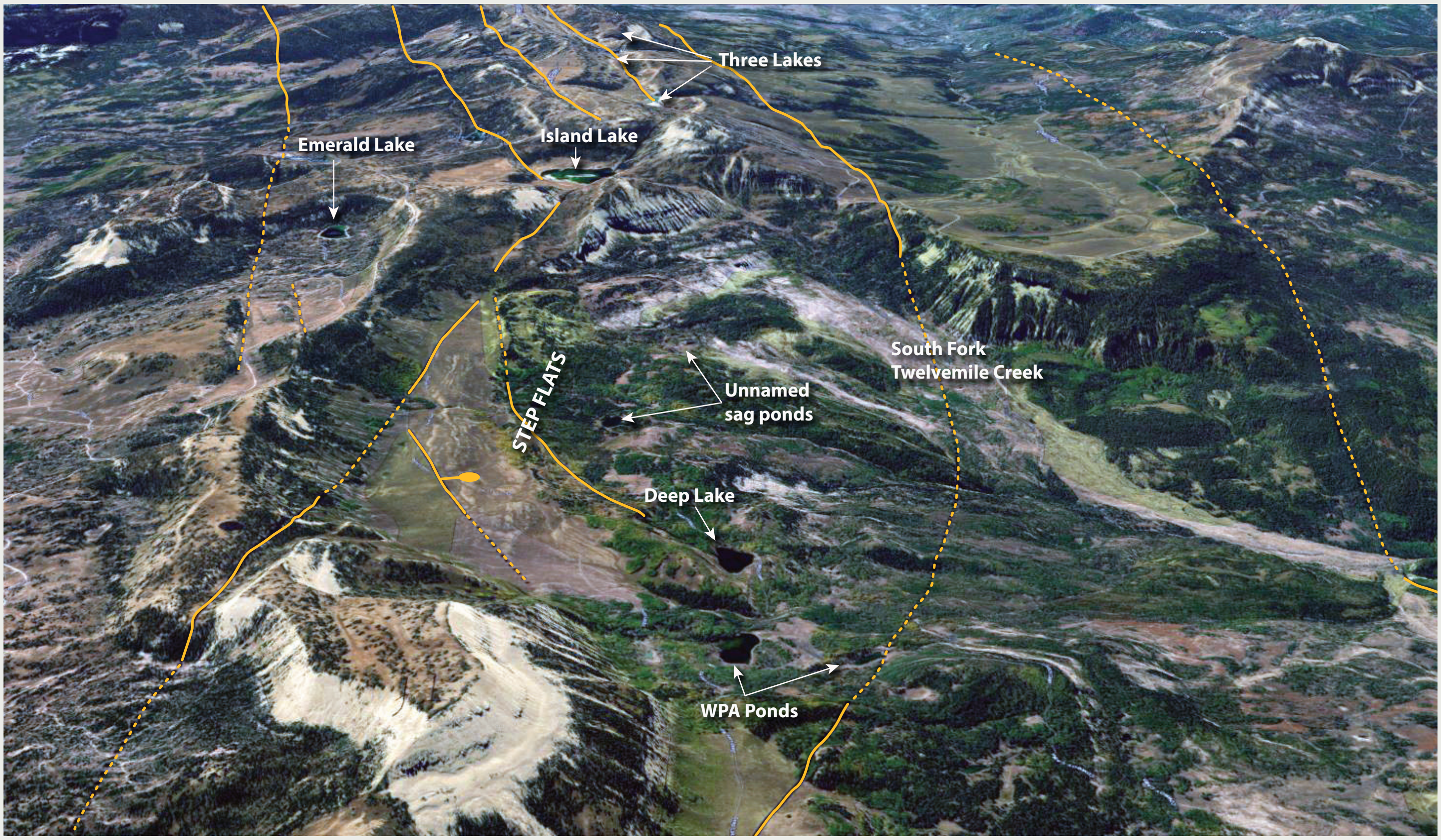
The second process responsible for the location of the largest lakes on the Wasatch Plateau is extensional faulting. The Wasatch Plateau has many north-to-south-oriented normal faults that are created by the incredibly slow westward extension or pulling apart of the plateau. The rocks on either side of a normal fault move up or down relative to each other and the down-dropped side creates a depression or valley called a graben. Several major Wasatch Plateau lakes, such as Scofield Reservoir and Joes Valley Reservoir, are located in such fault-bounded valleys. A string of smaller graben lakes also exists along the upper axis of the Wasatch Plateau in the Island Lake and Three Lakes area of White Mountain.



Block diagram showing the formation of a graben between normal faults as Earth's crust extends and pulls apart.

The third factor responsible for the many lakes on the Wasatch Plateau is glaciation. During the Pleistocene the upper elevations of the plateau accumulated several sprawling glaciers. Existing mostly above an elevation of 9,500 feet, these glaciers carved out many notable steep-sided, bowl-shaped depressions called cirques, leaving behind several small lakes and ponds called tarns. Some examples of lake basins formed by glaciation are Ferron Reservoir, Blue Lake, and Emerald Lake, which are located in the high southeast section of the Wasatch Plateau.

The lakes, ponds, and reservoirs of Utah's Wasatch Plateau are hidden gems for recreation. A trio of geological processes contributed to the formation of its many small and large water bodies, which include a unique combination of ponds from landslides, reservoirs in extensional faulted valleys, and lakes in ancient glacial cirques.



Many of the Wasatch Plateau's lakes are visible in this aerial image looking southward along the axis of Skyline Drive east of Gunnison, Utah. Deep Lake, the WPA ponds, and many of the other unnamed lakes and ponds of the Step Flats area are sag ponds created at the head of landslides within the Twelvemile Creek drainage. Island Lake and several other small lakes along the axis of the Plateau are graben lakes bounded by normal faults. Solid and dashed orange lines are normal faults, the bar and ball symbol indicates the down-dropped side of the fault. Emerald Lake is in a Pleistocene-age glacial cirque. Aerial imagery courtesy of ESRI, Earthstar Geographics.

Springhill Geologic Park. March 2023.

Springhill Geologic Park

Davis County, Utah

by Mark Milligan

Akin to a ghost town, intrigue and tragedy shroud this peaceful park in the Springhill area of North Salt Lake, which was created after a slow-moving landslide ultimately destroyed 18 homes over a torturous 15 years.

Homeowners were shocked to learn that their homes were located on an active landslide. Imagine finding doors that will not shut and hearing creaking and popping as the ground beneath your home incrementally inches down a gentle slope, not knowing how much deformation your house can withstand before being deemed unsafe. Unfortunately, homeowners insurance does not cover landslide damage, ultimately leaving owners with a mortgage on a nearly worthless lot. This dilemma led Springhill residents to stay as long as possible.

In the late 1990s, residents began to notice cracking and other damage, which progressed until a house on Springhill Drive was condemned in 1998. The landslide also damaged homes on Valley View Drive, Barry Circle, and Springhill Circle, but a dry period slowed movement and damage from 1999 to 2004. Unfortunately, 2005 was a wet year and movement again increased, intermittently and incrementally causing damage until five more homes were condemned by 2010. In 2012, the City of North Salt Lake, with help from partners including the Utah Geological Survey (UGS), secured a U.S. Federal Emergency Management Agency grant of nearly $2 million. That money, coupled with roughly $600,000 in matching funds from the city, was used to purchase (at full unaffected value) and demolish the 12 homes remaining on the landslide, capture and channel spring water into a stormwater drain, and create the Springhill Geologic Park, which will forever remain open space.

The Springhill landslide measures roughly 300 by 720 feet and has 150 feet of surface relief. This gentle slope likely accounts for its very slow movement. The landslide moved approximately 5 feet from the time the UGS began monitoring in 1998 to 2012 when the city began to purchase the remaining homes. The slide moved an additional 21 inches from when the park was completed in 2014 to 2020 when it was last surveyed. The UGS plans to survey the slide again in the spring of 2023.

The landslide formed in an old gravel quarry where gravels from ancient Lake Bonneville were excavated nearly down to a layer of highly weathered clay-rich volcanic ash, sand, and silt (tuffaceous rock) at the base of the landslide. This weak, poorly drained layer of clay-rich tuffaceous rock and ample groundwater likely account for the decades of recurrent creep along this gentle slope. In places the tuffaceous rock is overlain by a unit of volcanic rock fragments (the gray "volcaniclastic conglomerate" exposed at the northeast edge of the park). The Wasatch fault zone crosses the lowermost part of the slide and may have enhanced weathering and clay development by providing a prehistoric flowpath for rising deep, hot groundwater.

Springhill Drive is named for the numerous natural springs formed when groundwater easily flows downward through the Lake Bonneville gravels but is impeded by the clays and weathered rocks below, and then flows laterally along this contact until reaching the surface.

The same highly weathered tuffaceous rock unit with overlying Lake Bonneville gravels was also the culprit two-thirds of a mile to the south at the 2014 Parkway Drive landslide, the bulk of which slid down a very steep slope in one morning, destroying a single home and tennis facility.

Damaged and condemned house on Springhill Circle that has since been demolished. Photo courtesy of Adam McKean, February 2011.

Continued damage to sidewalk, fencing, curb and gutter, asphalt, and stone mailbox pillar on north flank of the landslide, on Springhill Drive. March 2023.

Left—August 2012. Google street view looking southwest on Springhill Drive, showing many houses still standing. Right—October 2022. Same view after home demolition and creation of Springhill Geologic Park. Aerial imagery courtesy of Google Earth.

When visiting the park, look for:

- Remnants of landscaping structures and plants from the demolished homes.
- Ground distortion—evidence of ongoing movement, especially along the northeast flank, main scarp, and toe.
- The drainage system used to capture and divert spring water off the slide in an attempt to help keep it dry and stable.

For more information about the Springhill landslide, see https://geology.utah.gov/hazards/landslides/springhill-landslide-north-salt-lake/.

Location—Springhill Geologic Park is located just north of Eagle Ridge Drive in North Salt Lake at 191 Springhill Drive. The park can also be accessed from a trailhead at 367 East Barry Circle, which Google Street View (August 2012) still shows with a now-demolished home.

Coordinates: 40.837397° N, 111.904000° W

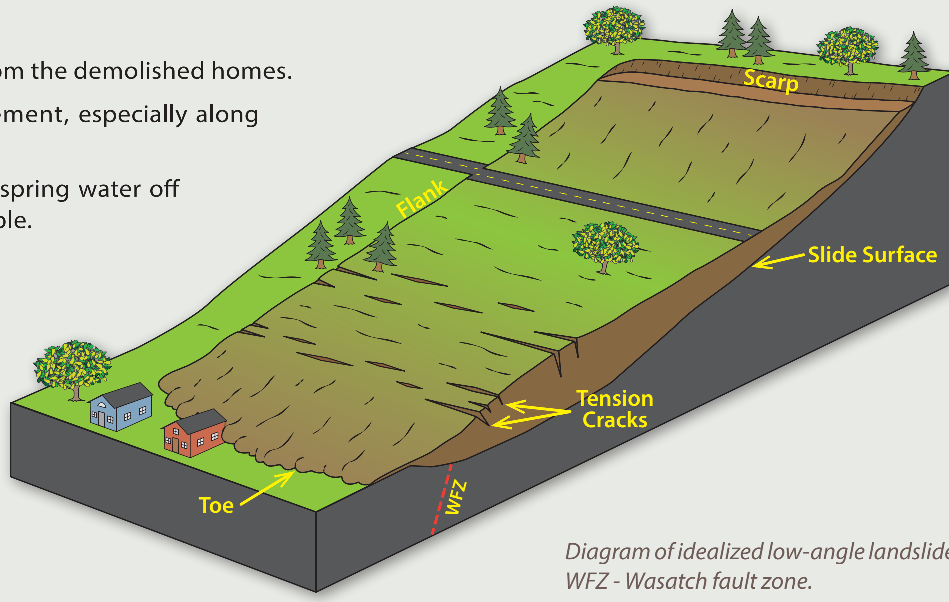


Diagram of idealized low-angle landslide. WFZ - Wasatch fault zone.

Left—Aerial image with the landslide boundary (light blue line) in 2009. Yellow arrows show landslide movement direction. Yellow highlighted area is the Wasatch fault zone. Middle—Aerial image of same area in 2023. Right—Location map. Aerial imagery courtesy of Google Earth.

ENERGY NEWS

Utah Returns to Being a Net Energy Importer

by Michael D. Vanden Berg

Utah is fortunate to have abundant and diverse energy resources including large reserves of conventional fossil fuels and several areas suitable for renewable resource development. Producing these resources has always been a priority for Utah—not only does responsible development provide good high-paying jobs, mostly in rural areas of the state, but it also contributes significant tax revenue. And of course, this energy also drives our modern way of life. For the past 40+ years, Utah has enjoyed the status of being a net energy exporter, meaning Utah produced/generated more energy than needed and was able to export the excess energy to surrounding states (and sometimes to other countries). Energy production in Utah began decreasing in 2015 and continued to drop until it crossed the consumption line in 2020, flipping Utah back to being a net energy importer. This new situation continued into 2021, with an even larger differential, and is predicted to continue in the near term.

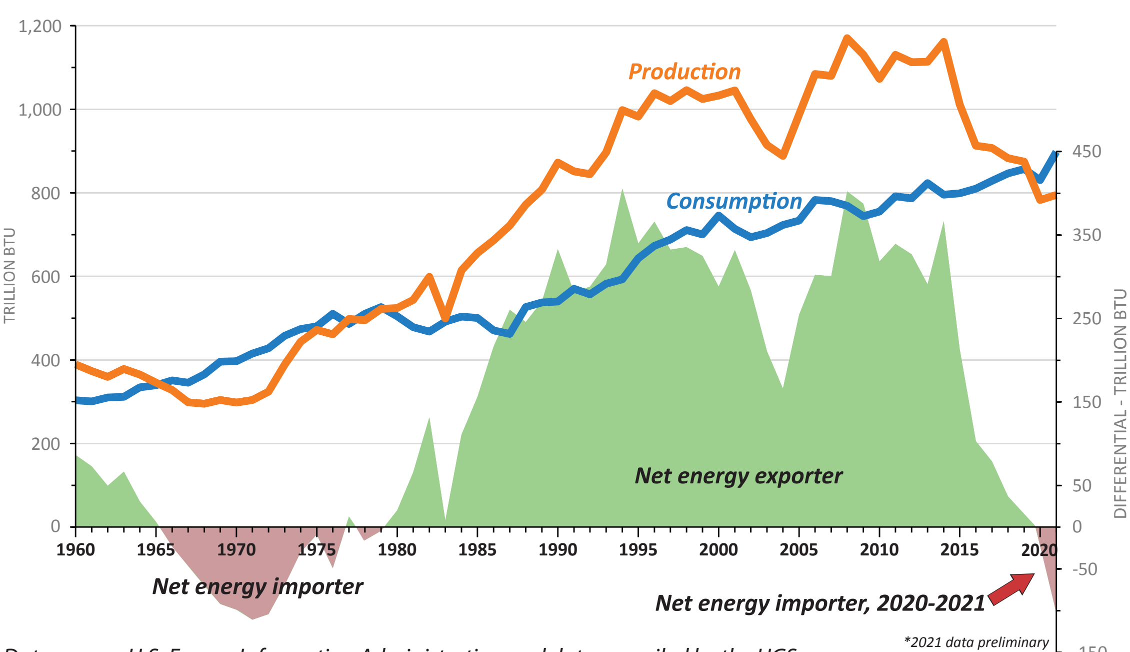
In the late 1960s and throughout most of the 1970s, energy production in Utah could not keep up with energy consumption. Then in the early to mid-1980s, two interesting things happened: Utah's energy consumption plateaued, and energy production skyrocketed—these events flipped Utah squarely into net energy exporter status. The consumption plateau was probably related to the late-1970s to early-1980s recession; individuals were simply not using as much energy during this time. The large increase in energy production was specifically tied to increased fossil fuel production related to high commodity prices in the early to mid-1980s. Utah experienced a near doubling of coal production during this time, some to feed the newly built Intermountain Power Plant near Delta, Utah, and more to feed a growing domestic export market. Crude oil production ramped up to what was a record high at the time, near 41 million barrels in 1985, and production of natural gas also greatly increased due to similar high prices.

Starting in the late 1980s, energy consumption in Utah resumed a steady climb, averaging about a 2 percent annual increase. Energy production remained high based on the continued success of fossil fuel production. Single-year fluctuations in production can typically be tied to specific events, such as the temporary closure of the Skyline coal mine in 2004 (and subsequent dip in the production curve), which removed about 4 million tons of coal from the market.

Several events led up to the significant production decline that started in 2015 and continued into 2021, shifting Utah back to net energy importer status. Natural gas prices never really recovered after the 2008 Great Recession but stayed particularly low after the oil and gas downturn in 2015. Natural gas production peaked in 2012 at about 490 billion cubic feet (Bcf) and then steadily dropped to just 240 Bcf in 2021. Coal production in Utah was already in decline since about 2008 but dropped a significant 3.4 million tons between 2014 and 2015, and continued to slide, reaching only 12.5 million tons by 2021. Crude oil production reached a near record high in 2014 of 41 million barrels, but quickly collapsed after the 2015 price shock, down to only 30.5 million barrels. Oil production has since been volatile, going up to 37 million barrels in 2018 just to crash again down to 30.5 million barrels in 2020. Renewable energy production has been on the rise, more than doubling from 2015 to 2021 with the development of significant wind and solar resources, but still only represents about 7 percent of total energy production, which is still mostly drowned out by the massive decreases in coal and natural gas production.

Although it is attractive for the State of Utah to be "energy independent" and have the luxury of exporting energy to other states, Utah enjoys good relationships with surrounding states and will not be deprived of the energy needed to keep its economy and way of life moving forward. However, the significant decrease in production, mostly natural gas and coal, does have impacts in the rural communities that rely on related jobs and economic contributions. Consumption of energy in Utah will continue to march forward, increasing about 2 percent every year as population increases and as individuals use more energy each year. This ever-increasing energy demand will need to be supplied from somewhere, whether from increases in renewable generation, or an increase in fossil fuel production, or both. Luckily, Utah has the diverse energy landscape needed to fulfill energy demands well into the future.

Utah Energy Balance: Production and Consumption, 1960-2021



Data source: U.S. Energy Information Administration and data compiled by the UGS.

Utah enjoys good relationships with surrounding states and will not be deprived of the energy needed to keep its economy and way of life moving forward.

Notes: Lines are total production/consumption in trillion British thermal units (Btu) (left vertical axis). Shaded area is the differential, trillion Btu of production minus trillion Btu of consumption (right vertical axis), with "net energy importer" in red and "net energy exporter" in green.

SURVEY NEWS

2023 UGA Teacher of the Year

Iain Harvey of North Davis Junior High is this year's recipient of the Utah Geological Association's (UGA) Utah Earth Science Teacher of the Year Award. Iain embraces the three-dimensional learning strategy and makes excellent use of the engineering design process to help students apply their science skills to real-world scenarios. In addition to his work at North Davis Junior High, Iain serves the Davis School District as the Science Lead for the 8th-grade collaborative team. Congratulations Iain!

GEOLOGY OF THE INTERMOUNTAIN WEST
UGA
UTAH GEOLOGICAL ASSOCIATION
SINCE 1970

2023 Utah Legislative Session Events

On February 10th the Natural Resources Map & Bookstore helped the Division of Outdoor Recreation and other local organizations celebrate the depth, uniqueness, and innovation of the outdoor recreation industry by attending Outdoor Recreation Day on the Hill at the Utah State Capitol. The event was well attended and gave our staff the opportunity to personally interact with multiple lawmakers and their staff. Then on February 14th the UGS participated in the 11th annual Maps on the Hill event at the Capitol to present our wetland map application, Great Salt Lake research, and various other wetland projects. This event showcases the diversity of mapping resources in Utah and demonstrates how mapping technology can support decision-makers. To view the wetland web application and more, view our interactive maps page at: geology.utah.gov/map-pub/maps/interactive-maps.

Employee News

Congratulations to **Jackson Smith**, current Natural Resources Map & Bookstore manager, who accepted the position of geologist with the Geologic Information & Outreach Program. The Data Management Program welcomes **Nathan Payne** who accepted the position of data manager, but also bids farewell to **Martha Jensen** who accepted a job with the Bureau of Land Management. The Energy & Minerals Program wishes **Julia Mulhern** well in her new job with the National Energy Technology Laboratory. **Miles McCoy-Sulentic** departed the Groundwater & Wetlands Program and has moved on to a job with the Colorado Natural Heritage Program. The Editorial Section bids farewell to **Jessica Pierson** who accepted a GIS Analyst position with the Utah Division of Wildlife Resources. Congratulations to Jackson and Nathan and best wishes to Martha, Julia, Miles, and Jessica.

RECENT OUTSIDE PUBLICATIONS

BY UGS AUTHORS

Significance of a Small Regurgitalite Containing Lissamphibian Bones, From the Morrison Formation (Upper Jurassic), Within a Diverse Plant Locality Deposit in Southeastern Utah, USA, by J.R. Foster, A.P. Hunt, and **J.I. Kirkland**: Palaios, v. 37, p. 433-442, http://dx.doi.org/10.2110/palo.2021.058

Applications and Limitations of Portable Density Meter Measurements of Na-Ca-Mg-K-Cl-SO_4 Brines, by **J.A. Bernau, E.A. Jagniecki**, E.L. Kipnes, and B.B. Bowan: Chemical Geology, v. 616, https://doi.org/10.1016/j.chemgeo.2022.121240

Middle Miocene Faulting and Basin Evolution During Central Basin and Range Extension—A Detailed Record From the Upper Horse Spring Formation and Red Sandstone Unit, Lake Mead Region, Nevada, USA, by M.A. Lamb, T.A. Hickson, P.J. Umhoefer, **Z.W. Anderson**, C. Pomerleau, K. Souders, L. Lee, N. Dunber, and W. McIntosh: Geosphere, v. 18, p. 1394–1434

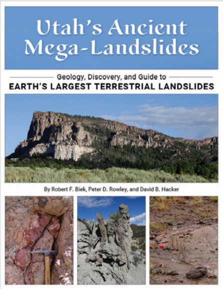
UTAH GEOLOGICAL SURVEY
1594 W North Temple, Suite 3110
PO Box 146100
Salt Lake City, UT 84114-6100

Address service requested
Survey Notes

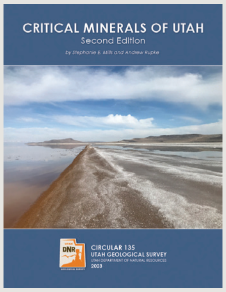
PRSRT STD
U.S. Postage
PAID
Salt Lake City, UT
Permit No. 4728

NEW PUBLICATIONS

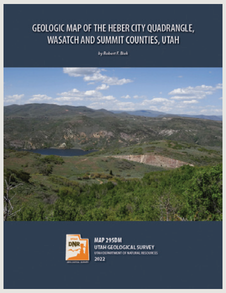
Available for download at **geology.utah.gov** *or for purchase at* **utahmapstore.com**.



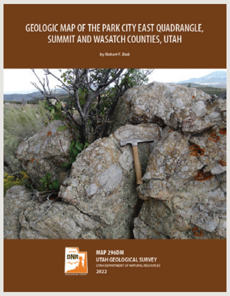
Utah's Ancient Mega-Landslides: Geology, Discovery, and Guide to Earth's Largest Terrestrial Landslides, by Robert F. Biek, Peter D. Rowley, and David B. Hacker, 67 p., **C-132**, https://doi.org/10.34191/C-132



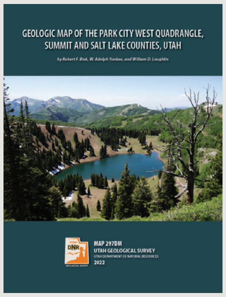
Critical Minerals of Utah, Second Edition, by Stephanie E. Mills and Andrew Rupke, 47 p., **C-135**, https://doi.org/10.34191/C-135



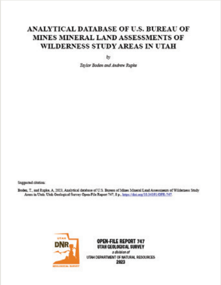
Geologic Map of the Heber City Quadrangle, Wasatch and Summit Counties, Utah, by Robert F. Biek 24 p., 2 plates, scale 1:24,000, **M-295DM**, https://doi.org/10.34191/M-295DM



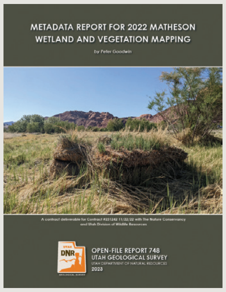
Geologic Map of the Park City East Quadrangle, Summit and Wasatch Counties, Utah, by Robert F. Biek 23 p., 2 plates, scale 1:24,000, **M-296DM**, https://doi.org/10.34191/M-296DM



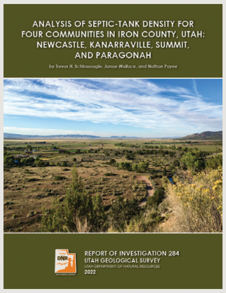
Geologic Map of the Park City West Quadrangle, Summit and Salt Lake Counties, Utah, by Robert F. Biek, W. Adolph Yonkee, and William D. Loughlin 21 p., 2 plates, scale 1:24,000, **M-297DM**, https://doi.org/10.34191/M-297DM



Analytical Database of U.S. Bureau of Mines Mineral Land Assessments of Wilderness Study Areas in Utah, by Taylor Boden and Andrew Rupke, 8 p., **OFR-747**, https://doi.org/10.34191/OFR-747



Metadata Report for 2022 Matheson Wetland and Vegetation Mapping, by Peter Goodwin, 6 p., **OFR-748**, https://doi.org/10.34191/OFR-748



Analysis of Septic-Tank Density for Four Communities in Iron County, Utah—Newcastle, Kanarraville, Summit, and Paragonah, by Trevor H. Schlossnagle, Janae Wallace, and Nathan Payne, **RI-284**, 27 p., https://doi.org/10.34191/RI-284

Available from:

THE NATURAL RESOURCES

MAP & BOOKSTORE

1594 WEST NORTH TEMPLE • SALT LAKE CITY • MON–FRI 10AM–5PM • UTAHMAPSTORE.COM

CALL US AT 801-537-3320 OR 1-888-UTAHMAP

CONNECT WITH US!
UGS BLOG geology.utah.gov/blog

FACEBOOK @UTGeologicalSurvey

TWITTER @utahgeological

INSTAGRAM @utahgeologicalsurvey

LINKEDIN utah-geological-survey