

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

SURVEY NOTES

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**Geologic Hazard Resources for
Cities, Towns, and Counties**

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Cover | Geologist Adam McKean points at a landslide in City Creek Canyon while monitoring landslide movement during the UGS 2023 landslide response.

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DIRECTOR'S PERSPECTIVE

by L. Darlene Batatian



Summer and fall are busy seasons for the Utah Geological Survey (UGS), as our staff fan out across Utah conducting field work. Summer is also a time of resource challenges for Utah, particularly for water and geologic hazards. The UGS assists with water challenges by conducting groundwater studies in various basins in support of the Utah Division of Water Rights (DWRi). We study and constrain water supply and usage via real time monitoring of evapotranspiration, stream and springflow monitoring for DWRi and the Department of Natural Resources (DNR) Watershed Restoration Initiative, and investigate areas of groundwater pumping-induced land subsidence using InSAR satellite information. To address water critical for wetlands, the State Wetlands Coordinator is updating the State Wetlands Program Plan and, together with our groundwater section, has participated in preparing the DWRe State Water Plan. The UGS is also working with other agencies to better understand the groundwater and its relationship to the Great Salt Lake.

Utah's 2026 wildfire season has claimed over 475,000 acres. Monsoonal rains over some burned areas soon followed, generating debris flows and flooding from fresh burn areas as well as the 2024 Silver King and 2025 Forsyth burn areas. Debris and flooding from the Cottonwood fire burn area inundated homes and farms in Beaver, Utah, and overran I-15. The UGS Geologic Hazards team is experimenting with InSAR and Sentinel 2 satellite data to map debris flows from recent burn scars, and is building a tool to overlay infrastructure maps to expedite assessment of debris flow impacts. Our lead article in this issue focuses on the information the UGS provides to assist Utah's cities, towns and counties with geologic hazards management.

Energy is always "in season" at the UGS. Using funding from the State's \$1.75M Operation Gigawatt Geothermal award, our Energy and Minerals Program purchased state-of-the-art magneto-telluric (MT) equipment to perform deep-basin geophysical surveys for geothermal resource assessments, this equipment may also be used for groundwater basin studies as well.

This issue of *Survey Notes* underscores the UGS's mission to address real-time natural resource needs that keep Utah moving forward—in all seasons. Decision makers rely on the UGS for sound and reliable scientific data from an unbiased, trusted source, and we will continue to do important work during this challenging season.

To meet ongoing research demands, the UGS is welcoming four new scientists to our staff. On a separate note, we would like to say farewell to DNR Commissioner Joel Ferry, who has provided outstanding leadership and support to the UGS (and to me, personally). Commissioner Ferry has been a tireless advocate for Utah's natural resources, particularly the health of Great Salt Lake and its wetlands. We are excited to work under DNR's newly appointed Commissioner Jamie Barnes, who will lead DNR with her very high level of experience, initiative, and success as Director of Forestry, Fire and State Lands. 🏠

Geologic Hazard Resources for Cities, Towns, and Counties

by Adam McKean and Steve Bowman

How can the Utah Geological Survey (UGS) Geologic Hazards Program help your city, town, or county understand, prepare for, and respond to geologic hazards?

The goal of the UGS's Geologic Hazards Program is to help reduce risk to Utah's life safety, property, and economy by assisting local governments (cities, towns, and counties) with geologic hazard issues and providing unbiased scientific information to all for informed decision-making. The UGS has a variety of resources available to support local government and help the public understand geologic hazards, prepare for them, and respond after an event. Many of these resources are web-based and easily accessible online, including our website designed specifically for local governments and other agencies (<https://geology.utah.gov/hazards/assistance>).

Resources for Understanding Geologic Hazards

General educational information about geologic hazards, including earthquakes, landslides, problem soils and rocks, flooding, volcanoes, and more, can be accessed on our website at <https://geology.utah.gov/hazards>. The UGS has also published a variety of fact sheets on hazards that are available for download or online viewing. A few noteworthy publications include:

- Wildfires and debris flows (<https://doi.org/10.34191/PI-90>)
- Rockfall (<https://doi.org/10.34191/PI-94>)
- Landslides (<https://doi.org/10.34191/PI-98>)
- Liquefaction (<https://doi.org/10.34191/PI-100>)
- Shallow groundwater (<https://doi.org/10.34191/PI-105>)

The UGS website also hosts an online interactive hazards map, the *Geologic Hazards Portal* (<https://maps.geology.utah.gov/hazards>), which allows a user to select and view hazards anywhere in the state. Additionally, our website has a searchable database of geologic hazard maps and publications that can be viewed online or downloaded and printed for use (<https://geology.utah.gov/hazards/info/publications>).

An excellent online resource for earthquake information in Utah is "earthquakes.utah.gov," for which the UGS provides content as a collaborator. This website discusses the geology and history of earthquakes in Utah and provides access to publications, including the preparedness manual *Putting Down Roots In Earthquake Country* (2nd edition). This guide explains how to prepare for an earthquake and what to do after an earthquake happens. It is available as an English and Spanish print version or as an interactive web version:

- English print version (https://ugspub.nr.utah.gov/publications/non_lib_pubs/putting-down-roots.pdf)
- English interactive web version (<https://roots.geology.utah.gov>)
- Spanish print version (https://ugspub.nr.utah.gov/publications/non_lib_pubs/putting-down-roots-es.pdf)

Assistance Preparing for Geologic Hazards

The UGS provides geologic hazards planning assistance to local governments several of ways.

- The UGS prepares maps showing areas subject to geologic hazards. These maps are generally published at 1:24,000-scale, and can be used to define special study areas where further site-specific investigations should be considered prior to new development. These maps, and related downloadable GIS files, are available on the *Geologic Hazards Portal* (<https://maps.geology.utah.gov/hazards>).
- The UGS provides a "model" geologic hazard ordinance that can be adopted into a community's zoning ordinance to address geologic hazards during development (<https://doi.org/10.34191/C-128>). The model geologic hazard ordinance can be easily modified for different conditions found in many Utah local governments (Appendix E in <https://doi.org/10.34191/C-128>). While the UGS has not published comprehensive geologic hazard maps for all of Utah, the model ordinance defines "geologic hazards study areas" for areas where current mapping is not available, based upon specific geologic and other conditions.
- The UGS provides suggested guidelines for investigating geologic hazards and preparing engineering-geology reports that can be implemented as part of a building or land development review and permitting process. These guidelines recommend appropriate, minimum investigative techniques, standards, and report content to ensure adequate geologic site characterization and geologic-hazard investigations to protect public safety and facilitate risk reduction (<https://doi.org/10.34191/C-128>).
- The UGS also reviews geologic hazard reports for essential public facilities (police and fire stations, emergency operation centers, schools, etc.).



Ben Erickson and Torri Duncan launch a UGS UAV to collect digital elevation data after the 2024 Silver King Fire to support the emergency response for the town of Marysville. Photo courtesy of William Davis, Mayor of Marysville.

Assistance Responding to Geologic Hazards

The UGS is available to assist communities with geologic hazards' response immediately during and after geologic hazard events and natural disasters, including earthquakes, landslides, debris flows, floods, and ground subsidence. We assist and advise emergency-response officials and assess the nature and extent of the hazard. We also determine the likelihood for short- and long-term recurrence of the hazard, and assist in risk assessment.

Other Useful Tools

The UGS website (<http://geology.utah.gov>) hosts a wide variety of additional resources and tools that include:

- **Survey Notes**, a UGS newsletter magazine with articles like this one that is an informative, non-technical source on geologic topics in Utah (<https://geology.utah.gov/map-pub/survey-notes>);
- **The Utah Geological Survey GeoData Archive**, which contains public domain documents, photographs, and other digital materials related to geology topics (<https://geodata.geology.utah.gov>); and
- **The Utah Aerial Imagery Database**, which contains aerial photographs dating from 1935 to present day, with associated index sheets, orthophotomaps, mosaics, camera calibration reports, and other materials (<https://imagery.geology.utah.gov>).

ABOUT THE AUTHORS



Adam McKean is the Geologic Hazards Program Manager with the UGS. Adam joined the UGS in 2010, and since 2011 he has been a geologic mapper for the Geologic Hazards Program. His work focuses on mapping the geology of the greater Wasatch Front urban area. In addition to geologic mapping, Adam has also been involved in Lake Bonneville and Great

Salt Lake research, mapping of the Wasatch fault zone, geologic hazard emergency response and monitoring, paleoseismic trenching, and geologic map and geologic data archiving.



Steve Bowman joined the UGS in 2008 and has 23 years of experience as a geological engineer/engineering geologist, 9 of those years were on projects throughout the western United States for geotechnical consulting firms. Steve is a Licensed Professional Geologist and Engineer in Utah, a Professional Geological Engineer in Nevada, certified as a

LEED Accredited Professional, and serves on the Utah Seismic Safety Commission and the Utah Professional Geologists Licensing Board. He co-led the acquisition of over 20,000 square miles of lidar elevation data in Utah, and leads the geologic data preservation activities at the UGS.

What Local Government Can Do to Help the Utah Geological Survey

In 2024, House Bill (HB) 384 *Utah Geological Survey Data Submission Amendments* was passed by the Utah Legislature and took effect on May 1, 2024. HB 384 requires agencies in Utah to submit final geologic, fault hazard, and geotechnical reports received as part of a building or other infrastructure permitting process, to the UGS within 90 days of receipt. Once the reports have been processed through our archival workflow, they are available online in the *UGS GeoData Archive System* (https://geodata.geology.utah.gov/pages/collections_featured.php?parent=186081). The UGS uses these reports to support our geologic and geologic-hazard mapping and our *Subsurface Geotechnical Database* (<https://borehole.geology.utah.gov/>). After the reports are uploaded to our database, original reports are returned to the submitting agency/business.

To submit reports, please mail the report using one of the following methods:

By mail through the U.S. Postal Service:

Utah Geological Survey
Geologic Report Submission
P.O. Box 146100
Salt Lake City, Utah 84114-6100

By mail through an alternate delivery service:

Utah Geological Survey
Geologic Report Submission
1594 West North Temple
Salt Lake City, Utah 84116

For digital PDF submittals, use one of the following methods:

- Email the file to: ugs_georeports@utah.gov
- Upload the file to a Google shared drive that the UGS can set up for the compliance agency. Please email ugs_georeports@utah.gov requesting access with a list of your authorized user email addresses.
- Mail a USB flash drive or portable hard drive to one of the UGS addresses above, which can be returned upon request.

Invitation to Meet

As a non-regulatory, scientific state agency, our goal is to collect, analyze, and provide the best available science and information for our community. To help that goal, we invite each local government to meet with us to discuss how we can support their understanding, preparation, and response to geologic hazards. Interested entities can schedule a visit by contacting the UGS at (801) 537-3300 or reaching out to the authors.



Utah Geological Survey Geologic Hazard Resources for Cities, Towns, and Counties



Scan the QR codes to access resources and learn more!

⚠️ UNDERSTANDING Geologic Hazards

GENERAL INFORMATION



Earthquakes



Landslides



Problem Soils
and Rocks



Flooding



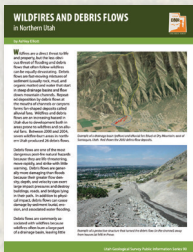
Volcanoes



DETAILED FACT SHEETS



SCAN ME



PI-90 Wildfires and
Debris Flows



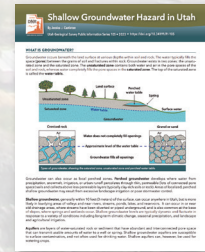
PI-94 Rockfall



PI-98 Landslides

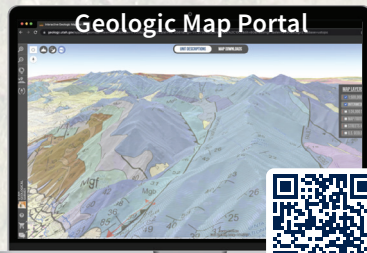
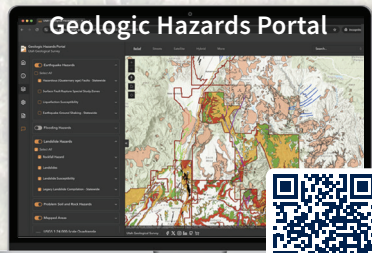


PI-100 Liquefaction



PI-105 Shallow
Groundwater

INTERACTIVE MAPS



MAPS & PUBLICATIONS

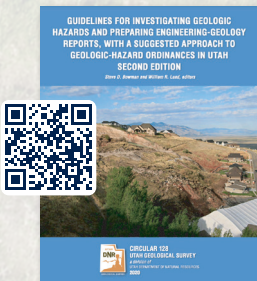


EARTHQUAKES.
UTAH.GOV



PREPARING FOR Geologic Hazards

Guidelines and Model Hazard's Ordinance



Putting Down Roots In Earthquake Country

PUBLICATION AND WEB APPLICATION



RESPONDING TO Geologic Hazards

Services for Local Government and Other Agencies

What role do we serve and what
services are provided?



SCAN ME

OTHER USEFUL LINKS

UTAH GEOLOGICAL SURVEY
SURVEY NOTES



GeoData
ARCHIVE SYSTEM



Aerial
Imagery
Database



How Groundwater Contributes to Great Salt Lake

by Erin Brinkman and Hugh Hurlow

Groundwater plays an important but often overlooked role in the Great Salt Lake (GSL) watershed system. Groundwater moves in underground aquifers from the surrounding mountains and valleys toward the lake, providing a steady source of supply that supports lake levels, wetlands, stream flow, springs, and water quality. Recent work revealed that groundwater flow to the lake is more significant than previously recognized, making it an important part of GSL's water system. GSL is a terminal basin for both surface flow and groundwater, meaning no stream flow leaves the lake basin and groundwater moves towards GSL from all directions within its watershed. Groundwater in the GSL watershed is also used extensively for drinking water, agriculture, industry, and mining. Therefore, GSL's condition reflects the climate and hydrogeologic variations as well as the human uses surrounding it.

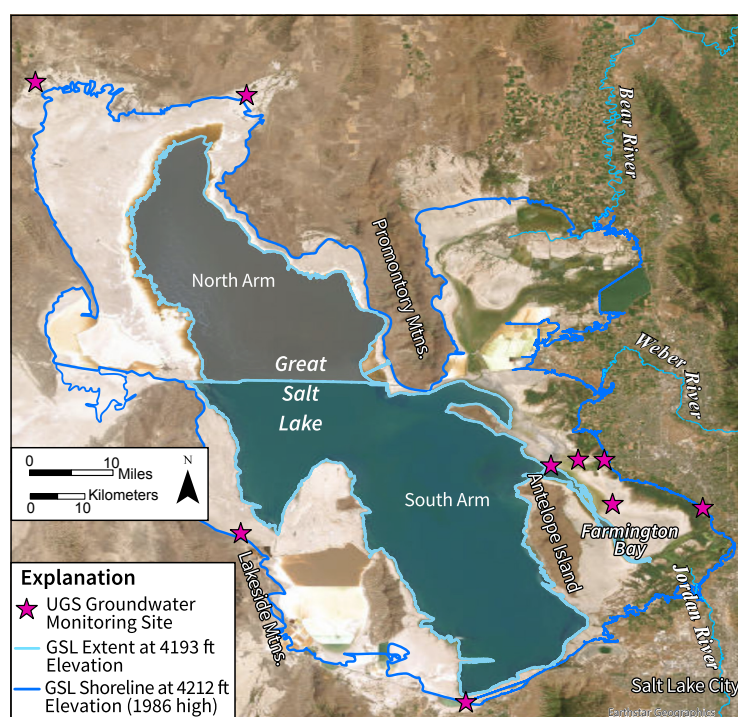
Over the past decade, concerns about the ecological and economic health of GSL have grown among scientists, community members, and policymakers. Discussion has focused on declining lake levels, which has led to increasing salinity, additional exposed lakebed and dust generation, loss of wetlands and bird habitat, and challenges for the mineral extraction and brine shrimp industries. Stress on the groundwater system, including drought and increased groundwater pumping, has caused water-level declines in wells and springs around the lake. The need to better understand the role of groundwater in these important and complicated issues is noted in two key initiatives for long-term planning to sustain GSL and its benefits: the Great Salt Lake Strategic Plan and the Great Salt Lake Basin Integrated Plan.

Recognizing the need for better information about the role of groundwater, the Utah Geological Survey (UGS) began studying how groundwater flows into GSL during the mid-2010s. UGS researchers compiled existing data on water chemistry, spring flows, and ground-

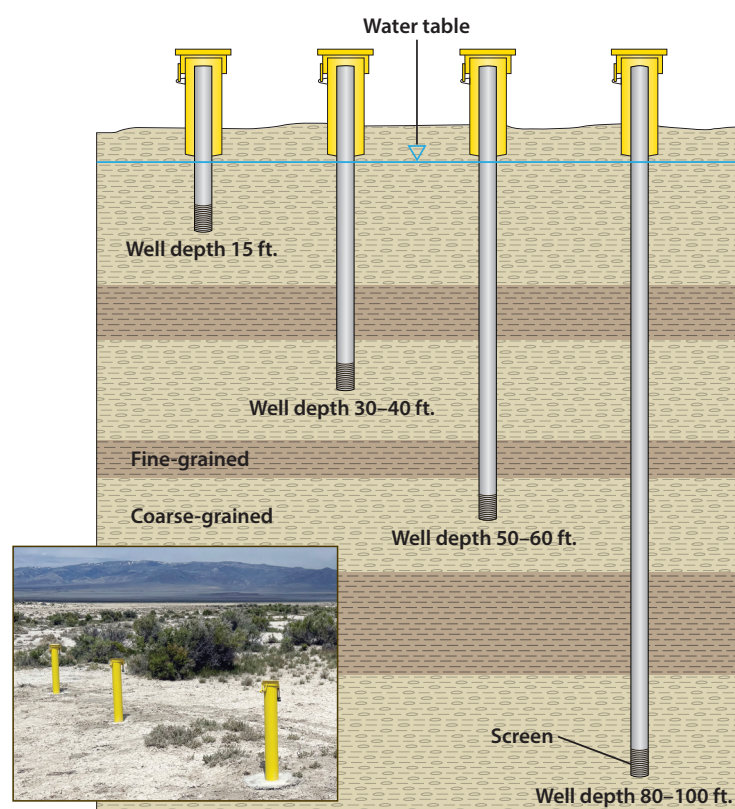
water levels around the GSL perimeter. We discovered a significant lack of data for the lake's marginal wetlands, shoreline, and dry lakebed, mainly because these areas had been underwater for decades or had not yet experienced troubling groundwater declines. Now these areas are exposed, creating a new opportunity for the UGS to obtain data directly from the exposed lakebed, subsurface, and its margins.

To address this data gap, the UGS and partners installed the GSL Groundwater Monitoring Network, consisting of nine new monitoring well sites, each with several wells screened (open to the aquifer) at different depths (nested). The first group of wells were installed in 2023–24 near Farmington Bay in collaboration with the University of Utah, and the resulting data contributed to three master's theses. The UGS installed the next set of wells in 2025–26 on the southwest, northeast, and northwest corners of GSL. During installation of these nested wells, we collected sediment cores up to 100 feet deep at each site that provided important data on the chemistry of the pore water and sedimentation history at the site.

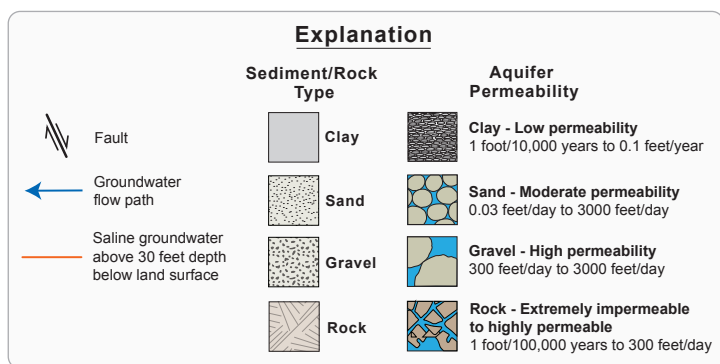
The nested wells are open to aquifers at multiple depths at each site, allowing us to observe how groundwater levels and water quality vary vertically beneath the surface. The data collected from these wells improve our understanding of groundwater flow and geochemistry, provide subsurface information needed to calibrate groundwater flow models, and establish a long-term monitoring network to evaluate the effectiveness of future water management and conservation efforts.



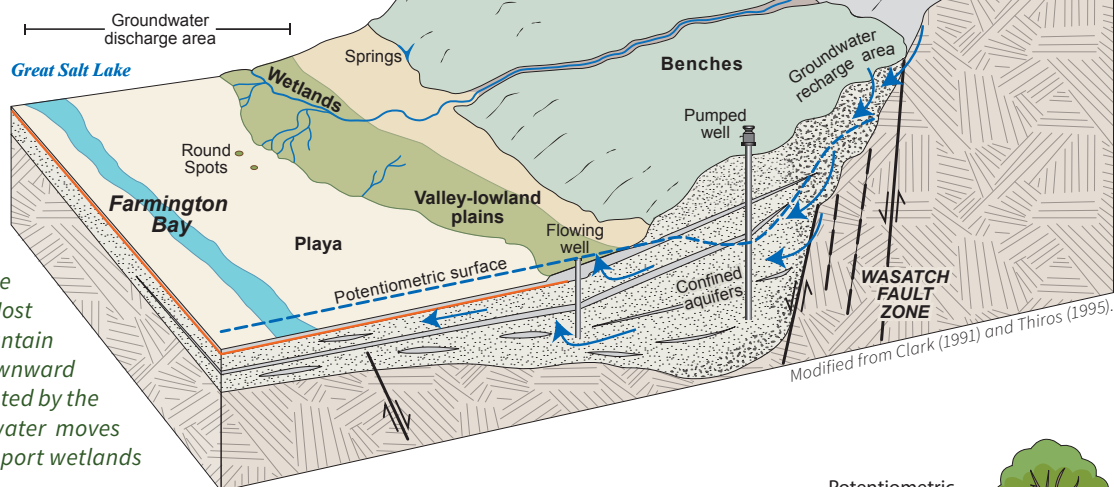
Great Salt Lake, UGS groundwater monitoring sites, and major streams.



The well configuration for our monitoring sites allows groundwater levels and chemistry to be measured over specific depth ranges in the basin-fill aquifer. The diagram does not represent the stratigraphy at any particular site; the depth and thickness of fine-grained materials varies from site to site.



Schematic diagram showing how groundwater flows from the Wasatch mountains to GSL. Groundwater resides in, and flows through, pore spaces between sediment grains in the Wasatch Front basin-fill aquifer (permeable sand and gravel). Precipitation, snowmelt, and streamflow soak into the ground and replenish the aquifer, a process called recharge. Most of this recharge occurs near the mountain front, and the groundwater flows downward and horizontally toward GSL as illustrated by the blue arrows. Near the lake, groundwater moves toward the land surface and helps support wetlands and streams along the eastern shore.

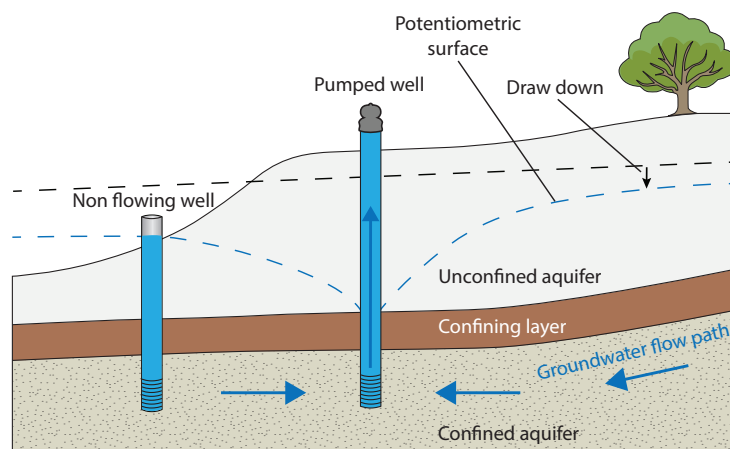
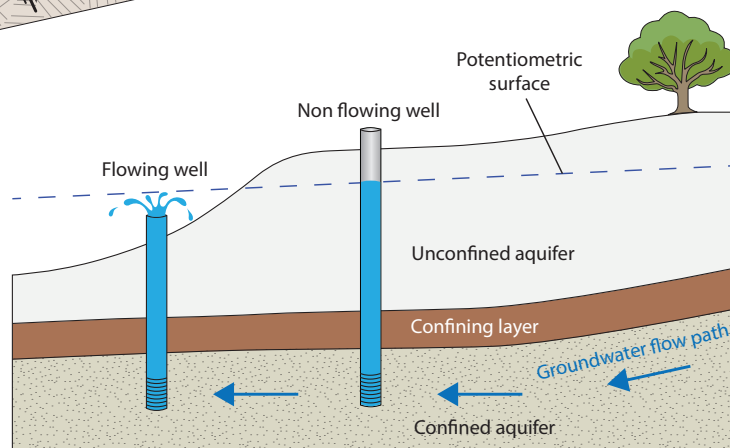


The Farmington Bay wells demonstrated that below 30 feet depth, groundwater is less saline and produces flowing (artesian) wells under “confined” conditions (the aquifer is between layers of clay or impermeable rock). Detailed water chemistry analyses showed that the fresh groundwater below Farmington Bay entered the aquifer 15 to 20 miles to the east along the Wasatch Range front and took more than 100 years to reach its present location. This fresh groundwater reaches the surface in places as circular upwelling features (“round spots”). Antelope Island is a fault-bounded structural block that forms a barrier to westward groundwater flow toward the south arm of GSL, unlike the southern, western, and northern margins where groundwater may flow with less restriction toward the lake center.

Along the GSL eastern margin, groundwater moves upward from the deeper confined aquifer toward the land surface and also moves laterally within the shallow unconfined basin-fill aquifer where it helps support wetlands and streams. This groundwater flow is essential to ecological health and is vulnerable to depletion from groundwater pumping, surface pollution, and consumption by the invasive plant *Phragmites* (see *Survey Notes* v. 58, no. 1 and PI-108, <https://doi.org/10.34191/PI-108>).

Since 1956, the height of water in flowing wells near and within the wetlands along the GSL eastern shore has dropped by more than 45 feet due to groundwater pumping to the east, reducing their flow to a mere trickle. This effect is widespread—groundwater levels have decreased by more than 50 feet during the past 70 years along much of the Wasatch Front.

Groundwater pumping from the basin-fill aquifer creates cone-shaped areas of lowered groundwater levels, known as cones of depression, around heavily pumped wells. These cones of



Changes in a water table caused by groundwater pumping. The top diagram illustrates an aquifer and well configuration before pumping, and the bottom diagram illustrates changes to the water table due to pumping. A previously flowing well no longer flows, and the root zone of phreatic vegetation may be dewatered.

depression may extend over large distances, reducing groundwater flow to springs, wetlands, streams, and other wells. Although groundwater entered the aquifer more than 100 years ago, groundwater levels still respond to present-day pumping. Lowering the pressure in an aquifer drops water levels far faster than the water can be replenished from sources in the mountains, so even century-old groundwater levels fall in response to modern pumping.

Groundwater conditions around the rest of GSL likely vary significantly compared to the Farmington Bay area. Differences in precipitation and groundwater recharge rates, and aquifer composition result in variable groundwater flow and chemistry. The amount of potential recharge to the groundwater table from precipitation varies significantly around GSL because the mountains to the east and south of the lake receive a much higher amount of precipitation than those on the west side. Groundwater chemistry reflects chemical reactions with minerals in sediments that compose the basin-fill aquifer, which vary around the lake. Input of geothermal fluids rising along faults also causes local variations in groundwater chemistry. Preliminary data from our new wells on the north, south, and southwest lake margins show a range of groundwater chemistry and groundwater levels, and differences in salinity with depth compared to Farmington Bay. To fully understand groundwater processes around GSL, we are analyzing data from the wells and sediment cores collected during installation of our monitoring wells, and we are preparing the data for release on the online UGS *Groundwater Monitoring Portal* (<https://gwportal.geology.utah.gov/>).

Many important questions remain about groundwater's role in sustaining GSL ecology and water levels. These include how the permeability of subsurface sediments shapes groundwater flow rates and paths; how declining groundwater levels affect flow rates toward GSL and overall lake levels; how much groundwater reaches GSL indirectly through streams that flow into the lake; and how much groundwater flow sustains wetland water supply and habitat. The newly established groundwater monitoring network, combined with continued research, will help improve our understanding of these processes and provide the data needed to answer these questions in the future. A better understanding of groundwater flow into the GSL will help managers and decision-makers as they seek opportunities to restore lake levels and wetlands habitat.

For more information and references, please see the Great Salt Lake page of the online UGS *Groundwater Data Hub* (<https://gwdatahub.geology.utah.gov/?page=Great-Salt-Lake>). 

Energy & Mineral News

UGS, BHP Xplor, and Utah's Mineral Future

by Stephanie E. Mills and James McVey

In early 2026, the Utah Geological Survey (UGS) was selected to join the prestigious BHP Xplor minerals industry accelerator program. The UGS Xplor team is led by Senior Geologist and Metallic Minerals section manager Dr. Stephanie Mills and Project Geologist James McVey. Run by BHP, the world's largest global mining company, the Xplor program is designed to support and fast-track innovative, early-stage geological concepts in mineral exploration.

The UGS's selection represents a major achievement and global recognition for public geoscience—out of hundreds of applications globally, the UGS was chosen as part of a highly selective cohort from the top 2% of applications. The partnership between the UGS and BHP pairs decades of rigorous mapping and baseline research of a state geological survey with the global framework and the technical skills of a major minerals explorer.

What is BHP Xplor?

BHP Xplor operates as a unique global accelerator program targeting early-stage projects with unconventional or high-potential geological concepts. The program provides selected participants with \$500,000 in funding, alongside structured technical, commercial, and operational coaching. The overarching goal is to lower the risk of new, innovative exploration concepts, expanding the generative pipeline for mineral discoveries essential to all aspects of modern economy and infrastructure.

The initiative features ongoing technical and business coaching as well as three in-person technical workshops and a final showcase where participants demonstrate how their project has grown during the course of the program. Xplor participants gain direct access to BHP's network of world-class technical specialists and service providers, enabling small exploration entities to advance their scientific frameworks at an accelerated pace.

First Geological Survey Participant in Program History

While BHP Xplor has historically targeted early-stage exploration startups, the selection of the UGS marks the first time in the history of the program that a government geological survey—or any public agency—has been accepted. UGS's success through the rigorous interview process was based on a foundation of technical excellence, quality public geoscience data, and a team motivated to do impactful work on Utah's mineral resources.

The partnership between the UGS and BHP through the Xplor program highlights an evolving paradigm in public-private partnerships. State geological surveys serve as non-biased, objective scientific organizations providing pre-competitive (i.e., public) geoscience data. Within Xplor, the UGS is building a new blueprint for how public entities can leverage their expertise in foundational geoscience data within the framework of commercial exploration. The data and interpretations we produce from the Xplor program will help identify prime areas for mineral prospectivity in the state and de-risk early stage exploration for all explorers in Utah.

“

*The UGS
is a crucial
part of the
upstream
minerals
economy
in Utah.*

”



Mills and McVey (right of center) pictured with other members of the 2026 BHP Xplor cohort while visiting the Olympic Dam mine in South Australia.

UGS Xplor Project

The \$500,000 grant provided by the Xplor program will advance regional mineral systems analysis across western Utah. Our research integrates traditional UGS mapping with new, high-resolution regional datasets, such as aeromagnetic and aeroradiometric data, released by the U.S. Geological Survey's Earth MRI program. Central to this initiative is the concept of pre-competitive data as a form of fundamental public infrastructure. The project employs an iterative, data-driven approach that includes regional spatial-temporal mapping for copper-prospective units, crustal architecture mapping, and integration of data to map out porphyry copper prospectivity.

True to the mission of a public survey, all the data and interpretations the UGS builds throughout the Xplor program will be publicly available. Maintaining public accessibility ensures an equal opportunity ecosystem where small-cap startups, academic researchers, and major corporations operate from the same high-quality data foundation.



Intrusive unit from the Newfoundland Mountains, sampled as part of the regional fertility study the UGS is conducting through BHP Xplor.

Future Outlook for Utah's Mineral Resources

The UGS is a crucial part of the upstream minerals economy in Utah. The pre-competitive data that UGS and other surveys produce and deliver to the public helps create a well-characterized pipeline of generative exploration projects, which in turn supports the development of downstream operations such as mine development, operation, and mineral processing. The primary goal of minerals research at the UGS is to define Utah's resources and deliver quality data.

By systematically mapping out Utah's mineral provinces, including those prospective for critical minerals, we build authoritative geological foundations for mineral exploration and development. Ultimately, this cooperative framework helps anchor long-term wealth generation inside the state by reducing exploration risk, attracting minerals development, and promoting responsible stewardship of Utah's mineral resources for generations to come. 

Stretched-Pebble Conglomerate in the Raft River Mountains, Box Elder County

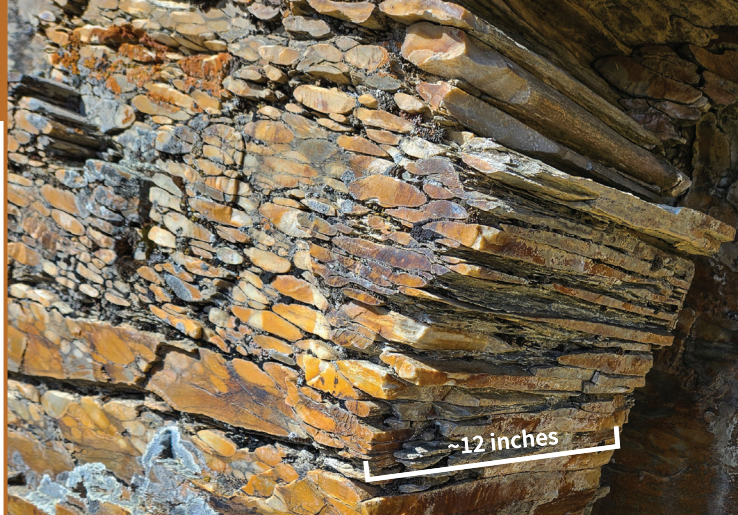
by Jackson Smith and Rachel Willmore

Tucked in the northwestern corner of Utah in the Raft River Mountains, a stretched-pebble conglomerate found within the late Precambrian-age Elba Quartzite preserves an epic period of *tectonic strain*. Tectonic strain is the physical change a rock undergoes in response to tectonic forces. Stretched-pebble conglomerates are created when high heat and pressure transform originally spherical cobbles and pebbles into elongated, cigar-like, or disk-like shapes.

The key to understanding the creation of the Elba Quartzite stretched-pebble conglomerate is in the formation of the distinctive Raft River Mountains. This mountain range is one of only two ranges in Utah that trends east to west, and is part of the larger Raft River-Albion-Grouse Creek metamorphic core complex (see *Survey Notes* v. 44, no. 1). A metamorphic core complex forms when Earth's crust rapidly extends and stretches enough that shallow layers of rock fracture and slide apart along large, low-angle normal faults, partially uncovering deeper rocks. Once unburied by the weight of the upper layers, the underlying crust rebounds upwards into a mountainous dome. This tectonic process allows us to see rocks that have endured a history of enormous deformation from pressure and strain.

In the Raft River Mountains, the middle-Precambrian-age Green Creek Complex* forms the foundation ("basement") of the continental crust and is broadly divided into three main groups: the informal "older schist," a suite of metamorphosed igneous rocks, and a banded granite. This basement complex comprises the oldest rocks in Utah—the "older schist" is roughly 2.6 billion years old (see *Survey Notes*, v. 54, no. 3).

The Elba Quartzite is much younger, around 700 million years old, and rests directly on top of the older schist. The contact between these two rock formations represents a massive 2-billion-year-long time gap in the geologic record! The missing rock record, known as the Great Unconformity, represents an episode of prolonged global erosion with pauses in deposition that were likely caused by the assembly and subsequent breakup of a supercontinent called Rodinia (see *Survey Notes*, v. 53, no. 3).



Stretched-pebble conglomerate of the Elba quartzite.

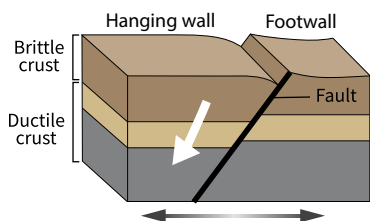
Around 700 million years ago as Rodinia was splitting apart, the crust in what would become northwestern Utah began to subside. Fed by intense erosion from rivers, this new basin filled with rounded quartz gravel and sand. With burial, this jumbled mixture of rocks was cemented together into the parent rock of the Elba Quartzite's stretched-pebble conglomerate. As the basin sank further and sea level rose, the environment transitioned into a shallow marine shelf, further burying the gravel beneath layers of quartz sand.

For roughly 450 million years from the time that Rodinia split apart until the early Triassic Period, Utah was covered by oceans that deposited thick sequences of marine sediments over the former supercontinent's coastal sand and pebble conglomerate. Then, western North America had a major shift in tectonics. Instead of warm shallow seas, volcanoes arose and mountain ranges formed. During the Sevier and Laramide mountain building events (between ~160 and 50 million years ago), the western edge of North America was compressed—rock layers were thrust to the east, stacked onto each other, and folded, creating mountain ranges at least 30 miles (50 kilometers) thick. The Elba Quartzite's coastal sandstone and conglomerate were buried further—to as deep as 22 miles (35 kilometers), where intense heat and pressure metamorphosed the sedimentary rocks into quartzite.

This episode of compression and mountain building eventually gave way to extension around 17 million years ago, and this area of overthickened crust began to relax and pull apart, essentially collapsing under its own weight. As this happened, the deeply buried

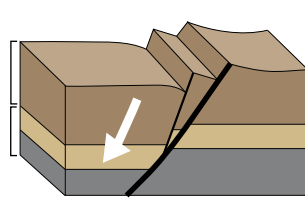
Formation of a Metamorphic Core Complex

Shallow crust Metamorphic rock Crystalline basement rock



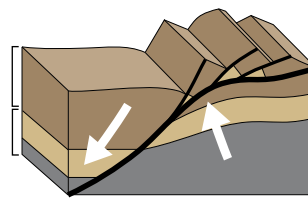
1

As extension of the Earth's crust begins, a fault forms through the brittle crust, extending down into the more ductile layers.



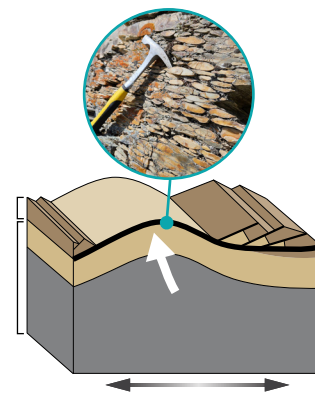
2

Extension continues and smaller faults form in the hanging wall of the "master" fault, thinning the layers in the brittle crust while the master fault becomes less steep.



3

With much of the heavy rock removed from the hanging wall, the hot, ductile basement rock buoyantly rebounds upward, forcing the master fault to flatten.



4

The basement rock rapidly bulges up into a broad dome, bringing the deep crust to the surface.

rocks were subjected to brutal heat and strain from nearby plumes of rising magma that helped soften the rocks so that they deformed plastically. As the area extended along low-angle faults, an unroofing (removal) of the upper crust allowed the hot, softened basement rocks to rapidly rebound upwards, causing the Elba Quartzite's quartz pebbles to stretch like taffy and shear at a microscopic level. The crustal rebound formed the mountainous dome (metamorphic core complex) that we now call the Raft River Mountains. In geological terms, this event was remarkably fast, taking roughly only six million years. At its most active, the Raft River detachment fault slipped at about 7 millimeters per year, compared to around 1–2 millimeters per year across the Wasatch fault's five central segments.

Now that the supercontinent Rodinia's coastline pebbles and sands have been exposed as metamorphosed rock, the fierce physical trauma on the Elba Quartzite is very apparent. The reason the quartz pebbles stretched instead of breaking apart is because the surrounding matrix (the finer-grained material surrounding the pebbles) contains the mineral muscovite. While quartz is naturally a very hard and stubborn mineral, muscovite is made of thin, flaky sheets that easily slide past each other, much like a deck of cards. By providing a slippery matrix, the muscovite acted almost like a lubricant, allowing the quartzite and pebble conglomerate to flow and stretch. Therefore, the Elba Quartzite was able to absorb the brunt of the tectonic strain affecting the area, accommodating massive deformation while the multi-billion-year-old schist beneath it was virtually unaffected.

The older schist beneath these stretched pebbles is intriguing. The physical juxtaposition of these two formations separated by eons is a stunning reminder of the immensity of geologic time. The highly deformed rocks spanning billions of years of earth's history exposed in the Raft River Mountains are an incredible monument to the awesome forces that have shaped our very old world, and what is, for the time being, the world beneath our feet.

* Note: The word *complex* is used here to describe a chaotic group of different rocks that are intricately mixed together. In a metamorphic core complex, the word refers to the structural system.



The Great Unconformity, a 2-billion-year time gap, separates the stretched-pebble conglomerate of the Elba Quartzite and the older schist of the Green Creek Complex.



Directions

From Salt Lake City, take Interstate 15 north to Interstate 84 west, following signs to Boise, Idaho. After about 37 miles, take exit 5 for Park Valley/Elko. Turn left onto State Route (SR)-30 and head west for about 16 miles, then continue straight onto SR-42 for about 8.5 miles. Turn left onto E Naf Road S/Strevell Rd (unpaved) and drive for about 3 miles. Turn left onto S Clear Creek Road East (which becomes N 51600 West Rd) for 3 miles.

Turn right onto Clear Creek Rd and drive for about 3 miles until you see the Clear Creek Campground entrance on the left.

Coordinates

Clear Creek Campground entrance: 41.953402, -113.322933

Switchback trail start: 41.953875, -113.323632

Stretched-pebble outcrop: 41.95680, -113.328095

Boulder 1: 41.955723, -113.325085

Boulder 2: 41.956207, -113.325369

Parking and Hiking

There are pullout spots along the Clear Creek Road where you can park. Directly across from the entrance to the campground is an unmarked trail with switchbacks leading up the mountain. Hike about 0.5 miles toward the top of the ridge to find outcrops of the stretched-pebble conglomerate. This trail is a steep, 600 feet climb with loose rock. Use caution, wear sturdy shoes, and bring water. Several boulders of the conglomerate can also be found at spots lower on the trail (see coordinates above).

Rock Collecting Rules

Most of this area is within the Sawtooth National Forest. Please respect private property boundaries. Limited collection of rocks for personal use is allowed on most National Forest System lands without a permit, provided the collecting is for personal, hobby, and non-commercial use. Contact the Sawtooth National Forest Minidoka Ranger District for more information at 208-678-0430.

UTAH HAS A STATE CRUSTACEAN?

by Jim Davis

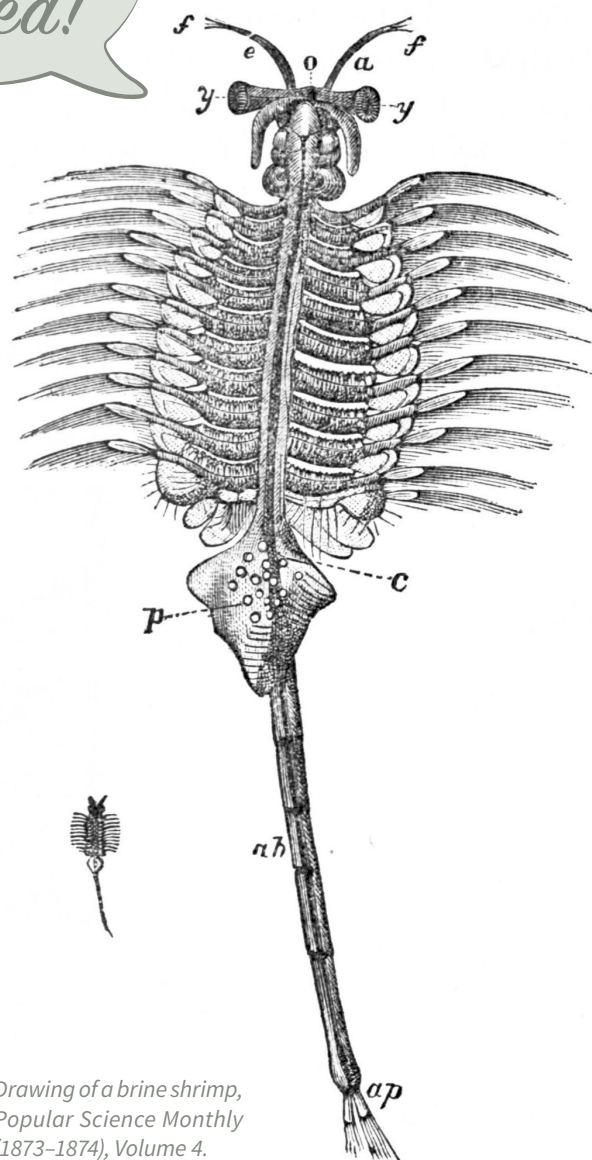
Glad You Asked!

In March of 2023, Utah became the seventh and only landlocked state to adopt an official state crustacean—the humble brine shrimp (*Artemia franciscana*). Additionally, Hawaii has a state shrimp (‘ōpae‘ula) and Missouri a state invertebrate (crayfish), both of which are crustaceans. So, what are crustaceans? They are a large group of mainly aquatic animals with hard shells (exoskeletons), segmented bodies, jointed limbs, and two pairs of antennae. Notable crustaceans included lobsters, shrimp, crabs, barnacles, pill bugs, and of course, brine shrimp. Utah's state symbol, while primitive for a crustacean, is well qualified for this designation: it is ancient, extraordinarily resilient, a keystone species of the ecosystem, and prospers in its saline aquatic realm.

Brine shrimp are renowned extremophiles and halophiles, meaning they can survive in extreme environments and thrive in water having high salt concentrations. Their resilience allows them to successfully endure an astonishing range of physical and chemical conditions. The crustacean order Anostraca, which includes both brine shrimp and fairy shrimp (freshwater cousins to brine shrimp), has persisted for more than 400 million years. Anostraca has weathered four of Earth's "Big Five" global extinction events. Its ability to weather difficult times is connected to its highly durable cysts (eggs) that remain in a dormant state of suspended animation called anhydrobiosis (life without water), until favorable conditions return. A single brine shrimp can produce thousands of offspring in her lifetime.

As a demonstration of their resilience to extreme conditions, brine shrimp cysts were famously fixed to the outside of spacecraft and satellites in the 1980s through the 2010s and exposed to long stretches in the vacuum of space, severe temperature swings of several hundred degrees, the absence of both oxygen and water, and zero to microgravity. Once back on Earth, many of these cysts hatched, even after 31 months in outer space. Experiments that shielded cysts from direct ultraviolet and ionizing radiation in space showed almost no drop in cyst viability. Brine shrimp also flew to the Moon twice on Apollo missions in 1972, though they rode inside the spacecraft for this feat. In the laboratory, cysts have remained viable even after exposure to near absolute zero (-459°F) and can survive short periods of water-boiling temperatures (212°F).

Anostraca can be found on all continents in isolated and ephemeral pools and wetlands, desert playas, salt evaporation ponds, coastal lagoons, or any environment that is free of fish. The earliest known fossilized Anostraca (a diminutive and delicate organism that is famously difficult to fossilize) is 365 million years old. The exceptionally well-preserved specimen from Belgium closely resembles modern species and shows that they already had adapted to the extreme environments of ephemeral waters by the Late Devonian Period.



Drawing of a brine shrimp, *Popular Science Monthly* (1873–1874), Volume 4.



Two brine shrimp in hand. Photo courtesy of Utah Division of Wildlife Resources.

As the largest saline lake in the Western Hemisphere, Utah's Great Salt Lake provides the perfect environment for brine shrimp to thrive, creating a population so large that it is a part of the global economy. Great Salt Lake contributes around 40% to 45% of world market demand for brine shrimp cysts and is the largest sole producer. These cysts are converted to millions of tons of protein-rich seafood. The 2019 to 2020 brine shrimp season (October through January) set a record for biggest catch at 44 million pounds of raw cysts. Most of these are used in the commercial aquaculture industry as highly nutritious food for fry (baby fish), shrimp, prawns, lobster, and crab. They are also used for science as a model organism for toxicity studies and education.

Great Salt Lake brine shrimp (*Artemia franciscana*) is one of seven to eight formally recognized sexual species of brine shrimp in the world and is one of two or three species native to the Americas. Numbering around 17 trillion (it would take more than half a million years to count them all at one per second) the brine shrimp is vital to Great Salt Lake's food web. They fuel millions of migratory birds, none more than North America's eared grebes, that eat 30,000 brine shrimp a day, at a rate of more than one per



A brine shrimp cyst "slick" on open water in Great Salt Lake's south arm, measuring hundreds of feet across. Eggs concentrated from winds and currents are located by brine shrimpers, then boats corral the eggs by deploying spill containment booms and then pump them into drainable mesh sacks. The eggs are dried, processed, and packaged for distribution across the globe. Bottom photo courtesy of Utah Division of Wildlife Resources.

Great Salt Lake Brine Shrimp Scientific Classification

Domain: Eukaryota

Kingdom: Animalia

Phylum: Arthropoda

Subphylum: Crustacea

Class: Branchiopoda

Order: Anostraca – sometimes known as fairy shrimp, this order includes both freshwater fairy shrimp and brine shrimp

Family: Artemiidae

Genus: *Artemia*

Species: *A. franciscana* – Great Salt Lake brine shrimp, Utah's official state crustacean

second for seven hours, while they shed old worn-out feathers and grow new ones. Snowy plovers, American avocets, Wilson's and red-necked phalarope and the California gull (Utah's State Bird) as well as several specials of waterfowl are also heavy consumers. Brine shrimp rely on birds for long-range dispersal in disparate saline water bodies by either clinging to migrating birds or passing through their bodies when consumed and subsequently deposited intact and viable.

Although the brine shrimp genus, *Artemia*, is likely tens of millions of years old, researchers estimate that it reached its modern form some five to six million years ago during the Messinian Salinity Crisis, when the Mediterranean Sea was physically isolated from the Atlantic Ocean. As a result, the sea repeatedly dried up either partially or almost entirely, precipitating thick layers of salt on the exposed former sea floor. These conditions lasted around six hundred thousand years before the sea was swiftly reclaimed by the Atlantic Ocean during the great Zanclean Flood. By this time, *Artemia* had adapted to becoming entirely dependent on brine or brackish waters for survival and spread into saline waters on six of the seven continents (only freshwater fairy shrimp are found in Antarctica).

Brine shrimp have inhabited Great Salt Lake and its predecessors for millions of years. Brine shrimp fecal pellets have been identified in sediments from five oil wells drilled in Great Salt Lake between 1978 and 1981, three in the north arm and two in the south. Cores from the wells record five million years of sedimentation and revealed periods of marsh wetlands, and fresh, brackish, and hypersaline open water conditions. Fecal pellets were found in well cuttings in a single sample within the 5- to 3.5-million-year interval of the north arm. In a south arm well, fecal pellets were found within the 3.1- to 2.4-million-year interval, becoming more common across well sediments with the onset of the Ice Age around 2.6 million years ago. By 400,000 thousand years ago, brine shrimp pellets became the most dominant fossil in the sediments, indicating that a hypersaline lake prevailed in the basin, at least periodically, from this time forward. 🏠

SURVEY NEWS

Martha Hayden retired in late June after 43 years of dedicated service as a Paleontology Assistant with the State of Utah. Martha's remarkable career began in 1979 when she started working for Utah's first State Paleontologist, James Madsen, shortly after graduating from the University of Utah with a degree in anthropology. She officially joined the Utah Geological Survey (UGS) in 1995 when the Paleontology Program transitioned from the Utah Division of State History to the UGS. Throughout her tenure, her extensive duties included managing the vital statewide paleontological database and donating numerous volunteer hours to various paleontological endeavors, including coordinating with the Utah Friends of Paleontology volunteer organization. In 2012, *Martharaptor greenriverensis* was named in her honor after she co-discovered the fossilized skeletal remains near Green River in east-central Utah. Martha's knowledge, expertise, and dedication will be greatly missed, and we wish her the absolute best in her well-deserved retirement.



The Utah Geological Survey's (UGS) prestigious 2026 Crawford Award was presented to **Tyler Knudsen** in recognition of his study of geologic hazards in Bryce Canyon National Park and the surrounding area culminating in the outstanding publication: *Geologic Hazards of Bryce Canyon National Park and Vicinity, Garfield and Kane Counties, Utah* (UGS Special Study 178). This foundational scientific work conducted under a cooperative agreement between the Bryce Canyon Association and the UGS identifies numerous geologic hazards within Bryce Canyon National Park through detailed, full-sized maps. Beyond its scientific value for hazard awareness, decision-making, and risk reduction, the publication is a remarkable cartographic achievement. The aesthetic quality of the maps mirrors the natural beauty of the park, making this an outstanding contribution to our understanding of the geologic hazards in Bryce Canyon National Park and the surrounding area. 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.



Stephen Odd joins the Groundwater & Wetlands program as an environmental scientist. Stephen holds a B.S. in biology and an M.S. in environmental science from the University of Utah. His work will focus on updating wetland monitoring protocols and researching wetland protection ordinances. **Eytan Bos Orent** joins the Energy & Minerals program as a project geologist. Eytan earned his Ph.D. from the University of Arizona where he researched uranium and copper deposits in the Colorado Plateau. He will be working on the Intrusive Basemap Earth MRI and BHP Xplor projects. A warm welcome to Stephen and Eytan!

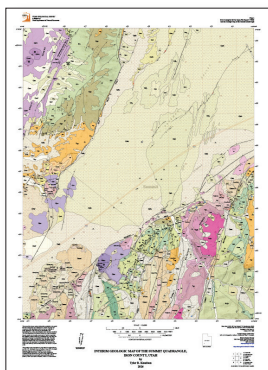
Announcing the Utah Geological Survey Annual Report! This new publication will replace the January issue of *Survey Notes* and will highlight our programs, research projects, and how the UGS is fulfilling our strategic plan and mission. Expect the first edition to roll out in December, followed by the spring and fall issues of *Survey Notes* in April and August, respectively.



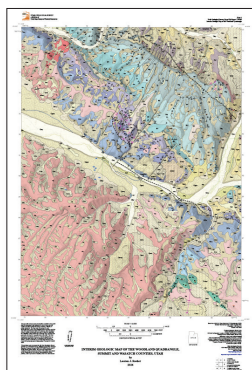
UGS staff and Board members at the summer picnic, June 2026.

NEW PUBLICATIONS

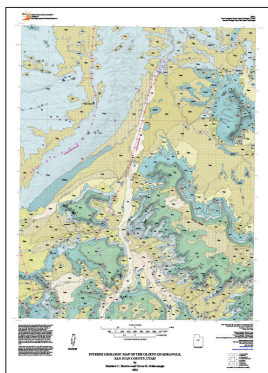
Available at the Natural Resources Map & Bookstore—utahmapstore.com—and for download at geology.utah.gov.



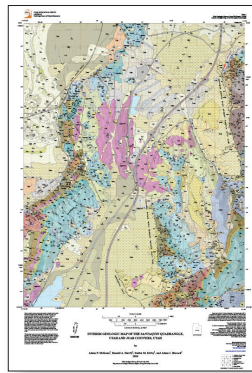
Interim Geologic Map of the Summit Quadrangle, Iron County, Utah, by Tyler R. Knudsen, 19 p., 2 plates, scale 1:24,000, **OFR-775DM**, <https://doi.org/10.34191/OFR-775DM>



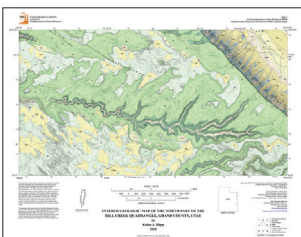
Interim Geologic Map of the Woodland Quadrangle, Summit and Wasatch Counties, Utah, by Lauren J. Reeher, 14 p., 2 plates, scale 1:24,000, **OFR-778DM**, <https://doi.org/10.34191/OFR-778DM>



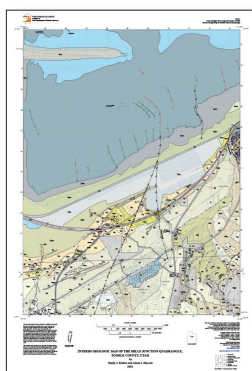
Interim Geologic Map of the Oljeto Quadrangle, San Juan County, Utah, by Matthew C. Morriss and Trevor H. Schlossnagle, 20 p., 1 appendix, 2 plates, scale 1:24,000, **OFR-781DM**, <https://doi.org/10.34191/OFR-781DM>



Interim Geologic Map of the Santaquin Quadrangle, Utah and Juab Counties, Utah, by Adam P. McKean, Ronald A. Harris, Stefan M. Kirby, and Adam I. Hiscock, 24 p., 2 plates, scale 1:24,000, **OFR-782DM**, <https://doi.org/10.34191/OFR-782DM>



Interim Geologic Map of the North Part of the Rill Creek Quadrangle, Grand County, Utah, by Keilee A. Higgs, 7 p., 2 plates, scale 1:24,000, **OFR-783DM**, <https://doi.org/10.34191/OFR-783DM>



Interim Geologic Map of the Mills Junction Quadrangle, Tooele County, Utah, by Emily J. Kleber and Adam I. Hiscock, 11 p., 2 plates, scale 1:24,000, **OFR-784DM**, <https://doi.org/10.34191/OFR-784DM>

Statewide Inventory of Utah's Significant Mine Waste Features, by Claire Decker, Austin Jensen, Ben Sears, Josh Dustin, Subigya Shah, Rosemary Fasselin, and Stephanie Mills, 8 p., **DS-8**, <https://doi.org/10.34191/DS-8>

Pilot Study to Evaluate Measurement of Evapotranspiration in a *Phragmites Australis* Stand in Farmington Bay, Utah, by Paul Inkenbrandt, Trevor Schlossnagle, Emily Jainarain, and Rachel Willmore, 39 p., **OFR-785**, <https://doi.org/10.34191/OFR-785>

RECENT OUTSIDE PUBLICATIONS by UGS Authors

Mass Addition to Timpanogos Rock Glacier—Debris Covered Snow and the Importance of Interannual Variability in Headwall Erosion and Climate, by I. Davies, J. Munroe, L.S. Anderson, M.S. Thorne, and M. Morriss: *Geophysical Research Letters*, v. 53, <https://doi.org/10.1029/2025GL121482>



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