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

SURVEY NOTES

Volume 49, Number 2 May 2017

TOOELE 30′ x 60′ QUADRANGLE GEOLOGIC MAP

Contents

Design | *Jennifer Miller*
Cover | View northeast of the northern Oquirrh Mountains, the south arm of Great Salt Lake, and Antelope Island. Photo by Donald Clark.

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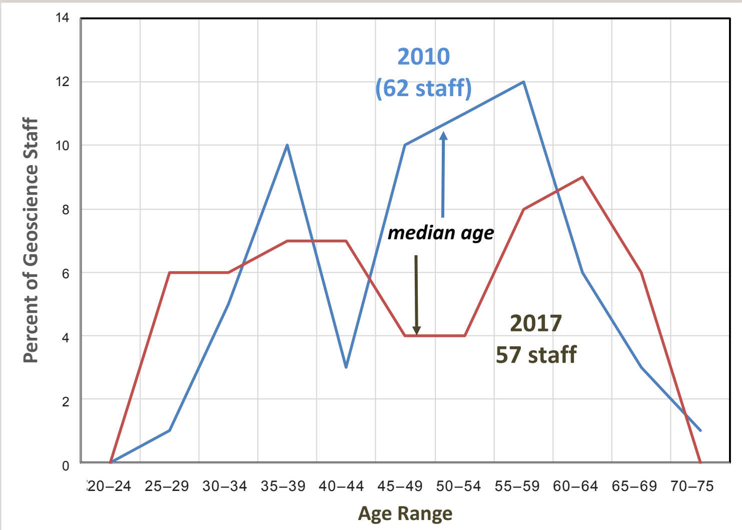
THE DIRECTOR'S PERSPECTIVE

by Richard G. Allis

In the May 2016 issue of *Survey Notes*, I wrote about the tough time the Utah Geological Survey (UGS) had been through regarding decreased revenue from Mineral Lease royalties due to the crash in oil prices, and a loss of 16 staff through a combination of layoffs and retirements that amounted to a reduction of close to 20 percent. The 2016 Utah legislature awarded the UGS an additional $1 million of ongoing general funds, and our staffing level was stabilized at close to 67 full-time equivalents. Fortunately, there have been only minor changes in the ensuing ten months, and we have adjusted to the reduced size of the UGS. The number of retirements during 2015 and 2016 was unprecedented and a helpful coincidence at the time of down-sizing. The large number was due to the demographic peak in our staff's age, which in 2010 was in the 55 to 60 range (see graph below). This graph, which includes all geoscientific staff, shows that there is still a peak in the 60 to 64 age range in 2017, but it is not nearly as pronounced. Baby boomers are gradually retiring and being replaced by younger staff. The median age has moved from 50.5 in 2010 to 48 in 2017.

In 2010 the UGS had 62 geoscientific staff. Now only 29 of those remain and the rest are new hires. This surprisingly high turnover rate is due in part to the changes described above and represents a major loss of expertise. However, the breakdown of qualifications of the geoscientific staff in 2017 looks similar to 2010: 11 percent have a Ph.D., 59 percent have a M.S., 27 percent have a B.S., and 4 percent have an associate or no degree. There have been many studies in recent years on the "great crew change" as baby boomers retire, and some wonder whether the universities are producing enough graduates with the required qualifications to fill the vacancies. So far, the UGS has filled vacancies with outstanding applicants. The future of the UGS is in good hands!



COUNTDOWN TO THE GRC ANNUAL MEETING
October 1–4, 2017

This year, Salt Lake City will host the annual industry conference on geothermal energy run by the Geothermal Resources Council (GRC). In addition to three days of papers on topics of geothermal energy potential and development, there will be four days of workshops, a pre-conference field trip to Yellowstone National Park, and a post-conference field trip to Utah's geothermal power plants.

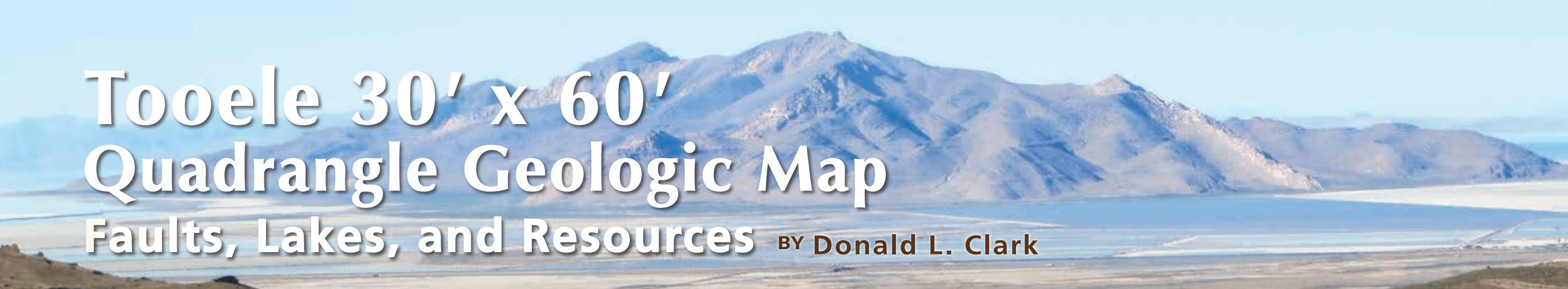
For more information go to: *https://geothermal.org/home.html*

Salt Lake City will also host the Annual Convention and Exhibition of the American Association of Petroleum Geologists (AAPG) next year, May 20–23, 2018.

Tooele 30′ x 60′ Quadrangle Geologic Map

Faults, Lakes, and Resources

BY Donald L. Clark

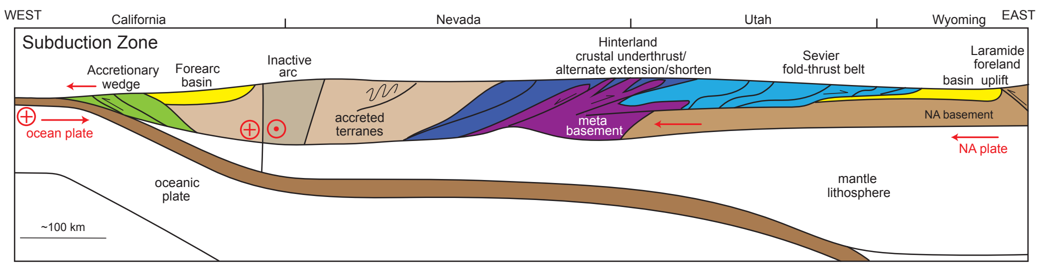


View north of southern Stansbury Island with Mississippian through Cambrian rocks. Lighter-colored beds are quartzite of the Devonian Stansbury Formation on the flanks of the Stansbury anticline.

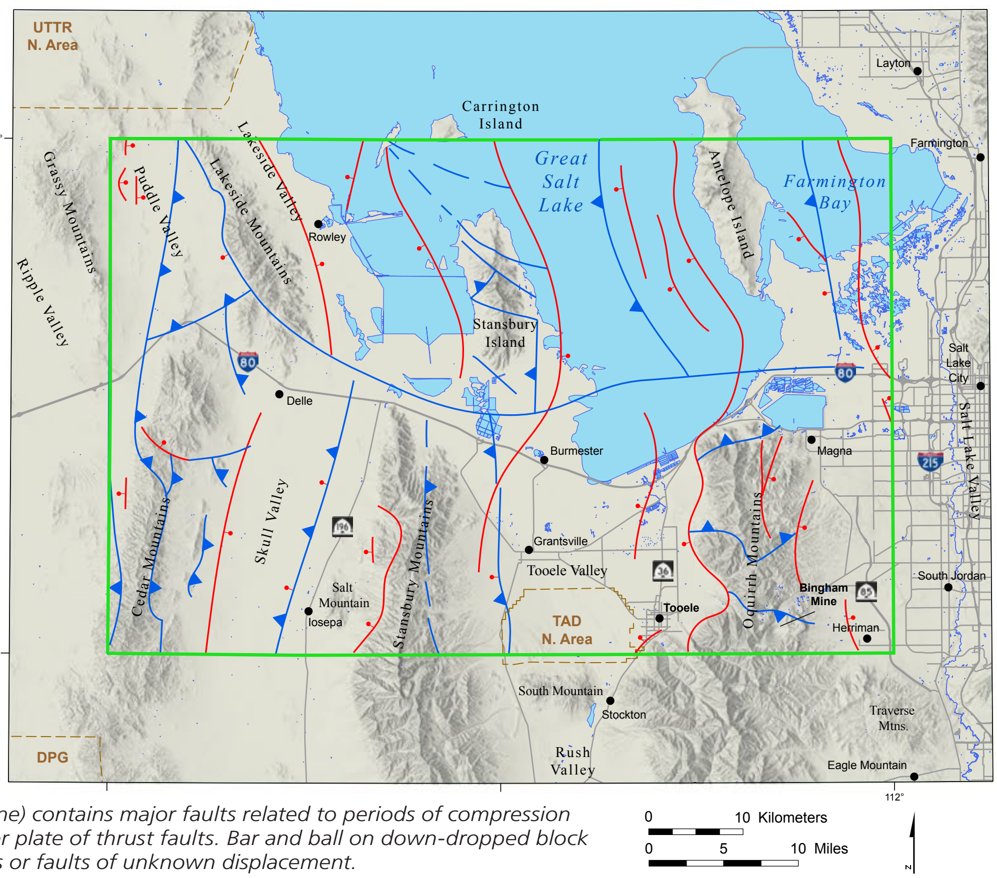
With one of the largest open-pit copper mines in the world, parts of four military testing and training ranges and installations, large industrial centers, Great Salt Lake mineral extraction operations, and mega-scale waste management facilities, Tooele and western Salt Lake Counties are Utah's mining, industrial, and military heartland. These operations, which support thousands of jobs and provide hundreds of millions of dollars of cash flow, are an essential part of Utah's economy. They also all have one common denominator: geology. Each operation is strongly tied to the land. A thorough understanding of the geological environment is essential to long-term profitability, protecting infrastructure from geologic hazards, and protecting the environment. The UGS is nearing completion of one of the most sought-after geologic maps in Utah because it will be at the foundation of many studies and decisions related to these issues. The Tooele 30′ x 60′ quadrangle geologic map covers part of this key area along the Interstate 80 corridor, straddling urban and rural areas that have large tracts of federal, state, and private land. The map is the culmination of decades of geologic data collection by numerous geoscientists; we touch on just a few aspects of this compilation here.

Faults

The exposed rocks and sediments in the map area span about 2 billion years of geologic time, from Utah's basement rock at Antelope Island to grains of sand, silt, and clay deposited today in streams and dunes, and mud and oolites in Great Salt Lake. The area has been affected by two primary periods of structural disturbance and deformation. An older period (Cretaceous to Eocene, 140 to 50 million years ago), attributed to collision of tectonic plates to the west, formed the Sevier fold-thrust belt in Utah. Compressional structures include folded rock, thrust faults, and tear faults. Similar to working on a complicated jigsaw puzzle, geologists have gradually unraveled the chaotic geometry of these compressional structures. We now have a better picture of some aspects of the thrust belt, but other details remain unclear due to the blanket of younger rocks and sediments in the valleys, scarcity of subsurface information (deep drill holes and geophysical data), and the lack of deposits similar in age to the deformation. The Tooele map updates current thinking on the fold-thrust belt architecture and can assist with resource management issues.

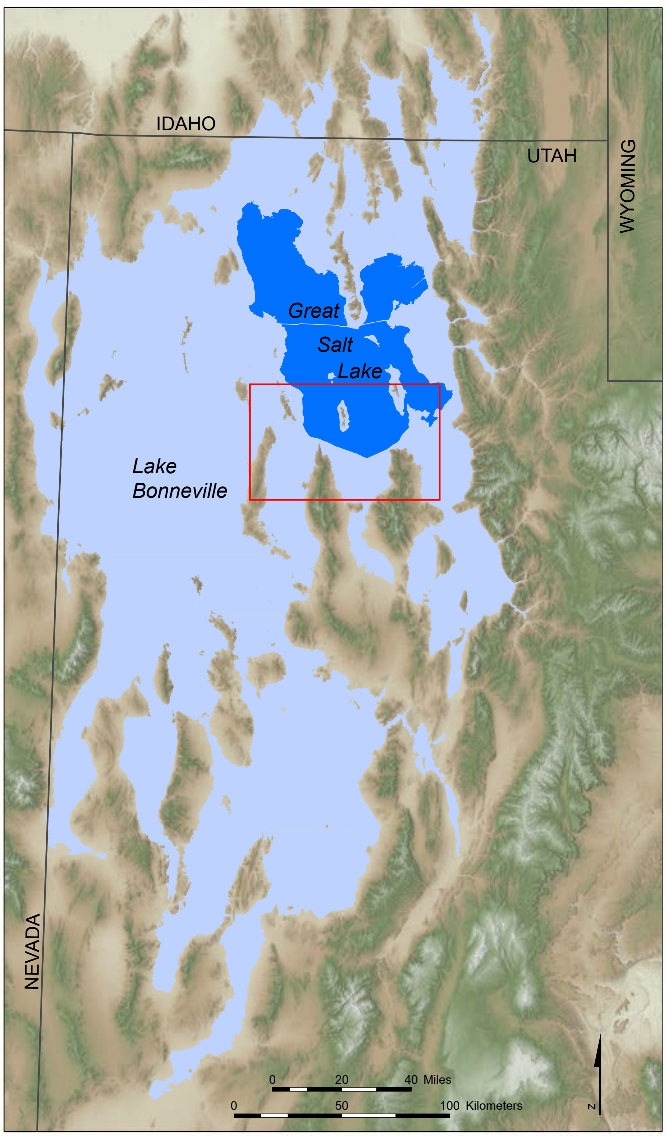


West-to-east cross section across the western U.S. Cordillera during early Tertiary time (~60 Ma) showing the tectonic framework. Arrows indicate direction of movement. Dot indicates toward, + indicates away directions of movement. Modified from Yonkee and Weil (2011), Evolution of the Wyoming Salient of the Sevier Fold-Thrust Belt, Northern Utah and Western Wyoming, *Utah Geological Association Publication 40.*



The Tooele 30′ x 60′ quadrangle (green outline) contains major faults related to periods of compression (blue) and extension (red). Sawteeth on upper plate of thrust faults. Bar and ball on down-dropped block of normal faults. No decoration on tear faults or faults of unknown displacement.

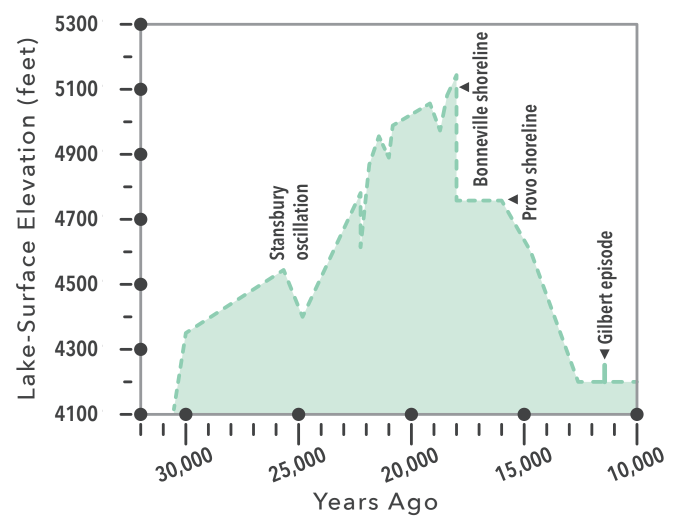
A younger period of deformation, referred to as basin and range extension, occurred from 20 million years ago to the present. In contrast to the earlier compression, moving tectonic plates caused east-west stretching across the Great Basin, ripping the crust into large blocks along numerous north-south-trending normal faults. This created the distinctive basin and range topography of mountain ranges with intervening valleys. In the Tooele quadrangle, some normal fault zones are young enough to cut young surficial deposits along valley margins in Salt Lake, Tooele, Skull, and Puddle Valleys. Mapping of the fault zones is critical to evaluating the associated seismic risk. A major normal fault zone follows the western margin of the Oquirrh Mountains before heading under Great Salt Lake. Tooele map coauthor David Dinter, geologist at the University of Utah, employed seismic geophysical techniques by boat to map the normal faults underlying Great Salt Lake. His mapping shows the fault zone extending northward on the west sides of Antelope Island, Fremont Island, the Promontory Mountains, and Rozel Hills; in addition, a fault splay exists north and west of Carrington Island. Some of these younger faults cut young lake bed sediments, but others are older and do not. Additionally, the UGS and U.S. Geological Survey have collected numerous geophysical data in the Tooele quadrangle and adjacent areas. These data will be used to evaluate basin geometry and depth, and the potential for additional fault zones.



At its maximum extent, Lake Bonneville covered much of western Utah and parts of Nevada and Idaho. Its salty remnant, Great Salt Lake, has varied greatly in size over time; this map shows its average extent. Red rectangle is the Tooele 30′ x 60′ quadrangle.

Lakes

Much of the blanket of Quaternary deposits on the lower parts of the mountains and in the valleys is related to late Pleistocene (Ice Age) Lake Bonneville. This huge lake, which covered one-third of Utah, was centered near the northwest corner of the map area and existed throughout the Last Glacial Maximum. The extensive lake deposits and paleoshorelines have been studied in detail by Tooele map coauthor Charles "Jack" Oviatt, emeritus geologist at Kansas State University. Oviatt has helped document the chronology of the lake as it developed from 30,000 years ago, transgressed to its maximum at 18,000 years ago when it flooded catastrophically into the Snake River of Idaho, and as the climate dried and warmed, shrunk to its salty demise 11,500 years ago. Oviatt's focus on the lake has culminated in a recent (2016) compilation entitled *Lake Bonneville—A Scientific Update* (Oviatt and Shroder, editors; see page 5). Great Salt Lake has also waxed and waned over time due to climatic fluctuations, but because of lack of data and other complications, we know much less about its overall chronology.



Lake Bonneville hydrograph shows the changes in the level of Lake Bonneville over time. Since it was a terminal lake in a closed basin, the level of Lake Bonneville fluctuated greatly in response to climate changes during the last ice age. Modified from Reheis and others (2014), Pluvial Lakes in the Great Basin of the Western U.S.—A View from the Outcrop, *Quaternary Science Reviews.*

View of northern Cedar Mountains and Bonneville-level shoreline.

Resources

The quadrangle hosts numerous geologic resources we use in our daily lives. Easily visible (even from space!) is the Kennecott/RioTinto Bingham Canyon mine in the Oquirrh Mountains. One of the largest copper mines in the world, it has a long history of mining (since 1863) and later porphyry copper production (since 1906), including gold, molybdenum, and silver resources, and is projected to continue production into 2028 (see related GeoSights article in this issue of *Survey Notes*). Industrial minerals are also extracted for use and include sand and gravel primarily from Lake Bonneville shoreline deposits, and limestone and quartzite from Paleozoic bedrock. The salty waters of Great Salt Lake are distilled down in expansive evaporation ponds to provide salt and magnesium. Yet, probably the most precious resource in a state with a dry climate and ever-growing population is water. The mountains of the quadrangle are important recharge areas and the valleys have large freshwater aquifers. Underground geothermal resources of the area are largely untapped. Intermediate-scale maps, such as the Tooele 30′ x 60′ map, provide an important geologic framework for evaluating these water resources. Although sometimes forgotten, Great Salt Lake also contributes to our water supply by inducing lake-effect storms that significantly increase the snow pack in the mountains in and near the quadrangle. Lastly, one cannot forget world-class recreational sites including Antelope Island State Park, Great Salt Lake, wilderness areas in the Stansbury and Cedar Mountains, and other public lands.

ABOUT THE AUTHOR

Don Clark joined the Utah Geological Survey in 2004 as a mapping geologist. He has authored/coauthored 15 geologic maps in central and northwest Utah, and considers himself fortunate to have collaborated with experienced geoscientists at the Utah Geological Survey, U.S. Geological Survey, universities, and industry. His current focus is on 30′ x 60′ quadrangle mapping in Utah's Basin and Range Province.

WANT TO HELP FUND SCIENTIFIC RESEARCH?

Private Funding Sought for Utahraptor Megablock Project

In November 2014, the UGS Paleontology Section (now part of the Geologic Mapping Program) recovered a gargantuan 9-ton block of sandstone filled with baby to adult *Utahraptor* dinosaurs that were trapped in quicksand about 125 million years ago (see *Survey Notes*, v. 47, no. 3). A five-year agreement was made with Thanksgiving Point in Lehi, Utah, to prepare the mega-specimen in their paleontology lab at their North American Museum of Ancient Life (NAMAL). Thanks to funding support and the engineering talents of Cross Marine Projects, the block was moved from Salt Lake City to the NAMAL lab to be prepared under live cameras so that the public can view and be part of the exciting discovery of specimens that have not seen daylight in millions of years!

That is where we stand today. To continue the next step, a private/public partnership has been established to collect funds needed to begin the labor-intensive task of exposing and preserving the hundreds (thousands?) of fossils likely present in the block. Utah Friends of Paleontology volunteers have put together a "Go Fund Me" site to purchase critical equipment and fund former UGS paleontologist Scott Madsen to oversee the very technical preparation. Once preserved, these fossils should yield years of scientific research and education about the growth and lifestyles of one of the most fascinating groups of dinosaurs.

If you are interested in contributing to help preserve and display this priceless scientific treasure trove, visit https://www.gofundme.com/utahraptor.

Utah State Paleontologist Jim Kirkland and Scott Madsen filming at NAMAL with Utahraptor *block for "Go Fund Me" site. Inset: baby* Utahraptor *premaxilla prepared by Scott Madsen compared to penny and adult* Utahraptor *premaxilla.*

Practical Uses of Geologic Maps

BY Donald L. Clark, Jon K. King, and Grant C. Willis

A geologic map shows the distribution of geologic features, including different kinds of rocks and surficial deposits, faults that displace the rocks and may be indicated by scarps in surficial deposits, and folds that indicate the rocks have been bent. These maps are the primary source of geologic data in the earth sciences, and together with derivative products, have immense economic and societal value. They are used in land-use planning, geohazards, geohistory, water/energy/mineral resource development, waste disposal, and national defense, which in turn are used to solve the many problems and challenges that affect our quality of life (see accompanying chart). Improved and more detailed geologic maps provide more accurate data, leading to more reliable conclusions. Geologic maps are fundamental elements for informing the policy decisions of federal, state, and local agencies. Positive benefit-to-cost ratios as much as 50:1 have been determined for geologic maps (see, for example, Illinois State Geological Survey Circular 549, 1991). Although geologic maps are typically depicted in two dimensions, a third dimension is represented with topographic contours, cross sections, block diagrams, and virtual reality displays (rotating transparent block diagrams). The fourth dimension of time can also be shown through sequential cross sections, chronostratigraphic diagrams, and displays that go by names like kinematic and retrodeformation. Maps can be tailored to fit the needs of specific projects such as bedrock maps, surficial deposit maps, or material engineering properties maps. We make maps at different scales depending on expected use of the map—more detail for smaller areas (such as hazards or geologic engineering studies), and less detail in regional maps for resource and land management. Geologic maps often serve as the foundation or starting point for derivative or topical research such as resource studies (groundwater, energy, metallic and industrial minerals) and geohazard portfolios. Today most geologic maps are produced in digital forms such as geographic information system (GIS) databases, downloadable Internet files, and interactive website maps that provide users with many options, increasing availability and usefulness. For example, in GIS format one might sum the areas of landslides in a geologic unit and divide by the area of the geologic unit to get a relative idea of which units are most prone to landslides.

Some recent specific uses of geologic maps in Utah include (1) siting of the new state prison, (2) Warm Springs fault location and North Salt Lake landslide, and (3) Uinta Basin oil and gas exploration and water resource protection. For example, the task force charged with selecting the new state prison site hired local geotechnical consulting companies to conduct the detailed geologic investigations. These companies immediately contacted the UGS requesting the best geologic maps of the six sites in consideration. Fortunately, due to mapping completed over the past dozen years, we had recently released new geologic maps that covered five of the six sites; we were actively mapping the Tooele 30′ x 60′ quadrangle that covered the remaining site. The companies were so anxious to get the newest Tooele mapping in time to use for their evaluation that they requested we "fast-track" it to open-file release, which we did. Geologic investigations using these geologic maps played a key role in selecting the final site in northern Salt Lake Valley.

GEOLOGIC MAP USES

Land-Use Planning
- Roads and transportation routes and facilities (air, rail, bus)
- Critical facilities siting (hospitals, schools, police, fire stations)
- Civil engineering, building codes
- Underground storage facilities
- Water treatment and water delivery systems
- Energy facilities (power generation, power distribution, refining, storage)
- Protect sensitive ecosystems

Geologic Hazards
- Earthquake research
- Landslide and ground failure research
- Volcanic hazards research
- Flooding, karst, clay-rich materials
- Research on human-induced geohazards (CO_2, acid rain, erosion)
- Identify human health hazards (radon, toxic elements and particles)

Geologic History
- Plate tectonics
- Long-term earth changes (climate, sea level)
- Impact by human activity
- Paleontologic Resources Preservation Act

Water Resources
- Groundwater development and protection
- Water injection and withdrawal issues
- Water pollution and contamination
- Safe dam, reservoir, canal sites

Recreational Resources
- Selection and siting of parks and recreation areas
- Preservation and identification of unique geologic sites

Energy Resources
- Oil and natural gas, coal
- Radioactive materials
- Renewable resources (geothermal, wind, solar)

Mineral Resources
- Metallic minerals
- Chemicals and fertilizers
- Industrial minerals (abrasives to zeolites)
- Construction materials
- Rare earth elements, lithium, magnetic materials

Waste Disposal
- Landfill facility siting
- Toxic and nuclear waste disposal
- Sewage collection and treatment
- Underground facilities

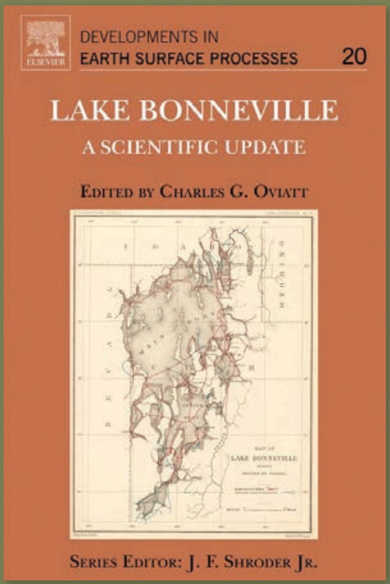
National Defense
- Strategic minerals
- Military testing and training facilities
- Safe weapons repositories
- Underground command facilities
- Space port facilities
- FEMA facilities siting

New Landmark Publication on Lake Bonneville

BY Grant C. Willis

Bonneville shoreline near Magna, Utah. Photo by Bob Biek.

Utah has many world-famous geologic icons—huge arches, deep canyons, giant folds, amazing fossils, and more. Among them, the superbly preserved shorelines, spits, and bars left behind by late Pleistocene Lake Bonneville are familiar to nearly every Utahn, admired by many, and studied by most geology students worldwide. In 140 years of research by geologists, geographers, biologists, climatologists, archeologists, and others, a tremendous amount has been learned about the rise of the ice-age lake, the cataclysmic Bonneville flood, climate-induced decline, residual geomorphic features, fauna and flora of the lake and its environment, and the life of early human inhabitants who arrived during or soon after lake demise. However, this research is dispersed through a vast assortment of books and journals and has been difficult to locate or use. That all changed with the 2016 publication of *Lake Bonneville—A Scientific Update*, a new 659-page volume of papers by leading scientists that assembles into one place the latest in-depth scientific knowledge in nearly every research field related to Lake Bonneville. The lead editor, Charles "Jack" Oviatt (former UGS employee recently retired from Kansas State University), is widely regarded as the leading expert on the geologic history of Lake Bonneville. He worked with John Shroder (University of Nebraska) to compile the latest research of 51 scientists. You can purchase your copy at www.elsevier.com (search on Lake Bonneville).



Ink sketch from 1890 monograph on Lake Bonneville by G.K. Gilbert.

TEACHER'S CORNER

EARTH SCIENCE WEEK

October 2–5, 2017

Hands-on Activities for School Groups

Come celebrate Earth Science Week with the Utah Geological Survey! This popular annual event features educational activities that are particularly suited for the 4th and 5th grades, where earth science concepts are taught as outlined in the Utah Science Core Curriculum standards. Earth Science Week activities take place at the Utah Core Research Center in Salt Lake City and include panning for "gold," identifying rocks and minerals, experimenting with erosion and deposition on a stream table, and examining dinosaur bones and other fossils.

Groups are scheduled for 1½-hour sessions. Reservations typically fill early; to inquire about an available time slot for your group, contact Jim Davis at 801-537-3300.

Launched by the American Geosciences Institute (AGI) in 1998, Earth Science Week is an international event highlighting the vital role earth sciences play in society's use of natural resources and interaction with the environment. For more information, please visit our web page at http://geology.utah.gov/teachers/earth-science-week/.

Call for Nominations for the 2017 UTAH EARTH SCIENCE TEACHER OF THE YEAR AWARD for Excellence in the Teaching of Natural Resources* in the Earth Sciences

The Utah Geological Association (UGA) is seeking nominations for the 2017 Utah Earth Science Teacher of the Year Award. The UGA awards $1,200 to the winning teacher plus $300 reimbursement for procuring resources related to earth science education (e.g., materials, field trip expenses, etc.). All K–12 teachers of natural resources* in the earth sciences are eligible.

UGA

Application deadline is June 2, 2017. Additional information, requirements, and entry forms are available on the UGA website (www.utahgeology.org) under the Education tab.

**Natural resources are defined as earth materials used by civilization past and present, such as natural gas, petroleum, coal, oil shale, mineral ores, building stone, and energy resources from the earth such as geothermal energy.*

“core center news”

BY Thomas C. Chidsey, Jr.

Utah Core Research Center
RECEIVES A TREASURE TROVE DONATION OF GREATER ANETH OIL FIELD CORES

Core storage area of the Utah Core Research Center—a view reminiscent of the final scene from the classic movie Raiders of the Lost Ark*!*

The Utah Core Research Center (UCRC) has added to its inventory an amazing and scientifically significant collection of cores taken from wells in Utah's largest oil field, Greater Aneth in the southeasternmost part of the state in the Four Corners area. Cores taken while drilling provide an incredible wealth of information about oil- and gas-producing rocks (reservoirs) that geologists and engineers can use to increase production, reduce risks, and find new reserves. Surprisingly, many fields have no or very few cores, due in part to the high cost of acquisition (as much as $2,500 per foot). In addition, at a time of low oil prices many oil companies are opting to permanently dispose of their cores rather than pay fees for continued storage. This was the case at Greater Aneth field, but instead of being disposed, this massive collection of cores was generously donated to the UCRC by the field operator Resolute Energy Corporation of Denver, Colorado. Resolute and Peter Nielsen, UCRC Curator, worked very hard to permanently preserve the Aneth core collection and make it publicly available for study and education by other oil companies, universities, and research organizations.

The Resolute collection consists of cores from 127 wells totaling 24,318 feet—or about 4.6 miles. Prior to this donation, the UCRC had only seven cores from the northwest part of the field and a dense concentration of cores (acquired over many years since the field was discovered in 1956) in the southwest of the horseshoe-shaped field boundary, leaving vast areas of Greater Aneth with no publicly available core coverage. Now the UCRC has cores from an incredible 43 percent of the Greater Aneth wells, especially unusual for such a large field (i.e., 444 active wells). It took six semi trucks to haul the cores from a storage facility in Texas to Utah!

Besides donating the Aneth core, Resolute also provided generous funding to cover most of the shipping and logistical costs. The remaining funds to move the cores were provided by generous donations from the Utah Geological Association, the Rocky Mountain Section of the American Association of Petroleum Geologists (RMS AAPG), and the RMS AAPG Foundation. These organizations also recognized the great importance of preserving this truly remarkable collection for future generations of geologists. Besides the cores, Resolute also donated thin sections (microscope slides made from rocks), drill-hole cuttings, core analyses, core descriptions, and other important data and company reports. Peter Nielsen estimates the approximate cost in today's dollars to obtain these cores (drill-rig time, special core-drilling equipment, core preparation, etc.), as well as the other donated materials, would be an astonishing $60 million!

Graduate students and their professor from Brigham Young University examining newly donated Greater Aneth cores as part of their thesis research. Inset is an example of Paradox Formation core from Greater Aneth field well, McElmo Creek No. J-15, showing the lower producing reservoir. The environment of deposition of this sample was a reef-like buildup of algae in a shallow, warm sea.

Greater Aneth field has produced over 481 million barrels of oil and 437 billion cubic feet of gas from the limestone and dolomite (carbonate rocks) of the Pennsylvanian (308 million years ago) Paradox Formation. (For more details on the geology and UGS studies of Greater Aneth field see articles titled "Cores from Greater Aneth Oil Field: A Trip Back in Time to Utah's 'Bahama Islands' and 'Florida Keys,'" *Survey Notes*, v. 48, no. 3, p. 7–8, and "Geological Sequestration of Carbon Dioxide and Enhanced Oil Recovery—the Utah Geological Survey's Efforts to Reduce Global Warming While Increasing Oil Production," *Survey Notes*, v. 39, no. 2, p. 4–7.) Not only is Greater Aneth the largest oil field in Utah, it is the largest field that produces from carbonate rocks in the Rocky Mountain region. Over half of the world's oil production comes from carbonate rocks. This fact makes the Greater Aneth core collection that much more important in terms of research and training, not only as it pertains to Utah's oil resources but those throughout the globe. These cores beautifully display a wide variety of characteristics that are critical for understanding carbonate oil reservoirs—depositional environments, changes to the rocks that have occurred since deposition (diagenesis), petrophysical properties (porosity, permeability, etc.), and sea-level cycles, to name but a few. For years, the UGS has used its small set of Aneth cores for numerous industry workshops and student petroleum classes. Now we have a plethora of Aneth carbonate cores to choose from for these teaching activities. Dr. David E. Eby, a prominent carbonate-rock specialist and industry consultant based in Denver, Colorado, stated concerning the new core collection:

"Acquisition of the Aneth field core collection is a magical and important addition to the teaching/research collection of the Utah Geological Survey. Academic and industry researchers will, for the first time, have access to a complete core collection from Utah's largest oil field. This collection will surely be the basis for numerous future student research projects and teaching workshops devoted to classic Pennsylvanian and carbonate reservoirs. Congratulations UGS and Resolute Energy for making this happen!!"

Already two graduate students from Brigham Young University (BYU), Provo, Utah, are using the new Aneth core collection for their Master of Science thesis projects. These students are conducting in-depth studies of the depositional environments of the upper and lower Aneth reservoirs and how they fit into various stacked packages of rocks, created over time at small and large scales. Their advisor, Dr. Scott M. Ritter, BYU Department of Geological Sciences, said,

"The significance of this donation both for the students involved and for the larger geological community is the integration of data from a variety of related sources to develop a holistic understanding of this remarkable carbonate field. The core and other materials donated by Resolute could profitably occupy an entire research career. I intend to spend much of my remaining career working on Aneth field."

It is our hope that the UCRC can acquire additional sets of these incredibly important cores from other Utah oil and gas fields, especially if they are in jeopardy of heading to a landfill. To geologists, whether in the petroleum industry or a bright young university student, these cores are true "treasure troves" that may hold the keys to future oil and scientific discoveries.

To see the new Greater Aneth oil field core set or schedule a workshop at the UCRC, contact Peter Nielsen, Curator (Ph.: 801-537-3359, email: peternielsen@utah.gov).

Top: Location of Greater Aneth and other oil fields in southeastern Utah. Bottom: Location of cores in Greater Aneth field now available at the Utah Core Research Center.

GLAD YOU ASKED

Do Ants Mine Gold?

BY Jim Davis

*A western harvester ant (*Pogonomyrmex occidentalis*). Photo: Dale Ward,* Ants of the Southwest, *tightloop.com/ants. Used with permission.*

An ant does not necessarily have an affinity for gold; to her it is just another fragment of earth to transport when constructing tunnels, chambers, paths, and nest cones. Gold is one of the heaviest elements, nearly twice the density of lead. Still, ants can lift or drag many times their weight and at today's gold prices taking a nugget from her could pay for your lunch.

Gold-digging ants have persisted in the Western tradition since the 5th century B.C. writings of Herodotus, and later Pliny the Elder. In Herodotus' *The Histories*, giant ants in the vicinity of modern Afghanistan were said to mine gold dust that people would collect from their mounds. Although Herodotus' story is not entirely factual, ants are premier miners and to geologists "the world's oldest prospecting tool." Soil covers most of Earth's dry land, cloaking bedrock. Ants, hauling up subterranean material and gathering weathered bits of rock and minerals from their territory for deposit on the colony mound, can provide a window into the subsurface. Thanks to the ant's undertakings, prospectors have discovered rich lodes of gold, copper, nickel, turquoise, diamonds, and many other minerals and gemstones.

Ants are premier miners and to geologists, "the world's oldest prospecting tool."

Most ants do not build above-ground nests or true mounds that have living quarters, but some species of the New World harvester ants (e.g., *Pogonomyrmex* sp.) are a remarkable exception in the American West. Some harvester ant species will build conspicuous, pebbly mounds. These ants are known to forage items of uniform size from many yards away and place them on their nest cones to armor and acclimatize the nest—likely to protect the mound from wind and rain erosion and to increase solar heating and retain water vapor. The conical mound of the western harvester ant (*P. occidentalis*) is typically about a few inches to more than a foot high, has an average volume of about a cubic foot, and can be 3 feet or more in diameter. The size of the pebbles used, consistent with their mandible spread, is about 0.1 to 0.2 inch (2–6 mm) and they may carry up to about half a carat items (0.0035 ounce). The mound itself is typically oriented—the long or shallow slope faces southeast to capture the energy of the morning sun, and the mound entrance is on the southeast in more than four of five mounds in southern Utah. The nest cone exterior is built of prudently selected pebbles, but can include dirt pellets, shells, charcoal, dried bits of vegetation, human artifacts (especially near roads), and of course gemstones and precious metals when in proximity to these deposits.

Harvester nests have a circular zone free of vegetation ringing the mound, called an ant disk or yard, which can be small or more than 25 feet in diameter. Often radiating from the disk are some three to eight cleared trunk trails or the "ant highway system." Visible on the landscape from high above, estimates from aerial photographs indicate these barren disks can occupy up to 2 percent of the total ground surface in semi-arid climates.

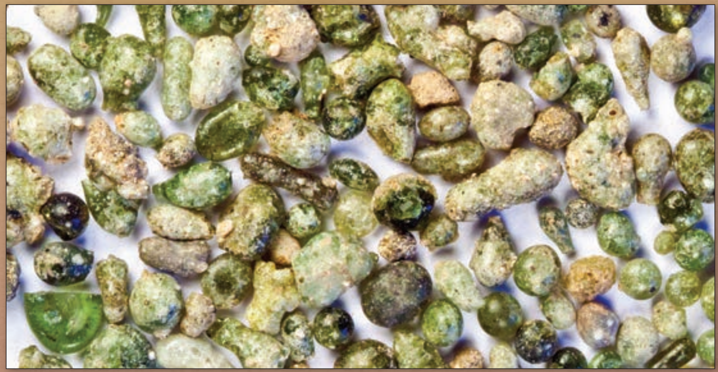
Oblique aerial view to the north of harvester ant mounds dotting the ground in western Skull Valley, Utah. Road at right is about 15 feet wide. Image © Google Earth. Imagery date June 27, 2015.

Harvester ant mound in Millard County, covered in black obsidian. Although the nearest outcrop of obsidian is 100 yards distant, the ants collect and concentrate it on the anthill. The entrance to the mound is under the stone to the left of scale bar. View to the northwest with Cricket Mountains in background.

Ant mounds have long been a practical tool in locating diamond-bearing kimberlites—upper mantle-derived igneous rocks with a vertical structure—around the world. Diamond indicator minerals up to 0.2 inch (6 mm) have been found on ant mounds in the Green River Basin in Utah and Wyoming that originated from the Bishop Conglomerate, sourced from the Uinta Mountains, including ilmenite (titanium-iron oxide), pyrope and almandine garnet, chrome diopside, and spinel. Despite the occurrence of these minerals, it is currently believed unlikely that diamonds developed in this area. A rancher in Manila, Utah, had reported finding "rubies" on anthills as far back as the 1950s, which were later identified as pyrope garnet. The Four Corners region is known for the "Ant Hill Garnet" or "Arizona Ruby," a pyrope garnet gemstone that is novel in being hand-picked from harvester ant mounds. The pyropes, derived from diatremes or volcanic pipes in the Navajo volcanic field, have an attractive, dark-red color and when moved by ants are less than a carat in weight—a perfect size because any more than a carat darkens the red color.

Pyrope garnets gathered from harvester ant mounds. The roundish crystal habit of the garnets and their relatively high specific gravity lets them roll down to the perimeter of the nest cone for easy gathering. Garnets approach a carat in weight. Photo: Mouser Williams http://flickr.com/photos/mouser-nerdbot/. Used with permission.

Ants were integral in debunking "The Great Diamond Hoax of 1872." Investigating the story of a diamond discovery in northwest Colorado near Diamond Peak, Clarence King, the first director of the U.S. Geological Survey and the namesake for Utah's highest point, Kings Peak, noted harvester ant mounds as one line of geologic evidence proving the diamond field was fraudulent. King's team observed artificial holes in the mounds, as if gemstones had been pushed into the nest. If there were no holes or footprints or otherwise disturbed ground near an ant nest, no gemstones were present. King's conclusion: the area was salted with garnets, rubies, sapphires, diamonds, and other precious gemstones to scam investors. The con even duped a prominent mining engineer of the time who first investigated the area. The northwest Colorado location was close to King's Geological Exploration of the Fortieth Parallel survey, and an oversight of diamonds would be a bruise to the expedition team's reputation. King and his government team were compelled to investigate and in doing so blew the cover of one of the most notorious swindles in American history.



Trinitite glass from the July 16, 1945, atomic explosion near Alamogordo, New Mexico, collected from ant mounds during a tektite investigation. Material from the ground such as quartz and feldspar were ejected into the fireball and then rained out as molten glass. Ants then carried these spherical and dumbbell-shaped glass beads to their mounds. Photo: Mouser Williams, http://flickr.com/photos/mouser-nerdbot/. Used with permission.

Ants also like to decorate their mounds with bones and teeth. One harvester ant mound contained over 1,100 modern-day bones from at least nine species of small mammal. Paleontologists use harvester ant mounds to efficiently collect fossils. The ant hill method can increase bone collection rates by more than 40-fold. Besides fossil collecting, ant mounds assist in pinpointing subterranean bone beds through surface sampling of nests to calculate and compare ant mound fossil density. An Upper Cretaceous bone bed was pinpointed in Wyoming using western harvester ant mounds that yielded fossil fragments of crocodile, shark, skate, fish, three mammals, two ornithischian dinosaurs, and three theropod dinosaurs. A single ant mound held 327 fossil teeth.

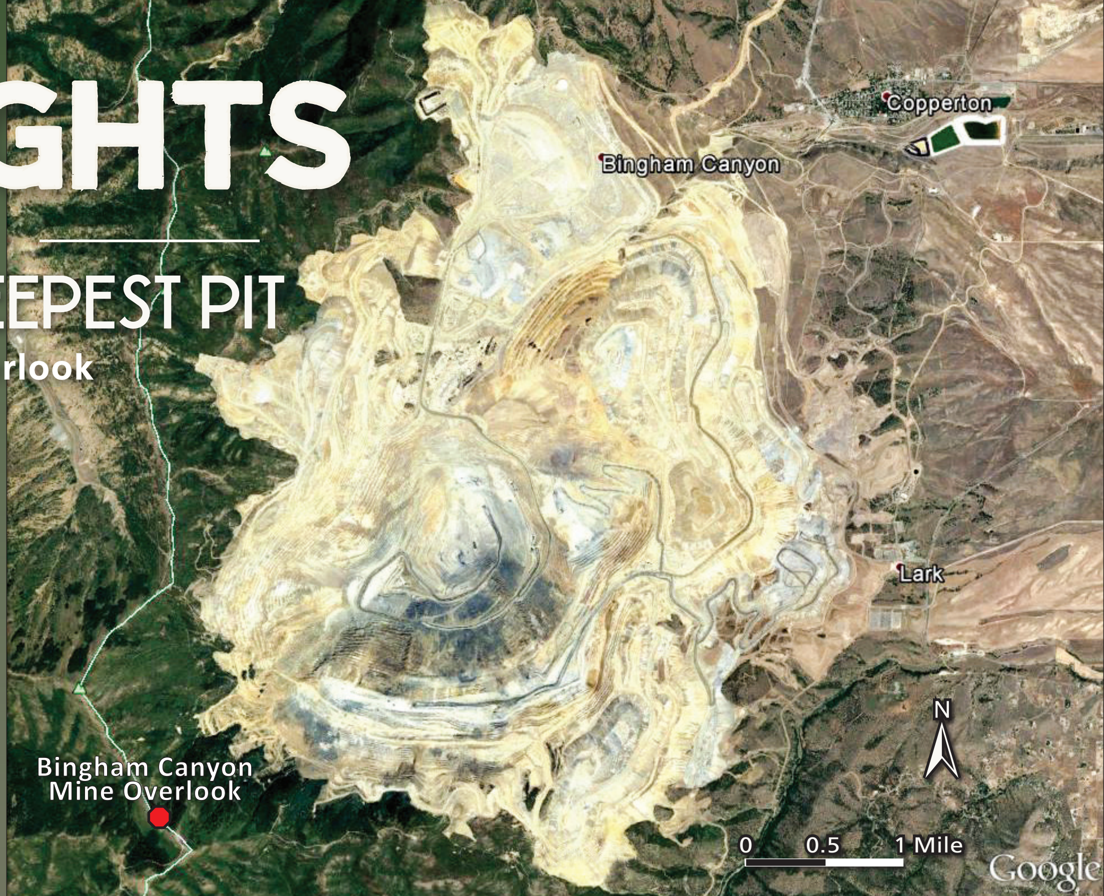
So, the next time you come across an anthill, take a closer look at the surface and see what the ants have chosen for construction. Remember to watch your feet, too, as ants will swiftly muster. The harvester ant (*Pogonomyrmex* sp.) reputedly possess the most venomous sting of any insect, and if you are prone to allergic reactions, or even if you are not, always carry medication that arrests anaphylaxis.

Petrified shark teeth and ant mound pebbles from Tooth Ridge, central New Mexico. The ridge is an outcrop of the Upper Jurassic Morrison Formation. Photo: Mouser Williams, http://flickr.com/photos/mouser-nerdbot/. Used with permission.

GEOSIGHTS

A View Of
THE WORLD'S DEEPEST PIT
Bingham Canyon Mine Overlook

BY **Mark Milligan**



Aerial view of KUC's Bingham Canyon mine, Salt Lake County. Image © Google Earth. Imagery date July 8, 2016.

Although Kennecott Utah Copper's (KUC) Bingham Canyon mine visitor center is closed until further notice, the public can still view the world's deepest open-pit mine from a lesser known, unstaffed overlook atop the Oquirrh Mountains.

The Bingham Canyon mine visitor center was one of Salt Lake County's busiest tourist attractions, hosting over 3 million visitors in its 20 years of seasonal operation from 1992 to 2012. On April 10, 2013, before its scheduled annual re-opening, two massive landslides carrying about 145 million tons of rock scoured away the visitor center's building pads, overlook, and parking lot (for more information, see "Bingham Canyon's Manefay Landslides and the Future of the Mine" in *Survey Notes*, v. 48, no. 3, p. 5–6). Although this was the largest mining-induced landslide in history, causing lost production and hundreds of millions of dollars of damage, it resulted in no injury or loss of life. KUC used sophisticated monitoring of the pit walls to predict the slide and move personnel and some equipment, including the visitor center's portable buildings, out of harm's way.

Left image shows the former KUC visitor center in 2011. Right image shows the same area after the 2013 Manefay landslides removed the building pads, overlook, and parking lot. Image © Google Earth; left image USDA Farm Service Agency, right image no image provider indicated.

With the indefinite closure of the visitor center, KUC has offered a virtual online tour as a substitute (*http://www.kennecott.com/virtual-tour*). However, the enormity of the mine is something that one must see in person to fully appreciate.

The scale of the pit is hard to comprehend when seeing it and even harder to convey in words or pictures. This September 2012 view from the former visitor-center overlook shows the top of the southern side of the pit. The speck indicated by the arrow is a full-size school bus.

Mine Information:

The geology of the Bingham mine orebody is complex. In simplified terms, about 30 to 40 million years ago magma was injected into a sequence of predominantly quartzite and limestone beds that are part of the roughly 300- to 350-million-year-old Oquirrh Group. The magma cooled to form a body of igneous rock (monzonite porphyry) known as the Bingham stock. Hot fluids generated from this magma deposited various copper-sulfide (mainly chalcopyrite) and other metallic minerals, forming a large low-grade orebody.

KUC's Bingham Canyon mine is one of the largest and most efficient mines in the world. It has produced more copper than any other district in the U.S., accounting for over 16 percent of total U.S. copper production. In addition to copper, the mine produces gold, molybdenum, and silver. KUC's combined annual value of these metals peaked in 2011 at $2.9 billion.

The mine owes its success to economies of scale. The ore is low grade, producing about 10.6 pounds of copper per ton of ore, but a massive amount of it is mined. Furthermore, for every ton of ore, about two tons of overburden must be removed. Mining in Bingham Canyon began in 1863 with small underground mines that targeted high-grade ore. Mining activities remained relatively limited until 1906 when the district became the first in the world to begin large-scale (for the time) open-pit copper mining (for more mine history, see "Race to Ore: The Beginnings of Open-Pit Copper Mining—A Century of Open-Pit Mining at Bingham Canyon" in *Survey Notes*, v. 39, no. 2, p. 1–3).

The mine still has about 700 million tons of ore in place. Mining this ore will take about 11 years, push the south wall of the pit out about 1,000 feet, and deepen the pit by about 300 feet. Dependent on external factors such as metal prices, 2028 could be the end of 121 years of open-pit mining at Bingham Canyon.

HOW TO GET THERE

The overlook is near the crest of the Oquirrh Mountains, southwest of the pit, and can be accessed seasonally from both Salt Lake and Tooele Valleys. Both routes are generally open from approximately June 1st to November 1st depending on snow pack and weather conditions. For more information on road conditions and closures, contact Salt Lake County Public Works (*www.slco.org/operations*) or the Tooele County Road Department, (*www.co.tooele.ut.us/roads.htm*).

From Salt Lake Valley: Take I-15 to Draper City, then take exit 291 for UT-71/12300 South and head west. After about a mile, 12300 South jogs to the left and becomes 12600 South, continue west. After 6.4 miles from I-15, turn left onto Main Street in Herriman. Main Street has several bends before becoming Herriman Highway, continue west. After 11 miles from I-15, immediately before the road curves to the right, continue straight ahead onto the unsigned Butterfield Canyon Road. Continue up Butterfield Canyon Road for 7 additional miles until the pavement ends at the ridgeline and turn right onto the unsigned "copper pit overlook road." The 2.5-mile-long road ends at the overlook. This section of road is unpaved and can be rough and rutted, but is generally passable in a passenger car with reasonable ground clearance.

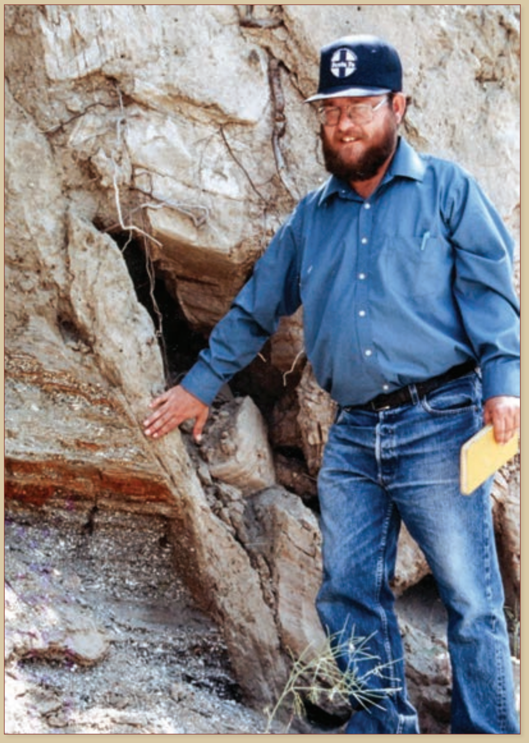
*Note that GPS and online mapping services may route you through Tooele, a much longer route from the Wasatch Front. This is likely due to the programs defaulting to Butterfield Canyon Road being closed for the winter, regardless of the season.

From Tooele Valley: Take Main Street (UT-36) in Tooele City to Vine Street and head east on Vine. After about 1.3 miles, Vine curves to the right and becomes Middle Canyon Road. Continue up Middle Canyon Road for a total of 8.2 miles from Main Street and turn left onto the unsigned "copper pit overlook road." See paragraph above for details.

Bingham Canyon mine overlook, June 2016. View to the northeast from the top of the Oquirrh Mountains. The mine spans 2.75 miles from the pit wall below the overlook to the farthest visible edge of the mine. The vertical distance from the pit's bottom to rim is roughly 3,650 feet, which is more than double the height of One World Trade Center, the tallest building in the Western Hemisphere.

UGS EMPLOYEE NEWS

Suzanne Sawyer has accepted the position as librarian for the Utah Geological Survey Library. She has an M.S. in Library Science from the University of North Texas. Suzanne replaces **Robyn Keeling** who left the UGS to devote her time to family after the arrival of her second daughter. The Groundwater and Paleontology Program bid farewell to **Rich Emerson**, who left to pursue work in the private sector, and welcomed **Emily Keller** and **Stan Smith** as hydrogeologists. Emily is finishing an M.S. in Geology at Utah State University, and Stan has an M.S. in Hydrogeology from the University of Utah. Welcome to Suzanne, Emily, and Stan, and best wishes to Robyn and Rich.



MIKE LOWE Mike Lowe retired in January after a 27-year career with the UGS, including 23 years as manager of the Groundwater and Paleontology Program. Mike began working at the UGS in 1989. He made many contributions to the geology of Utah during his career, including surficial geologic mapping, geologic hazards evaluations, and groundwater studies. Major projects included development of geologic framework studies to help the Utah Division of Water Rights better understand their groundwater basins, and recharge-area and water-quality mapping for the Utah Division of Water Quality. Mike was named the Utah Department of Natural Resources Manager of the Year in 2004, and throughout his career he received numerous awards and honors for his work. Outside the UGS, Mike taught Environmental Geology at Weber State University, acted as section chairperson for the Association of Engineering Geologists, served as president for the Utah Geological Association, and served on several other geology-related committees. Mike's knowledge and expertise will be greatly missed, and we wish him well in his retirement!

2016 UGS Employee of the Year
MARK MILLIGAN

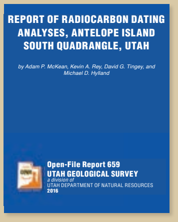
Congratulations to Mark Milligan who was named the 2016 UGS Employee of the Year. Mark is a geologist in the Geologic Information and Outreach Program and has worked for the UGS for 19 years. He handles an enormous number of public inquiries that require patience, persistence, and a broad understanding of Utah geology. He has authored numerous popular UGS publications and contributed many informative articles to *Survey Notes*. Mark has a strong work ethic and friendly personality that endears him to co-workers and the public he often interacts with. Mark is an outstanding role model and a deserving recipient of the UGS Employee of the Year award.

NEW PUBLICATIONS

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

Major oil plays in Utah and vicinity, edited and compiled by Thomas C. Chidsey, Jr., 294 p., ISBN 978-1-55791-922-9, **Bulletin 137**

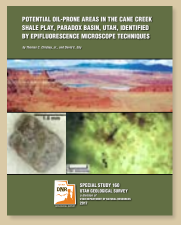
Great Salt Lake's north arm salt crust, by Andrew Rupke, Taylor Boden, and Peter Nielsen, 22 p. + appendices, 1 pl., ISBN 978-1-55791-932-8, **Report of Investigation 276**



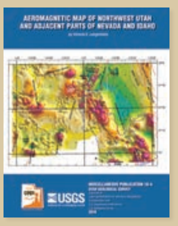
Report of radiocarbon dating analyses, Antelope Island South quadrangle, Utah, by Adam P. McKean, Kevin A. Rey, David G. Tingey, and Michael D. Hylland, 3 p., **Open-File Report 659**

Utah Wetland Functional Classification: Version 1, by Richard Emerson and Ryhan Sempler, 10 p., **Open-File Report 661**

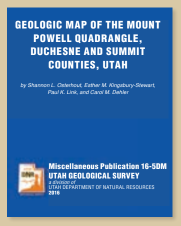
Hydrogeology of the Malad–Lower Bear River basin, north-central Utah and south-central Idaho, by Hugh Hurlow, 39 p., 3 pl., ISBN 978-1-55791-934-2, **Special Study 157**



Potential oil-prone areas in the Cane Creek shale play, Paradox Basin, Utah, identified by epifluorescence microscope techniques, by Thomas C. Chidsey, Jr., and David E. Eby, 44 p. + 126 p. appendices, ISBN 978-1-55791-937-3, **Special Study 160**



Aeromagnetic map of northwest Utah and adjacent parts of Nevada and Idaho, by Victoria E. Langenheim, 8 p., 1 pl., ISBN 978-1-55791-931-1, **Miscellaneous Publication 16-4**



Geologic map of the Mount Powell quadrangle, Duchesne and Summit Counties, Utah, by Shannon L. Osterhout, Esther M. Kingsbury-Stewart, Paul K. Link, and Carol M. Dehler, CD (2 pl. [contains GIS data]), ISBN 978-1-66791-927-4, scale 1:24,000, **Miscellaneous Publication 16-5DM**

OUTSIDE PUBLICATIONS BY UGS AUTHORS

Depositional constraints on the Lower Cretaceous Stikes Quarry dinosaur site–upper Yellow Cat Member, Cedar Mountain Formation, Utah, by **J.I. Kirkland**, E.L. Simpson, **D.D. DeBlieux**, S.K. Madsen, E. Bogner, and N.E. Tibert: Palaios, v. 31, p. 421–439, DOI: http://dx.doi.org/10.2110/palo.2016.041.

The Lower Cretaceous in east-central Utah–the Cedar Mountain Formation and its bounding strata, by **J.I. Kirkland**, M. Suarez, C. Suarez, and R. Hunt-Foster: Geology of the Intermountain West, v. 3, p. 101–228. https://www.utahgeology.org/openjournal/index.php/GIW/article/view/9/9.

An early bothremydid (Testudines, Pleurodira) from the Late Cretaceous (Cenomanian) of Utah, North America, by W.G. Joyce, T.R. Lyson, and **J.I. Kirkland**: PeerJ 4:e2502; DOI 10.7717/peerj.2502.

The Late Cretaceous lamniform shark, Cretoxyrhina mantelli, from the Fairport Chalky Shale Member of the Carlile Shale in northeastern Nebraska, by E. Johnson-Ranson, K. Shimada, and **J.I. Kirkland**: Transactions of the Kansas Academy of Science, v. 119, p. 208–210.

Geothermal Energy—challenges for EGS development—an editorial perspective, by J. McLennan, J. Moore, and **R. Allis**: Hydraulic Fracturing Journal, v. 4, no. 1.

Diagenetic sequestration of rare earths and actinides in phosphatic oil shale from the lacustrine Green River Formation (Eocene), Utah, USA—an SEM and LA-ICP-MS study, by D. Keighley, C. McFarlane, and **M.D. Vanden Berg**: Journal of Paleolimnology, p. 1–22, DOI:10.1007.

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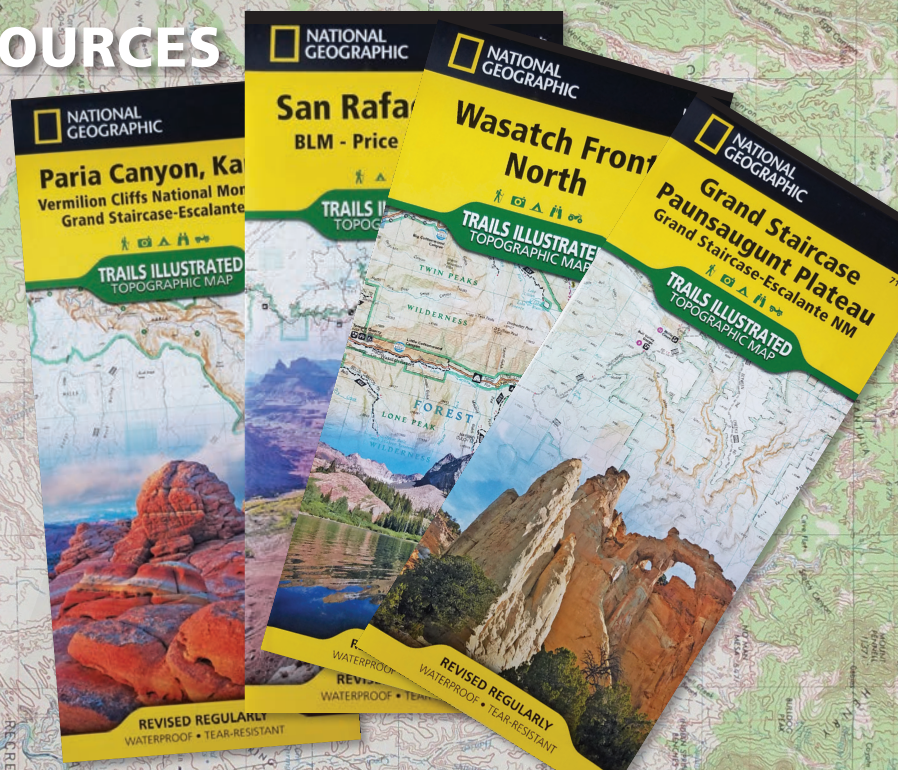

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