UTAH GEOLOGICAL SURVEY

SURVEY NOTES

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Mysteries of the Uinta Mountains

Contents

Design | *Jennifer Miller*
Cover | View to the east of the Green River as it flows through Island Park, Dinosaur National Monument, northeastern Utah. The river exits Whirlpool Canyon in the center of the photograph and flows to the right where it enters Split Mountain (not seen). The Island Park fault juxtaposes the Pennsylvanian-Permian Weber Sandstone (light-colored cliffs) with the reddish-colored Moenkopi and Chinle Formations in the distance. Photo by Douglas A. Sprinkel

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THE DIRECTOR'S PERSPECTIVE

by Richard G. Allis

The Utah Geological Survey (UGS) has been publishing a non-technical newsletter for over 50 years. For the first decade it was known as *Quarterly Review*, and in 1976 it became *Survey Notes*. In 1993 we started publishing three issues a year instead of four, and in 2002 the publication became full color. Although all of the UGS's scientific publications are now digital and accessible through our website (print-on-demand is offered at the Utah DNR Map & Bookstore), a printed version of *Survey Notes* is still produced and mailed to nearly 2000 people (the digital version is also posted on our website). Many state geological surveys have stopped producing newsletters, or only publish them online with an email alert when a new one is produced. We have resisted that trend because the printed version of *Survey Notes* is a chance to reach out to potential stakeholders who may not take the time to read an online version, although they may pick up an issue that has been mailed to their home. Our target audience for *Survey Notes* is the non-specialist who is interested in Utah's unique and fascinating geology. Our audience also includes the members of the legislative appropriations committee that determines each year what funding the UGS will receive. *Survey Notes* is a chance to remind all readers of the role the UGS has in providing information about our geological resources and hazards that assists in making wise land-use decisions. Over the years I have received many compliments from our committee, and from readers in general, about *Survey Notes*.

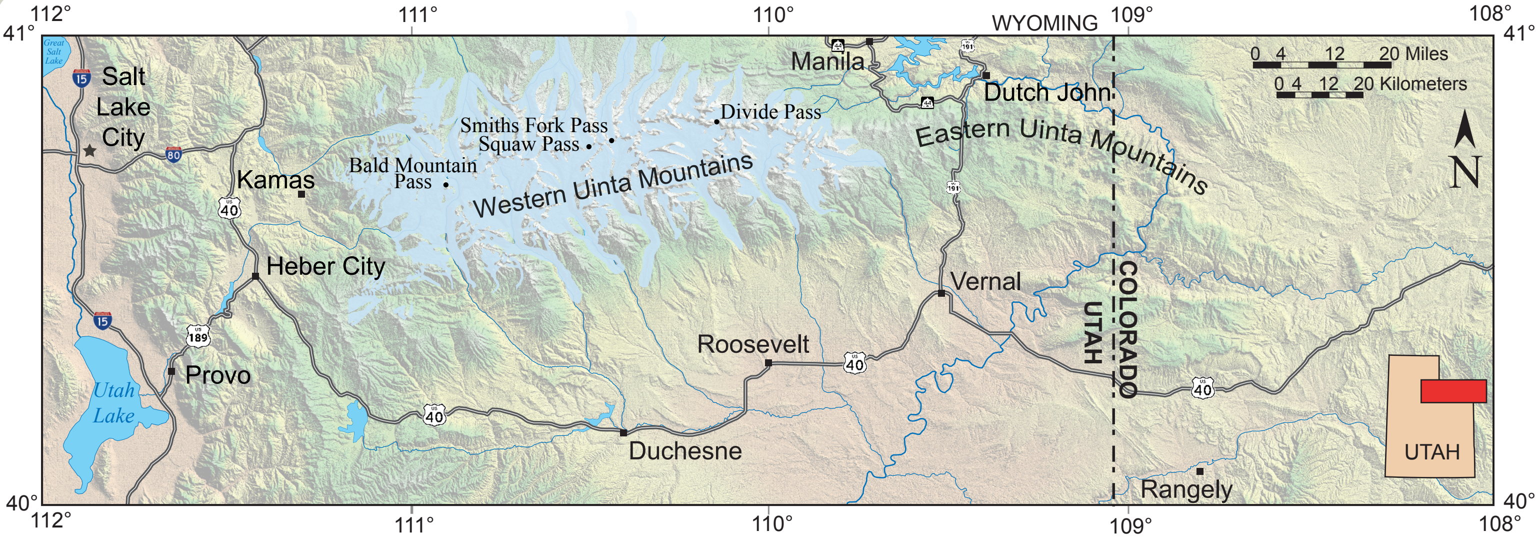
Although *Survey Notes* maintains this traditional form of outreach, the "store-front" of the UGS these days is our website. We are constantly reviewing how to make geological information about Utah more accessible, and hopefully seeing that information widely used. We monitor what pages on our website are the most popular. During the first six months of this year there were 495,000 page-views. I would have guessed our interactive maps of resources, hazards, and Utah's geology would have been the most heavily viewed, but that is not the case. The most frequently viewed pages for many years have been popular geology articles written for *Survey Notes*. Top of the list for the first half of this year is a Glad You Asked article titled "What are Igneous, Sedimentary, & Metamorphic Rocks?" published in the April 1996 issue by Rebecca Hylland (21,000 views), followed by rock and mineral collecting sites (18,000 views—the page has links to 17 articles mostly written for *Survey Notes* over the last 25 years); a Glad You Asked article "How do Geologists Know How Old a Rock Is?" (12,000 views, September 1997 by Mark Milligan); and a Glad You Asked article "Ice Ages—What Are They and What Causes Them?" (12,000 views, September 2010 by Sandy Eldredge and Bob Biek). Clearly, past issues of *Survey Notes* on our website have generated worldwide interest through search engines finding some of our popular geology articles. An example of this occurred on March 28th this year when there was a spike in page views (8000 that day compared to our average of 2500). It turns out reddit/Colorado, a blog site, posted a headline saying Colorado is not a perfect rectangle because of a surveying error on the boundary with Utah. This headline linked to a *Survey Notes* article written in October 2000 by Bill Case titled "Why Does the Eastern Border of Utah have a Kink in It?" Around the same time, the UGS received inquiries from a Colorado reporter and a National Public Radio reporter about this article.

The feature article in this issue of *Survey Notes* is "Mysteries of the Uinta Mountains—Commonly Asked Questions and Answers" by Doug Sprinkel. Maybe one of these questions, such as "Why do the Uinta Mountains trend east-west?," will appear in a future list of top-ten page views on our website.

Mysteries of the Uinta Mountains

Commonly Asked Questions and Answers

BY Douglas A. Sprinkel



Shaded relief map of the Uinta Mountains and vicinity. Glacial ice (light blue) during the Pleistocene was mostly restricted to the western Uintas. In most places, glacial ice did not cross the crest of the range, except at Bald Mountain Pass, Squaw Pass, Smiths Fork Pass, and Divide Pass.

The majestic Uinta Mountains extend 150 miles from Kamas, Utah, eastward to Cross Mountain, Colorado. The range is a collection of mountains and plateaus that includes the high western peaks, lower eastern peaks, Diamond Mountain Plateau, Split Mountain, Blue Mountain Plateau, Yampa Plateau, and Douglas Mountain. The Uinta Mountains have been a source of natural resources and subject of exploration beginning several thousand years ago with the first Native Americans and followed by Spanish explorers, trappers, settlers, and scientists. Today, the Uinta Mountains still provide natural resources like timber harvesting, hunting, and recreation. The range also provides water for surrounding communities as well as the Wasatch Front. Stories of lost Spanish gold mines and questions about its east-west orientation are just some of the mysteries of the Uinta Mountains. I have been asked many questions about the Uinta Mountains over my past two decades of mapping the geology of the region, so it seems worthwhile to address the most commonly asked questions.

Do the Uinta Mountains have the oldest rocks in Utah?

The oldest rocks exposed in the Uinta Mountains are the 1.7 billion-year-old metamorphic rocks of the Red Creek Quartzite exposed in a small part of the eastern Uintas on Goslin Mountain and in Jesse Ewing Canyon north of Browns Park. However, they are not the oldest rocks in Utah. Those belong to the 2.7 billion-year-old metamorphic rocks of the Raft River Mountains in northwest Utah.

Are the Uinta Mountains the only mountain range in Utah that is oriented east-west?

The dominance of north-south-oriented mountains in Utah, especially in the western half of the state, gives the impression that the Uinta Mountains are unique. However, other mountains in Utah run east-west. The Traverse Mountains form a nearly east-west-oriented spur of the Wasatch Range that crosses Interstate 15 at Point of the Mountain. The eastern Book Cliffs, Roan Cliffs, and Tavaputs Plateau in east-central Utah also run east-west as do the Raft River Mountains.

Why do the Uinta Mountains trend east-west?

Regional mountain-building events drive the uplifts that form most major mountain ranges like the Uintas. The Uintas owe their east-west trend to an ancient crustal boundary where the Paleoproterozoic (2.0 to 1.7 billion-year-old) Mojave and Yavapai provinces were sutured onto the Archean (greater than 2.5 billion-year-old) Wyoming province, Grouse Creek block, and Farmington zone during a plate-tectonic collision event about 1.7 billion years ago. This suture zone, called the Cheyenne Belt, is an area of weakness that has influenced formation of structures and deposition of strata in the Uintas ever since. Later, a normal fault developed along the reactivated suture zone that formed the northern boundary of a Neoproterozoic (770 to 740 million-year-old) basin in which thick sand, gravel, and mud accumulated—today's Uinta Mountain Group and the core of the Uinta Mountains. Prior to deposition of Cambrian strata about 550 million years ago, the basin was inverted along the same zone of weakness and the Uinta Mountain Group was slightly uplifted and broadly folded into the initial Uinta arch (also called the Uinta-Cottonwood-Tooele arch). Between 70 and 34 million years ago, the Uinta Mountains took shape during the Laramide orogeny (mountain-building event).

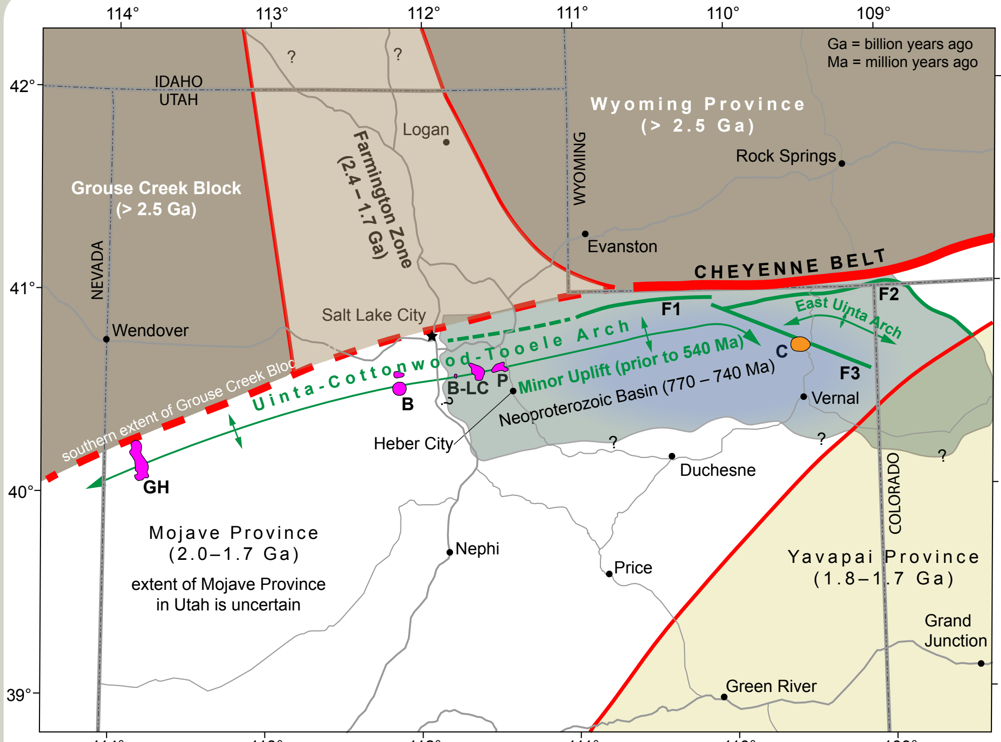
How much have the Uinta Mountains been uplifted?

Throughout much of its history the area of the Uinta arch was slightly below to slightly above sea level. When submerged, marine sediments were deposited over the arch, ultimately burying the top of the Uinta Mountain Group under about 20,000 feet of rock. During the Laramide orogeny, the mountains rose rapidly along faults. To bring Uinta Mountain Group rocks to their present elevation in the present Uinta highlands there must have been between 25,000 and 30,000 feet of uplift. But this is even more impressive when we consider that the Uinta Mountain Group in the adjacent Uinta Basin was simultaneously buried beneath an additional 10,000 feet of Tertiary-age rocks—an amazing 35,000 to 40,000 feet of vertical deformation! The Uinta Mountains probably reached their maximum elevation by the end of the Laramide uplift about 34 million years ago. The maximum elevation reached is uncertain but was likely never much more than the current elevation because erosion probably kept pace with uplift.

What is the difference between the western and eastern Uinta Mountains?

Most people notice the difference in topography across the Uintas—high-elevation peaks in the west and lower-elevation peaks in the east. The informal line topographically dividing the western and eastern Uintas is roughly 10 to 15 miles west of U.S. Highway 191. In addition to topography, there are several geologic reasons to divide the range. The broad generally east-west-trending Uinta arch is actually two offset anticlinal structures. The western anticline trends nearly east-west whereas the eastern anticline trends more southeast-northwest. The change in trend and misalignment were caused by a northwest-trending fault that cuts diagonally across the range. Not only does the fault explain the misalignment of the two anticlines, it also explains why older Uinta Mountain Group rocks on the east are displaced next to younger rocks on the west, and why the oldest rocks in the Uintas are exposed in the eastern part.

Lithologic changes also occur from west to east within the range. For example, the Mississippian Madison Limestone is mapped in the east but the distinctive, age-equivalent Gardison, Delle Phosphatic Member, and Deseret Limestones are mapped in the west. The Triassic marine Thaynes Formation in the west pinches out eastward and becomes part of the non- to marginal-marine Moenkopi Formation. Middle Jurassic formations transition from mostly marine beds of the Arapien Formation in the west to more nearshore, tidal flat, and fluvial beds of the Carmel Formation in the east. Interestingly, all of the lithologic changes occur at about the middle of the range.



Paleoproterozoic basement rocks (Mojave and Yavapai) were sutured onto the Archean Wyoming province about 1.7 billion years ago along the Cheyenne Belt, a zone of weakness that has influenced sedimentation and structural deformations ever since. Soon after the Laramide uplift (between 70 and 34 million years ago), igneous intrusions and mineralization occurred along the Uinta arch creating rich mining districts (shown in purple) that extend from the Uinta Mountains west to the Utah-Nevada state line. These are: GH – Gold Hill, B – Bingham, B-LC – Big and Little Cottonwood, and P – Park City. The Carbonate mining district (shown in orange and labeled C) is located along a northwest-trending fault that bisects the Uinta Mountains. Labeled faults are: F1 – North Flank fault, F2 – Uinta-Sparks fault, and F3 – northwest-trending fault.

Why are the highest peaks found only in the western Uinta Mountains?

The Uintas have more peaks higher than 11,000 feet than any other mountain range in Utah, and have Utah's only peaks over 13,000 feet, including Kings Peak, our highest at 13,528 ± 6 feet. These peaks are concentrated in the western part of the range whereas peaks in the eastern Uintas barely reach 10,500 feet in elevation. The western peaks may have always been a little higher because the earlier Sevier orogeny may have thickened the crust beneath the western part of the range. However, the peaks in the eastern Uinta Mountains were likely taller at the end of the Laramide orogeny than they are now. About 25 million years ago, extension caused the eastern Uintas to collapse down relative to the western Uintas mostly along the previously mentioned northwest-trending fault, augmented by additional downward movement of the Uinta and Sparks faults on the north flank. The eastern Uinta Mountains were lowered a minimum of about 500 feet but may have dropped as much as about 1000 feet.

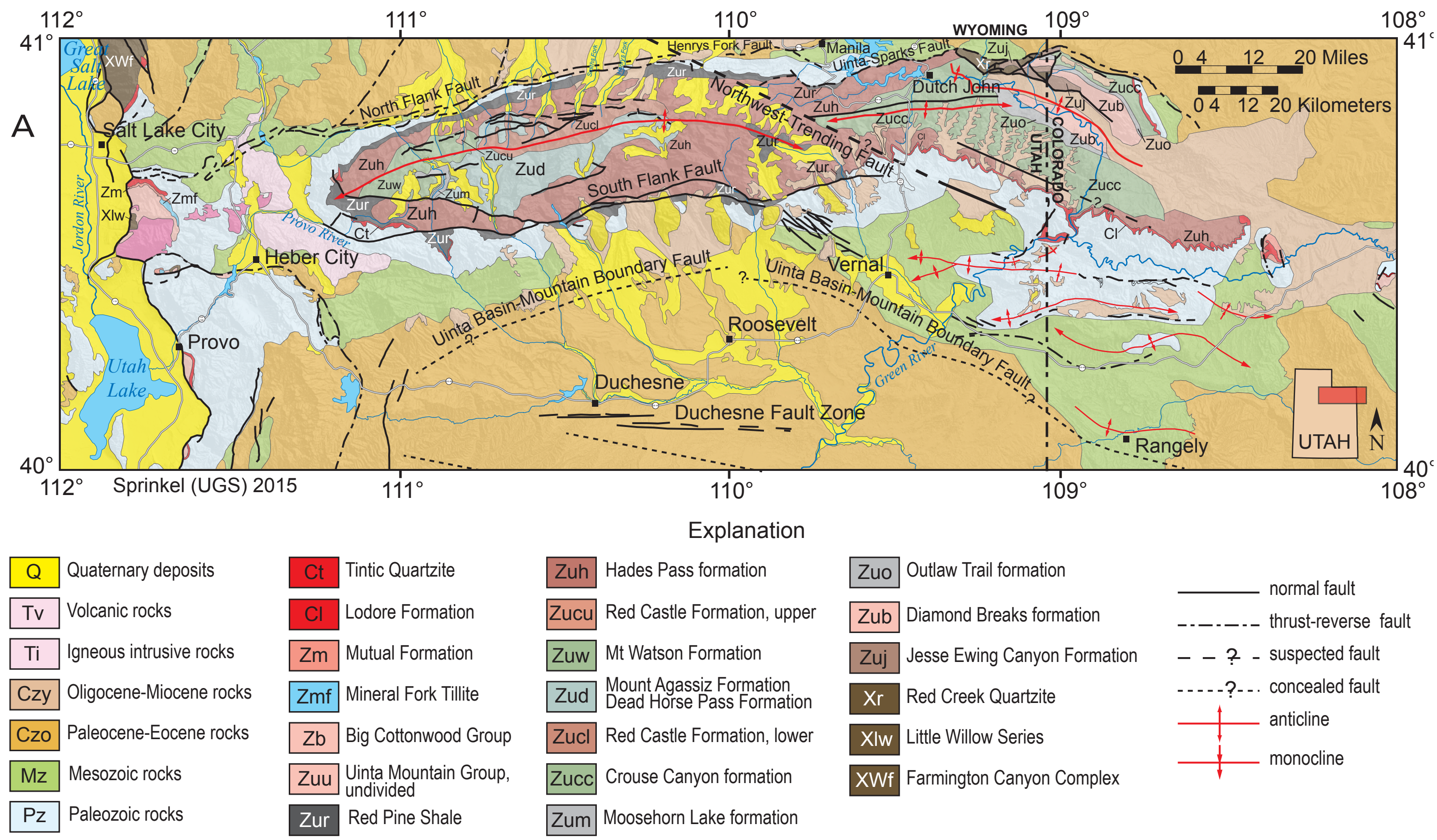
Were the Uinta Mountains completely covered in glaciers during the Pleistocene ice ages?

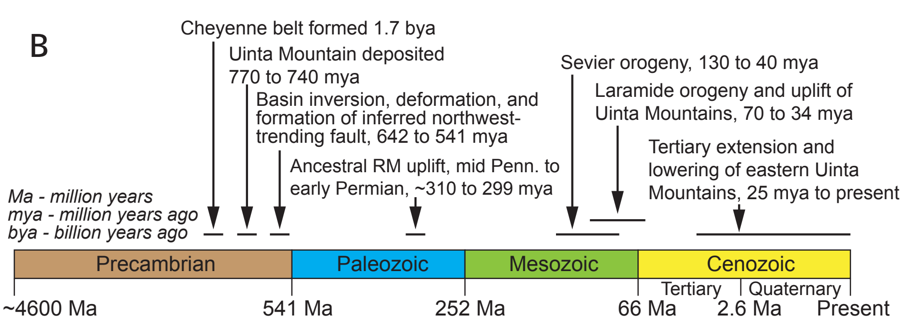
The eastern Uinta Mountains did not accumulate enough ice to form glaciers due to their lower elevation, but they were no doubt covered in snow much of each year. The western Uintas, on the other hand, did have thick ice and glaciers. Most of the glaciers started in cirques (steep-walled basins) near the range crest on the north and south sides of the topographic divide, forming a chain of glaciers bounded by protruding snowed-covered "island" peaks. However, glacial ice did cross the crest at Bald Mountain Pass on the Mirror Lake Scenic Highway (Utah State Highway 150), Squaw Pass, Smiths Fork Pass, and Divide Pass.

Do the Uinta Mountains have mineral deposits?

The Uinta Mountains seemingly have only limited concentrations of mineral and ore deposits, which is surprising since the western extension of the Uinta arch is associated with large mining districts like the Park City, Big and Little Cottonwood, Bingham Canyon, and Gold Hill. The mineralization that is present tends to be localized iron, copper, and manganese deposits along the south flank fault zone; an example is the Iron Mine Creek area. The Carbonate district at Dyer Mountain, located along the northwest-trending fault zone near the center of the range, includes the now-inactive Dyer, Silver King, and Pope mines that produced copper, silver, lead, zinc, and minor gold. Minor copper and associated minerals also occur in Jesse Ewing Canyon and in the Red Creek area. These occurrences are associated with metamorphic and igneous rocks (Red Creek Quartzite) along the Uinta fault zone. Finally, ornamental fibrous calcite is being mined in the Blind Springs area along the south flank fault zone.

As for the infamous Lost Spanish Gold Mine—no one has ever found a trace—yet!





(A) Simplified geologic map of the Uinta Mountains showing major faults including the northwest-trending fault and the two anticlinal culminations that form the Uinta arch. (B) Timeline of structural events that shaped the Uinta Mountains.

ABOUT THE AUTHOR

DOUG SPRINKEL is a senior geologist in the Geologic Mapping Program at the Utah Geological Survey. His principal responsibility is to map the geology of 30′ x 60′ quadrangles that cover the Uinta Mountains and Uinta Basin. In addition to his mapping efforts in northeastern Utah, Doug has mapped quadrangles in the central Utah thrust belt. Other ongoing projects include a regional study of Early and Middle Jurassic strata and regional Mesozoic unconformities. Doug has co-edited four popular books on Utah geology and authored or co-authored 15 geologic maps and about 100 professional reports, articles, and abstracts.

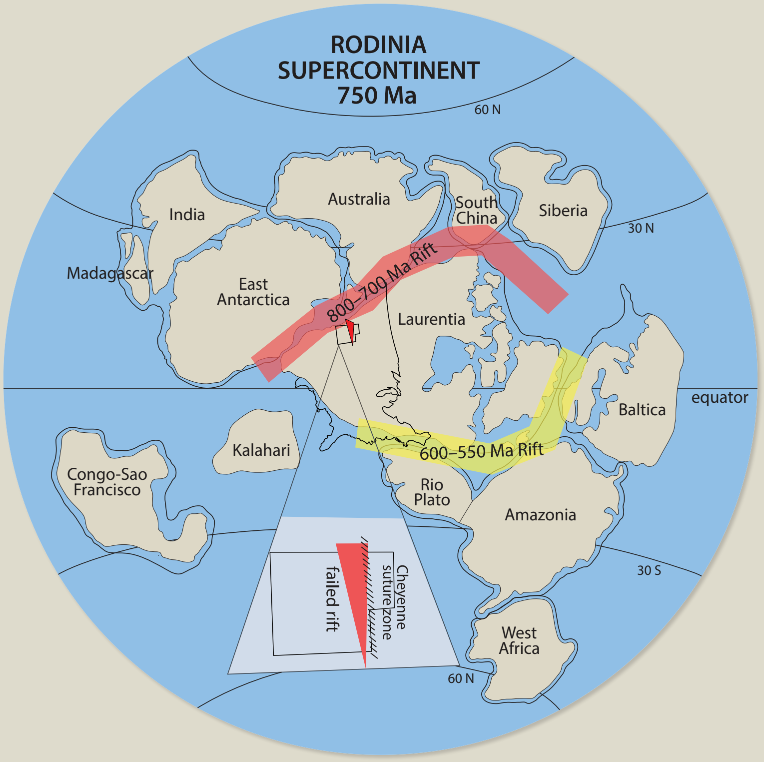
Ancient Volcanoes of the Central Wasatch Range

BY Robert F. Biek

Who among us knew that a series of volcanoes, lined up east to west, once towered over what is now the central Wasatch Range? The roots of these long-gone volcanoes are preserved in the granitic rocks of Big and Little Cottonwood Canyons, and eastward beyond Park City. Volcanic rocks—the eruptive products of these volcanoes—are preserved in the gap between the Wasatch Range and Uinta Mountains, and they hold important clues to what the landscape and life looked like during the Eocene and Oligocene Epochs when the volcanoes were active some 30 to 40 million years ago. This igneous activity was also the ultimate source of mineralization for the Park City mining district, once one of the West's most important silver-lead-zinc districts.

The unusual east-west alignment of these ancient volcanoes can be traced back to geologic events 1.7 billion years ago when tectonic plates collided with the southern margin of the North American craton, forming the Cheyenne suture zone, an east-west zone of weakened rock near the present-day Utah-Wyoming state line (see Doug Sprinkel's "Mysteries of the Uinta Mountains" article in this issue). Those tectonic collisions were part of the long process of building the supercontinent Rodinia. About 780 million years ago, Rodinia began to break apart along a north-trending rift that cut through what is now central Nevada, splitting Laurentia, the Precambrian core of North America, from the western part of the supercontinent. A failed arm of that rift opened to form the Uinta trough, a fault-bounded rift basin that collected sediment shed off the continent.

The weakness of this failed rift controlled the subsequent geologic evolution of northeastern Utah. During the Cretaceous Period it influenced the emplacement of thrust faults. During the Late Cretaceous to early Tertiary the trough was "inverted" or elevated to form the east-west Uinta Mountains. During the middle Tertiary it controlled faults related to early crustal extension and served to focus magmatic activity of the Wasatch igneous belt, described below. This zone of crustal weakness continues to affect the location of faults associated with modern extension.



Rifting or breaking apart of the supercontinent Rodinia began about 780 million years ago. The rift ran through what is now central Nevada. A failed rift (see inset) created the Uinta trough just south of today's Utah-Wyoming border. Image modified from Goodge, J.W., and others, 2008, A positive test of East Antarctica–Laurentia juxtaposition within the Rodinia supercontinent: Science, v. 321, no. 5886, p. 235–240.

Wasatch Igneous Belt

The Wasatch igneous belt is a 30-mile-long, east-west-trending string of 30- to 40-million-year-old granitic intrusions in the Wasatch Range. The belt is part of a longer zone of intrusions that reaches westward into the Oquirrh Mountains and beyond. The east-west alignment is the latest manifestation of the long tectonic history of the building and ultimate demise of Rodinia. The granitic intrusions are the "roots" of long-gone volcanoes—I like to think of them as frozen magma chambers—what remained after the cones themselves eroded away. Because of relative uplift and tilting of the Wasatch Range, the depth of emplacement of the exposed portion of the intrusions increases from east to west.

Silver, lead, zinc, copper, and gold mineralization of mining districts in Park City, Big and Little Cottonwood Canyons, and American Fork Canyon, and those of Bingham, Stockton, and Ophir in the Oquirrh Mountains to the west, owe their existence to these intrusions. As magma that fed volcanoes worked its way into the upper crust, the resultant heat created hydrothermal systems that mineralized favorable host rocks and fractures. The Park City mining district was the most important mining district in the Wasatch Range; it was Utah's third largest producer of base and precious metals and was active from the late 1860s to the early 1980s. The district produced over 45 tons of gold, nearly 8000 tons of silver, over 1,224,000 tons of lead, nearly 700,000 tons of zinc, and nearly 60,000 tons of copper. For several years in the late 19th century, vein deposits of the Ontario mine (the first large discovery in the Wasatch Range, which formed the basis of the Hearst family fortune) made it the largest source of silver in the U.S. Like many mining districts in the West, the Park City area has transformed itself into a year-round recreation center. The Park City Historical Society has placed dozens of interpretive signs in town and on the mountain to share this fascinating history.

Keetley Volcanics

Keetley Volcanics is the name given to volcanic rocks derived from Cascade-like stratovolcanoes and other vents that once towered over the Wasatch igneous belt. Two of the easternmost intrusions, east of Jordanelle Reservoir, may be the source of most of the Keetley Volcanics. The Indian Hollow plug is a volcanic neck surrounded by a radial dike swarm. The nearby Park Premier porphyry is composed of several shallow, hydrothermally altered intrusions with precious-metal mineralization.

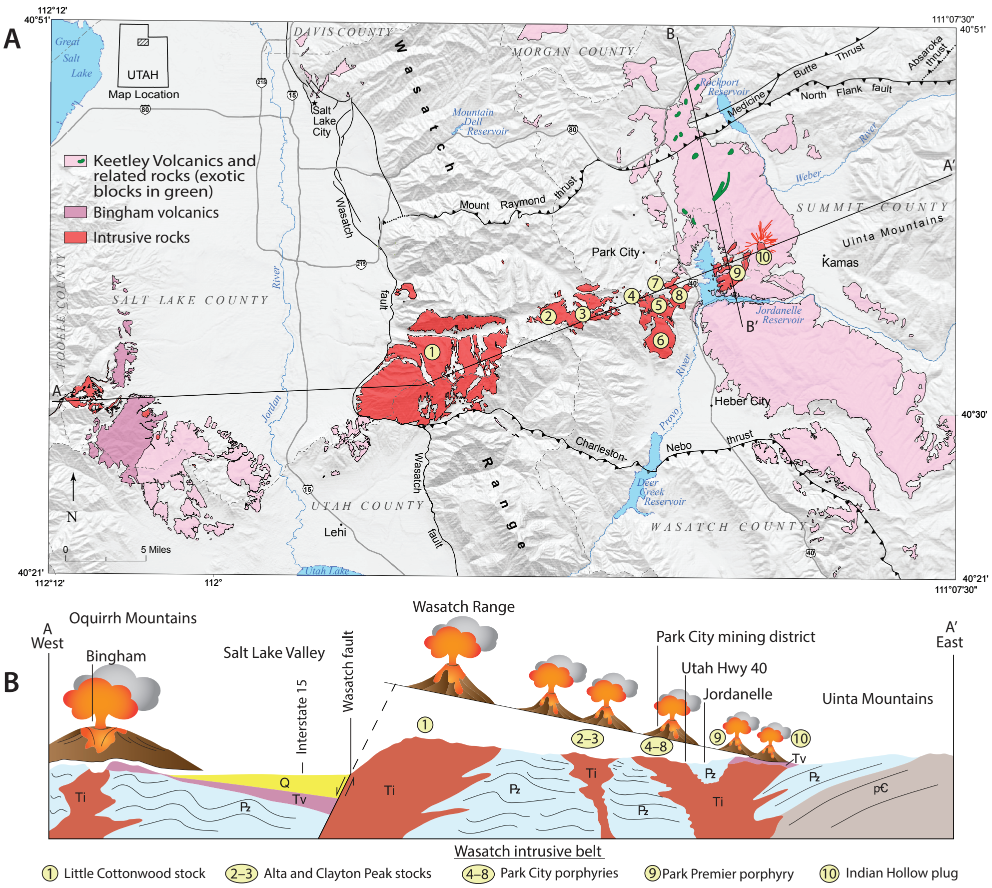
The Keetley Volcanics are divided into three parts:

upper—lava flows and lesser volcanic mudflow breccia;

middle (the bulk of the formation)—volcanic mudflow breccia and lesser conglomerate; and

lower—fine-grained tuffaceous mudstone and sandstone.

These three parts record evolution of the volcanic field, beginning with (1) fine-grained volcanic ash deposited on floodplains and in small lakes that were eventually buried by (2) encroaching aprons of coarse sediment shed off the volcanoes as lahars (debris flows of volcanic rock and mud) and as gravel in braided-stream channels, which in turn were ultimately buried by (3) lava flows on the flanks of the volcanoes themselves. Today, the Keetley Volcanics partly fill a structural and topographic saddle between the Wasatch Range and Uinta Mountains.



(A) Map showing intrusive and volcanic rocks of the central Wasatch area. The intrusions are the roots of volcanoes that once towered over the belt—they line up to form the Wasatch igneous belt, aligned along a long-lived zone of crustal weakness known locally as the Uinta-Cottonwood arch. The Keetley Volcanics, the eruptive products of the igneous belt, were likely derived from the Indian Hollow plug and Park Premier porphyry stock 30 to 40 million years ago. (B) Cross section through the Wasatch igneous belt (granitic intrusions and vents labeled 1 through 10) showing relative uplift and tilting of the Wasatch Range in the footwall of the Wasatch fault. Notice that the depth of emplacement of the remaining parts of the intrusions increases from east to west (from less than 3000 feet to over 30,000 feet), a result of greater uplift and thus erosion closer to the Wasatch fault. The volcanic cones above these intrusions have long since eroded away.

Brecciated Weber Quartzite block. This and other exotic, brecciated blocks of Mesozoic strata appear to "float" within the Keetley Volcanics and are thought to be debris-avalanche deposits that resulted from partial collapse, 35 million years ago, of the Park Premier volcano, the remnants of which are exposed near Jordanelle Reservoir.

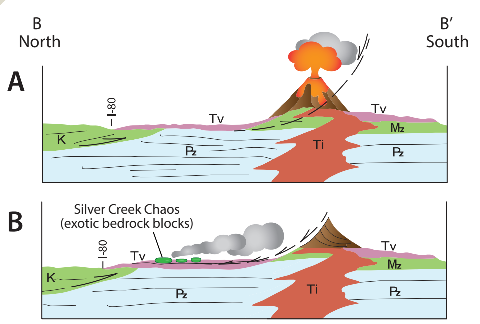
The lower part of the Keetley Volcanics has yielded petrified wood belonging to at least two different types of conifers, one a species of pine and the other possibly a tree of the cypress family, which includes junipers and redwoods. These trees grew low on the slopes of the volcanoes, probably on floodplains that radiated away from the volcanoes. The rocks in which the petrified trees were found are non-resistant and poorly exposed, so the best outcrops are found in excavations during development, which is how petrified logs were first discovered near Silver Creek Junction. The trees may have been buried by a large ash eruption or they may have been swept away and deposited during a flood. Regardless, the petrified wood offers a glimpse of life at the close of the Eocene, some 35 million years ago; the fossil wood is the focal point of a new geologic park now being built near the junction of I-15 and Utah Highway 40 (see sidebar on page 7).

The lower part of the Keetley Volcanics also yielded fossils of early mammals, including *Leptomeryx*, a small, slender, deer-like animal; the rodent *Paradjidaumo minor*; and *Agriochoerid*, a small, forest herbivore unlike any living mammal. Doubtless many other plants and animals were present, collectively comprising a forest ecosystem not unlike that found today in high mountain areas of the western U.S.

Volcanic Mudflow Breccia of Silver Creek and the Silver Creek Chaos

The Keetley Volcanics include an intriguing group of rocks known as the Silver Creek chaos. The "chaos" consists of unusual, highly fractured and broken (brecciated) pieces of non-volcanic sedimentary bedrock that are commonly bus to house size, but several are larger in size than a football stadium. These brecciated blocks include red mudstone of the Ankareh Formation, pink sandstone of the Nugget Sandstone, and light-brown sandstone of the Weber Quartzite. The blocks are unusual in that they are brecciated sedimentary blocks found near the base of a Keetley unit known as the volcanic mudflow breccia of Silver Creek. The volcanic mudflow breccia of Silver Creek—the middle unit that composes much of the Keetley Volcanics—represents deposition as lahars on the distal flanks of volcanoes that once towered over the Indian Hollow plug and Park Premier porphyry stocks of the Wasatch igneous belt.

The Silver Creek chaos appears to be debris-avalanche deposits consisting of semi-coherent slabs of rock that travelled 10 miles or more across fine-grained tuffaceous strata of the lower Keetley Volcanics. This likely resulted from partial collapse of the volcano that once towered over the Park Premier porphyry stock (see cross section below). The roots of this old volcano are well exposed in road cuts east of Jordanelle Reservoir, where sedimentary bedrock is juxtaposed against volcanic porphyry rocks emplaced at shallow depths near the base of the long-gone volcano. Since the 1980 landslide and eruption of Mount St. Helens in Washington State, geologists have recognized hundreds of similar collapse events at modern volcanoes worldwide. The Silver Creek chaos is an example of a debris-avalanche deposit—a fossil landslide—derived from a long-extinct 35-million-year-old volcano.



Cross sections through the Park Premier porphyry stock showing inferred collapse of volcanic cone and underlying bedrock, source of the Silver Creek chaos. (A) before collapse, (B) after collapse. See map for cross section location.

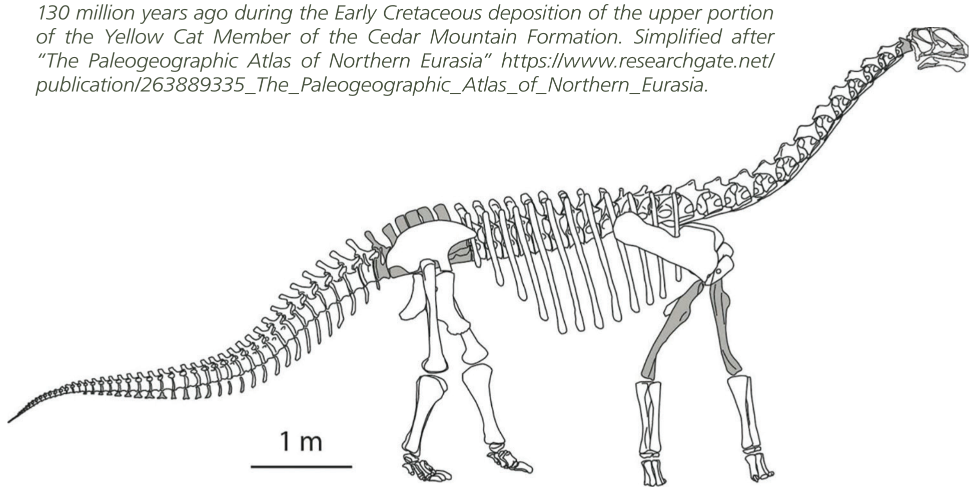
UTAH'S EARLY CRETACEOUS FOSSILS PROVIDE CRITICAL DATA ON THE OPENING OF THE ATLANTIC OCEAN

BY **James I. Kirkland**
State Paleontologist

The Cedar Mountain Formation of east-central Utah preserves the most complete North American record of life on land during the Early Cretaceous (see *Survey Notes* v. 37, no. 1, p. 1–5) and has convincing evidence that the basal Yellow Cat Member in Grand County preserves the two oldest dinosaur faunas in North America (see *Survey Notes* v. 49, no. 1, p. 4–5). As far back as the 1990s, I and others noted that the presence of polacanthid ankylosaurs in both Utah and Europe suggested a paleobiogeographic connection across the Atlantic Basin during Yellow Cat deposition. However, the identification of polacanthid ankylosaurs in the Late Jurassic Morrison Formation (see *Survey Notes* v. 43, no. 4, p. 4–5) indicates that rather than migrating across a land connection that hypothetically remained into the Early Cretaceous, the Early Cretaceous species on both continents may merely be separate descendants of related Jurassic species that migrated between Europe and North America when a land connection is more widely accepted.

Last year, working with our European colleagues led by Spanish researcher Rafael Royo-Torrez of Dinopolis Foundation, we described North America's first turiasaur sauropod from the most complete individual sauropod skeleton ever found in North America's part of the lower fauna of Yellow Cat. The Turiasauria are only known from Upper Jurassic species in southern Europe and are more primitive than any of the many sauropod species preserved in the Morrison Formation. Thus, North America's most basal (primitive) sauropod *Mierasaurus bobyoungi* is from the Early Cretaceous of Utah. Our scientific hypothesis that following a mass extinction at the end of the Jurassic wiping out the abundant diplodocid and camarasaurid sauropods of the Morrison Formation, a turiasaur succeeded in crossing the proto-Atlantic Ocean to re-colonize western North America in the Early Cretaceous. Additionally, we determined that the recently described *Moabosaurus utahensis* from the upper fauna of Yellow Cat Member was also a species of Turiasauria.

Above: Oblique polar projection of continental positions in the northern hemisphere 130 million years ago during the Early Cretaceous deposition of the upper portion of the Yellow Cat Member of the Cedar Mountain Formation. Simplified after "The Paleogeographic Atlas of Northern Eurasia" https://www.researchgate.net/publication/263889335_The_Paleogeographic_Atlas_of_Northern_Eurasia.



Mierasaurus*; mired turiasaur skeleton, art by Mike Skepnick (used with permission). Missing bones dark gray.*

Cifelliodon skull in white light and ultraviolet light; Hippodraco *meets* Cifelliodon*, art by Jorge Gonzalez (used with permission).*

The presence of an Early Cretaceous connection with Europe has been substantiated and even further supported with the discovery of North America's first haramiyid mammalimorph from another UGS locality, only a few miles away from the *Mierasaurus* site, in the upper Yellow Cat Member which also preserved the thumb-spiked bipedal plant eating iguanodont dinosaur *Hippodraco* (see *Survey Notes* v. 45, no. 1, p. 1–3). The Haramiyida are just outside the crown group of "true" mammals that include modern egg-laying monotremes, marsupials, and placental mammals, meaning all living mammals share a common recent ancestor that slightly post-dates the Haramiyida. Haramiyida were only known from fragmentary fossils from the Upper Triassic of Europe and Greenland and have recently been described from a series of diverse, fur-covered species that are preserved as flattened skeletons in lake beds from the upper Middle Jurassic of northeastern China described by our colleague Zhe-Xi Luo of the University of Chicago. Utah has a diverse (~100 species) record of Late Cretaceous mammals known from isolated teeth and jaw fragments. This recent discovery is Utah's first Early Cretaceous mammal and the first skull of a Cretaceous mammal. Additionally, it is both the youngest known haramyid and the first ever found in North America. The new haramiyid is named *Cifelliodon wahkarmoosuch* for Richard Cifelli of the University of Oklahoma, a pioneer in researching Mesozoic mammals, and the species name is a reflection of the Ute Indian words for "Yellow Cat." Zhe-Xi and I asked University of Utah post-doctoral student Adam Huttenlocker, now at the University of Southern California, to take the lead on the project. Adam extracted an extraordinary amount of information from this three-dimensional skull by creating digital models of the molars and the brain permitting some critical connections. First, he recognized that the teeth were nearly identical to some problematic, isolated teeth from the Early Cretaceous of North Africa named *Hahnodon*, placed in its own family the Hahnodontidae. Thus, he found that the hahnodontids were Haramiyids and that *Cifelliodon* should be assigned to the haramyid family Hahnodontidae. Furthermore, he was able to show a possible connection with the oddball, problematic Late Cretaceous Southern Hemisphere mammalian group the gondwanatheres based on procumbent incisors and several other cranial characters.

Once again, Utah fossils demonstrate not only international significance, but global paleobiogeographic significance. Both the largest and the smallest of our Yellow Cat terrestrial vertebrates indicate that the opening of the North Atlantic, which acted as an oceanic barrier to faunal exchange, occurred as much as 30 million years later than previously thought, and faunal exchange between the Northern and Southern Hemisphere was possible across the supercontinent of Pangaea as much as 15 million years into the Early Cretaceous.

New Park Highlights Petrified Wood Near Park City

Ever since the discovery of petrified logs during construction in the Silver Creek Business Park area in the 1990s, community leaders dreamt of a park highlighting Park City's petrified wood and its geologic story. That park, just southeast of the Interstate 80-U.S. Highway 40 junction, is now a reality and will soon be open to the public.

Eight panels at the Sunrise Rotary Geologic Park at Silver Creek Village describe petrified wood, local geology, and Park City mining history. A committee of local community leaders—including Bill Loughlin, Loughlin Water Associates, LLC; Andy Armstrong of Armstrong Project Management; Doug Evans, Mountain Regional Water Special Service District; Mike Luers, Snyderville Basin Water Reclamation District; Sandra Morrison, Park City Historical Society and Mining Museum; Ericka Wells, Park City Sunrise Rotary Club; and Sherie Harding, Adjunct, Westminster College—is working with the Utah Geological Survey to design the panels.

Funding for the park was provided by Matt Lowe, developer of Silver Creek Village; Park City Sunrise Rotary Club; Summit County Recreation Arts and Parks (RAP) Tax Cultural Committee; the Association for Women Geoscientists, Salt Lake Chapter; the Association of Environmental and Engineering Geologists, Rocky Mountain Section; Sinclair Oil Corporation; and the Utah Geological Association.

The Sunrise Roatary Geologic Park at Silver Creek Village at Lot 4 on Silver Creek Drive. Completion of the park is scheduled for early fall 2018. Photo courtesy of Bill Loughlin.

The Unsung Hero of Energy Conservation in Utah

ENERGY NEWS

BY **Michael Vanden Berg**

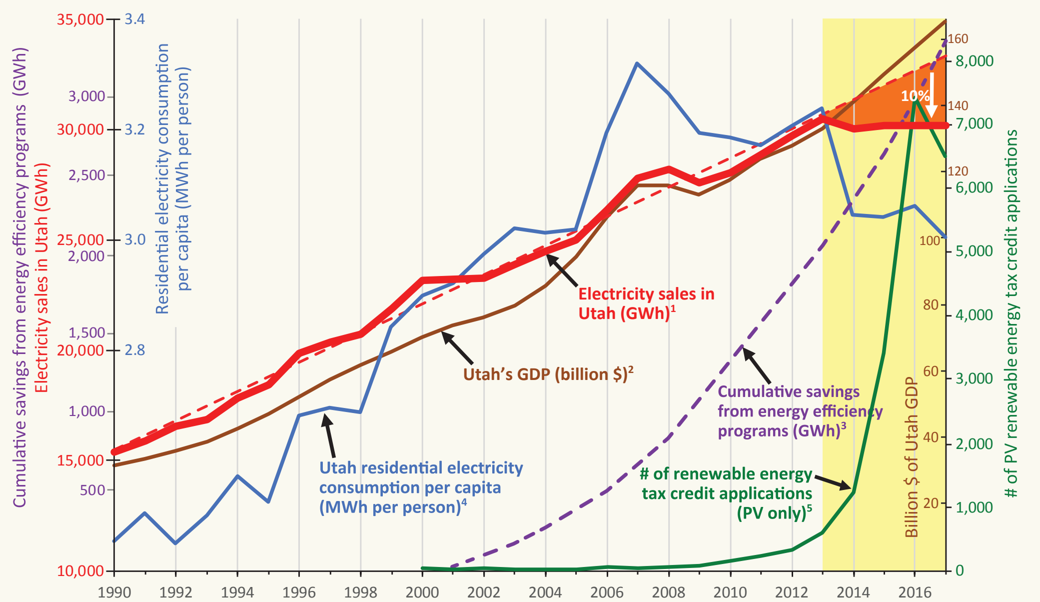
Since 1960, Utah electricity consumption (sales) has increased at an average rate of 4.3 percent each year. While the year-over-year rate of increase can fluctuate with broad economic conditions, the overall rate of increase is fairly steady and correlates with the rate of population increase as well as a steady increase in per capita electricity usage—at least up until 2013. After 2013, data show that electricity consumption in Utah decreased slightly and then plateaued. One year of consumption decrease, or one or two years of only minor increases, are normal and usually correspond to economic recessions (like in 2008). However, with full-year data for 2017 now available, electricity sales in Utah are in their fourth year of stagnant growth and this is occurring at a time when the Utah economy is performing at an all-time high. So, what might be happening? What has changed?

The graph to the right displays total electricity sales for the state of Utah (bold red line) from 1990 to 2017. This line shows a steady growth rate of 3 percent per year, illustrated by the red dashed trend line, at least until 2013. After 2013, electricity sales decreased slightly then remained steady until 2017 when consumption totaled 30,202 gigawatthours (GWh). If sales growth had continued at the same steady rate seen from 1990 to 2013, electricity demand in 2017 should have increased to 33,320 GWh. It appears that something has reduced utility-scale electricity sales in 2017 by over 3000 GWh, or roughly 10 percent. One possible culprit is the recent explosion in distributed (residential and commercial) rooftop photovoltaic (PV) solar systems; all one needs to do is drive around Salt Lake City (or any other city) to see all the new glistening PV panels adorning numerous rooftops. Tracking total electric generation from these new solar arrays is difficult because power companies only track net electricity sent back to the grid, not necessarily all electricity generated and used onsite—and often this data is not available in the public domain. However, as more and more PV systems come online throughout the state, there inevitably will be an effect on utility-scale electricity demand.

The exponential growth of Utah's residential and commercial PV capacity is most easily recognized by plotting the number of renewable energy tax credits processed each year. In 2009, Utah processed only 86 renewable tax credits for PV systems in the state. By 2016, that number jumped to over 7000, a true "hockey stick" of spectacular growth (green line on graph). In contrast to utility-scale solar systems (which also have increased dramatically in the state to over 800 megawatts in capacity), the net generation from rooftop systems does not get recorded in publicly-available statewide statistics. On the other hand, the effect of Utah's vast new rooftop solar capacity does seem to be showing up as a reduction in electricity consumption, since residential and commercial customers are consuming less utility-generated electricity. But does this account for the entire 3000 GWh reduction in sales? Let's do the math: non-utility-scale solar capacity averaged 162 megawatts in 2017 (data from the U.S. Energy Information Administration). If we apply an estimated 20 percent capacity factor (CF, annual average for Utah), we can expect that these PV panels generated about 284 GWh of electricity in 2017 (162 MW x 24 hours x 365 days x 0.2 CF). So, the current distributed solar in Utah can only account for about 10 percent of the estimated reduction in consumption (or 284 GWh of the 3000 GWh of decreased sales). So, what about the remaining 90 percent?

Let's look at another electricity consumption metric that also shows a decrease after 2013—residential electricity sales per person in Utah, the blue line on the graph. Consumption per capita steadily increased from 1990 to 2007 (at a rate of 1.2 percent per year), where it peaked at 3.32 megawatthours (MWh) per person per year. Usage decreased between 2007 and 2011 due to the economic recession, before increasing again in 2012 and 2013 to 3.24 MWh per person. Instead of continuing an upward trend, which should have resulted in a usage of about 3.6 MWh per person in 2017, per person sales decreased to 3.01 MWh, a 16 percent reduction. But the question remains, what is driving this post-2013 decrease in sales?

Have you recently changed your lightbulbs from incandescent to compact-fluorescents? What about to LEDs? Have you installed a new air conditioning unit lately? What about adding insulation in your attic? These seemingly small home improvements can all add up to make



1Data from U.S. Energy Information Administration
2Data from U.S. Bureau of Economic Analysis
3Utah Public Service Commission, Rocky Mountain Power, Utah Clean Energy
4Utah population data from Kem C. Gardner Policy Institute, University of Utah
5Data from Utah Office of Energy Development; 2017 data estimated

a dramatic impact on Utah's overall electricity demand. The true effects of the often-overlooked energy efficiency practices on Utah's overall demand are difficult to quantify, but the evidence is quite clear—Utah has experienced a dramatic decrease in demand that cannot be totally explained by an increase in distributed solar. Since 2001, PacifiCorp's Rocky Mountain Power, which serves 80 percent of Utah's consumers, has saved an estimated 3356 GWh (cumulative total from 2001 to 2017) of electricity through its various energy efficiency programs (purple line on graph). This is slightly higher than the estimated 2700 GWh mentioned above but is in the right ballpark.

Energy efficiency effects can also be qualitatively examined by studying the relationship between electricity use and Utah's gross domestic product (GDP). As stated previously, total demand for electricity has flattened since 2013, but Utah's GDP still shows significant annual growth (brown line on graph). This comparison suggests that the strong energy efficiency programs being pushed by Rocky Mountain Power, other smaller utilities, and by local and state governments are having a dramatic effect on Utah's electricity demand.

The data clearly show a major change in electricity usage in Utah starting in 2013. Undoubtably a small portion of this change is the direct result of exponential growth in residential and commercial solar systems. But, solar only accounts for roughly 10 percent of the change; the other 90 percent is harder to nail down but is most likely the result of an increase in energy efficiency programs implemented by Rocky Mountain Power and other groups over the past 5 to 10 years. At some point, growth in the electricity sector will return. The "low hanging fruit" of energy efficiency will soon be exhausted (at least until new technology arrives and the cycle repeats), and incentives for rooftop solar are being reduced—already resulting in a slow down of the total number of tax credits processed, down to about 6500 in 2017 compared to the 7400 in 2016. In addition, there is the looming electrification of our transportation system that could create major changes to our electricity demand. But in the meantime, Utah should be proud of the progress it has made in becoming more efficient and more green.

GLAD YOU ASKED

TEACHER'S CORNER

BY Suzanne Sawyer

Why Are Natural Resources, Such As Coal, Found In Some Places But Not In Others?

This question is one that comes up regularly and is also a concept that Utah 8th grade students are asked to explore. To answer the question, we'll use an illustration from the Utah Core Standards for 8th grade.

> Standard 8.4.1 – Construct a scientific explanation based on evidence that shows that the uneven distribution of Earth's mineral, energy, and groundwater resources is caused by geological processes. Examples of uneven distribution of resources could include Utah's unique geologic history that led to the formation and irregular distribution of natural resources like copper, gold, natural gas, oil shale, silver and uranium.

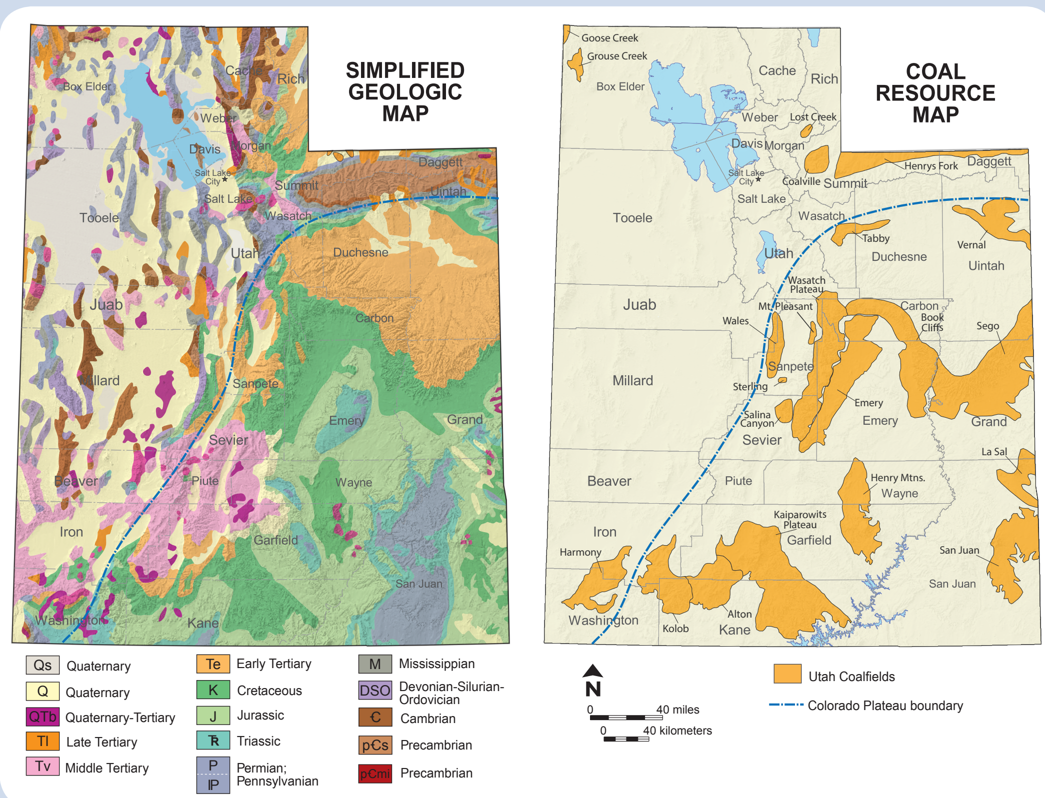
Students will need to understand two concepts to be able to construct the explanation:
1. The geological processes that create various types of resources.
2. The geological processes and timing of events that have occurred in different parts of Utah.

A suggested lesson plan for this standard (see the resource list below) has each student choose a resource that can be found in Utah. The students are given an opportunity to research their resource to determine why it is important to society and how it is formed. Students then compare a resource map with a geologic map and form a hypothesis about how their resource relates to geology. Finally, students do additional research to back up their claims.

As an example, let's return to the opening question and explore coal and its relationship to geology. By researching, I discover that coal is formed in areas where millions of years ago there were shallow seas in a tropical climate. Lush vegetation grew in swamps around the seas. Over time the plant material was buried under layers of sand and mud. Over millions of years, pressure from the overlying rocks and heat from the Earth changed the plant matter into coal.

I find out that coal is an important energy resource. In the past coal was used to heat homes and run machinery in factories. Today coal is mostly used to generate electricity.

When I compare a coal resource map to a geologic map of Utah, I find that coal deposits are mostly found in the Colorado Plateau. I hypothesize that the Colorado Plateau area must have once had the right climate and conditions to host swamps containing lots of plants and organic material that converted to coal. I also expect to find layers of sandstone and mudstone.



Next, I research the Colorado Plateau. The Colorado Plateau is made of many layers of sandstone, mudstone, limestone, and other sedimentary rocks. The rocks in the Colorado Plateau are 65 to 300 million years old and were deposited in deserts, floodplains, tidal flats, and seas. Over the past 20 million years or so, the Colorado Plateau has been uplifted a mile or more, causing rivers to cut deep canyons in the plateau, exposing the layers of various sedimentary rocks, including coal.

After completing this process, students will understand some relationships between the distribution of resources and the geologic history of Utah.

The Utah Geological Survey (UGS) has many online publications that can be used as teacher resources and to aid student research including maps and booklets. Many of these publications and other resources are highlighted under the "For Teachers" tab on the UGS website (geology.utah.gov). These publications are also available for purchase through the Utah Department of Natural Resources Map & Bookstore: https://www.utahmapstore.com/.

Teacher Resources:

Utah State Core Resources and Lesson Plan:
https://www.uen.org/core/displayLinks.do?courseNumber=3880&standardId=77980
https://www.seedstorylines.org/8-4-1

Utah Geological Survey Publications:

Geologic Resource Maps:
Energy and mineral resource maps, available at: https://geology.utah.gov/map-pub/maps/geologic-resource-maps/, including oil and gas, coal, geothermal, metallic and non-metallic minerals, and others.

Geologic Maps:
The Geologic Map Portal (https://geology.utah.gov/apps/intgeomap/) is an interactive map that can be used to explore Utah geology. It shows geologic mapping at varying levels of detail (scale), gives detailed map unit descriptions and can be viewed in 3D mode to highlight relationships between geology and topography.

The UGS Geologic Maps page (https://geology.utah.gov/map-pub/maps/geologic-maps/state-of-utah-geologic-maps/) features several simplified geologic maps of Utah, including a postcard-sized map. The postcard map provides a good overview of the geology of the state.

Research Sources for Students:

These publications offer excellent resources for students to use in researching the distribution and related geology of various resources in several Utah counties.

Geologic Resources of Salt Lake County - https://ugspub.nr.utah.gov/publications/public_information/PI-5.pdf

Geologic Resources of Summit County - https://ugspub.nr.utah.gov/publications/public_information/PI-7.pdf

Geologic Resources of San Juan County - https://ugspub.nr.utah.gov/publications/public_information/PI-14.pdf

Geologic Resources of Washington County - https://ugspub.nr.utah.gov/publications/public_information/PI-20.pdf

Geologic Resources of Box Elder County - https://ugspub.nr.utah.gov/publications/misc_pubs/MP-89-3.pdf

The American Association of Petroleum Geologists (AAPG) held their annual convention in Salt Lake City this past May. The meeting, hosted by the Utah Geological Association, drew nearly 4000 professionals from over 50 countries. Several UGS employees served on the volunteer organizing committee, including General Chair Michael Vanden Berg, short course chair Tom Chidsey, social event co-chair Stephanie Carney, and educator program co-chairs Mark Milligan and Jim Davis. Several other UGS staff participated by leading fields trips, giving presentations, staffing the UGS exhibit booth, and organizing a massive well core display and large display of Utah dinosaurs. The meeting was a huge success (an estimated $4 million contribution to Utah's economy) receiving significant positive feedback on the quality of the technical program, the fantastic field trips and short courses, the nearly sold out exhibition hall, and the geologic beauty of our state.

Rincon is a term used in the southwestern U.S. to describe a dry, semicircular canyon with a butte in the middle. It is the remnant of an entrenched cutoff river meander. Rincons are found along a few rivers across the Colorado Plateau; some are very prominent, while others are not. Many rincons in Utah are inaccessible by car and may only be seen via air, boat, or very long hike. Of those that are accessible by car, an even smaller portion are *easily* accessed by car. One rincon on the San Juan River in southwestern Utah between Bluff and Mexican Hat fits the bill. This unnamed rincon is worth visiting as you can drive to its edge. The San Juan River rincon is approximately 1 mile in diameter at its widest, over 600 feet deep, and the butte in the middle of the rincon towers over 550 feet above the surrounding ancestral river bed.

Entrenched river meanders occur when low-velocity meandering streams later increase velocity (due to uplifted headwaters) and down-cutting power, causing the channel pattern to become "entrenched" in the underlying bedrock over millions of years of erosion (for additional information on the geologic processes that create entrenched river meanders see *Survey Notes* v. 45, no. 3, p. 12). River meanders, entrenched or not, can eventually become abandoned or cutoff due to the erosive power of rushing water along the outer banks of the entering and exiting meander corners. The river channel corners move ever-so-slowly toward each other, until the neck of land separating the channel bends finally erodes away completely, leaving behind an oxbow lake that is no longer connected to the main river channel. In the case of *entrenched* cutoff river meanders, oxbow lakes rarely (if ever) stick around for very long as the main river channel's erosive power washes away the sediment at the ends of the lake causing the lake's water to flow back into the main river channel. The lack of water in the rincon could also have something to do with the fact that entrenched cutoff river meanders are generally only present in desert environments.

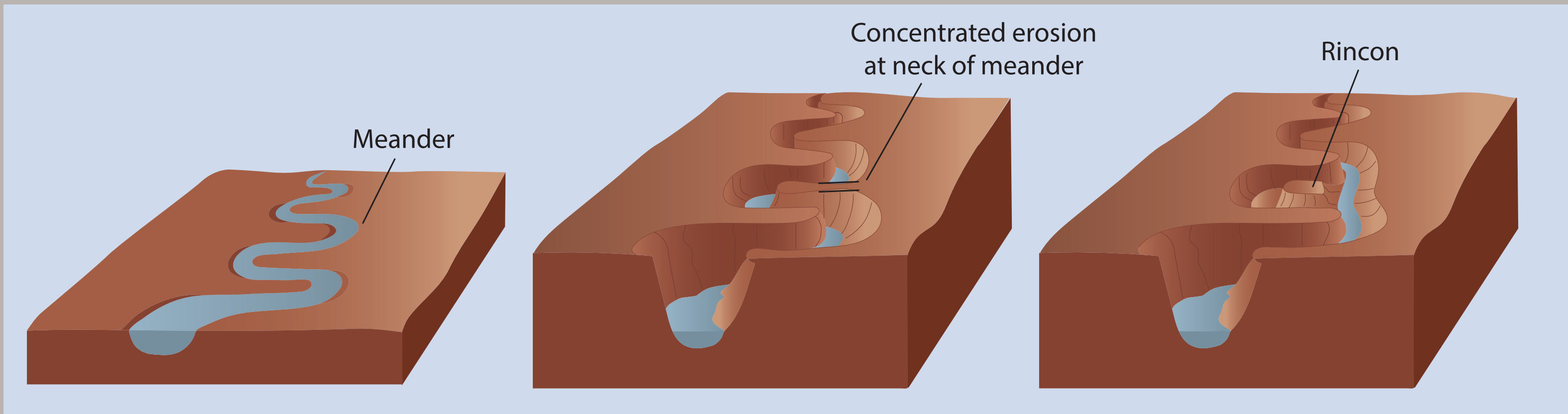
SIGHTS

San Juan River Rincon, San Juan County

BY Marshall Robinson

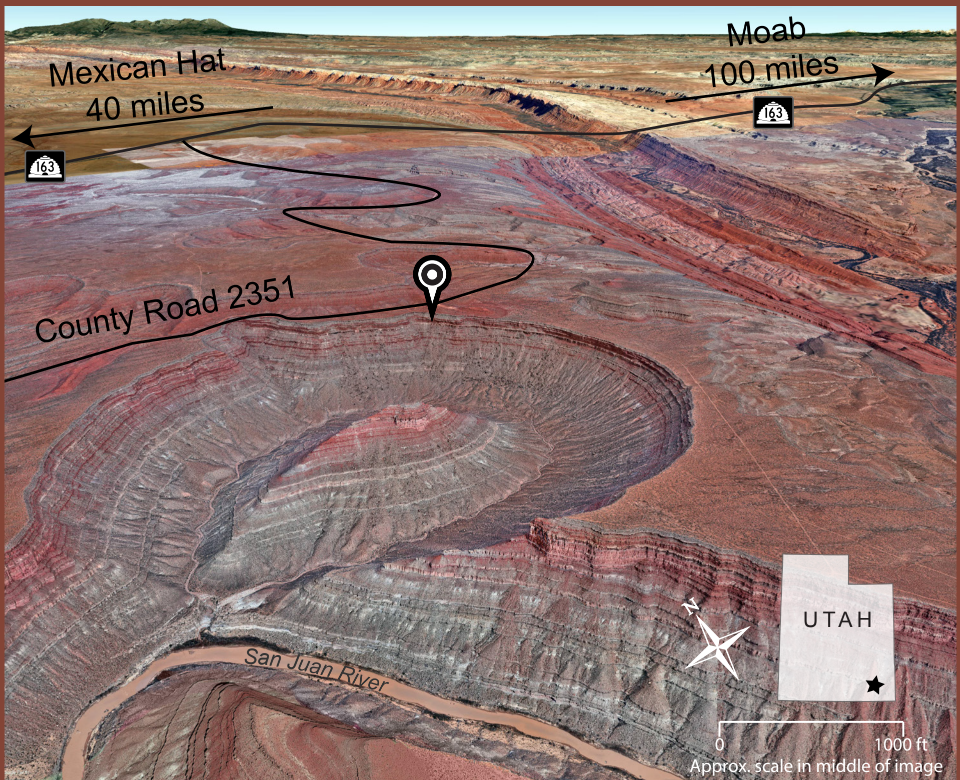
View southwest of rincon on San Juan River between Bluff and Mexican Hat.

At the San Juan River rincon, the Halgaito Formation overlies the Honaker Trail and Paradox Formations. These roughly 300-million-year-old rock formations consist of limestone, siltstone, sandstone, and shale. Deposition of these rocks occurred at a time when the dominant landscape was marine and the sea level fluctuated widely. After the sea receded, a mostly flat terrain was left behind for the ancestral San Juan River to slowly meander across before uplift of the Colorado Plateau occurred during the past few tens of millions of years. This uplift caused the meandering stream to begin downcutting, entrenching itself over 1,000 feet below its original elevation. The present-day rincon was part of the original river path, but at some point, the San Juan River cut a straighter path, abandoning the now-dry canyon.



HOW TO GET THERE

From Moab, drive south on U.S. Highway 191 for approximately 100 miles to Bluff. About 6 miles west of Bluff where U.S. Highway 191 turns south, continue west on U.S. Highway 163 for approximately 7.25 more miles. Turn left onto County Road 2351 (dirt road), then continue for approximately 4.5 miles where you can pull off the road and walk to the edge of the rincon. Do not continue past this point in a sedan as the road becomes very rough. According to Google Maps, County Road 2351 creates a loop with U.S. Highway 163. This may have been true at some point but is no longer the case. The overlook's coordinates are 37.2238° N, 109.7343° W.



SURVEY NEWS

2018 Crawford Award

The prestigious 2018 Crawford Award was presented to **Steve D. Bowman**, **William R. Lund** (editors), **Gregg Beukelman**, **Rich Giraud**, **Mike Hylland**, and **Tyler Knudsen** (contributing authors) in recognition of their work on the outstanding publication *Guidelines for Investigating Geologic Hazards and Preparing Engineering-Geology Reports, with a Suggested Approach to Geologic-Hazard Ordinances in Utah* (UGS Circular 122).

Left to right: Rich Giraud, Steve D. Bowman, Tyler Knudsen, William R. Lund (not pictured Gregg Beukelman, Mike Hylland).

UGS Circular 122 merits the Crawford Award because of its scope, clarity, incorporation of state-of-the-science knowledge and methods, and, most importantly, because it will become a reference guide for engineering geologists conducting geologic-hazard investigations in Utah, a model for the development of similar practice guidelines by other jurisdictions, and a model for regulatory report reviewers.

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.

Employee News

The American Association of Petroleum Geologists (AAPG) presented the 2018 Public Service Award to **Thomas C. Chidsey, Jr.,** in recognition of his career in petroleum geology that has included a dedication to the geologic education of the public, government officials, regulators, stakeholders, tribal representatives, students, and others in Utah. The AAPG Public Service Award is given to acknowledge contributions by members of the Association to public affairs and to encourage geologists to take a more active part in such affairs.

Award presented by AAPG President Charles Sternbach (left).

Grant Willis was honored with a Geological Society of America (GSA) Fellowship in recognition of his distinguished contributions to the geosciences as both a working geologist and as a geologic administrator. Grant's contributions to geologic mapping and deciphering the basic geologic framework of Utah have set a high standard for years to come. Other Utah geologists elected as GSA Fellows in 2018 are Carol M. Dehler and Tammy M. Rittenour of Utah State University, and Michael J. Dorais of Brigham Young University.

Chris Wilkerson retired in July after 30 years of service.

Chris joined the UGS in 1987 as a receptionist. She later became a geologist with the Geologic Information and Outreach Program where she focused on translating geologic articles and publications for a non-technical audience, assisted in answering public inquiries, managed the UGS website, and contributed to many of the regular columns in *Survey Notes*. We will miss her passion for sharing geologic information and wish her well in her retirement!

Vicky Clarke retired in September after 25 years of service. Vicky

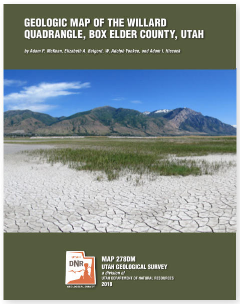
joined the UGS in 1993 as a graphic designer responsible for the design and layout of numerous UGS publications, including *Survey Notes*. In 2006, she was promoted to Publications Manager of the Editorial Section, and it is largely through her leadership that the UGS is recognized for its high-quality publications. She pioneered the yearly UGS *Calendar of Utah Geology* and helped make it the major success it is today. Vicky has been a great asset to the UGS, and her creative talent and knowledge will be greatly missed. We wish her well in her retirement!

Elliot Jagniecki and **Ryan Gall** have accepted positions in the Energy and Minerals Program. Elliot received his PhD from Binghamton University and has over six years of experience in the petroleum industry. Ryan attended the University of Utah and has worked in the petroleum industry for the past two years. Elliot fills the position left by **Craig Morgan** who retired, and Ryan replaces **Mark Gwynn** who left the UGS for a position with the Utah Division of Oil, Gas and Mining.

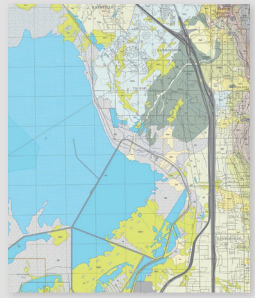
Lindsey Smith and **Trevor Scholssnagle** are the newest members of the Groundwater Program. Lindsey is a wetland ecologist and former consultant in Louisiana. He replaces **Rhyan Sempler** who moved to Montana. Trevor is a geologist and former consultant in New York. Trevor replaces **Stan Smith** who moved to the private sector. Welcome to Elliot, Ryan, Lindsey, and Trevor, and best wishes to Mark, Rhyan, and Stan!

NEW PUBLICATIONS

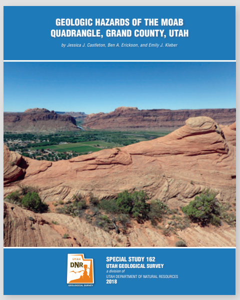
UGS publications are available for download at geology.utah.gov or for purchase at utahmapstore.com.



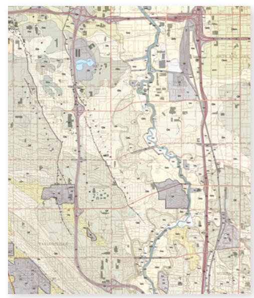
Geologic map of the Willard quadrangle, Box Elder County, Utah, by Adam P. McKean, Elizabeth A. Balgord, W. Adolph Yonkee, and Adam I. Hiscock, 18 p., 2 pl., GIS data, scale 1:24,000, **Map 278DM**



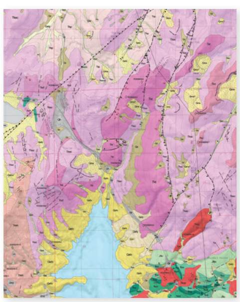
Geologic map of the Farmington quadrangle, Salt Lake and Davis Counties, Utah, by Mike Lowe, Stefan M. Kirby, and Kimm M. Harty, 2 plates, GIS data, scale 1:24,000, ISBN 978-1-55791-946-5, **Map 279DM**



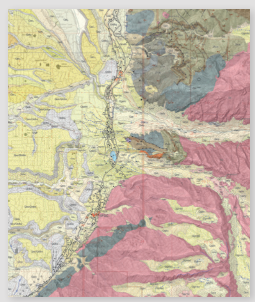
Geologic hazards of the Moab quadrangle, Grand County, Utah, by Jessica J. Castleton, Ben A. Erickson, and Emily J. Kleber, 33 p., 13 pl., ISBN 978-1-55791-945-8, **Special Study 162**



Interim geologic map of the Salt Lake City south quadrangle, Salt Lake County, Utah, by Adam P. McKean, 17 p., 1 pl., scale 1:24,000, **Open-File Report 676**



Interim geologic map of the Park City East quadrangle, Summit and Wasatch Counties, Utah, by Robert F. Biek, 19 p., 2 pl., scale 1:24,000, **Open-File Report 677**



Interim geologic map of the Draper quadrangle, Salt Lake and Utah Counties, Utah, by Adam P. McKean and Barry J. Solomon, 33 p., 1 pl., GIS data, scale 1:24,000, **Open-File Report 683DM**

RECENT OUTSIDE PUBLICATIONS BY UGS AUTHORS

Catastrophic mega-scale landslide failure of large volcanic fields, by **R.F. Biek** , D.B. Hacker, and P.D. Rowley: GSA Today, v. 27, no. 12, p. 30–31.

Charophyte flora from the Brian Head Formation, southwestern Utah, and its biostratigraphic implications, by J. Sanjuan, J.G. Eaton, K.C. Rafferty, and **R.F. Biek**: Micropaleontology, v. 63, no. 1, http://doi.org/10.29041/Micro.63.1.1–14.

Catastrophic collapse features in volcanic terrains—styles and links to subvolcanic magma systems, by D.B. Hacker, P.D. Rowley, and **R.F. Biek**, in C. Breitkreuz and S. Rocchi, editors, Physical geology of shallow magmatic systems—Advances in volcanology series: Springer International Publishing, p. 1–34, doi: 10.1007/11157_2017_1001.

Incremental growth of therizinosaurian dental tissues: implications for dietary transitions in Theropoda, by K. Button, H. You, **J.I. Kirkland**, and L. Zanno: PeerJ5: e4129; DOI 10.7717/peerj.4129.

Testing the efficiency of rover science protocols for robotic sample selection: A geoheuristic operational strategies test, by R.A. Yingst, J.K. Bartley, **T.C. Chidsey Jr.**, B.A. Cohen, G.J. Gilleaudeau, B.M. Hynek, L.C. Kah, M.E. Minitti, R.M.E. Williams, S. Black, J. Gemperline, R. Schaufler, and R.J. Thomas: Acta Astronautica, Online: https://www.sciencedirect.com/science/article/pii/S0094576517312651.

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