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MARKAGUNT MEGABRECCIA

UTAH'S LARGEST CATASTROPHIC LANDSLIDE

THE DIRECTOR'S PERSPECTIVE

by *Richard G. Allis*

This *Survey Notes* issue is being compiled as the Utah legislature nears the end of its 2013 session. Notable this year is the passage of a bill that will require school districts to complete a seismic safety evaluation for each school building constructed before 1975 whenever they issue a bond for improvements. The vulnerability of some school buildings to severe damage in a major local earthquake has been a priority issue for the Utah Seismic Safety Commission for many years, but repeated requests for funding to identify the buildings in most urgent need of strengthening have been unsuccessful. Schools are high-occupancy facilities, and they are often major gathering places and emergency shelters after disasters, so ensuring they will survive earthquakes is extremely important. Although the most populous parts of the Wasatch Front have not experienced a very damaging earthquake, paleoseismic studies in trenches across the Wasatch fault indicate a large (about magnitude 7) earthquake occurs on average about every 300 years on some segment of the fault. The last major earthquake on the Salt Lake City segment was 1400 years ago.

According to the Utah Division of Emergency Management, the most recent HAZUS modeling of the impacts of a large, central Wasatch Front earthquake highlights the vulnerability not just of Wasatch Front cities, but of the whole state to devastating property and economic losses. HAZUS is the loss-estimation methodology developed by the Federal Emergency Management Agency and the National Institute of Building Sciences for local and state officials to estimate losses from a natural hazard event, and the scale of response and recovery that will be needed. HAZUS has been calibrated against many recent natural hazard events, both nationally and globally, and the model discussed here is based on the actual building infrastructure across the Wasatch Front. Modeling of a magnitude 7 earthquake on the Salt Lake City segment of the Wasatch fault estimates that 200,000 (about a third) of the buildings across the Wasatch Front will be at least moderately damaged, with the greatest damage being to single-family residences (47,000 homes destroyed). By far the greatest building damage will occur in unreinforced masonry buildings (44,000 destroyed). When essential facilities such as hospitals, schools, police, and fire stations are considered, over half the hospitals and a quarter of the schools will have at least moderate damage. On the day of the earthquake, the damage will result in only 2000 hospital beds (38 percent) being available for existing patients and those injured in the earthquake. The extent of injuries and deaths depends on the time of day of the earthquake, with the greatest casualties occurring with a nighttime earthquake. The number of injured people requiring hospitalization but not having life-threatening injuries varies between 5000 and 8000; those having life-threatening injuries ranges between 900 and 2200, and between 1700 and 2500 people will be killed by the earthquake. The greatest disruption to utility services will be to the potable water supply, with 380,000 households initially without water on day 1, and even after a month this will only be reduced to 320,000 households. On day 1, 380,000 households will be without power, but this has reduced to 30,000 after a month. The total economic loss is estimated to be $33 billion, with most of this coming from capital stock losses ($24 billion, half being residential), and $7 billion from lost income.

These numbers are staggering, and the long-term economic impacts on Utah of a magnitude 7 central Wasatch Front earthquake are obvious. Perhaps the best example of damaging earthquakes in an urban area with buildings similar to Salt Lake City is the recent earthquake sequence near Christchurch, New Zealand (population 380,000 compared to 190,000 in Salt Lake City and 2 million across the Wasatch Front). A magnitude 7.1 earthquake occurred 30 miles from Christchurch in 2010, followed by several magnitude 6 quakes and many magnitude 5 quakes closer to the city in the subsequent two years. There were nearly 200 fatalities, 1000 buildings in the central building district have been demolished so far, 1500 houses have been demolished, 70 miles of replacement wastewater pipe and 15 miles of freshwater pipe have been installed so far, and total losses are estimated to be in the range of $10–20 billion. Reconstruction of the city is expected to take about 20 years. Clearly, we all need to take the risk of earthquakes in Utah seriously, and the process of improving the resilience of our schools is an important step forward.

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THE EARLY MIOCENE MARKAGUNT MEGABRECCIA

UTAH'S LARGEST CATASTROPHIC LANDSLIDE

by Robert F. Biek

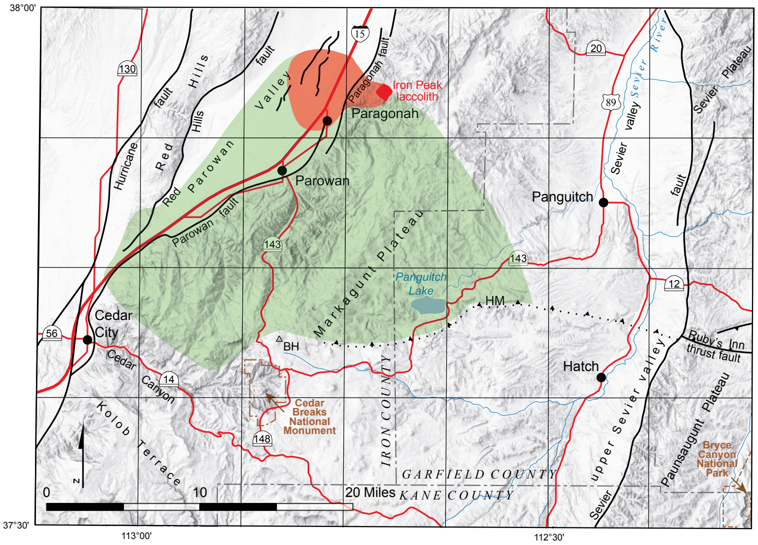
Numerous very large landslides, known as gravity slides, are preserved throughout the western U.S. The desert basins of southern California contain many well-studied examples, as does southwestern Utah (for example, large gravity slides associated with the Iron Axis intrusions and the west side of the Beaver Dam Mountains—see *Survey Notes*, v. 34, no. 3, p. 1–3 and v. 41, no. 2, p. 4–6). What few people know, however, is that Utah has another, much larger gravity slide northeast of Cedar City on the Markagunt Plateau of southwestern Utah. The story of the discovery of this enigmatic deposit and how it came to be understood is a testimony to the patient research of many geologists, recently culminating in a new geologic map of the region.

What is the Markagunt Megabreccia?

The Markagunt Megabreccia was named in 1993, just over a decade after geologists first began to realize that the gently east-tilted, high-elevation Markagunt Plateau was capped by something other than the normal sequence of volcanic rock commonly found in southwest Utah. At its simplest, the Megabreccia is a great sheet of volcanic rock that slid many miles, placing older rock on younger rock above a subhorizontal surface. Blanketing much of the central and northern Markagunt Plateau, it consists of very large blocks of Miocene and Oligocene regional ash-flow tuffs (originally erupted from calderas near the Utah-Nevada border) and locally derived volcanic and volcaniclastic rocks. One way to think of the Markagunt Megabreccia is like a deck of thick cards that are sheared between one's hands—strata are intensely deformed along the shears themselves, but remain relatively undisturbed in the interior of the blocks. The fact that the Megabreccia consists of large blocks many square miles in size, bounded below by an inconspicuous shear plane, is one of the reasons it remained undiscovered for so long. Elsewhere, the Megabreccia is a structurally chaotic assemblage or consists of large tilted blocks of these rocks. Nearly everywhere, rocks immediately below the Megabreccia are undisturbed.

The Markagunt Megabreccia is indeed Mega! It covers at least 300 square miles of the northern and central Markagunt Plateau, an area somewhat larger than the whole of Salt Lake Valley and nearly ten times the size of New York City's Manhattan Island. Because the inferred source area of the Markagunt Megabreccia is partly concealed beneath north-central Parowan Valley, the full extent of the Megabreccia must be greater still, probably at least 360 square miles (additional debris avalanche deposits south of Cedar Breaks National Monument suggest that the original gravity slide was larger yet, perhaps closer to 500 square miles). It is by far the largest of a dozen or so gravity slides known in Utah.

The Markagunt Megabreccia exhibits the full range of structural features commonly seen in modern landslides, including compression and resultant folding and thrust faulting in the landslide's toe area, simple translational movement across the main body of the landslide, and extensional faulting in the upper parts of the landslide. The diagram on page 2 illustrates the main features of gravity slides, which are a special class of extremely large landslides.



Index map showing extent of Markagunt Megabreccia (green) and Iron Peak laccolith (red); parts of each may be concealed beneath Parowan Valley. The Megabreccia may have extended even farther south to the junction of State Highways 14 and 148 at the western escarpment of the Markagunt Plateau. BH = Brian Head peak; HM = Haycock Mountain.

There is no single place where we can go to see the entire story encapsulated by the Megabreccia. Different geologists have seen different parts of the beast, and thus understandably came to different conclusions about this complex unit. It reminds me of the allegory of the "blind men and the elephant." Part of it feels like one thing, other parts like something else; in the beginning it was simply too big and too strange for any one person to understand. Early, small-scale geologic maps of the plateau didn't even recognize the Megabreccia. Those geologists—who necessarily mapped in reconnaissance mode, setting the stage for later more detailed geologic mapping—mapped just the back of the elephant and understandably did not recognize the Megabreccia for what it was at the time.

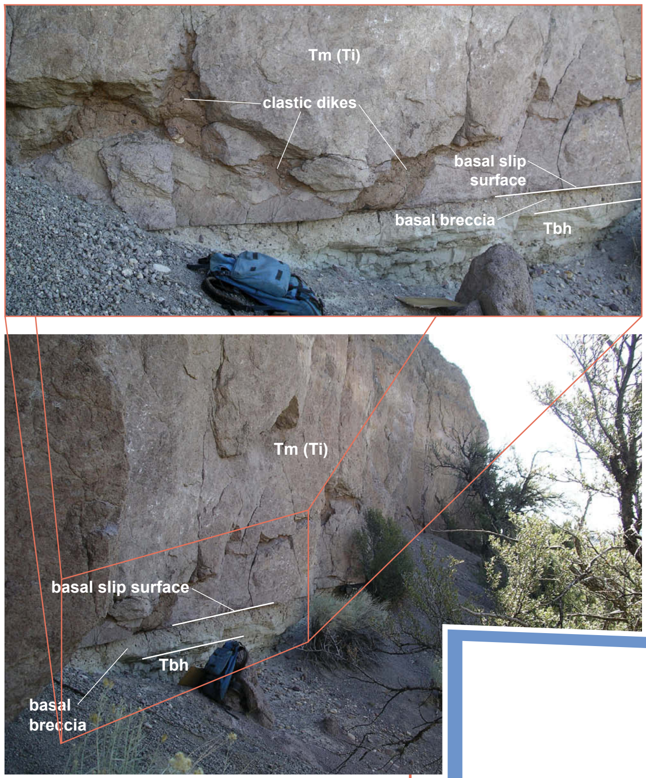
The discovery and our still-unfolding understanding of the Megabreccia began in the early 1960s when John Anderson, then working on his dissertation at the University of Texas at Austin, mapped the geology of the northern Markagunt Plateau. He and his student assistant, Pete Rowley, found several small areas of older volcanic rocks resting on younger volcanic rocks, and attributed their origin to sliding down the flanks of over-steepened volcanic domes. It wasn't until the late 1980s to early 1990s, when John (then a Professor at Kent State University) and half a dozen U.S. Geological Survey-supported Master's students continued mapping in this area, that they finally had enough information to grasp what they were dealing with. Unfortunately, their work was cut short following reorganization of the USGS in the mid 1990s, when they had only just begun to appreciate the scale of this beast. Nevertheless, their combined work laid a solid foundation for future mapping in the region. I'm the lucky guy who, having been able to build on what John and his colleagues learned, stumbled across the beast's trunk, which let us revise much of what we now know about the Megabreccia.

The All-Important Haycock Mountain Exposures

Any geologist familiar with the volcanic stratigraphy of southwest Utah would stand atop Haycock Mountain and with utter confidence declare that the Isom Formation, a densely welded, 27- to 26- million-year-old ash-flow tuff that forms its resistant caprock, is undisturbed and in-place. Several have done just that. But while mapping that area, I came across several exposures—preciously small and hidden by mountain mahogany, pinyon, and juniper trees—of the base of the Megabreccia that no geologist had ever seen. There, the lower few tens of feet of the Isom Formation were brecciated and locally pulverized to rice-size pieces and then resilicified, grading upward into undeformed Isom at the crest of the mountain. The rock is technically called a cataclasite, having formed through extensive fracturing of the parent rock; it everywhere overlies a thin layer, typically one inch to one foot thick, of what looks like concrete. This thin basal breccia represents broken up, over-pressured debris that the gravity slide rode on and that was injected as dikes at the base of the Megabreccia. The base of the Megabreccia is a sharp, planar surface with striations, grooves, and small-scale brittle microfabrics including fractures known as Riedel shears, all of which serve as directional indicators, telling us that the Megabreccia was emplaced from north to south.

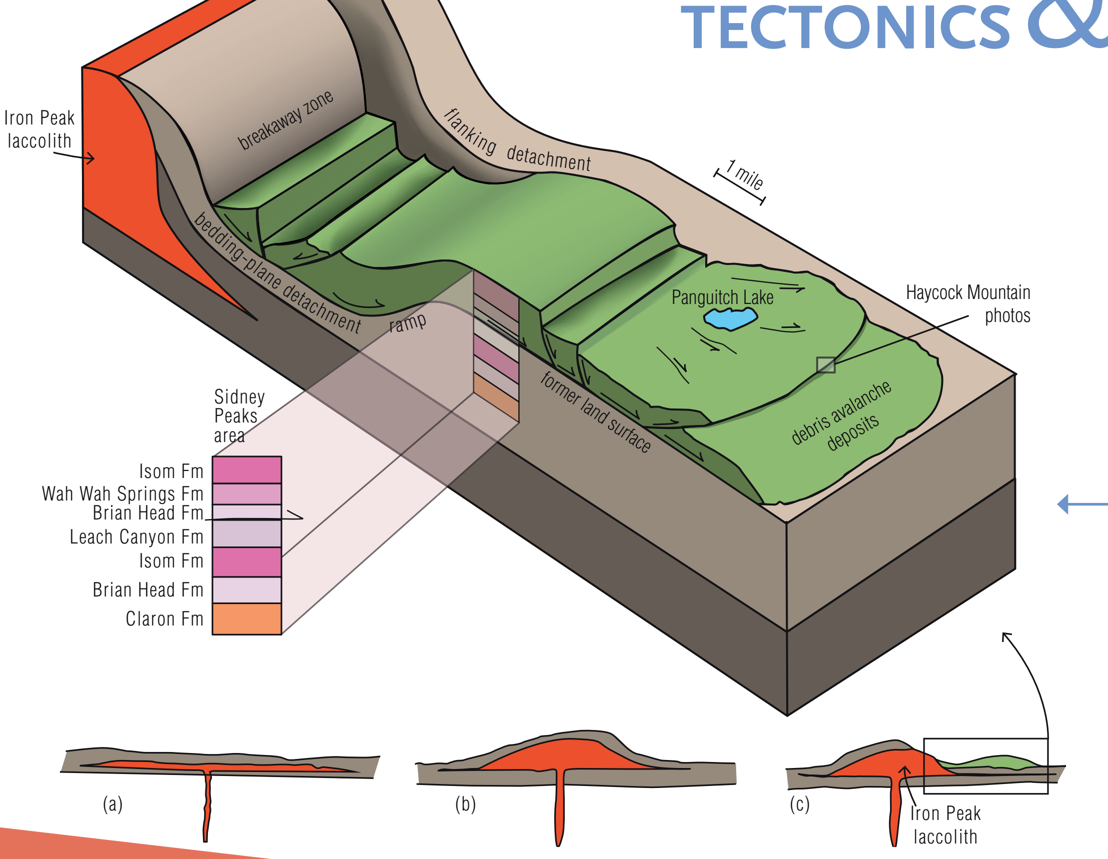
The Haycock Mountain exposures are the "trunk" of our mythical beast, something that no geologist had previously seen or understood. The exposures are important because the cataclasite, basal breccia and clastic dikes, and brittle microstructures provide strong evidence of catastrophic emplacement by gravity sliding, not by slow gravitational spreading or creep nor by seismically cycled thrust faulting. Further, these exposures unequivocally demonstrate south to southeast transport of the Megabreccia, not northward transport as originally inferred. This is the kind of evidence that most of us can only dream about finding (and which commonly comes about only after others have appreciably narrowed the search for instructive exposures!).

Geologists designate type sections of rock formations, a place where characteristic features of the rocks are well developed and can be readily studied. John Anderson designated a 2-mile stretch along Utah Highway 143, just east of Panguitch Lake, as his Markagunt Megabreccia reference section. Given what was known at the time, John and his colleagues reasonably interpreted the caprock of Haycock Mountain as in-place—part of the lower



Base of Markagunt Megabreccia exposed just south of Haycock Mountain. Thin basal breccia overlies volcaniclastic pebbly sandstone of the Brian Head Formation (Tbh) and consists of both angular (Isom) and rounded (intermediate volcanics and quartzite) clasts floating in a well-cemented sandy matrix; the breccia is texturally similar to concrete and was derived from pulverized Isom and underlying strata immediately above and below the slip surface. The breccia was injected as clastic dikes into the basal part of the Megabreccia, which here is a cataclasite that consists of pulverized and resilicified Isom Formation (Tm[Ti]). Pulverized Isom Formation forms a cliff 15 to 30 feet high and grades abruptly upward into fractured but otherwise undisturbed Isom Formation. Without seeing critical exposures such as this, Haycock Mountain appears to present a normal section of Isom Formation atop the older Brian Head Formation, an apparently normal sequence and one reason the Megabreccia remained undiscovered for so long.

GRAVITY & TECTONICS



plate, undisturbed volcanic Isom Formation. But what he could not have known is that the true size of the Megabreccia was even larger than he imagined. Ironically, his reference section turned out to include just the uppermost part of the Megabreccia—a fuller story of the Megabreccia awaited discovery in exposures just a few miles to the south at Haycock Mountain.

In their defense, early mappers of the Megabreccia started out in puzzling northern exposures, in essence high on the back of the elephant, so it wasn't readily apparent exactly what kind of creature they had. Mapping of the frontal margin of the Megabreccia, where critical exposures are best preserved, came last, and fell into my lucky hands. Yet still, as described in the recently open-filed geologic map of the Panguitch 30' x 60' quadrangle (UGS Open-File Report 599), we remain uncertain about several aspects of the Markagunt Megabreccia: its full northern extent, the location of its flanking faults, and certain features of its southern exposures, including possible debris avalanche deposits south of Cedar Breaks National Monument.

When did the Megabreccia form?

The age of emplacement of the Markagunt Megabreccia is constrained by the age of its underlying and overlying rocks. The Megabreccia was originally thought to be overlain by the apparently undisturbed 22.8-million-year-old Haycock Mountain Tuff, but we now recognize that this tuff simply rode along on the back of the great slide as a mostly undisturbed block many square miles in extent. During our recent mapping, we discovered exposures of the Megabreccia that overlie the 22.0-million-year-old Harmony Hills Tuff and stream gravel deposits that contain rounded cobbles of eroded Harmony Hills Tuff. Thus, the Megabreccia must be younger than 22 million years old.

Unfortunately, we lack overlying, post-Megabreccia rocks to significantly constrain its upper age. However, because the Megabreccia is preserved in grabens at the west margin of the Markagunt Plateau, we infer that emplacement of the Megabreccia predates the main phase of basin-range deformation, which resulted in the present topography and which began about 10 million years ago at this latitude. The Megabreccia was thus emplaced between 10 to 22 million years ago, and likely about 20 million years ago as described next.

Base of Markagunt Megabreccia at Haycock Mountain. The basal part of the Megabreccia is a cataclasite like that described in the previous photo. Here, the pulverized Isom (just above hand) and its associated basal breccia overlie Miocene gravels eroded into the Brian Head Formation; the gravels are younger than the Isom, thus creating an older-on-younger relationship. Geologists Pete Rowley (right, Geologic Mapping Inc.), Dave Hacker (center, Kent State University), and Tyler Knudsen (left, UGS) discuss significance of gravels.

GRAVITY SLIDES

Gravity tectonics describes the movement of large slabs or blocks of the Earth's brittle, uppermost crust under the dominant influence of gravity. It is a general term that encompasses a variety of very large scale, gravitationally induced earth movements that include gravity slides, rock and debris avalanches, spreading and collapse of volcanic centers, submarine slope failures, and other large earth movements, each of which is bounded below by a distinct plane of detachment. A variety of mechanisms are known to form such features, for example, the collapse of steep range fronts possibly triggered by earthquake shaking, and shallow igneous intrusions or caldera inflation that tilt overlying strata causing it to fail. Rates of emplacement can range from slow (inches or feet per year) to fast (at speeds approaching that of a bullet train).

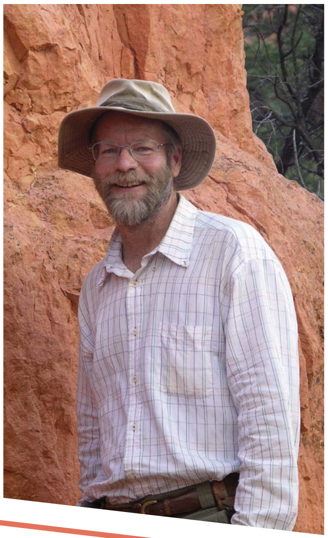
There are two schools of thought regarding the description of gravity slides, one that uses terminology adopted from the field of structural geology, the other from the study of modern landslides. Descriptive terms thus reflect the inherent bias of geologic specialization and of scale, but confusion also results from inferred rates and style of emplacement and on whether movement takes place in the upper crust or at the Earth's surface. Many geologists prefer the term detachment fault to describe the basal gravity slide surface, but, more and more, geologists are using landslide terminology to describe what in many cases are truly gargantuan, commonly catastrophic landslides, not fault blocks emplaced by episodic tectonic faulting. Descriptive terminology is also confusing because every style of tectonic faulting can be produced by landsliding, and it is not always apparent whether such features result from gravitational or tectonic forces. But one thing is certain—gravity slides are a type of landslide of terrifyingly, inconceivably large proportions.

Vertically exaggerated block diagram of an idealized gravity slide. Here, the trigger is a shallow igneous intrusion (the Iron Peak laccolith) emplaced within a few hundred feet of the Earth's surface, causing arching of overlying strata and consequent failure on over-steepened slopes. Note the four main bounding surfaces: the bedding-plane detachment in mechanically weak clay-rich rocks of the Brian Head Formation; the ramp, where the slide mass breaks upward to the surface; the former land surface, now covered by the slide mass; and the flanking detachment, in essence a strike-slip fault that bounds the margin of the slide. The basal detachment resembles shallow low-angle faults, complete with slickensided and striated surfaces, gouge zones, and brittle microfabrics. Extensional deformation characterizes the upper part of the slide, whereas compressional deformation characterizes the toe area. The main part of the gravity slide remains mostly intact with individual blocks as much as several square miles in size, preserving a stratigraphy inherited from the source area. Frontal portions of the slide mass disaggregate into debris avalanche deposits. Because gravity is the ultimate driver of such large landslides, the dip of the slip surface must be sufficient to overcome the shear or frictional strength of the detachment layer (but still is likely less than a few degrees). Once moving, however, the slides can travel many miles over former land surfaces.

Inset shows growth of laccolith: (a) initial lateral injection of igneous intrusion to its fullest extent, (b) vertical growth of laccolith from continued injection of magma, and (c) gravity sliding of oversteepened flanks.
Modified from Hacker and others (2002).

Close-up of slickenlines and fractures at the base of the Megabreccia. Here, brittle microstructures known as Riedel shears demonstrate emplacement from the north.

ABOUT THE AUTHOR



Bob Biek is a Senior Scientist with the Utah Geological Survey's Geologic Mapping Program. Since joining the Survey in 1996, he has published over two dozen geologic maps of 7.5' quadrangles along Utah's Wasatch Front and in southwestern Utah. He is the senior author on the St. George and Panguitch 30' x 60' quadrangle geologic maps, and is starting to map the southeast sector of the Marysvale volcanic field in the west half of the Loa 30' x 60' quadrangle.

How did the Markagunt Megabreccia form?

Geologists don't know for sure what triggered the gravity slide that led to formation of the Markagunt Megabreccia. This is a particularly vexing problem because the northern part of the Megabreccia, and areas even farther north, are mostly volcanic mudflow deposits of the Mount Dutton Formation; it is difficult to know where these rocks are part of the Megabreccia and where they may postdate and thus bury the Megabreccia. But given what we do know, there are two plausible explanations: (1) doming and subsequent southward sliding of roof rocks off the Iron Peak laccolith or related intrusions in the northern Markagunt Plateau, or (2) related to inflation of the crust due to emplacement of intra-caldera intrusions following eruption of the 21- to 20-million-year-old Mount Belnap caldera.

Utah's Miocene landscape looked very different than that of today; Utah occupied the east side of the Great Basin altiplano, a high-elevation plateau studded with volcanic mountains and intervening basins, analogous perhaps to the modern Altiplano of South America. The oldest volcanic rocks in southwest Utah belong to the Brian Head Formation, clay-rich volcaniclastic rocks and rhyolitic ash beds that spread across the southwest part of this high-elevation region. Brian Head strata are overlain by several aerially extensive, densely welded ash-flow tuffs that erupted from calderas near the Utah-Nevada border, which in turn are overlain by volcanic mudflow deposits and lava flows that erupted from vents on the northern Markagunt Plateau and in the southern Marysvale volcanic field. The foundation on which at least the southern part of the Marysvale volcanic field rests is thus non-resistant, clay-rich, fine-grained volcaniclastic strata of the Brian Head Formation that even today are highly susceptible to landsliding. This weak foundation is key to either explanation of the Megabreccia's origin.

Given our current understanding of the Megabreccia, our favored trigger is the 20-million-year-old Iron Peak laccolith, an idea first suggested by USGS geologists Florian Maldonado and Ed Sable in the mid-1990s. The laccolith was emplaced as molten rock from deep within the earth moved upward via vertical dikes into the Bear Valley and Brian Head Formations, where it spread out into a shallow, mushroom-shaped intrusive dome. Although modern exposures of the Iron Peak laccolith appear too small to have created a dome large enough to produce the Markagunt Megabreccia, only a small part of the Iron Peak laccolith is preserved—it must have been much larger. Evidence for its larger size includes numerous dikes in Claron strata immediately to the west of the laccolith; these were likely feeder dikes, suggesting that large parts of the laccolith must have overlain this block before being removed by erosion. An even larger laccolith can be envisioned if we postulate that part was faulted down to the west and buried by basin-fill deposits of Parowan Valley. Aeromagnetic anomaly maps and well data also suggest the Iron Peak laccolith is part of a much larger intrusive complex that underlies the Red Hills, northern Parowan Valley, northern Markagunt Plateau, and the valley north of Panguitch. In this intrusive complex, most if not all intrusions are laccoliths. Inflation of this larger complex, or several individual laccoliths within it, may have triggered catastrophic sliding of the Megabreccia. The 20-million-year-old Iron Peak laccolith is the correct age as a trigger for the Megabreccia.

It is also possible that the Markagunt Megabreccia resulted from collapse of the southwest part of the Marysvale volcanic field. In 1993, University of Arizona geologist George Davis and USGS colleague Pete Rowley proposed a "two-tiered" model wherein the southeast part of the volcanic field spread and collapsed under its own weight, creating southward-directed thrust faults rooted in evaporite strata of the Middle Jurassic Carmel Formation. These thrust faults are part of the Ruby's Inn thrust fault zone on the adjacent Paunsaugunt Plateau, which displaced Upper Cretaceous strata over early Tertiary Claron Formation. They also envisioned the Markagunt Megabreccia to be a surficial part of this process, perhaps triggered by near-surface laccolith emplacement and consequent doming and catastrophic failure of overlying strata. Collapse of the volcanic field could also have resulted from inflation of the 21-million-year-old Mount Belnap caldera in the southwest part of the Marysvale volcanic field. If so, the Megabreccia would be at least twice as long and nearly three times the aerial extent of what we now envision (this is comparable to but still the junior of the famous 1300-square-mile Heart Mountain detachment in northwest Wyoming, the World's largest terrestrial gravity slide).

Thus, we have several possibilities but lack a definitive trigger for the formation of the Markagunt Megabreccia. Of the possibilities, gravity sliding off the Iron Peak laccolith seems the most likely. This idea is supported by similar gravity-slide deposits in the Pine Valley Mountains, which are tied to shallow igneous intrusions that domed up overlying strata, leading to catastrophic failure on oversteepened slopes (see Survey Notes, v. 34, no. 3, p. 1–3).

UGS RELEASES NEW INTERACTIVE GEOLOGIC MAP

by Grant C. Willis

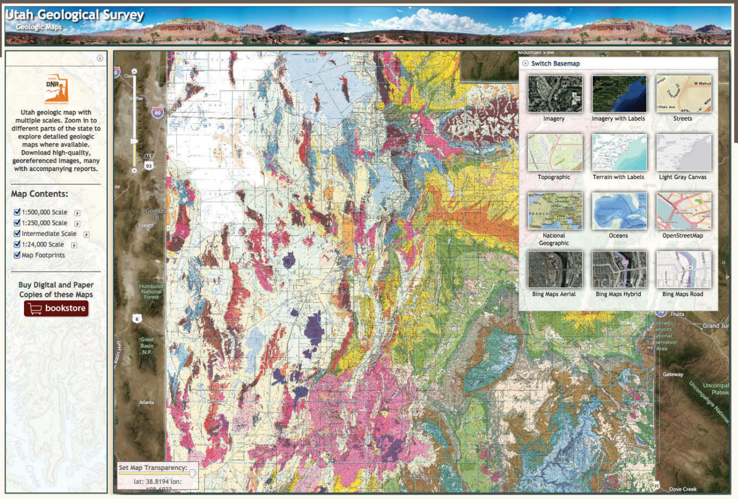
Have you ever wanted to know the geologic formation your house is built on, the name and age of the rocky ridge exposed across the valley, or the identity of that colorful formation that caught your eye on your last vacation? Now you can find out this and other basic geologic information for much of the state with just a few clicks of a mouse.

The UGS recently posted a new interactive geologic map database to our website that allows you to quickly learn these types of facts, plus download many geologic maps as PDFs, georeferenced tifs, or GIS (Geographic Information System) shapefiles. Over 300 of our most popular geologic maps are already posted to the interactive map; approximately 400 more will be posted over the next year or two.

Created by UGS geologists/computer specialists Marshall Robinson and Lance Weaver, with many suggestions from Grant Willis, Buck Ehler, Kent Brown, Bob Biek, and other UGS personnel, the interactive map quickly became one of the most popular hits on our website.

To make the interactive map, UGS personnel scanned, cleaned, cropped, and geo-referenced (placed in correct geographic position) published geologic maps. Users can view any of these maps by simply clicking anywhere on the map screen, turning layers of maps on or off, and zooming in or out. Most of these maps can be downloaded as well.

Perhaps the most useful feature of the interactive map, the ability to query any location in the state, is based on approximately 35 key geologic maps of 30' x 60' quadrangles and similar areas. Over the past 15 years, the UGS Mapping Program has produced GIS databases of existing maps where possible, and of new geologic maps of other areas, most at scales of 1:24,000, 1:62,500, or 1:100,000. Every map "polygon" (formation, outcrop, or deposit) is "attributed" with its name, geologic age, primary composition, and other basic information. Additional detailed descriptions of map units accompany most maps. When you click on any polygon, this information pops up in a text window beside the map, giving you a quick answer to your question. Approximately 70% of the state is now completed and posted to the interactive map; another 15% is in progress. Popup information on the incomplete areas is based on the less-detailed state geologic map, which is being supplanted block by block as new maps are completed. Users can quickly switch between base (background) maps that show roads and towns, topographic contours, detailed orthophotographic images, or other features, so they can see the geology in relation to places or features they know. To access the map, go to our website at geology.utah.gov and click on the Interactive Geologic Map button on the right side of the page directly beneath Popular Geology.


Utah geologic map with multiple scales. Zoom in to different parts of the state to explore detailed geologic maps where available. Download high-quality, georeferenced images, many with accompanying reports.

Map Contents:

- ☑ 1:500,000 Scale
- ☑ 1:250,000 Scale
- ☑ Intermediate Scale
- ☑ 1:24,000 Scale
- ☑ Map Footprints

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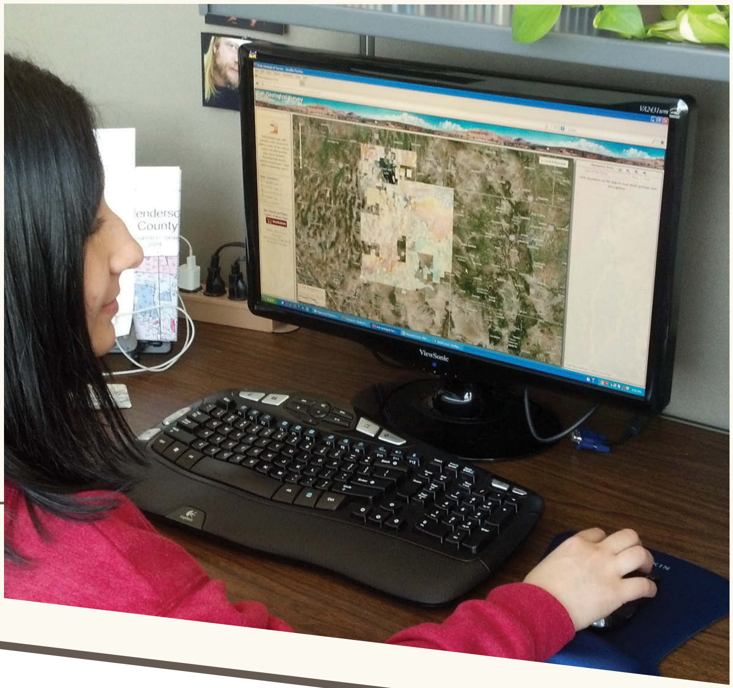


The new Interactive Geologic Map of Utah is built from more than 300 published geologic maps.

The densely forested, high-elevation Markagunt Plateau has long been a refuge for those seeking both winter recreation and a cool respite from the summer heat of the valleys below. We all see this landscape somewhat differently. Botanists and wildlife enthusiasts revel in the diversity of plant and animal life and its profound changes with elevation along its 5000-foot-high western escarpment, culminating with spruce forests, isolated groves of ancient bristlecones pines, wildflower-filled meadows, and plentiful elk. Those whose life's work revolves around water will see the plateau as the ultimate watershed that sustains life in the dry basins below. Even those of us with no specific bias enjoy the scenic diversity and open space the plateau offers. But who else besides a few geologists have ever really seen and understood the rocks that cap much of the northern Markagunt Plateau? Who knew about the collapsed remains of an ancient volcanic center that covers an area at least as large as the entire Salt Lake Valley? It's exciting to think that such spectacular geologic phenomena remain to be discovered and understood.

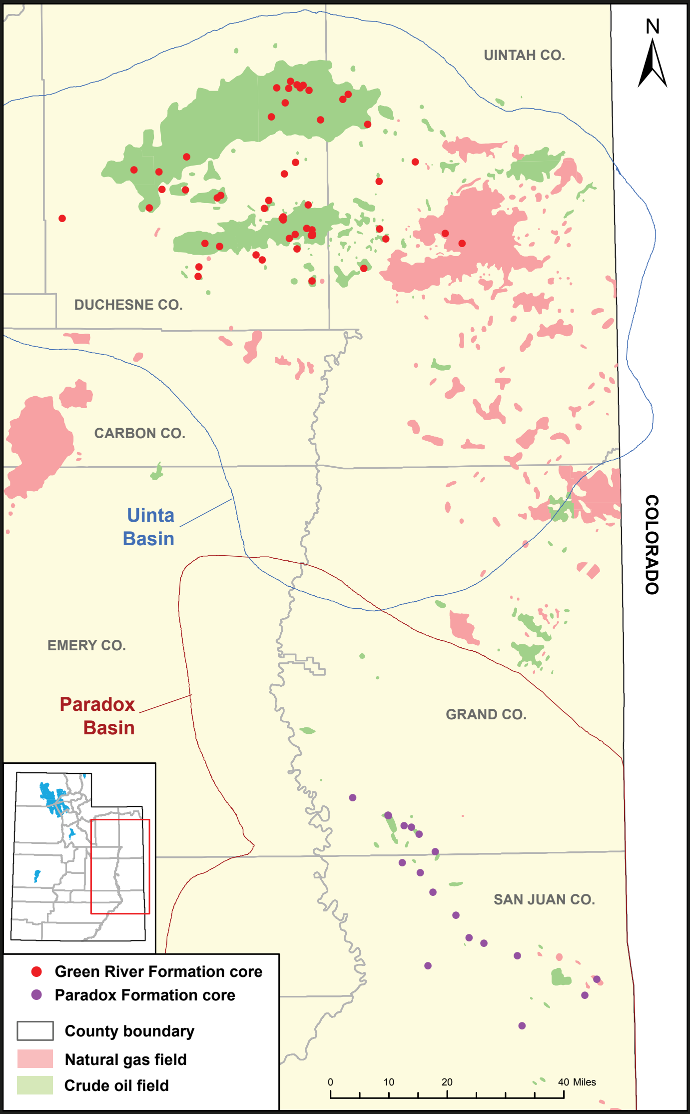
LIQUID-RICH SHALE POTENTIAL OF

by Michael Vanden Berg

The National Energy Technology Laboratory, part of the U.S. Department of Energy, recently funded the Utah Geological Survey to analyze and characterize the potential of Utah's shale formations for liquid hydrocarbon production. In particular, this new three-year study will research organic-rich units within the Green River Formation of the Uinta Basin in northeastern Utah and the Paradox Formation of the Paradox Basin in southeastern Utah.

The current high price of crude oil, coupled with lower natural gas prices, has generated renewed interest in exploration and development of liquid hydrocarbon reserves. Following the success of the recent shale gas boom (e.g., Barnett shale in Texas, Woodford shale in Oklahoma, Marcellus shale in Pennsylvania and surrounding states) and employing many of the same well completion techniques (e.g., horizontal drilling and hydraulic fracturing), petroleum companies are now exploring for liquid petroleum in shale formations (e.g., Bakken shale in North Dakota, Eagle Ford shale in Texas). In fact, many shales targeted for natural gas also include areas in which the shale is more prone to liquid production. In Utah, organic-rich shales in the Uinta and Paradox Basins have been the source of significant hydrocarbon generation; companies have traditionally targeted the interbedded porous sands or carbonates with conventional recovery techniques (e.g., vertical or near-vertical wells). However, with the advances in horizontal drilling and hydraulic fracturing, operators in these basins are now starting to explore the potential of the shale units themselves.

The Green River Formation in the Uinta Basin has been studied for over 50 years since the first hydrocarbon discoveries. However, early studies focused on the many conventional sandstone reservoirs



Map of the Uinta and Paradox Basins showing the location of cores available for this study.

Core from the Uteland Butte Member of the Green River Formation, Uinta Basin, Utah (Bill Barrett Corp., 14-1-46). One of the productive horizontal targets is the roughly 5-foot-thick tan dolomitic bed with porosities ranging from 20 to 30%. The oil is sourced from the surrounding darker gray organic-rich limestones, which contain abundant shell fossils, indicating that these layers were deposited in a freshwater lake.

currently producing large quantities of oil and gas. In contrast, little information exists on the more unconventional crude oil production potential of thinner, organic-rich shale/carbonate units such as the Uteland Butte member, black shale facies, and deep Mahogany zone. For information on the distinction between shale oil and oil shale, which also occurs in the Green River Formation, see article by Thomas Chidsey, *Survey Notes*, September 2012, v. 44, no. 3 (in short, oil shale refers to rock that contains immature organic material called kerogen, while shale oil has experienced sufficient heat/pressure, converting organic matter into crude oil, which is still trapped in the micro-pores of the shale).

The Paradox Formation in the Paradox Basin consists of multiple layers of salt interbedded with clastic deposits (sands, silts, clays, or carbonates), many of which contain organic-rich shales. One such clastic interval, the Cane Creek shale, has been a target for exploration on and off since the 1960s and produces oil from several small fields. The play generated much interest in the early 1990s with successful use of horizontal drilling in a handful of wells. Despite this limited success, little research has been conducted or published to further define the play and its reservoir characteristics.

Over the next three years, the UGS plans to characterize the geology of these prospective shale formations to better predict the areas, or "sweet spots," with the greatest production potential. In addition, our research partners at the Energy and Geoscience Institute at the University of Utah will investigate the geomechanical properties (rock strength, brittleness, elasticity, etc.) of these rocks to help determine the best drilling and well completion strategies. A more complete understanding of the geology and geomechanical properties of these formations will help maximize potential recoverable reserves and limit the drilling of nonproductive wells, which in turn will help reduce environmental impacts.

Geologist recording rock properties from an outcrop of the Uteland Butte Member of the Green River Formation in Ninemile Canyon.

Core from the Cane Creek shale of the Paradox Formation (right), Paradox Basin, Utah (Union Pacific Resources Company, Remington 21-1H). The source of the oil is the dark gray to black, organic-rich shale intervals, which are interbedded with mottled anhydrite (lightest gray).

GEOLOGIC MAPS AS ART

by Grant Willis and Kent Brown

Glass collage entitled "Fairpark Convergence" (above) by artist Nancy Gutkin O'Neil at the North Temple TRAX station near the State Fair Park. A part of USGS Map I-1404 by Richard Van Horn is the backdrop for four of the panels. The artist applied unique colors to the same geologic units in each panel.

People have long noted that geologic maps have artistic appeal—we have seen geologic maps displayed on walls by non-geologists who just admire the aesthetics. Recently, this appreciation was taken to a new level when a nationally recognized artist used parts of a popular old geologic map of the Salt Lake City North 7.5' quadrangle (USGS Map I-1404 by Richard Van Horn) as part of a major work of art along the North Temple TRAX line in Salt Lake City. The artist, Nancy Gutkin O'Neil from New Orleans, describes herself as a "collage artist who works in glass." She stated, "My designs are research-based and full of information. They often deal with a sense of place." Her goal was to unite the geology, geography, history, and local cultural diversity of the State Fair area in a mosaic called "Fairpark Convergence." "I like geologic maps because they are so beautiful and colorful...these maps (including an historic fire insurance map she used) reveal another way of looking at our natural world and our manmade landscape. They became my primary background for everything else happening in the design." She added black and white photographs from the neighborhood and old State Fairs, lively textile patterns from many countries whose people now live in the neighborhood, and Ute and Navajo design motifs to create "a complex woven 'fabric,' a good metaphor for life in the Fairpark community." The artwork, commissioned by the Utah Transit Authority and the Salt Lake City Arts Council, is at the new TRAX Fairpark Station at approximately 1100 West North Temple.

Close-up of geologic map "idealized" as background in glass collage (right). Gutkin O'Neil (above) chose a cutoff meander of the Jordon River as the focus point of the map.

CAN ROCKFALLS CAUSE WILDFIRES?

by Stephanie Earls

The source of the July 2012 Lighthouse Fire in Range Creek, Emery County, Utah, was where a falling boulder (pictured left, near center) hit a large stationary rock (photo left) and the resulting friction ignited the surrounding dry brush. Pictured below is an overhead closeup of the point of impact (red circle) and broken rock fragments on the ground. Photos courtesy of Jason Curry (Utah Division of Forestry, Fire, and State Lands).

During the onslaught of wildfires in Utah and surrounding states in the summer of 2012, the Utah Geological Survey received a question about whether rockfalls were a legitimate cause of wildfires or just a tall tale told to explain fires of unknown origin. If you look at wildfire statistics, causes are typically broken down into two main categories: human-caused or lightning. However, various publications and websites claim four major natural causes of wildfires: lightning, volcanoes, spontaneous combustion of organic material, and rockfalls. Rockfall-ignited fires, which are difficult to identify, make up a tiny fraction of total wildfires.

In an article published in 2000 titled *Synopses of Wildfires Caused by Rockfalls*, Richard T. Ford (retired division chief of the California Department of Forestry and Fire Protection) makes the case that although rare, blazes of this origin do exist. He cites a study by geologist Richard F. Madole and physicist Dr. Joe Romig indicating that the abrasive friction between rocks scraping against each other at a certain velocity can reach ignition temperatures without a spark.

Additionally, the article contains case histories from around the world. The common denominator of all scenarios was dry grass and brush that caught fire, but how the rockfall was triggered varied between the following actions:

- earthquakes (Riverside County, California, and Sonora, Mexico)
- construction activity (Mariposa and Fresno Counties, California)
- gravity/erosion (Riverside County, California, and Fynbos area of South Africa)
- launching rocks down a slope/over a cliff (Explorer Scouts in southern Utah)

Evidence—such as charred and burned grass imbedded on the rock face where fire originated, eye witness accounts, or ruling out of other factors (e.g., being in an area with rare lightning occurrence)—was used in deducing the ignition source.

One-tenth of a percent of all Utah's wildfires are estimated to be the result of rockfalls according to Jason Curry, fire investigator for the Utah Division of Forestry, Fire, and State Lands. In his five years as a fire investigator, he has seen only one example, referred to as the Lighthouse Fire that took place in Range Creek, Emery County, Utah, on July 18, 2012 (see Deseret News article http://tinyurl.com/bvhfekn). University of Utah archeology students and staff had been excavating a Fremont Indian site when the fire was spotted. A thorough investigation eliminated all other possible incendiaries, and, in conclusion, Curry designated rockfall as the cause. Now that Curry has seen first-hand evidence of this type of wildfire, he is considering revisiting previous wildfires of unknown origin to determine if rockfalls could have been responsible.

Although rare and difficult to identify, rockfalls do indeed trigger wildfires. The next time you find yourself bulldozing large rocks at the top of a steep slope, or tossing rocks with your Boy Scout troop, beware of the possibility of starting a wildfire!

Notch Peak—BIG Cliff

Millard County

By Mark Milligan

The enormity and vastness of the cliff forming the north face of Notch Peak is difficult to describe. Standing near the cliff's base and looking up is awe inspiring. The view while standing at the top and looking over the edge? I would not know as I was on my hands and knees, too fearful to stand and look over the edge at one of the greatest vertical drops in the contiguous U.S.

Reported estimates of the cliff's actual height vary significantly from under 2,000 feet to over 4,500 feet, which is likely due to differences in defining where the base of the cliff starts. Photogrammetry (measurements from digital stereoscopic photographs), verified with a paper 7.5' topographic map, suggests the cliff has an uninterrupted near-vertical drop of over 1,500 feet. The addition of cliff below a small bench 50 to 100 yards wide increases the distance to approximately 2,250 feet. Adding a portion of the very steep base of the sheer drop increases the distance to nearly 2,900 feet.

How does Notch Peak rank among other tall cliffs? The heights of other huge cliffs are also problematic to define and measure. There is no objective definition for a cliff. At what angle does a cliff become a steep slope? When does a single ledge or bench turn one cliff into two? When do multiple small ledges turn a cliff into a slope? Where does a cliff begin or end? Must a cliff be measured down a straight and vertical fall line or can a transect be taken for a lower base elevation? Finding reliable and consistent measurements for cliffs of the world or even North America would be a dissertation for a doctoral degree in trivial drivel. However, Notch Peak's cliff seems to rank among or near the top ten in the contiguous U.S.

Cliffs (or slopes steep enough to perhaps be called a cliff, you be the judge) near the top of this lower 48 states list are found at:

- Yosemite National Park, California. Examples: El Capitan (~2,900 feet of near vertical drop) and Half Dome (~2,000 feet of near vertical drop).
- Kings Canyon National Park, California. Example: Tehipite Dome (~3,400 feet of near vertical drop).
- Balloon Dome (outside of Kings Canyon and Yosemite but also in the Sierra Nevada), California. Example: the west face (~3,000 to 4,000 feet of cliff and/or very steep slope).
- Cascade Range, Washington. Example: the northeast face of Johannesburg Mountain (~4,000 feet of cliff and/or very steep slope).
- Glacier National Park (carbonate cliffs similar to Notch Peak), Montana. Examples: the east face of Mt. Gould and the north face of Mount Siyeh (~3,800 and ~3,500 feet respectively of cliff and/or very steep slope).
- Grand Teton National Park, Wyoming. Example: the south face of Mt. Moran (~4,500 feet of interrupted near vertical drop).
- Black Canyon of the Gunnison National Park, Colorado. The Painted Wall (~2,000 feet of near vertical drop).
- Zion National Park, Utah. Sandstone cliffs (~2,000 feet of near vertical drop).

Notch Peak at sunset, view from the west. Layered limestones and dolomites form the cliff face and talus slope. Jointed granite is seen in the foreground.

The summit of Notch Peak presents stunning views for miles in all directions. The summit can be reached via several rock climbing routes on the cliff face. Not up for the climb? Not to worry, the summit is also accessible via a rugged hike of approximately 7½ miles round trip. The hiking route trailhead is in Sawtooth Canyon on the east side of the peak. Sawtooth Canyon is accessed from a dirt road at milepost 46 on U.S. Highway 6/50. Necessary detailed driving and hiking directions can be found on the web at sites such as SummitPost.org or WillhiteWeb.com. Left photo, view of Notch Peak summit from the "notch." Right photo, view from the summit toward north.

Though Notch Peak is a natural wonder rivaling those commonly seen in state and national parks, its remote location in a state filled with competing natural wonders results in it not being well known, nor often visited.

Geologic Information:

Notch Peak is composed of 500-million-year old limestones and dolomites of the Notch Peak, Orr, and Weeks Formations. A 17-million-year old granite intrusion (sill) crops out at the base of this limestone sequence.

Following the pattern found across the Basin and Range Province from western Utah to eastern California, a north-south oriented high-angle fault uplifted the mountain front on the west side of Notch Peak. This uplift allowed erosion to carve the peak's great cliff.

At least two factors contributed to make Notch Peak's north-face cliff grander than any other in the Basin and Range Province. First, the cliff is composed of a nearly uninterrupted sequence of strong, weather-resistant, massive limestone and dolomite beds that generally lack shale or other weak layers. Where significant shale beds do exist, they create a small bench near the top of the Orr Formation approximately 1,500 feet below the peak's summit.

Secondly, the massive limestone and dolomite bedding is nearly flat and horizontal (not folded). Tectonic folding could have resulted in fractures that weaken rock layers. Similarly, tectonic compressional forces have not thrusted these rock layers over one another. Elsewhere in the Basin and Range past episodes

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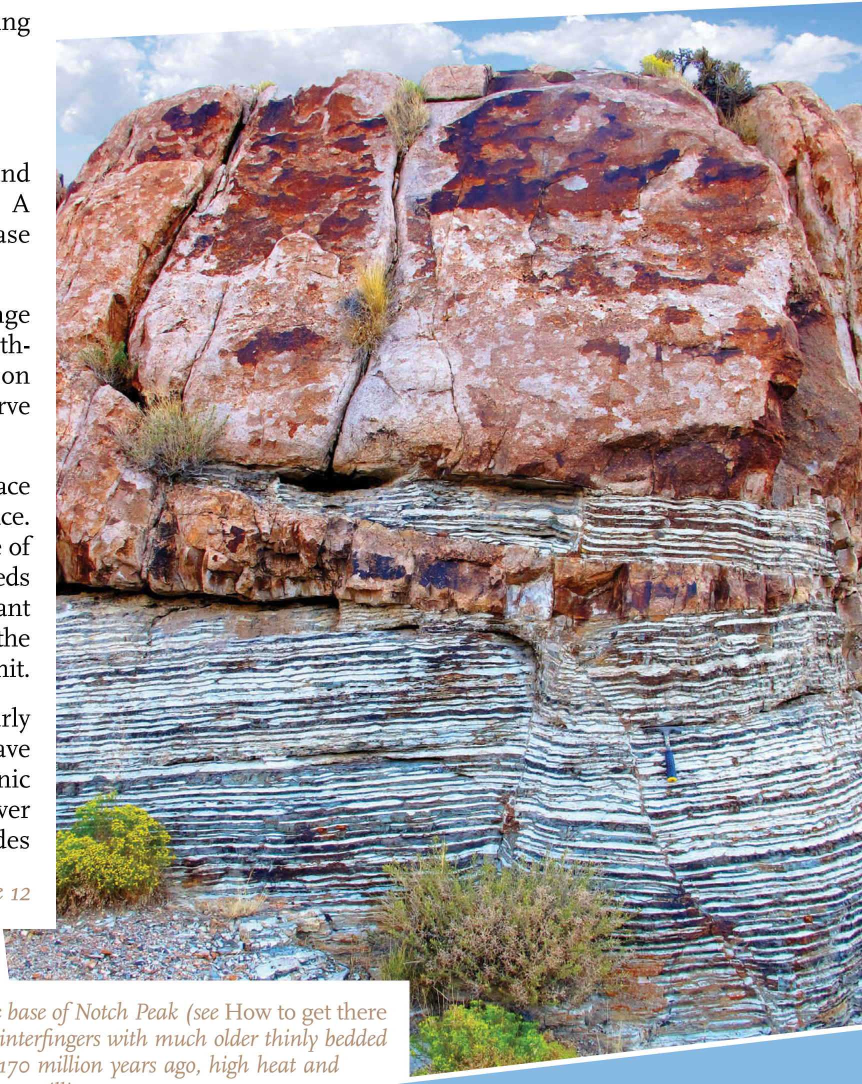


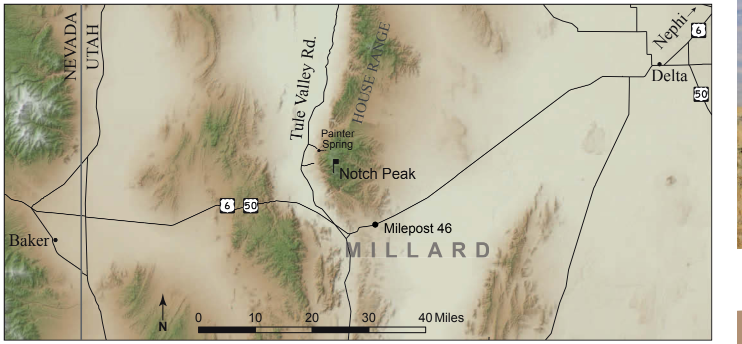
Visible from the dirt road that leads from Tule Valley Road towards the base of Notch Peak (see How to get there *in this article), pink granite (named Notch Peak quartz monzonite) interfingers with much older thinly bedded gray argillite and white marble of the Marjum Formation. At depth 170 million years ago, high heat and fluids from the granite metamorphosed limestone to marble and shale to argillite.*

Notch Peak is so named because of the large notch in its profile as seen when viewed from the east.

continued from page 11

of tectonic folding and thrusting have fractured and weakened otherwise similar formations and thereby reduced their integrity and ability to form towering cliffs.

Though there is no clear evidence for such, an east-west oriented fracture (perpendicular to the range-front fault) could have provided a zone of weakness contributing to the north-facing orientation of the peak's greatest cliff.



How to Get There

Notch Peak is part of Sawtooth Mountain, which comprises the southern part of the House Range. It is immediately north of U.S. Route 6/50, between Delta, Utah, and Baker, Nevada. Be advised, there are no gas stations, nor any other services in the vicinity of Notch Peak. It is in the proverbial middle of nowhere.

For best viewing, from the Wasatch Front take I-15 to exit 225 for State Route 132 in Nephi. Travel west on State Route 132 for 34 miles, then turn left onto U.S. Route 6 towards Ely, Nevada. In Delta, U.S. Route 6 merges with U.S. Route 50 at a stop sign where the road turns right to become U.S. Route 6/50. Continue west from this stop sign for 54 miles to a dirt road (Tule Valley Road) on the right that is signed "Painter Spring 14, Old Highway 50/6 19."

Between U.S. Route 6/50 and Painter Spring, Tule Valley Road provides stunning views of Notch Peak and its cliffs. Located 9½ miles north of U.S. Route 6/50, a less traveled dirt road leaves Tule Valley Road and leads towards the base of the cliff. Use discretion when driving this second dirt road as it does not appear to be maintained and may be impassible.

TEACHER'S CORNER

CALL FOR NOMINATIONS FOR THE
2013 UTAH EARTH SCIENCE TEACHER OF THE YEAR AWARD
FOR EXCELLENCE IN THE TEACHING OF NATURAL RESOURCES* IN THE EARTH SCIENCES

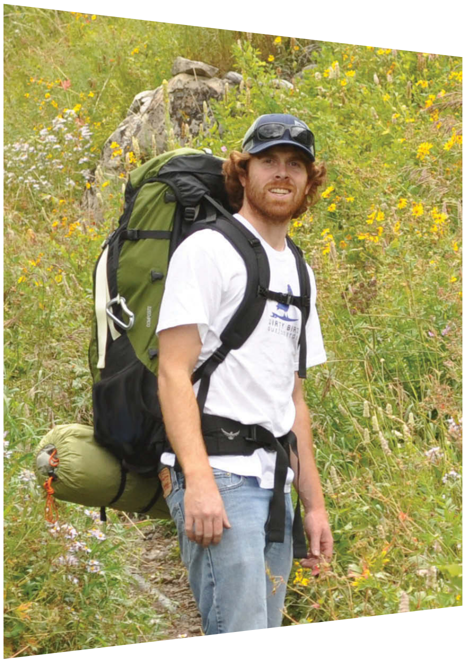
The Utah Geological Association (UGA) is seeking nominations for the Utah Earth Science Teacher of the Year Award until June 1, 2013.

The UGA awards $1,200 to the winning teacher plus $300 reimbursement for procuring resources related to earth science (e.g., materials, bus for a field trip, etc.) All K-12 teachers of natural resources* in the earth sciences are eligible. Application deadline is June 1, 2013.

The purpose of UGA's award is to recognize and support an outstanding K-12 earth science/natural-resource science teacher in Utah. The UGA's participation in the Earth Science Teacher of the Year competitions held nationwide enables them to provide a candidate for the regional competition sponsored by the Rocky Mountain Section of the American Association of Petroleum Geologists (AAPG). The Section winner receives $2,000 and is then entered into the national AAPG contest, which awards $6,000 as well as an expense-paid trip to the 2014 AAPG Annual Convention.

Additional information, requirements, and entry forms are available on the UGA website at http://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.*



2012 UGS EMPLOYEE OF THE YEAR

Congratulations to **Jay Hill** who was named the UGS Employee of the Year. Jay is a GIS Analyst in the Editorial Section and has worked at the UGS for four years. The UGS has benefitted greatly from Jay's talents and his commitment to produce excellent GIS/cartographic work. Jay has developed an excellent working relationship with other GIS staff and is continually looking for ways to improve and upgrade the GIS process. He has a great sense of humor, and his excellent work, productivity, and positive attitude make Jay a first-rate example to follow. We are proud to recognize Jay for his outstanding contributions to the UGS.

FORMER UGS BOARD MEMBER MILTON WADSWORTH PASSES AWAY

Milton E. Wadsworth, former UGS Board member and University of Utah professor, passed away on January 31, 2013, in Salt Lake City. He was 90 years old. Dr. Wadsworth was a distinguished professor emeritus of metallurgy at the U of U, and his career there spanned 45 years. According to his family, he was "...an intellectual, adventurer, world traveler, tap dancer, WWII veteran, motorcycle rider, carpenter, and family man..." Professor Wadsworth served for eight years on the Utah Geological Survey Board, from 1989 to 1997. He represented the scientific interests of the Board and was known for always imparting great wisdom on UGS Board issues.

EMPLOYEE NEWS

The Groundwater and Paleontology Program welcomes **Diane Menuz** as the new Wetland Ecologist. She has an M.S. in Ecology from Utah State University and is coming to Utah from Madison, Wisconsin, where she has worked for the Wisconsin Department of Natural Resources.

Robyn Krohn is the new librarian for the Department of Natural Resources Library. She has a B.S. in Geology from Utah State University and is currently working on a Master of Library Science degree from Kent State University.

The Mapping Program bids farewell to **J. Buck Ehler** who accepted a position as GIS and Technology Manager with DNR's Division of Forestry, Fire, and State Lands. Congratulations and best wishes in his new endeavor!

Mike Laine left the UGS at the end of 2012 after serving seven years as Curator for the Utah Core Research Center. His enthusiasm for science and unique sense of humor will be missed, and we wish him well as he joins his family in California.

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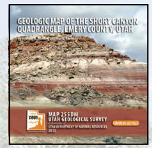
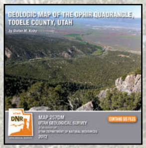
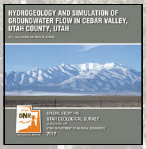
NEW PUBLICATIONS



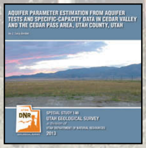
Geologic map of the Short Canyon quadrangle, Emery County, Utah, by Hellmut H. Doelling and Paul A. Kuehne, CD (13 p., 2 pl. [contains GIS data]), scale 1:24,000, ISBN 978-1-55791-862-8, **M-255DM** **$24.95**



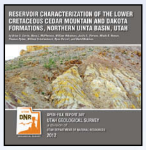
Geologic map of the Ophir quadrangle, Tooele County, Utah, by Stefan M. Kirby, CD (13 p., 2 pl. [contains GIS data]), scale 1:24,000, ISBN 978-1-55791-867-3, **M-257DM** **$24.95**



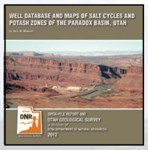
Hydrogeology and simulation of groundwater flow in Cedar Valley, Utah County, Utah, by J. Lucy Jordan and Walid W. Sabbah, CD (125 p. + 96 p. appendices, 2 pl.), ISBN 978-1-55791-868-0, **SS-145** **$24.95**



Aquifer parameter estimation from aquifer tests and specific-capacity data in Cedar Valley and the Cedar Pass area, Utah County, Utah, by J. Lucy Jordan, CD (53 p.), ISBN 978-1-55791-869-7, **SS-146** **$19.95**

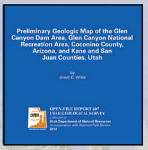


Reservoir characterization of the Lower Cretaceous Cedar Mountain and Dakota Formations, northern Uinta Basin, Utah, by Brian S. Currie, Mary L. McPherson, William Hokanson, Justin S. Pierson, Mindy B. Homan, Thomas Pyden, William Schellenbach, Ryan Purcell, and David Nicklaus, CD (34 p., 5 pl.), **OFR-597** **$19.95**

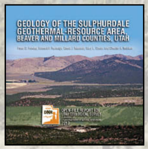


Well database and maps of salt cycles and potash zones of the Paradox Basin, Utah, by Terry W. Massoth, CD (18 p., 21 pl.), **OFR-600** **$24.95**

Summary of results from the Courthouse Wash monitoring well, by Stefan M. Kirby, J. Lucy Jordan, and Gary Hunt, 9 p., **OFR-606** **$4.95**



Preliminary geologic map of the Glen Canyon Dam area, Glen Canyon National Recreation Area, Coconino County, Arizona, and Kane and San Juan Counties, Utah, by Grant C. Willis, 12 p., 2 pl., scale 1:24,000, **OFR-607** **$14.95**



Geology of the Sulphurdale geothermal-resource area, Beaver and Millard Counties, Utah, by P.D. Rowley, E.F. Rutledge, D.J. Maxwell, G.L. Dixon, and C.A. Wallace, CD (27 p., 2 pl.), **OFR-609** **$19.95**

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