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

SURVEY NOTES

Volume 41, Number 2 May 2009

Utah's Natural Rock Arches

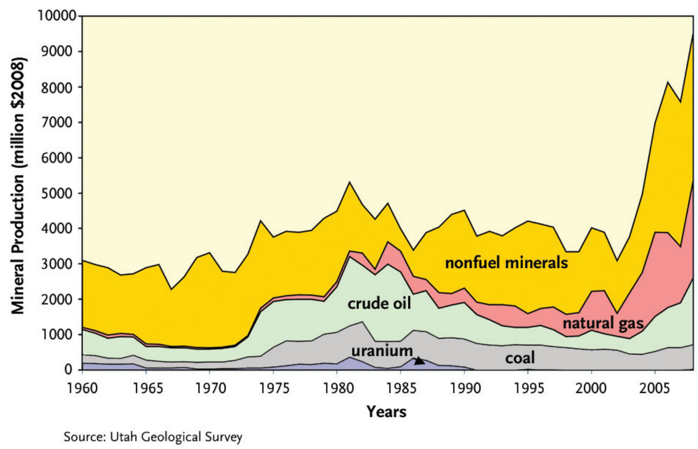
The Director's Perspective

by Richard G. Allis

In the September 2008 issue of *Survey Notes* I wrote in the Director's Perspective: "Although supply-and-demand fluctuations for geologic commodities will cause short-term volatility in their prices, it seems likely that the global trend of increasing demand will sustain generally high prices." As we all know, the world is now in an economic slump, triggered by a loss in confidence in the financial markets. Many commodity prices have fallen due to decreased demand, and experts are divided on how long the slump will continue. There are signs of a turnaround in some commodities however, with base metals such as copper, lead, and possibly oil showing predominantly rising trends since price minima in late December 2008.

The dramatic price swings from record highs during mid- to late 2008 are likely to make 2008 a historically important year for revenue generated from geologic commodities extracted in Utah. The graph below shows the updated, inflation-adjusted trends since 1960. The gross revenue for 2008 exceeds 2007 by over $1 billion, and hits a new high of close to $10 billion. Half the total is from non-fuel minerals (primarily copper and molybdenum), and half is from fossil fuels (primarily natural gas). With most commodities now at prices less than half their peak, 2008 is likely to remain as the record high-revenue year for at least another few years.

Geologic commodities are critical to our quality of life, and one of the drivers of global demand has been the improvement in living standards in Asia, especially China. Although China's average per capita income is still between 10 and 20 times smaller than that of the U.S., its gross domestic product is now close to that of Japan, which ranks second after the U.S. Furthermore, China's economy is projected to grow by 8 percent in 2009 despite the global recession. China's pursuit of a higher standard of living is rapidly consuming recent surpluses in commodity supplies caused by the global downturn, and may already be contributing to rising base metal prices. Although the U.S. economy may take several years to bounce back from its financial and housing market problems, expect to see many commodity prices begin to grow again this year. The mining industry has gone from boom to bust in only six months, but perhaps this industry is already on the road to recovery.



Total annual value of Utah's energy and mineral production 1960–2008, inflation adjusted to 2008 dollars.

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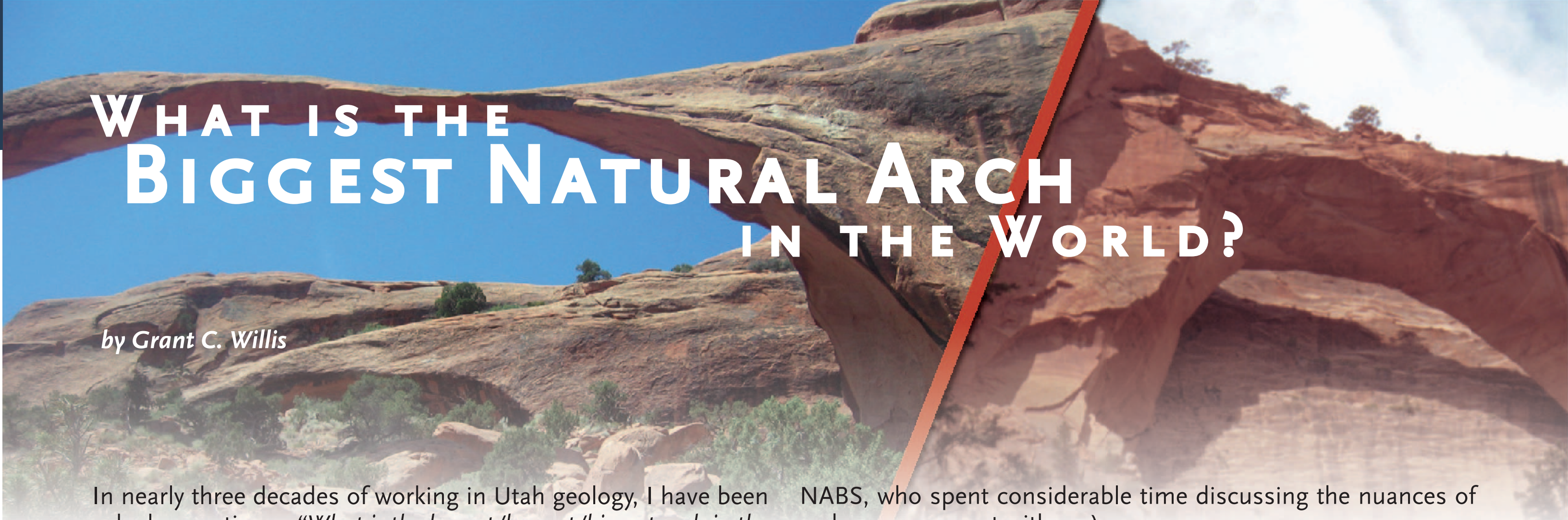
Design: *Stevie Emerson*
Cover: *Utah's most famous landform, Delicate Arch, lit by the setting sun. The arch is composed of Jurassic-age sandstone, including the Slick Rock Member of the Entrada Sandstone (base and pedestals) and the Moab Member of the Curtis Formation (bridge). Photo by Michael Vanden Berg.*

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



What is the Biggest Natural Arch in the World?

by Grant C. Willis

In nearly three decades of working in Utah geology, I have been asked many times, *"What is the largest/longest/biggest arch in the world?"* For years I told people it was Landscape Arch in Arches National Park. Then, about 20 years ago, a Zion National Park ranger told me that Kolob Arch is bigger. Occasionally, I would even hear someone claim that Rainbow Bridge is the biggest. But a cloud of uncertainty always hung over all of these Utah arches because of stories of a great arch in China that could eclipse them all. A National Geographic Society article in December 2000 reported on an expedition that located and photographed, but did not measure, the rumored Chinese arch called Tushuk Tash or Shiptons Arch.

Thanks to a small but dedicated organization, the Natural Arch and Bridge Society (NABS; www.naturalarches.org), the question has finally been answered. Soon after it was founded in 1988, NABS realized that it first had to answer another more difficult question—how do you define "biggest arch"? NABS invited every interested scientist, mathematician, and enthusiast it could find and set to work. NABS determined that the key dimension most people are interested in, and that can be uniformly measured in all arches, is the "span." The formal definition is complex—in simple terms, it is the maximum total horizontal length of the arch opening (thanks to Jay Wilbur of NABS, who spent considerable time discussing the nuances of arch measurement with me).

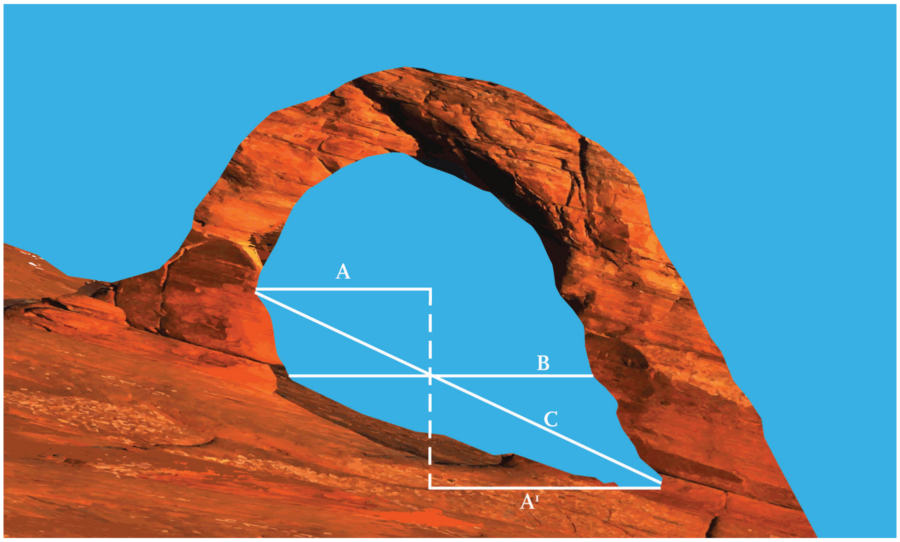


Illustration showing "correct" way to measure the span of an arch according to the Natural Arch and Bridge Society. Because arches are seldom symmetrical, the span must often be measured in parts. Determining the proper points to measure can also be challenging. Horizontal line A added to A' gives the correct span (dashed line is a hypothetical vertical line). Lines B and C give incorrect results; line C is actually the "breadth" of an arch (Wall Arch in Geosights article is an example in which the breadth was commonly incorrectly reported as the arch's span).

Armed with this rigorous definition, and with high-precision laser devices, NABS began measuring spans of all likely candidates. Some were easy—Landscape Arch and Rainbow Bridge are right next to trails and have relatively simple shapes. But some are exceedingly difficult—Kolob Arch is reached only by difficult bushwhacking followed by challenging technical rope work, and has a complex shape since it is "scabbed" onto the side of a cliff. Tushuk Tash in China and Aloba Arch in Chad are both logistically and politically difficult to access. Even after reaching Tushuk Tash, unstable slopes and rock-fall hazards make getting into position to accurately measure the span unacceptably risky. NABS used triangulation on various photographs to calculate its span at about 180 ± 20 feet. However, it leans out over a deep chasm, giving it an astounding vertical drop of 1200 feet, the highest of any natural arch. Similarly, in-place measurements of Aloba Arch have not been done because the point of the maximum span is a couple of hundred feet up near-vertical walls. However, a large flat area in front of the arch allowed accurate triangulation measurements, giving it a span of about 250 feet.

It soon became clear that Landscape and Kolob Arches had the longest spans in the world by a considerable margin, but which was actually the longest? Previous measurements over the past 50 years, including some that involved rigorous methods and controls, yielded spans of 282 to 310 feet for Kolob Arch (with the best estimate of 294 feet) and 291 to 306 feet for Landscape Arch. The NABS team accurately measured Landscape in 2004, yielding a measurement of 290 feet—it looked like Kolob would be the winner.

Accurately measuring Kolob Arch was the last major hurdle. Because Landscape and Kolob were so close in span length, the NABS team knew the measurements had to be very accurate and precise, with sufficient control and redundancy to remove any room for doubt. The huge cliff and irregular shape of Kolob made the task even more difficult. In October 2006, Jay Wilbur, who did many of the high-precision measurements and calculations on several of the largest arches, led a team of climbers and experienced NABS surveyors to Kolob Arch. He noted that it was "with the full expectation that the results would finally confirm that Kolob Arch had the

While truly impressive with a 287-foot span, Kolob Arch is difficult to observe. The park-designated viewpoint requires a 7-mile hike through spectacular canyons, but viewing the arch is somewhat disappointing because it is high on a massive cliff about 1/3 mile away from the viewpoint. Photo by Jim Davis.

greater span" (www.naturalarches.org/archinfo/kolob.htm). At last, in late 2006, the results were in—Kolob Arch has a span of 287 feet. Landscape Arch is the biggest in the world by a mere 3 feet!

These two great natural wonders stand in a class by themselves. A distant third is Aloba Arch in Chad with a span of about 250 feet. Rainbow Bridge, with a span of 234 feet, was relegated to 6th position. National Park Service brochures and many books give it an incorrect measurement of 275 feet and commonly state that it is the longest natural bridge in the world (a natural bridge is a specific type of arch that spans a waterway); however, Aloba Arch is also a natural bridge and its span is about 16 feet longer and its opening is about 100 feet higher than Rainbow Bridge.

Only 10 natural arches in the world have measured spans that exceed 200 feet; the Colorado Plateau has nine of these, with six in Utah. Utah also has half a dozen or more arches with spans that exceed 150 feet, several dozen that exceed 100 feet, and probably several hundred with spans exceeding 50 feet. In fact, Utah has several times more large arches than any other state. Other Utah arches in the top 10 are Morning Glory Natural Bridge near Moab (misnamed—it is not a true bridge), Sipapu Natural Bridge in Natural Bridges National Monument, and

Top 10 Arches in the World
(from Natural Arch and Bridge Society Web site at www.naturalarches.org)

Rank	Name	Location	Span Length
1	Landscape Arch	Arches National Park, Utah	290 ft
2	Kolob Arch	Zion National Park, Utah	287 ft
3	Aloba Arch	Ennedi Range, Chad (Sahara Desert)	~250 ft
4	Wrather Arch	Paria Canyon, Arizona	246 ft
5	Morning Glory Natural Bridge	Moab, Utah	243 ft
6	Rainbow Bridge	Rainbow Bridge National Monument, Utah	234 ft
7	Sipapu Natural Bridge	Natural Bridges National Monument, Utah	225 ft
8	Stevens Arch	Escalante River, Utah	~220 ft
9	Outlaw Arch	Dinosaur National Monument, Colorado	206 ft
10	Snake Bridge	Sanostee, New Mexico	204 ft

Landscape Arch in Arches National Park has a span of 290 feet, the longest of any arch in the world, and is unquestionably the most mind-boggling due to its gravity-defying ribbon of rock that in places narrows to only 7 feet in thickness.

Stevens Arch in a side canyon of the Escalante River near Lake Powell. Other Colorado Plateau arches in the top 10 are Wrather Arch, just across the Utah border in Paria Canyon, Arizona; Outlaw Arch in the Colorado part of Dinosaur National Monument; and Snake Bridge in New Mexico. Utah also has one fallen arch that may have dwarfed all modern arches—Fallen Monarch in Natural Bridges National Monument, which likely fell just a few hundred years ago, had a span of 330 to 360 feet. Incidentally, Great Arch near the Highway 6 tunnel in Zion National Park is not an arch at all under the NABS definition—it is an "alcove" since it does not have an open space ("daylight") behind the arch-shaped rock. Utah also has hundreds of exceptionally large alcoves.

So why does Utah have huge arches?

Natural rock arches are actually quite common. Nearly every state and country has natural arches large enough for people to walk through. For example, due to karstic weathering (dissolution of limestone bedrock), Kentucky may have the second-largest number of "significant" arches of any state. What makes Utah unique is the gigantic size of many of its arches.

Exceptionally large arches require several criteria that must all come together in just the right way—a very rare occurrence indeed. These include:

- Very thick, isotropic rock—all of Utah's largest arches are in massive quartz sandstone; the homogenous nature of the sandstone allows for large conchoidal (curved) fractures that are required to produce the inherently stable arch shape.
- Weaknesses in or below the otherwise isotropic rock, such as bedding planes or joints, that act as "seed" sites for arch formation.
- Rock that is moderately, but not exceptionally, strong or brittle.
- High erosion and incision rates that create many deep canyons and exposed rock faces—big arches need big cliffs, fins, or canyons.
- Near-vertical, subparallel, properly spaced joints (fractures)—a variety of geologic events have produced abundant joints in Utah rock.
- An arid climate—whereas small and medium arches are common in many environments, all of the largest arches are in areas having dry climates.
- In some settings, abundant loose sand that holds moisture against the base of sandstone fins for days to months, allowing the moist basal rock to weather and erode at higher rates than exposed rock, eventually forming an arch (in contrast, rare rain and snow on exposed rock in the arid climate commonly evaporates in minutes to hours).

In Utah, these major factors come together over huge areas of the Colorado Plateau, giving the state an abundance of large natural rock arches.

About The Author

Grant Willis has been a mapping geologist with the UGS for 26 years, including 15 years as manager of the Geologic Mapping Program. He has authored or coauthored over 40 geologic maps, and is currently mapping Glen Canyon National Recreation Area.

Ancient Landslides of the Beaver Dam Mountains, Washington County, Utah

by Robert F. Biek

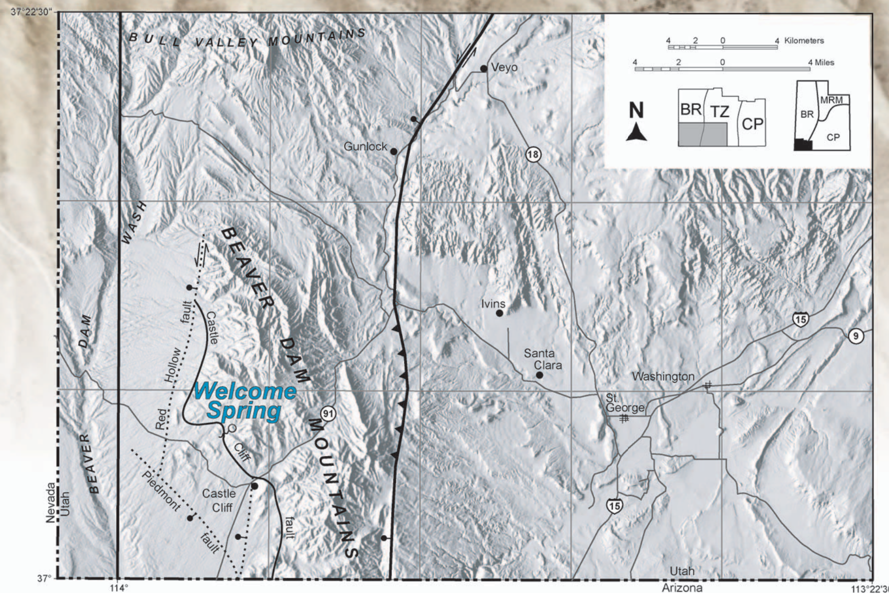
Introduction

West of Welcome Spring, at the west edge of the Beaver Dam Mountains in southwest Utah, over a dozen enormous blocks of limestone stick up above the surrounding alluvial fans. The limestone is out-of-place and badly broken up, vividly showing that something unusual happened here long ago. Exactly how and when these large blocks of limestone got to be where they are is a fascinating story, and our collective effort to understand their history is also a reminder of how our science evolves through time.

Visitors to Welcome Spring, an undeveloped yet popular camping spot at the east edge of the Basin and Range Province, probably pass by the limestone blocks with nary a thought to their origin, intent as they are on the welcome respite of water on the edge of the Mojave Desert. The spring is located a few miles north of Castle Cliff, where U.S. 91 (the old highway between Mesquite, Nevada, and St. George) exits the range via a route pioneered by the explorer Jedediah Smith in 1827. Heading southwest from Castle Cliff, Smith entered a broad basin sparsely covered with Joshua trees, yucca, cactus, creosote bush, and sagebrush that slopes westward toward Beaver Dam Wash. He called the wash Pautch Creek, which appears to mean "to walk in deep mud," but it later became known as Beaver Dam Wash after once-plentiful beaver that lived in the creek's mile-high headwaters area; the wash has since lent its moniker to the incongruously named Beaver Dam Mountains. The edge of this Joshua tree forest is where we find the large displaced blocks of limestone at the base of the range.

Regional Setting

The limestone blocks are adjacent to a structurally complicated part of the transition zone between the Basin and Range Province and Colorado Plateau. This part of southwest Utah is replete with unusual folds, faults, and shattered rocks that are the subject of considerable disagreement as to the relative influence of Late Cretaceous compressional deformation of the Sevier orogeny and late Tertiary and Quaternary extension of the Basin and Range. Ideas about the structural evolution of this region are chronicled in a report that accompanies the new geologic map of the St. George 30' x 60' quadrangle (currently in the final stages of review). Collectively, these ideas offer "...a wonderful illustration of how science progresses: not on a smooth trajectory, but in fits and starts and sometimes 'backward' steps, with long periods of accumulation of evidence and gestation of ideas, a certain amount of serendipity, occasional brilliant flashes of insight, and, especially in more recent times, technological advances" (quote from page 5 of Doug MacDougall's book *Frozen Earth—The Once and Future Story of Ice Ages*). For now, in the Beaver Dam Mountains area, we are in that uncomfortable state of "long periods of accumulation of evidence and gestation of ideas." But, our collective uncertainty about nearby structures need not concern us here, for now, nearly 70 years after their discovery, there is widespread agreement on the age and origin of one small part of this fascinating area—the large, displaced blocks of limestone west of Welcome Spring, which we now know to be ancient landslides (known as gravity slides).



The Beaver Dam Mountains area of southwest Utah is well known for its extraordinarily complex geology. Among the most enigmatic features are the Beaver Dam Mountains culmination itself and associated unusual faults and folds. Yet perhaps some of the most interesting features in this area are enormous brecciated blocks of 350-million-year-old Redwall Limestone encased in 5- to 10-million-year-old basin-fill deposits near Welcome Spring. These blocks resulted from catastrophic landslides, known as gravity slides, during early uplift of the Beaver Dam Mountains. Inset shows transition zone between Basin and Range Province and Colorado Plateau in Washington County.

Gravity-Slide Blocks

The largest gravity-slide blocks are several thousand feet long and range from a few tens of feet to about 200 feet thick—larger than many city blocks in size. They consist of Mississippian-age Redwall Limestone, as first reported by Brigham Young University student Spencer Reber in 1952. Where undeformed on the east side of the Beaver Dam Mountains, the Redwall Limestone forms bold cliffs and is conspicuously bedded with alternating chert and limestone. However, in the gravity-slide blocks, bedding is commonly destroyed and chert is concentrated in chaotic fractured masses (breccias) that contain

Where undeformed, Redwall Limestone typically contains well-bedded chert and limestone. But in this and other gravity-slide blocks bedding is mostly destroyed and chert is concentrated in breccias with little limestone, suggesting dissolution of the limestone layers prior to emplacement of the slide blocks.

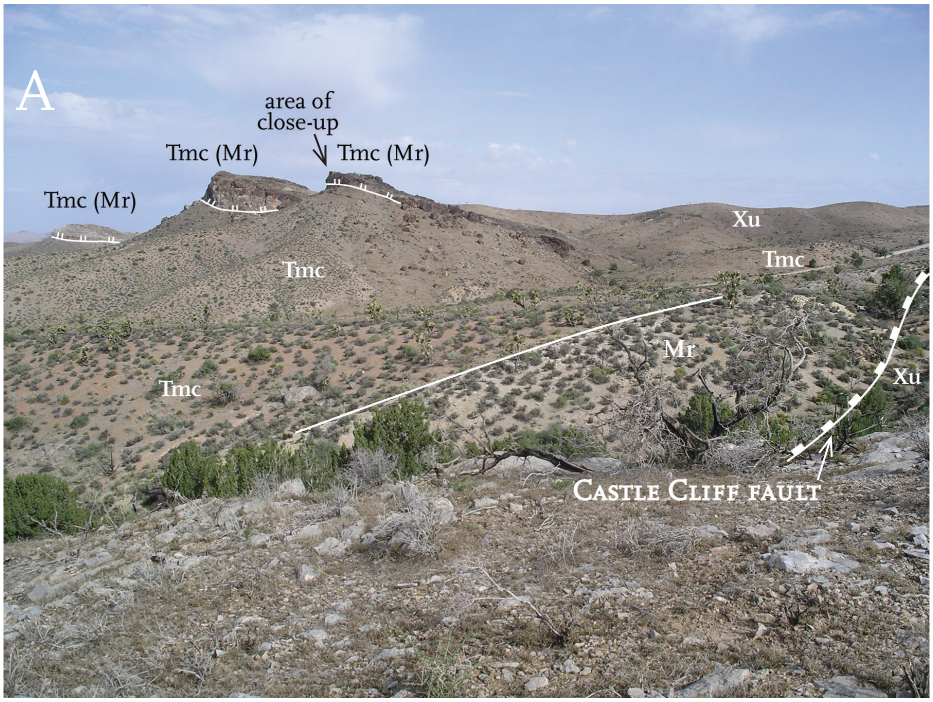
little limestone. In the 1990s, U.S. Geological Survey (USGS) geologists Sharon Diehl and Ernie Anderson and their colleagues showed that the breccias are evidence of significant dissolution of the limestone layers prior to emplacement of the slide blocks. At the base of the gravity-slide blocks, a shear plane and a distinctive, thin, poorly sorted conglomerate is exposed; clastic dikes of the same conglomeratic material fill fractures at the base of the blocks.

A good example of the displaced limestone blocks is immediately north of the dirt road to Welcome Spring. There, a large block of brecciated Redwall Limestone is sandwiched between alluvial-fan deposits of the Muddy Creek Formation; the whole package dips east, back toward the Beaver Dam Mountains. The gravels are mostly pebble- to boulder-size Paleozoic carbonate clasts, with red sandstone clasts (likely from the Kayenta or Moenkopi Formations), all set in a well-cemented reddish-brown sandy matrix. Interestingly, no clasts of the Precambrian crystalline basement are present in these deposits, even though today Precambrian rocks form the exposed bulk of the west-central Beaver Dam Mountains. Another instructive exposure about a mile to the northwest reveals interbedded fine- and coarse-grained Muddy Creek strata with a more diverse clast composition of andesitic volcanic rocks, Triassic and Jurassic sandstone, and Paleozoic carbonate clasts, but still no Precambrian clasts.

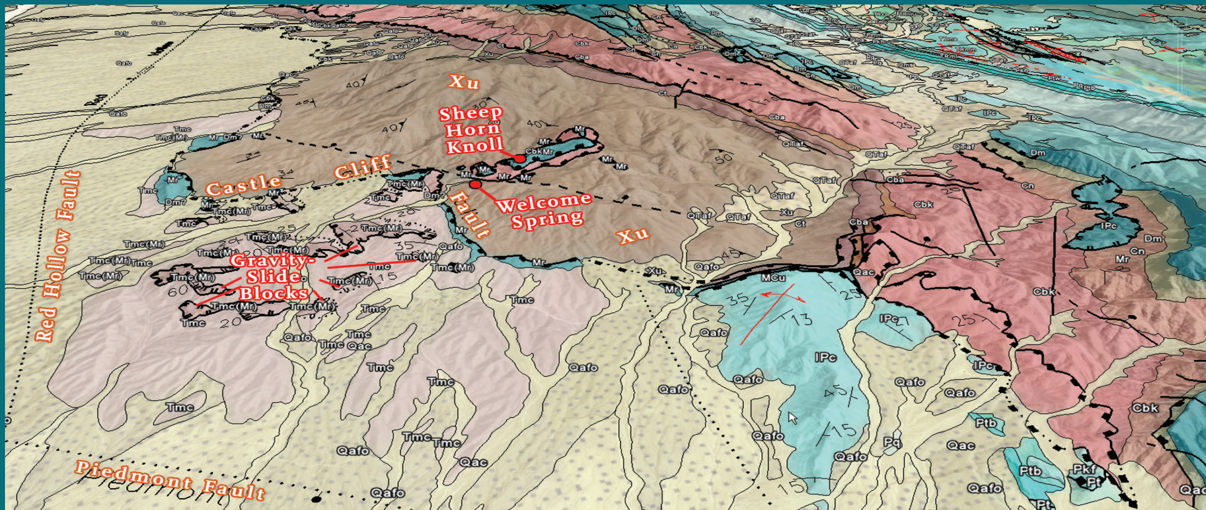
Age and Origin of the Displaced Blocks

Early workers believed that the gravity-slide blocks were the remnants of a late Tertiary thrust sheet emplaced from the west (the "fits and starts" stage of our understanding of these unusual features). We now know that the blocks were emplaced from the east by catastrophic landslides off the ancestral Beaver Dam Mountains in the late Miocene, 5 to 10 million years ago. Let's work backwards to see how we can confidently make such an interpretation.

Among our first observations is that the west flank of the Beaver Dam Mountains is carved from Precambrian gneiss and granite, so it is no surprise that young, Quaternary-age alluvial fans at the base of the range consist of cobbles and boulders eroded from these 1.8-billion-year-old rocks. The alluvial fans form an apron of sediment that slopes gently west toward Beaver Dam Wash and stands in stark contrast to the older Muddy Creek Formation, which both underlies and overlies the gravity-slide



A. *View north to Castle Cliff fault and large gravity-slide blocks of Redwall Limestone (Tmc[Mr]). The gravity-slide blocks and enclosing Muddy Creek (Tmc) strata are tilted to the east. The Castle Cliff fault dips gently west and places highly sheared Mississippian Redwall Limestone (Mr) against Precambrian crystalline basement rocks (Xu). The dirt road to Welcome Spring traverses the wash below the nearest gravity-slide block and is visible at the right of the photograph.* ***B.*** *Close-up view of gravity-slide block and underlying Muddy Creek Formation; rock hammer for scale. The coarse alluvial-fan deposits lack clasts of the Precambrian crystalline basement, now widely exposed in the Beaver Dam Mountains, showing that this and other gravity-slide blocks were emplaced prior to unroofing of the Beaver Dam Mountains in late Miocene time, 5 to 10 million years ago. Note brecciated nature of Redwall Limestone.*



Screen-capture image from Google Earth, showing an oblique, northward view of the west side of the Beaver Dam Mountains. The gravity-slide blocks are visible for us to see and ponder because they are exposed in a structural high known as a relay ramp, which links the Red Hollow and Piedmont faults. Sheared and tectonically thinned strata of the upper plate of the Castle Cliff fault hug the mountain front and are also present at Sheep Horn Knoll just above Welcome Spring. These upper-plate strata, which once covered Precambrian metamorphic and igneous rocks (Xu) that now form the exposed core of the range, were the source of the gravity-slide blocks.

blocks. Muddy Creek strata are deeply dissected and show no geomorphic expression of their former depositional environments of alluvial fans and playas. The basin in which Muddy Creek strata were deposited no longer exists—it was part of an early episode of basin-range extension now overprinted by today's basins and ranges.

Another thing we notice about the Muddy Creek Formation is a lack of Precambrian clasts, which is a strong indication that the formation was deposited and the gravity-slide blocks emplaced prior to unroofing of the crystalline basement. This was first observed by USGS geologist C.E. Dobbin in 1939, who was investigating the petroleum potential of southwest Utah. Dobbin described the large block west of Welcome Spring, noting that it lies on limestone conglomerate of assumed Miocene age, and that blocks to the west lie on "...soft, whitish and pinkish deposits that may represent playa deposits of the same age as the limestone conglomerate." More recently, however, some geologists interpreted some of these beds as being younger than Muddy Creek Formation (the important "backwards" steps that make us re-evaluate evidence thoroughly). Admittedly we lack fossil or radiometric ages for these beds at the west edge of the Beaver Dam Mountains, but the consensus now is that they are indeed the Muddy Creek Formation.

It was Earl Cook, then a student at the University of Idaho, who in 1960 made several key observations that set our story on its correct course. Although none were definitive, collectively they suggested that the blocks were derived from the east by landsliding off the Beaver Dam Mountains, not emplaced from the west as the upper plate of a thrust fault. Then in 1963, Standard Oil Company geologist Robert Jones found kinematic indicators – folds and other structures – that confirmed an eastern source for the blocks. Jones was one of many geologists who were re-evaluating what the previous generation of geologists had interpreted as compressional features (highly unusual younger-over-older "thrust" faults), but that we now know to be related to extension (low-angle normal faults and gravity-slide structures).

Another key piece of evidence came to light when geologists realized that the Muddy Creek strata also contain pebbles and cobbles of Navajo and Kayenta strata, and locally of volcanic rocks of intermediate composition, showing that those formations, in addition to Paleozoic carbonates, were once exposed in the source area of the gravity-slide blocks. Mesozoic and Paleozoic strata are not now present on the west flank of the Beaver Dam Mountains, and the nearest volcanic rocks are more than 10 miles to the north, indicating significant uplift and erosion of the range since deposition of the Muddy Creek Formation. In support of this idea, paleocurrent indicators also show that the coarse Muddy Creek sediments were derived from the east.

The final piece of the puzzle came from a recently published paper (the "occasional brilliant flash of insight") in which Columbia University geologist Mark Anders and his colleagues compared distinctive structures produced by gravity slides and seismically cycled faults and concluded that the brecciated and attenuated (structurally thinned) strata that make up the upper plate of the Mormon Peak detachment in adjacent Nevada represent an assemblage of gravity-slide blocks, not the remnants of a large crustal block bounded by a detachment fault. (The same could hold true for the nearby Castle Cliff fault and its attenuated upper plate rocks, but they have not yet been studied in such detail.) Importantly, Anders and colleagues also showed that the basal conglomerate below large gravity-slide blocks, and associated clastic dikes, formed by fluidization of granular material at the base of the slide and are unique features characteristic of many large gravity-driven slide blocks.

Summary

It is difficult to imagine enormous, city-block-size slabs of brecciated limestone bedrock catastrophically sliding off the mountain front and traveling a mile or more onto alluvial-fan deposits of the old Muddy Creek basin. What triggered the sliding is not known. Gravity sliding was no doubt facilitated by the attenuated and sheared nature of the Paleozoic strata that once was continuous over the crest of the range, and by the rapid uplift of the range early in its history. The large brecciated limestone blocks at the base of the Beaver Dam Mountains reflect a unique early episode in the history of the modern Beaver Dam Mountains. Today, the blocks stand as sentinels to Welcome Spring, encouraging visitors to ponder their remarkable past.

Virtual Geologic Map Overlays

A New Way to Visualize Geologic Map Information

by Robert F. Biek, Kent D. Brown, and Lance Weaver

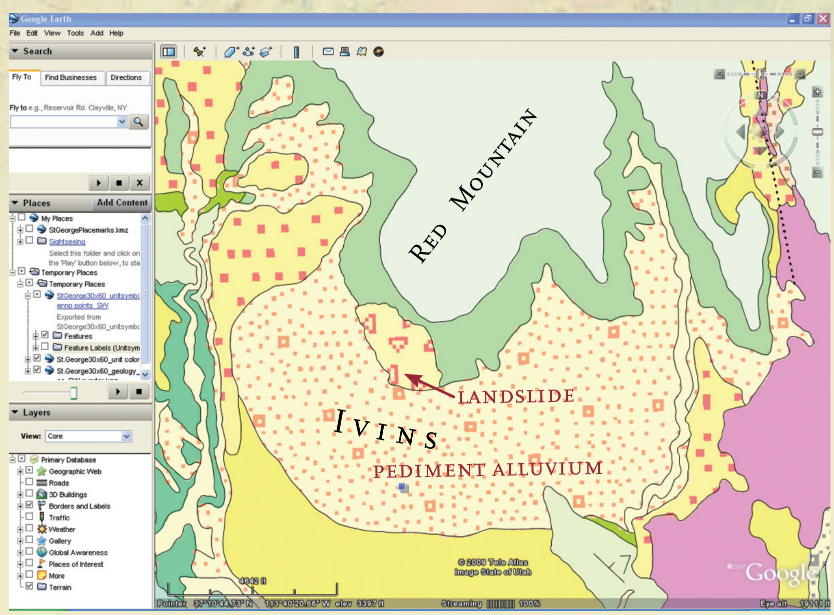
There is no better way to understand how the landscape has evolved and how it relates to underlying rocks and sediments than through the use of a regional-scale geologic map. Yet no matter how much geologists relish them, and how much planners, engineers, and natural resource professionals use them in their daily work, geologic maps are a specialty tool that requires training to be properly used and interpreted. It's a crime—for all the important information that they convey, geologic maps remain obscure to most of the general population who could benefit from their use.

The principal difficulty that most people have when looking at a geologic map is not being able to visualize the third dimension—the surface topography that is portrayed by contour lines on most geologic maps. Without an understanding of topography, of what the landscape actually looks like, a geologic map appears to most people as just a pretty (or weird looking!) color image. A good base map, however, allows savvy map users to accurately locate landscape and major cultural features and, importantly, see their relationship to underlying rocks and sediments.

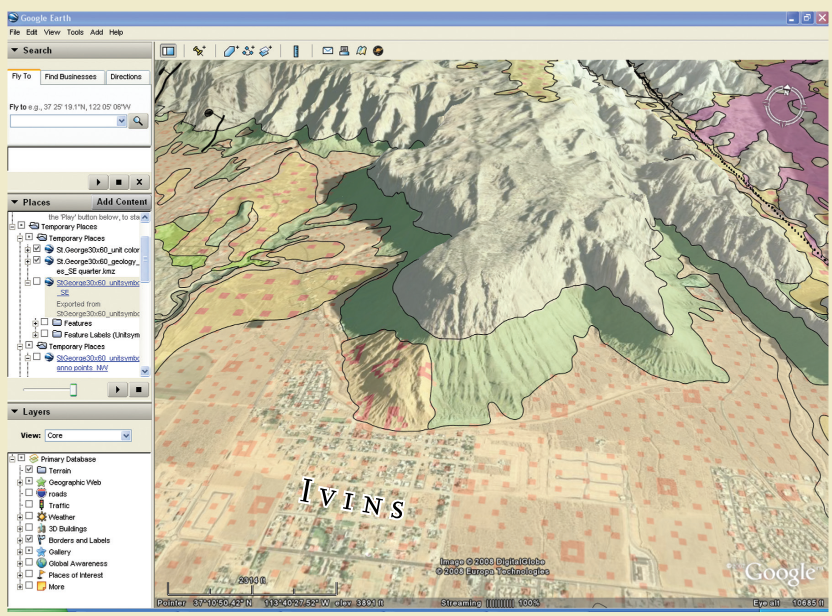
Through the use of computers and the Internet, and virtual globes such as Google Earth, we now have a way around the inherent limitations of depicting the third dimension on a standard paper geologic map. In fact, one of the most powerful applications of Google Earth or other virtual globes is the ability to overlay transparent geologic maps on a three-dimensional surface, and, using built-in navigational tools, view the landscape and geology at any angle and at any scale. This "bird's-eye view" enables users to better appreciate what geologic maps show.

To help users gain this 3-D advantage, we created an overlay of the new geologic map of the St. George 30' x 60' quadrangle in southwest Utah (the map is currently in final stages of review), in addition to the standard published map. This 3-D visualization brings the map to life, dramatically showing the relationship between geology and topography. It also enables map users to better appreciate the fourth dimension shown by geologic maps—geologic time, as represented by the stacking order of bedrock formations, because younger rock layers typically overlie older rock layers—and to better appreciate the shape and extent of surficial deposits, which are where most development takes place and most geologic hazards are found.

We also created a virtual field trip for the St. George



Traditional vertical geologic map view of Red Mountain in southwest Utah, partly ringed by pediment alluvium. Note landslide, near Ivins, at the southwest end of Red Mountain.



When viewed obliquely, and especially when viewed from a variety of different angles, the landslide comes clearly into view, and its relationship to the topographically higher Red Mountain and the broad pediment becomes clear.

30' x 60' quadrangle, which uses placemarks to highlight selected geologic features. Users can navigate the map and placemarks on their own, or take a virtual tour that will automatically travel from one selected feature to another. The virtual geologic map and field trip are available on the UGS Web site at geology.utah.gov/fieldtrip/index.htm.

Energy News

Utah's Renewable Energy Zone Assessment

by Jason Berry

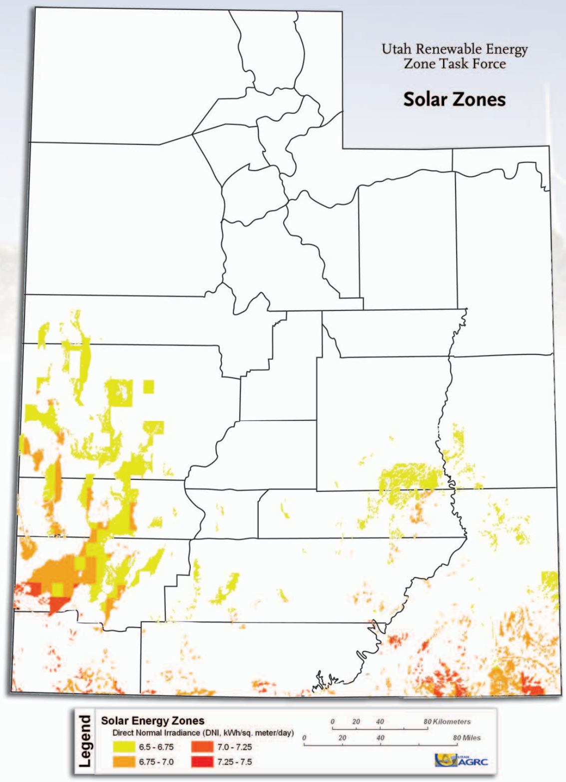
Unlike many states, Utah is blessed with its own diverse array of energy resources. Fossil fuels, like coal and natural gas, have been used for a century or more to heat our homes, power our lights, and build a thriving community and industry. Due to local resource abundance and decades of developing an energy infrastructure (i.e., power plants, pipelines, and transmission), Utah's energy rates are among the lowest in the nation. Utah's inexpensive electrical energy production and consumption portfolio is fueled primarily by coal and natural gas.

However, in today's energy policy and planning landscape, it is common practice to diversify energy portfolios in order to mitigate several growing concerns—looming federal carbon dioxide emissions regulation and volatile market trends in the gas industry among them. Policymakers and utilities are predicting these two issues will affect the cost and reliability of energy in the years and decades ahead. Adding renewable energy to the energy portfolio is a hedge against future price increases that result from carbon-constrained markets and volatile fuel prices.

In 2008, policymakers began to address this issue; Utah set a goal to have 20 percent of its adjusted electrical retail sales come from renewable energy by the year 2025. To help meet this goal, Governor Huntsman commissioned the Utah Renewable Energy Zones (UREZ) Task Force. The UREZ Task Force was directed to assess Utah's utility-scale solar, wind, and geothermal resource potential and address other factors, such as transmission and generation costs, in order to understand what it will take to develop Utah's renewable energy resources. Phase I of the UREZ initiative was designed to assess the location and quality of these resources, and the transmission and generation costs will be addressed in Phase II. Phase I was completed in January 2009 and identified an abundance of renewable energy resources. The Utah Geological Survey's State Energy Program (SEP) was chosen to lead the Phase I investigation and analysis, and Rick Allis, director of the Utah Geological Survey (UGS), was appointed co-chair of the UREZ Task Force. With support and collaboration from the UREZ Task Force, UREZ participants, energy resource consultants, and the UGS, SEP developed a report that addressed all of the UREZ Phase I goals (available at geology.utah.gov/sep/renewable_energy/urez/index.htm).

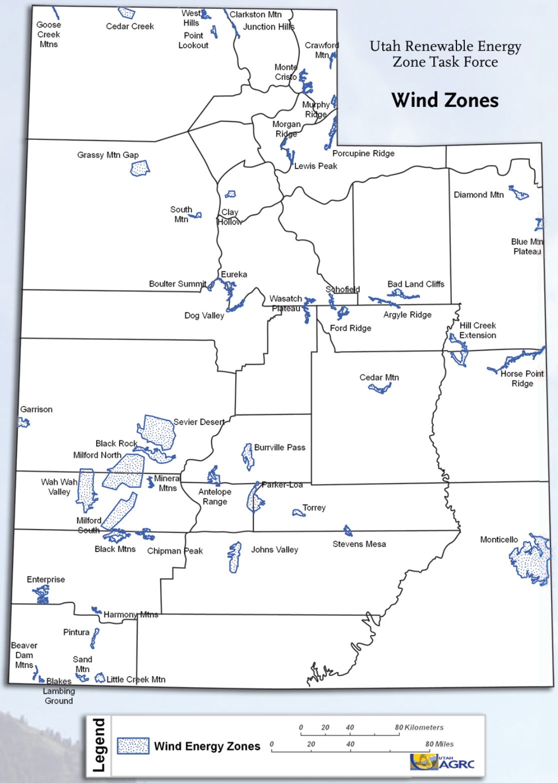
Utah's total solar, wind, and geothermal renewable energy resource is great. Phase I identified over 13,000 square miles of energy zones totaling 837 gigawatts (GW) of generating capacity. To put this number into perspective, assume only 1 GW of each of the three resources is developed. Accounting for specific energy generation characteristics of each resource—solar and wind are intermittent resources and geothermal is a constant generating resource—the combined electrical energy output from 3 GW would produce enough power to light approximately 16 million homes. Although Utah is unlikely to develop 837 GW capacity in the foreseeable future, it puts into perspective the potential contribution of the state's renewable energy resources, even if only a fraction of the resource is developed.

It is clear from Utah's sunny climate that its solar resource is robust. In total, the UREZ Phase I investigation identified 6,371 square miles of solar energy zones, which have a potential of 826 GW of generating capacity. Approximately 95 square miles located in the southern half of Utah are considered the highest quality with a generating capacity of 12 GW.

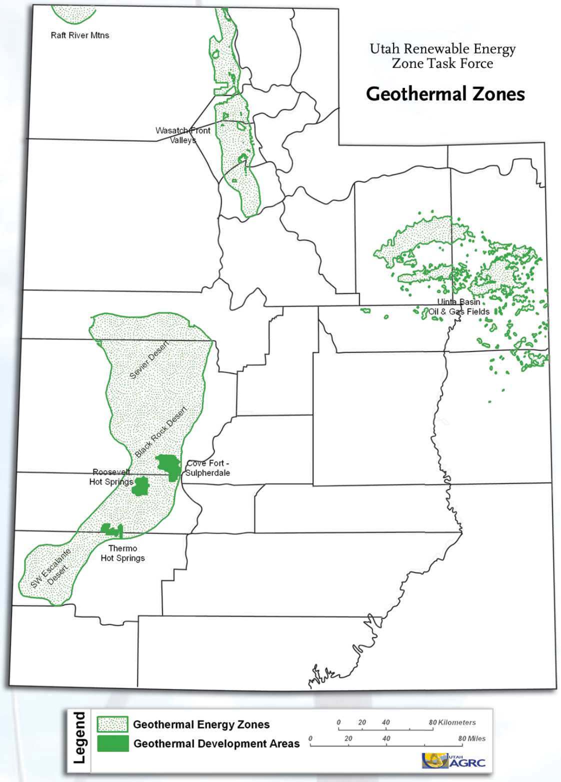


Utah has abundant high-quality sites for utility-scale development. The UREZ study identified over 6,000 square miles of land that could support the development of solar electrical-generation plants.

While Utah faces a tough competitor in Wyoming, which has a world-class wind resource, Utah holds its own in wind power potential. The UREZ assessment identified approximately 9,145 megawatts (MW) generating capacity from 51 distinct energy zones covering 1,830 square miles. The greatest concentration of a high-quality wind resource, totaling over 2,500 MW, is located in Escalante Valley in Iron, Beaver, and Millard Counties. This area is already beginning to see significant wind development. Utah wind resources are also geographically dispersed; 24 out of 29 Utah counties have identified wind energy zones.



Utah has a diverse and large quantity of viable wind resources. The UREZ study identified over 1,800 square miles of wind-energy zones.

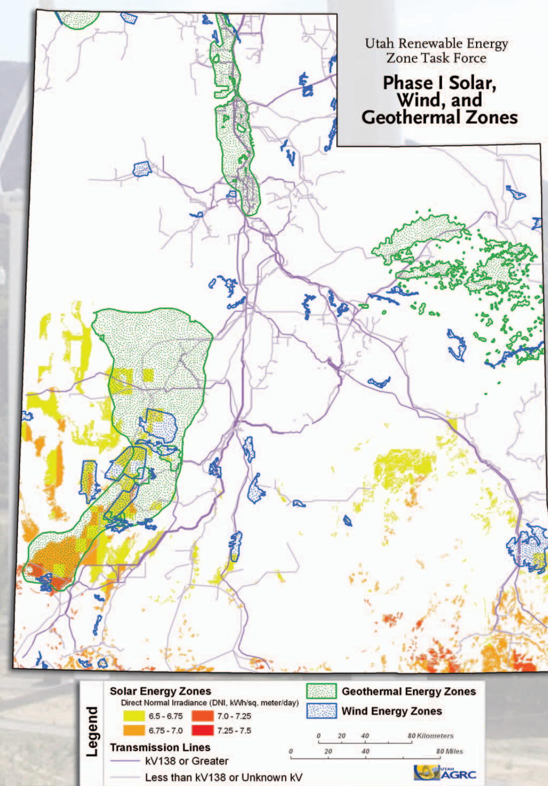


Utah has one of the most abundant geothermal resources in the world. The UREZ study found over 5,000 square miles of geothermal zones having development potential.

UGS geothermal geologist Robert Blackett co-authored the UREZ report's section on Utah's geothermal resources. The report found that Utah's identified higher-quality geothermal energy zones exist in a 50-mile-wide strip along the I-15 corridor stretching from Iron County to Millard County. In addition, geothermal energy zones were identified throughout the western half of the state as far north as Box Elder County. The estimated potential for electric generation from geothermal energy zones is approximately 2,166 MW encompassing approximately 5,000 square miles.

One of the significant findings of the UREZ study is that a high concentration of solar, wind, and geothermal resources are co-located in southwestern Utah, specifically in Iron, Beaver,

continued on p. 13



The UREZ study identified over 13,000 square miles of potentially developable zones in the state. Location and type of resource is very diverse. However, a significant co-location of wind, solar, and geothermal is found in southwest Utah.

National Stimulus Dollars for Utah come to State Energy Program

The American Recovery and Reinvestment Act (recovery funds), signed into law on February 17, 2009, presents an extraordinary opportunity to strengthen Utah's clean energy economy and create new green jobs across the state. The State Energy Program (SEP) will be the recipient of $40 million that will be directed towards energy efficiency, energy conservation, and renewable energy projects and programs in an effort to promote clean energy technologies as well as create jobs for Utahns.

SEP is preparing for the influx of recovery funds and will work diligently to manage this responsibility to the taxpayers and the public. Information pertaining to SEP's implementation of the federal recovery funds will be periodically updated on the following Web site: geology.utah.gov/sep/stimulus.

GeoSights

Wall Arch
A Fallen Giant

by Grant Willis

Wall Arch in June 2007. Note the apparent bow or sag near the middle of the arch and the large fresh scar where a slab fell in 1969.

During the night of August 4, 2008, Utah lost a popular giant when Wall Arch, a prominent arch along the Devils Garden Trail in Arches National Park, collapsed. While not the largest or most famous arch in the park, Wall Arch was still a favorite due to its proximity to Landscape Arch along the always-busy trail. With a measured span of 55 feet, it was ranked as 12th largest in the park (some publications and Web sites give the span as 71 feet—this is actually the "breadth" [line C in illustration on page 1], a dimension that is not useful for comparing arches). While no arch lasts forever, it is still extremely rare to see such a dramatic example of "geology in action." We do not have a good geologic tool for dating arch formation, but we are sure that Wall Arch had stood nearly unchanged for hundreds, and probably thousands of years.

Wall Arch was classified as a "fin natural arch" (Natural Arch and Bridge Society definition) that was carved into a rib or fin of the Slick Rock Member of the Entrada Sandstone. Though not a particularly long span, Wall Arch appeared to be precariously supported—note in the "before" photograph that the central part of the arch lacked a sturdy arch shape, but rather seemed to have a bow or sag. The first sign of trouble occurred in 1969 when a large slab of rock fell from the underside of the south lintel. In 2007, I remember looking up at the span and saying to my son, "There sure doesn't seem to be much holding that arch up"—evidently there was not. Fortunately, Wall Arch collapsed at night when no one was near—that very day many people had scrambled around under the arch much of the time. Probably, nighttime cooling-induced contraction following a day in the hot sun was the final straw that caused the fall.

The Devils Garden loop trail remains open. The collapse area is currently roped off because open fractures suggest that large blocks on the arch remnants are still unstable, but the trail has been rerouted close enough to see the fallen arch debris.

And while you are there, be sure to stop and admire Landscape Arch, which at 290 feet has the longest span in the world (see article on page 1). Landscape is also near the end of its life; who knows how long we will be allowed to admire this gravity-defying natural wonder?

Thanks to Tim Connors and Paul Henderson (NPS) and Jay Wilbur (NABS) who contributed information for this article.

Remnants of Wall Arch on August 6, 2008, two days after the collapse. Blocks occasionally fell from the remaining "arms" for a few days after the collapse, but none are known to have fallen since. Photo by Rich Giraud.

How to get there: Enter Arches National Park about 3 miles north of Moab on U.S. Highway 191. Proceed through the entrance station (*fee required*) and follow the paved road 16.7 miles northeast through the park to Devils Garden Trailhead (the branch road at 11.7 miles goes to Delicate Arch). On popular summer, holiday, and weekend days, the Devils Garden Trailhead parking lot fills up, though cars come and go frequently, so you can usually find a parking place if you are patient. Walk the easy, well-signed sand and gravel trail about 0.8 mile to see collapsed remnants of Wall Arch just a few hundred feet beyond Landscape Arch.

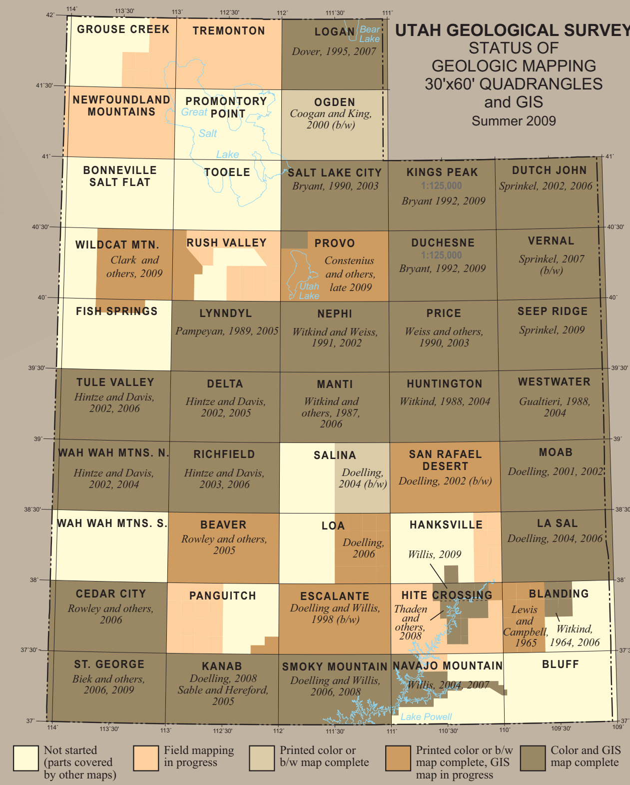
SURVEY NEWS

Geologic Mapping News and Short Notes

by Grant Willis

The Utah Geological Survey Geologic Mapping Program continues to map Utah geology in two primary scales and map series: 1:24,000 (7.5' quadrangle series) and 1:100,000 (30' x 60' quadrangle series). All 30' x 60' quadrangles, and a few 7.5' quadrangles and other maps, are also produced in geographic information system (GIS) format. All maps are released as formally published maps or open-file reports as soon as possible after completion, and are available in printed (press run), digital (on CD), or plot-on-demand formats from the Natural Resources Map and Bookstore, and for viewing and downloading from the UGS Web site (geology.utah.gov).

The Mapping Program is generally actively involved in about 50 geologic mapping projects at one time—about 65 percent are our own projects, and the rest are outside cooperative projects with academic, U.S. Geological Survey, and consulting geologists. Each project requires several years, including planning, acquiring funding, field mapping, digital compilation, writing, review, administrative approvals, and finally publication and distribution to the public. Needless to say, the process seems endless—I often feel like I'm caught in the movie *Groundhog Day*, in which Bill Murray had to live the same day over and over until he finally got it right. But what better place to get caught in a geologic mapping time warp than Utah! Information about geologic mapping products is available from the Natural Resources Map and Bookstore and on the UGS Web site.



New STATEMAP Award

The UGS was recently awarded $230,975 to conduct new geologic mapping through the National Cooperative Geologic Mapping Program administered by the U.S. Geological Survey, once again making Utah one of the top three states in size of award. This is the 17th year of this highly successful program that nationally has funded several thousand geologic maps, and in Utah alone, has partly funded mapping of approximately sixty-four 7.5' quadrangles and thirty-two 30' x 60' quadrangles. This year's award will be used to fund mapping of the Rush Valley, Grouse Creek, and Panguitch 30' x 60' quadrangles, and Santaquin and Payson Lakes (Quaternary only), Faust, St. John, Devils Slide, Co-op Creek, George Mountain, and Gooseberry Creek 7.5' quadrangles, and to produce GIS data for the San Rafael Desert and parts of the Wildcat Mountain and Loa 30' x 60' quadrangles.

Employee News

Sharon Hamre retired after 17 years with the UGS. She worked as a graphic designer in the Editorial Section and was responsible for the design and layout of many UGS publications. We wish Sharon well in her retirement. **Richard Austin** has joined us as our new graphic designer. He has a Bachelor of Fine Arts degree from Weber State University and has been working as a graphic designer for four years. **Jay Hill** has also joined the Editorial Section as a GIS Analyst. Jay relocated to Utah from North Carolina and has a bachelor's degree in geography, specializing in cartography, from Ohio University. Welcome to Richard and Jay!

Meghan Golden accepted a position with the State Energy Program as a Clean Energy Program Specialist. She is a graduate of the University of Utah with a degree in architecture and an MBA with an emphasis in sustainability. Meghan has a background in green building design.

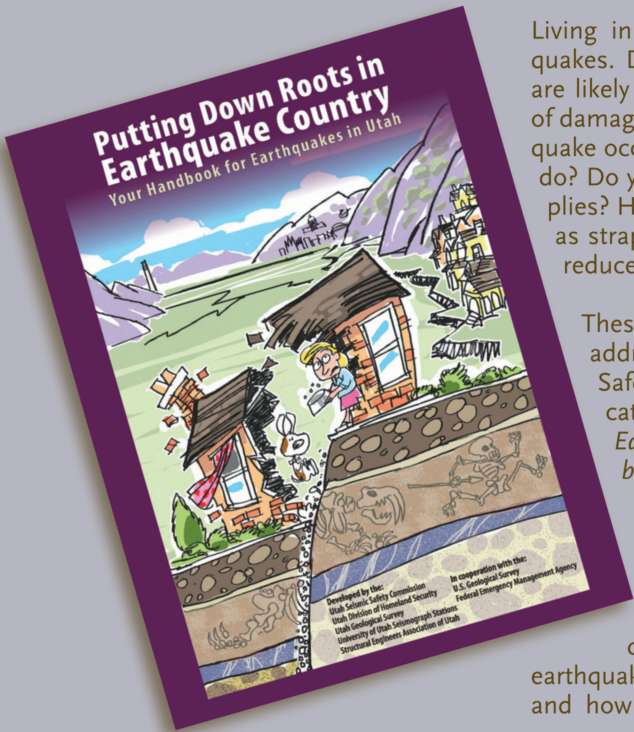
New UGS Board Members

The UGS Board has three new members who were appointed by Governor Huntsman and confirmed by the Senate during this year's legislative session. They began serving their terms on April 1, 2009.

Donald Harris, our new minerals (hydrocarbons) representative, is employed by Sinclair Oil Corporation and has been an oil and gas geologist for 27 years. **Tom Tripp,** our new minerals (metals) representative, is Director of Technical Services and Development for US Magnesium LLC, and has worked in the field of mineral extraction for 31 years. **William Loughlin,** representing geology as applied to the practice of civil engineering, is the owner and senior hydrogeologist for Loughlin Water Associates LLC, and has 25 years experience as a consulting hydrogeologist. We are pleased to welcome them on board.

Terms have expired for **Geoff Bedell, Steve Church, and David Simon**. They have served us well as members of the UGS Board, and we thank them for their efforts.

New comprehensive handbook on earthquakes in Utah



Living in Utah means living with earthquakes. Do you know where earthquakes are likely to occur in Utah and what kind of damage they can cause? If a large earthquake occurred right now, what would you do? Do you have a disaster plan and supplies? Have you taken simple steps, such as strapping down your water heater, to reduce your earthquake risk at home?

These questions and others are addressed in a new Utah Seismic Safety Commission (USSC) publication called *Putting Down Roots in Earthquake Country – Your Handbook for Earthquakes in Utah*. The handbook is a comprehensive resource that provides a variety of information on earthquakes in Utah in an easy-to-read format. It outlines why Utah is seismically active, areas where strong earthquake shaking is expected to occur, and how earthquakes cause damage. In addition, it includes seven steps to follow to reduce your risk from earthquakes, and what you should know about the potential financial impacts of earthquakes.

The USSC developed and published the *Putting Down Roots* handbook together with the Utah Geological Survey, Utah Division of Homeland Security, University of Utah Seismograph Stations, and Structural Engineers Association of Utah. The handbook is adapted from California versions of the *Putting Down Roots* handbook developed by the U.S. Geological Survey and Southern California Earthquake Center.

To obtain a free copy of the handbook, visit the Natural Resources Map & Bookstore (1594 W. North Temple, Salt Lake City). To request multiple copies (group orders), contact Bob Carey at bcarey@utah.gov. The handbook is also available online at the USSC Web site (ussc.utah.gov).

Teacher's Corner

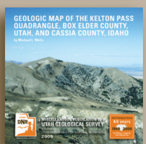
Student-UGS Partnership Produces High School Science Fair Winner

The occasional opportunity for a Utah Geological Survey employee to be a mentor to a student becomes a rewarding experience for both. In September 2008, UGS geologist J. Wallace Gwynn was contacted by Faith Martinez, a senior from Carbon High School in Price, Utah, who requested some suggestions for a science fair project. From their discussions evolved a most interesting project. Her project initially focused on the chemistry of the sediments from three cores taken at the south end of Farmington Bay, located in the southern part of Great Salt Lake. The scope of her project continued to grow, however. Radiocarbon dating of a mollusk shell found at a depth of 47 centimeters in one of the cores yielded an age of 2760 to 2920 years before present. Cesium-137, a product of the 1950s and 1960s atomic testing in Nevada, was found in the upper 4 centimeters of another core. Faith also obtained information from the U.S. Geological Survey on a core they had taken near one of her cores. Their analyses indicate the presence of numerous inorganic, organic, and pesticide contaminants in the sediments, decreasing in concentration with increasing depth.

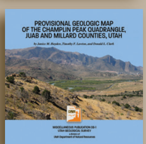
Faith entered her project in the Carbon District science fair under the title "Analysis of Farmington Bay Sediments to Identify Their Chemistry and Causes of Human Contamination." She placed first in the category of Earth and Planetary Sciences, was awarded the Most Outstanding Project in the Senior Division, and was awarded a two-year scholarship to the College of Eastern Utah. Through her work, she was also the winner of the Carbon High School's Science Sterling Scholar. Faith's next challenge was the Regional Science Fair held at Southern Utah University in late March. There she received first place in the Earth Science category, first place from the SUU Geology Club, first place from the Air and Waste Management Association, and first place from the Utah Department of Natural Resources. The UGS congratulates Faith on her accomplishments!

New Publications

Compilation of 1970s Woodward-Lundgren & Associates Wasatch fault investigation reports and oblique aerial photography, Wasatch Front and Cache Valley, Utah and Idaho, by Steve D. Bowman, Keith Beisner, and Corey Unger, 9 DVDs (3 p., 6 pl., [contains GIS data]), **OFR-548** $74.95

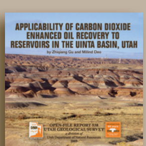


Geologic map of the Kelton Pass quadrangle, Box Elder County, Utah, and Cassia County, Idaho, by Michael L. Wells, CD (22 p., 3 pl.), **MP-09-3** $19.95

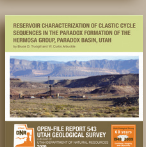


Provisional geologic map of the Champlin Peak quadrangle, Juab and Millard Counties, Utah, by Janice M. Hayden, Timothy F. Lawton, and Donald L. Clark, CD (3 pl., 1:24,000), ISBN 1-55791-779-5, **MP-08-1** $14.95

Wetlands in the Farmington Bay area, Davis and Salt Lake Counties, Utah—An evaluation of threats posed by ground-water development and drought, by Charles E. Bishop, Mike Lowe, Janae Wallace, Richard L. Emerson, and J. Scott Horn, CD (36 p.), **RI-264** $14.95

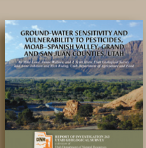


Applicability of carbon dioxide enhanced oil recovery to reservoirs in the Uinta Basin, Utah, by Zhiqiang Gu and Milind Deo, CD (13 p.), **OFR-538** $14.95

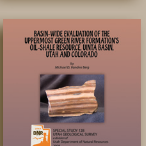


Reservoir characterization of clastic cycle sequences in the Paradox Formation of the Hermosa Group, Paradox Basin, Utah, by Bruce D. Trudgill and W. Curtis Arbuckle, CD (106 p. + 39 p. appendices), **OFR-543** $14.95

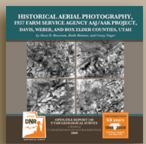
Multiproxy environmental characterizaion of lake level cycles in the Green River Formation of Utah and Colorado, by Jessica H. Whiteside and Marc A. Van Keuren, CD (22 p.), **OFR-544** 14.95



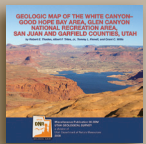
Ground-water sensitivity and vulnerability to pesticides, Moab-Spanish Valley, Grand and San Juan Counties, Utah, by Mike Lowe, Janae Wallace, J. Scott Horn, Anne Johnson, and Rich Riding, CD (27 p., 2 pl.), **RI-263** $19.95



Basin-wide evaluation of the uppermost Green River Formation's oil-shale resource, Uinta Basin, Utah and Colorado, by Michael D. Vanden Berg, CD (19 p., 8 pl., [contains GIS data]), **SS-128** $24.95



Historical aerial photography, 1937 Farm Service Agency AA/AAK Project, Davis, Weber, and Box Elder Counties, Utah, by Steve D. Bowman, Keith Beisner, and Corey Unger, 2 DVDs (2 p., 1 pl., [contains GIS data]), **OFR-540** $34.95



Geologic map of the White Canyon–Good Hope Bay area, Glen Canyon National Recreation Area, San Juan and Garfield Counties, Utah, by R.E. Thaden, A.F. Trites, Jr., T.L. Finnell, and G.C. Willis (digitized and modified from U.S. Geological Survey Bulletin 1125, published in 1964), CD (1 pl., scale 1:100,000 [contains GIS data]), **MP-08-3DM** $24.95

Utah Renewable Energy Zones Task Force: Phase I Report: Renewable Energy Zone Resource Identification, by Jason Berry, David Hurlbut, Richard Simon, Joseph Moore, and Robert Blackett, CD (56 p.), ISBN 1-55791-808-2, **MP-09-1** $14.95

Provisional geologic map of the Tintic Mountain quadrangle, Juab and Utah Counties, Utah, by Jeffrey D. Keith, David G. Tingey, Judith L. Hannah, Steven T. Nelson, Daniel K. Moore, Teresa M. Cannan, Alexander P. MacBeth, and Tamalyn Pulsifer, 15 p., 1 pl., 1:24,000, **OFR-545** $9.95

Interim geologic map of the Temple Mountain quadrangle, Emery County, Utah, by Hellmut H. Doelling and Paul A. Kuehne, 13 p., 1 pl., scale 1:24,000, **OFR-541** $8.50

continued from p. 9

and Millard Counties. By identifying the state's utility-scale resources, Phase I creates a data foundation for analyzing new electrical transmission development, which would be required to deliver this renewable electricity to market. In addition, the UREZ process will help to identify which zones are economically feasible for development, and in turn may prioritize which transmission routes need to be upgraded or developed. In 2009, Phase II will continue to explore these critical issues, and SEP will provide continued technical support and consultation to assist the UREZ Task Force.

Utah certainly has an opportunity to be a leader in renewable energy development. Its diversity and co-location of resources—such as solar, wind, and geothermal—make Utah attractive to energy markets throughout the West.

Natural Resources Map & Bookstore

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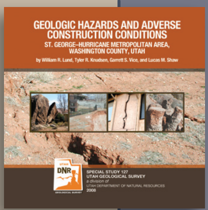
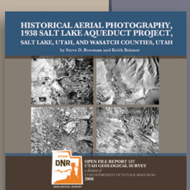
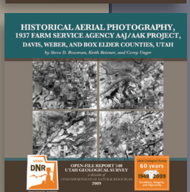


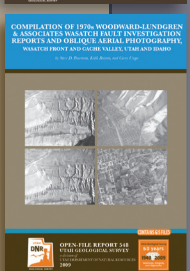
Geologic hazards and adverse construction conditions, St. George–Hurricane metropolitan area, Washington County, Utah

by William R. Lund, Tyler R. Knudsen, Garrett S. Vice, and Lucas M. Shaw

The Utah Geological Survey has prepared a GIS-based map folio containing 14 1:24,000-scale geologic-hazard and adverse-construction-condition maps for the St. George–Hurricane metropolitan area. The maps are an aid for general planning to indicate where site-specific studies are required. A GIS search application permits the maps to be queried by geologic hazard or adverse condition type, and location. Geologic-hazard maps include surface faulting, liquefaction, flooding, landslides, and rock fall. Adverse-construction-condition maps include expansive soil and bedrock, collapsible soil, gypsiferous soil and bedrock, shallow bedrock, caliche, wind-blown sand, breccia pipes and paleokarst, shallow ground water, and piping- and erosion-susceptible soils. Each map has an accompanying document that provides information on the nature of the hazard or adverse condition in the study area. **Special Study 127** **$24.95**







Historical Aerial Photography Compilations

by Steve D. Bowman, Keith Beisner, and Corey Unger

Historical aerial photography is used in geologic, geotechnical, and environmental assessment and investigation projects; land-use planning; ASTM Phase I Environmental Site Assessments; projects documenting land-use, geomorphologic, geologic-hazard, and other changes that may have occurred in a particular area; and as a historical archive.

Each aerial photography compilation includes digitally scanned aerial photography frames in TIFF format, explanatory text, Google Earth index with reduced resolution thumbnail images of the frames, an ESRI Shapefile for use with GIS software, and one or more frame center point index sheets in Adobe PDF format.

Historical aerial photography, 1938 Salt Lake Aqueduct Project, Salt Lake, Utah, and Wasatch Counties, Utah **Open-File Report 537 (DVD)** **$24.95**

Historical aerial photography, 1937 Farm Service Agency AA/AAK Project, Davis, Weber, and Box Elder Counties, Utah, **Open-File Report 540 (2 DVD set)** **$34.95**

Compilation of 1970s Woodward-Lundgren & Associates Wasatch fault investigation reports and oblique aerial photography, Wasatch Front and Cache Valley, Utah and Idaho, **Open-File Report 548 (9 DVD set)** **$74.95**

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