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DIGGING UP INFORMATION ON EARTHQUAKE SOURCES IN SALT LAKE VALLEY

The Director's Perspective

by Richard G. Allis

This issue of *Survey Notes* highlights some of the geologic hazards that Utahns live with—in particular earthquakes and landslides. Looking back over the past year, the UGS published eight papers and reports on a variety of geologic-hazard events, and UGS authors submitted 17 abstracts on similar topics to conferences and professional societies. One report that has just been published investigates a type of hazard that has been subtly occurring in parts of Utah for decades but in recent years has had a greater impact on property, namely ground subsidence due to a declining groundwater level. This report, by Richard Forster (University of Utah), evaluated what is called the InSAR technique for measuring the subsidence in Escalante Valley between 1998 and 2006 (UGS Open-File Report 589, 2012). The technique uses satellite radar imagery of the ground surface, and by overlaying images generated at different times an interference pattern (interferogram) is created that indicates changes in ground elevation. InSAR is capable of detecting changes in elevation as small as fractions of an inch in areas where there has not been significant ground disturbance (such as from plowing), or where crop growth or snow accumulation has not obscured the ground surface at different times of the year. An especially powerful aspect of InSAR is that interferograms can be retrospectively compiled from radar images collected as far back as the early 1990s when the first radar satellites were launched.

Open-File Report 589 shows that the subsidence rates in Escalante Valley between 1998 and 2006 ranged to over 2 inches per year. In the main area of irrigated cropland there was poor coherence and subsidence rates could not be determined. The report also shows that the area of subsidence increased in extent and the rate of subsidence accelerated by about 1/8 inch per year between the late 1990s and 2006. The total maximum subsidence since the late 1990s has been over 2 feet. The rate of groundwater-level decline due to withdrawal in the Beryl Junction area of Escalante Valley has been around 2 feet per year since the 1950s, and the total decline is now more than 100 feet in some wells. In January 2005, a warm winter storm on top of a melting snowpack caused a large flood which enlarged previously unnoticed ground fissures in the valley. One fissure cut across and briefly closed the main road near Beryl Junction (SR-56), and fissures occurred discontinuously over a total distance of 5.6 miles. A UGS report documenting the effects and investigating the causes found some fissures were over 10 feet deep, over 6 feet wide, and over 1000 feet long (Special Study 115; Lund and others, 2005). The report concluded that groundwater withdrawal was causing permanent compaction of fine-grained deposits at depth, and that where a lateral gradient exists in the thickness of the more compressible deposits, fissures could form at the surface. This phenomenon has also occurred in Arizona and Nevada, where it has also been attributed to groundwater declines.

The UGS has recently been studying fissures and subsidence in Cedar Valley, west of Cedar City, at the request of the Central Iron County Water Conservancy District. This study was triggered by the occurrence of fissures that disrupted roadway pavement and curbs, and reversed the grade of sewage lines in a new subdivision under construction near Enoch. Our groundwater scientists have been working with our Cedar City-based hazards geologists to characterize the hydrogeologic characteristics beneath the valley, water withdrawal patterns and water-level changes with time, and fissure patterns and evidence for the extent of subsidence. An InSAR survey has revealed a long history of subsidence over much of Cedar Valley, with local centers near Enoch in the north and Quichapa Lake in the south. This work adds to the results from an earlier InSAR study commissioned by the UGS in 2006 that found evidence for subsidence in Escalante, Parowan, and Milford valleys. These valleys have all seen several decades of significant water-level declines. With ongoing groundwater-level declines in many valleys of southern Utah, ground subsidence is another hazard that some Utahns will have to adapt to. In contrast to many geologic hazards, subsidence due to groundwater extraction is human-induced, and can be controlled to some extent through prudent land-use and water-use decisions.

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Design: *Stevie Emerson*
Cover: *Eastward view of research trench across a small (about 3 feet high) fault scarp on the West Valley fault zone in Salt Lake Valley. Photo by Michael Hylland.*

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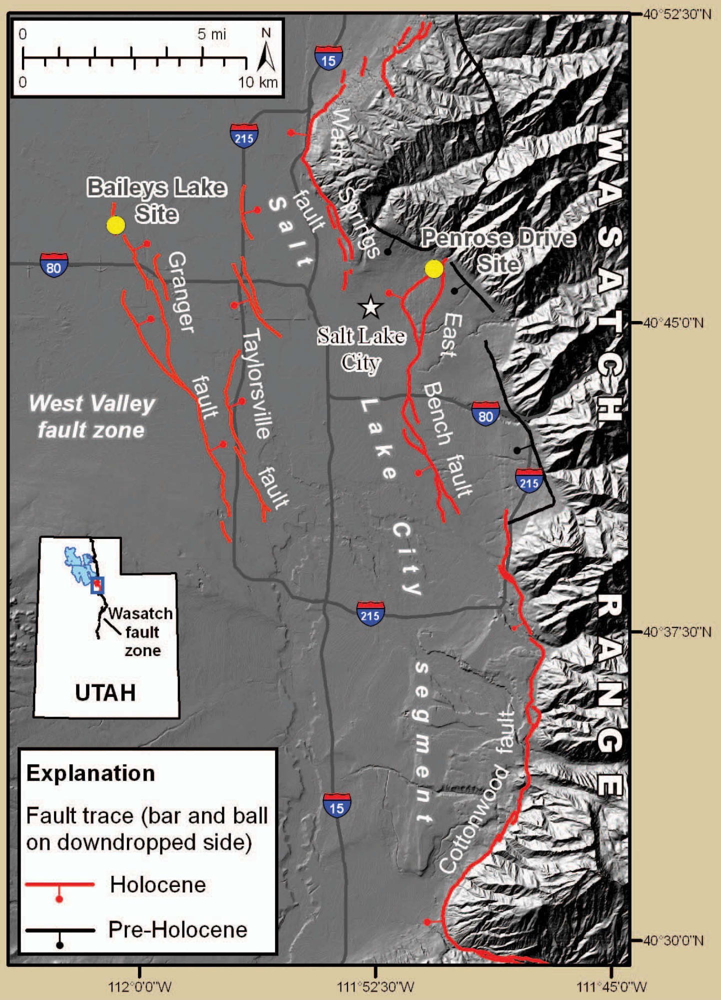
EVALUATING THE SEISMIC RELATION BETWEEN THE WEST VALLEY FAULT ZONE AND SALT LAKE CITY SEGMENT OF THE WASATCH FAULT ZONE, SALT LAKE VALLEY, UTAH

Michael D. Hylland, Christopher B. DuRoss, and Greg N. McDonald

Background

The Wasatch fault zone has long been known to be a serious earthquake threat to the Wasatch Front region. In Salt Lake Valley, strands of the Salt Lake City segment of the fault zone pass directly through Utah's capital city. However, another possible source of large (approximately magnitude [M] 6.5) earthquakes lies just a few miles west of Salt Lake City—the West Valley fault zone, comprising a system of faults on the floor of northern Salt Lake Valley. Like the Wasatch fault zone, the West Valley fault zone shows evidence of recurrent movement in the geologically recent past (i.e., the past 10,000 years). But unlike the Wasatch fault zone, which has been the subject of dozens of detailed scientific studies, relatively little is known about the behavior of the West Valley fault zone.



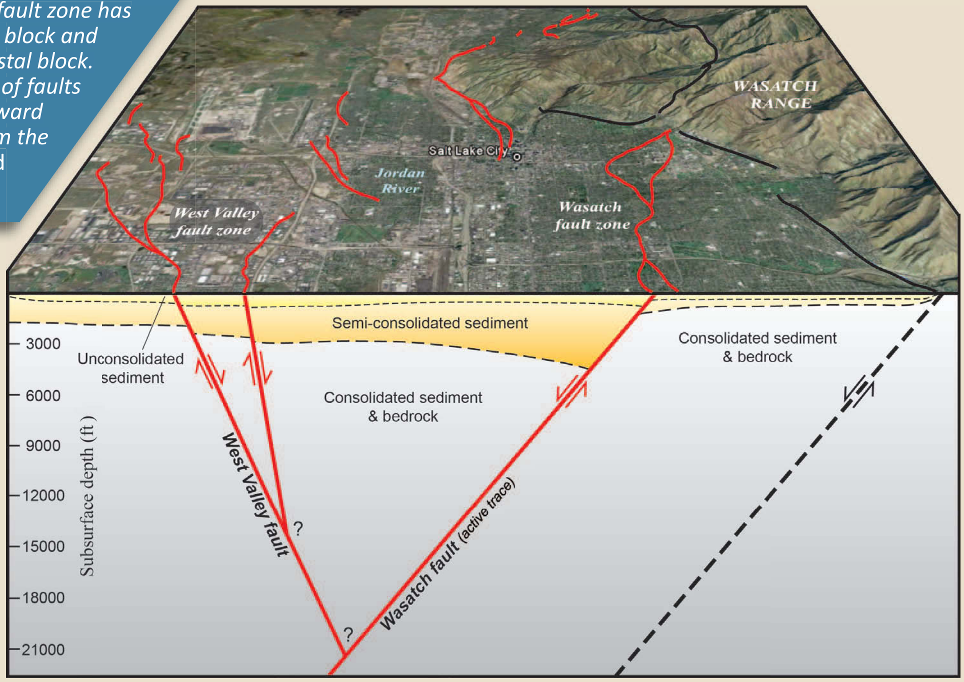
The West Valley fault zone comprises two strands: the Granger and Taylorsville faults. The Salt Lake City segment, one of the central, most active segments of the Wasatch fault zone, comprises three strands: the Warm Springs, East Bench, and Cottonwood faults. In 2010, the UGS conducted fault trenching studies at the Penrose Drive and Baileys Lake sites.

The Utah Geological Survey (UGS) recently conducted paleoseismic (fault trenching) studies of large, prehistoric earthquakes on the West Valley fault zone (Baileys Lake site; September 2010) and Salt Lake City segment (Penrose Drive site; May 2010). In addition to UGS geologists, the investigative team included geologists with the U.S. Geological Survey, URS Corporation, and Kansas State University. The new data collected during these detailed studies will allow us to better characterize earthquake activity on both fault zones. We can then compare the timing of past earthquakes on the two fault zones—an important step in improving our understanding of how the fault zones interact and what kind of earthquake activity to expect in the future.

The West Valley fault zone is *antithetic* to the Salt Lake City segment; that is, the fault plane of the Salt Lake City segment slopes westward beneath Salt Lake Valley, whereas the fault plane of the West Valley fault zone slopes eastward, toward the Salt Lake City segment. Important questions pertain to the seismic relation between the two fault zones: When the Salt Lake City segment moves and generates a large earthquake, does the West Valley fault zone also move at the same time? Or can the West Valley fault zone move independently of the Salt Lake City segment, and therefore need to be considered a separate source of large earthquakes? The answers to these questions have significant implications for the seismic hazard of the greater Salt Lake City metropolitan area.

Our trenches at the Penrose Drive site exposed geologic evidence for five or six large earthquakes on the East Bench fault in the past 17,000 years. The near-vertical fault plane (indicated by arrows) separates lighter-colored alluvial-fan deposits from darker-colored slope deposits including soil, fill, and sediments eroded from the fault scarp (scarp-derived colluvium). Horizontal string grid lines are spaced 1 meter (3.2 feet) apart.

Vertical movement on the west-dipping Wasatch fault zone has created the Wasatch Range in the uplifted crustal block and Salt Lake Valley in the adjacent downdropped crustal block. The West Valley fault zone is an antithetic system of faults in the Salt Lake Valley block, dipping eastward toward the Wasatch fault zone. (Mapped fault traces from the Quaternary Fault and Fold Database of the United States*, superimposed on a Google Earth image.)*

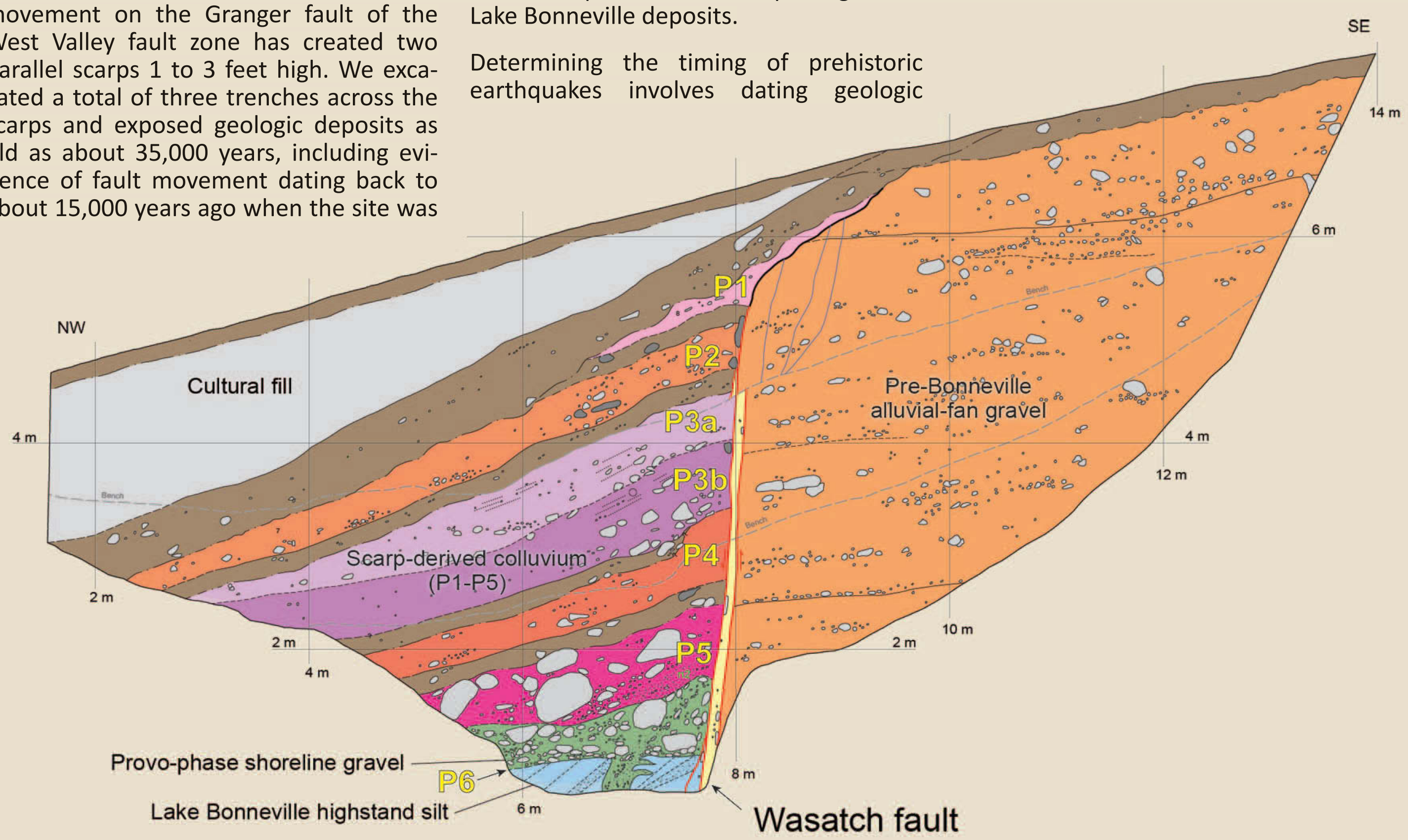


Summary of Results

At the Penrose Drive site, immediately north of the University of Utah campus, fault movement on the East Bench fault of the Salt Lake City segment has created a steep scarp about 30 feet high. We excavated two trenches across the scarp and exposed geologic deposits as old as 60,000–70,000 years, including deposits resulting from surface faulting dating back to about 17,000 years ago when the site was along the Provo shoreline of late Pleistocene-age Lake Bonneville. Geologic evidence indicates five or perhaps six post-Provo earthquakes, each one displacing the ground surface vertically by about 3 to 6 feet. The older (pre-Bonneville) alluvial-fan deposits have been displaced vertically by at least 52 feet.

At the Baileys Lake site, immediately west of Salt Lake City International Airport, movement on the Granger fault of the West Valley fault zone has created two parallel scarps 1 to 3 feet high. We excavated a total of three trenches across the scarps and exposed geologic deposits as old as about 35,000 years, including evidence of fault movement dating back to about 15,000 years ago when the site was deeply submerged beneath the waters of Lake Bonneville. Geologic evidence indicates four or perhaps five post-Bonneville-highstand earthquakes, each one displacing the ground surface vertically by about 1.5 feet and resulting in about 6 feet of vertical displacement of the pre-highstand Lake Bonneville deposits.

Determining the timing of prehistoric earthquakes involves dating geologic deposits that are closely associated with fault movement. Two methods that we have found most useful are radiocarbon dating, which measures concentrations of the radioactive isotope carbon-14, and optically stimulated luminescence (OSL),



Log of the east trench at the Penrose Drive site shows faulted alluvial-fan deposits on the upthrown (right) side of the fault, and stacked deposits of scarp-derived colluvium on the downthrown (left) side of the fault. Colluvial units P1 through P5 provide evidence for five or six large earthquakes that occurred after Lake Bonneville retreated from this site around 14,500 years ago, and P6 is stratigraphic evidence for an earthquake during the time that the lake's Provo shoreline was at or near this site. Grid-line spacing is 2 meters (6.4 feet).

Our trenches at the Baileys Lake site exposed geologic evidence for four or five large earthquakes on the Granger fault in the past 15,000 years. Layers of Lake Bonneville sediment have been folded and displaced downward on the left (east) side of the steeply dipping fault plane along which the geologist is placing red markers. String grid-line spacing is 1 meter (3.2 feet).

which measures the effects of "trapped" electrons that accumulate over time in the mineral grains of buried sediment. We analyze our dating results in a computer program that uses the geologic deposit ages to mathematically model the timing of fault movement. Although this is a rigorous process, the resulting earthquake times typically have uncertainties of hundreds of years, so comparing earthquake times on different fault zones is somewhat problematic. Still, our results for this study show close similarities in the timing of West Valley fault zone and Salt Lake City segment earthquakes, and suggest that West Valley fault zone earthquakes likely occur in response to earthquakes on the Salt Lake City segment.

Ongoing Work

We cannot presently determine whether West Valley fault zone earthquakes occur coseismically (nearly instantaneously) with Salt Lake City segment earthquakes, or are triggered by them, occurring as aftershocks hours to perhaps months later. To help answer this question, we are looking at historical analogs of antithetic faulting from elsewhere in the world, including the 1984 Devil Canyon earthquake (M 5.8) in Idaho, 1980 Campania–Basilicata earthquake

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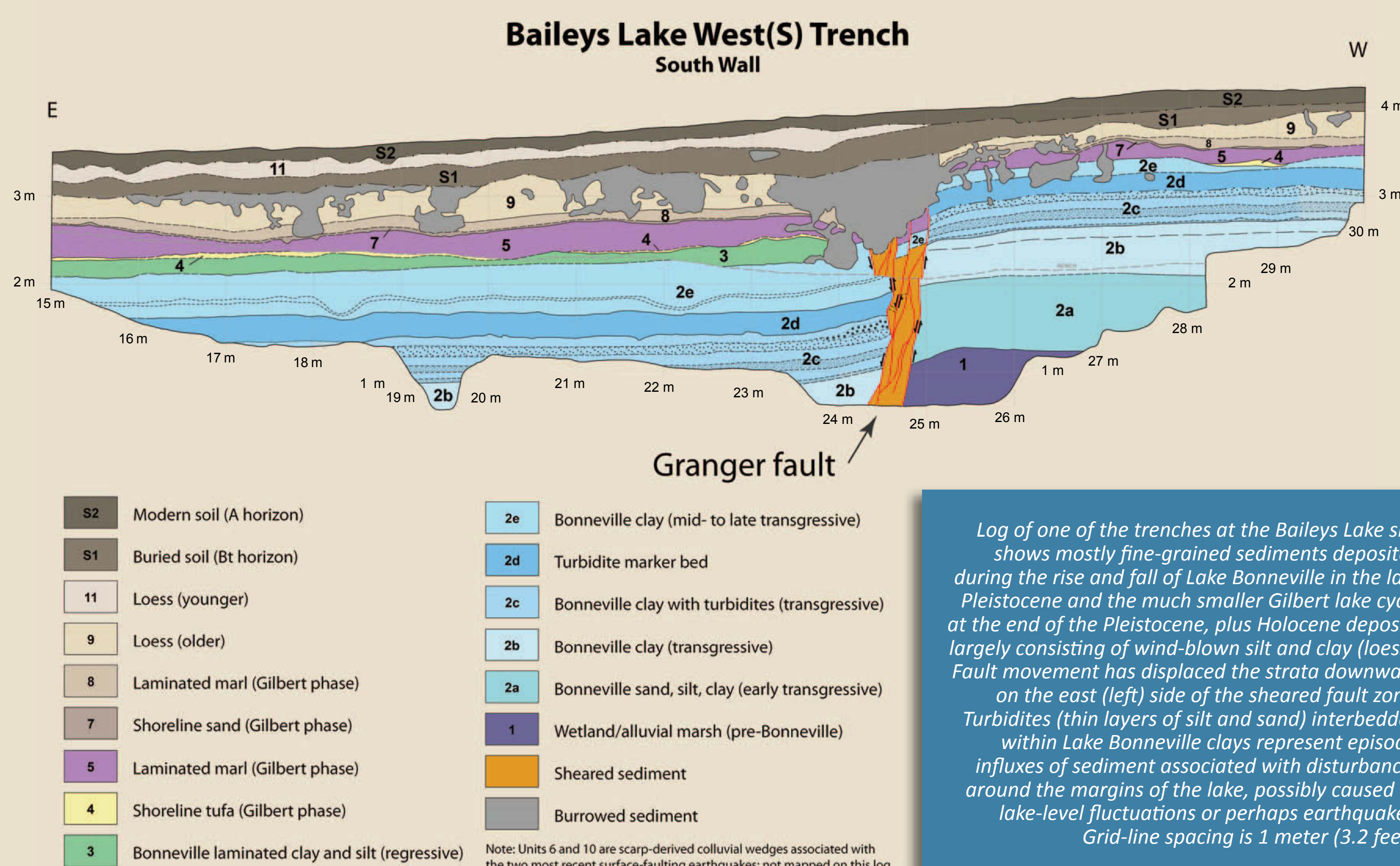
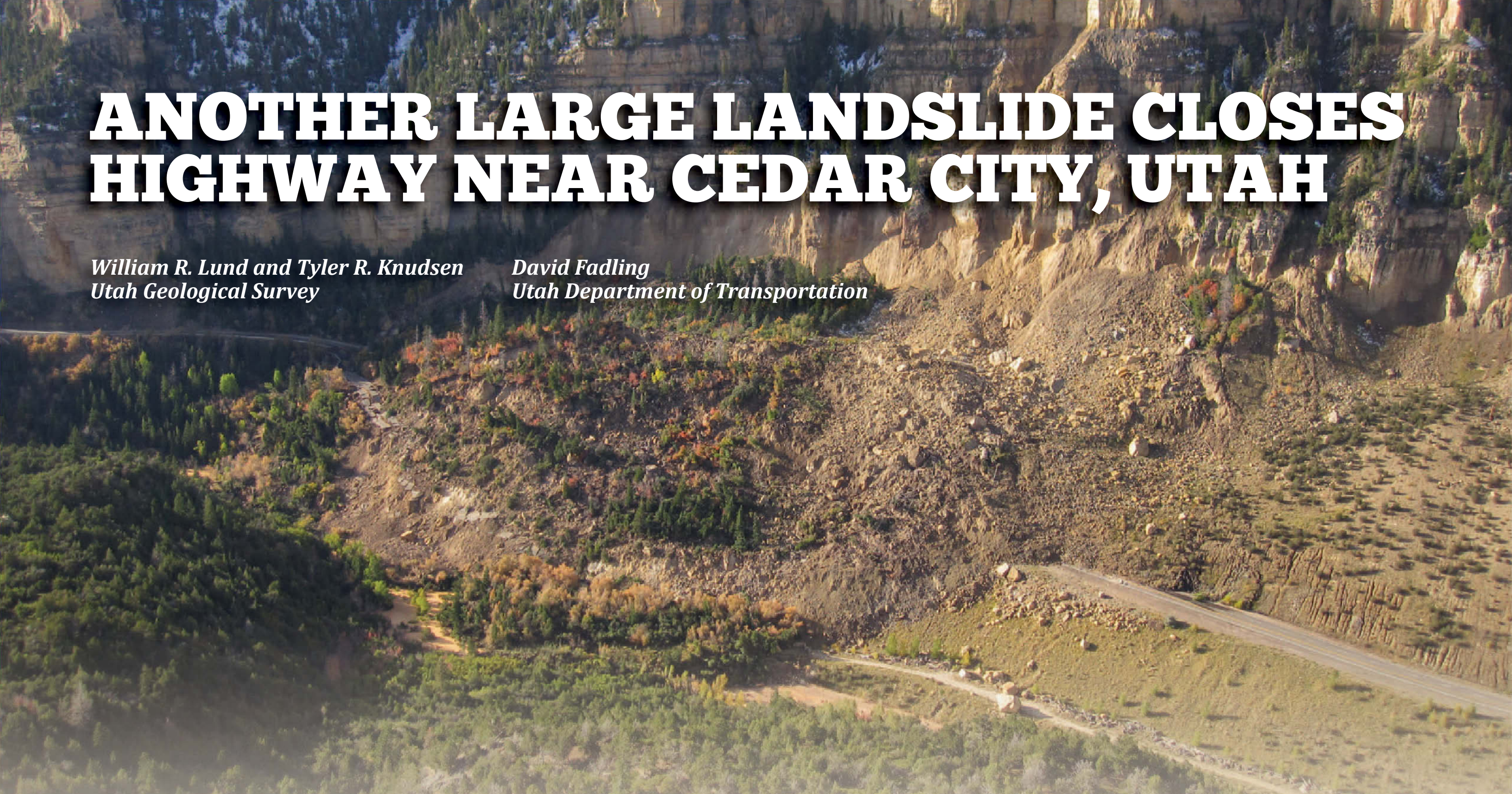


Log of one of the trenches at the Baileys Lake site shows mostly fine-grained sediments deposited during the rise and fall of Lake Bonneville in the late Pleistocene and the much smaller Gilbert lake cycle at the end of the Pleistocene, plus Holocene deposits largely consisting of wind-blown silt and clay (loess). Fault movement has displaced the strata downward on the east (left) side of the sheared fault zone. Turbidites (thin layers of silt and sand) interbedded within Lake Bonneville clays represent episodic influxes of sediment associated with disturbances around the margins of the lake, possibly caused by lake-level fluctuations or perhaps earthquakes. Grid-line spacing is 1 meter (3.2 feet).



ANOTHER LARGE LANDSLIDE CLOSES HIGHWAY NEAR CEDAR CITY, UTAH

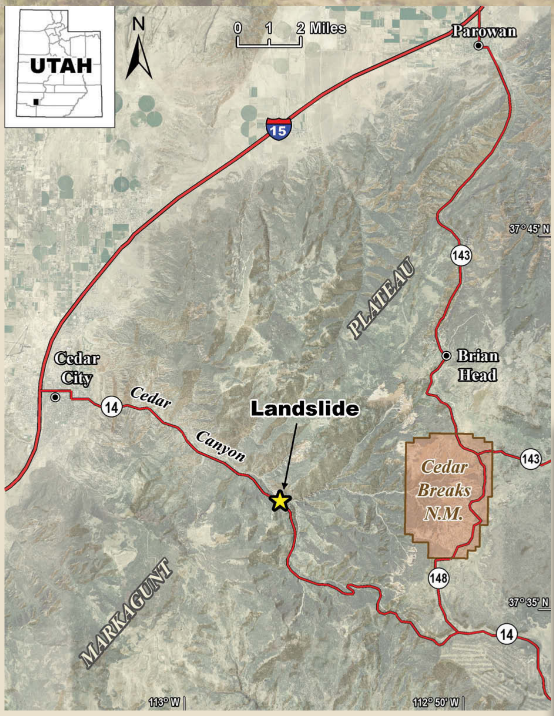
William R. Lund and Tyler R. Knudsen
Utah Geological Survey

David Fadling
Utah Department of Transportation

At approximately 5:00 a.m. on Saturday, October 8, 2011, a large landslide detached from the south side of Cedar Canyon about 8 miles east of Cedar City, Utah. The landslide quickly moved downslope, displacing part of and burying the remainder of an approximately 1200-foot-long section of Utah State Route 14 (SR-14), an important transportation link between Interstate 15 at Cedar City and U.S. Highway 89 to the east. The landslide then continued to the bottom of Cedar Canyon where it partially blocked Coal Creek, causing a series of small ponds to form before the stream re-established its flow path. The landslide was approximately 1000 feet long, up to 1700 feet wide, and an estimated 50–75 feet thick. The Utah Department of Transportation (UDOT) estimates the landslide volume at about 4 million cubic yards. Fortunately, no motorists were on the affected section of SR-14 when the landslide occurred.

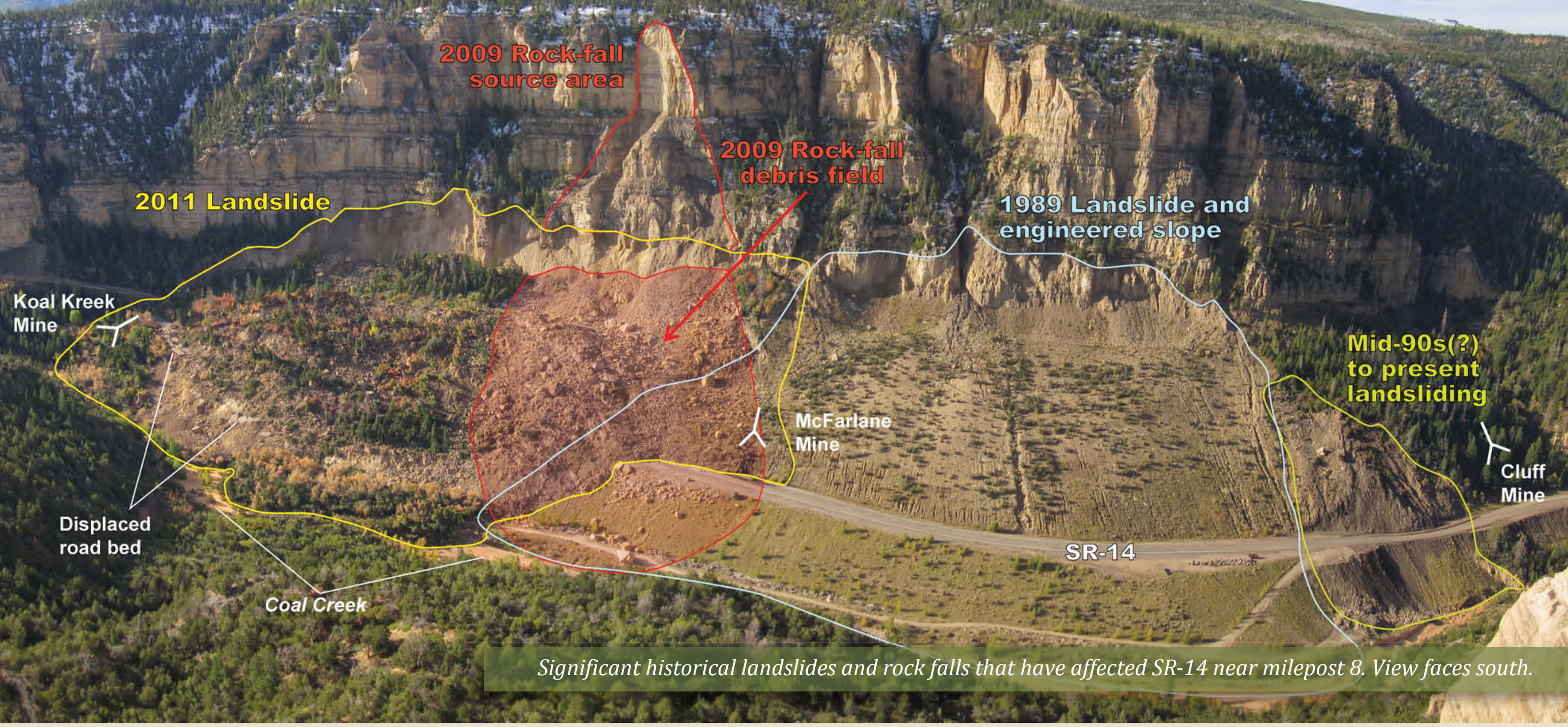
Cedar Canyon incises the western margin of the Markagunt Plateau at the transition between the Basin and Range and Colorado Plateau physiographic provinces. Deformed Mesozoic sedimentary strata in the transition zone are exposed in the lower several miles of the canyon; however, at the landslide, the canyon is in the Colorado Plateau proper, and rock units are largely undeformed, dipping a few degrees to the east. The stratigraphic section at the landslide includes the cliff-forming Tibbet Canyon Member of the Straight Cliffs Formation, and the underlying slope-forming Tropic Shale and Dakota Formation, all Cretaceous in age. The 600-foot-thick Tibbet Canyon Member is chiefly fine- to coarse-grained, limey sandstone; the 30-foot-thick Tropic Shale is sandy mudstone and muddy sandstone; and the greater than 600-foot-thick Dakota Formation is chiefly interbedded mudstone and sandy mudstone with thin sandstone beds and coal horizons up to several feet thick.

About a half mile west of the landslide, SR-14 leaves the bottom of Cedar Canyon and begins climbing the steep, south canyon wall toward the top of the Markagunt Plateau. The Tropic Shale and Dakota Formation are exposed in the lower part of the canyon wall and are susceptible to landsliding. Published reports of landslides along this section of SR-14 go back to at least 1949, and a similar large landslide (estimated volume 2 million cubic yards) just west of the current slide closed SR-14 for several months in 1989. In 2009, a large rock fall (estimated volume 60,000 cubic yards) detached from the Tibbet Canyon Member cliff at this location and closed SR-14 for several days (see article in *Survey Notes*, v. 41, no. 3, September 2009). Most of the rock-fall material fell onto what is now the western flank of the 2011 landslide. An examination at that time showed no evidence of associated landsliding either prior to or following the rock fall.



Landslide location along SR-14, 8 miles east of Cedar City, Utah.

The present landslide is a complex debris slide that originated at the base of the Tibbet Canyon Member cliff in the Tropic Shale and Dakota Formation portion of the stratigraphic section. However, the extent to which the underlying bedrock and pre-existing landslide



Significant historical landslides and rock falls that have affected SR-14 near milepost 8. View faces south.

deposits are involved in the sliding is unclear. A thick section of colluvium and talus had accumulated at the base of the Tibbet Canyon Member cliff, and it is that material that comprises the landslide at the surface. UDOT has undertaken a geotechnical investigation to determine whether bedrock or ancient landslide deposits were involved in the failure, the depth and orientation of the failure plane, groundwater conditions in the slide mass, and the extent to which the landslide may have included a component of rotational movement.

The immediate triggering mechanism for the 2011 landslide was a rain and snow storm that moved through the area the previous day and evening. The longer term cause is undoubtedly more complex, possibly involving loading from the large 2009 rock-fall event, erosion of the slope toe by Coal Creek, and the presence of several thousand feet of abandoned coal-mine workings beneath the landslide area, all combined with a wetter-than-normal 2010–11 winter that may have raised the groundwater level and pore-water pressure in the pre-failure landslide mass. At least three abandoned coal mines are known to be near the landslide, but the extent to which underground workings may have contributed to this and previous landsliding at this location is unclear.

UDOT has completed the planning and design phases for a new roadway across the landslide. Construction began in mid-March 2012, and a temporary road across the landslide is expected to be available for limited public use by early summer. UDOT hopes to fully reopen SR-14 by July 4, 2012.


SR-14 buried by landslide debris at the west landslide boundary.


SR-14 sheared and displaced downslope at the east landslide boundary.

2011 LANDSLIDES IN UTAH

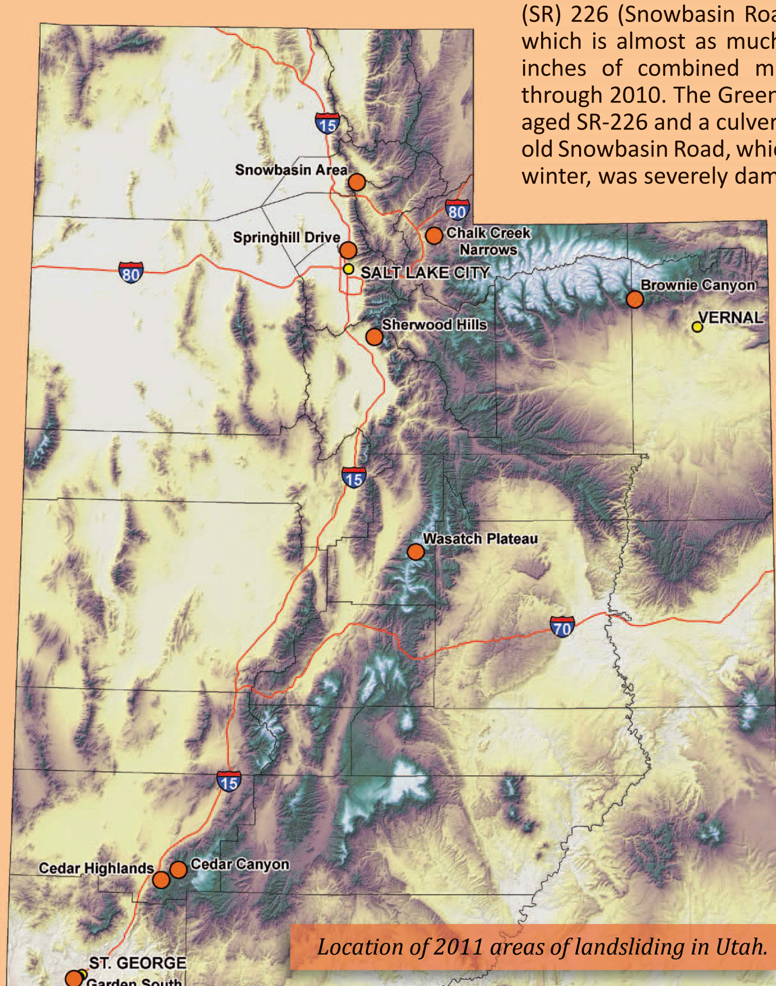
Richard Giraud and Tyler Knudsen

Above-normal precipitation during 2011 triggered landslide movement in many areas throughout Utah, and the UGS Geologic Hazards Program assisted several local government agencies with emergency response for landslide problems. Significant economic loss resulted where landslides damaged homes, underground utilities, highways, and roads. The 2011 landslides followed patterns of previous landsliding during years with above-normal precipitation. Many landslides were reactivations of preexisting landslides and many had moved previously during the wet years of 1982–83, 1997–98, and 2004–05.

Mountain snowpacks in 2011 were 300 to 400 percent of average in many areas. Many 2011 snowpacks contained more water than 1983 snowpacks, which melted rapidly and triggered numerous landslides and produced widespread flooding. Surprisingly, the 2011 snowmelt triggered fewer landslides than the 1983 snowmelt. In the Wasatch Range east of Farmington, the 1983 snowmelt produced 57 inches of water in 35 days in one rapid continuous melt period. In contrast, the 2011 snowmelt produced 67 inches of water in 60 days during several melt periods. Cool spring temperatures combined with multiple, short-duration melt periods resulted in a longer and slower release of melt water from the 2011 snowpack compared to the rapid melt water release from the 1983 snowpack.

However, snowmelt from the record or near-record 2011 mountain snowpacks triggered many landslides throughout Utah that are visible on 2011 statewide National Agricultural Imagery Program aerial photography taken later in the year. Many of these landslides are shallow landslides that were triggered at or near the end of snowmelt, such as the landslide that stripped trees from the mountainside, closed a road, and partially blocked the creek in Brownie Canyon, 17 miles northwest of Vernal. Some landslides started moving before the overlying snowpack had melted. Movement of these landslides deformed or fractured the overlying snowpack.

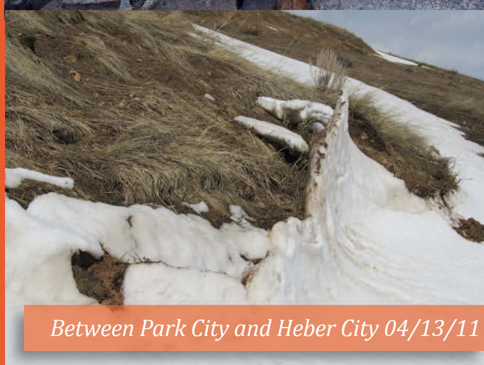
In northern Utah, many landslides reactivated around the Snowbasin area. The upper part of the Bear Wallow landslide above State Route (SR) 226 (Snowbasin Road) moved 11 inches, which is almost as much as the observed 12 inches of combined movement from 2005 through 2010. The Green Pond landslide damaged SR-226 and a culvert under the road. The old Snowbasin Road, which is closed during the winter, was severely damaged by several land-



Location of 2011 areas of landsliding in Utah.

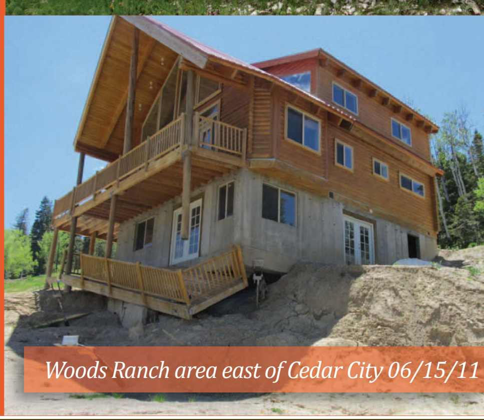
Garden South landslide in St. George 11/09/11

Old Snowbasin Road 06/02/11



Between Park City and Heber City 04/13/11

Wasatch Plateau east of Ephraim 08/01/11



Woods Ranch area east of Cedar City 06/15/11 slides, including one that completely destroyed the road. Many landslides along SR-167 (Trappers Loop Road) also reactivated. South of Snowbasin in Mountain Green several landslides reactivated, causing further damage to houses already damaged by landsliding. Landslides also ruptured a culinary water line and damaged subdivision roads in Mountain Green. All of these landslides involve the Norwood Tuff, a clay-rich geologic unit that is widely recognized for producing landslides.

Elsewhere in northern Utah, the Chalk Creek Narrows landslide east of Coalville reactivated and threatened to block the creek. The landslide moved 3 to 6 feet into the creek, but high stream flows eroded the landslide toe as it advanced and kept the landslide from damming the creek. In North Salt Lake, another house was demolished on the Springhill Drive landslide due to distress from continued slow landslide movement. Landslides were also active in the Sherwood Hills area of Provo.

Many landslides also occurred in southern Utah. The largest and most impressive landslide was the October 8 landslide that destroyed a section of State Route 14 in Cedar Canyon east of Cedar City (see article in this issue). Previous landslides in this area have also closed the highway. Farther east up Cedar Canyon, landslides damaged several houses in the Woods Ranch area. Movement in part of the Green Hollow landslide on Cedar Mountain southeast of Cedar City continued to damage property within the Cedar Highlands subdivision. The Garden South landslide in St. George has moved slowly for several years, and accelerated landslide movement in 2011 further damaged condominium units, a motel, a restaurant, parking lots, and a retaining wall.

Years with above-normal precipitation like 2011 continue to show Utah's vulnerability to landslides and the associated economic losses. Communities that have developed areas on landslides continue to face difficult challenges when landslides damage commercial buildings, houses, and public infrastructure. The 2011 landslides provide important lessons on how to manage active landslides, where to build safely, and how to plan for landslide hazards. The UGS continues to map landslides, document historical landslide events, and monitor groundwater and landslide movement in select areas to aid in reducing landslide hazards in Utah.

For more information:

Geologic Hazards Program: http:/geology.utah.gov/ghp

Landslides: Events and Information: http://geology.utah.gov/utahgeo/hazard/landslide

Geologic Hazard Resources for Homebuyers and Real Estate Agents: http://geology.utah.gov/utah.geo/hazards/realtors.htm

(continued from page 3)

(M 6.9) in Italy, and 1954 Fairview Peak (M 7.2) and Dixie Valley (M 6.8) earthquakes in Nevada. Additionally, we are evaluating the possible role of antithetic faulting in the 1934 Hansel Valley earthquake (M 6.6), Utah's largest historical earthquake.

Our recent studies of the West Valley fault zone and Salt Lake City segment are part of a broader effort to continually improve our understanding of Utah's earthquake hazards and risk. Ultimately, our goals are to increase public awareness and understanding of earthquake hazards, provide information used in building codes for the safe and cost-effective design and construction of buildings and other structures, and contribute to the development of public policies that lead to more effective earthquake-preparedness and emergency-response efforts in Utah.

Our study of the West Valley fault zone and Salt Lake City segment was partially funded by the National Earthquake Hazards Reduction Program. The study results are currently available in a Final Technical Report that can be obtained through the U.S. Geological Survey's External Research Support web page (http://earthquake.usgs.gov/research/external/reports/G10AP00068.pdf). The report will be more formally released by the UGS as part of the *Paleoseismology of Utah* series in the near future.

ABOUT THE AUTHORS

Mike Hylland has been a geologist with the UGS since 1994, and splits his time as a UGS technical reviewer and Geologic Hazards Program researcher. Current projects include paleoseismic studies, geologic mapping, involvement in various earthquake working groups, and management of Utah's database of active faults.

Chris DuRoss has been a geologist with the UGS Geologic Hazards Program since 2004. He specializes in studying geologic evidence of large, prehistoric earthquakes in Utah, and has completed several fault-trench investigations on the Wasatch fault zone. He is also part of a working group tasked with assessing the probability of a future large earthquake in the Wasatch Front region.

Greg McDonald has been a geologist with the UGS Geologic Hazards Program since 1998 and has been involved with many of the UGS' paleoseismic studies performed during that time. Greg has also worked on a variety of other projects including landslide, debris-flow, and rock-fall investigations, surficial geologic mapping, earthquake ground-shaking-related studies, and landslide inventory mapping on the Wasatch Plateau.

ENERGY NEWS
HYDRAULIC FRACTURING AND SHALE GAS

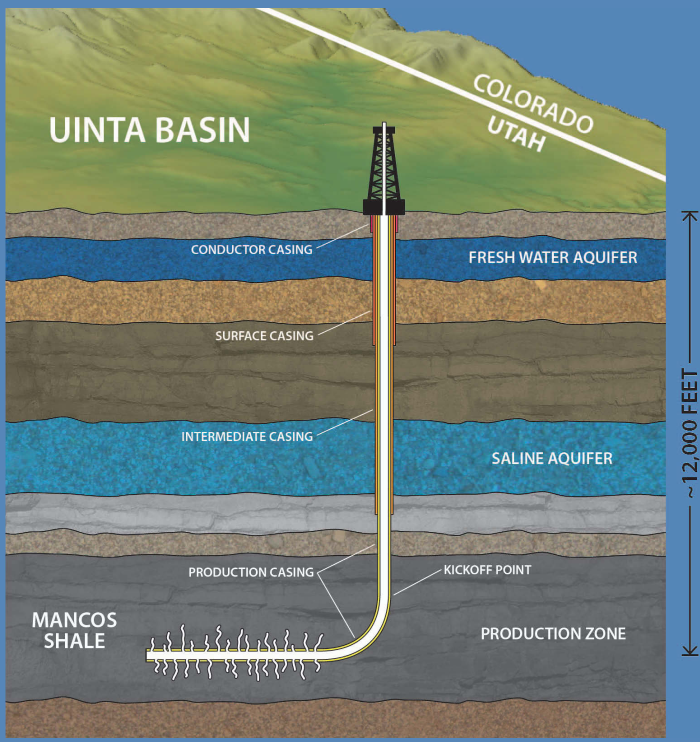
Robert Ressetar

The coupling of horizontal drilling and hydraulic fracturing of shale formations has been the most significant development in domestic hydrocarbon production in the past decade. But, as with many aspects of the energy business, controversy has accompanied it. To date, Utah has experienced little shale-gas production compared to other states. However, energy companies have shown interest in several shale formations in Utah, and Utah's first commercial horizontally drilled natural gas well began production in the Uinta Basin in late 2010. A review of the controversy that has grown around hydraulic fracturing is therefore timely.

Geologists have long known that shale can contain significant amounts of oil and gas. But the small size of the pores in shale and their low degree of connectedness (i.e., low permeability) usually made extracting hydrocarbons from shale uneconomical. By artificially fracturing the rocks, drilling engineers can create cracks through which the natural gas will flow to the well bore in much greater amounts than would otherwise be possible. The technique of hydraulic fracturing (or "fracking") refers to pumping liquids into the well under great pressure, thereby inducing the fractures. Frack fluids are typically about 95% water and 3% sand, which acts as a "proppant," wedging into the fractures and keeping them open after the frack fluid is withdrawn. The remaining 2% of the fluid is chemicals that serve a variety of purposes—e.g., flow enhancers, scale preventers, bactericides—and whose precise composition depends on the characteristics of the specific frack job.

Fracking is not a new technique; it dates back to the 1940s. About 35,000 wells in the U.S. are fracked annually, and the domestic total of fractured wells is nearly one million. Historically, most fractured wells were drilled vertically and the target reservoirs were sandstone or limestone. The current excitement about fracking stems from its use in horizontally directed wells to provide extended well contact with the heretofore noncommercial shale reservoirs. Like fracking, horizontal drilling has been employed for decades, but was relatively unused until technological advances allowed more accurately aimed and longer horizontal well segments. In horizontal drilling, the well is first drilled vertically to a certain depth (the kickoff point), then steered with a directional motor into a horizontal plane within the reservoir. The horizontal part of the well may extend thousands of feet, thus exposing a larger volume of the reservoir to the well than would be possible in a vertical well, and allowing more gas to be produced.

After drilling, the hole is cased with pipe and cement to prevent collapse and to prevent fluid migration into permeable, non-reservoir rocks. The actual high-pressure pumping of a frack stage lasts only a few hours, and several frack stages may be performed over three to five days. The fluid creates fractures about 1/10 of an inch wide, commonly widening natural fractures and exploiting weaknesses in the rock. The distance the fractures extend from the well depends on the fluid injection rate, the volume of fluid injected, and the rock's physical properties, but is designed to stay within the target shale interval. Some of the



Schematic diagram of a fractured horizontal gas well completed in the Mancos Shale of the Uinta Basin. Induced fractures are several thousand feet below the fresh-water aquifer.

Aerial view of typical frack equipment operating in the southern U.S. Photo courtesy of Halliburton.

frack fluid is retrieved from the well before natural gas production begins.

The main environmental concern contributing to the controversy over fracking is that natural gas and frack fluids could migrate along the fractures and enter groundwater used for domestic or agricultural purposes. This is unlikely for several reasons. In most fracking operations the induced fractures are 2800 to 7500 feet below the deepest fresh groundwater aquifers. Engineers monitor the orientation of fractures during the process, and have strong economic and environmental incentives to prevent fractures reaching aquifers above the reservoir, because they risk losing the gas they hope to produce, and water flowing from aquifers would damage the gas reservoir.

Several recent news reports have linked contaminated drinking water in Colorado, Ohio, and Pennsylvania to fracking. Investigations showed, however, that poor well casings, naturally occurring gas in the aquifer, or overpressuring a well during production were the causes. These are still environmental concerns, but suggest that the controversy over fracking per se is misdirected. The one instance where a causal link may exist between fracking and water contamination is at Pavillion, Wyoming, according to a draft report by the Environmental Protection Agency in December 2011. However, in Congressional testimony EPA officials emphasized that these findings were unique to Pavillion, where the fractured zones were as little as 400 feet deeper than some water wells, and did not imply that fracking was inherently unsafe.

Earthquakes caused by fracking are another concern. Geologists have known since the 1960s that pumping fluids underground near active faults may cause "induced seismicity," but induced earthquakes are typically very small. For example, Youngstown, Ohio, experienced several earthquakes up to magnitude 4 in 2011, near a disposal well that pumped used frack fluid underground. Youngstown sits above the northeast Ohio seismic zone, a region of moderately frequent naturally occurring earthquakes, and geologists determined that the well activated a previously unknown fault. The well operator agreed to shut down the well, and Ohio issued new regulations requiring geologic monitoring of new disposal wells. But since an induced earthquake is unlikely to be stronger than those that occur naturally in a given area, the risk of damage from fracking-induced seismicity is low in areas with no geological evidence for strong earthquakes.

For additional information see: http://energy.utexas.edu/index.php?option=com_content&view=article&id=151&Itemid=160

Another environmental concern is disposal of the used frack fluid. The fluid can be temporarily stored in lined pits at the frack site, but eventually must be pumped back underground or treated. Drilling companies are increasingly recycling used fluid in other frack jobs to conserve additives and reduce use of water and disposal wells.

Regulations controlling fracking, well completions, and waste disposal are largely a matter of state law. However, Congress recently directed the EPA to investigate the safety of fracking regarding drinking water. A first draft of the report should be released later this year; the final report is due in 2014. Meanwhile, state laws on fracking are rapidly changing, mostly by requiring disclosure to some degree of the frack fluid compositions. Many companies voluntarily post the composition of fluids on the website http://fracfocus.org. By following the links on this site, the reader can find information on more than 400 hydraulically fractured wells in Utah.

The great majority of the evidence indicates that hydraulic fracturing has been and can continue to be done safely. But as with any industrial process, careful planning and monitoring are necessary to prevent accidental environmental harm.

THE GREAT ROCK UNVEILING!

Kimm M. Harty

At 6:00 p.m. on January 26, 2012, former and current Utah Geological Survey (UGS) staff members Jim Davis, Valerie Davis, and Kimm Harty joined teachers and students at Lincoln Elementary school in Salt Lake City to dedicate a substantial rock and mineral collection that was donated to the school by neighborhood resident Glenda Parker. Glenda's spouse was Jim Parker, a UGS cartographer who passed away in 2008. One of Jim's varied interests in life was collecting rocks and minerals from all over the country. Many of the specimens in this beautiful collection will be displayed at the school and adjacent community center to be built in the next few years, and some are currently used to teach hands-on science. Even the school's art teacher has requested specimens to use in class.

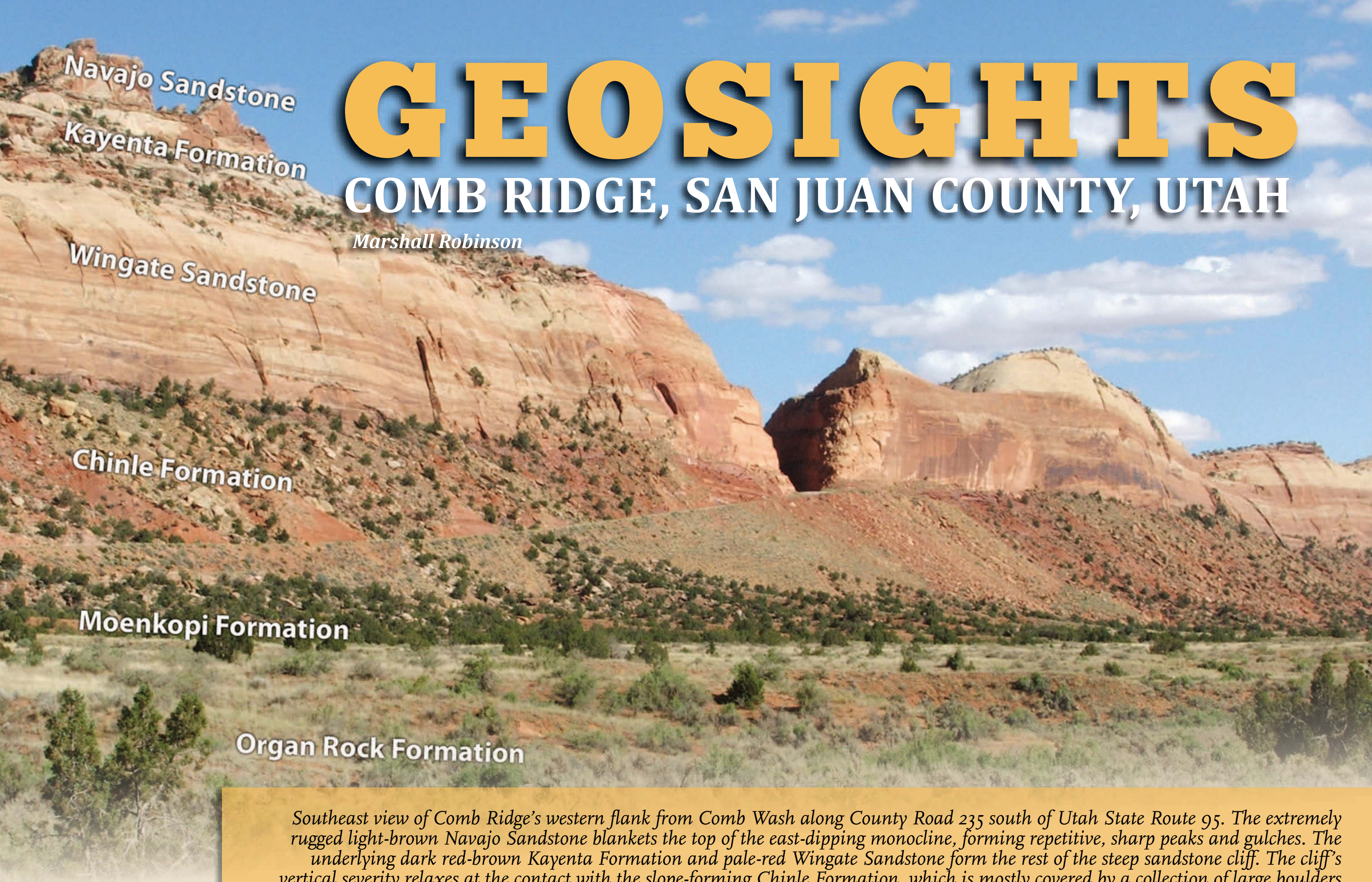
Prior to the dedication, specimens in Jim's collection were identified and organized by UGS student intern, Patrick McAtee, who educated Lincoln school teachers about the types and origins of the rocks and minerals. Ellie Hardman, reading teacher at Lincoln Elementary, organized the dedication ceremony. We were happy to see the enthusiasm expressed by the students and teachers receiving the collection, and how joyful Glenda was to see the donation through its journey of rising out of dusty basement storage and becoming a focal point for learning about earth science at Lincoln Elementary.

Photo Credit: Clint Barnett

GEOSIGHTS

COMB RIDGE, SAN JUAN COUNTY, UTAH

Marshall Robinson

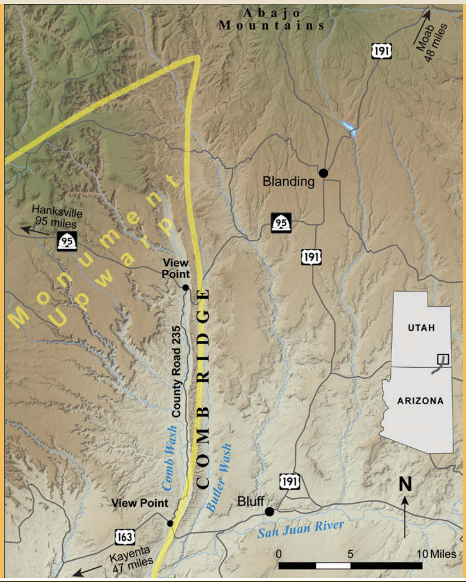


Southeast view of Comb Ridge's western flank from Comb Wash along County Road 235 south of Utah State Route 95. The extremely rugged light-brown Navajo Sandstone blankets the top of the east-dipping monocline, forming repetitive, sharp peaks and gulches. The underlying dark red-brown Kayenta Formation and pale-red Wingate Sandstone form the rest of the steep sandstone cliff. The cliff's vertical severity relaxes at the contact with the slope-forming Chinle Formation, which is mostly covered by a collection of large boulders which have fallen from above. The Moenkopi and Organ Rock Formations make up the rocks along Comb Wash.

Introduction: One may say Comb Ridge was Mother Nature's way of splitting southern San Juan County with an enormous wall. Another may say it was a giant skateboard ramp for dinosaurs. One thing is certain: Comb Ridge is a spectacular ridge of steeply tilted sandstone rock layers, trending north-south for approximately 80 miles from Utah's Abajo Mountains to Kayenta, Arizona. Similar to a rooster's comb, the jagged appearance of Comb Ridge provides the logic behind its name.

Geologic Information: Comb Ridge is a classic example of a step-like crease (or fold) in the Earth's crust known as a monocline. Along the axis of the monocline, the rock layers are tilted skyward, whereas they remain relatively flat away from the monocline. The exposed rocks at Comb Ridge range in age from the Permian-aged Organ Rock Formation (280 million years old) to the Jurassic-aged Navajo Sandstone (185 million years old).

(continued on page 12)



How to get there: If traveling from the north, drive south from Moab on U.S. Highway 191 for approximately 80 miles to the junction with Utah State Route 95. To view Comb Ridge from the northern road cut, turn west (right) on SR-95 and follow it for 14 miles. Or, continue south from Blanding on U.S. 191 through Bluff (here the highway turns into U.S. Highway 163) 30 miles to the southern road-cut view.

If traveling from the west, drive south and east from Hanksville on Utah State Route 95 for approximately 108 miles to County Road 235. From this view point, you can continue east on SR-95 to U.S. Highway 191, and travel as described above to the southern view point.

The best time and place to view Comb Ridge is in the afternoon on the west side, from breathtaking road cuts (either Utah State Route 95 southwest of Blanding, or U.S. Highway 163 west of Bluff). If you have an extra hour and 4-wheel drive, travel along Comb Wash on County Road 235 between SR-95 and U.S. 163 to take in 18 miles of beautiful scenery.

GLAD YOU ASKED

ARE THOSE ANIMAL TRACKS IN THE SIDEWALK?

Mark Milligan

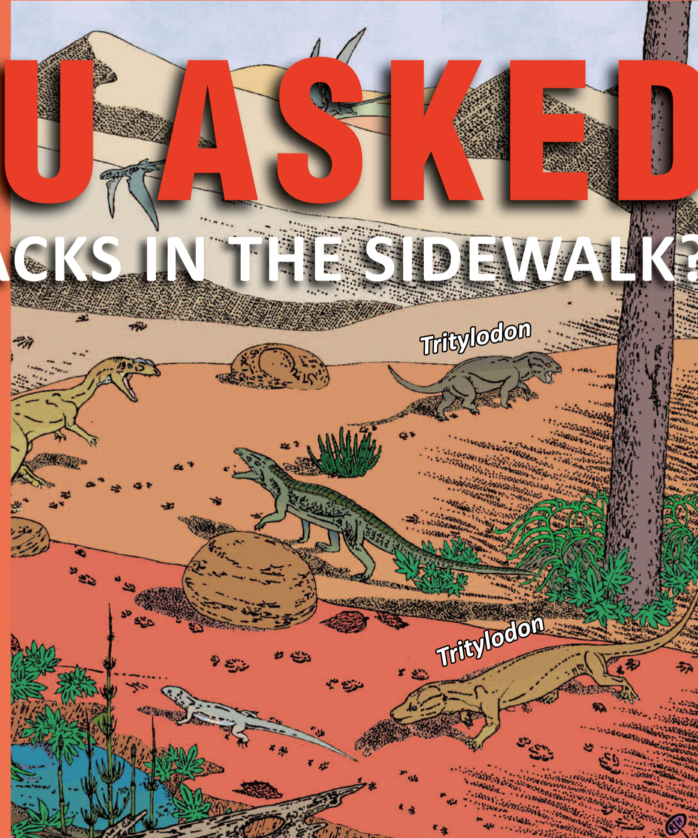
Fascinating geology is all around us, even when standing in an urban park just a stone's throw from downtown Salt Lake City. We recently received a call from someone curious about footprint impressions in the sidewalk at Memory Grove Park, which is in City Creek Canyon immediately northeast of downtown Salt Lake City. While there is a sidewalk leading to Memory Grove Park that includes artist representations of local wildlife tracks on inset granite plaques, the caller was referring to ancient tracks in the sandstone slab sidewalk within the park itself.

The caller, Phoebe Bergvall, is a writer for Salt Lake City's Examiner.com, and she found what she described in an online article (www.examiner.com/counterculture-in-salt-lake-city/limping-squirrel-tracks-memory-grove) as "actual tracks made by a small animal millions of years ago." She further speculated that the tracks could have been made by a squirrel-like creature with an injured leg. Phoebe's observation that the small marks were tracks proved correct, and her speculation that the tracks were made by a limping squirrel-like creature was pretty close.

To learn more about the tracks, UGS geologists contacted track researcher and University of Utah student Tracy Thomson. Tracy visited Memory Grove Park and found four sandstone slabs with good trackways and a few blocks with other types of less distinct tracks. Tracy identified what Phoebe found as 180-million-year-old (Jurassic) *Brasilichnium* trackways, which are thought to be made by a burrowing mammal-like animal named *Tritylodon*. One of these newly discovered *Brasilichnium* trackways is significant because it appears to show a galloping or loping locomotion not previously described. Tracy also found scorpion-like trackways that appear to be very similar to *Paleohelcura* trackways found at Dinosaur National Monument.

The sandstone sidewalk has been in Memory Grove Park longer than anyone working for Salt Lake City can remember, so the stone's origin is uncertain. However, the flagstone slabs are believed to be Nugget Sandstone, probably quarried in Wasatch County just east of Heber City. The Nugget Sandstone was once part of a huge sand "sea" called the Navajo erg, which is thought to have covered Utah and parts of surrounding states. This vast expanse of sand was not completely dry. Within the dune fields were shallow lakes that created hospitable oases for *Tritylodons*, dinosaurs, reptiles, and other animals and plants. Quarried Nugget Sandstone has been used extensively along the Wasatch Front, so other urban trackways and similar wonders may be awaiting discovery.

While fascinating, these trackways are not obvious. I have run over them many times without noticing. How did Phoebe recognize these small divots in the sidewalk as trackways? She may be predisposed to acute geologic observation; although she is not a geologist, both her parents were. Furthermore, Phoebe's mother, Martha Smith, worked as a geologist for the UGS from 1977 to 1987 (see the September 2011 issue of *Survey Notes*). Martha Smith was the UGS's first Information Specialist, a predecessor to the position I now have.

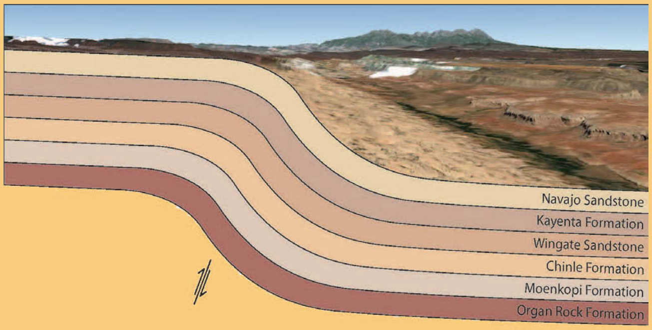


Artist conception of the plants and animals living in the Jurassic Navajo erg (sand sea). Note the two Tritylodons *and their* Brasilichnium *trackways. Illustration by Russell Hawley.*

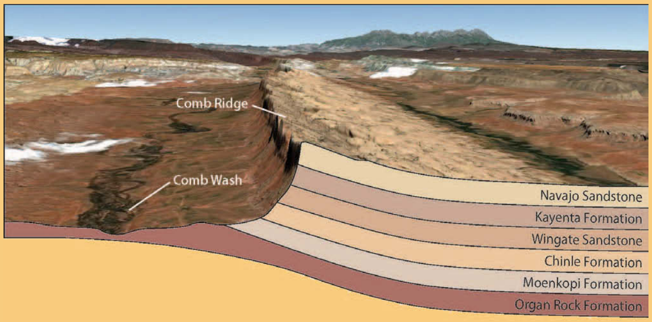
Immediately northeast of downtown Salt Lake City, the sandstone slab sidewalk in Memory Grove Park contains several ancient and unique trackways. This Brasilichnium *trackway lies northwest (up canyon) of the pond, adjacent to the second tree past the fire hydrant (hydrant visible near the top, center-left of photo). U.S. quarter for scale.*

(continued from page 10)

Compressional forces during the Laramide mountain-building event (40–70 million years ago) uplifted an area of southeast Utah known as the Monument Upwarp. Comb Ridge is the abrupt eastern flank of the Monument Upwarp. The San Rafael Swell, Uinta Mountains, and Rocky Mountains are examples of other geologic features that were formed during Laramide time.



Block diagram of the Comb Ridge monocline. Deep, underlying rock layers ruptured along a compressional fault (blind thrust), pushing the rocks in the west much higher than those in the east. Overlying rocks, not ruptured by the deep fault, deformed by folding over the ruptured layers, creating a monocline.



The steep cliffs common on one side of many monoclines are mainly the result of stream erosion. Stream flow in Comb Wash played a significant role in eroding away hundreds of feet of rock, carving the beautiful sandstone cliffs on Comb Ridge's west side. Aerial images from Google Earth.

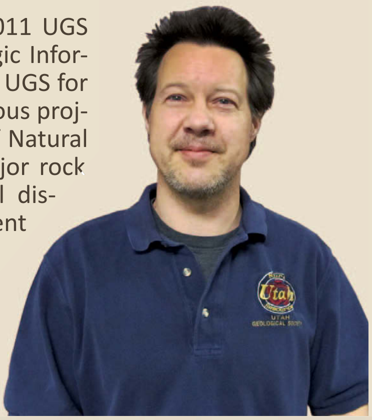
SURVEY NEWS

EMPLOYEE NEWS

Welcome to **Pam Perri**, who accepted a secretary position with the Geologic Hazards Program (GHP). Pam previously worked as a medical technologist and legal secretary. The GHP also welcomes **Amanda Hintz** as a geologist. Amanda is currently completing a Ph.D. in Geology from State University of New York at Buffalo. The Groundwater and Paleontology Program bids farewell to **Toby Hooker** who accepted a position with the Division of Water Quality, a division of the Department of Environmental Quality.

2011 UGS EMPLOYEE OF THE YEAR

Congratulations to **Jim Davis** who was named the 2011 UGS Employee of the Year. Jim is a geologist in the Geologic Information and Outreach Program and has worked for the UGS for five years. He is most often the "volunteer" for numerous projects that come up, such as leading the Department of Natural Resources finance team field trip, cataloging two major rock and mineral donations, setting up rock and mineral displays for various events, supervising high-school student interns, and handling much of the Earth Science Week logistics. Jim's sense of humor and affability draw people to him, and he is always enthusiastic to help both UGS staff and the general public. Jim is knowledgeable and professional, and his positive attitude makes him a deserving recipient of this award.



TEACHER'S CORNER

Sandy Eldredge

K–12 TEACHERS OF EARTH SCIENCES IN UTAH

EARTH SCIENCE TEACHER OF THE YEAR AWARD

for Excellence in the Teaching of Natural Resources in the Earth Sciences

CALL FOR NOMINATIONS

The Utah Geological Association (UGA) is accepting nominations for this award until June 1, 2012. The UGA will award $1,500 to the winning teacher and will also provide the teacher's school with an educational gift.

ELIGIBLE TEACHERS

Utah educators most eligible (who meet the award requirements) to apply are those who teach:

- 4th grade
- 5th grade
- 8th grade Integrated Science
- 9th grade Earth Systems

The purpose of UGA's award is to recognize and support an outstanding K–12 earth science/natural resource science teacher. 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 $500 and is then entered into the national AAPG contest, which awards $5,000 as well as an expense-paid trip to the 2013 AAPG Annual Convention.

Application deadline is June 1, 2012.

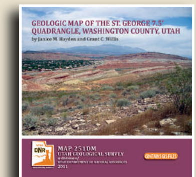
Additional information, requirements, and entry forms are available on the UGA website at:

www.utahgeology.org/wp/?p=474.

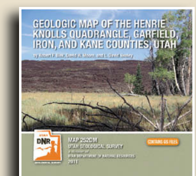
UTAH GEOLOGICAL SURVEY RECEIVES NATIONAL AWARD FOR EARTHQUAKE RESEARCH

The Utah Geological Survey received a 2012 National Award in Excellence for Research from the Western States Seismic Policy Council. The award recognizes the significant contributions to earthquake research and risk reduction made by the Utah Earthquake Working Groups, convened under the auspices of the UGS in cooperation with the Utah Seismic Safety Commission and U.S. Geological Survey (USGS). The Utah Earthquake Working Groups have met annually since 2003 to review ongoing earthquake studies and help prioritize and coordinate Utah's earthquake-hazard research agenda. Three separate working groups focus on active faulting, earthquake ground shaking, and liquefaction, and have involved over 60 geologists, seismologists, engineers, and geophysicists from the UGS, USGS, universities, consulting companies, and other Utah state agencies. William Lund (UGS) accepted the award on behalf of the working group members at the joint 2012 National Earthquake Conference/Earthquake Engineering Research Institute Annual Meeting in Memphis, Tennessee.

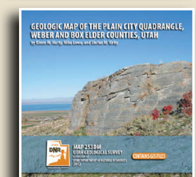
NEW PUBLICATIONS



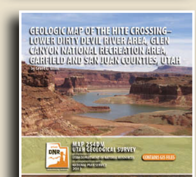
Geologic map of the St. George 7.5' quadrangle, Washington County, Utah, by Janice M. Hayden and Grant C. Willis, CD (19 p., 2 pl. [contains GIS data]), scale 1:24,000, ISBN 978-1-55791-848-2,
M-251DM $24.95



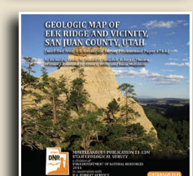
Geologic map of the Henrie Knolls quadrangle, Garfield, Iron, and Kane Counties, Utah, by Robert F. Biek, David W. Moore, and L. David Nealey, CD (2 pl. [contains GIS data]), scale 1:24,000, ISBN 978-1-55791-850-5,
M-252DM $24.95



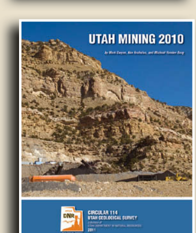
Geologic map of the Plain City quadrangle, Weber and Box Elder Counties, Utah, by Kimm M. Harty, Mike Lowe, and Stefan M. Kirby, CD (2 pl. [contains GIS data]), scale 1:24,000, ISBN 978-1-55791-859-8,
M-253DM $24.95



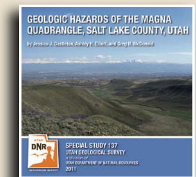
Geologic map of the Hite Crossing–Lower Dirty Devil River area, Glen Canyon National Recreation Area, Garfield and San Juan Counties, Utah, by Grant C. Willis, CD (12 p., 1 pl. [contains GIS data]), scale 1:62,500, ISBN 978-1-55791-860-4,
M-254DM $24.95



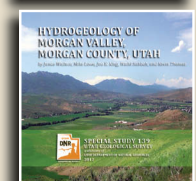
Geologic map of Elk Ridge and vicinity, San Juan County, Utah (digitized and modified from U.S. Geological Survey Professional Paper 474-B, published in 1965), by R.Q. Lewis, Sr., R.H. Campbell, R.E. Thaden, W.J. Krummel, Jr., G.C. Willis, and B. Matyjasik, DVD (12 p., 1 pl. [contains GIS data]), scale 1:62,500, ISBN 978-1-55791-845-1,
MP-11-1DM $24.95



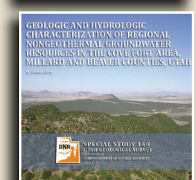
Utah Mining 2010, by Mark Gwynn, Ken Krahulec, and Michael Vanden Berg, 21 p., ISBN 978-1-55791-855-0,
C-114 .... $9.95



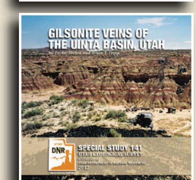
Geologic hazards of the Magna quadrangle, Salt Lake County, Utah, by Jessica J. Castleton, Ashley H. Elliott, and Greg N. McDonald, CD (73 p., 10 pl.), ISBN 978-1-55791-849-9,
SS-137 .... $24.95



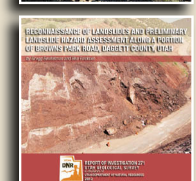
Hydrogeology of Morgan Valley, Morgan County, Utah, by Janae Wallace, Mike Lowe, Jon K. King, Walid Sabbah, and Kevin Thomas, CD (137 p., 9 pl.), ISBN 978-1-55791-854-3,
SS-139 .... $19.95



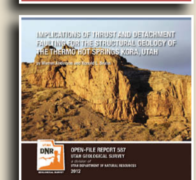
Geologic and hydrogeologic characterization of regional nongeothermal groundwater resources in the Cove Fort area, Millard and Beaver Counties, Utah, by Stefan Kirby, CD (64 p., 2 pl.), ISBN 978-1-55791-854-3,
SS-140 .... $19.95



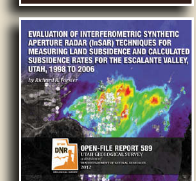
Gilsonite Veins of the Uinta Basin, by Taylor Boden and Bryce T. Tripp, CD (50 p., 1 pl.), ISBN 978-1-55791-856-7,
SS-141 .... $19.95



Reconnaissance of landslides and preliminary landslide hazard assessment along a portion of Browns Park Road, Daggett County, Utah, by Gregg Beukelman and Ben Erickson, CD (14 p.), ISBN 978-1-55791-858-1,
RI-271 .... $14.95



Implications of thrust and detachment faulting for the structural geology of the Thermo Hot Springs KGRA, Utah, by Warren Anderson and Ronald L. Bruhn, CD (23 p.),
OFR-587 .... $14.95



Evaluation of interferometric synthetic aperture radar (InSAR) techniques for measuring land subsidence and calculated subsidence rates for the Escalante Valley, Utah, 1998 to 2006, by Richard R. Forster, CD (25 p.),
OFR-589 .... $14.95

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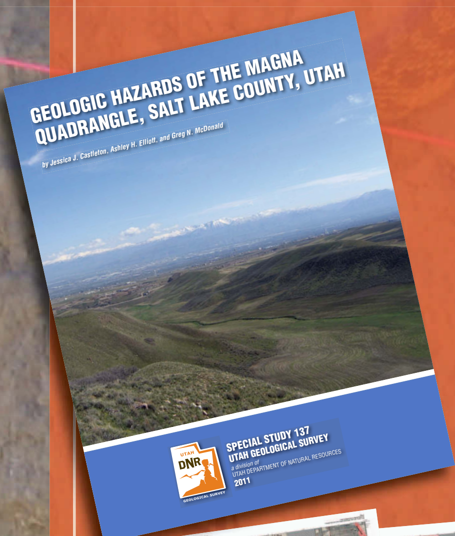

Geologic Hazards of the Magna Quadrangle, Salt Lake County, Utah

by Jessica J. Castleton, Ashley H. Elliott, and Greg N. McDonald

The Magna quadrangle, in the western part of Salt Lake Valley, is expected to experience a significant population increase in the next several decades. As urbanization expands into areas less suited for development, geologic hazards become of increasing concern in the planning, design, and construction of new facilities. This study includes ten 1:24,000-scale GIS-based geologic-hazard maps that include liquefaction, surface fault rupture, flood hazard, landslides, rock-fall, indoor radon potential, collapsible soils, expansive soils, shallow bedrock, and shallow groundwater potential. The maps are an aid for general planning to indicate where site-specific studies and geotechnical/geologic-hazard investigations are necessary. The accompanying 73-page report describes the hazards and provides background information on data sources, the nature and distribution of the hazards, and possible hazard-reduction measures.

Special Study 137..$24.95