UTAH GEOLOGICAL SURVEY

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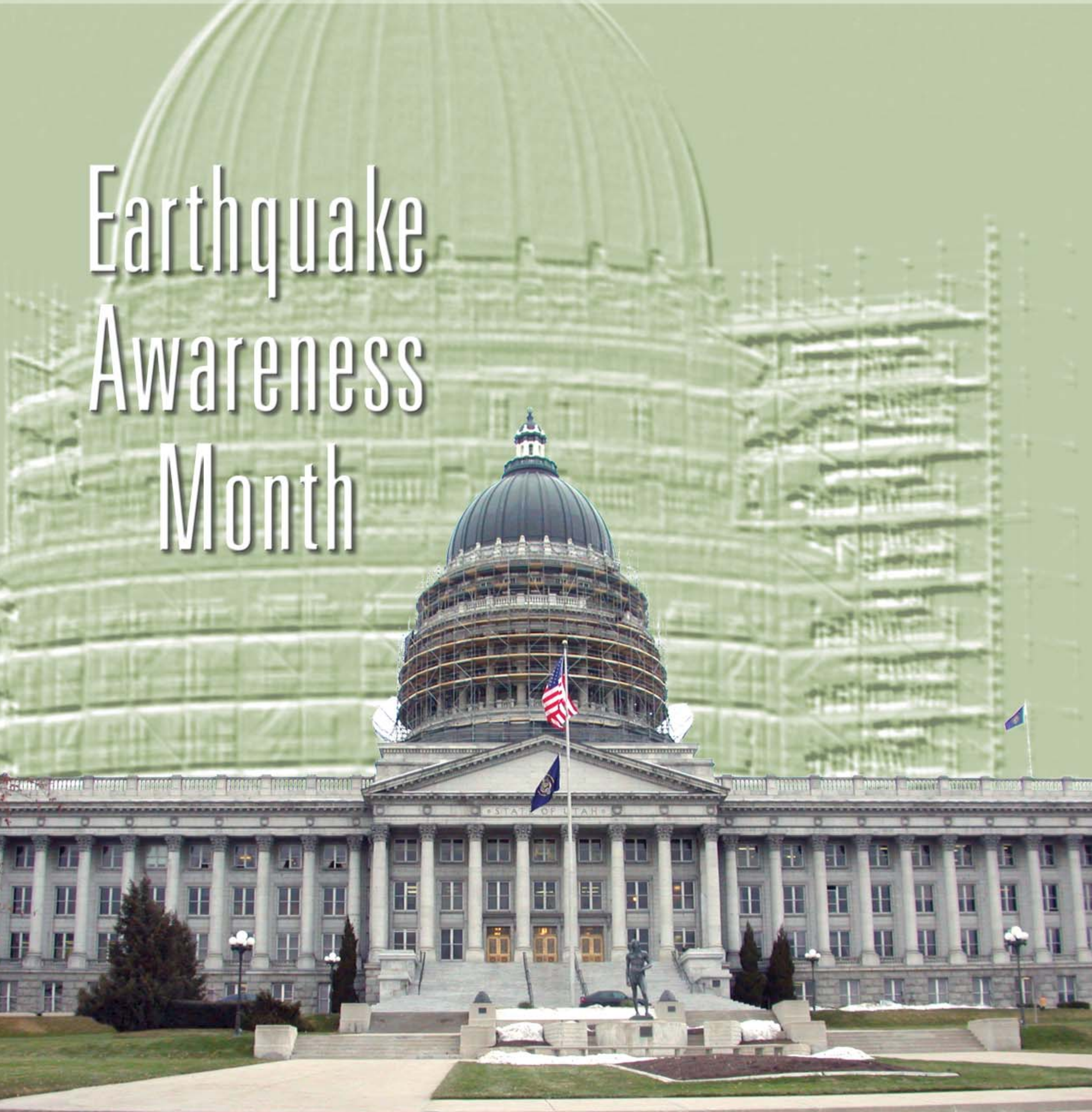
Earthquake Awareness Month



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Design by Vicky Clarke

Cover: Retrofitting the Capitol building. Photo by Mark Milligan.

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The Director's Perspective

by Richard G. Allis

This issue has geologic hazards, and earthquakes in particular, as a theme. Several news items during the past few months have highlighted the need to remind Utahns of the dangers from geologic hazards and the precautions that should be taken in the more hazardous parts of the state. In the feature article, Gary Christenson compares the magnitude 6.6 earthquake that devastated the city of Bam in southeast Iran, killing over 40,000 people and damaging or destroying 85% of the buildings, and the magnitude 6.5 earthquake that shook the town of San Simeon in central California. Here, two people were killed, 40 buildings were damaged or collapsed, and 10,000 homes were without power. At the time of this writing (late February), a magnitude 6.5 earthquake had just occurred in Morocco, killing hundreds. A major factor causing the contrast in damage between these events was the quality of the building stock – in particular the abundance and performance of unreinforced masonry structures.

These earthquakes raise the question about what will likely happen in the urban areas of the Wasatch Front when a magnitude 6.5 or greater earthquake occurs here. On average, such earthquakes occur about every 120 years in the Wasatch Front area, and every 50 years in all of Utah. The Richfield magnitude 6.5 event in 1901 and the Hansel Valley magnitude 6.6 event in 1934 are historic examples. HAZUS, a computer model developed by FEMA that allows simulation of the potential damage under various geologic hazard scenarios, estimates that a Salt Lake City area magnitude 6.5 earthquake would cause between 40 and 90 deaths (depending on time of day), and economic losses of over $2.5 billion (unpublished scenario, Utah Division of Emergency Services). Over half of the economic losses would come from damage to residential buildings, with 10% of unreinforced masonry structures being destroyed and 12% (30,000) of all buildings at least moderately damaged. These large numbers highlight that Wasatch Front residents cannot afford to be complacent. Relatively inexpensive measures can be taken around our offices and homes that can greatly improve safety and reduce damage.

Recent publicity about adoption of a geologic hazards ordinance by Draper City at the south end of the Salt Lake Valley has emphasized the potential conflict caused by pressures for urban growth versus the need to inform buyers of potential geologic hazards, protect development by requiring appropriate mitigation, or in some cases to prevent development in unsafe locations. Development on pre-existing landslides is a particular concern in the area due to the possibility that they can be reactivated by wet conditions, earthquakes, and changes to slopes and ground water accompanying development. At what point does the risk from geologic hazards get elevated to a level that either requires mitigation prior to development or prevents

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Improving Our Understanding of Earthquake Hazards in Utah

by Gary E. Christenson

Introduction

Earthquakes continue to make headlines worldwide. Recent earthquakes in coastal California near San Simeon (magnitude 6.5; December 22, 2003; 2 killed) and in Bam, Iran (magnitude 6.6; December 26, 2003; more than 40,000 killed) dramatically demonstrate how earthquake risk depends not only on earthquake size, but also on the number of people living near the epicenter and on local building and land-use practices. Because Utah's population is concentrated along the Wasatch Front in the state's area of greatest earthquake hazard, wise building and land-use practices based on a thorough understanding of earthquake hazards are essential.

Earthquake hazards include a wide variety of damaging geologic effects, including strong ground shaking, surface faulting, liquefaction, and landslides. Each of these hazards is unique in how often and where it occurs, how damaging it is, and how well scientists understand it. The Utah Geological Survey (UGS) performs and supports others performing studies to better understand each hazard, show it on hazards maps, and use the information to reduce risks.

Earthquake Working Groups

To help set priorities for earthquake studies in Utah, and in particular to develop a consensus among experts on earthquake-hazards mapping needs, the UGS in cooperation with the U.S. Geological Survey (USGS) has established formal Ground Shaking, Liquefaction, and Earthquake-Induced Landslide Working Groups to define research programs to produce new earthquake hazards maps. The working groups include geologists, engineers, seismologists, and geophysicists from Utah State University (USU), Brigham Young University (BYU), University of Utah (U. of U.), UGS, USGS, and various consulting companies and other state agencies. Working groups met in early 2003 and agreed upon the types of maps needed, new data required, and data-collection and mapping techniques. A summary of the process, funded through a grant from the USGS, and final working group plans for future earthquake-hazards maps are posted on the UGS Web site (geology.utah.gov).

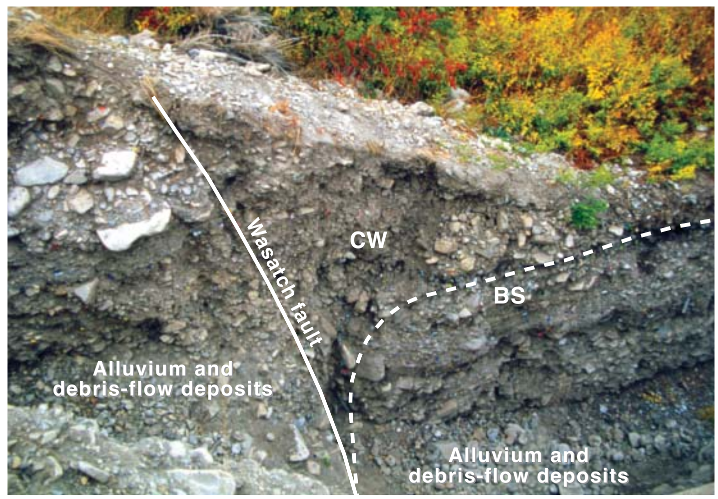

Photo-log of a fault trench across the Provo segment of the Wasatch fault at Rock Canyon in Provo showing the fault and a scarp-derived colluvial wedge (CW) that was deposited following the faulting event and that buried a soil (BS) radiocarbon dated at 550 years old, indicating the approximate time of the earthquake.

In a parallel process, the UGS established the Utah Quaternary Fault Parameter Working Group, also partially funded by the USGS, to develop a consensus among paleoseismologists regarding earthquake timing, slip rates, and recurrence intervals for Utah's Quaternary faults. Quaternary faults are those that have moved in the past 1.6 million years and thus are considered capable of producing modern earthquakes. Fault parameters such as earthquake timing, slip rates, and recurrence intervals are important in making the probabilistic earthquake ground-shaking maps used in the International Building Code (IBC) and in the design and retrofit of bridges and dams in Utah. Fault experts from the UGS, USGS, U.S. Bureau of Reclamation, other state geological surveys, and various universities and consulting companies have analyzed fault-trenching data and met to develop consensus values for the important fault parameters.

Faults

Faults are the source of earthquakes, and a thorough understanding of their characteristics is necessary, both for estimating levels of ground shaking for building design and for recognizing where surface fault rupture may occur. When estimating levels of ground shaking, the frequency and size of past large earthquakes along each fault must be determined. To do this, geologists evaluate a fault's history by analyzing scarps, mapping displaced surficial geologic units, and digging trenches to determine ages of geologic units. Preliminary results of such a study are described in the accompanying article in this issue on the Mapleton "megatrench."

In 2003, the UGS published a new map and database summarizing what is presently known about prehistoric large earthquakes and rates of earthquake activity on faults in Utah (UGS Map 193DM). The publication is an interactive compact disk; the map and database are also posted on the UGS Web site. Results of trenching studies on Utah faults are currently under scrutiny by the Utah Quaternary Fault Parameter Working Group to derive consensus values for average recurrence and slip rates. These values will be used in the next update of the USGS National Seismic-Hazard Maps used in the IBC, and by consultants to develop site-specific ground-shaking design levels.

In addition to causing earthquakes and resulting ground shaking, faults may also rupture the ground surface in large earthquakes (magnitude 6.5 and greater). Surface fault rupture beneath a building may cause severe damage and possible collapse, and represents a life-safety as well as property-damage concern. The article in this issue on the new UGS guidelines for evaluating surface-fault-rupture hazards provides more information on this hazard in Utah.

The central segments of the Wasatch fault from Brigham City to Nephi (see map on page 4) are the most active faults in Utah, and the most likely sources of the next large earthquake. Geologists have mapped and trenched these central segments, but similar detailed studies have not been performed on the northern and southern segments. The UGS is presently mapping the Levan and Fayette segments at the south end of the Wasatch fault to better define their location and level of activity, and the U. of U. is studying the next segment to the north, the Nephi.

Ground Shaking

The destructiveness of earthquake ground shaking depends not only on the size and location of the earthquake, but also on local geologic conditions that can amplify or reduce levels of ground shaking. The soil type in the upper 100 feet of the soil column, deeper soil conditions, and depth to bedrock are all important in estimating levels of ground shaking. The prime soil characteristic used to estimate earthquake ground-shaking amplification or reduction is shear-wave velocity, or the speed at which earthquake-generated shear waves pass through the soil. The IBC uses this soil characteristic in estimating ground motions for earthquake-resistant building design.

USU engineers determine shear-wave velocities of shallow (less than 150 feet) soils by dropping a weight (trailer) and recording the resulting ground motions on geophones strung along the road.

The UGS, in cooperation with BYU engineers, developed a database and map of Salt Lake Valley showing soil types in the upper 100 feet grouped according to average shear-wave velocities based on existing data. To improve the map, USU, with assistance from the UGS and U. of U. Seismograph Stations, is collecting additional shallow shear-wave-velocity data using geophysical techniques. USU collected data at 44 sites along the Wasatch Front in 2003. The geophysical equipment used by USU uses a drop-weight to artificially generate shear waves, and records them on geophones strung in a line about 300 feet long. The system can measure shear-wave velocities of soils to depths of up to 150 feet.

On a basin-wide scale, the depth and configuration of bedrock and semi-consolidated sediments deeper than 100 feet also affects the degree to which seismic waves, particularly low-frequency (long-period) waves, are reflected within the basin and amplified or reduced. The UGS has compiled a database of existing information regarding deep-basin structure and depth to bedrock, which includes deep water wells and oil-company seismic lines (mostly in and around Great Salt Lake). To better characterize this deep-basin structure, the USGS performed a 2-mile-long seismic-reflection survey in South Jordan along 3200 W. Street in September 2003. The USGS system uses a "vibroseis" truck that literally shakes the ground in a manner similar to a small earthquake. Geophones strung along 3200 W. Street recorded the shaking, and analysis of the records determines shear-wave velocities and depths to bedrock and semi-consolidated layers down to about 2500 feet.

This information on shallow shear-wave velocities and deep-basin configuration will ultimately be used to generate a "community velocity model." This 3D model will depict Salt Lake Valley's shape and shear-wave-velocity profile at any given location, and will be used to improve seismic design of buildings and bridges.

Liquefaction and Landslides

The USGS funded the U. of U., USU, and UGS in 2004 to develop state-of-the-art Geographic Information Systems (GIS) methods to make probabilistic liquefaction potential and liquefaction-induced ground failure maps for the Wasatch Front. The project will focus on northern Salt Lake County and will begin by compiling a geotechnical database from existing consultant's reports. The database will be used to produce GIS maps, geologic maps, and to assess both liquefaction potential and the type and amount of associated ground failure (settlement, lateral spreading, flow failure).

Large earthquakes in mountainous areas typically generate hundreds to thousands of landslides, mostly rock falls but also larger slides and flows. Historically, magnitude 5 and larger earthquakes in Utah have generated many rock falls, and the 1992 magnitude 5.8 St. George earthquake generated a massive landslide in Springdale, 27 miles from the epicenter. Along the Wasatch Front, little is known regarding the earthquake-induced landslide hazard, and the Earthquake-Induced Landslide Working Group recommended several studies to improve our understanding.

Home damaged by the Springdale landslide caused by the 1992 St. George earthquake.

The UGS has compiled a database of geotechnical soil shear-strength tests from landslide studies throughout Utah to characterize geologic units for generalized landslide-hazard mapping and to indicate where more data are needed. As a pilot project, the UGS is studying several landslides in Salt Lake County and nearby Wasatch Front areas to determine whether they may have been generated or reactivated by earthquakes. One goal of the project is to date landslide movements and compare them to the timing of known large earthquakes determined from fault studies to assess whether the landslides may have moved as a result of earthquakes.

Concluding Remarks

Much work regarding earthquake hazards is underway in Utah. Cooperative efforts between the UGS and USGS, including establishing interdisciplinary earthquake working groups, have helped direct and coordinate studies. In addition, the USGS has performed independent studies as well as being the principal funding source for many other projects.

Researchers presented the results of ongoing earthquake studies at the UGS-sponsored Earthquake Conference in Salt Lake City on February 26, 2004. The following day, working groups met to update plans (see UGS Web site for updated plans) and coordinate 2004 cooperative studies and 2005 proposals. These efforts are greatly improving our understanding of earthquake hazards, and ultimately will improve our ability to reduce risks in a cost-effective manner.

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development? Although such decisions involve political as well as technical considerations and rest with the permitting local authorities, impartial advice from geoscientists about the probability and effects of a particular hazard is essential. In some cases where several professional opinions are sought, these opinions highlight the real uncertainties in the quantification of hazard potential.

Draper City is to be congratulated for recognizing the importance of landslide and other geologic hazards within the city limits and for adopting their geologic hazards ordinance so that there is adequate study, appropriate mitigation, and full disclosure of geologic hazards to help protect future buyers. The issue has hopefully also raised awareness of the geologic hazard potential in the foothills along the Wasatch Range and caused other jurisdictions to examine the adequacy of their ordinances.

The Mapleton "Megatrench"

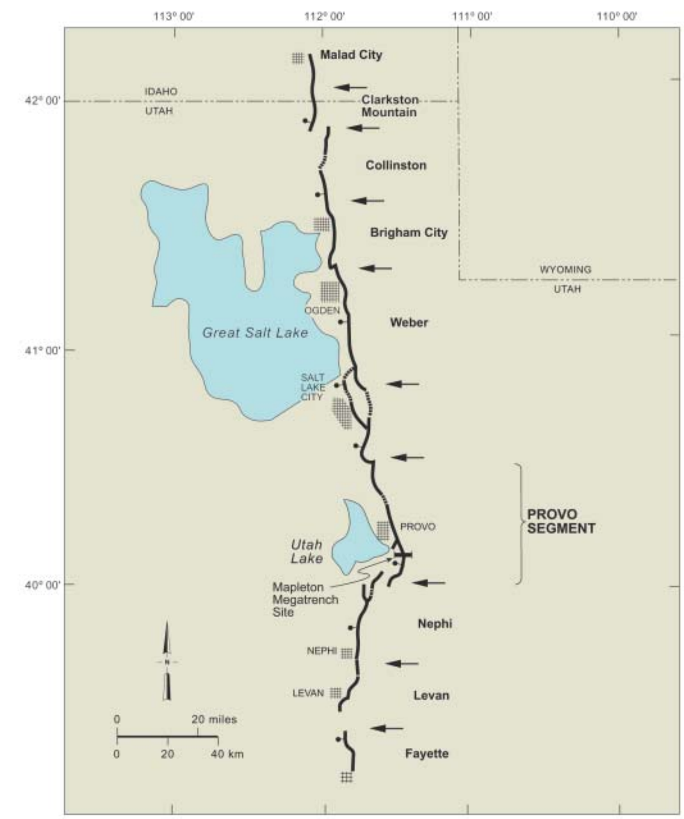
Deciphering 11,000 Years of Earthquake History on the Wasatch Fault near Provo

by Susan Olig, Greg McDonald, Bill Black, Chris DuRoss, and Bill Lund

This past summer, URS Corporation and the Utah Geological Survey (UGS), with assistance from the University of Utah (U. of U.), embarked on a "megatrench" study of the Provo segment of the Wasatch fault zone). The goal was to dig deeper than any previous trench dug across the fault, with the purpose of exposing evidence for prehistoric earthquakes (paleoseismicity) back in time to more than 11,000 years ago, doubling the length of the paleoseismic record for the Provo segment. Despite extreme logistical challenges, we accomplished our goal through unprecedented cooperation between federal and state government agencies, local universities, and private industry. The study was managed by URS and funded by the UGS and U.S. Geological Survey through the National Earthquake Hazards Reduction Program.

Why the need to study older earthquakes? A recent large trench study by James McCalpin of GEO-HAZ Consulting on the adjacent Salt Lake City segment of the Wasatch fault to the north found evidence for considerable variation in rates of earthquake occurrence. Subsequent studies by Ivan Wong and Susan Olig at URS indicate that these rate variations significantly impact probabilistic seismic hazard evaluations, and can either increase estimated ground motions by as much as 60 percent, or decrease them by as much as 20 percent, depending on how rates are used in the analysis. Results from this study will help determine if these same rate variations have also occurred on the Provo segment, and if so, what may have caused them and how we may better incorporate them in future seismic hazard evaluations.

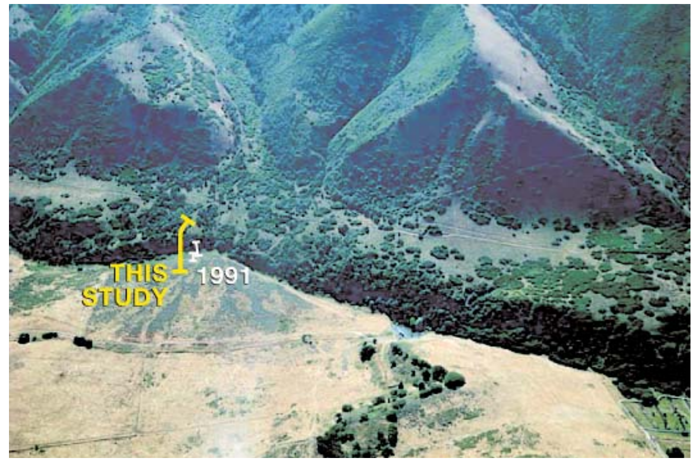
The Mapleton megatrench was about 8 miles southeast of Provo, on the southern third of the Provo segment. It was excavated across a large main fault scarp and several antithetic faults that form a trough-like graben at the base of the Wasatch Range. Here, the faults offset alluvial-fan deposits from Big Slide Canyon. The fan sediments are mostly debris-flow deposits and contain abundant charcoal that can be radiocarbon dated to determine the timing of earthquake events.



Location of the Mapleton megatrench site. Segments of the Wasatch fault are labeled in bold.

The megatrench excavation included a slot trench in the center with two benches flanking both sides. It was over 30 feet deep, 35 to 50 feet wide, and about 275 feet long. Its size was complicated by the large, steep slope of the main fault scarp, which is over 60 feet high and has an average slope of 35 degrees. In addition to excavating and logging the trench, we dug three shallow soil pits, mapped the surficial geology in detail, and constructed topographic profiles across the fault scarp. To "see" even deeper and

Eastward view of the Mapleton megatrench during the field review.

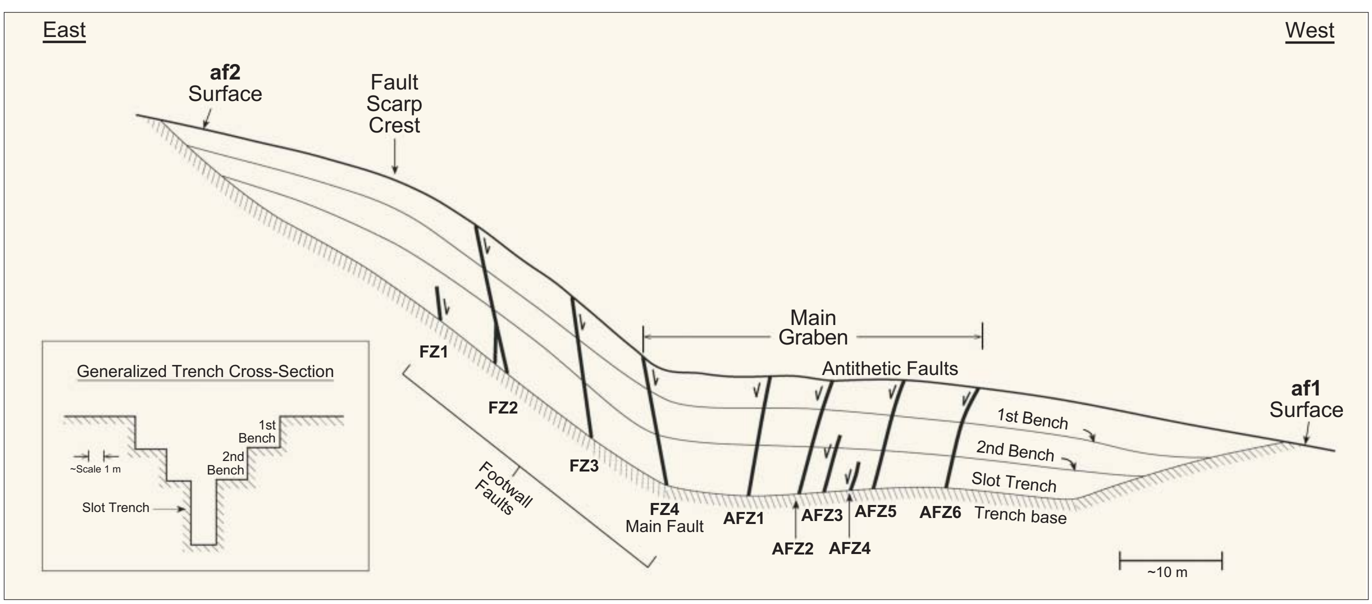


Aerial view showing locations of the Mapleton megatrench and earlier (1991) trenches. Photo by Ronald Bruhn.

decipher even older fault behavior, the U. of U. conducted geophysical experiments to measure seismic velocities of sediments. We also drilled three boreholes that were 110 to 120 feet deep. The drilling and geophysics were funded by the National Science Foundation as part of a broader study of several faults, which is being directed by Ronald Bruhn and Gerard Schuster at the U. of U.

Our fieldwork is nearly complete and the excavations are backfilled, but we are still analyzing data and have only preliminary results to report here. For example, we are still drafting final trench logs, and of the 52 charcoal samples that we collected for radiocarbon dating, we have completed only eight age analyses so far. However, the initial results are promising and include some intriguing surprises. In particular, the unusually extensive exposure of the footwall (upthrown side of the fault) revealed a much more complex deformation zone than expected, with a thick sequence of debris-flow deposits offset across four, not just one, significant down-to-the-west faults, identified as FZ1 through FZ4. Although faulting appears to have generally stepped basinward (westward toward the base of the slope) through time, all of the faults show compelling evidence for repeated movement during the Holocene (past 10,000 years).

Preliminary stratigraphic correlations suggest that over 10 feet of vertical offset occurred during two separate faulting events on FZ1 sometime between 5,000 and 11,000 years ago. A thick package of unfaulted debris-flow deposits overlies FZ1, indicating that activity on this fault had ceased by 5,000 years ago. In contrast, colluvial-wedge deposits along both FZ2 and FZ3 provide evidence for surface-faulting earthquakes that occurred after 5,000 years ago, each of which may or may not have been contemporaneous with one of the three youngest events on the main fault (FZ4). The trench also exposed evidence for at least two older faulting events on FZ2 that occurred prior to 6,000 years ago. Additional radiocarbon ages will help us



Schematic diagram showing the general location of significant faults exposed in the Mapleton megatrench.

determine if these older events were contemporaneous with any of the older events on FZ1.

The trench also exposed several antithetic faults (faults that dip in the opposite direction of the main fault) that, together with FZ4, form the main graben and are identified as AFZ1 through AFZ6. Altogether, we found evidence for at least five separate surface faulting events on the graben faults. The evidence includes differential offsets of sediments across faults, fault terminations, and faulting-related deposits (e.g., fissure fills and colluvial wedges). One of the more spectacular discoveries was evidence for the youngest event on FZ4, where an apparently very large earthquake created a scarp at least 20 feet high that was subsequently buried by colluvium shed off the scarp, forming a "mega-" colluvial wedge. Evidence for this event was previously exposed in a shallow trench investigation at this site by Bill Lund of the UGS, who determined that the event occurred about 600 years ago based on radiocarbon analyses. We collected charcoal samples from most of the offset sediments exposed in the graben to constrain the timing of older events, but need to obtain additional funding to analyze these samples.

Close-up view of the main fault (FZ4). Photo by Alan Nelson.

Once additional radiocarbon analyses are complete, we expect to constrain the ages for all the events on the graben faults, and hopefully determine how their timing compares to the timing of events on the footwall faults. Then we can ultimately address our original question as to whether rates of earthquake occurrence have varied significantly on the Provo segment, as observed on the Salt Lake City segment. One striking fact is clear from even our preliminary results: slip rates based on offsets measured from scarp profiles and ages from shallow excavations alone would be much too high due to the pre-existing topography created by

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More UGS Publications on the Wasatch and Other Faults in Utah

Paleoseismology of Utah, Volume 1: Fault behavior and earthquake recurrence on the Provo segment of the Wasatch fault zone at Mapleton, Utah County, Utah, by W.R. Lund, D.P. Schwartz, W.E. Mulvey, K.E. Budding, and B.D. Black, 1991, 41 p. $7.00

Paleoseismology of Utah Volume 2: Paleoseismic analysis of the Wasatch fault zone at the Brigham City trench site, Brigham City, Utah and the Pole Patch trench site, Pleasant View, Utah, by S.F. Personius, 39 p., 1991 $6.00

Paleoseismology of Utah Volume 3: The number and timing of paleoseismic events on the Nephi and Levan segments, Wasatch fault zone, Utah, by Michael Jackson, 23 p., 3 pl., 1991 . . . . $6.50

Paleoseismology of Utah Volume 4: Seismotectonics of north-central Utah and southwestern Wyoming, by Michael W. West, 93 p., 5 pl., 1994 . . . . $15.00

Paleoseismology of Utah Volume 5: Neotectonic deformation along the East Cache fault zone, Cache County, Utah, by J.P. McCalpin, 37 p., 1994 . . . . $5.00

Paleoseismology of Utah Volume 6: The Oquirrh fault zone, Tooele County, Utah: surficial geology and paleoseismicity, W.R. Lund, editor, 64 p., 2 pl., 1:24,000, 1996 . . . . $14.50

Paleoseismology of Utah Volume 7: Paleoseismic investigation on the Salt Lake City segment of the Wasatch fault zone at the South Fork Dry Creek and Dry Gulch sites, Salt Lake County, Utah, by B.D. Black, W.R. Lund, D.P. Schwartz, H.E. Gill, and B.H. Mayes, 22 p., 1 pl., 1996 . . . . $5.25

Paleoseismology of Utah Volume 8: Paleoseismic investigation at Rock Canyon, Provo segment, Wasatch fault zone, Utah County, Utah, by W.R. Lund and B.D. Black, 21 p., 2 pl., 3/98 . . . . $8.00

Paleoseismology of Utah Volume 9: Paleoseismic investigation of the Clarkston, Junction Hills, and Wellsville faults, West Cache fault zone, Cache County, Utah, by B.D. Black, R.E. Giraud, and B.H. Mayes, 23 p., 1 pl., 3/00 . . . . $10.50

Paleoseismology of Utah Volume 10: Post-Bonneville paleoearthquake chronology of the Salt Lake City segment, Wasatch fault zone, from the 1999 "megatrench" site, by James P. McCalpin, 5/02, 37 p., ISBN 1-55791-670-5, MP-02-7 . . . . $15.95

Paleoseismology of Utah Volume 11: Post-Provo paleoearthquake chronology of the Brigham City segment, Wasatch fault zone, Utah, by James P. McCalpin and Steven L. Forman, 46 p., 5/02, ISBN 1-55791-671-3, MP-02-9 . . . . $11.95

Paleoseismology of Utah Volume 12: Neotectonics of Bear Lake Valley, Utah and Idaho; a preliminary assessment, by James P. McCalpin, 43 p., ISBN 1-55791-694-2, 12/03, MP-03-4 . . . . $11.00

New Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah

by Gary E. Christenson, L. Darlene Batatian, and Craig V Nelson

Utah has over 200 Quaternary faults capable of causing surface faulting in earthquakes of magnitude 6.0-6.5 and larger. Most of these faults are normal faults in which fault displacement at the surface is primarily vertical with one side dropping down relative to the other. Vertical ground-surface displacements of 6 feet or more may occur in a magnitude 7 earthquake. Because such surface faulting typically recurs along pre-existing faults, repeated faulting has created fault scarps in Utah tens to hundreds of feet high.

If a normal fault were to break the ground surface through the foundation of a building, significant structural damage is likely and collapse is possible, causing injuries and perhaps death. The most common land-use practice to reduce the risk from surface faulting is to avoid placing buildings directly on faults. Therefore, site-specific investigations are needed to accurately locate faults, determine their level of activity and rupture characteristics, and establish appropriate building setbacks prior to development.

The Utah Geological Survey (UGS) recently published new *Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah* (UGS Miscellaneous Publication 03-6), replacing the 1987 guidelines (UGS Miscellaneous Publication N). The guidelines recommend appropriate surface-fault-rupture hazard-investigation techniques and report content to ensure that adequate studies are performed to aid in land-use regulation and to facilitate risk reduction.

Surface-fault-rupture hazard studies use the characteristics of past surface faulting at a site as a scientific basis for reducing the potential for damage and injury from future, presumably similar, surface faulting. A site-specific surface-fault-rupture hazard evaluation typically includes literature review, aerial photograph analysis, and field investigation, usually involving surficial geologic mapping and trenching to determine the location, age, amount of displacement, and dip of faults. Setbacks are then determined based on these factors, structure footing depths, and the criticality (relative importance and risk) of the structure. Risk-reduction measures in addition to setbacks include foundation reinforcement and disclosure.

Ground-surface displacement caused by surface fault rupture in the 1954 magnitude 6.8 Dixie Valley, Nevada, earthquake.

Scarp of the Wasatch fault (arrows) in Kaysville, Davis County, formed by repeated surface-faulting earthquakes over thousands of years.

To determine the need for site-specific study and setbacks, faults are grouped into Holocene (<10,000 years), Late Quaternary (<130,000 years), or Quaternary (<1.6 million years) activity classes based on the time of last movement. More active faults, as indicated by a more recent time of last movement, present a greater risk and therefore are

Fault scarp of the 1959 M7.6 Hebgen Lake, Montana, earthquake causing damage and partial collapse of a barn (photo by I.J. Witkind, U.S. Geological Survey).

more important to study and avoid. At a minimum, the UGS recommends site-specific studies and setbacks for all critical facilities (for example, schools, hospitals, fire stations) and structures for human occupancy along Holocene faults, and for critical facilities along Late Quaternary faults.

To define where studies are needed, we provide recommendations for delineating special-study areas along faults. For well-defined faults with obvious scarps and other surficial evidence of geologically recent faulting, we recommend a special-study area 500 feet wide on the downthrown side and 250 feet wide on the upthrown side to map faults. For proposed development in the special-study area, faults must be accurately mapped and trenched to determine setbacks. Where faults are poorly defined and buried or approximately located, we recommend a special-study area 1000 feet on either side of the mapped fault. Surficial geologic studies are recommended within the special-study area to look for evidence for faults to determine whether further study and possible trenching are needed.

The new guidelines are based largely on minimum standards adopted by Salt Lake County in 2002, which were developed from existing guidelines and standards used in California, Nevada, and Utah. We hope the guidelines establish a uniform approach to surface-fault-rupture hazards statewide, and aid consultants and local governments in adequately assessing and reducing risks from surface faulting.

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much older faulting on FZ1. Without the deep exposures of FZ1, FZ2, and FZ3 in the slot trench, we likely would have assumed that all of the offset we see across the main scarp occurred after 5,000 years ago. This would erroneously yield a slip rate exceeding 4 millimeters/year. Clearly, going deeper in this case paid off, but for unexpected reasons! After decades of research by some of the leading paleoseismologists of our time, the Wasatch fault is arguably the best studied normal-slip fault in the world. And so it is amazing to us how much we still have to learn about this incredible fault that has fundamentally shaped the Wasatch Front landscape and will continue to do so for generations to come.

Acknowledgments: Many have contributed to the Mapleton megatrench study, but we are particularly thankful to: Ronald Bruhn, Maike Buddensiek, Chris Busch, Gary Christenson, Scott Cragen, Mike Hozik, Mike Hylland, Rich Giraud, Justin Johnson, Ann Mattson, Craig Nelson, Eliza Nemser, Gerard Schuster, David Schwartz, Gordon Seitz, David Simon, and Ivan Wong. We also thank the following for their logistical assistance: Bob Gunnell, Joergen Pilz, Don White, Mapleton City, the Suburban Land Reserve, and the Division of Wildlife Resources.

New Publications

Geologic map of the Mona quadrangle, Juab and Utah Counties, Utah, by Tracy J. Felger, Michael N. Machette, and Martin L. Sorensen, 23 p., 2 pl., 1:24,000, 3/04, OFR-428 . . . .$11.30

Geologic map of The Divide quadrangle, Washington County, Utah, by Janice M. Hayden, 32 p., 2 pl. 1:24,000, ISBN 1-55791-597-0, 2/04, M-197 . . . . . $11.95

Ground-water sensitivity and vulnerability to pesticides, East Shore area of Great Salt Lake, Davis and Weber Counties, Utah, by Mike Lowe, Janae Wallace, and Matt Butler, 2/04, CD-ROM (28 p., 2 pl. 1:75,000), ISBN 1-55791-700-0, MP-04-1 . . . . $14.95

Interim geologic map of the Francis Canyon quadrangle, Lost Creek drainage, Morgan, Rich, and Summit Counties, Utah, by James C. Coogan, 10 p., 1 pl., 1:24,000, 2/04, OFR-425 . . . . $6.00

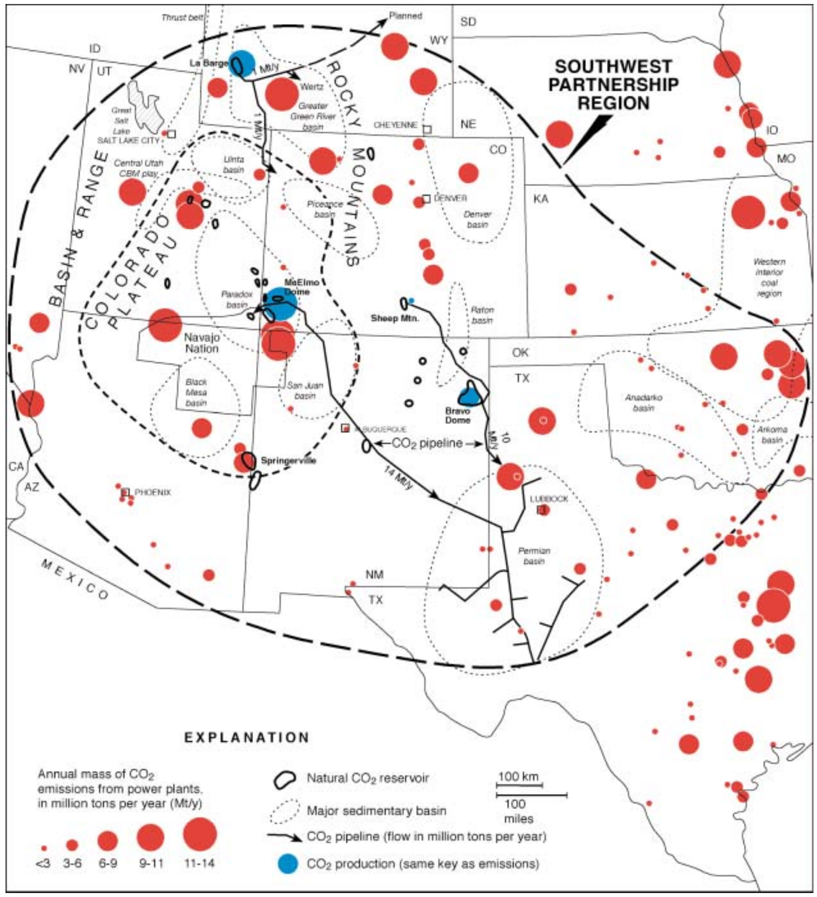
Interim geologic map of the Lost Creek Dam quadrangle, Lost Creek drainage, Morgan and Weber Counties, Utah, by James C. Coogan, 10 p., 1 pl., 1:24,000, 2/04, OFR-426 . . . . $6.00

Interim geologic map of the Peck Canyon quadrangle, Lost Creek drainage, Morgan and Rich Counties, Utah, by James C. Coogan, 10 p., 1 pl., 1:24,000, 2/04, OFR-427 . . . . $6.00

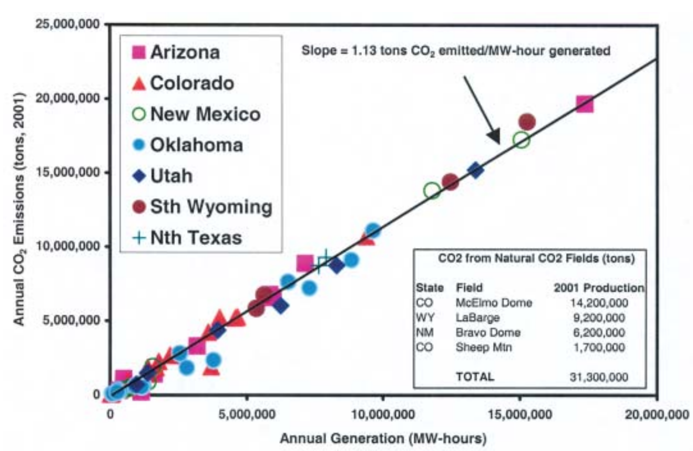
Energy News

Storing Carbon Dioxide Emissions Underground — New Projects

The Southwest Regional Partnership area contains numerous oil, gas, and coal fields in various stages of development, a well-developed energy infrastructure including two major CO_2 pipeline networks, and numerous large coal-fired power plants. Potential geologic options for sequestration include mature oil and gas fields, deep unmineable coal fields, and deep saline aquifers. Also, injected CO_2 could be used for enhanced oil recovery or enhanced gas recovery from coalbed methane prospects, resulting in CO_2 stored underground. Non-geologic options include enhanced biomass (e.g., through forest growth), increased soil organic carbon storage through improved agricultural practices (e.g., minimizing tillage), and surface storage through new techniques for chemically converting CO_2 into carbonate.



In contrast to the terrestrial storage options that extract CO_2 from the air, the geologic storage options require a point source of CO_2 for injection, and therefore need to be close to a CO_2 pipeline, or to a large coal-fired power plant. The graph shows the close relationship between electricity generation in the Southwest Regional Partnership area, and CO_2 emissions from the power plants. The 10 largest power plants generate 50% of the region's power plant emissions, and all 10 use nearby bituminous coal as a fuel. Studies of total CO_2 emissions indicate that power plant emissions are about half the total, with a major part of the remaining emissions being from transportation. One implication of Utah's rapid growth rate, and its growing demand for electricity (over 2% per year), is that its CO_2 emissions will also continue to grow. These trends are typical of the Intermountain West.



The CO_2 sequestration partnership grants are for two years. Information about DOE's carbon sequestration priorities can be found at: http://www.netl.doe.gov/coalpower/sequestration/index.html

The Southwest Partnership Web site is at: http://southwestcarbonpartnership.org/. Information about these projects is also available on the UGS Web site.

GeoSights

Sand Dunes at Little Sahara Recreation Area

by Christine Wilkerson

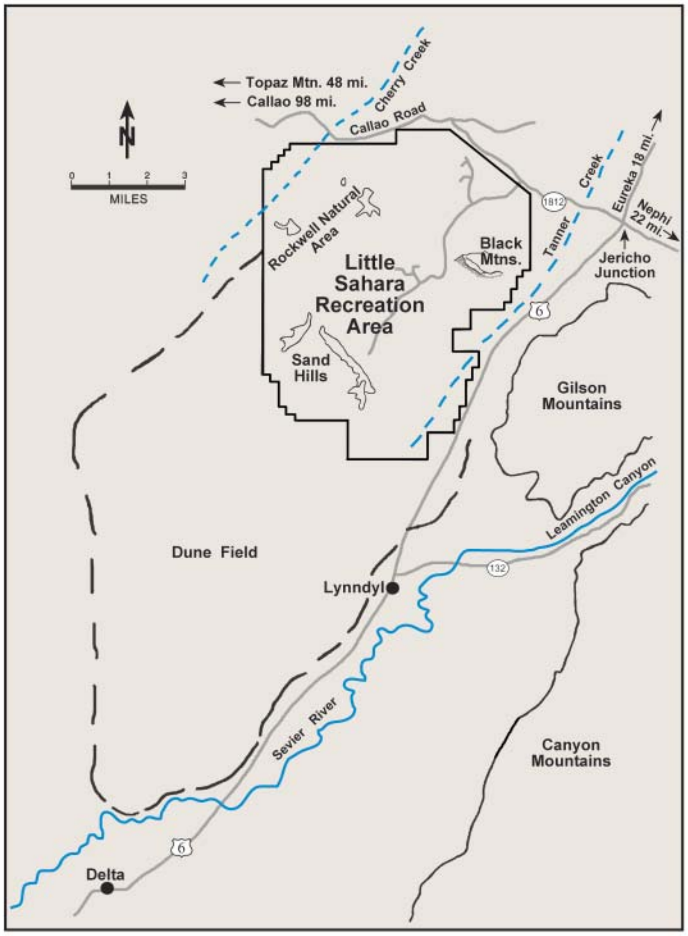
The Little Sahara sand dunes, located in the northeastern part of the Sevier Desert in western Utah, lie within the northern half of one of Utah's largest dune fields (about 220 square miles). This dune field contains both actively forming or migrating dunes and plant-stabilized dunes. Administered by the Bureau of Land Management, Little Sahara Recreation Area is mostly devoted to off-road vehicle use. The Rockwell Natural Area, located in the northwest corner of Little Sahara, is a 14-square-mile section off limits to vehicles in order to preserve and shelter desert plants and animals.

Sand dunes on the east side of Little Sahara Recreation Area. Gilson Mountains in background.

Geologic Information: The Sevier Desert was inundated by waters of prehistoric Lake Bonneville from about 20,000 to 12,500 years ago. Lake Bonneville was a large freshwater lake that at its greatest extent covered most of Utah's western valleys and small parts of Idaho and Nevada. Two distinct shorelines were created while the lake occupied this area, the Bonneville (highest) and the Provo shorelines. Each formed when the level of the lake remained relatively constant for hundreds of years.

A large delta formed where the Sevier River, after leaving Leamington Canyon, entered Lake Bonneville while at the Provo level. This ancient delta extends from the area near the mouth of Leamington Canyon to just north of the town of Delta. After Lake Bonneville receded, winds dominantly from the southwest began to transport some of the exposed deltaic sand northeasterly, eventually creating the current dune field. Most of this dune field is still active, with dunes migrating between 5 to 9 feet per year.

Generally, the quantity of wind-blown sand in the dune field increases as you move farther northeast. A gradual rise in elevation to the northeast and bedrock barriers within the dune field cause the moving sand to slow or stall and accumulate. The most prominent barrier is the Sand



Hills (also known as Sand Mountain) located within the recreation area. The Sand Hills lie directly in the path of migrating dunes and are aligned at right angles to the prevailing wind direction. Sand travels around the ends of the hills or through passes to form dunes on the other side.

Although the sand consists mostly of quartz grains, minor amounts of felspar, biotite, calcite, garnet, magnetite, and other minerals are also present. Try dragging a magnet through the fine-grained sand to see how "hairy" it becomes when the magnetite particles cling to it. The magnetite probably eroded from volcanic rocks along the path of the Sevier River.

How to get there: The Little Sahara Recreation Area is about 110 miles from Salt Lake City via Nephi. Travel on I-15 to Nephi. Take exit 225 and travel west 14.5 miles on State Route 132 to Juab County Route 1812 ("Sand Dunes" sign). Turn right (northwest) onto Route 1812, travel about 14 miles, passing through Jericho Junction (intersection with U.S. Highway 6), until you reach the turnoff sign for Little Sahara Recreation Area. Turn left (southwest) to enter the area. There is a daily use fee.

Survey News

Lots of new people are with us:

Neil Burk has joined the Environmental Sciences Program and is working primarily on a U.S. EPA-funded wetlands grant. Neil recently completed his M.S. in Geology from Utah State University.

The Energy and Minerals Program welcomes two new members, **Dallas Rippy** and **Taylor Boden**. They have been hired as geotechnicians to assist with mineral resource evaluation projects in Utah. And **Angie Marx**, an intern working for the Geologic & Information Outreach Program, now researches sand and gravel for E&M Program.

Nancy Carruthers begins an internship with GIO doing web outreach.

Welcome aboard to **Lucas Shaw**, the new GIS analyst for the Geologic Hazards Program. The Hazards program will also be getting additional help from **Chris DuRoss**. His time here will increase once he gets his MSc defense behind him.

Peter Thompson was doing GIS work for the Geologic Mapping Program and is moving to Nevada.

The UGS welcomes two new secretaries. **Lisa Brown** will be working for the Geologic Hazards and Mapping Programs, and **Rebecca Medina** is joining the GIO and ESP programs.

NEW Teaching Kits Available

Ice Age teaching kits contain over 14 fossils and fossil casts from the small snail shells of Lake Bonneville to the large teeth and/or claws of cave bears, giant sloths, and saber-toothed cats; a Utah relief map showing glaciers and Lake Bonneville coverage during the recent Ice Age, and a teaching manual. The teaching manual contains information on Ice Ages, especially in Utah and describes and shows what Utah looked like 18,000 years ago and what animal life was like. It also includes a power point presentation, resources, and activities. Appropriate for all grade levels. Available for a two-week loan with a $25.00 refundable deposit.

Kits must be picked up and returned to the UGS office at the Department of Natural Resources (DNR) Building at 1594 West North Temple, Suite 3110, Salt Lake City, 801-537-3300.

Other teaching kits are available as well: Rock, mineral, and fossil kit; Dinosaur kit; Earthquake kit.

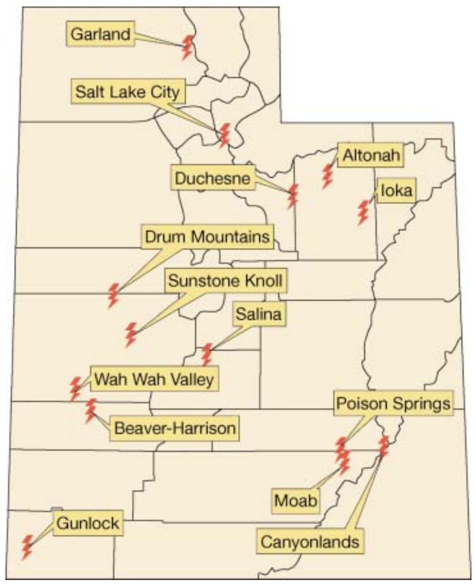
"Glad You Asked"

by William F. Case

Have meteorites or meteorite craters been found in Utah?

Fourteen meteorite finds in Utah are officially recorded in London's National History Museum Catalogue of Meteorites. Meteorite numbers in neighboring states range from 69 in Colorado to two in Nevada. Most likely there are meteorite finds and falls in Utah that are not reported.

Utah's meteorites are the stony and iron types. Stony meteorites are the most diverse group of meteorites. They come from a parent body of primordial material that, unlike the Earth, did not differentiate into layers such as a core, mantle, and crust. Their ages range from billions of years to 170 million years. Iron meteorites are the most familiar meteorites. They are heavy because they are mainly iron-nickel alloy, they do not weather very fast, they do not easily fragment when they fall, and they are magnetic. Iron meteorites come from the core of differentiated bodies. Six iron meteorites have been found in Utah. The eighth heaviest (529 kg, 1164 lbs) iron meteorite in the U.S. was found near Delta, Utah.

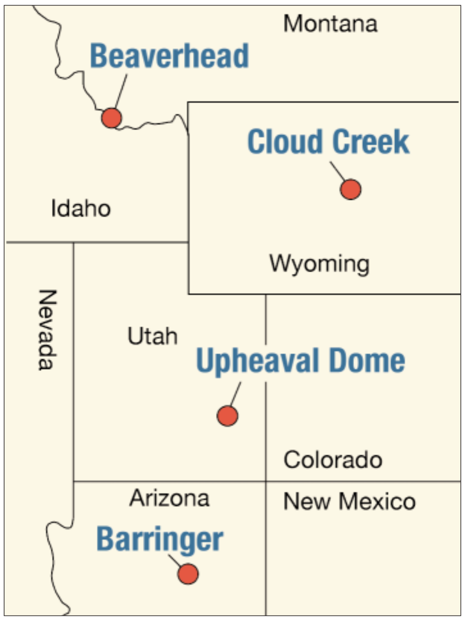


Meteorite finds in Utah.

The Geological Survey of Canada Impact Database lists four meteorite craters in Utah and nearby states. They are (1) the controversial (some think it is a salt dome) Upheaval Dome in Canyonlands National Park, Utah, (2) Beaverhead Crater, Montana, (3) Barringer Crater (Canyon Diablo,

Utah Meteorites (data from Hey, 1966; Grady, 2000)					
Name	Type	Date	Weight, kg	Weight, Lbs (calculated)	Comments
Garland	Stone	1950	0.1	0.22	Seen falling, summer, 11AM; 1 stone recovered
Salt Lake City	Stone	1869	0.88	1.96	Found between Salt Lake City & Echo
Altonah	Iron	1932	22	48.4	Found 0.6km (0.4mi) SE of Moon Lake outlet
Duchesne	Iron	1961	23	50.6	Found 47km (31mi) NW of Duchesne on Mount Tabby
Ioka	Stone	1931	0.3	0.66	Weathered stone exposed by plow
Drum Mountains	Iron	1944	529	1164	Eighth heaviest in U.S., found on basalt
Sunstone Knoll	Stone	1985	0.16	0.35	Single mass found on west shore of Little Salt Lake
Salina	Iron	1908	0.24	0.59	Weathered mass & balls with metallic core, found in Pavant Mountains
Wah Wah Valley	Stone	1986	0.009	0.02	Mass found on dry lake bed; NW corner of Wah Wah Valley hardpan
Beaver-Harrison	Stone	1979	0.93	2.1	Found on alluvial fan near mine, Beaver Lake Mountains
Poison Spring	Iron	1971	0.5	1.1	
Canyonlands	Stone	1961	1.52	3.34	Partly encrusted stone found near confluence of Green & Colorado Rivers
Moab	Iron	pre-1962	19.5	42.9	Recorded in the 1966 Catalogue of Meteorites, but not the 2000 catalogue.
Gunlock	Stone	1982	6.8	14.96	Two pieces that fit together were found 0.05km (0.03mi) apart on the south slope of Padre Hill

Drum Mountains meteorite before it was moved and sliced for analyses.



Impact (meteorite) craters in Utah and nearby states.

Meteor Crater), Arizona, and (4) Cloud Creek Crater, Wyoming (known only from drilling records).

Additional information on meteorites can be found in the following references, which provided the data summarized in this article:

Geological Survey of Canada, June 9, 2003, Earth Impact Database: Online, <www.unb.ca/passc/ImpactDatabase>, accessed January 27, 2004

Grady, M.M., 2000, Catalogue of Meteorites, 5th Edition: National History Museum, London, 690 p.

Henderson, E.P. and Perry, S.H., 1948, Smithsonian Miscellaneous Collections, v.110, no. 12, 7 p., 5 pl.

Hey, M.H., 1966, Catalogue of Meteorites, 3rd Edition: National History Museum, London, 637 p.

Teacher's Corner

by Sandy Eldredge

Summer Workshop for 5th Grade Teachers

The Earth's Surface is Constantly Changing

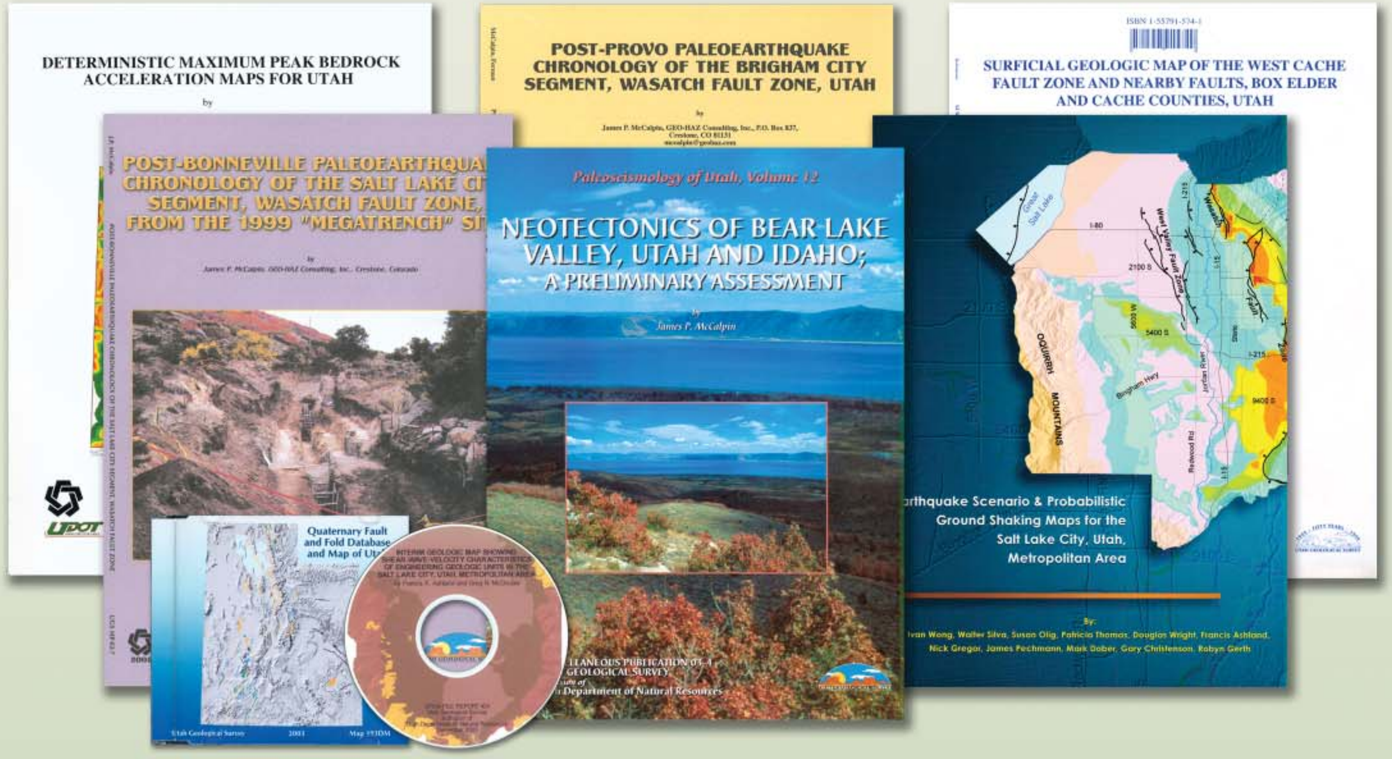
1 Hour Inservice Credit

The Utah Geological Survey will be offering this two-day workshop in August. We will investigate earth processes, including earthquakes, volcanoes, erosion, and deposition, and their effects on landforms both in the field and in the classroom. The Salt Lake City-based workshop will be available for 1-Hour Inservice Credit.

The course, designed specifically for 5th-grade teachers, will provide a follow up for those of you who will be attending one of the CORE academies this summer.

We will advertise the specific dates and information at the CORE academies.

For more information, please contact Sandy Eldredge at 801-537-3325, sandyeldredge@utah.gov.



Surficial geologic map of the West Cache fault zone and nearby faults, Box Elder and Cache Counties, Utah, by Barry J. Solomon, 20 p., 2 pl., 1:50,000, 3/99 M-172 . . $7.95

Quaternary fault and fold database and map of Utah, by Bill D. Black, Suzanne Hecker, Michael D. Hylland, Gary E. Christenson, and Greg N. McDonald, CD-ROM, scale 1:500,000, ISBN 1-55791-593-8, 2/03, Map 193DM . .$24.95

Earthquake scenario and probabilistic ground shaking maps for the Salt Lake City, Utah, metropolitan area, by Ivan Wong, Walter Silva, Susan Olig, Patricia Thomas, Douglas Wright, Francis Ashland, Nick Gregor, James Pechmann, Mark Dober, Gary Christenson, and Robyn Gerth, 50 p. + CD-ROM, ISBN 1-55791-666-7, MP-02-5 . . . . $25.00

Interim map showing shear-wave-velocity characteristics of engineering geologic units in the Salt Lake City, Utah metropolitan area, by Francis X. Ashland and Greg N. McDonald, CD-ROM (43 p., 1 pl., 1:75,000), 12/03, OFR-424 . . . . $19.95

Post-Bonneville paleoearthquake chronology of the Salt Lake City segment, Wasatch fault zone, from the 1999 "megatrench" site, by James P. McCalpin, 5/02, 37 p., MP-02-7 . . . . $15.95

Deterministic maximum peak acceleration maps for Utah, by M.W. Halling, J.R. Keaton, L.R. Anderson, and W. Kohler, 8/02, 57 p., 1 CD-ROM, MP-02-11 . . . . $20.95

Guidelines for evaluating surface-fault-rupture hazards in Utah, by Gary E. Christenson, L. Darlene Batatian, and Craig V Nelson, 14 p., 8/03, MP-03-6 . . . . $5.50

Neotectonics of Bear Lake Valley, Utah and Idaho; a preliminary assessment, by James P. McCalpin, 43 p., ISBN 1-55791-694-2, 12/03, MP-3-4 . . . . $11.00

Earthquake publications are available from:

NATURAL RESOURCES MAP & BOOKSTORE

1594 West North Temple, Salt Lake City, UT
801-537-3320 or 1-888-UTAHMAP • http://mapstore.utah.gov

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