DATABASE COMPILATION, COORDINATION OF EARTHQUAKE-HAZARDS MAPPING, AND STUDY OF THE WASATCH FAULT AND EARTHQUAKE-INDUCED LANDSLIDES, WASATCH FRONT, UTAH

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INVESTIGATIONS UNDERTAKEN

The Utah Geological Survey (UGS), in cooperation with the U.S. Geological Survey (USGS) and Utah Seismic Safety Commission, convened a series of working group meetings to define a multi-year plan for developing the next generation of earthquake ground shaking, liquefaction, and earthquake-induced landslide maps for Utah. Three working groups were established and meetings were held to develop long-term plans, partnerships for investigations, and topics for future NEHRP proposals. In support of the planning effort, the UGS compiled interactive shallow shear-wave-velocity, deep-basin-structure, and geotechnical landslide shear-strength databases to identify data available for earthquake-hazards mapping along the Wasatch Front.

In addition, the UGS is mapping the surficial geology of the Levan segment of the Wasatch fault zone as a continuation of USGS and UGS surficial geologic mapping of segments of the Wasatch fault. This mapping is used in paleoseismic characterization of the fault for both the UGS and USGS Quaternary fault databases used in the National Seismic Hazard Maps. We also initiated studies to identify likely earthquake-induced landslides in the Salt Lake County area for later detailed geotechnical characterization and paleoseismic investigations (trenching to date events, back-calculating accelerations needed to induce movement) to better understand their behavior in earthquakes.

RESULTS

Working Groups

An initial one-day meeting of the Ground Shaking and Liquefaction Working Groups was held in Salt Lake City on March 18, 2003, and of the Earthquake-Induced Landslide Working Group on July 21, 2003. Working groups held follow-up meetings and email correspondence to finalize long-term plans and identify partnerships and projects for future proposals. Working group members include geologists, engineers, seismologists, and geophysicists from Utah State University, Brigham Young University,

University of Utah, UGS, USGS, and various consulting companies and other state agencies. Each working group developed a consensus among the technical experts regarding the types of hazards maps that could be produced, new data required, preferred data-collection and mapping techniques, and possible funding sources. Working group results help define the State's plan for new earthquake-hazards maps so that investigators can use the plan to demonstrate the relevance of their proposed work. Final working group plans for future earthquake-hazards maps are available on the UGS website at geology.utah.gov.

The Ground-Shaking Working Group plan identifies steps to develop detailed spectral-acceleration maps for ground motions at various periods that consider both shallow shear-wave velocities (Vs30) and deep-basin structure. The first maps will be completed for Salt Lake Valley. The Liquefaction and Earthquake-Induced Landslide plans outline steps to compile databases and pilot projects to evaluate various hazard mapping methods, with final-product formats to be determined pending these studies. Working group plans were used to help identify investigations and potential partnerships for future proposals.

Databases

To help working groups develop earthquake-hazards-mapping plans, the UGS compiled three databases to show: 1) shallow shear-wave velocities (Vs30), 2) deep-basin-structure data, and 3) geotechnical landslide shear strengths. All databases are in an interactive, searchable GIS format (HTML Image Mapper®, version 3.0).

The shallow shear-wave-velocity database was originally compiled for the UGS site-response map of Salt Lake Valley for another NEHRP project. The database included shear-wave-velocity data to depths of 100 feet (30 m) or greater in Salt Lake Valley only. The database was updated, the format was changed, and coverage extended to statewide under this grant. The database includes only direct shear-wave-velocity measurements, including downhole, cone penetrometer (CPT), and geophysical (SASW, Rayleigh-wave inversion) data. No standard-penetration test (SPT) or undrained shear strength test data converted to estimate shear-wave velocities are included.

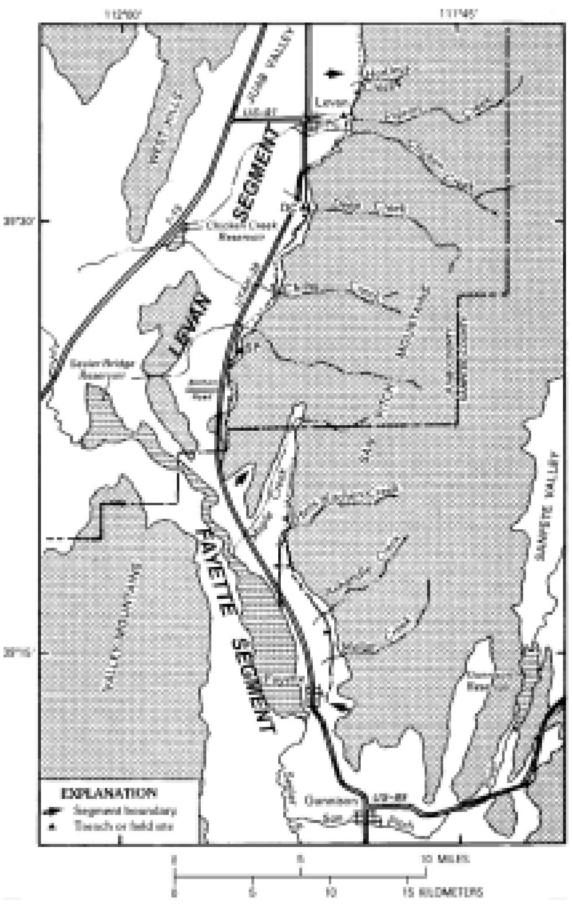
The deep-basin-structure database includes all deep water wells and geotechnical boreholes, particularly those that encountered bedrock. Deep geophysical data, mostly oil-company seismic-reflection lines in and around Great Salt Lake, are also included. Existing depth of Quaternary deposits (Arnow and others, 1970) maps and gravity interpretations of the thickness of unconsolidated and semi-consolidated alluvial/lacustrine basin fill are included. The prime sources of borehole, gravity, and seismic data were the Utah Division of Water Rights (unpublished water-well logs), Case (1985), Radkins and others (1989), and McNeil and Smith (1992).

The geotechnical landslide shear-strength database includes soil-test data from various sources, principally from geotechnical consultants and the Utah Department of

Transportation. For each data point, the soil type, geologic unit, type of test, and shear strength (friction angle, cohesion) are given.

Levan Segment Wasatch Fault Zone Mapping

We are mapping the geology of the Levan segment of the Wasatch fault zone in central Utah (figure 1), with an emphasis on the relations between surficial Quaternary deposits and faults. The Levan segment is near the southern end of the Wasatch fault zone, the longest active normal-slip fault zone in the western United States and the most active fault zone in Utah. Our map extends 1:50,000-scale surficial-geologic mapping of the fault zone south of the five central segments that trend through the populous Wasatch Front area of north-central Utah (figure 2).



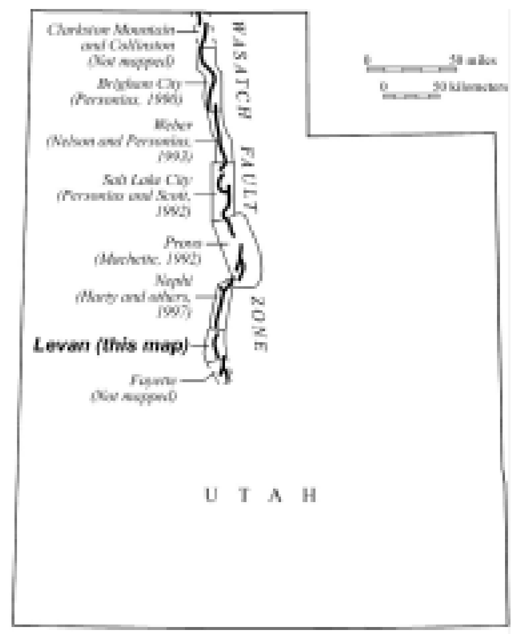


Figure 1 (left). Levan and Fayette segments of the Wasatch fault zone; faults shown by heavy lines, dotted where uncertain, bar and ball on downthrown side. PC, Pigeon Creek (site of radiocarbon age of faulted fan alluvium reported by Schwartz and Coppersmith, 1984); DC, Deep Creek stream-cut exposure of fault; SP, Skinner Peaks trench of Jackson (1991). Modified from Machette and others (1992).

Figure 2 (above). Index maps of the Wasatch fault zone in Utah, showing segments and published 1:50,000 scale strip maps.

Our mapping has involved aerial-photograph interpretation and field verification of fault scarps and surficial-geologic units along the fault zone, compilation of bedrock geology using published geologic maps, and age analysis of 25 scarp profiles measured by M.N. Machette (U.S. Geological Survey) in 1984. The Levan segment is distinguished by discontinuous Holocene scarps that extend for about 30 km. The segment is separated from late Holocene scarps to the north (Nephi segment) by a 15-km gap in Holocene faulting. In this gap, older scarps are preserved on middle Pleistocene fan alluvium, but we found no evidence of latest Pleistocene or Holocene faulting. The south end of the Levan segment is marked by a substantial left step in Quaternary faulting; the Fayette segment (which lacks Holocene scarps) continues to the south.

Levan-segment scarps on Holocene alluvial fans range up to about 4 m high, whereas scarps on middle Pleistocene alluvial fans are as high as about 12 m. These higher scarps indicate recurrent late Quaternary faulting but relatively low long-term slip rates. On the northern half of the segment, scarp profiles on Holocene alluvial fans indicate a single faulting event; scarp-height – slope-angle relationships for these scarps plot near the Fish Springs (late Holocene) regression line of Bucknam and Anderson (1979), and scarp ages calculated using the linear-plus-cubic diffusion model of Andrews and Bucknam (1987) are consistent with late Holocene faulting. On the southern half of the segment, scarp profiles on Holocene alluvial fans also generally indicate a single faulting event, although scarp-height – slope-angle relationships for these scarps plot near the Drum Mountains (early Holocene) regression line of Bucknam and Anderson (1979), and calculated scarp ages are consistent with early Holocene faulting. Also, scarp profiles in the vicinity of Chriss Creek show a composite form that may reflect two faulting events, consistent with stratigraphic evidence for two events from the nearby Skinner Peaks trench (figure 1; Jackson, 1991). These data seem to provide evidence for partial segment rupture during the most recent faulting event (MRE); the MRE appears to have ruptured the segment north of the Skinner Peaks trench site, overlapping older scarps preserved to the south.

A few radiocarbon and thermoluminescence ages obtained by others (Crone, 1983; Schwartz and Coppersmith, 1984; Jackson, 1991) from faulted fan alluvium provide maximum limits for the age of the MRE, and indicate the MRE may have occurred around 1000 yr B.P. We obtained a bulk-soil sample from a buried A horizon directly beneath the MRE colluvial wedge, exposed in a stream cut at Deep Creek (figure 1), to obtain a radiocarbon age to compare with the 1000 yr B.P. thermoluminescence age obtained by Jackson (1991) from the same soil. The new age results are pending.

Earthquake-Induced Landslide Investigations

This study focuses primarily on the recognition of possible earthquake-induced landslides in the Salt Lake City metropolitan area taking advantage of ongoing efforts by the Utah Geological Survey to inventory landslides in Salt Lake County and landslide investigations being conducted by geologic consultants. We investigated four landslide areas as part of this study:

1. the Grandview Peak rock slide in upper City Creek Canyon, Salt Lake County,
2. the Baskin Spring landslide in North Salt Lake City and Bountiful,
3. the Little Valley-Red Rock landslide in Draper, and
4. shallow, disrupted landslides in and near Steep Mountain in Draper.

Our reconnaissance of the Grandview Peak rock slide revealed similarities to the Madison Slide caused by the 1959 Hebgen Lake earthquake, including topographic setting, geomorphic and geologic characteristics, and volume. We speculate the

Grandview Peak rock slide is a candidate for a catastrophic earthquake-induced landslide, and with detailed study could provide an understanding of the hazard from catastrophic failure elsewhere in the Wasatch Range. We are assessing the feasibility of dating the landslide and correlating it with a documented large earthquake on the nearby Wasatch fault zone. Slide debris blocks City Creek and three other tributary streams, resulting in temporary ponds. Radiocarbon dating of the lowermost pond sediments, buried soils beneath the pond sediments, or buried tree stumps preserved in the pond sediments would likely provide the approximate age of the slide. Cosmogenic dating of slide debris and exposed rock in the main scarp may be the most feasible method to date the failure. Numerous limestone and quartzite boulders are at the ground surface in areas that are unlikely to have been significantly eroded since the failure. In addition, a steep main scarp exposes fractured limestone and quartzite. However, a talus slope at the base of the main scarp suggests possible main scarp retreat since the initial failure.

The Baskin Spring landslide, a large prehistoric slide on the northern flank of the Salt Lake salient, is an area of ongoing residential development. The landslide has an overall slope of 16 percent or less. Based on the low overall slope angle and the landslide's location at the southern termination of the Weber segment of the Wasatch fault zone, the slide may have been reactivated or possibly initially triggered by large prehistoric earthquakes. We conducted a preliminary slope-stability analysis of this low-angle landslide following the methods of Jibson (1996) to determine if the possibility of aseismic failure could be eliminated. Our initial results do not preclude aseismic failure, but identify a strong susceptibility to seismic failure, partly because of the inferred low-angle basal shear surface.

The Little Valley-Red Rock landslide in Draper is the largest landslide in southern Salt Lake County. Two rotational landslide blocks exist: one in the head and one along the east flank of the slide. Each is characterized by a back-tilted surface partly buried by pond deposits. Tilted and faulted sediments in a graben at the head of the landslide date older than 29 ka (conventional radiocarbon age), suggesting initial landslide movement predates Lake Bonneville. An antithetic (landslide-related) fault that bounds the downslope edge of sag pond sediments offsets organic silt (loess and/or pond sediments) and forms a colluvial wedge that dates at about 4,700 cal B.P. (4,555-4,860 cal B.P.). The age of this movement episode predates by about 600 years the estimated mean age of a documented mid-Holocene large earthquake on the Salt Lake City segment of the Wasatch fault zone estimated to have occurred shortly after 5,300 cal B.P. (Black and others, 1996), but could be contemporaneous if the uncertainty in the age estimates is considered.

Whereas shallow disrupted landslides are commonly triggered by large earthquakes (Harp and Jibson, 1996), these types of landslides have not been recognized in the Wasatch Front, despite that the most recent events on the Wasatch fault zone in the Salt Lake City metropolitan area are as young as 500 to 1,350 cal B.P. We evaluated the possibility that the Draper Heights landslide, a post-Lake Bonneville slide that occurred on the steep north slope of Steep Mountain in Draper, is an earthquake-triggered shallow disrupted soil slide. Our analysis suggests that triggering could have occurred from ground shaking less than would be anticipated from a scenario characteristic surface-faulting earthquake on the Wasatch fault zone. We mapped other nearby scars in colluvial slopes as possible shallow disrupted landslides and believe an earthquake origin is consistent with the earthquake-induced landslide potential zonation of Keaton and others (1987) for the area.

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NON-TECHNICAL SUMMARY

The UGS, in cooperation with the USGS and university/private sector personnel, established working groups to build consensus and develop plans for the next generation of earthquake-hazards maps in Utah. Working groups defined data needs and established partnerships to produce new ground shaking, liquefaction, and earthquake-induced landslide hazard maps. In support of this effort, the UGS compiled databases needed to produce the maps. We extended the surficial geologic mapping of the Wasatch fault to the south to include the Levan segment in central Utah. We performed geologic studies of several important landslides in the Salt Lake County area to help determine whether movement was likely earthquake induced.

REPORTS PUBLISHED

All working group earthquake-hazard-mapping plans are posted at the UGS website (geology.utah.gov). We plan to have the Levan segment surficial geology map available as a UGS Open-File Report by December 31, 2003. Results of all studies will be presented at a February 26, 2004, earthquake conference in Salt Lake City.

AVAILABILITY OF DATA

The shallow shear-wave-velocity, deep-basin-structure, and geotechnical landslide shear-strength databases (HTML Image Mapper®, version 3.0) are available from Greg McDonald, 801-537-3383, email gregmcdonald@utah.gov.