RECONNAISSANCE OF THE GRANDVIEW PEAK ROCK SLIDE, SALT LAKE COUNTY, UTAH: A POSSIBLE EARTHQUAKE-INDUCED LANDSLIDE?

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Francis X. Ashland and Greg N. McDonald

OPEN-FILE REPORT 518
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
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Cover photo: Upper part of the Grandview Peak rock slide.

Research supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award number 03HQAG0008. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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ABSTRACT

Earthquake-induced landslides, with the exception of liquefaction-induced lateral spreads, have not been recognized in the Salt Lake City metropolitan area. Based on the inferences of previous researchers that some prehistoric, catastrophic rock slides in the Wasatch Front may have been triggered by earthquakes, we evaluated the feasibility of determining the timing of the Grandview Peak rock slide in upper City Creek Canyon northeast of Salt Lake City and correlating it with a documented surface-faulting earthquake. Recognition of the seismic origin of the landslide would provide a model for characterizing the earthquake-induced catastrophic rock slide hazard elsewhere in the Wasatch Range and provide guidance for future earthquake-induced landslide studies. Our reconnaissance revealed similarities to the Madison Slide triggered by the 1959 Hebgen Lake earthquake, suggesting the rock slide may be a candidate for an earthquake-induced landslide.

Radiocarbon dating of buried trees and paleosols, or organic-rich sediments at the base of ponds that formed upstream of the rock slide deposit where it blocked City Creek and three tributary drainages, may constrain the timing of the landslide, but is considered impractical given the probable depths of the ponds and the setting of the landslide. Cosmogenic dating of quartzite and limestone boulders on the surface of the rock slide deposit or of exposed Paleozoic rock in the main scarp or on the slide surface appear the most practical approach to determining the timing of the landslide.

INTRODUCTION

Van Horn and Crittenden (1987) mapped a large rock-slide deposit (figures 1, 2, and 3) in the upper part of City Creek Canyon that was described previously by Van Horn and others (1972). The rock slide formed due to the failure of a southeast-trending spur of Grandview Peak, and thus is referred to in this report as the Grandview Peak rock slide. Previous researchers (Pashley and Wiggins, 1972; Cardoso, 2002) inferred a possible earthquake origin for other large rock slides on the slopes of the Wasatch Range in the Ogden area. This reconnaissance study of the Grandview Peak rock slide assessed the feasibility of determining the timing of the slide and possibly identifying it as an earthquake-induced landslide. Future detailed study may provide an understanding of the hazard from catastrophic rock slides elsewhere in the Wasatch Range.

LANDSLIDE DESCRIPTION AND GEOLOGY

Van Horn and Crittenden (1987) mapped the Grandview Peak rock slide as a large, irregularly shaped deposit that measures about 1.2 miles (1.9 km) along the main City Creek drainage and about 0.7 miles (1.1 km) between the base of the main scarp and runup on the opposite canyon wall (figure 3). The main scarp of the rock slide faces southeast and is about 1400 feet (427 m) wide and about 395 feet (120 m) high. Part of the main scarp is buried by talus.

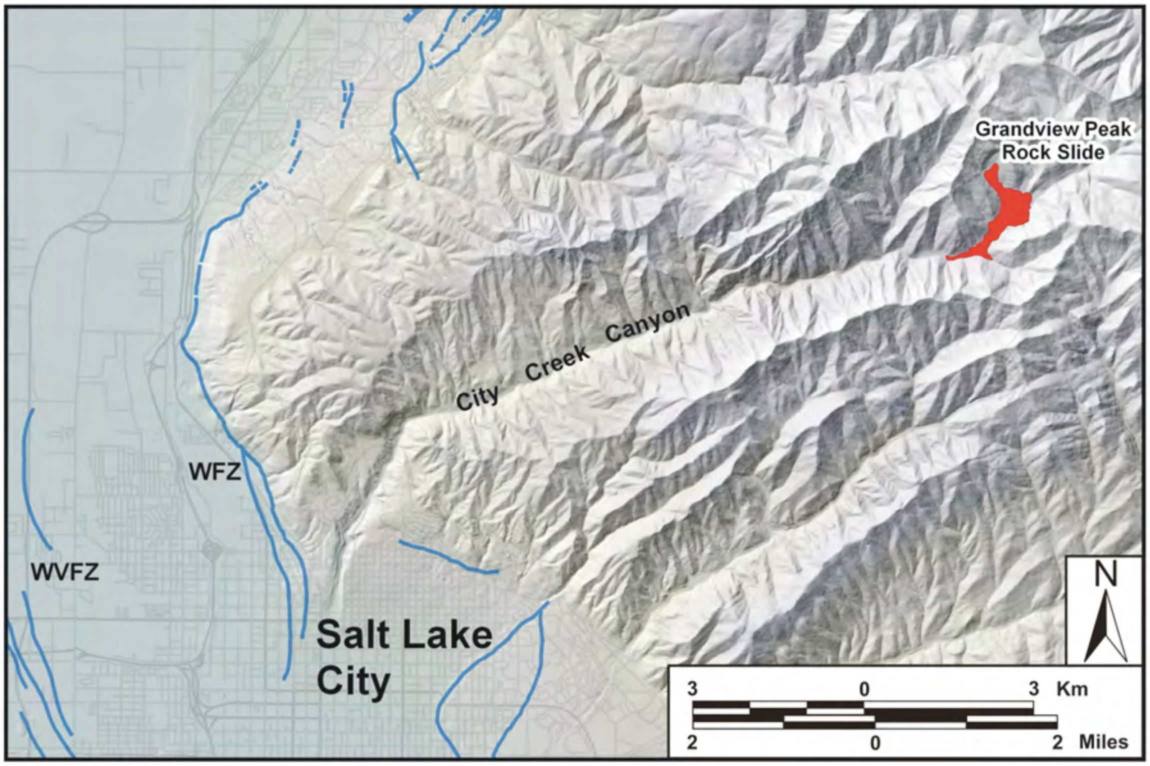

Figure 1. *Location of the Grandview Peak rock slide near Salt Lake City. Blue lines are traces of active faults. Fault traces from Black and others (2003). Abbreviations: WFZ – Wasatch fault zone, WVFZ – West Valley fault zone.*

Van Horn and others (1972) described the Grandview Peak rock slide as a possible rock-fall avalanche. However, based on an interpretation by Van Horn and others (1972) that the landslide failed initially along a moderately dipping bedding plane, the slide is more accurately described as an extremely rapid rock slide using the terminology of Cruden and Varnes (1996). Slide debris traveled southeastward from the source area and blocked City Creek and an unnamed tributary drainage north of City Creek (figures 3 and 4). Debris also traveled down City Creek Canyon about 1 mile (1.6 km) from the main body of the slide, blocking two other tributaries.

Van Horn and Crittenden (1987) mapped the Grandview Peak rock slide as being solely in the Pennsylvanian-Permian Weber Quartzite. The formation consists of fine- to medium-grained, cross-bedded quartzite and medium-gray to pale-gray limestone (Van Horn and Crittenden, 1987). Our reconnaissance confirmed that rock-slide debris consists of these two rock types. In upper City Creek Canyon, the Weber Quartzite is apparently thickened as a result of folding and fault repetition. Van Horn and Crittenden (1987) mapped a plunging syncline intersecting the source area of the rock slide; however, bedding attitudes on their map do not unequivocally support this structural interpretation (see also the geologic mapping of Montgomery and Everitt [1983]). Based on our review of aerial photographs of the area and the structural information on Van Horn and Crittenden's (1987) map, bedding in the Weber Quartzite directly upslope of

Figure 2. *View to the north of the upper part of the Grandview Peak rock slide. Southeast-facing main scarp visible in background exposes fractured Pennsylvanian-Permian Weber Quartzite. Talus buries the lower part of the main scarp. Rock-slide debris occupies most of the right edge (right of saddle in front of talus slope) and lower foreground of the photograph. Note boulder-debris field along the north flank of the rock slide (lower central part of the photograph). Aspen-covered, southeast-facing slope left of the rock slide is a relatively shallow colluvial debris slide (DS). An aspen-Douglas fir forest occupies the rock-slide deposit and adjacent slopes.*

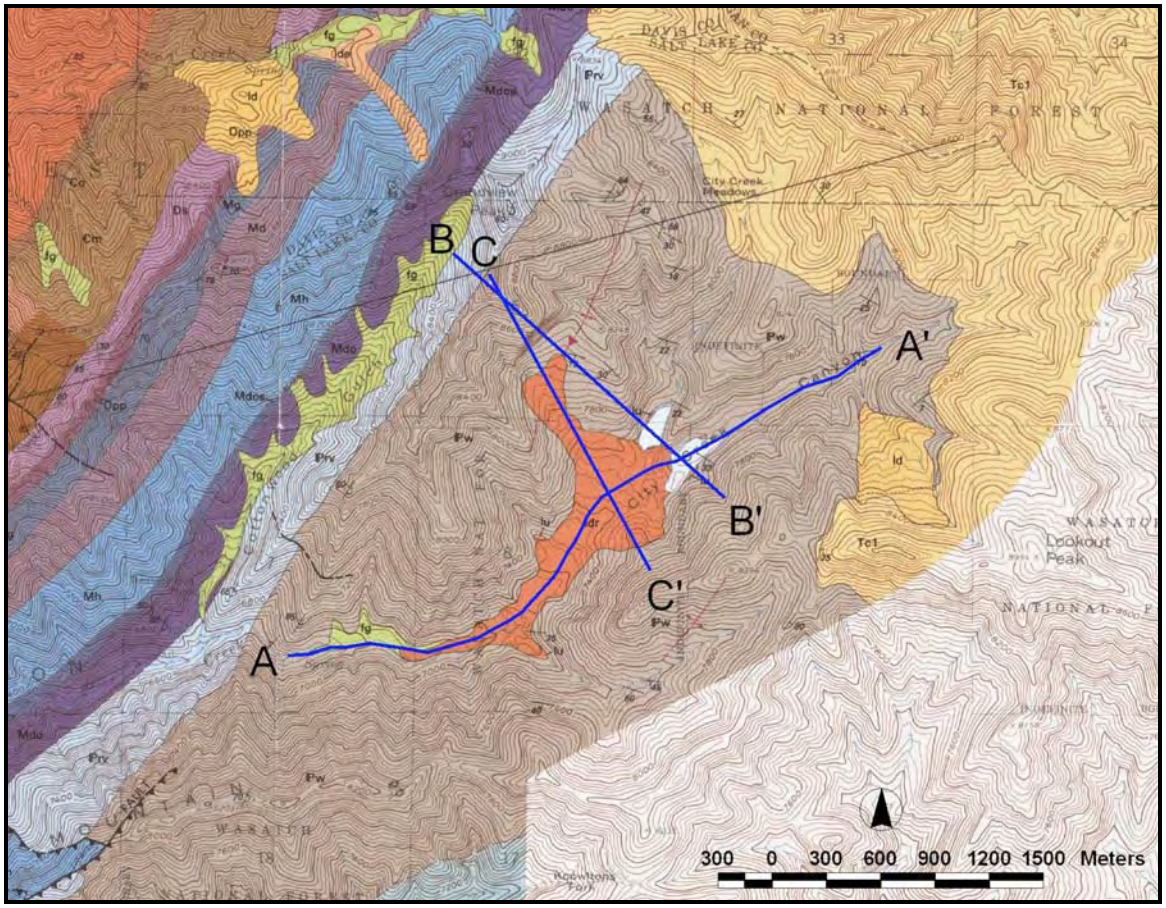

Figure 3. *Geologic map and locations of profiles (shown on figure 4) of the Grandview Peak rock slide. Geologic map from Van Horn and Crittenden (1987). Grandview Peak area map units: ldr – Grandview Peak rock-slide deposit, lu – pond sediments upstream of rock slide, fg - alluvial-fan gravel, IPw –Pennsylvanian-Permian Weber Quartzite.*

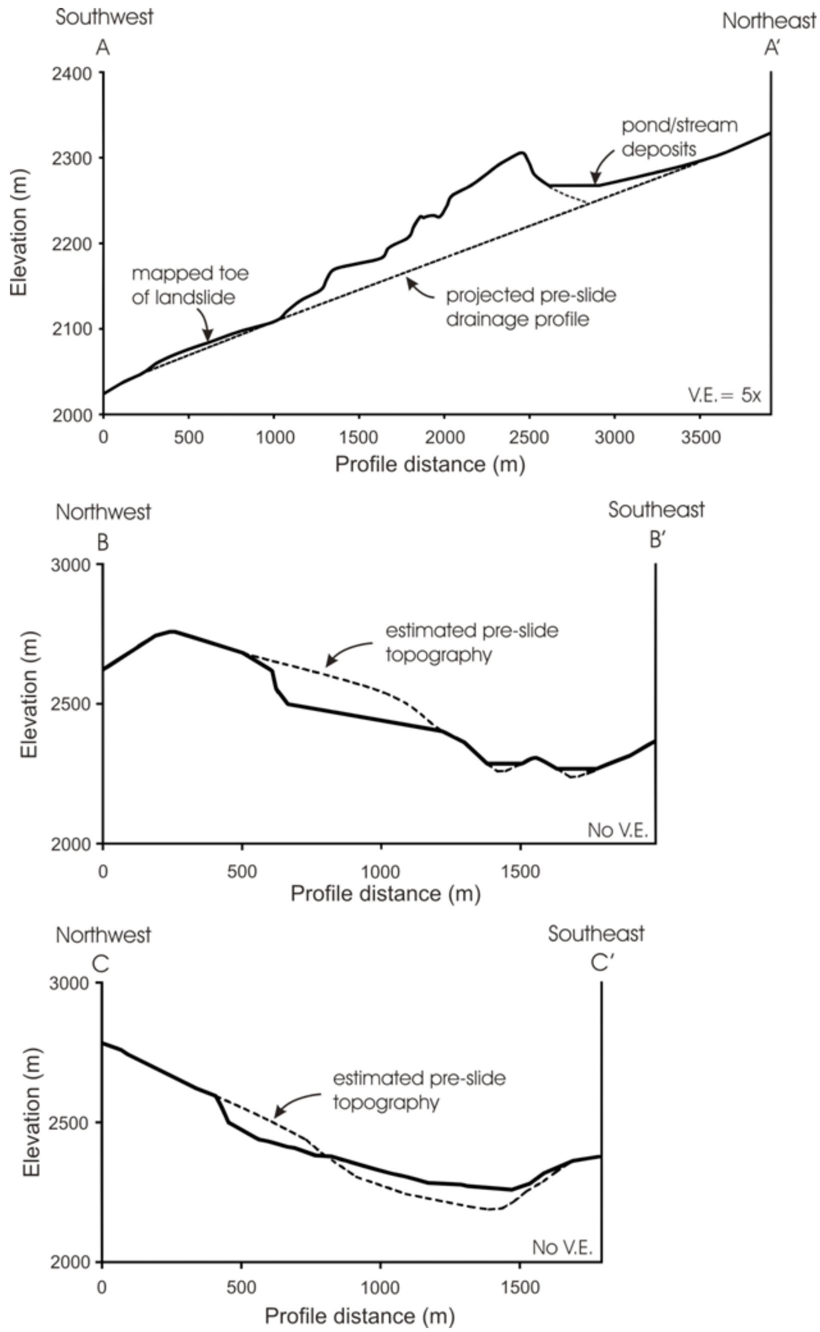

Figure 4*. Topographic profiles of the Grandview Peak rock slide. See figure 3 for profile line locations. Profile A-A' follows the City Creek drainage and shows the upstream and downstream profiles, the approximate height of the deposit, and depth of upstream pond sediments in the main City Creek drainage. Profile B-B' is perpendicular to the main scarp and shows the estimated pre-slide topography and the elevation differences between the two upstream pond areas. Profile C-C' follows the axis of the northwest arm of the rock-slide deposit.*

the main scarp appears to strike northeast and dip steeply. Thus, the main scarp may have broken along bedding and sliding occurred along another type of discontinuity such as a shallow-dipping fault or joint. However, we did not investigate the source area as part of our field reconnaissance.

SIMILARITIES TO THE HISTORICAL EARTHQUAKE-INDUCED MADISON SLIDE

Our reconnaissance of the Grandview Peak rock slide revealed similarities to the Madison Slide in southwestern Montana (Hadley, 1964) triggered by the 1959 magnitude 7.5 Hebgen Lake earthquake, including topographic setting, local relief, landslide area, and rock-mass condition (table 1). In addition, both slides formed landslide dams. These similarities, although possibly coincidental, are noted as a basis of comparison of the Grandview Peak rock slide with a landslide known to be triggered by an earthquake. Both slides occurred in narrow and steep-walled canyons. The pre-existing local relief of the Grandview Peak rock slide is estimated to be nearly identical to that of the Madison Slide, about 1350 feet (412 m). Whereas the rock types differ in the two slides (the Madison Slide occurred in Precambrian dolomite, schist, and gneiss, and the Grandview Peak rock slide occurred in Pennsylvanian-Permian quartzite and limestone), some similarities exist in the overall rock-mass condition such as the fractured nature of the rock. Hadley (1964) described the role of a shear zone in controlling the upper extent of the Madison Slide. In the Grandview Peak rock slide, the main scarp appears to have broken along a steeply dipping bedding discontinuity.

Table 1. *Comparison of the Grandview Peak rock slide and Madison Slide (Madison Slide data from Hadley [1964]).*

	Grandview Peak rock slide	**Madison Slide**
Local relief	1350 ft (412 m)	1335 ft (407 m)
Area	148 acres (60 ha)	131 acres (53 ha)
Head width	1410 ft (427 m)	2200 ft (671 m)
Maximum depth of deposit	290 ft (88 m)	220 ft (67 m)

FEASIBILITY OF DETERMINING THE TIMING OF THE ROCK SLIDE

We assessed the feasibility of determining the timing of the rock slide and correlating it with a documented large earthquake on the nearby Wasatch fault zone. The overall geomorphic expression of the rock slide suggests movement in the latest Pleistocene or Holocene. Dating methods considered include cosmogenic and radiocarbon dating, and dendrochronology.

Cosmogenic Dating

Cosmogenic dating of slide debris and exposed rock in the main scarp and on the slide surface may be the most feasible method to determine the rock-slide timing (see Zreda, 2003). Both ^{3}He and ^{36}Cl methods are applicable to the quartzite and limestone rock types in the slide. Numerous boulders locally cover the ground surface including areas that are unlikely to have been significantly eroded since the rock slide occurred (figure 5). In addition, a steep main scarp exposes fractured limestone and quartzite (figure 5c). However, the talus slope at the base of the main scarp suggests main-scarp retreat since the initial rock slide, indicating that dating of the scarp face or talus may yield an age younger than the slide event. A part of the slide surface exposed downslope of the talus is likely the best site for cosmogenic dating.

Radiocarbon Dating

Slide debris blocked City Creek and three other tributary forks resulting in temporary ponds (figure 6). Radiocarbon dating of the lowermost pond sediments, buried soils (paleosols) beneath the pond sediments, or buried stumps of trees predating the landslide and preserved in the pond sediments would likely provide limits on the timing of the rock slide. However, topographic profiles across the two ponds upstream of the landslide (profiles A-A' and B-B' in figure 4) suggest the pond sediments may exceed tens of meters in depth, requiring a drill rig to reach their base. We evaluated the nature of the shallow sediments in the two upstream pond areas by a combination of hand-excavated test pits and hand-auger holes. Figure 7 shows the logs of the two shallow explorations that reached depths of about 6.5 feet (2 m) in the northern (tributary drainage) pond and 8.2 feet (2.5 m) in the southern (main City Creek drainage) pond. In general, the shallow sediments appeared to contain adequate organic content to obtain a bulk radiocarbon age. However, dating of the uppermost pond sediments would poorly constrain the timing of the rock slide unless sedimentation in the pond areas was relatively rapid following the slide. In such a case, the difference between the age of the uppermost sediments and the timing of the slide could be small. However, we believe sedimentation rates have been slow, so a more accurate age estimate of the rock slide would be obtained by dating either the lowermost pond sediments or underlying paleosols.

The backcountry setting of the rock slide, accessed only by a narrow hiking trail, and its location in a protected watershed, make drilling impractical. The base of pond sediments in the northern of two downstream tributaries blocked by debris is likely shallower than in the upstream ponds. Reaching the lowermost pond sediments or underlying paleosols in this area may be feasible using a hand auger or by excavating test pits by hand.

Figure 5. *Possible opportunities for cosmogenic dating of the Grandview Peak rock slide. (A) Large boulder field along north flank of deposit. (B) Cluster of cobbles and boulders on central part of deposit. (C) Main scarp of rock slide and post-slide talus.*

Figure 6. *Possible opportunities for radiocarbon dating of the Grandview Peak rock slide. (A) Pond sediments in northern fork upstream of deposit (edge of deposit visible along the right edge of the photograph). Low ridge in background separates pond from lower (southern) pond in main City Creek drainage (shown in B). (B) Pond sediments in main City Creek drainage upstream of deposit. View is from spillway notch in ridge dividing the northern and southern ponds. (C) Pond sediments and alluvium (?) in northern tributary drainage downstream of rock slide source area. Base of the pond sediments is likely shallower than in either of the upstream pond areas. Specific targets for radiocarbon dating in the pond areas include buried soil developed on the valley fill/slope sediments beneath the pond sediments, the lowermost organic-rich pond sediments (unit lu on figure 3 from Van Horn and Crittenden, 1987), and buried trees preserved in the pond sediments.*

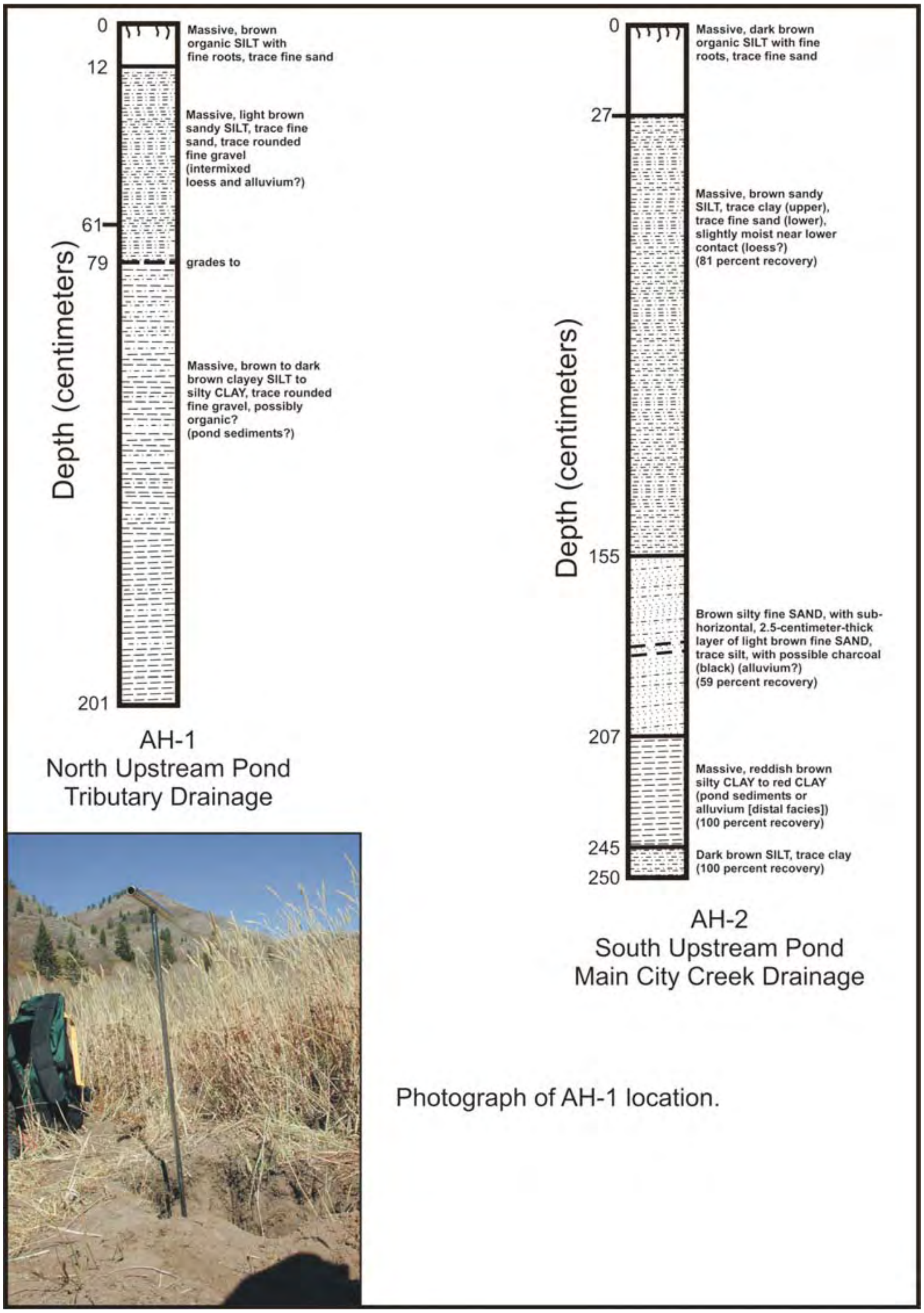

Figure 7. *Logs of composite test pits and auger holes in upstream ponds. Hand-excavated test pits extend to depths of 61 and 27 centimeters in AH-1 and AH-2 respectively. Exploration continued with hand auger below those depths.*

Dendrochronology

Our observations suggest limited opportunities for using either living or toppled (by the slide) trees to constrain the timing of the rock slide. The slide is currently covered by an aspen-Douglas fir forest. The largest observed trunks of living Douglas firs on the landslide reach a diameter of 27 inches (69 cm). However, we observed no obvious difference between the trunk diameters of trees on or off the slide, suggesting the age of the forest is related to a natural event younger than the slide such as a forest fire (i.e., the existing live trees are not first-generation growth subsequent to the slide).

Nevertheless, tree-ring dating of the largest living trees on the rock slide using an increment borer could provide a minimum limit on the timing of the slide that could be of some use in correlating the slide with a documented earthquake on the Wasatch fault zone. The oldest known Douglas fir is about 1300 years old (Rocky Mountain Tree-Ring Research, 2003) while one of the oldest known Douglas firs in the Rocky Mountains is an 820-year-old tree in Colorado. Since the observed Douglas firs on the rock slide are unlikely to be this old, a tree-ring age from one of the largest trees on the rock slide would probably not be useful in correlating the event to a surface-faulting earthquake unless the slide was triggered by one of the most recent events on the Wasatch fault zone, specifically Weber segment events dated at 200 to 800 cal yr B.P. and 500 to 1400 cal yr. B.P. (Lund, 2005). Use of a minimum tree-ring age to correlate the rock slide to the latter earthquake would not be possible unless the earthquake occurred in the younger part of the estimated earthquake age range. In addition, the sole use of a minimum date to correlate the Grandview Peak rock slide to one of the youngest Wasatch fault zone events is insufficient because an older age of the slide cannot be precluded.

Photographs of the Madison Slide (Hadley, 1964) show toppled trees covering areas of the slide debris. However, rare dead Douglas fir trunk fragments on the ground surface of the Grandview Peak rock slide are likely associated with the modern forest and, in our opinion, do not represent trees toppled by the slide debris.

DISCUSSION

The possibility that the Grandview Peak rock slide is an earthquake-induced catastrophic event, although a rare occurrence, has implications for understanding this type of hazard in the canyons and mountain front areas of the Wasatch Range. Additionally, the recognition of an earthquake-induced rock slide in the Wasatch Range may provide the impetus for continuation of seismic rock-slope-stability studies such as that of Harp and Noble (1993) to define where future earthquake-induced rock slides and falls are most likely to occur. Presently, the Madison Slide is the characteristic landslide triggered in mountainous terrain by a major Basin and Range earthquake. However, given the similarities of the Wasatch Range to other ranges including that at the Madison Slide, earthquake-induced catastrophic rock slides are likely part of the geologic record and pose a hazard in and near the Wasatch Range. In the Wasatch Front, Pashley and Wiggins (1972) identified at least three other prehistoric rock slides, which they inferred could have been triggered by major earthquakes. At least two of these would have devastated major urban areas if they occurred today. The youngest of these is the North Ogden rock slide, inferred to have occurred in the latest Pleistocene by Nelson and Personius (1993) (predating the surface-faulting chronology of the Weber segment of the Wasatch fault zone [Lund, 2005]). Presently, no data preclude the possibility that the Grandview Peak rock slide occurred within the time period bracketing the chronology of the two nearest segments (Weber and Salt Lake City) of the Wasatch fault zone. Thus, the rock slide is the best candidate for determining whether catastrophic rock slides may occur in surface-faulting earthquakes in the Wasatch Front. However, constraints on the timing of the earthquakes must also be improved to make reliable correlations with the landslide.

SUMMARY

Our preliminary evaluation of the Grandview Peak rock slide reveals similarities to the earthquake-triggered Madison Slide in southwestern Montana. Whereas these similarities alone do not indicate an earthquake triggered the rock slide, they provide justification, in our opinion, for further evaluation of the possibility that the Grandview Peak rock slide is an earthquake-induced catastrophic landslide that may help characterize the hazard elsewhere in the Wasatch Range. Our assessment of the feasibility of determining the timing of the rock slide suggests that cosmogenic dating of exposed slide plane and boulder debris may be the most cost-effective method of obtaining a timing estimate. Radiocarbon dating of the lowermost pond sediments deposited adjacent to the deposit or underlying paleosols would provide the most accurate timing estimate of the slide, but obtaining samples of these soils may be costly and impractical given their probable depths and the setting of the slide.

ACKNOWLEDGMENTS

This study was funded through a cooperative agreement between the Utah Geological Survey (UGS) and U.S. Geological Survey (USGS) (National Earthquake Hazards Reduction Program contract no. 03HQAG0008). Ben Everitt, formerly with the Utah Division of Water Resources, shared his knowledge on the Grandview Peak rock slide. We appreciate helpful reviews of the manuscript by Gary Christenson, Michael Hylland, and Kimm Harty (UGS).

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