Black, Lund, Schwartz, Gill, Mayes

PALEOSEISMIC INVESTIGATION, SALT LAKE CITY SEGMENT, WFZ, SALT LAKE COUNTY, UTAH

UGS Special Study 92

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
Bill D. Black, William R. Lund, David P. Schwartz, Harold E. Gill, and Bea H. Mayes

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UTAH GEOLOGICAL SURVEY
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FOREWORD

This Utah Geological Survey Special Study, *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*, is the seventh report in the *Paleoseismology of Utah* series. This series makes the results of paleoseismic investigations in Utah available to geoscientists, engineers, planners, public officials, and the general public. These studies provide critical information on earthquake timing, recurrence, displacement, slip rate, and fault geometry which can be used to characterize potential seismic sources and evaluate the long-term earthquake hazard presented by Utah's Quaternary faults.

The South Fork Dry Creek and Dry Gulch sites lie within a few hundred meters of each other in the southeastern part of the Salt Lake Valley, and together provide the only location on the heavily urbanized Salt Lake City segment of the Wasatch fault zone where it is possible to develop a complete surface-faulting chronology for the segment since middle Holocene time (the past 6,000 years). Investigations at the two sites took place intermittently between 1985 and 1995 as permission was obtained to trench more and more of the scarps within the broad fault zone. The new information reported here on the size, timing, and especially recurrence of surface-faulting earthquakes on the Salt Lake City segment shows that the earthquake hazard presented by this segment of the Wasatch fault is greater than previously thought. Such information is vital to public officials, planners, and others making decisions regarding earthquake-hazard mitigation.

William R. Lund, Series Editor
Utah Geological Survey

Other reports in the *Paleoseismology of Utah* series

Special Study 75. 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, 41 p., 1991

Special Study 76. 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

Special Study 78. 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

Special Study 82. Paleoseismology of Utah Volume 4: Seismotectonics of north-central Utah and southwestern Wyoming, by Michael W. West, 93 p., 5 pl., 1:100,000, 1994

Special Study 83. Paleoseismology of Utah Volume 5: Neotectonic deformation along the East Cache fault zone, Cache County, Utah by J.P. McCalpin, 37 p., 1994

Special Study 88. 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

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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
Bill D. Black[1], William R. Lund[1], David P. Schwartz[2], Harold E. Gill[3], and Bea H. Mayes[1]

ABSTRACT

The Wasatch fault zone (WFZ) is one of the longest and most active normal-slip faults in the world. The fault trends through the densely populated Salt Lake City metropolitan area and is a potential source for large earthquakes that pose a significant seismic hazard. Previous paleoseismic studies at two sites (Little Cottonwood Canyon and South Fork Dry Creek) on the Salt Lake City (SLC) segment of the WFZ showed that at least three large-magnitude surface-faulting earthquakes occurred in Holocene time (past 10,000 years), including two earthquakes in the past 6,000 years. Timing for these earthquakes suggested the average recurrence interval of surface faulting on the SLC segment was 4,000 ± 1,000 years. However, not all of the fault scarps at either site were trenched. A subsequent study at Dry Gulch discovered a previously unrecognized surface-faulting earthquake on an untrenched scarp at the nearby South Fork Dry Creek (SFDC) site, which reduced the average recurrence interval to 2,400 ± 500 years in the past 10,000 years and 2,150 ± 400 years in the past 6,000 years.

To develop a comprehensive Holocene chronology of surface-faulting earthquakes on the SLC segment, the Utah Geological Survey reoccupied the SFDC site to complete the investigation started there in 1985. We excavated five trenches across fault scarps at this site. When combined with the 1985 study, all fault scarps at SFDC are now trenched. Radiocarbon age analyses of buried soils and organic-rich sediment in two trenches on different scarps show that a previously unrecognized surface-faulting earthquake occurred about 3,950 years ago. These new data, combined with evidence from the previous studies, show that four surface-faulting earthquakes (rather than three) occurred on the SLC segment in the past 6,000 years: (1) a most recent event shortly after 1,300 (+250, -200) cal B.P., (2) a second event shortly after 2,450 ± 350 cal B.P., (3) a third event shortly after 3,950 (+550, -450) cal B.P., and (4) a fourth event shortly after 5,300 (+450, -350) cal B.P. The newly discovered earthquake reduces the average recurrence of surface faulting on the SLC segment in the past 6,000 years from 2,150 ± 400 years to 1,350 ± 200 years.

INTRODUCTION

This report summarizes the results of a cooperative project between the Utah Geological Survey (UGS) and the U.S. Geological Survey (USGS), National Earthquake Hazards Reduction Program (contract no. 1434-94-G-2495), to investigate Holocene activity on the Salt Lake City (SLC) segment of the Wasatch fault zone (WFZ). The SLC segment trends through the densely populated Salt Lake Valley and poses a significant earthquake risk to citizens living in the Salt Lake City metropolitan area. The WFZ is a normal-slip fault that extends for 343 kilometers (213 mi) along the western base of the Wasatch Range from southeastern Idaho to north-central Utah (Machette and others, 1992). The WFZ is near the center of the Intermountain seismic belt (Smith and Sbar, 1974; Smith and Arabasz, 1991), a north-south-trending zone of historical seismicity that extends from northern Arizona to central Montana (figure 1). Schwartz and Coppersmith (1984)

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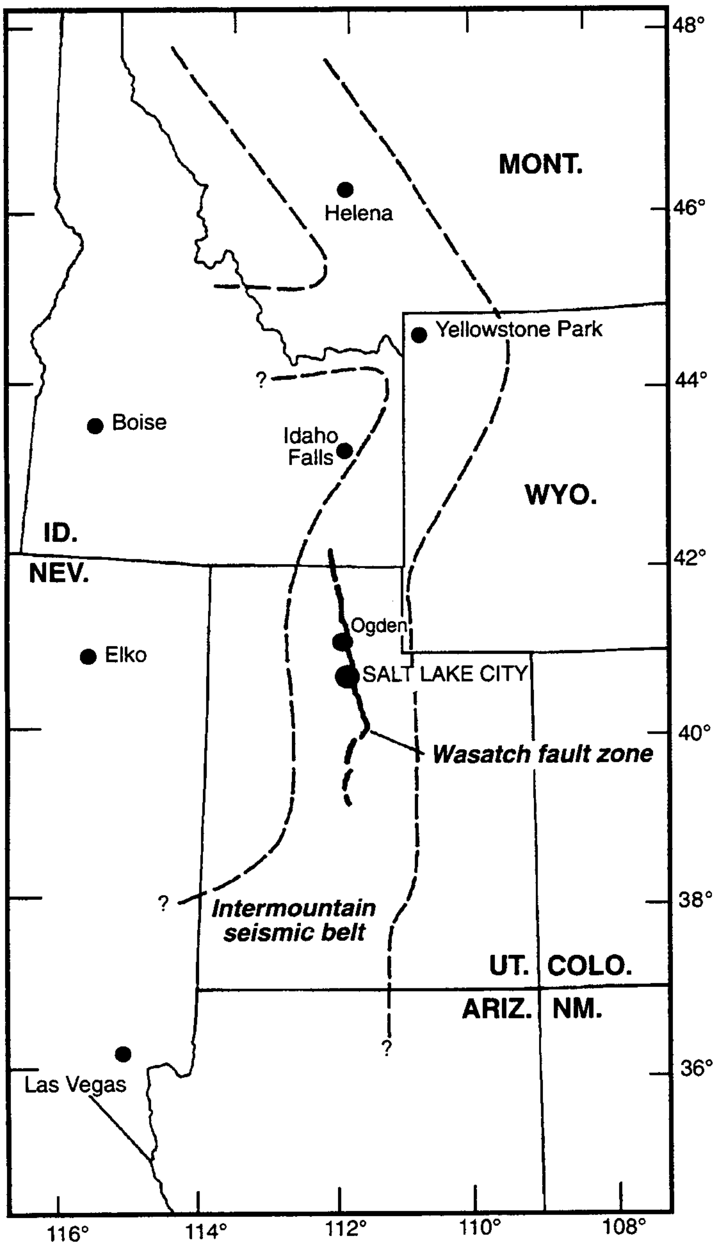


Figure 1. Location of the Wasatch fault zone with respect to the Intermountain seismic belt (modified from Arabasz and others, 1992).

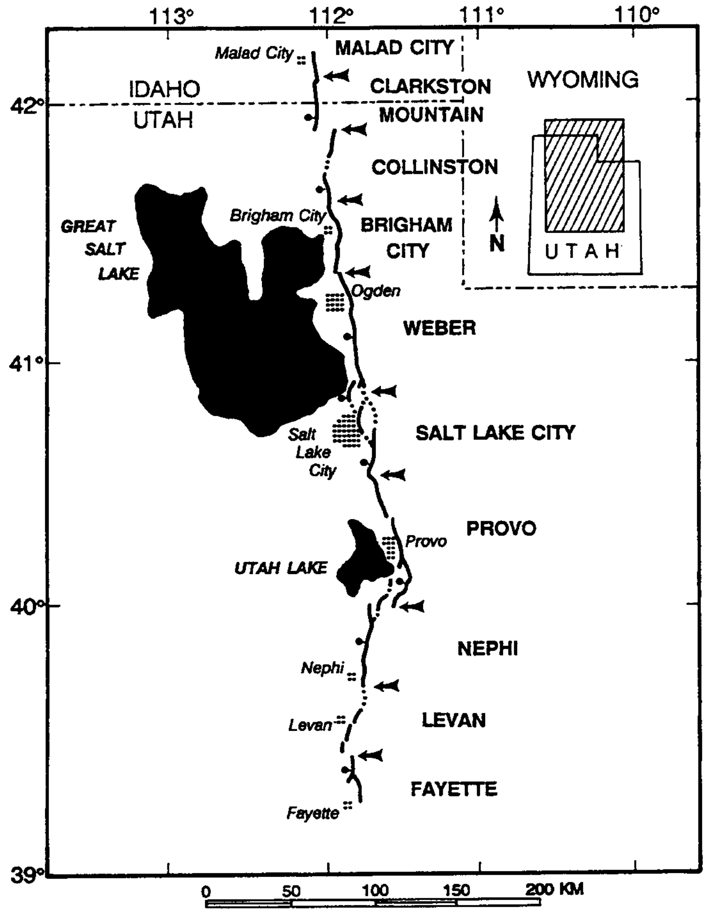


Figure 2. Segments of the Wasatch fault zone (modified from Machette and others, 1992).

originally divided the WFZ into six independent, seismogenic segments based on scarp morphology, surface-fault-rupture patterns, range-crest morphology, geophysical evidence, and limited trenching information. Based on additional detailed trenching studies and geologic mapping (1:50,000 scale), Machette and others (1992) proposed a revised segmentation scheme consisting of 10 segments (figure 2). Five of the fault segments (Brigham City through Nephi, figure 2) generated two or more surface-faulting earthquakes in the past 6,000 years.

Displacement in unconsolidated deposits from a surface-faulting earthquake on a normal fault (such as the WFZ) produces a vertical scarp that erodes rapidly and deposits material at the scarp base. Although Wallace (1977) recognized deposits produced by fault-scarp erosion, Swan and others (1980) first described the sequence of erosion and deposition. Erosion of the scarp forms a wedge-shaped deposit of colluvium (colluvial wedge) at the scarp base, burying soil horizons forming at the ground surface prior to the earthquake. Eventually, the scarp erodes to a stable slope on which soil development continues. Each subsequent surface-faulting earthquake forms another colluvial wedge stacked on the older wedge and buried soil horizon (paleosol). Earthquake timing can be constrained by radiocarbon dating of organic material in these wedges and paleosols, and paleoseismic studies along the WFZ used this technique to define the timing of past surface-faulting earthquakes (for example, Swan and others, 1981; Schwartz and Coppersmith, 1984; Lund and Schwartz, 1987; Lund and others, 1991; Personius, 1991; Lund, 1992).

The Holocene chronology of surface-faulting earthquakes on the SLC segment has been the subject of paleoseismic studies for more than a decade (Swan and others, 1981; Lund and Schwartz, 1987; Schwartz and Lund, 1988; Lund, 1992). The earthquake chronology was initially based on paleoseismic investigations at Little Cottonwood Canyon (LCC) in 1979 and South Fork Dry Creek (SFDC) in 1985. However, not all of the fault scarps at either location were trenched. A subsequent study at Dry Gulch (DG) in 1991 discovered a previously unrecognized event on a scarp not trenched at the SFDC site, which indicated the surface-faulting chronology was incomplete. Because questions remained regarding timing and recurrence of surface-faulting earthquakes on the densely populated SLC segment, we reoccupied the SFDC site in 1994 to complete the 1985 investigation. The intent of the new investigation was to establish a complete surface-faulting earthquake chronology from at least the middle Holocene for the SLC segment, thus eliminating the uncertainty caused by the scattered and incomplete nature of the available data. Results of this study provide more accurate information on which to base critical land-use decisions and manage risk.

PREVIOUS STUDIES ON THE SALT LAKE CITY SEGMENT

The first paleoseismic investigation of the SLC segment of the WFZ was done in 1979 at the LCC site (figure 3) by Woodward-Clyde Consultants, under contract to the USGS (Swan and others, 1981). The WFZ at LCC is defined by a prominent west-facing main scarp that splays northward at the site into three sub-parallel branching scarps, and an east-facing antithetic scarp. Two trenches were excavated across the westernmost branching scarp north of the splay, and one trench was excavated across the antithetic fault (Swan and others, 1981). The remaining branching scarps north of the splay were not trenched due to landowner constraints. A fourth trench was excavated across the main scarp south of the splay, but did not expose the fault zone and was not logged (Swan and others, 1981).

The trenches at LCC exposed evidence for two surface-faulting earthquakes (Swan and others, 1981). Radiocarbon dating of detrital charcoal showed the older earthquake occurred shortly before 8,000 to 9,000 radiocarbon years ago. However, no material suitable for radiocarbon dating was found to constrain the timing of the younger event. Swan and others (1981) calculated a recurrence interval of 2,200 years at the LCC site, based on an average slip rate of 0.9 mm/yr (3.5×10^{-2} in/yr), and an average displacement per event of 2 meters (6.6 ft), based on scarp profiling and stratigraphic evidence exposed in the trenches.

The UGS, in cooperation with the USGS, conducted a paleoseismic investigation at the SFDC site (figure 3) in 1985 (Lund and Schwartz, 1987; Schwartz and Lund, 1988). The WFZ at SFDC consists of six sub-parallel, west-dipping main fault scarps (S-1 to S-6, figure 4), and a single east-dipping antithetic scarp (Personius and Scott, 1992). Four trenches were excavated across three of the main scarps (DC-1 to DC-4, figure 4), but not all of the scarps could be trenched due to landowner constraints. Two trenches on scarp S-1 (DC-1 and 2, figure 4) exposed two stacked colluvial wedges that document two middle- to late-Holocene surface-faulting earthquakes on the SLC segment. Radiocarbon age estimates from paleosols in trenches DC-1 and 2 indicated that the earthquakes occurred: (1) shortly after 1,100 to 1,800 years ago, and (2) shortly after 5,500 to 6,000 years ago. No samples suitable for radiocarbon dating were available in trenches across the remaining scarps. Based on this information, Schwartz and Lund (1988) estimated a recurrence interval of 3,000 to 5,000 years for the SLC segment. However, they acknowledged that the identification of two post-6,000 year events at the SFDC site (compared to only one post-8,000-9,000 year event at LCC) introduced uncertainty regarding the paleoseismic history of the SLC segment. They also cautioned that a true paleoseismic history for the SLC segment could only be developed if information is obtained for every scarp at a site.

The incomplete nature of the SLC segment's earthquake history was demonstrated in 1991, when a geotechnical consulting firm excavated a trench across the WFZ at the DG site (figure 3) a few hundred meters south of SFDC. Detailed geologic mapping by Personius and Scott (1992) shows the scarp at DG (S-5, figure 4) extends northward to SFDC. However, scarp S-5 was not trenched in 1985 at the SFDC site. The UGS was offered the opportunity to inspect the trench and found two stacked colluvial wedges (Lund, 1992). Radiocarbon dating of paleosols buried by the wedges indicated two surface-faulting earthquakes: (1) an event that occurred roughly 1,600 years ago, which coincided with timing for the most recent event (MRE) at SFDC; and (2) a new event that occurred shortly after 2,400 years ago, which did not correspond to any previously known event (Lund, 1992). This newly discovered event showed that there have been at least three (rather than two) surface-faulting earthquakes on the SLC segment in the past 6,000 years, and at least four events (rather than three) in the past 8,000-9,000 years (Lund, 1992). Resampling and retesting in 1992 (the trench remained open over the winter) confirmed the timing of the new event (Lund, 1992).

The additional event discovered at DG raised concern about possible inaccuracies or contamination of radiocarbon samples obtained from SFDC in 1985. Because of these concerns, the UGS re-excavated trench DC-1 (figure 4) in 1992. Two colluvial wedges observed in trench DC-1 were re-exposed, and paleosols buried by the wedges were resampled. The radiocarbon results confirmed the original results for the timing of the MRE and older event at the SFDC site.

SETTING AND GEOLOGY

The SLC segment of the WFZ extends for about 46 kilometers (29 mi) through the Salt Lake Valley from the Traverse Mountains on the south to the Salt Lake Salient on the north (figure 3). The SLC segment displays abundant geologic and geomorphic evidence for multiple surface-faulting earthquakes during Holocene time (Schwartz and Coppersmith, 1984). Although urbanization within the Salt Lake Valley has obscured or modified scarps in many places, relatively undisturbed scarps remain in the southeastern part of the valley where the SFDC site is located.

The SFDC site ranges from 1,575 to 1,660 meters (5,160-5,440 ft) in elevation, and lies just above the highest shoreline of Pleistocene Lake Bonneville (termed the Bonneville shore-

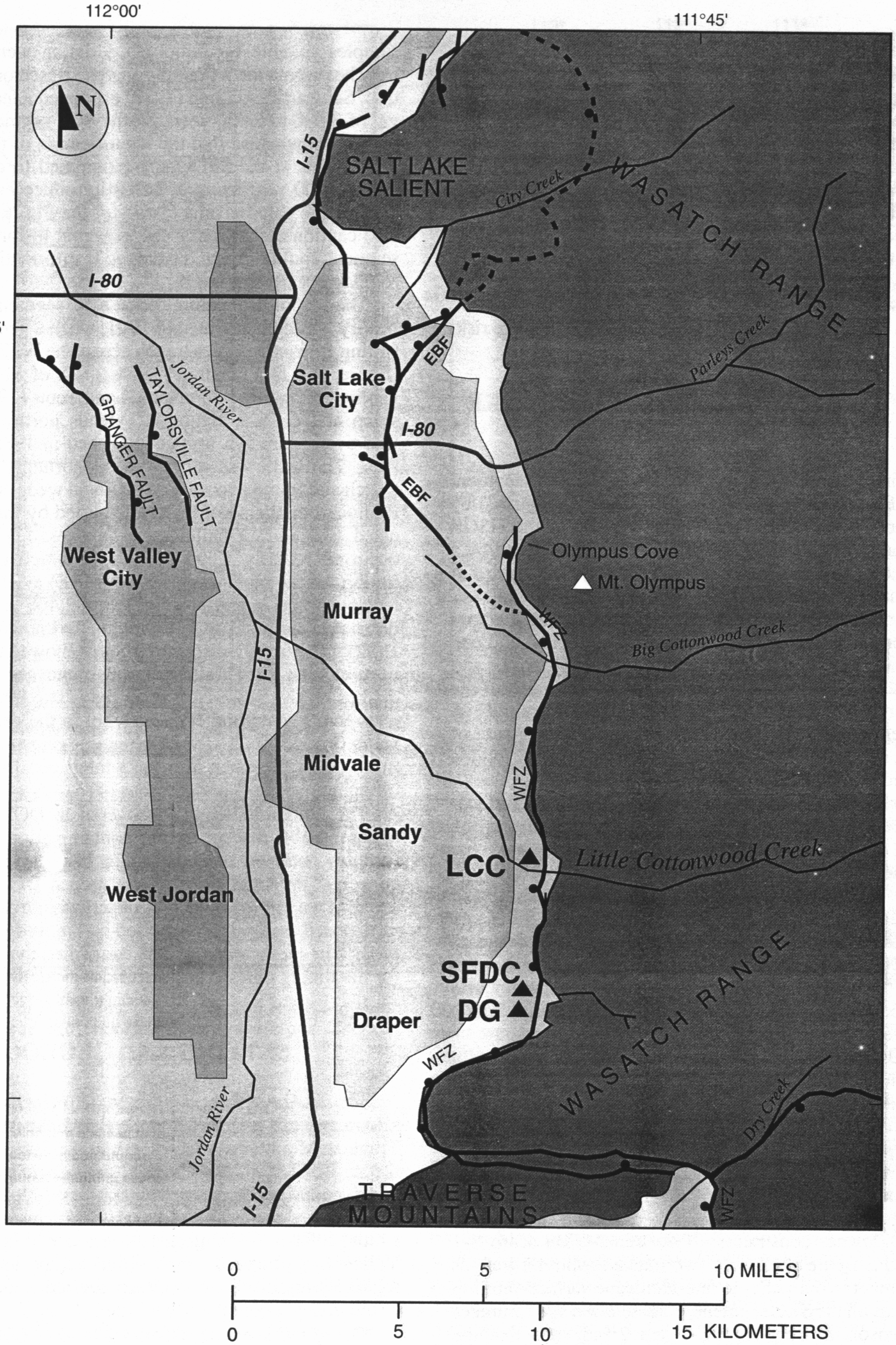


Figure 3. Salt Lake City segment of the Wasatch fault zone and locations of the Little Cottonwood Canyon (LCC), South Fork Dry Creek (SFDC), and Dry Gulch (DG) trench sites.

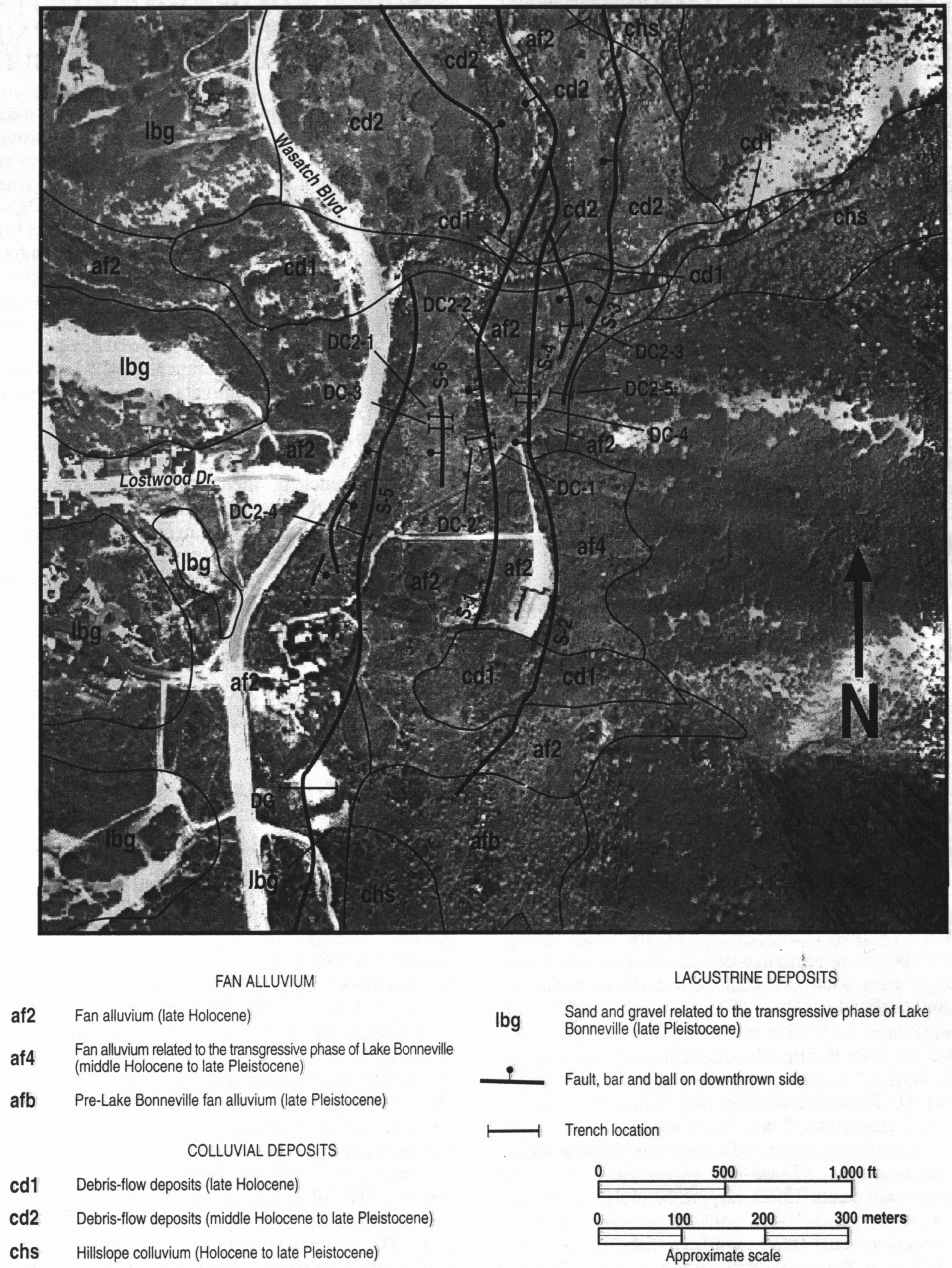


***Figure 4.** Aerial photograph geologic map of the South Fork Dry Creek site (modified from Personius and Scott, 1992).*

line) at an elevation of 1,560 meters (5,120 ft). Vegetation at the site consists of scrub oak, sage brush, and grasses. Residential development is rapidly encroaching on the site, and road building combined with development to the west has removed surficial evidence of portions of the fault zone. One scarp at the SFDC site (S-4, figure 4) has also been modified by excavation for a water-tank pad.

Surficial deposits at the SFDC site include from oldest to youngest: (1) small remnants of a middle Pleistocene alluvial-fan deposit (af4), (2) late Pleistocene to late Holocene alluvial-fan deposits (af2), and (3) a late Holocene debris flow (cd1) (figure 4; Personius and Scott, 1992). Bedrock in the Wasatch Range immediately to the east is chiefly Precambrian quartzite intruded by quartz monzonite of the Oligocene Little Cottonwood stock (Personius and Scott, 1992). The middle Pleistocene alluvial fan predates the Bonneville lake cycle and is displaced down to the west by fault S-3 (figure 4). Scott and Shroba (1985) believe this deposit is at least 150,000 years old. A late Pleistocene to late Holocene alluvial-fan complex underlies most of the site (figure 4), and is estimated to be less than 15,000 years old based on soil profile development (Scott and Shroba, 1985). A late Holocene debris-flow levee (cd1) is found along South Fork Dry Creek (figure 4; Personius and Scott, 1992), and is thought to be 2,000 to 4,000 years old (Scott and Shroba, 1985).

Six west-dipping fault scarps, and a single east-dipping antithetic scarp, form a fault zone roughly 400 meters (1,312 ft) wide at the SFDC site. Four of the west-dipping faults (S-1 to S-4, figure 4) displace the 2,000 to 4,000 year-old debris-flow levee along South Fork Dry Creek (cd1, figure 4). Cumulative displacement of the levee is smaller than adjacent (older) alluvial-fan deposits (af2, figure 4; Schwartz and Lund, 1988). Although the levee was originally interpreted to be displaced only by the MRE (Lund and Schwartz, 1987; Schwartz and Lund, 1988), its age combined with new information on earthquake timing shows that it could have been displaced by additional surface-faulting earthquakes. Scarps S-1 to S-4 merge northward, but die out to the south of the SFDC site (figure 4). Scarp S-5 (figure 4) is the main trace of the WFZ to the south and the same scarp trenched at DG, but scarp S-5 does not appear to cross the levee. Scarp S-6 (figure 4) is a small scarp that does not displace the levee or continue north or south of the SFDC site. Road construction obscured surficial evidence of an antithetic fault west of the site.

Although no Lake Bonneville sediments are present at the SFDC site, fault S-5 displaces these sediments at DG to the south (figure 4). The lake sediments (lbg, figure 4) consist of coarse-grained gravel, sand, and interbedded silt and clay deposited as the lake transgressed to and stood at the Bonneville shoreline roughly 15,000 to 16,000 radiocarbon years ago (Personius and Scott, 1992). Approximately 14,500 radiocarbon years ago, Lake Bonneville breached its outlet in the Zenda-Red Rock Pass area of southern Idaho and receded to equilibrium at the Provo shoreline (1,445 meters [4,740 ft]; Scott and others, 1983; Currey and others, 1984; Jarrett and Malde, 1987; Currey and Burr, 1988). The nearest Provo-age deposits are about one kilometer (0.6 mi) to the west of SFDC.

SEQUENCE OF DEPOSITION AND FAULTING EXPOSED IN TRENCHES AT SOUTH FORK DRY CREEK AND DRY GULCH

Between 1985 and 1994, the UGS excavated nine trenches across fault scarps at the SFDC site (DC-1 through 4, and DC2-1 through 5; figure 4). The UGS also investigated a trench excavated by a local consultant at DG (figure 4) in 1991. Detailed logs of the fault zone in DC-1, DC-2, the DG trench, and DC2-1 through 5 are shown on plate 1 (A though H). Unit descriptions are included in the appendix. We did not include logs of trenches DC-3 and DC-4 (1985) because they were not sampled for radiocarbon dating and are on scarps where subsequent trenches exposed similar stratigraphic and structural relations. Trenches DC-1 and DC-2 cross scarp S-1 (figure 4). Trenches DC2-1 and DC2-2 cross scarps S-6 and S-2 respectively (figure 4), previously cut by trenches DC-4 and DC-3. The DG trench and trench DC2-4 cross scarp S-5 (figure 4). Trenches DC2-3 and DC2-5 cross scarps S-3 and S-4 respectively (figure 4), which were not previously trenched. Including trenches excavated at SFDC and DG from 1985 to 1994, all west-dipping fault scarps at SFDC have been trenched. Calendar-calibrated age estimates from radiocarbon samples obtained from these trenches were derived using the methods described in the Earthquake Timing section.

South Fork Dry Creek (1985) And Dry Gulch (1991) Trenches

Trenches DC-1 and DC-2

Trenches DC-1 and DC-2 were excavated in 1985 across a three-meter-high scarp (S-1) at SFDC (figure 4). The trenches exposed a similar sequence of deposition and faulting, and contained evidence for two surface-faulting earthquakes. Trenches DC-1 and DC-2 were the only trenches sampled at SFDC in 1985 for radiocarbon dating. Total displacement across the fault zone could not be determined due the lack of correlative stratigraphy.

Trenches DC-1 and DC-2 both exposed a fault (F1) that displaced fan alluvium and colluvium down to the west from two surface-faulting earthquakes (plates 1A and 1B). Trench DC-1 also exposed three small antithetic faults (F2 to F4, plate 1A) that displaced these deposits down to the east. The oldest unit exposed in the trenches is an alluvial-fan deposit (unit 1) on which a soil A horizon (paleosol S1) formed (plates 1A and 1B). The older earthquake displaced unit 1, and formed a small graben between faults F1 and F4 in trench DC-1 (plate 1A). The event was followed by formation of a colluvial wedge (unit 2) on top of paleosol S1 (plates 1A and 1B). Unit 2 was subsequently buried by an organic-rich debris flow (unit 3) on which another soil A horizon (paleosol S2) formed. The younger earthquake displaced units 1 through 3 and tilted them to the east along the fault, produced a small graben between F1 and F3 in trench DC-1, and produced a shear zone 0.4 meters (1.3 ft) wide along F1 in trench DC-2 (plates 1A and 1B). The younger earthquake was followed by formation of a colluvial wedge (unit 4) that buried paleosol S2 (plates 1A and 1B). Unit 4 is buried by slope colluvium (unit 5), on which the modern soil (S3) is forming.

Radiocarbon analysis of bulk sediment samples taken from paleosol S1 beneath the older wedge (unit 2) gave age estimates of 5,750 (+400, -350) cal B.P. (DC-1 RC1, plate 1A), 5,400 (+450, -500) cal B.P. (DC-1 RC2, plate 1A), and 5,150 ± 500 cal B.P. (DC-2 RC1, plate 1B). Radiocarbon analysis of bulk sediment samples taken from paleosol S2 beneath the younger wedge (unit 4) gave age estimates of 1,500 (+350, -250) cal B.P. (DC-1 RC3, plate 1A), 2,050 (+350, -300) cal B.P. (DC-1 RC4, plate 1A), 900 ± 200 cal B.P. (DC-2 RC2, plate 1B), and 1,350 (+150, -200) cal B.P. (DC-2 RC3, plate 1B). These age estimates showed that two surface-faulting earthquakes occurred on fault S-1 at SFDC: (1) shortly after 1,100 to 1,800 years ago (MRE), and (2) shortly after 5,500 to 6,000 years ago (Lund and Schwartz, 1987; Schwartz and Lund, 1988).

Because of improved sampling techniques and concerns about possible contamination of radiocarbon samples obtained (for the older event) in 1985, the UGS re-excavated trench DC-1 in 1992 and resampled paleosols S1 and S2. Radiocarbon analysis gave age estimates of 700 (+300, -100) cal B.P. from the upper 5 centimeters (2 in) of paleosol S2 beneath unit 4 (DC-1 RC5, plate 1A), and 4,950 (+450, -200) cal B.P. from the upper 5 centimeters (2 in) of paleosol S1 beneath unit 2 (DC-1 RC6, plate 1A). The results confirm timing for the MRE and older event on fault S-1.

Dry Gulch Trench

The DG trench was excavated by a local consultant across scarp S-5 in 1991, a few hundred meters south of SFDC. The UGS was offered the opportunity to inspect the trench and found evidence for two surface-faulting earthquakes (Lund, 1992). Surficial geologic mapping (figure 4) shows scarp S-5 extends northward to SFDC, but this scarp was not previously trenched. The scarp at DG has been obscured by prior excavation and backfilling, and total displacement across the fault zone could not be determined.

The oldest unit exposed in the DG trench consists of gravelly sand deposited by Lake Bonneville as it transgressed to the Bonneville shoreline (unit 1, plate 1C). Unit 1 is overlain by sandy clay (unit 2, plate 1C) deposited by the lake as it stood at this level. Unit 1 appears to have liquefied, causing unit 2 to break into several faulted, coherent blocks that are tilted down to the east. Unit 2 is surrounded and overlain by silty sand (unit 3, plate 1C) ejected upward from unit 1 during liquefaction. Unit 3 is overlain by alluvial-fan sediments (unit 4) deposited after liquefaction, on which a soil A horizon (paleosol S1) formed (plate 1C).

Units 1 though 4 are displaced down to the west by two surface-faulting earthquakes on scarp S-5. The older event formed a colluvial wedge (unit 5) that buried paleosol S1 (plate 1C). A soil A horizon (paleosol S2) subsequently formed on unit 5. The younger event formed a second colluvial wedge (unit 6) stacked on top of unit 5 and paleosol S2 (plate 1C). The upper portion of units 4 and 6 have been removed, and the units are overlain by nearly 2.0 meters (6.6 ft) of artificial fill that contains barbed wire (unit 7, plate 1C). Radiocarbon analysis gave age estimates of 1,550 (+250, -200) cal B.P. from the upper 5 centimeters (2 in) of paleosol S2 beneath unit 5 (APST-BS1, plate 1C), and 2,300 ± 400 cal B.P. from the upper 5 centimeters (2 in) of paleosol S1 (APST-BS2, plate 1C). Results from APST-BS1 coincided with timing for the MRE from previous studies. Results from APST-BS2 did not correspond with any known event, and indicated a new surface-faulting earthquake (Lund, 1992). An additional radiocarbon sample from paleosol S1 taken in 1992 (APST-BS3; the trench remained open over the winter) gave an age estimate of 2,300 (+400, -300) cal B.P., which confirmed the new event (Lund, 1992).

South Fork Dry Creek (1994) Trenches

Trench DC2-1

We excavated trench DC2-1 across a short scarp 1 meter (3 ft) high (S-6), slightly north of trench DC-3 excavated in 1985 (figure 4). Trench DC-3 contained evidence for only one surface-faulting earthquake, and trench DC2-1 exposed no new stratigraphic or structural relations. Diffusion modeling suggests that scarp S-6 is about 900 years old (Lund and Schwartz, 1987; Schwartz and Lund, 1988; Machette and others, 1992). However, timing for the earthquake could not be determined from evidence exposed in trench DC-3.

Trench DC2-1 exposed a single fault trace that displaces a sequence of debris-flow deposits (units 1-3) on which a soil A horizon (paleosol S1) formed (plate 1D). These deposits are displaced roughly 1.4 meters (4.6 ft) down to the west across the fault, which appears as a wide crack. The crack is filled with organic-rich material (unit 4a, plate 1D). A colluvial wedge 0.9 meter (3.0 ft) thick (unit 4b) lies on unit 4a. The wedge is buried by slope colluvium (unit 5) on which a modern soil (S2) is forming (plate 1D). Radiocarbon analysis of organic-rich sediment collected from the upper 5 centimeters (2 in) of paleosol S1 beneath unit 4b (DC2-1 RC2, plate 1D) gave an age estimate of 1,600 ± 250 cal B.P. Organic-rich sediment collected from the base of the fissure fill (unit 4a, DC2-1 RC1; plate 1D) gave an age estimate of 2,800 ± 400 cal B.P. Results from DC2-1 RC2 coincide with timing for the MRE from previous studies. Although the age of DC2-1 RC1 could be due to a variety of older organic sources, it coincides with the 2,400-year-old event at DG. This earthquake may have formed the crack filled by unit 4a, without displacing the ground surface sufficiently to produce a colluvial wedge.

Trench DC2-2

We excavated trench DC2-2 across a scarp (S-2) 4 meters (13 ft) high slightly north of trench DC-4 excavated in 1985 (figure 4). Trench DC2-2 contained direct evidence for two surface-faulting earthquakes, and indirect evidence for a third event. The trench exposed stratigraphic and structural relations similar to those in trench DC-4. However, only one earthquake was recognized in trench DC-4 and timing for that event was not constrained.

The oldest unit in trench DC2-2 is a debris flow (unit 1) on which a weakly developed soil A horizon (paleosol S1) formed (plate 1E). The lower portion of this deposit (unit 1a) contains strong accumulations of ground-water-related $CaCO_3$, primarily in highly permeable sandy and cobbly zones in its upper portion. Between stations at 8 and 10 meters (plate 1E), unit 1b is truncated by what we interpret as a degraded free face from an old surface-faulting earthquake. The trench was not deep enough to expose the fault trace and colluvial wedge from this event. The degraded free face is buried by a debris-flow deposit (unit 2, plate 1E).

Trench DC2-2 exposed two faults (F1 and F2, plate 1E) and evidence for two surface-faulting earthquakes. Unit 1 is displaced roughly 1.6 meters (5.2 ft) down to the west by the two events. The older earthquake formed a colluvial wedge (unit 3) 0.8 meter (2.6 ft) thick that buried paleosol S1 (plate 1E). The younger earthquake produced a narrow crack filled with organic-rich material. A colluvial wedge (unit 4) 0.6 meter (2.0 ft) thick formed on unit 3 after fissure filling (plate 1E). No paleosols or other depositional units are evident between units 3 and 4, and the units are buried by slope colluvium (unit 5) on which a modern soil (S2) is forming (plate 1E). Radiocarbon analysis gave age estimates of 3,950 (+550, -450) cal B.P. from organic-rich sediment collected from the upper 5 centimeters (2 in) of paleosol S1 beneath unit 3 (DC2-2 RC1); and 1,200 (+200, -250) cal B.P. from organic-rich crack fill from the younger event (DC2-2 RC2, plate 1E). The age estimate from DC2-2 RC1 does not correspond to timing for any previously known event and indicates a new event. Results from DC2-2 RC2 coincide with timing for the MRE from previous studies.

Trench DC2-3

We excavated trench DC2-3 across a scarp (S-4, figure 4) 2 meters (7 ft) high that was not previously trenched. The trench is on the eastern edge of an abandoned water-tank pad excavated in the late 1980s (Charles Horman, landowner, verbal communication, May 1994). Although a large portion of the colluvial wedge was removed, the trench still exposed evidence for one surface-faulting earthquake.

Trench DC2-3 exposed a debris-flow deposit (unit 1) on both the upthrown and downthrown sides of the fault, on which a soil A horizon (paleosol S1, plate 1F) formed. The earthquake displaced unit 1 roughly 2.1 meters (6.9 ft) down to the west, and produced a crack that was rapidly filled by material from the scarp free face (unit 2a, plate 1F). Fissure filling was followed by formation of a colluvial wedge estimated at 1.6 meters (5.2 ft) thick containing blocks of unit 1 and paleosol S1 (units 2b through 2d, plate 1F). A modern soil (S2) is forming on units 1 and 2. On the downthrown side of the fault, the upper portion of unit 1 and portions of unit 2b were removed by excavation for the water tank, and the remnants of those units are overlain by well-sorted fine sand fill placed for the water-tank foundation. Radiocarbon analysis gave age estimates of 1,050 ± 300 cal B.P. from an organic-rich block of paleosol S1 in the colluvial wedge (unit 2c, DC2-3 RC1); 1,250 (+200, -250) cal B.P. from organic-rich sediment collected from the upper 5 centimeters (2 in) of paleosol S1 beneath unit 2b (DC2-3 RC2); and 900 ± 300 cal B.P. from organic-rich colluvium in unit 2b (DC2-3 RC3) (plate 1F). All three age estimates are coincident with timing for the MRE from previous studies.

Trench DC2-4

We excavated trench DC2-4 across a scarp (S-5, figure 4 5 meters (16 ft) high that is the westernmost down-to-the-west fault at the SFDC site. Scarp S-5 is the same scarp trenched at DG, but this scarp was not previously trenched at SFDC (figure 4). The trench exposed two fault traces (F1 and F2) and a degraded scarp free face from a third fault (F3) (plate 1G). These faults form a fault zone roughly 9.0 meters (29.5 ft) wide at the eastern boundary of a wide, deep graben. We extended the trench several tens of meters to the west, as far as landowner constraints would allow, but did not reach the western edge of the graben. F1 has two colluvial wedges; F2 and F3 each have one colluvial wedge. The wedges formed from three or four surface-faulting earthquakes on fault S-5. Units exposed on the upthrown side of the fault zone were not exposed on the downthrown side in the graben, and therefore the total displacement across the fault zone could not be determined due to the lack of correlative stratigraphy. Most deposits exposed in the trench were organic rich; deposits along F1 also showed considerable penetration by modern roots.

The oldest unit in trench DC2-4 is a debris-flow deposit (unit 1, plate 1G). However, unlike other units exposed in the trench, unit 1 contained few organics and no material suitable for radiocarbon dating. Unit 1 is displaced at least 3.3 meters (10.8 ft) down to the west from two surface-faulting earthquakes on F1 (plate 1G). The older event on F1 produced a colluvial wedge (unit 2) 1.5 meters (4.9 ft) thick on which a soil A horizon (paleosol S1) formed (plate 1G). The younger event on F1 displaced unit 2 and produced a narrow shear zone (unit 6a), followed by formation of a colluvial wedge (unit 6b) 2.4 meters (7.9 ft) thick on top of paleosol S1 (plate 1G). These units are truncated to the west by a degraded scarp free face extending from F2 (plate 1G). A modern soil (S2) is forming on unit 6b at the surface. Radiocarbon analysis of organic-rich sediment collected from the upper 5 centimeters (2 in) of paleosol S1 beneath unit 6b (DC2-4 RC1, plate 1G) gave a modern age that suggests contamination by bomb carbon or other sources. We resampled the buried soil (DC2-4 RC5) in 1995, and radiocarbon analysis of this new sample gave a similar age. Because of possible contamination of paleosol S1 and lack of organic material in unit 1, we could not constrain timing for the events along F1.

Unit 1 is also displaced at least 2.3 meters (7.5 ft) below the floor of the trench by surface-faulting earthquakes on F3 and F2. The event on F3 formed a colluvial wedge (unit 3, plate 1G) estimated at 1.5 meters (4.9 ft) thick. No soil is evident on unit 3, and its distal portion has been eroded by a series of debris flows/floods that deposited units 4 and 5 in the graben (plate 1G). The event on F2 formed a colluvial wedge (unit 7) 1.2 meter (3.9 ft) thick on units 4 and 5, which is buried by colluvium (unit 8) (plate 1G). Soil S2 is also forming on units 7 and 8 (plate 1G). Radiocarbon analysis gave age estimates of 1,250 (+150, -250) cal B.P. from organic-rich sediment collected from the base of unit 7 (DC2-4 RC2); 3,900 (+400, -350) cal B.P. from unit 4 (DC2-4 RC3); and 3,700 (+450, -350) cal B.P. from organic-rich sediment collected from unit 3 (DC2-4 RC4) (plate 1G). Results from DC2-4 RC2 coincide with timing for the MRE from previous studies. Results from DC2-4 RC4 confirm timing for the new event found in trench DC2-2. Sample DC2-4 RC3 was taken only for control purposes, but shows a similar age to DC2-4 RC4.

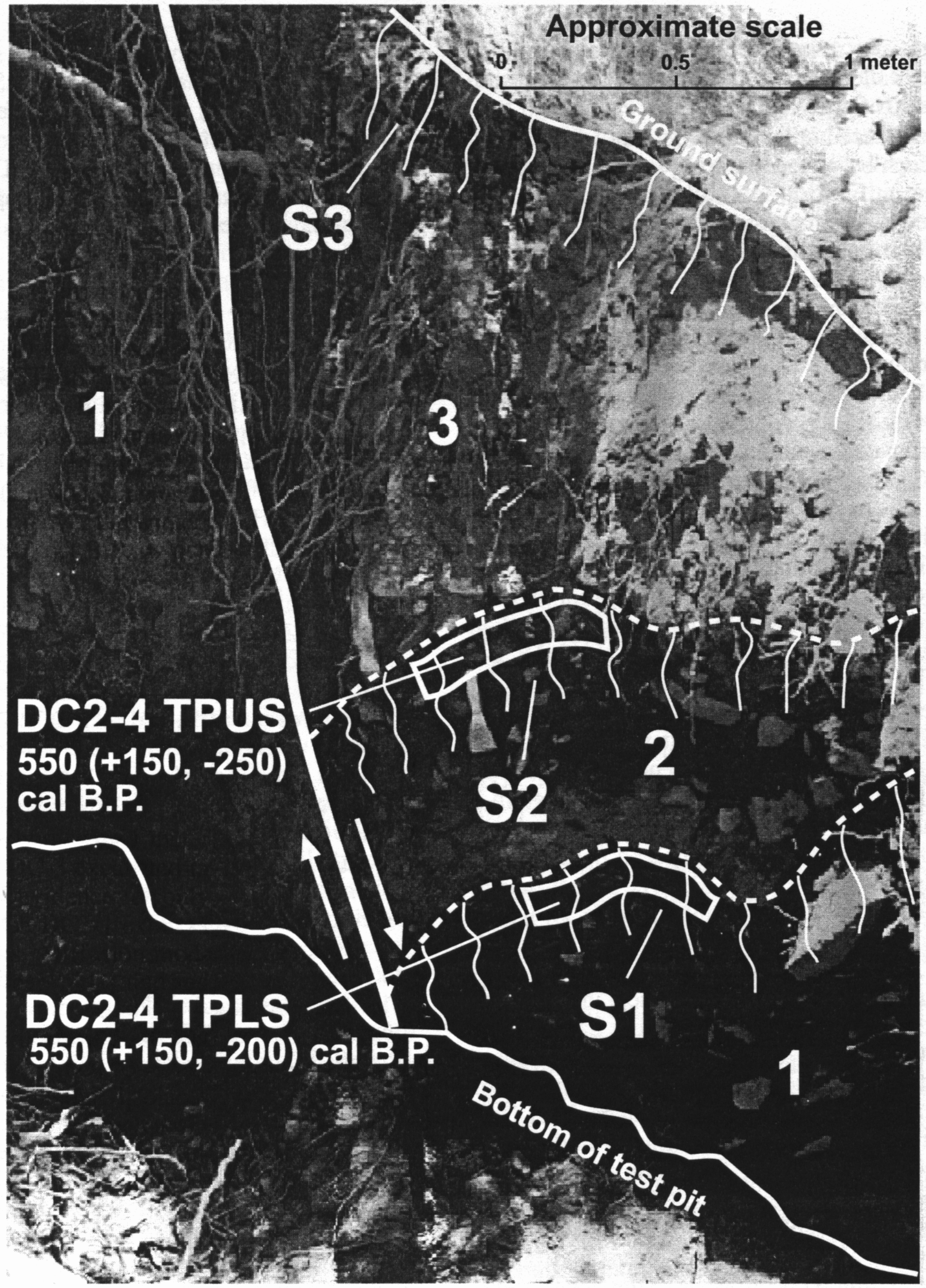
To resolve questions about timing for events along fault F1 in trench DC2-4, we excavated a test pit on scarp S-5 roughly 10 meters (33 ft) north of the trench. The test pit exposed a single fault trace and two colluvial wedges in a similar stratigraphic relation to those along F1. Deposits in the test pit (like those along F1) also showed considerable penetrations by modern roots (figure 5). The oldest unit in the test pit is a debris-flow deposit (unit 1, figure 5), which corresponds to unit 1 in the trench (plate 1G). A soil A horizon (paleosol S1) was present on unit 1 in the test pit (figure 5); however, this paleosol was not present in the trench (plate 1G). Evidence for two surface-faulting earthquakes was found along the fault in the test pit. The older event displaced unit 1 down to the west, followed by formation of a colluvial wedge (unit 2, figure 5) on top of paleosol S1. Unit 2 in the test pit corresponds to the lower colluvial wedge (unit 2) in the trench (plate 1G). A soil A horizon (paleosol S2, figure 5) subsequently formed on unit 2, which corresponds to paleosol S1 in the trench (plate 1G). A second colluvial wedge (unit 3) formed after the younger event and buried paleosol S2 (figure 5); unit 3 corresponds to the upper colluvial wedge (unit 6b) in the trench (plate 1G). A modern soil (S3, figure 5) is forming on unit 3 and corresponds to soil S2 in the trench (plate 1G). No graben-fill deposits were exposed in the test pit, which suggests the edge of the graben (and faults F2 and F3) is farther west. Radiocarbon analysis of samples taken from the test pit gave age estimates of 550 (+150, -200) cal B.P. from the upper 5 centimeters (2 in) of paleosol S1 directly beneath unit 2 (DC2-4 TPLS, figure 5), and 550 (+150, -250) cal B.P. from the upper 5 centimeters (2 in) of paleosol S2 directly beneath unit 3 (DC2-4 TPUS, figure 5). Both results are younger than the youngest radiocarbon age estimate for the MRE from previous studies. The age estimates also suggest that paleosols S1 and S2 were buried at the same time, which contradicts stratigraphic relations in the test pit; the age estimates should show some time interval between burial of paleosols S1 and S2. Because of the young results, lack of age difference, and amount of modern root penetration, we believe the paleosols are likely contaminated (similar to paleosol S1 in the trench). Therefore, we were unable to constrain timing for the events along the fault in the test pit.

Trench DC2-5

We excavated trench DC2-5 across a scarp (S-3, figure 4) 1 meter (3 ft) high that is the easternmost scarp at the SFDC site. This scarp is located on a steep slope at the base of the mountain front, and was not previously trenched. The trench exposed two fault traces (F1 and F2) and an antithetic fault (F3) (plate 1H). The faults displace alluvial-fan deposits and slope colluvium. F1 is evident at the surface, but F2 has apparently been modified by slumping and is not evident. Stratigraphic and structural relations in the trench were complex and difficult to interpret.

The oldest unit in trench DC2-5 is a debris-flow deposit (unit 1, plate 1H) that contains abundant $CaCO_3$ and may correlate with unit 1a in trench DC2-2 roughly 10 meters (33 ft) to the west (plate 1E). Unit 1 is buried by two debris-flow deposits (units 2 and 3, plate 1H) that may correlate with unit 1b in trench DC2-2 (plate 1E). These units are overlain by a wedge-shaped pocket of colluvium of unknown origin (unit 4), and two additional debris-flow deposits (units 5 and 6) that become progressively thinner to the west and eventually pinch out. A soil A horizon (paleosol S1) formed on top of the uppermost debris flow (unit 6, plate 1H). These units are displaced roughly 0.7 meters (2.3 ft) down to the west across F1 by one earthquake. The event was followed by formation of a 0.8-meter- (2.6-ft-) thick colluvial wedge (unit 8), and the wedge is buried by slope colluvium (unit 9) on which a modern soil (S2) is forming. Radiocarbon analysis of organic-rich sediment collected from the upper 5 centimeters (2 in) of paleosol S1 beneath unit 8 gave an age estimate of 2,750 (+250, -350) cal B.P. (DC2-5 RC3, plate 1H). Results from DC2-5 RC3 coincide with timing for the 2,400-year-old event from DG.

Stratigraphic and structural relations on F2 were complex and difficult to interpret. This fault trace is represented by a degraded free face that truncates units 1 through 6. However, we are uncertain if the free face was formed by an earthquake, a slope failure, or some combination of the two. Units 1 through 6 are displaced roughly 3.5 meters (11.5 ft) down to the west, in a shallow graben bounded by an antithetic fault (F3) that has roughly 0.2 meters (0.7 ft) of displacement down to the east (plate 1H). The colluvial wedge on F2 (unit 7, plate 1H) is large and complex (1.7 meters [5.6 ft] thick), and contains several intact upright blocks surrounded by organic-rich material that suggest it may have formed from slumping. Unit 7 is buried by unit 9 and soil S2 (plate 1H). Radiocarbon analysis gave age estimates of 2,300 $\pm$ 400 cal B.P. from organic-rich material in unit 7 (DC2-5 RC1); and 4,800 (+400, -500) cal B.P. from the upper 5 centimeters (2 in) of



SYMBOLS

Fault (arrows indicate relative movement)

Contact, dashed where inferred

Paleosol and soil A horizons

Radiocarbon bulk sample location and calendar-calibrated age estimate

UNIT DESCRIPTIONS

1. Debris flow (matrix supported).
S1. Paleosol A horizon formed on unit 1.
2. Colluvial wedge.
S2. Paleosol A horizon formed on unit 2.
3. Colluvial wedge.
S3. Soil A horizon formed on unit 3.

***Figure 5.** Photolog of fault zone in the south wall of the test pit near trench DC2-4, South Fork Dry Creek site, Wasatch fault zone, Utah.*

paleosol S1 beneath unit 7 (DC2-5 RC2) (plate 1H). Although DC2-5 RC2 and DC2-5 RC3 apparently come from the same paleosol (S1, plate 1H), results from DC2-5 RC2 are considerably older and further question the origin of unit 7. Because questions remain regarding the origin of unit 7, we did not use DC2-5 RC1 and RC2 in our analysis of earthquakes at the SFDC site.

EARTHQUAKE TIMING AND RECURRENCE

Table 1 shows radiocarbon laboratory results and calendar-calibrated age estimates for all samples taken from the SFDC and DG trenches between 1985 and 1995. We use a scheme similar to Sieh and others (1989) to define the chronologic sequence of past earthquakes on the SLC segment. In this scheme, the earthquake chronology is in inverse-alphabetic order. Thus, the MRE is event Z, the next older event is event Y, and so on (table 1). We calibrated the lab results using the computer program CALIB 3.0.3 (Stuiver and Reimer, 1993). We used an error multiplier of two for all samples. We estimated carbon age span (CAS) and mean residence correction (MRC) for the samples using methods described in Machette and others (1992). CAS is the estimated age span between the youngest and oldest carbon in the sample, and is used by the calibration program to smooth fluctuations in the calibration curve (Machette and others, 1992; Stuiver and Reimer, 1993). MRC is the composite age of carbon in the sample prior to burial (Machette and others, 1992). MRC was subtracted from the radiocarbon age prior to calibration (Minze Stuiver, University of Washington, personal communication to W.R. Lund, 1992). Two-sigma (2σ) error limits are shown for the age estimates (table 1). We recalibrated radiocarbon samples taken from previous studies at SFDC and DG to maintain uniformity between the samples.

Age estimates in this report are apparent mean residence time (AMRT) ages on organic concentrates, and represent the approximate time of soil burial for A horizons or age of carbon incorporated in crack fill and colluvial wedges derived from soils at the surface. Although we used the calibration procedure to improve accuracy of the AMRT ages, the corrected ages are not accurate enough to be termed dates and thus represent intervals of time.

We calculated earthquake timing by averaging the AMRT age estimates and two-sigma error bounds of samples from paleosols beneath colluvial wedges or intact blocks of paleosol in wedges. Samples from fissure fill and fault-scarp colluvium were used only to support timing for the events. For event Z, we discarded the oldest and youngest age estimates (DC-1 RC4 and RC5, table 1) and averaged the remaining age estimates. We did not use DC2-4 RC1, DC2-4 RC3, DC2-4 RC5, DC2-4 TPLS, DC2-4 TPUS, DC2-5 RC1, and DC2-5 RC2 (table 1) because of uncertain stratigraphic relations or possible contamination. Although DC2-1 RC1 may constrain event Y (table 1), it was not used because we are uncertain of the sampled unit's origin.

Eight age estimates from paleosols, and one age estimate from an intact block of paleosol in a wedge, constrain timing for event Z. APST-BS1 gives a limiting age of 1,550 (+250, -200) cal B.P. for the event on fault S-5 at DG (table 1). DC-1 RC3, DC-2 RC2, and DC-2 RC3 give limiting ages of 1,500 (+350, -250) cal B.P., 900 ± 200 cal B.P., and 1,350 (+150, -200) cal B.P. for the event on fault S-1 at SFDC (table 1). DC2-1 RC2 gives a limiting age of 1,600 ± 250 cal B.P. for the event on fault S-6 at SFDC (table 1). DC2-3 RC1 and DC2-3 RC2 give limiting ages of 1,050 ± 300 cal B.P. and 1,250 (+200, -250) cal B.P. for the event on fault S-4 at SFDC (table 1). The age estimates show event Z likely occurred shortly after 1,300 (+250, -200) cal B.P. (figure 6), and ruptured scarps S-1, S-4, S-5, and S-6. Three age estimates from fault colluvium (DC2-2 RC2, DC2-3 RC3, and DC2-4 RC2; table 1) support timing for event Z; DC2-2 RC2 suggests the earthquake also ruptured scarp S-2.

Three age estimates from paleosols constrain timing for event Y. APST-BS2 and APST-BS3 give limiting ages of 2,300 ± 400 cal B.P. and 2,300 (+400, -300) cal B.P. for the event on fault S-5 at DG (table 1). DC2-5 RC3 gives a limiting age of 2,750 (+250, -350) cal B.P. for the event on fault S-3 at SFDC (table 1). The age estimates show event Y occurred shortly after 2,450 ± 350 cal B.P. (figure 6), and ruptured scarps S-3 and S-5. Although we could not determine timing for formation of the upper F1 wedge in trench DC2-4, it may also be from event Y. DC2-1 RC1 may support timing for event Y (table 1), but the sampled unit's origin is unclear.

Event X is a previously unrecognized surface-faulting earthquake on the SLC segment. Timing for this event is constrained by one age estimate from a paleosol in trench DC2-2. DC2-2 RC2 gives a limiting age of 3,950 (+550, -450) cal B.P. (table 1), which does not correspond to timing for any previously known event. This shows the event occurred 3,500 to 4,500 years ago (figure 6) and ruptured scarp S-2 at SFDC. One age estimate from fault colluvium (DC2-4 RC4) supports timing for the event, and suggests the earthquake also ruptured scarp S-5 at SFDC. This evidence shows there have been four surface-faulting earthquakes in the past 6,000 years (figure 6), rather than three as previously thought.

Four age estimates from buried paleosols in trenches DC-1 and DC-2 constrain timing for event W on the SLC segment. Although we could not determine timing for formation of the lower F1 wedge in trench DC2-4, it is probably from event W. Other trenches excavated at SFDC and DG were not deep enough to expose direct evidence of this event. DC-1 RC1, DC-1 RC2, and DC-1 RC6 give limiting ages of 5,750 (+400, -350) cal B.P.; 5,400 (+450, -500) cal B.P.; and 4,950 (+450, -200) cal B.P. for the event on fault S-1 at SFDC (table 1). DC-2 RC1 also gives a limiting age of 5,150 ± 500 cal B.P. for the event on fault S-1 (table 1). The age estimates show the earthquake occurred shortly after 5,300 (+450, -350) cal B.P. (figure 6), and ruptured scarp S-1. The lower F1 wedge in trench DC2-4 suggests event W also ruptured scarp S-5.

Events W through Z show a varying pattern of surface rupture at the SFDC site. Slip from the last three and possibly all four events was concentrated on fault S-5 south of DG, but S-5 dies out near SFDC. As S-5 dies out, slip is distributed eastward to faults S-1 through S-4, which continue northward.

Table 1.
Radiocarbon results and calendar-calibrated age estimates for samples taken from trenches at the SFDC and DG sites between 1985 and 1995. The paleoearthquake constrained by each age estimate is shown in the last column (queried if uncertain, short dash if the sample has ambiguous stratigraphic relations or possible contamination).

Laboratory number (field sample number)	Material sampled	Radiocarbon age in ^{14}C yr B.P. minus MRC	AMRT ^{14}C age estimate in cal B.P. (two-sigma error)	MRC (in yr)	CAS (in yr)	Paleoearthquake contstrained
DRY GULCH 1991-92						
Dry Gulch trench (scarp S-5)						
Beta-50879 (APST-BS1)	Paleosol A horizon buried by the upper wedge	1,660 ± 120	1,550 (+250, -200)	100	200	Event Z
Beta-50880 (APST-BS2)	Paleosol A horizon buried by the lower wedge	2,270 ± 140	2,300 ± 400	100	200	Event Y
Beta-54017 (APST-BS3)	Paleosol A horizon buried by the lower wedge	2,310 ± 120	2,300 (+400, -300)	100	200	Event Y
SOUTH FORK DRY CREEK 1985						
Trench DC-1 (scarp S-1)						
Beta-21299 (DC-1 RC1)	Paleosol A horizon buried by the lower wedge	5,030 ± 160	5,750 (+400, -350)	200	200	Event W
Beta-21300 (DC-1 RC2)	Paleosol A horizon buried by the lower wedge	4,710 ± 200	5,400 (+450, -500)	200	200	Event W
Beta-21304 (DC-1-RC3)	Paleosol A horizon buried by the upper wedge	1,630 ± 160	1,500 (+350, -250)	200	200	Event Z
Beta-28319 (DC-1 RC4)	Paleosol A horizon buried by the upper wedge	2,110 ± 140	2,050 (+350, -300)	200	200	Event Z
Trench DC-2 (scarp S-1)						
Beta-21302 (DC-2 RC1)	Paleosol A horizon buried by the lower wedge	4,510 ± 180	5,150 ± 500	200	200	Event W
Beta-21303 (DC-2 RC2)	Paleosol A horizon buried by the upper wedge	970 ± 120	900 ± 200	200	200	Event Z
Beta-28320 (DC-2 RC3)	Paleosol A horizon buried by the upper wedge	1,440 ± 100	1,350 (+150, -200)	200	200	Event Z
SOUTH FORK DRY CREEK 1992						
Trench DC-1 (scarp S-1)						
Beta-54648 (DC-1 RC5)	Paleosol A horizon buried by the upper wedge	830 ± 120	700 (+300, -100)	100	200	Event Z
Beta-54649 (DC-1 RC6)	Paleosol A horizon buried by the lower wedge	4,420 ± 120	4,950 (+450, -200)	100	200	Event W
SOUTH FORK DRY CREEK 1994						
Trench DC2-1 (scarp S-6)						
Beta-79185 (DC2-1 RC1)	Fissure fill beneath fault-scarp colluvium	2,700 ± 160	2,800 ± 400	300	200	Event Y?
Beta-80845 (DC2-1 RC2)	Paleosol A horizon buried by fault-scarp colluvium	1,700 ± 120	1,600 ± 250	150	200	Event Z
Trench DC2-2 (scarp S-2)						
Beta-77140 (DC2-2 RC1)	Paleosol A horizon buried by the lower wedge	3,660 ± 180	3,950 (+550, -450)	150	200	Event X
Beta-77139 (DC2-2 RC2)	Fissure fill beneath the upper wedge	1,270 ± 120	1,200 (+200, -250)	300	200	Event Z

Table 1 *(continued)*

Laboratory number (field sample number)	Material sampled	Radiocarbon age in ^{14}C yr B.P. minus MRC	AMRT ^{14}C age estimate in cal B.P. (two-sigma error)	MRC (in yr)	CAS (in yr)	Paleoearthquake contstrained
Trench DC2-3 (scarp S-4)						
Beta-79186 (DC2-3 RC1)	Block of soil A horizon in fault-scarp colluvium	1,140 ± 140	1,050 ± 300	100	200	Event Z
Beta-77141 (DC2-3 RC2)	Paleosol A horizon buried by fault-scarp colluvium	1,320 ± 160	1,250 (+200, -250)	100	200	Event Z
Beta-77142 (DC2-3 RC3)	Fault-scarp colluvium	960 ± 160	900 ± 300	200	200	Event Z
Trench DC2-4 (scarp S-5)						
Beta-79187 (DC2-4 RC1)	Paleosol A horizon buried by the upper F1 wedge	170 ± 120	Negative age B.P.	150	200	—
Beta-79188 (DC2-4 RC2)	Upper F2 Wedge	1,320 ± 100	1,250 (+150, -250)	300	200	Event Z
Beta-79181 (DC2-4-RC3)	Graben fill	3,610 ± 140	3,900 (+400, -350)	300	200	—
Beta-79920 (DC2-4 RC4)	Lower F2 wedge	3,460 ± 160	3,700 (+450, -350)	300	200	Event X
Beta-81339 (DC2-4 RC5)	Paleosol A horizon buried by the upper F1 wedge	100 ± 100	Negative age B.P.	150	200	—
Beta-83500 (DC2-4 TPLS)	Paleosol A horizon buried by the lower wedge	530 ± 120	550 (+150, -200)	150	200	—
Beta-83501 (DC2-4 TPUS)	Paleosol A horizon buried by the upper wedge	510 ± 140	550 (+150, -250)	150	200	—
Trench DC2-5 (scarp S-3)						
Beta-79182 (DC2-5 RC1)	Colluvium (possibly from slope failure)	2,270 ± 140	2,300 ± 400	300	200	—
Beta-79183 (DC2-5 RC2)	Paleosol A horizon buried by F2 wedge	4,200 ± 160	4,800 (+400, -500)	200	200	—
Beta-79184 (DC2-5 RC3)	Paleosol A horizon buried by F1 wedge	2,790 ± 120	2,750 (+250, -350)	300	200	Event Y

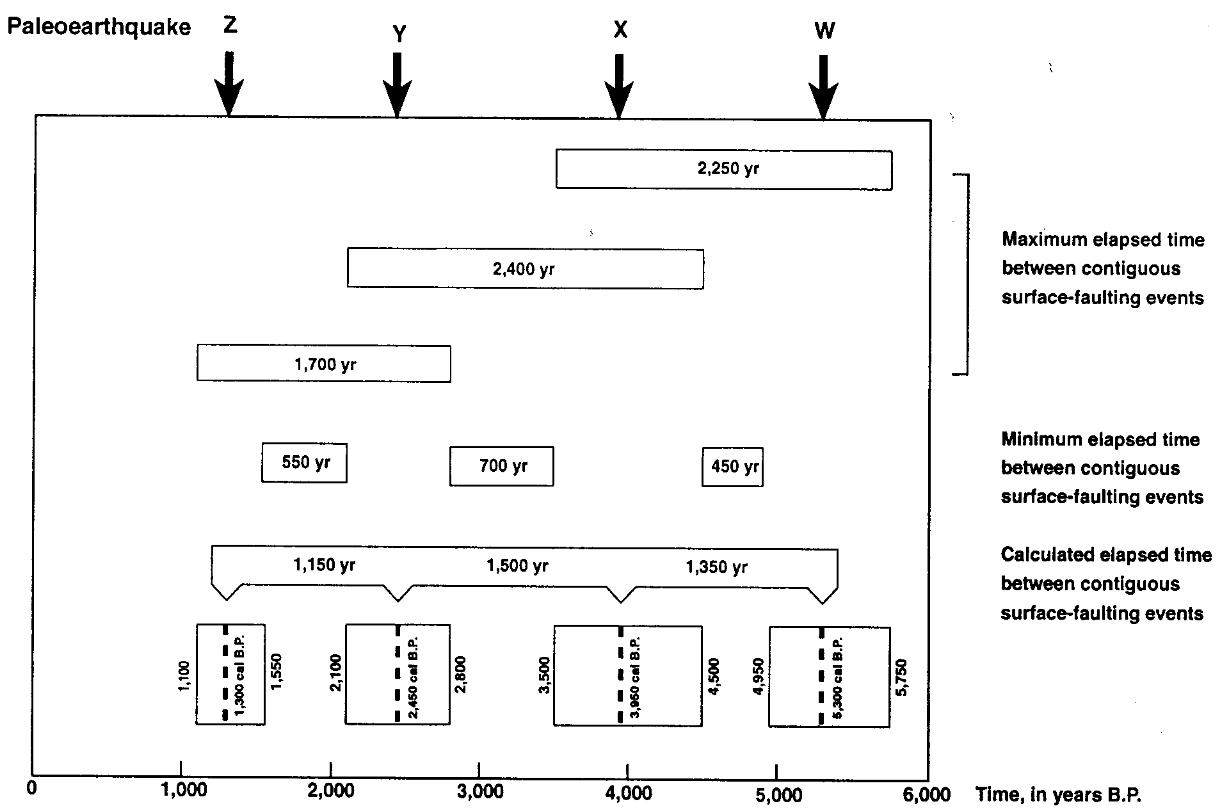


Figure 6. *Timing of surface-faulting earthquakes on the Salt Lake City segment in the past 6,000 years.*

During event W (4,950-5,750 years ago), surface rupture on S-5 shifted eastward and continued north on S-1 (figure 7). During event X (3,500-4,500 years ago), surface rupture on S-5 shifted eastward again, but instead continued north on S-2 (figure 7). During event Y (2,100-2,800 years ago), surface rupture on S-5 shifted to S-3 (figure 7). During event Z (1,100-1,550 years ago), surface rupture on S-5 shifted eastward to S-1, S-2, S-4, and S-6, which converge to the north to a single trace (figure 7). In events W, X, and Y, ruptures shifted progressively eastward. Rupture in event Z, however, ruptured all but the easternmost trace.

Based on evidence for three surface-faulting earthquakes from SFDC in 1985 and DG in 1991, Lund (1992) calculated an average recurrence interval for surface faulting of 2,150 ± 400 years in the past 6,000 years on the SLC segment. However, new information from the SFDC site shows a previously unrecognized surface-faulting earthquake roughly 3,950 years ago. This additional event increases the total to four surface-faulting earthquakes in the past 6,000 years, and shows that surface faulting on the SLC segment occurs more frequently than previously thought. Using mean times for each event, elapsed times between each of the last four surface-faulting earthquakes at SFDC are: 1,150 years between event Z and event Y; 1,500 years between event Y and event X; and 1,350 years between event X and event W (figure 6). Therefore, based on the average of these intervals, a recurrence interval of 1,350 ± 200 years best characterizes recurrence of surface-faulting earthquakes on the SLC segment during the late Holocene. Further work is needed to characterize recurrence in early Holocene time.

FAULT DISPLACEMENT AND ESTIMATED EARTHQUAKE MAGNITUDE

Net vertical tectonic displacement (NVTD) is the net vertical offset that occurs on a fault from a surface-faulting earthquake (figure 8). Determining NVTD per event gives an estimate of earthquake size and allows comparison between successive earthquakes. NVTD consists of apparent slip (the amount of displacement between correlative units on both sides of a fault) minus the effects of backtilting and antithetic faulting. NVTD can be determined from scarp profiles by measuring the displacement between the same undeformed surface on both sides of a fault zone (figure 8), or crudely estimated based on colluvial wedge thickness (Ostenaa, 1984; McCalpin, 1991). However, we could not calculate NVTD per event at the SFDC site because evidence of antithetic faulting to the west is obscured and was not exposed in our trenches. The amplitude of antithetic faulting (which would reduce NVTD) is uncertain. In addition, road construction

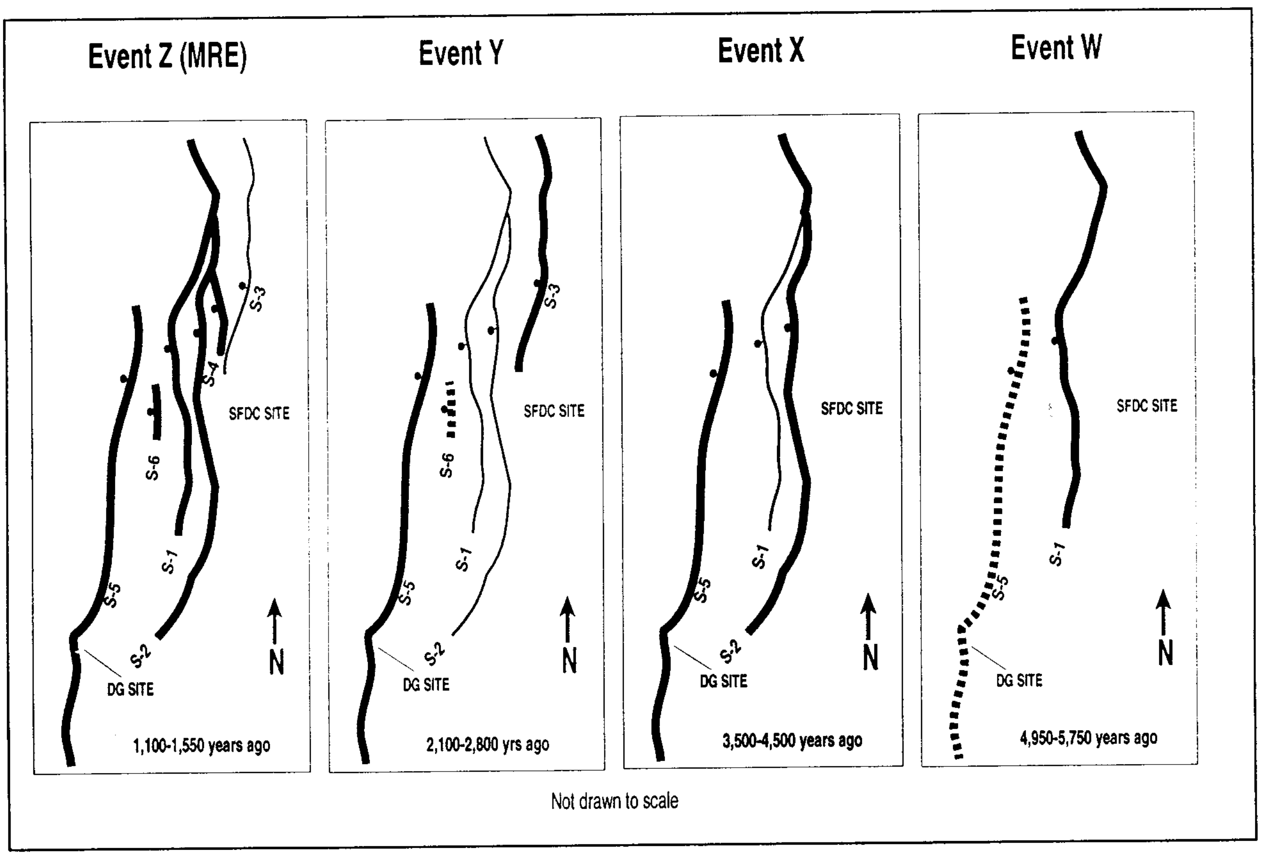


Figure 7. Pattern of surface rupture at the South Fork Dry Creek (SFDC) and Dry Gulch (DG) sites. Main scarps (S-1 through S-6) known to have been active during surface-faulting earthquakes on the Salt Lake City segment in the past 6,000 years are shown by heavy solid lines; scarps possibly active are shown by heavy dashed lines.

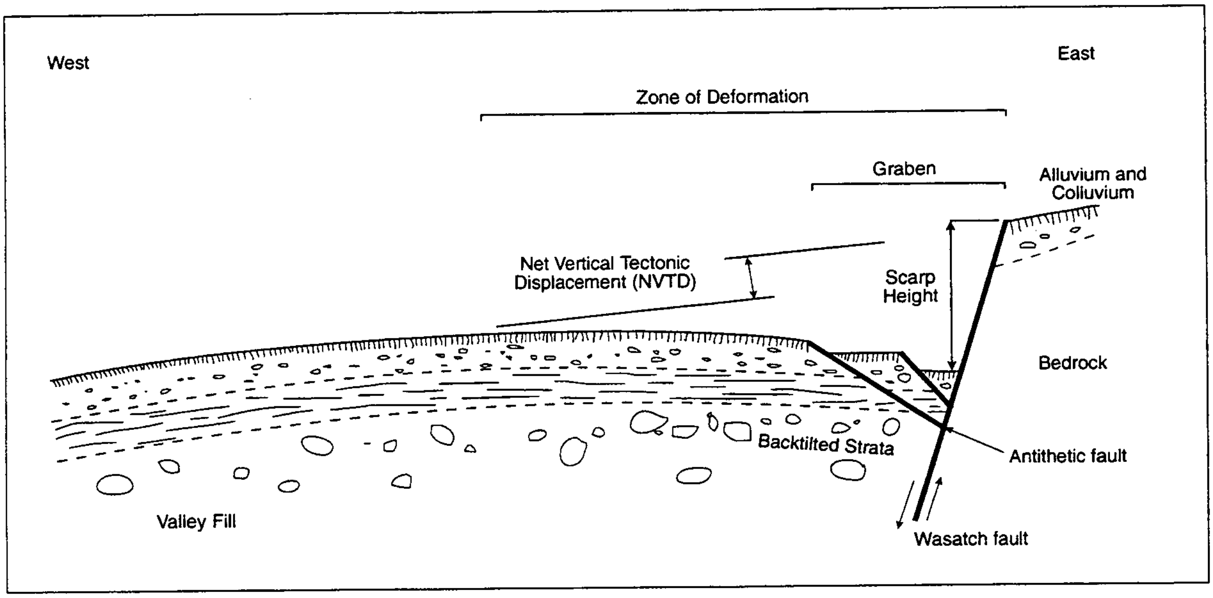


***Figure 8.** Schematic diagram showing relations among scarp height, backtilting, antithetic faulting, and net vertical tectonic displacement for normal-slip faults (modified from Robison, 1993).*

combined with development has disturbed undeformed areas west of the fault zone.

Swan and others (1981) determined an average NVTD of 2 meters (6.6 ft) per event for the SLC segment from scarp profiling across glacial moraines near the LCC site. Scarp profiling on the 2,000 to 4,000 year-old debris-flow levee along SFDC showed 4.5-5.0 meters (14.8-16.4 ft) of displacement (Lund and Schwartz, 1987; Schwartz and Lund, 1988). Although the levee was initially thought to be displaced only by the MRE, new information from this study shows that up to three surface-faulting earthquakes may have displaced the levee in the past 4,000 years. Average NVTD per event at SFDC would thus be 2.3 to 2.5 meters (7.5-8.2 ft) if the levee was displaced by two events (rather than one), and 1.5 to 1.7 meters (4.9-5.6 ft) if the levee was displaced by three events. A substantial amount of antithetic faulting would be needed to reconcile the difference in average NVTD between LCC and SFDC if the levee was displaced only by the MRE.

Empirical relations that correlate earthquake magnitude with various fault parameters can assign estimated maximum magnitudes to prehistoric earthquakes. Table 2 shows the estimated maximum magnitudes for prehistoric surface-faulting earthquakes on the SLC segment. However, because NVTD could not be calculated at the SFDC site, only calculations based on length relations are shown. Inferred moment magnitude (Mw) is generally considered to be a better estimate of earthquake magnitude than surface-wave magnitude (Ms) (Hanks and Kanamori, 1979; Machette, 1986); moment magnitude (from length relations) for surface-faulting earthquakes on the SLC segment is M_W 6.9 (table 3). This magnitude is similar to the 1983 Borah Peak, Idaho earthquake which was M_W 7.0 (Stein and Bucknam, 1985).

Table 2.
Magnitude estimates (based on length relations) for surface-faulting earthquakes on the Salt Lake City segment of the Wasatch Fault Zone.

Based on:	**Moment magnitude (M_w)** References: [A][1]	**Surface-wave magnitude (M_s)** [B][2]
Length[3]	6.9 (L_s = 39 km)	7.1 - 7.2 (L_s = 39 km, L_t = 46 km)

References: [A] Wells and Coppersmith (1994), [B] Bonilla and others (1984).

[1] $M_w = 5.08+1.16 \log L_s$ (standard deviation = 0.28).

[2] Ordinary least-square relations for North America: $M_s = 5.17+1.237 \log L$ (standard deviation = 0.324).

[3] Segment length from Machette and others (1992), where L_s is the straight-line and L_t is the surface-trace distance.

SUMMARY

The Wasatch fault zone (WFZ) is one of the longest and most active normal-slip faults in the world, extending from southeastern Idaho to north-central Utah along the western edge of the Wasatch Range. The Salt Lake City (SLC) segment of the WFZ trends through the densely populated Salt Lake Valley, and has long been recognized as a potential source of large earthquakes that pose a risk to citizens living in this area. Previous studies at Little Cottonwood Canyon, South Fork Dry Creek, and Dry Gulch on the SLC segment indicated that at least four surface-faulting earthquakes occurred on this segment in the past 8,000-9,000 years; at least three events occurred in the past 6,000 years. However, a complete paleoseismic history for the SLC segment was not assured because all fault scarps at these sites were not trenched.

The UGS reoccupied the SFDC site to establish a complete earthquake chronology for the SLC segment since at least middle Holocene time. We excavated five trenches so that, when combined with the previous investigation, all fault scarps at this site were trenched. Evidence from these trenches refine timing for known surface-faulting earthquakes, and show a previously unrecognized earthquake (event X) that increases the total number of events in the past 6,000 years to four. Radiocarbon age estimates from DG and SFDC show these earthquakes occurred: (1) shortly after 1,300 (+250, -200) cal B.P. (event Z), (2) shortly after 2,450 ± 350 cal B.P. (event Y), (3) shortly after 3,950 (+550, -450) cal B.P. (event X), and (4) shortly after 5,300 (+450, -350) cal B.P. (event W).

New information from the SFDC site indicates that surface-faulting earthquakes on the SLC segment occur more frequently than previously thought. The addition of a new event roughly 3,950 years ago reduces the average recurrence interval of surface faulting in the past 6,000 years from 2,150 ± 400 years to 1,350 ± 200 years. Elapsed time since event Z (about 1,300 years) is close to this new shorter recurrence interval and within the assigned range of uncertainty, which suggests there is an increased risk for a future surface-faulting earthquake on the SLC segment. Evidence of antithetic faulting is obscured and was not exposed in our trenches. Therefore, we could not determine net vertical tectonic displacement at SFDC or estimate maximum earthquake magnitude of prehistoric earthquakes based on displacement. Based on length relations, estimated earthquake magnitude on the SLC segment is M_W 6.9, or M_S 7.1-7.2.

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APPENDIX

DESCRIPTION OF GEOLOGIC UNITS EXPOSED IN TRENCHES AT THE SOUTH FORK DRY CREEK AND DRY GULCH SITES, WASATCH FAULT ZONE, SALT LAKE COUNTY, UTAH

DC-1 AND DC-2 (PLATES 1A AND 1B)

Unit 1 — **ALLUVIAL-FAN DEPOSITS** - *Silty sand with gravel (SM)*[1]*, interbedded with clayey sand (SC) and lean clay with sand (CL) in trench DC-2; maximum clast size 550 mm; poorly to moderately stratified; locally indurated with* $CaCO_3$ *in trench DC-2.*

Paleosol S1 — **SOIL A HORIZON FORMED ON UNIT 1** - *Same description as unit 1; contains considerable organics.*

Unit 2 — **FAULT-SCARP COLLUVIUM**

- 2a *Colluvial wedge - Silty sand with gravel (SM); maximum clast size 550 mm; poorly stratified; derived primarily from unit 1.*
- 2b *Block of paleosol S1 in trench DC-1.*

Unit 3 — **DEBRIS FLOW** *(matrix supported) - Silty sand with gravel (SM); nonstratified; contains considerable organics.*

Paleosol S2 — **SOIL A HORIZON FORMED ON UNIT 3** - *Silty sand with gravel (SM); nonstratified; contains considerable organics.*

Unit 4 — **FAULT-SCARP COLLUVIUM**

- 4a *Colluvial wedge - Silty sand with gravel (SM); maximum clast size 550 mm; poorly stratified.*
- 4b *Block of paleosol S2 in trench DC-1.*
- 4c *Fissure fill in trench DC-1.*

Unit 5 — **SLOPE COLLUVIUM** - *Silty sand with gravel (SM); maximum clast size 120 mm; poorly stratified, locally well stratified.*

Soil S3 — **SOIL A HORIZON FORMED ON UNIT 5 IN TRENCH DC-1** (UNITS 1, 4a, AND 5 IN TRENCH DC-2) *- Silty sand with gravel (SM); poorly to well stratified; contains organics.*

DRY GULCH TRENCH (PLATE 1C)

Unit 1 — **LAKE BONNEVILLE TRANSGRESSIVE BEACH DEPOSIT** - *Silty sand with gravel (SM); very pale brown (10YR 7/3); maximum clast size 30 mm; nonstratified; appears to have been liquefied.*

Unit 2 — **LAKE BONNEVILLE DEEP-WATER DEPOSIT** - *Sandy lean clay (CL); light yellowish brown (10YR 6/4); maximum clast size 3 mm; well stratified; contains a thin red clay marker horizon.*

Unit 3 — **SAND BLOW** - *Poorly graded sand with silt and gravel (SP-SM); light yellowish brown (10YR 6/4); maximum clast size 20 mm; non- to poorly stratified; contains some krotovina; derived from unit 1.*

Unit 4 — **DEBRIS FLOW** *(matrix supported) - Sandy silt with gravel (SM); yellowish brown (10YR 5/4); maximum clast size 50 mm; nonstratified; numerous krotovina.*

Paleosol S1 — **SOIL A HORIZON FORMED ON UNIT 4** - *Sandy silt with gravel (SM); black (10YR 2/1); maximum clast size 50 mm; nonstratified; contains considerable organics, texture heavily influenced by organics.*

[1] *Classification of soils follows the Unified Soil Classification System (USCS) as per American Society for Testing and Materials (ASTM) Standard D2488-84 (Visual-Manual Procedure).*

Unit 5 — **COLLUVIAL WEDGE** - *Sandy silt with gravel (SM); brownish yellow (10YR 6/6); maximum clast size 40 mm; non- to poorly stratified; contains some organics from paleosol S1.*

Paleosol S2 — **SOIL A HORIZON FORMED ON UNIT 5** - *Sandy silt with gravel (SM); dark gray (10YR 4/1); maximum clast size 40 mm; non- to poorly stratified; contains considerable organics, but not as much as paleosol S1.*

Unit 6 — **COLLUVIAL WEDGE** - *Sandy silt with gravel (SM); yellowish brown (10YR 5/4) to brownish yellow (10 YR 6/6); maximum clast size 50 mm; non- to poorly stratified; derived primarily from unit 2.*

Soil S3 — **SOIL A HORIZON FORMED ON UNITS 4, 5, AND 6** - *Sandy silt with gravel (SM); gray (10YR 5/1); maximum clast size 50 mm; non- to poorly stratified; truncated by fill cut, likely the modern soil buried by fill.*

Unit 7 — **ARTIFICIAL FILL** - *Contains barbed wire; truncates units 2 and 6, and soil S3.*

TRENCH DC2-1 (PLATE 1D)

Unit 1 — **DEBRIS FLOW** *(matrix supported) - Sandy elastic silt (MH); yellowish brown (10YR 5/4); 10 percent gravel (4.75 mm - 76 mm)[2], 35 percent sand (0.074 mm - 4.75 mm), 55 percent fines (mm); maximum clast size[3] 50 mm; subangular to subrounded; medium toughness[4]; slow dilatancy[1]; medium dry strength[1]; nonstratified.*

Unit 2 — **DEBRIS FLOW** *(matrix supported) - Silty sand with gravel (SM); brown (10YR 5/3); 30 percent gravel, 50 percent sand, 20 percent fines; maximum clast size 150 mm; subangular; low toughness; slow to rapid dilatancy; low to medium dry strength; poorly stratified; elongate clasts parallel to flow direction with discontinuous sand lenses.*

Unit 3 — **DEBRIS FLOW** *(matrix supported) - Silty sand with gravel (SM); grayish brown (10YR 5/2); 25 percent gravel, 45 percent sand, 30 percent fines; maximum clast size 150 mm; subangular to subrounded; low toughness; slow to rapid dilatancy; low to moderate dry strength; poorly stratified; paleosol S1 on top of unit.*

Paleosol S1 — **SOIL A HORIZON FORMED ON UNIT 3** - *Silty sand with gravel (SM); very dark grayish brown (10YR 3/2); 20 percent gravel, 50 percent sand, 30 percent fines; maximum clast size 150 mm; subangular to subrounded; low toughness; slow to rapid dilatancy; low dry strength; poorly stratified; weakly developed.*

Unit 4 — **FAULT-ZONE MATERIAL AND FAULT-SCARP COLLUVIUM**

4a — *Fissure Fill - Silty sand with gravel (SM); Very dark grayish brown (10YR 3/2); 10 percent gravel, 70 percent sand, 20 percent fines; maximum clast size 50 mm; subangular to subrounded; low toughness; slow to rapid dilatancy; low dry strength; nonstratified.*

4b — *Colluvial Wedge - Silty sand with gravel (SM); dark grayish brown (10YR 4/2); 35 percent gravel, 50 percent sand, 15 percent fines; maximum clast size 80 mm; subangular to subrounded; low toughness; slow to rapid dilatancy; low to medium dry strength; nonstratified.*

Unit 5 — **SLOPE COLLUVIUM** - *Silty sand with gravel (SM); dark grayish brown (10YR 4/2); 35 percent gravel, 50 percent sand, 15 percent fines; maximum clast size 80 mm; subangular to subrounded; low toughness; slow to rapid dilatancy; low dry strength; poorly stratified; soil S2 on top of unit.*

Soil S2 — **SOIL A HORIZON FORMED ON UNIT 5** - *Silty sand with gravel (SM); very dark grayish brown (10YR 3/2); 35 percent gravel, 50 percent sand, 15 percent fines; maximum clast size 80 mm; subangular to subrounded; low toughness; slow to rapid dilatancy; low dry strength; poorly stratified.*

TRENCH DC2-2 (PLATE 1E)

ALLUVIAL-FAN DEPOSITS *(incised by a degraded free face of unknown origin).*

Unit 1 — 1a — *Debris Flow (matrix supported) - Composition varies from clayey gravel with sand (GC) to clayey sand with gravel (SC); light yellowish brown (10YR 6/4) to pale yellow (2.5Y 8/3); 20-35 percent gravel, 25-50 percent sand, 30-40 percent fines; maximum clast size 300 mm; subangular; medium*

[2]*Percentages reported for size fractions are field estimates.*

[3]*Predominantly quartz monzonite.*

[4]*Toughness, dilatancy, and dry strength were estimated using ASTM Standard D2488-84 (Visual-Manual Procedure); for coarse-grained units characteristics apply to the matrix (fine-grained portion).*

toughness; none to rapid dilatancy; medium to high dry strength; poorly to moderately stratified; reacts strongly with HCl, unit possibly altered by $CaCO_3$ deposition from ground water moving through cobbly and gravelly permeable zones.

1b *Debris Flow (matrix supported) - Gravelly lean clay with sand (CL); brown (7.5YR 5/4); 35 percent gravel, 20 percent sand, 45 percent fines; maximum clast size 300 mm; subangular to subrounded; medium toughness; none dilatancy; high dry strength; nonstratified; possibly unaltered unit 1A; very weak reaction to HCl; paleosol S1 on top of unit on the downthrown side of the fault.*

Paleosol S1 **WEAKLY DEVELOPED SOIL A HORIZON FORMED ON UNIT 1b** - *Gravelly lean clay with sand (CL); brown-dark brown (10YR 3/3); 35 percent gravel, 20 percent sand, 45 percent fines; maximum clast size 100 mm; subrounded; medium toughness; none dilatancy; high dry strength; nonstratified.*

Unit 2 **DEBRIS-FLOW DEPOSIT** *(matrix supported) - Silty sand with gravel (SM); brown (10YR 5/3); 25 percent gravel, 45 percent sand, 30 percent fines; maximum clast size 250 mm; subangular to subrounded; low toughness; none to slow dilatancy; low to medium dry strength; poorly stratified; weak reaction to HCl; mantles the degraded free face truncating unit 1.*

Unit 3 **COLLUVIAL WEDGE** - *Silty sand with gravel (SM); grayish brown (10YR 5/2); 35 percent gravel, 45 percent sand, 20 percent fines; maximum clast size 200 mm; subangular to subrounded; low toughness; rapid dilatancy; medium dry strength; nonstratified; includes blocks of unit 1b.*

Unit 4 **COLLUVIAL WEDGE** - *Silty gravel with sand (GM); dark brown (10YR 4/3); 50 percent gravel, 35 percent sand, 15 percent fines; maximum clast size 200 mm; subangular; low toughness; rapid dilatancy; low to medium dry strength; nonstratified.*

Unit 5 **SLOPE COLLUVIUM** - *Silty sand with gravel (SM); grayish brown (10YR 5/2); 25 percent gravel, 60 percent sand; 15 percent fines; maximum clast size 150 mm; subrounded; low toughness; rapid dilatancy; low dry strength; poorly to moderately stratified; soil S2 on top of unit.*

Soil S2 **SOIL A HORIZON FORMED ON UNIT 5** - *Silty sand with gravel (SM); grayish brown (10YR 5/2); 30 percent gravel, 55 percent sand, 15 percent fines; maximum clast size 200 mm; subrounded; low toughness; rapid dilatancy; low dry strength; poorly to moderately stratified.*

TRENCH DC2-3 (PLATE 1F)

Unit 1 **DEBRIS FLOW** *(matrix supported) - Well-graded gravel with sand (GW); light yellowish brown (10YR 6/4); 50 percent gravel, 45 percent sand, 5 percent fines; maximum clast size 1,300 mm, grusified quartz monzonite boulders; subrounded to rounded; low toughness; rapid dilatancy; low dry strength; poorly to moderately stratified on upthrown side of the fault, well stratified sand layers on downthrown side; paleosol S1 on top of unit on the downthrown side of the fault, soil S2 on top of unit on the upthrown side.*

Paleosol S1 **SOIL A HORIZON FORMED ON UNIT 1** - *Well-graded sand with silt and gravel (SW-SM); dark grayish brown (10YR 4/2); 30 percent gravel, 60 percent sand, 10 percent fines; maximum clast size 50 mm; subangular; low toughness; rapid dilatancy; low to medium dry strength; poorly stratified; truncated by fill cut to west.*

Unit 2 **FAULT-ZONE MATERIAL AND FAULT-SCARP COLLUVIUM**

2a *Fissure Fill - Well-graded sand with gravel (SW); yellowish brown (10YR 5/4); 35 percent gravel, 60 percent sand, 5 percent fines; maximum clast size 120 mm; subangular to angular; low toughness; rapid dilatancy; low to medium dry strength; nonstratified.*

2b *Colluvial Wedge - Well-graded sand with silt and gravel (SW-SM); pale brown to dark brown (10YR 6/3 - 10YR 4/3); 30 percent gravel, 60 percent sand, 10 percent fines; maximum clast size 250 mm; subangular to subrounded; low toughness; rapid dilatancy; low to medium dry strength; nonstratified to poorly stratified; soil S2 formed on top of unit, truncated by fill cut to west.*

2c *Block of paleosol S1.*

2d *Block of unit 1.*

Soil S2 **SOIL A HORIZON FORMED ON UNITS 1 AND 2b** - *Well-graded sand with silt and gravel (SW-SM); dark grayish brown (10YR 4/2); 30 percent gravel, 60 percent sand, 10 percent fines; maximum clast size 50 mm; subangular; low toughness; rapid dilatancy; low to medium dry strength; poorly stratified; truncated by fill cut to west.*

TRENCH DC2-4 (PLATE 1G)

Unit 1 **DEBRIS FLOW** *(matrix supported) - Well-graded gravel with sand (GW); pale brown (10YR 6/3); 55 percent gravel, 40 percent sand, 5 percent fines; maximum clast size 700 mm; subangular to subrounded; low toughness; rapid dilatancy; low to medium dry strength; poorly stratified with bedded sand lenses; upper contact unconformable with unit 3, truncated to west by degraded scarp free faces from faults F2 and F3.*

Unit 2 **COLLUVIAL WEDGE** - *Well-graded sand with gravel (SW); grayish brown (10YR 5/2); 45 percent gravel, 50 percent sand, 5 percent fines; maximum clast size 450 mm; subangular to subrounded; low toughness; rapid dilatancy; low dry strength; nonstratified; paleosol S1 formed on top of unit, truncated to the west by a degraded scarp free face from fault F2; contains few organics.*

Paleosol S1 **SOIL A HORIZON FORMED ON UNIT 2** - *Well-graded sand with gravel (SW); dark grayish brown (10YR 4/2); 45 percent gravel, 50 percent sand, 5 percent fines; maximum clast size 250 mm; subangular to subrounded; low toughness; rapid dilatancy; low dry strength; nonstratified; truncated to the west by a degraded scarp free face from fault F2; considerable modern root penetration and organics.*

Unit 3 **COLLUVIAL WEDGE** - *Well-graded sand with gravel (SW); very-dark grayish brown (10YR 3/2); 30 percent gravel, 60 percent sand, 10 percent fines; maximum clast size 1,300 mm; subangular; low toughness; rapid dilatancy; low dry strength; nonstratified; truncated to the west by unit 4; contains organics.*

Unit 4 **DEBRIS FLOOD** *(matrix supported) - Silty sand with gravel (SM); dark grayish brown (10YR 4/2); 35 percent gravel, 50 percent sand, 15 percent fines; maximum clast size 200 mm; subangular to rounded; low toughness; rapid dilatancy; low dry strength; poorly to moderately stratified, interbedded sand and gravel layers with elongate clasts parallel to the flow direction; truncates unit 3; contains organics.*

Unit 5 **DEBRIS FLOW** *(matrix supported) - Well-graded sand with silt and gravel (SW-SM); dark brown (10YR 4/3); 45 percent gravel, 45 percent sand, 10 percent fines; maximum clast size 450 mm; angular to subangular; low toughness; rapid dilatancy; low dry strength; poorly to moderately stratified, bedded sand layers incorporating boulders, cobbles, and gravel; contains organics.*

Unit 6 **FAULT-ZONE MATERIAL AND FAULT-SCARP COLLUVIUM**

6a *Sheared material from units 1 and 2.*

6b Colluvial wedge - *Well-graded gravel with silt and sand (GW-GM); dark grayish brown (10YR 4/2); 50 percent gravel, 40 percent sand, 10 percent fines; maximum clast size 500 mm; angular to subrounded; low toughness; rapid dilatancy; low dry strength; nonstratified, except upper portion poorly stratified (slope wash?); upper contact indistinct; soil S2 formed on top of unit; contains organics.*

Unit 7 **COLLUVIAL WEDGE** - *Well-graded gravel with sand (GW); light yellowish brown (10YR 6/4); 60 percent gravel, 40 percent sand, trace fines; maximum clast size 400 mm; angular to subangular; low toughness; rapid dilatancy; low dry strength; nonstratified, except upper portion poorly stratified (slope wash?); soil S2 formed on top of unit; contains organics.*

Unit 8 **DEBRIS FLOW** *(matrix supported) - Well-graded sand with silt and gravel (SW-SM); dark brown (10YR 4/3); 45 percent gravel, 45 percent sand, 10 percent silt; maximum clast size 250 mm; subangular to rounded; low toughness; rapid dilatancy; low dry strength; poorly stratified; soil S2 formed on top of unit; contains organics.*

Soil S2 **SOIL A HORIZON FORMED ON UNITS b, 7, AND 8** - *Well-graded gravel with sand (GW-GM); very-dark grayish brown (10YR 3/2); 50 percent gravel, 40 percent sand, 10 percent fines; maximum clast size 250 mm; subangular to subrounded; low toughness; rapid dilatancy; low dry strength; poorly stratified; contains numerous roots and considerable organics, soil development thicker to the west.*

TRENCH DC2-5 (PLATE 1H)

Unit 1 **DEBRIS FLOW** *(matrix supported) - Clayey sand (SC); light gray (10YR 7/2); 5-10 percent gravel, 50-55 percent sand, 40 percent fines; maximum clast size 70 mm; subrounded to rounded; medium toughness; none dilatancy; low to medium dry strength; poorly to moderately stratified; strong reaction to HCl; possibly unit 1a in trench DC2-2.*

Unit 2 **DEBRIS FLOW** *(generally matrix supported with clast-supported pockets) - Well-graded gravel with clay and sand (GW-GC); light brown (7.5YR 6/4); 45-50 percent gravel, 40-45 percent sand, 10 percent fines; maximum clast size 150 mm; angular to subangular; low to medium toughness; slow dilatancy; low to medium dry strength; poorly stratified; pockets of cobbles and gravel east of fault F2, finer grained to the west.*

Unit 3 **DEBRIS FLOW** *(matrix supported) - Sandy lean clay (CL); very pale brown (10YR 7/4); 5-10 percent gravel, 40-45 percent sand, 50 percent fines; maximum clast size 30 mm; subangular; medium toughness; none to slow dilatancy; medium to high dry strength; poorly stratified.*

Unit 4 **SLOPE COLLUVIUM/TALUS** *(uncertain origin); Well-graded gravel with sand (GW); strong brown (10YR 5/6); 70 percent gravel, 30 percent sand; maximum clast size 200 mm; angular to subangular; low toughness; rapid dilatancy; low dry strength; nonstratified; forms wedge-shaped pocket displaced along fault F1.*

Unit 5 **DEBRIS FLOW** *(matrix supported) - Clayey sand with gravel (SC); light yellowish brown (10YR 6/4); 35 percent gravel, 40 percent sand, 25 percent fines; maximum clast size 100 mm; subangular; low to medium toughness; slow to rapid dilatancy; low to medium dry strength; poorly stratified.*

Unit 6 **DEBRIS FLOW** *(matrix supported) - Silty sand with gravel (SM); brown (10YR 5/3); 30 percent gravel; 55 percent sand, 15 percent fines; maximum clast size 100 mm; angular to subangular; low toughness; rapid dilatancy; medium dry strength; poorly stratified; paleosol S1 formed on top of unit.*

Paleosol S1 **SOIL A HORIZON FORMED ON UNIT 6** - *Silty sand with gravel (SM); dark brown (10YR 4/3); 30 percent gravel, 55 percent sand, 15 percent fines; maximum clast size 30 mm; subangular to subrounded; low toughness; rapid dilatancy; medium dry strength; poorly stratified; some organics.*

Unit 7 **COLLUVIAL WEDGE/SLUMP DEPOSIT *(uncertain origin)*** - *Silty sand with gravel (SM); dark grayish brown (10YR 4/2); 25 percent gravel, 60 percent sand, 15 percent fines; maximum clast size 30 mm; angular to subrounded; low toughness; rapid dilatancy; low dry strength; nonstratified; contains numerous blocks of units 1, 2, 3, and 5 with intact bedding, possibly deposited by post-event slumping; blocks are surrounded by organic-rich material.*

Unit 8 **COLLUVIAL WEDGE** - *Well-graded sand with silt and gravel (SW-SM); very-dark grayish brown (10YR 3/2); 20 percent gravel, 70 percent sand, 10 percent fines; maximum clast size 100 mm; subangular to subrounded; low toughness; rapid dilatancy; low dry strength; nonstratified; considerable organics.*

Unit 9 **SLOPE COLLUVIUM** - *Well-graded sand with silt and gravel (SW-SM); dark brown (10YR 3/3); 15 percent gravel, 75 percent sand, 10 percent fines; maximum clast size 120 mm; subangular; low toughness; rapid dilatancy; low dry strength; poorly stratified; soil S2 formed on top of unit.*

Soil S2 **SOIL A HORIZON FORMING ON UNIT 9** - *Well-graded sand with silt and gravel (SW-SM); dark brown (10YR 3/3); 15 percent gravel, 75 percent sand, 10 percent fines; maximum clast size 120 mm; subangular; low toughness; rapid dilatancy; low dry strength; poorly stratified.*

Plate 1. Trench logs

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Plate 1A. Log of fault zone in the south wall of trench DC-1, South Fork Dry Creek site, Wasatch fault zone, Utah.

EXPLANATION

SYMBOLS

- Rock
- Contact, dashed where indistinct
- Bedding in sands
- Fault, dashed where indistinct (arrows indicate relative movement)
- Degraded scarp free face, dashed where indistinct
- Paleosol and soil A horizons
- Krotovina (animal burrow)
- Radiocarbon bulk sample location and calendar-calibrated age estimate

UNIT DESCRIPTIONS

1. Alluvial-fan deposits.
S1. Paleosol A horizon formed on unit 1.
2. Fault-scarp colluvium.
   2a. Colluvial wedge.
   2b. Block of paleosol S1.
3. Debris flow (matrix supported).
S2. Paleosol A horizon formed on unit 3.
4. Fault-scarp colluvium.
   4a. Colluvial wedge.
   4b. Block of paleosol S2.
   4c. Fissure fill.
5. Slope colluvium.
S3. Soil A horizon formed on unit 5.

Mapped by William R. Lund and David P. Schwartz
Planimetric base constructed on a 1m x 1m grid
Drafted by Lori Douglas

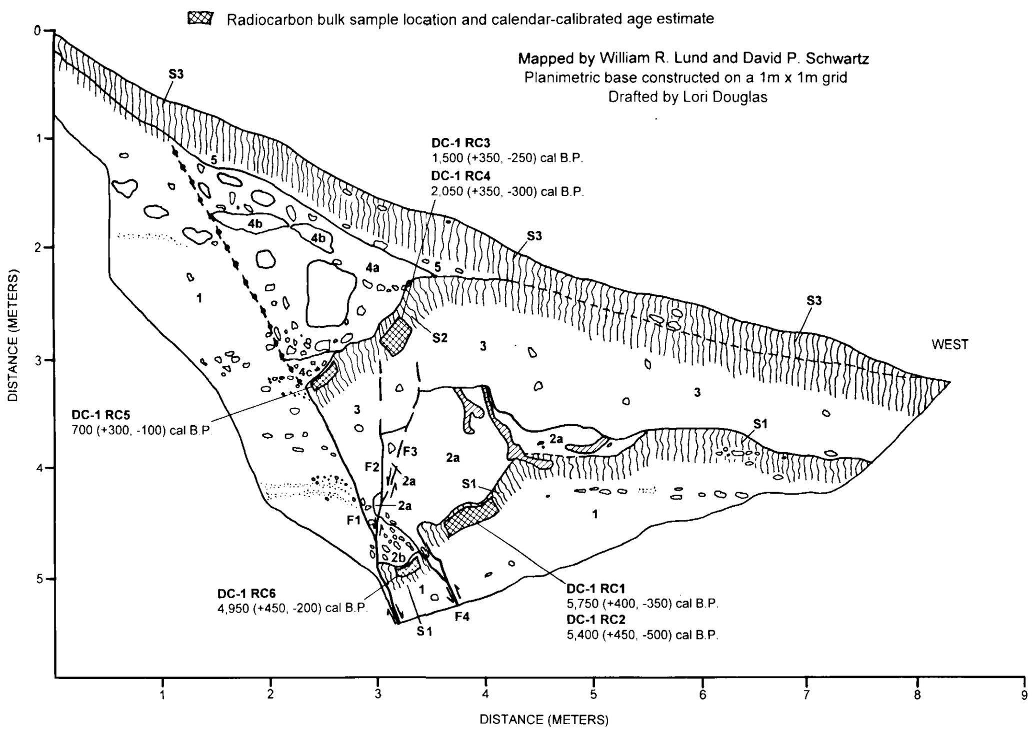

Plate 1B. Log of fault zone in the south wall of trench DC-2, South Fork Dry Creek site, Wasatch fault zone, Utah.

EXPLANATION

SYMBOLS

- Rock
- Contact, dashed where indistinct
- Bedding in sands
- Fault, dashed where indistinct (arrows indicate relative movement)
- Crack, dashed where indistinct
- Degraded scarp free face, dashed where indistinct
- Paleosol and soil A horizons
- Krotovina (animal burrow)
- Radiocarbon bulk sample location and calendar-calibrated age estimate

UNIT DESCRIPTIONS

1. Alluvial-fan deposits.
S1. Paleosol A horizon formed on unit 1.
2. Fault-scarp colluvium.
   2a. Colluvial wedge.
3. Debris flow (matrix supported).
S2. Paleosol A horizon formed on unit 3.
4. Fault-scarp colluvium.
   4a. Colluvial wedge.
5. Slope colluvium.
S3. Soil A horizon formed on units 1, 4a, and 5.

Mapped by Harold E. Gill and Kimm M. Harty
Planimetric base constructed on a 1m x 1m grid
Drafted by Bea H. Mayes

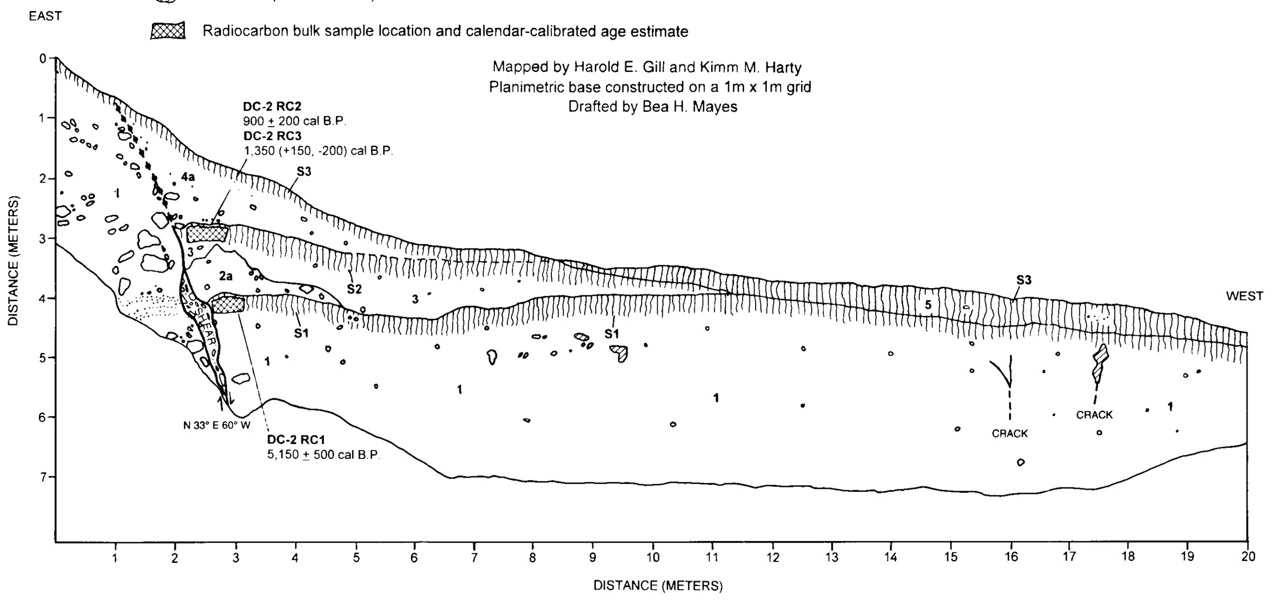

Plate 1C. Log of fault zone in the south wall of the Dry Gulch trench, Dry Gulch site, Wasatch fault zone, Utah.

EXPLANATION

SYMBOLS

- Rock
- Contact, dashed where indistinct
- Bedding in sands
- Bedding in fine-grained sediments
- Fault, dashed where indistinct (arrows indicate relative movement)
- Degraded scarp free face, dashed where indistinct
- Paleosol and soil A horizons
- Krotovina (animal burrow)
- Radiocarbon bulk sample location and calendar-calibrated age estimate

UNIT DESCRIPTIONS

1. Lake Bonneville transgressive beach deposit.
2. Lake Bonneville deep-water deposit.
3. Sand blow.
4. Debris flow (matrix supported).
S1. Paleosol A horizon formed on unit 4.
5. Colluvial wedge.
S2. Paleosol A horizon formed on unit 5.
6. Colluvial wedge.
S3. Soil A horizon formed on units 4, 5, and 6.
7. Artificial fill.

Mapped by William R. Lund and Bill D. Black
Planimetric base constructed on a 1m x 1m grid
Drafted by Lori Douglas

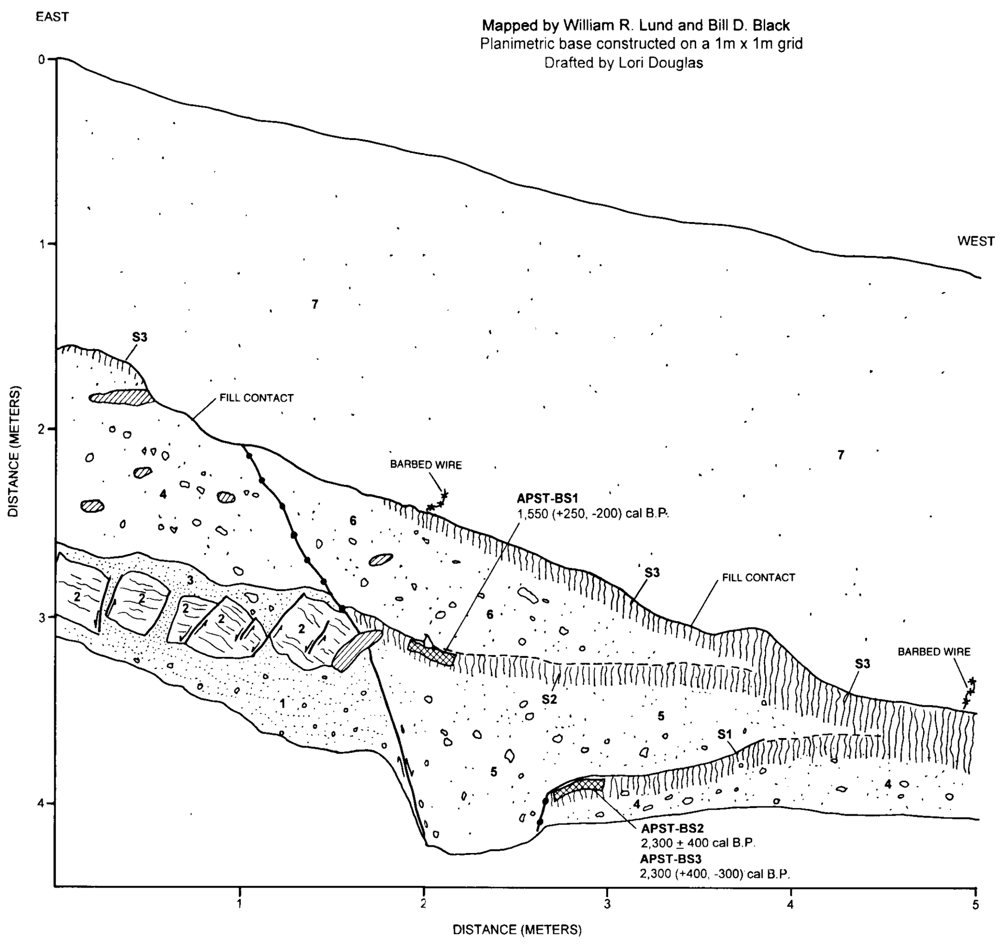

Plate 1D. Log of fault zone in the south wall of trench DC2-1, South Fork Dry Creek site, Wasatch fault zone, Utah.

EXPLANATION

SYMBOLS

- Rock
- Contact, dashed where indistinct
- Bedding in sands
- Fault, dashed where indistinct (arrows indicate relative movement)
- Degraded free face, dashed where indistinct
- Paleosol and soil A horizons
- Krotovina (animal burrow)
- Radiocarbon bulk sample location and calendar-calibrated age estimate

UNIT DESCRIPTIONS

1. Debris flow (matrix supported).
2. Debris flow (matrix supported).
3. Debris flow (matrix supported).
S1. Paleosol A horizon formed on unit 3.
4. Fault-zone colluvium.
   4a. Fissure fill.
   4b. Colluvial wedge.
5. Slope colluvium.
S2. Soil A horizon formed on unit 5.

Mapped by Bill D. Black, William R. Lund, and Michael D. Hylland
Planimetric base constructed on a 1 m x 1 m grid
Drafted by Noah P. Snyder

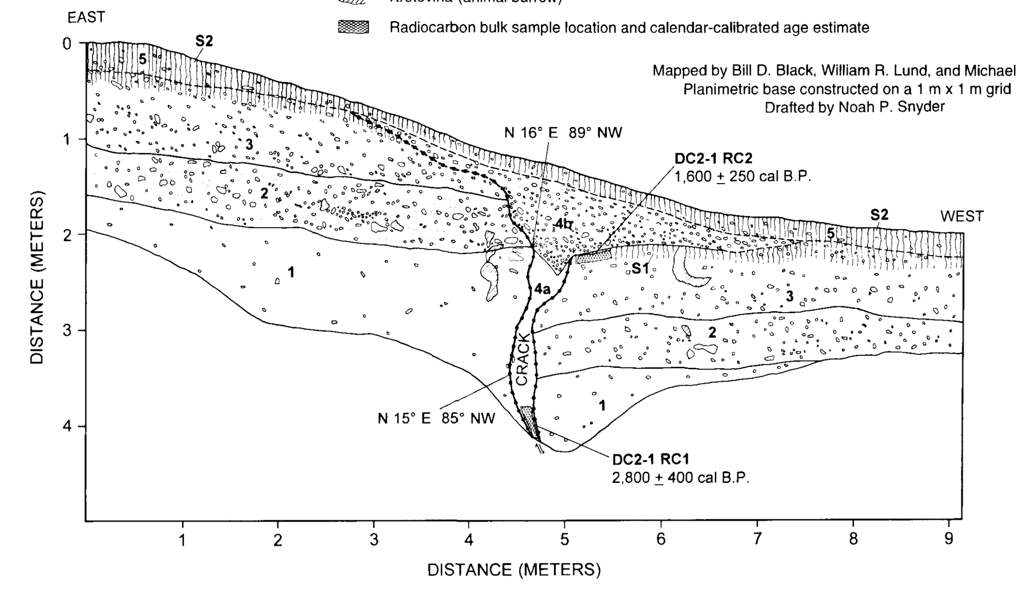

Plate 1E. Log of fault zone in the south wall of trench DC2-2, South Fork Dry Creek site, Wasatch fault zone, Utah.

EXPLANATION

SYMBOLS

- Rock
- Contact, dashed where indistinct
- Bedding in fine-grained sediments and calcium carbonate-rich layers
- Fault, dashed where indistinct (arrows indicate relative movement)
- Degraded free face, dashed where indistinct
- Paleosol and soil A horizons
- Radiocarbon bulk sample location and calendar-calibrated age estimate

UNIT DESCRIPTIONS

1. Alluvial-fan deposits cut by an old degraded free face (fault and colluvium not exposed).
   1a. Debris flow (matrix supported, $CaCO_3$ rich).
   1b. Debris flow (matrix supported).
S1. Paleosol A horizon formed on unit 1b.
2. Debris flow (matrix supported) mantling an old degraded free face.
3. Colluvial wedge.
4. Colluvial wedge.
5. Slope colluvium.
S2. Soil A horizon formed on unit 5.

Mapped by Bill D. Black, William R. Lund, Gary E. Christenson, and Rebecca L. Hylland
Planimetric base constructed on a 1 m x 1 m grid
Drafted by Noah P. Snyder

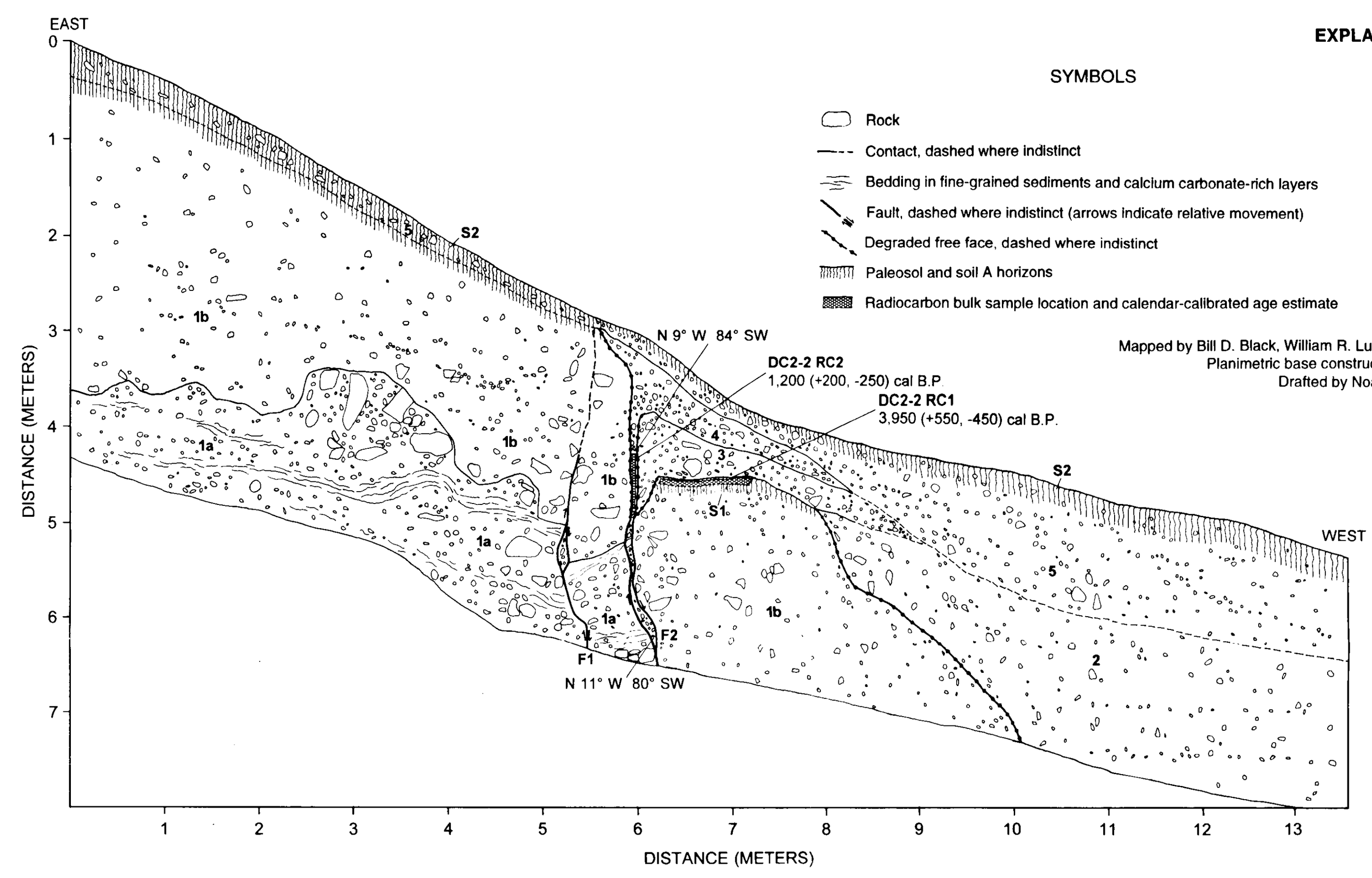

Plate 1F. Log of fault zone in the south wall of trench DC2-3, South Fork Dry Creek site, Wasatch fault zone, Utah.

EXPLANATION

SYMBOLS

- Rock
- Contact, dashed where indistinct
- Bedding in sands
- Fault, dashed where indistinct (arrows indicate relative movement)
- Degraded scarp free face, dashed where indistinct
- Paleosol and soil A horizons
- Man-made fill
- Radiocarbon bulk sample location and calendar-calibrated age estimate

UNIT DESCRIPTIONS

1. Debris flow (matrix supported).
S1. Paleosol A horizon soil formed on unit 1.
2. Fault-zone colluvium.
   2a. Fissure fill.
   2b. Colluvial wedge.
   2c. Block of paleosol S1 in unit 2b.
   2d. Block of unit 1 in unit 2b.
S2. Soil A horizon formed on units 1 and 2b.

Mapped by Bill D. Black, William R. Lund, and Bea H. Mayes
Planimetric base constructed on a 1 m x 1 m grid
Drafted by Noah P. Snyder

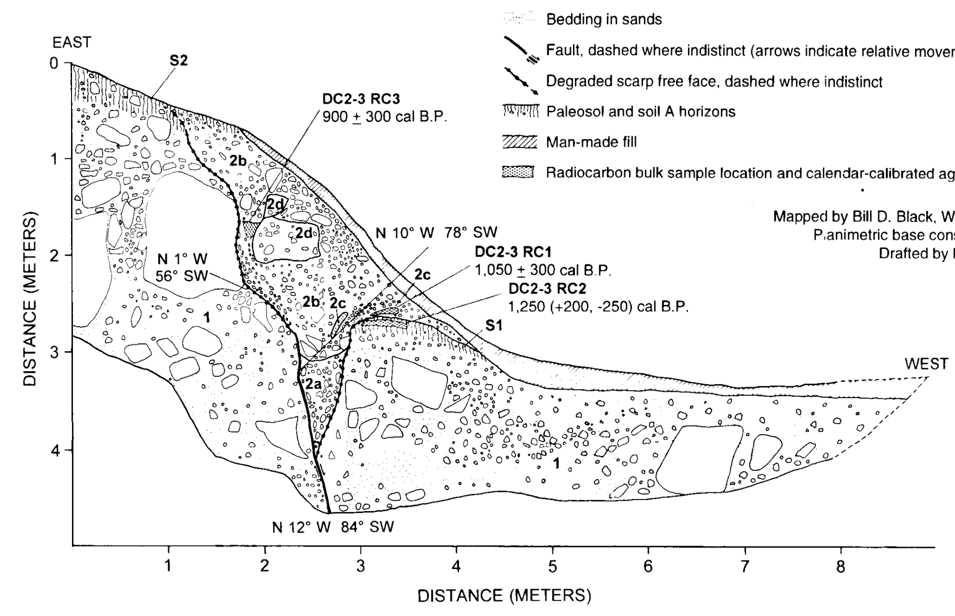

Plate 1G. Log of fault zone in the south wall of trench DC2-4, South Fork Dry Creek site, Wasatch fault zone, Utah.

EXPLANATION

SYMBOLS

- Rock
- Contact, dashed where indistinct
- Bedding in sands
- Fault, dashed where indistinct (arrows indicate relative movement)
- Degraded scarp free face, dashed where indistinct
- Paleosol and soil A horizons
- Krotovina (animal burrow)
- Radiocarbon bulk sample location and calendar-calibrated age estimate

UNIT DESCRIPTIONS

1. Debris flow (matrix supported).
2 Colluvial wedge.
S1. Paleosol A horizon formed on unit 2.
3. Colluvial wedge.
4. Debris flood (matrix supported).
5. Debris flow (matrix supported).
6. Fault-zone colluvium.
   6a. Sheared material from units 1 and 2.
   6b. Colluvial wedge.
7. Colluvial wedge.
8. Debris flow (matrix supported).
S2 Soil A horizon formed on units 6b, 7, and 8.

Mapped by Bill D. Black, William R. Lund, and Bea H. Mayes
Planimetric base constructed on a 1 m x 1 m grid
Drafted by Noah P. Snyder

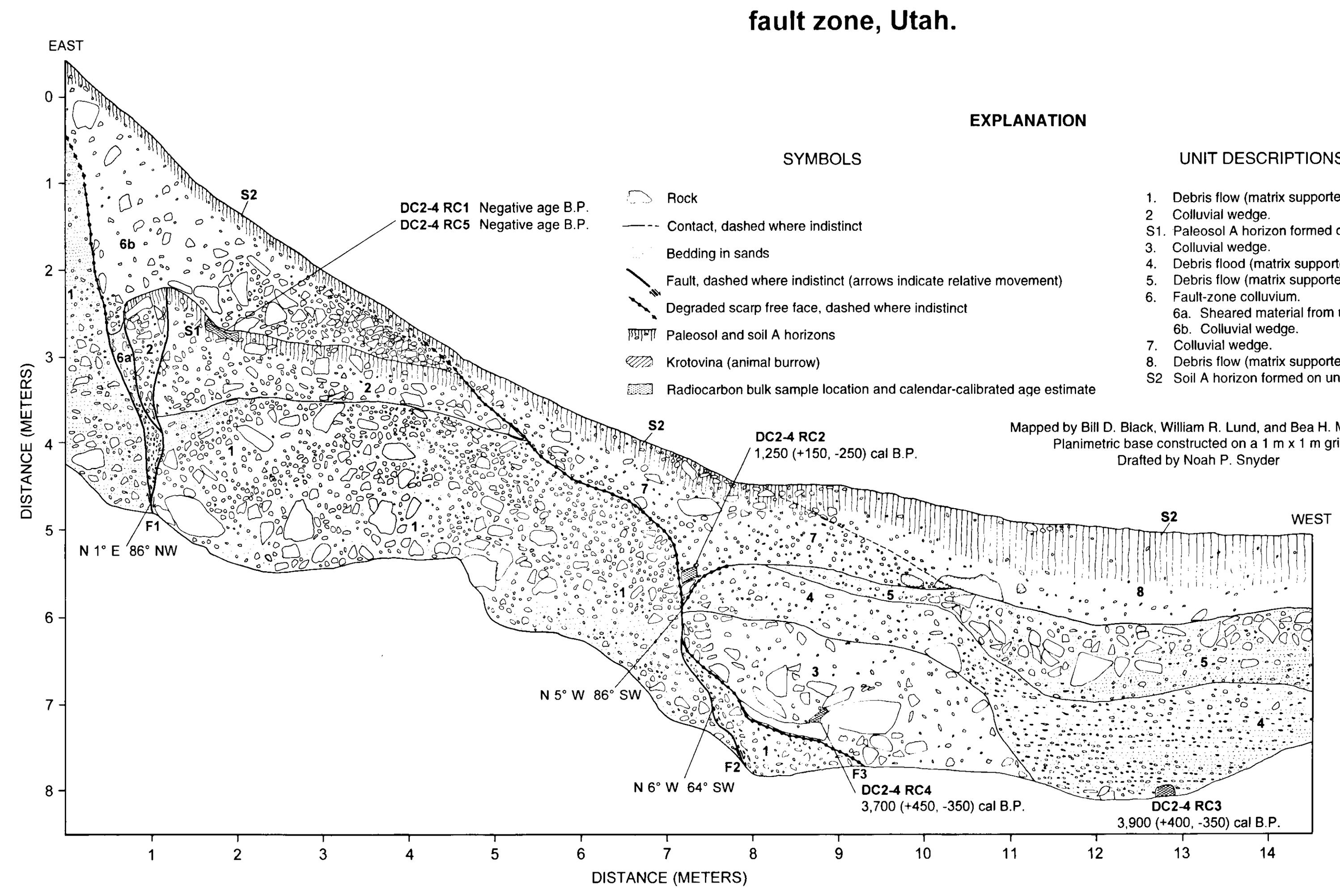

Plate 1H. Log of fault zone in the south wall of trench DC2-5, South Fork Dry Creek site, Wasatch fault zone, Utah.

EXPLANATION

SYMBOLS

- Rock
- Contact, dashed where indistinct
- Bedding in sands
- Bedding in fine-grained sediments and calcium carbonate-rich layers
- Fault, dashed where indistinct (arrows indicate relative movement)
- Crack, dashed where indistinct (fill of mixed origin)
- Degraded free face, dashed where indistinct
- Paleosol and soil A horizons
- Radiocarbon bulk sample location and calendar-calibrated age estimate

UNIT DESCRIPTIONS

1. Debris flow (matrix supported, $CaCO_3$ rich).
2. Debris flow (matrix supported, locally clast supported).
3. Debris flow (matrix supported).
4. Slope colluvium/talus (uncertain origin).
5. Debris flow (matrix supported).
6. Debris flow (matrix supported).
S1. Paleosol A horizon formed on unit 6.
7. Colluvium/slump deposit (uncertain origin).
8. Colluvial wedge.
9. Slope colluvium.
S2. Soil A horizon soil formed on unit 9.

Mapped by Bill D. Black, William R. Lund, Bea H. Mayes, and Rebecca L. Hylland
Planimetric base constructed on a 1 m x 1 m grid
Drafted by Noah P. Snyder