2351, WASATCH FAULT ZONE

Structure number: 2351.
Comments:
Structure name: Wasatch fault zone (WFZ).
Comments:
Synopsis: The WFZ is one of the longest and most tectonically active normal faults in North America. The fault zone shows abundant evidence of recurrent Holocene surface faulting and has been the subject of detailed studies for over three decades (for example, Schwartz and Coppersmith, 1984; Machette and others, 1991, 1992). Half of the estimated 50 to 120 post-Bonneville surface-faulting earthquakes in the Wasatch Front region have been on the WFZ (Hecker, 1993).
Date of compilation: 8/01.
Compiler and affiliation: Bill D. Black, Mike Hylland, and Greg N. McDonald (Utah Geological Survey), and Suzanne Hecker (U.S. Geological Survey).
State: Utah, Idaho.
County: Box Elder, Weber, Davis, Salt Lake, Utah, and Juab; Oneida.
1° x 2° sheet: Brigham City, Ogden, Salt Lake City, and Price.
Province: Basin and Range.
Geologic setting: Generally north-trending range-bounding normal fault along the western side of the Malad Range (Clarkston Mountain), Wellsville Mountains, Wasatch Range, and San Pitch Mountains. The WFZ marks the eastern boundary of the Basin and Range in northern Utah. Allluvial-fan sediment and deposits of Pleistocene Lake Bonneville dominate the surficial geology along the fault zone. The Wasatch Range is several kilometers higher than valleys to the west and is the result of repeated fault movement in Cenozoic time.
Number of sections: 10.
Comments: The WFZ is divided into 10 discrete, independent sections, totaling 343 kilometers in length. The sections are thought to represent segments (Schwartz and Coppersmith, 1984; Machette and others, 1991). The southern eight sections are wholly in Utah; the Clarkston section straddles Idaho and Utah, and the northernmost (Malad City) section is in Idaho. The chronology of surface-faulting earthquakes on the fault is one of the better dated in the world and includes 16 earthquakes since 5.6 ka, with an average repeat time of 350 years (McCalpin and Nishenko, 1996). Four of the central five sections (2351E-H) ruptured between 600 and 1,250 years ago; the remaining section (Brigham City, 2351d) has not ruptured in the past 2,125 years (McCalpin and Forman, 1994: McCalpin and Nishenko, 1996). Slip rates of 1-2 millimeters/year are typical for the central sections during Holocene time. In contrast, late Quaternary (<150-250 ka) slip rates on these sections are about 0.1-0.3 millimeters/year, an order of magnitude lower than the Holocene rates. This suggests a causal relation between increased slip rates and isostatic rebound/crustal relaxation following deep lake cycles such as Bonneville (Machette and others, 1986, 1992). Based on comparisons with historical surface fault ruptures in the region, the central fault sections may produce up to magnitude (M_s) 7.5-7.7 earthquakes. McCalpin and Nishenko (1996) suggest the probability for a surface-faulting earthquake somewhere on the fault is 13 and 25 percent in the next 50 and 100 years, respectively.

Length: End to end (km): 308
Cumulative trace (km): 566
Average strike (azimuth): N6°W

2351b, CLARKSTON MOUNTAIN SECTION

Section number: 2351b.
Section name: Clarkston Mountain section.
Comments: Hecker's (1993) fault number 6-16.
Reliability of location: Good.
Comments: Mapped or discussed by Cluff and others (1974), Machette and others (1992), and Biek and others (2000). Mapping from Cluff and others (1974). Part of the section is in Idaho.
Sense of movement: N.
Comments:
Dip: No data.
Comments:
Dip direction: W.
Geomorphic expression: Steep linear escarpment along the western flank of the Malad Range (Clarkston Mountain). Section boundaries are based on structural and geomorphic relations only and are more tenuous than the boundaries of other WFZ sections to the south. Machette and others (1992) place the boundary between the Clarkston Mountain and Collinston sections at Short Divide, which is marked by a prominent east-striking down-to-the-south normal fault that places Tertiary lacustrine sediment against Paleozoic rock.
Age of faulted deposits: Late Pleistocene.
Paleoseismology studies: None.
Timing of most recent paleoevent: (3) Late Quaternary (<130 ka).
Comments: Regressional shorelines below the Provo level wrap around, and thus postdate, a probable fault escarpment, and deep-water sediments of Lake Bonneville are not faulted.
Recurrence interval: No data.
Comments:
Slip rate: Unknown, probably <0.2 mm/yr.
Comments:
Length: End to end (km): 10
Cumulative trace (km): 16
Average strike (azimuth): N5°W

2351c, COLLINSTON SECTION

Section number: 2351c.
Section name: Collinston section.
Comments: Hecker's (1993) fault number 6-5.

Reliability of location: Good to poor.

Comments: The location of the Collinston section north of the Wellsville Mountains is poorly constrained and subject to interpretation. Gravity data and topography suggested to Machette and others (1992) that the fault is west of the Junction Hills (the low hills north of the Wellsville Mountains), and ends where it intersects the prominent east-trending Short Divide fault at the south end of Clarkston Mountain. Cluff and others (1974) mapped the WFZ as continuous around the south end of Clarkston Mountain, whereas Machette and others (1992) recognized a 7-kilometer left step and gap in late Pleistocene faulting between the Collinston and Clarkston Mountain sections, and interpreted Cluff and others' (1974) supposed connecting fault as a shoreline. Goessel and others (1999) suggest that at the northern end of the Wellsville Mountains, displacement on the Collinston section is transferred several kilometers eastward to the Beaver Dam fault; they tentatively suggest the northern boundary of the Collinston section is in the area between the northern Wellsville Mountains and the Cache Butte divide. Mapping from Doelling (1980), Machette and others (1992), Oviatt (1986a,b), and Personius (1990).

Sense of movement: N.

Comments:

Dip: No data.

Comments:

Dip direction: W.

Geomorphic expression: West-facing escarpment along the western flank of the Malad Range (Clarkston Mountain) and Wellsville Mountains. Machette and others (1992) place the boundary between the Collinston and Brigham City sections at a reentrant near the mouth of Jim May Canyon, 2 kilometers northeast of Honeyville, where the trend of the fault and amount of pre-Bonneville displacement changes.

Age of faulted deposits: Late Pleistocene.

Paleoseismology studies: None.

Timing of most recent paleoevent: (3) Late Quaternary (<130 ka).

Comments: Faulting generally predates the transgressive phase of Lake Bonneville (~30 ka). A 2-kilometer-long scarp in alluvium (equivalent in age to the Provo level of Lake Bonneville) at the south end of the section is probably related to sympathetic or subsidiary rupturing from faulting on the Brigham City section. The remainder of the section shows no evidence of Holocene faulting (Machette and others, 1992).

Recurrence interval: No data.

Comments:

Slip rate: (D) <0.2 mm/yr.

Comments: At the south end of the section, alluvium estimated from soil-profile development to be several hundred thousand years old is displaced 12 meters.

Length: End to end (km): 30
Cumulative trace (km): 37

Average strike (azimuth): N21°W

2351d, BRIGHAM CITY SECTION

Section number: 2351d.
Section name: Brigham City section.
Comments: Hecker's (1993) fault number 6-6.
Reliability of location: Good.
Comments: Mapping from Personius (1990).
Sense of movement: N.
Comments:
Dip: 65-80°W (Personius, 1991).
Comments: 65-80°W at Bowden Canyon trench in fluvial and debris-flow deposits; 70-80°W at Pleasant View trench in lacustrine deposits.
Dip direction: W.
Geomorphic expression: West-facing scarps along the western base of the Wellsville Mountains and Wasatch Range. Scarps on the valley floor between Willard and Brigham City may be associated with incipient lateral spreads, but have orientations and relief consistent with a faulting origin. In the southern part of the section,15- to 20-meter-high scarps on a Provo-level delta suggest as many as 6-10 surface-faulting events occurred since about 16 ka (assuming an average displacement per event of 2+ meters). However, only a few short, discontinuous scarps are in upper Holocene deposits near the southern section boundary, which is in contrast to the abundance of Holocene scarps on the Weber section to the south. Displacement per event is from 1.0 to 2.5 meters.
Age of faulted deposits: Holocene.
Paleoseismology studies: A trench excavated in 1986 across a fault scarp on the Bowden Canyon alluvial fan (Brigham City trench; site 2351d-1), east of Brigham City, exposed evidence for three surface-faulting earthquakes (Personius, 1991). The oldest of these events could not be directly dated. Radiocarbon age estimates on bulk-soil samples from paleosols and the base of the modern soil provide limiting ages for the penultimate and most recent events on the fault. Timing of the penultimate event may correlate with the timing of the most recent surface-faulting earthquake documented in a trench across a fault scarp on the Pleasant View salient (Pole Patch trench; site 2351d-3), about 20 kilometers south of the Brigham City trench (Personius, 1991). This scarp is associated with a short, off-trend fault in the area of the boundary between the Brigham City and Weber sections of the Wasatch fault. The trench exposed evidence for three surface-faulting earthquakes. Although a bulk-soil sample yielded a radiocarbon age estimate that closely approximates the age of the most recent event, other radiocarbon ages only poorly constrain the timing of the older events.

In 1992 and 1993, 14 additional trenches were excavated across scarps of the Brigham City section to lengthen the paleoseismic record for this fault (McCalpin and Forman, 1994). These trenches were on the Provo-level delta at the mouth of Box Elder Canyon (site 2351d-2). In total, the trenches exposed evidence for five, or possibly six, surface-faulting events. Earthquake timing is constrained by limiting ages obtained from radiocarbon and thermoluminescence dating of bulk soil samples. The most recent event here (event Z) is younger than the most recent event at the Brigham City trench; the timing of that earthquake correlates well with event Y here. Evidence was not observed for an earthquake correlative with the penultimate event at the Brigham City trench. A relatively wide range in limiting ages for event V suggests either a poorly constrained single event, or two separate events. McCalpin and Nishenko (1996) prefer the two-event interpretation, resulting in a total of seven paleoearthquakes on the Brigham City section since 13 ka.

Timing of most recent paleoevent: (2) Latest Quaternary (<15 ka).

Comments: The Brigham City section is the northernmost WFZ section that exhibits clear evidence of recurrent Holocene faulting along its entire length (Personius, 1988; Machette and others, 1992). McCalpin and Nishenko (1996) show seven paleoearthquakes on the section since 13 ka; mean ages of these events are 2.1 ka (event Z), 3.4 ka (event Y), 4.7 ka (event X), 6.0 ka (event W), 7.3 ka (event V), 8.5 ka (event U), and 13.0 ka (event T).

Recurrence interval: 1.3 ky (<8.5 ka).

Comments: The overall temporal pattern since 13 ka is one earthquake every 1-2 ky since 8.5 ka, with a long seismic gap between 8.5 and 13 ka. McCalpin and Forman (1994) indicate the ~5 ky seismic gap may have been influenced by changes in crustal stress regime associated with Lake Bonneville dessication, possibly causing crustal rebound to suppress extensional movements. Elapsed time since the last earthquake (2,125 years) exceeds the mean recurrence and suggests that the section is due for a surface-faulting earthquake, unless strain-accumulation rates have declined during the late Holocene. McCalpin and Nishenko (1996) suggest that the Brigham City section has a time-dependent earthquake probability that approaches or exceeds regional and fault-specific probabilities.

Slip rate: (C) 0.2-1 mm/yr (<4.7 ka), (B) 1-5 mm/yr (<15 ka).

Comments: 0.75 millimeters/year since 4.7 ka and 1.0-1.3 millimeters/year for the past 15 ky. Net slip gradually decreases to the north. The middle to late Holocene slip-rate estimate is based on trench data from near the center of the section at Brigham City. The late Pleistocene estimate is based on the post-Provo displacement in the southern part of the section.

Length: End to end (km): 37
Cumulative trace (km): 81

Average strike (azimuth): N9°W

2351e, WEBER SECTION

Section number: 2351e.

Section name: Weber section.

Comments: Hecker's (1993) fault number 11-22.

Reliability of location: Good.

Comments: Mapping from Nelson and Personius (1993).

Sense of movement: N.

Comments:

Dip: 68-78°W (Swan and others, 1980); 68-70°W (McCalpin and others, 1994).

Comments: Measured in Kaysville trench A (Swan and others, 1980) and reopened Kaysville trench A (McCalpin and others, 1994) in lacustrine deposits juxtaposed against slope colluvium.

Dip direction: W.
Geomorphic expression: West-facing scarps along the western base of the Wasatch Range. The Weber section is the longest WFZ section. The southern boundary of the section is at the prominent Salt Lake salient, but fault scarps in this area are easily confused with nontectonic features and scarp distribution is less certain (Machette and others, 1992). The northern section boundary is at the Pleasant View salient. Scarp heights in the northern part of the Weber section suggest a higher rate of late Holocene faulting than on the Brigham City section to the north (Machette and others, 1992). Net displacement measured at three sites (Garner Canyon, East Ogden, and Kaysville), which are about 20 kilometers apart, is from 1.0 to 3.5 meters per event. Individual faulting events may not have ruptured the entire section, although the general timing of events at the three sites appears similar.
Age of faulted deposits: Holocene.
Paleoseismology studies: One of the earliest detailed paleoseismic investigations of the Wasatch fault (1978) was conducted on the Weber section between Bair (or Baer; variant spelling) and Shepard Creeks, about 3 kilometers east-southeast of Kaysville. This study was particularly important from the standpoint of developing two fundamental concepts of modern paleoseismology: colluvial-wedge stratigraphy (Swan and others, 1980), and characteristic earthquakes (Schwartz and Coppersmith, 1984). The Kaysville site (site 2351e-3) included five test pits and seven trenches, which exposed evidence for at least three surface-faulting earthquakes since about 12 ka (Swan and others, 1980; Swan, Schwartz, and others, 1981). A single radiocarbon age estimate on detrital charcoal indicated that two earthquakes had occurred since 1,580 ± 150 yr B.P. The Kaysville site was reoccupied in 1988 to refine the paleoearthquake chronology; a trench was excavated parallel to and slightly deeper than the 1978 trench A. Detailed stratigraphic analysis and geometrical reconstructions based on data from both the 1978 and 1988 trenches indicate five or six surface-faulting earthquakes since 13 ka (McCalpin and others, 1994). Radiocarbon and thermoluminescence age estimates on bulk-soil samples from paleosols constrain the timing of the three youngest faulting events. The earlier two or three events could not be directly dated because stratigraphic evidence for these postulated events was not exposed.

In 1986, five trenches were excavated across multiple scarps of the Weber section at the East Ogden site (site 2351e-2), about 1.5 kilometers north-northwest of the mouth of Ogden Canyon. The trenches exposed evidence for three, and possibly four, surface-faulting earthquakes since middle Holocene time (Nelson, 1988; Machette and others, 1992). Radiocarbon age estimates on bulk-soil samples from paleosols developed on colluvial wedges provided poor constraint on paleoearthquake timing (Nelson, 1988), but thermoluminescence age estimates on fault-related colluvial sediments reduced some of the uncertainty (Forman and others, 1991). One of the trenches (EO-3) showed stratigraphic evidence for a small-displacement event within the past 500-600 years, but obscure stratigraphic relations and problems with radiocarbon age estimates make interpretation of this event tenuous (Nelson, 1988). Although Nelson and Personius (1993) characterize this event as “probable,” it has not been observed in any other trenches on the Weber section.

At Garner Canyon (site 2351e-1), 2 kilometers south of Coldwater Canyon near North Ogden, an artificial exposure across the fault revealed stratigraphic evidence for four surface-faulting earthquakes (Nelson and others, 1987; Machette and others, 1992; Nelson and Personius, 1993). Radiocarbon age estimates on bulk-soil samples from paleosols developed on colluvial wedges constrain the timing of the two youngest paleoearthquakes.

Timing of most recent paleoevent: (2) Latest Quaternary (<15 ka).

Comments: McCalpin and Nishenko (1996) show four paleoearthquakes on the section since 6.1 ka; mean ages of these events are 1.0 ka (event Z), 3.1 ka (event Y), 4.4 ka (event X), and 6.1 ka (event W)

Recurrence interval: 1.7 ky (<6.1 ka).

Comments:

Slip rate: (B) 1-5 mm/yr.

Comments: 0.9 to 1.9 millimeters/year for the past 15 ky for the central three-quarters of the section. Slip rates are highest in the central and northern part of the section, and decrease toward the ends.

Length: End to end (km): 56

Cumulative trace (km): 81

Average strike (azimuth): N6°W

2351f, SALT LAKE CITY SECTION

Section number: 2351f.

Section name: Salt Lake City section.

Comments: Hecker's (1993) fault number 12-6.

Reliability of location: Good.

Comments: Mapping from Personius and Scott (1992) with the following exceptions: (1) The southernmost extent of the Warm Springs fault is from Scott and Shroba (1985). (2) The northernmost middle and late Quaternary trace (Virginia Street fault) is from Van Horn and Crittenden (1987; City Cemetery fault). (3) The central middle and late Quaternary trace (University Hospital fault) is from Hecker (1993), based on interpretation of data contained in Everitt (1980). (4) The southernmost middle and late Quaternary trace is from Crittenden (1965) and Van Horn (1972).

Sense of movement: N.

Comments:

Dip: 60-86°W (Black and others, 1996).

Comments: Measurements taken at the South Fork Dry Creek site in Holocene alluvial-fan and Pleistocene Lake Bonneville deposits.

Dip direction: W.

Geomorphic expression: The Salt Lake City section is divided into three en-echelon subsections (from north to south): the Warm Springs fault, East Bench fault, and Cottonwood subsection (Personius and Scott, 1992). The Warm Springs fault forms a prominent escarpment along the western flank of the Salt Lake salient, then trends south into basin fill and dies out. Location of the southern end of the Warm Springs fault beneath urbanized Salt Lake City is subject to interpretation (Schlenker and others, 1999). Pre-urbanization studies of the Warm Springs fault at Jones Canyon by G.K. Gilbert (1890, *in* Hunt, 1982) showed evidence for three post-Bonneville events, with displacements totaling 9 meters. However, these estimates are probably minima;

perhaps six to eight latest Quaternary events with displacements totaling 14-16 meters have occurred on this part of the section (Personius and Scott, 1992). Robison and Burr (1991) estimated a maximum displacement of about 12 meters at a site (Washington Elementary School) at the south end of the Warm Springs fault. Based on variations in elevation of correlative Lake Bonneville deposits indicating paleolake level, Currey (1992) infers the presence of three faults (Capitol Hill fault zone) east of the Warm Springs fault, having a maximum cumulative offset of about 21 meters since 20,400 yr B.P.

In northeastern Salt Lake Valley, faulting activity shifted westward from the range front to the East Bench fault during the late Quaternary (Personius and Scott, 1992). The East Bench fault forms prominent northwest- to southwest-facing intrabasin fault scarps from Salt Lake City (about 2 kilometers east of the southern end of the Warm Springs fault) along about 1100 East Street and Highland Drive south to Big Cottonwood Creek. A trench site at the north end of the East Bench fault revealed evidence for 7 meters of deformation in transgressive Lake Bonneville deposits, including 3 meters of monoclinal folding that occurred prior to 12.5 ka and 4 meters of Holocene-age brittle faulting (Machette and others, 1992). A Quaternary(?) fault (Rudys Flat fault) cutting bedrock of the Salt Lake salient east of the Warm Springs fault appears to connect the East Bench fault with the Weber section of the Wasatch fault zone (2351E), but has no conclusive evidence of Quaternary movement.

The Cottonwood subsection forms a prominent (often wide and complex) zone of faulting along the range front from just north of Big Cottonwood Canyon to the Traverse Mountains. At the mouth of Little Cottonwood Canyon, the fault zone forms a 50-meter-wide graben with a 25-meter-high main scarp and 10-meter-high antithetic scarp. Farther south at South Fork Dry Creek, the graben is 400 meters wide, and six en-echelon scarps comprise the main fault zone. The complexity of the fault zone and poor exposure of antithetic faults has precluded accurate determination of net tectonic displacement. However, profiling of moraine surfaces across the fault zone in the Little Cottonwood Canyon area indicates approximately 14-14.5 meters of net vertical tectonic displacement (Madsen and Currey, 1979; Swan, Hanson, and others, 1981). The main fault zone shows stratigraphic evidence for seven events since 15 ka (McCalpin and Nelson, 2000), and estimates of displacement per event range from 1.5 to 5 meters (Schwartz and Lund, 1988; Black and others, 1996). Based on structural geology, distribution and size of fault scarps, and comparisons with large historical earthquakes elsewhere, surface rupture on the Salt Lake City section may initiate at the southern end of the Cottonwood subsection and propagate northward (Bruhn and others, 1987; Personius and Scott, 1992).

Age of faulted deposits: Holocene.

Paleoseismology studies: Most of the paleoseismic record for the Salt Lake City section comes from two sites on the Cottonwood subsection of the fault: the mouth of Little Cottonwood Canyon, and the South Fork of Dry Creek. Four trenches were excavated in 1979 across fault scarps just north of the mouth of Little Cottonwood Canyon (site 2351f-4). One trench did not expose the fault and was not logged. The other trenches exposed evidence for two or three surface-faulting earthquakes during the Holocene (Swan, Hanson, and others, 1981). Accelerator-mass-spectrometry radiocarbon age estimates on charcoal provided a minimum limiting age for the penultimate event, but the most recent event could not be dated (Schwartz and Lund, 1988). Because of the width and complexity of the fault zone at this site, not all fault traces were trenched.

To improve the paleoseismic record of the Salt Lake City section, trenches were excavated in 1985 in another complex zone of faulting at the South Fork Dry Creek site (site 2351f-5), about 4 kilometers south of the Little Cottonwood Canyon site. Four trenches were excavated across three of the six scarps present at the site; the trenches exposed evidence for two surface-faulting earthquakes, and radiocarbon age estimates on bulk-soil samples from paleosols beneath colluvial wedges provided maximum limiting ages for the events (Schwartz and Lund, 1988). Still, the late Quaternary paleoseismic record of the Salt Lake City section remained incomplete, as was shown by a trench excavated in 1991 as part of a geotechnical study at Dry Gulch (site 2351f-6), a few hundred meters south of the South Fork Dry Creek site. This trench also exposed evidence for two surface-faulting earthquakes; however, although radiocarbon age estimates on bulk-soil samples showed that the most recent event in this trench coincided with the age determined in the South Fork Dry Creek trenches, the penultimate event was previously unrecognized (Lund, 1992).

Five additional trenches were excavated at the South Fork Dry Creek site in 1994, across scarps that had not previously been trenched, to establish a complete late Holocene paleoseismic chronology for the Salt Lake City section. Stratigraphic relations exposed in the trenches, combined with limiting ages from radiocarbon age estimates on bulk-soil samples, provided evidence for yet another previously unrecognized surface-faulting earthquake, increasing the number of events since 6 ka to four (Black and others, 1996). This study also provided insights into the variable nature of recurrent surface faulting along existing fault traces in complex fault zones.

The Little Cottonwood Canyon site was reoccupied in 1999 as part of an investigation to document all of the post-Bonneville surface-faulting earthquakes on the Salt Lake City section. A “megatrench” and accompanying auger hole exposed a 26-meter vertical sequence that revealed evidence for seven surface-faulting events, including three in the period 6-15 ka (McCalpin and Nelson, 2000). Radiocarbon age estimates on bulk-soil samples and charcoal provided timing constraints for the paleoearthquakes. A significant finding from this study is that the average earthquake recurrence interval is much longer between 6 and 15 ka than it is after 6 ka. The megatrench also documented a prolonged early Holocene aseismic interval on the Wasatch fault, consistent with observations made by McCalpin and Forman (1994) at their trench site (2351d-2) on the Brigham City section.

Geotechnical studies have provided information on the late Quaternary paleoseismic history of the Warm Springs fault, at the northern end of the Salt Lake City section of the Wasatch fault. Trenches at the Washington Elementary School property at 400 North and 200 West Streets in northern Salt Lake City (site 2351f-1) revealed evidence of faulting; however, lack of correlative hanging-wall and footwall strata precluded measurement of offset, and no radiometric dating was done. Based on a minimum 12-meter displacement of Lake Bonneville sediments and assumed 2- to 3-meter displacement per event, four to six faulting events were estimated to have occurred since 15 ka (Robison and Burr, 1991). At the Salt Palace Convention Center at 200 South West Temple Street in downtown Salt Lake City (site 2351f-2), construction excavations and exploratory trenches revealed evidence for three faulting events; radiocarbon age estimates on bulk-soil samples provide a minimum limiting age for the oldest event and a maximum limiting age for the two younger events (Simon and Shlemon, 1999). The observed deformation at the Salt Palace was alternatively interpreted as being related to liquefaction-induced lateral spread (Korbay and McCormick, 1999).

Two trenches were excavated across the East Bench fault as part of a geotechnical study at the Dresden Place site at 550 South 900 East Street in eastern Salt Lake City (site 2351f-3). Although the number and timing of individual faulting events were not determined, the trenches did reveal intriguing evidence for contrasting deformational styles (including monoclinal warping and planar fault rupture) associated with faulting before and after regression of Lake Bonneville to an elevation below that of the site (results summarized by Machette and others, 1992).

Timing of most recent paleoevent: (2) Latest Quaternary (<15 ka).

Comments: Combined observations at two sites on the Cottonwood section in 1979 and 1985 showed a total of three events since 8-9 ka, but not all scarps at either site were trenched. Complete trenching at the South Fork Dry Creek site in 1994, combined with observations at Dry Gulch in 1991 and at South Fork Dry Creek in 1985, showed four paleoearthquakes occurred since 6 ka and at least five events occurred since 8-9 ka (Black and others, 1996). McCalpin and Nishenko (1996) indicate mean ages for the last four events are 1.2 ka (event Z), 2.5 ka (event Y), 3.9 ka (event X), and 5.4 ka (event W). Results from the “megatrench” at the mouth of Little Cottonwood Canyon indicated an additional three events in the time period 6-15 ka, rather than the six or seven events that would be expected if the post-6 ka recurrence interval had continued throughout latest Quaternary time (McCalpin and Nelson, 2000). The East Bench fault has evidence for at least two events in the past 26 ka (during and after the Bonneville lake cycle). The earliest documented event appears as 3 meters of monoclinally warped, deep-water sediments and probably occurred subaqueously, before the lake level dropped below the site about 12.5 ka. Subsequent events occurred as brittle, presumably subaerial, deformation. Simon and Shlemon (1999) found evidence for three events on a possible southern extension of the Warm Springs fault in downtown Salt Lake City, one between ~7.1 and 8.1 ka and two events after ~6.4 ka, alternatively interpreted by Korbay and McCormick (1999) as liquefaction-related deformation (lateral spreading).

Recurrence interval: 1.4 ky (<5.4 ka).

Comments: Based on the mean interevent time between events Z through W. McCalpin and Nelson (2000) indicate that recurrence has been irregular, with a much longer recurrence interval in the period 6-15 ka following and perhaps attributable to the drying up of Lake Bonneville.

Slip rate: (B) 1-5 mm/yr.

Comments: 1.4 millimeters/year (<5.4 ka) based on an average net slip per event of 2 meters and a recurrence interval of 1.4 ky. Hecker (1993) indicates a post-19 ka slip rate of 0.8 millimeters/year and recurrence interval of 2.4-3.0 ky based on 2-meter-displacement events and evidence from the Little Cottonwood Canyon site. A rough latest Quaternary slip-rate estimate of 1 millimeter/year for the East Bench fault is

significantly greater than a rough long-term (Quaternary) estimate of 0.04-0.14 millimeters/year based on shallow seismic-reflection data (Crone and Harding, 1984).
Length: End to end (km): 43
Cumulative trace (km): 92
Average strike (azimuth): N4°W

2351g, PROVO SECTION

Section number: 2351g.
Section name: Provo section.
Comments: Hecker's (1993) fault number 12-3.
Reliability of location: Good.
Comments: Mapping from Machette (1992).
Sense of movement: N.
Comments:
Dip: 77°W (Lund and Black, 1998); 79°W (Lund and others, 1991); 58°W (Swan and others, 1980).
Comments: Measurements are from the main fault in the trench at Rock Canyon in alluvium and debris-flow deposits (Lund and Black, 1998), south trench at Mapleton in lacustrine deposits (Lund and others, 1991), and Hobble Creek trench HC-1 in Provo fan-delta deposits.
Dip direction: W.
Geomorphic expression: Based on fault geometry and apparent recency of movement as indicated by scarp morphology, Machette and others (1986) tentatively subdivided the Provo section (as originally proposed by Schwartz and Coppersmith, 1984) into three subsections (from north to south, the American Fork, Provo "restricted sense," and Spanish Fork). However, based on the timing of the last two events deciphered from trench studies, the entire length of the WFZ in Utah Valley appears to be a single section (Machette, 1992; Lund and others, 1991; Machette and others, 1991; Lund and Black, 1998). Lund and Black (1998) measured 3.3 meters of displacement from the most recent event at Rock Canyon in correlative geologic units across the fault zone, which is one of the most accurate available for the WFZ. The Woodland Hills splay of the Spanish Fork subsection has evidence for three or four events, totaling 3 meters of displacement, in about the past 130 ka, yielding a slip rate of 0.01-0.02 millimeters/year and an average recurrence interval of about 40-65 ky (Machette, 1992). Movement on the splay apparently occurs during only some of the events on the main fault, although the most recent event on the splay occurred about 1.0 ka and may be correlative with the most recent event on the main fault. Movement on a couple of short subsidiary faults at the northern end of Utah Valley appears to have occurred during, and may be related to, the recession of Lake Bonneville.
Age of faulted deposits: Holocene.
Paleoseismology studies: Machette and Lund (1987) excavated three trenches in 1986 just south of the mouth of American Fork Canyon (site 2351g-1) (results also described in Machette, 1988, 1992; Machette and others, 1992). The trenches crossed several traces of the fault, and collectively revealed stratigraphic and structural evidence for four surface-faulting events since 8 ka. Radiocarbon and thermoluminescence age

estimates on charcoal and bulk-soil samples from colluvial-wedge deposits and buried A horizon soils constrain the timing of the events.

In 1986, M.N. Machette (USGS) and W.E. Mulvey (UGS) mapped a natural stream-cut exposure of the fault northeast of Provo at Rock Canyon (site 2351g-2). They observed evidence for the most recent surface-faulting event; radiocarbon age estimates on bulk-soil samples from a colluvial-wedge deposit and a paleosol buried by post-event deposits constrain fault timing (Machette, 1992; Machette and others, 1992). In 1988, a trench excavated across the fault scarp about 50 meters south of the stream-cut exposure (Lund and others, 1990; Lund and Black, 1998) also revealed evidence for the most recent event, and re-examination of the cut identified a second fault trace. Radiocarbon age estimates from bulk-soil samples of three buried paleosols exposed in the trench provided additional constraints on the timing of the most recent event. Also, additional samples (collected in 1988 and 1995) of a paleosol that was buried by scarp-derived colluvial-wedge material, and exposed at the stream cut, yielded a radiocarbon age estimate that provides a maximum limiting age for the most recent event.

Near Springville, Swan and others (1980) profiled scarps where the main fault trace crosses a large alluvial-fan complex near the mouth of Hobble Creek Canyon, and excavated three trenches about 2 kilometers northwest of Hobble Creek at Deadmans Hollow (site 2351g-3). Collectively, the study area showed evidence for six or seven post-Provo (14.3 ka) surface-faulting events. The trenches revealed colluvial stratigraphy indicating three young events, and three or four older events are inferred from tectonic strath terraces preserved along Hobble Creek upstream from the fault zone.

In 1987, Lund and others (1991) excavated a total of five trenches at two closely spaced sites southeast of the town of Mapleton. The “Mapleton North” (2351g-4) and “Mapleton South” (2351g-5) sites are 4 and 5.5 kilometers, respectively, south of the Hobble Creek site. The north trench site revealed stratigraphic and structural evidence for the most recent surface-faulting event; radiocarbon age estimates from charcoal contained in pre- and post-event deposits constrain the timing of this event. Trench exposures at the south site revealed evidence for two surface-faulting events. A lack of datable material precluded determining the timing of the most recent event. Timing of the penultimate event was estimated from radiocarbon and thermoluminescence age estimates obtained from a buried soil that was displaced by faulting shortly before the time of burial.

The U.S. Bureau of Reclamation (USBR) excavated two trenches in 1987 in alluvial-fan deposits at the mouth of Water Canyon (site 2351g-6), about 8 kilometers south of the town of Spanish Fork (Ostenaa, 1990). The trenches revealed evidence for at least three Holocene surface-faulting events. Radiocarbon age estimates from charcoal in surface-burn horizons buried by scarp-derived colluvium provide maximum limiting ages for the two most recent events. Radiocarbon age estimates from detrital charcoal in alluvium and colluvium bracket the ages of the older events. Just prior to the study at Water Canyon, the USBR excavated two trenches across the Woodland Hills fault, a splay of the Provo section of the Wasatch fault. This site (2351g-7) is about 2 kilometers southwest of the Water Canyon site. The trenches revealed evidence for three or four surface-faulting events since about 130 ka, based on correlations of faulted alluvial-fan soils with similar soils in the area (Machette, 1992; Machette and others, 1992). Radiocarbon age estimates on bulk-soil samples from an A horizon soil buried by scarp-derived colluvium provide an approximation for the timing of the most recent event.

Timing of most recent paleoevent: (2) Latest Quaternary (<15 ka).

Comments: The most recent surface-faulting earthquake at the Rock Canyon site occurred just prior to 650 yr ago (Lund and Black, 1998), which corresponds well with the timing of the most recent surface-faulting earthquakes at the American Fork (500 yr ago; Machette, 1990) and Mapleton (600 yr ago; Lund and others, 1991) sites to the north and south, respectively. The penultimate event occurred about 2.6-3.0 ka; based on results from the American Fork site, two prior events also occurred about 5.3 ka and 5.5-8.0 ka. A conflicting chronology of faulting from a site near the southern boundary of the section (at Water Canyon, where two events have occurred in the last 1.0 ka) may be explained by spatial overlap of the Nephi and Provo sections, whereby events from both sections are recorded at the site (Machette, 1992; Ostenaa, 1990).

Recurrence interval: 2.4 ky (<5.3 ka).

Comments: Based on data from the American Fork site, where rates of activity appear to have been constant during post-Bonneville time. Six or seven post-Provo events are inferred to have occurred at the Hobble Creek site (east of Spanish Fork) site, yielding an average recurrence interval of 1.7-2.6 ky.

Slip rate: (B) 1-5 mm/yr.

Comments: 1.1-1.3 millimeters/year since 5.3 ka and 1.0-1.7 millimeters/year in the past 15 ka based on data from the American Fork site. However, two-to-three times more displacement is recorded in Bonneville transgressive deposits than in Provo-age regressive deposits at the Hobble Creek site. Twenty to thirty meters of displacement in just a few thousand years represents slip rates as high as 10 millimeters/year and may be related to the presence of Lake Bonneville.

Length: End to end (km): 59
Cumulative trace (km): 127

Average strike (azimuth): N14°W

2351h, NEPHI SECTION

Section number: 2351h.

Section name: Nephi section.

Comments: Hecker's (1993) fault number 13-21.

Reliability of location: Good.

Comments: Mapping from Machette (1992) and Harty and others (1997).

Sense of movement: N.

Comments:

Dip: 72°W (Jackson, 1991).

Comments: Measured at the Red Canyon trench in alluvial-fan, mudflow, and fluvial deposits.

Dip direction: W.

Geomorphic expression: Scarps in Quaternary lacustrine deposits and alluvium. The northern end of the section overlaps the Provo section at the Payson salient. The

Benjamin fault forms the west side of the salient and dies out as it extends northward into Utah Valley (Harty and others, 1997). Sediments of the Provo phase of the Bonneville lake cycle are only offset up to 2 meters along this fault (Machette,1992). The southern section boundary is at a 15-kilometer gap in Holocene and latest Pleistocene surface faulting where a large alluvial fan (Levan Ridge) extends westward from the San Pitch Mountains (Harty and others, 1997). Gravity data suggest the fault continues through and beneath Levan Ridge, but has been inactive for perhaps tens of thousands of years (Zoback, 1983; Machette and others, 1992). Faults associated with young scarps north of the town of Nephi are probably continuous with near-surface faults in the town identified from seismic-reflection data (Crone and Harding, 1984). A number of small faults in Quaternary deposits have been identified on the western flank of the Gunnison Plateau east of Nephi (Biek, 1991). Displacement per event for the last three surface-faulting earthquakes is 1.4-2.5 meters.

Age of faulted deposits: Holocene.

Paleoseismology studies: Hanson and others (1981) excavated three trenches at North Creek (site 2351h-1), about 6 kilometers northeast of the town of Mona (results also summarized in Schwartz and others, 1983; Schwartz and Coppersmith; 1984; Machette and others, 1992). Colluvial-wedge stratigraphy exposed in the trenches indicated two surface-faulting events; an older, third event was inferred from a tectonic strath terrace incised in an uplifted part of the North Creek alluvial fan. Charcoal obtained from deposits exposed in the trenches, although not from stratigraphically definitive positions, yielded radiocarbon age estimates that provide a maximum limiting age for the most recent event; scarp morphology suggests the age of this event may be considerably younger than the limiting radiocarbon age estimate. An organic-rich soil that formed on scarp-derived colluvium deposited after the penultimate event yielded a radiocarbon age estimate that provides a minimum limiting age for this event. Radiocarbon dating of a buried, offset burn layer in the North Creek alluvial-fan deposits provides a maximum limiting age for the antepenultimate event.

Jackson (1991) excavated one trench at Red Canyon near the southern end of the Nephi segment (site 2351h-2), about 3.5 kilometers north of the town of Nephi. The trench revealed colluvial-wedge stratigraphy indicating three surface-faulting events since about 4.5 ka. Thermoluminescence and radiocarbon age estimates from soil buried by the youngest colluvial wedge provide a maximum limiting age for the most recent event. Samples collected from colluvial-wedge material associated with the penultimate event yielded radiocarbon age estimates that constrain the upper age of this event. A maximum age for the antepenultimate event is thought to be close to the oldest radiocarbon age estimate for the colluvium, about 4-4.5 ka.

Timing of most recent paleoevent: (2) Latest Quaternary (<15 ka).

Comments: Scarp morphology and continuity suggest very recent displacement (~300-500 years ago), although a combination of ^{14}C and TL dates suggest an age of about 1.2 ka for the most recent event (event Z). Schwartz and Coppersmith (1984) determined that the penultimate event (event Y) occurred before about 4 ka, whereas Jackson (1991) constrained the event between about 3 and 3.5 ka. Event X may have occurred between 4 and 4.5 ka (Jackson, 1991). Thus, actual middle to late Holocene recurrence intervals may vary from less than 1 to more than 3 ky. Three middle to late Holocene events post-date a late Pleistocene(?) fan at the southern end of the section (at Red Canyon), suggesting a possible hiatus in faulting activity during latest Pleistocene to early Holocene time (Jackson, 1991).

Recurrence interval: 1.7-2.7 ky (<5.5 ka).

Comments:

Slip rate: (B) 1-5 mm/yr.

Comments: 0.8-1.3 millimeters/year since 5.5 ka. The range of displacement and slip-rate values reflects a systematic decrease in slip between the middle (larger values) and southern end (smaller values) of the section.

Length: End to end (km): 43

Cumulative trace (km): 80

Average strike (azimuth): N4°E

2351i, LEVAN SECTION

Section number: 2351i.

Section name: Levan section.

Comments: Hecker's (1993) fault number 13-22.

Reliability of location: Poor.

Comments: Mapping from Machette and others (1992).

Sense of movement: N.

Comments:

Dip: 68°W (Jackson, 1991).

Comments: Measured at the Skinner Peaks trench in sandstone bedrock in fault contact with Holocene mudflow and fluvial deposits.

Dip direction: W.

Geomorphic expression: A 15-kilometer-long gap in Holocene faulting marks the boundary between the Levan and Nephi sections (Harty and others, 1997). The range front in this area is marked by old, degraded scarps on middle(?) Pleistocene surfaces, with little evidence for latest Pleistocene faulting. In contrast to the planar fault geometry at the southern end of the Nephi section (Zoback, 1992), this section of the fault appears to have a listric subsurface geometry and/or to terminate at a shallow detachment fault (Standlee, 1982; Smith and Bruhn, 1984). Displacement from the most recent event was 1.8 to 2.0 meters.

Age of faulted deposits: Holocene.

Paleoseismology studies: Two natural exposures have provided paleoseismic data for the most recent surface-faulting event on the Levan section (Schwartz and Coppersmith, 1984; Machette and others, 1992). At Pigeon Creek (site 2351i-1), just east of the town of Levan, radiocarbon age estimates on charcoal from faulted alluvium provide a maximum limiting age for the most recent event. At Deep Creek (site 2351i-2), about 5 kilometers south of Levan, a radiocarbon age estimate on charcoal from within a debris-flow deposit on the upthrown block broadly constrains the maximum limiting age for the most recent event. Jackson (1991) also studied the Deep Creek exposure and obtained a thermoluminescence age estimate from a buried A horizon that formed on the ground surface prior to faulting. This age estimate is interpreted to closely approximate the timing of faulting at about 1 ka.

Jackson (1991) also excavated a trench (Skinner Peaks trench; site 2351i-3) 1.5 kilometers northwest of Skinner Peaks and about 200 meters east of Utah Highway 26. Although correlation of stratigraphy exposed in the trench from the footwall block to the hanging-wall block was problematic, Jackson's (1991) preferred interpretation indicates evidence for two surface-faulting earthquakes. Thermoluminescence and radiocarbon age estimates on samples from a burn horizon in the footwall block provide a maximum limiting age for the most recent surface-faulting event. Similarly derived age estimates on samples (including disseminated charcoal) from a buried incipient A horizon in the hanging-wall block provide a minimum limiting age for the penultimate event.

Timing of most recent paleoevent: (2) Latest Quaternary (<15 ka).

Comments: Stratigraphic relations indicate that 1 ka is a close maximum limiting age for the most recent event; TL and ^{14}C dates provide maximum ages of about 1.5 and 1.7 ka. An alluvial fan dated at 7.3 ka is crossed by a single-event scarp (~1 ka?), providing a minimum time interval since the penultimate event of ~6.3 ka. At one site, the penultimate event, which is inferred from greater stratigraphic thicknesses on the downthrown side of the fault, predates TL and ^{14}C dates of 3 to 4 ka.

Recurrence interval: No data.

Comments:

Slip rate: Unknown, probably <0.2 mm/yr.

Comments: A maximum slip rate of ~0.3 mm/yr is indicated by a maximum displacement of 2.0 meters in a minimum 6.3 ka since the penultimate event, but evidence for only one Holocene event indicates that the slip rate is probably much lower.

Length: End to end (km): 30
Cumulative trace (km): 32

Average strike (azimuth): N17°E

2351j, FAYETTE SECTION

Section number: 2351j.

Section name: Fayette section.

Comments: Hecker's (1993) fault number 13-23.

Reliability of location: Poor.

Comments: Mapping from Machette and others (1992).

Sense of movement: N.

Comments:

Dip: No data.

Comments:

Dip direction: W.

Geomorphic expression: The Fayette section is the southernmost WFZ section, and is similar in many aspects to the northern WFZ end-sections except that Lake Bonneville was shallower and remained below (west of) the main fault trace. The Fayette section consists of a concave-west southeast-trending eastern trace, and a shorter north-trending western trace. Fault scarps along the section are eroded at canyon mouths, but preserved on elevated streams terraces (2-5 meters above stream level). Some antiquity is suggested by the lack of scarp preservation at canyon mouths.

Age of faulted deposits: Late Pleistocene.
Paleoseismology studies: None.
Timing of most recent paleoevent: (2) Latest Quaternary (<15 ka).
Comments: Morphologically, the fault scarps plot between regression lines for data from the Drum Mountains fault scarps and the highest shoreline of Lake Bonneville, suggesting an age of 10-15 ka.
Recurrence interval:
Comments:
Slip rate: Unknown, probably <0.2 mm/yr.
Comments: Lack of evidence for Holocene events indicates a generally lower slip rate than central WFZ sections, perhaps similar to northern end-sections.
Length: End to end (km): 16
Cumulative trace (km): 20
Average strike (azimuth): N5°W

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