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Wasatch fault zone, Salt Lake City section (Class A) No. 2351f

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Synopsis	**General:** The Wasatch fault zone 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. Half of the estimated 50 to 120 post-Bonneville surface-faulting earthquakes in the Wasatch Front region have been on the Wasatch fault zone. Earthquake-timing, recurrence-interval, and displacement-rate estimates for the Brigham City, Weber, Salt Lake City, Provo, Nephi, and Levan sections of the Wasatch fault

	zone reflect the consensus values of the Utah Quaternary Fault Parameters Working Group (Lund, 2005 #6733). Lund (2005 #6733) did not evaluate the Clarkston Mountain, Collinston, and Fayette sections due to a lack of fault-trench data. The preferred values reported in Lund (2005 #6733) approximate mean values based on available paleoseismic-trenching data, and the minimum and maximum values approximate two-sigma (5th and 95th percentile) confidence limits. The confidence limits incorporate both epistemic (data limitation) and aleatory (process variability) uncertainty (Lund, 2005 #6733). **Sections:** This fault has 10 sections. The nearly 350-km-long Wasatch fault zone has traditionally been divided into seismogenic segments that are thought to rupture at least somewhat independently. The established model is used to define the sections described in this report. The southern eight sections are entirely in Utah. To the north, the Clarkston Mountain section straddles the state line between Idaho and Utah and the northernmost (Malad City) section is entirely in Idaho. The chronology of surface-faulting earthquakes on the Wasatch fault is one of the best dated chronologies in the world and includes 16 earthquakes since 5.6 ka, with an average repeat time of 350 yr. Four of the central five sections [2351e-h] ruptured in the last hundreds to about a thousand years ago, whereas the next section to the north, Brigham City [2351d], has not ruptured in the past 2,125 yr. Vertical displacement rates of 1–2 mm/yr are typical for the central sections during Holocene time. In contrast, middle and late Quaternary (<150–250 ka) rates on these sections are about an order of magnitude lower. This substantial change in the displacement rate may indicate a causal relation between increased Holocene rates of deformation and isostatic rebound/crustal relaxation following deep lake cycles such as Bonneville.
Name comments	**General:** **Section:** All section names follow those proposed by Machette and others (1991 #189; 1992 #607).
County(s) and State(s)	DAVIS COUNTY, UTAH SALT LAKE COUNTY, UTAH
Physiographic province(s)	BASIN AND RANGE
Reliability of	Good

location	Compiled at 1:50,000 scale. *Comments:* Traces taken from 1:50,000 scale mapping of Personius and Scott (1992 #4632) with the following exceptions: (1) The southernmost extent of the Warm Springs fault is from Scott and Shroba (1985 #5008). (2) The northernmost middle and late Quaternary trace (Virginia Street fault) is from Van Horn and Crittenden (1987 #5018; City Cemetery fault). (3) The central middle and late Quaternary trace (University Hospital fault) is from Hecker (1993 #642), based on interpretation of data contained in Everitt (1980 #4981). (4) The southernmost middle and late Quaternary trace is from Crittenden (1965 #4977) and Van Horn (1972 #5017).
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 Wasatch fault zone marks the eastern boundary of the Basin and Range in northern Utah. Alluvial-fan deposits and lacustrine deposits of Pleistocene Lake Bonneville dominate the surficial geology along the fault zone.
Length (km)	This section is 43 km of a total fault length of 357 km.
Average strike	N4°W (for section) versus N10°W (for whole fault)
Sense of movement	Normal
Dip	60–86° W. *Comments:* Measurements taken at the South Fork Dry Creek site in Holocene alluvial-fan and Pleistocene Lake Bonneville deposits (Black and others, 1996 #4615).
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 2351-2). 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 and others, 1981 #4640). 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 #4635). 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 2351-5), about 4 km 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 #4635). 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 2351-21), a few hundred m 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 #4623).

Five additional trenches were excavated at the South Fork Dry Creek site (2351-28) 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 #4615). 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-m vertical sequence that revealed evidence for seven surface-faulting events, including three in the period 6-17 ka (McCalpin and Nelson, 2000 #4331, 2001 #7003; McCalpin, 2002 #5176). 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 17 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 #4626) at their trench site (2351-27) 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 2351-22) 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-m displacement of Lake Bonneville sediments and assumed 2- to 3-m displacement per event, four to six faulting events were estimated to have occurred since 15 ka (Robison and Burr, 1991 #4633). At the Salt Palace Convention Center at 200 South West Temple Street in downtown Salt Lake City (site 2351-29), 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 #4637). The observed deformation at the Salt Palace was alternatively interpreted as being related to liquefaction-induced lateral spread (Korbay and McCormick, 1999 #4622). 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 2351-26). 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 #607).
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 #4632). The Warm Springs fault forms a prominent escarpment for about 7 km 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 #4634). Pre-urbanization studies of the Warm Springs fault at Jones Canyon by G.K. Gilbert (1890 #4618) (cited in Hunt, 1982 #4620) showed evidence for three post-Bonneville events, with displacements totaling 9 m. However, these estimates are probably minima; perhaps six to eight latest Quaternary events with displacements totaling 14–16 m have occurred on this part of the section (Personius and Scott, 1992 #4632). Robison and Burr (1991 #4633) estimated a maximum displacement of about 12 m at 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 #4978) infers the presence of three faults (Capitol Hill fault zone) east of the Warm Springs fault, having a maximum cumulative offset of about 21 m 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 #4632). The East Bench fault forms prominent northwest- to southwest-facing intrabasin fault scarps from Salt Lake City (about 2 km 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 m of deformation in transgressive Lake Bonneville deposits, including 3 m of monoclinal folding that occurred prior to 12.5 ka and 4 m of Holocene-age brittle faulting (Machette and others, 1992 #607). 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-m-wide graben with a 25-m-high main scarp and 10-m-high antithetic scarp. Farther south at South Fork Dry Creek, the graben is 400 m 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 m of net vertical tectonic displacement [Madsen, 1979 #4997; Swan, 1981 #4640]. The main fault zone shows stratigraphic evidence for seven events since 17 ka (McCalpin and Nelson, 2000 #4331, 2001 #7003; McCalpin, 2002 #5176), and estimates of displacement per event range from 1.5 to 5 m (Schwartz and Lund, 1988 #4635; Black and others, 1996 #4615). 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 #4616; Personius and Scott, 1992 #4632).
Age of faulted surficial deposits	Holocene alluvial fan, debris-flow and stream deposits; late Pleistocene glacial, lacustrine, and alluvial fan deposits, and middle (?) Pleistocene alluvial fan deposits.
Historic earthquake	
Most recent prehistoric deformation	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 #4615). Lund (2005 #6733) reports the following paleoearthquake chronology, utilizing the Little Cottonwood Canyon and South Fork Dry Creek/Dry Gulch trench sites, the four-earthquake model (events W-Z) of McCalpin and Nishenko (1996 #6770) and Black and others (1996 #4615), and results from the Little Cottonwood Canyon megatrench (events S-V; McCalpin and Nelson, 2000 #4331, 2001 #7003; McCalpin, 2002 #5176). The uncertainties in the timing of events reflects both geologic and laboratory error. Z 1300±650 cal yr B.P. Y 2450±550 cal yr B.P. X 3950±550 cal yr B.P. W 5300±750 cal yr B.P. V ~7.5 ka (after 8.8–9.1 ka, but before 5.1–5.3 ka) U ~9 ka (shortly after 9.5–9.9 ka) T ~17 ka S (?) 17-20 ka

	The earthquake chronology implies longer interevent intervals between 6 and 20 ka, with a significant period of quiescence between events T and U; however, events V, U, and T are based on a retrodeformation analysis of stratigraphic and structural relations in the Little Cottonwood Canyon megatrench, rather than direct geological evidence (e.g., colluvial wedges, crack fill, fault terminations) (McCalpin, 2002 #5176). The queried oldest event (S) is evidenced by an inferred seismically-induced subaqueous (below Lake Bonneville) landslide deposit (McCalpin, 2002 #5176). 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 m 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 #4637) 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 #4622) as liquefaction-related deformation (lateral spreading).
Recurrence interval	1300 yr (preferred); minimum 500, maximum 2400 yr (<5.3 ka) *Comments:* Consensus recurrence-interval range reported in Lund (2005 #6733), based on the three intervals between the four most recent earthquakes (W–Z). McCalpin and Nelson (2000 #4331; 2001 #7003) indicate that recurrence has been irregular, with a much longer recurrence interval in the period 6–17 ka following and perhaps attributable to the drying up of Lake Bonneville.
Slip-rate category	Between 1.0 and 5.0 mm/yr *Comments:* Lund (2005 #6733) indicates a Holocene paleoseismic vertical displacement rate of 1.2 mm/yr (preferred), and a consensus minimum-maximum range of 0.6–4.0 mm/yr. Due to poorly constrained displacement-rate data for the section, the range in possible rates is based partly on the rate of fault displacement along the adjacent Weber and Provo sections (Lund, 2005 #6733). The mean long-term geologic vertical displacement rate is estimated at 0.7 mm/yr, with a range between 0.4–1.4 mm/yr, based on 14.5 +10/-3 m of displacement (Swan and others, 1981 #4640) across the 18–26 ka (Scott, 1989 #6749) Bells Canyon moraine, south of Little Cottonwood Canyon.

	Hecker (1993 #642) indicates a post-19 ka geologic vertical displacement rate of 0.8 mm/yr and recurrence interval of 2.4–3.0 k.y. based on 2-m-displacement events and evidence from the Little Cottonwood Canyon site. A rough latest Quaternary geologic vertical displacement rate estimate of 1 mm/yr for the East Bench fault is significantly greater than a rough long term (Quaternary) estimate of 0.04 0.14 mm/yr based on shallow seismic-reflection data (Crone and Harding, 1984 #4545).
Date and Compiler(s)	2004 Bill D. Black, Utah Geological Survey Christopher B. DuRoss, Utah Geological Survey Michael D. Hylland, Utah Geological Survey Greg N. McDonald, Utah Geological Survey Suzanne Hecker, U.S. Geological Survey
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