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Eastern Bear Lake fault, southern section (Class A) No. 2364c

Last Review Date: 2010-07-20

Compiled in cooperation with the Idaho Geological Survey and the Utah Geological Survey

citation for this record: **Black, B.D., Haller, K.M., DuRoss, C.B., Hylland, M.D., and Hecker, S., compilers, 2010, Fault number 2364c, Eastern Bear Lake fault, southern section, in Quaternary fault and fold database of the United States: U.S. Geological Survey website, https://earthquakes.usgs.gov/hazards/qfaults, accessed 12/14/2020 02:57 PM.**

Synopsis	**General:** Long, range-front, normal fault that bounds the west side of the Bear Lake Plateau and Pruess Range. The fault zone contains multiple strands in some locations, and defines the eastern edge of the Bear Lake graben, an 80-km-long, north-trending topographic low that extends from Idaho into Utah. The history of this fault is defined by reconnaissance mapping along the northern two sections and additional detailed site studies,

	including trenching, along the southern section. Late Pleistocene slip rates increase from south to north along the eastern Bear Lake fault zone, which is consistent with the tectonic geomorphology. However, slip rates on the southern part of the fault zone have apparently decreased over the past 50 k.y. Earthquake-timing, recurrence-interval, and slip-rate estimates for the southern section of the eastern Bear Lake fault as reported in this compilation reflect the consensus values of the Utah Quaternary Fault Parameters Working Group (Lund, 2005 #6733). 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 3 sections. McCalpin (1990 #4419) divides the fault into a northern, central, and southern segments on the basis of fault-rupture patterns, strike of fault scarps, youthfulness of fault scarps, and subsurface geophysical data; this subdivision is used in this compilation.
Name comments	**General:** The earliest known name for this fault is "Bear Lake fault" (Mansfield, 1927 #4416); in this publication Mansfield notes that "there seems therefore little doubt that this part of the valley wall is determined by fault." But on Plate 1, the fault is shown only extending about 9 km south of Dingle. The name "eastern Bear Lake fault" came into use only after detailed fault studies were completed and the nearby western Bear Lake fault [622], which bounds the west side of the valley, was recognized (McCalpin, 1990 #4419). Evans (1991 #4425) uses the name "East Bear Lake fault." The fault, as mapped and described by McCaplin (1990 #4419) extends along the west edge of the Bear Lake Plateau and Preuss Range from about 3.5 km northeast of Georgetown, Idaho, to about 3.6 km south of Laketown, Utah. **Section:** We follow the names established by McCalpin (1990 #4419) for the three parts of the eastern Bear Lake fault; also called the S segment in McCalpin (1993 #796). The southern section extends from the northeast end of Bear Lake south to about 3.6 km south of Laketown, Utah. The southern boundary of fault is from Hecker (1993 #642); however, McCalpin (1990 #4419) shows an inferred extension of the fault extending at least 8.5 km south of Laketown.

	Fault ID: Refers to fault number 24 ("fault east side Bear Lake [east side of graben]") of Witkind (1975 #320) in Idaho. Section 2364c in this compilation refers to fault number 11-8 ("southern segment of the eastern Bear Lake fault") of Hecker (1993 #642).
County(s) and State(s)	BEAR LAKE COUNTY, IDAHO RICH COUNTY, UTAH
Physiographic province(s)	MIDDLE ROCKY MOUNTAINS
Reliability of location	Good Compiled at 1:24,000 scale. *Comments:* Fault location is based on the 1:50,000-scale map of Reheis (2005 #7008). Reheis (2005 #7008) shows numerous synthetic and antithetic faults east of the one depicted in this compilation. Poorly constrained locations are based on the approximately 1:475,000-scale map of McCalpin (1990 #4419). This section is also mapped and discussed by Coogan (1994 #4426).
Geologic setting	West-dipping normal (possibly listric) fault bounding the west side of the Bear Lake Plateau in Utah and Preuss Range in Idaho. This fault and the complimentary western Bear Lake fault [622] define the Bear Lake graben, an asymmetric basin as much as 3-km deep extending from Idaho into Utah. These faults are part of a belt of right-stepping en-echelon faults that extend from the northern Wasatch Range in Utah to the Yellowstone area in Wyoming (McCalpin, 1990 #4419). Interpretation of high-resolution seismic-reflection profiles adjacent to the southern part of the fault shows changes in the location of depocenters adjacent to the master fault through time, which probably mirrors the general pattern of slip on the fault (Colman, 2006 #7012). Net Tertiary slip is 1.9–4.0 km (Evans, 1991 #4425).
Length (km)	This section is 35 km of a total fault length of 78 km.
Average strike	N12°E (for section) versus N1°W (for whole fault)
Sense of movement	Normal *Comments:* (McCalpin, 1990 #4419)
Dip	60–70° W.

	Comments: Interpretations of the fault geometry vary. Some investigators document the fault as steeply dipping (Mansfield, 1927 #4416; Williams and others, 1962 #4409; Armstrong and Cressman, 1963 #4417), and others maintain that it is listric and soles into the Meade thrust at depth (Evans, 1991 #4425). Dip of 60–70° W is a near-surface dip based on seismic-reflection data reported by Evans (1991 #4425). Evan's interpretation of the seismic data suggests that the fault may be listric and that it flattens to 25–30° at 6-km depth and merges with the Meade thrust near the north end of Bear Lake. The data, however, does not preclude that the eastern Bear Lake fault maintains at least a 40° dip and cuts the Meade thrust at 4 km below the surface (Evans, 1991 #4425). Coogan and Royse (1990 #7006) suggest that the fault dips 65° at the surface and becomes flat at a depth of 5.8 km below sea level.
Paleoseismology studies	Two trenches were opened in June and July of 1989 on the North Eden fan. Both trench sites were on a surface mantled by 9.1-ka loess deposit, and both show evidence that the penultimate event occurred at 2.6–4.6 ka. Site 2364-1 in this compilation refers to the western trench of McCalpin (1990 #4419; 1993 #796). Log of this trench is shown in figure 2 in McCalpin (1993 #796). The scarp at this site is 8 m high, and the trench exposed evidence for five to seven faulting events having 23.3 m of total vertical displacement since 40 ka (McCalpin, 1990, 2003 #4419, #6750). A radiocarbon age estimate on a bulk-soil sample from scarp-derived colluvium closely approximates the age of the most recent event on the fault, and a thermoluminescence age estimate from loess at the base of a second colluvial-wedge deposit constrains the time of the penultimate event. Site 2364-2 refers to the eastern trench of McCalpin (1990 #4419; 1993 #796). Log of this trench is shown in figure 3 in McCalpin (1993 #796). The scarp at this site is 14 m high, and the trench exposed evidence of at least four earthquakes, which ruptured the eastern fault trace prior to two later events on the western fault trace, exposed in the western fault trench (McCalpin, 1990 #4419; 1993 #796; 2003 #6750). A thermoluminescence age estimate from basal scarp-derived colluvium constrains the time of the youngest fault movement, which is potentially older than the youngest two events identified in the western trench.

Geomorphic expression	The fault is marked by multiple, parallel to subparallel fault scarps on Quaternary deposits at the base of a steep escarpment of Mesozoic rocks on the east side of Bear Lake (Williams and others, 1960 #4410; Kaliser, 1972 #4413; Robertson, 1978 #4418; McCalpin, 1990 #4419). Seismic-reflection data show that the lake floor and reflectors within the Neogene sediments dip eastward into the eastern Bear Lake fault (Skeen, 1975 #4428), and fathograms of the lake bottom show the presence of sublacustrine scarps (Williams and others, 1960 #4410). Total throw of the top of the Eocene Wasatch Formation is about 1.5 kilometers at the north end of Bear Lake (McCalpin, 1990 #4419). Displacement from the last two earthquakes on the fault at one site was 8.3 m (5.6 m from the penultimate event, and more than 2.6 m from the most recent event).
Age of faulted surficial deposits	"Recent sediments" both subaerial and lacustrine (Williams and others, 1962 #4409).
Historic earthquake	
Most recent prehistoric deformation	latest Quaternary (<15 ka) *Comments:* The most recent event on this part of the fault is clearly Holocene in age (Robertson, 1978 #4418), but evidence for this event is present only in the western trench (McCalpin, 1993 #796). A radiocarbon age estimate from the base of scarp-derived colluvium in the western trench (site 2364-1) places the most recent event (event Z) at about 2.1 ka (McCalpin, 2003 #6750). The time of the penultimate event (event Y) is constrained by a 2.5 ka thermoluminescence age on a loess deposit separating the two youngest colluvial wedges; however, event Y may be as old as 5.0 ka if it correlates with the youngest event in the eastern trench (McCalpin, 1990 #4419; 1993 #796; 2003 #6750). The interval between these events (500–2,900 yr) may be considerably shorter than the prior recurrence interval (assuming event X occurred prior to 15.2 ka, and probably nearer to 23 ka), but the data are insufficient to demonstrate this. Lund (2005 #6733) reports the following paleoearthquake chronology, which incorporates the trench investigations of McCalpin (1990 #4419; 2003 #6750), with event uncertainties that reflect both geologic and laboratory error: Western trench event Z: <2.1 ±0.2 ka, but >0.6 ±0.08 ka; event Y: about 5 ka (constraining 2.5 ka TL age estimate considered erroneously young). Eastern trench event

	Y: >5.0 ±0.5 ka, but likely not much greater; event X: <31 ±6 ka, but much >15.2 ±0.8 ka; event W >31 ±6 ka, but <39 ±3 ka; event V >31±6 ka, but <39 ±3 ka; event U >39 ±3 ka, but likely not much greater that this age.
Recurrence interval	8 k.y. (preferred); minimum 3 k.y., maximum 15 k.y. *Comments:* McCalpin (1993 #796) states that the most recent recurrence interval is 0.5–2.5 k.y. based on evidence from both trenches that indicate a poorly constrained event occurred about 2.6–4.6 ka. The time of the penultimate event is based on the degree of soil development. However, the recurrence interval reported above only characterizes the most recent interval. Additional Holocene events have not occurred suggesting that the prior recurrence interval is at least 8.1–10.1 k.y. These data led Hecker (1993 #642) to estimate an average Holocene recurrence interval of greater than 5.3 k.y. for the past 12.7 k.y. The consensus recurrence-interval range reported in Lund (2004 #6733) is based on the five most recent recurrence intervals between events U and Z, yielding a mean of 7.6 k.y. (McCalpin, 2003 #6750). The broad uncertainty reflects variable recurrence intervals between events Y and Z (about 2.9 k.y.) and between X and Y (>10.2 k.y.), and a generally poorly constrained earthquake chronology (Lund, 2004 #6733). Event X appears to be the only event between 15.2 and about 5 ka, although McCalpin (1990 #4419) indicates that surface rupture may have occurred on other fault strands.
Slip-rate category	Between 0.2 and 1.0 mm/yr *Comments:* McCalpin and Forman (1991 #299) first reported a slip rate of 0.8 mm/yr based on about 10 m of offset since 12.3 ka. Hecker (1993 #642) later calculated an equivalent maximum slip rate, based on an average displacement of 4.2 m with a minimum recurrence interval of 5.3 k.y. Evans (1991 #4425) calculates long-term (10 and 17 m.y.) slip rates of 0.4 mm/yr and 0.25 mm/yr respectively. Lund (2004 #6733) indicates a paleoseismic slip rate of 0.6 mm/yr (preferred), and a consensus minimum-maximum range of 0.2–1.6 mm/yr, based on a cumulative (>22.1 m) slip released in the last five interevent intervals (38 k.y.) based on McCalpin (2003 #6750). The broad uncertainty reflects variations in slip rate associated with individual interevent intervals (less than 2.9 to more than 10.2 k.y.), and a variable amount of slip per event ranging from 1.2 to 6.1 m (McCalpin,

	2003 #6750; Lund, 2004 #6733). Reheis and others (2009 #7004) estimate late Quaternary slip rates on the eastern Bear Lake fault zone by using the water-level history of Bear Lake. Their model assumes little or no displacement on dated deposits on the west side of the valley, which is thought to be at their original depositional elevations. Furthermore, total slip rates are estimated assuming that footwall uplift has been 10–20 percent of total fault slip. They conclude that late Pleistocene slip rates on the southern part of the fault zone have decreased over the past 200 k.y. The maximum slip rates for 47–39 and 16–15 ka deposits are approximately equivalent to the minimum slip rates for 200–100 ka deposits (table 3, Reheis and others, 2009 #7004). Uncertainties arise in assumptions that the same age deposit is associated with the same lake phase. To summarize table 3 of Reheis and others (2009 #7004), post 47–35 ka slip rates for the eastern Bear Lake fault are 0.8–3.1 mm/yr with the exception of extraordinary slow slip rate at the Dingle site. Slip rates based on trenching data for this time (post 47–39 ka) is 1.4–1.5 mm/yr (McCalpin, 2003 #6750 as reported in Reheis and others, 2009 #7004). Far fewer data exist for 16–15 ka deposits, but both Reheis and others (2009 #7004) and McCalpin (2003 #6750) suggest rates less than 1 mm/yr; assigned slip rate category reflects the most recent data.
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