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Bear River fault zone (Class A) No. 730

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Compiled in cooperation with the Utah Geological Survey

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Synopsis	The Bear River fault zone is one of the most extensively studied faults in the Rocky Mountain region. It is located in the Bear River drainage of southwestern Wyoming and northeastern Utah. Its surface trace consists of numerous echelon scarps 1–3 km long and 0.5–15 m high, most of which face west. The scarps have been mapped in detail and trenching or natural exposures at eight locations (supported by numerous radiocarbon dates) constrain the late Quaternary history of faulting. The west-dipping normal faults are inferred to merge into a ramp of the Laramide-age Darby-Hogsback thrust fault at a depth of about 5–7 km. There is no evidence, at this time, that the fault zone has discrete rupture

	segments. Earthquake-timing, recurrence-interval, and slip-rate estimates for the Bear River fault zone documented here reflect consensus values of the Utah Quaternary Fault Parameters Working Group (Lund, 2004 #6733). The preferred values reported in Lund (2004 #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 (e.g., data limitation) and aleatory (e.g., process variability) uncertainty (Lund, 2004 #6733).
Name comments	Fault zone was named by West (1984 #823), but first recognized by Gibbons and Dickey (1983 #821). Fault expressed by echelon scarps that extend from about 3 km southeast of Aspen, Wyoming, south to the Stillwater Fork of the Bear River in Utah. **Fault ID:** Originally shown on compilation of Quaternary faults by Gibbons and Dickey (1983 #821) and shown by Hecker (1993 #642) as fault number 12-18.
County(s) and State(s)	SUMMIT COUNTY, UTAH UINTA COUNTY, WYOMING
Physiographic province(s)	MIDDLE ROCKY MOUNTAINS
Reliability of location	Good Compiled at 1:24,000 scale. *Comments:* Location in Wyoming is from 1:24,000-scale mapping by West (1989 #824); the part of the fault in Utah is from Sullivan and others (1988 #4437). Fault also shown by West (1988 #4464; 1994 #4412). Trace further constrained by satellite imagery and topography at scale of 1:24,000. Reference satellite imagery is ESRI_Imagery_World_2D with a minimum viewing distance of 1 km (1000 m).
Geologic setting	The generally north-striking fault zone east of the Bear River drainage is on the west flank of the Uinta Mountains in Utah. The fault lies between the leading edges of the Absaroka and Darby-Hogsback thrust faults. Normal faulting is thought to have recently initiated (about 5 ka, West, 1993 #825) and is supported by a normal throw that is roughly equivalent to the observed displacement of upper Quaternary deposits. This newly activated fault zone is east of the Bear River and is expressed as short,

	generally right-stepping, north-trending scarps that abruptly change to east-northeast trend at southern end. The associated west-dipping normal faults are inferred to merge into a ramp of the Laramide-age Darby-Hogsback thrust fault at a depth of about 5–7 km. East-facing scarps are presumed to be antithetic to the major west-dipping faults.
Length (km)	35 km.
Average strike	N11°W
Sense of movement	Normal *Comments:* Normal movement is shown by Gibbons and Dickey (1983 #821).
Dip	45–80° W *Comments:* West (1989 #824) documented fault dips of 80–83° W., near-vertical, and 53° SW., but locally overturned (76° E.); measurements are from the Lester Ranch trenches in Tertiary Wasatch Formation, which is in fault contact with alluvium and colluvium (West, 1994 #4412). He also noted that the eastward and near-vertical dips probably reflect near-surface rotation of the fault due to downslope creep. The fault is shown schematically in cross section by West (1989 #824) as having a dip of about 80° W. in the upper 2 km, flattening to 45° W. at a depth of about 3 km.
Paleoseismology studies	The Bear River fault is one of the most well-investigated faults within the Rocky Mountain region. West's comprehensive investigations of the Bear River fault zone (summarized in West, 1989 #824) included 12 scarp profiles, seven trenches, and a log of an irrigation-ditch exposure. The irrigation-ditch exposure and four of the trenches (sites 730-1 to 730-5) were in southwestern Wyoming; the other three trenches (sites 730-6 to 730-8) were in northeastern Utah. Multiple samples were obtained for radiocarbon analysis and collectively their ages define a best-fit timing scenario for the two most recent earthquakes. Age constraints for faulting events were provided by radiocarbon age estimates and amino acid racemization ratios. The most recent event is thought to have occurred at 2,320±860 yr BP, and the penultimate event at 4,120±510 yr BP. Average displacements of 2.0–5.3 m per event are estimated from the trenches.

La Chapelle, Wyo. (site 730-1): one trench, one profile. The trench was excavated across the La Chapelle scarp about 850 m south of Short Draw, where the north-trending, west-facing scarp is about 5 m high and has a maximum slope of 12°. The trench revealed two distinct subvertical fault zones about 2.7 m apart with evidence of two surface-faulting events. The faults displace fluvial sediments interpreted to be late Pleistocene to earliest Holocene in age based on amino acid racemization ratios derived from snail shells. Seven radiocarbon ages constrain the timing of two Holocene earthquakes. Total net vertical displacement across the fault zone was estimated to be 4.6–5.1 m, with individual event displacements ranging from 1.6–2.6 m.

Lester Ranch, Wyo. (site 730-2): one trench, five profiles. The trench was excavated about 50 m north of Blacks Fork Road in strath-terrace gravels near a water-filled sag pond across the north-trending, west-facing scarp, and exposed evidence for two surface-faulting events. Radiocarbon ages were obtained from the base of the modern soil and two buried A horizons. Five radiocarbon ages constrain the timing of the most recent Holocene earthquake and provide a minimum constraint for the earlier event. Estimates of total net vertical displacement from scarp-profile data range from 3.9–11.3 m. Surface offset, stratigraphic offset, and colluvial-wedge geometry suggest per-event vertical displacements of 1.3–3.1 m.

Lester Ranch South, Wyo. (site 730-3): one trench. The trench was excavated about 180 m south of Blacks Fork Road in alluvial and colluvial deposits where the north-trending, west-facing scarp is about 4–5.5 m high and has a maximum scarp angle of 20.5°. The trench exposed Wasatch Formation bedrock in the footwall and evidence of two surface-faulting events. The presence of multiple fault planes precluded estimates of individual displacements based on colluvial-wedge stratigraphy. Seven radiocarbon ages constrain the timing of two Holocene earthquakes. Net vertical tectonic displacements for each event, determined from geologic data and surface offsets, range from 2.0–2.9 m.

Austin Reservoir, Wyo. (site 730-4): irrigation ditch exposure. The roughly 1.5-m-high, north-trending, west-facing fault scarp at Austin Reservoir displaces colluvium overlying Wasatch Formation bedrock. An exposure has formed where an irrigation ditch, about 250 m south of the road to the reservoir, was constructed to replenish the reservoir and has been allowed to spill over the fault scarp, producing a gully several feet deep. The exposure reveals evidence of two surface-faulting events, each producing vertical displacements ranging from 0.6–2.0 m. A youthful, faulted, buried A horizon and a radiocarbon age estimate of about 800 yr BP from the base of a second displaced A horizon indicate the age of faulting to be late Holocene.

Sulphur Creek, Wyo. (site 730-5): one trench, one profile. The fault scarp was trenched about 500 m southwest of Austin Reservoir where the scarp height is estimated at 4.6–5.6 m. The trench shows evidence of one to three surface-faulting events depending on stratigraphic interpretation. Seven radiocarbon ages constrain the timing of the most recent Holocene earthquake and provide a minimum constraint on the age of the earlier event. West (1994 #4412) prefers an interpretation of two events with single-event net vertical displacements of 2.5–7.2 m. Radiocarbon-age estimates from a buried A horizon, discontinuous pods of soil, and the base of the modern A horizon provide limiting ages for the faulting, although the age estimate associated with the modern A horizon is suspect.

Big Burn, Utah (site 730-6): one trench, three profiles. The north-trending, west-facing Big Burn scarp is, in places, more than 15 m high with slope angles locally exceeding 30°. The scarp was trenched about 550 m south of the East Fork of the Bear River where the scarp forms a closed, dry depression in glacial deposits (inferred to be Pinedale-age till) and is 12.3 m high with a 31° maximum slope angle. Seven radiocarbon ages constrain the timing of the most recent Holocene earthquake and provide a minimum constraint for the earlier event. Radiocarbon-age estimates were obtained from the modern A horizon (including detrital charcoal), buried A-horizon soils, and scarp-derived colluvium. Trenching revealed clear evidence for one surface-faulting event, and at least one other event is inferred based on scarp height and colluvial stratigraphy. Single-event net vertical displacement appears to range from 3.9–6.3 m.

Lower Little Burn, Utah (site 730-7): one trench. The trench was excavated about 1.5 km west of the East Fork of the Bear River, where the scarp crosses a ravine floor (presumed by West to be tectonically derived) forming a subtle break in slope with an estimated height of 1.5–2.0 m and a maximum slope angle of 13°. The trench revealed two poorly defined faults as well as evidence

	of possibly two surface-faulting events that displace tills and glaciofluvial deposits associated with the Bull Lake and Pinedale glaciations. The age of the latest surface rupture could not be determined due to the lack of buried soils. Radiocarbon-age estimates were obtained from detrital charcoal in colluvium overlying inferred colluvial-wedge material, but the ages do not necessarily constrain the timing of faulting because the relationship between the ages of the charcoal and colluvium is uncertain (the charcoal may be considerably older than the colluvium). Single-event tectonic displacement, estimated from total surface offset and assuming two events, ranges from 0.4–0.7 m. Colluvial-wedge relations indicate displacements for the penultimate and most recent events of 1.0 and 1.8 m, respectively. Upper Little Burn, Utah (site 730-8): one trench, two profiles. The trench was excavated about 100 m southwest of the Lower Little Burn trench across one of two east-northeast-trending, north-northwest-facing scarps that displace glacia deposits on the downthrown block of the Big Burn scarp. The Upper Little Burn trench exposed similar stratigraphy as the Lower Little Burn trench, but no conclusive correlative relationship was determined. No material for age determination was recovered at the site. The trench showed evidence for at least two surface-faulting events displacing sediments in a complex en echelon transition zone between two adjacent fault scarps; however, the possibility of more than two events cannot be discounted based on stratigraphy. No radiometric ages were obtained. The lack of strong soil development across the scarp suggests late Holocene movement. Scarp profiles and stratigraphic offsets indicate total tectonic displacement of 2.0–4.4 m with single-event offsets of 1.0–2.2 m.
Geomorphic expression	The Bear River fault zone extends from southeast of Evanston, Wyoming, south to the Uinta Mountains in Utah, where it ends at a complex juncture with the North Flank fault. The trend of scarps at the southern end of the zone is sharply discordant with the main, northerly trend of faulting, perhaps due to the buttressing effect of the Uinta Mountains. A 5-km-long Holocene scarp (the Martin Ranch scarp), together with at least 10 km of related surface warping, lies west of the Bear River fault zone in Wyoming and is coincident with the Absaroka thrust. Scarp heights and tectonic displacements increase markedly from north to south along the Bear River fault zone; the range in slip rates (below) reflects the range in displacement (1.9 to 6.2 m) along the fault zone. Fault scarps are between 0.5 and 15 m high on upper

	Quaternary deposits; sag ponds, beheaded drainages, and antithetic fault scarps are also present (West, 1994 #4412). West (1994 #4412) furthermore reports that net tectonic displacement during single events range from less than 1 m to more than 5 m. Fault-activity parameters for the Bear River fault zone are comparable to values for the Wasatch fault zone [2351]. No evidence has been found to suggest that the Bear River fault zone is segmented. Northern portions of the fault zone in Utah are expressed only as drainage lineaments or are obscured by recent landslide deposits. The southernmost part of the Bear River fault zone displaces Pinedale glacial deposits and forms scarps up to more than 15 m high, suggesting the scarps may have formed from more than two Holocene events.
Age of faulted surficial deposits	Holocene deposits, upper Quaternary (Pinedale) alluvium and glacial till and outwash, Paleocene Wasatch Formation (West, 1984 #823; 1989 #824).
Historic earthquake	
Most recent prehistoric deformation	latest Quaternary (<15 ka) *Comments:* The youthfulness of faulting is demonstrated by the presence of beheaded and reversed drainages, sag ponds, and displacements in the youngest flood-plain deposits. Most recent event is inferred to have occurred 2,320±860 yr ago (West, 1989 #824). This time is based on a best fit for the multiple radiocarbon ages obtained from the trenches and on inferring that the rupture extended along the entire length of fault zone. However, the most recent event may be slightly younger because mean residence times of organic matter in the dated paleosols were not incorporated in the interpretation. Later publications by West (1992 #826; 1993 #825) rounded the above date to indicate that the most recent event occurred 2.4±1.1 ka. The age of most recent movement on the Martin Ranch scarp (coincident with the Absaroka thrust) is consistent with that on the Bear River fault zone, suggesting that it represents movement that is simultaneous and sympathetic with that on the main fault zone. Lund (2004 #6733) reports the following paleoearthquake chronology, based on the paleoseismic trench investigations of West (1994, #6769): Z 2370±1050 yr BP Y 4620±690 yr BP The earthquake timing is reported as "yr BP," because 14C ages on soil organics were calendar-calibrated, but not mean residence-

	time corrected (Lund, 2004 #6733). West (1994 #6769) estimates the inherited soil age (at the time of burial) to be 200–400 yr.
Recurrence interval	1–100 k.y. *Comments:* Consensus recurrence-interval range from 1 to 100 k.y., as reported in Lund (2004 #6733), based on the possibility of two alternative fault-behavior models (short vs. long recurrence-interval models) and the lack of long-term slip-rate data. The short recurrence-interval model is based on the current paleoseismic data, which indicate faulting events at 2.4 ka and 4.6 ka, and a recurrence interval of about 2.2 k.y. (West, 1992, 1993, 1994 #826, #825, #6769). The long recurrence-interval model suggests that the fault may have inter-event periods on the order of 100 k.y., evidenced by the youthful geomorphic expression of the fault zone (*i.e.*, lacking a mountain range).
Slip-rate category	Between 1.0 and 5.0 mm/yr *Comments:* West published a number of vertical displacement rates for this fault zone. In his original work, he cited a rate of 1.0–3.1 mm/yr (West, 1989 #824); later he cited 0.8–2.7 mm/yr (West, 1992 #826; 1993 #825, 1994 #4412). However, these displacement-rate estimates are based on open-ended time intervals, incorporating the elapsed time since the most recent event. If one takes his values of single-event throw and the recurrence interval between the two Holocene events, then lower rates are obtained, which are consistent with the assigned slip-rate category above. The two closely spaced Holocene events (an earthquake cluster) demand a relatively high slip rate; if one considers a longer time window, the late Quaternary geologic (<130 ka) slip rate is probably much less than 1 mm/yr. Lund (2004 #6733) indicates a paleoseismic slip rate of 1.5 mm/yr (preferred), and a consensus minimum-maximum range of 0.05–2.5 mm/yr, based on recalculated slip-rate estimates from West (1994 #6769) that use the most recent inter-event interval (events Y-Z) and consider the possibility of two alternative fault-behavior models.
Date and Compiler(s)	2011 Bill D. Black, Utah Geological Survey Christopher B. DuRoss, Utah Geological Survey Greg N. McDonald, Utah Geological Survey Suzanne Hecker, U.S. Geological Survey James P. McCalpin, GEO-HAZ Consulting, Inc.

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