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UTAH GEOLOGICAL SURVEY

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August 15, 2003

TO: Members, Utah Quaternary Fault Parameters Working Group

FROM: William Lund, UQFPWG Coordinator

SUBJECT: UQFPWG Meeting Information:

Meeting Location, Time, Date, and Purpose

The second meeting of the Utah Quaternary Fault Parameters Working Group (UQFPWG) is scheduled for 8:30 a.m., September 4 & 5, 2003 in room 1050 (first floor) of the Utah Department of Natural Resources Building, 1594 West North Temple, Salt Lake City, Utah. The purpose of the meeting is to evaluate the Quaternary faults in Utah, exclusive of the Wasatch fault zone, for which trench-derived paleoseismic data are available, and to arrive at consensus slip rate and/or recurrence interval values with appropriate confidence levels for those faults.

Fault Synopsis Forms

The accompanying packet of Fault Synopsis Forms should be added to the three-ring binder that you received prior to our first meeting. Each Fault Synopsis Form summarizes the paleoseismic information available for the subject fault and lists sources of uncertainty associated with the data. Please familiarize yourselves with the information available for each of the faults prior to our September meeting, and be prepared to discuss the paleoseismic information available for them as it pertains to slip rate and recurrence. Some questions to consider while reviewing the data include:

1. Given the wide range in the quantity and quality of data available for individual faults, what is the best way to assign a confidence level to the slip rate(s) and recurrence interval(s) available for each fault.
2. Which of the faults that we are considering are critical players in Utah regarding earthquake hazard and risk and are they adequately characterized?

Meeting Format

The format for our September meeting will follow that established for our first meeting in June. We will discuss the faults in the order in which they appear in your packet, beginning with the Joes Valley faults and ending with the Fish Springs fault, reviewing the available paleoseismic data, considering the uncertainty associated with the data, and establishing a consensus slip rate and/or recurrence interval for each fault. As meeting coordinator, I will again prepare a PowerPoint presentation highlighting the issues related to each fault to facilitate our discussion; however, please bring your three-ring binder, since the PowerPoint presentation is not meant to reproduce all of that information contained in the Fault Synopsis Forms.

Gigatrench Field Review

Following our meeting, Susan Olig invites all the members of the Working Group to attend a field review of her "Gigatrench" at Mapleton on the Provo segment of the Wasatch fault on Saturday, September 6th. To take advantage of the best light for viewing the trench walls, the review will begin at 7:00 a.m. A van will be available at 6:00 a.m. at the Holiday Inn to transport those members of the Working Group who wish to attend the field review. The van will return to the Salt Lake City airport by 2:00 p.m. so Working Group members can catch a Saturday afternoon flight home.

General Housekeeping

1. Meetings will begin at 8:30 a.m. sharp each morning and will continue until 5 p.m. each day, unless consensus is easily achieved and we get done early. However, if reaching consensus proves difficult, provisions have been made for an evening meeting on the 4th to ensure that we do complete our full task in the two days allotted. For those traveling from out of state, make your airline reservations accordingly.
2. A continental breakfast will be available at 8:00 a.m. each morning in the meeting room, and a box lunch will be provided each day along with soft drinks, juice, and snacks for breaks.
3. The Airport Holiday Inn is conveniently located directly across the street from the Utah Department of Natural Resources building and has an airport shuttle. The reservation number is 1-801-533-9000.
4. A van will be available on Thursday evening to take folks to dinner, and to make a run to the airport on Friday after the meeting for those individuals not staying for the "Gigatrench" field review on Saturday.
5. The van to the "Gigatrench " will depart the Airport Holiday Inn at 6:00 a.m. on Saturday morning the 6th and will return to the Salt Lake City airport by 2:00 p.m.

I look forward to seeing all of you on September 4th and to two days of productive meetings. If you have any questions regarding the meeting or the enclosed information, feel free to contact me at 1-435-865-8126 or lund@suu.edu.

UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP

Utah Department of Natural Resources
Utah Geological Survey

Salt Lake City, Utah
June 4-5, 2003

1	Joes Valley Faults
2	West Valley Fault Zone
3	West Cache Valley Fault Zone
4	East Cache Fault Zone
5	Hurricane fault (Anderson Junction section)
6	Oquirrh Fault Zone
7	Southern Oquirrh Mountains Fault Zone
8	Eastern Bear Lake fault (southern section)
9	Bear River Fault Zone
10	Morgan Fault (central section)
11	James Peak Fault
12	Towanta Flat Graben
13	Bald mountain Fault
14	Strawberry Fault
15	Hansel Valley Fault
16	Hogsback Fault (southern section)
17	North Promontory Fault
18	Sugarville Area Faults
19	Washington Fault Zone (northern section)
20	Fish Springs Fault
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Notes

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section:
Joes Valley fault zone (JVFZ), San Pete County, Utah

Paleoseismic Data Source Documents:
Foley, L.L., Martin, R.A., Jr., and Sullivan, J.T., 1986, Seismotectonic study for Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report No. 86-7, 132 p., scale 1:60,000 and 1:155,000.

Geomorphic Expression:
The JVFZ consists of parallel, en echelon, and occasionally overlapping, north to northeast-trending faults which extend for 120 kilometers on the east side of the Wasatch Plateau (Foley and others, 1986; see map). The fault system contains two major structures, a southern and a northern graben, each of which have distinct geomorphic characteristics that may reflect differences in total displacement and recency of movement on bounding faults. The northern part of the fault zone is characterized by greater total stratigraphic throw; the presence of straighter, more linear graben-bounding faults than in the south; and scarps formed on Quaternary deposits, which are absent to the south (Foley and others, 1986).

The northern part of the JVFZ extends from the vicinity of Ferron Canyon to Electric Lake, a distance of about 50 kilometers and is bounded by the East and West Joes Valley faults (EJVF & WJVF) and contains several intragraben faults the most prominent being the Middle Mountain fault (MMF), and the Bald Mountain faults (BMF). Pronounced scarps have formed where Quaternary unconsolidated deposits are displaced by both the graben-bounding faults and the intragraben structures (Foley and others, 1986).

Evidence for Segmentation:
Based primarily on geomorphic expression and total stratigraphic throw, Foley and others (1986) subdivide the EJVF and WJVF into three sections each. However, the end sections for both faults are only a few kilometers long and it is unlikely that they represent independently seismogenic fault segments.

Age of Youngest Faulting:
Latest Pleistocene/Holocene?

Summary of Existing Recurrence Interval Information:
EJVF: <60 ka, but this is a maximum value that assumes four surface-faulting events; Foley and others (1986) believe that four events is a minimum number and that there likely were additional young events that they were unable to recognize.
WJVF: 9-19 ka (single cycle between penultimate [PE] and most recent [MRE] events)
MMF: 8-24 ka (single cycle between PE and MRE)
BMF: No data

Summary of Existing Slip-Rate Information:

Foley and others (1986) do not report slip rates for any of the Joes Valley faults.

Black and others (2003) report slip rates for the EJVF and WJVF and the MMF, which they determined by dividing the maximum displacement recorded in Quaternary deposits along those faults by the estimated age of the displaced deposits. In some instances the Black and others (2003) slip rates are as high as 1.4 mm/yr; however, all their slip rates have open seismic cycles at both ends, and the displacements are reported by Foley and others (1986) as "scarp heights" not as net slip. Because Foley and others (1986) did distinguish between scarp height and net slip on the EJVF where they measured scarp profiles, it is assumed that when they report a value as a "scarp height" that is what they meant and that the measurement does not represent net slip.

Slip rates calculated for this review using reported interevent recurrence intervals and the best estimate available for net slip were as follows:

EJVF: timing of events is poorly constrained, as is the number of events; a best estimate for a late Quaternary long-term slip rate is 0.01-0.04 mm/yr - but this slip rate is open at both ends.

WJVF: 0.03 to 0.06 mm/yr based on an interval of 9 to 19 kyr between the PE and MRE, and a net slip of 0.5 meters for the MRE.

MMF: 0.02 - 0.06 mm/yr using an average net slip of 0.5 meters for the MRE and an elapsed time of 8-24 ka for the interval between the PE and MRE.

BMF: No data

Comments:

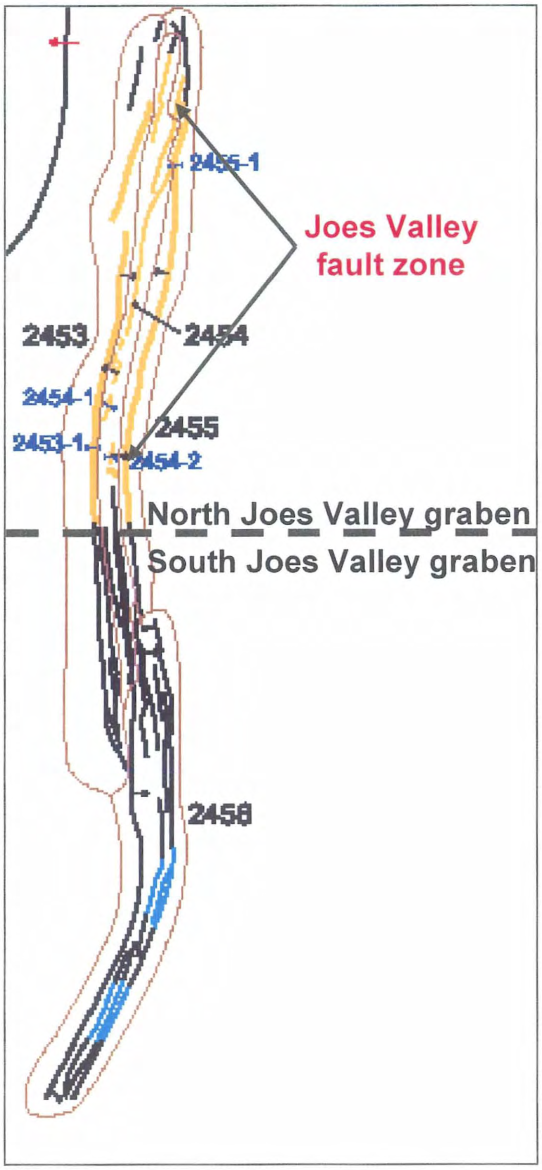
The EJVF has had three small (0.5-1.0 m) older events and a large (2.5 m) MRE, while the WJVF and MMF had large penultimate events (PE; 5.5+ and 2.5-3.0 m, respectively) and small (0.5 m) MREs. In the case of the WJVF and the MMF, the recurrence intervals required to generate the 0.5-meter events were on the order of 9 to 24 ka. The recurrence interval required to produce the large MRE on the EJVF is not known, nor are the intervals required to produce the large PEs on the WJVF and MMF. Additionally, Foley and others (1986) believe that the large MRE displacement on the EJVF may be the result of more than one event. <u>Given the general lack of information on event timing and net slip for the JVFZ, it would appear that the slip rates reported by Black and others (2003) are systematically too high and that the rate of slip on all of the Joes Valley faults is likely measured in hundredths of millimeters per year, rather than tenths or whole millimeters.</u>

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:

Map of the Joes Valley fault zone taken from the Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites:

2453-1; West Joes Valley fault
2454-1; Middle Mountain fault
2454-2; Intragraben reservoir fault
2455-1; East Joes Valley fault

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: East Joes Valley Fault (EJVF), Sanpete County, Utah.

Study Synopsis ID: EJVF-1

Map Reference: 2455

Paleoseismic Data Source Documents:

Foley, L.L., Martin, R.A., Jr., and Sullivan, J.T., 1986, Seismotectonic study for Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report No. 86-7, 132 p., scale 1:60,000 and 1:155,000.

General Fault Information

Geomorphic Expression

The EJVF is a 57-kilometer-long, north-trending fault bounding the east side of the northern Joes Valley graben. Bedrock displacement along the fault is greatest at its center and diminishes toward the north and south. Foley and others (1986) divide the fault (based on relative age and displacement) into the Miller Flat, Straight Canyon, and Ferron sections (from north to south). Section lengths are 8, 42, and 5 kilometers, respectively. A zone of parallel and branching faults with up to 100 meters of total stratigraphic throw in bedrock marks the Miller Flat section. The Ferron section also has about 100 meters of total throw, and is marked by a low, deeply incised scarp in colluvial veneer and bedrock. Paleoseismic data available for the EJVF are from a single trench on the Straight Canyon section, which is marked by a steep linear escarpment in bedrock with up to 900 meters of total throw. Only the Straight Canyon section has significant inferred late Quaternary (<300 ka) displacement based on the presence of scarps formed on alluvial fans.

Evidence for Segmentation

Foley and others (1986) divided the EJVF into three sections based on the amount of total stratigraphic displacement, the degree of topographic expression, and the presence of scarps formed on late Quaternary deposits (see discussion above).

Age of Youngest Faulting

Latest Pleistocene/Holocene(?)

Paleoseismic Parameter Data

Type of Study/Commentary

Foley and others (1986) excavated a trench on the southeast side of Scad Valley at the north end of the Straight Canyon section (site 2455-1, see map). Stratigraphic and structural relations indicate a minimum of four surface-faulting events since 150-300 ka, which is the age (based on amino acid racemization dates from shells) of the oldest unit exposed in the trench. The four events appear to have involved both brittle rupture and monoclinal folding. Two bulk-soil samples and one charcoal sample from the modern (unfaulted) soil profile yielded ^{14}C age estimates that place a minimum limiting age on the most recent event.

Number of Surface-Faulting Events/How Identified

Minimum of four, but Foley and others (1986) believe that there could be several more (especially in the more recent geologic past) small events. The interpretation of the number of events was based on the recognition of a series of event horizons overlying shear zones and faults and one colluvial-wedge (?) deposit. The event horizons terminate some shears/faults and are displaced by others. Foley and others (1986) interpret a minimum of 4 events based on those relations, but conclude from the relatively small displacements associated with the three older events (< 1 m total) and the large displacement associated with the most recent event (MRE; 2.5 m) that the large young displacement may be the result of several smaller events.

Age of Events/Datum Ages/Dating Techniques

Based on the amino acid racemization results from shells contained in the oldest unit exposed in the trench, all four surface-faulting events occurred post 150-300 ka. Timing of the four events is interpreted from the trench stratigraphy as follows: Event 1 postdates units 1, 2, and 3 and predates deposition of unit 4. Event 2 postdates deposition of Unit 4 and predates unit 5 (possible colluvial wedge). Event 3 postdates deposition of Unit 7 and the formation of a thick soil on that unit interpreted as requiring more than 130 ka to develop, and predates deposition of unit 8. Event(s) 4 postdates deposition of unit 8, which is interpreted to be no younger than 14-30 ka, based on the soil formed on it. After faulting, unit 8 was buried by colluvium (units 9 and 10) that is ~1.5 ka.

Age control for this study is provided by amino acid racemization dates from shells (see above) and three ^{14}C age estimates. A ^{14}C age of 1400 ± 230 ^{14}C yr B.P. was obtained from charcoal in post-faulting Unit 9 and ^{14}C AMRT ages of 1620 ± 80 and 880 ± 70 ^{14}C yr B.P. were obtained from organics in the modern soil forming on Unit 10.

Event Slip/Cumulative Slip

Foley and others (1986) report cumulative net slip on EJVF scarps obtained from scarp profiles of 5.7, 6.3, and 2.8 meters. The two larger displacements were measured on an older alluvial-fan surface, the smaller displacement on the younger fan surface where the trench was excavated.

Cumulative net slip measured from displaced stratigraphy in the trench (top of unit 3) is about 3 meters for the past 150-300 ka. Less than 1 meter of slip is interpreted to have occurred in the three older events and about 2.5 meters in the youngest event. The 2.5 meters is expressed chiefly as a monoclinal fold. Foley and others (1986) state that if the EJVF has behaved consistently, the 2.5 meters of recent displacement is likely the result of several small events rather than a single large event, but offer no other evidence for repeated young events. No explanation is provided regarding why the 3 meters of net slip measured in the trench for the past 150-300 ka is only about half that measured from scarp profiles on the older fan surface.

Published Recurrence Interval

Reported as <60 kyr between events, but Foley and others (1986) state that this is a maximum value because the four surface-faulting events identified on the EJVF are considered a minimum number, and there could be as many as several more small events.

Published Slip Rate

None reported.

Black and others (2003) report a short-term slip rate of 0.2-1.0 mm/yr and a long-term rate of 0.1-0.3 mm/yr. A short-term rate of 0.2 mm/yr can only be achieved if the maximum displacement reported for the most recent event(s) of 2.5 meters is divided by the minimum possible elapsed time since that event of 12,500 years (2500 mm/12,500 yrs = 0.2 mm/yr), resulting in slip rate that is not only open at each end but that uses net slip and elapsed time values that are not correlative. The strain that produced the 2.5 meters of net slip accumulated between the PE and MRE not in post-MRE time. Additionally, Foley and others (1986) doubt that the entire 2.5 meters of displacement reported for the MRE occurred in a single event. If that is the case, the Black and others (2003) short-term slip rate is substantially too high.

Additionally, regardless of which cumulative net slip value is selected (6.3, 5.7, 3, or 2.8 meters) dividing those values by either 150 or 300 ka results in long-term slip rates that range from 0.01-0.04 mm/yr, a minimum of an order of magnitude less than those reported by Black and others (2003).

Sources of Uncertainty

1. The number of surface-faulting events reported is a minimum value.
2. Event timing is poorly constrained between 150-300 ka and ~1.5 ka, timing of individual events is not constrained, except for the MRE between 14-30 ka and 1.5 ka.
3. Cumulative net slip measured in the trench for the past 150-300 ka is significantly less than that obtained from scarp profiles on older fan surfaces, where is the missing slip?
5. The 2.5 meters of slip reported for the MRE is monoclinal folding not discrete slip and Foley and others (1986) believe it likely represents more than one event.

Summary:

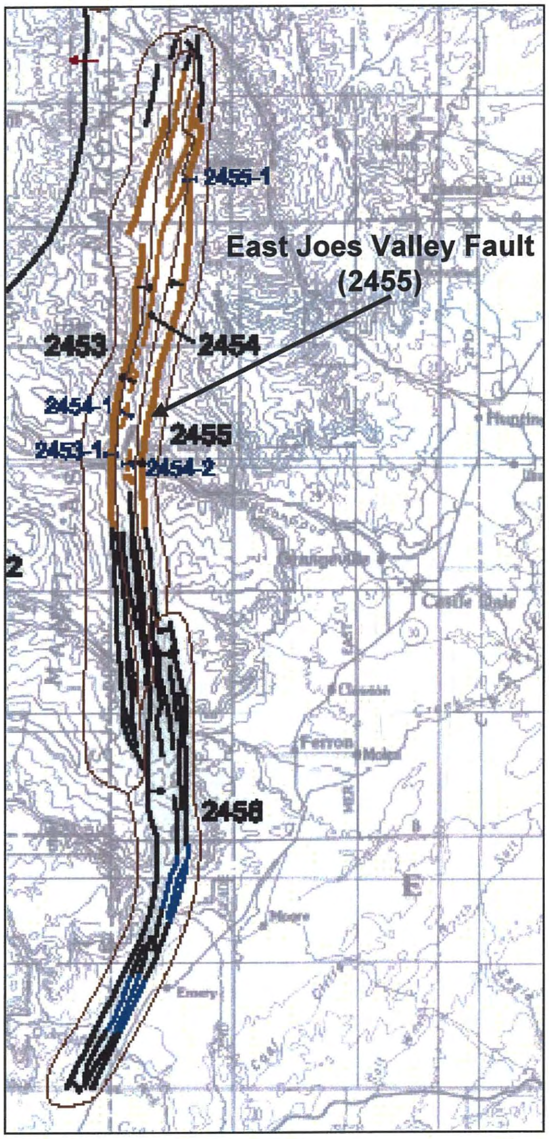
The recurrence interval resulting from this study (<60 kyr) is a maximum value based on a minimum of four surface faulting events in the past 150-300 ka. The authors believe it is likely that there were more than four events and that the actual recurrence interval is therefore shorter by an unknown amount. <u>Based on the paleoseismic information presented in this report, the short- and long-tem slip rates reported by Black and others (2003) for the EJVF are considered questionable and likely too high by at least a factor of ten.</u>

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:

Map of the East Joes Valley fault (2455) taken from the Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench site:

2455-1

Foley and others (1986)

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: West Joes Valley Fault (WJVF), San Pete County, Utah

Study Synopsis ID: WJVF-1

Map Reference: 2453

Paleoseismic Data Source Documents:

Foley, L.L., Martin, R.A., Jr., and Sullivan, J.T., 1986, Seismotectonic study for Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report No. 86-7, 132 p., scale 1:60,000 and 1:155,000.

General Fault Information

Geomorphic Expression

The 60-kilometer-long WJVF bounds the west side of the northern Joes Valley graben and is divided into three sections (Dugway Hollow [7.5 km], Seely [42 km], and Huntington [4 km]) based on total stratigraphic displacement in bedrock, degree of topographic expression, and the presence or absence of fault scarps on Quaternary deposits (Foley and others, 1986). Evidence for Quaternary displacement is found only on the Seely section, which consists of two en echelon fault strands. Scarps formed on late Quaternary deposits are present at five locations along the Seely section. Scarps ranging in height from 8 to 12 meters are found in terrace deposits of latest Pleistocene age at the mouths of Littles and Black Canyons. Along the fault between Browns and Lake Canyons, scarps possibly as high as 12 to 14 meters are present at three locations in moraines attributed to the Pinedale glacial advance (Foley and others, 1986). Therefore, there are five locations along the Seely section of the WJVF where there is evidence of 12+ meters of displacement in deposits that range between 11 and 30 ka.

Evidence for Segmentation

Foley and others (1986) divided the WJVF into the Dugway Hollow, Seely, and Huntington sections (see above). The Dugway Hollow section is marked by a low, deeply incised scarp in colluvial veneer and bedrock with about 150 meters of throw. The Seely section consists of two en-echelon faults in Quaternary deposits (total throw is uncertain). Scarps 8 to12 meters high are in latest Pleistocene-age (<30 ka) deposits along the longer en-echelon fault. The shorter en-echelon fault has 12- to14-meter-high scarps in latest Pinedale (11-14 ka) glacial deposits. The Huntington section has up to 500 meters of throw and is marked by an eroded bedrock scarp partially buried by Pinedale (11-14 ka) terminal moraines.

Age of Youngest Faulting

Latest Pleistocene

Paleoseismic Parameter Data

Type of Study/Commentary

Foley and others (1986) excavated a trench on the Seely section of the fault, about 270 meters north of Littles Creek near the north end of a 450-meter-long scarp crossing the highest of three alluvial terraces (site 2453-1, see map). Stratigraphic relations indicate a minimum of two surface-faulting events. Radiocarbon age estimates from a bulk-soil sample and charcoal derived from unfaulted colluvium provide a minimum age for the most recent event (MRE). Geomorphic relations and soils data provide additional broad constraints on the age of the terrace and therefore earthquake timing.

Number of Surface-Faulting Events/How Identified

Two events/stratigraphic relations (event horizons) in the trench. No mention is made of colluvial-wedge stratigraphy or other tectonically derived deposits, although what may be colluvial-wedge deposits are shown on the trench log.

Age of Events/Datum Ages/Dating Techniques

Units 1 through 4 (bedrock and debris-flow and alluvial deposits forming the terrace deposits) exposed in the trench were faulted and displaced a minimum of 5.5 meters (depth of trench) by the penultimate event (PE). Unit 8 overlies the faulted units and contains charcoal dated at 23,140±350 ^{14}C yr B.P. A maximum age for the terrace derived from geomorphic relations and soils data is about 30 ka, thus bracketing the PE between about 30 and 23 ka. The MRE displaced units 7, 8, and 9, which are in turn overlain by unit 10, which is not faulted. Charcoal from unit 10 yielded a ^{14}C age of 6575±220 ^{14}C yr B.P., and a ^{14}C AMRT age from the "soil organic fraction" of unit 10 gave an age of 5005±215 ^{14}C yr B.P., thus bracketing the MRE between about 23 and 5 ka. On the trench log unit 10 appears to be a colluvial wedge related to the MRE although it is not specifically identified as such in the report. The AMRT ^{14}C age on "soil organics" comes from the approximate middle of Unit 10, and so likely is from organic matrix material and not from a buried soil.

Geomorphic and stratigraphic evidence related to moraines attributed to the latest Pinedale glacial advance at Blacks Canyon about 9 kilometers north of the trench site suggest that the MRE on the Seely section occurred between 11 and 14 ka.

All ^{14}C ages are reported in radiocarbon years and are not calendar calibrated.

Event Slip/Cumulative Slip

Net slip for the PE is reported as a minimum of 5.5 meters, based on the depth of the trench and a lack of correlative deposits in the footwall and the hanging wall. Units exposed in the footwall are displaced below the bottom of the trench in the hanging wall. Net slip for the MRE is reported as 0.5 meters, based on the displacement of the contact between Units 7 and 8. No explanation is provided regarding the more than 10-fold difference in net slip between the PE and MRE.

Where trenched, the scarp formed on the terrace surface was 8 meters high.

Published Recurrence Interval

Based on their interpretation of stratigraphic evidence in the trench at Littles Canyon and geomorphic evidence from other locations along the Seely section, Foley and others

(1986) believe that the two events recognized on the Seely section in the past 30 ka were separated by an interval of 10 to 20 kyr.

If the PE occurred between about 30 and 23 ka and the MRE occurred between 11 and 14 ka, the interval between events could be as short as 9 kyr or as long as 19 kyr.

Published Slip Rate

None reported by Foley and others (1986).

Black and others (2003) report slip rates ranging from 0.4-1.1 mm/yr for the WJVF based on reported scarp heights of 8 to 12 meters in deposits that are 11 to 30 kyr old. However, their slip-rate estimate is based on scarp heights, not on net slip, and also has an open seismic cycle at each end of the time interval. Based on an interval of 9 to 19 kyr between the PE and MRE and a net slip of 0.5 meters for the MRE, the slip rate for that closed seismic cycle ranges from 0.03 to 0.06 mm/yr.

Since the timing of the antepenultimate event (APE) could not be determined, it is not known if the recurrence interval between the APE and PE is similar to that between the PE and MRE, or possibly much longer as would be suspected considering the much larger displacement reported for the PE compared to the MRE. Therefore, the long-term slip rate for the WJVF is not known, but is suspected to also be <0.01 mm/yr.

Sources of Uncertainty

1. The ages of surface-faulting events are only broadly constrained within time windows several thousands of years wide.
2. There is a more than 10-fold difference in the net slip reported for the two most recent events on this fault. No explanation is provided for the difference (unrecognized events?), as was the case on the East Joes Valley fault (Foley and others, 1986).
3. All values related to the size of the scarps on the Seely section are scarp heights not net slip.

Summary:

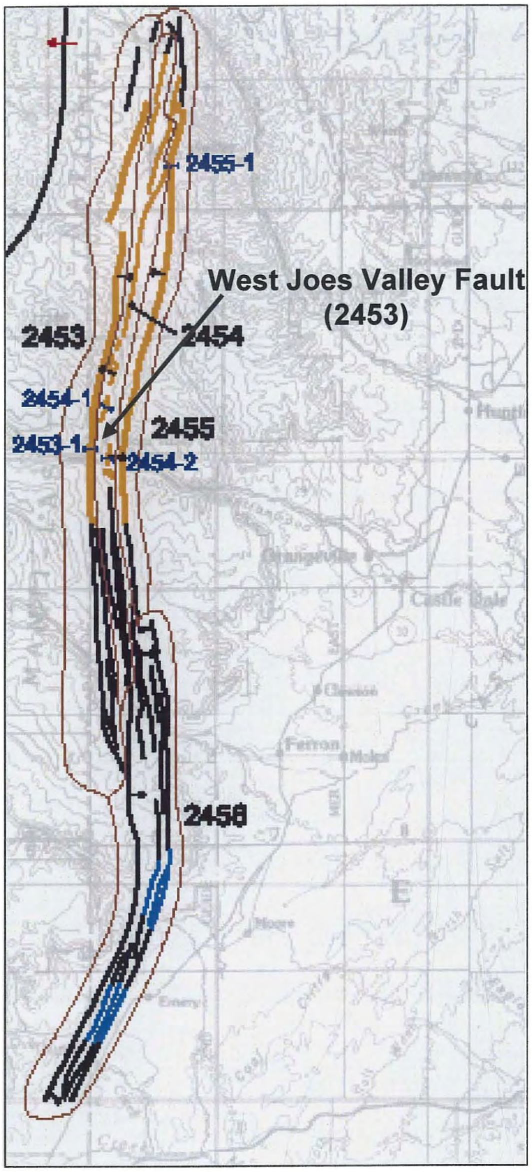
A greater than 10-fold difference exists between the displacements reported for the PE and MRE. Based on the elapsed time between those two events and the 0.5 meters of displacement reported for the MRE, the slip rate for the most recent closed seismic cycle on the WJVF ranges from 0.03 to 0.06 mm/yr. Black and others (2003) report slip rates ranging from 0.4 to 1.1 mm/yr for the WJVF; however, those slip rates are based on scarp-height measurements not net slip and they have open seismic cycles on both ends.

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:

Map of the Joes Valley fault zone West fault (2453) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench site:

2453-1

Foley and others (1986)

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Joes Valley Intragraben Faults (JVIGF)

Study Synopsis ID: JVIGF-1

Map Reference: 2454

Paleoseismic Data Source Documents:

Foley, L.L., Martin, R.A., Jr., and Sullivan, J.T., 1986, Seismotectonic study for Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report No. 86-7, 132 p., scale 1:60,000 and 1:155,000.

General Fault Information

Geomorphic Expression

Joes Valley graben north of Joes Valley Reservoir contains scarps formed on late Quaternary deposits between the main graben–bounding East and West Joes Valley faults. Only the Middle Mountain fault (MMF) and Bald Mountain faults (BMF), which occur along intragraben horst blocks, and a series of short scarps near Joes Valley Reservoir, show clear evidence for surface displacements in the Quaternary.

The MMF bounds the Middle Mountain horst block, and is the longest of the intragraben faults with evidence for Quaternary displacement. The fault trace consists of numerous NNE-trending, en echelon, down-to-the-west scarps. Recurrent late Pleistocene surface rupture is shown by increasing scarp heights in deposits of progressively older Pleistocene age, and by the absence of scarps in late Holocene alluvial-fan deposits (Foley and others, 1986). The northern end of the MMF appears to merge with the East Joes Valley fault, while at its southern end the fault is obscured by landslide deposits.

The BMF (east and west) lie at the extreme northern end of the Joes Valley graben and bound the Bald Mountain horst block. Quaternary displacement at the north end of the graben appears to be restricted to the BMF since neither graben-bounding fault shows evidence of Quaternary surface displacement (Foley and others, 1986). The east BMF scarp is 2.5 kilometers long and 3 to 5 meters high in a late Pleistocene outwash terrace. The west BMF is covered at its northern and southern ends by late Pleistocene glacial moraines. Several small (<2 m) scarps along the trace of the BMF are not preserved in the moraines, indicating either that the most recent faulting is older than the moraines, that the fault does not extend beneath the moraines, or that the scarps were not preserved in the moraines (Foley and others, 1986).

The reservoir scarps are a series of small (<2 m), north-trending, subdued, west-facing scarps on the west side of Joes Valley Reservoir. The scarps show no relation to known bedrock faults and several of the scarps now lie beneath the reservoir. The scarps still above the level of the reservoir displace a debris-flow deposit that originated in Seely Canyon to the west.

Evidence for Segmentation
None

Age of Youngest Faulting
Late Pleistocene

Paleoseismic Parameter Data

Type of Study/Commentary
Foley and others (1986) excavated four trenches across intragraben faults in Joes Valley. Three trenches (trenches 1, 2, and 3) were excavated across the MMF east of the mouth of Reeder Canyon where two en echelon scarps cross the three oldest of four upper Pleistocene alluvial fans (site 2454-1, see map). The fourth trench (Foley and others' [1986] trench 5) was excavated about 3.5 kilometers south of the other trenches across a subdued, west-facing scarp on the west side of Joes Valley Reservoir that may be a southern extension of the MMF (site 2454-2). No trenches were excavated on the BMF.

Trench 1 was excavated on a projection of the MMF trace across a depression (no scarp) on an older alluvial-fan surface where Foley and others (1986) hoped to find organic material; however, no organic material was encountered. Stratigraphic relations in trench 1 indicated at least two surface-faulting events. Trench 3 was excavated across a 1.7-meter-high, uphill-facing scarp on the same lineament as, and about 300 meters south of, trench 1 also on an older alluvial-fan surface. Again stratigraphic relations indicated at least two surface-faulting events. Radiocarbon age estimates from three bulk-soil samples of an unfaulted, organic-rich buried A horizon provide a minimum limiting age for the most recent event (MRE). Trench 2 was excavated on a young alluvial-fan surface across an uphill-facing, discontinuous, 0.5-meter-high scarp on an en echelon section of the MMF about 200 meters west of the trace on which trenches 1 and 3 were excavated. Trench 2 exposed generally coarse alluvial-fan deposits that contained abundant animal burrows that obscured evidence of fault displacement. In trench 2, Foley and others (1986) infer a single surface-faulting event of small (<1 meter) displacement of similar age as the MRE recorded in trenches 1 and 3.

Trench 5 was excavated on a late Pleistocene debris-flow surface across a 1.6-meter-high, subdued, west-facing scarp on the west side of Joes Valley Reservoir. The trench revealed an area of loose, disturbed, and bioturbated gravel interpreted to be the fault zone. Foley and others (1986) infer small-displacement (<1 meter) faulting due to the lack of a colluvial wedge. A step in the lower portion of the calcareous zone of the modern soil horizon suggests a second small-offset event may have occurred on this fault in very recent geologic time.

Number of Surface-Faulting Events/How Identified
Trench 1: At least two events; the penultimate event (PE) displaced alluvial-fan deposits, the MRE was recognized by microshears in loess (unit 5) and a small displacement in the upper contact of a debris-flow deposit.

Trench 3: Two events; the PE created a scarp-derived colluvial wedge, the MRE displaced the colluvial wedge and created shear fabric in the wedge deposit.

Trench 2: One event; this trench lacks evidence for displacement of stratigraphic units or for the existence of a fault scarp. The trench contains numerous krotovina; that largely obscure stratigraphic and structural relations in the trench. However Foley and others (1986) interpret an area of very loose gravel near the center of the trench that is extensively disturbed by krotovina as a fault zone. A second area of loose gravel is interpreted as a tectonic crack. Foley and others (1986) interpret a single surface-faulting event in this trench; however, they do not state the basis for that conclusion.

Trench 5: Two events; a vertical zone of loose, disturbed, and bioturbated gravel is interpreted as a fault; however, the event apparently did not create a free face high enough to shed a colluvial wedge, nor is mention made of measurable displacement of the geologic units in the trench. Foley and others (1986) interpret a step in the lower boundary of the calcareous part of the modern soil as evidence for a second small, young event.

Age of Events/Datum Ages/Dating Techniques

Of the four trenches excavated across the MMF, two were in older alluvial-fan deposits (trenches 1 and 3), one was in a young alluvial-fan deposit (trench 2) and one was in a late Pleistocene debris-flow deposit (trench 5). Each of the trenches (1, 3, and 5) in the older deposits was interpreted to contain evidence for two surface-faulting earthquakes. The trench (2) in younger alluvial-fan deposits was interpreted to contain evidence for a single surface-faulting event.

Foley and others (1986) interpreted the timing of these events using surface age estimates based on soil-profile development and ^{14}C ages from trench 3. The soils formed on the older surfaces are estimated to be 14-30 ka in age and therefore the PE occurred after that time. An unfaulted soil horizon that overlies the fault yielded three ^{14}C AMRT ages of 6100±195, 3975±200, and 2335±150 ^{14}C yr B.P. The three ages are consistently older with depth and indicate that the MRE is older than approximately 6 ka. So, both events occurred sometime after 14-30 ka and before 6 ka.

All ^{14}C ages are reported in radiocarbon years and are not calendar calibrated or adjusted for the estimated mean residence time of the carbon in the soil.

Event Slip/Cumulative Slip

Trench 1: PE 2-3.5 m, MRE ~0.5 m: scarp height 0 (buried by loess)
Trench 2: MRE small but unknown amount of displacement (<1 m); scarp height 0.5 m
Trench 3: PE ~2.5 m, MRE ~0.5 m; scarp height 1.7 m (partially buried by loess)
Trench 5: PE unknown but <1 m, MRE unknown but < 1m; scarp height 1.6 m

Published Recurrence Interval

Foley and others (1986) used the degree of soil development on buried soils in trenches 1 and 3 and the surface soil at trench 5 to estimate the elapsed time between the PE and MRE and determined the interval between them could have been not less than 10 kyr. In a later summary of their trenching results, they use the minimum and maximum age bounds for the events (14-30 ka and 6 ka) to estimate the recurrence interval between the PE and MRE as 8-24 ka.

Published Slip Rate

None reported by Foley and others (1986).

Using an estimated average net slip of 0.5 meters for the MRE and an elapsed time of 8-24 ka for the interval between the PE and MRE results in a single closed seismic cycle slip rate of 0.02-0.06 mm/yr.

Black and others (2003) report a slip rate for the MMF of 0.1-0.2 mm/yr, based on 3 meters of displacement in 14-30 ka, but that slip rate has open seismic cycles at both ends and is likely substantially too high.

Sources of Uncertainty

1. The ages of the surface-faulting events are only broadly constrained in time windows that are up to several thousands of years wide.
2. Due to uncertainties in the ages of events, the maximum and minimum bounds on the recurrence interval between the PE and MRE vary by a factor of three.
3. As on the Joes Valley graben-bounding faults there is a significant difference (~6 fold) in the amount of net slip between the PE and MRE, with no explanation of why the size of the two events is so different.
4. Stratigraphic and structural relations in trenches 2 and 5 are largely obscured by krotovina, making the interpretation of the number and size of surface-faulting events difficult.

Summary:

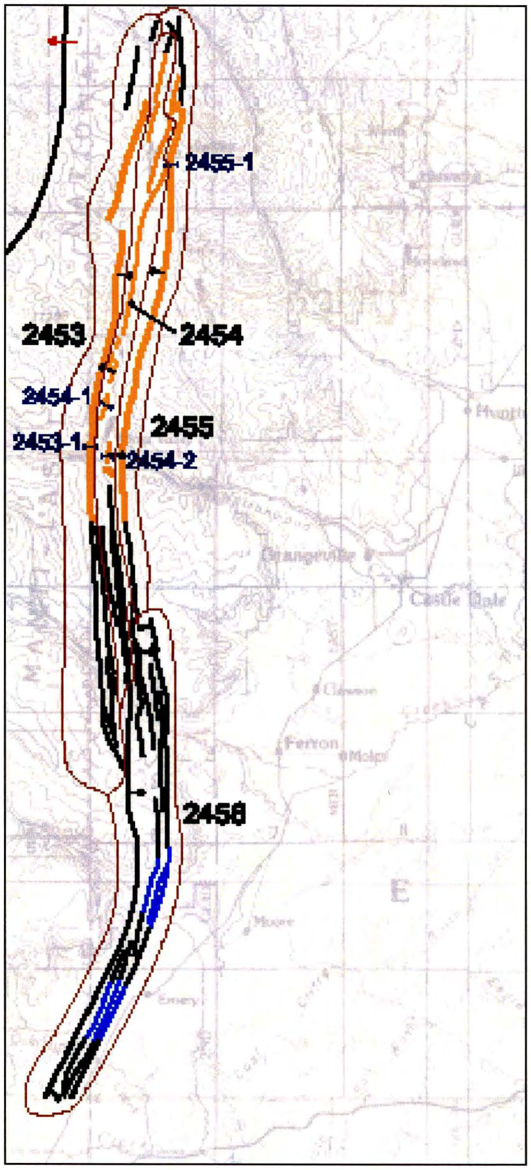
The JVIGF have apparently experienced two surface-faulting earthquakes within the past 30 ka, but the sizes of those events were widely divergent. The PE produced 2 to 3 meters of net slip, while the MRE produced 0.5 to <1 meter of displacement. Using the 8-24 kyr recurrence interval between the PE and MRE and the 0.5 meters of displacement actually measured for the MRE, results in a slip rate of 0.02 to 0.06 mm/yr. Since the timing of the antepenultimate event (APE) was not be determined, it is not known if the recurrence interval between the APE and PE is similar to that between the PE and MRE, or possibly much longer as would be suspected considering the much larger displacement reported for the PE compared to that reported for MRE. Therefore, the long-term slip rate for the JVIGF is not known with certainty, but is suspected to be <0.01 mm/yr.

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:

Map of the Joes Valley Intragraben faults (2454) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites:

2454-1 (Trenches 1, 2, & 3)
2454-2 (Trench 5)
Foley and others (1986)

Notes

2

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section:
West Valley fault zone (WVFZ), Salt Lake County, Utah.

Paleoseismic Data Source Documents:
Keaton, J.R., and Currey, D.R., 1989, Earthquake hazard evaluation of the West Valley fault zone in the Salt Lake City urban area, Utah: Salt Lake City, Dames and Moore, Final Technical Report for U.S. Geological Survey, Contract No. 14-08-001-G1397, 69 p.; published as Utah Geological Survey Contract Report 93-7, 1993.

Keaton, J.R., Currey, D.R., and Olig, S.J., 1987, Paleoseismicity and earthquake hazards evaluation of the West Valley fault zone, Salt Lake City urban area, Utah: Salt Lake City, Dames and Moore, Final Technical Report for U.S. Geological Survey, Contract No. 14-08-0001-22048, 55 p.; published as Utah Geological Survey Contract Report 93-8, 1993.

Solomon, B.J., 1998, New evidence for the age of faulting on the West Valley fault zone: Utah Geological Survey, Survey Notes, v. 30, no. 3, p. 8 and 13.

Utah Geological Survey, unpublished data

Geomorphic Expression:
The WVFZ is a north- to northwest-trending fault zone about 15 kilometers long and 7 kilometers wide that consists of generally east-dipping faults that form the western boundary of a fault-bounded basin in the center of the Salt Lake Valley. The Salt Lake City section of the Wasatch fault zone (WFZ) traverses the eastern side of the valley at the base of the Wasatch Range and forms the eastern side of the basin. The WVFZ is at about the midpoint of the valley and exhibits scarps up to 6.1 meters high formed on late Pleistocene Lake Bonneville lacustrine deposits.

Evidence for Segmentation:
The southern portion of the WVFZ consists of two subparallel east-dipping faults, the Taylorsville fault (TF) to the east, and Granger fault (GF) to the west (see map), whereas the northern portion is broader and characterized by many smaller, east- and west-dipping faults. Seismic-reflection data from an area on-trend with the fault zone at the south end of Great Salt Lake (north of the fault zone) indicate a buried, east-dipping fault that cuts the inferred base of the Quaternary section (Wilson and others, 1986). Deformation includes monoclinal flexure of near-surface sediments as well as surface rupture. Single-event displacement is inferred from a post-Bonneville monoclinal flexure on the TF.

Age of Youngest Faulting:
Holocene. The fault zone shows evidence for Holocene surface faulting, but exposures are poor and often lack clear evidence of faulting/event timing or datable material. Recent events on the WVFZ appear to be similar in age to known surface-faulting earthquakes on the Salt Lake City section of the WFZ (Solomon, 1998; Utah Geological Survey, unpublished data).

Summary of Existing Recurrence Interval Information:

Keaton and others (1989) report a recurrence interval of 1.8-2.2 kyr for the WVFZ based on 6 to 7 events in the past 13 kyr.

Summary of Existing Slip-Rate Information:

Keaton and others (1989) report a slip rate of 0.1 to 0.2 mm/yr for the TF based on 1.2 to 1.5 meters of flexural offset in the past >12 ka. The GF exhibits 5.2 to 6.7 meters of displacement in the top of the Bonneville Alloformation (~13 ka) giving a late Pleistocene slip rate of 0.4 to 0.5 mm/yr.

A total displacement of 6.4 to 8.2 meters across the entire WVFZ in the past ~13 ka gives an average latest Pleistocene slip rate of 0.49 to 0.63 mm/yr.

Long-term slip rates (60 to 140 kyr) on the GF are as much as a factor of ten smaller than slip rates for latest Pleistocene/Holocene time.

Comments:

The relationship of the WVFZ to the WFZ remains uncertain. Movement on the WVFZ may be independent or directly tied to movement on the Salt Lake City section of the WFZ. The age of the MREs on the TF and GF are similar to those for the last two events on the Salt Lake City section of the WFZ (Solomon, 1998; Utah Geological Survey, unpublished information). Given Keaton and others (1989) estimate of 6 to 7 surface faulting earthquakes in the past ~13 ka on the WVFZ, if the WVFZ does act independently of the WFZ, then the Salt Lake Valley has experienced 12 to 13 surface-faulting earthquakes in the past ~13 ka.

References:

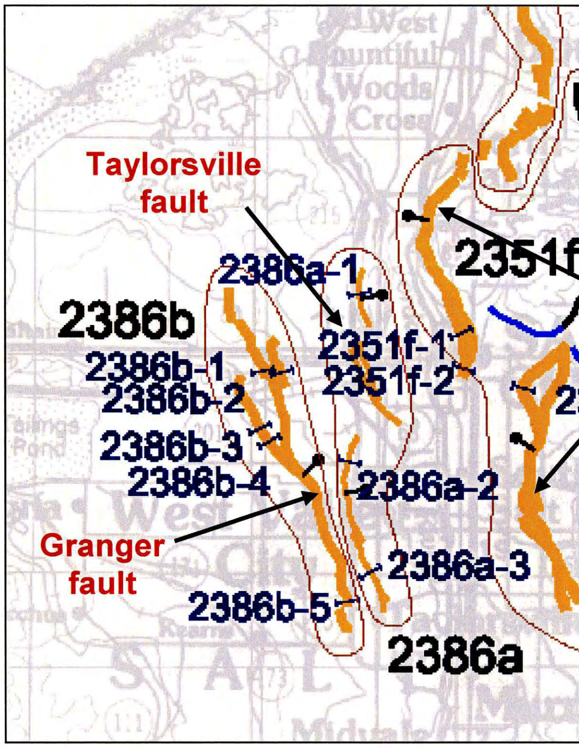
Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Hecker, Suzanne, 1993, Quaternary tectonics of Utah with emphasis on earthquake-hazard characterization: Utah Geological Survey Bulletin 127, 2 plates, scale 1:500,000, 257 p.

Wilson, E.A., Saugy, Luc, and Zimmermann, M.A., 1986, Cenozoic tectonics and sedimentation of the eastern Great Salt Lake area, Utah: Bulletin de Société Géologicque Francaise, v. 2, no. 5, p. 777-782.

Map:

Map of the West Valley fault zone (2386) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Taylorsville fault = 2386a
Granger fault = 2386b

Salt Lake City section Wasatch fault zone = 2351f

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Taylorsville fault (TF) of the West Valley Fault Zone (WVFZ), Salt Lake County, Utah

Study Synopsis ID: TF-1

Map Reference: 2386a

Paleoseismic Data Source Documents:

Keaton, J.R., and Currey, D.R., 1989, Earthquake hazard evaluation of the West Valley fault zone in the Salt Lake City urban area, Utah: Salt Lake City, Dames and Moore, Final Technical Report for U.S. Geological Survey, Contract No. 14-08-001-G1397, 69 p.; published as Utah Geological Survey Contract Report 93-7, 1993.

Keaton, J.R., Currey, D.R., and Olig, S.J., 1987, Paleoseismicity and earthquake hazards evaluation of the West Valley fault zone, Salt Lake City urban area, Utah: Salt Lake City, Dames and Moore, Final Technical Report for U.S. Geological Survey, Contract No. 14-08-0001-22048, 55 p.; published as Utah Geological Survey Contract Report 93-8, 1993.

Solomon, B.J., 1998, New evidence for the age of faulting on the West Valley fault zone: Utah Geological Survey, Survey Notes, v. 30, no. 3, p. 8 and 13.

General Fault Information

Geomorphic Expression

The near-surface expressions of the approximately 19-kilometer-long TF is characterized by monoclinal flexuring and minor step-faulting that warp Lake Bonneville and younger sediments 1.2 to 1.5 meters down-to-the-east across a discontinuous fault scarp. The style of deformation suggests earthquakes near the threshold magnitude for surface faulting (M~6.5). Geomorphic evidence suggests that two events occurred on the Taylorsville fault in post-Gilbert shoreline time (<12 ka). Solomon (1998) reported 0.5 meters of most-recent-event (MRE) displacement in lacustrine silt, sand, and clay exposed in a consultant's trench, just below the Holocene highstand of Great Salt Lake.

Evidence for Segmentation

None

Age of Youngest Faulting

Holocene

Paleoseismic Parameter Data

Type of Study/Commentary

Keaton and others, 1987 excavated four trenches in the mid-1980s at two locations along the southern part of the Taylorsville fault trace. Two trenches were at a northern site (2386a-2; see map) in Pioneer Industrial Park about 0.8 kilometers north of 2100

South Street, and two trenches were at a southern site (2386a-3) about 3 kilometers south-southeast of Decker Lake on the northwest corner of 4100 South Street and Redwood Road. None of the trenches showed evidence for a discrete fault trace, but minor discontinuous faults were observed at the northern site. Both sites exposed a monoclinal fold in the near-surface sediments at appropriate locations to represent the surface expression of the fault, and subsurface offsets of strata were consistent with the amount of topographic relief across the scarp (Keaton and others, 1987). The timing of individual earthquakes could not be determined. Subsequently, Keaton and Currey (1989) excavated seven additional trenches at the Pioneer Industrial Park site, which provided additional constraints on the location of the fault trace, but no additional information on earthquake timing.

Solomon (1998) described an exposure of the TF in a consultant's trench near the northern end of the fault trace, between I-215 and the Salt Lake City International Airport (site 2386a-1).

Number of Surface-Faulting Events/How Identified

Two. Keaton and others (1987) and Keaton and Currey (1989) were unable to identify discrete fault zones or evidence for individual surface-faulting events in trenches excavated across the TF. They interpret a minimum of two surface-faulting events in post-Gilbert shoreline time (<12 ka) based on the presence of a 1.2-1.5 meter-high scarp they believe formed during the penultimate event (PE) followed by a MRE that truncates that scarp. Solomon (1998) examined a consultant's trench across the TF and identified the MRE based on the presence of a tectonic crack filled with organic-rich sediment.

fluvial scarp?

Age of Events/Datum Ages/Dating Techniques

Keaton and others (1987) interpret two events post formation of the Gilbert shoreline (~12 ka), but were unable to determine individual event timing. Solomon (1998) obtained two ^{14}C age estimates on bulk-soil samples from organic crack-fill material and pre-fault-event sag-pond sediments that indicate the MRE on the TF occurred at about 2.2 ka.

Event Slip/Cumulative Slip

The TF scarp exhibits 1.2-1.5 meters of flexural displacement of post-Gilbert (<12 ka) deltaic sediments that Keaton and Currey (1989) believe represents two earthquakes. Solomon (1998) reported 1.5 feet (0.45 m) of displacement in sand, silt, and clay layers exposed in a consultant's trench.

Published Recurrence Interval

~6 kyr (2 events in ~12 kyr); this is an average recurrence interval, since event timing is unknown and therefore the actual interval between events also is unknown.

double?

Published Slip Rate

0.1 to 0.2 mm/yr based on a flexural displacement of 1.2-1.5 meters in deposits that are < 12 ka.

Sources of Uncertainty

1. Trenches excavated by Keaton and Currey (1987) and Keaton and others (1989) revealed evidence for monoclinal folding on the TF but did not contain evidence of

discrete faulting, so the number, timing, and displacement of individual surface-faulting earthquakes could not be determined. Solomon (1998) documented the approximate age of the MRE based on ^{14}C ages obtained from bulk samples of organic crack-fill material and pre-event sage pond deposits.
2. Number of events is based on the interpretation of geomorphic features along the fault trace, and the age of the events is based chiefly on the relationship of geomorphic features (Gilbert shoreline and fault scarps) to one another.
3. The published slip rate has an open seismic cycle at each end.
4. Only two of three principal strands of the TF have been trenched.

Summary:

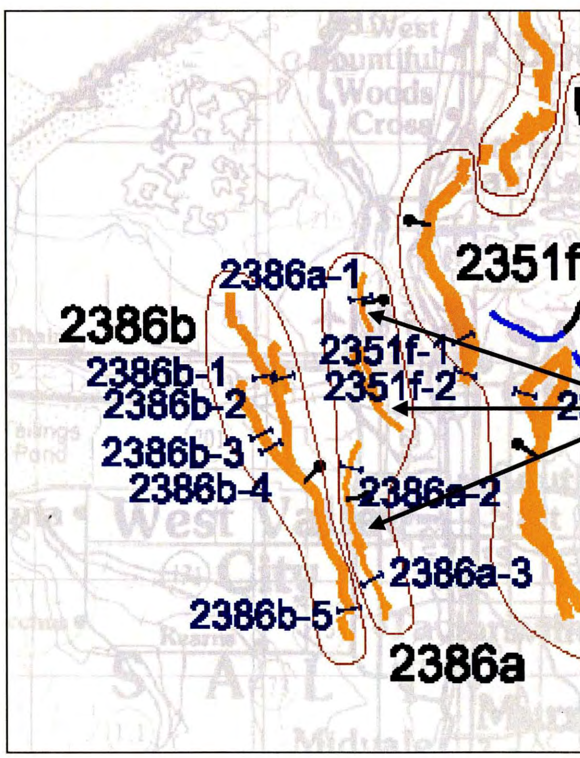
For at least the past 12 kyr large earthquakes on the TF portion of the WVFZ have been at or below the threshold for surface faulting (M~6.5) and have been expressed chiefly by monoclinal folding at the surface. The interpretation of the number, timing, and displacement of events on the TF in latest Pleistocene/Holocene time is based chiefly on geomorphic relations, and on an exposure in a consultant's trench that allowed Solomon (1998) to date the MRE as occurring slightly after 2.0-2.4 ka; therefore, the timing of the MRE on the TF compares in a general way with the timing of the PE on the Salt Lake City segment of the Wasatch fault zone about 10 kilometers to the east.

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:

Map of the West Valley fault zone (2386) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Taylorsville fault = 2386a
2386a-1 = International Airport site
2386a-2 = Pioneer Industrial Park site
2386a-3 = UDOT site

2386b = Granger fault

2351f = Salt Lake City section Wasatch fault zone

Taylorsville fault

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP
FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Granger fault (GF) of the West Valley Fault Zone (WVFZ), Salt Lake County, Utah

Study Synopsis ID: GF-1

Map Reference: 2386b

Paleoseismic Data Source Documents:

Keaton, J.R., and Currey, D.R., 1989, Earthquake hazard evaluation of the West Valley fault zone in the Salt Lake City urban area, Utah: Salt Lake City, Dames and Moore, Final Technical Report for U.S. Geological Survey, Contract No. 14-08-001-G1397, 69 p.; <u>published as Utah Geological Survey Contract Report 93-7, 1993</u>.

Keaton, J.R., Currey, D.R., and Olig, S.J., 1987, Paleoseismicity and earthquake hazards evaluation of the West Valley fault zone, Salt Lake City urban area, Utah: Salt Lake City, Dames and Moore, Final Technical Report for U.S. Geological Survey, Contract No. 14-08-0001-22048, 55 p.; <u>published as Utah Geological Survey Contract Report 93-8, 1993</u>.

Utah Geological Survey unpublished data

General Fault Information

Geomorphic Expression
The GF is expressed chiefly by scarps in lacustrine deposits up to 6.1 meters high. Geomorphic relations along the northern part of the GF suggest post-Bonneville faulting prior to formation of the Gilbert shoreline and four or more events since 13 ka. Apparent single-event scarps of the GF have inferred displacement consistent with that from monoclinal flexures on the Taylorsville fault.

Evidence for Segmentation
None

Age of Youngest Faulting
Holocene

Paleoseismic Parameter Data

Type of Study/Commentary
Keaton and others (1987) excavated two trenches and drilled eight boreholes at a Utah Department of Transportation (UDOT) facility (site 2386b-5) at 2700 West Street and about 4500 South Street where the fault was expressed as a prominent, discrete, planar trace in both trenches. Keaton and Currey (1989) drilled 24 additional boreholes at three sites: four boreholes were drilled at the Three Flags site (site 2386b-1) south of the Salt Lake International Center, 12 boreholes were drilled at the Goggin Drain site (site 2386b-2) southwest of the intersection of Interstate 80 and the 4000 West (Bangerter)

Highway, and eight boreholes were drilled at the 1300 South site (site 2386b-3) northwest of the intersection of the 2100 South Freeway and the 4000 West (Bangerter) Highway. Stratigraphic relations revealed by the subsurface explorations, including juxtaposition of Cutler Dam and Bonneville lake-cycle deposits, allowed interpretation of the generalized late Quaternary displacement history of the fault, but the timing of individual earthquakes could not be determined. A ^{14}C age estimate on a bulk-soil sample from fault-zone colluvium, obtained by the Utah Geological Survey from a consultant's trench at about 4450 West 1700 South (site 2386b-4), provides a close approximation of the age of the most recent surface-faulting event (MRE).

Number of Surface-Faulting Events/How Identified

Based on borehole information at their UDOT site (2386b-5; see map), Keaton and others (1989) interpret a minimum of two surface-faulting earthquakes within the past ~13 ka on the GF at that location. Geomorphic evidence (small scarps and displaced paleochannels of the Jordan River) to the north suggests a minimum of an additional three scarp-forming events on the GF for a total of 5 events in the past ~13 ka.

Age of Events/Datum Ages/Dating Techniques

Keaton and others (1989) identified two events on the GF at their UDOT site based on the presence of displaced Lake Bonneville deposits and calcareous playa deposits buried by scarp-generated colluvium in Boring 4-5. Their interpretation is that the penultimate event (PE) formed the depression in which the playa formed and that the MRE generated the colluvium. The remaining three events were identified on the basis of morphostratigraphic relations on minor scarps to the north all of which displace deposits that are <12 ka.

One ^{14}C age estimate from fault-zone colluvium in a trench across the fault indicates the MRE occurred slightly after 1.3-1.7 ka (Utah Geological Survey unpublished data), which is similar to mean timing for the MRE (1.2 ka) on the Salt Lake City section of the Wasatch fault zone (2351f; see map).

Alloformation (Bonneville, Cutler Dam, Little Valley) ages were determined from TL and amino acid ages.

Event Slip/Cumulative Slip

Individual event slip could not be determined.

The MRE and PE at the UDOT site displaced the top of the Bonneville Alloformation a minimum of 5.2 to 6.7 meters.

Based on stratigraphic relations in trenches and borings, Keaton and others (1989) identified a minimum of 12.8 to 14.3 meters of displacement of the top of the Cutler Dam Alloformation since 60±20 ka, and a minimum of 17.4 to 18.9 meters of displacement in the top of the Little Valley Alloformation in the past 140±10 ka.

Published Recurrence Interval

Five events in ~13 ka, result in a recurrence interval of ~2.6 kyr for the latest Pleistocene/Holocene.

Published Slip Rate

Latest Pleistocene/Holocene: 0.4-0.5 mm/yr (5.2 to 6.7 m in ~13 kyr)
Past ~60 ka: 0.16-0.36 (12.8 to 14.3 m in 60±20 ka); revised from Keaton and others (1989).
Past ~140 ka: 0.12-0.14 mm/yr (17.4 to 18.9 m in 140±10 ka); revised from Keaton and others (1989).
Difference in displacement Bonneville and Cutler Dam Alloformations: 0.09-0.33 mm/yr (6.1 to 9.1 m in ~47±20 ka).
Difference in displacement Cutler Dam and Little Valley Alloformations: 0.03-0.12 mm/yr (3.1 to 6.1 m in ~80±30 ka).

Sources of Uncertainty

1. With the exception of the MRE, the timing of individual surface-faulting earthquakes could not be determined.
2. Displacement of individual events could not be determined.
3. The estimated number of events was determined on the basis of stratigraphic relations in boreholes and geomorphic relations, not on direct evidence from trenches.
4. Displacements of major stratigraphic units (alloformations) are based on correlations between boreholes and are considered minimum values.
5. Reported slip rates are averages with open seismic cycles at each end.
6. The slip rate reported for the latest Pleistocene/Holocene is as much as a factor of ten greater than longer term Quaternary slip rates determined from displaced lake-cycle sediments.

Summary:

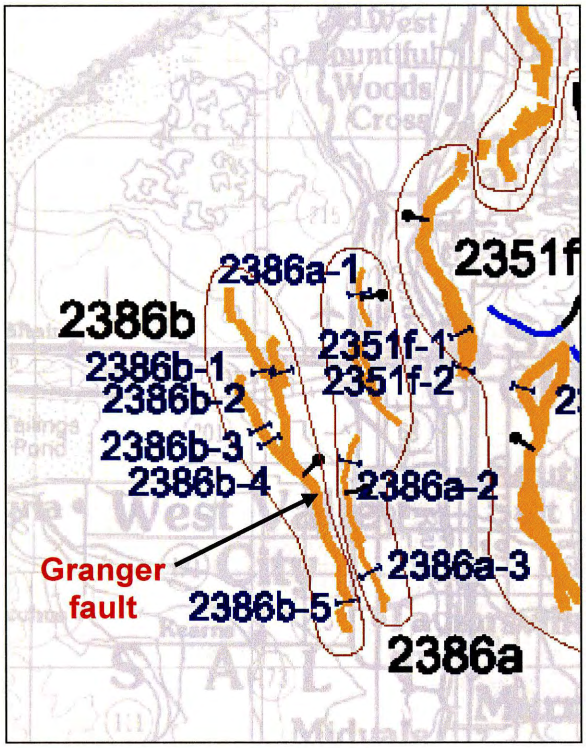
This study provides both long- and short-term slip rates for the GF based on stratigraphic displacement of lacustrine alloformations (Bonneville, Cutler Dam, and Little Valley) determined from boreholes and shallow trenches. A ^{14}C age from a consultant's trench provides an age for the MRE, which approximates the timing of the MRE on the Salt Lake City section of the Wasatch fault.

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:

Map of the Granger fault (2386b) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Granger fault = 2386b
- 2386b-1 Three Flags site
- 2386b-2 Goggin Drain site
- 2386b-3 1300 South site
- 2386b-4 Consultant's trench site
- 2386b-5 UDOT site

Taylorsville fault = 2386a

2351f = Salt Lake City section Wasatch fault zone

Notes

3

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section:
West Cache fault zone (WCFZ), Cache County, Utah

Paleoseismic Data Source Documents:
Black, B.D., Giraud, R.E., and Mayes, B.H., 2000, Paleoseismic investigation of the Clarkston, Junction Hills, and Wellsville faults, West Cache fault zone, Cache County, Utah: Utah Geological Survey Special Study 98, 23 p.

Geomorphic Expression:
The WCFZ consists of three related east-dipping normal faults (Clarkston, Junction Hills, and Wellsville faults) along the west side of Cache Valley in northern Utah and southern Idaho. All three faults show evidence for recurrent late Quaternary activity. Cache Valley is a north-south structural basin formed by repeated movement on the west-dipping East Cache fault zone and east-dipping WCFZ. The valley was occupied by Pleistocene Lake Bonneville until shortly after 17 ka, when a substantial volume of water drained from the lake due to failure of the Red Rock Pass threshold at the north end of Cache Valley.

Evidence for Segmentation:
From north to south, the Clarkston, Junction Hills, and Wellsville faults are subparallel and extend for 80 kilometers along the west side of the Cache Valley at the base of the Malad Range, Junction Hills, and Wellsville Mountains, respectively. The age of each fault's most recent surface-faulting event (MRE) is different, as are their estimated slip rates, and each is considered an independent seismogenic segment of the WCFZ (Solomon, 1999; Black and others, 2000).

Age of Youngest Faulting:
Holocene

Summary of Existing Recurrence Interval Information:
Clarkston fault: MRE; 3.8 ± 0.2 ka, penultimate event (PE) timing is unknown but geomorphic evidence indicates two to three events in the past 16.8 kyr.

Junction Hills fault: MRE; 8.45 ± 0.2 ka, PE is prior to 22.5 ka, so recurrence is greater than ~14 ka.

Wellsville fault: MRE; 4.6 ± 0.2 ka, PE between 15 and 25 ka, so PE/MRE recurrence is ~10.5 to 20.5 kyr.

Summary of Existing Slip-Rate Information:
Clarkston fault: unknown, but based on geomorphic evidence long-term rates are probably <0.68 mm/yr for the late Pleistocene.

Junction Hills fault: unknown, but based on geomorphic evidence long-term rates are probably <0.21 mm/yr for the late Pleistocene.

Wellsville fault: 0.11-0.22 mm/yr based on an average of 2.2 meters net slip in 10.2 to 20.6 kyr. 0.09-0.18 mm/yr based on 1.9 meters of MRE net slip for the same time interval.

Comments:

The three faults that comprise the WCFZ (Clarkston, Junction Hills, and Wellsville faults) have experienced Holocene MREs, the ages for which are all different. Therefore, Solomon (1999) and Black and others (2000) consider each of the three faults an independent seismogenic segment of the WCFZ. The MRE ages for each segment are well constrained from trench and natural stream cut exposures; however, the PE ages are only broadly constrained. MRE net slip can be measured directly for the Junction Hills and Wellsville faults and estimated from scarp profiles for the Clarkston fault. PE net slip is either unknown or only broadly constrained. Consequently, the late Pleistocene/Holocene slip rates and recurrence intervals reported for each segment are poorly constrained due to the uncertainty in the age of the PE on each segment.

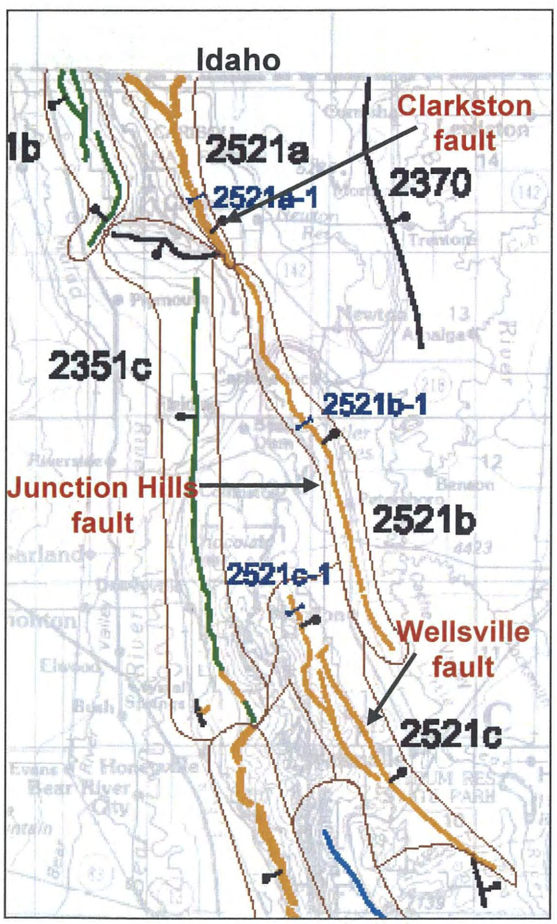
References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Solomon, B.J., 1999, Surficial geologic map of the West Cache fault zone and nearby faults, Box Elder and Cache Counties, Utah: Utah Geological Survey Map 172, scale 1:50,000, 21 p. pamphlet.

Map:

Map of the West Cache fault zone (2521) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Clarkston fault (CF), Cache County, Utah

Study Synopsis ID: CF-1

Map Reference: 2521a

Paleoseismic Data Source Documents:

Black, B.D., Giraud, R.E., and Mayes, B.H., 2000, Paleoseismic investigation of the Clarkston, Junction Hills, and Wellsville faults, West Cache fault zone, Cache County, Utah: Utah Geological Survey Special Study 98, 23 p.

General Fault Information

Geomorphic Expression

The CF is 35 kilometers long (11 km in Utah and 24 km in Idaho) and consists of a single, sinuous fault strand with discontinuous down-to-the-east normal fault scarps, except near Hammond Flat, where two faults diverge northward from the single range-front fault (Solomon, 1999). South of the divergence, the Clarkston fault mostly juxtaposes upper to middle Pleistocene fan alluvium and Tertiary sedimentary rock in the hanging wall against Paleozoic sedimentary rock in the footwall; the fault is covered by upper Holocene and uppermost Pleistocene fan alluvium and debris flows at canyon mouths. An east-west transverse fault in Short Divide at the south end of the fault forms the segment boundary between the Clarkston and Junction Hills faults.

Evidence for Segmentation

The CF is considered a seismogenic segment of the 80-kilometer-long West Cache fault zone (Solomon, 1999; Black and others, 2000).

Age of Youngest Faulting

Holocene

Paleoseismic Parameter Data

Type of Study/Commentary

Black and others (2000) excavated a trench across a 4-meter-high scarp of the Clarkston fault just north of the mouth of Winter Canyon (site 2521a-1, see map) that exposed a single fault trace and evidence for one surface-faulting earthquake. Radiocarbon age estimates on bulk-soil samples from a colluvial wedge and underlying paleosol provide limiting ages for the most recent event (MRE) on the fault.

Number of Surface-Faulting Events/How Identified
One/colluvial wedge

Age of Events/Datum Ages/Dating Techniques
MRE: best estimate 3600 to 4000 cal yr B.P. (3.8±0.2 ka)

AMRT ^{14}C age estimates were obtained from the upper few centimeters of a paleosol beneath the MRE colluvial wedge (3650+150/-100 cal yr B.P.), from organic-rich wedge matrix near the middle of the wedge (2200+100/-150 cal yr B.P.), and from organic-rich wedge matrix from the wedge heel immediately adjacent to the scarp (3800±200 cal yr B.P). All ^{14}C ages were obtained using conventional gas-proportional methods and calendar calibrated using CALIB 3.0.3C (Stuiver and Reimer, 1993) with appropriate carbon age spans and mean residence corrections.

Event Slip/Cumulative Slip
Displacement could not be measured directly in the Winter Canyon trench. Topographic profiles across fault scarps at the trench site and in similar age deposits at Raglanite Canyon to the north indicate 3.1 to 3.7 meters of net slip, which Black and others (2000) believe represents a single surface-faulting event.

Published Recurrence Interval
Lack of evidence in the trench for the PE prevented Black and others (2000) from directly determining the recurrence interval between the PE and MRE. Based on an age for the Bonneville shoreline of 16.8 ka, Black and others (2000) report possible recurrence intervals of 13.2 kyr (shoreline age minus MRE age [3.6 ka]) if there have been two post-Bonneville shoreline events and 6.6 kyr if there have been three surface-faulting earthquakes in that interval. Both these recurrence interval estimates assume that the oldest event occurred shortly after abandonment of the Bonneville shoreline, a supposition for which there is no direct evidence.

Published Slip Rate
Lacking evidence for a PE, Black and others (2000) used the approximately 9 meters of displacement of the Bonneville shoreline to make a slip-rate estimate for the CF. Considering the approximately 13 kyr interval between abandonment of the Bonneville shoreline and the MRE and the 9 meters of displacement in that interval results in an average slip rate for the late Pleistocene/Holocene of the CF of 0.69 mm/yr. This is a maximum slip rate because it has an open seismic cycle at one end.

Sources of Uncertainty
1. The trench on the CF contained evidence for only the MRE.
2. Per event net slip could not be measured directly, the reported cumulative net slip measurement was determined from scarp profiles.
3. The reported recurrence interval and slip rate for the CF are estimates based on the age and displacement of the Bonneville shoreline.

Summary:
Only the age of the MRE could be determined for the CF and it was not possible to make net-slip measurements from the trench exposure. The slip rate and recurrence interval reported by Black and others (2000) for the CF are estimates based on geomorphic relations along the fault and the age of the Bonneville shoreline.

References:

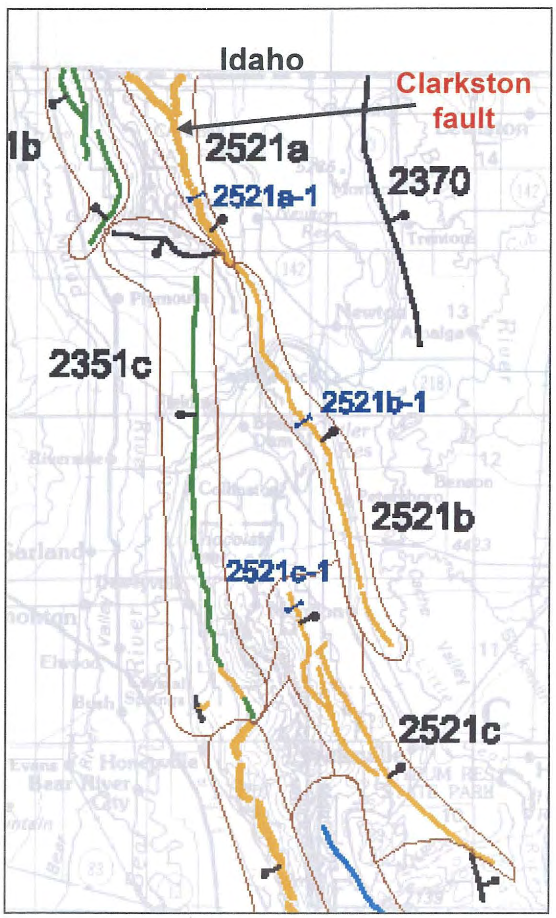
Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Solomon, B.J., 1999, Surficial geologic map of the West Cache fault zone and nearby faults, Box Elder and Cache Counties, Utah: Utah Geological Survey Map 172, scale 1:50,000, 21 p. pamphlet.

Stuiver, Minze, and Reimer, P.J., 1993, Extended ^{14}C database and revised CALB 3.0 ^{14}C calibration program: Radiocarbon, v. 35, no. 1, p. 215-230.

Map:

Map of the Clarkston fault (2521a) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Clarkston fault = 2521a
2521a-1 = Winter Canyon site

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Junction Hills fault (JHF), Cache County, Utah

Study Synopsis ID: JHF-1

Map Reference: 2521b

Paleoseismic Data Source Documents:

Black, B.D., Giraud, R.E., and Mayes, B.H., 2000, Paleoseismic investigation of the Clarkston, Junction Hills, and Wellsville faults, West Cache fault zone, Cache County, Utah: Utah Geological Survey Special Study 98, 23 p.

General Fault Information

Geomorphic Expression

The JHF is 25 kilometers long and is poorly expressed as a discontinuous, down-to-the-east normal fault trace, beginning at the range front east of Short Divide and continuing southeastward along the eastern margins of the Junction Hills and Cache Butte to east of the northern Wellsville Mountains. For most of its length, Lake Bonneville deposits and locally Holocene to upper Pleistocene landslide debris conceal the JHF (Solomon, 1999). The only conclusive evidence of Quaternary displacement is associated with three short lineaments northeast of Cache Butte. Fault scarps at the surface along the lineaments are subtle and subdued due to degradation from repeated agricultural plowing (Solomon, 1999). Oviatt (1986) reports 2.4 meters of displacement in the basal transgressive gravel of Lake Bonneville in a stream cut across the central lineament, and evidence for multiple pre-Bonneville events.

Evidence for Segmentation

The JHF is considered a seismogenic segment of the 80-kilometer-long West Cache fault zone (Solomon, 1999; Black and others, 2000).

Age of Youngest Faulting

Holocene

Paleoseismic Parameter Data

Type of Study/Commentary

A natural stream-cut exposure (site 2521b-1) at Roundy Farm, about 2 kilometers southwest of Cache Junction, provides the only conclusive evidence of late Quaternary faulting on the JHF (Solomon, 1999). Black and others (2000) logged the stream-cut exposure and found evidence for two surface-faulting earthquakes. A single ^{14}C age estimate on a bulk-soil sample from the base of a colluvial wedge approximates the age of the most recent event (MRE) on the fault. The penultimate event (PE) could not be directly dated.

Number of Surface-Faulting Events/How Identified

Two. MRE/colluvial wedge, PE/degraded scarp free face, PE colluvial wedge is buried beneath the trench floor.

Age of Events/Datum Ages/Dating Techniques

MRE: 8.25 to 8.65 ka; (best estimate 8450±200 cal yr B.P.)
PE: Unknown, but the PE degraded free face is overlain by Lake Bonneville transgressive sediments.

A ^{14}C age of 8450+200 cal yr B.P. was obtained from slightly organic sediment collected from the bottom of the MRE colluvial wedge and the top of an underlying paleosol. No material was found that would allow the age of the PE to be constrained other than the probable age of overlying Lake Bonneville transgressive deposits that Black and others (2000) believe were deposited about 22.5 kyr.

The ^{14}C age was obtained using conventional gas-proportional methods and calendar calibrated using CALIB 3.0.3C (Stuiver and Reimer, 1993) with an appropriate carbon age span and mean residence correction.

Event Slip/Cumulative Slip

MRE: Black and others (2000) measured a net vertical slip of 2.9 meters between displaced correlative strata in the stream cut exposure. The JHF scarp is highly degraded due to agricultural activities so Black and others (2000) made no attempt to measure a scarp profile.

PE net slip is unknown.

Published Recurrence Interval

Black and others (2000) estimate a minimum recurrence interval of 13.85 kyr between the MRE (8.65 ka) and PE (minimum 22.5 ka). However, there is a high degree of uncertainty regarding the age of the PE, which could be considerably older than 22.5 kyr

Published Slip Rate

None based on the stream cut exposure. Black and others (2000) report a maximum slip rate between the PE and MRE of 0.21 mm/yr based on 2.9 meters of slip during the MRE and a minimum elapsed time of 13.85 kyr between the two events.

Sources of Uncertainty

1. The ^{14}C sample dated to determine the age of the MRE consisted of a combination of colluvial-wedge matrix material and the upper part of a buried paleosol beneath the wedge. The effect of combining the two different materials is unknown.
2. Recurrence interval and slip rate estimates are based on a very poorly constrained age for the PE. The recurrence interval estimate is a minimum and the corresponding slip-rate estimate is therefore a maximum.

Summary:

A natural stream cut exposure on the JHF allowed the age and displacement of the MRE to be constrained and a broadly limiting minimum age to be established for the PE.

Reported slip rate and recurrence information are estimates based on a poorly constrained minimum age for the PE.

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

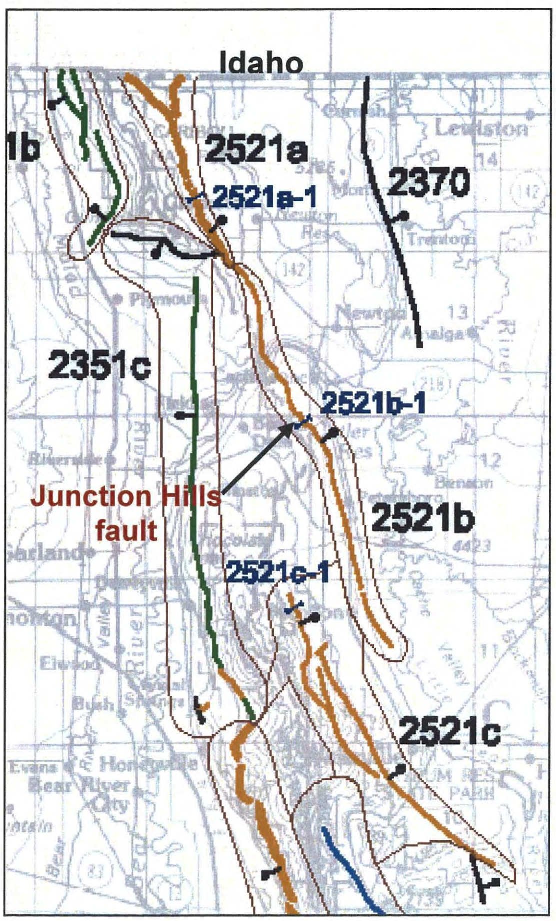
Oviatt, C.G., 1986, Geologic map of the Cutler Dam quadrangle, Box Elder and Cache Counties, Utah: Utah Geological and Mineral Survey Map 91, 7 p. pamphlet, scale 1:24,000.

Solomon, B.J., 1999, Surficial geologic map of the West Cache fault zone and nearby faults, Box Elder and Cache Counties, Utah: Utah Geological Survey Map 172, scale 1:50,000, 21 p. pamphlet.

Stuiver, Minze, and Reimer, P.J., 1993, Extended ^{14}C database and revised CALB 3.0 ^{14}C calibration program: Radiocarbon, v. 35, no. 1, p. 215-230.

Map:

Map of the Junction Hill fault (2521b) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Junction Hills fault = 2521b
2521b-1 = Roundy Farm stream cut exposure

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Wellsville fault (WF), Cache County, Utah

Study Synopsis ID: WF-1

Map Reference: 2521-c

Paleoseismic Data Source Documents:
Black, B.D., Giraud, R.E., and Mayes, B.H., 2000, Paleoseismic investigation of the Clarkston, Junction Hills, and Wellsville faults, West Cache fault zone, Cache County, Utah: Utah Geological Survey Special Study 98, 23 p.

General Fault Information

Geomorphic Expression
The WF is 20 kilometers long and consists of two large subparallel, left-stepping, down-to-the-east normal faults, and several smaller normal faults. The western fault is expressed as a sinuous, north-trending trace on the east side of the Wellsville Mountains which marks a sharp boundary between Oquirrh Formation dip slopes and Tertiary and Quaternary deposits (Solomon, 1999). The eastern fault is covered by Quaternary deposits between bedrock outcrops, and separates a narrow wedge of Tertiary sedimentary rocks in the hanging wall from Paleozoic sedimentary rocks in the footwall (Solomon, 1999). Two areas of possible Quaternary displacement were noted by Solomon (1999): (1) south of Deep Canyon, where Oviatt (1986) reported 15 meters of displacement in middle to upper Pleistocene alluvial-fan deposits; and (2) at Pine Canyon where several small faults and tilted beds are exposed in the wall of a gravel pit which Solomon (1999) believes may be due to landsliding.

Evidence for Segmentation
The WF is considered a seismogenic segment of the 80-kilometer-long West Cache fault zone (Solomon, 1999; Black and others, 2000).

Age of Youngest Faulting
Holocene

Paleoseismic Parameter Data

Type of Study/Commentary
Black and others (2000) excavated a trench across a 7-meter-high scarp of the western Wellsville fault north of the mouth of Deep Canyon (site 2521c-1; see map) exposed evidence for two surface-faulting earthquakes. Radiocarbon age (^{14}C) estimates on bulk-soil samples from a colluvial wedge and underlying paleosol provide limiting ages for the most recent event (MRE) on the fault. A ^{14}C estimate from small pieces of degraded detrital charcoal in alluvial-fan sediments that predate the penultimate event (PE) provides a maximum limiting age for the PE.

Number of Surface-Faulting Events/How Identified

Two/colluvial wedges

Age of Events/Datum Ages/Dating Techniques

MRE = Between 4.4 and 4.8 ka
PE= Between 15 and 25 ka

Black and others (2000) collected five samples of organic material for ^{14}C dating from the Deep Canyon trench. Detrital charcoal from the base of unit 2 (pre-PE alluvial-fan deposit) yielded an age of 21,350±160 ^{14}C yr B.P. This ^{14}C age is too old to calendar calibrate directly. Following the method of Currey (Dr. Donald Currey, University of Utah, verbal communication, 1988), Black and others (2000) multiplied the ^{14}C age by the slope (1.16) of a best-fit line to the marine portion of the Stuiver and Reimer (1993) calibration curve to obtain an approximate calendar-calibrated age of 25 kyr for the charcoal. This charcoal age estimate provides a maximum limiting age for the timing of the PE. A post-event loess deposit buries the PE colluvial wedge. Based on information provided by Currey (Dr. Donald Currey, University of Utah, verbal communication, 1988) Black and others (2000) interpreted the loess as being deposited around 15 ka following the desiccation of many pluvial lakes in the region and the retreat of glaciers in the mountains. Therefore, the PE at Deep Canyon is constrained between broadly limiting ages of 15 and 25 ka.

A bulk sample of organic sediment from the lower contact of the paleosol beneath the MRE colluvial wedge yielded an age of 5250+100/-250 cal yr B.P. A sample from the upper contact of the same paleosol beneath the distal portion of the MRE colluvial wedge gave an age of 4500+100/-150 cal yr B.P. Organic-rich sediment from near the center of the MRE colluvial wedge produced an age of 3200+100/-150 cal yr B.P., and organics from the base of the modern soil yielded an age of 1700±150 cal yr B.P. Because some time must have elapsed between the earthquake and burial of the pre-event soil by the accreting wedge, Black and others (2000) adjusted the calendar-calibrated soil age by a few tens to hundreds of years to obtain a preferred age for the MRE of 4.4 to 4.8 ka.

The ^{14}C age for the detrital charcoal sample was obtained using an accelerator mass spectrometer and was calendar calibrated as described above. The AMRT ^{14}C ages for the bulk organic samples were obtained using conventional gas-proportional methods and calendar calibrated using CALIB 3.0.3C (Stuiver and Reimer, 1993) with appropriate carbon age spans and mean residence corrections.

Event Slip/Cumulative Slip

MRE: 1.9 meters based on correlative stratigrapy (unit 5) displaced across the fault zone in the trench.
PE = unknown

Black and others (2000) report a cumulative net-slip measurement from a scarp profile at Deep Canyon of 6.6 meters, which, based on scarp bevels, they believe represents three faulting events and therefore an average slip per event of 2.2 meters.

Published Recurrence Interval

10.2 to 20.6 kyr based on the age estimates for the MRE and PE

Published Slip Rate

0.11-0.22 mm/yr based on an average of 2.2 meters net slip in 10.2 to 20.6 kyr.
0.09-0.18 mm/yr based on 1.9 meters of MRE net slip.

Sources of Uncertainty

1. Only the westernmost of the two WF scarps was trenched; no information is available regarding the number and timing of events on the eastern fault trace.
2. The Deep Creek trench site is at the extreme northern end of the westernmost fault trace; it is unknown if the fault parameter information recorded there is representative of the trace further south.
3. Only the age and displacement of the MRE on the western fault trace are known with relative certainty.
4. Existing recurrence-interval and slip-rate estimates represent a single closed seismic cycle between the PE and MRE; however, the age of the PE is poorly constrained within an approximate 10-kyr window.

Summary:

Only one of the two principal fault strands that comprise the WF was trenched. Existing slip rate and recurrence information are for the westernmost fault trace, and are estimates based on a poorly constrained age for the PE.

References:

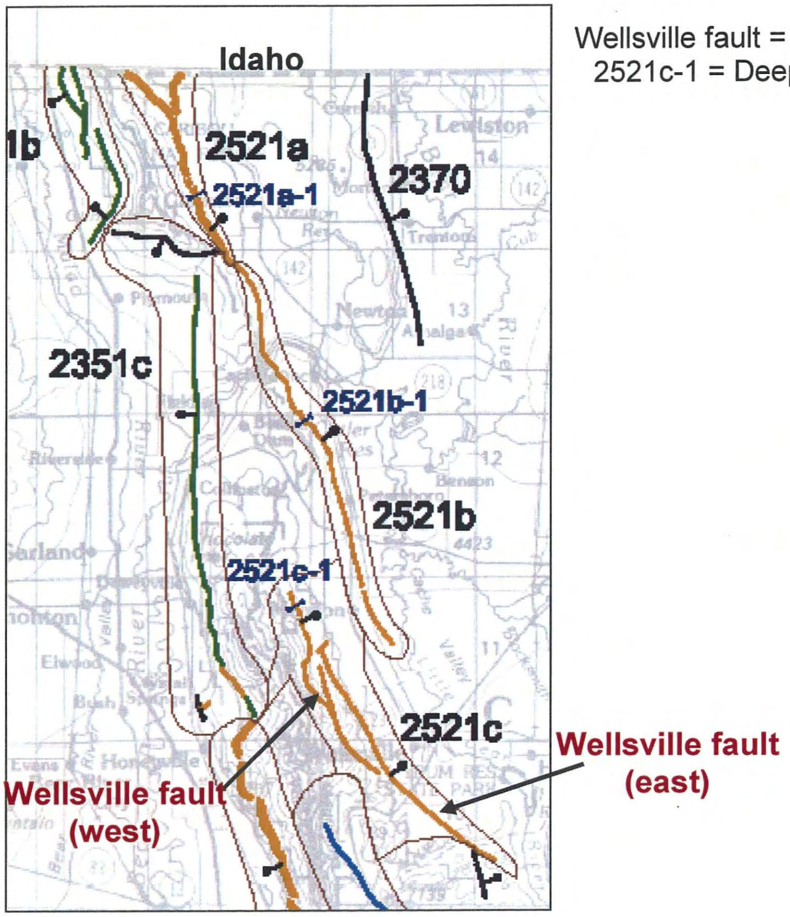
Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Oviatt, C.G., 1986, Geologic map of the Honeyville quadrangle, Box Elder and Cache Counties, Utah: Utah Geological and Mineral Survey Map 88, 13 p. pamphlet, scale 1:24,000.

Solomon, B.J., 1999, Surficial geologic map of the West Cache fault zone and nearby faults, Box Elder and Cache Counties, Utah: Utah Geological Survey Map 172, scale 1:50,000, 21 p. pamphlet.

Stuiver, Minze, and Reimer, P.J., 1993, Extended ^{14}C database and revised CALB 3.0 ^{14}C calibration program: Radiocarbon, v. 35, no. 1, p. 215-230.

Map:
Map of the Wellsville fault (2521c) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Wellsville fault = 2521c
2521c-1 = Deep Canyon site

Notes

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UTAH QUATERNARY FAULT PARAMETER WORKING GROUP
FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: East Cache fault zone, central section (ECFZ), Cache County, Utah.

Study Synopsis ID: ECFZ-1

Map Reference: 2352

Paleoseismic Data Source Documents:

McCalpin, J.P., 1994, Neotectonic deformation along the East Cache fault zone, Cache County, Utah: Utah Geological Survey Special Study 83, 37 p.

McCalpin, J.P., and Forman, S.L., 1991, Late Quaternary faulting and thermoluminescence dating of the East Cache fault zone, north-central Utah: Bulletin of the Seismological Society of America, v. 81, no. 1, p. 139-161.

General Fault Information

Geomorphic Expression

The ECFZ is a roughly 80-kilometer-long, generally north-trending range-front normal fault along the western base of the Bear River Range in eastern Cache Valley. McCalpin (1989, 1994) subdivided the ECFZ into three physiographic sections (northern, central, and southern) based on fault zone complexity, tectonic geomorphology, and expression of fault scarps. The central section is the only one that shows evidence of Holocene activity, and is the only section on which paleoseismic studies have been conducted. The northern and southern sections are less active and show evidence of middle to late Pleistocene surface faulting.

The 16-kilometer-long central section of the ECFZ is typified by a single, straight fault trace located at the base of the rugged Bear River Range. Fault scarps displace Bonneville-lake-cycle or younger deposits along the northern half (8 kilometers) of the section, where scarps may diverge as much as 400 meters from the range front. On the southern half of the section post-Bonneville faulting may have occurred, but no scarps are preserved, possibly due to mass movements at the base of faceted spurs (McCalpin, 1994). Unlike the northern and southern sections, the central section (which is composed of Paleozoic rocks) does not show evidence for post-Bonneville warping, attributed to depositional loading. This may be because faulting along the central section has decoupled the upthrown block from the loaded downthrown block.

Evidence for Segmentation

McCalpin (1994) uses the descriptive term "section" to refer to three stretches of the ECFZ that appear physiographically and structurally distinct, but for which paleoseismic evidence is insufficient to prove that they function as discrete seismogenic rupture segments. The structure of faceted spurs suggests that the boundary between the northern and central sections has shifted southward several kilometers during the middle to late Quaternary, probably along with development of a younger, western fault strand in the northern section. Similarities in the structure of faceted spurs and the absence of a gravity-defined boundary between the central and southern sections suggest that they may have behaved as a single 44-kilometer-long seismogenic section during much of the late Cenozoic. However, the past two events on the ECFZ were limited to the 16-kilometer-long central section. The south end of the southern section abuts the northeast-trending James Peak fault (JPF-1).

Age of Youngest Faulting
Holocene

Paleoseismic Parameter Data

Type of Study/Commentary
McCalpin and Forman (1991) excavated two trenches across the central section of the ECFZ. The "Bonneville trench" (site 2352b-2, see map) was on a Lake Bonneville-highstand delta, and exposed evidence for two surface-faulting earthquakes. Within the main fault zone, quantitative pedogenic soil analysis, TL age estimates on shallow lacustrine sand and silty colluvial deposits, and an AMS ^{14}C age on gastropod shells within a beach-sand deposit provide limiting ages for the penultimate event (PE) and poorly constrain the timing of the most recent event (MRE). To better determine the age of the MRE, the "Provo trench" (site 2352b-1) was excavated about 1 kilometer north of the Bonneville trench at the Logan Country Club on a Provo-age delta surface. This trench exposed stratigraphic evidence for the MRE, and ^{14}C age estimates were obtained from bulk samples of crack-fill material, debris-facies colluvium, and a paleosol beneath the colluvial wedge that more tightly constrain the age of this event (McCalpin, 1994).

Number of Surface-Faulting Events/How Identified
Bonneville trench; two, colluvial-wedge stratigraphy
Provo trench: one, colluvial-wedge stratigraphy

Age of Events/Datum Ages/Dating Techniques
MRE: 4.0-4.2 ka
PE: Between 13 and 15.5 ka

Stratigraphic and numerical age data from the Bonneville trench bracket the PE between a TL age estimate of 8.7±1.0 ka and a ^{14}C age estimate of 15,540±130 ^{14}C yr B.P. The fact that scarp heights at the Bonneville trench site on a Bonneville-high-stand delta are roughly twice the height of the scarps at the Provo trench on a Provo delta surface implies that the earlier faulting event predates formation of the Provo delta surface at 12.8-13.4 ka (Currey and Oviatt, 1985). Therefore McCalpin (1994) concludes that the PE occurred between about 13 and 15.5 ka.

Radiocarbon ages from three locations constrain the timing of the MRE in the Provo trench. Organic matrix from the basal part of material filling a crack created by the MRE yielded an age of 3100±80 ^{14}C yr B.P. Organic basal debris facies colluvium from the MRE colluvial wedge yielded an age of 4240±80 ^{14}C yr B.P., and a soil buried by the colluvial wedge gave an age of 4040±60 ^{14}C yr B.P. McCalpin (1994) interprets the crack fill ^{14}C age as too young, likely due to contamination by modern rootlets. He considers the small age difference between the earliest debris-facies colluvial wedge material and the top of the underlying buried soil to constrain the time of the MRE to about 4 ka.

Event Slip/Cumulative Slip
MRE: 0.5-1.2 meters
PE: 1.4-1.9 meters

McCalpin (1994) reports the above net displacement values for the PE and MRE, but does not document how they were determined. It is assumed that the values represent measurements of displacement correlative units across the fault zone.

Published Recurrence Interval
PE-MRE closed seismic cycle: minimum = 9kyr, maximum = 11.5 kyr, average 10.3 kyr

Evidence for an earlier event during the Bonneville transgression is equivocal, but an event may have occurred at that time.

Published Slip Rate:
McCalpin (1994) reports a long-term slip rate for the central section of the ECFZ based on 8.5 meters of displacement in pre-Bonneville alluvium of as high as 0.06 mm/yr, depending on the age selected for the alluvium.

The minimum (9 kyr), maximum (11.5 kyr), and average (10.3 kyr) length of the recurrence interval between the PE and MRE, and the displacement for the MRE of 0.5-1.2 meters, results in a range of slip rates for the most recent closed seismic cycle on the central segment of the ECFZ of 0.04-0.13 mm/yr and an average slip rate of 0.08 mm/yr (850 mm/10.3 kyr).

Based on geomorphic relations, McCalpin (1994) reports long-term slip rates for the northern and southern sections of the ECFZ of about 0.05-0.10 mm/yr and as high as 0.07 mm/yr, respectively.

Sources of Uncertainty
1. Paleoseismic data available for the ECFZ are restricted to the central section of the fault only.
2. The central section of the ECFZ is short (16 km) and only the northern 8 kilometers show evidence of recent (latest Pleistocene faulting).
3. Net slip values for the PE and MRE are reported but not documented.
4. Radiocarbon ages are not calendar calibrated.

***Summary*:**
The ECFZ is a comparatively long fault (80 km), which McCalpin (1989, 1994) has divided into three physiographic sections based on geomorphology and apparent age of latest surface faulting. Only the central section shows evidence of latest Pleistocene/Holocene faulting and is the only section for which paleoseismic data are available. Trenching shows evidence for two moderate sized surface-faulting events in the past approximately 15.5 ka on the central section. The closed seismic cycle between the PE and MRE has an average length of 10.3 kyr and an average slip-rate value of 0.08 mm/yr.

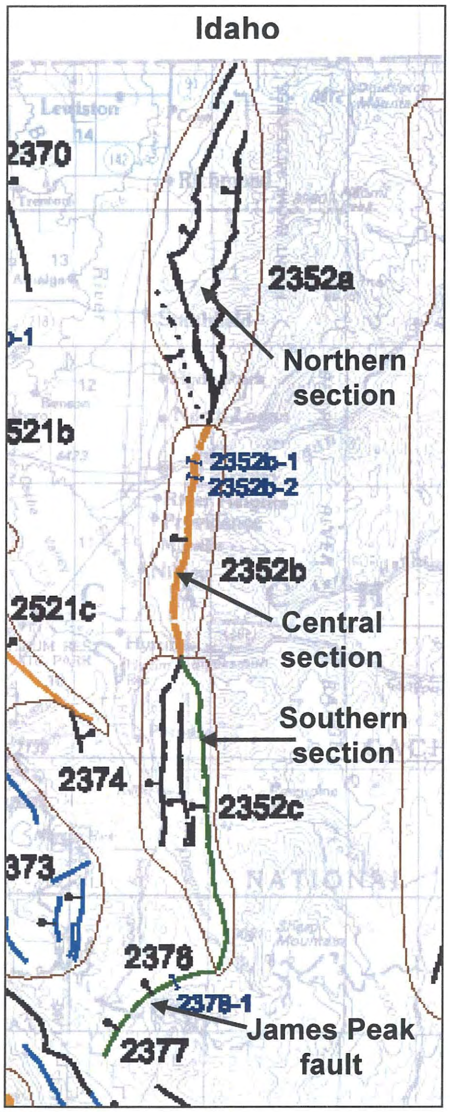
References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

McCalpin, J.P., 1989, Surficial geologic map of the East Cache fault zone, Cache County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2107, scale 1:50,000.

Map:

Map of the East Cache fault zone central section (2352b) taken from the Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites:
- 2352b-1 "Provo" trench
- 2352b-2 "Bonneville" trench
  - McCalpin and Forman (1991)
  - McCalpin (1994)

Notes

5

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Hurricane fault zone, Anderson Junction section (HFAJS), Washington County, Utah and Mohave County, Arizona

Study Synopsis ID: HFAJS-1

Map Reference: 998c

Paleoseismic Data Source Documents:

Stenner, H.D., Crosby, C.J., Dawson, T.E., Amoroso, L., Pearthree, P.A., and Lund, W.R., 2003, Evidence for variable slip from the last three surface-rupturing earthquakes along the central Hurricane fault zone [abs.]: Seismological Research Letters, v. 74, no. 2, p. 238.

Stenner, H.D., Lund, W.R., Pearthree, P.A., and Everitt, B.L., 1999, Paleoseismic investigation of the Hurricane fault, northwestern Arizona and southwestern Utah: Arizona Geological Survey Open-File Report 99-8, 137 p.

General Fault Information

Geomorphic Expression

<u>Hurricane Fault</u>

The Hurricane fault is a long (250 km), generally north-trending Holocene to late Pleistocene fault along the base of the Hurricane Cliffs near the western margin of the Colorado Plateaus in southwestern Utah and northwestern Arizona. The fault zone shows considerable Cenozoic displacement, which increases northward from Arizona into Utah.

From the Utah-Arizona border, the fault trends north, then northeast along the steep and linear Hurricane Cliffs, forming a narrow zone of sub-parallel, en-echelon, west-dipping normal faults that displace generally horizontal Paleozoic through Cenozoic rocks and Quaternary basalt flows down to the west. Stewart and Taylor (1996) document 450 meters of stratigraphic separation in Quaternary basalt displaced by the fault, and a total separation of 2,520 meters across a portion of the Hurricane fault near Anderson Junction. Displacement decreases southward; Pearthree (1998) indicates Cenozoic displacement of only 200-400 meters across the fault zone along most of its length in Arizona. Several swarms of historical seismicity have occurred adjacent to, but cannot be correlated directly with, the north end of the Hurricane fault. The earliest of these swarms (1942) included two approximately magnitude 5 earthquakes (Arabasz and Smith, 1979; Richins and others, 1981). The 1992 magnitude 5.8 St. George earthquake was likely on the Hurricane fault (Pechmann and others, 1995).

<u>Anderson Junction Section</u>

The Anderson Junction section is one of six sections identified along the Hurricane fault (see below). The Anderson Junction section extends approximately 45 kilometers, from north of Toquerville in Utah to south of Cottonwood Canyon in Arizona. The fault trace generally follows a high, north-trending, west-facing escarpment in Paleozoic bedrock.

Fault scarps up to 30 meters high with slopes up to 35 degrees on late Pleistocene colluvium and alluvium mark the fault along the base of the escarpment.

Evidence for Segmentation

Stewart and Taylor (1996) define two fault sections in Utah, the Ash Creek and Anderson Junction sections, based on hanging-wall and footwall shortening structures, fault geometry, differences in complexity of faulting, and scarp morphology. Lund and others (2001) propose a third section (Cedar City section) in Utah, at the northern end of the Ash Creek section, based on differences in the timing of surface faulting at two sites along the fault. The boundary between the Cedar City and Ash Creek sections is likely at a pronounced right bend in the fault at Murie Creek just north of Coyote Gulch (Lund and others, 2001). The boundary between the Ash Creek and Anderson Junction sections is north of Toquerville, where the fault intersects a zone of Sevier-age folds and thrust faults and bends to the northeast (Stewart and Taylor, 1996). The remaining sections (Shivwitz, Whitmore Canyon, and Southern Hurricane sections; Pearthree, 1998) are to the south in Arizona.

Age of Youngest Faulting

Holocene

Paleoseismic Parameter Data

Type of Study/Commentary

Stenner and others (1999) excavated two trenches on the HFAJS at Cottonwood Canyon in Arizona. They excavated trench Q1 across a low fault scarp less than 1 meter high formed on a stream terrace. Trench Q2 extended across a 5-meter-high scarp formed on an older Q2 alluvial-fan surface, 25 meters south of trench Q1.

Stenner and others (2003) excavated a trench across a single fault scarp formed on an alluvial-fan surface at Rock Canyon approximately 4 kilometers south of Cottonwood Canyon. The trench reveled evidence for three surface-faulting events of variable displacement. Laboratory results from bulk samples collected from the trench for ^{14}C dating are not yet available.

Number of Surface-Faulting Events/How Identified

Cottonwood Canyon: Two events identified on the basis of stratigraphic displacement, shear fabric, and fault drag.

Rock Canyon: Three events identified on the basis of stratigraphic displacement, shear fabric, fault drag, fissuring, and minor graben formation.

Age of Events/Datum Ages/Dating Techniques

Cottonwood Canyon

Soil development on the Q1 stream terrace implies an age of 8-15 ka, but most likely early Holocene, for the faulted Q1 terrace surface. Based on stratigraphic relations in the trench exposure, Stenner and others (1999) estimate an age of 5-10 ka for the most recent event (MRE) at Cottonwood Canyon. No carbon or other material suitable for dating was recovered from the trench Q1.

A charcoal sample from slope colluvium above fissure-fill material in trench Q2 yielded a ^{14}C age of 870 years, which Stenner and others (1999) interpret as too young to be representative of the age of the colluvium and conclude that the young carbon in older deposits is likely the result of bioturbation. Based on stratigraphic relations in trench Q2 and its close proximity to trench Q1 (a few tens of meters), Stenner and others (1999) believe the age of the MRE in trench Q2 is the same as in trench Q1. No age could be determined for the penultimate event (PE) in trench Q2.

<u>Rock Canyon</u>

No ages are presently available for the three surface-faulting events at Rock Canyon. Bulk samples possibly containing carbon suitable for dating collected by Stenner and others (2003) have not yet been processed and dated.

Event Slip/Cumulative Slip

<u>Cottonwood Canyon</u>

Trench Q1 exposed 58-60 centimeters of down-to-the-west displacement across a fault zone that is 2 meters wide. Trench Q2 exposed at least two fault strands in a complex fault zone, across which a minimum net vertical offset of 35-37 centimeters occurred during the MRE. The offset during the penultimate event (PE) could not be determined from exposures in trench Q2.

On the basis of scarp profiling, Stenner and others (1999) report 0.6 meters, 5-7 meters, and 18.5-20 meters of displacement in a younger Holocene stream and debris-flow deposit (Q1), an intermediate-age (~20-50 ka) Quaternary stream and debris-flow deposit (Q2), and an older (~70-125 ka) Quaternary alluvial-fan deposit (Q3), respectively. Ages of the faulted surfaces were established using a combination of soil profile development and cosmogenic isotope dating.

<u>Rock Canyon</u>

Stenner and others (2003) report variable slip during the three most recent surface-faulting events at Rock Canyon. The MRE produced 0.3 to 0.4 meters of net vertical slip based on stratigraphic displacement. The two prior events accommodated 2.6-3.7 meters of vertical slip, but how that slip was partitioned between the two events is poorly constrained. However, there is some evidence to indicate that the PE may also have been small (<1 m), thus making the antepenultimate event larger than the two younger earthquakes.

Published Recurrence Interval

None reported, no ages available for the older faulting events.

Published Slip Rate

Stenner and others (1999) calculate long-term slip rates of 0.1-0.3 mm/yr in the ~70-125 ka Q3 unit, and 0.1-0.4 millimeters/year in the ~25-50 ka Q2 unit at Cottonwood Canyon. Lund and others (2001) geochemically correlated and radiometrically dated ($^{40}Ar/^{39}Ar$) displaced basalt flows across the fault at the Ash Creek/Anderson Junction section boundary, and at South Black Ridge, at Pah Tempe Hot Springs, and at Grass Valley, all on the HFAJS. These flows indicate middle Quaternary slip rates of 0.44-0.45 mm/yr, slowing to 0.21 mm/yr sometime before 350,000 years ago.

Sources of Uncertainty

1. Only the age of the MRE at Cottonwood Canyon could be constrained, and then only within a 5-kyr-time window.
2. Net slip per event is well constrained for the MRE at Cottonwood Canyon but either unknown or poorly constrained for earlier events.
3. Neither slip rates nor recurrence intervals have resulted from the trenching on the HFAJS to date. Existing slip rates are based on scarp profiles and displaced basalt flows.

Summary:

Neither the age of events nor the age of geologic units exposed in trenches on the Anderson Junction section are sufficiently well constrained to permit calculation of meaningful slip rates or recurrence intervals. Long-term slip rates (middle to late Quaternary) are available from geochemically correlated displaced basalt flows and from displaced alluvial fan and stream terrace surfaces. Slip rates from the middle Quaternary are as high as 0.44-0.45 mm/yr, but slow beginning about 350 ka to ~0.3 mm/yr or less.

References:

Arabasz, W.J., and Smith, R.B., 1979, The November 1971 earthquake swarm near Cedar City, Utah, *in* Arabasz, W.J., Smith, R.B., and Richins, W.D., editors, Earthquake studies in Utah, 1850 to 1978: Salt Lake City, University of Utah Seismograph Stations Special Publication, p. 423-432.

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Lund, W.R., Pearthree, P.A., Amoroso, Lee, Hozik, M.J., and Hatfield, S.C., 2001, Paleoseismic investigation of earthquake hazard and long-term movement history of the Hurricane fault, southwestern Utah and northwestern Arizona: unpublished Final Technical Report for the U.S. Geological Survey, award no. 99HQGR0026, 67 p. 4 appendices.

Pearthree, P.A., 1998, Quaternary fault data and map for Arizona: Arizona Geological Survey Open-File Report 98-24, scale 1:750,000, 122 p.

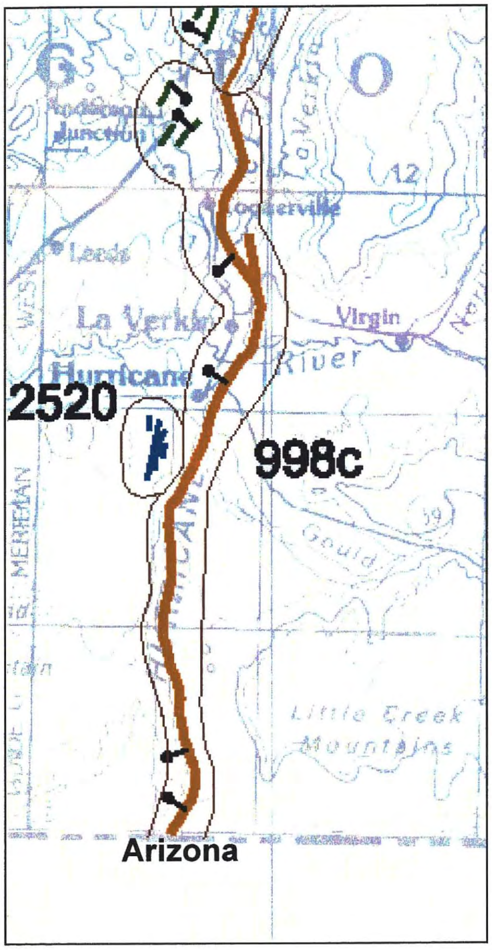
Pechmann, J.C., Arabasz, W.J., and Nava, S.J., 1995, Seismology, *in* Christenson, G.E., editor, The September 2, 1992 ML 5.8 St. George earthquake, Washington County, Utah: Utah Geological Survey Circular 88, p.1.

Stenner, H.D., Lund, W.R., Pearthree, P.A., and Everitt, B.L., 1999, Paleoseismic investigation of the Hurricane fault, northwestern Arizona and southwestern Utah: Arizona Geological Survey Open-File Report 99-8, 137 p.

Stewart, M.E., and Taylor, W.J., 1996, Structural analysis and fault segment boundary identification along the Hurricane fault in southwestern Utah: Journal of Structural Geology, v. 18, p. 1017-1029.

Map:

Map of the Hurricane fault zone, Anderson Junction section (998c) taken from the Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites:
- Cottonwood Canyon, Arizona (not shown)
  - Stenner and others (1999)
- Rock Canyon, Arizona (not shown)
  - Stenner and others (2003)

Notes

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Oquirrh fault zone (OFZ), Tooele County, Utah

Study Synopsis ID: OFZ-1

Map Reference: 2398

Paleoseismic Data Source Documents:

Olig, S.S., Lund, W.R., Black, B.D., and Mayes, B.H., 1996, Paleoseismic investigation of the Oquirrh fault zone, Tooele County, Utah, *in* Lund, W.R., editor, Paleoseismology of Utah, Volume 6, The Oquirrh fault zone, Tooele County, Utah - Surficial geology and paleoseismicity: Utah Geological Survey Special Study 88, p. 22-64.

General Fault Information

Geomorphic Expression

The OFZ is a north-trending, range-front normal fault bounding the east side of Tooele Valley at the western base of the Oquirrh Mountains (see map). The Oquirrh Mountains are the easternmost of the distinctive north-south mountain ranges in the Utah portion of the Basin and Range Province and lie immediately west of the high central part of the Wasatch Range. Lake deposits and alluvium dominate the surficial geology in Tooele Valley to the west. Several buried faults that do not cut surficial deposits are postulated in the vicinity of the Oquirrh fault zone. Those faults are likely older than and not directly related to the Oquirrh fault. One such fault, the Occidental fault, may have been reactivated by activity on the Oquirrh fault (Solomon, 1996).

Scarps formed on lake deposits and alluvium provide the primary surface expression of the OFZ. Topographic profiles of scarps at Big Canyon yield scarp heights ranging from 12 to 18 meters, maximum slope angles of 24 to 32 degrees, and surface offsets of 4.0 to 6.8 meters.

Evidence for Segmentation

Everitt and Kaliser (1980) and Barnhard and Dodge (1988) divide the OFZ into two sections: a northern section expressed as Quaternary fault scarps on basin-fill sediments, and a southern section expressed as a prominent break in slope at the base of the range front. Large displacements documented on the northern section of the fault zone imply a rupture length greater than 12 kilometers (the length of the northern trace), suggesting both sections of the fault probably form a single rupture segment extending from Stockton to Great Salt Lake.

Age of Youngest Faulting

Holocene

Paleoseismic Parameter Data

Type of Study/Commentary

Olig and others (2001) excavated trenches at two sites where the trace of the OFZ crosses Lake Bonneville deposits that are overlain by modern alluvium/colluvium. Three trenches (BC-1, 2, & 3) were excavated at the Big Canyon site (see map; site 2398-1), about 2 kilometers southeast of Lake Point and 0.3 kilometers west of the mouth of Big Canyon. Radiocarbon age estimates on bulk samples from debris-flow deposits directly overlain by colluvial-wedge material, and from unfaulted fluvial deposits that bury the fault scarp, constrain timing of the most recent faulting event (MRE). The trenches at Big Canyon were not deep enough to expose evidence of older events.

A single (76-meter-long) trench was excavated at the Pole Canyon site (see map; site 2398-2), 2.7 kilometers southwest of the Big Canyon site and 1.7 kilometers northwest of the mouth of Pole Canyon. A lack of diagnostic stratigraphy and dateable organic material precluded resolving the timing of the MRE beyond a post-Bonneville age. Radiocarbon age estimates from charcoal contained in a Bonneville transgression marsh deposit and an older fluvial deposit constrain timing of the penultimate event (PE). A ^{14}C age estimate from charcoal contained in fluvial sediments that bury the eroded free face of the antepenultimate event (APE) provides a broadly limiting minimum age for that event.

Number of Surface-Faulting Events/How Identified

Two/colluvial wedges, a third, older event (APE) was identified from indirect stratigraphic evidence (buried eroded free face).

Age of Events/Datum Ages/Dating Techniques

<u>MRE</u>

At both the Big Canyon and Pole Canyon sites, trenches exposed faulted Lake Bonneville sediments and thick deposits of unfaulted, scarp-derived colluvium associated with the MRE. At Big Canyon, bulk sediment samples from the youngest faulted deposit, an organic-rich debris flow, yielded ^{14}C age estimates of 6840±100 (trench BC-2) and 7650±90 (trench BC-3) ^{14}C yr B.P. Because the ^{14}C age estimates from the debris flow came from a mix of detrital material entrained in the debris flow when it was active, the younger age was considered to offer a better maximum limiting age for the MRE. Calendar calibrated and rounded to the nearest century, the younger age is 7600+300,-100 cal yr B.P.

Trench BC-1 exposed a 4-meter-thick package of unfaulted, interbedded debris-flow deposits and alluvium that buries the main fault scarp. A bulk sample of an organic-rich, debris-flow deposit 0.5 meters above the bottom of the sediment package yielded an age of 4340±60 ^{14}C yr B.P., which calendar calibrates to 4900±100 cal. yr B.P. and provides a broad minimum limit on the timing of the MRE.

Therefore, MRE at Big Canyon is constrained between a maximum limiting age of 7600+300,-100 cal yr B.P. and a broad minimum limiting age of 4900±100 cal. yr B.P. When within that possible 3.1 kyr time window the event occurred is not known. A "best estimate" average age for the MRE would be 6350±1550 cal yr B.P.

The Pole Canyon trench provided neither stratigraphic relations nor datable organic material that would allow the MRE to be constrained more closely than was possible at the Big Canyon site.

PE

At the Pole Canyon trench site, three AMS ^{14}C age estimates help constrain the age of the PE. Two of the ages came from unit B2, a faulted, channel-fill deposit rich in detrital charcoal fragments. An age of 33,950±1160 ^{14}C yr B.P. was obtained from a single detrital charcoal fragment. A second sample consisting of numerous small detrital fragments from an approximately two square meter area of unit B2 yielded an average age of 26,200±200 ^{14}C yr B.P. Both ^{14}C ages were too old to calendar calibrate, and the younger average age was considered the best limiting age for the deposit, which must be somewhat younger than the detrital charcoal it contains.

The third ^{14}C age estimate came from a dime-sized piece of detrital charcoal recovered from unit D1a, a lake-marginal marsh deposit at the base of the Lake Bonneville transgressive sequence, which directly overlies the PE colluvial wedge. The charcoal yielded a ^{14}C age of 20,370±120 ^{14}C yr B.P., which was also too old to calendar calibrate.

Therefore, the PE at the Pole Canyon site occurred in a possible ~6.2-kyr time window represented by the ages of the charcoal in units B2 and D1a. A paleosol (S3) formed on top of the PE colluvial wedge exhibits a weakly clay-enriched Bt horizon but no A horizon. The presence of the Bt horizon implies a considerable period of soil formation prior to the transgression of Lake Bonneville and burial of the PE wedge by marsh and then lake deposits. Therefore it is not known where within the time window the PE occurred. A "best estimate" average age for the PE would be 23,350±3100 ^{14}C yr B.P.

APE

There is some evidence to constrain the timing of the APE at the Pole Canyon trench site. Unit B2 unconformably overlies stratigraphic package A, which includes the APE eroded free and the post-event slope colluvium that mantles the free face. The APE colluvial wedge was not exposed and is buried beneath the trench floor. The sedimentary units comprising stratigraphic package A did not contain recognizable organics and could not be directly dated. However, the APE is older than unit B2, which contains detrital charcoal with an average age of 26,200±200 ^{14}C yr B.P., and which contains individual pieces of detrital charcoal as old as 33,950±1160 ^{14}C yr B.P. So the APE is significantly older than unit B2, which is probably about 26 kyr old, but how much older is not known. However, the paleosol formed on the colluvial unit overlying the APE free face includes both strong Bt and Bk (Stage III) horizons, implying a long period of soil formation. Therefore, the APE could easily be a minimum of several thousands of years older than the PE or as much as several tens of thousands of years older.

Dating Techniques

Radiocarbon samples from the Big Canyon site were all bulk samples from organic-rich debris-flow deposits (not paleosols), and were analyzed using conventional gas-proportional ^{14}C methods. Samples from Pole Canyon were all small bits of detrital charcoal and were analyzed using an accelerator mass spectrometer. All ages for bulk sediment samples were rounded to the nearest century. Calibration procedures for the bulk samples followed Stuiver and Reimer (1993) using a lab error multiplier of 2, the 20-year atmospheric record (data set 1), a carbon age span of 300 years (maximum permissible), and the intercept method. Note that the actual age span of the charcoal in the organic debris-flow deposits is unknown, but could be as great as 1000 years. The ^{14}C ages returned for the Pole Canyon detrital charcoal were too old to calibrate.

Event Slip/Cumulative Slip

MRE

Net vertical displacement for the MRE at Big Canyon could not be directly measured. Based on the geometry of the deposits exposed in the trench, the initial slope of the surface on which the MRE colluvial wedge was deposited, and the extent of antithetic faulting, the MRE net slip at Big Canyon is estimated to be 2.0-2.7 meters, with a "best estimate" of 2.2 meters determined from stratigraphic exposures in trench BC-2, the most straight forward at this site.

At Pole Canyon, displacement during the MRE could be directly measured using the base of unit D4, which is present on both sides of the fault zone. Total displacement was 3.3 meters; however, unit D4 is clearly draped over a pre-existing scarp. Retrodeformation analysis showed that the base of unit D4 was displaced about 0.6 meters across the fault zone prior to the MRE. Subtracting 0.6 meters from the total displacement results in a MRE displacement of 2.7 meters.

PE

Net displacement for the PE at Pole Canyon was estimated from the thickness of the PE colluvial wedge and by comparison with the dimensions of the overlying MRE colluvial wedge and the net slip determined for that event. The MRE colluvial wedge is 2.2 meters thick, which is 82 percent of the best estimate for the net vertical tectonic displacement produced by that event (2.7 m). The PE wedge is 1.9 meters thick. If it is assumed that the PE wedge also represents 82 percent of the net slip produced by the PE, then a "best estimate" for PE net slip is about 2.3+0.6,-0.4 meters.

APE

No estimate possible.

Cumulative Slip

Modification of the OFZ scarps at both the Big and Pole Canyon sites by the transgression of Lake Bonneville prevented making a reasonable estimate of total net slip from topographic profiles at those sites.

Published Recurrence Interval

Using ^{14}C years so a direct comparison can be made between the timing of the MRE and PE, the interval between those events ranges from a minimum of 13,300 ^{14}C yr B.P. to a maximum of 22,100 ^{14}C yr B.P.

Published Slip Rate

Using the above maximum and minimum values for the interval between the PE and MRE and a net slip for the MRE of 2.0-2.7 meters, the slip rate for the interval between the PE and MRE ranges from 0.1 mm/yr to 0.2 mm/yr.

Sources of Uncertainty

1. Timing of the MRE and PE are only constrained within relatively broad time windows; the "best estimates" for the ages of those events simply represent the middle of the corresponding window.
2. The timing of the APE could only be constrained by a very broadly limiting minimum age, the actual age of the event is likely several thousands to tens of thousands of years older.
3. Net slip for the MRE is reasonably well constrained from two sites. The PE displacement is an estimate based on the thickness of the PE wedge and comparison with the MRE net slip and wedge thickness.
4. Radiocarbon ages from the Big Canyon site were on bulk samples of organic debris-flow deposits. The true age span of the organics in the debris flow is unknown.
5. The average age obtained for unit B2 at the Pole Canyon site (26,200±200 ^{14}C yr B.P.) came from a composite sample of several very small pieces of detrital charcoal.

***Summary*:**

The OFZ is a relatively low slip rate (0.1-0.2 mm/yr) normal fault typical of many similar faults in the Basin and Range Province. Comparison of the timing of surface-faulting earthquakes on the OFZ with similar events on the Salt Lake City segment (SLCS) of the Wasatch fault zone (WFZ) approximately 45 kilometers to the east, shows little or no correlation in event timing. The SLCS has had as many as six surface-faulting events in the Holocene, the OFZ has only had one. Because of the broad time window in which the OFZ event occurred, it is not possible to correlate it with confidence with any of the Holocene events on the WFZ.

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Barnhard, T.P., and Dodge, R.L., 1988, Map of fault scarps formed on unconsolidated sediments, Tooele 1° x 2° quadrangle, northwestern Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1990, scale 1:250,000.

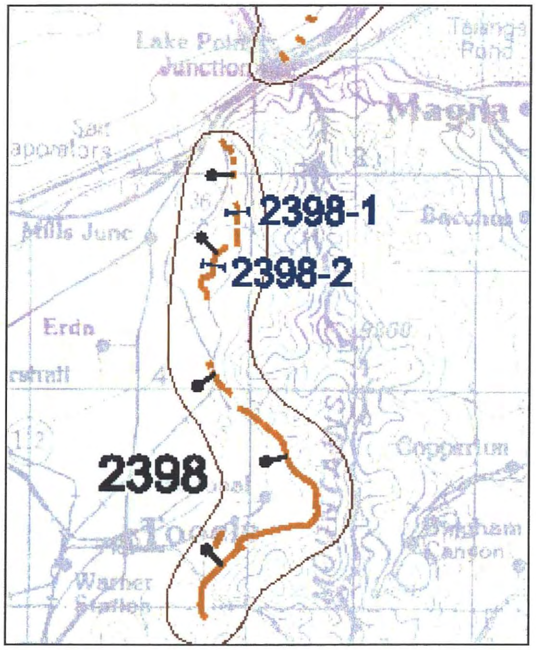
Everitt, B.L, and Kaliser, B.N., 1980, Geology for assessment of seismic risk in Tooele and Rush Valleys, Tooele County, Utah: Utah Geological and mineral Survey Special Studies 51, 33 p.

Solomon, B.J., 1996, Surficial geology of the Oquirrh fault zone, Tooele County, Utah, *in* Lund, W.R., editor, Paleoseismology of Utah, Volume 6, The Oquirrh fault zone, Tooele County, Utah -Surficial geology and paleoseismicity: Utah Geological Survey Special Study 88, p. 1-17.

Stuiver, Minze, and Reimer, P.J., 1993, Extended ^{14}C database and revised CALB 3.0 ^{14}C calibration program: Radiocarbon, v. 35, no. 1, p. 215-230.

Map:

Map of the Oquirrh fault zone (2398), taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites

2398-1 = Big Canyon

2398-2 = Pole Canyon

Olig and others (1996)

Notes

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UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Southern Oquirrh Mountains fault zone (SOMFZ), Tooele County, Utah

Study Synopsis ID: SOMFZ-1

Map Reference: 2399

Paleoseismic Data Source Documents:

Barnhard, T.P., and Dodge, R.L., 1988, Map of fault scarps formed on unconsolidated sediments, Tooele 1° x 2° quadrangle, northwestern Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1990, scale 1:250,000.

Everitt, B.L., and Kaliser, B.N., 1980, Geology for assessment of seismic risk in the Tooele and Rush Valleys, Tooele County, Utah: Utah Geological and Mineral Survey Special Studies 51, 33 p.

Olig, S.S., Gorton, A.E., Black, B.D., and Forman, S.L., 2000, Evidence for young, large earthquakes on the Mercur fault - implications for segmentation and evolution of the Oquirrh-East Great Salt Lake fault zone, Wasatch Front, Utah [abs.]: Geological Society of America Abstracts with Programs, 2000 Annual Meeting, v. 32, no. 7.

----2001, Paleoseismology of the Mercur fault and segmentation of the Oquirrh - East Great Salt Lake fault zone, Utah: Oakland, California, URS Corporation, unpublished technical report for U.S. Geological Survey, Award No. 98HQGR1036, variously paginated.

Barnhart and Dodge (1988), Everitt and Kaliser (1980), and Olig and others (2000) are either early studies of the SOMFZ or present preliminary information that was later superceded by a more complete report. The results of those three studies were ultimately incorporated into and revised by the Olig and others (2001) study. For that reason, the three early studies are referenced below when appropriate, but only the paleoseismic data resulting from the Olig and others (2001) study are summarized here.

General Fault Information

Geomorphic Expression

The SOMFZ consists of en-echelon, down-to-the-west normal faults bounding the western flank of the southern Oquirrh Mountains (see map). The Oquirrh Mountains are the easternmost and highest of three distinctive north-south mountain ranges in the Basin and Range Province west of the high central part of the Wasatch Range. Alluvial-fan sediments and deposits of Pleistocene Lake Bonneville dominate the late Quaternary sediments along the western side of the Oquirrh Mountains.

As defined by Olig and others (1999), the SOMFZ includes the Mercur, West Eagle Hill, Soldier Canyon, and Lakes of Kilarney faults. The Mercur and West Eagle Hill faults comprise 17 kilometers of the total along-strike length of 25 kilometers for the SOMFZ, and show evidence for repeated Quaternary displacement in late Pleistocene alluvial fans and terraces (Olig and others, 1999). The Soldier Canyon and Lakes of Killarney faults comprise the remaining 8 kilometers and are primarily evident in bedrock or as bedrock-alluvial contacts. Barnhard and Dodge (1988) indicate the Mercur scarps show displacements of 1.8 to 5.6 meters. Faulted alluvium exposed in a mining shaft, and an uplifted bedrock pediment, suggest a minimum of 60 meters of Quaternary displacement on the Mercur fault (Everitt and Kaliser, 1980). Olig and others (1999) indicate net vertical displacements of intermediate-age surfaces average 5.3 to 6.3 meters and 1.0 to 2.0 meters on the Mercur and West Eagle Hill faults, respectively. Maximum displacements on older surfaces displaced by those faults 21.7 and 2.8 meters, respectively. Displacement patterns indicate faulting has shifted basinward and most Quaternary displacement was partitioned on the Mercur fault, though coseismic rupture on both faults is a possibility.

Evidence for Segmentation

The SOMFZ is part of the hypostasized Oquirrh-East Great Salt Lake fault zone, a north-striking, west dipping, range-bounding 205-kilometer-long normal fault that lies 22 to 55 kilometers west of the Wasatch fault in the eastern Basin and Range Province (Olig and others, 2000). Paleoseismic evidence resulting from the Olig and others (2000, 2001) study of the Mercur fault (part of the SOMFZ) indicates that the SOMFZ may rupture coseismicly with the Oquirrh fault zone (see Study Synopsis OFZ-1) to the north.

Age of Youngest Faulting

Latest Quaternary.

Paleoseismic Parameter Data

Type of Study/Commentary

Everitt and Kaliser (1980) excavated a trench near the southern end of the Mercur fault (site 2399-2, see map), about 4.5 kilometers west of Fivemile Pass and just south of where the scarp intersects the Bonneville shoreline. Trench stratigraphy revealed evidence for repeated surface faulting during the late Pleistocene, and a 2-foot-high scarp was interpreted as indicating post-Bonneville displacement. Barnhard and Dodge (1988) reinterpreted Everitt and Kaliser's trench data, analyzed fault-scarp morphology from 11 profiles, and excavated a shallow trench just south of Everitt and Kaliser's trench; they found no evidence of post-Bonneville surface faulting. Neither of these two studies included numeric dating.

Olig and others (2000, 2001) trenched three traces of the Mercur fault where it crosses alluvial-fan deposits about 30 kilometers south of Tooele, near the intersection of Utah Highway 73 and Mercur Canyon Road (site 2399-1, see map). The trenching revealed evidence for five to seven surface-faulting events since about 92 ka. Radiocarbon (^{14}C) and infrared stimulated luminescence (IRSL) age estimates from deposits exposed in the trenches provide good to poor constraint on the timing of faulting events. Paleoseismic evidence indicates basinward migration of faulting and possible coseismic rupture with the Oquirrh fault (2398) to the north.

Number of Surface-Faulting Events/How Identified

West trench: Four events/stacked colluvial wedges
Central trench: Not logged, obscure stratigraphic evidence for one event
East trench: Two events/differential offset and cross-cutting relations

Age of Events/Datum Ages/Dating Techniques

West trench:

- Z_W: Shortly after 4430 to 4830 cal yr B.P. and before 1295 to 1530 cal yr B.P.
- Y_W: <42 ka and >4.4 ka, likely closer to 42 ka
- X_W: Before Y_W and likely shortly after 42±8 ka
- W_W: Shortly after 75±10 ka and well before 42±8ka.

Central trench:

- V_C: One event, age unknown, but old.

East trench:

- V_E: Close to but likely shortly after 92±14 ka, thus pre-dating all events in the West trench, extensive krotovina obscure any scarp-derived colluvium.
- W_E: Younger than event V_E, but how much younger is not known: likely correlates with one of the older events recognized in the West trench, but which event is not know either. The authors express a slight preference for correlation with event W_W in the West trench at shortly after 75±10 ka and well before 42±8ka.

Mercur Fault Event Summary:

- Z_M: Shortly after 4.6±0.2 ka and well before 1.4±0.1 ka
- Y_M: Between 20 and 50 ka
- X_M: Shortly after 42±8 ka – may or may not correlate with events V_C or W_E
- W_M: Shortly after 75±10 ka – may or may not correlate with events V_C and W_E, although event V_C is probably older
- V_M: Around (shortly after?) 92±14 ka

Note that the timing of the above 5 events, although sometimes broadly constrained, is well established by this study. The uncertainty regarding the total number of events at this site comes from the uncertainty associated with the timing of events V_C and W_E, which may correlate with one or more of the older events in the West trench, or which may represent separate events. Hence, the possibility of 5 to as many as 7 surface-faulting earthquakes recorded at this site.

The event ages were constrained by two ^{14}C AMS dates on charcoal from West trench units 6a and 7a, and by six IRSL ages from West trench units 2 and 4 (4) and East trench unit 2a (2). The IRSL ages are from the vesicular A horizons of buried soils.

Event Slip/Cumulative Slip

Cumulative net slip from scarp topographic profiles:

- East scarp: 2.5±0.5 m
- Middle scarp: 1.0 m
- West scarp: 6.25 – 7.1m
- Total: 9.75 – 11.1m

Individual event net slip – estimated from retrodeformation analysis:

West trench

- Z_W: 1.0±0.5 m
- Y_W: 2.0 – 2.25 m
- X_W: 1.0-2.0 m, preferred estimate 1.75 m
- W_W: 1.0-2.25 m, preferred estimate 1.5 m

Central trench:

~1.0 m in an older event, the age of which is unknown

East trench:

V_E: 1.95$\pm$0.35 m
W_E: 0.55$\pm$0.1 m

Published Recurrence Interval

Given the uncertainty associated with event timing, the Olig and others (2001) calculated average recurrence intervals based on 5 to 7 events in the interval 92$\pm$14 to 4.6$\pm$0.2 ka: yielding average recurrence intervals of 12,000 to 25,000 years. Olig and others (2001) note that the lack of soil development between events X_W and Y_W in contrast to the strong soil development between events X_W and Z_W, suggests an order of magnitude or more in variation between the timing of individual surface-faulting earthquakes.

Published Slip Rate

0.09-0.14 mm/yr for the past 4 to 6 closed seismic cycles, ~ the past 100 ka.

Sources of Uncertainty

1. Only the MRE is tightly constrained based on ^{14}C AMS ages. The remaining events are constrained only to broad time intervals that sometimes represent tens of thousands of years.
2. The total number of events is not known with certainty – 5 to 7 in the past ~100 ka.
3. Event ages except for the MRE are constrained by IRSL dates only.

Summary:

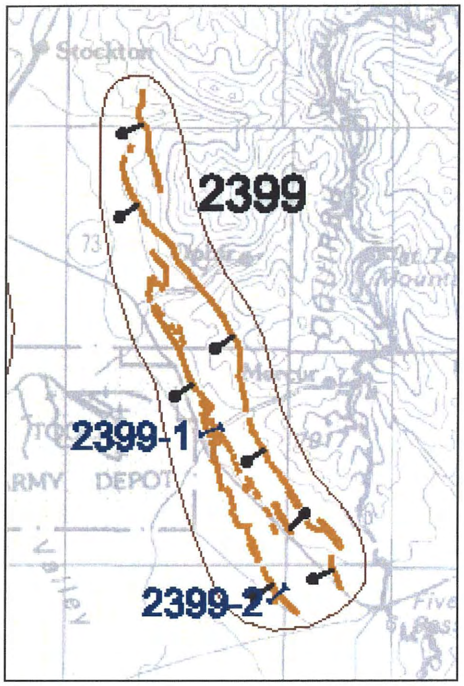
The SOMFZ is a low slip rate, long recurrence interval normal fault typical of the Basin and Range Province. Also likely typical of many Basin-and-Range faults, the timing for most surface-faulting events identified by trenching could only be broadly constrained even after intensive paleoseismic study.

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Olig, S.S., Gorton, A.E., and Chadwell, Lori, 1999, Mapping and Quaternary fault scarp analysis of the Mercur and West Eagle Hill faults, Wasatch Front, Utah: Oakland, California, URS Greiner Woodward Clyde, National Earthquake Hazards Reduction Program Final Technical Report, Award No. 1434-HQ-97-GR 03154, variously paginated, scale 1:48,000.

Map:
Map of the Southern Oquirrh Mountains fault zone (2399) taken from the Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench Sites:
- 2399-1 Mercur fault
  - Olig and others (2001)
- 2399-2 Mercur fault
  - Everitt and Kaliser (1980)

Notes

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Eastern Bear Lake fault southern section (EBLF), Rich County, Utah and Bear Lake County, Idaho.

Study Synopsis ID: EBLF-1

Map Reference: 2364c

Paleoseismic Data Source Documents:

McCalpin, J.P., 1990, Latest Quaternary faulting in the northern Wasatch to Teton corridor (NWTC): Final Technical Report for U.S. Geological Survey, Contract No. 14-08-001-G1395, 42 p. McCalpin, J.P., 1990, Latest Quaternary faulting in the northern Wasatch to Teton corridor (NWTC): Final Technical Report for U.S. Geological Survey, Contract No. 14-08-001-G1395, 42 p.

----1993, Neotectonics of the northeastern Basin and Range margin, western USA, *in* Stewart, I., Vita-Finzi, C., and Owen, L., editors, Neotectonics and active faulting: Zeitschrift fur Geomorphologie, Supplement Bd., p. 137-157.

McCalpin (2003), below, is an revised version of McCalpin (1990 and 1993), above, with regard to the East and West Bear Lake faults, and was released by the Utah Geological Survey to make the results of the studies on those faults more readily available to the geologic community and the general public. Only the paleoseismic information contained in McCalpin (2003) was evaluated for this review.

----2003 (in press), Neotectonics of Bear Lake Valley, Utah and Idaho; A preliminary assessment: Utah Geological Survey Miscellaneous Publication 03-4.

General Fault Information

Geomorphic Expression

The EBLF is a 78-kilometer-long, west-dipping normal fault bounding the east side of the Bear Lake Valley half graben in Utah and Idaho (McCalpin, 1990, 1993, 2003). Seismic-reflection data show that the lake floor and reflectors within the underlying Neogene sediments dip eastward into the EBLF (Skeen, 1975). Total throw of the top of the Eocene Wasatch Formation across the fault is about 1.5 kilometers at the north end of Bear Lake (McCalpin, 1990). McCalpin (2003) divides the EBLF into three geometric sections (southern, central, and northern) based on geomorphic and topographic characteristics along the fault zone (see below).

The southern section of the EBLF extends for 32 kilometers from Laketown, Utah in the south to Bear Lake Hot Springs at the northeastern corner of Bear Lake in Idaho. Along its length, the southern section is marked by discontinuous fault scarps up to 13 meters high in Quaternary deposits at the base of a steep escarpment of Mesozoic rocks on the east side of Bear Lake. Scarps are best developed where the fault crosses the mouths of major drainages such as at North Eden Creek, where McCalpin (1990, 1993, 2003) excavated two trenches.

Evidence for Segmentation

McCalpin (2003) divides the EBLF into northern, central, and southern sections on the basis of fault-rupture patterns, youthfulness of fault scarps, and subsurface geophysical data. Only a portion of the southern section is in Utah. Whether these geomorphic sections define earthquake rupture segments cannot be determined from currently completed paleoseismic studies because paleoseismic data are only available for the southern section of the fault (McCalpin, 2003).

Age of Youngest Faulting

Holocene

Paleoseismic Parameter Data

Type of Study/Commentary

McCalpin (2003) excavated two trenches across two parallel fault traces at the mouth of North Eden Creek on the southern section of the EBLF (site 2364c-1, see map). The fault scarps trend north-south and displace the subaerial part of the North Eden fan-delta complex deposited by North Eden Creek into Bear Lake. Together the two faults have uplifted the eastern part of the fan-delta surface about 22 meters, 8 meters on the western fault and 14 meters on the eastern fault.

Number of Surface-Faulting Events/How Identified

The western trench contained two scarp-derived colluvial wedges related to surface-faulting earthquakes. The eastern trench revealed colluvial-wedge and other stratigraphic evidence for four surface-faulting earthquakes.

Age of Events/Datum Ages/Dating Techniques

<u>Western Trench</u>

Scarp-derived colluvium (unit 5) from the penultimate event (PE; Event Y) both fills a fissure in and overlies a loess deposit (unit 4), the top of which was TL dated at 2.5±0.5 ka. The most recent event (MRE; Event Z) was followed by deposition of a second scarp-derived colluvial wedge, the base of which contained dispersed organic material ^{14}C dated at 2119±220 cal yr B.P., indicating that both surface-faulting earthquakes identified in the western trench occurred after 2.5±0.5 ka but before 2119±220 cal yr B. P. (McCalpin, 2003). The absence of a soil between the PE (unit 5) and MRE (unit 6) colluvial wedges implies that the time between the two events was too short for soil formation to take place. Unit 6 (MRE colluvial wedge) buries a soil at the scarp toe dated at 586±80 cal yr B.P.

<u>Eastern Trench</u>

Structural and stratigraphic relations in the eastern trench are complex. The trench exhibits three widely spaced fault zones of different ages. The eastern fault zone (F1) is a poorly defined zone of minor fractures and warping. The central zone (F2 and F3) is a well-defined zone of down-to-the-west normal faulting. The western zone (F4 and F5) consists of two discrete faults one of very small displacement (F4) and one of large throw.

The oldest surface-faulting event (Event U) occurred on fault F1 and created a trough into which the active stream channel of North Eden Creek was diverted. The stream deposited alluvial gravel at the base of the fault scarp (unit 2) on which the scarp-derived colluvium of unit 3 was deposited. Faulting then moved to the western fault zone (F4 and F5). The greater than 11 meters of throw on the western zone implies three faulting events. The first two events (Events V and W) resulted in colluvial or fissure-fill deposits that are grouped together in unit 4. The third event (Event X) resulted in a colluvial wedge deposit (unit 5). The MRE in the eastern trench (Event Y) then occurred on the central fault zone (F2 and F3).

Five TL age estimates and one ^{14}C age help constrain the timing of the surface-faulting events recognized in the eastern trench. Units 3a and 4d yielded TL age estimates of 39±3 ka and 31±6 ka, respectively. Unit 3 is the Event U colluvial wedge, so Event U occurred prior to 39 ka. Event V and Event W are represented by the scarp colluvium and fissure-fill deposits comprising unit 4, and therefore are younger than 39±3 ka and older than 31±6 ka. The Event X colluvial wedge (unit 5) overlies unit 4 and so is younger than 31±6 ka. Organic silt associated with unit 6 (beach gravel and sand) yielded a ^{14}C age of 15,150±760 cal yr B.P. and provides a broadly limiting minimum age for Event X. A TL age from the base of the Event Y colluvial wedge (unit 9) gave an age of 5.0±0.5 ka, and indicates the event occurred shortly prior to that time at about 5 ka (McCalpin, 2003).

<u>Summary</u>
Structural relations in the trenches at North Eden Creek indicate 6 surface-faulting events have occurred on the southern section of the EBLF in approximately 39 ka.

Event timing is constrained as follows:
- East Trench
  - Event U: >39±3 ka, but likely not much greater
  - Event V: >31±6 ka but <39±3 ka
  - Event W: >31±6 ka but <39±3 ka
  - Event X: <31±6 ka but >15.2±0.8 ka
  - Event Y: >5.0±0.5 ka, but likely not much greater
- West Trench
  - Event Y: <2.5 ka but >2.1±0.2 ka (the 2.5 ka TL age used to constrain this event may be too young)
  - Event Z: <2.1+0.2 ka but >0.6±0.08 ka

McCalpin (2003) questions how both surface-faulting events in the western trench can be younger than 2.5 ka, and why neither event was recognized in the eastern trench only a few tens of meters away. He hypothesizes that Event Y in the western trench may in fact be older than 2.5 ka, and that the soil sample from the western trench that gave the 2.5±0.5 ka TL age may in fact have been inadvertently collected from younger material in an animal burrow. In that case, Event Y in the western trench may correlate with Event Y in the eastern trench (hence the same letter designation) and there would only be one event at the site younger than about 2 ka. However, he concludes that he has no evidence to support the young sample hypothesis, so the actual number of events at the site remains unresolved.

Event Slip/Cumulative Slip

<u>Western Trench</u>
Cumulative net slip measured across the fault zone in the trench was 8.3 meters, on a scarp that is 6.5 to 7 meters high. McCalpin (2003) indicates that the difference between

net slip and scarp height is due to 1.1 to 1.3 meters of loess that has accumulated on the hanging wall but that is not present on the footwall. McCalpin (2003) further states that of the 8.3 meters of fault throw measured in the trench, it is difficult to estimate how much occurred in the PE and how much occurred in the MRE, but that fault relations indicate that the displacements for the two events were approximately similar, or an assumed ~4 meters each. However, later in his report McCalpin (2003) reports 5 meters of net slip for the MRE in the western trench, but does not explain how he arrived at that value.

Eastern Trench
Event U: 1.2 meters
Events V, W, & X: combined total, minimum of 11.3 to 11.5 meters
Event Y: 1.9 to 2.1 meters

Cumulative slip measured in trench: minimum 14.6 meters

Published Recurrence Interval

None reported.

Given the paleoseismic data presented in McCalpin (2003) it is possible to make several slip-rate calculations for the southern section of the EBLF. Six surface-faulting events in the past ~39 kyr results in an average recurrence interval of 6.5 kyr, but that value includes the time since the MRE, an open seismic cycle, and fails to adequately consider how much time elapsed between Event T (no evidence at this site) and Event U, the oldest event recognized at this site. Five events in the closed 38.4 kyr (39 ka – 0.6 ka) interval between Events V and Z produce an average recurrence interval of ~7.7 kyr. If the Event Ys in each trench are in fact the same event, then there would be four events in 38.4 kyr, resulting in an average long-term recurrence interval of 9.6 kyr.

The intervals between individual events as determined by McCalpin (2003) are as follows:

1. One event prior to 39+3 ka, unknown elapsed time since the preceding event.
2. Two events in the interval between 39±3 ka and 31±6 ka (~4 kyr)
3. One event in the interval 31±6 ka and 15.2±0.8 ka (~15.8 kyr)
4. One event in the interval 15.2±0.8 ka and 5.0±0.5 ka (~10 kyr)
5. Possibly two events post 2.5 ka (~1.25 kyr), or two events post 5 ka (~2.5 kyr)

In summary, individual recurrence intervals between surface-faulting events on the southern section of the EBLF have been non-uniform, varying in length by as much as several thousands of years. Long-term average recurrence likely ranges between about 6.5 and 9.6 kyr.

Published Slip Rate

McCalpin (2003) states that all but 1.2 meters of the net 21.8 meters of net slip at the North Eden site has occurred since about 39 ka. Therefore, 20.6 meters of slip has occurred over the past ~39 ka (4 to 5 seismic cycles), giving an open slip rate of 0.53 mm/yr, which McCalpin (2003) considers a minimum long-term slip rate because it extends to the present. He goes on to state that slip rates for individual closed seismic cycles can be much higher, citing 5 meters of displacement released in Event Z, which may have accumulated in an interval as long as 2.5 kyr or as short as 0.5 kyr, depending on the age accepted for Event Y in the western trench. If the interval between Events Y and Z in the west trench is 2.5 kyr, the slip rate for the interval between the PE and MRE is 2.0 mm/yr. However, earlier McCalpin (2003) stated that the MRE had a displacement of ~2.6 meters and it is unclear where the 5 meter net slip value came from.

Considering the interval between 39±3 ka and 0.6±0.08 ka in which 4 to 5 events representing 20.6 meters of slip occurred, results in a long-term closed slip rate of 0.5 to 0.54 mm/yr.

Sources of Uncertainty

1. The total number of events that occurred within the time interval represented by the trenches is not known with certainty.
2. McCalpin (2003) considers the timing of the PE (Event Y) in the western trench suspect, and believes it may be as much as twice as old as indicated by TL dating. If so, it likely is the same event as Event Y in the eastern trench.
3. Net slip reported for the MRE in the western trench is stated as ~2.6 meters in one part of the McCalpin (2003) report and as 5 meters elsewhere in the report.
4. The timing of Events U, V, W, and X are only broadly constrained to wide time windows.
5. The paleoseismic information available for the EBLF is restricted to one site on the southern section of the fault; no detailed paleoseismic information is available for the central and northern sections of the fault.

Summary:

The southern section of the EBLF has had as many as six surface-faulting earthquakes in the past ~39 ka. Questions remain regarding the timing of the PE event, and the ages of events older than the PE are only broadly constrained. The long-term slip rate for the southern section is 0.5-0.54 mm/yr and average long-term recurrence ranges between 6.5 to 9.6 kyr. No paleoseismic data are available for the central and northern sections of the fault.

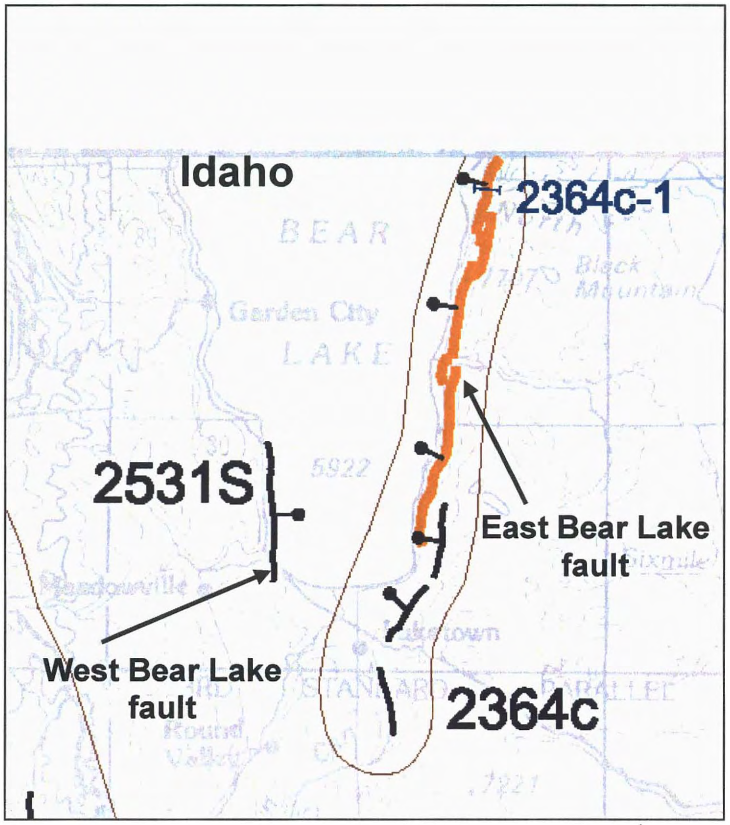
References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Skeen, R.C., 1975, A reflection seismic study of the subsurface structure and sediments of Bear Lake, Utah-Idaho: Salt Lake City, University of Utah, senior thesis, 25 p.

Map:

Map of the Eastern Bear Lake fault southern section (2364c) taken from the the Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench site
2364c-1: North Eden Creek
McCalpin (2003)

Notes

9

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Bear River fault zone (BRFZ), Summit County, Utah and Uinta County, Wyoming

Study Synopsis ID: BRFZ-1

Map Reference: 730

Paleoseismic Data Source Document(s):

West, M.W., 1994, Paleoseismology of Utah, Volume 4 - Seismotectonics of north central Utah and southwestern Wyoming: Utah Geological Survey Special Study 82, 93 p.

General Fault Information:

Geomorphic Expression

The BRFZ extends 34 to 40 km from southeast of Evanston, Wyoming to the north flank of the Uinta Mountains in Utah, where it ends at a complex juncture with the Laramide-age North Flank thrust fault (map 1). In general, the fault zone consists of distinct individual scarps each about 3.0 to 3.5 kilometers long arranged in a right-stepping, en echelon pattern. Major scarps trend N. 20° W. to N. 20° E., and show consistent down-to-the-west displacement. Scarps with lesser, down-to-the-east displacements, are interpreted to be antithetic faults, trend N. 15-20° W. Near the south end of the fault zone, scarps show a strong angular discordance (70°) with the main north-northeast pattern of faulting, likely due to the buttressing effect of the Uinta Mountains. Scarp heights and tectonic displacements increase markedly from north to south along the BRFZ. Fault scarps are between 0.5 meters and 15 meters high on upper Quaternary deposits; sag ponds, beheaded drainages, and antithetic fault scarps are also present. Late Holocene to historic landsliding obscures evidence of faulting through an approximately 9-kilometer-wide gap between the southernmost clearly defined scarps in Wyoming and the northernmost scarps in Utah.

A 5-kilometer-long Holocene scarp (the Martin Ranch scarp), together with at least 10 kilometers of related surface warping, lies west of the BRFZ in Wyoming coincident with the Absaroka thrust.

Evidence for Segmentation

None reported.

Age of Youngest Faulting

Holocene

Paleoseismic Parameter Data

Type of Study/Commentary

West (1994) excavated seven trenches, logged an irrigation ditch exposure, and measured 14 scarp profiles of the BRFZ. The irrigation ditch exposure and four of the trenches were in Wyoming; the other three trenches were in Utah (see map). The trenching results are summarized below.

La Chapelle scarp (Wyo.) – one trench, one profile. The trench revealed two distinct sub-vertical fault zones about 2.7 meters 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.

Lester Ranch scarp (Wyo.) – one trench, five profiles. The trench was excavated in strath-terrace gravels near a water-filled sag pond and exposed evidence for two surface-faulting events. Radiocarbon age estimates were obtained from the base of the modern soil and two buried A horizons.

Lester Ranch South scarp (Wyo.) – one trench. The trench was excavated in alluvial and colluvial deposits where the scarp is about 4 to 5.5 meters high and has a maximum scarp angle of 20.5°. The trench exposed Wasatch Formation bedrock in the footwall and revealed evidence of two surface-faulting events. The presence of multiple fault planes precluded estimates of individual displacements based on colluvial-wedge stratigraphy.

Austin Reservoir scarp (Wyo.) – irrigation ditch exposure. The roughly 1.5-meter-high, scarp at Austin Reservoir displaces colluvium overlying Wasatch Formation bedrock. The exposure reveals evidence of two surface-faulting events. A youthful, faulted, buried A horizon and a ^{14}C estimate of about 800 ^{14}C yr B.P. from the base of a second displaced A horizon indicate the age of faulting to be late Holocene.

Sulphur Creek scarp (Wyo.) – one trench, one profile. The fault scarp height is estimated at 4.6 to 5.6 meters. The trench shows evidence of one to three surface-faulting events depending on stratigraphic interpretation. The author prefers an interpretation of two events. Radiocarbon age estimates from a buried A horizon, discontinuous pods of soil, and the base of the modern A horizon provide limiting ages of faulting, although the age estimate associated with the modern A horizon is suspect.

Big Burn scarp (Utah; site 730-6, map 2) – one trench, three profiles. The Big Burn scarp is, in places, 15+ meters high with slope angles locally exceeding 30°. Where trenched the scarp is 12.3 meters high with a 31° slope angle. 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.

Lower Little Burn scarp (Utah; site 730-7, map 2) – one trench. The scarp forms a subtle break in slope with an estimated height of 1.5 to 2.0 meters and a maximum slope angle of 13°. The trench revealed two poorly defined faults as well as evidence of possibly two surface-faulting events displacing 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 relations between the ages of the charcoal and colluvium are equivocal.

Upper Little Burn (Utah; site 730-8, map 2) – one trench, two profiles. The trench was excavated across one of two east-northeast-trending, north-northwest-facing scarps displacing glacial 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 relations were determined. 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.

Number of Surface-Faulting Events/How Identified

Minimum of two/stacked colluvial wedges, additional events are possible on some scarps

Age of Events/Datum Ages/Dating Techniques

Age constraints for faulting events were provided by ^{14}C estimates and amino acid racemization ratios obtained from land snail shells.

Estimated event ages are:

MRE: 2370 ±1050 yr B.P.
PE: 4620±690 yr B.P.

Both the MRE and PE ages above are "best estimate" mean values calculated from the youngest and oldest constraining ages obtained for the two events, as determined from trenches across the various scarps. The "±" values reflect the greater of the differences between the mean value and the youngest or oldest possible event ages, and are considered by the West (1994) to incorporate both the analytical uncertainty of the ^{14}C dates and the geologic uncertainty associated with the event ages. However, the ages for the events are reported as "yr B.P." because, while all ^{14}C ages on soil organics were calendar-calibrated according to de Jong and others (1986), Linick and others (1986), and Pearson and Stuiver (1986), no Mean Residence Corrections (Machette and others, 1992, appendix A) were subtracted from the calibrated ages to account for the age of the carbon in the soil at time of burial. As a result, the West (1994) states that:

> ***It is likely that the estimated ages of the surface-faulting events in the project area (4620±690 and 2370±1050 yr B.P.) may be too old by at least several hundred years.***

The estimate of several hundred years too old reflects the author's belief that the soils in his study area are significantly better developed and therefore older than the soil A horizons studied by Machette and others (1992) along the Wasatch fault, where the average soil age was estimated as 200-400 years.

Event Slip/Cumulative Slip

West (1994) estimated the total net vertical tectonic displacement for the trenched scarps in the BRFZ from scarp-profile data. Per event displacement estimates were made from scarp-profile data, from total vertical stratigraphic displacements measured or estimated in trenches, and from colluvial-wedge thicknesses. The per event displacements obtained from scarp-profile and total vertical-stratigraphic-displacement data are averages for the two events recognized on the BRFZ, unless otherwise noted below. The per event net-slip estimates from colluvial-wedge thicknesses are event specific. All net-slip data for the BRFZ are summarized below.

Scarp	Scarp[1] Profile Total	Scarp[1] Profile Event	Strat.[1] Displace. Event	Colluvial Wedge[1] Event		Summary[1]		
				PE	MRE	Min	Max.	Mean[2]
LaChapelle	4.6-5.1	2.3-2.6	1.6-2.4			1.6	2.6	2.1
Lester Ranch N.	3.9-11.3	2.0-2.7	3.13	1.4-2.3	1.3-2.0	1.3	3.1	2.2
Lester Ranch S.		2.0 3.7-5.7	2.0-2.9 ---	---	---	2.0 3.7	2.9 5.7	2.5 4.7[3]
Austin Reservoir			0.6-0.8	1.4-2.0	0.7-0.8	0.6	2.0	1.3
Sulphur Ck #1[4]	6.7-8.6	3.3-4.3	>2.8	2.5	4.2-4.7	2.5	4.7	3.6
Sulphur Ck. #2[4]		3.3-4.3	>2.8		6.7-7.2	>2.8	7.2	5.0
Big Burn	2.9-12.7	4.8-6.3	---		3.9	3.9	6.3	5.1
Upper Little Burn	4.8-7.2							
Lower Scarp		1.4-2.2[5]	1.0-1.1	---	---	1.0	2.2	1.6
Total		4.8-7.2[6]	---			4.8	7.2	6.0
Lower Little Burn	0.8-1.4	0.4-0.7[5] 0.8-1.4[6]	--- ---	1.4-1.8	1.0	0.4 0.8	1.8 1.8	1.1 1.3

[1]Reported in meters; [2]Represents the mean of all methods used to calculate net slip; [3]Unable to determine how the author generated these displacement values; [4]Two possible faulting scenarios: #1 two events, #2 one event; [5]Assumes two equal displacement scarp-forming events; [6]Assumes a single scarp-forming event

Published Recurrence Interval:

Single cycle recurrence of 2250 (+690/-1050) yrs between the PE and MRE using the mean ages of those events (above). The mean age of the MRE is 2370±1050 yr B.P., indicating the elapsed time since the MRE has exceeded the single mean recurrence interval available for the BRFZ.

Published Slip Rate:

Slip rates reported for the BRFZ scarps are open, time intervals extend to the present. The table below presents the reported slip rates (calculated using total net vertical tectonic displacement determined from scarp profiles) and slip rates determined using the mean recurrence interval between the PE and MRE and the mean net slip determined for each scarp (table above).

Scarp	Reported Slip Rate mm/yr	Mean Single Interval Slip Rate mm/yr
LaChapelle	1.0-1.1	0.9
Lester Ranch North	0.8- 2.4	1.0
Lester Ranch South		1.1
Sulphur Creek #1	1.5-1.9	1.6
Sulphur Creek #2		Single event scenario[1]
Big Burn	0.6-2.7	2.3[2]
Upper Little Burn[3, 4]	1.0-1.6	0.7
Lower Little Burn[4]	0.2-0.3 0.3-0.6	0.5 Single event scenario[1]

[1]Single-event scenario precludes calculating closed slip rate; [2] Big Burn scarp shows clear evidence for one event, a second and possibly more events are possible – slip rate too high? [3]Single-event scenario for the Upper Little Burn scarp (see above) not considered in author's slip-rate computations; [4] Little Burn scarps are at the south end of the BRFZ.

Sources of Uncertainty:

1. All bulk samples of modern and buried soils were obtained from the bottom 10-15 centimeters of each horizon. West's (1994) rational for this sampling procedure was that AMRT ages from the base of a soil horizon would provide an estimate of the maximum age of the horizon, and therefore the minimum age for the underlying deposit or event. In retrospect, he considers this approach an oversimplification, and for a variety of reasons now believes that sampling the base of a soil horizon provides an age younger than the inception of soil formation and younger than the age of fault surface rupture. To compensate for the problem, he multiplied the laboratory error reported for the ^{14}C ages on soils by a factor of two (2 x sigma) to arrive at a geologically more meaningful AMRT age.
2. Calibrated ^{14}C ages from soil organics are not corrected for the mean residence time of carbon in the soil and therefore are estimated to be up to several hundred years too old.
3. Uncertainty exists as to the number of events represented by the Sulphur Creek, Big Burn, and Little Burn scarps.
4. Reported mean per event net slip values are an amalgamation of three different methods used to estimate net slip.
5. Event ages are mean values, but associated error limits likely incorporate both the laboratory analytical and geologic uncertainty.
6. The published slip rates are open across at least one seismic cycle and were calculated using total net-slip values determined from scarp profiling rather than per event measurements across a closed seismic cycle.
7. Several different per event net slip values are available for a number of the scarps, making it possible to calculate a variety of net slip values. I chose to use the mean per event net slip data provided by the author to calculate slip rates for the PC/MRE closed seismic cycle (see above).

Summary:

The BRFZ is situated over the Sevier-age Darby-Hogsback thrust ramp and likely represents an early stage in the development of normal faulting in what was previously thrust faulting terrain as basin-and-range style faulting now extends eastward. The BRFZ exhibits evidence of recurrent Holocene movement over a length of 34 to 40 kilometers, with per event net vertical tectonic displacements ranging from about 1 to 5 meters. Six trench sites and a natural exposure along its relatively short length, make the BRFZ one of the most intensively studied normal faults in the western U.S. The largest sources of uncertainty associated with this study include the manner in which both modern and buried soil A horizons were sampled and the way the resulting ^{14}C ages were calendar calibrated; the number of events represented by some scarps, and the wide range in possible per event net slip values calculated by different methods for the same site (scarp).

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

deJong, A.F.M., Becker, Bernd, and Mook, W.G., 1986, High-precision calibration of the radiocarbon time scale, 3930-3230 BC, *in* Stuiver, Minze and Kra, R.S., editors, Radiocarbon calibration issue – Proceedings of the 12th International Radiocarbon Conference, Trondheim, Norway: Radiocarbon, v. 28, no. 2B, p. 939-942.

Linick, T.W., Long, Austin, Damon, P.E., and Ferguson, C.W., 1986, High-precision radiocarbon dating of bristlecone pine from 6554 to 5350 BC, *in* Stuiver, Minze and Kra, R.S., editors, Radiocarbon calibration issue – Proceedings of the 12th International Radiocarbon Conference, Trondheim, Norway: Radiocarbon, v. 28, no. 2B, p. 943-953.

Machette, M.N., Personius, S.F., and Nelson, A.R., 1992, Paleoseismology of the Wasatch fault zone – A summary of recent investigations, interpretations, and conclusions, *in* Gori, P.L., and Hays, W.H., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500 - A - J, p. A1-A71.

Pearson, G.W., and Stuiver, Minze, 1986, High-precision calibration of the radiocarbon time scale, 500-2500 BC, *in* Stuiver, Minze and Kra, R.S., editors, Radiocarbon calibration issue – Proceedings of the 12th International Radiocarbon Conference, Trondheim, Norway: Radiocarbon, v. 28, no. 2B, p. 839-862.

Map:

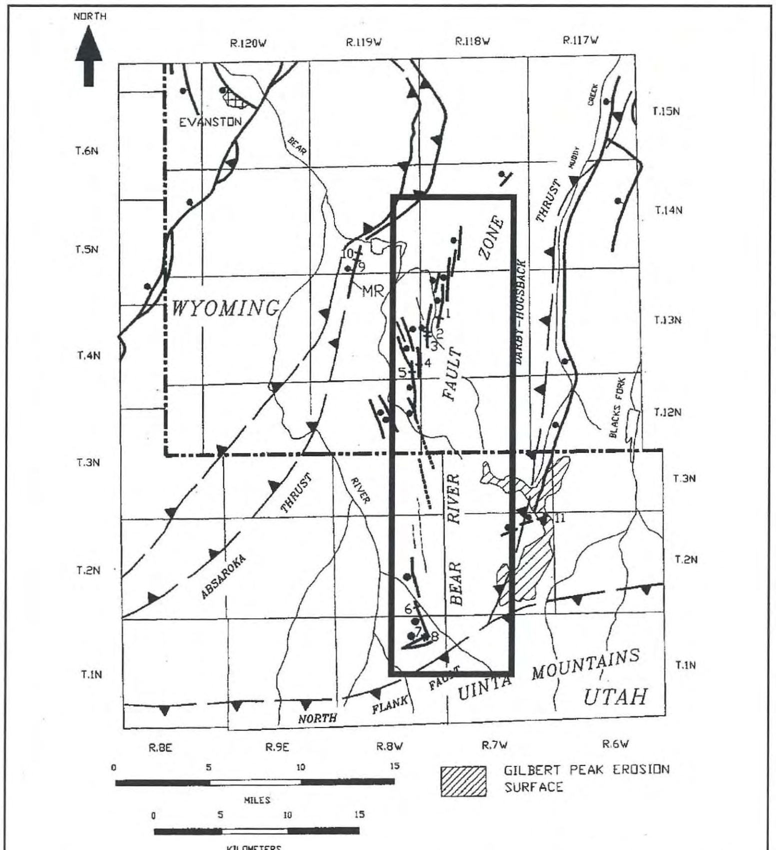
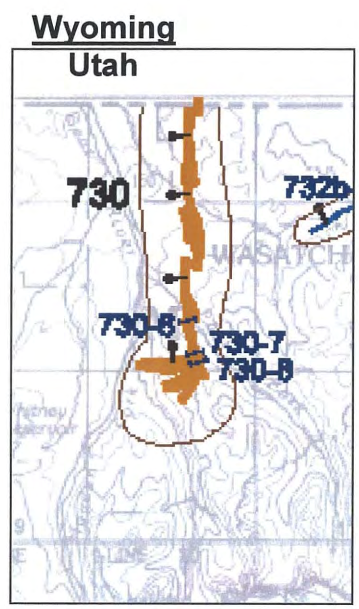


Figure 24. Map of neotectonic features in the project area. The Bear River fault zone is located between the Darby-Hogsback and Absaroka thrusts. 1=La Chapelle trench/scarp profile. 2=Lester Ranch trench/scarp profiles. 3=Lester Ranch South trench/scarp profiles. 4= Austin Reservoir ditch exposure. 5=Sulphur Creek trench-scarp profile. 6=Big Burn trench/scarp profile. 7=Upper Little Burn trench/scarp profile. 8=Lower Little Burn trench/scarp profile. 9=Upper Martin Ranch (MR) trench/scarp profile. 10=Lower Martin trench/scarp profile. 11= Elizabeth Ridge trench/scarp profiles.

Map 1. From West (1992), showing the Bear River fault zone and its relation to Sevier-age thrust faults in southwestern Wyoming and northeastern Utah.

Map 2. From Black and others (2003) showing the location of BRFZ trenches in Utah (see text for name of trenched scarps).



Notes

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Morgan fault, central section (MF), Morgan County, Utah

Study Synopsis ID: MF-1

Map Reference: 2353b

Paleoseismic Data Source Documents:

Sullivan, J.T., and Nelson, A.R:, 1992, Late Quaternary displacement on the Morgan fault, a back valley fault in the Wasatch Range of northeastern Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front: U.S. Geological Survey Professional Paper 1500-I, 19 p.

Sullivan, J.T., Nelson, A.R., LaForge, R.C., Wood, C.K., and Hansen, R.A., 1988, Central Utah regional seismotectonic study for USBR dams in the Wasatch Mountains: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-5, 269 p., scale 1:250,000.

General Fault Information

Geomorphic Expression

The MF is a range-front normal fault that extends for 22 kilometers at the base of a bedrock escarpment along the eastern side of Morgan Valley, a back valley of the Wasatch Range. The escarpment consists of three linear 5- to 8-kilometer-long sections that correspond to en echelon steps in the fault. There are no fault scarps in unconsolidated deposits along the three fault sections. The central section of the fault shows evidence of Holocene movement, whereas the northern and southern sections only show evidence for late Quaternary movement, although scarp morphology is similar for all three areas.

The central section of the MF consists of a north-trending range-front main fault trace and an inferred northeast-trending antithetic fault trace to the west. Although early Holocene colluvium is faulted, scarps are not preserved along the fault. This is attributed to the steepness (20-25 degrees) of escarpment slopes and the presumably small amounts of surface displacement. Small, single-event displacements (0.5 to 1.0 meters per event) are suggested by a lack of discrete colluvial wedges. Analyses of soils developed on faulted deposits at different sites yielded age estimates that are generally between 200 and 400+ ka, but which range from about 70 to >500 ka. The antithetic, graben-bounding fault is inferred to occur along the west side of a topographic low west of the main fault.

Evidence for Segmentation

Sullivan and others (1988) divide the MF into three sections based on the morphology of the bedrock escarpment in the fault footwall. The northern section is 13 kilometers long and consists of a main western fault trace and an older eastern fault trace. The central section is 7 kilometers long and consists of a main fault trace and an antithetic fault trace inferred to the west. The southern section consists of a single, short (2-km-long), northwest-trending fault trace. Only the central section was trenched, so it is unknown if the three sections are independently seismogenic.

Age of Youngest Faulting
Holocene

Paleoseismic Parameter Data

Type of Study/Commentary
Sullivan and others (1988) excavated five trenches near Robeson Springs at the southern end of the central section of the MF (site 2353b-2; see map). All five trenches were at or near the break in slope at the base of the footwall escarpment and two of the trenches exposed the main trace of the MF. Stratigraphic relations and ^{14}C dating of bog deposits that predate the most recent surface-faulting event (MRE) indicate a Holocene age for the MRE, and a series of small-displacement (0.5 to 1 meter) events during the middle and late Pleistocene (Sullivan and others, 1988; Sullivan and Nelson, 1992). At Mahogany Creek (site 2353b-1), about 2.5 kilometers north of the Robeson Springs site, a road cut and three trenches exposed gastropod-bearing sediments that provided age estimates (based on amino acid ratios) for correlative deposits at Robeson Springs (Sullivan and others, 1988; Sullivan and Nelson, 1992). Tilted strata suggest local rotation into the fault, but the fault trace was not exposed at this site.

Number of Surface-Faulting Events/How Identified
Sullivan and others (1988) and Sullivan and Nelson (1992) interpret a massive, moderately indurated sandy silt unit in trench M4 at the Robeson Springs site as a complex, fault-derived colluvial deposit that represents an unknown number of small surface-faulting events that occurred between middle Pleistocene and early Holocene time. Evidence for the MRE consists of a scarp-derived colluvial wedge also exposed in trench M4.

Age of Events/Datum Ages/Dating Techniques
Radiocarbon age estimates on pre-MRE peat (8320 ± 100 ^{14}C yr B.P.) and wood (9105 ± 270 ^{14}C yr B.P.) from a bog deposit exposed in the Robeson Springs trench provide a maximum limiting age for the MRE on the central section of the MF. It was not possible to establish a minimum limiting age, so all that is known with certainty regarding the timing of the MRE is that it occurred during the Holocene. The ages of individual older surface-faulting events recorded by the older complex colluvial unit is unknown.

Event Slip/Cumulative Slip
Sullivan and Nelson (1992) report a net slip of about 1 meter for the MRE. The net slip for earlier surface-faulting earthquakes is unknown, but is estimated to average between 0.5 to 1.0 meters.

Published Recurrence Interval
Sullivan and Nelson (1992) state that if 0.5 meters is the average slip per event, then the 4 meters of displacement recorded in the Robeson Springs trenches represents eight individual events. If the average per event slip is 1.0 meter, then the 4 meters represents 4 surface-faulting events. Assuming that the displacement occurred over the

past 200 to 400 ka, the average middle to late Quaternary slip rate for eight events would be 25 to 50 kyr, and 50 to 100 kyr for four events.

Published Slip Rate

Sullivan and Nelson (1992) report a minimum average long-term slip rate of 0.01 to 0.02 mm/yr based on 4 meters of displacement in deposits that are 200 to 400 kyr old.

Sources of Uncertainty

1. The MRE on the central section of the MF occurred during the Holocene, but cannot be constrained more closely than that.
2. The actual number and timing of earlier surface-faulting events extending back to the middle Pleistocene is unknown.
3. The age of the older deposits exposed in trenches is only broadly constrained at 200 to 400 ka, but they may be older.
4. Slip per event could only be measured for the MRE, the average displacement of 0.5 to 1.0 meters reported for older events is estimated based on stratigraphic relations in trenches.

Summary:

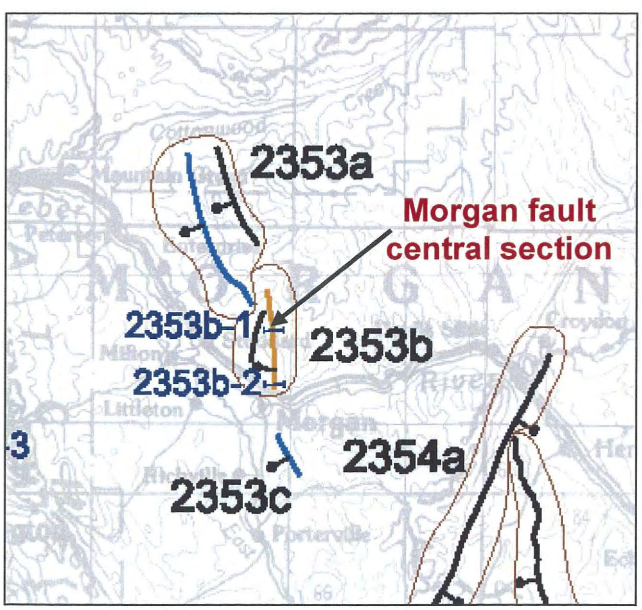
The MF is a low slip-rate fault that has experienced a one-meter displacement event in the Holocene. The timing and size of earlier events are unknown, but are estimated at 4 to 8 events of 0.5 to 1.0 meter each over the past 200 to 400 ka.

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:

Map of the Morgan fault (2353) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites
2353b-1 Mahogany Creek site
2353b-2 Robeson Springs site

Notes

11

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: James Peak fault (JPF), Cache County, Utah

***Study Synopsis ID*:** JPF-1

Map Reference: 2378

Paleoseismic Data Source Documents:

Sullivan, J.T., Nelson, A.R., LaForge, R.C., Wood, C.K., and Hansen, R.A., 1988, Central Utah regional seismotectonic study for USBR dams in the Wasatch Mountains: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-5, 269 p., scale 1:250,000.

Nelson, A.R., and Sullivan, J.T., 1992, Late Quaternary history of the James Peak fault, southernmost Cache Valley, north-central Utah, *in* Gori, P.L., and Hays, W. W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-G, p. J1-J13.

General Fault Information

Geomorphic Expression

The JPF is a short (7 km) northeast-trending range-front normal fault along the northern flank of James Peak at the south end of Cache Valley. Cache Valley is a north-trending intermontane graben (bounded by high-angle normal faults on the east and west) between the Bear River and Wasatch Ranges. Faulting occurs in Bull Lake outwash deposits (~140 ka). The short fault length suggests that surface faulting may have extended northward, rupturing the southern section of the East Cache fault zone (ECFZ). Faceted spurs at the base of James Peak suggest recurrent Quaternary displacements, though the spurs are smaller, less continuous, and less steep than those along the nearby East Cache and Wasatch fault zones.

Evidence for Segmentation

The JPF may be a less active southern section of the ECFZ, which bounds the east side of Cache Valley to the north.

Age of Youngest Faulting

Late Pleistocene

Paleoseismic Parameter Data

Type of Study/Commentary

Sullivan and others (1988) excavated a trench (see map) about 2.5 kilometers north-northwest of James Peak across a 7-meter-high scarp on a Bull Lake (~140 ka) glacial outwash fan. The trench exposed white, coarse, sandy, quartzite-derived outwash on which was developed a reddish argillic soil horizon overlain by bouldery, silty colluvial wedges. Silty colluvial units marked by thick cambic and argillic B horizons overlay the wedges.

Number of Surface-Faulting Events/How Identified

Two(?)/colluvial wedges. The data are ambiguous, but lithofacies analysis of fault colluvium, cumulative displacement across the scarp (4.2 meters), and the short fault length suggest two colluvial wedges indicative of two surface-faulting events rather than a single, large wedge representing one large event.

Age of Events/Datum Ages/Dating Techniques

All age estimates are based on the degree of soil-profile development on Quaternary deposits of different ages. Based on their analysis of soil forming conditions at the site and the degree of soil-profile development, the authors estimate that the soil formed on the pre-event glacial outwash and the soil formed on the post-event colluvial wedges each required 30 to 70 kyr to develop. Therefore, the two surface-faulting events happened after 110-70 ka (140 ka – 30,000 to 70,000 years) and before 30-70 ka (period of post event soil formation). However, where in that time window the events actually took place is unknown, except that no soil was found on the older wedge, indicating a relatively short time interval between the two events.

Event Slip/Cumulative Slip

Cumulative displacement across the scarp at the trench site determined from a topographic profile is about 4.2+0.6,-0.2 meters. Based on stratigraphic relations exposed in the trench, the authors estimate about 1.8+0.4/-0.2 meters of displacement occurred during the oldest event, with and additional 2.4+0.8/-0.6 meters during the youngest event.

Published Recurrence Interval

Because the soils developed on the outwash and on the colluvium overlying the fault-related wedges provide only maximum and minimum age constraints for the wedges, the true intervals of time between the surface-faulting events are difficult to estimate. Both the soil formed on the glacial outwash beneath the colluvial wedges and the soil formed on top of the wedges probably required several tens of thousands of years to form (>30 kyr and possibly even 70 kyr). Thus the first event could have occurred as early as 110 ka or as late as 70 ka. Considering that the soil on top of the wedges could be as young as 30 ka, a time interval of 80,000 years is available in which the two events could have occurred. If it were assumed that 40,000 years separates the two events, the average recurrence interval would be at least 50,000 years (50,000 + 40,000 + 50,000 = 140,000 years). However, the absence of a soil formed on the first colluvial wedge argues for a short time interval between the two events, indicating that surface-faulting recurrence has been non-uniform.

Published Slip Rate

Based upon 4.2 meters of net slip in ~140 ka, the Nelson and Sullivan (1992) estimate an average late Quaternary vertical slip rate of 0.03mm/yr on the James Peak fault.

Sources of Uncertainty

1. The data supporting two surface-faulting events are equivocal, and it is possible to make a reasonably strong case that only one event has occurred on the JPF in the past ~140 ka.
2. There are no numeric ages available for this study. All age estimates used to constrain the time of faulting are broad estimates based on the time required to form soils with thick argillic B horizons.
3. The JPF may in fact be an extension (southernmost section) of the larger and more active ECFZ to the north.
4. The long-term slip rate reported for this fault has open seismic cycles at each end.

Summary:

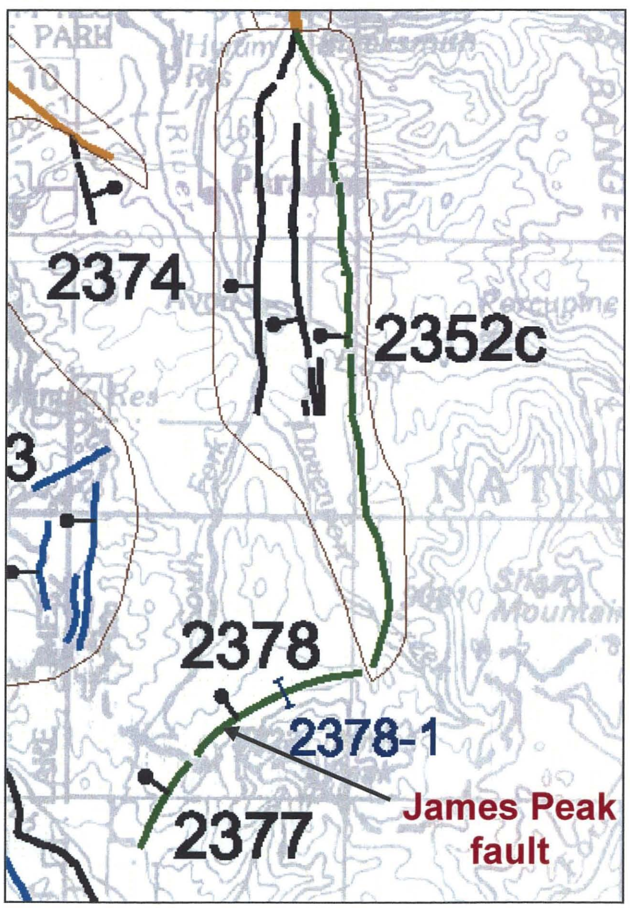
The JPF is a very short, low slip rate fault that has experienced at most two surface-faulting events in the past ~140 ka, and no surface-faulting events since at least 30 ka, based on relative age estimates determined from the degree of soil profile development on faulted and unfaulted deposits at the single trench site on the fault.

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:

Map of the James Peak fault (2378) taken from the Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench site: 2378-1
Sullivan and others (1988)
Nelson and Sullivan (1992)

Notes

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Towanta Flat graben (TFG), Duchesne County, Utah

Study Synopsis ID: TFG

Map Reference: 2401S.

Paleoseismic Data Source Documents:

Martin, R.A., Jr., Nelson, A.R., Weisser, R.R., and Sullivan, J.T., 1985, Seismotectonic study for Taskeech Dam and Reservoir site, Upalco Unit and Upper Stillwater Dam and Reservoir site, Bonneville Unit, Central Utah Project, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report 85-2, 95 p.

Nelson, A.R., and Weisser, R.R., 1985, Quaternary faulting on Towanta Flat, northwestern Uinta Basin, Utah, *in* Picard, M.D., editor, Geology and energy resources, Uinta Basin of Utah: Utah Geological Association Publication 12, p. 147-158.

General Fault Information

Geomorphic Expression

Nine short, northeast-striking fault scarps are present on Towanta Flat about 6 kilometers south of the Uinta Mountain front northeast of Mountain Home in the northern part of the Uinta Basin. The scarps bound a 5-kilometer-long graben that varies in width from 170 to 610 meters. The scarps parallel the Tertiary-age Uinta Basin and related South Flank faults. Slopes in the northern part of the Uinta Basin are pediments planed by erosion and covered with a veneer of gravel and sand from the Uinta Mountains. The faults are expressed as scarps in alluvium forming a generally northeast-trending graben. Scarp heights range from 5-15 meters. Nelson and Weisser (1985) found no significant net tectonic displacement across the graben (although the average throw across individual scarps was 2.1-2.6 meters per event). This lack of net slip across the graben, together with an orientation that differs from planes defined by microseismicity (aftershock sequence of a 1977 M_L 4.5 earthquake near Towanta Flat), the limited extent of the scarps, and an average recurrence interval that has been exceeded by the most recent event (MRE), <u>suggests to Martin and others (1985) that the faults may not have a seismogenic origin and may not be capable of significant future surface-rupturing events.</u>

A reported late Pleistocene fault east of Tabiona that lies along the projected strike of the Towanta Flat faults (Ritzma, referenced in Anderson and Miller, 1979) shows no displacement in bedrock. An anomalous linear drainage used to infer the presence of the fault (Ritzma, referenced in Martin and others, 1985) is apparently a strike stream.

Evidence for Segmentation

None reported

Age of Youngest Faulting
Middle and late Quaternary.

Paleoseismic Parameter Data

Type of Study/Commentary
The U.S. Bureau of Reclamation (USBR; Martin and others, 1985; Nelson and Weisser, 1985) excavated three trenches on Towanta Flat. Two trenches (trenches 2 and 3) were excavated across aerial-photo lineaments in a glacial meltwater channel in the southeastern part of Towanta Flat (site 2401S-1; see map). The other trench (trench 1) was excavated across a 5-meter-high scarp bounding the graben on the north near its western end (site 2401S-2), about 3.5 kilometers southwest of trenches 2 and 3. No samples were collected from the trenches for laboratory age determinations. Trench 1 revealed stratigraphic and structural relations that indicate at least three surface-faulting events. These events are interpreted to be pre-Bull Lake (>130-150 ka) in age, based on soil development and correlation with similar soils in the region. Trenches 2 and 3 exposed unfaulted Bull Lake deposits.

Number of Surface-Faulting Events/How Identified
Minimum of three/colluvial-wedge deposits

Age of Events/Datum Ages/Dating Techniques
Three surface faulting events in the past 250-500 ka, with no scarps mapped in deposits interpreted to be younger than Bull Lake age (130-150 ka; Martin and others, 1985). These age estimates are based on stratigraphic relations between colluvial-wedge deposits, the paleosols formed on them, and the degree of soil-profile development exhibited by the paleosols.

Event Slip/Cumulative Slip
Average individual event net slips were estimated from colluvial-wedge thickness (x 2) and range from 2.1 to 2.6 meters. Scarp heights range from 1.5 meters on an assumed single-event scarp to 11.2 meters for an estimated 3 to 4 event scarp.

Published Recurrence Interval
Martin and others (1985) report an average recurrence between 250-500 ka and 130-150 ka of 25 to 90 kyr, with no events since 130-150 ka. Black and others (2003) report a recurrence interval of 50 to 100 kyr. Using Martin and others (1985) bounding ages for the faulting events and their number of events, I calculated recurrence intervals ranging from 25 to 123 kyr.

Published Slip Rate
Using scarp heights and surface ages, Martin and others (1985) estimate maximum slip rates across individual scarps for the TFG ranging from 0.02 to 0.04 mm/yr. Piety and Vetter (1999) indicate the maximum slip rate for the TFG faults is less than or equal to 0.09 mm/yr. These slip-rate estimates appear to have open seismic cycles at both ends.

Using the largest estimated average single event displacement (2.6 m) and the shortest estimated recurrence interval (25 kyr), I calculated a hypothetical single event, closed seismic-cycle slip rate of 0.1 mm/yr, but actual rates are probably lower.

Sources of Uncertainty

1. The timing of surface-faulting on the TFG is only broadly constrained to a 100 to 370 kyr window in middle to late Quaternary time.
2. The ages of faulted deposits are estimates based chiefly on soil-profile development; no ^{14}C or other numeric ages were obtained during this study.
3. The lack of net slip across the Towanda Flat graben, a fault orientations that differ from planes defined by microseismicity, the limited extent of the scarps, and an elapsed time since the most recent surface-faulting event that is approaching twice the average recurrence interval, suggests to Martin and others (1985) that the TFG may not have a seismogenic origin and may not be capable of significant future surface-rupturing events.
4. Recurrence intervals on the TFG are long (25-123 kyr), but have been exceeded by the elapsed time since the most recent event (MRE; 130-150 kyr); if the TFG is an active fault system is it now "over due" for a surface-faulting earthquake?
5. Total length of the graben is 5 kilometers.

Summary:

The TFG has experienced three to four surface-faulting events in the past 250-500 ka, but the most recent event was more than 130-150 ka. Closed single seismic-cycle slip rates may be as high as 0.1 mm/yr, but likely are lower. Recurrence intervals between past events ranged from 25 to 123 kyr. The USBR questions if this slow slip rate fault system is seismogenic, but if it is, the current elapsed time since the MRE exceeds the average recurrence interval by 7 to 125 kyr.

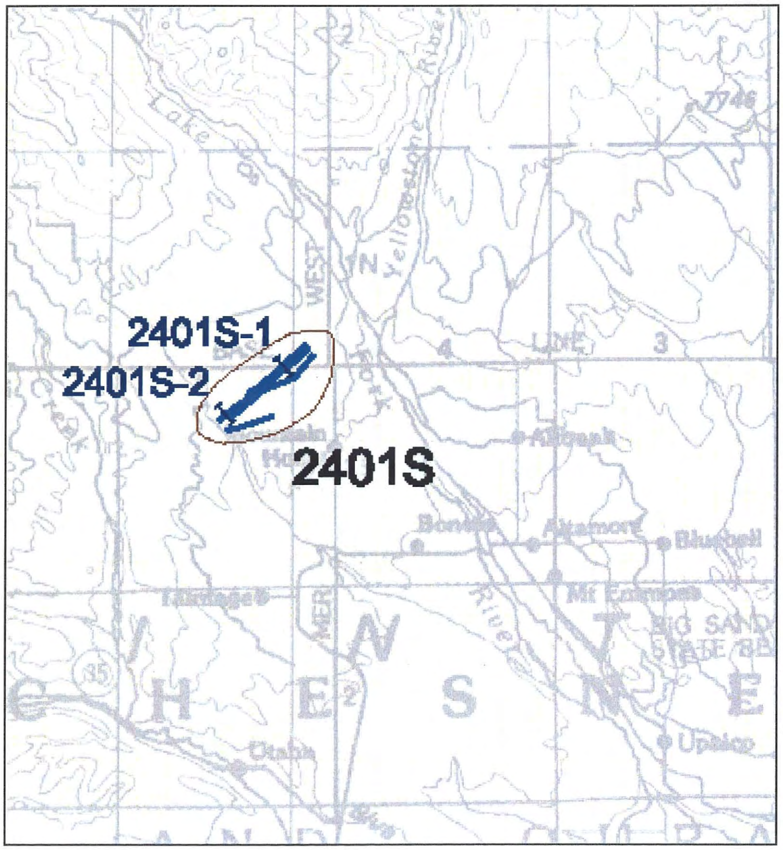
References:

Anderson, L.W., and Miller, D.G., 1979, Quaternary fault map of Utah: Long Beach, California, Fugro, Inc., 35 p., scale 1:500,000.

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Piety, L.A., and Vetter, U.R., 1999, Seismotectonic report for Flaming Gorge Dam, Colorado River Storage Project, northeastern Utah: Denver, Bureau of Reclamation Seismotectonic Report 98-2, 78 p.

Map:
Map of the Towanta Flat graben (2401S) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites:
2401S-1 (trenches 2 & 3)
2401S-2 (trench 1)
Martin and others (1985)

Notes

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UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Bald Mountain fault (BMF), Wasatch County, Utah

Study Synopsis ID: BMF-1

Map Reference: 2390

Paleoseismic Data Source Documents:

Sullivan, J.T., Martin, R.A., and Foley, L.L., 1988a, Seismotectonic study for Jordanelle Dam, Bonneville Unit, Central Utah Project, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-6, 76 p., scale 1:24,000.

Sullivan, J.T., Nelson, A.R., LaForge, R.C., Wood, C.K., and Hansen, R.A., 1988b, Central Utah regional seismotectonic study for USBR dams in the Wasatch Mountains: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-5, 269 p., scale 1:250,000.

General Fault Information

Geomorphic Expression

The BMF is a northeast-trending normal fault on the east side of Bald Mountain, west of Jordanelle Reservoir and close to Jordanelle Dam. Tertiary volcanic rocks, primarily highly erodible tuff, dominate the geology of the area. The fault escarpment is more eroded, but appears similar to those in other back valleys in the Wasatch Hinterlands east of the Wasatch Front. A steep-sided trough (imaged by seismic refraction) beneath the Provo River Valley to the south may be fault bounded, but trenching studies for Jordanelle Dam determined that late Quaternary (~130 ka) deposits are unfaulted.

Evidence for Segmentation

None, very short (2 km) surface trace.

Age of Youngest Faulting

>130 ka

Paleoseismic Parameter Data

Type of Study/Commentary

Sullivan, Martin, and Foley (1988a) excavated three trenches in surficial deposits across the inferred fault trace, as projected from adjacent bedrock and borehole control, about 1.5 kilometers northwest of the west abutment of Jordanelle Dam (site 2390-1, see map). Late Quaternary faulting was not recognized in the trenches. Fault timing is constrained by the estimated age of unfaulted colluvial-wedge and basin-fill deposits (age >130 ka based on soil development) that overlie the fault and by the overall geomorphic expression of the fault.

Number of Surface-Faulting Events/How Identified
Unknown, minimum of one.

Age of Events/Datum Ages/Dating Techniques
>130 ka based on profile development of an unfaulted soil formed on colluvial-wedge and slope-wash deposits that overlie the fault.

Event Slip/Cumulative Slip
Unknown

Published Recurrence Interval
No data

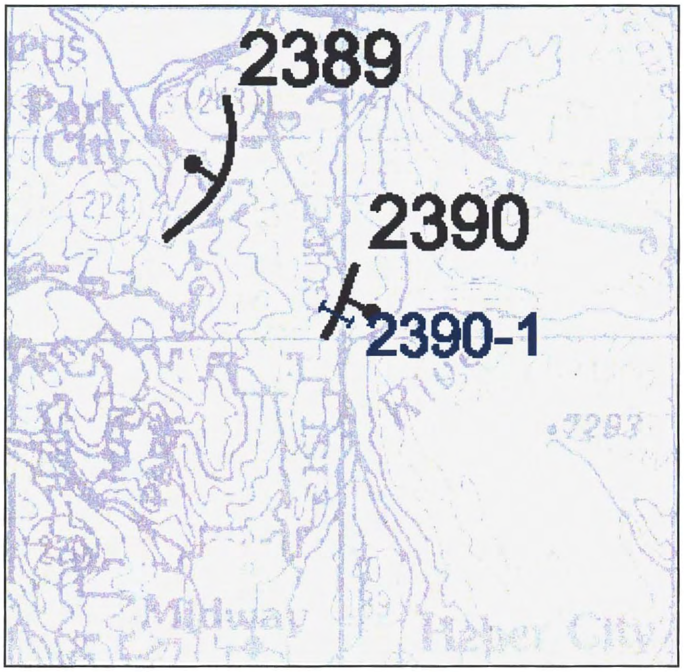
Published Slip Rate
None; slip rate is unknown but probably <0.02 mm/yr (Black and others, 2003).

Sources of Uncertainty
1. Reconnaissance study; unfaulted deposits believed to be >130 ka overlie the fault zone in three trenches. Based on the long elapsed time since the most recent surface-faulting event, more detailed studies were not performed.
2. Number and displacement of surface-faulting events unknown.
3. No numerical age dates, all deposit ages estimated on the basis of soil-profile development.

Summary:
The BMF is a very short (2 km) normal fault marked by a liner escarpment at the base of a bedrock slope. There are no scarps formed on unconsolidated deposits. Trenching showed that the fault, which juxtaposes two distinct rock types (andesite and quartzite) is overlain by unfaulted colluvial-wedge and unconsolidated basin-fill deposits that are estimated to be >130 ka.

References:
Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:
Map of the Bald Mountain fault (2490) taken from the Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench site
2390-1 (three trenches)
Sullivan and others (1988a)

Notes

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Strawberry fault (SF), Wasatch County, Utah

Study Synopsis ID: SF-1

Map Reference: 2412

Paleoseismic Data Source Documents:

Nelson, A.R., and Martin, R.A., Jr., 1982, Seismotectonic study for Soldier Creek Dam, Central Utah Project: Denver, U.S. Bureau of Reclamation Seismotectonic Report 82-1, 115 p., scale 1:250,000.

Nelson, A.R., and VanArsdale, R.B., 1986, Recurrent late Quaternary movement on the Strawberry normal fault, Basin and Range - Colorado Plateau transition zone, Utah: Neotectonics, v. 1, p. 7-37.

General Fault Information

Geomorphic Expression

The Strawberry fault an approximately 43-kilometer-long, down-to-the-west normal fault characterized by a zone of north- to northwest-trending faulting along the eastern and northern side of Strawberry Valley near the western edge of the Uinta Basin about 40 kilometers east of the Wasatch Front. Strawberry Valley is one of several "back valleys of the Wasatch," a line of discontinuous valleys in the Wasatch Hinterlands east of the Wasatch Range. The fault forms a single bedrock scarp, 100 to 230 meters high, from its southern end northward to Trout Creek. From Trout Creek north, the Strawberry fault forms multiple scarps in alluvium and bedrock across a zone 5 kilometers wide. At Co-op Creek, a 200-meter-high escarpment that juxtaposes Quaternary alluvial-fan sediments against Tertiary bedrock marks the main fault, while subsidiary scarps formed on the Co-op Creek alluvial fan about 1.3 kilometers west of the main fault can only be traced about 3 kilometers and are as much as 7 meters high. However, stratigraphic displacement on these scarps is much greater than net displacement, due to backtilting and graben formation. Recency of deformation is also indicated by the asymmetry of stream channels (evidence for tectonic tilting) and the presence of knickpoints in small channels above the scarps.

Evidence for Segmentation

The en-echelon pattern of faulting north of the Strawberry Reservoir suggests that the main Strawberry fault is segmented, although similarities in escarpment morphologies suggest a similar movement history along the entire fault.

Age of Youngest Faulting

Early to middle Holocene

Paleoseismic Parameter Data

Type of Study/Commentary

Nelson and Martin (1982) excavated two trenches across a 7-meter-high fault scarp subsidiary to and west of the main trace of the Strawberry fault. In addition, scarp profiles and boreholes provided data for slip-rate estimates. Co-op Creek trench 1 (site 2412-1, see map) was about 2.5 kilometers north of U.S. Highway 40, and Co-op Creek trench 2 (site 2412-2) was about 1.5 kilometers north of the highway. Both trenches exposed faulted alluvial-fan deposits estimated to be 15,000-30,000 years old, based on soil-development characteristics.

The 7-meter-high scarp was one of four scarps mapped on the Co-op Creek alluvial fan. A 5-meter-high scarp lies to the west of the trenched scarp, as does a down-to-the-east antithetic scarp that parallels the northern portion of the 7-meter-high scarp. A second down-to-the-east antithetic fault scarp lies to the east of the 7-meter-high scarp, apparently forming the west side of a graben with the main fault trace at the mountain front a kilometer to the east. Trench 1 may have crossed the trace of the parallel antithetic fault, but evidence for the fault was apparently removed by erosion and deposition of later stream and debris-flow deposits. Mapping showed no evidence that Quaternary deposits are displaced along the main fault trace at the base of the bedrock escarpment.

Number of Surface-Faulting Events/How Identified

Two to three/scarp-derived colluvial deposits. The trench exposures suggest two to three surface-faulting events. Trench 1 revealed evidence for two and possibly three events. Trench 2 provided evidence for two events, correlative with the two youngest events in Trench 1. Not all units interpreted as scarp colluvium were associated with a recognizable fault shear plane.

Age of Events/Datum Ages/Dating Techniques

Event ages are bracketed by age estimates based on soil-profile development. Radiocarbon ages were obtained on buried organic-rich material in trench 2 that was interpreted as burrow infilling and not directly related to faulting.

Based on stratigraphic relations in the two trenches, Nelson and VanArsdale (1986) interpret two to three surface-faulting earthquakes have occurred in the past 15,000 to 30,000 years. Age estimates based on soil development indicate that the most recent event (MRE) occurred during the early to mid-Holocene; with a minimum possible age of 1.5 kyr based on a ^{14}C age from burrow infillings.

Event Slip/Cumulative Slip

Stratigraphic relations in both trenches suggest stratigraphic displacements of 1 to 2 meters for each fault event. Stratigraphic displacements were estimated by measuring contacts of faulted units, by dividing total displacement by the number of events suggested by colluvial units, and by doubling colluvial wedge thicknesses.

Nelson and VanArsdale (1986) state that while the scarps formed on the alluvial fans may represent most of the displacement within the fault zone during the faulting events that produced them, it is more likely that larger displacements occurred on the main fault during these events [even though there is no evidence for young faulting on the main fault]. Therefore, they did not assume that the displacement represented by the alluvial-fan scarps was the total displacement in the fault zone during the events that produced the scarps.

The two down-to-the-west faults on the alluvial-fan surface are reported to be 7 and 5 meters high, respectively. No information is provided regarding the height of the two antithetic faults, so total net slip across the fault zone is unknown.

Published Recurrence Interval

5000 to 15,000 years based on the estimated number of events on a single fault strand. The recurrence interval range is broad because both the age and number of events are only broadly constrained. It appears that these recurrence interval estimates extend to the present and are open across at least one seismic cycle.

Published Slip Rate

A latest Pleistocene and Holocene slip rate calculated from the estimated net tectonic displacement across the 7-meter-high subsidiary scarp is 0.04-0.17 mm/yr. Nelson and VanArsdale (1986) report a minimum longer term late Quaternary rate (~70 – 90 ka) from ^{14}C and amino acid dating of alluvial-fan cores is 0.03-0.06 mm/yr.

Sources of Uncertainty

1. All paleoseismic data for this study comes from a scarp identified as "subsidiary" to the main Strawberry fault. The relation of the subsidiary fault, which is 1.3 kilometers west of the main fault trace, to the main fault in terms of the number and timing of events is unknown.
2. Only one of four "subsidiary" faults at the site was trenched; a second down-to-the-west and two down-to-the-east antithetic faults were not trenched, so it is not known if the record of surface-faulting events at the site is complete, nor is the total net slip across the subsidiary fault zone or the net slip for individual events known.
3. The number of events on the trenched scarp is not well constrained. There is a minimum of two, but possibly three events, and units in the downthrown block correlative with upthrown units were not reached in trench 1. Nelson and VanArsdale (1986) state that one to two earlier events may remain unrecognized on the 7-meter scarp, and that the estimate of two to three surface-faulting events is probably a minimum value.
4. Individual event ages were not determined; the time interval over which the events are thought to have occurred is an estimate based on soil-profile development.

Summary:

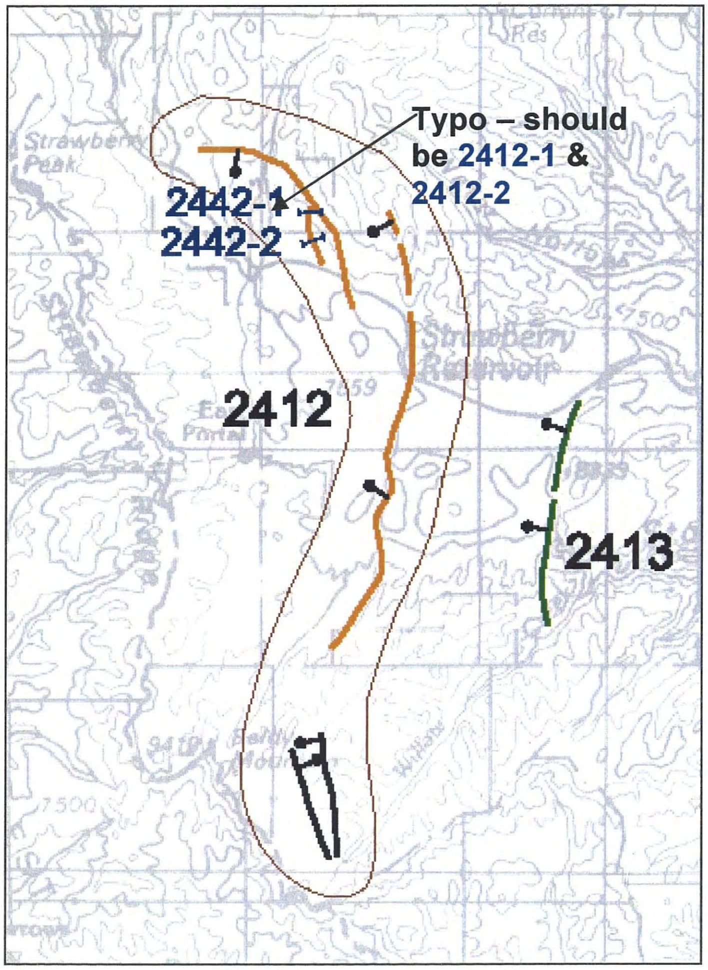
The Strawberry fault is the easternmost of the basin-and-range style normal faults that bound the back valleys of the Wasatch Range. Slip rates reported by this study are low and recurrence intervals are long, but none of the paleoseismic data comes from the main Strawberry fault. The available data are constrained to a single "subsidiary" fault nearly 1.5 kilometers west of the main fault trace, and the relation of that subsidiary fault to the main fault trace is unknown. Additionally, the trenched scarp is only one of four scarps in the subsidiary fault zone; the other three faults were not trenched, so the total number of events, displacement per event, and total displacement across the subsidiary fault zone also remain unknown, and published values for those parameters should be considered minimums. The absence of ^{14}C or other numerical age dates from trenches restricts event timing to a broad 15 to 30 ka time interval.

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:

Map of the Strawberry fault (2412) taken from the Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites
2442-1
2442-2
Nelson and Martin (1982)

Notes

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UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Hansel Valley fault (HVF), Box Elder County, Utah

***Study Synopsis ID*:** HVF-1

Map Reference: 2358

Paleoseismic Data Source Documents:

McCalpin, J.P., 1985, Quaternary fault history and earthquake potential of the Hansel Valley area, north-central Utah: Final Technical Report to the U.S. Geological Survey, Contract No. 14-08-001-21899, 37 p.

McCalpin, J.P., Robison, R.M., and Garr, J.D., 1992, Neotectonics of the Hansel Valley-Pocatello Valley corridor, northern Utah and southern Idaho, *in* Gori, P.L., and Hays, W. W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-G, p G1 – G18.

For purposes of this review, information pertaining to the Hansel Valley fault was summarized chiefly from McCalpin and others (1992), which is the more recent and most up-to-date of the two Paleoseismic Data Source documents for this fault.

General Fault Information

Geomorphic Expression

The HVF is an east-dipping normal fault in southwestern Hansel Valley characterized by northeast-trending scarps several kilometers east of the Hansel Mountains range front (see map). Hansel Valley is in an aggregation of low, north-trending ranges and narrow valleys in northern Utah between Curlew Valley on the west and the Malad River Valley on the east.

The Hansel Valley fault is the site of the 1934 M_L 6.6 Hansel Valley earthquake, Utah's only historical surface-faulting earthquake. The northern half of the fault is a single continuous trace, whereas the southern half is a wide zone of several short, en-echelon fault traces (see map). The most recent prehistoric event on the fault is estimated to have produced a total displacement of 2.2-2.5 meters; the 1934 earthquake produced a maximum vertical displacement of 0.5 meters where the southern portion of the fault intersects the mudflats at the north end of the Great Salt Lake (Walter, 1934; dePolo and others, 1989).

Evidence for Segmentation

None. Cumulative trace length is 22 kilometers

Age of Youngest Faulting

Historic

Paleoseismic Parameter Data

Type of Study/Commentary
McCalpin (1985) logged a gully exposure (West Gully; site 2358-1; see map) near the northern end of the Hansel Valley southwestern margin fault scarp (results summarized in McCalpin and others, 1992). Stratigraphy, sedimentology, ostracode assemblages, and TL dating provide a framework within which to interpret faulting events within the context of pluvial lake cycles. The gully exposure reveals complex faulting patterns indicating multiple events of unknown displacement since about 140 ka. These include one or more events between 13 and 15 ka (based on dating of deformed lake deposits, interpreted as probable lateral spreads) and an event shortly before deposition of Bonneville transgressive gravels about 26 ka. Post-Bonneville alluvium truncates all exposed faults at the West Gully site, indicating no Holocene events, including the 1934 earthquake, have induced surface rupture at this location.

Number of Surface-Faulting Events/How Identified
Minimum of 4 since 58 ka, multiple events (exact number unknown) between roughly 140 and 72 ka.

Age of Events/Datum Ages/Dating Techniques
Taken together, stratigraphic and structural relations in the logged stream cut (West Gully) on the northern, single-strand portion of the fault, along with TL dates (5) and ^{14}C dates on gastropod shells (1), argues for multiple events between about 140 and 72 ka, no events between 72 to 58 ka, at least one event (but possibly more) between 58 and 26 ka (nearer the latter), an event around 14 to 15 ka, and possibly another event at 13 ka. The exposed portion of the stream cut did not include any colluvial wedges or other evidence of individual events, so it was not possible to determine the ages or displacement of individual surface-faulting earthquakes. Post-Bonneville alluvium truncates all exposed faults at the West Gully site, indicating no Holocene events, including the 1934 earthquake, have induced surface rupture at this location. The 1934 event only ruptured the southern few kilometers of the fault.

Event Slip/Cumulative Slip
Eight meters of surface displacement across a scarp formed on a 15-ka Bonneville delta. Other than for the 1934 event (0.5 m) it was not possible to directly measure the displacement associated with individual past surface-faulting earthquakes. Eight meters of displacement in a 15-ka surface implies multiple ruptures (three or four if the displacement per event is 2.0-2.5 m), so McCalpin and others (1992) estimate that previous surface-faulting events likely had displacements in the 2-2.5-meter range.

Published Recurrence Interval
The faulting history deciphered from the stream cut (see above) implies widely varying recurrence intervals through time. One event from 72 to 26 ka produces a recurrence interval of 46 ka; followed by one at 14-15 ka and possibly a second event at about 13 ka, giving a possible recurrence interval of 1-2 ka; and then an elapsed time of about 13 ka until the 1934 earthquake.

Although McCalpin and others (1992) admit that the field evidence is ambiguous, they believe recurrence intervals have been shorter when large lakes existed in the Bonneville Basin (oxygen isotope stages 6 and 2) and shorter during times of smaller or no lakes (oxygen isotope stages 5, 4, and 3). An exception being the 1934 event that occurred during an interpluvial episode. However the authors state that the maximum displacement of only 0.5 meters in the 1934 event is small in comparison with the displacements inferred for stage 2 time, and may indicate that interpluvial earthquakes are smaller than pluvial earthquakes.

Published Slip Rate

None.

Black and others (2003) estimate a slip rate of 0.14-0.22 mm/yr, based on a 10-16 kyr recurrence and prehistoric displacement of 2.2-2.6 meters. The slip rate based on displacement in the 1934 event (and a recurrence of 10-15 ky) would be much lower. Eight meters of surface displacement across a scarp formed on a 15-ka Bonneville delta gives an average slip rate with open seismic cycles at each end of 0.53 mm/yr.

Sources of Uncertainty

1. No individual paleo-surface-faulting earthquakes could be identified; consequently all event ages are broad estimates based on stratigraphic and structural relations in a natural stream cut exposure and limited TL and ^{14}C dates.
2. Net slip per event values are estimates based on an expected number of earthquakes required to produce a scarp of a certain size.
3. The recurrence of surface-faulting earthquakes on the HVF is highly variable. The overall impression is one of a low slip rate fault, but slip could be as high as 0.5 mm/yr (or higher?) during periods of increased activity.

Summary:

The Hansel Valley fault remains poorly understood, but available paleoseismic evidence indicates that this fault exhibits a very irregular pattern of recurrence with interevent intervals ranging from possibly as little as 1 to 2 kyr to as much as 46 kyr. However, the overall impression is one of a fault with a low slip rate, probably averaging <0.2 mm/yr for the past ~140 ka.

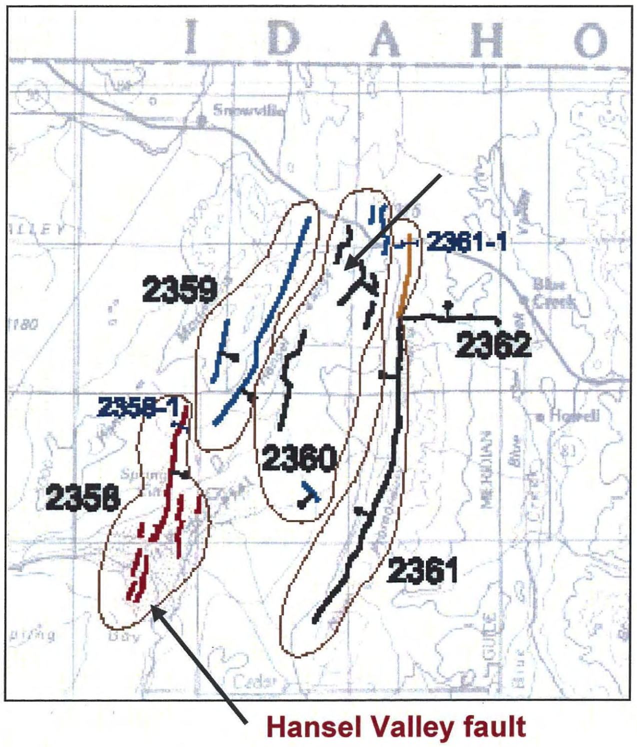
References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

dePolo, C.M., Clark, D.G., Slemmons, D.B., and Aymard, W.H., 1989, Historical Basin and Range Province surface faulting and fault segmentation, *in* Schwartz, D.P., and Sibson, R.H., editors, Fault segmentation and controls of rupture initiation and termination - Proceedings of conference XLV: U.S. Geological Survey Open-File Report 89-315, p. 131-162.

Walter, H.G., 1934, Hansel Valley, Utah, earthquake: The Compass of Sigma Gamma Epsilon, v. 14, no. 4, p. 178-181.

Map:
Map of the Hansel Valley fault (2358) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench site:
2358-1 = West Gully
McCalpin and others (1992)

Notes

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Hogsback fault, unnamed south section (HFS)

Study Synopsis ID: HFS-1

Map Reference: 732b

Paleoseismic Data Source Documents:

West, M.W., 1994, Paleoseismology of Utah, Volume 4 - Seismotectonics of north central Utah and southwestern Wyoming: Utah Geological Survey Special Study 82, 93 p.

General Fault Information

Geomorphic Expression

The Hogsback fault is expressed as linear drainage alignments, lineaments, and subdued west-facing scarps on Pleistocene terrace and pediment surfaces. The amount of east-directed tilt of terrace surfaces increases with increasing age of the surfaces suggesting recurrent movement. The southern part of the fault (Elizabeth Ridge scarps) lies in Utah and is expressed as southwest-trending scarps, one of which is uphill facing and down to the south; the other two are downhill and north facing. These scarps have apparent displacements of about 1.5-2.5 meters and are subparallel to the North Flank thrust fault. The east scarp displaces the Oligocene Bishop Conglomerate on the Gilbert Peak erosion surface. Trenching revealed no direct evidence for faulting, although geomorphic evidence is more in line with a tectonic rather than erosional origin. The subdued expression of the scarps (maximum scarp angles ~5 degrees) suggests that they are substantially older than similar discordant scarps at the south end of the Bear River fault zone (730).

Evidence for Segmentation

None

Age of Youngest Faulting

Late Quaternary

Paleoseismic Parameter Data

Type of Study/Commentary

West (1994) excavated the Elizabeth Ridge trench (732-b-1; see map) 1 kilometer north of Elizabeth Pass, which crossed a down-to-south, uphill-facing, 2.5-meter-high scarp. No datable material was recovered from the trench nor did the trench expose clear evidence of faulting. Although trenching was inconclusive, West (1994) prefers a tectonic interpretation for the trench.

Number of Surface-Faulting Events/How Identified
This study resulted in no reliable data concerning either the onset of faulting, minimum age of faulting, number of faulting events, or recurrence interval on the southern section of the Hogsback fault.

Age of Events/Datum Ages/Dating Techniques
Unknown/none/estimates based on the age of geomorphic surfaces.

No absolute dates were obtained from the trench on the southern section of the Hogsback fault so no constraints can be placed on minimum or maximum ages of surface rupture.

Event Slip/Cumulative Slip
Event slip is unknown. Bigelow Bench, which has an estimated age of 150-600 ka, is displaced 200 meters across the Hogsback fault to the north in Wyoming, but the scarp trenched for this study at the southern end of the fault was only 2.5 meters high.

Published Recurrence Interval
None. West (1994) suggests that the recurrence interval for the nearby Bear River fault zone because of analogous tectonic setting may approximate the recurrence interval for the Hogsback fault as a whole. Thereby he would suggest a recurrence interval of a few thousand years. However, little evidence suggests similar short recurrence intervals during the Holocene for the Hogsback fault (Black and others, 2003).

Published Slip Rate
Poorly constrained slip-rate estimates for the Hogsback fault to the north in Wyoming range from 0.33-1.5 mm/yr (West 1994). These slip-rate estimates are based on a variety of possible ages for Bigelow Bench (150-600 ka), which is displaced as much as 200 meters across the Hogsback fault in Wyoming. The highest estimate is based on inferring a similar slip rate as that of the Bear River fault zone. A lower rate of 0.33-1.33 mm/yr is obtained based on a 200-meter offset of the 150-600 ka Bigelow Bench surface. West (1994) indicated the maximum displacement at the trench site at the southern end of the fault is 1.5-2.47 meters based on profile data and estimated vertical stratigraphic displacement of possibly Bishop Conglomerate (Oligocene), which suggests a low slip rate on the Utah portion of the fault.

Black and others (2003) assign a slip rate of 0.2-1 mm/yr to the Hogsback fault as a whole based on a belief that the Bigelow Bench surface is substantially older than 150 ka.

Sources of Uncertainty
1. No reliable data are available concerning the onset, minimum age, or recurrence of faulting on the Hogsback fault in either Wyoming or Utah.
2. A tectonic origin of the southern unnamed portion of the Hogsback fault is uncertain; no conclusive evidence of faulting was observed in the trench excavated on this part of the fault.

3. Slip-rate estimates for the Hogsback fault are based on geomorphic relations only, the estimated age (150-600 ka) and height (200 m) of a geomorphic surface. The large age range and the possibility that the scarp height is enhanced by erosion give the slip-rate estimates a high level of uncertainty.

Summary:

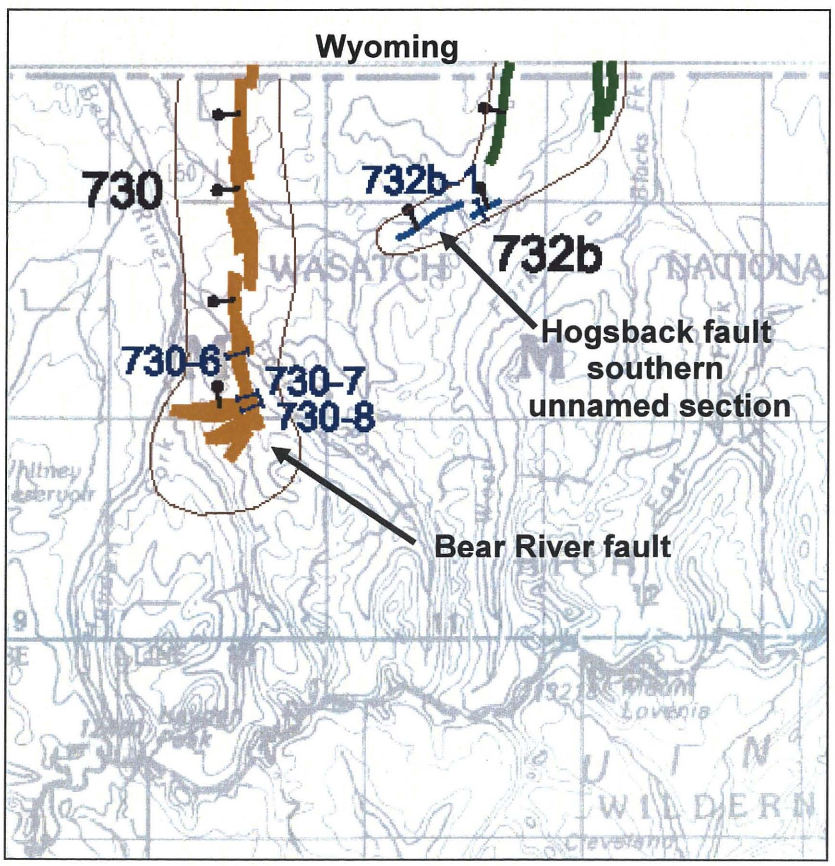
No reliable paleoseismic information resulted from trenching the Hogsback fault in Utah. West (1994) believes that on the basis of geomorphic relations the initiation of surface rupture on the Hogsback fault could be as young as about 150 ka and that slip rates could be as high as 0.33-1.5 mm/yr depending on the age of displaced surfaces further north along the fault in Wyoming. However, in the absence of substantive paleoseismic data and given the large uncertainty associated with both the age and amount of displacement of critical geomorphic surfaces, assigning a slip rate to the Hogsback fault comparable to that of the Wasatch fault is highly questionable.

References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:

Map of the Hogsback fault, southern unnamed section (732b) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench site
732b-1
West (1994)

Notes

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UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: North Promontory fault (NPF), Box Elder County, Utah

***Study Synopsis ID*:** NPF-1

Map Reference: 2361

Paleoseismic Data Source Documents:

McCalpin, J.P., 1985, Quaternary fault history and earthquake potential of the Hansel Valley area, north-central Utah: Final Technical Report to the U.S. Geological Survey, Contract No. 14-08-001-21899, 37 p.

McCalpin, J.P., Robison, R.M., and Garr, J.D., 1992, Neotectonics of the Hansel Valley-Pocatello Valley corridor, northern Utah and southern Idaho, *in* Gori, P.L., and Hays, W. W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-G, p G1 – G18.

The data contained in McCalpin (1985) and McCalpin and others (1992) regarding the NPF are not always in agreement. Where differences exist, the information provided in McCalpin and others (1992) is given preference because that report is the more recent and therefore considered the most up-to-date.

General Fault Information

Geomorphic Expression

The NPF is a 27-kilometer-long Basin and Range normal fault bounding eastern Hansel Valley in northern Utah. Hansel Valley is in an aggregation of low, north-trending ranges and narrow valleys in northern Utah between Curlew Valley on the west and the Malad River Valley on the east. Scarps appear in only two locations where the fault trace is not otherwise covered by Holocene talus. At the northern location, a 13-meter-high scarp (8 meters net slip?) displaces a delta graded to the Bonneville shoreline. At the southern site, a branch fault diverges southwesterly from the range front and creates a scarp 12.9 meters high (9.5 meters net slip) on a pre-Bonneville alluvial fan. Although the fault scarps appear unbeveled, they likely resulted from more than one event.

The southern portion of the fault (expressed as a prominent range front) does not displace upper Pleistocene deposits and likely last moved in the early to middle Pleistocene (Miller and Schneyer, 1990). An antithetic fault 100 meters east of the north end of the fault shows evidence for a single event at roughly 10-15 ka (based on soil development) that produced a vertical displacement of 2.6 meters. This fault also cuts deposits as old as 100+ ka.

Evidence for Segmentation

None reported.

Age of Youngest Faulting

Latest Quaternary < 15 ka

Paleoseismic Parameter Data

Type of Study/Commentary

Chiefly a geomorphic study, logged one road-cut exposure along I-84 of a subsidiary fault near the north end of the main fault trace.

Number of Surface-Faulting Events/How Identified

Unknown. Both scarps (above) are probably the result of multiple surface-faulting events, but because each is limited to a single geomorphic surface and neither displays evidence of multiple crests or bevels, reliable evidence of recurrent movement is lacking. A subsidiary fault exposed in an I-84 road cut at Rattlesnake Pass at the north end of the main fault trace shows evidence for a single surface-faulting event in the past ~ 100 ka. McCalpin and others (1992) believe that the Rattlesnake Pass event is young (<15 ka) and that it produced 2.6 meters of displacement.

Age of Events/Datum Ages/Dating Techniques

Late Pleistocene or early Holocene (?) based on the 13-meter-high scarp formed on a delta graded to the Bonneville shoreline. Slope angle versus scarp-height data suggest that the northern scarp is roughly contemporaneous with the Bonneville shoreline, while the splay scarp is older than the shoreline. Based on stratigraphic relations and soil-profile development, McCalpin and others (1992) believe the event on the subsidiary fault at Rattlesnake Pass to be <15 ka, but one event in ~100 ka does not match the evidence for probable multiple late Pleistocene and early Holocene (?) surface faulting on the main fault trace just 100 meters to the west.

Event Slip/Cumulative Slip

2.6 meters of displacement during the single event recorded on the subsidiary fault. An estimated 2.0-2.5 meters per event for the three to four events estimated to be required to create the two scarps on the main fault trace.

Published Recurrence Interval

McCalpin and others (1992) assume that 3 to 4 events, each exhibiting 2.0-2.5 meters of displacement in the past 15 ka would be required to construct the northern scarp observed on the NPF. On that basis, the recurrence interval for surface-rupturing events would be 3.75 to 5.0 kyr. The authors however believe that interval is too short in comparison with nearby faults, particularly the much more active appearing Wasatch fault.

The southern scarp on the NPF displaces a pre-Bonneville alluvial fan of otherwise uncertain age. The fan may correlate with either isotope stage 4 (58-72 ka) or stage 6 (140 ka). Depending on the age assumed for the fan, the McCalpin and others (1992) state recurrence intervals of 8.6-10.75 kyr and 25-31.25 kyr are possible.

Given the uncertainties, the McCalpin and others (1992) state that all that can be said with certainty is that the NPF has sustained surface rupture at least once since Bonneville time and several times since either oxygen isotope stage 4 or 6.

Published Slip Rate

None. However, 8 meters of net slip in approximately 15 ka gives a late Pleistocene slip rate of 0.5 mm/yr. If the net slip is 13 meters, the slip rate could be as high as 0.9 mm/yr.

Sources of Uncertainty

1. No individual surface-faulting events identified on the main fault trace.
2. No individual net slip measurements available for the main fault trace.
3. No numerical ages available to constrain the timing of events.
4. The only available fault exposure is on a subsidiary fault about 100 meters east of the main fault trace at the north end of the fault. The timing of events on the subsidiary fault does not appear to match the timing of events on the main fault.
5. Information provided for the NPF in McCalpin (1985) and McCalpin and others (1992) is sometimes contradictory, particularly regarding scarp heights and surface offsets.

Summary:

Two 10+ meter high scarps at isolated locations along NPF provide evidence for probable multiple surface-faulting events in the late Pleistocene and possibly early Holocene, but detailed information on the age and displacement of those events is lacking. If 8 to 13 meters of net slip has occurred on the northern scarp since Bonneville shoreline time, late Pleistocene/Holocene slip rates could be as high as 0.5-0.9 mm/yr. However, the general geomorphic appearance of the scarp argues against such a high slip rate. Black and others (2003) have assigned the NPF a slip rate of <0.2 mm/yr. Information generated from a road-cut exposure of a subsidiary fault indicates a single 2.6 meter displacement event in the past ~100 ka.

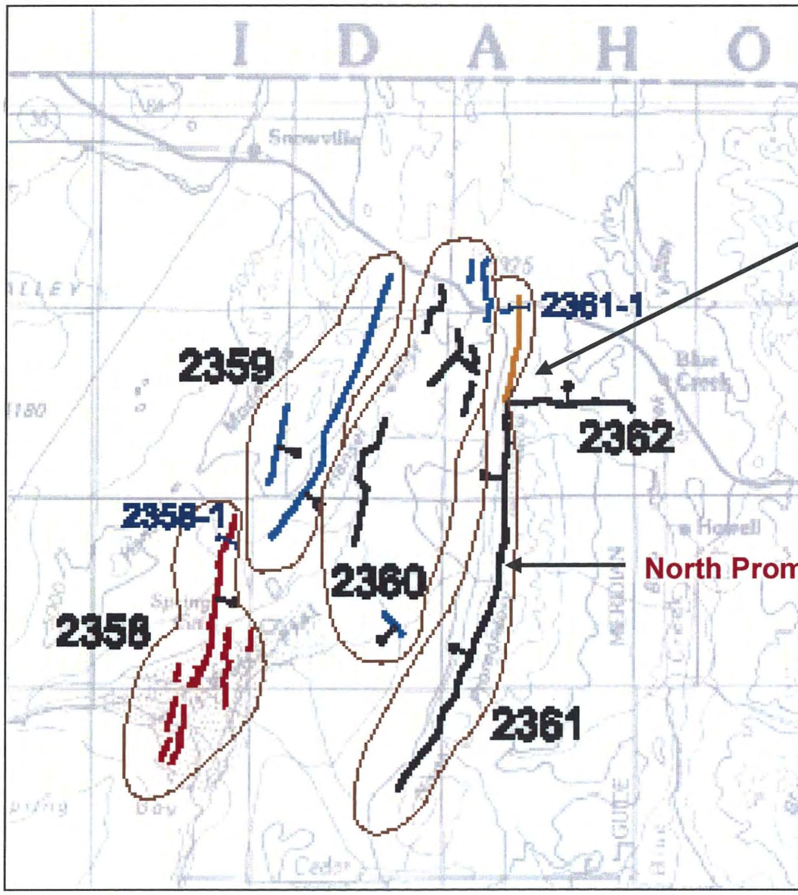
References:

Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Miller, D.M., and Schneyer, J.E., 1990, Geologic map of the Sunset Pass quadrangle, Box Elder County, Utah: Utah Geological and Mineral Survey Open-File Report 201, 32 p., scale 1:24,000.

Map:
Map of the North Promontory fault (2361) taken from the Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).

Road-Cut Exposure:
2361-1 = Rattlesnake Pass
McCalpin (1985)
McCalpin and others (1992)



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UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Sugarville area faults (SAF), Millard County, Utah.

***Study Synopsis ID*:** SAF-1

Map Reference: 2437

Paleoseismic Data Source Documents:

Dames and Moore, 1978, Phase II - preliminary geotechnical studies, proposed power plant, lower Sevier River area, Utah: Los Angeles, unpublished consultant's report for Intermountain Power Project, Job nos. 10629-00206 and 10629-003-06, 45 p., scale 1:24,000.

General Fault Information

Geomorphic Expression

The SAF is a short (<5 km), northeast-trending zone of Quaternary normal faults or fractures in the northern Sevier Desert (see map). Deposits of Pleistocene Lake Bonneville dominate the surficial geology of the area. Lineaments and subtle relief in lake deposits characterize the SAF. Parallel tonal lineaments 10 kilometers to the north of the zone may be related faults, but are not mapped. Trenching revealed underlying faults, but their relation to deeper structures is unknown. A minimum throw of 3.8 meters across one of the faults, combined with the short apparent rupture length, suggests that numerous small-displacement events occurred along the fault zone.

Evidence for Segmentation

None reported

Age of Youngest Faulting

Pliocene to Holocene

Paleoseismic Parameter Data

Type of Study/Commentary

At the Intermountain Power Project site (2437-1, see map) about 6 kilometers northeast of Sugarville, Dames & Moore (1978) excavated eight and logged five trenches across two suspected fault-related lineaments (referred to as the northwestern fault zone and southeastern fault). Liquefaction features, including injection dikes and distorted bedding, were observed in one of the trenches across the southeastern fault. Trenches across the northwestern fault zone revealed stratigraphic evidence for two distinct surface-faulting events as well as complex faulting relations. No age estimates were obtained to constrain earthquake timing.

Number of Surface-Faulting Events/How Identified
Minimum of two surface-faulting events; identified by differential displacement of geologic horizons of different ages - older horizons are displaced more than younger horizons.

Age of Events/Datum Ages/Dating Techniques
Latest Pleistocene or Holocene based on displacement of Lake Bonneville deposits. No numerical age dates, age of faulting established by broad correlation with Lake Bonneville stratigraphy.

Event Slip/Cumulative Slip
Dames and Moore (1978) assumed a minimum of 3.8 meters of cumulative slip on one fault based on maximum trench depth and the lack of correlative stratigraphic units across faults in the trenches – true net displacement is not known. Given the short length of the fault zone (4.3 km) the authors conclude that the 3.8 meters of displacement must have occurred in multiple events of likely 30 to 60 centimeters each.

Published Recurrence Interval
None reported

Published Slip Rate
None; slip rate is unknown but probably <0.02 mm/yr (Black and others, 2003)

Sources of Uncertainty
1. Total number of events not constrained, minimum of two but possibly more.
2. Age of events only broadly constrained, two younger than the high stand of Lake Bonneville.
3. Trench logs are generalized and lack evidence for colluvial-wedge stratigraphy or other tectonically derived deposits.
4. No numerical age dates to constrain the time of faulting.
5. Total fault length <5 kilometers.

Summary:
This investigation was performed by a geotechnical consulting company conducting a preliminary geologic-hazards evaluation of a site proposed for a coal-fired electrical generating plant. The study was reconnaissance in nature, even though eight trenches were excavated, and the resulting data are insufficient to determine either a reliable slip rate or recurrence interval for this fault zone, other than to state that a minimum of two small surface-faulting events have probably occurred since the Bonneville highstand.

References:
Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Map:
Map of the Sugarville area faults (2437) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).

Trench site
2437-1 (8 trenches total)
Dames and Moore (1978)

Notes

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Washington fault zone, northern section (WFZNS), Washington County, Utah and Mohave County, Arizona.

Study Synopsis ID: WFZNS-1

MapReference: 1004a

Paleoseismic Data Source Documents:

Earth Sciences Associates, 1982, Phase I report, seismic safety investigation of eight SCS dams in southwestern Utah: Palo Alto, California, unpublished consultant's report for U.S. Soil Conservation Service, 2 volumes, variously paginated.

General Fault Information

Geomorphic Expression

The Washington fault is a north- to northeast-trending fault zone along the western margin of the Colorado Plateau, extending northward from the Shivwits Plateau in Arizona into the St. George basin of southwestern Utah. The fault has an estimated maximum throw of 750 meters in Arizona, but displacement decreases northward in Utah. The fault displaces older geologic structures and has normal-drag and reverse-drag folding genetically associated with it (Anderson and Christenson, 1989). Pearthree (1998) divided the Washington fault zone into three sections (Northern, Mokaac, and Sullivan Draw) based on structural and geomorphic evidence. Only the Northern section is in Utah.

Along the Northern section, the Washington fault zone has generated two prominent bedrock escarpments and shows several hundred meters of normal displacement in the St. George Basin. North of the town of Washington, a Pleistocene pediment deposit (tentatively estimated to be roughly 300 ka in age), which underlies a 8-meter-high scarp, appears undisplaced. Here, as along much of the fault, scarp development is largely the result of differential erosion of contrasting lithologies on the upthrown and downthrown blocks (Petersen, 1983). Near Washington, a subsidiary fault displaces an early Pleistocene basalt flow (the Washington flow) up to 4.5 meters. Small (up to 5 cm) displacements in "younger" alluvium may be due to differential compaction rather than coseismic surface faulting (Earth Sciences Associates, 1982). A single profile of a southern scarp on a highly dissected pediment indicates a morphologic age comparable to the Bonneville shoreline (Anderson and Christenson, 1989).

Age of Youngest Faulting

Latest Quaternary (<15 ka).

Paleoseismic Parameter Data

Type of Study/Commentary

Earth Sciences Associates (1982) excavated trenches across lineaments of uncertain origin at three flood-control dams (Gypsum Wash, Warner Draw, and Stucki) on the northern section of the Washington fault. Relative ages of Quaternary deposits were estimated from soil development and stratigraphy; no radiometric dating was performed. The trenches at the Warner Draw and Stucki dam sites revealed no evidence of faulting. At Gypsum Wash (site 1004a-1, see map), Earth Sciences Associates (1982) excavated five trenches near the south end of the dam. Trenches G-1, G-4, and G-X, excavated along lineaments about 45 meters west of the main fault trace, revealed a wide zone of high-angle shears that form a series of horsts and grabens with a net down-to-the-west displacement. Younger unfaulted alluvial-fan deposits overlie older faulted alluvial-fan deposits estimated to be 5-10 ka. Trenches G-2 and G-3 were excavated across the main fault trace and revealed bedrock in fault contact with late Pleistocene(?) alluvial-fan deposits, showing at least 1.2 meters of offset. Younger alluvial-fan deposits, estimated to be no older than 1-1.5 ka, showed only 5 centimeters of vertical displacement. Earth Sciences Associates (1982) states that this displacement could be the result of one of several possible non-tectonic processes, including differential settlement due to gypsum dissolution.

Number of Surface-Faulting Events/How Identified

Individual events were not identified, this study documented displacement only.

Age of Events/Datum Ages/Dating Techniques

Individual events were not dated, this study documented displacement only. All age estimates are based on soil development and stratigraphy; no radiometric dating was performed for this study.

Event Slip/Cumulative Slip

Five centimeters in deposits estimated to be no older than 1-1.5 ka, but the displacement may not be tectonic. Up to 1.2 meters of slip in older alluvial-fan deposits estimated to be 5-10 ka.

Published Recurrence Interval

None reported, individual surface-faulting events not recognized.

Published Slip Rate

None reported. However, Earth Science Associates (1982) states that there has been up to 5 centimeters of displacement in the past 1.5 kyr and a minimum of 1.2 meters in the past 10-25 kyr. Those displacements and deposit ages result in slip rates of 0.003mm/yr for the past 1.5 ka and 0.05-0.12 mm/yr for the past 10 to 25 kyr.

Several kilometers to the north, a subsidiary strand of the Washington fault displaces the Washington basalt flow approximately 4.5 meters. Best and others (1980) determined an K-Ar age of 1.7$\pm$0.1 Ma for the Washington flow. Assuming the 4.5-meter displacement represents a close approximation of net slip, the long-term (early Quaternary) slip rate for the subsidiary fault is 0.003 mm/yr.

Sources of Uncertainty

1. This study identified displacement only; neither the number nor the ages of individual surface-faulting events were determined.

2. Ages of deposits are estimates based on soil development, stratigraphy, and crosscutting fault relations. Although the estimated ages for the deposits were reported, the rational for arriving at those ages is poorly documented.

Summary:

This consultant's study provides insufficient information on the number or timing of surface-faulting earthquakes on the Washington fault to determine meaningful slip-rate or recurrence interval information, other than to state that the long-term slip rate for the fault is likely $\leq$ 0.1 mm/yr.

References:

Anderson, R.E., and Christenson, G.E., 1989, Quaternary faults, folds, and selected volcanic features in the Cedar City 1° x 2° quadrangle, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 89-6, 29 p., scale 1:250,000.

Best, M.G., McKee, E.H., and Damon, P.E., 1980, Space-time-composition patterns of late Cenozoic mafic volcanism, southwestern Utah and adjoining areas: American Journal of Science, v. 280, p. 1035-1050.

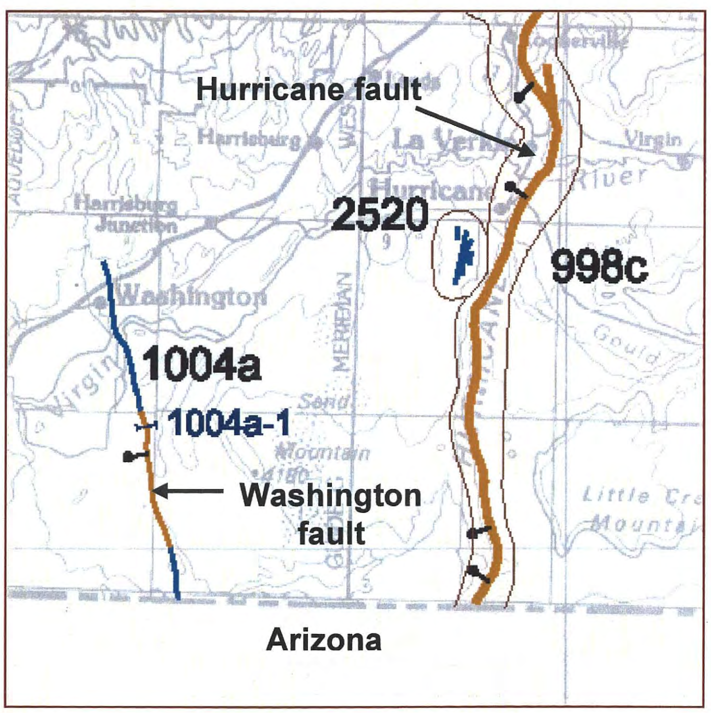
Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Pearthree, P.A., 1998, Quaternary fault data and map for Arizona: Arizona Geological Survey Open-File Report 98-24, scale 1:750,000, 122 p.

Petersen, S.M., 1983, The tectonics of the Washington fault zone, northern Mojave County, Arizona: Brigham Young University Geology Studies, v. 30, pt. 1, p. 83-94.

Map:

Map of the Washington fault zone, northern section (1004a) taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench site: 1004a-1
Gypsum Wash dam
Earth Science Associates (1982)

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UTAH QUATERNARY FAULT PARAMETER WORKING GROUP FAULT/FAULT SECTION SYNOPSIS FORM

Name and Location of Fault/Fault Section: Fish Springs fault (FSF), Juab County, Utah

Study Synopsis ID: FSF-1

Map Reference: 2417

Paleoseismic Data Source Documents:

Bucknam R.C., Crone, A.J., and Machette, M.N., 1989, Characteristics of active faults, *in* Jacobson, J.L., compiler, National Earthquake Hazards Reduction Program, summaries of technical reports volume XXVIII: U.S. Geological Survey Open-File Report 89-453, p. 117.

U.S. Geological Survey unpublished data.

General Fault Information

Geomorphic Expression

The FSF is a 20-kilometer-long, range-front normal fault along the eastern base of the Fish Springs Range, a north-trending mountain range in the Basin and Range Province in western Utah. The mountains have a complex structural history and expose mainly Paleozoic sedimentary rocks. Unconsolidated deposits in the valley east of the range are mainly lake deposits and alluvium. Extreme youth for the time of most recent surface faulting (MRE) is suggested by a lack of scarp dissection and by sharply defined knickpoints in small washes within several tens of meters of the scarps, but the scarps lack free faces and thus are likely hundreds to thousands of years old. Oviatt (1991) reports that an exposure of Holocene alluvium overlying older, more steeply dipping alluvium on the east side of Fish Springs Flat, across from the Fish Springs fault, shows about 6.5 degrees of pre-Holocene westward backtilting.

Evidence for Segmentation

Hecker (1993) shows two ages of faulting (a youthful northern half, and an older southern half).

Age of Youngest Faulting

Late Holocene

Paleoseismic Parameter Data

Type of Study/Commentary

The U.S. Geological Survey excavated three trenches to determine timing of fault movement to calibrate scarp-morphology data collected by Bucknam and Anderson (1979). One trench, near the northern end of the Fish Springs Range (site 2417-1), exposed monoclinally folded Lake Bonneville sediments (Provo-aged and younger) but no fault ruptures (Michael Machette, USGS, e-mail communication, September 2001).

The other two trenches, excavated across a prominent fault scarp (site 2417-2) about 12 kilometers south of the northern trench both exposed faulted sediment (Michael Machette, e-mail communication, September 2001). The larger of these two trenches revealed an A horizon buried by scarp-derived colluvium; radiocarbon dating of the A-horizon provided a maximum limiting age of faulting.

Scarps appear to be distinctly younger than the nearby Drum Mountains fault scarps; dated at about 9 ka, and they have a diffusion-based morphologic age of 3 ka (Hanks and others, 1984). Quantitative morphometric indices used by Sterr (1985) yielded a scarp age of 4.8 ka. Faulted post-Provo alluvial fans provide an upper limit for scarp age.

Number of Surface-Faulting Events/How Identified
One/colluvial wedge

Age of Events/Datum Ages/Dating Techniques
About 2 ka, based on an AMRT ^{14}C age of 2280$\pm$70 ^{14}C yr B.P. from a soil A-horizon buried by MRE scarp-derived colluvium.

Event Slip/Cumulative Slip
Scarp profiles by Bucknam and Anderson (1979) indicate 3.3 meters of MRE displacement.

Published Recurrence Interval
None, single event

Published Slip Rate
None, single event; however, estimated as less than 0.02 mm/yr by Black and others, (2003).

Sources of Uncertainty
1. Information available for this fault investigation is very limited; there are no published trench logs, and descriptions of the study are brief summaries only.
2. Single event only, not possible to determine a slip rate or recurrence interval.

Summary:
The FSF is a basin-and-range fault characterized by a young, single-event fault scarp formed on lacustrine and alluvial deposits. Available information is insufficient to determine either a recurrence interval or a slip rate.

References:
Black, B.D., Hecker, Suzanne, Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000.

Bucknam, R.C., and Anderson, R.E., 1979, Estimation of fault-scarp ages from a scarp-height-slope-angle relationship: Geology, v. 7, no. 1, p. 11-14.

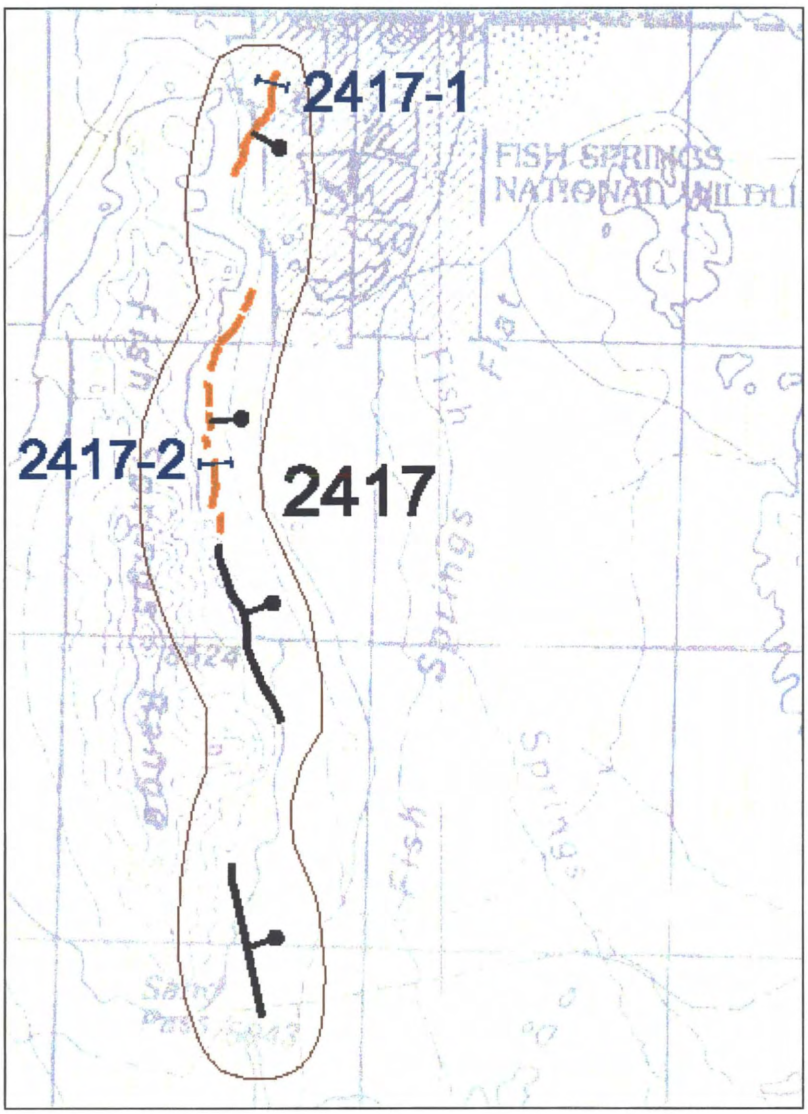
Hanks, T.C., Bucknam, R.C., Lajoie, K.R., and Wallace, R.E., 1984, Modification of wave-cut and faulting-controlled landforms: Journal of Geophysical Research, v. 89, no. B7, p. 5771-5790.

Oviatt, C.G., 1991, Quaternary geology of the Fish Springs Flat, Juab County, Utah: Utah Geological Survey Special Studies 77, 16 p.

Sterr, H.M., 1985, Rates of change and degradation of hill slopes formed in unconsolidated materials, a morphometric approach to dating Quaternary fault scarps in western Utah, USA: Zeitschrift fur Geomorphologie, v. 29, no. 3, p. 315-333.

Map:

Map of the Fish Springs fault (2417) taken from the Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites
2417-1
2417-2
Bucknam and others (1989)