AGENDA
UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP
WASATCH FAULT ZONE MEETING
JUNE 4 & 5 2003
Room 1050
(Note room number change)
Utah Department of Natural Resources Building
1594 North Temple, Salt Lake City, Utah

June 4, 2003

8:00 a.m. Continental breakfast

8:30 a.m. Welcome and introductions

8:35 a.m. Review meeting purpose, background information, and relevant issues

9:00 a.m. Evaluate Wasatch fault paleoseismic data

> **GOAL: Establish consensus slip rate and/or recurrence intervals with appropriate uncertainty limits for the Brigham City, Weber, and Salt Lake City sections of the Wasatch fault by the end of Day 1.**

10:30 a.m. Break

10:45 a.m. Evaluate Wasatch fault paleoseismic data

12:00 p.m. Lunch – box lunch provided

1:00 p.m. Evaluate Wasatch fault paleoseismic data

2:45 p.m. Break

3:00 p.m. Evaluate Wasatch fault paleoseismic data

5:00 p.m. End session

6:00 p.m. Dinner (van available for transportation to consensus restaurant)

8:00 p.m. Evening session if necessary (please don't make this necessary)

AGENDA

June 5, 2003

8:00 a.m. Continental breakfast

8:30 a.m. Call to order

8:35 a.m. Review previous day's activities/decisions

9:00 a.m. Evaluate Wasatch fault paleoseismic data

GOAL: Establish consensus slip rate and/or recurrence intervals with appropriate uncertainty limits for the Provo, and Nephi sections and review/advise on Levan section of the Wasatch fault by the end of Day 2.

10:30 a.m. Break

10:45 a.m. Evaluate Wasatch fault paleoseismic data

12:00 p.m. Lunch – box lunch provided

1:00 p.m. Evaluate Wasatch fault paleoseismic data

2:45 p.m. Break

3:00 p.m. Evaluate Wasatch fault paleoseismic data

4:00 p.m. Review consensus slip rate/recurrence intervals for all segments

5:00 p.m. End of meeting – van available for transportation to SLC airport

Meeting Format

During our two days of deliberations, we will begin at the north (Brigham City section) and work our way progressively to the south (Levan section) reviewing the available paleoseismic data, considering the uncertainty associated with the data, and establishing a consensus slip rate and/or recurrence interval for each of the six fault sections. As meeting coordinator, I will prepare a PowerPoint presentation highlighting the issues related to each fault section 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 your binders.

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, or worldwide toll free 1-800-465-4329.
4. A van will be available on the evening of the 4th to take folks to dinner – another consensus decision, and to make a run to the airport on Thursday after the meeting.
5. Both an overhead and LCD projector will be available at the meeting.
6. A complimentary copy of Utah Geological Survey Map 193DM *Quaternary Fault and Fold Database and Map of Utah* is included for those UQFPWG members to whom the UGS has not already made a copy available.

I look forward to seeing all of you on June 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.

Sincerely,

William Lund,
UQFPWG Coordinator

UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP

Utah Department of Natural Resources
Utah Geological Survey

Salt Lake City, Utah
June 4-5, 2003

May 7, 2003

TO: Members, Utah Quaternary Fault Parameters Working Group

FROM: Bill Lund, UQFPWG Coordinator

SUBJECT: UQFPWG Meeting Information:

Meeting Location, Time, Date, and Purpose

The first meeting of the Utah Quaternary Fault Parameters Working Group (UQFPWG) is scheduled for 8:00 a.m., June 4 & 5, 2003 in room 1060 (first floor) of the Utah Department of Natural Resources Building, 1594 North Temple, Salt Lake City, Utah. The purpose of the meeting is to evaluate the paleoseismic information available for the six central sections of the Wasatch fault zone (WFZ) and to arrive at consensus slip rate and/or recurrence interval values with appropriate confidence levels for those six sections of the fault.

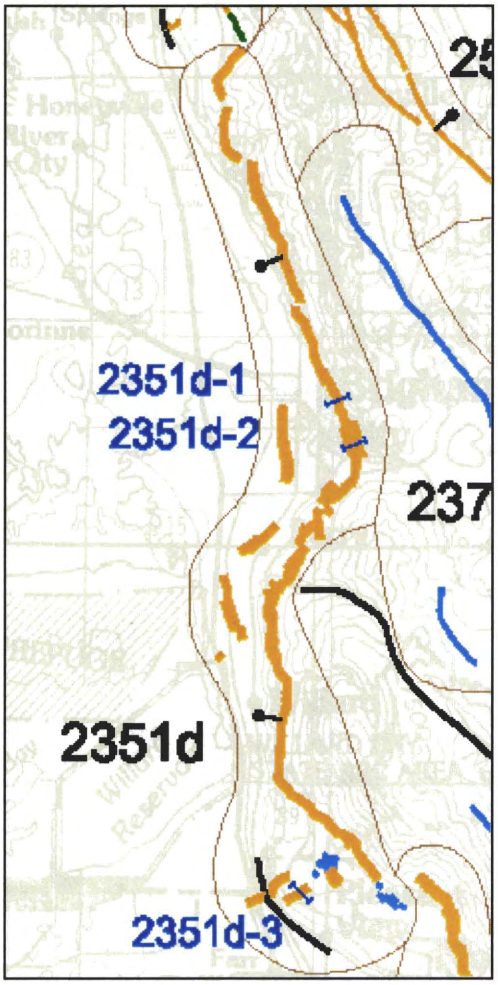
Synopsis Forms

The accompanying three-ring binder is divided into six sections, one for each of the six central sections of the WFZ. Within each section of the binder you will find a *Fault Section Synopsis Form* (FSSF) that: (1) lists the paleoseismic source documents for that fault section, (2) briefly characterizes the fault section and its boundaries, (3) summarizes existing slip rate and recurrence interval information, and (4) presents a map of the fault section showing paleoseismic study locations. Following the FSSF, there are a series of *Paleoseismic Study Synopsis Forms* (PSSF), one for each paleoseismic source document, unless otherwise noted, listed on the FSSF. Each PSSF summarizes the paleoseismic information resulting from a given study, and lists sources of uncertainty associated with the data. Members of UQFPWG should familiarize themselves with the FSSFs and PSSFs prior to our June meeting, and be prepared to discuss the paleoseismic information available for the six central sections of the WFZ as it pertains to slip rate and recurrence. Some questions to consider while reviewing the data include:

1. Short-term (mid-Holocene to present) versus long-term (latest Pleistocene to present) slip rates or recurrence intervals and which best characterize the present behavior of the WFZ.
2. The possibility of/evidence for multiple segment ruptures and their potential affect on slip rate and recurrence.
3. Assigning confidence levels (quantitative or qualitative) to the consensus slip rates and recurrence intervals for each fault section.

Map:

Map of Brigham City Section (2351d), Wasatch fault zone, take from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites:

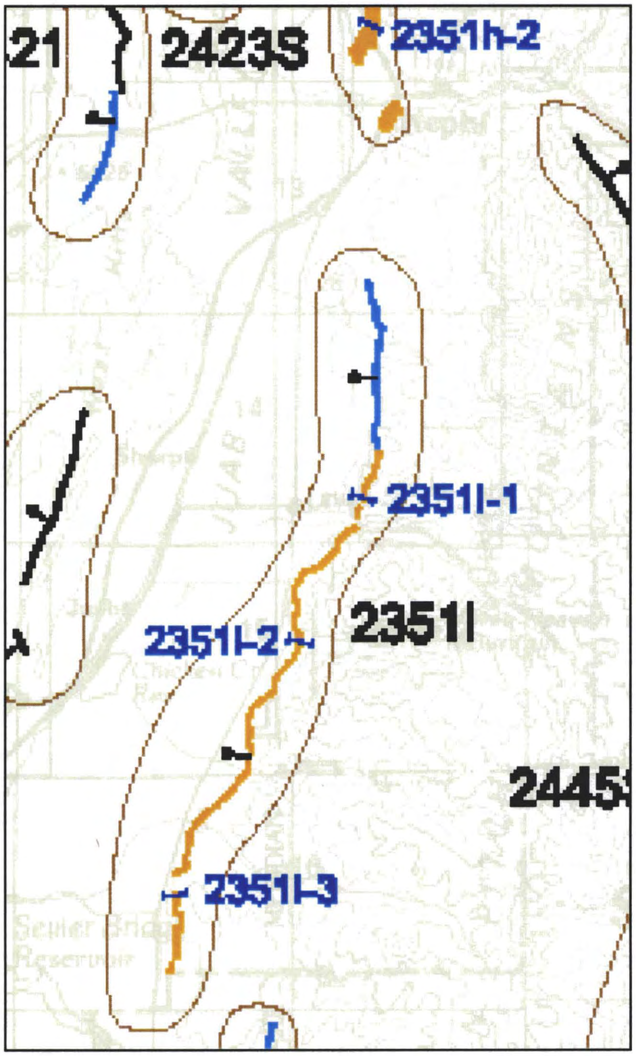
2351d-1 = Brigham City (Personius)
Personius (1991)

2351d-2 = Brigham City (McCalpin)
McCalpin and Forman (1994, 2002)

2351d-3 = Pole Patch
Personius (1991)

Map:

Map of the Nephi Section (2351h), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



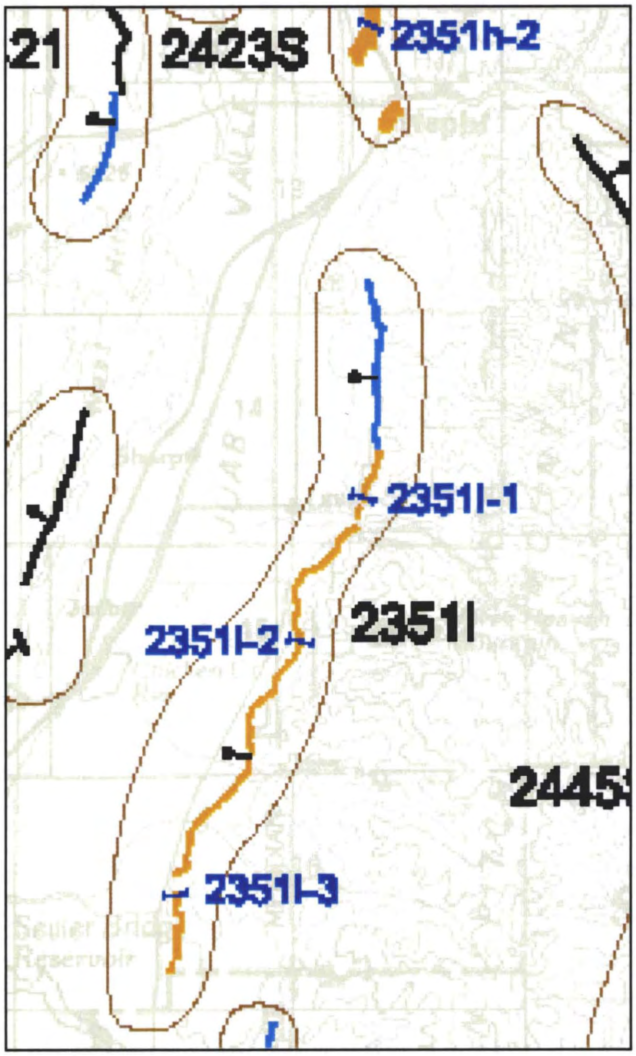
Trench sites:

2351i-1 = Pigeon Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-2 = Deep Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-3 = Skinners Peak
Jackson (1991)

Map:
Map of the Nephi Section (2351h), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



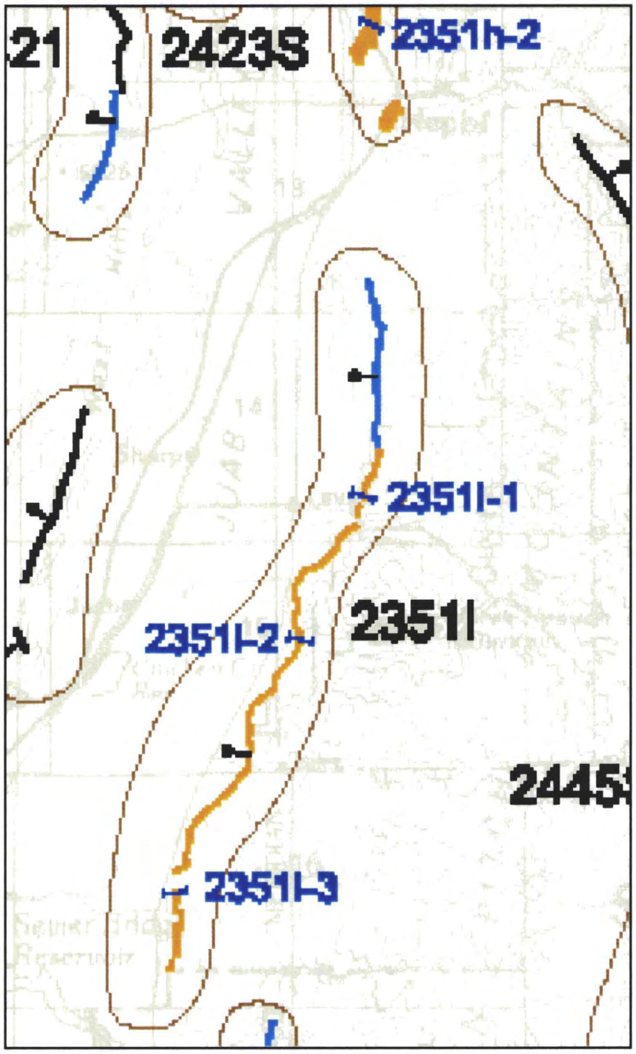
Trench sites:

2351i-1 = Pigeon Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-2 = Deep Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-3 = Skinners Peak
Jackson (1991)

Map:
Map of the Nephi Section (2351h), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites:

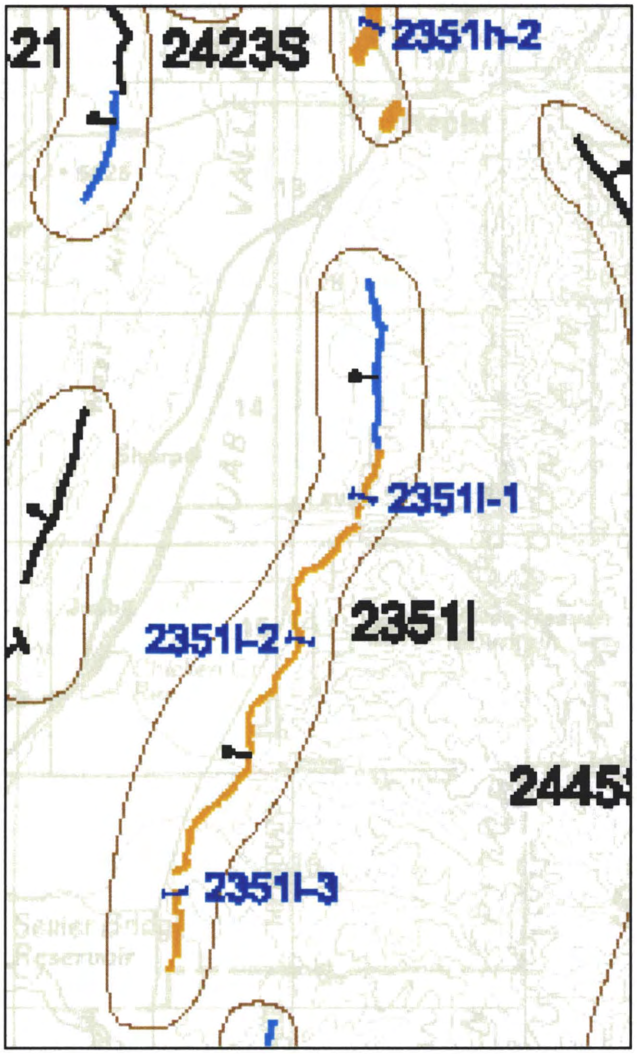
2351i-1 = Pigeon Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-2 = Deep Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-3 = Skinners Peak
Jackson (1991)

Map:

Map of the Nephi Section (2351h), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites:

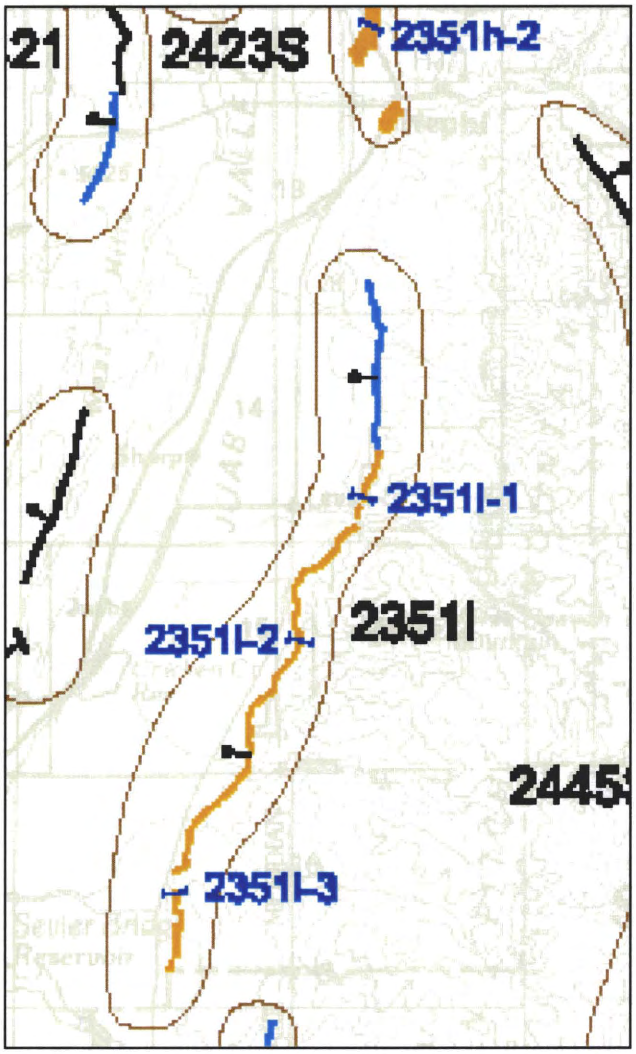
2351i-1 = Pigeon Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-2 = Deep Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-3 = Skinners Peak
Jackson (1991)

Map:

Map of the Nephi Section (2351h), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



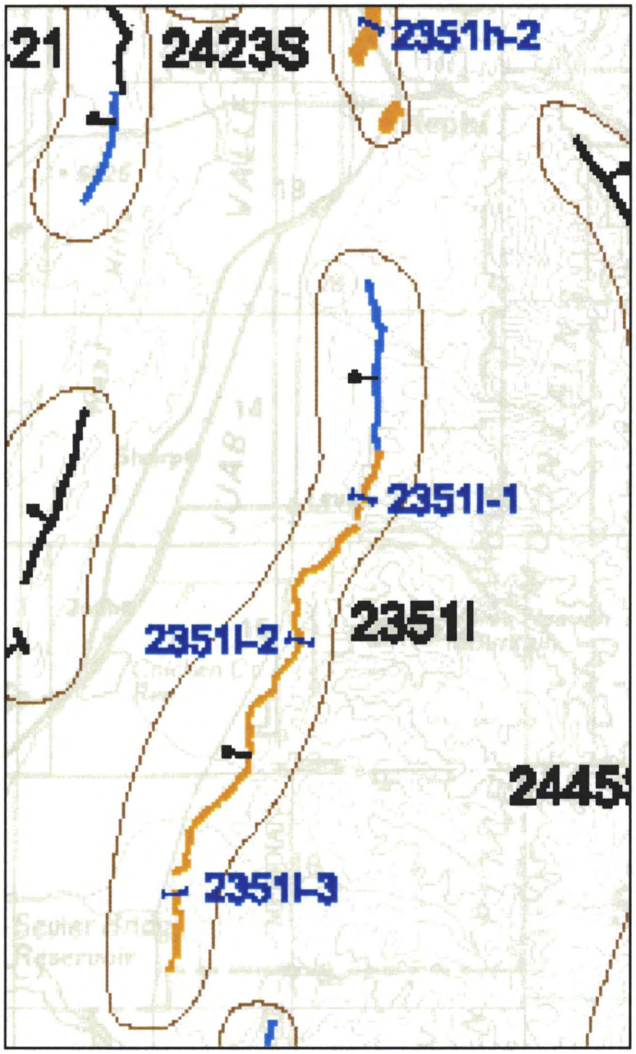
Trench sites:

2351i-1 = Pigeon Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-2 = Deep Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-3 = Skinners Peak
Jackson (1991)

Map:
Map of the Nephi Section (2351h), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



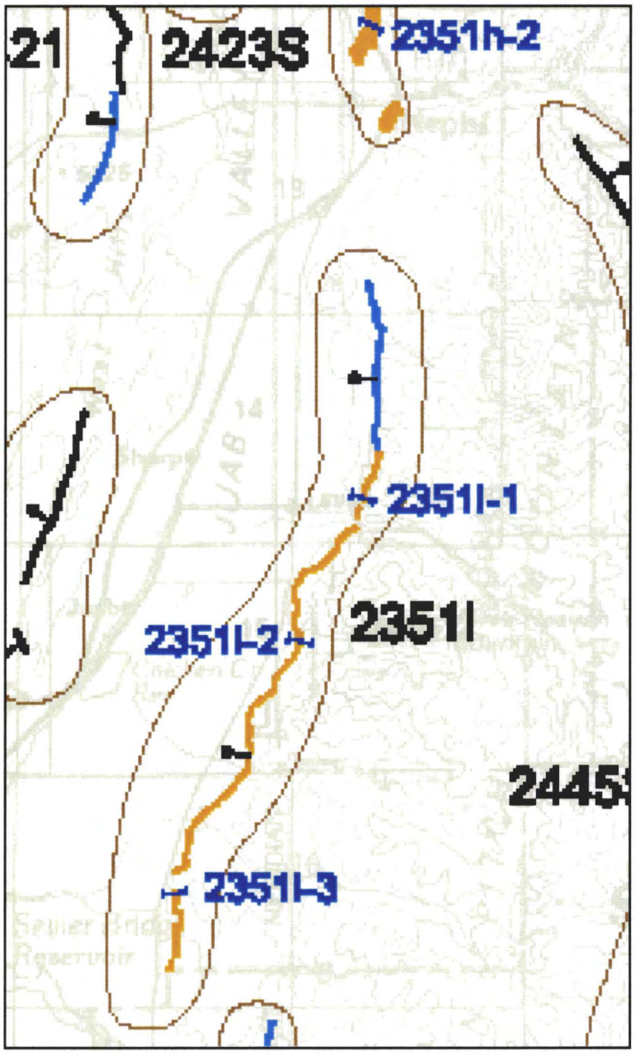
Trench sites:

2351i-1 = Pigeon Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-2 = Deep Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-3 = Skinners Peak
Jackson (1991)

Map:
Map of the Nephi Section (2351h), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites:

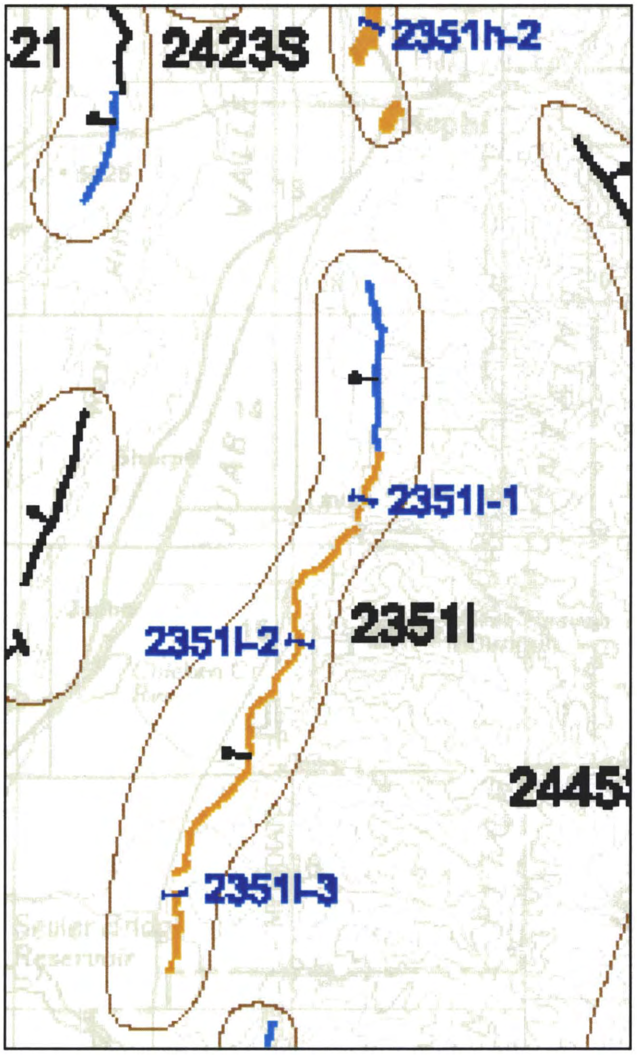
2351i-1 = Pigeon Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-2 = Deep Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-3 = Skinners Peak
Jackson (1991)

Map:

Map of the Nephi Section (2351h), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



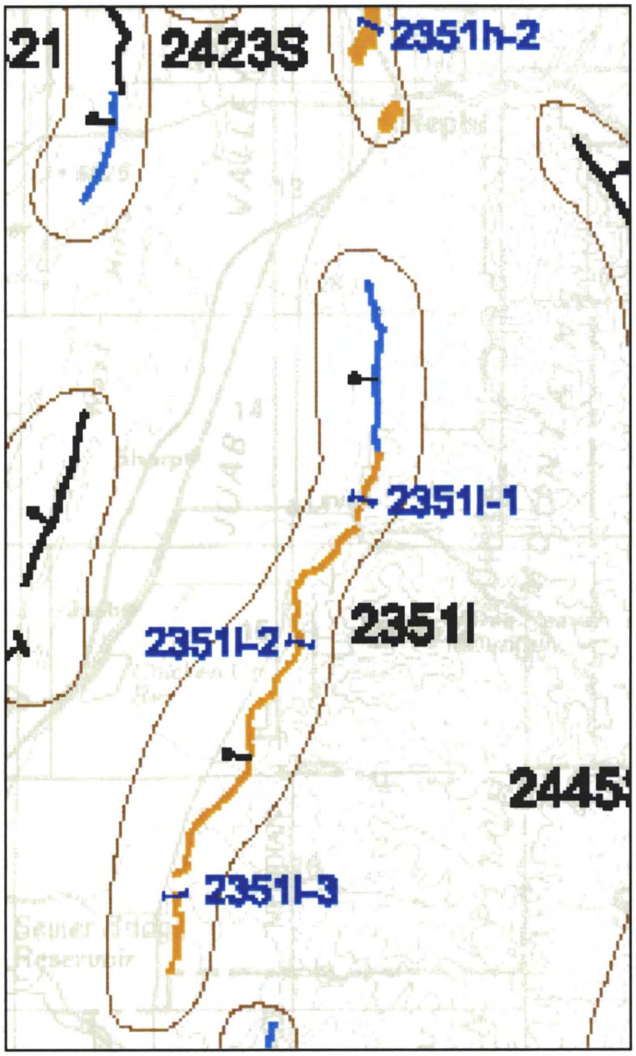
Trench sites:

2351i-1 = Pigeon Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-2 = Deep Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-3 = Skinners Peak
Jackson (1991)

Map:
Map of the Nephi Section (2351h), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



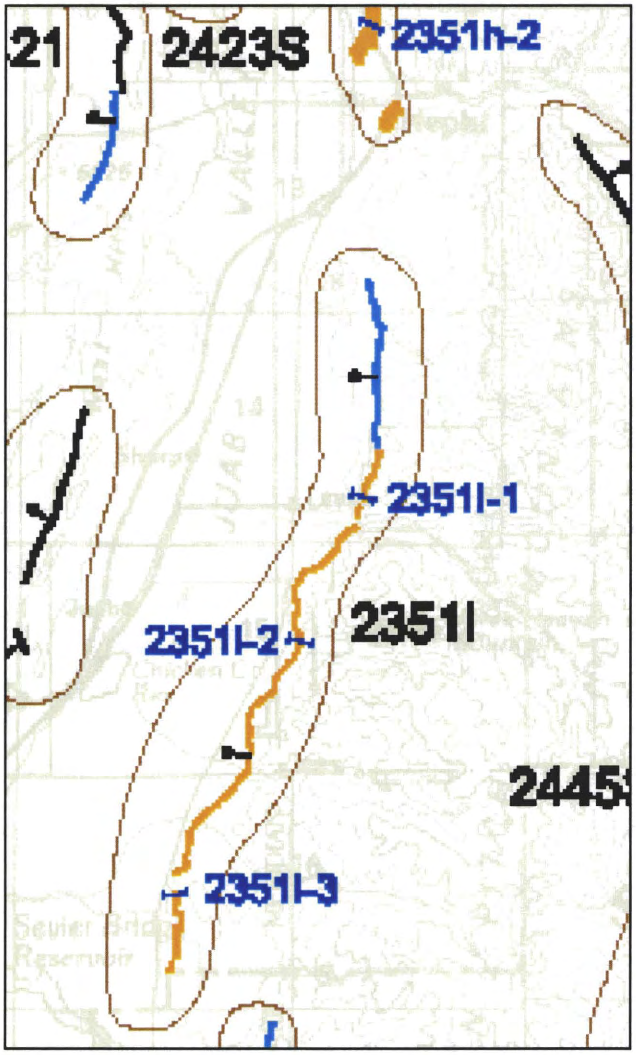
Trench sites:

2351i-1 = Pigeon Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-2 = Deep Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-3 = Skinners Peak
Jackson (1991)

Map:
Map of the Nephi Section (2351h), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



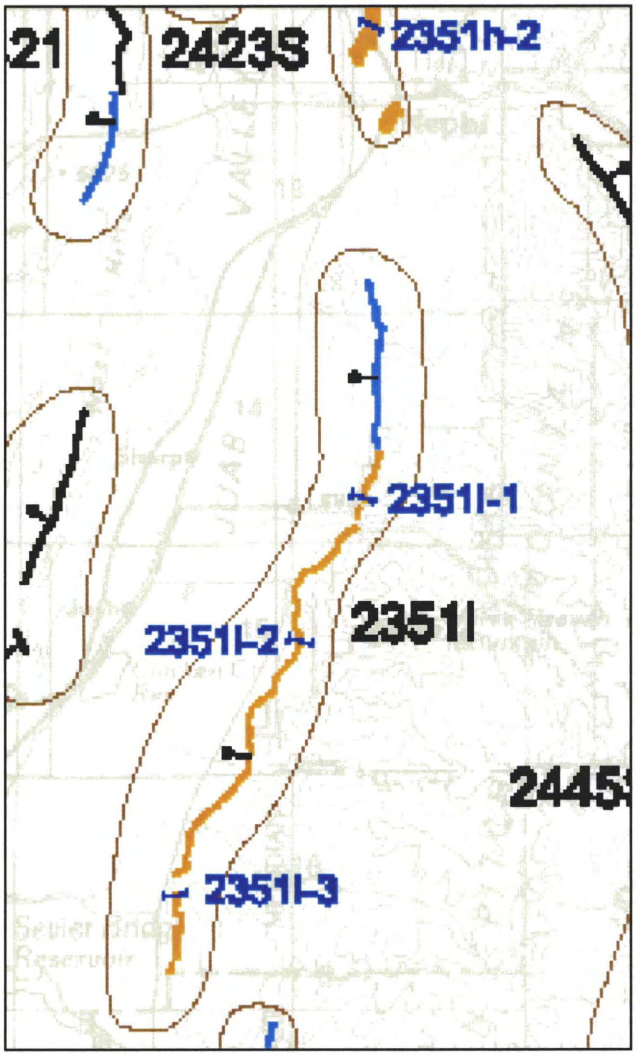
Trench sites:

2351i-1 = Pigeon Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-2 = Deep Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-3 = Skinners Peak
Jackson (1991)

Map:
Map of the Nephi Section (2351h), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



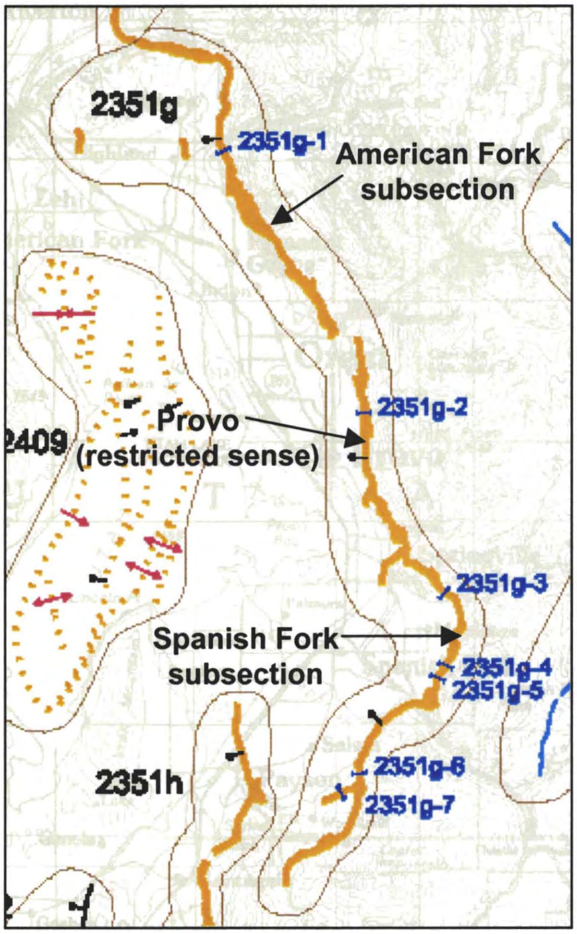
Trench sites:

2351i-1 = Pigeon Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-2 = Deep Creek
Schwartz and Coppersmith (1984)
Jackson (1991)

2351i-3 = Skinners Peak
Jackson (1991)

Map:
Map of Provo Section (2351g), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench Sites
2351g-1 = American Fork Canyon
Machette and Lund (1987)
Machette (1988)
Machette and others (1992)

2351g-2 = Rock Canyon
Lund and others (1990)
Lund and Black (1998)

2351g-3 = Hobble Creek
Swan and others (1980)
Machette and others (1992)

2351g-4 = Mapleton North
2351g-5 = Mapleton South
Lund and others (1991)

2351g-6 = Water Canyon
Ostenaa (1990)

2351g-7 = Woodland Hills fault
Machette and others (1992)
Small subsidiary fault active only during some surface-faulting events on the WFZ.

Hunt, C.B., editor, 1982, Pleistocene Lake Bonneville, ancestral Great Salt Lake, as defined in the notebooks of G.K. Gilbert, 1875-1880: Brigham Young University Geology Studies, v. 29, pt. 1, p. 1-225.

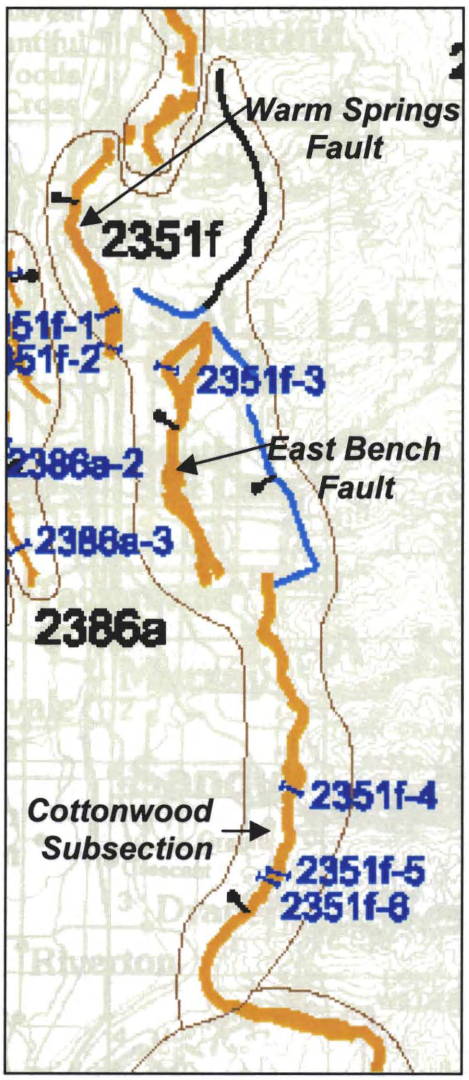
Madsen, D.B., and Currey, D.R., 1979, Late Quaternary glacial and vegetation changes, Little Cottonwood Canyon area, Wasatch Mountains, Utah: Quaternary Research, v. 12, p. 254-270.

Personius, S.F., and Scott, W.E., 1992, Surficial geologic map of the Salt Lake City segment and parts of adjacent segments of the Wasatch fault zone, Davis, Salt Lake, and Utah Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2106, scale 1:50,000.

Schlenker, G.C., Helm, J.M., and Batatian, L.D., 1999, Ontogeny of the Warm Springs fault-Special studies zone mapping in the West Capitol and Downtown neighborhoods, Salt Lake City, Utah [abs.]: Association of Engineering Geologists, 42nd Annual Meeting Program with Abstracts, p. 84.

Map:

Map of Salt Lake City Section (2351f), Wasatch fault zone, taken from Quaternary Fault and Fold Database and Map of Utah (Black and others, 2003).



Trench sites:

2351f-1 = Washington Elementary School
Robison and Burr (1991)

2351f-2 = Salt Palace Convention Center
Simon and Shlemon (1999)
Korbay and McCormick (1999)

2351f-3 Dresden Place
Machette and others (1992)
No information on slip rate or recurrence is available from this site.

2351f-4 = Little Cottonwood Canyon
Swan and others (1981)
Schwartz and Coppersmith (1984)
Schwartz and Lund (1988)
McCalpin and Nelson (2000)
McCalpin (2002)

2351f-5 = South Fork Dry Creek
Lund (1992)
Black and others (1996)

2351f-6 = Dry Gulch
Lund (1992)
Black and others (1996)

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

Name and Location of Fault/Fault Section:
Brigham City section (BCS), Wasatch fault zone (WFZ), Box Elder County, Utah

Paleoseismic Data Source Documents:
McCalpin, J.P., and Forman, S.L., 2002, Post-Provo paleoearthquakes chronology of the Brigham City segment, Wasatch fault zone, Utah: Utah Geological Survey Miscellaneous Publication 02-9, 46 p.

McCalpin and Forman (2002), above, is an revised version of McCalpin and Forman (1993), below, which was released by the Utah Geological Survey to make the results of this study more readily available to the geologic community and the general public. For purposes of this project, only McCalpin and Forman (2002) was reviewed.

McCalpin, J.P., and Forman, S.L., 1993, Assessing the paleoseismic activity of the Brigham City segment, Wasatch fault zone, Utah - Site of the next major earthquake on the Wasatch Front?, *in* Jacobson, M.L., compiler, Summaries of Technical Reports, v. XXXIV: U.S. Geological Survey Open-File Report 93-195, p. 485-489.

Personius, S.F., 1991, Paleoseismology of Utah, volume 2-Paleoseismic analysis of the Wasatch fault zone at the Brigham City trench site, Brigham City, Utah, and Pole Patch trench site, Pleasant View, Utah: Utah Geological and Mineral Survey Special Studies 76, 39 p.

Geomorphic Expression:
The BCS is 37 kilometers long end-to-end and has a cumulative (trace) length of 81 kilometers. West-facing scarps located along the western base of the Wellsville Mountains and Wasatch Range characterize the section along most of its length. Scarps on the valley floor between Willard and Brigham City may be associated with incipient lateral spreads, but have orientations and relief consistent with a faulting origin. In the southern part of the section, 15- to 20-meter-high scarps on a Provo-level delta suggest as many as 6-10 surface-faulting events occurred since about 16 ka (assuming an average displacement per event of 2+ meters). However, only a few short, discontinuous scarps are in upper Holocene deposits near the southern section boundary, which is in contrast to the abundance of Holocene scarps on the Weber section (WS) to the south.

Evidence for Segmentation:
The BCS is the northernmost section of the Wasatch fault zone that exhibits clear evidence of recurrent Holocene faulting along its entire length (Machette and others, 1992).

The northern boundary of the BCS with the Colliston section (Machette and others, 1992) is a reentrant on the west side of the Wellsville Mountains near Jim May Canyon, 2 kilometers northeast of Honeyville, Utah. The boundary is defined by a change in fault trend, differences in displacement of similar aged pre-Bonneville deposits, and a lack of Holocene faulting to the north on the Colliston section (Machette and others, 1992). Wheeler and Krystinik (1992) identify this section boundary as likely nonpersistant through time, although Machette and others (1992) believe it may represent a foundered bedrock salient.

The boundary between the BCS and the WS (Machette and others, 1992) to the south is near the northeast corner of the Pleasant View salient, 3 kilometers north of North Ogden. The Pleasant View salient is a foundered bedrock block stranded at an intermediate structural level along the WFZ (Crittendon and Sorenson, 1985). Rates of faulting differ on either side of the salient, with more recent faulting occurring to the south. Wheeler and Krystinik (1992) identify the Pleasant View salient as a persistant section boundary through time.

Age of Youngest Faulting:
Holocene

Summary of Existing Recurrence Interval Information:
~1.3 ka (<8.5 ka): The overall temporal pattern is an average of one earthquake every 1275 year since 8.5 ka based on five (?) closed seismic cycles identified by McCalpin and Forman (2002). A long seismic gap exists between 8.5 and 14.8 ka (McCalpin and Forman, 2002). The 6 ka seismic gap may have been influenced by changes in crustal stress regime associated with Lake Bonneville desiccation, possibly causing crustal rebound to suppress extensional movements. However, McCalpin and Forman (2002) are unable to categorically rule out the possibility of another surface-faulting earthquake sometime within that 6-ka gap. Elapsed time since the most recent surface-faulting earthquake is 2,125 years, which is approaching twice the mean recurrence interval and suggests that the section is due for a surface-faulting earthquake, unless strain-accumulation rates have declined during the late Holocene. McCalpin and Forman (2002) state that based on a renewal model for fault behavior, the probability of an M>7 earthquake on the BCS in the next 100 years is significantly greater than for the other four central sections of the WFZ.

Summary of Existing Slip-Rate Information:
Slip rate information for the BCS is limited. Data are insufficient at the Pole Patch and McCalpin and Forman (2002) Brigham City sites to determine a slip rate. The slip-rate information at the Personius (1991) Brigham City trench is limited to a single closed seismic cycle between the penultimate and most recent events.

Comments:
Available slip-rate data for the BCS are either limited or highly speculative (see individual paleoseismic source study summaries). McCalpin and Forman's (2002) study provides sufficient information to calculate a recurrence interval for the BCS for the past ~8.5 ka, but questions remain to be answered regarding the number of closed seismic cycles to use (4 or 5) in calculating surface-faulting recurrence.

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.

Crittenden, M.D., and Sorenson, M.L., 1985, Geologic map of the North Ogden quadrangle and part of the Ogden and Plain City quadrangles, Box Elder and Weber

Counties, Utah: U.S. Geological Survey Miscellaneous Investigation Series Map I-1606, scale 1:24,000.

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.

McCalpin, J.P., and Forman, S.L., 1993, Assessing the paleoseismic activity of the Brigham City segment, Wasatch fault zone, Utah - Site of the next major earthquake on the Wasatch Front?, *in* Jacobson, M.L., compiler, Summaries of Technical Reports, v. XXXIV: U.S. Geological Survey Open-File Report 93-195, p. 485-489.

McCalpin, J.P., and Forman, S.L., 2002, Post-Provo paleoearthquakes chronology of the Brigham City segment, Wasatch fault zone, Utah: Utah Geological Survey Miscellaneous Publication 02-9, 46 p.

McCalpin, J.P., and Nishenko, S.P., 1996, Holocene paleoseismicity, temporal clustering, and probabilities of future large (M>7) earthquakes on the Wasatch fault zone: Journal of Geophysical Research, v. 101, no. B3, p. 6233-6253.

Personius, S.F., 1991, Paleoseismology of Utah, volume 2-Paleoseismic analysis of the Wasatch fault zone at the Brigham City trench site, Brigham City, Utah, and Pole Patch trench site, Pleasant View, Utah: Utah Geological and Mineral Survey Special Studies 76, 39 p.

Wheeler, R.L., and Krystinik, K.B., 1992, Persistent and nonpersistant segmentation of the Wasatch fault zone, Utah = Statistical analysis for evaluation of seismic hazard, *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. B1-B47.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SYNOPSIS FORM

Site Name: Brigham City (Personius) ***Study Synopsis ID:*** BCS-1A

Fault/Fault Section: Brigham City section (BCS), Wasatch fault zone (WFZ)

Map Reference: 2351d-1

Study:

Personius, S.F., 1991, Paleoseismic analysis of the Wasatch fault zone at the Brigham City trench site, Brigham City, Utah, *in* Lund, W.R., editor, Paleoseismology of Utah, Volume 2 - Paleoseismic analysis of the Wasatch fault zone at the Brigham City trench site, Brigham City, Utah and Pole Patch trench site, Pleasant View, Utah: Utah Geological and Mineral Survey Special Studies 76, p. 1-17.

Type of Study/Commentary:

Trenching: Single trench excavated across an 8-m-high fault scarp formed on a Holocene alluvial fan. The trench exposed a complex 4-m-wide fault zone of stepped normal faults that form three discrete fault zones (F1, F2, F3) that offset a sequence of lower and middle Holocene alluvial-fan deposits.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

Three. There is good stratigraphic evidence (colluvial wedges) for the two most recent surface-faulting earthquakes (MRE and PE), but evidence for the oldest event (APE) wedge is equivocal.

Age of Events/Datum Ages/Dating Techniques:

MRE: 3.6 $\pm$ 0.5 ka/ ^{14}C AMRT age on a buried soil
PE: 4.7 $\pm$ 0.5 ka/^{14}C AMRT age on a buried soil
APE: undated, estimated age 5–7 ka.

Note: A ^{14}C AMRT age estimate obtained from a buried soil formed on pre-faulting unit 8 was 3,610$\pm$100 cal yr B.P., which is younger than the AMRT age estimates obtained from younger paleosols higher in the stratigraphic column. This inversion of dates was attributed to bioturbation.

Both ^{14}C AMRT ages were converted to calendar years following the procedure outlined in Machette and others (1992, appendix A), and using high-precision radiocarbon calibration curves for calibrating ^{14}C ages provided by Stuiver and Reimer (1986).

Event Slip/Cumulative Slip:

MRE: 1.0 m vertical displacement
PE: 2.5 m vertical displacement

APE: 2.5 m vertical displacement

Note: Good correlation of displaced units is possible across faults F2 and F3, but not across F1, so cumulative net slip reported at this site includes both direct measurement of displaced stratigraphic units and estimates based on scarp profiling and tentative correlation of pre-APE units across the fault zone.

Published Recurrence Interval:

Relations in trench showed non-uniform recurrence of surface faulting in middle and late Holocene time. The PE and MRE define a single closed recurrence interval of 1100 ± 1000 yrs.

Published Slip Rate:

Reported post-middle-Holocene open slip rate of 0.75 + 0.3 mm/yr based on 3.5± 1.0 meter of combined displacement in the PE and MRE and 4.7 ± 0.5 kyr of elapsed time from the PE to the present. Slip rate for single closed seismic cycle between the PE and MRE is 0.91 mm/yr.

Sources of Uncertainty:

1. Stratigraphic evidence for APE is problematic, due to complex stratigraphic relations exposed near the bottom of the trench and the resulting uncertainty regarding the origin and age of deposits identified as the APE colluvial wedge.
2. Net vertical displacements on faults F2 and F3 are clear based on displaced stratigraphy, but similar stratigraphic correlations could not be made across fault F1. A tentative correlation of pre-APE unit 8-1A based on similar stratigraphic position and apparent vertical stratigraphic displacement provides an estimate of cumulative net slip.
3. Sampling technique employed for the ^{14}C AMRT samples unknown; uncertainties generally associated with ^{14}C AMRT ages.
4. Stratigraphic inversion of one ^{14}C AMRT age probably due to bioturbation - affect on other dates?
5. A later study on the BCS (McCalpin and Forman, 2002) indicates that all a second down-to-the-west scarp at this site was not trenched during this study.
6. The McCalpin and Forman (2002) chronology of Holocene surface faulting on the BCS includes a late Holocene surface-faulting event that was not recognized at this site.

Summary:

This study provides good evidence for the two surface-faulting earthquakes and possibly for a third, older event. Recurrence-interval information from this site is limited because only the two youngest surface faulting events are constrained by ^{14}C AMRT ages; those dates provide a single closed recurrence interval of 1100 ± 1000 years. The interval between the APE and the PE may be longer than 1100 years, and the elapsed time since the MRE is 3600±500 years, indicating that surface-faulting recurrence at this site is non-uniform. The slip rate reported for this site includes two seismic cycles, the youngest of which is not closed. It is possible that all of the scarps present at this site were not trenched, and a later trenching study conducted a few kilometers to the south identified a late Holocene event that is younger than any of the events recognized at this site.

References:

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.

McCalpin, J.P., and Forman, S.L., 2002, Post-Provo paleoearthquakes chronology of the Brigham City segment, Wasatch fault zone, Utah: Utah Geological Survey Miscellaneous Publication 02-9, 46 p.

Stuiver, Minze, and Reimer, P.J., 1986, A computer program for radiocarbon age calibration (Rev. 2.0): Radiocarbon, v. 28, no. 2B, p. 1022-1030.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Pole Patch trench site ***Study Synopsis ID***: BCS-1B

Fault/Fault Section: Brigham City section (BCS), Wasatch fault zone (WFZ)

Map Reference: 2351d-3

Study:

Personius, S.F., 1991, Paleoseismic analysis of the Wasatch fault zone at the Pole Patch trench site, Pleasant View, Utah, *in* Lund, W.R., editor, Paleoseismology of Utah, Volume 2 - Paleoseismic analysis of the Wasatch fault zone at the Brigham City trench site, Brigham City, Utah and Pole Patch trench site, Pleasant View, Utah: Utah Geological and Mineral Survey Special Studies 76, p. 19-36.

Type of Study/Commentary:

Trenching: A single trench was excavated on the Pleasant View salient across a 1.2-kilometer-long, northeast-trending normal fault that is subsidiary to the northwest-trending main trace of the WFZ. The Pleasant View salient forms the boundary between the BCS and the Weber section (WS) of the WFZ. The trench exposed a fault zone that displaced transgressive phase Lake Bonneville deposits with a net throw of 5.0 meters (4.6 m with back tilting removed) across three fault strands (F1, F2, and F3 [east to west]; F3 is an antithetic fault with movement down to the southeast).

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

Three. Three scarp-derived colluvial wedges (units 3, 4, and 5) overlie the eroded remnants of the original pre-fault ground surface (unit 6).

Age of Events/Datum Ages/Dating Techniques:

The two oldest events are undated. An ^{14}C AMRT age of 4.6 ka $\pm$ 0.5 cal yr B.P. on organic sediment in a tectonic crack formed in the PE colluvial wedge (unit 4-1) during the MRE provides a maximum-limiting age for the MRE. This age estimate also serves as a minimum-limiting age for the PE.

Organic sediment from unit 6-A, the original pre-faulting ground surface, was dated to establish a maximum-limiting age for the APE. The age obtained, 2.2 ka $\pm$ 0.5 cal yr B.P., is younger than the age of the crack-fill material in unit 4-1, which is higher in the stratigraphic column and therefore younger than unit 6-A. This age inversion was attributed to one of three possible causes, including the possibility that the older age is incorrect, but regardless of the cause, it was concluded that the young age estimate does not provide a limiting age for the APE.

Based on the degree of soil development on unit 6, the pre-faulting ground surface, the author believes that the APE and PE post-date the Bonneville flood (~15 ka) by several thousand years and that both events probably occurred in latest Pleistocene or early Holocene time.

Both ^{14}C AMRT age estimates were converted to calendar years following the procedure outlined in Machette and others (1992, appendix A) and using the CALIB computer calibration program of Stuiver and Reimer (1986).

***Event Slip/Cumulative Slip*:**

APE: F1 = 1.8 - 2.1 meters net vertical displacement (NVD); 50 cm across F2 and 10 cm antithetic displacement across F3 for a combined NVD of 40 cm (F2 and F3 active only during APE). Total APE NVD = 2.2 – 2.5 meters based on a combination of stratigraphic reconstruction of the colluvial wedge at F1 and net displacement across F2 and F3.

PE: F1 = 1.5 – 1.8 meters NVD (only F1 active), based on stratigraphic reconstruction of the colluvial wedge.

MRE: F1 = 0.7 – 1.3 meters NVD (only F1 active), based on total displacement across fault zone minus the combined displacements determined for the APE and PE.

Cumulative displacement = 4.6±0.5 meters based on projection of the base of unit 7 (pre-faulting lacustrine silt unit) to the fault zone from both the footwall and hanging-wall sides of the fault and removal of 3° of back tilt from the stratigraphic units in the hanging wall. Projecting unit 7 from outside the zone of near-fault deformation in the hanging wall accommodates the 10 centimeters of antithetic faulting on F3.

***Published Recurrence Interval*:**

Since only the MRE could be dated, recurrence intervals published for the Pole Patch site are highly speculative. The average recurrence interval is 5000±333 years given three events in the past 15 ka. However, if the three events recorded at Pole Patch occurred in as little as 5000 to 7000 years, as indicated by soil development on unit 6, then the estimated average recurrence would be 2-3 times higher than that calculated above for post-Bonneville time.

***Published Slip Rate*:**

0.3 ± 0.05 mm/yr based on a total NVD of 4.6±0.5 meters and an assumed elapsed time of 15±1 ka since the Bonneville flood. This is a minimum slip rate since the APE and PE are both estimated to have occurred several thousand years after the Bonneville flood, so the time period selected is a maximum. The slip rate is also open since the 15 ka time period extends to the present and includes at least one open seismic cycle.

***Sources of Uncertainty*:**

1. The Pole Patch fault is subsidiary to the WFZ, so the paleoseismic data developed by this study do not pertain directly to the main WFZ.
2. The Pole Patch fault is on the Pleasant View salient, which forms the boundary between the BCS and WS of the WFZ. It is unclear to which, if either, of the two WFZ sections the paleoseismic data at Pole Patch may pertain.

3. Only the most recent of the three surface-faulting events identified in the Pole Patch trench could be dated.
4. The two AMRT age estimates available for the site are inverted, with no clear resolution of which age estimate is correct.

Summary:
Evidence for three surface-faulting earthquakes was identified at the Pole Patch site, but only the MRE could be dated. Due to a lack of information on the timing of the two earlier events, the slip rates and recurrence intervals published for this site are speculative and the slip rate includes an open seismic cycle between 4.6 ka and the present. Because the Pole Patch fault is subsidiary to and trends differently than the main WFZ, it is unclear what if any relevance the paleoseismic data from this site has to the main WFZ. The MRE at this site was tentatively correlated with the PE at the Brigham City trench site.

References
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.
Stuiver, Minze, and Reimer, P.J., 1986, A computer program for radiocarbon age calibration (Rev. 2.0): Radiocarbon, v. 28, no. 2B, p. 1022-1030.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Brigham City (McCalpin & Forman) ***Study Synopsis ID:*** BCS-2

Fault/Fault Section: Brigham City section (BCS), Wasatch fault zone (WFZ)

Map Reference: 2351d-2

Study:

McCalpin, J.P., and Forman, S.L., 2002, Post-Provo paleoearthquake chronology of the Brigham City segment, Wasatch fault zone, Utah: Utah Geological Survey Miscellaneous Publication 02-9, 46 p.

McCalpin and Forman (2002), above, is a revised version of McCalpin and Forman (1993), below, released by the Utah Geological Survey in 2002. Only McCalpin and Forman (2002) was reviewed and summarized for the UQFPWG project.

McCalpin, J.P., and Forman, S.L., 1993, Assessing the paleoseismic activity of the Brigham City segment, Wasatch fault zone, Utah - Site of the next major earthquake on the Wasatch Front?, *in* Jacobson, M.L., compiler, Summaries of Technical Reports, v. XXXIV: U.S. Geological Survey Open-File Report 93-195, p. 485-489.

Type of Study/Commentary:

Trenching. Fourteen trenches were excavated across seven sub-parallel fault scarps that form a 300-meter-wide fault zone on a Lake Bonneville Provo-age delta at the mouth of Box Elder Creek near Brigham City, Utah. Scarps on the delta surface range from 1 to 9 meters high, and the ages of the deposits trenched include upper Pleistocene delta deposits, upper Pleistocene to lower Holocene landslide deposits, upper Pleistocene to middle Holocene alluvial-fan deposits, and upper Holocene fan alluvium. Cumulative down-to-the-west throw across the seven scarps in the fault zone is about 20 meters.

The scarps are labeled A through G from west to east across the fault zone. Scarp B was visible on 1980 aerial photographs of the site, but had been completely removed by commercial gravel pit excavations by the time of this study (1992) and could not be trenched. The remaining six scarps were all trenched at least once and most have two or more trenches across them.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

Seven (possibly 6 or 8) since abandonment of the Provo delta surface about 16–17 cal. ka. based on colluvial-wedge stratigraphy at this site and at the Personius (1991) Brigham City and Pole Patch trench sites.

Age of Events/Datum Ages/Dating Techniques:

Events are labeled Z through T from the youngest (Z) to the oldest (T).

Event Z (MRE): Mean age 2125±104 cal yr B.P.; constrained by 5 closely limiting ages (4 ^{14}C AMRT and 1 TL) from trenches 2, 12, 13, and 14. Personius (1991) did not recognize this event at either the Brigham City or Pole Patch trench sites.

Event Y (PE): Mean age 3434±142 cal. yr B.P.; constrained by 2 closely limiting ^{14}C ages from trenches 5 and 13, and by a ^{14}C age estimate obtained by Personius (1991) at his Brigham City trench site. This event corresponds to Personius' (1991) MRE at his Brigham City trench site.

Event X (APE): Mean age 4674±108 cal. yr B.P.; this event was not recognized at this site, but Personius (1991) documented it at both his Brigham City and Pole Patch trench sites. Since trenches for this study exposed stratigraphy spanning the time period in which this event occurred, the authors surmise that this event only ruptured scarp B, which was removed by the gravel pit excavations prior to their study.

Event W: 5970±242 cal. yr B.P.; this event is documented by a single maximum age from trench 14. The colluvial-wedge stratigraphy for this event was reported as being unambiguous.

Event V: 7500±1000 yr B.P. constrained by a single TL age on loess from trench 2.

Event U: Mean age 8,500±845 yr B.P. constrained by two TL age, on loess from trenches 3 and 6.

The identification of Events V and U is based on three total-bleach TL ages obtained on post-Provo loess exposed in trenches across scarps D (trench 2) and G (trenches 3 & 6). A fourth, partial-bleach age estimate on the loess in trench 6 gave a considerably older age of 12.0±1.5 ka. McCalpin and Forman (2002) believe that the total-bleach age estimates are more accurate, despite the fact that the partial-bleach estimate is similar to a ^{14}C age (13,010+490 ^{14}C yr B.P.) obtained on detrital charcoal recovered from loess in trench 6. The authors' reasons for preferring the total-bleach ages include: (1) stratigraphic and soil relations showed that the loess in the trenches is almost certainly early Holocene in age, (2) the three total-bleach ages are relatively similar, and (3) the three TL ages are similar to TL ages obtained on loess from the American Fork trench site on the Provo section of the WFZ (Forman and others, 1989). Believing that the age differences between the total-bleach age estimates were significant, the authors inferred two surface-faulting events, one at 7.5 ka (event V) and the other at 8.5 ka (event U). They rejected the alternative explanation that all three total-bleach TL ages are statistically indistinguishable and only a single surface-faulting event occurred sometime around 7.5-8.5 ka, because there are other interevent times in the paleoearthquake sequence that are within 1 ka of each other.

Event T: The evidence for Event T includes: (1) scarp-derived (?) colluvium beneath a Av soil horizon in trench 6 that yielded a ^{14}C AMRT age of 14,165-15,557 cal yr B.P., and (2) liquefaction features in the deltaic topset beds exposed in trench 3. These data require an event earlier than 14.2–15.6 ka but later than abandonment of the delta surface at

16.5–17 ka. Therefore, the authors infer a surface faulting event that is >14,800±1200 cal yr B.P. and <17,000 cal yr B.P., the time of the Bonneville flood.

Possible Eighth Event: There is no stratigraphic evidence for a surface-faulting earthquake in the interval between Event T, which occurred while the delta surface was active, and Event U, but there is ambiguity in age estimates for abandonment of the delta and deposition of an early Holocene loess. Because of the ambiguity, the authors cannot disprove the occurrence of an additional faulting event (unlettered) that caused burial of an early phase of the loess at ~ 12 ka.

Dating Techniques

Radiocarbon dating: All samples except one were bulk, low-carbon-content soil A horizons. AMRT radiocarbon ages were converted to calendar years following the procedure outlined in Machette and others (1992, appendix A) and using the CALIB computer calibration program of Stuiver and Reimer (1993).

Thermoluminescence dating: TL analyses followed the procedures outlined in Forman and others (1989, 1991). Infrared stimulated luminescence analyses followed Forman (1999).

Quantitative analysis of soils: Soils were described using the horizon nomenclature of the Soil Survey Staff (1990) and Birkeland (1999). Particle-size samples were sieved to determine gravel content and analyzed by the hydrometer method to determine silt and clay content. Bulk-density data are gravel-free values determined using the paraffin-clod method.

Event Slip/Cumulative Slip:

None reported other than a general value of about 20 meters of cumulative down-to-the-west throw across the 300-meter-wide fault zone at the trench site.

Published Recurrence Interval:

Mean recurrence for the latest six events (Z through U; 5 closed seismic cycles) is 1275 years. In contrast the interval between Events T and U is 6300 years, with no evidence for an eighth event between those events.

Published Slip Rate:

None reported

Sources of Uncertainty:

1. Are Events V and U separate surface-faulting earthquakes at 7.5 ka and 8.5 ka, or was there only a single event sometime around 7.5-8.5 ka?
2. Is the scarp-derived colluvium denoted with a (?) in trench 6 and reported as evidence for Event T really tectonic in origin and indicative of a surface-faulting earthquake?

3. No evidence at this site for the ~ 4.6 ka event recognized by Personius (1991) at both his Brigham City and Pole Patch trench sites.
4. Uncertainties generally associated with the ^{14}C AMRT dating technique.

Summary:

McCalpin and Forman (2002) expand on the work of Personius (1991) on the BCS. They extend the chronology of surface-faulting earthquakes beyond the ~6 ka achieved by Personius to the abandonment of the Provo delta surface at about 16-17 ka. In the process they identify a MRE at their site that is younger than the MRE identified by Personius at his Brigham City trench site approximately 1 kilometer to the north. Although not reported by Personius, possible reasons given by McCalpin and Forman (2002) for not observing the younger MRE at the site to the north include: (1) not trenching a second scarp present at the Personius Brigham City site, and (2) not identifying or dating a possible post-3.6 ka colluvial wedge in the Personius Brigham City trench due to the wedge's small size and lack of organics (verbal communication, Personius to McCalpin). The younger MRE identified in this study reduces the post-MRE elapsed time on the BCS from 3.6 ka to ~ 2.1 ka.

The lack of information on net slip at this site precludes making a slip-rate determination, but 5 (?) closed seismic cycles allows calculation of a average surface-faulting recurrence interval of 1275 years for the past 8.5 ka.

References:

Birkeland, P.W., 1999, Soils and geomorphology: New York, Oxford University Press, 488 p.

Forman, S.L., 1999, Infrared and red stimulated luminescence dating of late Quaternary nearshore sediments from Spitsbergen, Svalbard: Arctic, Antarctic, and Alpine Research, v. 31, no. 1, p. 34-49

Foreman, S.L., Machette, M.N., Jackson, M.E., and Maat, P., 1989, An evaluation of thermoluminescence dating of paleoearthquakes on the American Fork segment, Wasatch fault zone, Utah: Journal of Geophysical Research, v. 94, p. 1622-1630.

Forman, S.L., Nelson, A.R., and McCalpin, J.P., 1991, Thermoluminescence dating of fault-scarp derived colluvium – Deciphering the timing of paleoearthquakes on the Weber segment of the Wasatch fault zone, north-central Utah: Journal of Geophysical Research, v. 96, no. B1, p. 595-605.

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.

Soil Survey Staff, 1990, Keys to soil taxonomy, 4th edition: Blacksburg, Virginia, SMSS Technical Monograph No. 19.

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

Name and Location of Fault/Fault Section:

Weber section (WS), Wasatch fault zone (WFZ), Weber and Davis Counties, Utah

Paleoseismic Data Source Documents:

Swan, F.H. III, Schwartz, D.P., and Cluff, L.S., 1980, Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault zone, Utah: Bulletin of the Seismological Society of America, v. 70, no. 5, p. 1431-1462.

Swan, F.H. III, Schwartz, D.P., Hanson, K.L., Knuepfer, P.L., and Cluff, L.S., 1981, Study of earthquake recurrence intervals on the Wasatch fault at the Kaysville site, Utah: U.S. Geological Survey Open-File Report 81-228, 30 p.

Nelson, A.R., Klauk, R.H., Lowe, Michael, and Garr, J.D., 1987, Holocene history of displacement on the Weber segment of the Wasatch fault zone at Ogden, northern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 5, p. 322.

Nelson, A.R., 1988, The northern part of the Weber segment of the Wasatch fault zone near Ogden, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 33-37.

Forman, S.L., Nelson, A.R., and McCalpin, J.P., 1991, Thermoluminescence dating of fault-scarp-derived colluvium - Deciphering the timing of paleoearthquakes on the Weber segment of the Wasatch fault zone, north-central Utah: Journal of Geophysical Research, v. 96, no. B1, p. 595-605.

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2199, 22 p. pamphlet, scale 1:50,000.

McCalpin, J.P., Forman, S.L., and Lowe, Mike, 1994, Reevaluation of Holocene faulting at the Kaysville site, Weber segment of the Wasatch fault zone, Utah: Tectonics, v. 13, no. 1, p. 1-16.

Geomorphic Expression:

The WS is the second longest section (56 km end-to-end; 81 km cumulative [trace]) of the WFZ, and is characterized by west-facing scarps along the western base of the Wasatch Range. The southern boundary of the section is at prominent bedrock salient (Salt Lake salient), but fault scarps in that area are easily confused with nontectonic features and scarp distribution is less certain (Machette and others, 1992). The northern section boundary is at another bedrock salient (Pleasant View salient). Scarp heights in the northern part of the WS suggest a higher rate of late Holocene faulting than on the Brigham City section to the north (Machette and others, 1992).

Evidence for Segmentation:

The WS extends from Barrett Canyon 3 kilometers north of North Ogden on the south side of the Pleasant View salient, to the Salt Lake City salient, a major footwall spur of bedrock that lies between Bountiful and northern Salt Lake City. The chronology of Holocene surface-faulting events differs between the WS and the BCS to the north and the Salt Lake City section (SLCS) to the south, indicating that the WS is an independent seismogenic source. At the Salt Lake City salient, the WFZ makes a 2 kilometer right step to the Warm Springs fault at the north end of the SLCS.

Age of Youngest Faulting:
Holocene

Summary of Existing Recurrence Interval Information:
Information about surface-faulting recurrence on the WS comes from three paleoseismic trenching studies: Garner Canyon (GC; WS-3, WS-6, & WS-7), East Ogden (EO; WS-3, WS-4, WS-5, WS-6, & WS-7), and Kaysville (WS-1, WS-2, & WS-8). At least three mid to late Holocene surface-faulting events were identified at each site. However, information regarding GC and EO is limited, particularly so for GC, so it is not known with certainty that the surface-faulting chronologies reported for those sites are complete. Two trenching studies at Kaysville combine to provide good information about the timing of the three most recent (mid to latest Holocene) surface-faulting events there. Evaluating long-term (latest Pleistocene) recurrence is more problematic. A post-Provo alluvial fan is displaced 10-11 meters at Kaysville, but estimates of the age of the fan vary by as much as 4-6 ka between studies, and the number of events that caused the displacement is not know with certainty.

Summary of Existing Slip-Rate Information:
Similarly, information on slip rates for the WS comes from the three paleoseismic studies conducted on the section (GC, EO, and Kaysville), as well as from 375 scarp profiles measured along the section by Nelson and Personius (1993). Neither individual event information nor cumulative net-slip values are well constrained at GC or EO over any time period. At Kaysville, a post-Provo alluvial fan is displaced 10-11 meters (net slip) across the fault zone, but estimates of the age of the fan vary by as much as 6 ka. The three most recent events at Kaysville are reliably dated, but there are no correlative geologic units exposed across the fault zone, so the reported slip-per-event values are estimates calculated from the geometry of deposits exposed in the trenches.

Nelson and Personius (1993) estimate that about 15 percent of the profiles they measured along the WS provide reliable information on net slip. Those data show that slip rates are relatively high (up to 2.8 mm/yr) along the central part of the WS but drop off toward both ends of the section. The decrease in slip appears to be more rapid to the north.

Comments:
There appear to have been a minimum of four, and possibly 5 (or more), mid to late Holocene surface faulting events on the WS. Statistical analysis shows that the MRE and PE events are the same at Kaysville and 25 kilometers to the north at EO, but that the APEs are different, resulting in minimum of four mid to late Holocene surface-faulting earthquakes on the WS. Based on information in a single trench at EO, a possible fifth, smaller event may have ruptured the northern part of the WS in the latest Holocene. The fact that the APEs at Kaysville and EO are different, and that the possible latest

Holocene event at EO is not recognized at either Kaysville to the south or at GC to the north, raises the possibility that the WS may be divided into subsections, with at least one possible subsection boundary suggested near Weber Canyon (McCalpin and others, 1994).

The record of mid to latest Holocene surface-faulting events is well constrained at Kaysville, and the per event net slip values for those earthquakes, while estimates, appear reasonable, so calculating recurrence and slip-rate estimates are possible for the mid Holocene at that location. Questions regarding both age of the post-Provo alluvial fan and the number of events that have displaced it makes calculating recurrence and slip-rate estimates more problematic for the latest Pleistocene at Kaysville. The number of events and displacement per event information are less well constrained at EO and GC, making recurrence and slip-rate values for those locations also less certain.

The Nelson and Personius (1993) scarp-profile data provides what they believe is reliable slip-rate information at several locations along the WS. The summary information reported regarding their profile database does not permit an independent evaluation of their results; however, their data are distributed all along the trace of the WS and show apparent systematic changes in slip rate along the trace of the section

References: (see list above)

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.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP
PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Kaysville ***Study Synopsis ID:*** WS-1

Fault/Fault Section: Weber section (WS), Wasatch fault zone (WFZ)

Map Reference: 2351e-3

Study:
Swan, F.H. III, Schwartz, D.P., and Cluff, L.S., 1980, Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault zone, Utah: Bulletin of the Seismological Society of America, v. 70, no. 5, p. 1431-1462.

Type of Study/Commentary:
This document includes a summary of the paleoseismic trenching study conducted by Woodward Clyde Consultants at the Kaysville site. A detailed report of that study is provided in Swan and others (1981; see WS-2). Included in this summary report is a mid-Holocene slip-rate estimate for the WFZ that is based on an explicitly stated age for the post-Provo alluvial-fan surface exposed at the site. Neither the slip rate, nor the estimated age of the fan surface are included in the Swan and others (1981) detailed report. However, Swan and others (1981) do imply a similar age for the fan in their discussion of the buried soils at the site.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:
See WS-2 for discussion

Age of Events/Datum Ages/Dating Techniques:
Information on the number and timing of mid- to late Holocene surface-faulting events is the same as reported in Swan and others (1981). However, this document provides an explicit age for the post-Provo alluvial fan of 6000±2000 years based on an estimated age of the soil formed on the fan surface.

Event Slip/Cumulative Slip:
See WS-2

Published Recurrence Interval:
See WS-2

Published Slip Rate:
1.8 (+1.0; -0.6) mm/yr determined by dividing the cumulative net vertical tectonic displacement of the post-Provo alluvial-fan surface (10-11 m) by 6000±2000 years. This appears to be an open slip rate with the time interval extending to the present.

Sources of Uncertainty:

1. The age of the soil formed on the post-Provo alluvial-fan surface is an estimate based on stratigraphic and topographic relations at the site and on soil-profile development. This study predates the ability to accurately ^{14}C date soil organics.
2. Based on their work at the Kaysville site, McCalpin and Forman (1994; WS-8) believe that the post-Provo fan is significantly older (> 8.5-10.4 ka) than 6 ka and that the slip rate reported here is therefore too high.
3. The reported slip rate includes at least one open seismic cycle.

Summary:

The slip rate reported may be too high based on later information developed at the Kaysville site, and for unknown reasons, the slip rate was not included in the more detailed Swan and others (1981) report on the Kaysville site.

References:

Swan, F.H. III, Schwartz, D.P., Hanson, K.L., Knuepfer, P.L., and Cluff, L.S., 1981, Study of earthquake recurrence intervals on the Wasatch fault at the Kaysville site, Utah: U.S. Geological Survey Open-File Report 81-228, 30 p.

McCalpin, J.P., Forman, S.L., and Lowe, Mike, 1994, Reevaluation of Holocene faulting at the Kaysville site, Weber segment of the Wasatch fault zone, Utah: Tectonics, v. 13, no. 1, p. 1-16.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Kaysville ***Study Synopsis ID*:** WS-2

***Fault/Fault Section*:** Weber section (WS), Wasatch fault zone (WFZ)

Map Reference: 2351e-3

Study:

Swan, F.H. III, Schwartz, D.P., Hanson, K.L., Knuepfer, P.L., and Cluff, L.S., 1981, Study of earthquake recurrence intervals on the Wasatch fault at the Kaysville site, Utah: U.S. Geological Survey Open-File Report 81-228, 30 p.

Type of Study/Commentary:

Trenching. This site includes a prominent west-facing main scarp at the base of Wasatch Range on the east, a set of en echelon, east-facing antithetic scarps on the west, and an intervening graben. The height of the main scarp decreases from 22 meters in the central part of the site to less than 10 meters to the north, where it is partially buried by stream alluvium. The antithetic scarps vary in height from less than 1 to 2.5 meters. The site lies below the Provo shoreline of Lake Bonneville, and lacustrine sediments are exposed in the main fault scarp. Post-Provo alluvial-fan deposits overlie the lacustrine sediments. Faulting has displaced the alluvial-fan surface down-to-the-west across the main fault scarp and the graben.

Five test pits and seven trenches (A through G) were excavated across the southern end of a closed depression in the graben in the central part of the site. The test pits were used to locate the contact between alluvial-fan and lacustrine deposits and to search for dateable material within the graben. Trench A was the longest and extended from the main scarp, across the graben, and through the antithetic fault. Trench G was on the main scarp only. Trenches C and E were excavated across the antithetic fault, and trenches B, D, and F were all within the graben.

Quaternary stratigraphy exposed in the trenches included: (unit 1) Lake Bonneville lacustrine deposits, (unit 2) post-Provo alluvial-fan deposits, (unit 3) sag-fill deposits in the graben and interbedded APE scarp-derived colluvium, (unit 4) locally derived sag-fill deposits and associated PE scarp-derived colluvium, (unit 5) pond deposits, (unit 6) MRE scarp-derived colluvium, (unit 7) pre-settlement pond deposits (first post-faulting unit), and (unit 8) historical deposits. Two weak to moderately developed paleosols were identified in the trenches. Soil S1 is formed on the post-Provo alluvial fan, and soil S2 is formed on gravelly colluvium of unit 4B and fine-grained sag deposits of unit 3B.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

Three late Holocene surface-faulting events based on the presence of scarp-derived colluvial-wedge deposits (units 3A, 4A & 4B, 6A & 6B) identified in trenches.

Age of Events/Datum Ages/Dating Techniques:

Detrital charcoal recovered from unit 3C, a sag-fill deposit that grades laterally into and partially underlies colluvium derived from the APE (unit 3A), provided a conventional radiocarbon age of 1580±150 ^{14}C yr B.P. This is the only ^{14}C age estimate obtained during this study. Bits of detrital charcoal in other units were too small to date given the ^{14}C dating techniques available at that time, and even though organic-rich paleosol A-horizons were present in the trenches, this study pre-dates the advent of ^{14}C AMRT dating procedures. Based on the stratigraphy exposed in the trenches, the **APE pre-dates 1580±150 ^{14}C yr B.P. and the PE and MRE post-date that age estimate**.

This study also predates the revised Lake Bonneville chronology that has emerged in the two decades since this investigation was completed. Based on the lake chronology current at the time, the Provo shoreline was abandoned ~12 ka, implying that the 10 to 11 meters of net slip measured at this site occurred in that time period. More recent information shows that Lake Bonneville dropped below the Provo shoreline approximately 17,000 cal ka, adding an additional ~5 ka to the time period during which the 10 to 11 meter displacement of the Lake Bonneville – post-Provo alluvial fan contact occurred.

Event Slip/Cumulative Slip:

Displacements are estimates based on stratigraphic and structural relations in trenches for the MRE and PE and are unknown for the APE and earlier events.

MRE = minimum 1.8 meters
PE = minimum 1.7 meters
APE = unknown, 10 to 11 meters of total post-Provo net slip minus a minimum 3.5 meters net slip during the MRE and PE = a maximum of 6.5 to 7.5 meters of remaining slip. Stratigraphic relations at the site allow the possibility that more than one event may have occurred between the PE and abandonment of the Provo shoreline, thus reducing the net slip associated with the APE.

Cumulative tectonic displacement of the contact between the lacustrine sediments and the post-Provo alluvial-fan deposits across the main fault and the graben is 10 to 11 meters down-to-the-west.

Published Recurrence Interval:

Based on the 1580±150 ^{14}C yr B.P. radiocarbon age and stratigraphic relations between the PE and MRE colluvial wedges and associated deposits, the authors conclude that the interval between the two most recent surface-faulting events is unlikely to be greater than 1000 years or less than 500 years. If the MRE displacement is typical of past surface-faulting earthquakes, it would take five to six events to produce the 10 to 11 meters of cumulative net displacement observed at this site. Since the displacement occurred over an assumed time period of 12 ka, the authors conclude that recurrence between surface-faulting earthquakes here is probably closer to 1000 years than 500 years.

Published Slip Rate:

None (see WS-1)

Sources of Uncertainty:

1. Only a single ^{14}C date on which to base all event timing.
2. Recurrence estimate is based on an age for abandonment of the Provo shoreline that is now known to be too young by several thousand years.
3. Net slip per event values could not be measured directly and are estimates based on stratigraphic and structural relations in the trenches
4. McCalpin and others (1994) revisited the Kaysville site in 1988 and established a revised chronology for the three most recent surface-faulting events on the basis of additional ^{14}C and thermoluminescence (TL) age estimates. The results of that study are not in close agreement with the surface-faulting chronology reported here.

Summary:

This is one of the earliest (field work conducted in 1978) trenching studies conducted on the WFZ, and it was at this site that many of the concepts now regularly employed to interpret stratigraphic and structural relations exposed in trenches excavated on normal-slip faults were first developed. However, the study predates several advances in ^{14}C dating technology and TL dating entirely, thus limiting the study to a single conventional ^{14}C age. This study also predates development of a detailed, calendar-calibrated Lake Bonneville chronology. It is now known that the Provo shoreline was abandoned ~5 ka earlier than the authors of this study believed, providing significant additional time in which the displacement observed at this site could occur and lengthening the average recurrence between events.

References:

McCalpin, J.P., Forman, S.L., and Lowe, Mike, 1994, Reevaluation of Holocene faulting at the Kaysville site, Weber segment of the Wasatch fault zone, Utah: Tectonics, v. 13, no. 1, p. 1-16.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: East Ogden/Garner Canyon ***Study Synopsis ID:*** WS-3

Fault/Fault Section: Weber section (WS), Wasatch fault zone (WFZ)

Map Reference: 2351e-1 & 2351e-2

Study:

Nelson, A.R., Klauk, R.H., Lowe, Michael, and Garr, J.D., 1987, Holocene history of displacement on the Weber segment of the Wasatch fault zone at Ogden, northern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 5, p. 322.

Type of Study/Commentary:

Trenching. This is an abstract for a poster session presented at a Geological Society of America meeting in 1987. It summarizes preliminary information for the East Ogden and Garner Canyon trench sites on the northern portion of the WS. Because it is short, the abstract is reproduced below in its entirety.

Abstract

Colluvial wedges in six exposures at two sites on the Weber segment of the Wasatch fault zone in northern Utah were deposited following the last three to four >1-m displacement events on the fault. At the site in north Ogden [Garner Canyon], *the last two events, each of 1.4-m displacement, occurred <2 ka and 1.1 ka based on A-horizon mean-residence* ^{14}C *ages. At the site in east Ogden* [East Ogden], *two scarps displace lower to middle Holocene fan deposits 5 m and 7 m. Where these scarps cut upper Holocene fan deposits, displacements are only 1 m and 2.5 m, respectively. Colluvial stratigraphy in a trench across the 5-m scarp suggests a 3- to 4-m event during the early to middle Holocene followed by a 1-m event in the late Holocene. On the 7-m scarp, a 2.5- and to 4-m event occurred during the middle or late Holocene followed by a 1.5- to 2.5-m event during the late Holocene; there may also have been an early Holocene event. An antithetic fault moved about 1 m during the latest event on the 7-m scarp. Radiocarbon analysis of charcoal and concentrated organic-rich sediment from buried A horizons should provide maximum and minimum ages for these events. The ages may show whether displacements occurred on both scarps during some events and whether slip rates on the fault decreased during the late Holocene.*

Summary:

This abstract presents preliminary information about the East Ogden and Garner Canyon trench sites. The information for both sites was refined in later publications (Nelson, 1988; Machette and others, 1992); however, because the available data are very limited for both sites, the abstract is presented here for completeness.

References:

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Nelson, A.R., 1988, The northern part of the Weber segment of the Wasatch fault zone near Ogden, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 33-37.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP
PALEOSEISMIC STUDY SUMMARY FORM

Site Name: East Ogden (EO) ***Study Synopsis ID***: WS-4

Fault/Fault Section: Weber section (WS), Wasatch fault zone (WFZ)

Map Reference: 2351e-2

Study:
Nelson, A.R., 1988, The northern part of the Weber segment of the Wasatch fault zone near Ogden, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 33-37.

Type of Study/Commentary:
Trenching. At EO three down-to-the-west fault scarps and one down-to-the-east antithetic scarp define a fault zone that is about 100 meters wide. Five trenches were excavated across three of the scarps: two on the easternmost 5-meter-high scarp (scarp S1), two on the next scarp to the west, which is 8 meters high (scarp S2), and one across the antithetic scarp (scarp S2a), which parallels scarp S2. No trenches were excavated across the westernmost down-to-the-west scarp.

The trenches across scarps S1 and S2 exposed a thick (> 3 m) sequence of bouldery stream and debris-flow deposits overlying deltaic sands and gravels probably deposited near the Provo-level of Lake Bonneville about 14 ka. Scarp-derived, colluvial-wedge deposits allowed interpretation of the number and size of surface-faulting events.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:
Three, possibly four/colluvial-wedge deposits

Age of Events/Datum Ages/Dating Techniques:
Colluvial-wedge stratigraphy and both ^{14}C and TL ages from trenches across the two down-to-the-west scarps suggest two events during the middle Holocene followed by a third event in the late Holocene. Mixing of near-surface stratigraphic units by burrowing animals and interpretive problems with ^{14}C ages made it difficult to determine if the S2 scarp was also displaced by a smaller fourth event in the past 0.5-0.6 ka. Evidence for this latest Holocene event is confined to single trench (EO-3). The trench across antithetic scarp S2a contained evidence for a single late Holocene event.

The authors labeled the four surface-faulting earthquakes at this site from oldest (a) to the youngest (d). The estimated ages of the events in thousands of years are shown below as determined in each trench.

EO-1 (scarp S1): a <4.7, b <2.6, c <1.1
EO-2 (scarp S2): a >3.5 & <5.2, b >1.2 & <3.5, c <0.9
EO-3 (scarp S2): c <1.1, d <0.6
EO-4 (scarp S2a): c >0.5 & <1.1
EO-5 (scarp S1): c >0.6 & <0.8

A total of 19 ^{14}C ages, three on charcoal and 16 on soil organics, were obtained at this site. Numerous problems were encountered with the ^{14}C AMRT ages on soil organics. Two pairs of ages were inverted and four samples yielded greater than 112 percent modern carbon – likely due to contamination with modern "bomb" carbon.

Thermoluminescence analysis of fine-grained, distal colluvium helped constrain the age of the faulting events, particularly the older events, and allowed correlation of events between trenches that were not possible with ^{14}C ages alone.

***Event Slip/Cumulative Slip*:**
Stratigraphic displacements ranged from 0.6 to 3.5 meters per event in individual trenches. Total displacement per event could not be calculated because the westernmost down-to-the-west scarp in the fault zone was not trenched.

No cumulative slip value was reported for this site.

***Published Recurrence Interval*:**
The recurrence of surface-faulting earthquakes for the past 6 ka is reported as ranging from 0.4 to 2.2 ka and averaging about 1.4 ka.

***Published Slip Rate*:**
About 6.5 feet/1000 yrs. (2 meters post 5.5 ka), which contains at least one open seismic cycle.

***Sources of Uncertainty*:**

1. This is a summary report that presents few details regarding the study (lacks trench logs) or about how the resulting data were analyzed.
2. One main, down-to-the-west fault scarp was not trenched, so it is unclear if the information presented on the number, timing, and displacement of surface-faulting earthquakes is complete.
3. No details are provided regarding how the ^{14}C and TL ages were used to constrain the timing of the surface-faulting events.
4. Numerous interpretive problems were encountered with the ^{14}C AMRT ages as the result of contamination of buried soil horizons with "bomb" carbon and by the effects of burrowing animals.
5. The report contains no information on how the samples for AMRT ^{14}C dating were collected, or the manner in which the ^{14}C ages were calibrated.
6. Displacements are reported on a "per/scarp" basis, with no information on total displacement per event or on cumulative displacement across the entire fault zone.

***Summary*:**

This is a summary report that presents few details about how the study was conducted or how the new paleoseismic data were interpreted. In addition, a prominent scarp at this site was not trenched, thus likely making the record of surface faulting at this site incomplete.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP
PALEOSEISMIC STUDY SUMMARY FORM

Site Name: East Ogden (EO) ***Study Synopsis ID***: WS-5

Fault/Fault Section: Weber section (WS), Wasatch fault zone (WFZ)

Map Reference: 2351e-2

Study:

Forman, S.L., Nelson, A.R., and McCalpin, J.P., 1991, Thermoluminescence dating of fault-scarp-derived colluvium - Deciphering the timing of paleoearthquakes on the Weber segment of the Wasatch fault zone, north-central Utah: Journal of Geophysical Research, v. 96, no. B1, p. 595-605.

Type of Study/Commentary:

Trenching. Two of this study's co-authors (Forman & McCalpin) used trench exposures at EO resulting from the paleoseismic study conducted there by the third co-author (Nelson) to examine the relationship between TL and ^{14}C ages and their utility for dating paleo-surface-faulting earthquakes. The work reported upon in this study is limited to two of the five trenches excavated by Nelson at EO, and no additional trenches were excavated as part of this investigation.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

Three/colluvial-wedge stratigraphy (see WS-4)

Age of Events/Datum Ages/Dating Techniques:

MRE = 1.0-1.4 ka.
PE = 2.5-3. ka
APE = 3.5-4.5 ka

The age estimates for the three surface-faulting earthquakes recognized in the two EO trenches examined as part of this study are based on a combination of TL (11) and ^{14}C (9) ages. The relatively broad range of the age estimates for the three events reflects the authors' interpretation of the precision of the TL and ^{14}C dating, and the ambiguities of relating the age estimates to faulting events. Based on those considerations, the authors felt that determining the times of past faulting events is limited to intervals of 1000-500 years.

Event Slip/Cumulative Slip:

None reported

Published Recurrence Interval:

None reported

***Published Slip Rate*:**
None reported

***Sources of Uncertainty*:**
1. Only information from two of the five trenches excavated at this site was included in this study.
2. The original paleoseismic study at this site, Nelson (1988; WS-4) recognized a possible fourth, smaller surface-faulting event. This study did not address the evidence for that event or attempt to date it.
3. There are three prominent down-to-the-west fault scarps at this site, the westernmost of which was not trenched, so the record of surface-faulting earthquakes at this site may not be complete (see similar comment WS-4).

***Summary*:**
The intent of this study was to demonstrate the utility of using TL age dating in conjunction with ^{14}C ages to constrain the timing of surface-faulting earthquakes recognized in trench exposures. The study was limited to a selected data set and did not address all of the trenches excavated at the East Ogden site or all of the possible events recognized by previous workers. The three age estimates provided for the surface-faulting earthquakes recognized in the two trenches examined (trenches 1 and 2 this study; trenches EO-1 and EO-2 of Nelson [1988]) represent a refinement of the ages reported by Nelson (1988). However, because the westernmost down-to-the-west scarp at this site remained untrenched, the completeness of the paleoearthquake record at East Ogden is in doubt.

References:
Nelson, A.R., 1988, The northern part of the Weber segment of the Wasatch fault zone near Ogden, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 33-37.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: East Ogden/Garner Canyon (EO/GC) ***Study Synopsis ID***: WS-6

Fault/Fault Section: Weber section (WS), Wasatch fault zone (WFZ)

Map Reference: 2351e-1, 2351e-2

Study:
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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Type of Study/Commentary:
This is a summary presentation of the USGS paleoseismic investigations conducted at EO and GC on the northern portion of the WS. The Swan and others (1980 [WS-1], 1981 [WS-2]) Kaysville publications are referenced, as is the Forman and others (1991 [WS-5]) study at EO, but this document predates McCalpin and others (1994 [WS-8]) reevaluation of the Kaysville site.

Other studies (Nelson, 1988 [WS-4]; Forman and others, 1991) present a map and description of the paleoseismic investigations at EO. No map of the GC site is available in either this or in other documents. The scarp at GC is reported to be 6 meters high and to have a vertical displacement of 4.4 meters. The authors believe three to four surface-faulting earthquakes produced the scarp in middle to late Holocene time. No information is provided regarding the geologic setting at GC, so it is not known if more than one scarp is present at the site. The GC trench log is believed to be of a natural exposure and not a trench.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:
East Ogden
Three to four/colluvial-wedge stratigraphy (see WS-4)
Garner Canyon
Three to four/combination of colluvial-wedge stratigraphy and scarp height

Age of Events/Datum Ages/Dating Techniques:
East Ogden
This document summarizes the results of Nelson (1988) and Forman and others (1991), and discusses the problems encountered with the ^{14}C ages at the site and the combined use of TL and ^{14}C ages to constrain the timing of the three unequivocal faulting events recognized at EO. The

authors present a somewhat different set of age ranges for the three events than those reported by Nelson (1988) or Forman and others (1991). The new age ranges are shown below with the Forman and others (1991) ranges following in parentheses:

MRE = 0.8-1.2 ka (1.0-1.4 ka)
PE = 2.5-3.0 ka (2.5-3.5 ka)
APE = 3.5-4.0 ka (3.5-4.5 ka)

No explanation is provided regarding why the age ranges for the three events were changed. The fourth, smaller event identified by Nelson (1988) was acknowledged as a probable event, based on a comparison with the results obtained by Swan and others (1981) at the Kaysville site 23 kilometers to the south.

Garner Canyon

The age ranges for the three most recent events at Garner Canyon are reported as follows:

MRE = 0.8-1.2 ka
PE = 1.5-2.0 ka
APE = >2.2 ka

These ages are based on comparison with the timing of events at EO and on ^{14}C AMRT ages on organic matter concentrated from soil A-horizons.

***Event Slip/Cumulative Slip*:**

East Ogden

Five-meter scarp

Two middle Holocene events each with about 2.2 meters of displacement

One late Holocene event with 0.9 meters of displacement

Eight-meter scarp

Two middle or late Holocene events of 2.5 and 3.5 meters displacement, respectively

Followed by a late Holocene event of 2.2 meters

Gardner Canyon

The two most recent events each produced about 1.0 meter of displacement. No information is reported for the oldest event.

***Published Recurrence Interval*:**

None reported

***Published Slip Rate*:**

0.9-1.9 mm/yr over the past 15 ka for the central three-quarters of the WS based on 77 topographic profiles across scarps in the field and an additional 298 profiles measured from aerial photographs using a photogrammetric plotter. No slip-rate information was reported specifically for either the EO or GC sites.

***Sources of Uncertainty*:**

1. See WS-4 and WS-6
2. Published information available for GC is cursory. Neither the topographic nor the geologic settings of the site are described; the number of fault scarps at the site is unknown.
3. Ages of the three faulting events at GC appear to be poorly constrained and rely to some extend on correlation with dated events at EO.
4. No information is provided regarding how the samples for the ^{14}C ages were collected or if the age estimates are calendar calibrated.
5. Net slip is not known with certainty at GC; it may be 4.4 meters if there is only a single scarp.
6. Although the EO and GC are relatively close to one another, there is a very large difference in displacement per event values.
7. Slip-per-event values are presented on a per scarp basis. They do not account for the effects of possible back tilting and graben formation, and do not include the possible contribution to total slip from the westernmost, untrenched scarp.

***Summary*:**

This document presents a slightly revised set of age estimates for the three mid- to late Holocene surface-faulting events recognized at EO, and is the most complete source of information for GC; however, the information presented for GC remains very limited.

References:

Swan, F.H. III, Schwartz, D.P., and Cluff, L.S., 1980, Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault zone, Utah: Bulletin of the Seismological Society of America, v. 70, no. 5, p. 1431-1462.

Swan, F.H. III, Schwartz, D.P., Hanson, K.L., Knuepfer, P.L., and Cluff, L.S., 1981, Study of earthquake recurrence intervals on the Wasatch fault at the Kaysville site, Utah: U.S. Geological Survey Open-File Report 81-228, 30 p.

Nelson, A.R., Klauk, R.H., Lowe, Michael, and Garr, J.D., 1987, Holocene history of displacement on the Weber segment of the Wasatch fault zone at Ogden, northern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 5, p. 322.

Nelson, A.R., 1988, The northern part of the Weber segment of the Wasatch fault zone near Ogden, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 33-37.

Forman, S.L., Nelson, A.R., and McCalpin, J.P., 1991, Thermoluminescence dating of fault-scarp-derived colluvium - Deciphering the timing of paleoearthquakes on the Weber segment of the Wasatch fault zone, north-central Utah: Journal of Geophysical Research, v. 96, no. B1, p. 595-605.

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

McCalpin, J.P., Forman, S.L., and Lowe, Mike, 1994, Reevaluation of Holocene faulting at the Kaysville site, Weber segment of the Wasatch fault zone, Utah: Tectonics, v. 13, no. 1, p. 1-16.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Weber section summary document ***Study Synopsis ID*:** WC-7

***Fault/Fault Section*:** Weber section (WS), Wasatch fault zone (WFZ)

Map Reference: 2351e

Study:

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2199, 22 p. pamphlet, scale 1:50,000.

Type of Study/Commentary:

This document (map and accompanying booklet) presents the results of the authors' mapping of the WS. It includes a brief description of the paleoseismic studies conducted at Garner Canyon (GC), East Ogden (EO), and Kaysville, and presents new information on slip rates at GC and EO (see below). This document does not include the results of McCalpin and others (1994 [WS-8]) re-evaluation of the Kaysville site. This document also summarizes the results of an extensive scarp profiling effort on the WS that included 77 scarp profiles measured in the field and 298 additional profiles measured from aerial photographs using a photogrammetric plotter. The results of this scarp-profiling study provide the most complete slip-rate information currently available for the WS.

Fault Parameter Data:

See the paleoseismic source document forms completed for the GC, EO, and Kaysville sites (WS-1, WS-2, WS-3, WS-4, WS-5) for details of the paleoseismic studies conducted at those locations.

The authors of this document estimate that approximately 15 percent of the 375 profiles they measured along the WS gave surface-offset values that were within 10 percent of the total vertical offset (net slip) across the fault zone during the elapsed time since deposition of the map units that were profiled, and therefore provide reliable displacement data for slip-rate calculations. A north to south summary along the WS of what the authors consider reliable slip-rate information follows:

1. Slip rates throughout the Holocene at the north end of the Weber segment are about **0.5-1.2 mm/yr**. Limited data at two sites in the northern boundary area suggest post-Bonneville rates may be as low as **0.7 mm/yr**.
2. Southeast of North Ogden, scarps at the mouth of Coldwater Canyon indicate a rapid increase in slip on the fault to the south. Scarp data provide late Holocene slip rates of about **1.0-2.3 mm/yr** and rates of about **1.1-1.8 mm/yr** for the post-middle Holocene and post-Bonneville periods north of the canyon mouth.
3. Late Holocene slip rates calculated at GC using stratigraphic and scarp-profile data are about **1.2$\pm$0.3 mm/yr**. A scarp with 21 meters of offset in lacustrine gravel below

the Provo shoreline on the north edge of the GC fan is considered representative of post-Provo level offset and yields a rate of about **1.4±0.2 mm/yr**.

4. The post-mid-Holocene slip rate reported for the EO site north of Ogden Canyon is **2.8±0.4 mm/yr**, but it is unclear if this value was obtained from scarp-profile data or from displacements measured in trenches.
5. Slip rates based on displacements across scarps south of Taylor Canyon east of Ogden are **1.1-2.8 mm/yr** for the late Holocene and **1.2-1.9 mm/yr** since the latest Pleistocene.
6. South of the Weber River and east of Hobbs Reservoir scarp-profile data give a pre-late Holocene slip rate of **2.7±0.8mm/yr**. Three profiles across a 27-meter-high scarp formed on Bonneville-cycle lacustrine deposits suggest a slip rate of **2.0 mm/yr**.
7. One kilometer south of Shepards Creek (south of the Kaysville trench site) surface offset was 23.5 meters in Lake Bonneville undifferentiated gravel and sand yielding a post 14-ka slip rate of about **1.6±0.1 mm/yr**.
8. Latest Pleistocene slip rates are high near Farmington (**1.1-1.6 mm/yr**), but begin to decrease to the south.
9. About 1 kilometer north of Ricks Creek northeast of Centerville the post-Provo slip rate is **1.5±0.2 mm/yr**, but at Parish Creek and south of Centerville Canyon east of Centerville the slip rate has decreased to **1.1±0.2 mm/yr** (time period not specified).
10. Near Bountiful offset measurements across the main scarp indicate a post-Provo slip rate of about **0.7±0.2 mm/yr**.
11. Near North Canyon at the southern boundary of the Weber segment the slip rate is **0.6±0.2 mm/yr** for the past 1.5 ka.

The authors conclude that although post-latest Pleistocene slip rates are fairly uniform in the center of the WS, they decrease toward both ends of the section, but decrease more rapidly to the south than to the north.

Sources of Uncertainty:

1. The authors estimate that uncertainties due to errors in calculating displacements across scarps are probably ±10-30 percent.
2. The authors estimate that errors in estimating the numerical age of Holocene deposits at many sites are as much as ±50-100 percent.
3. All slip-rate estimates include at least one open seismic cycle.

Summary:

This document summarizes the results of an extensive scarp profiling effort along the WS, and provides what the authors believe are reasonable constraints on slip rates at locations along the WS. The complete 375-profile data set is not provided, and no attempt was made to demonstrate if systematic changes in slip have occurred between the latest Pleistocene and the late Holocene based on these data.

References:

McCalpin, J.P., Forman, S.L., and Lowe, Mike, 1994, Reevaluation of Holocene faulting at the Kaysville site, Weber segment of the Wasatch fault zone, Utah: Tectonics, v. 13, no. 1, p. 1-16.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Kaysville ***Study Synopsis ID***: WS-8

Fault/Fault Section: Weber section (WS), Wasatch fault zone (WFZ)

Map Reference: 2351e-3

Study:
McCalpin, J.P., Forman, S.L., and Lowe, Mike, 1994, Reevaluation of Holocene faulting at the Kaysville site, Weber segment of the Wasatch fault zone, Utah: Tectonics, v. 13, no. 1, p. 1-16.

Type of Study/Commentary:
Trenching. In 1988 the authors excavated a 39-meter-long trench parallel to and 2 meters south of Swan and others' (1981; WS-2) Trench A at the Kaysville site. Both walls of the new trench exposed undisturbed sediment. Unlike the Swan and others (1981) trench, the new trench did not extend entirely across the graben and therefore did not expose the antithetic fault zone. The purpose of the new trench was to reevaluate the timing and nature of latest Pleistocene and Holocene faulting at Kaysville by taking advantage of advances in ^{14}C dating techniques and the advent of TL dating technology.

Stratigraphic units in the 1988 trench were subdivided into nine lithologic facies based on differences in grain size and sedimentary structures. The oldest deposits exposed in the trench include nearshore Lake Bonneville lacustrine deposits (unit 1) and post-Provo alluvial-fan deposits (unit 2). The remaining geologic units in the trench fall into one of two broad categories, either graben fill (from oldest to youngest, units 3, 4, 5, 6A-6B, 7A-7C, 8, and 9A) or scarp-derived colluvium (units 6D-6E, 7D-7E, and 9B-9D). The graben-fill and colluvial-wedge deposits interfinger and are separated by buried soil A-horizons into three generally contemporaneous couplets, each characteristic of a surface-faulting earthquake.

Two deformation zones were present in the trench, the main normal-fault zone at the east end of the trench and a broader zone of tension fissures and small normal faults at the west end. The main fault consists of highly sheared lacustrine sand in a zone up to 40 centimeters wide along a steeply dipping fault trace. The fissure zone extends from the 11-meter mark in the trench to beyond the west end of the trench. The authors interpret this densely fissured zone as a tilt "hingeline" separating faulted but nearly horizontal graben-fill deposits on the west from progressively east-tilted, but relatively unfaulted graben deposits to the east.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:
Five to six in post-Provo time (past 13,000 ^{14}C yr B.P.). Identification of the two to three oldest events relies heavily on sedimentary characteristics of geologic units, indicators of original dip angle in the trench, and the number of events

required to account for the total net vertical tectonic displacement across the fault zone. Evidence for the three youngest events is provided by scarp-derived, colluvial-wedge deposits (units 6D-6E, 7D-7E, and 9B-9D) exposed in the trenches (see below for a discussion of the uncertainty associated with unit 5).

Age of Events/Datum Ages/Dating Techniques:

The authors' preferred interpretation of surface faulting at this site is for four surface-faulting earthquakes recognized from colluvial wedges and tilting of graben-fill deposits (Events 2, 3, 4, 5) and an additional 1-2 events (1a, 1b[?]) suggested by the total height of the scarp and depth of the graben. All five or six events postdate deposition of the post-Provo alluvial fan, the age of which could not be constrained.

Event(s) 1a (1b?): One or two events postdate deposition of unit 2 (post-Provo alluvial fan), but predate deposition of unit 3 (perennial pond deposit). Interpretation of this event(s) is based on geometrical reconstruction of the deposits in the trench. Scarp-derived colluvium associated with this event(s) is presumed to be buried beneath the floor of the trench. Based on extrapolation of a constant deposition rate, the authors assign an age of circa 8.5-10.2 ka for the lower part of unit 3 (see below). Unit 3 could not be dated directly because TL ages on older, water-laid sediments gave ages that were consistently too old. However, the authors believe that the absence of a soil on the post-Provo alluvial-fan surface beneath unit 3 implies that earliest graben sedimentation began immediately after cessation of post-Provo fan deposition.

> ***Swan and others (1981; WS-2) dated unit 3 at 1.5 ka based on a ^{14}C age on detrital charcoal. The authors of this study suggest that the Swan and others (1981) charcoal sample was actually a root that was carbonized or burned in situ, and that their 1580±150 ^{14}C yr B.P. age represents the age of the land surface on which the plant was growing (soil S3) not the age of unit 3. Also, Swan and others (1980; WS-1) report an estimated age for the post-Provo fan based on the profile development recognized in a buried paleosol formed on the fan deposits. This study states that no soil is present on the buried fan deposits (see above) and assigns an age to the fan that is approximately twice that reported by Swan and others (1980) for unit 2.***

Event 2: Postdates unit 3, predates unit 4 (coarse stream alluvium deposited following diversion of a stream into the graben formed by the faulting event), and is reported to be represented by scarp-derived colluvium of unit 5 (p. 11). Uncertainty exists regarding the stratigraphic evidence for this earthquake (see below), and no age estimate is provided for this event.

> ***In the "Stratigraphy" section of this report, unit 5 was specifically identified as a graben-fill deposit and not a colluvial-wedge deposit (p. 2). In table 1 (p. 4), "Sedimentology of Deposits Exposed in the 1988 Kaysville Trench," unit 5 is identified as hillslope colluvium and is not attributed to a surface-faulting earthquake, unlike other colluvial-wedge deposits described in the table. In the section on "Displacement of Individual Paleoevents," the authors state that the colluvial wedge for Event 2 is buried beneath the trench floor.***

Consequently, the origin and significance of unit 5, and therefore the evidence for Event 2, is unclear based on the conflicting information contained in this report.

Event 3: This event tilted soil S1, which had formed on the Event 2 colluvial wedge (unit 5?). Post-faulting colluvial-wedge deposits 6C and 6D bury soil S1. After a stable scarp slope was achieved, soil S2 forms on the Event 3 colluvial wedge. Estimated event age 3.8-7.9 ka (preferred event range 5.7-6.1 ka).

Soil S2, which formed on the Event 3 colluvial wedge (unit 6), was not dated by either ^{14}C or TL methods.

Event 4: Scarp-derived colluvial-wedge unit 7 deposited in response to this event. Soil S3 formed on the distal wash facies (units 7A and 7B) colluvium. Estimated event age 2.8±0.7 ka

Event 5: Scarp-derived colluvial-wedge (unit 9) buried soil S3 in response to this event. Estimated event age 0.6-0.8 ka.

The authors' preferred ages for Events 3, 4, and 5 (see above) are presented in the report abstract and again in the section on "Slip Rates, Recurrence Intervals, and Paleomagnitude Estimates," but the report does not report the details of how the ages for the three events were determined from available ^{14}C and TL age estimates, nor is information presented on how the preferred age range for Event 3 was determined.

<u>Dating Techniques</u>

Three ^{14}C AMRT ages were obtained from buried soil A-horizons (S1 & S3), and one ^{14}C AMRT age was obtained from organic material filling a fissure in unit 5. The ^{14}C AMRT ages were adjusted following the procedure of Machette and others (1992, appendix A) using a MRC for carbon in the soil of 300±200 years. The ^{14}C ages were then calendar corrected using the CALIB computer calibration program of Stuiver and Reimer (1986).

The TL ages for this study followed the procedures outlined by Forman and others (1989, 1991). All TL samples were analyzed by both the total- and partial-bleach techniques. Good correlation was achieved between TL ages and ^{14}C AMRT ages, but water-borne sediments yielded TL ages that were consistently too old. The authors believe that rapid transport and deposition of these sediments did not allow for complete zeroing of their inherited TL signals.

Event Slip/Cumulative Slip:

The displacement for individual surface-faulting earthquakes could not be measured directly because no correlative strata were preserved on both sides of the fault zone in the trench. Individual cumulative net vertical tectonic displacements (CNVTD) were estimated based on nested assumptions regarding deposit geometry in the trench.

EVENT	CNVTD
5	1.7 – 1.9 m
4	2.3 – 3.4 m
3	1.4 m
Total 3 most-recent events	4.9 – 6.1 m
Mean displacement	1.6 – 2.0 m
Total across entire fault zone	10.0 – 11.0 m
Total displacement minus latest 3 events	3.9 – 6.1 m
Number of events accounting for the residual	2 – 3

***Published Recurrence Interval*:**
2.7-3.6 ka for the time span 0.8-6.1/7.9 ka (interval between events 3 and 5). Composite recurrence interval for post-Provo time ($\leq$13 ka) assuming five or six paleoearthquakes is 2.2 to 2.6 ka.

The reported composite recurrence interval extends across all post-Provo time to the present and therefore includes at least one open seismic cycle. Also note that the authors used "post-Provo" time ($\leq$13 ka) to calculate the composite recurrence interval, but used the estimated age of the post-Provo alluvial fan (10-12 ka) to calculate the composite slip rate (see below). Additionally, the composite recurrence estimate relies on a now outdated age (too young) for abandonment of the Provo shoreline.

***Published Slip Rate*:**
Composite slip rate of 0.8-1.1 mm/yr based on 10 to 11 meters of net tectonic displacement in ~12 ka (estimated age of the post-Provo fan) to the present.

The reported composite slip-rate extends to the present and includes at least one open seismic cycle. The composite slip rate is based on the estimated age of the post-Provo fan, in contrast to the composite recurrence interval, which was calculated using the time since abandonment of the Provo shoreline. Additionally, 11,000mm/12,000yr = 0.9 mm/yr not 1.1 mm/yr as stated in the report.

A mid-Holocene slip rate defined by Events 3, 4, and 5 ranges from 0.7-1.7 mm/yr to 0.9-1.2 mm/yr depending on the maximum age assumed for Event 3.

Comparison of Event Timing With Other Sites:
The authors compared their revised Kaysville earthquake chronology with the chronology determined by Nelson (1988; WS-4); Forman and others (1991; WS-5), and Machette and others (1992; WS-6) at the East Ogden (EO) site 25 kilometers to the north. The timing deduced for the three most recent surface-faulting earthquakes at each site is presented below:

Event	Kaysville (This study)	East Ogden (Machette and others, 1992)
MRE	0.6-0.8 ka	0.8-1.2 ka

PE	2.8±0.7 ka	2.5-3.0 ka
APE	3.8-7.9 ka (preferred 5.7-6.1 ka)	3.5-4.0 ka

Based on a statistical analysis of the ^{14}C and TL ages from the two sites, the authors concluded that the MRE and PE were the same for both locations, but that the APEs were different, implying that the 3.5-4.0 ka surface rupture at EO died out before reaching Kaysville, and that the APE at Kaysville (5.7-6.1 ka) was too old to be detected at EO, where the trenches were excavated in a mid-Holocene alluvial fan circa 5 ka. The authors speculate that the reason for an event with over 5 meters of vertical displacement at EO terminating before reaching Kaysville may indicate the presence of a subsegment boundary between the two sites, possibly near Weber Canyon.

The authors also note that they found no evidence for a very young surface-faulting event at about 0.5 ka at Kaysville. Nelson (1988) and Machette and others (1992) postulated the possibility of such an event based on an exposure in one trench at EO. The authors point out that the earthquake chronology at Garner Canyon 5 kilometers north of EO (Machette and others, 1992) similarly lacks evidence for a 500-year event.

Sources of Uncertainty:

1. The total number of events that displace the post-Provo alluvial fan is an estimate, five or possibly six events is the preferred number, but there could be more.
2. The displaced post-Provo alluvial-fan deposits that constrain the total net slip across the fault zone and graben could not be accurately dated, so the time period over which the net slip occurred remains an estimate based chiefly on Lake Bonneville chronology.
3. Contradictory information is provided regarding unit 5; is it or is it not a colluvial-wedge deposit formed in response to Event 2?
4. No information is provided on how the age estimates for three most recent events (3, 4, and 5) were determined from available ^{14}C and TL age estimates, how the preferred age range for Event 3 was established, or whether the published ages for the events are maximums or minimums.
5. Soil S2, which formed on the Event 3 colluvial wedge was not dated by either ^{14}C or TL methods.
6. ^{14}C AMRT age estimates were obtained from channel samples of the upper 10-15 centimeters of buried soil A-horizons and fissure-fill deposits.
7. Net slip for Events 3, 4, and 5 could not be measured directly, displacement values determined for those events are estimates based on deposit geometry exposed in the trench.
8. The composite recurrence-interval and slip-rate values calculated for this site extend to the present and include at least one open seismic cycle.
9. Calculation of the composite slip rate used the estimated age of the post-Provo fan, which is a shorter time period than "post-Provo time," which was used to calculate the composite recurrence interval.

Summary:

This report expands the record of paleoearthquakes at the Kaysville site and revises the timing of the three most recent surface-fault events as originally reported by Swan and others (1980, 1981). The new age and displacement-per-event estimates for the three most recent surface-faulting earthquakes allow calculation of an early/mid-Holocene slip rate and recurrence interval across two closed seismic cycles. Neither the timing nor the number of earlier post-Provo surface-faulting earthquakes are well constrained. The earlier events postdate deposition of the post-Provo alluvial fan, but the actual age of the fan remains unknown. Two events at this site appear to correlate well with events at EO, but the APE at Kaysville is not the same event as the APE at EO, and there is no evidence of a very young late Holocene event at Kaysville comparable to a possible young event at EO.

References:

Forman, S.L., 1989, Applications and limitations of thermoluminescence to Quaternary sediments: Quaternary International, no. 1, p. 47-59.

Forman, S.L., Nelson, A.R., and McCalpin, J.P., 1991, Thermoluminescence dating of fault-scarp-derived colluvium - Deciphering the timing of paleoearthquakes on the Weber segment of the Wasatch fault zone, north-central Utah: Journal of Geophysical Research, v. 96, no. B1, p. 595-605.

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.

Nelson, A.R., 1988, The northern part of the Weber segment of the Wasatch fault zone near Ogden, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 33-37.

Stephenson, W.J., Smith, R.B., and Pelton, J.R., 1993, A high-resolution seismic reflection and gravity survey of Quaternary deformation across the Wasatch fault, Utah: Journal of Geophysical Research, v. 98, p. 8211 –8223.

Stuiver, Minze, and Reimer, P.J., 1986, A computer program for radiocarbon age calibration (Rev. 2.0): Radiocarbon, v. 28, no. 2B, p. 1022-1030.

Swan, F.H. III, Schwartz, D.P., and Cluff, L.S., 1980, Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault zone, Utah: Bulletin of the Seismological Society of America, v. 70, no. 5, p. 1431-1462.

Swan, F.H. III, Schwartz, D.P., Hanson, K.L., Knuepfer, P.L., and Cluff, L.S., 1981, Study of earthquake recurrence intervals on the Wasatch fault at the Kaysville site, Utah: U.S. Geological Survey Open-File Report 81-228, 30 p.

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

Name and Location of Fault/Fault Section:

Salt Lake City section (SLCS), Wasatch fault zone (WFZ), Salt Lake County, Utah

Paleoseismic Data Source Documents:

Black, B.D., Lund, W.R., Schwartz, D.P., Gill, H.E., and Mayes, B.H., 1996, Paleoseismology of Utah, Volume 7 - Paleoseismic investigation on the Salt Lake City segment of the Wasatch fault zone at the South Fork Dry Creek and Dry Gulch sites, Salt Lake County, Utah: Utah Geological Survey Special Study 92, 22 p.

Korbay, S.R., and McCormick, W.V., 1999, Faults, lateral spreading, and liquefaction features, Salt Palace Convention Center, Salt Lake City [abs.]: Association of Engineering Geologists, 42nd Annual Meeting Program with Abstracts, p. 73.

Lund, W.R., 1992, New information on the timing of earthquakes on the Salt Lake City segment of the Wasatch fault zone - Implications for increased earthquake hazard along the central Wasatch Front: Utah Geological Survey, Wasatch Front Forum, v. 8, no. 3, p. 12-13.

McCalpin, J.P., 2002, Post-Bonneville paleoearthquake chronology of the Salt Lake City segment, Wasatch fault zone, from the 1999 "Megatrench" site: Utah Geological Survey Miscellaneous Publication 02-7, 37 p.

McCalpin, J.P., and Nelson, C.V., 2000, Long recurrence records from the Wasatch fault zone, Utah: U.S. Geological Survey, National Earthquake Hazards Reduction Program Final Technical Report, Contract No. 99HQGR0058, 61 p.

Robison, R.M., and Burr, T.N., 1991, Fault-rupture hazard analysis using trenching and borings - Warm Springs fault, Salt Lake City, Utah, *in* McCalpin, J.P., editor, Proceedings of the 27th Symposium on Engineering Geology and Geotechnical Engineering: Boise, Idaho Department of Transportation, p. 26-1 - 26-13.

*Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes - Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Simon, D.B., and Shlemon, R.J., 1999, The Holocene "Downtown Fault" in Salt Lake City, Utah [abs.]: Association of Engineering Geologists, 42nd Annual Meeting Program with Abstracts, p. 85.

Swan, F.H. III, Hanson, K.L., Schwartz, D.P., and Knuepfer, P.L., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah - Little Cottonwood Canyon site: U.S. Geological Survey Open-File Report 81-450, 30 p.

Schwartz, D.P., and Lund, W.R., 1988, Paleoseismicity and earthquake recurrence at Little Cottonwood Canyon, Wasatch fault zone, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert - Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 82-85.

* Not on original list of source documents for this fault segment.

Geomorphic Expression:

The SLCS is divided into three en-echelon subsections (from north to south): the Warm Springs fault, East Bench fault, and Cottonwood subsection (Personius and Scott, 1992). The Warm Springs fault forms a prominent escarpment for about 7 kilometers along the western flank of the Salt Lake salient, then trends south into basin fill and dies out beneath downtown Salt Lake City. Because the Warm Springs fault is probably too short to be seismically independent, Personius and Scott (1992) assigned it to the SLCS. The location of the southern end of the Warm Springs fault beneath urbanized downtown Salt Lake City is subject to interpretation (Schlenker and others, 1999). Pre-urbanization studies of the Warm Springs fault at Jones Canyon by G.K. Gilbert (1890, *in* Hunt, 1982) showed evidence for three post-Bonneville events, with displacements totaling 9 meters. However, these estimates are probably minima; perhaps six to eight latest Quaternary events with displacements totaling 14-16 meters have occurred on this part of the section (Personius and Scott, 1992). Robison and Burr (1991) estimated a maximum displacement of about 12 meters at a site (Washington Elementary School) at the south end of the Warm Springs fault. Based on variations in elevation of correlative Lake Bonneville deposits indicating paleolake levels, Currey (1992) infers the presence of three faults (Capitol Hill fault zone) east of the Warm Springs fault, having a maximum cumulative offset of about 21 meters since about 20.4 ka.

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

The Cottonwood subsection forms a prominent (often wide and complex) zone of faulting along the range front from just north of Big Cottonwood Canyon to the Traverse Mountains. At the mouth of Little Cottonwood Canyon, the fault zone forms a 50-meter-wide graben with a 25-meter-high main scarp and 20-meter-high antithetic scarp. Farther south at South Fork Dry Creek, the graben is 400 meters wide, and six en-echelon scarps comprise the main fault zone. The complexity of the fault zone and poor exposure of antithetic faults has precluded accurate determination of net tectonic displacement on the Cottonwood subsection. However, profiling of moraine surfaces across the fault zone at Bells Canyon in the Little Cottonwood Canyon area indicates approximately 14-14.5 meters of net vertical tectonic displacement (Madsen and Currey, 1979; Swan and others, 1981). The main fault zone shows evidence for seven events since ~17 ka (McCalpin, 2002).

Evidence for Segmentation:

The Salt Lake City salient marks the boundary between the northern end of the SLCS and the southern end of the WS (Personius and Scott, 1992). The Warm Springs fault extends about 2 kilometers north of Becks hot springs before dying out on the north side of the Salt Lake salient. An approximately 2-kilometer-wide gap between the north end of the Warm Springs fault and the first large scarps to the northeast at the southern end of the WS marks the boundary between the two fault sections.

Personius and Scott (1992) place the southern end of the SLCS at the mouth of Corner Canyon at the northeastern end of the Traverse Mountains salient in the extreme southeastern corner of Salt Lake County. Machette and others (1992) indicate that at that location the WFZ turns to the southeast up Corner Canyon and extends across the

Traverse Mountains salient, eventually connecting with the north end of the Provo section of the fault near Alpine, Utah. Personius and Scott (1992) state that the rate of Quaternary movement on the WFZ where it crosses the salient is much lower than on the fault sections to the north and south, which is consistent with the lower structural relief across the salient.

Age of Youngest Faulting:
Holocene

Summary of Existing Recurrence Interval Information:
The two most recent investigations on the SLCS at South Fork Dry Creek (SFDC) by Black and others (1996) and at Little Cottonwood Canyon (LCC) by McCalpin (2002) document 7 and possibly 8 surface faulting events in the past ~ 17 to 20 ka. The timing of the four most recent events (Events Z, Y, X, and W) is well constrained and shows that recurrence between events ranges from 1150 to 1500 years with a preferred value of 1350±200 yrs. Timing of the next two events (Events V and U) is less well constrained, but is about 2000 years. The oldest surface-faulting event (Event T) dates from about 17 ka, and implies a long interval (mean 8350 yrs) without a surface faulting event on the southern part of the SLCS. Fault studies from farther north on the SLCS in the more urbanized Salt Lake City metropolitan area provide little useful information regarding faulting recurrence.

Summary of Existing Slip-Rate Information:
Slip-rate information is limited for the SLCS. Early studies at LCC did not trench all of the scarps in the fault zone at that location, so net slip per event is not known. Cumulative sip across the entire fault zone was measured where the WFZ displaces a lateral moraine at Bells Canyon, but the uncertainty associated with that measurement is high and the age of the moraines is estimated. Later, more detailed studies at SFDC and again at LCC, did not trench all possible antithetic faults at those sites, so net slip measurements are incomplete. Fault studies from farther north on the SLCS in the more urbanized Salt Lake City metropolitan area provide little useful information regarding fault slip rates.

Comments:
The SLCS is heavily urbanized; consequently, trenching studies on the northern portions of the section (Warm Springs fault, and East Bench fault) have largely been sites of opportunity, and due to the constraints of urbanization, have provided very limited information of surface-faulting recurrence and slip rates. Two sites to the south on the Cottonwood subsection at LCC and SFDC have been the locations of multiple studies, and together now provide what is considered to be a complete chronology of surface-faulting events on the SLCS to about 17 ka.

References: (Also see references listed above)

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.

Currey, D.R., 1992, Limneotectonics constraints on Quaternary tectonokinematics - Part 1, Inferred Capitol Hill fault zone, Salt Lake City, Utah: Salt Lake City, University of Utah, unpublished Limneotectonics Laboratory Technical Report 92-1, U.S. Geological Survey contract no. 14-08-0001-G1536, 26 p.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Little Cottonwood Canyon (LCC) ***Study Synopsis ID***: SLCS-1

Fault/Fault Section: Salt Lake City section (SLCS), Wasatch fault zone (WFZ)

Map Reference: 2351f-4

Study:
Swan, F.H. III, Hanson, K.L., Schwartz, D.P., and Knuepfer, P.L., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah - Little Cottonwood Canyon site: U.S. Geological Survey Open-File Report 81-450, 30 p.

Type of Study/Commentary:
Trenching. This site is just north of Little Cottonwood Creek at the mouth of formerly glaciated Little Cottonwood Canyon. In the southern part of the site the WFZ is defined by a prominent, curvilinear, west-facing main scarp as much as 25 meters high; however, a short distance to the north, the main fault splays into three smaller, west-facing scarps. A zone of down-to-the-east antithetic faults parallels the main fault zone and creates a graben that in places is more than 50 meters wide. Heights of the antithetic faults vary from less than 10 meters to about 20 meters.

Four trenches were excavated for this study. Trenches LC-1 and LC-2 crossed the westernmost scarp north of where the single main scarp splays to form three subparallel traces. Trench LC-4 was excavated on the main scarp south of where it bifurcates; however, the height and steepness of the scarp and the thickness of the bouldery colluvium at its base made it impossible to expose the fault. Trench LC-3 was excavated on the main antithetic scarp. Deposits in the trenches across the westernmost down-to-the-west scarp (LC-1 & LC-2) included: lacustrine sediments of the Bonneville Lake cycle (unit 1), post-lake alluvial-fan deposits (unit 2), graben-fill deposits (unit 3), silty sand (fault-scarp colluvium) derived chiefly from unit 2 (unit 4), and MRE scarp-derived colluvium (unit 5). Deposits exposed in trench LC-3 excavated across the antithetic scarp consisted of glacial till (unit 1), gravely silty sand of an older graben-fill deposit (unit 2), and unit 3a which is colluvium derived from the antithetic fault scarp, and unit 3b, which consists of finer graben-fill deposits. A weak to moderate calcic paleosol was present on the Lake Bonneville sediments, and several poorly developed buried soil A-horizons occur within the graben-fill deposits.

Samples of detrital charcoal recovered from graben-fill deposits in trench LC-1 were too small for conventional ^{14}C dating. A small sample of detrital charcoal was also collected from the graben-fill in trench LC-3.

In trenches LC-1 and LC-2 the main fault juxtaposes Bonneville Lake deposits and the overlying post-lake alluvial-fan deposits against graben-fill and colluvium. Young scarp colluvium overlies the fault and is not displaced. Based on the depth to lake deposits in test pits in the graben, displacement may be as much as 13 meters on this fault. The faulted graben fill is overlain by unit 4, which is scarp-derived colluvium from the PE.

Unit 4 is in turn faulted and overlain by unit 5, scarp-derived colluvium of the MRE. Trench LC-3 crosses most of the graben and exposes many small faults with displacements of up to 36 centimeters. Where the trench exposes the main antithetic fault, till is overlain by scarp-derived colluvium that grades eastward into the graben-fill deposits. Renewed movement on the fault has displaced the scarp colluvium.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

Minimum of two, possibly three events, but additional events are probable. Evidence for the two most recent events consists of scarp-derived colluvium in the trenches.

Age of Events/Datum Ages/Dating Techniques:

No ^{14}C dates were available at the time this report was written. All deposit ages are estimates based on the relation of sediments to Lake Bonneville deposits.

Event Slip/Cumulative Slip:

A scarp profile was measured near trench LC-1, but the steepness of the terrain, complexity of the fault zone, and differences in the ages of the surficial deposits made it difficult to determine the cumulative net tectonic displacement across the fault at this location. The estimated post-Bonneville displacement across the entire fault zone there is 9.5 to10 meters.

Topographic profiles were also measured along the crest of lateral moraines displaced by the fault at the mouths of Little Cottonwood and Bells Canyons to the south. Based on a projection of the moraine surface across the fault zone, displacement is estimated at 14.5 (+10, -3) meters in the Bells Canyon moraine.

Multiple fault traces in a wide zone of deformation made determining the displacement for individual faulting events difficult. Information from the trenches and test pits excavated in the graben indicate that the top of the Lake Bonneville deposits is displaced approximately 13 meters down-to-the-west across the main fault exposed in the trenches. On the west side of the graben, the top of the Lake Bonneville deposits is displaced about 9 meters down-to-the-east across the main antithetic fault. Therefore, the net vertical tectonic displacement (NVTTD) across the fault zone and graben is about 4 meters. It is estimated that this displacement was produced by two or three events, making the average NVTD per event 1.3 to 2 meters. However, available data show that per event NVTD may have ranged from 0.4 to 3 meters. **Note however, that only one of the three fault scarps in the main fault zone at the site was trenched and that additional events or additional displacement during recognized events may have occurred on those scarps.**

Published Recurrence Interval:

The results of ^{14}C dating of detrital charcoal collected from the trenches were not available at the time this report was written. Recurrence for this site was estimated using a slip-rate value of 0.9 mm/yr and a range of 0.3-4 meters for the displacement per surface-faulting event gives an average recurrence interval of

450-3300 years. The preferred per event displacement was 2 meters which suggests a recurrence interval of about 2200 years.

Published Slip Rate:

The late Pleistocene-Holocene slip rate at Little Cottonwood Canyon is reported as 0.9 (+1.0, -0.3) mm/yr based on an estimated 14.5 (+10. –3) meters of cumulative displacement of the Bells Canyon moraine, and an estimated moraine age of 16±3 ka (this age for the moraine was revised upward in later publications).

Sources of Uncertainty:

1. Only one of three down-to-the-west scarps in the main fault zone was trenched, making it probable that the information resulting from this study on both the number of events and the displacement per event is incomplete.
2. No ^{14}C or other numeric ages were available at the time this report was written to constrain the ages of surface-faulting events.
3. Scarp profiles measured on moraine crests south of the site have high uncertainty limits, so both the cumulative slip and estimates of slip per event reported for this site likewise have high associated uncertainty.

Summary:

This is one of the earliest (field work done in 1979) trenching studies conducted on the WFZ, and it was at this site that many of the concepts now regularly employed to interpret stratigraphic and structural relations exposed in trenches excavated on normal-slip faults were first developed. However, the study predates several advances in ^{14}C dating technology and TL dating entirely, thus limiting the availability of dateable material. This study also predates development of a detailed, calendar-calibrated Lake Bonneville chronology, a chronology that has changed significantly since this study was done. Because only one of the three down-to-the-west fault scarps in the main fault zone was trenched, information on timing and displacement of individual events is incomplete.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Little Cottonwood Canyon (LCC) ***Study Synopsis ID:*** SLCS-2

Fault/Fault Section: Salt Lake City section (SLCS), Wasatch fault zone (WFZ)

Map Reference: 2351f-4

Study:

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes - Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Type of Study/Commentary:

This document briefly summarizes the Swan and others (1981; SLCS-1) study at LCC, and reports the results of the ^{14}C dating of detrital charcoal that were not available at the time the Swan and others (1981) report was submitted to the USGS.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

Two/colluvial wedges

Age of Events/Datum Ages/Dating Techniques:

An early use of accelerator-mass-spectrometry ^{14}C dating yielded an age of 9000 (+400, -600) ^{14}C yr B.P. on detrital charcoal recovered from graben-fill deposits that grade to scarp-derived colluvium from the antithetic fault (trench LC-3, see SLCS-1). Additional accelerator dates of 7800 (+400, -600) and 8600 (+500, -400) ^{14}C yr B.P. were obtained on detrital charcoal from graben-fill deposits in trench LC-1 across the westernmost down-to-the-west fault scarp in the main fault zone. This alluvium is considered correlative with the graben-fill alluvium near the antithetic scarp. A single surface-faulting earthquake (MRE) displaces the graben-fill units in trenches LC-1 and LC-3, from which the charcoal samples were obtained.

Based on the stratigraphy exposed in the trenches and the new ^{14}C ages, the authors conclude that there is evidence for two surface-faulting events at the Little Cottonwood site, a PE that occurred shortly before 8-9 ka, and the MRE, which is younger than 8-9 ka but whose timing could not be further constrained.

Event Slip/Cumulative Slip:

See SLCS-1

Published Recurrence Interval:

4000-4600 years, based on two events within the past 8-9 ka. Note, that this is an open recurrence interval estimate that extends to the present and is based on an incomplete record of surface faulting at the site.

An alternative recurrence interval of 2.4-3 ka was calculated using a net tectonic displacement of 14.5 meters on the Bells Canyon moraine south of the LCC site, and age for the moraine of 19,000$\pm$20,000 years (note this is a revised age estimate for the moraine compared to that used by Swan and others [1981]), and an average displacement per event of 2 meters.

***Published Slip Rate*:**
None reported

***Sources of Uncertainty*:**

1. See SLCS-1 for sources of uncertainty related to not trenching all of the scarps at the site.
2. The three ^{14}C ages are not calendar calibrated and no information is provided on the source of the charcoal, or its age prior to being deposited with the alluvium.
3. All three ^{14}C ages come from graben-fill deposits, not scarp-derived colluvium, and only one of the three ages was correlated directly with scarp-derived colluvium. That correlation was made with colluvial-wedge deposits on the antithetic fault in trench LC-3. The other two ages come from trench LC-1 excavated on the main fault. The authors state that the graben fill from which the two dates were obtained is correlative with the graben fill exposed in the trench on the antithetic fault. Because the trench on the main fault did not extent across the graben, that correlation is considered speculative. No explanation is provided for why the dated graben-fill deposits in the trench on the main fault, weren't correlated with colluvium derived from the scarp on the main fault.
4. All reported recurrence intervals contain at least one open seismic cycle.

***Summary*:**

Multiple uncertainties exist at this site regarding the possible number and timing of surface-faulting events, cumulative displacement and displacement per event, and the correlation of the ^{14}C ages with surface-faulting earthquakes.

References:

Swan, F.H. III, Hanson, K.L., Schwartz, D.P., and Knuepfer, P.L., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah - Little Cottonwood Canyon site: U.S. Geological Survey Open-File Report 81-450, 30 p.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Little Cottonwood Canyon (LCC) ***Study Synopsis ID***: SLCS-3

Fault/Fault Section: Salt Lake City section (SLCS), Wasatch fault zone (WFZ)

Map Reference: 2351f-4

Study:

Schwartz, D.P., and Lund, W.R., 1988, Paleoseismicity and earthquake recurrence at Little Cottonwood Canyon, Wasatch fault zone, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert - Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 82-85.

Type of Study/Commentary:

This document briefly summarizes the available information at LCC (Swan and others, 1981 [SLCS-1]; Schwartz and Coppersmith, 1984 [SLCS-2}), and presents a revised slip rate for LCC based on a new age for the left lateral moraine at Bells Canyon. In addition, this document reports summary information on the initial paleoseismic study conducted at the South Fork Dry Creek site (SFDC; Lund and Schwartz, 1987; Schwartz and others, 1988) in 1987. The SFDC site lies about 5 kilometers south of Little Cottonwood Canyon. The results of the initial work at SFDC and of an extensive subsequent study performed there are reported in detail in Black and others (1996).

Fault Parameter Data:

Initial investigations at the SFDC demonstrated the occurrence of at least two post-middle-Holocene surface-faulting events. Based on AMRT ^{14}C age estimates on buried soil A-horizons, the PE occurred shortly after 5595-5975 ^{14}C yr B.P., and the MRE, while less well constrained, occurred shortly after 1130-1830 ^{14}C yr B.P. Black and others (1996) subsequently refined both of these age estimates.

Both post-middle-Holocene surface-faulting events identified at SFDC should also have occurred at LCC, but at least one of the events was not recognized there. The difference in fault behavior at LCC and SFDC demonstrates that a complete surface-faulting history for a site can only be developed when all scarps present in a fault zone are trenched. Recognition of that fact eventually led to the Black and others (1996) study, since the original 1987 SFDC study only trenched 2 of the 6 scarps present there.

Published Slip Rate:

The revised slip rate for LCC is based on a new age estimate for the lateral moraine at Bells Canyon. Swan and others (1981) stated that the age of the moraine was 16±2 ka, and reported a slip rate of 0.9 (+1.0, -0.3) mm/yr based on an estimated 14.5 (+10, –3) meters of cumulative displacement across the WFZ on the moraine surface. The authors of this document take the age of the moraine as 19±2 ka, retain the 14.5 meters of displacement across the fault zone in the moraine surface, and report a revised slip rate of **0.76 (+0.6, -0.2 mm/yr)**.

Sources of Uncertainty:

1. For LCC see SLCS-1 and SLCS-2.
2. At SFDC only two of five scarps were trenched, subsequent studies at that site resulted in a significant revision of the sites surface-faulting chronology.

Summary:

This is a summary document that reports a revised slip rate for LCC, and presents summary paleoseismic information for an initial investigation at SFDC 5 kilometers to the south. Differences in the chronology of surface-faulting events at the two sites showed that the information on surface faulting at LCC was incomplete because not all main scarps there had been trenched. That result called into question the results of the initial study at SFDC, where only two of six scarps were trenched, and eventually led to Black and others (1996) detailed study at SFDC.

References:

Black, B.D., Lund, W.R., Schwartz, D.P., Gill, H.E., and Mayes, B.H., 1996, Paleoseismology of Utah, Volume 7 - Paleoseismic investigation on the Salt Lake City segment of the Wasatch fault zone at the South Fork Dry Creek and Dry Gulch sites, Salt Lake County, Utah: Utah Geological Survey Special Study 92, 22 p.

Lund, W.R., and Schwartz, D.P., 1987, Fault behavior and earthquake recurrence at the Dry Creek site, Salt Lake City segment, Wasatch fault zone, Utah [abs]: Geological Society of America Abstracts with Programs, v. 19, no. 5, p. 317.

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes - Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Schwartz, D.P., Lund, W.R., Mulvey, W.E., and Budding, K.E., 1988, New paleoseismic data and implications for space-time clustering of large earthquakes on the Wasatch fault zone [abs.]: Seismological Research Letters, v. 59, no. 1, p. 15.

Swan, F.H. III, Hanson, K.L., Schwartz, D.P., and Knuepfer, P.L., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah - Little Cottonwood Canyon site: U.S. Geological Survey Open-File Report 81-450, 30 p.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Washington Elementary School ***Study Synopsis ID***: SLCS-4

Fault/Fault Section: Salt Lake City section (SLCS), Wasatch fault zone (WFZ)

Map Reference: 2351f-1

Study:

Robison, R.M., and Burr, T.N., 1991, Fault-rupture hazard analysis using trenching and borings - Warm Springs fault, Salt Lake City, Utah, *in* McCalpin, J.P., editor, Proceedings of the 27th Symposium on Engineering Geology and Geotechnical Engineering: Boise, Idaho Department of Transportation, p. 26-1 - 26-13.

Type of Study/Commentary:

Trenching/Borings. Three trenches were excavated and 16 test borings drilled at Washington Elementary School (between 400 and 500 North Streets and 158 West Street and 200 West Street in Salt Lake City) to define the trace and determine the paleoseismic characteristics of the Warm Springs fault where it crosses the school property.

Four stratigraphic units were identified in trench exposures and test borings. From youngest to oldest they are: unit 1 – post-Lake Bonneville alluvium, unit 2 – post-Lake Bonneville fluvial sand and gravel, unit 3 – Lake Bonneville lacustrine deposits, and unit 4 – pre-Lake Bonneville alluvium. Considerable excavation and filling for school construction left few areas on site where natural materials extend to the ground surface.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

An estimated four to six events based on a 40-foot maximum displacement across the fault zone identified on the site, and an estimated 6 to 10-foot surface displacement per surface-faulting event as reported by Schwartz and Coppersmith (1984) for the Little Cottonwood Canyon site approximately 25 kilometers to the south on the Cottonwood subsection of the SLCS.

Due to extensive grading for school construction, none of the trenches preserved evidence of scarp-derived colluvium.

Age of Events/Datum Ages/Dating Techniques:

Stratigraphic unit ages are estimates based on their stratigraphic position relative to Lake Bonneville lacustrine sediments, whose age is estimated as 13 to 15 ka based on a chronology of Lake Bonneville's expansion and regression during the latest Pleistocene (Currey and Oviatt, 1985). No numerical age estimates were obtained during this study.

The authors conclude that there have been 4 to 6 surface-faulting events at this site in the past 15 ka, but lack stratigraphic or structural evidence that permits identification of individual events

Event Slip/Cumulative Slip:

The authors estimate a total displacement of 40 feet based on displacement of the surface of the pre-Lake Bonneville alluvium across the fault zone in the "South" trench. It is unclear if that estimate represents "net slip," or is the maximum displacement within the zone of deformation associated with the fault.

Published Recurrence Interval:

2.5-3.75 ka based on an estimated 4 to 6 events in the past 15 ka.

Published Slip Rate:

0.8-1.0 mm/yr based on based on an estimated 2 to 3 meters of surface displacement every 2.5-3.75 ka.

Sources of Uncertainty:

1. No evidence for individual surface-faulting events.
2. No numerical age estimates for any deposits on site.
3. No slip per event information.
4. Unclear if the "total displacement" value represents net slip.
5. Recurrence interval and slip rate are based on a slip-per-event estimate taken from a site 25 kilometers to the south on a different subsection of the SLCS, and an age of faulting estimated from a now outdated lake Bonneville chronology.

Summary:

The only new paleoseismic data provided by this study is a "total displacement" value for the WFZ since Bonneville time, which may or may not represent the cumulative net slip across the fault zone.

References:

Currey, D.R., and Oviatt, C.G., 1985, Durations, average rates, and probable causes of Lake Bonneville expansions, stillstands, and contractions during the last deep-lake cycle, 32,00 to 10,000 years ago, in Kay, P.A., and Diaz, H.F., editors, Problem of and prospects for predicting Great Salt Lake levels: Salt Lake City, University of Utah Center for Public Affairs and Administration, p. 9-24.

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes - Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Dry Gulch/South Fork Dry Creek ***Study Synopsis ID***: SLCS-5

Fault/Fault Section: Salt Lake City section (SLCS), Wasatch fault zone (WFZ)

Map Reference: 2351f-5, 2351f-6

Study:
Lund, W.R., 1992, New information on the timing of earthquakes on the Salt Lake City segment of the Wasatch fault zone - Implications for increased earthquake hazard along the central Wasatch Front: Utah Geological Survey, Wasatch Front Forum, v. 8, no. 3, p. 12-13.

Type of Study/Commentary:
Trenching. This two-page article briefly recounts the results of trench studies at the Little Cottonwood Canyon (LCC; Swan and others, 1981; SLCS-1) and South Fork Dry Creek (SFDC; Lund and Schwartz, 1987; Schwartz and others, 1988;) sites performed prior to 1992, and presents new information on a previously unrecognized late Holocene surface-faulting earthquake on the SLCS at Dry Gulch (DG). The DG site is approximately 250 meters south of the SFDC site.

In 1991, a consultant's trench excavated for a new subdivision near DG exposed a pair of stacked colluvial wedges and buried paleosols adjacent to a fault scarp. The fault zone at DG is more than 100 meters wide, and contains several down-to-the-west fault scarps. The exposure of opportunity provided by the trench only crossed one of the scarps.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:
Two/stacked colluvial wedges on a single fault trace in a broad fault zone.

Age of Events/Datum Ages/Dating Techniques:
Radiocarbon ages from bulk organics in the buried soil A-horizons showed that the timing of the MRE (1600 cal yr B.P.) generally agreed with that determined from previous studies (Schwartz and Lund, 1988). However, the PE occurred shortly after 2400 cal yr B.P. rather than 5500-6000 ^{14}C yr B.P. as previously determined (Schwartz and Lund, 1988). Resampling confirmed the age of the newly recognized event at DG, and likewise the 5000+ year event at SFDC.

Event Slip/Cumulative Slip:
None reported

Published Recurrence Interval:

The new ^{14}C ages from DG combined with the results of studies at LCC and SFDC provided strong evidence for at least four surface-faulting earthquakes on the SLCS in the past 8 to 9 ka. The addition of a fourth event in that time span lowered the average recurrence on the SLCS from approximately 4000±1000 years to 2400±500 years. However, even with this new information, scarps remained untrenched at all three sites (LCC, SFDC, and DG) on the Cottonwood subsection, so a possibility still exists for the discovery of additional unrecognized events.

***Published Slip Rate*:**
None reported

Sources of Uncertainty:

1. This summary report provides no details on how the buried A-horizon paleosols at Dry Gulch were sampled, or how they were calendar calibrated. (They were in fact channel sampled across their entire width and calibrated in accordance with Machette and others [1992] and Stuiver and Reimer [1986].
2. Other details of the study are lacking.

Summary:

This exposure of opportunity demonstrated once again that in the absence of a site where all of the scarps in the fault zone are trenched, it is still possible to have unrecognized Holocene surface-faulting events on the SLCS. The new information on event timing from DG provided the primary impetus for the Black and others (1996) reoccupation of the SFDC site.

References:

Black, B.D., Lund, W.R., Schwartz, D.P., Gill, H.E., and Mayes, B.H., 1996, Paleoseismology of Utah, Volume 7 - Paleoseismic investigation on the Salt Lake City segment of the Wasatch fault zone at the South Fork Dry Creek and Dry Gulch sites, Salt Lake County, Utah: Utah Geological Survey Special Study 92, 22 p.

Lund, W.R., and Schwartz, D.P., 1987, Fault behavior and earthquake recurrence at the Dry Creek site, Salt Lake City segment, Wasatch fault zone, Utah [abs]: Geological Society of America Abstracts with Programs, v. 19, no. 5, p. 317.

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Schwartz, D.P., Lund, W.R., Mulvey, W.E., and Budding, K.E., 1988, New paleoseismic data and implications for space-time clustering of large earthquakes on the Wasatch fault zone [abs.]: Seismological Research Letters, v. 59, no. 1, p. 15.

Stuiver, Minze, and Reimer, P.J., 1986, A computer program for radiocarbon age calibration (Rev. 2.0): Radiocarbon, v. 28, no. 2B, p. 1022-1030.

Swan, F.H. III, Hanson, K.L., Schwartz, D.P., and Knuepfer, P.L., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah - Little Cottonwood Canyon site: U.S. Geological Survey Open-File Report 81-450, 30 p.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: South Fork Dry Creek/Dry Gulch ***Study Synopsis ID***: SLCS-6

Fault/Fault Section: Salt Lake City section (SLCS), Wasatch fault zone (WFZ)

Map Reference: 2351f-5, 2351f-6

Study:

Black, B.D., Lund, W.R., Schwartz, D.P., Gill, H.E., and Mayes, B.H., 1996, Paleoseismology of Utah, Volume 7 - Paleoseismic investigation on the Salt Lake City segment of the Wasatch fault zone at the South Fork Dry Creek and Dry Gulch sites, Salt Lake County, Utah: Utah Geological Survey Special Study 92, 22 p.

Type of Study/Commentary:

Trenching. Prior to this investigation, trenching studies at Little Cottonwood Canyon (LCC; SLCS-1, SLCS-2), South Fork Dry Creek (SFDC; SLCS-3), and Dry Gulch (DG; SLCS-5) determined that four surface-faulting earthquakes had occurred at the south end of the SLCS over the past ~6 ka. At each of these three sites, the WFZ consists of a broad zone of multiple down-to-the-west faults and associated down-to-the-east antithetic faults. During the earlier studies, some scarps remained untrenched at all three sites, thereby leaving open the possibility of additional, unrecognized surface-faulting earthquakes in the Holocene record on the Cottonwood subsection of the SLCS.

The intent of this study was to develop a comprehensive chronology of surface-faulting earthquakes for the SLCS from at least middle-Holocene time. To that end, the SFDC site was reoccupied and five additional trenches excavated, so that when combined with the trenches excavated for earlier study at this site, each scarp at SFDC had been trenched at least once.

The SFDC site lies just above the highest shoreline of Lake Bonneville. Surficial deposits consist of small remnants of middle Pleistocene alluvial-fan deposits near the mountain front, latest Pleistocene to middle Holocene alluvial-fan deposits over most of the site, and a late Holocene debris-flow levee along South Fork Dry Creek.

Six down-to-the-west faults and a single, short, down-to-the-east antithetic fault form a fault zone that is roughly 400 meters wide. Four of the west-dipping faults (S1 to S4) displace the debris-flow levee, which, based on soil-profile development (Scott and Shroba, 1985), is estimated to be 2000 to 4000 years old. Faults S1 to S4 merge to the north, but die out to the south. Fault S5 is the main trace of the WFZ to the south, and was the scarp trenched at DG, a few hundred meters to the south (Lund, 1992). Fault S5 does not displace the levee to the north, so it appears that slip coming from the south (Bruhn and others, 1987) is being transferred from fault S5 to faults S1 to S4, which quickly merge and then continue to the north as a single scarp. Fault S6 is only a few tens of meters long and dies out quickly to the north and south. The antithetic fault is the westernmost fault in the fault zone and trends subparallel to fault S5.

A total of nine trenches were excavated across fault scarps at SFDC in two trenching campaigns (1985 [DC-1 through DC-4], and 1994 [DC2-1 through DC2-5]). In addition, a consultant's trench excavated across fault S5 in 1991 at DG, about 250 meters to the south, exposed two stacked colluvial wedges and associated buried soil A-horizons.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

Four/colluvial-wedge stratigraphy

Age of Events/Datum Ages/Dating Techniques:

Event Z (MRE): 1300 (+250, -200) cal yr B.P.
Event Y (PE): 2450±350 cal yr B.P.
Event X (PE): 3950 (+550, -450) cal yr B.P.
Event W: 5300 (+450, -350) cal yr B.P.

All ^{14}C age estimates for this study are AMRT ages on organic concentrates from soil A-horizons, crack-fill deposits, or fault-scarp colluvium. The reported event ages are based on a combination of ^{14}C AMRT ages from both the 1985 and the 1994 studies and the information obtained at DG. During the 1991 investigation at DG and this study at SFDC, only the upper few centimeters of buried soil A-horizons were sampled in an attempt to recover and date only the youngest carbon in the soil. The samples collected in 1985 were channel samples taken across the full width of the buried A-horizons, and therefore contain a greater carbon age range.

The ^{14}C ages from 1985, 1991, and 1994 were calibrated using the computer program CALIB 3.0.3 (Stuiver and Reimer, 1993) and according to the method of Machette and others (1992, appendix A). The mean residence correction and carbon age span used to calibrate each sample are reported in table 1 of the report.

Earthquake timing was determined by averaging the ^{14}C AMRT ages and two-sigma error bounds of samples from paleosols beneath colluvial wedges or intact blocks of paleosols incorporated in colluvial wedges. Age estimates from fissure fill and fault-scarp colluvium were used only to support/check the timing of events.

Eight age estimates from paleosols beneath colluvial-wedge deposits (trenches DC-1, DC-2, DC2-1, DC2-3, and DG-1), and one age estimate from an intact block of a paleosol in a colluvial wedge (trench DC2-3) constrain the timing of Event Z (MRE). Three age estimates from paleosols beneath colluvial-wedge deposits (trenches DC2-5 and DG-1) constrain the timing of Event Y (PE). Event X (APE) is constrained by one age estimate on a paleosol beneath a colluvial-wedge deposit in trench DC2-2. Supporting evidence for Event X is provided by an age estimate on fault-scarp colluvium from trench DC2-4. Four age estimates from paleosols beneath colluvial-wedge deposits (trenches DC-1 and DC-2) constrain the timing of Event W.

Event Slip/Cumulative Slip:

Neither per event nor cumulative slip could be determined at SFDC because antithetic faults known to exist (identified on pre-development aerial photographs) to the west of the six down-to-the-west faults are obscured by a new road and housing development. Therefore, the amplitude of the antithetic faulting is unknown and it was not possible to determine net slip.

A scarp profile along the crest of the 2-4 ka old debris-flow levee along South Fork of Dry Creek showed a total of 4.5 to 5.0 meters of displacement across four fault scarps. Up to three surface-faulting events may have displaced the levee in the past 4 ka, but because the age of the levee is uncertain, the exact number of surface-faulting events causing the displacement is also uncertain. The average net slip per event would be 2.3-2.5 meters if two events are involved, and 1.5-1.7 meters if the levee was displaced by three events. The road along the west side of the site has destroyed a portion of the levee, and may obscure evidence of antithetic faulting in that area.

***Published Recurrence Interval*:**
1350±200 yrs for the past 6 ka. Note that this slip rate was calculated using the three closed seismic cycles provided by the four well-dated Holocene events identified at SFDC.

***Published Slip Rate*:**
None reported

***Sources of Uncertainty*:**
1. Damn guys, this looks like a good study!
2. Event X hinges on a single ^{14}C AMRT age on a buried paleosol, but the age obtained and the stratigraphic evidence relating the paleosol to a surface-faulting event are both good.

***Summary*:**
At SFDC all down-to-the-west fault scarps have been trenched and deposits related to surface-faulting events dated. The resulting chronology of surface-faulting earthquakes from middle Holocene time is believed to be complete for the SLCS at this site. No information was obtained on events older then middle Holocene (~6 ka) and it was not possible to determine either per event or cumulative net slip values at this site.

References:
Bruhn, R.L., Gibler, P.R., and Parry, W.T., 1987, Rupture characteristics of normal faults – An example from the Wasatch fault zone, in Coward, M.P., Dewey, J.F., and Hancock, P.L., editors, Continental extensional tectonics: Geological Society of London Special Publication 28, p. 337-353.

Lund, W.R., 1992, New information on the timing of earthquakes on the Salt Lake City segment of the Wasatch fault zone - Implications for increased earthquake hazard along the central Wasatch Front: Utah Geological Survey, Wasatch Front Forum, v. 8, no. 3, p. 12-13.

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Scott, W.E., and Shroba, R.R., 1985, Surficial geologic map of an area along the Wasatch fault zone in the Salt Lake Valley, Utah: U.S. Geological Survey Open-File Report 85-488, pamphlet, 2 plates, scale 1:24,000.

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.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Salt Palace Convention Center ***Study Synopsis ID***: SLCS-7

Fault/Fault Section: Salt Lake City section (SLCS), Wasatch fault zone (WFZ)

Map Reference: 2351f-2

Study:
Simon, D.B., and Shlemon, R.J., 1999, The Holocene "Downtown Fault" in Salt Lake City, Utah [abs.]: Association of Engineering Geologists, 42nd Annual Meeting Program with Abstracts, p. 85.

Type of Study/Commentary:
Trenching. A foundation excavation in downtown Salt Lake City for a major expansion of the Salt Palace Convention Center exposed a previously unrecognized Holocene "fault zone" and related liquefaction dikes. Foundation excavations up to ~14 meters below the original ground surface showed that the "fault" trends north-south, and displaces Holocene alluvial-fan deposits and intercalated paleosols. The "fault" flowers upward from an east-dipping 60° basal slip surface to form at least two near-surface grabens, each ~7-8 meters wide. The westernmost graben slip surface apparently records a single 1.5 meter vertical separation that occurred between ~7.1 and 8.1 ka. The eastern graben slip surface displaces a younger stratigraphic surface and a "fault-derived" colluvial wedge, and thus records two additional tectonic events of 0.8 meters each, that occurred after ~6.4 ka. Cone Penetrometer Test soundings indicate that the "fault" displaces the ~27 ka old base of the underlying Lake Bonneville lacustrine sequence at least 3 meters and the ~13 ka old top of the Lake Bonneville sequence by about 1 meter.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:
Three, based on displaced stratigraphic units and at least one "fault-derived" colluvial wedge.

Age of Events/Datum Ages/Dating Techniques:
Oldest event occurred between ~7.1 and 8.1 ka. The two younger events occurred after ~6.4 ka.

The Holocene alluvial fan is ^{14}C dated, but this document provides no details concerning how the dating was accomplished or where or from which units the samples were collected. It is assumed that the age estimates reported in the abstract are ^{14}C AMRT ages obtained on bulk organics from the paleosols "intercalated" with the alluvial-fan deposits. Age estimates for the top and bottom of the Lake Bonneville lacustrine sequence are assumed to be from published chronologies of the lake's transgression and regression.

Event Slip/Cumulative Slip:

Westernmost slip surface = 1.5 meters of vertical separation in a single event.
Easternmost slip surface = two displacements of 0.8 meters each.

Based on the above values the authors report a "characteristic" vertical separation of ~0.8-1.5 meters per event, but it is not clear if this estimate represents net slip.

Cumulative slip across the "fault" zone in the top of the Lake Bonneville lacustrine sequence is reported as 1 meter.

Published Recurrence Interval:

~2-3 ka, based on three events in ~7-8 ka

Published Slip Rate:

None reported

Sources of Uncertainty:

1. This document is an abstract and provides only summary paleoseismic information regarding this site.
2. Three Holocene events are postulated for this site, but the presence of only one scarp-derived colluvial wedge is reported.
3. Other than the age estimates themselves, no information is provided regarding the details of the ^{14}C dates, the units they came from, the kind of material dated, whether the dates are calendar calibrated, etc.
4. It is unclear if the "vertical separation" values reported for the two grabens are net slip values.
5. This site is controversial and was the subject of investigation by more than one consulting company. Liquefaction-caused lateral spreading was proposed as an alternative explanation for the feature exposed in the foundation excavation.

Summary:

This document is an abstract prepared for a presentation at the 42nd Annual Meeting of the Association of Engineering Geologists. It provides only summary paleoseismic information on the possible timing and displacement of individual surface-faulting earthquakes at the extreme south end of the Warm Springs fault. The origin of the feature exposed in the foundation excavation was highly controversial, and was the subject of study by multiple geological consulting firms. Differing opinions regarding the nature of the feature resulted from those studies. One group (this document) holds that the feature is an active fault. A second group (Korbay and McCormick, 1999; SLCS-8) believes that the feature represents lateral spreading resulting from liquefaction triggered by an earthquake, but that the feature itself is not a seismogenic fault. It was on the basis of the second opinion that construction of the convention center was allowed to proceed.

References:

Korbay, S.R., and McCormick, W.V., 1999, Faults, lateral spreading, and liquefaction features, Salt Palace Convention Center, Salt Lake City [abs.]: Association of Engineering Geologists, 42nd Annual Meeting Program with Abstracts, p. 73.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Salt Palace Convention Center ***Study Synopsis ID***: SLCS-8

Fault/Fault Section: Salt Lake City section (SLCS), Wasatch fault zone (WFZ)

Map Reference: 2351f-2

Study:

Korbay, S.R., and McCormick, W.V., 1999, Faults, lateral spreading, and liquefaction features, Salt Palace Convention Center, Salt Lake City [abs.]: Association of Engineering Geologists, 42nd Annual Meeting Program with Abstracts, p. 73.

Type of Study/Commentary:

Trenching. The authors of this document dispute the “fault” origin for the feature exposed in the foundation excavation for the Salt Palace Convention Center expansion in downtown Salt Lake City (see SLCS-7). The authors believe that the feature is the result of lateral spreading related to liquefaction during past earthquakes. They base their interpretation on the fact that displacements generally decrease with depth and sometimes terminate along one or more horizontal bedding planes or along vertical sand- or gravel-filled “fracture intrusion dikes.” They also state that deep exploration borings and Cone Penetrometer Test soundings show that the surface of the Lake Bonneville lacustrine sequence is not significantly displaced across the two graben except at one isolated location. Based on ^{14}C dating (no details) the authors believe the latest lateral spread event occurred about 6.5 ka.

Fault Parameter Data:

None – if the lateral spreading premise is correct.

Summary:

This document is an abstract prepared for a presentation at the 42nd Annual Meeting of the Association of Engineering Geologists. It provides only summary paleoseismic information on the possible timing and displacement of basin-fill deposits at the extreme south end of the Warm Springs fault. The origin of the feature exposed in the foundation excavation was highly controversial, and was the subject of study by multiple geological consulting firms. Differing opinions regarding the nature of the feature resulted from those studies. One group (Simon and Shlemon, 1999; SLCS-7) holds that the feature is an active fault. A second group (this document) believes that the feature represents lateral spreading resulting from liquefaction triggered by an earthquake, but that the feature itself is not a seismogenic fault. It was on the basis of the second opinion that construction of the convention center was allowed to proceed.

References:

Simon, D.B., and Shlemon, R.J., 1999, The Holocene “Downtown Fault” in Salt Lake City, Utah [abs.]: Association of Engineering Geologists, 42nd Annual Meeting Program with Abstracts, p. 85.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Little Cottonwood Canyon (LCC) ***Study Synopsis ID*:** SLCS-9

***Fault/Fault Section*:** Salt Lake City section (SLCS), Wasatch fault zone (WFZ)

Map Reference: 2351f-4

Study:

McCalpin, J.P., 2002, Post-Bonneville paleoearthquake chronology of the Salt Lake City segment, Wasatch fault zone, from the 1999 "Megatrench" site: Utah Geological Survey Miscellaneous Publication 02-7, 37 p.

> ***McCalpin (2002), above, is an revised version of McCalpin and Nelson (2000), below, released by the Utah Geological Survey to make the results of this study more readily available to the geologic community and the general public. For purposes of this project, only McCalpin (2002) was reviewed.***

McCalpin, J.P., and Nelson, C.V., 2000, Long recurrence records from the Wasatch fault zone, Utah: U.S. Geological Survey, National Earthquake Hazards Reduction Program Final Technical Report, Contract No. 99HQGR0058, 61 p.

Type of Study/Commentary:

Trenching. This study reports on a reoccupation of the LCC site of Swan and others (1981; SLCS-1). A single "megatrench" was excavated across two fault scarps totaling 18 meters high. The purpose of the study was to date a long series of consecutive surface-faulting earthquakes on the SLCS, and to measure the variability of the recurrence times between these events.

The trench and an accompanying auger hole exposed 26 meters of vertical section, roughly four times that of a typical trench on the WFZ. Each of the two fault scarps was underlain by a major, down-to-the-west normal fault with 7 to 9.5 meters of vertical displacement measured on top of Lake Bonneville lacustrine sediments. Two minor antithetic faults were also exposed which had no surface expression, having been buried by wash-facies colluvium shed from the larger scarps. The "megatrench" was 65 meters long and did not extend across the graben (see SLCS-1), and therefore did not expose the antithetic fault on the west side of the graben west of Wasatch Boulevard.

Deposits in the trench were grouped into four genetic groups from oldest to youngest: (1) Lake Bonneville lacustrine sediments, (2) early Holocene loess, (3) mid-Holocene alluvial fan sand and gravel, and (4) fault-scarp-derived colluvium and crack-fill deposits. The lake sediments contained two bouldery diamictons that may represent earthquake-induced landslide deposits, but otherwise do not contain recognizable tectonic colluvium. The alluvial-fan deposits contain one small colluvial wedge on a minor fault. The remaining four colluvial wedges and an underlying fissure-fill alluvium overlie the Holocene alluvium.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

The "megatrench" contained stratigraphic evidence for seven paleoearthquakes younger than the Bonneville flood (~17.2 ka), and possibly an eighth event that occurred while Lake Bonneville was at or near its highstand at the Bonneville shoreline. Recognition of the four youngest events is based on colluvial-wedge stratigraphy, the oldest three events are hypothesized based on stratigraphic relations in the trench that include the absence or thinning of deposits attributed to erosion following surface faulting. Evidence for a possible eight event is a diamicton (landslide?) deposit interbedded with Lake Bonneville lacustrine sediments

Age of Events/Datum Ages/Dating Techniques:

There are two main down-to-the-west fault zones in the megatrench (F1 [east] and F4 [west]). The surface-faulting chronology on each fault zone is summarized below.

Fault F1

In fault zone F1 there are four colluvial-wedge deposits (E11, E10, E9, and E8) excluding a deep crack-fill mélange (7e) in underlying unit 7. The ^{14}C age constraints for the four most recent events are:

Summary of ^{14}C age constraints on the latest four faulting events on fault zone F1 (east main fault); after McCalpin (2002).

Event	Colluvial Unit	Minimum Age (cal yr B.P.)	Maximum Age (cal yr B.P.)
Ze	E11	1330-1530	1260-1505
Ye	E10	1620-2000	Bad date
Xe	E9	3060-3330 3870-4530	None close
We	E8		5060-5320 (close)

A small, suspected colluvial wedge (unit 7a1) lies below the stacked colluvial wedges of unit 11 and provides the only stratigraphic evidence for a paleoseismic event between ca. 17.2 ka (age of unit 5c – regressive Bonneville sand) and ca. 5 ka. Believing that additional events in that time period were probable, the author constructed a series of retrogressive cross-sections that progressed backward in time from the present trench geometry in fault zone F1.

The retrodeformation sequence relied on colluvial wedges, crack fills, and the thickness of colluvial-wedge units to reconstruct the latest four surface-faulting events (Events Ze, Ye, Xe, and We). Additionally, based on stratigraphic constraints as the retrodeformation sequence was taken back in time, additional events were required between units 7 and 8 (Event Ve), another event following deposition of unit 6 (Event Ue), and a third, subaqueous event between units 5a and 5b (Event T), which is indicated by boulders up to a meter in diameter mixed with lacustrine sediments. Inclusion of those three events within the time period ~20 ka to 5 ka satisfied all geometric constraints in the trench. Note that the interpretations of Events Ve, Ue, and Te are based chiefly on the absence or thinning of certain deposits in some parts of the megatrench, which is attributed to erosion accompanying paleoearthquakes. **There are no colluvial-wedge deposits or other positive stratigraphic evidence in the megatrench associated with Evens Ve, Ue, or Te.**

Timing of events Ve and Ue are constrained by sparse ^{14}C ages. Event Ve occurred after 8.8-9.1 ka, but before 5.1-5.3 ka. Event Ue occurred shortly after 9.5-9.9 ka. Event T was subaqueous and its timing is inferred from Lake Bonneville stratigraphy at the site, which places the event between 17.2 and 20.4 ka.

<u>Fault F4</u>

The simple geometry of fault zone F4 allowed all units younger than unit 7 (the four most recent events) to be reconstructed during retrodeformation from colluvial-wedge evidence. The trench was not deep enough on the hanging wall of fault F4 to expose the stratigraphic levels at which evidence for the three pre-5 ka events might be found. After "removal" of the latest four events, there was still 2.5 meters of throw to be accounted for on fault zone F4 by pre-5 ka events. How those 2.5 meters are apportioned among the three pre-5 ka events recognized on fault zone F1, or among some subset of those three events, is not known.

The ^{14}C age constraints for the four latest events on fault zone F4 are:

Summary of ^{14}C age constraints on the latest four faulting events on fault zone F4 (west main fault); after McCalpin (2002).

Event	Colluvial Unit	Minimum Age (cal yr B.P.)	Maximum Age (cal yr B.P.)
Zw	W11	NA	925-1230
Yw	W10	NA	1080-1315*
Xw	W9	NA	NA
Ww	W8	NA	7235-7815

contaminated age

Based on the results of this study, the surface-faulting chronology established by the author for LCC is as follows:

Event Z (MRE): 1.3 ka
Event Y (PE): 2.3 ka;
Event X (APE): 3.5 ka
Event W: 5.3 ka
Event V: 7.5 ka
Event U: 9 ka
Event T: 17 ka
Event S (?): possibly between 17 and 20 ka

The most detailed chronology of surface-faulting events on the SLCS prior to this study was that by Black and others (1996) at the South Fork Dry Creek (SFDC) site about 5 kilometers to the south. For comparison, the ages determined by

Black and others (1996) for the four most recent events at SFDC are shown below.

Black and others (1996) estimated ages for the four latest surface faulting events on the Salt Lake City section; after McCalpin (2002).

Event	Minimum Age (cal yr B.P.)	Preferred Age (cal yr B.P.)	Maximum Age (cal yr B.P.)
Z	1100	1300	1550
Y	2100	2450	2800
X	3500	3950	4500
W	4950	5300	5750

The author notes that the age constraints for surface-faulting events resulting from this study are not as closely limiting as those resulting from the Black and others (1996) study at SFDC. This is in part attributed to the fact that organic matter in the megatrench could not always be found near paleoearthquake event horizons, and that some event ages from the megatrench are based on ^{14}C age estimates on organics from crack fills rather than paleosols beneath colluvial wedges. As a result, the author had some difficulty in making an exact correlation between the timing of first four surface-faulting events in the megatrench, especially on fault zone F4, and the timing for the four most recent events reported by Black and others (1996). A number of plausible explanations are presented for this discrepancy, the most reasonable being that not all of the events recognized by Black and others (1996) at SFDC ruptured fault zone F4. At SFDC, Black and others (1996) demonstrated that not all of the fault strands there were active during every surface-faulting event, and a similar situation may have occurred at LCC.

<u>Dating Techniques</u>
Charcoal and buried organic soils were present throughout the stratigraphic section in the megatrench, and 25 ^{14}C age estimates (7 detrital charcoal, 18 AMRT) were obtained to constrain the timing of surface-faulting events. All ^{14}C age estimates were calendar calibrated using the computer program CALIB 4.0 (Stuiver and Reimer, 1993) and in accordance with Machette and others (1992, appendix A).

Soil profile development was also used as a basis for estimating the sequence and crude timing of paleoearthquakes, particularly for Events Ve, Ue, and Te, for which no colluvial-wedge deposits were present in the megatrench.

Event Slip/Cumulative Slip:
Cumulative slip could not be determined because the main antithetic scarp on the west side of the graben was not trenched. Total throw across fault zones F1 and F4 is 18.3 meters. If that total throw is divided among 7 events, the average is 2.6 meters per event; however, that average does not take into account the affect of antithetic faulting and possible back tilting in the graben.

Published Recurrence Interval:
The author states that mean recurrence between the latest four surface-faulting events based on Black and others (1996) is 1150 to 1500 years (preferred

estimate 1350±200 yrs). Based on the megatrench, the recurrence between Events U and V, and between Events V and W is roughly 2000 years. However, the recurrence between Events T and U ranges from 7100 to 9600 years, with a mean value of 8350 years, implying a long hiatus in surface faulting from the latest Pleistocene to the early Holocene. Additional evidence for a hiatus is provided by a well developed buried soil formed on units 5 (Bonneville lacustrine deposits) and 6 (early Holocene loess), which developed over a long period of time when no scarp-derived sediments or structures formed at the site, even as close as 1 meter to the faults.

***Published Slip Rate*:**
None reported – no accurate measurements were made of cumulative or per event slip.

***Sources of Uncertainty*:**

1. The interpretations for the tree oldest events at the site (Events V, U, and T), are based on a retrodeformation analysis of megatrench stratigraphy that relies on negative evidence, the absence or thinning of deposits, rather than the presence of scarp-derived colluvium to identify the three events.
2. The correlation between the timing of surface faulting at LCC and SFDC is not exact, but is consistent in a general way, with the exception of Event W on fault zone F4.
3. No cumulative net slip or net slip per event measurements resulted from this study.

***Summary*:**
When combined with the Black and others (1996) study at SFDC, this study documents the surface-faulting record on the SLCS to approximately 20 ka, the time of or just prior to the highstand of Lake Bonneville.

References:
Black, B.D., Lund, W.R., Schwartz, D.P., Gill, H.E., and Mayes, B.H., 1996, Paleoseismology of Utah, Volume 7 - Paleoseismic investigation on the Salt Lake City segment of the Wasatch fault zone at the South Fork Dry Creek and Dry Gulch sites, Salt Lake County, Utah: Utah Geological Survey Special Study 92, 22 p.

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Stuiver, Minzie, and Reimer, P.J., 1993, Extended ^{14}C database and revised CALIB 3.0 ^{14}C age calibration program: Radiocarbon, v. 35, p. 215-230.

Swan, F.H. III, Hanson, K.L., Schwartz, D.P., and Knuepfer, P.L., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah - Little Cottonwood Canyon site: U.S. Geological Survey Open-File Report 81-450, 30 p.

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

Name and Location of Fault/Fault Section:

Provo section (PS), Wasatch fault zone (WFZ), Utah County, Utah

Paleoseismic Data Source Documents:

Swan, F.H. III, Schwartz, D.P., and Cluff, L.S., 1980, Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault zone, Utah: Bulletin of the Seismological Society of America, v. 70, no. 5, p. 1431-1462.

Machette, M.N., and Lund, W.R., 1987, Trenching across the American Fork segment of the Wasatch fault zone, Utah: Geological Society of America Abstracts with Programs, v. 19, no. 5, p. 317.

Machette and Lund (1987), above, is an abstract that presents preliminary information from the American Fork Canyon site, some of which was significantly revised following the later availability of ^{14}C and TL age estimates for the site. Machette (1988), below, provides updated information for AFC; consequently, only Machette (1988) was reviewed for this project.

Machette, M.N., 1988, American Fork Canyon, Utah – Holocene faulting, the Bonneville fan-delta complex, and evidence for the Keg Mountain oscillation, *in* Machette, M.N., editor, In the Footsteps of G.K. Gilbert – Lake Bonneville and Neotectonics of the Eastern Basin and Range: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 89-95.

Lund, W.R., Black, B.D., and Schwartz, D.P., 1990, Late Holocene displacement on the Provo segment of the Wasatch fault zone at Rock Canyon, Utah County, Utah [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 6, p. 37.

Lund and others (1990), above, is an abstract that presents preliminary information from early investigations at the Rock Canyon site. Lund and Black (1998), below, reports the results of both the above study and of additional later work performed at Rock Canyon. Consequently, only Lund and Black (1998) was reviewed for this project.

Ostenaa, Dean, 1990, Late Holocene displacement history, Water Canyon site, Wasatch fault zone [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 6, p. 42.

Lund, W.R., Schwartz, D.P., Mulvey, W.E., Budding, K.E., and Black, B.D., 1991, Paleoseismology of Utah, Volume 1 - Fault behavior and earthquake recurrence on the Provo segment of the Wasatch fault zone at Mapleton, Utah County, Utah: Utah Geological and Mineral Survey Special Studies 75, 41 p.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2095, scale 1:50,000.

Both Machette (1992), above, and Machette and others (1992), below, summarize trenching studies performed on the PS up to 1992. There are some small differences (mostly related to rounding of numbers) between the two documents. The summaries in Machette and others (1992) are

generally more detailed, so I only prepared a Study Summary Form for that document. Additionally, I only reported information for Machette and others (1992) when there were significant differences (revision) with the information presented in the original site studies.

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Lund, W.R., and Black, B.D., 1998, Paleoseismology of Utah, Volume 8 - Paleoseismic investigation at Rock Canyon, Provo segment, Wasatch fault zone, Utah County, Utah: Utah Geological Survey Special Study 93, 21 p.

Geomorphic Expression:

Based on fault geometry and apparent recency of movement as indicated by scarp morphology, Machette and others (1986) tentatively subdivided the Provo section (as originally proposed by Schwartz and Coppersmith, 1984) into three subsections; from north to south, the American Fork, Provo "restricted sense," and Spanish Fork. However, based on the timing of the past two events determined from trench studies, the entire length of the WFZ in Utah Valley appears to be a single section (Lund and others, 1991; Machette, 1992; Machette and others, 1992; Lund and Black, 1998).

The American Fork part of the PS is 22.5 kilometers long and ends at a 2-kilometer left step in the fault at the Provo River, which Machette and others (1986) originally proposed as a possible segment boundary. The Provo "restricted sense" subsection extends from Provo Canyon south to Springville, Utah, a distance of 18.5 kilometers and includes the Springville fault, which continues into Utah Valley after the main WFZ makes a large left bend. Very large Quaternary landslides along the Wasatch Range characterize much of the central section of the PS. The Spanish Fork subsection of the PS extends from Springville to Payson Canyon in the southeastern corner of Utah Valley. The Spanish Fork subsection forms a major concave-to-the-west bend in the WFZ, which is the only such large bend along the entire fault zone. Machette (1992) states that the absence of a salient at the bend indicates there is no prominent change in structural throw across this part of the fault, and if the bend forms a section boundary it is a nonpersistant feature.

Evidence for Segmentation:

At the north end of the PS the west-trending Traverse Mountains form a major salient along the front of the Wasatch Range between Salt Lake and Utah Valleys. The salient is the structural boundary between the Salt Lake City section (SLCS) on the north and the PS on the south (Wheeler and Krystinik, 1992). At the south end of the SLCS, the WFZ turns abruptly to the east up Corner Canyon and can be traced continuously across the Traverse Mountain to the mouth of Dry Creek northeast of Alpine in northeastern Utah Valley (Machette, 1992). Late Pleistocene glacial outwash is displaced 3 to 5 meters near Dry Creek and time-equivalent fan alluvium along the crest of the Traverse Mountains is also displaced, but by an lesser amount than to the north and south on the SLCS and PS sections (Machette, 1992). The Traverse Mountains' intermediate structural position between the deep Salt Lake and Provo Valleys shows that the net slip on the WFZ is much reduced across this boundary.

The boundary between the PS and the Nephi section (NS) to the south is an echelon, overlapping right step in the WFZ (Machette, 1992) at the Payson salient (Wheeler and Krystinik, 1992), which forms a north-trending bedrock spur between the two fault sections. The PS terminates southeast of Tithing Mountain at Payson Canyon on the northeast side of the salient. The NS picks up about 2 kilometers to the west on the west side of Dry Mountain near the town of Payson.

Age of Youngest Faulting:
Holocene

Summary of Existing Recurrence Interval Information:
There are five major trench sites on the PS: American Fork Canyon (AFC), Rock Canyon (RC), Hobble Creek (HC), Mapleton, and Water Canyon (WC). Three well-dated paleoearthquakes are reported from AFC, one from RC, none from HC, two from Mapleton, and two from WC. In addition, other less-well-constrained events are reported from AFC (1), HC (6 or 7), and WC (2 or 3). Based on the sequence of events recognized at AFC, there have been three surface-faulting earthquakes on the PS in the past 5.3 ka. Information from RC and Mapleton shows that at least the past two events are likely correlative along the length of the PS. The age of at least one, and possibly both of the two most recent events at WC do not coincide with the sequence of surface faulting established farther north on the fault section. This may be due to WC's location close to the southern PS boundary, and the resulting influence of surface-faulting earthquakes on the Nephi section to the south.

Only the HC study reports a long-term (late Pleistocene) recurrence interval (1500 to 2600 years; revised by Schwartz and Coppersmith [1984] to 1700-2600 yrs). It is a poorly constrained estimate, because the total number of events is not known with certainty; and it is based on an outdated Lake Bonneville chronology.

Summary of Existing Slip-Rate Information:
Well-constrained, middle- to late-Holocene interevent intervals are available at AFC (2), Mapleton (1), and WC (1). The information available from AFC and Mapleton shows that the elapsed time between middle to late Holocene events at those sites has been on the order of 2100 to 2700 years. The data from WC are considerably different, there the two most recent events occurred within the past 1000 years and the elapsed time between them was 300-500 years. The elapsed time between the PE and the third oldest event at WC is >2600 to <4500 years. The best-constrained slip rate for the PS encompasses the two Holocene closed seismic cycles at AFC and is 1.0-1.4 mm/yr.

Long-term (latest Pleistocene) slip rate estimates for the PS were made at AFC and HC. At AFC, the long-term rate is based on displaced Bonneville shoreline deposits. Although there are uncertainties associated with the net slip recorded in those deposits, the long-term slip rate there (1.0-1.7 mm/yr; Machette and others, 1992) appears reasonably well constrained, but could be further refined using the most recent Lake Bonneville chronology. At HC, displacement in the Provo fan-delta surface is well documented and gives a slip rate for the past ~ 12-13 ka of 1.0+0.1 mm/yr, but is based on an outdated Lake Bonneville chronology. The net slip recorded by Bonneville shoreline deposits at HC has high uncertainty limits, and the resulting long-term slip rate estimates have correspondingly high uncertainty (3.9 [+7.9, -1.4] mm/yr for the past ~17±2 ka; later revised by Machette and others [1992] to 1.8-2.5 mm/yr).

At HC, the large difference in displacement recorded by Provo (11.5-13.5 m) and Bonneville (40-45 m) age deposits produces speculation regarding the possibility of very high (10 mm/yr) slip during and immediately following the catastrophic drop of Lake Bonneville from the Bonneville to the Provo level.

Comments:
Information pertaining to middle to late Holocene slip and recurrence is well distributed along the length of the PS, and shows reasonable consistency between sites, with the notable exception of WC near the southern section boundary. Long-term (latest Pleistocene) slip and recurrence intervals are much less well constrained because the chronology of surface-faulting events is poorly established beyond middle-Holocene time.

References: (also see above)
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.

Machette, M.N., Personius, S.F., and Nelson, A.R., 1986, Late Quaternary segmentation and slip-rate history of the Wasatch fault zone, Utah [abs.]: Transactions of the American Geophysical Union, v. 67, no. 44, p. 1107.

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes - Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Wheeler, R.L., and Krystinik, K.B., 1992, Persistent and nonpersistant segmentation of the Wasatch fault zone, Utah = Statistical analysis for evaluation of seismic hazard, *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. B1-B47.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Hobble Creek (HC) ***Study Synopsis ID***: PS-1

Fault/Fault Section: Provo section (PS), Wasatch fault zone (WFZ)

Map Reference: 2351g-3

Study:
Swan, F.H. III, Schwartz, D.P., and Cluff, L.S., 1980, Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault zone, Utah: Bulletin of the Seismological Society of America, v. 70, no. 5, p. 1431-1462.

Type of Study/Commentary:
Trenching. The HC site is about 12 kilometers south of Provo, Utah, on the central portion of the PS. There a prominent main fault scarp, several small grabens, and a wide zone of back tilting of the hanging wall toward the main fault characterize the WFZ. Lake Bonneville sediments are exposed in the fault scarp, and geomorphic surfaces associated with Lake Bonneville are displaced down-to-the-west across the fault. Displacements along the fault become progressively larger in deposits of increasing age.

Three trenches were excavated across the main fault and an associated graben about 1 kilometer northwest of the mouth of Hobble Creek Canyon. The graben at the trench site is formed in an alluvial-fan complex and is 50 to 65 meters wide. The main fault scarp is partially buried by younger alluvial-fan deposits, and the height of the scarp decreases where it displaces these younger sediments.

The Quaternary deposits at HC consist of lacustrine sediments associated with the high stand of Lake Bonneville (Bonneville level), a broad fan-delta complex associated with the Provo level of Lake Bonneville, alluvial-fan deposits of varying ages, loess, stream sediments, and scarp-derived colluvium. Provo fan-delta deposits are the oldest sediments exposed in the trenches at HC, and are juxtaposed against scarp-derived colluvium at the main fault.

Three paired strath terraces and one unpaired terrace are incised into the Provo fan-delta deposits near the mouth of Hobble Creek in the footwall of the main fault. These terraces lie below the Provo fan-delta surface and above a terrace along Hobble Creek that is underlain by post-Provo, pre-Utah Lake alluvium. The strath terraces are, therefore, estimated to be younger than about 12 ka and older than middle-Holocene (6 ± 2 ka)

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:
Structural and stratigraphic relations indicate that at least six and possibly seven surface-faulting earthquakes have occurred at HC in post-Provo time. Three, and possibly four of these events occurred in latest Pleistocene and early

Holocene time and are indicated by the strath terraces along Hobble Creek. Scarp-derived colluvial-wedge deposits in the trenches provide evidence for three additional events since the middle Holocene (past ~ 6 ka).

Age of Events/Datum Ages/Dating Techniques:

Ages of the three to four pre-middle Holocene/post-Provo events are based on the stratigraphic position of strath terrace inset into the Provo fan-delta complex (~12 ka old), and above a post-Provo, pre-Utah Lake terrace along Hobble Creek (~6 ka old). The terraces bracket the timing of the three to four events between ~12 and 6 ka, based on the Lake Bonneville chronology current at the time of this study. No ^{14}C ages were performed for this study, so the ages of the three most recent surface-faulting events identified from scarp-derived colluvium in the trenches are only generally dated as younger than about 6 ka.

Event Slip/Cumulative Slip:

Cumulative net slip measured from scarp profiles across the WFZ on the Provo terrace (fan-delta surface), and on the post-Provo/pre-Utah Lake terrace are **11.5 to 13.5 meters and 7 to 8.5 meters**, respectively. The cumulative net displacement of the Bonneville level lacustrine deposits (Bonneville shoreline) is uncertain because the effect of back tilting on those deposits is not know, but the net slip is estimated to be **30±5 meters**.

Displacements for individual surface-faulting events are not clearly defined at HC. Estimates of average tectonic displacement per event range from **0.8 to 2.8 meters** during the Holocene depending on the cumulative displacement recorded in deposits of different ages and on the number of surface-faulting earthquakes thought to have occurred during those time intervals (Schwartz and Coppersmith [1984] later revised the net slip estimate to 1.6-2.3 m).

Published Recurrence Interval:

This study did not permit absolute dating of individual events; however, it is estimated that six to seven events have occurred at HC since formation of the Provo fan-delta complex at ~12-13 ka. For six events and depending upon when the first identified event occurred, the recurrence interval would range from 2600 to 1857 years. For seven events, the range in recurrence is 1500 to 2000 years. Therefore, the authors' preferred average recurrence interval at HC is **1500 to 2600 years** – the maxima and minima of their estimated values (Schwartz and Coppersmith [1984] later revised the recurrence interval estimate to 1700–2600 yrs).

Published Slip Rate:

A slip rate calculated using displacement of the Provo fan-delta surface gives a latest Pleistocene/Holocene slip rate of **1.0+0.1 mm/yr**. A poorly constrained slip rate for post-Bonneville shoreline time (~17±2 ka) is **3.9 (+7.9,-1.4) mm/yr** (Machette and others [1992] later revised the long-term slip-rate estimate to 1.8-2.5 mm/yr).

Sources of Uncertainty:

1. Ages of individual surface-faulting events could not be determined, so actual elapsed time between events is unknown.

2. The net slip per event is not known, and cumulative slip values have significant uncertainty associated with them.
3. The number of events that have occurred in post-Provo time is not known with certainty (6 or 7), and the Lake Bonneville chronology used to estimate the ages of displaced deposits has been significantly revised in the 20+ years since this study was performed.
4. Evidence for the three to four pre-middle Holocene events is geomorphic (stacked strath terraces) and not confirmed by trench data.
5. Recurrence estimates account for differences in timing of the earliest identified earthquake, but it is unclear if the estimates include the time since the most recent surface-faulting event.
6. Slip-rate estimates extend to the present and include at least one open seismic cycle.

***Summary*:**

This is one of the earliest trenching studies conducted on the WFZ, and it was at this site that many of the concepts now regularly employed to interpret stratigraphic and structural relations exposed in trenches excavated on normal-slip faults were first developed. However, this study predates several advances in ^{14}C dating technology and TL dating entirely, thus severely limiting the availability of dateable material. This study also predates development of a detailed, calendar-calibrated Lake Bonneville chronology, a chronology that has changed significantly since this study was completed. Because absolute dating (^{14}C ages) was not possible at this site, information is lacking about the actual timing of events and about the elapsed time between events. Similarly, per event slip was not forthcoming from this study; consequently, all slip rates and recurrence intervals reported are estimates that were subsequently refined by later work at other trench sites on the PS.

References:

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes - Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: American Fork Canyon (AFC) ***Study Synopsis ID***: PS-2

Fault/Fault Section: Provo section (PS), Wasatch fault zone (WFZ)

Map Reference: 2351g-1

Study:
Machette, M.N., 1988, American Fork Canyon, Utah – Holocene faulting, the Bonneville fan-delta complex, and evidence for the Keg Mountain oscillation, *in* Machette, M.N., editor, In the Footsteps of G.K. Gilbert – Lake Bonneville and Neotectonics of the Eastern Basin and Range: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 89-95.

Type of Study/Commentary:
Trenching. At the AFC site, the WFZ consists of a prominent, west-facing, 7- to 8-meter-high main scarp at the foot of the Wasatch Range, and an east-facing antithetic scarp that forms a 25-meter-wide graben subparallel to the main scarp.

Three trenches each 25 to 50 meters long were excavated across scarps at AFC. All three trenches were placed on Holocene alluvial fans comprised chiefly of debris-flow deposits. Two ^{14}C ages, one on detrital charcoal recovered from loess beneath the debris-flow deposits, and the second on detrital charcoal from the upper part of the debris-flow sequence dates the accumulation of the alluvial-fan deposits to a period from <8.1 ka to about 5.4 ka.

Trench AF-1 was on the main fault and exposed a relatively simple sequence of three scarp-derived colluvial wedges. Trench AF-2 crossed the antithetic scarp and contained stratigraphic evidence for the MRE and probably the PE events. Trench AF-3 crossed a small synthetic fault scarp at the northern end of a left-stepping, en echelon splay of the main fault zone, and contained evidence for the PE and an older (fourth) event.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:
Four. Evidence for the three most recent events is provided by scarp-derived colluvial-wedge stratigraphy in the trenches. The evidence for the older (fourth) event is not explicitly stated, but is assumed also to be a colluvial wedge.

Age of Events/Datum Ages/Dating Techniques:
MRE = 550±100 cal yr B.P.
PE = 2650±150 cal yr B.P.
APE = 5300±200 cal yr B.P.
Event 4 = >5.4 ka and <8.1 ka

Ages of the surface-faulting earthquakes at AFC were determined using a combination of conventional and accelerator mass spectrometer ^{14}C dating of charcoal and soil carbon from paleosols, and TL dating analysis. The ^{14}C ages were calendar calibrated using a dendrochronologically corrected scale (not referenced), and for ^{14}C age estimates from soil organics, also calibrated by applying an appropriate mean residence correction to account for the age of the carbon in the soils prior to their burial.

Two ^{14}C AMRT ages (0.5 and 0.6 ka) from a paleosol beneath the MRE colluvial wedge, and two TL ages (400±100 and 500±200 yr ago) from trenches AF-1 and AF-2 provide good constraints on the timing of the MRE at AFC. Because TL ages from deposits less than 1000 years old typically have large associated uncertainty limits, more weight was given to the ^{14}C AMRT ages and the MRE was assigned a mean age of 550±100 cal yr B.P.

A paleosol beneath the PE colluvial wedge yielded a calendar-calibrated ^{14}C AMRT age of 2.6 ka and a TL age estimate of 2.7 ka. Because the ^{14}C and TL ages were in stratigraphic accord and have concordant uncertainty limits they were averaged to provide a mean age for the PE of 2650±150 cal yr B.P.

A calibrated ^{14}C AMRT age from a weakly organic paleosol beneath the APE colluvial wedge produced an age of slightly older than 5300±200 cal yr B.P. for the APE.

No information was provided on how the age constraints for the fourth event were determined.

Event Slip/Cumulative Slip:

The PE and APE events combined to produce 5-6 meters of net slip between 5.3 and 0.55 ka. No per event slip data are reported. A net slip of 15-26 meters measured on the Bonneville shoreline is reported across the main fault where back tilting is considered minor and there is no graben formed along the fault.

Published Recurrence Interval:

Inter-event intervals were reported as follows:

MRE-PE = 2100±250 yr
PE-APE = 2650±350 yr

Published Slip Rate:

Middle to late Holocene slip rate reported as 1.1-1.4 mm/yr (5-6 m/4750±350 yrs), which the author considers consistent with a slip rate of 1.0-1.5 mm/yr determined for the past ~15 ka from the faulted Bonneville beach gravels.

Sources of Uncertainty:

1. This document summarizes the paleoseismic investigation conducted at AFC. It lacks many details relevant to the study, most significantly logs of the three trenches and additional information regarding the fourth event.
2. No slip per event values reported for the three most recent events.

3. Cumulative slip measured on the Bonneville shoreline is an estimate that may include some near fault deformation.
4. No details are provided regarding how the ^{14}C ages were calendar calibrated.
5. Timing of the three most recent events, interevent times, and slip rates are slightly revised in Machette and others (1992).

Summary:

The study at AFC provides good age estimates for the three most recent surface-faulting earthquakes on the PS, and for the two closed interevent intervals between the three earthquakes.

References:

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Water Canyon (WC) ***Study Synopsis ID*:** PS-3

***Fault/Fault Section*:** Provo section (PS), Wasatch fault zone (WFZ)

Map Reference: 2351g-6

Study:

Ostenaa, Dean, 1990, Late Holocene displacement history, Water Canyon site, Wasatch fault zone [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 6, p. 42.

Type of Study/Commentary:

Trenching. This document is an abstract for a paper presented at a Geological Society of America meeting. The document is short and since it represents the most detailed information available for the WC site, it is reproduced here in its entirety.

Abstract

Two trenches in alluvial-fan deposits at the mouth of Water Canyon, 8 km south of Spanish Fork, UT, reveal a record of 3+ Holocene surface-faulting events on the Wasatch fault. Twelve ^{14}C ages constrain the chronology. Charcoal ages from surface burn horizons buried by fault-scarp colluvium limit the ages of the two most recent events. Older events are bracketed by ages on detrital charcoal in alluvium and colluvium.

The two most recent events both produced a 1- to 2-meter-thick colluvial wedge adjacent to the free face. Both wedges lie directly on thin A-horizons with abundant charcoal. ^{14}C ages of 320±120 and 890±60 radiocarbon years suggest calendar-corrected age ranges of 0.54-0.28 ka or 0.23-0.15 ka for the most recent event and 0.94-0.70 ka for the next oldest event.

An underlying sequence of organic colluvium with buried soils, overbank, and small channel deposits records a long period of inactivity. The oldest of five ^{14}C ages in stratigraphic succession from this sequence is 3445±100 radiocarbon years (4.0-3.5 ka). Stratigraphic relations and an additional age suggest the occurrence of 1 or 2 faulting events shortly before this date, but well after deposition of a unit from which charcoal gave an age of 4600±75 radiocarbon years (5.5-5.0 ka). Additional faulting postdates alluvial-fan deposits on the footwall. Charcoal from this unit gave an age of 9425±105 radiocarbon years.

The ages and stratigraphic relations suggest that inter-event times are variable. The inter-event time for the two most recent events and from the present to the most recent event is about 300-500 years. The interval to the preceding events was >2600 to <4500 years.

Water Canyon is near the southern end of the Spanish Fork segment of the Wasatch fault. The number of events and their ages are in modest conflict with data from other trenches on this segment. The apparent conflict may be resolved if surface faulting from an event on the Nephi segment to the south continued past Water Canyon, but not as far as Mapleton.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

Three(+) surface-faulting earthquakes, the two most recent events were identified on the basis of scarp-derived colluvial-wedge deposits. Evidence for older events is provided by "stratigraphic relations" in the trenches, but the nature of those relations is not made clear.

Age of Events/Datum Ages/Dating Techniques:

MRE: 0.54-0.28 ka or 0.23-0.15 ka
PE: 0.94-0.70 ka
1 or 2 events: >4.0-3.5 ka but <5.5-5.0 ka
Additional events: <9425 ^{14}C yr B.P.

The ^{14}C ages used to constrain the two most recent surface-faulting events came from charcoal recovered from paleosols buried by colluvial-wedge deposits. Additional ^{14}C ages bracket the timing of earlier events, but details of the relations between the age estimates and stratigraphic units in the trenches are not provided.

Event Slip/Cumulative Slip:

None reported. Two most recent events produced 1- to 2-meter-thick colluvial-wedge deposits.

Published Recurrence Interval:

Inter-event time between the two most recent events is 300-500 years. Elapsed time to the preceding event is reported as >2600 to <4500 years.

Published Slip Rate:

None reported

Sources of Uncertainty:

1. This document provides only a brief summary of the results of the Water Canyon paleoseismic study. Many details of the investigation, including trench logs; information on how and where ^{14}C samples were collected, analyzed, and calibrated; the characteristics of the fault zone at the site; other details of site and trench geology; etc. are lacking.
2. The number and timing of events prior to the PE are poorly constrained.
3. Data on cumulative slip and slip per event are unavailable.
4. The timing of the two most recent events conflicts with the timing of those events at the Mapleton, Rock Canyon, and American Fork sites farther north on the PS.

Summary:

The Water Canyon site is close to the southern end of the PS. Conflicts in the timing of surface-faulting events recorded at Water Canyon with events determined at trench sites farther north my result from ruptures on the Nephi section to the south "leaking" through the section boundary as far as Water Canyon, but not as far as the more northerly sites.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP
PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Mapleton ***Study Synopsis ID***: PS-4

Fault/Fault Section: Provo section (PS), Wasatch fault zone (WFZ)

Map Reference: 2351g-4 (MN) & 2351g-5 (MS)

Study:

Lund, W.R., Schwartz, D.P., Mulvey, W.E., Budding, K.E., and Black, B.D., 1991, Paleoseismology of Utah, Volume 1 - Fault behavior and earthquake recurrence on the Provo segment of the Wasatch fault zone at Mapleton, Utah County, Utah: Utah Geological and Mineral Survey Special Studies 75, 41 p.

Type of Study/Commentary:

Trenching. The Mapleton site is in the southeastern part of Utah Valley on the formerly proposed Spanish Fork subsection of the WFZ (Machette and others, 1986). Five trenches were excavated at two closely spaced sites. Two trenches were at the Mapleton North (MN) site and three trenches were at the Mapleton South (MS) site, about 0.8 kilometers to the south.

At MN, the WFZ consists of a single west-dipping main fault with an 18-meter-high scarp, and an accompanying subparallel, east-facing antithetic scarp. Together the two faults displace upper and middle Holocene alluvial-fan deposits. The middle Holocene fan has been displaced down-to-the-west by multiple surface-faulting earthquakes, leaving the fan apex stranded on the footwall of the fault. Post-faulting erosion has incised the stranded fan deposits and resulted in deposition of a younger, late Holocene fan, which partially buries the middle Holocene fan on the fault hanging wall. The late Holocene fan has also been displaced by surface faulting, and is back-tilted to the east toward the main fault. The graben is almost completely filled with recent debris-flow deposits and scarp-derived colluvium.

At MS, the WFZ consists of two subparallel, west-dipping faults; a main fault with a scarp more than 20 meters high, and a secondary, subparallel fault about 10 meters farther west expressed by a more gentle 5-meter-high scarp. Both faults displace a late Holocene alluvial fan. The fan surface is tilted toward the east between the two fault strands. Although a wide zone of anomalously low ground parallels the fault zone to the west, no evidence of an antithetic fault was found.

Fault Parameter Data:

> ***Number of Surface-Faulting Events/How Identified***:
> Two/colluvial-wedge stratigraphy in trenches
>
> ***Age of Events/Datum Ages/Dating Techniques***:

Most Recent Event

Mapleton North

Radiocarbon dates on charcoal from trench MN-1 on the main fault allows the MRE to be closely constrained. A ^{14}C age on charcoal from a paleosol buried by the MRE colluvial wedge provides a maximum limiting age for the event of 680 (+40, -20) cal yr B.P. A ^{14}C age on charcoal from a post-MRE burn layer provides minimum limiting ages for the event of 510 (+120, -190) and 520 (+120, -60) cal yr B.P. Considering the uncertainties associated with the ^{14}C ages, the MRE could have occurred between 720 and 320 cal yr B.P. However, the preferred time range is the 160-year window between 680 and 520 cal yr B.P., resulting in a best estimate for the timing of the MRE in the middle of the window at 600 (±80) cal yr B.P.

Charcoal from a paleosol in trench MN-2 across the antithetic fault predates the MRE and yielded a ^{14}C age of 690 (+230, _140) cal yr B.P., and thus provides a maximum limiting age for the event. Charcoal collected at the contact between the youngest faulted deposit and the oldest post-MRE deposit in the graben yielded ages of 430, 360, and 330 (+70, -40) cal yr B.P., which provide a minimum limiting age for the event. The two ^{14}C ages provide a broad time range for the MRE between 920 and 290 cal yr B.P., with a preferred 260 year window between the reported ages of 690 and 430 cal. yr B.P. The best estimate for the timing of the MRE in trench MN-2 was also placed in the middle of the time window at 560 (±130) cal yr B.P.

Because the age estimate for the MRE in trench MN-1 was better constrained than the estimate from trench MN-2, **600 (±80) cal. yr B.P.** was selected as the preferred age for the timing of the MRE at MN.

Mapleton South

The timing of the MRE at Mapleton South is poorly constrained. A maximum limiting age of 1290 (+130, -230) cal yr B.P. is provided by a single ^{14}C age on detrital charcoal from a faulted debris-flow deposit. However, stratigraphic and soil relations in the trench show that the MRE is considerably younger than the ^{14}C date. Four intervening debris-flow units and a weakly developed soil A-horizon separate the debris flow with the charcoal from the MRE colluvial wedge. Given the close proximity of the MN and MS sites, the authors believe that the same MRE occurred at both locations and that the time required for the four debris-flow units to accumulate and for the weak soil to form is consistent with a 600 cal yr B.P. age for the MRE at MS.

Penultimate Event:

Mapleton North

The PE at MN predates the 680 (+40, -20) cal yr B.P. age obtained in trench MN-1, but a lack of datable material prevented the event from being more closely constrained.

Mapleton South

Two ^{14}C ages, one on soil organics and the other on charcoal, and a TL age estimate, all from the same pre-event paleosol help constrain the timing of the PE at MS. The PE colluvial wedge rests on top of the buried soil at the main fault zone; however, all three age estimates come from farther west in the trench, where a post-faulting debris-flow deposit buries the soil. The ^{14}C AMRT and TL samples were collected there because the soil A-horizon is better developed at that location. The soil beneath the PE colluvial wedge was weakly developed, and there was concern that there might not be sufficient organics available for a reliable ^{14}C age estimate.

The soil organics yielded an ^{14}C AMRT age of 2820 (+150, -130) cal yr B.P., and the TL age estimate from the same location was 3300±300 yrs. The age of the detrital charcoal ranged from 2930 to 2890 (+280, -130) cal yr B.P. Although displaced by the PE, the soil at the location from which the TL and AMRT ages were obtained, continued to form for an unknown period of time following the PE until buried by a debris flow. Therefore, the ^{14}C AMRT and TL age estimates represent minimum limiting ages for the timing of the PE. However, the absence of soil development, other than a thin A-horizon, argues for a young soil age, and the authors believe that the PE is probably not much older than the time of soil burial. Because the TL method had a maximum resolution of about 500 years (Forman and others, 1989), the ^{14}C AMRT age was considered more accurate, and the author's preferred estimate for the time of the PE is **shortly before 2820 (+150, -130) cal. yr B.P.**

Dating Techniques

All ^{14}C ages were calendar corrected using the CALIB computer program (Stuiver and Reimer, 1986), and the ^{14}C AMRT age on soil organics was calibrated according to the method of Forman and others (1989). Accordingly, a mean residence correction of 200 years was subtracted from the ^{14}C age on the soil organics to account for the accumulated age of the carbon in the soil, prior to calendar correcting the ^{14}C date.

Event Slip/Cumulative Slip:

Net slip per event could not be directly measured at Mapleton because geologic units could not be correlated across the faults exposed in the trenches. Scarp profiles measured at both MN and MS provided little reliable information on cumulative slip due to difficulty in correlating equivalent surfaces across the fault zone.

The net slip for the MRE was estimated at MN from the thickness of the MRE colluvial wedge and by subtracting the effects of back-tilting and antithetic faulting. The resulting net slip estimate was **1.4-3.0 meters**. The complexity of the faulting at MS made evaluating the effect of back tilting difficult, and the possible presence of a graben west of the main fault zone could not be disproved without additional trenching.

Published Recurrence Interval:

Timing of the MRE at Mapleton is well constrained at 600±80 cal yr B.P. Timing of the PE is less well constrained, but likely occurred shortly before 2820 (+150, -130) cal yr B.P. The elapsed time between the two events is at least 2010 yrs and could be somewhat more than 2450 yrs. Assuming that the uncertainty in the timing of the PE may be as much as 200 years, the authors believe that a reasonable estimate for the PE-MRE interevent interval is **2200-2700 yrs**. The authors compare this to the estimated recurrence interval at Hobble Creek (Swan and others, 1980) of 1500-2600 years over the past ~14 ka.

***Published Slip Rate*:**
Due to the variability in both the estimate recurrence interval (2200-2700 yrs) and MRE net slip (1.4-3.0 m), the slip rate for the PE-MRE closed seismic cycle ranges from 0.52-1.36 mm/yr. Using median values for net slip of 2.2 meters and 2450 years for recurrence, gives an "average" slip rate of **0.9 mm/yr** for one closed seismic cycle between the PE and MRE. For comparison, Swan and others (1980) estimated an average slip rate for middle to late Holocene time at Hobble Creek of 1.36 mm/yr.

***Sources of Uncertainty*:**
1. Timing of the PE relies on ^{14}C and TL age estimates that are west of the main fault zone, and therefore not directly beneath the PE colluvial wedge. The event may be as much as a few hundred years older than the author's preferred age estimate.
2. Neither per event nor cumulative net slip could be directly measured at Mapleton.
3. The soil organics collected in trench MS-1 and used to date the PE, came from a channel sample taken across the entire width of the soil A-Horizon, and for that reason contained the full range of carbon age in the soil.

***Summary*:**
This study provides a well-constrained age for the time of the MRE on the southern part of the PS, and less well-constrained age for the PE. Estimates of per event slip and the length of the interval between the PE and MRE result in a "best estimate" slip rate of 0.9 mm/yr for one late Holocene closed seismic cycle.

References:
Forman, S.L., Machette, M.N., Jackson, M.E., and Maat, Paula, 1989, An evaluation of thermoluminescence dating of paleoearthquakes on the American Fork segment, Wasatch fault zone, Utah: Journal of Geophysical Research, v. 94, no. B2, p. 4537-4555.
Machette, M.N., Personius, S.F., and Nelson, A.R., 1986, Late Quaternary segmentation and slip-rate history of the Wasatch fault zone, Utah: EOS (Transactions of the American Geophysical Union), v. 67, no. 44, p. 1107
Stuiver, Minze, and Reimer, P.J., 1986, A computer program for radiocarbon age calibration (Rev. 2.0): Radiocarbon, v. 28, no. 2B, p. 1022-1030.
Swan, F.H. III, Schwartz, D.P., and Cluff, L.S., 1980, Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault zone, Utah: Bulletin of the Seismological Society of America, v. 70, no. 5, p. 1431-1462.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Summary document covering several trench sites

Study Synopsis ID: PS-5

Fault/Fault Section: Provo section (PS), Wasatch fault zone (WFZ)

Map Reference: 2351g-1 (AFC) & 2351g-3 (HC)

Study:
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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Type of Study/Commentary:
Summary. This document summarizes the paleoseismic information for the American Fork Canyon, Rock Canyon, Hobble Creek, Mapleton, and Water Canyon trench sites on the PS up to 1992. Information for those sites is only reported here if it is significantly different or updated from the information presented in the original site studies. Information for Rock Canyon was not included here because Lund and Black (1998; PS-6a) provides updated detailed information for that site.

Fault Parameter Data:
<u>American Fork Canyon</u>
- Revised paleoearthquake chronology
  - MRE = 500±200 cal yr B.P. (revised from 550±100; Machette, 1988)
  - PE = 2650±250 cal yr B.P. (revised from 2650±150; Machette, 1988)
  - APE = 5300+300 cal yr B.P. (revised from 5300±200; Machette, 1988)
- Revised interevent intervals
  - MRE-PE = 2150±450 yrs (revised from 2100±250 yr; Machette, 1988)
  - PE-APE = 2650±450 yrs (revised from 2650±350 yr; Machette, 1988)
- Revised slip rate
  - Middle Holocene slip rate calculated across two closed seismic cycles
    - 5-6 m/4800±500 yr = 1.0-1.4 mm/yr
  - Compare to a 1.0-1.7 mm/yr late Pleistocene slip rate based on displaced ~15 ka Bonneville lake cycle deposits.
- Revised per event slip
  - Estimated 2.2-2.7 meters based on reconstruction of the volume of colluvial-wedge deposits, no further details provided.

<u>Hobble Creek</u>
- Revised estimate of cumulative net slip on Bonneville shoreline deposits
  - Swan and others (1980) estimate 30±5 meters; the new estimate, based on an evaluation of the geometry associated with back tilting at the site, is 40-45 meters.

Revised late Pleistocene slip rate (based on an outdated Lake Bonneville chronology)

1.8-2.5 mm/yr

Because the net displacement recorded across transgressive Lake Bonneville deposits (30-45 m) is two to three times greater than that recorded by regressive Bonneville deposits (11.5-13.5 m), and the potential difference in age (1-4 ka) is small, faulting at this site may have occurred at very high rate (perhaps as high as 10 mm/yr) during and after the catastrophic fall of Lake Bonneville ~ 15 ka.

***Summary*:**

Slightly revised paleoseismic information is provided for the American Fork Canyon site, along with a figure depicting the main fault zone in trench AF-1. It is the only known trench log published for that site. A revised estimate for cumulative net slip recorded by Bonneville shoreline deposits is reported for Hobble Creek. The new estimate results in a change in the late Pleistocene slip rate at the site, and raises questions regarding the rate of faulting (very high?) on the PS during and immediately after the Bonneville Flood.

References:

Lund, W.R., and Black, B.D., 1998, Paleoseismology of Utah, Volume 8 - Paleoseismic investigation at Rock Canyon, Provo segment, Wasatch fault zone, Utah County, Utah: Utah Geological Survey Special Study 93, 21 p.

Machette, M.N., 1988, American Fork Canyon, Utah – Holocene faulting, the Bonneville fan-delta complex, and evidence for the Keg Mountain oscillation, *in* Machette, M.N., editor, In the Footsteps of G.K. Gilbert – Lake Bonneville and Neotectonics of the Eastern Basin and Range: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 89-95.

Swan, F.H. III, Schwartz, D.P., and Cluff, L.S., 1980, Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault zone, Utah: Bulletin of the Seismological Society of America, v. 70, no. 5, p. 1431-1462.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Rock Canyon (RC) ***Study Synopsis ID:*** PS-6

Fault/Fault Section: Provo section (PS), Wasatch fault zone (WFZ)

Map Reference: 2351g-2

Study:

Lund, W.R., and Black, B.D., 1998, Paleoseismology of Utah, Volume 8 - Paleoseismic investigation at Rock Canyon, Provo segment, Wasatch fault zone, Utah County, Utah: Utah Geological Survey Special Study 93, 21 p.

Type of Study/Commentary:

Trenching/natural exposure. The RC site is at the mouth of Rock Canyon, a narrow, steep-walled drainage in the Wasatch Range immediately east of Provo, Utah. Rock Creek has incised its channel into a Bonneville-level fan-delta complex that formed at the canyon mouth when Lake Bonneville stood at its highest level. The Bonneville-level delta sediments rise as a steep-sided bluff south of the RC site. The deltaic sediments in the bluff are displaced down-to-the-west in stair-step fashion by several north-trending, west-dipping traces of the WFZ. A down-to-the-east antithetic fault forms a graben parallel to the westernmost west-dipping fault. Only a single, west-dipping fault extends northward from the delta deposits onto the Rock Creek floodplain. Gilbert (1890) showed an antithetic fault displacing the floodplain deposits, but neither Hintze (1978), Machette (1992), nor the authors of this study could find evidence of an antithetic fault scarp on the flood plain.

In the deltaic deposits to the south, WFZ scarps are as much as 15 meters high, but the single scarp formed on the floodplain is only 5 meters high, indicating that the younger deposits have been displaced by fewer surface-faulting events. Continuing north across the floodplain, the scarp bifurcates into two subparallel strands that are exposed in the south wall of the modern Rock Creek stream channel. Neither fault displaces young fluvial deposits associated with Rock Creek.

A trench was excavated across the 5-meter fault scarp formed on the Rock Creek floodplain deposits south of the point where the fault bifurcates. A backhoe was used to clean the south bank of the Rock Creek stream channel to better expose the two strands of the fault observed there.

Fault Parameter Data:

> ***Number of Surface-Faulting Events/How Identified:***
> One/colluvial wedge deposits
>
> ***Age of Events/Datum Ages/Dating Techniques:***

Trench

The RC trench exposed a sequence of coarse-grained fluvial and debris-flow deposits, and three intervening A-Horizon paleosols displaced across the main, west-dipping fault zone, an east-dipping antithetic fault, and the intervening 15-meter-wide graben. A single, scarp-derived, colluvial-wedge deposit was present on the downthrown side of the main fault, and similar scarp-derived deposits filled a wide crack along the antithetic fault.

Calendar-calibrated ^{14}C AMRT ages were obtained for all three paleosols from soil organics. Ages for the three paleosols from oldest to youngest are:

Paleosol 7s: 2400 (+350, -150) cal yr B.P.
Paleosol 8s: 1600 (+250, -200) cal yr B.P.
Paleosol 11s: 550 (+50, -50) cal yr B.P.

Paleosols 7s and 8s predate the faulting event exposed in the RC trench. Paleosol 11s lies directly beneath the colluvial-wedge deposits on the main fault, and extends from there westward into the graben. Paleosol 11s is very weakly developed beneath the colluvial wedge, so the sample collected for ^{14}C AMRT dating was taken from a location west of the fault zone, where a post-MRE debris-flow deposit buried the paleosol. The age obtained for paleosol 11s at that location dates the time of its burial by the debris flow, not the time of the MRE, which occurred prior to the soils burial. However, the debris flow laps onto the colluvial wedge about 3 meters from the main fault zone, showing that sufficient time had elapsed for a large wedge to form before the debris flow buried the paleosol in the graben. Therefore, the elapsed time between the MRE and burial of paleosol 11s at 550 (+50, -50) cal yr B.P. could be tens to more than a 100 years.

Stream Cut

The 3- to 4-meter-high RC stream cut exposed a sequence of late Holocene debris-flow and fluvial deposits and two strands (East and West) of the WFZ. The two faults are about 40 meters apart in the stream cut and coalesce to the south to form the single 5-meter-high scarp at the trench.

East Fault

At the East fault, the pre-event ground surface is represented by a 40-centimeter-thick, dark black, organic paleosol (unit 6s). Near the fault zone, scarp-derived colluvial-wedge deposits directly overlie paleosol 6s. Organic-rich materials at the East fault zone have been sampled three different times for ^{14}C dating. In 1986 a joint USGS/UGS team (Machette and Mulvey; Machette and others, 1992) collected bulk samples of organic colluvial-wedge matrix and what they thought was a young soil formed on the wedge for dating analysis. Their calendar-calibrated ^{14}C AMRT ages for those samples were 1005 (+145, -55) cal yr B.P. and 512 (+40, -55) cal yr B.P., respectively.

In 1988 during detailed logging of the RC stream cut by a second UGS/USGS team (Lund, Black, and Schwartz; Machette and others, 1992), it was realized that the East fault colluvial wedge rested directly upon paleosol 6s, and a channel sample of the paleosol was collected for dating. The resulting calendar-calibrated ^{14}C AMRT age was 1000 (+50, -200) cal yr B.P., a result very close to that obtained by Machette and Mulvey for the colluvial-wedge matrix material. Not an unexpected development considering that paleosol 6s on the upthrown side of the fault contributed considerable organic material to the wedge deposit.

Finally in 1995 (this study), realizing that all previous ^{14}C dates from the East fault zone had been on soil organics from bulk channel samples, just the uppermost 5 centimeters of paleosol 6s directly beneath the colluvial wedge were sampled and dated. The resulting ^{14}C AMRT age was **650 (+50, -100) cal yr B.P.**, which just postdates the time of the MRE.

West Fault
Much of the colluvial wedge at the West fault has been removed by post-faulting erosion; only remnants of the basal portion of the wedge near the fault and the distal toe of the wedge remain. Paleosol 6s is preserved on the downthrown side of the fault and was warped upward by the faulting. A thin debris-flow and a thin fluvial deposit overlie the up-warped soil, and are in turn overlain by the toe of the colluvial wedge, implying that the debris-flow and fluvial units were deposited very shortly after the MRE. A channel sample of the 6s paleosol was collected from beneath the toe of the wedge in 1989, and yielded a ^{14}C AMRT age of 1100 (+200, -100) cal yr B.P. Due to extensive sluffing of the stream cut between 1989 and 1995, it was not possible to resample the upper few centimeters of paleosol 6s beneath the colluvial wedge toe in 1995, so the existing AMRT age for that unit at the West fault includes the total range of carbon ages in the buried soil.

MRE Timing
Information on the timing of the MRE at RC comes from both the trench and the stream-cut exposure. Exposures and ^{14}C AMRT ages from the trench show that the MRE occurred sometime between 1600 and 550 cal yr B.P. (ages of paleosols 8s and 11s). In the stream cut, exposures at the East fault show that the colluvial wedge from the MRE buried paleosol 6s at **650 cal yr B.P.**, and therefore the MRE occurred just prior to that time. The ^{14}C AMRT age from the West fault zone contains a full range of carbon ages in the paleosol and provides a maximum limiting age for the MRE.

^{14}C AMRT Ages
All ^{14}C ages in radiocarbon years were calendar corrected using the CALIB 3.0.3 computer program (Stuiver and Reimer, 1993). In addition, ^{14}C ages on soil organics were calibrated according the method of Machette and others (1992, appendix). The mean residence corrections (MRC) applied to compensate for the age of the carbon in the soil prior to burial ranged from 100 to 300 years, depending on the degree of soil development. In retrospect, a greater MRC (perhaps 600-700 years) should have been applied to the channel samples of the well-developed, 40-centimetr-thick 6s paleosol exposed in the stream cut.

***Event Slip/Cumulative Slip*:**

Trench
Several faulted geologic units extend the full length of the RC trench, and it was possible to directly measure the displacement produced by the MRE. The event produced 4.5 meters of slip down-to-the-west across the main fault zone and 0.8 meters of down-to-the-east displacement across the antithetic fault. Back tilting

and drag near the fault zones were a factor, so net slip for the MRE was determined by projecting contacts of displaced units in the footwall and the hanging wall to the fault zone. The result was a net-slip measurement for the MRE of **3.3 meters**.

***Published Recurrence Interval*:**
Not available – only one event

***Published Slip Rate*:**
Not available, only one event

***Sources of Uncertainty*:**

1. Key ^{14}C ages used to determine the timing of the MRE are all AMRT dates. Selection of the proper MRC to calibrate the calendar-corrected ^{14}C ages is always a "best guess" procedure that may affect the final AMRT age by several tens to a100 years or more. This is true for all ^{14}C AMRT ages on the WFZ.
2. The samples collected from the paleosols in the trench were channel samples taken across the full width of the buried soil, and therefore contain the full range of carbon ages in the soil. The paleosols were generally thin and the authors believe the MRC values selected to calibrate the ^{14}C ages from those soils were appropriate, based on the results of other studies conducted on the WFZ (Forman, 1989; Forman and others, 1991; Machette and others, 1992). However, more accurate, and probably slightly younger ages could have been obtained for the paleosols if only the upper few centimeters of those units had been sampled and dated.
3. The age determined for the MRE at RC is about 100 years older than the age determined at Mapleton, and 50 years older than the age determined at Rock Canyon. Considering the vagaries of ^{14}C dating and the calibration of AMRT ages from soil organics, the authors consider these ages to be in good agreement.

***Summary*:**
The study at RC confirmed the age of the MRE on the proposed Provo segment (restricted sense) and showed that for at least the MRE, the entire PS ruptured as a single fault section. The age of the PE on the PS, as determined at the American Fork Canyon and Mapleton trench sites, is older than the age of the deposits exposed at RC, so no evidence for that event was observed at RC.

References:

Forman, S.L., 1989, Applications and limitations of thermoluminescence to Quaternary sediments: Quaternary International, no. 1, p. 47-59.

Forman, S.L., Nelson, A.R., and McCalpin, J.P., 1991, Thermoluminescence dating of fault-scarp-derived colluvium - Deciphering the timing of paleoearthquakes on the Weber segment of the Wasatch fault zone, north-central Utah: Journal of Geophysical Research, v. 96, no. B1, p. 595-605.

Gilbert, G.K., 1890, Lake Bonneville: U.S. Geological Survey monograph 1, 438 p.

Hintze, L.F., 1978, Geologic map of the Y Mountain area, east of Provo, Utah: Brigham Young University Geology Studies Special Publication 5, scale 1:24,369.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2095, scale 1:50,000.

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Stuiver, Minze, and Reimer, P.J, 1993, Extended 14C database and revised CALIB 3.0 ^{14}C age calibration program: Radiocarbon, v. 35, p. 212-230.

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

Name and Location of Fault/Fault Section:
Nephi section (NS), Wasatch fault zone (WFZ), Juab County, Utah

Paleoseismic Data Source Documents:
Hanson, K.L., Swan, F.H., III, and Schwartz, D.P., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah: San Francisco, Woodward-Clyde Consultants, sixth semi-annual technical report prepared for the U.S. Geological Survey, Contract No. 14-08-0001-16827, 22p.

Schwartz and others (1983), below, present a brief summary of several early trenching studies conducted on the WFZ. In all cases, the original site studies and summaries in other documents provide greater details; consequently, I did not review this document for this project.

Schwartz, D.P., Hanson, K.L., and Swan, F.H., III, 1983, Paleoseismic investigations along the Wasatch fault zone – An update, in Gurgel, K.D., editor, Geologic Excursions in Neotectonics and Engineering Geology in Utah: Utah Geological and Mineral Survey Special Studies 62, p. 45-48.

Schwartz and Coppersmith (1984), below, present a brief summary of the paleoseismic investigation at North Creek and recalibrate critical ^{14}C ages using a more recent set of radiocarbon calibration curves (Klein and others, 1982) than the curves employed by Hanson and others (1981). However, the Klein and others (1982) curves also are now obsolete, and later workers (Jackson, 1991; Machette and others, 1992) recalibrated the Hanson and others (1981) dates using more modern ^{14}C correction curves (Stuiver and Reimer, 1986); consequently, Schwartz and Coppersmith (1984) was not reviewed for this project.

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes - Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Jackson, M.E., 1991, Paleoseismology of Utah, Volume 3 - The number and timing of Holocene paleoseismic events on the Nephi and Levan segments, Wasatch fault zone, Utah: Utah Geological Survey Special Studies 78, 23 p.

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Geomorphic Expression:
Scarps in Quaternary lacustrine deposits and alluvium. The northern end of the section overlaps the Provo section (PS) at the Payson salient. The Benjamin fault forms the west side of the salient and dies out as it extends northward into Utah Valley (Machette, 1992; Harty and others, 1997). Sediments of the Provo phase of the Bonneville Lake cycle are only offset up to 2 meters along this fault (Machette, 1992). Faults associated

with young scarps north of the town of Nephi are probably continuous with near-surface faults in the town identified from seismic-reflection data (Crone and Harding, 1984). A number of small faults in Quaternary deposits have been identified on the western flank of the Gunnison Plateau east of Nephi (Biek, 1991).

Evidence for Segmentation:
The boundary between the PS to the north and the NS to the south is an en echelon, overlapping right step in the WFZ (Machette, 1992) at the Payson salient (Wheeler and Krystinik, 1992), which forms a north-trending bedrock spur between the two fault sections. The PS terminates southeast of Tithing Mountain at Payson Canyon on the northeast side of the salient. The NS picks up about 2 kilometers to the west on the west side of Dry Mountain near the town of Payson.

The southern section boundary is at a 15-kilometer gap in Holocene and latest Pleistocene surface faulting where a large alluvial fan (Levan Ridge) extends westward from the San Pitch Mountains (Machette and others, 1992; Harty and others, 1997). Gravity data suggest the fault continues through and beneath Levan Ridge, but has been inactive for perhaps tens of thousands of years (Zoback, 1983; Machette and others, 1992).

Age of Youngest Faulting:
Holocene

Summary of Existing Recurrence Interval Information:
Trenching studies conducted at North Creek (NC; Hanson and others, 1981) and Red Canyon (RC; Jackson, 1991) show that there have been three surface-faulting earthquakes on the NS since probable middle Holocene time (post 5.3 ka). Timing of the events is not well constrained at NC, evidence for the two most recent events consists of colluvial-wedge stratigraphy in trenches, but evidence for the APE consists of an inset strath terrace along North Creek in the fault footwall. At RC, scarp-derived colluvial wedges with soil A-horizons formed on their surfaces document all three events. A combination of ^{14}C AMRT and TL dates provides closely limiting minimum ages for the MRE and PE. A ^{14}C AMRT age for the soil formed on the APE wedge provides a broadly limiting minimum age for the oldest event. If the inset terrace at NC is accepted as evidence for the APE, and if the APE at NC and RC are the same event, then that event occurred post 5.3 ka (age of charcoal in a pre-faulting burn layer at NC) at both trench sites.

Using the paleoseismic data from RC and the maximum limiting age for the APE from NC, and recognizing that the soil ages determined at RC are minimum limiting ages for the surface-faulting events rather than maximum ages as stated by the author, I reinterpreted the surface-faulting chronology for the NS as follows:

MRE: Shortly before 1.4 ka (~1.5 ka)
PE: Shortly before 3.9 ka (~4.0 ka)
APE: >3.9 ka and <5.3 ka, but probably closer to 5.3 ka (~5.0-5.3 ka)

The corresponding inter-event intervals are:

MRE-PE: ~2.5 ka

PE-APE: maximum 1.4 ka

Note that at both NC (NS-1) and RC (NS-2) there are conflicting sets of age dates for some buried soils. If the alternative dates were used to interpret the ages of the soils, it would result in a significantly different surface-faulting chronology for the NS. A crucial question for the NS is: Were the appropriate sets of dates used to determine the ages of the events?

Summary of Existing Slip-Rate Information:

Hanson and others (1981) report a slip rate at NC of 1.3±0.1 mm/yr based on a cumulative slip across the fault zone of 7.0±0.5 meters in the past 4580 ^{14}C yr B.P (calibrated age 3525-3270 B.C.). The time interval used to calculate that slip rate extents to the present and is open across at least one seismic cycle. Except for the MRE at NC, slip-per-event values on the NS are generally poorly constrained. If the slip resulting from the MRE at NC (2.0-2.2 m) is used in conjunction with the elapsed time between the PE and MRE determined at RC (~2.5 ka), the slip rate for the closed seismic cycle between the PE and MRE on the NS is 0.8-0.9 mm/yr.

Comments:

As currently interpreted, there is general synchronicity between surface-faulting events recorded at the NC and RC trench sites. However, conflicting age dates, both ^{14}C and TL, were obtained for paleosols at both sites. The authors of the NC and RC studies selected the ages that they felt most closely constrained the timing of surface-faulting events, but using the alternative sets of dates would result in a significantly different faulting chronology for the NS. A determination needs to be made regarding which sets of dates were the most appropriate to use for estimating the time of surface faulting.

References:

Biek, R.F., 1991, Provisional geologic map of the Nephi quadrangle, Juab County, Utah: Utah Geological and Mineral Survey Map 137, scale 1:24,000.

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.

Crone, A.J., and Harding, S.T., 1984, Near-surface faulting associated with Holocene fault scarps, Wasatch fault zone, Utah-A preliminary report, *in* Hays, W.W., and Gori, P.L., editors, A workshop on "Evaluation of regional and urban earthquake hazards and risk in Utah": U.S. Geological Survey Open-File Report 84-763, p. 241-268.

Harty, K.M., Mulvey, W.E., and Machette, M.N., 1997, Surficial geologic map of the Nephi segment of the Wasatch fault zone, eastern Juab County, Utah: Utah Geological Survey Map 170, 14 p. booklet, scale 1:50,000.

Klein, J., Lerman, J.C., Damon, P.E., and Ralph, E.K., 1982, Calibration of radiocarbon dates – Tables based on the consensus data of the workshop on calibrating the radiocarbon time scales: Radiocarbon, v. 24, p. 103-150.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2095, scale 1:50,000.

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.W., editors, Assessment of regional

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: North Creek (NC) ***Study Synopsis ID***: NS-1

Fault/Fault Section: Nephi section (NS), Wasatch fault zone (WFZ), Juab County, Utah

Map Reference: 2351h-1

Study:

Hanson, K.L., Swan, F.H., III, and Schwartz, D.P., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah: San Francisco, Woodward-Clyde Consultants, sixth semi-annual technical report prepared for the U.S. Geological Survey, Contract No. 14-08-0001-16827, 22p.

Type of Study/Commentary:

Trenching. The NC site is at the mouth of North Creek Canyon about 16 kilometers north of Nephi. The late Quaternary deposits there consist of coarse, poorly sorted alluvial-fan sediments. The WFZ at NC is confined to a narrow zone only a few tens of meters wide at the base of the Wasatch Range, and is characterized by a very fresh appearing, steep, west-facing main scarp, associated antithetic faulting, and an intervening narrow graben.

Three trenches across the main fault scarp and two test pits were excavated at NC. Deposits exposed in the trenches consisted of coarse fan alluvium, debris-flow deposits, and scarp-derived colluvium.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

Three. Evidence for the two most recent events consists of colluvial-wedge deposits exposed in the trenches. A third, older event is postulated on the basis of a strath terrace inset below the North Creek alluvial-fan surface on the upthrown side of the fault.

Age of Events/Datum Ages/Dating Techniques:

Charcoal from a burn layer 1.5 meters below the surface of the NC terrace yielded an age of 4580 ^{14}C yr B.P (calibrated age 3525-3270 B.C. [after Clark, 1975]) (Bucknam, 1978); all three events identified at NC are younger than this ^{14}C age.

MRE: Charcoal-bearing deposits from trenches NC-2 and NC-3 provide the basis for dating the MRE. In trench NC-2 detrital charcoal from unit 7c (sandy silt fan alluvium), which is displaced by the MRE yielded an age of 1350$\pm$70 ^{14}C yr B.P. (calibrated age 770-965 A.D. [after Clark, 1975]). An age of 1110$\pm$60 ^{14}C yr B.P. (calibrated age 553-710 A.D. [after Clark, 1975]) was obtained from a displaced soil (unit 3as) formed on fan alluvium in trench NC-3. Neither of these ^{14}C ages are directly associated with scarp-derived colluvium and provide maximum limiting ages for the MRE. There is no minimum limiting age for the MRE, but the authors state that the steep scarp angles measured along this part of the fault (37° and greater), and the lack of upstream migration of a knickpoint just above the fault scarp in the channel of South Creek a short distance south of NC, suggest a very recent displacement that **may be as young as 300-500 years**.

PE: Constraints on the timing of the PE were obtained from ^{14}C dates on soil and charcoal in trench NC-3. Radiocarbon ages were obtained on bulk soil organics from an organic-rich soil formed on PE scarp-derived colluvium, and on detrital charcoal recovered from the same soil. The soil organics gave conflicting ^{14}C ages of 3640±75 and 1650±50 ^{14}C yr B.P. A second set of accelerator mass spectrometer (AMS) ^{14}C ages from the soil organics showed a similar discrepancy (3894 [+288, -278] and 1645 [+270, -262] ^{14}C yr B.P.). The detrital charcoal from the soil yielded an accelerator age of 1389 (+181, -177) ^{14}C yr B.P. The authors conclude that the younger ^{14}C ages appear to represent younger material incorporated into the soil prior to its burial by unit 3a (fan alluvium), and they prefer the older date of 3640±75 ^{14}C yr B.P. (calibrated age 2235-1940 B.C. [after Clark, 1975]) as the true soil age. **On that basis, authors concluded that the PE occurred prior to 3640±75 ^{14}C yr B.P.**

APE: The strath terrace considered as evidence for a third, older event presumably formed in response to a surface-faulting earthquake, the colluvial-wedge evidence for which was either removed by erosion or lies buried beneath the floors of the NC trenches. The age of the APE must be younger than 4580 ^{14}C yr B.P., the age of the charcoal in the burn layer found 1.5 meters below the terrace surface, and older than 3640±75 ^{14}C yr B.P., the preferred age of the soil formed on the PE colluvial wedge.

Surface-Faulting Event Age Summary
MRE: <1110±60 ^{14}C yr B.P., but possibly as young as 300-500 yrs
PE: >3640±75 ^{14}C yr B.P., <4580 ^{14}C yr B.P.
APE: >3640±75 ^{14}C yr B.P., <4580 ^{14}C yr B.P.

Radiocarbon Ages

The ^{14}C ages from NC represent a combination of both conventional and AMS dates on bulk soil organics and detrital charcoal. The ^{14}C ages were calendar corrected following Clark (1975), but it does not appear that the age estimates for the soil organics incorporate a mean residence correction (MRC) for the age of the carbon in the soil at the time of burial. Considering the age discrepancies obtained on bulk soil organics from the 2s soil formed on the PE colluvial wedge, and the fact that the authors believe young carbon was still being added to that soil as much as 2000 years after their preferred age for the soil, the MRC likely is substantial and may greatly affect the age estimate for the timing of the PE.

***Event Slip/Cumulative Slip*:**

MRE: Estimates of the net slip during the MRE are based on fault geometry, scarp morphology, colluvial-wedge thickness, displacement on antithetic faults, and scarp profiles. The authors consider their net-slip estimate of **2.0-2.2 meters** for the MRE to be a well-constrained value.

PE/APE: Displacement estimates for the two older events at NC are much less well constrained. The strath terrace, which provides evidence for the APE, is inset below the NC alluvial-fan surface. If the terrace formed in response to surface faulting, the height of the terrace riser measured adjacent to the fault scarp (**2.6 m**) may approximate displacement during the APE. The cumulative displacement measured from scarp profiles across the WFZ on the NC fan surface is 7.0±0.5 meters. By combining the estimated displacements for the MRE and APE, the **PE displacement estimated as 2.0-2.5 meters**.

Cumulative Slip: Based on a topographic profile and exposures in a test pit in the graben, the vertical stratigraphic separation of the NC fan surface is 12 meters. Cumulative net slip across the WFZ was obtained by projecting the fan surfaces on both sides of the fault zone to the main fault plane; the resulting cumulative net slip was **7.0±0.5 meters**.

***Published Recurrence Interval*:**

None reported. However, based on stratigraphic relations in trench NC-3 and the calibrated ^{14}C ages, the inter-event interval between the MRE and PE is greater than 2900 years and may be as long as 4000 years. If the PE and APE both occurred prior to burial of soil 2s at 3640±75 ^{14}C yr B.P. (calibrated age 2235-1940 B.C.), but after 4580 ^{14}C yr B.P (calibrated age 3525-3270 B.C.), then the interval between the two older events can be no longer than 1600 years and is probably considerably less, resulting in two inter-event intervals of very unequal lengths.

***Published Slip Rate*:**

1.3±0.1 mm/yr based on a cumulative slip across the fault zone of 7.0±0.5 meters in the past 4580 ^{14}C yr B.P (calibrated age 3525-3270 B.C.). Note that this slip-rate estimate extends to the present and is open across at least one seismic cycle.

***Sources of Uncertainty*:**

1. Surface-faulting event age estimates are loosely constrained.
2. Two sets of highly contradictory ^{14}C ages were obtained from soil organics in the 2s soil formed on the PE colluvial wedge; the reason why that conflict was resolved in favor of the older age estimates is not clearly explained.
3. The evidence for the APE is geomorphic (a strath terrace) no evidence for the event was recognized in trenches.
4. The ^{14}C ages were calendar corrected using an early, now obsolete, radiocarbon calibration curve.
5. The ^{14}C ages obtained from soil organics are not corrected for the mean residence time of the carbon in the soil prior to burial, and therefore are likely too old by some unknown amount of time.

6. No details are provided regarding how the buried soils were sampled for dating, it is assumed that the samples were channel samples collected across the full width of the organic-rich horizon and therefore contained the full range of carbon ages in the soil.
7. The per event net slip for all three surface-faulting earthquakes could not be directly measured and are estimates. Net slip for the PE and APE are poorly constrained.

Summary:
This is one of the earliest trenching studies conducted on the WFZ, and it was at this site that many of the concepts now regularly employed to interpret stratigraphic and structural relations exposed in trenches excavated on normal-slip faults were first developed. However, the study predates several advances in ^{14}C dating technology and TL dating entirely, thus limiting the availability and the methods of analyzing dateable material.

References:
Bucknam, R.C., 1978, Northwestern Utah seismotectonic studies: U.S. Geological Survey National Earthquake Hazards Reduction Program, Summaries of Technical Reports, v. VII, p. 64.

Clark, R.M., 1975, A calibration curve for radiocarbon dates: Antiquity, v. XLIX, p. 251-256.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Red Canyon (RC) ***Study Synopsis ID***: NS-2

Fault/Fault Section: Nephi section (NS), Wasatch fault zone (WFZ), Juab County, Utah

Map Reference: 2351h-2

Study:

Jackson, M.E., 1991, Paleoseismology of Utah, Volume 3 - The number and timing of Holocene paleoseismic events on the Nephi and Levan segments, Wasatch fault zone, Utah: Utah Geological Survey Special Studies 78, 23 p.

Type of Study/Commentary:

Trenching. The RC site lies near the southern terminus of the NS about 3.5 kilometers north of Nephi, Utah and approximately 12 kilometers south of the North Creek (NC) trench site (Hanson and others, 1981). At RC a 5.5-meter-high scarp crosses the distal portion of the Red Canyon alluvial fan. Within 1.5 kilometers to the south the scarp dies out in basin-fill sediments. To the north at Gardner Creek, the fault displaces late Pleistocene sediments and the scarp is as much as 30 meters high. The age of the Red Canyon alluvial fan is estimated at latest Pleistocene (10-15 kyr).

A single trench was excavated across the RC scarp. The trench exposed coarse-grained alluvial-channel deposits, locally derived silty mudflow deposits, and scarp-derived colluvium.

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

Three/stacked colluvial-wedge deposits

Age of Events/Datum Ages/Dating Techniques:

The ages of surface-faulting events at RC are estimated from a combination of ^{14}C AMRT ages on soil organics and TL ages on fine-grained sediments from buried soil A-Horizons in the trench. On the basis of those age estimates, the author believes that the MRE probably occurred between 1.0 to 1.2 ka, the PE occurred 3.0 to 3.5 ka, and the APE occurred after 4.0 to 4.5 ka, but well before the late Pleistocene.

In comparison, at NC, the other major trench site on the NS, Hanson and others (1981) identified three surface-faulting events in the past 4580±250 ^{14}C yr B.P. The maximum constraining age for the MRE at NC is 1110±60 ^{14}C yr B.P.; however, based on the freshness of scarp morphology and other geomorphic indicators the authors prefer an age of faulting as young as 300 years for the MRE. Both the PE and APE occurred in the interval between 3640±75 ^{14}C yr

B.P. and 4580±250 ^{14}C yr B.P. So there is general agreement in the number and timing of mid- to late Holocene surface-faulting events at the two sites.

Details of Event Timing

MRE: Two TL age estimates and a ^{14}C AMRT age from the soil buried by the MRE colluvial wedge provide a maximum limiting age for the MRE. The TL ages were 1300±500 and 1500±400 yrs B.P.; the ^{14}C AMRT age was 2900 (+300, -200) cal yrs B.P. The author believes that the ^{14}C sample may have been contaminated by older carbon and that therefore the ^{14}C AMRT age is too old. The TL ages were considered consistent and the two dates were averaged to obtain a maximum limiting age of 1400 yrs B.P. for the MRE.

PE: A TL age estimate and a ^{14}C AMRT age from the soil buried by the PE colluvial wedge provide a maximum limiting age for the PE. The TL age estimate was 7000±800 yrs B.P., while the ^{14}C AMRT age was 3900 (+500, -400) cal yr B.P. The author believes that the TL sample may have been contaminated by well-zeroed, but older material and that the ^{14}C AMRT age provides a closer maximum for the PE.

A second TL/^{14}C AMRT age pair from the soil buried by the PE colluvial wedge yielded results of 1700±200 yr B.P. and 1300 (+200, -300) cal yr B.P., respectively. The author considered these ages too young and postulated that either the samples had been unknowingly collected from an animal burrow that was filled with younger material, or the preferred explanation which is that an unrecognized splay in the fault zone created a graben that displaced the younger soil (3s) formed on the PE wedge down to the same stratigraphic level as the older soil (4s) beneath the wedge, and that the younger soil was then sampled by mistake.

APE: The timing of the APE is less well constrained because the APE colluvial wedge does not rest on a buried soil. The event predates burial of the soil formed on the APE colluvial wedge at 3900 (+500, -400) cal yr B.P., and is younger than the displaced fan surface which Machette (personal communication, 1988) estimated as late Pleistocene (10-15 ka) in age. The author states that the maximum limiting age for the APE is probably close to 3900 (+500, -400) cal yr B.P., estimated at between 4 and 4.5 ka without giving a basis for that reasoning.

Dating Techniques
This study employs a combination of ^{14}C AMRT dating and at the time of the study, the relatively new TL dating technique. All new ^{14}C ages are calendar corrected according to Stuiver and Reimer (1986) and a mean residence correction (MRC) of 100 years was subtracted from each calendar-calibrated age. The author also calendar calibrated the ^{14}C ages available in the literature for NC, again using Stuiver and Reimer (1986) and subtracting a MRC of 100 years when appropriate for ^{14}C AMRT ages on soil organics.

Event Slip/Cumulative Slip:

Event slip estimates at RC are based chiefly on colluvial-wedge thickness.

MRE = 1.4±0.3 meters
PE = 1.5±0.2 meters
APE = 1.7±0.3 meters

Cumulative slip at RC was measured from the displacement of unit 7 (alluvium and colluvium) across the fault zone and is 5.4±0.3 meters. The author concludes that the per event slip estimate total of 4.6+0.8 meters is in general agreement with the cumulative slip value.

Published Recurrence Interval:

None reported, but the following inter-event intervals are reported.

MRE-PE: maximum 3350 years, minimum 1500 years
PE-APE: maximum 2200 years, minimum 1700 years

It appears that these inter-event intervals are based on incorrect age estimates for the MRE and PE (see below).

Published Slip Rate:

None reported.

Sources of Uncertainty:

1. Conflicts between the TL and ^{14}C ages used to constrain the timing of the MRE and PE required the author to select preferred dates for each of those events. For the MRE the TL ages were preferred, while for the PE the ^{14}C age was selected. In both cases, the preferred dates were the ones that caused the RC results to most closely conform to those at NC.
2. Similarly, the author assigned an age of 4.0 to 4.5 ka for the timing of the APE. However, the only age estimate that constrains that event is the ^{14}C AMRT age obtained for the soil formed on the APE colluvial wedge of 3900 (+500, -400) cal yr B.P. Therefore, the APE is older than 3.9 ka, but there is no evidence, other than an estimated late Pleistocene age (10-15 ka) for the displaced fan, to provide a maximum limiting age for the event. The author's preferred age of 4.0 to 4.5 ka, selected without explanation, seems to be based entirely on desire to mimic NC results.
3. The author has the concept of "maximum" and "minimum" limiting ages confused with regard to buried paleosols, which results in a systematic under estimation of the timing of the MRE and PE. "Maximum" limiting ages are proposed for the MRE and PE based on TL and ^{14}C age estimates for the soils buried by the MRE and PE colluvial wedges. Since neither soil could be buried by scarp-derived colluvium until after the events occurred, these soil ages are in fact closely limiting minimums on the time of faulting. In both cases the events had to have occurred (shortly) before the soils were buried. Because the author considered the ages maximums, a number of hundreds of years were subtracted from the soil ages when estimating the timing of the MRE and PE, making the age estimates for those events too young.

From the information provided in this document, it appears that the MRE occurred shortly before 1400 yr B.P., based on the average of the two TL ages obtained on the soil buried by the MRE wedge, and the PE occurred shortly before 3900 (+500, -400) cal yr B.P., based on the ^{14}C AMRT age for the soil buried by the PE wedge. As indicated above, the evidence available

from this site only provides a minimum limiting age for the APE of 3900 (+500, -400) cal yr B.P. The elapsed time between the APE event and burial of the soil formed on the APE wedge at 3900 (+500, -400) cal yr B.P., had to be sufficient for the APE wedge to be deposited and for the soil on the wedge to form. Although that may have occurred in as little as 100 to 600 years, it is doubtful, and the time interval between the APE and PE is likely on the order of 1000 years or longer. At NC, a calendar-corrected ^{14}C age on charcoal from a burn layer in alluvial-fan sediments that predates all three surface-faulting events at that site indicates that the APE on the NS occurred prior to 5.3 ka. Considering the thickness of the APE wedge and the soil formed on it at RC, if the APE a RC and NC are the same, the event must have occurred close in time to, but after, 5.3 ka.

4. Correlative stratigraphy extends across the fault zone in the RC trench. The author used the displacement of unit 7, a pre-faulting alluvial-fan unit, to measure cumulative net slip across the fault zone. Unit 7 dips $3^\circ \pm 1^\circ$ in the fault footwall and $7^\circ \pm 2^\circ$ in the fault hanging wall, indicating that within the confines of the RC trench, the pre-faulting units in the hanging wall are warped upward against the fault zone, since alluvial-fan sediments should increasingly dip more gently as they approach the valley. Therefore, the cumulative net slip measurement of 5.4 ± 0.3 meters is likely a minimum value.
5. No information is provided on how the buried soils were sampled for ^{14}C dating. It is assumed that a channel sample was collected across the full width of the soil, and that the resulting ^{14}C AMRT ages reflect the entire range of carbon ages in those soils, and therefore may over estimate the time of burial.

Summary:

This study confirms that a minimum of three surface-faulting earthquakes has occurred on the NS since the middle Holocene, and that the timing of the events at RC is roughly synchronous with the timing of events at NC. The presence in the trench of colluvial wedges for all three events and TL and ^{14}C AMRT ages from soils developed on the PE and APE wedges allows the ages of the two most recent events to be more closely constrained than at the NC site to the north. The APE remains poorly constrained at both sites. The RC trench is comparatively deep, and exposes several alluvial-fan units in the fault hanging wall beneath the APE colluvial wedge, thus implying a long (?) period of quiescence on the fault prior to the APE. The age of those alluvial-fan sediments is not known, but conceivably they could represent several thousand years.

References:

Hanson, K.L., Swan, F.H., III, and Schwartz, D.P., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah: San Francisco, Woodward-Clyde Consultants, sixth semi-annual technical report prepared for the U.S. Geological Survey, Contract No. 14-08-0001-16827, 22p.

Stuiver, Minze, and Reimer, P.J., 1986, A computer program for radiocarbon age calibration (Rev. 2.0): Radiocarbon, v. 28, no. 2B, p. 1022-1030.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP
PALEOSEISMIC STUDY SUMMARY FORM

Site Name: North Creek (NC) and Gardner Canyon (GC)

Study Synopsis ID: NS-3

Fault/Fault Section: Nephi section (NS), Wasatch fault zone (WFZ), Juab County, Utah

Map Reference:

Study:
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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Type of Study/Commentary:
This document presents a summary of the paleoseismic studies conducted on the NS up to approximately 1992. The document only reports preliminary data for the Red Canyon trench site, and Jackson (1991; NS-2) supersedes those results. In the discussion of North Creek (NC), key ^{14}C ages resulting from that study (Hanson and others, 1981; NS-1) are calendar corrected according to Stuiver and Reimer (1986); however, the ^{14}C date obtained on soil organics at NC is not assigned a mean residence correction (MRC) to account for the age of the soil at burial. The corrected ages and their implication to the surface-faulting chronology on the NS are reviewed below. Although not a trench site, Gardner Creek on the NS is one of the few places along the entire WFZ where it is possible to estimate a long-term (250 ka) slip rates for the fault. The information available for Gardner Creek is also reviewed below.

Fault Parameter Data:

North Creek
Calendar-corrected ^{14}C ages for NC are as follows:

Field Number	Material Sampled	^{14}C Age	Calibrated Age
Bucknam (1978)	Charcoal	4580±250	5300
WC-12-80-7	A horizon	3640±75	4.2+0.2 kyr[1]
WC-12-80-5	Charcoal	1350±70	1289
WC-12-80-6	Charcoal	1110±60	975 or 1028

1 Does not include an MRC for the soil, which may be several hundred years.

The above calendar-corrected ages combined with the stratigraphy exposed in the trenches at NC show that all three surface-faulting events at NC occurred prior to 5300 cal yr B.P., and that the PE occurred before 4.2 ka, although that age is probably too old by a number of hundreds of years.

Gardner Creek

Gardner Creek issues from the Wasatch Range about 8 kilometers north of Nephi, Utah and about 2 kilometers north of the Red Canyon trench site. At Gardner Creek, 150 to 250 ka alluvial-fan deposits that have well-developed calcic soils are displaced about 30 meters across the WFZ. Based on those relations, the WFZ has had a slip rate of 0.12 to 0.20 mm/yr during the past 150 to 250 ka. At the same site, middle-Holocene sediment is displaced 3.9 meters, indicating an average slip rate of 0.8 to 1.0 mm/yr for the past 4 to 5 ka. The authors state that these average slip rates, which reflect an approximate fivefold increase in slip rate during the latest Quaternary, are typical for the central parts of the WFZ and that similar large temporal changes in slip have been observed at sites on the Provo, Salt Lake City, and Brigham City sections of the fault.

Summary:

The calendar-corrected ^{14}C ages reported for NC help better constrain the time of faulting on the NS. The information from Gardner Canyon shows that latest Pleistocene and Holocene slip rates on the WFZ may be anomalously high compared to long-term average rates. Several workers have speculated that this burst of latest Quaternary surface-faulting activity is in some way related to the rapid transgression and subsequent regression of Lake Bonneville in the late Pleistocene.

References:

Hanson, K.L., Swan, F.H., III, and Schwartz, D.P., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah: San Francisco, Woodward-Clyde Consultants, sixth semi-annual technical report prepared for the U.S. Geological Survey, Contract No. 14-08-0001-16827, 22p.

Jackson, M.E., 1991, Paleoseismology of Utah, Volume 3 - The number and timing of Holocene paleoseismic events on the Nephi and Levan segments, Wasatch fault zone, Utah: Utah Geological Survey Special Studies 78, 23 p.

Stuiver, Minze, and Reimer, P.J., 1986, A computer program for radiocarbon age calibration (Rev. 2.0): Radiocarbon, v. 28, no. 2B, p. 1022-1030.

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

Name and Location of Fault/Fault Section:
Levan section (LS), Wasatch fault zone (WFZ), Juab County, Utah

Paleoseismic Data Source Documents:
Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes - Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Jackson, M.E., 1991, Paleoseismology of Utah, Volume 3 - The number and timing of Holocene paleoseismic events on the Nephi and Levan segments, Wasatch fault zone, Utah: Utah Geological Survey Special Studies 78, 23 p.

Machette and others (1992), below, summarizes the results of studies at Deep Creek, Pigeon Creek, and Skinners Peak on the LS, but provides no new data, and consequently, was not reviewed for this project.

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.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Geomorphic Expression:
A 15-kilometer-long gap in Holocene faulting marks the boundary between the LS and the Nephi sections (NS; Harty and others, 1997) of the WFZ. South of the gap, most of the fault scarps on Holocene deposits are less than 3 meters high, while scarps on upper to middle Pleistocene alluvium are 5 to 10 meters high or higher, suggesting recurrent late Quaternary surface faulting. Holocene ruptures on the LS extend from about 4 kilometers north to 18 kilometers south of the town of Levan where the fault steps left about 0.5 kilometers and enters bedrock. Clear evidence of faulting extends for another 3 kilometers to the south, but it is unclear if the most recent movement is Holocene.

Evidence for Segmentation:
Although the gap between Nephi and Levan sections lacks evidence of Holocene and latest Pleistocene surface faulting, it does contain older fault scarps formed on middle Pleistocene alluvial fans extend along the front of the San Pitch Mountains south of Nephi (Machette and others, 1992; Harty and others, 1997). The presence of older fault scarps in the gap may indicate that the boundary between the Levan and Nephi sections is nonpersistant, at least in earlier Quaternary time. To the south, the boundary between the Levan and Fayette sections of the WFZ is marked by a 3.5-kilometer step to the east and 5-kilometer step to the south in late Quaternary faulting. The morphology of the fault scarps on the Fayette section shows no evidence of Holocene surface faulting (Machette and others, 1992).

Age of Youngest Faulting:
Holocene

Summary of Existing Recurrence Interval Information:
None. Only a single surface-faulting earthquake can be identified with confidence on the LS, so the data are not available to determine a recurrence interval for this section of the fault.

Summary of Existing Slip-Rate Information:
None. Only a single surface-faulting earthquake can be identified with confidence on the LS, so the data are not available to determine a slip rate for this section of the fault.

Comments:
Geomorphic evidence and the results of trenching and investigation of natural stream cut exposures indicates that there has only been one surface-faulting earthquake on the LS since the early middle Holocene and that there may not have been an older surface faulting event since the latest Pleistocene. In which case, individual recurrence intervals between surface faulting on the LS are measured in several thousands of years or longer.

References: (also see above)
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.

Harty, K.M., Mulvey, W.E., and Machette, M.N., 1997, Surficial geologic map of the Nephi segment of the Wasatch fault zone, eastern Juab County, Utah: Utah Geological Survey Map 170, 14 p. booklet, scale 1:50,000.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Deep Creek (DC)/Pigeon Creek (PC) ***Study Synopsis ID:*** LS-1

Fault/Fault Section: Levan section (LS), Wasatch fault zone (WFZ), Juab County, Utah

Map Reference: 2351i-1 (PC) & 2351i-2 (DC)

Study:
Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes - Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Type of Study/Commentary:
Scarp geomorphology. The information presented for the LS in this document is limited and is reproduced here in its entirety.

Deep Creek: Detailed subsurface investigations have not been made along the Levan segment of the fault. However, reconnaissance mapping between Levan and Gunnision indicates that only one surface-faulting event has occurred along this segment since the early to middle Holocene. At Deep Creek a single-event, 2.5-meter-high scarp displaces alluvial deposits dated by accelerator mass spectrometry at 7300±1000 ^{14}C yr B.P. At Pigeon Creek, 2 kilometers to the north, the same scarp displaces an alluvial fan dated at 1750+350 ^{14}C yr B.P.

Sources of Uncertainty:
1. Reconnaissance investigation only, no trenching.
2. Source material for ^{14}C dates unknown.
3. Radiocarbon ages are not calendar corrected and it is not known if a mean residence correction needs to be applied.

Summary:
This reconnaissance investigation of the LS was part of the earliest paleoseismic investigations conducted on the WFZ. The data presented is brief and summary in nature (see above), in the absence of trenching, it is unknown if the scarps at Deep and Pigeon Creeks are in fact single-event scarps, or other than in a broad sense, when the surface-faulting earthquakes that created the scarps occurred.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Deep Creek (DC)/Pigeon Creek (PC) ***Study Synopsis ID***: LS-2

Fault/Fault Section: Levan section (LS), Wasatch fault zone (WFZ), Juab County, Utah

Map Reference: 2351i-1 (PC) & 2351i-2 (DC)

Study:

Jackson, M.E., 1991, Paleoseismology of Utah, Volume 3 - The number and timing of Holocene paleoseismic events on the Nephi and Levan segments, Wasatch fault zone, Utah: Utah Geological Survey Special Studies 78, 23 p.

Type of Study/Commentary:

Natural exposure. The DC natural exposure is about 8 kilometers south of Levan, Utah. There, a stream cut incised into a Holocene alluvial fan exposes a sequence of stacked debris-flow deposits with interbedded thin alluvial deposits. A 2.4-meter-high, west-facing main scarp and a 0.5-meter-high, east-facing antithetic scarp displace the fan deposits, and together form a graben roughly 50 meters wide.

Fault Parameter Data:

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

Age of Events/Datum Ages/Dating Techniques:
MRE: 1.0-1.6 ka and likely closer in time to 1.0 ka.

Schwartz and Coppersmith (1984) were the first to study the DC exposure and collected charcoal from a debris-flow deposit on the upthrown side of the fault that yielded an age of 7300+1000 ^{14}C yr B.P. The debris flow is faulted so this age provides a broad maximum limit on the time for what Schwartz and Coppersmith (1984) considered a single surface-faulting event. At Pigeon Creek (PC) 2 kilometers north of DC, Schwartz and Coppersmith (1984) obtained a ^{14}C age from faulted alluvial-fan sediments of 1750$\pm$350 ^{14}C yr B.P. Schwartz and Coppersmith (1984) considered the surface-faulting event recognized at PC to be the same as the DC event, and the new date to provide a closer maximum constraint on the time of faulting.

The DC site was revisited for this study and a scarp-derived colluvial wedge was recognized in the stream cut exposure. The wedge was deposited directly upon a soil A-horizon formed on the pre-faulting fan surface. A TL sample collected from the upper few centimeters of the buried soil beneath the colluvial wedge yielded an age estimate of 1000$\pm$100 yr B.P., which provides a closely limiting minimum age for the event. Therefore, the MRE on the LS occurred in an approximately 600-year interval between 1000 yr B.P and 1750±350 ^{14}C yr B.P. (1600 [+500, -300] cal yr B.P.; calibrated this study), and based on stratigraphic relations in the stream cut, likely occurred closer to 1.0 ka.

Event Slip/Cumulative Slip:

The author states that the net vertical tectonic displacement for the single event at DC was calculated at 1.8 meters from the log of the stream cut. No details regarding how the measurement was made were provided, and I was unable to replicate the measurement. My measurements were consistently too large and need to account for the effect of antithetic faulting, but the log of the stream exposure does not extent to the antithetic fault.

Based on the heights of the main (2.3 m) and antithetic (0.55 m) scarps, Machette (unpublished data, 1985) documented 1.75 meters of displacement for the single event at DC.

Published Recurrence Interval:

None

Published Slip Rate:

None

Sources of Uncertainty:

1. TL age estimate on buried soil not confirmed with a ^{14}C date.
2. One of the two age estimates used to constrain the time of faulting came from a second site 2 kilometers to the north, where the faulting is assumed to be the same as at DC.
3. Unable to duplicate net-slip measurement from the log of the stream exposure.

Summary:

A TL age estimate from this site combined with a ^{14}C age estimates from PC (Schwartz and Coppersmith, 1984) constrains the MRE on the LS between approximately 1.0 and 1.6 ka. The absence of evidence for a second, older event prevents calculating either recurrence or slip-rate values for this site.

References:

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes - Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

UTAH QUATERNARY FAULT PARAMETER WORKING GROUP PALEOSEISMIC STUDY SUMMARY FORM

Site Name: Skinner Peaks (SP) ***Study Synopsis ID*:** LS-3

***Fault/Fault Section*:** Levan section (LS), Wasatch fault zone (WFZ), Juab County, Utah

Map Reference: 2351i-3

Study:

Jackson, M.E., 1991, Paleoseismology of Utah, Volume 3 - The number and timing of Holocene paleoseismic events on the Nephi and Levan segments, Wasatch fault zone, Utah: Utah Geological Survey Special Studies 78, 23 p.

Type of Study/Commentary:

Trenching. The SP site is about 17 kilometers south of Levan, Utah and 200 meters east of Utah State Highway 26. A single trench was excavated across a 3.3-meter-high scarp formed on a Holocene alluvial fan.

On the footwall block of the fault, the trench exposed approximately 2 meters of mudflow and alluvial-fan deposits resting on bedrock. The bedrock is cut by numerous calcium carbonate-filled fractures that in places extend into the overlying unconsolidated sediments. The main, west-dipping fault zone truncates both the overlying alluvium and the bedrock. In the fault hanging wall, the trench exposed a thick sequence of mudflow and alluvial-fan sediments but did not encounter bedrock. A crack filled with tectonic alluvium formed next to the fault zone and a single colluvial wedge overlies the crack and the uppermost pre-faulting mudflow deposit.

Stratigraphic units could not be traced between the thin alluvial deposits on the upthrown and downthrown sides of the fault. The author considered the difference in thickness of the alluvial packages on either side of the fault zone problematic

Fault Parameter Data:

Number of Surface-Faulting Events/How Identified:

A single, well-preserved, scarp-derived colluvial wedge records the MRE at SP. However, the author believes that a single rupture event cannot explain the excess thickness of alluvium on the downthrown side of the fault, and presents several possible explanations to account for the additional alluvium. The preferred interpretation is that there are two events recorded in the SP trench; the MRE represented by a scarp-derived colluvial wedge and an older event inferred from the thick pre-MRE stratigraphy in the fault hanging wall. It is hypothesized that the pre-MRE alluvium came from a drainage system to the south and was deposited against a pre-existing fault scarp, and in the process destroying any evidence of earlier colluvial-wedge stratigraphy. Conversely, the alluvium on the upthrown block is believed to have originated from a small drainage immediately east of the trench, and therefore, having two different sources, the stratigraphic units exposed in the trench do not correlate across the fault zone.

Age of Events/Datum Ages/Dating Techniques:

TL and ^{14}C ages from an in situ burn layer in faulted alluvial-fan sediments in the fault footwall provides a maximum limiting age for the time of faulting. The TL method yielded an age of 2000±300 yr B.P., and charcoal from the burn layer yielded an age of 1700±200 cal yr B.P. These dates place a broad maximum constraint on the time of faulting since they come from the upthrown block and their stratigraphic relation to the MRE colluvial wedge (other than that they are older) on the fault hanging wall is unknown. How closely these maximum ages relate to the time of faulting depends on how long it took for the additional 0.5 meters of sediment that overlies the burn layer to be deposited and the time required for fan stabilization and fault movement. The author assumes a range of 300-800 years to accomplish those tasks and concludes that the MRE probably occurred between **1.0 and 1.5 ka**, which is in general agreement with the results at Deep Creek, where the MRE is estimated to have occurred about 1.0 ka (this document).

A TL age estimate of 3100±300 yr B.P., and a ^{14}C AMRT age of 3900±300 cal yr B.P. from a buried soil A-horizon a meter below the MRE colluvial wedge, provide broadly limiting minimums on the timing of an older event if one assumes that either (1) the stratigraphic evidence for older event is buried beneath the trench floor, or (2) the PE colluvial wedge was removed as the debris-flow sediments exposed in the fault hanging wall were deposited against a pre-existing scarp. In either case, evidence for a PE is weak and such an event can only be said to be older than about 3.9 ka.

Event Slip/Cumulative Slip:

The description of how the MRE net slip was determined is reproduced below in its entirety. I believe the description is problematic and leave it to the panel experts to evaluate its veracity.

> ***The NVTD for the MRE is estimated from the amount of offset of the paleoground surfaces. Projecting from the burn layer on the upthrown block to the base of the colluvial-wedge package provides a minimum NVTD of 2.0±0.2 meters. Projecting from the modern fan surface yields a maximum NVTD of 2.8±0.2 meters for the MRE. Slight back tilting (<3 degrees) of the stratigraphic units near the main scarp zone was observed. Slight movement occurred on steeply east-dipping faults producing 0.5-0.7 meters of antithetic displacement. This displacement was attributed to post-seismic settling and was not included in measurement of NVTD.***

Judging from the above description, it appears that the net slip for the MRE is somewhere between 2.0 and 2.8 meters, but the burn layer wasn't at the surface at the time of MRE faulting, and it is unclear why the author considered the back tilting and antithetic faulting observed in the trench to be nontectonic.

Where trenched, the scarp created by the main fault is 2.8 meters high. It may represent one or possibly two surface faulting events. No mention is made in this document of a scarp profile, and no cumulative net slip value is reported for the scarp.

***Published Recurrence Interval*:**
None

***Published Slip Rate*:**
None

***Sources of Uncertainty*:**

1. MRE timing is poorly constrained by broadly limiting maximum TL and ^{14}C ages. There is no minimum constraining age on the time of faulting.
2. A second older surface-faulting event is inferred, but there is no direct stratigraphic evidence to support its occurrence, and TL and ^{14}C AMRT ages on a pre-MRE/post-PE buried soil A-horizon, provide only a broadly limiting minimum age constraint.
3. Both cumulative and per event slip are poorly constrained at this site.

***Summary*:**
The study at SP confirms a late Holocene age for the MRE on the LS, but the actual time of faulting can is only be bracketed within an approximate 500 year window between ~1.0 and 1.5 ka. The absence of verifiable information on the timing or displacement of earlier events precludes determining a slip rate or recurrence interval at this site. The absence of stratigraphic evidence for a second, older surface-faulting event in the 5.5-meter-deep trench at SP argues for a PE in late Pleistocene or early Holocene time, and implies that recurrence intervals on the LS may be several thousands of years long.