DETERMINATION OF PALEOEARTHQUAKE TIMING AND MAGNITUDES ON THE SOUTHERN SEGMENT OF THE EAST CACHE FAULT, UTAH

Program Element II: Evaluate Urban Hazard and Risk.

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TABLE OF CONTENTS

1. ABSTRACT....4
2. INTRODUCTION....6
2.1 Purpose and Scope of Study....6
2.2 Significance of the project....6
2.3 Tectonic Setting....7
3. OBJECTIVES AND METHODS....11
3.1 Geophysical Surveys of Trench Sites on the Northern Transect....14
3.2 Geologic Mapping....14
3.3 Geochronology....15
4. WESTERN STRAND....15
4.1 Local structural geology and geomorphology....15
4.2 The Western Trench....15
4.2.1 Stratigraphy....18
4.2.2 Soils....19
4.2.3 Structure....19
4.2.4 Geochronology....19
4.2.5 Interpretation....19
5. CENTRAL STRAND....20
5.1 Local structural geology and geomorphology....20
5.2 The Central Upper Trench....23
5.2.1 Stratigraphy....23
5.2.2 Soils....23
5.2.3 Structure....24
5.2.4 Geochronology....24
5.2.5 Interpretation....24
The Soil Pit....26
5.3 The Central Lower Trench....26
5.2.1 Stratigraphy....26
5.2.2 Soils....28
5.2.3 Structure....28
5.2.4 Geochronology....28
5.2.5 Interpretation....28
6. EASTERN STRAND....30
6.1 Local structural geology and geomorphology....30
6.2 Previous Results for the Range Front Fault Strand....31
6.3 GPR Survey....32
6.4 The Eastern Trench....33
6.4.1 Stratigraphy....33
6.4.2 Soils....33
6.4.3 Structure....33
6.4.4 Geochronology....36
6.4.5 Interpretation....36
7. CONCLUSIONS....36
7.1 Rupture Scenarios....37

7.2 Displacement per Event and Paleomagnitude 37
7.3 Recurrence Intervals 37
7.4 Slip Rate.....38
7.5 Elapsed Time, and Implications for Conditional Probability of the next surface Rupture 38
8. REFERENCES 39
9. APPENDIX 1; Characteristics of the East Cache fault, southern section, from USGS Quaternary Fault and Fold Database.....41
APPENDIX 2; Final OSL Age Report, Utah State University.....48
APPENDIX 3; McCalpin's Review of the Trenches on the Western and .. Central Fault Strands, 13-NOV-2007 51
APPENDIX 3: Logan Herald Journal article (July 23, 2008) on trenching 53

List of Figures..... Page

Fig. 1. Satellite image of the East Cache fault zone (center) on the eastern margin of Cache Valley 8
Fig. 2. Map of the geometric sections (rupture segments?) of the ECFZ 9
Fig. 3. Two cross-sections of southern Cache Valley at the latitude of Paradise 10
Fig. 4. Location map of Section B-B' of Oaks, 1997, shown in Fig. 3 11
Fig. 5. Map showing options for trench sites..... 13
Fig. 6. Top, east-west GPR profile across the scarp ("scarp face") at the location of the western trench 16
Fig. 7. Upper panel, photomosaic of the 39 m-long southern trench wall..... 17
Fig. 8. Google Earth oblique view of the three fault strands of the southern segment, and trenches of the northern trench transect 20
Fig. 9. East-west GPR profile across the central strand escarpment (at left) and saddle (at center).. 22
Fig. 10. Photograph of the east-facing escarpment of the central strand, looking WNW..... 22
Fig. 11. Upper panel, photomosaic of the Upper Trench..... 25
Fig. 12. Projection of unit contacts across the 6.5 m-wide gap between the Upper Trench and the soil pit..... 26
Fig. 13. Annotated photomosaic of the south wall of the eastern trench on the McKenzie Flat strand of the East Cache fault zone..... 27
Fig. 14. Upper part, trench location shown on the geologic map of the Paradise quadrangle..... 30
Fig. 15. Comparison of the faceted spur structure of the Bear River Range front between the central segment and southern segment of the ECFZ..... 31
Fig. 16. Field sketches of faults of the main trace of the East Cache exposed in canal cuts north of the East Fork 32
Fig. 17. GPR reflectors along a long survey line across the range-front slope break..... 32
Fig. 18. Photomosaic of the south wall of the trench across the range-front strand of the East Cache fault zone..... 34
Fig. 19. Close-up of the main fault in the trench 35

List of Tables

Table 1. Parameters of the GPR surveys..... 14
Table 2. Unit descriptions from the Western Trench..... 18
Table 3. Unit Descriptions - Central Fault Strand, Western Trench..... 23
Table 4. Mapped units on the south wall of the trench on the range-front strand 33

1. ABSTRACT

We investigate the late Quaternary rupture history of the southern East Cache Fault zone [ECFZ], northern Utah with geologic mapping, paleoseismic logging of fault trenches, ground-penetrating radar, and optically stimulated luminescence dating. McCalpin (1989) indicated that the southern segment of the ECFZ consisted of three strands. We excavated four trenches across these strands, and evaluate the stratigraphy and structure of the sites.

Detailed mapping in Bonneville lacustrine shoreline deposits along the western strand did not reveal a fault scarp, and the 39-m long trench across a younf 1.5 m-high scarp indicates that no recent fault rupture cut the lacustrine deposits. We conclude that either the western strand is a bedrock fault, displacing Salt Lake Group against Salt Lake Group, but it does not displace late Quaternary deposits, or the western fault strand does not exist. In either case, the fault would not be an active fault by definition in the State of Utah.

The complex geomorphic expression of the central fault strand is defined by a discontinuous, 6-km long, 20-30 m-high east-facing escarpment that crosses a low-relief, west-sloping pediment surface cut into a dipping section of Tertiary sediments. The 325-m long GPR profile suggested the presence of a small graben, and the possible presence of several east-dipping faults along an east-facing escarpment. A 37-m long trench along the western part of the site, and a 44-m long trench through the graben, is separated by 31-m long gaps in trenching. We observed no signs of faulting in the Salt Lake Group or in overlying Quaternary colluvium that yielded a minimum age of 66 ka. The Tertiary Salt Lake Group beds define a syncline with its axis near the topographic saddle and the mapped location of the McKenzie Flats fault. Thus, the topographic expression of the McKenzie Flat fault may be interpreted as erosional rather than tectonic. The McKenzie Flats fault may have experienced vertical Quaternary movement that displaced the pediment surface 20 m vertically, but faults were absent in the three trenches. This could have occurred because faults were locally present, but they came to the surface in the untrenched intervals between our three excavations. The larger eastern interval contained the topographic saddle and the anomalies imaged on the GPR survey.

The eastern strand of the ECFZ was exposed along a 32-m long trench, where a single 45° west-dipping fault was exposed near its head. The fault juxtaposes dolostone in the footwall against late Quaternary loess (mostly older than 58.8±4.5 ka to 62.5±5.0 ka) in the hanging wall. Quaternary loess of the hanging wall is truncated against Paleozoic bedrock to the base of a thin modern A horizon. The absence of colluvial wedge depositsagainst the fault here is the signature of a fault whose last movement predates the ground surface developed above it. The absence of scarp-derived colluvium here indicates that the latest movement on this fault plane is older than the Bonneville lake cycle (older than the ca. 20 ka highstand, and possibly older than the beginning of the cycle at ca. 35 ka). Such an old age is consistent with the deformation dated farther south on this same fault strand by McCalpin (1994) as older than 26 ka and younger than 46 ka.

We conclude that the western fault strand of the ECFZ has had no late Quaternary displacement or does not exist; the central strand has not had any late Quaternary movement and may be a drape fold; and the eastern (range-front) strand has had one movement younger than 59-63 ka but older than the Bonneville lake cycle. The results of this study indicate that the late Quaternary slip rate on the southern segment has been significantly lower than that of the central segment. On the southern segment the elapsed time since the MRE is at least 26 ka (30 ka if connected to the James Peak MRE rupture), and may be as much 46 ka, which is much longer than the elapsed time (4 ka) and recurrence interval (9-11 ka) of the central segment.

This study and earlier studies shows that the southern segment of the East Cache Fault zone did not rupture simultaneously with the central segment in the latest three large earthquakes (4 ka, 15 ka, and 20 ka). The southern segment does not link with the central segment during rupture. We propose two rupture scenarios: (1) the southern segment ruptures by itself (rupture length of 22.1 km, and an M6.6±0.3 earthquake), or (2) the southern segment ruptures along with the James Peak fault (combined rupture length of 34 km, for a M6.9±0.3 earthquake). The maximum 46 ka age since the MRE on the southern

segment, and a vertical displacement that is same as the central segment (1.4 m), would yield a maximum closed-cycle slip rate of 0.03 mm/yr (but only if the next event occurs tomorrow). Therefore the likely range of slip rates lies between 0.01 and 0.03 mm/yr.

The very low Quaternary slip rates and the long recurrence times deduced for the southern segment can be interpreted to indicate that the segment poses much less hazard than the central segment. However, the large cumulative throw on the southern segment indicates a post-Miocene slip rate of 0.35 mm/yr, yet a mid-late Quaternary slip rate of only 0.01 to 0.03 mm/yr. In order for the southern segment to “catch up” to its long-term slip rate, displacement event(s) might be expected in the near future. Additionally, the three late Quaternary displacements on the central segment may have increased the Coulomb stress on the southern segment, thus “loading” it and advancing its time to failure.

2. INTRODUCTION

This report was written by Co-PI Jim McCalpin, based on his field notes from two field reviews of the trenches, and from fragmentary data provided by the trench logger, Utah State University grad student Stephanie Davi.

2.1 Purpose and Scope of Study

The East Cache fault zone (ECFZ), northern Utah, is an ~80-km-long active normal fault that poses a significant hazard to a growing population center. The overall trace of the fault has been well established (McCalpin, 1989, 1994) and consists of three segments. Timing and magnitude of paleoearthquakes on the central segment are well documented, but few data constrain the slip history of the northern or southern segments. The current version of the National Seismic Hazard Map treats the ECFZ as an unsegmented fault on which the characteristic earthquake is permitted to "float" along the length of the fault (K. Haller, pers. comm. 2004). This approach was adopted because there are insufficient data on slip rate or recurrence in the northern and southern segments. The fault source characteristics currently used for the ECFZ are derived only from the central segment, which has the youngest scarps. Therefore, it is possible that using these values in an unsegmented rupture model overestimates the hazard posed by the ECFZ, if the slip rates on the end segments are significantly lower than those of the central segment. We will examine the rupture history of the segments in order to constrain the likely rupture lengths and recurrence times. We will begin the effort to evaluate the seismic hazard posed by the poorly studied segments by focusing on the southern segment in this proposal.

The goal of this study was to determine the paleoearthquake timing and magnitude on the southern segment of the East Cache fault with a paleoseismic investigation using trenching and mapping methods. We used data to test the hypothesis that the ECFZ is persistently segmented, and to examine if the segments have distinctly different slip rates, recurrence and perhaps characteristic magnitudes.

The Utah Quaternary Fault Parameters Working Group (UQFPWG) held its Annual Meeting on, February 15, 2006. The Working Group adopted these faults as priorities for study in 2007 (listed below in no particular order).

1. West Valley fault zone (trenched by Utah Geological Survey in 2010)
2. Weber segment – most recent event (trenched by UGS/USGS)
3. Weber segment – multi-event trench (trenched by UGS/USGS)
4. Faults beneath Utah Lake
5. East Cache fault zone (THIS STUDY)

2.2 Significance of the project

The Cache Valley (Figure 1) is a rapidly urbanizing graben with a current population of ~115,000 people, projected to be 275,000 to 300,000 by 2050 (Utah Office of Planning and Budget, Demographic and Economic Analysis, 2005). This growth primarily occurs in the communities along the eastern edge of the basin, and in the southern part of the valley. The southern portion of the Cache Valley, the area subjected to ground shaking from slip along the southern segment of the East Cache fault, is 35 miles from the northern terminus of the Wasatch

commuter rail line [original completion date of 2008]. Some local communities in the area have adopted geologic hazards ordinances and improved hazards assessments will impact the planning of future development in the area. Incorporation of geologic hazards analyses into city ordinances and recognition of recent fault rupture hazard has been incorporated into new developments in Logan and North Logan, where the work of McCalpin (1989, 1993, 1994) along with geotechnical investigations for new developments, resulted in the preservation of setback zones along the East Cache fault. Further efforts to establish quality growth guidelines that are compatible with seismic and slope failure hazards are currently underway within the county. Accurate identification of the location of the active traces of faults, along with the estimation of the seismic hazard, has been combined with recent planning efforts combine seismic risk reduction with and preservation of greenspace buffers and trail development. The work outlined here will contribute to this effort by quantifying the slip history along a segment that will soon see much development.

The area adjacent to the southern segment of the East Cache fault is under heavy development pressure, and analysis of rupture chronologies proposed here will significantly impact the future design of housing developments in the valley. In addition, the evaluation of multi-rupture scenarios will provide the engineering community with a set of probability-based rupture scenarios for the maximum credible earthquake in the area, including limits as to the likely earthquake magnitude and rupture lengths that can occur in the area.

2.3 Tectonic Setting

Cache Valley, northern Utah, is a rapidly urbanizing graben east of the Wasatch Fault (Figure 1). The valley is bounded on both sides by active normal faults, which are part of the northeast-trending Intermountain Seismic Belt (Smith and Sbar, 1974). Historic earthquakes of up to M_s 7.5 (Hebgen Lake, 1959) have occurred in the region. Closer to the study area, an M_s 6.6 earthquake (1939) ruptured 50 km west of the study area, and the 1962 M_s 5.7 Richmond earthquake caused damage in the Cache Valley (Arabesz et al., 1992, Smith and Arabesz, 1991).

The East Cache Fault bounds the eastern edge of the valley and forms the prominent geomorphic and structural break between the valley and mountain range. Clear geomorphic evidence indicates the fault is at least 54 km long (McCalpin, 1989, 1994) and may be ~80 km long if the fault connects with the James Peak Fault at its southern end. The latter interpretation was approved by a consensus of the Utah Quaternary Fault Parameters Working Group at a meeting in Salt Lake City on March 4, 2005. Analysis of subsurface data (Evans and Oaks, 1996; Oaks et al., 2005) indicates that the East Cache Fault changes character along strike.

McCalpin (1989, 1994) used geomorphic expression, paleoseismology, and Quaternary dating to identify three rupture segments of the East Cache Fault. The central segment is the most well documented, with two surface-faulting earthquakes in the past 14,000 years. The central segment of the East Cache Fault has an average slip rate of 0.2–1.0 mm/yr and a recurrence interval of 9–11.5 Ka. Surface ruptures of 1–2 m/event were recognized in trenches (McCalpin, 1994) and confirmed by new trenches opened in 2003 for a hazards analysis of new subdivisions (Nelson and Black, 2004). Earthquake magnitudes were inferred to have been M 6.9-7.1 on the central segment.

The geomorphic expression of the southern segment is characterized by fault traces that bifurcate (Figure 1). The southern segment is 22 – 28 km long and is composed of three parallel fault traces. The eastern fault strand lies at the foot of the Bear River range and forms the

boundary between Tertiary deposits and Paleozoic bedrock. This is the fault strand labeled as the East Cache fault on the USGS Quaternary Fault and Fold Database.

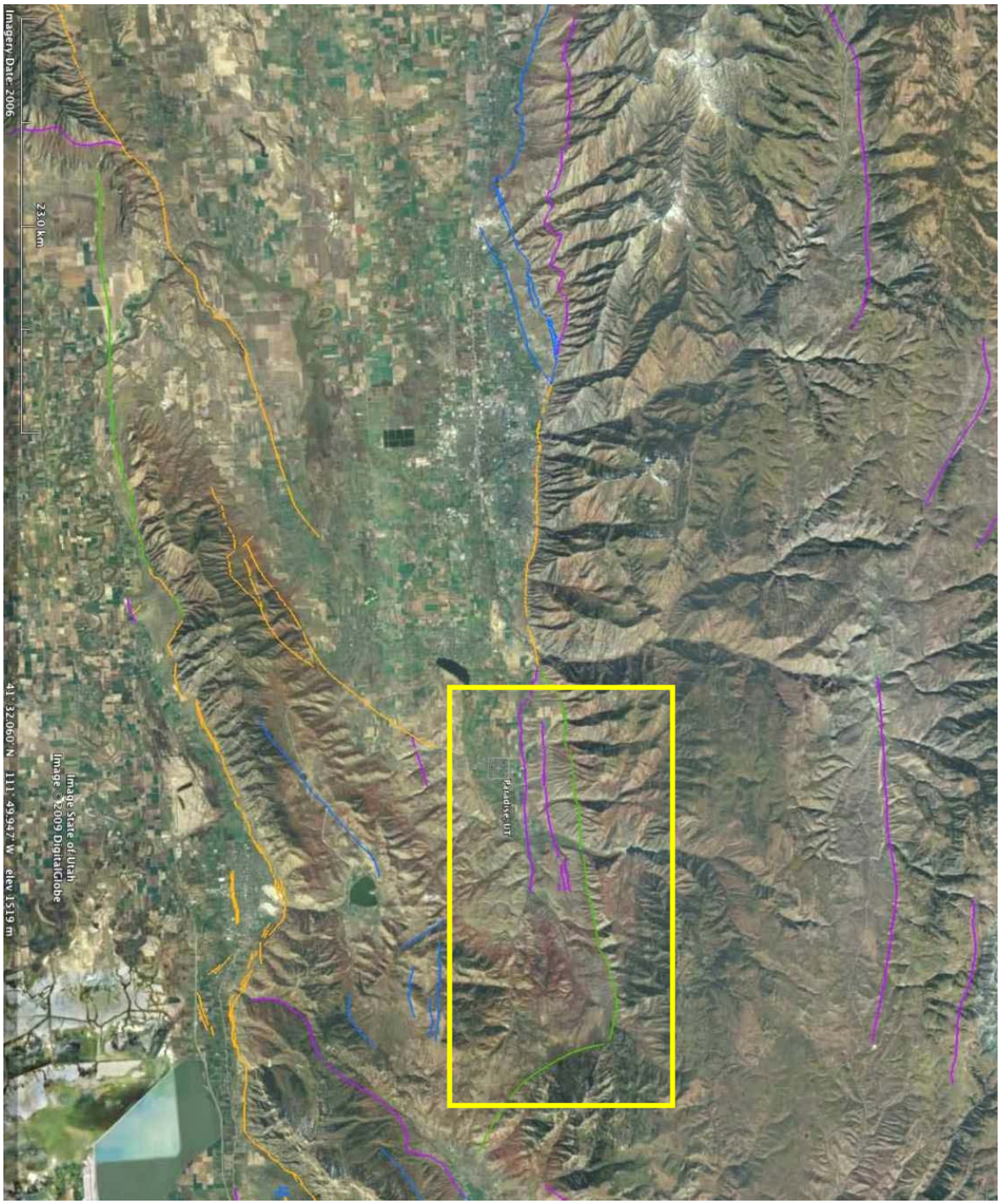


Fig. 1. Satellite image of the East Cache fault zone (center) on the eastern margin of Cache Valley, with the southern section in the yellow box. Fault color indicates age of latest movement, according to the USGS Quaternary Fault & Fold Database: orange, Holocene; blue, late Pleistocene; green, middle Pleistocene; purple, Pleistocene. Holocene faults northwest of the box are the West Cache fault zone; west of the box is the Brigham City segment of the Wasatch fault zone.

The central strand lies entirely within Tertiary deposits and is marked by prominent saddles and aligned drainages. Oaks et al. (1999) informally named this strand the McKenzie Flat fault and indicate it may be an antithetic fault to the East Cache fault (Fig. 3). The western strand separates Quaternary Lake Bonneville deposits from Tertiary units (Fig. 3), and was named the Paradise fault by Oaks et al. (1999).

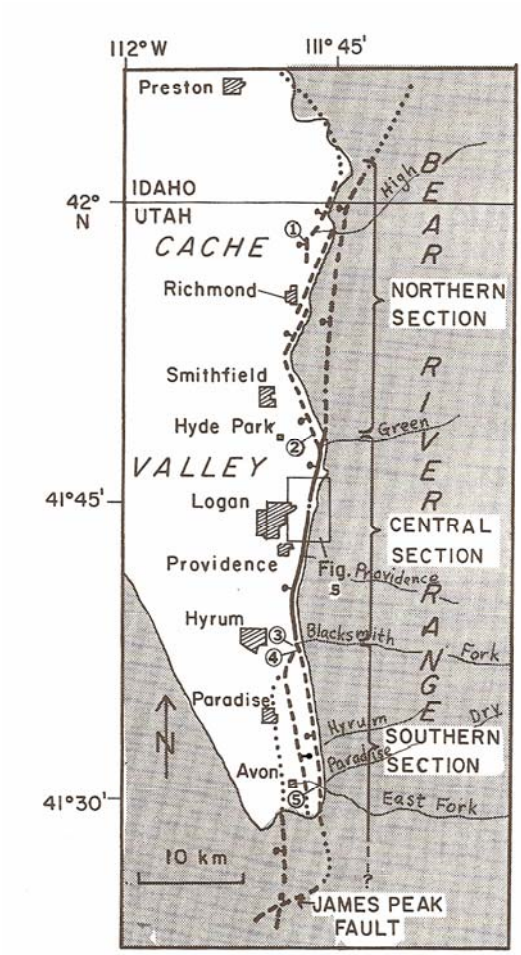


Fig. 2. Map of the geometric sections (rupture segments?) of the ECFZ. From McCalpin, 1994.

Timing of past ruptures on the southern segment is poorly constrained, and is the topic of this proposed research. McCalpin (1989, 1994) reports bedrock scarps along the eastern fault strand that are ~16 m high with a geomorphic surface offset of 10 m. Scant timing evidence indicates one rupture that was younger than 44 ka, but before 25 ka (McCalpin, 1989).

The geometric connections and rupture history between the well-documented central segment of the East Cache Fault and the southern segment are not known.

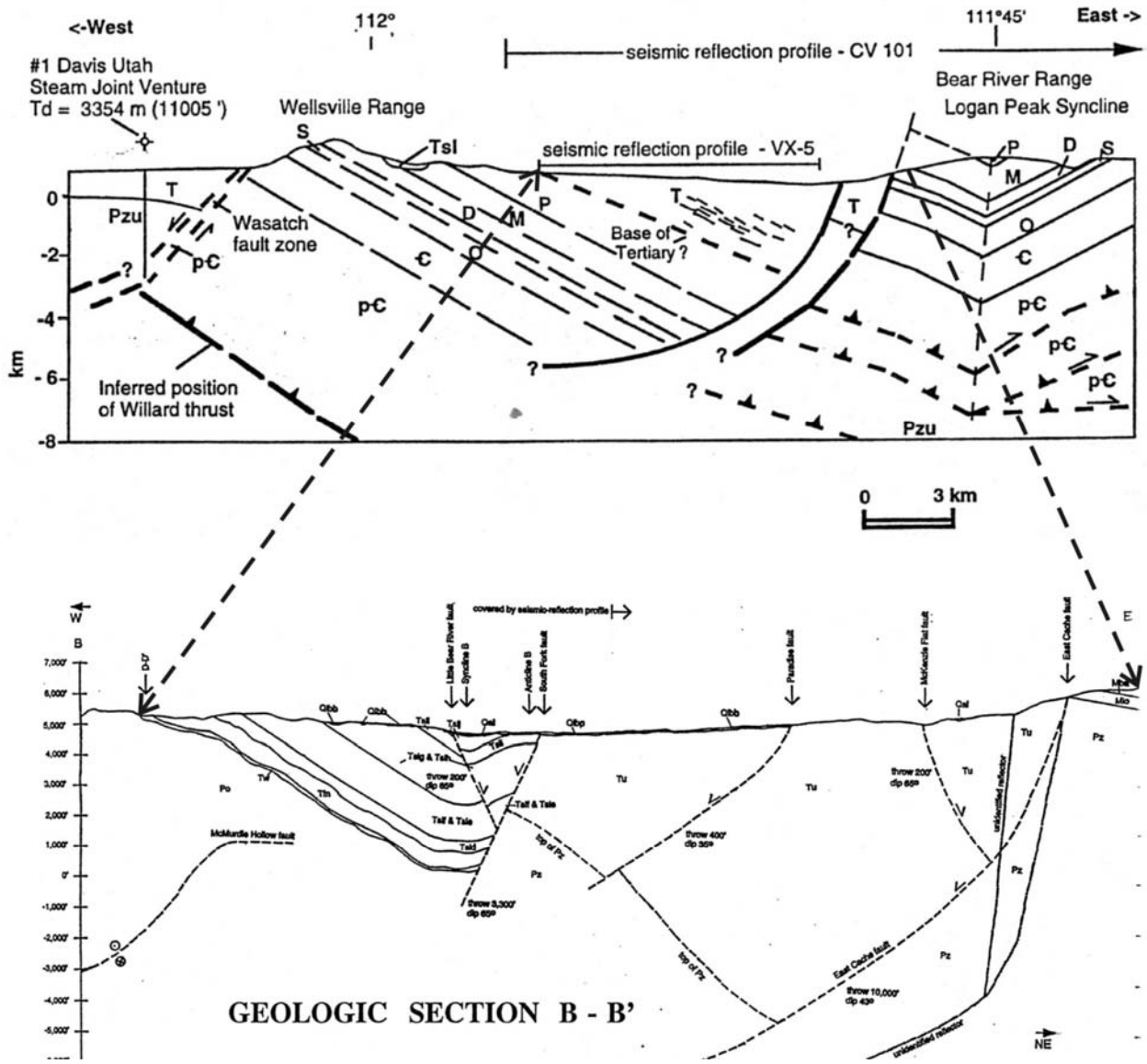


Fig. 3. Two cross-sections of southern Cache Valley at the latitude of Paradise. Upper section is from Evans and Oaks (1996) and covers the entire Cache Valley graben as well as the flanking horsts. Lower section is from Oaks (1997) and only covers the graben and its Tertiary-Quaternary graben fill. The three fault strands of the southern segment of the ECFZ are shown at right (from right to left, East Cache fault, McKenzie Flat fault, and Paradise fault).

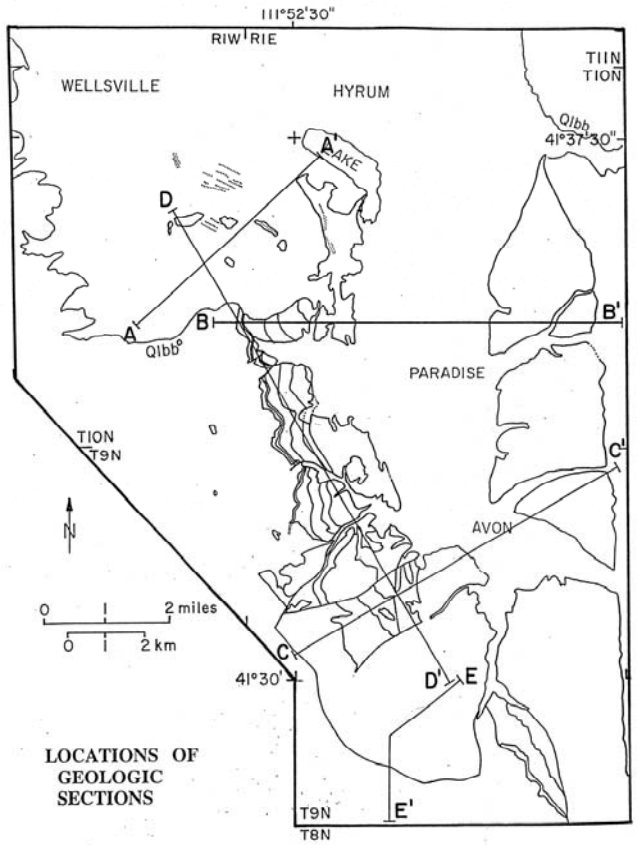


Fig. 4. Location map of Section B-B' of Oaks, 1997, shown in Fig. 3.

3. OBJECTIVES AND METHODS

The objectives of the study are fourfold:

1-- Determine the Quaternary rupture history of the southern segment of the East Cache Fault with a combination of paleoseismic trenching studies, surficial mapping, and analysis of shallow drill holes. This work will determine the timing and surface displacements of recent earthquakes which are responsible for slip on fault segment.

2-- Create a new surficial geologic "strip" mapping along the known fault traces, at scales of ca. 1:12,000 will be necessary to pinpoint the best trench locations. This mapping can also be combined with unpublished subsurface analyses (R.Q. Oaks, pers. comm.) to help constrain the cross-section geometry and to provide a more accurate analysis of the location of the fault traces. This will be extremely useful for planners, as development encroaches to the fault in some cases.

3-- Compare the results of our study with previous work on the East Cache Fault central segment to determine which rupture scenarios may occur: single segment vs. multi segment rupture.

4-- Calculate closed-interval geologic slip rates and recurrence intervals for the southern segment, to support a multi-segment source model for the ECFZ, for inclusion into the National Seismic Hazard Map.

Characterizing the late Quaternary paleoseismic record of the southern segment required a minimum of three trenches, one across each of the major N-S fault strands. The optimum location for these trenches was: (1) at the same latitude, so that all slip across the zone could be measured, (2) near the center of the section, to avoid any slip decreases near the ends, and (3) where Quaternary deposits are clearly displaced. Those criteria suggested two possible locations for a three-trench, east-west transect, a northern one east of Paradise and a southern one east of Avon (Fig. 5).

The target north transect includes a trench across correlative (?) pediment gravels on the eastern strand, a trench on the western tip of a truncated pediment and uneroded saddle on the central strand, and a trench across the Bonneville highstand wave-cut cliff on the western strand. The saddle is the best location to sample the central strand. The eastern trench may have experienced erosion of pediment gravels from the upper half of the fault scarp, but hopefully a colluvial record will still be preserved on the hanging wall.

The target south transect includes a trench across a better scarp in pediment gravels on the eastern strand, a trench in a somewhat eroded saddle on the central strand, and a trench across the Bonneville highstand wave-cut cliff on the western strand. The saddle is not as pristine as in the north transect. The trench site on the western (Bonneville) strand is about the same quality as in the north transect.

After field reconnaissance and talking to landowners, we decided on the northern transect (Fig. 5).

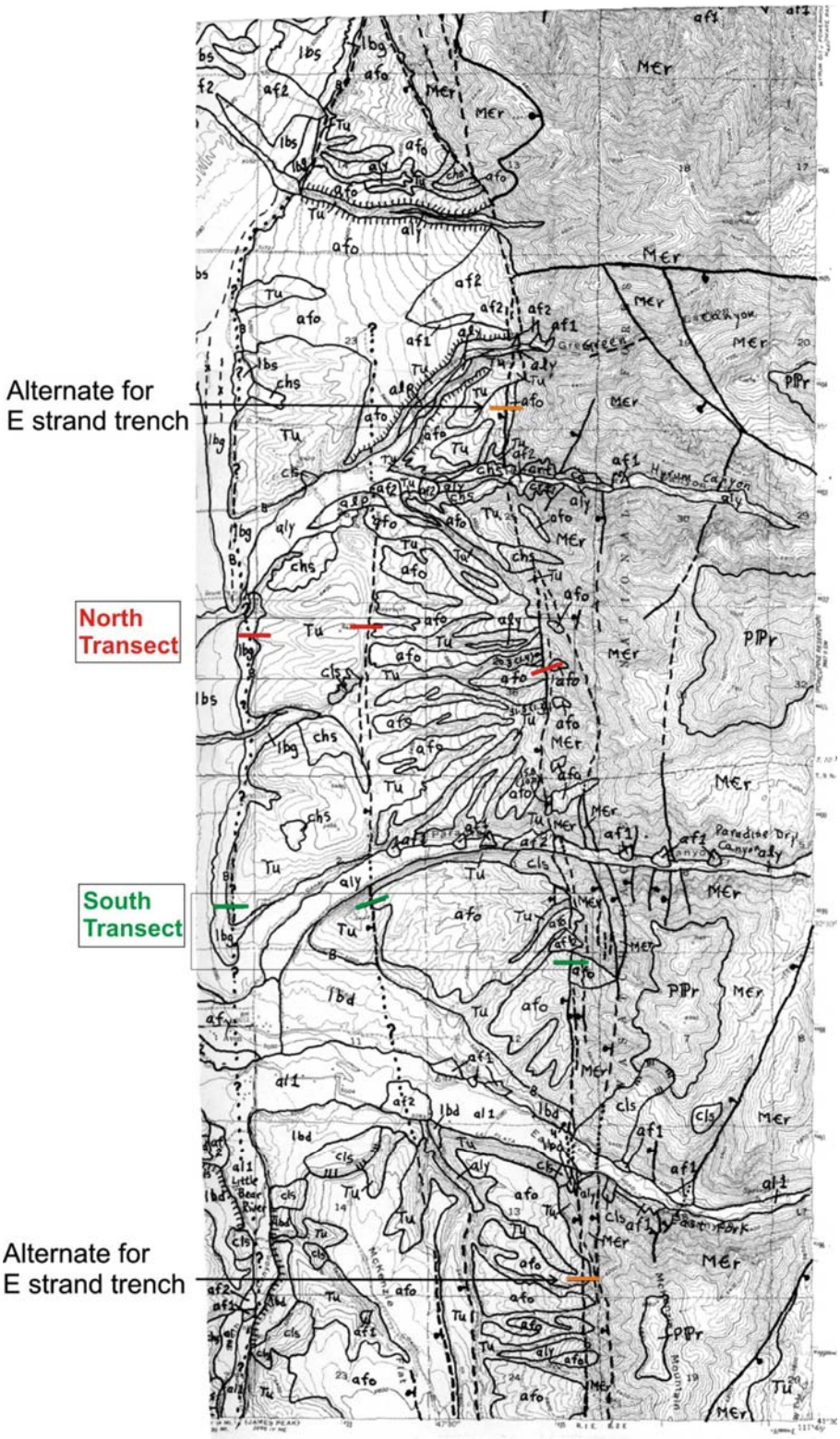


Fig. 5. Map showing options for trench sites. The north (red) and south (green) transects included trenches on all 3 fault strands at the same latitude. Due to landowner constraints we chose the north transect. Base map from McCalpin (1989); faults are thicker lines. For explanation of map units, download the map file (9.2 Mb) at http://ugspub.nr.utah.gov/publications/united_states_geological_survey/geologic_maps/mf/MF-2107.pdf

3.1 Geophysical Surveys of Trench Sites on the Northern Transect

Before trenching began, we ran ground penetrating radar (GPR) surveys through the proposed trench sites in order to determine how much Quaternary cover we will have to trench through before we get to the displaced sediments. This helped us determine whether or not the trench sites were useful locations, and whether or not the fault actually lies where previously mapped. It also helped us determine the thickness and internal structure of the colluvial wedge sequence.

The data were acquired by a Sensors & Software PE Pro unit with a 100 MHz antennae and a 1000 Volt transmitter. Trace spacing was 0.25 meters. The sampling rate was 0.8 nano seconds (ns) and the recording time was 500 ns. There were 16 stacks per trace. The GPR survey over the western strand of the fault was 90 meters in length. The survey over the central strand was 375 meters in length. The survey over the eastern strand was 200 meters in length. All GPR surveys were conducted under the supervision of John Bradford, director for the Center for Geophysical Investigation of the Shallow Subsurface at Boise State University.

Table 1. Parameters of the GPR surveys.

Project:	Utah State Neotectonics GPR
Date of Acquisition:	09/08/2007
GPR System:	Sensors and Software PE Pro
Antennas:	100 MHz
Transmitter:	1000 V
Trace spacing:	0.25 m
Polarization mode:	Transverse electric
Trigger Method:	Odometer Wheel
Sampling rate:	0.8 ns
Recording time:	500 ns
Stacks /trace:	16
Collected by:	John Bradford, Boise State Univ.

3.2 Geologic Mapping

Detailed surficial geologic mapping was conducted at a scale of 1:12,000. The topographic base map was created in ArcMap 9.2, ESRI software, using the 5 meter Digital Elevation Model (DEM) for the Paradise Quadrangle. The surficial geological map was digitized also using ArcMap. Aerial photographs were used to assist in the mapping process. A high accuracy Real Time Kinematic (cm-scale) Global Positioning System (GPS) unit was used in order to create topographic profiles of each trenching location. This survey was conducted using a Topcon HiPer Lite high accuracy GPS system. Topographic profiles were created using Microsoft Excel using the Northing and Easting components of the survey. A 5 meter DEM was used in GIS Arc Map to create additional topographic profiles at the central strand site. These profiles were used to calculate surface offset/displacements or cumulative surface offset of the beheaded drainages and between the pediment surface and the adjacent hillside.

3.3 Geochronology

Optically-stimulated luminescence (OSL) samples were collected at the lower trench at the central strand and at the trench on the eastern strand. The OSL dating technique can date sediment deposition ranging in age from 50 to 350,000 years (Murray and Olley, 2002). The OSL dating method provides an age estimate for the last exposure of quartz grains to sunlight during transport/deposition. This resets the OSL signal which in time after burial the luminescence signal grows with time due to exposure to radiation with the surrounding sediments. This signal is used to calculate the dose rate for the sample and in turn, a numerical age for the sediments. At the central strand the sample was taken at 1.7 meters below the ground surface (bgs). This sample was taken in order to date the colluvium under the A soil horizon. At the eastern strand site two OSL samples were taken. The first was sampled at 92 cm bgs and the second was taken at 130 cm bgs right below the first sample. The two samples were taken just west of the fault exposure right on top of each other about a meter apart. These are thought to be possible colluvial wedges of the last two events that occurred on this fault. These samples were taken in order to determine the age of the sediment directly beneath the fault zone. The OSL samples were analyzed at the Utah State University Luminescence Lab (Appendix 2).

4. WESTERN FAULT STRAND

4.1 Local structural geology and geomorphology

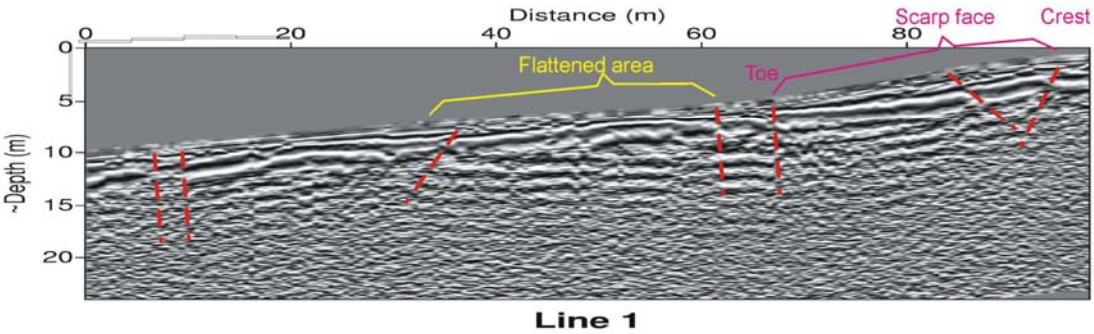
The western fault strand was first mapped by McCalpin (1989), but had not been mapped by Mullens and Izett (1963). McCalpin (1989) inferred this fault trace based on the alignment of two north-south geomorphic features: (1) the linear Bonneville highstand shoreline escarpment from Paradise southward, and (2) the South Fork of the Little Bear River south of Avon. He stated: "*The western trace is inferred merely based on the alignment of topographic features, but it does project southward to align with the Middle Mountain fault (Nelson and Sullivan, 1987).*"

4.2 The Western Trench

During the investigation of the western strand, one large trench was excavated across a ca. 1.5 m-high west-facing scarp at 1551 m elevation (approximately coincident with the Lake Bonneville highstand shoreline), and one small test pit (3 m long) was excavated 30 m west of the trench. The trench was 39 meters in length, 1.5 meters in width, and 1.5 meters in depth. The trench was excavated across the only small scarp on the western escarpment, that offset a single, young geomorphic surface (that is, the upthrown and downthrown surface appeared to be the same surface). This low-gradient geomorphic surface lies in a broad, shallow gully incised into the western escarpment. To the north and south, the western escarpment is a steeper, higher wave-cut cliff cut into the Salt Lake Group, with the upper geomorphic surface consisting of a middle Pleistocene (?) pediment, and the lower surface covered by Lake Bonneville shoreline deposits.

We did not think that a relatively shallow trench excavated across the higher parts of the escarpment would reveal whether that escarpment was tectonic or erosional, because the Bonneville sediments at the base would be too thick to trench through. On our small scarp, in contrast, a fault would easily be observed in a shallow trench if the scarp was tectonic.

The excavations took place in the same location as the GPR survey (see below), roughly where anomalies that were noted on the survey.



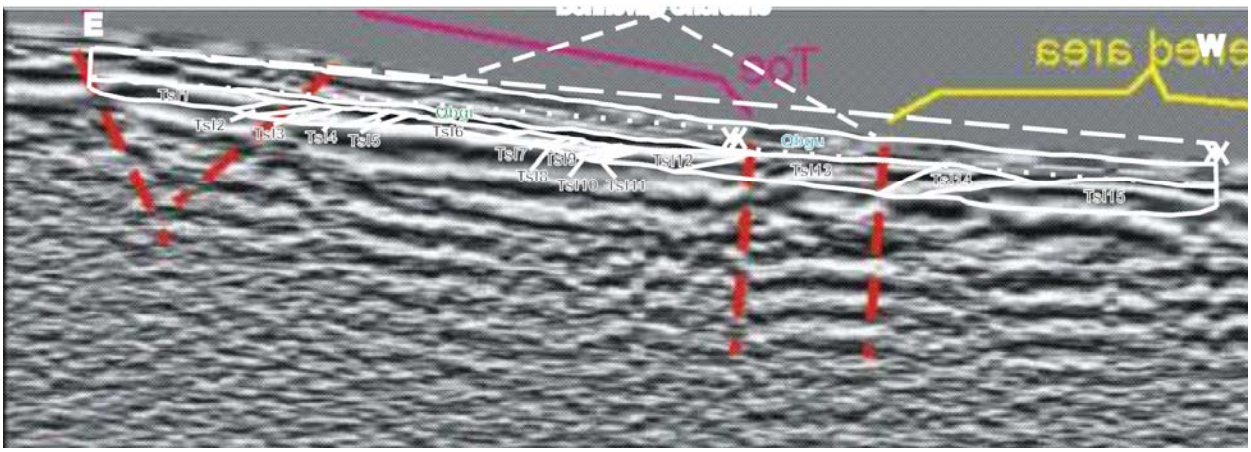
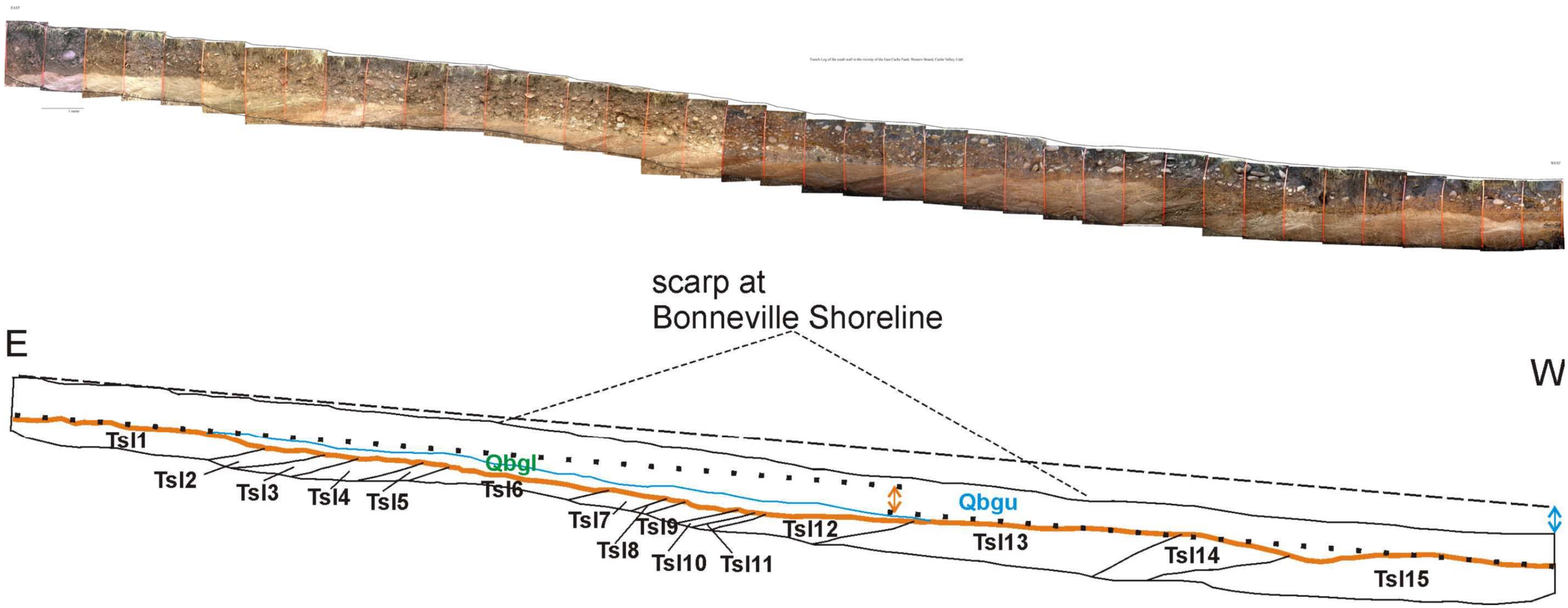


Fig. 6. Top, east-west GPR profile across the scarp ("scarp face") at the location of the western trench. Red dashed lines show faults inferred by John Bradford; labeled parts of the profile are by Jim McCalpin. The western trench extended from 50 m to 90 m on the horizontal scale. Bottom, a mirrored version of the GPR profile along the trench. The trench log (white lines and labels) has been superimposed to show the relative locations of the inferred faults.

Of the three faults inferred from GPR in the area of the western trench (the fourth one just misses the head of the trench), the farthest east (beneath the scarp crest) coincided with the contact between Tsl1 and Tsl 2-Tsl3 (Fig. 6, bottom). This was one of the strongest lithologic contacts in the trench, because unit Tsl 1 contained little clay, and Tsl2 and 3 contained significant clay. The two western inferred faults correspond roughly to the unit Tsl 12/13 contact and Tsl 13/14 contact. The former contact does not have a strong lithologic contrast (silt and clay/ clay-rich silt), but the latter contact has strong contrast (clay-rich silt/ pebble-rich sandstone). We conclude that the "faults" inferred by John Bradford were actually the contacts between east-dipping beds of the Salt Lake Group (see Fig. 7) that contained different percentages of clay.



b.

Fig. 7. Upper panel, photomosaic of the 39 m-long southern trench wall of the Western Trench. The lower trench wall exposes a continuous homoclinal sequence of east-dipping beds of the Salt Lake Group. Bottom panel, schematic log of the southern trench. Below the orange line, east-dipping beds of the Salt Lake Group are numbered Tsl 1 through Tsl 15. For unit descriptions, see Table 1.

4.2.1 Stratigraphy

The stratigraphy exposed in the western trench was quite simple, composed of bedrock of the Salt Lake Group in the lower half, unconformably overlain by Quaternary pebble gravel (Table 2). The pebble gravel was divided into two map units, Qbgu (with clasts imbricated showing current to the west), and a lower, thinner Qbgl (clasts not imbricated). The unconformaity was erosional and had the appearance of wave-cut surface beveling off the top of the soft Tertiary bedrock. The unconformity mimics the shape of the surface scarp on the ground, such that it resembles a laid-back wave-cut cliff and adjacent wave-cut platform. Unit Qbgl is a coarse gravel lens limited to the cliff-platform transition, which we interpret as a coarse lag of the shoreline cobbles that cut the wave-cut cliff.

Table 2. Unit description from the western trench, by Stephanie Davi.

Unit Descriptions - Western Fault Strand					
Unit	**Carbonate Content %**	**Sand %**	**Silt %**	**Clay %**	**Description**
Qbgu	0.40	38	26	36	Medium Brown gravel rich Lake Bonneville shoreline deposit, 30% gravel and rounded cobbles
Qbgl	33.4	66	20	14	Medium Brown gravel rich Lake Bonneville shoreline deposit, 40% pebble and gravel
Tsl - 1	25.4	25	43	31	Salt Lake Formation, buff colored tuffaceous clay loam
Tsl - 2	3.70	13	40	47	Salt Lake Formation, light brown silt and clay
Tsl - 3	5.60	22	34	44	Salt Lake Formation, redish-brown clay
Tsl - 4	45.8	30	34	36	Salt Lake Formation, buff colored clay loam
Tsl - 5	14.9	59	16	25	Salt Lake Formation, light brown sandy clay loam with minor pebbles
Tsl - 6	21.7	36	37	27	Salt Lake Formation, light brown to buff colored sand and silt
Tsl - 7	11.8	15	42	43	Salt Lake Formation, light to medium brown silty clay
Tsl - 8	1.50	32	37	31	Salt Lake Formation, light to medium brown sand and clay rich silt
Tsl - 9	24.1	28	33	39	Salt Lake Formation, light brown to buff colored silty clay
Tsl - 10	2.50	18	41	41	Salt Lake Formation, light to medium brown silty clay
Tsl - 11	37.8	28	39	33	Salt Lake Formation, buff to light brown clay rich silt with minor pebbles
Tsl - 12	15.5	25	41	34	Salt Lake Formation, light brown silt and clay
Tsl - 13	23.5	27	40	33	Salt Lake Formation, buff to medium brown clay rich silt
Tsl - 14	5.60	66	16	18	Salt Lake Formation, medium brown, pebble rich (55%) sandstone interbedded with clay
Tsl - 15	53.3	25	42	33	Salt Lake Formation, buff to medium brown silty clay

The bedrock of Salt Lake Group beneath the unconformity was softer than the overlying Quaternary gravels, and would have been called “soil” by most engineers. With the exception of unit Tsl 14, a pebbly sandstone, all other subunits had the texture of unconsolidated or weakly

consolidated clay, silty clay, and clay loam. Presumably these beds were highly tuffaceous sandstones and siltstones when deposited, and had subsequently weathered into a soil-like consistency. In most beds no traces of the original bedding or sedimentary structures could be observed. Instead, the most prominent structures in the beds were abundant veins of white, secondary calcium carbonate.

4.2.2 Soils

The surface soil developed in the uppermost stratigraphic unit (Qbgu) contained a reddish-brown, weak textural B horizon less than 50 cm thick. This degree of soil profile development is similar to that of soils developed on Bonneville highstand deposits elsewhere in the Bonneville basin, as described by Morrison (1965, p. 34-35, Graniteville Soil) and Shroba (1980).

4.2.3 Structure

The only structure observed in the trench was the consistent 25° east dip of strata in the Salt Lake Group bedrock (Fig. 7). This dip is similar to that exposed in the central trenches, and probably indicates that the trench area lies in the western limb of a broad north-south-trending syncline, the axis of which defines lies just east of the central fault strand. Notably, none of the 4 faults interpreted on the GPR profile (between 50 m and 90 m on Fig. 7) could be observed in the trench walls.

4.2.4 Geochronology

No dating samples were collected from this trench, because the scarp was interpreted to be a nontectonic feature. Based on the degree of soil development, the Quaternary gravels were deposited around the time of the Lake Bonnveille highstand, ca. 15 ka.

4.2.5 Interpretation

Two lines of evidence suggest that the scarp trenched is an erosional shoreline feature, rather than a tectonic fault scarp. First, the scarp does not line up exactly with the base of the western escarpment to the north and south, but bends eastward into the broad gully. Although fault scarps sometimes bend when crossing a gully, their bend usually arcs out into the downthrown block (see McCalpin, 2009, p. 189), the reverse of the geometry at our trench site. Second, there are no faults exposed in the trench beneath the topographic scarp. Instead, a late Quaternary erosional unconformity is cut onto bedrock and mimics the shape of the surface scarp. Based on this evidence, we conclude that this mapped portion of the westernmost strand of the ECF is actually the Lake Bonneville highstand shoreline.

Does the western fault strand (Paradise fault) of the ECF actually exist? Based on the lack of demonstrable fault scarps in Bonneville-age and younger deposits, and the lack of faults in our trench, we have to conclude that either: (1) the western strand exists as a bedrock fault, displacing Salt Lake Group against Salt Lake Group (as shown in Evans and Oaks, 1996), but it displace late Quaternary deposits, or (2) the western fault strand does not exist. In either case, the fault would not be an active fault by definition in the State of Utah.

5. CENTRAL STRAND

5.1 Local structural geology and geomorphology

The central strand of the southern section of the ECFZ (McKenzie Flat fault of Oaks et al., 1999) was first mapped by Mullens and Izett (1963) as an approximately located fault (dashed line) crossing Salt Lake Group (Tsl) terrain, with a queried sense of slip (west side up?). At its southern end east of Avon, the fault is dotted for a distance of about 500 m across the highstand deposits of Pleistocene Lake Bonneville. The fault is defined by a discontinuous, 20-30 m-high east-facing escarpment about 6 km long that crosses a low-relief, west-sloping erosional surface cut across dipping Tsl (Fig. 8). The dissected pediment is mantled with thin pediment gravels (not mapped by Mullens and Izett), that were first mapped by Williams (1962) as part of the McKenzie Flat pediment gravels (middle to early Pleistocene?). At the base of the escarpment is a system of aligned topographic saddles across several drainage divides formed by the incision of the pediment by west-flowing streams. The saddles are separated by north-south-trending gullies that trend perpendicular to the rest of the drainage network, and look structurally controlled.

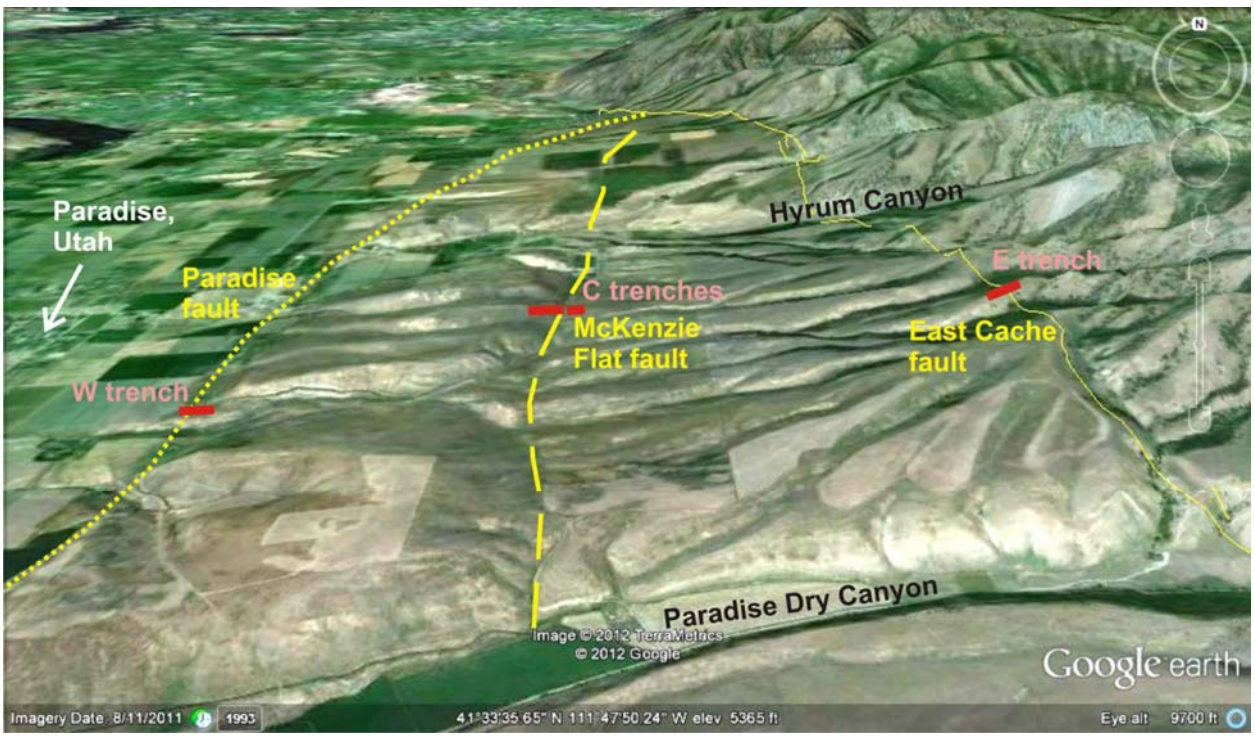


Fig. 8. Google Earth oblique view of the three fault strands of the southern segment, and trenches of the northern trench transect.

As shown on Fig. 8, the McKenzie Flat fault appears to offset the McKenzie Flat pediment surface about 20-30 m up-to-the-west. The only other interpretation of the geomorphology would be that the pediment surface between the Paradise and McKenzie Flat faults is an older pediment separate from the McKenzie Flat surface. However, in that case it should be possible to trace remnants of the younger McKenzie Flat surface through the stream valleys that cut west through this higher pediment. We did not observe any such surfaces in the field, and concluded that there is only a single-age pediment surface here that has an apparent 20-30 m offset along the central fault strand.

Mullens and Izett (1963) measured only three strike-and-dips in the Tsl terrain near the central strand, one just west of the central fault strand (6° NE) and two farther east, near the range front of the Bear River Range (9° and 15° W). These dips could result from block faulting and rotation, or could indicate a broad north-trending syncline in Tsl. Later mapping by Smith (1997) and Oaks (1997) also recognize the central fault strand (their McKenzie Flat fault), but interpret it as an east-dipping normal fault antithetic to the eastern fault strand (East Cache fault).

Prior to trenching we measured a 325 m-long GPR profile east-west across the entire central strand, roughly centered on the saddle (labeled "C trenches" on Fig. 8). The GPR profile (Fig. 9) shows, at its western end, an upper zone of well-defined, subhorizontal surface reflectors pinches out on the crest of the scarp. Our subsequent trenches did not extend uphill far enough to intersect this pinchout, but we infer that the zone represents Quaternary pediment gravels that overlie Salt Lake Group west of the escarpment. At the pinchout point the character of deeper reflections on the GPR profile changes, from subhorizontal, to dipping east parallel to the ground surface. John Bradford interpreted this break as a possible fault (red dashed line on Fig. 9). Bradford then interpreted three short east-dipping faults on the upper scarp face. The lower scarp face was an area of junky, disorganized reflectors, which changed only beneath the topographic saddle, where Bradford interpreted a graben. East of the saddle a zone of well-defined, subhorizontal surface reflectors becomes increasingly well developed, and coincides with Quaternary pediment gravels that cover Salt Lake Group bedrock.

During the investigation two trenches were excavated across the central strand. Both of trenches were located on the same line as the GPR survey and were specifically excavated in order to expose the anomalies noted on the GPR survey.

The Upper Trench was excavated in the summer of 2007 on the escarpment's east-facing hillside, where we inferred the main fault plane to lie. This trench was 37 meters in length, 2 meters in width, and 1.5 meters in depth. A north-south ranch fence lay across the toe of our preferred trench alignment, so we ended the Upper Trench just west of the fence, but dug a soil pit east of the fence to see if the stratigraphic units projected to the same locations. The soil pit was located 7 meters east of the Upper Trench and was 5 meters in length, 2 meters in width, and 1.75 meters in depth. After we cleaned and logged these two exposures and realized there was no fault exposed in either one, we brought the trackhoe back to the site in October of 2007. The trackhoe backfilled the Upper Trench and soil pit, and excavated a new trench (the Lower Trench) across the saddle where most previous mappers located the fault, and where the GPR survey indicated a graben might exist. The Lower Trench was 42 meters in length, 3 meters in width, and 3 meters in depth (double-bench design). The landowner required us to leave a 31 m-wide untrenched gap between the Upper and Lower trenches, to permit north-south vehicle access. In all these trenches and pits, only the south wall was logged.

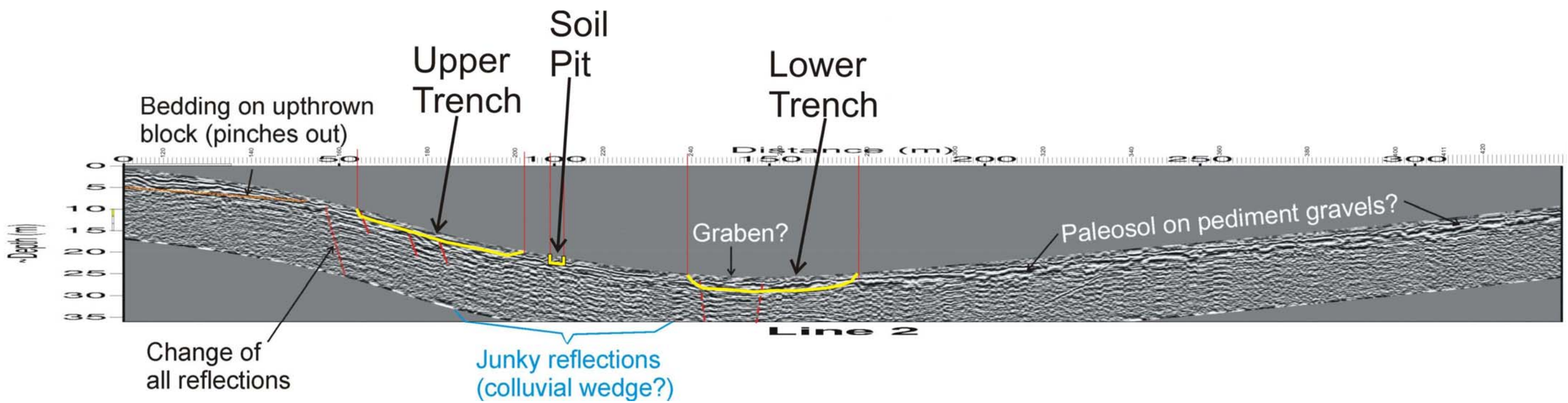


Fig. 9. East-west GPR profile across the central strand escarpment (at left) and saddle (at center); West is to the left. Red dashed lines show faults inferred by John Bradford; labeled parts of the profile are by Jim McCalpin. Yellow lines show bottoms of Upper Trench, soil pit, and lower trench. Small 3-digit numbers on X axis are UTM coordinates, 433xxx m E.

Fig. 10. Photograph of the east-facing escarpment of the central strand, looking WNW. The Upper Trench is in the distance, lying on the face of the escarpment. The lower end of the Upper Trench stops at a north-south fence, then there is a small soil pit dig on the east side of the fence (see Fig. 12 for correlation across the fence gap). The lower trench is in the foreground, crossing the saddle.

5.2 The Central Upper Trench (Trench A)

5.2.1 Stratigraphy

The stratigraphic sequence exposed in the Upper Trench is similar to that in the western trench, composed of bedrock of the Salt Lake Group in the lower half, unconformably overlain by Quaternary deposits (Table 3, Fig. 11). The Quaternary deposits are divided into two map units, unit Soil A (an organic surface soil horizon), and its underlying parent material colluvium (unit Qc). These two units lie unconformably atop Tertiary bedrock of the Salt Lake Group (Tsl). At the toe of the trench a second, older colluvium appeared between unit Qc and the top of Tsl bedrock. This older colluvium thickened to the east, and contained a strongly developed buried soil.

The strata of the Salt Lake Group were in general coarser-grained than strata exposed in the western trench, with 9 of 11 subunits containing gravel (as opposed to only 3 of 15 subunits in the western trench). In most beds no traces of the original bedding or sedimentary structures could be observed. Instead, the most prominent structures in the beds were abundant veins of white, secondary calcium carbonate, which comprised a peculiar rectilinear network.

Table 3. Unit Descriptions - Central Fault Strand, Upper Trench

Units	Carbonate Content	Sand %	Silt %	Clay %	Description
Soil A	0.00	23	47	30	Soil A horizon, younger slope colluvium silt and clay
Qc	1.60	23	53	25	Brown to reddish brown slope colluvium silt rich, minor pebbles and gravels (includes the modern and two older colluviums; see Fig. 12)
Tsl - 1	0.00	35	36	30	Salt Lake Formation, medium brown silty sand with minor pebbles (5 %)
Tsl - 2	0.00	36	32	32	Salt Lake Formation, medium brown silty sand with minor pebbles (10 %) very minor angular cobbles (1%)
Tsl - 3	0.00	28	53	19	Salt Lake Formation, medium brown sandy silt
Tsl - 4	0.00	35	28	37	Salt Lake Formation, medium brown sandy clay with minor pebbles (5%)
Tsl - 5	0.00	13	55	33	Salt Lake Formation, medium brown silty clay
Tsl - 6	0.00	35	41	24	Salt Lake Formation, light brown sandy silt with minor pebbles (5%)
Tsl - 7	0.00	11	56	33	Salt Lake Formation, light brown silt and clay, very minor pebbles (1%)
Tsl - 8	0.00	19	42	40	Salt Lake Formation, light to medium brown silt and clay with pebbles (10%) and gravels (3%)
Tsl - 9	0.00	18	49	33	Salt Lake Formation, light to medium brown silt and clay with minor pebbles (1%)
Tsl - 10	0.00	29	32	40	Salt Lake Formation, light to medium brown sandy clay with pebbles (10%) and gravels (3%)
Tsl - 11	0.00	19	29	53	Salt Lake Formation, light to medium brown silty clay with pebbles (5%)

5.2.2 Soils

The surface soil developed on the modern colluvium (Fig. 12) was composed of a cumulic A horizon that varied from 30-40 cm thick to 0 cm thick along the trench wall. This A horizon was unconformably underlain by strong textural B horizon developed on an older, more oxidixed colluvium. We interpret that the modern colluvium is actively creeping down the slope and being

subjected to bioturbation from roots and animals. The older colluvium, based on its textural B horizon, appears to be Bonneville or pre-Bonneville in age.

Beneath the older colluvium at the toe of the trench was a buried A horizon (Ab) developed in the top of the Salt Lake Group bedrock. This soil was not visible farther up the trench, and coincided with the appearance of the older colluvium near the trench toe (Fig. 12). Clearly, most of the trench was excavated into the scarp where erosion and/or transportation processes dominated, but the toe of the trench was beginning to be cut into a zone of colluvial deposition at the foot of the scarp.

5.2.3 Structure

We did not observe any faults in the Upper Trench walls, despite the fact that the GPR survey showed one inferred fault near the head of the trench, and two more faults beneath the floor of the trench farther down. Instead, the only structure was the monotonous eastward dip of the strata in the Salt Lake Group at about 27°.

5.2.4 Geochronology

No dating samples were collected from this trench, because there were no faults or colluvial edges exposed in the trench walls. Based on the degree of soil development, the older Quaternary colluvium was of Bonneville or pre-Bonneville age.

5.2.5 Interpretation

The excavation of the Upper Trench at the central strand of the ECF revealed tuffacous sandstones of the Salt Lake Group dipping uniformly eastward at about 27°. Slope wash colluvium was located above the Tsl. No fault was found in this trench, and given the well-defined nature of unit contacts, vertical fault displacement would have been relartively easy to see if it had been present.

The most prominent GPR anomaly (interpreted as an east-dipping normal fault) was inferred by John Bradford to lie at the head of the trench. However, no such fault was visible on the southern trench wall. If a major normal fault had existed just upslope of the head of the trench, then the head of the trench should have been cut into the colluvial wedge shed from that fault free face. However, the Quaternary colluvium was not any thicker at the head of the trench than elsewhere; in fact it was thinner than at the toe of the trench. Therefore, there was neither direct or indirect evidence for a normal fault at or near the head of the trench.

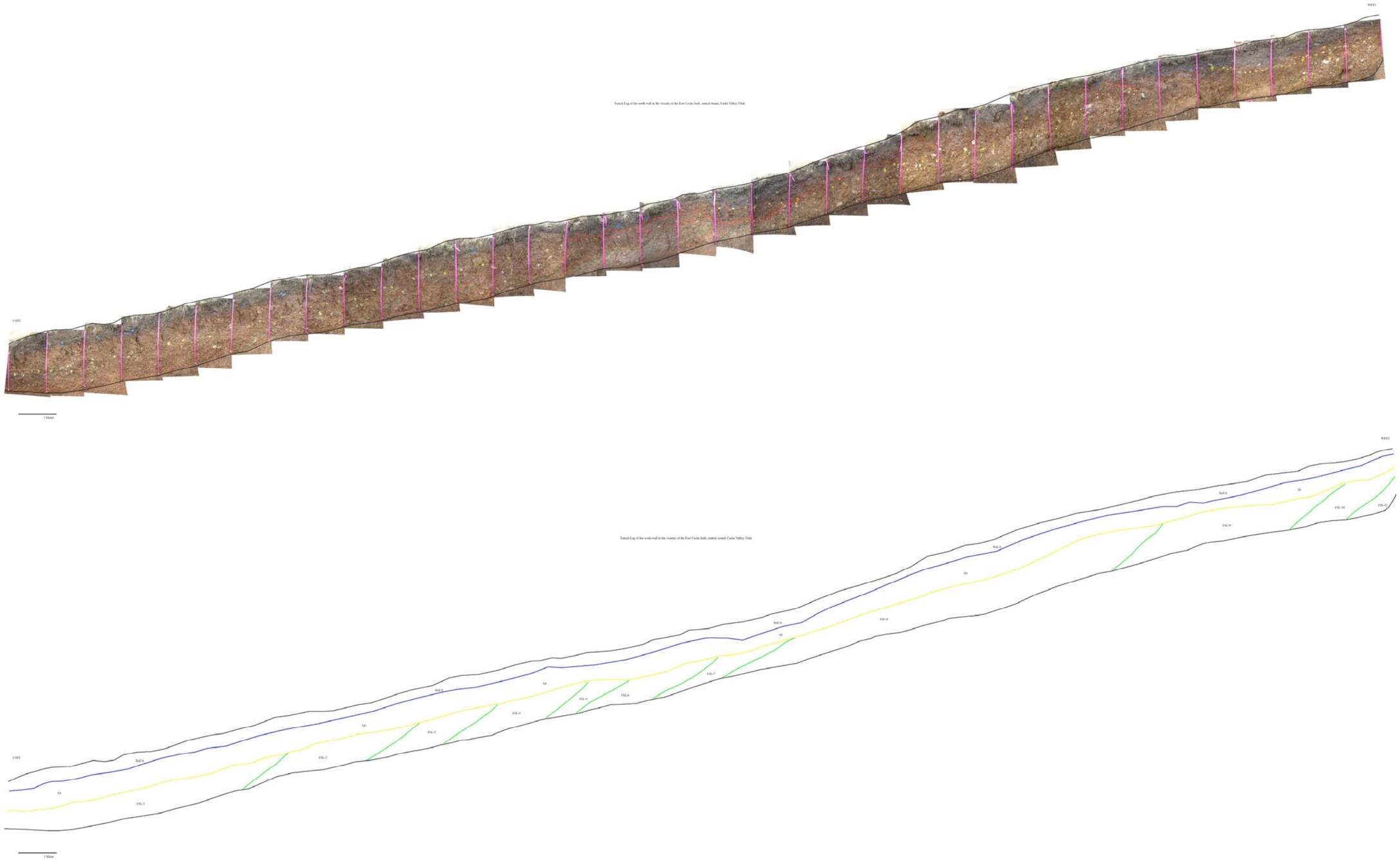


Fig. 11. Upper panel, photomosaic of the Upper Trench. Lower panel, geologic contacts in the Upper Trench.In both panels east is to the left and west is to the right. The Quaternary geology shown in the lower panel was simplified from the original field logs (see Fig. 12).

The Soil Pit

The soil pit was excavated on the east side of the north-south ranch fence, in case there might be a down-to-the-east fault beneath the fence where we could not trench. When we project the stratigraphic contacts from the toe of the Upper Trench beneath the fence and to the Soil Pit, the projections lie higher than the correlative units in the Soil Pit. The amount of vertical misalignment is greater (ca. 1.5 m) for a more gentle downslope projection than for a teeper one (ca. 0.5 m). Given the fact that the misalignment is based projecting a soil horizon (rather than a stratigraphic unit) and is rather small, we do not feel that this is compelling evidence of a fault between the two exposures.

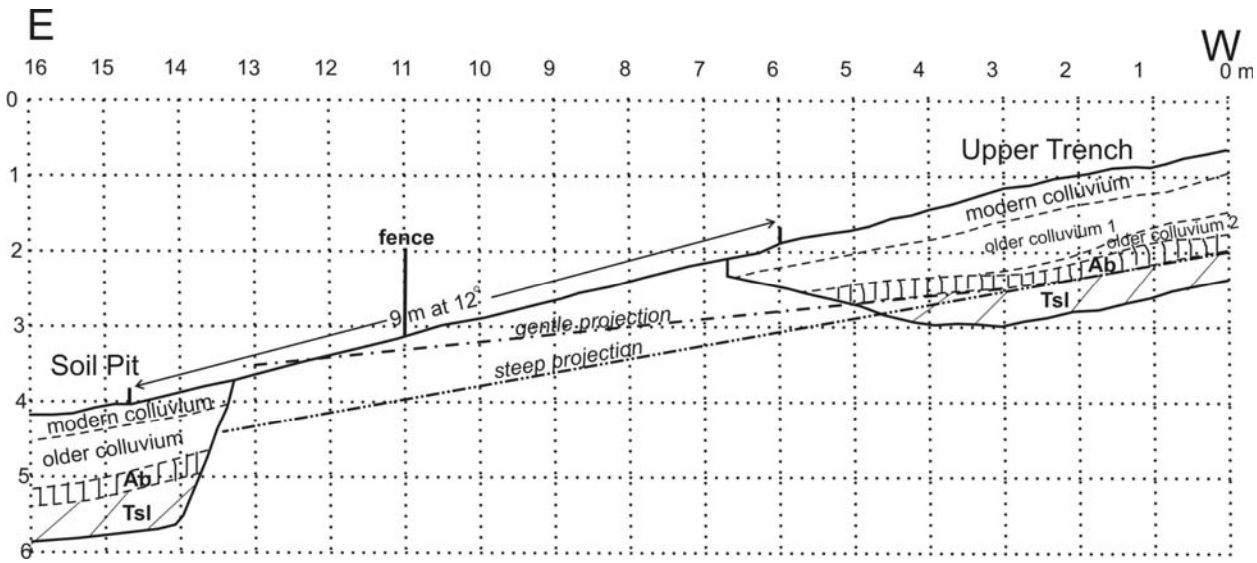


Fig. 12. Projection of unit contacts across the 6.5 m-wide gap between the Upper Trench and the soil pit. Projecting the bottom of the Ab horizon from the Upper Trench to the soil pit results in a vertical misalignment of 0.5 m (steep projection) to 1.5 m (gentle projection). This misalignment is in the correct sense (down-to-the-east) for an antithetic fault, yet no faults were observed in any of the central trenches, nor interpreted from the GPR survey beneath this part of the scarp. The misalignment may be the result of an undulating lower contact on the Ab soil horizon, which after all is not a stratigraphic unit (deposit), but a soil horizon boundary.

5.3 The Central Lower Trench

5.3.1 Stratigraphy

The 44 m-long lower trench exposed strata of the Salt Lake Group generally similar to those exposed in the western trench, e.g. highly weathered tuffaceous pebbly sandstones weathered to clayey sands. The lower 1.5 m of the trench exposed four mappable subunits, from older to younger:

Unit Tsl1, which contained about 30% clasts in a sand-clay matrix

Unit Tsl2a, a dark-toned clayey sand with sparse pebbles

Unit Tsl2b, a lighter toned bed of similar texture

Unit Tsl3 (not labeled on Fig. 13), a pebbly sand with clasts concentrated in the upper part. This unit is the parent material of the major buried soil described next.

Overlying the Tsl units an old colluvial unit (Qco) probably correlative with that mapped in the toe of the Upper Trench and in the Soil Pit. This deposit is a clayey sand which thickens from east to west and contains the modern (relict) surface soil.

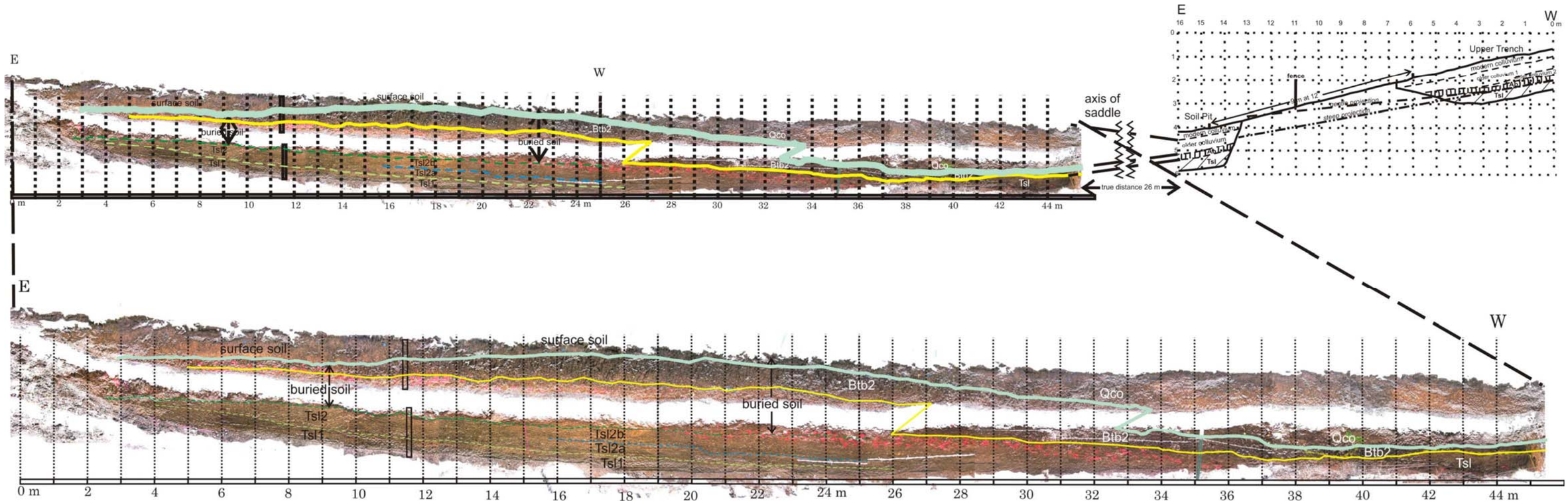


Fig. 13. Annotated photomosaic of the south wall of the Lower Trench on the McKenzie Flat strand of the East Cache fault zone. Tsl1, pebbly sandstone of the Salt Lake Group, highly altered; Tsl2a and 2b, ashy sandstone of the Salt Lake Group, altered to a clayey sand; buried soil, a 1- to 1.5 m-thick well-developed soil profile developed on unit Tsl3, a gravelly bed (clasts are spray-painted red); the textural B horizon (Btb2) with maximum development (soil ped structure) has a dark brown color, and lies between the yellow line and thick green line at the top of Tsl. Overlying Tsl in the western part of the trench is an older Quaternary colluvium (Qco) correlated to the older colluvium exposed in the soil pit, 26 m farther west. The surface soil is developed on Qco. There are no faults or other structures exposed in the trench wall.

5.3.2 Soils

The trench exposed two soil profiles, a lower buried soil and an overlying modern surface soil. The buried soil is composed of a strongly developed, dark brown textural B horizon at the top, and lower B/C and Cox horizons beneath, al developed in unit Tsl3. The textural B horizon thickens from 20 cm in the eastern part of the trench to 80 cm in the central part (as the soil profile thickens from ca. 1 m to 1.5 m), and then thins again at the western end of the trench. If this paleosol developed maximum thickness and development in the axis of the saddle, it implies that the axis was formerly farther east than it is today. The surface soil in the eastern part of the trench is this same soil brought up to the suurafec by the dip of Tsl beds. In the western part of the trench the surface soil is a younger coil, developed on Qco, and is so weak it is not mapped as a separate unit on Fig. 13.

5.3.3 Structure

The beds of the Salt Lake Group (Tsl1, Tsl2, Tsl3) dip gently to the west, at a slightly steeper angle than the modern ground surface, so that a given bed (e.g., Tsl3) is found deeper below the surface as traced westward in the trench wall. There are no structures (faults, folds, angular unconformities) visible that disrupt the strata.

5.3.4 Geochronology

Because there were no faults exposed in this trench, we did not devote much resources to dating the Quaternary sequence. A single OSL sample was collected from high in the undeformed unit Qco, and it yielded an age of 66.0±6.3 ka (see Appendix 3).

5.3.5 Interpretation

The Western Trench, Soil Pit, and Eastern Trench did not expose any signs of faulting in either the Salt Lake Group or in overlying Quaternary colluvium that yielded a minimum age of 66 ka. The Tsl beds east of the topographic saddle dipped 14°W and the beds west of the saddle dipped 27° east, thus describing a syncline with its axis near the topographic saddle and mapped location of the McKenzie Flats fault.

The observed data can be interpreted in two ways. First, the topographic expression of the McKenzie Flat fault could be interpreted as erosional rather than tectonic. In this interpretation the 20 m-high east-facing scarp was formed by erosion along resistant bedding planes in the Salt Lake Group, such that the scarp face is essentially an erosional dipslope. The aligned saddles would have been formed by headward erosion of tributary streams up the axis of the syncline, which apparentely has a long N-S axis. This erosional hypothesis explains why no faults were observed in any of the trenches, because there has been no Quaternary faulting here, only erosional stripping of folded Salt Lake Group

The difficulty with the erosional hypothesis is that it cannot explain: (1) the apparent 20 m vertical offset of the McKenzie Flat pediment, (2) the deep seismic reflection data that show a down-to-the-east normal fault beneath the line of saddles, and (3) the GPR shows several disruptions of reflectors, especially beneath the saddle.

The second interpretation is that the McKenzie Flats fault has experienced vertical movement in the Quaternary, and that it has displaced the pediment surface 20 m vertically, but for some reason no faults were seen in the three trenches. This could have occurred because faults were locally present, but they came to the surface in the 9 m-wide and 31 m-wide

untrenched intervals between our three excavations. The larger eastern interval contained the topographic saddle and the anomalies imaged on the GPR survey. This untrenched interval was supposed to be only 6 m wide, but misunderstanding by the graduate student who sited the trench led to it being larger.

A variant of this hypothesis is that the 20 m-high scarp and the entire syncline were created by drape folding over a blind normal fault. In this case there never were normal faults in the shallow subsurface, because the highly weathered Salt Lake Group acted as a ductile medium over a buried normal fault.

Davi (pers. comm., 2009) wrote the following interpretation of the trenches on the central strand, reproduced below: "*In the second large trench* [eastern trench] *at this site we found a conglomerate Tsl formation deposit dipping westward at 14 degrees. This excavation reveled a syncline that is mapped to the east of the central strand of the ECF by Kristine Smith (1997). Unfortunately the trench was not excavated much further west of the syncline in order to reveal the possible fault surface is in a gap between the excavated trenches buried very deeply. No Holocene fault scarps were located in this gap and it is believed that there is no Holocene fault rupture on this fault strand. The DEM and RTK GPS system topographic profiles reveal approximately 20 meters of offset between the displaced McKenzie Flat pediment surface at this location. The preliminary results for the OSL sample, taken in the second larger trench, indicate that the slope wash/debris flow deposits in the upper portion of the trench are approximately 45,000 years old*."

6. THE EASTERN (range-front) STRAND OF THE EAST CACHE FAULT ZONE

6.1 Local structural geology and tectonic geomorphology

As shown in Fig. 8, the front of the Bear River Range is composed of steep faceted spurs eroded on Paleozoic clastic and carbonate lithologies (see McCalpin, 1994, p. 28). The base of these spurs rises sharply above the beveled pediment surface eroded on the softer Salt Lake Group (Fig. 14), along a well-defined north-south line. Streams flowing west out of the range have incised both the footwall and the hanging wall, dissecting the McKenzie Flats pediment and underlying Salt Lake Group in canyons 30-50 m deep. This geomorphology indicates that the hanging wall block is not subsiding rapidly, and thus the fault has not had a high slip rate since the formation of the McKenzie Flats pediment.

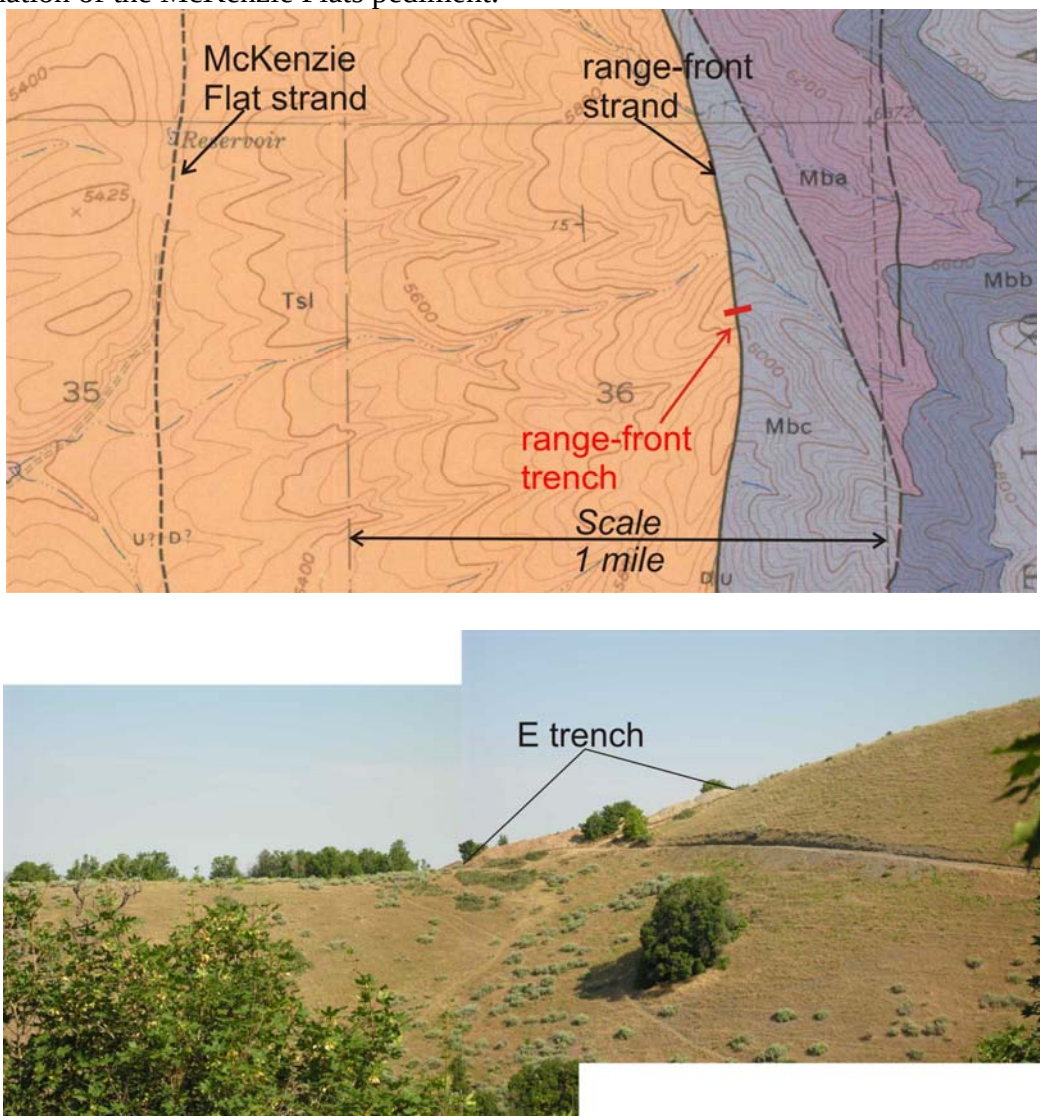


Fig. 14. Upper part, trench location shown on the geologic map of the Paradise quadrangle (Mullens and Izett, 1963). Tsl, salt Lake Group; Mba, Mbb, Mbc, members of the Brazier Limestone; Lower part, photograph of the slope break at the range front of the Bear River range, caused by the main (eastern) strand of the East Cache fault zone. The flat ridgeline at left is underlain by Salt Lake Group strata dipping west at about 14° (i.e., part of the syncline described in the previous section). The steeper ridgeline at right is underlain by dolostones of the Brazier Limestone, uppermost member C (Upper Mississippian).

6.2 Previous Results the Range-Front Fault Strand

McCalpin (1994) studied the tectonic geomorphology of the range-front faceted spurs and concluded that the southern segment contained the same two lowest sets of spurs as the central segment (Fig. 15). However, the elevations of the spur crests on the southern segment were higher, such that the crest of spur set 1 on the southern segment is about the same elevation as the crest of spur set 2 on the central segment. This suggests that the amount of relative Quaternary vertical slip across the fault was probably similar in the two segments, but that the absolute subsidence of the hanging wall and footwall had been greater in the central segment. He attributed this difference to uplift of the southern segment along the western fault strand (Paradise fault of Oaks), which would also explain the anomalous existence of the well-developed McKenzie Flats pediment on the hanging wall.

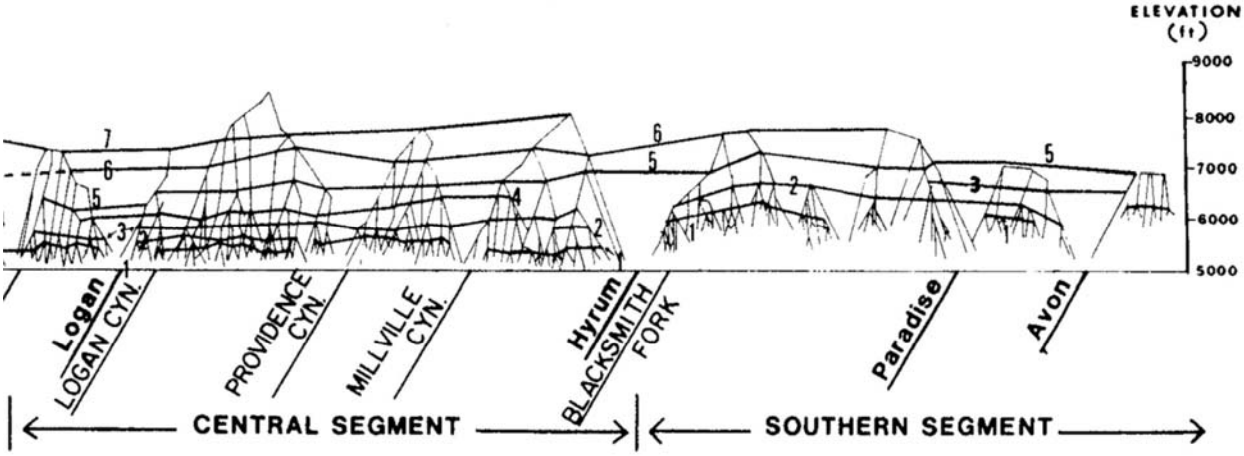


Fig. 15. Comparison of the faceted spur structure of the Bear River Range front between the central segment and southern segment of the ECFZ (from McCalpin, 1994, p. 29). Spur sets are numbered from 1 at the bottom (youngest) to 7 at the top (oldest). McCalpin correlated the spur sets based on their topographic position at the range front and their degree of steepness and erosional modification.

McCalpin (1994) also discovered two canal cuts into the range-front strand of the East Cache fault in the southern segment, on the north side of the East Fork (Fig. 16). Two TL ages indicated that a lower, faulted colluvium was pre-Bonneville in age (ca. 46 ka), while an upper, unfaulted colluvium was roughly contemporaneous with the Bonneville highstand transgression (ca. 26 ka). These bracketing ages for latest faulting were compatible with the lack of fault scarps across deposits of the Bonneville lake cycle on the southern segment. The age range was also roughly compatible with the age of latest faulting on the James Peak fault, estimated by Nelson and Sullivan (1987, 1992) at between 30 ka and 70 ka, but nearer the younger age. In addition, the 26-46 ka age range for the MRE indicated that neither of the two latest surface ruptures on the central segment of the ECFZ had propagated into the southern segment.

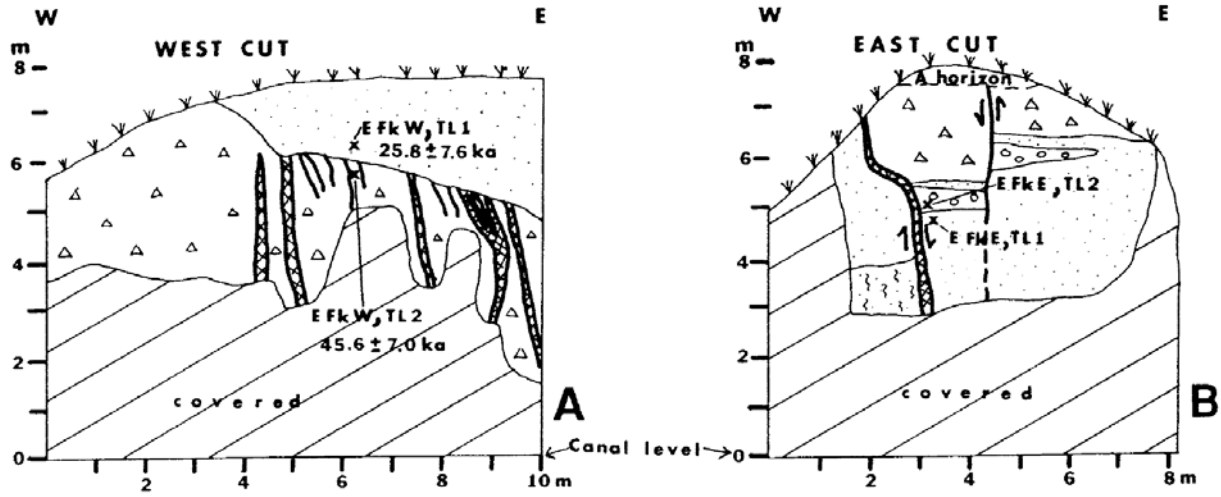


Fig. 16. Field sketches of faults of the main trace of the East Cache exposed in canal cuts north of the East Fork. (A), triangles indicate faulted and sheared (cross-hatched) hillslope colluvium with abundant angular clasts and pedogenic CaCO3; dots indicate finer sandy colluvium. TL ages bracket the latest faulting event in this exposure between about 26 ka and 46 ka. (B), All colluvial units in this exposure are faulted, so the two TL samples shown were never dated, because they would provide only a one-sided age constraint on latest faulting. From McCalpin, 1994, Fig. 14.

6.3 GPR Survey

Prior to excavating the eastern trench we performed a GPR survey along the proposed line of the trench, to try to pinpoint the exact location of the fault plane and/or colluvial wedges deposits. The survey revealed three breaks in the reflections, shown by dashed red lines in Fig. 17. We interpreted these breaks as steeply-dipping normal faults, and placed the head of the trench to intersect the break farthest upslope. However, there was no fault at that position in the trench wall. Instead, the main fault lay about 7 m farther downslope (solid red line on Fig. 17), and was a relatively low-angle normal fault.

In addition, the prominent topographic slope break was underlain by a zone without any prominent reflectors, which we speculated might be a graben. However, the landowner had built a road in this graben and did not give us permission to trench across the road, so our trench (blue outline in Fig. 16) ended upslope of the graben.

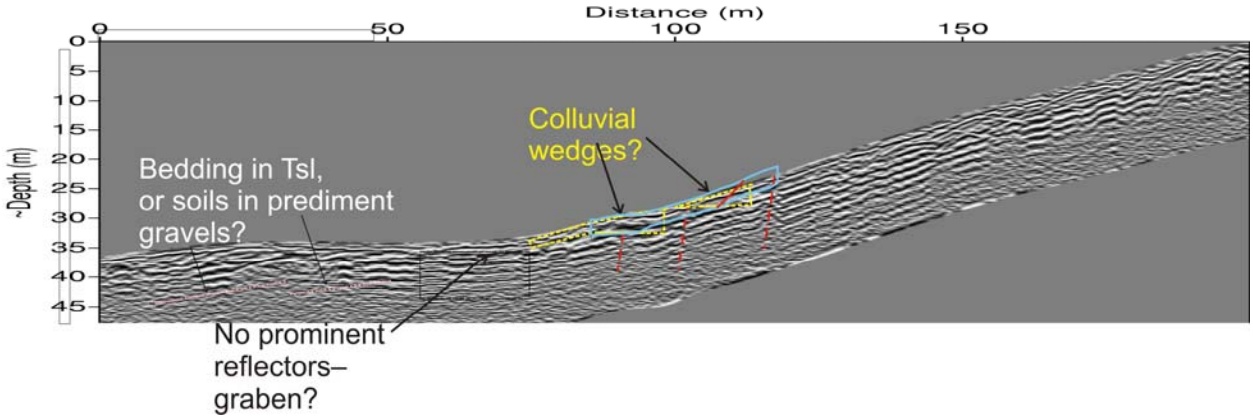


Fig. 17. GPR reflectors along a long survey line across the range-front slope break (same site as shown in Fig. 14). Red dashed lines are faults inferred from the GPR; yellow dotted lines show colluvial wedges inferred from GPR. Blue line shows the outline of the trench dug, and solid red line is the only fault exposed in the trench.

6.4 The Eastern Trench

During the investigation at the eastern strand one large trench was excavated over a very steep fault scarp. This trench was 32 meters in length, 3 meters in width, and 3 meters in depth. This trench was benched on the north wall and had a straight south wall.

6.4.1 Stratigraphy

Davi (pers. comm., 2009) defined six units on the southern trench wall, as shown in Table 4, but did not provide any unit descriptions.

Table 4. Mapped units on the south wall of the trench on the range-front strand.

Unit	Description (by JPM from photographs)
Soil A	Soil A horizon, younger slope colluvium silt and clay
Disturbed soil	Gray-brown to dark brown pebbly sand; massive, unstratified; forms a wedge-shaped mass in the hanging-wall, but 2 m away from the fault plane
Ql3	Quaternary loess, upper bed
Ql2	Quaternary loess, middle bed
Ql1	Quaternary loess, lower bed
Mbc	Mississippian dolostone of the Brazier Limestone Formation

6.4.2 Soils

Davi (pers. comm., 2009) did not map soil horizons in the trench.

6.4.3 Structure

The trench exposed a single fault near its head, a west-dipping normal fault (Fig. 18). Over most of the trench wall the apparent dip of the fault is 45°, but it flattens to 40° in the lowest 1 m of the wall, and steepens to 50° in the uppermost 1 m of the wall (Fig. 19). The fault juxtaposes dolostone of the Brazier Formation in the footwall against Quaternary loess (unit Ql3) in the hanging wall. Dolostone beds in the footwall dip 28°-30°W, similar to dips mapped in the same unit in Paradise Dry Canyon 1.6 km south (Mullens and Izett, 1963). On the footwall side the fault is marked by a 10 to 20 cm-thick zone of white-weathering clay gouge, presumably crushed and altered dolostone, perhaps with a hydrothermal component. Next in the footwall is a yellowish band of finely sheared limestone of about the same thickness, in which the shear bands are slightly undulating with a wavelength of about 30-50 cm. Based on trench wall photographs provided by Davi (pers. comm.), the fault extends nearly to the ground surface, displacing all units except for the A horizon of the thin modern soil.

There are two subvertical fissures in the hanging wall that cut loess unit Ql2 and appeared to be filled with overlying loess unit Ql3. Between these fissures is a calcite-filled fracture that extends upwards into unit Ql3, but is not associated with a vertical offset of its upper boundary. Because unit Ql3 is clearly faulted against the main fault, we infer that this is a secondary fracture formed at the same time as that latest faulting.

Fig. 18. Photomosaic of the south wall of the trench across the range-front strand of the East Cache fault zone. From Davi (pers. comm.).

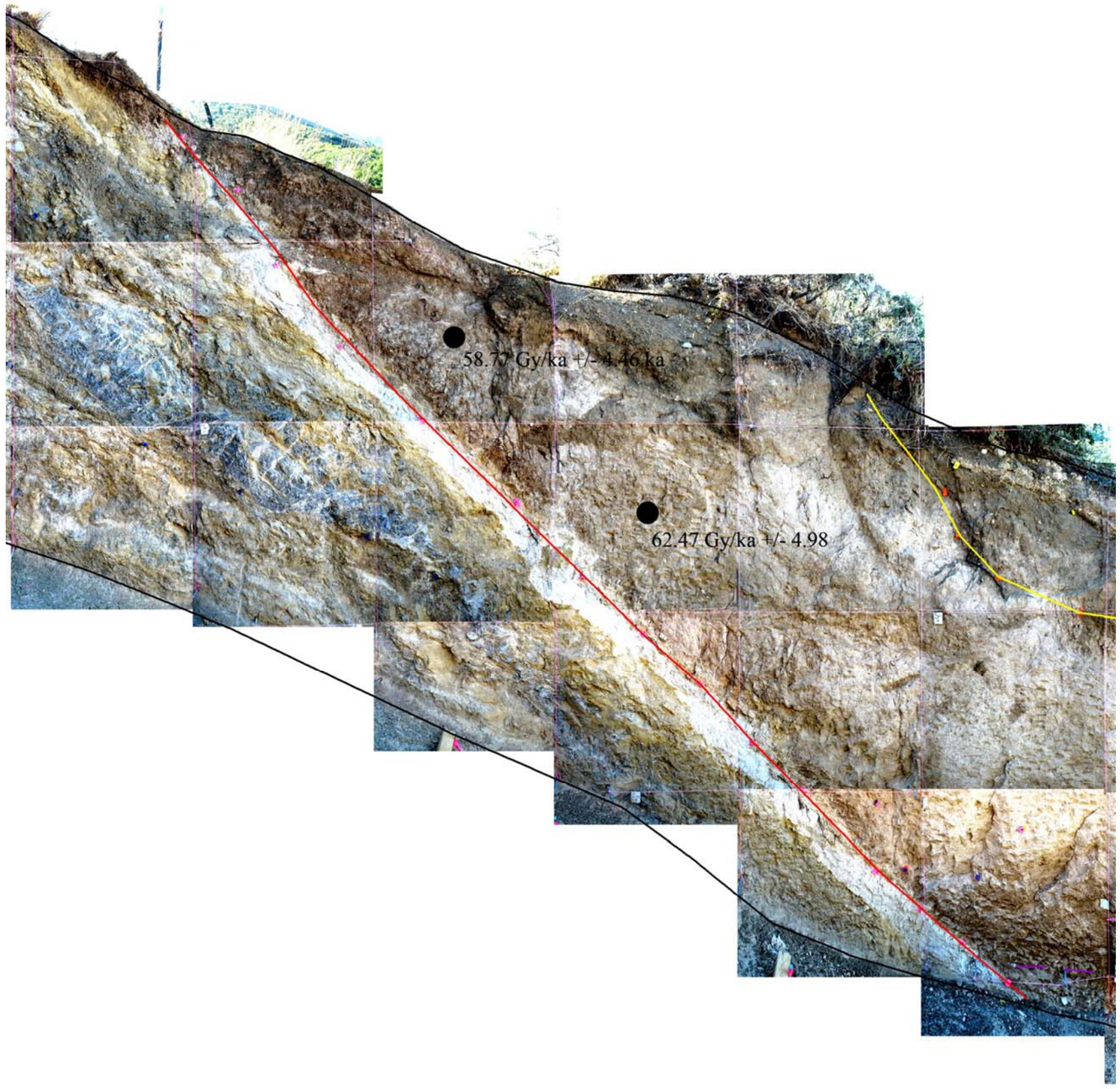


Fig. 19. Close-up of the main fault in the trench. The photo contrast has been greatly increased to highlight the complex the fault zone architecture. Labels at the two OSL samples incorrectly state units as “Gy/ka”; the correct units are “ka.”

6.4.4 Geochronology (see Table 1)

Two samples were dated by OSL from the upper part of the faulted hanging wall loess (unit Ql3) within about 0.5 m of the main fault plane. The upper sample dated at 58.8±4.5 ka and the lower sample at 62.5±5.0 ka.

6.4.5 Interpretation

The trench on the eastern (main) strand of the ECFZ exposes a normal fault separating Paleozoic dolostone and a ≥3 m thick Quaternary loess deposit dated at 59-63 ka in its upper part. However, there is no scarp-derived colluvial wedge deposit in the hanging wall adjacent to the fault. Instead, Quaternary loess of the hanging wall is cleanly truncated against Paleozoic bedrock all the way up to the base of a thin modern A horizon. Whatever colluvial wedge sediments were deposited on the hanging wall here have been eroded away subsequent to the latest movement on this fault strand. This geometry is the signature of a fault whose last movement considerably predates the ground surface developed above it.

Based on many trench exposures on the Wasatch and East Cache faults (see McCalpin, 2009, Chapter 3), all normal faults that have moved in the Holocene or late Pleistocene (Bonneville lake cycle) contain obvious, preserved colluvial wedges in the hanging wall adjacent to the fault. The absence of that geometry here indicates that the latest movement on this fault plane is older than the Bonneville lake cycle (i.e., older than the highstand at ca. 20 ka, and possibly older than the beginning of the cycle at ca. 35 ka). Such an old age is consistent with the deformation dated farther south on this same fault strand by McCalpin (1994) as older than 26 ka and younger than 46 ka. Along with the tectonic geomorphology (stream incision of the hanging wall, absence of Quaternary deposits on the hanging wall), the trench evidence suggests that the fault's vertical slip rate in the Quaternary has been less than the local stream incision rate.

Even though no young faulting was exposed in this trench, it is possible that faulting younger than the post-59- to -63 ka faulting on the main fault, might have occurred on faults beyond the western end of the trench. Specifically, we wondered whether younger faults might lie beneath the sharp slope break at the road, where GPR survey showed incoherent refections. However, the landowner did not give us permission to extend the trench across the road. Admittedly, there are no surface scarps or west-facing topographic anomalies downslope of our trench, which there should be if Holocene or late Pleistocene faulting had occurred at the slope break. So, until additional work is done, we must conclude that the Most Recent Event on the range-front strand is definitely younger than 59-63 ka, probably younger than 46 ka, and older than 26 ka.

7. CONCLUSIONS

Based on the four trenches dug in this study, the western fault strand of the ECFZ (Paradise fault) either has had no late Quaternary displacement or does not even exist; the central strand (McKenzie Flats fault) has not had any late Quaternary movement and may be a drape fold; and the eastern (range-front) strand has had one movement younger than 59-63 ka but older than the Bonneville lake cycle.

This lack of evidence for late Quaternary fault activity at our trench sites is strange, considering that the southern segment has the greatest cumulative Neogene throw among the three segments of the ECFZ (maximum of 7.8-8.1 km), compared to 4 km and 2.5 km on the central and northern segments, respectively (Evans and Oaks, 1996; Oaks et al., 2005). The

long-term vertical slip rate since the beginning of graben formation (Miocene, ca. 23 Ma) would thus be about 0.35 mm/yr.

Analysis of faceted spur sets (McCalpin, 1994) suggests that the vertical slip rate of the range-front faults strands over the Quaternary was roughly similar between the southern and central segments. However, the results of this study indicate that the late Quaternary slip rate on the southern segment (at least since the early?-to mid-Pleistocene age of the McKenzie Flat pediment) has been significantly lower than that of the central segment. For example, the central segment has experienced at least three surface-rupturing earthquakes in the past 15-20 ka (McCalpin, 1994), a time span in which there have not been any ruptures on the southern segment. On the southern segment the elapsed time since the MRE is at least 26 ka (30 ka if connected to the James Peak MRE rupture), and may be as much 46 ka, which is much longer than the elapsed time (4 ka) and recurrence interval (9-11 ka) of the central segment. Thus, it appears that the southern segment of the ECFZ has “slowed down” relative to the central segment in the Quaternary, and certainly since the mid-Quaternary, compared to the central segment. As a result of this slowdown, the hanging wall has not been a locus of deposition in the Quaternary, and instead has been incised by the Little Bear River and its tributaries.

7.1 Rupture Scenarios

The evidence from this study and from earlier studies shows that the southern segment did not rupture simultaneously with the central segment in the latest three large earthquakes (dated at 4 ka, 15 ka, and 20 ka in the central segment). Therefore, the southern segment does not typically link with the central segment during rupture. There are thus two likely rupture scenarios: (1) the southern segment ruptures by itself (rupture length of 22.1 km), or (2) the southern segment ruptures along with the James Peak fault (combined rupture length of 34 km). The latter scenario is permissible because the age range for the MRE on the southern segment and the James Peak fault overlaps. At this time we have insufficient data to know how often the southern segment ruptures by itself, versus how often its ruptures continue to the James Peak fault. In a logic tree analysis for the southern segment, each of these rupture scenarios should be weighted 50%.

7.2 Displacement per Event and Paleomagnitude

This study did not succeed in measuring any displacements on the southern segment attributable to an individual paleoearthquake. Neither the Western or Central Trenches exposed faults. In the Eastern Trench which did expose a fault, critical evidence such as the thickness of the MRE colluvial wedge had been eroded in the long time span since the MRE. Farther south a the East Fork, the canal cut exposures sketched by McCalpin (1994; Fig. 16 of this paper) cannot be used to get a meaningful estimate of displacement-per-event, because in the west exposure displacement could not be measured, and in the east exposure the net displacement across the small graben exposed was essentially zero. Therefore, it does not seem possible to use displacement to estimate magnitude of paleoearthquakes.

Paleomagnitudes can be estimated from the surface rupture lengths in the two rupture scenarios described above. A 22.1 km-long rupture on a normal fault correlates with a M6.6±0.3 earthquake, and a 34 km-long rupture correlates with a M6.9±0.3 earthquake (Wells and Coppersmith, 1994).

7.3 Recurrence Intervals

Because we dated only the MRE in a single trench (the Eastern Trench), and with a one-sided maximum age constraint, we have no field data from which to calculate recurrence interval. McCalpin (1994) made some crude estimates of recurrence by dividing fault scarp heights at the range front by the single-event displacements observed on the central segment (to dertived the number of faulting events), and then by further assuming an age range for the surfaces cut by the scarps. These highly uncertain estimates range from 7.5 ky to 143 ky, and are essentially useless for seismic hazard analysis.

7.4 Slip Rate

McCalpin (1994) crudely estimated the Quaternary slip rate based on the height of range-front fault scarps (10 m) and their inferred ages (0.15 to 1 Ma), at 0.010 to 0.067 mm/yr. It has been at most 46 ka since the MRE on the southern segment. If a surface-rupturing earthquake occurred tomorrow recurrence interval would equal 46 ka, and if the event had the same vertical displacement as events on the central segment (1.4 m), that would yield a closed-cycle slip rate of 0.03 mm/yr. This is a crude maximum estimate of slip rate, since the next event is unlikely to occur tomorrow, and thus the recurrence time will be greater than 46 ka, and the slip rate lower. Therefore the likely range of slip rates lies between 0.01 and 0.03 mm/yr.

7.5 Elapsed Time, and its Implications for Conditional Probability of the Next Surface Rupture

At first glance, the very low slip rates and the long recurrence times deduced for the southern segment seem to indicate that the segment poses much less hazard than the central segment. However, if we consider the longer history of the southern segment, and the recent behavior of the central segment, we see three lines of evidence that the seismic hazard may be higher, perhaps higher even than in the central segment.

First, the cumulative throw on the southern segment is much greater than on the other segments, yet in the mid-late Quaternary there has been very little activity on it, compared to other segments such as the central segment.

Second, the mid-late Quaternary slip rate of only 0.01 to 0.03 mm/yr is more than an order of magnitude less than the long-term (post-Miocene) slip rate of 0.35 mm/yr. From a purely empirical viewpoint, the only way that the southern segment could “catch up” to its long term slip rate, is to have displacement event(s) in the near future.

Third, the three late Quaternary displacements on the central segment have probably increased the Coulomb stress on the southern segment, thus “loading” it and advancing its time-to-failure.

The three lines of evidence above would not indicate a higher level of hazard, if the southern segment has experienced a long-term decrease in its slip in the Quaternary, as opposed to its slip style earlier Tertiary history. Such a fundamental change might, for example, involve transfer of the extension formerly accommodated by the southern segment to another segment along strike (such as the central segment), or to another fault perpendicular to strike (such as the West Cache fault). Evans and Oaks (1996) found subsurface evidence that the East Cache and West Cache faults had alternated in dominance during the Tertiary over periods lasting many millions of years. Thus, if the southern segment of the ECFZ is currently in a phase of non-dominance (submission?), then its low slip rate and lack of activity would not translate into a higher seismic hazard as suggested above.

Data from the southern segment of the West Cache fault zone (the Wellsville fault) indicate that it has been nearly as active in the late Quaternary as the central segment of the ECFZ, and much more active than the southern segemt of the ECFZ. Black et al. (2000) dated the MRE on the Wellsville fault at 4400-4800 cal yr BP and the PE at 15-25 ka. Both of these ruptures are younger than the MRE on the southern section of the ECFZ. In addition, they calculated a late Pleistocene slip rate of 0.13 mm/yr for the Wellsville fault, compared to the 0.01-0.03 mm/yr calculated by us for the southern segment of the ECFZ. Based on this comparison, it seems that the east-west extension across southern Cache Valley is now being accommodated mainly by the West Cache fault zone, rather than the East Cache fault zone. If that dominance continues in the current seismic cycle, then the seismic hazard of the southern segment of the ECFZ is much lower than that of either the central segment of the ECFZ, or the southern segment of the West Cache fault zone.

8. REFERENCES

Black, B.D. and Nelson, C.V., 2003, Surface fault rupture hazard analysis, proposed Bonneville Trail Estates subdivision, North Logan, UT: unpublished consulting report submitted to Cache-Landmark Engineering, Logan UT by Western GeoLogic, Salt Lake City, UT, Nov. 11, 2003, 67 p.

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

Evans, J.P., and Oaks, R.Q., Jr., 1996, Three-dimensional variations in extensional fault shape and basin form: The Cache Valley basin, eastern Basin and Range province, United States: Geological Society of America Bulletin, v. 108, no. 12, p. 1580-1593.

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

McCalpin, J., 1993, Neotectonics of the northeastern Basin and Range margin, western USA: Zeitschrift fur Geomorphologie, Supplement, v. 94, p. 137-157.

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

McCalpin, J.P. (ed.), (2009) Paleoseismology, 2nd Edition. Academic Press, 680 p.

Morrison, R.B., 1965, Quaternary geology of the Great Basin, in Wright, H.E. Jr and Frey, D.G. (eds.), The Quaternary of the United States: Princeton University Press, Princeton, NJ, p. 265-285.

Mullens, T.E. and Izett, G.A., (1963) Geology of the Paradise Quadrangle. U.S. Geological Survey Map GQ-185, scale 1:24,000.

Nelson, C., and Black, W., 2004, Surface rupture study, Bonneville Trails Subdivision Unpublished Technical Report, 22 p., 3 maps.

Oaks, R.Q., 1997, Subsurface Cenozoic deposits: Baseline for stratigraphic and structural interpretations of southern Cache Valley, Utah, with applications to groundwater in tuffaceous sediments of Tertiary age: unpublished consulting report, Dec. 1997, Utah State University.

Oaks, R.Q., Jr., Smith, K.A., Janecke, S.U., Perkins, M.E., and Nash, W.P., 1999, Stratigraphy and tectonics of Tertiary strata of southern Cache Valley, north-central Utah, in Spangler, L.E., and Allen, C.J., eds., Geology of northern Utah and vicinity: Utah Geological Association Publication 27, p. 71-110.

Oaks, R.Q., Janecke, S.U., Langenheim, V.E. and Kruger, J.M., 2005, Insights into geometry and evolution of extensional basins along the Wasatch fault and East and West Cache fault zones, Utah and Idaho, USA: Geol. Soc. Amer. Abstracts with Programs, 37(7): 497 (http://gsa.confex.com/gsa/2005AM/finalprogram/abstract 90595.htm)

Shroba, R.R., 1980, Influence of parent material, climate, and time on soils formed in Bonneville-age shoreline and younger deposits near Salt Lake City and Ogden, Utah: Geological Society of America, Abstracts with Programs, v.12, no. 6, p. 304.

Smith, K.A., (1997) Stratigraphy, Geochronology and Tectonics of the Salt Lake Formation (Tertiary) of Southern Cache Valley, Utah. Utah State University, unpublished M.S. thesis, 245 p.

Smith, R.B., and Arabasz, W.J., 1991, Seismicity of the Intermountain Seismic Belt, *in:* Slemmons, D.B., Engdahl, E.R., Zoback, M.D., and Blackwell, D.D., eds., *Neotectonics of North America*: Geological Society of America, Decade of North American Geology Map v. 1, p. 185-228.

Smith, R.B. and Sbar, M.L., 1974, Contemporary tectonics and seismicity of the western United States with emphasis on the Intermountain Seismic Belt: Geological Society of American Bulletin, v. 85, p. 1205-1218.

Utah Office of Planning and Budget, 2005, Office of Demographic and Economic Analysis, Report to the Governor, http://governor.utah.gov/dea/ERG2005.html

Williams, J.S., (1962) Lake Bonneville; Geology of southern Cache Valley, Utah: U.S. Geological Survey Professional Paper 257-C, p. 131-152

9. APPENDIX 1
DATABASE ENTRY FOR THE Southern section of the East Cache fault zone, Utah, from the U.S. Geological Survey's Quaternary Fault and Fold Database
(http://qfaults.cr.usgs.gov/faults/FMPro)

Complete Report for East Cache fault zone, southern section (Class A) No. 2352c

Brief Report || Partial Report

Compiled in cooperation with the Utah Geological Survey

citation for this record: Black, B.D., Hylland, M., Haller, K.M., and Hecker, S., compilers, 1999, Fault number 2352c, East Cache fault zone, southern section, in Quaternary fault and fold database of the United States, ver 1.0: U.S. Geological Survey Open-File Report 03-417, http://qfaults.cr.usgs.gov.

Synopsis:	**General:** Normal fault zone that separates Cache Valley from the Bear River Range to the east. The fault zone is at the boundary between the Basin and Range and the Middle Rocky Mountains physiographic provinces. The East Cache fault zone is one of several north-trending, northeast stepping, late Quaternary, normal faults that lie between the Wasatch fault zone in Utah and the Teton fault in Wyoming. **Sections:** This fault has 3 sections. Informally named sections defined here follow McCalpin (1987 #4999; 1994 #4414). McCalpin (1994 #4414) describes physiographic sections because the faulting history can not be constrained well enough to define seismogenic segments. The sections are differentiated based on fault zone complexity, tectonic geomorphology, and expression of surface fault scarps . Bailey (1927 #5186) eludes to the same sectioning of the fault based on gross differences in the range-front morphology. The central section of the fault is the most active in the latest Quaternary; the northern and southern sections are less active and show evidence of only middle to late Pleistocene activity. The morphology of faceted spurs along the range front suggests that the boundary between the northern and central sections has shifted southward several kilometers during the middle to late Quaternary, probably along with development of a younger, western fault strand in the northern section (McCalpin, 1994 #4414; 1989 #4999). Similarities in the structure of faceted spurs and the absence of a gravity-defined boundary between the central and southern sections suggest that they may have behaved as a single 44-km-long seismogenic section during much of the late Cenozoic. However, the last two events on the East Cache fault zone were limited to the 20-km-long central section, leading McCalpin (1994 #4414; 1989 #4999) to suggest that paleoearthquake magnitudes were in the

	in the range of 6.6 to 7.1. The south end of the southern section abuts the northeast-trending James Peak fault [2378].
	Name Comments: **General Name Comments:** Early workers in the area referred to this fault as the Bear River Range fault (Bailey, 1927 #5187; 1927 #5186) and Bear River fault (Peterson, 1936 #5184). More recent studies use the name East Cache fault or East Cache fault zone. Fault extends from east of Preston, Idaho, southward to its intersection with the James Peak fault [2378] southeast of Avon, Utah. **Section Name Comments:** Informal section names and are as defined by McCalpin (1994 #4414); this section extends from Blacksmith Fork Canyon southward to the James Peak fault (McCalpin, 1987 #4999; 1994 #4414). McCalpin (1987 #4999) also identified this as segment C; however, even in this paper he does not suggest that these are necessarily seismogenic segments. Oaks and others (1999 #5157) identify the western strand as the "Paradise fault" and the central strand as the "McKenzie Flat fault". **Number Comments:** Refers to fault number 11-3 (East Cache fault zone, southern segment) of Hecker (1993 #642).
State(s):	Utah
County(s):	Cache
AMS sheet(s):	Ogden view map
Physiographic province(s):	Basin and Range province
Geologic	Generally north-trending range-front normal fault along the western base of

setting:	the Bear River Range in eastern Cache Valley. The East Cache fault zone and opposing West Cache fault zone [2521] bound an intermontane graben forming Cache Valley (McCalpin, 1987 #4999). Faulting here probably had begun by at least late Eocene to early Oligocene (Brummer and Evans, 1989 #5185; Brummer and McCalpin, 1995 #4394). Oaks and others (1999 #5157) indicate that the vertical throw across the southern part of the East Cache fault zone is 7,750 m. Evans (1991 #4425) estimates net slip ranges from 2.7 km near the Idaho border to 8.1 km in southern Cache Valley; he indicates that in central Cache Valley, net slip is about 4.5-6.4 km. Brummer (1989 #5185) indicates that total net vertical offset is on the order of 2.7-3.0 km. Earlier estimates by Zoback (1983 #213) indicate that total late Cenozoic slip is 3.4-4.5 km. Faulting has resulted in a pronounced escarpment rising 1000 m above Cache Valley.
Reliability of location:	Poor. Compiled at 1:50,000 scale. *Comments:* Location of faults from 1:50,000 scale mapping of McCalpin (1989 #760). Poor designation is because the fault is poorly expressed; therefore, it is approximately located in original mapping.
Length (km):	This section is 22.1 km of a total fault length of 63.9 km. *Comments:*
Average strike:	N4°W (for section) versus N1°W (for whole fault)
Sense of movement:	Normal *Comments:*
Dip:	45-60°W *Comments:* We show that all of the strands dip to the west following the mapping of McCalpin (1989 #760). However Oaks and others (1999 #5157) indicate that the central strand is down to the east. Seismic reflection data indicate the fault dips 65-70° near the ground surface and shallows to 50° at depth (Evans, 1991 #4425). Additional interpretations of seismic reflection data indicate the fault dips at 60° near the surface, flattening at depth to 45-55° between 3.5 and 4.0 km (Smith and Bruhn, 1984 #4561), and probably cuts the Sevier-age Paris thrust (Evans and Oaks,

	1990 #4411).
Paleoseismology studies:	
Geomorphic expression:	McCalpin (1994 #4414) describes the fault as having three traces, similar to the northern section. However, along this part of the fault, the rangefront strand appears to be the most active as expressed in the low saddles that cross the heads of pre-Bonneville fans. The expression of faulting along the central and western strands is subtler and can be characterized as an alignment of low hills and stream channels. McCalpin (1992 #4423) documents the presence of a fault scarp near Paradise Dry Canyon that has a height of 15.8 m and a surface offset of 10 m. There are no fault scarps on latest Quaternary or younger deposits along this section. McCalpin (1992 #4423) does indicate however that observed displacement in young deposits are probably due to near surface deformation.
Age of faulted surficial deposits:	Most of the fault traces are poorly expressed along this section. Mapping by McCalpin (1989 #760) shows that the westernmost strand is generally buried, with a couple of scarps on Tertiary sedimentary rocks. The central strand has expression on Tertiary sediments and in middle Pleistocene alluvium. The eastern trace of the fault generally follows the bedrock-alluvium contact with discontinuous scarps on middle Pleistocene alluvium.
Year of historic deformation:	
Most recent prehistoric deformation:	Late Quaternary (<130 ka) *Comments:* McCalpin (1992 #4423) suggests that faulting occurred between 26 and 46 ka. However, and earlier report states the most recent event occurred between 25 and 44 ka based on constraining thermoluminescence ages (McCalpin, 1987 #4999). Using data from McCalpin and Forman (1991 #299), Mason (1992 #463) suggests the most recent event occurred 36±18 thousand years ago.
Recurrence interval:	15-30 k.y. (<150 ka - 1 Ma) *Comments:* McCalpin (1987 #4999; 1992 #4423) suggests a preferred recurrence interval for this section of 15-30 k.y. for the past 150 k.y. to 1 m.y. He bases this calculation on assuming that the 10 m of surface offset is

	the product of 0.5-1.5 m/event displacements. This yields 7-20 events since the deposition of the middle Pleistocene fan alluvium, which he assigns an age of 150 k.y.-1 m.y. The resulting recurrence interval is 7.5-143 k.y. Using data from McCalpin and Forman (1991 #299), Mason (1992 #463) suggests an average recurrence time of at least 35±17 k.y.
Slip-rate category:	Less than 0.2 mm/yr *Comments:* McCalpin (1987 #4999) indicates that the middle to late Quaternary slip rate is 0.07 mm/yr based on 10 m of offset of a pre-Bonneville surface. Longer-term slip rates are provided by Evans (1991 #4425). He indicates that post-17-Ma slip rates are considerably higher (0.47-0.8 mm/yr).
Compiled or modified by and affiliation:	Bill D. Black, Utah Geological Survey; Mike Hylland, Utah Geological Survey; Kathleen M. Haller, U.S. Geological Survey; Suzanne Hecker, U.S. Geological Survey, 1999
References:	#5186 Bailey, R.W., 1927, The Bear River Range fault, Utah: American Journal of Science, v. XIII, p. 496-502. #5187 Bailey, R.W., 1927, A contribution to the geology of the Bear River Range, Utah: Chicago, Illinois, University of Chicago, unpublished M.S. thesis, 63 p. #4394 Brummer, J., and McCalpin, J., 1995, Geologic map of the Richmond quadrangle, Cache County, Utah, and Franklin County, Idaho: Utah Geological Survey Miscellaneous Publication 95-3, 22 p. pamphlet, 2 sheets, scale 1:24,000. #5185 Brummer, J.E., and Evans, J.P., 1989, Evidence for the onset of extensional tectonics, western Bear River Range, Utah: Geological Society of America Abstracts with Programs, v. 21, no. 5, p. 60. #4425 Evans, J.P., 1991, Structural setting of seismicity in northern Utah: Utah Geological Survey Contract Report 91-15, 37 p. #4411 Evans, J.P., and Oaks, R.Q., Jr., 1990, Geometry of Tertiary extension in the northeastern Basin-and-Range Province superimposed on the Sevier fold and thrust belt, Utah, Idaho, and Wyoming: Geological Society of America Abstracts with Programs, v. 22, no. 6, p. 10. #642 Hecker, S., 1993, Quaternary tectonics of Utah with emphasis on

earthquake-hazard characterization: Utah Geological Survey Bulletin 127, 157 p., 6 pls., scale 1:500,000.

#463 Mason, D.B., 1992, Earthquake magnitude potential of active faults in the Intermountain seismic belt from surface parameter scaling: Salt Lake City, University of Utah, unpublished M.S. thesis, 110 p.

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

#299 McCalpin, J., and Forman, S.L., 1991, Late Quaternary faulting and thermoluminescence dating of the East Cache fault zone, north-central Utah: Bulletin of the Seismological Society of America, v. 81, p. 139-161.

#4999 McCalpin, J.P., 1987, Late Quaternary tectonics and earthquake hazard in Cache Valley, Utah: Technical report to U.S. Geological Survey, Reston, Virginia, under Contract 14-08-0001-G1091, July 1987, 187 p., 2 pls.

#4423 McCalpin, J.P., 1992, Paleoseismismicity of the northeastern Basin and Range margin, western U.S.A., and its implications for earthquake potential [abs.], in Geologic reason —A basis for decisions affecting society: American Institute of Professional Geologists, Symposium and Annual Meeting, Lake Tahoe, Nevada, September 27-30, 1992, Program with Abstracts, p. 20.

#4414 McCalpin, J.P., 1994, Neotectonic deformation along the East Cache fault zone, Cache County, Utah: Utah Geological Survey Special Study 83, 37 p.

#5157 Oaks, R.Q., Jr., Smith, K.A., Janecke, S.U., Perkins, M.E., and Nash, W.P., 1999, Stratigraphy and tectonics of Tertiary strata of southern Cache Valley, north-central Utah, in Spangler, L.E., and Allen, C.J., eds., Geology of northern Utah and vicinity: Utah Geological Association Publication 27, p. 71-110.

#5184 Peterson, V.E., 1936, The geology of a part of the Bear River Range and some relationships that it bears with the rest of the range: Logan, Utah State Agricultural College, unpublished M.S. thesis, 71 p.

#4561 Smith, R.B., and Bruhn, R.L., 1984, Intraplate extensional tectonics of the western U.S. Cordillera-Inferences on structural style from seismic-reflection data, regional tectonics and thermal-mechanical models of brittle-ductile deformation: Journal of Geophysical Research, v. 89, no. B7, p.

	5733-5762. #213 Zoback, M.L., 1983, Structure and Cenozoic tectonism along the Wasatch fault zone, Utah, in Miller, D.M., Todd, V.R., and Howard, K.A., eds., Tectonic and stratigraphic studies in the eastern Great Basin: Geological Society of America Memoir 157, p. 3-27.

APPENDIX 2

OSL Ages of Samples from Trenches on the McKenzie Flat fault, eastern trench (USU-374) and the range-front strand of the East Cache fault zone (ECF-Ward 1 and 2)

USU LUMINESCENCE LABORATORY 1770 north research park way, suite 123, north logan, ut, 84341

Final OSL Age Report

Project: **East Cache Fault**
Scientists: **Stephanie Davies, Jim Evans, USU**
Report Date: **10 August 2009**
Report created by: Tammy Rittenour

Dose rate information

USU #	Sample #	depth (m)	grain size (µm)	H_2O%*	U (ppm)	Th (ppm)	K_2O%	Rb_2O%	cosmic (Gy/ka)
USU-374	SLT-1	1.7	75-150	14.3	2.6±0.2	13.3±1.2	1.77±0.04	94.2±3.8	0.16±0.02
USU-478	ECF-Ward 1	0.9	63-125	1.8	2.3±0.2	7.9±0.7	1.51±0.04	67.8±2.7	026±0.03
USU-479	ECF-Ward 2	1.3	63-150	2.0	2.4±0.2	7.3±0.7	1.49±0.04	65.4±2.6	0.25±0.02

* assume 3±3%wt H2O is representative of burial history for samples USU-478 and USU-479

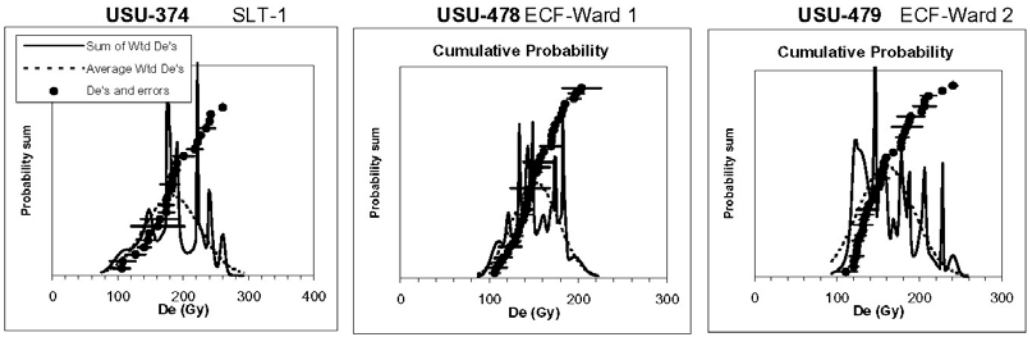
OSL Age information

USU #	Sample #	location	# aliquots*	Equivalent dose (De), Gy	Dose Rate (Gy/ka)	OSL Age (ka)
USU-374	Central Fault strand		**24** (58)	180.47 ± 11.82	2.74 ± 0.14	**65.95 ± 6.32**
USU-478	Eastern strand near Avon, upper		**36** (55)	150.29 ± 5.89	2.56 ± 0.12	**58.77 ± 4.46**
USU-479	Eastern strand near Avon, lower		**37** (53)	156.51 ± 7.24	2.51 ± 0.11	**62.47 ± 4.98**

* Number of aliquots used for age calculation, number of aliquots measured in parentheses

Equivalent Dose (De) calculated using the central age model of Galbraith et al (1999)
Error on De is 1 standard deviation
Error on age includes random and systematic errors caluclated in quadrature

Equivalent dose distributions: Probability Density Functions



USU LUMINESCENCE LABORATORY 1770 north research park way, suite 123, north logan, ut, 84341

USU Lab procedures for sample processing and age analysis

All samples were opened and processed under dim amber safelight conditions within the lab. Sample processing follows standard procedures involving sieving, gravity separation and acid treatments with HCl and HF to isolate the quartz component of a narrow grain-size range, usually 90-150 µm. The purity of the samples is checked by measurement with infra-red stimulation to detect the presence of feldspar. Sample processing procedures follow those outlined in Aitken (1998) and described in Rittenour et al. (2003, 2005).

The USU Luminescence Lab follows the latest single-aliquot regenerative-dose (SAR) procedures for dating quartz sand (Murray and Wintle, 2000, 2003; Wintle and Murray, 2006). The SAR protocol includes tests for sensitivity correction and brackets the equivalent dose (De) the sample received during burial by irradiating the sample at five different doses (below, at, and above the De, plus a zero dose and a repeated dose to check for recuperation of the signal and sensitivity correction). The resultant data are fit with a saturating exponential curve from which the De is determined. The reported De is based on the mean and standard deviation from the measurement of at least 20 aliquots of sand mounted on a 2 mm diameter area of the measurement disks.

Dose-rate measurements were determined by chemical analysis of the U, Th, K and Rb content using ICP-MS and ICP-AES techniques. The contribution of cosmic radiation to the dose rate was calculated using sample depth, elevation, and latitude/longitude following Prescott and Hutton (1994). Dose rates are calculated based on water content, sediment chemistry, and cosmic contribution (Aitken, 1998).

Under the collaborative agreement to analyze samples at the USU Luminescence Lab, it is expected that Dr. Rittenour is included as a co-author on all resultant publications. Please contact me for additional information when you plan your publication.

Dr Tammy Rittenour

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References cited

Aitken, M.J., 1998. An Introduction to Optical Dating. Oxford Science Publications, 267pp.

Galbraith, R.F., Roberts, R.G., Laslett, G.M., Yoshida, H., Oleey, J.M., 1999. Optical dating of single and multiple grains of quartz from Jinmium Rock Shelter, northern Australia: Part I, experimental design and statistical models. Archaeometry 41, 339-364.

Goble, R.J. and Rittenour, T.M., 2006, A linear modulation OSL study of the unstable ultrafast component in samples from glacial lake Hitchcock, Massachusetts, USA: Ancient TL 24, 37-46.

Prescott, J. R., Hutton, J.T., 1994. Cosmic ray contributions to dose rates for luminescence and ESR dating: Radiation Measurements 23, 497-500.

Murray, A.S., Wintle, A.G., 2000. Luminescence dating of quartz using an improved single aliquot regenerative-dose protocol. Radiation Measurements 32, 57-73.

Murray, A.S., Wintle, A.G., 2003. The single aliquot regenerative dose protocol: potential for improvements in reliability. Radiation Measurements 37, 377-381.

Olley, J.M., Pietsch, T., Roberts, R.G., 2004. Optical dating of Holocene sediments from a variety of geomorphic settings using single grains of quartz: Geomorphology 60, 337-358.

Rittenour, T.M., Goble, R.J., Blum, M.D., 2003, An Optical Age Chronology of Fluvial Deposits in the Northern Lower Mississippi Valley: Quaternary Science Reviews, v. 22, p. 1105-1110.

Rittenour, T.M., Goble, R.J., Blum, M.D., 2005, Development of an OSL chronology for late Pleistocene channel belts in the lower Mississippi valley: Quaternary Science Reviews, v.24, p.2539-2554.

Rittenour, T.M. 2008. Luminescence dating of fluvial deposits: applications to geomorphic, palaeoseismic and archaeological research. Boreas, 37, 613-635.

Wintle, A.G. Murray, A.S., 2006, A review of quartz optically stimulated luminescence characteristics and their relevance in single-aliquot regenerative protocols: Radiation Measurements, v. 41, p. 369-391.

APPENDIX 3
McCalpin's Review of the Trenches on the Western and Central Fault Strands

NEHRP East Cache Fault Trenching Project
Status Summary, 13-NOV-2007; by J. McCalpin

WESTERN STRAND:
The main trench is about 160 ft long and the smaller western pothole trench is about 10 feet long. Both show Tsl bedrock at depths of 3-5 feet, all beds dipping east at 15-25 degrees, overlain by Bonneville beach gravels, and then by some type of bouldery debris flow deposit. Walls have been cleaned, but no contacts were painted.

On 12-NOV Stephanie and I photographed the western half of the main trench wall, in order to start the photomosaic logging process. These photos will evidently be sufficient to log on, without painting the contacts, which are rather obvious on the wall.

TO DO:
1—Stephanie finish photographing the south wall of the main trench, in 1 m-wide panels, and clean and photograph the south wall of the pothole trench.
2—Stephanie processes the individual 1 m-wide photos by increasing the contrast, removing the keystoning, and somehow stretching the images vertically (non-linear stretch, or rubber-sheeting) to correct for the scale differences between the bottom and top of each image (photos had to be taken from the ground surface outside the trench, to the optical axis was highly oblique to the photographed trench wall). Once this is done, mosaic the photos.
3—Print the mosaic so a hard copy can be taken into the trench for defining which contacts to map and how to number/label them. One easy way to do this is to print the mosaic in sections on 11x17 paper, at a scale of 1"=0.5m (that fits about 8 m [25 ft] of trench wall on a single page, and the log is about 4" high on the paper). For a 160 ft-long trench, that would take 7 sheets at that scale to cover the entire trench. Mark the contacts to be mapped and the unit labels directly on the printouts. Write the unit descriptions for your defined mapping units while in the trench. Take whatever samples you want from the trench walls (dating, grain size, geochem, paleomag, etc.) and mark their locations on the printouts. Mark on the printouts the location of the GPR anomaly stakes on the ground just south of the trench.
DECISION: this one-time exposure of soft Tsl is an opportunity to study part of the Formation that is rarely exposed naturally. Do you want to sample each subunit of Tsl in case somebody wants to do a non-neotectonic type of study on it (sedimentology, etc.)?
4—Take the annotated printouts back to the office and transfer the contacts, unit labels, and all other annotations to the digital photomosaic. Make the final trench log drawing complete with title, explanation of map units, like a USGS published trench log. **This is the type of log to give to reviewers when they show up to review the trench.**

5—Once the western trench has been reviewed, it can be backfilled and reclaimed, per requirements of the landowner.
6—MAJOR DECISION: because no fault was found, the western strand is going to be removed from the geologic maps (and Quaternary fault databases), unless a fault can be found by digging additional trenches here. We already trenched the primary topographic anomaly, so the only other place to trench is EAST of the main trench, just in case our main trench started just west of the fault. However, this is unlikely. Because if there was a Quaternary fault here it would have to

displace Tsl downward on the west side, and our main trench shows Tsl only 3-5 feet below surface, so it doesn't look to be downdropped. Still, before 'killing" this fault strand off entirely, we might ask the landowner if we could dig a smaller trench that extends east of the main trench for about 50 feet (it would also have to be south of the main trench, to avoid intersecting the canal), AFTER we had backfilled and reclaimed the main trench and pothole. The eastern extension trench would have to slightly overlap the eastern end of the main trench in the E-W direction, so that no N-trending fault could snake between them undetected. ADVANTAGES OF THIS TRENCH: (1) it gives us a firmer justification for killing this fault strand as a Quaternary fault, (2) it will expose another 50 ft of Tsl, if anyone wants to study that stratigraphic sequence.

CENTRAL STRAND:
We started this trench quite far up the slope, it order to get about 50 ft upslope of the GPR anomaly A2 and its associated topographic break. We ended the trench at the upper of 2 N-trending barbed wire fences. No fault was encountered. Instead, Tsl bedrock is exposed from 2-5 ft below the surface, and it all dips east at 20-30 degrees. The bedrock is mainly gravelly facies, rather than the softer tuffaceous facies exposed in the Western Trench. Overlying the Tsl are an older slope colluvium overprinted with a strong B-horizon paleosol (this paleosol penetrates into the upper part of Tsl also), and an overlying 1 ft-thick younger slope colluvium that carries an A/AB soil (post-Bonneville?). As of 12-NOV, about half of this wall has been cleaned well enough to log on, and half of the most obvious contacts have been painted.
TO DO:
1—finish cleaning the wall well enough to log on; finish spray painting the stratigraphic contacts in the Tsl, and in the colluviums. Note: THE TRENCH CLEANERS HAVE NOT SHOWN UP AFTER THE FIRST DAY. SUGGEST YOU REPLACE THEM WITH A LANDSCAPE CREW WHO WILL ACTUALLY SHOW UP FOR WORK.
2—after defining and painting all STRATIGRAPHIC contacts, subdivide the B-horizon paleosol into 3 components horizons (upper big red peds= B1; middle smaller red-brown peds= B2; lower red-brown stained horizon with poor to no peds= B3). This can be done using a single paint color, to distinguish these contacts from the stratigraphic contacts.
3—Photograph and mosaic the wall, as described previously. Make the log.
4—When the log is finished, get the reviewer out to the trench.
5—The day after the review, bring in a trackhoe to backfill this upper trench. Have the trackhoe compact the dirt with his bucket as he backfills. When he is finished backfilling (and assuming you have landowner permission), continue to trench downslope, starting just east of the upper fence. This will leave a gap of about 20 feet between the 2 trenches, but there are no GPR anomalies there, so I don't think we'll miss a structure.
5—Continue the trench downslope towards the lower fence, which is nearly in the low point of the saddle. If a fault exists along the central strand, it should be exposed by this lower trench. BASED ON THE UPPER TRENCH, THE COLLUVIUM IN THIS LOWER TRENCH WILL BE MORE THAN 5 FT THICK. THEREFORE, TO KEEP THE TOP OF TSL EXPOSED IN THE TRENCH, AND TO DETECT ANY POST-TSL FAULTING, THIS LOWER TRENCH NEEDS TO BE A BENCHED DESIGN, WITH 2 5-FT HIGH WALLS ON EACH SIDE. This design will require a lot of wall cleaning.

APPENDIX 4

Article from the Logan Herald-Journal Describing This Study

The Herald Journal

Vol. 99 No. 205 Wednesday, July 23, 2008 Bridgerland's Daily Newspaper Logan, Utah $0.50

— WEDNESDAY —

JAYCEE AND JAZZ
Carroll scores 22 for New Jersey at RMR
— B1

DIGITAL MEMORIES
More people go online for scrapbook designs
— C1

Weather

High: 90
Low: 55
Mostly sunny
- Page A10

Update

People

Bale accused of assaulting mother, sister

LONDON (AP) — Batman star Christian Bale was arrested Tuesday over allegations of assaulting his mother and sister, police and British media said.

The 34-year-old actor spent four hours at a London police station before being released on bail.

Bale

British media had reported that Bale's mother and sister complained he had assaulted them at the Dorchester Hotel in London on Sunday night, a day before the European premiere of his latest film, "The Dark Knight."

The Sun newspaper said police did not question the actor Monday because they did not want to interfere with the premiere of the movie.

Asked Tuesday whether Bale had been arrested, a London police spokesman did not refer to him by name but said: "A 34-year-old man attended a central London police station this morning by appointment and was arrested in connection with an allegation of assault."

The spokesman spoke on condition of anonymity because force policy did not authorize him to be identified. British

See BALE on A10

Quick read

Definition of the Week

A closer look at words in the news

bias *n.* **1** a line, cut or sewn diagonally across the weave of cloth, as in making seams, binding tape, etc. **2** a mental leaning or inclination; partiality; bent **3** *Lawn Bowling a)* the bilge in the side of the ball (the *bowl*) that causes it to roll in a curve *b)* this curve or tendency to curve *c)* the force causing this **4** *Radio* the fixed voltage applied to an electrode circuit to control the mode of operation, usually measured with the cathode voltage as reference **5** *Statistics* any systematic error contributing to the difference between statistical values in a population and a sample drawn from it

— Webster's New World Dictionary Third College Edition

Cache 911 Valley

Today's headlines

• Wandering child
— See A10

Index

Classifieds.....C6 Obituaries.....A6
Comics.....C4 Opinion.....A4
Movies.....C2 Sports.....B1
TV.....C12

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BRHD going to 4-day workweek

By Charles Geraci
staff writer

The Bear River Health Department will follow the state's lead and move to a four-day workweek early next month.

On Monday, the Board of Health approved the new schedule for a one-year trial period.

Roughly 17,000 state employees will start working Monday through Thursday on Aug. 4 as part of Utah Gov. Jon Huntsman Jr.'s plan to cut energy costs and commuter expenses for employees.

Lloyd Berentzen, the Health Department's executive director/health officer, noted that the change will not affect providing essential public health services or emergency response.

"There are certain things that we still have to do," Berentzen said. "We've got to do HAZMAT responses. Let's say we have somebody who may be potentially suicidal — we've got to respond."

While the department's two buildings in Cache County will be closed to the public on Fridays, Berentzen said they could still be used on an "as needed basis."

In general, the department will not be providing immunization services, clinics for sexually transmitted diseases or issuing birth and death certificates, for example.

Berentzen said the agency relies on several state departments — such as the Utah Department of Health and the Department of Human Services — for support services during the week.

"All of their consultation and general support is now not available (on Fridays)," he said. "The governor's direction in doing this has the greatest impact on our decision to follow."

The department's extended hours will be from 7 a.m. to 6 p.m. Monday through Thursday, beginning Aug. 4 when the state makes the transition.

"Our hope is that people will take advantage and that it will be a convenience as they now have these extended hours," Berentzen said.

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Valley science

USU digging for clues

Meagan M. Reid/Herald Journal

Dr. Tammy Rittenour, center, and fellow geologists gather inside the East Cache Fault trench near Avon on Monday.

Geologists: Evidence along East Cache Fault points to inactivity

By Kim Burgess
staff writer

After examining a deep trench along the East Cache Fault, Utah State University geologists believe they have uncovered some good news.

So far, the research near Avon has not turned up any evidence of recent earthquakes along this section of the fault.

While more tests need to be done, USU geology master's student Stephanie Davi doesn't imagine that any tremblers happened here in the last 10,000 years — the cut-off point for an "active" fault. Davi is leading the investigation, which is funded by a grant from the federal National Earthquake Hazards Reduction Program.

"I'm just not seeing anything that young," Davi said, pointing to rock layers revealed along the side of the trench's 9-foot walls. "If there is something that is less than 10,000, it sure isn't expressed. ... So I'm thinking it may not be anything that recent. That's where I'm leaning."

► Cache Valley fault map — Page A10

USU geology associate professor Susanne Janecke agreed with the assessment and explained that, if it is correct, there is a smaller chance of a "large, future damaging earthquake" in the southern part of Cache Valley.

"The (earthquake danger) is possibly significantly less than we anticipated (near Avon)," Janecke said.

An inactive fault would simplify the area's development rules, according to Davi's advisor, geology professor Jim

See FAULT on A10

Hurricane Dolly headed for land

McALLEN, Texas (AP) — Dolly spun into a hurricane Tuesday, heading toward the U.S.-Mexico border and the heavily populated Rio Grande Valley, where officials feared heavy rains could cause massive flooding and levee breaks.

Dolly was upgraded from a tropical storm Tuesday afternoon with sustained winds near 75 mph, and some strengthening of the Category 1 storm was forecast before landfall Wednesday. At 8 p.m. EDT, the storm's center was about 130 miles east-southeast of Brownsville, moving northwest at about 11 mph.

A hurricane warning is in effect for the coast of Texas from Brownsville to Corpus Christi and in Mexico from Rio San Fernando northward.

In Mexico, Tamaulipas Gov. Eugenio Hernandez said officials planned to evacuate 23,000 people to government shelters in Matamoros, Soto La Marina and San Fernando.

Texas officials urged residents to move away from the Rio Grande levees because if Dolly continues to follow the same path as 1967's Hurricane Beulah, "the levees are not going to hold that much water," said

See DOLLY on A10

AP photo

Mike Pittman, right, and his son, Tyler, 7, wait as their Hurricane Dolly T-shirts are made at a shop Tuesday in South Padre Island, Texas.

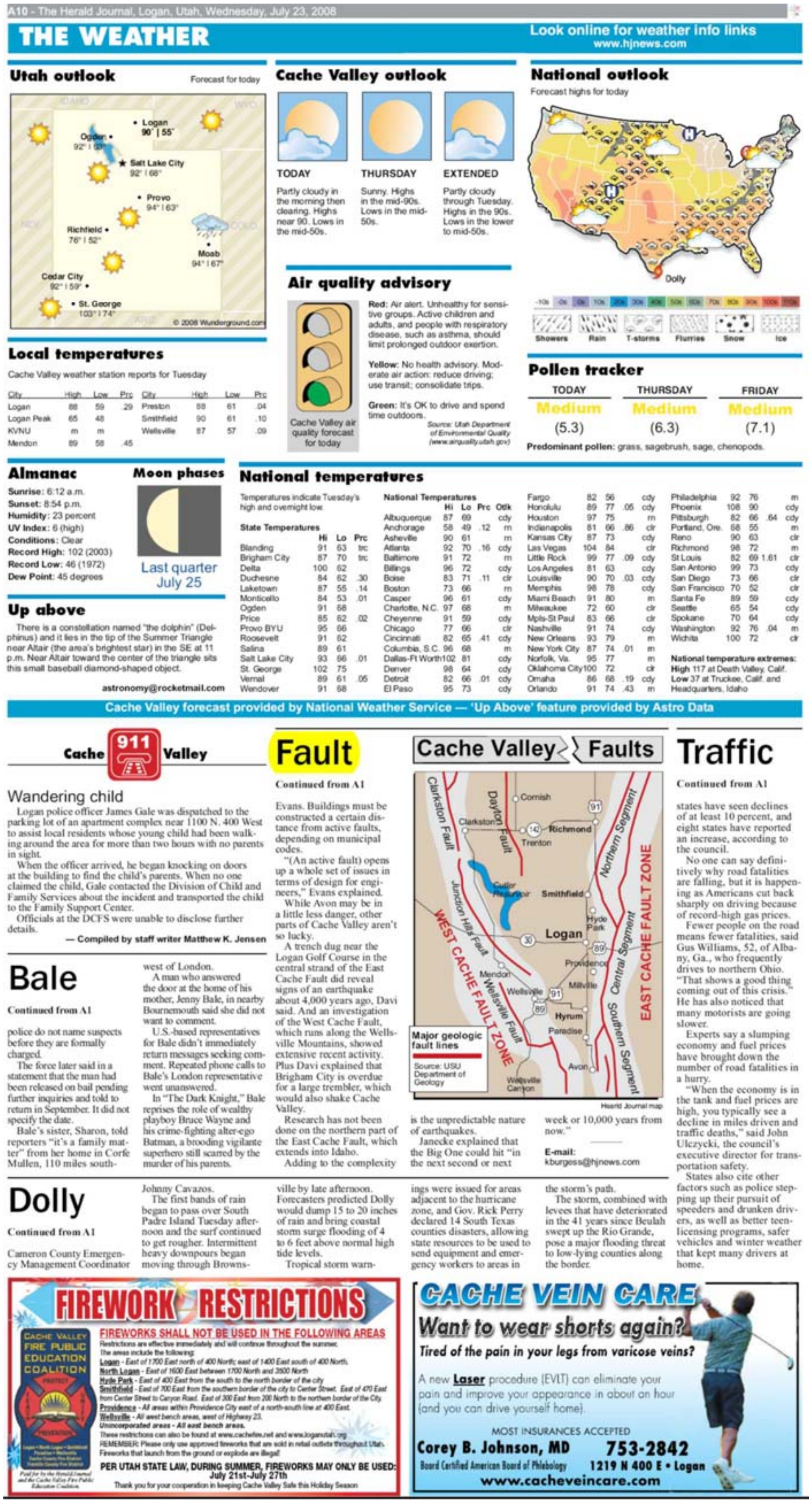
Traffic deaths drop as price of gas climbs

COLUMBUS, Ohio (AP) — Rising prices at the gas pump appear to be having at least one positive effect: Traffic deaths around the country are plummeting, just as they did during the Arab oil embargo three decades ago.

Researchers with the National Safety Council report a 9 percent drop in motor vehicle deaths overall through May compared with the first five months of 2007, including a drop of 18 percent in March and 14 percent in April.

Preliminary figures obtained by The Associated Press show that some states have reported declines of 20 percent or more. Thirty-one

See TRAFFIC on A10



A10 - The Herald Journal, Logan, Utah, Wednesday, July 23, 2008

THE WEATHER

Look online for weather info links
www.hjnews.com

Utah outlook

Forecast for today

Cache Valley outlook

TODAY
Partly cloudy in the morning then clearing. Highs near 90. Lows in the mid-50s.

THURSDAY
Sunny. Highs in the mid-90s. Lows in the mid-50s.

EXTENDED
Partly cloudy through Tuesday. Highs in the 90s. Lows in the lower to mid-50s.

National outlook

Forecast highs for today

Local temperatures

Cache Valley weather station reports for Tuesday

City	High	Low	Prc	City	High	Low	Prc
Logan	88	59	.29	Preston	88	61	.04
Logan Peak	65	48		Smithfield	90	61	.10
KVNU	m	m		Wellsville	87	57	.09
Mendon	89	58	.45				

Air quality advisory

Red: Air alert. Unhealthy for sensitive groups. Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.

Yellow: No health advisory. Moderate air action: reduce driving; use transit; consolidate trips.

Green: It's OK to drive and spend time outdoors.

Cache Valley air quality forecast for today

Source: Utah Department of Environmental Quality (www.airquality.utah.gov)

Pollen tracker

TODAY	THURSDAY	FRIDAY
Medium	Medium	Medium
(5.3)	(6.3)	(7.1)

Predominant pollen: grass, sagebrush, sage, chenopods.

Almanac

Sunrise: 6:12 a.m.
Sunset: 8:54 p.m.
Humidity: 23 percent
UV Index: 6 (high)
Conditions: Clear
Record High: 102 (2003)
Record Low: 46 (1972)
Dew Point: 45 degrees

Moon phases

Last quarter
July 25

Up above

There is a constellation named "the dolphin" (Delphinus) and it lies in the tip of the Summer Triangle near Altair (the area's brightest star) in the SE at 11 p.m. Near Altair toward the center of the triangle sits this small baseball diamond-shaped object.

astronomy@rocketmail.com

National temperatures

Temperatures indicate Tuesday's high and overnight low.

State Temperatures

	Hi	Lo	Prc
Blanding	91	63	trc
Brigham City	87	70	trc
Delta	100	62	
Duchesne	84	62	.30
Laketown	87	55	.14
Monticello	84	53	.01
Ogden	91	68	
Price	85	62	.02
Provo BYU	95	66	
Roosevelt	91	62	
Salina	89	61	
Salt Lake City	93	66	.01
St. George	102	75	
Vernal	89	61	.05
Wendover	91	68	

National Temperatures

	Hi	Lo	Prc	Otlk
Albuquerque	87	69		cdy
Anchorage	58	49	.12	m
Asheville	90	61		m
Atlanta	92	70	.16	cdy
Baltimore	91	72		m
Billings	96	72		cdy
Boise	83	71	.11	clr
Boston	73	66		m
Casper	96	61		cdy
Charlotte, N.C.	97	68		m
Cheyenne	91	59		cdy
Chicago	77	66		clr
Cincinnati	82	65	.41	cdy
Columbia, S.C.	96	68		m
Dallas-Ft Worth	102	81		cdy
Denver	98	64		cdy
Detroit	82	66	.01	cdy
El Paso	95	73		cdy
Fargo	82	56		cdy
Honolulu	89	77	.05	cdy
Houston	97	75		m
Indianapolis	81	66	.86	clr
Kansas City	87	73		cdy
Las Vegas	104	84		clr
Little Rock	99	77	.09	cdy
Los Angeles	81	63		cdy
Louisville	90	70	.03	cdy
Memphis	98	78		cdy
Miami Beach	91	80		m
Milwaukee	72	60		clr
Mpls-St Paul	83	66		clr
Nashville	91	74		cdy
New Orleans	93	79		m
New York City	87	74	.01	m
Norfolk, Va.	95	77		m
Oklahoma City	100	72		clr
Omaha	86	68	.19	cdy
Orlando	91	74	.43	m
Philadelphia	92	76		m
Phoenix	108	90		cdy
Pittsburgh	82	66	.64	cdy
Portland, Ore.	68	55		m
Reno	90	63		clr
Richmond	98	72		m
St Louis	82	69	1.61	clr
San Antonio	99	73		cdy
San Diego	73	66		clr
San Francisco	70	52		clr
Santa Fe	89	59		cdy
Seattle	65	54		cdy
Spokane	70	64		cdy
Washington	92	76	.04	m
Wichita	100	72		clr

National temperature extremes:
High 117 at Death Valley, Calif.
Low 37 at Truckee, Calif. and Headquarters, Idaho

Cache Valley forecast provided by National Weather Service — 'Up Above' feature provided by Astro Data

Cache 911 Valley

Wandering child

Logan police officer James Gale was dispatched to the parking lot of an apartment complex near 1100 N. 400 West to assist local residents whose young child had been walking around the area for more than two hours with no parents in sight.

When the officer arrived, he began knocking on doors at the building to find the child's parents. When no one claimed the child, Gale contacted the Division of Child and Family Services about the incident and transported the child to the Family Support Center.

Officials at the DCFS were unable to disclose further details.

— Compiled by staff writer Matthew K. Jensen

Bale

Continued from A1

police do not name suspects before they are formally charged.

The force later said in a statement that the man had been released on bail pending further inquiries and told to return in September. It did not specify the date.

Bale's sister, Sharon, told reporters "it's a family matter" from her home in Corfe Mullen, 110 miles south-west of London.

A man who answered the door at the home of his mother, Jenny Bale, in nearby Bournemouth said she did not want to comment.

U.S.-based representatives for Bale didn't immediately return messages seeking comment. Repeated phone calls to Bale's London representative went unanswered.

In "The Dark Knight," Bale reprises the role of wealthy playboy Bruce Wayne and his crime-fighting alter-ego Batman, a brooding vigilante superhero still scarred by the murder of his parents.

Fault

Continued from A1

Evans. Buildings must be constructed a certain distance from active faults, depending on municipal codes.

"(An active fault) opens up a whole set of issues in terms of design for engineers," Evans explained.

While Avon may be in a little less danger, other parts of Cache Valley aren't so lucky.

A trench dug near the Logan Golf Course in the central strand of the East Cache Fault did reveal signs of an earthquake about 4,000 years ago, Davi said. And an investigation of the West Cache Fault, which runs along the Wellsville Mountains, showed extensive recent activity. Plus Davi explained that Brigham City is overdue for a large trembler, which would also shake Cache Valley.

Research has not been done on the northern part of the East Cache Fault, which extends into Idaho.

Adding to the complexity is the unpredictable nature of earthquakes.

Janecke explained that the Big One could hit "in the next second or next week or 10,000 years from now."

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Cache Valley Faults

Traffic

Continued from A1

states have seen declines of at least 10 percent, and eight states have reported an increase, according to the council.

No one can say definitively why road fatalities are falling, but it is happening as Americans cut back sharply on driving because of record-high gas prices.

Fewer people on the road means fewer fatalities, said Gus Williams, 52, of Albany, Ga., who frequently drives to northern Ohio. "That shows a good thing coming out of this crisis." He has also noticed that many motorists are going slower.

Experts say a slumping economy and fuel prices have brought down the number of road fatalities in a hurry.

"When the economy is in the tank and fuel prices are high, you typically see a decline in miles driven and traffic deaths," said John Ulczycki, the council's executive director for transportation safety.

States also cite other factors such as police stepping up their pursuit of speeders and drunken drivers, as well as better teen-licensing programs, safer vehicles and winter weather that kept many drivers at home.

Dolly

Continued from A1

Cameron County Emergency Management Coordinator Johnny Cavazos.

The first bands of rain began to pass over South Padre Island Tuesday afternoon and the surf continued to get rougher. Intermittent heavy downpours began moving through Brownsville by late afternoon.

Forecasters predicted Dolly would dump 15 to 20 inches of rain and bring coastal storm surge flooding of 4 to 6 feet above normal high tide levels.

Tropical storm warnings were issued for areas adjacent to the hurricane zone, and Gov. Rick Perry declared 14 South Texas counties disasters, allowing state resources to be used to send equipment and emergency workers to areas in the storm's path.

The storm, combined with levees that have deteriorated in the 41 years since Beulah swept up the Rio Grande, pose a major flooding threat to low-lying counties along the border.

FIREWORK RESTRICTIONS

CACHE VALLEY FIRE PUBLIC EDUCATION COALITION

FIREWORKS SHALL NOT BE USED IN THE FOLLOWING AREAS
Restrictions are effective immediately and will continue throughout the summer.
The areas include the following:
Logan - East of 1700 East north of 400 North; east of 1400 East south of 400 North.
North Logan - East of 1600 East between 1700 North and 3500 North
Hyde Park - East of 400 East from the south to the north border of the city
Smithfield - East of 700 East from the southern border of the city to Center Street. East of 470 East from Center Street to Canyon Road. East of 300 East from 200 North to the northern border of the City.
Providence - All areas within Providence City east of a north-south line at 400 East.
Wellsville - All west bench areas, west of Highway 23.
Unincorporated areas - All east bench areas.
These restrictions can also be found at www.cachefire.net and www.loganutah.org
REMEMBER: Please only use approved fireworks that are sold in retail outlets throughout Utah. Fireworks that launch from the ground or explode are illegal!
PER UTAH STATE LAW, DURING SUMMER, FIREWORKS MAY ONLY BE USED: July 21st-July 27th
Thank you for your cooperation in keeping Cache Valley Safe this Holiday Season
Paid for by the Herald Journal and the Cache Valley Fire Public Education Coalition

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