Appendix A.
Topographic Profiles Across the Main Canyon Fault in the Vicinity of the Trench

Methods and Discussion

Twelve topographic profiles were measured in the vicinity of the trench across the Main Canyon fault (*Figure 1*). Seven of the profiles are along ridges; five are along intervening drainages. The profiles were measured on 1:24,000-scale topographic maps with 40-foot contour intervals. Points were measured along the topographic lines at each contour, at each bend in the profile, and at the fault.

The ridge profiles show the relationship between the fault and the low hills on the footwall (east side) of the fault (*Figure 2*). The hills are armored with quartzite cobbles and boulders and could be remnants of older alluvial fans as mapped by Coogan (2002) or a conglomerate within the Wasatch Formation. The hills have been uplifted along the Main Canyon fault. Incision has occurred in the uplifted area between the fault and the Henefer valley to the northeast. The ridge profiles also show the relationship between these hills on the footwall and younger alluvial-fan deposits on the hanging wall. The trench exposure shows that paludal deposits are preserved on the hanging wall adjacent to the fault. Marshes formed when surface rupture on the fault created a west-facing (upslope-facing) scarp that ponded drainage. The marshes slowly filled with fine-grained eolian and alluvial sediment between faulting events, and at least at times became dry enough that soils formed on the fine sediment. Lineaments that are visible on 1:40,000-scale aerial photographs south of the trench site may indicate the extent of the infilled marshes.

The drainage profiles were done to see if any change in gradient could be detected across the fault (*Figure 3*). Profile 6 and perhaps profiles 2 and 8 may show a change in stream gradient at the fault. Profile 8 has a slight inflection as it crosses the fault. Profile 4 does not have a gradient change at the fault. This profile is along a relatively large drainage that may regrade faster than the smaller drainages. Also, the 40-foot contour interval is likely too large to detect small changes in the gradients of the drainages.

In summary, possible changes in gradients of the smaller drainages, geomorphic features that may have a tectonic origin (e.g., scarps, saddles), and differences in incision on opposite sides of the fault are evident on the topographic profiles. Although drawn from the topographic quadrangles with a 40-foot contour interval, these profiles suggest that displacements on the Main Canyon fault have influenced topography in this area.

Reference

Coogan, J.C., 2002, Progress report geologic map of the Devils Slide quadrangle, Morgan and Summit counties, Utah [unpublished draft]: Utah Geological Survey, map scale 1:24,000.

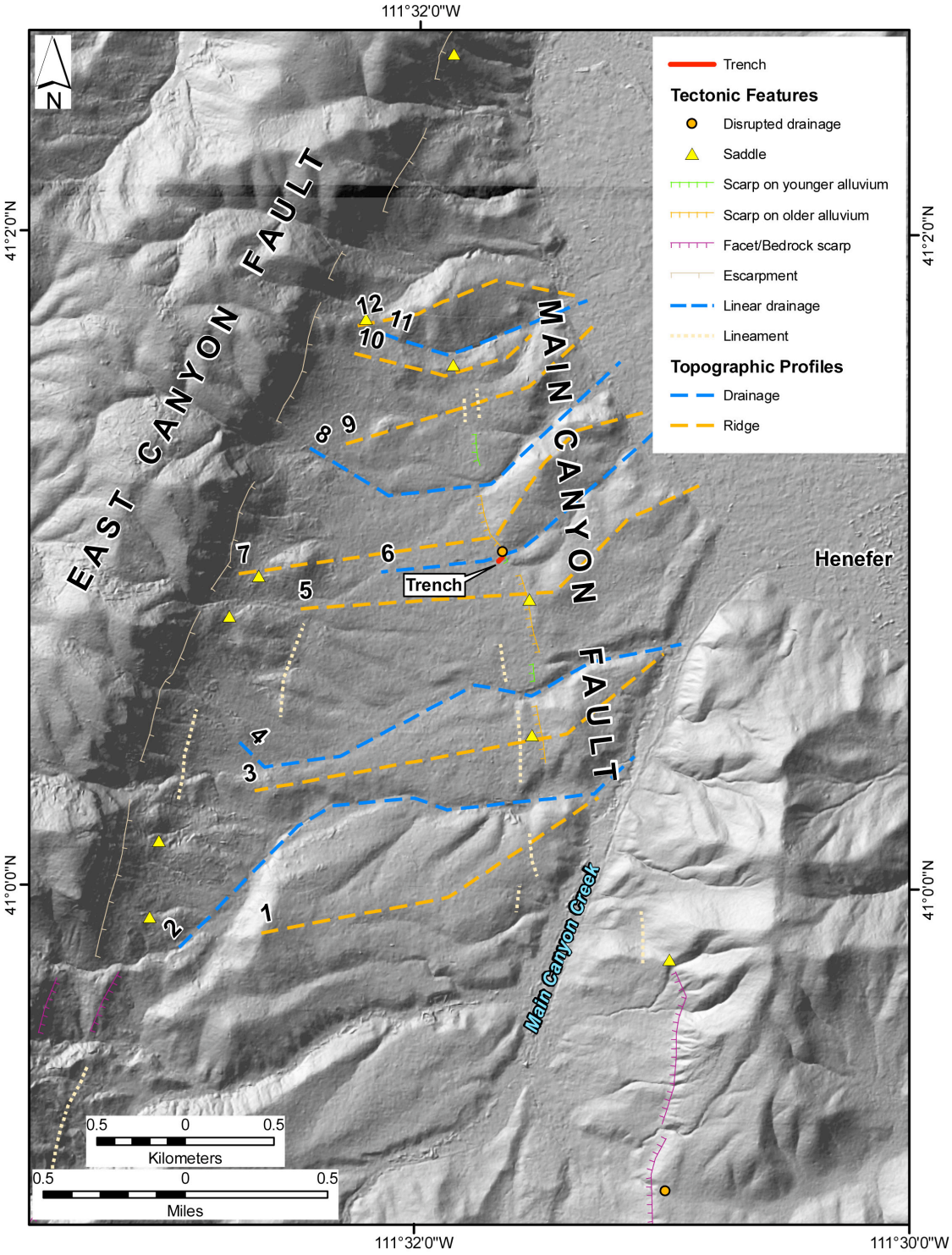
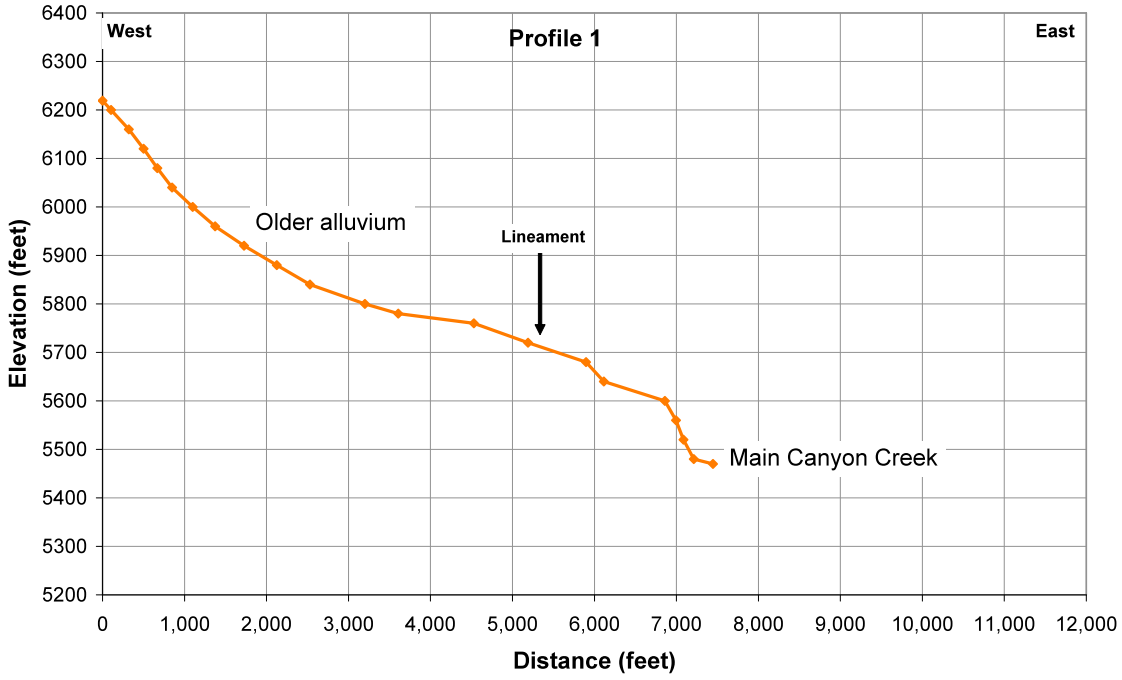
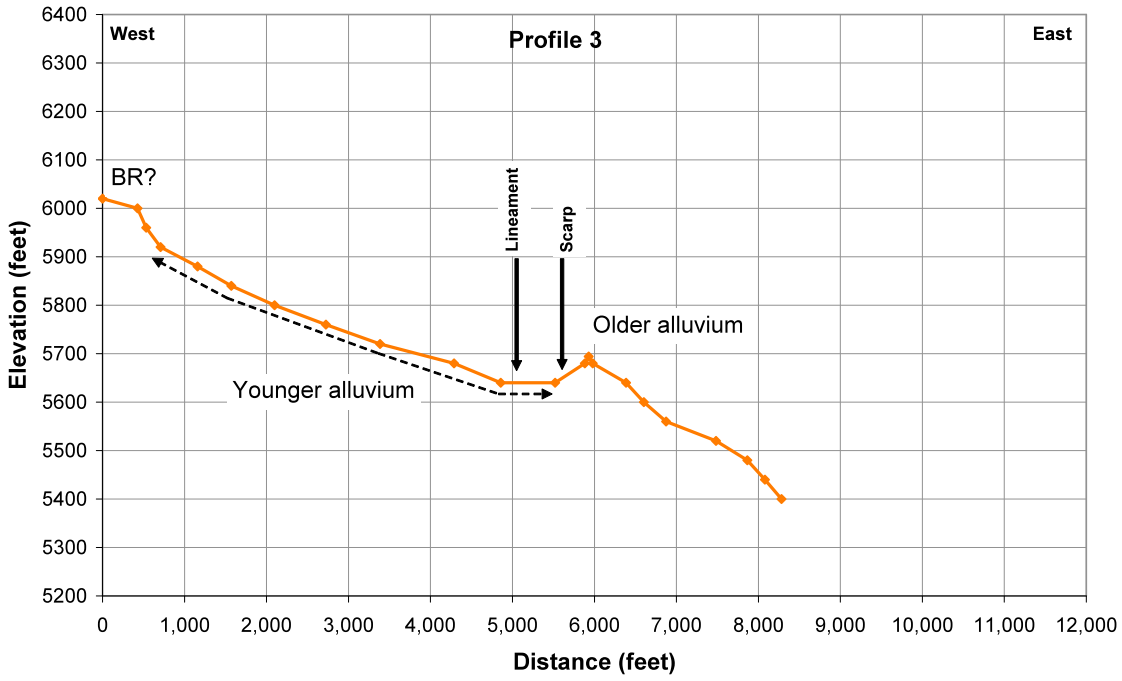
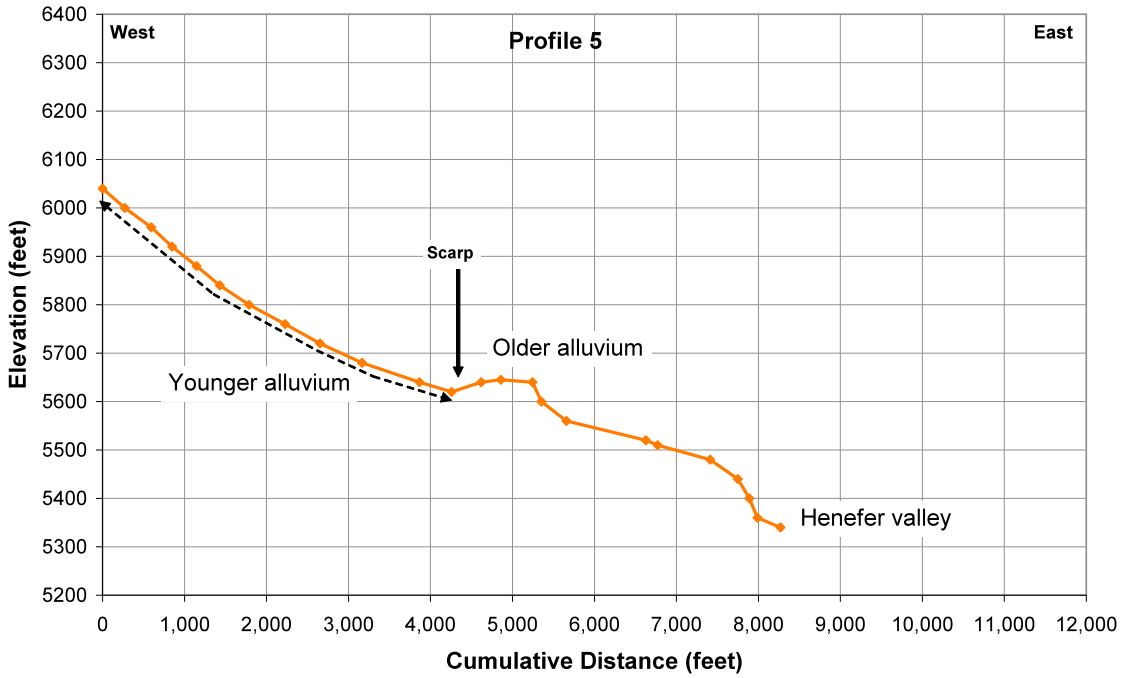


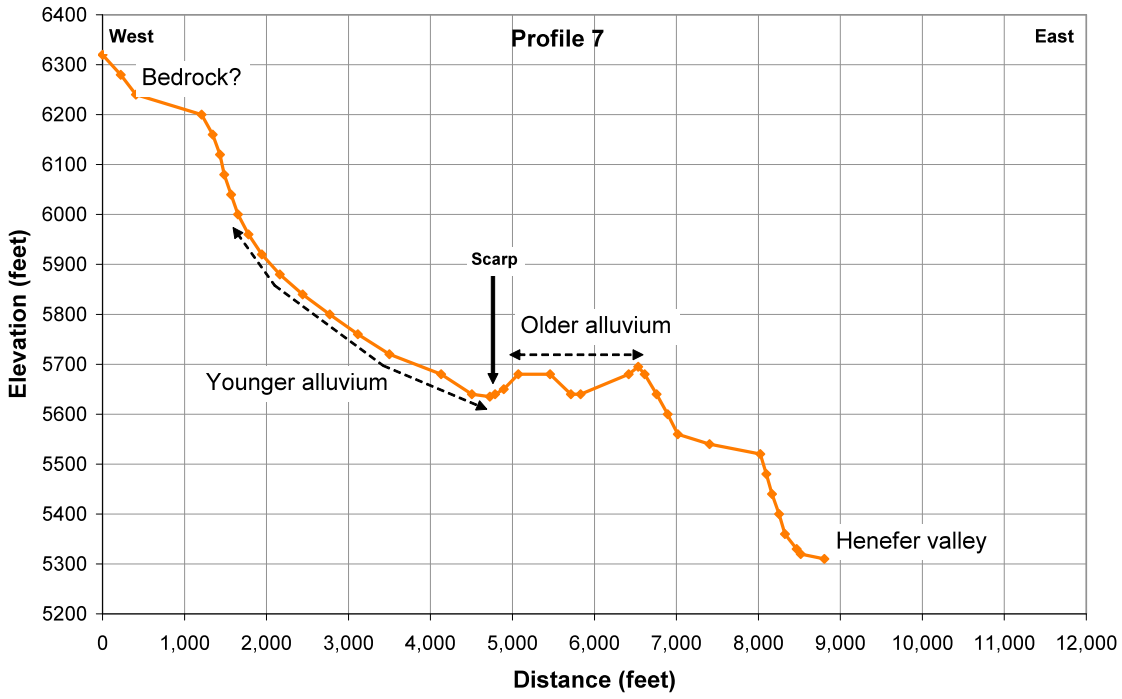
Figure 1. *Location of topographic profiles across the northern portion of the Main Canyon fault. Background is a hillshade created from 1997 aerial photographs, ground control, and a generated grid.*

Profiles Along Ridges






Profile 5
West
East
Elevation (feet)
Cumulative Distance (feet)
Scarp
Older alluvium
Younger alluvium
Henefer valley
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
5300
5200
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
12,000


Profile 7
West
East
Elevation (feet)
Distance (feet)
Bedrock?
Scarp
Older alluvium
Younger alluvium
Henefer valley
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
5300
5200
0
1,000
2,000
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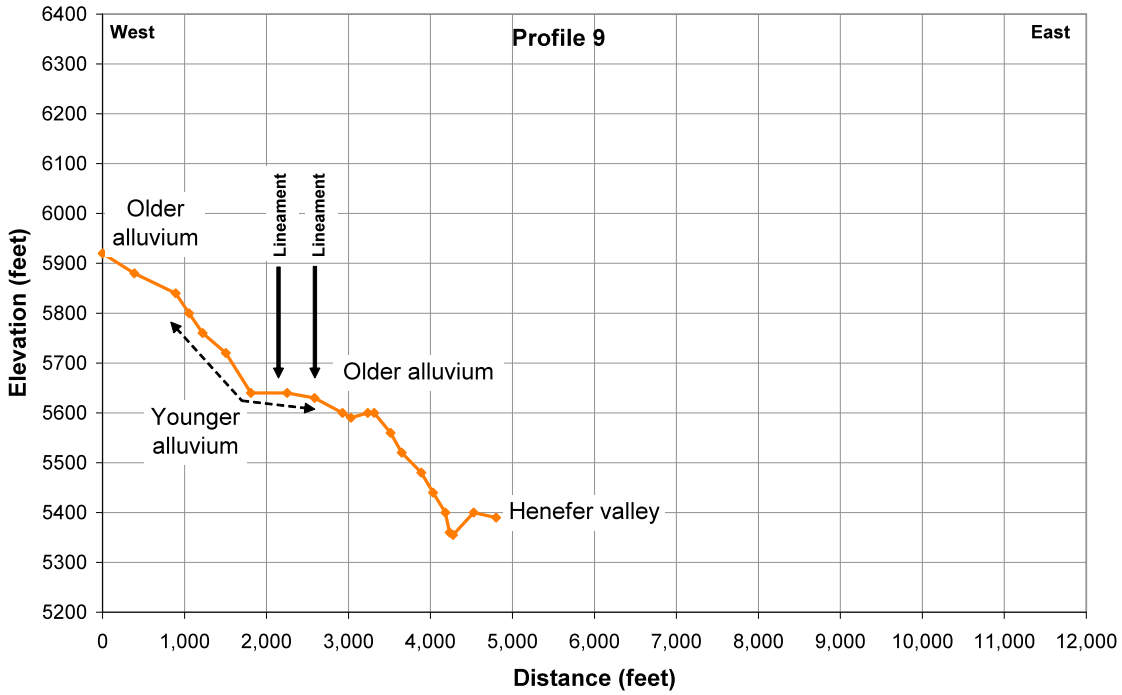
7,000
8,000
9,000
10,000
11,000
12,000


Profile 9
West
East
Elevation (feet)
Distance (feet)
Older alluvium
Lineament
Lineament
Older alluvium
Younger alluvium
Henefer valley
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
5300
5200
0
1,000
2,000
3,000
4,000
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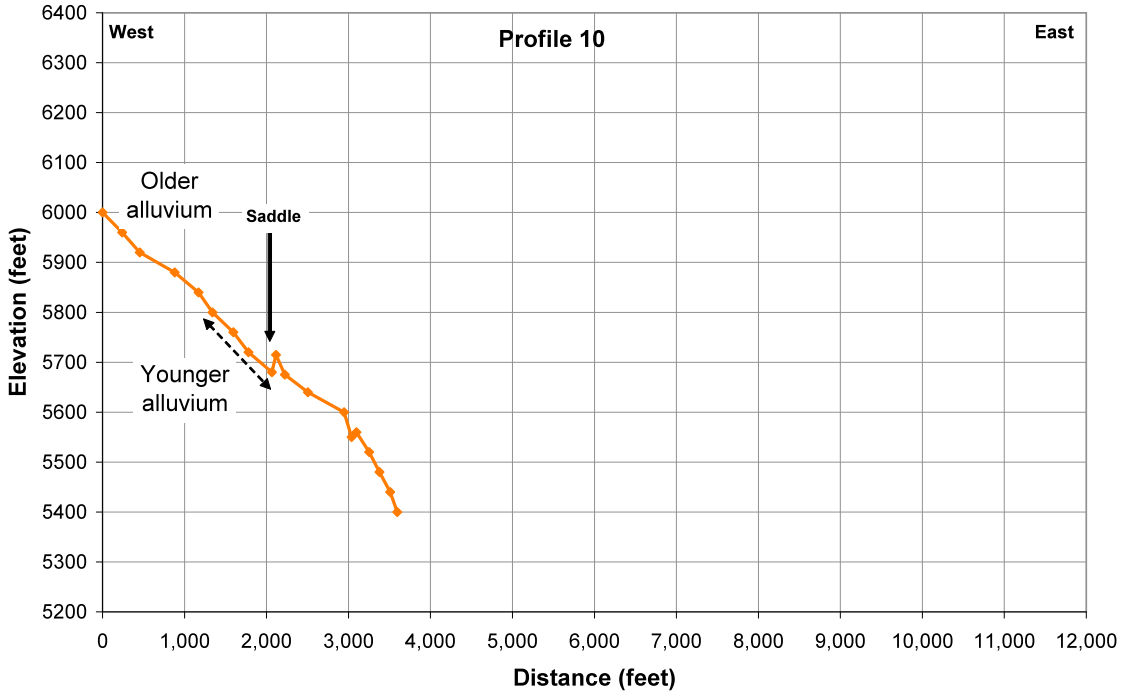
6,000
7,000
8,000
9,000
10,000
11,000
12,000


Profile 10
West
East
Elevation (feet)
Distance (feet)
Older alluvium
Saddle
Younger alluvium
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
5300
5200
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
12,000

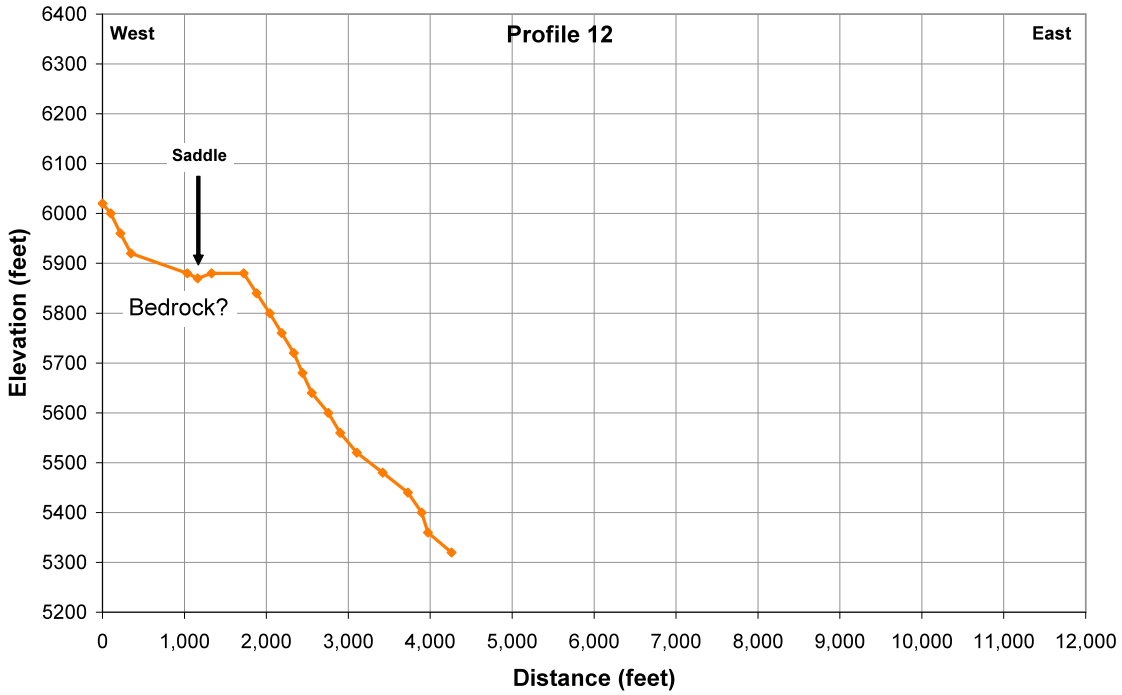
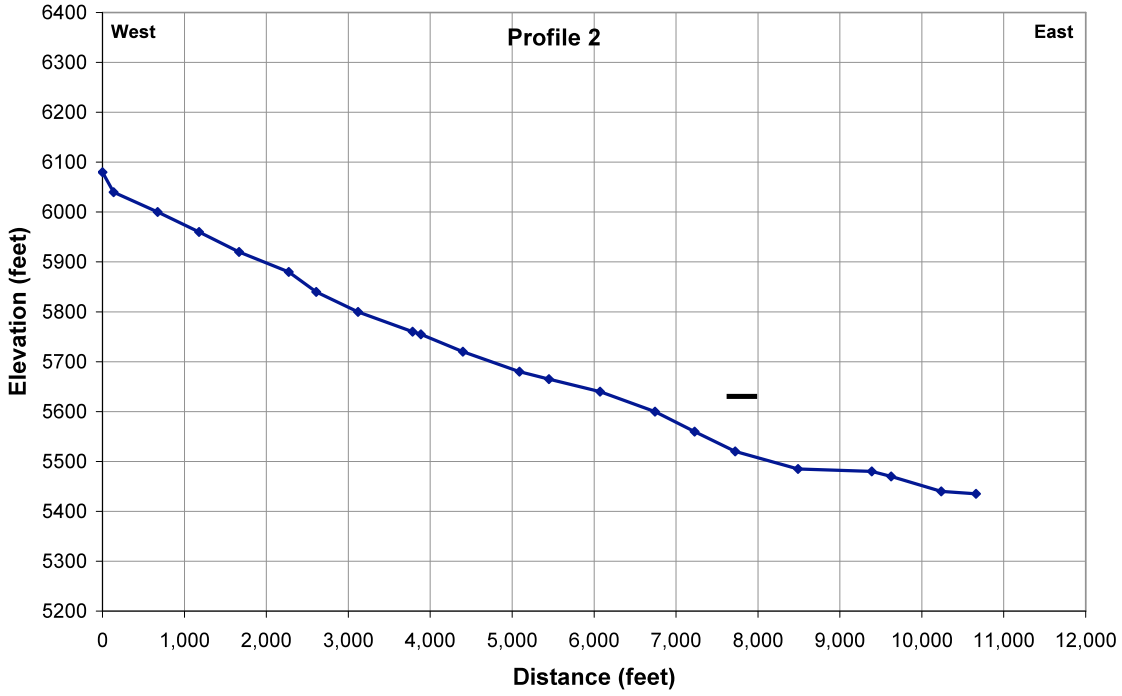
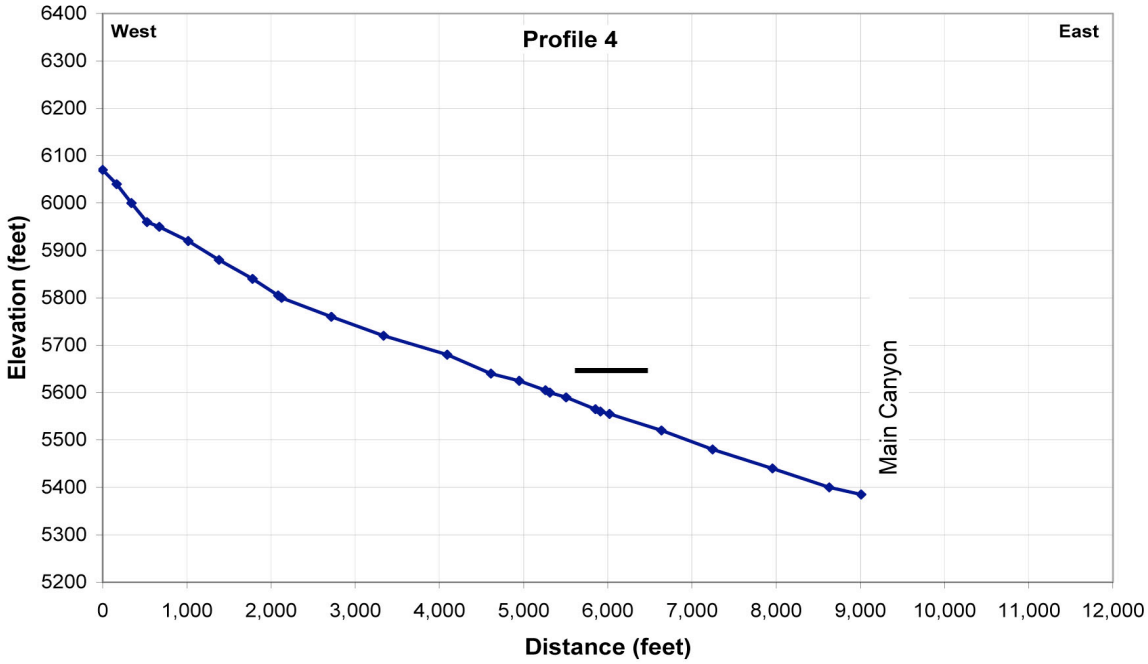
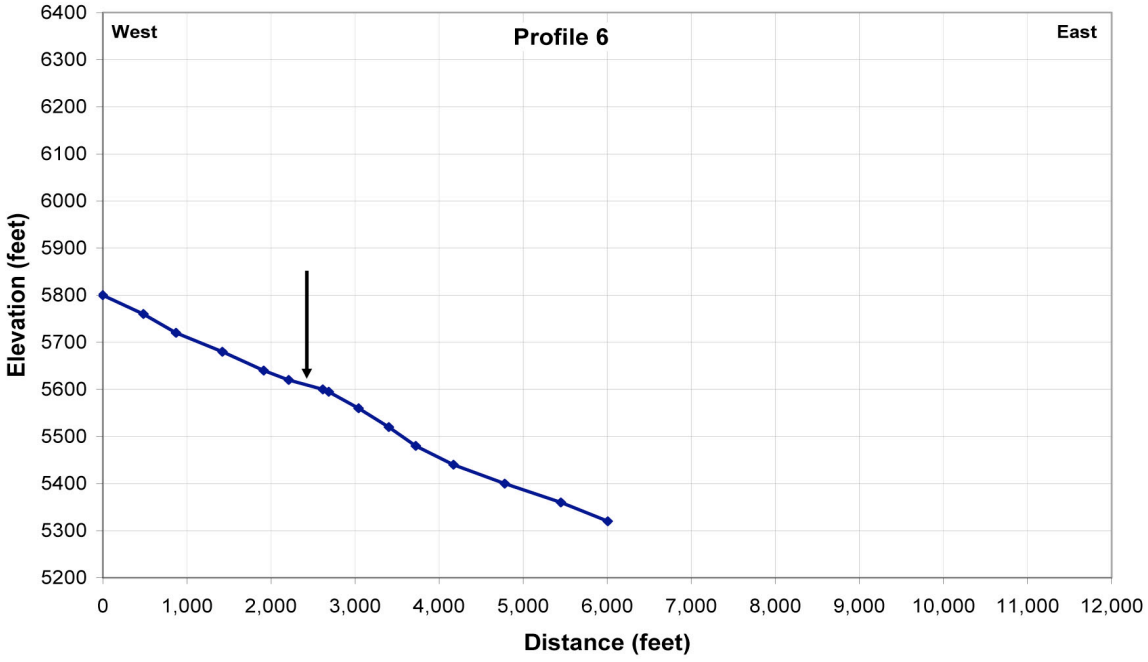


Figure 2. *Topographic profiles along ridges across the northern portion of the Main Canyon fault. Arrows indicate the location of possible tectonic geomorphic features as indicated.*

Profiles Along Drainages




Profile 4
West
East
Elevation (feet)
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
5300
5200
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
12,000
Distance (feet)
Main Canyon


Profile 6
West
East
Elevation (feet)
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
5300
5200
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
12,000
Distance (feet)

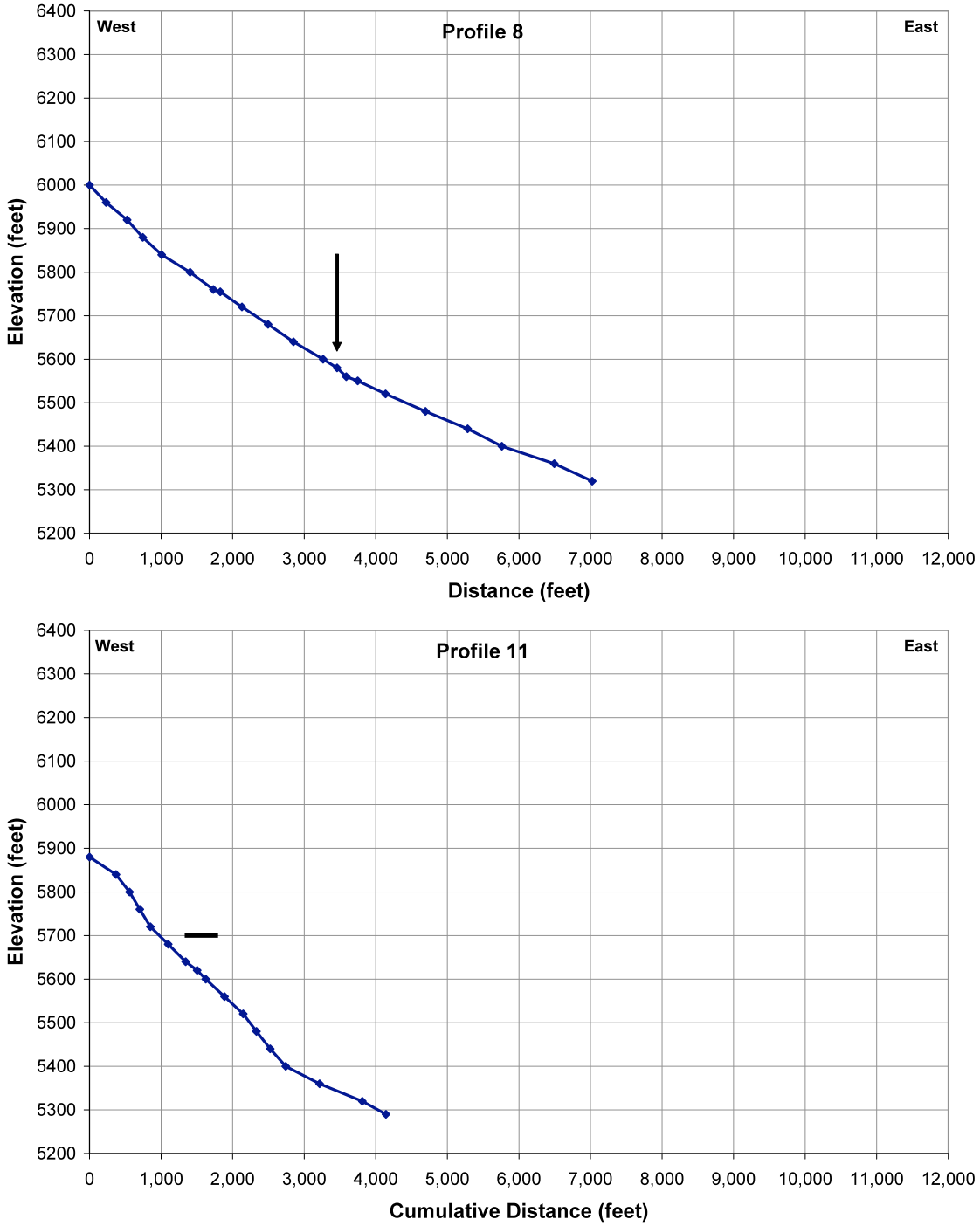
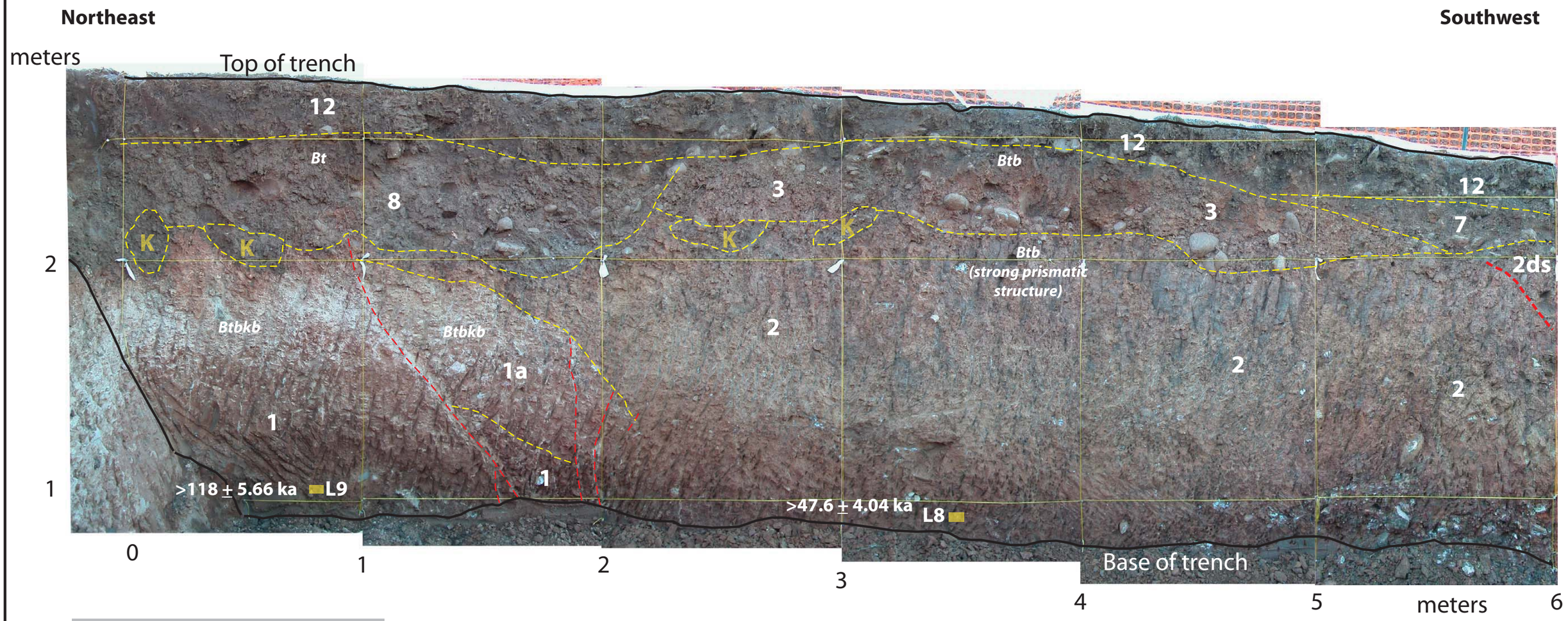


Figure 3. *Topographic profiles along drainages across the northern portion of the Main Canyon fault. Arrows or black horizontal lines show the location of possible tectonic features on ridges adjacent to the drainages.*

Appendix B.
Photograph Mosaics and Interpretative Logs of Trench Across the Main Canyon Fault, Utah

South Wall



Contact--Approximately located
Contact--Gradational
Soil horizon boundary
Probable shear (less defined than a shear)

3 Unit designation

Bt Soil horizon

B Block of soil (rotated/disturbed)

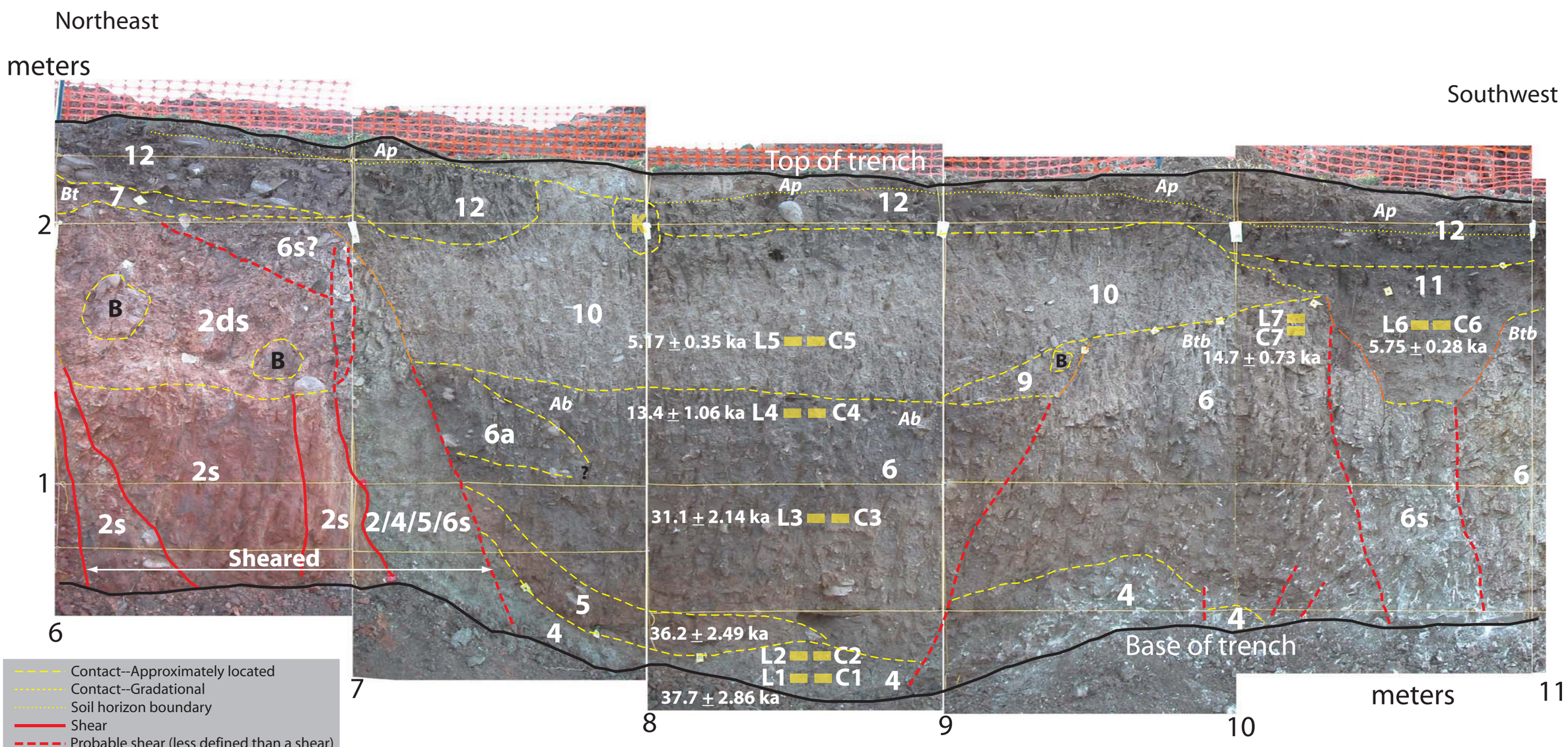
K Krotovina (burrow)

L3 Sample for luminescence date

See Appendix C for unit descriptions.

Figure 1. Log shown on photograph mosaic for the south wall between stations 0 and 6 meters of trench across the Main Canyon fault, Utah

South Wall

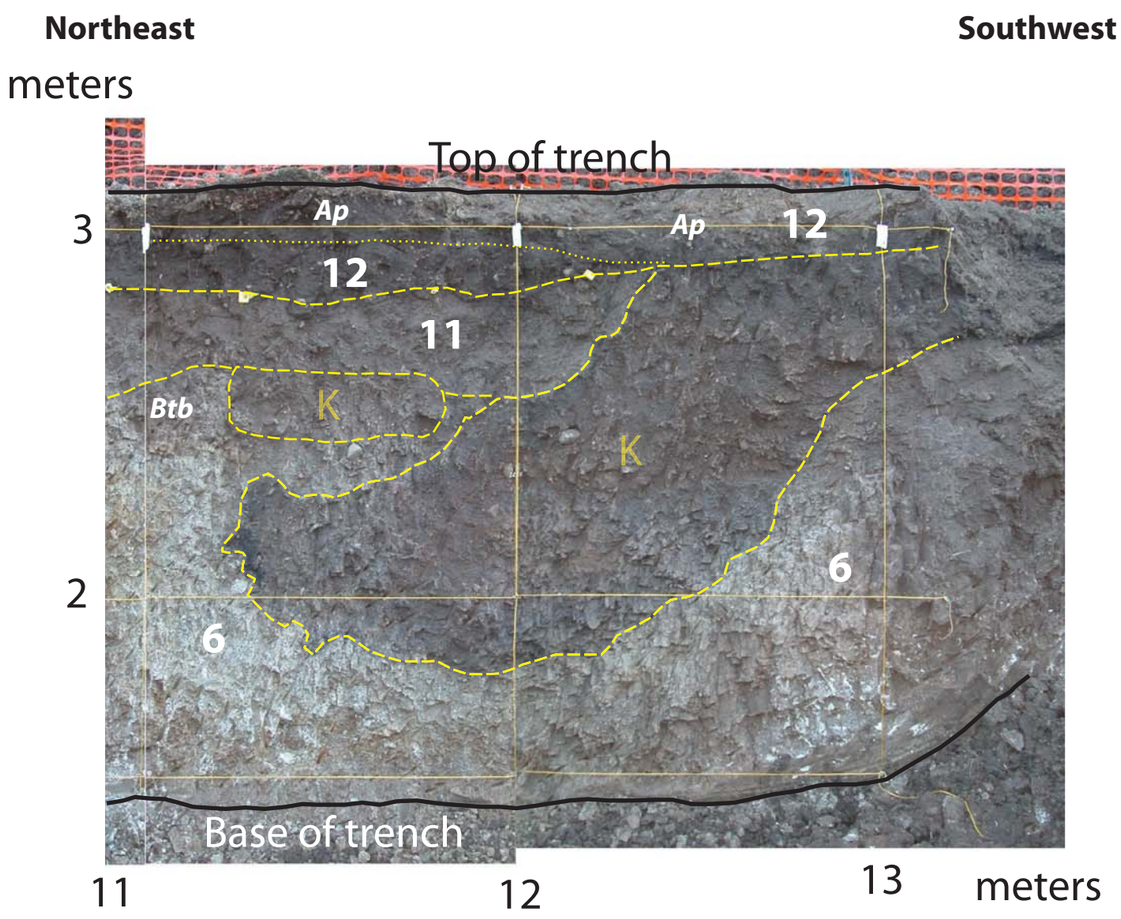


Contact--Approximately located
Contact--Gradational
Soil horizon boundary
Shear
Probable shear (less defined than a shear)
Probable buried free face
4 Unit designation
Ab Soil horizon
B Block of soil (rotated/disturbed)
K Krotovina (burrow)
L3 Sample for luminescence date
C3 Sample for radiocarbon date

See Appendix C for unit descriptions.

Figure 2. Log shown on photograph mosaic of the south wall between stations 6 and 11 meters of trench across the Main Canyon fault, Utah

South Wall



Contact--Approximately located
Contact--Gradational
Soil horizon boundary
6 Unit designation
Ap Soil horizon
K Krotovina (burrow)

See Appendix C for unit descriptions.

Figure 3. Log shown on photograph mosaic of south wall between stations 11 and 13 meters, trench across Main Canyon fault, Utah

North Wall

Southwest

Northeast

Top of trench

Ap

12

7

Btb

3

2

6s

10

6

B

Collapsed
10/19/06

Bench

C8
11,970 - 12,160 cal yr BP

Ab

1

2

0

12

11

10

9

8

7 meters

Contact--Approximately located
Contact--Gradational
Soil horizon boundary
Shear
Possible shear (less defined than a shear)
Possible buried free face

6 Unit designation
Ap Soil horizon
B Block of soil (rotated/disturbed)
C3 Sample for radiocarbon date

See Appendix C for unit descriptions.

Figure 4. Log shown on photograph mosaic of the north wall between stations 7 and 12 meters of trench across the Main Canyon fault, Utah

Appendix C.
Complete Descriptions of Stratigraphic Units and Soils Exposed in Trench Across the Main Canyon Fault, Utah

Unit	Subunit	Description	Soil Development
1		**ALLUVIUM/SLOPE COLLUVIUM:** Clayey, silty fine sand; <1% gravel; angular to well-rounded; angular stones are often split rocks; largest stones have intermediate diameters of about 5 cm; most stones have intermediate diameters of 1 to 2 cm; stones primarily quartzite; some reddish sandstone; massive; no stratification; some stones have a subhorizontal orientation (possibly a weak indication of bedding); soil is markedly better developed than it is in unit 2; red (2.5YR 4/6); unit includes steep, near-vertical, carbonate-filled fractures between stations 1.5 and 2 m that extend downward from unit 1a into unit 1; probably not Wasatch formation, but alluvium/colluvium that is derived from Wasatch formation and older units; present and described between stations 0 and 1 m on south wall; slope of unit appears to be to the northwest; unit also present on north wall near station 0 m	**Buried and faulted soil:** ***Btbk1b horizon:*** Very red clayey sediment (probably a Bt horizon) with carbonate overprinted on it (polycyclic); maximum carbonate development is stage III (carbonate continuous, but matrix is not completely whitened); thickness of maximum carbonate development is about 35-50 cm; carbonate is light red (2.5YR 7/6); matrix is light red (2.5YR 6/6) ***Btbk2b horizon:*** Carbonate in stringers; horizon about 15 cm thick ***Btb horizon:*** Very red clayey horizon (Bt horizon?); horizon about 20 cm thick
	1a	**POSSIBLE TECTONTIC COLLUVIAL WEDGE DERIVED FROM UNIT 1:** Same as unit 1, except that it contains slightly more gravel (~5% of unit) in a wedge-shaped deposit that extends downslope from a carbonate-filled shear zone between stations 1 and 1.5 m within unit 1; at least two steep, carbonate-filled fractures extend upward through unit 1 at station 2 m; unit truncated near station 2 m at a depth of about 1.25 m; abrupt, irregular basal contact with unit 1; maximum thickness of unit is about 0.5 m near station 1.5 m; present and described between stations 1.5 and 2 m on south wall	**Buried and faulted soil (weaker than soil in unit 1):** ***Btbkb horizon:*** Clayey sediment (possibly a Bt horizon) with carbonate overprinted on it (polycyclic); maximum carbonate development is stage II (carbonate in 25-30% of unit as nodules and filaments; filaments are on ped faces and in fractures); carbonate is reddish yellow (5YR 7/6); matrix is yellowish red (5YR 5/6) ***Bkb horizon:*** Carbonate in stringers along fractures in the hanging wall of the main shear between stations 1 and 1.5 m; matrix noneffervescent

Unit	Subunit	Description	Soil Development
2		**SLOPE COLLUVIUM/ALLUVIUM:** Clayey, silty fine sand; <1% gravel; angular to well-rounded; angular stones are often split rocks; largest stones have intermediate diameters of about 5 cm; most stones have intermediate diameters of 1 to 2 cm; stones primarily quartzite; some reddish sandstone; massive; no stratification; some stones have a subhorizontal orientation (possibly a weak indication of bedding); red (2.5YR 4/8); thickness of unit is >1.3 m; basal contact not exposed; ~5% of unit has black nodules (manganese?) that are angular and about 1 mm in diameter; black nodules are concentrated in some areas, but are distributed throughout unit; present and described between stations 2 and 6 m on south wall; also present on north wall between stations 0 and 8 m	**Buried soil:** ***Bt1b horizon:*** Coarse, strong prismatic structure with dark clay films on ped faces and stones; mixed color is red (2.5YR 5/6); clay films are commonly reddish brown (2.5YR 4/3); darkest clay films are weak red (2.5YR 4/2); interior of peds are red (2.5YR 4/6); horizon is best developed in upper 40 to 50 cm of horizon ***Bt2b horizon:*** Coarse, moderate to weak prismatic structure with some dark clay films; horizon 15 to 30 cm thick
	Gravel lenses	**SLOPE COLLUVIUM WITHIN UNIT 2:** Unit 2 includes gravel lenses that make up about 2% of entire unit; lenses contain about 50% gravel; angular to well-rounded, mostly subrounded; smaller stones tend to be more angular; angular stones are often split rocks; largest stones have intermediate diameters of about 20 cm; most stones have intermediate diameters between 2 and 5 cm; stones primarily quartzite; a couple of medium-grained crystalline rocks are grussified; lenses up to 25 to 30 cm thick; present and described between stations 2 and 6 m on south wall; prominent lens is present near base of trench near station 6 m	
	2s	**FRACTURED AND SHEARED UNIT 2:** Same as unit 2, except for vertical mottling related to fractures and shears, which are most common near station 7 m; weak to moderate vertical fabric; mottled red (2.5YR 4/8) and reddish yellow (7.5YR 7/8); reddish yellow is <10% of unit; ~5% of unit has black nodules (manganese?) that are angular and about 1 mm in diameter; present and described between stations 6 and 7 m on south wall below a depth of about 0.75 m	**Buried and faulted soil:** ***Btb horizon:*** Clay films on ped faces and stones in upper about 50 cm of unit

Unit	Subunit	Description	Soil Development
	2ds	**DISTURBED/SHEARED BLOCK OF UNIT 2:** Silty, sandy clay; gravel content similar to that described for unit 2, except for a gravelly lens, which has about 5% gravel, along the base of the unit; present between stations 6 and 7 m, between a shear zone/free face near station 6 m and a shear zone near station 7 m; red (2.5YR 4/6-4/8 (slightly moist)); basal contact gradational with unit 1; unit appears to be an area of mostly in-place unit 2 that has been broken, primarily along soil peds; peds are not continuous; reddish brown (5YR 4/3) clay films; contains areas of peds that may be disturbed blocks; some blocks have large prismatic peds (from unit 2?); some blocks have smaller blocky peds (from unit 3?); gravel and other sediment has filled in the spaces between the fractured peds; prismatic peds have been rotated between 10 to 20 degrees to the west from the general slope of the ground surface; sediment has probably not been totally re-deposited; present between stations 6 and 7 m on south wall	
3		**SLOPE COLLUVIUM:** Sandy, silty clay; variable gravel composition; 1 to 2% gravel between stations 2 and 3 m; 30% gravel along base of unit and about 10% gravel in rest of unit between stations 3 and 5.5 m; gravel angular to well-rounded, mostly subrounded to well-rounded; angular (split) stones common; largest stones have intermediate diameters of about 15 cm; most stones have intermediate diameters of 2 to 10 cm; stones primarily quartzite; stones parallel to basal contact between stations 2 and 5.5 m (slight slope to the west); abrupt basal contact erosional on unit 2; unit truncated along an east-sloping contact by unit 8 (debris flow deposit in channel) near station 2 m, and along a west-sloping contact by unit 7 (slope colluvium) between stations 5 and 5.5 m; present and described between stations 2 and 5.5 m on south wall	**Buried and present? soil:** ***Btb horizon:*** Strong, coarse blocky structure to weak, fine prismatic structure in upper part of unit where gravel content is lower; strong, coarse to medium blocky structure in areas where gravel content is higher; thick, prominent dark clay films on peds and stones; reddish brown (2.5YR 4/4) for horizon; clay films weak red to reddish brown (2.5YR 4/2-4/3); horizon is present through entire thickness of unit; upper boundary of horizon parallels ground surface

Unit	Subunit	Description	Soil Development
3 North wall		**SLOPE COLLUVIUM:** Clayey silt between stations 7 and 8 m grading into sandy, clayey silt near station 6.25 m; laterally variable gravel content that is highest near station 6.25 m and decreases to station 8 m; 15% gravel between station 6.25 and 7 m; angular to well-rounded, mostly subrounded and rounded; angular stones are often split rocks; largest stones have intermediate diameters of about 15 cm; most stones have intermediate diameters of 3 to 5 cm; stones primarily quartzite; 1% gravel between stations 7 and 8 m; mostly angular to subangular; most stones have intermediate diameters of 1 to 3 cm; ~5% of unit between stations 7 and 8 m is hard, dark, rounded clasts ≤5 mm diameters; clasts could be shale, coal, or carbon; well sorted; no stratification or bedding; abrupt, irregular basal contact eroded into unit 2; present and described between stations 7.5 and 8 m on north wall; probably correlative with unit 3 on the south wall	**Buried soil:** ***Btb horizon:*** Weak, fine to medium blocky structure where gravel content is higher; strong, medium prismatic structure and distinct, moderately thick brown (7.5YR 5/4) clay films on peds in areas where gravel content is lower; pale brown (10YR 6/3) for interior portions of peds; also in 1% of horizon has prominent, thick yellowish red (5YR 5/8) clay films on prismatic peds between stations 8 and 8.5 m
4		**PALUDAL DEPOSITS (MOTTLED WITH CARBONATE):** Clayey silt, 1% gravel; subangular to subrounded stones; largest stones have intermediate diameters of about 5 cm; ~3% of unit is hard, dark, rounded clasts ≤5 mm diameters; clasts could be shale, coal, or carbon; well sorted; no stratification or bedding; mottled: brown (7.5YR 5/4 and 10YR 5/3); includes carbonate between depths of 95 and 120 cm to the base unit and trench exposure with maximum development of stage II+ (nodules up to 1 to 2 cm diameters compose about 50% of unit; matrix whitened); nodules are irregular shaped; in places, nodules are elongate with lengths of up to 5 cm; elongated nodules oriented horizontal or subhorizontal; brown (10YR 5/3); carbonate may be related to pond/marsh conditions, but could be a buried soil; basal contact is not exposed; unit extends to the base of the trench exposure; unit truncated by possible shear zone near station 10.5	

Unit	Subunit	Description	Soil Development
		m; present and described between stations 7.5 and 10 m on south wall	
5		**TECTONIC COLLUVIAL WEDGE:** Silty, sandy clay; with about 5% gravel between stations 7.3 and 8.5 m; angular to well-rounded; stones have intermediate diameters ranging between about 3 and 10 cm; larger stones tend to be in the lower part of the unit; stones have a slight downslope orientation; unit is red (7.5YR 5/6)	
6		**PALUDAL DEPOSITS:** Clayey silt or sandy clayey silt; 1% gravel; angular to rounded; angular to well-rounded; most stones have intermediate diameters of 1 to 2 cm; well sorted; massive; not stratified; stones randomly oriented; brown (7.5YR 5/4 (dry) and 7.5YR 4/4 (moist)); between stations 9 and 10 m, unit is mottled brown and pale brown; contains common, hard, dark, rounded clasts $\leq$5 mm diameters; clasts are asphaltum (Appendix G); clear and smooth to slightly wavy basal contact with units 4 and 5; unit is truncated along a steep, well-defined shear with unit 2/4/5/6s between stations 7.25 and 7.5 m; unit also is truncated by a steep, east-sloping poorly defined shear between stations 9 and 9.5 m; description is based on the unit primarily between stations 7.25 and 9.25 m and between stations 9.5 to 10.25 m on south wall	**Buried soil between stations 9.5 and 10.5 m:** ***Btb horizon:*** Strong, very coarse prismatic structure; thin clay films on peds and stones; matrix brown (7.5YR 5/3); clay film brown (7.5YR 4/3) near top of horizon; pale brown (10YR 6/3) for middle of horizon; brown (10YR 5/3) for lower part of horizon; horizon about 55 cm thick ***Bkb horizon:*** Maximum carbonate has stage II development (nodules up to 1 cm diameters compose about 5% of unit); brown (10YR 4/3-5/3 (slightly moist)); horizon about 40 cm thick **Buried soil between stations 7.5 and 9.5 m:** ***Ab horizon:*** Clayey silt; silt content seems to be highest in the upper 30 cm of horizon between stations 7 and 8 m; highest silt content is in the darkest part of the horizon; silt also decreases in a downslope direction from a maximum content between stations 7 and 8 m; brown (7.5YR 4/3); dark brown (7.5YR 3/2) for the darkest areas

Unit	Subunit	Description	Soil Development
6 North wall		**PALUDAL DEPOSITS:** Clayey silt; 1 to 3% gravel; angular to rounded; <1% unit near station 8.5 m includes angular red (7.5YR 5/6) pieces between 5 and 10 cm diameter that appear to be pieces of unit 1; ~5% of unit is hard, dark, rounded clasts ≤5 mm diameters; clasts are asphaltum (Appendix G); brown to yellowish brown (7.5YR 5/3-5/4 to 10YR 5/3-5/4); well sorted; no stratification or bedding; basal contact is not exposed; unit extends to the base of the trench exposure; unit contains steep, poorly defined shears between stations 7.5 and 9 m; present and described between stations 8 and 9 m on north wall	**Buried soil:** ***Btb horizon:*** Strong, coarse prismatic structure; distinct, moderately thick clay films on peds; horizon 50 to 55 cm thick; strongest horizon development in upper 30 cm of unit
	6a	**TECTONIC COLLUVIAL WEDGE:** Similar to unit 6, except it contains about 10% gravel; stones have intermediate diameters ranging between 4 and 8 cm; stones oriented approximately parallel to unit contacts; unit interfingers with unit 6 near station 7.8 m; gradual decrease in gravel content	
	6s	**FRACTURED AND SHEARED PALUDAL DEPOSITS DERIVED FROM UNIT 6:** Similar to unit 6, except that elongated carbonate nodules are oriented vertically and extend throughout unit; basal contact not exposed; unit extends to base of trench; unit truncated laterally by steep, poorly defined shears between stations 10 and 11 m within unit 6; present and described between stations 10 and 11 m on south wall	
	6s North wall	**FRACTURED AND SHEARED PALUDAL DEPOSITS DERIVED FROM UNIT 6:** Fine sandy, clayey silt; 3% gravel that is present mostly along a steep, poorly defined shear at station 9.5 m; gravel angular or rounded; stones have intermediate diameters of up to about 10 cm; most angular stones are split rocks; between stations 7 and 8, ~5% of unit includes hard, dark, rounded clasts ≤5 mm diameters; clasts are asphaltum (Appendix G); well sorted; massive; no stratification or bedding; brown (7.5YR 5/4); unit tapers with depth; appears to join a shear zone	**Buried soil:** ***Btb horizon:*** Moderate to strong, medium prismatic structure

Unit	Subunit	Description	Soil Development
		that is visible below the bench at station 9.5 m; unit truncated laterally by a steep, poorly defined shear at stations 9 m with unit 6, and by a steep probably free face at station 9.5 m with unit 10; present and described between stations 9 and 10 m on north wall	
	2/4/5/6s	**SHEARED CLAY DERIVED FROM UNITS 2, 4, 5, AND 6:** Clay; no gravel, except in shear zone near station 7 m; rounded, black, soft?, clasts $\leq$ 5 mm diameters present below soil horizon; percent of clasts increases lower in exposure; $\leq$5% just below soil horizon to 10 to 15% with depth; contact with sediment from unit 2s near station 7 m is a shear zone in which the unit is mixed with unit 2s from about 10 cm below the base of the Bt horizon to the base of the trench exposure; mixed zone is about 10 cm wide, includes clasts from unit 2, and overlies a well-defined shear; shear texture is not visible within the Bt horizon; shearing and disturbance of the clay indicated by the way in which the clay breaks out from trench wall; pale brown (10YR 6/3); carbonate nodules present at a depth of about 1.3 m and extend to the base of the trench; nodules compose 10 to 15% of unit in this area; basal contact not exposed; unit extends to the base of the trench; unit truncated by steep shear along units 2s and 2ds at station 7 m; unit truncated by a steep shear (below a depth of 0.75 m) with unit 6 and a steep erosional contact (above 0.75 m) with unit 10; present and described between stations 7 and 7.5 m on south wall	**Buried soil:** ***Bt1b horizon:*** Strong, coarse prismatic structure; prominent, moderately thick reddish brown (5YR 4/3) clay films on peds; matrix light reddish brown to reddish brown (5YR 6/3 ranging to 5YR 5/4); horizon 55 cm thick ***Bt2b horizon:*** Moderate, medium blocky structure; light brown (7.5YR 6/3); horizon about 10 cm thick; soil extends to a depth of about 0.75 m below the present ground surface
7		**SLOPE COLLUVIUM:** Clayey, sandy silt; 30% gravel along base of unit; 15% gravel above; angular, subrounded, and rounded; most stones are angular (split); basal stone line 2 to 5 cm thick; unit about 20 cm thick; reddish brown (5YR 4/4); abrupt, slightly wavy basal contact; contact erosional on units 2 and 3; unit truncated by a west-sloping contact eroded into unit 2 and unit 2ds between stations 5 and 6.5 m; present and described between stations 5 and 6.5 m on south wall	**Buried and present(?) soil:** ***Bt horizon:*** Strong to moderate, fine blocky structure; prominent, moderately thick clay films on stones; prominent, thin clay films on blocky peds; horizon is present through entire thickness of unit

Unit	Subunit	Description	Soil Development
7 North wall		**SLOPE COLLUVIUM:** Sandy, silty clay; unit fines downslope; 5 to 25% gravel; angular to subrounded; angular stones, which are split rocks, dominate; a stone line at the base of the unit between stations 7 and 8 m is composed of angular (broken) stones; largest stones have intermediate diameters of about 15 to 20 cm; larger stones predominate upslope near stations 6.25 to 7 m; stones primarily quartzite; poorly sorted; color variable; brown (7.5YR 5/4-4/4) near station 6.25; brown (7.5YR 5/4) between stations 8 and 9 m; maximum thickness of unit is about 25 cm; thickness varies between 18 and 28 cm; unit truncated near station 9 m by erosional contact with unit 12; abrupt, slightly wavy basal contact, in part defined by the stone line; unit conformable with underlying units; present and described between stations 6.25 and 9 m on north wall	**Buried soil:** ***Btb horizon:*** Strong, fine to medium blocky structure; prominent, moderate thick clay films on stones; faint, thin clay films on peds
8		**MUDFLOW DEPOSIT FILLING CHANNEL:** Clayey, silty fine sand; 3 to 5% gravel; angular to well-rounded; angular stones are often split rocks; largest stones have intermediate diameters of about 20 cm; stones have a weak subhorizontal orientation; stones are approximately parallel to the channel margin near station 2 m; poorly sorted; massive; no stratification or bedding; reddish brown (5YR 4/3); abrupt, irregular basal contact eroded into unit 1; unit truncates unit 2 near station 2 m as an erosional contact at the channel margin; present and described between stations 0 and 2.5 m on south wall	***Bt horizon:*** Strong, medium blocky structure; prominent, moderately thick, dark reddish brown (5YR 3/3) clay films on peds and stones; organic coatings on peds; occasional very weak effervescence around fine roots
9		**POSSIBLE TECTONIC COLLUVIUM:** Clayey silt between stations 9.0 and 9.5 m; includes rotated pieces of soil	
10		**MUDFLOW DEPOSIT FILLING GRABEN:** Clayey silt; 3-5% gravel; angular to well-rounded; angular and subangular stones common; angular stones are often split rocks; largest stones have intermediate diameters of about 3 cm; most stones	***A horizon*** No visible pedogenic carbonate; no effervescence to base of unit

Unit	Subunit	Description	Soil Development
		have intermediate diameters of 1 to 2 cm; matrix supported; unsorted; massive; no stratification or bedding; brown (7.5YR 4/3-5/3); upper about 50 cm has common worm burrows; some burrows open; others filled with dark, organic-rich sediment; clear, smooth basal contact with unit 6; unit truncated by a steep erosional contact with unit 2/4/5/6s between stations 7 and 7.25 m; unit interfingers with unit 11 or pinches out near station 10.25 m; present and described between stations 7 and 10 on south wall; also present on north wall between stations 9.5 m and at least 11 m; source of debris flow was likely the slope north of the trench	
11		**TECTONIC COLLUVIUM:** Clay; 1% gravel; subangular to subrounded; stones have intermediate diameters between 1 and 3 cm; lower 15 cm of unit between station 10.5 and 10.75 m contains very small (≤1 mm) pieces of carbonate that appear to have been eroded from unit 6 (locally derived); upper 25 to 35 cm has 1 to 5% worm burrows; some burrows open; others filled with dark, organic-rich sediment; burrows more common in upper part of unit; unit has a maximum thickness of 20 to 50 cm; unit interfingers with unit 10 or pinches out near station 10 m, and is cut out by a large burrow(?) near station 12 m; similar unit is present near station 13 m; abrupt, irregular basal contact eroded into unit 6s; pinkish gray (7.5YR 6/2, slightly moist); present and described between stations 10 and 13 m on south wall	***A horizon*** No visible pedogenic carbonate; only effervescence is on the detrital carbonate; no other effervescence to base of unit
12		**SLOPE COLLUVIUM:** Variable texture; clayey, fine sandy silt between stations 0 and 7 m; fine sandy silt (less clay) between stations 7 and 13 m; variable gravel content (highest between stations 0 and 7 m); 1 to 10% gravel between stations 0 and 7 m; subangular to rounded; angular stones are often split rocks; largest stones have intermediate diameters of about 10 to 15 cm; most stones have intermediate diameters of 2 to 5 cm; stone line intermittent along base of unit; 1 to 3% gravel between stations 7	*A horizon* No visible pedogenic carbonate; no effervescence to base of unit

Unit	Subunit	Description	Soil Development
		and 13 m; gravel content decreases in downslope direction; rounding similar to that between stations 0 and 7 m; largest stones have intermediate diameters of about 5 to 10 cm (one stone this size is present about every 1 m); most stones have intermediate diameters of <2 cm; large stones are not present downslope of station 10 m; unsorted, massive, and not stratified between stations 0 and 13 m; sharp wavy basal contact between station 0 and 13 m; between stations 0 and 7 m, stones oriented mostly parallel or subparallel to the ground surface and the basal contact of unit; unit eroded into underlying units (units 3 and 7) between stations 3 and 7 m; unit conformable with underlying units (units 10 and 11) between stations 7 and 13 m; upper 10 to 15 cm of unit has been plowed between stations 8 and 13 m; brown (7.5YR 5/3) between stations 0 and 2 m and brown (7.5YR 4/3) between stations 2 and 4 m; dark brown (7.5YR 3/3, slightly moist) between stations 9 and 10 m; brown (7.5YR 4/3) between stations 10 and 11 m	

Descriptions are for south wall unless otherwise indicated. Colors are for dry samples, unless otherwise indicated. Soil nomenclature follows Birkeland, P.W., Machette, M.N., and Haller, K.M., 1991, Soils as a tool for applied Quaternary geology: Utah Geological and Mineral Survey Miscellaneous Publication 91-3, 63 p.

Appendix D.
Descriptions of Samples Collected From the Trench Across the Main Canyon Fault, Utah

Table 1. *Locations of samples collected for luminescence analysis.*

Sample Number	Type of Sample	Trench Stratigraphic Unit	Station (m)	Approximate Depth (cm) below Ground Surface	Depth (cm)	Trench Wall	Notes
ECT-L1	Tube	4 (lower)	8.45-8.50	215	35-45 below lowest string	South	
ECT-L2	Tube	4 (upper)	8.45-8.50	200	22-28 below lowest string	South	
ECT-L3	Tube	6 (lower)	8.50-8.55	133	5-10 below middle string	South	
ECT-L4	Tube	6 (upper)	8.48-8.53	100	23-28 above middle string	South	
ECT-L5	Clods (2)	10	8.65-8.75	70	40-50 below upper string	South	Could not collect a tube sample
ECT-L6	Tube	11	10.56-10.61	60	35-40 below upper string	South	
ECT-L7	Clods (2)	6	9.80-9.91	67	38-50 below upper string	South	Could not collect a tube sample
ECT-L8	Tube	2	3.50-3.55	155	2-8 below lower string	South	
ECT-L9	Tube	1	0.62-0.69	139	8-13 above lower string	South	
ECT-L1 (bulk)	Bulk sediment	4 (lower)	8.55-8.70	215	35-45 below lowest string	South	
ECT-L2 (bulk)	Bulk sediment	4 (upper)	8.50-8.55	200	22-28 below lowest string	South	
ECT-L3 (bulk)	Bulk sediment	6 (lower)	8.47-8.58	133	2-12 below middle string	South	Sample taken around ECT-L3
ECT-L4 (bulk)	Bulk sediment	6 (upper)	8.46-8.55	100	21-30 above middle string	South	Sample taken around ECT-L4
ECT-L5 (bulk)	Bulk sediment	10	8.65-8.75	70	40-50 below upper string	South	
ECT-L6 (bulk)	Bulk sediment	11	10.61-10.70	60	33-43 below upper string	South	Sample taken around ECT-L6
ECT-L7 (bulk)	Bulk sediment	6	9.80-9.91	67	38-50 below upper string	South	
ECT-L8 (bulk)	Bulk sediment	2	3.48-3.58	155	1-9 below lower string	South	Sample taken around ECT-L8
ECT-L9 (bulk)	Bulk sediment	1	0.60-0.70	139	7-15 above lower string	South	Sample taken around ECT-L9

Table 2. *Locations of samples collected for radiocarbon analysis.*

Sample Number	Trench Stratigraphic Unit	Station (m)	Approximate Depth (cm) below Ground Surface	Depth (cm)	Trench Wall	Notes
ECT-C1	4 (lower)	8.55-8.70	203-213	35-45 below lowest string	South	
ECT-C2	4 (upper)	8.50-8.70	188-196	20-28 below lowest string	South	Sample collected from 5 cm below contact with unit 6
ECT-C3	6 (lower)	8.50-8.70	120-130	2-12 below middle string	South	
ECT-C4	6 (upper)	8.40-8.60	88-98	20-30 above middle string	South	
ECT-C5	10	8.38-8.58	53-73	35-55 below upper string	South	
ECT-C6	11	10.60-10.75	45-55	33-43 below upper string	South	
ECT-C7	6	9.80-9.91	70-90	50-70 below upper string	South	
ECT-C8	6 (upper)	10.35-10.65	142	About 20 below old string line for center of sample	North	Sample from below bench on north wall; location approximate; old string line correlates with the middle string line on the south wall

Appendix E.
Informal Memo From USGS Luminescence Dating Laboratory

By
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Denver, Colorado

INFORMAL MEMO FROM USGS LUMINESCENCE DATING LAB
FEBRUARY 28, 2007
REPORT TO DEAN OSTENAA AND LUCY PIETY ON EAST CANYON FAULT TRENCH, HENEFER, UTAH

U.S. Department of the Interior

U.S. Geological Survey

This report contains the data and final luminescence ages generated from this data on samples ECT-L1 through samples ECT-L9. These samples were collected from a trench across the East Canyon fault near Henefer, Utah by Dean Ostenaa and Lucy Piety. The samples were primarily composed of either clayey silt (ECT-L1 through ECT-L7) or silty sand (ECT-L8 and ECT-L9) with the occasional pebble (see attachment B for detailed particle size analyses). The preferred size for optically stimulated luminescence (OSL) dating is between 250 and 90 μm. I obtained sufficient quantities of sand size grains of quartz for most of the samples after the first pass through wet sieving (except for ECT-L1 and ECT-L2, which had the least amount of sand). The samples had field moistures of 5.2% to 14.5% and total saturation moistures of 48% to ~100% (due to the very high abundance of clays). Saturated water content was obtained by weighing dry bulk soil material in a centrifuge tube, saturating and mixing, centrifuging, suctioning off the supernatant and weighing the resulting saturated soil.

Since mountainous Utah is classified as a mollisol xerolls regime (continuously dry in summer for long periods, moist in winter), I constructed a simple model to estimate average moisture content for the samples. This model assumed moisture contents between 20% and 25%, even though it was obvious some samples would be more saturated (or hold water better) than others.

OSL analyses were carried out in subdued orange-light conditions. One and a half centimeters of sediment was removed from the outer part of the OSL samples to prevent the possibility of contaminated sediments being dated. This left very little sample for OSL analyses as the PVC tubes were only 6 cm long. Luminescence

measurements were made on the central sections of sediment that were least likely to have been exposed to sunlight during sampling.

Samples were treated with 10% HCl and 30% H_2O_2 to remove carbonates and organic matter, and then sieved to extract the 90-125 μm-size fractions (170 to 120 mesh size apertures). Quartz and feldspar grains were separated by density using Li-Na tungstate (□=2.58 gcm^{-3}). The quartz fraction was etched using 40% HF for 40 min followed by 4N HCl for 45 min to remove the outermost layer affected by alpha radiation. The quartz grains were mounted on stainless steel discs using Silkospray□, generally about 150-200 grains centered in the middle of the disc in a single aliquot. Light stimulation of the quartz was achieved using a RISØ array of blue LEDs centered at 470 nm. Detection optics comprised Hoya 2·U340 and Schott BG-39 filters coupled to an EMI 9635 QA Photomultiplier tube. Measurements were taken with a RISØ TL-DA-15 reader. □ radiation was applied using a 25 mCi $^{90}Sr/^{90}Y$ in-built source.

The single-aliquot regenerative dose (SAR) protocol (Murray and Wintle, 2000) was used to determine the equivalent dose (see attachment A for more detail). A five-point measurement strategy was adopted with three dose points to bracket the equivalent dose, a fourth zero dose and a fifth repeat-equivalent dose point. The repeat equivalent dose was measured to correct for sensitivity changes and check that the protocol was working correctly (see figure 1 for details). All measurements were made at 125°C for 40 seconds after a pre-heat to 240°C for 10 seconds. For all aliquots the recycling ratio between the first and the fifth point ranged within 0.83-1.21. Data were analyzed using the ANALYST program of Duller (1999). Equivalent dose measurements were made on

aliquots of 9.6 mm diameter. In each case 15-30 aliquots from each sample were analyzed (except for ECT-2 for which only 8 usable aliquots were obtained) (table 1).

The dose rate (see attachment A for complete detail) was obtained by gamma spectrometry analyses. Most ionizing radiation in the sediment is from the decay of isotopes in the uranium and thorium decay chains and the radioactive potassium 40. In the laboratory the bulk samples were counted in a gamma spectrometry lab for elemental concentrations (table 1). The cosmic-ray dose rate was estimated for each sample as a function of depth, altitude and geomagnetic latitude (Prescott and Hutton, 1994). Alpha and beta contributions to the dose rate were corrected for grain-size attenuation, if needed (Aitken, 1985).

2. Discussion of OSL results:

These samples showed normal dispersion of equivalent dose scatter, except for ECT-5, ECT-9 and ECT-2 (figure 2). ECT-5 and ECT-9 show one or two outliers (positive skew) that are probably related in incomplete bleaching of grains in those aliquots that make up the outliers. ECT-2 showed a large variation in the grain population, but I could not resolve whether the problem can be attributed to the small number of aliquots (or equivalent doses) which was due to the fact that the sample had very little sand size grains (statistical problem) or whether the sample had many more partially bleached grains (geological problem). However, some of the samples exhibited a tighter than normal distribution (ECT-4, 5, 6, and 7) and look like they were very well bleached at deposition (perhaps having been exposed at the surface for some time before burial??).

In general, the older the sample, the more dispersion it displays. Samples that have a fluvial depositional history (i.e. terrace or colluvium) or short transport path, also display more dispersion than will a sample composed of mainly eolian grains or grains that were sub aerially exposed before burial (point bar deposits). A set of "individual value plots" from all accepted equivalent doses generated for each sample are shown in figure 2. Histograms for the luminescence samples from the upper, middle and lower units within the trench were also generated (figures. 3, 4, 5). Please note that the thick curve over the histograms bins is the normal distribution curve generated for that data set and that the simple mean is shown for the equivalent dose, not the weighted mean as was used in table 1.

The bin width of the histograms can be determined for the samples by defining it as the value of the standard deviation (see figures 3, 4, 5; Lepper and McKeever, 2002). I have attempted to come close to these standard deviation values while retaining a clear data presentation of multiple graphs in one group for comparison purposes. Histograms are unable to display the precision with which each De value is obtained, but the standard deviation generated for each sample is shown.

The comparison of equivalent doses (figure 2) shows tight clusters for ECT-4, ECT-5, ECT-6 and ECT-7, which attest to their well-bleached characteristics (except for the above mentioned outlier in ECT-5). ECT-3, ECT-1 and (of course) ECT-2 show a much broader distribution (and larger standard deviations), more like that of sediment from a fluvial environment or sediment that contains a strong component of partial bleaching. For this reason the mean on ECT-2 was weighted such that those grains that exhibited lower equivalent doses and more precise errors (i.e. well-bleached grains)

would control the total equivalent dose (96 Grays weighted vs. 111 Grays). ECT-2 also had outliers that probably should have been removed, but the outliers to the right of the fit were nulled by weighting the data. The other samples (except ECT-1 and ECT-3 in a minor way) did not really require a weighted mean, but nonetheless were reported in this way. This weighted mean affected the ages generated in only a minimal way (see subtitles in histogram figures for variations).

Material used to calculate the dose rates did not vary significantly in any way for the U and Th, although there was an increase in K at the top of the trench (table 1). It is unclear what this increase means, but it did not point to any disequilibrium problems in the bulk samples.

There were difficulties with the older samples returning reliable ages. The difficulty was not a problem with the laboratory applied SAR protocol on samples ECT-8 and ECT-9, as the samples did not show monotonic (saturating) behavior, did not show a lack of proportionality between the regenerative and test-dose signals and there was no difference in sensitivity corrections between the natural and the regenerative cycles. The excessive scatter and high standard deviations for the samples are instead attributed to problems in the geology of the sediment. The very weathered, red-colored alluvium (Bt soil and carbonate soil of Stage III development) simply presented too many mixing and overprinting problems to sort out using OSL. It was impossible to tell whether young equivalent doses were a result of bioturbation, short transport paths (one side of the fault to the other), clay migration or true burial ages. Older equivalent doses could not be separated out into those that were a result of non-bleaching (residual luminescence held), partial bleaching or true burial ages.

3. Conclusion:

Samples at the top of the trench, in sediment deposited after the MRE (unconformity/erosion boundary), are dated at 5.2 ka to 5.8 ka. Samples below the MRE faulting event are dated at 13.4 ka to 14.7 ka. A sample of charcoal collected near the OSL age of 13.4 ka returned an age of 12.1 ka (12,160-11,970 cal yr BP). The OSL age overlaps with the radiocarbon age when the error is applied (table 1). All of the upper OSL samples showed well bleached conditions before final burial.

OSL samples from the middle of the trench (event 1 or pre-event 1) are dated between 31.1 ka to 37.7 ka. These samples also show a fluvial origin and a broader distribution in bleaching conditions, with some aliquots containing many unbleached or partially bleached grains (these grains would carry a small residual luminescence that was not reset at burial, see ECT-2).

OSL samples from the bottom of the trench in older, weathered sediment (strong Bt soil development) could only be minimally dated at >50 ka and >120 ka. That is, these samples obviously contained many grains that were either partially bleached or not bleached at all (figures 1 and 5). Although the histograms may look acceptable, the quartz protocol used in obtaining the resultant ages was returning systematic underestimations. This is not attributed to differences in sensitivity corrections using the SAR protocol, but is attributed to problems with trying to date Bt soils or older overprinting carbonate (stage II or higher) soils using the OSL technique.

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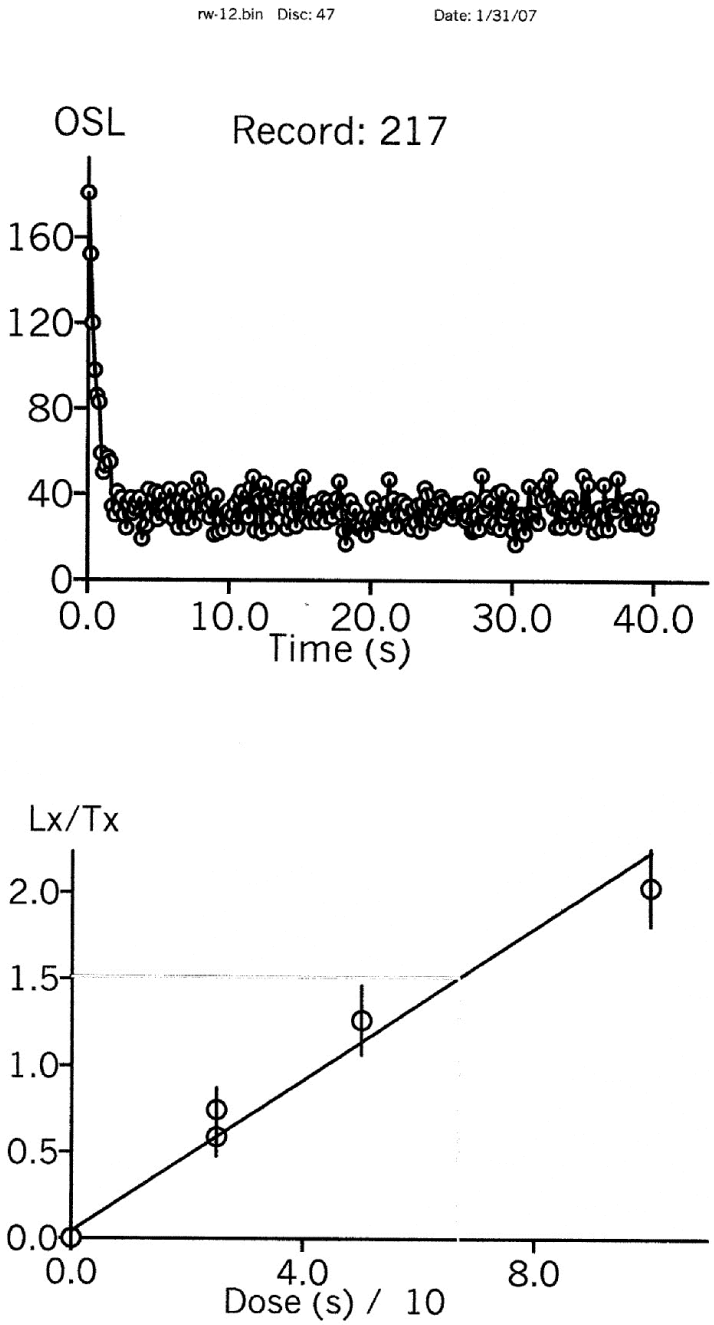

Figure 1a. OSL decay curve for ECT-5, showing quartz signal as measured with blue-light wavelength emitting diodes. Time is measured in seconds (s) and OSL is measured in photons counts/second.

Figure 1b. ECT-5 growth curve, with the natural plotted on the Lx/Tx axis near 1.5 as a gray line. Regeneration proceeded "normally", with a recycle within 22% of the first measurement and increases in responses to increasing beta radiation. Dose is measured in seconds x 10 (not / by 10) and OSL is measured in normalized OSL sensitivity measurements (Lx/Tx).

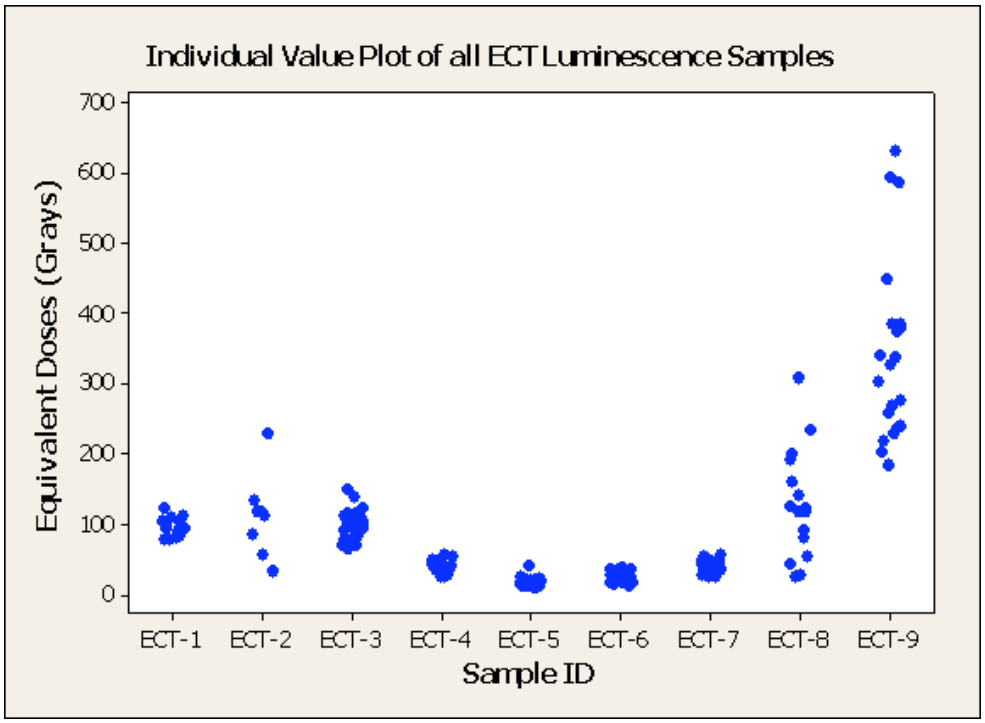

Figure 2. Comparison of dispersion (scatter) in the equivalent doses for the East Canyon Trench samples. Note the small number of aliquots in ECT-2.

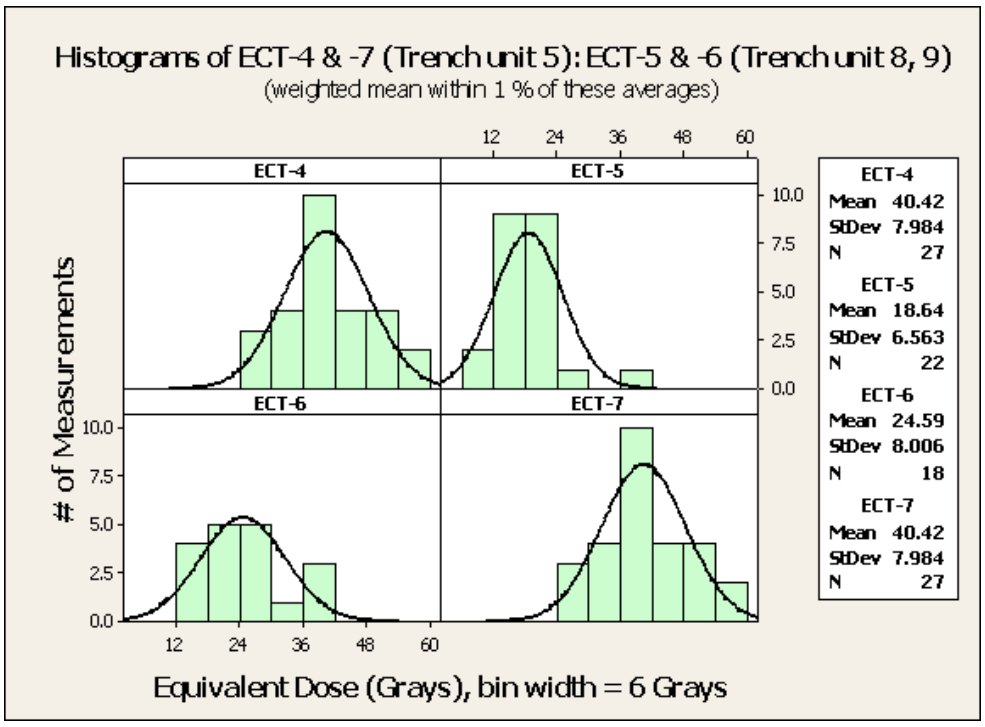

Figure 3. Multiple histograms for the upper trench units (no outliers have been removed).

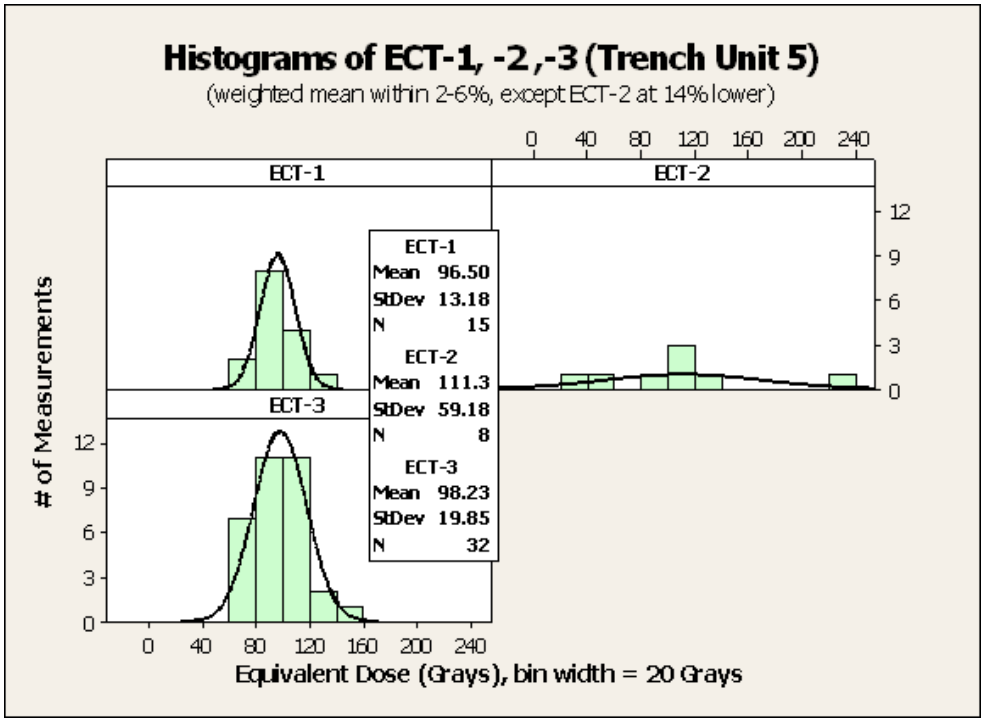

Figure 4. Multiple histograms for the middle trench units (no outliers have been removed).

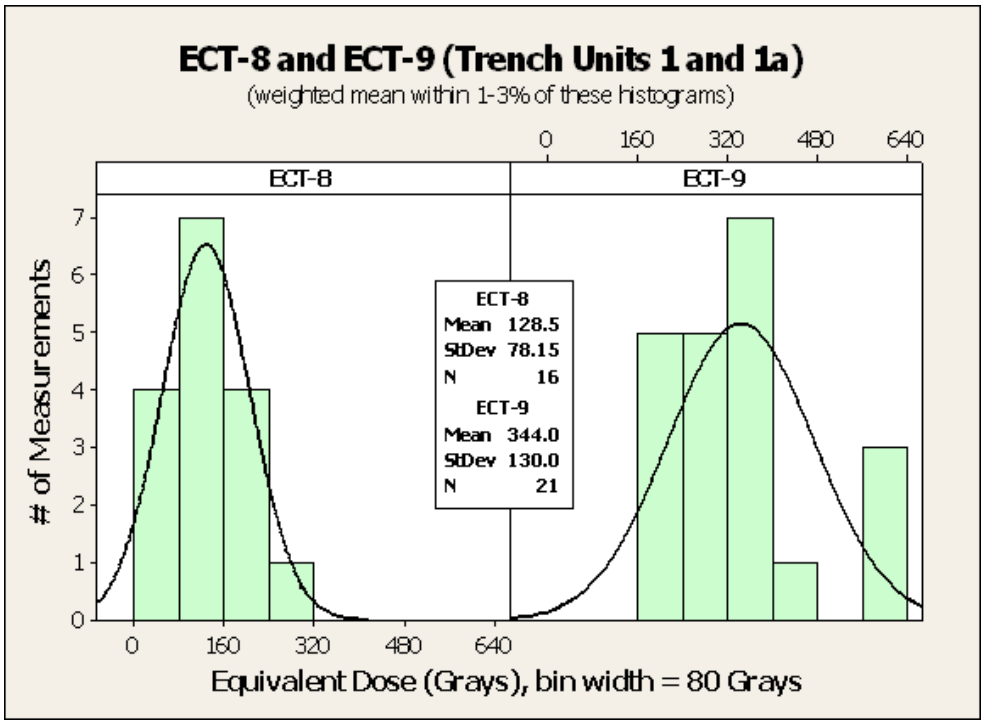

Figure 5. Multiple histograms for the lower trench units (no outliers have been removed).

Attachment A:

General Concepts of Luminescence Dating:

Most minerals react to ionizing radiation by essentially gaining energy at the electron level, which accumulates through time if that energy is not released (as light) by some outside stimuli (sunlight or intense heat over 200°C). Thus, sediment grains can record their exposure history to ionizing radiation, which can then be "read" in the laboratory and used as a clock. This procedure is referred to as luminescence geochronology (Aitken, 1998), the goal of which is to establish the timing of the burial of mineral grains in sedimentary deposits. If the mineral grains were transported at night, in turbid fluvial conditions or in those deposits generally considered to be deposited in massive, sudden discharge events (i.e. debris flows, colluvium, etc.) however, luminescence dating may produce depositional ages that are too old because the luminescence clock was not reset to "zero" just prior to burial.

Luminescence dating is based on solid-state dosimetric properties of natural mineral grains. Minerals react to ionizing radiation, which is generated by radioactive isotopes found in minor quantities in most terrestrial sediments and by cosmic radiation. Specifically, ionizing radiation creates charge pairs/carriers (e-, h+) in mineral crystals. The charge carriers are mobile within the crystals, but can become localized, or trapped, at lattice defects and held there over geologically significant time scales. Over time, the number of segregated, or trapped, charge carriers builds up in a way that can be described by a saturating exponential function.

Exposure to heat, light, or high pressures can release charge carriers from trapping sites and permit recombination, during which light is emitted from the mineral grains. This detrapping resets the system within the mineral grains. In terrestrial environments exposure to sunlight during sediment transport resets the clock and it is also why a

luminescence age is considered a burial age. In the laboratory, sediment is stimulated to emit light, which is measured. The sediment is stimulated by exposure to light of specific wavelengths (optically stimulated luminescence, OSL), or heat (thermoluminescence, TL), in proscribed manners. The intensity of emitted light measured in the laboratory is proportional to the trapped charge population, which is proportional to the total absorbed radiation dose (D_e) that the sedimentary deposit experienced, and that relation is proportional to the time elapsed since burial.

The simplest form of the OSL age equation is:

$$t_{OSL} = \frac{D_e}{D'}$$

where t_{OSL} = *age*
D_e = *total absorbed radiation dose,*
D' = *natural environmental dose rate.*

The accuracy of OSL ages is primarily dependent on the intensity and duration of the sediment grains' exposure to sunlight during transport, often referred to as "resetting" or "bleaching". Traditionally, sediments deposited from fluvial systems have been among the most challenging to date using OSL methods because the grains were not fully bleached prior to burial. Bleaching problems arise from the light filtering effects of water, particularly water turbid with high suspended-sediment concentrations, and from transport at night. A review of studies that used OSL to date fluvial sediments can be found in Wallinga (2002). Unfortunately, many of these studies met with mixed results, yet luminescence dating has important potential because fluvial deposits often lack the foreign objects (charcoal, potsherds, living trees) that are essential for alternative dating methods (e.g. Friedman and others, 2005).

Fortunately, modern luminescence dating equipment and experimental procedures show promise. For example geochronological measurements can be made on small collections of grains, termed single aliquots, or even single grains. This in turn permits hundreds or even thousands of absorbed doses to be determined for individual field samples. These data sets or dose distributions can then be visualized and statistically interrogated. Numerous studies have now documented that “incomplete resetting” or “partial bleaching” manifests itself as positive asymmetry in a sample’s dose distribution (Murray and others, 1995; Olley and others, 1998; Lepper and others, 2000). In these cases, standard measures of central tendency (mean, standard deviation) do not represent the true depositional age of the sediment. At least two analytical tools have been developed that address this issue and attempt to objectively determine a representative dose, including the "zero age model" (Galbraith and others, 1999) and the "leading edge method" (Lepper and McKeever, 2002).

Attachment B:

Particle Size analysis was performed on nine soil samples from trench sites around Park City, Utah.

Samples were submitted as bulk. Because most samples contained small sand - sized clumps, light agitation with a rubber mortar and pestle was performed to aid in disaggregation of the samples as needed.

Prior to analysis, all samples were treated with 30% H_2O_2 to remove organic matter. Sample ECT-L9 was also treated with 15% HCl to remove secondary carbonate.

Sodium hexametaphosphate was added to all samples and the samples were shaken on a shaker table for four hours to ensure deflocculation of the clays.

Particle size was determined using a Malvern Mastersizer-S long bed laser analyzer. The sample was introduced into an aqueous medium and pumped through the laser analyzer for grain size measurements.

After analysis was completed, no sample was retrieved per submitter's instructions. However, remaining un-treated sample has been returned to submitter.

LABORATORY NUMBER	TEST	WT (g)	% SAND	% SILT	% CLAY	TEXTURAL CLASSIFICATION
GRL -	ECT-1	0.50	10.80	49.54	39.66	Clayey Silt
-	ECT-2	0.53	9.89	54.84	35.27	Clayey Silt
-	ECT-3	0.60	19.42	50.43	30.15	Clayey Silt
-	ECT-4	0.56	16.91	51.13	31.96	Clayey Silt
-	ECT-5	0.53	15.44	53.45	31.12	Clayey Silt
-	ECT-6	0.64	14.94	54.82	30.24	Clayey Silt
-	ECT-7	0.45	12.57	54.61	32.82	Clayey Silt
-	ECT-9	0.46	48.68	35.85	15.47	Silty Sand
-	ECT-8	0.84	67.06	18.56	14.38	Silty Sand

Sample weight reported on oven dry basis (105 °C). Sample weight and particle size distribution exclusive of organic matter.
<2000µm material

Tested by Malvern Long Bed Laser Particle Size Analyzer and reported as volume percentage.

NAME: **Shannon Mahan Henefer**

LOCATION: **Utah**

SEDIMENTOLOGY LABORATORY - USGS - ESP
Particle Size Analysis Report –
Wentworth Grade Scale
Malvern Particle Size Analyzer

<2000µ. MINERAL MATERIAL SIZE DISTRIBUTION - PER FRACTION & CUMULATIVE PERCENT

[Size Separates are Expressed In Microns]

MICRONS		GRL -	ECT-1	GRL -	ECT-2	GRL -	ECT-3	GRL -	ECT-4	GRL -	ECT-5	GRL -	ECT-6	GRL -	ECT-L7	GRL -	ECT-L8	GRL -	ECT-L9
2000	1680	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.17	9.17	0.00	0.00
1680	1414	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.50	18.67	0.00	0.00
1414	1189	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.68	30.35	0.00	0.00
1189	1000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.60	39.95	0.00	0.00
1000	841	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.71	46.66	0.00	0.00
841	707	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.03	50.69	0.00	0.00
707	595	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.07	52.76	0.00	0.00
595	500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	53.67	0.00	0.00
500	420	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	53.99	0.12	0.12
420	354	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	54.10	1.37	1.48
354	297	0.00	0.00	0.00	0.00	0.67	0.67	0.46	0.46	0.31	0.31	0.31	0.31	0.31	0.31	0.24	54.34	3.11	4.59
297	250	0.06	0.07	0.00	0.00	1.38	2.05	0.99	1.44	0.65	0.96	0.61	0.93	0.54	0.84	0.56	54.90	4.23	8.82
250	210	0.42	0.49	0.03	0.03	1.79	3.84	1.30	2.74	0.98	1.94	0.90	1.83	0.76	1.60	0.94	55.84	4.94	13.76
210	177	0.71	1.20	0.22	0.25	1.79	5.63	1.33	4.07	1.08	3.02	0.97	2.79	0.78	2.38	1.20	57.04	5.08	18.84
177	149	1.02	2.22	0.60	0.85	1.69	7.32	1.33	5.40	1.16	4.18	1.02	3.81	0.80	3.18	1.40	58.44	5.15	23.98
149	125	1.29	3.52	0.93	1.78	1.68	9.00	1.45	6.85	1.33	5.51	1.18	4.99	0.93	4.12	1.57	60.01	5.23	29.22
125	105	1.49	5.01	1.26	3.04	1.86	10.86	1.72	8.57	1.65	7.17	1.54	6.53	1.24	5.36	1.67	61.68	5.15	34.36
105	88	1.72	6.72	1.75	4.79	2.33	13.19	2.25	10.82	2.21	9.38	2.16	8.69	1.80	7.16	1.81	63.49	5.12	39.48
88	74	1.95	8.67	2.33	7.12	2.92	16.11	2.85	13.66	2.83	12.21	2.88	11.56	2.46	9.62	1.84	65.33	4.88	44.36
74	63	2.13	10.80	2.78	9.89	3.31	19.42	3.24	16.91	3.24	15.44	3.38	14.94	2.95	12.57	1.73	67.06	4.32	48.68
63	53	2.68	13.48	3.61	13.50	4.12	23.54	4.03	20.93	4.03	19.47	4.27	19.21	3.81	16.38	1.82	68.88	4.34	53.02
53	44	3.34	16.82	4.46	17.96	4.72	28.26	4.75	25.68	4.75	24.22	5.08	24.29	4.63	21.01	1.86	70.74	4.23	57.25
44	37	3.44	20.27	4.46	22.42	4.35	32.61	4.43	30.12	4.57	28.79	4.90	29.19	4.55	25.56	1.59	72.33	3.49	60.73
37	31.2	3.57	23.83	4.45	26.87	4.16	36.77	4.18	34.29	4.33	33.12	4.63	33.82	4.46	30.02	1.41	73.74	3.00	63.73
31.2	26.3	3.61	27.44	4.24	31.10	3.93	40.70	3.95	38.24	4.09	37.21	4.33	38.15	4.21	34.23	1.26	75.00	2.62	66.35
26.3	22.1	3.52	30.97	4.02	35.13	3.69	44.39	3.71	41.95	3.88	41.08	4.06	42.20	3.97	38.20	1.15	76.15	2.32	68.67
22.1	18.6	3.32	34.29	3.68	38.81	3.32	47.71	3.35	45.30	3.54	44.62	3.65	45.85	3.62	41.82	1.04	77.19	2.04	70.71
18.6	15.6	3.21	37.50	3.46	42.26	3.06	50.76	3.09	48.39	3.31	47.93	3.37	49.22	3.39	45.20	0.98	78.17	1.88	72.58

15.6	13.1	3.03	40.53	3.18	45.44	2.77	53.54	2.81	51.20	3.03	50.96	3.04	52.26	3.10	48.31	0.94	79.11	1.73	74.31
13.1	11	2.92	43.46	2.99	48.43	2.58	56.12	2.62	53.82	2.84	53.81	2.82	55.08	2.92	51.23	0.92	80.03	1.64	75.96
11	9.3	2.75	46.21	2.76	51.19	2.36	58.48	2.41	56.23	2.61	56.41	2.56	57.64	2.69	53.92	0.89	80.92	1.52	77.48
9.3	7.8	2.87	49.07	2.83	54.03	2.40	60.88	2.46	58.69	2.65	59.06	2.59	60.23	2.76	56.68	0.95	81.87	1.55	79.03
7.8	6.6	2.73	51.80	2.65	56.68	2.24	63.12	2.31	60.99	2.46	61.52	2.40	62.63	2.59	59.27	0.91	82.78	1.43	80.46
6.6	5.5	2.98	54.78	2.86	59.54	2.40	65.52	2.49	63.48	2.63	64.14	2.55	65.18	2.80	62.06	1.00	83.78	1.49	81.95
5.5	4.6	2.91	57.69	2.74	62.28	2.29	67.81	2.40	65.88	2.51	66.65	2.42	67.60	2.69	64.76	0.97	84.75	1.38	83.33
4.6	3.9	2.65	60.34	2.45	64.73	2.04	69.85	2.16	68.04	2.24	68.89	2.15	69.76	2.42	67.18	0.87	85.62	1.20	84.53
3.9	3.3	2.61	62.95	2.39	67.12	1.98	71.83	2.11	70.15	2.17	71.06	2.08	71.84	2.36	69.54	0.85	86.47	1.12	85.65
3.3	2.8	2.49	65.44	2.24	69.36	1.85	73.69	1.99	72.13	2.04	73.09	1.95	73.79	2.23	71.77	0.79	87.26	1.01	86.66
2.8	2.3	2.86	68.30	2.53	71.89	2.09	75.77	2.25	74.38	2.30	75.39	2.19	75.98	2.52	74.29	0.89	88.15	1.10	87.76
2.3	1.95	2.31	70.61	2.01	73.90	1.64	77.41	1.78	76.16	1.81	77.20	1.73	77.72	1.99	76.27	0.70	88.85	0.84	88.60
1.95	1.64	2.34	72.96	2.01	75.91	1.63	79.04	1.77	77.92	1.79	78.99	1.72	79.44	1.97	78.24	0.69	89.54	0.80	89.40
1.64	1.38	2.27	75.23	1.94	77.85	1.55	80.59	1.67	79.60	1.69	80.69	1.64	81.08	1.86	80.11	0.65	90.19	0.73	90.13
1.38	1.16	2.21	77.43	1.87	79.73	1.48	82.06	1.59	81.19	1.61	82.30	1.58	82.66	1.77	81.87	0.62	90.81	0.68	90.80
1.16	0.98	2.05	79.48	1.75	81.48	1.37	83.44	1.47	82.66	1.48	83.78	1.46	84.12	1.62	83.49	0.59	91.40	0.62	91.42
0.98	0.82	2.07	81.56	1.80	83.28	1.40	84.84	1.49	84.15	1.50	85.28	1.49	85.61	1.62	85.11	0.61	92.01	0.63	92.04
0.82	0.69	1.93	83.48	1.72	85.00	1.33	86.17	1.40	85.56	1.42	86.70	1.41	87.02	1.50	86.61	0.59	92.60	0.59	92.64
0.69	0.58	1.89	85.37	1.75	86.74	1.37	87.53	1.43	86.99	1.45	88.15	1.43	88.45	1.51	88.12	0.64	93.24	0.62	93.26
0.58	0.49	1.84	87.21	1.76	88.51	1.40	88.93	1.46	88.45	1.48	89.62	1.45	89.89	1.52	89.64	0.68	93.92	0.65	93.91
	<0.49	12.80	100.00	11.49	100.00	11.07	100.00	11.55	100.00	10.38	100.00	10.11	100.00	10.36	100.00	6.08	100.00	6.09	100.00

Table 1. Gamma spectrometry analysis, cosmic and total dose rate, equivalent dose and age for ECT OSL samples.

Sample #	K%	Th (ppm)	U (ppm)	Water (%)[a]	Cosmic dose rate (Gy/ka)[b]	Total dose rate (Gy/ka)[c]	De (Gy)[d]	N[e]	Age (ka)[f]
ECT-L5	2.27 ± 0.11	12.5 ± 0.33	3.58 ± 0.13	5 (48)	0.26 ± 0.02	3.59 ± 0.07	18.6 ± 1.22	22 (30)	5.17 ± 0.35[e]
ECT-L6	3.23 ± 0.06	12.1 ± 0.33	3.30 ± 0.12	13 (57)	0.27 ± 0.02	4.28 ± 0.07	24.6 ± 1.15	29 (35)	5.75 ± 0.28[e]
ECT-L4	2.15 ± 0.07	12.5 ± 0.32	3.47 ± 0.12	9 (74)	0.26 ± 0.02	3.31 ± 0.06	44.3 ± 1.94	24 (28)	13.4 ± 1.06[e]
ECT-L7	1.62 ± 0.14	11.3 ± 0.27	2.54 ± 0.11	10 (54)	0.26 ± 0.02	2.78 ± 0.06	40.9 ± 3.11	27 (35)	14.7 ± 0.73[e]
ECT-L3	1.82 ± 0.12	12.0 ± 0.27	3.23 ± 0.12	9 (68)	0.25 ± 0.02	2.98 ± 0.05	92.6 ± 2.18	30 (37)	31.1 ± 2.14[e]
ECT-L2	1.50 ± 0.05	11.3 ± 0.29	3.16 ± 0.11	13 (58)	0.23 ± 0.02	2.65 ± 0.05	96.0 ± 6.21	8 (20)	36.2 ± 2.49[f]
ECT-L1	1.36 ± 0.06	10.8 ± 0.27	2.55 ± 0.10	15 (51)	0.21 ± 0.02	2.50 ± 0.04	94.2 ± 2.36	15 (15)	37.7 ± 2.86[f]
ECT-L8	1.56 ± 0.14	11.1 ± 0.23	2.38 ± 0.11	7 (51)	0.24 ± 0.02	2.67 ± 0.05	>127 ± 5.02	16 (29)	>47.6 ± 4.04[e]
ECT-L9	1.68 ± 0.09	11.0 ± 0.24	2.80 ± 0.10	7 (34)	0.24 ± 0.02	2.84 ± 0.05	>334 ± 8.34	21 (24)	>118 ± 5.66[e]

[a]Moisture value used in calculation of age (usually 45% of total saturation, except ECT-9 which was 60%). Figures in parentheses indicate the complete sample saturation %.

[b]Analyses obtained using laboratory Gamma spectrometry (low resolution NaI).

[c] Cosmic doses and attenuation with depth were calculated using the methods of Prescott and Stephans (1982) and Prescott and Hutton (1994). See text for details.

[d]Number of replicated equivalent dose (De) estimates used to calculate the mean. Figures in parentheses indicate total number of measurements made including failed runs with unusable data.

[e]Dose rate and age for fine-grained 90-125 μm quartz sand. Linear and exponential fit used on age, errors to one sigma.

[f]Dose rate and age for fine-grained 90-250 μm quartz sand. Exponential fit used on age, errors to one sigma.

Appendix F.
Examination of Bulk Soil and AMS Radiocarbon Analysis of Material From Trench Across the Main Canyon Fault, Utah

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EXAMINATION OF BULK SOIL AND AMS RADIOCARBON ANALYSIS OF MATERIAL FROM EAST CANYON TRENCH, UTAH

By

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With Assistance from
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Paleo Research Institute Technical Report 06-95

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Bureau of Reclamation
Reclamation Service Center
Denver, Colorado

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A total of eight bulk soil samples from the East Canyon Trench in Summit County, Utah, were floated to recover organic fragments suitable for radiocarbon analysis. These samples were recovered from tenches along the East Canyon fault, a northeast-trending range-front fault generally bounding the northern side of the intermontane valley between East Canyon and Croyden in the Wasatch Range (Black and Hecker 1999). Botanic components and detrital charcoal were identified, and potentially radiocarbon datable material was separated. One sample of charred organic material was processed for AMS radiocarbon analysis.

The bulk samples were floated using a modification of the procedures outlined by Matthews (1979). Each sample was added to approximately 3 gallons of water. The sample was stirred until a strong vortex formed, which was allowed to slow before pouring the light fraction through a 150 micron mesh sieve. Additional water was added and the process repeated until all visible macrofloral material was removed from the sample (a minimum of five times). The material that remained in the bottom (heavy fraction) was poured through a 0.5-mm mesh screen. The floated portions were allowed to dry.

The light fractions were weighed, then passed through a series of graduated screens (US Standard Sieves with 4-mm, 2-mm, 1-mm, 0.5-mm and 0.25-mm openings to separate charcoal debris and to initially sort the remains. The contents of each screen were then examined. Charcoal pieces larger than 1-mm in diameter were broken to expose a fresh cross section and examined under a binocular microscope at a magnification of 70x. The remaining light fraction in the 4-mm, 2-mm, 1-mm, 0.5-mm, and 0.25-mm sieves was scanned under a binocular stereo microscope at a magnification of 10x, with some identifications requiring magnifications of up to 70x. The material that passed through the 0.25-mm screen was not examined. The coarse or heavy fractions also were screened and examined for the presence of botanic remains. Remains from both the light and heavy fractions were recorded as charred and/or uncharred, whole and/or fragments. Individual detrital charcoal/wood samples also were broken to expose a fresh cross-section and examined under a binocular microscope at a magnification of 70x.

Macrofloral remains, including charcoal, were identified using manuals (Core, et al. 1976; Martin and Barkley 1961; Panshin and Zeeuw 1980; Petrides and Petrides 1992) and by comparison with modern and archaeological references. The term "seed" is used to represent seeds, achenes, caryopses, and other disseminules. Because charcoal and possibly other botanic remains were to be sent for radiocarbon dating, clean laboratory conditions were used during flotation and identification to avoid contamination. All instruments were washed between samples, and samples were protected from contact with modern charcoal.

Wood and charcoal samples submitted for radiocarbon dating are weighed prior to selecting subsamples for pre-treatment. The remainder of each sample is permanently curated at Paleo Research. The subsample selected for pre-treatment is first subjected to hot (at least 110 °C), 6N hydrochloric acid (HCl), with rinses to neutral between each HCl treatment, until the supernatant is clear. This removes iron compounds and calcium carbonates that would hamper removal of humate compounds later. Next the samples are subjected to 5% potassium hydroxide (KOH) to remove humates. Once again, the samples are rinsed to neutral and re-acidified with pH 2 HCl between each KOH step. This step is repeated until the supernatant is clear, signaling removal of all humates. After humate removal, each sample is made slightly acidic and left that way for the next step. Charcoal samples (but not wood samples) are subjected to a concentrated, hot nitric acid bath, which removes all modern and recent organics. This treatment is not used on unburned or partially burned wood samples because it oxidizes the submitted sample of unknown age.

Each submitted sample is then freeze-dried using a vacuum system, freezing out all moisture at -98 °C. Each individual sample is combined with cupric oxide (CuO) and elemental silver (Ag^o) in a quartz tube, then flame sealed under vacuum.

Standards and laboratory background samples also are treated in the same manner as the wood and charcoal samples of unknown age. A radiocarbon "dead" EUA wood blank from Alaska that is more than 70,000 years old (currently beyond the detection capabilities of AMS) is treated using the same chemical processing as the samples of unknown age in order to calibrate the laboratory correction factor. Standards of known age, such as Two Creeks wood that dates to 11,400 RCYBP and others from the Third International Radiocarbon Intercomparison (TIRI), are also processed simultaneously to establish the laboratory correction factor. Each wood standard is run in a quantity similar to the submitted samples of unknown age and sealed in a quartz tube after the requisite pre-treatment. Once all the wood standards, blanks, and submitted samples of unknown age are prepared and sealed in their individual quartz tubes, they are combusted at 820 °C, soaked for an extended period of time at that temperature, and then slowly allowed to cool to enable the chemical reaction that extracts carbon dioxide ($C0_2$) gas.

Following this last step, all samples of unknown age, the wood standards, and the laboratory backgrounds are sent to the Keck Carbon Cycle AMS Facility at the University of California, Irvine, where the $C0_2$ gas is processed into graphite. The graphite in these samples is then placed in the target and subjected to a cesium ion beam, which produces the numbers that are converted into the radiocarbon date presented in the data section. Dates are presented as conventional radiocarbon ages, as well as calibrated ages using Intcalc05 curves on Oxcal v.3.10.

Infrared (IR) spectrometry has been experiencing a renaissance for identifying organic substances during the past few decades. Today it is considered one of the more powerful tools in organic and analytical chemistry.

Fourier Transform infrared spectrometry (FTIR) is performed using a Nicolet 6700 optical bench with an ATR and a zinc selenoid crystal for examining organic remains. Sediments are measured using a silicon crystal. The sample is placed in the path of a specially encoded infrared beam. The infrared beam passes through the sample and produces a signal called an "inferogram." The inferogram contains information about the frequencies of infrared that are absorbed and the strength of the absorptions, which is determined by the sample's chemical make-up. A computer reads the inferogram and uses Fourier transformation to decode the intensity information for each frequency (wave numbers) and presents a spectrum.

One of the primary advantages to the FTIR is that it measures all wave lengths simultaneously. It has a relatively high signal-to-noise ratio and a short measurement time. Each peak in the spectrum represents either a chemical bond or a functional group. Samples containing many compounds are more difficult to identify – and many archaeological samples are complex mixtures. Mixtures sometimes have many absorption bands, which overlap, yielding only broad envelopes of adsorption and few distinctive features. Each spectrum collected from a sample is considered to serve as a chemical fingerprint. Comparison of this spectrum with a set of standard spectra, as well as a reference library that is continually being expanded, provides information critical to identifying the unknown material. Carbohydrates, lipids, proteins, etc. all are associated with specific wave number bands (Isaksson 2000:36-39). Identifying geologic materials, such as asphaltum, is simpler than working with the combinations of materials often found in archaeological samples.

The East Canyon fault is located between East Canyon and Croyden in the Wasatch Range, northeast Utah. Local vegetation in this area is dominated by sagebrush (*Artemisia*) and grasses (Poaceae). Eight samples from Trenches 5, 8, and 9 were analyzed for organic material that could be submitted for AMS radiocarbon analysis.

Sample ECT-C1 was recovered from Unit 5d - lower (Table 1). The only organic material present in this sample were a few uncharred rootlets from modern plants (Table 2). A moderate amount of possible asphaltum spheres were noted, as well as two pieces of coal. Natural asphaltum in eastern Utah is called gilsonite or uintahite.

Sample ECT-C2 from Unit 5d - upper yielded numerous possible asphaltum spheres and one piece of coal. One uncharred Boraginaceae seed (Table 3), a few Poaceae leaf/stem fragments, and a few uncharred rootlets represent modern plants. No charred organic material suitable for AMS radiocarbon analysis was present.

Sample ECT-C3 was collected from the lower portion of Unit 5e. This sample yielded six small fragments of charcoal too small for identification weighing less than 0.001 g. One piece of unidentified root charcoal weighing less than 0.001 g also was present. These charcoal fragments were too small for AMS radiocarbon dating. In addition, the sample contained a few uncharred rootlets from modern plants, a few possible asphaltum spheres, a piece of coal, and a rodent tooth fragment.

Four pieces of charcoal too small for identification and weighing less than 0.001 g were present in sample ECT-C4 from the upper portion of Unit 5e. One piece of charred PET fruity tissue weighing less than 0.001 g also was present. The term PET (processed edible tissue) was originated by Nancy Stenholm (1994) and refers to softer tissue types, such as starchy parenchymoid or fruity epitheloid tissues. PET fruity tissues resemble sugar-laden fruit or berry tissue without the seeds, as well as tissue from succulent plant parts such as cactus pads. A few uncharred roots and rootlets represent modern plants. Non-floral remains include a moderate amount of possible asphaltum spheres, a coal fragment, and one piece of rodent tooth enamel.

Samples ECT-C7 and ECT-C8 also were recovered from Unit 5. Sample ECT-C7 contained numerous possible asphaltum spheres, as well as a few uncharred roots and rootlets from modern plants.

Eight charred, vitrified monocot/herbaceous dicot stem fragments were present in sample ECT-C8. Vitrified material has a shiny, glassy appearance due to fusion by heat. These stem fragments weighed 0.018 g and were processed for AMS radiocarbon analysis. A conventional AMS radiocarbon date of 10280 ± 25 RC yr. BP (PRI-06-95-C8) was returned for the charred stem fragments, with a two-sigma calibrated date of 12160-11970 CAL yr. BP (Table 4, Figure 1). In addition, the sample yielded a moderate amount of possible asphaltum spheres and a few uncharred rootlets from modern plants.

Sample ECT-C5 from Unit 8 yielded several fragments of charcoal weighing less than 0.001 g. These charcoal fragments were too small for identification and too small for AMS radiocarbon dating. A few possible asphaltum spheres and a few uncharred roots and rootlets from modern plants also were present.

Sample ECT-C6 was collected from Unit 9. Organic remains in this sample consist of a moderate amount of uncharred rootlets from modern plants. Non-floral remains include a moderate amount of possible asphaltum spheres, two small fragments of coal, and one insect chitin fragment.

Fourier Transform infrared spectrometry (FTIR) was performed on the possible asphaltum spheres from sample ECT-C6. The spectrum obtained from this sample was compared to spectra from street asphalt, California asphaltum, and historic coal. No gilsonite currently is available for comparison. The spectrum from sample ECT-C6 compared most favorably with that from asphalt collected in the street (Figure 2). Asphalt in Colorado is made using natural asphalt obtained from Wyoming, the Colorado Basin in western Colorado, Kansas, Texas, Oklahoma, and others (personal communication, Tom Clayton, Colorado Asphalt Pavement Association, February 13, 2007).

Flotation of bulk samples from East Canyon Trench in northeast Utah resulted in recovery of very few charred organic remains. Charcoal was present in three of the samples; however, these charcoal fragments were too small for dating. Sample ECT-C8 yielded charred monocot/herbaceous dicot stem fragments in sufficient quantities for AMS radiocarbon dating.

These charred stem fragments yielded a conventional AMS radiocarbon date of 10280 ± 25 RC yr. BP (PRI-06-95-C8). All of the samples yielded varying amounts of possible asphaltum spheres that might represent a natural asphalt in northeast Utah called gilsonite. Initial FTIR analysis of this material from sample ECT-C6 compared most favorably with street asphalt. Further comparisons will be made when a sample or spectrum of gilsonite is available.

TABLE 1
PROVENIENCE DATA FOR SAMPLES FROM EAST CANYON TRENCH, UTAH

Sample No.	Trench Unit No.	Context/Significance; Morphologic/Sedimentary Constraints	Analysis
ECT-C1	5d (lower)	Pre-event 1 sed	Float/Charcoal ID
ECT-C2	5d (upper)	Pre-event 1 sed/soil	Float/Charcoal ID
ECT-C3	5e (lower)	Event 1 sed/wedge; Sedimentation appears continuous throughout Unit 5	Float/Charcoal ID
ECT-C4	5e (upper)	Sed/soil buried by MRE; Faulted, minimal overlying sediment/soils	Float/Charcoal ID
ECT-C7	5	Sed/soil buried by MRE; Faulted, minimal overlying sediment/soils	Float/Charcoal ID
ECT-C8	5	Sed/soil buried by MRE; Faulted, minimal overlying sediment/soils	Float/Charcoal ID AMS ^{14}C analysis
ECT-C5	8	Post-MRE sediments; Minimal soil development	Float/Charcoal ID
ECT-C6	9	Post-MRE sediments; Minimal soil development	Float/Charcoal ID

TABLE 2
MACROFLORAL REMAINS IN SAMPLES FROM EAST CANYON TRENCH, UTAH

Sample No.	Identification	Part	Charred		Uncharred		Weights/ Comments
			W	F	W	F	
C-1	Liters Floated						2.60 L
Unit 5d	Light Fraction Weight						0.67 g
(Lower)	FLORAL REMAINS:						
	Rootlets					X	Few
	NON-FLORAL REMAINS:						
	cf. Asphaltum - spheroid				X		Moderate
	Coal					2	0.040 g
	Rock/Gravel					X	Moderate
C-2	Liters Floated						2.40 L
Unit 5d	Light Fraction Weight						0.79 g
(Upper)	FLORAL REMAINS:						
	Boraginaceae	Seed			1		
	Poaceae	Leaf/stem				X	Few
	Rootlets					X	Few
	NON-FLORAL REMAINS:						
	cf. Asphaltum - spheroid					X	Numerous
	Coal					1	0.019 g
	Rock/Gravel					X	Moderate
C-3	Liters Floated						2.40 L
Unit 5e	Light Fraction Weight						0.31 g
(Lower)	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Unidentifiable - small	Charcoal		6			<0.001 g
	Unidentified root	Charcoal		1			<0.001 g
	NON-FLORAL REMAINS:						
	cf. Asphaltum - spheroid				X		Few
	Coal					1	0.008 g
	Rock/Gravel					X	Moderate
	Rodent tooth					1	

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred		Uncharred		Weights/ Comments
			W	F	W	F	
C-4	Liters Floated						2.40 L
Unit 5e	Light Fraction Weight						2.51 g
(Upper)	FLORAL REMAINS:						
	PET Fruity	Tissue		1			<0.001 g
	Roots					X	Few
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Unidentifiable - small	Charcoal		4			<0.001 g
	NON-FLORAL REMAINS:						
	cf. Asphaltum - spheroid				X		Moderate
	Coal					1	0.002 g
	Rock/Gravel					X	Moderate
	Rodent tooth enamel					1	
C-7	Liters Floated						2.10 L
Unit 5	Light Fraction Weight						0.71 g
	FLORAL REMAINS:						
	Roots					X	Few
	Rootlets					X	Few
	NON-FLORAL REMAINS:						
	cf. Asphaltum - spheroid					X	Numerous
	Rock/Gravel					X	Few
C-8	Liters Floated						2.60 L
Feature	Light Fraction Weight						0.29 g
Unit 5	FLORAL REMAINS:						
	Monocot/Herbaceous dicot - vitrified **	Stem		8			0.018 g
	Rootlets					X	Few
	NON-FLORAL REMAINS:						
	cf. Asphaltum - spheroid					X	Moderate
	Rock/Gravel					X	Few

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred		Uncharred		Weights/ Comments
			W	F	W	F	
C-5	Liters Floated						2.75 L
Feature	Light Fraction Weight						2.00 g
Unit 8	FLORAL REMAINS:						
	Root					1	
	Rootlets					X	Moderate
	CHARCOAL/WOOD:						
	Unidentifiable - small	Charcoal		14			<0.001 g
	NON-FLORAL REMAINS:						
	cf. Asphaltum - spheroid					X	Few
	Rock/Gravel					X	Few
C-6	Liters Floated						2.40 L
Unit 9	Light Fraction Weight						2.01 g
	FLORAL REMAINS:						
	Rootlets					X	Moderate
	NON-FLORAL REMAINS:						
	cf. Asphaltum - spheroid					X	Moderate
	Coal					2	0.01 g
	Insect	Chitin				1	
	Rock/Gravel					X	Few

W = Whole
F = Fragment
X = Presence noted in sample
L = Liters
g = grams
* = Estimated frequency
** = Submitted for AMS radiocarbon dating

TABLE 3
INDEX OF MACROFLORAL REMAINS RECOVERED FROM EAST CANYON TRENCH, UTAH

Scientific Name	Common Name
FLORAL REMAINS:	
Boraginaceae	Borage family
Monocot/Herbaceous dicot	A member of the Monocotyledonae class of Angiosperms, which include grasses, sedges, lilies and palms/A non-woody member of the Magnoliopsida class of Angiosperms, which is characterized by embryos with two cotyledons
Poaceae	Grass family
PET fruity tissue	Fruity epitheloid tissues; resemble sugar-laden fruit or berry tissue without the seeds, or succulent plant tissue such as cactus pads

TABLE 4
RADIOCARBON RESULTS FROM EAST CANYON TRENCH, UTAH

Sample No.	Sample Identification	AMS ^{14}C Date*	1-sigma Calibrated Date (68.2%)	2-sigma Calibrated Date (95.4%)	$\delta^{13}C$ ($^{o}/_{oo}$)
ECT-C8	Monocot/Herbaceous dicot stem - vitrified	10280 ± 25 RC yr. BP	12095-11995 CAL yr. BP	12160-11970 CAL yr. BP	-22.4

* Reported in radiocarbon years at 1 standard deviation measurement precision (68.2%), corrected for $\delta^{13}C$

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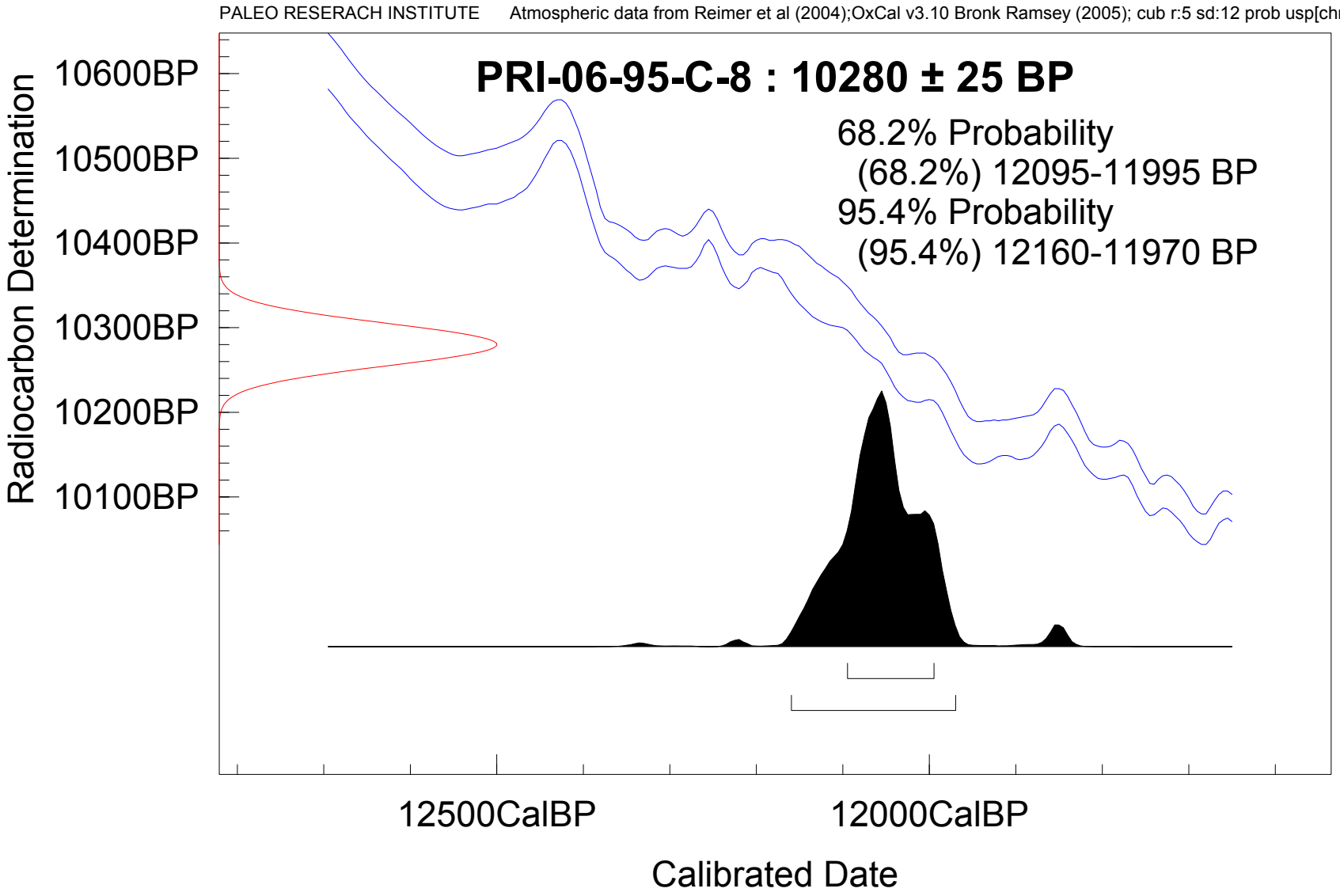

FIGURE 1. AMS RADIOCARBON RESULTS FROM EAST CANYON TRENCH, UTAH.

Appendix G.
Analyses on Asphaltum Samples From Trench Across Main Canyon Fault, Summit County, Utah

This appendix includes the following reports on asphaltum samples from the trench across the Main Canyon fault:

Report G-1.
Geochemical Analysis of an Asphaltum Sample, Summit County, Utah
By
B.M. Jarvie and D.M.Jarvie
Humble Instruments & Services, Inc.
Humble Geochemical Services Division
Humble, Texas

Report G-2.
FTIR Spectrum Analyses for Asphaltum in Sample ECT-C6
By
Paleo Research Institute
Golden, Colorado

Report G-1.
Geochemical Analysis of an Asphaltum Sample, Summit County, Utah

By
B.M. Jarvie and D.M.Jarvie
Humble Instruments & Services, Inc.
Humble Geochemical Services Division
Humble, Texas

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Geochemical Analysis of an Asphaltum Sample, Summit County, Utah

Prepared for U.S. Bureau of Reclamation

Prepared by B.M. Jarvie & D.M. Jarvie

Project 07-4355
Humble Geochemical Services Division
Humble Instruments & Services, Inc.

February, 2007

Interpretative Summary

Whole Extract Gas Chromatography (GC) and Gas Chromatography-Mass Spectrometry (GC-MS) has been performed on a sample (#ECT-C7) identified as asphaltum spheroids from a backhoe trench outcrop locality in Summit County, Utah. The sample was submitted for analysis by the U.S. Bureau of Reclamation and is noted as being found in Holocene aged alluvium at a depth of 0.7 meters. The sample provided for analysis was crushed in a mortar under solvent to rapidly extract the asphaltum and the recovered product was very light yellow in color. The limited amounts of extract precluded quantification and subsequent fractional liquid chromatographic separation techniques could not be applied.

To address the origin of this asphaltum sample, the extract was initially analyzed by GC to examine its hydrocarbon fingerprint (all data documented in the attachments to this report). The whole extract gas chromatographic fingerprint shows relatively abundant hydrocarbon components, along with low molecular weight aromatics and some unidentified peaks. Most of the major peaks are identified by abbreviation and consist predominantly of normal alkanes such as n-C_{13}, which is the predominant peak in the gas chromatogram. The alkane envelope is generally unimodal and extends from n-C_{13} to n-C_{29}. Attenuation of lower molecular weight components is attributable to weathering effects associated with this outcrop sample. Branched chain isoprenoids are also abundant in the asphaltum extract. The distribution of these isoprenoid biomarkers, such as pristane and phytane, can be used to assess source rock kerogen type and depositional environment. These ratios (Pr/Ph = 1.24) are generally indicative of an origin from low sulfur marine shale source rocks containing predominant Type II marine algal organic matter deposited under oxic to sub-oxic conditions, however, they are not entirely unique and other source rock types (e.g. lacustrine) can also have similar ratios.

The relatively wide distribution of alkanes indicates minimal secondary alteration effects on the extract from processes such as biodegradation. Further, this pattern is not typical of processed petroleum products, such as diesel, which tend to have narrow boiling point ranges due to fractional distillation during processing. Catalytic hydrocracking during processing also typically produces a complex and wide range of branched chained components that have rather diagnostic fingerprints. These features also appear to be missing from the asphaltum sample, although it contains abundant isoprenoids in a pattern common to naturally occurring crude oils. Low molecular weight aromatic compounds, such as toluene and xylenes are present in this extract and several unidentified peaks elsewhere in the chromatogram also likely represent aromatic or other functionalized hydrocarbon compounds (eg. the major peak just past n-C_{28}).

With preliminary GC analysis suggesting that the asphaltum was not a processed hydrocarbon sample, but likely represented a natural crude oil seep, further GC-MS biomarker analyses were undertaken. The patterns commonly found in saturated hydrocarbons, such as the steranes and hopanes, were analyzed in the whole extract using a single ion monitoring GC-MS program. The amounts of steranes and hopanes are considered low (judging from the moderately high signal/noise ratio) and they appear to possibly have some cross-over contamination from unidentified compounds. However, the patterns present are typical of natural crude oils and further support the interpretative conclusion that this asphaltum does not represent a processed hydrocarbon sample.

Steranes are dominated by the C_{27} regular sterane series of compounds, with relatively low abundances of the diasteranes. This pattern is typical of many marine carbonate sourced crude oils commonly associated with Cretaceous aged source rocks, but is also found in some lacustrine source rocks, such as the saline facies oil shales in the Green River

Formation. Some sterane maturity ratios, such as the C_{29} 20S/(S+R), appear to be near their thermal endpoint values of ~0.5, suggesting a peak oil window maturity. However, all sterane maturity ratios are not consistent due to relatively poor data quality. In general, the overall pattern within the sterane chromatograms is consistent with the asphaltum originating from thermally mature natural crude oil seep.

Hopane distributions show approximately equal abundances of tricyclic terpanes and pentacyclic hopanes. The hopanes are dominated by C_{30} hopane, with lesser amounts of the C_{29} norhopane. The biomarker gammacerane appears to be present in these sample, which is used to infer anoxic depositional conditions and is commonly found in lacustrine source rocks, such as the Tertiary Green River Formation. The Ts/Tm hopane maturity ratio shows depleted amounts of Tm indicating a peak oil window thermal maturity. This assessment is corroborated by C_{32} S/(S+R) terpane ratios that appear to have reached their thermal endpoints.

In summary, based on whole extract GC and GC-MS analyses the asphaltum sample collected from Summit County, Utah appears to be some type of a natural crude oil seep. The geochemical analyses are certainly not unequivocal, due to the generally insoluble nature of the asphaltum and low yields of extract recovered. However, the molecular fingerprints from the asphaltum show distributions of hydrocarbons, including alkanes, that are typical of natural crude oils and unlike processed hydrocarbon samples. Biomarker patterns in the steranes and hopanes also show distributions of compounds typical for natural crude oils of peak oil window maturity and further indicate that the asphaltum is not contamination from processed hydrocarbons nor associated with bitumen seepage from a low maturity source rock (eg. gilsonite type deposits located elsewhere in Utah). Although the extract from the asphaltum shows no indications of extensive secondary alteration by biodegradation, attenuation of low molecular weight compounds has undoubtedly occurred as a consequence of near-surface exposure. Such devolatilization may also explain the relatively insoluble nature of the asphaltum, although further quantitative experimentation and other analytical techniques, such as thermal extract gas chromatography (TE-GC) and/or pyrolysis gas chromatography (Py-GC) would need to be applied to address this aspect in more detail.

Experimental Methods

Extraction

Samples were extracted using carbon disulfide as a solvent. The samples were crushed in a mortar and pestle under solvent, filtered to remove and residual solid material and evaporated to a an ~1 ml aliquot size.

Whole Fluid Chromatography

Gas chromatography may be completed on whole extract or oil samples as well as on the saturate or aromatic fractions. Gas chromatography is performed using HP 6890 Series GC System with high-resolution column (50 m, PONA phase, 0.2 mm i.d., 0.5 µm film). A 2 µl aliquot of diluted sample is injected into the 300°C split inlet set at a 50/1 split ratio. The GC is temperature programmed from 35°C (20 min. hold) to 300°C at 8°C/min. and then to 325°C at 0.5°C/min. with a final hold time of 30 min. Light hydrocarbons, isoprenoids and normal paraffins are identified when they are present in the sample.

Biomarkers

Samples are prepared by performing liquid chromatography (LC) on oil or extracts samples to isolate saturate and aromatic fractions. Saturate fractions are diluted with 5 µl and aromatic fractions/whole extracts/whole oils with 10 µl of carbon disulfide per mg of fraction. β-cholane and o-terphenyl-d14 are used as saturate and aromatic internal standards, respectively. Samples are analyzed on an HP6890GC / 5973MSD system equipped with a high-resolution column (60 m, DB-1 phase, 0.2 mm i.d., 0.2 µm film). The GC is temperature programmed from 80°C (2 min. hold) to 320°C at 3.5°C/min. with a final hold time of 20 min. There is a 7.5 min. solvent delay on acquisition and selected ion monitoring (SIM) is the standard method for analysis. Reports of peaks and standard geochemical parameters are included for both the saturate and aromatic fractions.

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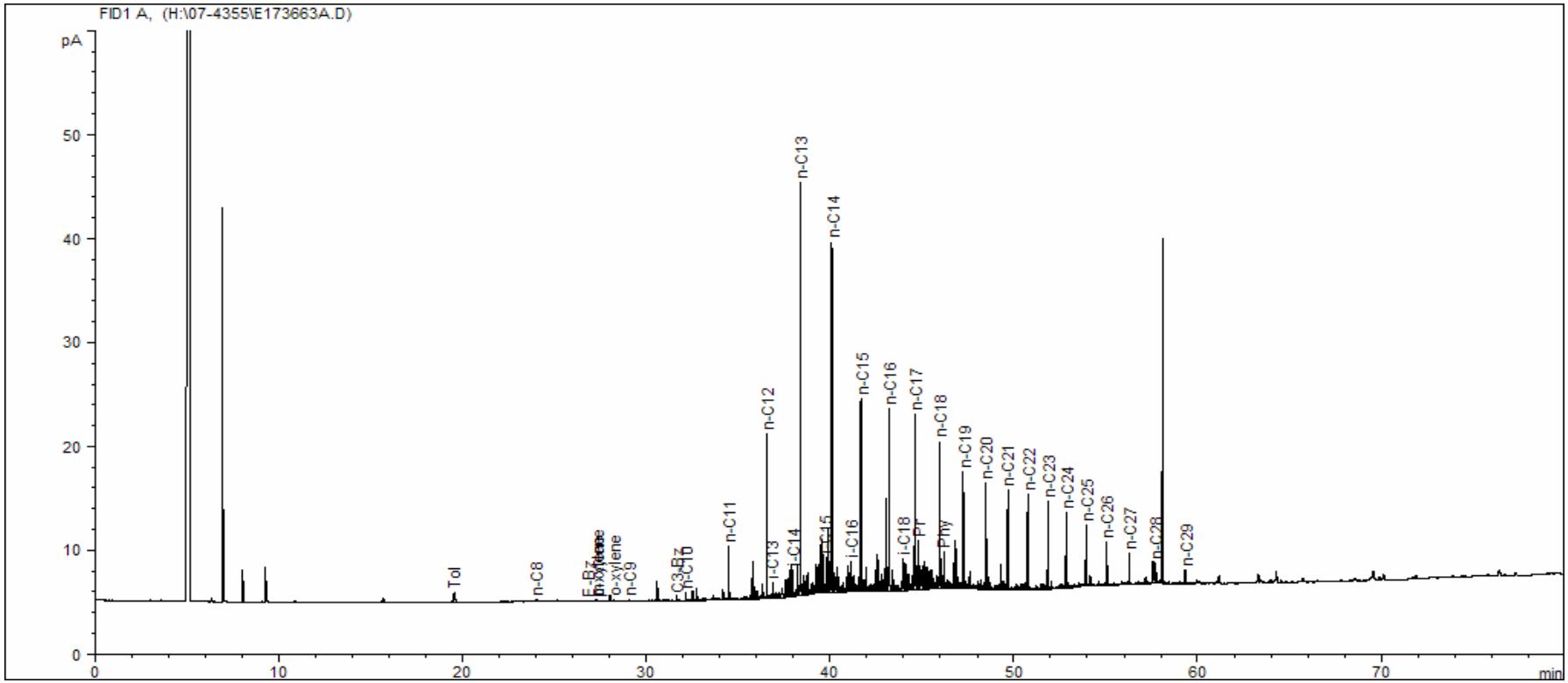
Client: United States Department o **Formation:** **API:**
Client ID: ECT-C7 **Basin:**
HGS ID: 07-4355-173663 **Country:**
Type: asphaltum spheroids **County,State:** Summit Co., UT
Well:
Depth:
Field:



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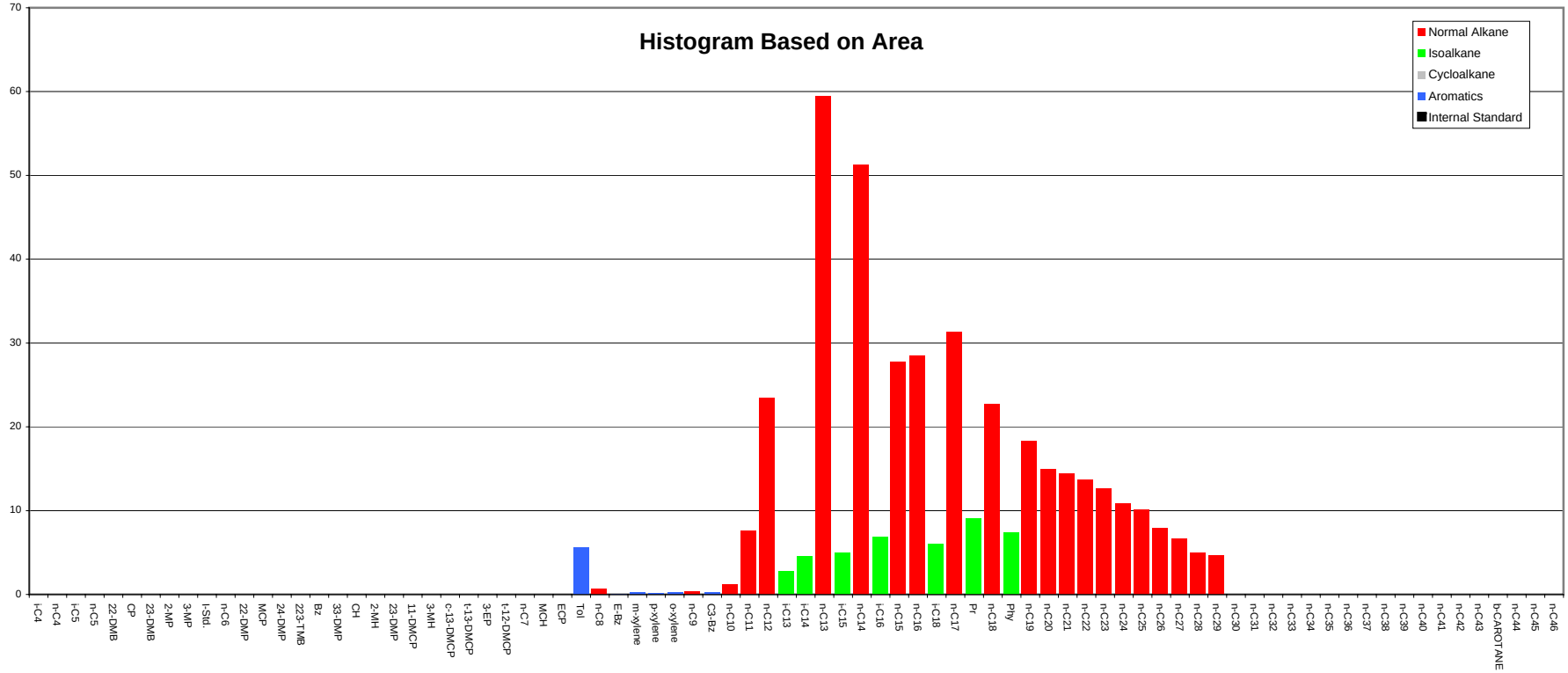

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Type: asphaltum spheroids
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Basin:
Country:

Gas Chromatography Integration Results

Peak Label	Compound Name	R.Time (min.)	Peak Height	Peak Area
i-C4	iso-butane	0.00	0	0
n-C4	butane	0.00	0	0
i-C5	iso-pentane	0.00	0	0
n-C5	pentane	0.00	0	0
22-DMB	2,2-dimethylbutane	0.00	0	0
CP	cyclopentane	0.00	0	0
23-DMB	2,3-dimethylbutane	0.00	0	0
2-MP	2-methylpentane	0.00	0	0
3-MP	3-methylpentane	0.00	0	0
I-Std.	Internal Standard	0.00	0	0
n-C6	hexane	0.00	0	0
22-DMP	2,2-dimethylpentane	0.00	0	0
MCP	methylcyclopentane	0.00	0	0
24-DMP	methylcyclopentane	0.00	0	0
223-TMB	2,2,3-trimethylbutane	0.00	0	0
Bz	benzene	0.00	0	0
33-DMP	3,3-dimethylpentane	0.00	0	0
CH	cyclohexane	0.00	0	0
2-MH	2-methylhexane	0.00	0	0
23-DMP	2,3-dimethylpentane	0.00	0	0
11-DMCP	1,1-dimethylcyclopentane	0.00	0	0
3-MH	3-methylhexane	0.00	0	0
c-13-DMCP	cis-1,3-dimethylcyclopentane	0.00	0	0
t-13-DMCP	trans-1,3-dimethylcyclopentane	0.00	0	0
3-EP	3-ethylpentane	0.00	0	0
t-12-DMCP	trans-1,2-dimethylcyclopentane	0.00	0	0
n-C7	heptane	0.00	0	0
MCH	methylcyclohexane	0.00	0	0
ECP	ethylcyclopentane	0.00	0	0
Tol	toluene	19.54	1	6
n-C8	octane	24.04	0	1
E-Bz	ethylbenzene	26.89	0	0
m-xylene	meta-xylene	27.29	0	0
p-xylene	para-xylene	27.34	0	0
o-xylene	ortho-xylene	28.23	0	0
n-C9	nonane	29.10	0	0
C3-Bz	propylbenzene	31.67	0	0
n-C10	decane	32.14	1	1
n-C11	undecane	34.52	5	8
n-C12	dodecane	36.56	16	23
i-C13	C13 isoprenoid	36.87	2	3
i-C14	C14 isoprenoid	37.97	3	5
n-C13	tridecane	38.40	40	59
i-C15	farnesane (C15 isoprenoid)	39.78	3	5
n-C14	tetradecane	40.10	34	51
i-C16	C16 isoprenoid	41.16	3	7
n-C15	pentadecane	41.70	19	28
n-C16	hexadecane	43.20	18	29
i-C18	norpristane (C18 isoprenoid)	43.96	3	6
n-C17	heptadecane	44.63	17	31
Pr	pristane (C19 isoprenoid)	44.78	5	9
n-C18	octadecane	45.98	14	23
Phy	phytane (C20 isoprenoid)	46.18	4	7
n-C19	nonadecane	47.26	11	18
n-C20	eicosane	48.49	10	15
n-C21	heneicosane	49.66	10	14
n-C22	docosane	50.79	9	14
n-C23	tricosane	51.86	8	13
n-C24	tetracosane	52.90	7	11
n-C25	pentacosane	53.93	6	10
n-C26	hexacosane	55.05	4	8
n-C27	heptacosane	56.31	3	7
n-C28	octacosane	57.72	2	5
n-C29	nonacosane	59.33	1	5
n-C30	triacontane	0.00	0	0
n-C31	hentriacontane	0.00	0	0
n-C32	dotriacontane	0.00	0	0
n-C33	tritriacontane	0.00	0	0
n-C34	tetratriacontane	0.00	0	0
n-C35	pentatriacontane	0.00	0	0
n-C36	hexatriacontane	0.00	0	0
n-C37	heptatriacontane	0.00	0	0
n-C38	octatriacontane	0.00	0	0
n-C39	nonatriacontane	0.00	0	0
n-C40	tetracontane	0.00	0	0
n-C41	henetetracontane	0.00	0	0
n-C42	dotetracontane	0.00	0	0
n-C43	tritetracontane	0.00	0	0
b-CAROTANE	beta-carotane	0.00	0	0
n-C44	tetratetracontane	0.00	0	0
n-C45	pentatetracontane	0.00	0	0
n-C46	hexatetracontane	0.00	0	0

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Well:
Depth:
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Formation:
Basin:
Country:

Gas Chromatography Interpretive Ratios

Interpretive Ratios		Interpretive Ratios	
Ratios by Area		**Mango Ratios[2]**	
Pristane / Phytane	1.24	P1	not available
Prisane / nC17	0.29	P2	not available
Phytane / nC18	0.32	P3	not available
nC18 / (nC18 + nC19)	0.55	5N1	not available
nC17 / (nC17 + nC27)	0.82	6N1	not available
Carbon Preference Index	1.18	N2	not available
Totals by Weight %		**Invariant Ratios**	
Normal Alkanes	not available	K1	not available
Isoalkanes	not available	K2	not available
Branched Alkanes	not available	***Ring Preference Ratios***	
Cycloalkanes	not available	5N1 / 6N1	not available
Aromatics	not available	P3 / N2	not available
Halpern Ratios[1]		**Thompson Ratios[3]**	
Tr1	#DIV/0!	Bz / nC6	#DIV/0!
Tr2	#DIV/0!	Tol / nC7	#DIV/0!
Tr3	#DIV/0!	(nC6 + nC7) / (CH + MCH)	#DIV/0!
Tr4	#DIV/0!	Isoheptane Value	#DIV/0!
Tr5	#DIV/0!	nC7 / MCH	#DIV/0!
Tr6	not available	CH / MCP	#DIV/0!
Tr7	#DIV/0!	nC7 / 2-MH	#DIV/0!
Tr8	#DIV/0!	nC6 / 2,2-DMB	#DIV/0!
C1	#DIV/0!	Heptane Value	#DIV/0!
C2	#DIV/0!		
C3	#DIV/0!		
C4	#DIV/0!		
C5	#DIV/0!		

1 Halpern, H.I., 1995. APPG Bull.: v.79, p801-815
2 Mango, F.D., 1994. GCS: V.58, p.895-901
3 Thompson, K.F.M., 1983. GCA: v.47, p303-316

Humble Geochemical

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Telephone: 281-540 6050 Fax: 281-540

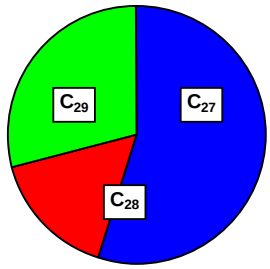
Client: United States Department of the Interior
Client ID: ECT-C7
HGS ID: 07-4355-173663
Well:
Depth:
Field:
Lease
Formation:
Basin:
County,State: Summit Co., UT
Country:

Bulk Properties

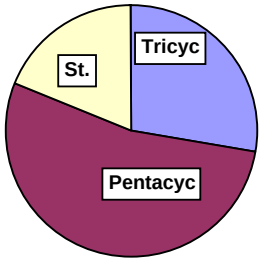
API (°)
S (%)
Saturate (%)
Aromatics (%)
Resin (%)
Asphaltene (%)
δ^{13}C Sat (‰)
δ^{13}C Aro (‰)
δ^{13}C Res (‰)
δ^{13}C Asp (‰)
δ^{13}C Oil (‰)

Whole Oil/Extract GC

CPI
Pristane/n-C17
Phytane/n-C18
Pristane/Phytane



C 27 -C 28 -C 29 αββ Steranes



Tricyclic, Pentacyclic Terpanes & Steranes

Saturate Biomarker Interpretive Ratios

Interpretive Ratios	By Area	By Height
Terpanes (m/z 191)		
C19t/C23t	0.36	0.30
C22t/C21t	0.55	0.41
C22t/C24t	1.18	0.87
C24t/C23t	0.36	0.36
C26t/C25t	0.84	0.79
C24Tet/C23t	0.21	0.19
C24Tet/C26t	0.81	0.74
C23t/C30H	0.63	0.68
C24Tet/C30H	0.14	0.13
C28BNH/C30H	0.00	0.00
25-Nor/C30H	0.00	0.00
C29H/C30H	0.63	0.59
C30DiaH/C30H	0.18	0.20
Ole/C30H	0.06	0.15
C30Ts/C30H	0.08	0.10
Gam/C30H	0.08	0.13
Gam/C31HR	0.27	0.49
C35HS/C34HS	#DIV/0!	#DIV/0!
C35 Homohopane Index	0.00	0.00
Ts/(Ts+Tm)	0.57	0.58
C29Ts/(C29Ts+C29H)	0.31	0.30
Mor/C30H	0.10	0.13
C32 S/(S+R)	0.63	0.60
Steranes (m/z 217)		
% C27 ααα 20R	32.3	38.4
% C28 ααα 20R	21.4	16.6
% C29 ααα 20R	46.3	44.9
C27 Dia/(Dia+Reg)	0.27	0.38
(C21+C22)/(C27+C28+C29)	0.13	0.20
C29 αββ/(ααα+αββ)	0.38	0.45
C29 ααα 20S/20R	0.72	0.48
C29 ααα 20S/(S+R)	0.42	0.33
αββ– Steranes (m/z 218)		
% C27 αββ 20(R+S)	54.6	50.6
% C28 αββ 20(R+S)	16.1	18.5
% C29 αββ 20(R+S)	29.3	30.9
C29/C27 αββ Sterane Ratio	0.54	0.61
Tricyclic/Pentacyclic Terpanes	0.52	0.55
Steranes/Terpanes	0.23	0.19
% Tricyclic Terpanes	27.6	29.9
% Pentacyclic Terpanes	53.5	53.9
% Steranes	18.8	16.1

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Client: United States Department of the Interior
Client ID: ECT-C7
HGS ID: 07-4355-173663
Well:
Depth:
Field:
Lease
Formation:
Basin:
County,State: Summit Co., UT
Country:

Saturate Biomarker Integration Results
(Steranes)

Ion	Peak Label	Compound Name	R.Time (min.)	Peak Area	ppm (A.)	Peak Height	ppm (Ht.)
217	S21	C21 sterane	47.24	4739	#DIV/0!	1659	#DIV/0!
217	S22	C22 sterane	49.93	1063	#DIV/0!	483	#DIV/0!
217	27DbaS	C27 ba 20S diacholestane	57.17	1827	#DIV/0!	708	#DIV/0!
217	27DbaR	C27 ba 20R diacholestane	57.92	990	#DIV/0!	438	#DIV/0!
217	28DbaSA	C28 ba 20S diasterane a	0.00	0	#DIV/0!	0	#DIV/0!
217	28DbaSB	C28 ba 20S diasterane b	0.00	0	#DIV/0!	0	#DIV/0!
217	28DbaRA	C28 ba 20R diasterane a	0.00	0	#DIV/0!	0	#DIV/0!
217	28DbaRB	C28 ba 20R diasterane b	0.00	0	#DIV/0!	0	#DIV/0!
217	27aaS	C27 aa 20S cholestane	60.29	4008	#DIV/0!	807	#DIV/0!
217	27bbR	C27 bb 20R cholestane	60.49	13175	#DIV/0!	2881	#DIV/0!
217	27bbS	C27 bb 20S cholestane	60.60	3794	#DIV/0!	1035	#DIV/0!
217	27aaR	C27 aa 20R cholestane	61.25	3508	#DIV/0!	1029	#DIV/0!
217	28aaS	C28 aa 20S ergostane	62.33	590	#DIV/0!	338	#DIV/0!
217	28bbR	C28 bb 20R ergostane	62.59	1938	#DIV/0!	371	#DIV/0!
217	28bbS	C28 bb 20S ergostane	62.75	2294	#DIV/0!	613	#DIV/0!
217	28aaR	C28 aa 20R ergostane	63.34	2325	#DIV/0!	445	#DIV/0!
217	29aaS	C29 aa 20S stigmastane	63.93	3612	#DIV/0!	583	#DIV/0!
217	29bbR	C29 bb 20R stigmastane	64.23	2881	#DIV/0!	775	#DIV/0!
217	29bbS	C29 bb 20S stigmastane	64.32	2521	#DIV/0!	711	#DIV/0!
217	29aaR	C29 aa 20R stigmastane	65.05	5029	#DIV/0!	1203	#DIV/0!
218	27bbR	C27 bb 20R cholestane	60.50	6925	#DIV/0!	1840	#DIV/0!
218	27bbS	C27 bb 20S cholestane	60.60	3706	#DIV/0!	1050	#DIV/0!
218	28bbR	C28 bb 20R ergostane	62.61	1490	#DIV/0!	422	#DIV/0!
218	28bbS	C28 bb 20S ergostane	62.76	1648	#DIV/0!	632	#DIV/0!
218	29bbR	C29 bb 20R stigmastane	64.23	3051	#DIV/0!	874	#DIV/0!
218	29bbS	C29 bb 20S stigmastane	64.33	2649	#DIV/0!	890	#DIV/0!
259	27DbaS	C27 ba 20S diacholestane	57.17	1340	#DIV/0!	450	#DIV/0!
259	27DbaR	C27 ba 20R diacholestane	57.92	850	#DIV/0!	282	#DIV/0!
259	28DbaSA	C28 ba 20S diaergostane a	0.00	0	#DIV/0!	0	#DIV/0!
259	28DbaSB	C28 ba 20S diaergostane b	0.00	0	#DIV/0!	0	#DIV/0!
259	28DbaRA	C28 ba 20R diaergostane a	0.00	0	#DIV/0!	0	#DIV/0!
259	28DbaRB	C28 ba 20R diaergostane b	0.00	0	#DIV/0!	0	#DIV/0!
259	29DbaS	C29 ba 20S diastigmastane	60.50	5211	#DIV/0!	1589	#DIV/0!
259	29DbaR	C29 ba 20R diastigmastane	61.83	424	#DIV/0!	195	#DIV/0!
259	30TP1	C30 Terpane	65.93	8348	#DIV/0!	2035	#DIV/0!
259	30TP2	C30 Terpane	66.01	2664	#DIV/0!	881	#DIV/0!
217	b-Cholane	*5b-cholane (inter. STD)*	0.00	0	#DIV/0!	0	#DIV/0!
218	b-Cholane	*5b-cholane (inter. STD)*	0.00	0	#DIV/0!	0	#DIV/0!

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Client: United States Department of the Interior
Client ID: ECT-C7
HGS ID: 07-4355-173663
Well:
Depth:
Field:
Lease
Formation:
Basin:
County,State: Summit Co., UT
Country:

Saturate Biomarker Integration Results (Terpanes)

Ion	Peak Label	Compound Name	R.Time (min.)	Peak Area	ppm (A.)	Peak Height	ppm (Ht.)
125	BCRT	b-carotane					
191	C19t	C19 tricyclic diterpane	40.27	6812	#DIV/0!	1967	#DIV/0!
191	C20t	C20 tricyclic diterpane	42.54	9039	#DIV/0!	3053	#DIV/0!
191	C21t	C21 tricyclic diterpane	44.86	14875	#DIV/0!	5011	#DIV/0!
191	C22t	C22 tricyclic terpane	46.99	8142	#DIV/0!	2064	#DIV/0!
191	C23t	C23 tricyclic terpane	49.40	18896	#DIV/0!	6633	#DIV/0!
191	C24t	C24 tricyclic terpane	50.72	6893	#DIV/0!	2363	#DIV/0!
191	C25tS	C25 tricyclic terpane (S)	53.28	2916	#DIV/0!	1115	#DIV/0!
191	C25tR	C25 tricyclic terpane (R)	53.36	3032	#DIV/0!	988	#DIV/0!
191	C24T	C24 tetracyclic terpane (TET)	54.88	4027	#DIV/0!	1232	#DIV/0!
191	C26tS	C26 tricyclic terpane (S)	55.16	2546	#DIV/0!	857	#DIV/0!
191	C26tR	C26 tricyclic terpane (R)	55.33	2447	#DIV/0!	810	#DIV/0!
191	C28tS	C28 extended tricyclic terpane (S)	0.00	0	#DIV/0!	0	#DIV/0!
191	C28tR	C28 extended tricyclic terpane (R)	0.00	0	#DIV/0!	0	#DIV/0!
191	C29tS	C29 extended tricyclic terpane (S)	0.00	0	#DIV/0!	0	#DIV/0!
191	C29tR	C29 extended tricyclic terpane (R)	0.00	0	#DIV/0!	0	#DIV/0!
191	C30tS	C30 extended tricyclic terpane (S)	0.00	0	#DIV/0!	0	#DIV/0!
191	C30tR	C30 extended tricyclic terpane (R)	0.00	0	#DIV/0!	0	#DIV/0!
191	Ts	Ts 18a(H)-trisnorhopane	61.66	8041	#DIV/0!	2563	#DIV/0!
191	Tm	Tm 17a(H)-trisnorhopane	62.42	6139	#DIV/0!	1893	#DIV/0!
191	C28BNH	C28 17a18a21b(H)-bisnorhopane	0.00	0	#DIV/0!	0	#DIV/0!
191	Nor25H	C29 Nor-25-hopane	0.00	0	#DIV/0!	0	#DIV/0!
191	C29H	C29 Tm 17a(H)21b(H)-norhopane	65.06	18652	#DIV/0!	5671	#DIV/0!
191	C29Ts	C29 Ts 18a(H)-norneohopane	65.17	8518	#DIV/0!	2429	#DIV/0!
191	C30DiaH	C30 17a(H)-diahopane	65.50	5387	#DIV/0!	1901	#DIV/0!
191	Normor	C29 normoretane	65.93	15061	#DIV/0!	3548	#DIV/0!
191	a-Ole	a-oleanane	66.49	1156	#DIV/0!	856	#DIV/0!
191	b-Ole	b-oleanane	66.51	609	#DIV/0!	572	#DIV/0!
191	C30H	C30 17a(H)-hopane	66.65	29766	#DIV/0!	9688	#DIV/0!
191	C30Ts	17a(H)-30-nor-29-homohopane	67.02	2451	#DIV/0!	968	#DIV/0!
191	Mor	C30 moretane	67.34	3012	#DIV/0!	1212	#DIV/0!
191	C31HS	C31 22S 17a(H) homohopane	68.47	11493	#DIV/0!	3408	#DIV/0!
191	C31HR	C31 22R 17a(H) homohopane	68.68	8566	#DIV/0!	2540	#DIV/0!
191	Gam	gammacerane	68.97	2285	#DIV/0!	1248	#DIV/0!
191	C32HS	C32 22S 17a(H) bishomohopane	69.89	12293	#DIV/0!	3073	#DIV/0!
191	C32HR	C32 22R 17a(H) bishomohopane	70.18	7255	#DIV/0!	2077	#DIV/0!
191	C33HS	C33 22S 17a(H) trishomohopane	71.55	7856	#DIV/0!	1934	#DIV/0!
191	C33HR	C33 22R 17a(H) trishomohopane	72.01	5579	#DIV/0!	1471	#DIV/0!
191	C34HS	C34 22S 17a(H) extended hopane	0.00	0	#DIV/0!	0	#DIV/0!
191	C34HR	C34 22R 17a(H) extended hopane	0.00	0	#DIV/0!	0	#DIV/0!
191	C35HS	C35 22S 17a(H) extended hopane	0.00	0	#DIV/0!	0	#DIV/0!
191	C35HR	C35 22R 17a(H) extended hopane	0.00	0	#DIV/0!	0	#DIV/0!

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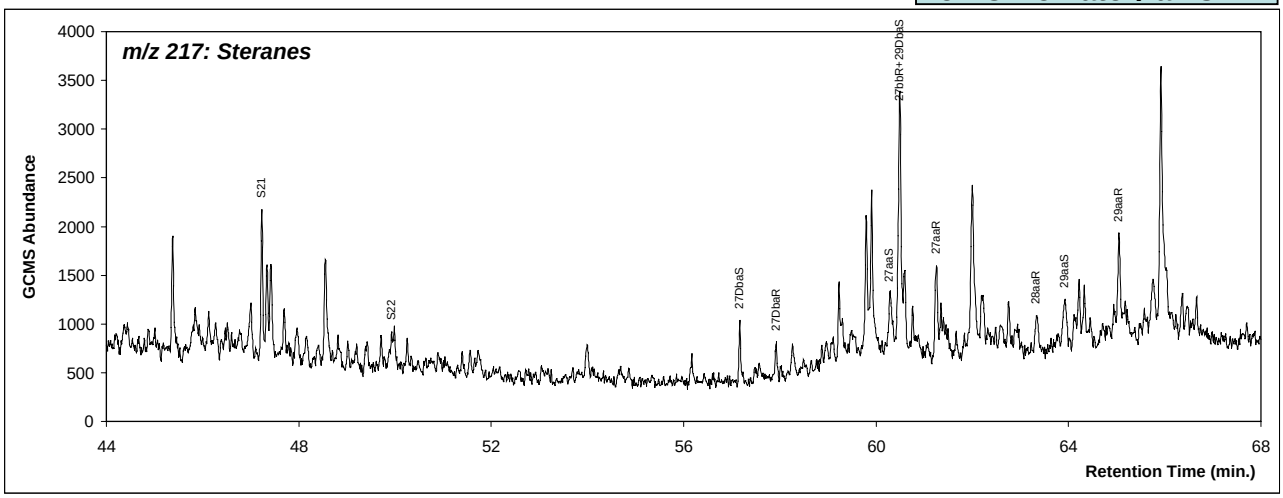
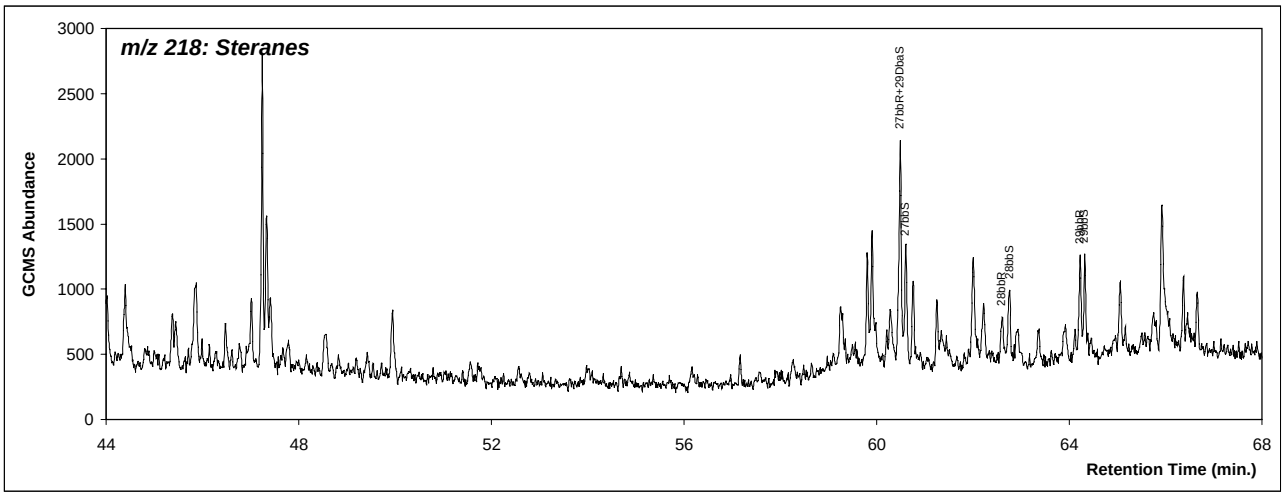
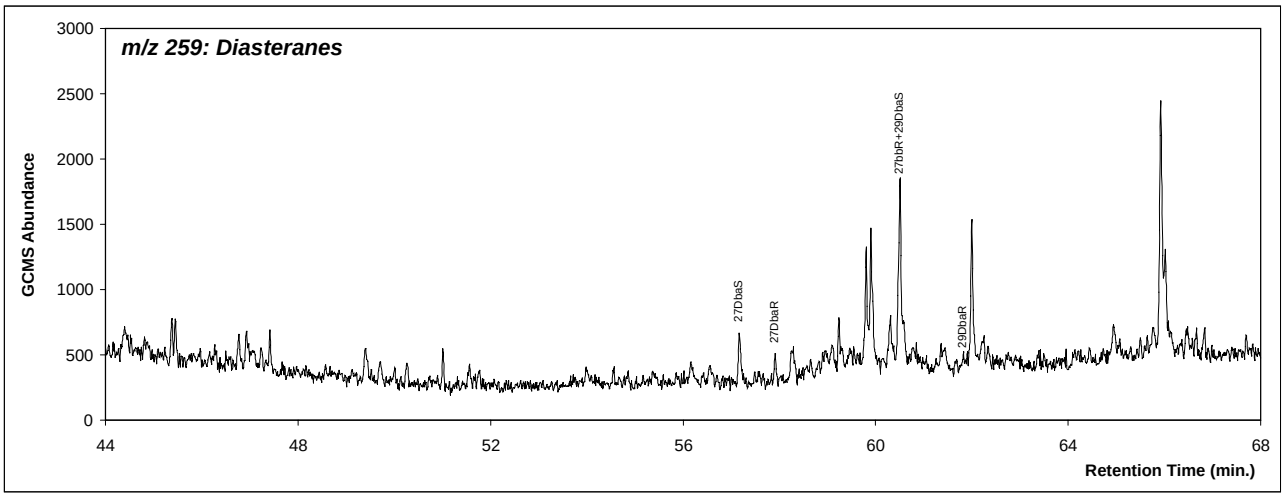
Client: United States Department **Client ID:** ECT-C7
HGS ID: 07-4355-173663

Key Saturate GC-MS Ion Chromatograms







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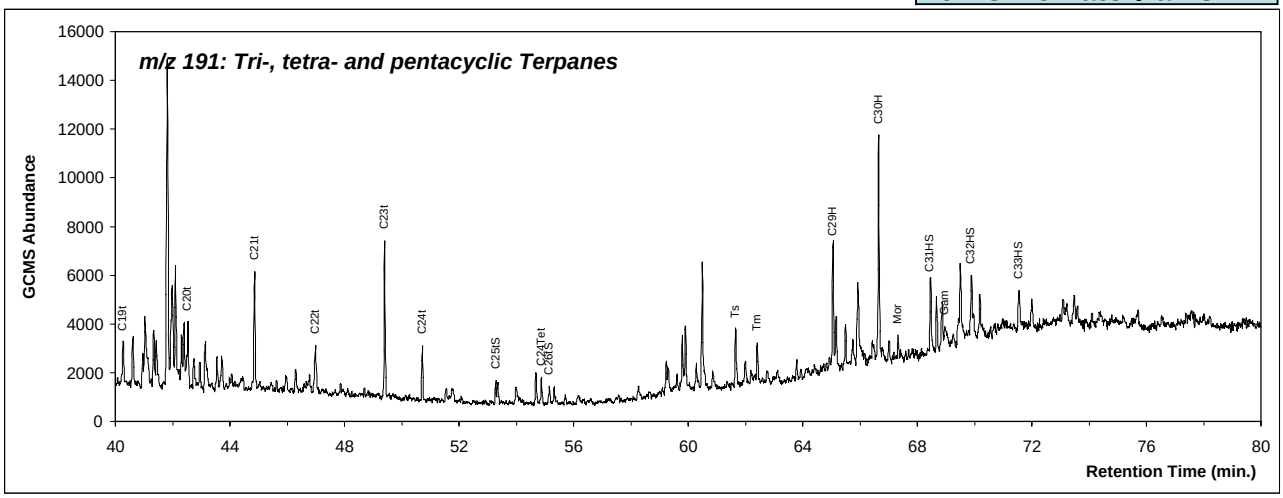
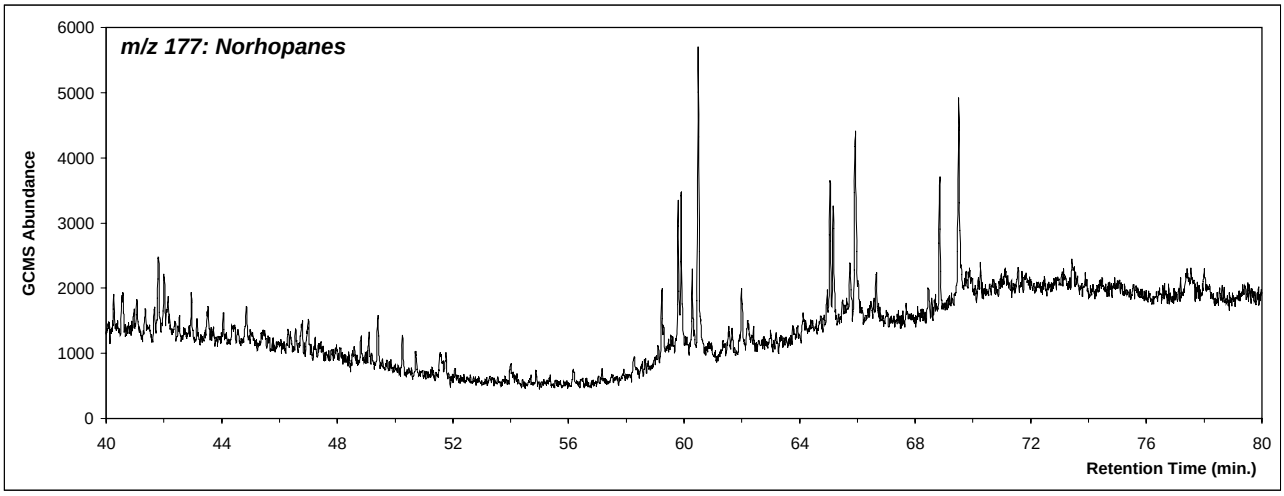
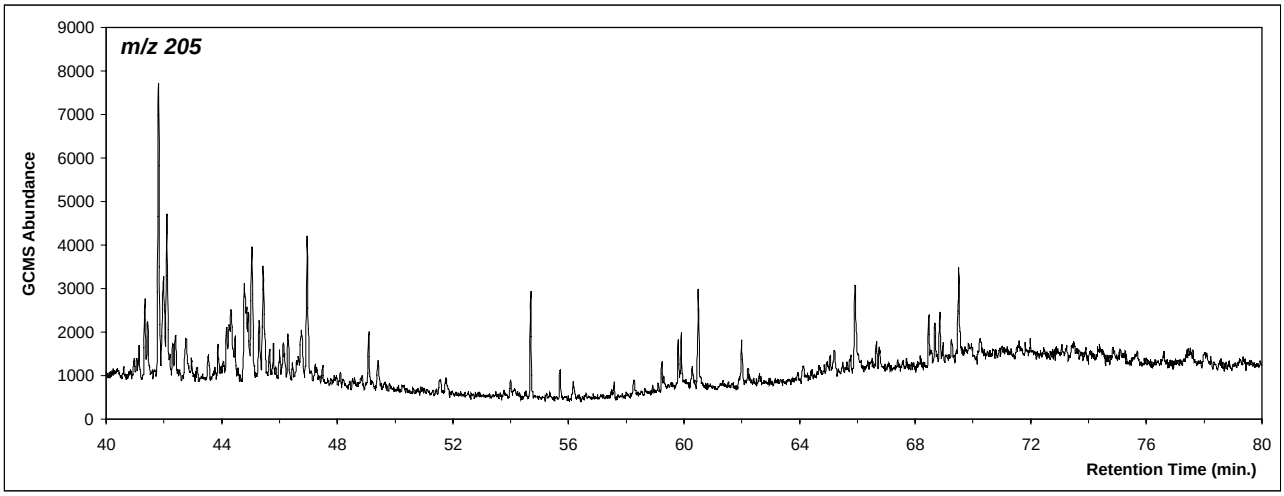
Key Saturate GC-MS Ion Chromatograms







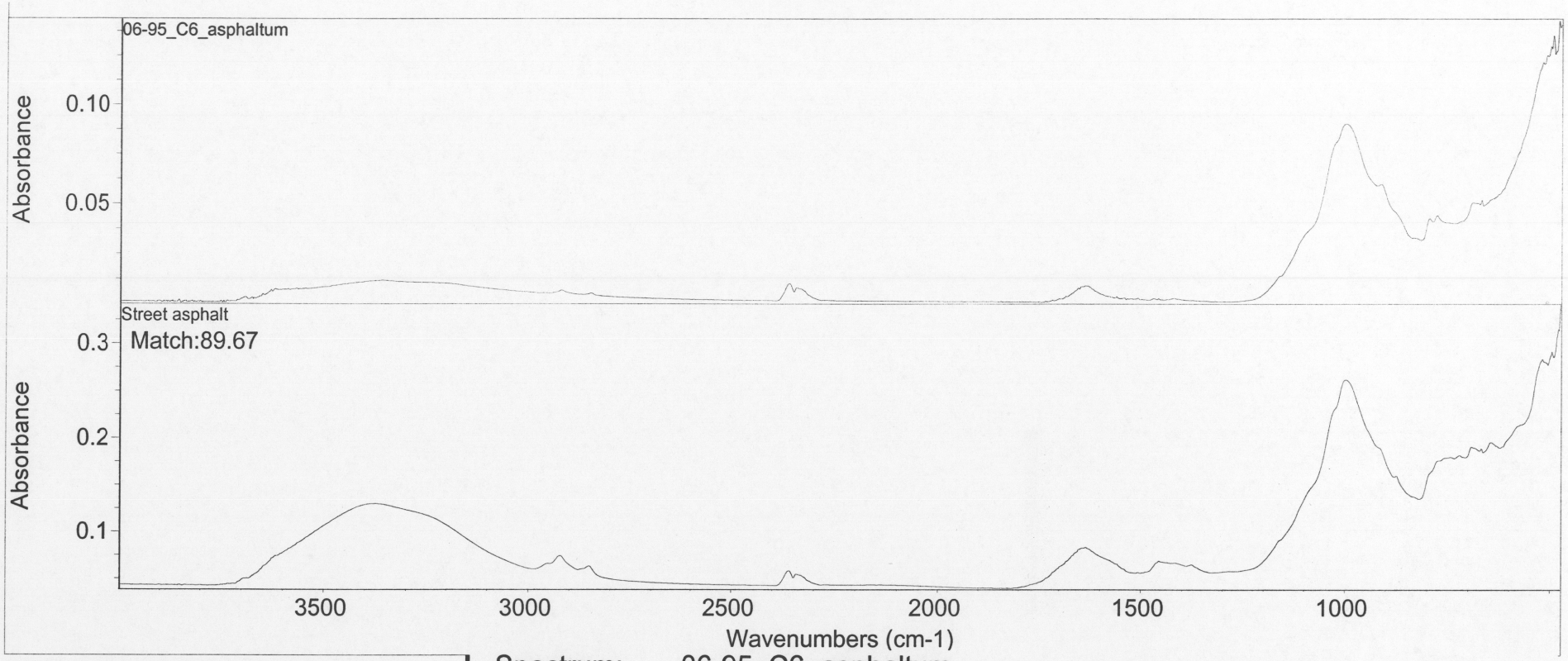
Report G-2.
FTIR Spectrum Analyses for Asphaltum in Sample ECT-C6

By
Paleo Research Institute
Golden, Colorado

Paleo Research Institute
Golden, CO 80401

Tue Feb 20 15:08:16 2007 (

06-95_C6_asphaltum



Number of sample scans: 64
Number of background scans: 64
Resolution: 4.000
Sample gain: 4.0
Mirror velocity: 0.6329
Aperture: 17.00

Tue Feb 20 14:58:07 2007 (GMT-07:00)
FIND PEAKS:
Spectrum: 06-95_C6_asphaltum
Region: 4000.00000 400.00000
Absolute threshold: 0.021
Sensitivity: 60
Peak list:

Position:	479.76328	Intensity:	0.144
Position:	493.48004	Intensity:	0.135
Position:	669.26569	Intensity:	0.0520
Position:	777.10791	Intensity:	0.0440
Position:	997.82703	Intensity:	0.0902

Spectrum: 06-95_C6_asphaltum
Region: 3495.26-651.85
Search type: Correlation
Hit List:

Index	Match	Compound name	Library
1	89.67	Street asphalt	Minerals

Figure 2. FTIR spectrum for possible asphaltum in sample ECT-C6, East Canyon Trench.

Appendix H.
Review of Trench Across the Main Canyon Fault, Utah, of October 2006

By
James P. McCalpin
GEO-HAZ Consulting, Inc.
Crestone, Colorado

REVIEW OF EAST CANYON TRENCH, UTAH, OF OCT. 2006; v2

By: James P. McCalpin
Date: 13 Dec 2006

At the request of the Seismotectonic Section of the US Bureau of Reclamation, Denver, CO, I attended a 1-day review of a trench across a strand of the East Canyon (Utah) fault zone on Wednesday, Oct. 25, 2006.

The purpose of the trench review was twofold:
1) to verify that the fault had indeed moved in the late Quaternary, and
2) to determine whether or not there was evidence for sudden vs gradual offset (colluvial wedges?).

Prior to the review, USBR had provided me with some previous work and current maps and trench location photographs. After the trench was excavated and the walls were cleaned, USBR provided the following preliminary observations:
"*So far, it appears that the trench does expose a fault, which juxtaposes very weathered, red-colored alluvium on the NE side against grey-brown pebbly alluvium and clay on the SW side. The clay, appears to be a ponded unit on the upslope side of the scarp, which was subsequently buried by younger alluvium/colluvium. Overlying the clay are silty and pebbly alluvial/colluvial units, partly in a fault-bounded depression, some of which appear to be derived locally from flanking scarps on either side of the depression. One possible explanation for what we have seen to date includes two distinct surface-faulting events here, both of which are late Quaternary. It is not immediately obvious how young the MRE may be, the surface has been plowed, but the surface soils that might overlie fault-related units are not particularly well-developed*."

1) Verify that the fault had indeed moved in the late Quaternary

The key evidence for late Quaternary faulting is found at the main fault zone between stations 7 and 7.5 (Fig. 1). Unfaulted units include a surface colluvium (unit 10) and its weak A/C soil, and a thicker alluvium-slopewash deposit (unit 8; however, see later comments on age of faulting). The minimal degree of soil formation in these 2 unfaulted deposits suggests that only ca. 10 ka has elapsed since the MRE. The youngest clearly faulted unit (the cumulic? buried A horizon developed on unit 5e) contains dark gray disseminated carbon. Preservation of this type of organic material is unusual in buried soils older than late Quaternary.

Therefore, if units 8-10 are unfaulted and units 5e and older are faulted, the MRE almost certainly occurred during the late Quaternary. Dating samples C5 and L5 (from unit 8) and C4 and L4 (from the buried A horizon) bracket the MRE event horizon, and will confirm whether the MRE is late Quaternary.

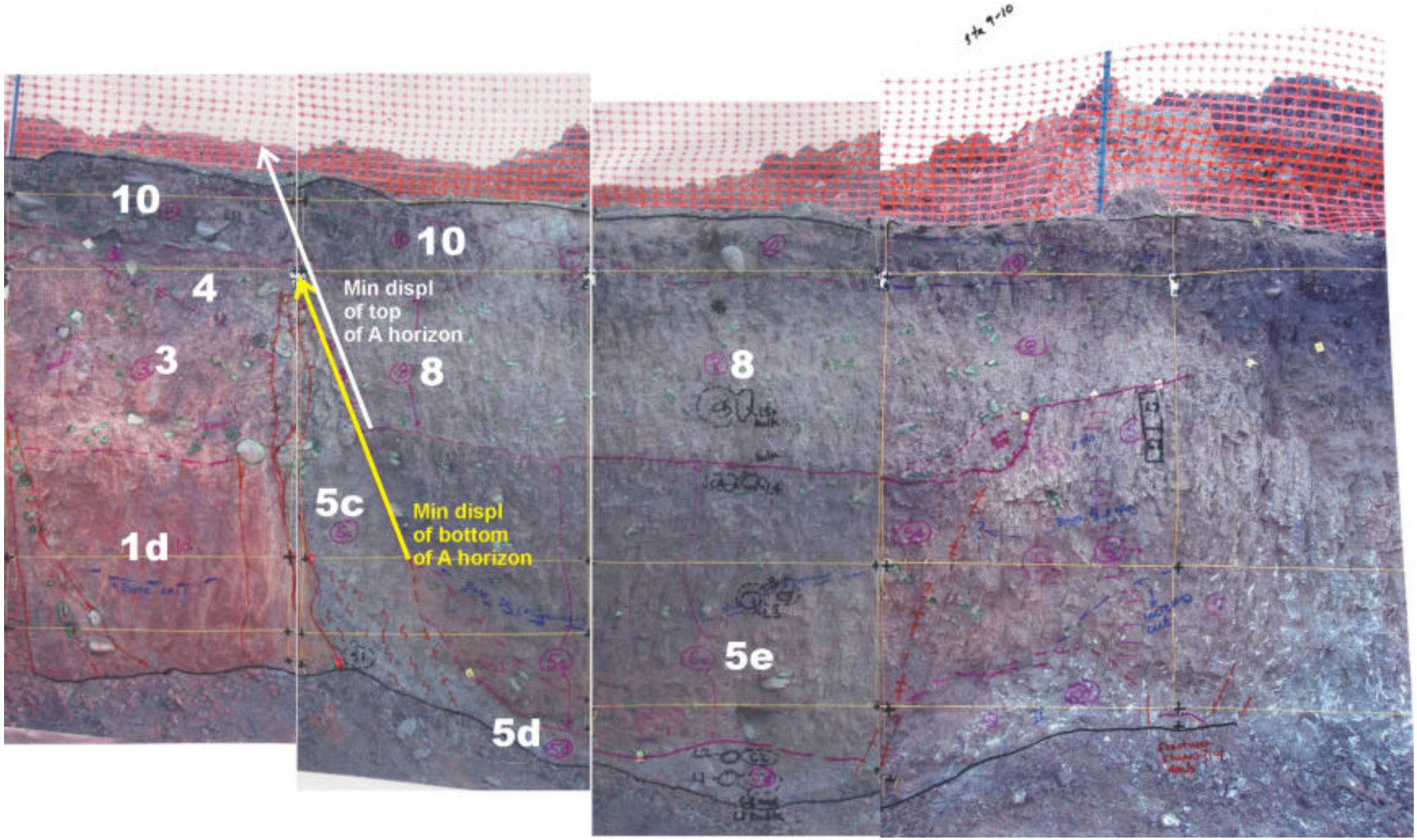


Fig. 1. Annotated photomosaic of stations 6 to 9.5. Unit numbers are from USBR. Footwall Unit 4 is assumed to be a piece of post-PE colluvium correlative with the lower part of unit 5e on the hanging wall. Yellow arrow shows the minimum MRE displacement necessary for the bottom of the buried A horizon in unit 5e, based on the above correlation. The white arrow shows how far this same displacement would have uplifted the top of the A horizon (above the present ground surface).

Suggestions for Unit Numbering

The current unit numbering scheme used in the USBR description of map units and in annotated photomosaics is the field numbering scheme. This field scheme has several internal contradictions, such as unit 4 being correlated to the lower part of unit 5e, whereas it's number (4) indicates it is older than all of unit 5. Likewise, the event horizon for the PE falls at the contact between units 5d and 5e, whereas the event horizon for the MRE falls at the contact between units 5e and 8. Normally, letter subscripts are used only to subdivide a major unit into nearly-contemporaneous units of slightly different texture. In contrast, major breaks in time or in style of deposition are represented by jumps in the units numbers; the longer the time break, the larger the jump in unit numbers. Thus, it is not appropriate to have an event horizon separate units with the same number and only a different letter subscript.

I would renumber the units in a more standard fashion, to let the unit numbering scheme tell the reader explicitly the sequence of events deduced from the trench, and where the major time breaks are. In such a scheme, the "unconformity/erosion" times marked on USBRs preliminary correlation of trench units would mark major jumps in the unit numbering sequence. One way to do this is to have the numbers jump from one decade (0-9) to the next higher decade (10-19), etc. This shows the reader the significance of the time break between units.

2) Determine whether or not there was evidence for sudden vs gradual offset (colluvial wedges?).

To distinguish between sudden versus gradual offset on the main fault zone, we have to consider if the geometry of trench deposits matches the expected physical evidence from those 2 deformation styles. During the trench review, I tried to list the salient geometric evidence from the trench wall and how it supported one of 4 faulting hypotheses:

Table 2. Four hypotheses for the type of faulting in the East Canyon trench.

	EPISODIC FAULTING	GRADUAL CREEP
UNIT 8 is younger than MRE	Hypothesis 1[1] Unit 5e is clearly truncated, but unit 8 is not Small amount of scarp colluvium Fault slightly bends at 5e/8 contact	Hypothesis 3[3] No scarp colluvium 5e cleanly truncated Unit 8 not bent (maybe insufficient time since MRE)
Unit 8 is older than MRE	Hypothesis 2[2] No unit 8 on footwall No colluvium younger than unit 8 No shear fabric in unit 8	Hypothesis 4[4] No scarp colluvium Unit 8 not bent

Green means trench evidence supports hypothesis
Red means trench evidence contradicts hypothesis

[1] unit 5e is cleanly truncated, not smeared out as it would be with creep; there is no shear fabric in unit 8 against contact with unit 5c; buried free face (unit 8/5c contact) is nearly as steep as underlying fault

[2] Unit 8 does not exist on the footwall; there is no thickened colluvium or other sediments on the hanging wall overlying unit 8; the contact of 5c against 8 does not have shear fabric

[3] There is little scarp-derived colluvium in the hanging wall; unit 5e is cleanly truncated by the fault, but creep should have smeared it out and stretched it; soil 5eAb should be present on a degraded free face, if formed by creep

[4] There is little scarp-derived colluvium in the hanging wall; unit 5e is cleanly truncated by the fault, but creep should have smeared it out and stretched it; unit 8 does not appear deformed in any way by creep

According to Table 2, hypothesis 2 is very unlikely. The gradual creep hypotheses (3 and 4) do have some lines of support, although in each case, there are possible alternative explanations for the absence of scarp-derived colluvium and for the presence of plastic deformation, even if deformation had been episodic. Hypothesis 1 seems to have the most positive evidence.

PALEOSEISMIC CHRONOLOGY OF THE TRENCH

The USBR interpretation of the trench includes an MRE younger than unit 8/ older than unit 5e, and a PE older than unit 5e/ younger than unit 5d (Fig. 4). In this interpretation, unit 5e was deposited as “tectonic colluvial wedge and pond-paludal deposits after the PE.

During the trench review, I tried to reconstruct the sequence of deposition and soil formation after the deposition of unit 5e. The existence of the antithetic fault that displaces unit 5e at station 9.5 caused me somewhat of a problem, however. I observed that the strong buried A horizon developed atop unit 5e was not continuously present at the top of 5e, but only existed between the main fault and antithetic fault. In contrast, the soil B horizon appears to be present everywhere in unit 5e. That would make sense, if the soil B horizon had already developed before the A horizon, then the antithetic fault had displaced the top of unit 5e downward to create a small graben, which then retained enough moisture to differentially develop an A horizon in the graben.

However, if movement on the antithetic fault was required to explain the limited spatial extent of the buried A horizon, in which faulting event did the antithetic fault move? It could not be the MRE, because the MRE postdates the buried A horizon. However, it could not be the PE either, because the PE predates the deposition of unit

5e. I tried to make a simple retrodeformation sequence to explain the observed geometry (Fig. 3). This sequence requires that movement on the antithetic fault occur after the B horizon had developed on unit 5e but before the cumulic A horizon had developed.

This sequence has a contradiction, in that there is no deposition in the graben after movement on the antithetic scarp forms the graben. In other words, no deposits such as 5e or 8 were deposited after this supposed event. Given the sedimentologic setting of this scarp, that is rather unlikely. It would require that movement on the antithetic fault was not accompanied by any movement on the main fault.

So, perhaps the limited spatial extent of the cumulic A horizon can be explained another way. In the USBR drawing “revised trench schematic.tif” of Dec. 4, 2006, the hand-written text says “organic A near fault, grades laterally to AB in clay.” There is no explanation given why this lateral soil horizon transition should have occurred. This may become apparent when the full retrodeformation sequence is drawn, after the C14 and OSL dates are processed.