2016 Utah Quaternary Fault Parameters Working Group (UQFPWG) Meeting

Wednesday, February 10, 2016

UTAH DNR GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY

Flat Canyon Site (Provo Segment)

Background

- One of three standing committees created to help set coordinate earthquake-hazard research in Utah.
- Reviews ongoing paleoseismic research in Utah, and helps update the Utah paleoseismic database (consensus slip-rate and recurrence intervals).
- Provides advice and insight regarding technical issues related to fault behavior in Utah and the Basin and Range Province.
- Identifies and prioritizes Utah Quaternary faults for future study; list incorporated into the annual U.S. Geological Survey, Earthquake Hazards Program, External Research Support (NEHRP) funding announcements (Request for Proposals).
- Thanks to all that have participated; the success of the Utah Earthquake Working Groups is dependent upon your active involvement.

- Due to the severe budget issues currently facing the Utah Geological Survey, we had to charge $25 to support the catering services – sorry.

Agenda

8:00	*Refreshments*
8:15 – 8:30	**Welcome, Overview of Meeting, and Review of Last Year's Activities**
8:30 – 10:30	**Technical Presentations**
10:30	*Break (15 min)*
10:45 – 12:00	**Technical Presentations**
12:00	*Lunch (1 hour, provided for those who have registered and paid the $25 fee)*
1:00 – 3:00	**Technical Presentations**
3:00	*Break (15 min)*
3:15 – 4:15	**Technical Presentations**
4:15 – 5:00	**2017 Fault Investigation Priorities Discussion** See printed agenda for background information and last year's priority list.

16 presentations

Active Faulting, Soil and Rock Type, and Groundwater Elevations Beneath Salt Lake City

Vp, Vs, and Reflection Images from a Seismic Land Streamer System

LEE LIBERTY, GABE GRIBLER AND BEN BROPHY

BOISE STATE UNIVERSITY

BOISE STATE UNIVERSITY

Wednesday, February 10, 2016 – Site response measurements

Project objectives
via USGS award G15AP00054

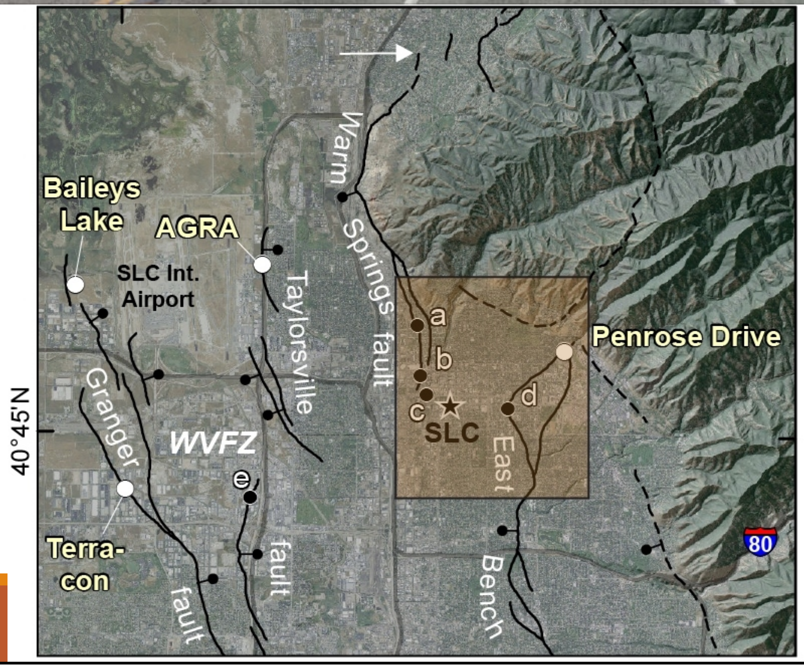
Identify and characterize active faults beneath the Salt Lake City urban corridor through p-wave reflection profiling to ~200 m depth - processing with Seismic Unix & ProMAX.

Shear wave velocity profiles beneath Salt Lake City through Rayleigh wave (MASW) inversions to estimate NEHRP-class soil/rock type to >30 m depth (Vs30) processing with Surfseis.

Depth to water table to assess liquefaction potential – p-wave refraction profiling to >20 m depth processing with Rayfract

Identify shallow bedrock locations that may produce localized earthquake site amplification – p-wave reflection/refraction profiling

Vp/Vs or Poisson's ratio to identify lithology or fluid pathways – p-wave/s-wave tomography to 20 depth



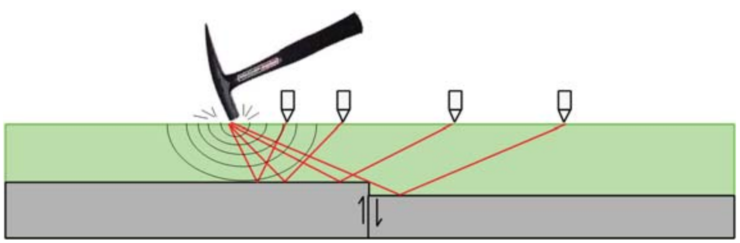
Approach
Multi-component Land Streamer

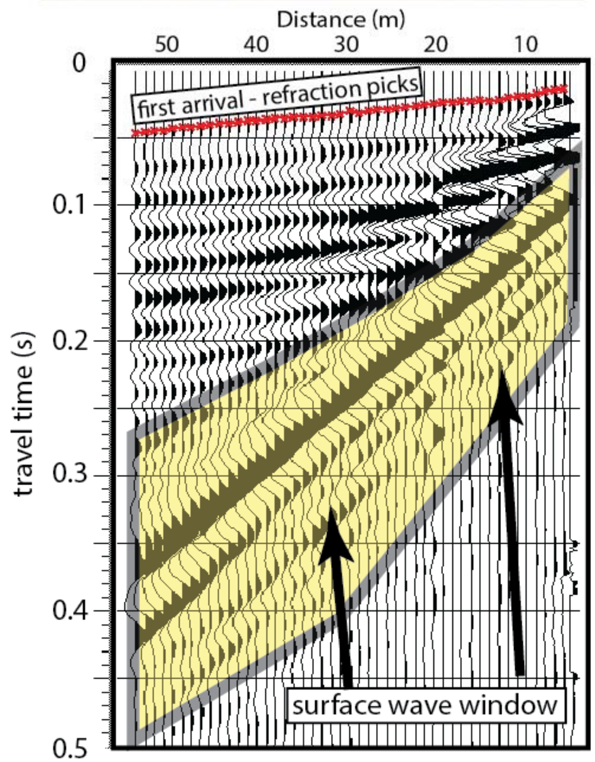
Land streamer first developed by van der Veen and Green (1998)

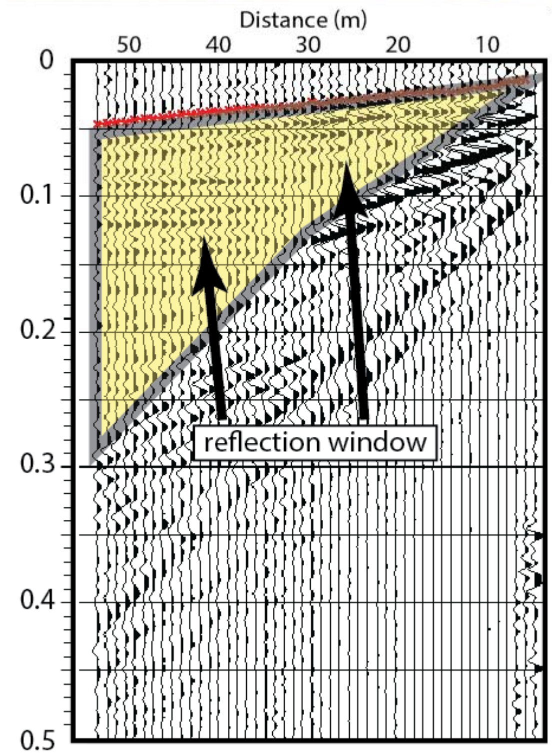
Contact-coupled geophones with seismic source
- P-wave and S-wave refraction
- Surface wave analysis (MASW - Vs estimates)
- P-wave and S-wave reflection (boundary information)

- On road and off-road applications

- Our focus is surface and body wave urban seismic characterization.







Boise State land streamers

1-, 2- and 3-component streamers with 4.5/10/40 Hz geophones

Comparable data quality to planted geophones

- Uniform plate coupling and consistent road surface/grade/base

Operations along straight (paved or gravel) roads

Coupled with accelerated 200 kg (vertical) weight drop source

- (8 seconds per 2 m shot spacing)

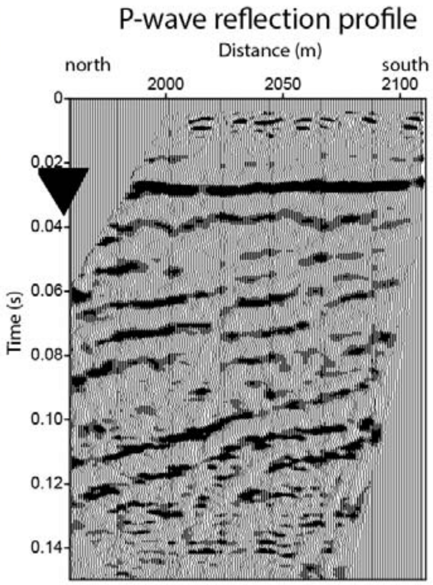
For Salt Lake City experiment

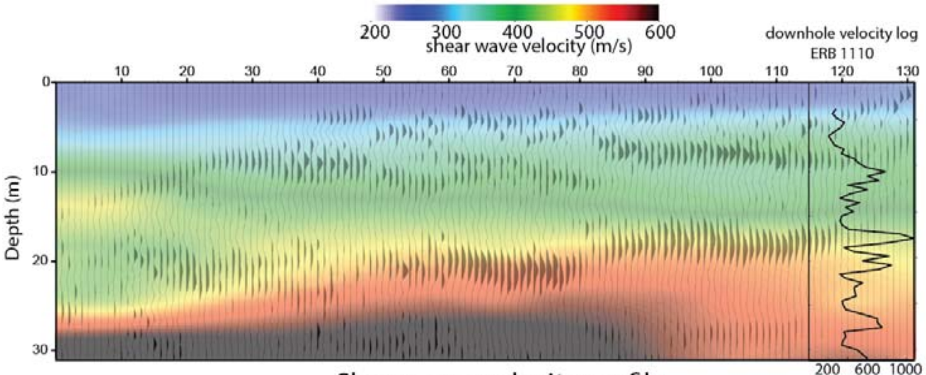
48 2-component shoes (vertical and in-line)

4.5 Hz geophones

1.25 m spacing (60 m aperture) with a 5 m near offset

2 m nominal shot spacing





Shear wave velocity profile

Salt Lake City land streamer acquisition

Salt Lake City 2015 Land Streamer Survey

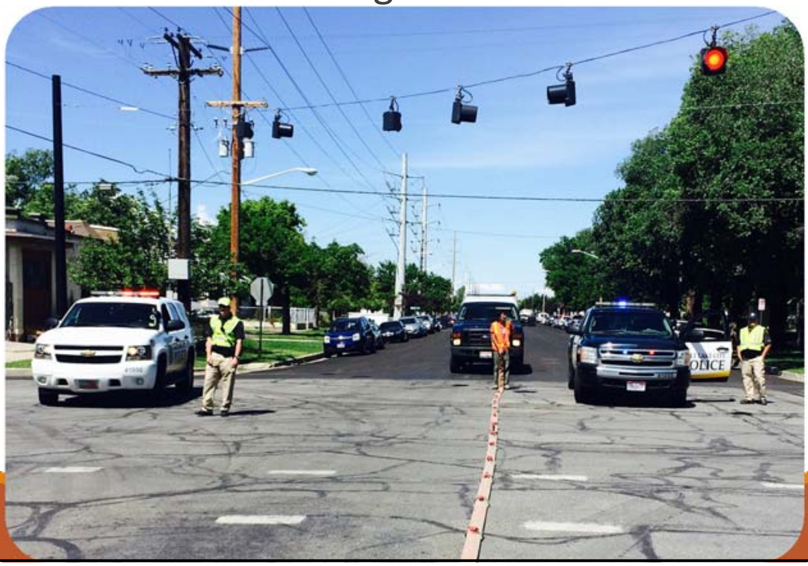
5,576 shot gathers – 2 m spaced shots (gaps at major roads)

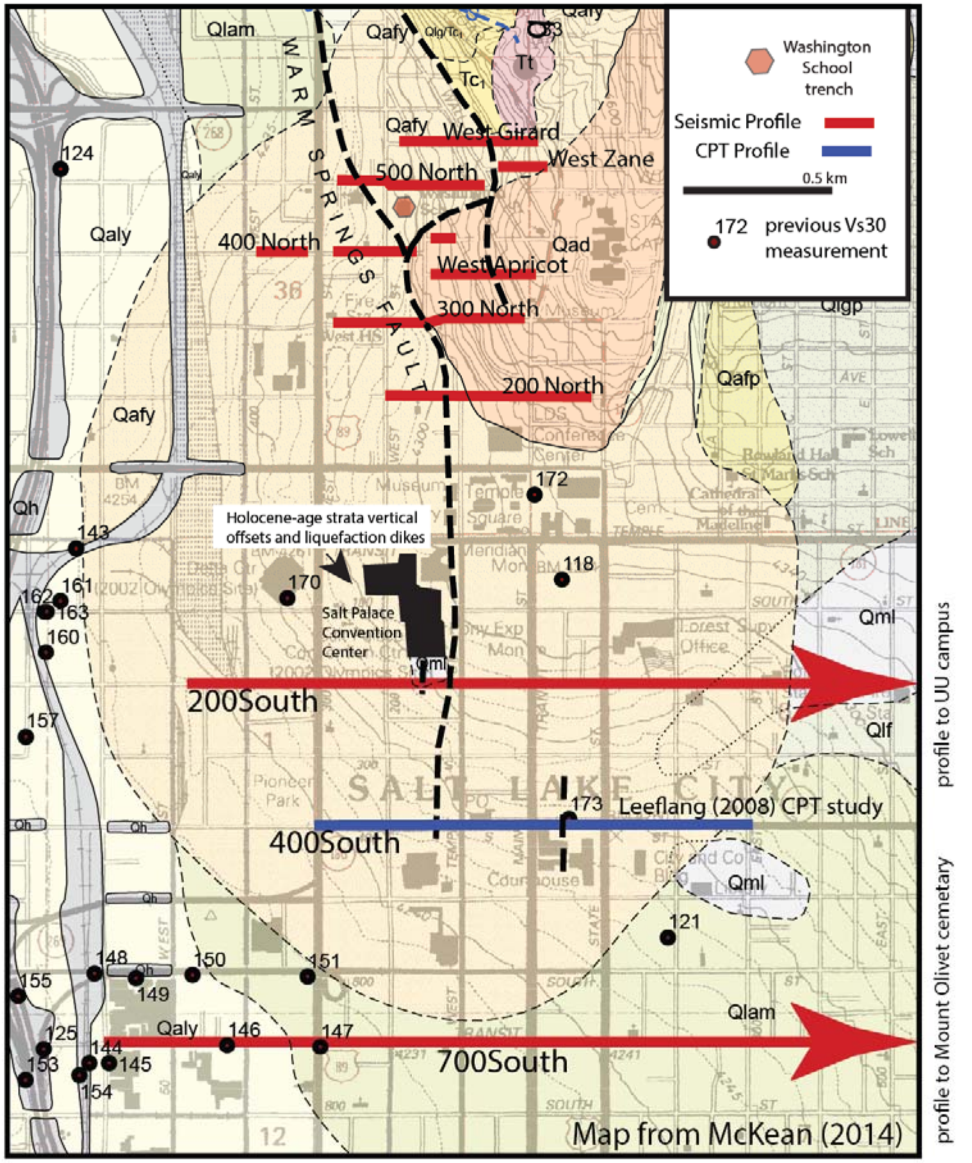
About 15 km length along 9 west-east profiles

3 field days

Flagger crew in North Salt Lake City

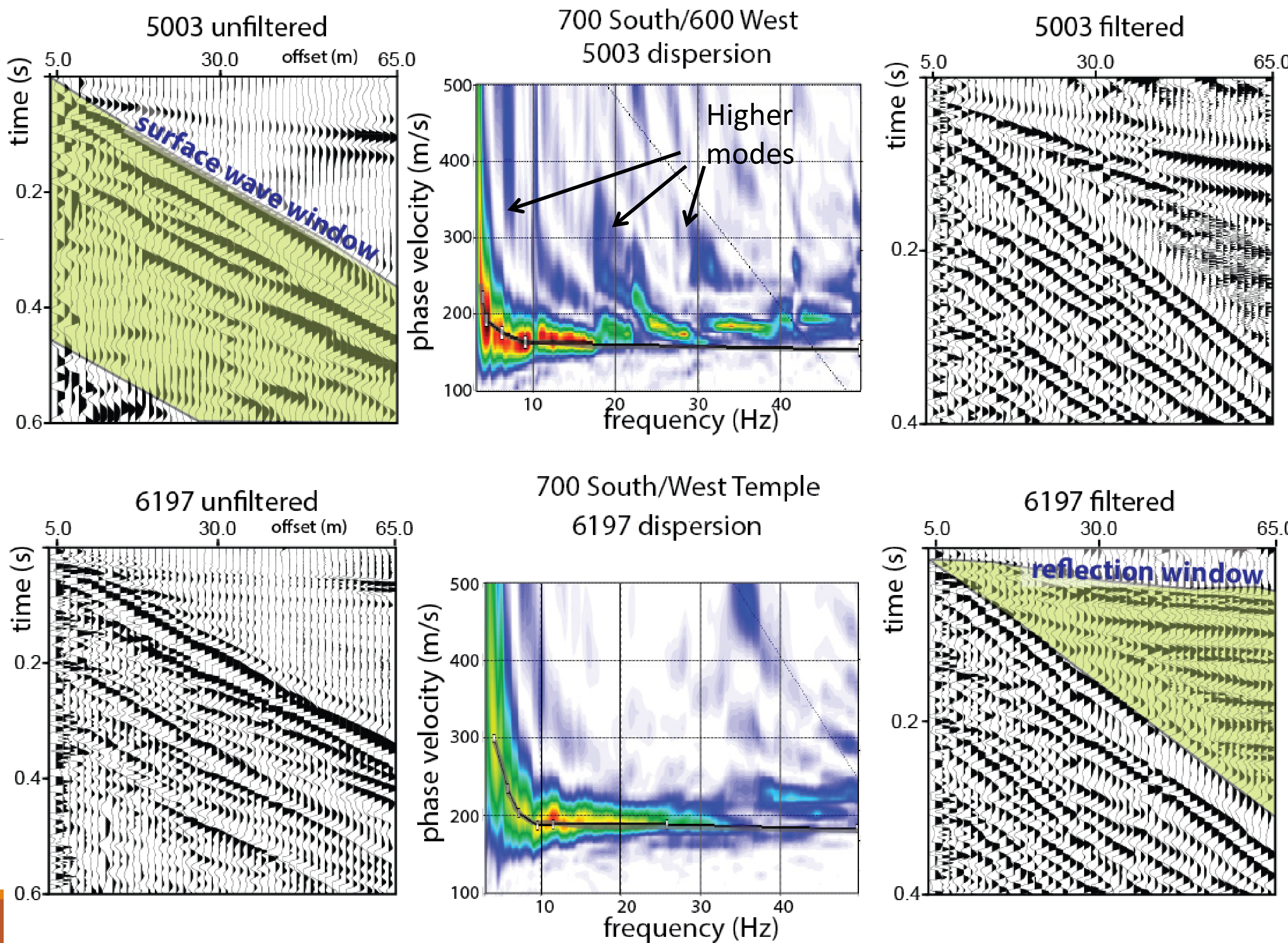
Police escort along 200 South and 700 South





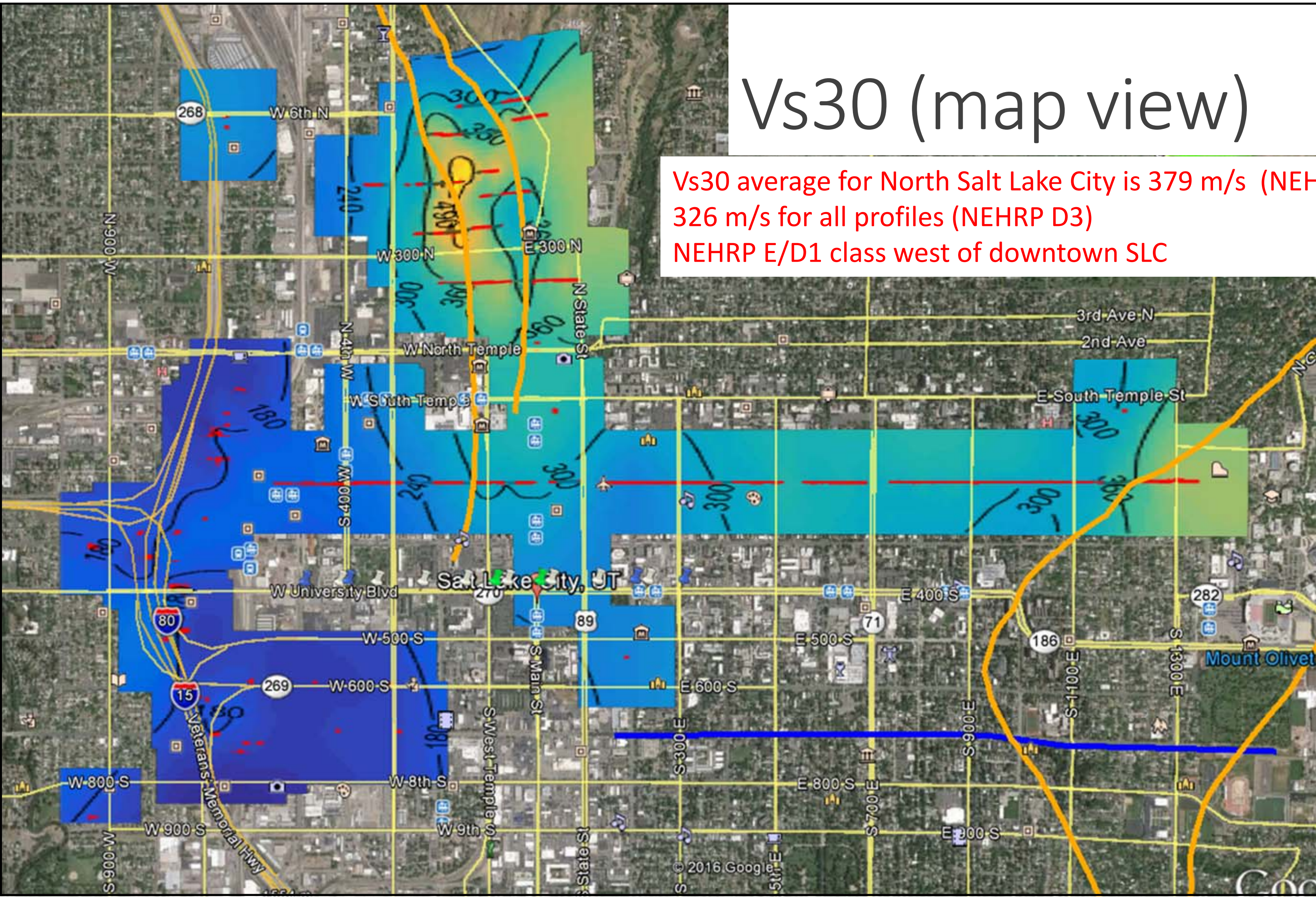
Vs (MASW) profiling

700 South shots and dispersion curves

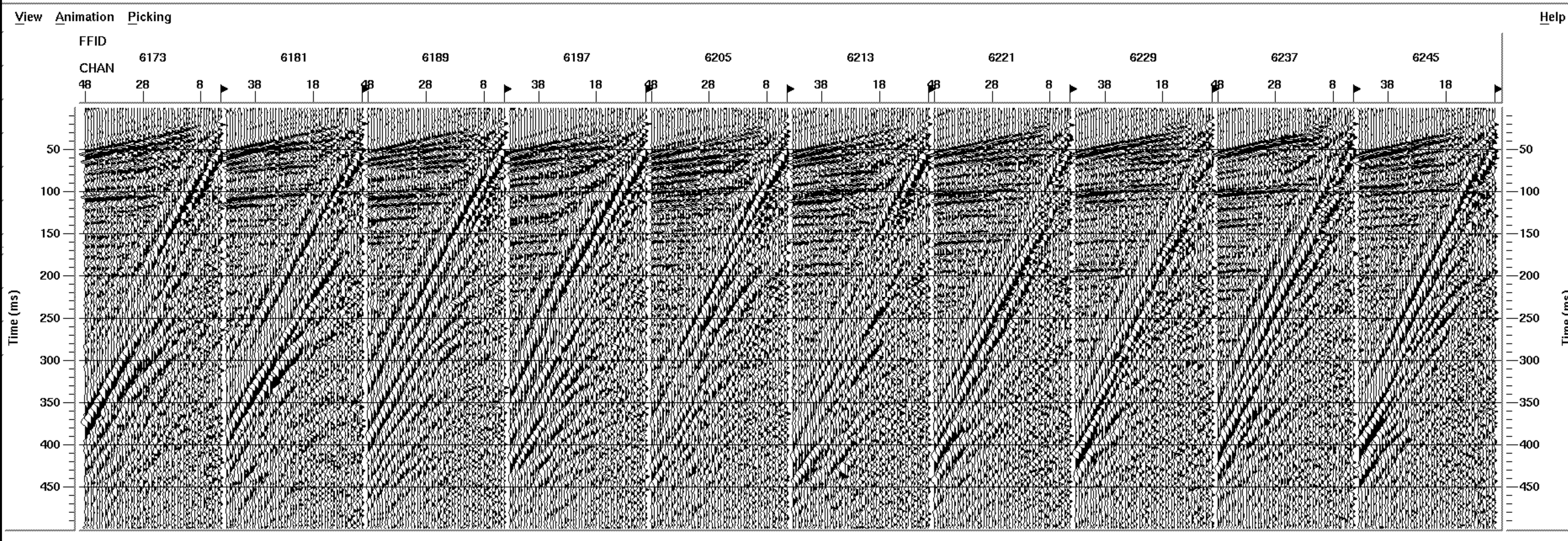


Vs30 (map view)

Vs30 average for North Salt Lake City is 379 m/s (NEHRP C1)
326 m/s for all profiles (NEHRP D3)
NEHRP E/D1 class west of downtown SLC

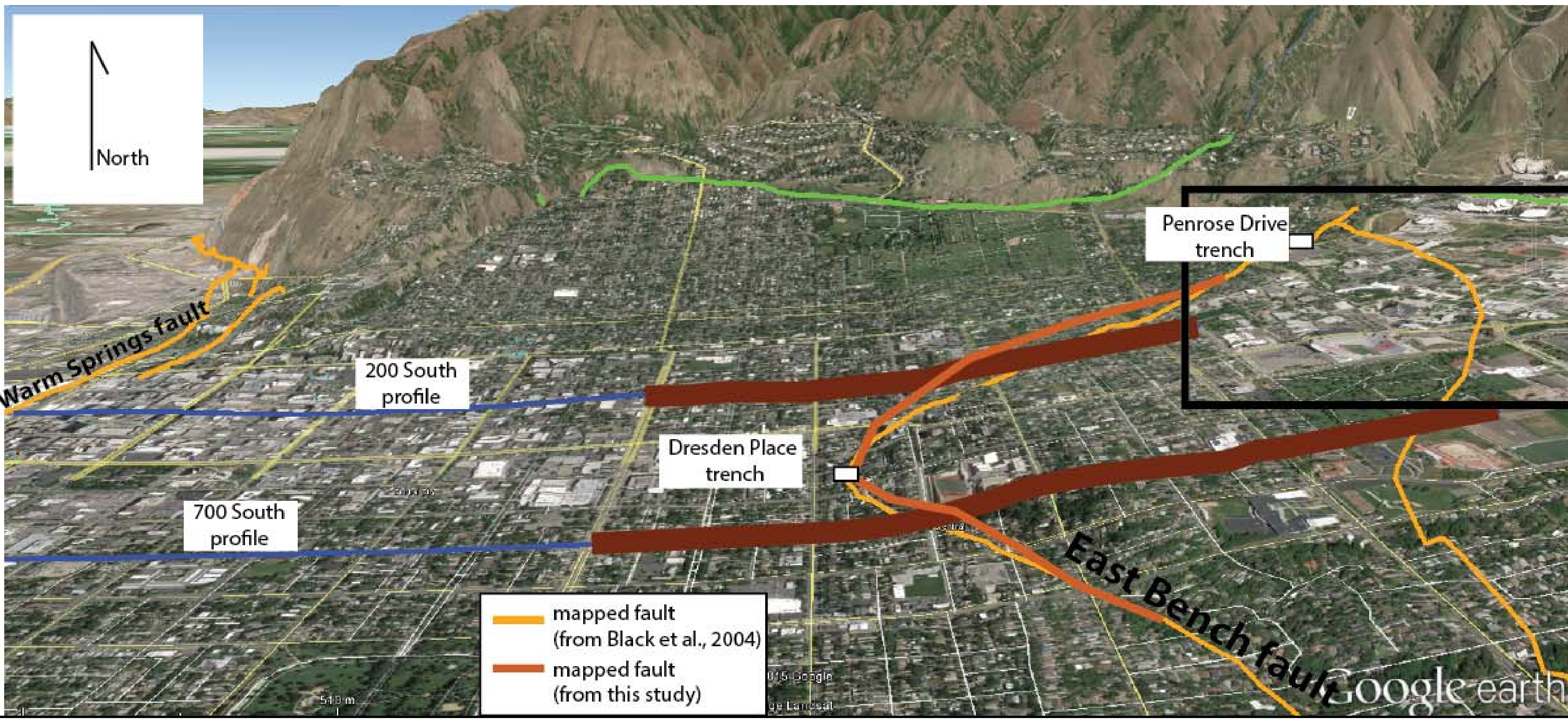


700 South shot gathers

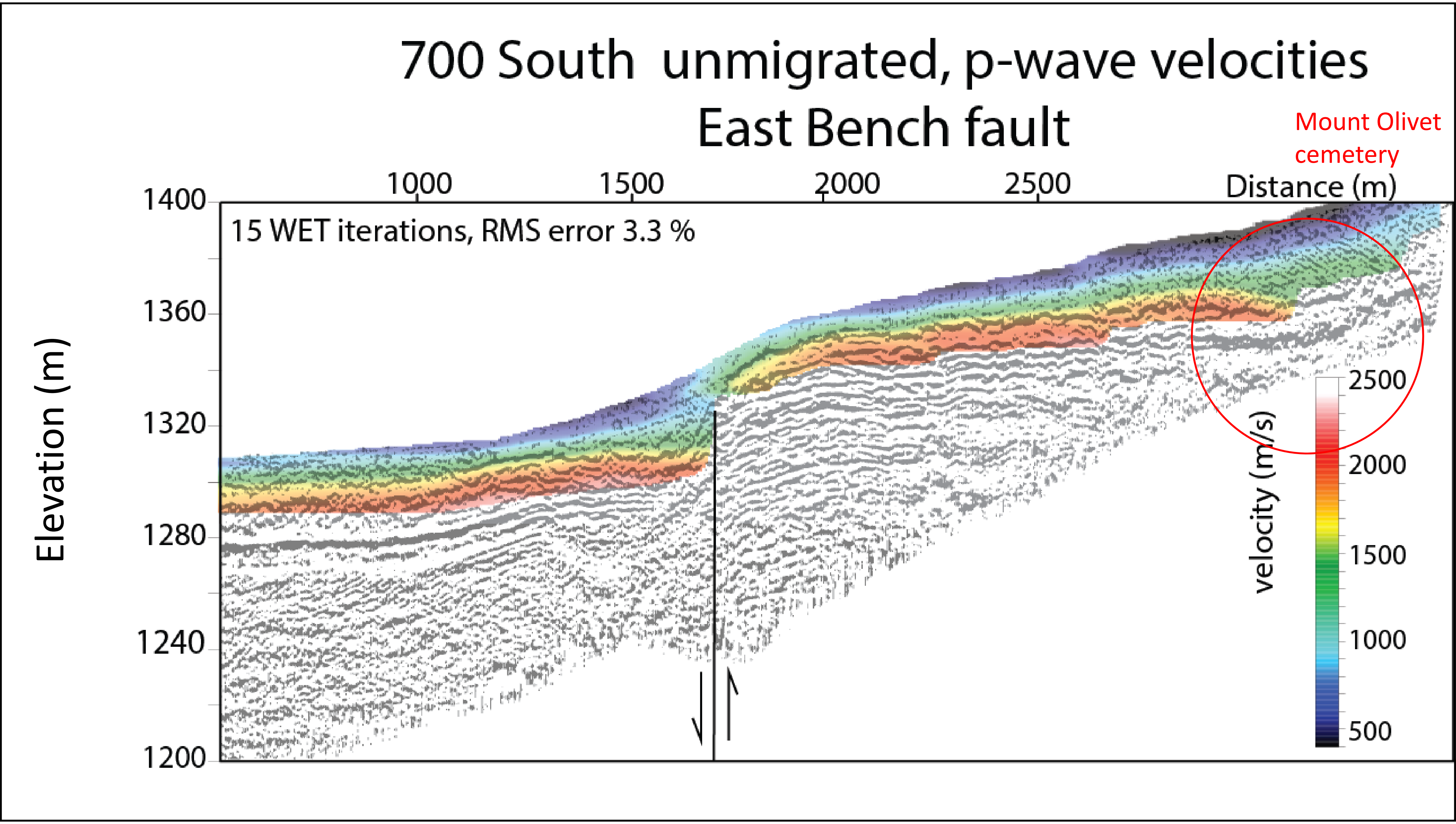


East Bench fault

Dresden Place trench ~7 m of deformation in 26-15 ka (lake sediments) & 3 m of latest Pleistocene time (15-10 ka) monoclinal warping
Penrose Drive trench - 11-m-high scarp exposed colluvial-wedge and 5 or 6 surface-faulting earthquakes postdating ~14–18 ka.

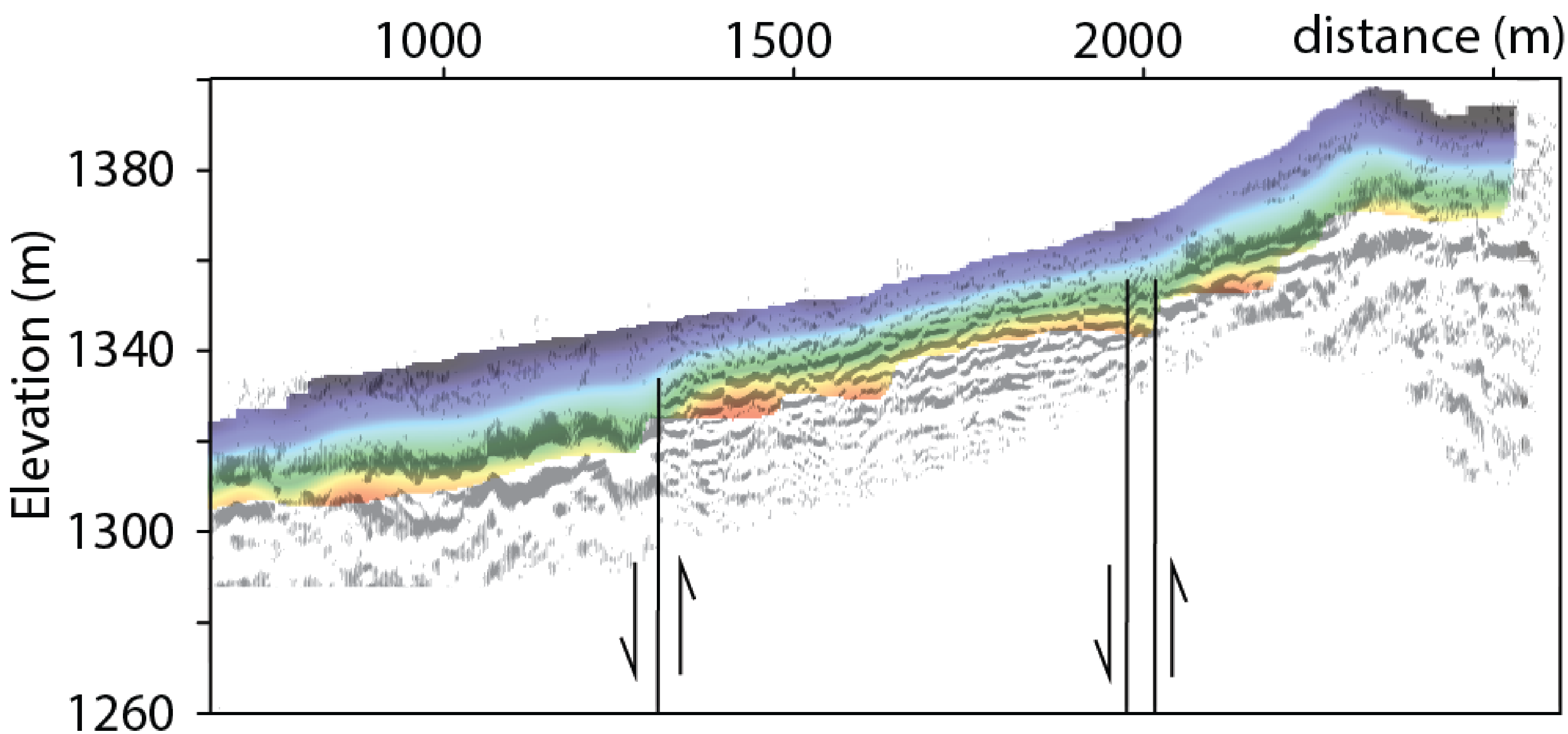


University
of
Utah



700 South unmigrated, p-wave velocities
East Bench fault
Mount Olivet
cemetery
Distance (m)
1000
1500
2000
2500
Elevation (m)
1400
1360
1320
1280
1240
1200
15 WET iterations, RMS error 3.3 %
velocity (m/s)
2500
2000
1500
1000
500

200 South unmigrated p-wave velocities East Bench fault



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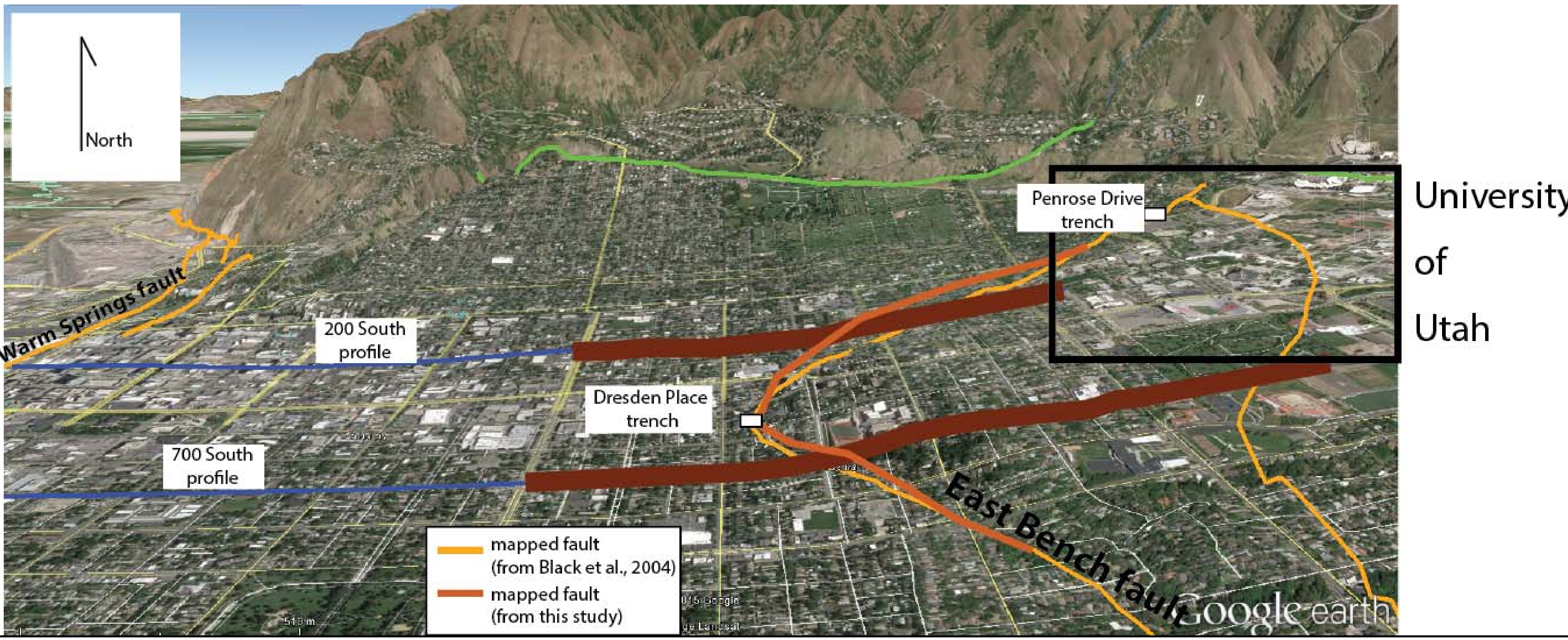
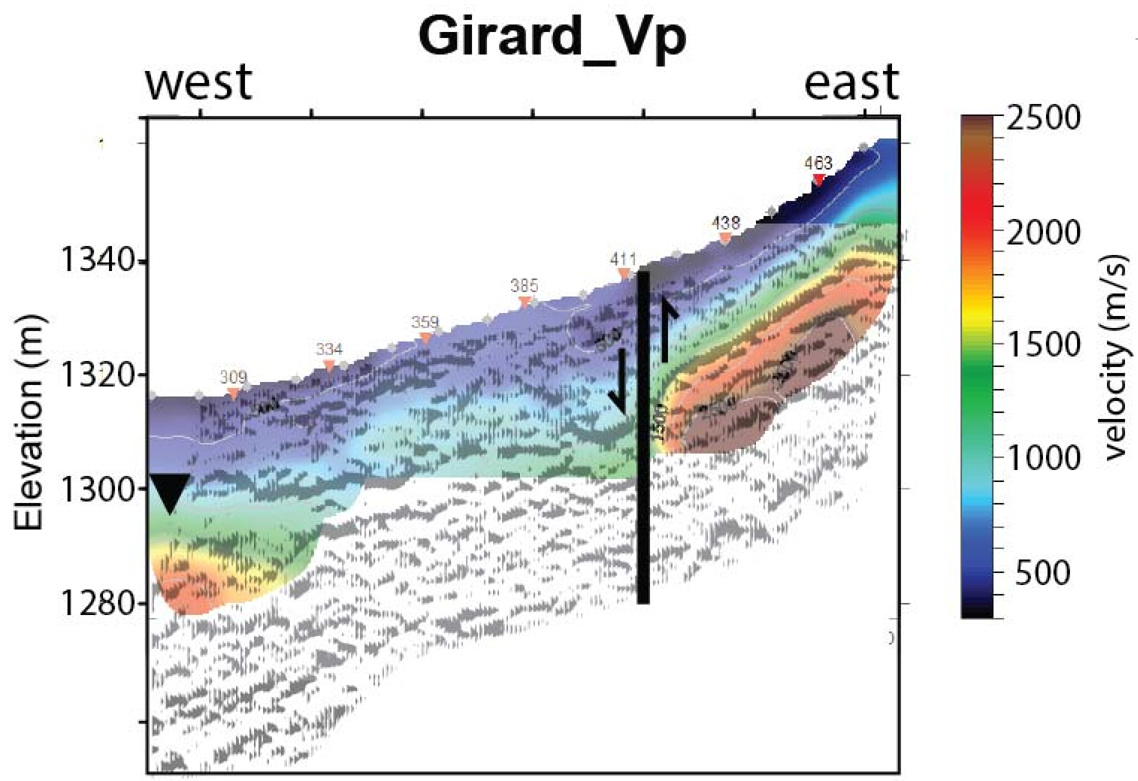
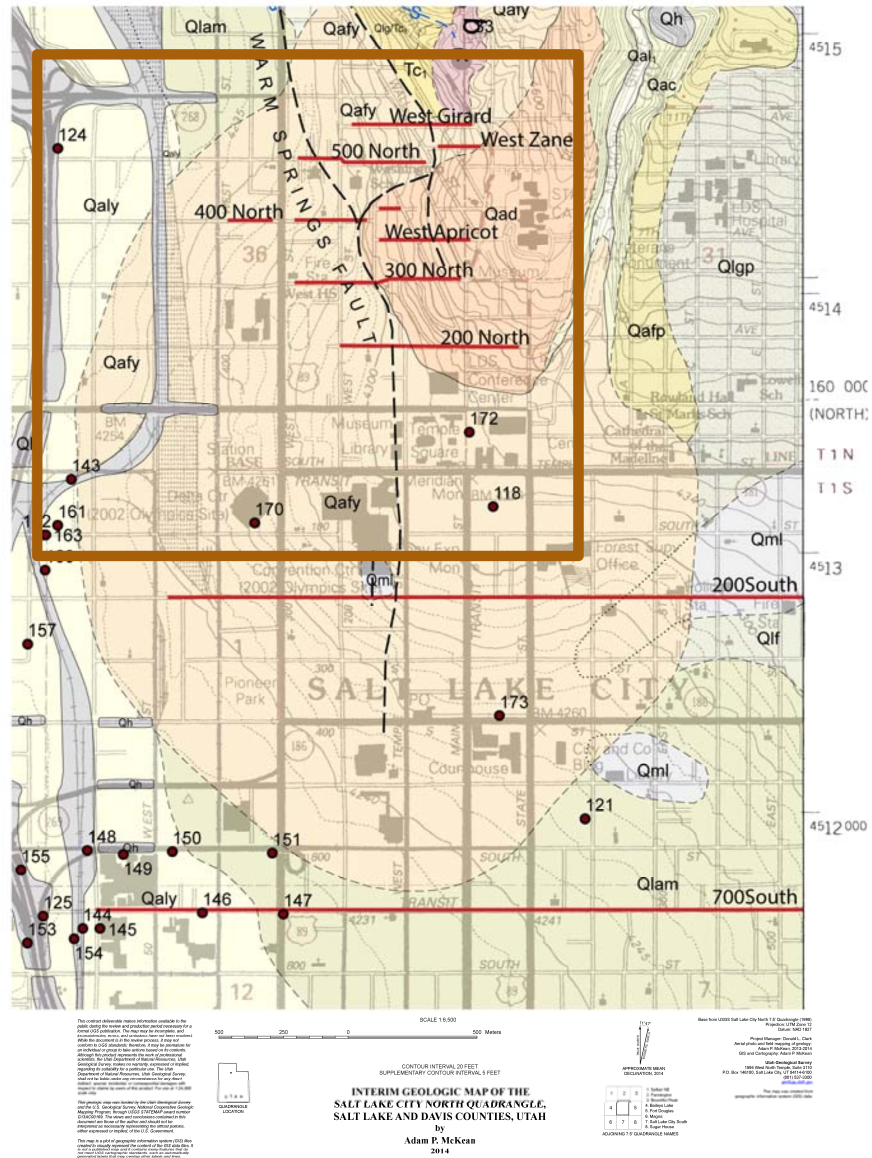
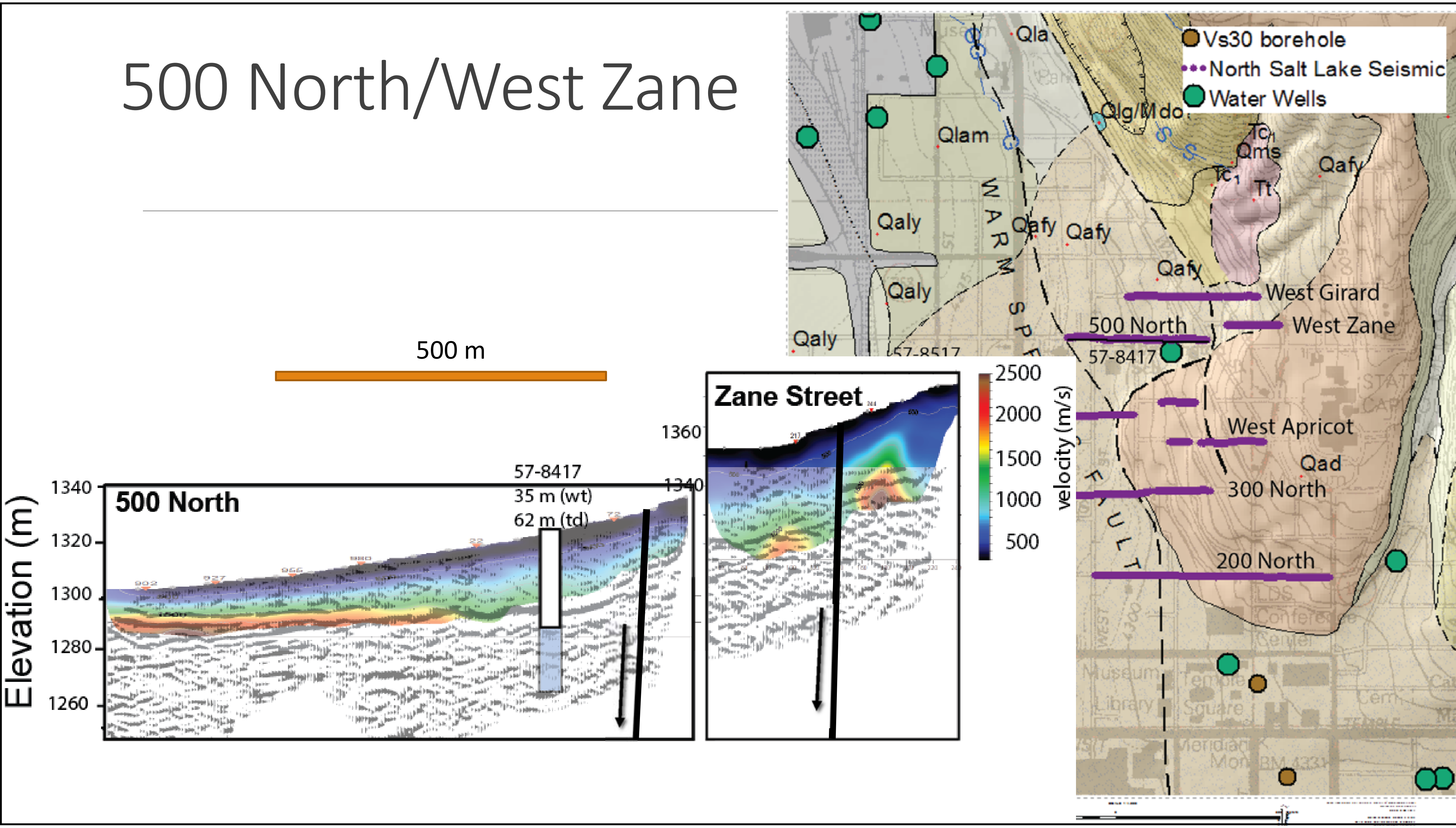


West Girard (shallow bedrock)



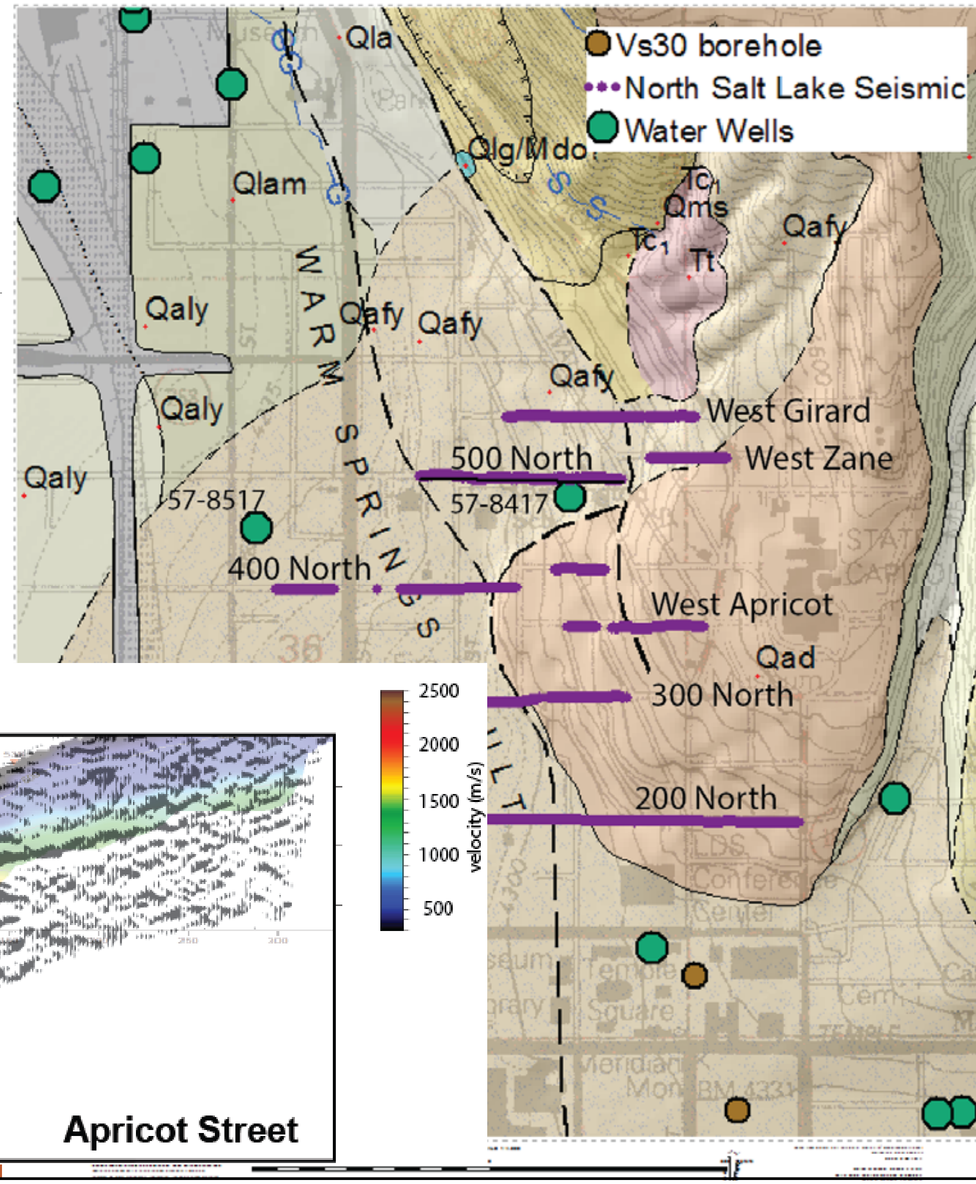


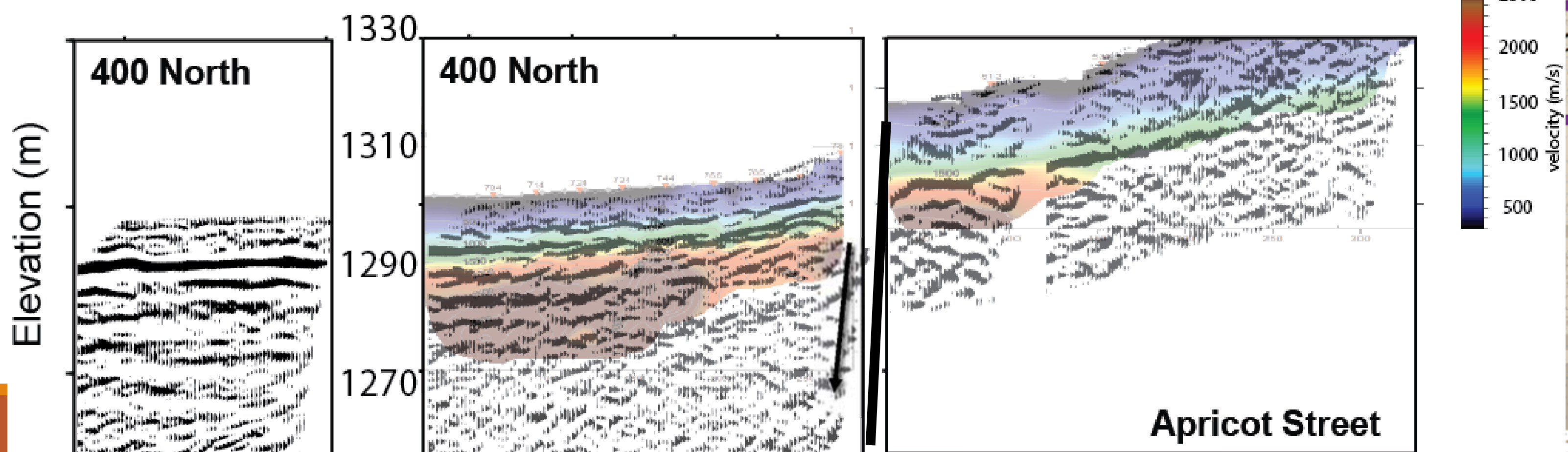
500 North/West Zane



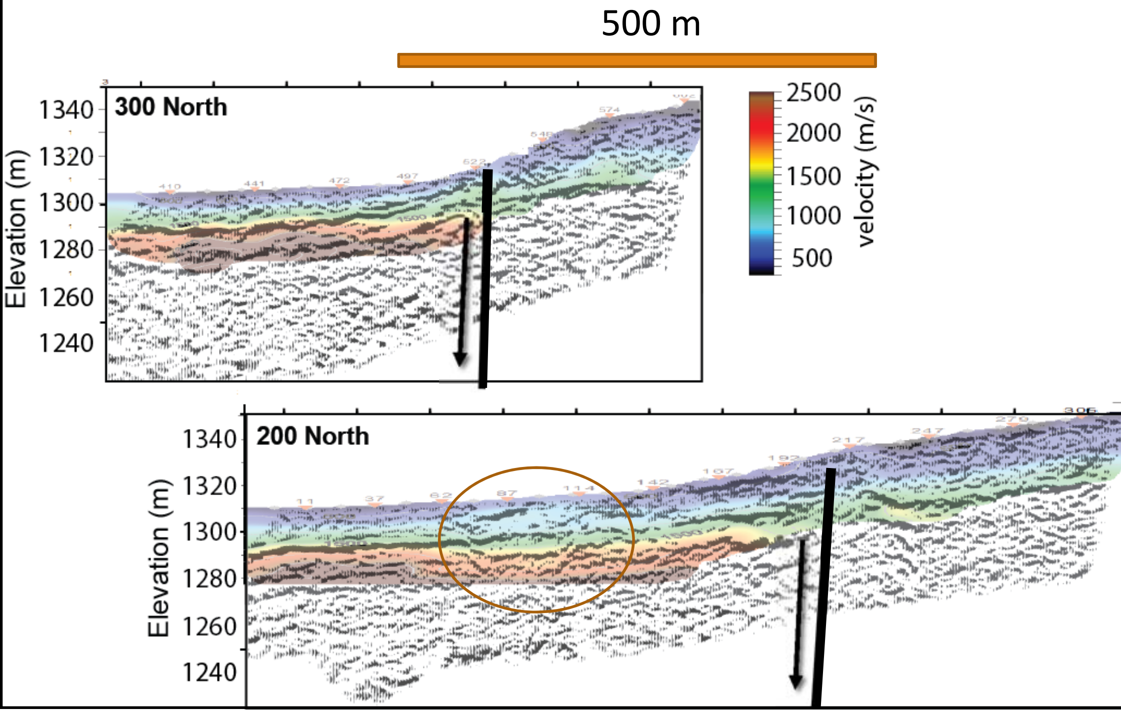
400 North/Apricot

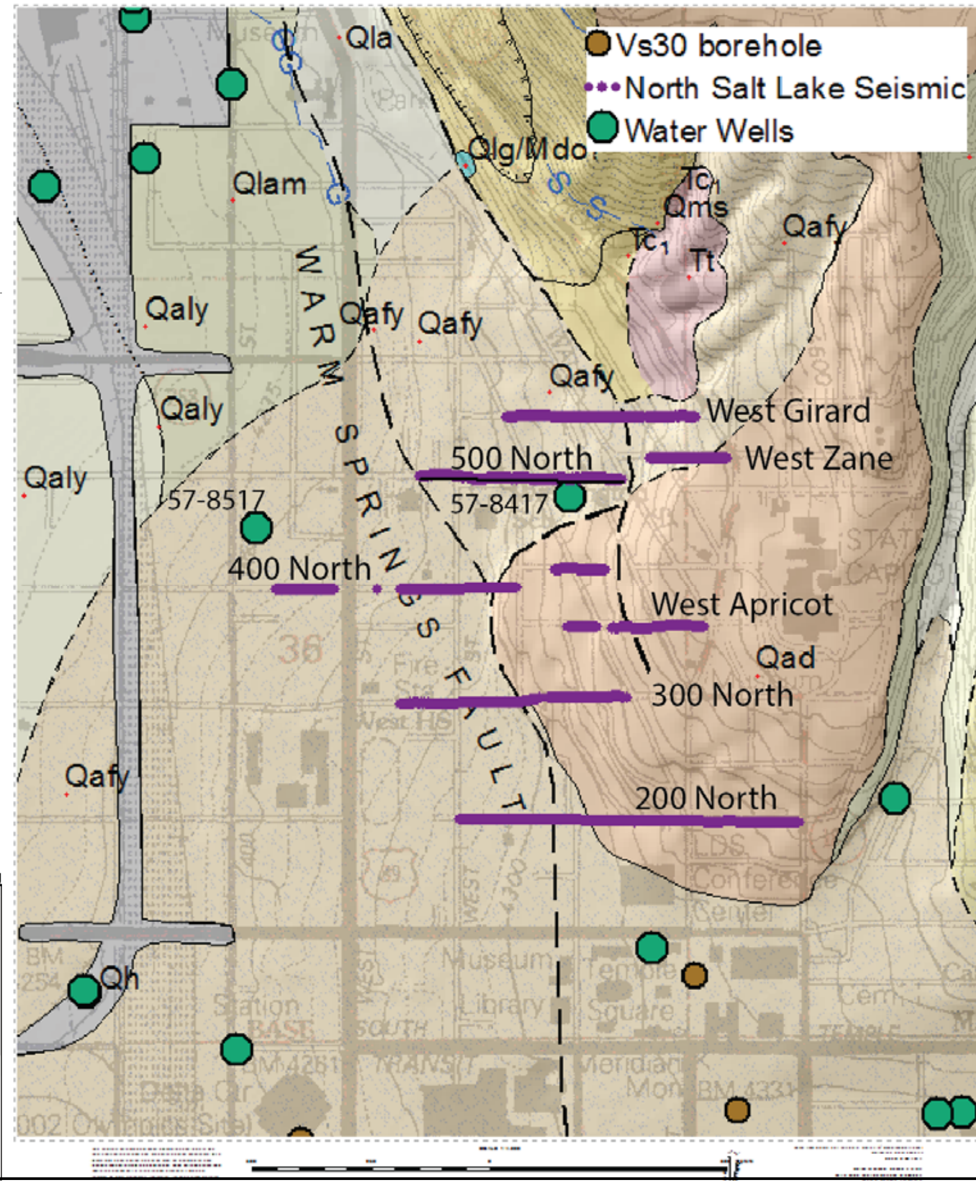
500 m



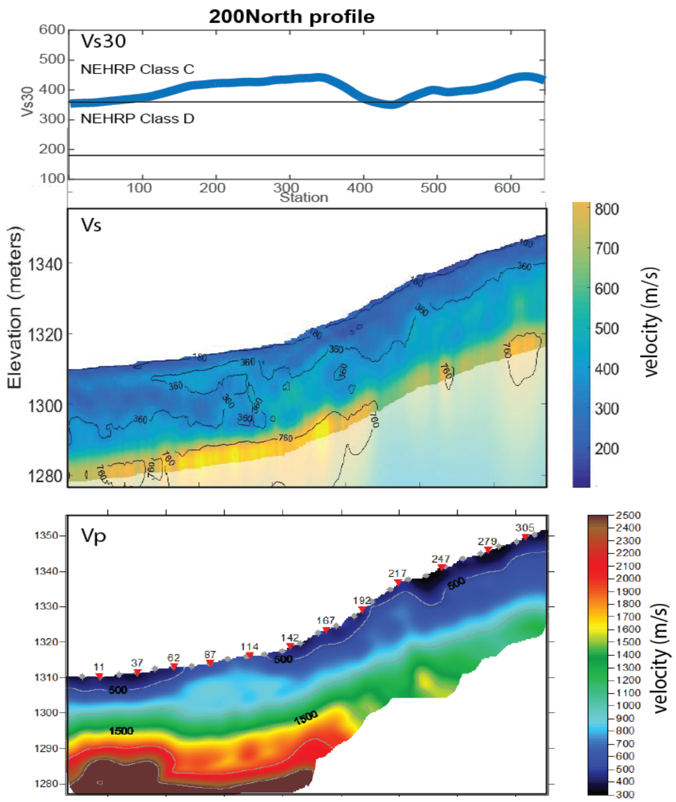


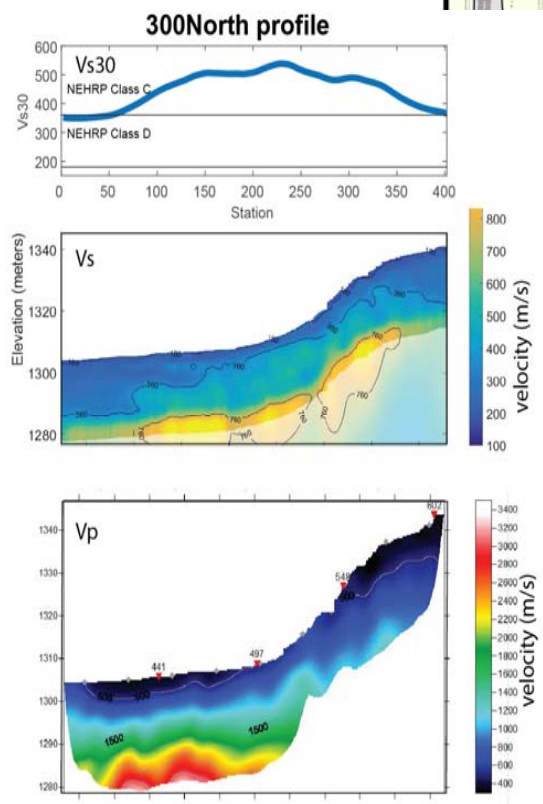
200 North/300 North

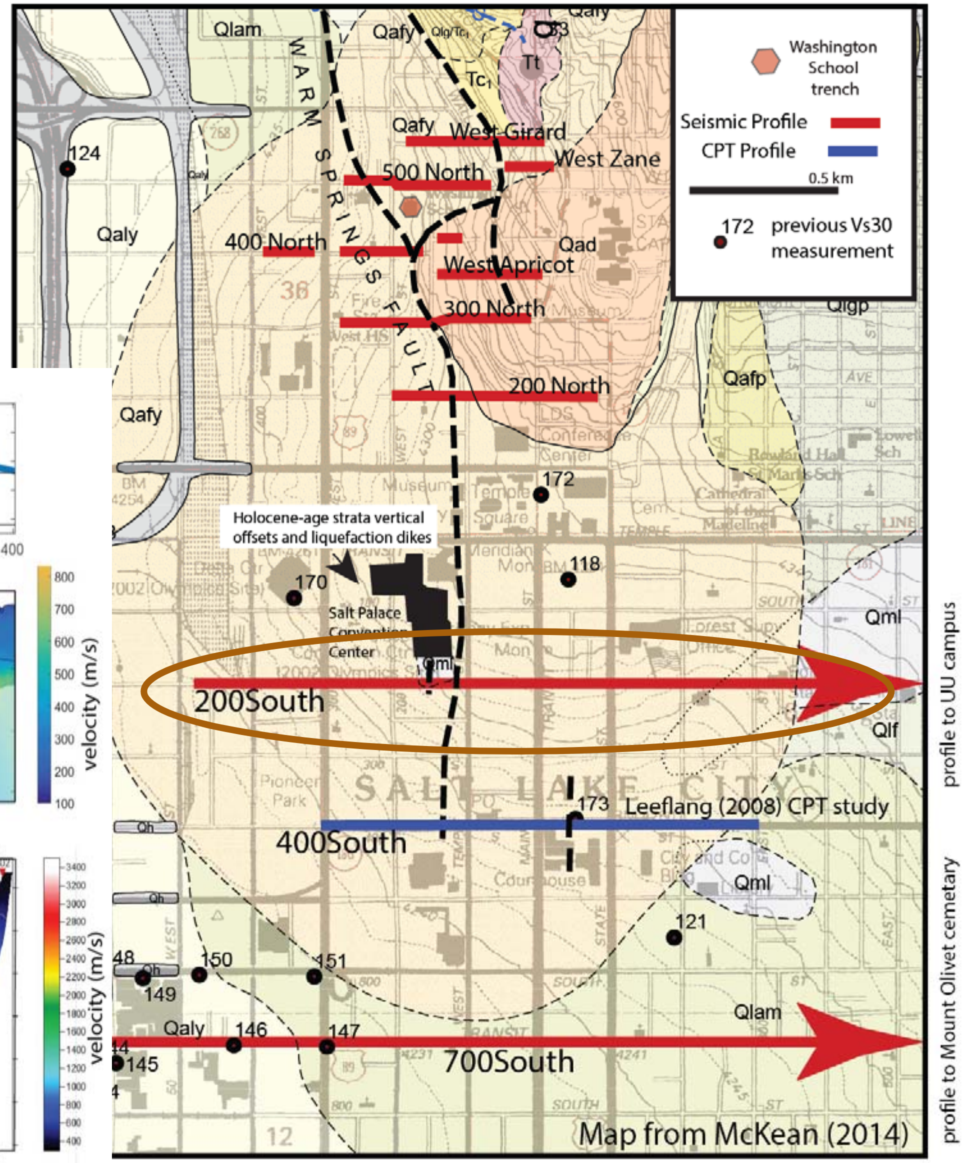


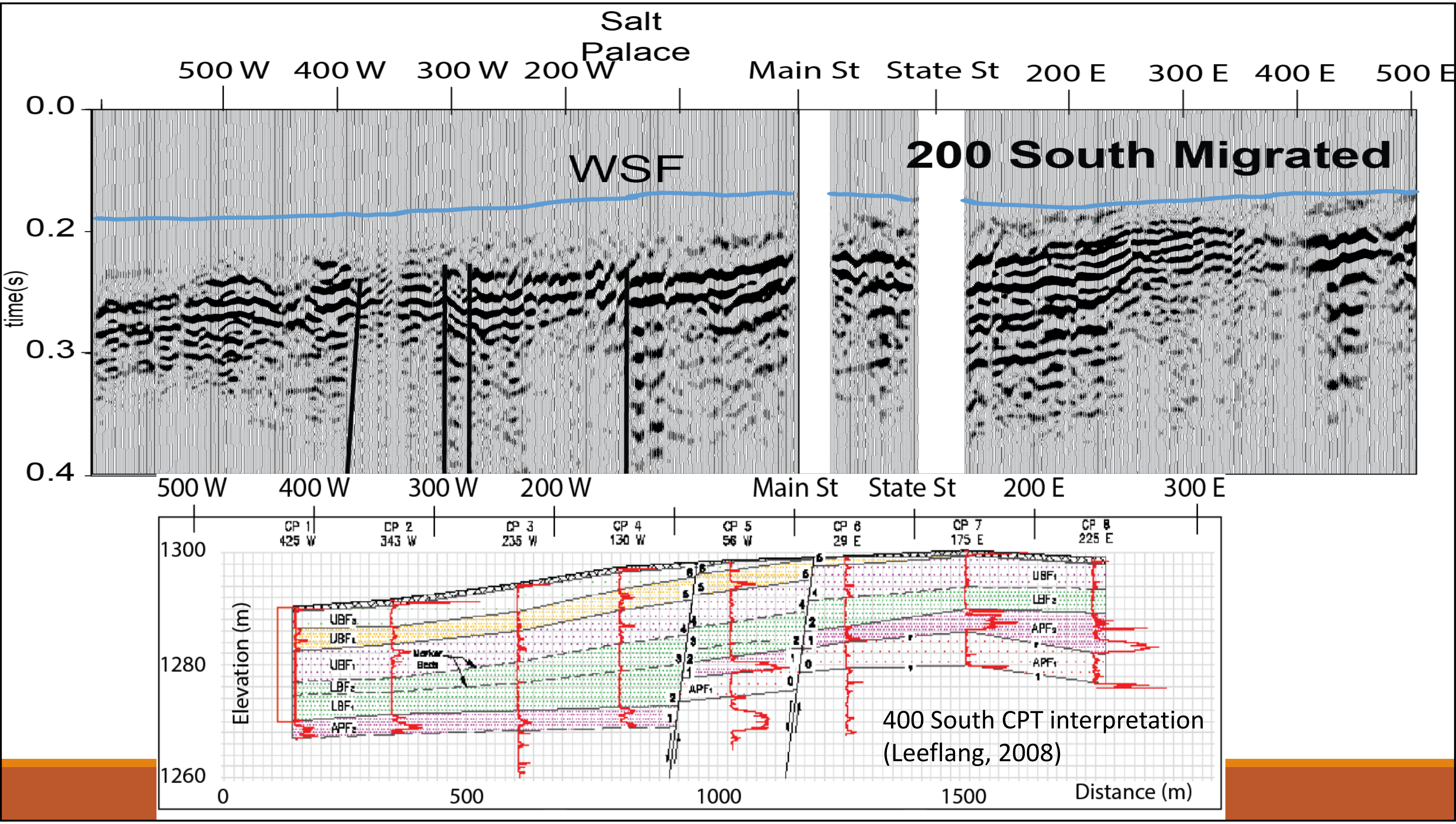


Salt Lake City 2015 Land Streamer Survey

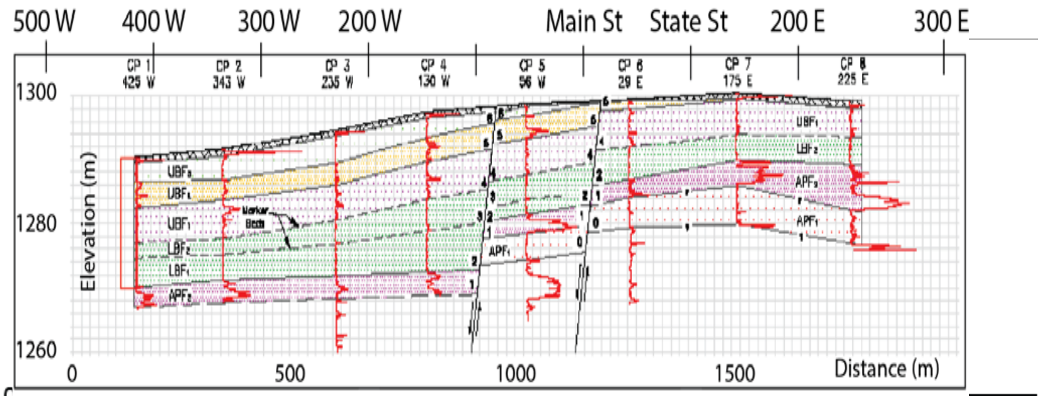


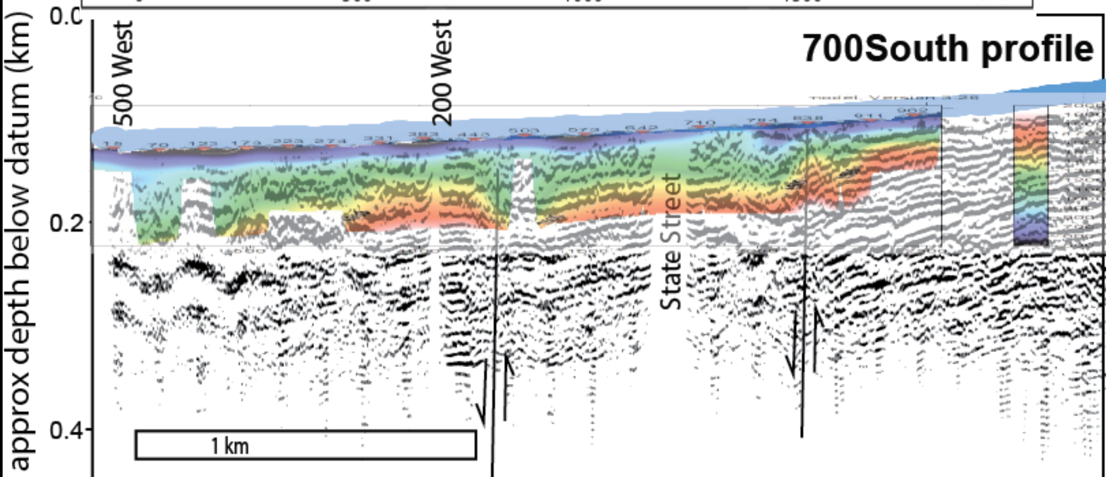




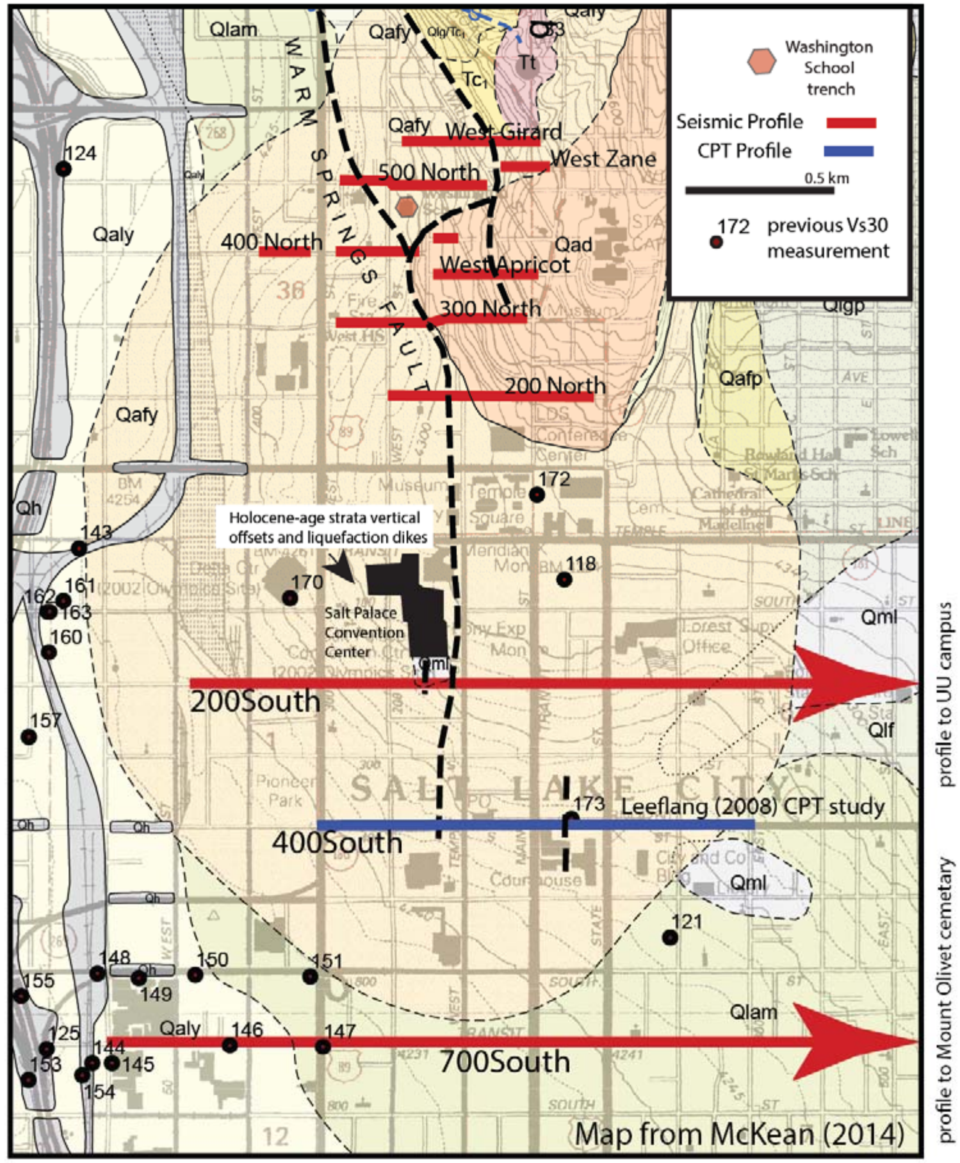

Salt Palace
500 W
400 W
300 W
200 W
Main St
State St
200 E
300 E
400 E
500 E
0.0
0.2
0.3
0.4
time(s)
WSF
200 South Migrated
1300
1280
1260
Elevation (m)
0
500
1000
1500
Distance (m)
400 South CPT interpretation
(Leeflang, 2008)

700 South/400 South CPT





400 South CPT interpretation (Leeflang, 2008)



Summary

North Salt Lake City/Warm Springs fault

Vs30 average for North Salt Lake City is 379 m/s (NEHRP C1) and 326 m/s for all profiles (NEHRP D3)

Vs30 values increase from west to east with increasing surface elevation.

Shallow bedrock (Vp > 2,500 m/s) is mapped to the north of the Capitol building

Step in water table and reflectors at the Warm Springs fault

Downtown Salt Lake City/Warm Springs fault extension

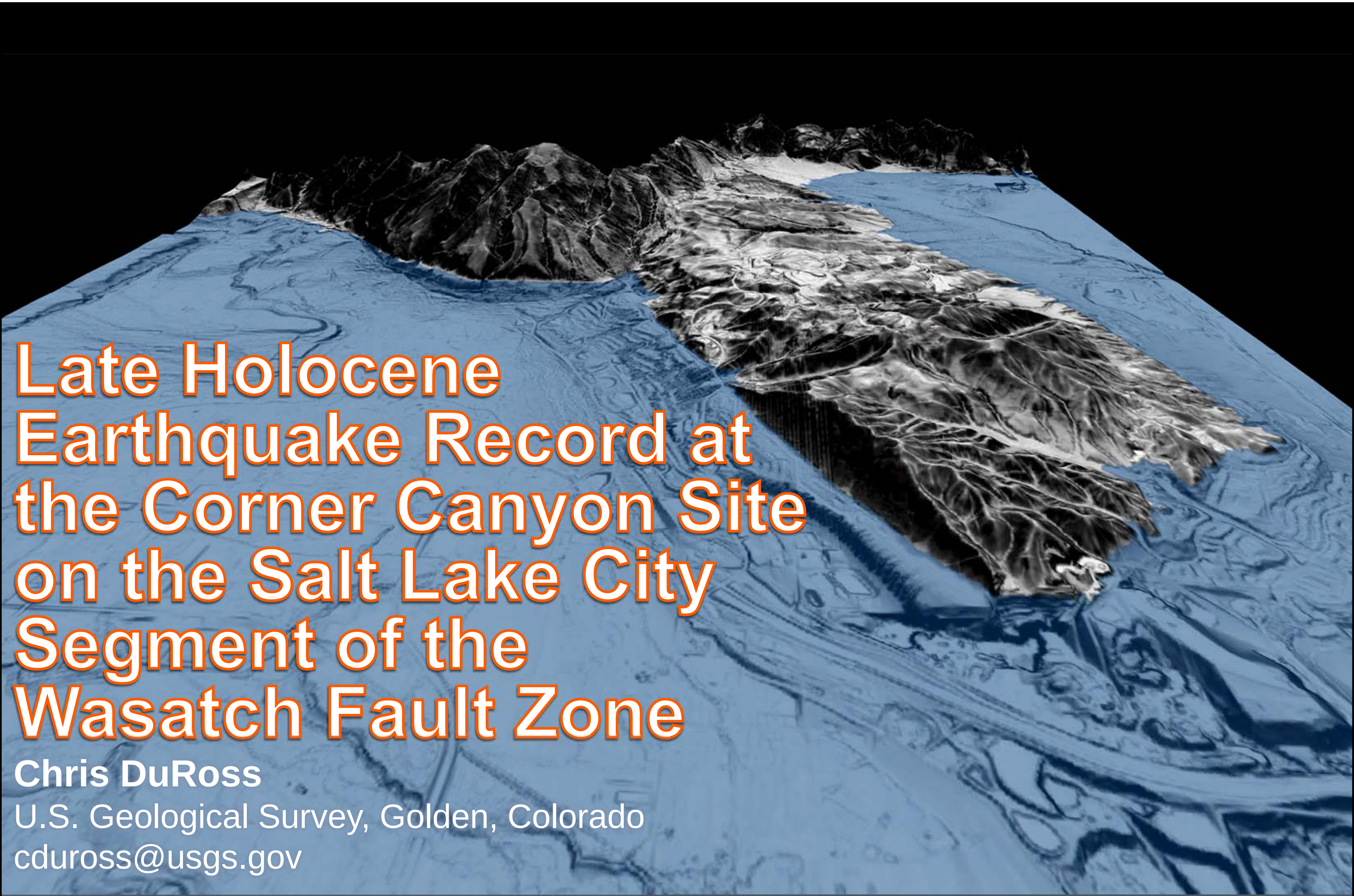
Vs30 values increase from west to east with increasing surface elevation.

We identify offset reflectors/Vs/Vp lateral variations consistent with active faults along 200 South and 700 South

Warm Springs fault extends to at least 700 South with decreasing offsets to the south and folded strata

East Bench fault

East Bench fault seen on both 200 S and 700 S with folded/offset strata and colluvial wedge material within fault zone



Late Holocene Earthquake Record at the Corner Canyon Site on the Salt Lake City Segment of the Wasatch Fault Zone

Chris DuRoss
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Utah Quaternary Fault Parameters Working Group, February 10, 2016

Salt Lake City segment (SLCS)

➢***High hazard***: Elapsed time since most recent earthquake (~1.4 ka) is comparable to the segment's mean recurrence interval (~1.3 kyr)

➢***High risk***: Adjacent to the most populous part of the Wasatch Front

➢***Remaining questions***: Timing and extent of Holocene surface-faulting earthquakes

Corner Canyon Site

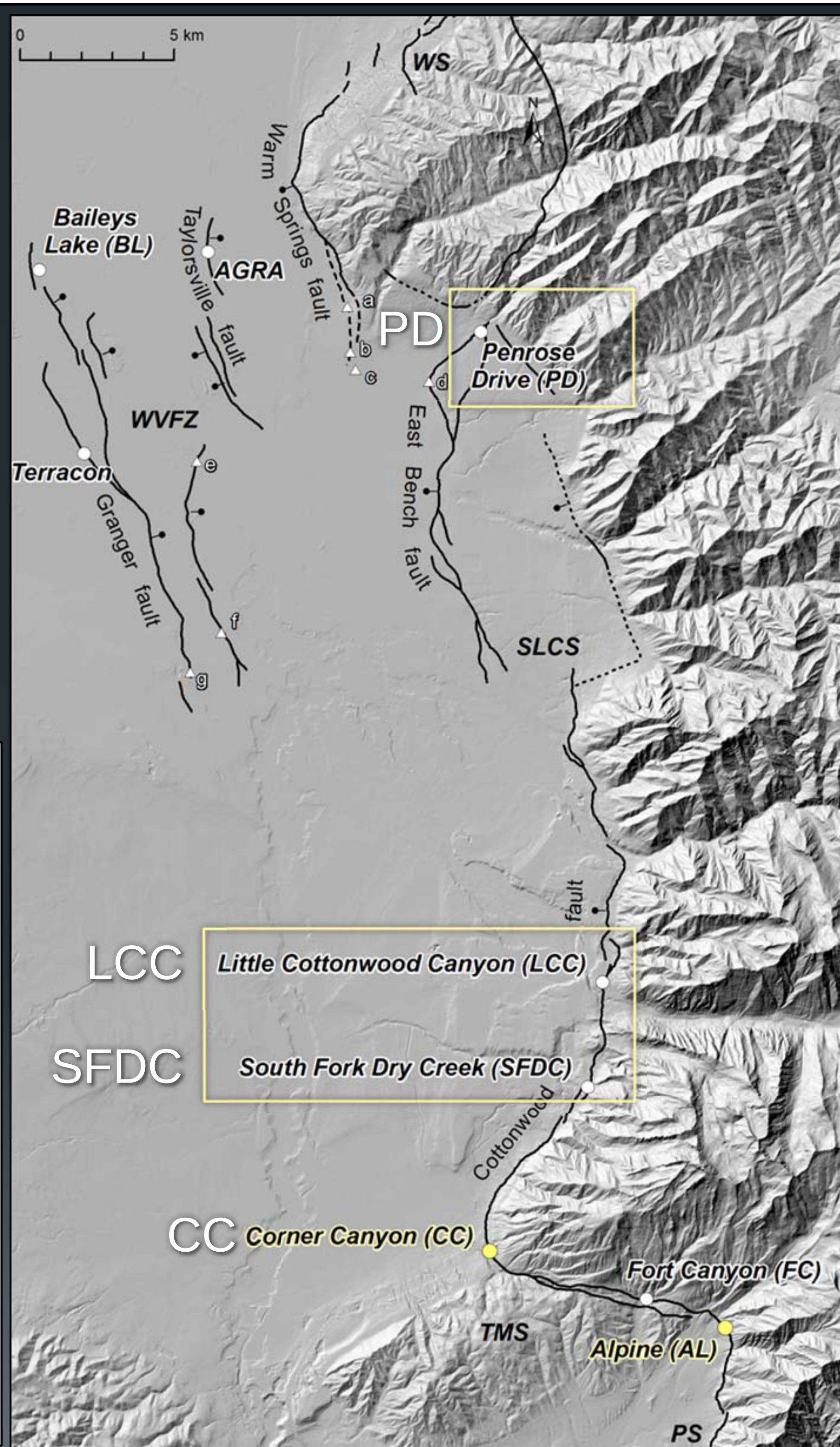
1. What is the timing earthquakes on the southernmost SLCS?

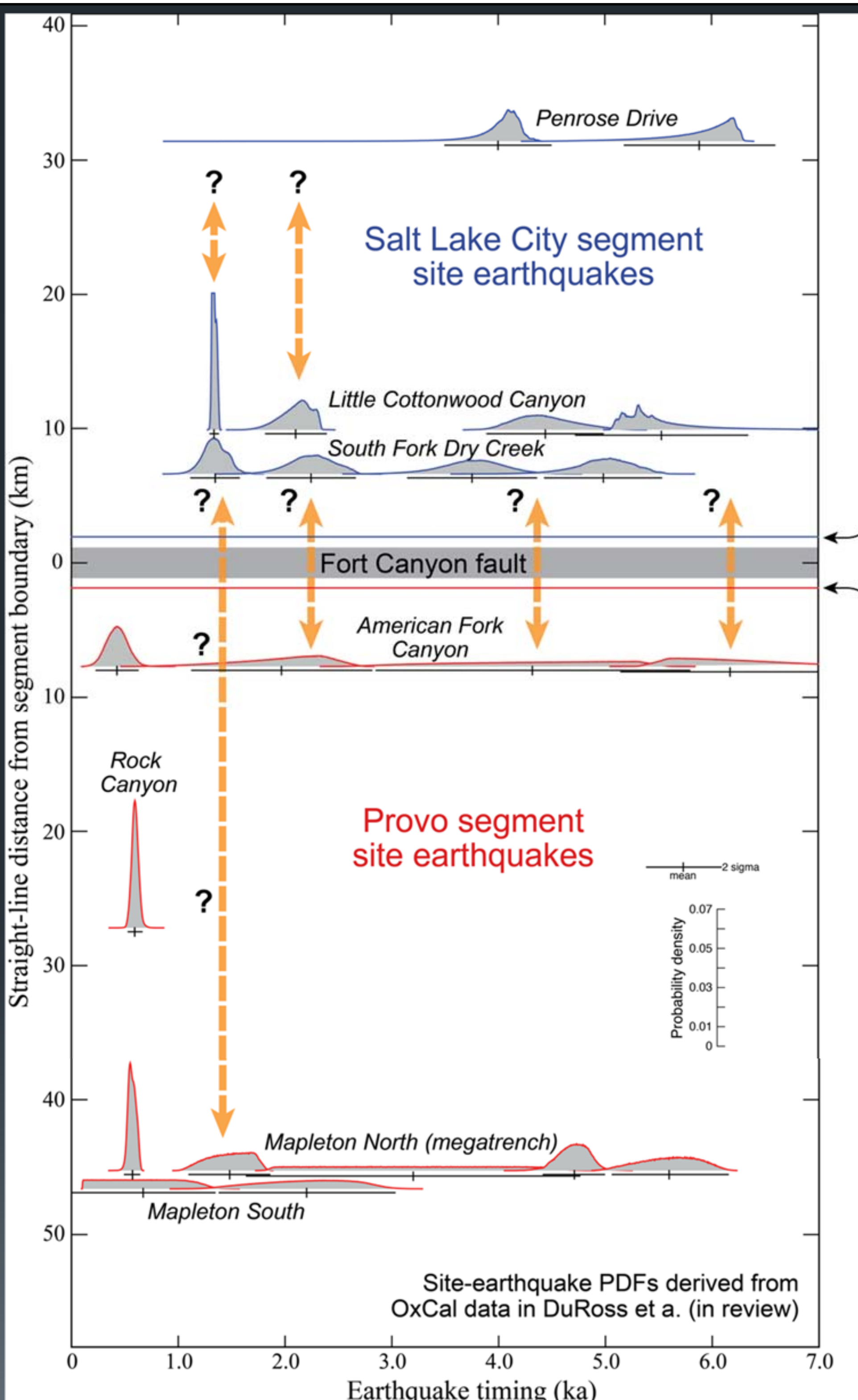
2. Have recent (~late Holocene) ruptures crossed the SLCS–Provo segment (PS) boundary?

Earthquake timing on the SLCS

EQ	East Bench fault	Cottonwood fault		SLCS Chronology (ka)
	PD (ka)	LCC (ka)	SFDC (ka)	
S1	-	1.3 ± 0.04	1.3 ± 0.2	1.3 ± 0.2
S2	-	2.1 ± 0.3	2.2 ± 0.4	2.2 ± 0.2
S3	4.0 ± 0.5	4.4 ± 0.5	3.8 ± 0.6	4.1 ± 0.2
S4	5.9 ± 0.7	5.5 ± 0.8	5.0 ± 0.5	5.3 ± 0.2
S5	7.5 ± 0.8	7.8 ± 0.7	-	7.7 ± 0.4
S6	9.7 ± 1.1	9.5 ± 0.2	-	9.5 ± 0.3
S7	10.9 ± 0.2	-	-	10.9 ± 0.2
S8	12.1 ± 1.6	-	-	11.4–13.8
S9	16.5 ± 1.9	16.5 ± 2.7	-	14.6–17.9

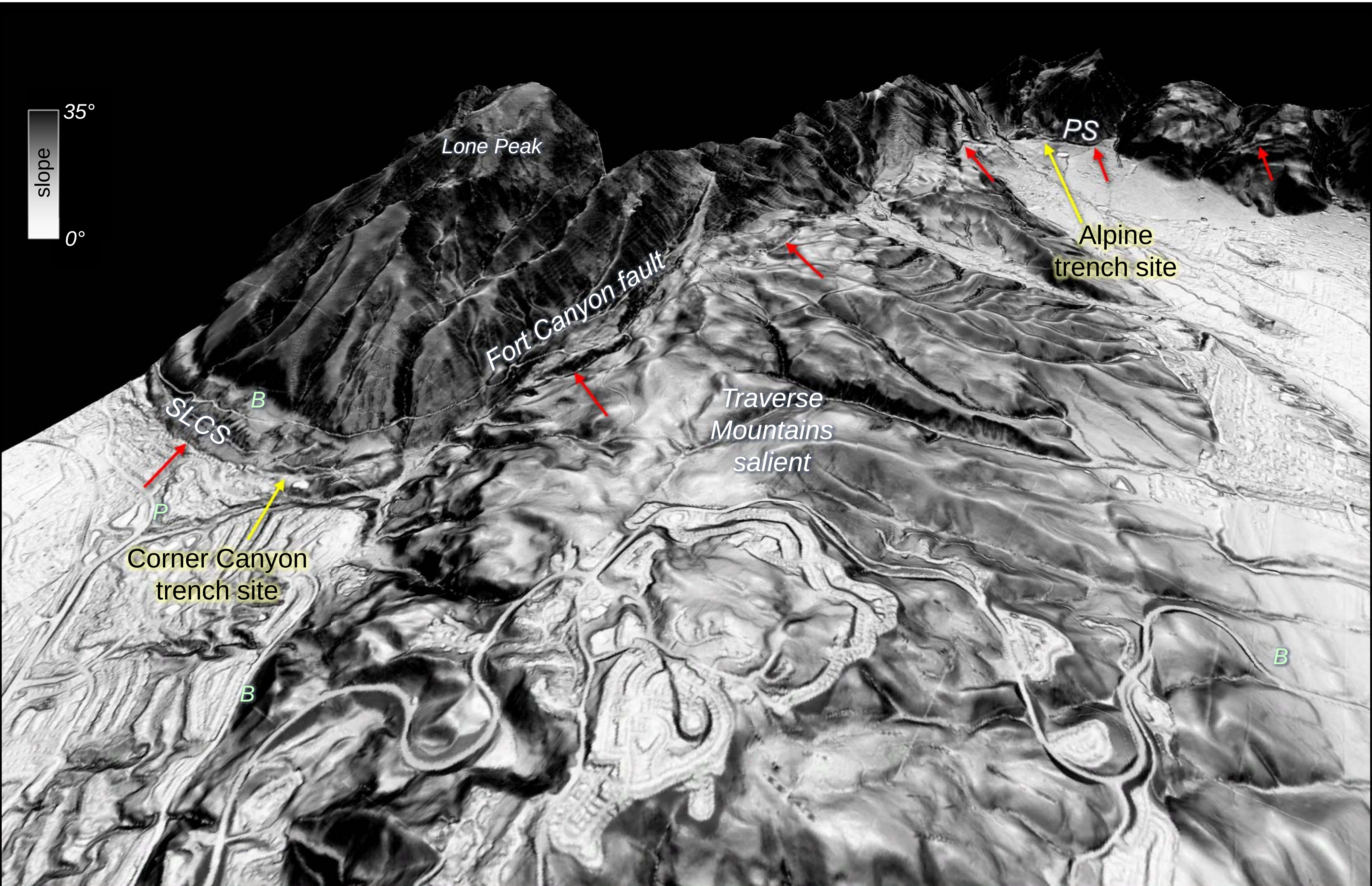
DuRoss & Hylland (2015)




Penrose Drive
Salt Lake City segment site earthquakes
Little Cottonwood Canyon
South Fork Dry Creek
Fort Canyon fault
American Fork Canyon
Rock Canyon
Provo segment site earthquakes
mean
2 sigma
Probability density
Mapleton North (megatrench)
Mapleton South
Site-earthquake PDFs derived from OxCal data in DuRoss et a. (in review)
Straight-line distance from segment boundary (km)
Earthquake timing (ka)

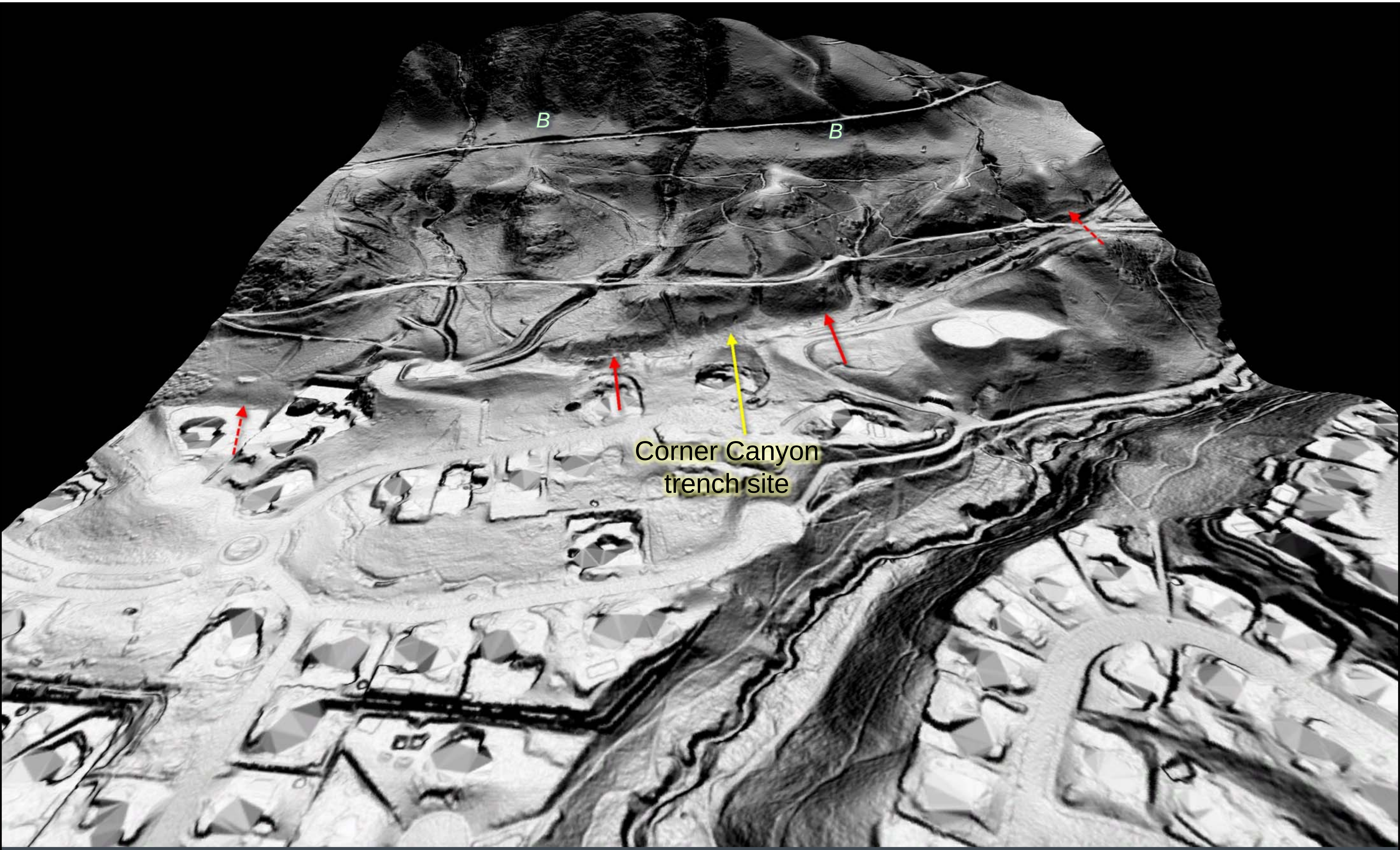
CC
AL


0
20 km
WSF - Warm Springs fault
EBF - East Bench fault
CF - Cottonwood fault
WVFZ - West Valley fault zone
FCF - Fort Canyon fault
ULFF - Utah Lake faults and folds
Baileys Lake
Salt
WSF
Salt Lake City
Penrose Drive
WVFZ
Lake
EBF
City
CF
Little Cottonwood Cyn.
segment
South Fork Dry Cr.
CC
Corner Canyon
FCF
Figure 5
Alpine
AL
Traverse Mountains salient
American Fork Cyn.
Provo
American Fork
ULFF
Rock Cyn.
Provo
segment
Hobble Cr.
Mapleton
Spanish Fork
UTAH
Wasatch Fault Zone
Nephi segment
Flat Cyn.
Water Cyn.
Woodland Hills
Spring Lake
Picayune Cyn.
Santaquin
Paleoseismic site
Salt Lake City & Provo seg's
Wasatch Fault zone
Quaternary fault
40°45'N
40°30'N
40°15'N
40°0'N

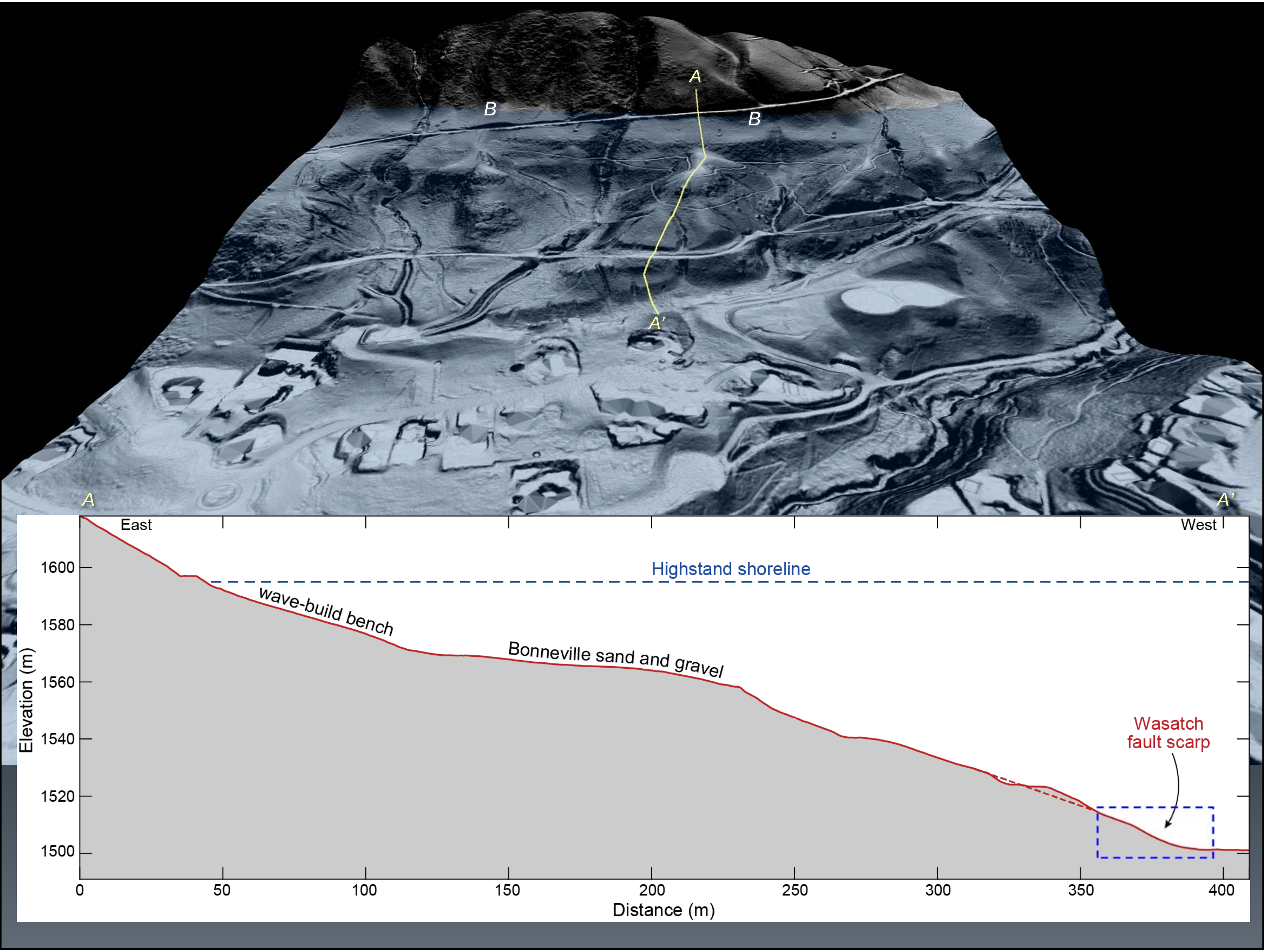


Corner Canyon site

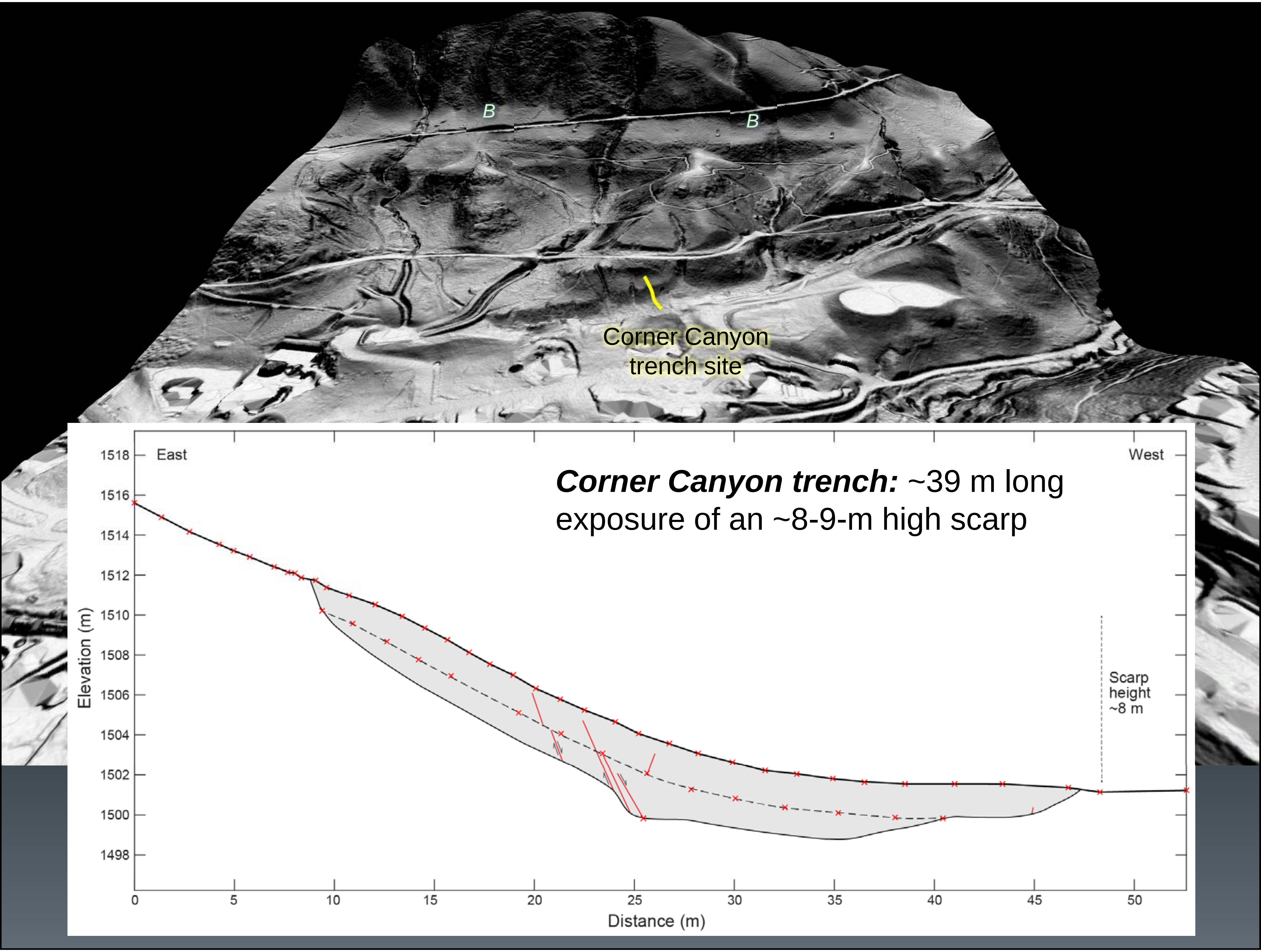
- ➢About 1 km north of the Traverse Mountains salient (TMS)



Lidar-based slopeshade map; oblique east view of the Corner Canyon trench site



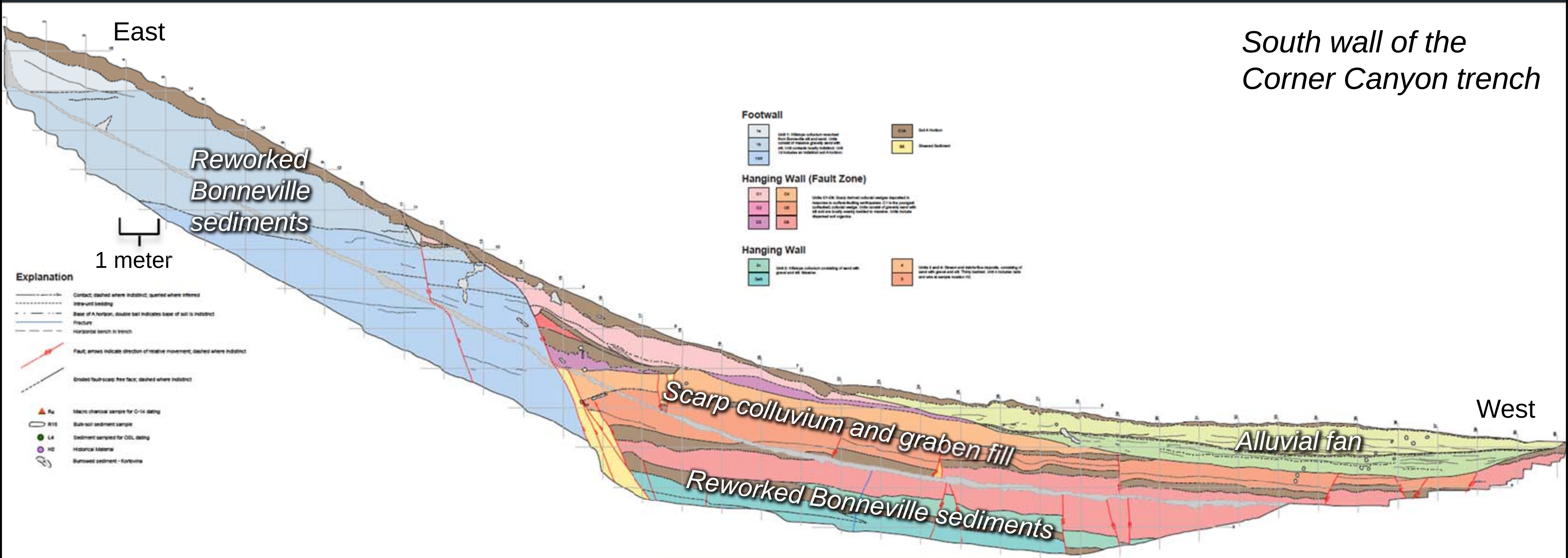
A
B
B
A'
A
A'
East
West
Highstand shoreline
wave-build bench
Bonneville sand and gravel
Wasatch fault scarp
Elevation (m)
1600
1580
1560
1540
1520
1500
0
50
100
150
200
250
300
350
400
Distance (m)


B
B
Corner Canyon
trench site
Corner Canyon trench: ~39 m long
exposure of an ~8-9-m high scarp
East
West
Scarp
height
~8 m
Elevation (m)
1518
1516
1514
1512
1510
1508
1506
1504
1502
1500
1498
0
5
10
15
20
25
30
35
40
45
50
Distance (m)


D
U

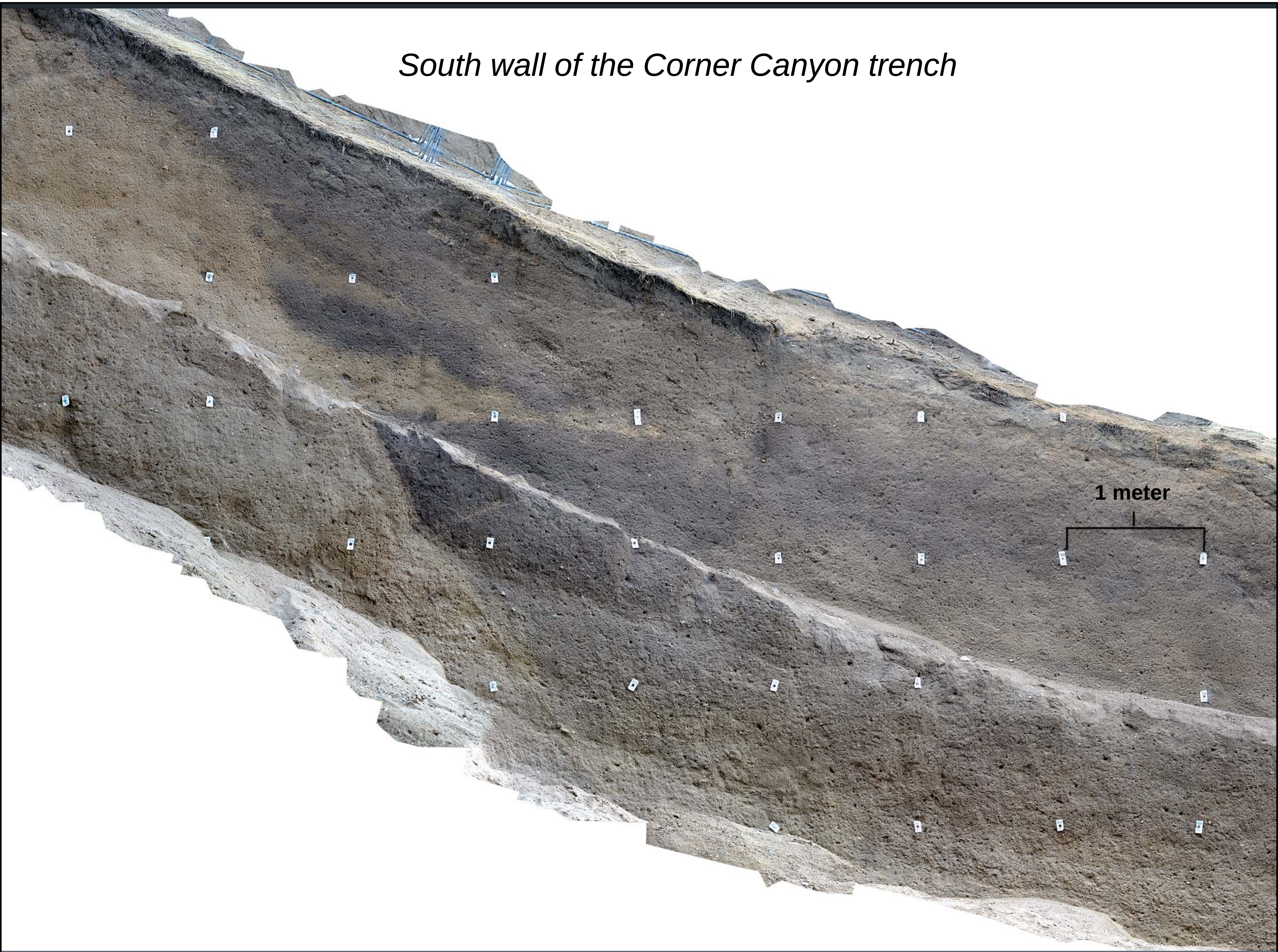
Stratigraphic Units

- Reworked (colluviated) fine-grained Bonneville sediments (units 1 and 2)
- Scarp-derived colluvium and graben-fill deposits (units C1 to C6)
- Young (including modern) alluvial-fan deposits (units 3 and 4)



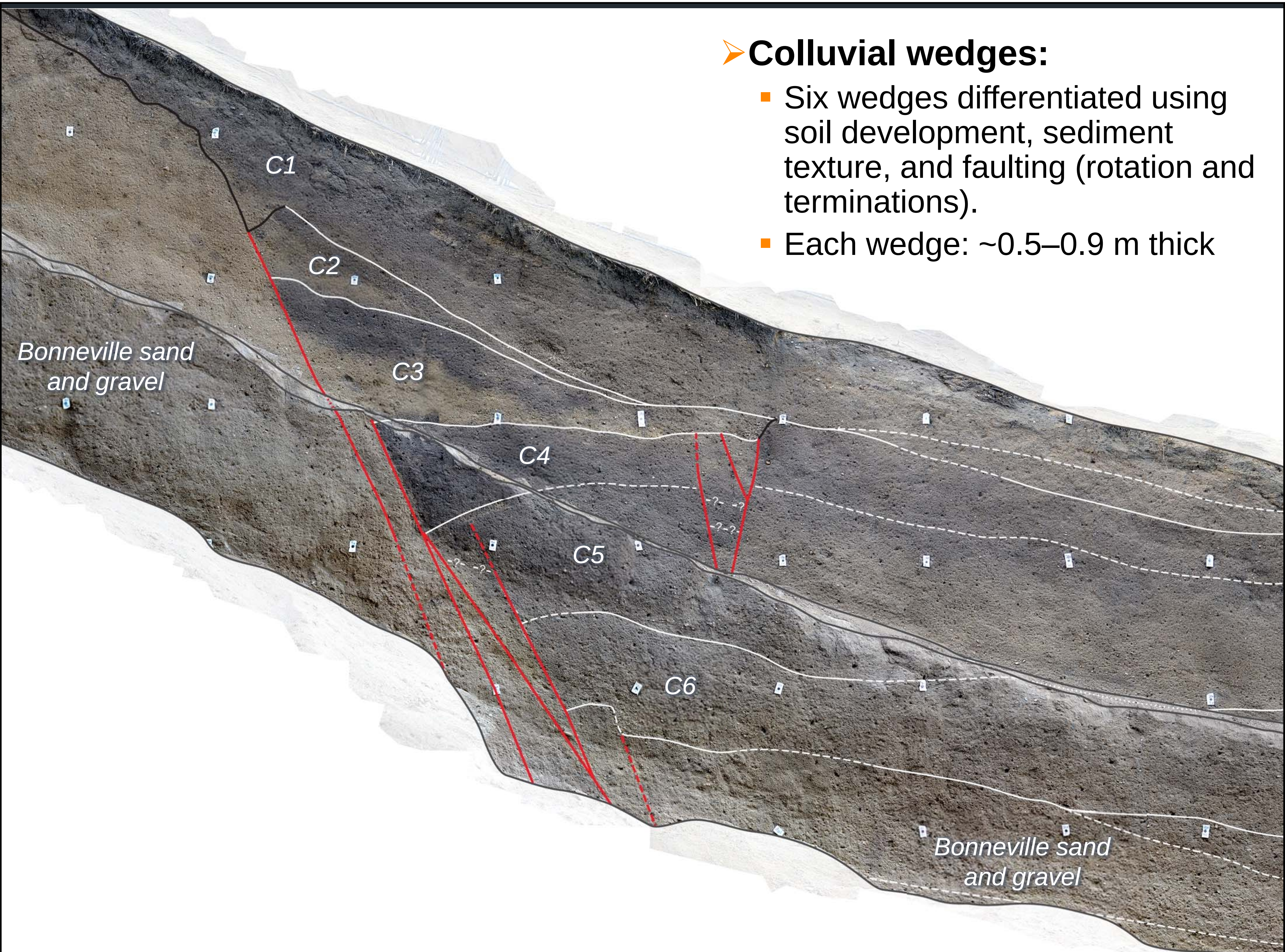
➢*Faulting*

- Main trace with several synthetic/antithetic faults
- ~20-m wide graben


South wall of the Corner Canyon trench
1 meter

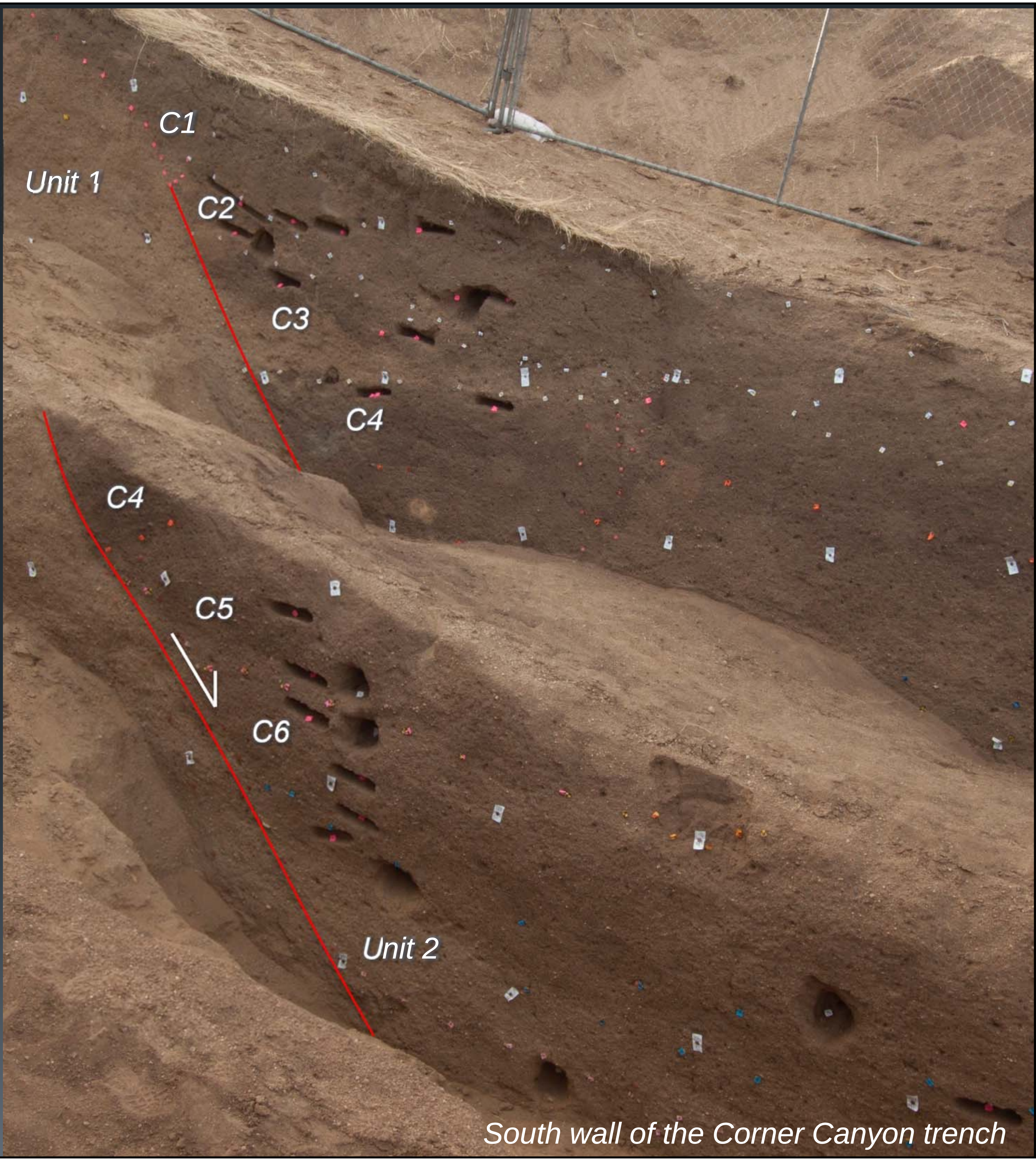
Colluvial wedges:

- Six wedges differentiated using soil development, sediment texture, and faulting (rotation and terminations).
- Each wedge: ~0.5–0.9 m thick



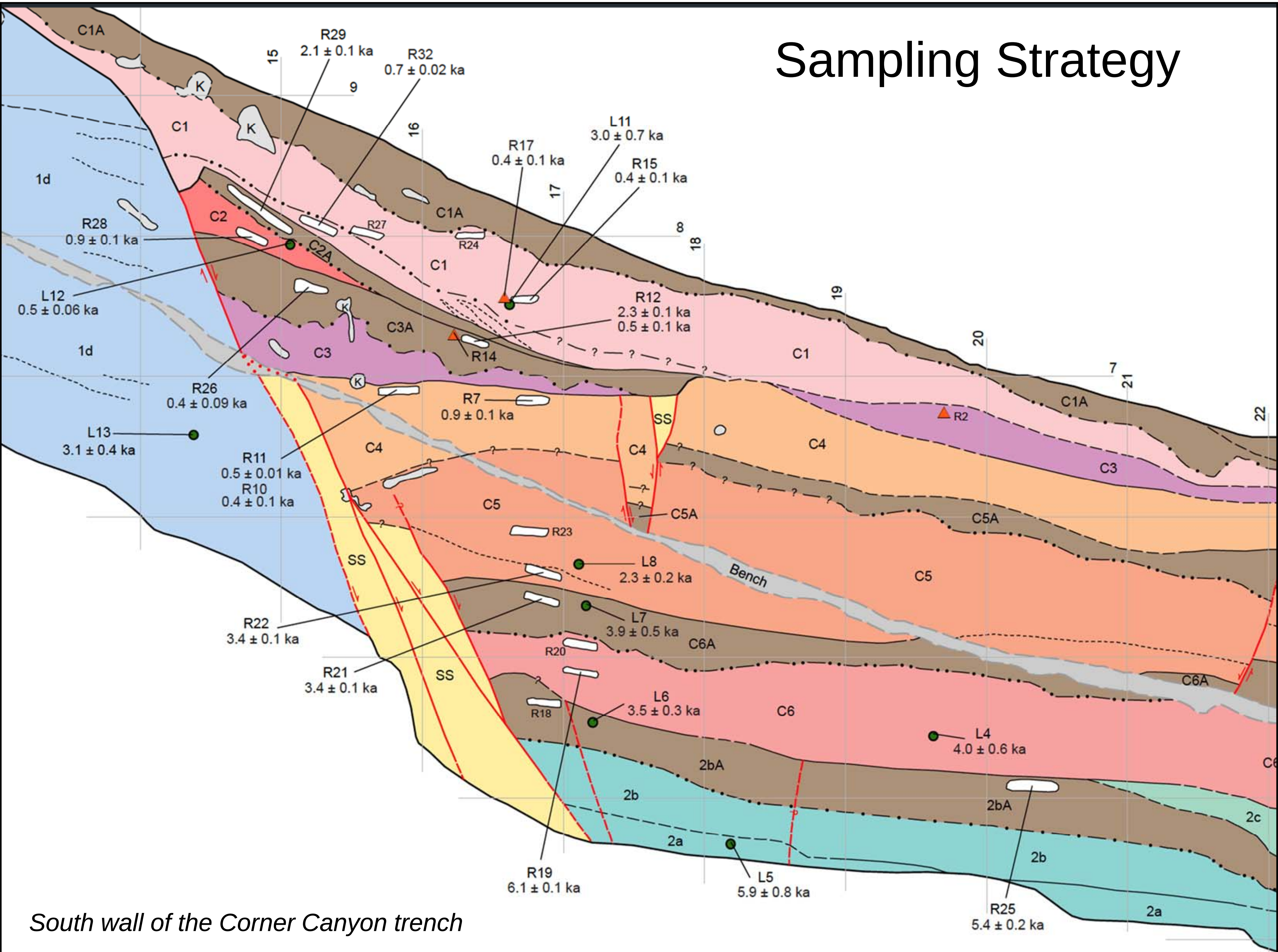
Sampling Strategy

- ***Radiocarbon***
  - *24 charcoal samples extracted from bulk-soil samples yielded ^{14}C ages*
- ***Optically Stimulated Luminescence** (OSL)*
  - *11 samples yielded OSL ages*

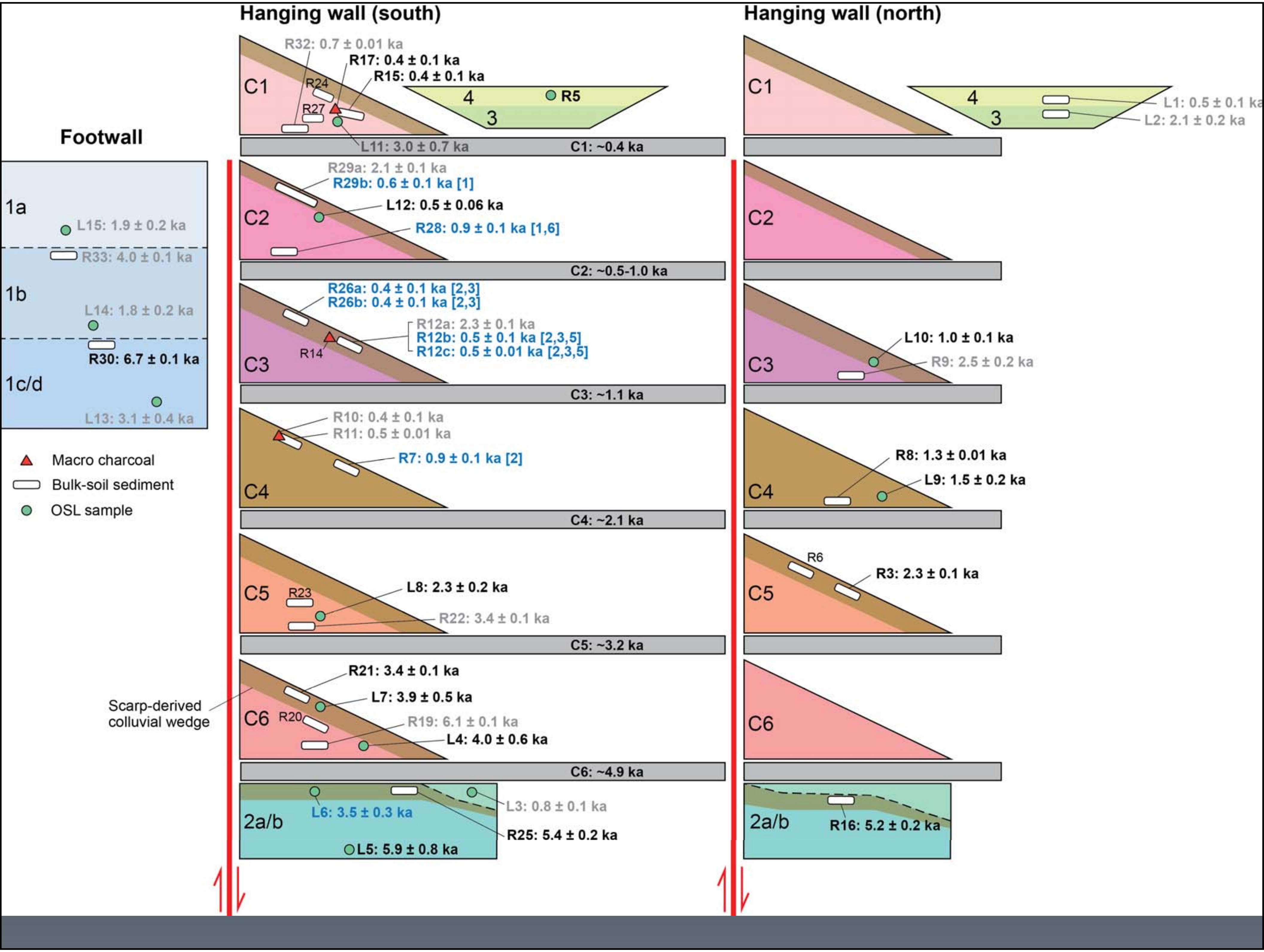


South wall of the Corner Canyon trench

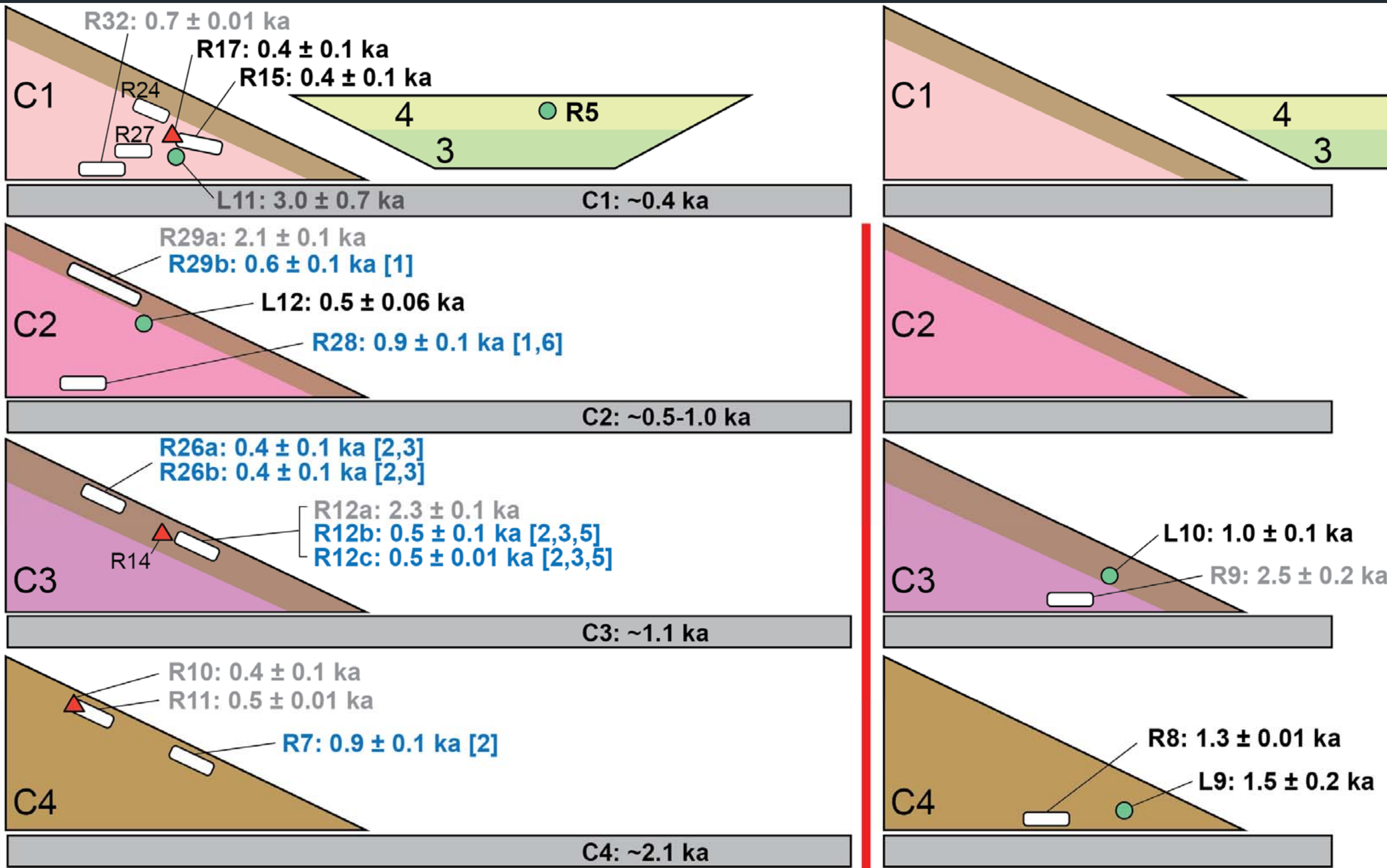
Sampling Strategy



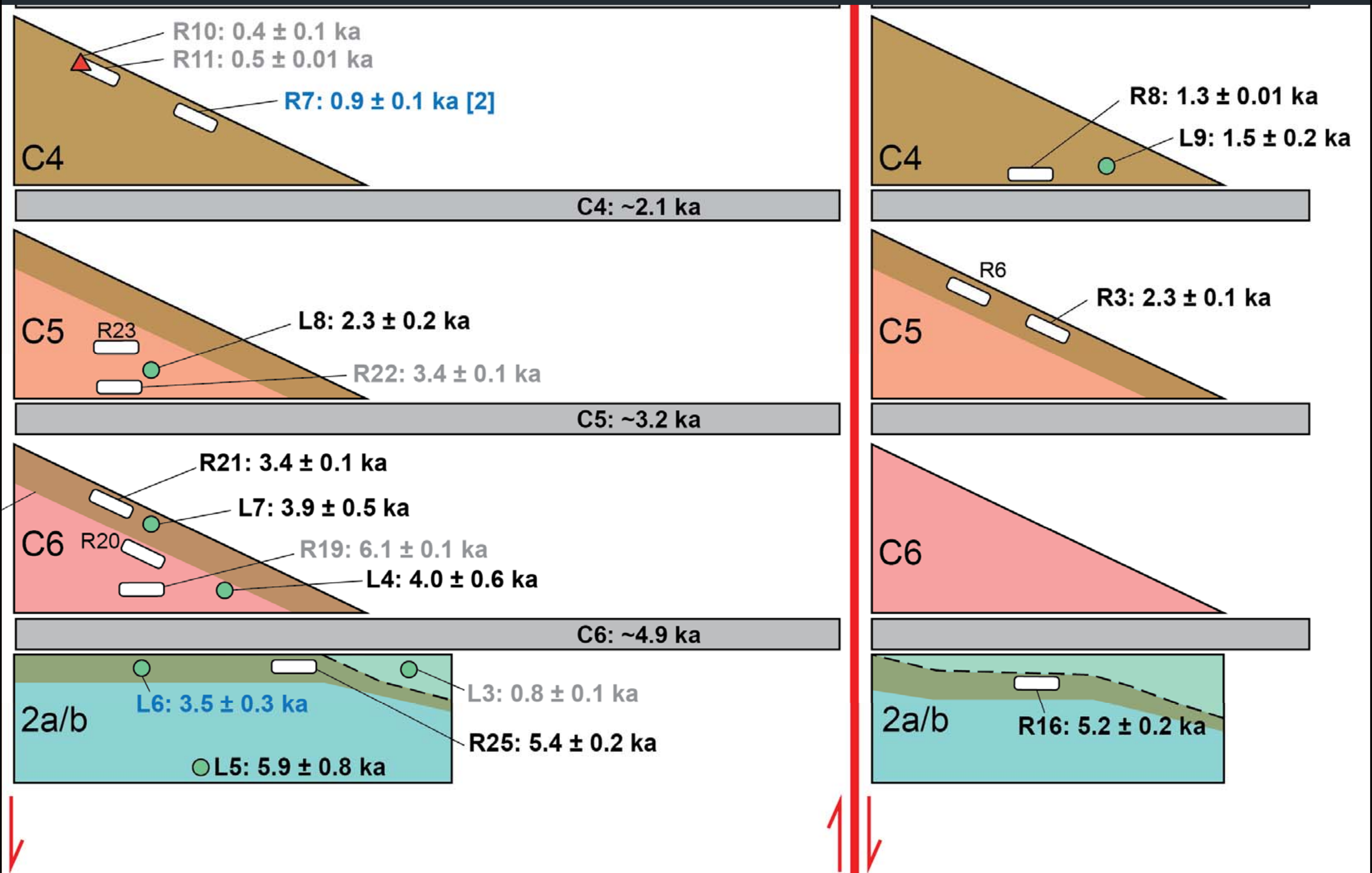
South wall of the Corner Canyon trench



Footwall
Hanging wall (south)
Hanging wall (north)
1a
L15: 1.9 ± 0.2 ka
R33: 4.0 ± 0.1 ka
1b
L14: 1.8 ± 0.2 ka
R30: 6.7 ± 0.1 ka
1c/d
L13: 3.1 ± 0.4 ka
Macro charcoal
Bulk-soil sediment
OSL sample
Scarp-derived colluvial wedge
R32: 0.7 ± 0.01 ka
R17: 0.4 ± 0.1 ka
R15: 0.4 ± 0.1 ka
C1
R24
R27
4
3
R5
L11: 3.0 ± 0.7 ka
C1: ~0.4 ka
L1: 0.5 ± 0.1 ka
L2: 2.1 ± 0.2 ka
R29a: 2.1 ± 0.1 ka
R29b: 0.6 ± 0.1 ka [1]
C2
L12: 0.5 ± 0.06 ka
R28: 0.9 ± 0.1 ka [1,6]
C2: ~0.5-1.0 ka
R26a: 0.4 ± 0.1 ka [2,3]
R26b: 0.4 ± 0.1 ka [2,3]
R12a: 2.3 ± 0.1 ka
R12b: 0.5 ± 0.1 ka [2,3,5]
R12c: 0.5 ± 0.01 ka [2,3,5]
R14
C3
C3: ~1.1 ka
L10: 1.0 ± 0.1 ka
R9: 2.5 ± 0.2 ka
R10: 0.4 ± 0.1 ka
R11: 0.5 ± 0.01 ka
R7: 0.9 ± 0.1 ka [2]
C4
C4: ~2.1 ka
R8: 1.3 ± 0.01 ka
L9: 1.5 ± 0.2 ka
C5
R23
L8: 2.3 ± 0.2 ka
R22: 3.4 ± 0.1 ka
C5: ~3.2 ka
R6
R3: 2.3 ± 0.1 ka
R21: 3.4 ± 0.1 ka
L7: 3.9 ± 0.5 ka
C6
R20
R19: 6.1 ± 0.1 ka
L4: 4.0 ± 0.6 ka
C6: ~4.9 ka
2a/b
L6: 3.5 ± 0.3 ka
L3: 0.8 ± 0.1 ka
R25: 5.4 ± 0.2 ka
L5: 5.9 ± 0.8 ka
R16: 5.2 ± 0.2 ka



R32: 0.7 ± 0.01 ka
R17: 0.4 ± 0.1 ka
R15: 0.4 ± 0.1 ka
C1
R24
R27
4
R5
3
L11: 3.0 ± 0.7 ka
C1: ~0.4 ka
R29a: 2.1 ± 0.1 ka
R29b: 0.6 ± 0.1 ka [1]
C2
L12: 0.5 ± 0.06 ka
R28: 0.9 ± 0.1 ka [1,6]
C2: ~0.5-1.0 ka
R26a: 0.4 ± 0.1 ka [2,3]
R26b: 0.4 ± 0.1 ka [2,3]
R12a: 2.3 ± 0.1 ka
R12b: 0.5 ± 0.1 ka [2,3,5]
R12c: 0.5 ± 0.01 ka [2,3,5]
R14
C3
C3: ~1.1 ka
R10: 0.4 ± 0.1 ka
R11: 0.5 ± 0.01 ka
R7: 0.9 ± 0.1 ka [2]
C4
C4: ~2.1 ka
C1
4
3
C2
L10: 1.0 ± 0.1 ka
R9: 2.5 ± 0.2 ka
C3
R8: 1.3 ± 0.01 ka
L9: 1.5 ± 0.2 ka
C4



R10: 0.4 ± 0.1 ka
R11: 0.5 ± 0.01 ka
R7: 0.9 ± 0.1 ka [2]
C4
R8: 1.3 ± 0.01 ka
L9: 1.5 ± 0.2 ka
C4
C4: ~2.1 ka
C5
R23
L8: 2.3 ± 0.2 ka
R22: 3.4 ± 0.1 ka
R6
R3: 2.3 ± 0.1 ka
C5
C5: ~3.2 ka
R21: 3.4 ± 0.1 ka
L7: 3.9 ± 0.5 ka
C6
R20
R19: 6.1 ± 0.1 ka
L4: 4.0 ± 0.6 ka
C6
C6: ~4.9 ka
2a/b
L6: 3.5 ± 0.3 ka
L3: 0.8 ± 0.1 ka
R25: 5.4 ± 0.2 ka
L5: 5.9 ± 0.8 ka
2a/b
R16: 5.2 ± 0.2 ka

CC Earthquake Record

Table S3. Summary of OxCal Modeling Results for the Corner Canyon Site[1]

EQ[2]	Model 1	Model 2	Model 3	Model 4[3]	Model 5	Model 6
CC1	490 ± 53	421 ± 21	420 ± 22	439 ± 35	436 ± 29	438 ± 35
CC2	885 ± 44	446 ± 16	445 ± 16	662 ± 146	478 ± 19	891 ± 45
CC3	1069 ± 116	878 ± 35	1019 ± 115	1093 ± 119	1062 ± 120	1069 ± 114
CC4	2097 ± 266	2078 ± 270	2114 ± 252	2092 ± 272	2100 ± 264	2098 ± 266
CC5	3212 ± 170	3213 ± 170	3210 ± 172	3212 ± 171	3210 ± 171	3212 ± 171
CC6	4858 ± 293	4858 ± 292	4858 ± 292	4857 ± 293	4859 ± 291	4858 ± 292
A_m	21	21	21	74	33	76

[1] Earthquake-timing results from OxCal models 1 to 6. Timing uncertainties are reported to one-sigma.

[2] Corner Canyon earthquakes. Earthquake CC1 corresponds to colluvial wedge unit C1 (plate 1). A_m indicates model agreement index from OxCal, which is a measure of how well the numerical ages agree with the stratigraphic model.

[3] Model 4 is used to calculate earthquake recurrence and slip rate values (table 5) because it includes the broadest range for earthquake CC2.

CC Earthquake Recurrence & Slip Rate

***Table 1**. Summary of Earthquake Parameters for the Corner Canyon Site*

EQ	**EQ timing** (ka)[1]	**Displacement** (m)[2]	**Mean Recurrence** (yr)[3]		**Slip rate** (mm/yr)[4]
	Mean ± 2σ (95%)	Midpoint (min-max)	EQs	Mean ± 2σ (95%)	Midpoint (min-max)
CC1	0.4 ± 0.1 (0.4–0.5)	1.1 (0.9–1.4)	-	-	-
CC2[5]	0.7 ± 0.3 (0.4–0.9)	0.7 (0.5–0.8)	-	-	-
CC3	1.1 ± 0.2 (0.9–1.3)	1.2 (0.9–1.4)	CC3-CC1	330 ± 120 (220–440)	2.8 (1.6–5.1)
CC4	2.1 ± 0.5 (1.5–2.3)	0.8 (0.7–1.0)	CC4-CC1	550 ± 180 (340–650)	1.8 (1.2–3.5)
CC5	3.2 ± 0.3 (2.8–3.4)	1.1 (0.8–1.3)	CC5-CC1	690 ± 90 (590–750)	1.4 (1.0–1.9)
CC6	4.9 ± 0.6 (4.2–5.3)	1.0 (0.8–1.2)	CC6-CC1	880 ± 120 (760–970)	1.1 (0.8–1.6)

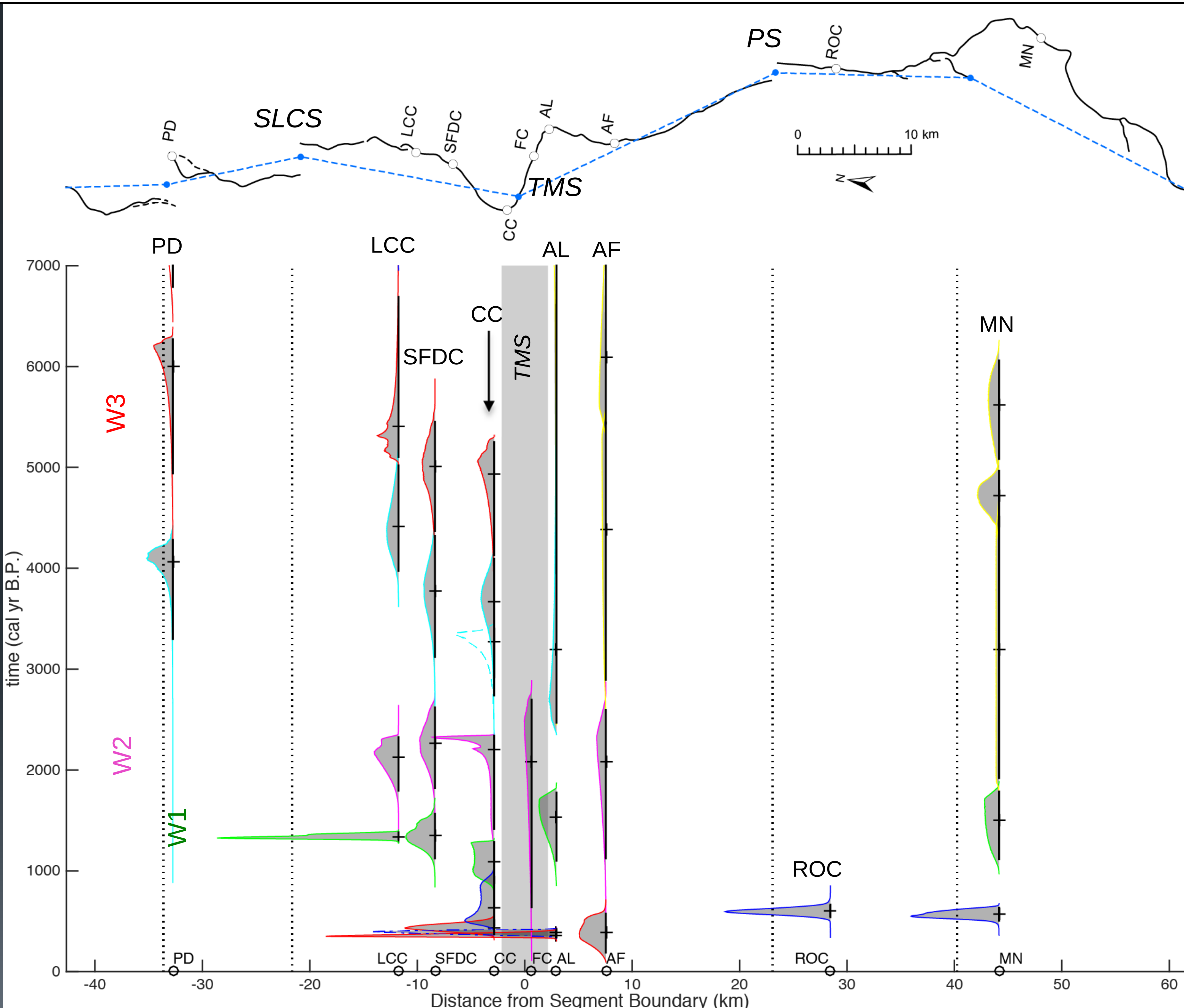
[1] Earthquake (EQ) timing based on OxCal model 4 (table 4) because it includes the broadest time range for earthquake CC2. 95% range in parentheses is based on the OxCal time distribution with the highest probability density.

[2] Per-event displacements based on scaled colluvial-wedge thickness (table 3).

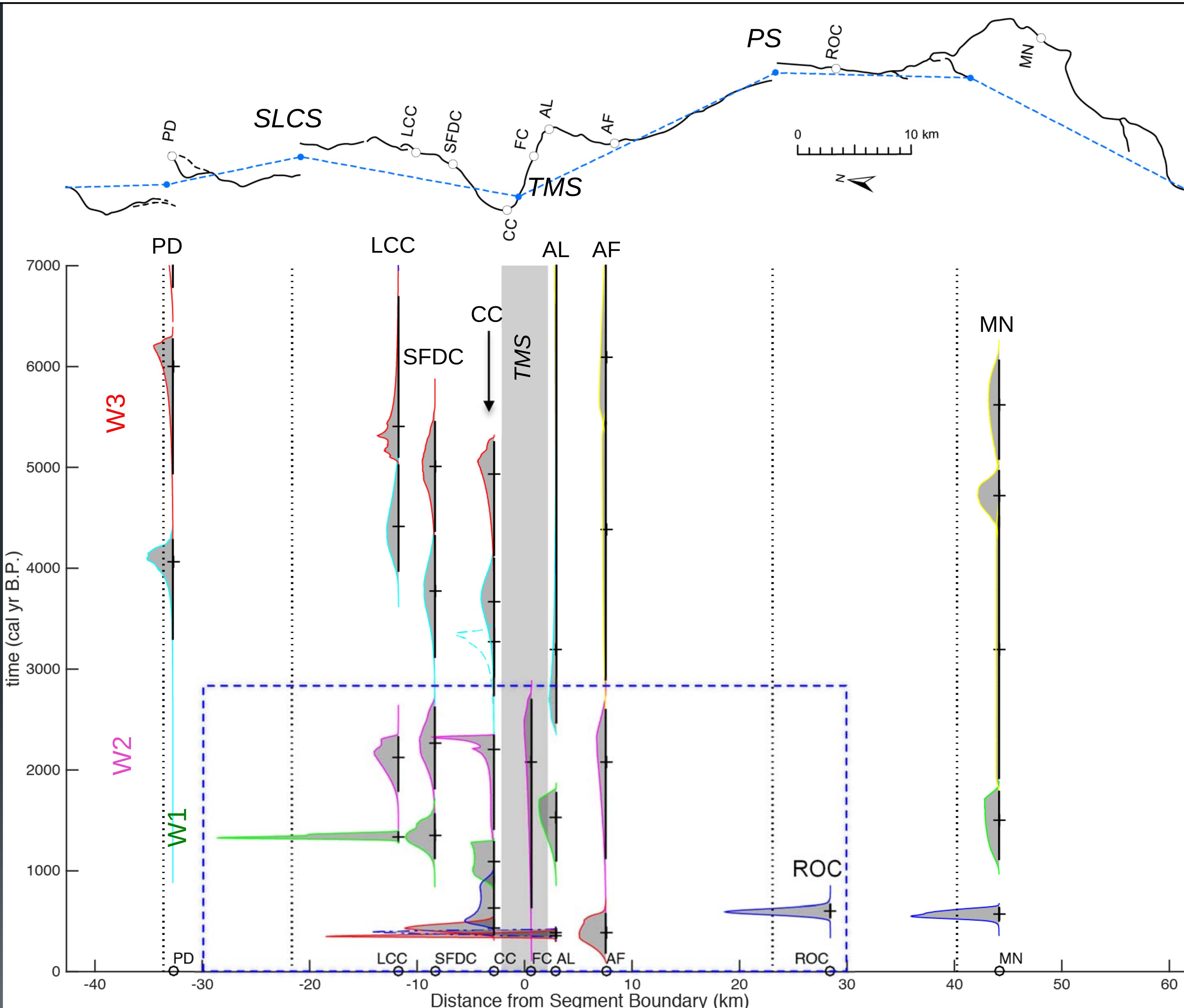
[3] Mean recurrence is elapsed time between events (e.g., CC6 to CC1) divided by the number of intervals in that period (e.g., five). See appendix X for calculations.

[4] Vertical slip rate is total displacement (e.g., for earthquakes CC5 to CC1; appendix X) based on summed per-event displacements (table 3) divided by the total time interval (e.g., CC6 to CC1). See appendix X for calculations.

[5] Probable spillover rupture from earthquake P1 on the adjacent Provo segment

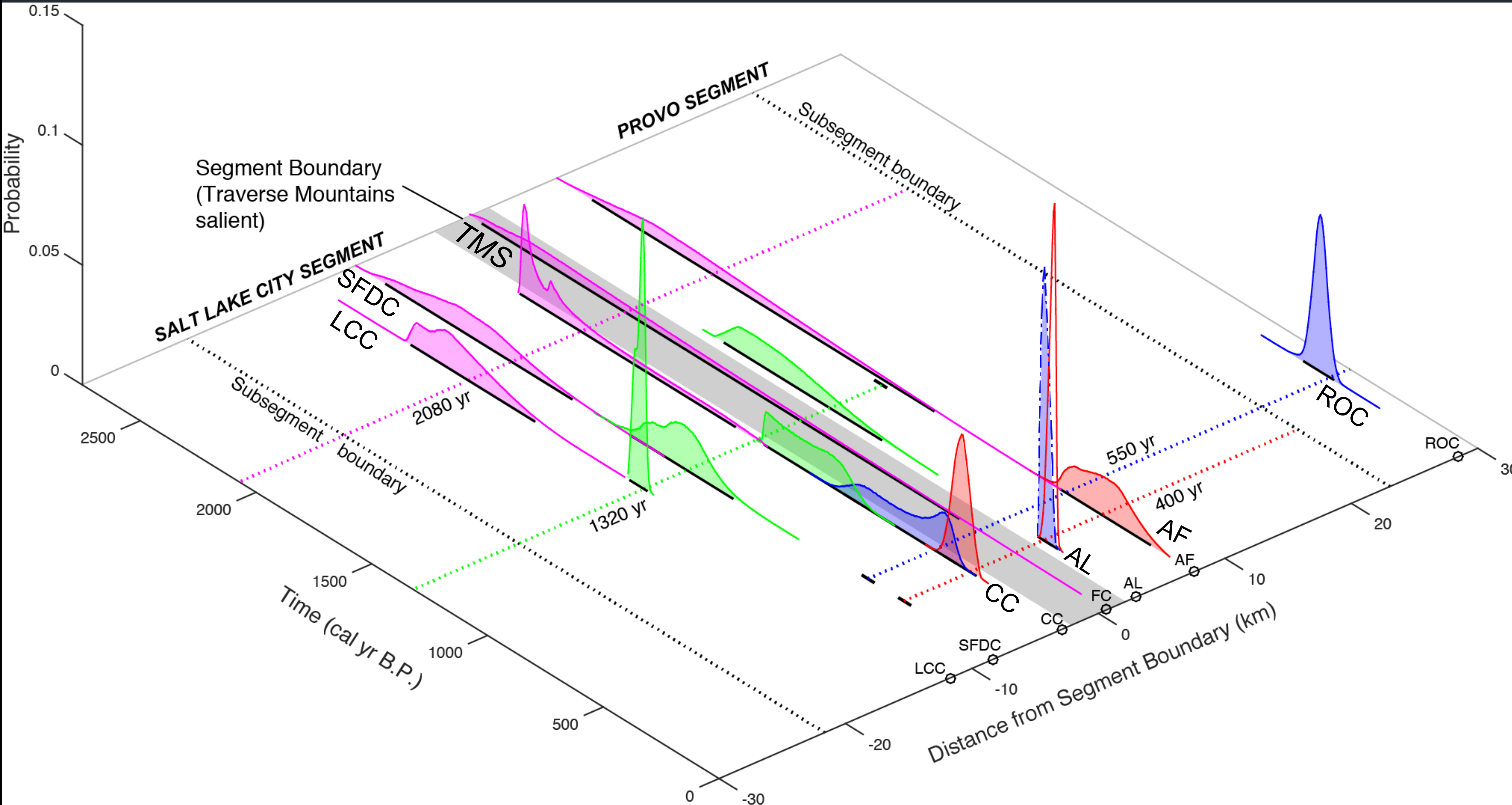


PS
ROC
MN
SLCS
PD
LCC
SFDC
FC
AL
AF
TMS
CC
0
10 km
N
PD
LCC
AL
AF
CC
SFDC
TMS
MN
ROC
W3
W2
W1
time (cal yr B.P.)
7000
6000
5000
4000
3000
2000
1000
0
PD
LCC
SFDC
CC
FC
AL
AF
ROC
MN
-40
-30
-20
-10
0
10
20
30
40
50
60
Distance from Segment Boundary (km)



PS
ROC
MN
SLCS
PD
LCC
SFDC
FC
AL
AF
TMS
CC
0
10 km
N
PD
LCC
AL
AF
CC
SFDC
TMS
MN
W3
W2
W1
ROC
time (cal yr B.P.)
7000
6000
5000
4000
3000
2000
1000
0
PD
LCC
SFDC
CC
FC
AL
AF
ROC
MN
-40
-30
-20
-10
0
10
20
30
40
50
60
Distance from Segment Boundary (km)

Earthquake Correlation



Earthquake Correlation

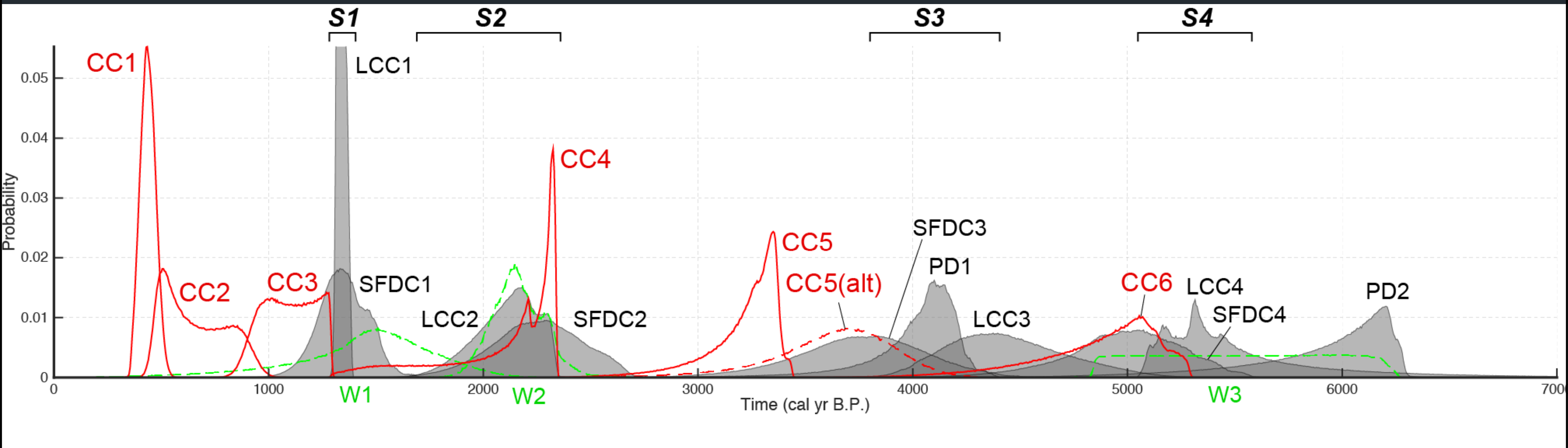


Figure 4

SLCS Chronology

S4 = ~5 ka (CC6, W3, LCC4, SFDC4, PD2?)

S3 = ~4 ka (CC5?, LCC3, SFDC3, PD1)

S2 = ~2.1 ka (CC4, W2, LCC2, SFDC2)

S1 = ~1.3 ka (CC3, W1, LCC1, SFDC1)

+ Spillover rupture from the PS to SLCS at ~0.6 ka (CC2)
+ Rupture of the segment boundary at ~0.4 ka (CC1)

Summary & Conclusions

- ***At least six earthquakes ruptured the CC site between ~4.9 and 0.4 ka:***
  - EQ times are moderately well constrained by ^{14}C and OSL ages
  - Per-event displacements are ~1 m
  - Mean recurrence is ~300-900 yr
- ***These data help us evaluate the potential for ruptures on the SLCS and through the TMS:***
  - 4 CC events correspond well with previous SLCS earthquakes
  - 2 events not recorded on the SCLS indicate complex rupture of the PS and SLCS, including spillover rupture (~0.6 ka) and rupture of the TMS segment boundary (~0.4 ka)
- ***Next steps:***
  - Integrate these results with data from the Alpine site
  - Evaluate rupture models for the SLCS and PS

UGS
Adam Hiscock
Adam McKean
Gregg Beukelman
Ben Erikson
Gregg McDonald
Rich Giraud
Mike Hylland
Jordan Culp
Sofia Agopian

USGS
Scott Bennett
Ryan Gold
Rich Briggs
Steve Personius
Nadine Reitman
Josh DeVore (OSU)
Shannon Mahan

Other
Salt Lake County
Draper City Engineering
Questar Gas
Salt Lake & Sandy Metro Water
Skyline Excavating
Utah House of Representatives

Preliminary results from the Airport East Trench Site, Taylorsville Fault, West Valley Fault Zone

Adam I. Hiscock
Utah Geological Survey, Salt Lake City, Utah
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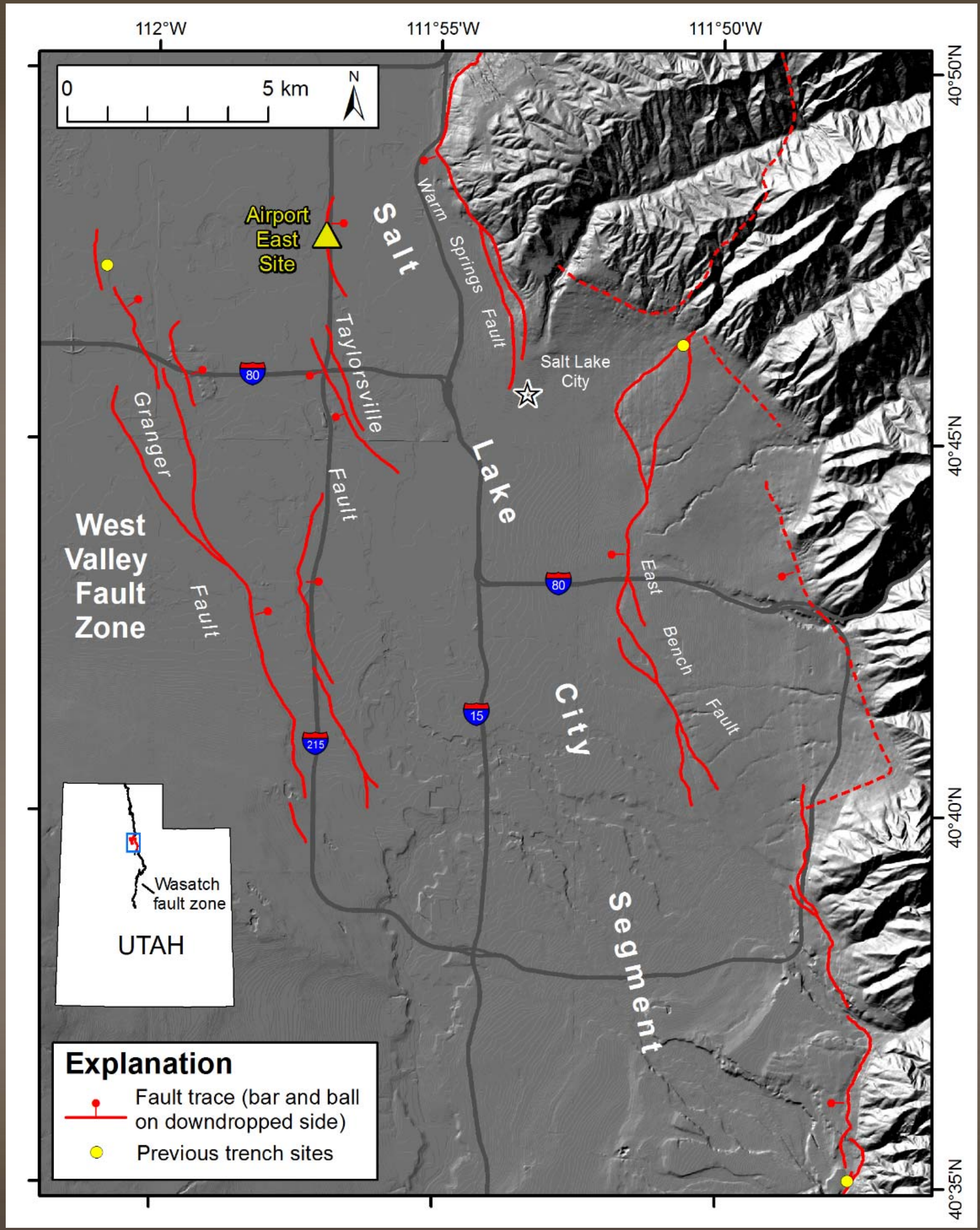
nehrp

USGS science for a changing world

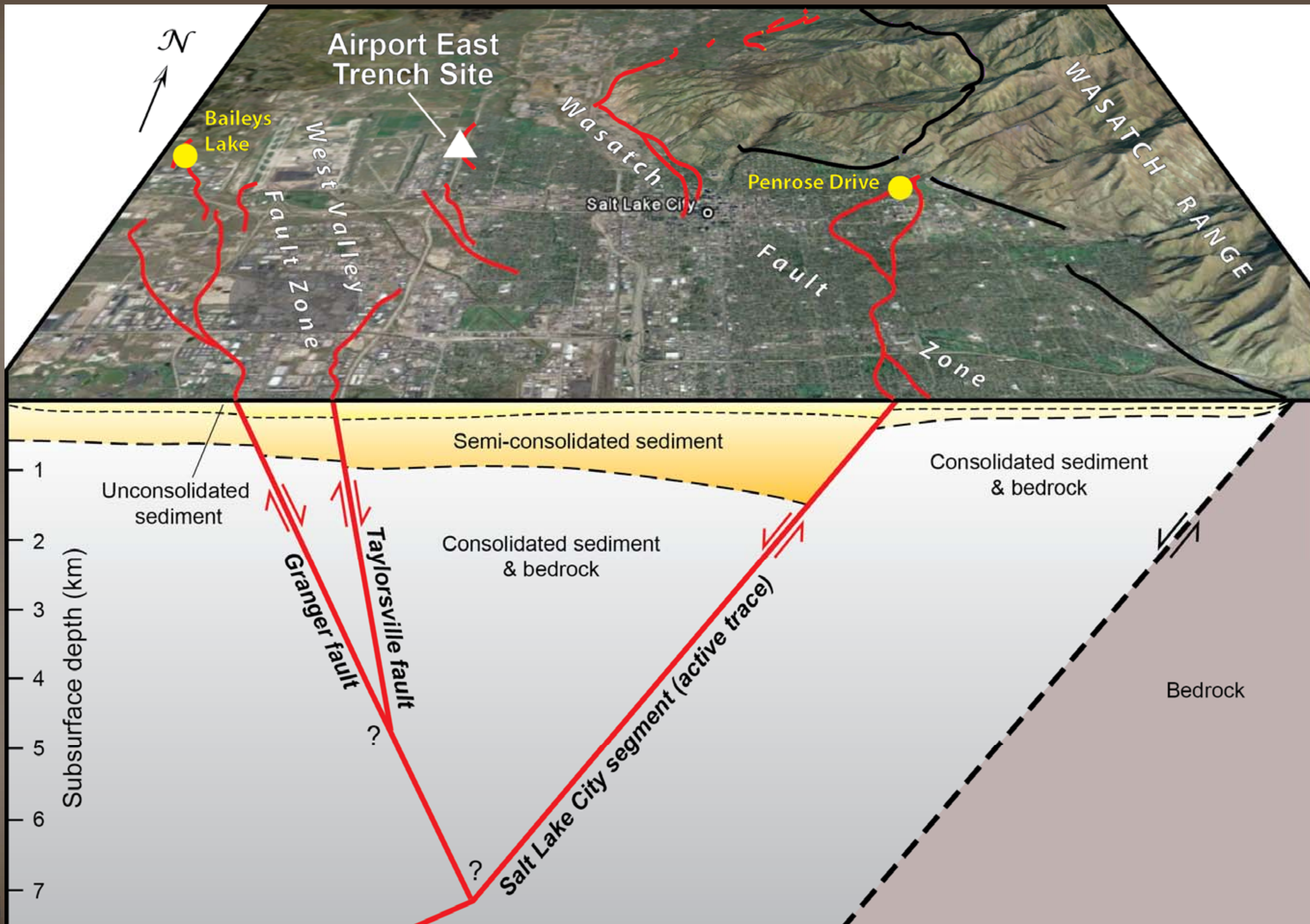
Quaternary Fault Parameters Working Group, February 10, 2016

Location & Purpose

- Does earthquake timing compare with Baileys Lake Site?
- Does the WVFZ rupture with the SLCS or independently?
- One of the last remaining sites on the Taylorsville fault for trenching.

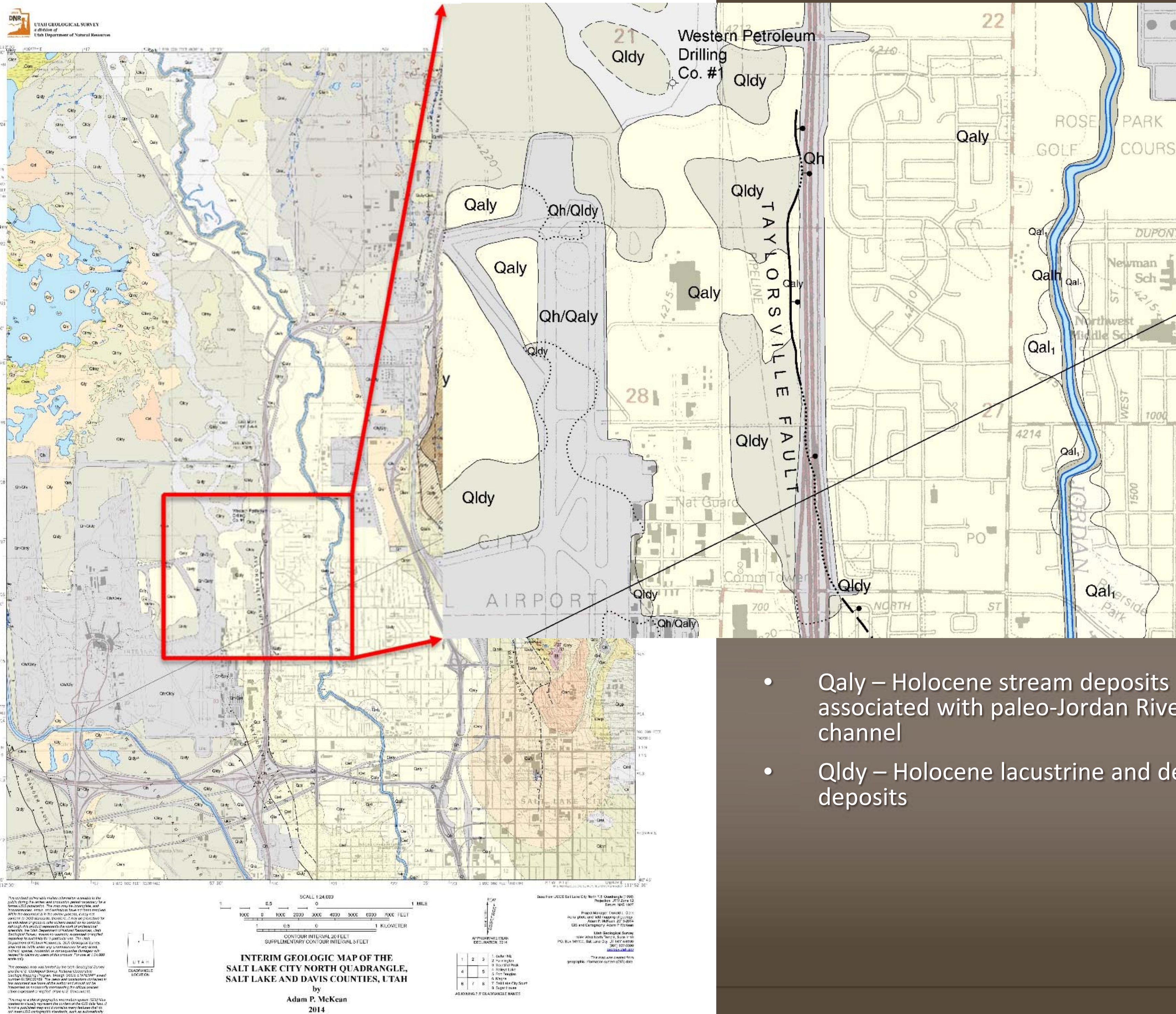


Location



N
Airport East Trench Site
Baileys Lake
West Valley Fault Zone
Wasatch Fault Zone
Salt Lake City
Penrose Drive
WASATCH RANGE
Semi-consolidated sediment
Consolidated sediment & bedrock
Unconsolidated sediment
Consolidated sediment & bedrock
Bedrock
Subsurface depth (km)
1
2
3
4
5
6
7
Granger fault
Taylorsville fault
Salt Lake City segment (active trace)
?
?

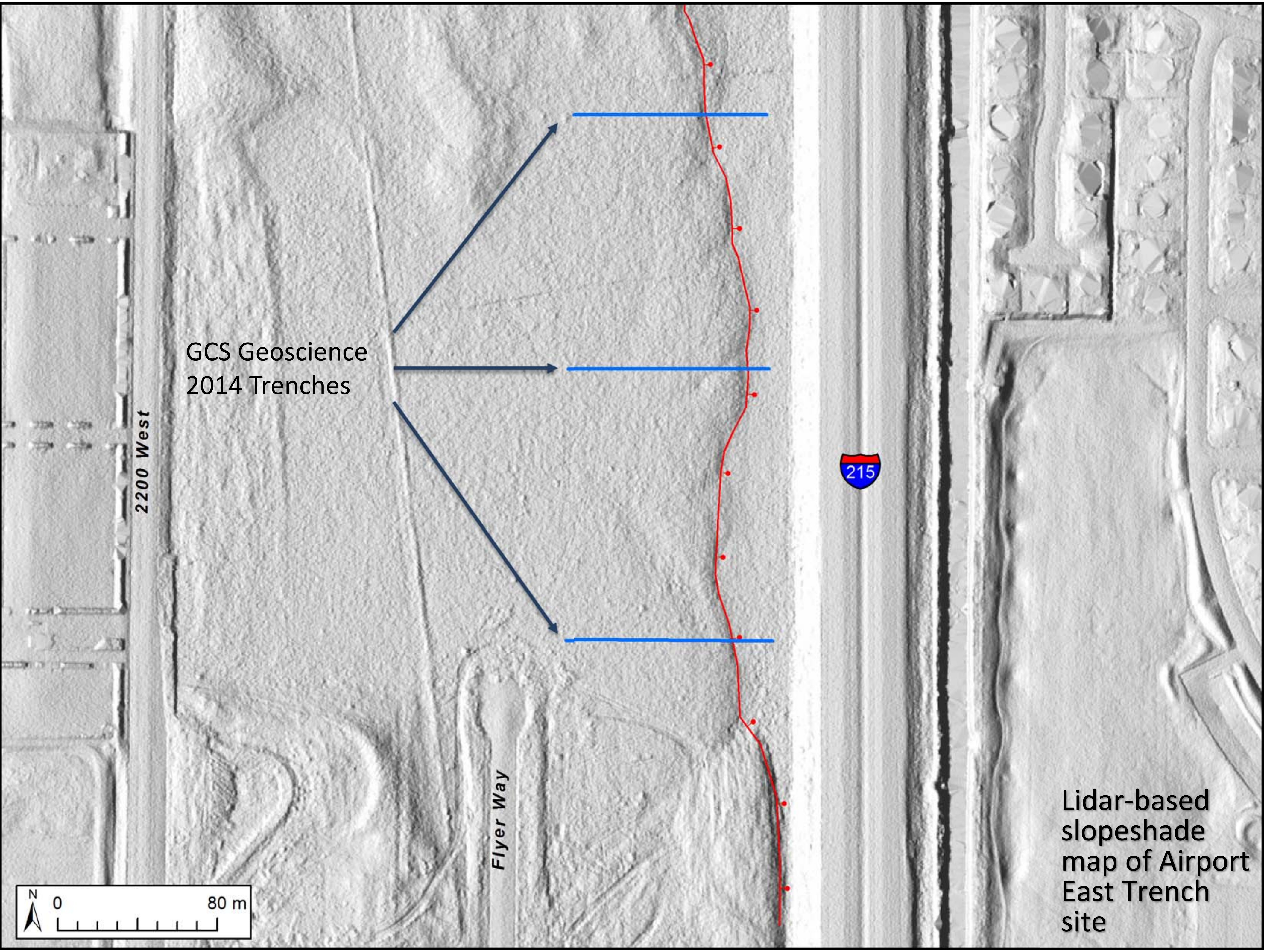
- Interim Geologic Map of the Salt Lake City North Quadrangle, Adam P. McKean, 2015

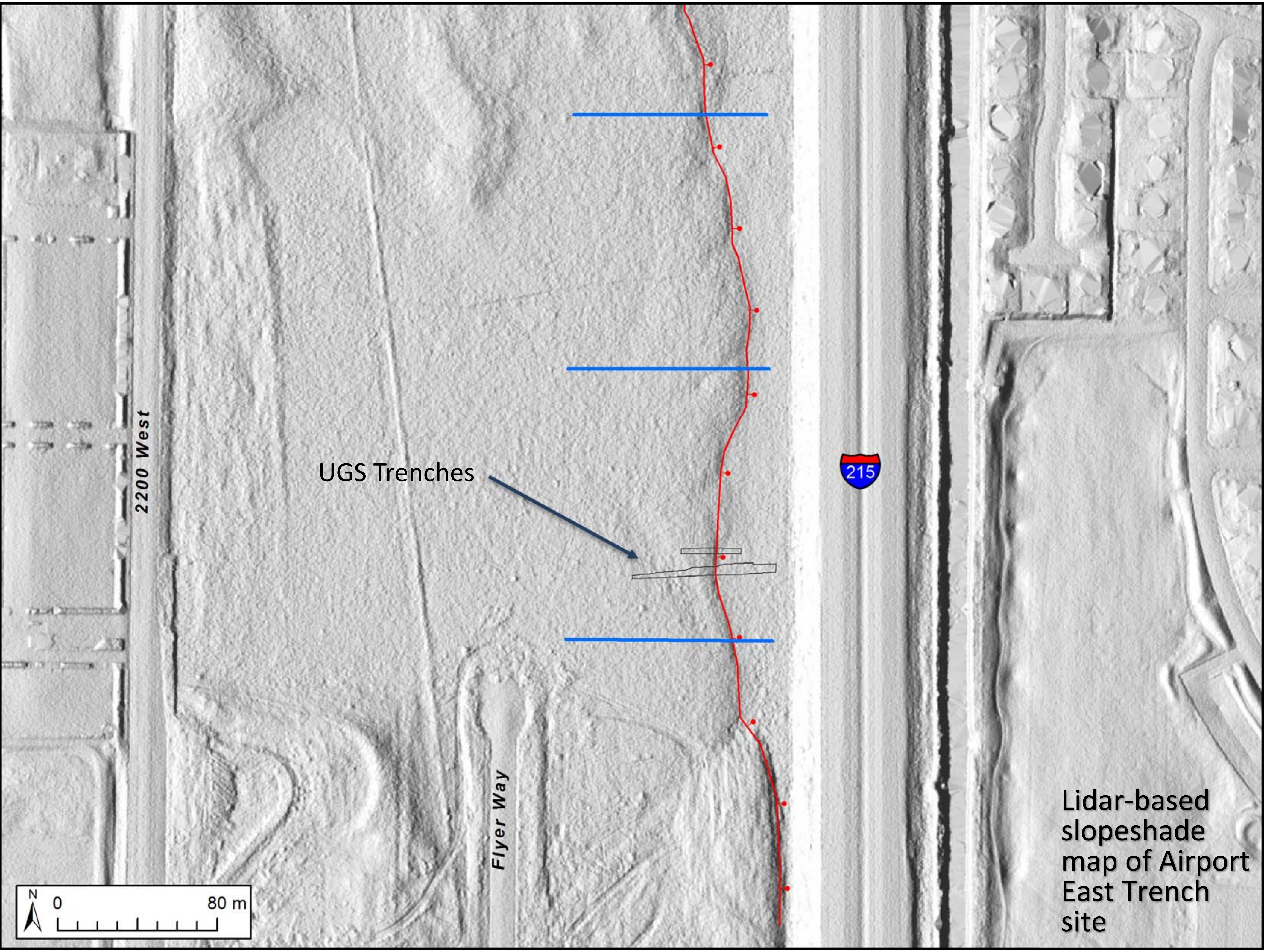


- Qaly – Holocene stream deposits associated with paleo-Jordan River channel
- Qldy – Holocene lacustrine and deltaic deposits

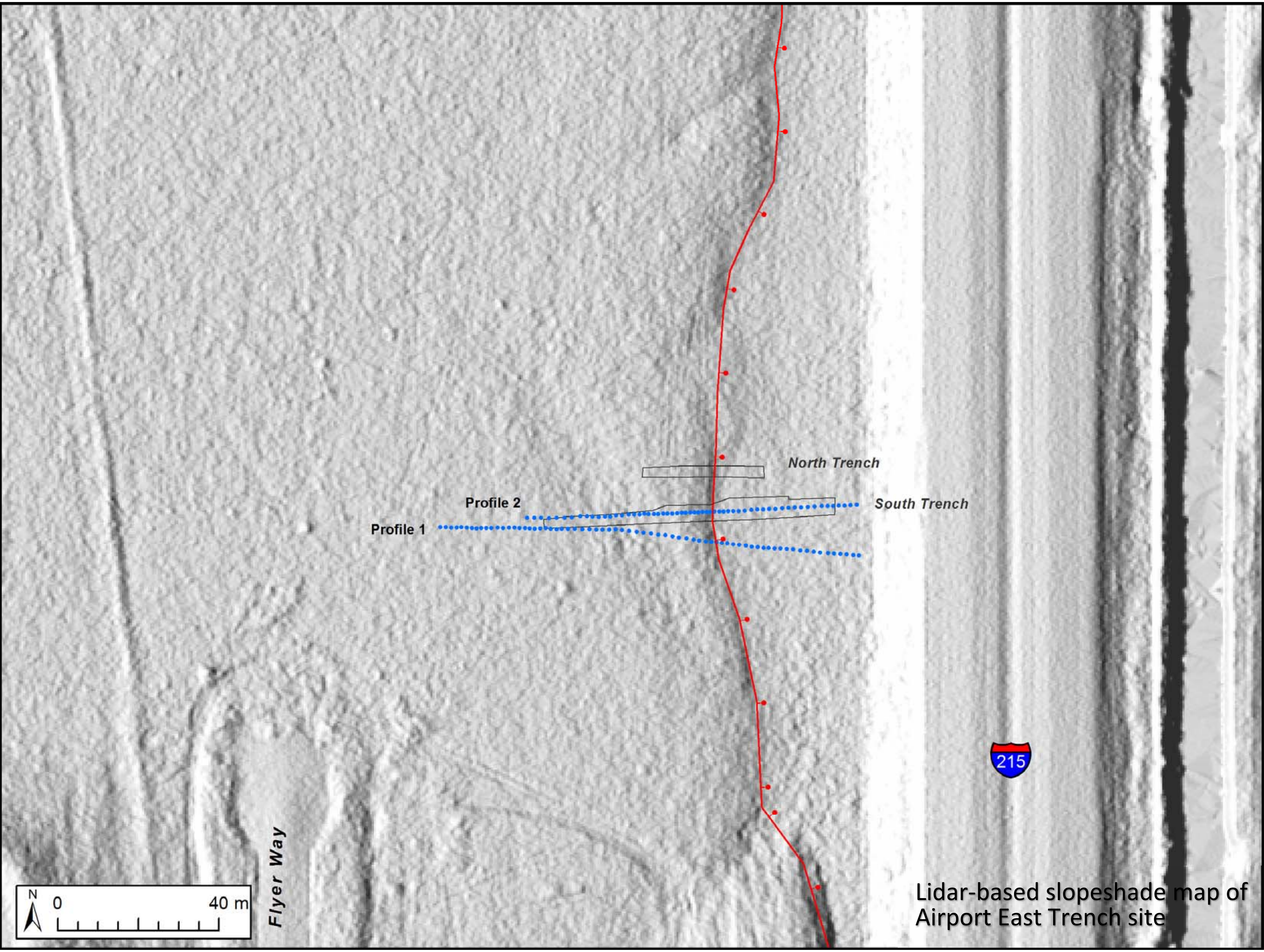

2200 West
215
Flyer Way
N
0
80 m
Lidar-based slopeshade map of Airport East Trench site


2200 West
Flyer Way
215
N
0
80 m
Lidar-based slopeshade map of Airport East Trench site

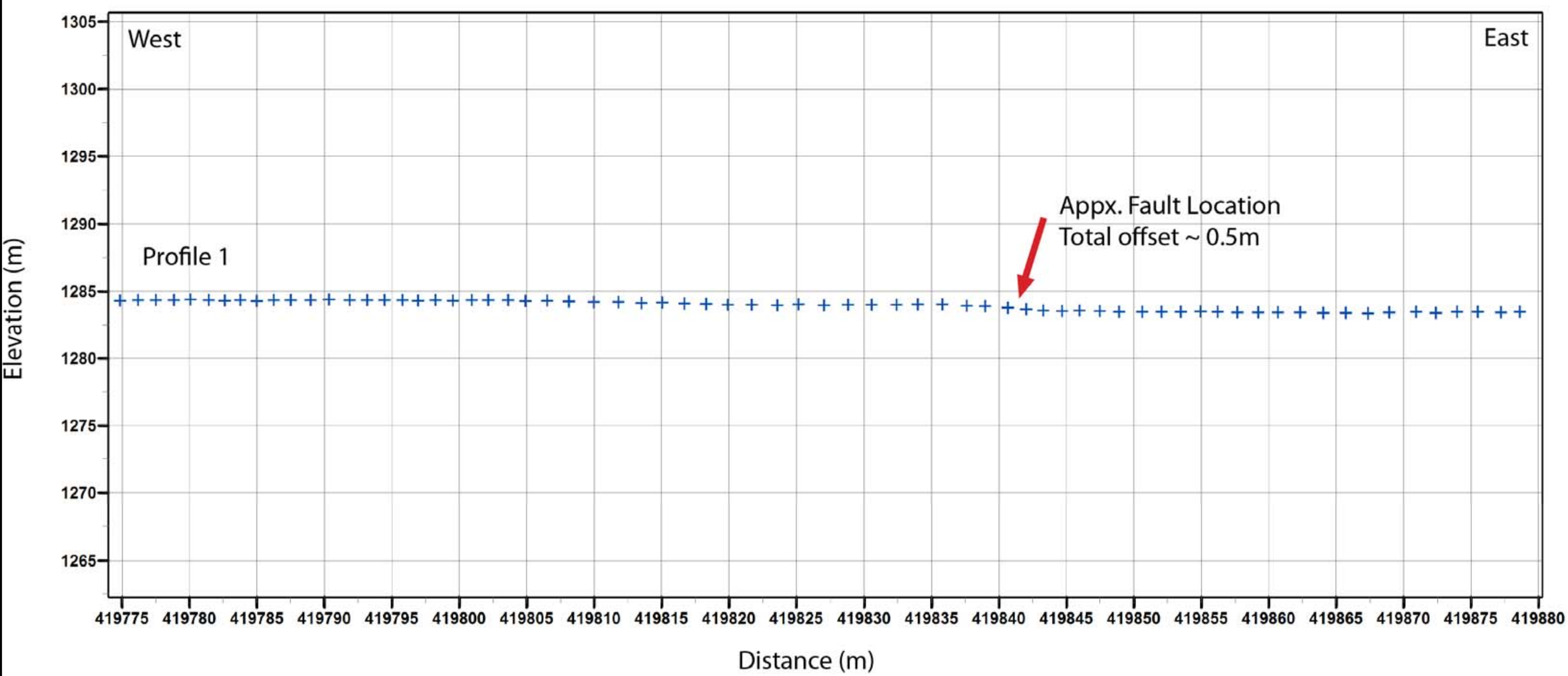

GCS Geoscience
2014 Trenches
2200 West
Flyer Way
215
N
0
80 m
Lidar-based
slopeshade
map of Airport
East Trench
site



2200 West
UGS Trenches
215
Flyer Way
N
0
80 m
Lidar-based slopeshade map of Airport East Trench site

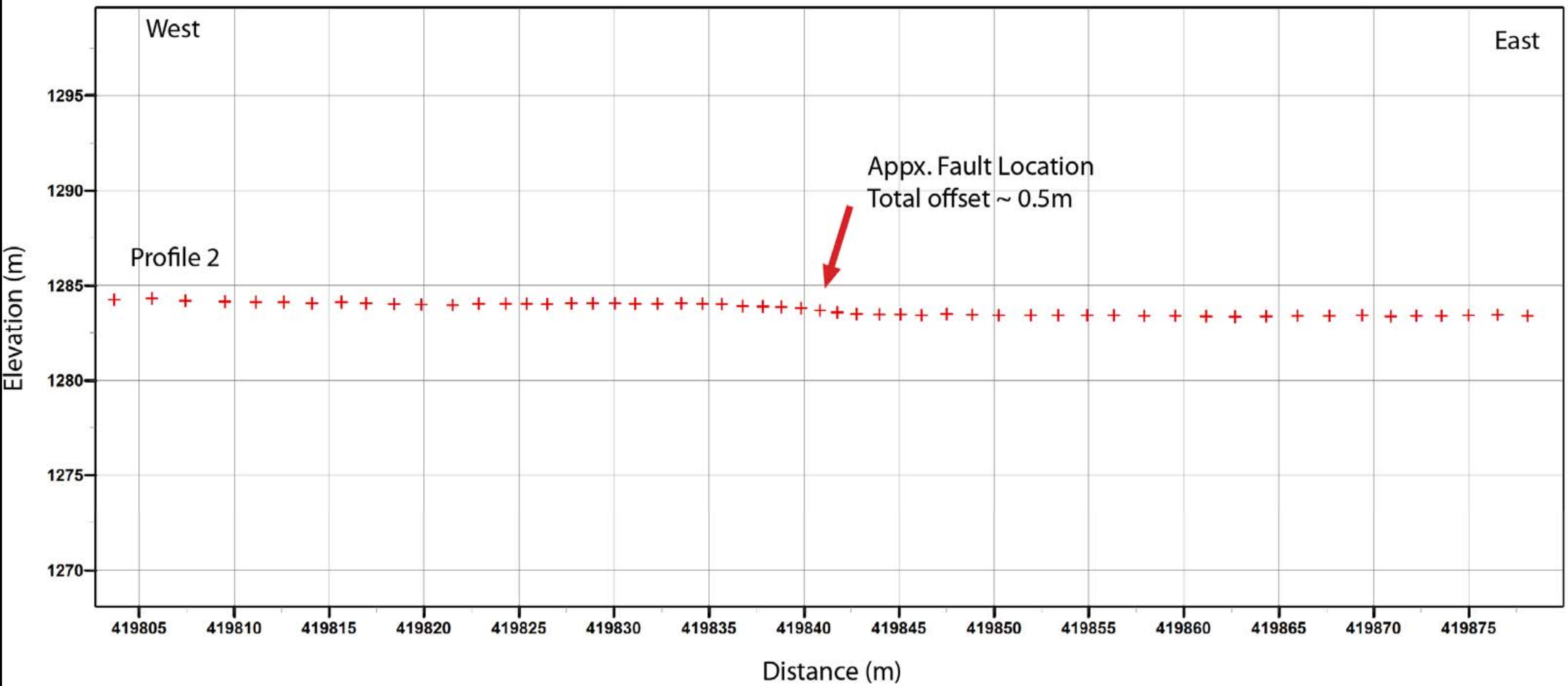

North Trench
South Trench
Profile 2
Profile 1
215
Flyer Way
N
0
40 m
Lidar-based slopeshade map of
Airport East Trench site

Profiles



West
East
Appx. Fault Location
Total offset ~ 0.5m
Profile 1
Elevation (m)
1305
1300
1295
1290
1285
1280
1275
1270
1265
419775 419780 419785 419790 419795 419800 419805 419810 419815 419820 419825 419830 419835 419840 419845 419850 419855 419860 419865 419870 419875 419880
Distance (m)

Profiles


West
East
Appx. Fault Location
Total offset ~ 0.5m
Profile 2
1295
1290
1285
1280
1275
1270
Elevation (m)
419805
419810
419815
419820
419825
419830
419835
419840
419845
419850
419855
419860
419865
419870
419875
Distance (m)

Foot Wall
Appx. 0.5m
Hanging Wall
For Lease
PACIFIC LANDING
801 869 8065
CBRE
Looking North along Taylorsville fault scarp at Airport East Trench Site. Approximate fault location shown in red.

Excavation – August 24, 2015

Excavation – August 24, 2015


CAUTION CUIDADO CAUTION CUIDADO CAUTION CUIDADO

- 2 parallel trenches
  - South Trench 73m long (only logged the western 50m)
  - North Trench 30m long
- Unable to trench deep enough to get into Bonneville deposits due to high water table

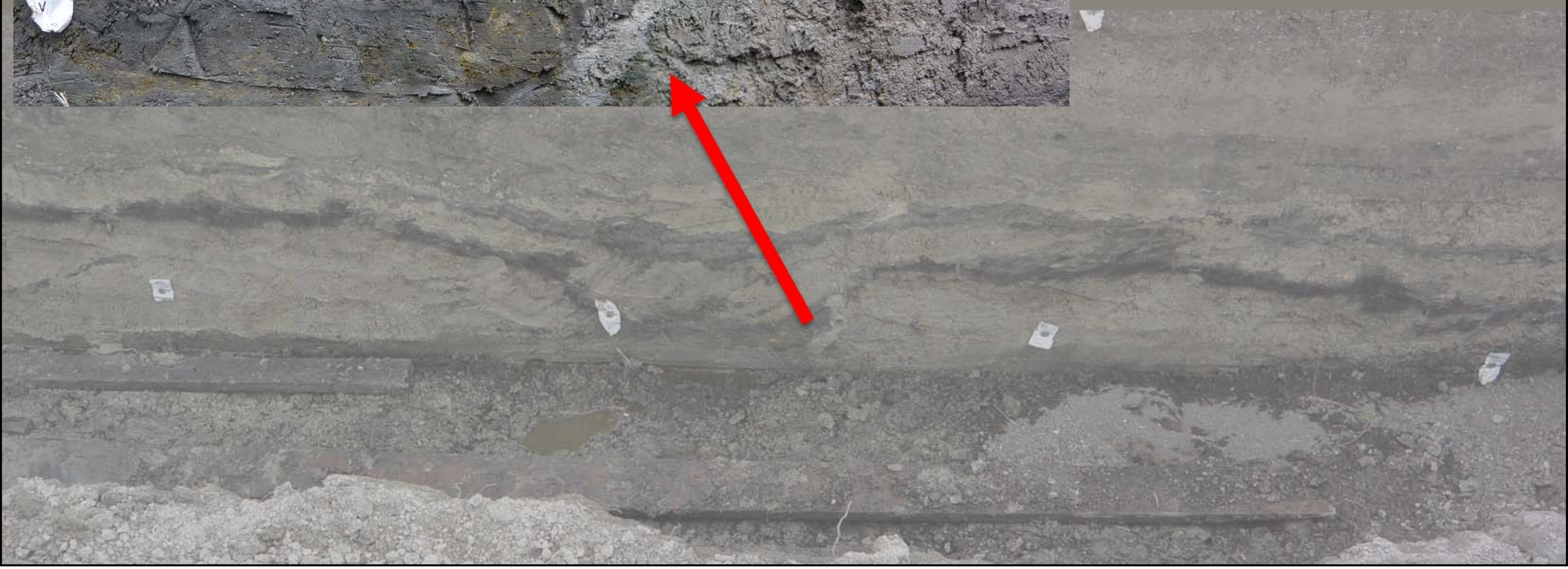

WARNING
AVISO

Stratigraphy

- Exposed fine-grained sand and silt deposits, deposited on Paleo-Jordan River floodplain and Great Salt Lake margin marshes.
- Mapped 7 stratigraphic units
- Broad warping of units in footwall
- Several injected sand dikes correlated with areas of localized warping and deformation; probably liquefaction induced

sits, deposited on
Salt Lake margin

th areas of
ably liquefaction



Fault Zone

- Evidence for 3 surface faulting earthquakes; possibility of a 4th or 5th (?) event shown by injected sand dikes and broad warping of footwall units.
- Complex rupture zone, spiderweb of faults
- Small events; 0.5 m total displacement exposed in trench

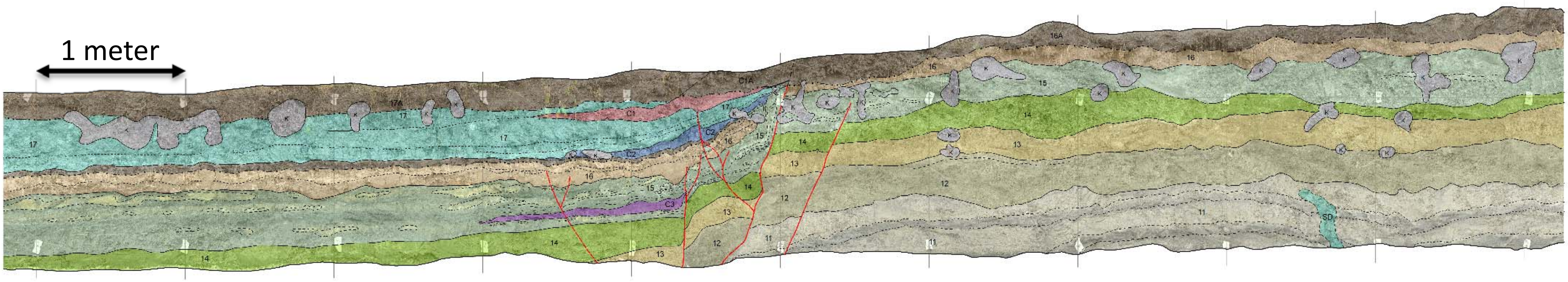
East

West

1 meter

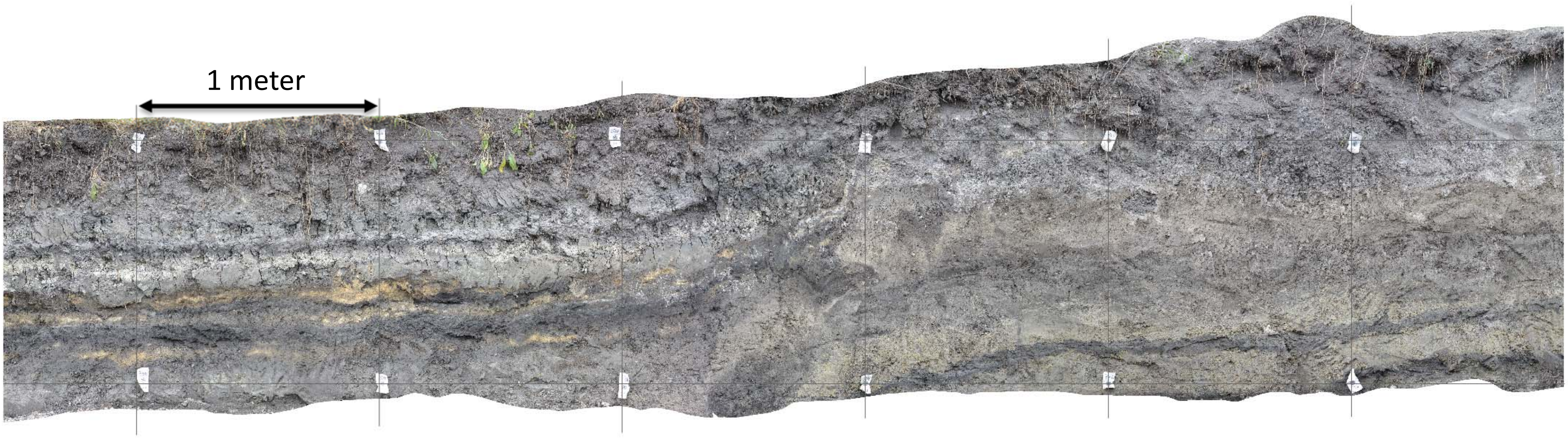
East

West



East

West



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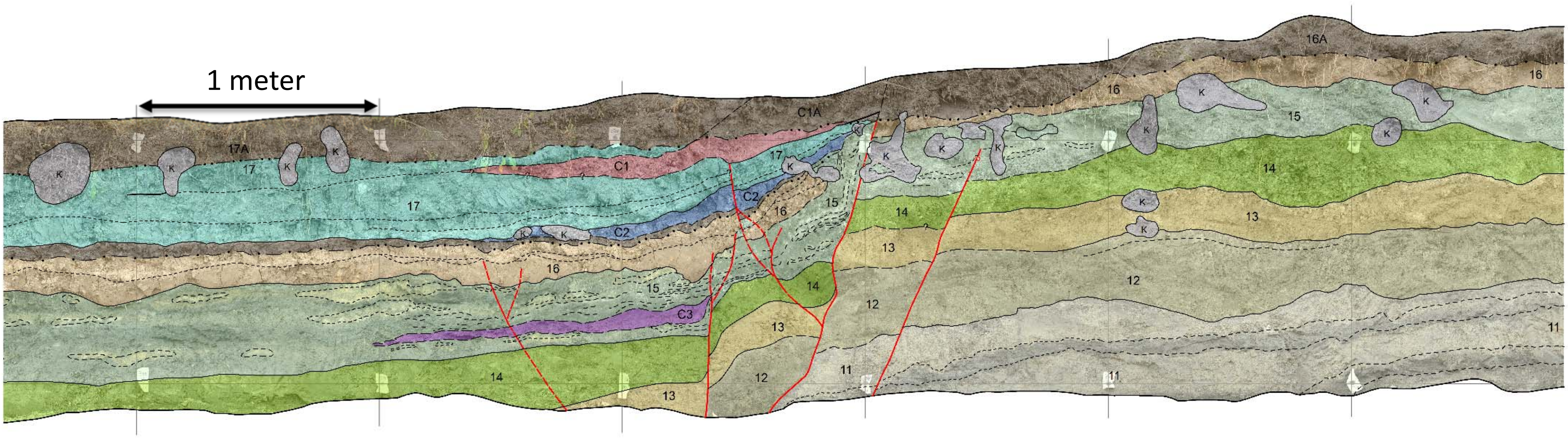
East West

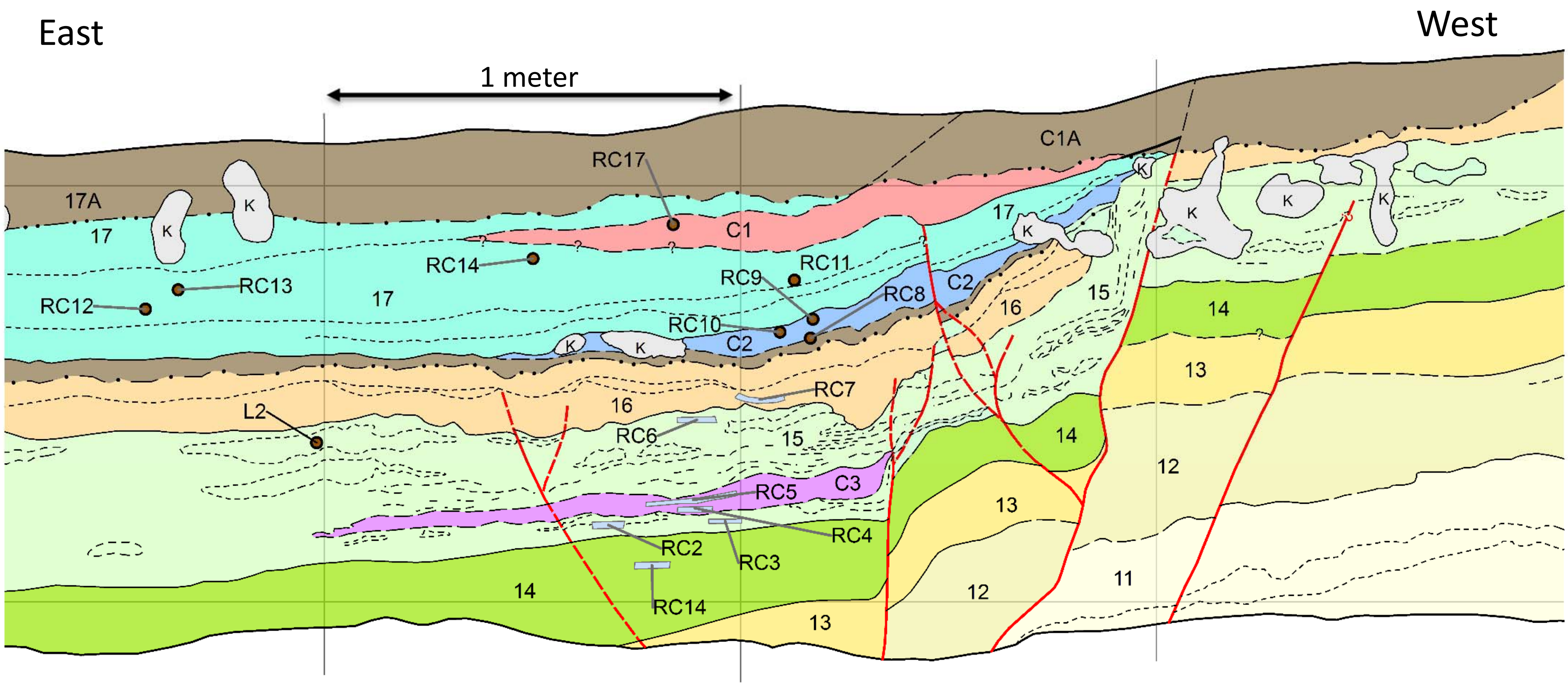


- Colluvial wedges:
  - Identified 3 wedges
  - Thin wedges; maximum thickness C2 & C3 – 10-13 cm; C1 – ~15 cm

- Faulting:
  - Main trace dips 70-75° E.
  - ~9 synthetic/ antithetic faults

Sampling Strategy

- Radiocarbon (C-14)
  - 24 total samples collected in the field – 13 bulk soil, 10 macrocharcoal, 1 wood (collected from bottom of borehole)
  - 22 samples processed by PaleoResearch Institute (PRI), Golden, Colorado
  - 14 samples sent to Woods Hole Oceanographic Institution (Woods Hole, Massachusetts) for Accelerator Mass Spectrometry (AMS) dating.
- Optically Stimulated Luminescence (OSL)
  - 3 samples collected – processed by Shannon Mahan (USGS) in Lakewood, Colorado.



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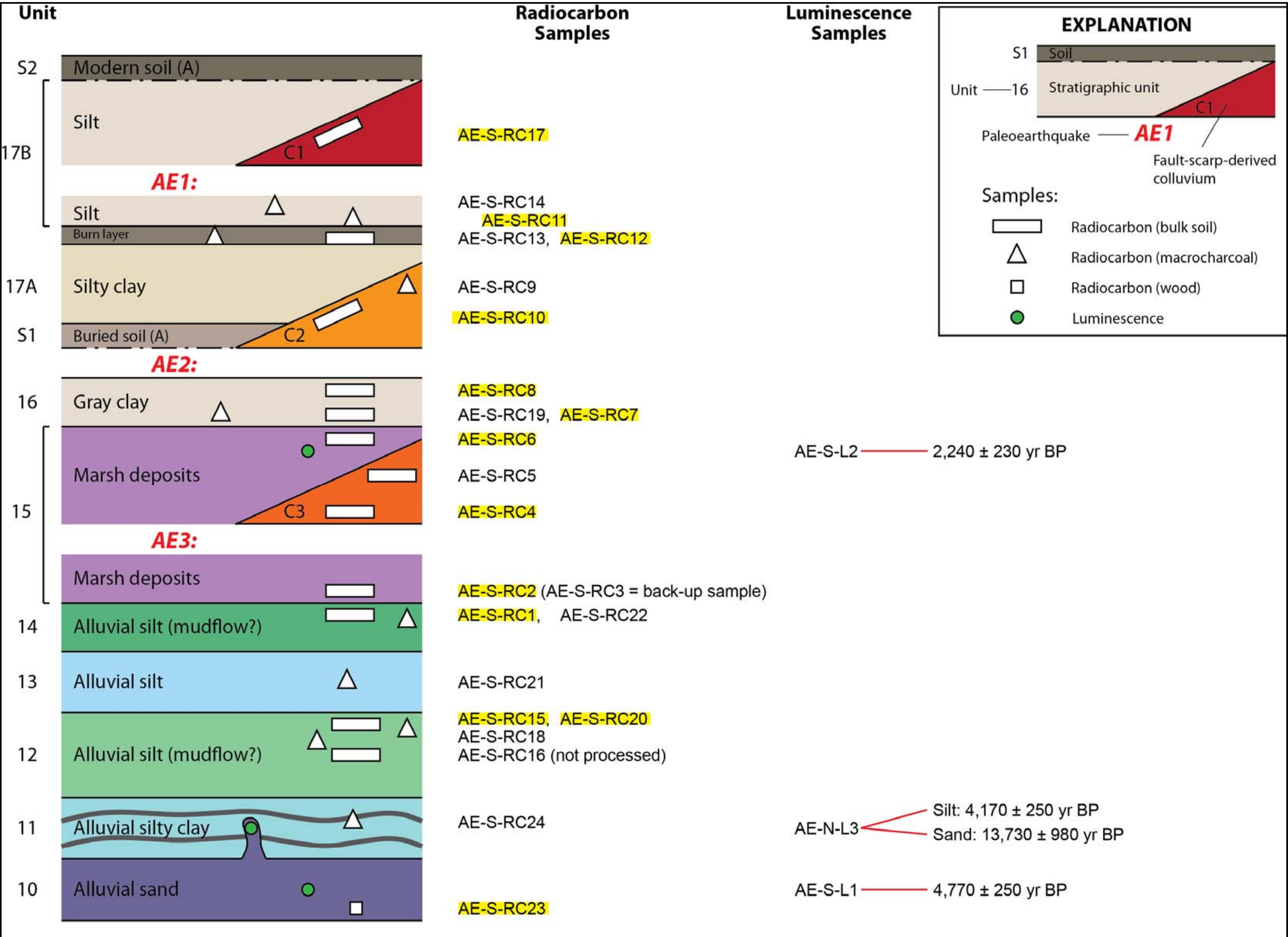
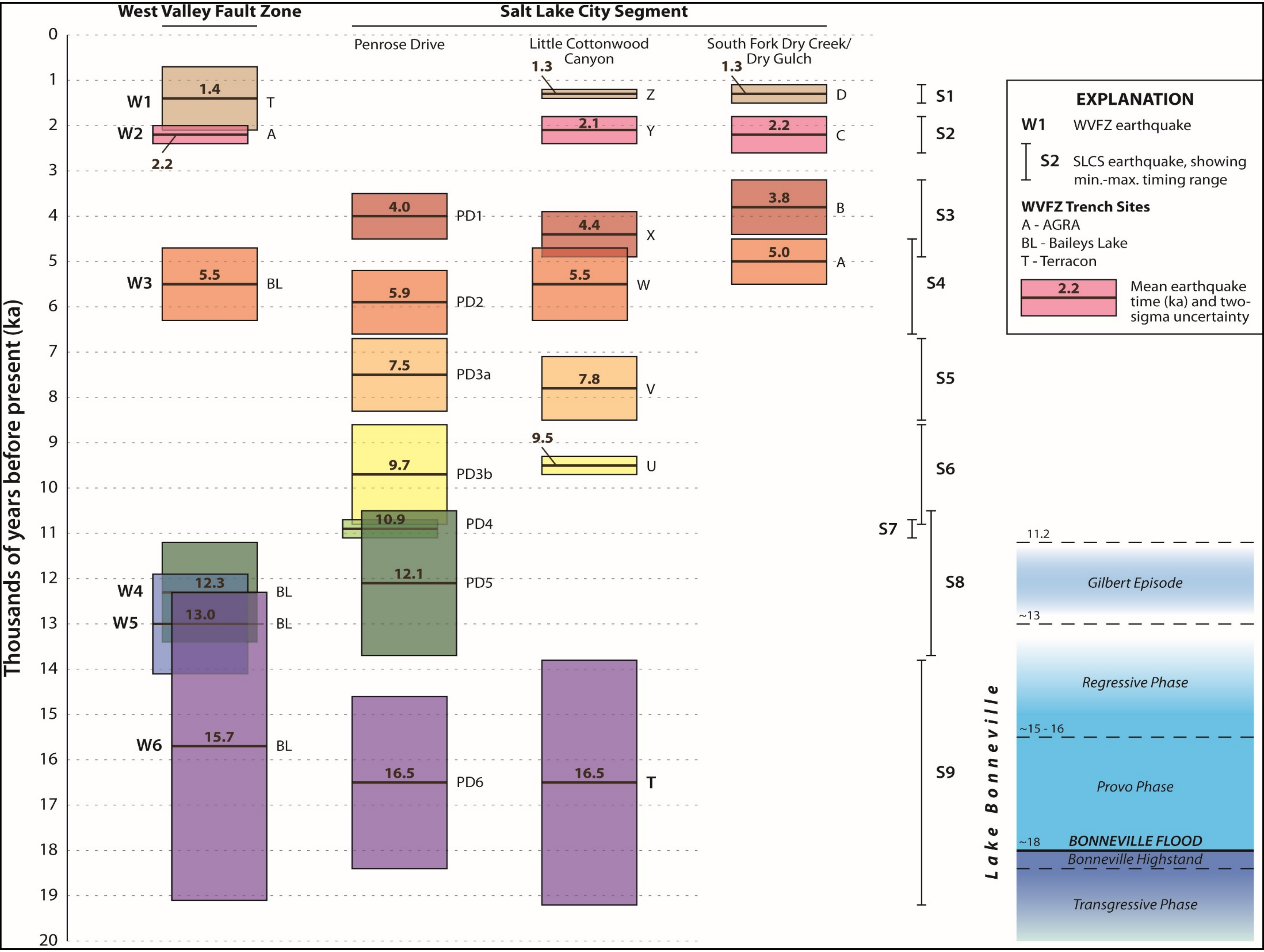


Chronostratigraphic Summary -- West Valley fault zone, Taylorsville fault, Airport East site



West Valley Fault Zone
Salt Lake City Segment
Penrose Drive
Little Cottonwood Canyon
South Fork Dry Creek/ Dry Gulch
Thousands of years before present (ka)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
W1
1.4
T
W2
2.2
A
W3
5.5
BL
W4
12.3
BL
W5
13.0
BL
W6
15.7
BL
4.0
PD1
5.9
PD2
7.5
PD3a
9.7
PD3b
10.9
PD4
12.1
PD5
16.5
PD6
1.3
Z
2.1
Y
4.4
X
5.5
W
7.8
V
9.5
U
16.5
T
1.3
D
2.2
C
3.8
B
5.0
A
S1
S2
S3
S4
S5
S6
S7
S8
S9
EXPLANATION
W1 WVFZ earthquake
S2 SLCS earthquake, showing min.-max. timing range
WVFZ Trench Sites
A - AGRA
BL - Baileys Lake
T - Terracon
2.2
Mean earthquake time (ka) and two-sigma uncertainty
11.2
Gilbert Episode
~13
Regressive Phase
~15 - 16
Provo Phase
~18
BONNEVILLE FLOOD
Bonneville Highstand
Transgressive Phase
Lake Bonneville

UGS

Mike Hylland
Greg McDonald
Ben Erickson
Gregg Beukelman
Adam McKean
Rich Giraud

USGS

Chris DuRoss
Rich Briggs
Steve Personius
Nadine Reitman
Shannon Mahan

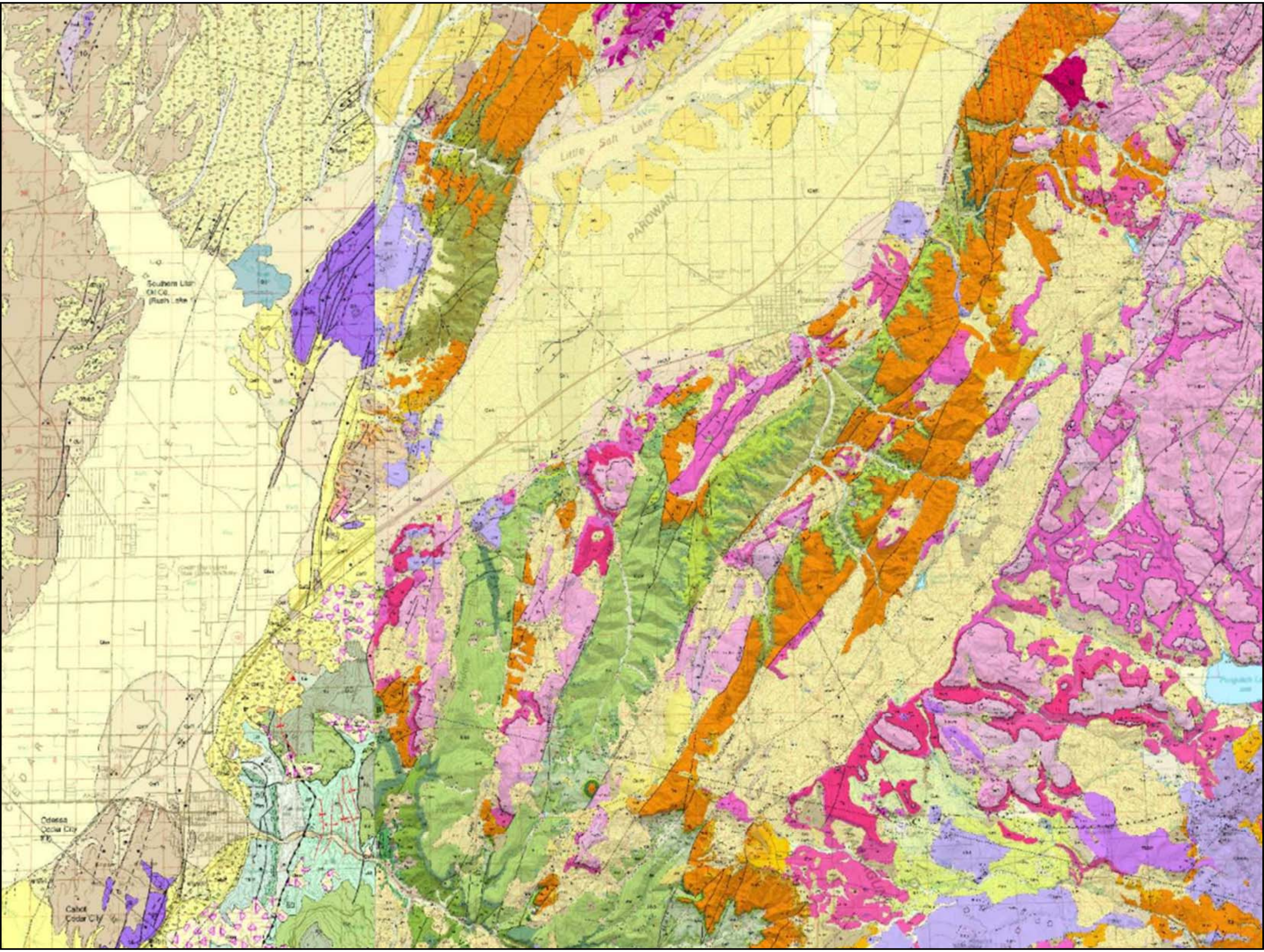
Other

Pacific Landing Inc.
Kuhn Project Management
Eckman & Mitchell Construction
Skyline Excavators – Todd Nielson
GCS Geoscience

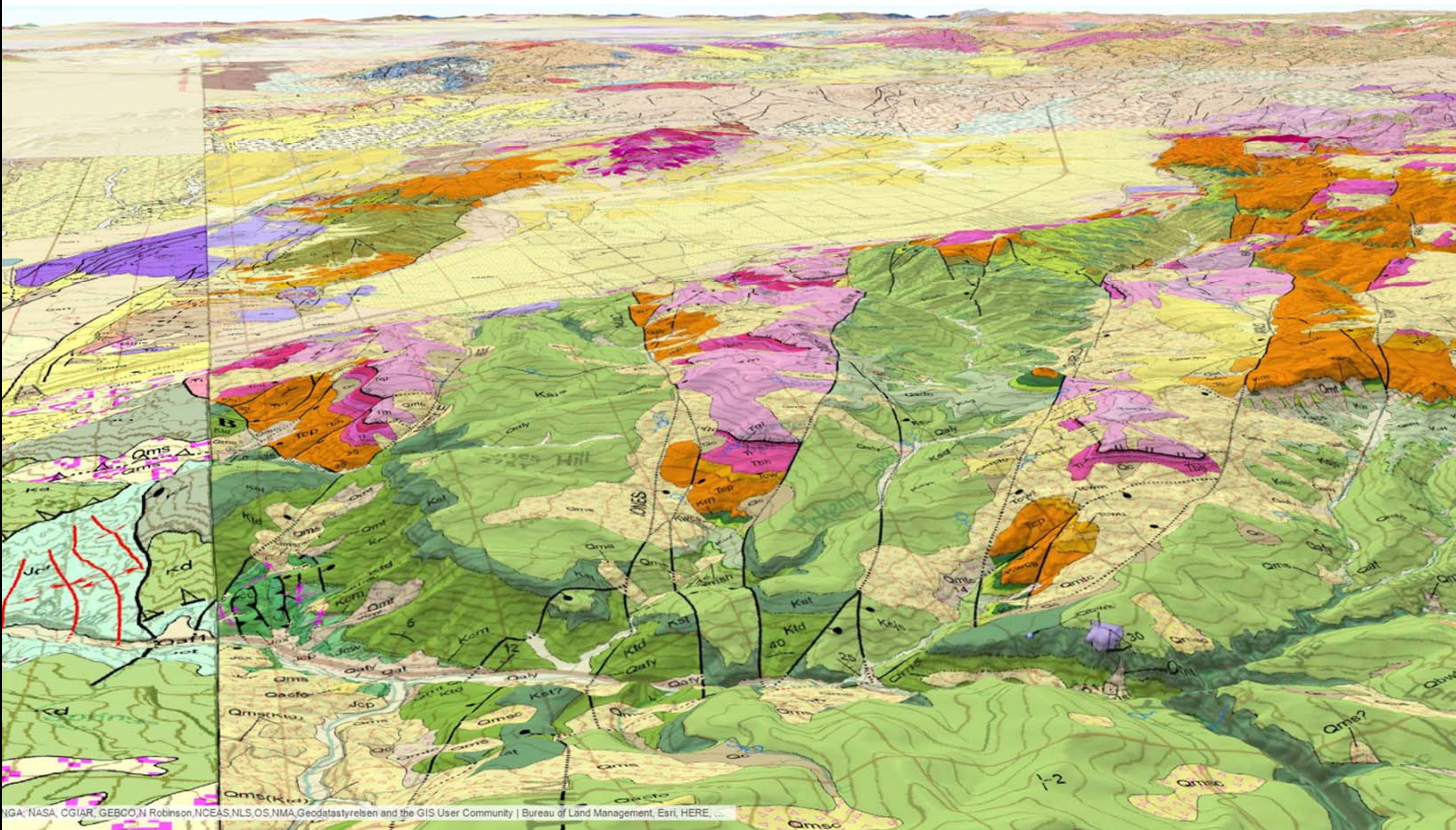
New insight into the Paleogene Cedar City-Parowan monocline: (UQFPWG need not worry)

Robert F. Biek

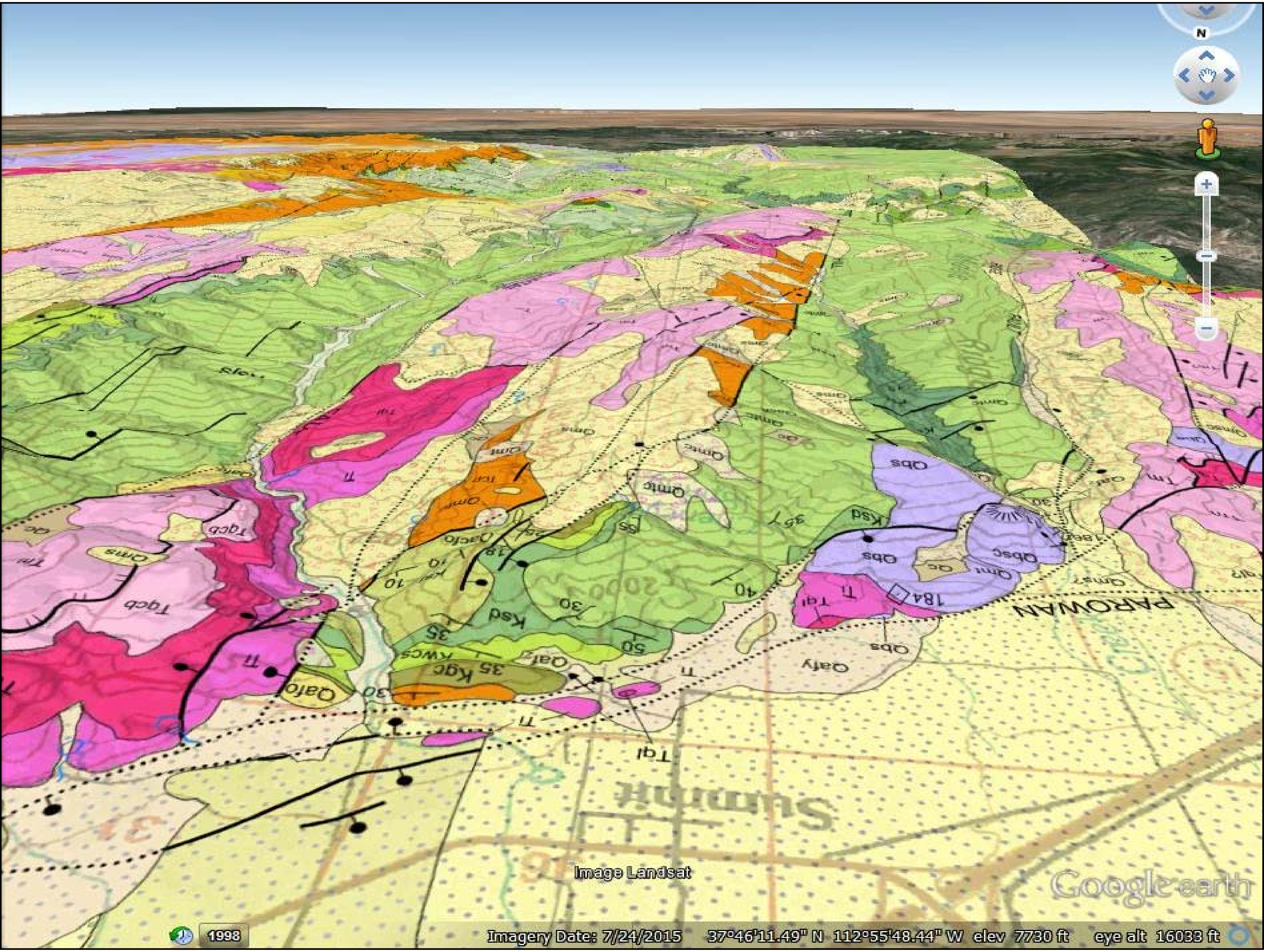
Utah Geological Survey



Little Salt Lake
VALLEY
PAROWAN



NGA, NASA, CGIAR, GEBCO,N Robinson,NCEAS,NLS,OS,NMA,Geodatastyrelsen and the GIS User Community | Bureau of Land Management, Esri, HERE, ...


PAROWAN
Image Landsat
Google earth
1998
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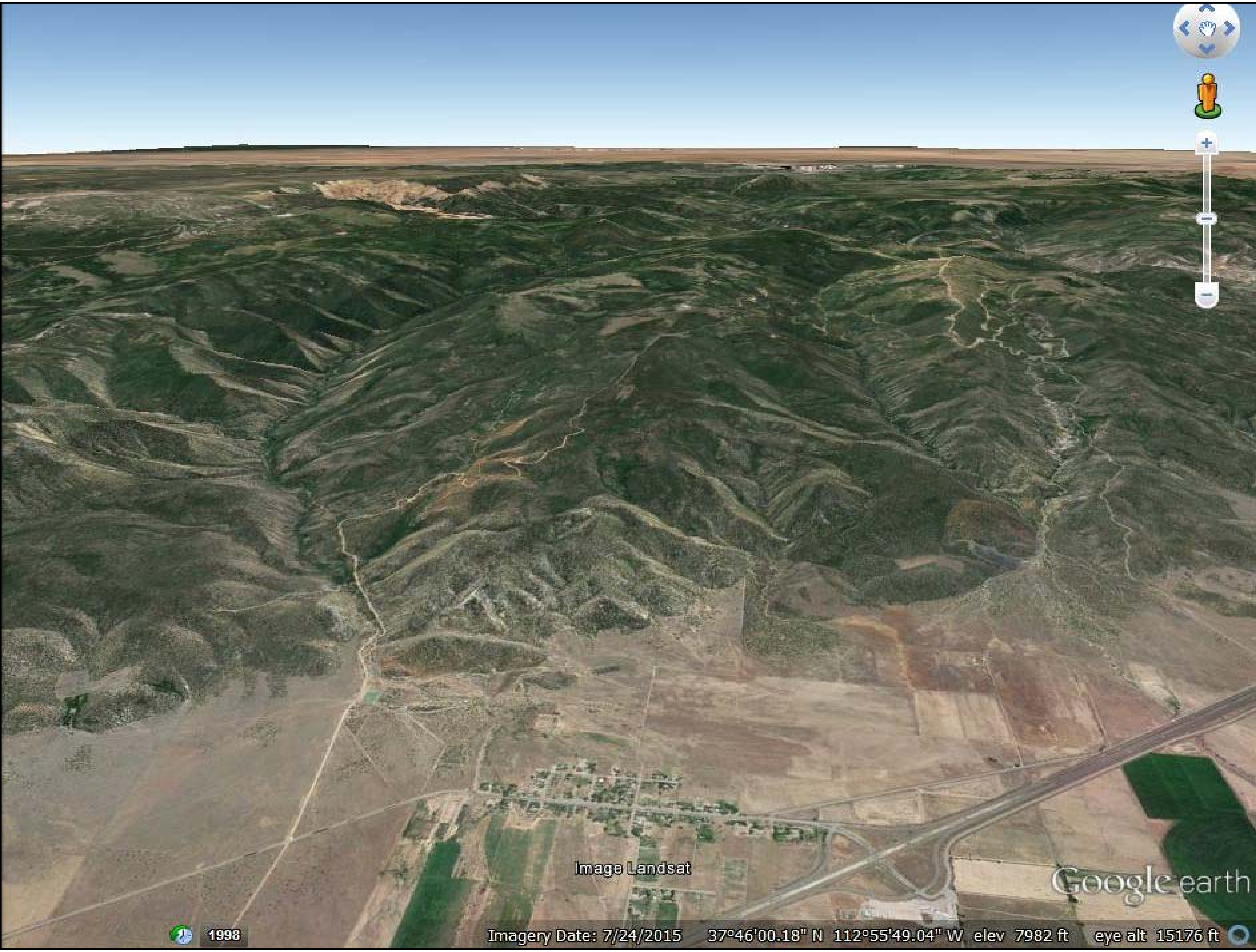
Image Landsat
Google earth
1998
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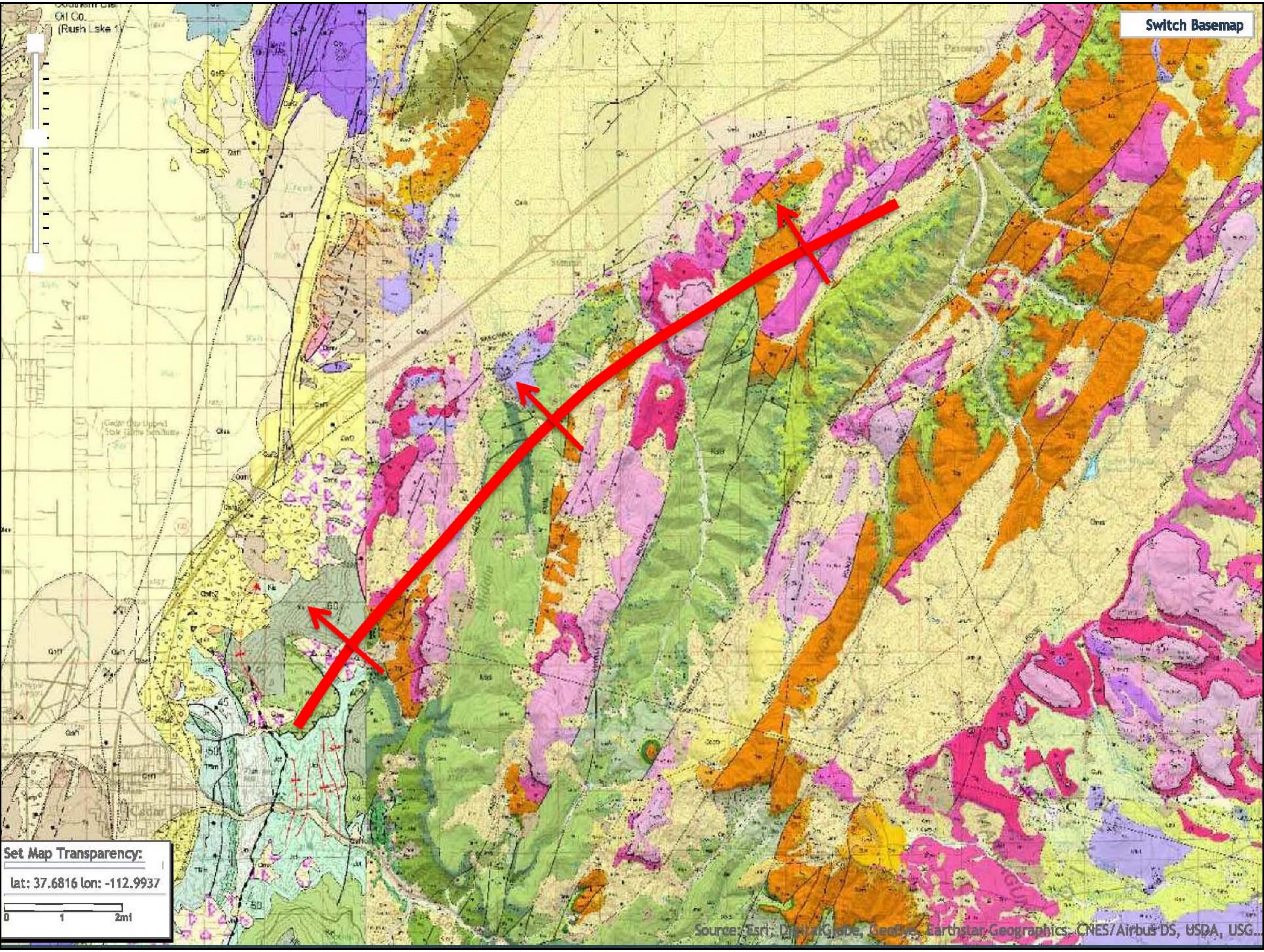
Switch Basemap
Set Map Transparency:
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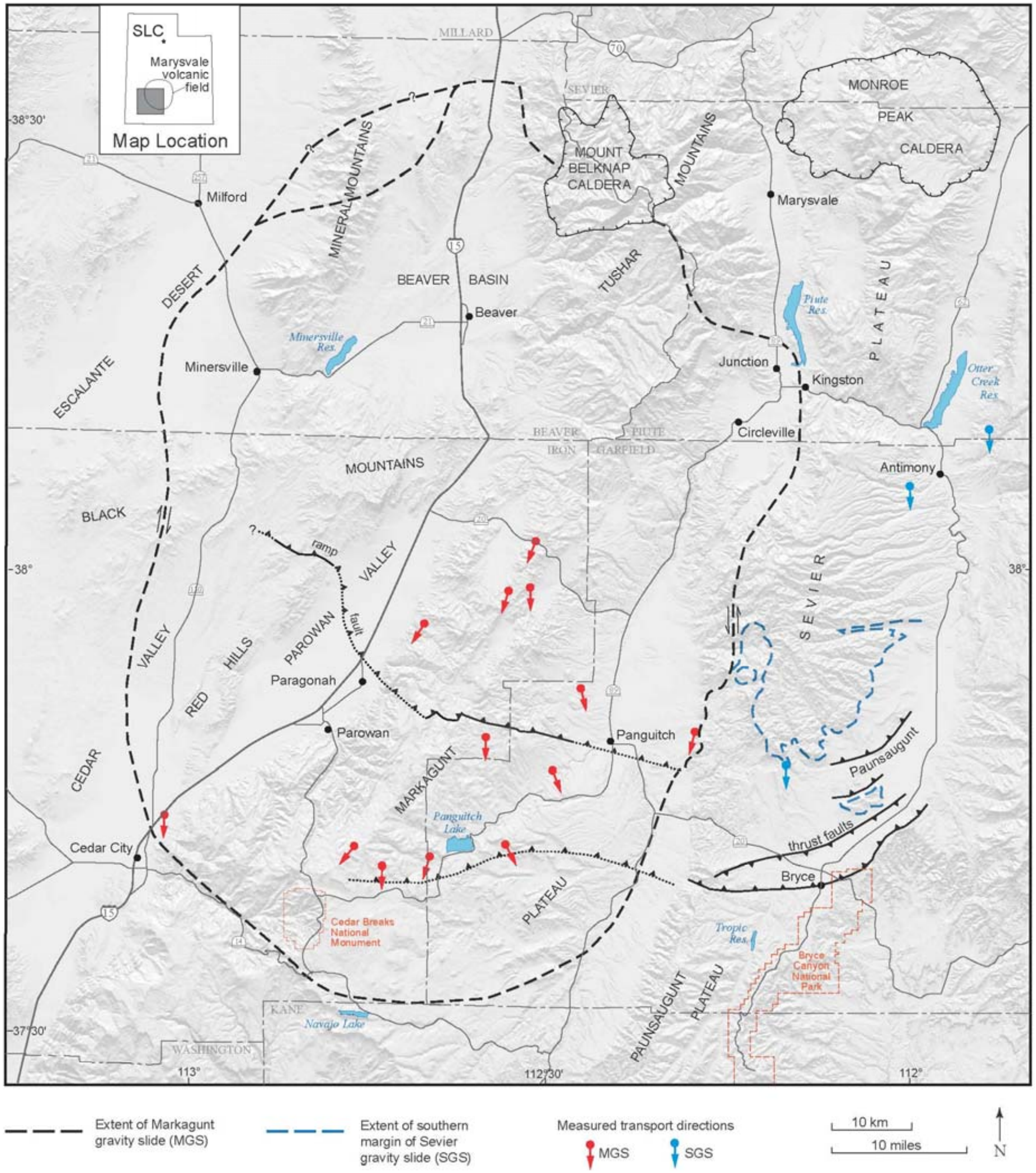
0
1
2mi
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USG...

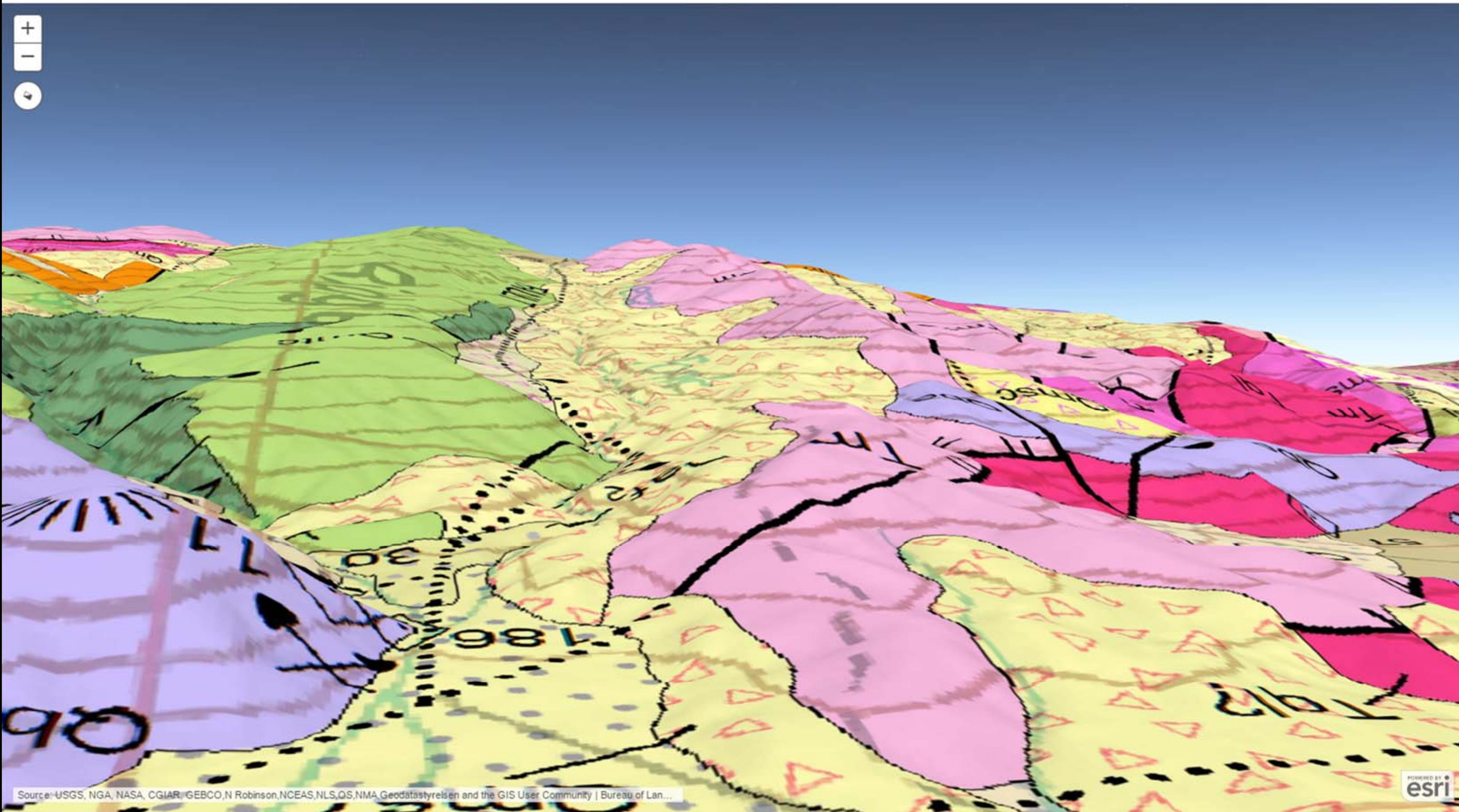

Tcp
Kgc
Kwcs

Cedar City-Parowan monocline

Author	Interpretation	Age
Thomas and Taylor (1946)	Tilting between closely spaced faults	Tertiary
Threet (1952, 1963)	Structural link between HFZ and Paragonah fault; named Summit or Parowan monocline	Mid-Cenozoic and later
Anderson and Mehnert (1979)	Ditto; regional ignimbrite distribution shows no barrier to eastward flow, therefore CCPM post-Mio.	Pliocene-Quaternary
Anderson and Barnhard (1979)	Ditto; Braffits Creek scarps; left-lateral strike-slip faults	Holocene
Anderson and Christenson (1989)	Ditto; renamed Cedar City-Parowan monocline;	Pliocene to Holocene
Hecker (1993)	Ditto; summary of previous work for QFF database	Holocene
Maldonado et al. (1994, 1997)	Ditto; assoc. with "Parowan thrust fault"; due to SE-vergent compression due to laccolith emplacement	early Neogene
Hurlow (2002)	Ditto	Neogene
Anderson et al. (2013)	Left-lateral slip on blind strike slip fault	Neogene
Biek et al. (2015)	Late Sevier-age thrust propagation fold	Paleogene (post-Claron and pre-ignimbrite)



SLC
Marysvale volcanic field
Map Location
MILLARD
SEVIER
MONROE PEAK CALDERA
MOUNT BELKNAP CALDERA
MINERAL MOUNTAINS
TUSHAR MOUNTAINS
Milford
Marysvale
BEAVER BASIN
Beaver
Minersville Res.
Minersville
Piute Res.
Junction
Kingston
Circleville
Otter Creek Res.
Antimony
SEVIER PLATEAU
ESCALANTE DESERT
BLACK MOUNTAINS
BEAVER
IRON
PIUTE
GARFIELD
ramp
PAROWAN VALLEY
fault
RED HILLS
CEDAR VALLEY
Paragonah
Parowan
Panguitch
MARKAGUNT PLATEAU
Panguitch Lake
Paunsaugunt
thrust faults
Cedar City
Bryce
Cedar Breaks National Monument
Tropic Res.
Bryce Canyon National Park
PAUNSAUGUNT PLATEAU
KANE
Navajo Lake
WASHINGTON
38°30'
38°
37°30'
113°
112°30'
112°
Extent of Markagunt gravity slide (MGS)
Extent of southern margin of Sevier gravity slide (SGS)
Measured transport directions
MGS
SGS
10 km
10 miles
N


Source: USGS, NGA, NASA, CGIAR, GEBCO,N Robinson,NCEAS,NLS,OS,NMA,Geodatastyrelsen and the GIS User Community | Bureau of Lan...

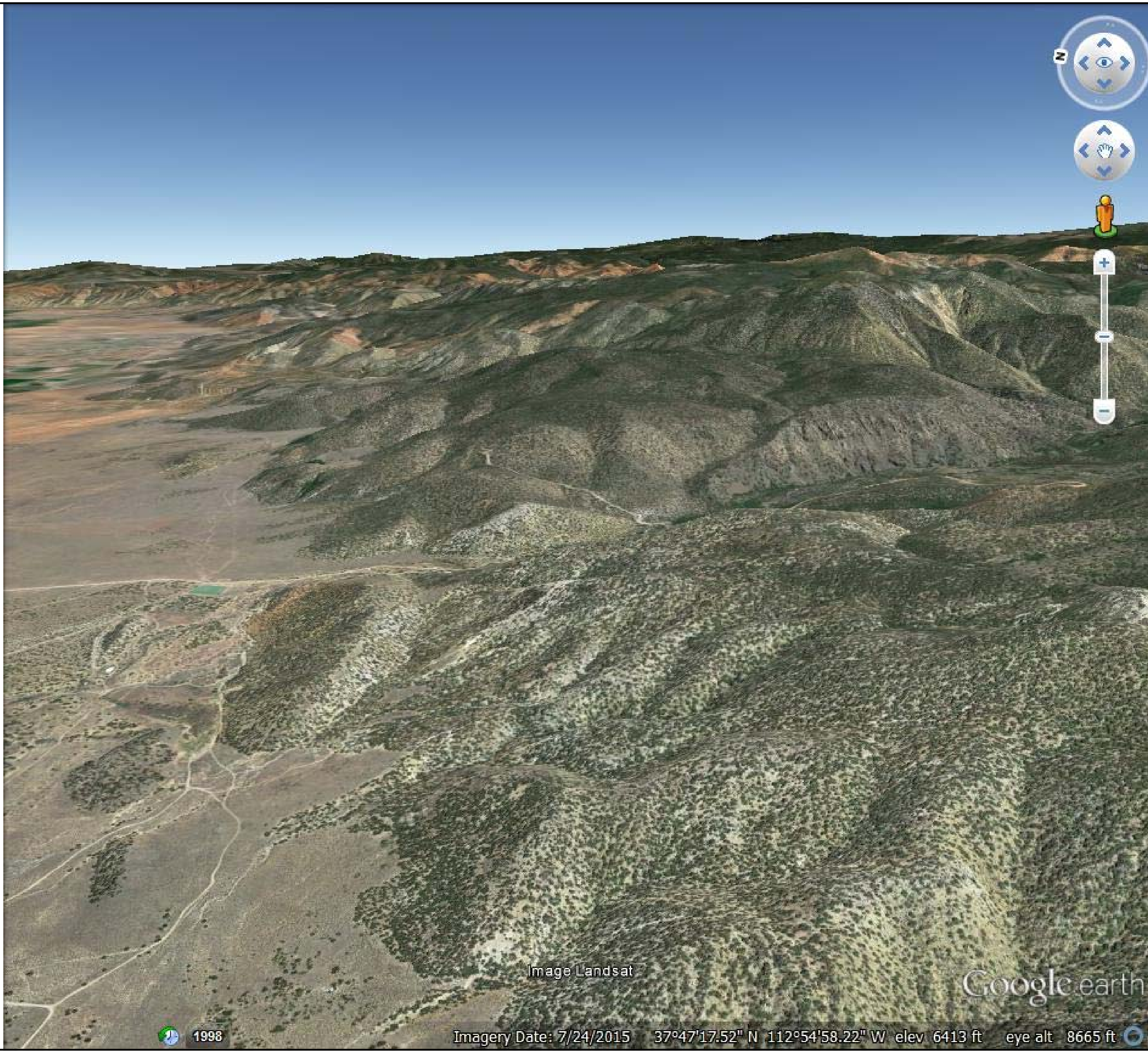
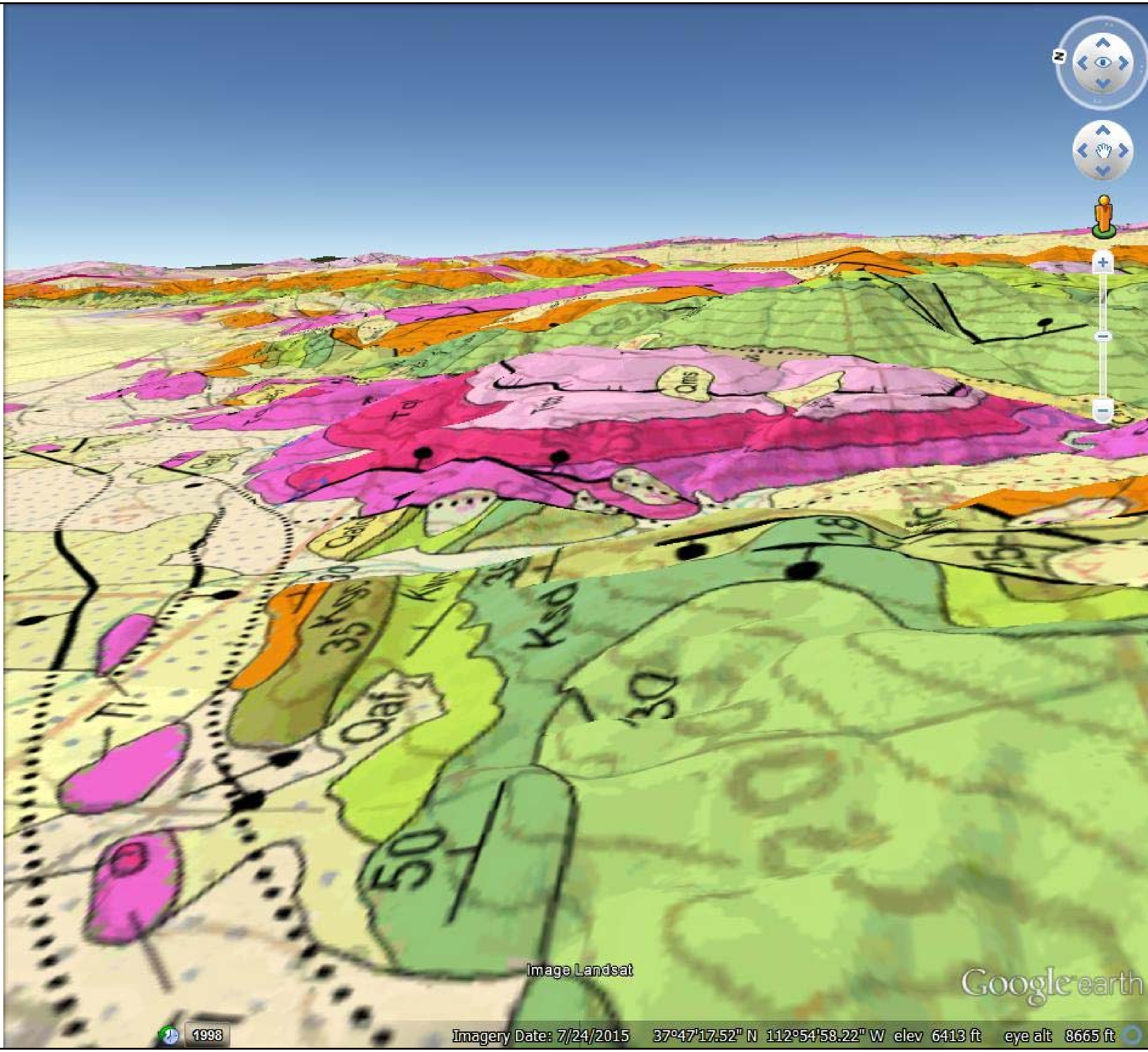


Image Landsat
Google earth
1998
Imagery Date: 7/24/2015 37°47'17.52" N 112°54'58.22" W elev 6413 ft eye alt 8665 ft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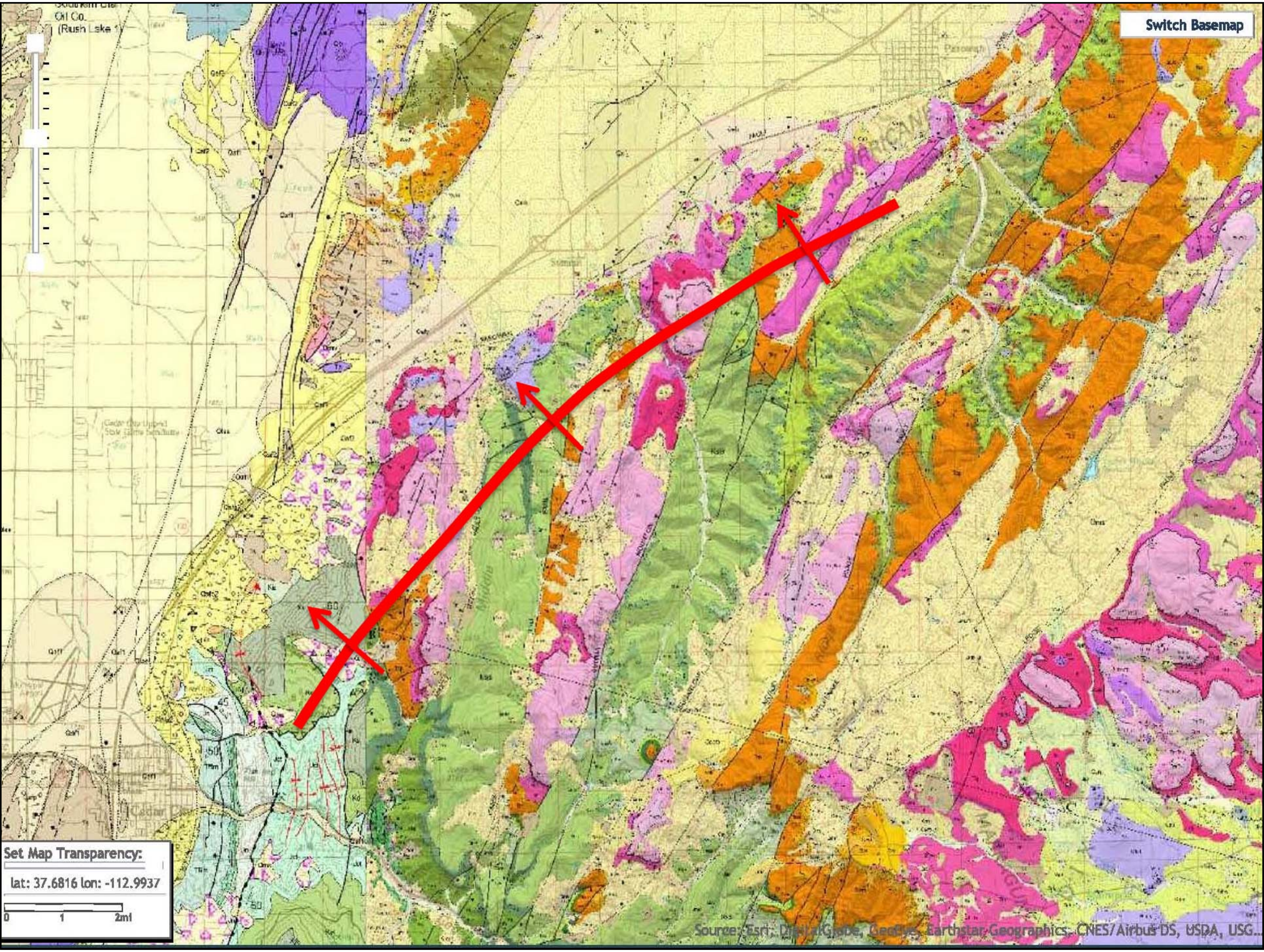
Google earth
1998
Imagery Date: 7/24/2015 37°47'17.52" N 112°54'58.22" W elev 6413 ft eye alt 8665 ft



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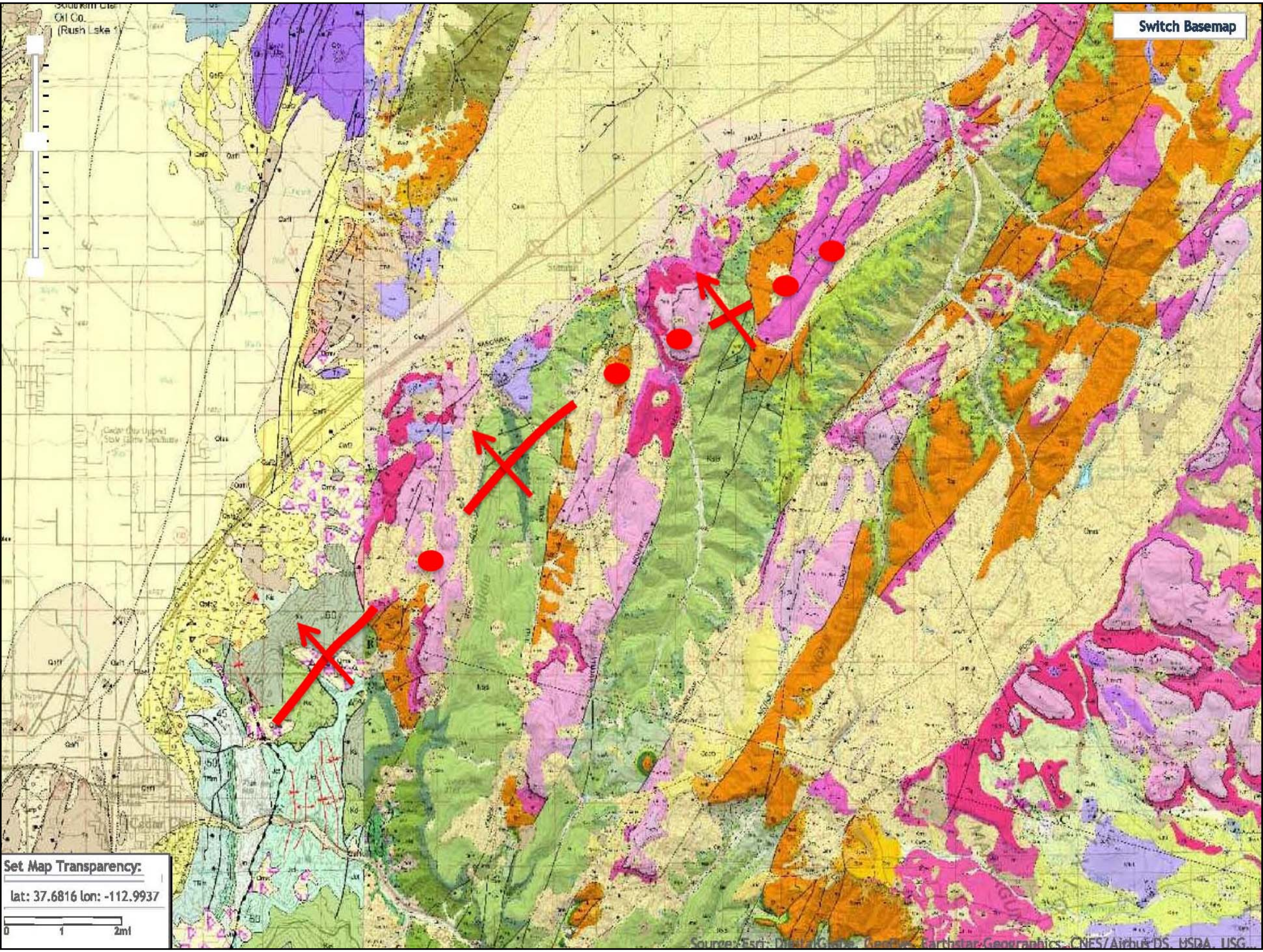
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USG...


Switch Basemap
Oil Co.
(Rush Lake 1)
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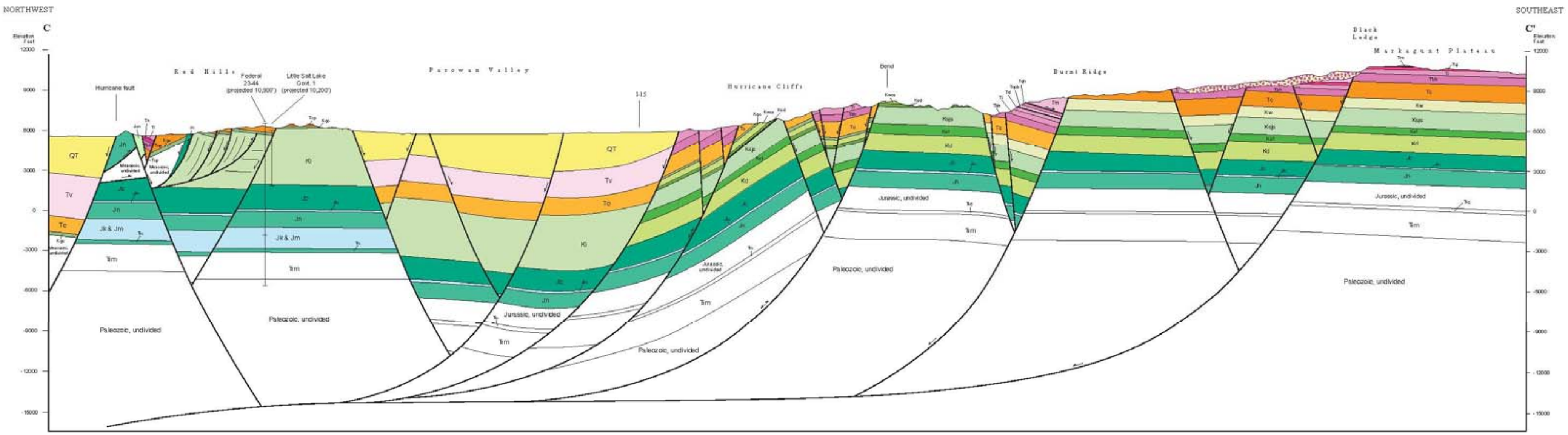
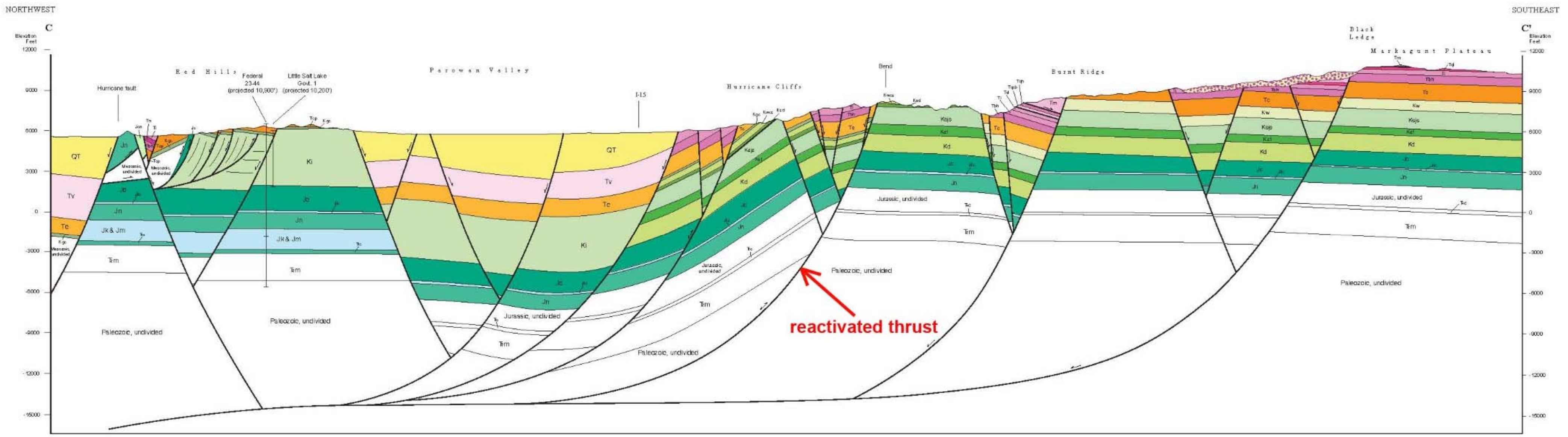
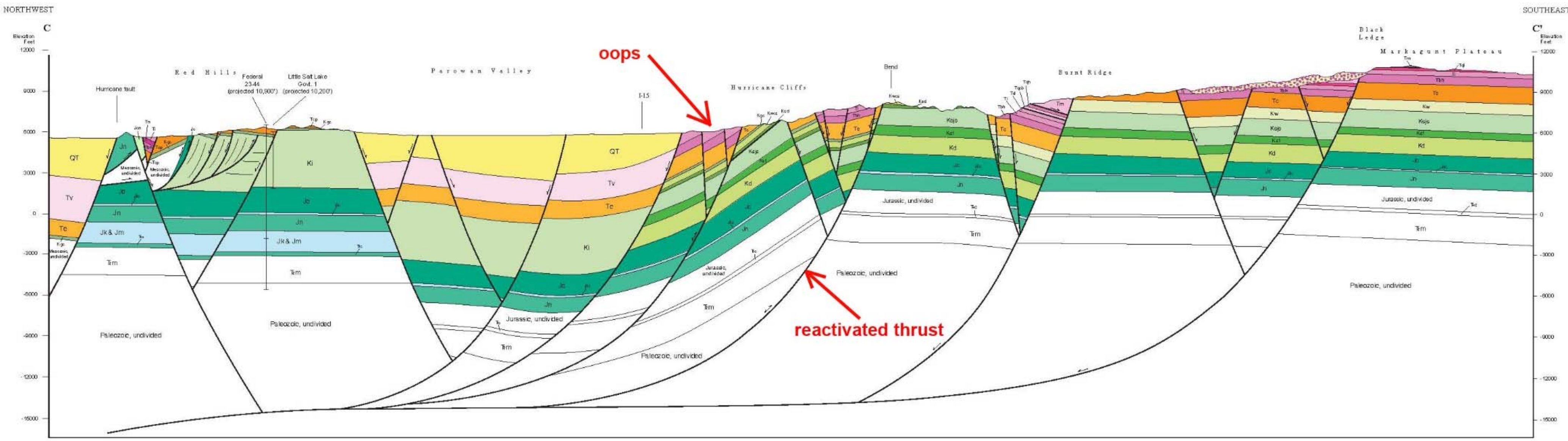
0 1 2mi
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USG...

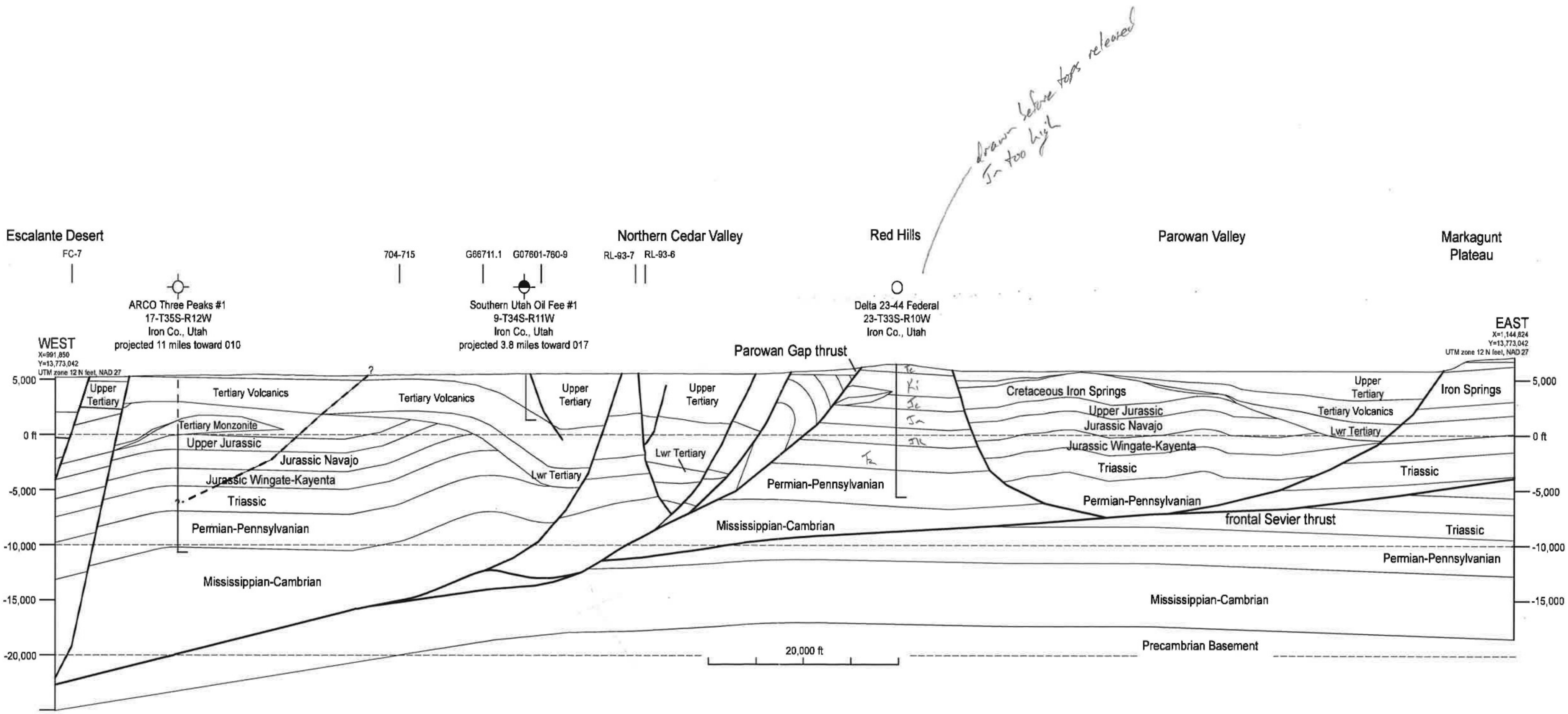


NORTHWEST
C
SOUTHEAST
C'
Elevation Feet
Red Hills
Parowan Valley
Hurricane Cliffs
Burnt Ridge
Black Ledge
Markagunt Plateau
Hurricane fault
Federal 23-44 (projected 10,800')
Little Salt Lake Govt. 1 (projected 10,200')
I-15
Bend
QT
Tv
Tc
Jk & Jm
Jn
Kt
Kd
Kcp
Jurassic, undivided
Paleozoic, undivided
Mesozoic, undivided



NORTHWEST
SOUTHEAST
C
C'
Elevation Feet
Red Hills
Parowan Valley
Hurricane Cliffs
Bend
Burnt Ridge
Black Ledge
Markagunt Plateau
Hurricane fault
Federal 23-44 (projected 10,900')
Little Salt Lake Govt. 1 (projected 10,200')
I-15
QT
TV
Tc
Jn
Jk & Jm
Ki
Kd
Jurassic, undivided
Paleozoic, undivided
reactivated thrust


NORTHWEST
SOUTHEAST
C
C'
Elevation Feet
Red Hills
Parowan Valley
Hurricane Cliffs
Burnt Ridge
Black Ledge
Markagunt Plateau
Hurricane fault
Federal 23-44 (projected 10,900')
Little Salt Lake Govt. 1 (projected 10,200')
I-15
Bend
oops
reactivated thrust
QT
TV
Tv
Tc
Ki
Jc
Jn
Jk & Jm
Tm
Kd
Kcf
Kcjs
Kw
Tbh
Jurassic, undivided
Paleozoic, undivided
Mesozoic, undivided
12000
9000
6000
3000
0
-3000
-6000
-9000
-12000
-15000



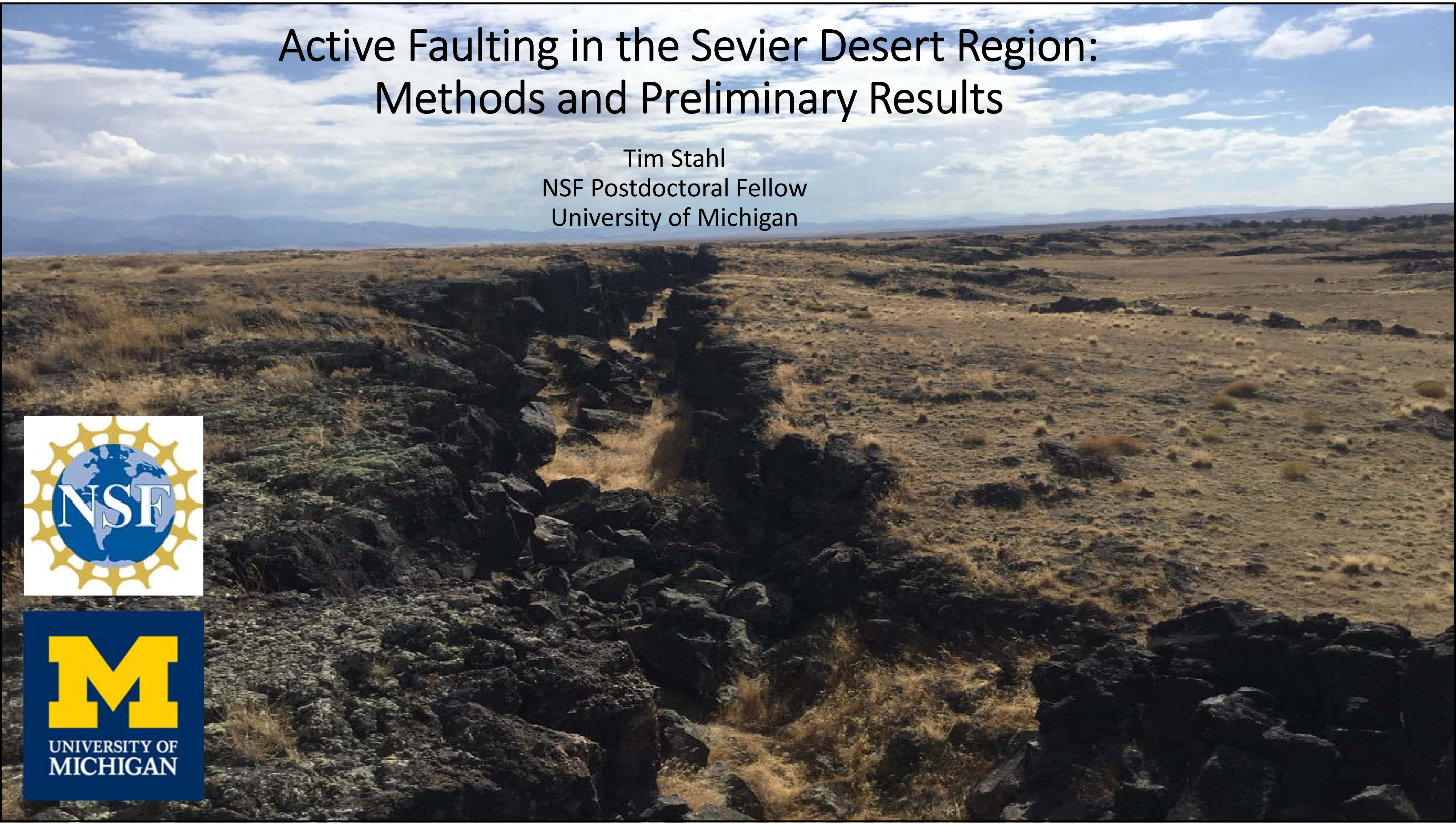
drawn before tops released
Jn too high
Escalante Desert
FC-7
ARCO Three Peaks #1
17-T35S-R12W
Iron Co., Utah
projected 11 miles toward 010
704-715
G66711.1
G07601-760-9
Southern Utah Oil Fee #1
9-T34S-R11W
Iron Co., Utah
projected 3.8 miles toward 017
Northern Cedar Valley
RL-93-7
RL-93-6
Red Hills
Delta 23-44 Federal
23-T33S-R10W
Iron Co., Utah
Parowan Valley
Markagunt Plateau
WEST
X=991,850
Y=13,773,042
UTM zone 12 N feet, NAD 27
EAST
X=1,144,824
Y=13,773,042
UTM zone 12 N feet, NAD 27
Parowan Gap thrust
5,000
0 ft
-5,000
-10,000
-15,000
-20,000
Upper Tertiary
Tertiary Volcanics
Tertiary Monzonite
Upper Jurassic
Jurassic Navajo
Jurassic Wingate-Kayenta
Triassic
Permian-Pennsylvanian
Mississippian-Cambrian
Lwr Tertiary
Cretaceous Iron Springs
Iron Springs
frontal Sevier thrust
Precambrian Basement
20,000 ft

Conclusions

- CCPM ≠ Holocene or even Neogene
- CCPM ≠ concern for UQFPWG
- CCPM ≠ Red Hills, Parowan Valley, Paragonah fault zones
- UQFPWG needs a new acronym

Active Faulting in the Sevier Desert Region: Methods and Preliminary Results

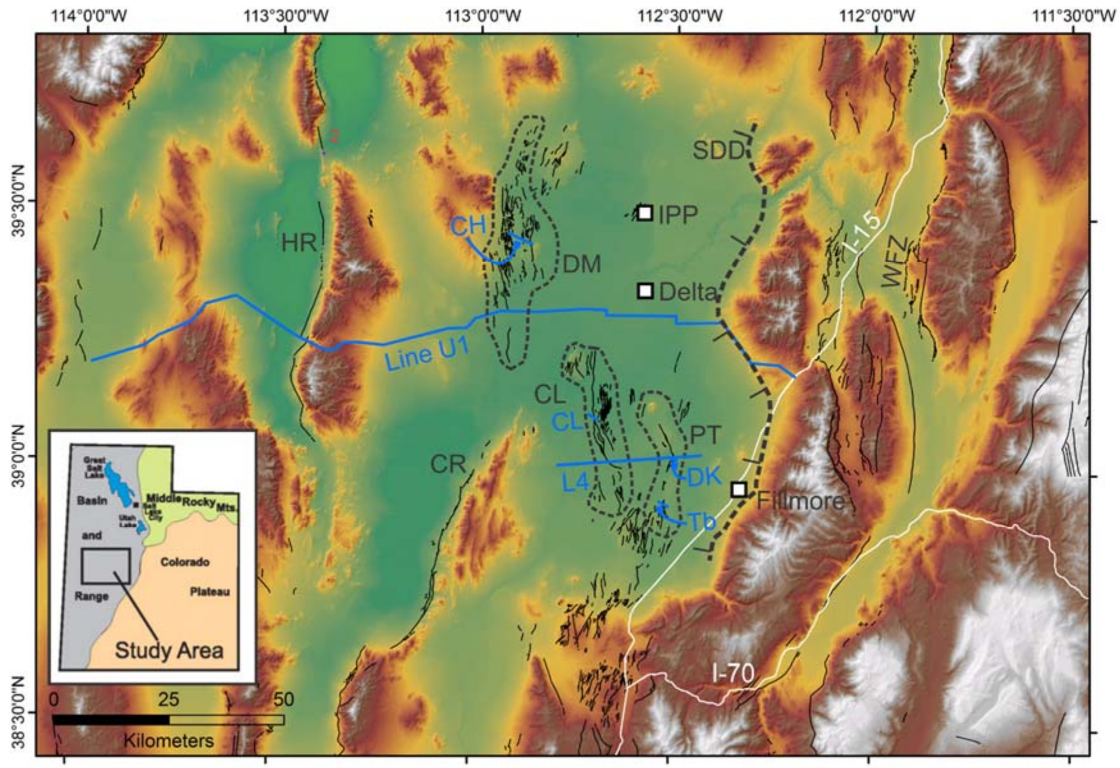
Tim Stahl
NSF Postdoctoral Fellow
University of Michigan



Overview

- Seismic sources and hazard in the Sevier Desert region
- Study sites and research aims
- I. Drum Mts. Fault Zone
- II. Tabernacle-Pavant Fault Zone
- III. House Range Fault Zone
- Summary

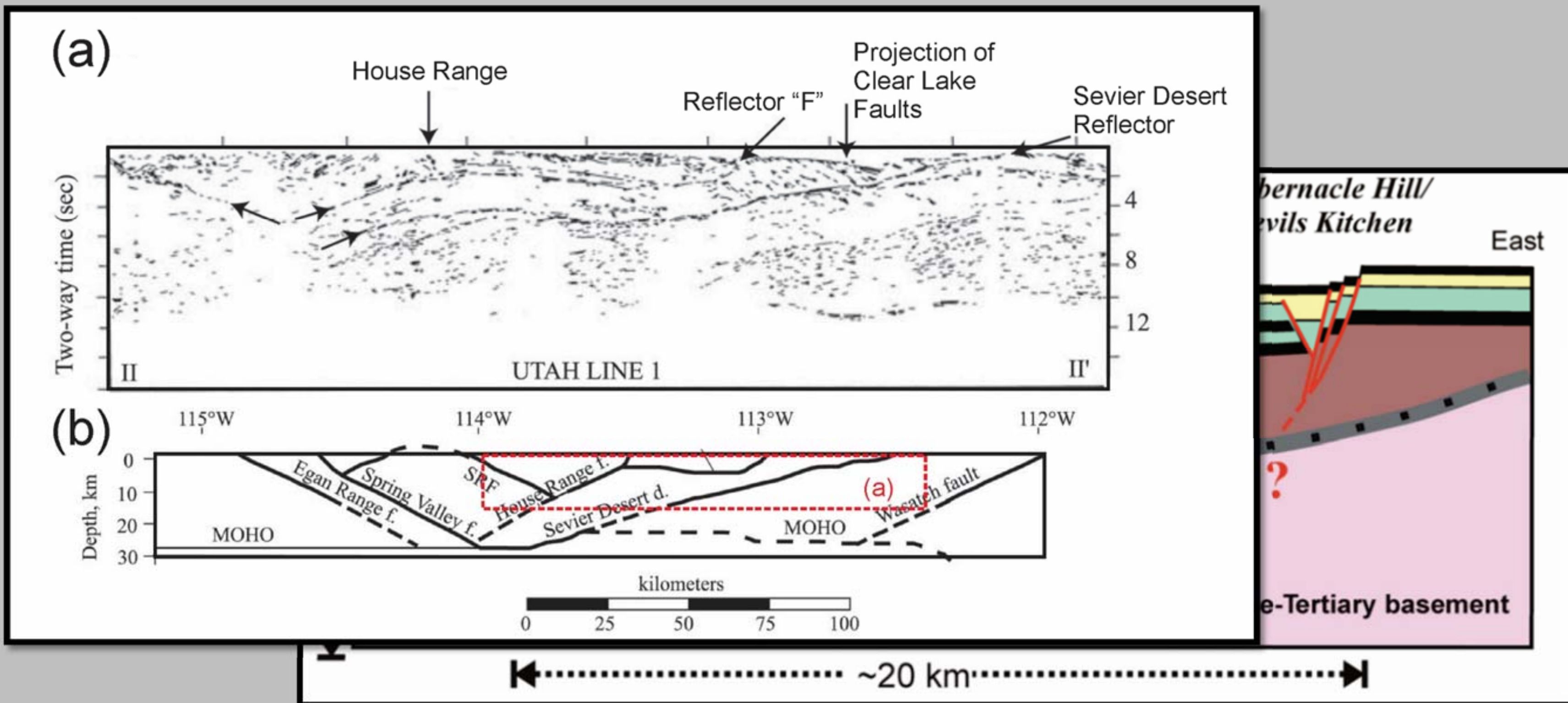
Sevier Desert Region



- Region spanning from House Range in the West to Canyon Range in the East
- Delta, Fillmore, I-15 & I-70, and Intermountain Power Plant
- Potential for geothermal development and subject of past oil industry surveys

Introduction-2

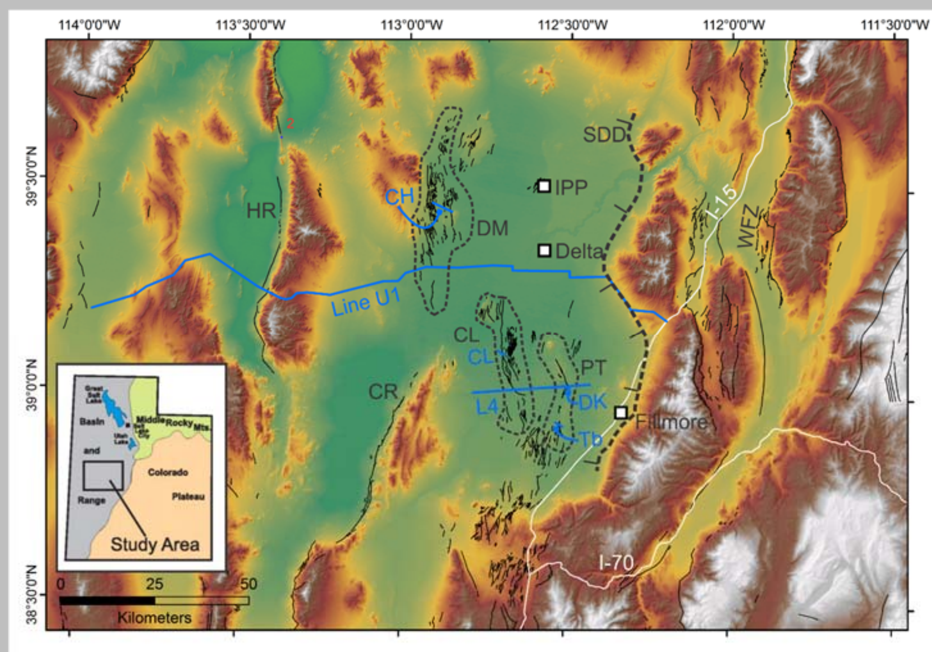
Sevier Desert Detachment



McBride et al., 2015

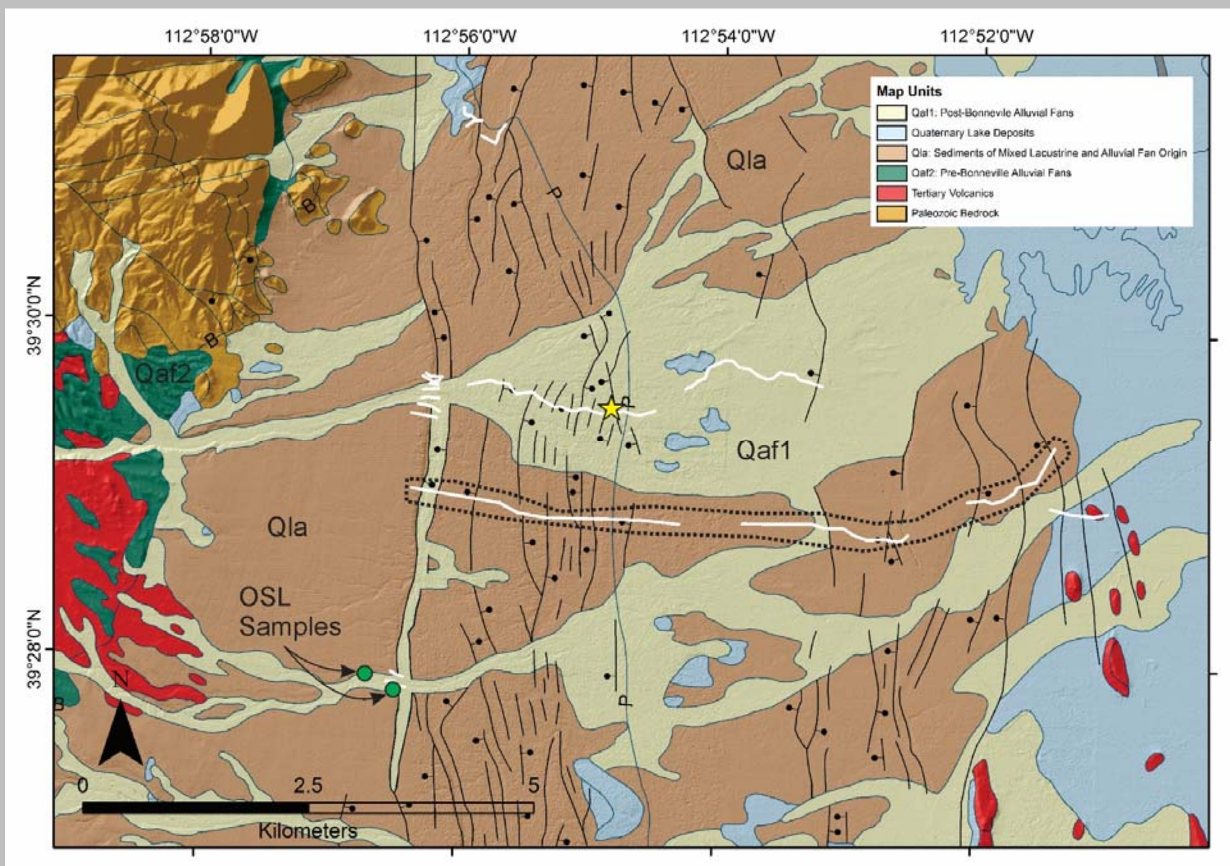
Aims

- Acquire high-resolution survey data and use advances in Quaternary geochronology to (attempt to) answer some of these questions

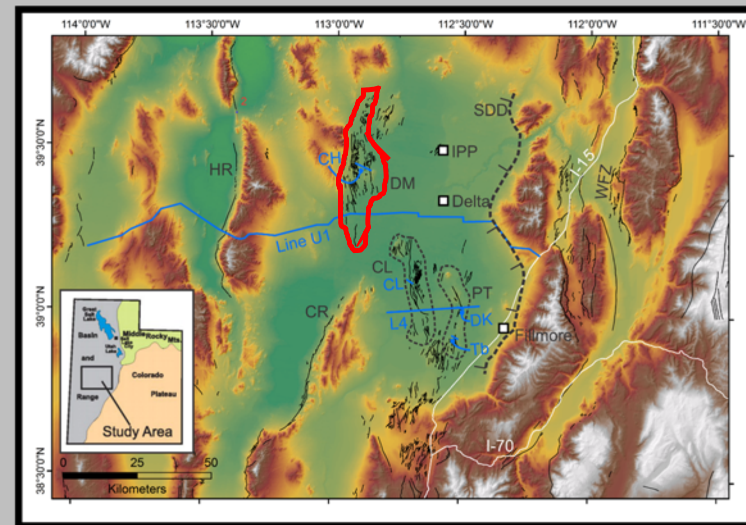


Drum Mountains Fault Zone-1

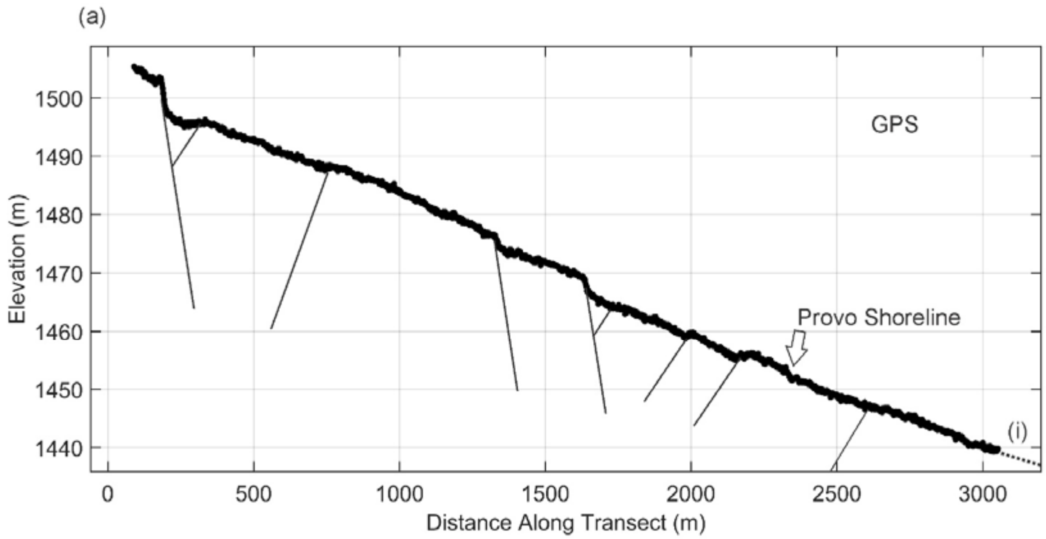
Drum Mountains

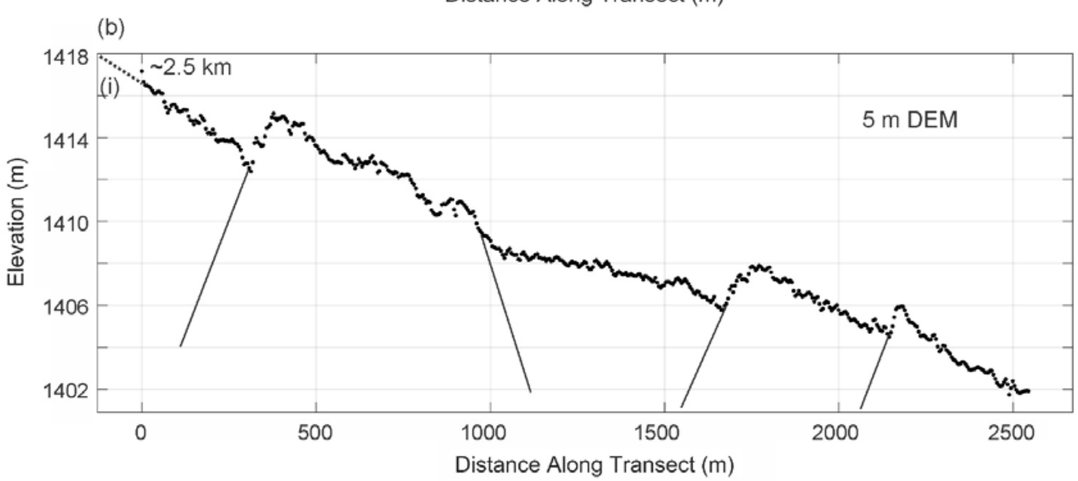


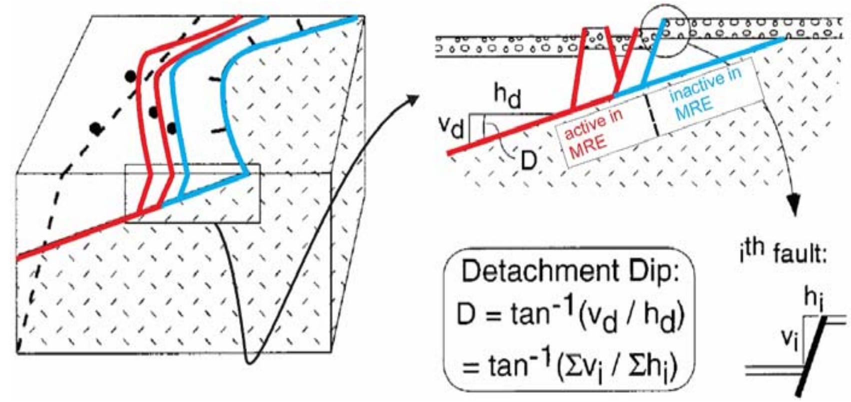
Modified after Hintze and Davis, 2002



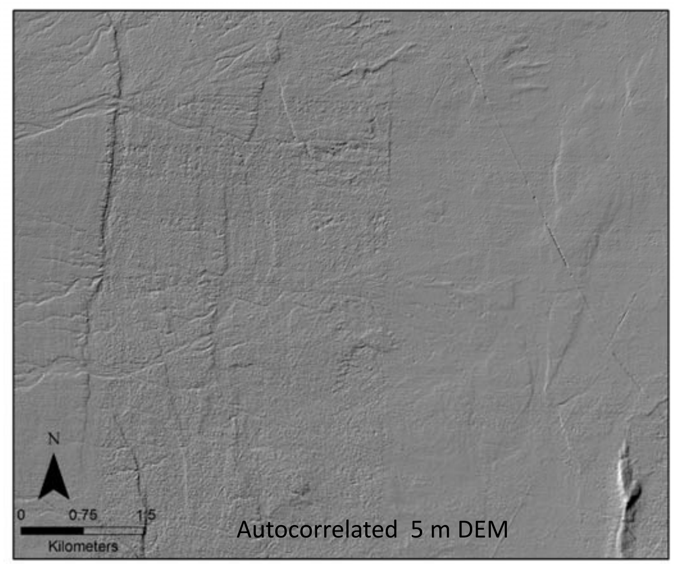
Drum Mountains Fault Zone-4





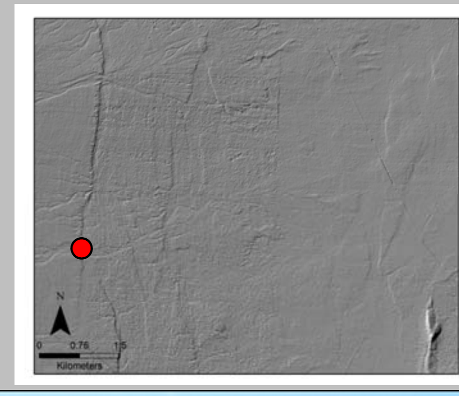


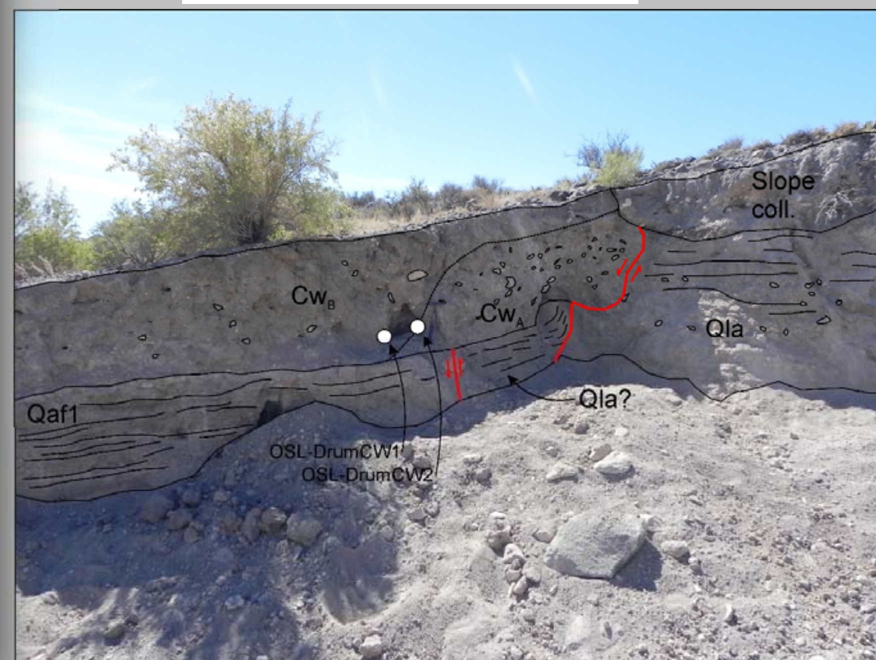
Axen et al., 1999



Drum Mountains Fault Zone-2

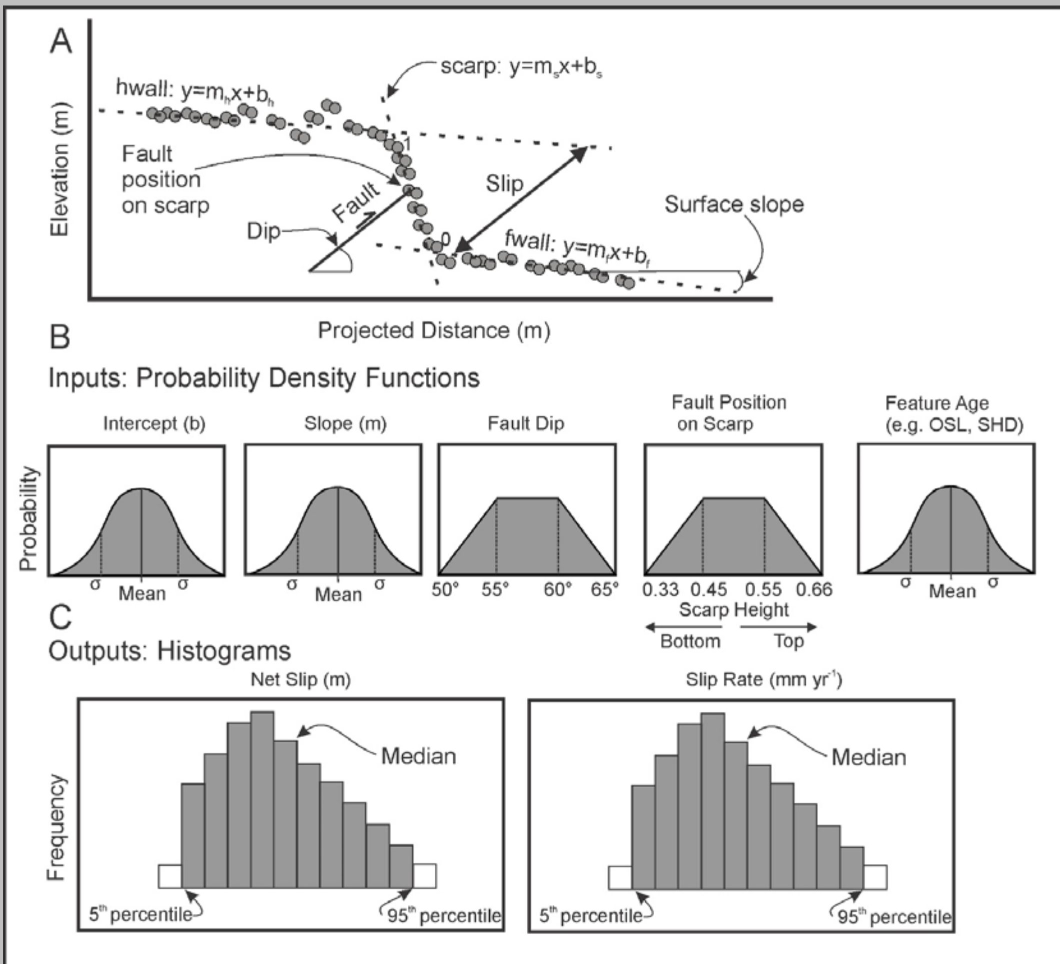
Semi-natural exposure



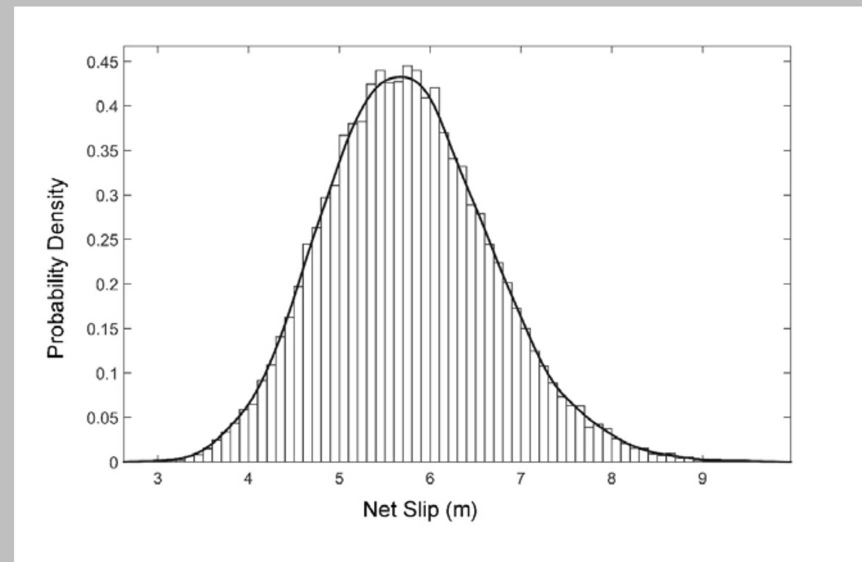


SED: <3-4 m

Drum Mountains Fault Zone-3



Stahl et al. (in revision)



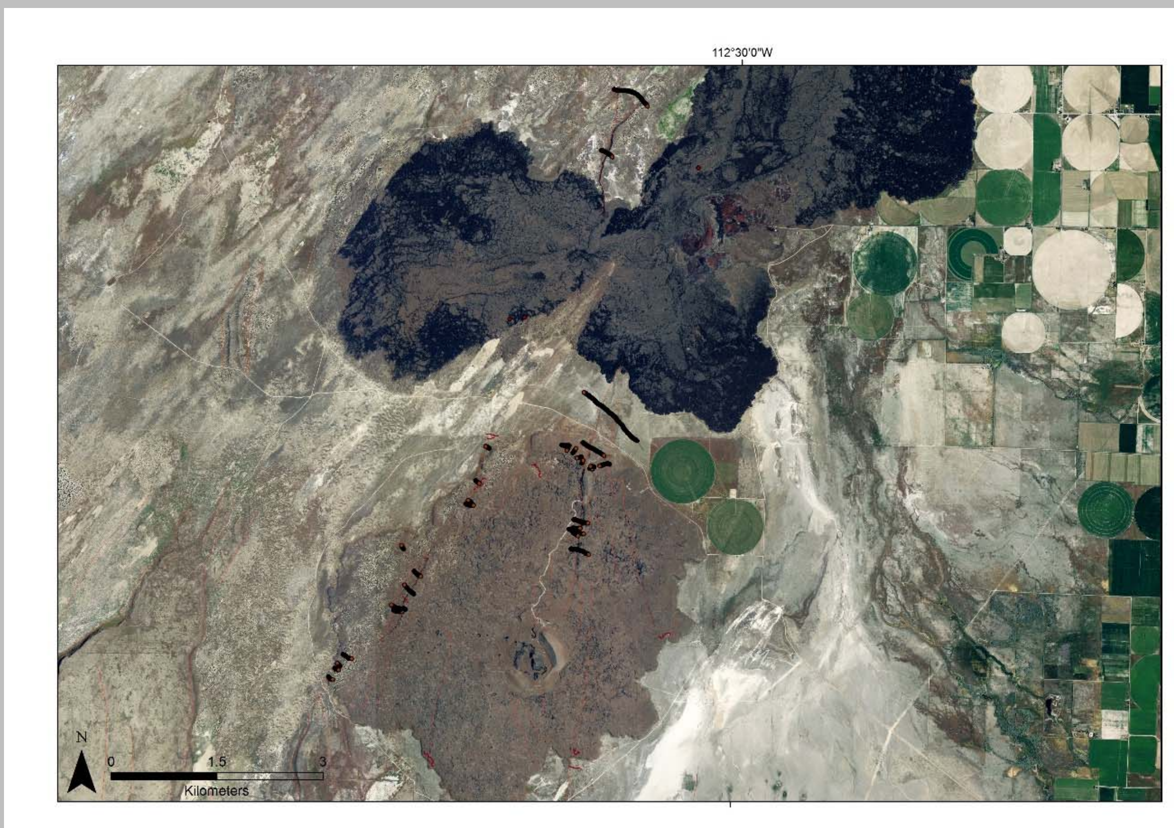
- Probably represents cumulative slip in 1-2 events, but is a minimum for the entire fault zone
- High-resolution topography will assist in surface mapping and measuring displacements
- Trenching will help determine if *some* scarps were produced by coeval rupture on underlying faults

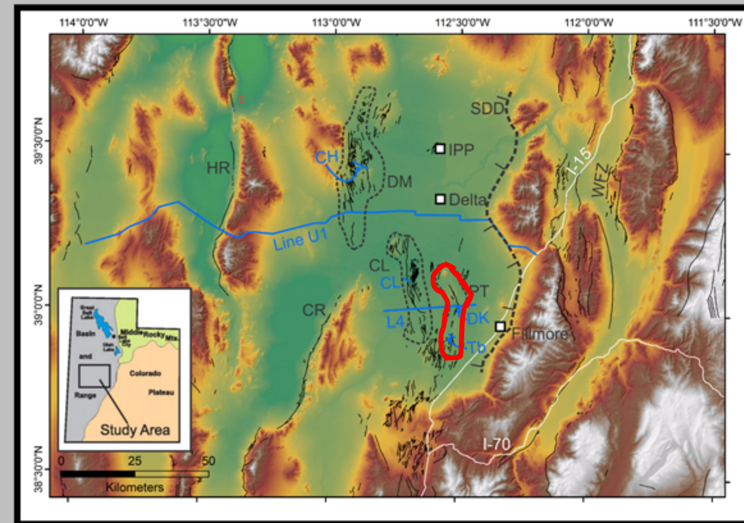
Drum Mountains

- Planned work for 2016:
  - TLS of Provo shoreline offsets
  - Paleoseismic trenching of trace antithetic to ‘main’ trace
  - Decipher detachment geometry
  - Cosmogenic dating of Qaf1 surface (pending) and OSL dating of fan sediments
  - Collect LiDAR across the entire fault zone (pending)

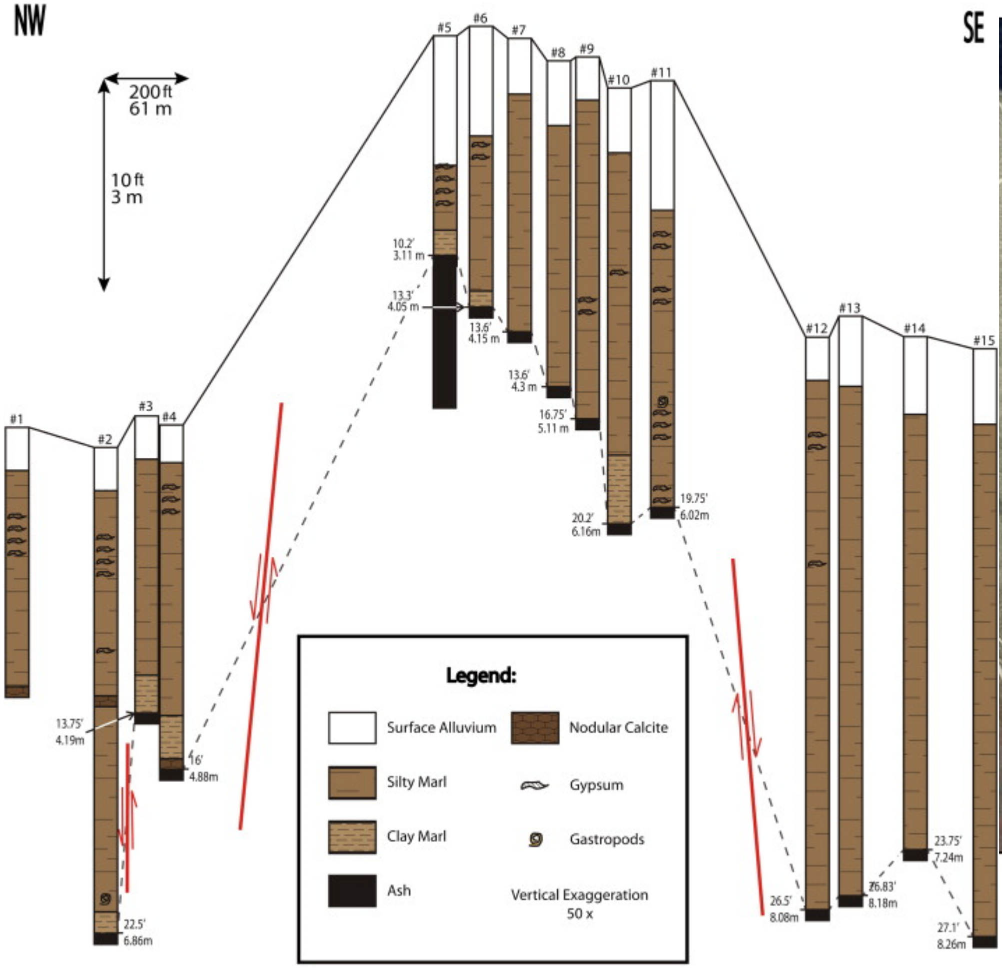
Tabernacle-Pavant Fault Zone-1

Tabernacle-Pavant

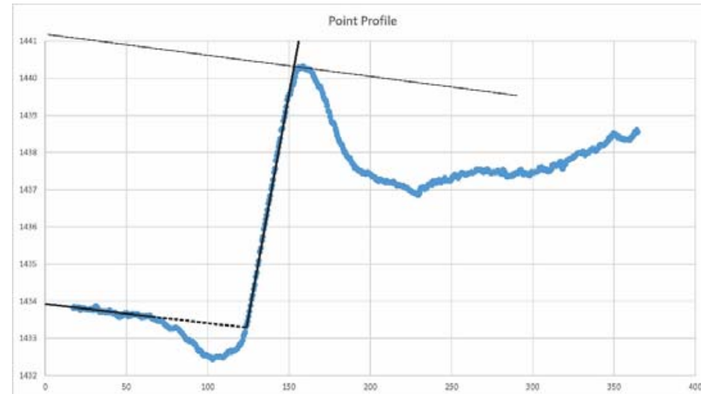


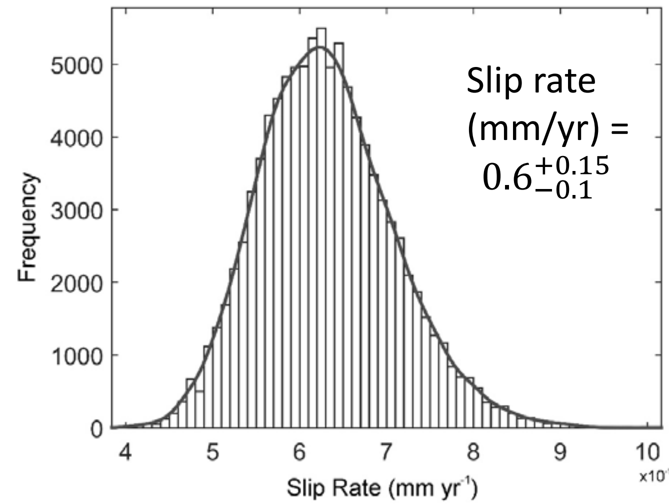


Tabernacle-Pavant Fault Zone-2

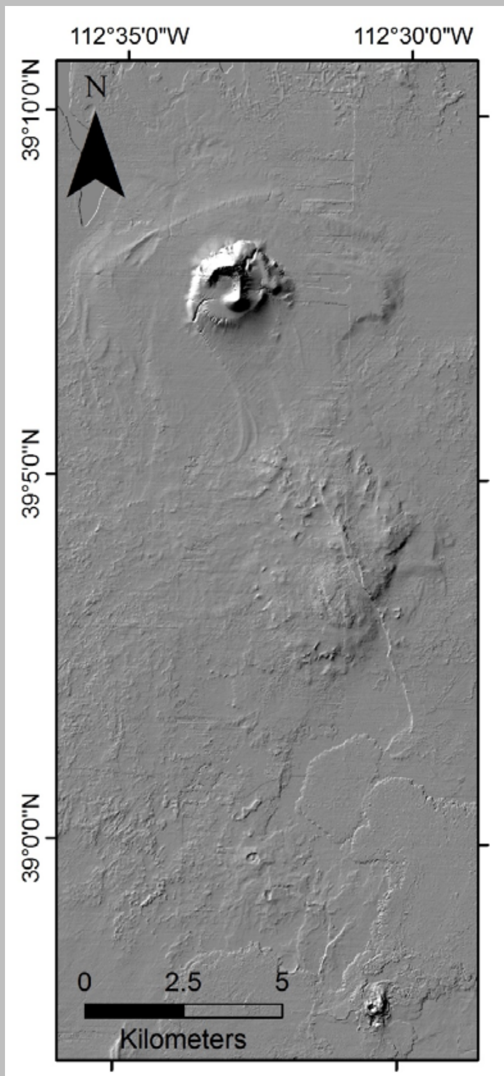


McBride et al., 2015





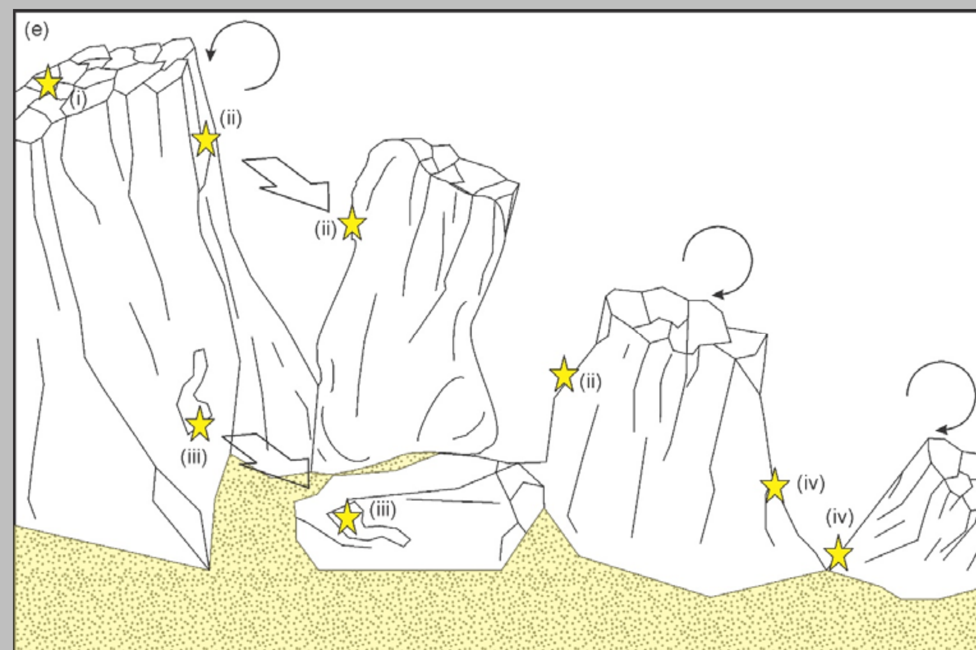
Tabernacle-Pavant Fault Zone-3



Tabernacle-Pavant Fault Zone-4

Devil's Kitchen

(a): Inner edges of two tension fissures and progressive(?) forelimb rotation



Tabernacle-Pavant Fault Zone-5

Cosmogenic ^{3}He exposure-age dating of tension fissures and toppled blocks

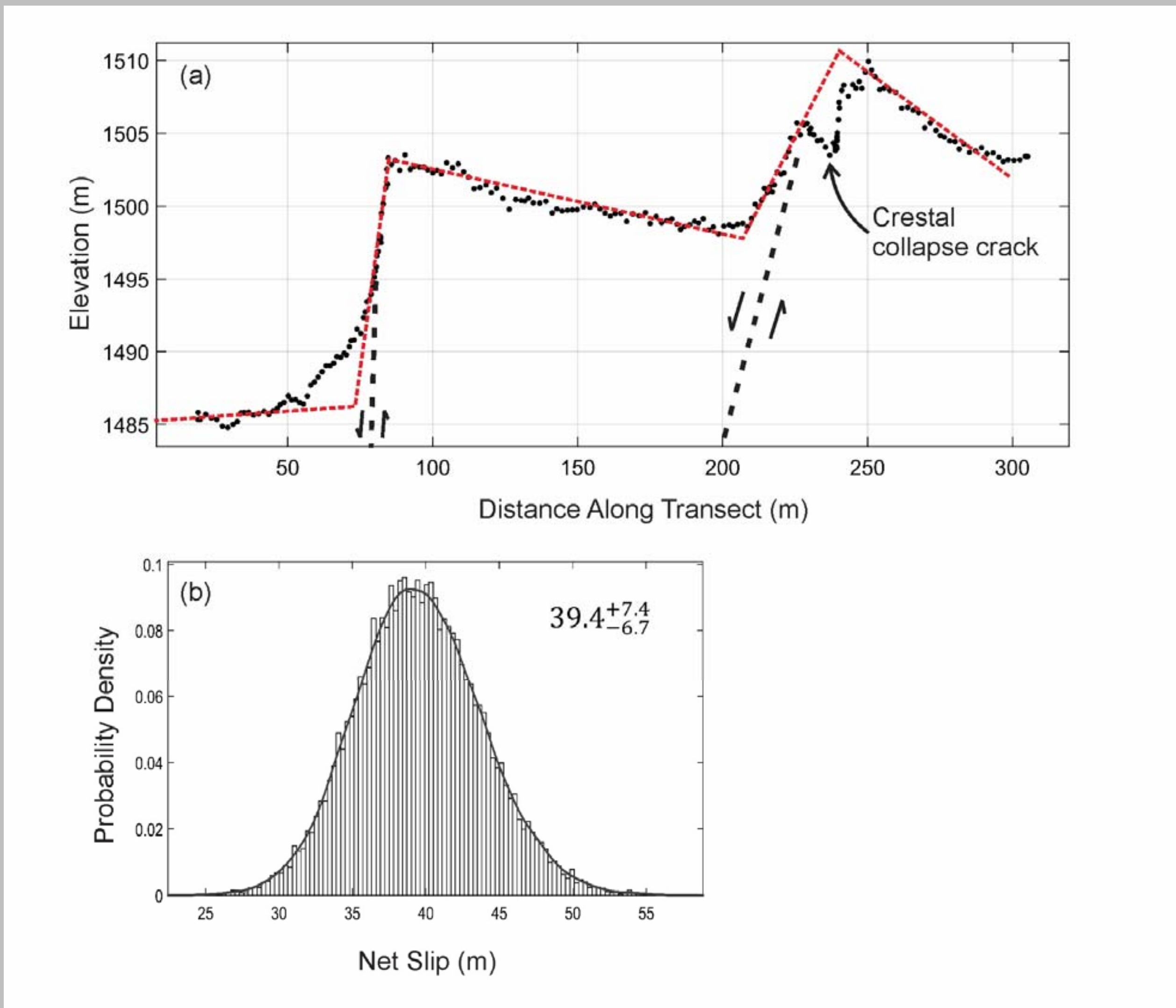
- Sample site selection (30 samples collected)

(b): Standing in a tension fissure

(c): Sampling >2 m below flow surface on the outer edge of a tension fissure

Basic Workflow:

- Identify sites suitable for dating (e.g. matching inner and outer edges of fissures; 'mega'-blocks and columns that can be reconstructed to fissure face
- Collect ~1 kg of material with portable saw and take shielding measurements
- Separate pyroxene and/or olivine phenocrysts
- Crush to release mantle gases
- Measure ^{3}He and calculate exposure age, correcting for local production rate



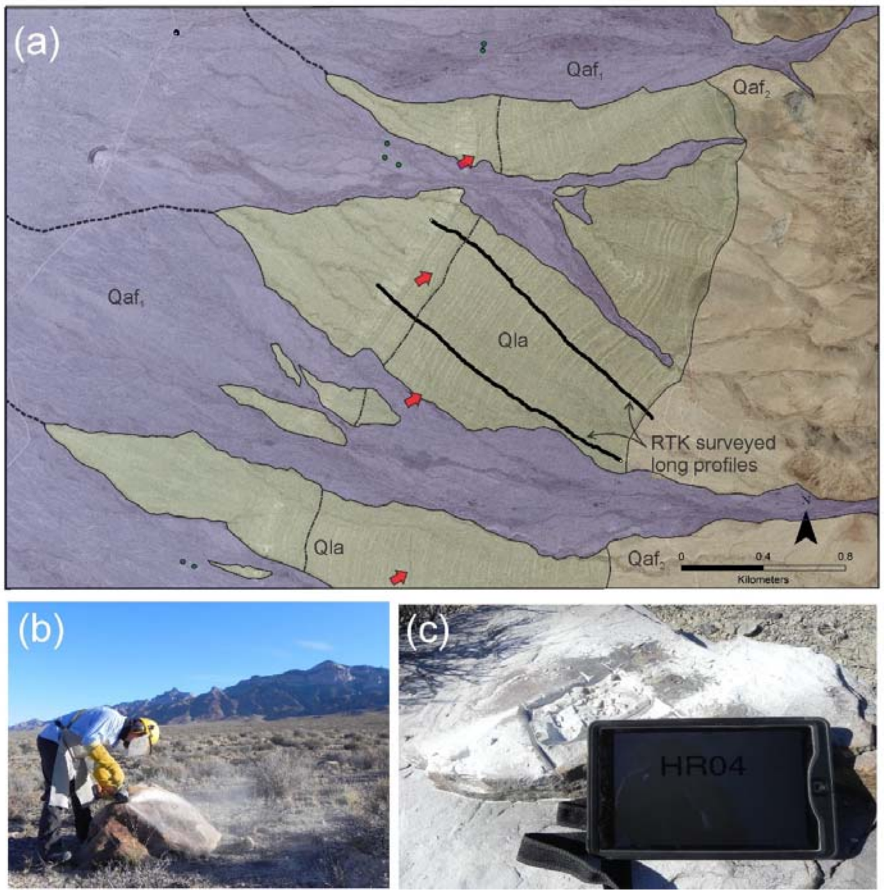
- Current age of Pavant Basalt: 31 ka – 220 ka, with error margins larger than the ages
- Ar-Ar dating and exposure-age dating of the flow surface will help get at a slip rate

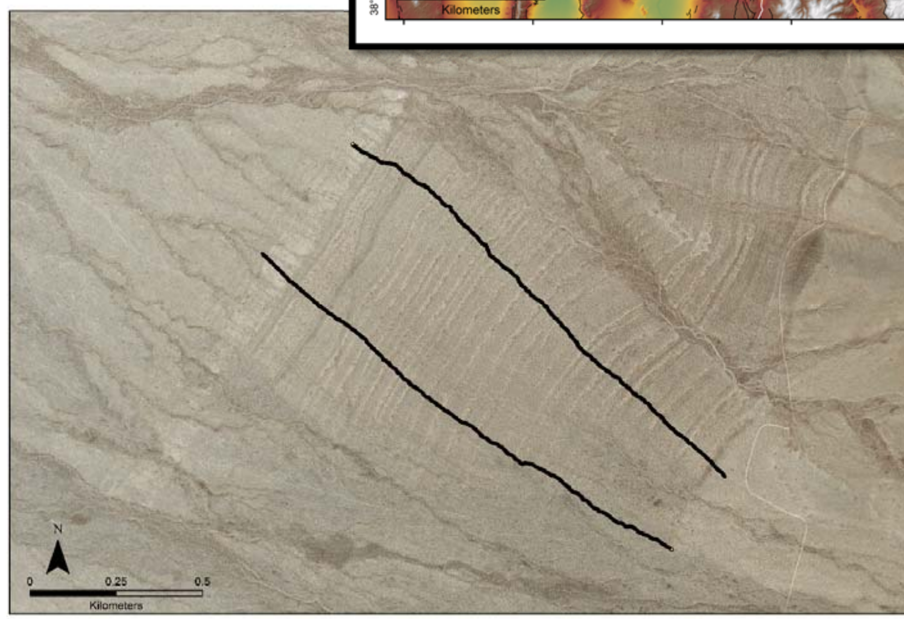
Tabernacle-Pavant Fault Zone

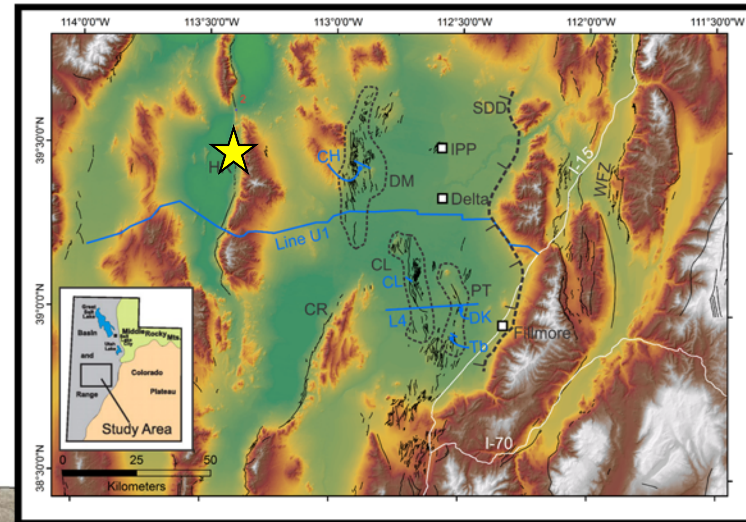
- Planned work for 2016:
  - Process samples for ^3He analysis and produce a suitable age model
  - TLS of scarps and displaced Provo shorelines; late Pleistocene slip rates
  - Ar-Ar dating of flow

House Range Fault-1

House Range

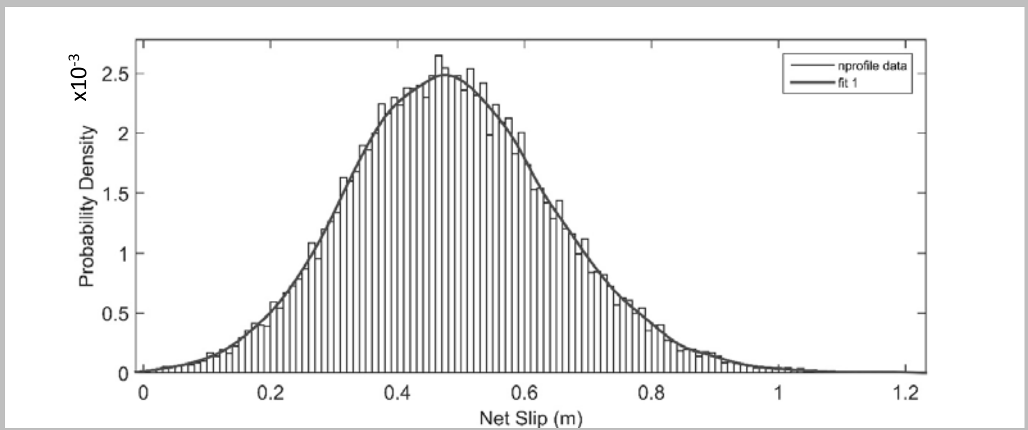




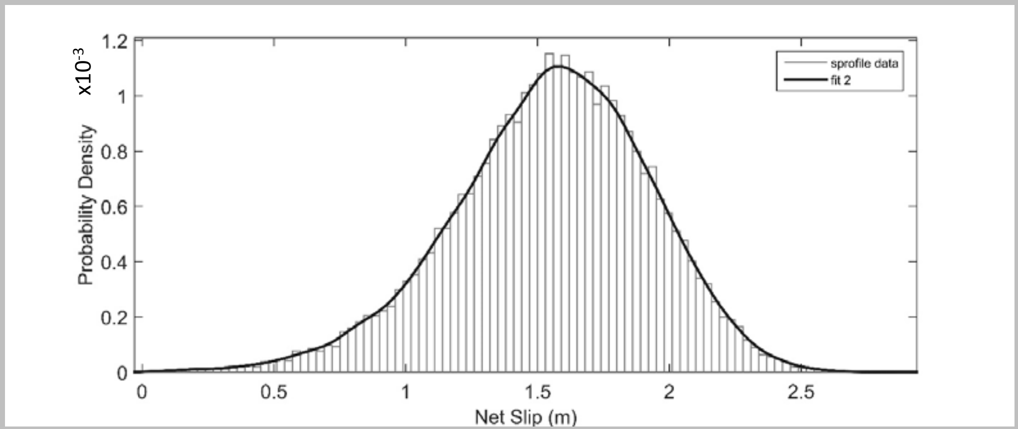


House Range Fault-2

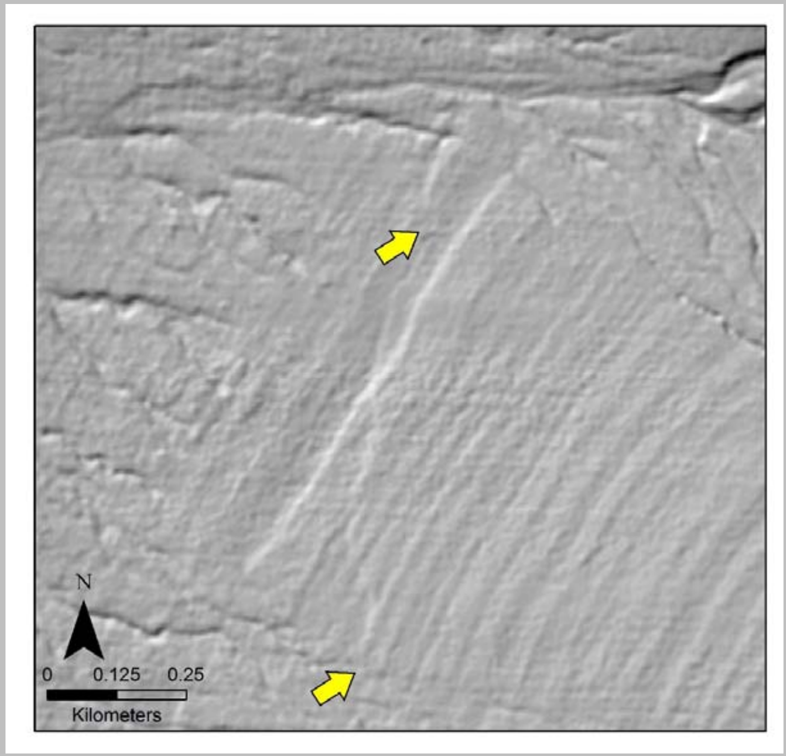
North Profile (below Provo level)



South Profile (above Provo level)



- Multiple displacements, or wave degradation of the scarp below the Provo shoreline?



House Range Fault

- Planned work for 2016:
  - Cosmogenic ^{10}Be dating of Qaf1 surface to constrain MRE
  - Aerial photogrammetry of scarp and shorelines to determine SED and constrain recurrence interval
  - (U-Th)/He thermochronology to determine long term uplift rates

Summary

- Work ongoing to determine the rates and nature of active faulting in the Sevier Desert
- Preliminary analyses could indicate a significant portion of extension west of the Wasatch Fault Zone being accommodated by a combination of the Drum Mts., Tabernacle-Pavant-Clear Lake, and, to a lesser extent, the House Range faults
- Trench on Drum Mts. Fault Zone in May 2016

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Mike Bunds
Nathan Toke

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John McBride
Steve Nelson

Snow College-
Renee Faatz

Utah State University-
Tammy Rittenour

Middlebury College-
Willy Amidon

Otago Regional Council-
Ben Mackey

NSF EAR #1451466

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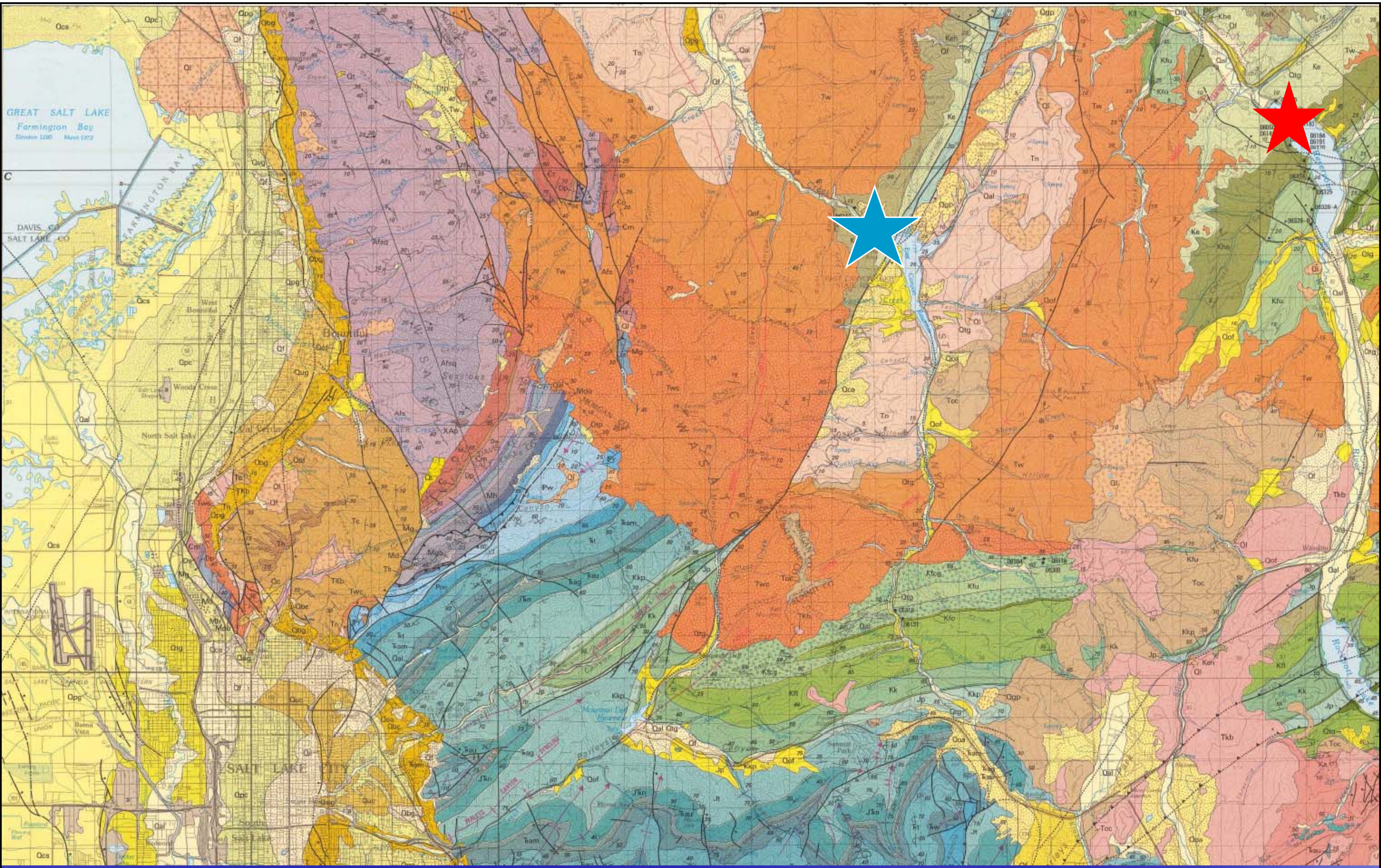
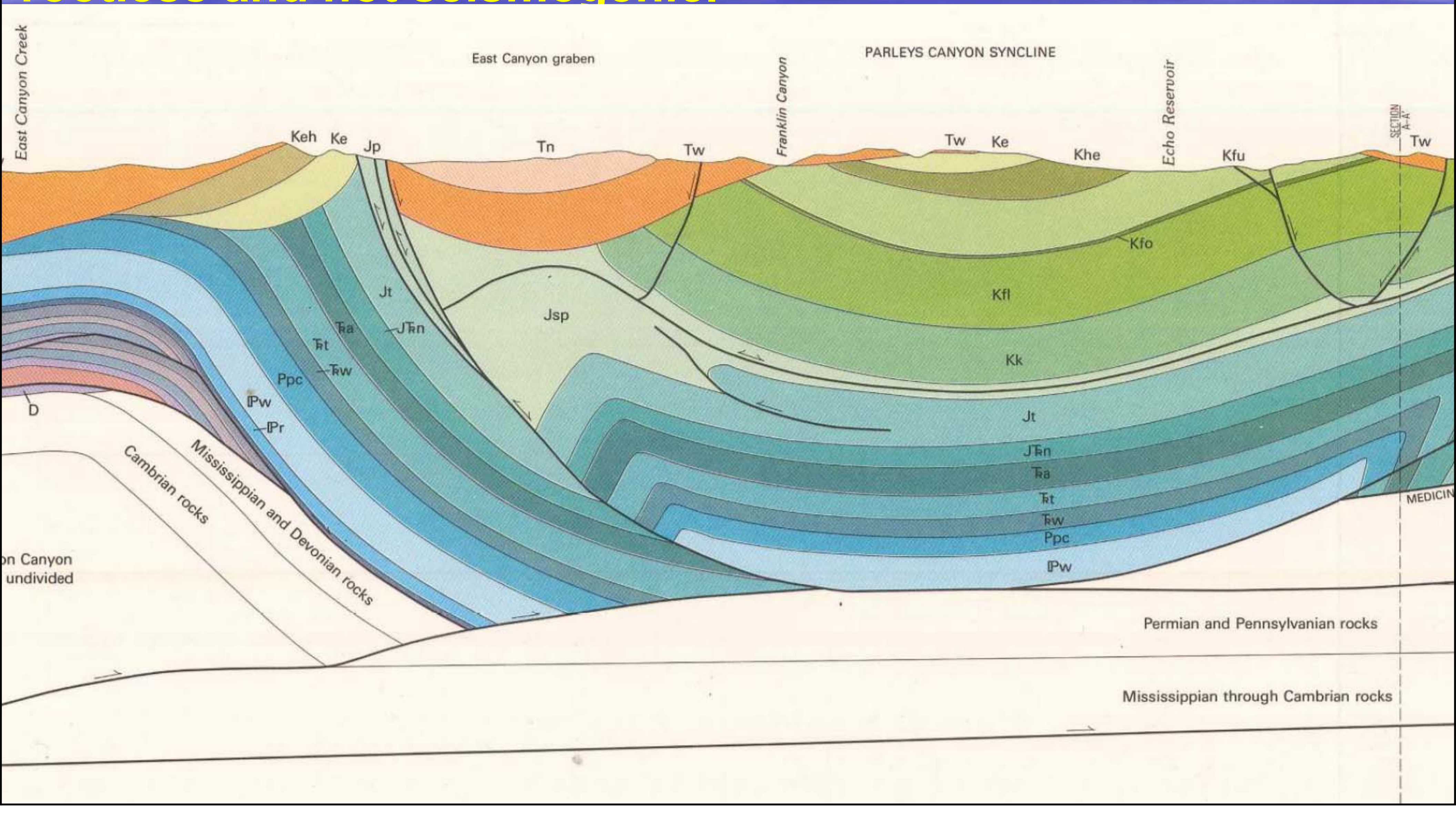
REVISITING UTAH QUATERNARY FAULTS; EAST CANYON, MOAB, JOES VALLEY, AND WASATCH FAULT SEGMENT BOUNDARIES

James P. McCalpin., GEO-HAZ Consulting
Crestone, CO, USA, www.geohaz.com



East Canyon graben lies between East Canyon Dam (blue) and Echo Dam (red). Filled with 1000 m of Norwood Tuff (Olig. 29 Ma) downdropped into Wasatch Fm. (Paleocene-Eocene). Geol from Bryant, 1990; X-section line goes E-W between stars. USBR trenched Main Canyon fault in 2006.

Bryant considered the East Canyon fault (W margin of graben) as master fault (backslip on thrust), whereas Main Canyon fault (E margin of graben) dies out in Preuss evaporites (Jsp; flowed into a large space). If so, MCF is rootless and not seismogenic.



Late Quaternary Faulting in East Canyon Valley, Northern Utah

by Lucille A. Piety, Larry W. Anderson, and Dean A. Ostenaa

the east-flowing drainages, which were ponded temporarily along the fault. The trench exposed a record of two faulting events during the past 30,000 to 38,000 years, but the difference in the stratigraphic units on opposite sides of the fault did not allow for an estimate of the amount of displacement. Age estimates based on luminescence and radiocarbon analyses, supported by an assessment of soil development, indicate that the most recent surface-rupturing earthquake likely occurred shortly before 5000 to 6000 years ago, but could be as old as 10,000 to 12,000 years ago.

Recurrent late Pleistocene and Holocene displacement on the Main Canyon fault is consistent with faulting histories determined for other northerly trending, mostly down-to-the-west normal faults east of the Wasatch Range in north-central Utah. Although the overall geomorphology and the trenching results indicate recurrent late Quaternary surface rupturing earthquakes associated with the Main Canyon fault, the East Canyon fault lacks evidence for late Quaternary or Quaternary surface faulting, which suggests that such activity has not occurred or has occurred at a very low rate. Finally, geology and geomorphology suggest that the Main Canyon fault has not had recurrent displacement throughout the late Cenozoic, but instead became active only during the past few million years.

p. 21, “A trench was excavated across one of these scarps in order to determine if the scarp has a tectonic origin and to estimate the age of any fault displacements.”

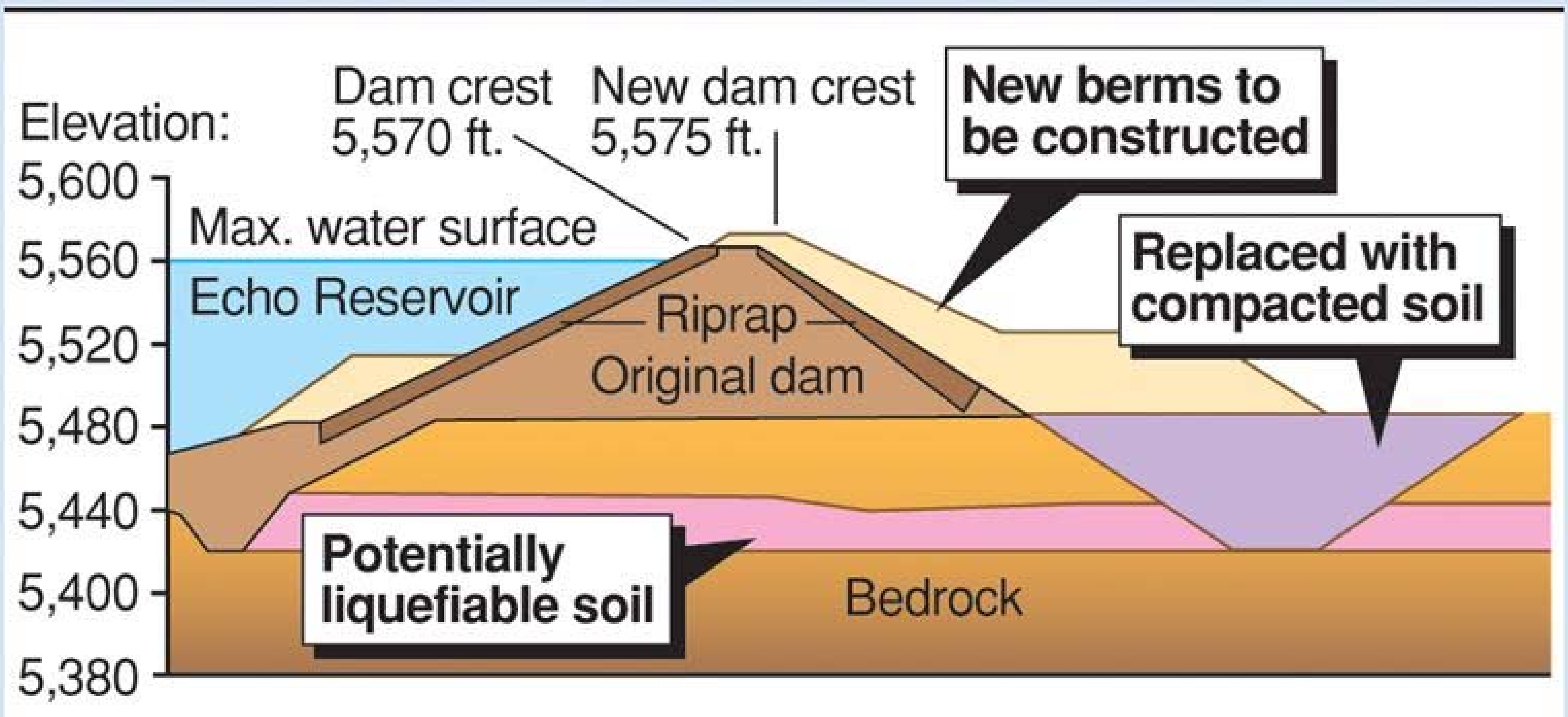
NOTE: the report nowhere mentions evaporites or the Jurassic Preuss formation, nor the cross-section of Bryant (1990) There is no description of how a tectonic origin would be distinguished from a non-tectonic origin, what the non-tectonic origin might be, and what criteria would be used

p. 39, CONCLUSIONS: “…Exposures in the trench confirm that the scarps along the northern Main Canyon fault have a tectonic origin, and were likely formed by recurrent surface-faulting events generated by earthquakes.”

Loose Ends: 1-If the MCF is antithetic to the ECF, why would it have late Q tectonic slip without any on the ECF? 2- Why are the late Q scarps only found in one small part of the MCF?

2008, USBR conc that MCF is Seismogenic; 2010, UGS publishes report; 2012, USBR begins $50M retrofit of Echo Dam (see below), to withstand M6.5 EQ on MCF.

The Bureau of Reclamation is modifying Echo Dam and spillway to meet current seismic standards:



Source: U.S. Bureau of Reclamation

Q: what was the seismogenic criterion? Was it reliable?

- 2003- met Francisco Gutierrez, Univ. of Zaragoza evaporite karst expert in Colo; made 1st trip to Spain to test paleoseismic trenching techniques for studying sinkhole chronologies
- 2006- start collaboration with Gutierrez and students to see whether Quat surface faulting from salt tectonics shows episodic or creep in trenches

Gutierrez, F., Carbonel, D. Guerrero, J., **McCalpin, J.P.**, Linares, R., Roque, C. and Zarroca, M., 2012, Late Holocene episodic displacement on fault scarps related to interstratal dissolution of evaporates (Teruel Neogene Graben, NE Spain): Journal of Structural Geology, v. 34, no. 1, p. 2-19 42.

Carbonel, D., Gutiérrez, F., Linares, R., Roqué, C., Zarroca, M., **McCalpin, J.**, Guerrero, J., and Rodríguez, V., 2013, Differentiating between gravitational and tectonic faults by means of geomorphological mapping, trenching and geophysical surveys. The case of the Zenzano Fault (Iberian Chain, N Spain): Geomorphology, v. 189, p. 93–108.

Carbonel, D., Rodriguez, V., Gutierrez, F., **McCalpin, J.**, Linares, R., Roque, C., Zarroca, M., Guerrero, J. and Sasowsky, I., 2014, Evaluation of trenching, ground-penetrating radar (GPR), and electrical resistivity tomography (ERT) for sinkhole characterization: Earth Surf. Proc. Landforms, v. 39, no. 2, p. 214-227

Guerrero, J., **Bruhn, R.L.**, **McCalpin, J.P.**, Gutierrez, F., **Willis, G**. and Mozafari, M., 2014, Salt-dissolution faults versus tectonic faults from the case study of salt collapse in Spanish Valley, SE Utah (USA): Lithosphere, First published online December 11, 2014, doi: 10.1130/L385.1

Gutierrez, F., Carbonel, D., Kirkham, R.M., Guerrero, J., Lucha, P. and Matthews, V., 2014, Can flexural-slip faults related to evaporite dissolution generate hazardous earthquakes? The case of the Grand Hogback monocline of west-central Colorado: Bull. Geol. Soc. Amer., First pub online June 23, 2014, doi: 10.1130/B

Carbonel, D., Rodriguez-Tribaldos, V., Gutierrez, F., Galve, J.P., Guerrero, J., Zarroca, M., Roque, C., Linares, R., **McCalpin, J.P.**, and Acosta, E., 2015, Investigating a damaging buried sinkhole cluster in an urban area (Zaragoza city, NE Spain) integrating multiple techniques; geomorphological surveys, DInSAR, DEMs, GPR, ERT, and trenching: Geomorphology, v. 229, p. 3-16.

Salt-dissolution faults versus tectonic faults from the case study of salt collapse in Spanish Valley, SE Utah (USA)

Jesús Guerrero[1,*], Ronald L. Bruhn[2], James P. McCalpin[3], Francisco Gutiérrez[1], Grant Willis[4], and Morteza Mozafari[5]
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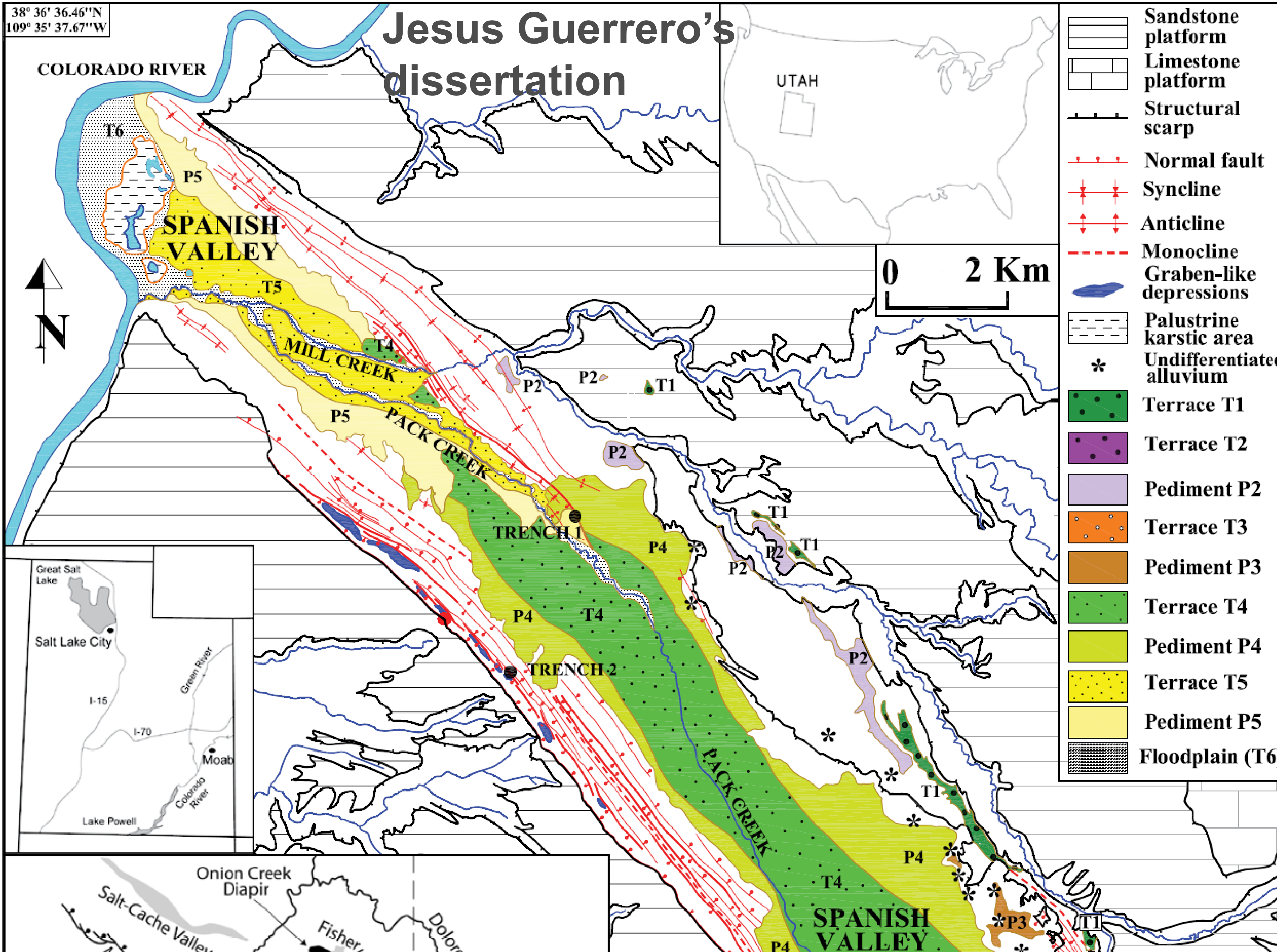
[2]DEPARTMENT OF GEOLOGY AND GEOPHYSICS, UNIVERSITY OF UTAH, SALT LAKE CITY, UTAH 84112, USA
[3]GEO-HAZ CONSULTING INC., 600 E GALENA AVENUE, CRESTONE, COLORADO 81131, USA
[4]1594 WEST NORTH TEMPLE, P.O. BOX 146100, SALT LAKE CITY, UTAH 84114-6100, USA
[5]DEPARTMENT OF EARTH SCIENCES, COLLEGE OF SCIENCES, SHIRAZ UNIVERSITY, 71454, SHIRAZ, IRAN

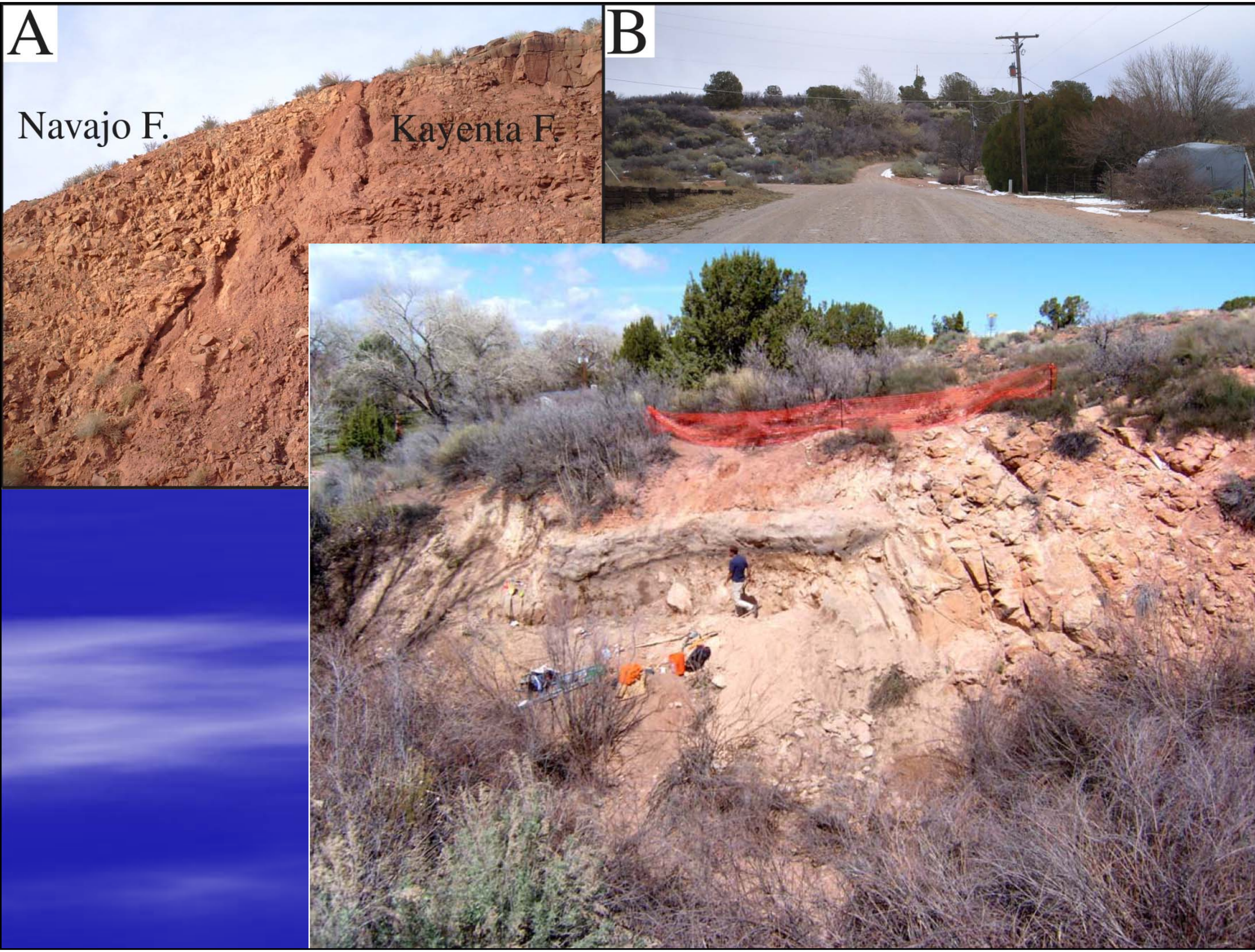
LITHOSPHERE; v. 7; no. 1; p. 46–58; GSA Data Repository Item 2015020 | Published online 11 December 2014 doi:10.1130/L385.1

Jochems, A.P. and Pederson, J.L., 2015, Active salt deformation and rapid transient incision along the Colorado Rover near Moab, Utah: JGR Earth Surf., First pub online April 2015, doi:10.1002/2014JF003169

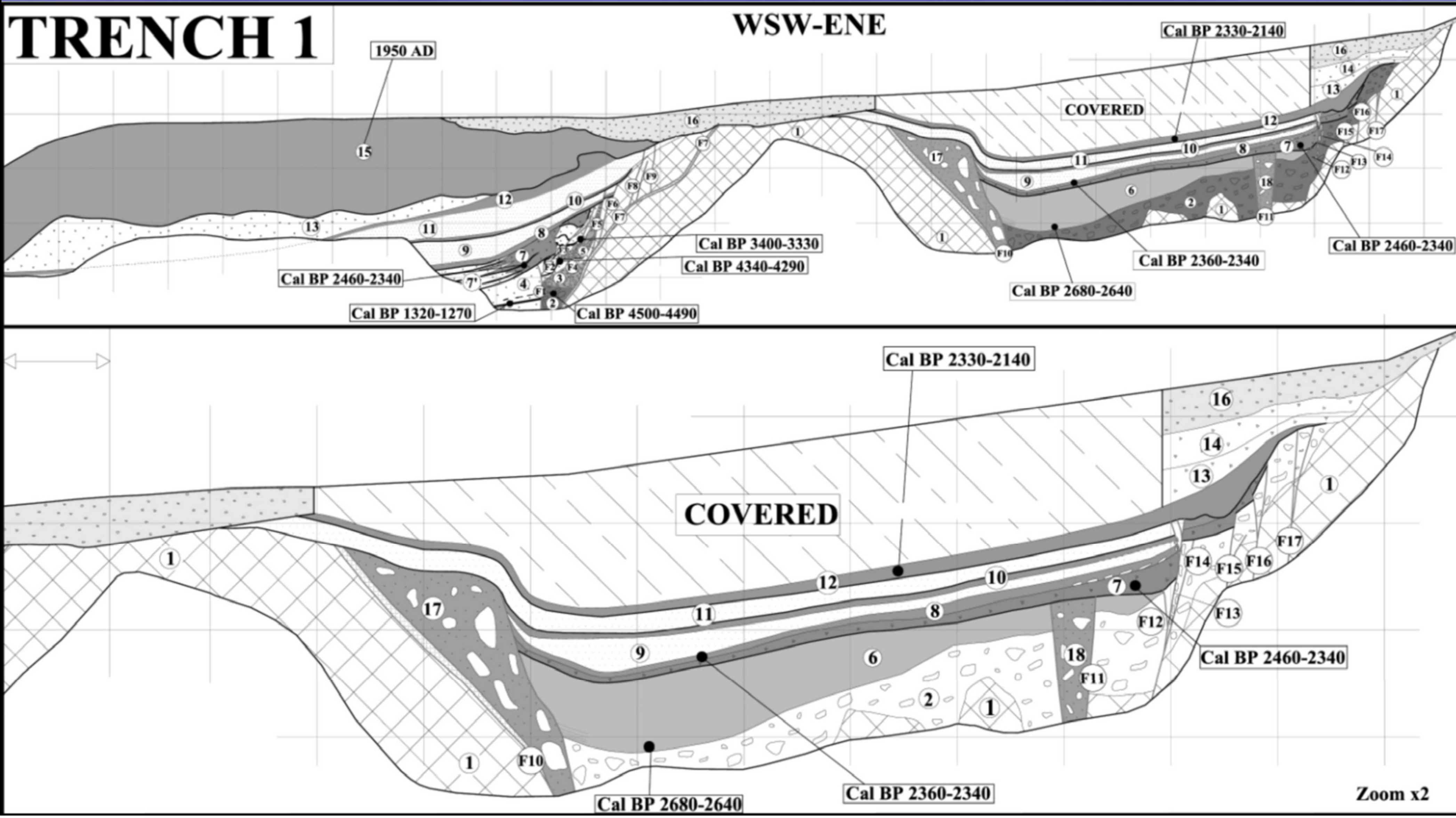
My suspicion: even if the extension beneath a fault was caused by continuous flow/dissolution, the fault plane must ascend thousands of feet of brittle rock to reach the surface. There, fault friction will impose a stick-slip regime, so surface faulting will be episodic. Just like coseismic ruptures.

Jesus Guerrero's dissertation

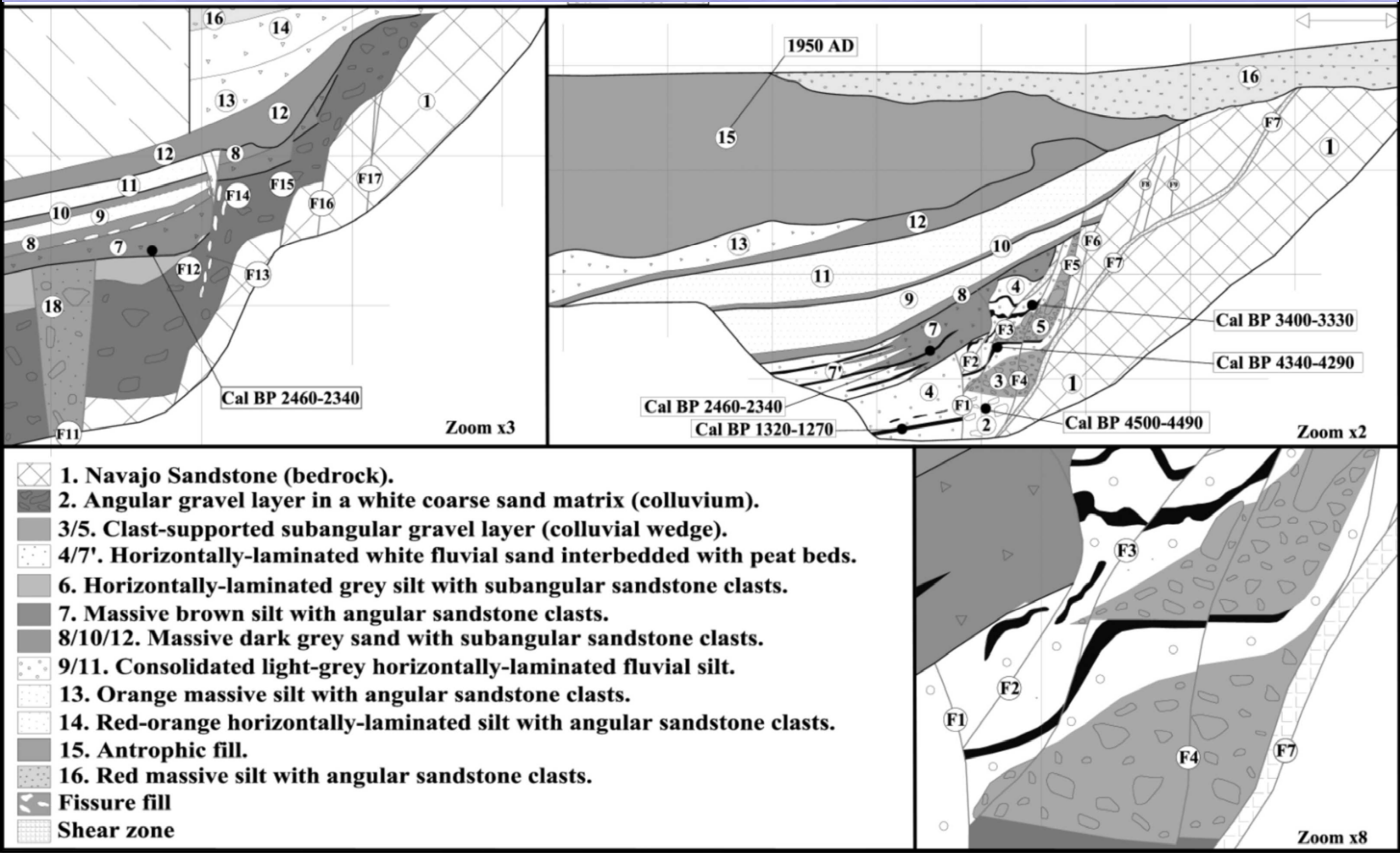


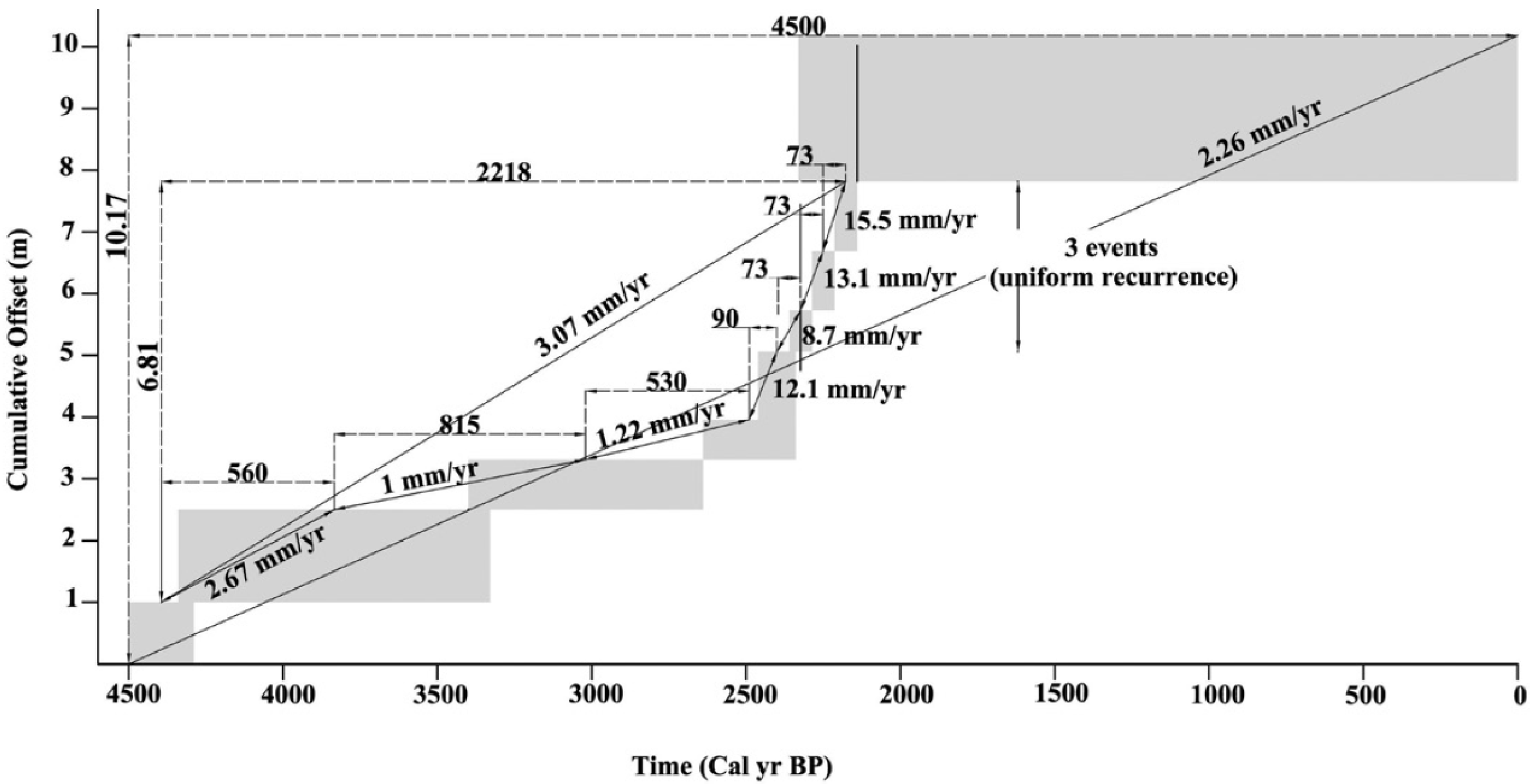

A
Navajo F.
Kayenta F.
B

The most recent event, or MRE (event Z), occurred after 2330 cal yr B.P. and affected the youngest dated unit in both grabens (unit 12). In the upper graben, movement along faults F10, F16, and F17 was accommodated by ductile deformation and the development of monoclinal drape folds at both margins of the graben

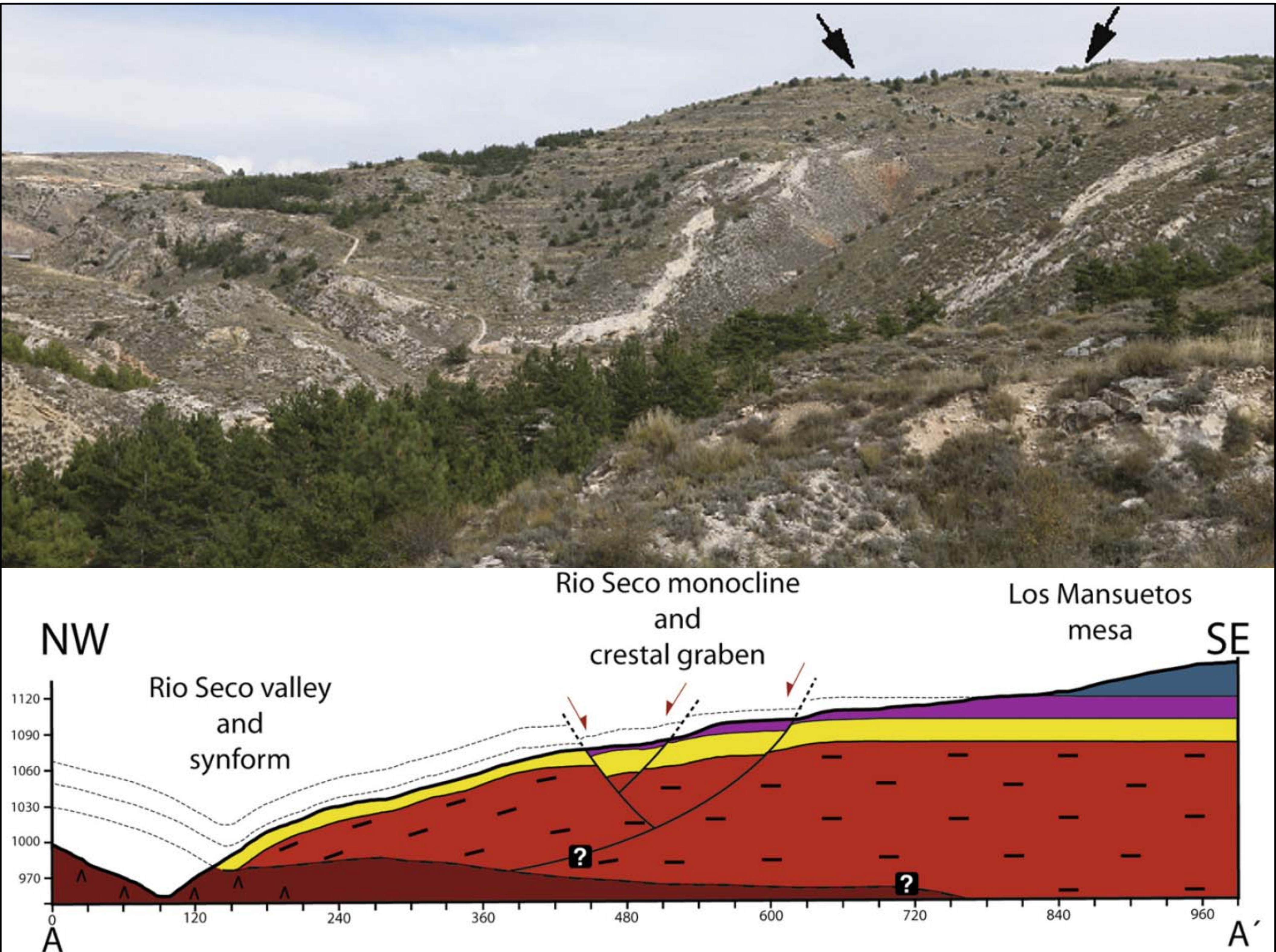


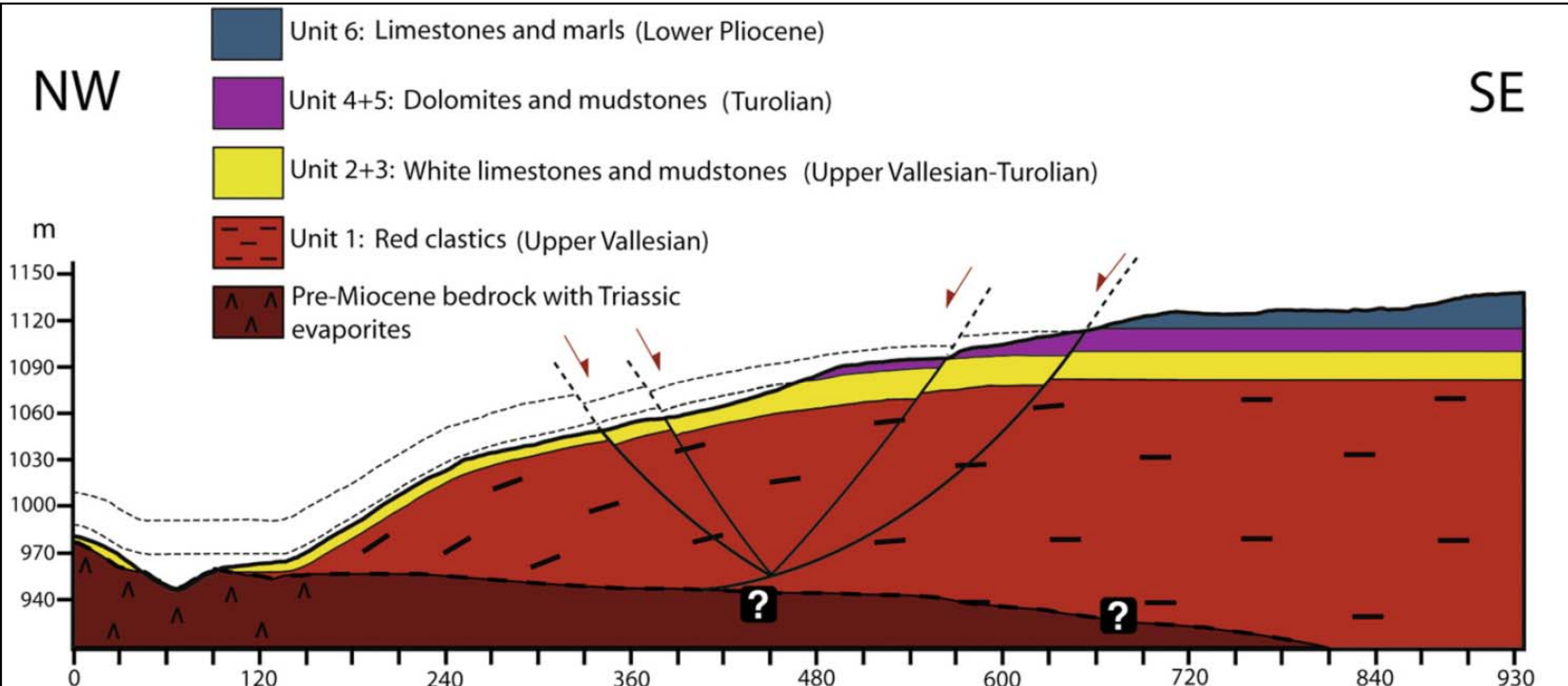
Lower graben; dragging along F7 tilted unit 13 and older. Assuming a syndepositional dip of 2° for unit 12 (=lowest present-day slope), yields minimum net vertical displacement due to tilting of 2.36 m, which is significantly greater than that of all previous events. It is possible this ductile deformation was caused by two or more events.



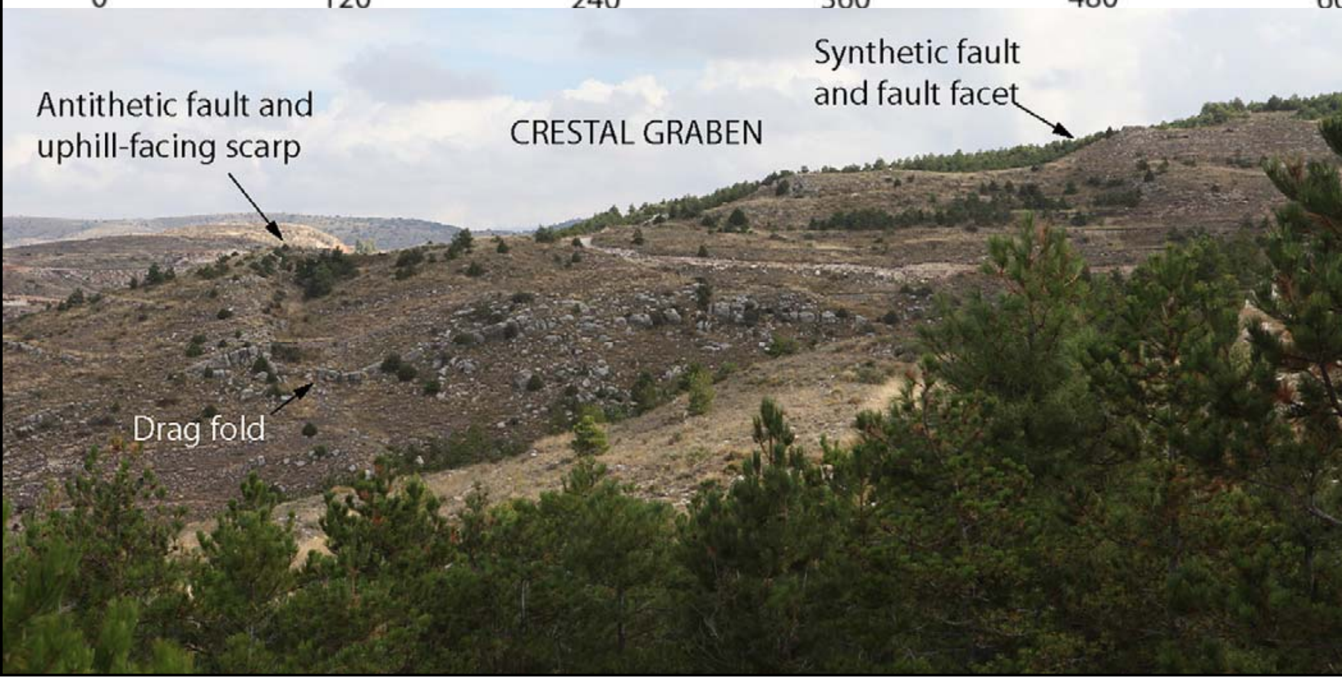


Slip history diagram of seven closed. Most slip rates are derived from minimum displacement values and are thus minimum estimates. Gray areas represent maximum length of every cycle with 2σ uncertainties. Uniform recurrence is assumed for the last three displacement cycles, all constrained by the same bracketing ages (2140–2360 cal yr B.P.). VERY SHORT RECURRENCE, VERY HIGH SLIP RATES, compared to other B&R tectonic faults


Rio Seco monocline
and
crestal graben
Los Mansuetos
mesa
NW
SE
Rio Seco valley
and
synform
1120
1090
1060
1030
1000
970
0
120
240
360
480
600
720
840
960
A
A´

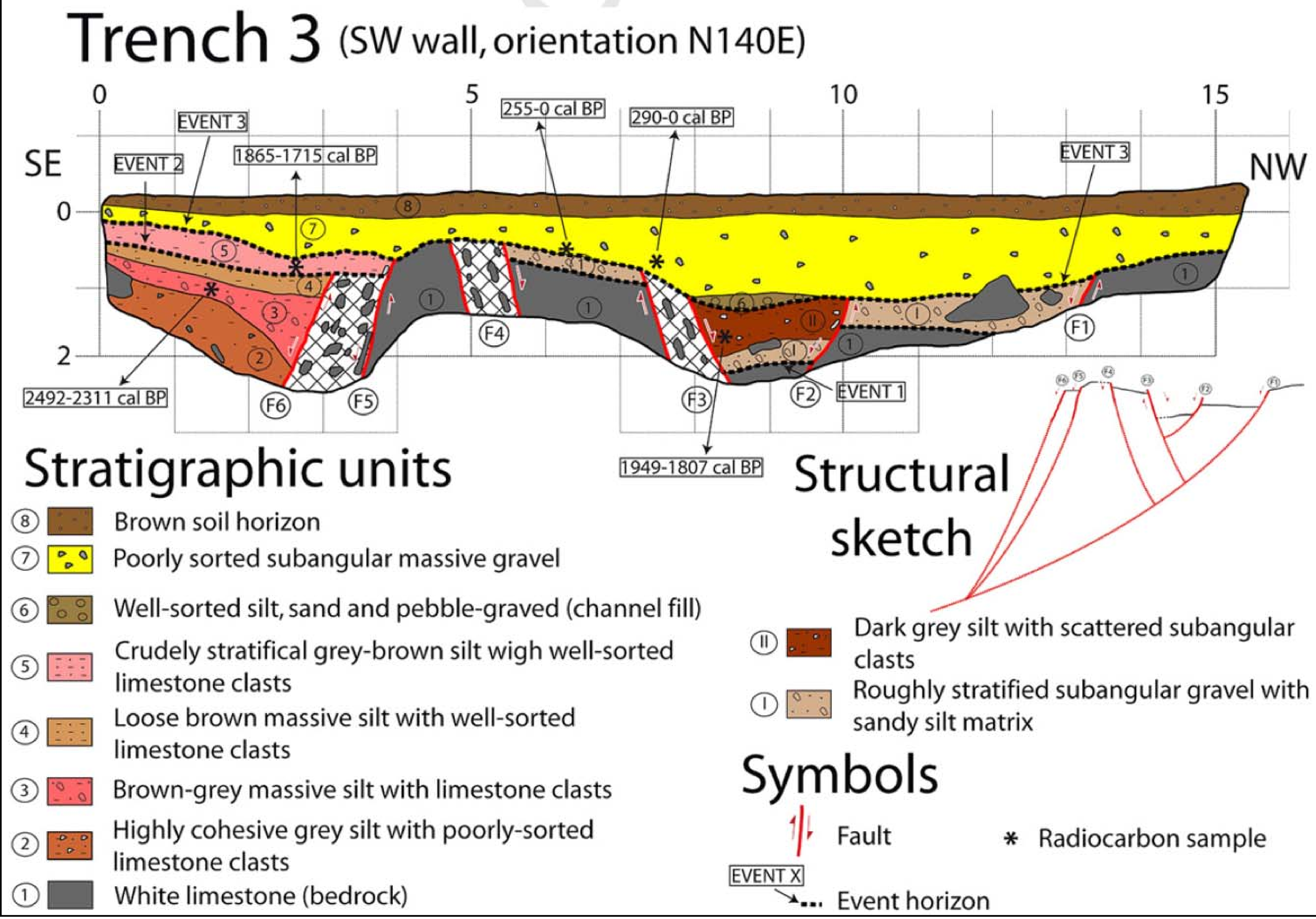


B′



Fault scarps are very fresh, offset young colluvium and ponded sediments.

Upward terminations at various strat levels; ang unconf=EPISODIC



Can flexural-slip faults related to evaporite dissolution generate hazardous earthquakes? The case of the Grand Hogback monocline of west-central Colorado

Francisco Gutiérrez[1,†], Domingo Carbonel[1], Robert M. Kirkham[2], Jesús Guerrero[1], Pedro Lucha[3], and Vincent Matthews[4]

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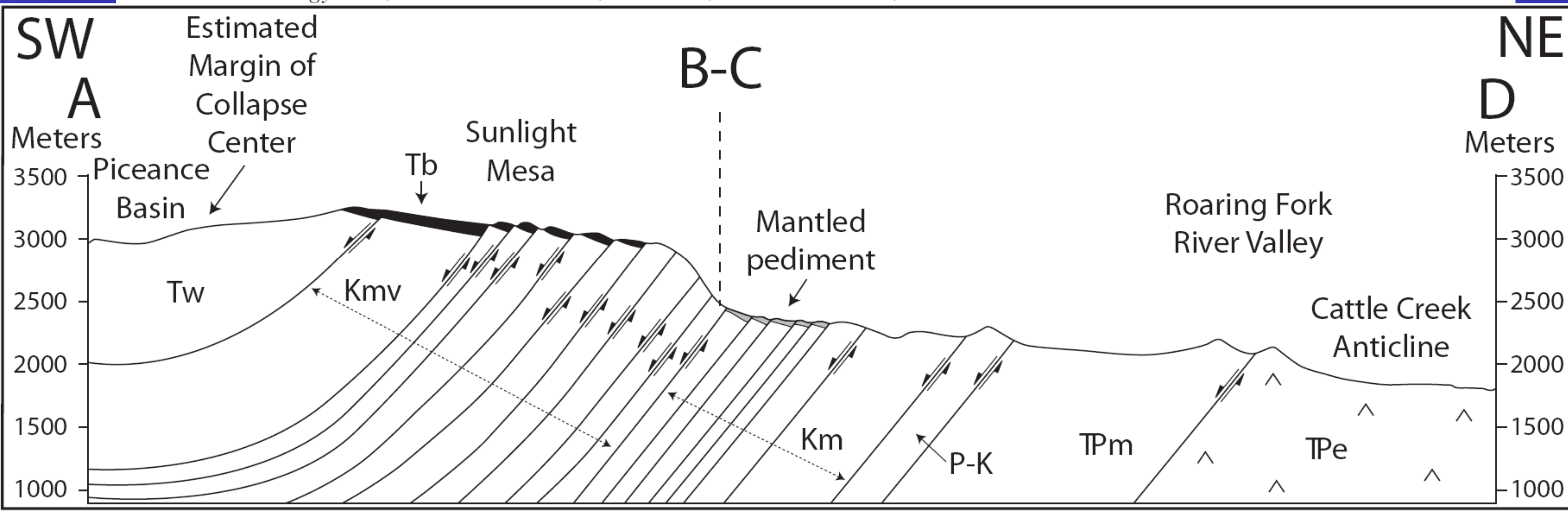
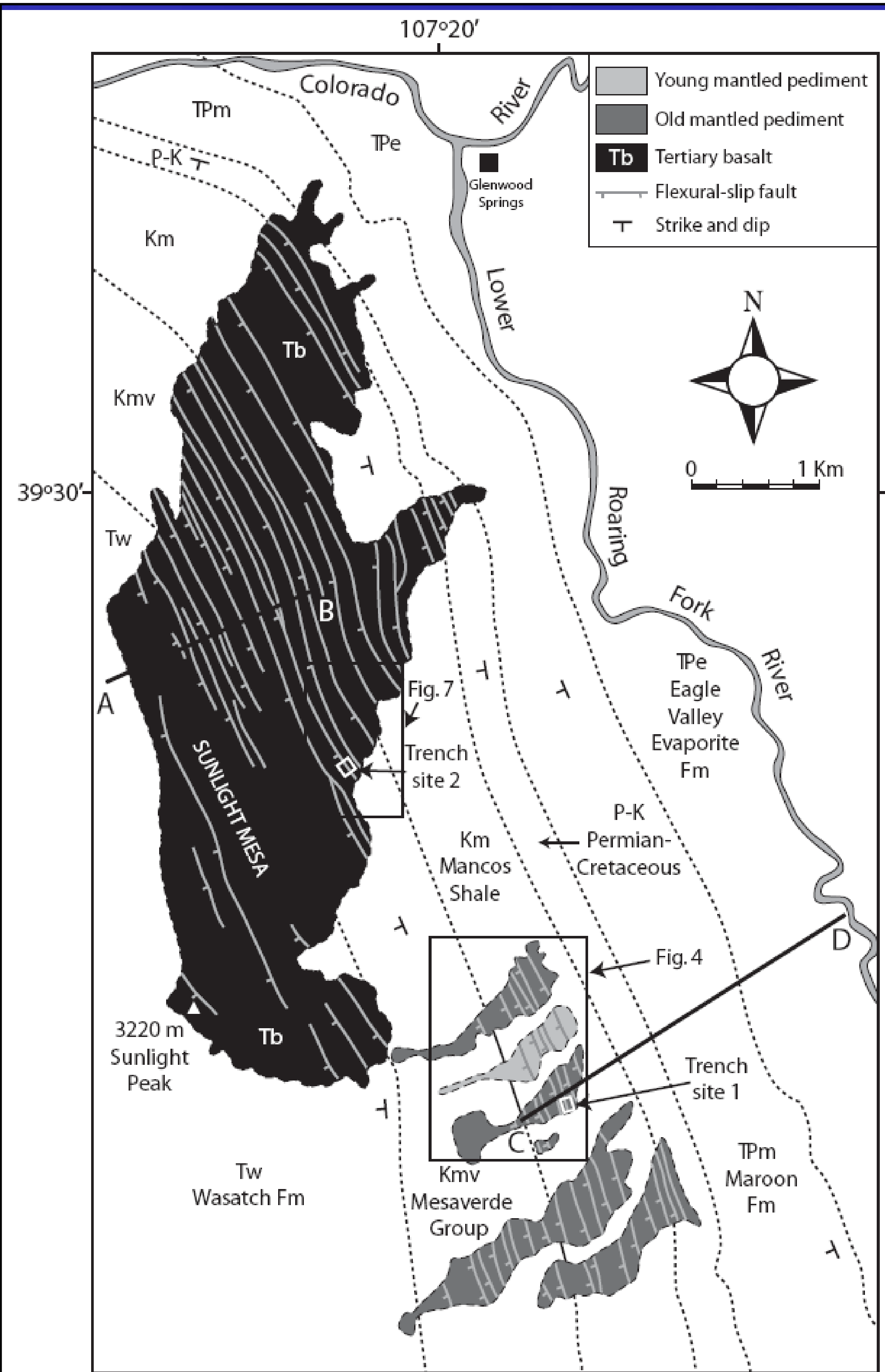
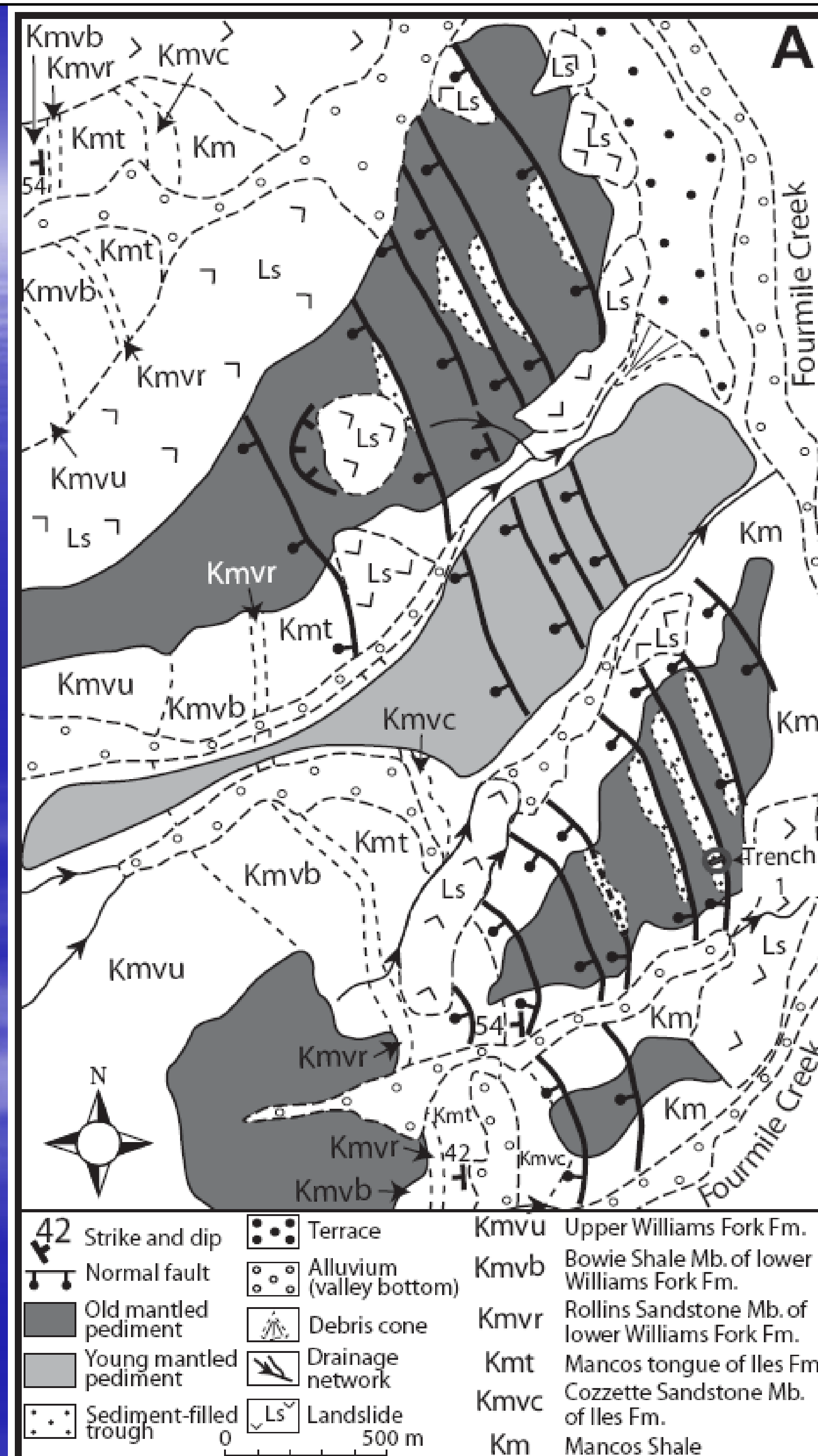
[2]*GeoLogical Solutions, 5253 County Road 1 South, Alamosa, Colorado 81101, USA*
[3]*Departamento de Didáctica de las Ciencias Experimentales, Universidad de Zaragoza, C/. San Juan Bosco 7, 50009 Zaragoza, Spain*
[4]*Leadville Geology LLC, 519 West 7th Street, Leadville, Colorado 80461, USA*



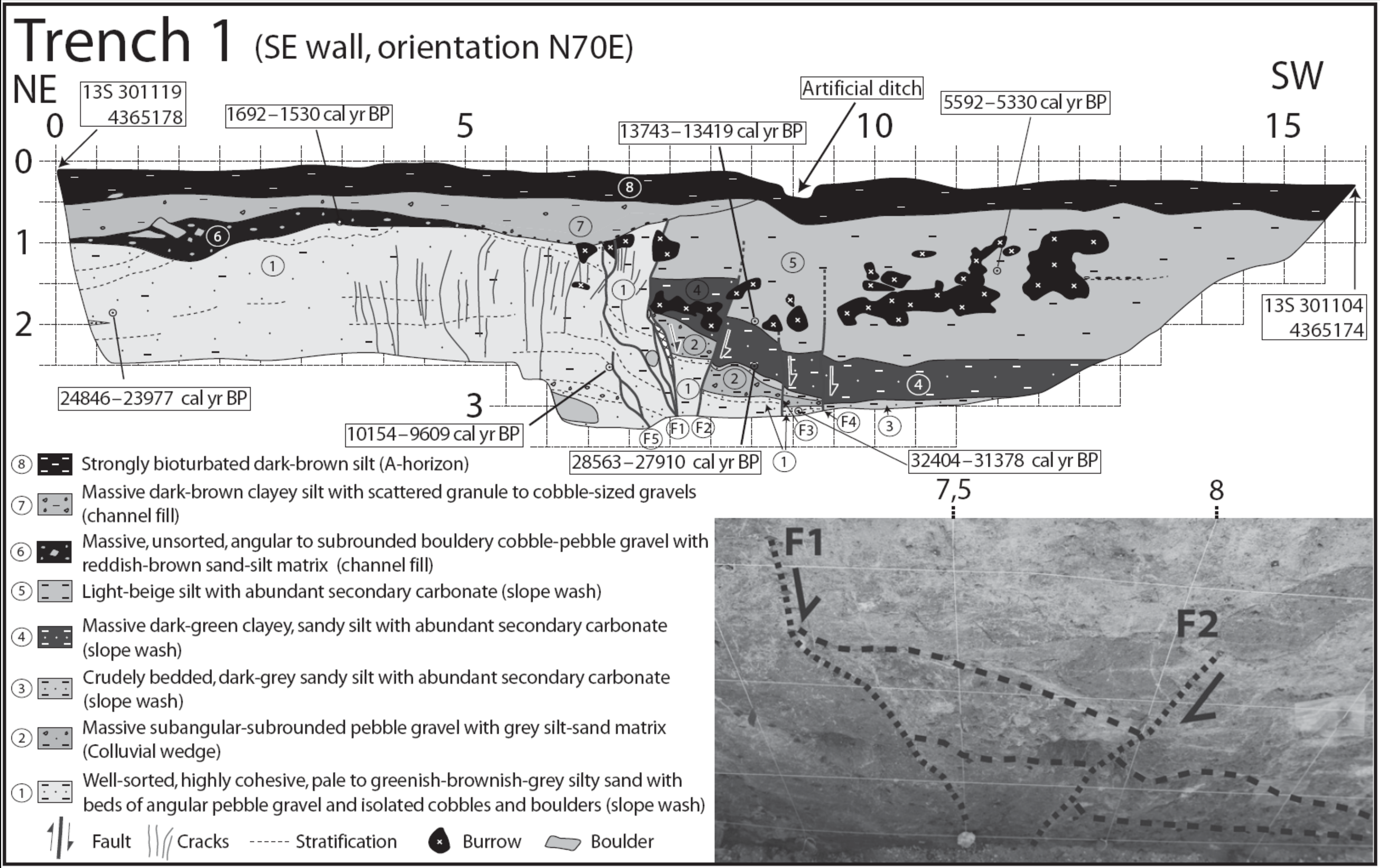
10 Ma basalts on eroded monocline core are displaced by ~40 antislope fault scarps, up to 90 m high. Scarps formed by normal flexural slip on bedding planes in Km and Kmv. Faults represent post -0 Ma extensional "unfolding" of the monocline, due to dissolution/volume loss of Tpe evaporites (Eagle Valley Fm). Known since 1996.



107°20′
39°30′
Young mantled pediment
Old mantled pediment
Tb Tertiary basalt
Flexural-slip fault
Strike and dip
Colorado River
Glenwood Springs
Lower Roaring Fork River
0 1 Km
N
TPm
TPe
P-K
Km
Kmv
Tw
Tb
SUNLIGHT MESA
B
A
Fig. 7
Trench site 2
TPe Eagle Valley Evaporite Fm
P-K Permian-Cretaceous
Km Mancos Shale
Fig. 4
D
Trench site 1
C
3220 m Sunlight Peak
Tw Wasatch Fm
Kmv Mesaverde Group
TPm Maroon Fm



A
Kmvb
Kmvr
Kmvc
Kmt
Km
54
Ls
Kmvu
Fourmile Creek
Trench 1
42
N
Strike and dip
Normal fault
Old mantled pediment
Young mantled pediment
Sediment-filled trough
Terrace
Alluvium (valley bottom)
Debris cone
Drainage network
Landslide
0 500 m
Kmvu Upper Williams Fork Fm.
Kmvb Bowie Shale Mb. of lower Williams Fork Fm.
Kmvr Rollins Sandstone Mb. of lower Williams Fork Fm.
Kmt Mancos tongue of Iles Fm.
Kmvc Cozzette Sandstone Mb. of Iles Fm.
Km Mancos Shale

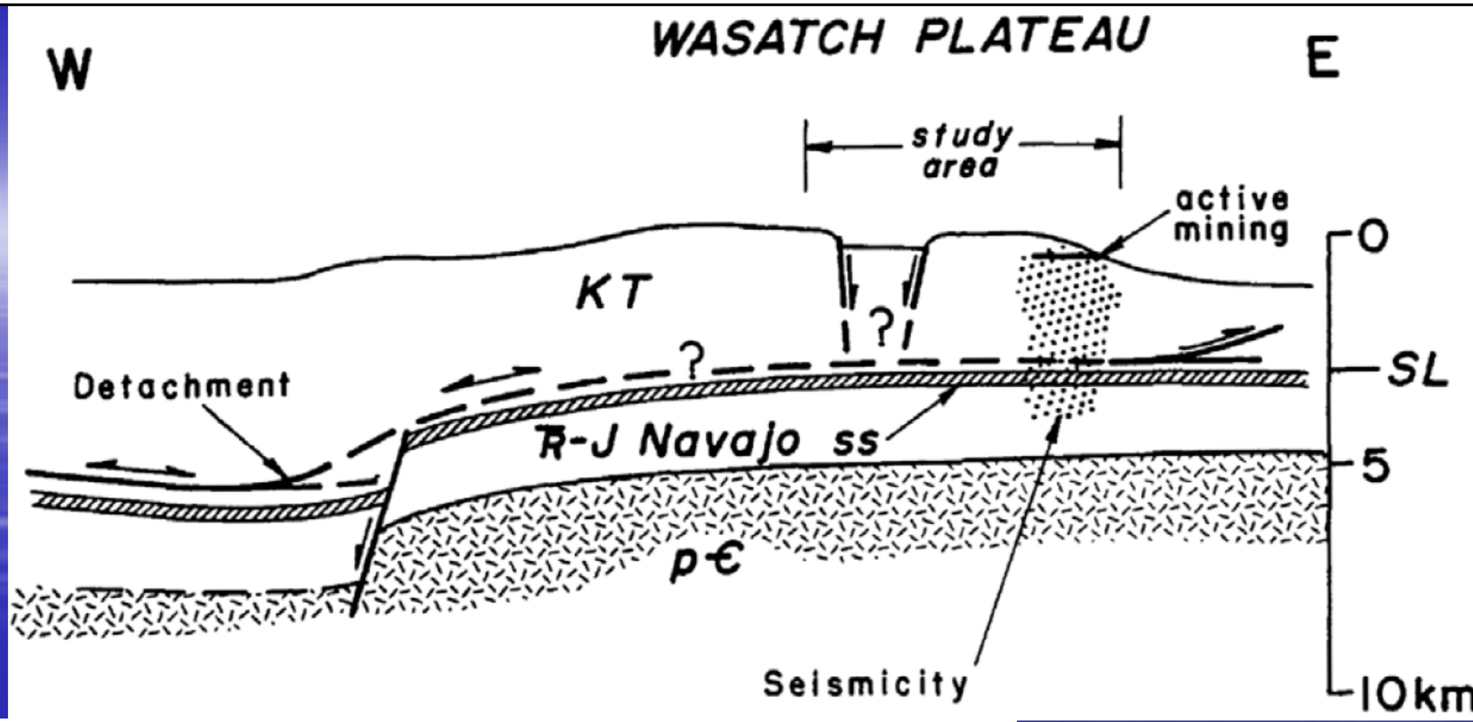


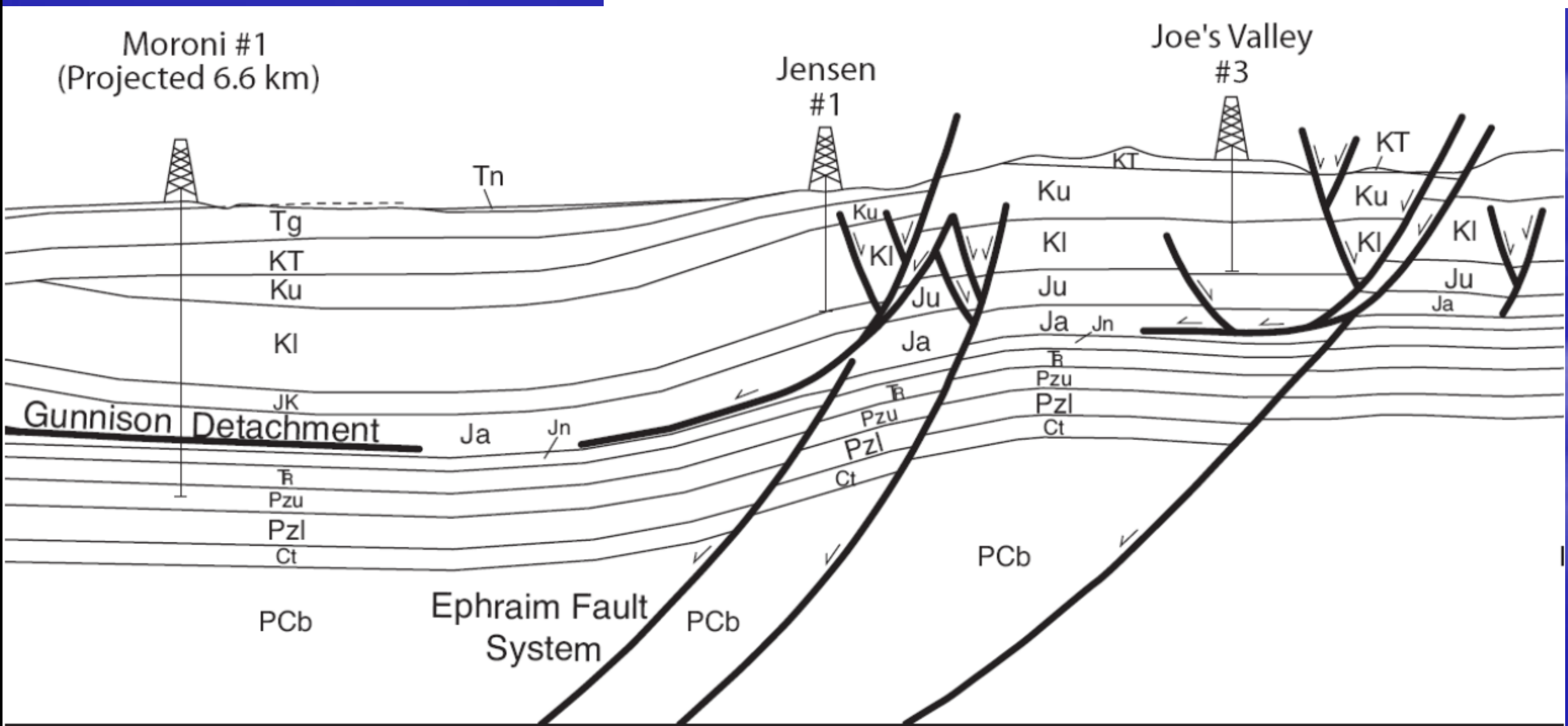
"Evidence of these abrupt surface rupture events include a faulted colluvial wedge, upward fault truncations, and sharp angular unconformities...This contrasts with our expectation of finding evidence of slow creep displacement in the trenched deposits (e.g., cumulative wedge-outs) related to progressive, dissolution-induced unfolding of the monocline." BUT does abrupt=seismogenic??

- “Kelsey et al. (2008) found independent geomorphic, paleoseismic, and stratigraphic evidence in the Seattle fault zone indicating that bedding-plane faults in a fault-bend fold associated with a major thrust may behave as independent seismic sources. They estimate 5.6–6.0 moment magnitude “folding earthquakes” considering 8–10-km long and 4–6-km-deep flexural-slip faults, which eventually might cause surface ruptures…”
- “According to the empirical relationships proposed by Wells and Coppersmith (1994), normal faults 25 km long might produce earthquakes with moment magnitudes as high as Mw = 6.7. Lower values are obtained for these shallow faults with the scaling relationships of the aforementioned authors, considering a downdip width of around 7.5 km as measured between the axis of the syncline of the monocline and the easternmost mapped fault (Fig. 1; Mw = 6.1), and a rupture area (length times downdip width) of 190 km2 (Mw = 6.3).”

- But Wait!
- Wells & Coppersmith, Wesnousky, and Stirling data sets were composed only of normal-faulting earthquakes where:
- 1-the focus was at or near the base of the seismogenic layer (15 km), meaning high confining stress
- 2-most of the area of the slipped fault, based on aftershocks, was in strong basement rocks, meaning high stress drop
- 3- NONE of their surface ruptures resulted from shallow (<6 km focus) earthquakes on bedding-plane faults in very weak sedimentary rocks (means low stress drop)
- 4-So, use of the above data sets and regressions of M on SRL or slip, to estimate magnitude for shallow & rootless faults in weak shales and evaporites, is not supported by any physical model; IT OVERESTIMATES MAGNITUDE
- Kelsey et al (2008) calculated M of Seattle fault (supposedly rootless) from 10 km L, 6 km W, 2 m slip, and typ shear modulus of sed rocks; but based on hypoth X-section

Arabasz, 1986

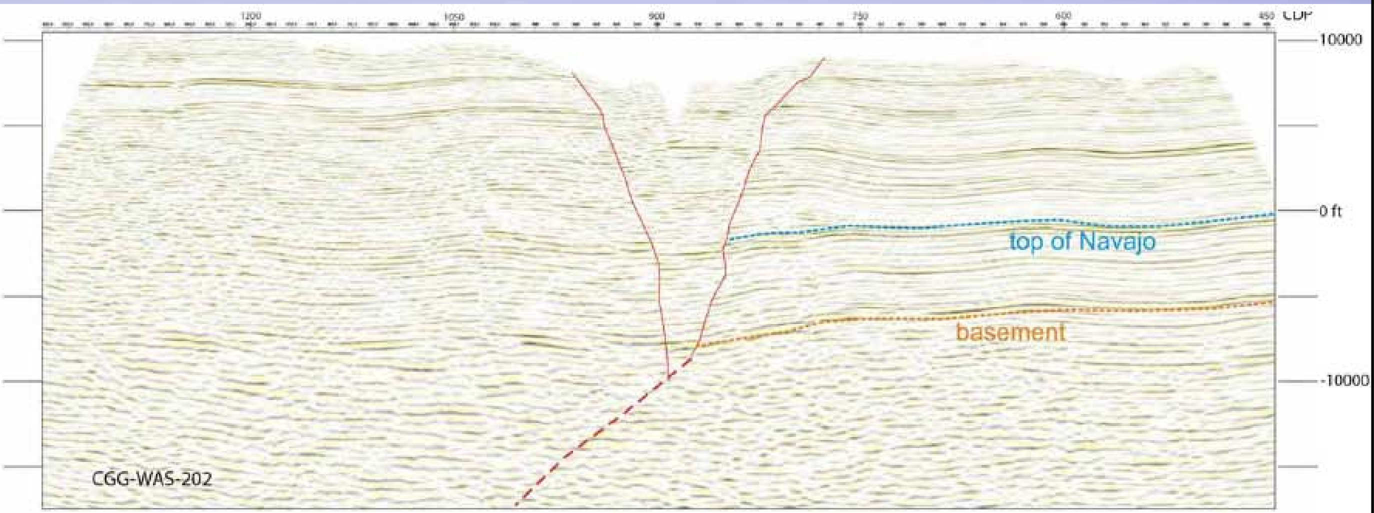


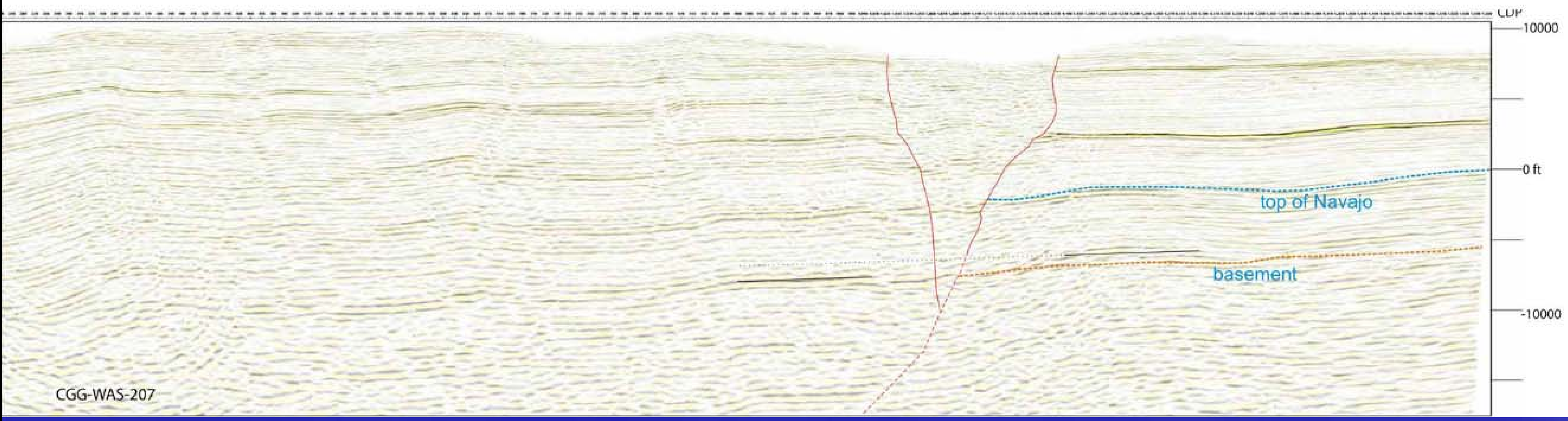


Scherer et al, 2007

Jim Coogan (x-USGS) report to USBR said JV Graben faults did not penetrate below top of Navajo Ss. (blue line)

Industry seismic
Reflection profiles
Across Joes Valley





However, I see disruptions of reflectors between top of Navajo and top of basement (red line), plus some truncations within basement

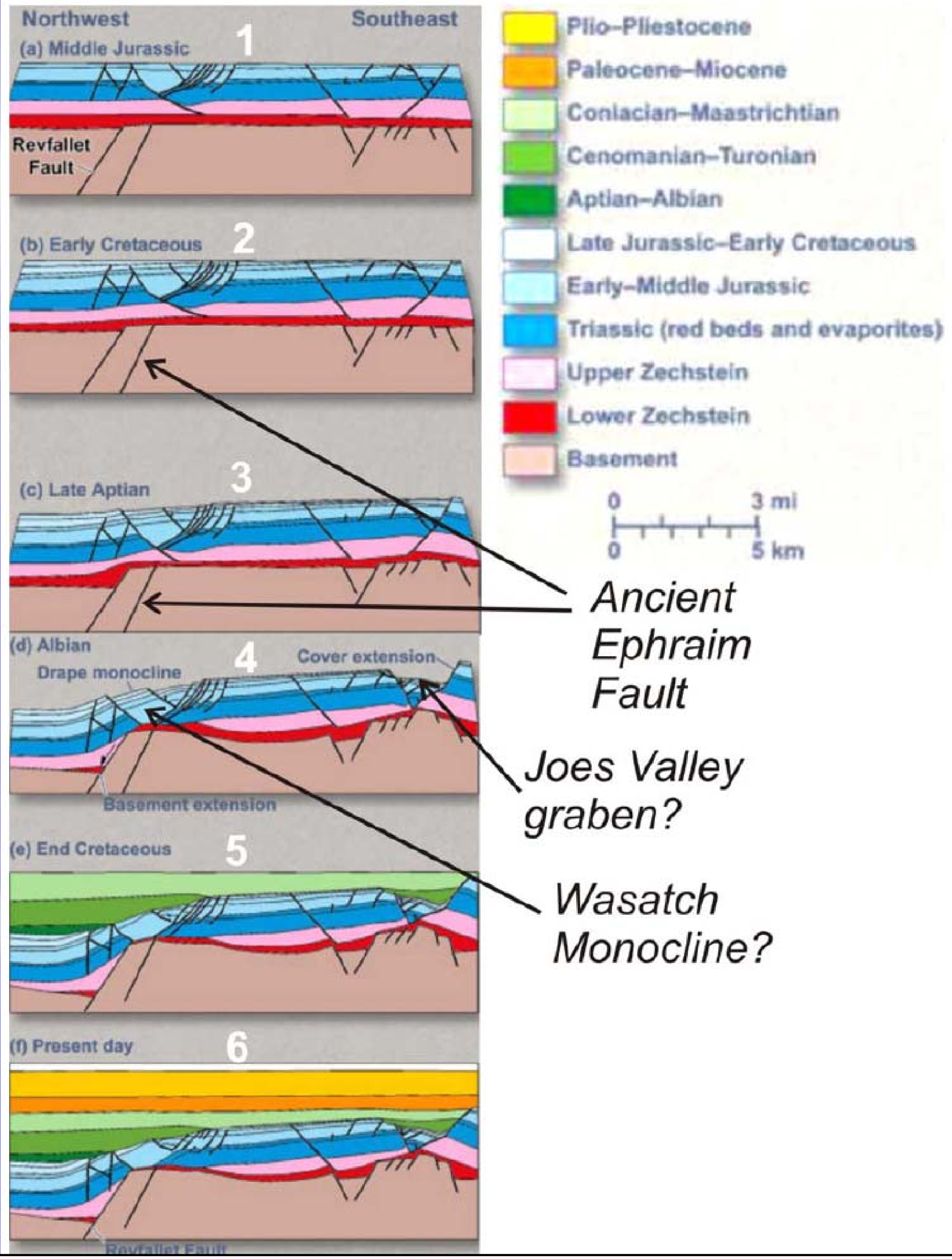
Example of extensional salt detachment (red) formed above a sub-salt, basement normal fault (brown). Revfallet fault, North Sea off Norway, which has several structures similar to those in the Wasatch Plateau:

(1) sub-salt basement fault like the Ancient Ephraim Fault;

(2) drape monocline over the basement fault, like the Wasatch Monocline, and

(3) graben that formed in the footwall above the salt detachment and affects all the strata above the salt, like the Joes Valley graben.

Analog model from Hudec and Jackson, 2012, “Salt Tectonics”, Texas Bur. Econ. Geol. & AAPG



Comparison of Characteristics of the Faults in Joes Valley to Parameters of Faults Associated with Grabens Formed by Tectonic and Salt Deformation Processes; red, strong tectonic; pink, weak tectonic; gray, ambiguous; light blue, weak salt; dark blue, strong salt

Morphologic Parameters

- Fault sinuosity
- Narrowness

Structural Parameters

- Lack of Net Vertical Displacement Across Graben
- Elevations of Footwall and Hanging Wall
- Presence of Evaporites at Shallow Crustal Depths (3 km)
- Presence of Many Intra-Graben Horsts and Blocks and Apparent Absence of Tertiary or Early-Mid Quaternary Deposits in the Graben
- Map Pattern of Oblique Intragraben Faults
- Fault Architecture in Joes Valley
    - Shear Zone Properties
    - Possible Tectonic Folding and Block Toppling
- Fault Architecture of Salt-Deformation Grabens
    - Extensional Salt Detachments
    - Evaporite Dissolution-Collapse Faults
    - ~~Evaporite Gravity-Slide Faults~~
    - Ratio of Fault Displacement to Fault Length
    - Ratio of Fault Damage Zone Width to Fault Displacement

Behavior Parameters

- High Slip Rate Compared to Other Quaternary Faults in Basin and Range Province
- Episodic Displacement Events Versus fault Creep
- Extension Direction of Fault versus GPS Vectors

CONCLUSIONS:

1-Episodic surface faulting has occurred on several structures that are known to be rootless, salt tectonics faults [Moab, Rio Seco]. Thus, episodic displacement cannot be used as a criterion to distinguish crustal tectonic faults from rootless (salt induced) faults [Main Canyon fault, Joes Valley graben].

2-Ductile surface deformation by itself is not evidence for fault creep, because historic normal surface ruptures have created that [monocline in 1983 Borah Peak rupture]. It tells you about style, not rate.

3-It is a mistake to use regression equations from seismogenic faults (Wells & Coppersmith) to estimate possible “earthquake magnitudes” on rootless faults. Coseismic surface ruptures form atop tectonic faults rooted in high-rigidity basement rocks under high confining pressures; slip on rootless faults involves low-rigidity clays or evaporites under low confining pressures [Carbondale flexural slip normal faults].

4-Work is continuing; see INQUA-sponsored “PATA Days” conference in Crestone, CO, May 30-June 3 (www.pata-days.org)

Updated Utah Geological Survey Surface-Fault-Rupture and Other Geologic-Hazard-Investigation and Report Guidelines

William Lund
Utah Geological Survey
Emeritus

The Utah Geological Survey is a non-regulatory state agency with impressive mission, vision, and values statements that anybody who is interested can look up on the UGS webpage at

www.geology.utah.gov

However, bottom line, it's the UGS' job to make Utah richer and safer by investigating and reporting on Utah's geology.

To help make Utah safer, the UGS has long maintained a hazards section devoted specifically to geologic hazards and engineering geology.

The name of the section has changed over the years; today it is known as the *Geologic Hazards Program*, and its principal charge is to investigate, map, and report on Utah's geologic hazards, so that timely, accurate hazards information can be incorporated into land-use-planning and other development decisions.

Early on, it became clear that just because the UGS was making geologic-hazard data available, there was no guarantee that those data would be incorporated in land-use planning and development decisions – and in some instances there was active resistance to doing so.

Because the UGS is non-regulatory, it has no statutory authority to require the use of its hazards data, so beginning in the 1980s, the UGS embarked on a process of education and persuasion to convince geotechnical consultants, municipalities, counties, and other government agencies to put our hazards data to beneficial use.

A key component of the educational process has been publication of a series of engineering-geology-report, geologic-hazard-ordinance, and geologic-hazard-investigation guidelines.

The purpose of the guidelines is to:

- **Protect the health, safety, and welfare of the public by minimizing the adverse affects of geologic hazards.**
- **Assist local governments in regulating land use in hazardous areas and provide standards for geologic-hazard ordinances.**
- **Assist property owners and developers in conducting reasonable and adequate geologic-hazard investigations.**
- **Provide engineering geologists with standardized minimum recommended criteria for performing geologic-hazard investigations and recommending geologic-hazard-mitigation strategies.**
- **Provide an objective framework for the preparation and review of geologic-hazard reports.**

Current UGS Guidelines

- **Engineering Geology Reports –** Association of Engineering Geologists (Utah Section), **1986**, Guidelines for preparing engineering geologic reports in Utah: Utah Geological and Mineral Survey Miscellaneous Publication M, 2 p.

- **Geologic Hazard Ordinances** – Christenson, G.E., **1987**, Suggested approach to geologic hazard ordinances in Utah: Utah Geological and Mineral Survey Circular 79, 16 p.

- **Landslides** – Hylland, M.D., **1996**, Guidelines for evaluating landslide hazards in Utah: Utah Geological Survey Circular 92, 16 p.

- **Surface Fault Rupture** – Christenson, G.E., Batatian, L.D., and Nelson, C.V., **2003**, Guidelines for evaluating surface-fault-rupture hazards in Utah: Utah Geological Survey Miscellaneous Publication 03-6, 14 p.

- **Debris Flows** – Giraud, R.E., **2005**, Guidelines for the geologic evaluation of debris-flow hazards on alluvial fans in Utah: Utah Geological Survey Miscellaneous Publication 05-6, 16 p.

- **Utah School-Site Reports –** Bowman, S.D., Giraud, R.E., and Lund, W.R., **2012**, Utah State Office of Education – Geologic-hazard report guidelines and review checklist for new Utah public school buildings: Utah Geological Survey, online.

By 2014 two things had become clear regarding the UGS guidelines:

- First, the existing guidelines were out of date, or rapidly becoming so, and
- Second, based on the kinds and frequency of damaging geologic-hazard events occurring in Utah, at a minimum, new geologic-hazard-investigation guidelines were required for rockfall hazards and for land-subsidence and earth-fissure hazards related to groundwater mining.

The Geologic Hazard Program began the process of updating existing and preparing new guidelines in 2014.

The decision has been made to consolidate the guidelines as chapters in a single comprehensive guidelines document, rather than to publish each guideline individually as was done in the past.

Drafts of all the guidelines are now complete and are in UGS review, with an anticipated publication date of later this year.

Chapters in the guidelines document include:

- **Chapter 2** – Bowman, S.D. and Lund, W.R., Guidelines for conducting engineering-geology investigations and preparing engineering-geology reports in Utah, 2nd edition
- **Chapter 3** – Lund, W.R., Christenson, G.E., Batatian, L.D., and Nelson, C.V., Guidelines for evaluating surface-fault-rupture hazards in Utah, 2nd edition
- **Chapter 4** – Beukelman, G.S., and Hylland, M.D., Guidelines for evaluating landslide hazards in Utah, 2nd edition
- **Chapter 5** – Giraud, R.E., Guidelines for the geologic investigation of debris-flow hazards on alluvial fans in Utah, 2nd edition
- **Chapter 6** – Lund, W.R., Guidelines for evaluating land-subsidence and earth-fissure hazards in Utah
- **Chapter 7** – Lund, W.R., and Knudsen, T.R., Guidelines for evaluating rockfall hazards in Utah
- **Chapter 8** – Lund, W.R., Bowman, S.D., and Christenson, G.E., Suggested approach to geologic-hazard ordinances in Utah, 2nd edition
- **Chapter 9** – Bowman, S.D., Giraud, R.E., and Lund, W.R., Engineering-geology investigation and report guidelines for new Utah public school buildings, 2nd edition

Chapter 3
Guidelines for Evaluating Surface-Fault-Rupture Hazards in Utah
(2nd Edition)

Lund, W.R.[1], Christenson, G.E.[1], Batatian, L.D.[2], and Nelson, C.V.[3]
[1]Utah Geological Survey, [2]Terracon, Inc., [3]Western GeoLogic, LLC

The UGS published the first edition of its Surface-fault rupture-hazard guidelines in 2003 as Miscellaneous Publication 03-6

Christenson, G.E., Batatian, L.D., and Nelson, C.V., 2003, Guidelines for evaluating surface-fault-rupture hazards in Utah: Utah Geological Survey Miscellaneous Publication 03-6, 14 p.

These guidelines have proven very successful, and have become the standard of practice for surface-fault-rupture investigations performed by geotechnical consultants in Utah. Additionally, several municipalities and counties have incorporated them in whole or in part into their geologic-hazard ordinances.

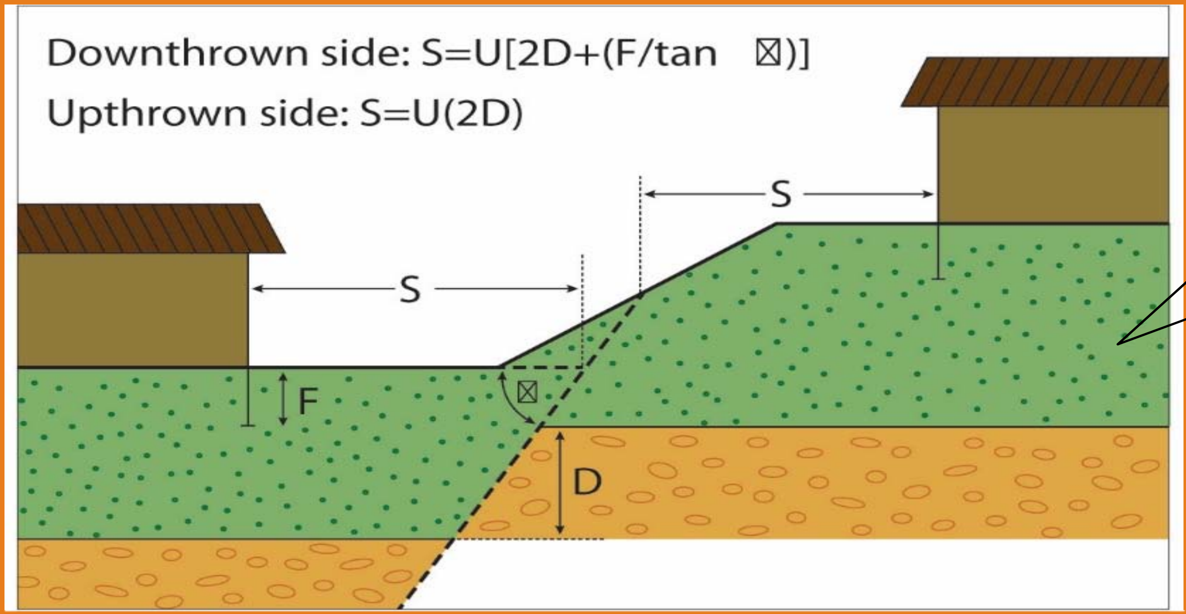
Summary of Christenson and others (1987)

- **Recommends avoidance (setting back) for mitigating surface-fault rupture.**
- **Establishes fault activity classes: Holocene, Late Quaternary, Quaternary**
- **Outlines how to identify faults, conduct surface and subsurface (trenching) investigations, and determine the time of most recent surface faulting.**
- **Provides a method to determine an appropriate fault setback distance either from a table or computed using a formula that accounts for maximum anticipated fault displacement, foundation depth, and building criticality.**
- **Whether a surface-faulting-hazard investigation is performed, depends on fault activity class, building occupancy class, and structure criticality.**
  - **Holocene faults** – investigations recommended for all structures for human occupancy and all critical facilities*.
  - **Late Quaternary** faults – investigations recommended for all critical facilities. Investigations for other structures for human occupancy remain prudent.
  - **Quaternary faults** – investigations recommended for all critical facilities. Investigations of other structures for human occupancy are optional.

***Critical facilities defined as Category II and III structures in the 2000 International Building Code (IBC) and Category III and IV structures in the 2003 IBC. Critical facilities include schools, hospitals, fire stations, high-occupancy buildings, water treatment plants, and facilities containing hazardous materials.**

However, the guidelines are now dated due to the evolving standard of practice in Utah. In particular, subsequent to release of Christenson and others (1987), some Utah jurisdictions have adopted ordinances that permit construction across active faults that show ≤ 4 inches of displacement. Additionally, a special City of Draper "Review Protocol" permits "super-engineered" foundations under limited circumstances to mitigate surface faulting greater than 4 inches. Under the Review Protocol, super-engineered foundations have been approved to accommodate as much as 6 feet of vertical displacement.

Additionally, the debate in California regarding the time period over which surface-faulting hazard should be mitigated, and whether it is necessary to categorically prohibit almost all development across Holocene-active faults regardless of the amount or timing of surface displacement was beginning to echo in Utah.



Method unique in the US and possibly in the world

The fault setback for the downthrown block is calculated using the formula:

$$S = U * \left[2D + \left(\frac{F}{\tan\theta}\right)\right]$$

where:

S = Fault setback distance in feet within which buildings are not permitted.

U = Criticality factor, based on IBC Building Occupancy class (table 6).

D = Expected maximum fault displacement in feet per earthquake (maximum vertical displacement)

F = Maximum depth of footing or subgrade portion of the building in feet.

θ = Dip of the fault (degrees).

The fault setback for the upthrown side of the fault is calculated as:

$$S = U * (2D)$$

Lund and others (2016)

Both updates and expands upon Miscellaneous Publication 03-6

- Fault setback parts of the guidelines are updated to incorporate recent advances in geologic understanding and the state of geotechnical practice.

- Investigation Methods, Surface-Faulting Investigation Report, and Field Review and Report Review sections updated.

- New sections added to expand the guidelines
  - Characterizing fault activity
  - Sources of paleoseismic information
  - Sub-lacustrine faults
  - Surface deformation from slip on a buried fault
  - Paleoseismic data required for engineering-design mitigation of surface faulting
  - Hazardous fault criteria
  - Disclosure

Updates

- **Fault activity class definitions updated after WSSPC (2011)**
  - **Holocene fault –** changed from 10,000 to 11,700 yr B.P.
  - **Late Quaternary –** fault remains unchanged at 130,000 yr B.P.
  - **Quaternary fault –** changed from 1.6 million to 2.6 million yr B.P.
- **IBC (2012) *Risk Category of Building and Other Structures* replaces IBC (2000) *Occupancy Classifications* in the minimum fault setback table. Surface-faulting investigations are now tied directly to risk.**
  - **Holocene faults** – investigation recommended for all structures for human occupancy and all IBC Risk Category II(a), II(b), III, and IV structures.
  - **Late Quaternary faults** – investigation recommended for all IBC Risk Category II(b), III, and IV structures; studies for IBC Risk Category II(a) and other structures for human occupancy remain prudent.
  - **Quaternary faults** - investigation recommended for all IBC Risk Category III and IV structures; studies for IBC Risk Category II(b) structures and other structures for human occupancy remain prudent because a low likelihood of surface faulting still exists.

Updates

- Investigation Methods section – expanded and updated to reflect current state of practice.
- Surface-Faulting Investigation Report section – expanded and updated to reflect current state of practice.
- Field Review and Report Review sections updated to reflect current state of practice.

Addition
Characterizing Fault Activity

Describes the fault parameters required to adequately characterize fault activity, particularly for engineering-design mitigation of surface faulting and for defining hazardous faults.

- **Rupture complexity – width and distribution of faulting and associated deformed land.**
- **Earthquake timing and recurrence – paleoearthquake timing, average recurrence interval, and variability (uncertainty) in paleoearthquake timing and average recurrence.**
- **Displacement – surface displacement associated with normal-slip faults in Utah.**
- **Slip rate – fault displacement normalized over time, open and closed slip rates.**

Additions

Sources of Paleoseismic Information

Directs guideline users to best current sources of paleoseismic information for Utah.

- **UGS Paleoseismology of Utah series (currently 27 volumes)**
- **UGS Quaternary Fault and Fold Database of Utah**
- **Utah Quaternary Fault Parameters Working Group annual meeting summaries posted on the UGS website**
- **Lund, W.R., 2014, HAZUS loss estimation software earthquake model revised Utah fault database – Updated through 2013**
- **Lund, W.R., 2005, Consensus preferred recurrence-interval and vertical slip-rate estimates - review of Utah paleoseismic-trenching data by the Utah Quaternary Fault Parameters Working Group**
- **Extensive reference list of all paleoseismic studies published for Utah through 2015.**

Addition

Sub-Lacustrine Faults

Acknowledges the presence of and summarizes what is known about sub-lacustrine faults in Utah (Great Salt Lake fault, Carrington fault, Utah Lake faults).

- **Potential source of large earthquakes.**
- **No known sub-aerial exposures so minimal/no surface-faulting hazard.**
- **Potential source of tsunamis on Great Salt Lake and Utah Lake.**

Surface Deformation from Slip on a Buried Fault

Surface deformation caused by a buried fault typically lacks a discrete zone of displacement at the surface and may be many feet wide. It is not possible to establish a standardized method of setting back from such faults. The UGS recommends that the engineering geologist in charge of the surface-faulting investigation for such faults make and justify an appropriate mitigation recommendation based on the results of a site-specific hazard investigation.

Addition

Engineering-Design Mitigation of Surface Faulting

Developing across an active (hazardous) fault requires that a structure be designed to withstand the effect of future surface-faulting displacement.

Past surface-faulting displacement at the site must be characterized to establish a reliable design displacement value that will not be significantly exceeded (2σ) during future surface-faulting earthquakes.

Displacement data for normal-slip faults in Utah and world wide show considerable variation in displacement at a point between successive earthquakes. ***Therefore, it can not be assumed that displacement at a point produced by the most recent surface-faulting earthquake is a good predictor of future surface-faulting displacement at the same location.***

Because displacement from a single surface-faulting earthquake does not provide a statistically significant basis for estimating future maximum earthquake displacement at a site, *the UGS recommends for engineering mitigation of surface faulting on normal faults in Utah that*

- **displacement be determined for a minimum of the three most recent surface-faulting earthquakes at the site (more if site geology permits), and**
- **the design displacement values be based on the maximum site-specific displacement observed on the fault including appropriate displacement uncertainty limits.**

Acquiring the adequate displacement data for engineering mitigation of surface faulting will likely require a more detailed and costly paleoseismic investigation than necessary to simply locate and setback from a potentially hazardous fault. Additionally, many sites may not possess the geologic conditions necessary to characterize displacement for a minimum of three paleoearthquakes. *For those reasons, the UGS believes fault setback and avoidance will remain the surface-faulting-mitigation option most frequently employed in Utah.*

Addition
Hazardous Fault Criteria

Some geologists and engineers in California are questioning what constitute a hazardous fault with regard to public health, safety, and welfare. The Holocene criterion used in California (Alquist-Priolo Act) to define an "active" fault has been questioned as unrealistically long when compared to time intervals used to mitigate other kinds of earthquake and natural hazards.

Those geologists argue that no specific deterministic recurrence number should be used to define a hazardous fault, but rather mitigating surface faulting should be data driven, and rely on professional judgment, cost, available technology, and social constraints (acceptable risk). Some Utah geologists have also begun discussing the appropriateness of the Holocene active-fault criterion as applied in Utah, and some advocate for data-based surface-faulting mitigation when sufficient paleoseismic data are available.

Addition
Hazardous Fault Criteria

Characterizing fault activity for engineering mitigation of surface faulting, requires determining the fault's average surface-faulting recurrence and variability over multiple paleoearthquake cycles, and the time of most recent surface faulting.

By comparing elapsed time since the most recent surface faulting earthquake with a well-constrained average recurrence interval, it is possible to estimate the probability that the fault will generate a future surface-faulting earthquake in a time interval of interest. ***Only when such detailed paleoseismic data are available can decisions regarding surface-faulting mitigation be reliably data driven.***

Addition

Hazardous Fault Criteria

The UGS recommends that timing and displacement data for a minimum of three closed earthquake cycles [four earthquakes]) is necessary to (1) compare the elapsed time since the most recent surface-faulting earthquake with an even minimally statistically relevant average recurrence, and (2) estimate the probability of future surface faulting within a time frame of interest.

Where paleoseismic data are available to characterize earthquake timing and displacement over multiple closed earthquake cycles (three minimum), the UGS recommends that those data may be used in conjunction with good professional judgment to determine the appropriateness of mitigating surface faulting-risk over a shorter time interval than the Holocene.

Disclosure

The UGS recommends disclosure during real-estate transactions whenever an engineering-geology/geologic-hazard investigation has been performed for a property to ensure that prospective property owners are made aware of geologic hazards present on the property, and can make their own informed decision regarding risk. Disclosure should include a Disclosure and Acknowledgment Form provided by the jurisdiction, which indicates an engineering-geology report was prepared and is available for public inspection.

Additionally, prior to approval of any development, subdivision, or parcel, the UGS recommends that the regulating jurisdiction require the owner to record a restrictive covenant with the land identifying any geologic hazard(s) present. Where geologic hazards are identified on a property, the UGS recommends that the jurisdiction require the owner to delineate the hazards on the development plat prior to receiving final plat approval.

Acknowledgments

Bill Black (Western GeoLogic, LLC), Gary Christenson (UGS retired), Robert Larson (Los Angeles County Department of Public Works), Jim McCalpin (GEOHAZ, Inc.), Pete Rowley (Geologic Mapping, Inc.), David Simon (Simon Associates, LLC), Robert Tepel (independent consultant), Chris Wills (California Geological Survey), and Steve Bowman, Gregg Beukelman, Chris DuRoss, Mike Hylland, Tyler Knudsen, and Adam McKean (Utah Geological Survey) provided insightful comments and/or additional data that substantially improved the utility of these guidelines.

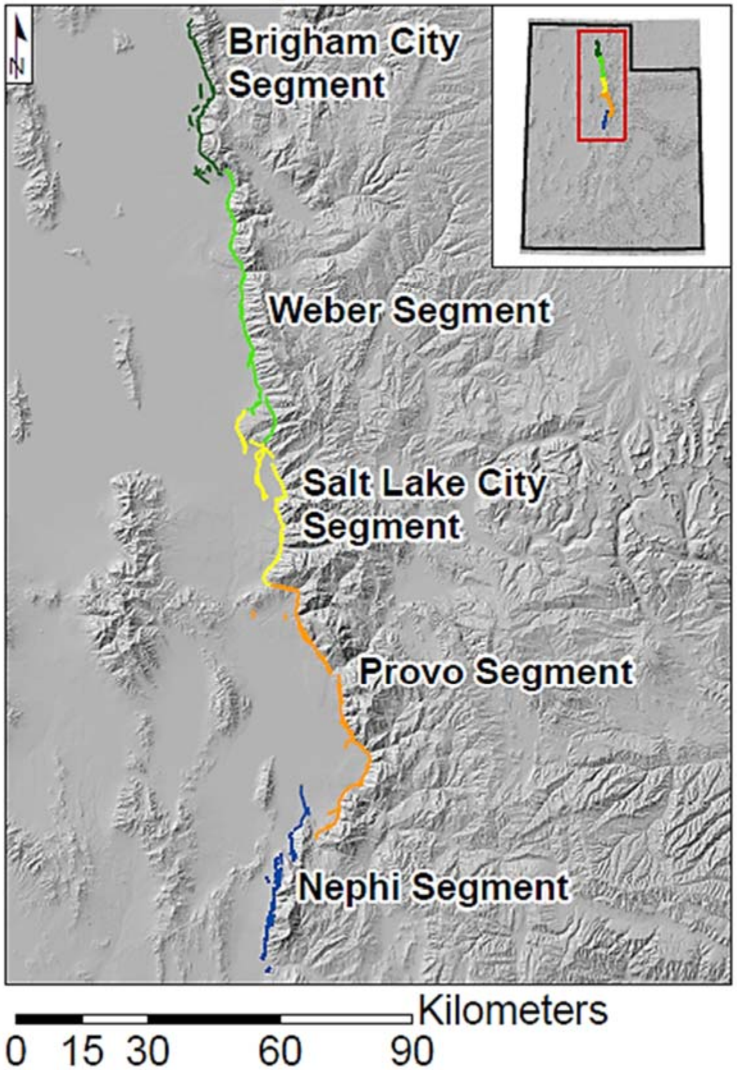
Characterization of Segmentation and Long Term Slip Rates of Wasatch Front Fault Systems, Utah

Julia Howe, M.S. Student
Paul Jewell
Ronald Bruhn
Department of Geology and Geophysics
University of Utah

The Problem

- **Extensive work examining Holocene paleoseismicity and vertical slip rates**
- **What are long term vertical slip rates? (>10ky B.P.)**
  - **Deformation of Lake Bonneville Shorelines**
- **Are earthquakes single segment or multi segment events?**
  - **Testing the segmentation model**

Study Area for this Project
Central Segments of the WFZ

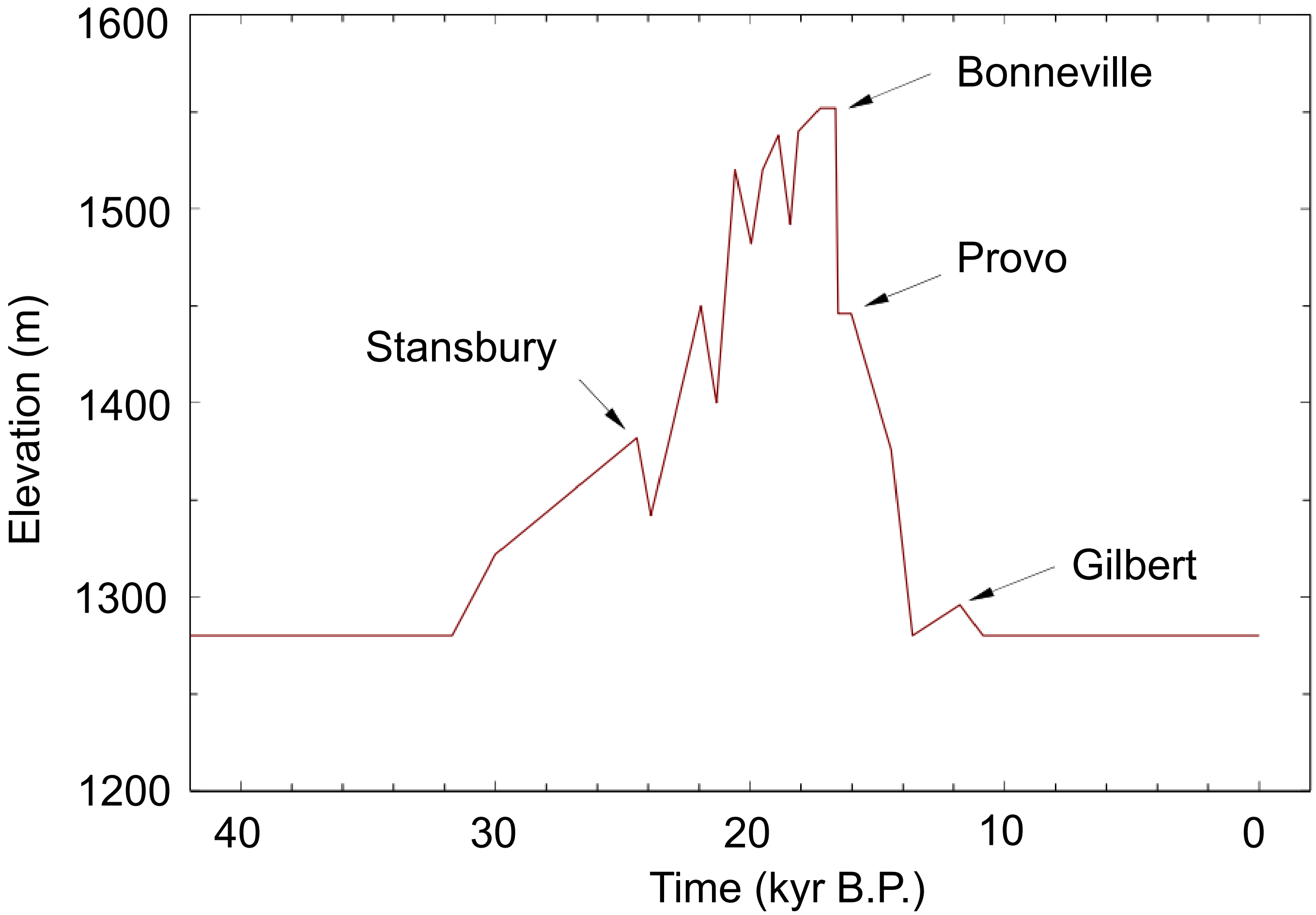


Lake Bonneville

- Quaternary pluvial lake
- Site of classic geological studies by G.K. Gilbert
- Continental paleoclimate archive
- How does deformation of Late Pleistocene shorelines record fault activity?

Oviatt, 2009

Lake Bonneville - Hydrograph

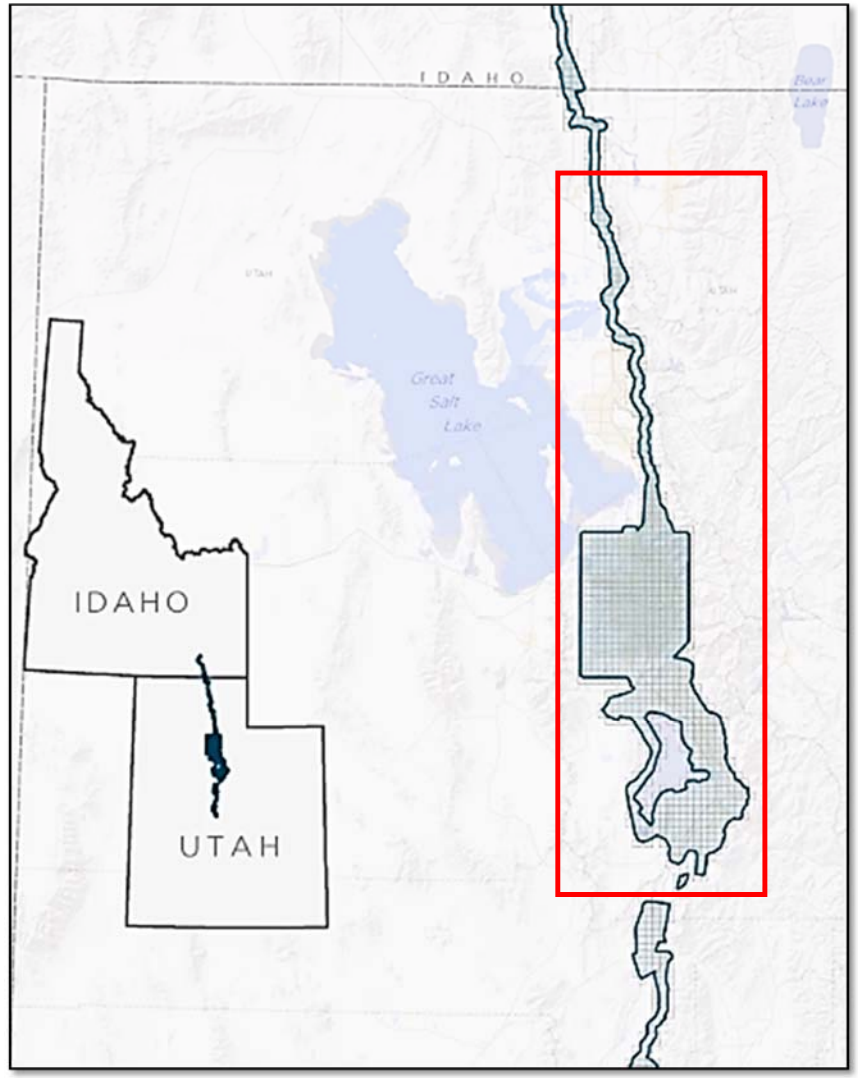


- Primary Shoreline Features
  - Bonneville (18 ky)
  - Provo (18 – 15 ky)
    - Calibrated Radiocarbon ages (Oviatt, 2015)

Figure modified from Oviatt, 1997

LiDAR

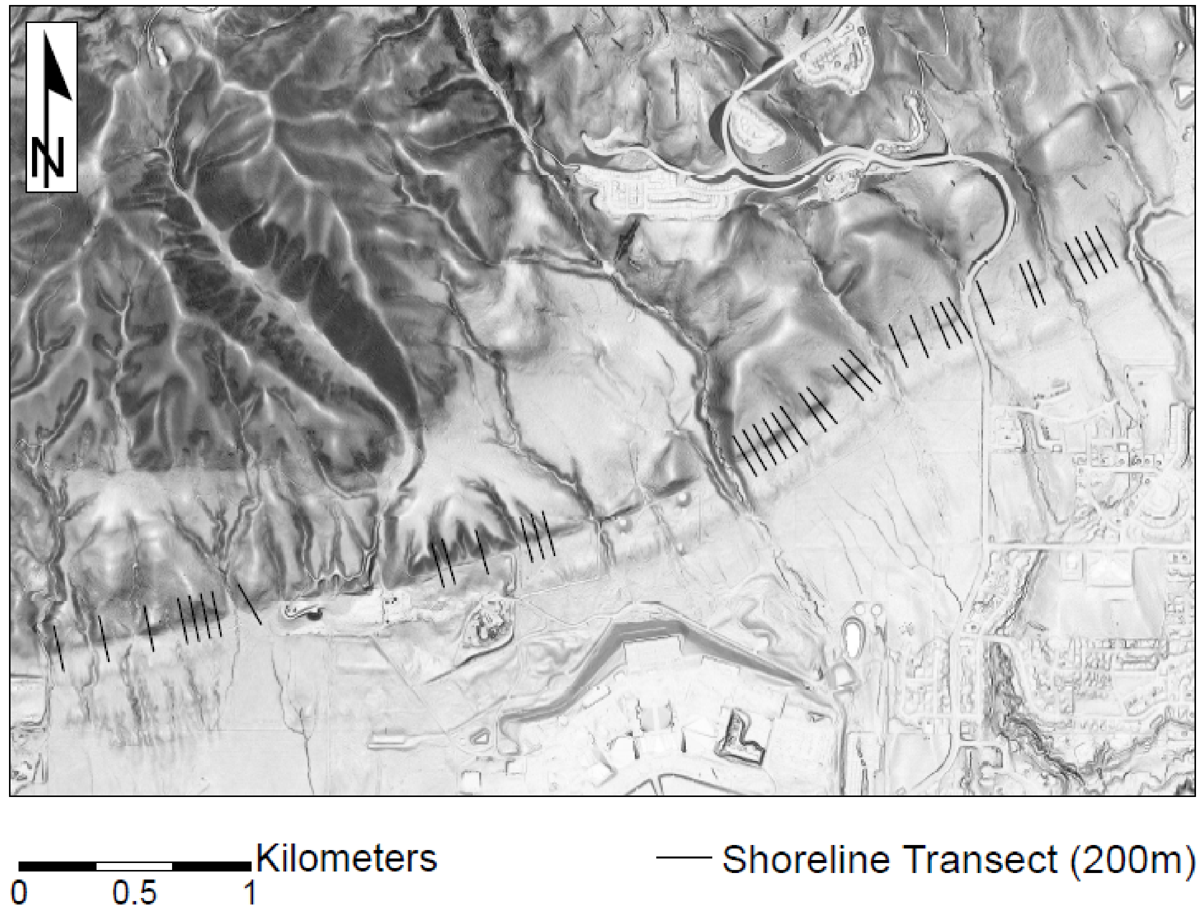
- 2013-2014 0.5 meter LiDAR
  - Larger area and greater accuracy than previous LiDAR surveys
  - Enhanced ability to locate geomorphic features
  - Directly extract 2-D cross sections of shoreline profiles



Utah AGRC

Mapping Appropriate Shorelines

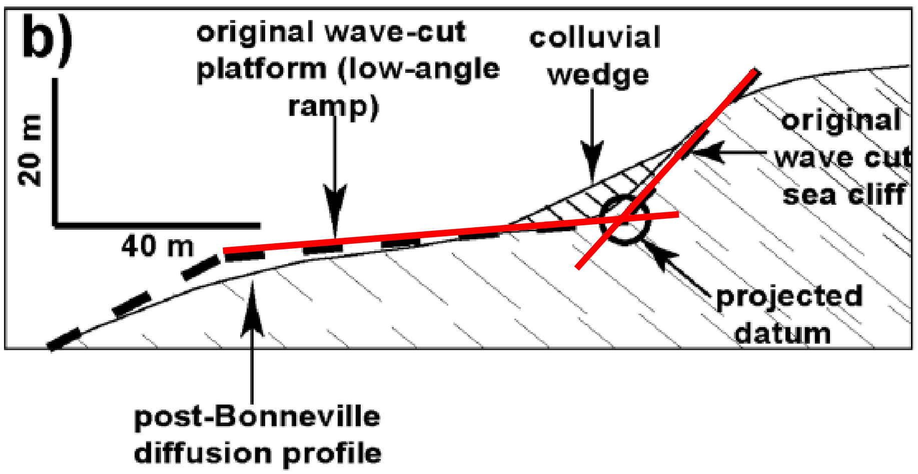
- Appropriate Shorelines
  - Minimal Holocene modification
    - Alluvial Fans
    - Landslides
    - Stream channel erosion
  - No cultural modification
    - Home building



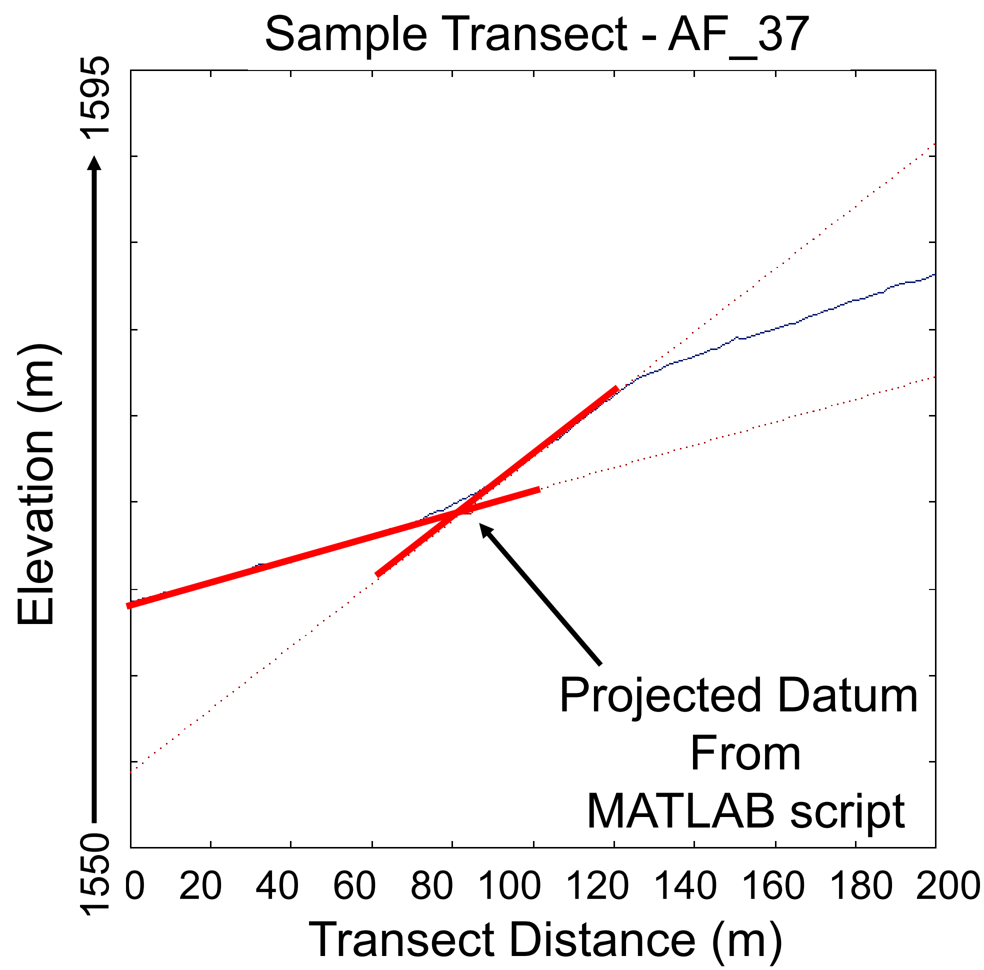
*Map represents slopeshade of 0.5m LiDAR

Locating Shoreline Datums

Generalized Shoreline Profile



Jewell and Bruhn, 2013

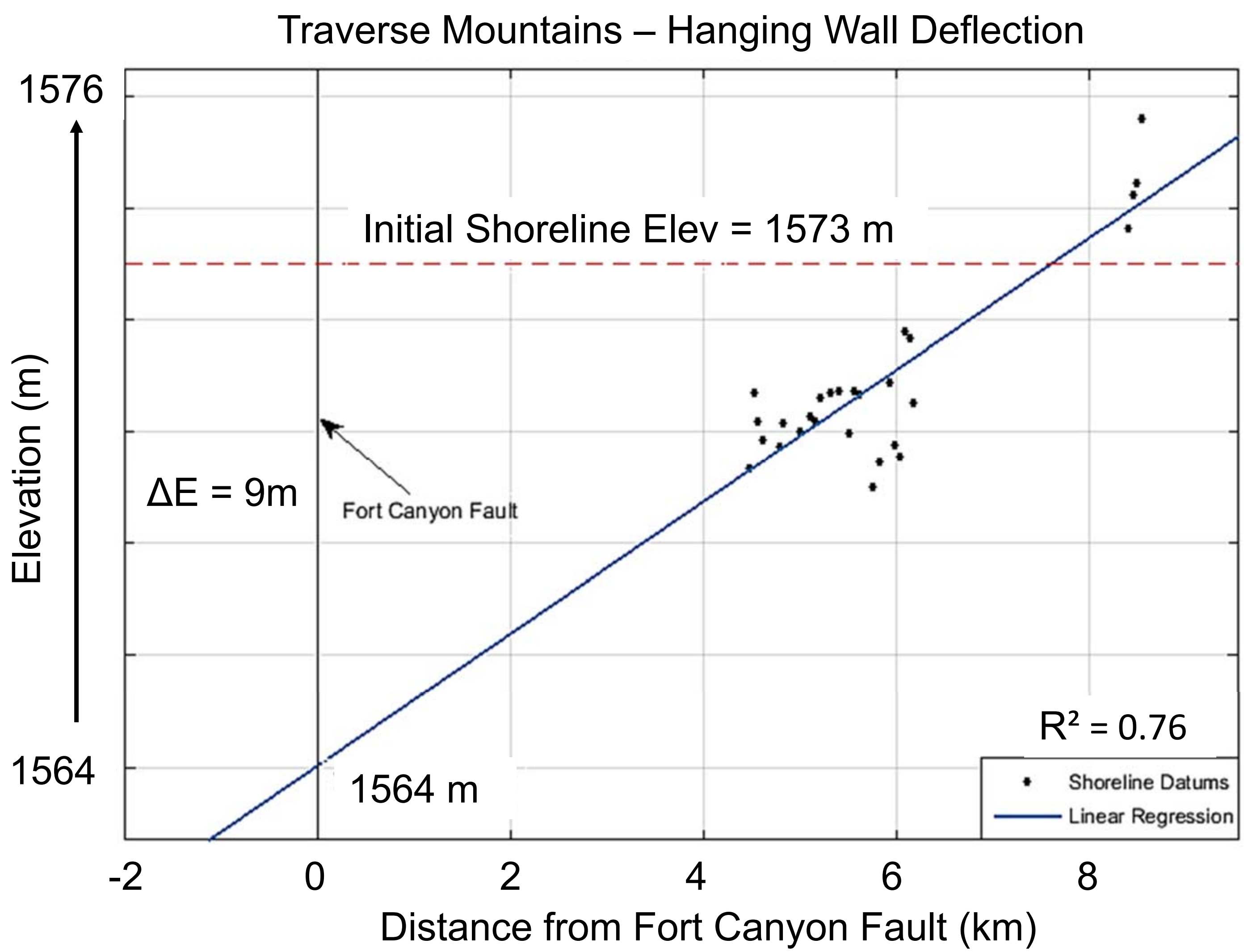


*Method from McCalpin et al., 1992

HW Deflection

- Traverse Mountains
- Hanging Wall Deflection =

  0.5 mm/yr
- Linear projection = minimum deflection value

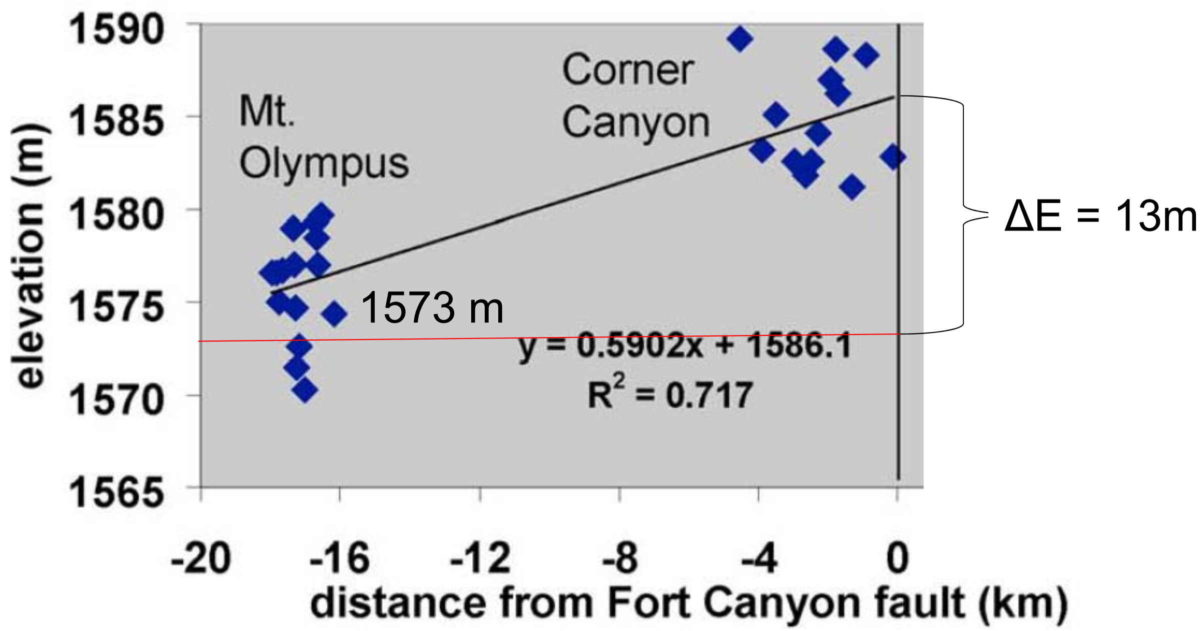


*Initial shoreline elevation from Currey, 1982

FW Deflection

- Corner Creek and Mt. Olympus
- Minimum Deflection =

  0.72 mm/yr

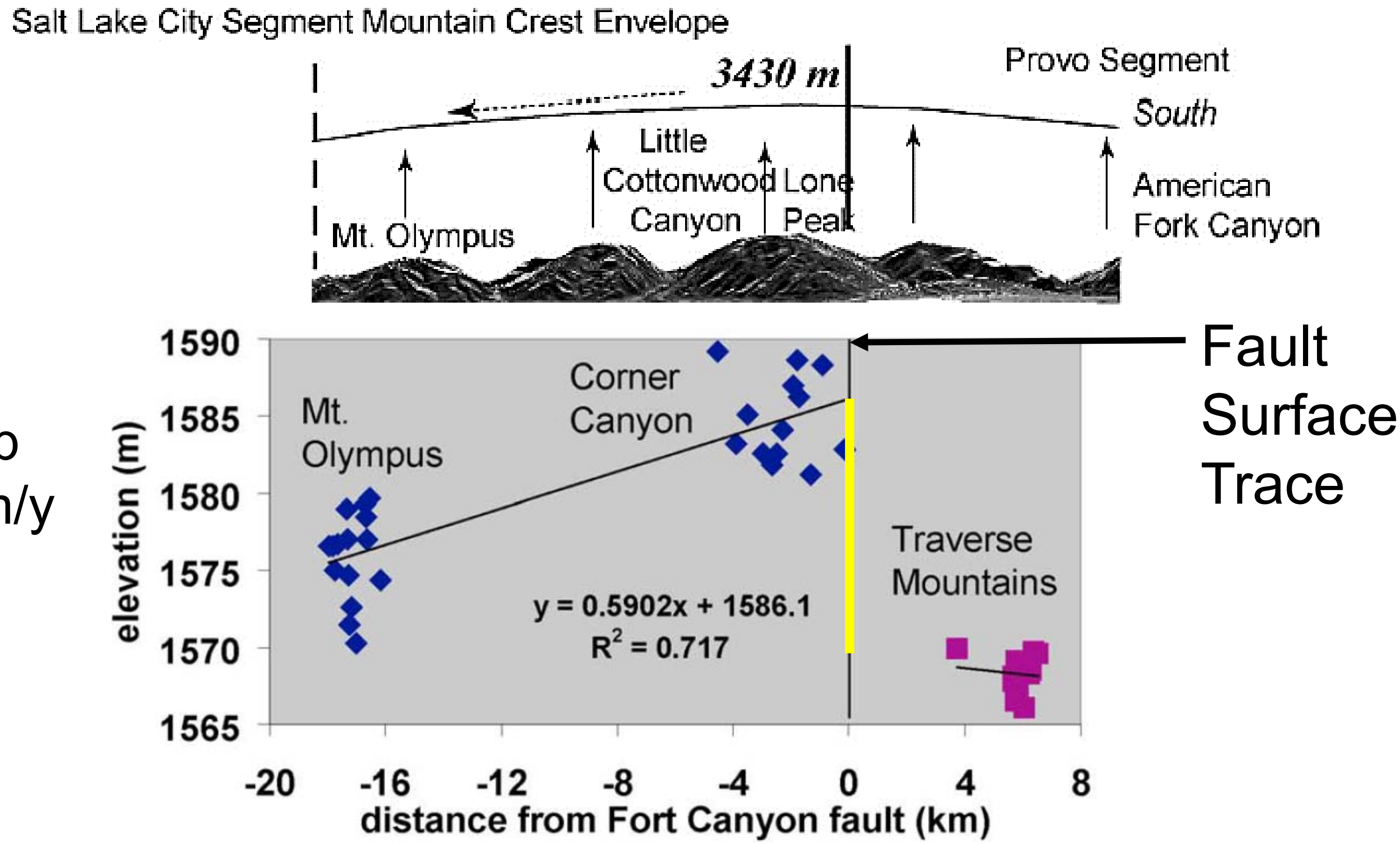


*Initial Shoreline Elevation from Currey, 1982

Jewell and Bruhn, 2013

Average Vertical Displacement

Average Vertical Slip Rate = 0.8 – 1.2 mm/y



Jewell and Bruhn, 2013

A Slip Rate Comparison

Method	Location	Vertical Slip Rate (mm/yr)	Time Scale	Source
Fission-Track Ages (Exhumation Rate)	Southern Salt Lake City Segment	0.6 - 1.0	5 My	Armstrong et al., 2004
Shoreline Deformation	Corner Canyon	0.8 - 1.2	18 ky	Jewell and Bruhn, 2013
Trenching	Corner Canyon	0.6 - 1.2 - 4.0	10 - 6 ky	Lund, 2005

Looking Forward

- Can shoreline deformation give a sense of fault block rotation?
- How do we account for isostasy?
- Do stresses imposed from the lake induce fault motion?
- Do longer term slip rates give new insight into seismic risk?


Thank You

Pleistocene Activity

- Deformation of geomorphic features
  - Alluvial Fans

- Mega-Trench Studies
  - Salt Lake City Segment

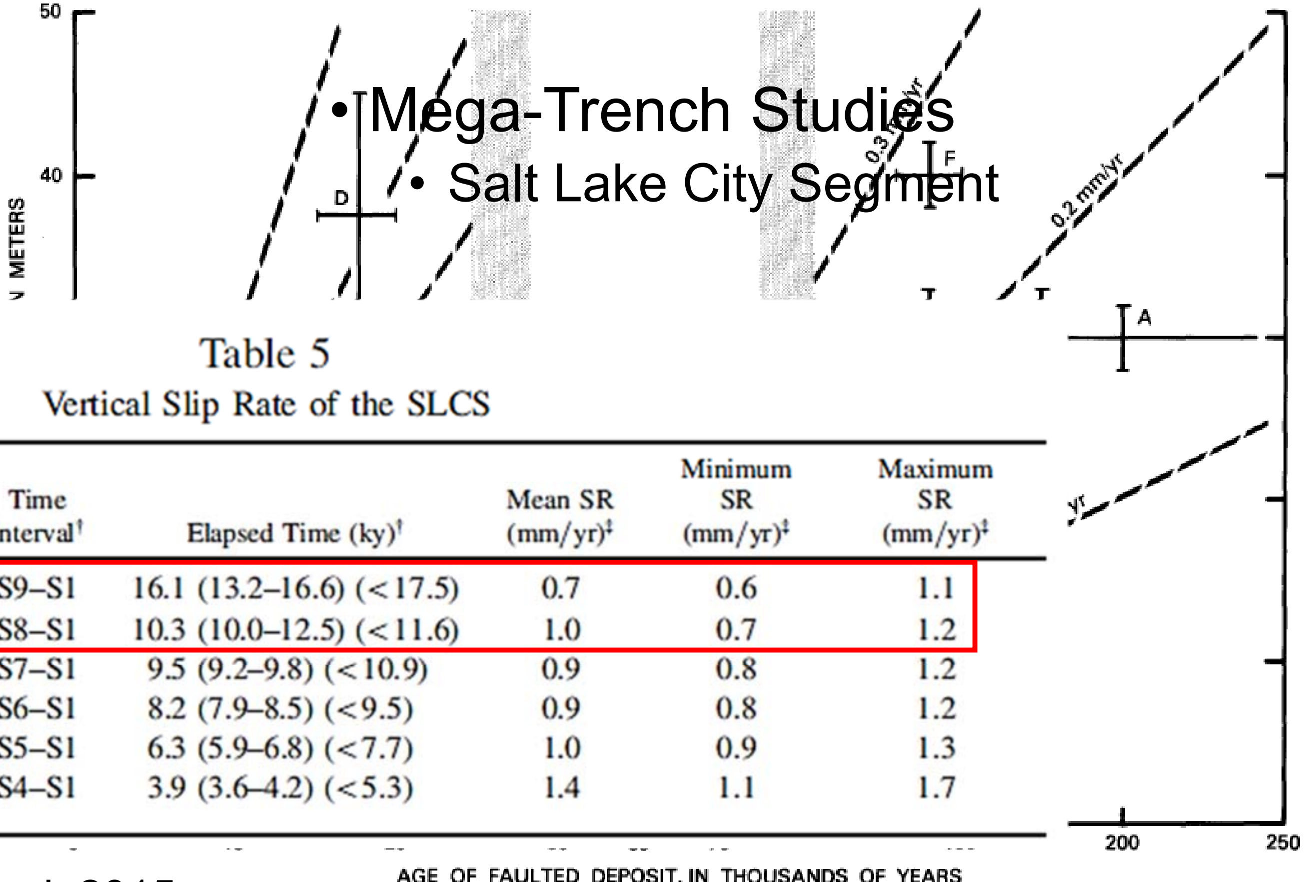


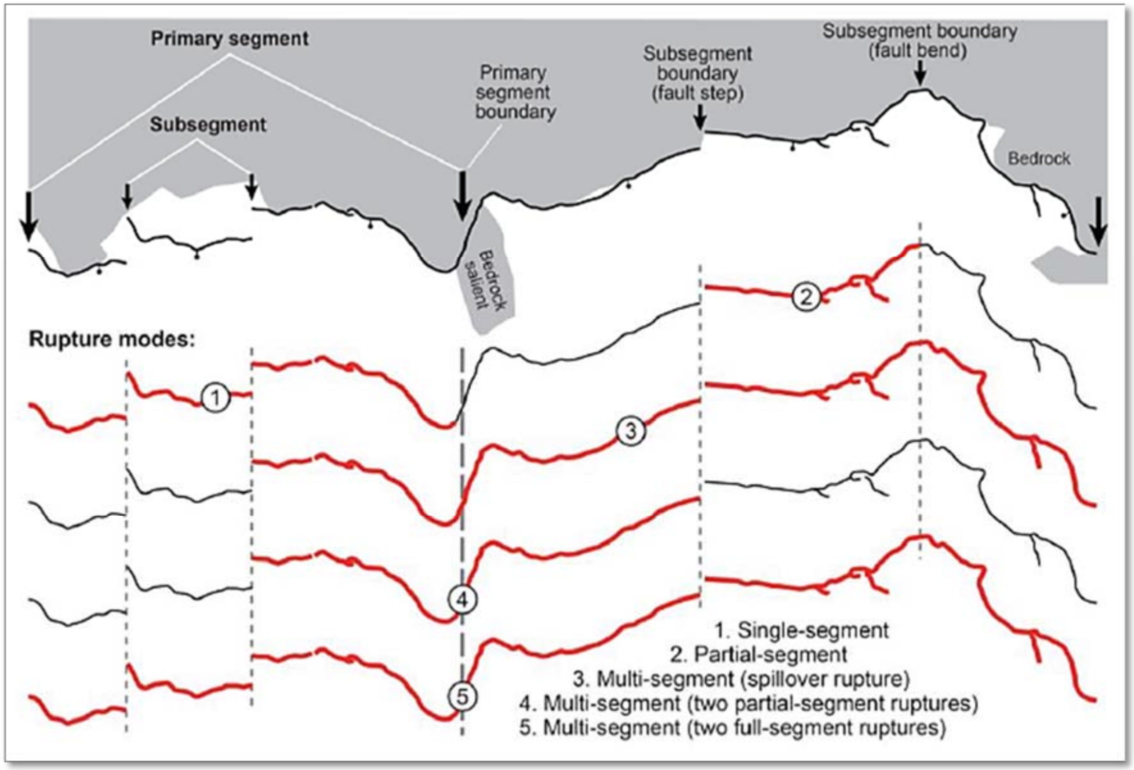
Table 5
Vertical Slip Rate of the SLCS

Displacement Interval*	Total Displacement (m)*	Time Interval†	Elapsed Time (ky)†	Mean SR (mm/yr)‡	Minimum SR (mm/yr)‡	Maximum SR (mm/yr)‡
S8–S1	11.5 (9.3–13.9)	S9–S1	16.1 (13.2–16.6) (<17.5)	0.7	0.6	1.1
S7–S1	10.1 (8.3–12.1)	S8–S1	10.3 (10.0–12.5) (<11.6)	1.0	0.7	1.2
S6–S1	8.9 (7.5–10.6)	S7–S1	9.5 (9.2–9.8) (<10.9)	0.9	0.8	1.2
S5–S1	7.8 (6.7–9.1)	S6–S1	8.2 (7.9–8.5) (<9.5)	0.9	0.8	1.2
S4–S1	6.6 (5.9–7.6)	S5–S1	6.3 (5.9–6.8) (<7.7)	1.0	0.9	1.3
S3–S1	5.3 (4.7–6.1)	S4–S1	3.9 (3.6–4.2) (<5.3)	1.4	1.1	1.7

Machette et al., 1992; DuRoss and Hylland, 2015

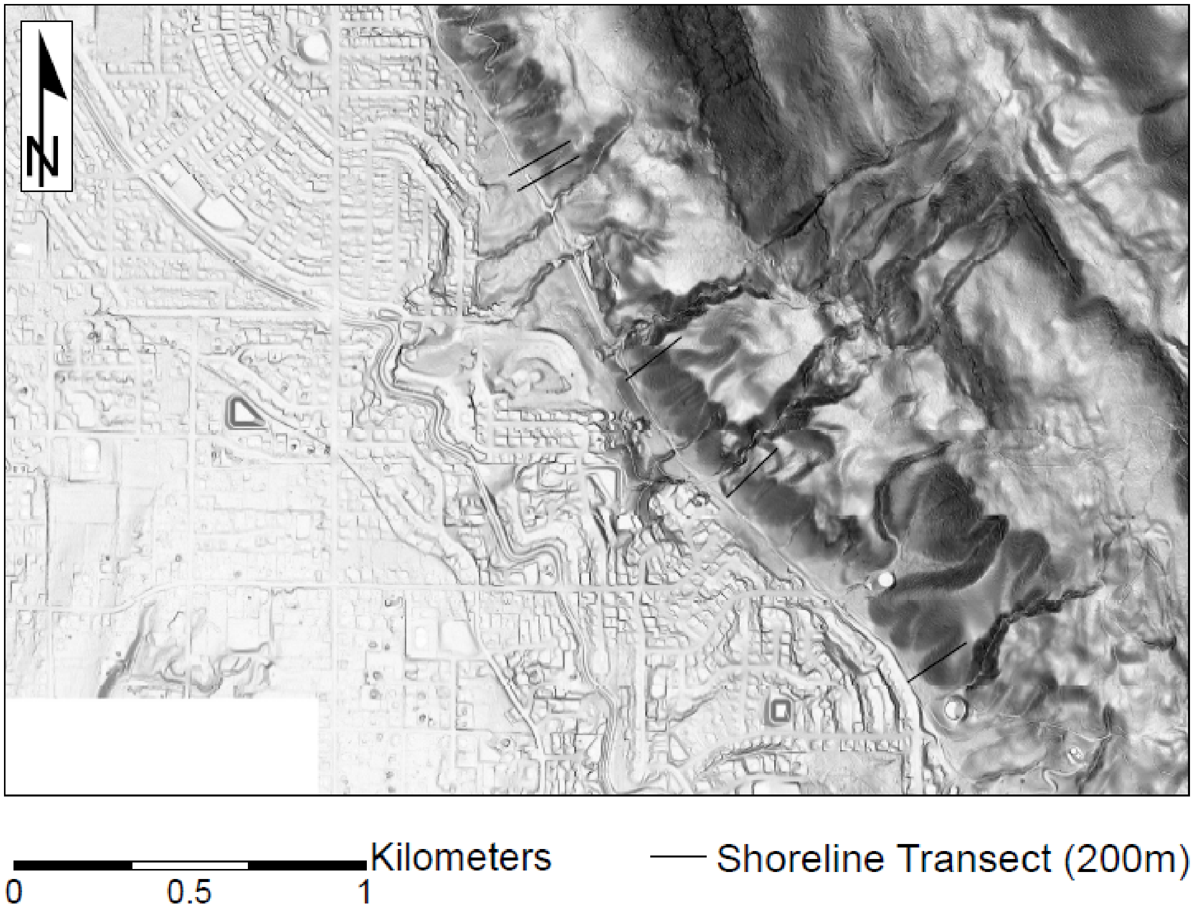
Current Segmentation Model

- Re-evaluation of segment boundaries is already underway
  - Based on Late Holocene paleoearthquakes
- Do mature fault zones act as barriers to, or facilitators of multisegment rupture?



DuRoss et al., 2016

Mapping Appropriate Shorelines



- Shoreline Transects
  - ArcGIS Transect tool
    - Exactly perpendicular to mapped features
    - Specified Length (200m)
    - Specified Distance
  - Visual Check
    - Heavily modified shoreline profiles are excluded from further analysis

*Map represents slopeshade of 0.5m LiDAR

Shoreline Deformation

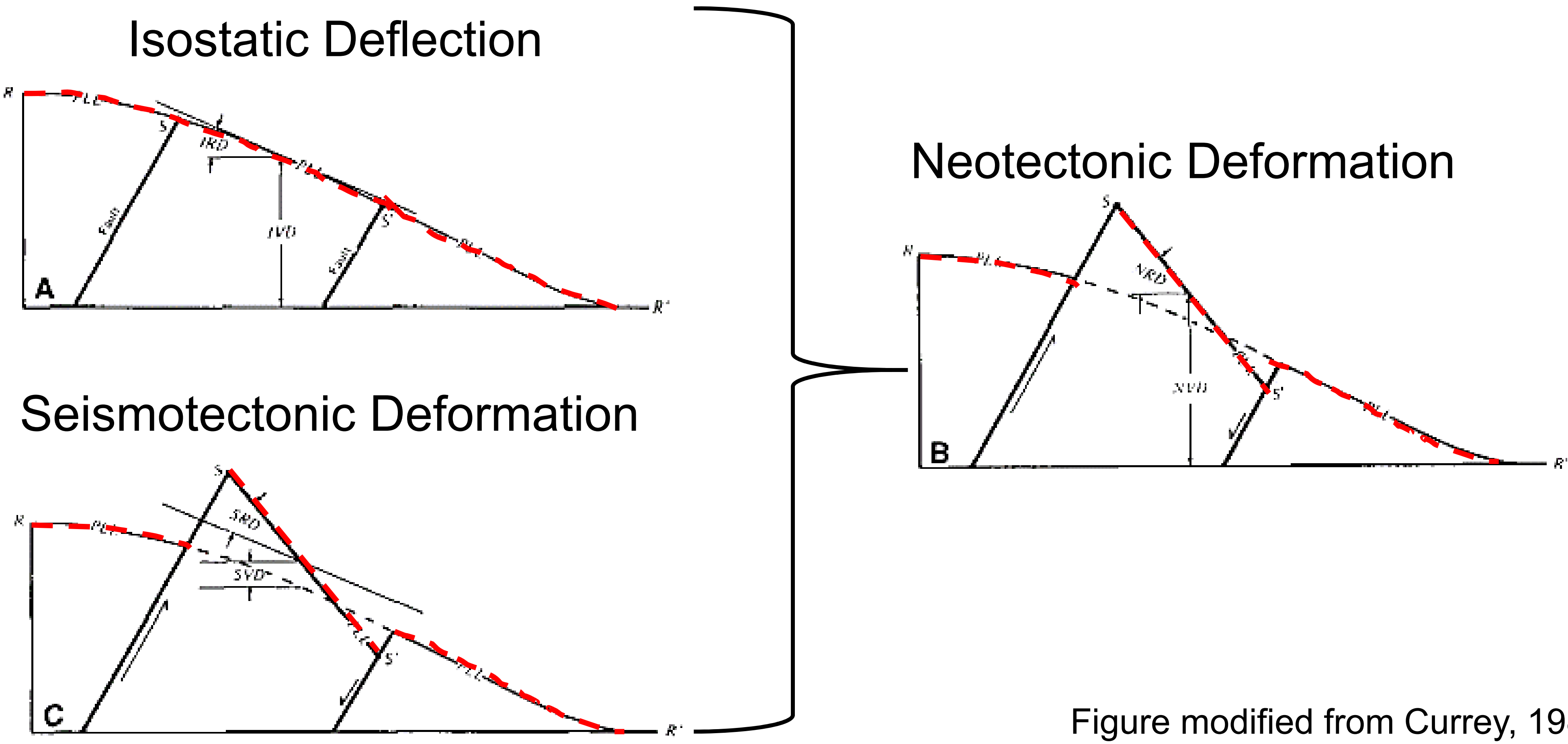
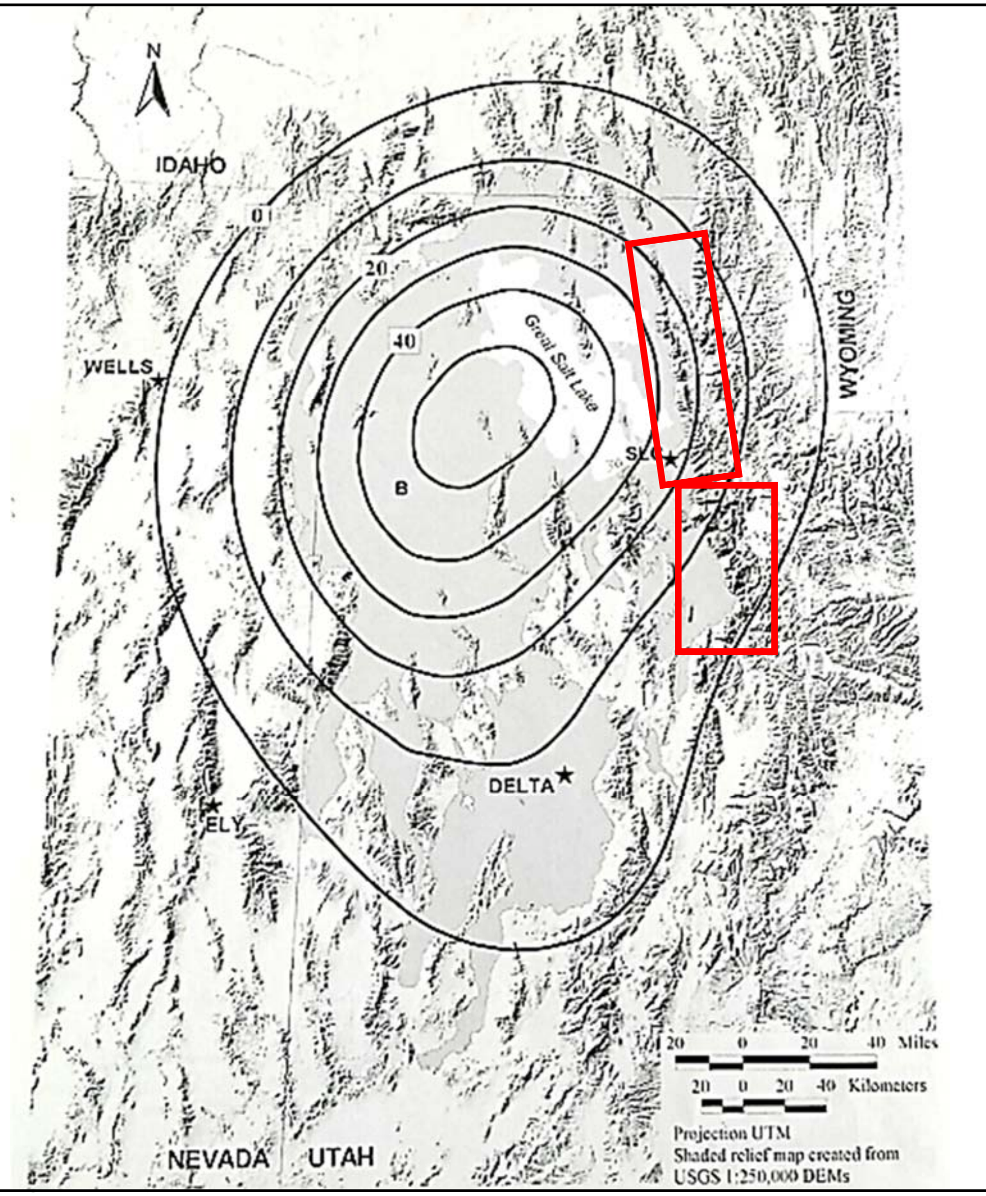


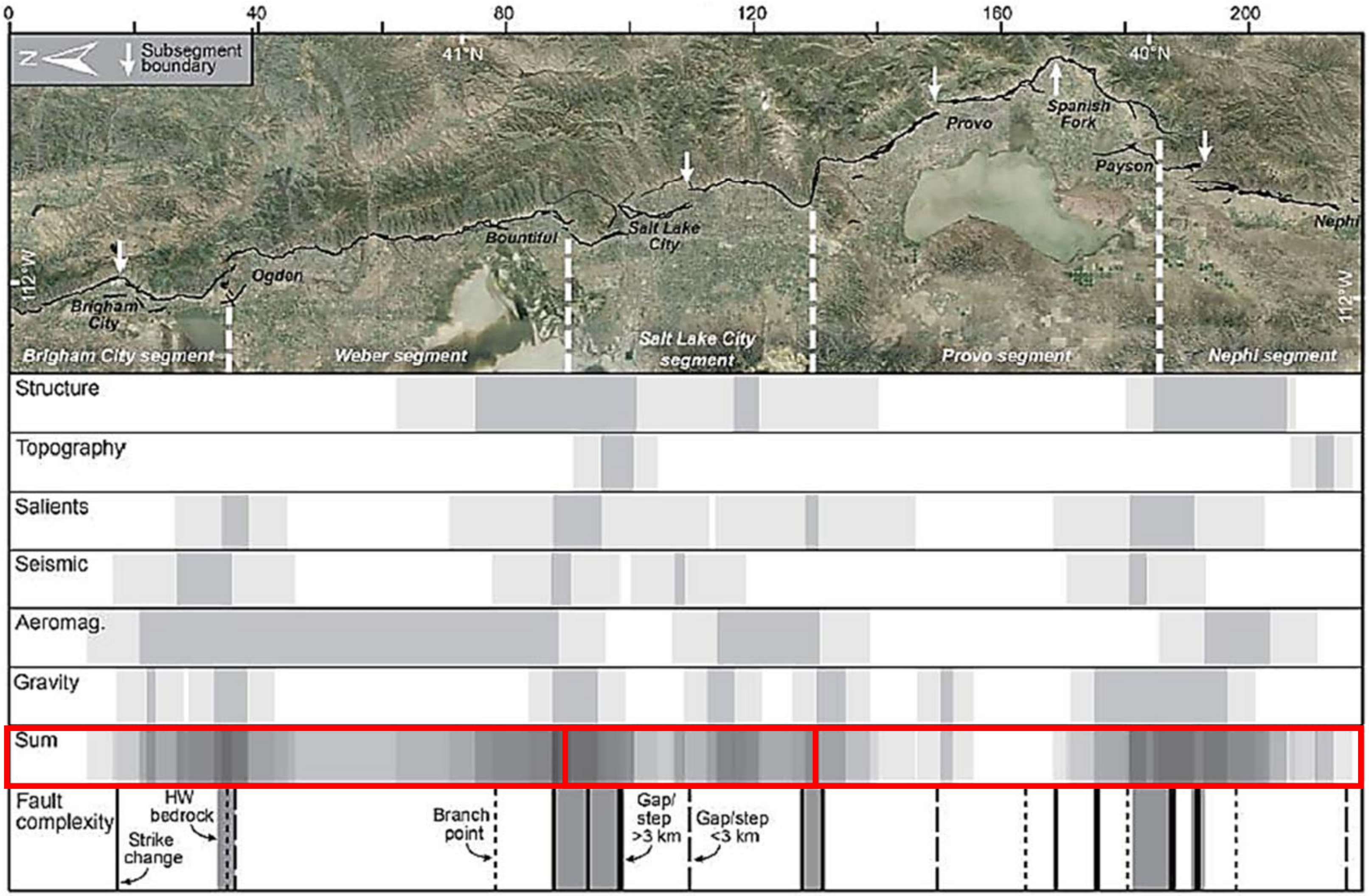
Figure modified from Currey, 1989

Isostasy

- How do we account for isostatic deflection?
- SLC to Brigham City
- Provo to Spanish Fork

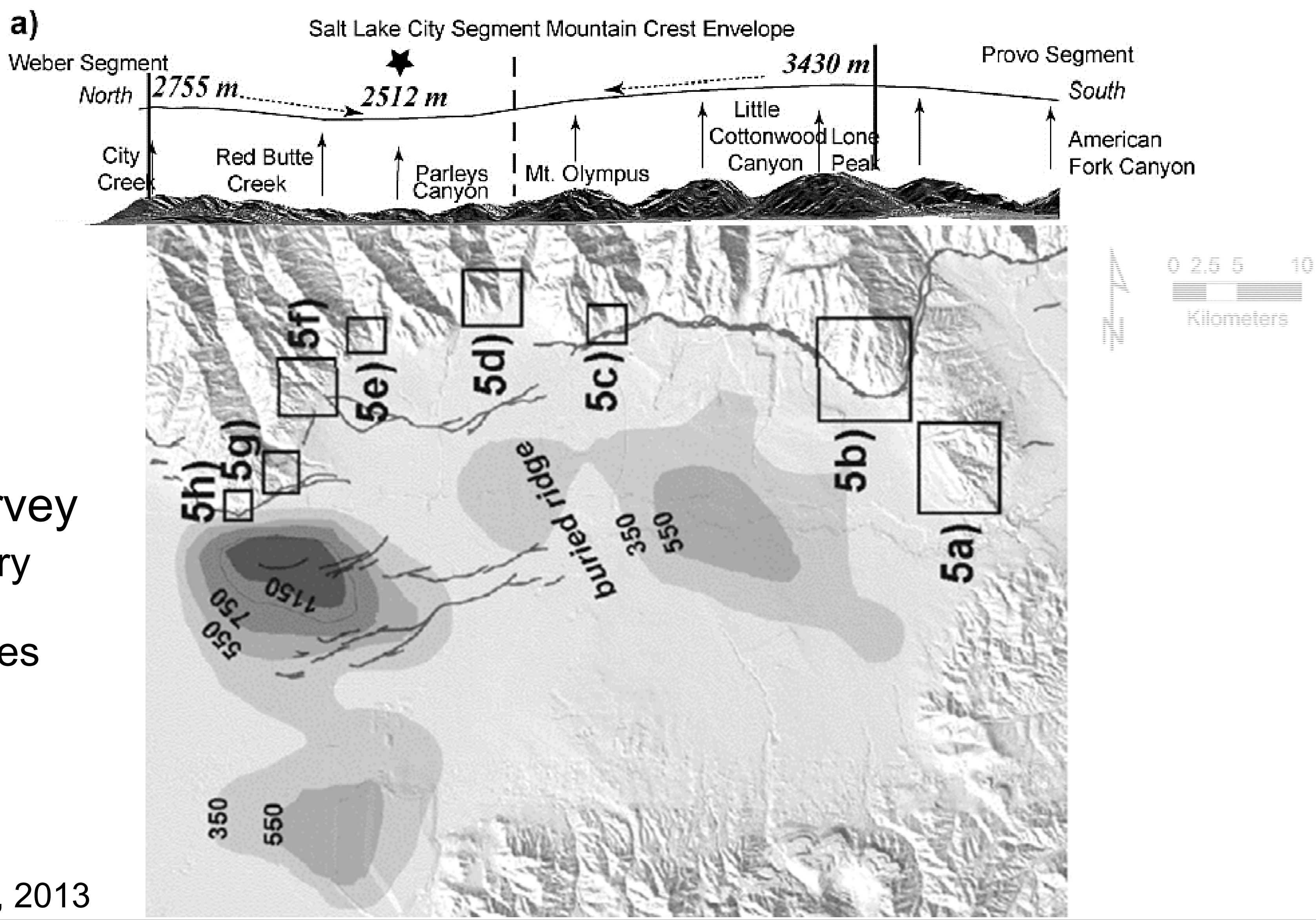


Bills et al., 2002



DuRoss et al., 2016 from Wheeler and Krystinik, 1992

- Gravity Survey
  - Quaternary sediment thicknesses



Jewell and Bruhn, 2013

Utah Quaternary Fault and Fold Database

Status of Updates and New Web Application

Michael Hylland

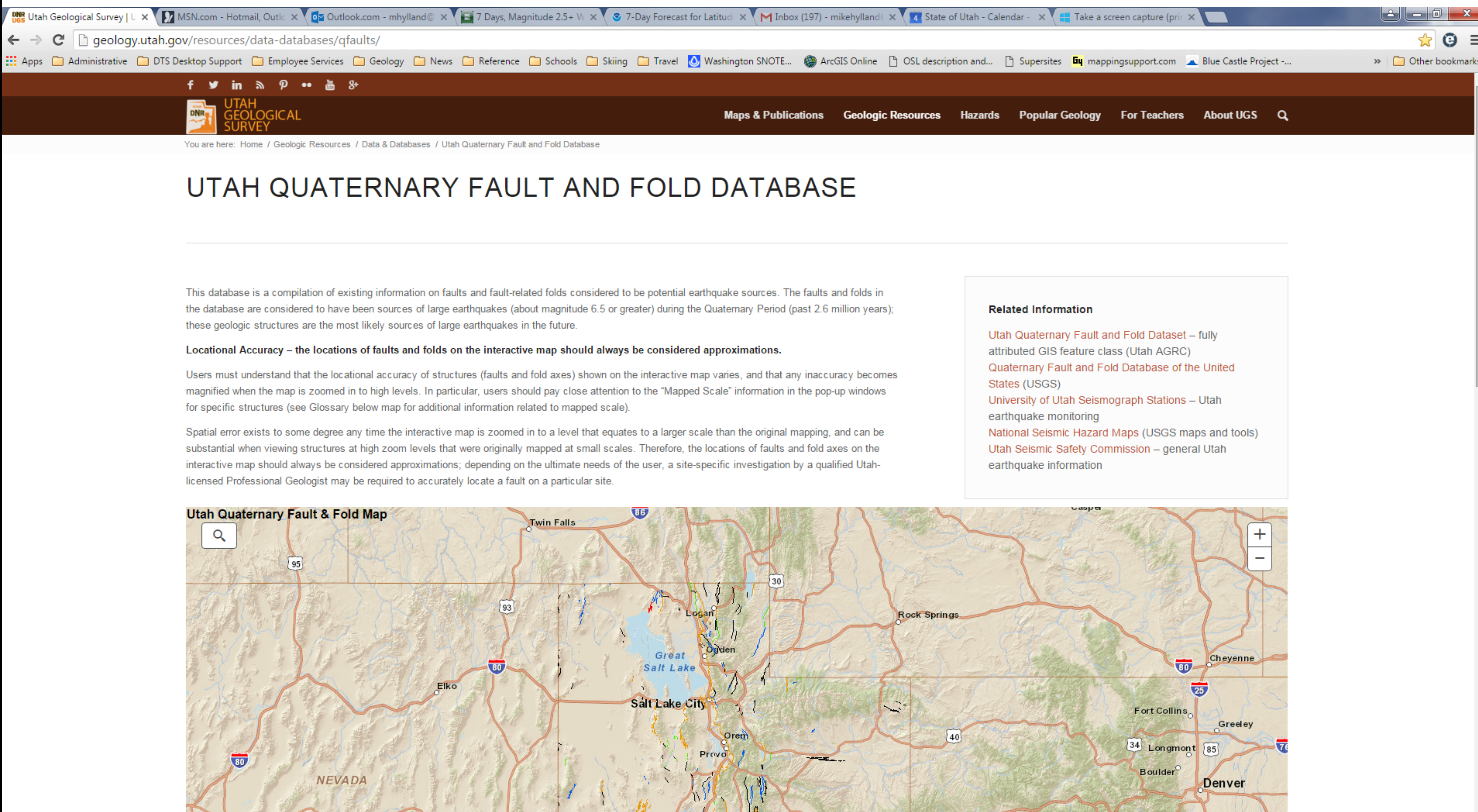
Utah Geological Survey

Contributors:
Sofia Agopian, Steve Bowman, Gordon Douglass, Kathleen Haller, Tara Hansen, Marshall Robinson, Brian Swaner, Corey Unger, Christine Wilkerson

Utah Quaternary Fault Parameters Working Group Meeting
February10, 2016

Updates Completed in 2015

Item No.	Fault Name	Fault No.	Update Completed	Source of New Mapping
1	Beaver Ridge faults	2464	Incorporate new mapping	Hintze & others, 2003 (UGS Map 195)
2	Black Rock Area faults	2461	Incorporate new mapping	Hintze & others, 2003 (UGS Map 195)
3	Clear Lake fault zone	2436	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184); Hintze & others, 2003 (UGS Map 195)
4	Clover fault zone	2396	Incorporate new mapping	Kirby, 2013 (UGS Map 264DM); Kirby, 2013 (UGS Map 265DM)
5	Cove Fort fault zone	2491	Incorporate new mapping	Hintze & others, 2003 (UGS Map 195)
6	Crater Bench faults	2433	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184)
7	Cricket Mountains (North End) faults	2434	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184)
8	Cricket Mountains (West Side) fault	2460	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 182); Hintze & Davis, 2002 (UGS Map 184)
9	Deseret faults	2435	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184)
10	Drum Mountains fault zone	2432	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184)
11	Faults of Cove Creek Dome	2462	Incorporate new mapping	Hintze & others, 2003 (UGS Map 195)
12	Gunlock fault	2515	Incorporate new mapping	Hintze & Hammond, 1994 (UGS Map 153); Biek & others, 2009 (UGS Map 242)
13	House Range (West Side) fault	2430	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 186)
14	Kolob Terrace faults	2525	Incorporate new mapping	Biek & Hylland, 2007 (UGS Map 221)
15	Little Valley faults	2439	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184)
16	Maple Grove faults	2443	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184); Hintze & others, 2003 (UGS Map 195)
17	Meadow-Hatton Area faults	2466	Incorporate new mapping	Hintze & others, 2003 (UGS Map 195)
18	Mineral Mountains (Northeast Side) fault	2490	Incorporate new mapping	Hintze & others, 2003 (UGS Map 195)
19	North of Wah Wah Mountains faults	2459	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 182)
20	Pavant faults	2438	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184); Hintze & others, 2003 (UGS Map 195)
21	Pavant Range fault	2442	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184)
22	Saint John Station fault zone	2397	Incorporate new mapping	Kirby, 2012 (UGS Map 257DM); Kirby, 2013 (UGS Map 264DM)
23	San Francisco Mountains (West Side) fault	2486	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 182)
24	Scipio faults	2441	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184)
25	Scipio Valley faults	2440	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184)
26	Snake Valley (South End) faults	1433	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 182)
27	Snake Valley faults	2428	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 186)
28	Southern Oquirrh Mountains fault zone	2399	Incorporate new mapping	Kirby, 2012 (UGS Map 257DM)
29	Sugarville Area faults	2437	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 184)
30	Tabernacle faults	2465	Incorporate new mapping	Hintze & others, 2003 (UGS Map 195)
31	Vernon Hills fault zone	2406	Incorporate new mapping	Kirby, 2013 (UGS Map 265DM)
32	Wasatch fault zone, Levan section	2351i	Incorporate new mapping	Hylland & Machette, 2008 (UGS Map 229)
33	Wasatch fault zone, Fayette section	2351j	Incorporate new mapping	Hylland & Machette, 2008 (UGS Map 229)
34	Wah Wah Mountains faults	2483	Incorporate new mapping	Hintze & Davis, 2002 (UGS Map 182)
35	Washington fault, Northern section	1004	Incorporate new mapping	Biek & others, 2009 (UGS Map 242)
36	White Sage Flat faults	2467	Incorporate new mapping	Hintze & others, 2003 (UGS Map 195)



- Interactive map currently has its own page within the UGS website (http://geology.utah.gov/resources/data-databases/qfaults/)
- The fault map will eventually be one of several layers that make up a geologic hazards interactive map
- Paleoseismic sites, with links to reports and data, will be added as a data layer

Updates In Progress

				Source of New Mapping			
Item No.	Fault Name	Fault No.	Update Needed	Publication	Name	Author	Comments
1	Great Salt Lake fault zone, Antelope Island section	2369	Incorporate new mapping	MP-15-5	BRPSHSIII Proceedings (poster); also see Don Clark	Dinter & Pechmann, 2015	Need to reassign section designation
				OFR 644	Tooele 30x60	Clark et al, 2015	
2	Great Salt Lake fault zone, Fremont Island section	2369	Incorporate new mapping	MP-15-5	BRPSHSIII Proceedings (poster); also see Don Clark	Dinter & Pechmann, 2015	Need to reassign section designation
3	Great Salt Lake fault zone, Promontory section	2369	Incorporate new mapping	MP-15-5	BRPSHSIII Proceedings (poster); also see Don Clark	Dinter & Pechmann, 2015	Need to reassign section designation
4	Great Salt Lake fault zone, Rozel section	2369	Incorporate new mapping	MP-15-5	BRPSHSIII Proceedings (poster); also see Don Clark	Dinter & Pechmann, 2015	New section; need to create dataset, reassign section designations
5	Long Ridge (Northwest Side) fault	2422	Incorporate new mapping	Map 272	Goshen 7.5	McKean et al, 2015	
6	Utah Lake faults	2409	Incorporate new mapping	MP-15-5	BRPSHSIII Proceedings (poster); also see Don Clark	Dinter, 2015	
7	Wasatch fault, Brigham City section	2351d	Incorporate LiDAR mapping	OFR 638	Honeyville SFR map	Harty & McKean, 2015	
8	Wasatch fault, Collinston section	2351c	Incorporate LiDAR mapping	OFR 638	Honeyville SFR map	Harty & McKean, 2015	
9	Wasatch fault, Fayette section	2351j	Incorporate LiDAR mapping	OFR 640	Levan/Fayette SFR maps	Hiscock & Hylland, 2015	
10	Wasatch fault, Levan section	2351i	Incorporate LiDAR mapping	OFR 640	Levan/Fayette SFR maps	Hiscock & Hylland, 2015	
11	Wasatch fault, Nephi section	2351h	Incorporate new mapping	Map 227	Spanish Fork 7.5	Solomon et al, 2007	
12	Washington fault, Fort Pearce section	1004	Rename section	MP-15-6	Washington fault study	Lund, 2015	Currently "Northern" section
13	Washington fault, Washington Hollow section	1004	Add fault traces	Map 242	St George 30x60	Biek et al, 2009	New section; need to create dataset, reassign section designations
				MP-15-6	Washington fault study	Lund, 2015	
14	West Valley fault zone, Granger fault	2386b	Incorporate new mapping	Map 216	Magna 7.5	Solomon et al, 2007	
				OFR 624	Baileys Lake 7.5	McKean & Hylland, 2013	
15	Carrington fault	new	Add fault traces	MP-15-5	BRPSHSIII Proceedings (poster); also see Don Clark	Dinter & Pechmann, 2015	New fault; need to create dataset
16	Dover fault zone	new	Add fault traces	Map 229	Levan/Fayette segments map	Hylland & Machette, 2008	New fault; need to create dataset
				MP 97-3	Hayes Canyon 7.5	Petersen, 1997	
17	East Cedar Valley fault zone	new	Add fault traces	Map 235	Soldiers Pass 7.5	Biek et al, 2009	New fault; need to create dataset
18	Goshen fault	new	Add fault traces	Map 272	Goshen 7.5	McKean et al, 2015	New fault; need to create dataset
19	Harkers fault	new	Add fault traces	Map 216	Magna 7.5	Solomon et al, 2007	New fault; need to create dataset
				Map 219	Copperton 7.5	Biek et al, 2007	
				OFR 644	Tooele 30x60	Clark et al, 2015	
20	South Mountain Marginal fault	new	Add fault traces	Map 264	Saint John 7.5	Kirby, 2013	New fault; need to create dataset
21	Wide Canyon faults	new	Add fault traces	Map 242	St George 30x60	Biek et al, 2009	New fault; need to create dataset

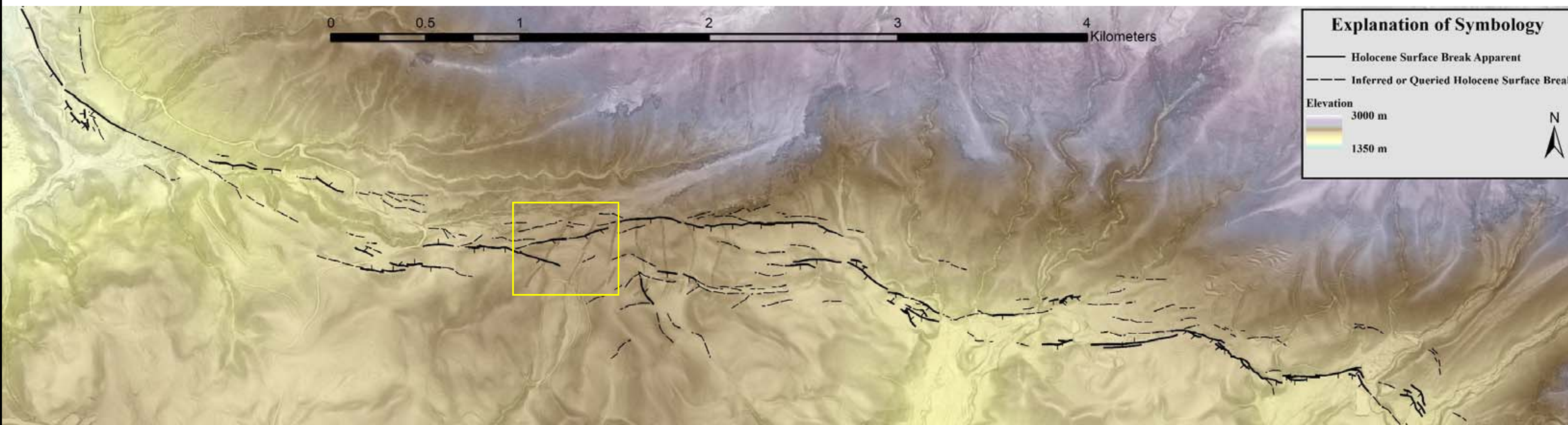
- 14 faults have new, more detailed mapping
- 7 new faults need to be added to the database

Note: Source data being expanded to include open-file mapping and other gray literature

Paleoseismic Investigation within the Traverse Ridge Segment Boundary: Initial Plans for Summer 2016 Field Work

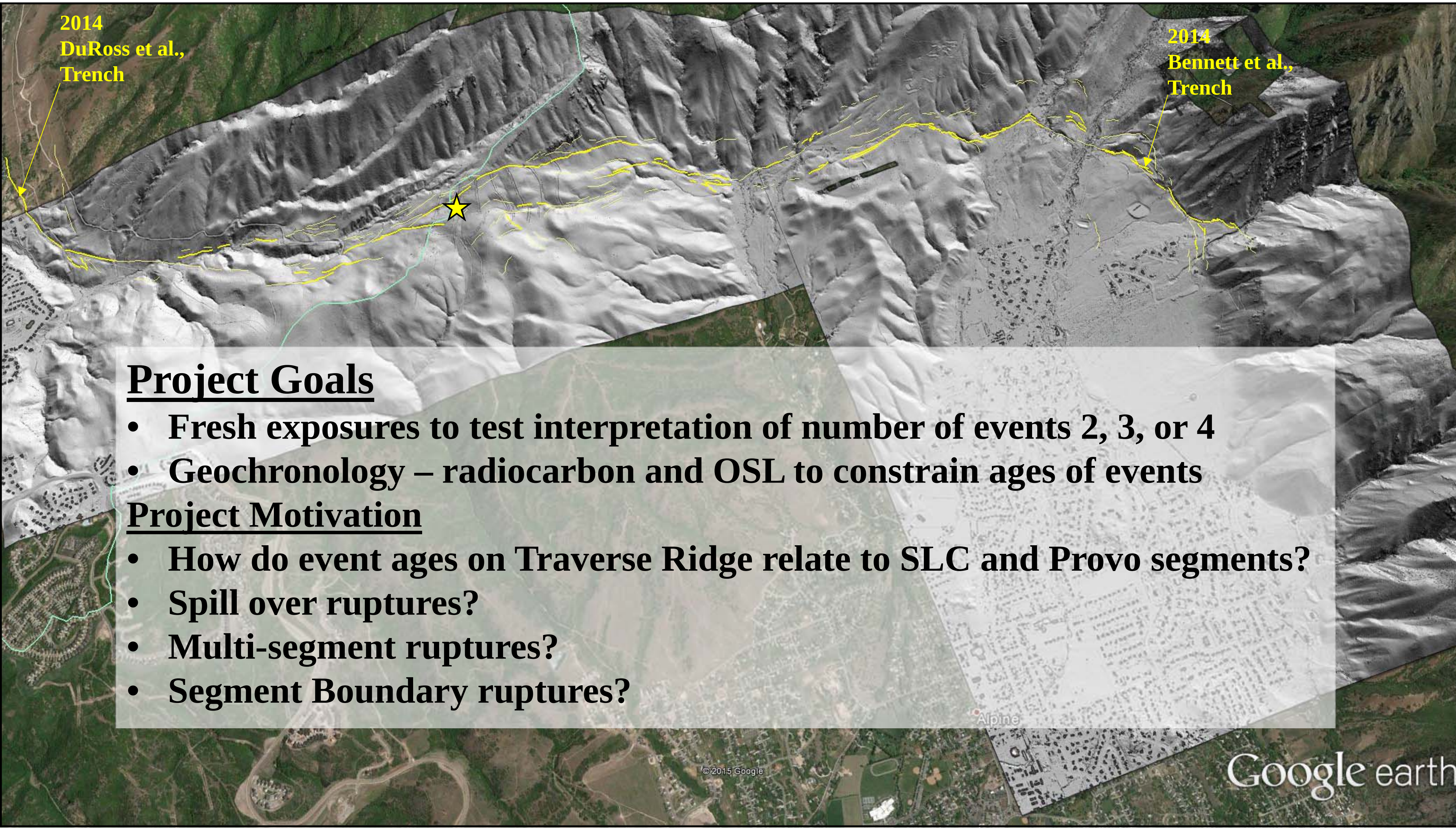
UTAH VALLEY UVU UNIVERSITY Department of EARTH SCIENCE

Nathan Toké and Daniel Horns with support from
Chris DuRoss and the USGS IMW Megaproject



Previous Work

- **Using existing trenches, UVU students interpret evidence for 2-4 events.**
- **Likely Holocene based upon soil characteristics and scarp morphology– (we think).**
- **Fault zone is characterized by discontinuous surface breaks (>100 of them).**
- **Surface breaks range from 15-500 m, most 50-200 m long.**



Project Goals

- **Fresh exposures to test interpretation of number of events 2, 3, or 4**
- **Geochronology – radiocarbon and OSL to constrain ages of events**

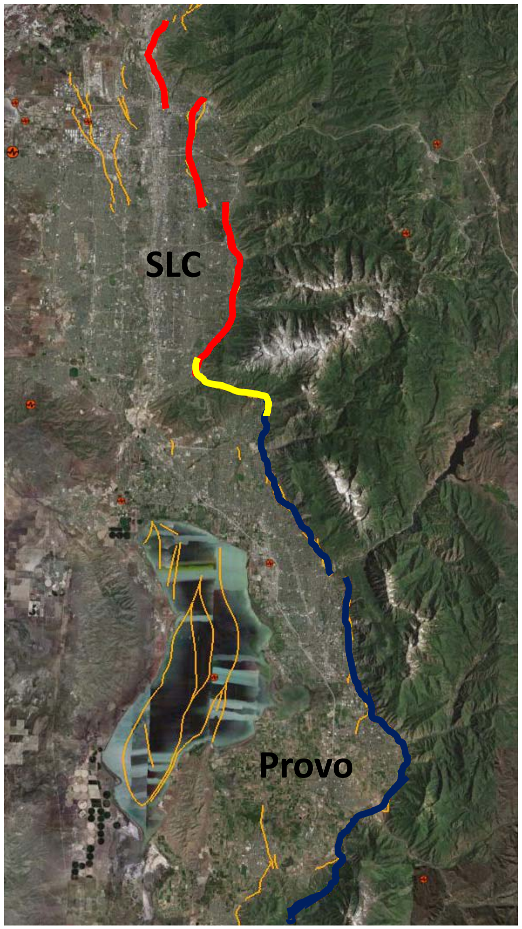
Project Motivation

- **How do event ages on Traverse Ridge relate to SLC and Provo segments?**
- **Spill over ruptures?**
- **Multi-segment ruptures?**
- **Segment Boundary ruptures?**

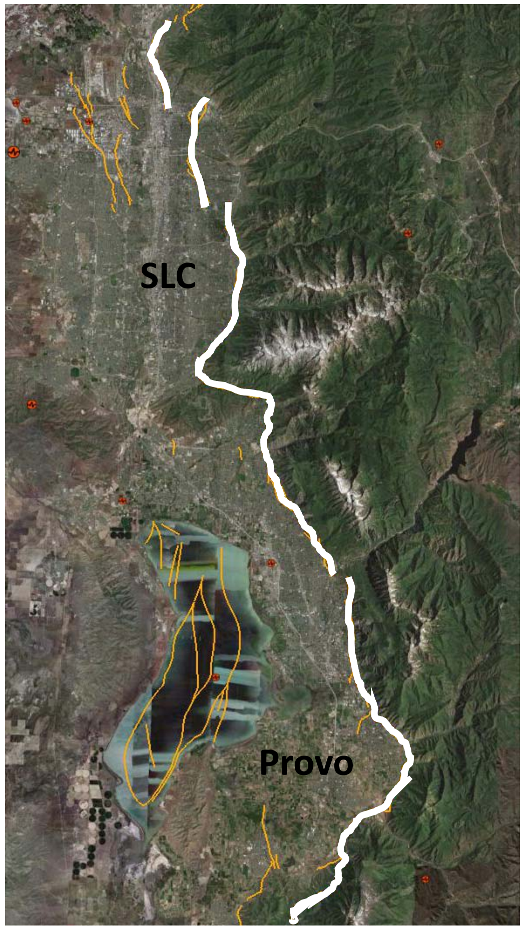
Rupture Models

from DuRoss, 2008

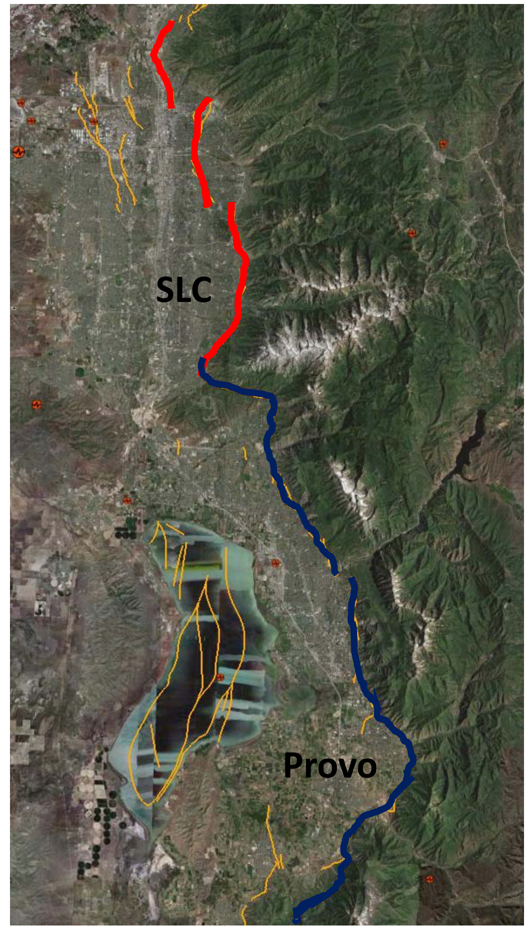
Segmented with In-fill Ruptures

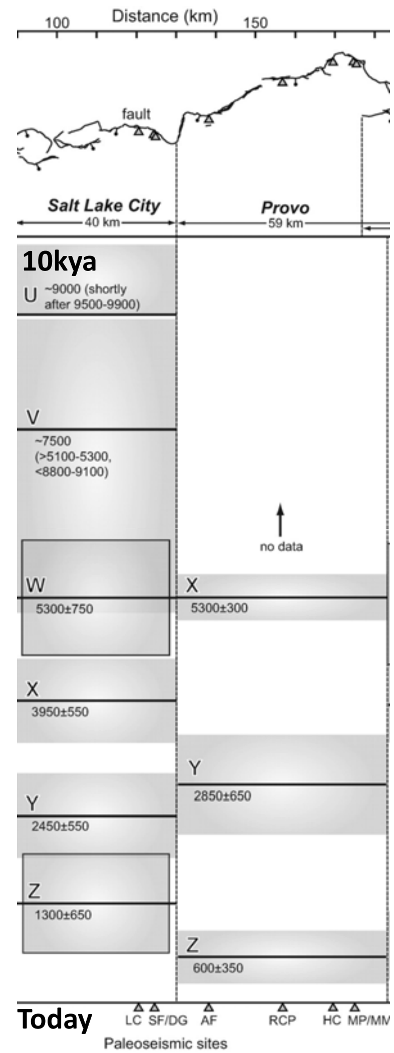


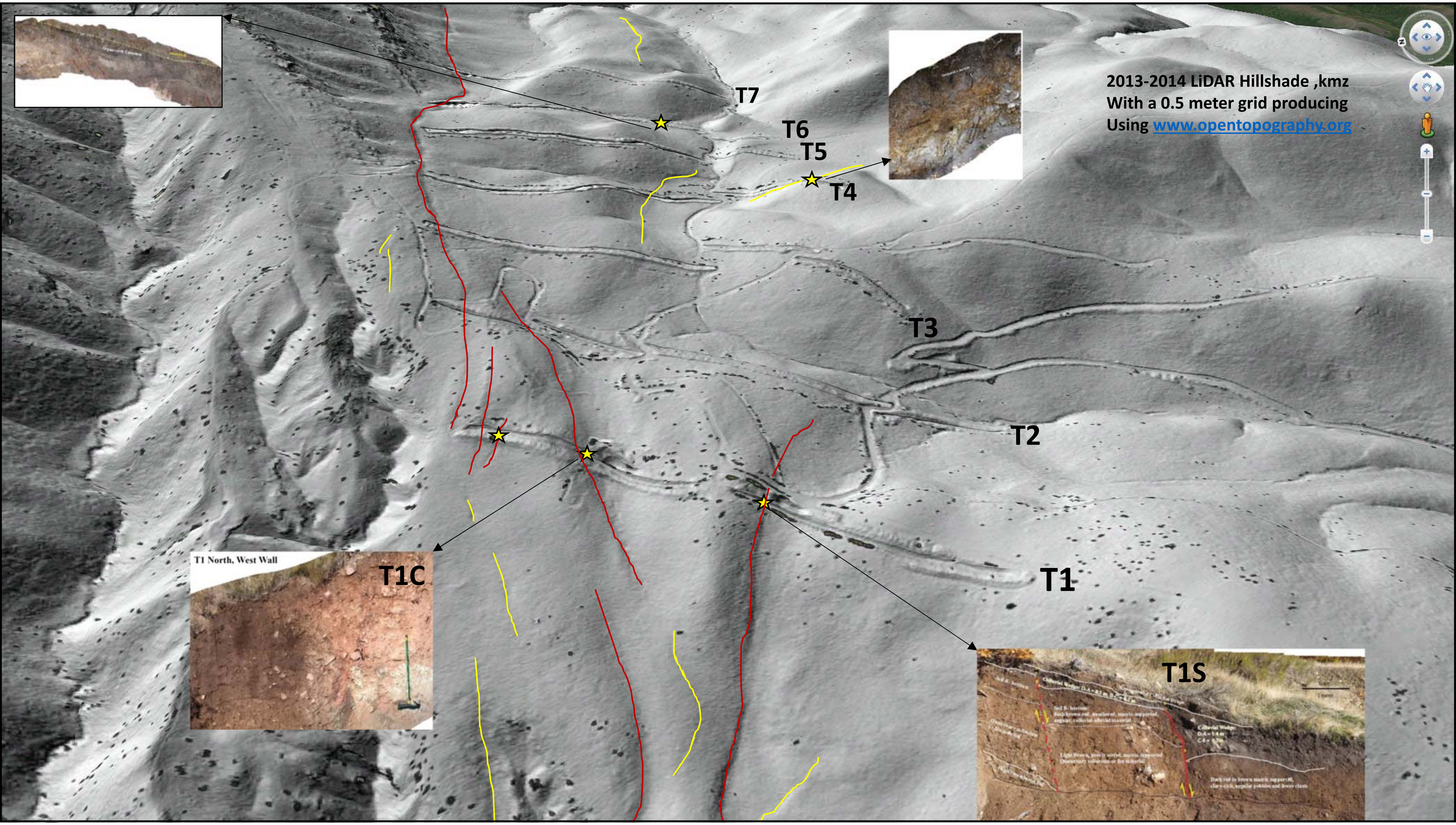
Multi-segment Ruptures



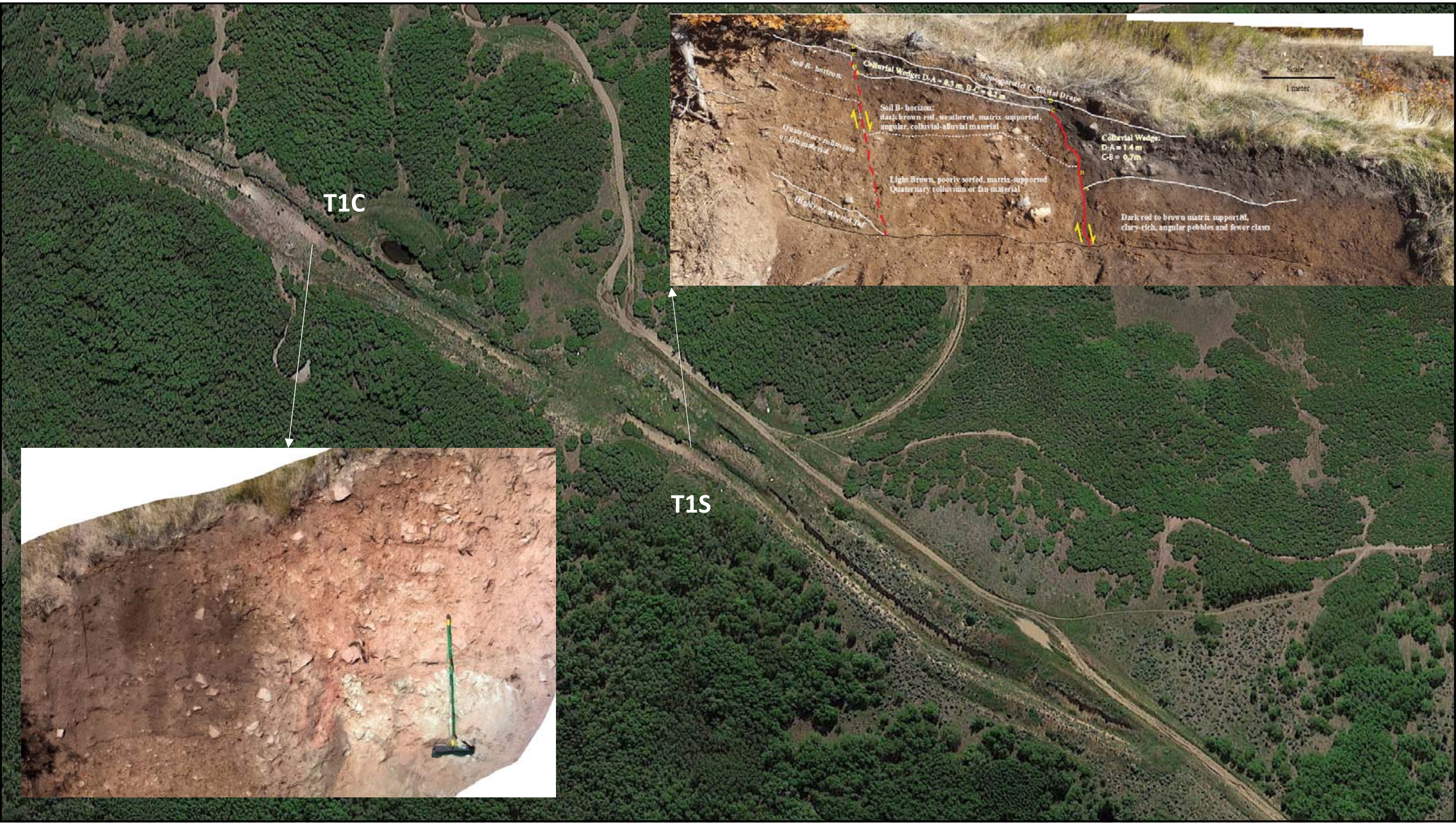
Spill-over Ruptures

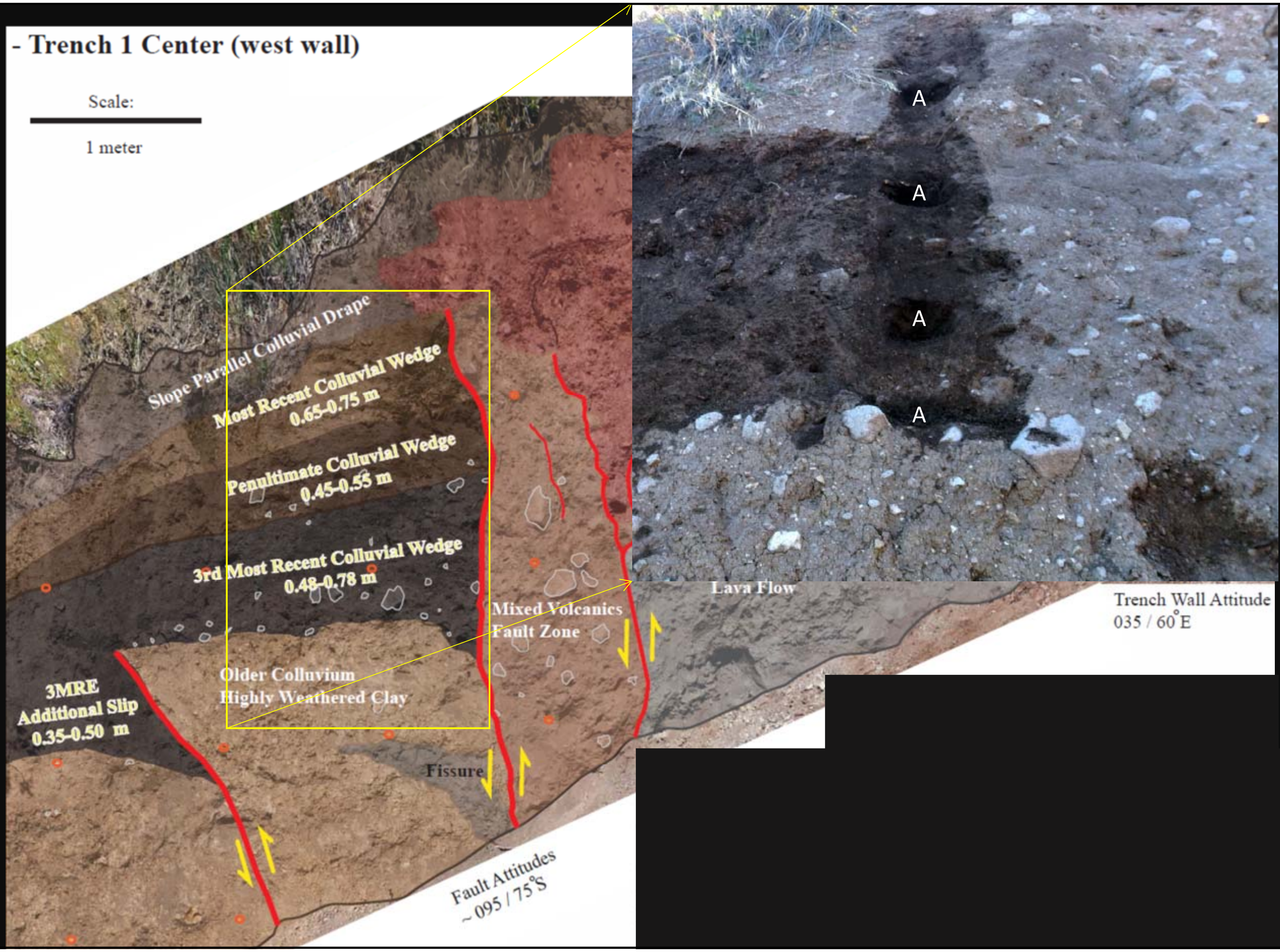





2013-2014 LiDAR Hillshade ,kmz
With a 0.5 meter grid producing
Using www.opentopography.org
T7
T6
T5
T4
T3
T2
T1
T1C
T1 North, West Wall
T1S

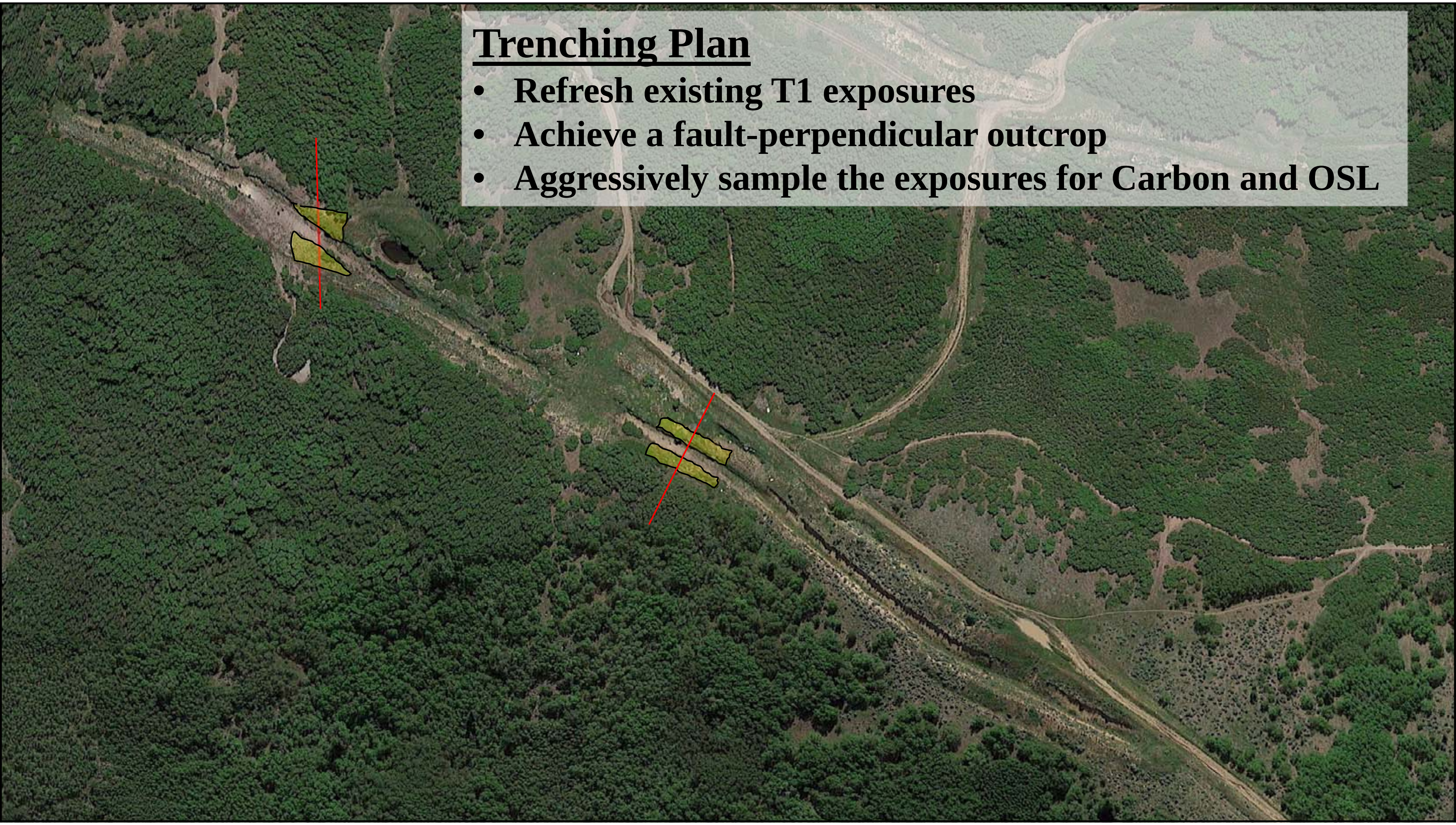

Trench 1 (westernmost)
Legend
T1


T1C
T1S
Soil B- horizon
Colluvial Wedge: D-A = 0.3 m, B-C = 0.2 m
Slope-parallel Colluvial Drape
Scale
1 meter
Soil B- horizon:
dark brown-red, weathered, matrix-supported,
angular, colluvial-alluvial material
Quaternary colluvium
or fan material
Colluvial Wedge:
D-A = 1.4 m
C-B = 0.7m
Light Brown, poorly sorted, matrix-supported
Quaternary colluvium or fan material
Highly weathered Tuf
Dark red to brown matrix supported,
clary-rich, angular pebbles and fewer clasts


- Trench 1 Center (west wall)
Scale:
1 meter
Slope Parallel Colluvial Drape
Most Recent Colluvial Wedge
0.65-0.75 m
Penultimate Colluvial Wedge
0.45-0.55 m
3rd Most Recent Colluvial Wedge
0.48-0.78 m
3MRE
Additional Slip
0.35-0.50 m
Older Colluvium
Highly Weathered Clay
Mixed Volcanics
Fault Zone
Fissure
Lava Flow
Fault Attitudes
~ 095 / 75°S
Trench Wall Attitude
035 / 60°E
A
A
A
A

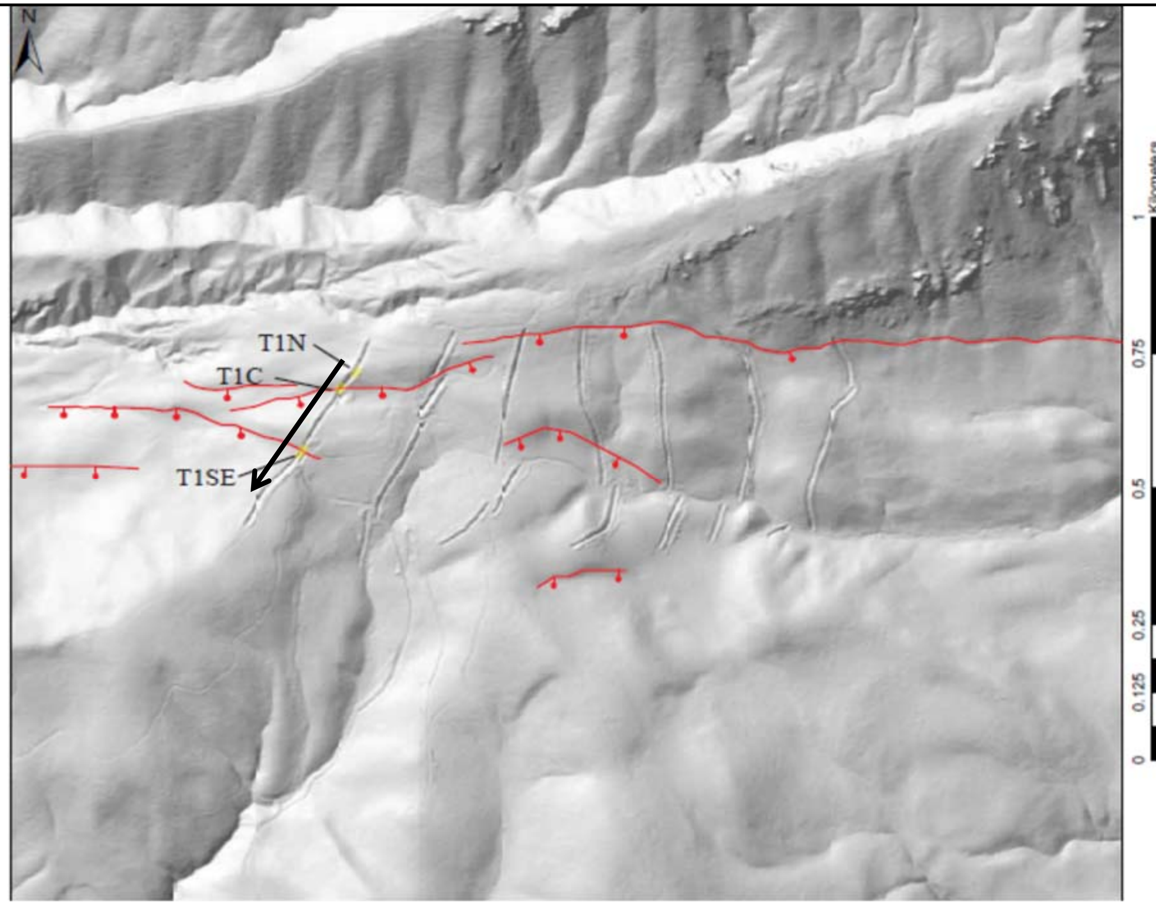
Trenching Plan

- Refresh existing T1 exposures
- Achieve a fault-perpendicular outcrop
- Aggressively sample the exposures for Carbon and OSL

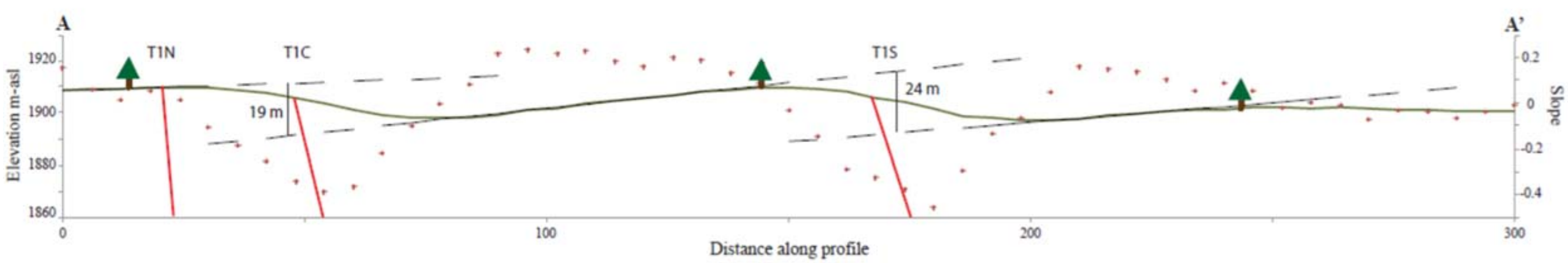


Tentative Timeline

Spring	Finalize agreement with Draper City
May	Train students using existing exposures
August 4-5th	**Re-excavation of the exposures**
August 6-26th	**Field work**
August 31st	**Trench review**
September 9th	Close trenches
Fall 2016	Geochronology and Logging Compilation
2017	Report Results – UQFPWG, SSA, and Publication



N
T1N
T1C
T1SE
Kilometers
0
0.125
0.25
0.5
0.75
1



A
A'
T1N
T1C
T1S
19 m
24 m
Elevation m-asl
1920
1900
1880
1860
Slope
0.2
0
-0.2
-0.4
0
100
200
300
Distance along profile

Table 1. Colluvial Wedge Heights, Displacement Magnitudes, and Estimated Rupture Length, Salt Lake City and Provo Segment Boundary along the Wasatch Fault - Traverse Ridge, Utah.

Location	Measurement	Apparent Height[1]	True Height[2]	Fault	Wall	*Est. Fault Slip*[3]	*Est. Rupture Length*[4]
South Exp. [5]	*South Scarp height*[6]	-	-	-	-	24 m	-
Trench-1S [7]	**Most Recent Event South Exp.**	**Min = 0.90 m Max = 1.40 m**	**0.80 m 1.25 m**	**100/70 s**	**190/73 w**	***1.4 m***	***54 km***
Central Exp.	*Central Scarp height*[6]	-	-	-	-	19 m	-
Trench-1C	**Most Recent Event Central Exp.**	**Min = 0.65 m Max = 0.75 m**	**0.50 m 0.57 m**	**095/75 s**	**035/60 e**	***0.8 m***	***32 km***
Trench-1C	**Penultimate Event Central Exp.**	**Min = 0.45 m Max = 0.55 m**	**0.34 m 0.42 m**	**095/75 s**	**035/60 e**	***0.5 m***	***24 km***
Trench-1C	**3rd Most Recent Event Central Exp.**	**Min = 0.83 m Max = 1.28 m**	**0.64 m 0.98 m**	**095/75 s**	**035/60 e**	***1.1 m***	***44 km***
North Exp.	*North Scarp Height*	Total Offset = 0 m	-	264/80 s	-	***0.0 m***	-
Trench -1N	V. Old Single Event[8]	Min = 0.60 m Max = 0.50 m	0.34 m 0.41 m	264/80 s	218/53 e	***0.5 m***	***24 km***

1 – Apparent colluvial wedge height was measured along the plane of the trench wall exposures. Trenches were sloping for safety.

2 – True colluvial wedge height was calculated by projecting the apparent wedge height (measured along the laid back trench wall exposures) into a vertical exposure.

3 – Estimated Fault slip was calculated presuming that colluvial wedge height represents ~60% of total fault slip in an earthquake due to scarp erosion.

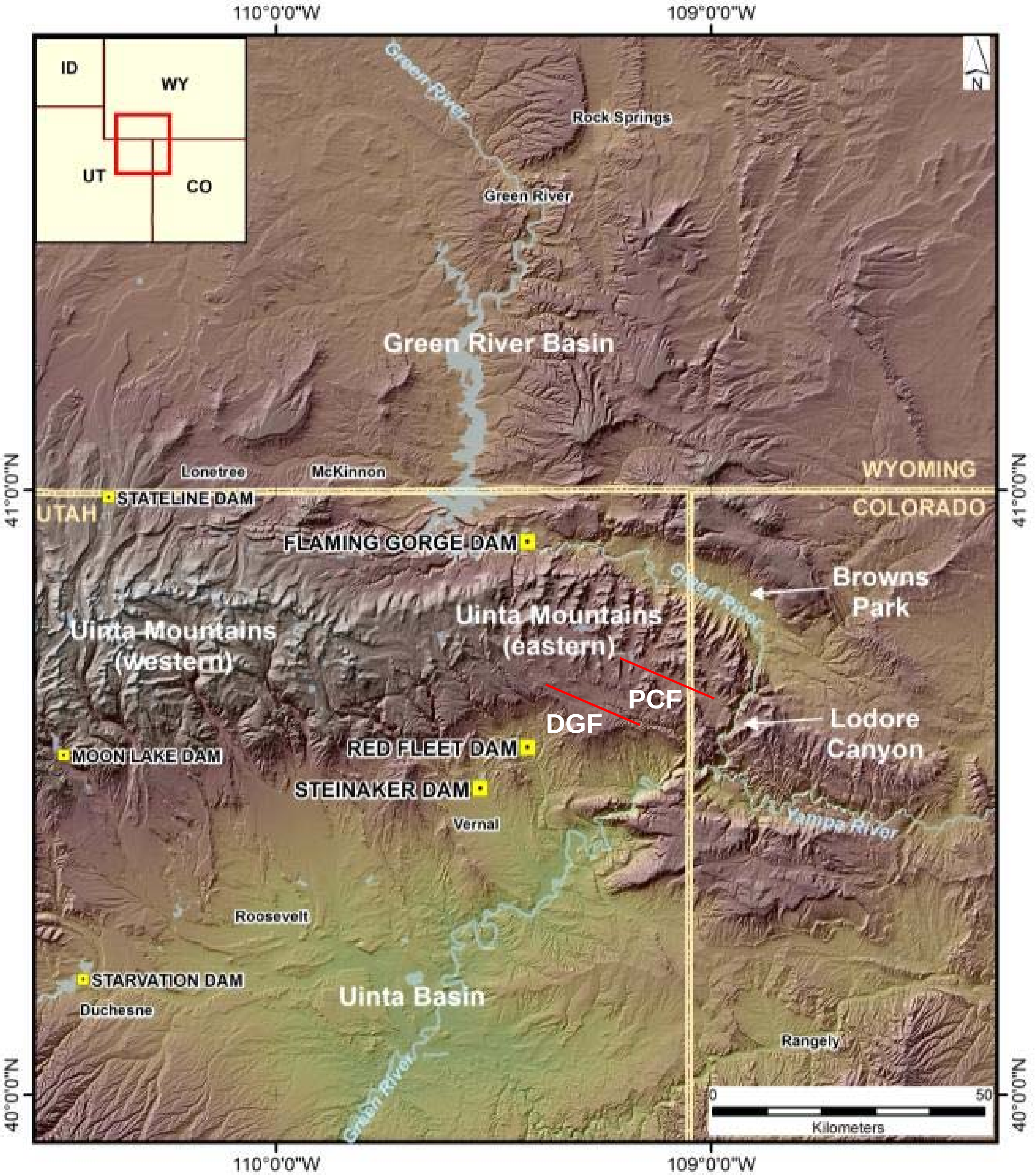
4 – Rupture lengths were estimated using the empirical equation: **Log (average displacement) = -1.99 + 1.24 Log (Surface Rupture Length)** from Wells and Coppersmith, 1994.

5 – See Site map for each trench exposure location.

6 – Scarp Heights were extracted from 2m LiDAR data (http://gis.utah.gov/data/elevation-terrain-data/2-meter-lidar/)

7 – Trench logging is shown in the middle panel of the poster.

8 – Because there is no surface scarp this event is likely Pleistocene (preBonneville) age or older.



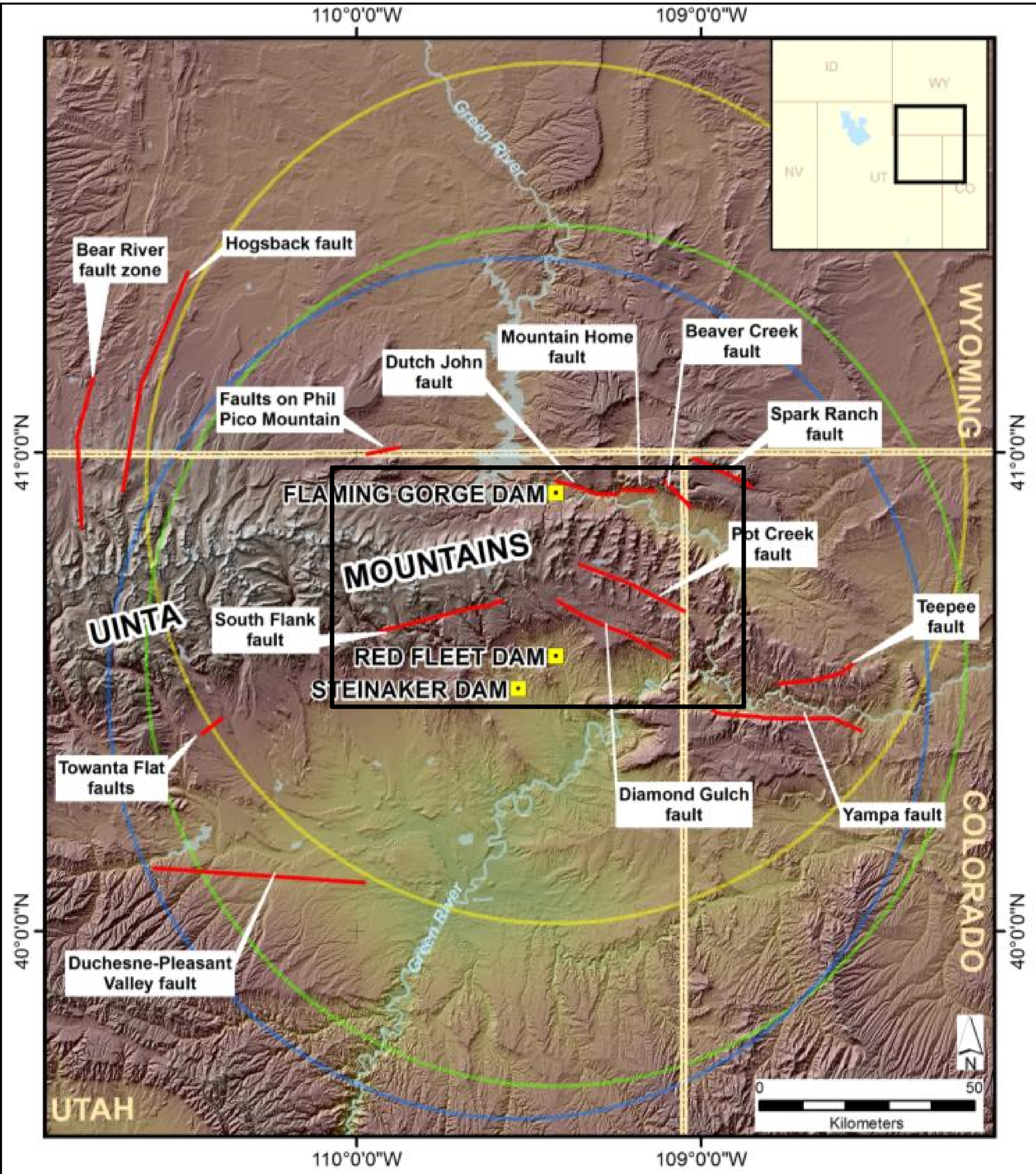
Pot Creek and Diamond Gulch faults in northeast Utah—

A preliminary evaluation

Lucy Piety
Joanna Redwine

Bureau of Reclamation

02/10/2016

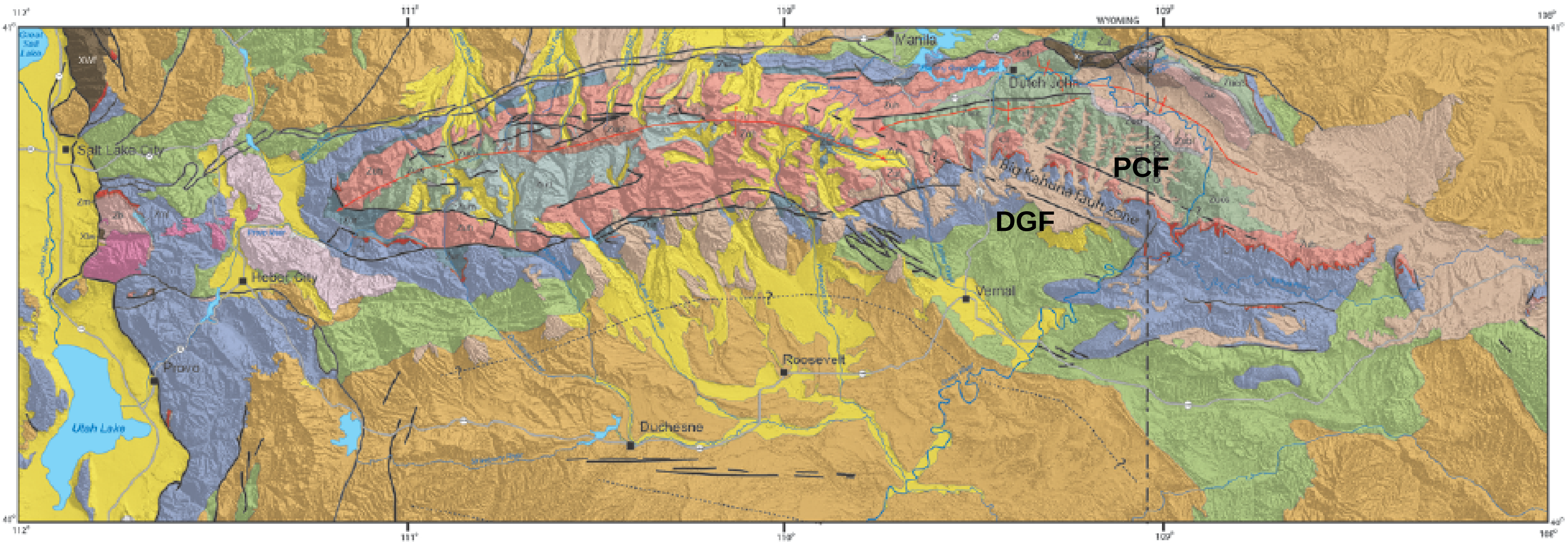


Background

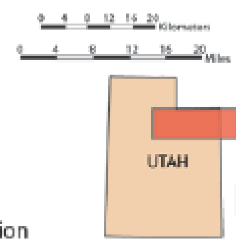
(Hansen, 1969,1986, Hansen et al., 1981; Springer, 2013, 2014; Springer et al., 2005)

- Laramide uplift of Uinta Mts.(70-34 Ma), Formation of Gilbert Erosion Surface, broad pediment (34-30 Ma)
- Deposit Bishop conglomerate from upland to the north within south-flowing drainages across the pediments (before and after 29 Ma)
- Renewed tectonic activity on rangefront faults of Uintas – tilting to the north and east (15 Ma)
- Normal faulting while Bishop cgl deposited, northwest striking faults, northeast-side down

Stratigraphic and Structural Overview of Uinta Mountains and Northern Uinta Basin



Explanation

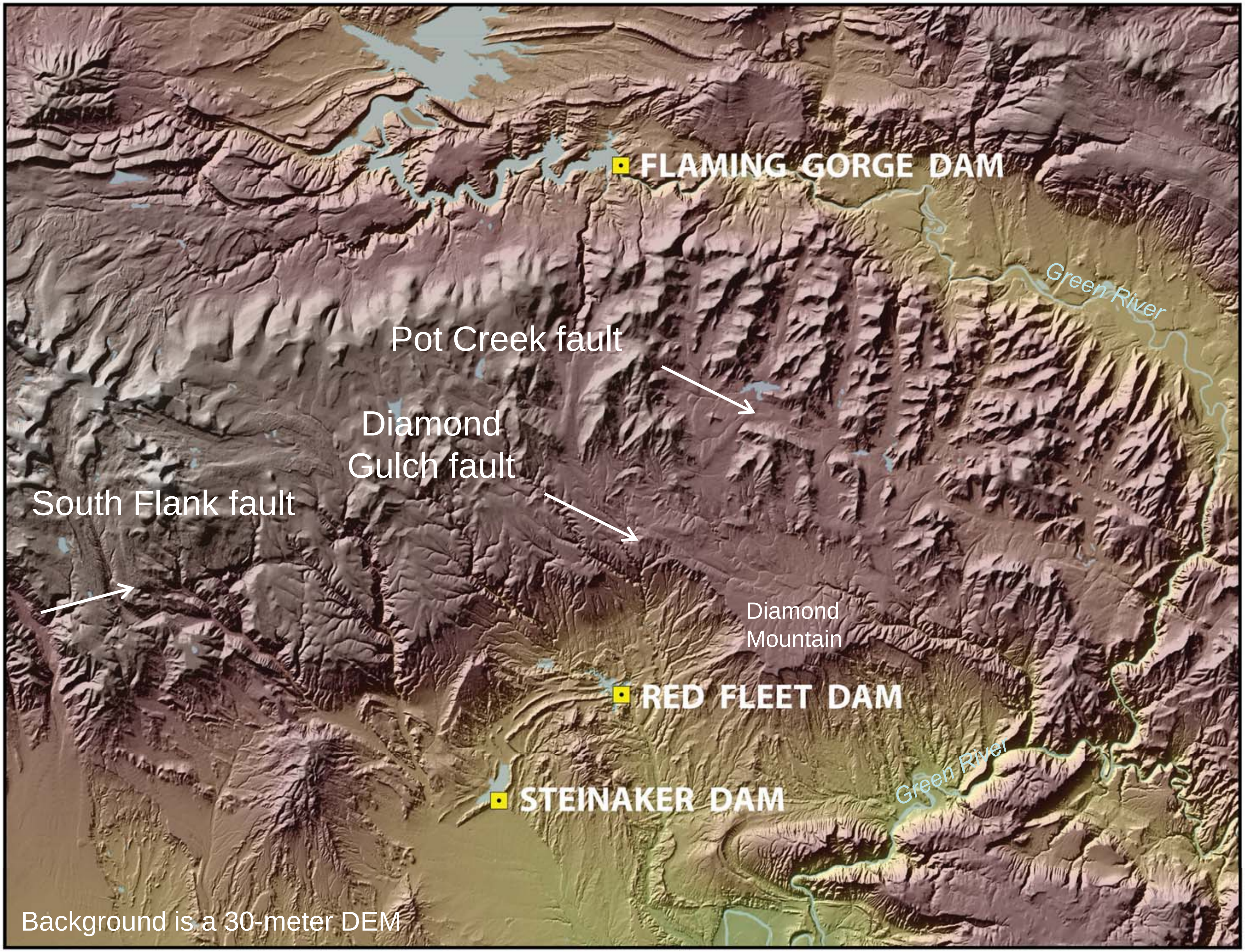


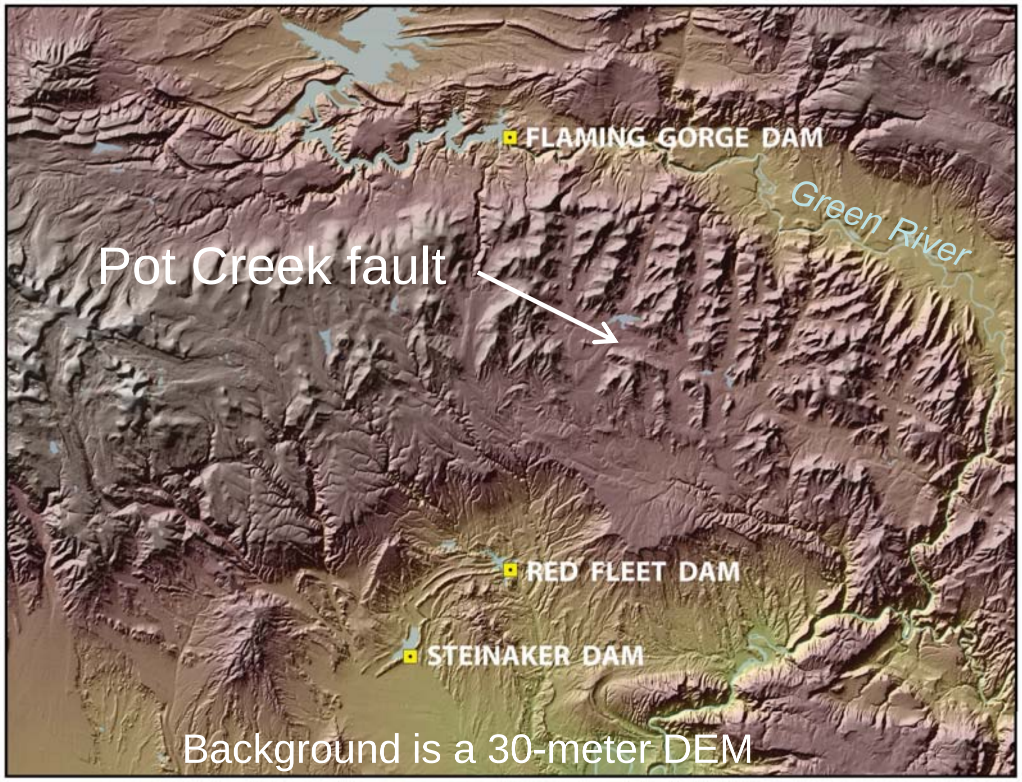
Q	Quaternary deposits	Ct	Tintic Quartzite
Tv	Volcanic rocks	Cl	Lodore Formation
Ti	Igneous intrusive rocks	Zm	Mutual Formation
Czy	Oligocene-Miocene rocks	Zmf	Mineral Fork Tillite
Czo	Paleocene-Eocene rocks	Zb	Big Cottonwood Group
Mz	Mesozoic rocks	Zuu	Uinat Mountain Group, undivided
Pz	Paleozoic rocks	Zur	Red Pine Shale

Zuh	Hades Pass formation	Zuo	Outlaw Trail formation
Zucu	Red Castle formation, upper	Zub	Diamond Breaks formation
Zuw	Mt Watson Formation	Zuj	Jesse Ewing Canyon Formation
Zud	Dead Horse Pass formation	Xr	Red Creek Quartzite
Zucl	Red Castle formation, lower	Xlw	Little Willow Series
Zucc	Crouse Canyon formation	XWf	Farmington Canyon Complex
Zum	Moosehorn Lake formation		

normal faults
thrust-reverse faults
? Buried faults
concealed faults
anticline

Slide from Doug Sprinkle (2013, presentation at AAPG)


FLAMING GORGE DAM
Green River
Pot Creek fault
Diamond
Gulch fault
South Flank fault
Diamond
Mountain
RED FLEET DAM
STEINAKER DAM
Green River
Background is a 30-meter DEM

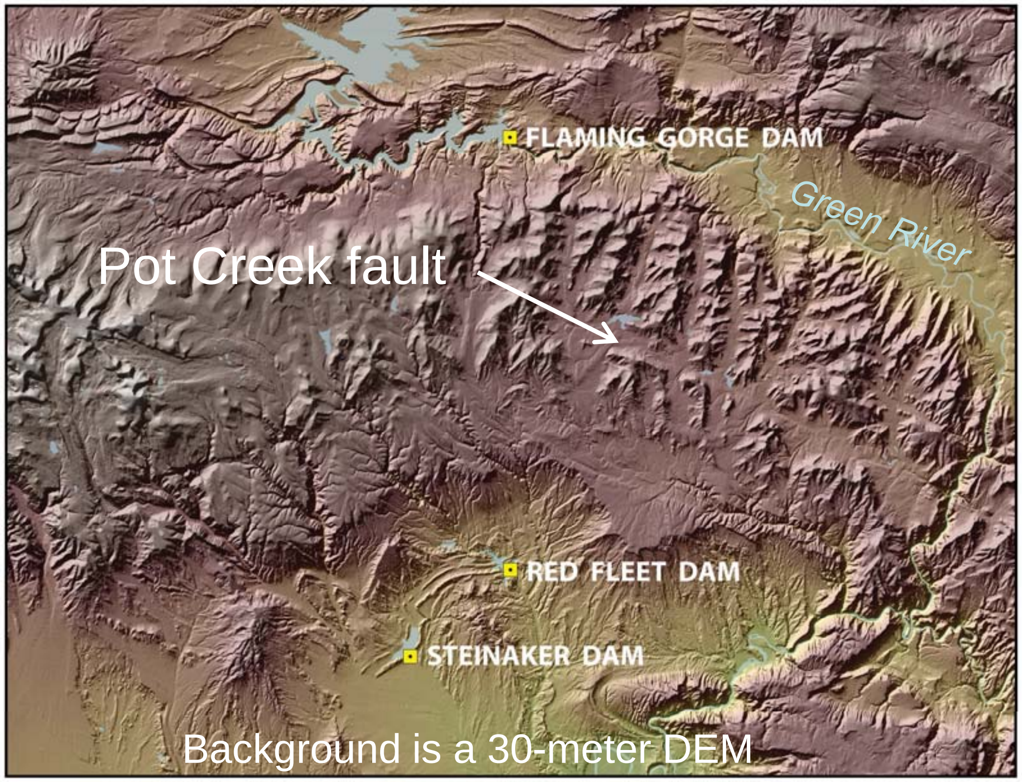


Questions:

- Is Pot Creek fault active?
- If yes, what type of motion and what is the recurrence interval/slip rate?

Previous Interpretations / New thoughts

- Previous studies considered this fault inactive (Piety and Vetter, 1999) or unlikely to be active (50%) (Wong et al., 2000).
- Inactive interpretation in part based on unlikely orientation (northwest striking) of a normal fault in what ‘should’ be east-west extension.
  - Data points sparse in this region and is it possible this is a transition area between the east-west extensional stress region to west and northeast extension in western and southwestern Colorado.

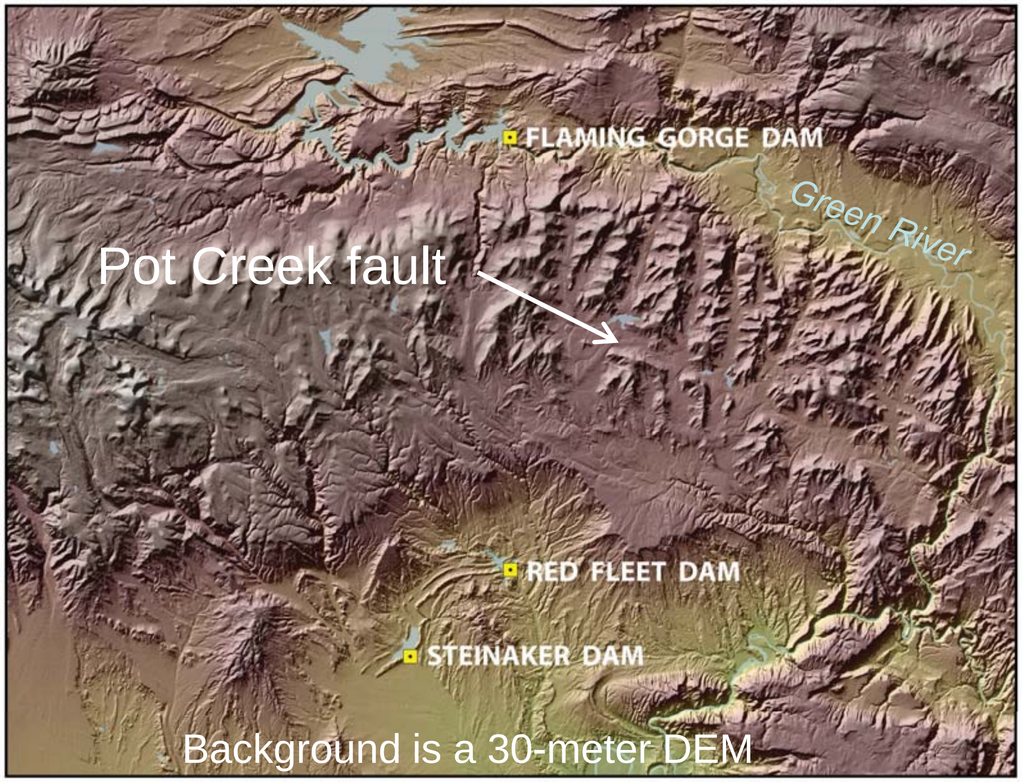


Questions:

- Is Pot Creek fault active?
- If yes, what type of motion and what is the recurrence interval/slip rate?

Previous Interpretations / New thoughts

- Hansen et al. (1981) and Hansen (1986) interpreted Pot Creek fault as a Tertiary Normal fault. Could the unexpected orientation be because this is a reactivated fault?
- Hansen (1986) and Sprinkle (2005) both reported suspected normal faulting that cut probable Quaternary deposits along the Pot Creek fault.



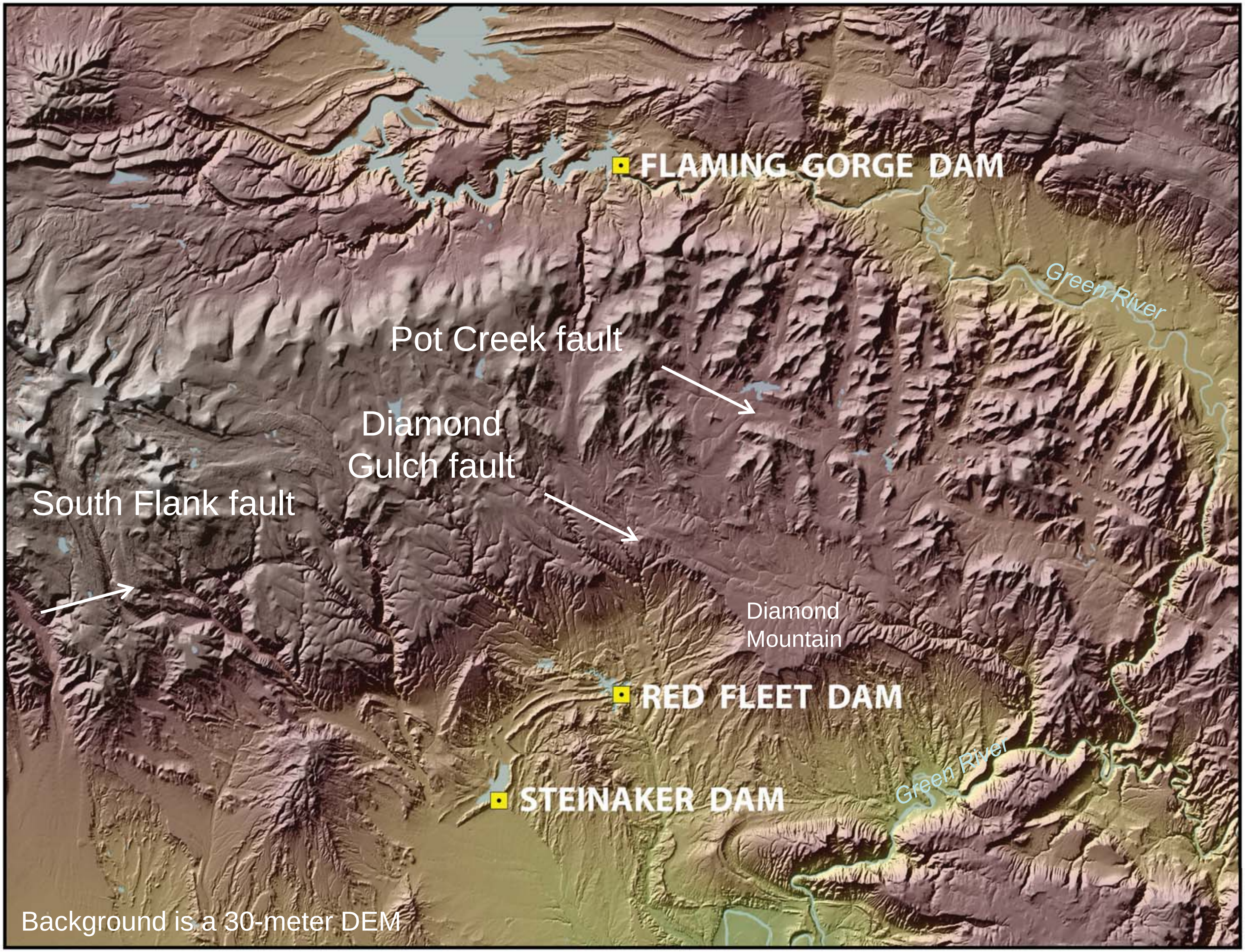
Questions:

- Is Pot Creek fault active?
- If yes, what type of motion and what is the recurrence interval/slip rate?

Observations that suggest Quaternary activity

(Liu and Piety, 2015)

- Topographic expression along the fault for ~30 km
- Inset surfaces with progressively less offset at scarps and less incision into the surfaces
- Drainages appear disrupted: bend at the fault and have been abandoned
- Alternating north and south-facing scarps along same lineament
- Apparently right-laterally offset surfaces


FLAMING GORGE DAM
Green River
Pot Creek fault
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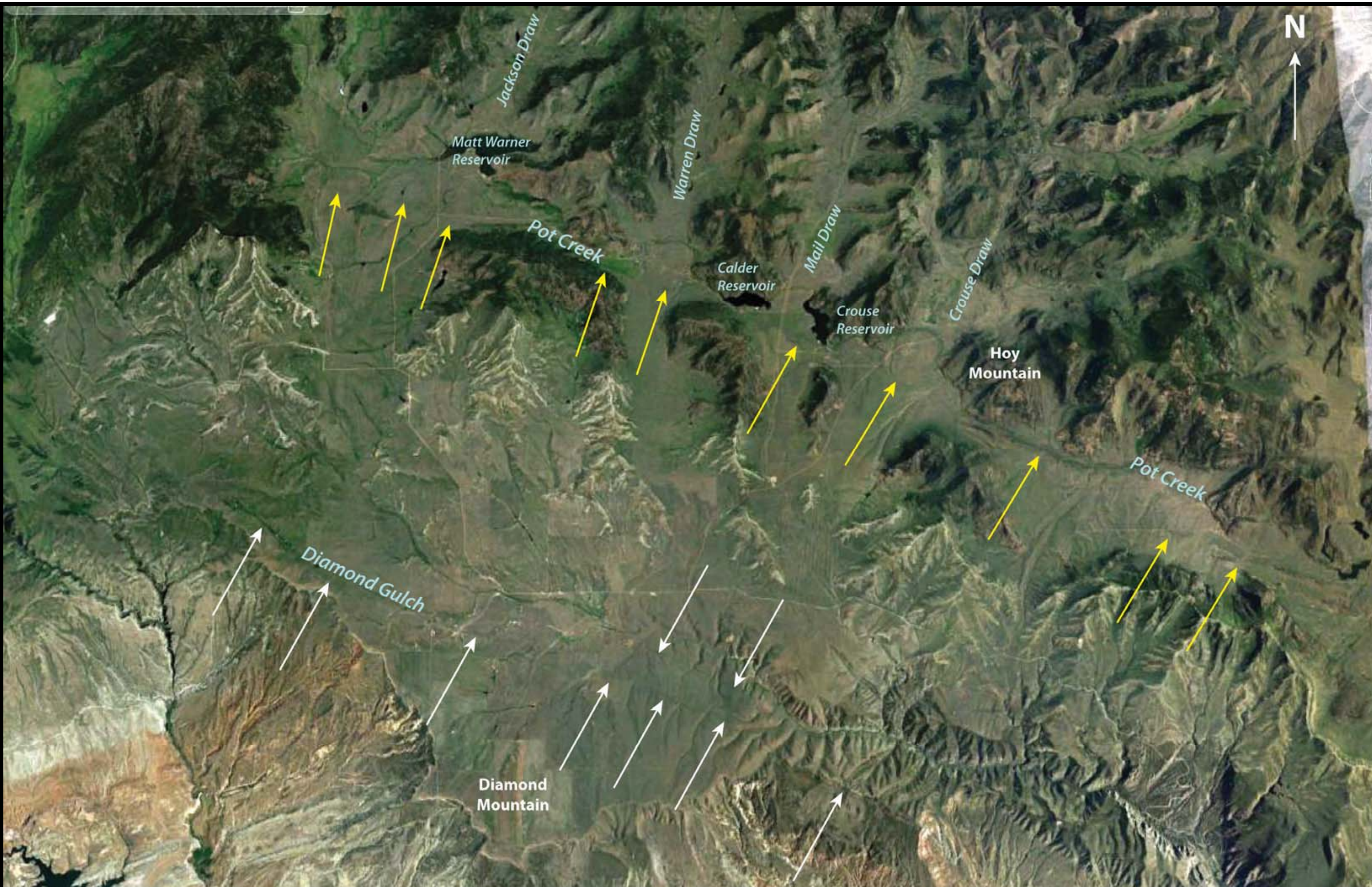
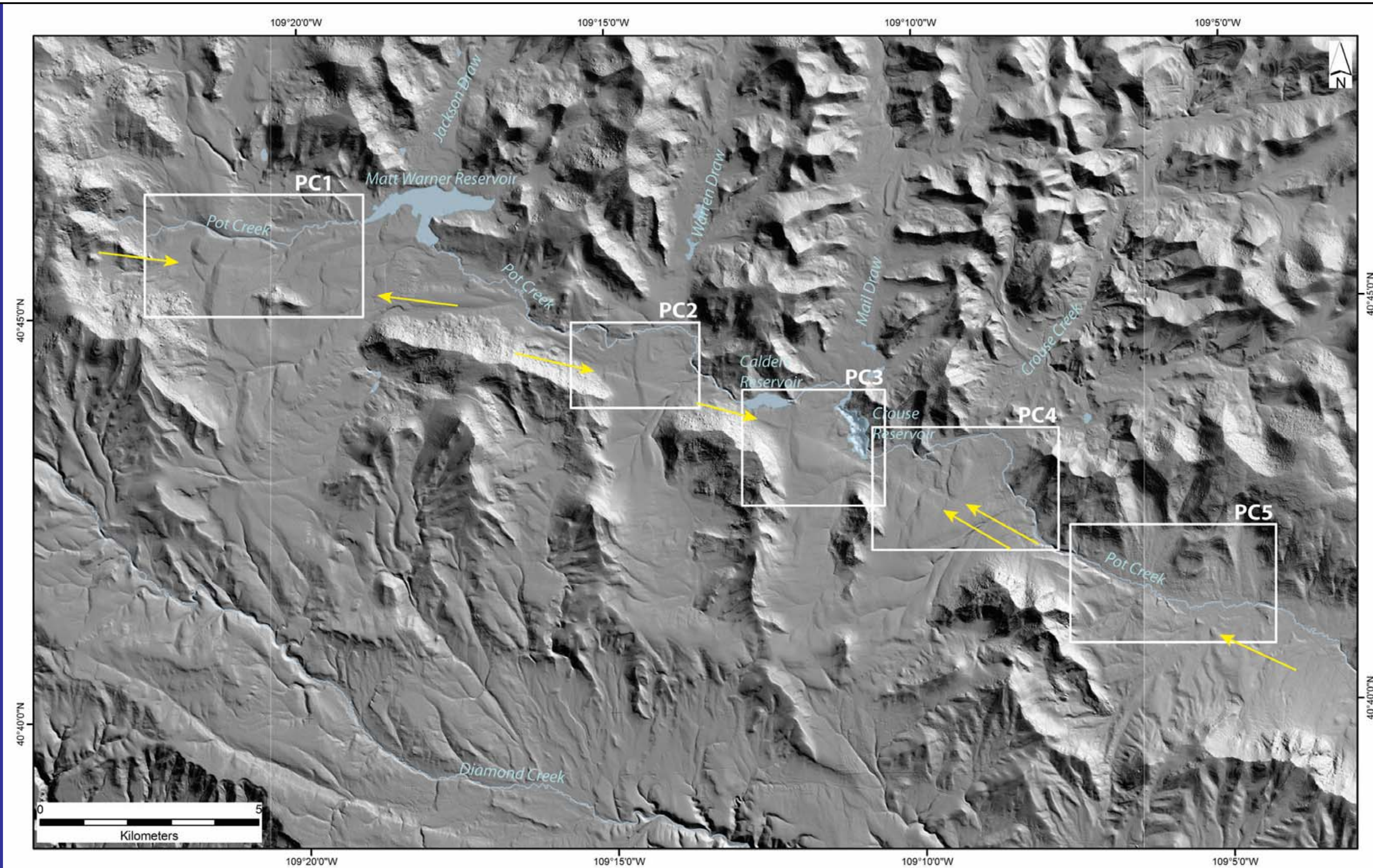
Green River
Background is a 30-meter DEM



Pot Creek fault (yellow arrows) Diamond Gulch fault (white arrows)

Topographic Expression of fault(s)

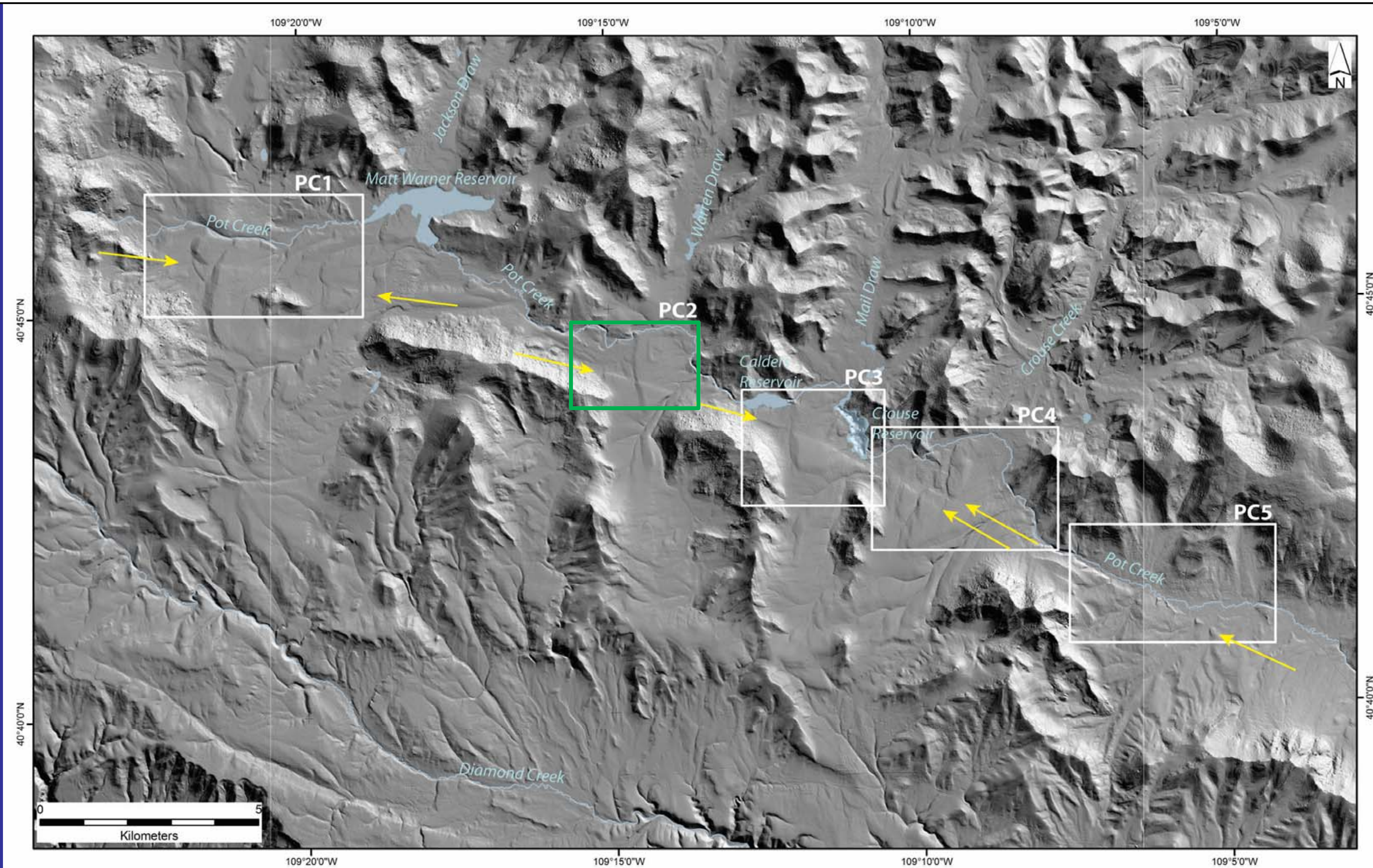


Geomorphic expression of the Pot Creek fault

Hillshades created from 5-meter DEMs from UGS

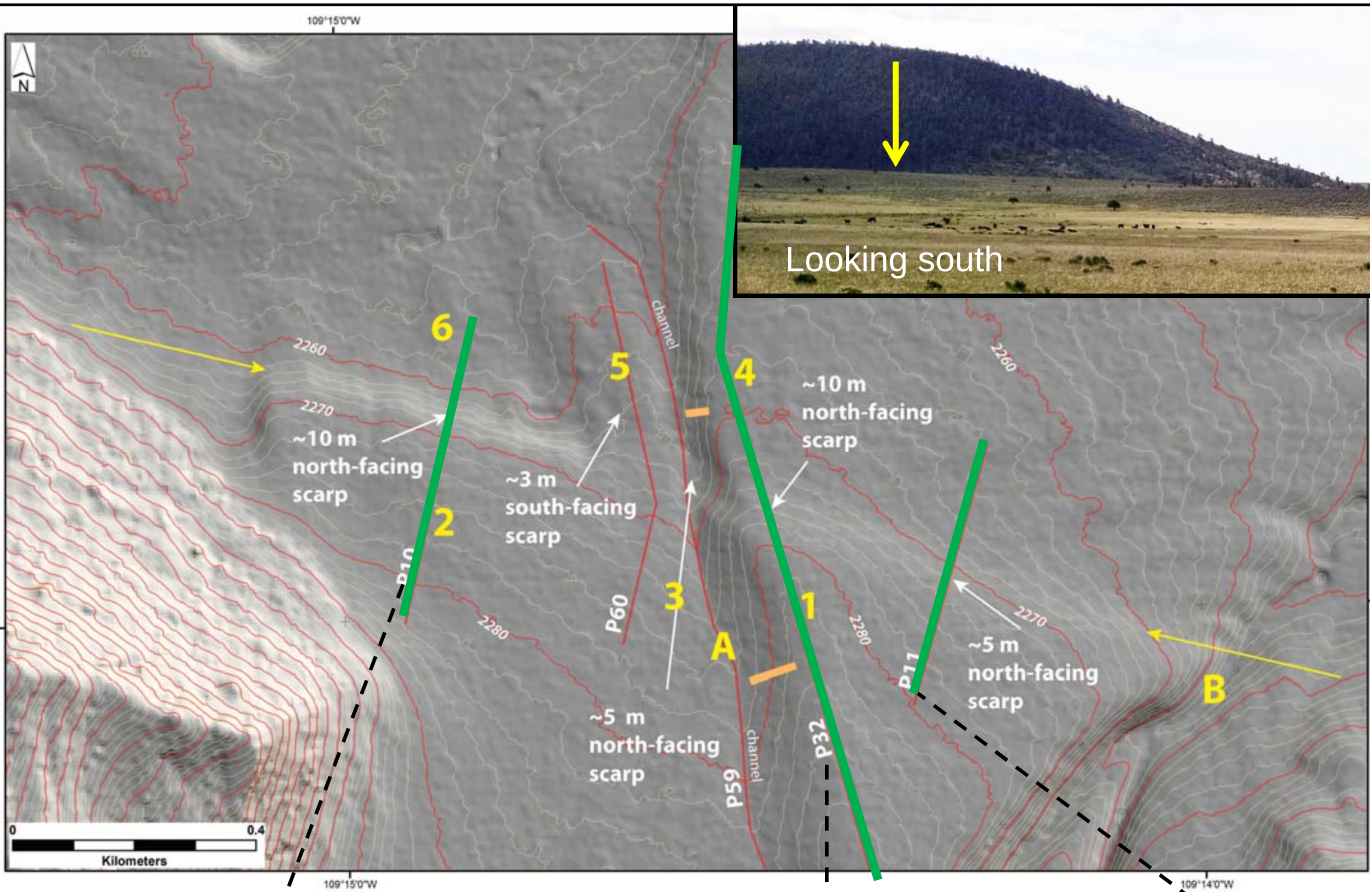
Pot Creek fault looking southeast

Areas PC3 (foreground) and PC4 (background)



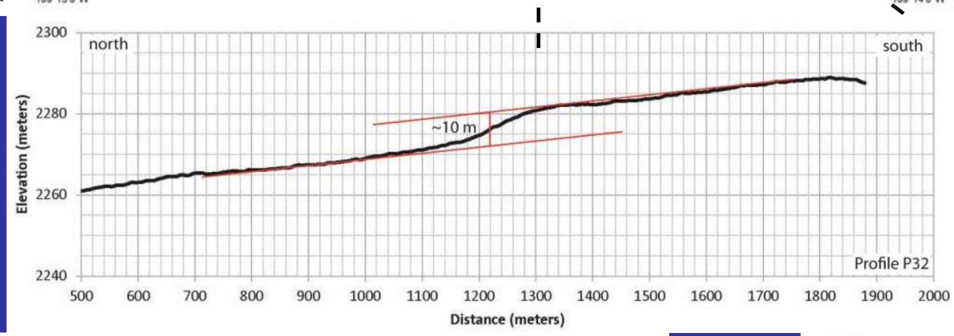
Geomorphic expression of the Pot Creek fault

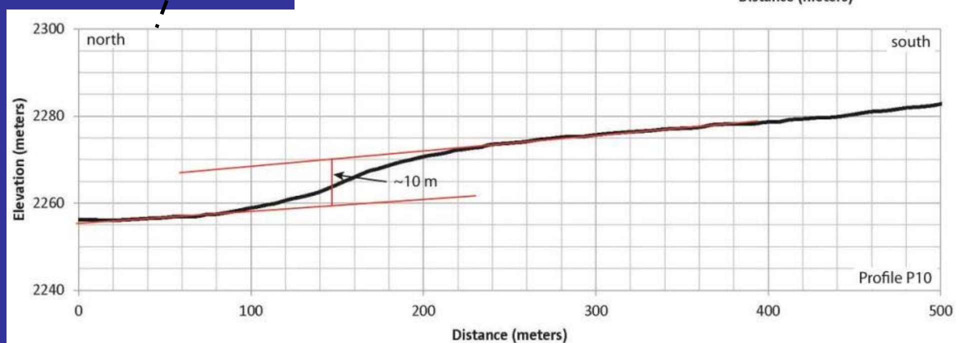
Hillshades created from 5-meter DEMs from UGS

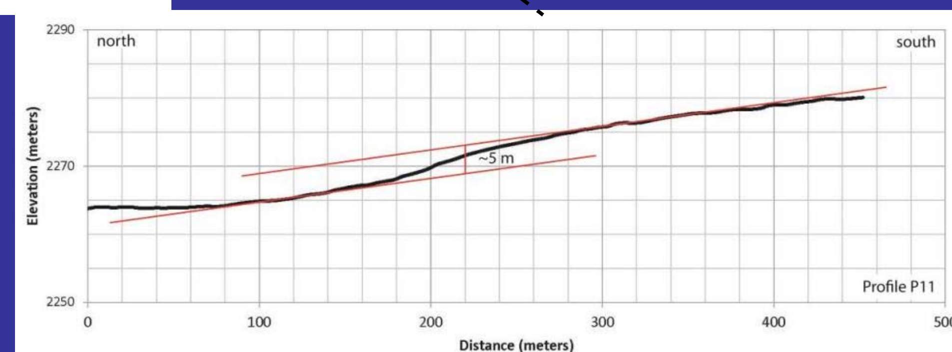


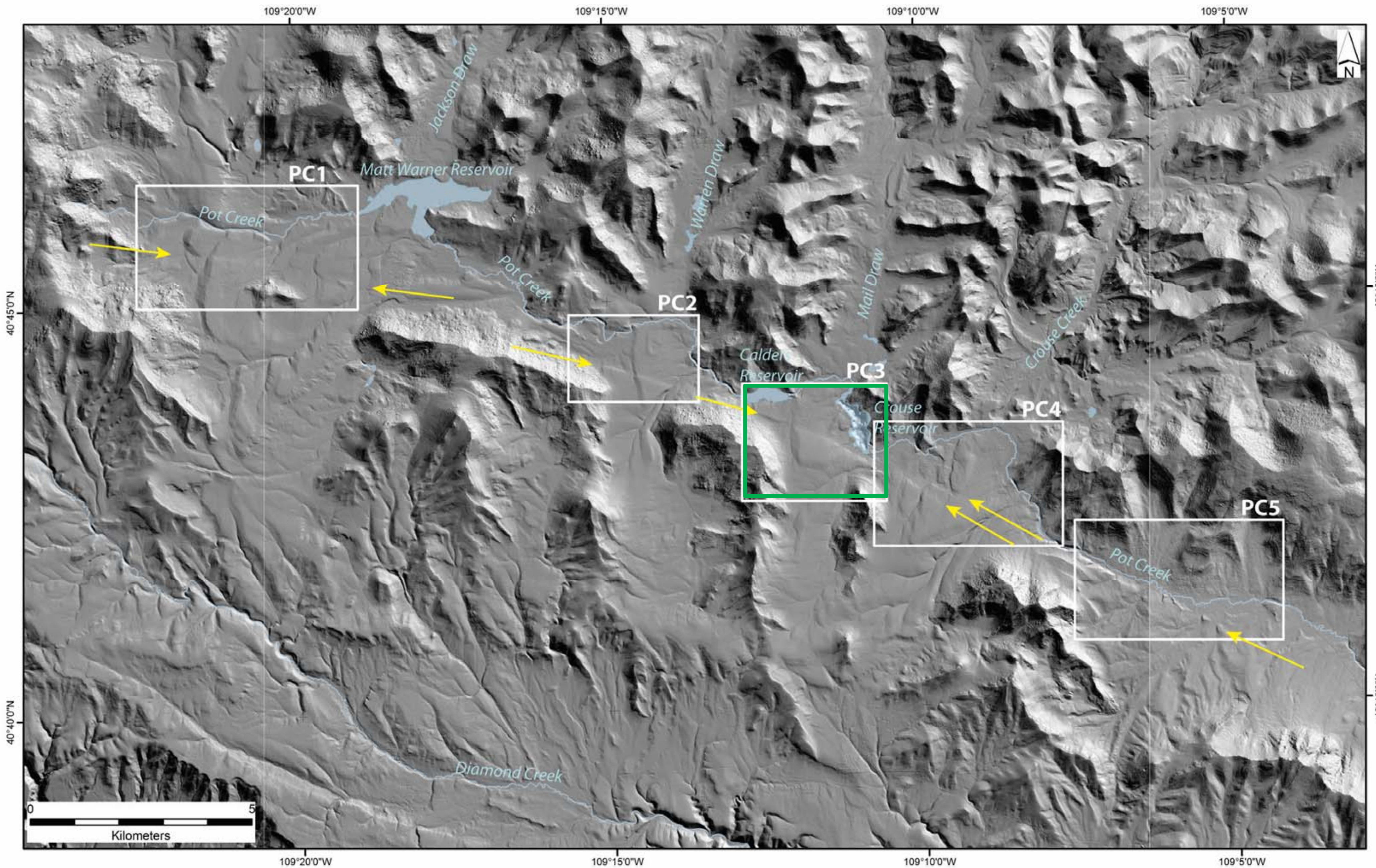
Area PC2

- North-facing scarps ~10 and 5 m
- South-facing scarps ~3 m
- Surfaces of three heights above the drainage on both sides of the scarps
- Change in incision at the scarps (orange lines)



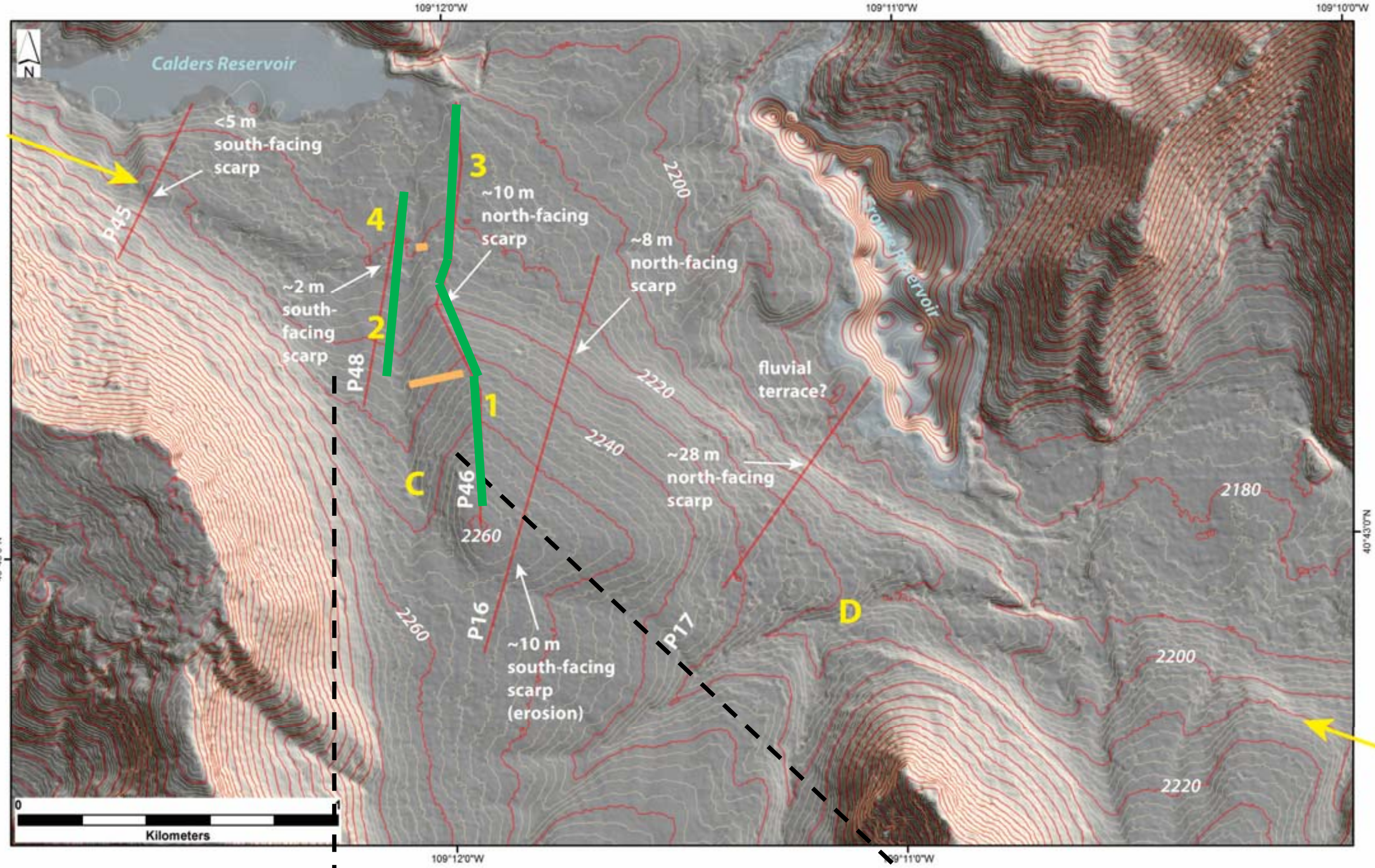






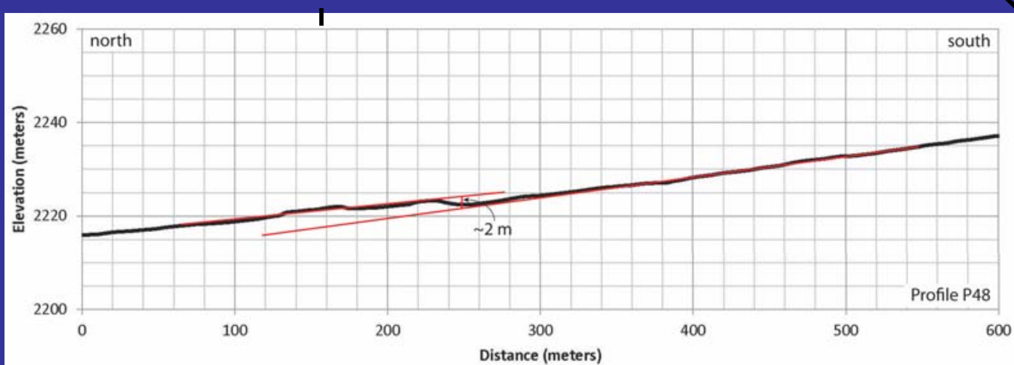
Geomorphic expression of the Pot Creek fault

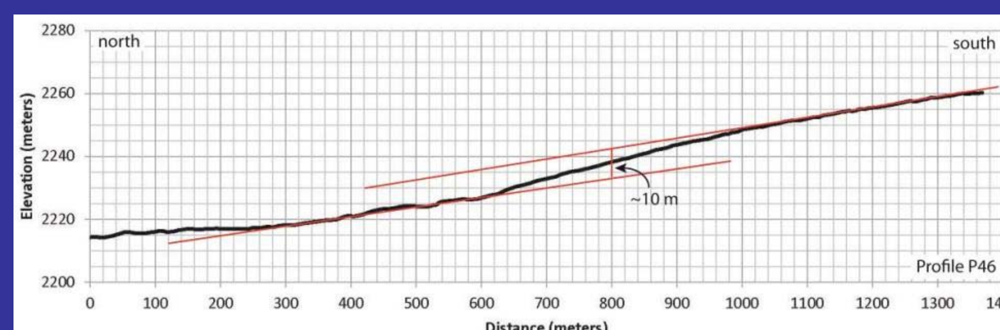
Hillshades created from 5-meter DEMs from UGS

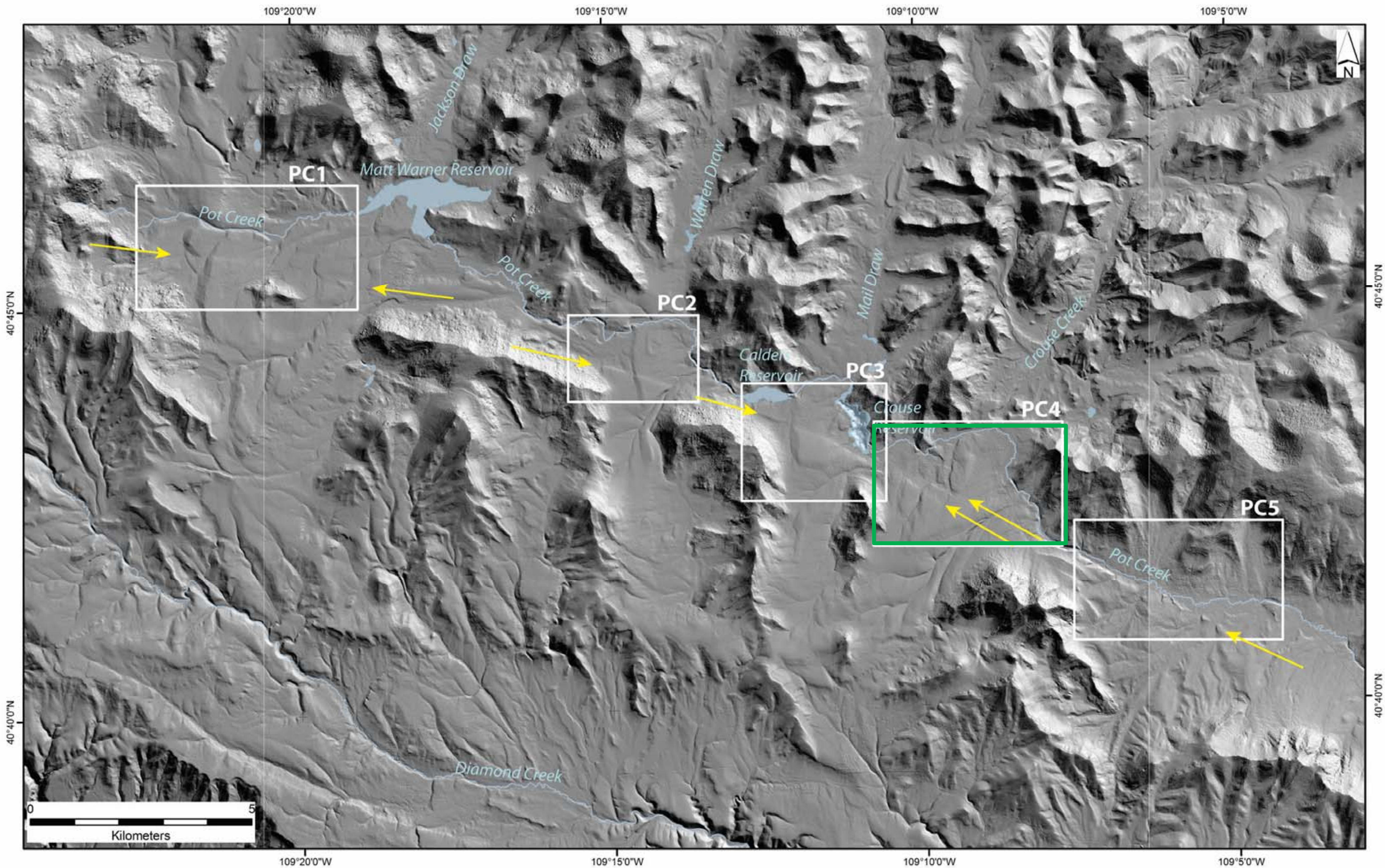


Area PC3

- North-facing scarps ~10 and 8 m
- South-facing scarps ~2 m
- Surfaces of two heights above the drainage on both sides of the scarps
- Change in incision at the scarps (orange lines)
- Do surfaces 1 &2 correlate to 3&4?
- Drainage ‘C’ now abandoned and ‘D’ is instead active





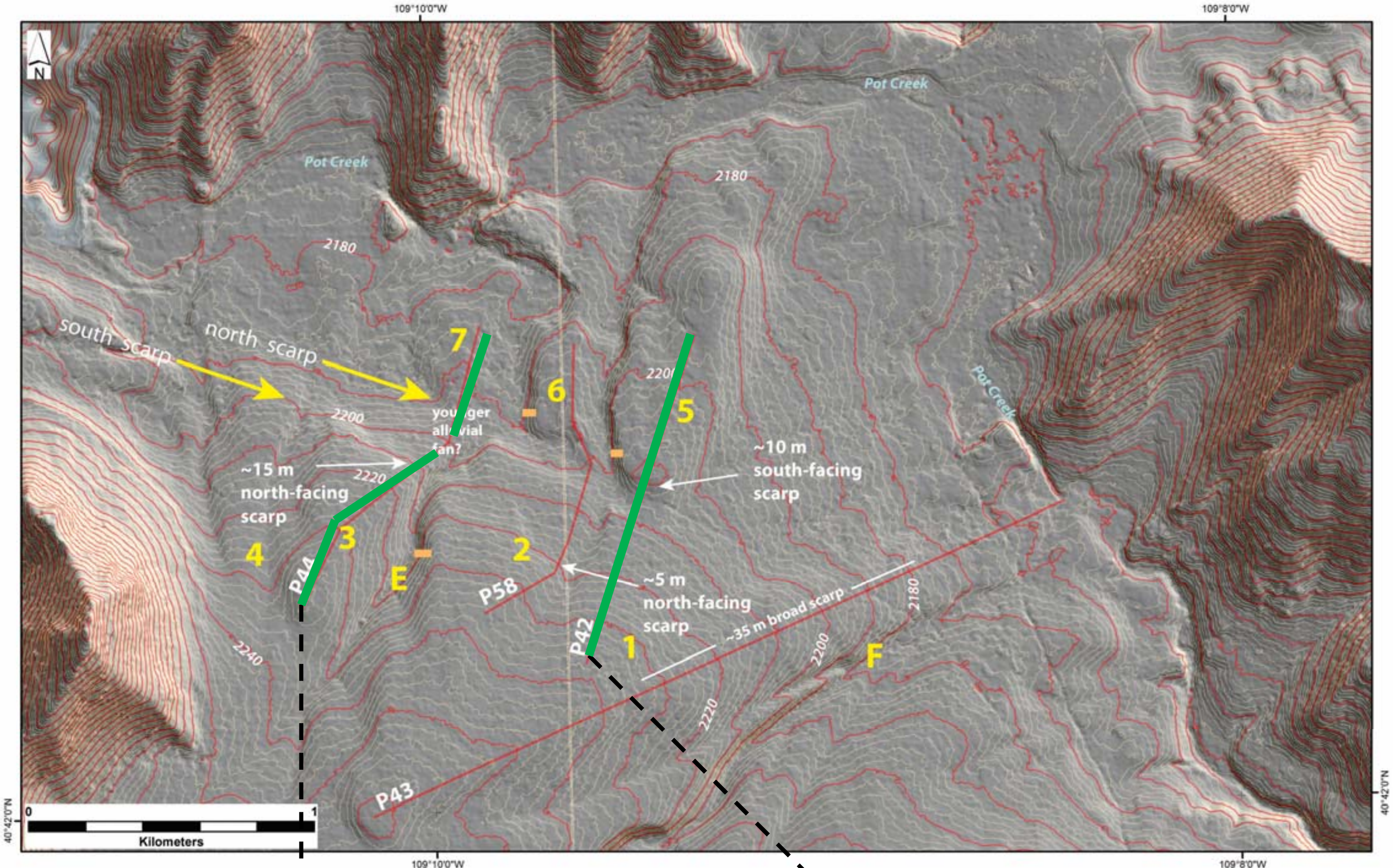


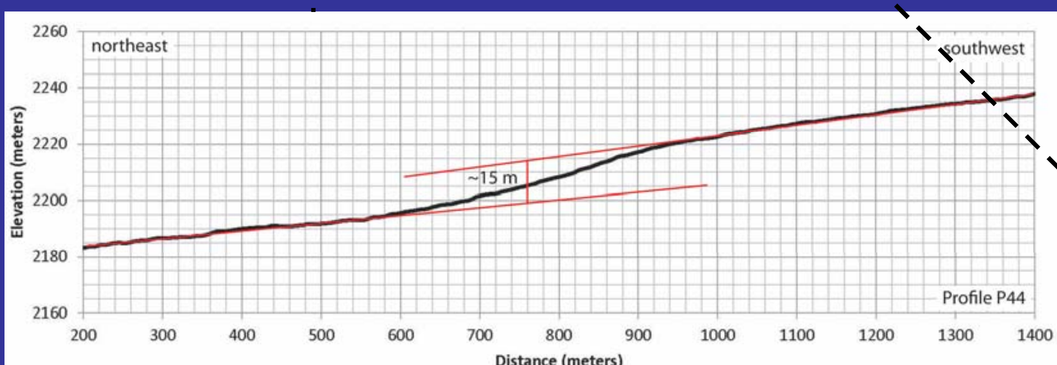
Geomorphic expression of the Pot Creek fault

Hillshades created from 5-meter DEMs from UGS

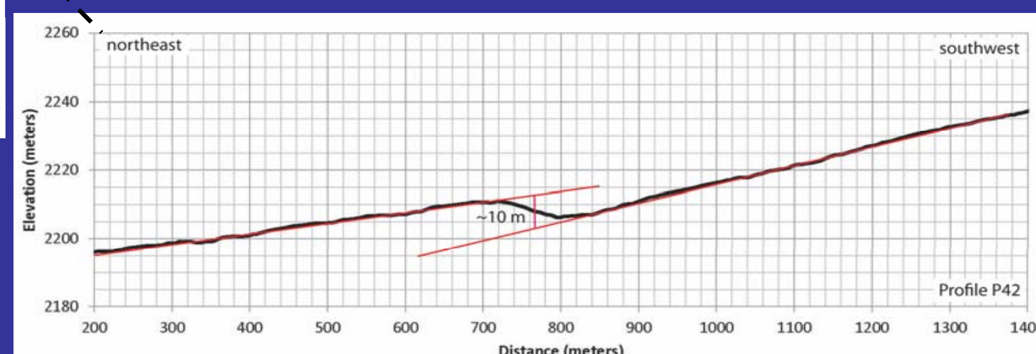
Area PC4

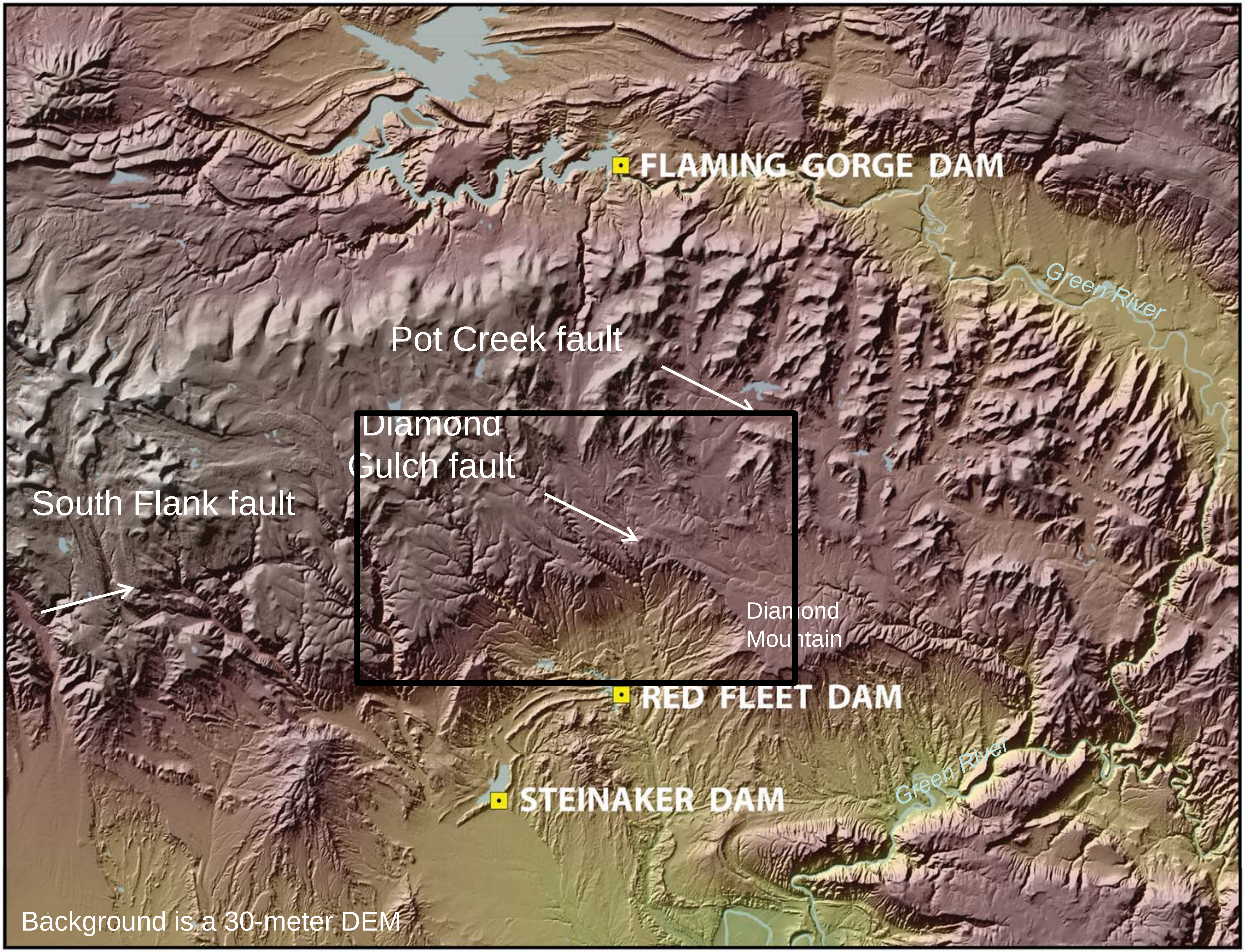
- Two north-facing scarps
- North-facing scarps ~15 and 5 m
- South-facing scarps ~10 m (eroded in part?)
- Surfaces of four heights above the drainage south of the scarps and three heights north of the scarps
- Change in incision at the scarps (orange lines)
- Do surfaces 2-4 correlate to 5-7?
- Drainage 'E' now abandoned and 'F' is instead active

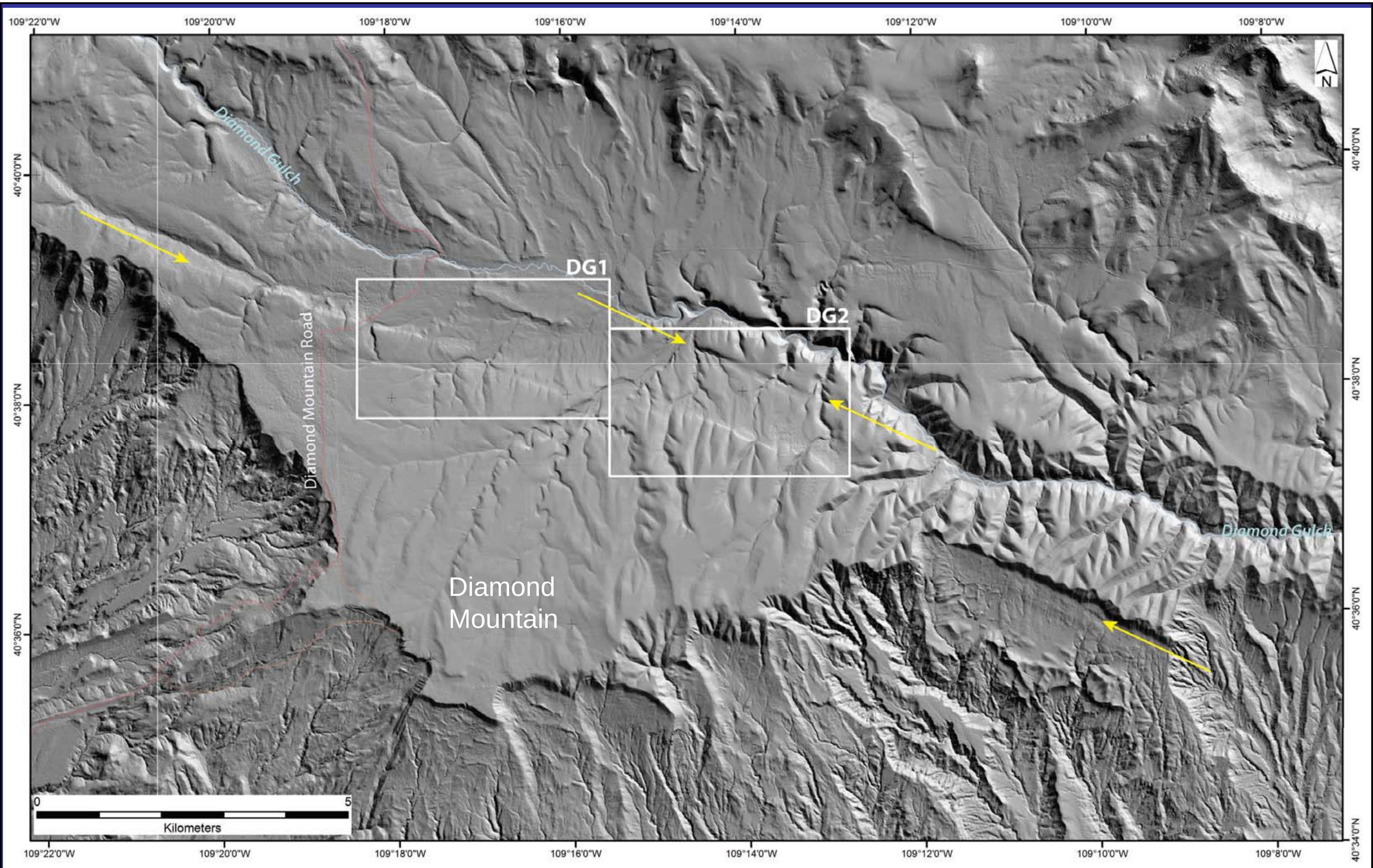




- Surfaces 5&6 are beheaded and they slope to the north, along with the modern channels



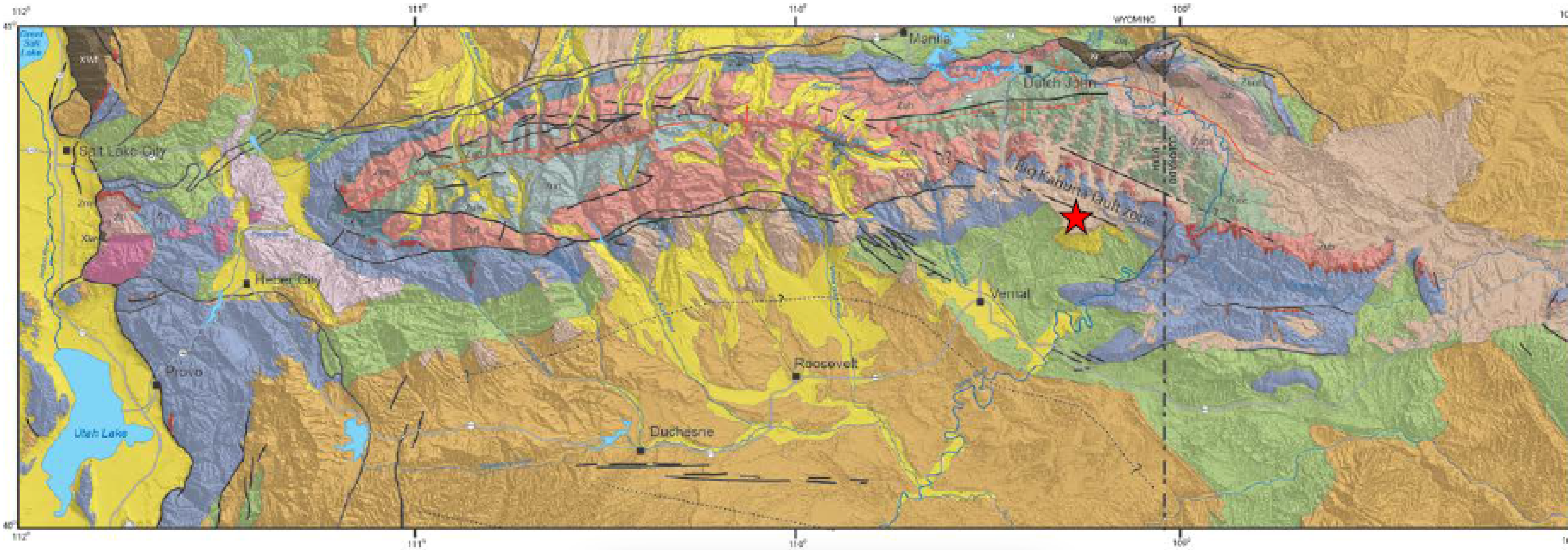

FLAMING GORGE DAM
Green River
Pot Creek fault
Diamond
Gulch fault
South Flank fault
Diamond
Mountain
RED FLEET DAM
STEINAKER DAM
Green River
Background is a 30-meter DEM



Geomorphic expression of the Diamond Gulch fault

Hillshades created from 5-meter DEMs from UGS

Age of Highest Piedmont Gravel



Slide from Doug Sprinkle (2013; presentation at AAPG)

Photograph by Nickolas Patch

- Piedmont gravel deposited on Bishop Conglomerate
- Mapped on Diamond Plateau, Yampa Plateau, and outliers in Ashley Valley
- U-series age obtained from innermost layer of laminated carbonate rind on boulders
- Age is 173±4 ka to 187±11 ka
- Approximates depositional age of gravel

Conclusions – Tentative and Preliminary

- Surfaces are Quaternary
  - Inset surfaces appear to be cut by modern (though abandoned) north-directed drainages
  - Surfaces are likely pediments cut into the Bishop cgl, with re-worked Bishop cgl gravels overlying the erosional surface
  - Age of surfaces along Pot Creek unknown, but presumed some may be similar in age to those identified and dated by Sprinkle et al. (2013).

- Fault is presumed Quaternary-active based on:
  - geomorphic expression
  - different scarp heights and amount of incision of progressively inset surfaces
  - Recurrence Interval is long and/or surface displacements small /event (broad scarps)

- Fault is right lateral strike-slip or trans-tensional based on:
  - Alternating south and north-facing scarps across same lineament
  - Relatively straight trace
  - Possible correlative surfaces across the fault with apparent right-lateral offset

- More Work is needed

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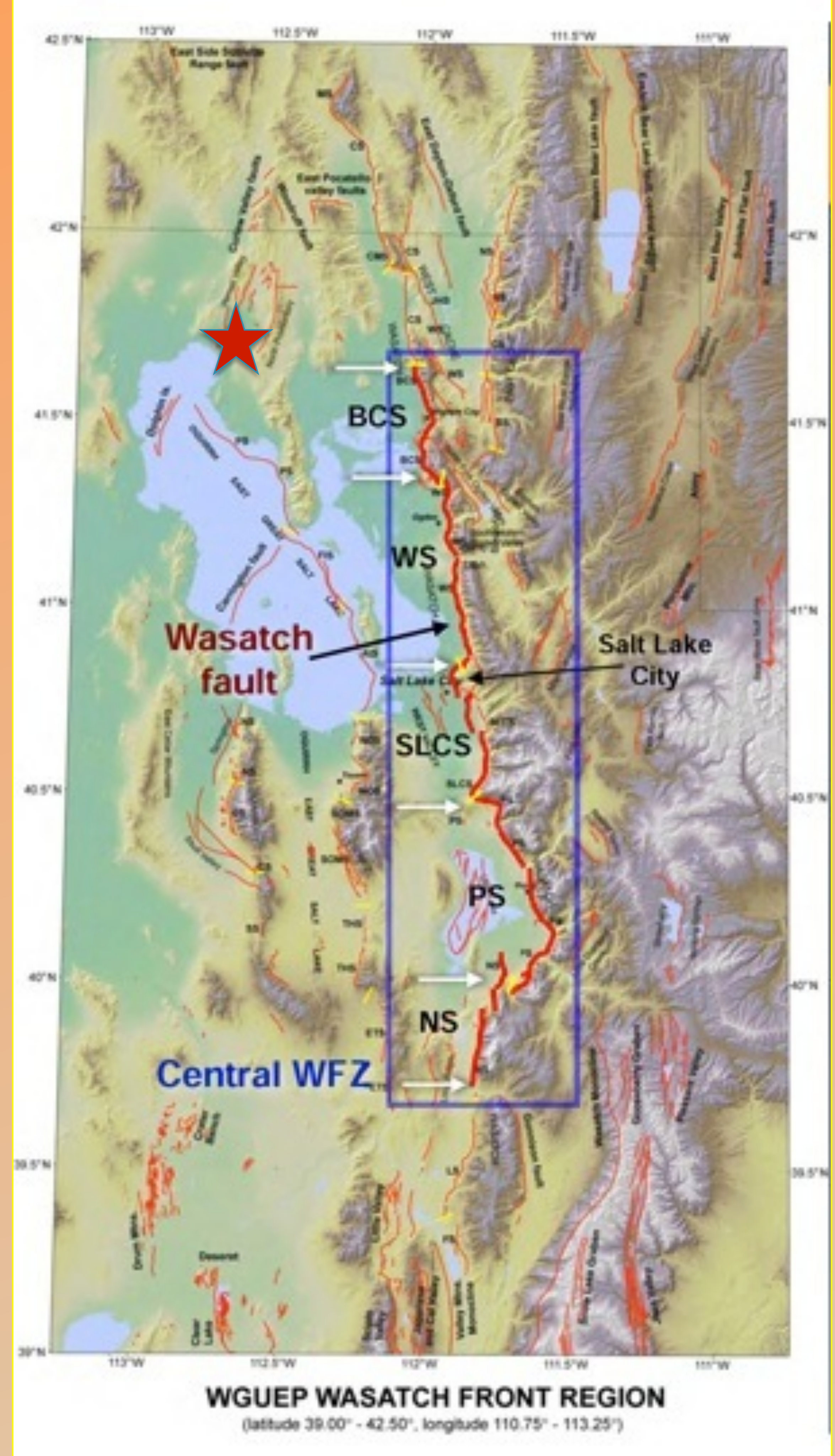
THE GREAT SALT LAKE FAULT AND ITS MICROBIAL MOUNDS

- Susanne U Janecke
- James P. Evans
- Utah State University

Hansel Valley eq, 1934, M6.6, had many small scarps

Great Salt Lake fault

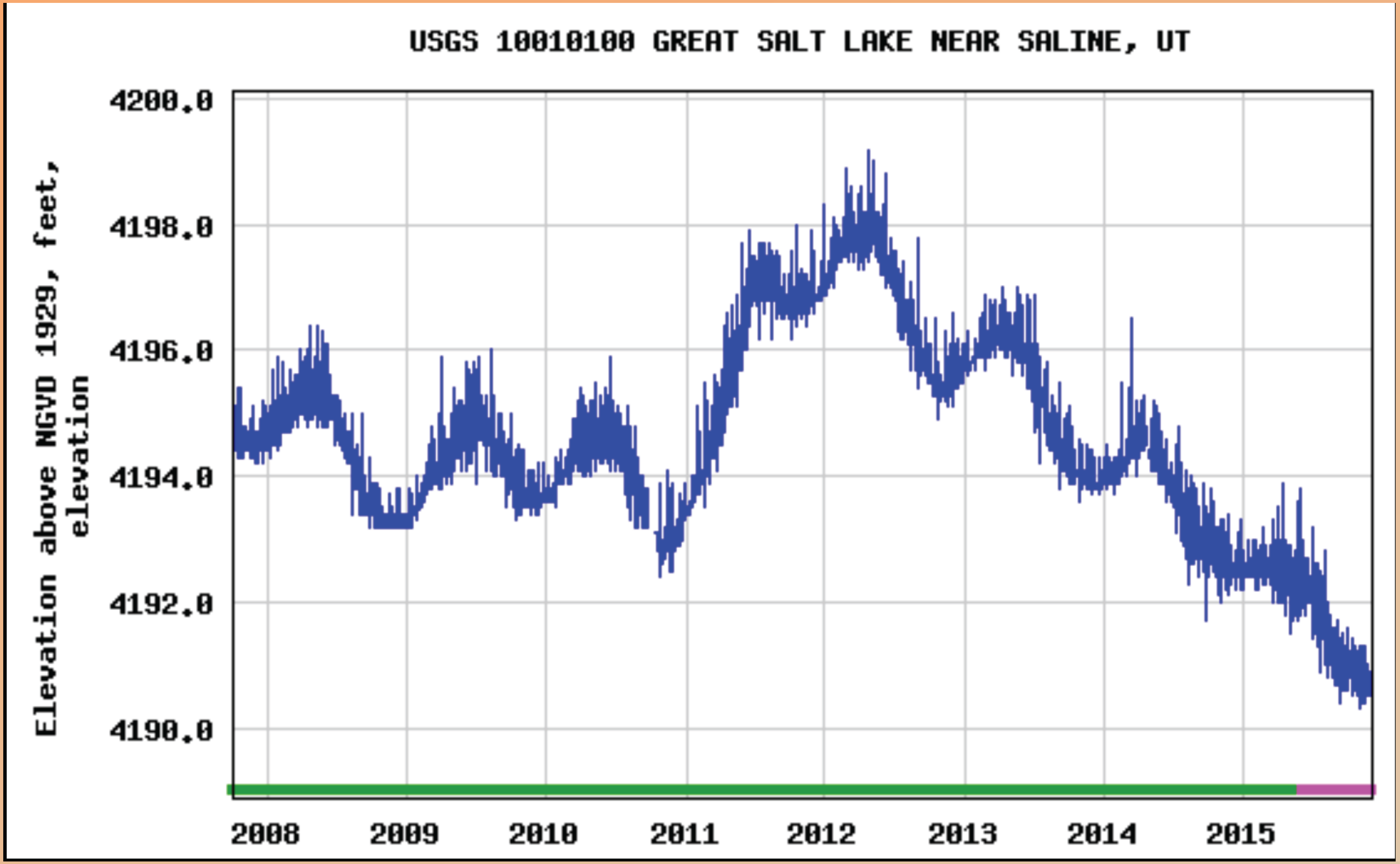
Our mapping of the GSL fault makes it longer, wavier, and more complex



Map from DuRoss 2005

HISTORIC LOW OF THE LAKE EXPOSES MORE AND MORE OF THE GSL FAULT ZONE

North and south differ by ~2 ft currently



NORTHERN UTAH'S FAULT ZONES

- Methods
  - Compilation of existing mapping and field analysis
  - Mapping on Google Earth
  - Bing images
  - Targeted field work
  - GSL: GOOGLE imagery from low water years. Especially 6/2015, 8/2014, 10/2011, 5/2010, 8/2009, 9/24/2006

- Methods
  - Consideration of bathymetry of Baskin and Allen (2005) and Baskin and Turner (2006).
  - Compared with reflection seismic and analysis of Dinter and Pechmann, 2014, 2015

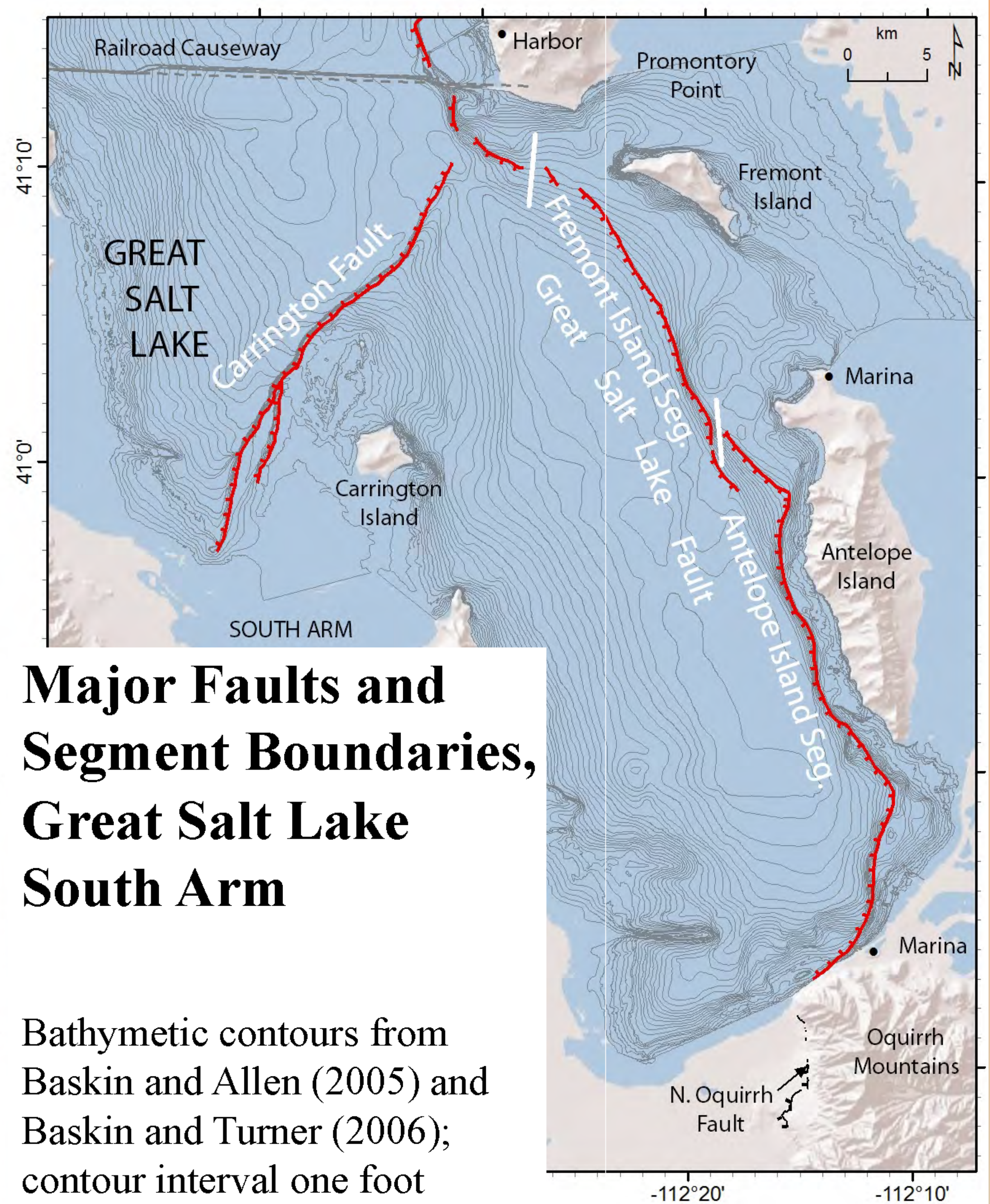
PRIOR WORKS SHOWS 4 SEGMENTS

Baskin's bathymetry and Dinter and Pechmann's reflection seismic work show 4 clear segments

- Antelope Island
- Fremont Island
- Promontory
- Rozel

On following ALL bathymetry is from Baskin's two maps

Dinter and Pechmann, 2015 UQFPWG

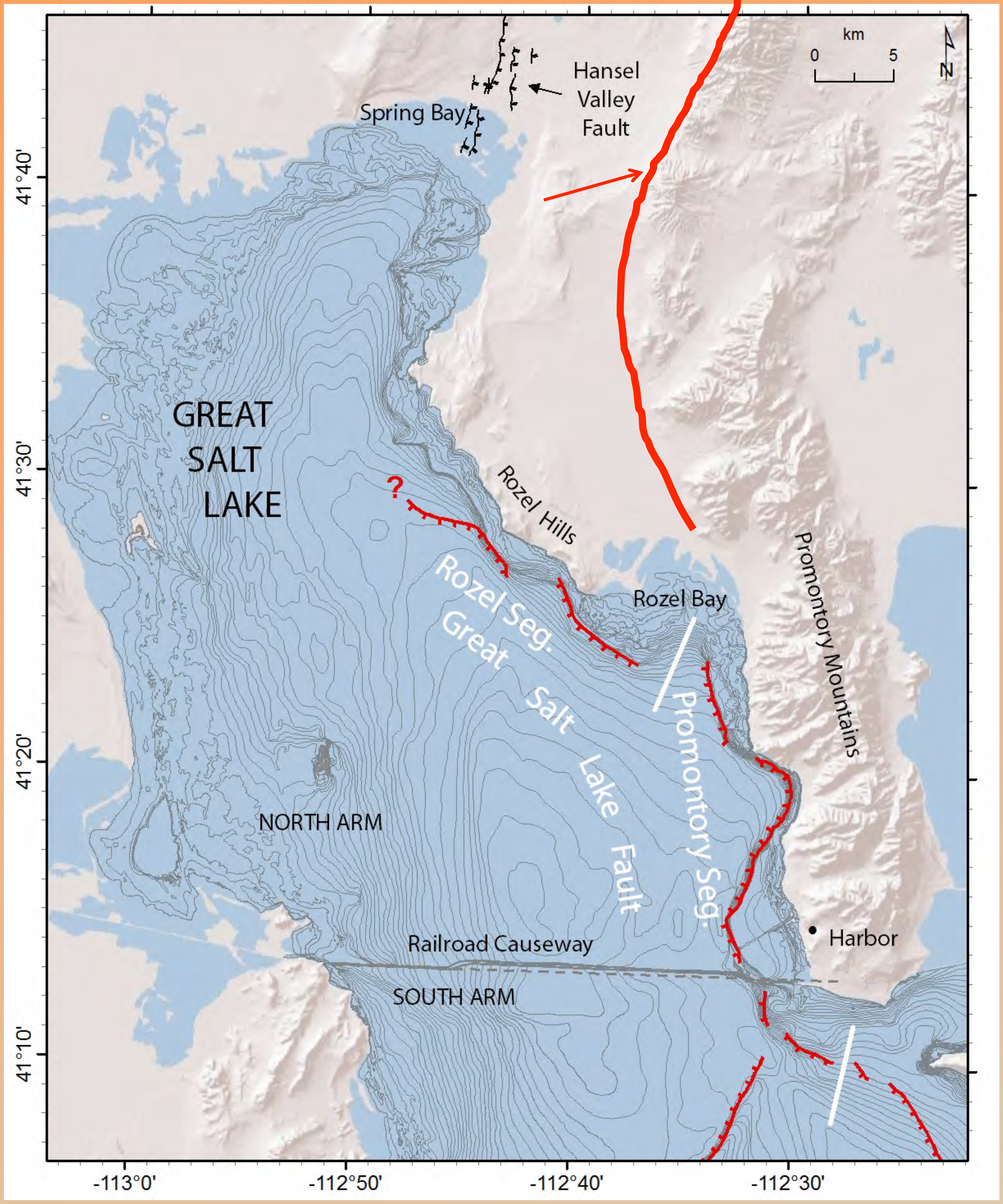


Major Faults and Segment Boundaries, Great Salt Lake South Arm

Bathymetic contours from Baskin and Allen (2005) and Baskin and Turner (2006); contour interval one foot

NORTH HALF

- Promontory
- Rozel
- North Promontory fault at red arrow is probably the north 70 km of GSL fault



Dinter and Pechmann, 2015
UQFPWG

Low stand of Great Salt Lake at 4190.8 ft exposes the GSL fault in the northwest arm of the lake

ROZEL fault AND PROMONTORY segment

This unusual event spurred my research

And explains my completely different topic

Next slides are from Rozel fault near Spiral Jetty

EXAMPLE OF A SMALL FAULT IN EN ECHELON ARRAY, LOOK EAST

Note partial polygon

VIEW ALONG STRIKE OF A MODEST-SIZED ESCARPMENT. LOOK SSE

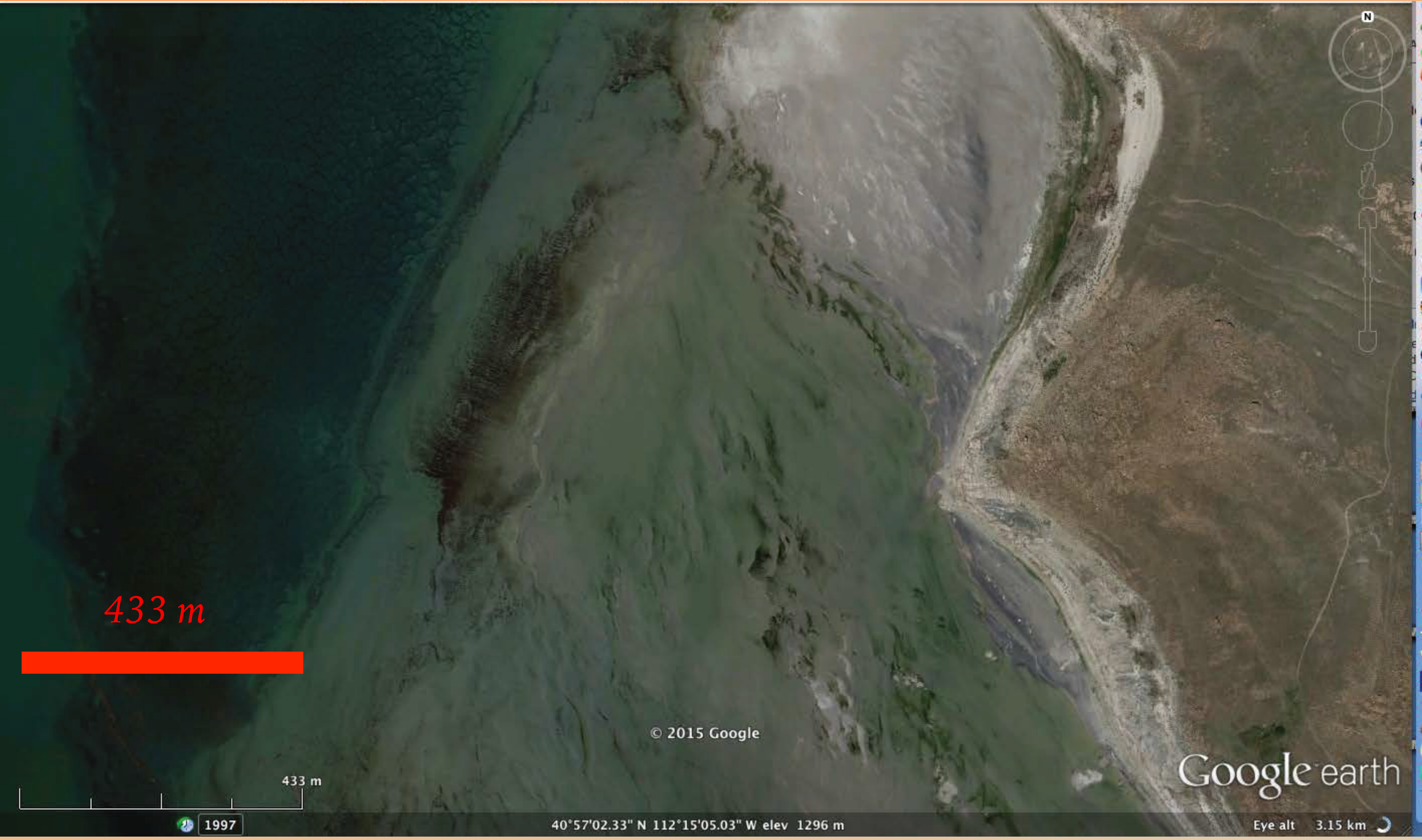
VIEW ALONG STRIKE OF A SMALL FAULT. LOOK NNW

PLATFORMS IN FOOTWALL OF FAULTS ARE EXCEPTIONALLY WIDE, FLAT, AND COVERED BY STROMATOLITES

In south arm, the GSL fault is visible through water

Fault mapping through water

Two faults are in this scene



Sometimes deeper water is lighter in color than shallow water-S of Antelope Island

Wavy fault trace

Resulting map pattern (orange) shows more complexity than original (white)

Several NE-striking fault splays

~1.5 km wide wave-cut platform between the fault trace and hard bedrock

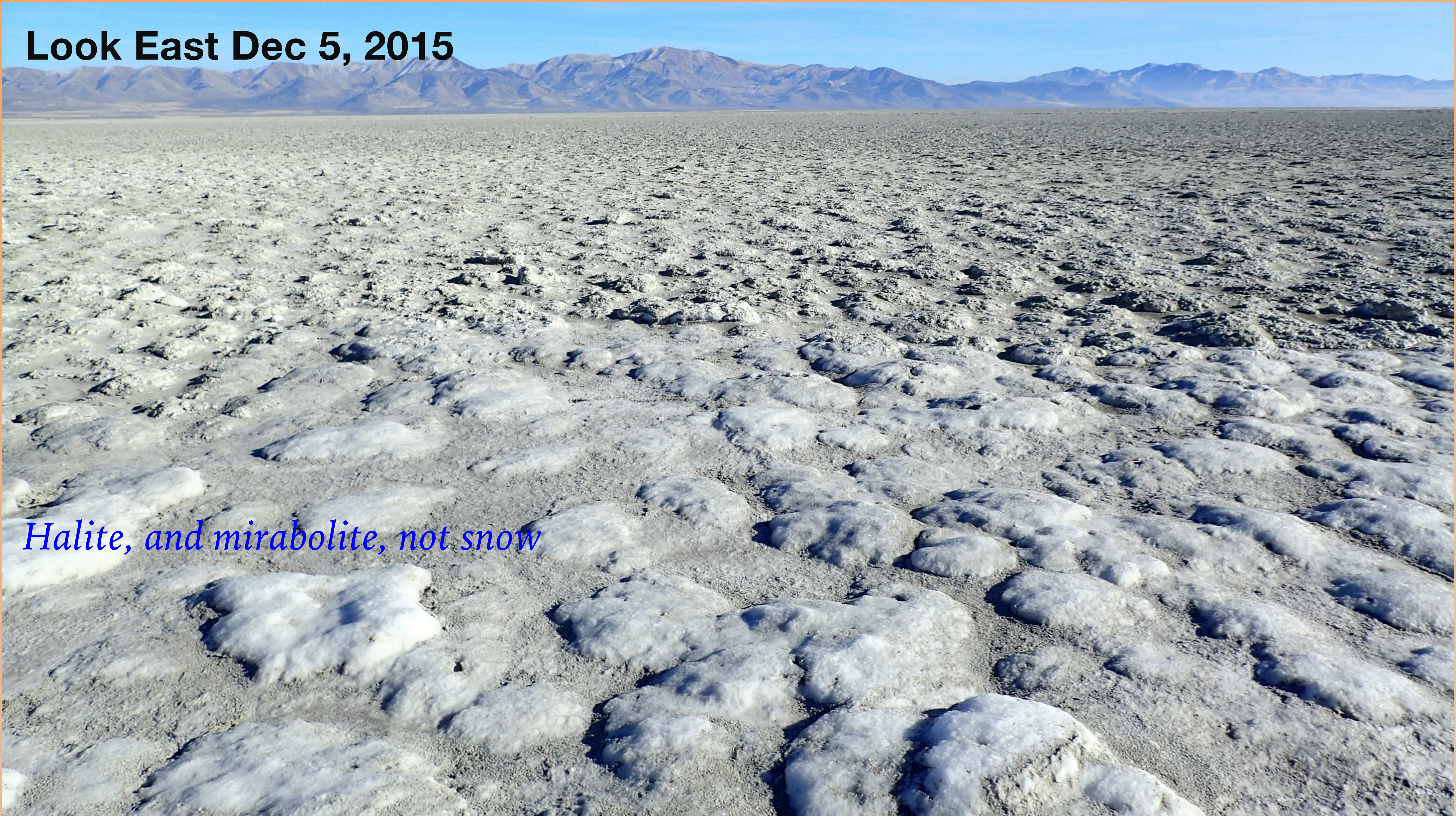
ANTELOPE ISLAND SEGMENT IS 32 KM LONG

Fremont Island has a significant bedrock step at its SW margin that is probably a normal fault

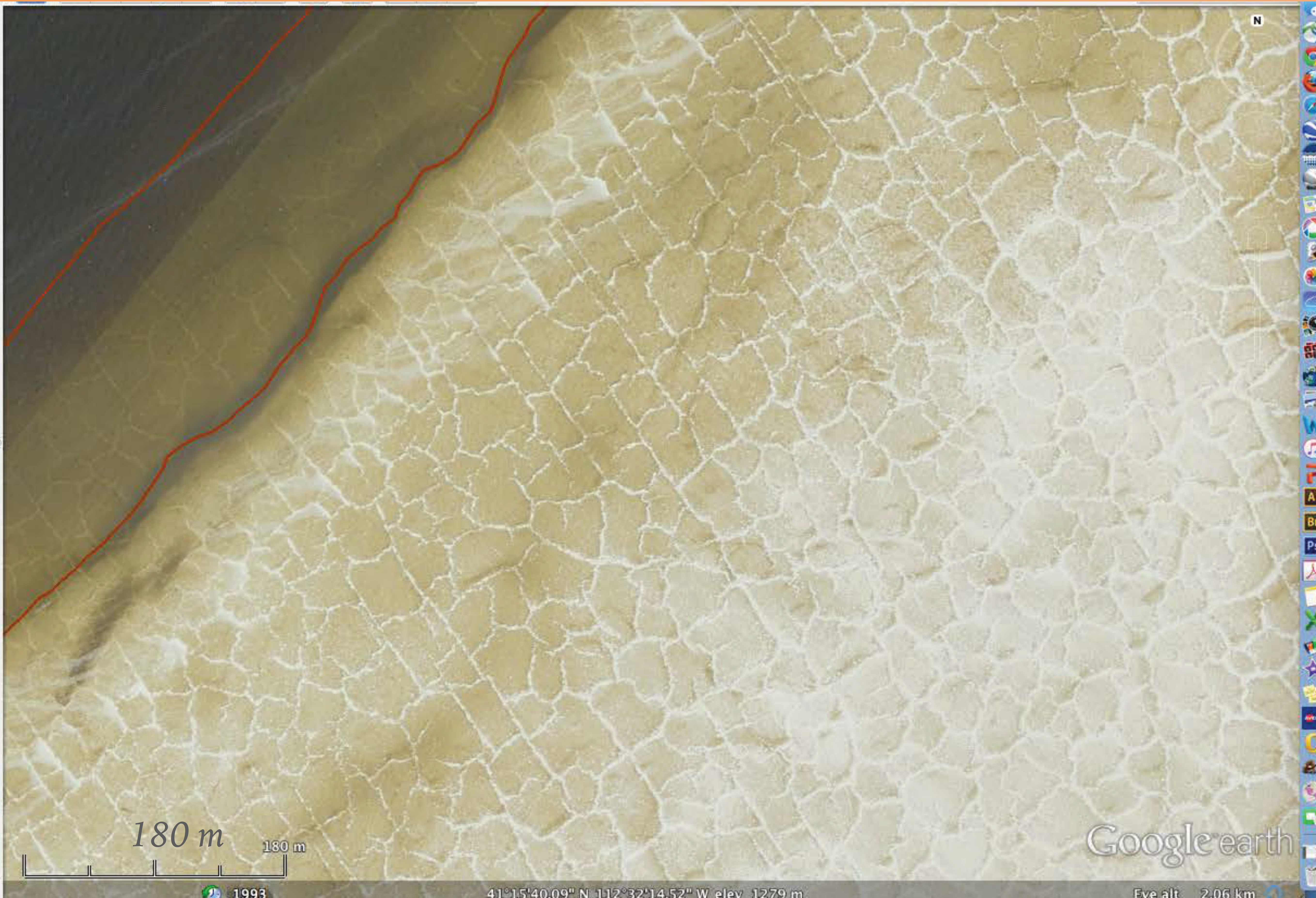
This trace is either an addition or relocation


Look west
Microbial mounds: A tutorial

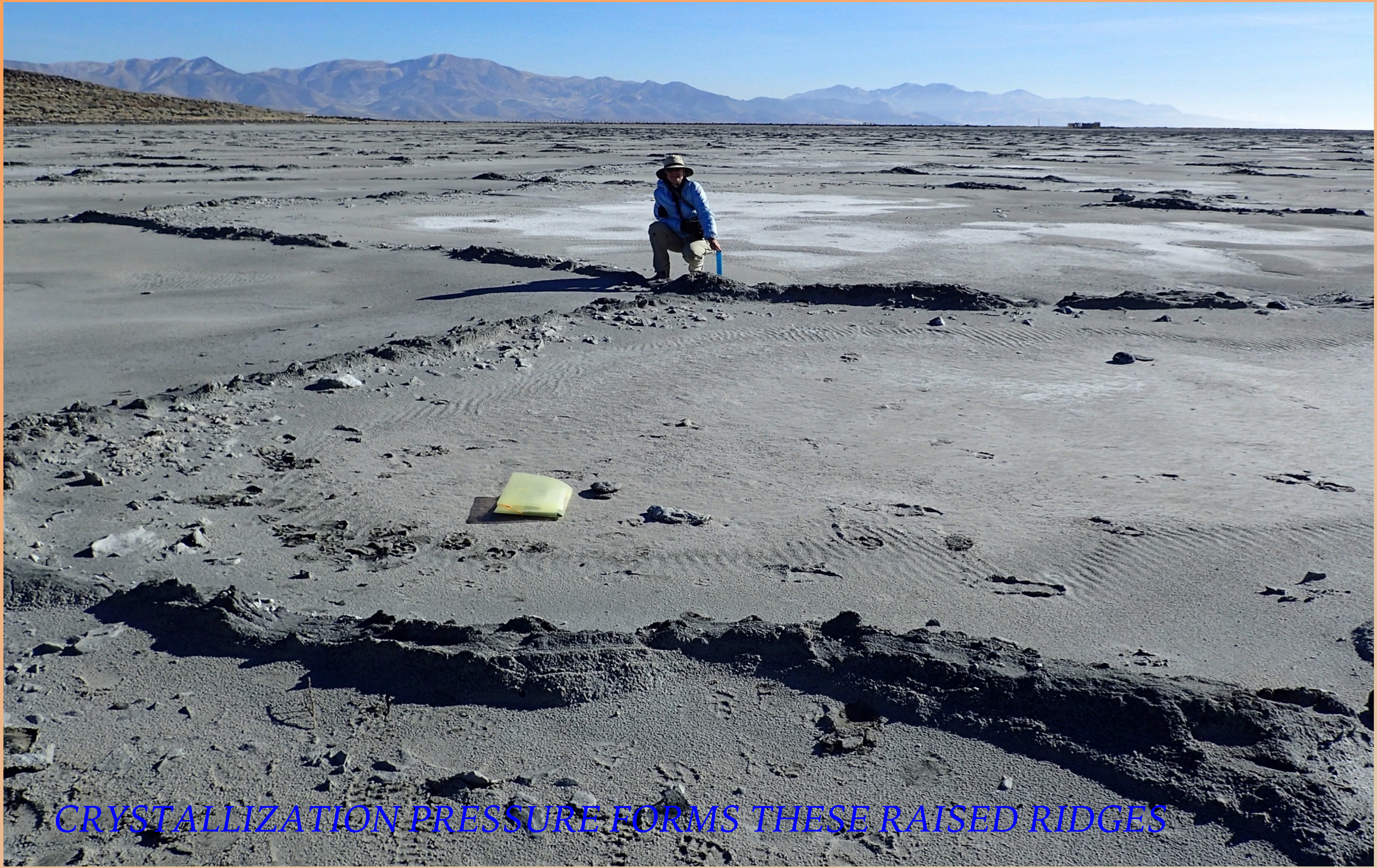
Microbial mounds are on the footwalls of all faults.
Dead ones are white and covered by salt,
Live ones are green due to cyanobacteria



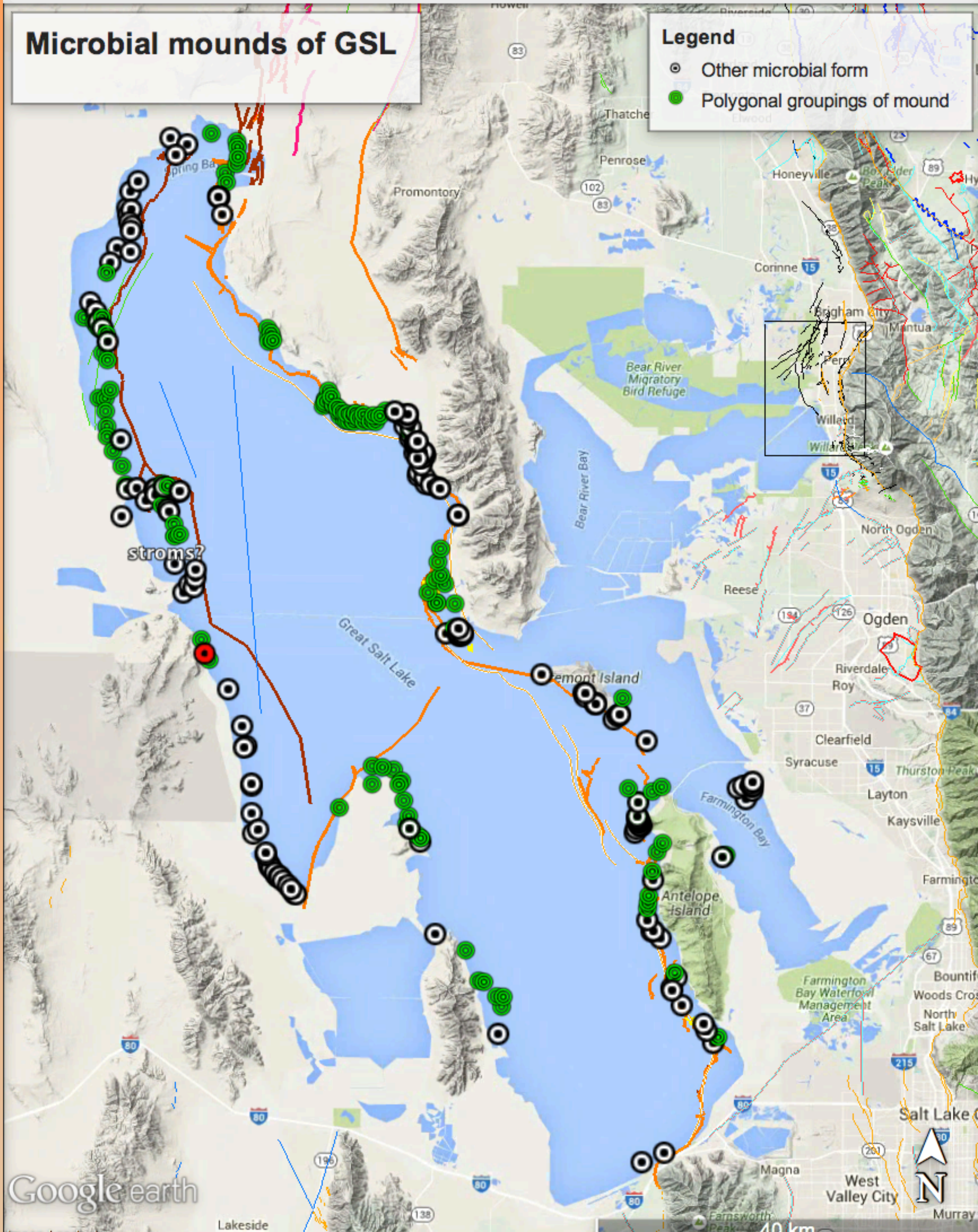
MANY MOUNDS FORM POLYGONAL COLONIES



DESICCATION-RELATED POLYGONS LIKE THIS ONE ARE **PROBABLY THEIR SUBSTRATE**



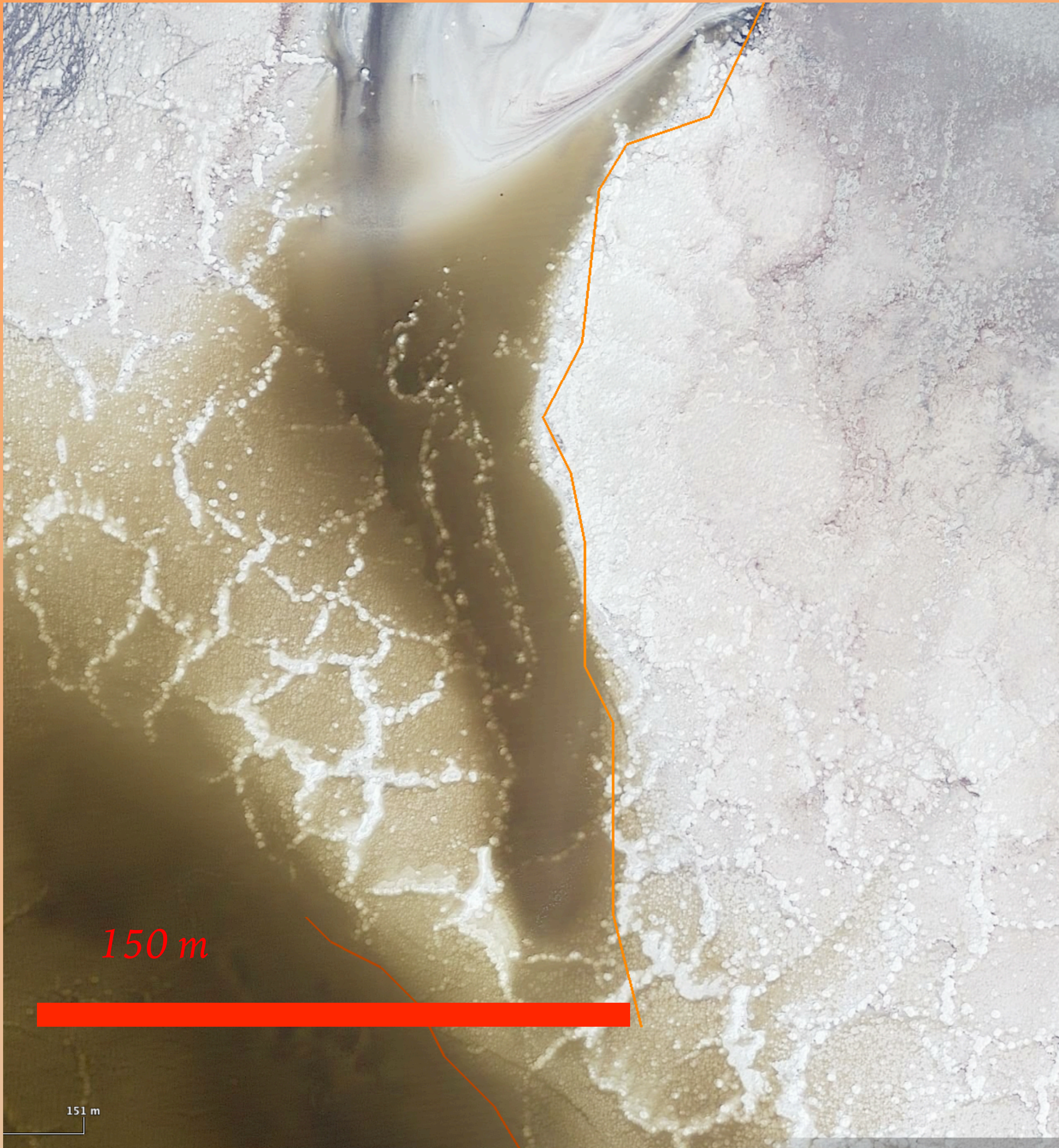
Polygonal mounds - green dot are more numerous in north



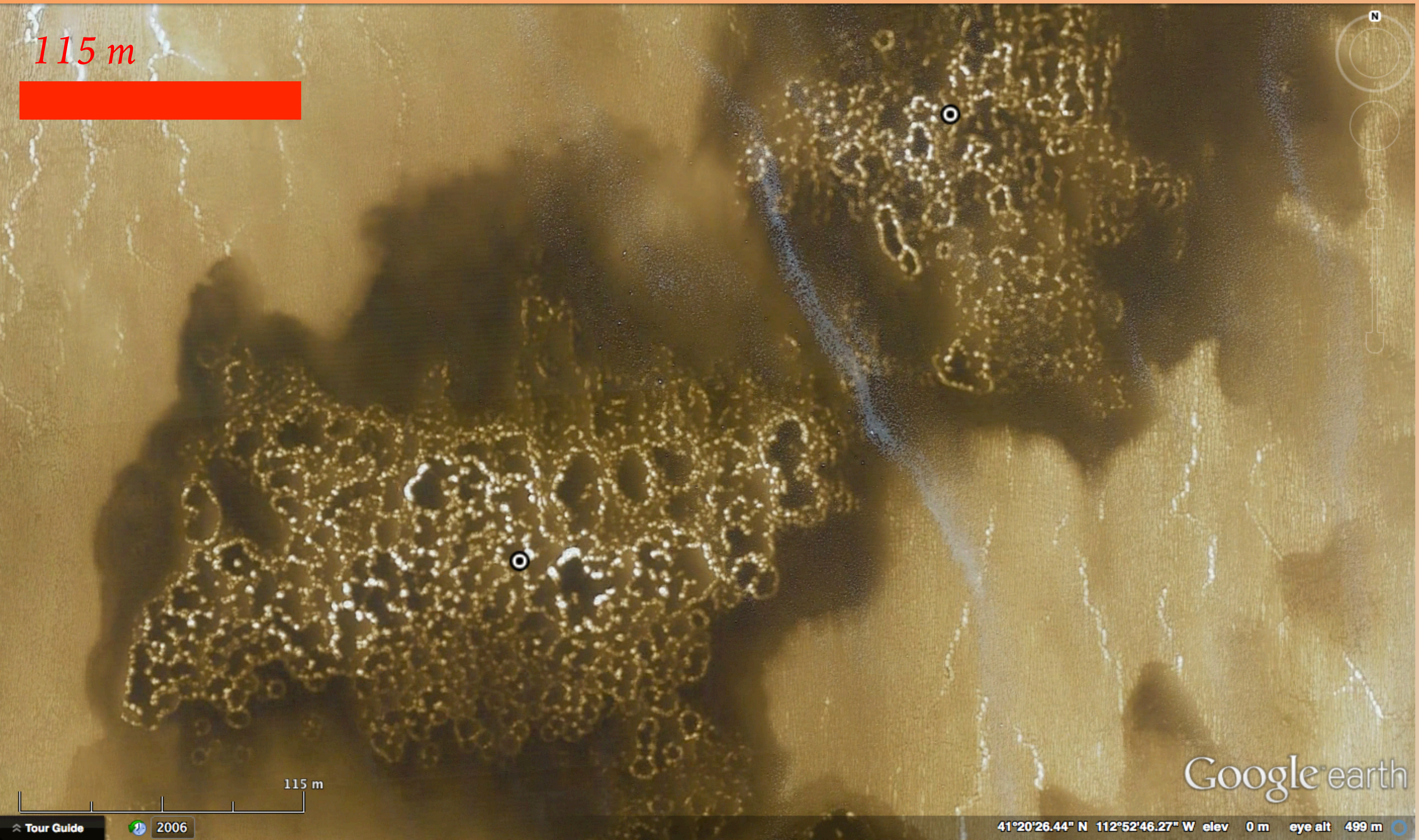
SEEPS, SPRINGS AND DISSOLUTION OCCUR ALONG FAULTS

Microbial colonies change their geometries in fault zones

Different cyanobacteria?



BROWN WATER SHOWS THERE ARE NO BRIGHT SALTS WITH POLYGONS



An example of fault-related mound, north arm

Note thin onion skin layers within this mound along fault zone

MOST MICROBIAL MOUNDS ARE GRANULAR AND COARSE

COLMAN ET AL SHOWED THAT SOME MICROBIAL MOUNDS COINCIDE WITH FAULTS IN GSL

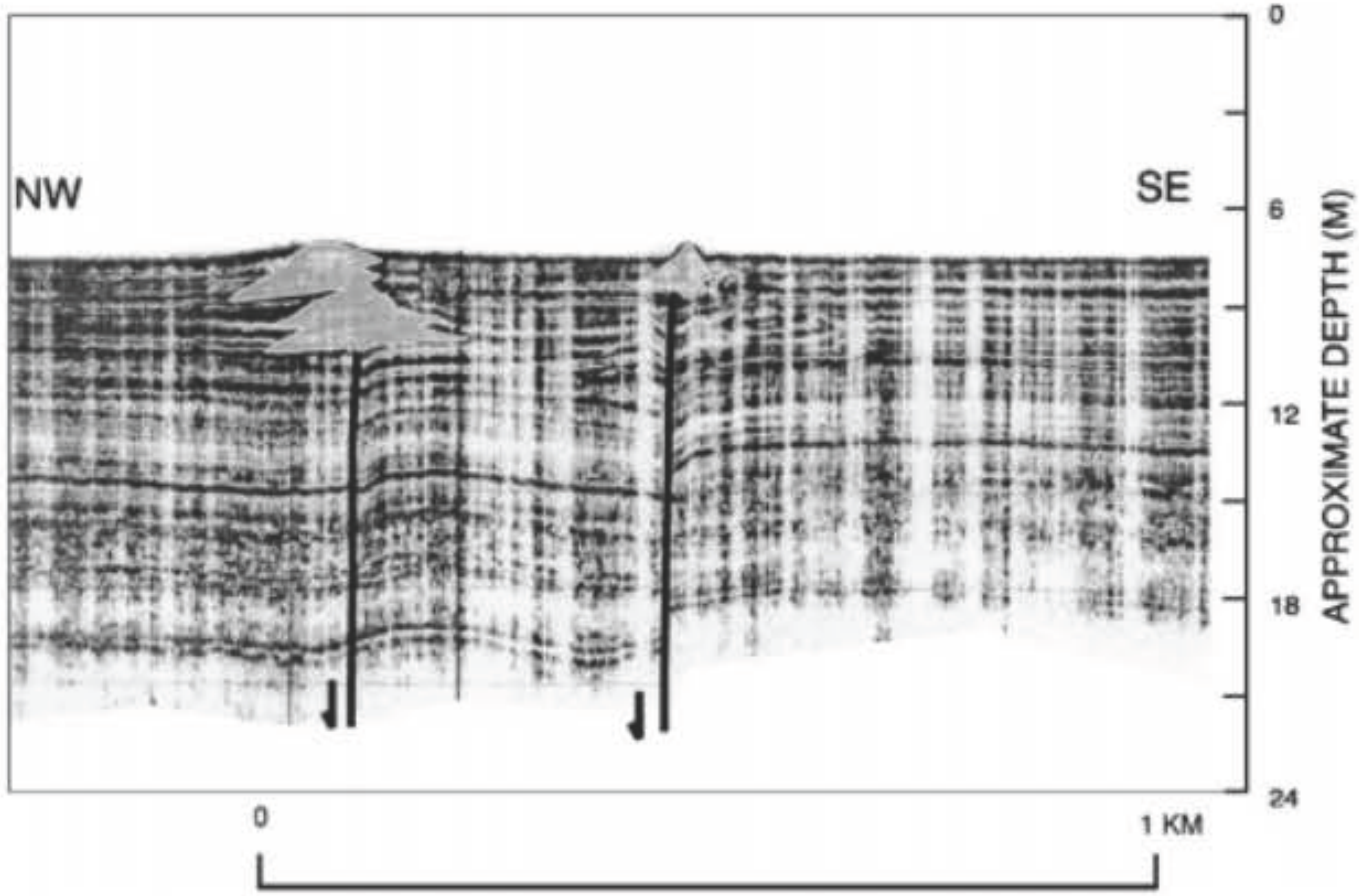


Fig. 14. Seismic-reflection profiles (7 kHz) showing inferred bioherm mounds (shaded) atop fault planes. Location shown in Fig. 2.

Promontory segment may be more related to the North Promontory fault than the Rozel fault

- Promontory segment has NE and NW striking sections
- Database map differs a lot from that of Dinter and Pechmann, 2014, 2015
- My map is quite similar to D and P's
- It also matches bathymetry well

Promontory segment may be more related to the North Promontory fault than the Rozel fault

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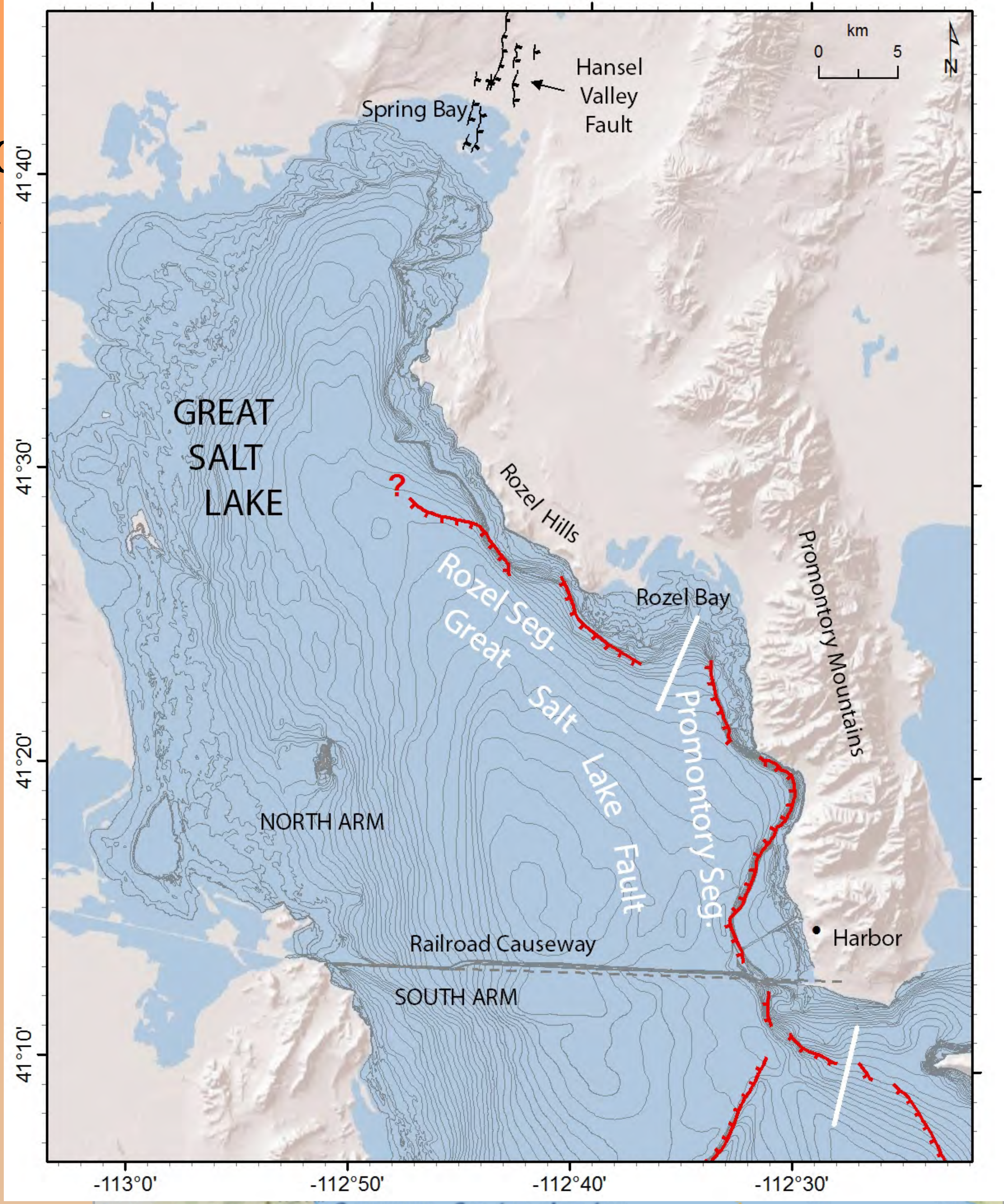


PROMONTORY SEGMENT:

- Steps, parallel strands and other details of the fault trace are emerging from the lake
- Overall, little change from most recent map
- No connection with the Rozel fault in NW
- The footwall platform of the Promontory fault is very wide 4.6 km
- It is also one of narrowest at Indian Cove
- Is there second fault near bedrock, as in Quaternary database?
- Seeps and mounds hint at other faults near bedrock

ROZEL FAULT IS ROUGHLY 40 KM LONG

MAROON LINES ARE STRANDS OF HANSEL VALLEY FAULT ZONE,

It dips east

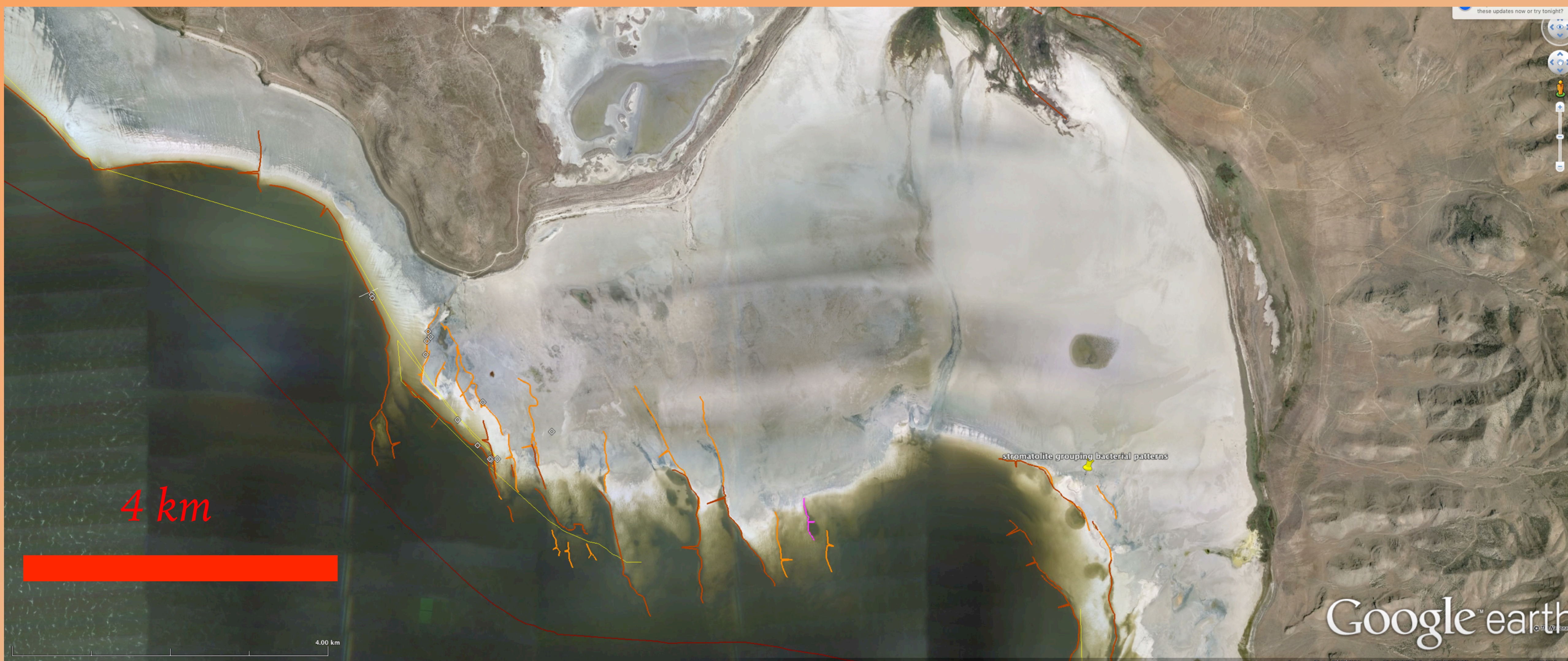
Black Rock is also sliced and diced

White salt on footwall platform defines the position of the Rozel fault extremely well

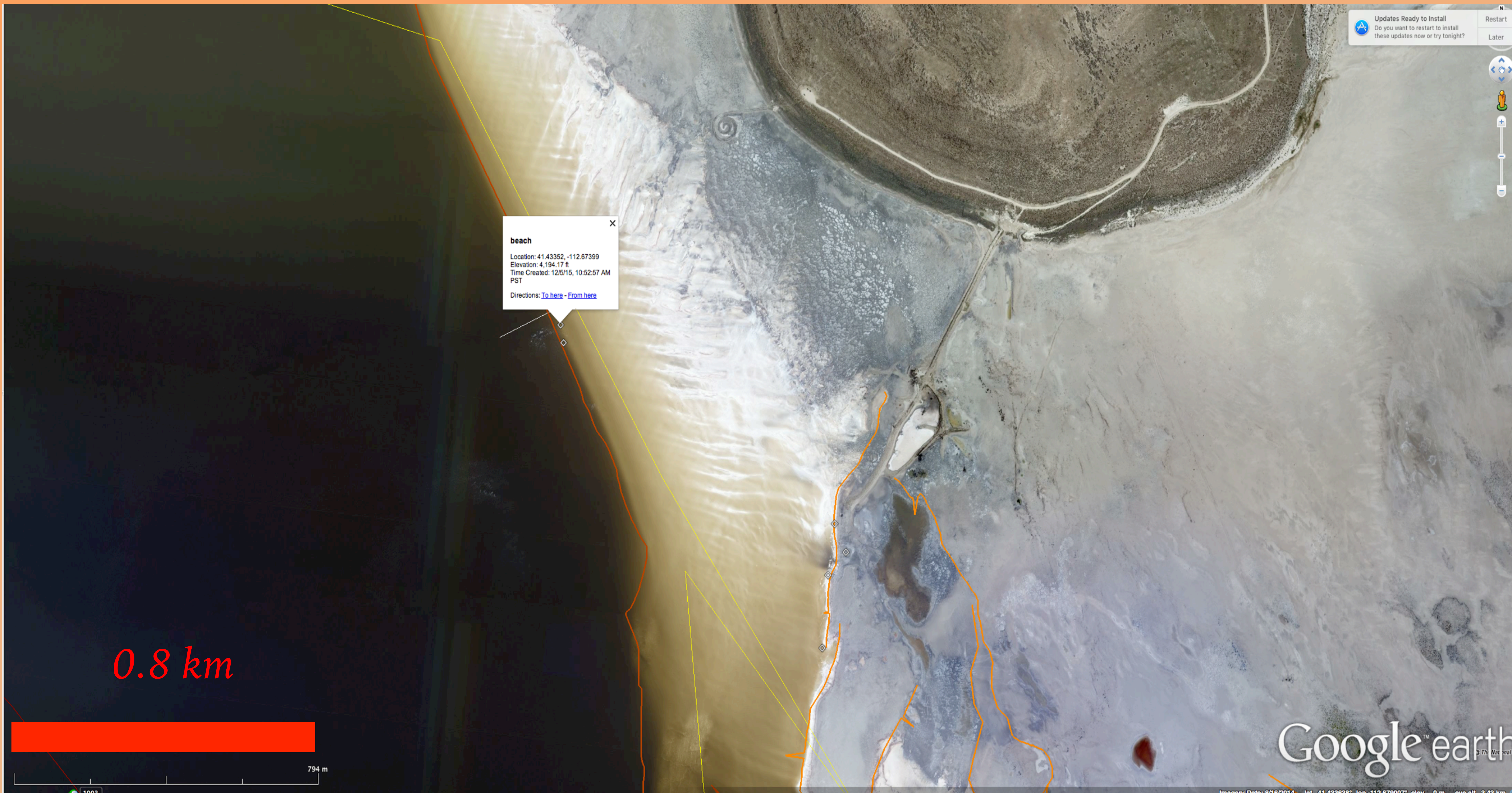
It matches bathymetry fairly well

with interesting structural differences

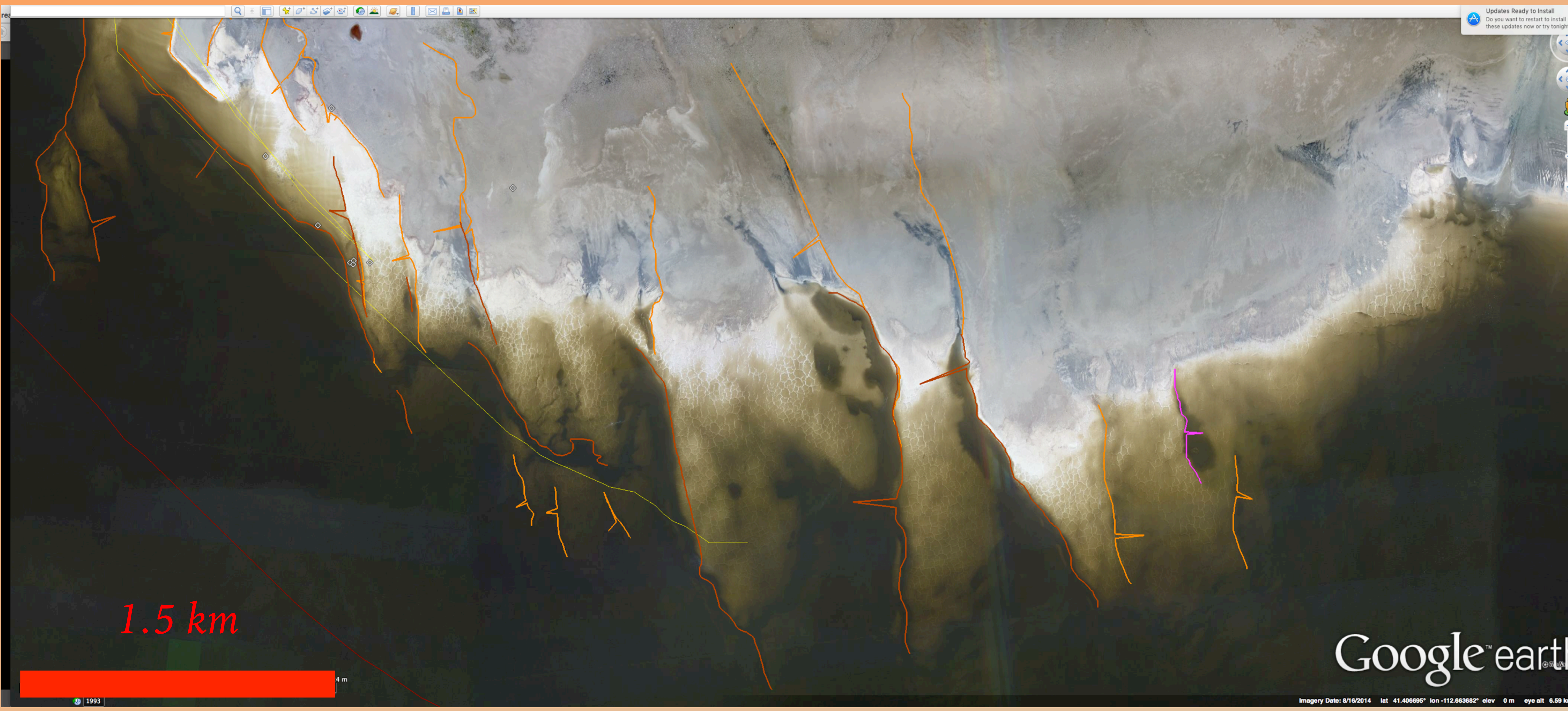
THE MOST COMPLEX PART OF THE ROZEL FAULT ZONE IS IN SOUTH (EARLIER FIELD SHOTS WERE HERE)



THE FAULT IS EFFECTIVELY EXPOSED AT SPIRAL JETTY



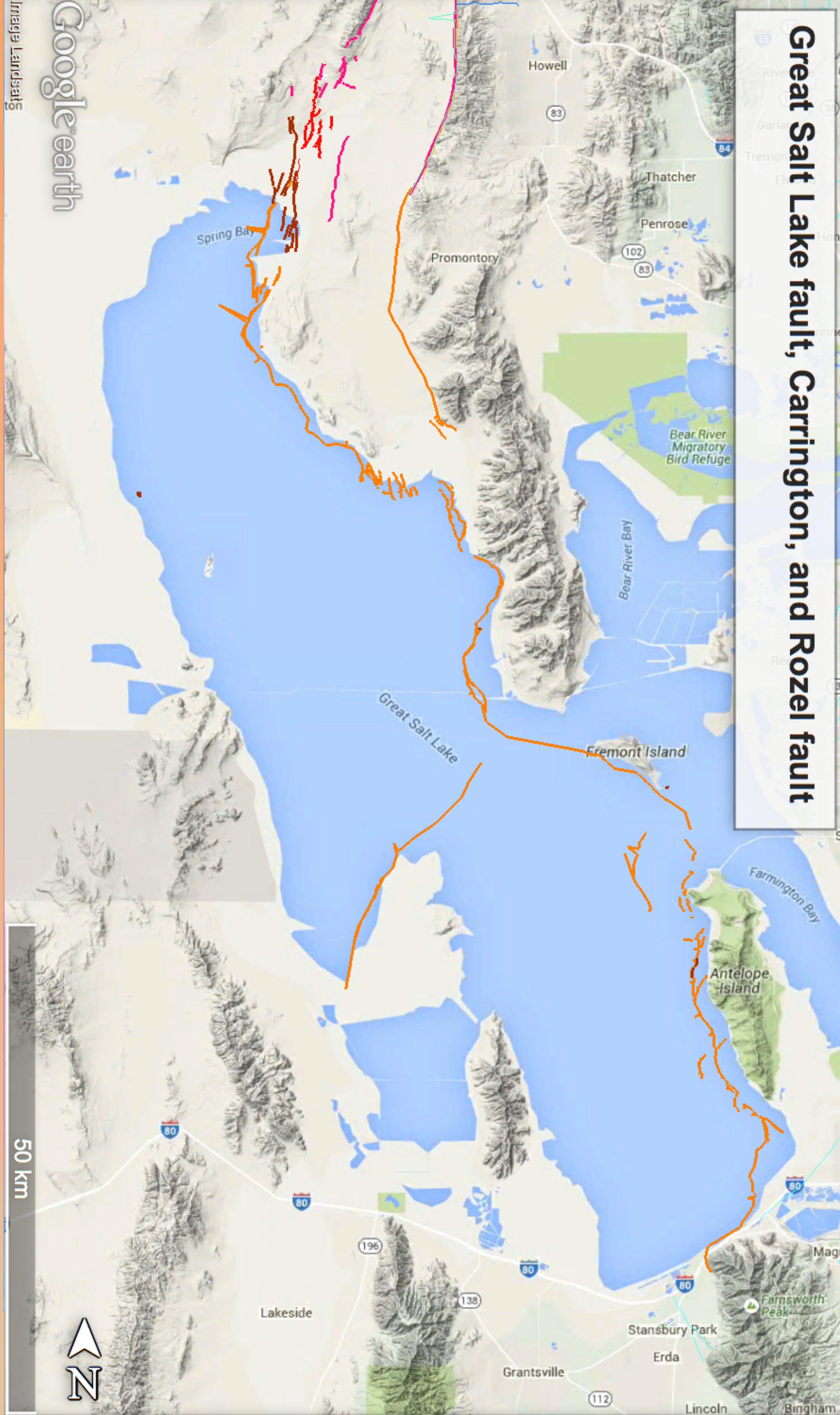
EAST AND WEST DIPPING STRANDS FLUID AND HYDROCARBON SEEPS PRODUCE DARK SMUDGES



QUASI-EN ECHELON FAULTS

SOME IMPLICATIONS

- The GSL fault probably connects to 70 km long North Promontory fault
- Rozel fault is a separate structure composed of many small displacement faults. This style may be related to the Rozel Pt. volcanic field
- GSL fault is quite curvy, like the Oquirrh fault, with both NW and NE-striking parts
- Wave cut platforms are wide an enigmatic. Most are 1-3 km wide and range to 4.6 km. They require LONG periods of planation.
- Does this imply that GSL flt is a low-slip rate fault with Holocene reactivation?



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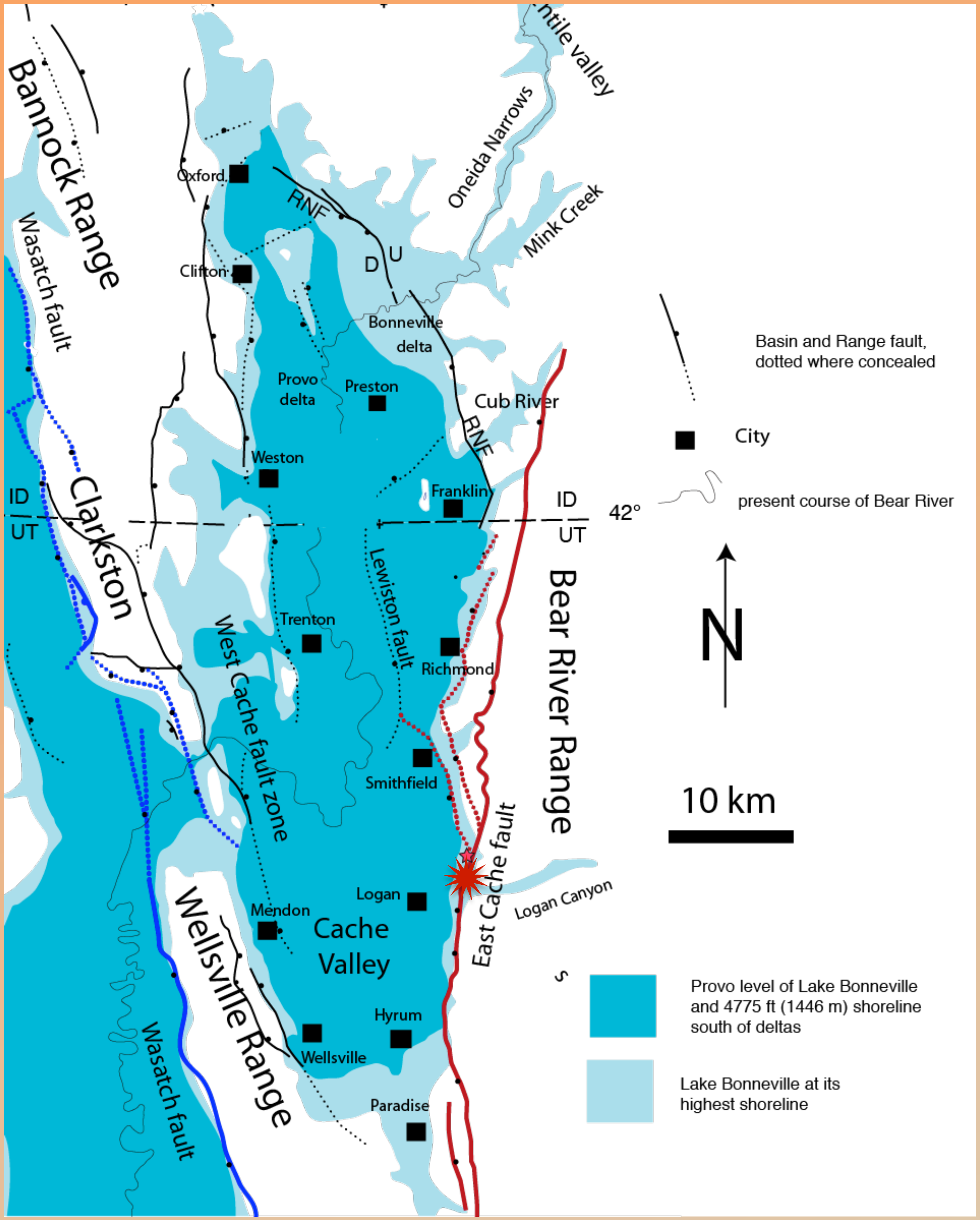
UAV-SURVEY AND PHOTOGRAMMETRY PRODUCE LIDAR-LIKE DEM OF SCARPS IN LOGAN, UTAH

- Susanne U Janecke
- Micheal Bunds
- Jeremy Andreini
- Jack Wells
- Utah State University
- Utah Valley University

CENTRAL SEGMENT OF ECF:
MRE 4.5 KA
PENULTIMATE EVENT WAS 15.6 TO 18.5 KA DURING PROVO TIME

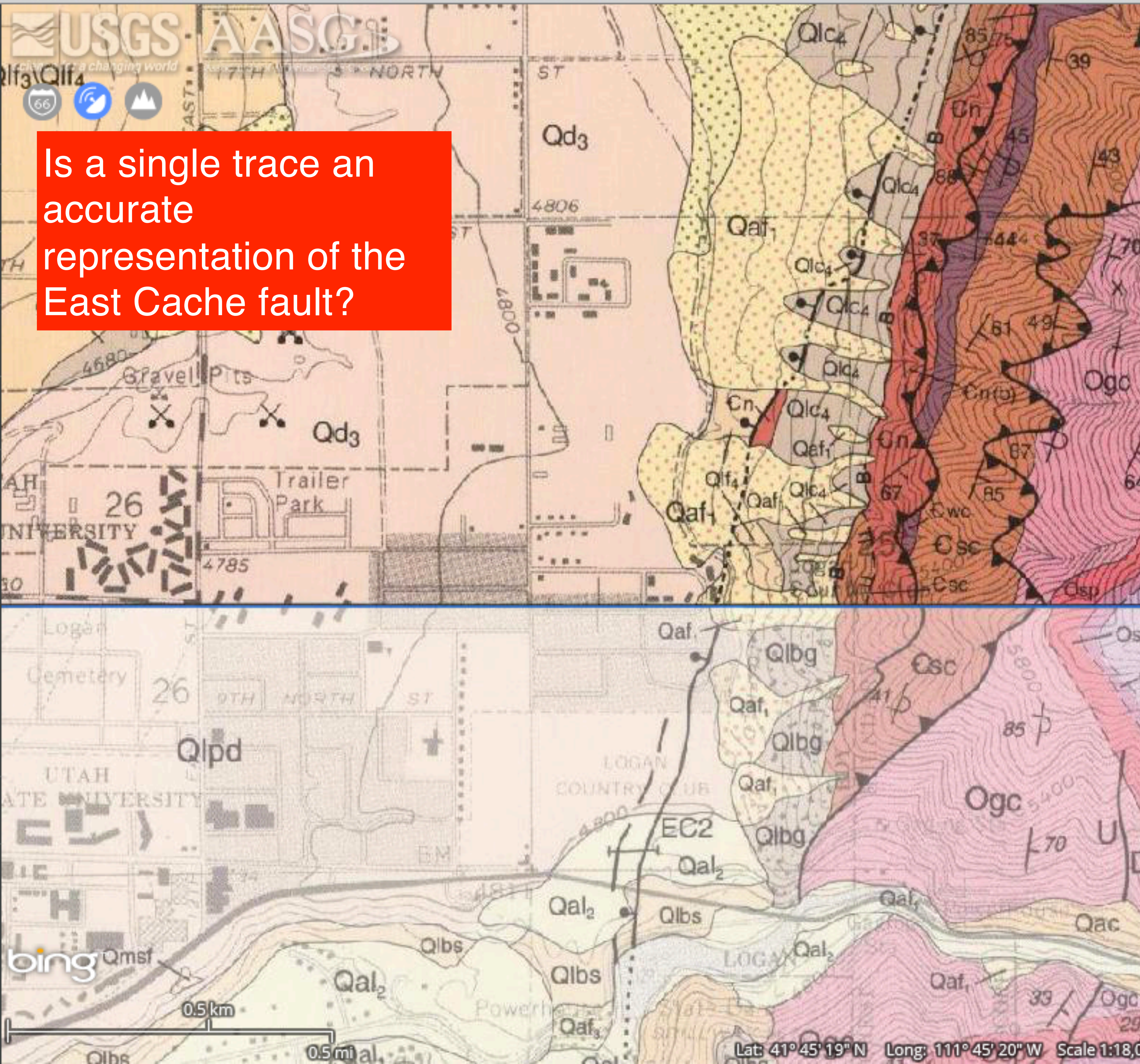
NORTHERN SEGMENT:
NO EVIDENCE OF LATEST QUATERNARY SLIP EXCEPT FOR A LATERAL SPREAD
(MCCALPIN, 1987, 1994)

FAULTS MAP FROM 1989



Janecke and Oaks, 2011

Is a single trace an accurate representation of the East Cache fault?



Geologic map of Evans et al., 1996

Lowe and Galloway, 1993.

MCCALPIN'S MAP MISSED SOME TRACES

Look SSE

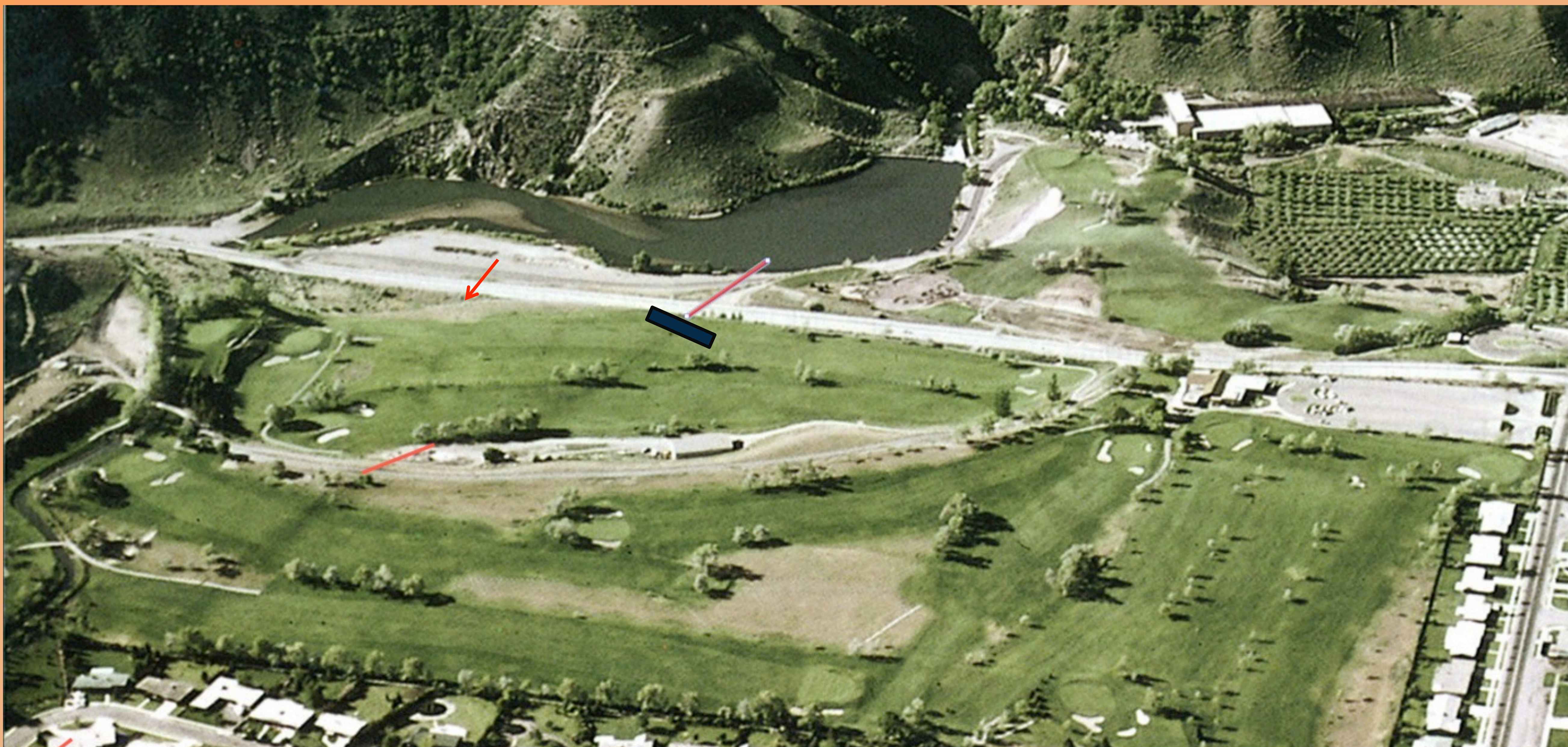
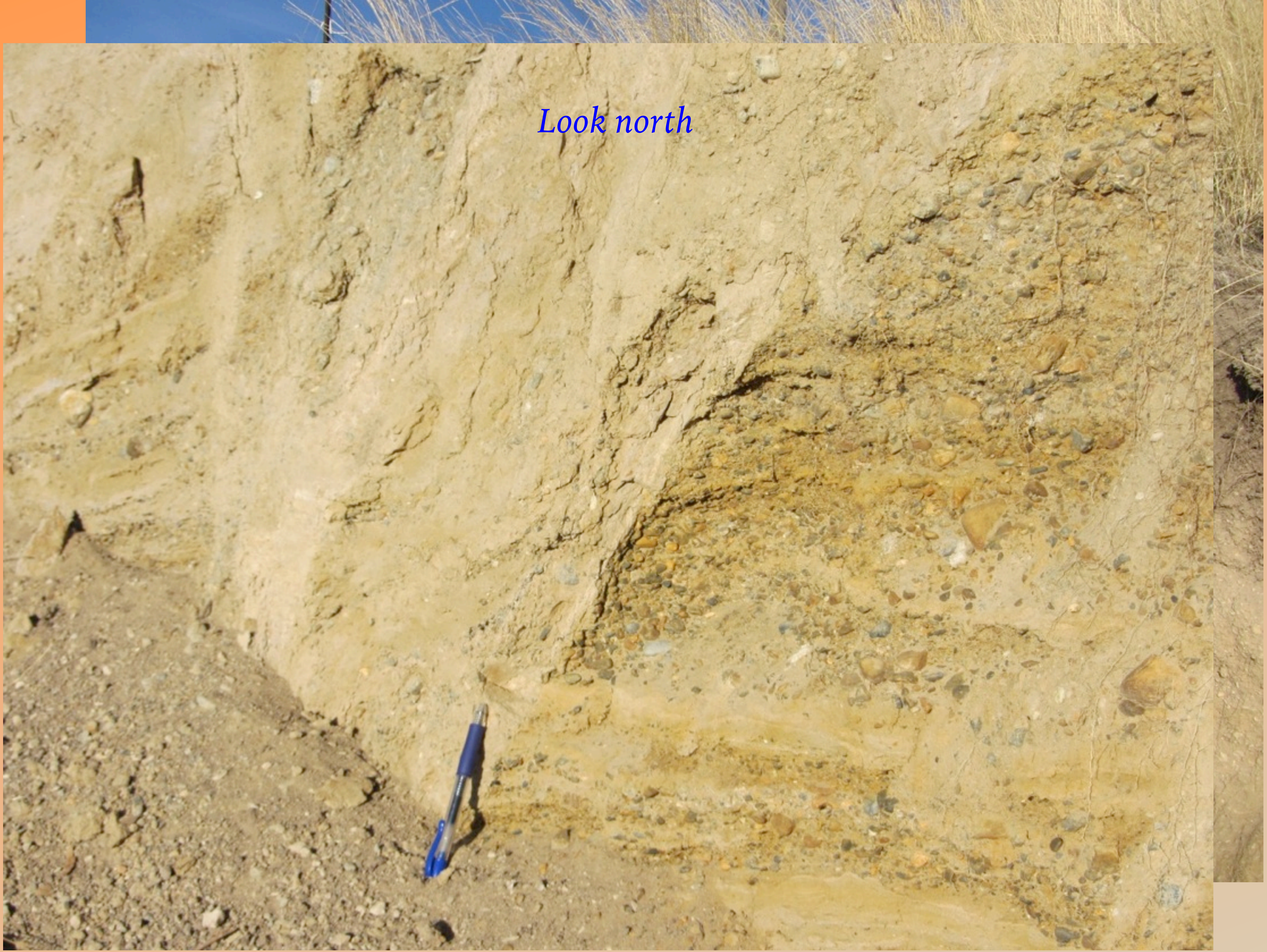


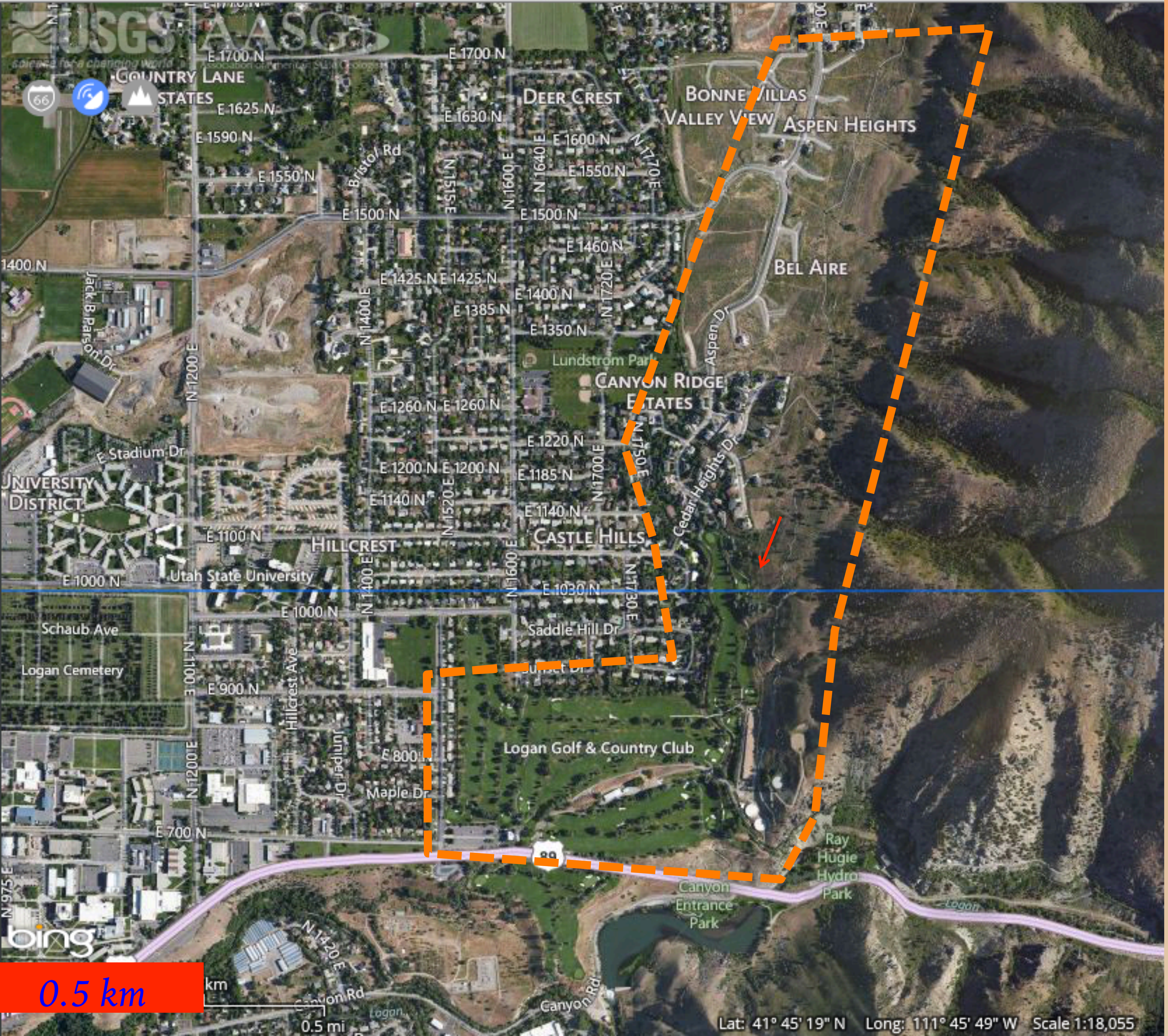
Figure 126 Oblique aerial photo of the East Cache fault looking south along the base of the Bear F
scarp, marked on our main panoramic view as a red line that crosses the golf course, can be seen on this pic

Hintze, 2005, Utah's spectacular Geology Book

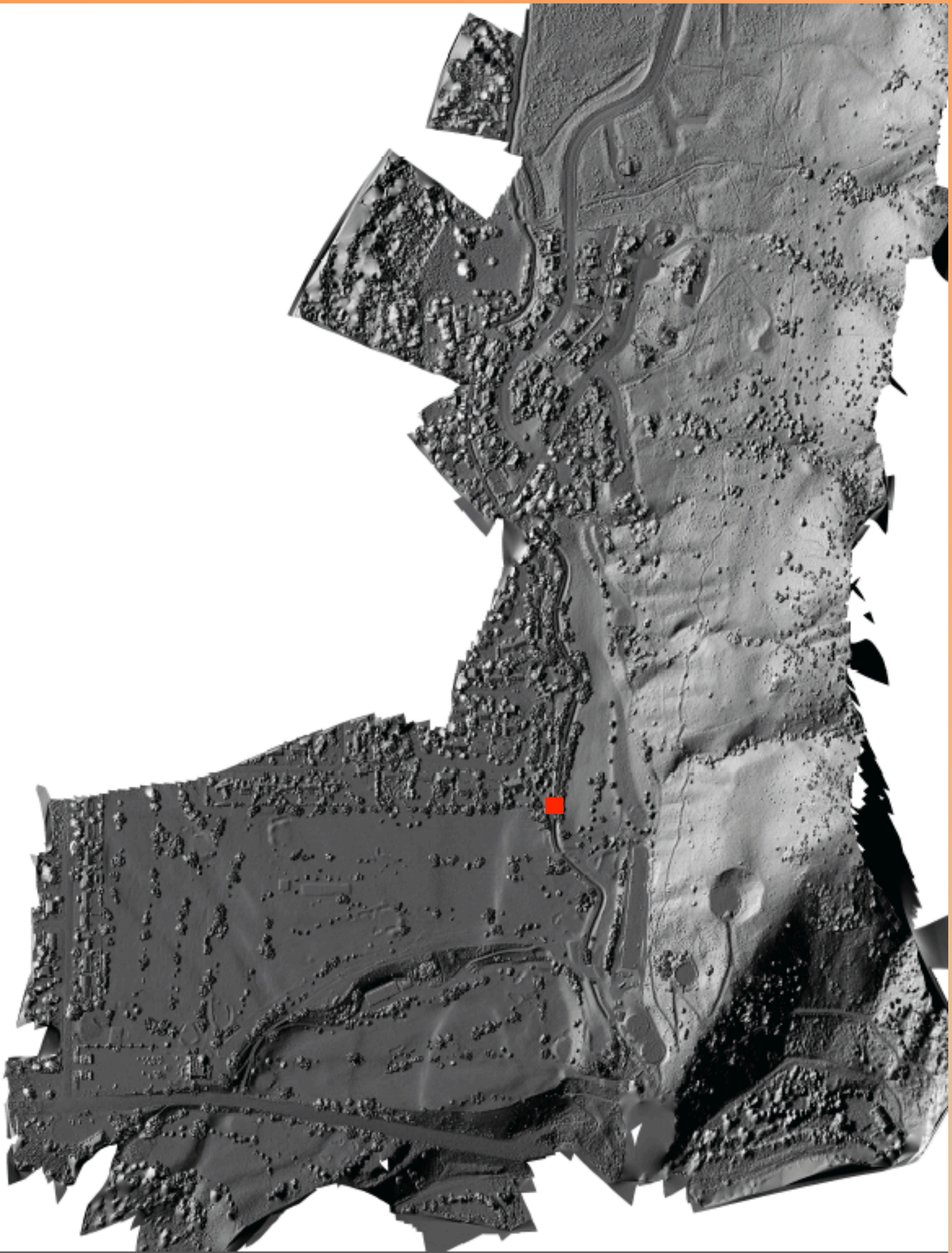
East Cache fault was temporarily exhumed by Rocky Mtn power company near Logan Country Club

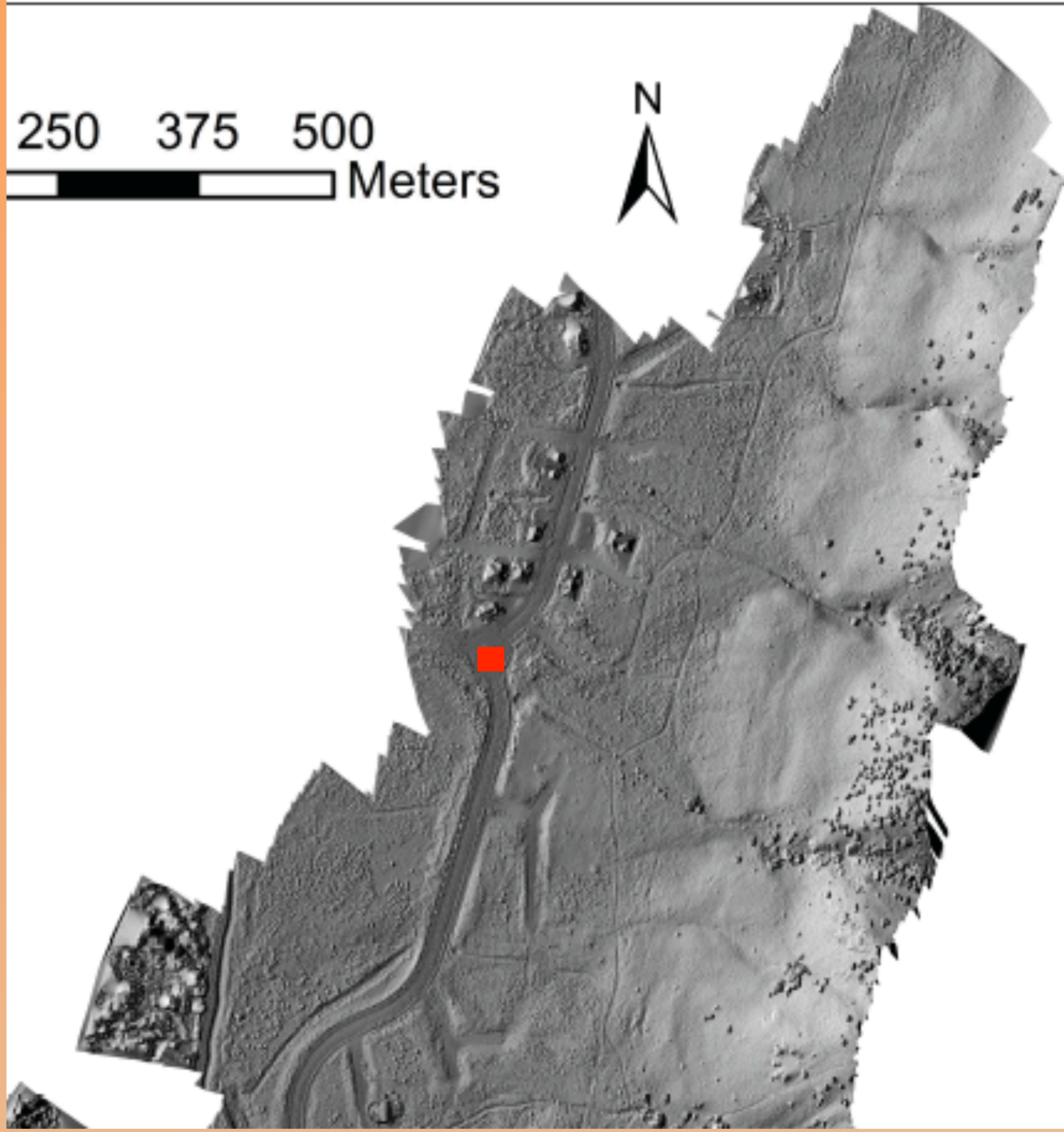

Look north


Look north


USGS
AASG
Country Lane Estates
Deer Crest
Bonne Villas
Valley View
Aspen Heights
Bel Aire
Canyon Ridge Estates
Lundstrom Park
Castle Hills
Hillcrest
University District
Utah State University
Schaub Ave
Logan Cemetery
Logan Golf & Country Club
Ray Hugie Hydro Park
Canyon Entrance Park
E 1700 N
E 1625 N
E 1630 N
E 1590 N
E 1600 N
E 1550 N
E 1500 N
E 1460 N
E 1425 N
E 1400 N
E 1385 N
E 1350 N
1400 N
E 1260 N
E 1220 N
E 1200 N
E 1185 N
E 1140 N
E 1100 N
E 1030 N
E 1000 N
E 900 N
E 800 N
E 700 N
Bristol Rd
Jack B Parson Dr
E Stadium Dr
Aspen Dr
Cedar Heights Dr
Saddle Hill Dr
Hillcrest Ave
Juniper Dr
Maple Dr
N 1200 E
N 1400 E
N 1515 E
N 1520 E
N 1600 E
N 1640 E
N 1700 E
N 1720 E
N 1730 E
N 1750 E
N 1770 E
N 1100 E
N 975 E
N 1420 E
Canyon Rd
89
Logan
bing
km
0.5 mi
Lat: 41° 45' 19" N
Long: 111° 45' 49" W
Scale 1:18,055

0.5 km

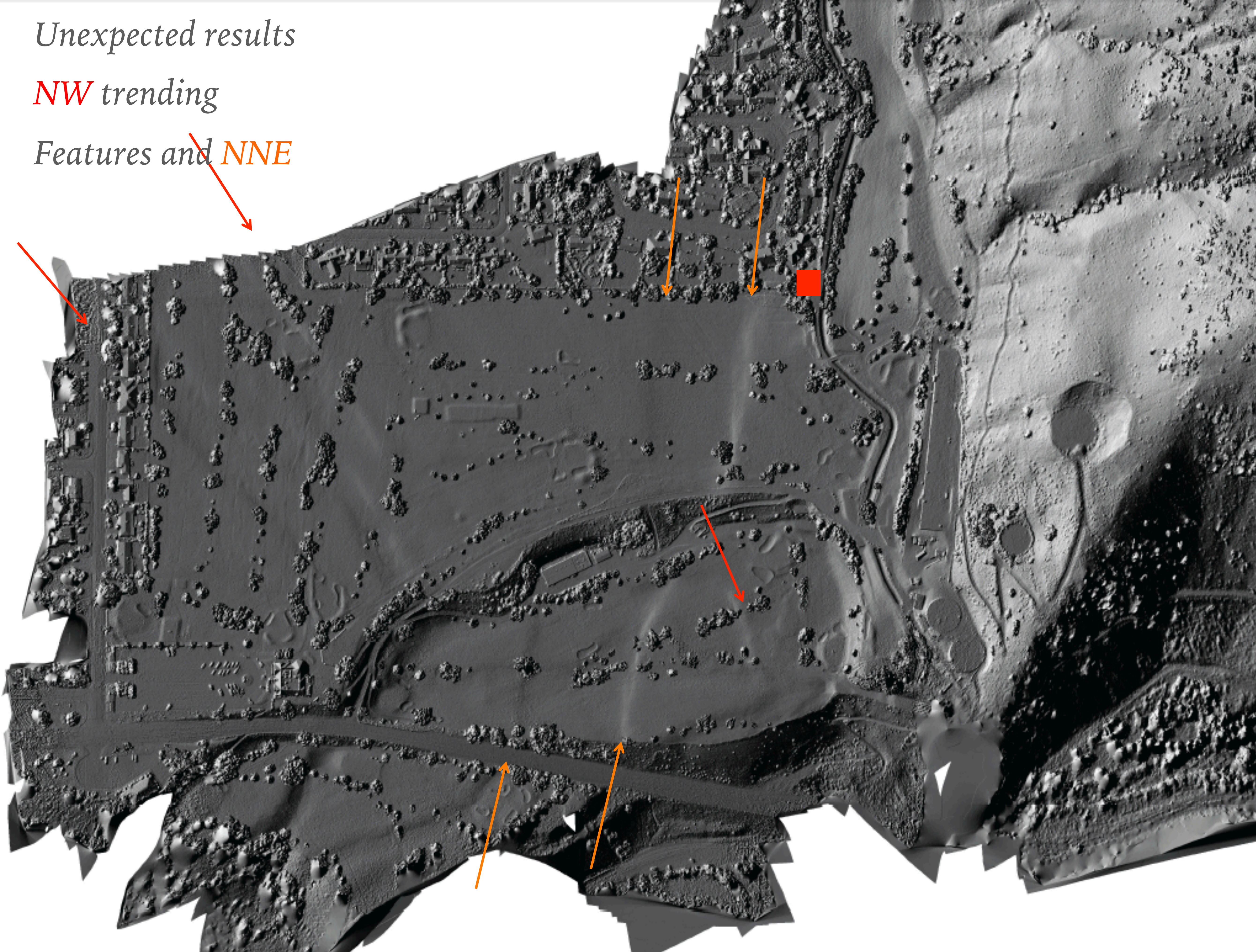



250
375
500
Meters
N

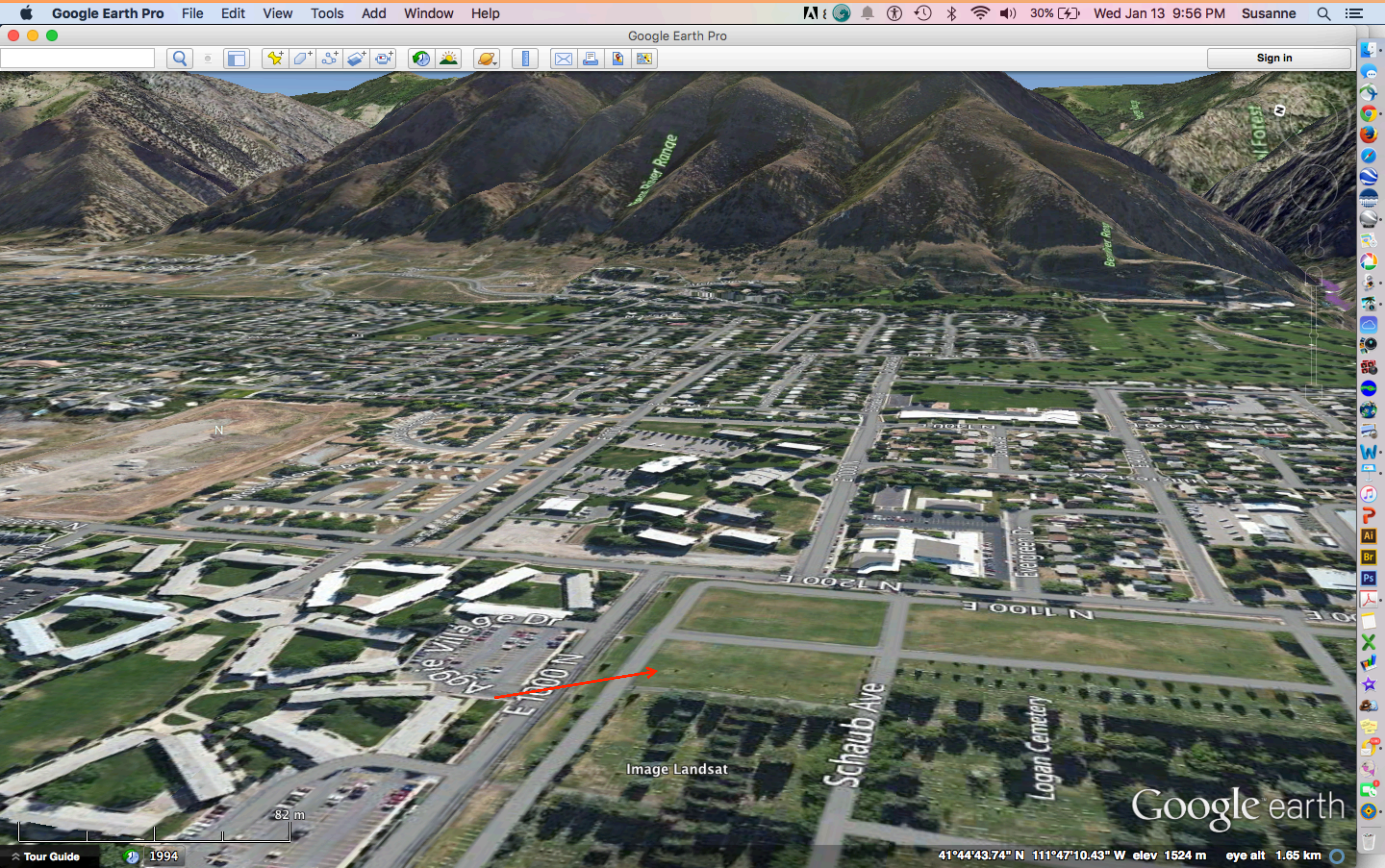
Unexpected results

NW trending

Features and NNE



100,000 PEOPLE LIVE IN CACHE VALLEY AND THE NW-TRENDING SCARPS PERSIST TO THE UNIVERSITY. THEY NEED TO BE INVESTIGATED FOR POSSIBLE TECTONIC ORIGIN



New Data on Holocene Offsets and Slip Rates for the Oquirrh Fault from DEMs Made with Structure-from-Motion Methods

Michael Bunds, Jeremy Andreini, Michael Arnold, Kenneth Larsen, Andrew Fletcher, and Nathan Toké

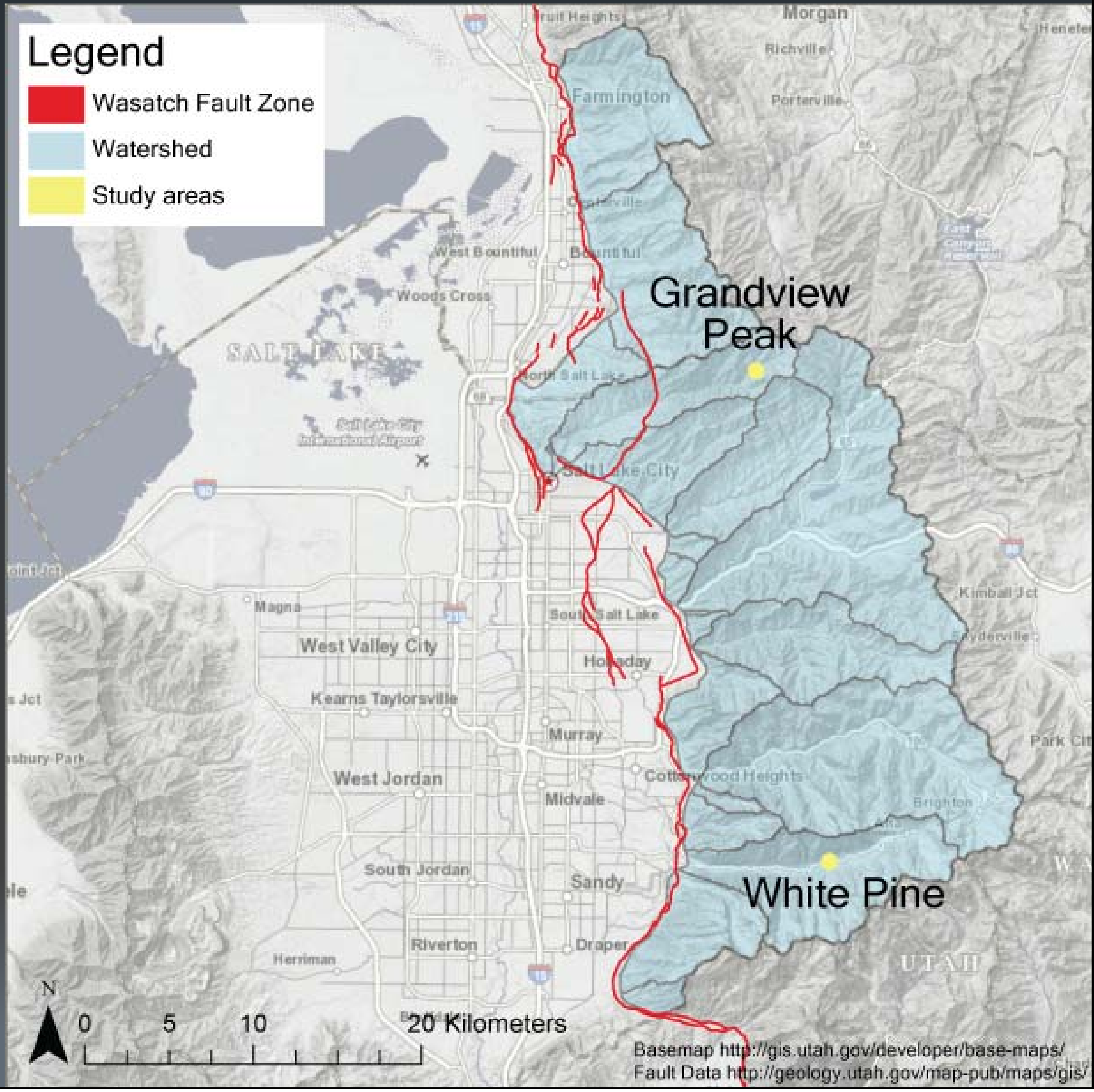
Department of Earth Science, Utah Valley University

michael.bunds@uvu.edu

UTAH VALLEY UVU UNIVERSITY Department of EARTH SCIENCE

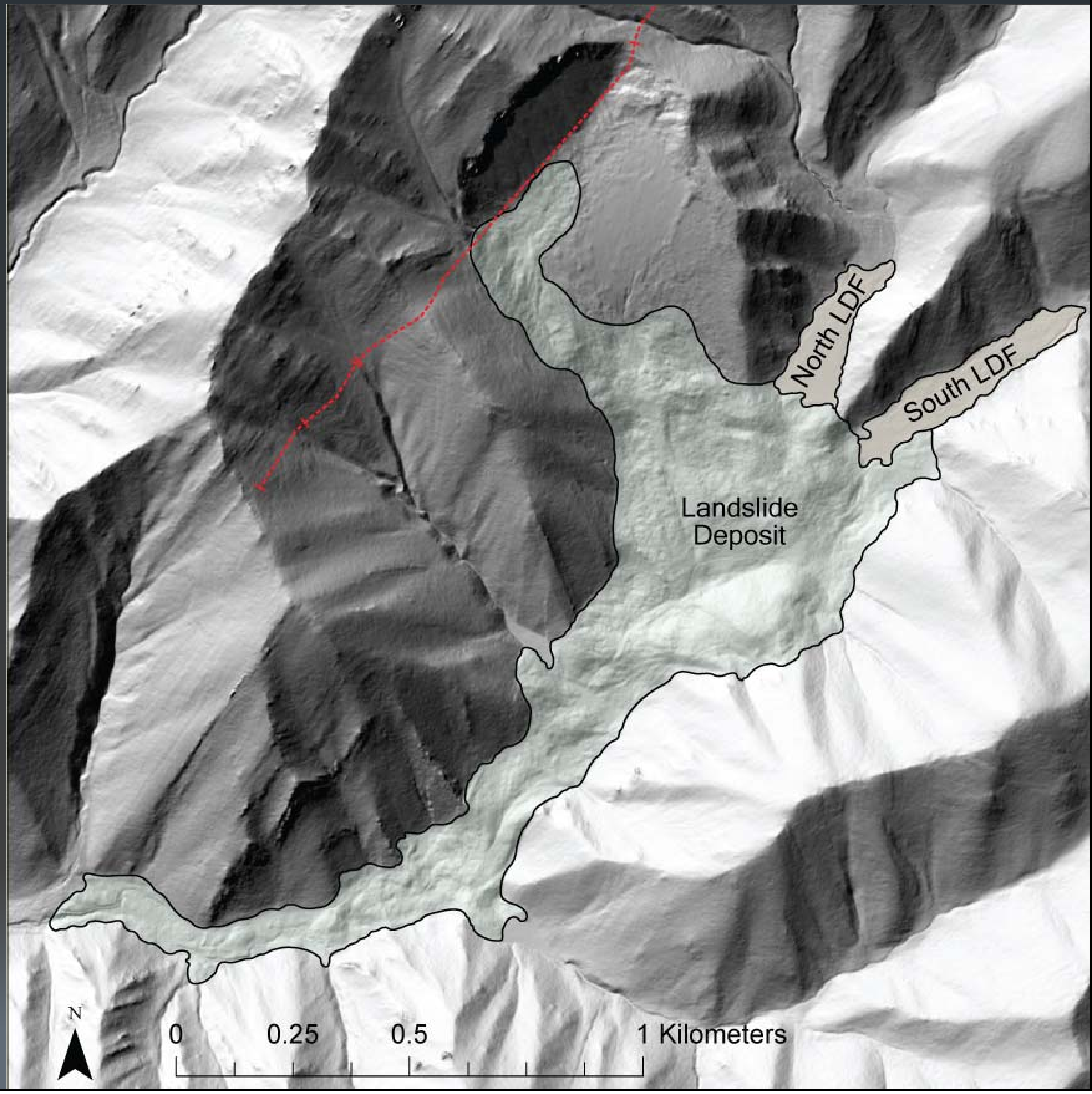
First, a trailer….

- Grandview Peak and White Pine Landslides
  - Funded and working CRN ages to test whether they may be seismically – induced



Grandview Peak Landslide Early Results

- Work of **Nick Butterfield** (UVU student)
- Modeled volumes:
  - Deposit (18 x 10^6 m^3)
  - Source (16 x 10^6 m^3)
  - Landslide-dammed floodplains (LDFs) (583 x 10^3 m^3)
- No overland flow across deposit



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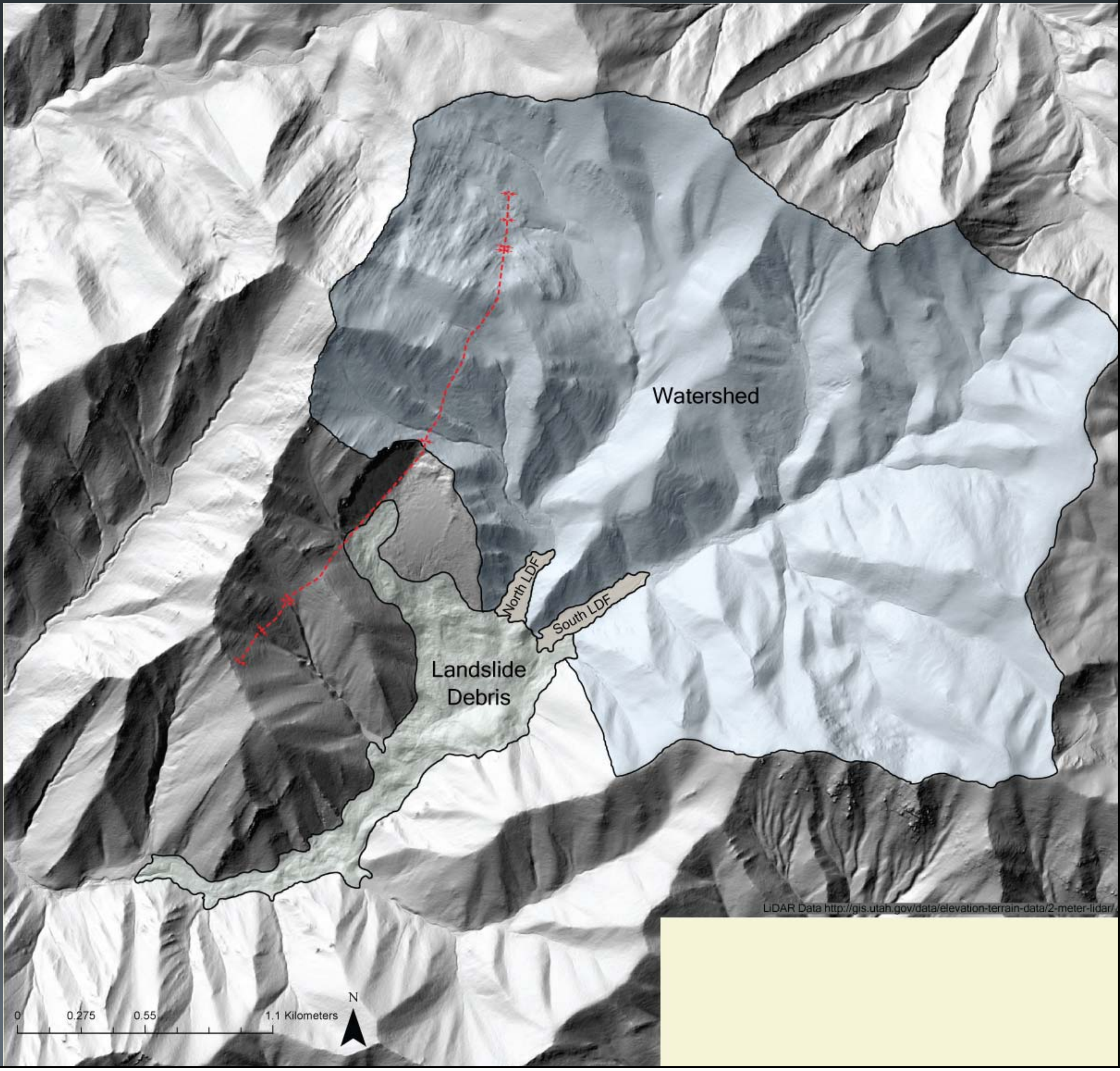
Grandview Peak Landslide Early Results

- Estimated age, based on time to fill LDFs, applying basin-wide erosion rates for Wasatch of Stock et al. (2010)
    - 499 ybp min age (0.17 mm/yr erosion rate)
    - 1211 ybp max age (0.07 mm/yr erosion rate)



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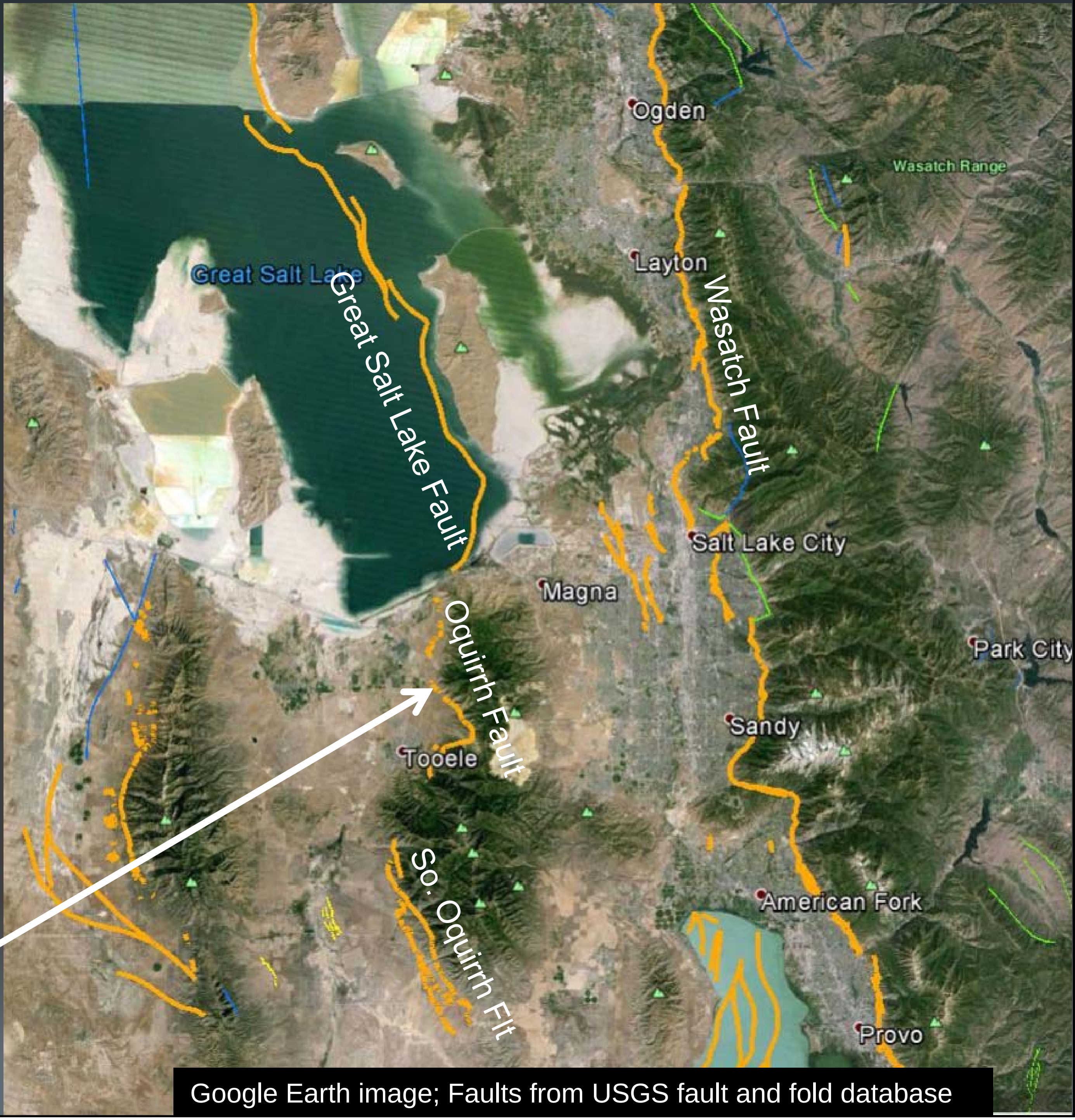
Oquirrh Fault Regional Setting

- Oquirrh Fault is west-dipping normal fault on west side of Oquirrh Mountains
- Probably contiguous with Great Salt Lake Fault, making second longest fault system in Utah

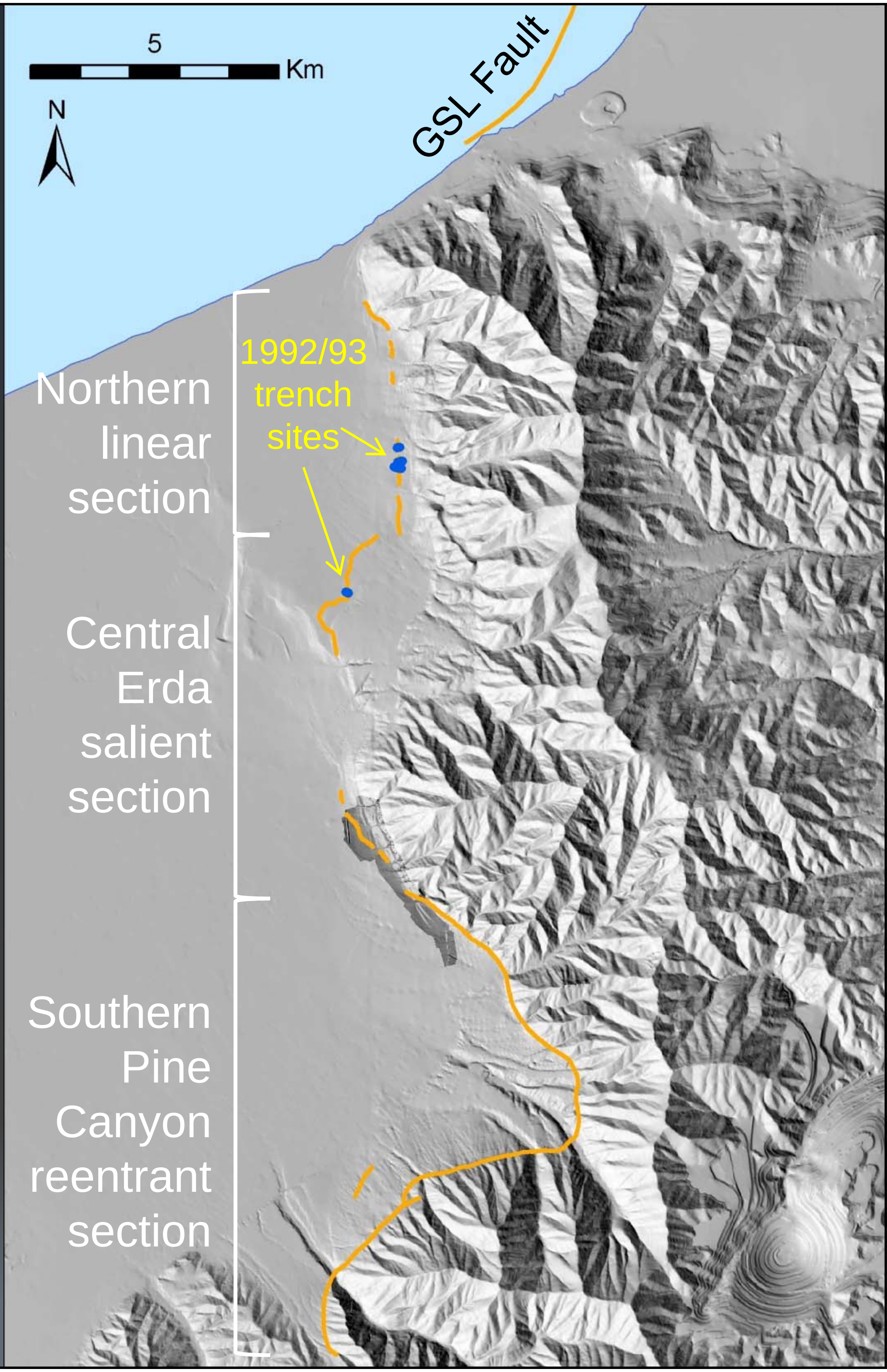
Study area



Google Earth image; Faults from USGS fault and fold database

Oquirrh Fault

- Borders Tooele, Stansbury Pk.
- Three sections
- Southern Oquirrh Fault lies to south
- Local compound scarps
- Mapped and trenched in 1992/1993
    - Lund, Olig, Solomon, et al., (1996)
    - Two trenching sites
    - Most Recent Event
        - 4300 – 6900 ybp (^{14}C yrs)
        - 2.0 – 3.3 m NVD
    - Penultimate Event
        - 20,300 – 26,400 ybp
        - 1.9 – 2.9 m NVD
    - Possible Antepenultimate Event
        - Pre – 32,800 ybp



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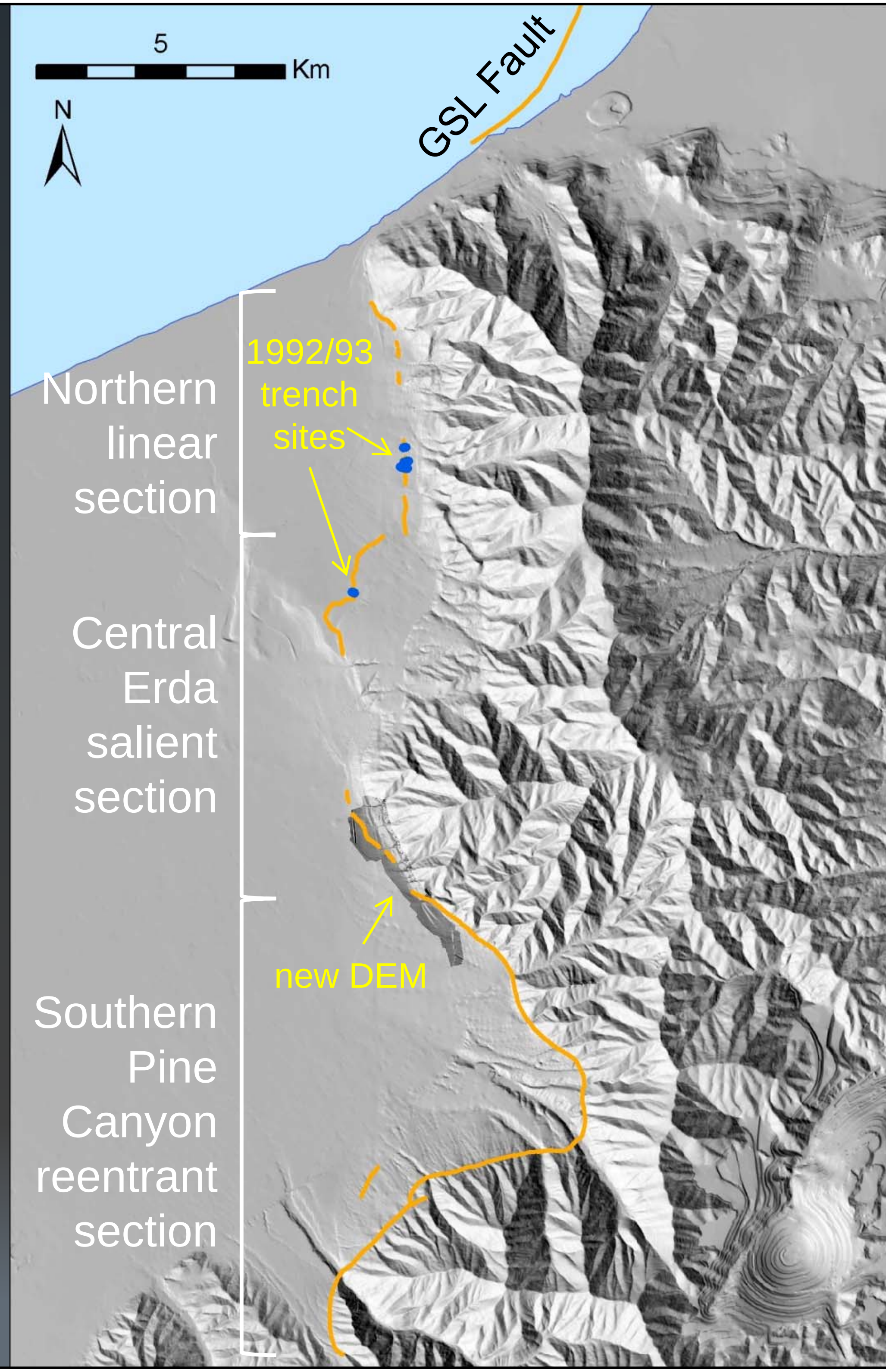
Project Goals

- Construct accurate, high-resolution DEMs along Oquirrh Fault
- Measure offset of shoreline features
    - Bench elevations in hanging wall and footwall
    - Scarp heights
- Explore future trenching sites
- Student class projects



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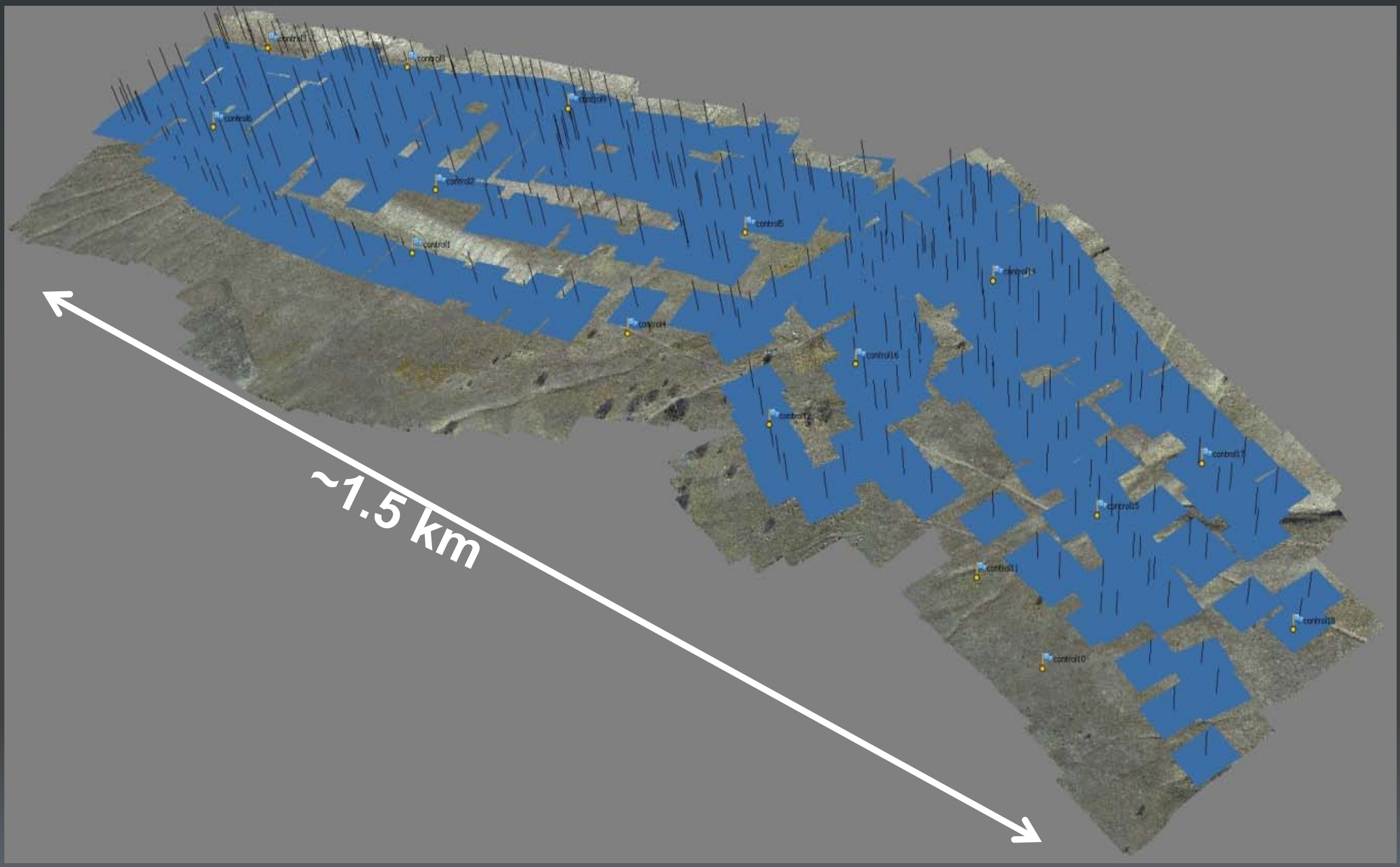
DEM Construction Methods: Aerial Imagery and Structure from Motion (SfM)

- Aerial imagery from quadcopter
- Processed with SfM (Agisoft Photoscan) to generate a point cloud
- Georeferenced with ground control points imaged in photographs and surveyed with RTK GPS
- Checkpoints on bare ground surveyed with RTK GPS used to assess DEM accuracy

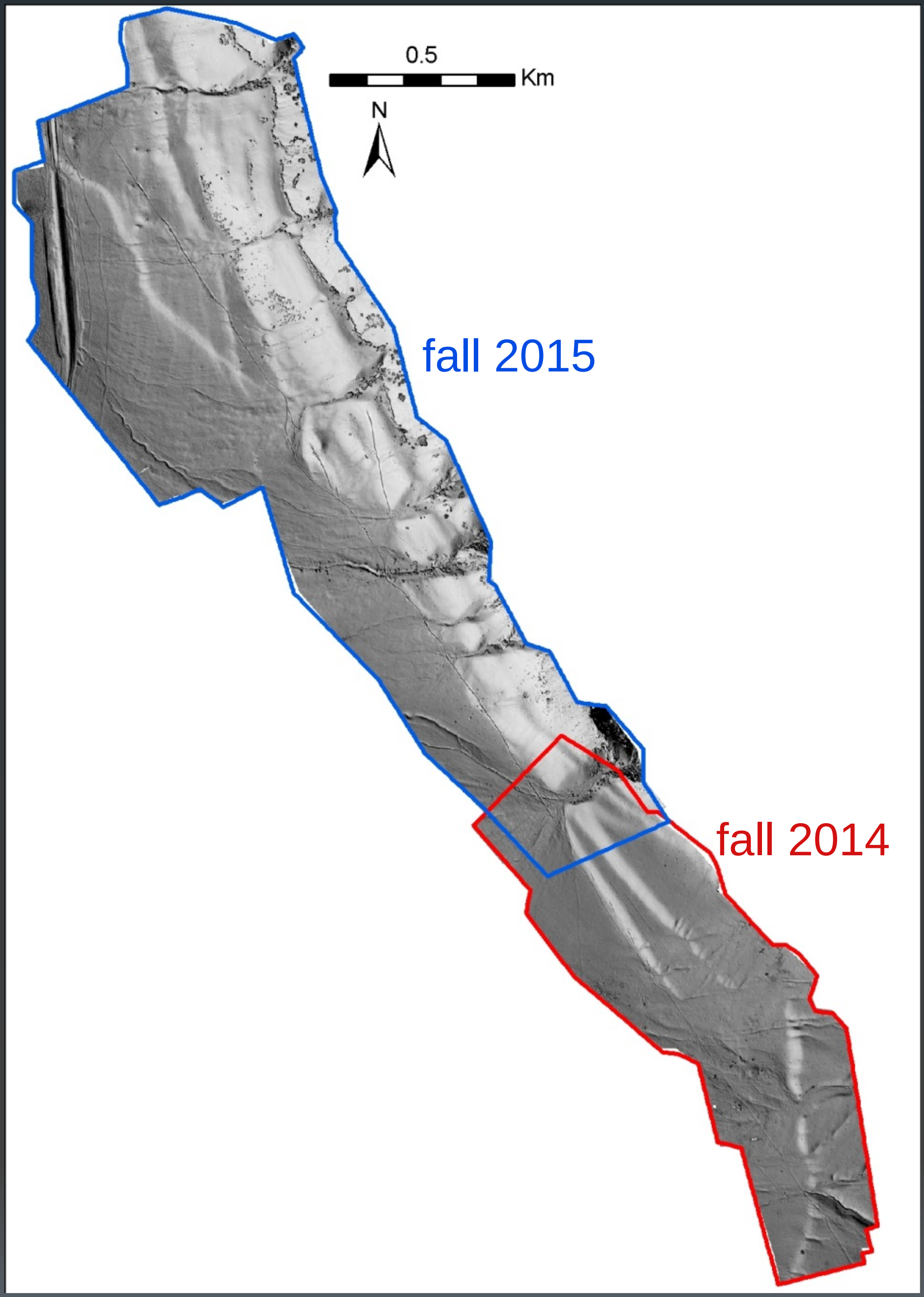


Blue squares are locations where photograph was taken from UAV.

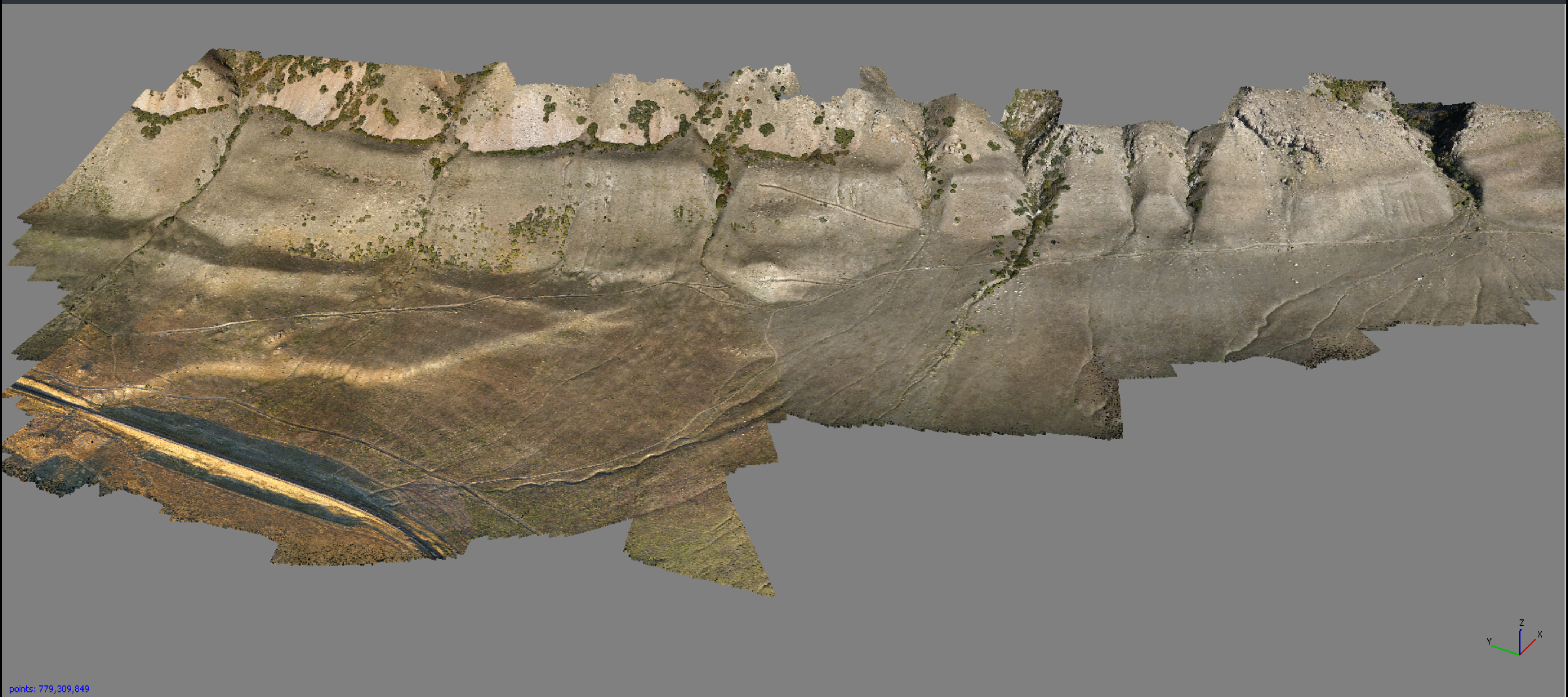
SfM software determined locations of the photos.

Oquirrh Fault DEM

- Constructed in two parts
- Spans ~ 3.9 km of Bonneville shoreline
- North, made fall 2015
    - 5 cm DEM
    - Sony A5100 camera (24 Mpixel)
    - 2.9 cm average ground resolution
    - 5.8 cm vertical RMS error relative to 63 checkpoints
    - ~2.5 km of Bonneville shoreline, 1.87 km^2
- South, made fall 2014
    - 10 cm DEM
    - GoPro camera (12 Mpixel)
    - 4.1 cm average ground resolution (photo pixels)
    - 9.5 cm vertical RMS error relative to 43 checkpoints
    - ~1.7 km of Bonneville shoreline, 0.85 km^2



Northern Area Point Cloud Screenshot



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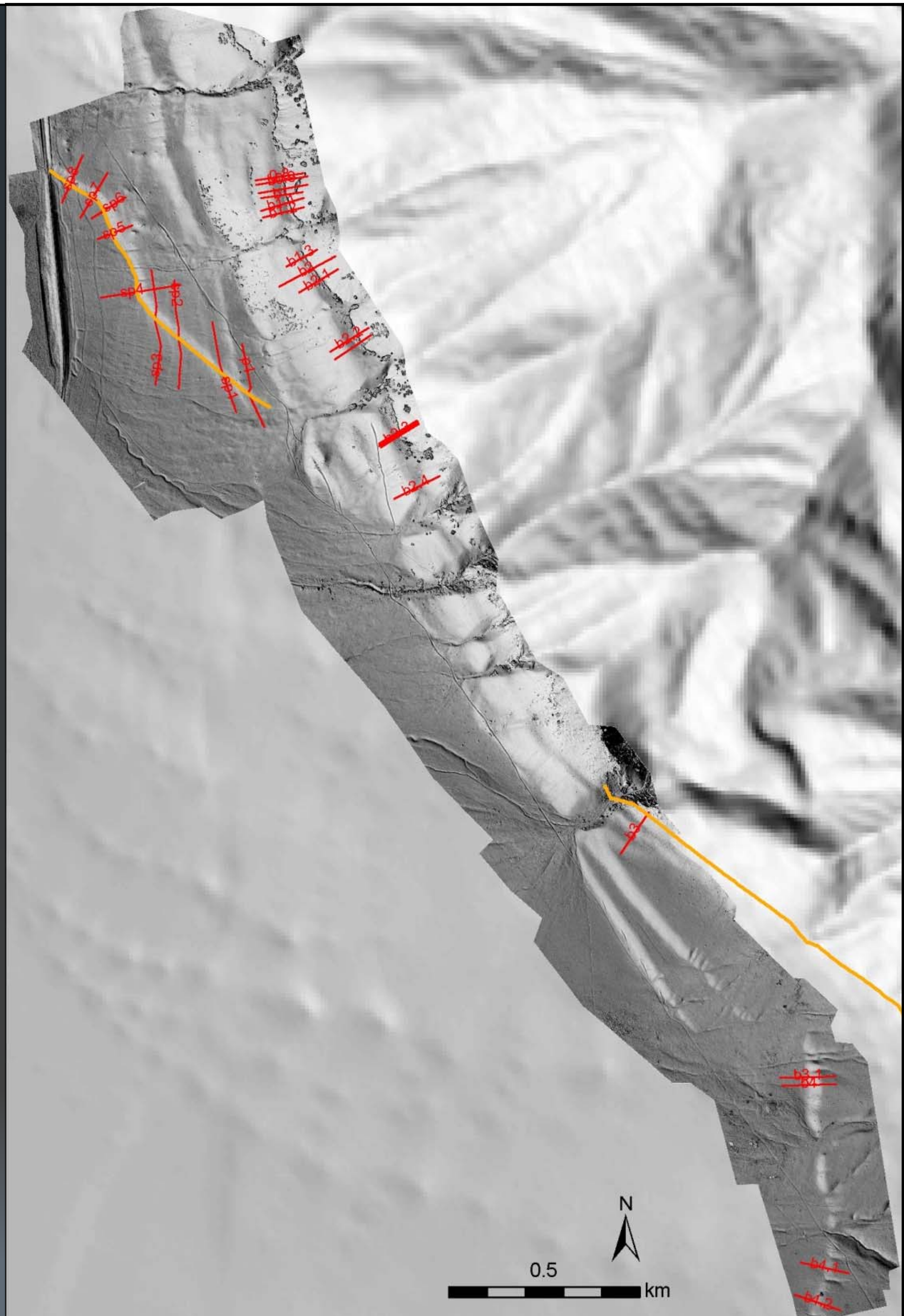
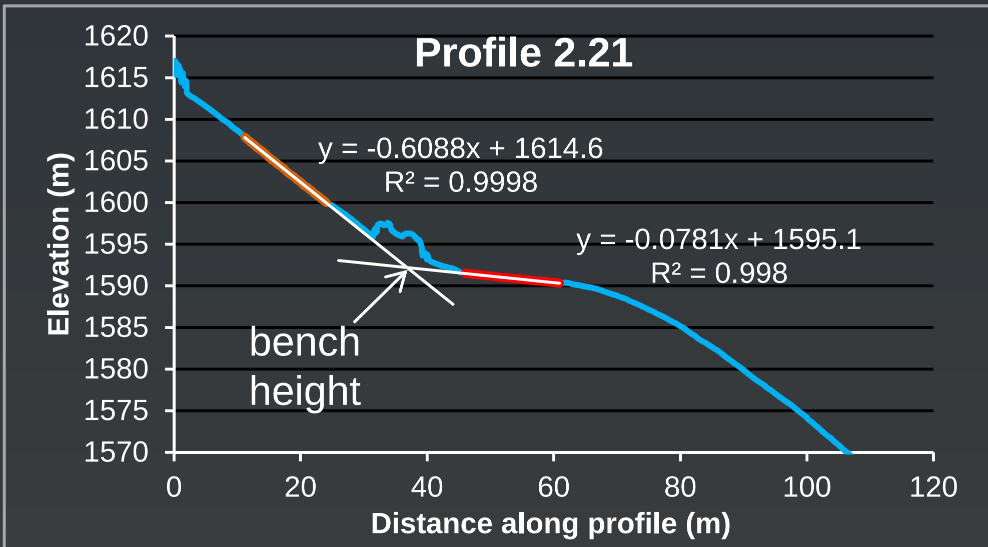
Oquirrh Fault DEM

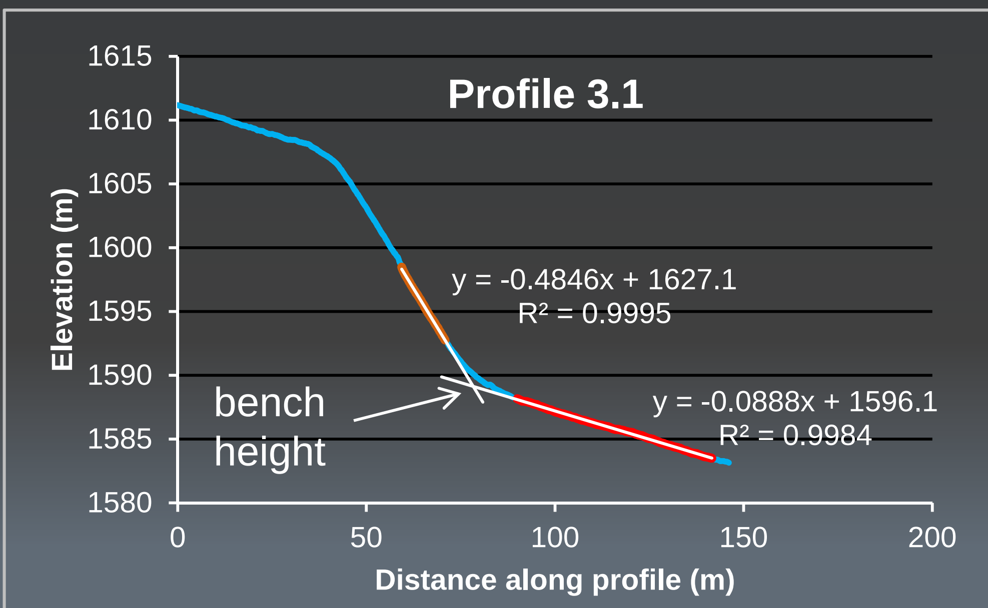
- Set of profiles across highstand bench
- Set of profiles across scarp
  - Some follow sub-Provo shoreline features
  - Some perpendicular to scarp

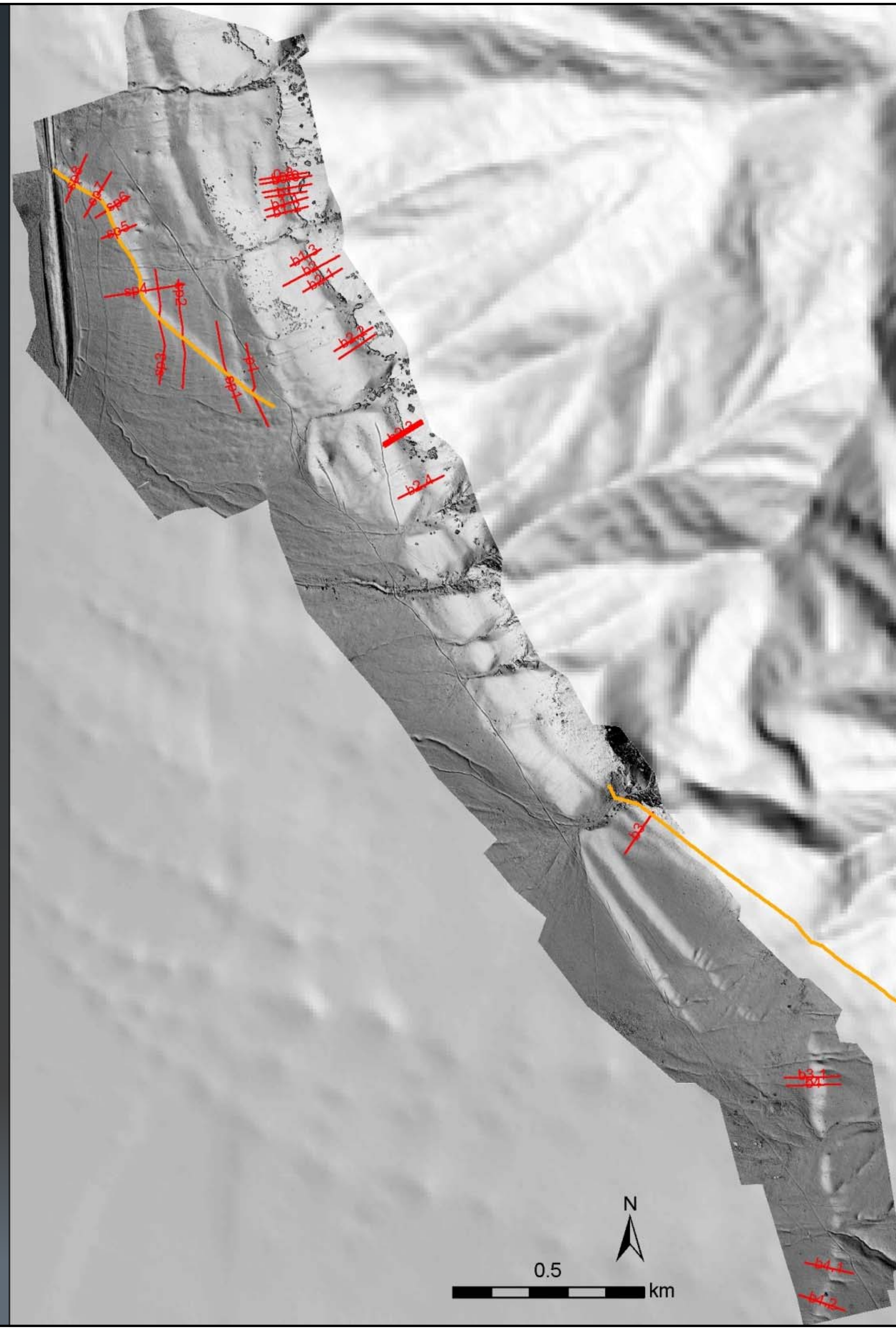


Highstand Bench

- On profiles, linear sections of wave-cut face and bench fit with lines
- Intersection of lines considered to be bench height

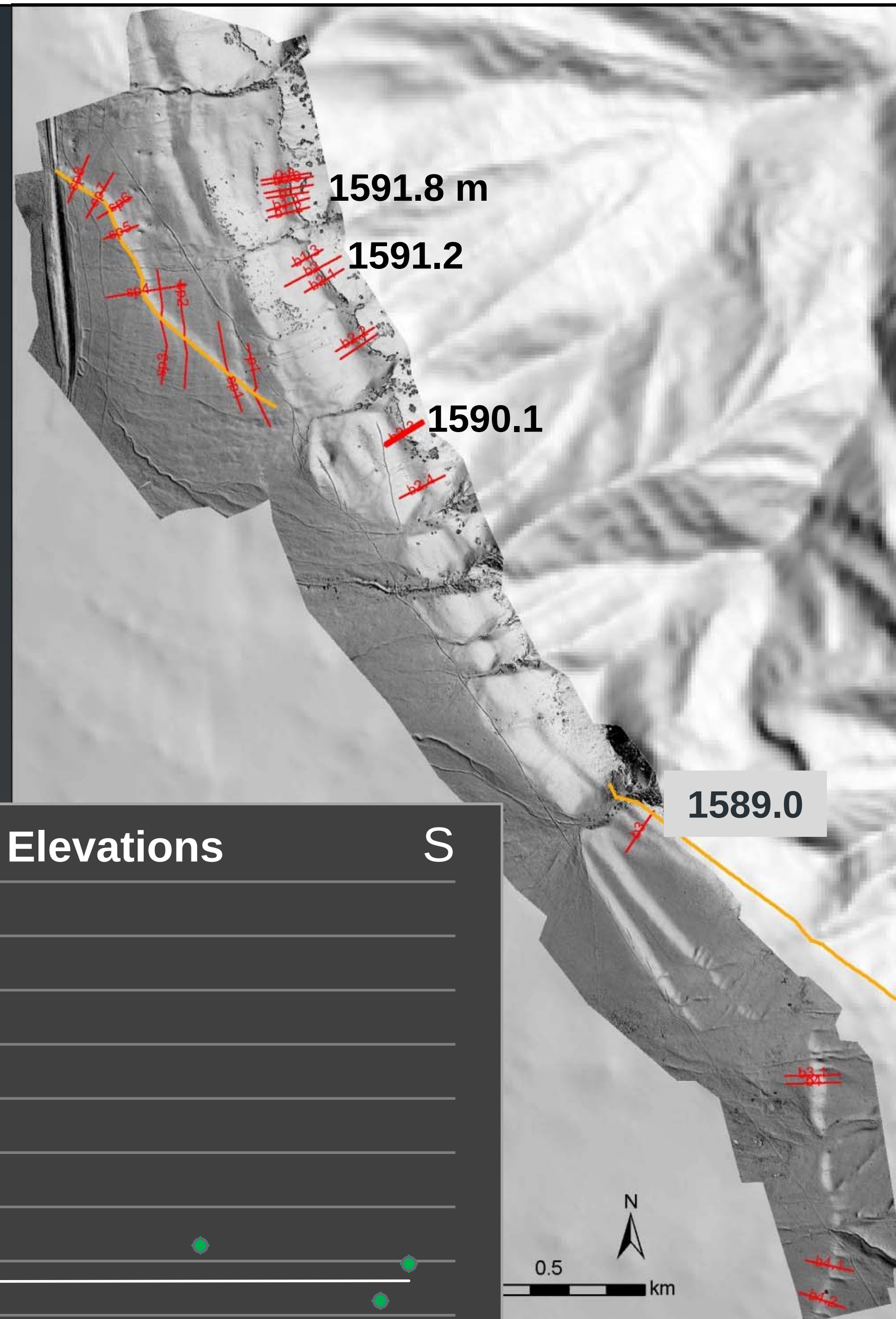


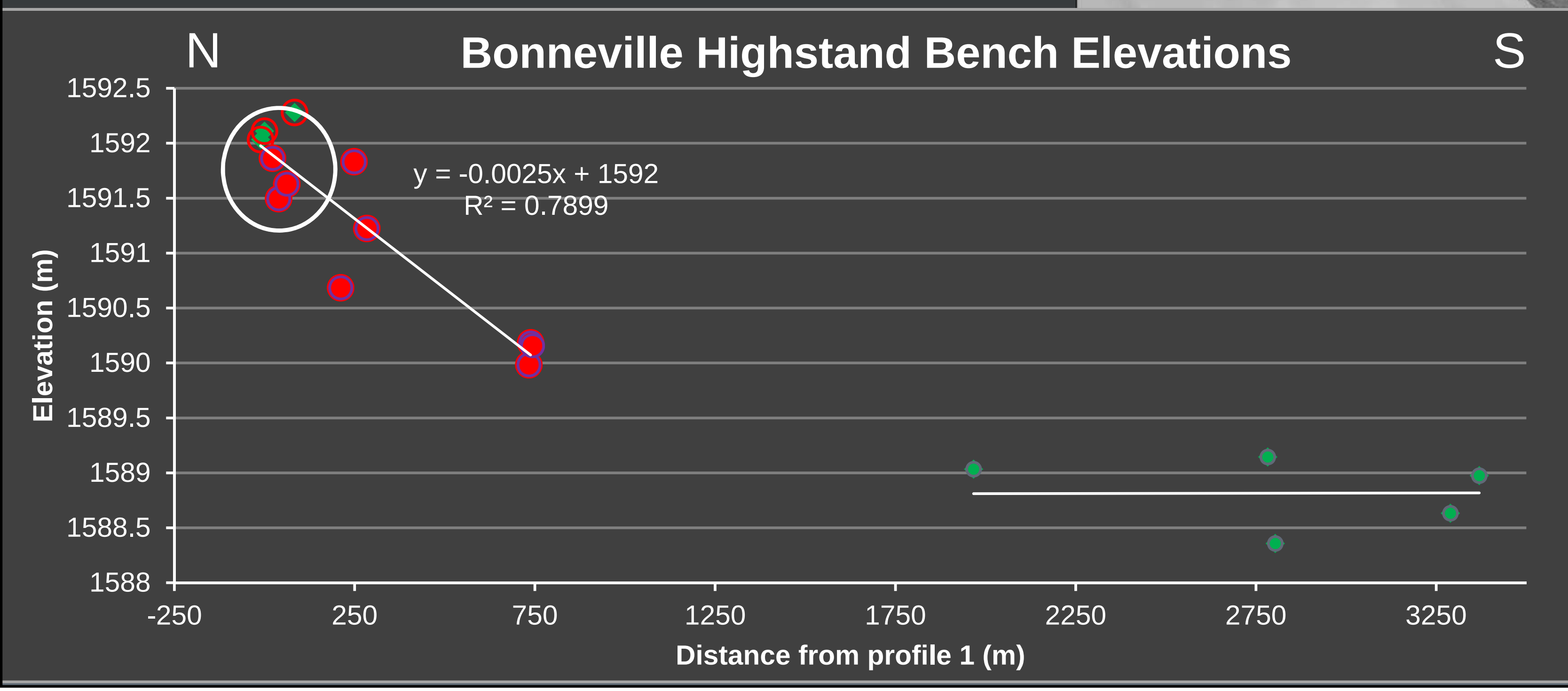




Highstand Bench

- Hanging wall average = 1588.83 m
- Footwall
  - Far north average = 1591.83 m
    - 1591.66 if three points are excluded (possible bench modification by deposition)
  - Gradient may reflect ramp, transfer of displacement to western scarp
- Post-highstand displacement = 2.83 – 3.0 m





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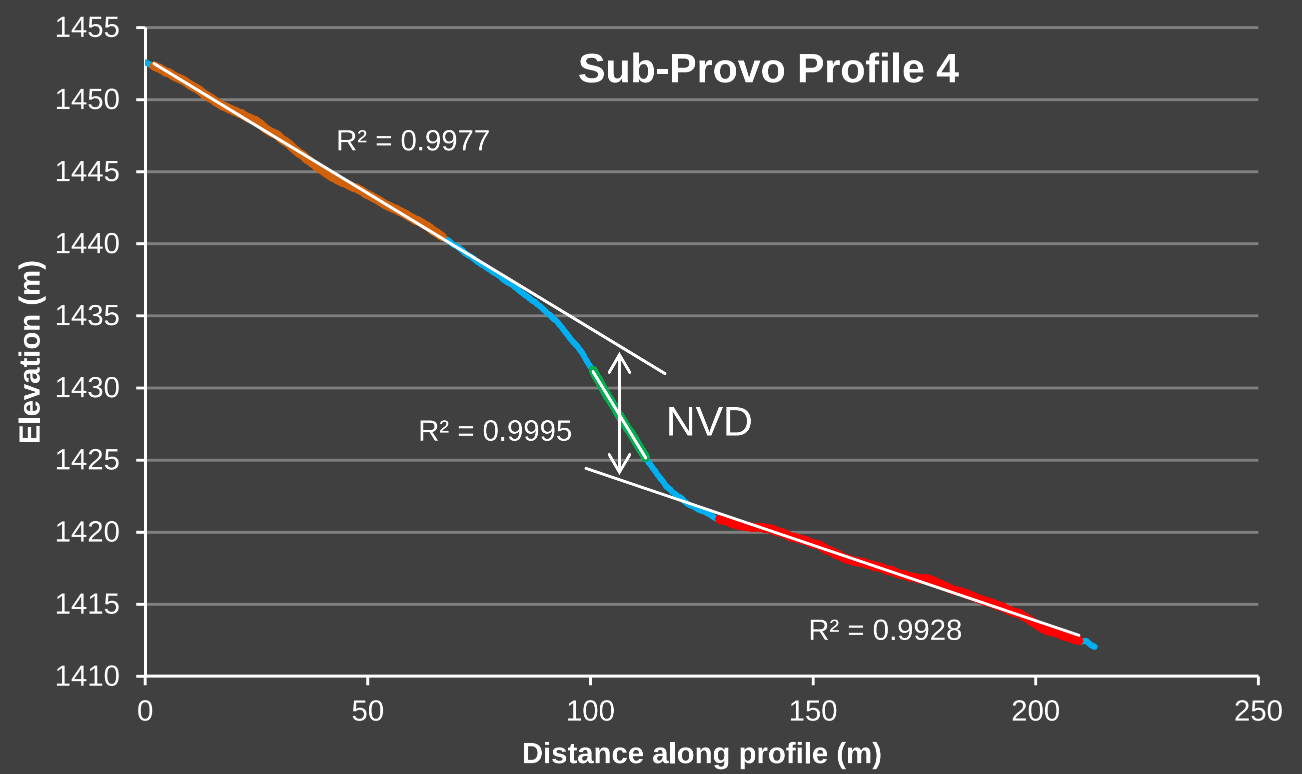
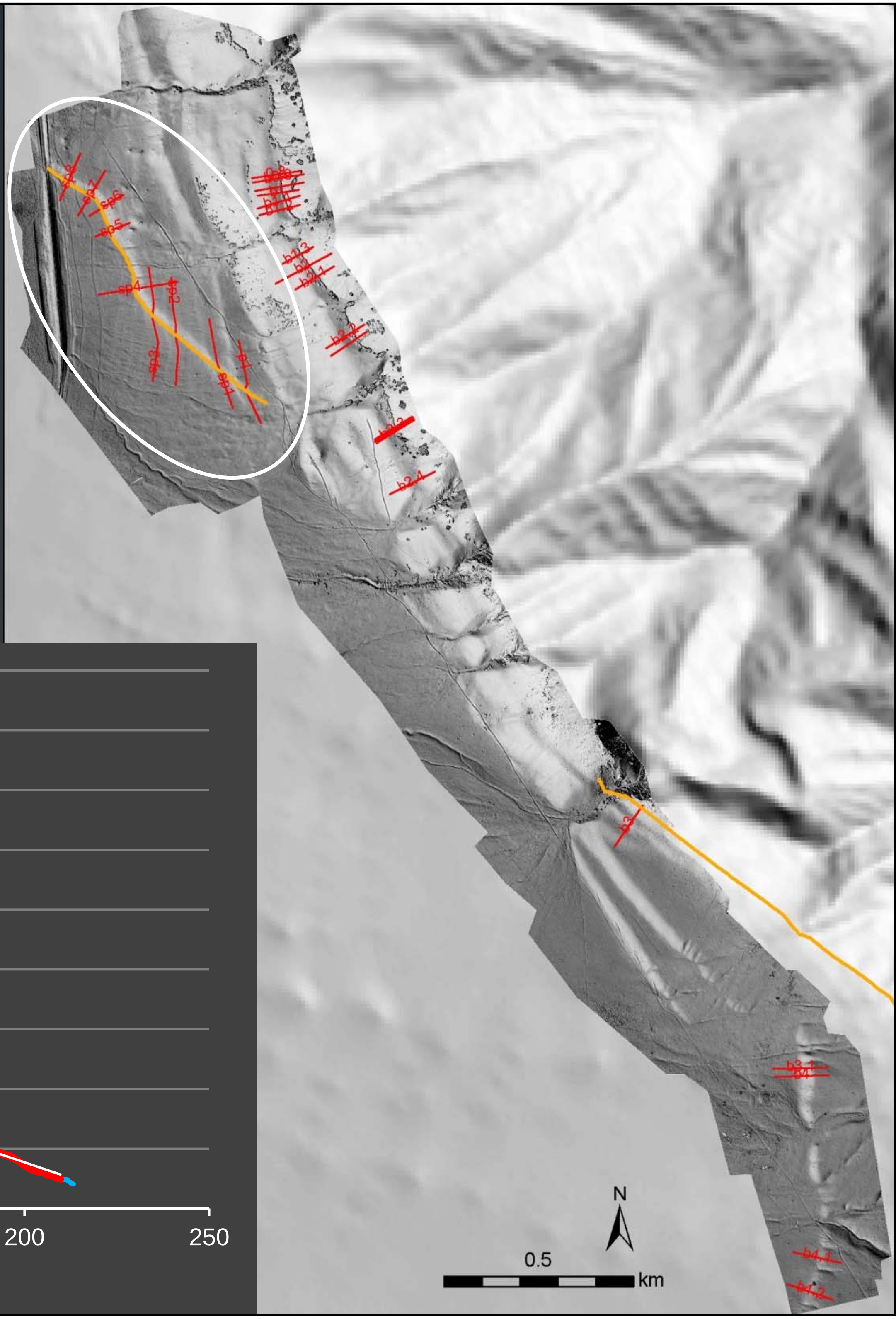
Scarp Heights

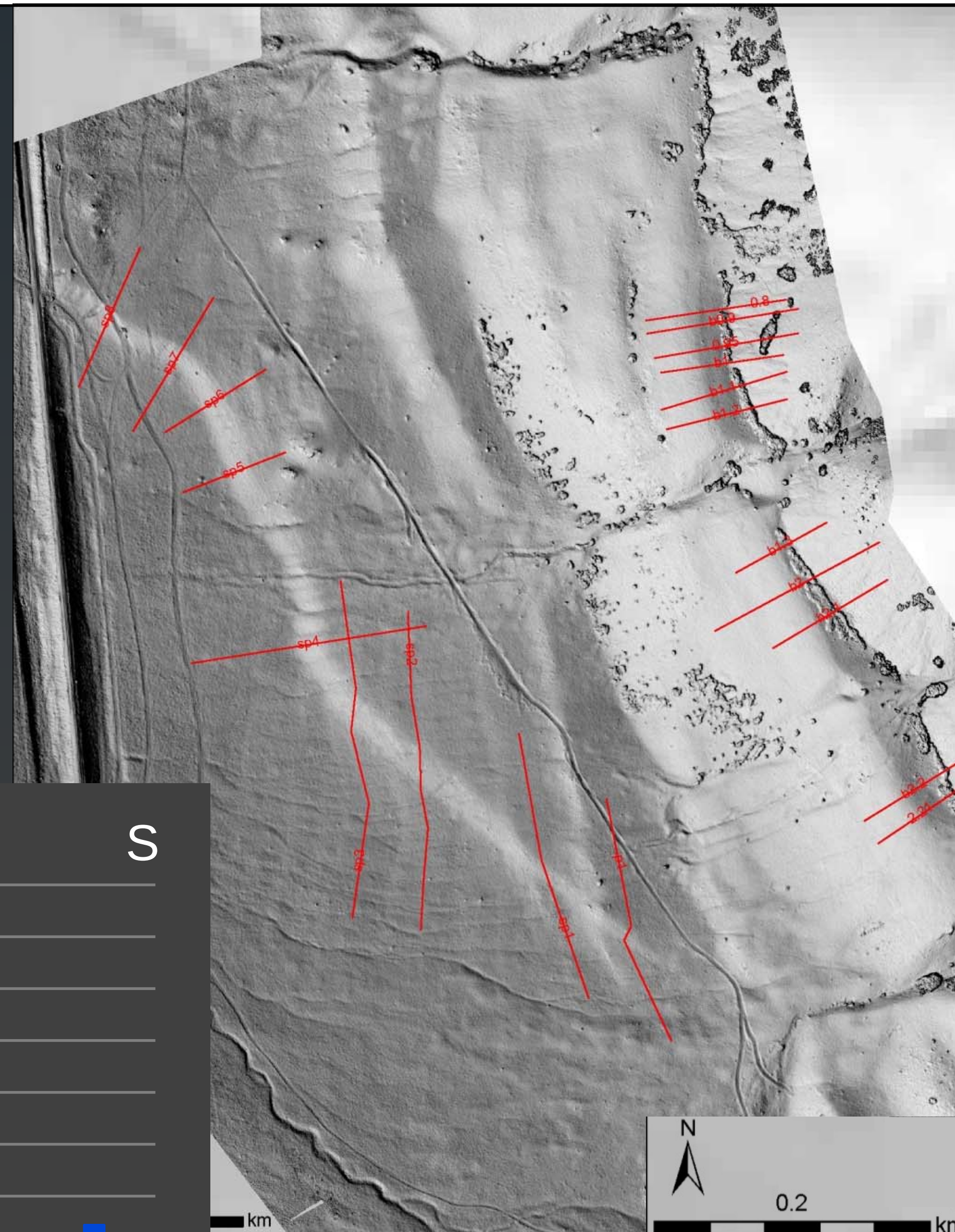
- On profiles, linear sections on footwall, hanging, and scarp face wall fit with lines
- Elevation difference between lines at midpoint of scarp taken as NVD

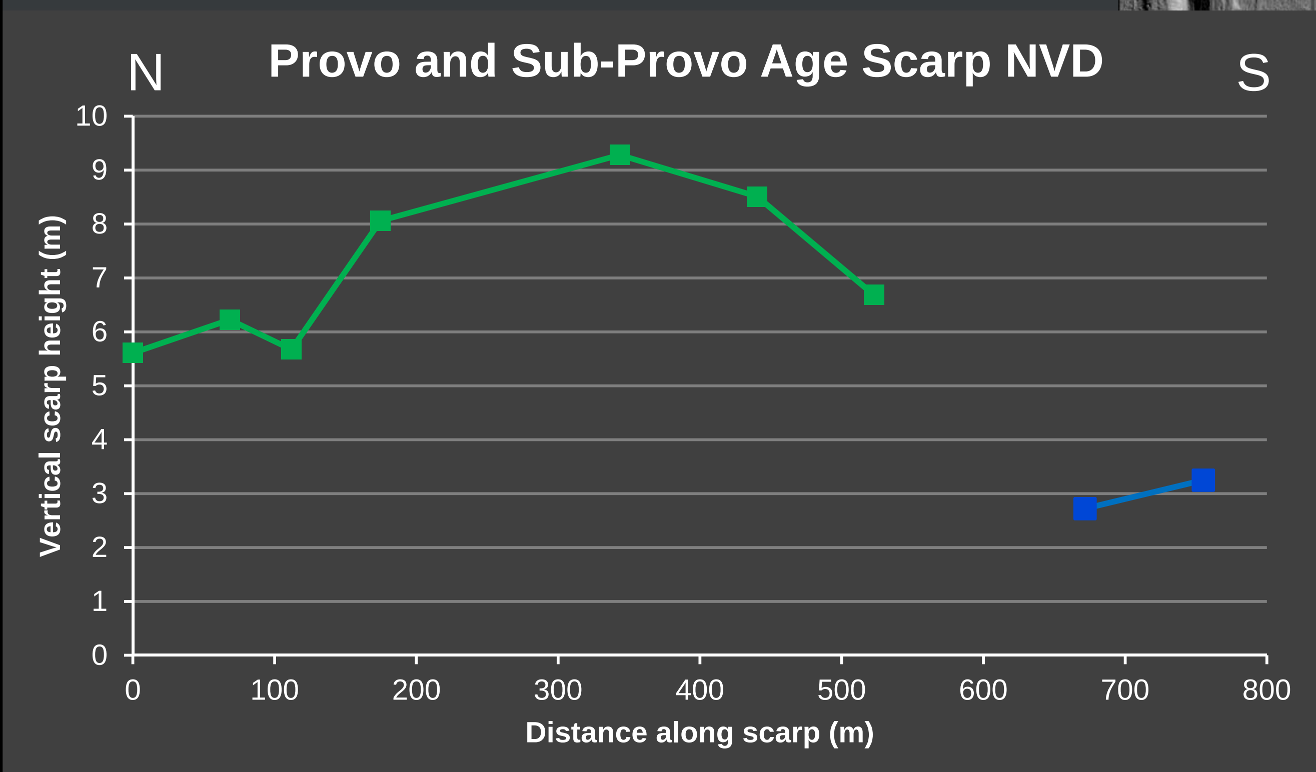




Scarp Heights

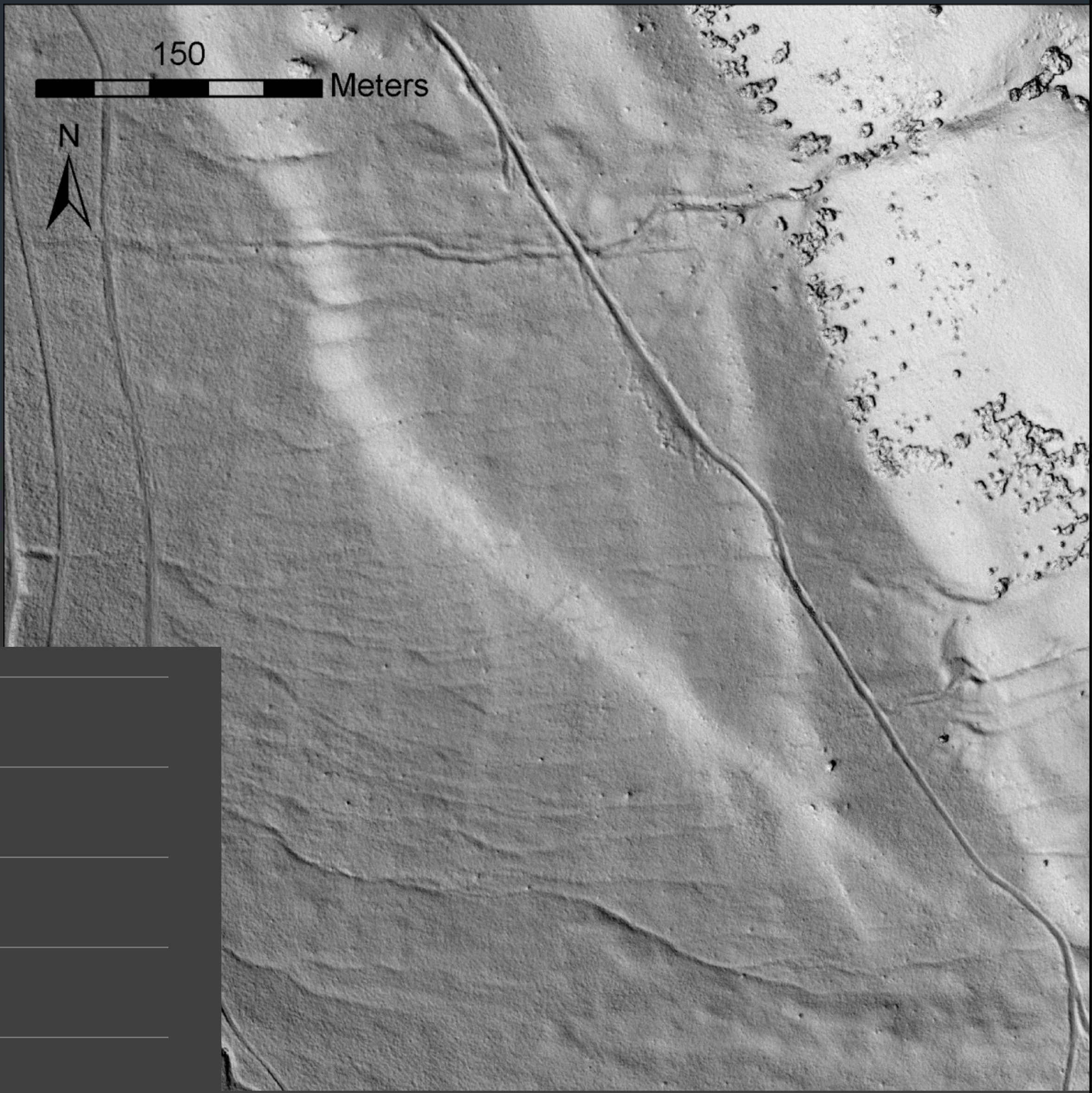
- Provo Bench offset = 3.25 m NVD
- Sub-provo bench 1 = 2.72 m NVD
- Lower levels 5.61 – 9.28 m
- Transgressive shorelines???

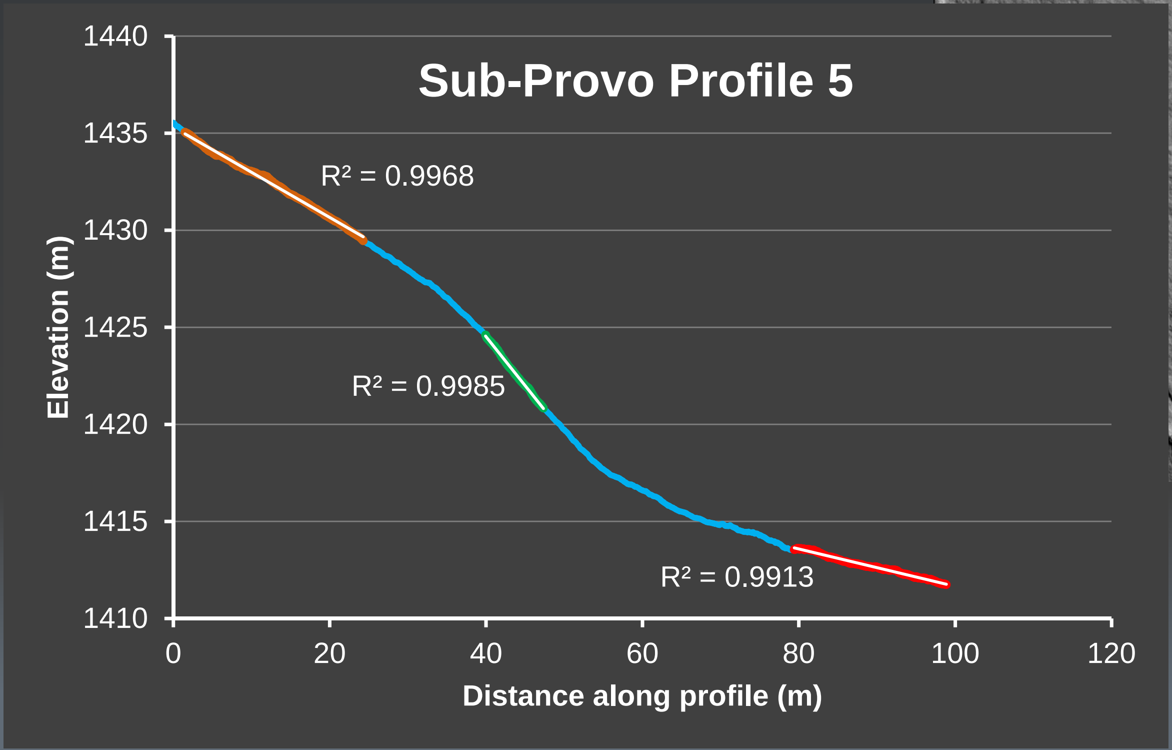




Scarp Heights

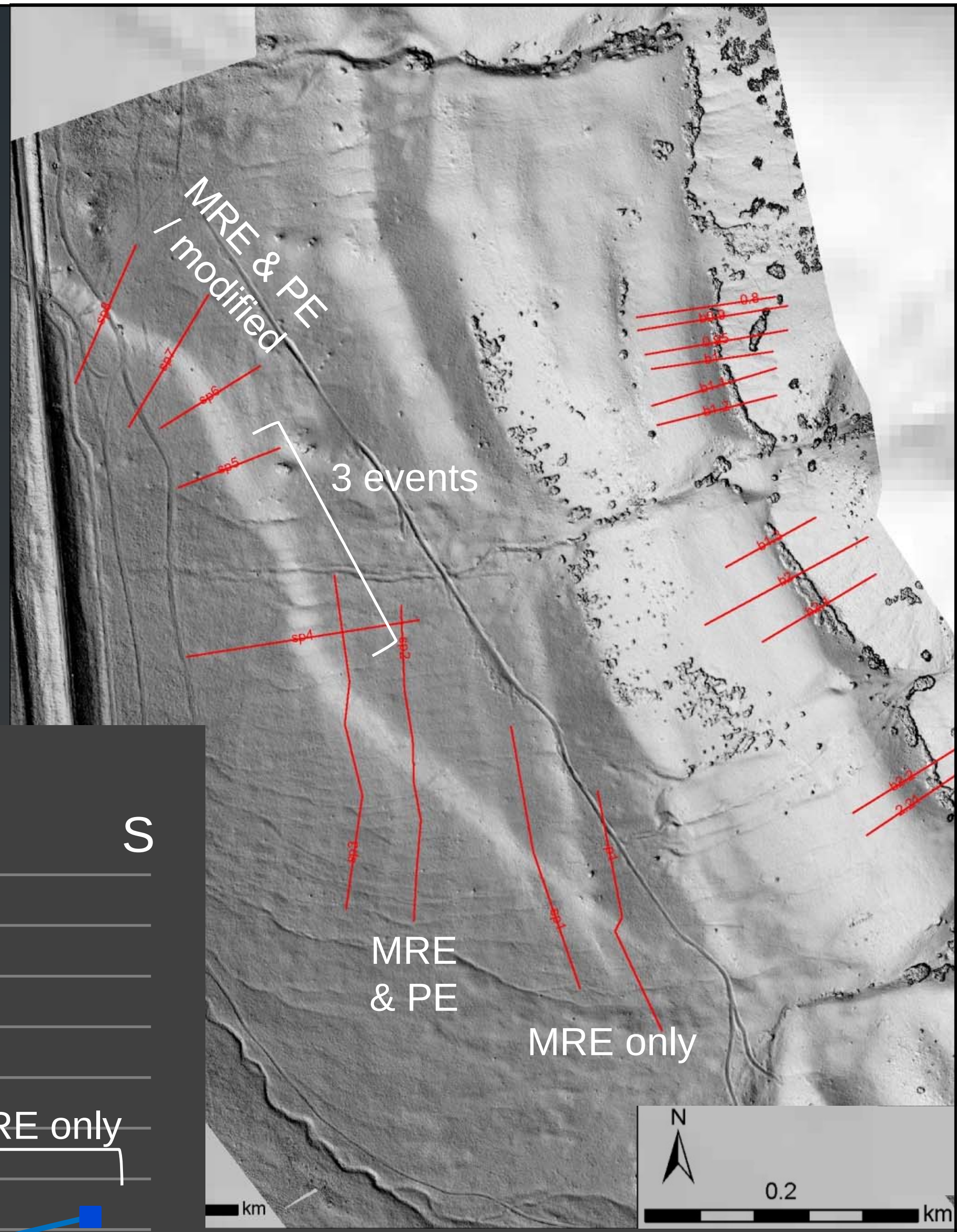
- Scarps across sub-Provo shorelines probably compound
  - Deflected shorelines
  - Scarp shape

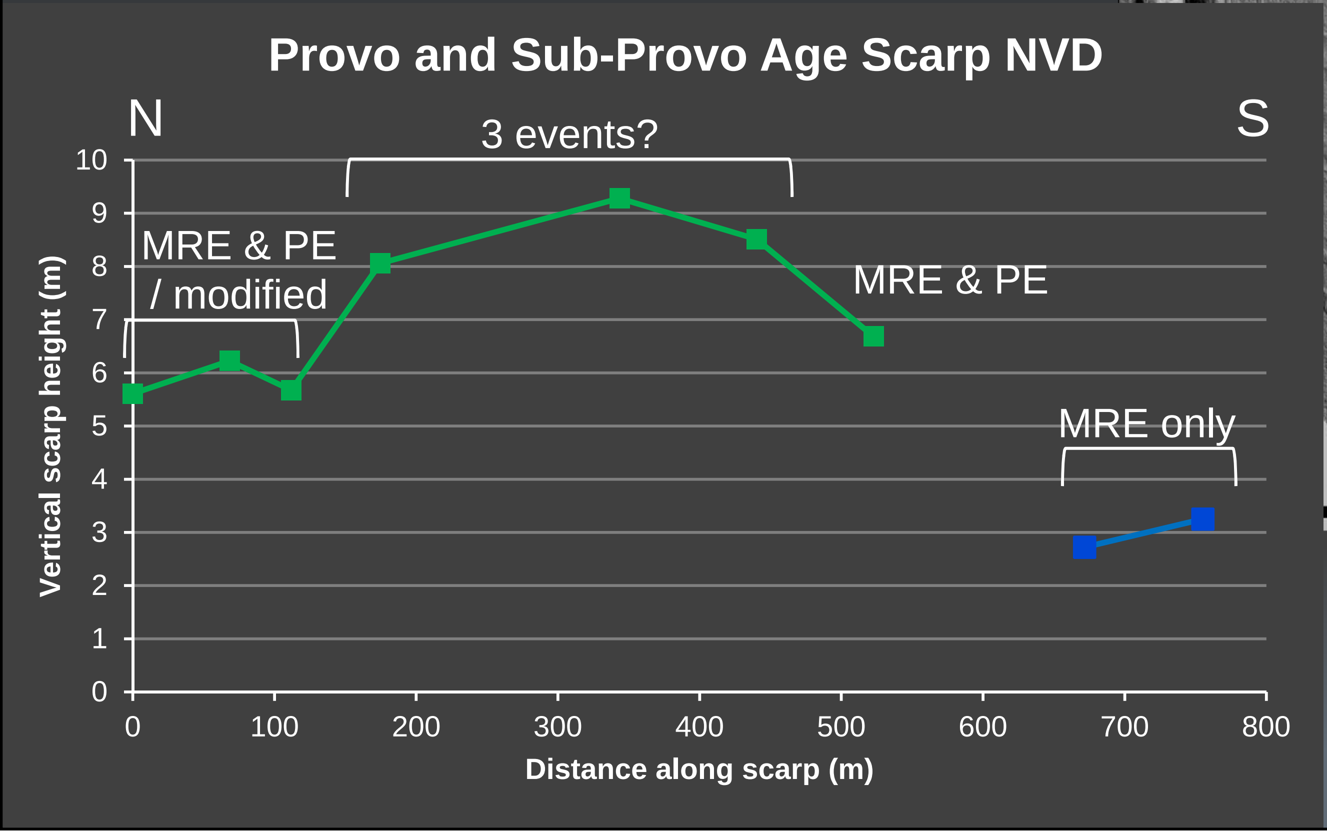




Scarp Heights

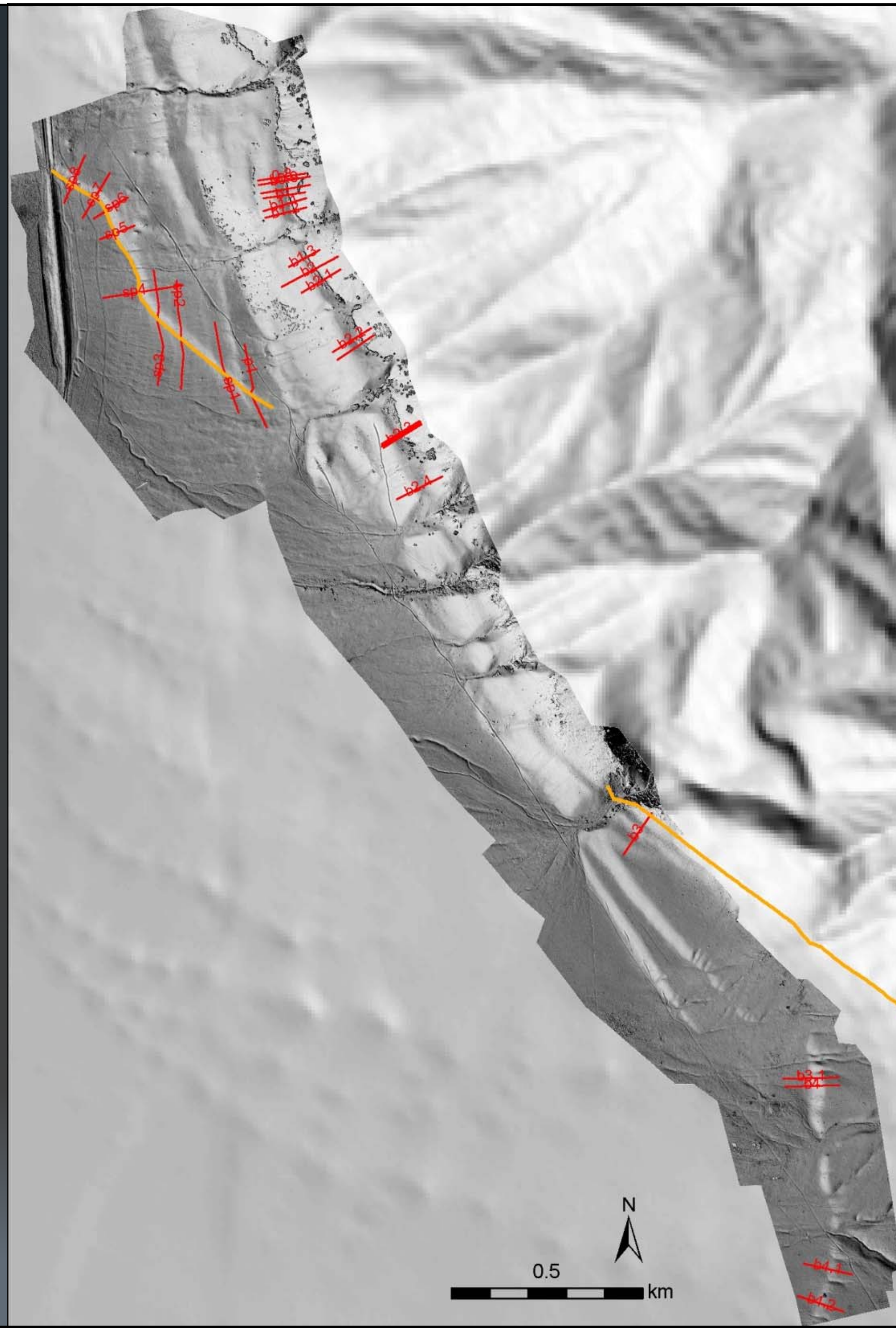
- Capturing MRE, PE and Antepenultimate event?





Displacement Summary

- MRE
  - Highstand offset 2.83 – 3.0 m
  - Provo level offset 2.98 m
  - **Average = 2.94 m**
  - Post Provo bench,
    - < 14,400 ybp (Godsey et al.; Miller et al.)
- PE
  - (6.68 to 5.61) minus (2.83 to 3.0) = 2.61 – 3.85 m, **3.1 average**
  - Post transgressive shorelines, pre-highstand
    - ~23,000 to 18,000 ybp (Oviatt)
- Antepenultimate
  - 1.3 – 3.8 m NVD?
  - Pre ~23,000 ybp



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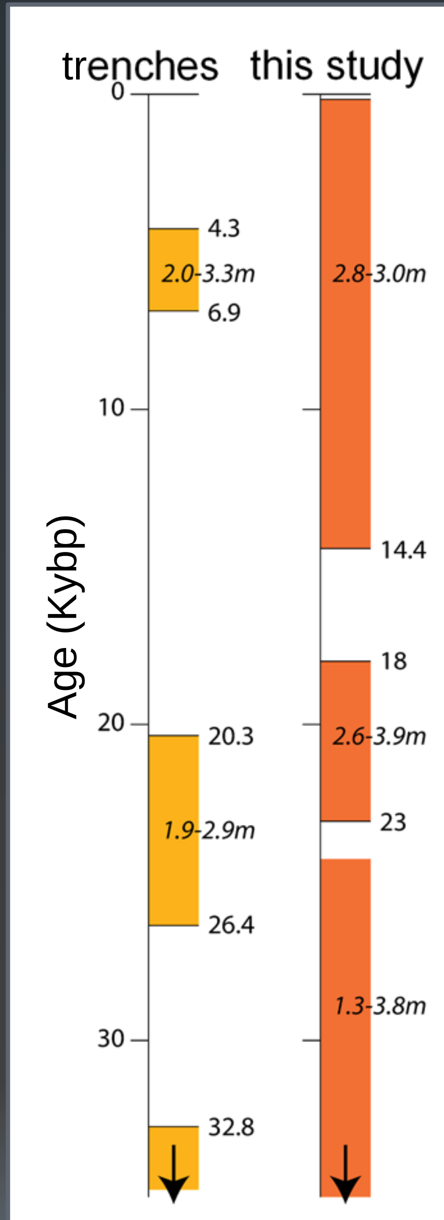
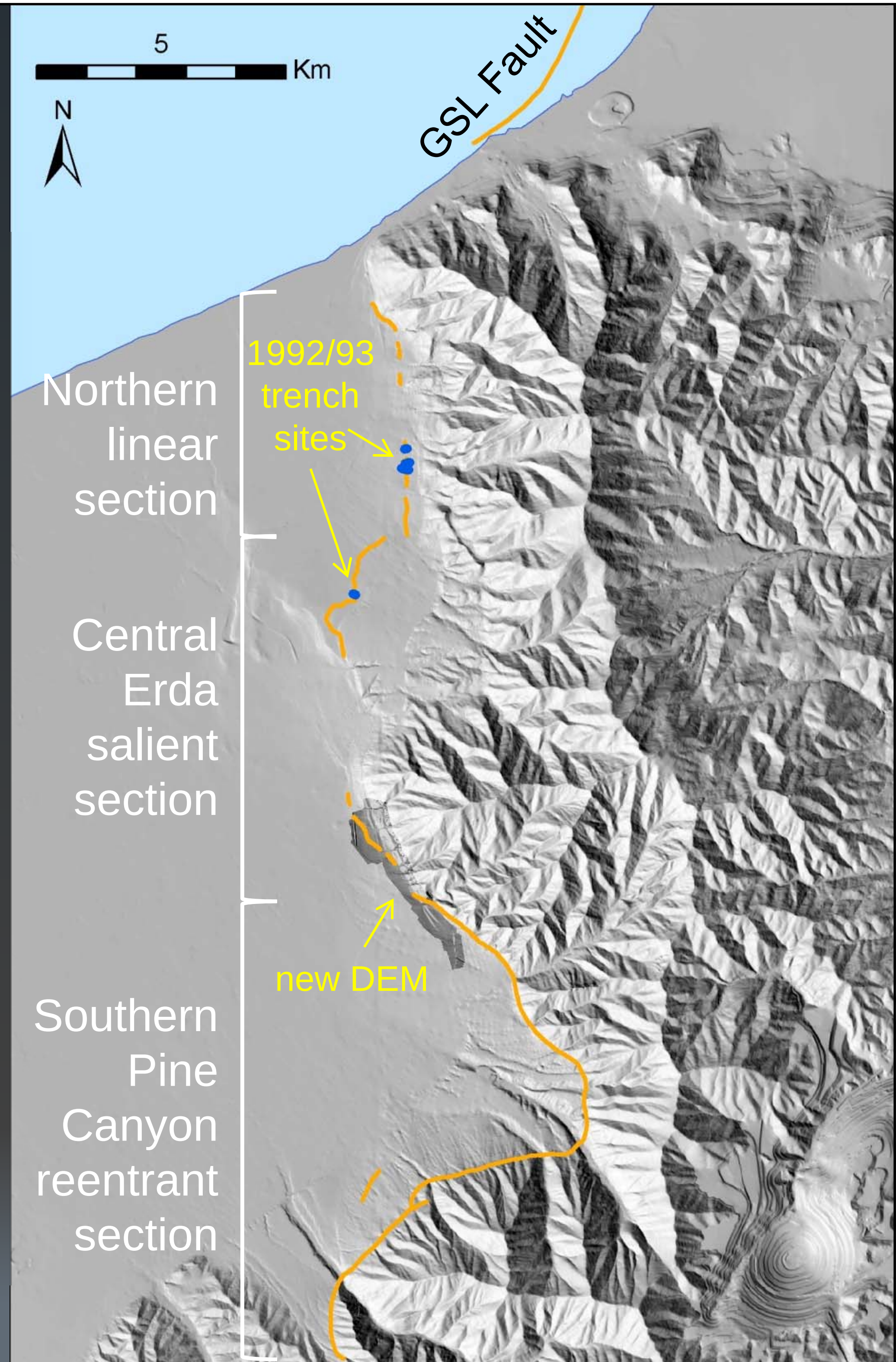
Correlation with Trenching

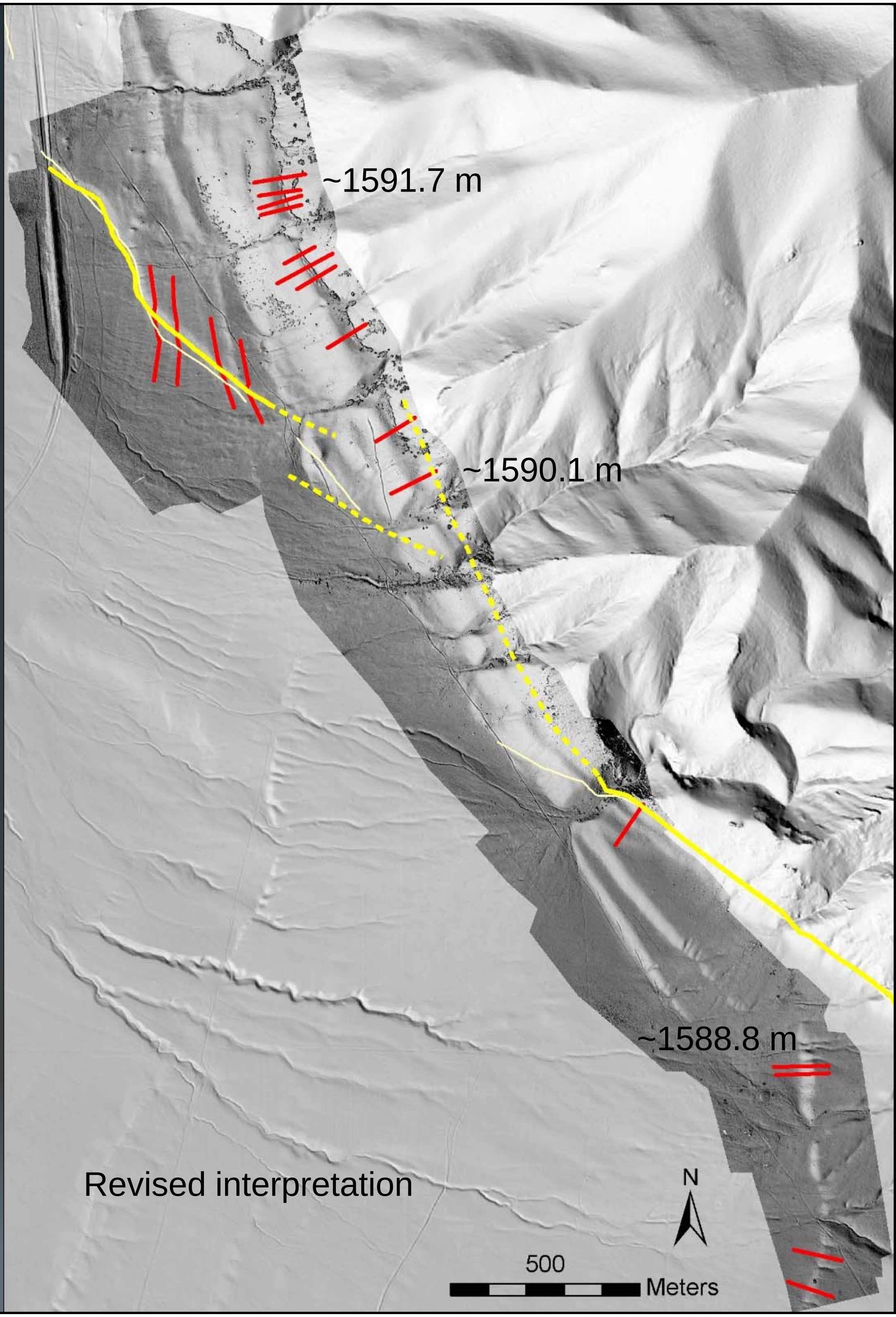
- Results are consistent with hypothesis that events dated in trenches to north produced ground rupture in study area
- ~11 km of fault trace spanned by trenches and this work





Structural Interpretation

- Southern strand (above Bonneville bench) extends to north
- Relay between western and eastern strands



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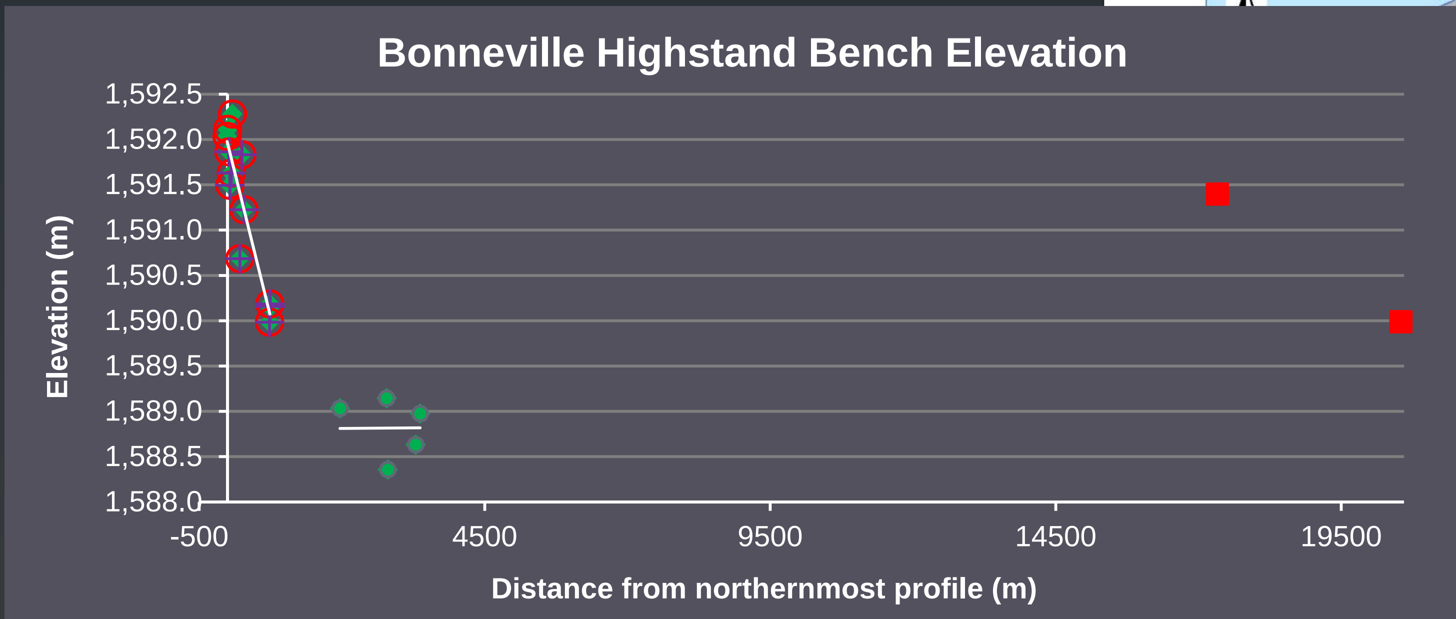
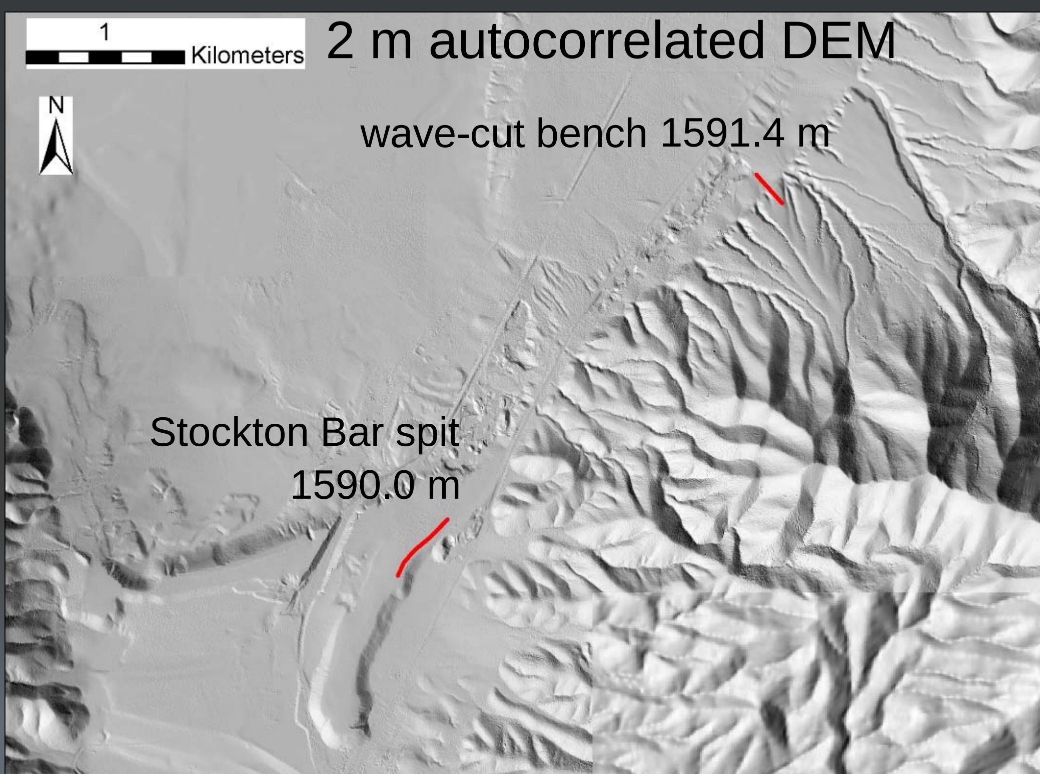
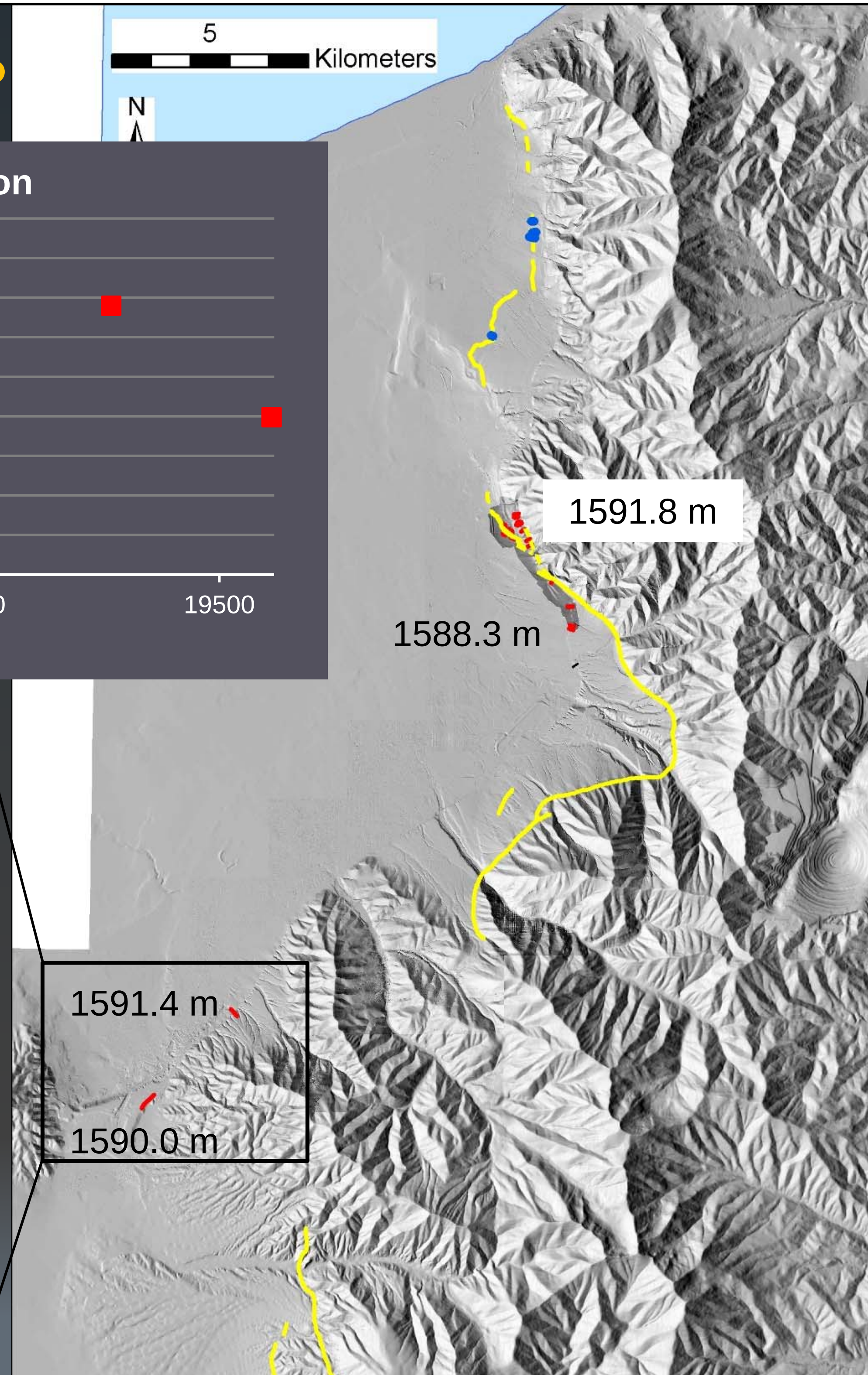
Moving South: Isostatic Rebound?

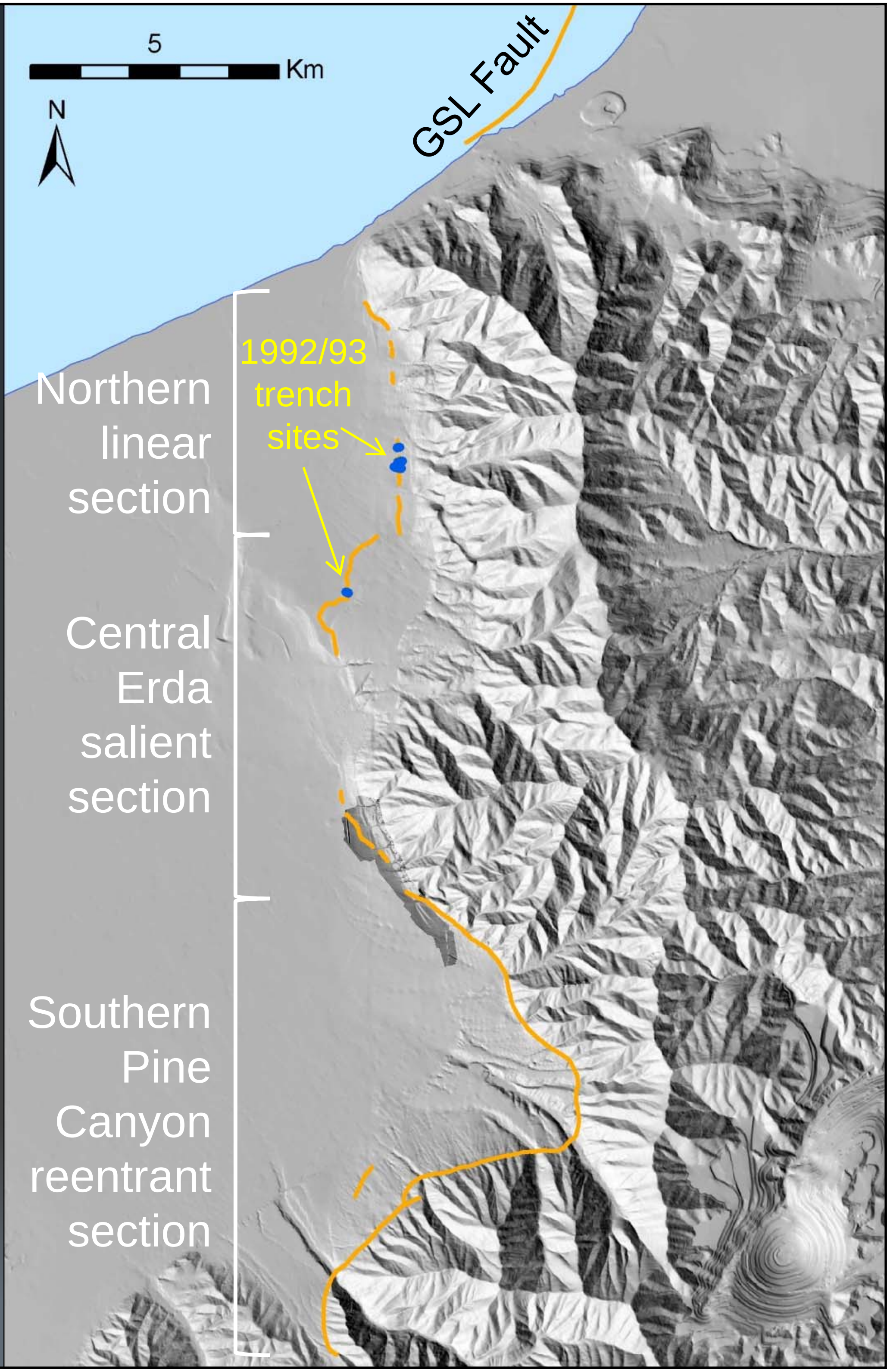






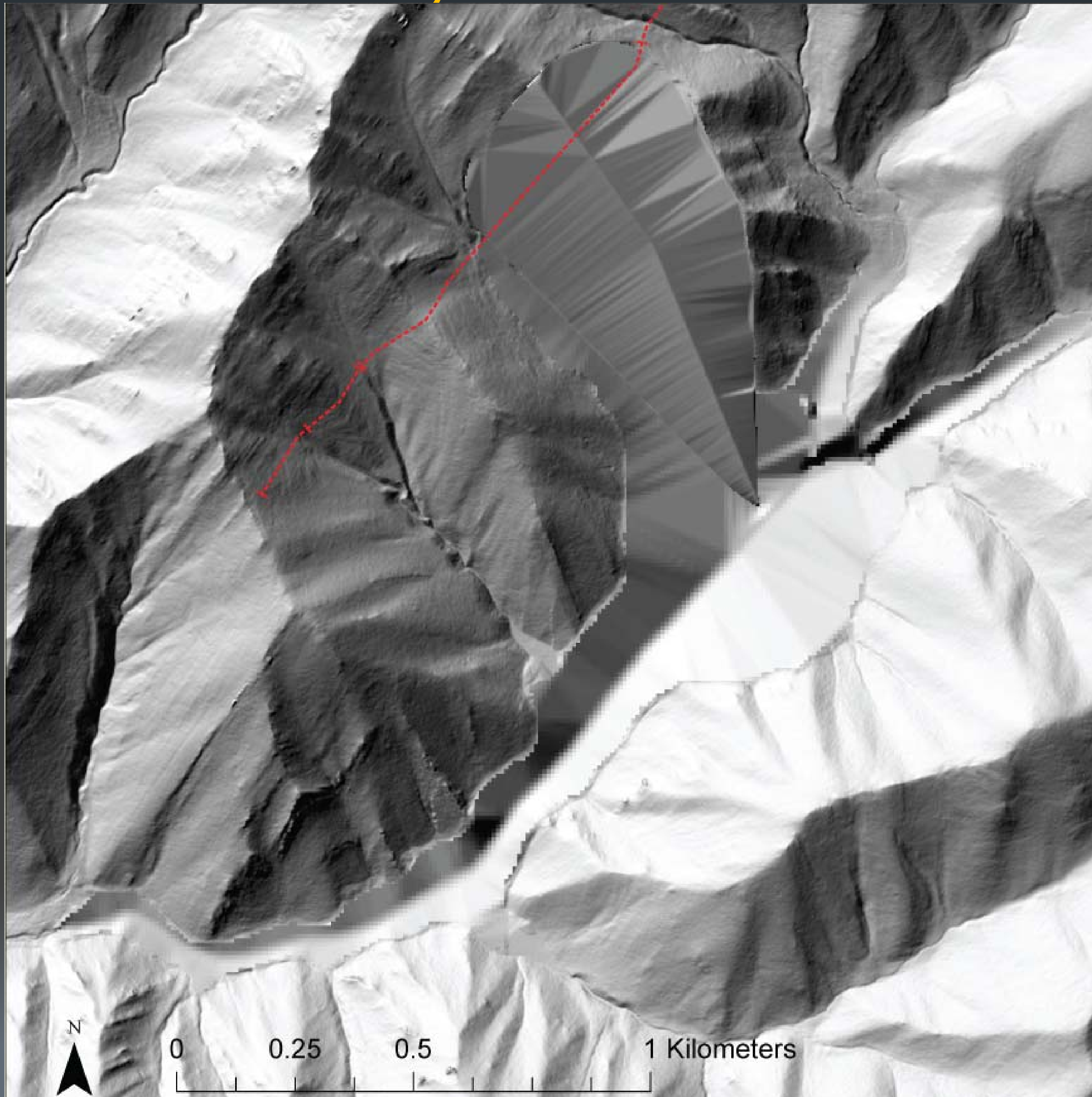
Future

- Extend DEM to north? (Possible class project next fall)
- Get better data for benches to south and Stockton Bar? But how to filter rebound signal?



Grandview Peak Landslide Early Results

- Work of **Nick Butterfield** (UVU student)
- Modeled volumes:
  - Deposit (18 x 10^6 m^3)
  - Source (16 x 10^6 m^3)
  - Landslide-dammed floodplains (LDFs) (583 x 10^3 m^3)
- No overland flow across deposit



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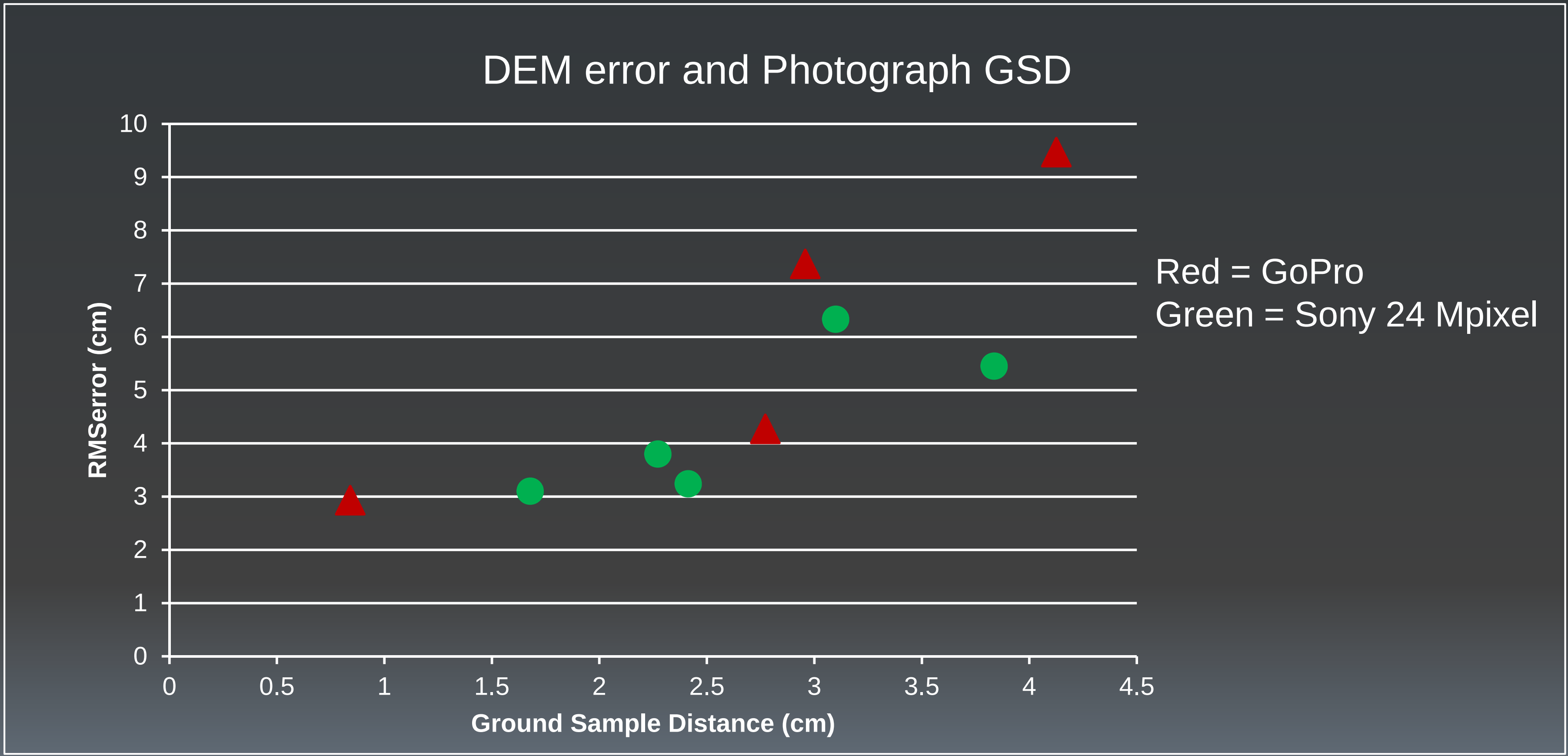
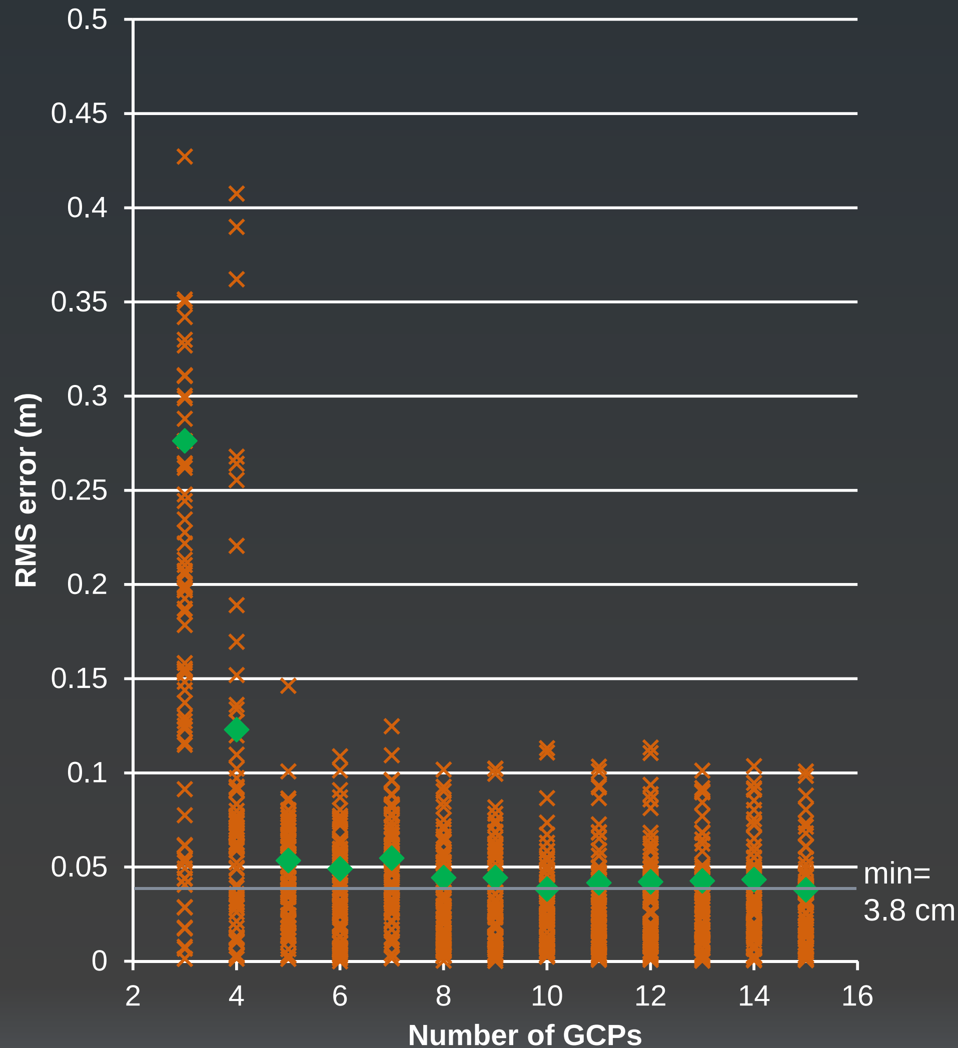
DEM Accuracy and Photograph Resolution

- DEM vertical accuracy (RMS error) typically 3 to 10 cm
- RMS error increases with ground sample distance (GSD; linear dimension of ground area covered by photograph pixels)
- Camera / lens less important than GSD
- Minimum RMS error limited by GCP and checkpoint measurement accuracy (RTK GPS)

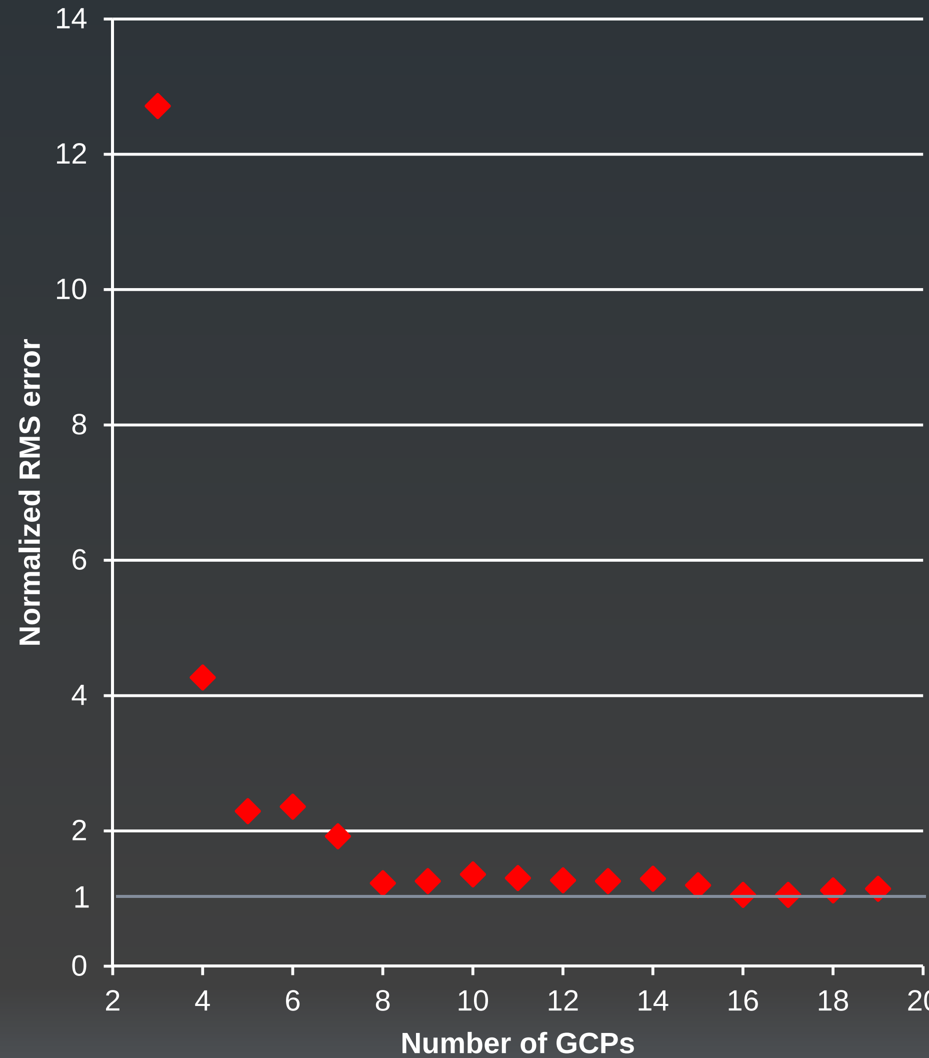


Number of GCPs and DEM Accuracy

DEM error plotted against # GCPs used to build DEM (using same photos)



Average normalized error for four test sites



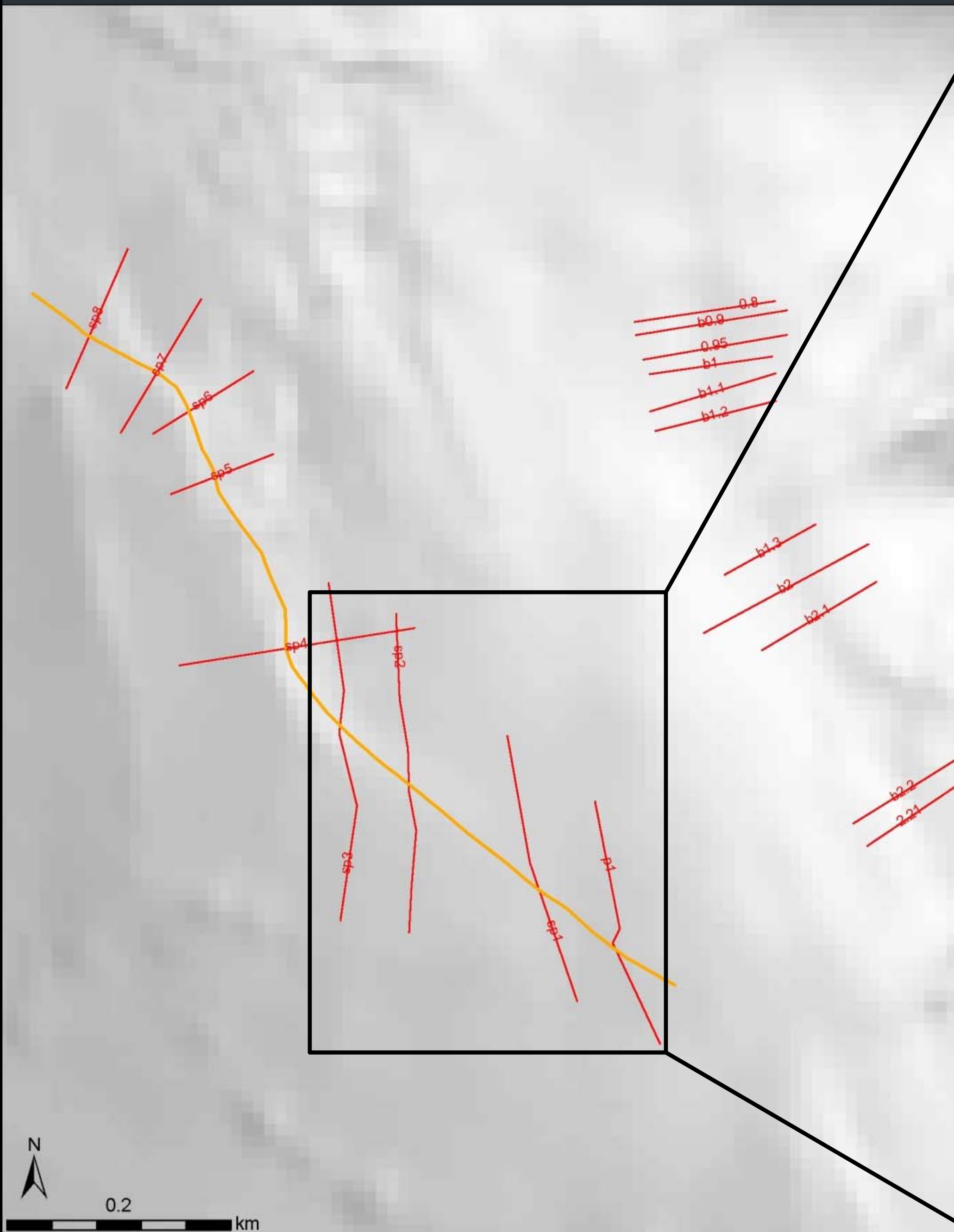
Green = DEM RMS error
Orange = misfit of individual surveyed checkpoints
Doublespring Pass Site (Lost River Fault, ID)

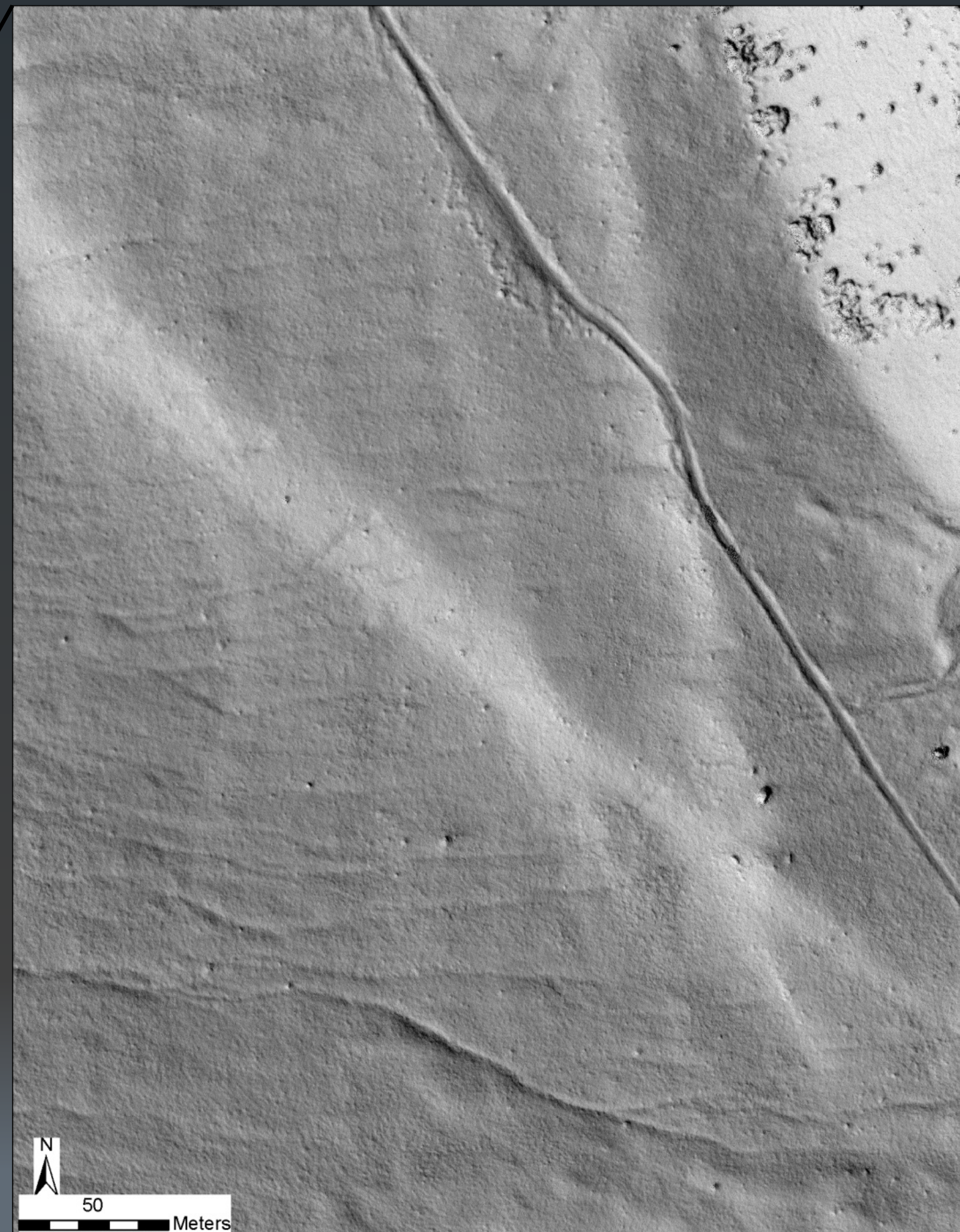
DEM Accuracy Summary

- 3 to 10 cm RMS error easily obtainable
    - comparable to USGS Level I specification airborne LiDAR
- GSD (photograph resolution) important
    - At ~ 1.5 cm GSD, RTK GPS insufficient to achieve best DEM accuracy
- 5 to 8 GCPs sufficient to achieve ~ 80 % of best possible accuracy for given GSD

Oquirrh Fault DEM

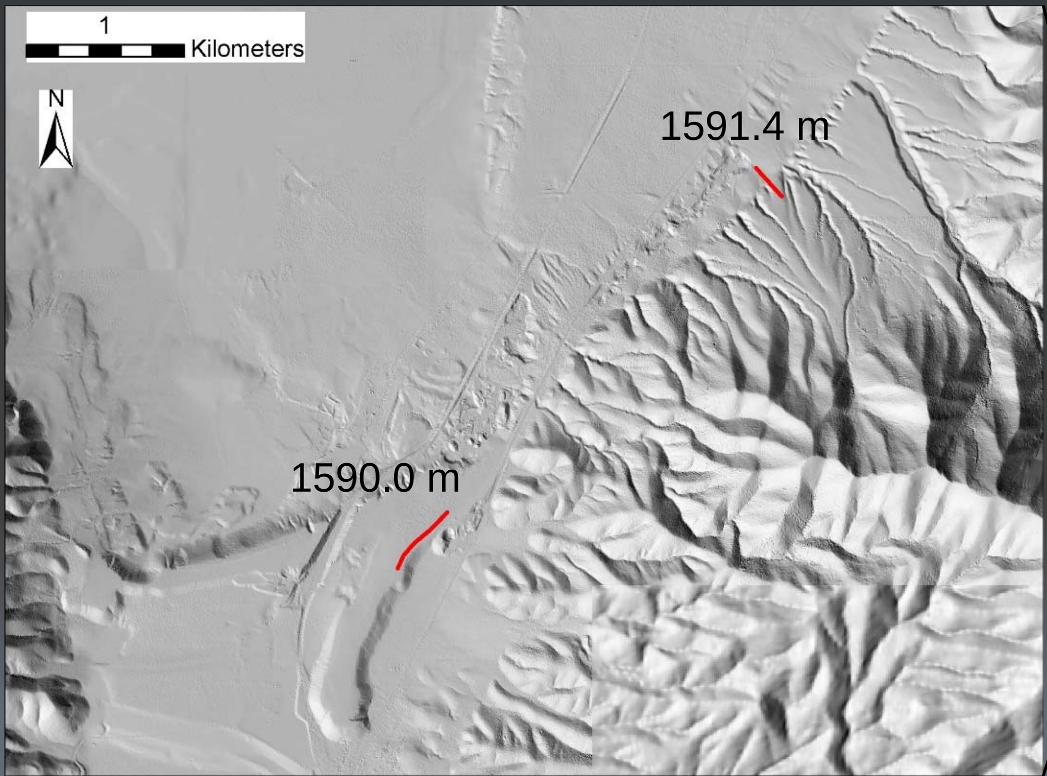
- 5 cm vs 5 m DEM

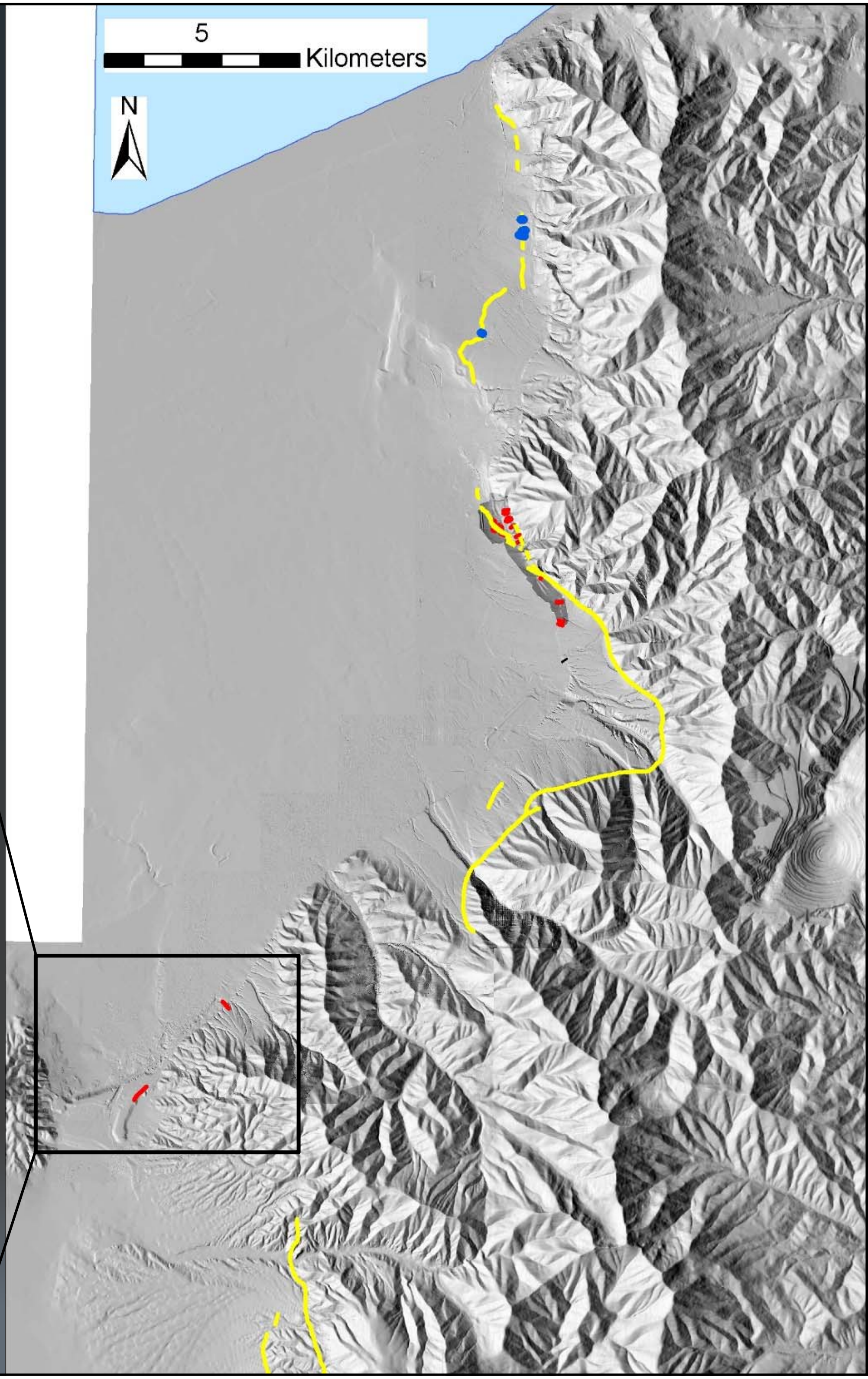




Looking South….

- Bonneville highstand to south
  - 2 m autocorrelated DEM
  - Unmodified morphology difficult to find
- Two data points
  - Wavecut bench = 1591.4 m
  - Top of spit at Stockton Bar = 1590.0 m (depositional surface)





Equipment

- Three DJI Phantom 2 quadcopters
- Multiple batteries, generator for charging in the field
- Sony A5100 Cameras
    - 24 Mpixel
    - APS-C sensor
- Four 64 GB, dual GPU workstations

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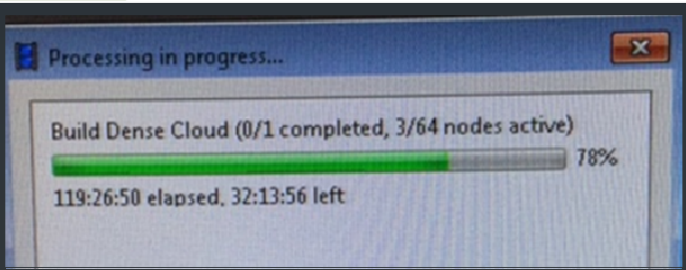

Forecasting Large Earthquakes Along the Wasatch Front

Ivan Wong
Seismic Hazards Group, URS Corporation, Oakland, CA

Bill Lund
Utah Geological Survey, Cedar City, UT

Patricia Thomas and Susan Olig
Seismic Hazards Group, URS Corporation, Oakland, CA

Mike Hylland
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Department of Geology and Geophysics, University of Utah, Salt Lake City, UT

Chris DuRoss, Tony Crone, Nico Luco, Steve Personius, and Mark Petersen
U.S. Geological Survey, Denver, CO

David Schwartz
U.S. Geological Survey, Menlo Park, CA

Utah Quaternary Fault Parameters Working Group
Salt Lake City, UT

10 February 2016

URS

WGUEP

- The Working Group on Utah Earthquake Probabilities was formed in late 2009.
- Funded by the USGS through the NEHRP external grants program for 3 years and the Utah Geological Survey.
- The final report will be released on 18 April 2016.

URS

WGUEP Members

Ivan Wong, URS (Chair)
Bill Lund, UGS
Mark Petersen, USGS
Tony Crone, USGS
Walter Arabasz, UUSS
Chris DuRoss, USGS
Mike Hylland, UGS
Nico Luco, USGS
Susan Olig, URS
Jim Pechmann, UUSS
Steve Personius, USGS
David Schwartz, USGS
Bob Smith, UU
Patricia Thomas, URS

Assistance from Steve Bowman, UGS

Introduction

- The WGUEP calculated the probability of moderate to large earthquakes (M $\geq$ 5.0) in the Wasatch Front region for a range of intervals varying from annually to 100 years.

- Time-dependent and time-independent earthquake probabilities that were estimated are:

  1. Segment-specific for the 5 central segments of the Wasatch fault.
  2. Total for the Wasatch fault central segments and the whole fault including the end segments.
  3. Segment-specific and fault-specific for the Oquirrh-Great Salt Lake fault.
  4. Time-independent fault-specific for all other faults in the Wasatch Front.
  5. Time-independent for background earthquakes (M 5.0 to 6.75).
  6. Total for the Wasatch Front region.

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Introduction (cont.)

- The WGUEP report has been reviewed by a USGS panel led by Rich Briggs and is awaiting Director approval. The report is undergoing review and editing by the UGS and will be published as a UGS Miscellaneous Publication.
- A media release is scheduled for 18 April to coincide with the Utah ShakeOut event. Results will also be presented at meetings for the general public and at professional and scientific society meetings.

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Scope of Work

- Time-dependent probabilities were calculated for Wasatch and the Great Salt Lake fault zones where the data is available on the expected mean frequency of earthquakes and the elapsed time since the most recent large earthquake.

- Even for these faults, significant weight was given to the time-independent model.

- Where such information is lacking on less well-studied faults, time-independent probabilities were calculated.

- Epistemic uncertainties in all input parameters were explicitly addressed by the WGUEP using logic trees.

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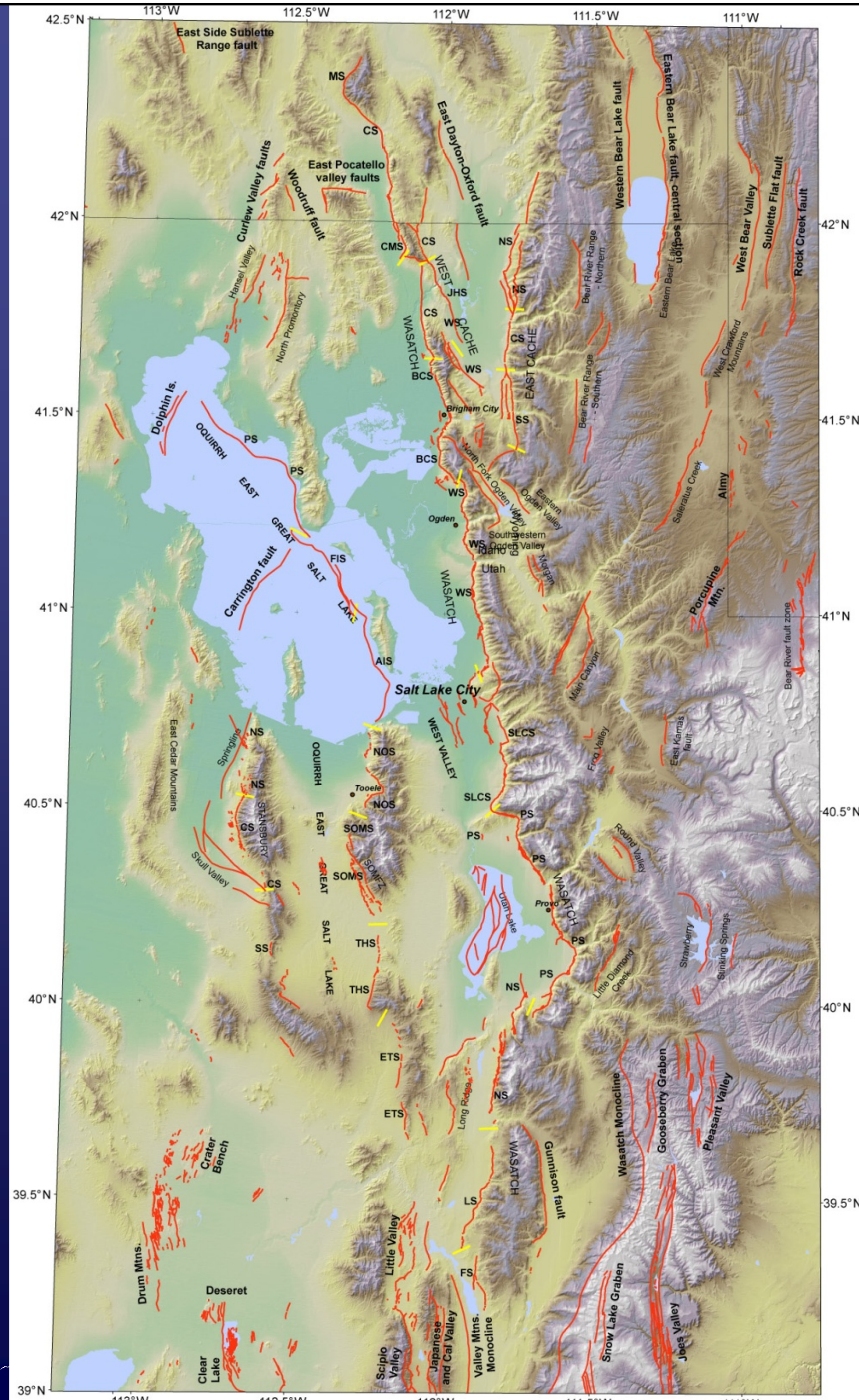
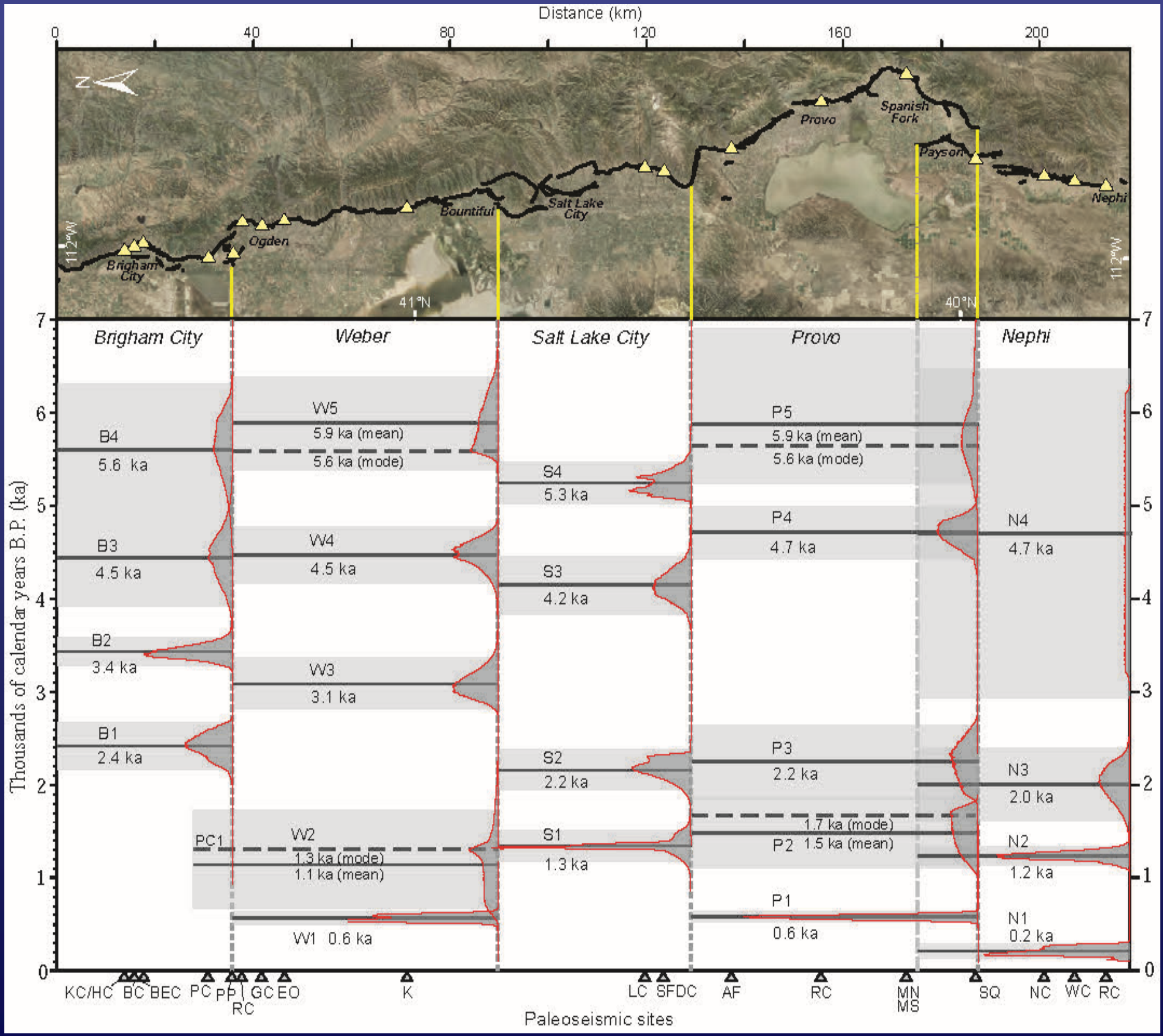
WGUEP Wasatch Front



URS

Segments of the Wasatch Fault Zone (WFZ) in Southern Idaho and Northern Utah

Single-Segment Rupture Model for the Central WFZ

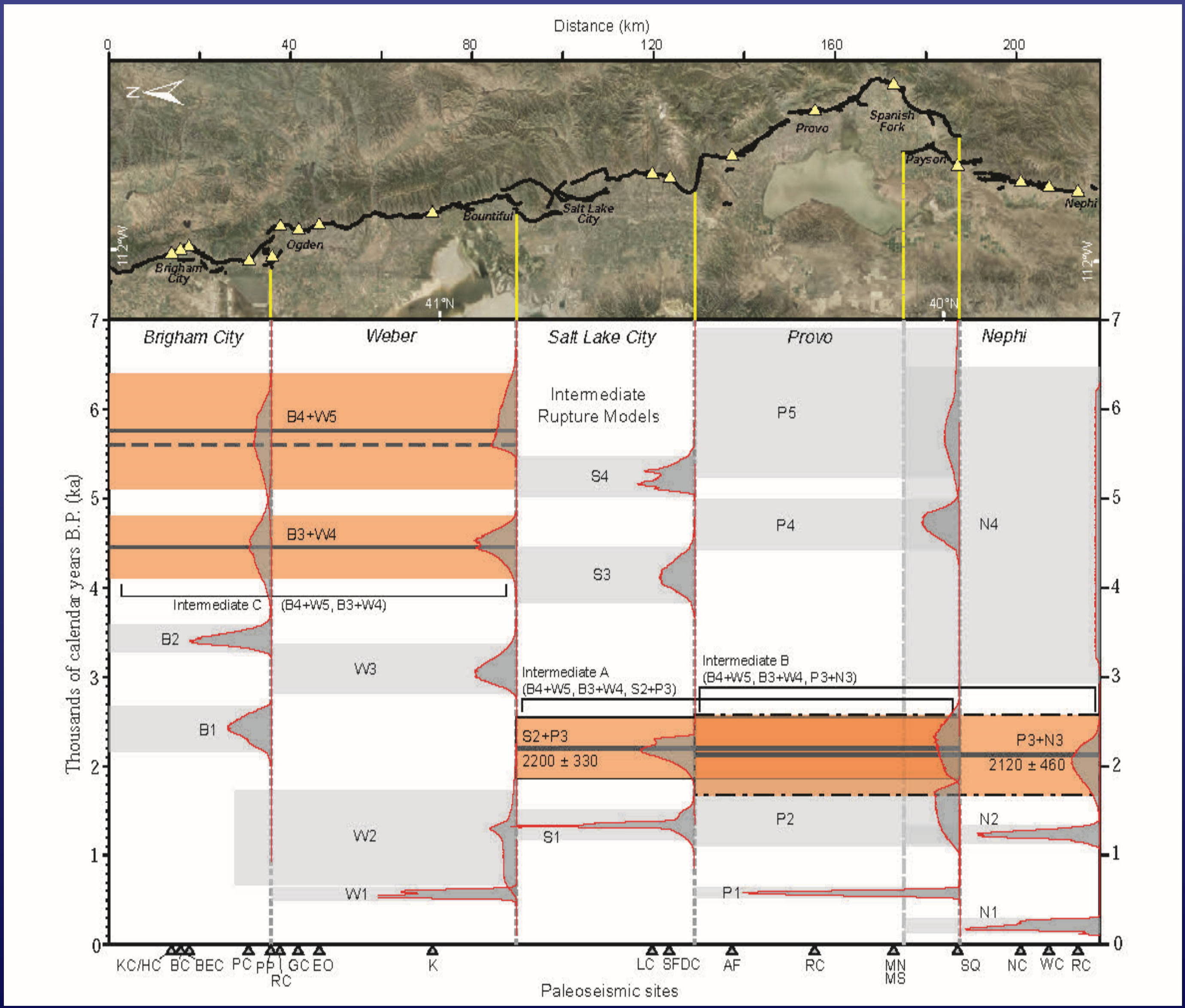


Intermediate Rupture Models for the Central WFZ

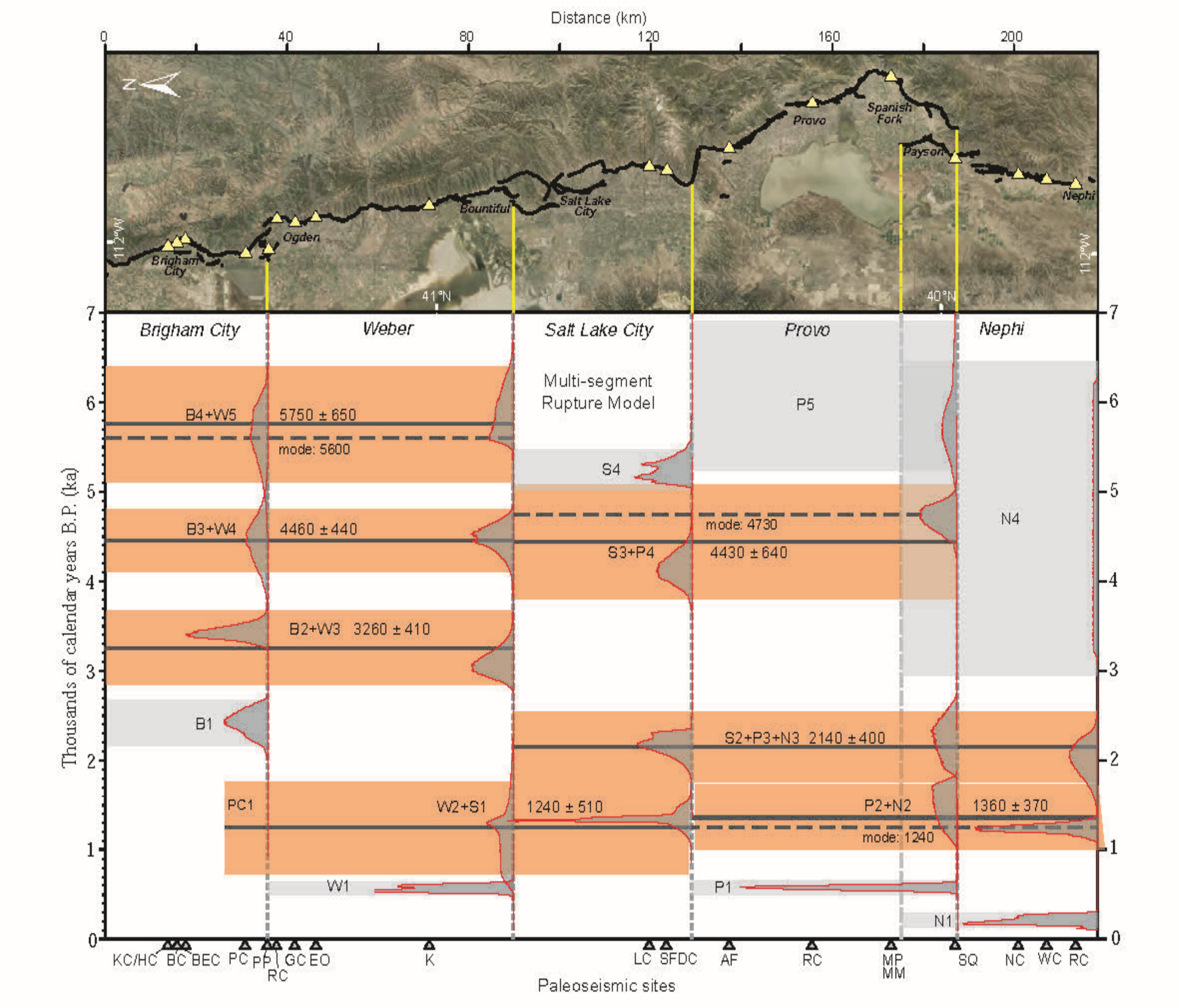
A – B4+W5, B3+W4 and S2+P3

B – P3+N3 in place of S2+P3

C – B4+W5 and B3+W4

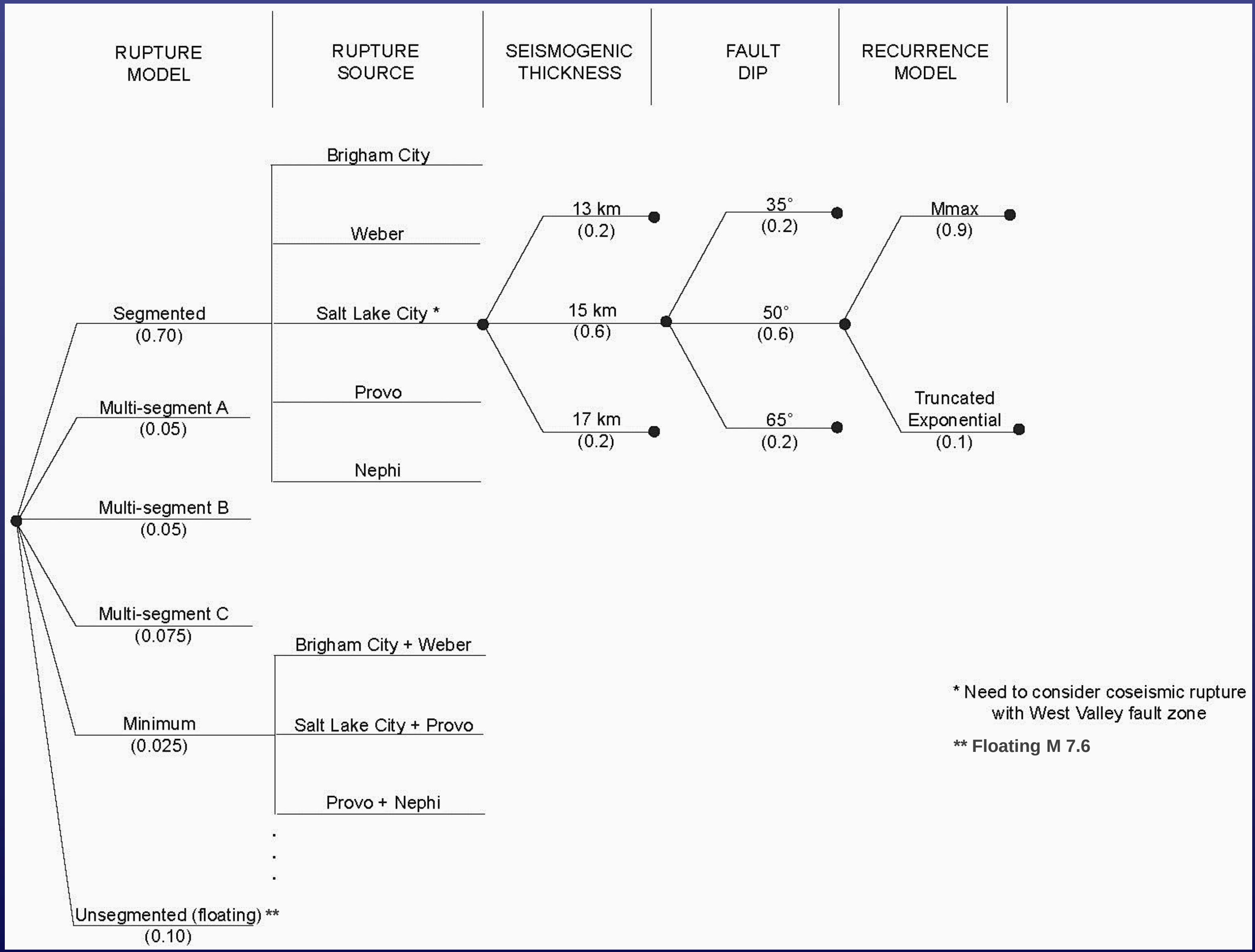


Multi-Segment Rupture Models for the Central WFZ



URS

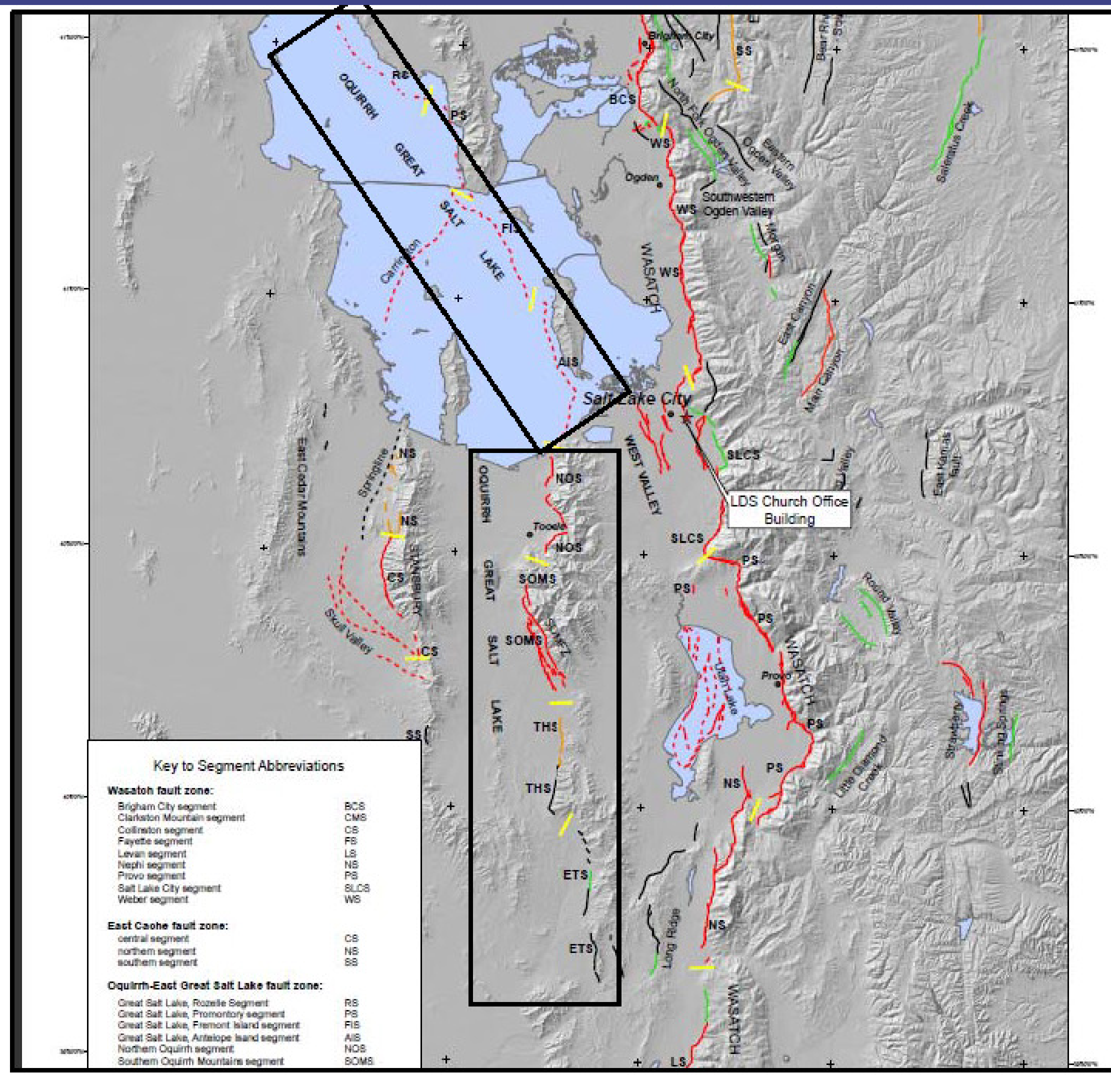
Generalized Logic Tree for Calculating the Recurrence of the Central Segments of WFZ



Segments of the Oquirrh-Great Salt Lake Fault Zone

O-GSLFZ SEGMENTS

Rozelle (RZ) – 25 km
Promontory (PY) – 25 km
Fremont Is. (FI) – 25 km
Antelope Is. (AI) – 35 km
No. Oquirrh (NO) – 30 km
So. Oquirrh (SO) – 31 km
Topliff Hills (TH) – 26 km
East Tintic (ET) – 35 km



"Other" Faults/Fault Segments in the Wasatch Front Region Retained in the WGUEP Probabilistic Earthquake Forecast

- Bear River fault zone
- Broadmouth Canyon faults[1]
- Carrington fault
- Crater Bench fault[2]
- Crawford Mountains (west side) fault
- Curlew Valley faults
- Drum Mountains fault zone[2]
- East Cache fault zone
  - Northern segment
  - Central segment
  - Southern segment[1]
- East Dayton – Oxford faults
- Eastern Bear Lake fault
  - Northern segment
  - Central segment
  - Southern segment
- Gunnison fault
- Hansel Valley fault[3]
- Hansel Valley (east side) faults[3]
- Hansel Valley (valley floor) faults[3]
- James Peak fault[1]
- Joes Valley faults
- Little Valley faults
- Main Canyon fault
- Maple Grove faults[4]
- Morgan fault
  - Northern section[5]
  - Central section[5]
  - Southern section[5]
- North Promontory fault
- Porcupine fault
- Pavant Range fault[4]
- Reactivated section Absaroka thrust fault
- Red Canyon faults[4]
- Rock Creek fault
- Scipio fault zone[4]
- Scipio Valley faults[4]
- Skull Valley (mid valley) faults
- Snow Lake graben
- Stansbury fault
- Stinking Springs fault
- Strawberry fault
- Utah Lake faults
- West Cache fault zone
  - Clarkston fault
  - Junction Hills fault
  - Wellsville fault
- West Valley fault zone
  - Granger fault
  - Taylorsville fault
- Western Bear Lake fault

URS

Accomplishments

- Characterized end segments of Wasatch fault and other faults in Wasatch Front.
- Characterized all other “significant” faults in the Wasatch Front.
- Developed model for coseismic rupture of antithetic faults
  - SLC Segment/West Valley (0.75/0.25)
  - Provo Segment/Utah Lake (0.5/0.5)
  - Hansel Valley/North Promontory (0.4/0.6)
  - Western/Eastern Bear Lake (0.5)/0.5)
- Compiled new consensus historical catalog through 2012 for the Wasatch Front.

Accomplishments (cont.)

- Developed a methodology to estimate Mmax.

  A faults (segmented with 2+ paleoseismic sites):
  45% Mo (Hanks and Kanamori)
  45% SRL-c (Stirling)
  5% SRL (W&C-all)
  5% W-SRL (Wesnousky)

  B faults (segmented, but limited D data):
  60% SRL-c (Stirling)
  40% SRL (W&C-all)

  C faults (not segmented, limited D data):
  50% SRL-c (Stirling)
  50% SRL (W&C-all)

- We have adopted a background earthquake Mmax of M 6.75 $\pm$ 0.25. USGS recurrence approach (e.g., recurrence models) is being used.

- Fault dip uncertainty adopted is 50 $\pm$ 15 degrees.

Accomplishments (cont.)

- Seismogenic crustal depths (km):
  - East of WFZ 12 (0.1), 15 (0.7), 18 (0.2)
  - West of WFZ 12 (0.2), 15 (0.7), 18 (0.1)
- We compared moment rates derived from available geodetic, historical seismicity, and paleoseismic data. There is general agreement betweeen the rates given the uncertainties. A discrepancy exists between the rates at the southern end of the Wasatch fault.
- The geodetic data was used as a constraint on regional moment rates but not to estimate slip rates.

Results

- Stay Tuned on 18 April.

Basin and Range Province Seismic Hazards Summit III

January 13 – 16, 2015
Utah Department of Natural Resources
Salt Lake City, Utah

William Lund and Steve Bowman

Sponsored By

UTAH DNR GEOLOGICAL SURVEY

WSSPC WESTERN STATES SEISMIC POLICY COUNCIL

DEPARTMENT of PUBLIC SAFETY UTAH DIVISION of EMERGENCY MANAGEMENT

University of Utah Seismograph Stations
THE UNIVERSITY OF UTAH

USGS science for a changing world

AEG ENVIRONMENTAL ENGINEERING GEOLOGISTS
Intermountain Section

Utah Seismic Safety Commission

Partial funding for this educational opportunity has been provided by the Utah Division of Occupational & Professional Licensing and the Education and Enforcement Fund.

- **The Utah Geological Survey and Western States Seismic Policy Council convened the third Basin and Range Province Seismic Hazards Summit (BRPSHSIII) in Salt Lake City, Utah, on January 12-17, 2015.**
- **Basin and Range Province Seismic Hazards Summits are held at approximately decadal intervals to "take the pulse" of earthquake-hazard research and mitigation in the Basin and Range Province.**
- **BRPSHSIII brought together geologists, seismologists, geodesists, engineers, emergency planners, and policy makers to:**

  (1) present and discuss the latest seismic-hazard research in the Basin and Range Province,

  (2) to evaluate the implications of that research for earthquake-hazard reduction and public policy, and

  (3) to identify a path forward to further reduce risk from earthquakes in the Basin and Range Province.

BRPSHSIII Included Seven Technical Sessions (42 speakers - 47 presentations) and 14 Poster Presentations

Technical sessions included:

TS-1 Perspectives and Overview of User Needs

TS-2 M_{max} Issues in the Basin and Range Province

TS-3 Ground Motions from Normal-Faulting Earthquakes

TS-4 Fault Segmentation and Rupture Patterns in the Basin and Range Province

TS-5 Earthquake Engineering and Risk Mitigation

TS-6 Emergency Management and Public Policy

TS-7 Using Geodesy to Characterize Seismic Hazard in the Basin and Range Province

BRPSHSIII Also Included

- **A pre-summit short course titled *Characterizing Hazardous Faults – Techniques, Data Needs, and Analysis*,**
- **A pre-summit U.S. Geological Survey workshop titled *Evaluation of Hazardous Faults in the Intermountain West Region*,**
- **A post-summit field trip titled *Salt Lake City's Earthquake Threat and What is Being Done About It*, and**
- **The AEG Richard H. Jahns Distinguished Lecture in Applied Geology – co-sponsored by AEG and UGA.**

BRPSHSIII Proceedings Volume
UGS Miscellaneous Publication 15-5

http://geology.utah.gov/map-pub/new-maps-publications/

- **Available technical session PowerPoint presentations, most with an accompanying abstract or short paper,**
- **Available poster presentations (10),**
- **The short-course manual,**
- **The field-trip guidebook,**
- **Results of the USGS workshop, and**
- **An invited paper on luminescence dating techniques.**

BRPSHSIII Surfaced Seismic-Hazard Questions, Needs, and Recommendations

Discussion periods following each BRPSHSIII technical session and the wrap-up session surfaced questions, unmet needs, and recommendations regarding seismic-hazard investigation, mitigation, and public policy in the Basin and Range Province.

1. **Is investing in Earthquake Early Warning (systems) more important/practical than continued earthquake hazard map refinement?**

2. **The U.S. Geological Survey (USGS) National Seismic Hazard Maps do not incorporate the timing of the most recent earthquake on the fault sources used to prepare the maps (time independent), and therefore do not accurately portray the current probabilistic hazard represented by those faults.**

3. **Geologic mapping and paleoseismic fault trenching studies remain key to reducing risk from seismic hazards in the BRP.**

BRPSHSIII Surfaced Seismic-Hazard Questions, Needs, and Recommendations

4. Recommend that the USGS and Basin and Range Province state geological surveys emphasize mapping and paleoseismic investigations of faults in and near urban areas, even where perceived probabilistic hazard is low because the faults have low slip rates.

5. Recommend developing a Unified Geologic Hazard Code minimally at the state level, but preferably at the national or international level similar to the International Building Code and the International Residential Code that could serve as an objective, standardized ordinance for all jurisdictions with potential geologic hazards (including earthquake hazards).

6. There is a need to develop new, self-consistent magnitude regressions that address inconsistencies in magnitude when derived from different source parameters.

BRPSHSIII Surfaced Seismic-Hazard Questions, Needs, and Recommendations

7. Geologic observations of the variability of displacement at a point on a fault from a global dataset have a coefficient of variation (CV) of 0.5. Forward modeling of displacement-at-a-point variability using the Youngs and Coppersmith (1985) characteristic earthquake model yields results consistent with the global data set. Using the Gutenberg-Richter distribution with large M_{max} yields CV values significantly larger than observed, and does not support the use of a large M_{max} exponential model for probabilistic seismic-hazard analysis to describe the distribution of magnitudes on a fault in the Basin and Range Province or globally.

8. The Enhancement of Next Generation Attenuation Relationships for Western US (NGA-West2) ground-motion-prediction models used to estimate ground-shaking hazard suffer from a lack of normal faulting strong-motion data not only from the Basin and Range Province, but globally. Hence, there may be considerable epistemic uncertainty on how applicable the models are for the Basin and Range Province. The models should be evaluated for regional differences in large distance attenuation and kappa prior to their use in the Basin and Range Province.

BRPSHSIII Surfaced Seismic-Hazard Questions, Needs, and Recommendations

9. **The hanging-wall effect contained in the NGA-West2 ground-motion models is a significant factor in estimating the seismic hazard in the Basin and Range Province because many urban centers are in the hanging wall of normal faults. Accurately capturing this effect in ground-motion models is critical particularly for bending faults which includes most normal faults.**

10. **Segmentation of faults in the Basin and Range Province is physically based (earthquake timing, fault structure, rupture kinematics) and provides the best approach for modeling earthquake rupture on long Basin and Range Province faults.**

11. **Surface faulting in the Basin and Range Province is typically regulated over the Holocene Epoch (past ~ 11 kyr), which is as much as an order-of-magnitude longer recurrence interval than is used to mitigate other dangerous and destructive natural hazards such as floods, debris flows, landslides, liquefaction, and strong earthquake ground shaking. Mitigation of fault rupture should be brought into compliance with other socially and technically accepted levels of risk management for other kinds of earthquake and geologic hazards.**

BRPSHSIII Surfaced Seismic-Hazard Questions, Needs, and Recommendations

12. Acceptable risk is a concept used by architects and structural and geotechnical engineers for engineering design to reduce risk to an acceptable level. Structural and geotechnical engineering mitigation solutions for surface faulting should be permitted if they demonstrate adequate safety factors.

13. How much paleoseismic information (earthquake timing, recurrence, displacement) is required to adequately characterize fault activity for performance-based (engineering) surface-faulting mitigation for the predominantly long recurrence interval (1000 plus years), normal-slip faults typical of the Basin and Range Province?

14. In property rights states (most if not all Basin and Range Province states) when a city or county approves a project, it accepts future liability (tax payers pay for developers mistakes). Recommend that jurisdictions in the Basin and Range Province with potential geologic hazards adopt laws, ordinances, and regulatory-review requirements to reduce future damage from geologic hazards.

15. Based upon the 2008 Wells, Nevada earthquake experience, jurisdictions in seismically hazardous areas of the Basin and Range Province should specifically plan not only for emergency response, but also for post-earthquake recovery. Recovery plans should include immediate, intermediate, and long-term phases.

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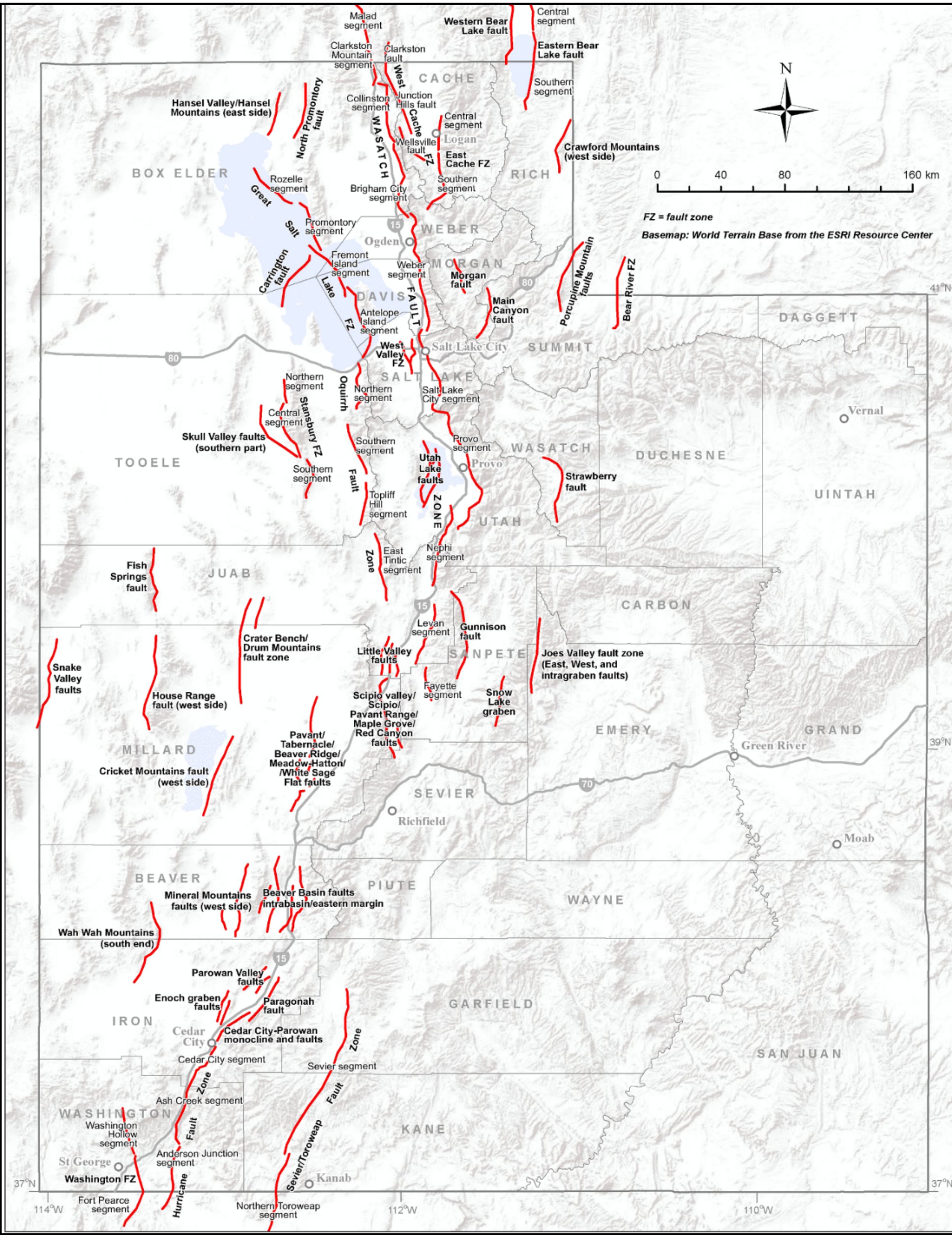
2017 Fault Investigation Priorities Discussion

Utah Fault or Fault Segment	UQFPWG Priorities	
	2005[1]	Additions
Nephi segment, Wasatch fault zone[2,3]	1	--
West Valley fault zone[2,3]	2	--
Weber segment, Wasatch fault zone[2,3] – most recent event	3	--
Weber segment, Wasatch fault zone[2,3] – multiple events	4	--
Utah Lake faults and folds[3]	5	--
Great Salt Lake fault zone[2,3]	6	--
Collinston and Clarkston Mountain segments, Wasatch fault zone[3]	7	--
Sevier and Toroweap faults[2,3]	8	--
Washington fault zone[3] (includes Dutchman Draw fault[2])	9	--
Cedar City-Parowan monocline[3] and Paragonah fault[2,3]	10	--
Enoch graben[3]	11	--
East Cache fault zone[2,3]	12	--
Clarkston fault[2,3]	13	--
Wasatch Range back-valley faults (includes Morgan fault[2] and Main Canyon fault[3])	14	--
Hurricane fault zone[2,3]	15	--
Levan segment, Wasatch fault zone[2,3]	16	--
Gunnison fault[3]	17	--
Scipio Valley faults[3]	18	--
Faults beneath Bear Lake	19	--
Eastern Bear Lake fault zone[2,3]	20	--
Bear River fault zone[2,3]	--	2007
Brigham City segment, Wasatch fault zone[2,3] – most recent event	--	2007
Carrington fault, Great Salt Lake fault zone[3]	--	2007
Provo segment, Wasatch fault zone[2,3] – penultimate event	--	2007
Rozelle section, East Great Salt Lake fault[3]	--	2007
Salt Lake City segment, Wasatch fault zone[2,3] – northern part	--	2009
Warm Springs fault/East Bench fault[2,3] subsurface geometry and connection	--	2010
Brigham City segment, Wasatch fault zone[2,3] rupture extent (north and south ends)	--	2011
Northern Provo segment, Wasatch fault zone[2,3] – long-term earthquake record	--	2011
Taylorsville fault, West Valley fault zone[3]	--	2011
Hansel Valley fault[2,3]	--	2011
Acquire new paleoseismic information to address paleoseismic data gaps for the five central segments of the Wasatch fault zone.	--	2012
Use recently acquired LiDAR data to more accurately map the traces of the Wasatch, West Valley, and Hurricane fault zones, and search for and map as appropriate previously undiscovered mid-valley Quaternary faults.	--	2014
Acquire high resolution aerial imagery (LiDAR, Structure from Motion, etc.) and map high-risk (chiefly urban) Utah hazardous faults. Identify future paleoseismic trench sites.	--	2015

Utah Fault or Fault Segment	Included In	
	NSHM	Utah Hazus
Beaver Basin intrabasin/eastern margin faults	--	Yes
Crater Bench/Drum Mountains fault zone	--	Yes
Crawford Mountains (west side)	--	Yes
Cricket Mountains fault (west side)	--	Yes
Fish Springs fault	--	Yes
House Range (west side) fault	--	Yes
Joes Valley fault zone	Yes	Yes
Little Valley faults	--	Yes
Malad segment, Wasatch fault zone	--	Yes
Mineral Mountains (west side) faults	--	Yes
North Promontory fault	Yes	Yes
Oquirrh fault zone	--	Yes
Oquirrh-Southern Oquirrh Mountains fault zone	Yes	Yes
Parowan Valley faults	--	Yes
Pavant/Tabernacle/Beaver Ridge/Meadow-Hatton/White Sage Flat faults	--	Yes
Porcupine Mountain faults	--	Yes
Scipio/Pavant Range/Maple Canyon/Red Canyon faults	--	Yes
Skull Valley faults (southern part)	--	Yes
Snake Valley faults	--	Yes
Snow Lake graben	--	Yes
Stansbury fault zone	Yes	Yes
Strawberry fault	Yes	Yes
Wah Wah Mountains (south end)	--	Yes
West Cache fault, Wellsville section	Yes	Yes
Western Bear Lake fault	--	Yes



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Fault or Fault Segment	UQFPWG Priority[1]	Investigations	
		Status[2,3] (as of 12/2015)	Institution[4]
Nephi segment, Wasatch fault zone[5,6]	1	UGS Special Study 124 and 151 USGS SI Map 2966 UGS FTR Report	UGS/USGS
Granger fault, West Valley fault zone[5,6]	2	UGS Special Study 149	UGS/USGS
Weber segment, Wasatch fault zone[5,6] – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment, Wasatch fault zone[5,6] – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds[6]	5	UUGG FTR Report	UUGG/BYU
Great Salt Lake fault zone[5,6]	6	UUGG FTR Report	UUGG
Collinston and Clarkston Mountain segments, Wasatch fault zone[6]	7	UGS Special Study 121 Map: UGS Open-File Report 638	UGS
Sevier and Toroweap faults[5,6]	8	UGS Special Study 122	UGS
Washington fault zone[6]	9	UGS Miscellaneous Publication 15-6 (in press)	UGS
East Cache fault zone[5,6]	12	USU FTR Report	USU
Wasatch Range back-valley faults	14	No activity	--
Main Canyon fault[6]		UGS Miscellaneous Publication 10-5	USBR
Hurricane fault zone[5,6]	15	UGS Special Study 119	UGS
Levan segment, Wasatch fault zone[5,6]	16	UGS Map 229 Map: UGS Open-File Report 640	UGS
Brigham City segment, Wasatch fault zone[5,6] – most recent event	2007	UGS Special Study 142	UGS/USGS
Bear River fault zone[5,6]	2007	Ongoing	USGS/UGS
Salt Lake City segment, Wasatch fault zone[5,6] – north part	2009	UGS Special Study 149	UGS/USGS
Hansel Valley fault zone[5,6]	2011	McCalpin (1985), Robinson (1986), McCalpin and others (1992) UUGG ongoing	UUGG
Nephi segment, Wasatch fault zone[5,6] – long-term earthquake record	2012	UGS FTR Report	UGS/USGS
Provo, Salt Lake City and Nephi segments, Wasatch fault zone[5,6] segmentation Flat, Maple, and Corner Canyons, and Alpine sites	2012	USGS work ongoing UGS FTR Report	USGS/UGS
Using LiDAR to map portions of the Hurricane[5,6], Wasatch[5,6], and West Valley[5,6] fault zones	2014	UGS Open-File Reports 638 and 640 Additional work ongoing	UGS
Acquire high resolution imagery and map Utah hazardous faults.	2015	Two proposals awaiting funding	UGS/State of Utah

Fault or Fault Segment (Not in Priority Order)		Investigations	
		Status (as of 12/2015)[1,2]	Institution
Acquire paleoseismic information to address paleoseismic data gaps for (1) the five central segments of the Wasatch fault zone, (2) the Oquirrh fault zone, and (3) the East and West Cache fault zones. Examples of paleoseismic data to acquire include extent of surface-faulting rupture, earthquake timing, displacement, and subsurface fault geometry.		Nephi segment, Spring Lake and North Creek sites: UGS FTR Report, Special Study ongoing	UGS/USGS
		Provo segment, Flat Canyon site: USGS ongoing, UGS FTR Report	USGS/UGS
		Salt Lake City segment, Corner Canyon site: ongoing	UGS/USGS
		Provo segment, Dry Creek and Maple Canyon sites: USGS ongoing, UGS FTR Report	USGS/UGS
Use recently acquired LiDAR data to more accurately map the traces of the Wasatch, West Valley, and Hurricane fault zones, and search for and map as appropriate previously undiscovered mid-valley Quaternary faults.		UGS Open-File Reports 638 and 640 The UGS is currently mapping portions of the Hurricane, Wasatch, and West Valley fault zones.	UGS
Acquire earthquake timing information for the Utah Lake faults to investigate the relation of earthquakes on that fault system to large earthquakes on the adjacent Provo segment of the Wasatch fault zone (independent or coseismic ruptures, fault pairs?).		No activity	--
Acquire high resolution aerial imagery (LiDAR, Structure from Motion, etc.) and map high-risk (chiefly urban) Utah hazardous faults. Identify future paleoseismic trench sites.		Two proposals awaiting funding	UGS/State of Utah
Fault or Fault Segment	UQFPWG Priority[1]	Investigations	
		Status (as of 12/2015)[2]	Institution
Cedar City-Parowan monocline and Paragonah fault[3,4]	10	Map: UGS Map 270	UGS
Enoch graben[5]	11	Map: UGS Open-File Report 628	UGS
Clarkston fault, West Cache fault zone[3,4]	13	UGS Special Study 98 Fault trace mapping proposal submitted, awaiting funding	UGS
Gunnison fault[4]	17	No activity	--
Scipio Valley faults[4]	18	No activity	--
Faults beneath Bear Lake	19	No activity	--
Eastern Bear Lake fault zone[4]	20	Fault trace mapping proposal submitted, awaiting funding	UGS
Carrington fault, Great Salt Lake fault zone[4]	2007	No activity	--
Rozelle section, Great Salt Lake fault zone[4,5]	2007	No activity	--