UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP

Tuesday, February 10, 2015

UQFPWG

- **One of three standing committees created to help set and coordinate Utah's earthquake-hazard research agenda.**

- **Reviews ongoing paleoseismic research in Utah, and updates the Utah consensus slip-rate and recurrence-interval database as necessary.**

- **Provides advice/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 – plugs directly into the annual NEHRP request for proposals.**

AGENDA
UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP
Tuesday, February 10, 2015

8:00 Refreshments

8:20 Welcome, overview of meeting, and review of last year's activities; Bill Lund, UGS

8:30 Technical presentations of work completed or in progress

- 8:30 – Paleoseismology of the northern segments of the Great Salt Lake fault; David Dinter, UUGG and Jim Pechmann, UUSS
- 9:00 – Paleoseismology of Utah Lake; David Dinter, UUGG
- 9:30 – Spatial and temporal fault offset patterns derived from Lidar along the central Wasatch fault zone; Scott Bennett, USGS
- 10:00 – Recent paleoseismic trenching studies along the Provo segment, Wasatch fault zone; Scott Bennett, USGS

10:30 Break

11: 00 Technical presentations of work completed or in progress

- 11:00 – Preliminary results from the Corner Canyon trench site on the Salt Lake City segment of the Wasatch fault zone; Chris DuRoss, USGS
- 11:30 – Remapping of the Warm Springs fault, Salt Lake City segment of the Wasatch fault zone; Adam McKean, UGS

12:00 Lunch

AGENDA
UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP
Tuesday, February 10, 2015

1:00 Technical presentations of work completed or in progress

- 1:00 – LiDAR mapping of the Levan and Fayette segments of the Wasatch fault zone; Adam Hiscock and Mike Hylland, UGS
- 1:30 – Fault strip mapping and continued exploration of the existing Traverse Ridge trenches from the Utah Valley University's 2014 summer field experience; Nathan Toke′, UVU
- 2:00 – Applying structure from motion techniques to neotectonic investigations—methods, error analysis, and examples; Michael Bunds, UVU
- 2:30 – New Boise State University NEHRP project: Seismic profiling in downtown Salt Lake City; Jim Pechmann, UUSS, and Lee Liberty, BSU
- 2:45 – Evidence of a third (barely prehistoric) earthquake on the Bear River fault zone; Chris DuRoss, USGS

3:00 Break

- 3:30 – Update on planned paleoseismic trenching on the Taylorsville fault; Adam Hiscock, UGS
- 3:45 – Update on Working Group on Utah Earthquake Probabilities; Patricia Thomas and Ivan Wong, AECOM
- 4:00 – Report on the Basin and Range Province Seismic Hazard Summit III; Bill Lund, UGS

4:15 UQFPWG 2015 fault study priorities (see table 1 for UQFPWG list of faults requiring additional study; see table 2 for UQFPWG 2014 fault priority list)

5:00 Adjourn

UQFPWG 2014 Fault Study Priorities

Fault/Fault Segment	Original UQFPWG Priority (2005)
Nephi segment WFZ	1
West Valley fault zone	2
Weber segment WFZ – most recent event	3
Weber segment WFZ – multiple events	4
Utah Lake faults and folds	5
Great Salt Lake fault zone	6
Collinston & Clarkston Mountain segments WFZ	7
Sevier/Toroweap fault	8
Washington fault	9
Cedar City-Parowan monocline/ Paragonah fault	10
Enoch graben	11
East Cache fault zone	12
Clarkston fault	13
Wasatch Range back-valley faults	14
Hurricane fault	15
Levan segment WFZ	16
Gunnison fault	17
Scipio Valley faults	18
Faults beneath Bear Lake	19
Eastern Bear Lake fault	20
Bear River fault zone	2007
Brigham City segment WFZ – most recent event	2007
Carrington fault (Great Salt Lake)	2007
Provo segment WFZ – penultimate event	2007
Rozelle section – East Great Salt Lake Fault	2007
Salt Lake City segment WFZ – northern part	2009
Warm Springs fault/East Bench fault subsurface geometry and connection	2010
Brigham City segment WFZ rupture extent (north and south ends)	2011
Long-term earthquake record northern Provo segment WFZ	2011
West Valley fault zone – Taylorsville fault	2011
Hansel Valley fault	2011
Acquire new paleoseismic information in data gaps along the five central segments of the WFZ	2012

2014 Highest Priority Faults/Fault Sections For Study		
Fault/Fault Section[1]	**Investigation Status**	**Investigating Institution[2]**
Acquire new paleoseismic information for the five central segments of the Wasatch fault zone (WFZ) to address data gaps – e.g., (a) the displacement and rupture extent of earthquakes on the Brigham City, Weber, and Salt Lake City segments, (b) long-term (early Holocene and latest Pleistocene) earthquake records for the southern Brigham City, southern Weber, and northern Provo segments, and (c) the subsurface geometry and connection of the Warm Springs and East Bench faults on the Salt Lake City segment.	1. Provo segment Flat Canyon site, ongoing 2. Salt Lake City segment Corner Canyon site, ongoing 3. Provo segment Dry Creek and Maple Canyon sites, ongoing	1. USGS/UGS 2. UGS/USGS 3. USGS/UGS
Acquire long-term earthquake record for the West Valley fault zone – Taylorsville fault	NEHRP-funded study to commence in 2015	UGS
Improve the long-term earthquake record for Cache Valley (East and West Cache fault zones)	No activity	
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.	The UGS is currently mapping portions of the Wasatch and West Valley (Granger fault) fault zones	UGS

Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**
Cedar City-Parowan monocline/Paragonah fault[3]	10	No activity	
Enoch graben	11	No activity	
Clarkston fault[3] (West Cache fault zone)	13	Black and others (2000)	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Rozelle section, Great Salt Lake fault[4]	2007	No activity	

Studies of Priority Faults Complete or Ongoing			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status[5]**	**Investigating Institution**
Nephi segment WFZ	1	UGS Special Study 124 USGS Map 2966 UGS Special Study 151	UGS/USGS
West Valley fault zone (Granger fault)	2	UGS Special Study 149	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Contract deliverable FTR (UUGG investigation)	UUGG/BYU
Great Salt Lake fault zone	6	Contract deliverable FTR	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
Washington fault zone	9	Contract deliverable FTR	UGS
East Cache fault zone	12	UGS Miscellaneous Publication 13-3	USU
Wasatch Range back-valley fault (Main Canyon fault)	14	UGS Miscellaneous Publication 10-5	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Contract deliverable FTR	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north part	2009	Contract deliverable FTR	UGS/USGS
Hansel Valley fault[3]	2011	McCalpin (1985), Robinson (1986), McCalpin and others (1992), UUGG ongoing	UUGG
Long-term earthquake record Nephi segment WFZ – North Creek	2012	Contract deliverable FTR	UGS/USGS
Provo/Salt Lake City/Nephi segment Holocene fault segmentation – Flat Canyon, Alpine, Maple Canyon, and Corner Canyon trench sites	2012/2013	On going	USGS/UGS

Paleoseismology of the Northern Segments of the Great Salt Lake Fault

by

David A. Dinter and James C. Pechmann

University of Utah, Salt Lake City, Utah

Utah Quaternary Fault Parameters Working Group Meeting
February 10, 2015

Outline

(1) The Oquirrh – Great Salt Lake Fault Zone

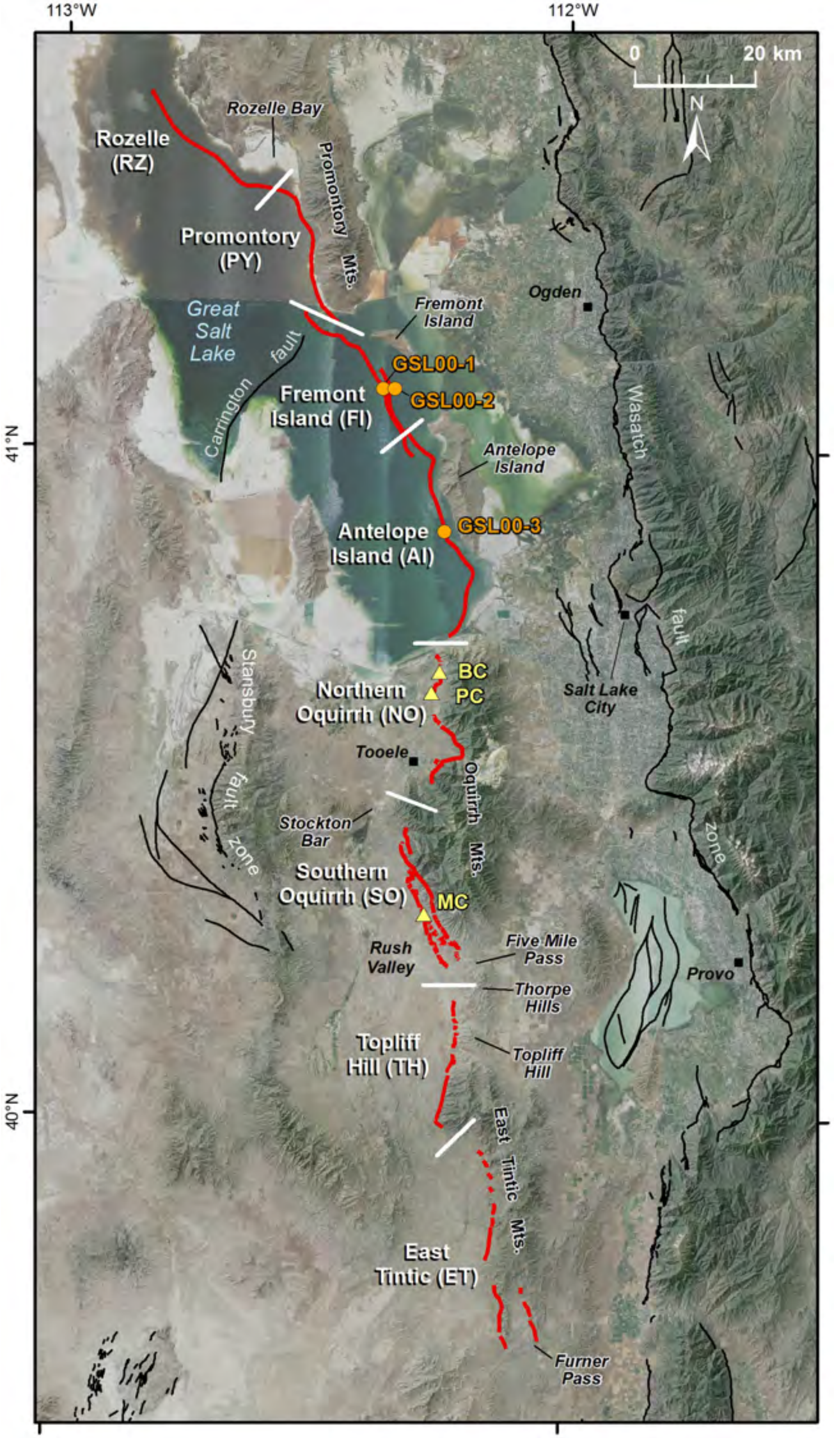
(2) Fieldwork: Seismic Reflection Profiling

- **--Logistical issues**
- **--Chronology**
- **--Data collection**

(3) Fault Maps

- **--New map for the GSL north arm**
- **--Revised map for the GSL south arm**
- **--Segmentation model**

(4) Seismic reflection evidence for paleoearthquakes, northern segments



Oquirrh – Great Salt Lake fault zone: red

Other faults: black

Figure prepared for the WGUEP by S. Olig, URS Corp., and by C. Duross and C. Unger, UGS

Great Salt Lake
Aug. 19, 2003
International Space Station Photo (NASA)

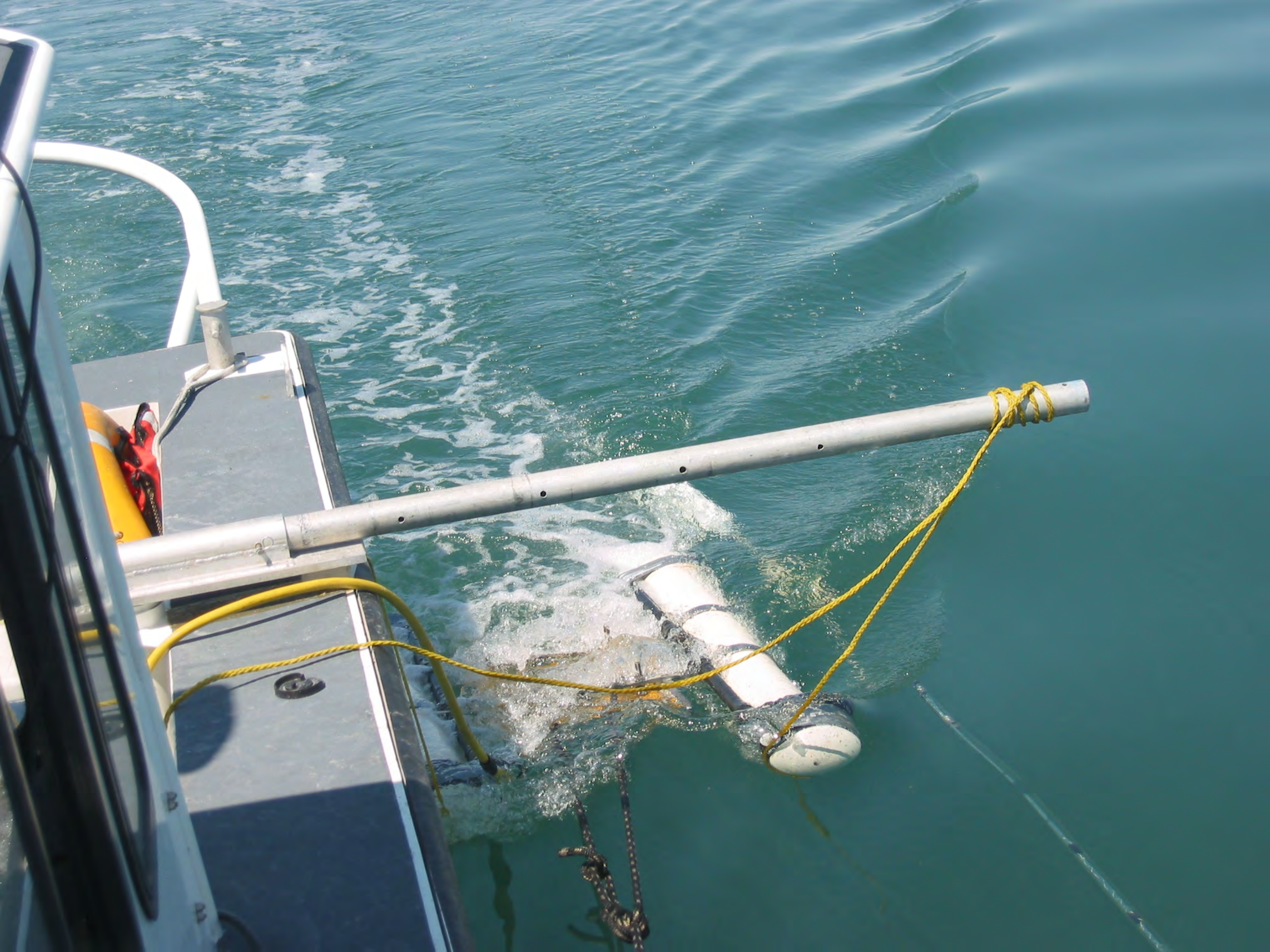
Challenges for N Arm Fieldwork

- Rock-fill railroad causeway divides lake into N and S arms
- N arm salinity ~9x that of seawater (vs. ~3x in the S arm)
- Boat access limited
- Salt layer on lake bottom

North Arm Fieldwork Chronology (4 field seasons over 8 years)

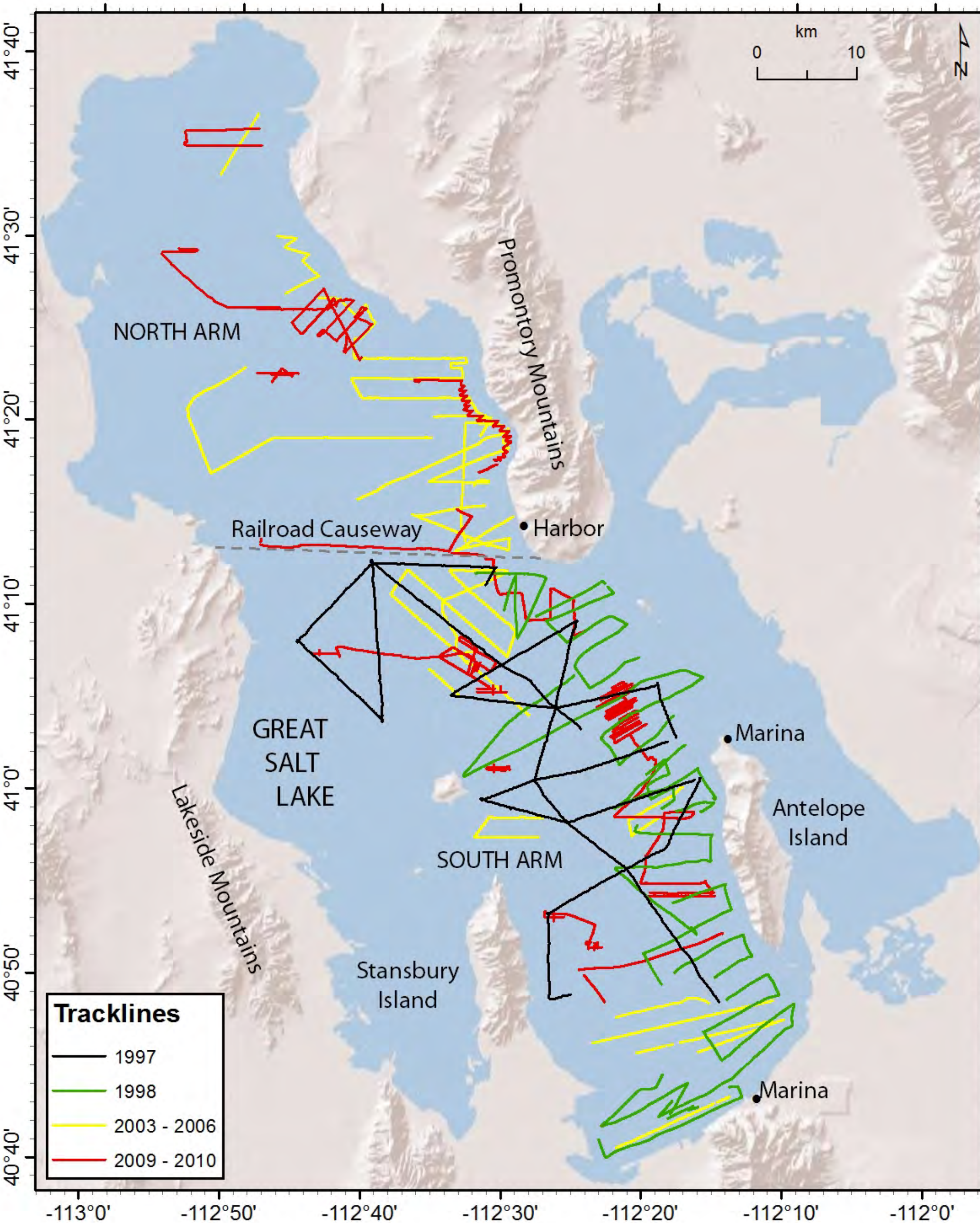
- 2002. Salt precipitation in N arm prevents use of boats with outboard motors
- 2003. Mechanical problems with USGS boat motors in the hypersaline N arm; only 2 days (75 km) of data
- 2004. Motors fixed, but lake level too low to launch boat from beach; concrete boat ramp opened on Oct 25
- 2006. Collected 130 km of data, but data quality was poor (as it was for the 2003 data)
- 2009. Good data obtained working with Rob Baskin, USGS, on stromatolite study; funded by BG Group
- 2010. Bootlegged more good data on Utah Lake study


EZ LOADER

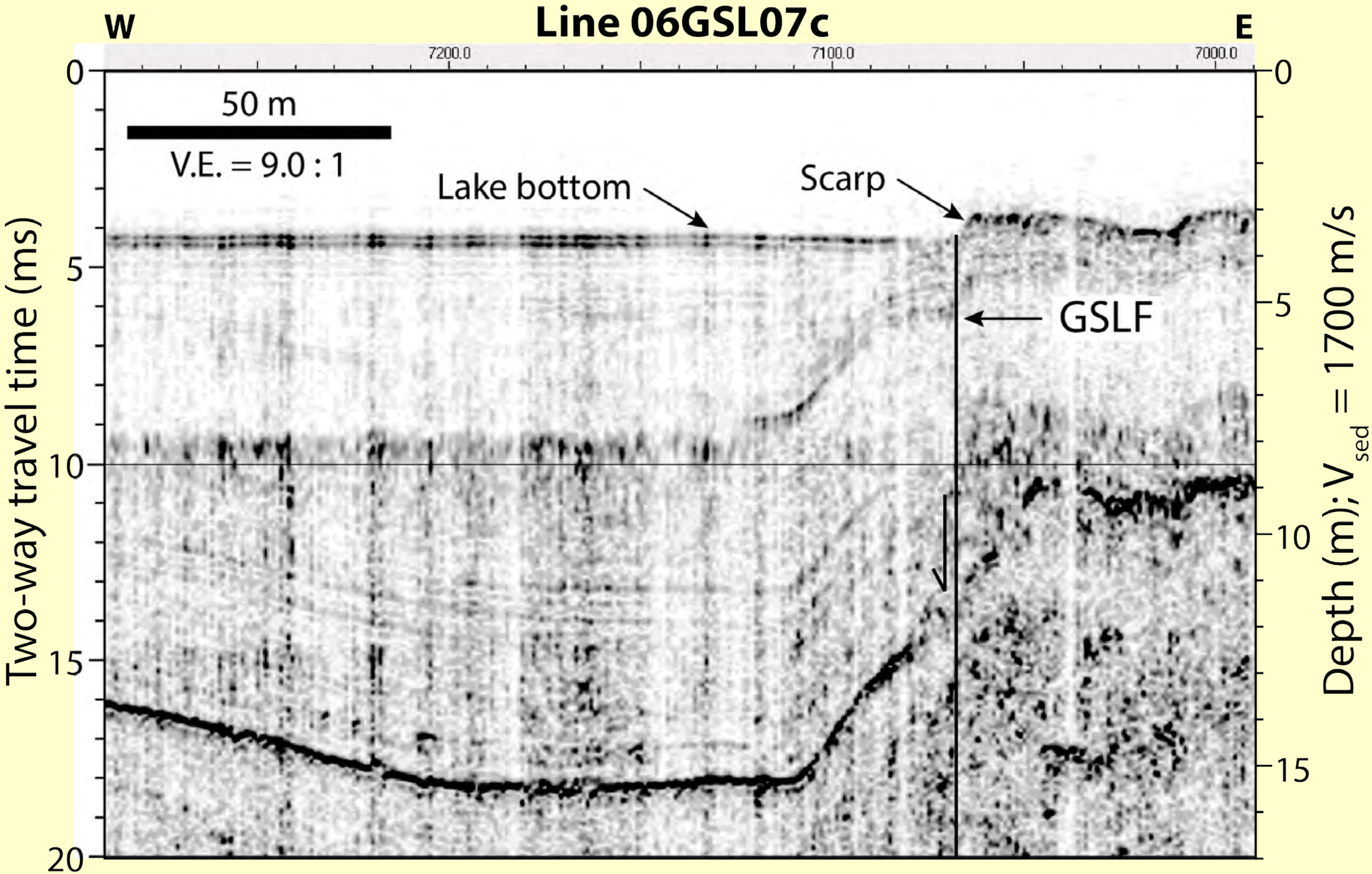



SB-216S
Full Spectrum™ Sub-Bottom Tow Vehicle

Trackline Map



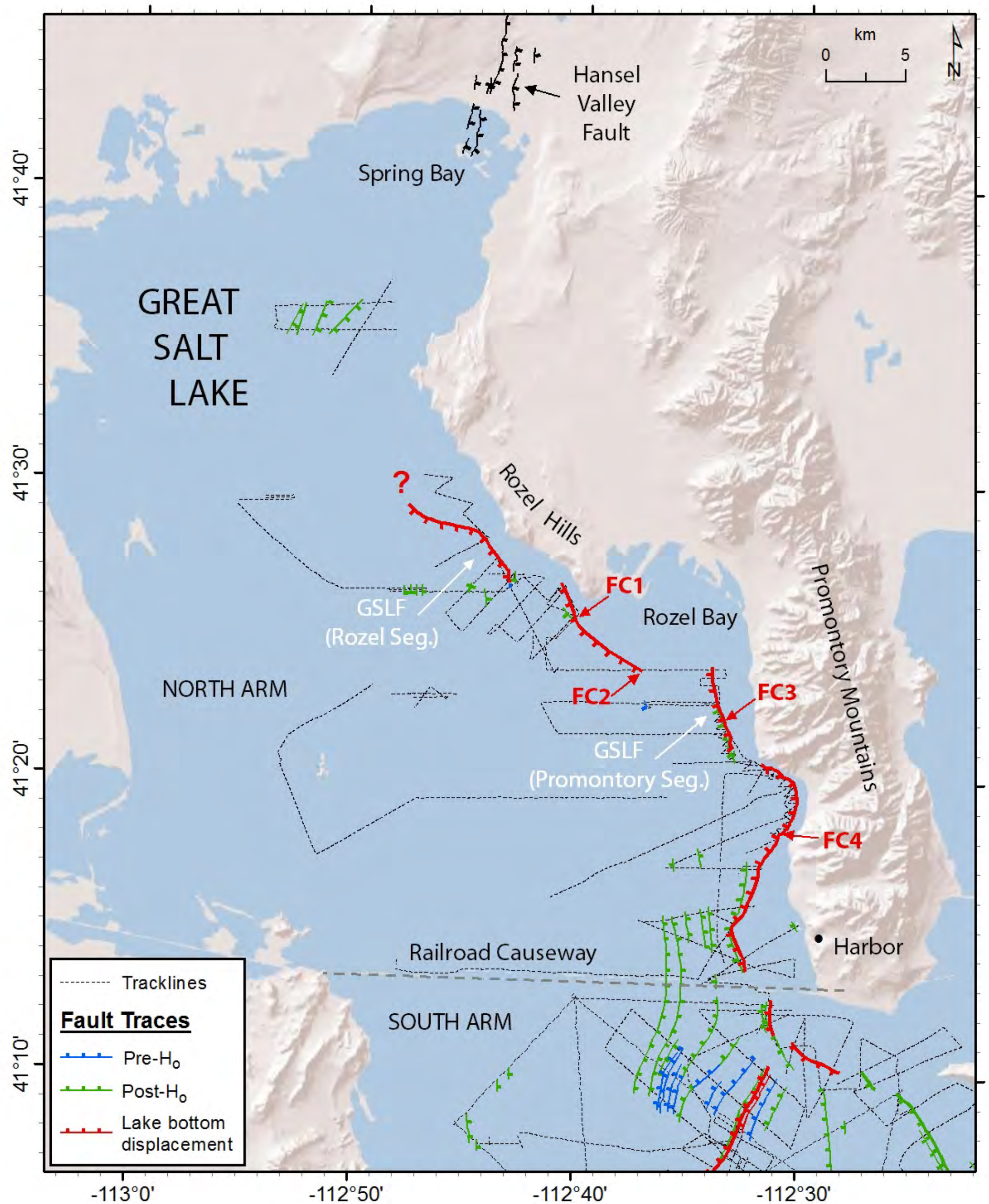
Collected 748 km of data from 2003-2010:
366 km in north arm
382 km in south arm



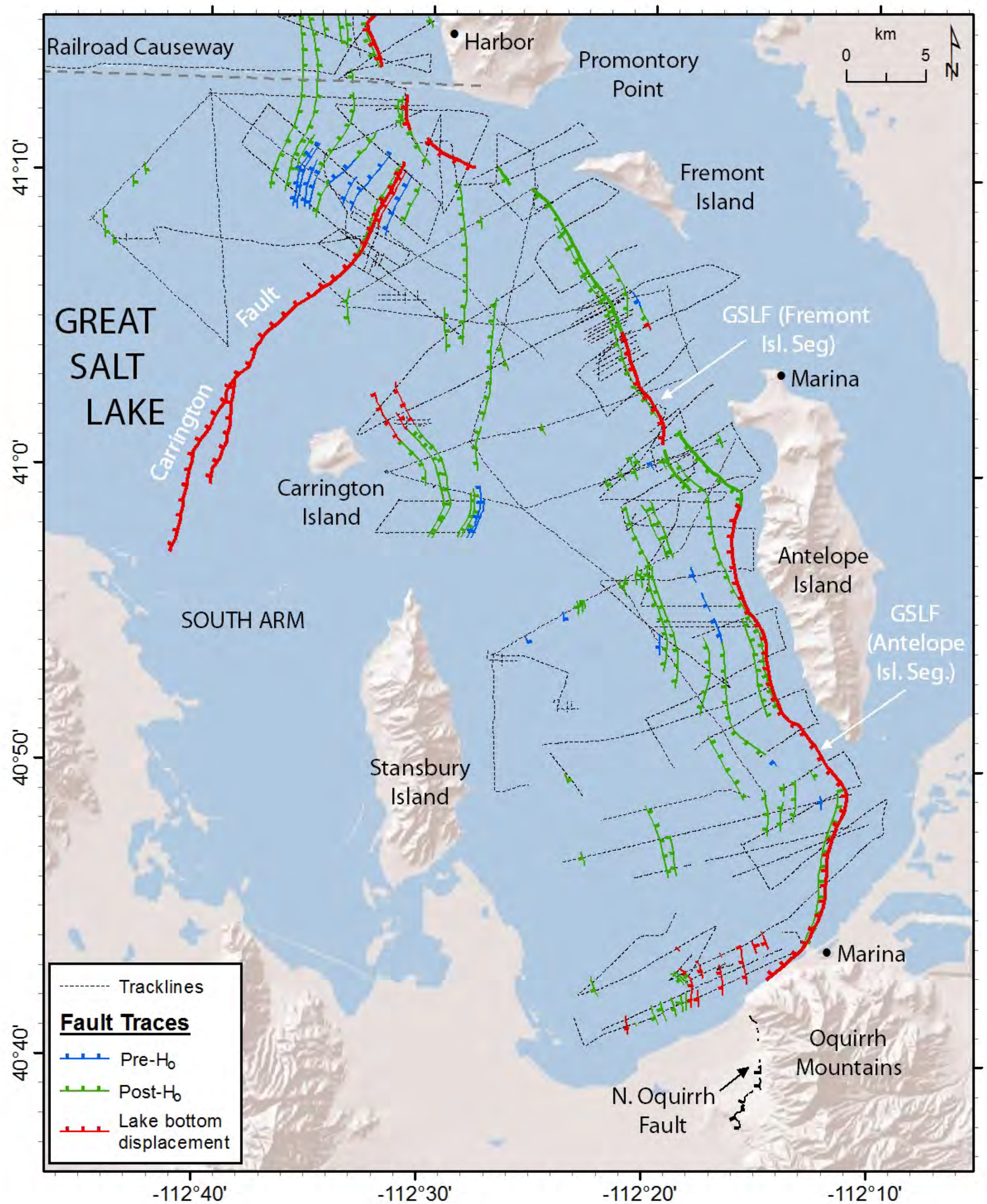
Line 06GSL07c
W
E
7200.0
7100.0
7000.0
50 m
V.E. = 9.0 : 1
Lake bottom
Scarp
GSLF
Two-way travel time (ms)
0
5
10
15
20
Depth (m); V_{sed} = 1700 m/s
0
5
10
15

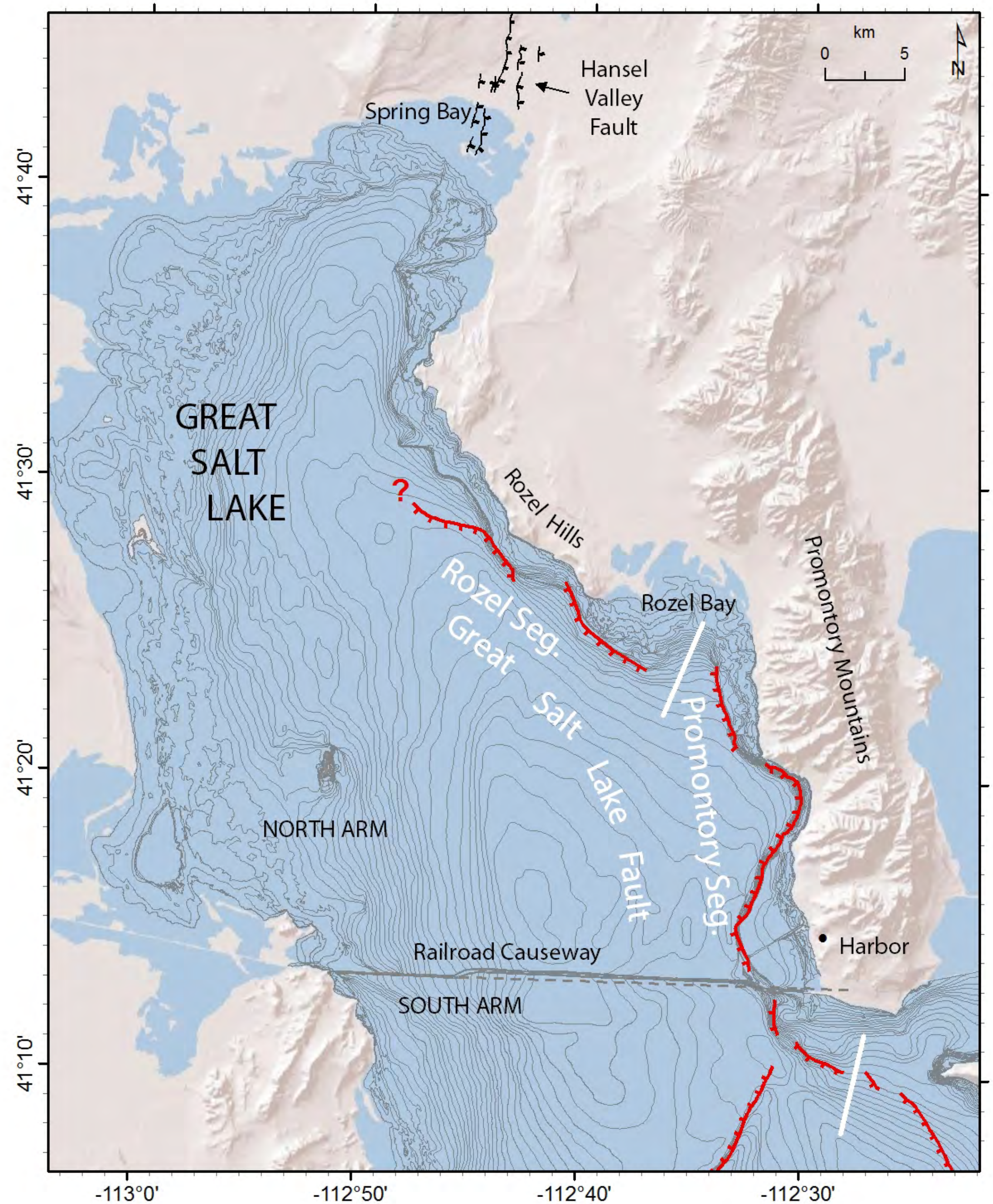
FC2

Fault Map of Great Salt Lake North Arm



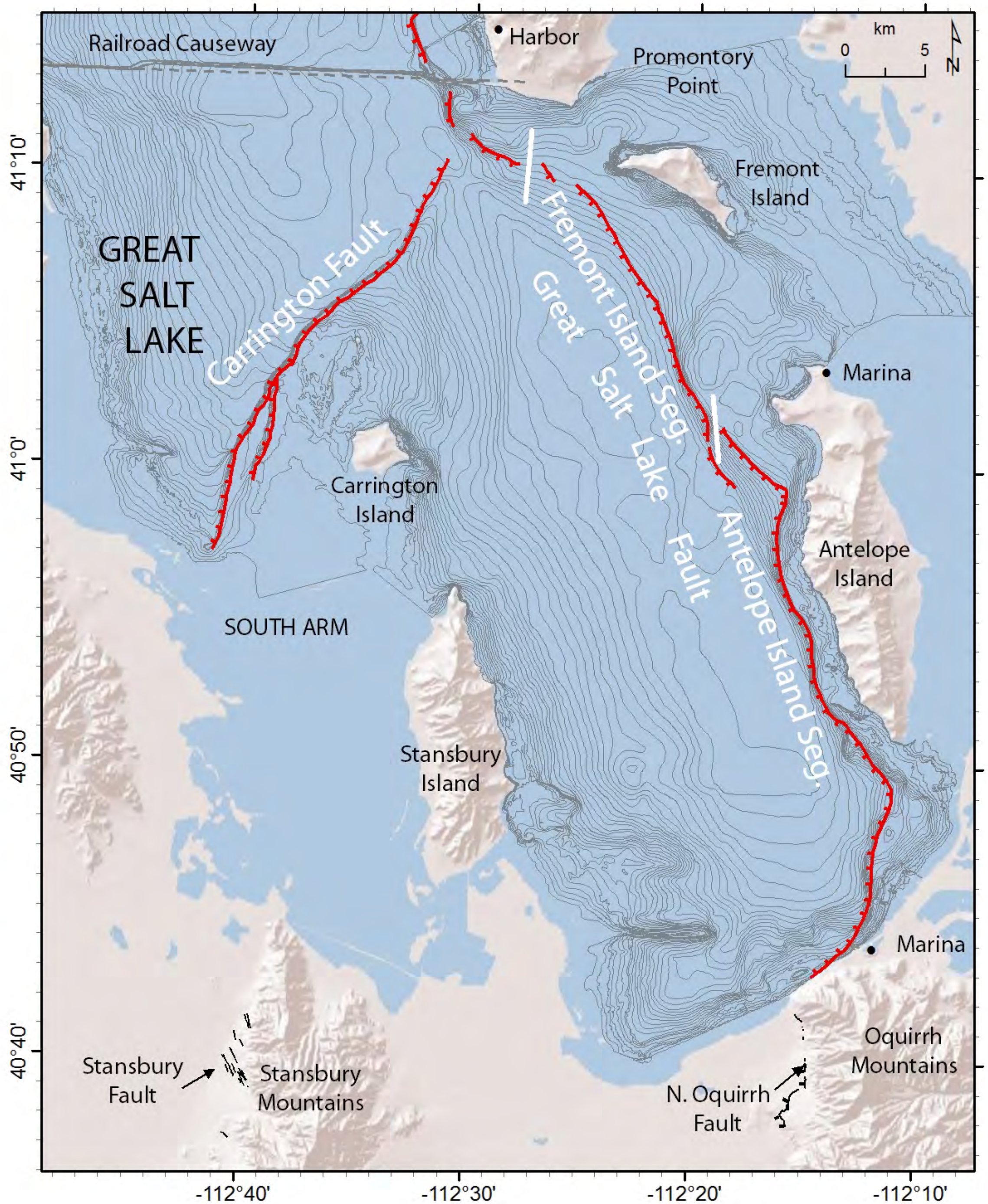
Fault Map of Great Salt Lake South Arm





Major Faults and Segment Boundaries, Great Salt Lake North Arm

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



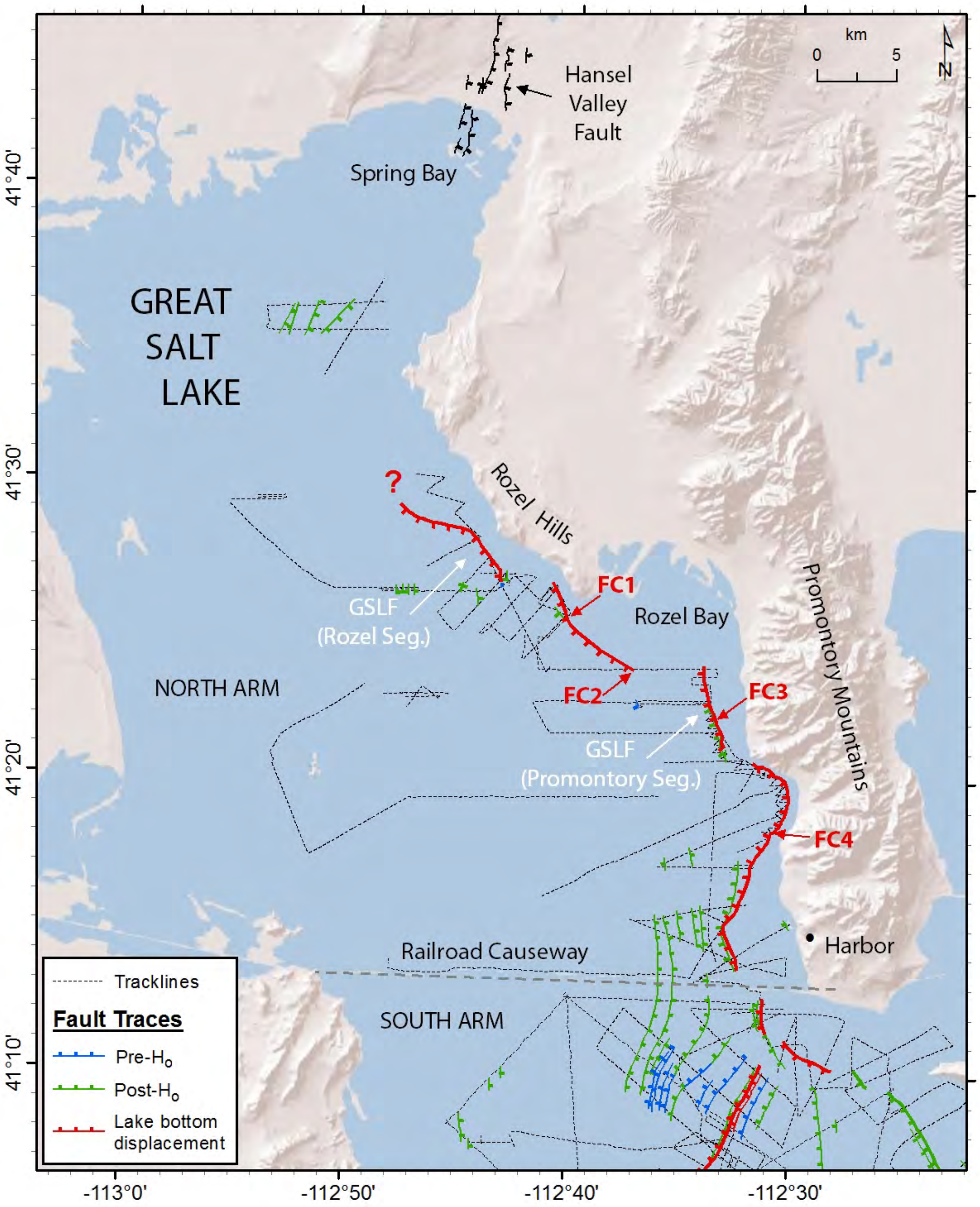
Major Faults and Segment Boundaries, Great Salt Lake South Arm

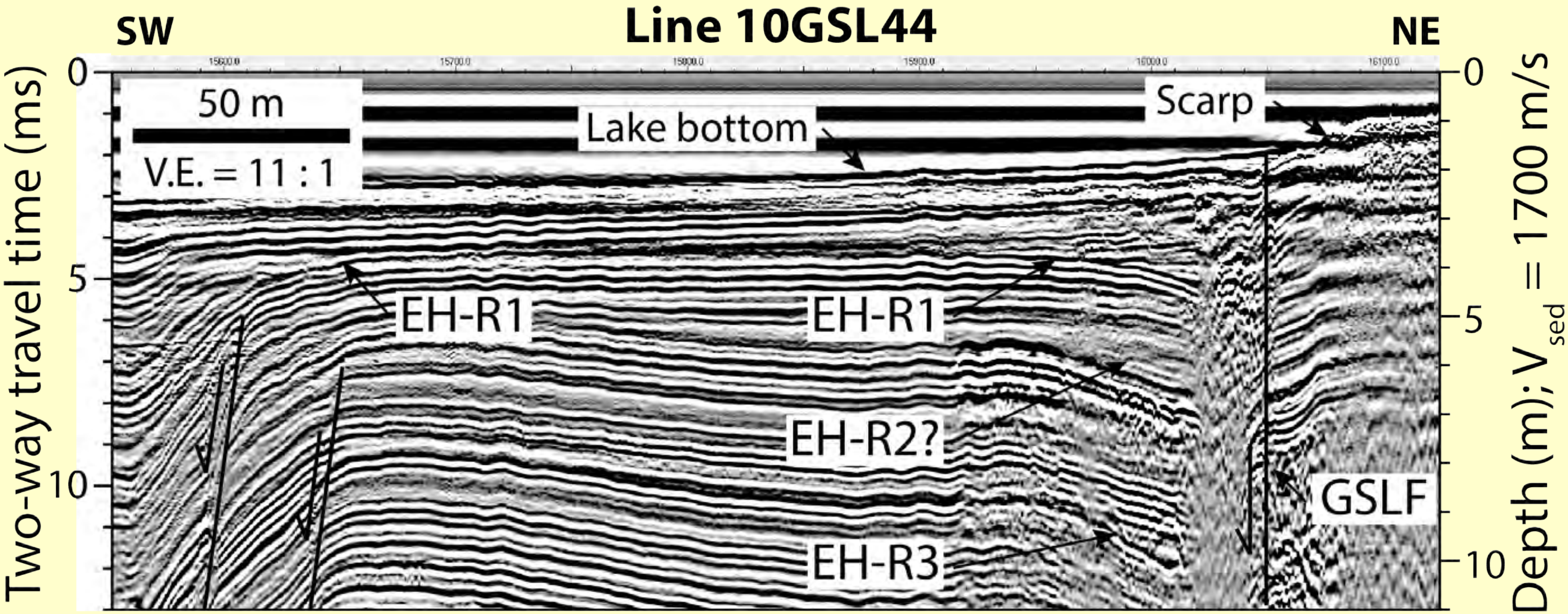
Bathymetic contours from Baskin and Allen (2005) and Baskin and Turner (2006); contour interval one foot

Segmentation Model for the Great Salt Lake Fault

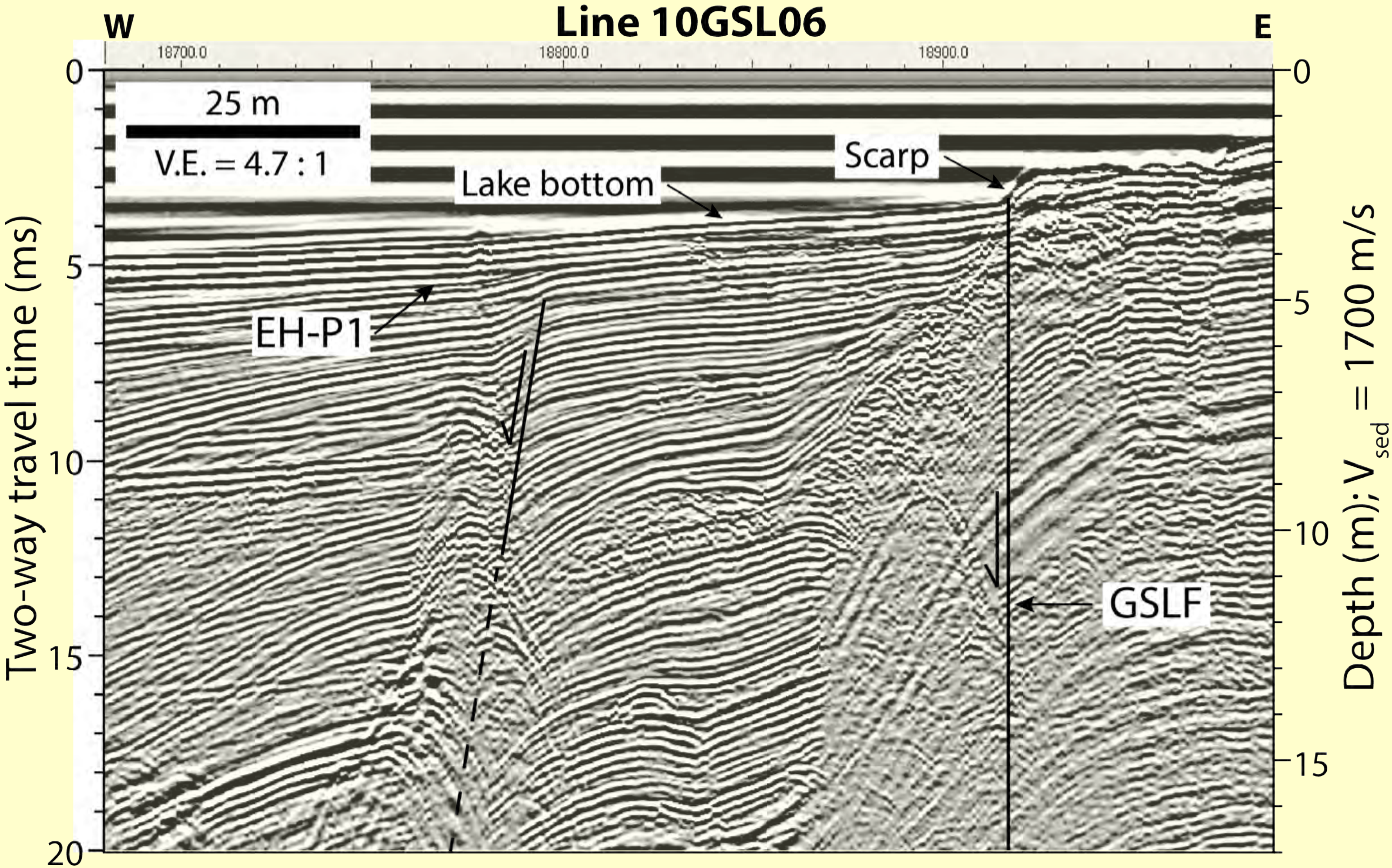
Segment Name	End-To-End Length (km)	Estimated Moment Magnitude	
		Wells and Coppersmith (1994)	Wesnousky (2008)
Rozel	≥ 18	≥ 6.5	≥ 6.7
Promontory	≥ 27	≥ 6.7	≥ 6.8
Fremont Island	24	6.7	6.8
Antelope Island	35	6.9	6.8

Locations of Fault Crossings on Seismic Reflection Profiles



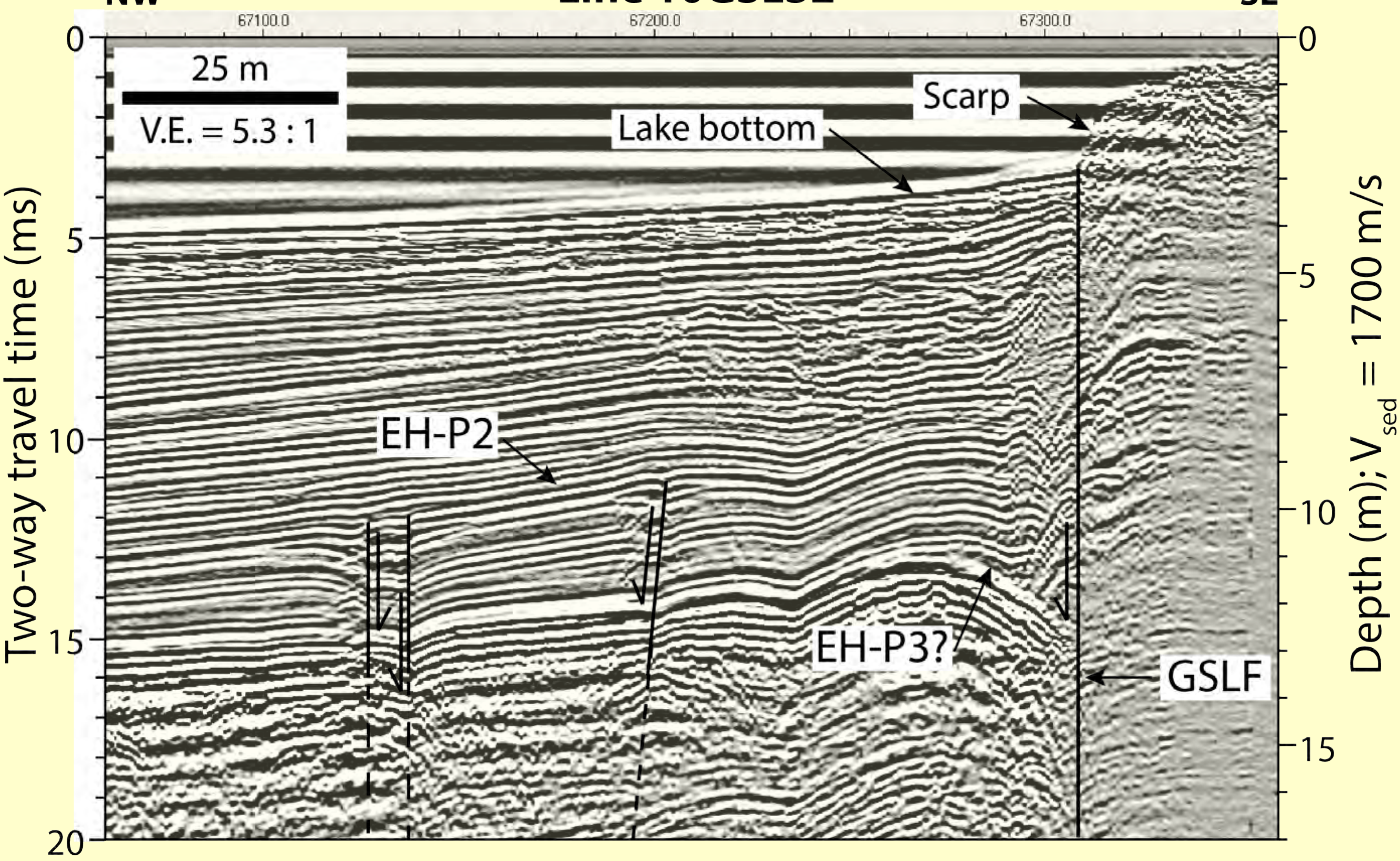

SW
Line 10GSL44
NE
50 m
V.E. = 11 : 1
Lake bottom
Scarp
EH-R1
EH-R1
EH-R2?
EH-R3
GSLF
Two-way travel time (ms)
Depth (m); V_{sed} = 1700 m/s
0
5
10
0
5
10

FC1


Line 10GSL06
W
E
18700.0
18800.0
18900.0
25 m
V.E. = 4.7 : 1
Scarp
Lake bottom
EH-P1
GSLF
Two-way travel time (ms)
0
5
10
15
20
Depth (m); V_{sed} = 1700 m/s
0
5
10
15

FC3

Line 10GSL32



FC4

Summary of Paleoearthquake Evidence

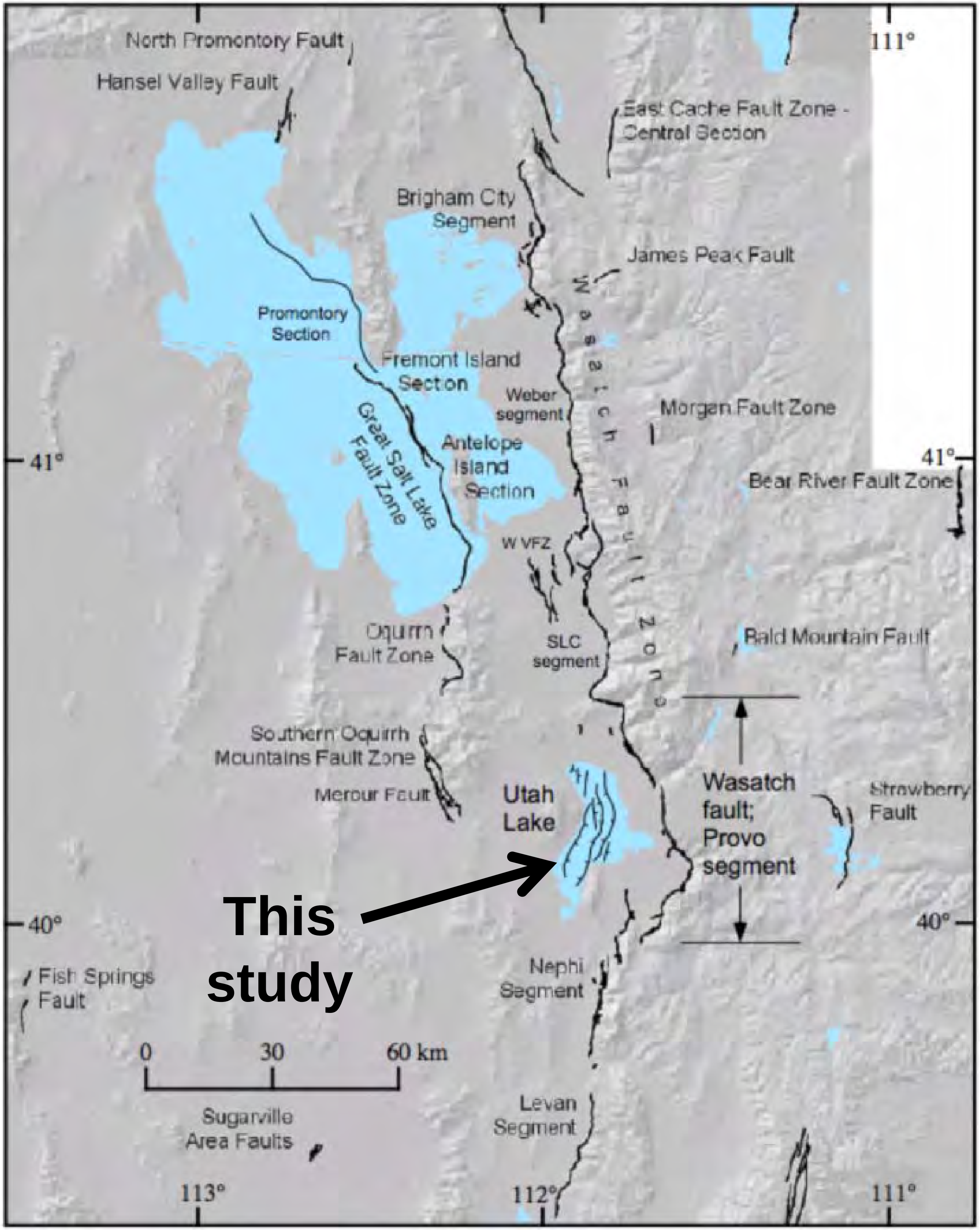
- One reflection profile provides evidence for 2 or 3 paleoearthquakes on the Rozel segment, with all event horizons in the top ~7 m of sediments
- Two reflection profiles in combination show evidence for 2 or 3 paleoearthquakes on the Promontory segment, with all event horizons in the top ~8 m.
- A possible fourth Promontory segment event is suggested by the higher fault scarps on this segment.
- Judging from sedimentation rates on the GSLF hanging wall in the S arm, it is likely that all of the paleoearthquakes interpreted on the reflection profiles in the N arm are of Holocene age (< 11,700 yrs BP).

Conclusions

- **Based on fault geometry and recency of faulting, the GSLF appears to consist of four segments with end-to-end lengths ranging from ≥ 18 to 35 km.**
- **Seismic reflection profiles across the GSLF in the north arm show clear evidence of individual paleoearthquakes: 2 or 3 of probable Holocene age on each of the two northern GSLF segments.**
- **Based on comparisons with dated seismic event horizons on the GSLF southern segments, it is reasonable to assume that the average single segment R.I. of 4200 ± 1400 yrs for the southern segments also applies to the northern segments.**

Paleoseismology of Faults Submerged Beneath Utah Lake

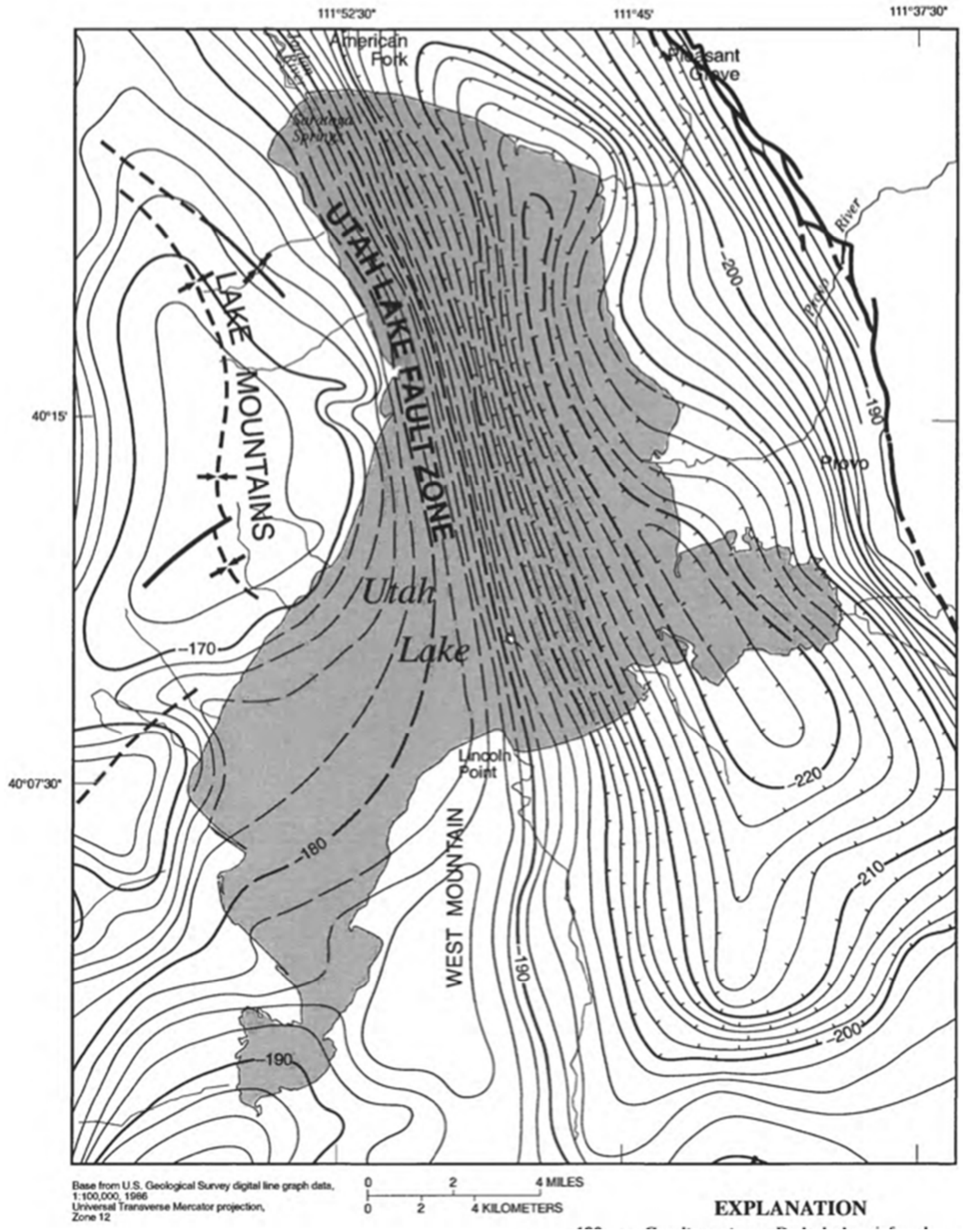
David A. Dinter
Department of Geology and Geophysics
University of Utah



Utah Lake lies in the distal hanging wall of the Provo segment of the Wasatch fault.

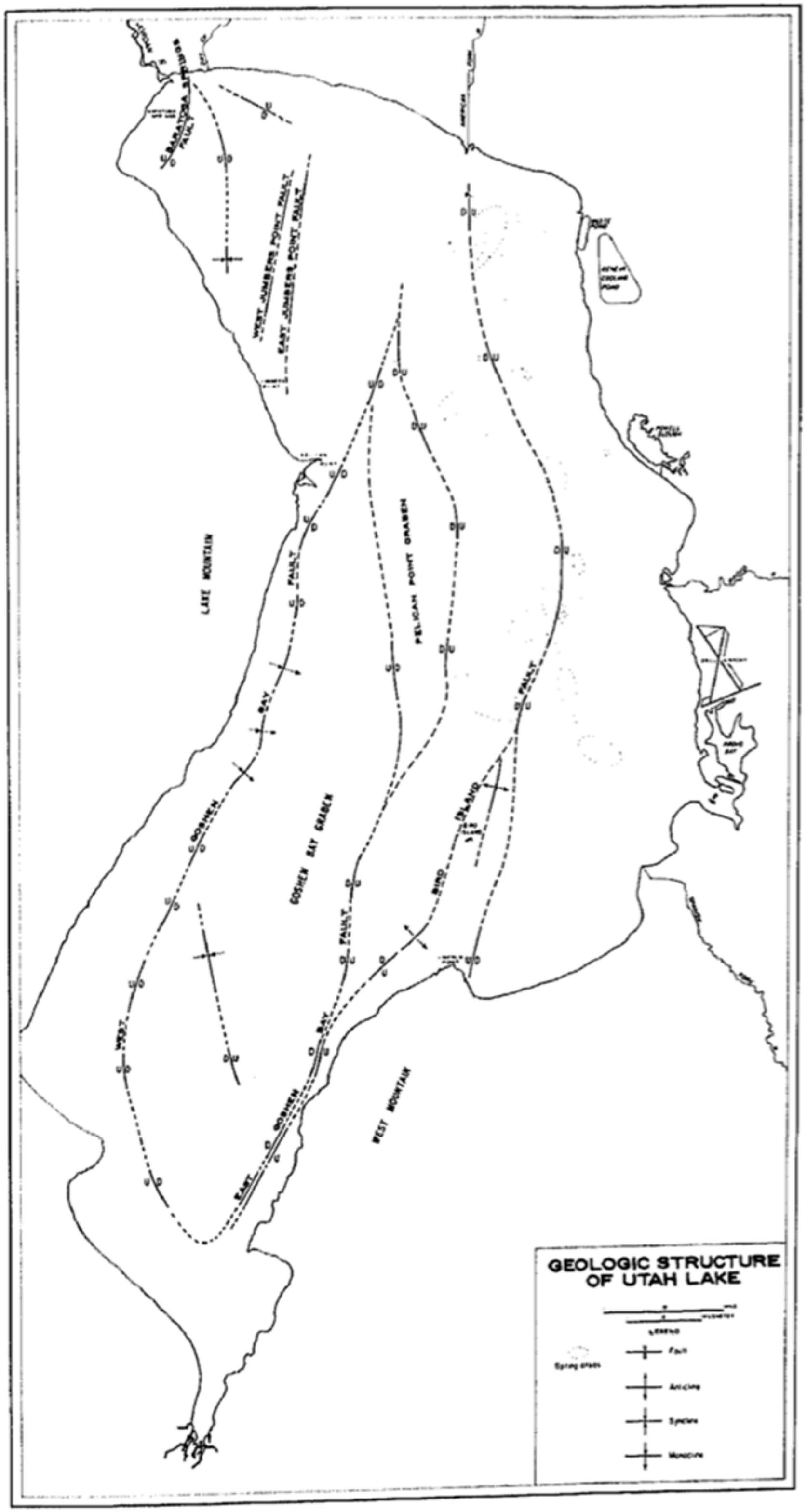
Earlier reflection seismic surveys (Brimhall et al., 1976; Baskin & Berryhill, 1996) profiled faults with recent surface ruptures underlying Utah Lake.

However, limited coverage and data quality precluded accurate mapping of fault traces and determination of displacement history.



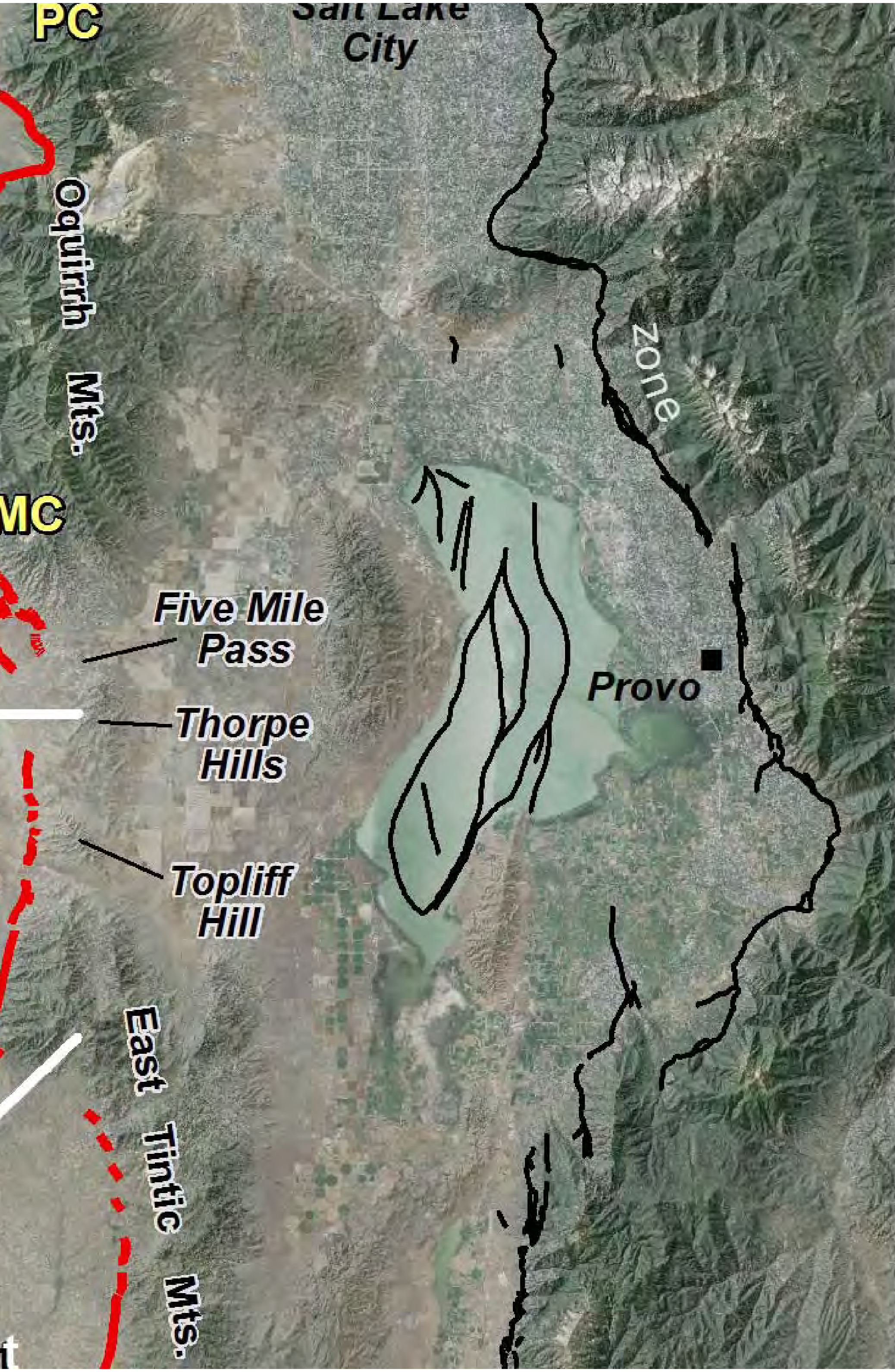
Background:

Cook & Berg (1961) postulated a "Utah Lake fault zone" striking NNW from Lincoln Point (West Mountain) to Jordan River outlet at north lakeshore, based on a steep gradient in the gravitational field.



Brimhall et al. (1976) published the first map of Utah Lake active faults based on reflection seismic profiling.

- E-dipping West Goshen Bay fault & W-dipping East Goshen Bay fault bound Goshen Bay graben, merge to the south (ellipsoidal geometry?)
- W. Goshen Bay fault splits northward into facing splays bounding Pelican Point graben.
- West-dipping Bird Island fault under-lies entire east-central basin.
- Shorter East and West Jumbers Point and Saratoga Springs faults underlie northwest basin.



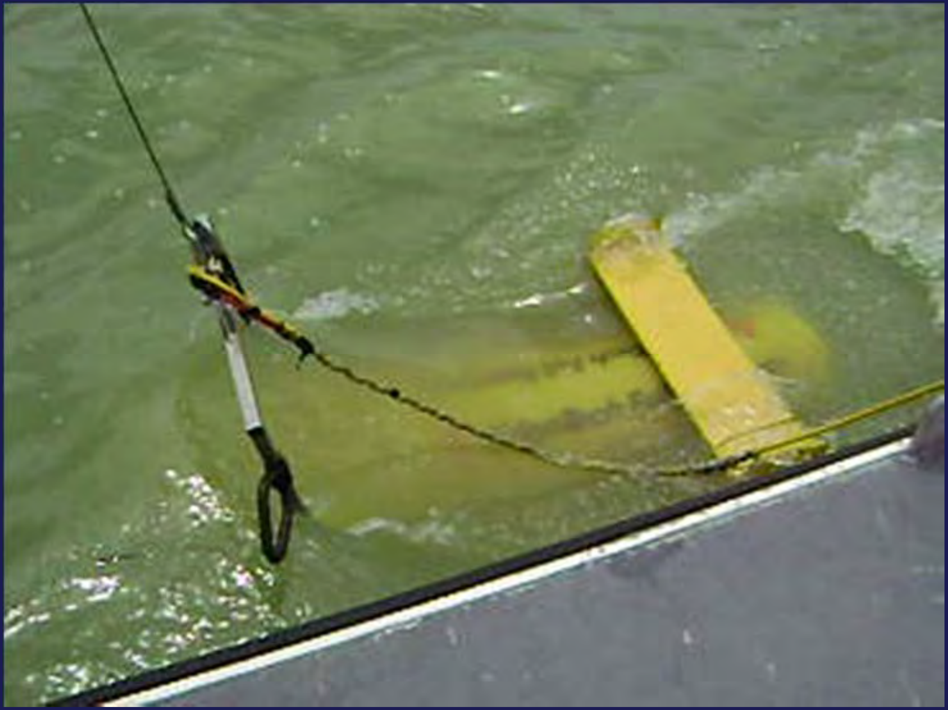
Brimhall et al. (1976) map is incorporated in National Quaternary Fault & Fold database, but:

- There are geometrical and structural inconsistencies,
- Navigation utilized compass bearings and dead reckoning,
- All original data & tracklines maps were lost (W. Brimhall, pers. commun., 2008)
- Line spacings were large (up to 5 km), and data quality poor.

NEHRP agreed, a new survey was needed....

Goals of this study:

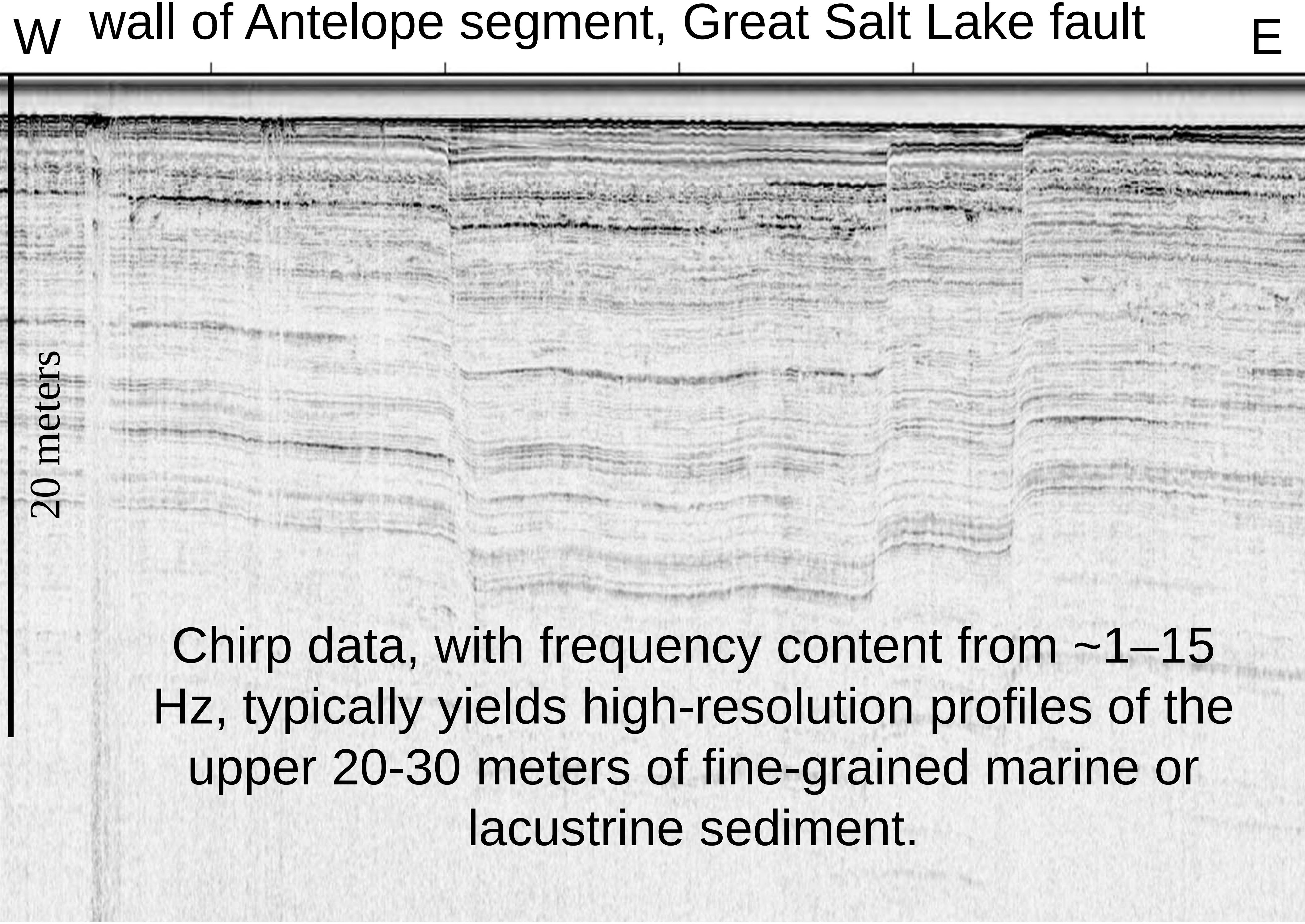
- Obtain high-quality seismic reflection data covering Utah Lake basin at 2- to 3-km spacing.
- Create an accurate map of all submerged faults with Holocene surface ruptures.
- Determine, if possible, displacement histories of these faults, and identify prospective coring sites.
- Assess whether Utah Lake faults are auxiliary to Provo segment of Wasatch fault (analogous to West Valley faults and Salt Lake City segment).
- Characterize any additional seismogenic structures or hazards present in the lake.



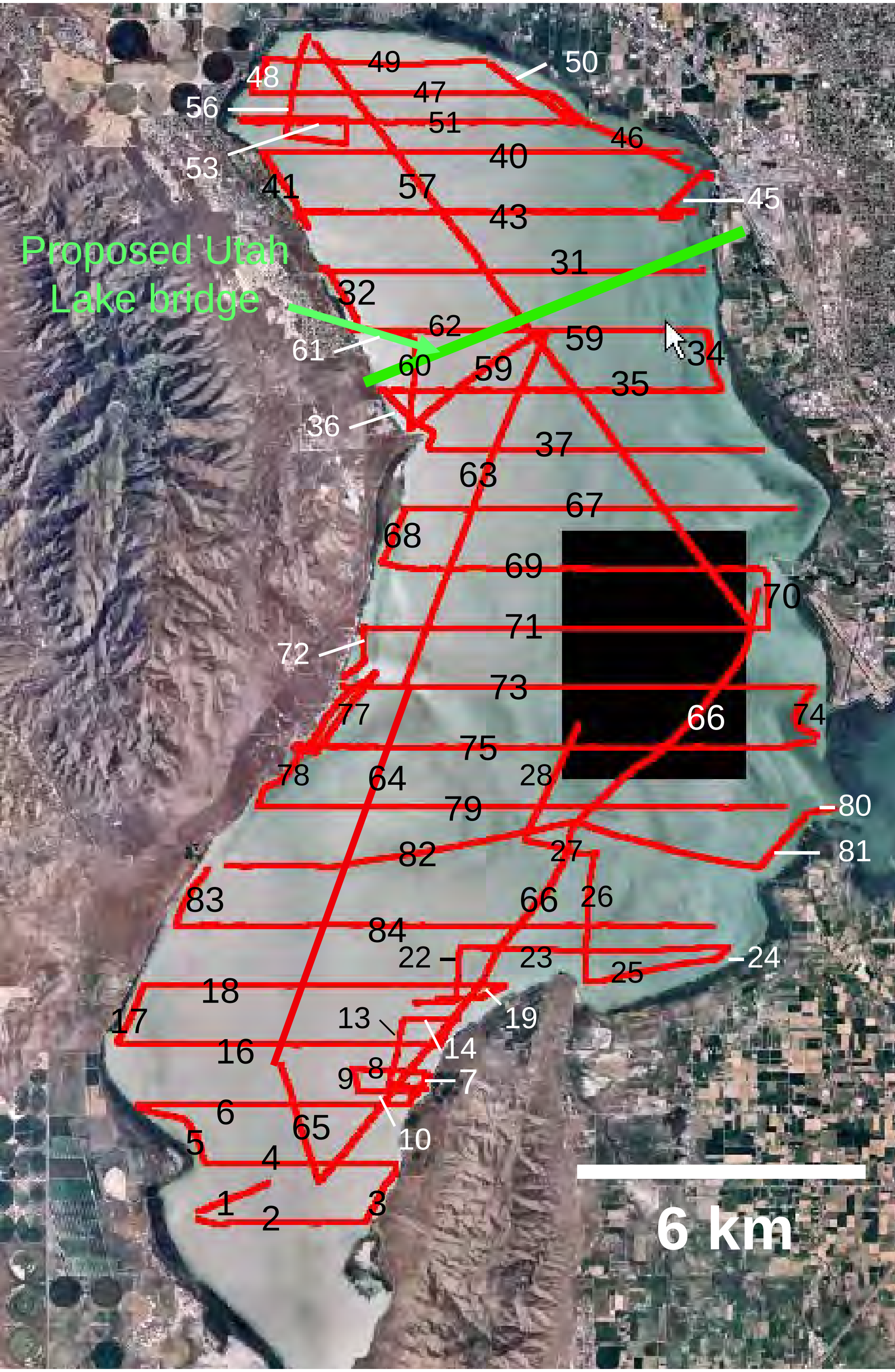
The “Chirp” system employed has a single transducer & hydrophone mounted in a towfish, towed at ~ 1 meter water depth and speeds 5 - 7 km/hr.


SB-216S
EZ LOADER
Rob Baskin, USGS
Geologist & Mariner
Deployed with davit and hand
winch from small survey boat.

Synthetic and antithetic auxiliary faults in hanging wall of Antelope segment, Great Salt Lake fault



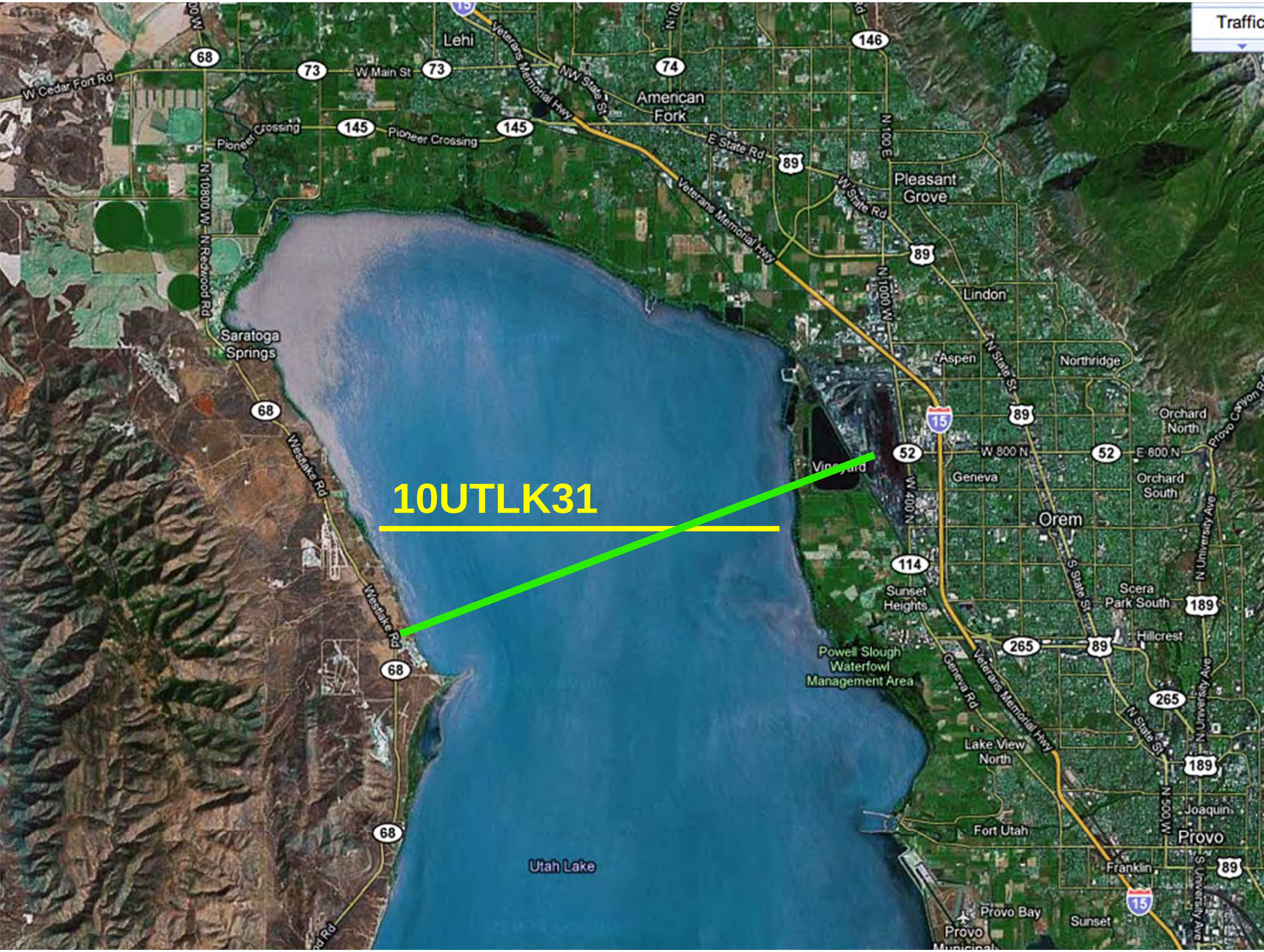
Chirp data, with frequency content from ~1–15 Hz, typically yields high-resolution profiles of the upper 20-30 meters of fine-grained marine or lacustrine sediment.

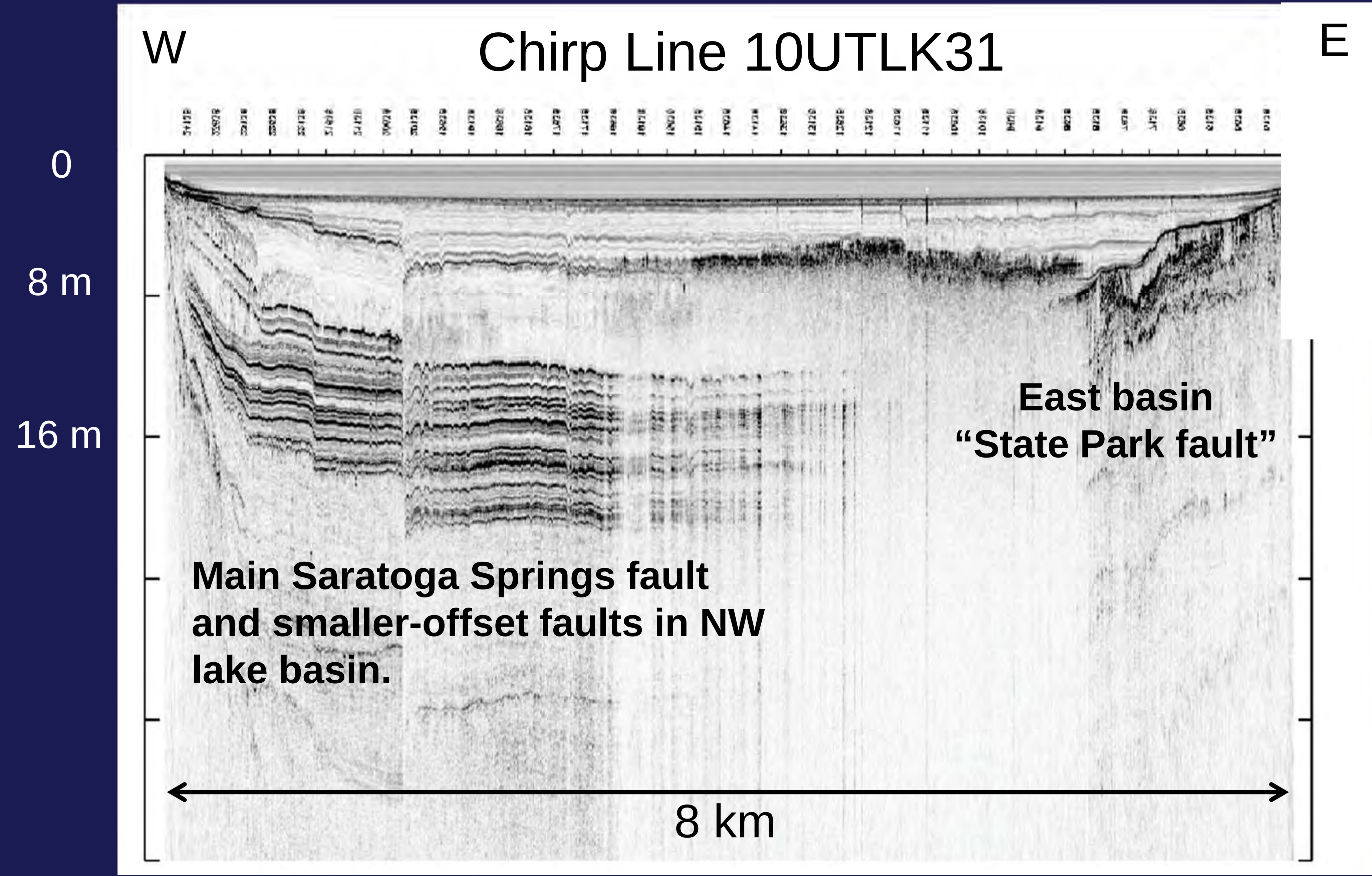


Utah Lake 2010 Seismic Reflection (Chirp 512i) Tracklines

- 84 profiles cover most of the lake at average spacings ~2-3 kilometers.

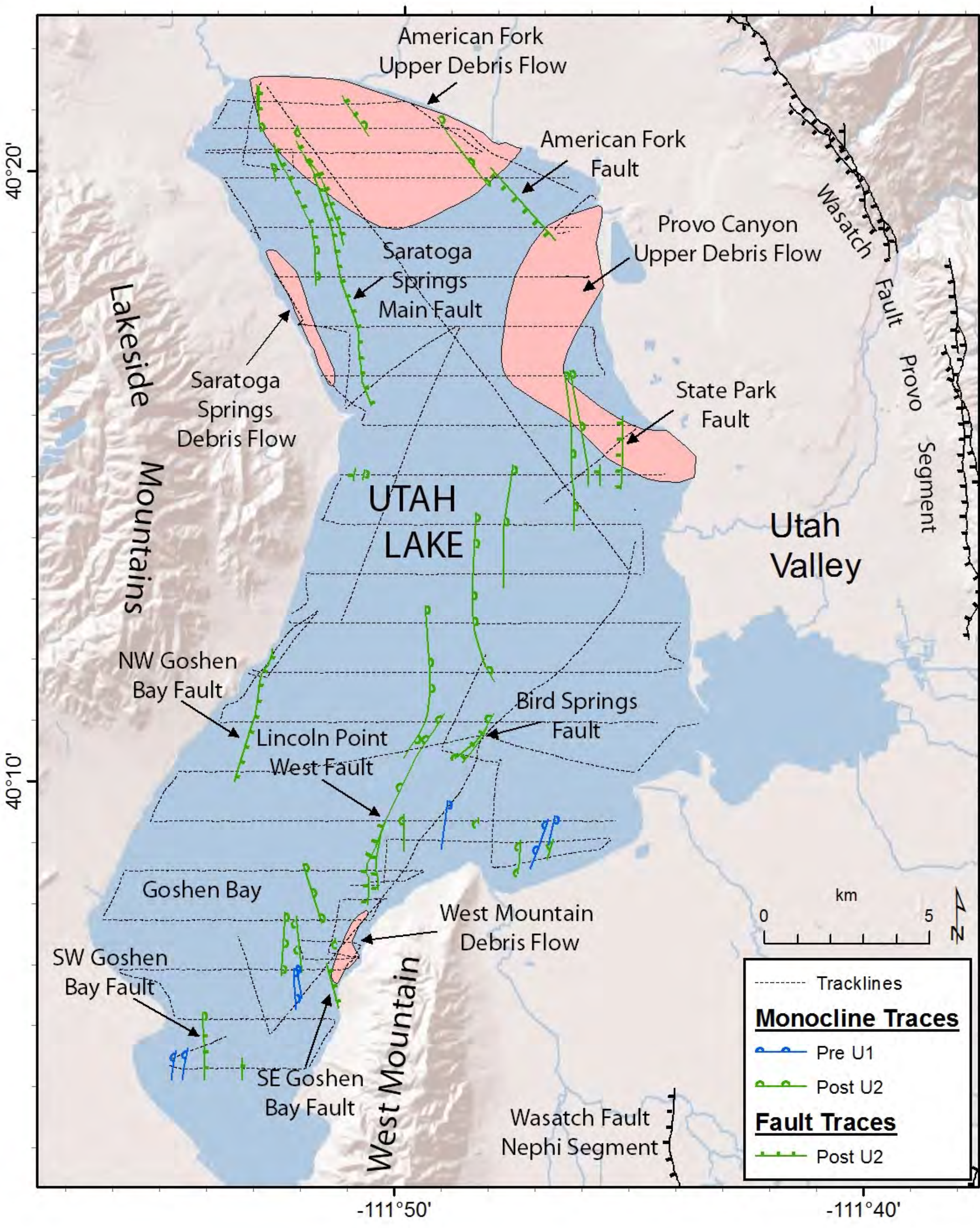
- Developers propose a bridge crossing to the Saratoga Springs housing development on the west lake shore.


10UTLK31
Utah Lake
Lehi
American Fork
Pleasant Grove
Lindon
Saratoga Springs
Vineyard
Orem
Geneva
Provo
Aspen
Northridge
Orchard North
Orchard South
Sunset Heights
Powell Slough Waterfowl Management Area
Lake View North
Fort Utah
Provo Bay
Scera Park South
Hillcrest
Joaquin
Franklin
Sunset
Traffic



Faults with recent surface ruptures are well-imaged utilizing the Scripps Chirp system, most on 2 or more east-west profiles.

Utah Lake fault map, new & improved



- Main Saratoga Springs fault (5.5 m post-U1 NVTD, 8 km tip-to-tip), & Lincoln Point west fault (4.7 m post-U1 NVTD, 6 km tip-to-tip) are longest, largest-displacement structures in Utah Lake.
- ~20 additional shorter normal faults and monoclines with smaller displacements disrupt strata within one meter below lakebed in 5 general areas.
- None of these structures displaces the current lakebed.

Utah Lake Stratigraphy

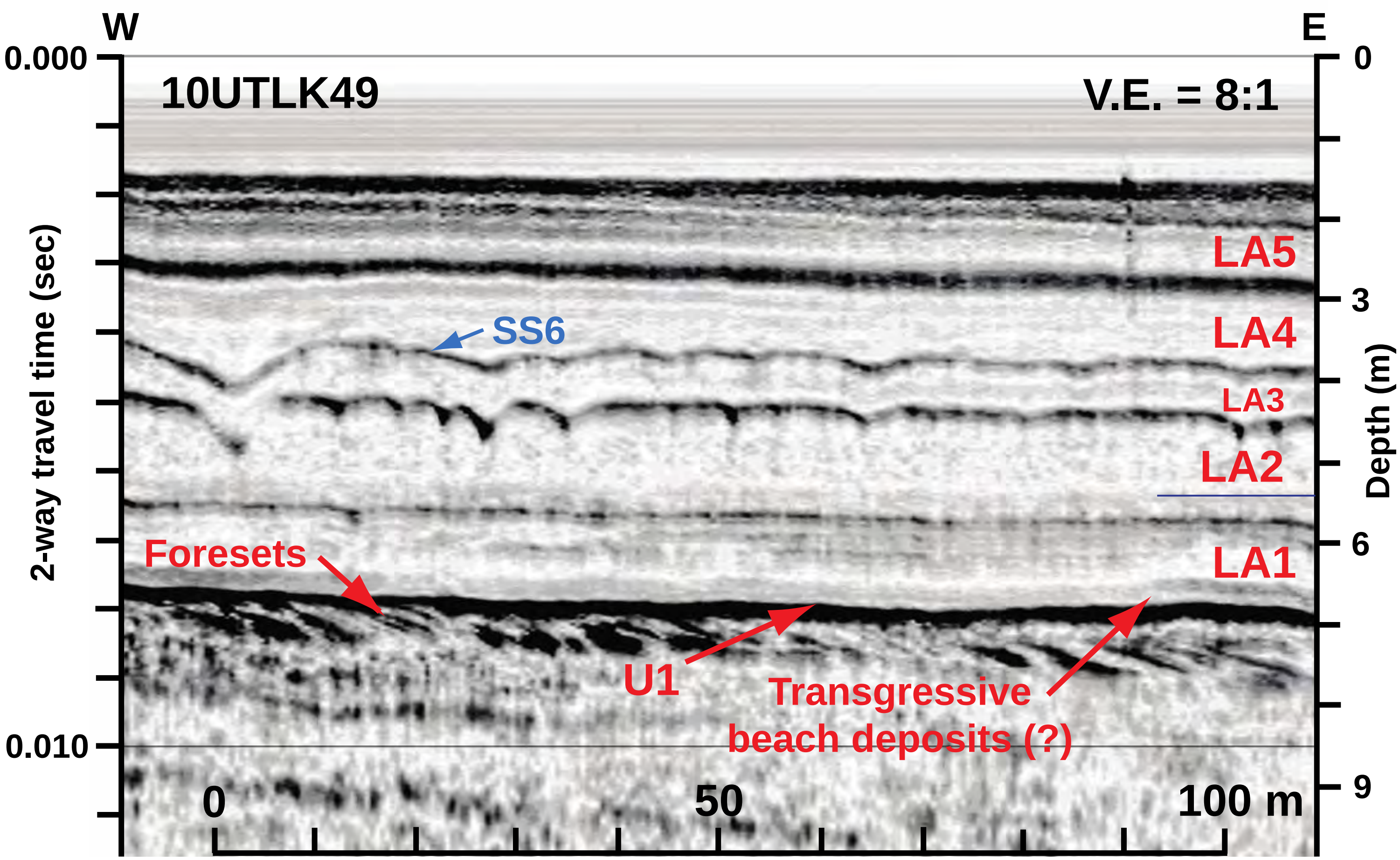
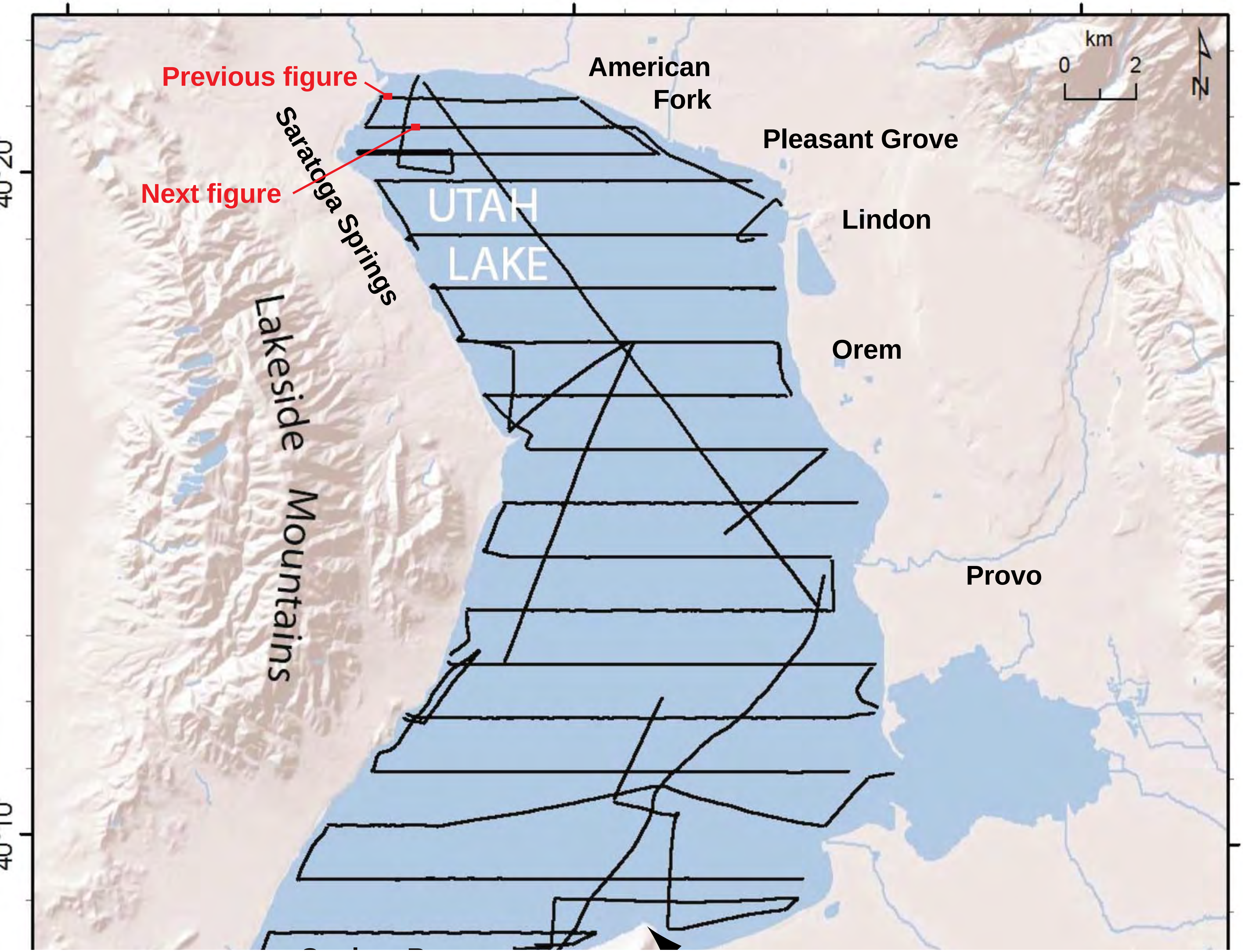


Figure 3. Chirp profile showing Unconformity U1, underlying foresets, and overlying lower strata of Lake A lacustrine sequence. LA2 is the “Lower Seismite” (see text), SS6 is earthquake event horizon SS6 (Saratoga Springs 6, see text). Note possible transgressive beach deposits at base of Unit LA1. See Fig. 2 for location.

Two lacustrine cycles are preserved in late Quaternary Utah Lake strata. Older “Lake A” strata overlie subaerial unconformity U1.



Previous figure
Next figure
American Fork
Pleasant Grove
Lindon
Orem
Provo
UTAH LAKE
Saratoga Springs
Lakeside Mountains
km
0
2
N
40°20'
40°10'

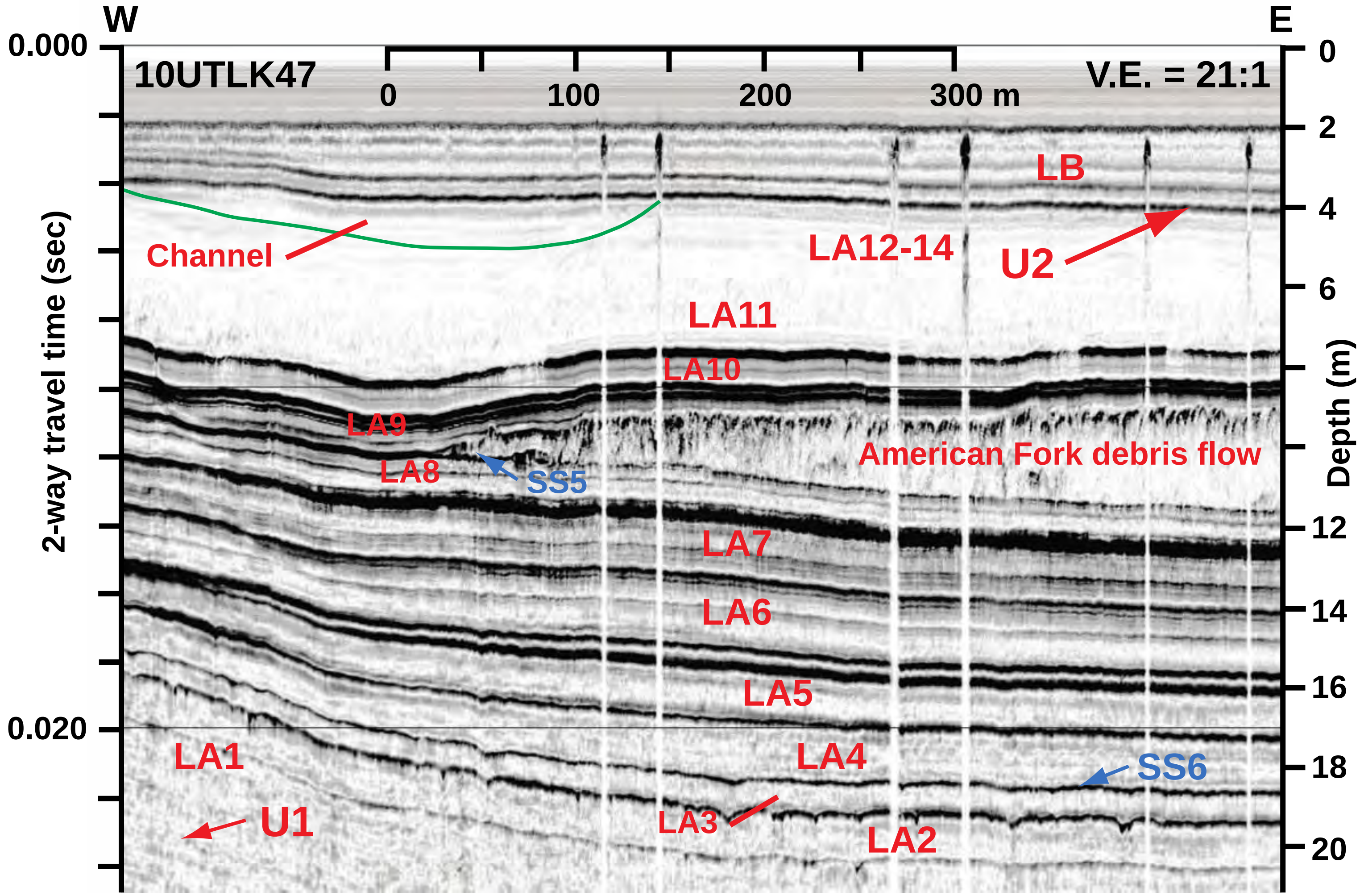
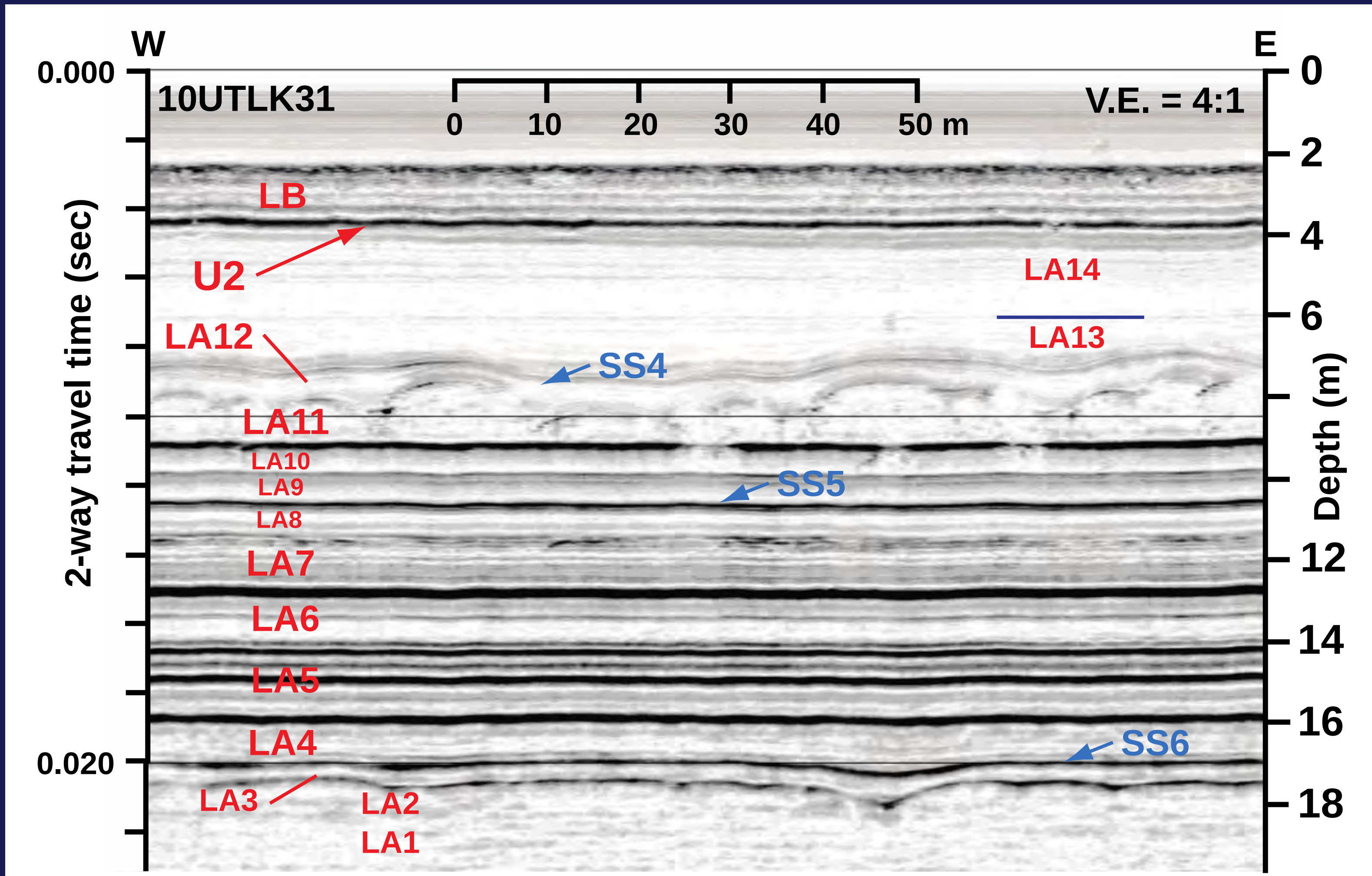


Figure 4. Chirp profile showing entire Lake A stratigraphic section between unconformities U1 & U2, and Lake B strata overlying U2. Note debris flow intercalated between LA8 & LA9 and fluvial channel below U2. SS5 & SS6 are earthquake event horizons

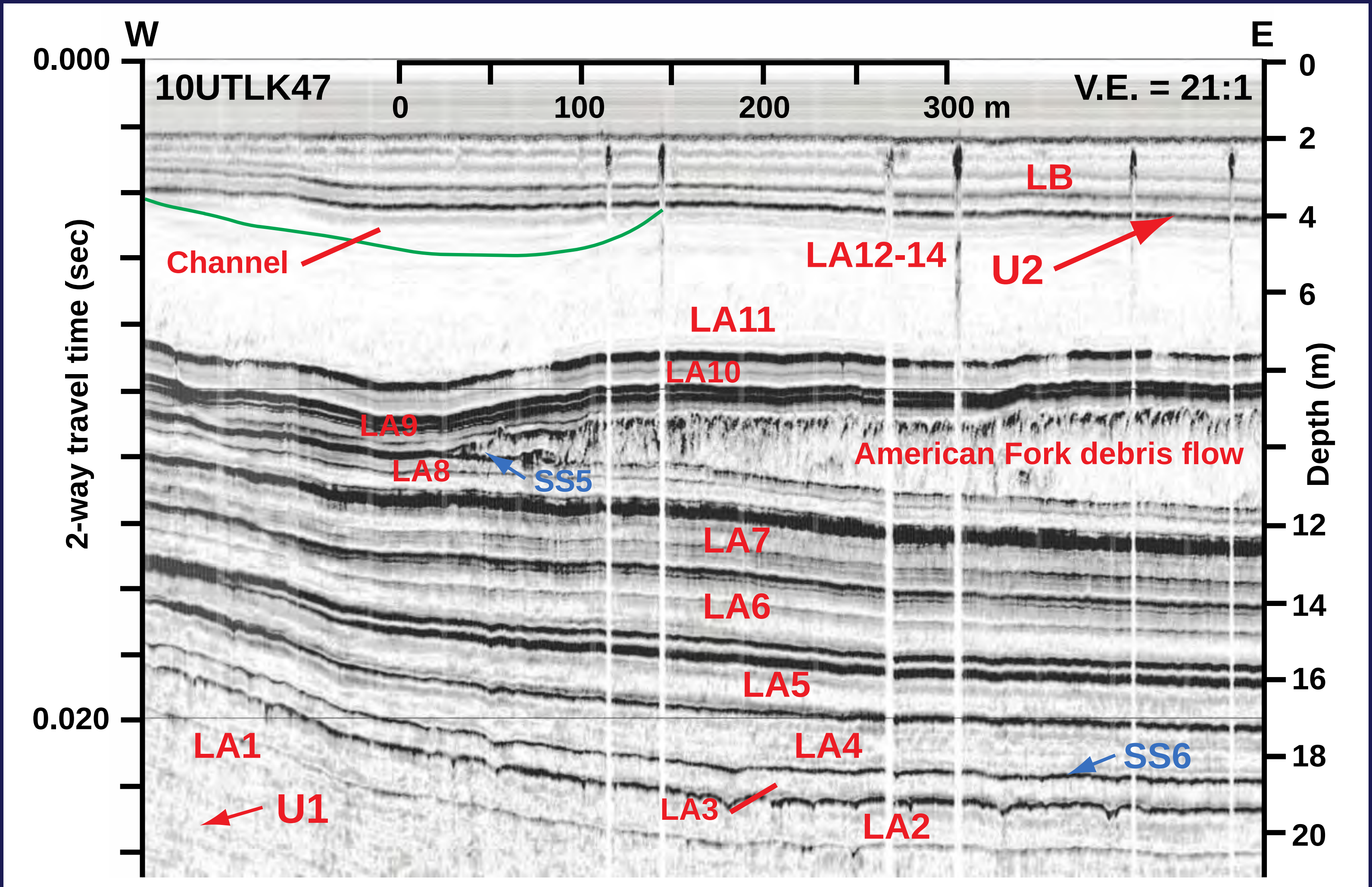
Lake A cycle contains 14 lacustrine beds with intercalated extrabasinal debris flows. Lake A cycle termination recorded by subaerial unconformity U2. Lake B cycle overlies U2, continues to present.

Seismites

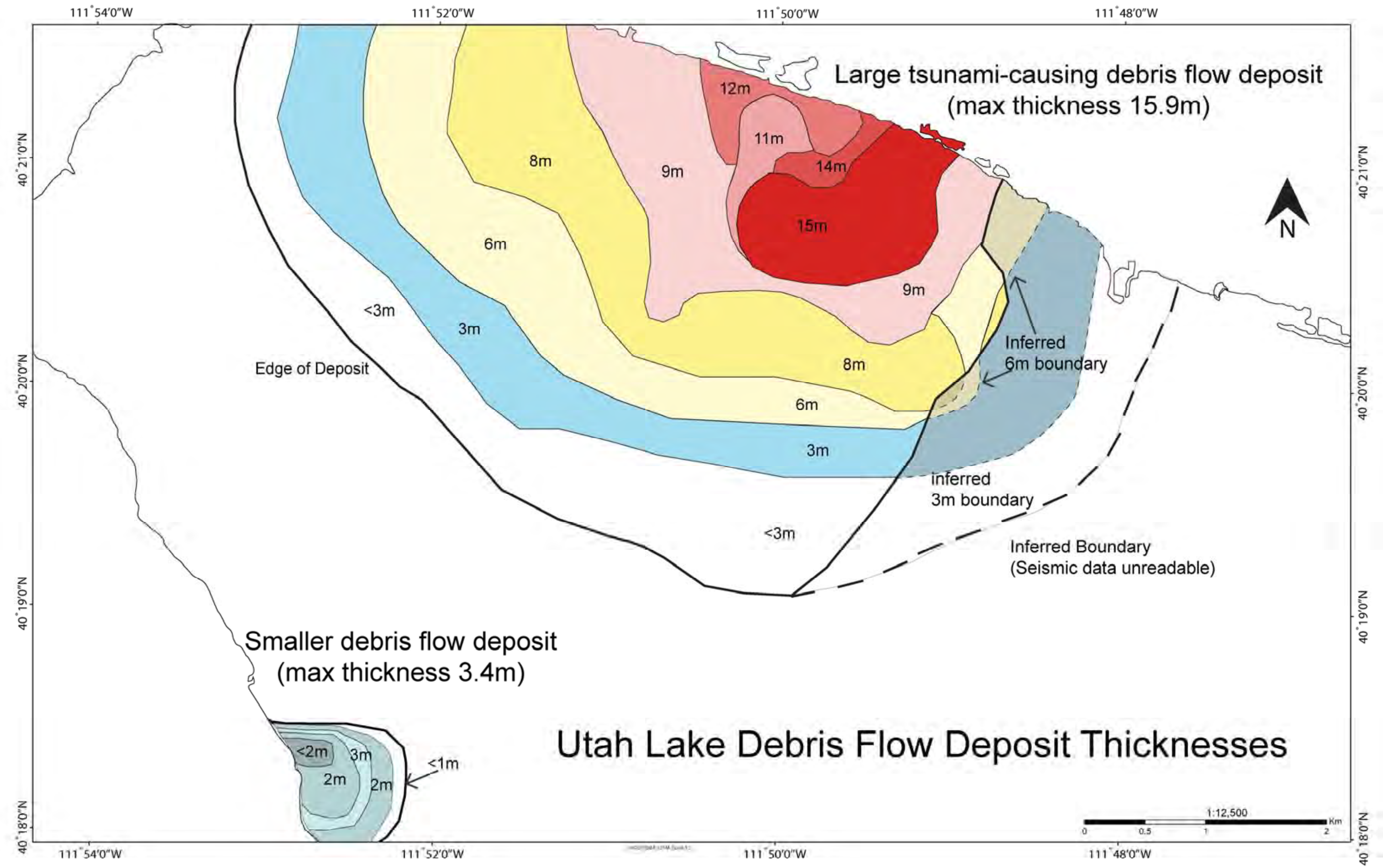


Lake A sequence includes two strata characterized by hummock-and-swale morphology – LA2 and LA11. Each is inferred to record partial or total liquefaction during a major earthquake on the Provo segment. Tops of LA11 and LA3 are event horizons.

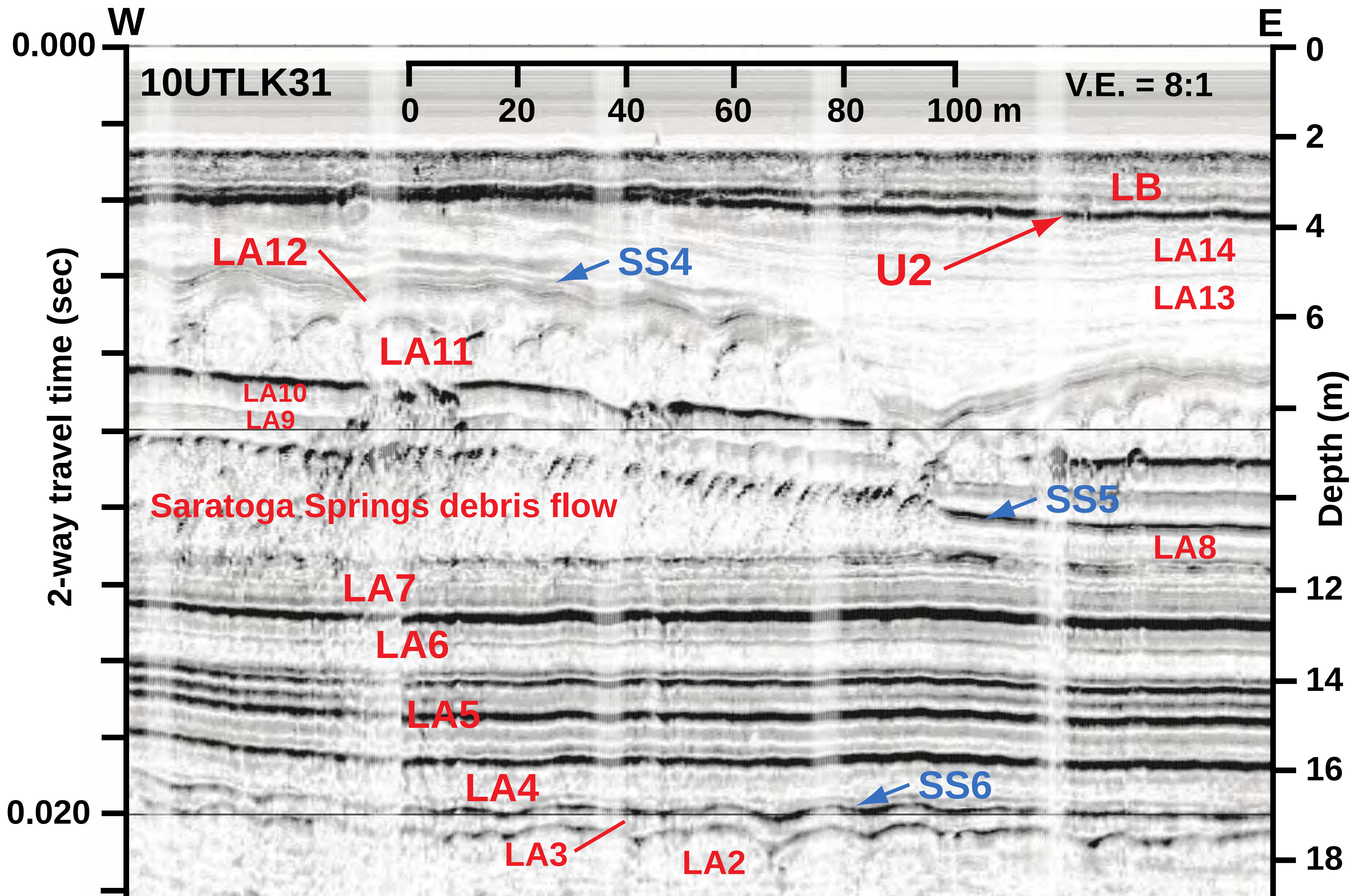
Debris Flows/Lateral Spreads



- Also intercalated within Lake A cycle strata are two extrabasinal debris flows and two intrabasinal gravity failures/lateral spreads.
  - American Fork debris flow overlies LA8, is overlain by LA9.

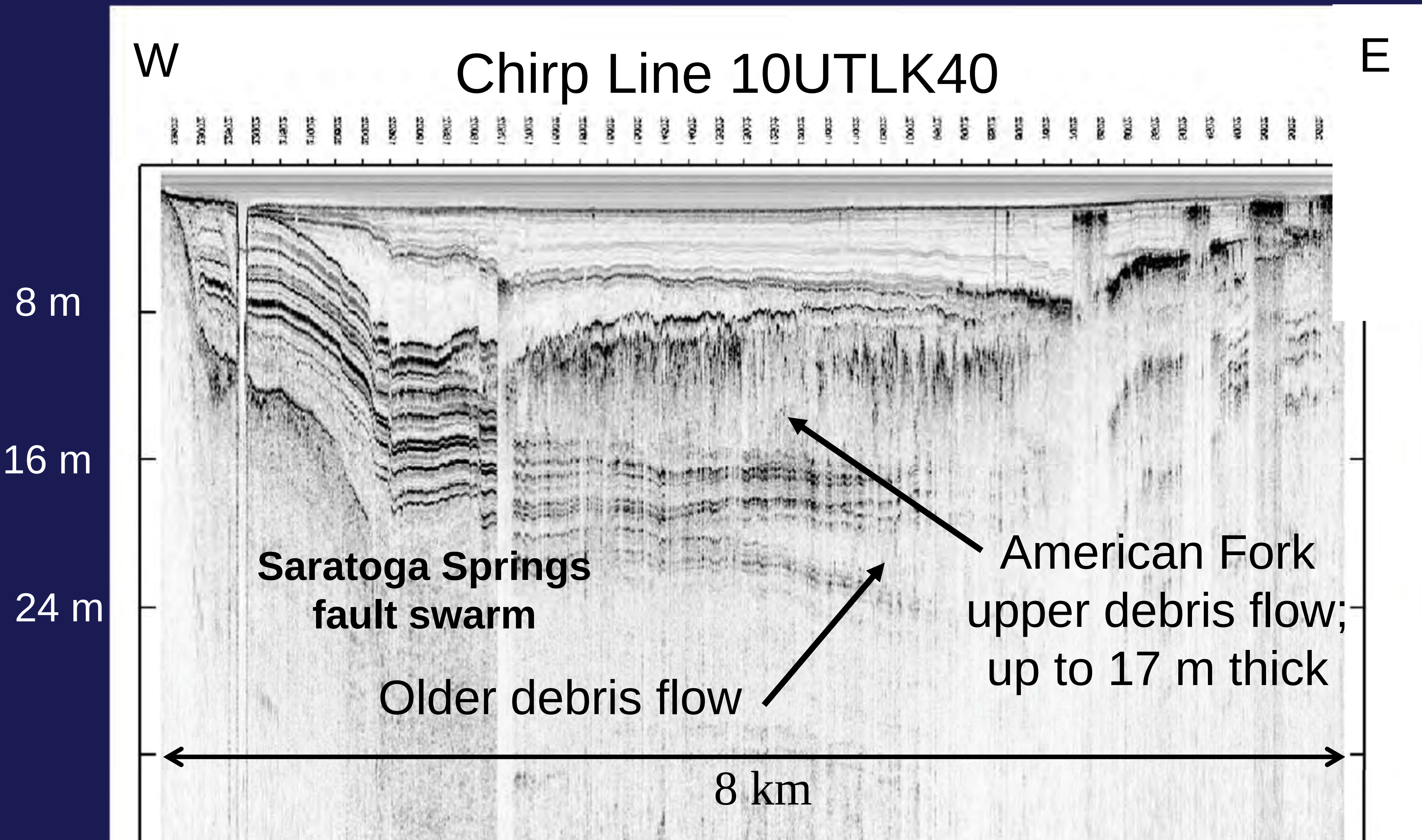


- Massive debris flows would likely have caused flooding around lake perimter, analogous to Hebgen Lake (1959)

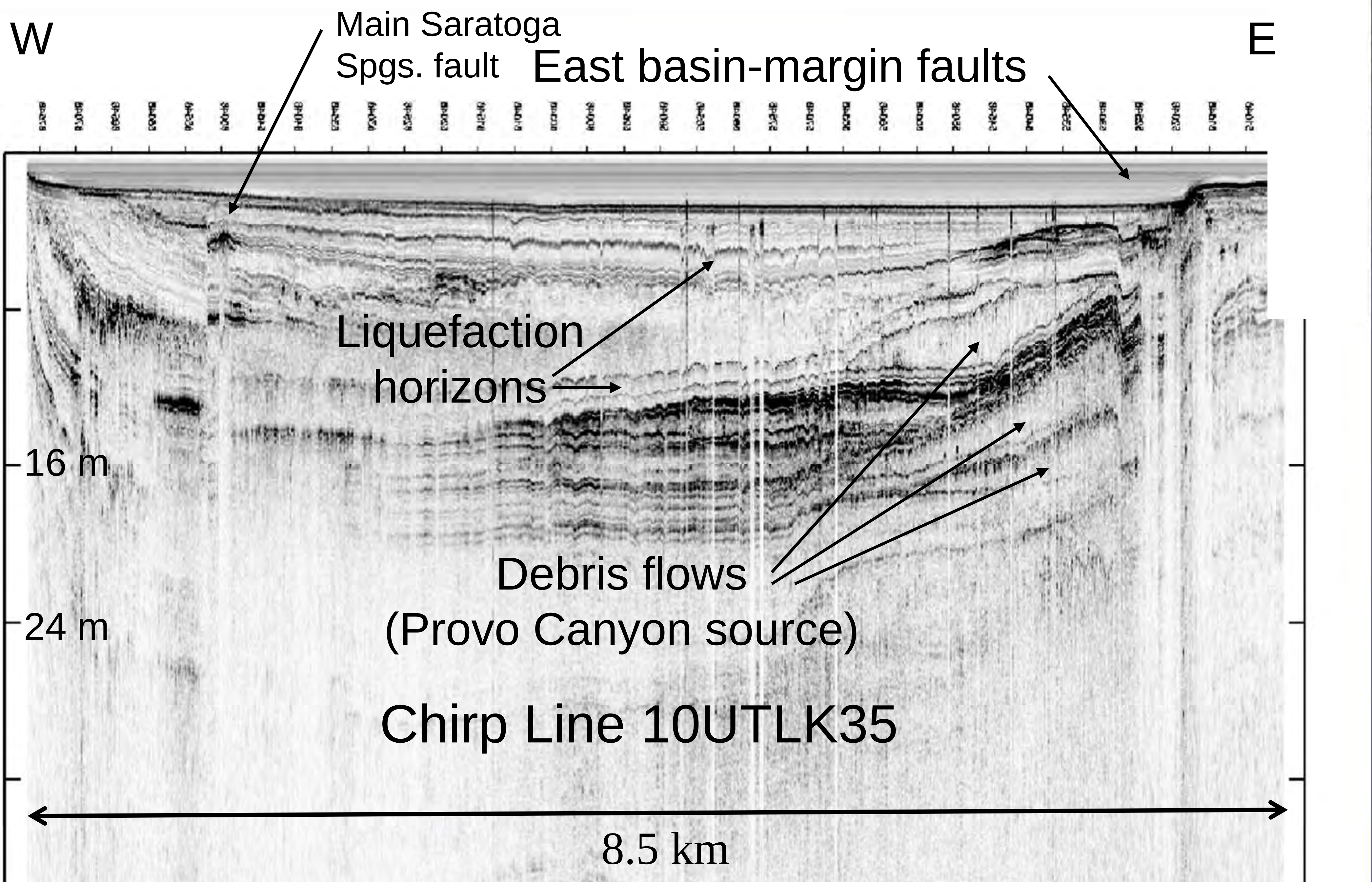


Saratoga Springs intrabasinal debris flow/lateral spread resulted from partial liquefaction/mass wasting of LA8. Note west-dipping shingling at toe of lateral spread

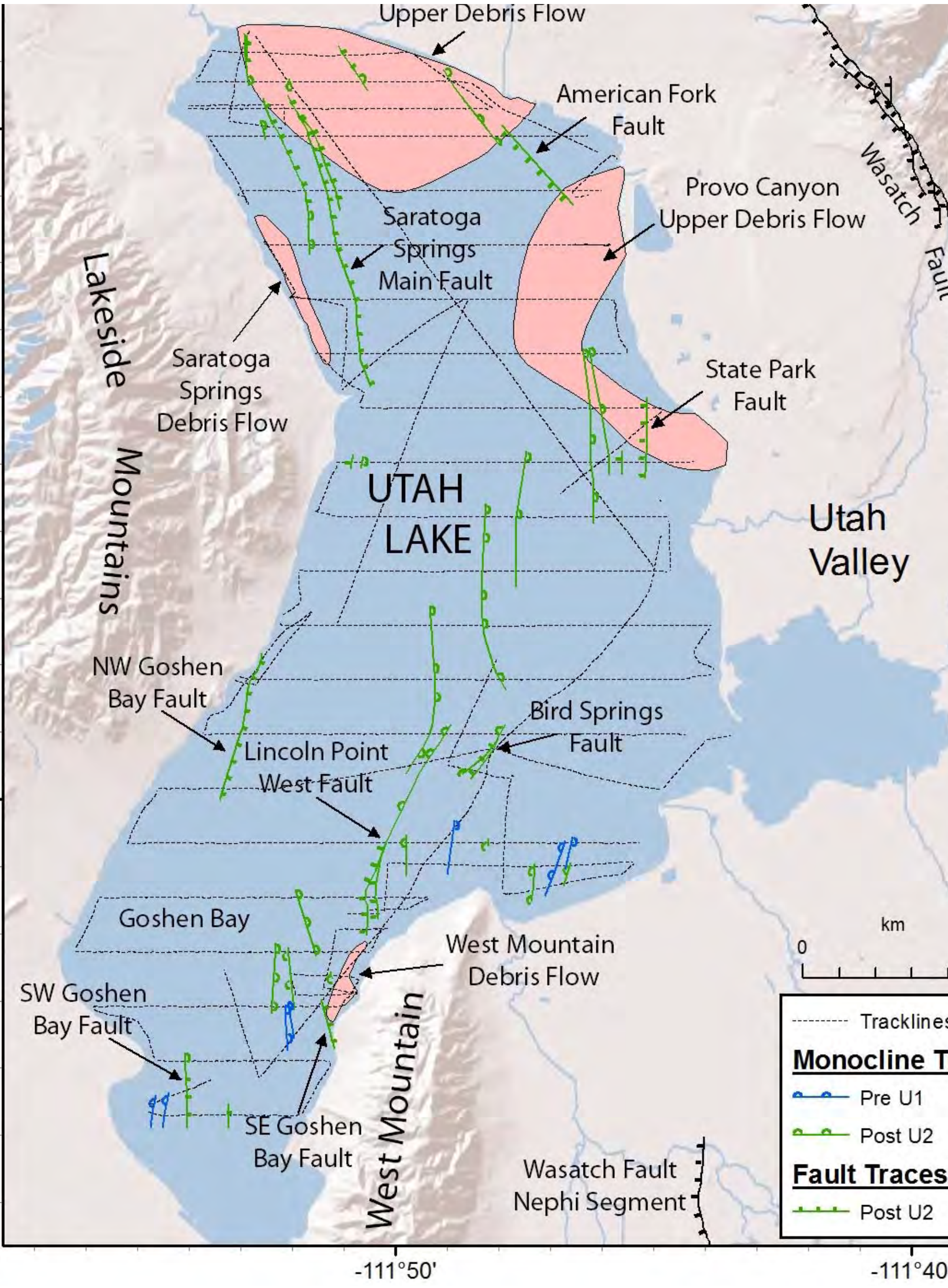
10UTLK40
Lehi
American Fork
Pleasant Grove
Lindon
Saratoga Springs
Aspen
Northridge
Orchard North
Vineyard
Geneva
Orchard South
Orem
Sunset Heights
Scera Park South
Hillcrest
Powell Slough Waterfowl Management Area
Lake View North
Joaquin
Fort Utah
Provo
Franklin
Provo Bay
Sunset
Utah Lake
W Cedar Fort Rd
W Main St
Pioneer Crossing
Veterans Memorial Hwy
NW State St
E State Rd
W State Rd
N State St
S State St
N 10800 W
N Redwood Rd
Westlake Rd
W 800 N
E 800 N
W 400 N
N 1000 W
N 100 E
Geneva Rd
N University Ave
S University Ave
Provo Canyon Rd
N 500 W
Traffic



Debris flows into Utah Lake from American Fork and Provo Canyons have occurred repeatedly in Holocene time.

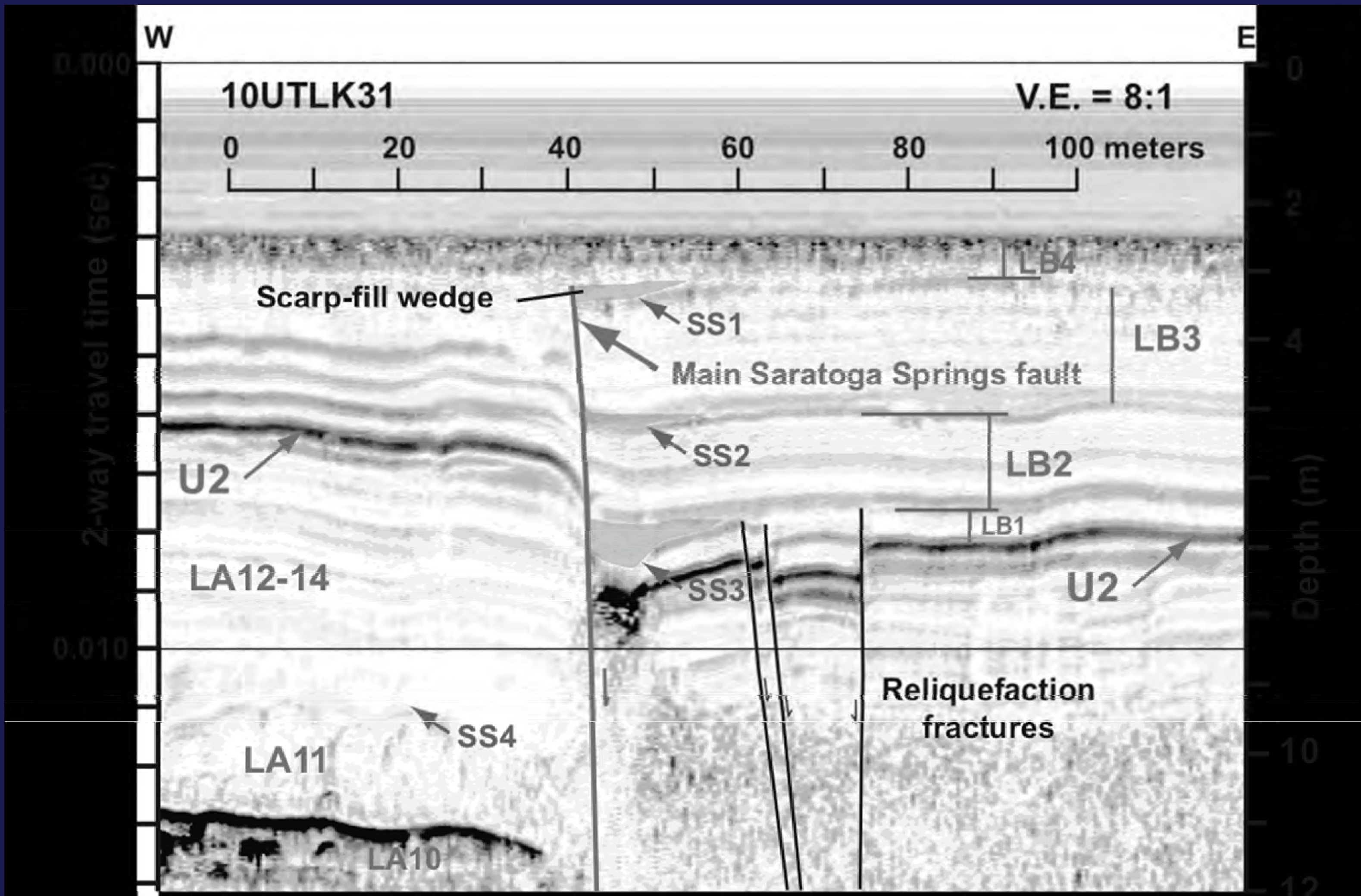


Multiple debris flows in east central Utah Lake basin west of Orem. Provo Canyon is probable source.

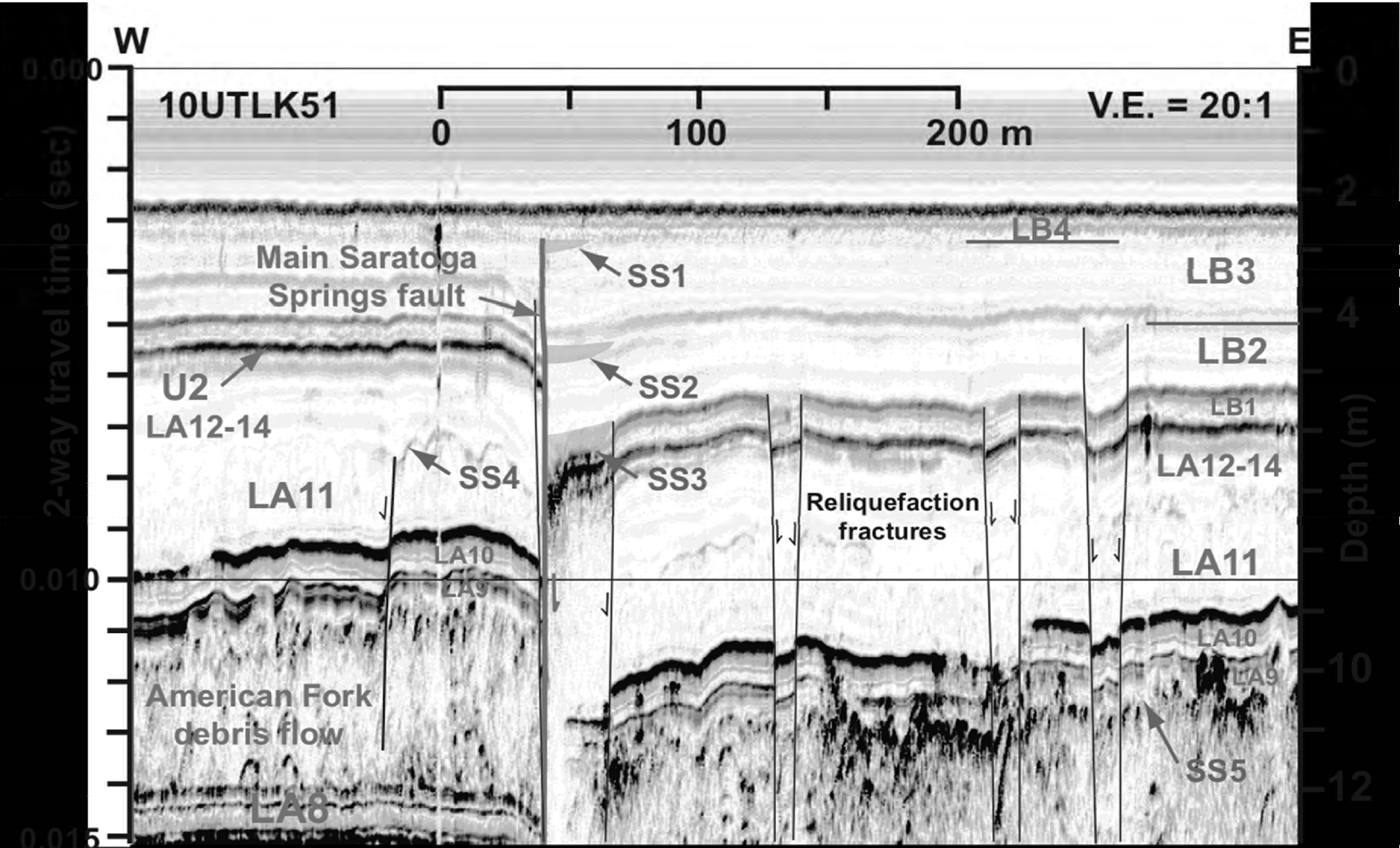


- American Fork (>15 m thick) and Provo Canyon (>8 m thick) debris flows are extrabasinal, flowed across Utah Valley into Utah Lake.
- Saratoga Springs and West Mountain debris flows are intrabasinal mass failures/lateral spreads.
- All four are the same age! Extrabasinal flows overlie LA8, are draped by LA9. Intrabasinal failures result from liquefaction of LA8.
- Upper debris flows are likely an EQ event horizon.

Earthquake Event Horizons

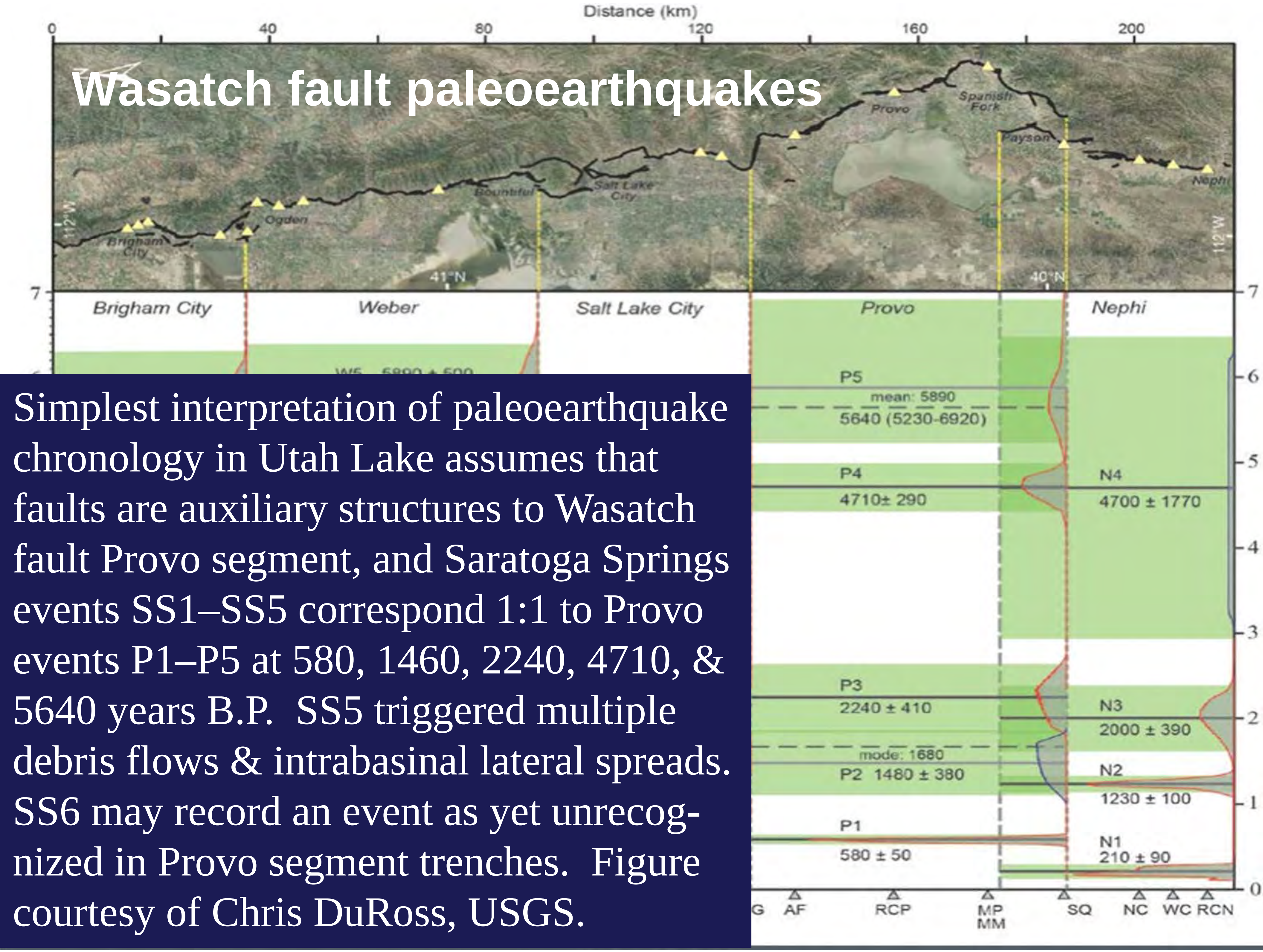


Earthquake event horizons in Utah Lake are defined by scarp-fill wedges, stratigraphically limited faults and auxiliary faults, reliquefaction fractures and sags, seismites, and debris flows.



“Scarp-fill wedges” and reliquefaction fractures define event horizons SS1, SS2, & SS3, with Lake B sequence. SS4 and SS6 are seismite strata tops, and SS5 is defined by four mass failures.

Wasatch fault paleoearthquakes



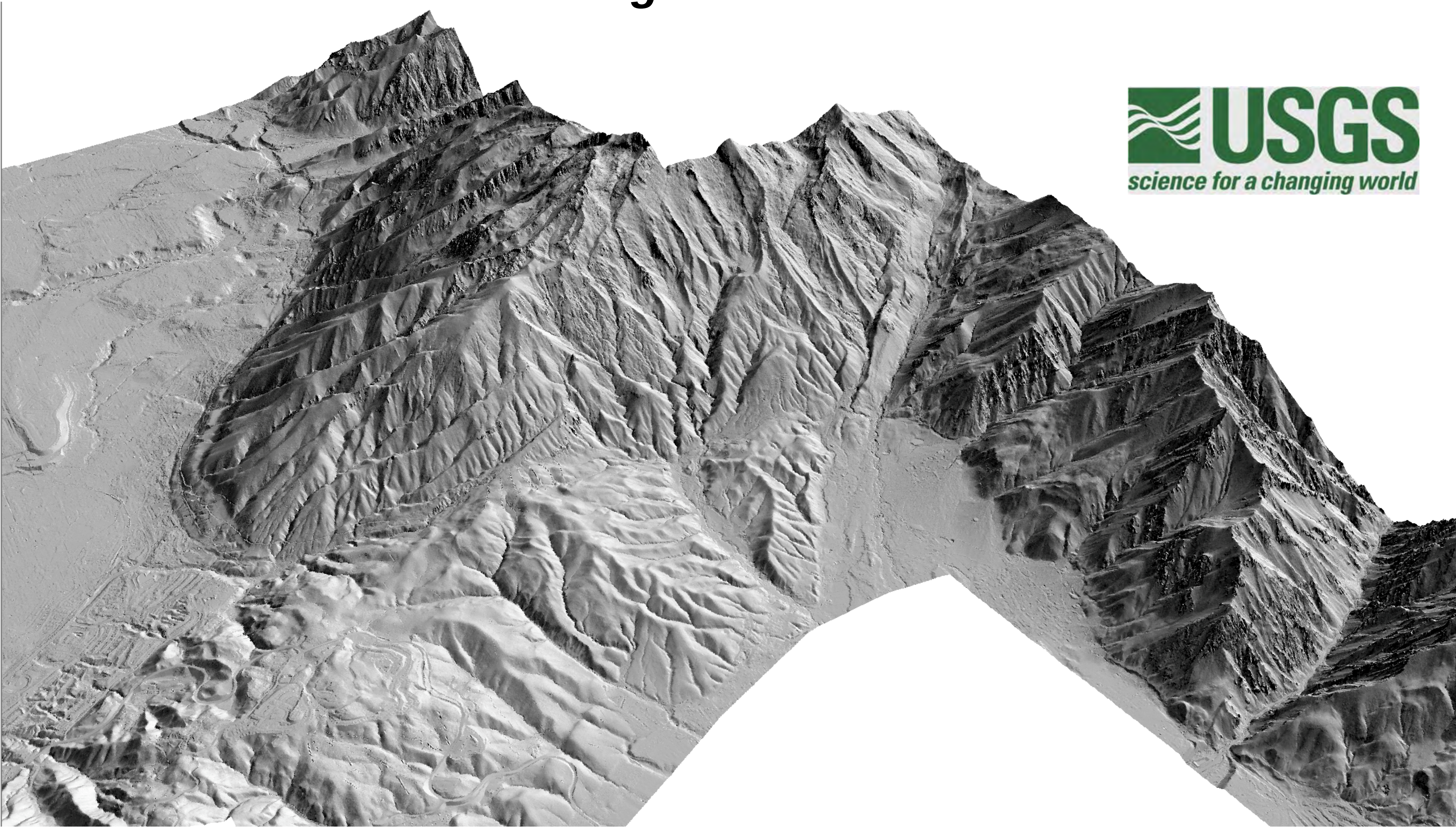
Simplest interpretation of paleoearthquake chronology in Utah Lake assumes that faults are auxiliary structures to Wasatch fault Provo segment, and Saratoga Springs events SS1–SS5 correspond 1:1 to Provo events P1–P5 at 580, 1460, 2240, 4710, & 5640 years B.P. SS5 triggered multiple debris flows & intrabasinal lateral spreads. SS6 may record an event as yet unrecognized in Provo segment trenches. Figure courtesy of Chris DuRoss, USGS.


GLAD-800 drill rig anchored west of Antelope Island, Great Salt Lake
Next step: Drill and date event horizons.

Conclusions

- Most Utah Lake faults are probably auxiliary to Wasatch fault Provo segment, analogous to West Valley faults in SL Valley.
- Lincoln Point West and Saratoga Springs Main fault have cumulative post-U1 NVTDs of ~5 meters and lengths > 6 km.
- Some 20 additional normal faults & monoclines are shorter & have post-U1 NVTDs ≤ 1 meter.
- Large Provo segment earthquakes have repeatedly triggered massive debris flows from American Fork and Provo Canyons.
- Two Provo segment earthquakes have caused wholesale liquefaction of shallow Utah Lake lacustrine strata.
- Event horizons SS1–SS6 in Utah Lake may provide an independent record of large Provo segment paleoearthquakes.

Spatial and Temporal Fault Offset Patterns Derived From Lidar Along the Central Wasatch Fault Zone



Scott Bennett, Ryan Gold, Christopher DuRoss, Richard Briggs, Stephen Personius

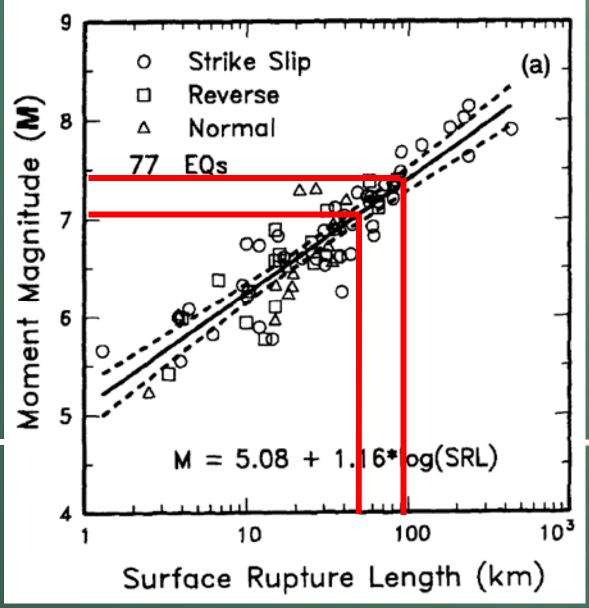
UQFPWG ***February 10, 2015*** ***Salt Lake City, UT***

Wasatch Fault Zone

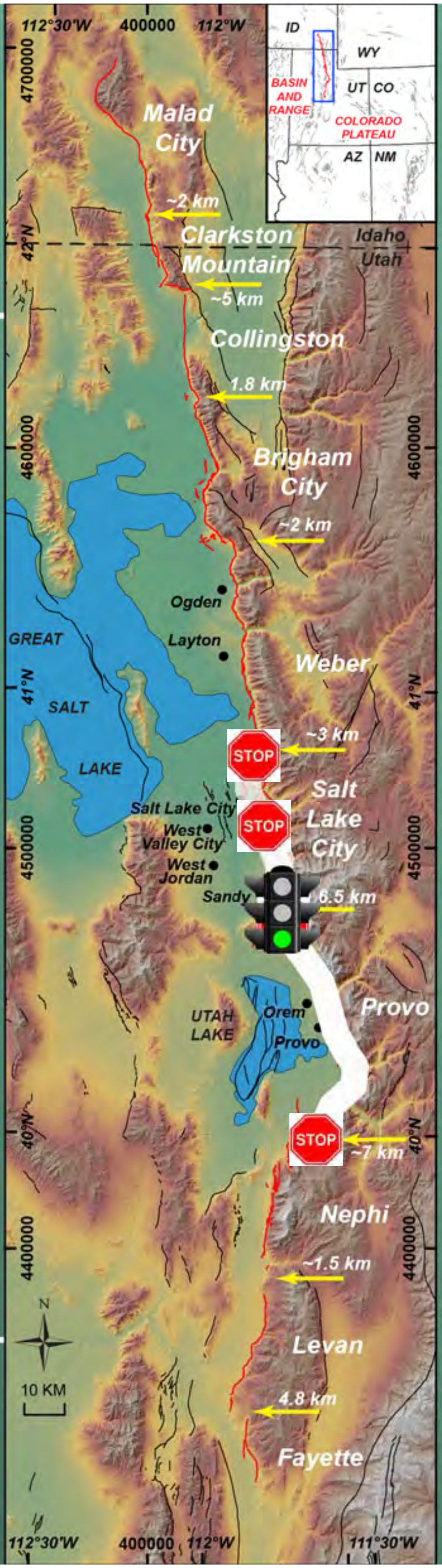
- 1st-order structure at eastern edge of Basin and Range province
- W-dipping normal fault zone
- 10 structural segments
  - fault step-over (relay ramp)
  - transfer structure (strike-slip fault)
  - abrupt changes in fault scarp morphology
  - similar earthquake chronologies from adjacent paleoseismic trenches
  - persistent earthquake source
- central segments are Holocene-active

Scientific Questions

- Are surface-rupturing earthquakes restricted to one fault segment or do they involve multiple fault segments?
- If the latter occurs, how frequent?
- Do multi-segment ruptures tend to break full or partial segments?
- How do these findings impact seismic hazard analysis along the Wasatch Front urban corridor?



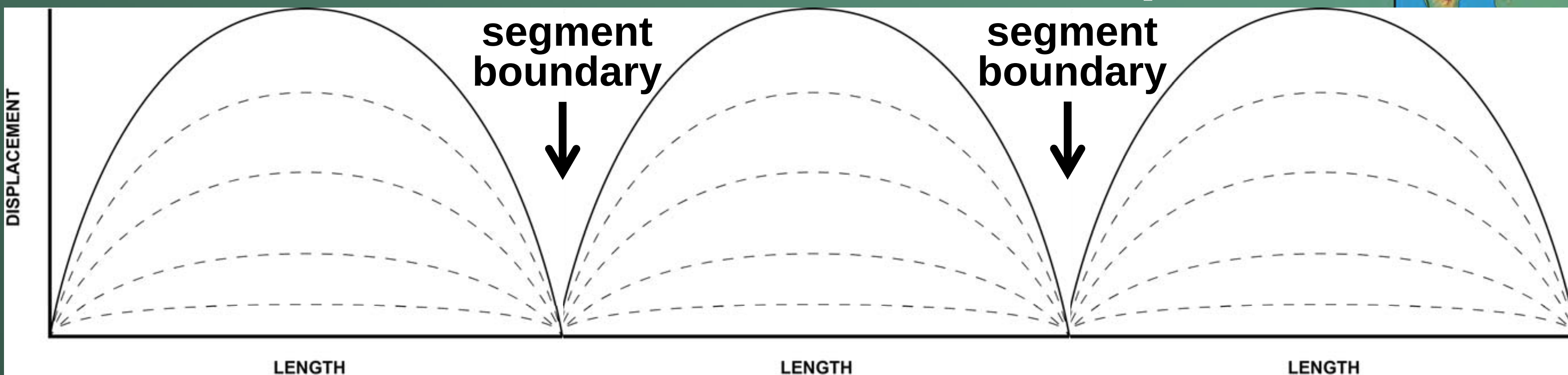
Wells and Coppersmith (1984)



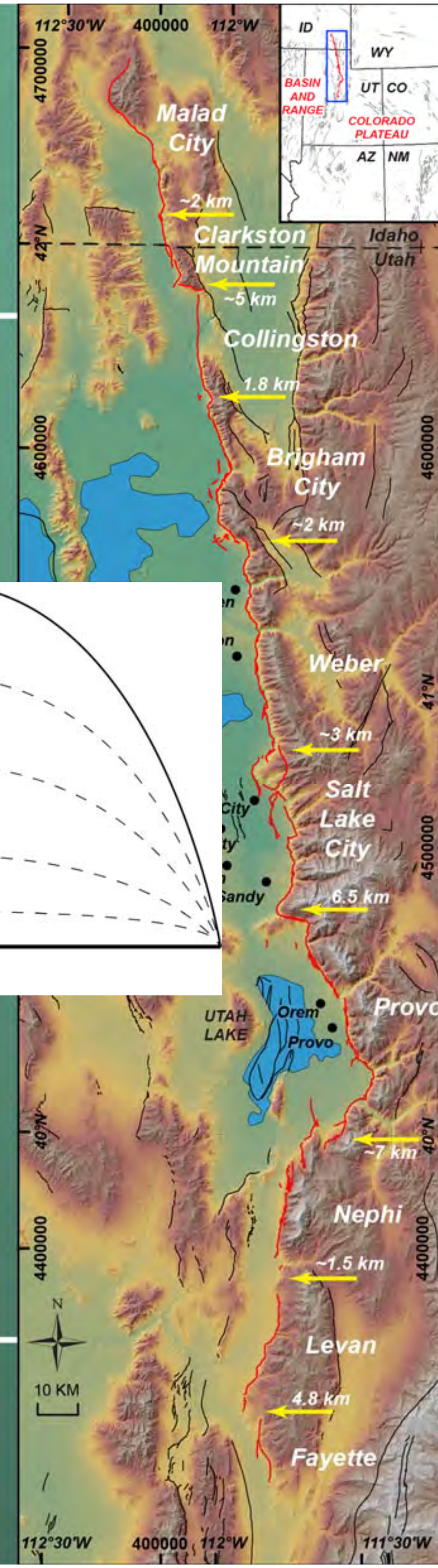
USGS

Scientific Questions

- What signature do single-segment ruptures with persistent rupture terminations leave in the landscape?



- What would the Wasatch Front look like if all earthquakes were single-segment ruptures?

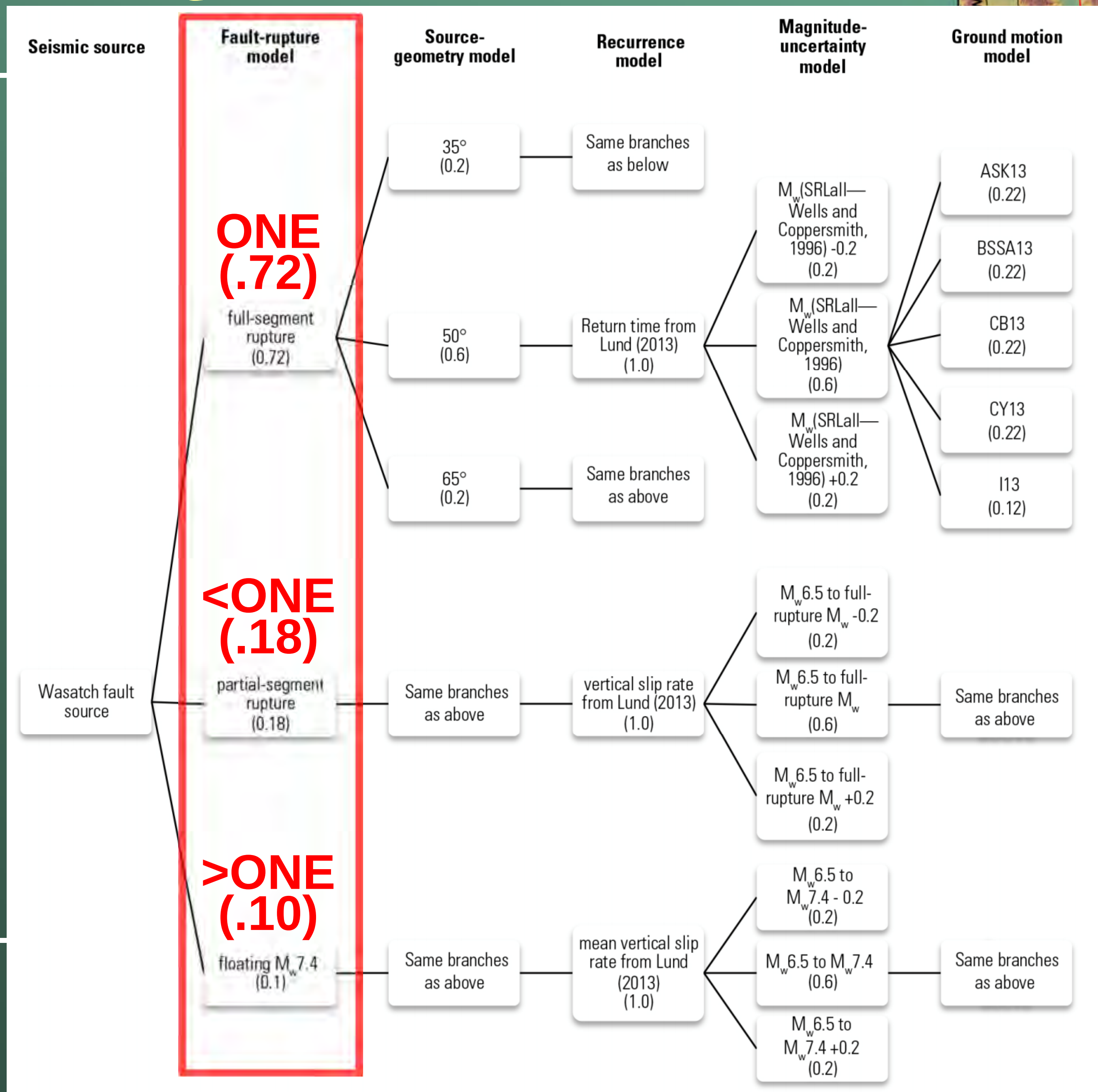


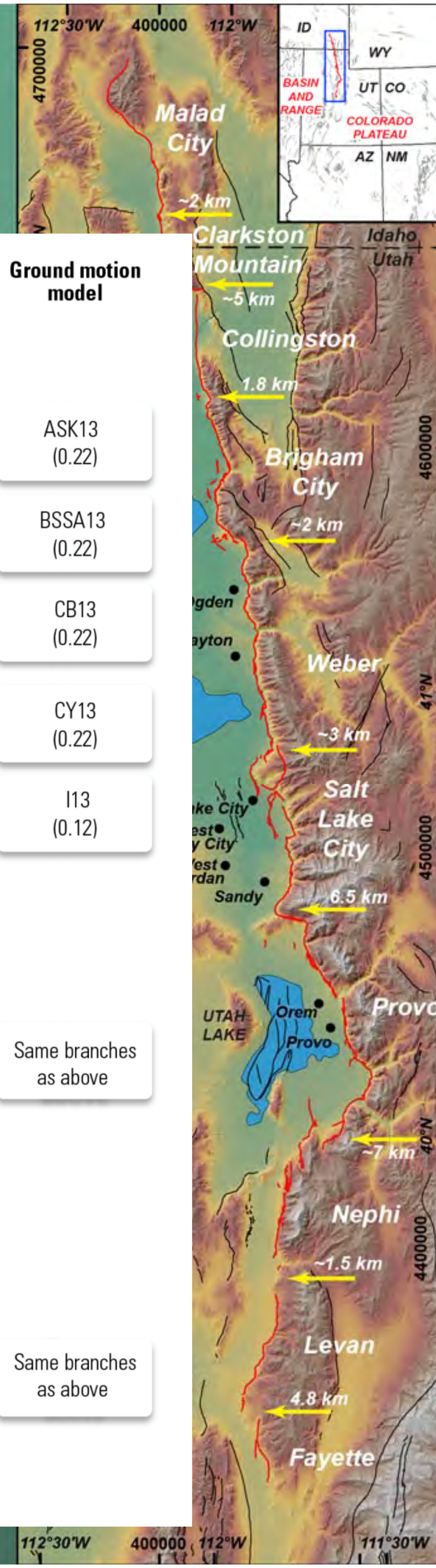
USGS

Scientific Questions

What weight should multi-segment ruptures be given in the NHSM?

Petersen et al. (2014)

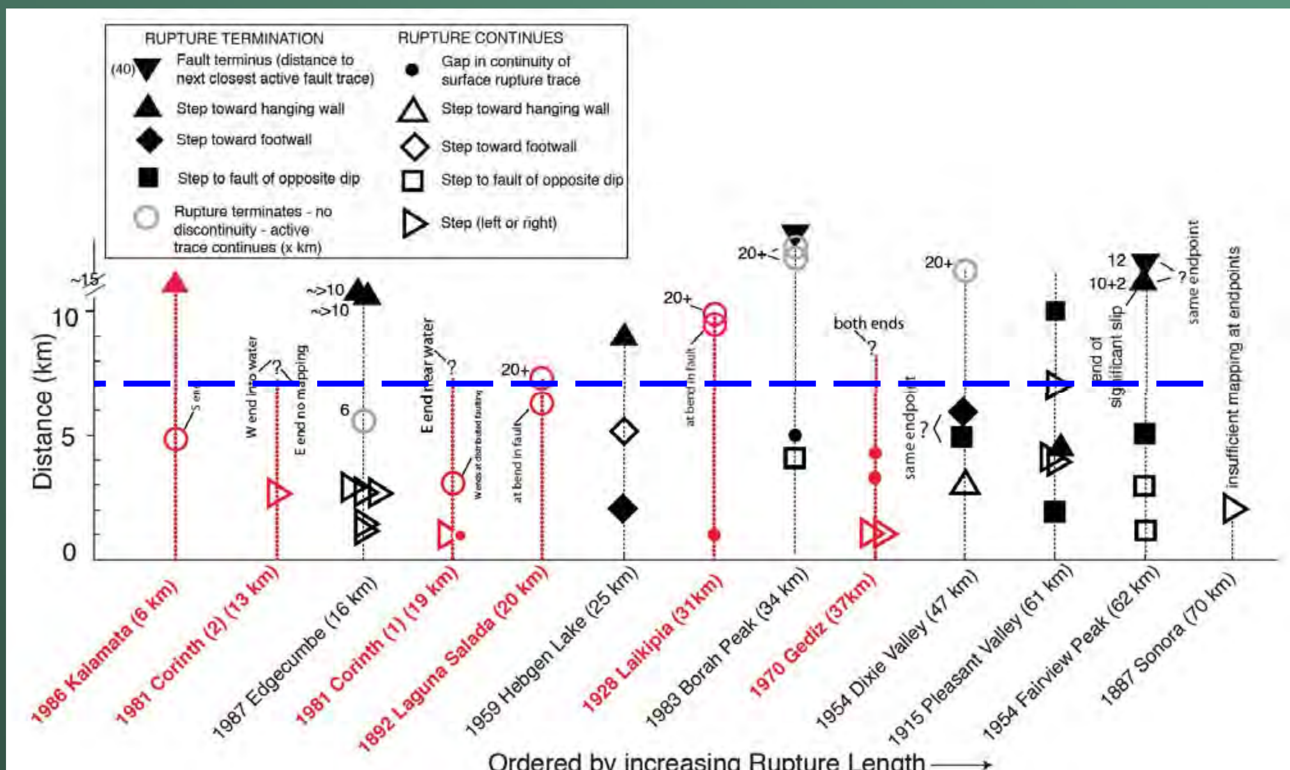




≋USGS

Scientific Questions

- **All WFZ stepover widths are within empirical limit (~7km) of successful rupture continuation**



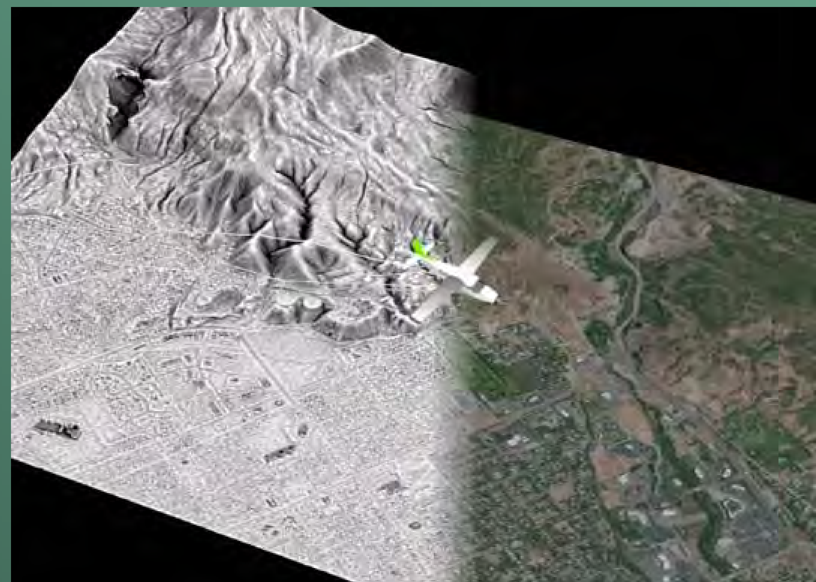
Morelan, Wesnousky, & Biasi (2012)

USGS

Methods

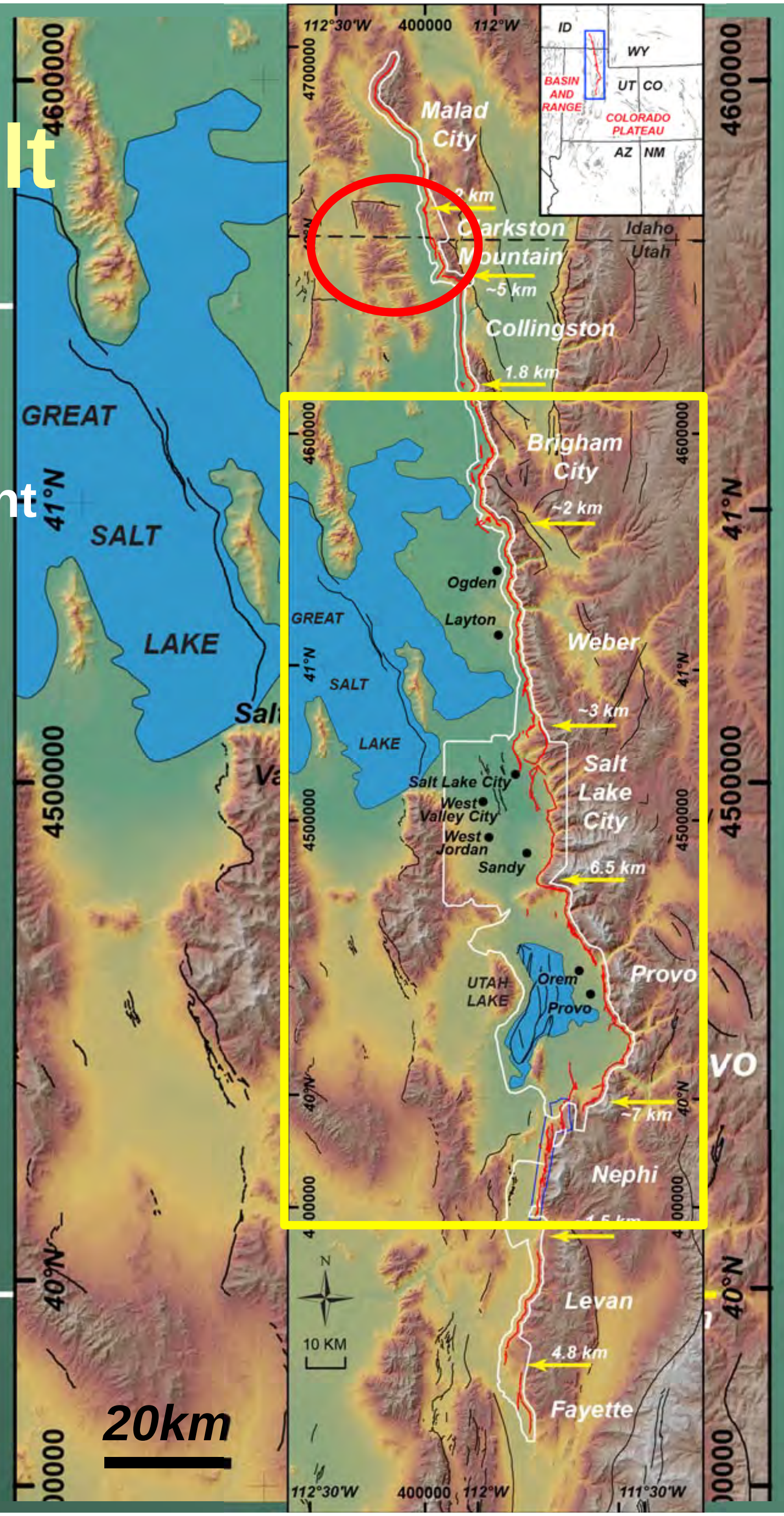
Acquire and examine airborne LiDAR

- map fault scarp patterns
- extract slip-rate data



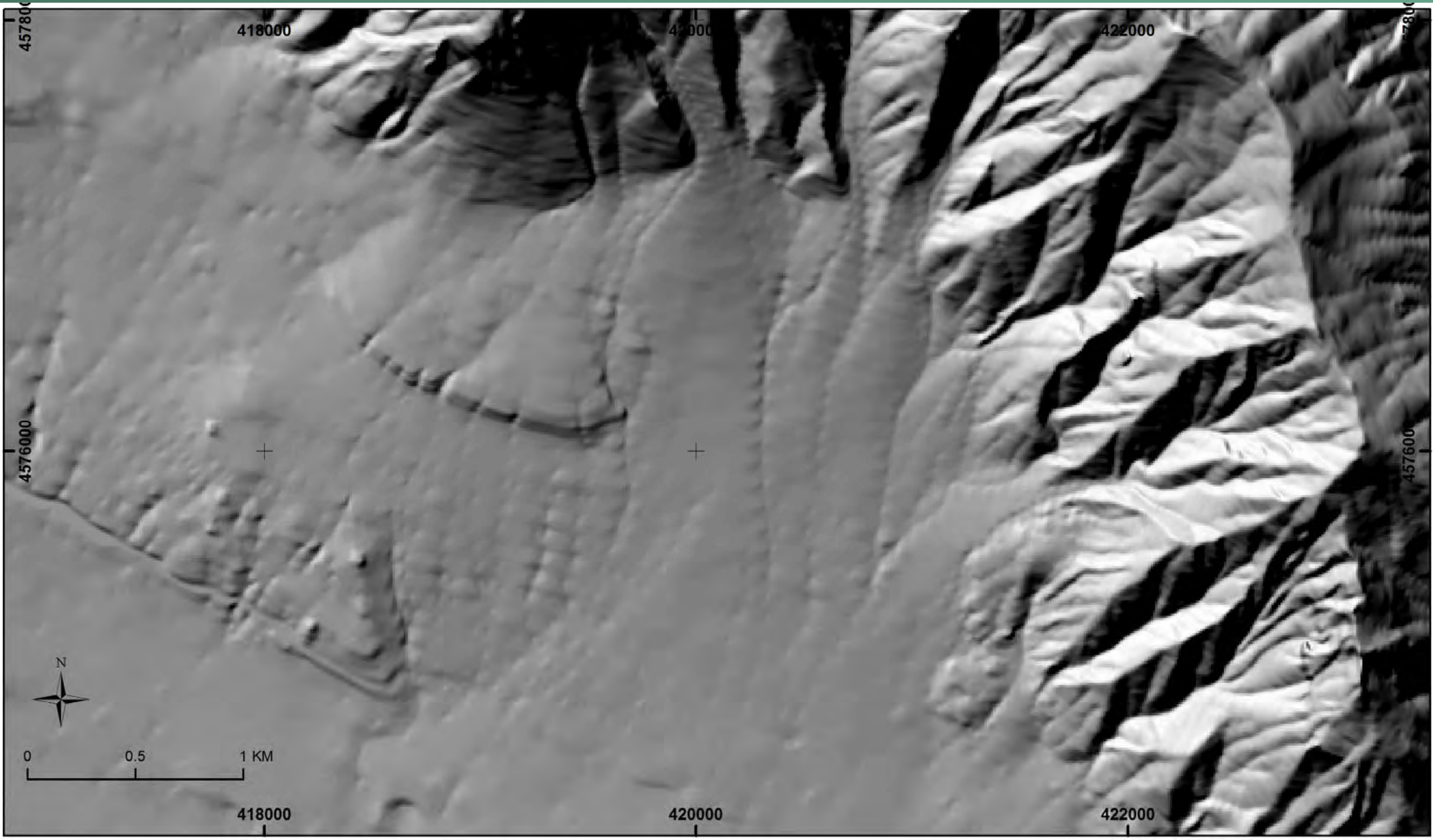
New LiDAR for Wasatch Fault

- Collaborative Acquisition
  - USGS, UGS, FEMA, SLC County,
    Utah Division of Emergency Management
- QL1: 8 pts/m^2
- 0.5 m/pixel bare-earth DEM
- 350 km long
- 3,684 km^2
- 1,422 mi^2
- 2.5 km wide fault buffer
- Salt Lake and Utah Valleys



Wasatch Fault LiDAR analysis

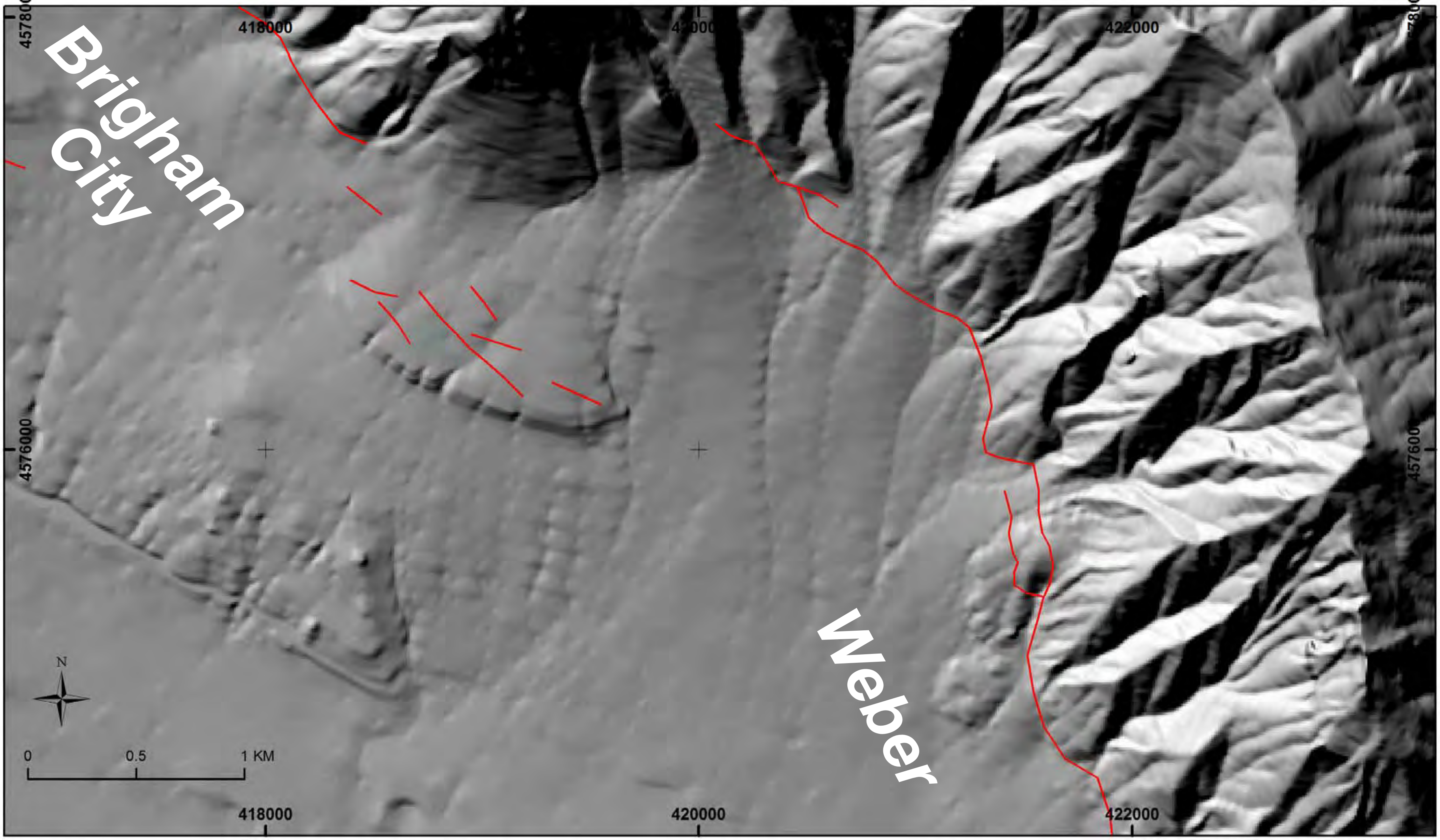
Brigham City-Weber segment boundary



10m NED

Wasatch Fault LiDAR analysis

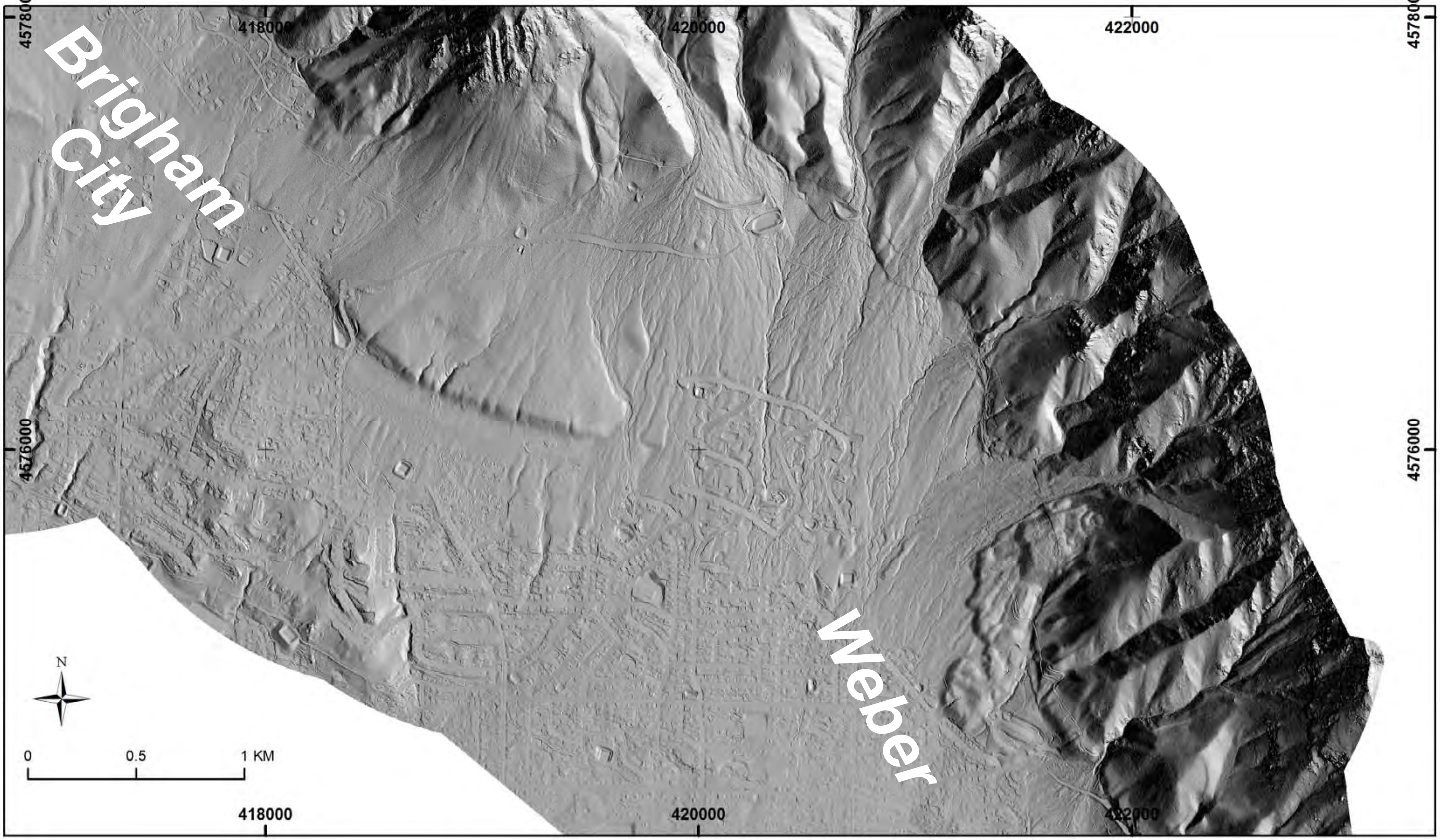
Brigham City-Weber segment boundary



10m NED

Wasatch Fault LiDAR analysis

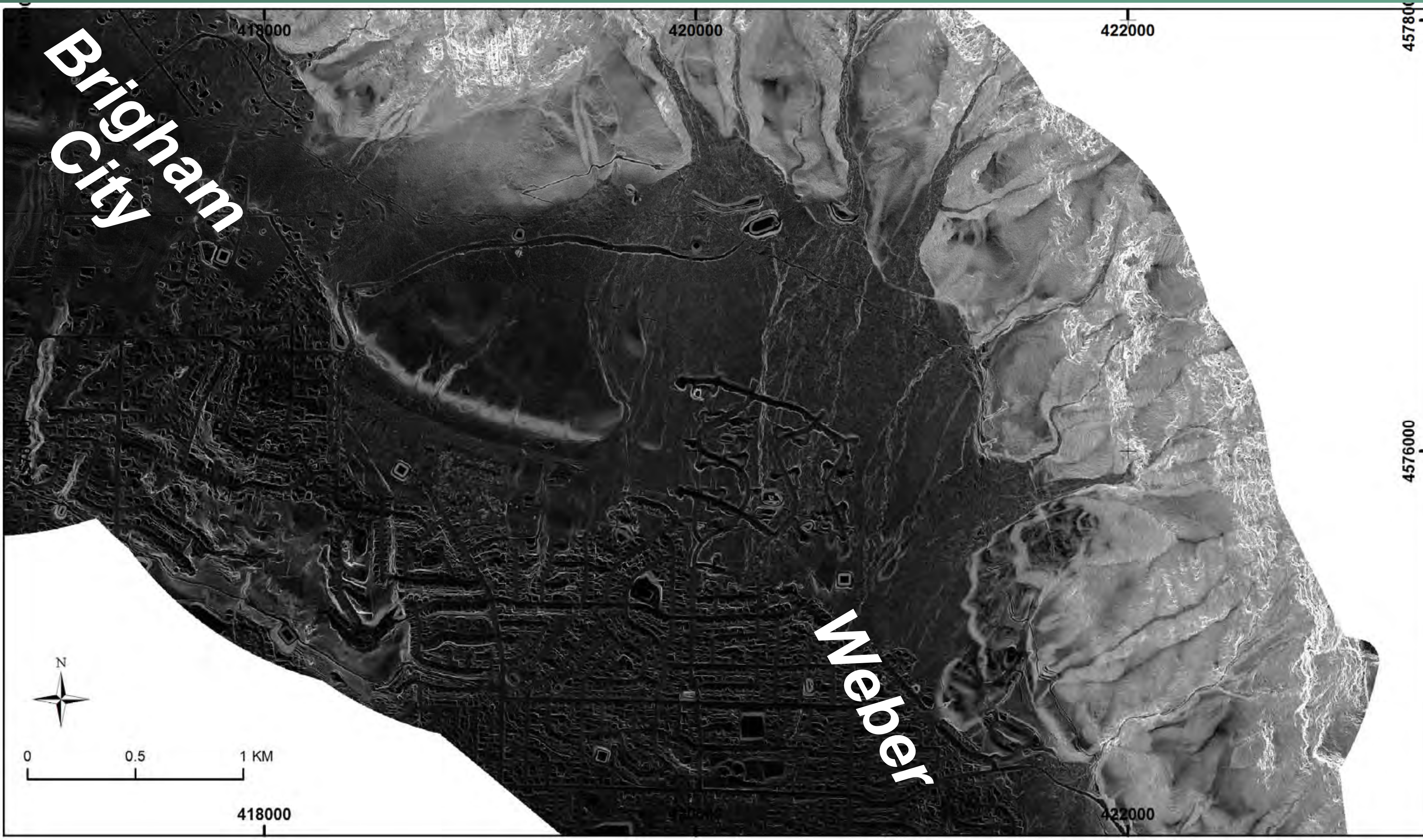
Brigham City-Weber segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

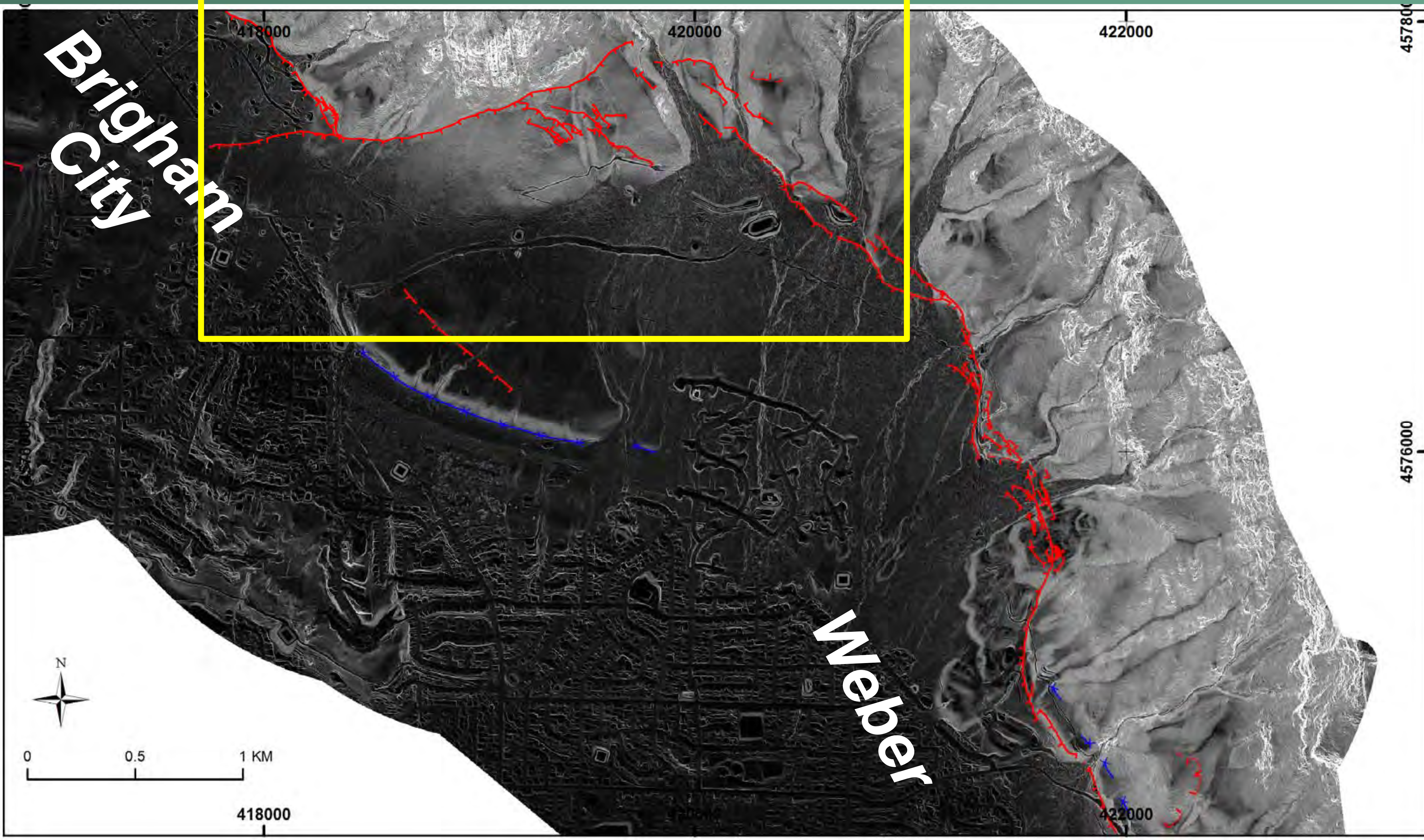
Brigham City-Weber segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

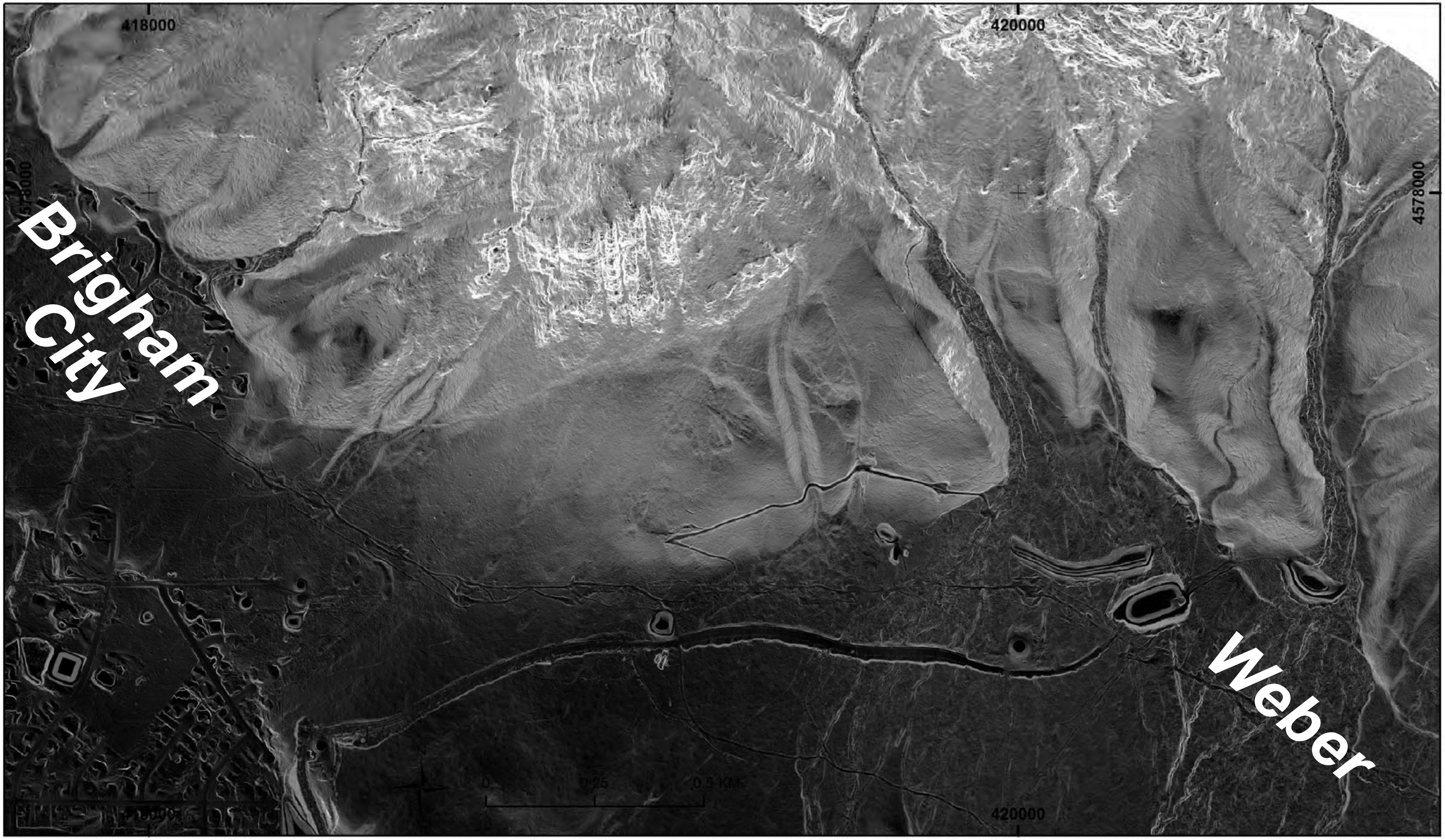
Brigham City-Weber segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

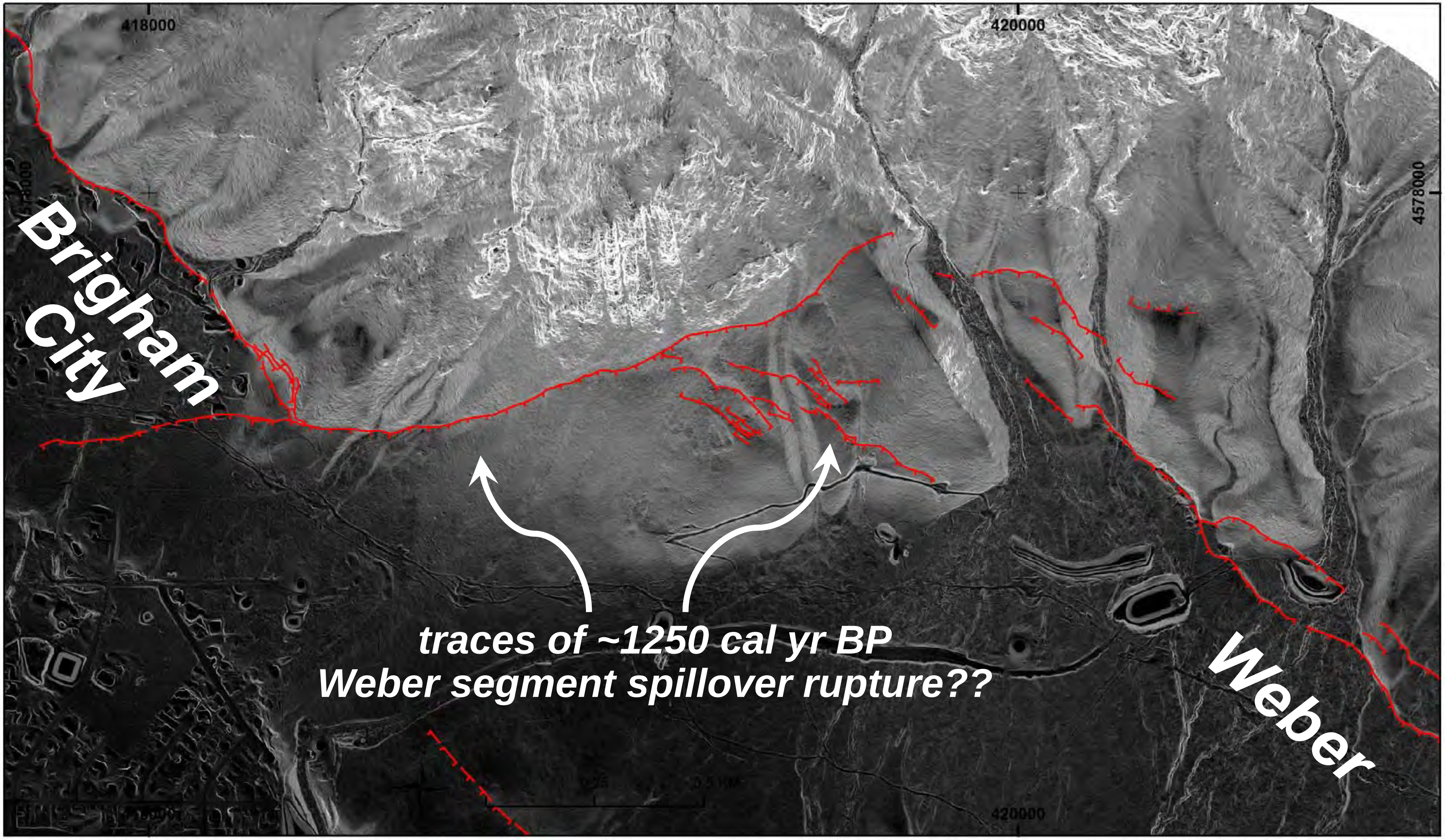
Brigham City-Weber segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

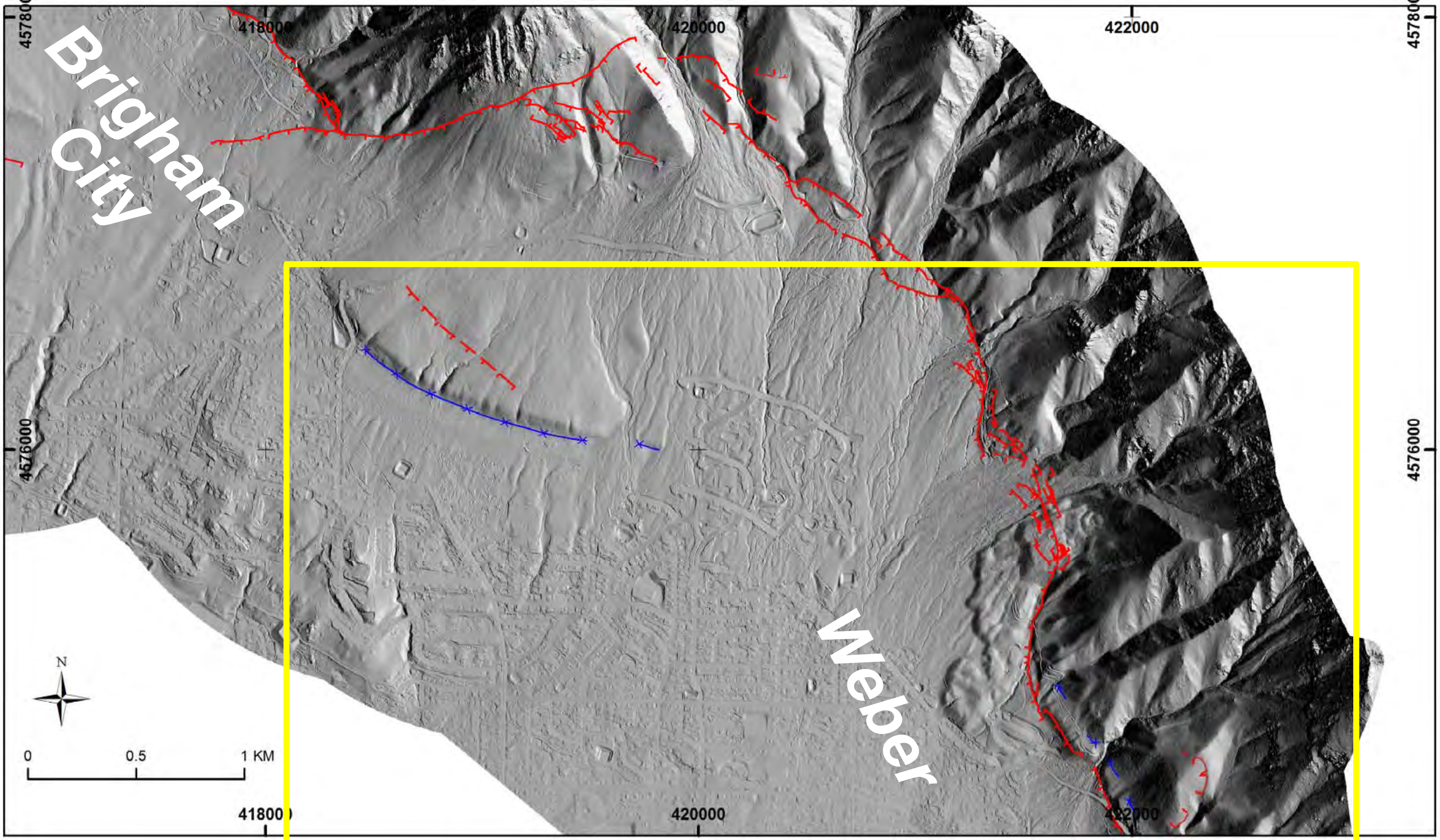
Brigham City-Weber segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

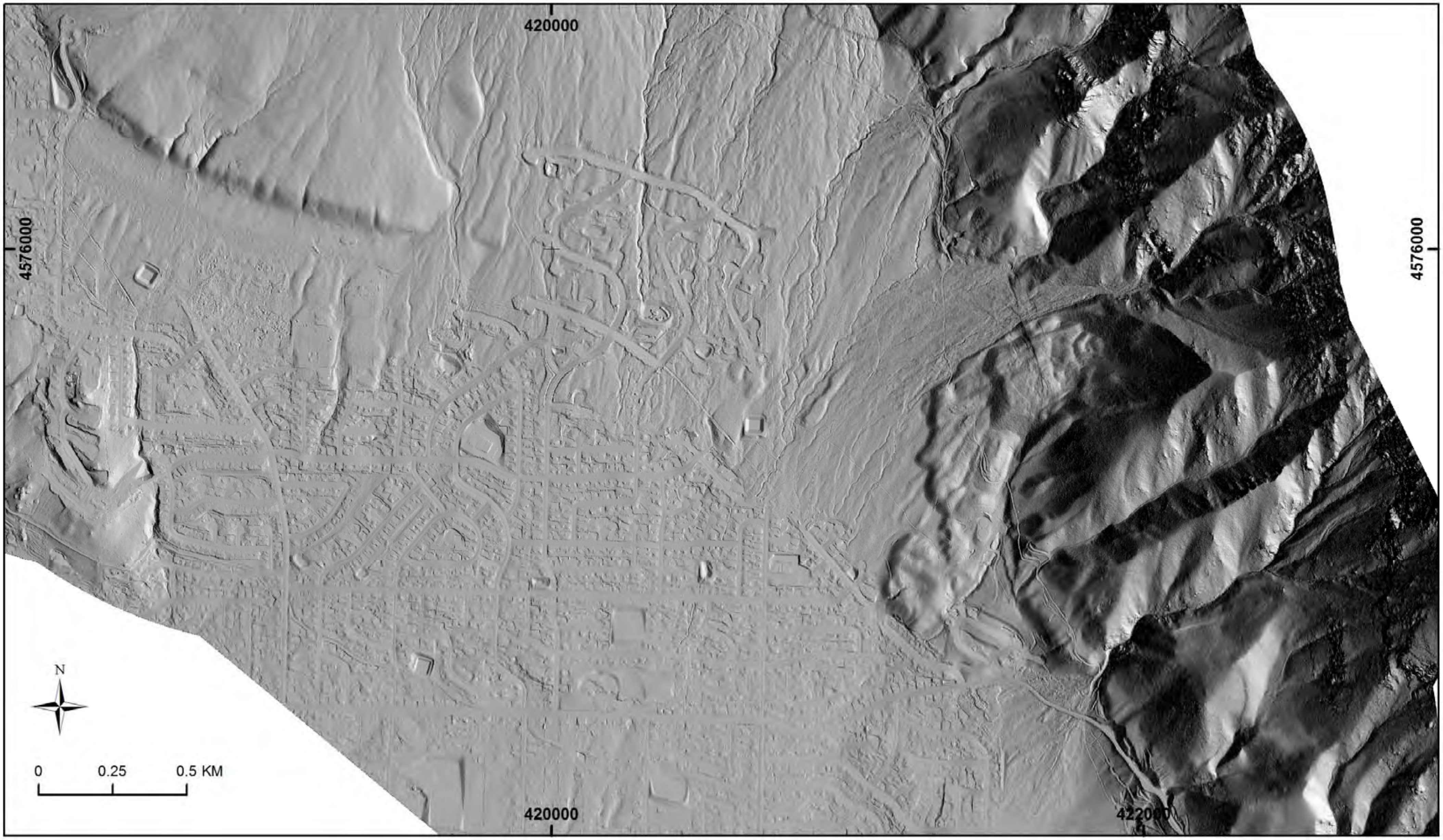
Brigham City-Weber segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

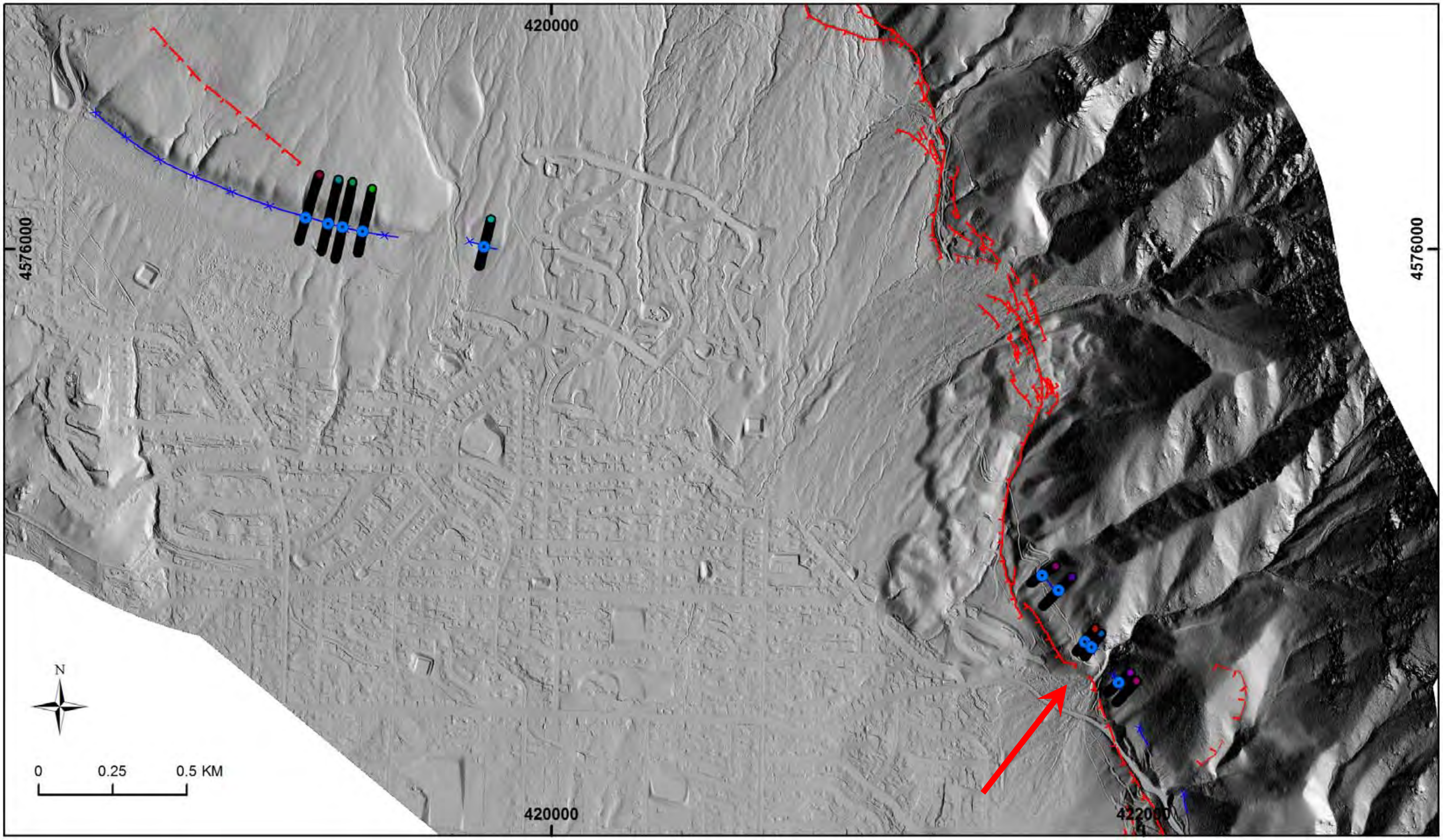
Brigham City-Weber segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

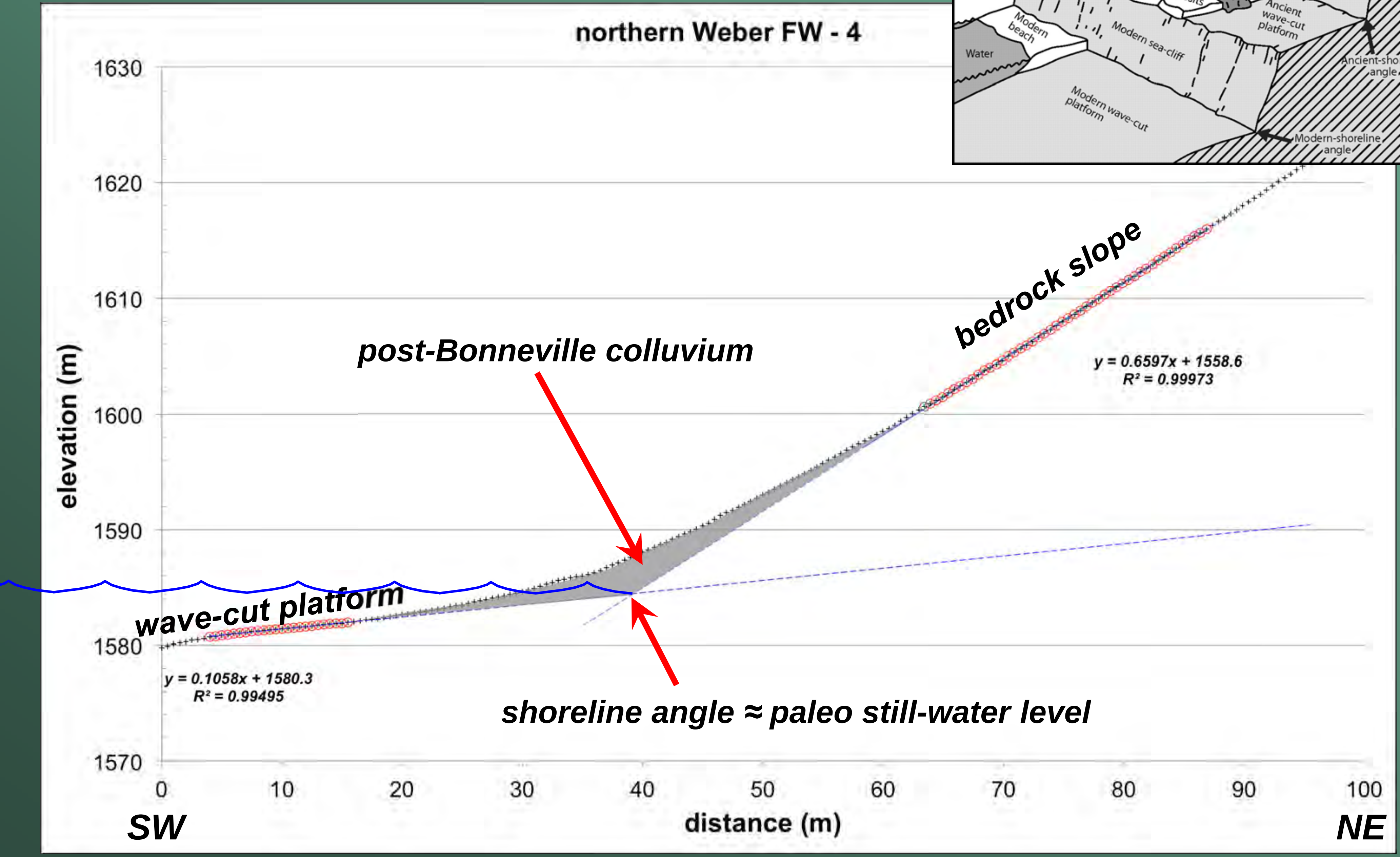
Brigham City-Weber segment boundary

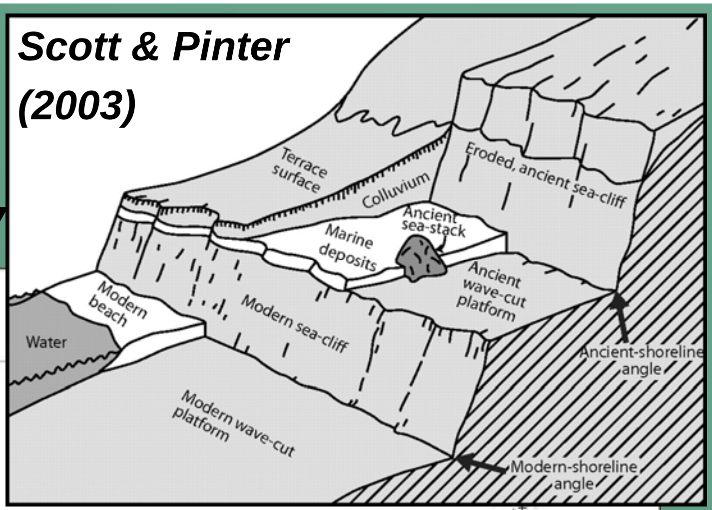


0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

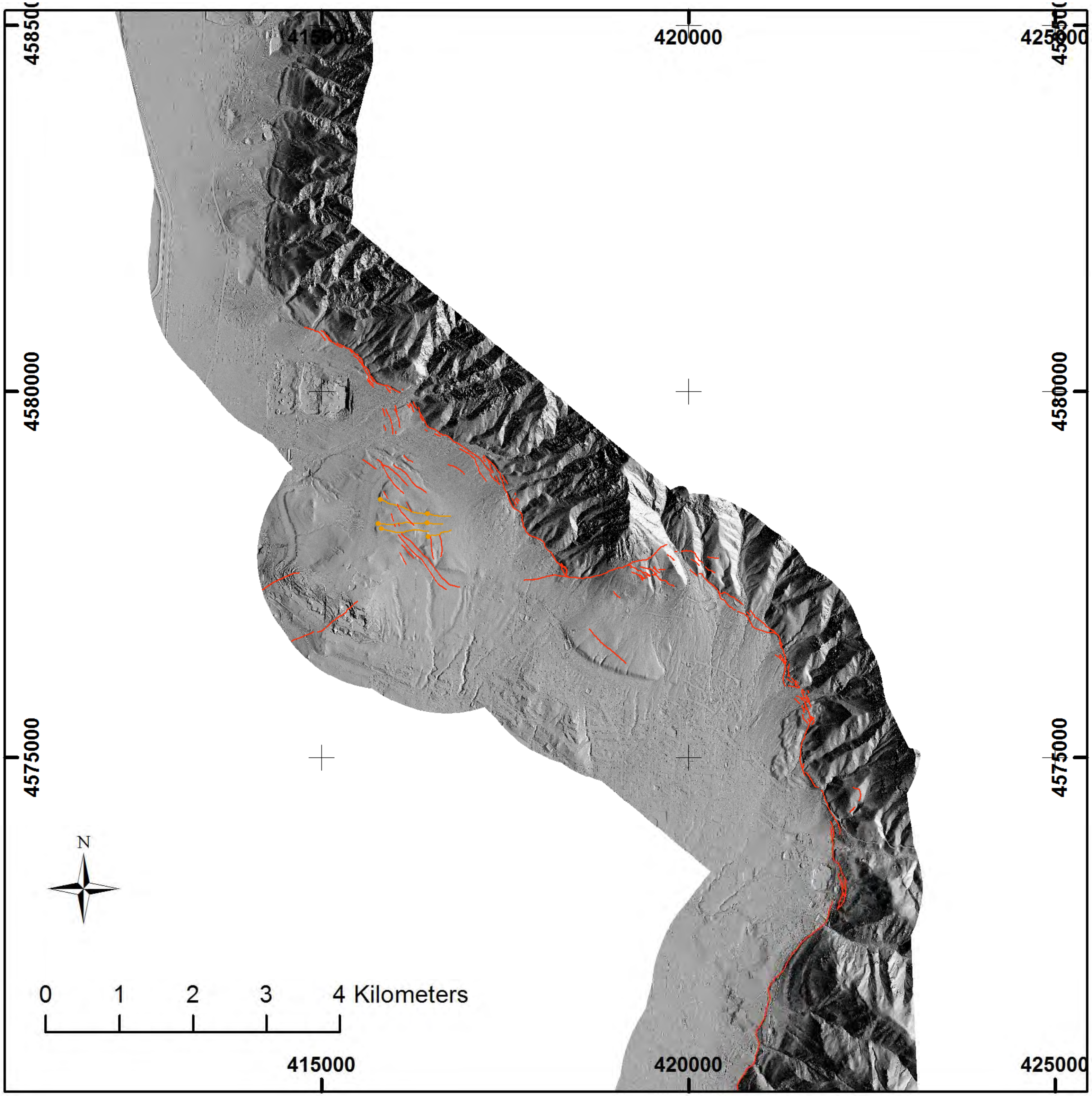
Brigham City-Weber segment boundary





Wasatch Fa

Brigham City-

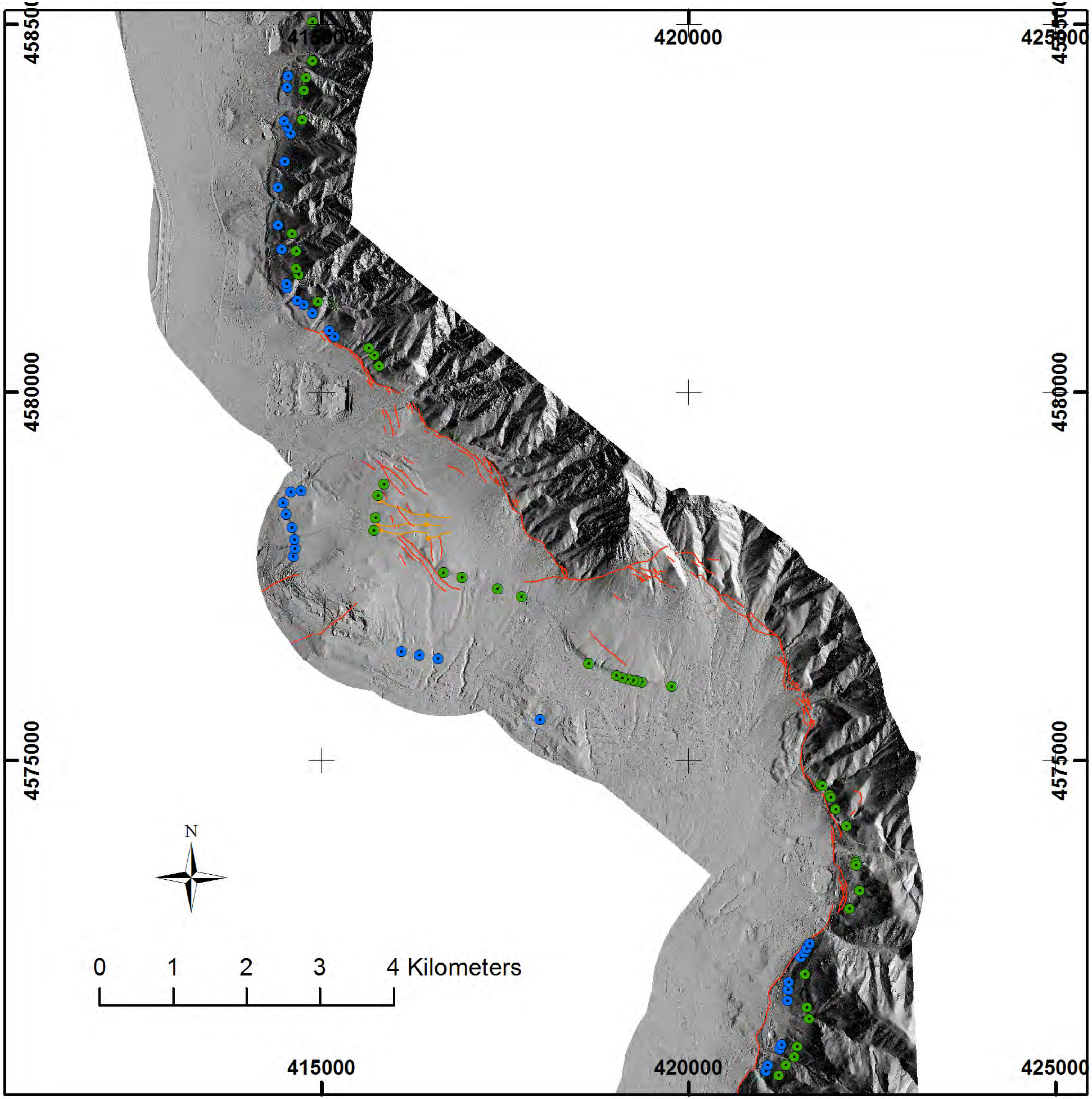


USGS

0.5m LiDAR (2014)

Wasatch Fa

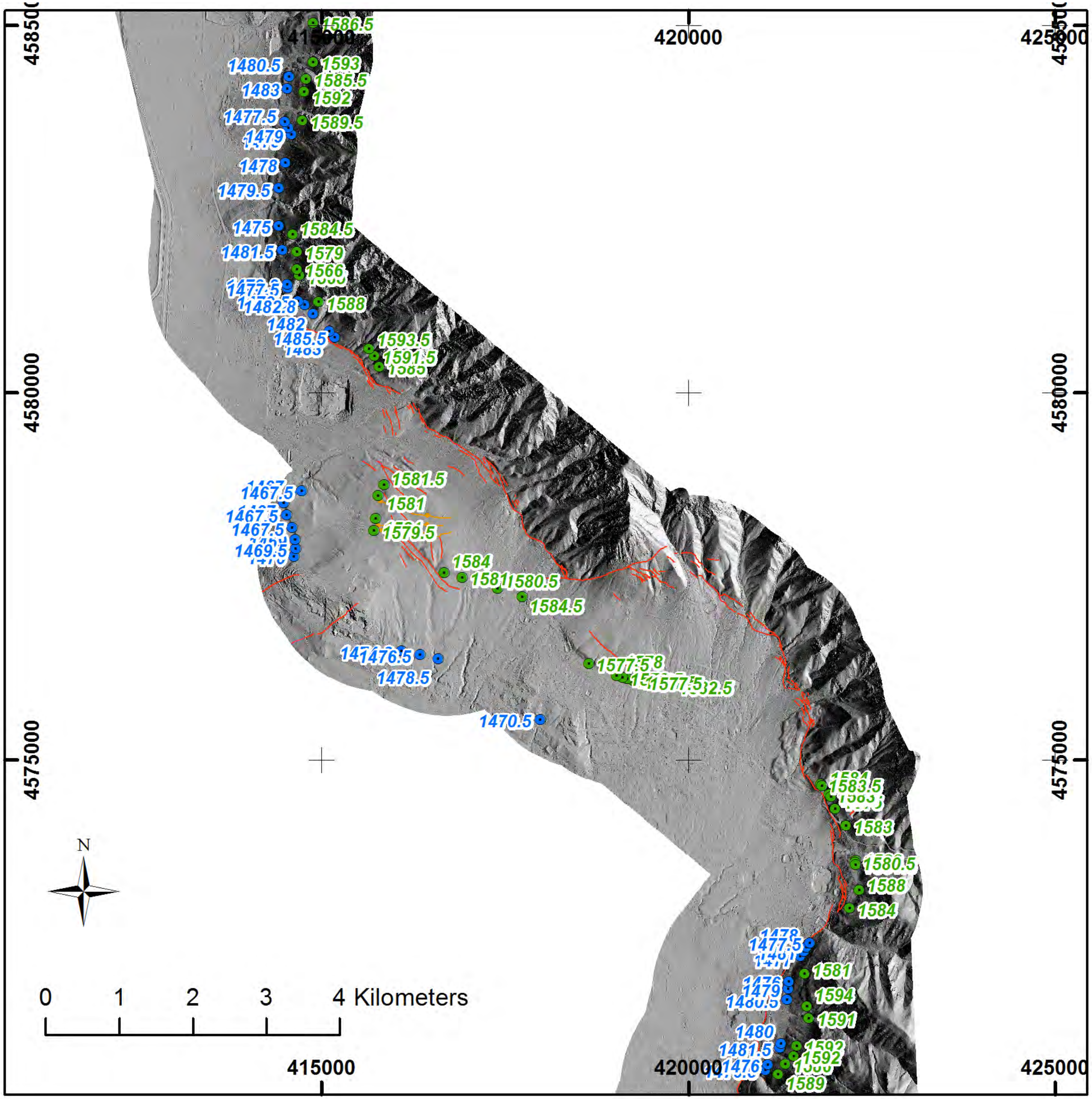
Brigham City-



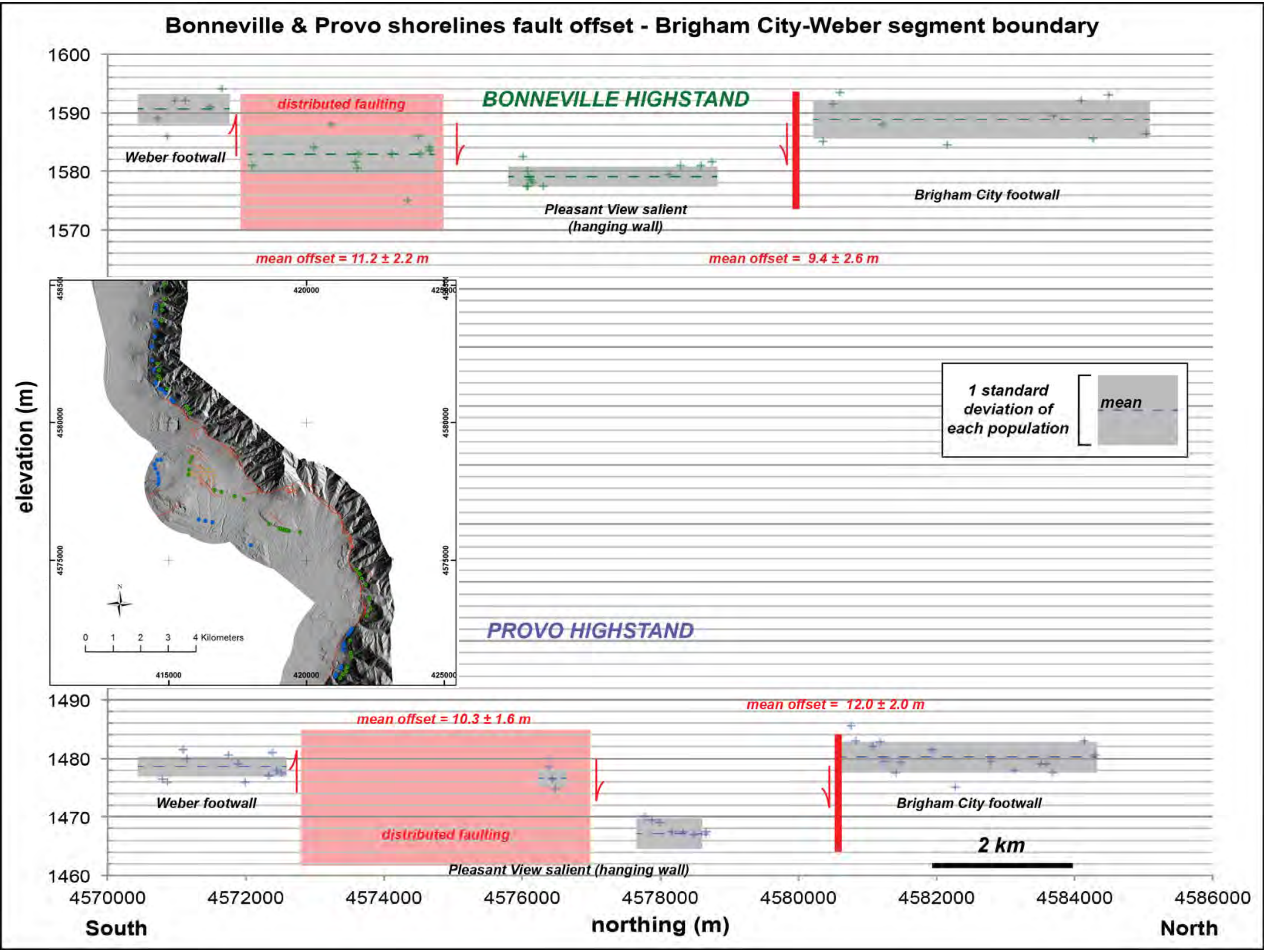
0.5m LiDAR (2014)

Wasatch Fa

Brigham City-



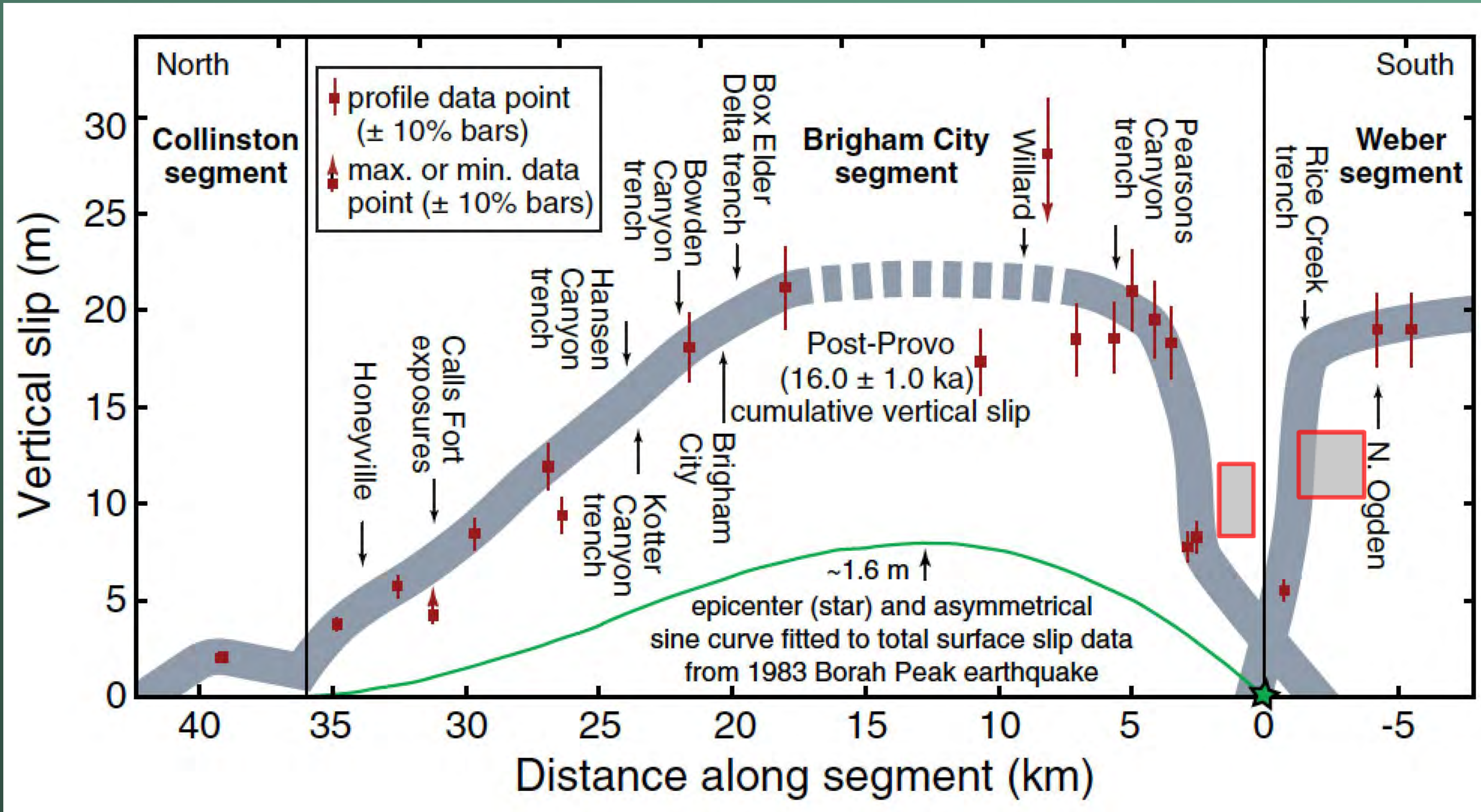
0.5m LiDAR (2014)



Bonneville & Provo shorelines fault offset - Brigham City-Weber segment boundary
BONNEVILLE HIGHSTAND
distributed faulting
Weber footwall
Pleasant View salient (hanging wall)
Brigham City footwall
mean offset = 11.2 ± 2.2 m
mean offset = 9.4 ± 2.6 m
1 standard deviation of each population
mean
PROVO HIGHSTAND
mean offset = 10.3 ± 1.6 m
mean offset = 12.0 ± 2.0 m
Weber footwall
distributed faulting
Brigham City footwall
Pleasant View salient (hanging wall)
2 km
elevation (m)
northing (m)
South
North
0 1 2 3 4 Kilometers

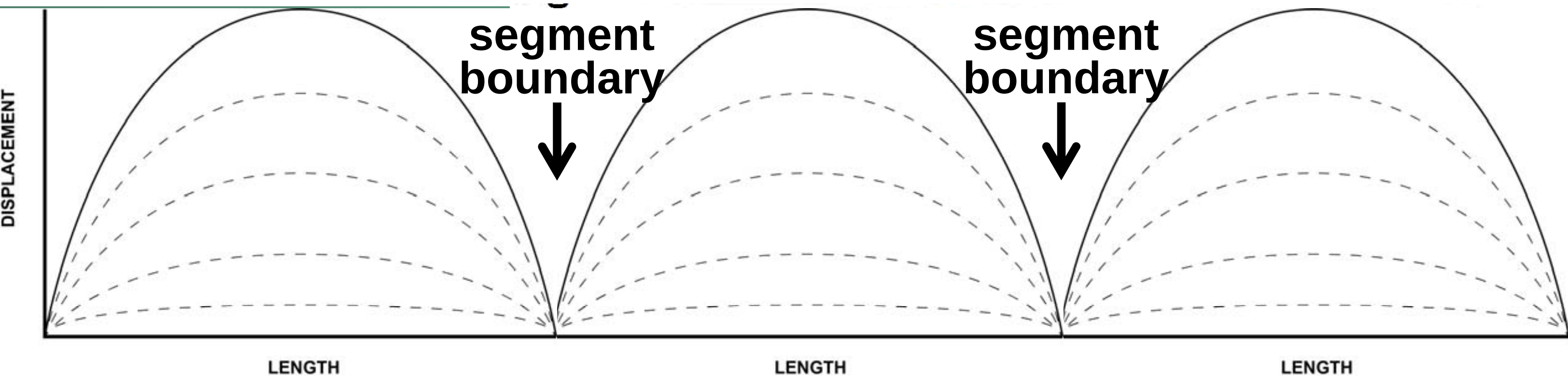
Wasatch Fault LiDAR analysis

Brigham City-Weber segment boundary



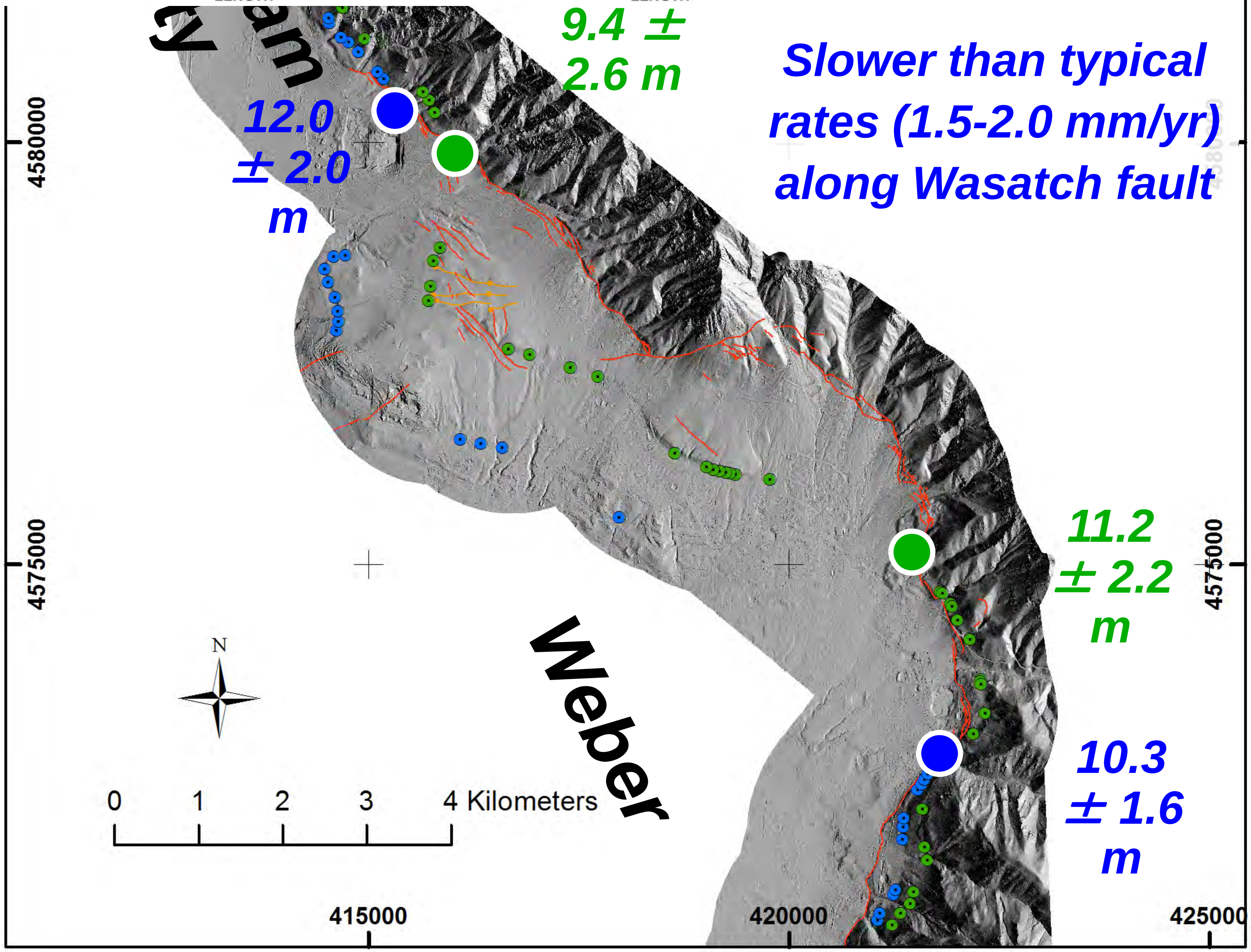
USGS

Personius et al. (2012)



~0.5 mm/yr
rtical slip rate
since ~18 ka

Slower than typical rates (1.5-2.0 mm/yr) along Wasatch fault



0.5m LiDAR (2014)

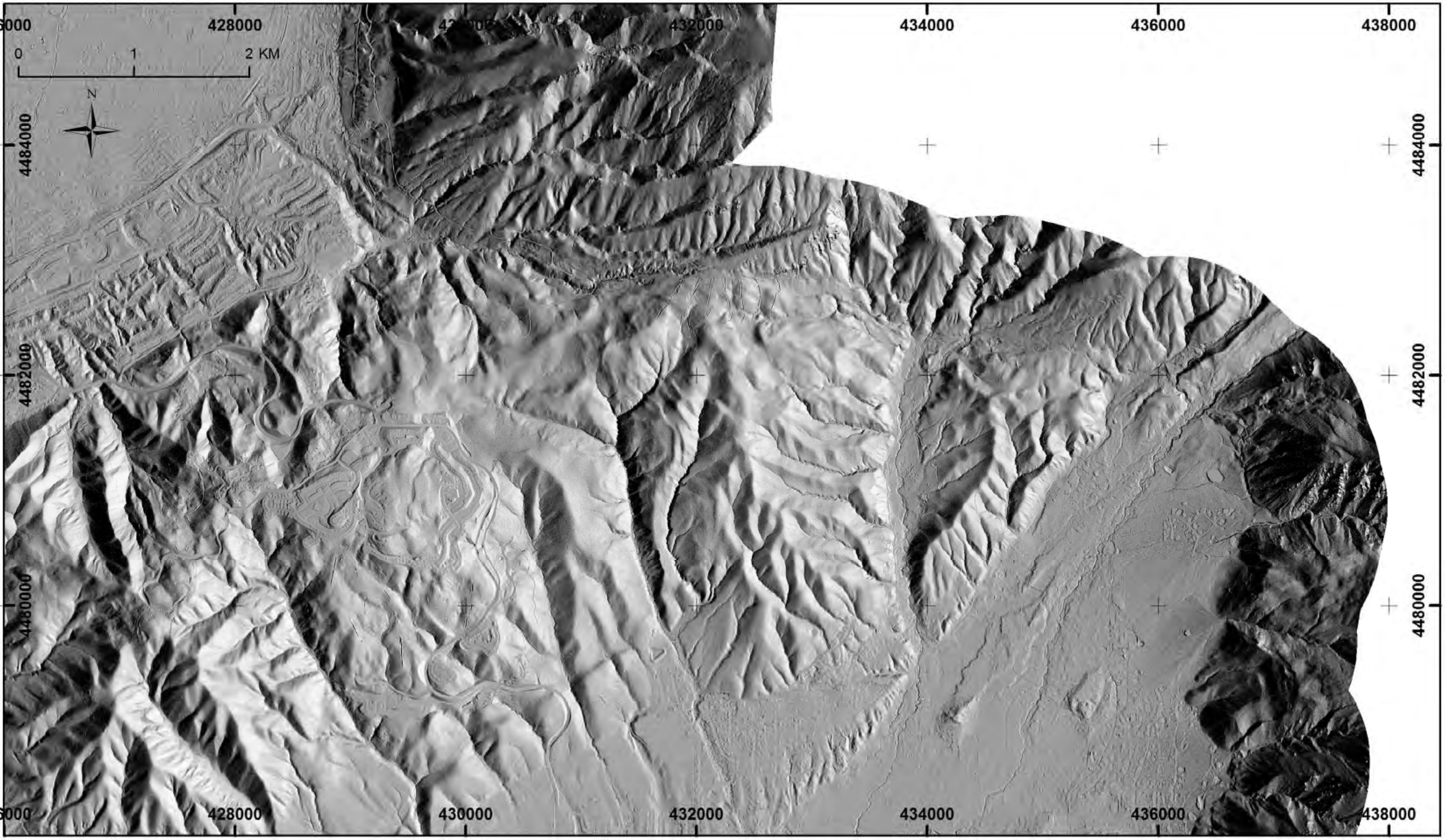
Wasatch Fault LiDAR analysis

Salt Lake City-Provo segment boundary

USGS

Wasatch Fault LiDAR analysis

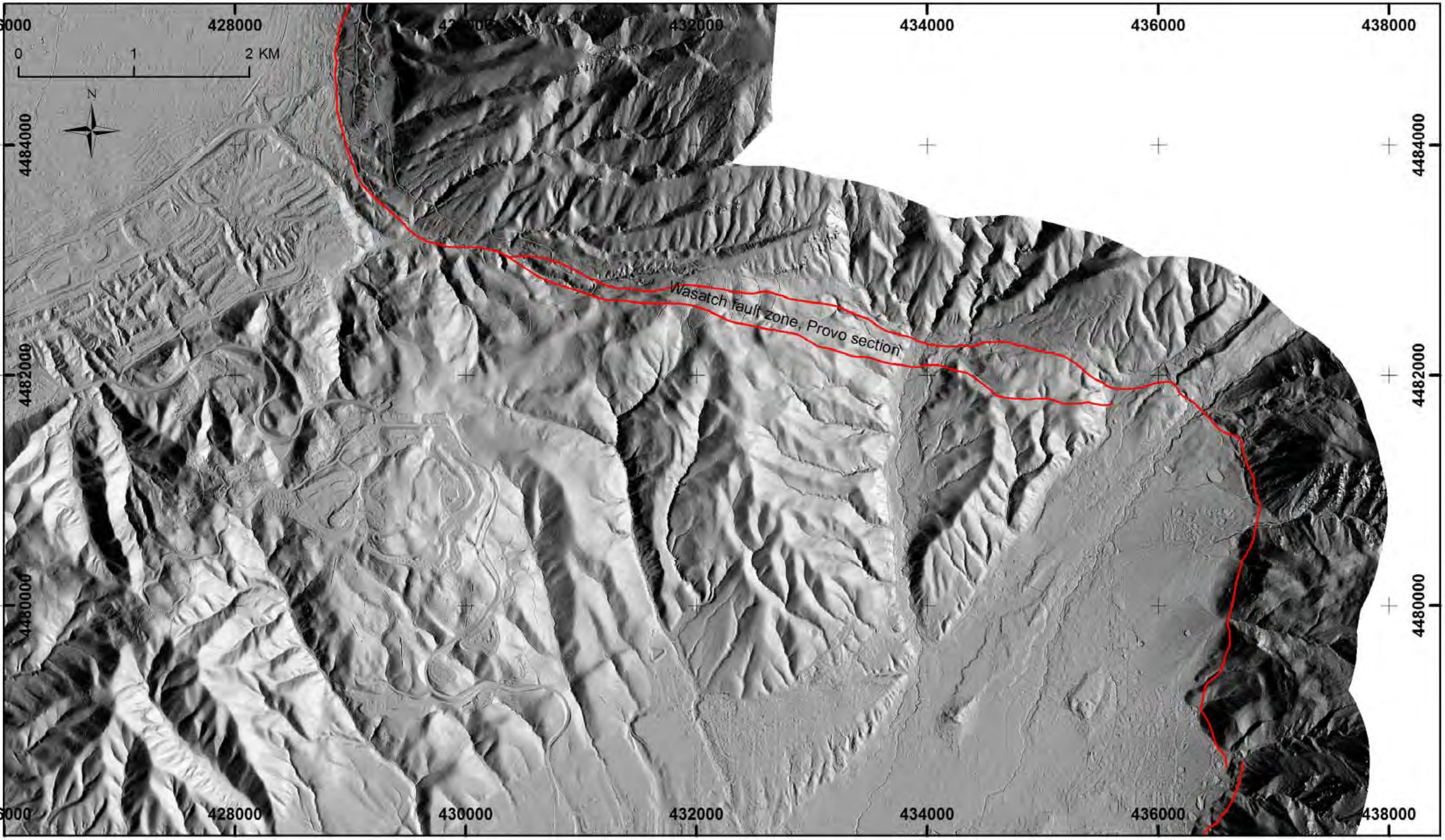
Salt Lake City-Provo segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

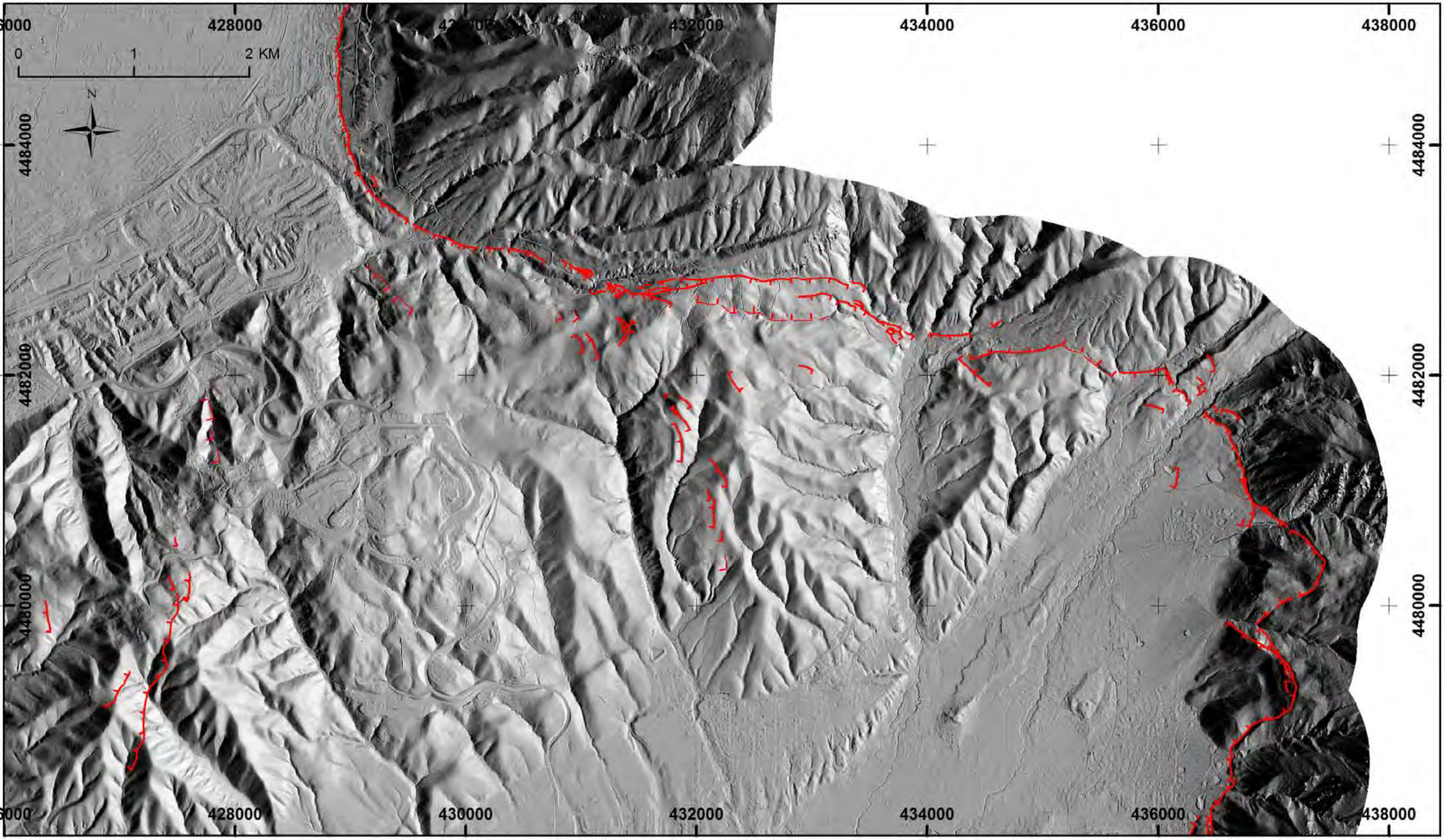
Salt Lake City-Provo segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

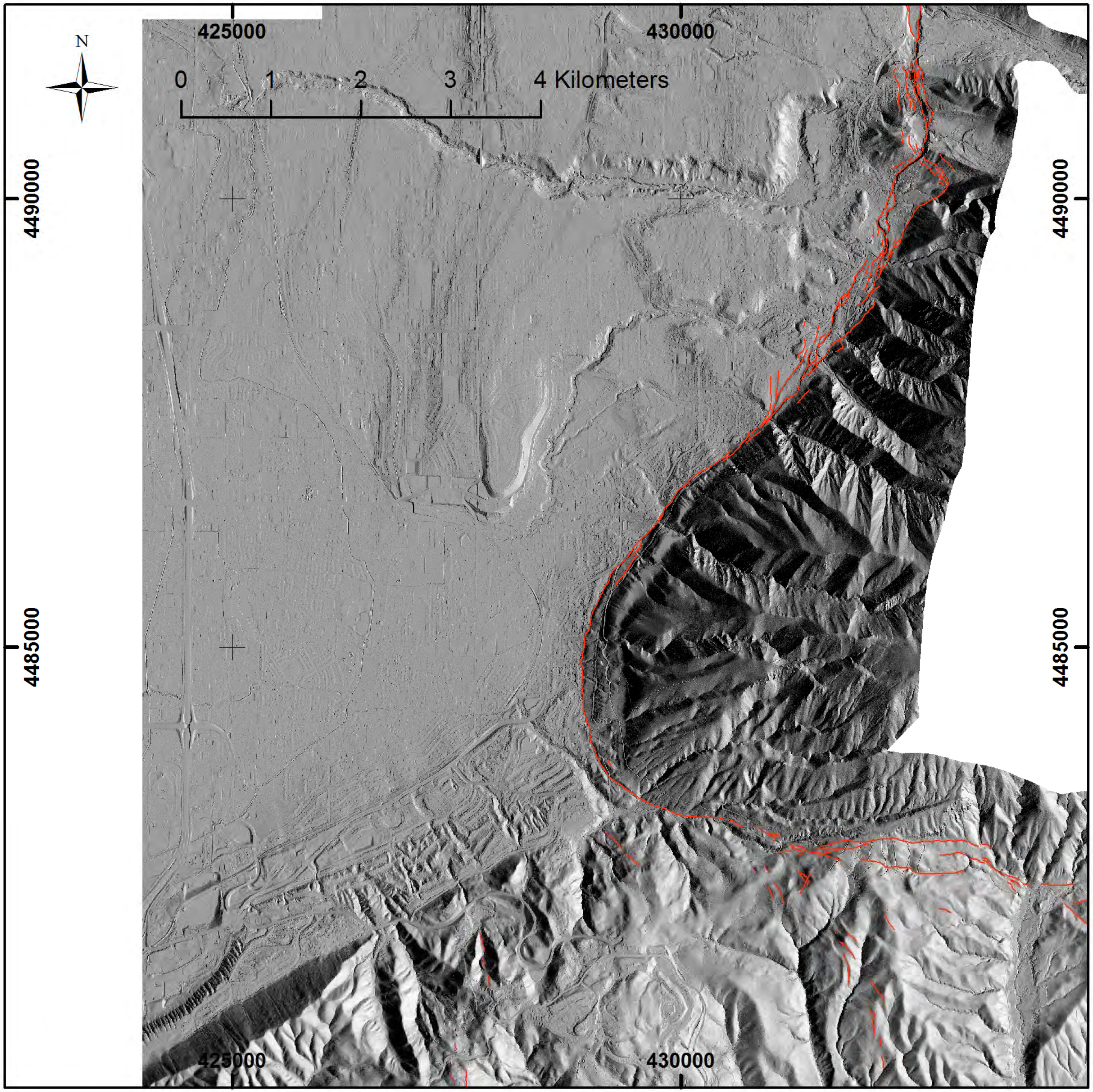
Salt Lake City-Provo segment boundary



0.5m LiDAR (2014)

Wasatch Fa

Salt Lake City

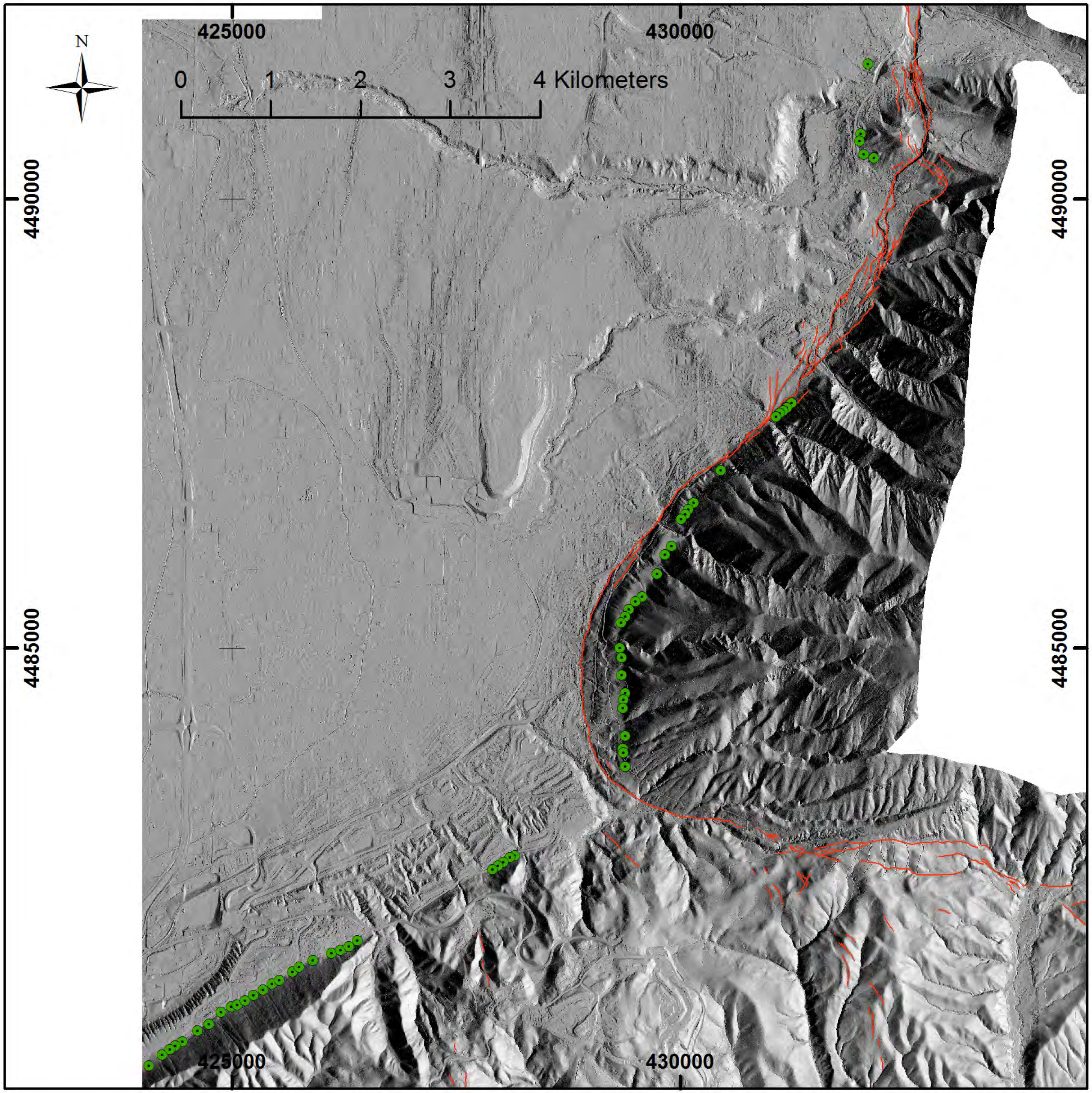


USGS

0.5m LiDAR (2014)

Wasatch Fa

Salt Lake City

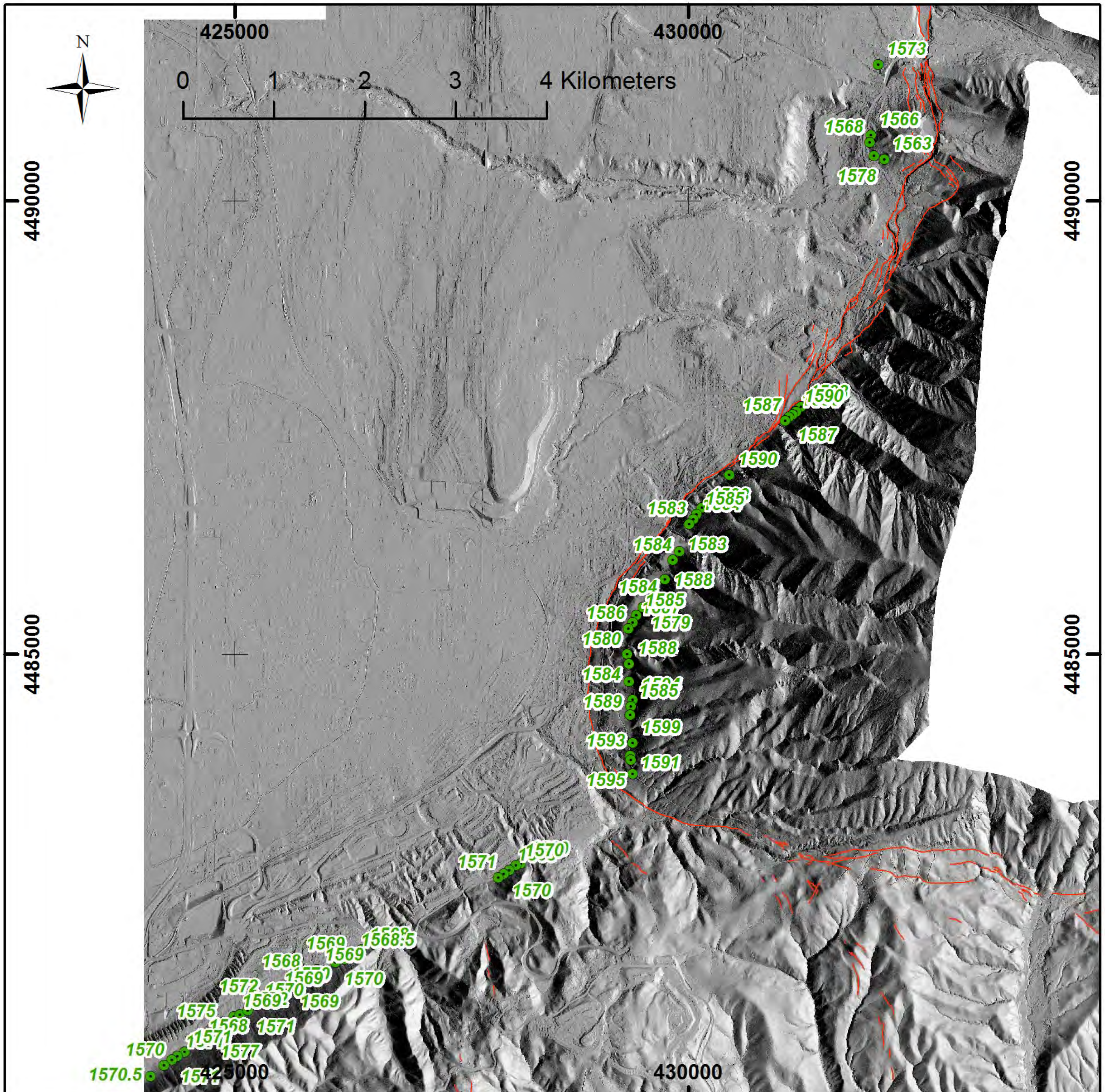


USGS

0.5m LiDAR (2014)

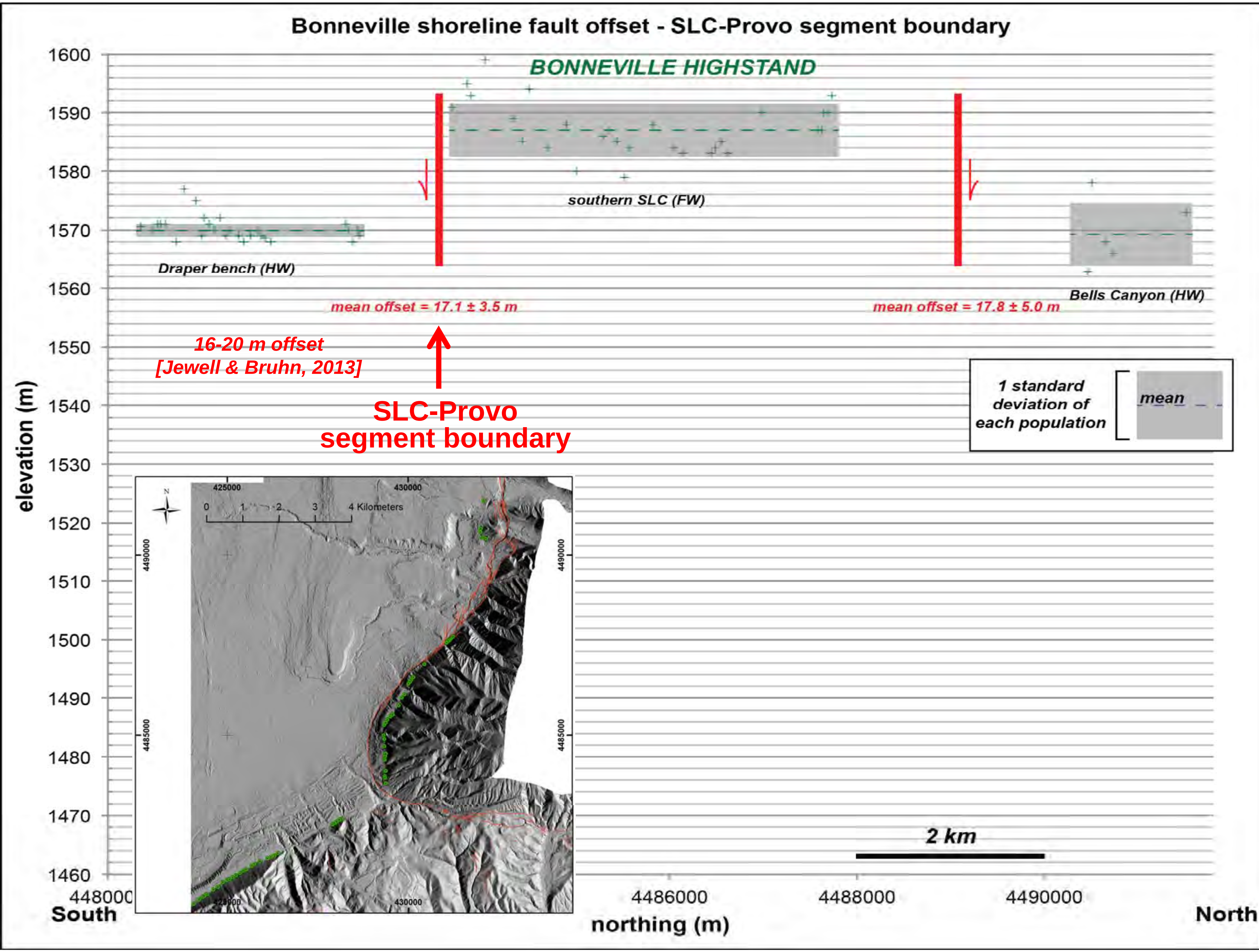
Wasatch Fa

Salt Lake City

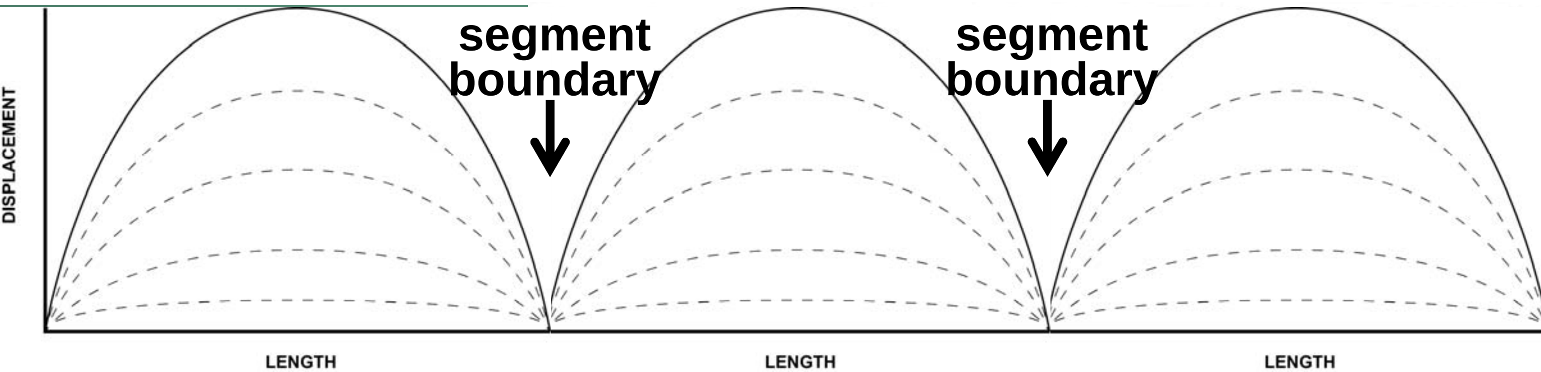


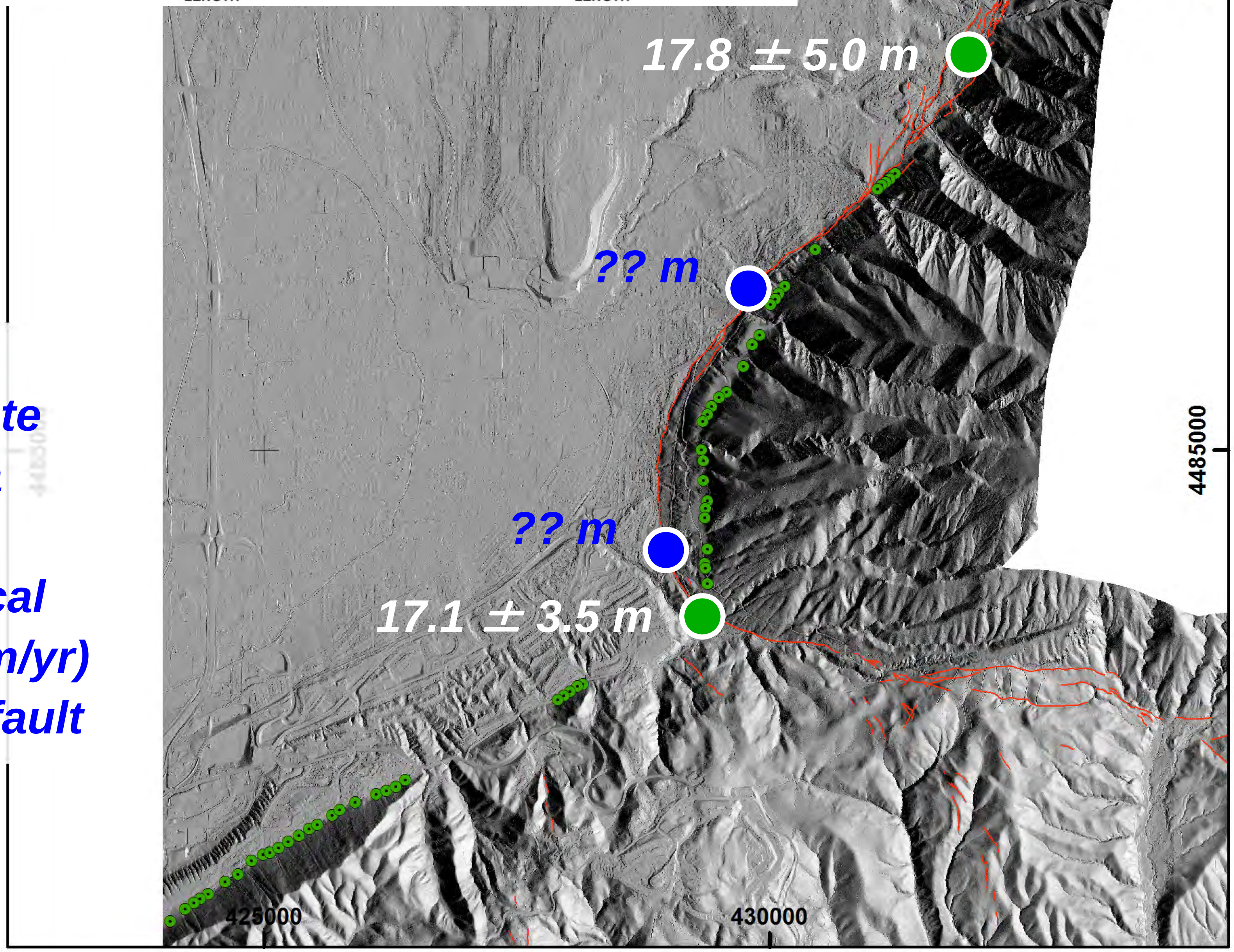
USGS

0.5m LiDAR (2014)



Bonneville shoreline fault offset - SLC-Provo segment boundary
BONNEVILLE HIGHSTAND
southern SLC (FW)
Draper bench (HW)
Bells Canyon (HW)
mean offset = 17.1 ± 3.5 m
mean offset = 17.8 ± 5.0 m
16-20 m offset
[Jewell & Bruhn, 2013]
SLC-Provo
segment boundary
1 standard
deviation of
each population
mean
2 km
elevation (m)
northing (m)
South
North
1600
1590
1580
1570
1560
1550
1540
1530
1520
1510
1500
1490
1480
1470
1460
448000
4486000
4488000
4490000
425000
430000
0
1
2
3
4 Kilometers
4490000
4485000
N





~1 mm/yr
vertical slip rate
since ~18 ka

Closer to typical
rates (1.5-2.0 mm/yr)
along Wasatch fault

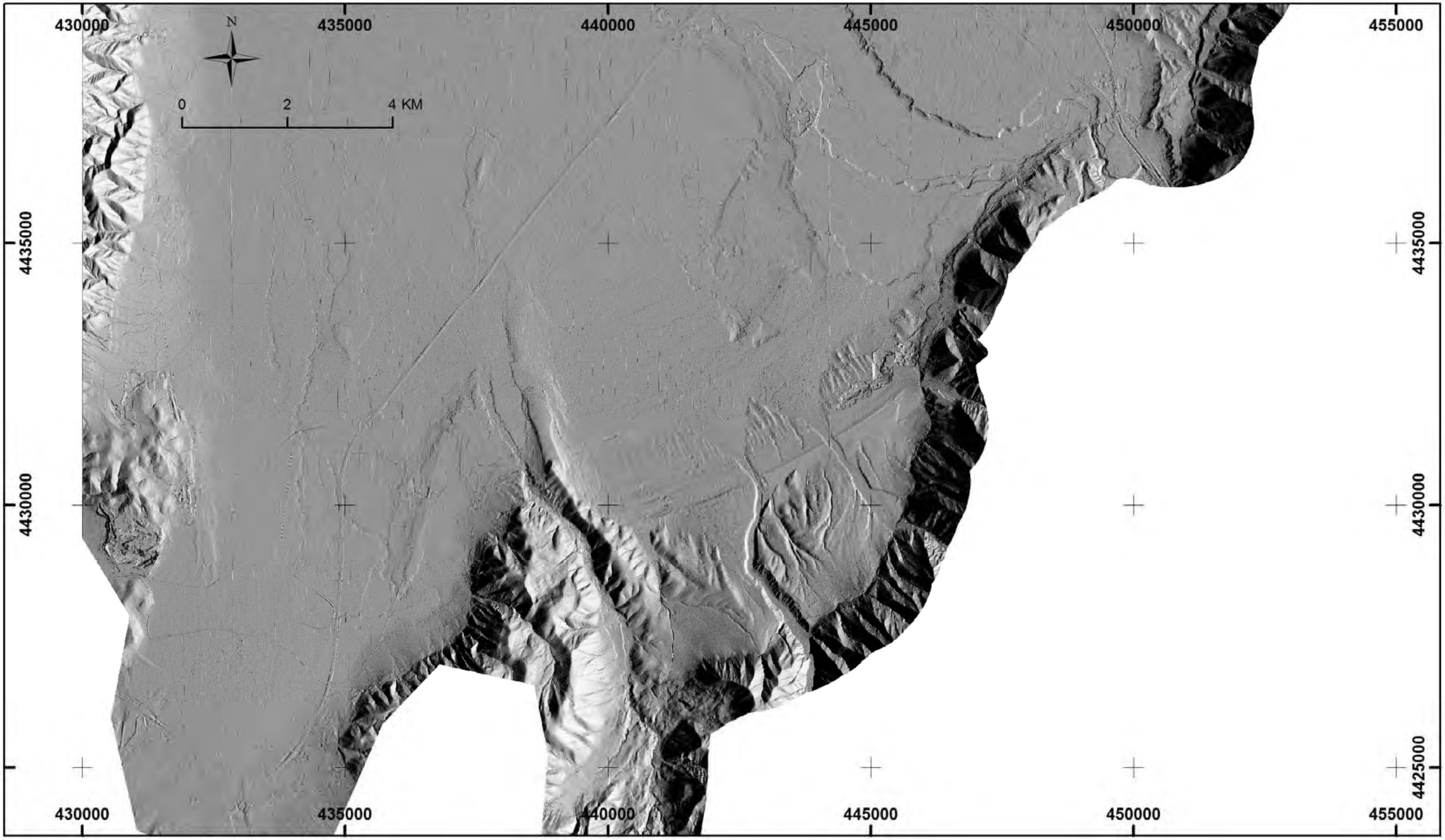
0.5m LiDAR (2014)

Wasatch Fault LiDAR analys

Provo-Nephi segment boundary

Wasatch Fault LiDAR analysis

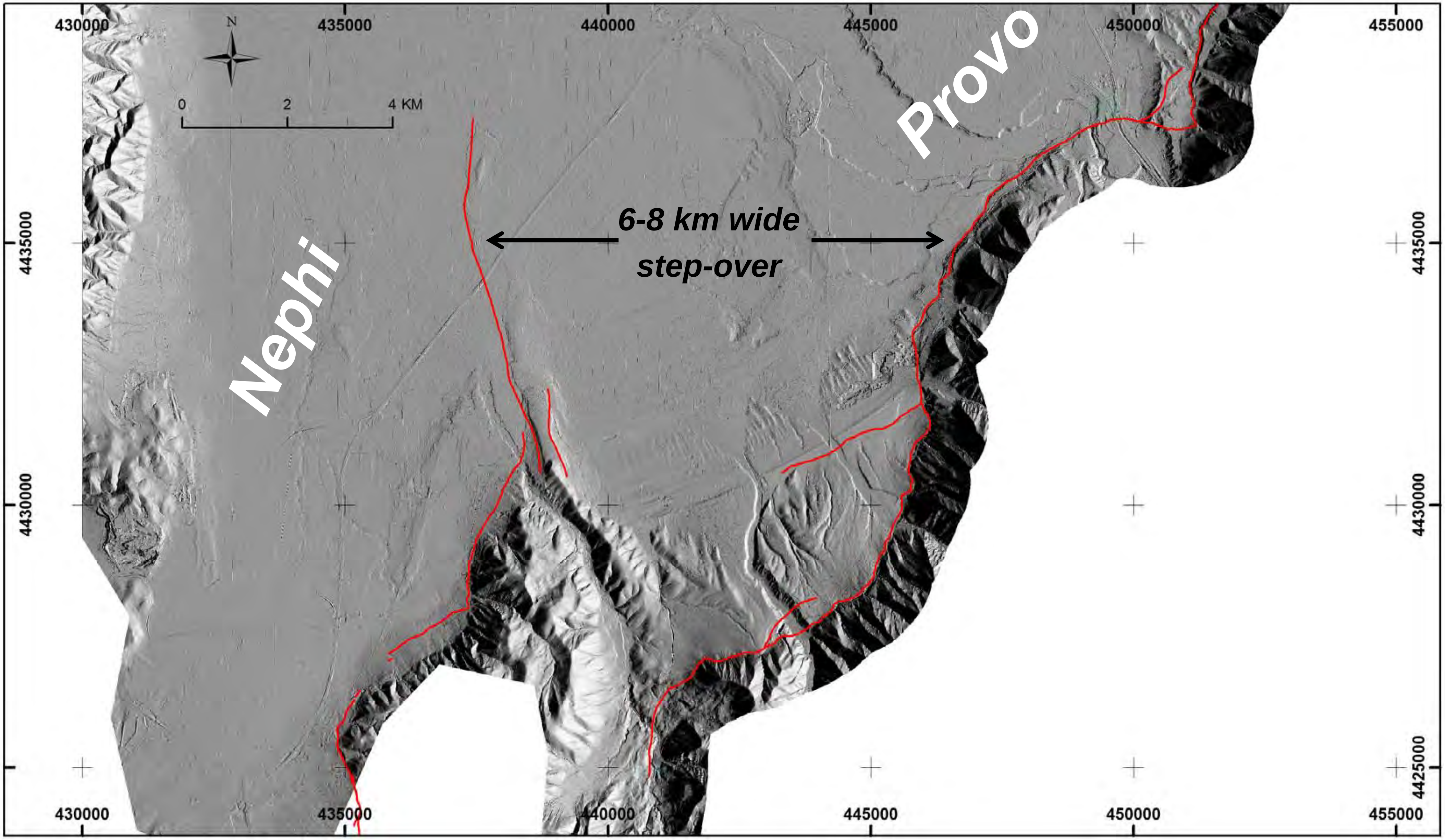
Provo-Nephi segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

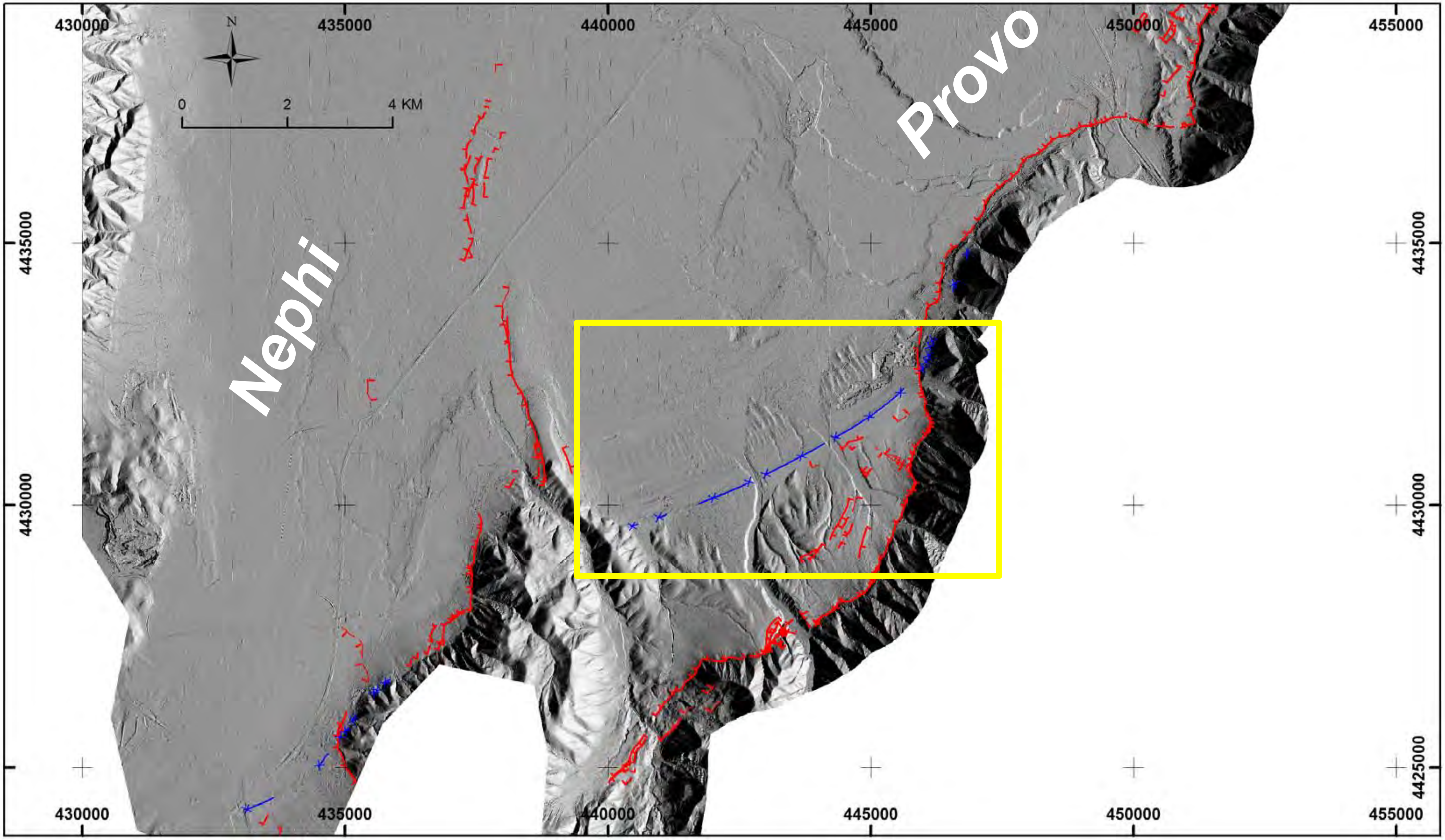
Provo-Nephi segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

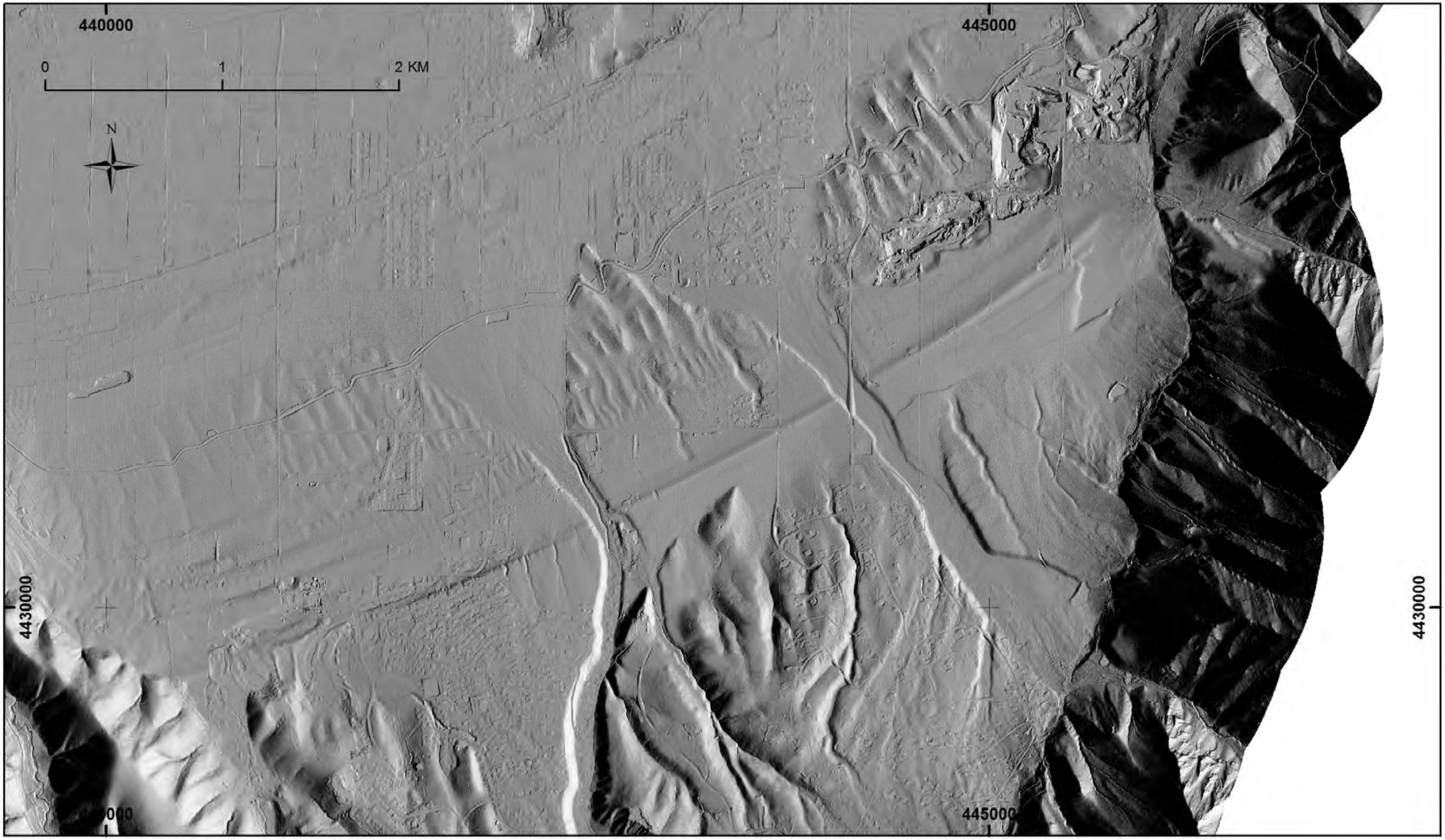
Provo-Nephi segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

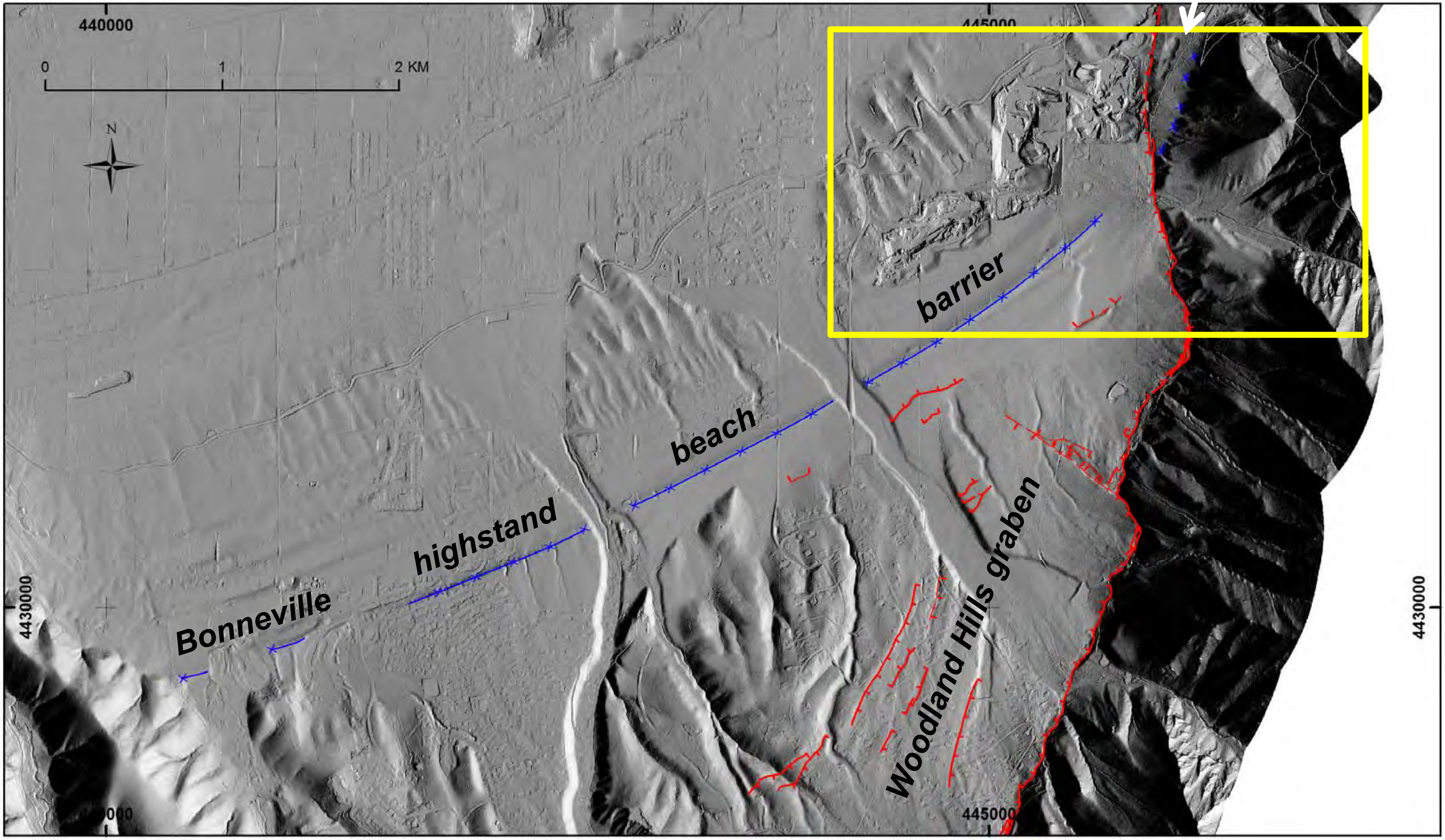
Provo-Nephi segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

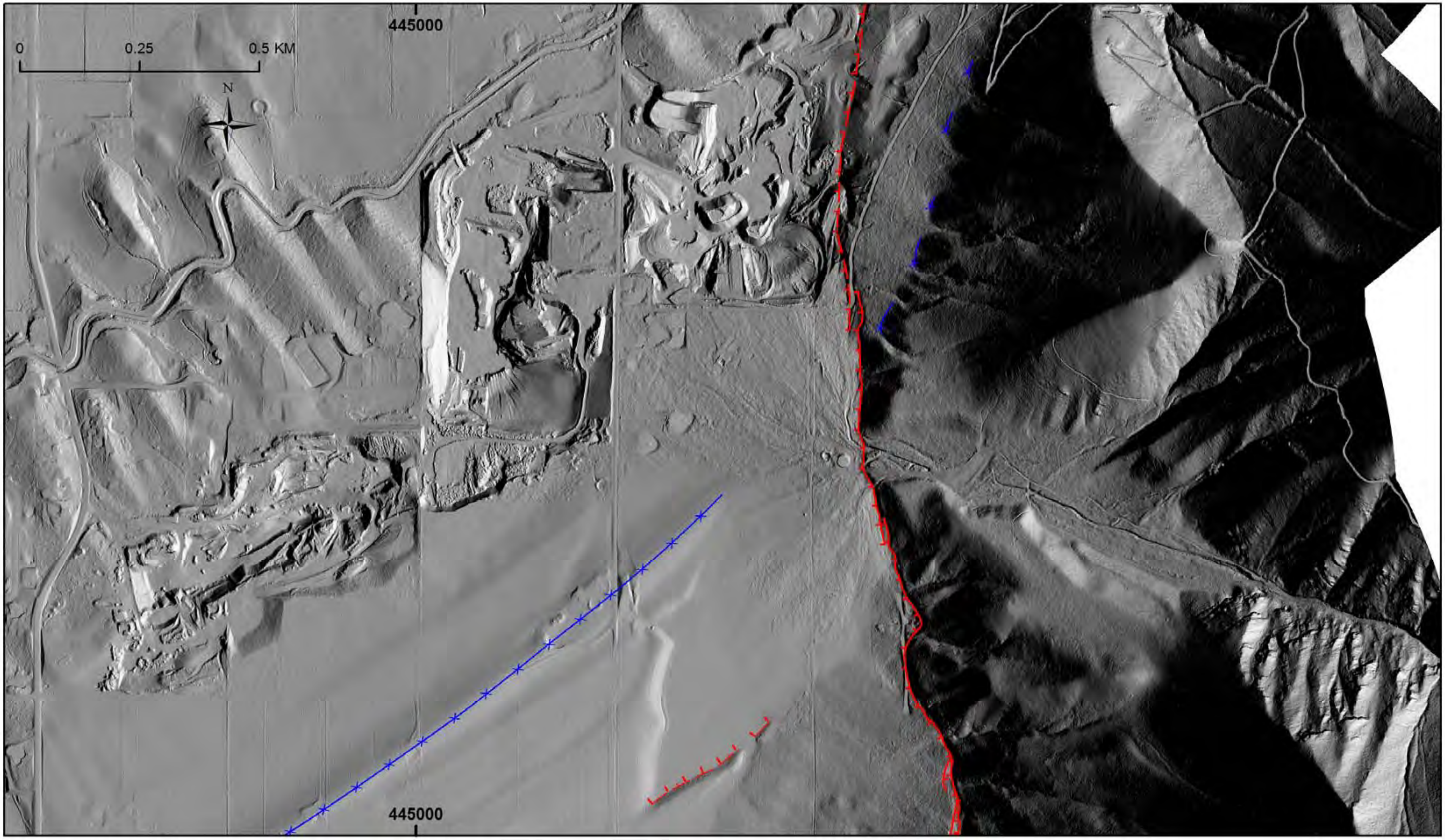
Provo-Nephi segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

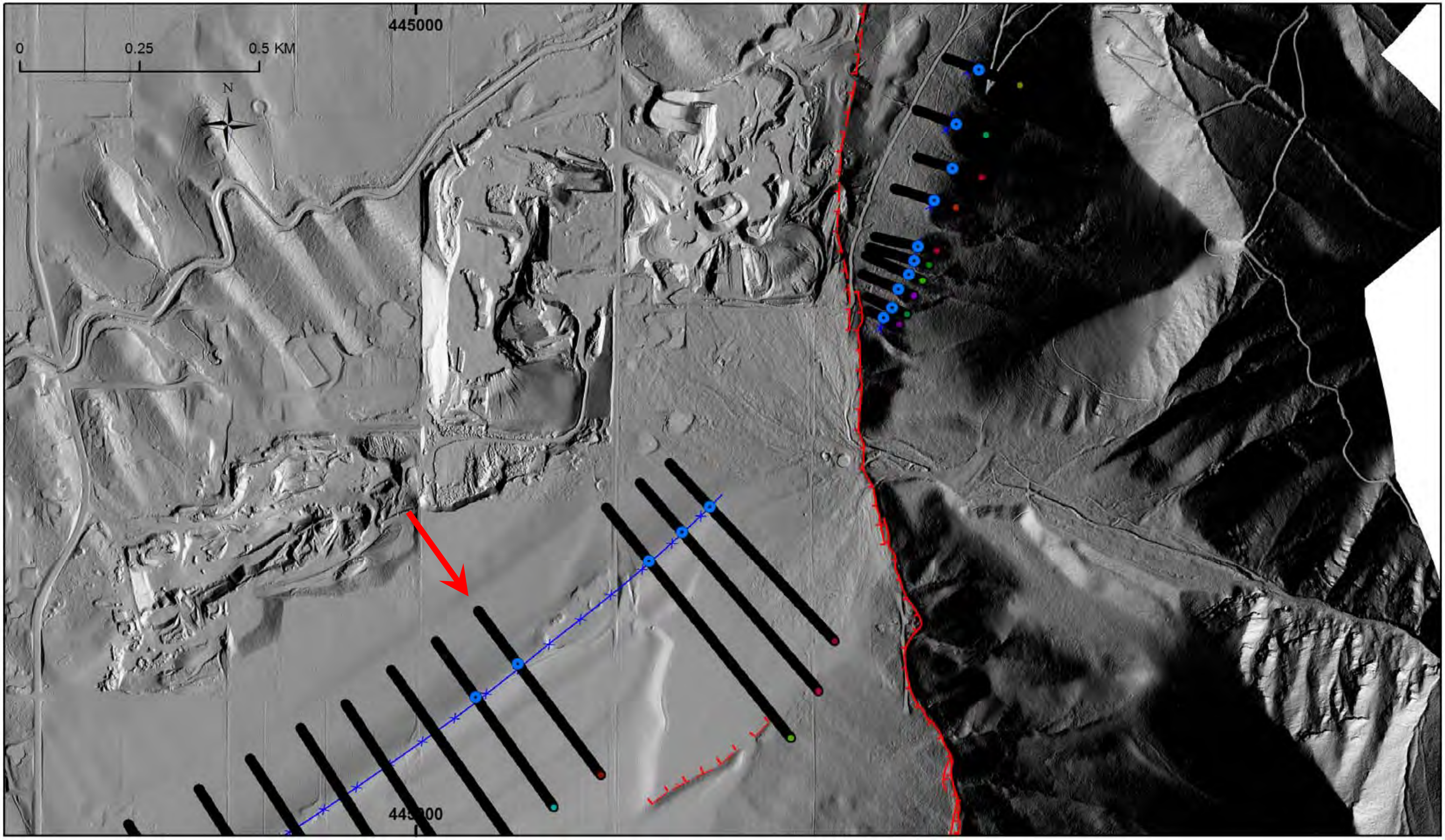
Provo-Nephi segment boundary



0.5m LiDAR (2014)

Wasatch Fault LiDAR analysis

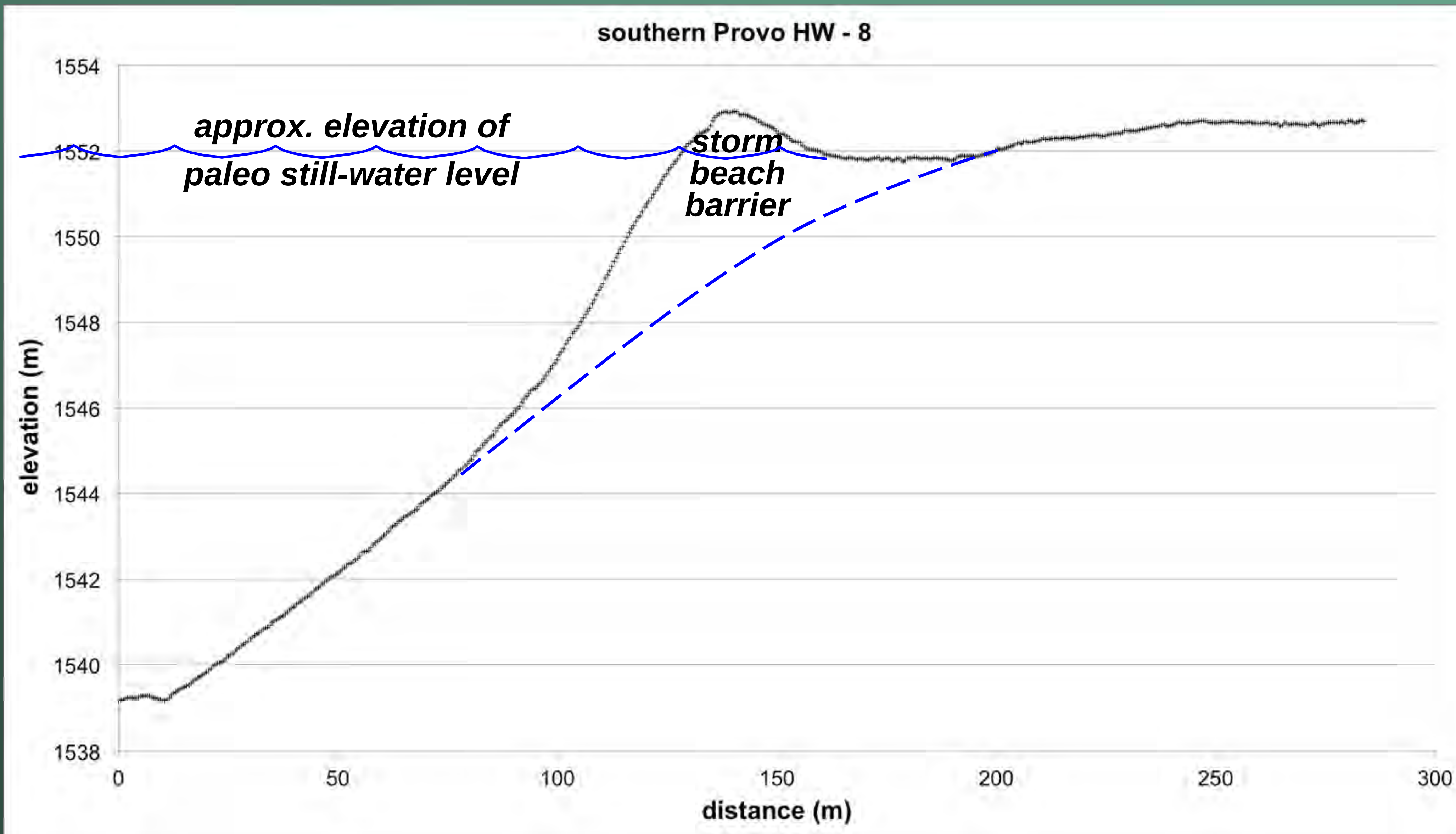
Provo-Nephi segment boundary



0.5m LiDAR (2014)

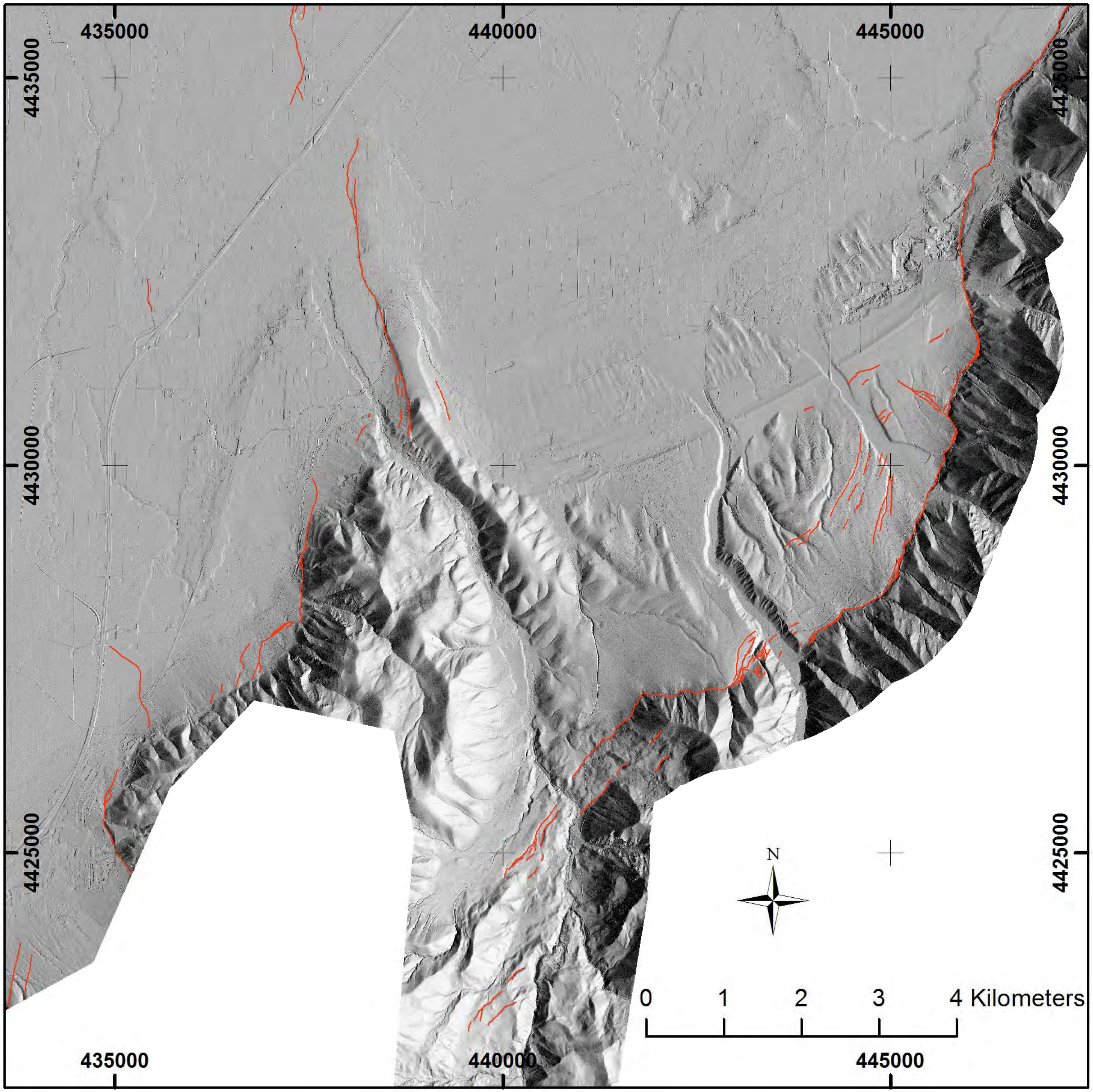
Wasatch Fault LiDAR analysis

Provo-Nephi segment boundary



Wasatch Fa

Provo-Nephi s

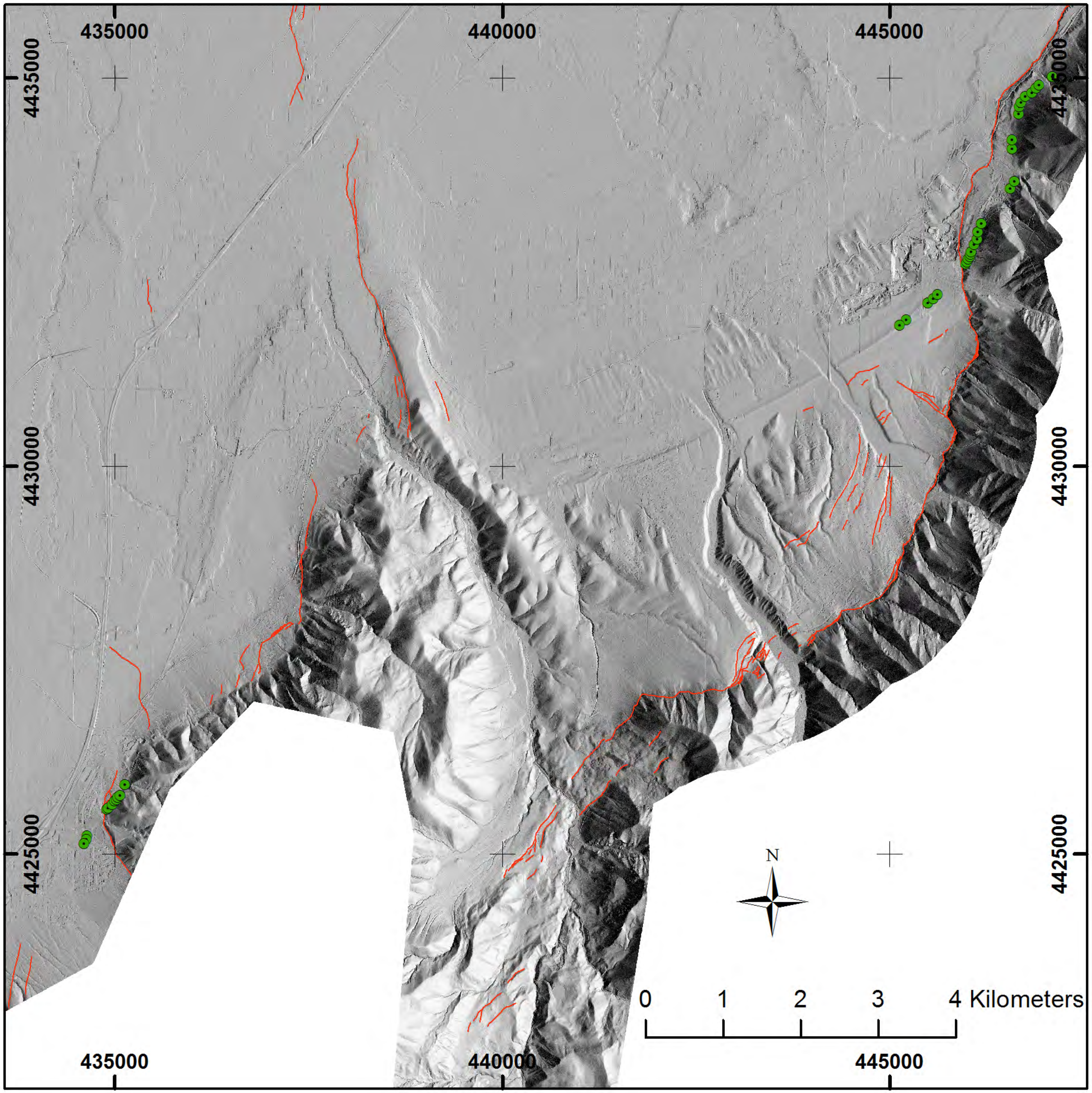


USGS

0.5m LiDAR (2014)

Wasatch Fa

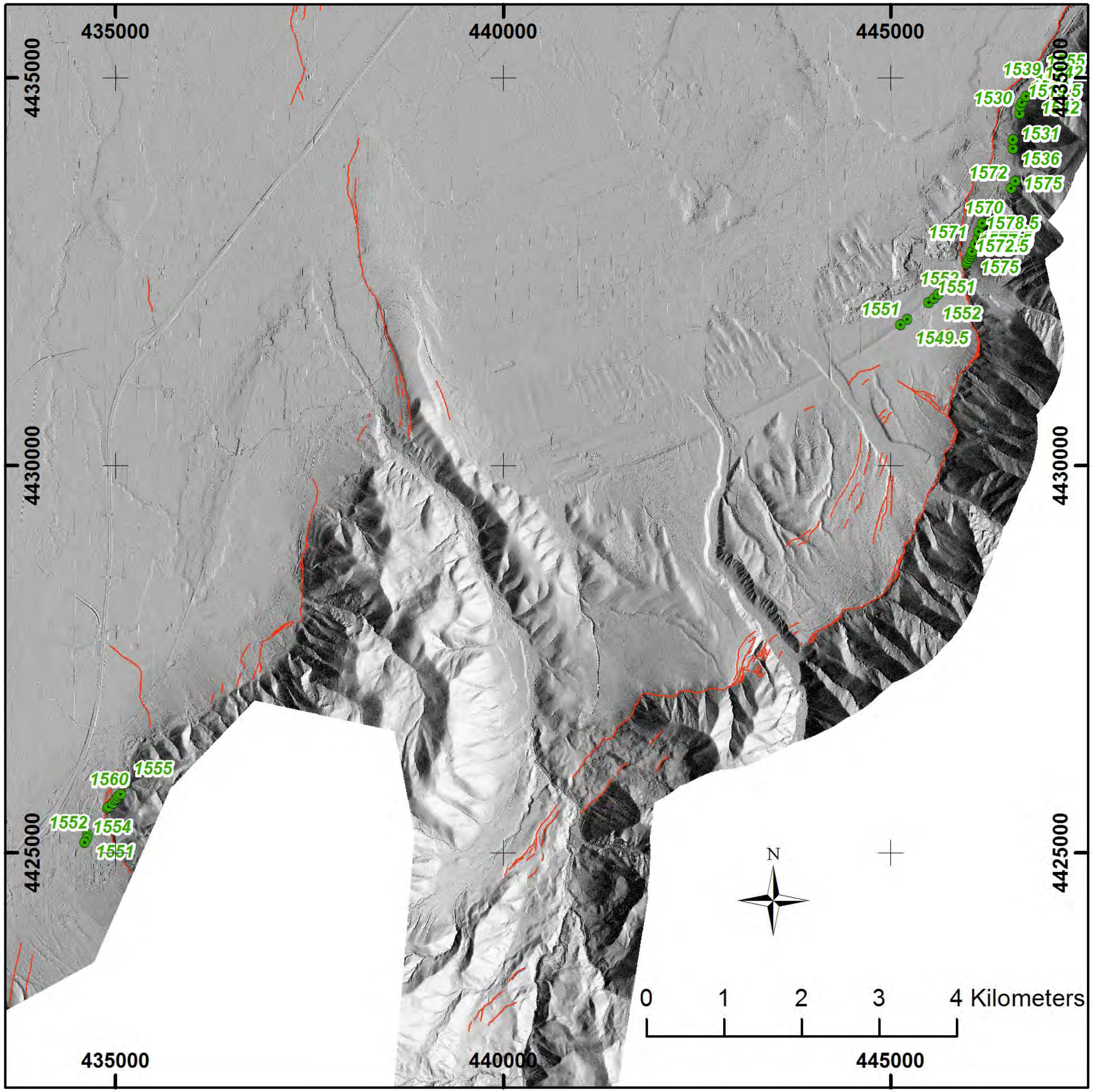
Provo-Nephi s



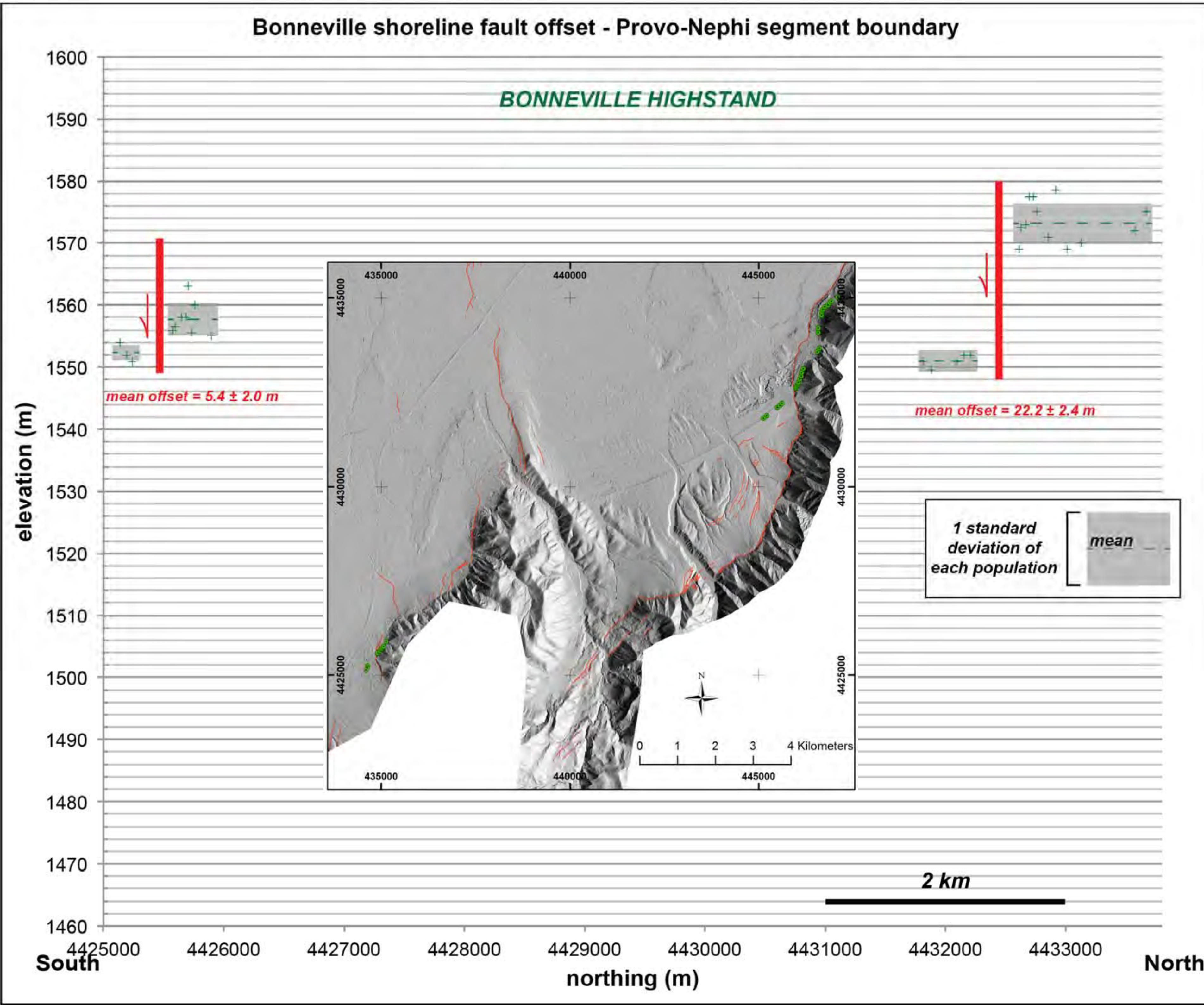
0.5m LiDAR (2014)

Wasatch Fa

Provo-Nephi s



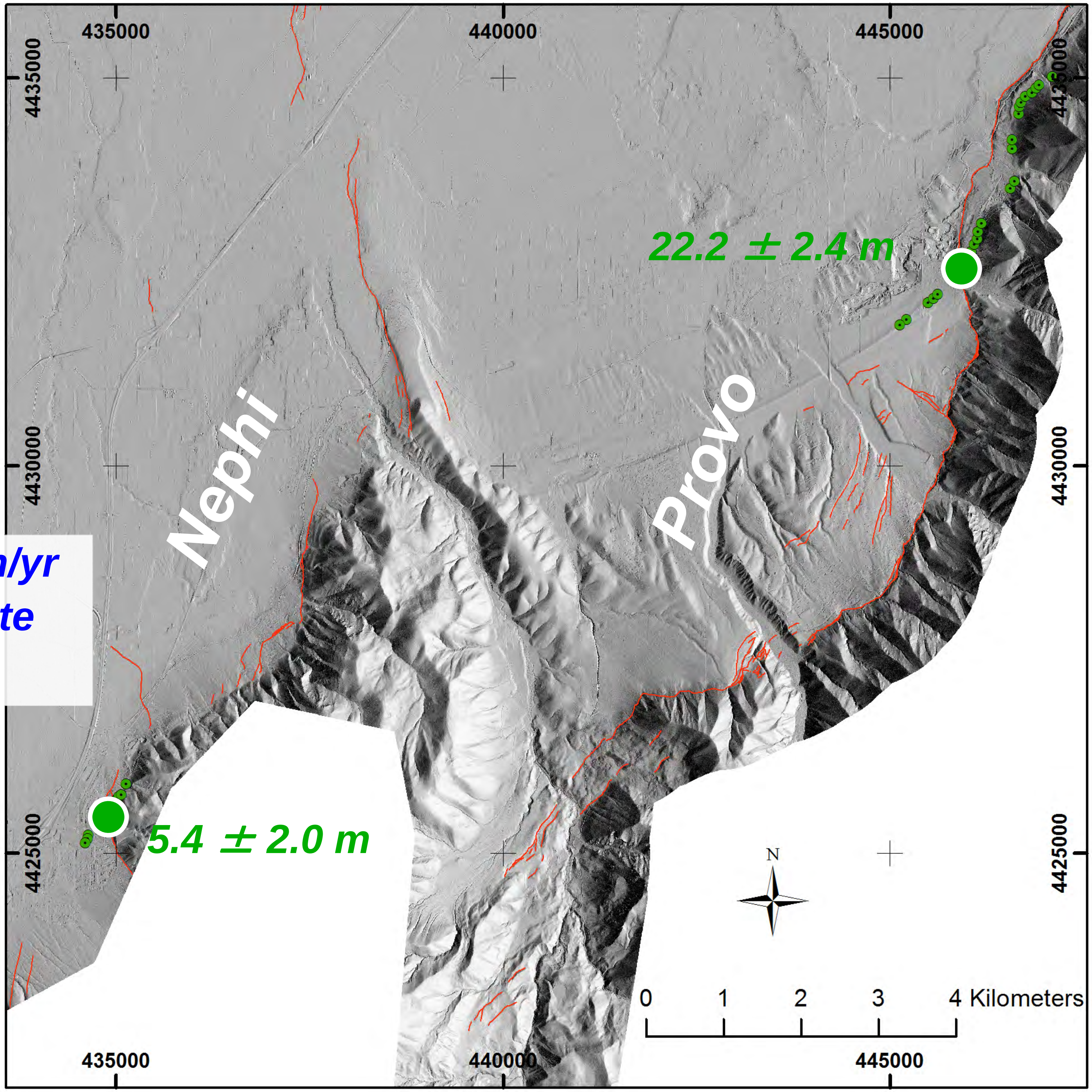
0.5m LiDAR (2014)



Bonneville shoreline fault offset - Provo-Nephi segment boundary
BONNEVILLE HIGHSTAND
elevation (m)
1600
1590
1580
1570
1560
1550
1540
1530
1520
1510
1500
1490
1480
1470
1460
mean offset = 5.4 ± 2.0 m
mean offset = 22.2 ± 2.4 m
1 standard deviation of each population
mean
435000
440000
445000
4435000
4430000
4425000
N
0 1 2 3 4 Kilometers
2 km
4425000
4426000
4427000
4428000
4429000
4430000
4431000
4432000
4433000
South
North
northing (m)

Wasatch Fa

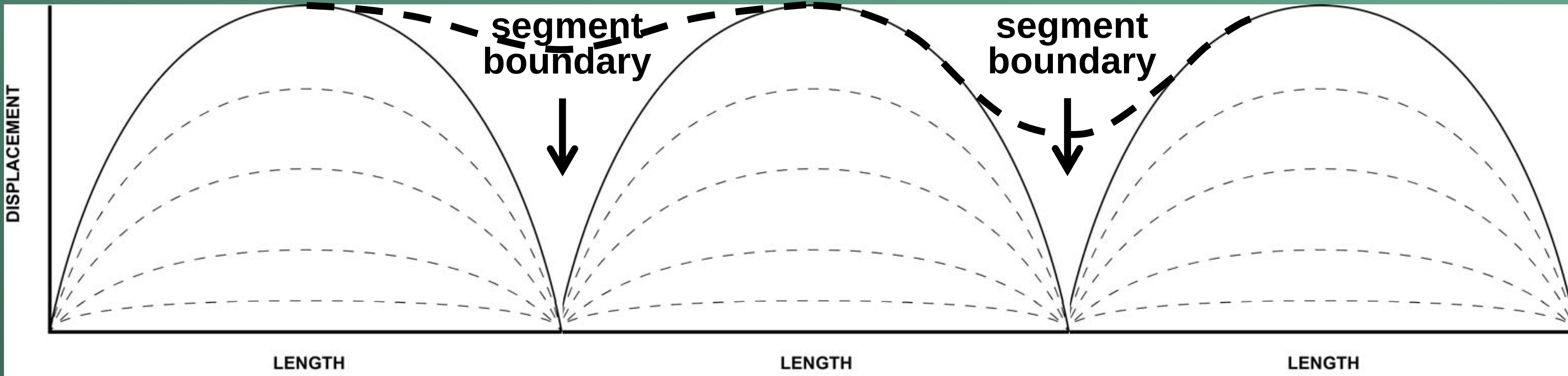
Provo-Nephi s



TOTAL ~1.5 mm/yr vertical slip rate since ~18 ka

USGS

Implications



NHSM

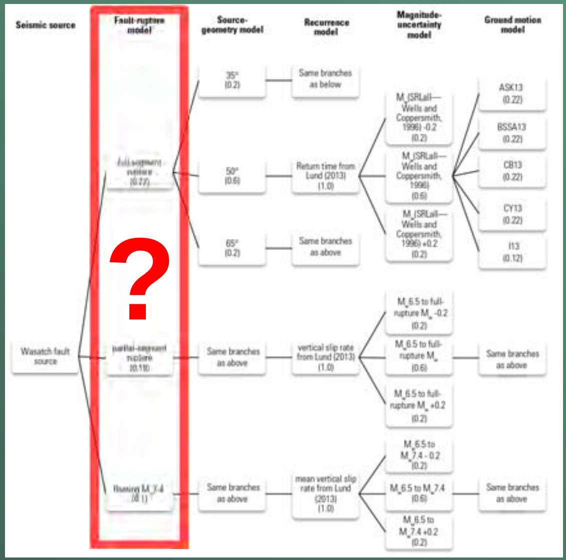
- EQ mag
- EQ frequency

Ground Motion

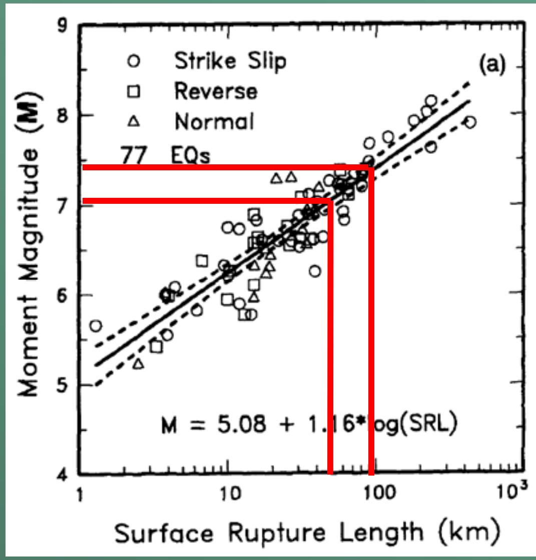
- variable sources

Rupture Scenarios

- fault length
- rupture directivity



Petersen et al. (2014)



Wells and Coppersmith (1984)

USGS

Summary

(1) New LiDAR analysis

- new fault traces
- dozens of new latest Pleistocene and Holocene slip-rate sites

(2) Findings help reduce uncertainties in seismic hazard models for Wasatch fault zone.

(3) Need earthquake chronologies from trenches

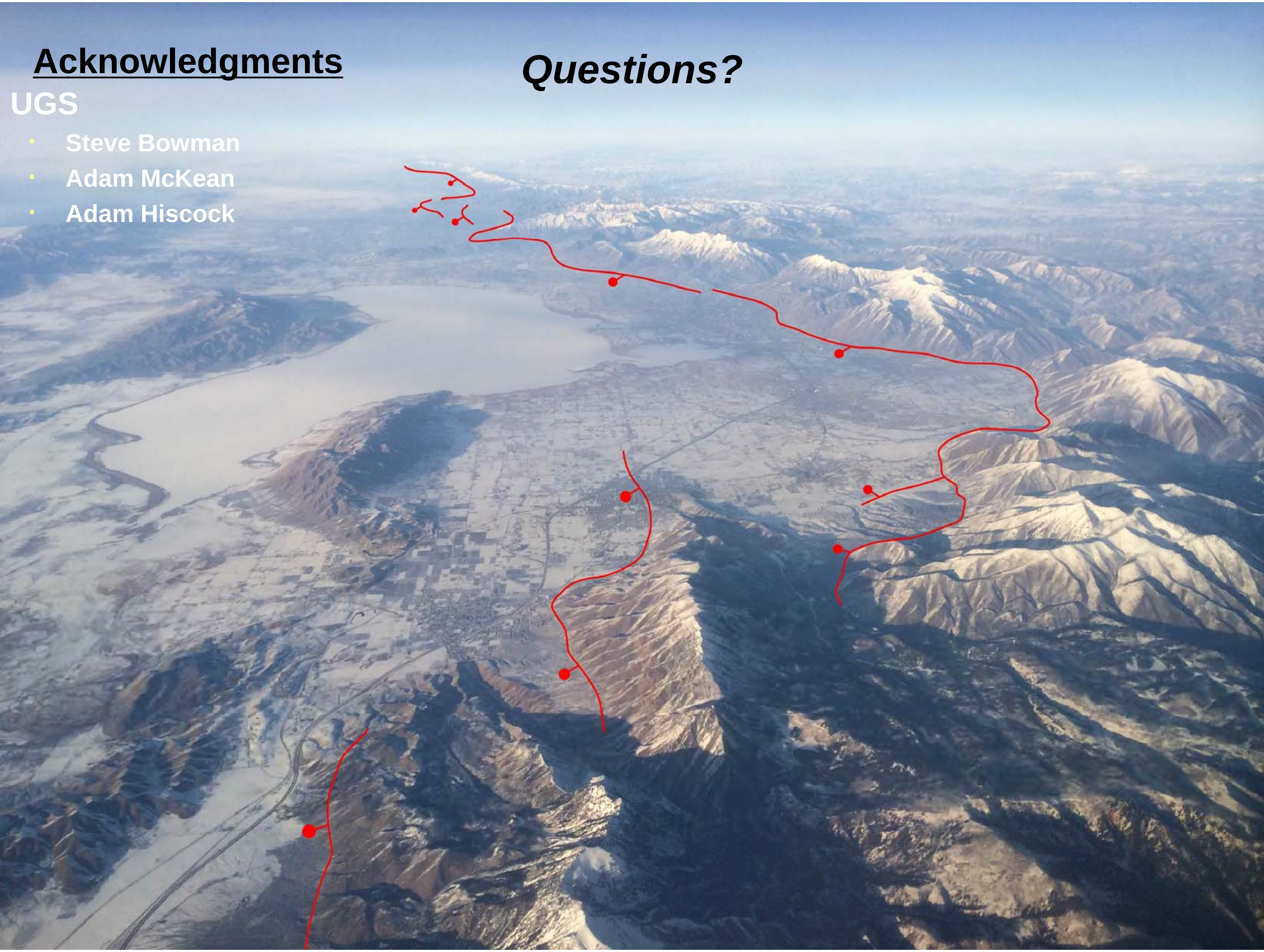
USGS

Acknowledgments

UGS

- **Steve Bowman**
- **Adam McKean**
- **Adam Hiscock**

Questions?



Recent Paleoseismic Trenching Studies Along the Provo Segment, Wasatch Fault Zone

Scott Bennett, Christopher DuRoss, Ryan Gold, Richard Briggs, Stephen Personius, Nadine Reitman, Josh DeVore, Adam Hiscock, Shannon Mahan

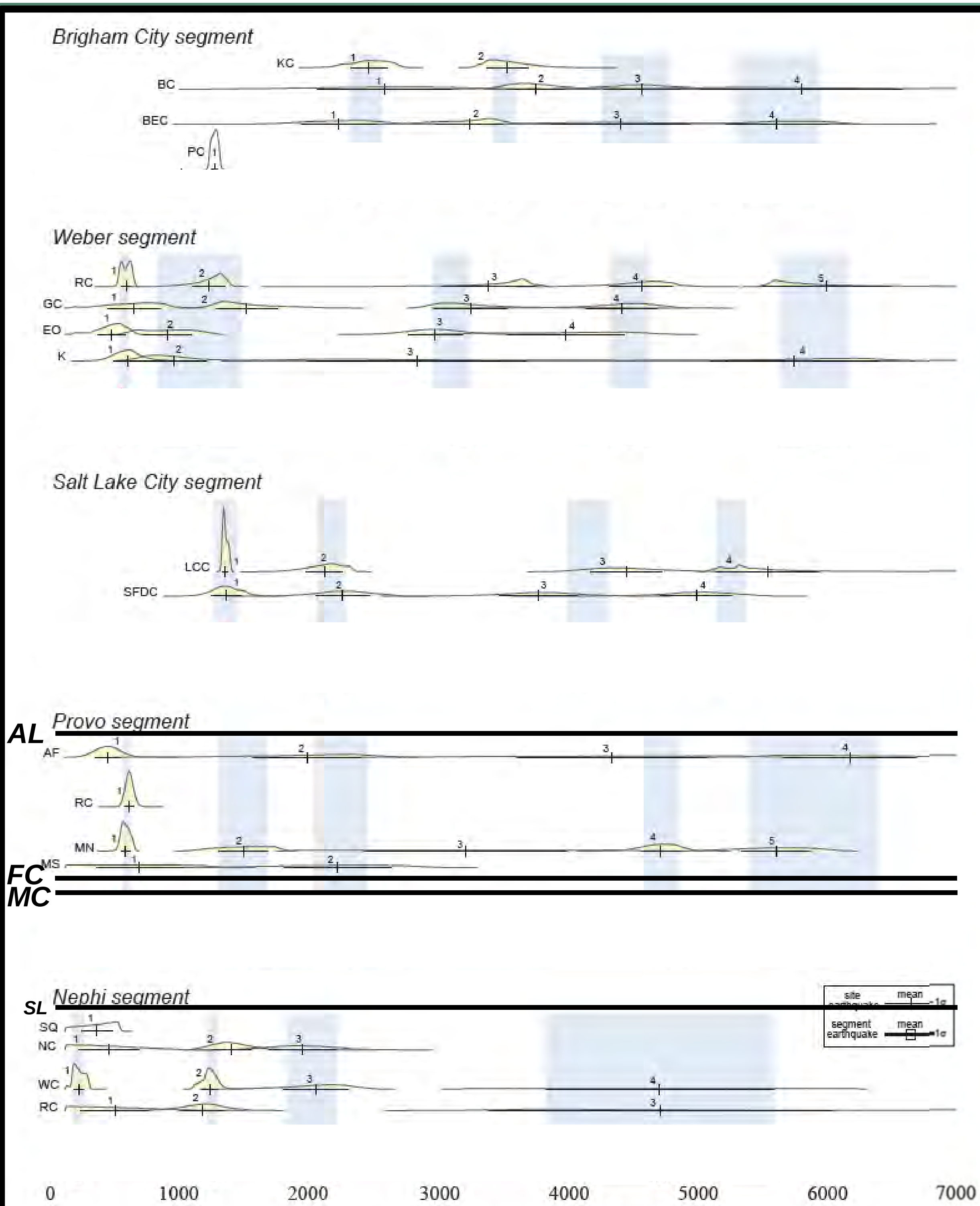
UQFPWG ***February 10, 2015*** ***Salt Lake City, UT***

Methods

Conduct Paleoseismic Trenching

- near segment boundaries
- temporal correlation of EQs
- significant displacements

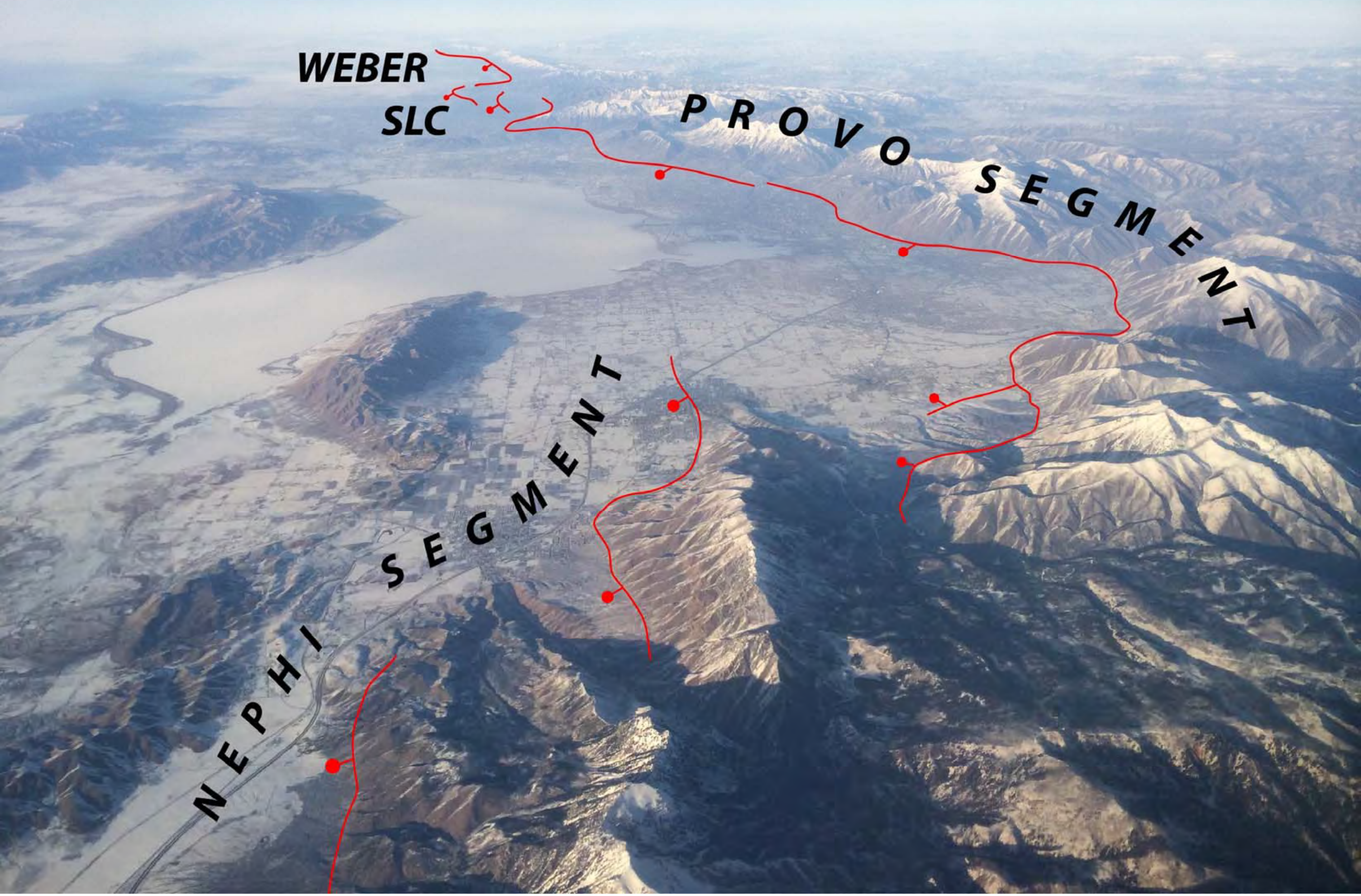
USGS



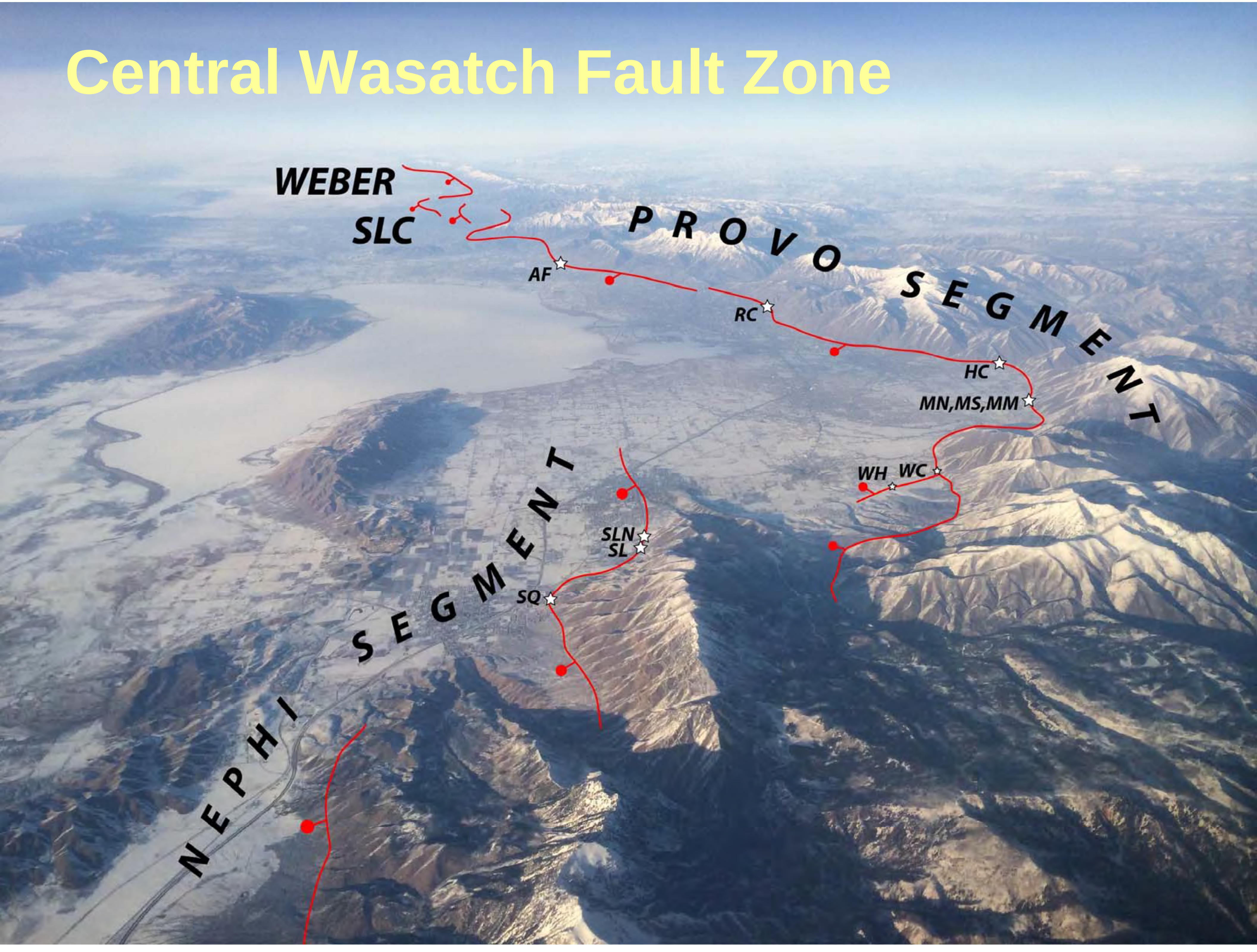
DuRoss et al. (in review)


Central Wasatch Fault Zone

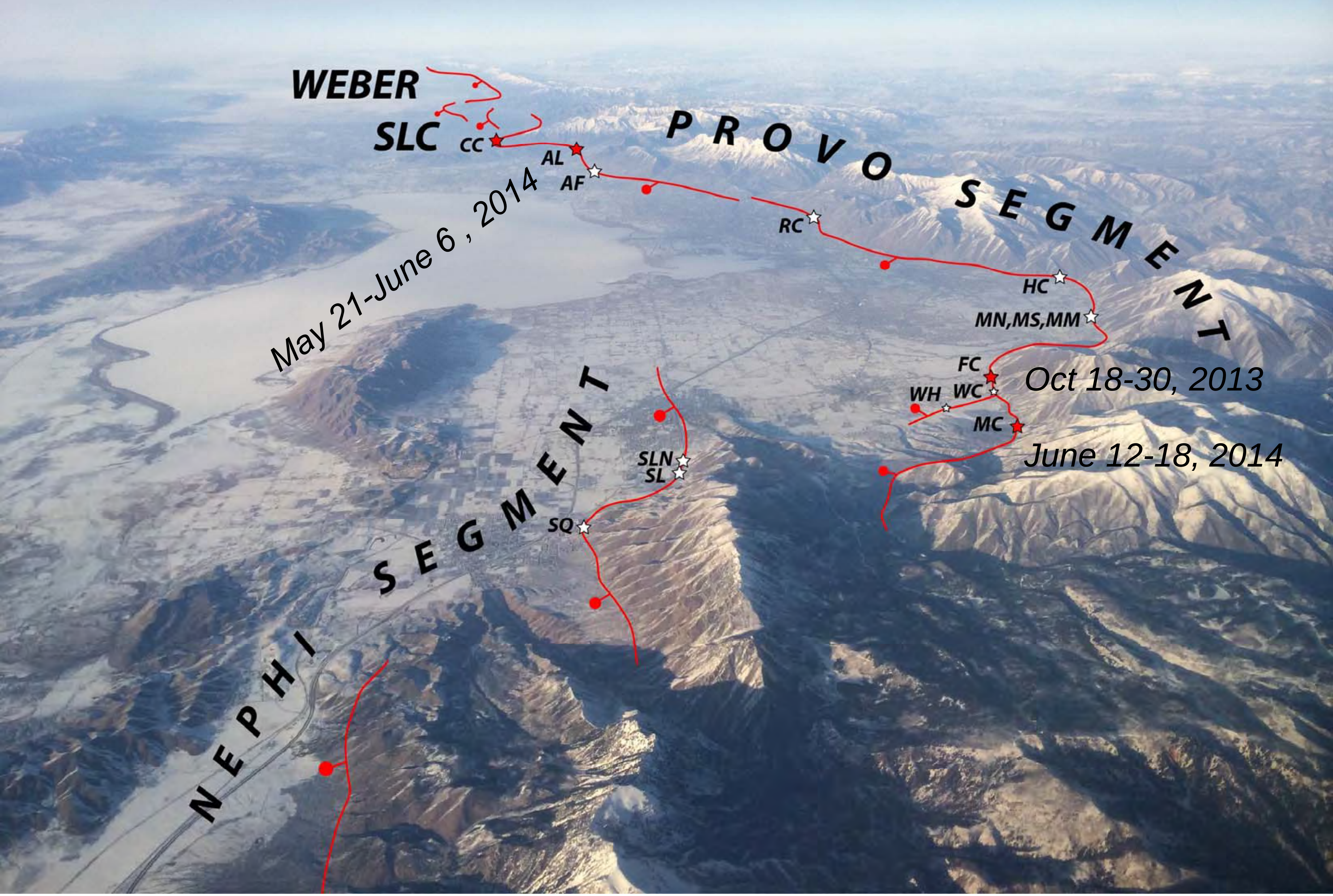
Central Wasatch Fault Zone



Central Wasatch Fault Zone

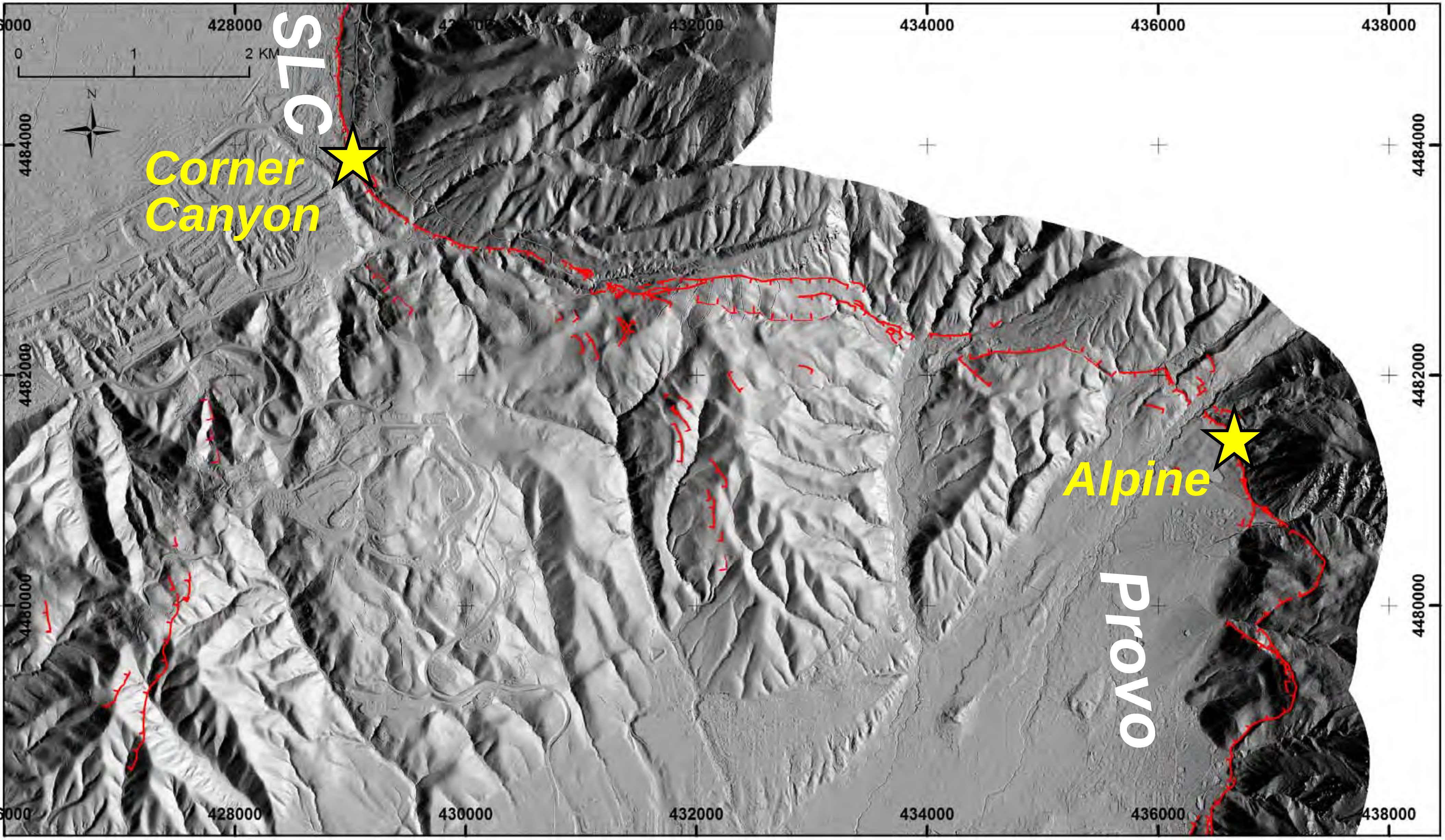


Central Wasatch Fault Zone



Wasatch Fault paleoseismology

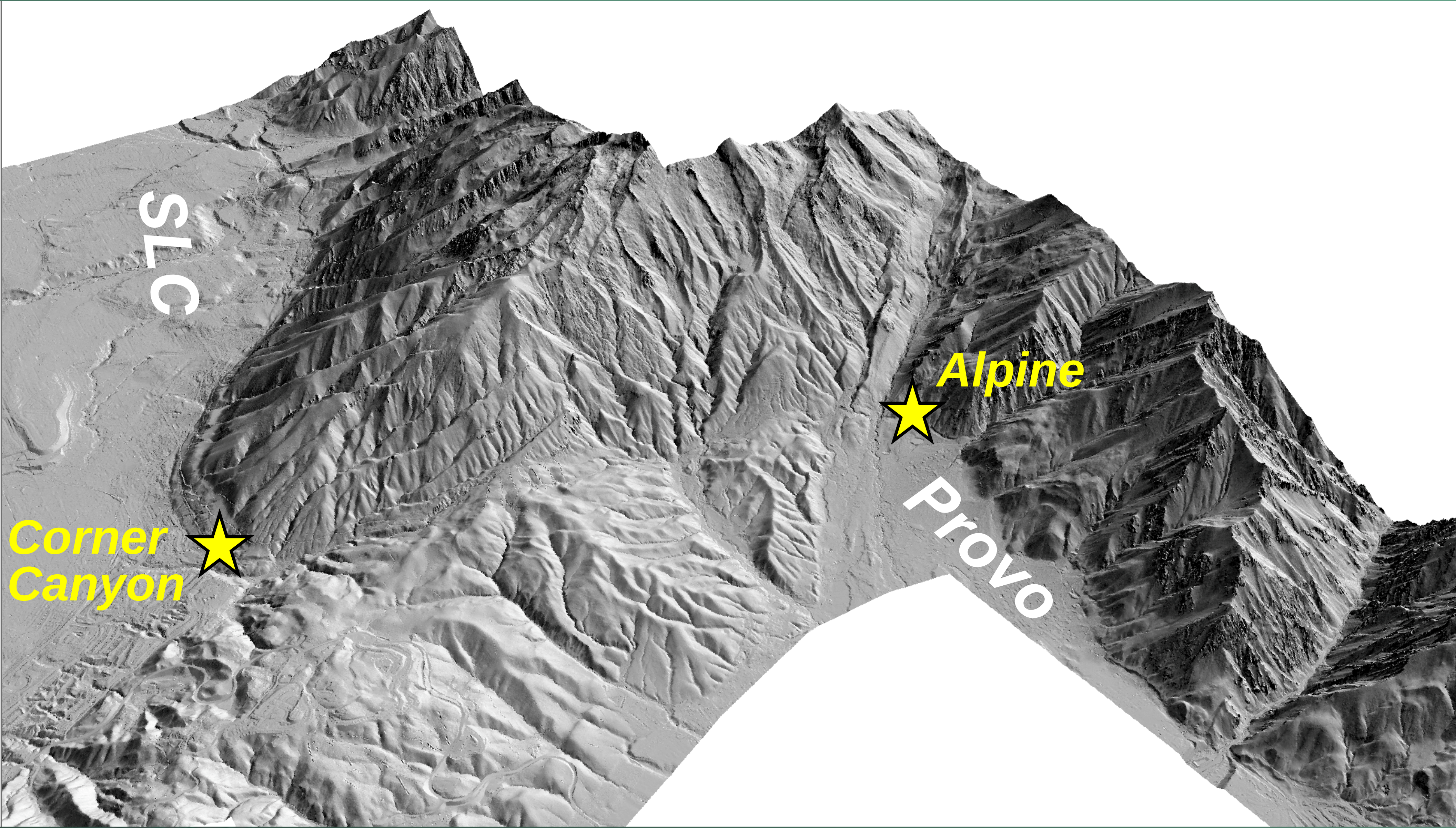
Salt Lake City-Provo segment boundary



0.5m LiDAR (2014)

Wasatch Fault paleoseismology

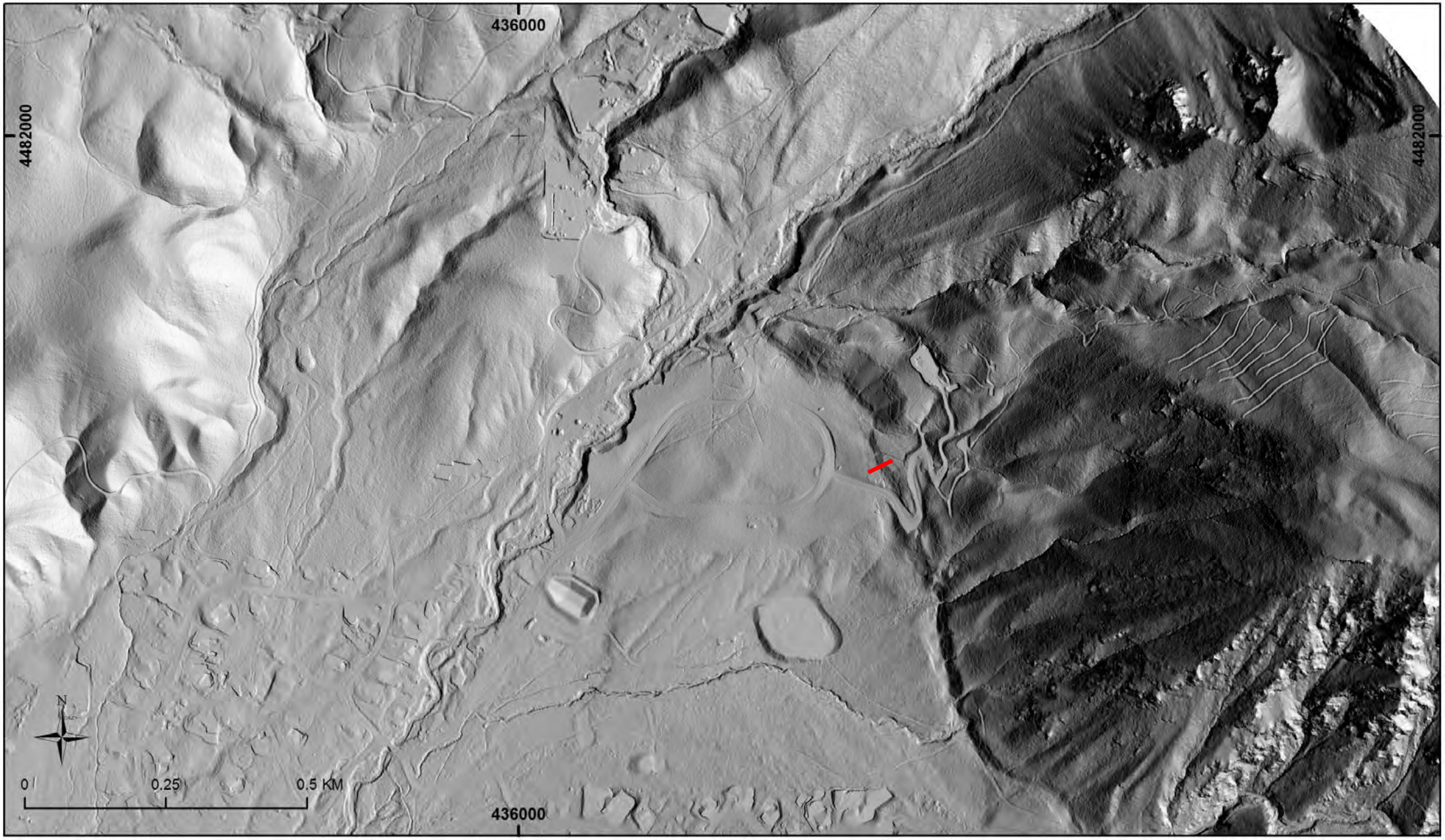
Salt Lake City-Provo segment boundary



0.5m LiDAR (2014)

Wasatch Fault paleoseismology

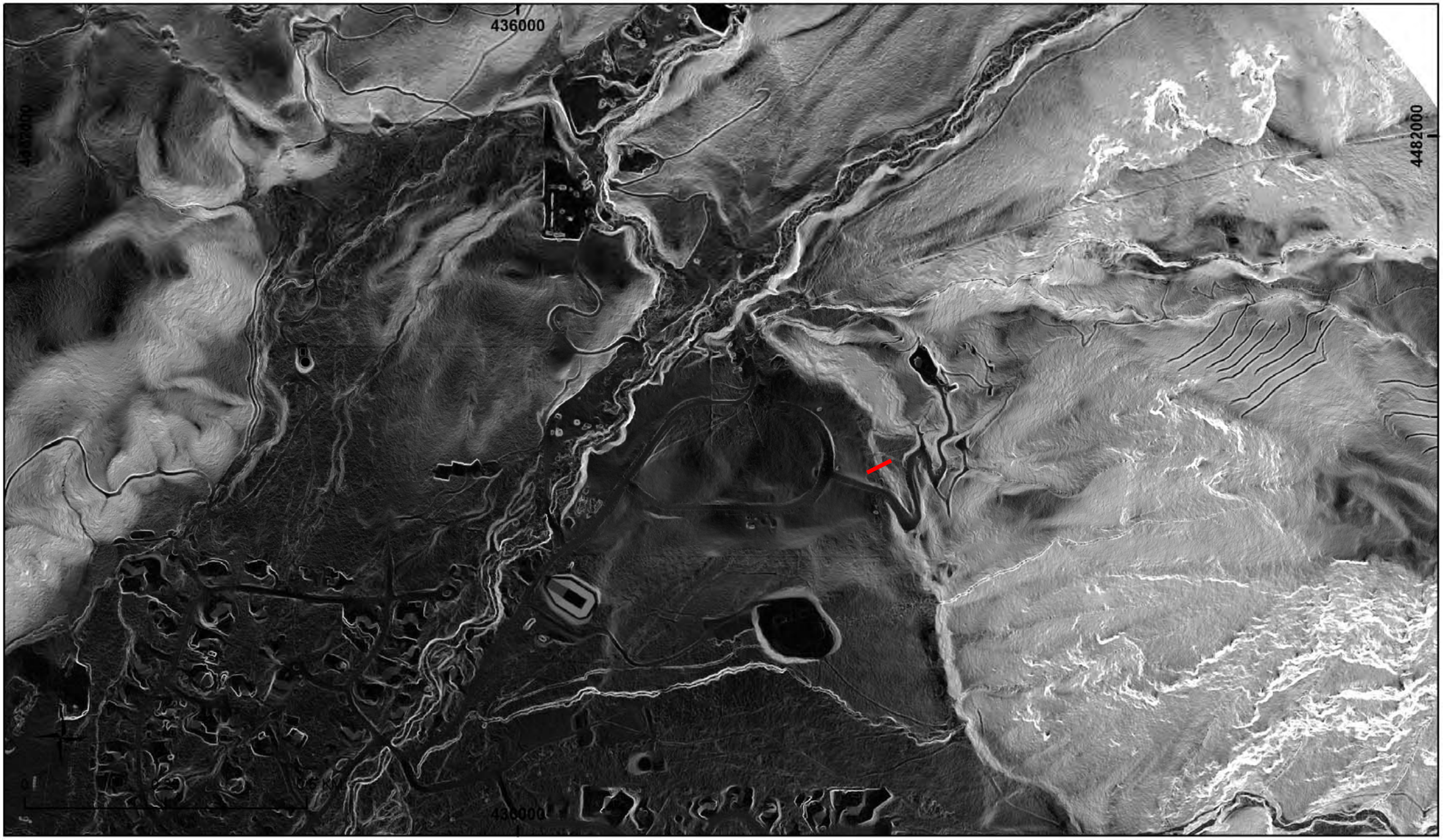
Alpine trench site



0.5m LiDAR (2014)

Wasatch Fault paleoseismology

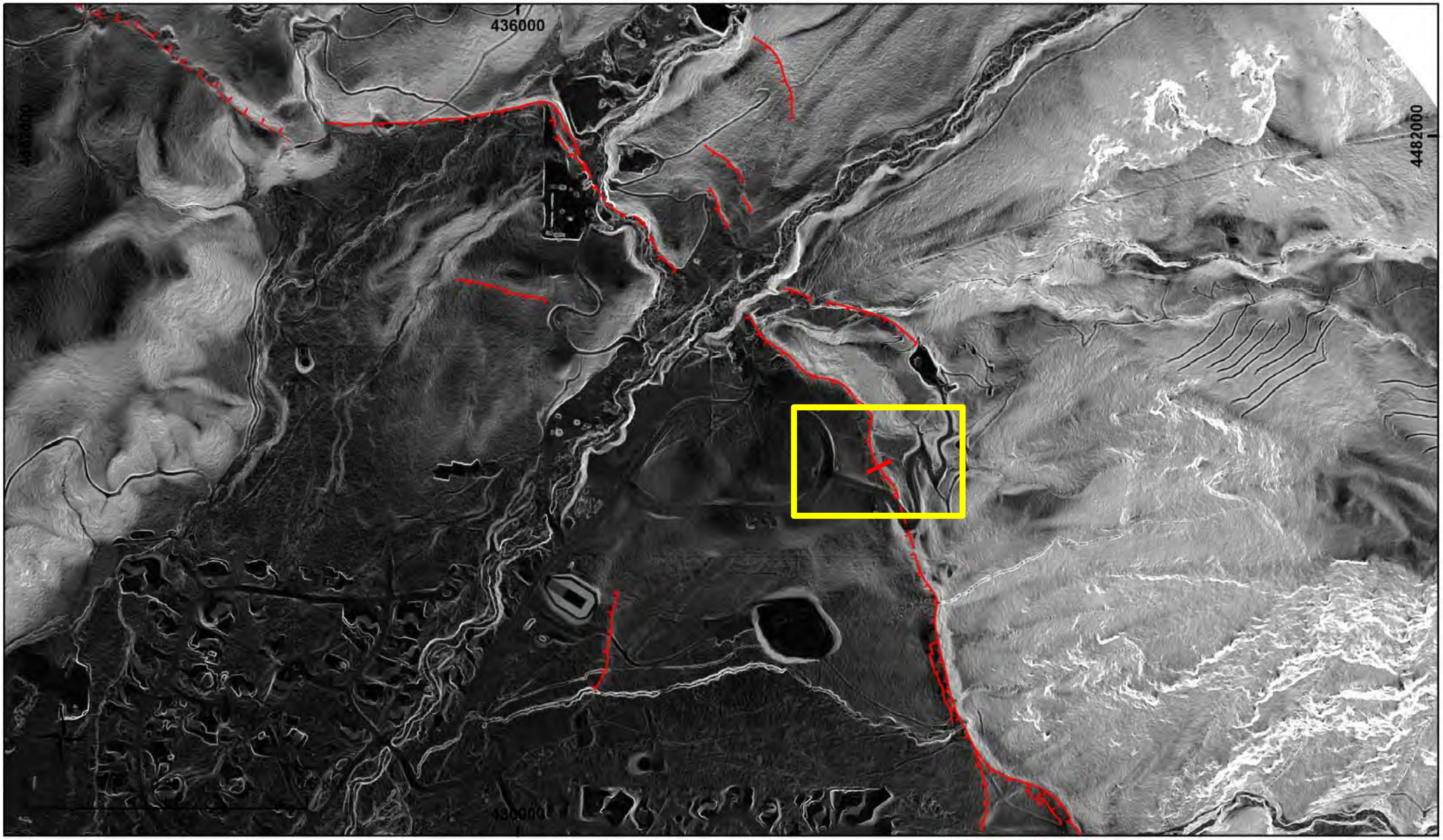
Alpine trench site



0.5m LiDAR (2014)

Wasatch Fault paleoseismology

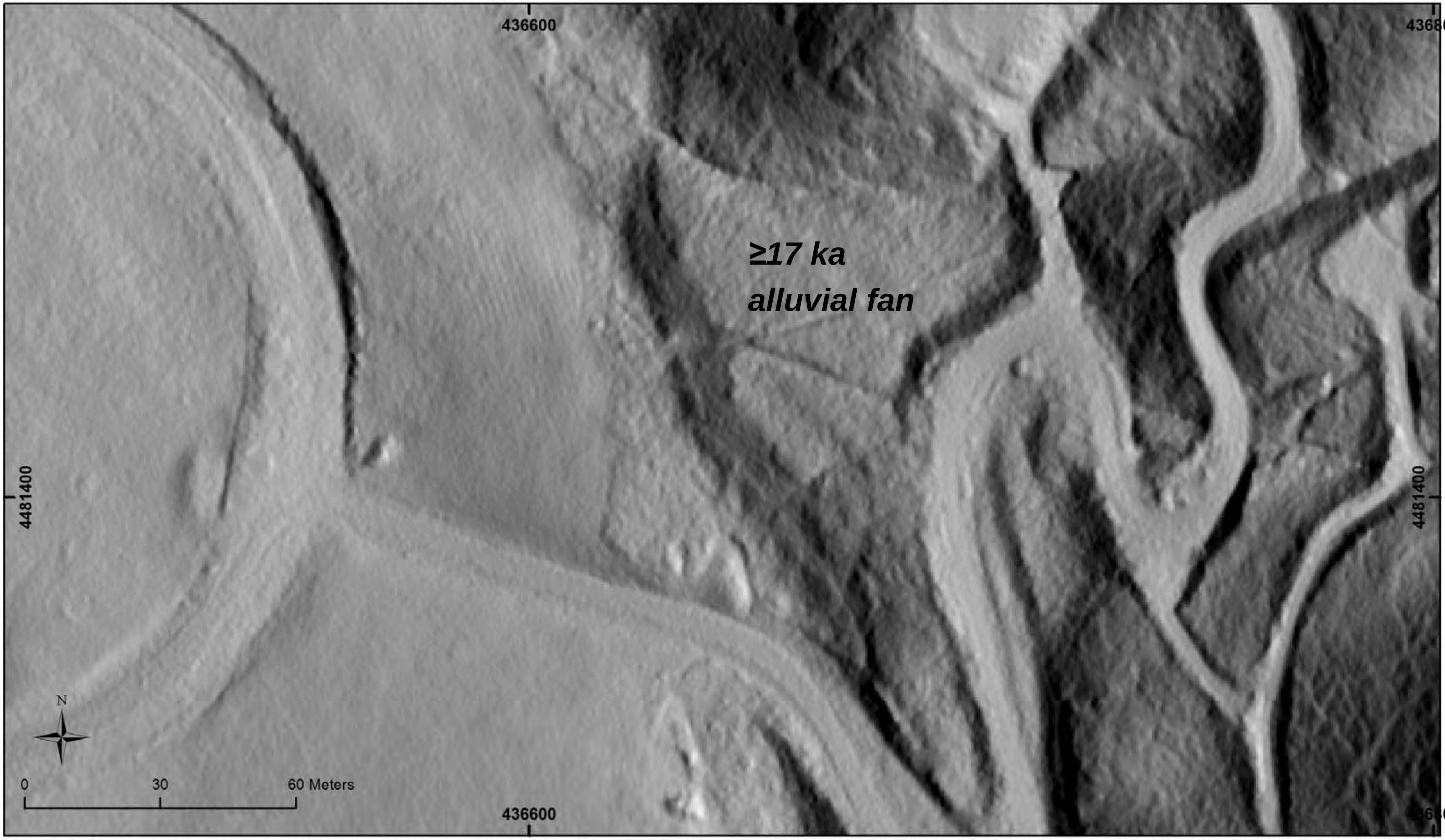
Alpine trench site



0.5m LiDAR (2014)

Wasatch Fault paleoseismology

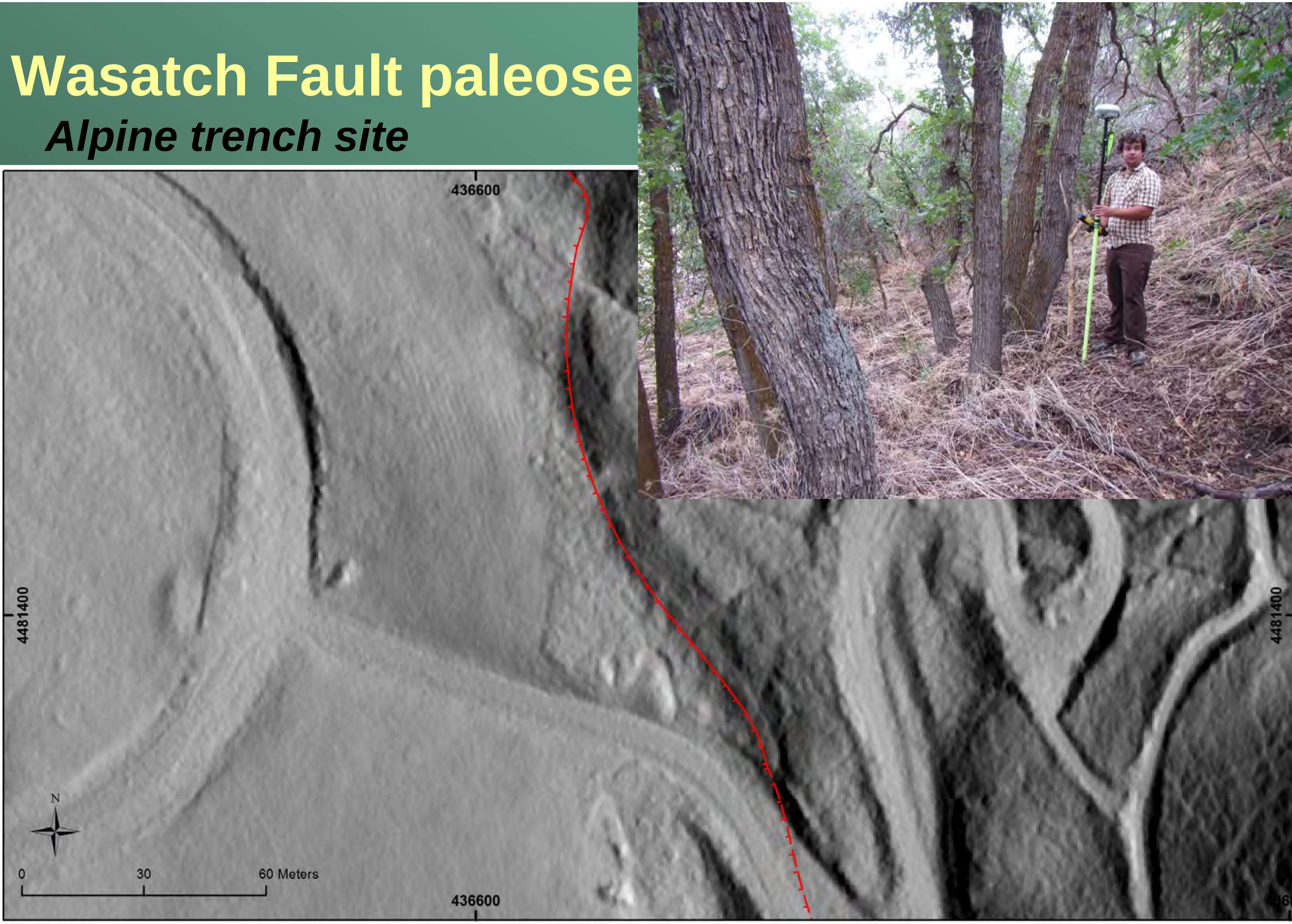
Alpine trench site



0.5m LiDAR (2014)

Wasatch Fault paleose

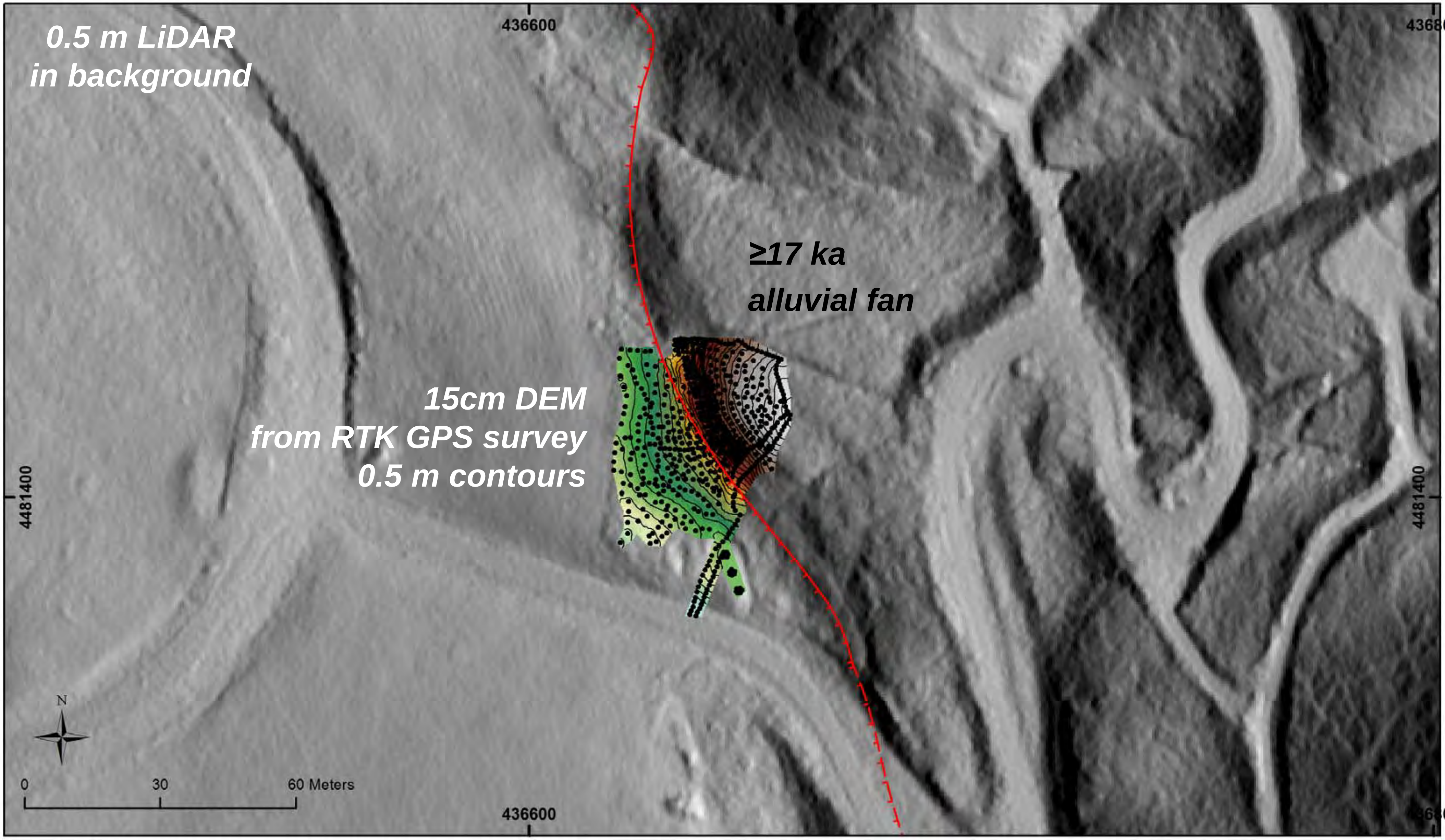
Alpine trench site



0.5m LiDAR (2014)

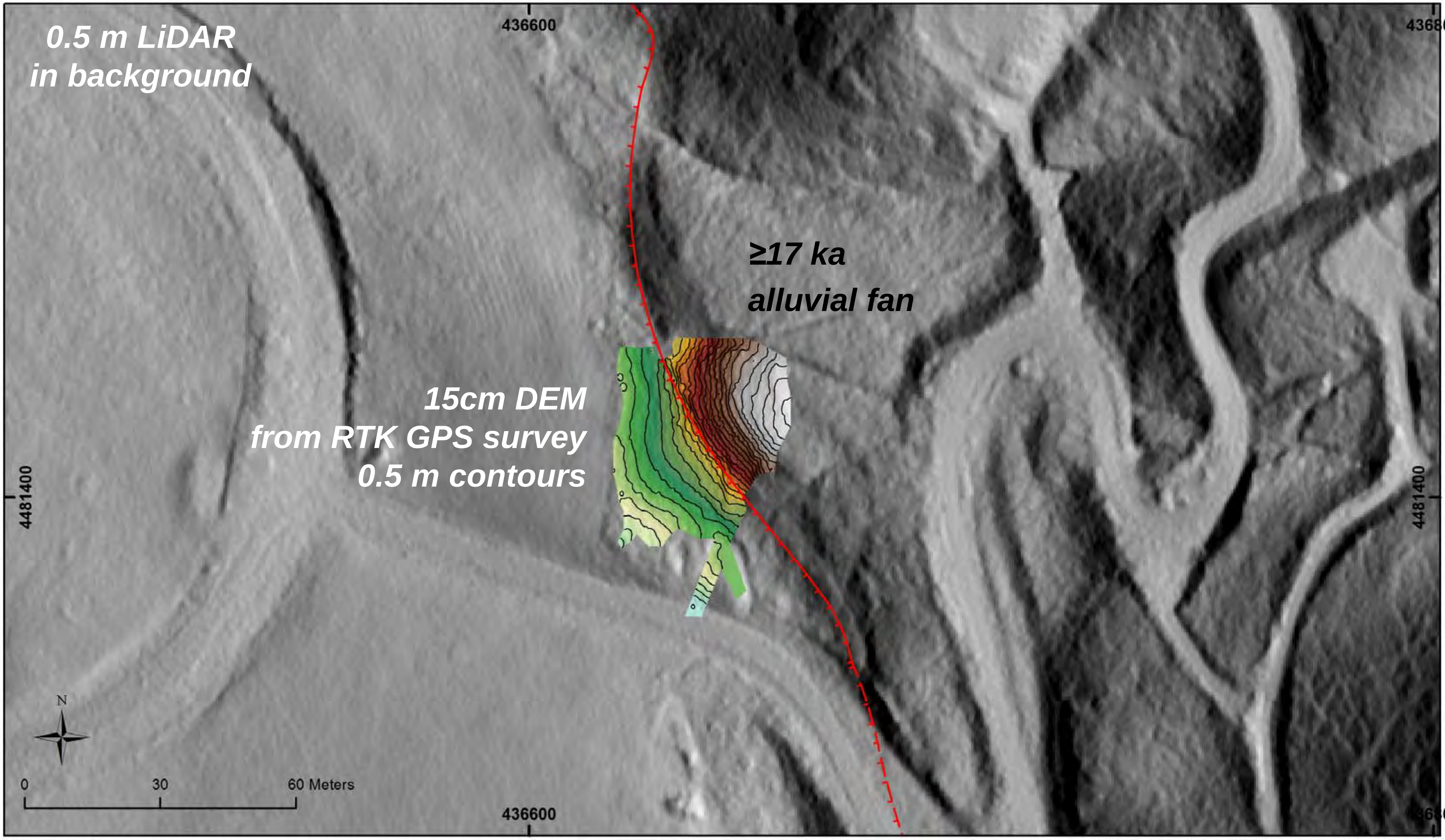
Wasatch Fault paleoseismology

Alpine trench site – RTK GPS Topo Survey



Wasatch Fault paleoseismology

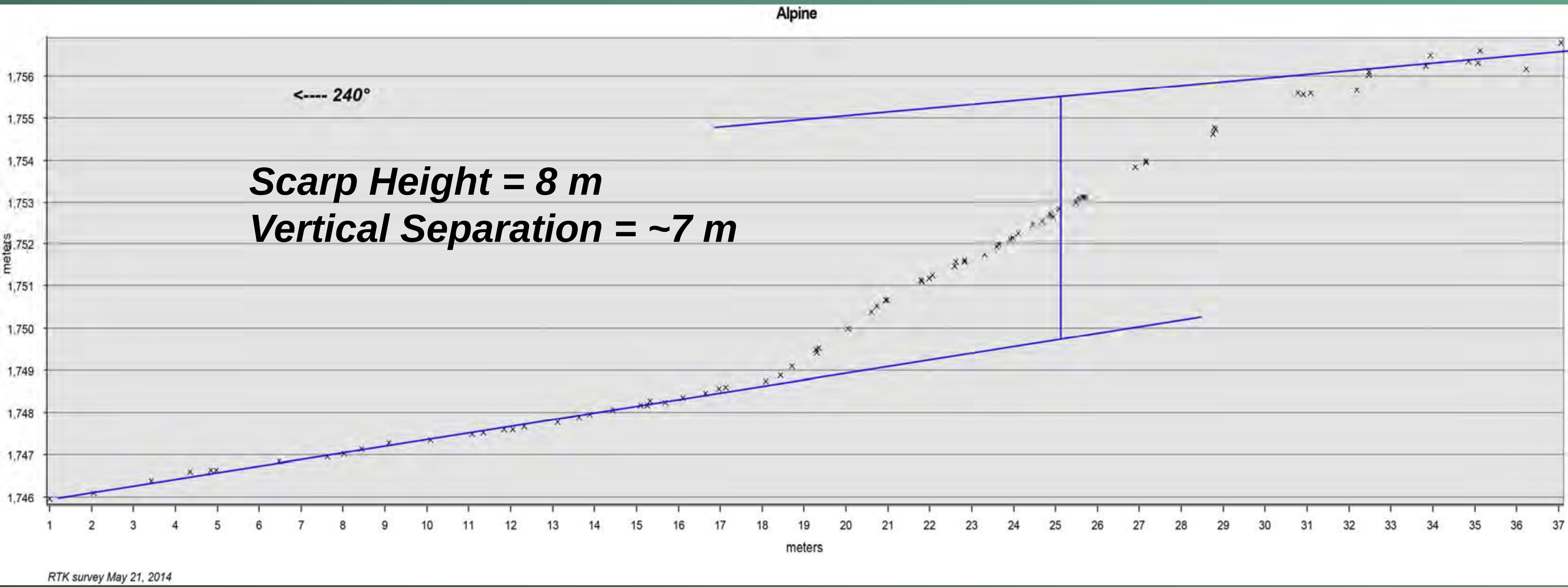
Alpine trench site – RTK GPS Topo Survey



Wasatch Fault paleoseismology

Alpine trench site – Fault Scarp Profile

WEST ***EAST***



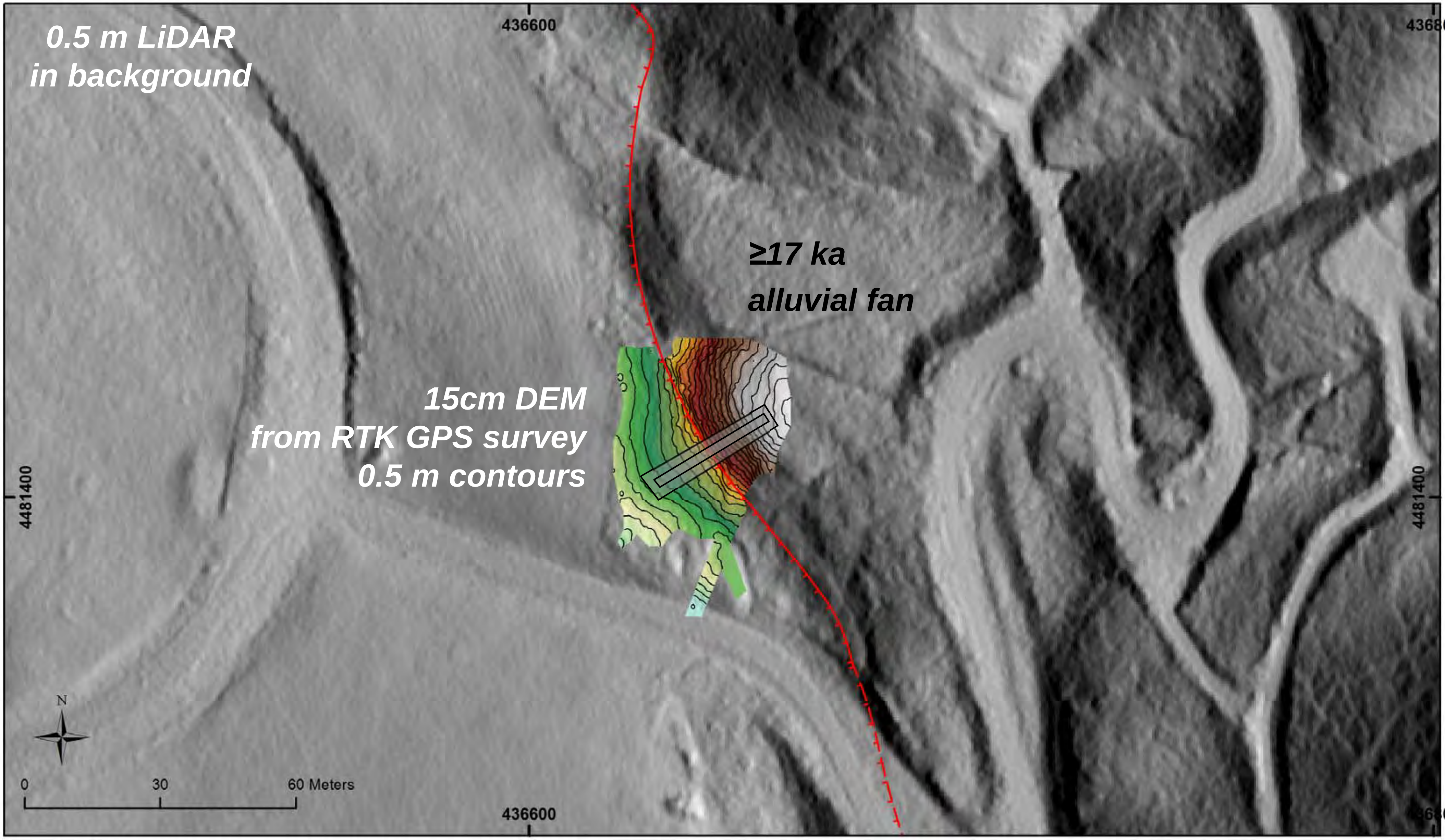
Wasatch Fault paleoseismology

Alpine trench site – Excavated May 22, 2014

USGS

Wasatch Fault paleoseismology

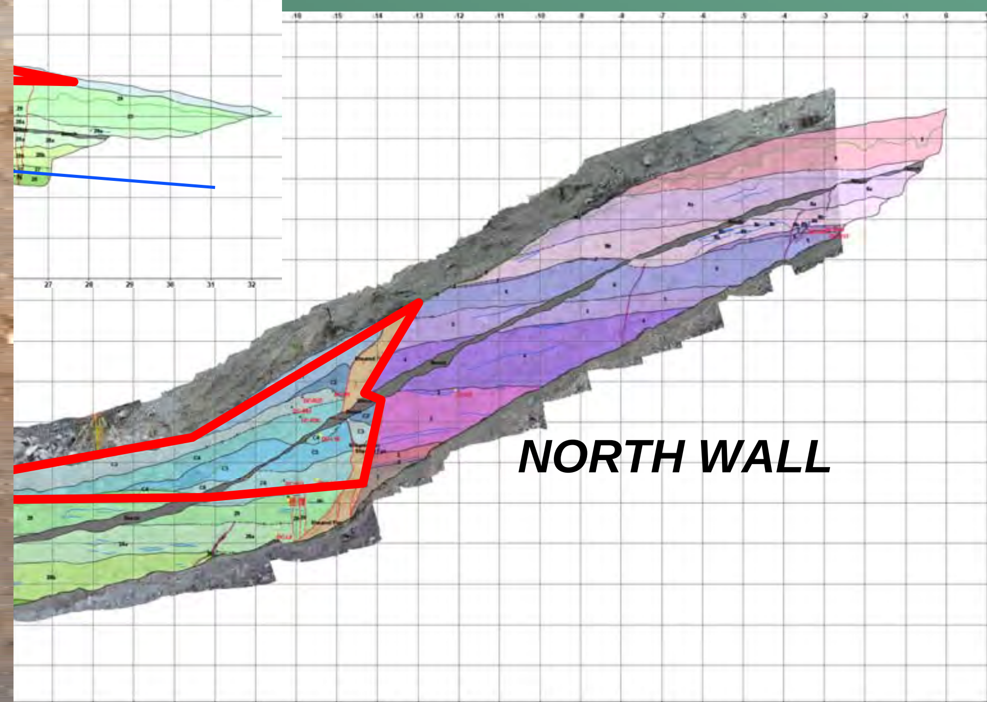
Alpine trench site – Excavated May 22, 2014



mology

s

~7m vertical separation of unique silt bed



Wasatch Fault paleoseismology

Example Geochronology Sampling

Radiocarbon

Optically Stimulated Luminescence

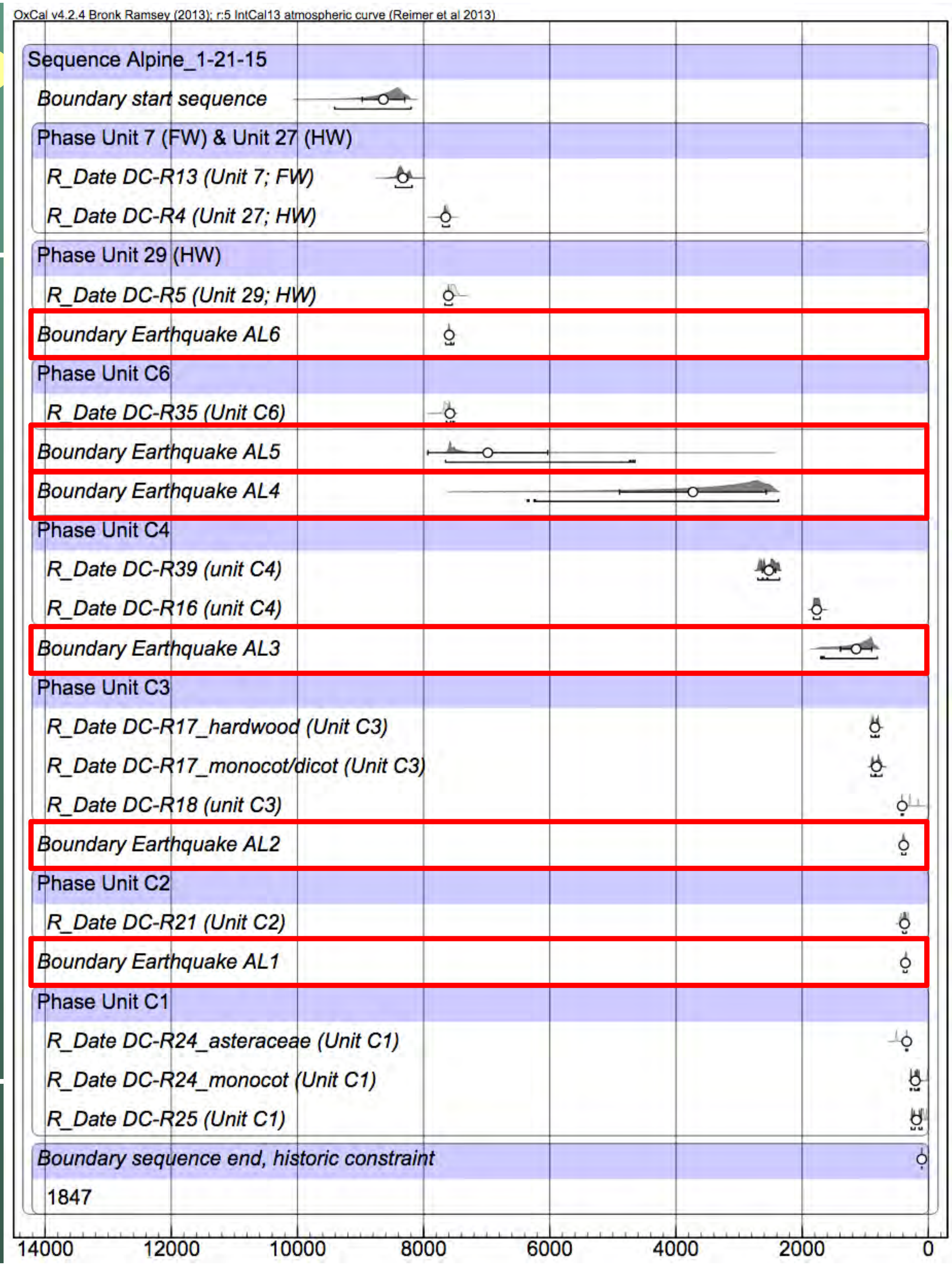
Wasatch Fault paleo

Alpine trench site

***PRELIM* OxCal Model**

Based on only 14 of 19 ^{14}C ages

No OSL ages yet



OxCal software by Bronk Ramsey (2013)

Wasatch Fault paleoseismology

Trench Review June 5, 2014

USGS

Wasatch Fault paleoseismology

Trench Backfilled June 6, 2014

photos taken June 13, 2014

Wasatch Fault paleoseismology

Alpine trench site – SUMMARY

Mapped age of fan = ≥18 ka (af3/af4)

Trench length = 32 m
Trench depth = 3-4 m

^{14}C samples collected = 41
^{14}C samples dated = 14 (5 more April 2015)

OSL samples collected = 18
OSL sample dated = 18 (April 2015)

Scarp Height = 8 m
Surface Offset = 7 m

# of earthquakes = 6

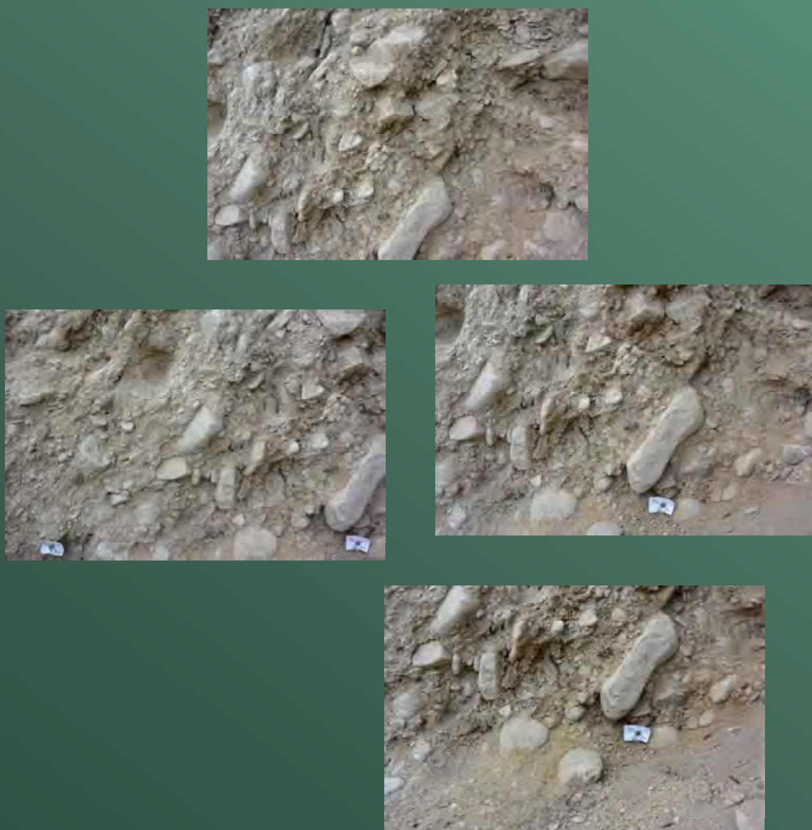
EQ timing = TBD

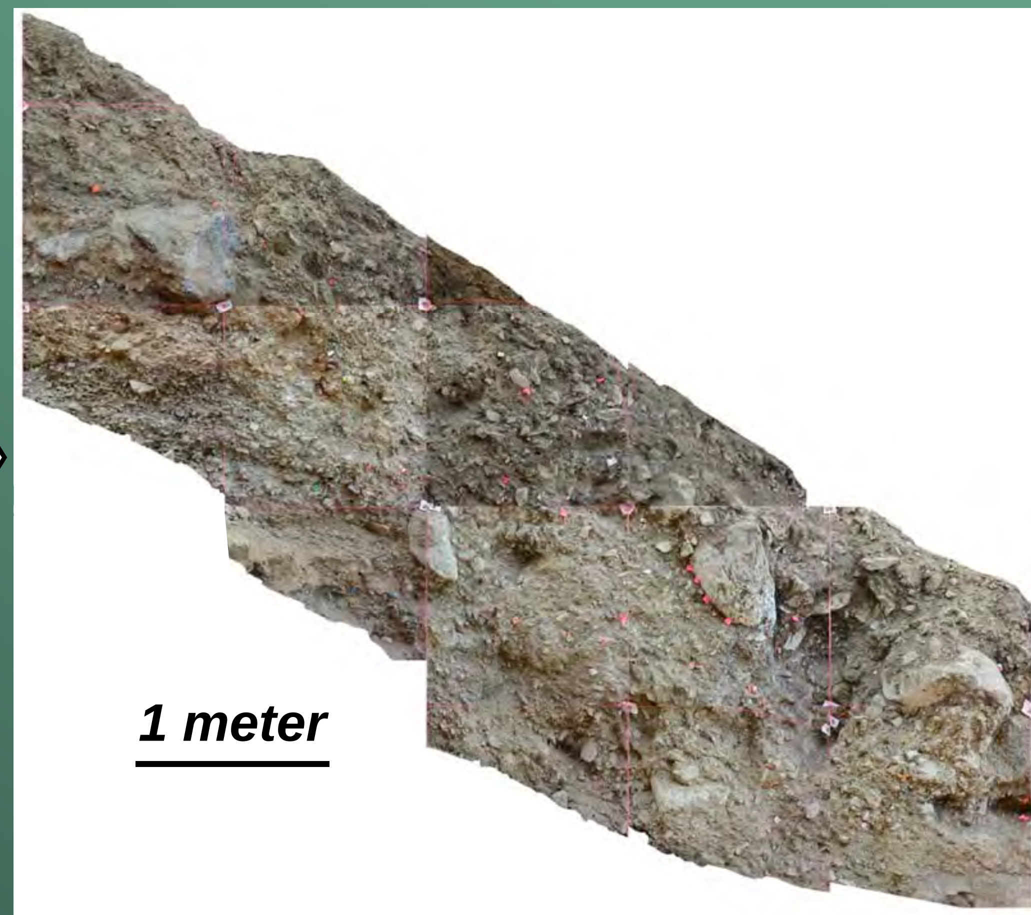
USGS

Next Generation Trench Log Photomosaics

Structure from Motion (Photogrammetry)

Traditional Photomosaic Method





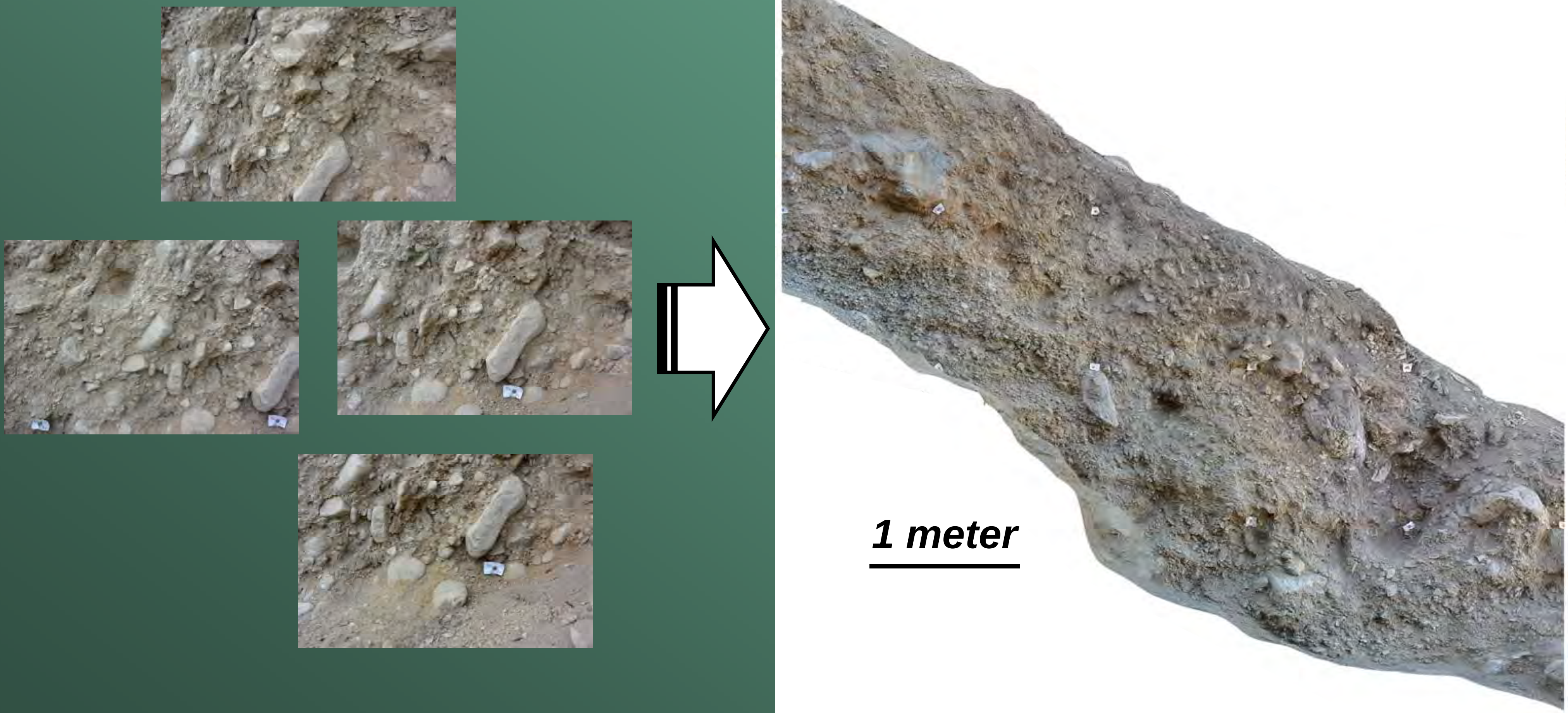
Reitman et al. (in review)

USGS

Next Generation Trench Log Photomosaics

Structure from Motion (Photogrammetry)

SfM Photomosaic Method



Reitman et al. (in review)

USGS

Next Generation Trench Log Photomosaics

Structure from Motion (Photogrammetry)

Traditional Photomosaic Method

SfM Photomosaic Method

- ***rapid***
- ***seamless***
- ***accurate***
- ***affordable***

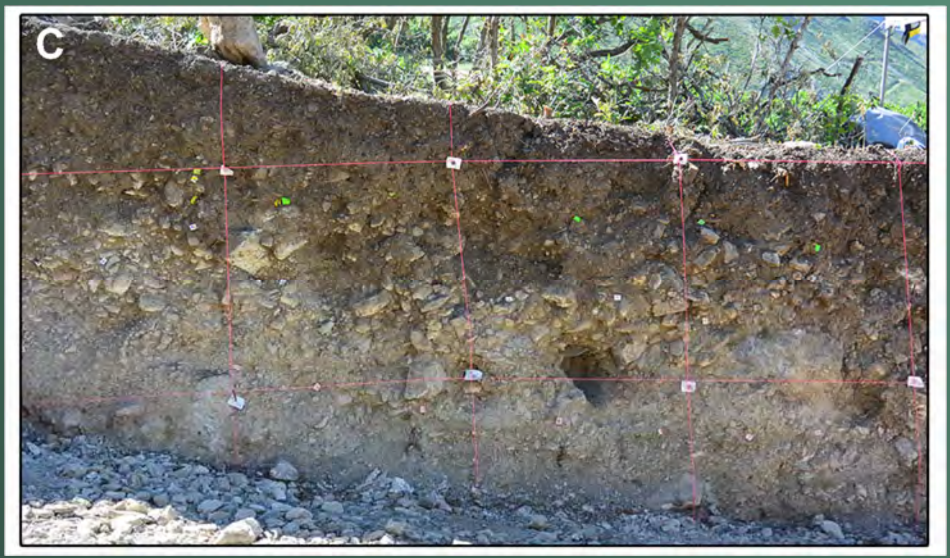
Reitman et al. (in review)

USGS

Next Generation Trench Log Photomosaics

Structure from Motion (Photogrammetry)

Traditional Photomosaic Method



relies on string grid

SfM Photomosaic Method

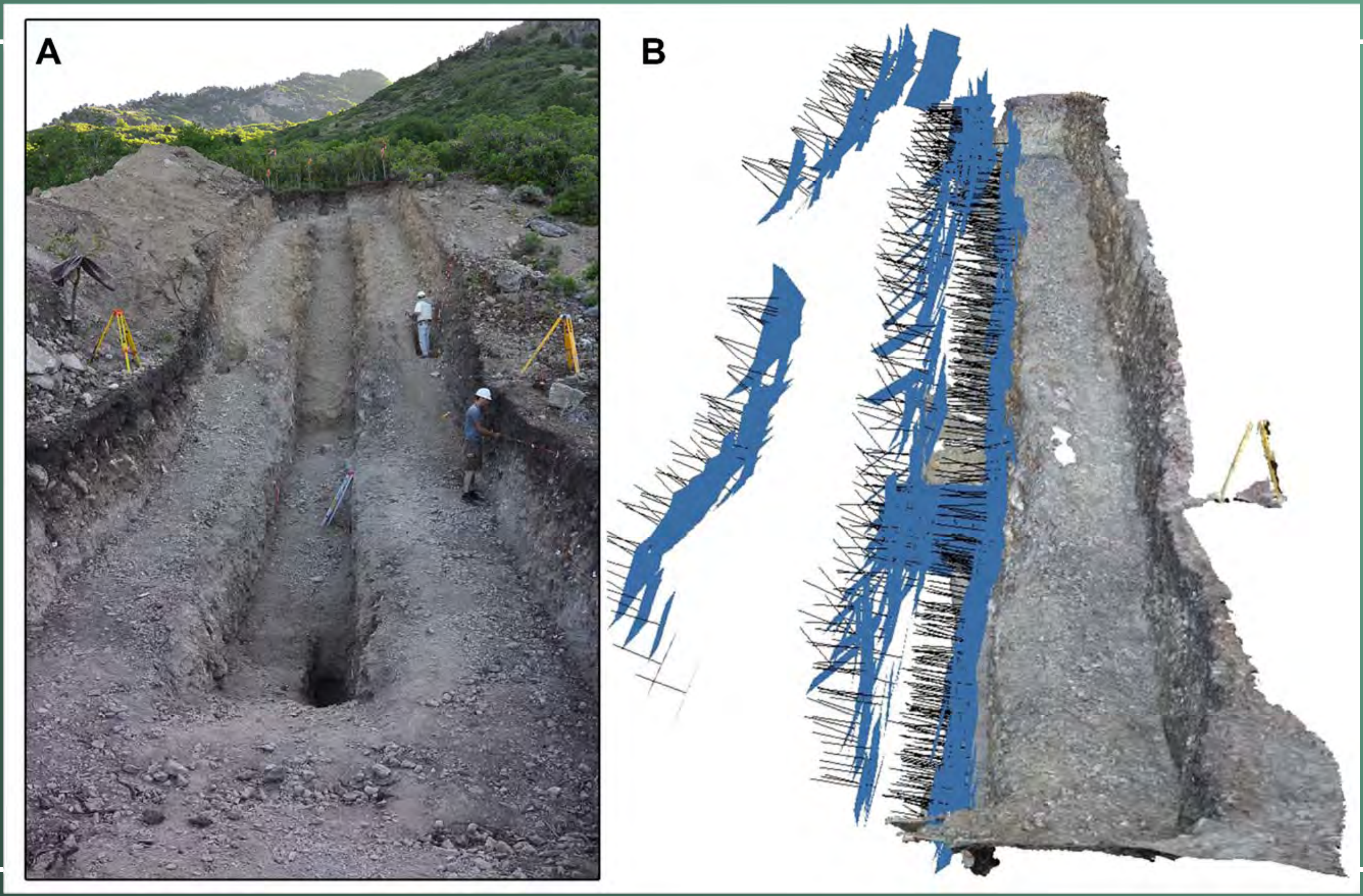
no need for string grid

USGS

Reitman et al. (in review)

Next Generation Trench Log Photomosaics

Structure from Motion (Photogrammetry)

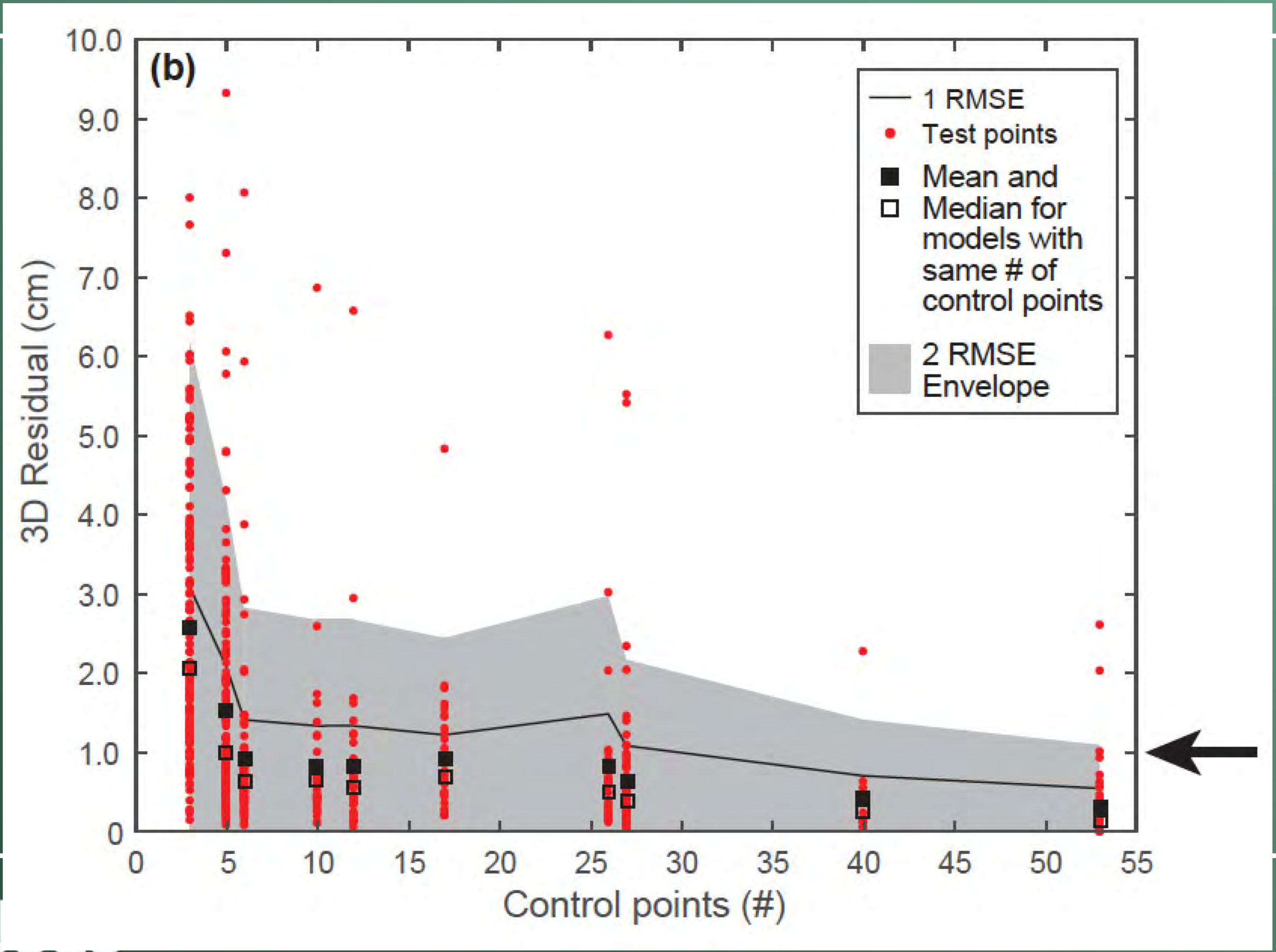


Reitman et al. (in review)

USGS

Next Generation Trench Log Photomosaics

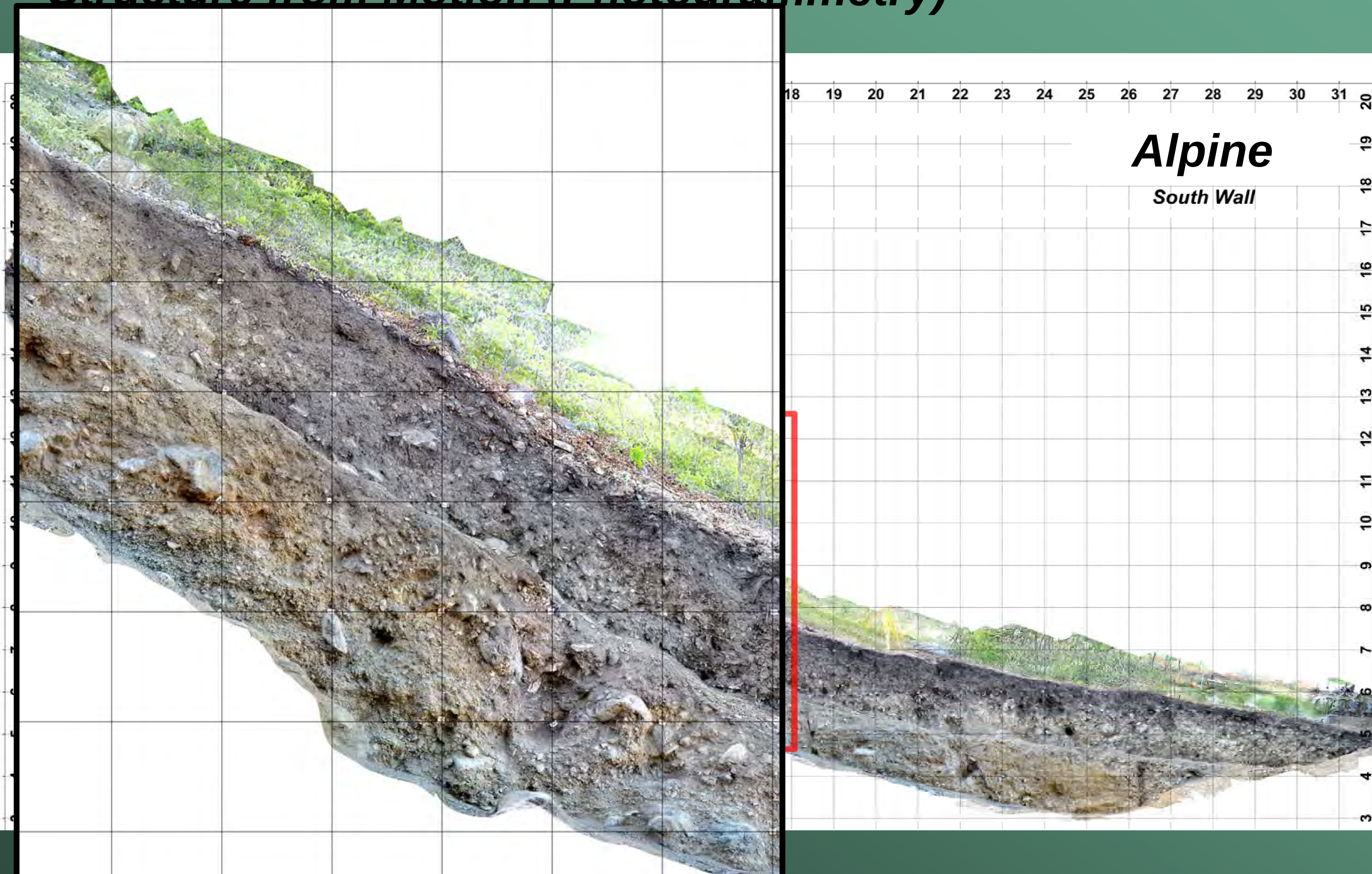
Structure from Motion (Photogrammetry)



Reitman et al. (in review)

Next Generation Trench Log Photomosaics

Structure from Motion (Photogrammetry)



Next Generation Trench Log Photomosaics

Helium Balloon Topo Survey Using Structure from Motion

Ed Nissen & Kendra Johnson (CSM)

USGS

Next Generation Trench Log Photomosaics

Helium Balloon Topo Survey Using Structure from Motion

USGS

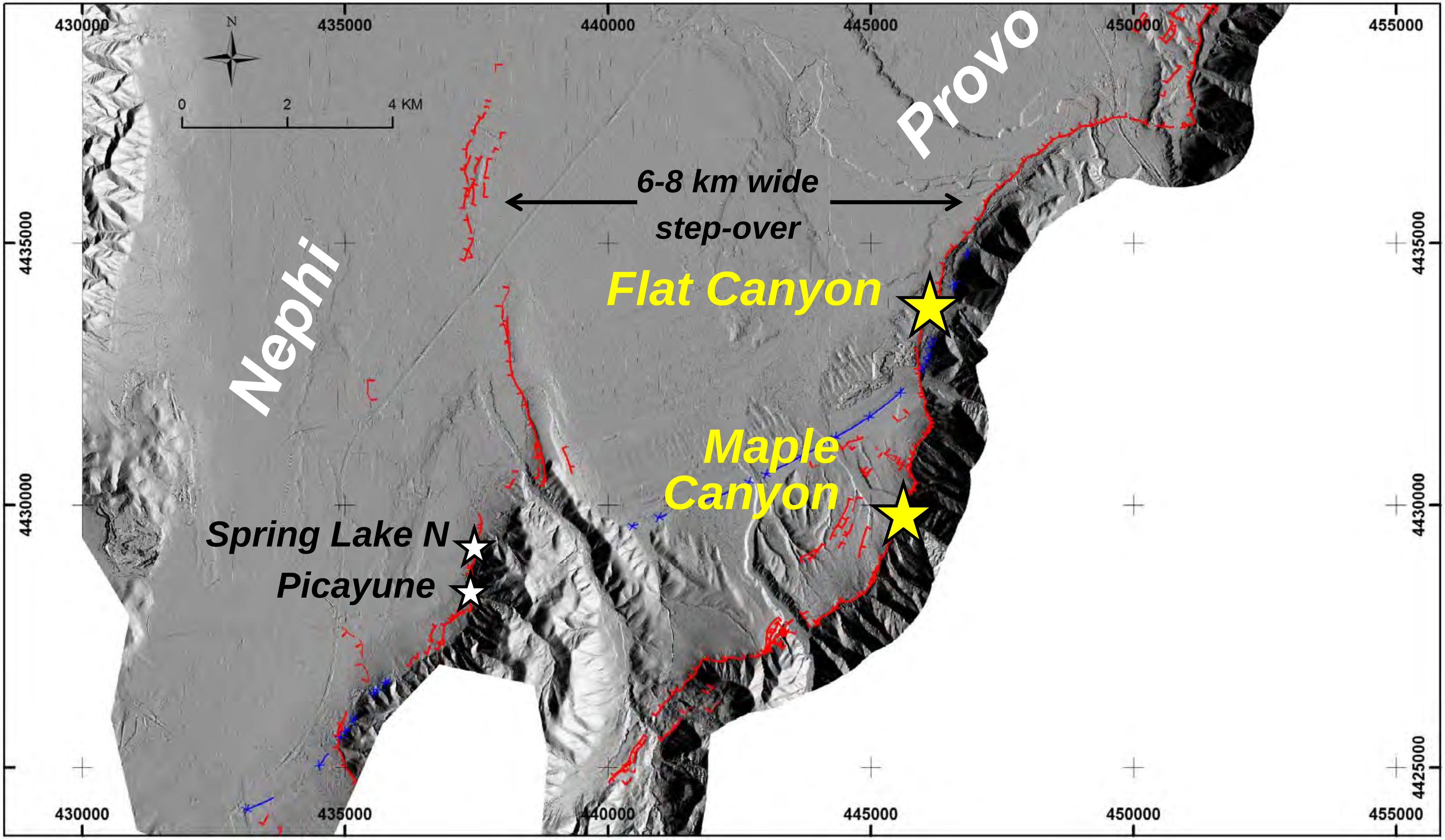
rotate trench model PDF……

Wasatch Fault paleoseismolo

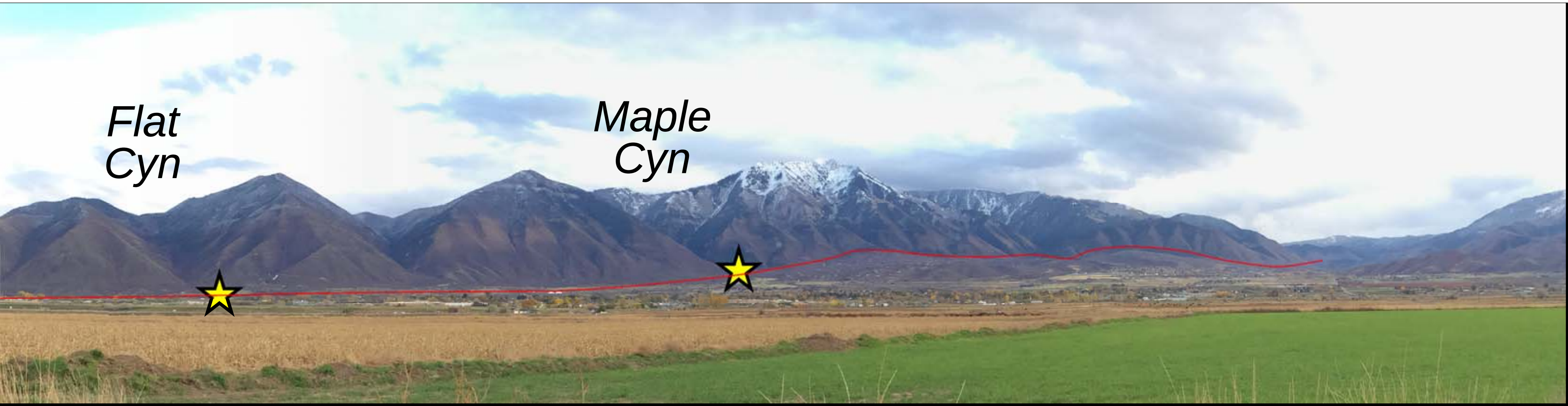
Provo-Nephi segment boundary

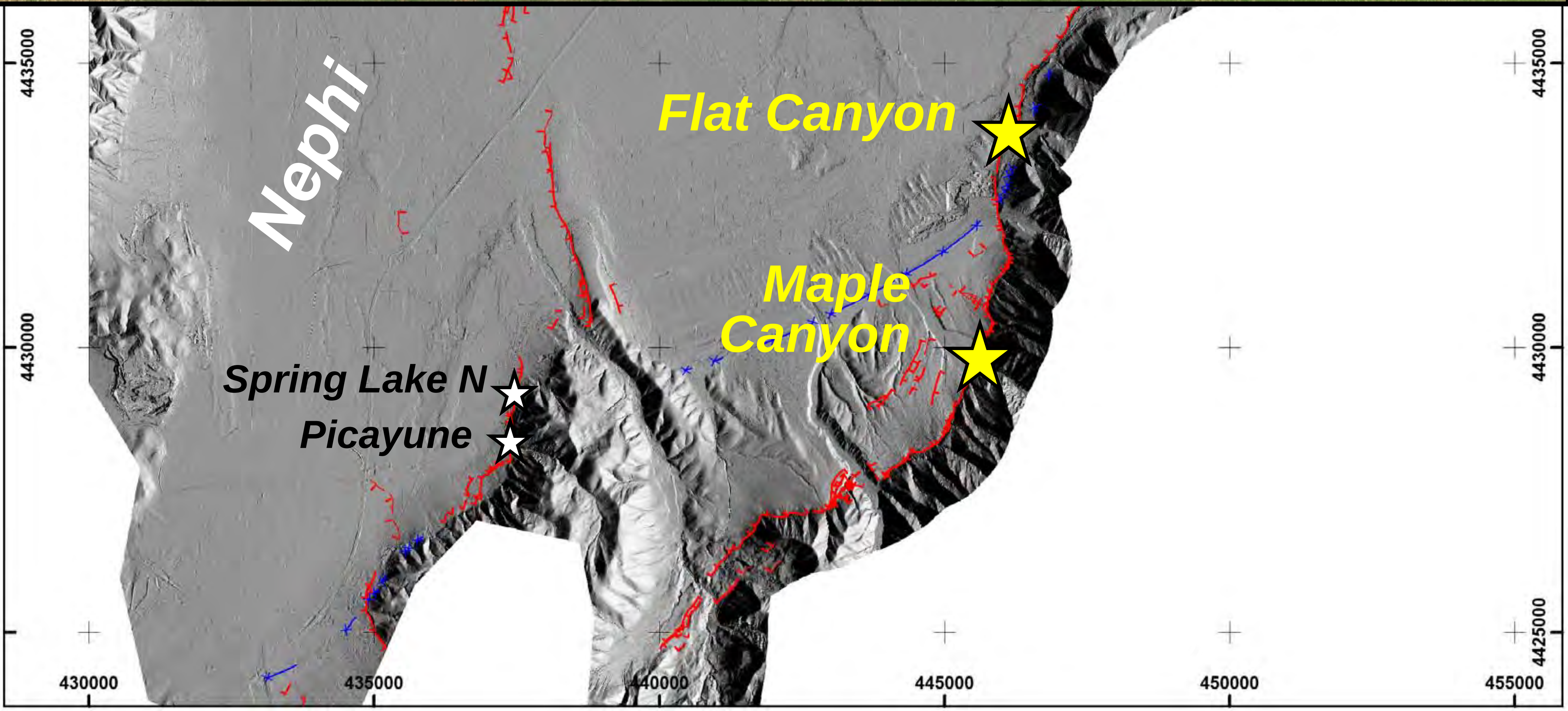
Wasatch Fault paleoseismology

Provo-Nephi segment boundary



0.5m LiDAR (2014)





0.5m LiDAR (2014)

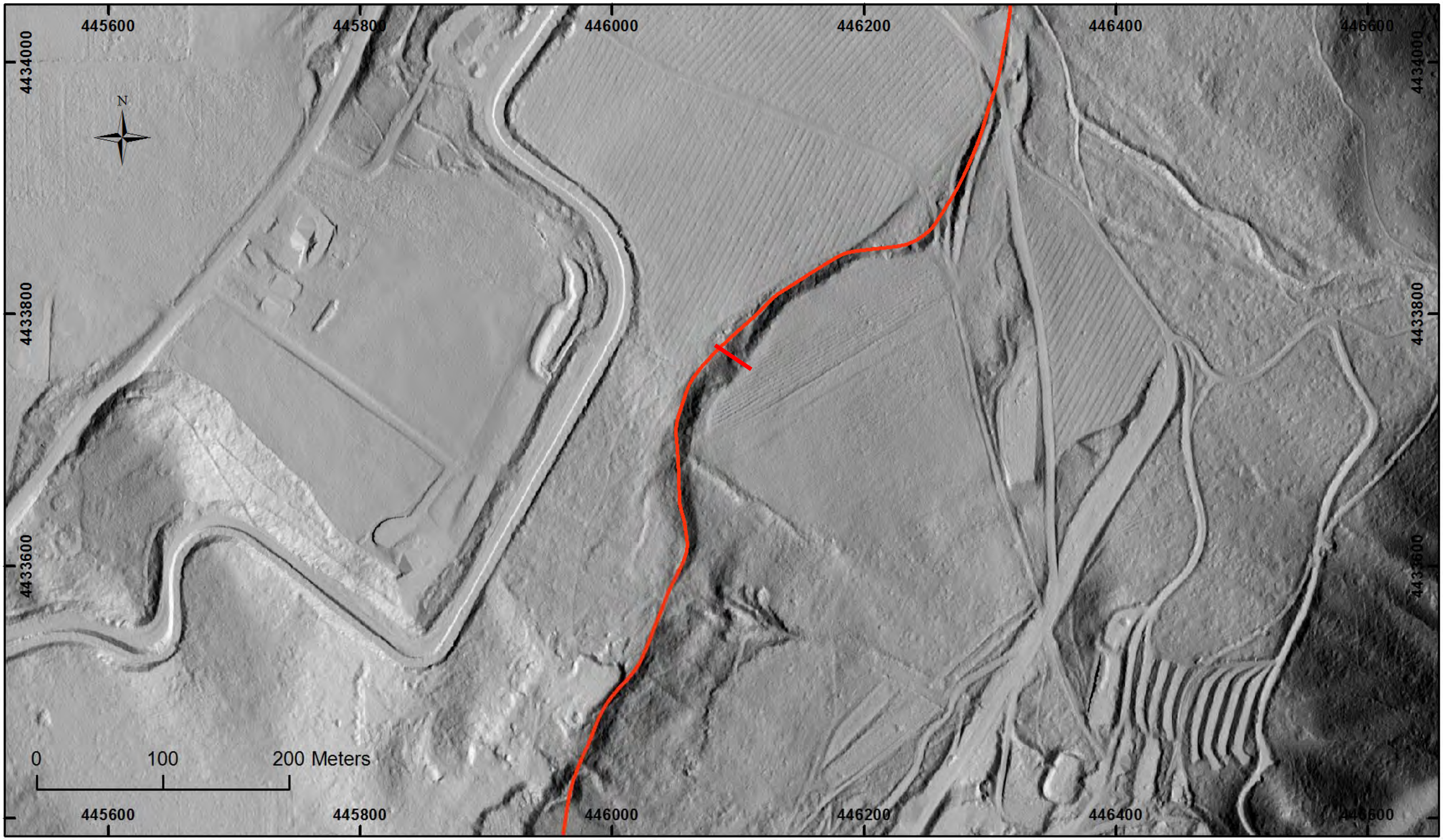
Wasatch Fault paleoseismology

Flat Canyon trench site

0.5m LiDAR (2014)

Wasatch Fault paleoseismology

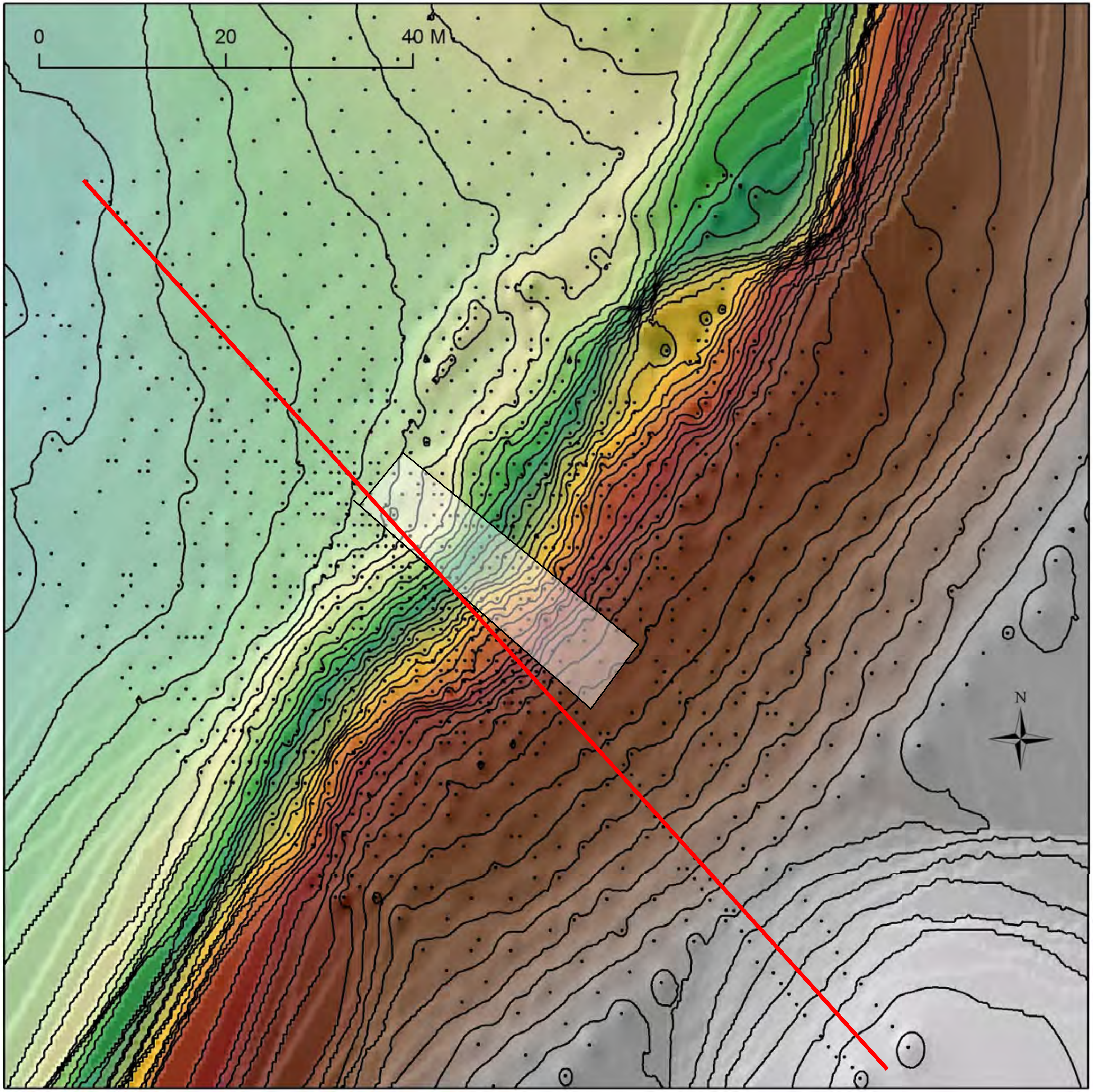
Flat Canyon trench site



0.5m LiDAR (2014)

Wasatch Fa

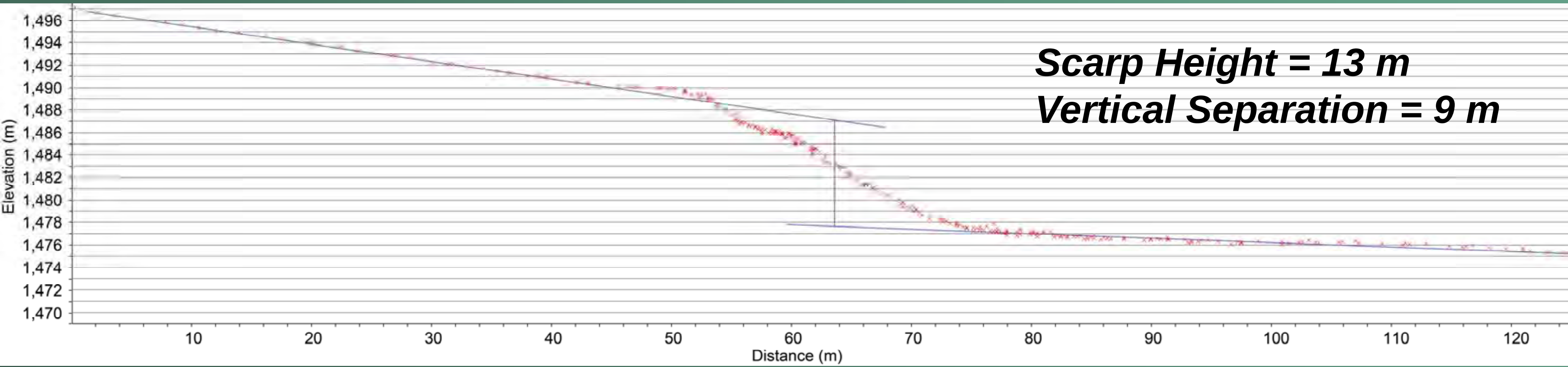
Flat Canyon t



0.5 m contours

Wasatch Fault paleoseismology

Flat Canyon – fault scarp profile



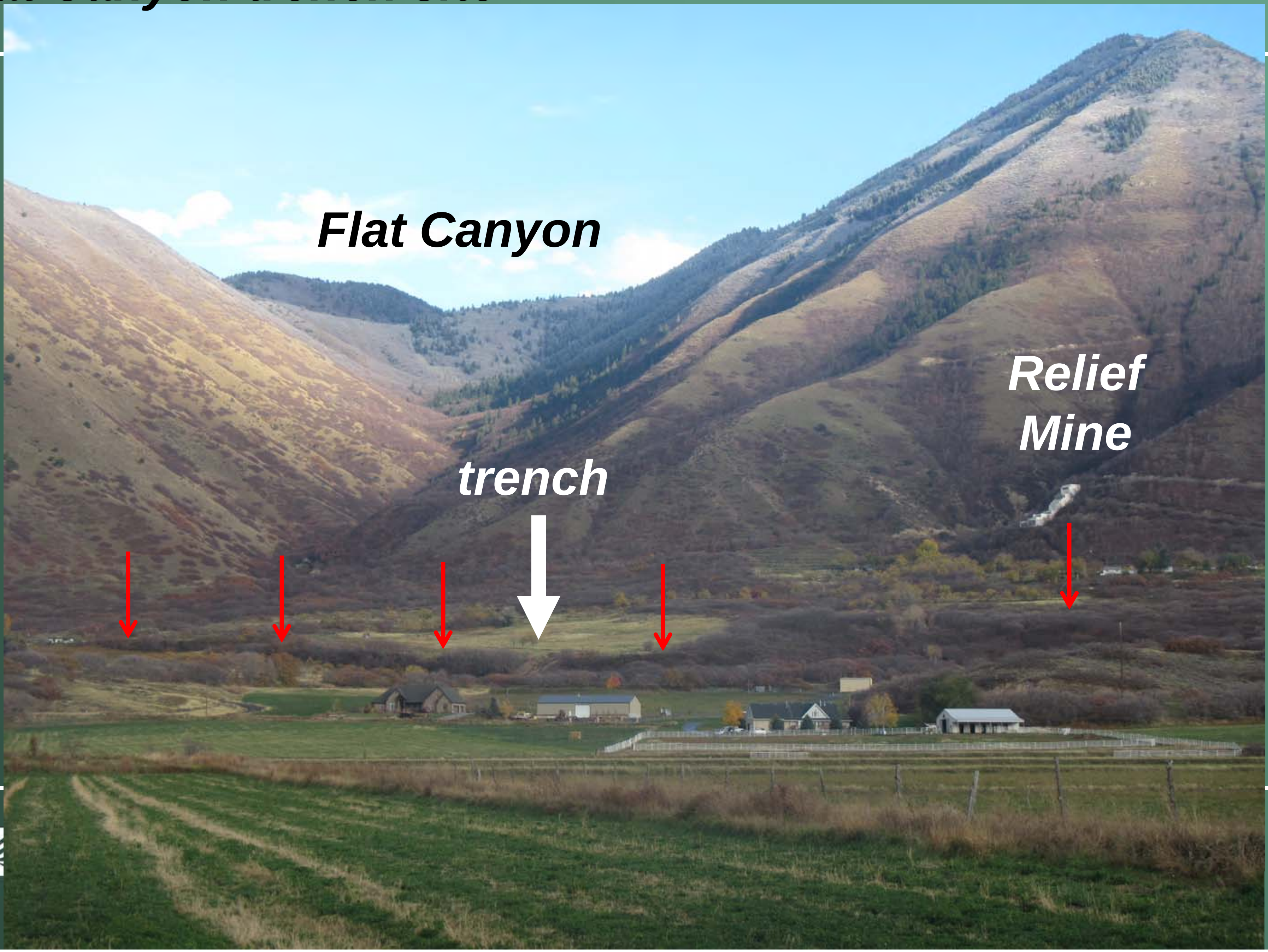
Wasatch Fault paleoseismology

Flat Canyon trench excavation – Oct 18-19, 2014

USGS

Wasatch Fault paleoseismology

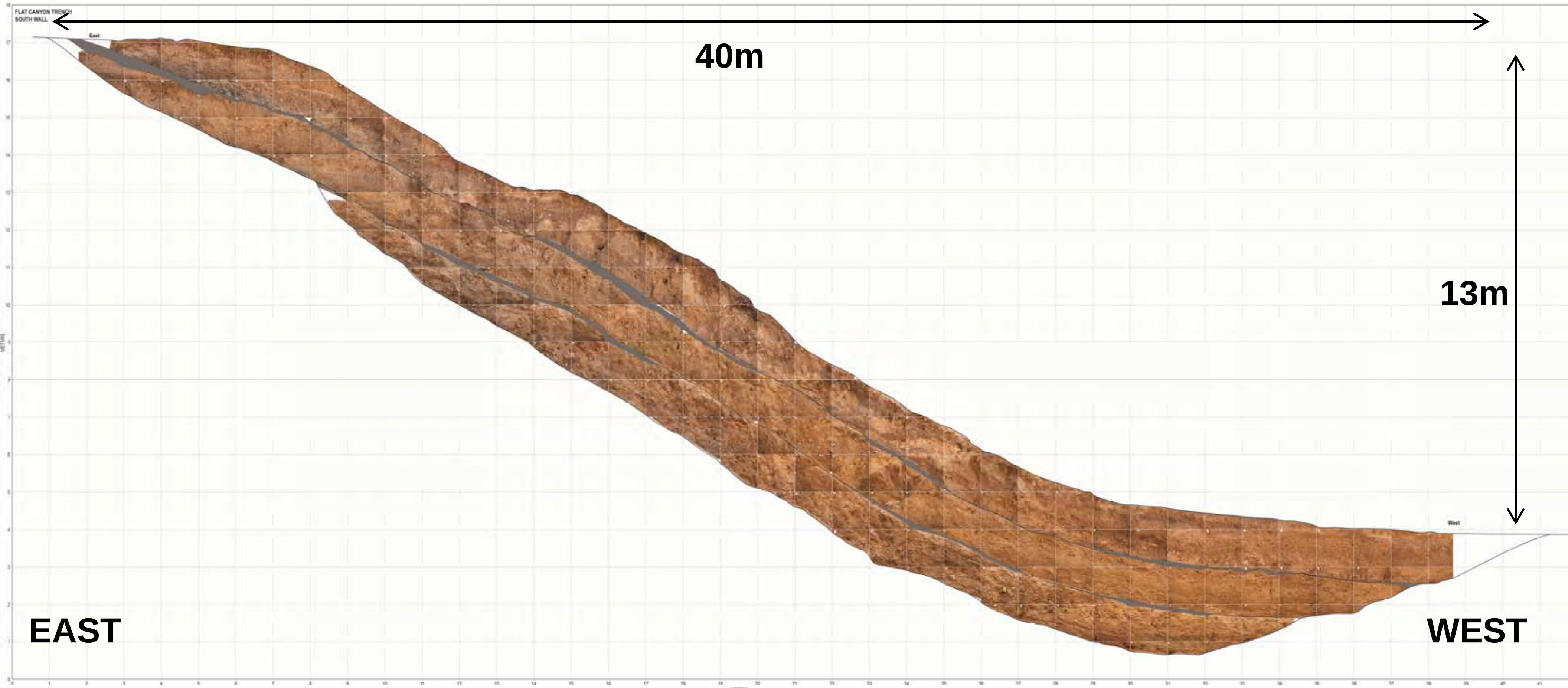
Flat Canyon trench site



Wasatch Fault paleoseismology

Flat Canyon trench site – 'traditional' photomosaic

- **3-bench excavation**

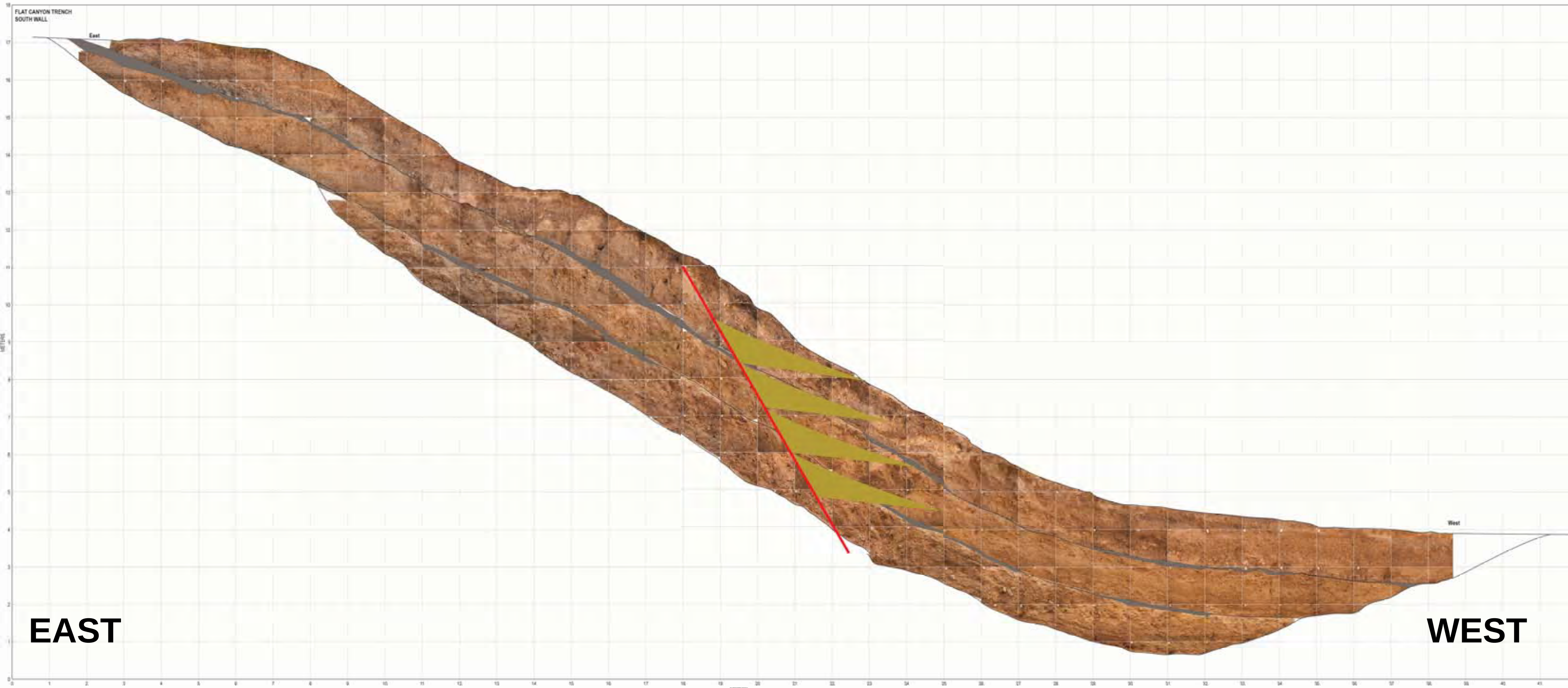


USGS

Wasatch Fault paleoseismology

Flat Canyon trench site – Trench Logs

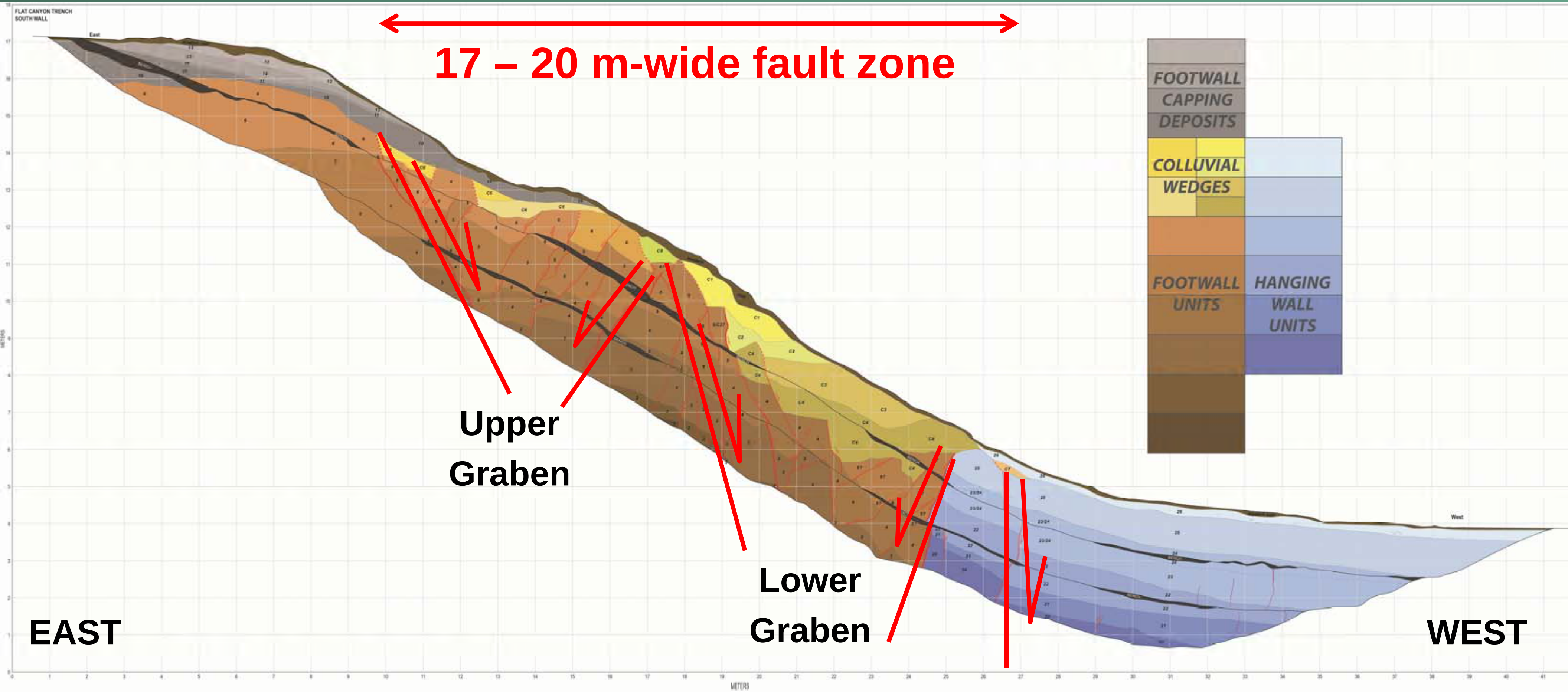
- **What we expected to find….**



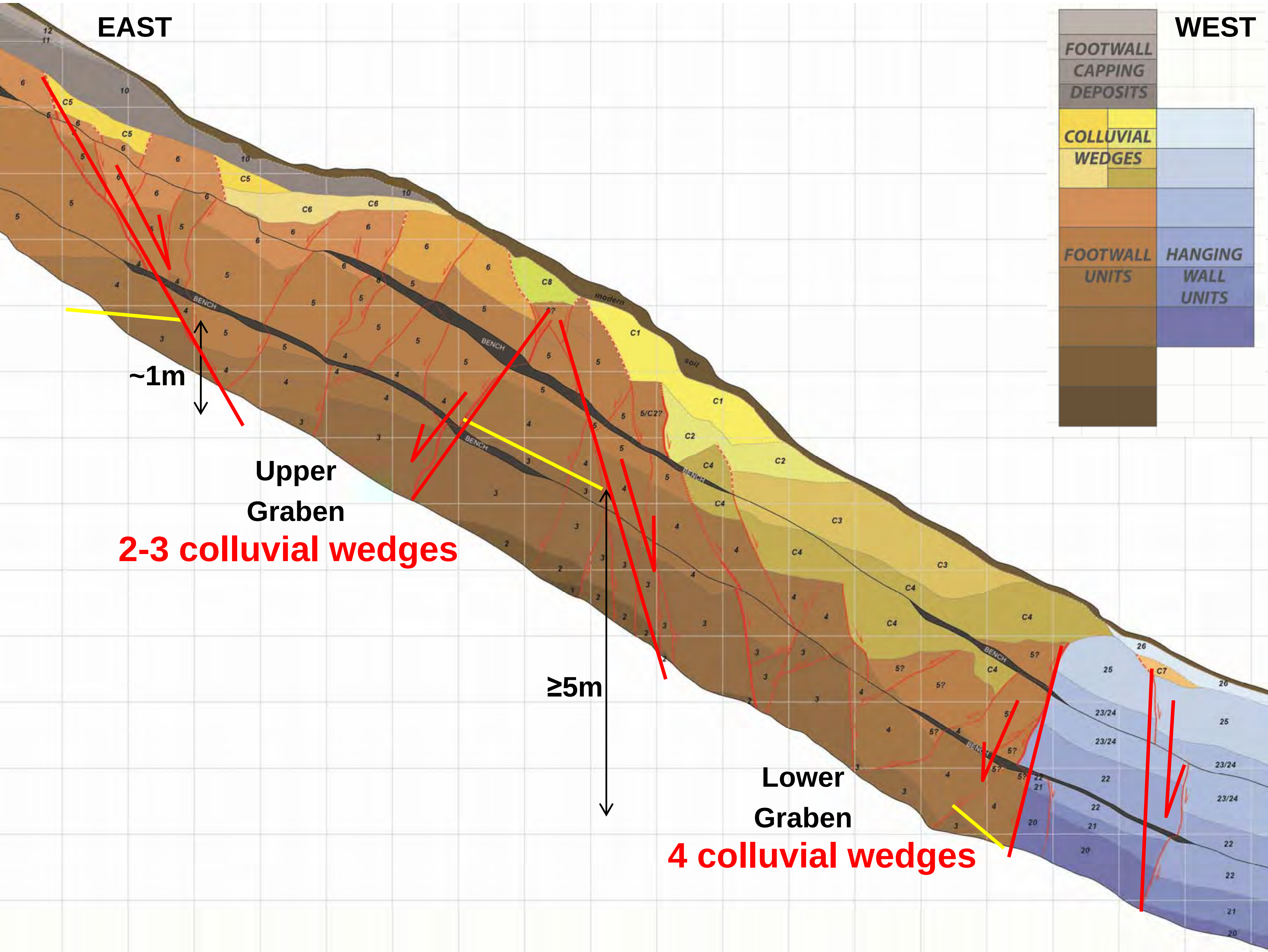
Wasatch Fault paleoseismology

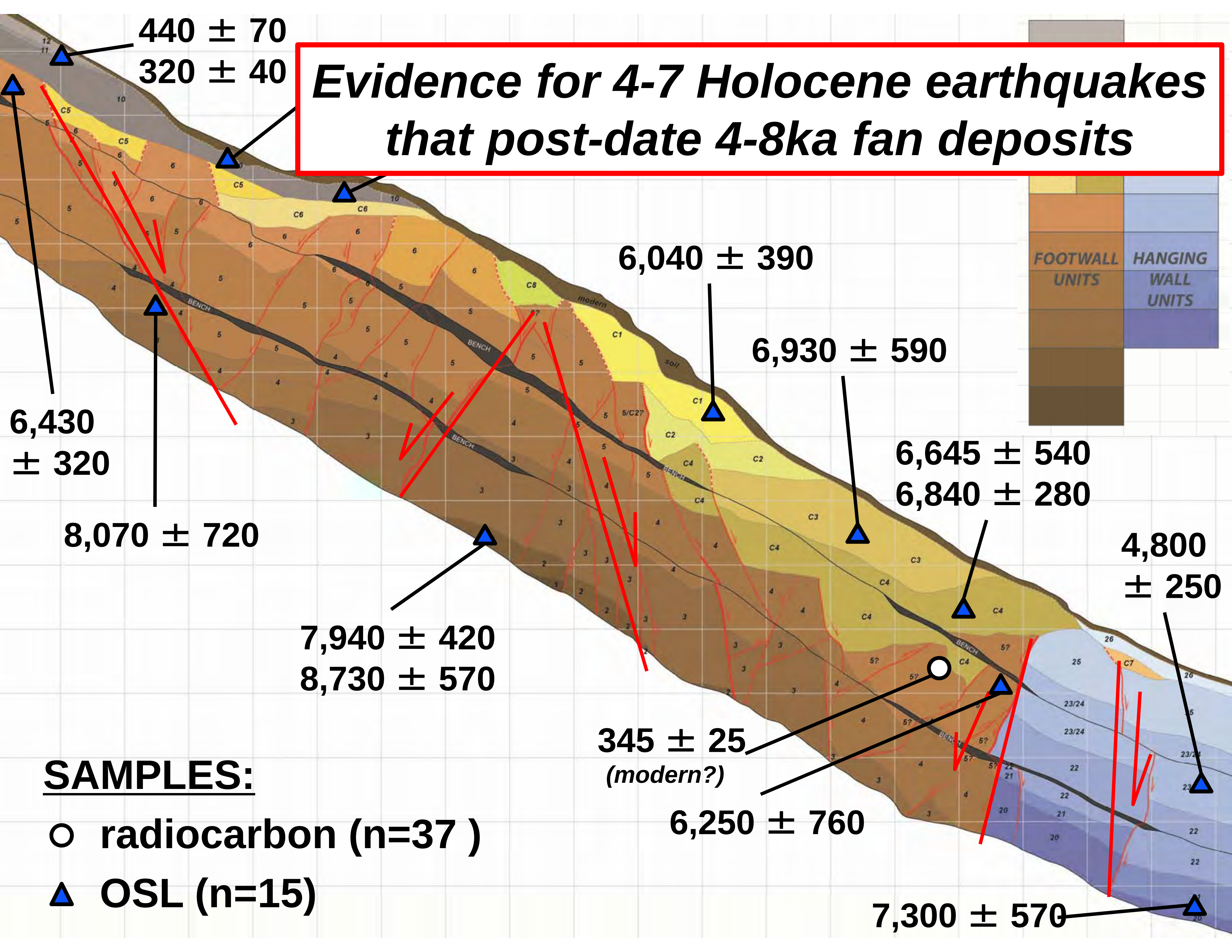
Flat Canyon trench site – Trench Logs

- ...and what we found.



USGS


EAST
WEST
FOOTWALL CAPPING DEPOSITS
COLLUVIAL WEDGES
FOOTWALL UNITS
HANGING WALL UNITS
~1m
≥5m
Upper Graben
2-3 colluvial wedges
Lower Graben
4 colluvial wedges

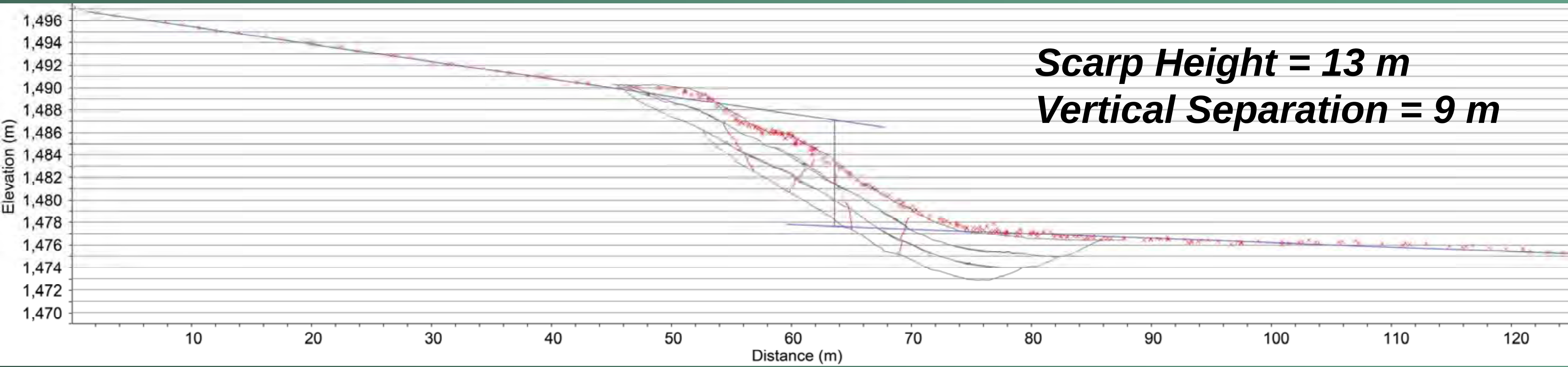


Evidence for 4-7 Holocene earthquakes that post-date 4-8ka fan deposits
440 ± 70
320 ± 40
6,430 ± 320
8,070 ± 720
7,940 ± 420
8,730 ± 570
6,040 ± 390
6,930 ± 590
6,645 ± 540
6,840 ± 280
4,800 ± 250
345 ± 25
(modern?)
6,250 ± 760
7,300 ± 570
FOOTWALL UNITS
HANGING WALL UNITS
SAMPLES:
radiocarbon (n=37)
OSL (n=15)

Wasatch Fault paleoseismology

Flat Canyon trench site – Scarp & Structures

EAST **WEST**



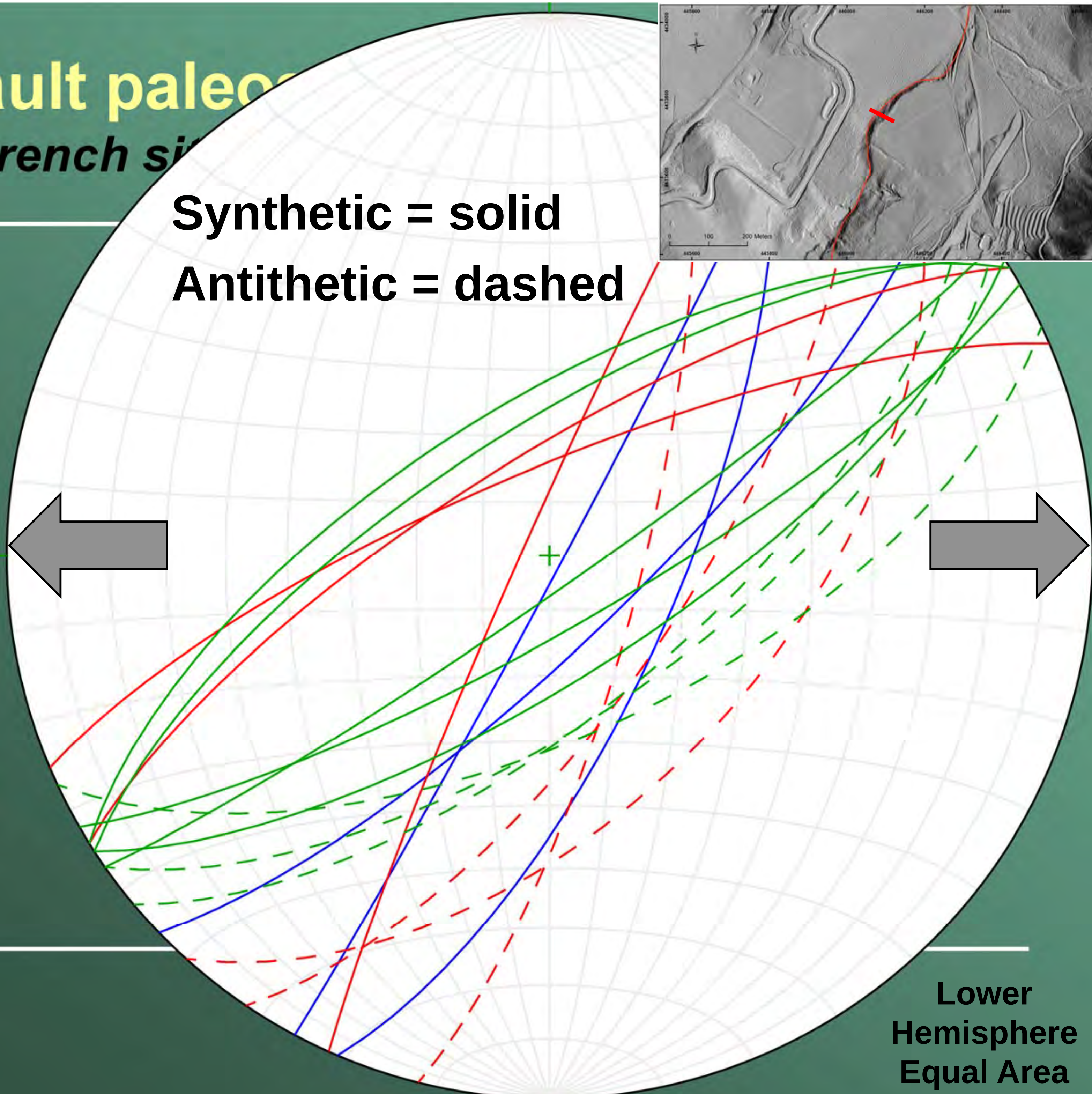
Wasatch Fault paleo

Flat Canyon trench si

Upper Graben

Lower Graben

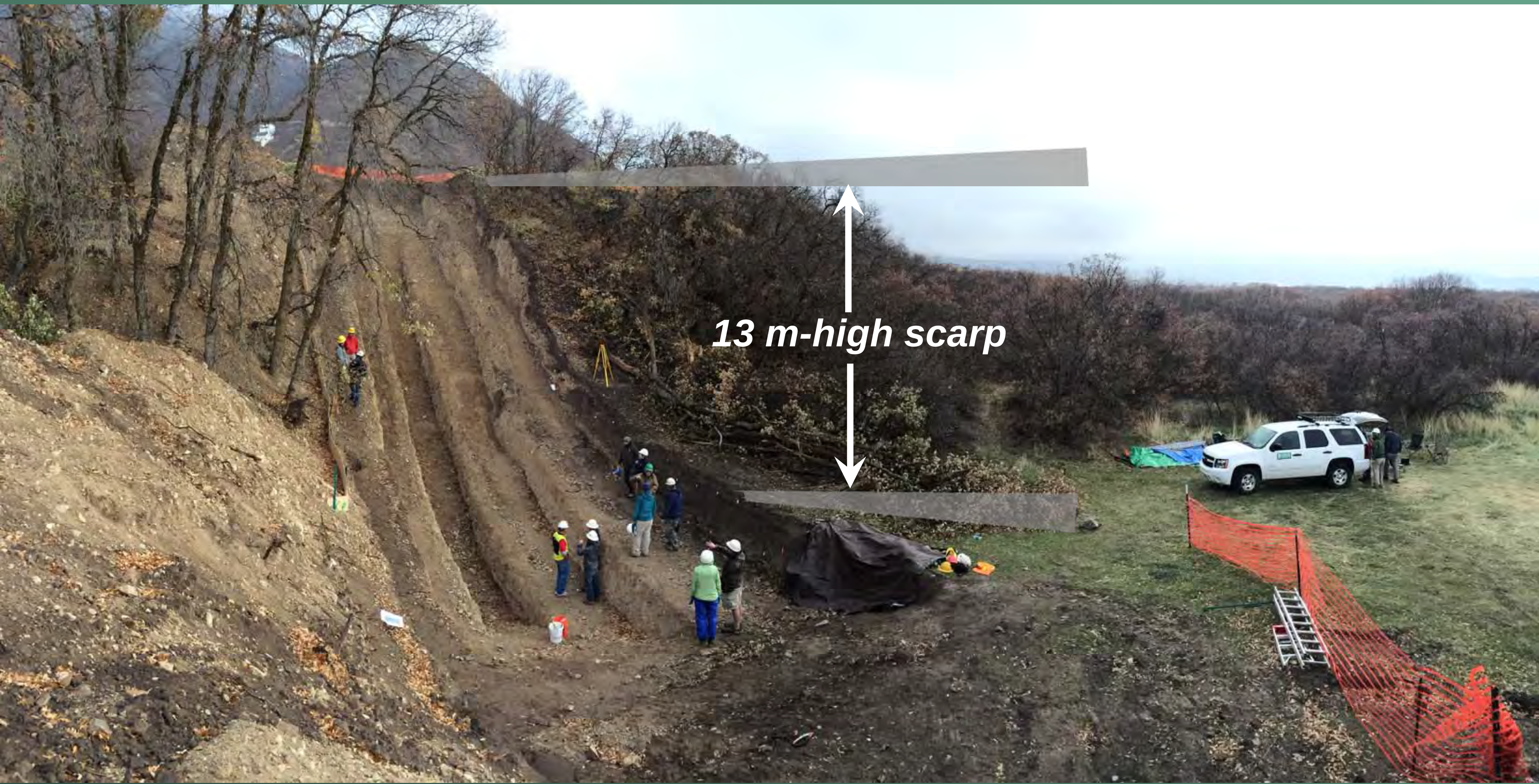
Outboard Fault



USGS

Wasatch Fault paleoseismology

Flat Canyon trench site – Trench Review Oct 30, 2013



USGS

Wasatch Fault paleoseismology

Flat Canyon trench site – Trench Review Oct 30, 2013

USGS

Wasatch Fault paleoseismology

Flat Canyon trench site – SUMMARY

Mapped age of fan = >18 ka (af4)

Trench length = 40 m
Trench depth = 4-5 m

^{14}C samples collected = 37
^{14}C samples dated = 10

OSL samples collected = 15
OSL sample dated = 15

Scarp Height = 13 m
Surface Offset = 9 m

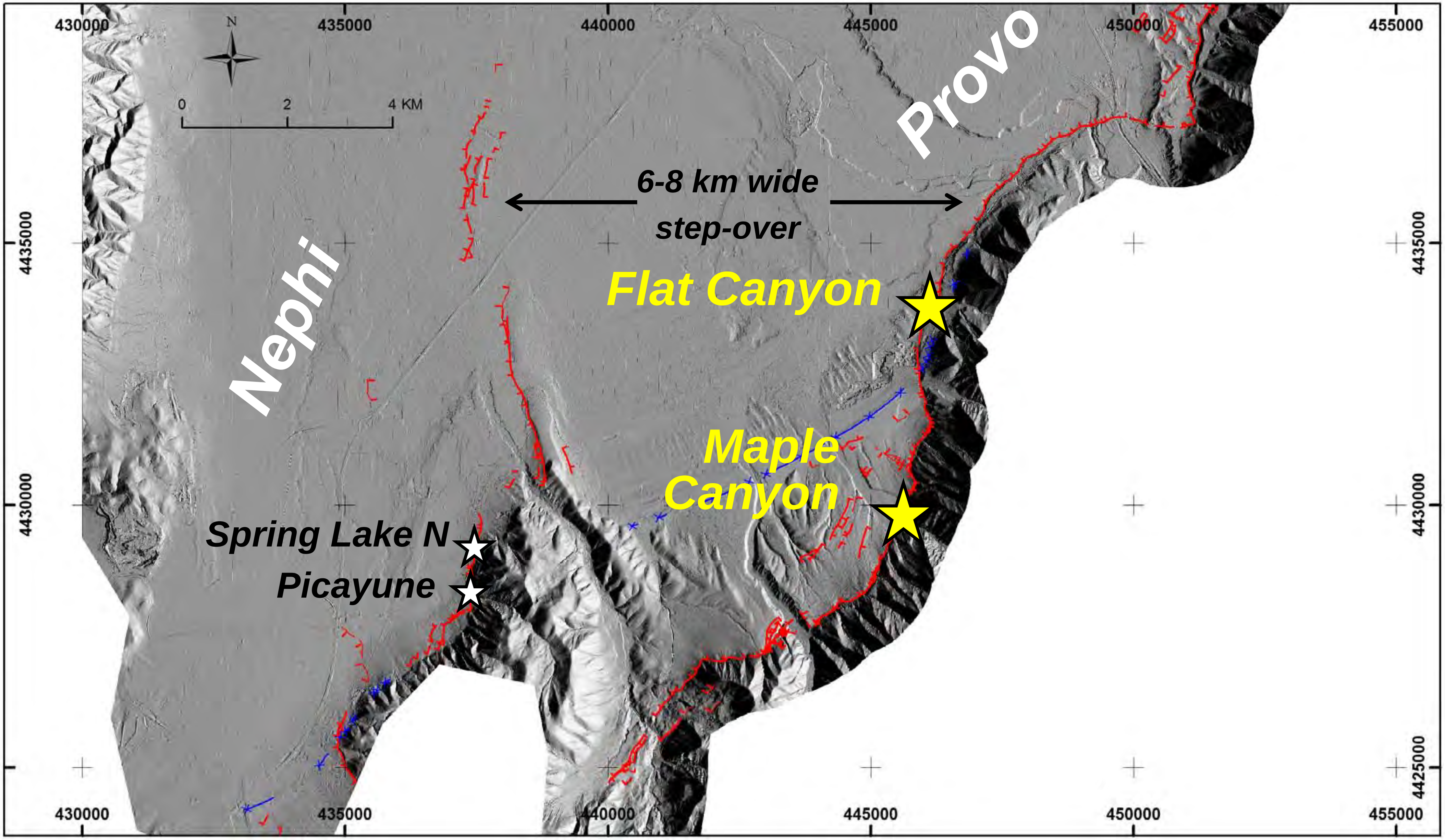
# of earthquakes = 4 to 7

EQ timing = post-date 4-7 ka alluvial fan deposits

USGS

Wasatch Fault paleoseismology

Provo-Nephi segment boundary



0.5m LiDAR (2014)

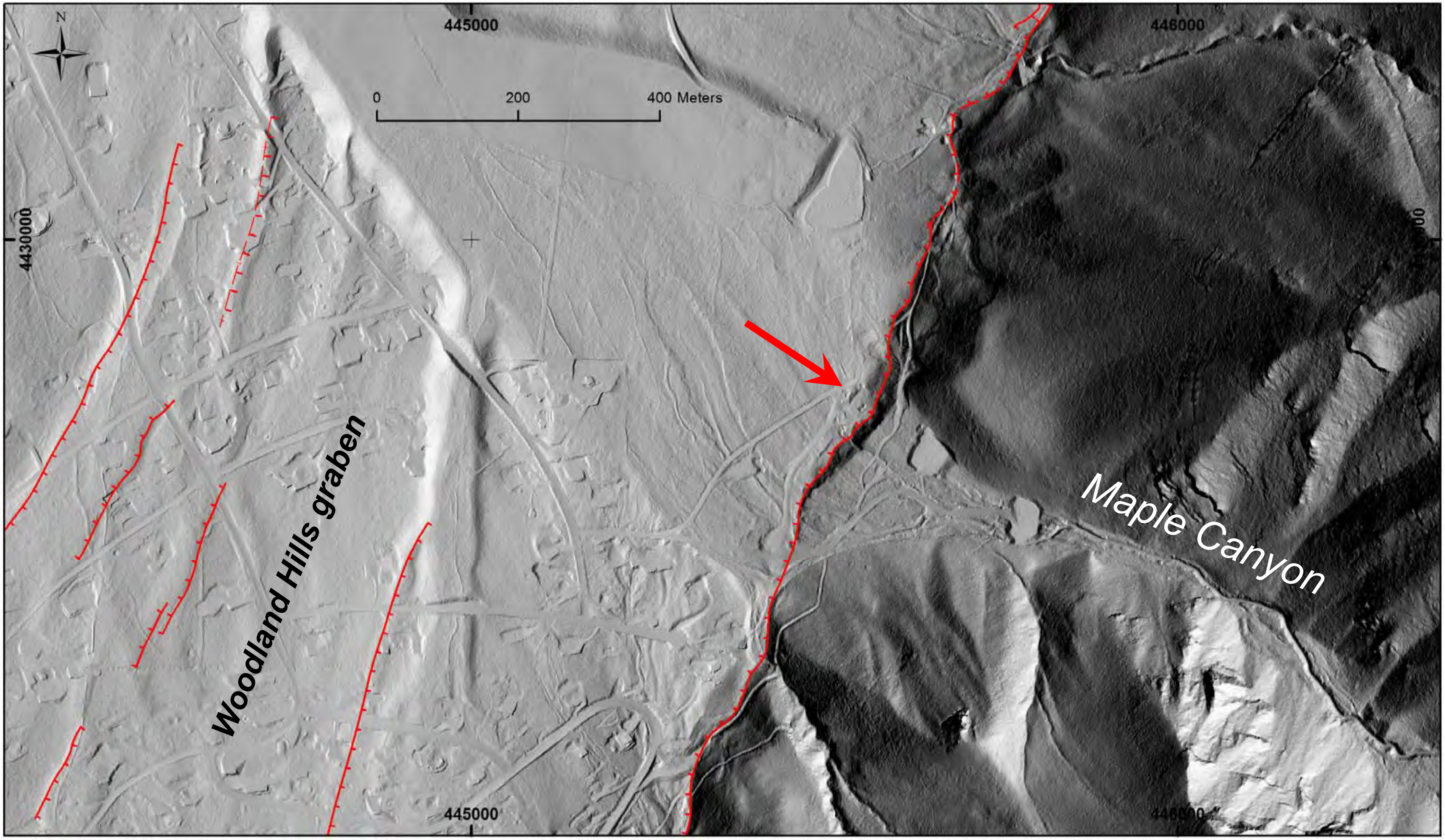
Wasatch Fault paleoseismology

Maple Canyon site

0.5m LiDAR (2014)

Wasatch Fault paleoseismology

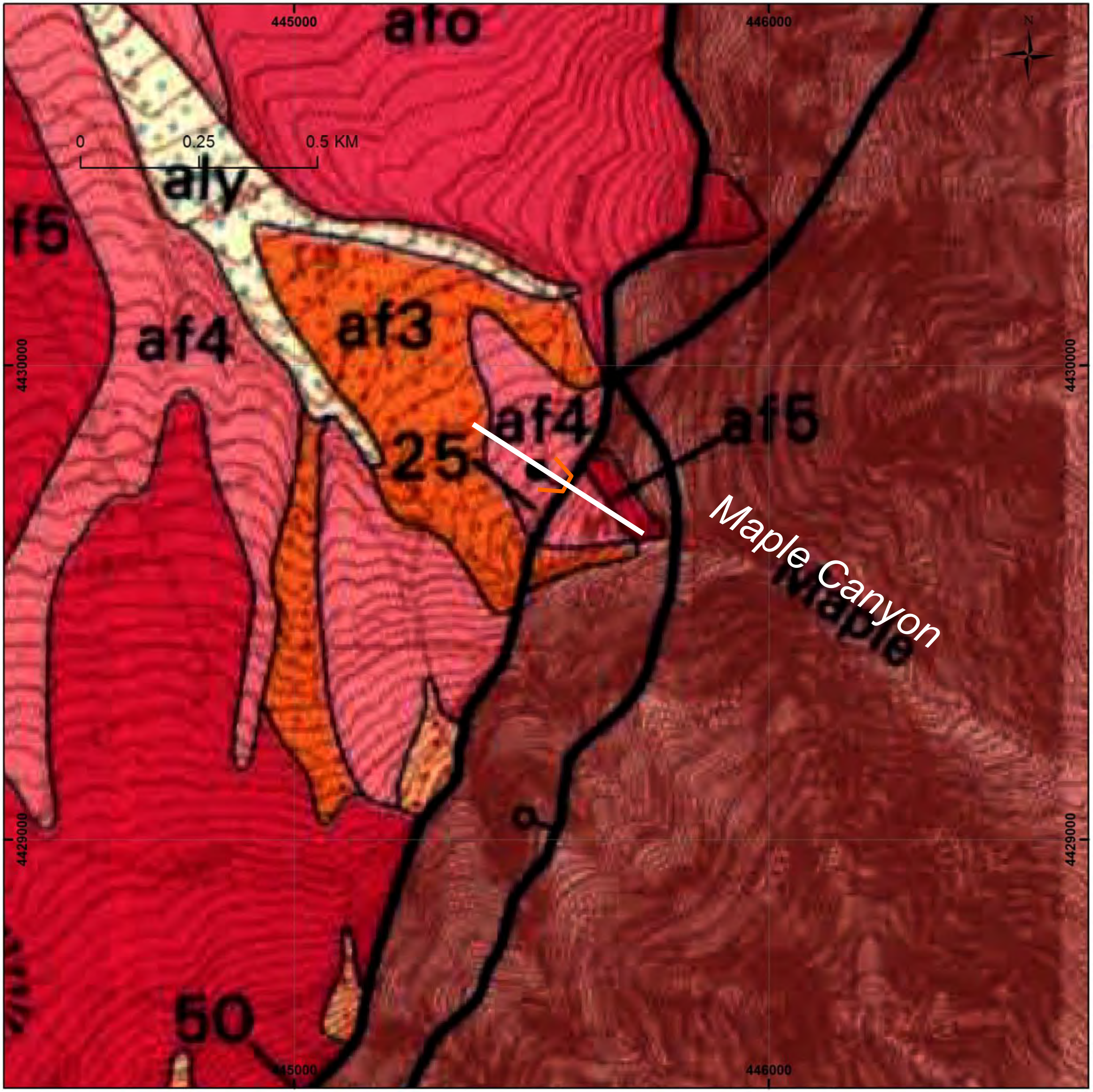
Maple Canyon site



0.5m LiDAR (2014)

Wasatch Fa

Maple Canyo

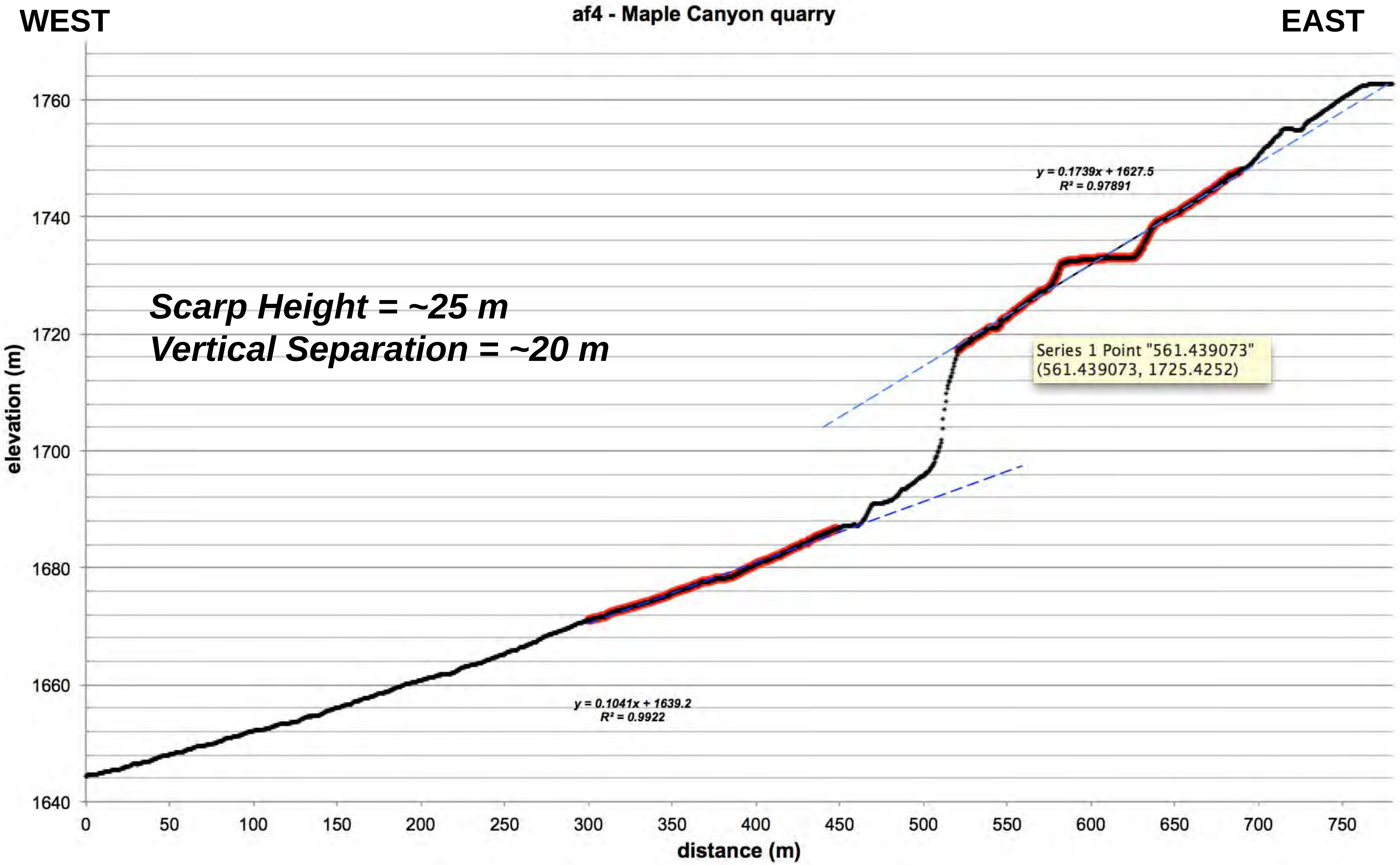


Machette (1992)

USGS

Wasatch Fault paleoseismology

Maple Canyon site – Scarp Profile



Wasatch Fault paleoseismology

Maple Canyon site

Maple Canyon

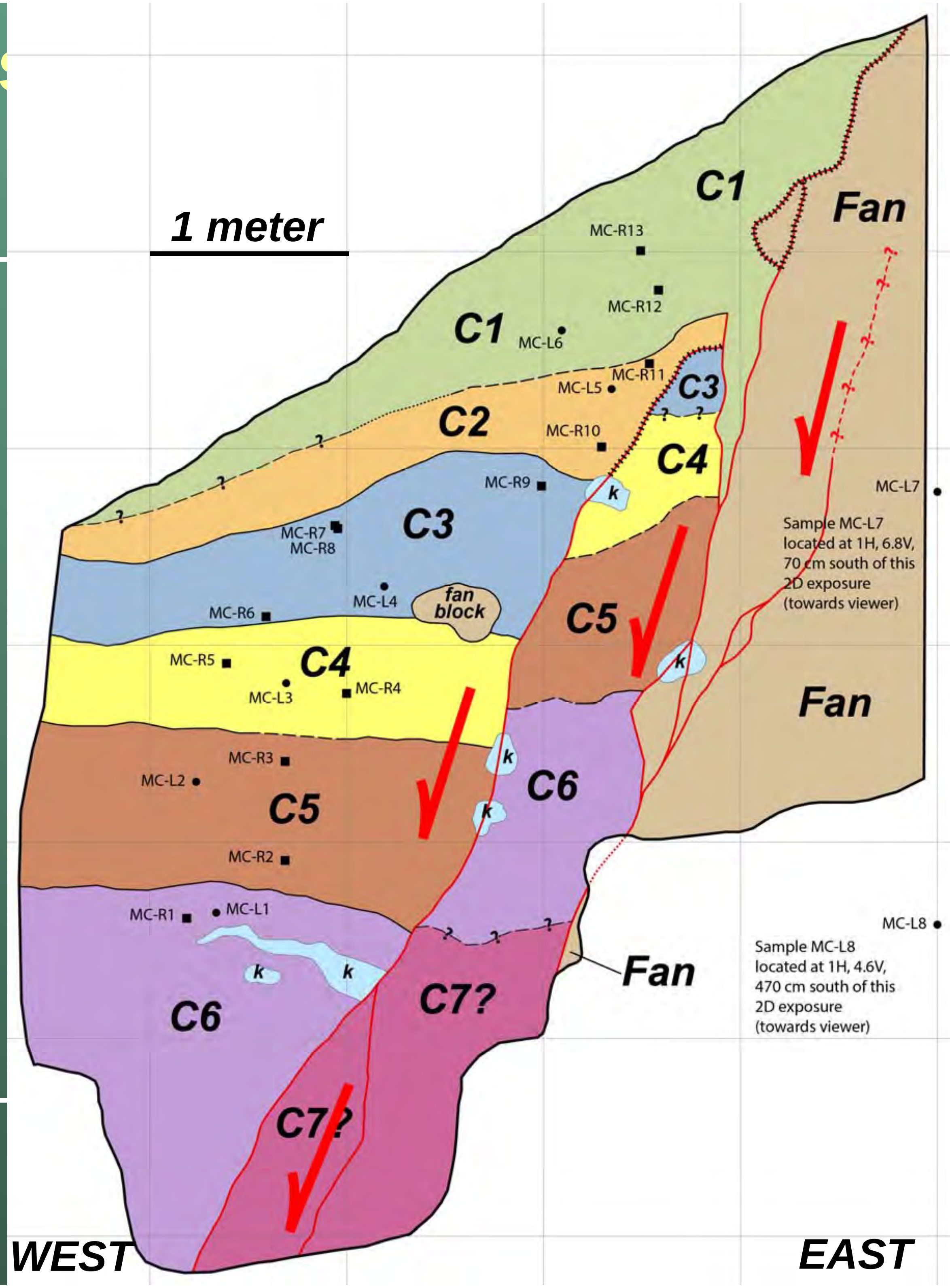
Maple Canyon

Before & After

USGS

Wasatch Fault paleos

Maple Canyon site
"Trench" Log



Evidence for at least 6 Holocene earthquakes

Wasatch Fault paleo

Maple Canyon site
OxCal Model

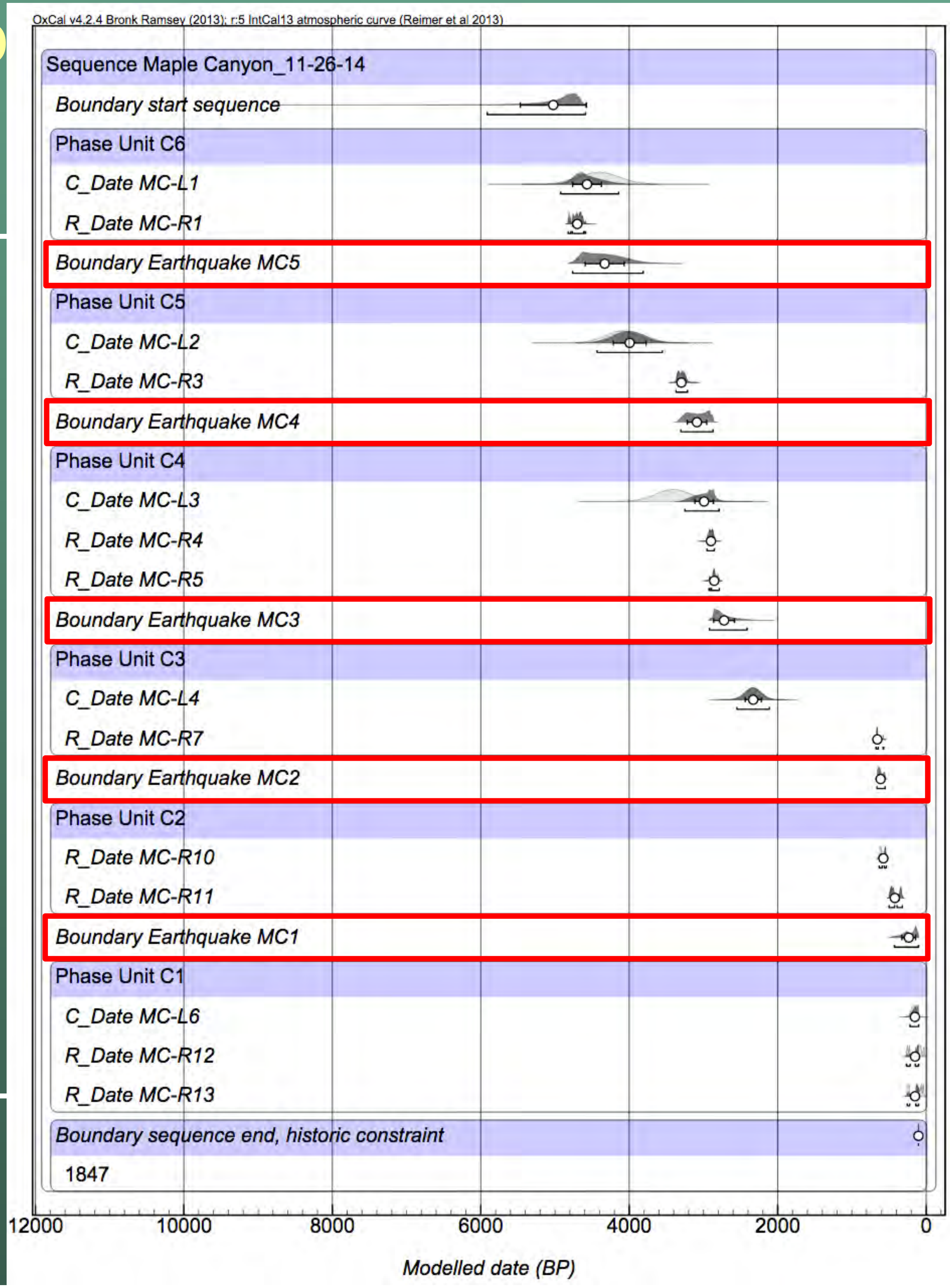
4330 ± 260 cal yr BP

3090 ± 130 cal yr BP

2720 ± 140 cal yr BP

610 ± 30 cal yr BP

230 ± 90 cal yr BP



USGS

OxCal software by Bronk Ramsey (2013)

Wasatch Fault paleoseismology

Maple Canyon site – SUMMARY

Mapped age of fan = >18 ka (af4)

“Trench” length = 5 m
“Trench depth” = 6 m

^{14}C samples collected = 13
^{14}C samples dated = 11

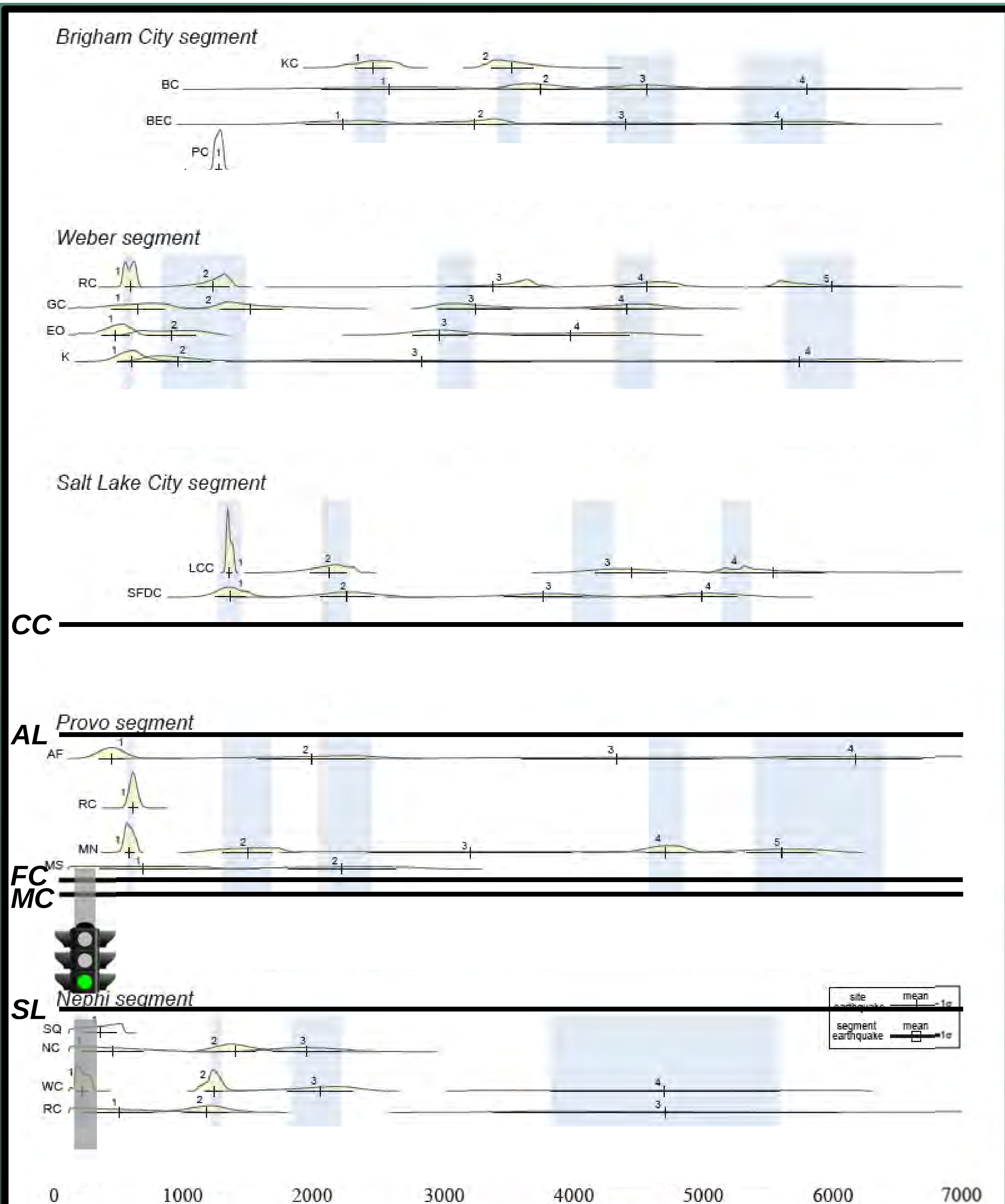
OSL samples collected = 8
OSL sample dated = 8

Scarp Height = ~25 m
Surface Offset = ~20 m

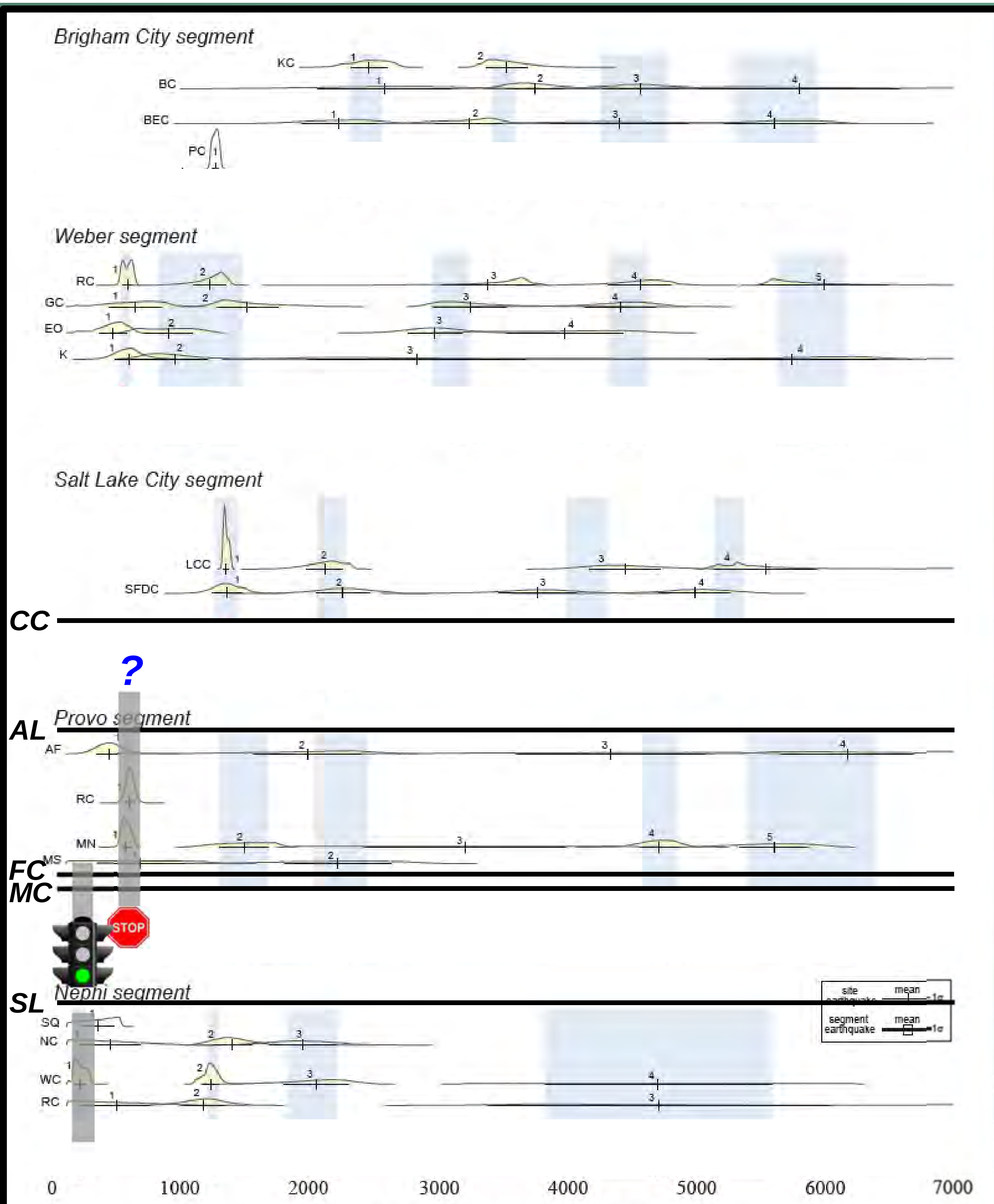
# of earthquakes = >6

EQ timing = 230±90, 610±30, 2720±140, 3090±130, 4330±260 cal yr BP

USGS



DuRoss et al. (in review)



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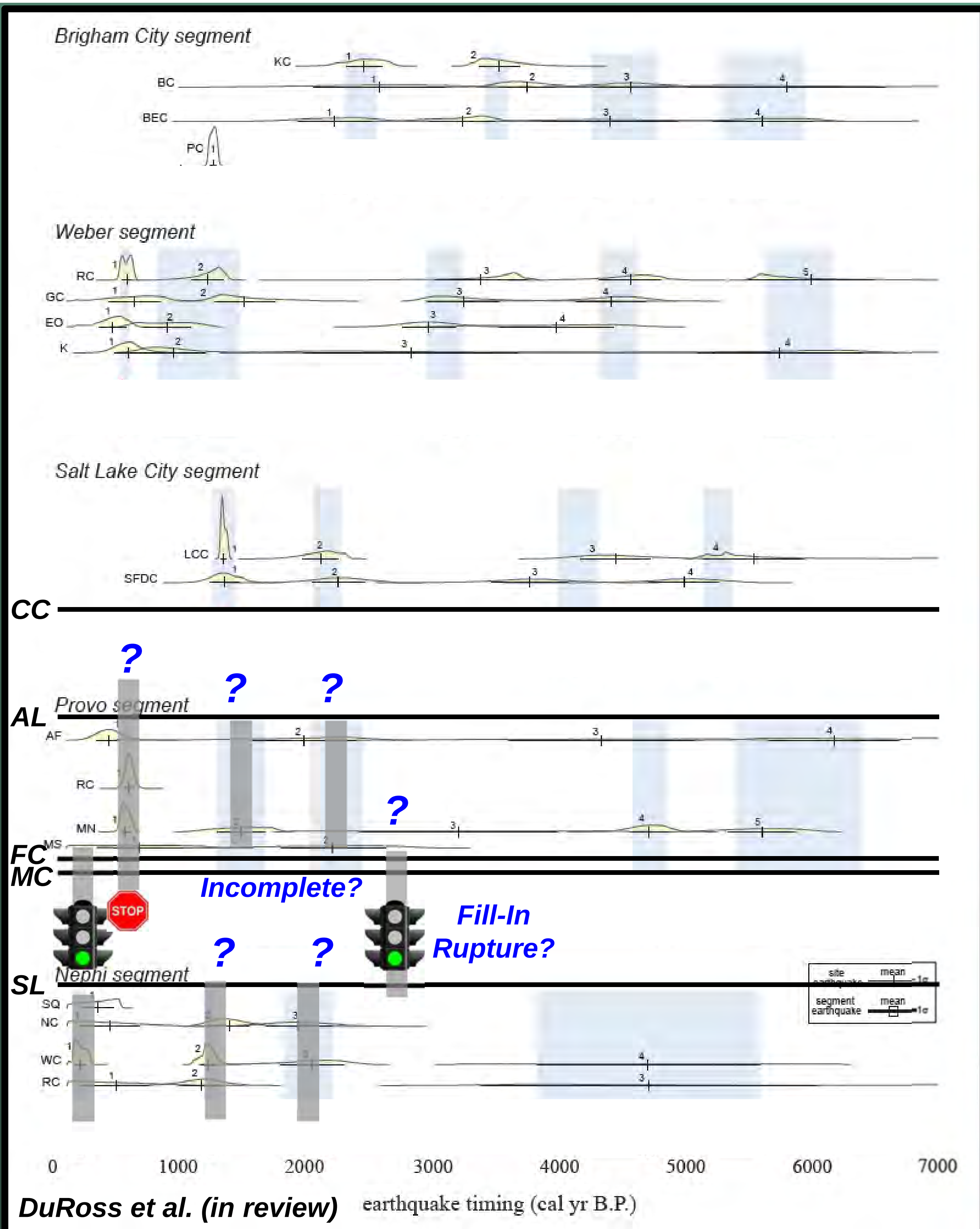
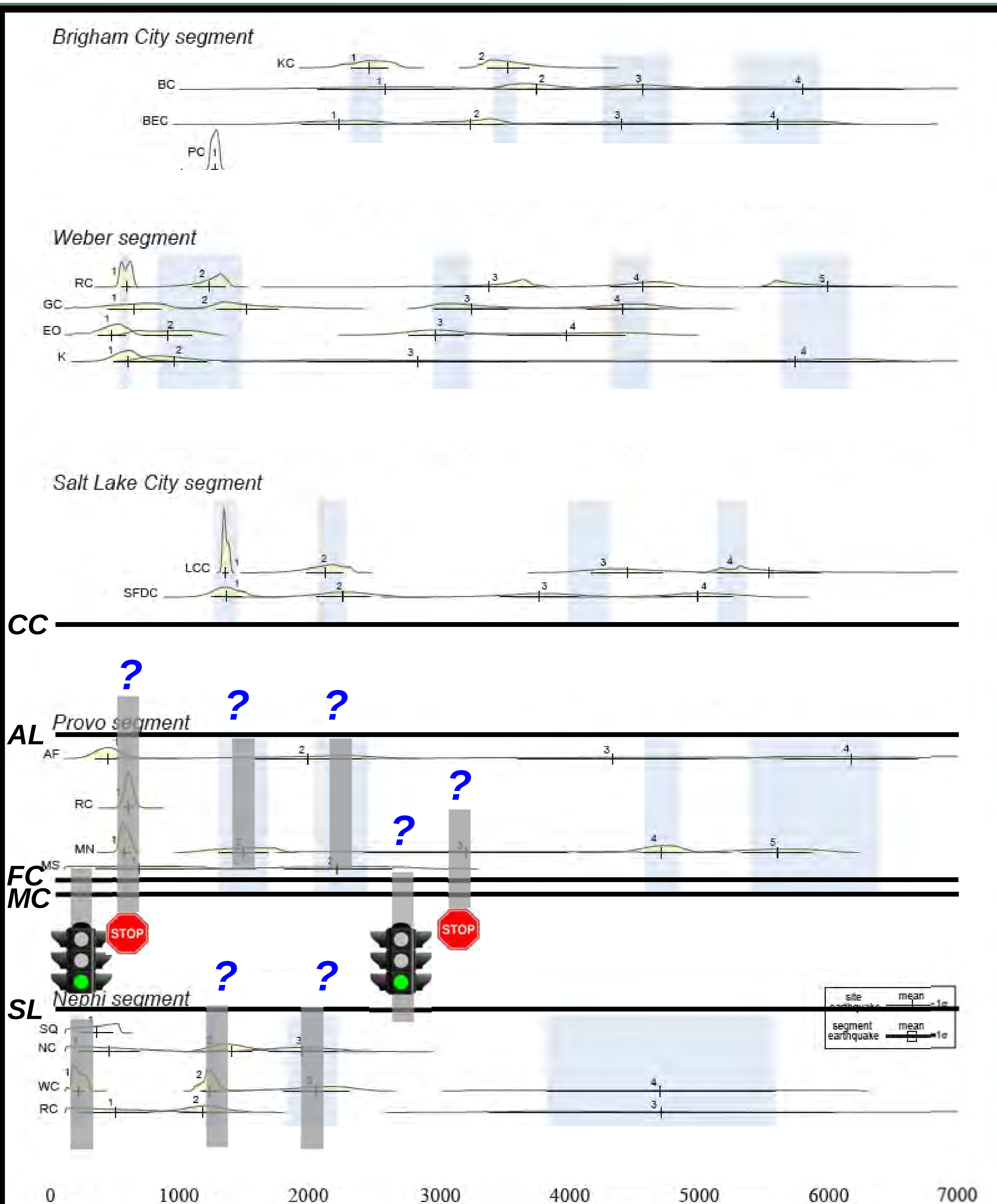
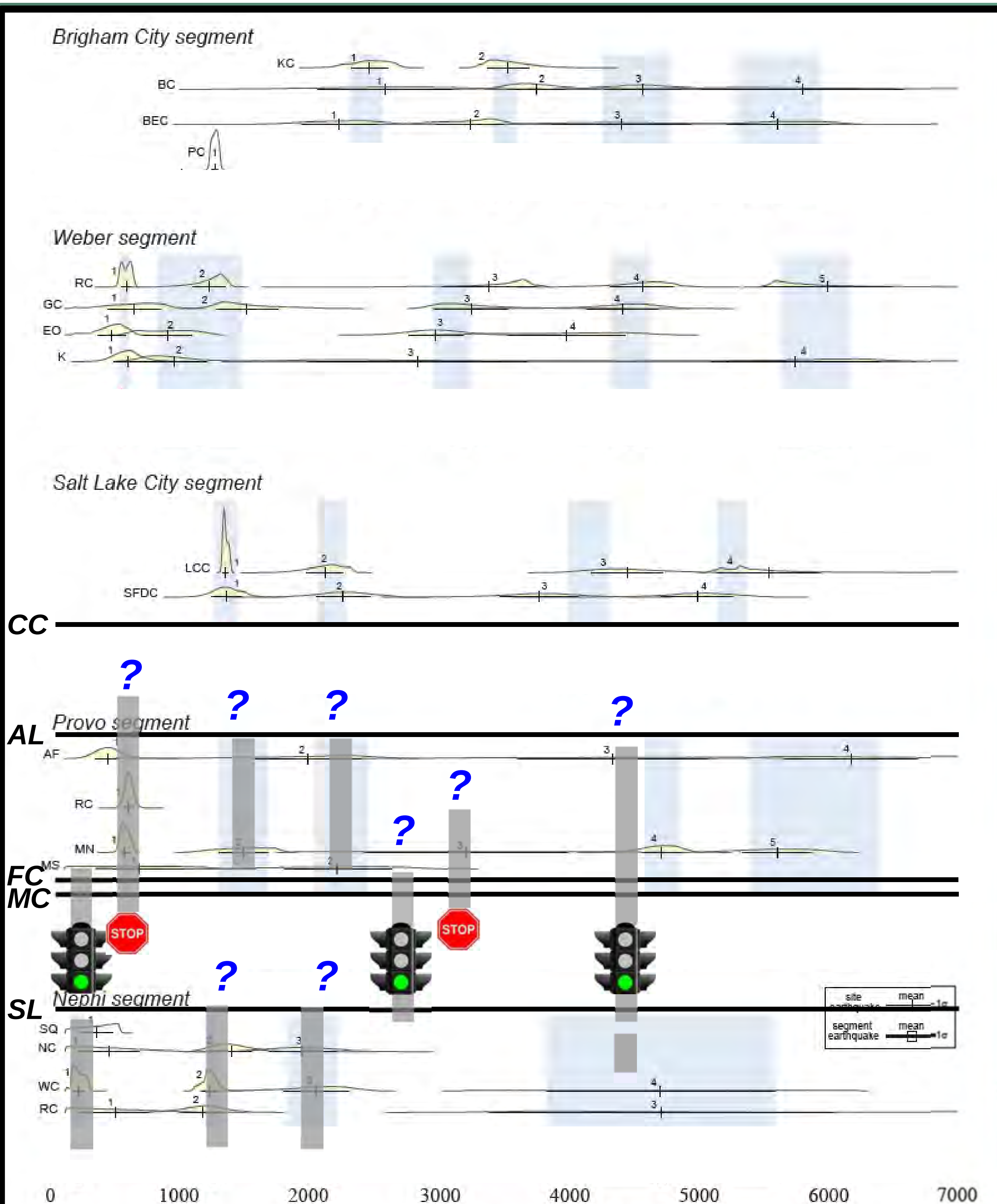

Brigham City segment
KC
BC
BEC
PC
Weber segment
RC
GC
EO
K
Salt Lake City segment
LCC
SFDC
CC
?
?
?
AL
Provo segment
AF
RC
MN
MS
?
FC
MC
Incomplete?
STOP
Fill-In
Rupture?
?
?
SL
Nephi segment
SQ
NC
WC
RC
site earthquake
segment earthquake
mean
1σ
0
1000
2000
3000
4000
5000
6000
7000
DuRoss et al. (in review)
earthquake timing (cal yr B.P.)

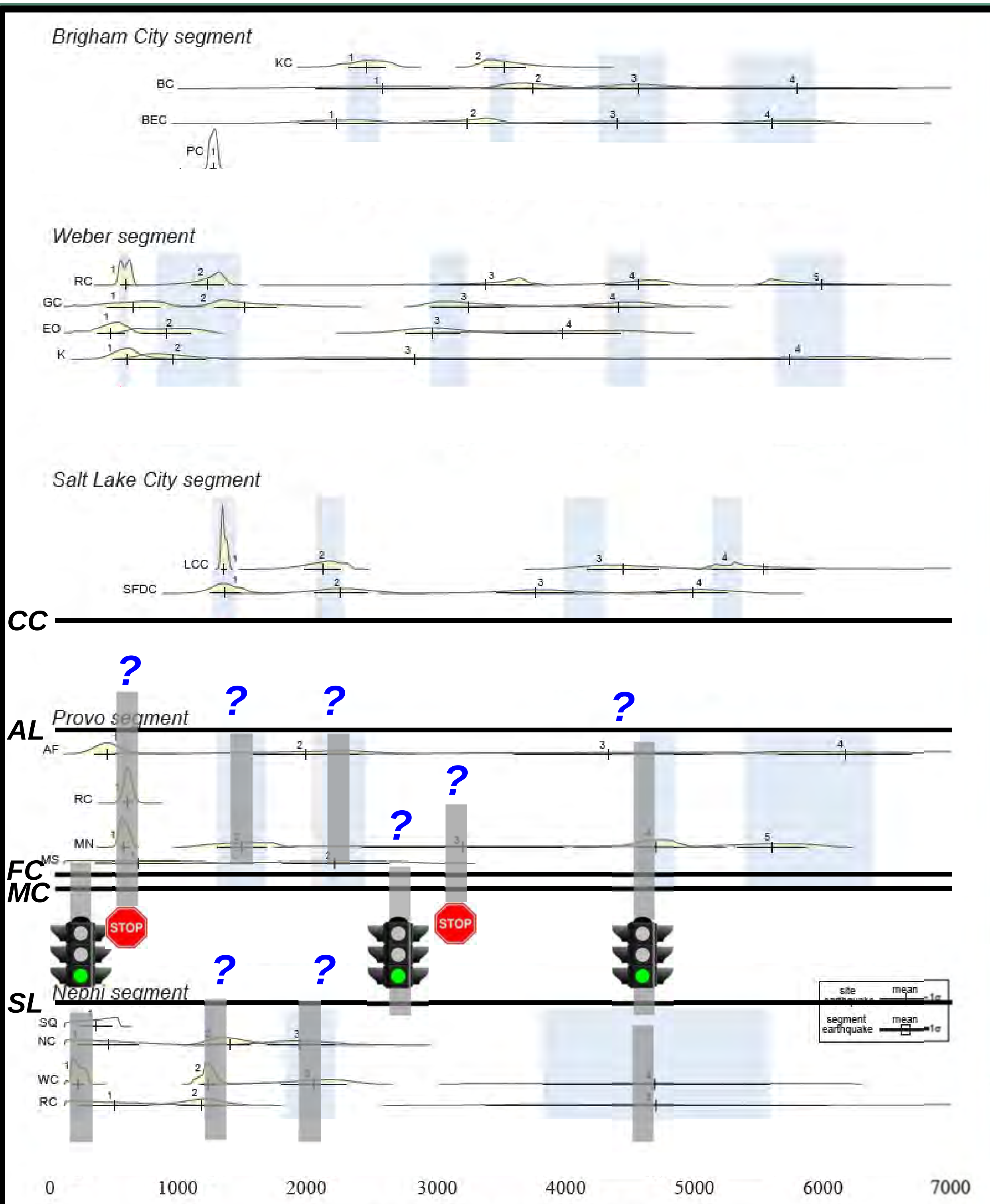
4600000
4500000
41°N
40°N
HC
KC
BC
BEC
Brigham
City
PC
~2 km
PP
RC
GC
EO
Ogden
GREAT
SALT
LAKE
Layton
Weber
K
~3 km
PD
Salt
Lake
City
Salt Lake City
West
Valley City
West
Jordan
Sandy
SFDC
LCC
6.5 km
CC
AL
AF
UTAH
LAKE
Orem
Provo
RC
Provo
HC
MN
MS
FC
MC
SL
PC
S
~7 km
20km
NC
WC
RC
Nephi



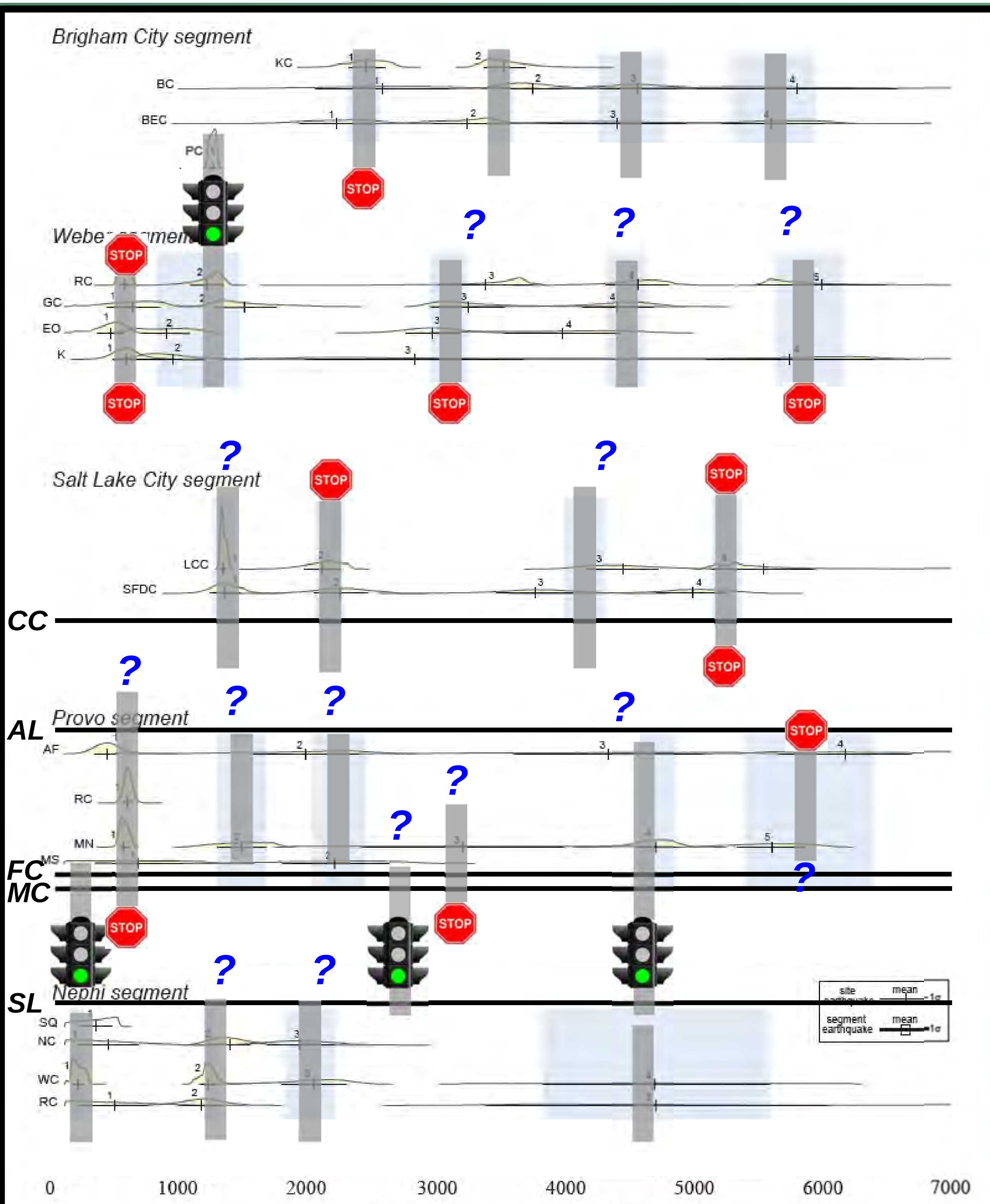
DuRoss et al. (in review)



DuRoss et al. (in review)



DuRoss et al. (in review)



DuRoss et al. (in review)

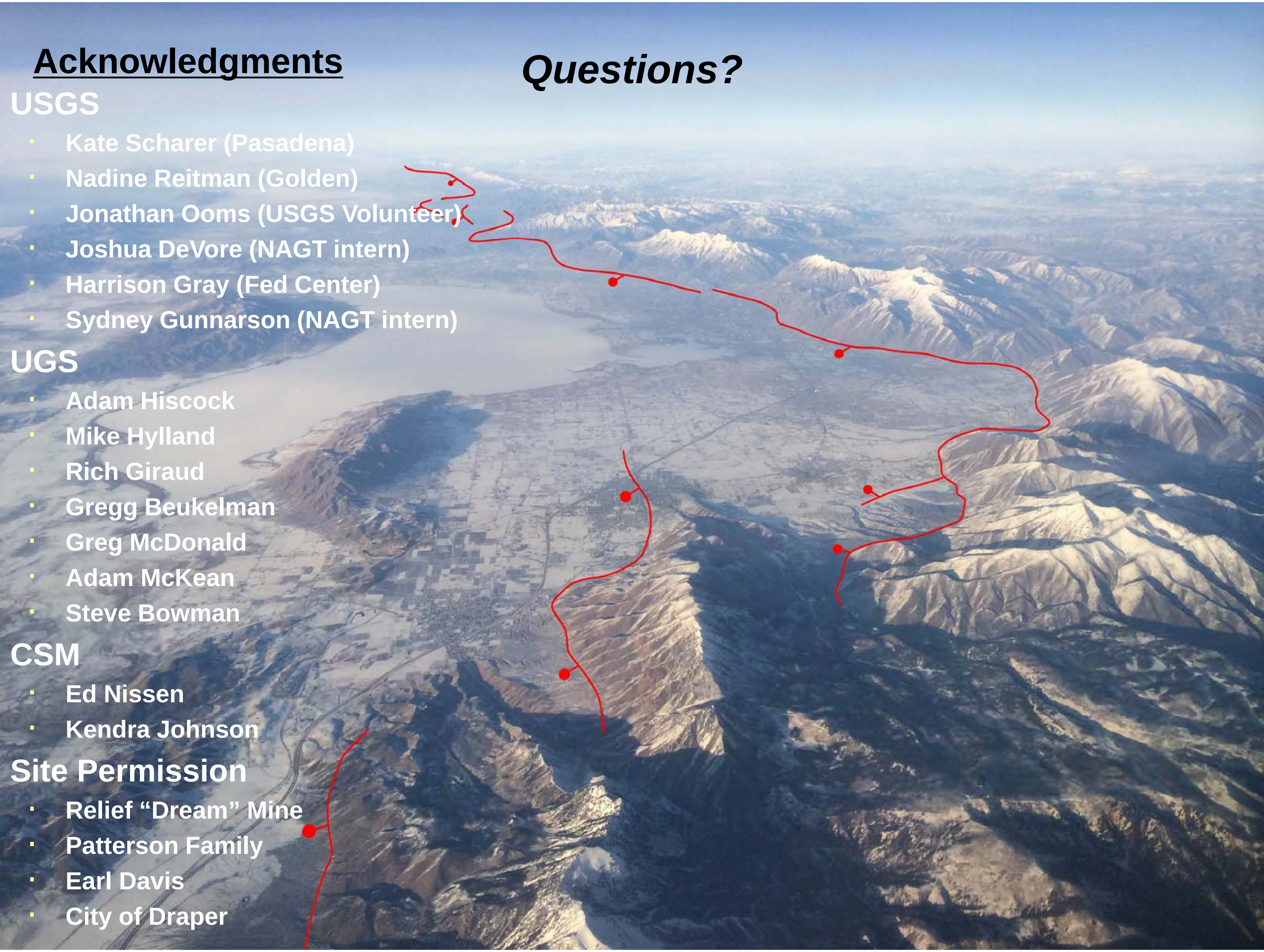
Summary

(1) Evidence for Non-persistent Rupture Terminations

- many ruptures end at a segment boundary
- some ruptures spillover at least 5-10 km
- rare multi-segment ruptures are permissible

(2) Findings help reduce uncertainties in seismic hazard models for Wasatch fault zone.

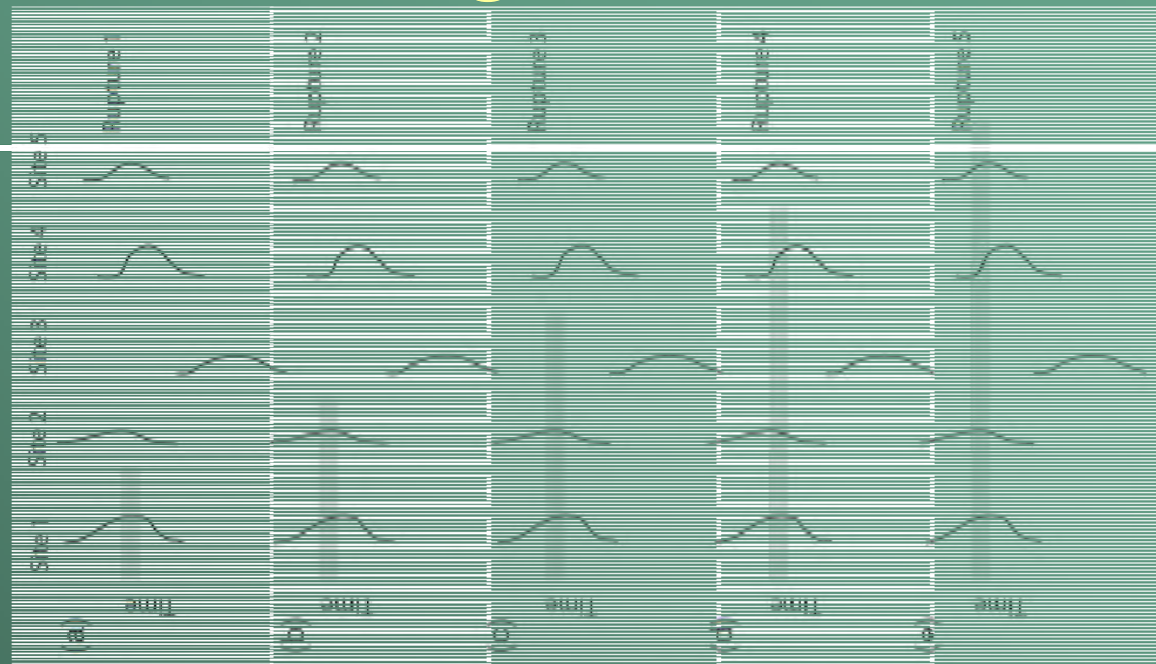
USGS

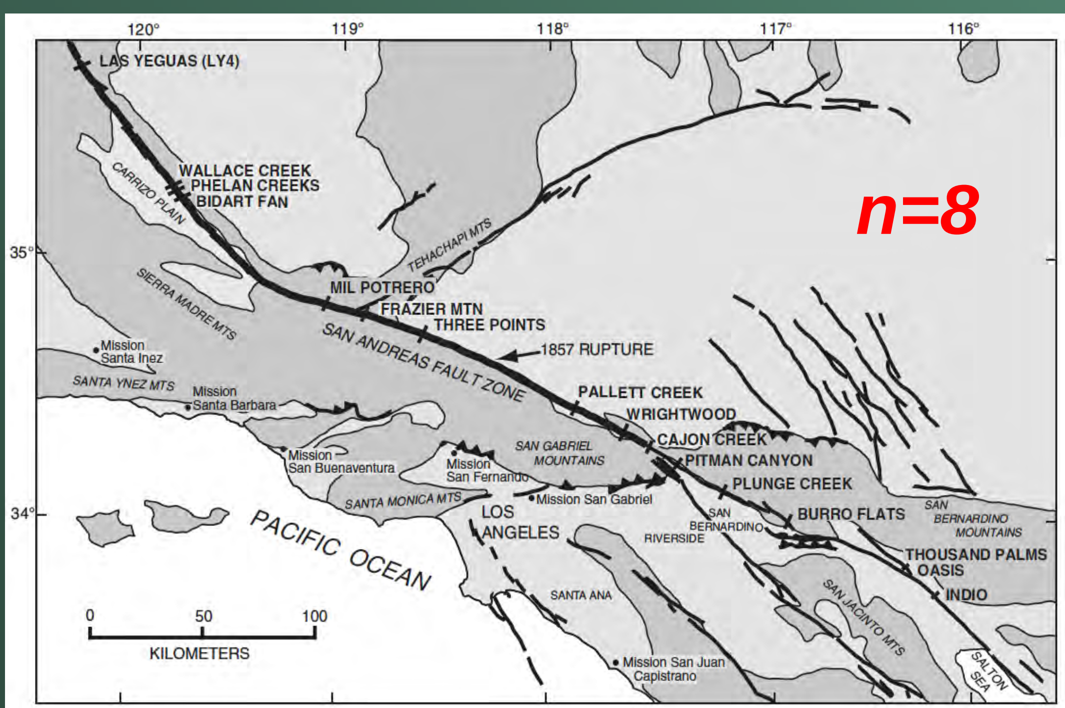

Acknowledgments
Questions?
USGS
Kate Scharer (Pasadena)
Nadine Reitman (Golden)
Jonathan Ooms (USGS Volunteer)
Joshua DeVore (NAGT intern)
Harrison Gray (Fed Center)
Sydney Gunnarson (NAGT intern)
UGS
Adam Hiscock
Mike Hylland
Rich Giraud
Gregg Beukelman
Greg McDonald
Adam McKean
Steve Bowman
CSM
Ed Nissen
Kendra Johnson
Site Permission
Relief “Dream” Mine
Patterson Family
Earl Davis
City of Draper

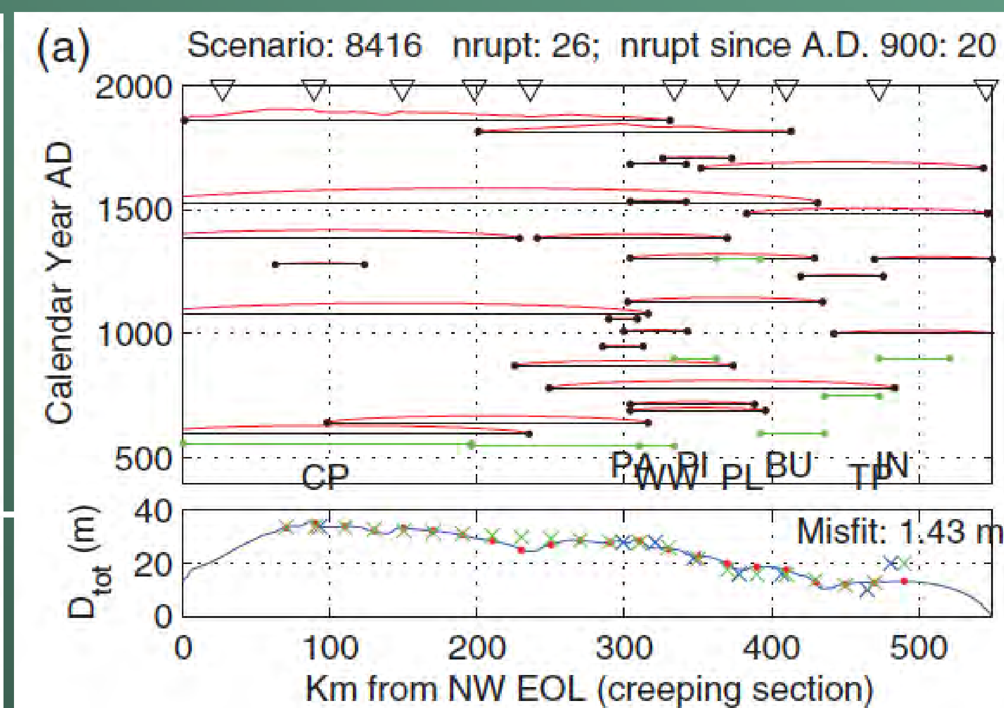
Rupture Scenario Modeling

"Stringing Pearls"

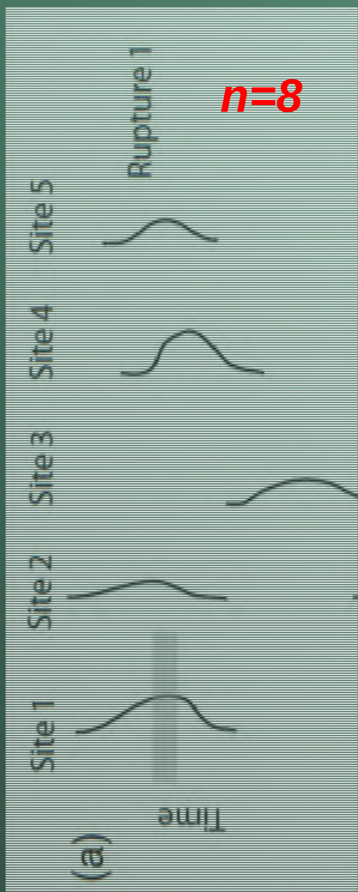
Biasi & Weldon (2009)



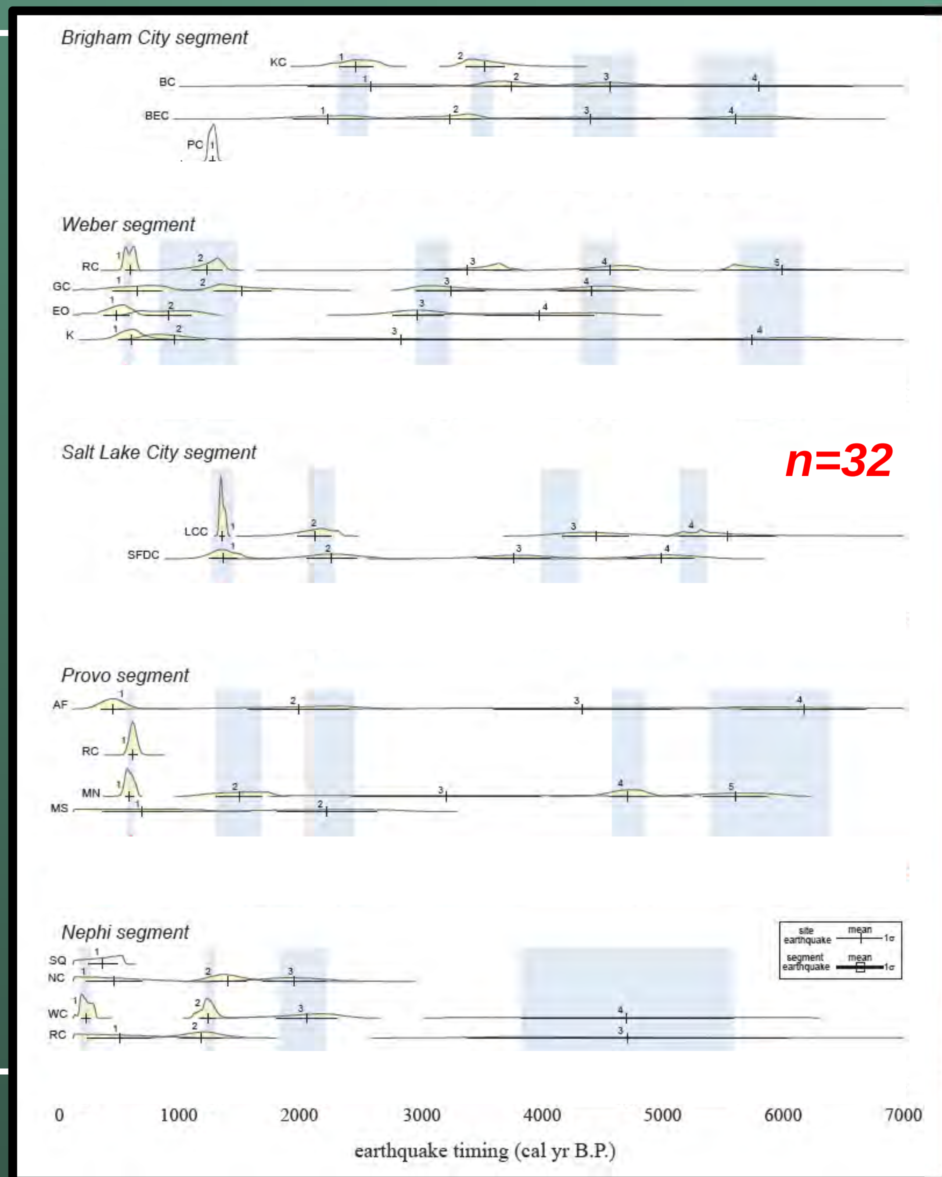




Rupture Scenario Modeling ("Stringing Pearls")

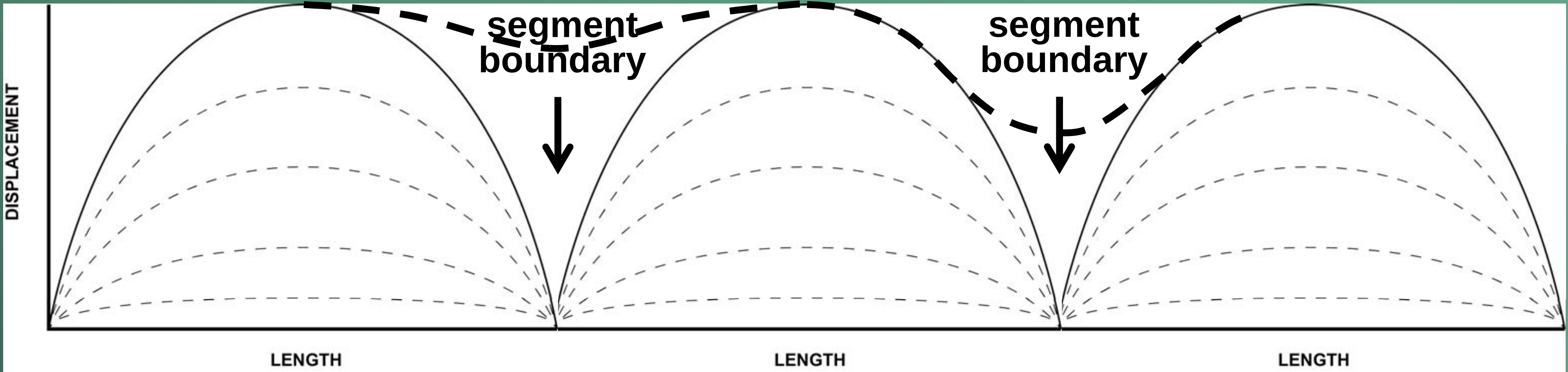


Biasi & Weldon (2009)



DuRoss et al. (in review)

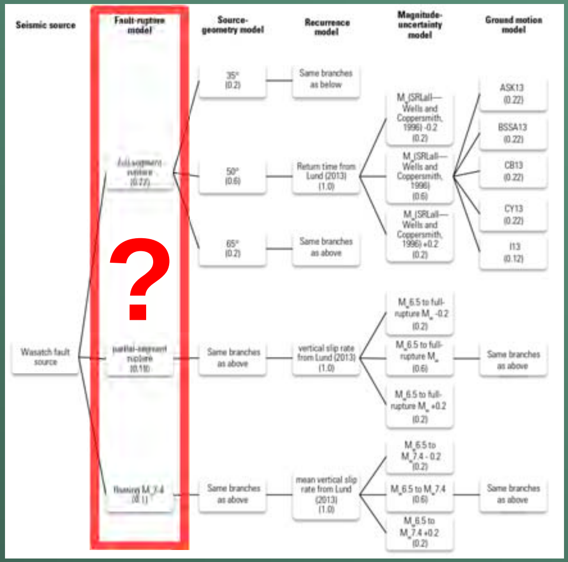
Implications



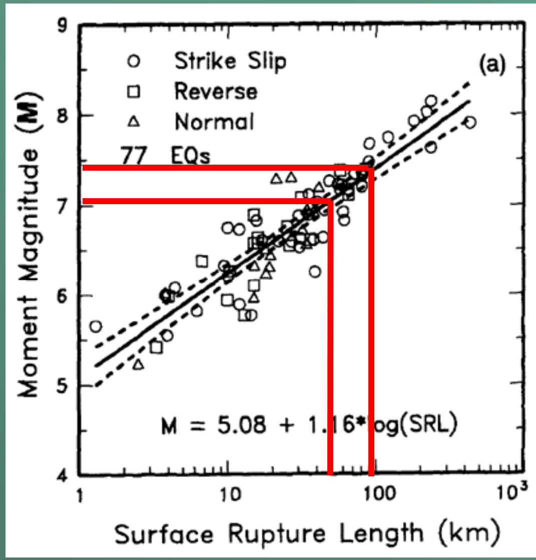
NHSM
- EQ mag
- EQ frequency

Ground Motion
- variable sources

Rupture Scenarios
- fault length
- rupture directivity

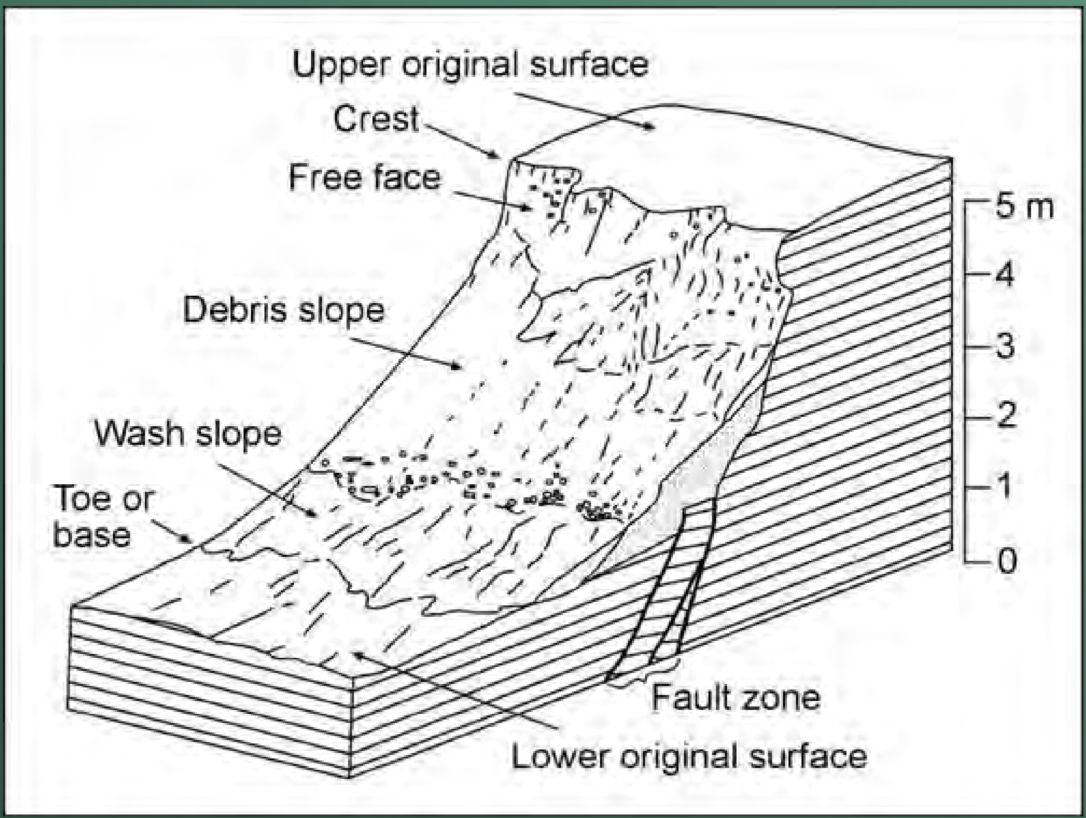


Petersen et al. (2014)

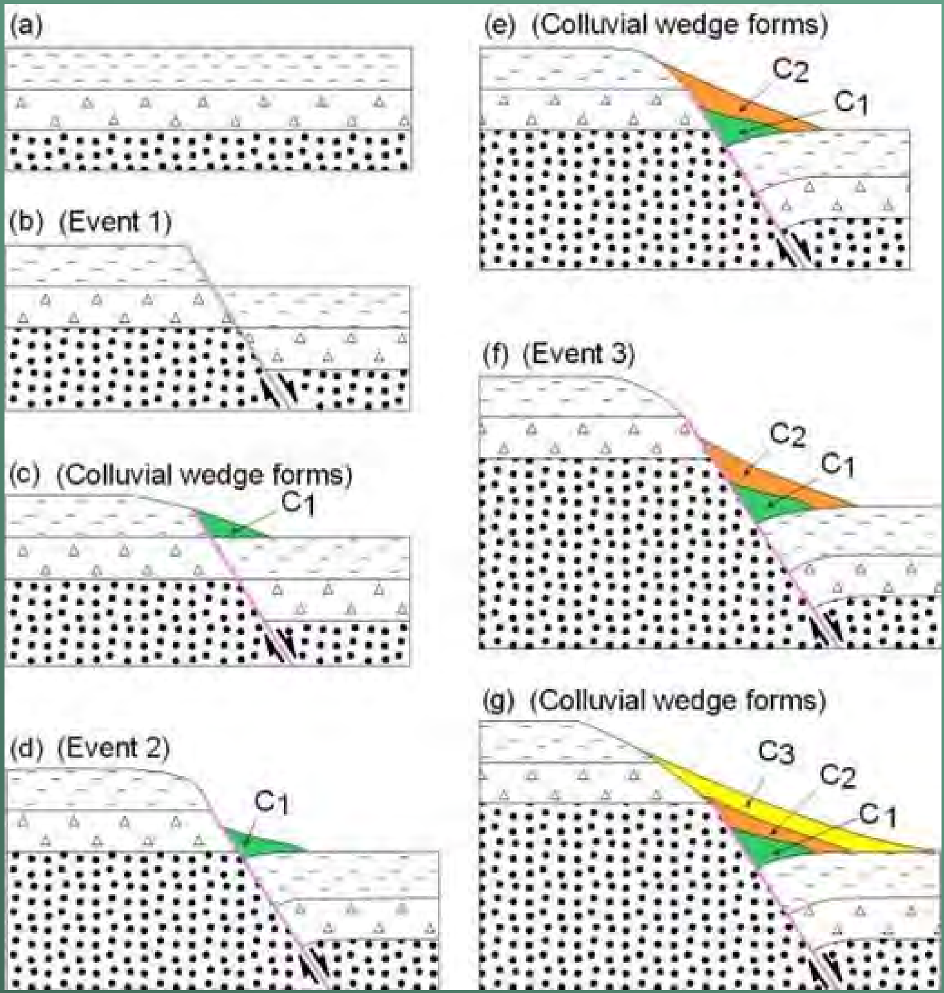


Wells and Coppersmith (1984)

Colluvial Wedge Formation

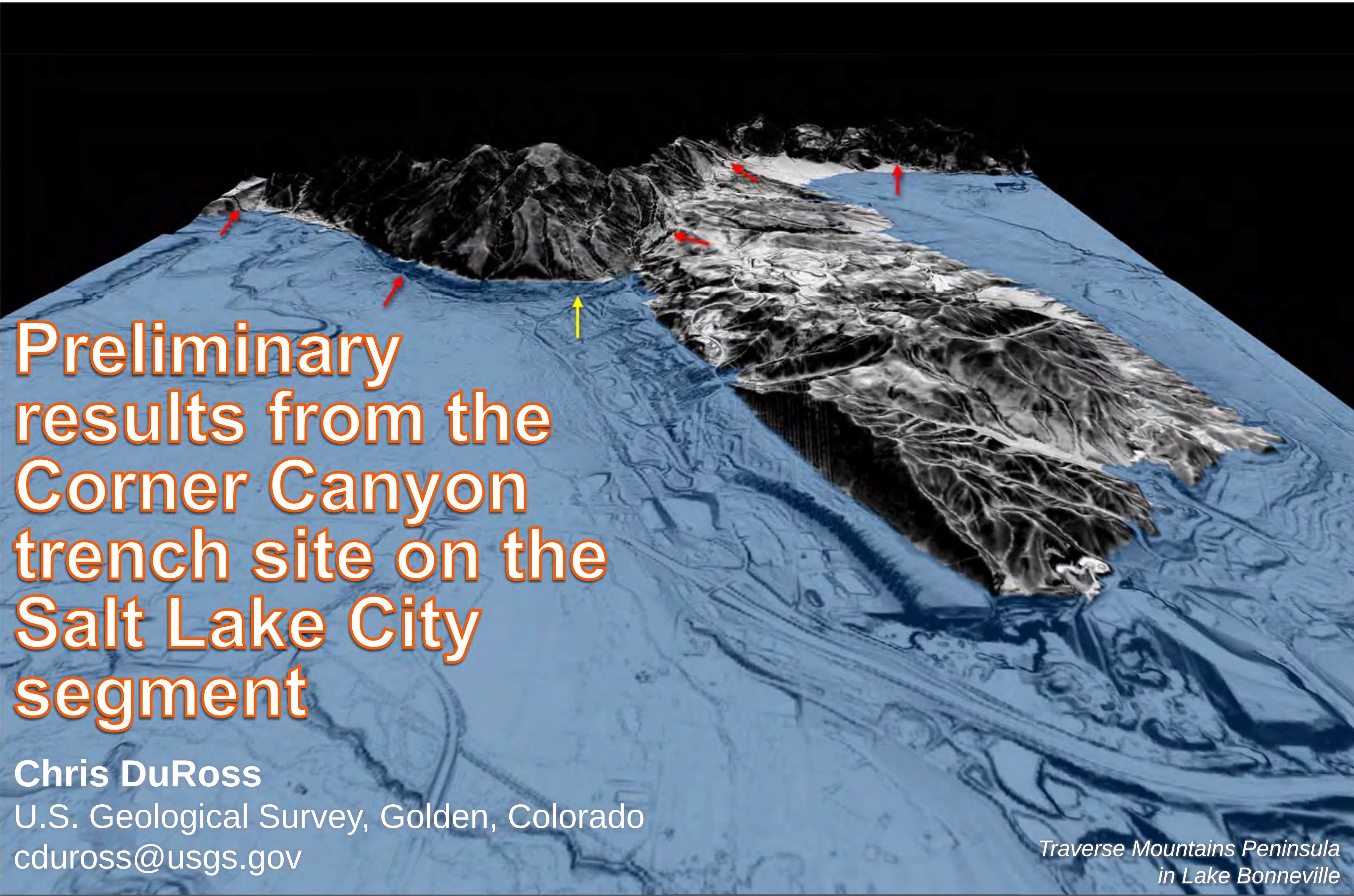


Wallace (1977)



modified from McCalpin (2009)

USGS



Preliminary results from the Corner Canyon trench site on the Salt Lake City segment

Chris DuRoss
U.S. Geological Survey, Golden, Colorado
cduross@usgs.gov

Traverse Mountains Peninsula in Lake Bonneville

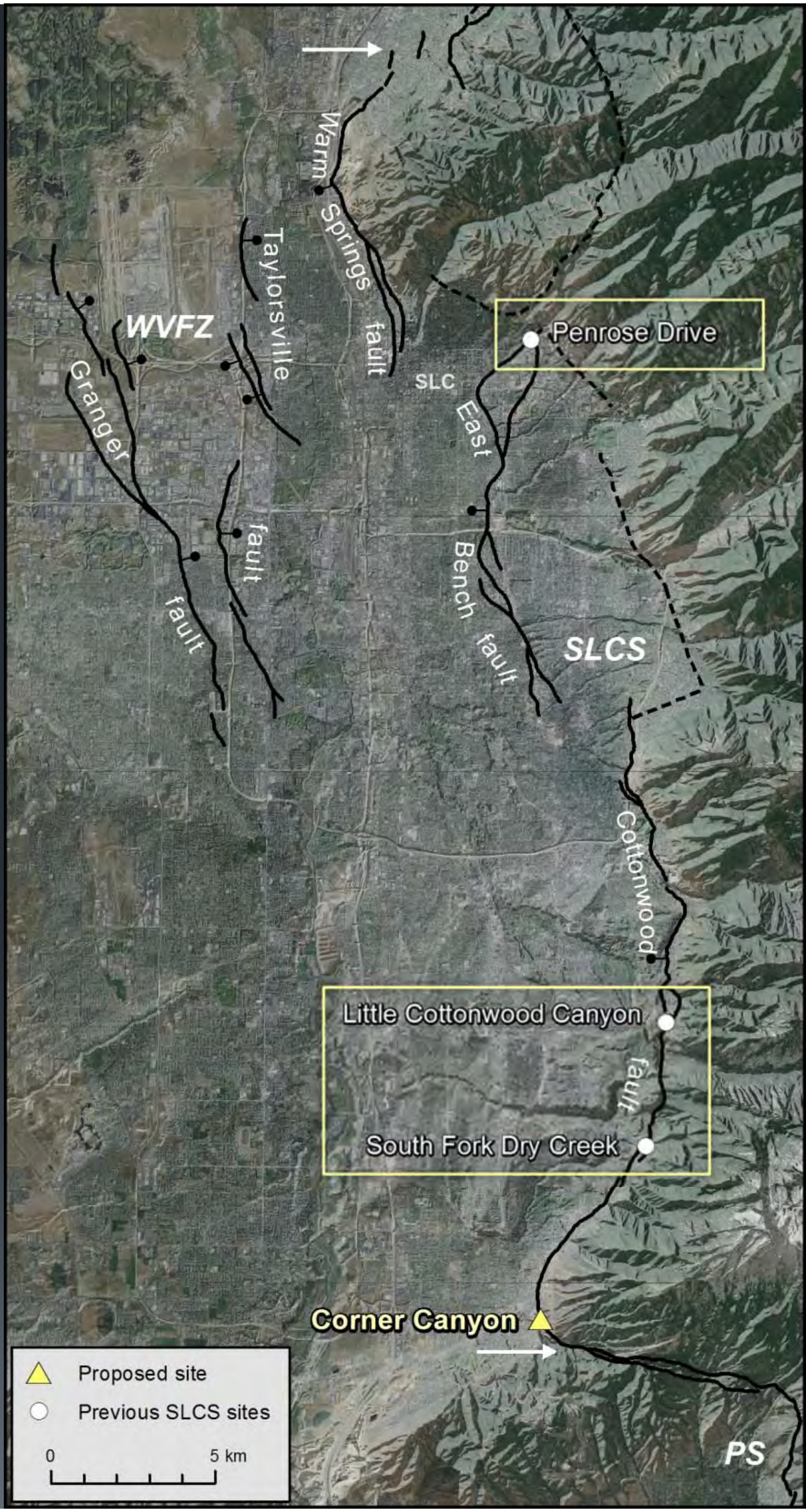
Salt Lake City segment (SLCS)

- Central of the central Wasatch fault zone segments; adjacent to the most populous part of the Wasatch Front
- Elapsed time since most recent earthquake (~1400 yr) comparable to mean recurrence interval (~1300 yr)
- Remaining uncertainties in earthquake timing and rupture extent

Purpose

1. What is the timing and extent of Holocene earthquakes on the SLCS?
   - *How do the three SLCS faults behave?*

2. Have recent (~late Holocene) ruptures crossed the SLCS–Provo segment (PS) boundary?
   - *Two-segment vs. spillover rupture?*



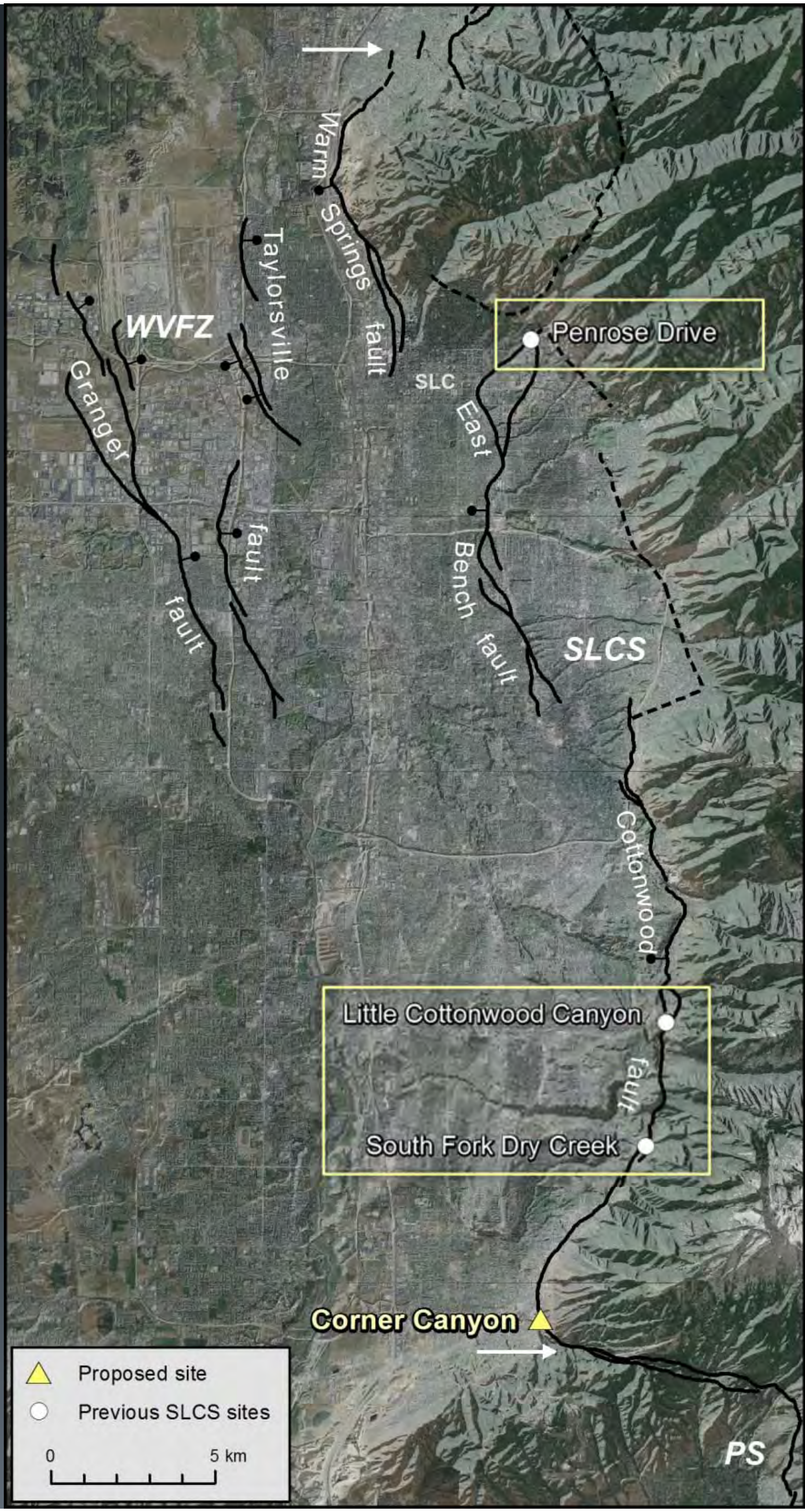
Earthquake Timing

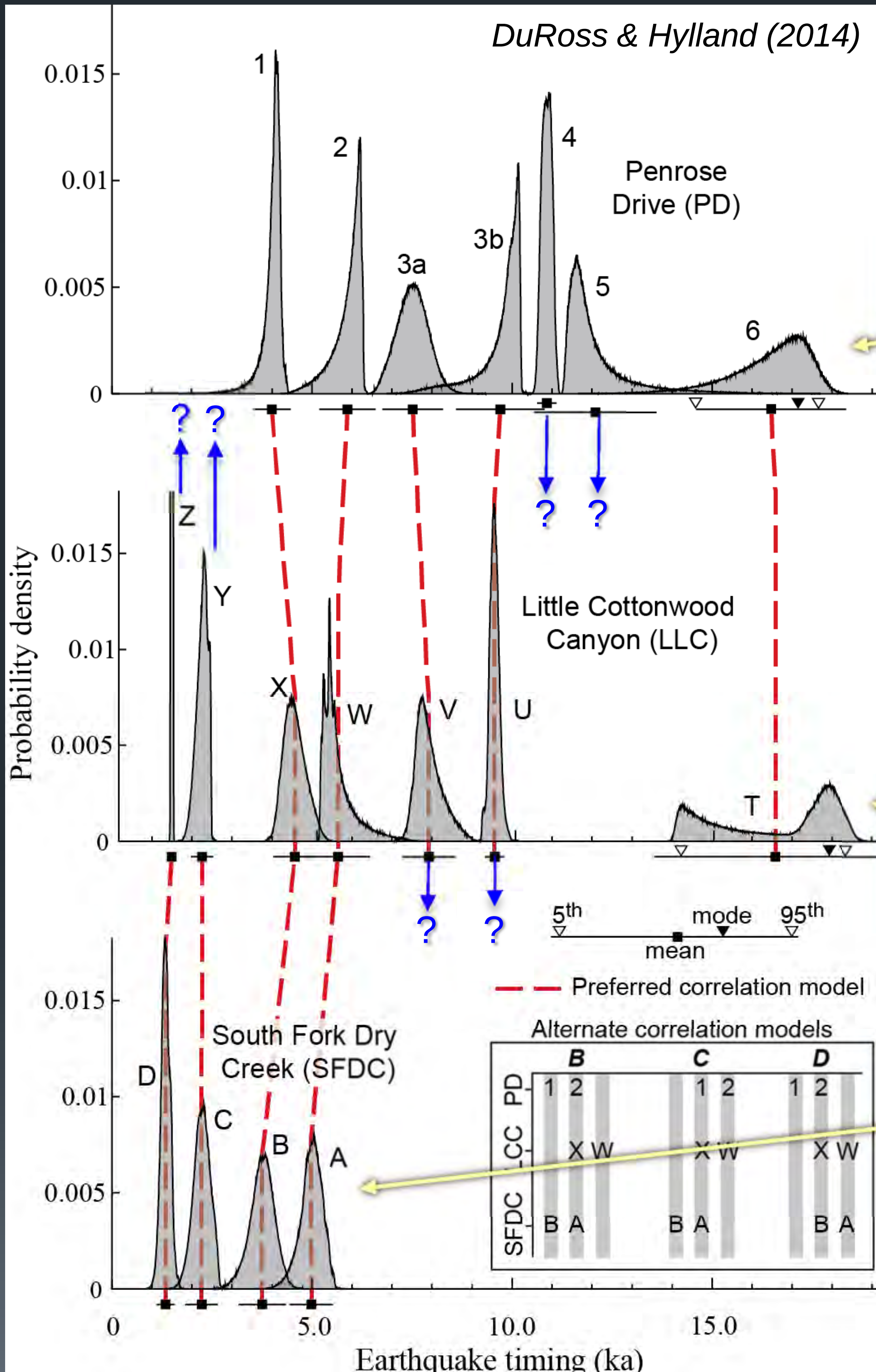
Earthquake timing on the SLCS

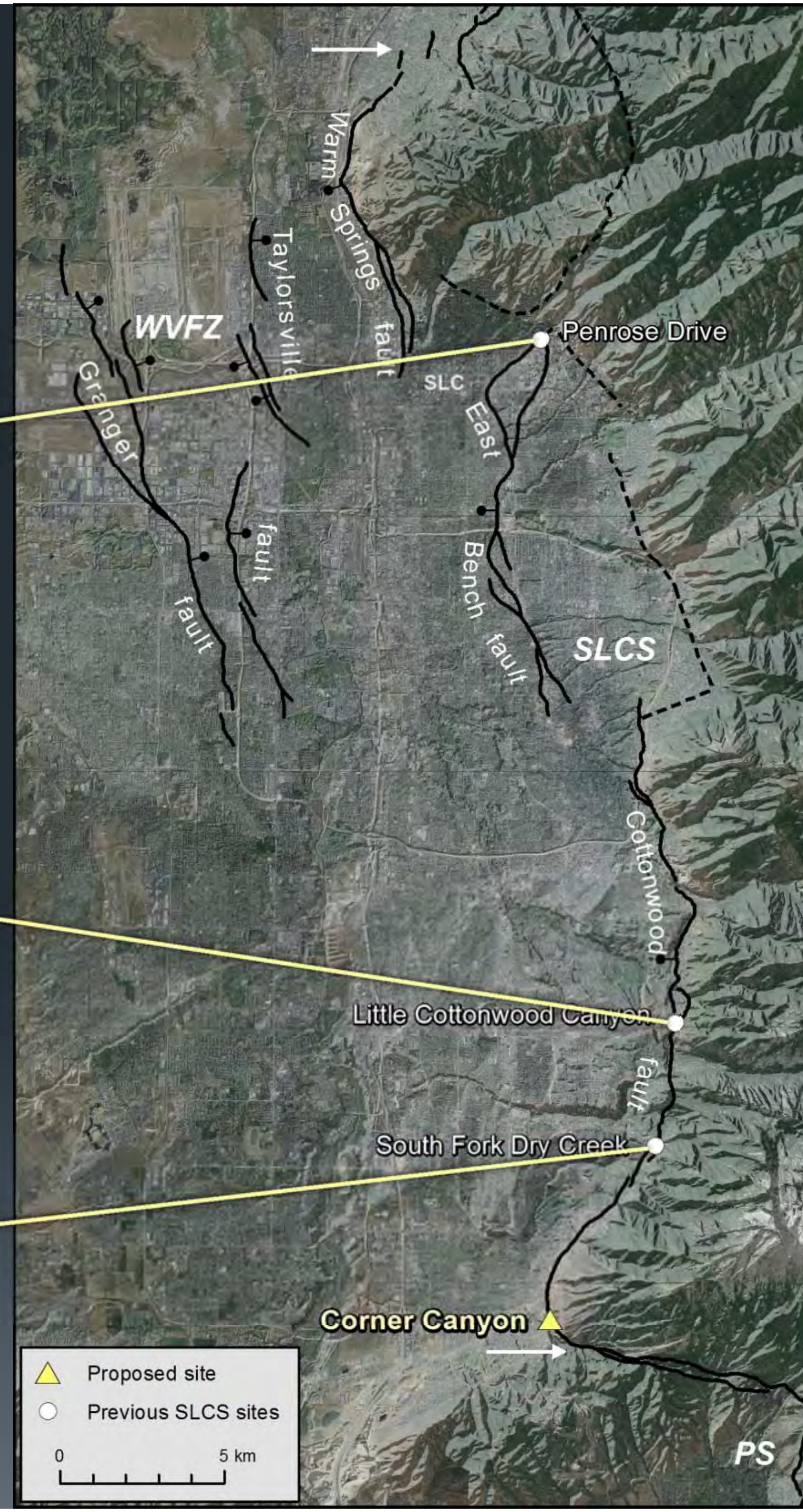
EQ	East Bench fault	Cottonwood fault		SLCS Chronology
	PD (ka)	LCC (ka)	SFDC (ka)	(ka)
S1	-	1.3 ± 0.04	1.3 ± 0.2	1.3 ± 0.2
S2	-	2.1 ± 0.3	2.2 ± 0.4	2.2 ± 0.2
S3	4.0 ± 0.5	4.4 ± 0.5	3.8 ± 0.6	4.1 ± 0.2
S4	5.9 ± 0.7	5.5 ± 0.8	5.0 ± 0.5	5.3 ± 0.2
S5	7.5 ± 0.8	7.8 ± 0.7	-	7.7 ± 0.4
S6	9.7 ± 1.1	9.5 ± 0.2	-	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 (2014)

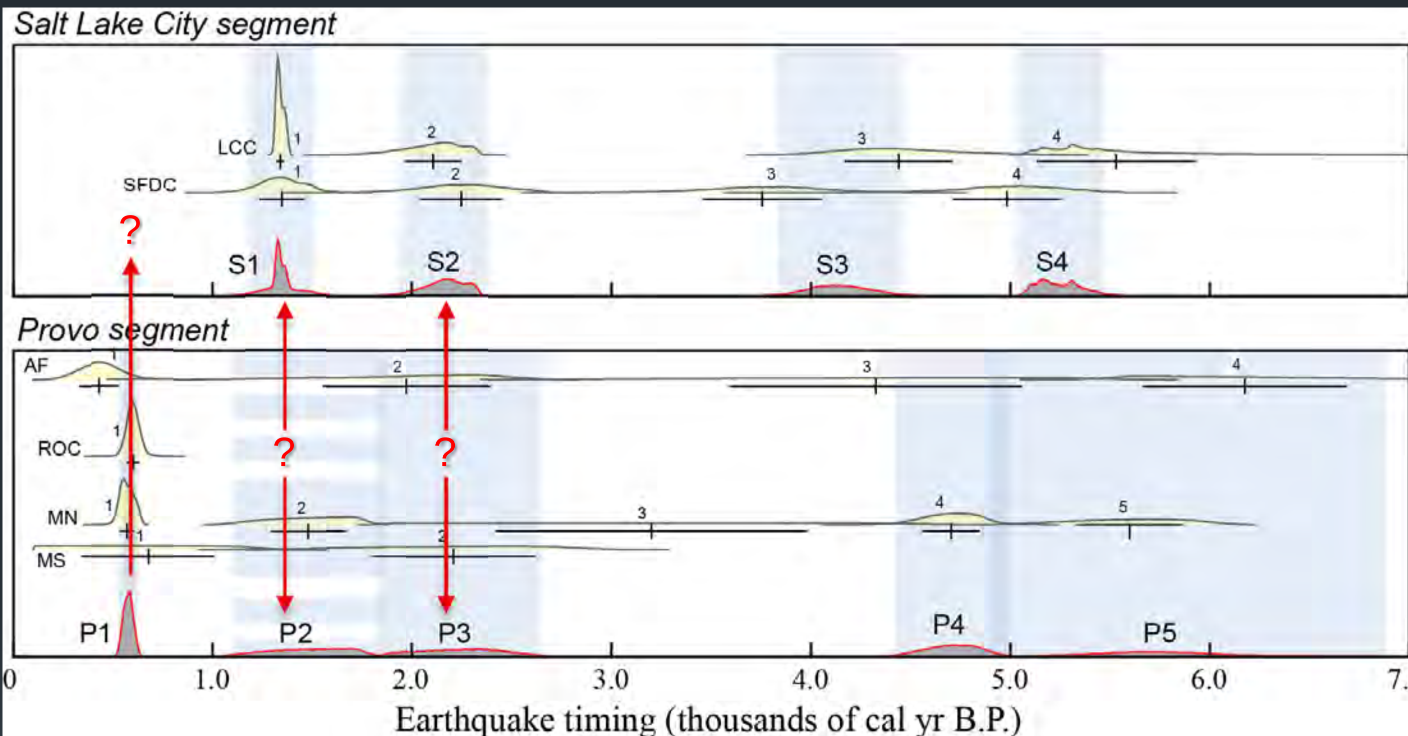
- **PD: Penrose Drive**
  (DuRoss and others, 2014)
- **LCC: Little Cottonwood Canyon**
  (Swan and others, 1981, McCalpin, 2002)
- **SFDC: South Fork Dry Creek**
  (Schwartz and Lund, 1988; Black and others, 1996)



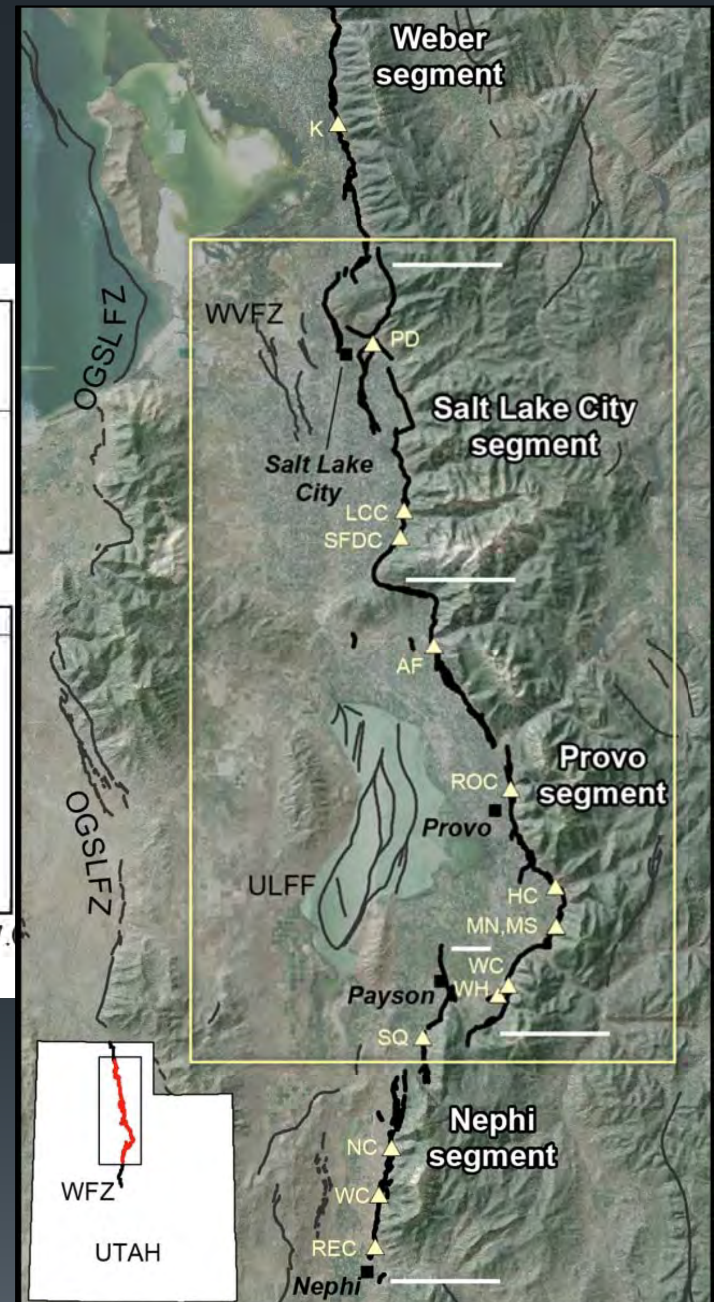

DuRoss & Hylland (2014)
Penrose Drive (PD)
1
2
3a
3b
4
5
6
Little Cottonwood Canyon (LLC)
Z
Y
X
W
V
U
T
South Fork Dry Creek (SFDC)
D
C
B
A
?
5th
mode
95th
mean
Preferred correlation model
Alternate correlation models
B
C
D
PD
LCC
SFDC
Probability density
Earthquake timing (ka)
0
0.005
0.01
0.015
5.0
10.0
15.0


Warm Springs fault
Taylorsville fault
WVFZ
Granger fault
SLC
East Bench fault
Penrose Drive
SLCS
Cottonwood fault
Little Cottonwood Canyon
South Fork Dry Creek
Corner Canyon
Proposed site
Previous SLCS sites
0
5 km
PS

Rupture Extent



Modified from DuRoss et al. (in review)

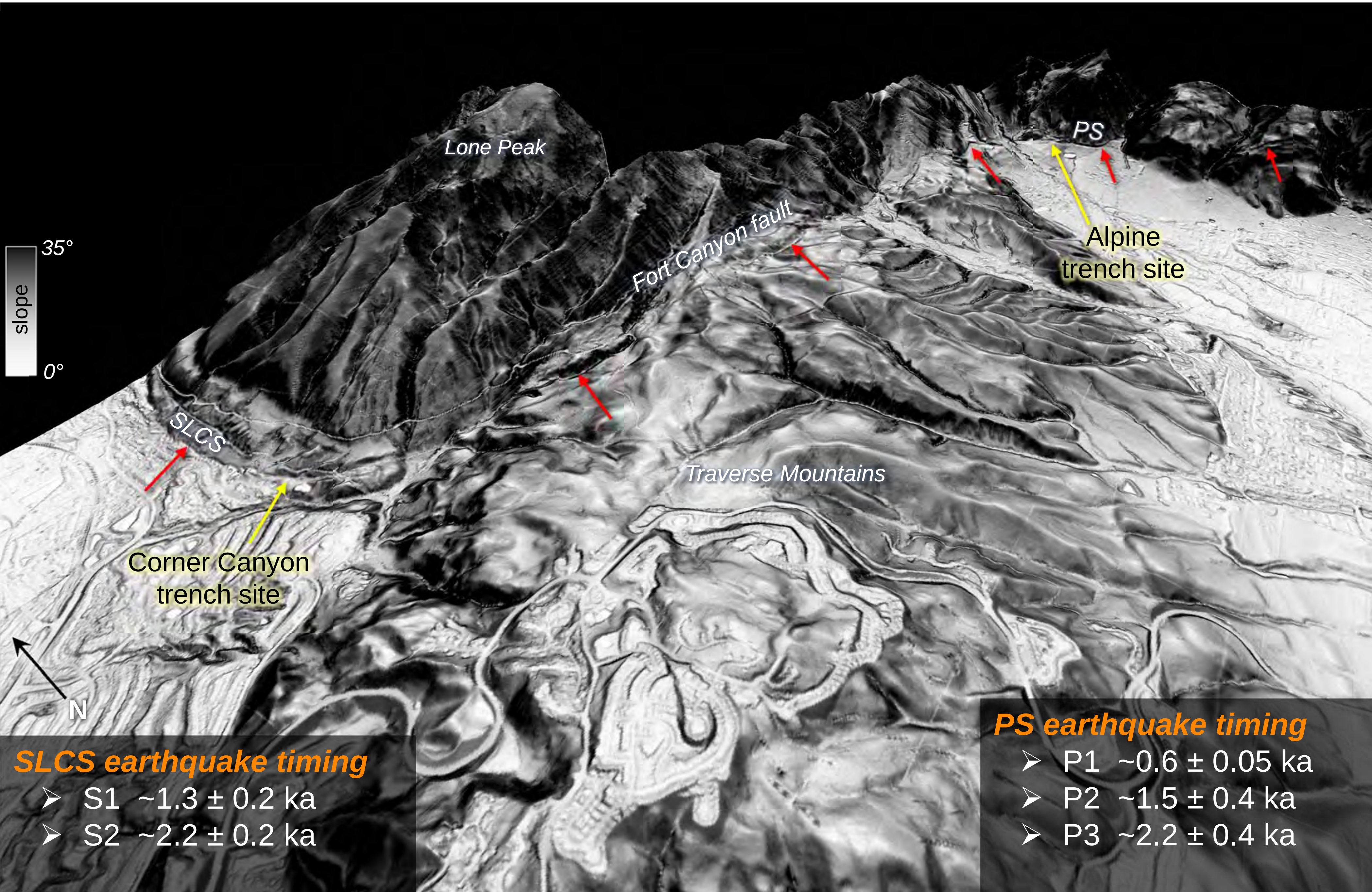


Corner Canyon site

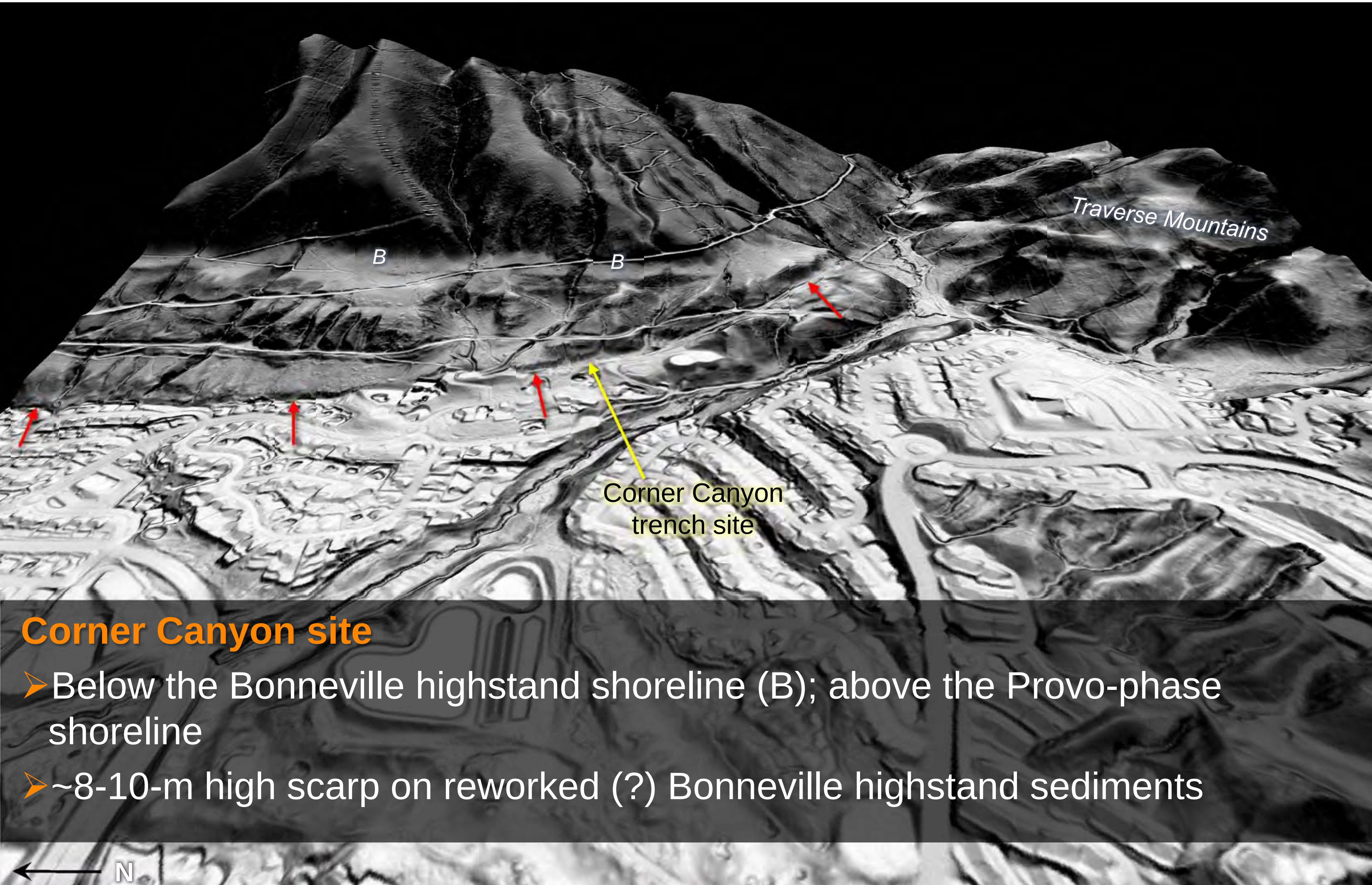
- ➢Southernmost SLCS, ~ 1km north or cross fault between SLCS and PS

- ➢Companion site to Alpine trench site (northernmost PS) led by Scott Bennett (USGS)

- ➢Ideally suited to compare timing of earthquake on the SLCS and PS and evaluate potential for single-segment, spillover-, and multi-segment ruptures



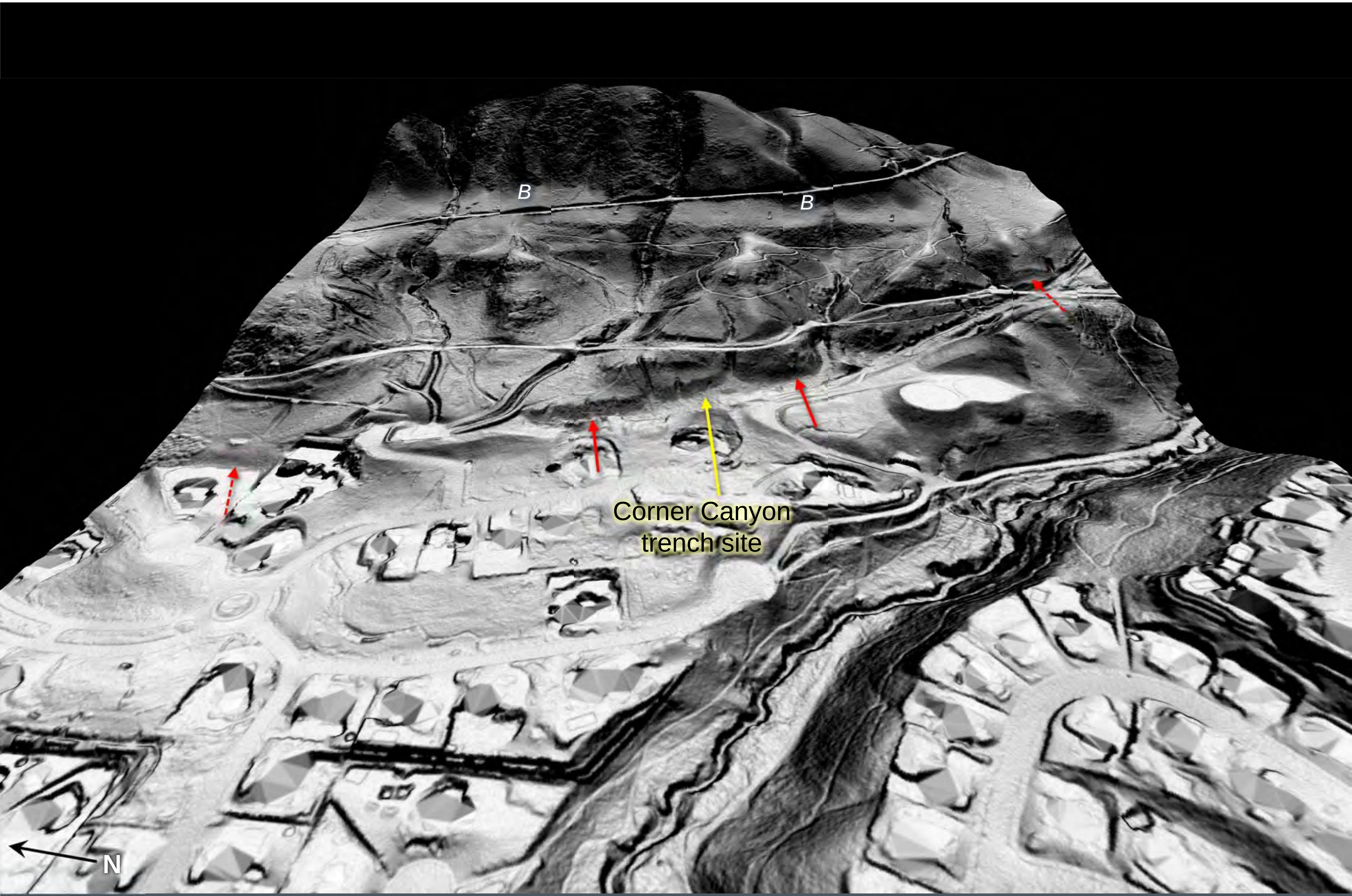
Lidar-based slopeshade map; oblique northeast view of the SLCS-PS segment boundary



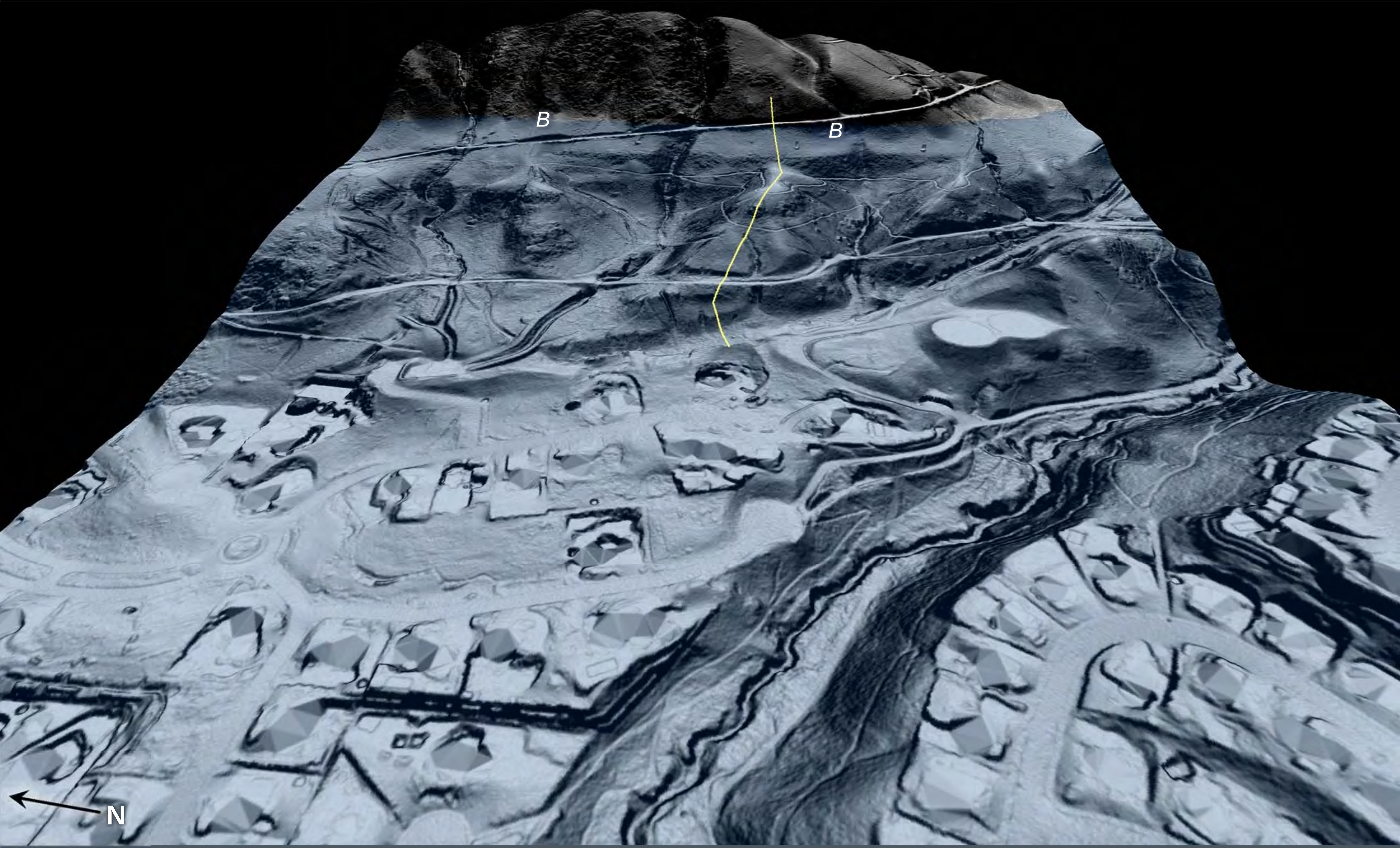
Corner Canyon site

- ➢Below the Bonneville highstand shoreline (B); above the Provo-phase shoreline
- ➢~8-10-m high scarp on reworked (?) Bonneville highstand sediments

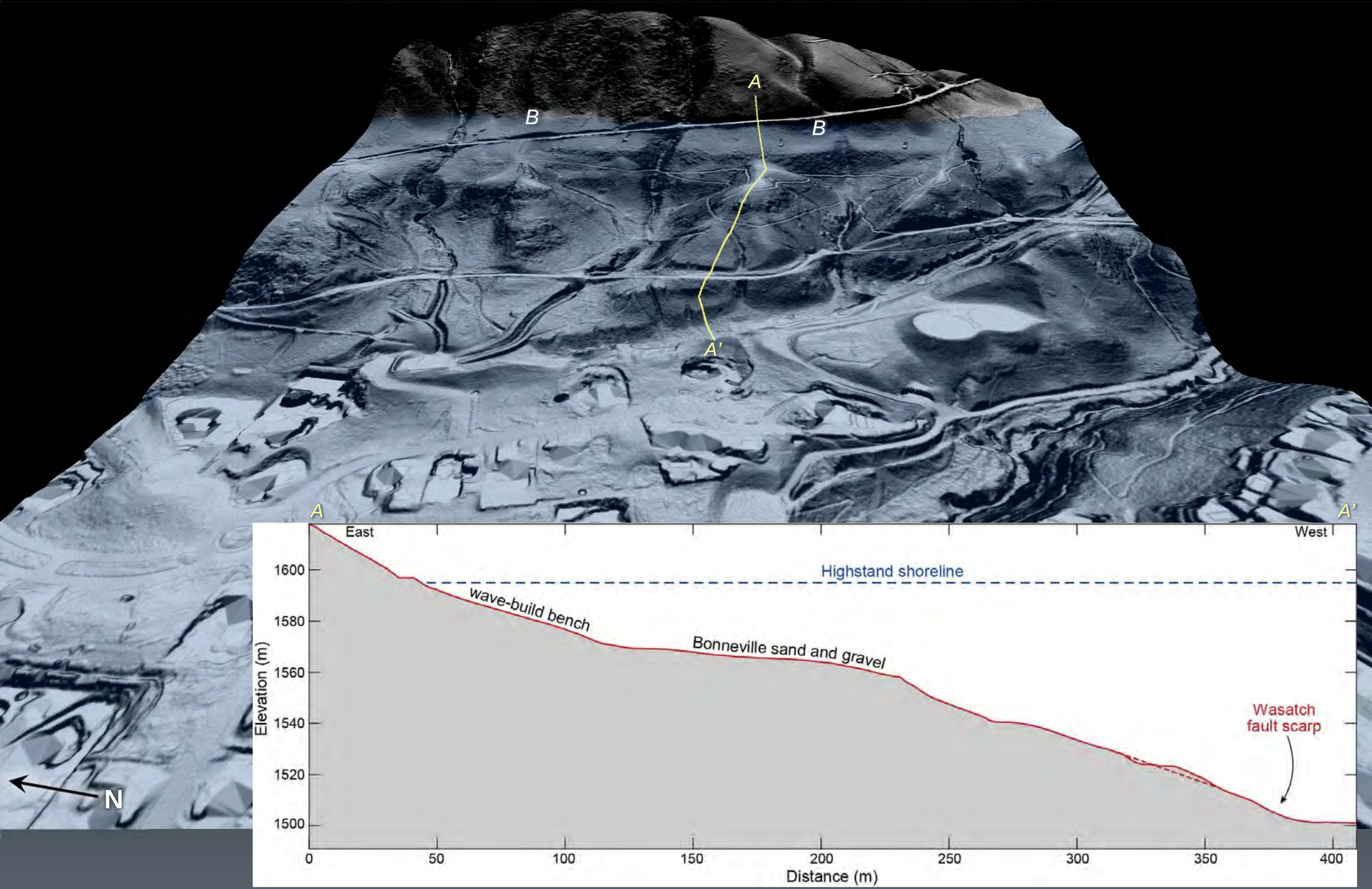
Lidar-based slopeshade map; oblique east view of the southernmost SLCS



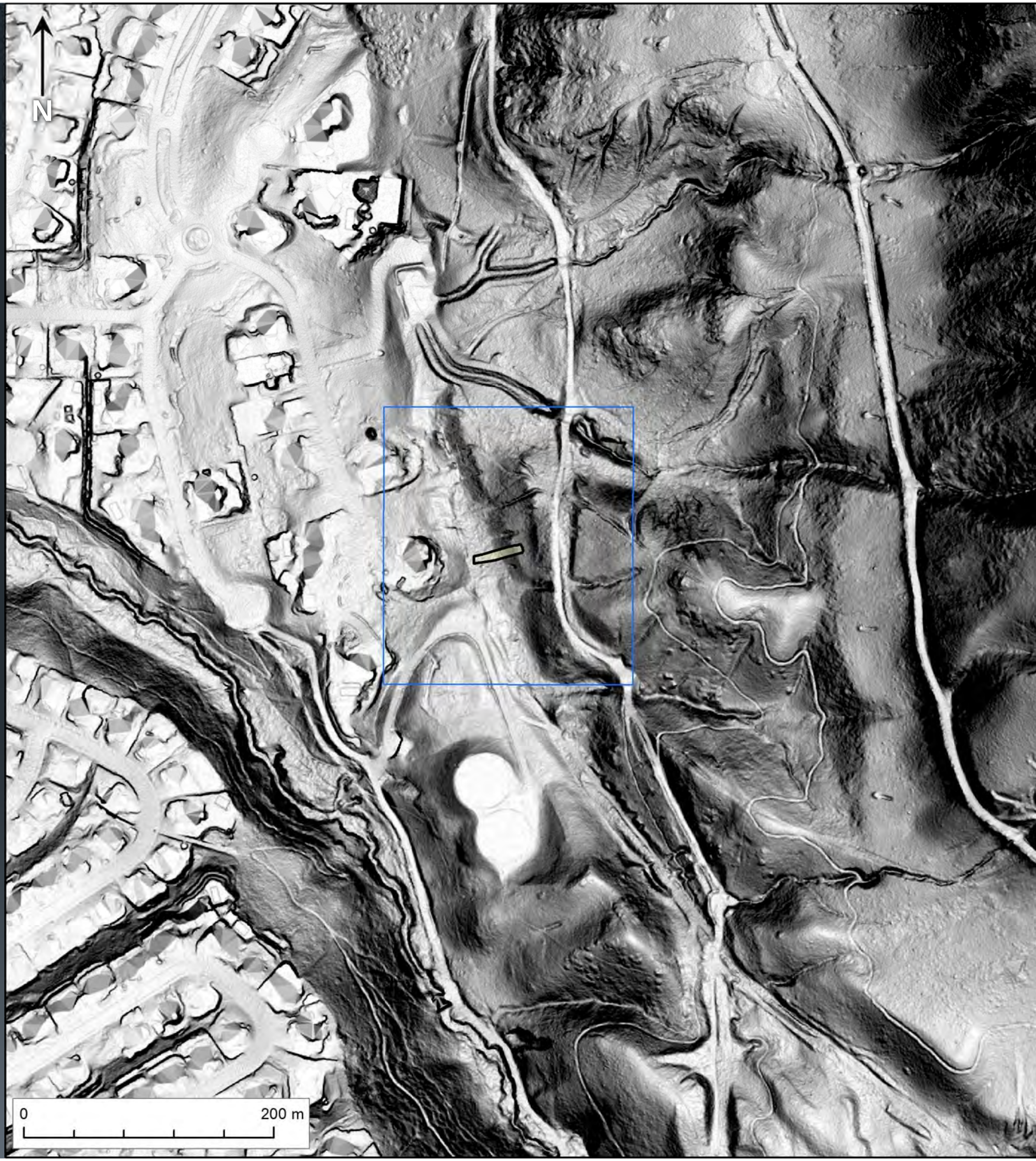
Lidar-based slopeshade map; oblique east view of the Corner Canyon trench site



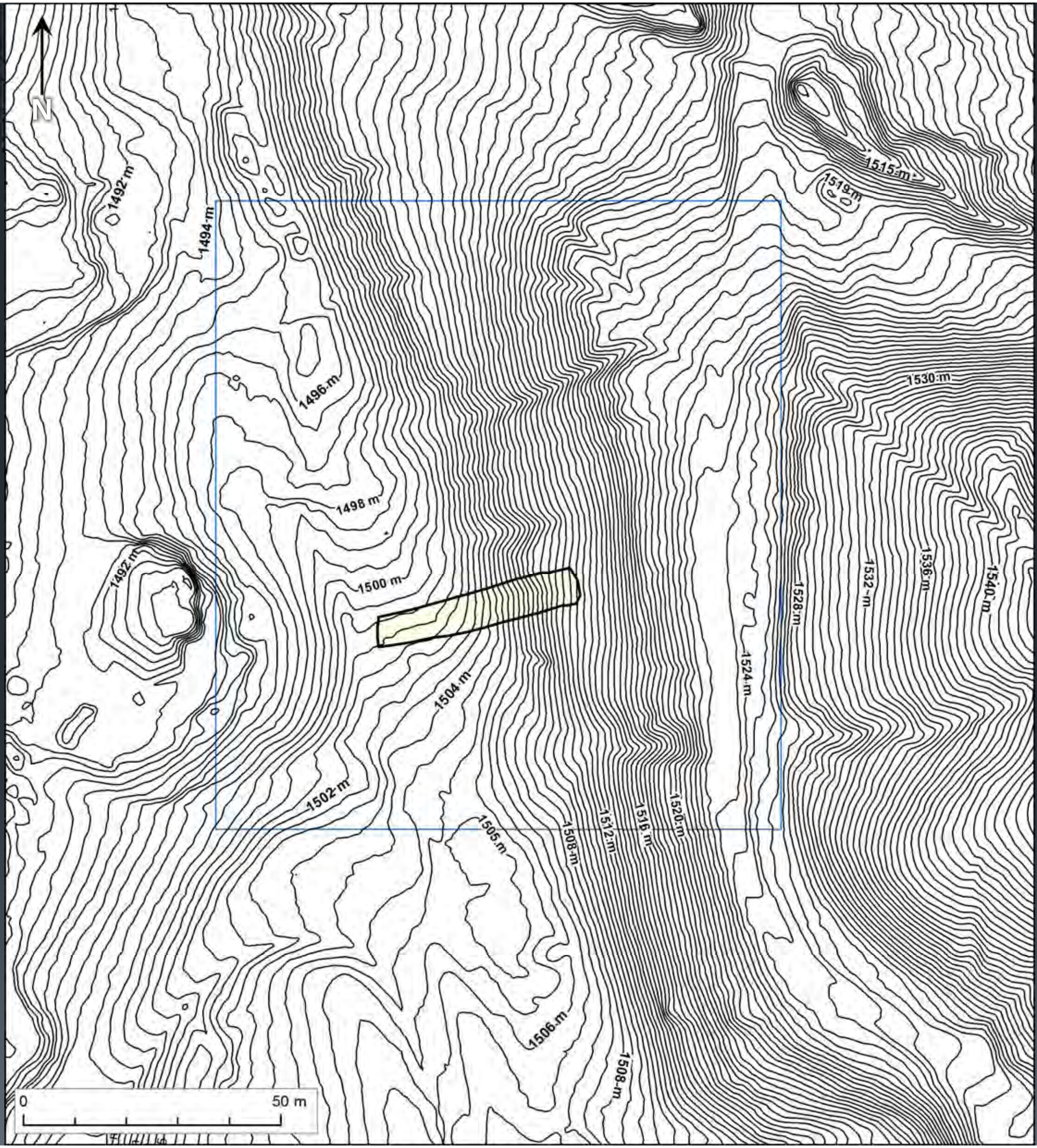
Lidar-based slopeshade map; oblique east view of the Corner Canyon trench site



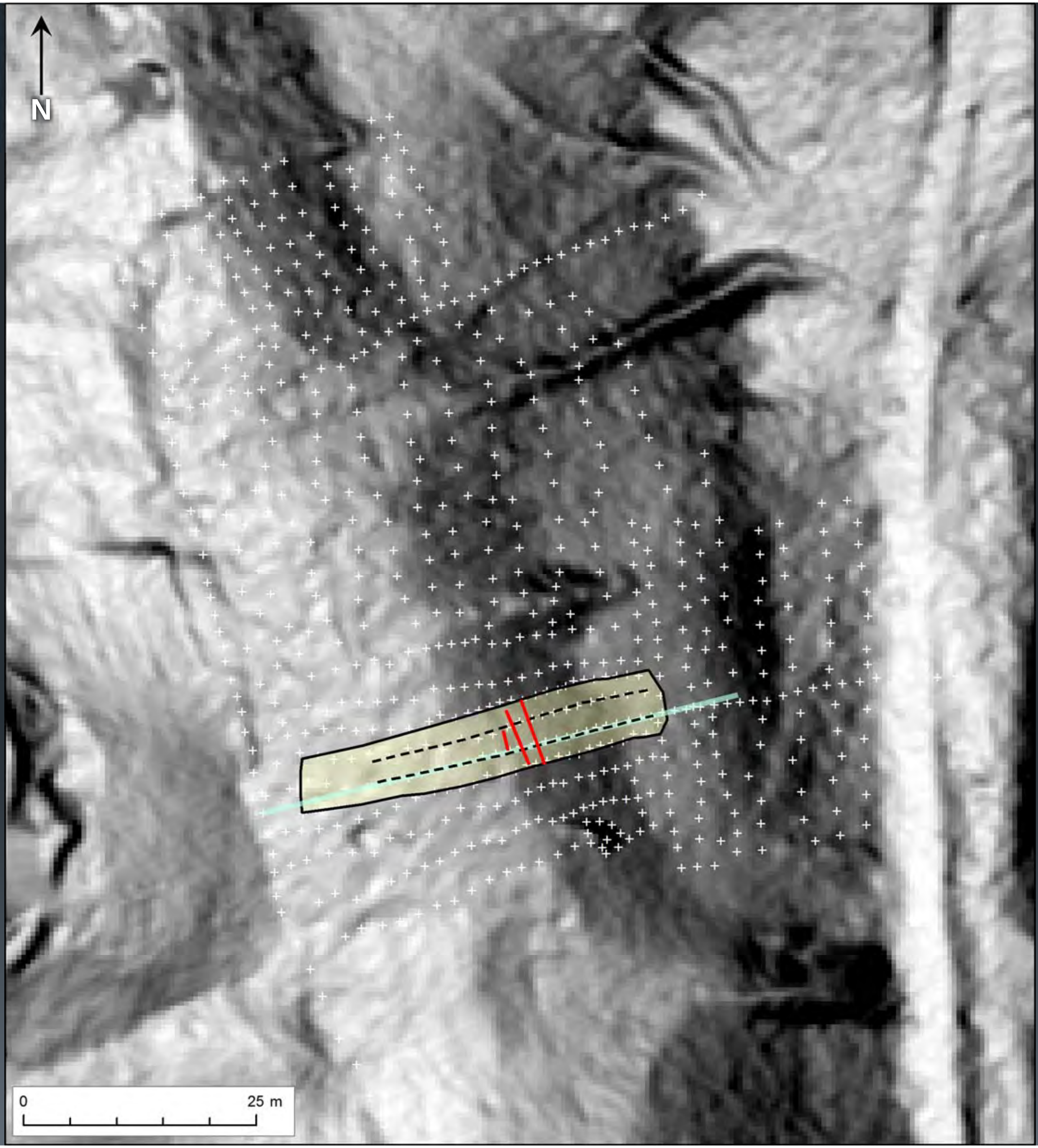
A
B
B
A'
N
A
A'
East
West
Highstand shoreline
wave-build bench
Bonneville sand and gravel
Wasatch
fault scarp
Elevation (m)
1600
1580
1560
1540
1520
1500
0
50
100
150
200
250
300
350
400
Distance (m)



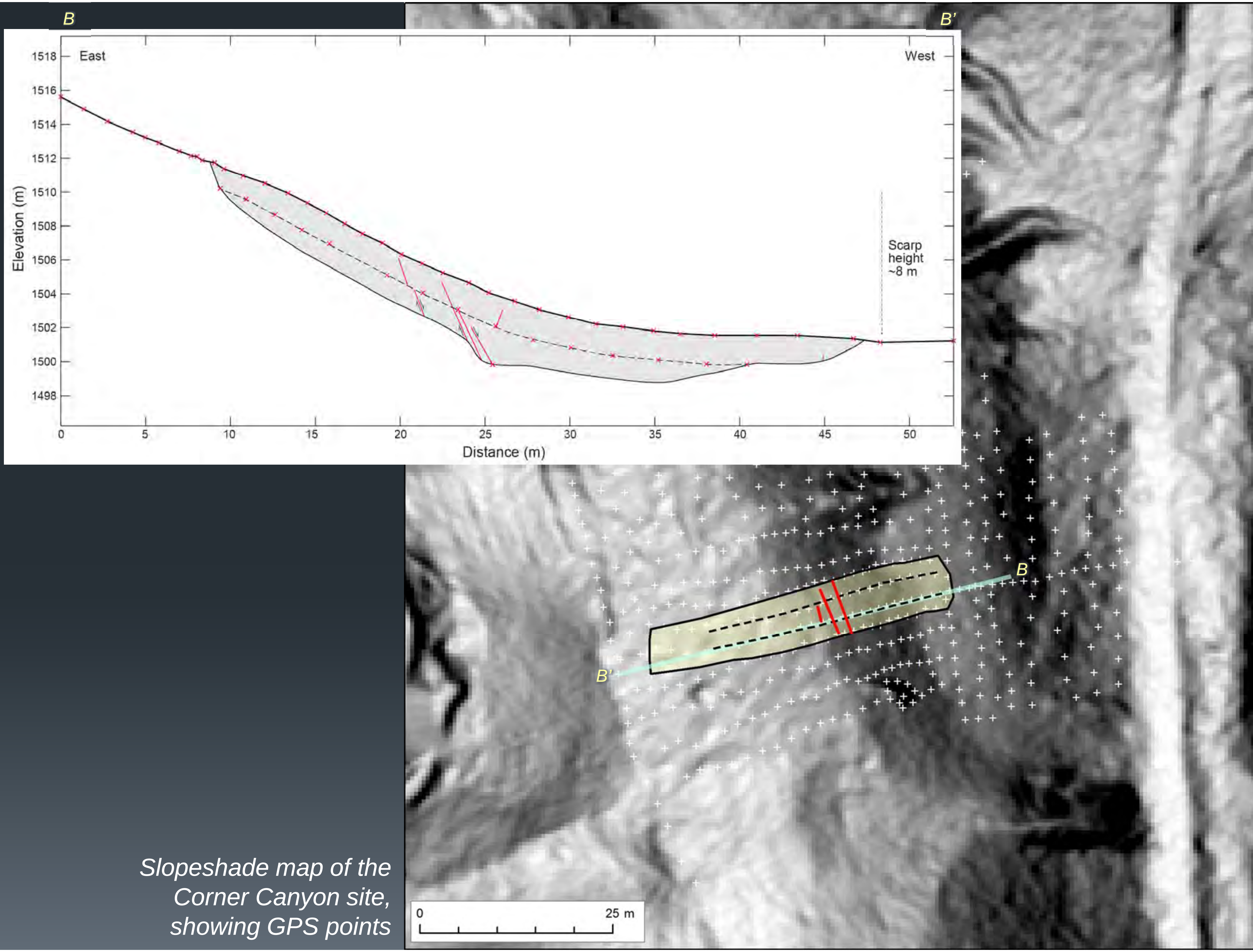
Lidar-based slopeshade map of the southernmost SLCS and Corner Canyon trench site



Contour map (0.5-m interval) derived from Lidar data



Slopeshade map of the Corner Canyon site, showing GPS points



Slopeshade map of the Corner Canyon site, showing GPS points

Excavation of the Corner Canyon trench; June 19, 2014

South wall of the
Corner Canyon trench

- **Trench**
  - 39 m long trench across ~8-m high scarp

➢ Stratigraphic Units

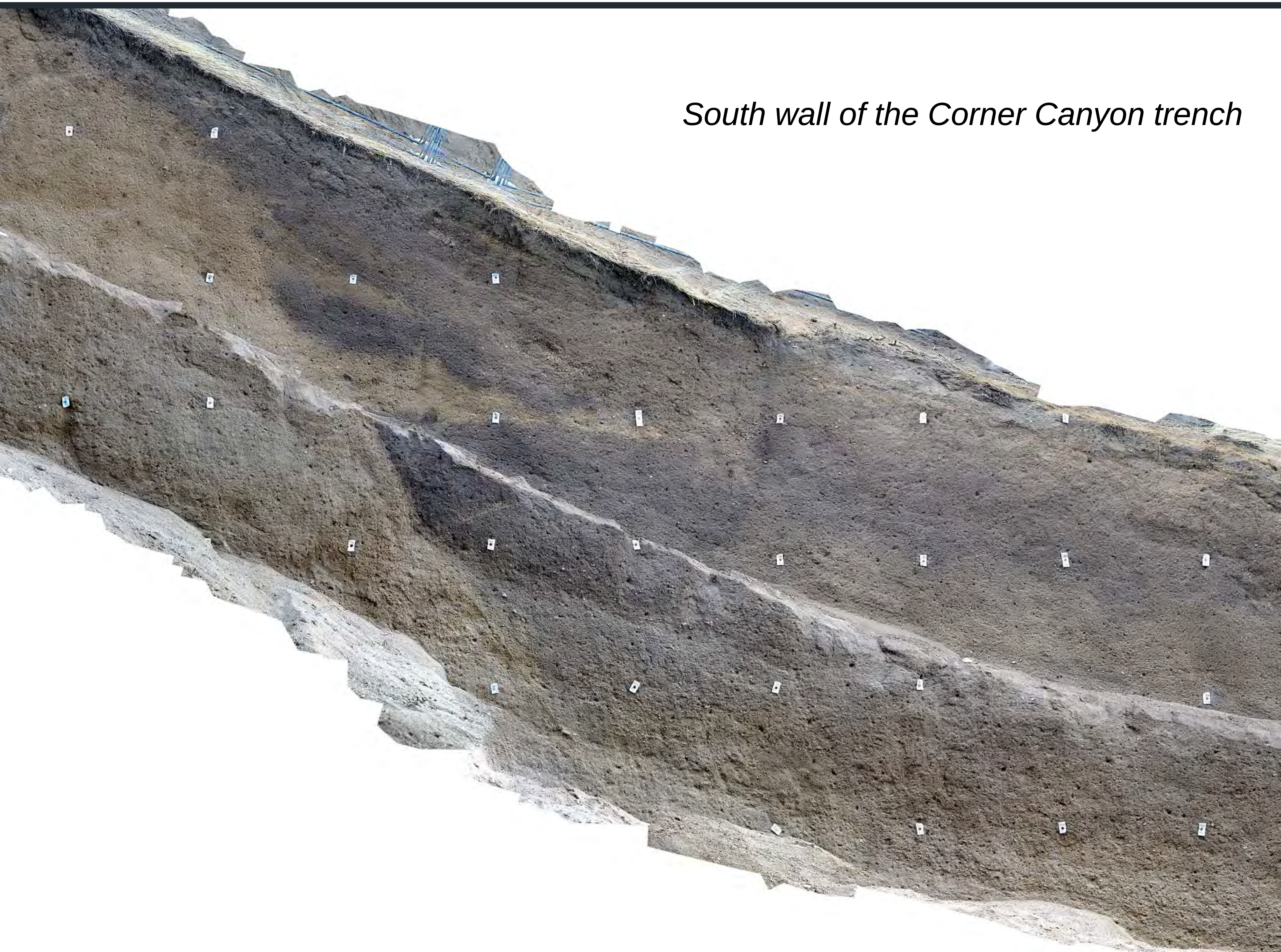
- Reworked (colluviated?) fine-grained Bonneville sediments
- Scarp-derived colluvium and graben-fill deposits
- Young (including modern) alluvial-fan deposits

➢Faulting

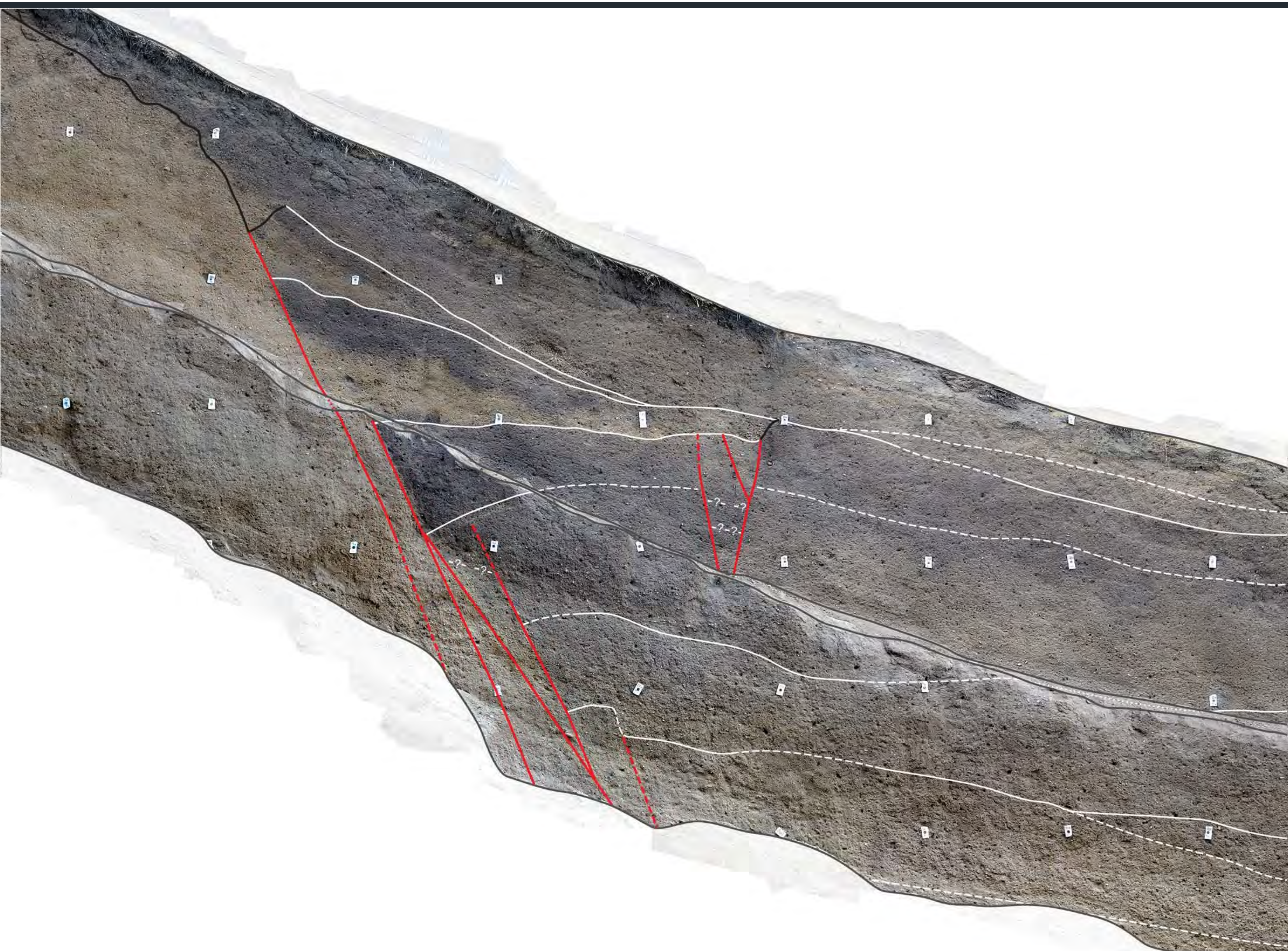
- Main trace dips 60–70° W
- ~9 synthetic/antithetic faults
- ~20-m wide graben

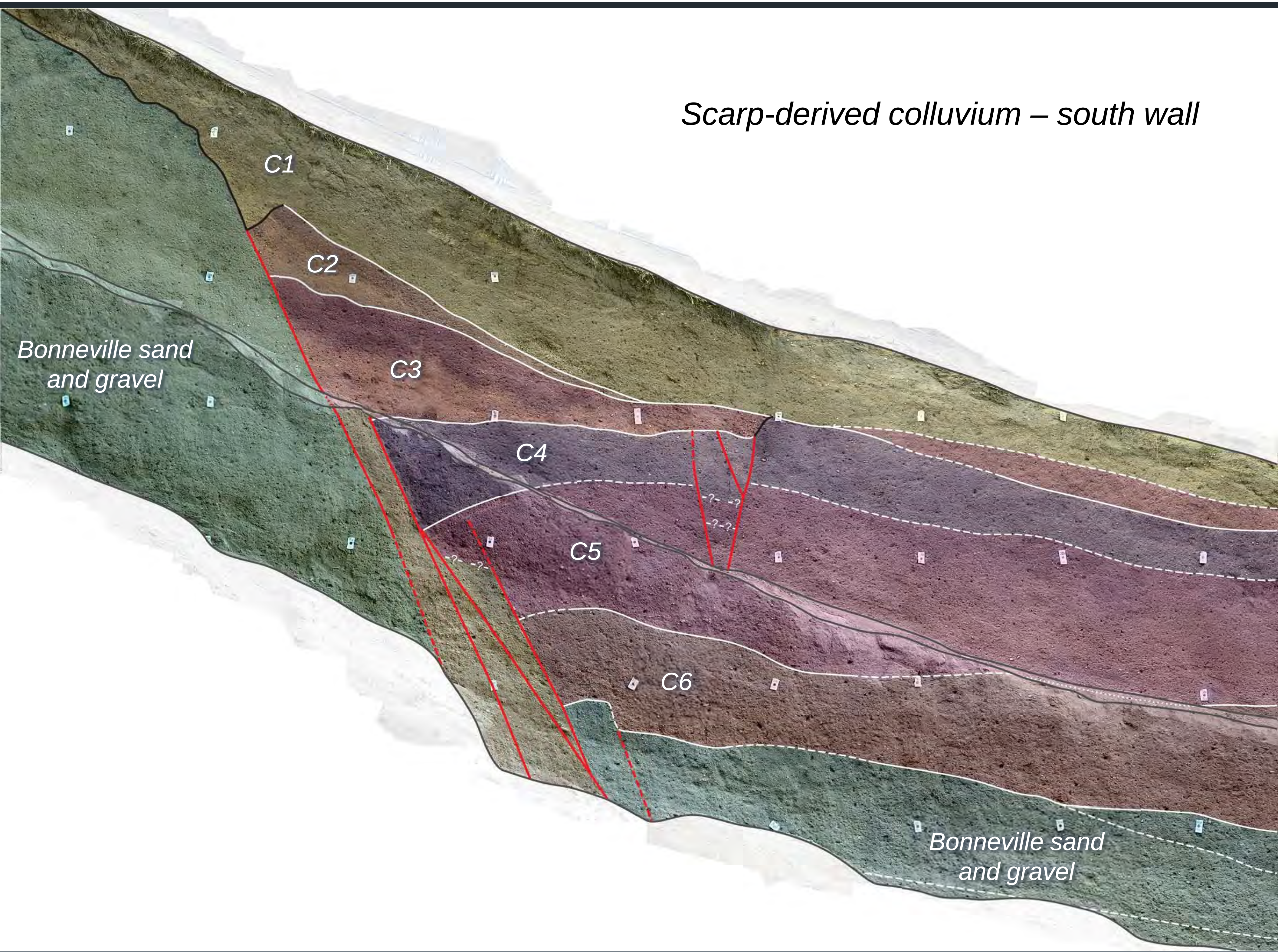
➢Colluvial wedges:

- At least six wedges
- Each ~0.5–0.9 m thick



South wall of the Corner Canyon trench




Scarp-derived colluvium – south wall
C1
C2
C3
C4
C5
C6
Bonneville sand and gravel
Bonneville sand and gravel

Evidence for Surface-Faulting Earthquakes

Scarp-derived colluvium:	C1	C2	C3	C4	C5	C6
Geometry (wedge shape)	X	X	X	X	X	X
Lower contact (with soil?)	X	X	X	X	X	X
Texture (sorting, slope fabric)	X	X	X	X	X	X
Soil development (upper/all?)	X	X	X	X	X	X
Fault terminations	X	X	X	X	X	X
Back rotation	X	X	X	X	X	X

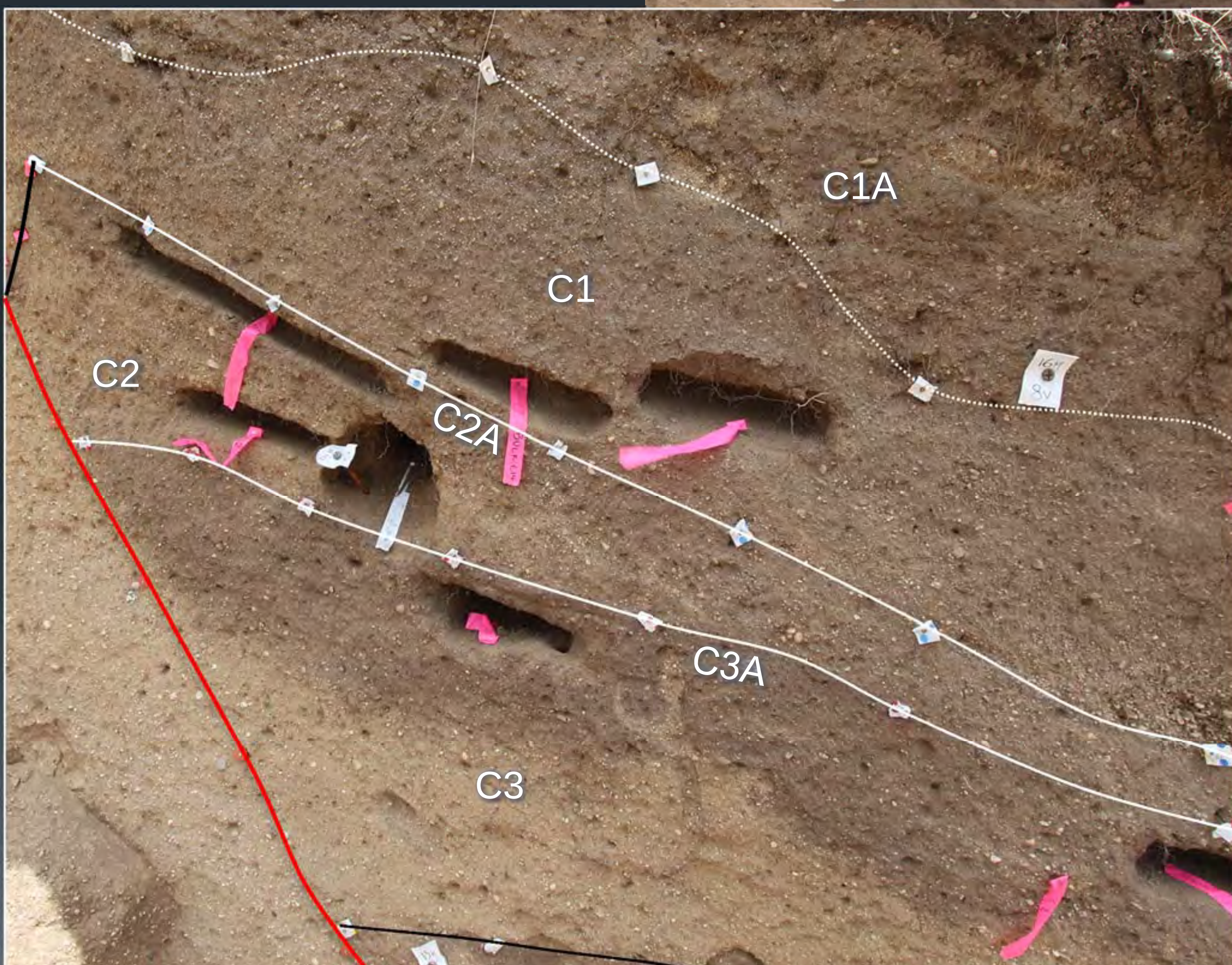
Evidence: X = good, X = weak, X = nonexistent

Sampling Strategy

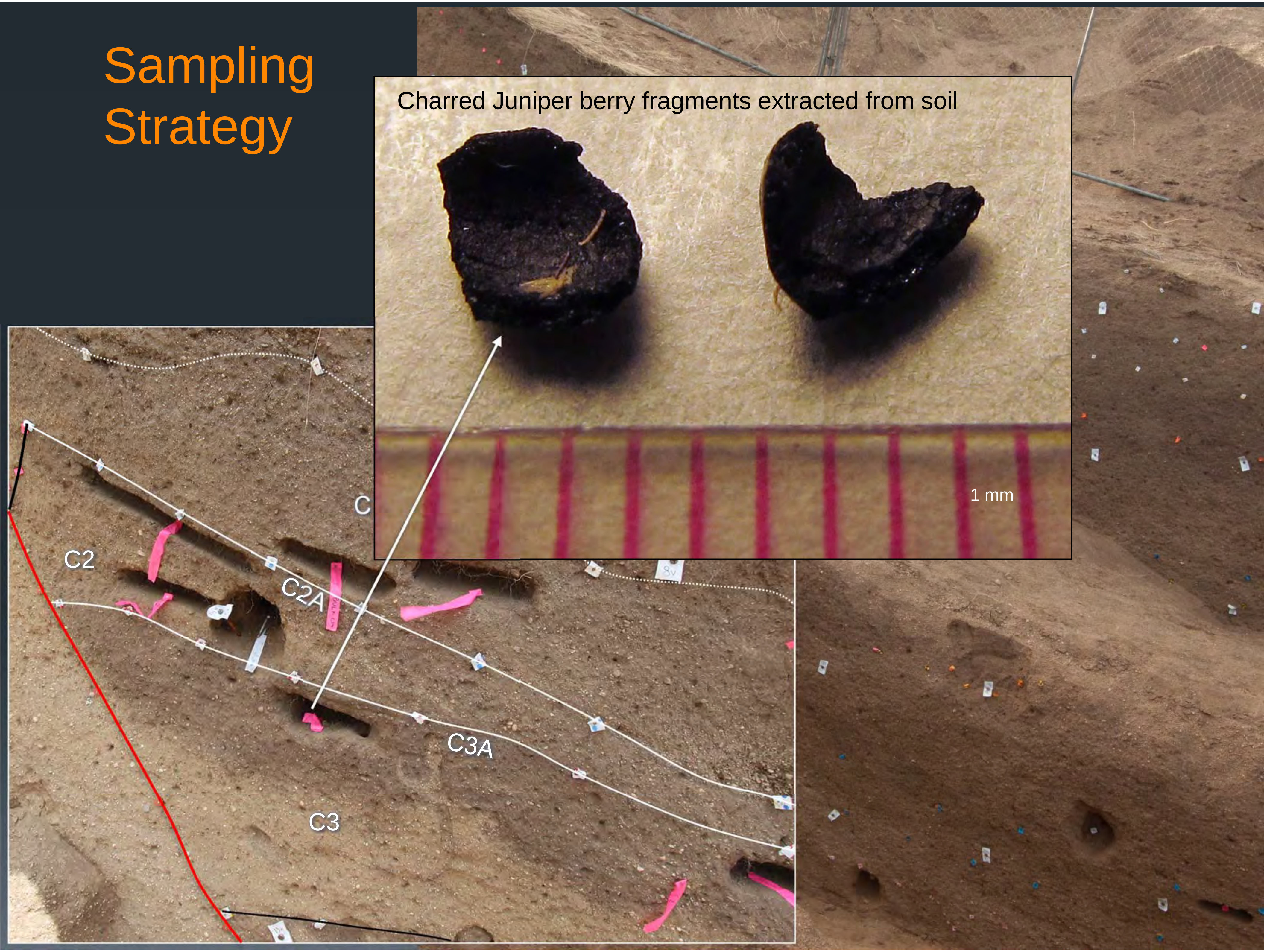
- *Radiocarbon (36)*
  - *27 colluvial-wedge samples (incl. 9 macro charcoal frag's)*
  - *8 samples for general age control*
  - *<u>Charcoal from 18 soil samples; 21 submitted for ^{14}C dating</u>*
- *OSL (15)*
  - *7 colluvial-wedge samples*
  - *8 samples for general age control*
  - *<u>Priority: 11</u>*

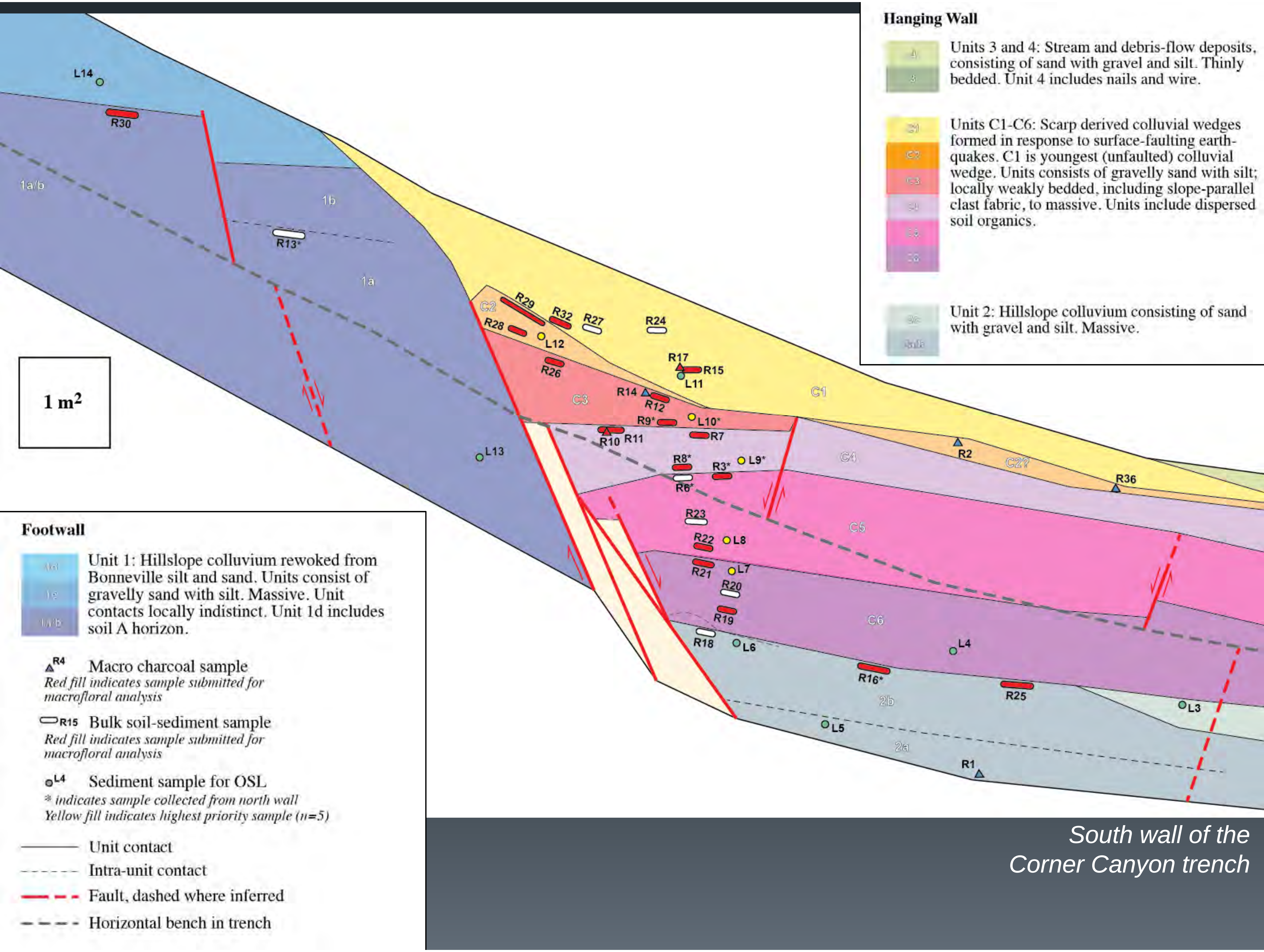
South wall of the Corner Canyon trench

Sampling Strategy



Sampling Strategy





South wall of the Corner Canyon trench

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

Geologic Remapping of the Warm Springs Fault

Adam McKean

Mapping Geologist with the Geologic Hazards Program

Warm Springs Fault of the Salt Lake City Segment of the Wasatch Fault Zone

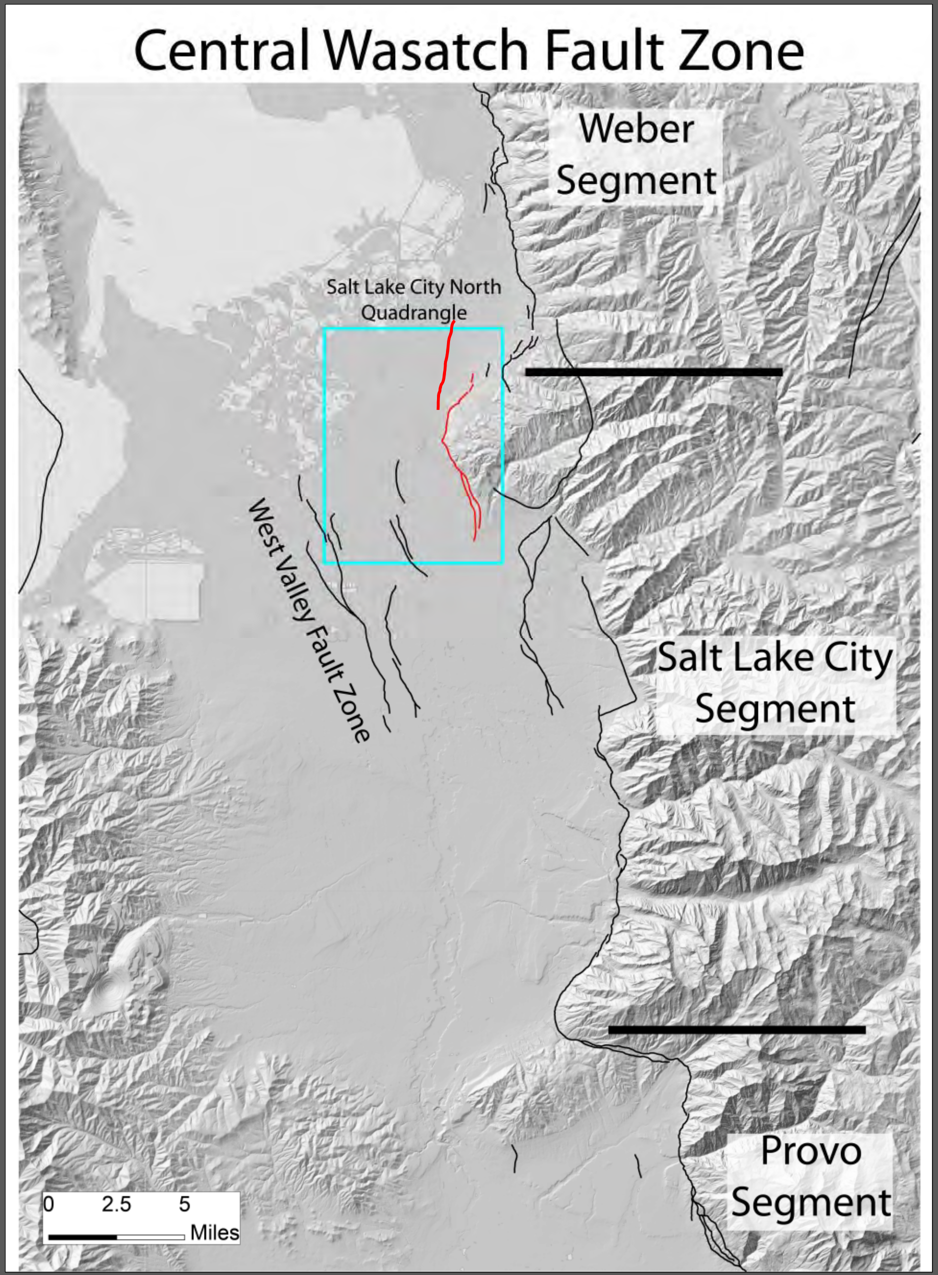
Warm Springs Fault

Current length - 6 mi. (10 km)

New length - 9 to 9.5 mi. (14.5-15.5 km)

Paleoseismic History

- 9 m displacement (3 events), Gilbert, 1890; in Hunt, 1982
- 14-16 m displacement (6-8 events in latest Quat.), Personius and Scott, 1992
- Est. max 12 m displacement at Washington School (Robinson and Burr, 1991)
- Currey, 1992, inferred 3 faults on Capitol Hill with max cumulative 21 m offset since ~20 ka
- Up to 2m offset at Salt Palace, 2-3 events since ~8.1 ka (fault and/or lateral spread interpretations) Korbay and McCormick, 1999; Simon and Shlemon, 1999



Remapping the Warm Springs Fault

Why is it needed?

- Determine southward extent of faulting, if possible
- Understand Warm Springs fault rupture history
  - Surface fault rupture length
  - Recurrence interval
  - Age of faulting
  - Magnitude of earthquake events
- Interest in a possible Warm Springs and East Bench fault connection (Lee Liberty and others, BSU, NEHRP funded seismic project)
- Update maps and data for city and county special study zone

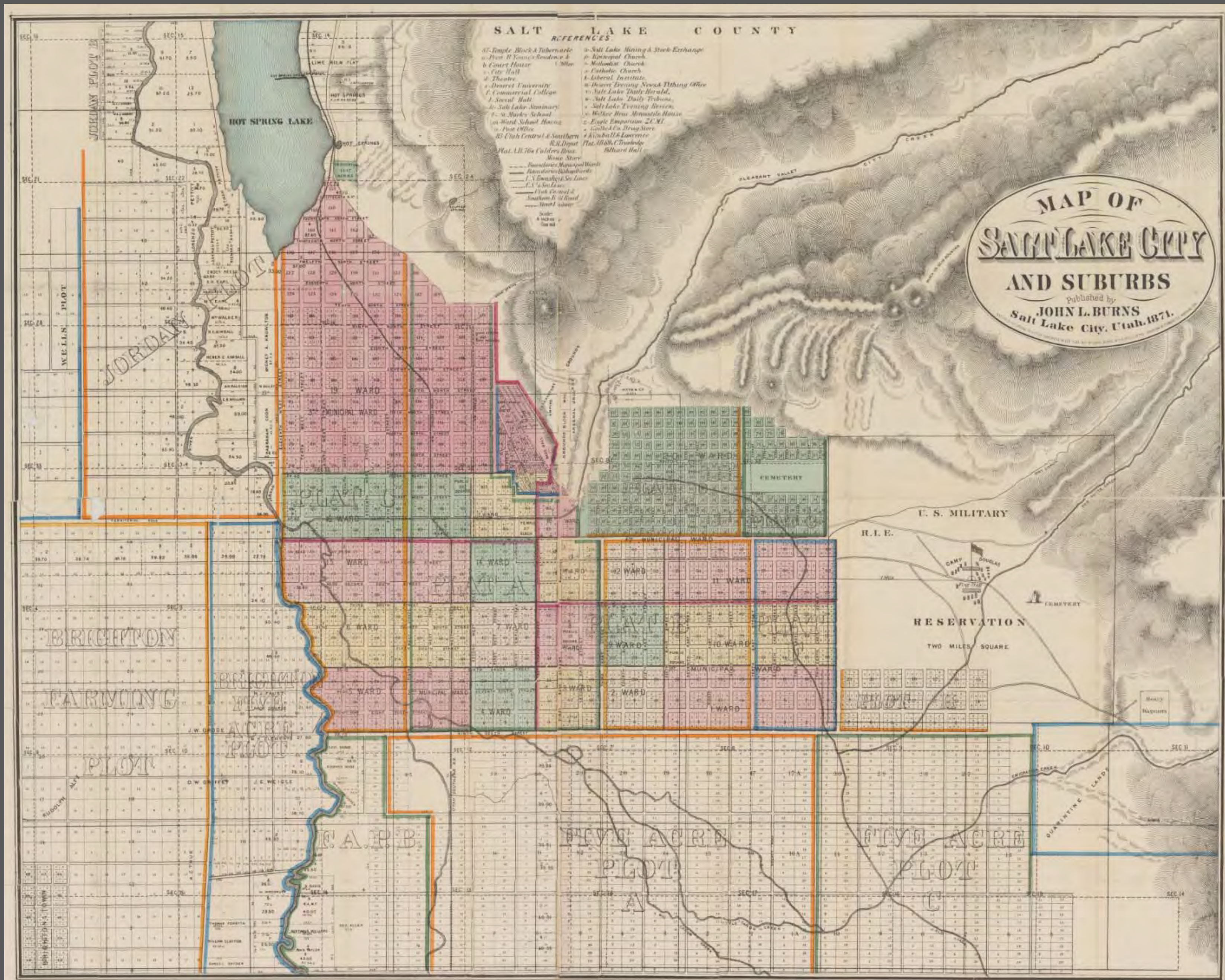
UGS Projects

- Remapping of the geology of the Salt Lake City North 7.5-minute quadrangle
  - STATEMAP 2013-2014
- Remapping of the Wasatch fault zone using LiDAR
  - 0.5 meter LiDAR acquired of the entire Wasatch fault zone (UGS and partners 2013-2014)
- Geologic Hazard Mapping Initiative
  - Currently mapping in Salt Lake and Utah Counties

Mapping Resources

- Historical photographs
- Aerial photographs
- LiDAR
- Gravity
- Previous geologic mapping
- Geotechnical investigations
- Surface fault rupture investigations
- Cone penetrometer test (CPT) investigations
- NRCS soil maps

One major problem…



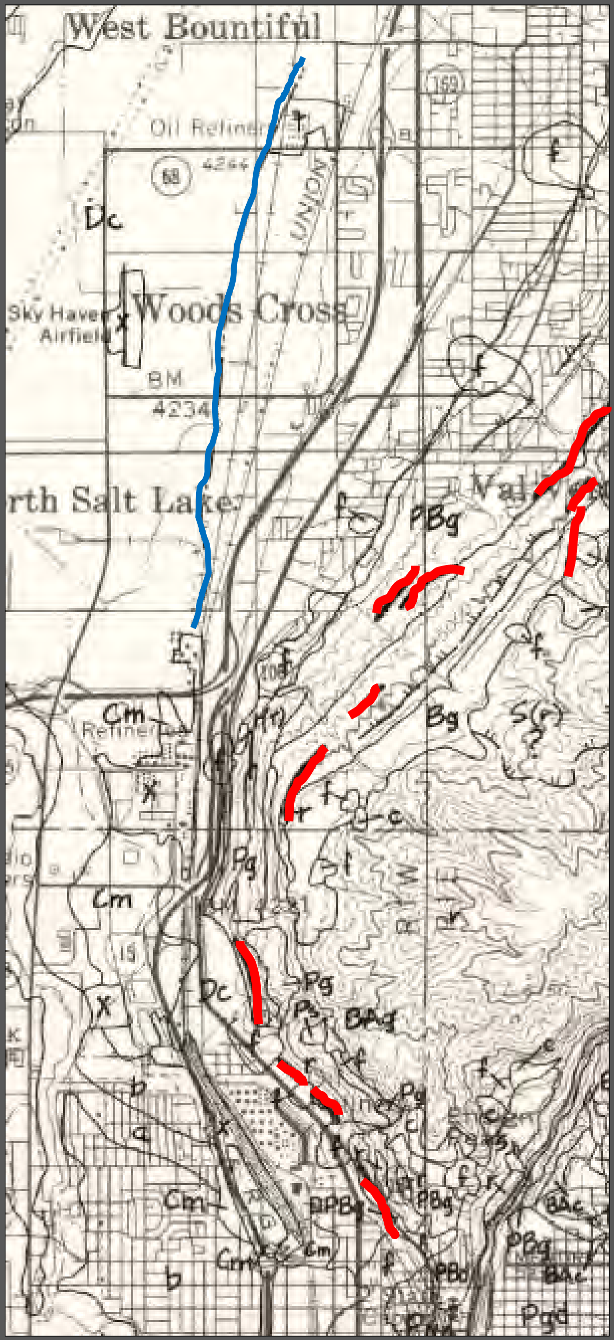
John L. Burns, 1871

Map courtesy of the Church History Library, The Church of Jesus Christ of Latter-day Saints

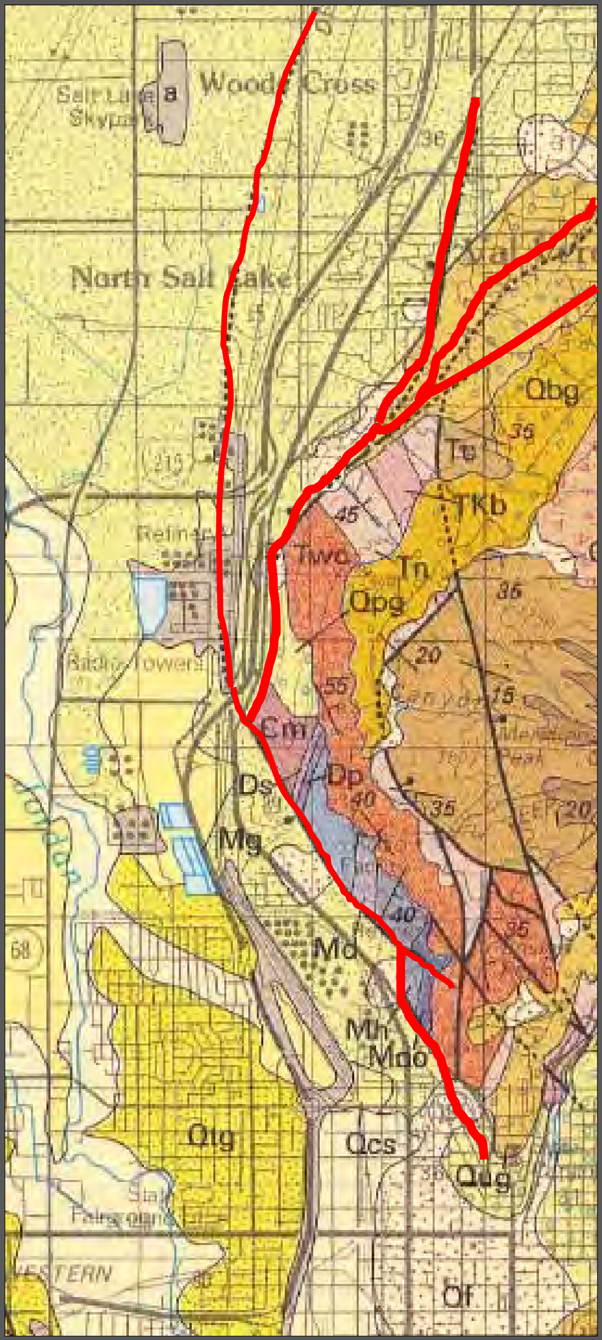
And its not getting better

Northern Warm Springs Fault

Northern Warm Springs Fault



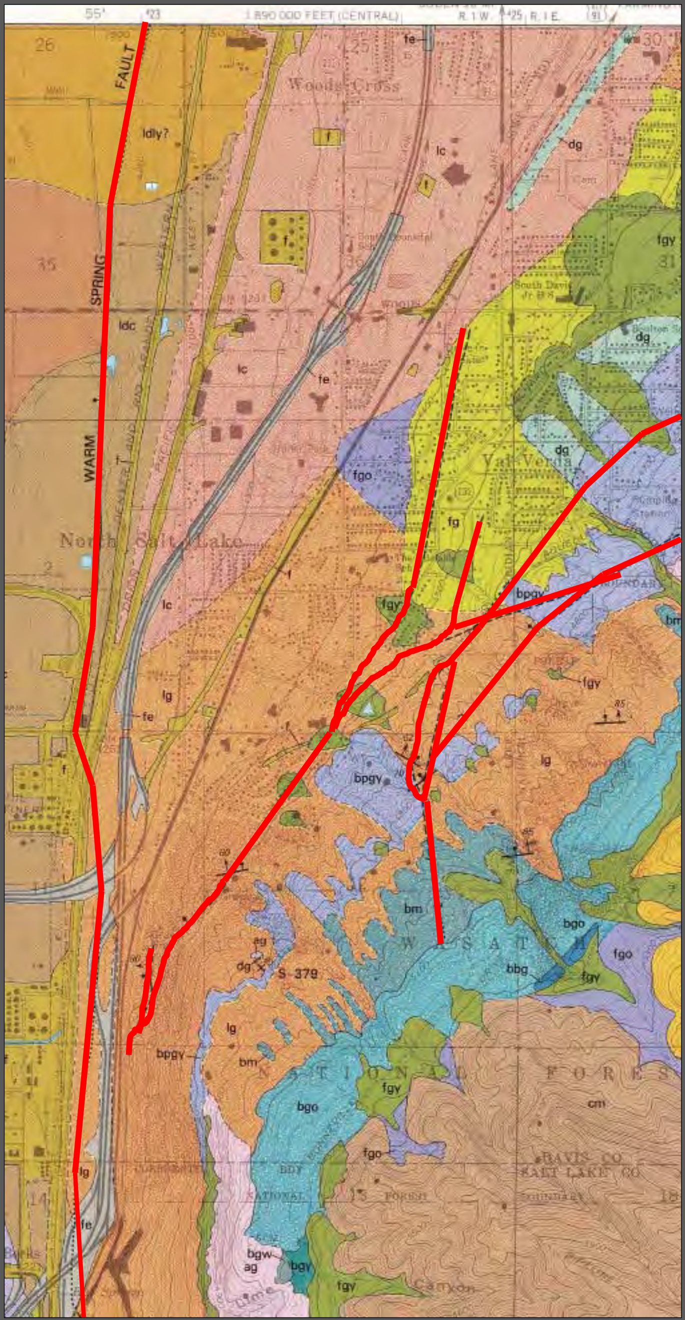
Miller, 1980



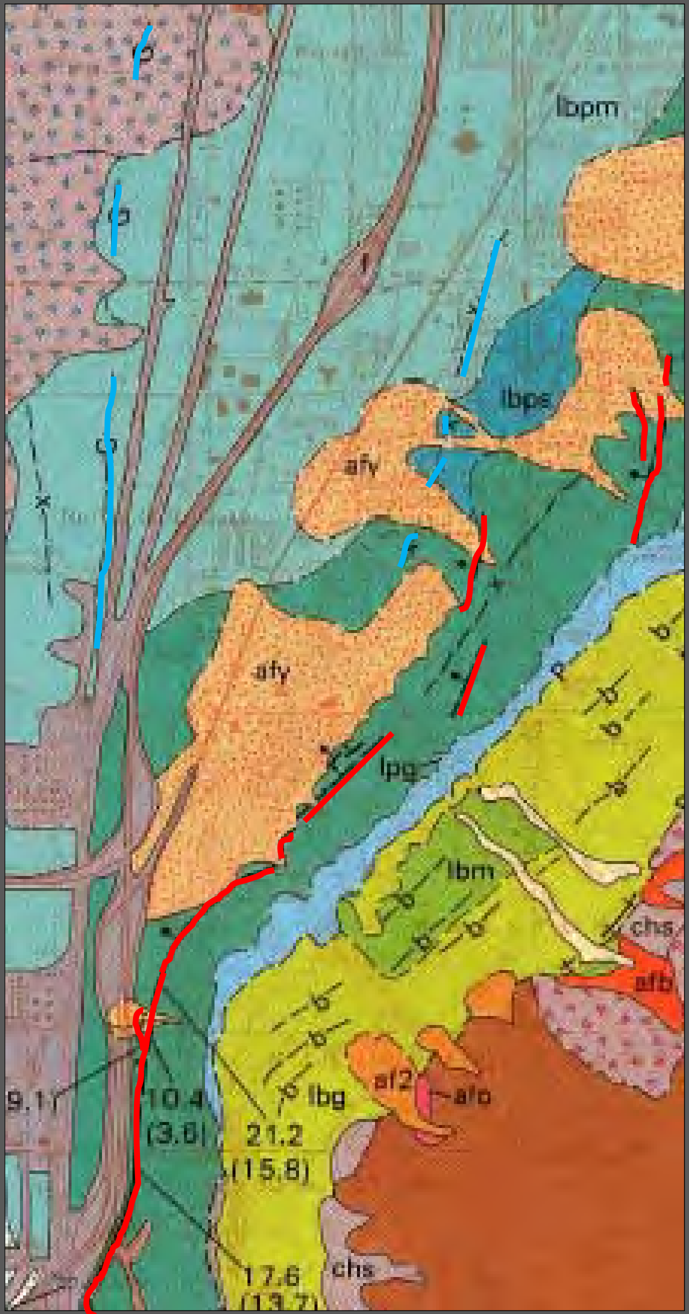
Bryant, 1990

- Multiple interpretations of western fault
  - Miller, 1980 mapped it as a Gilbert shoreline
  - Bryant, 1990 mapped it as a concealed fault

Northern Warm Springs fault



Van Horn, 1982

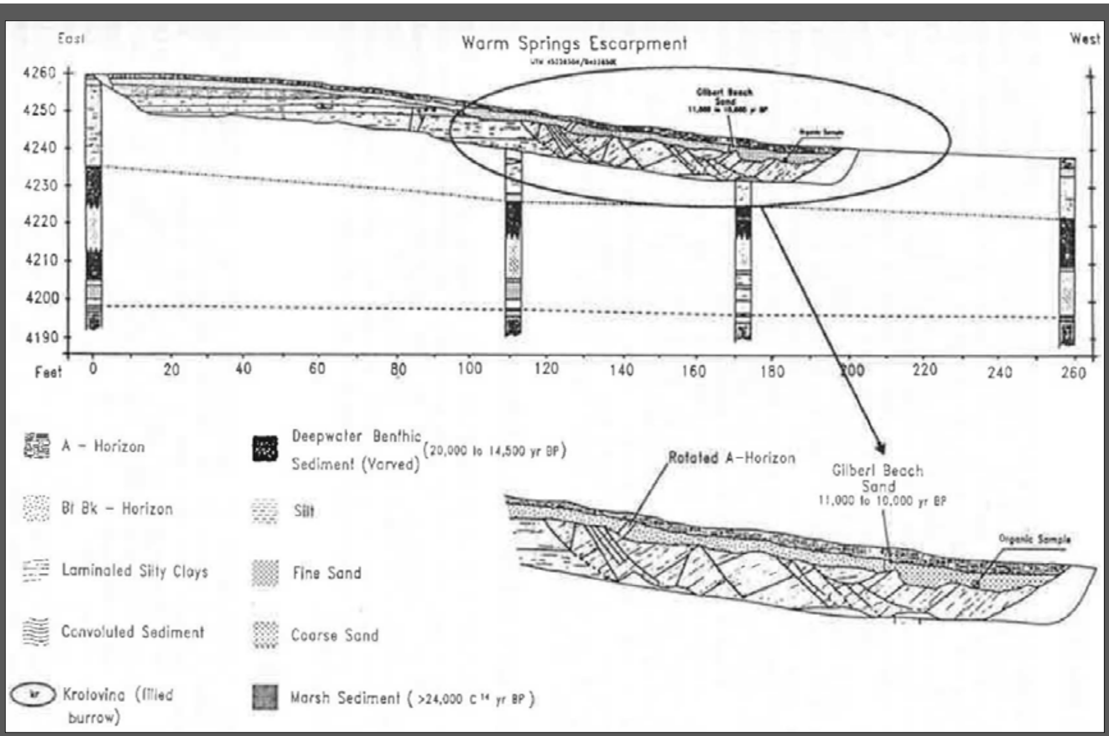


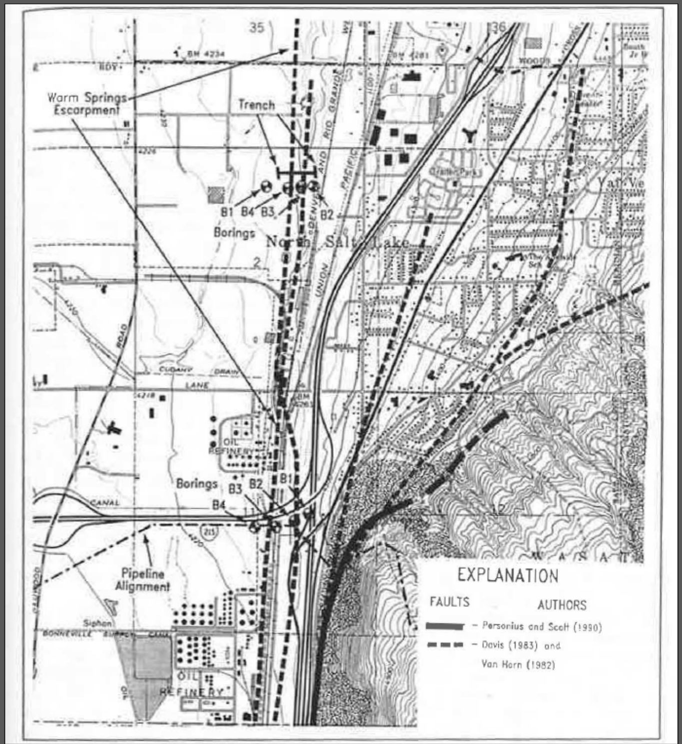
Personius and Scott, 1992

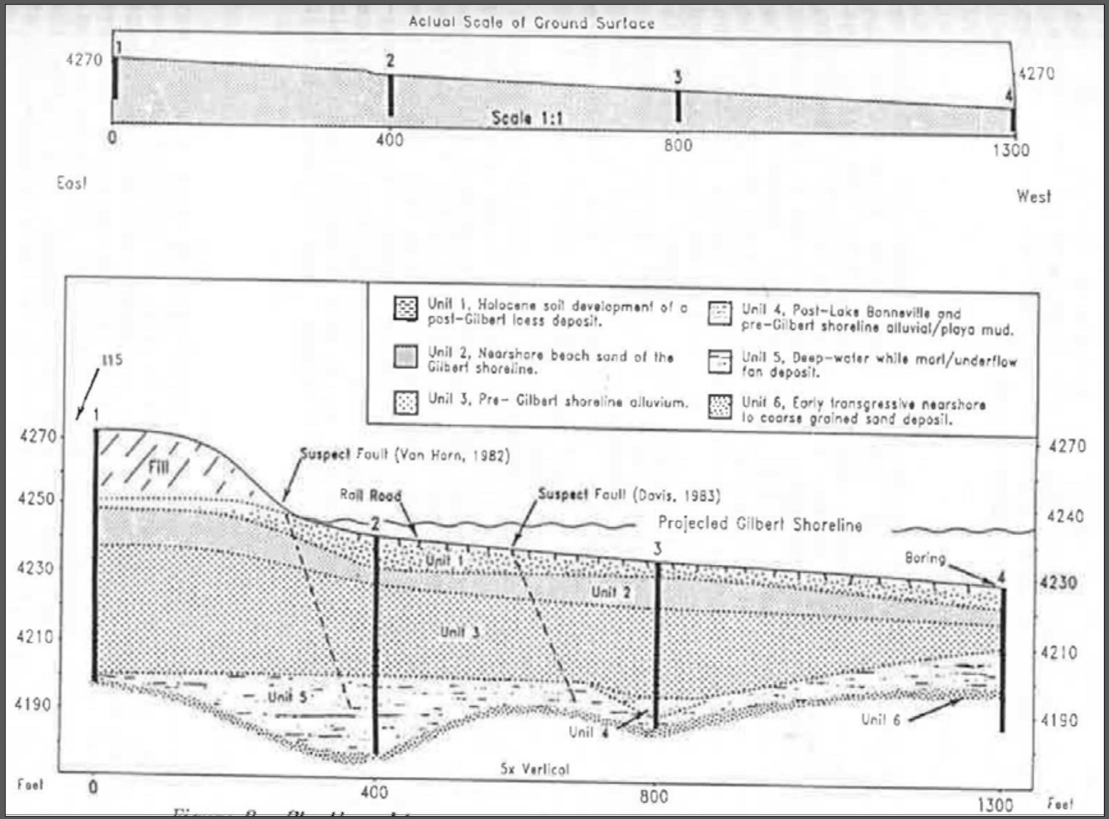
- Van Horn, 1982 mapped it as a fault
- Personius and Scott, 1992 mapped it as Gilbert shoreline

Robison et al., 1991

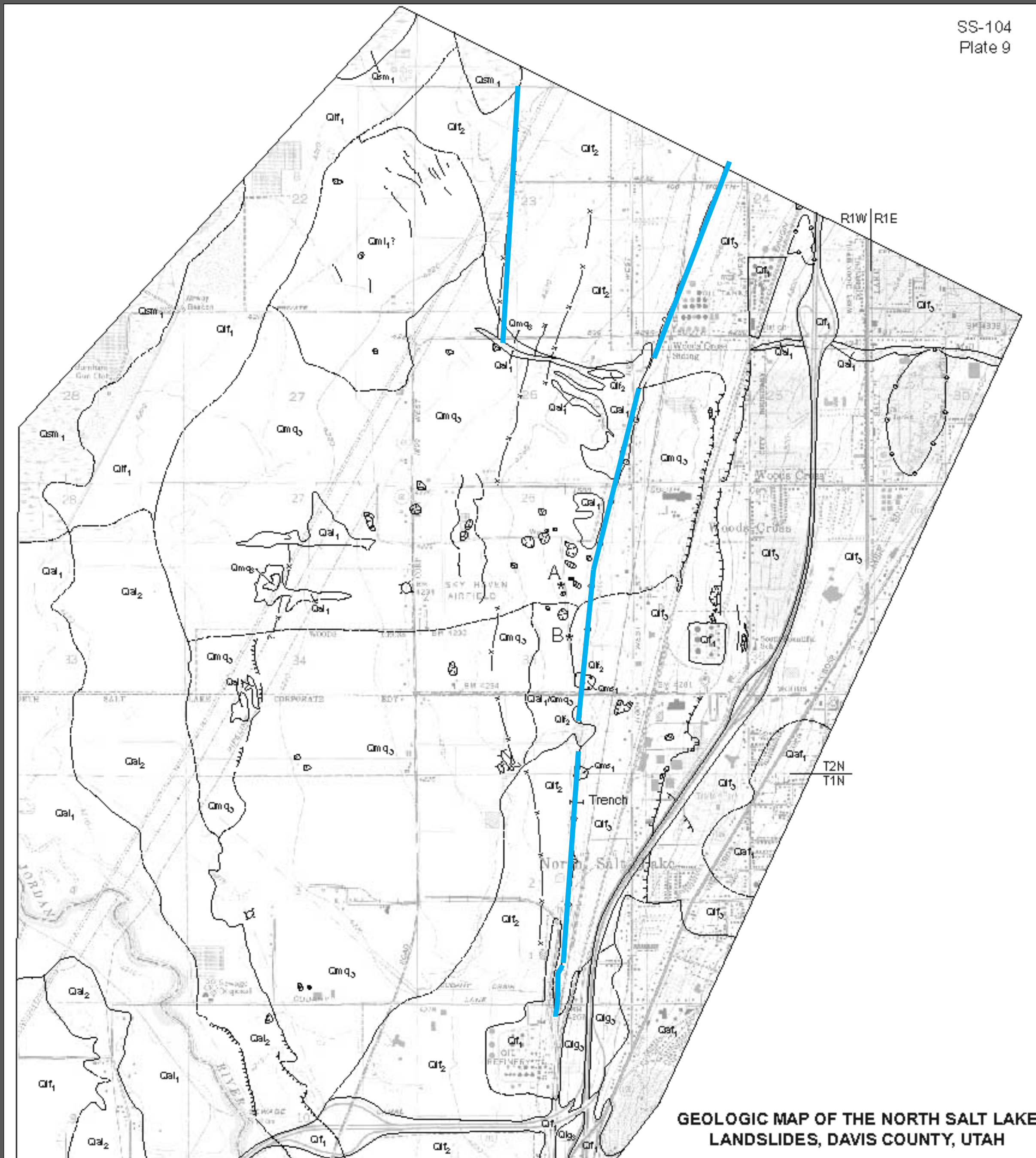
- 20-foot (6 m) escarpment was not tectonic faulting
  - likely the result of lateral spread landsliding
  - possibly slumping adjacent to Gilbert-episode lake highstand shorelines
- Logs show shallow listric faulting with continuous and undeformed deep-water sediments logged in widely spaced borings





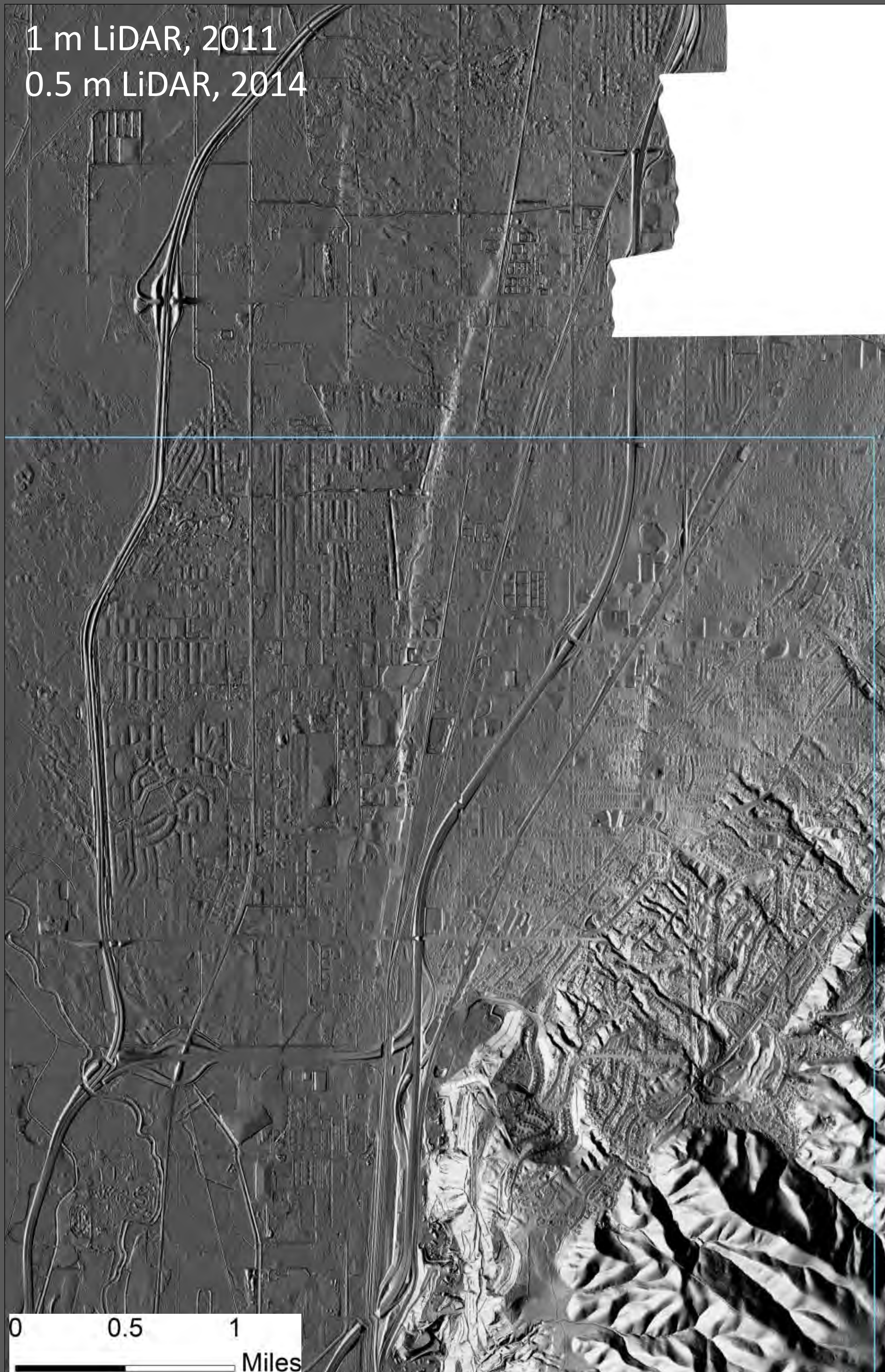


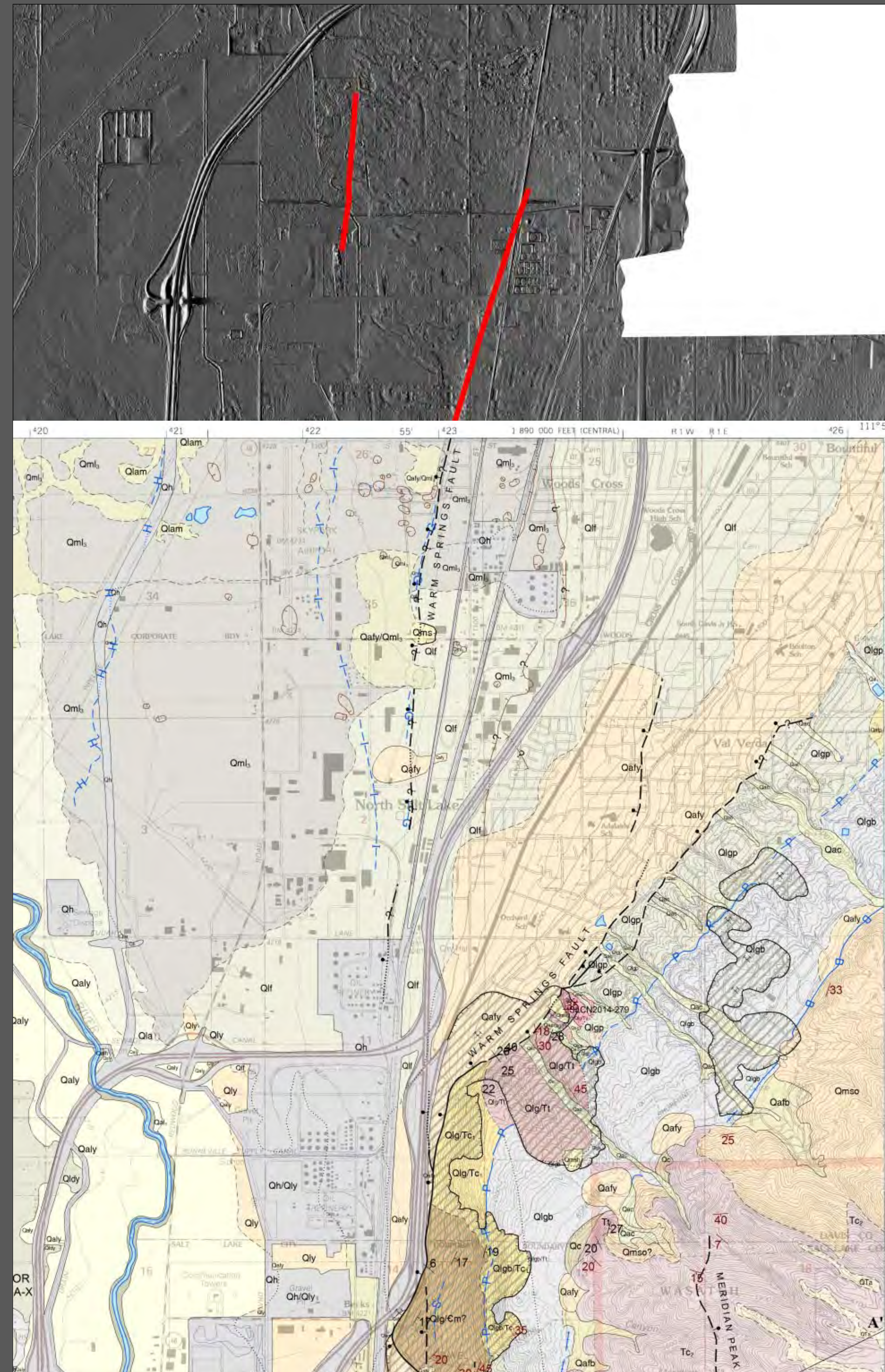
Northern Warm Springs Fault



Harty and Lowe, 2003

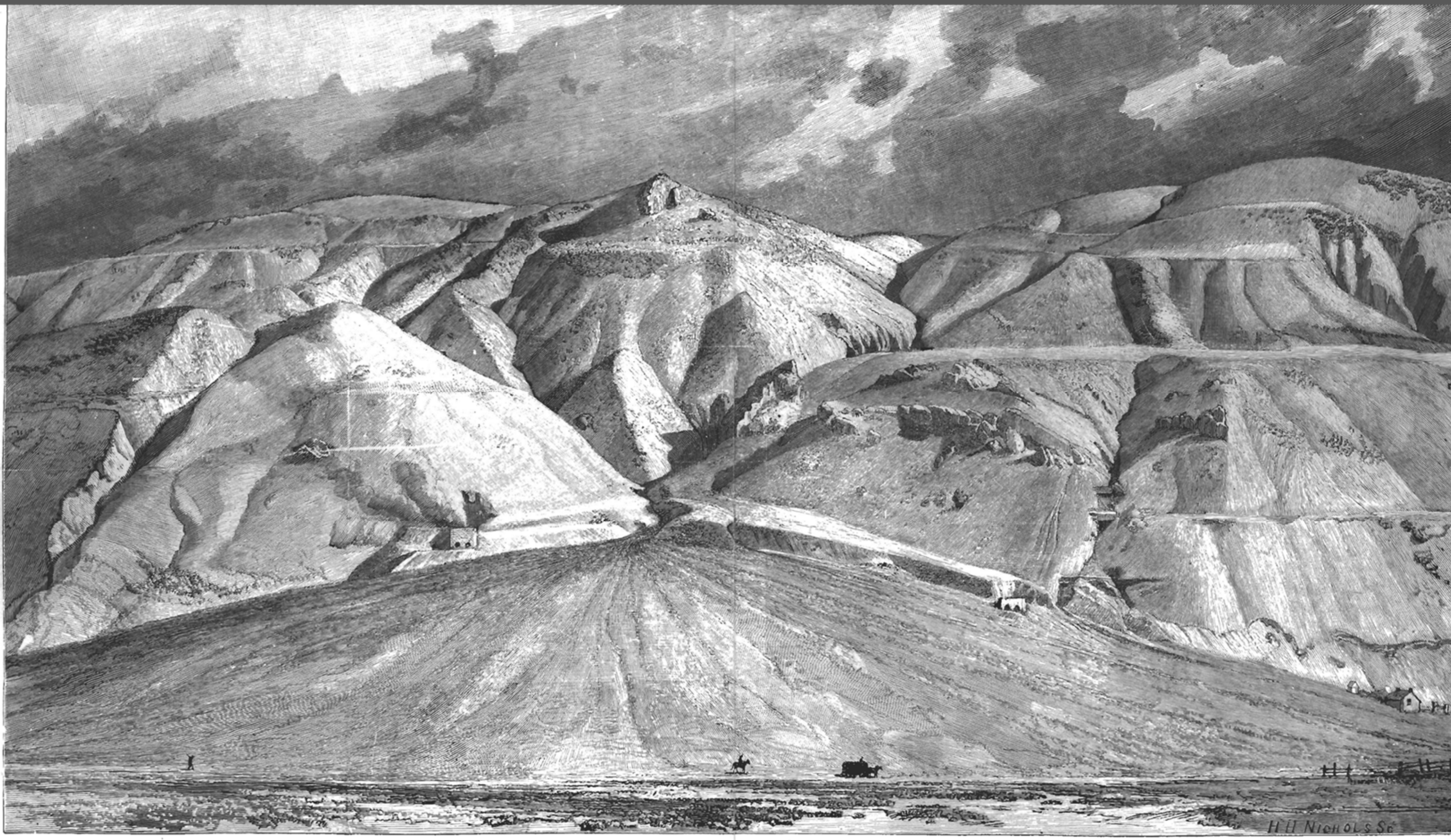
– Harty and Lowe, 2003 mapped it as Gilbert shoreline


1 m LiDAR, 2011
0.5 m LiDAR, 2014
0
0.5
1
Miles


WARM SPRINGS FAULT
Woods Cross
North Salt Lake
Val Verda
WARM SPRINGS FAULT
MERIDIAN PEAK F

Central Warm Springs Fault

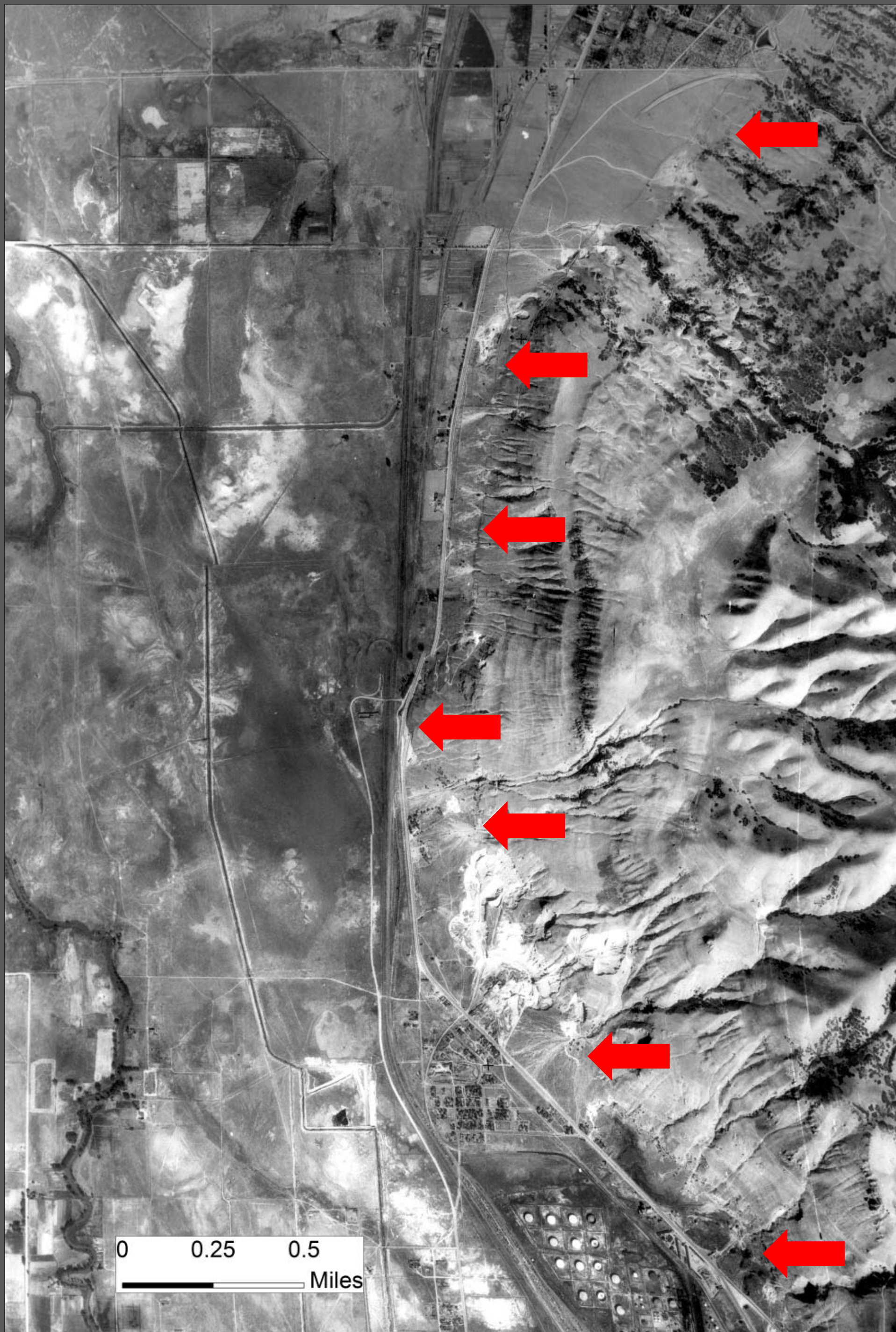
Jones Canyon, Holocene alluvial fan

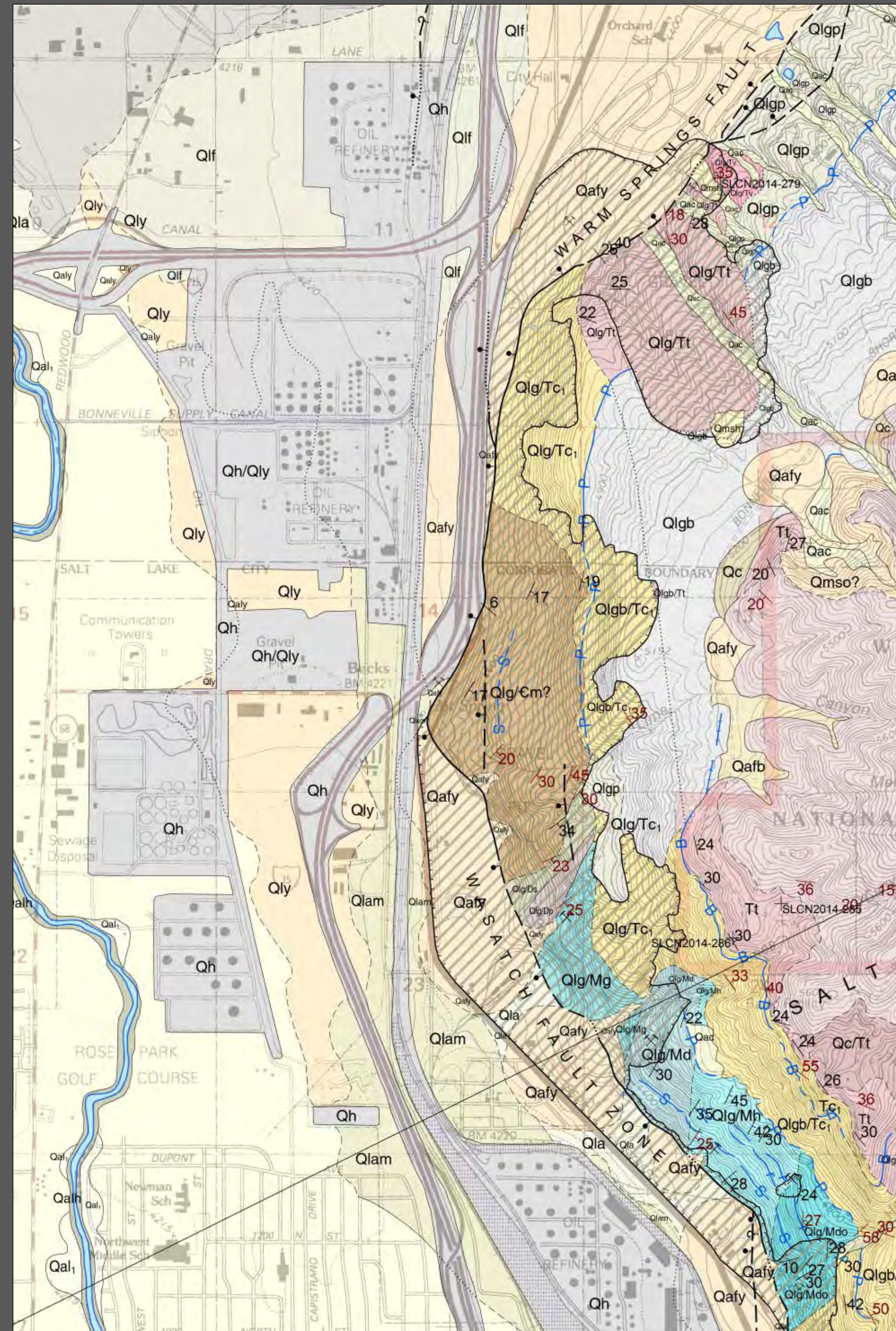


FAULT SCARP CROSSING ALLUVIAL CONE, NEAR SALT LAKE CITY.

Drawn by W. H. Holmes.

Gilbert, 1890



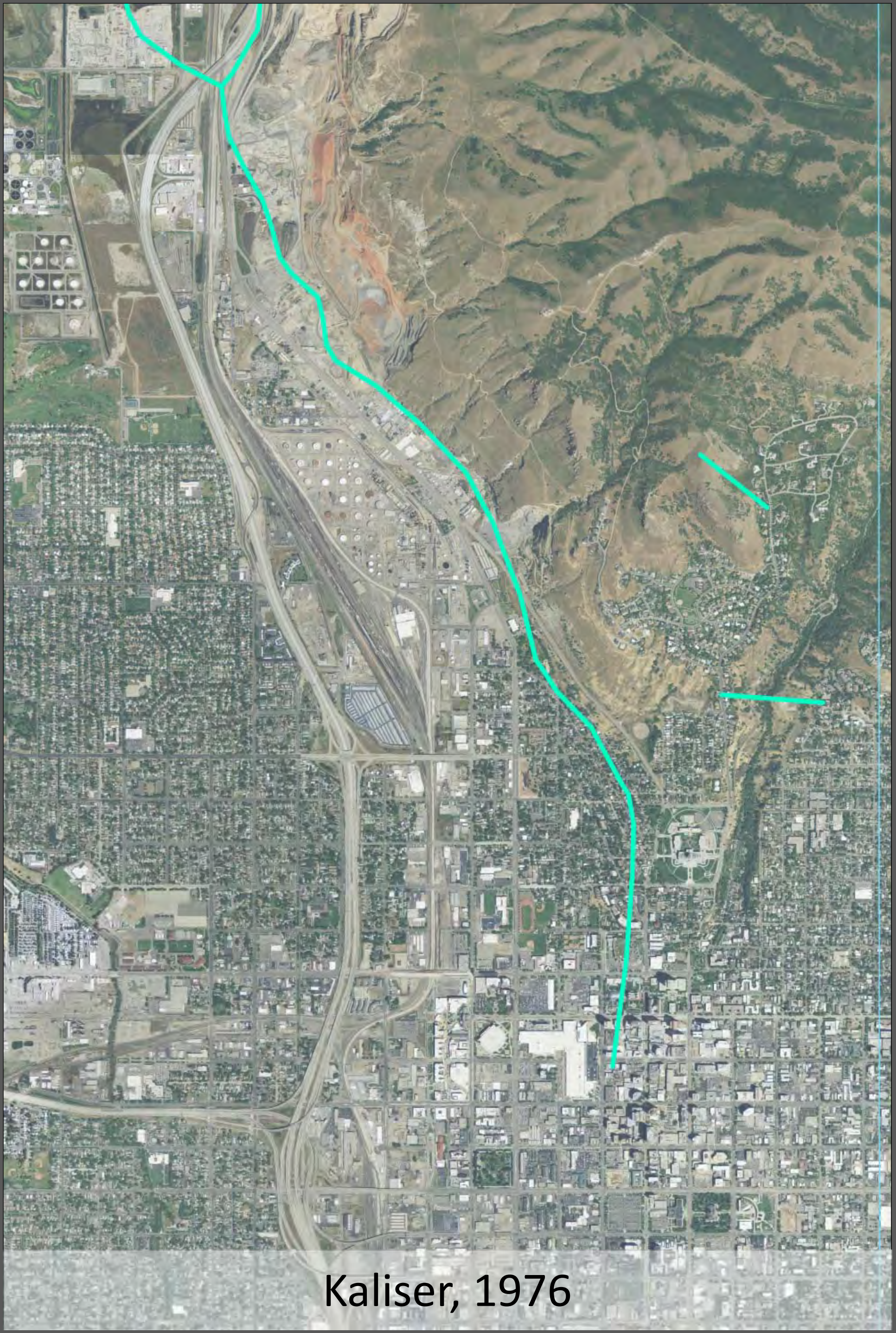


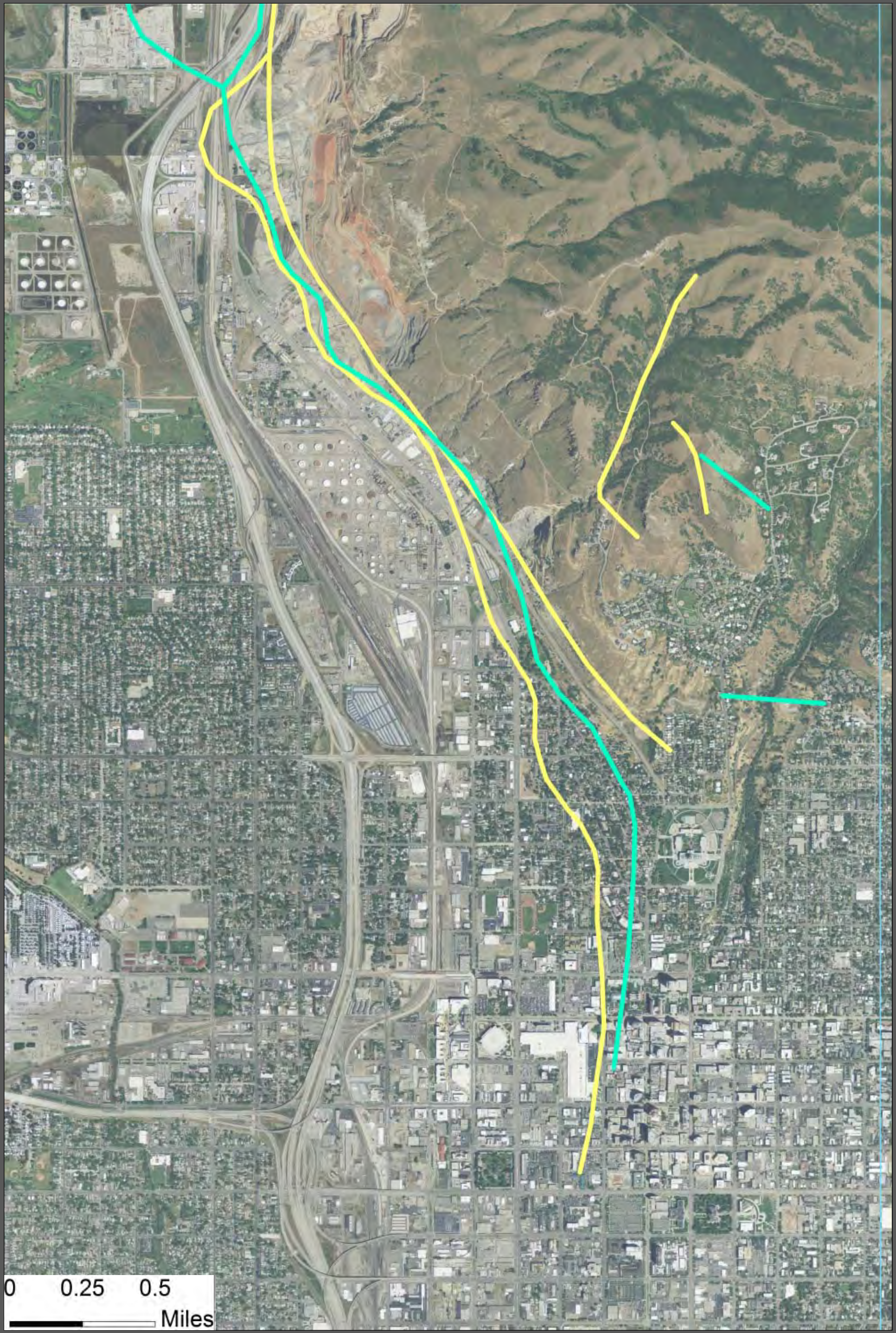
1937, USDA aerial photographs

Southern Warm Springs Fault

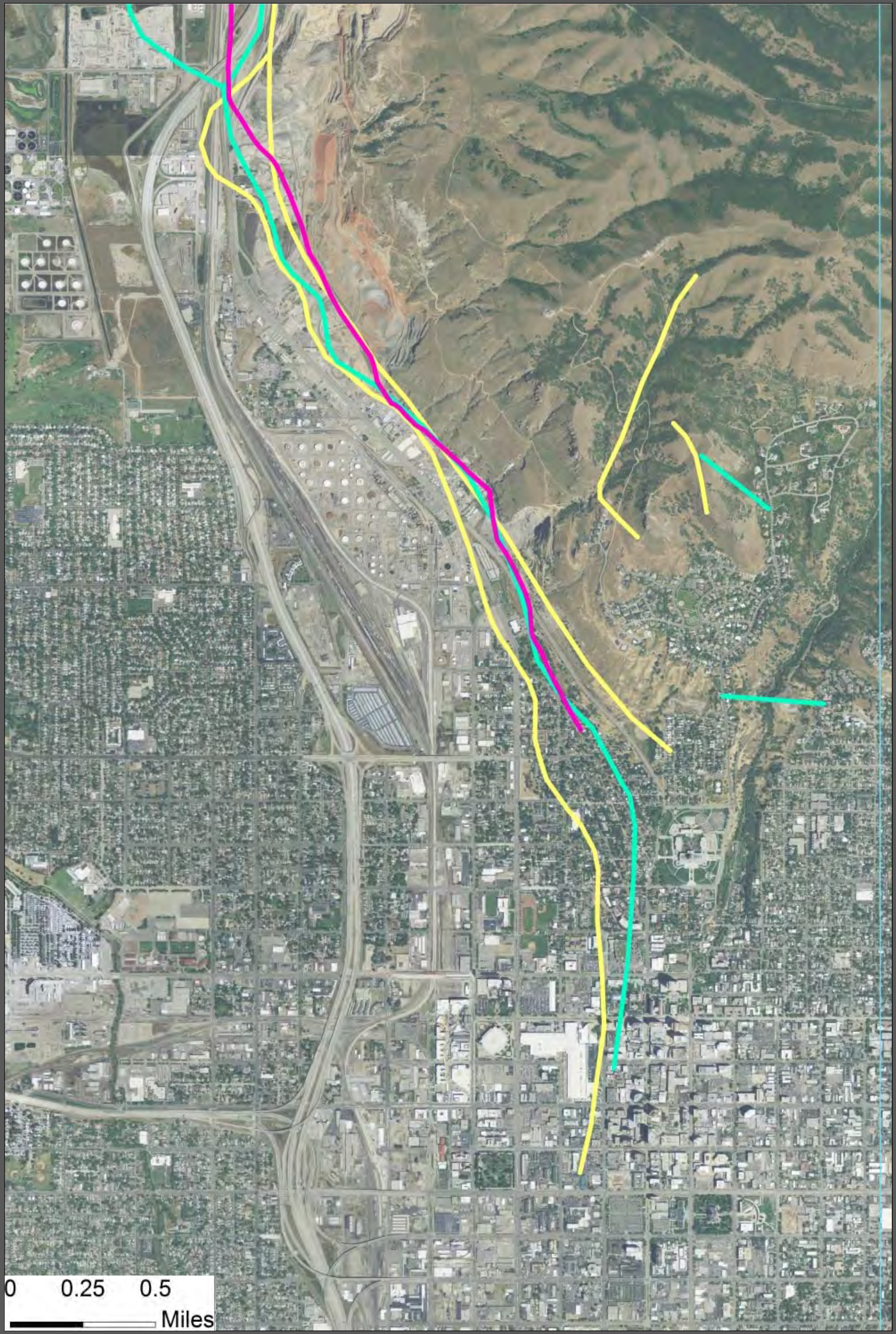

Marsell and Threet, 1960


0 0.25 0.5
Miles

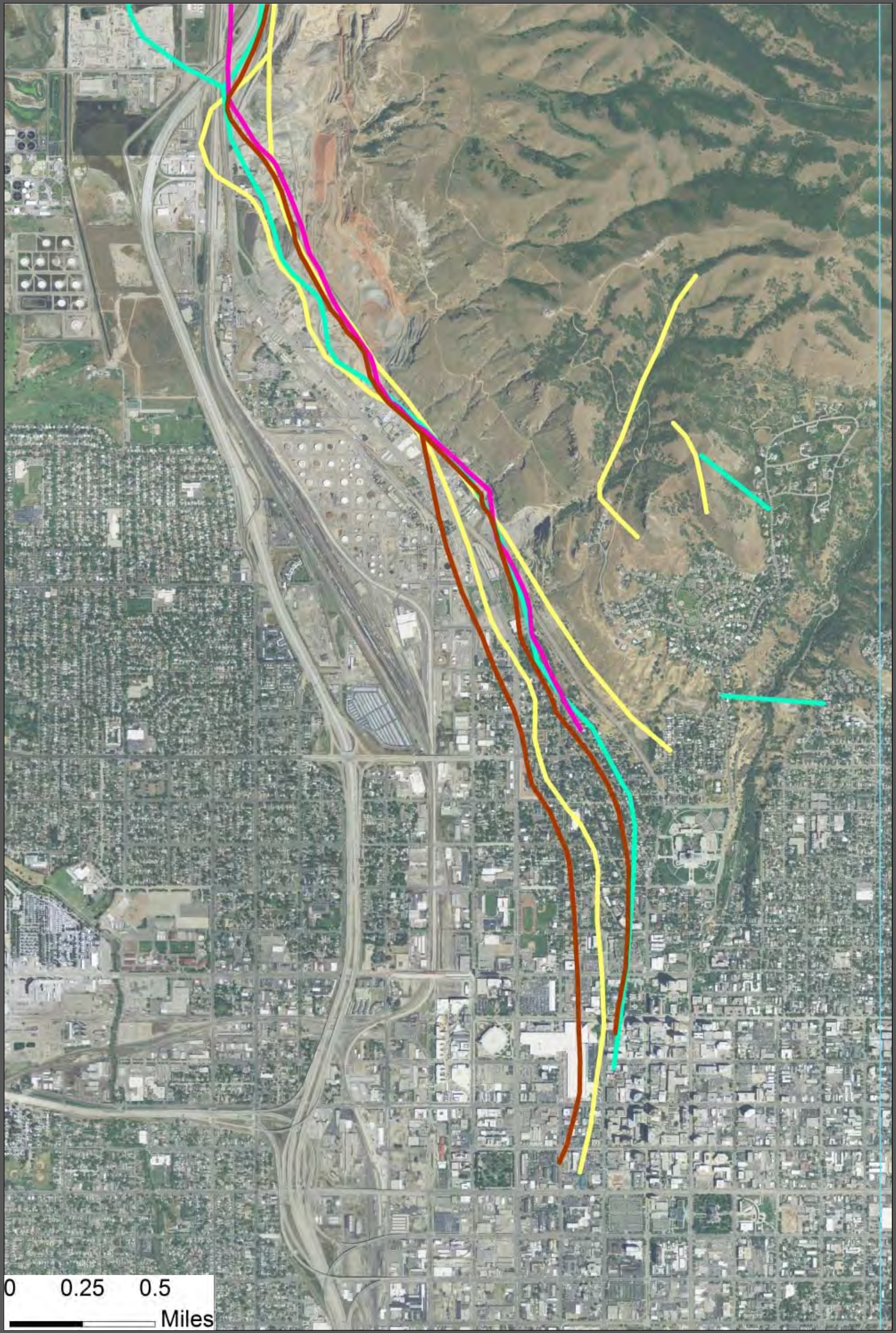

Kaliser, 1976


0 0.25 0.5
Miles

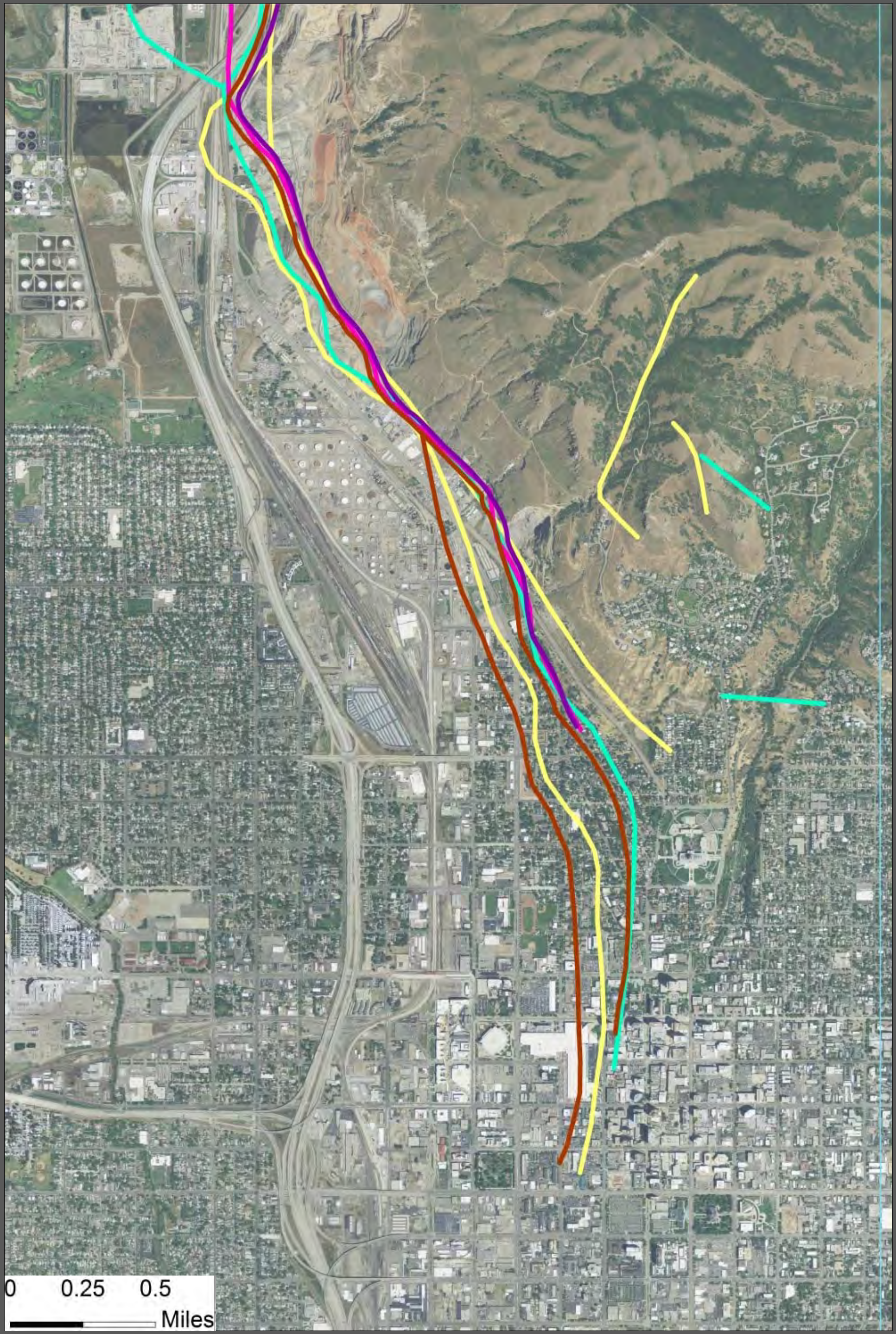

Van Horn, 1982

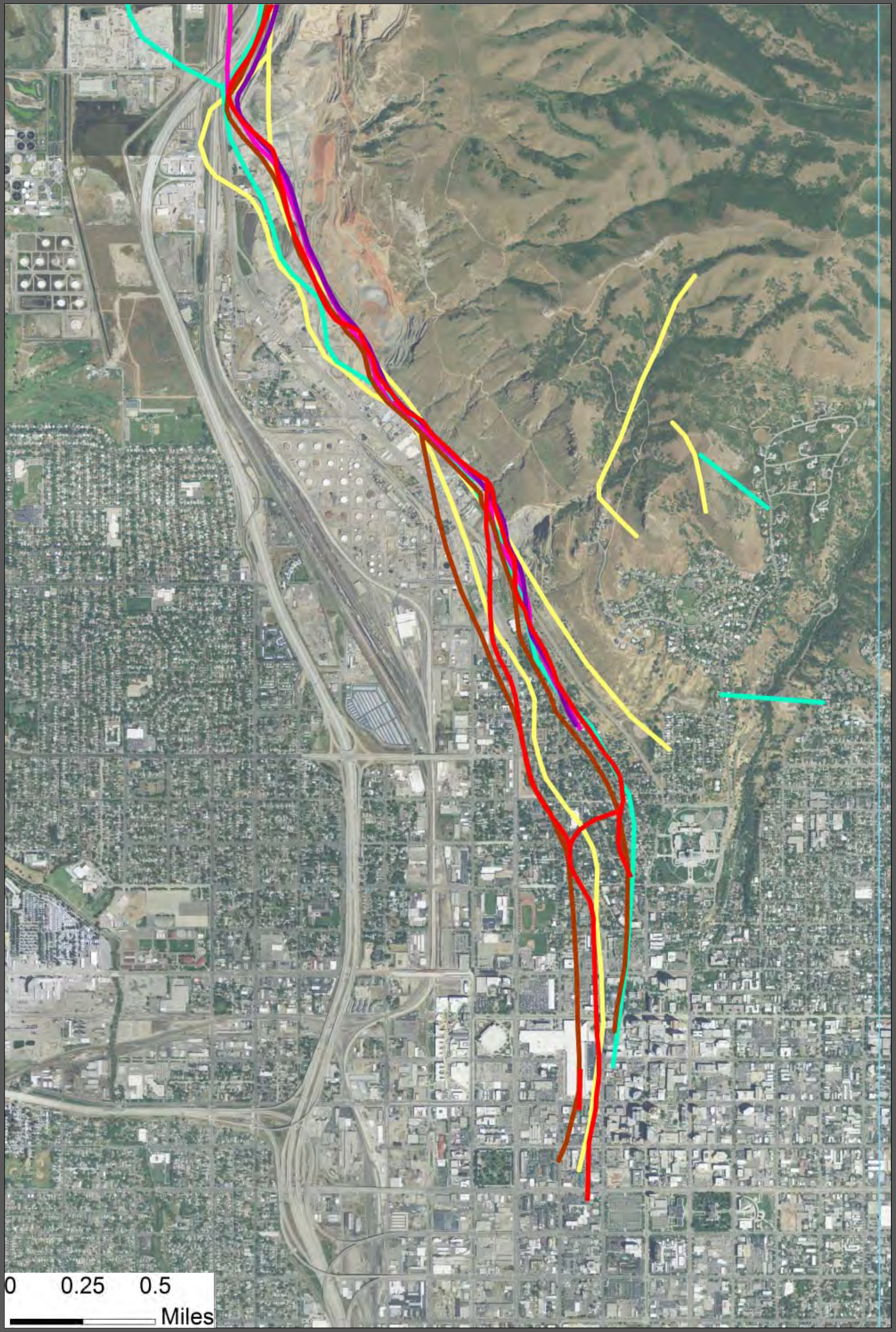

0 0.25 0.5
Miles

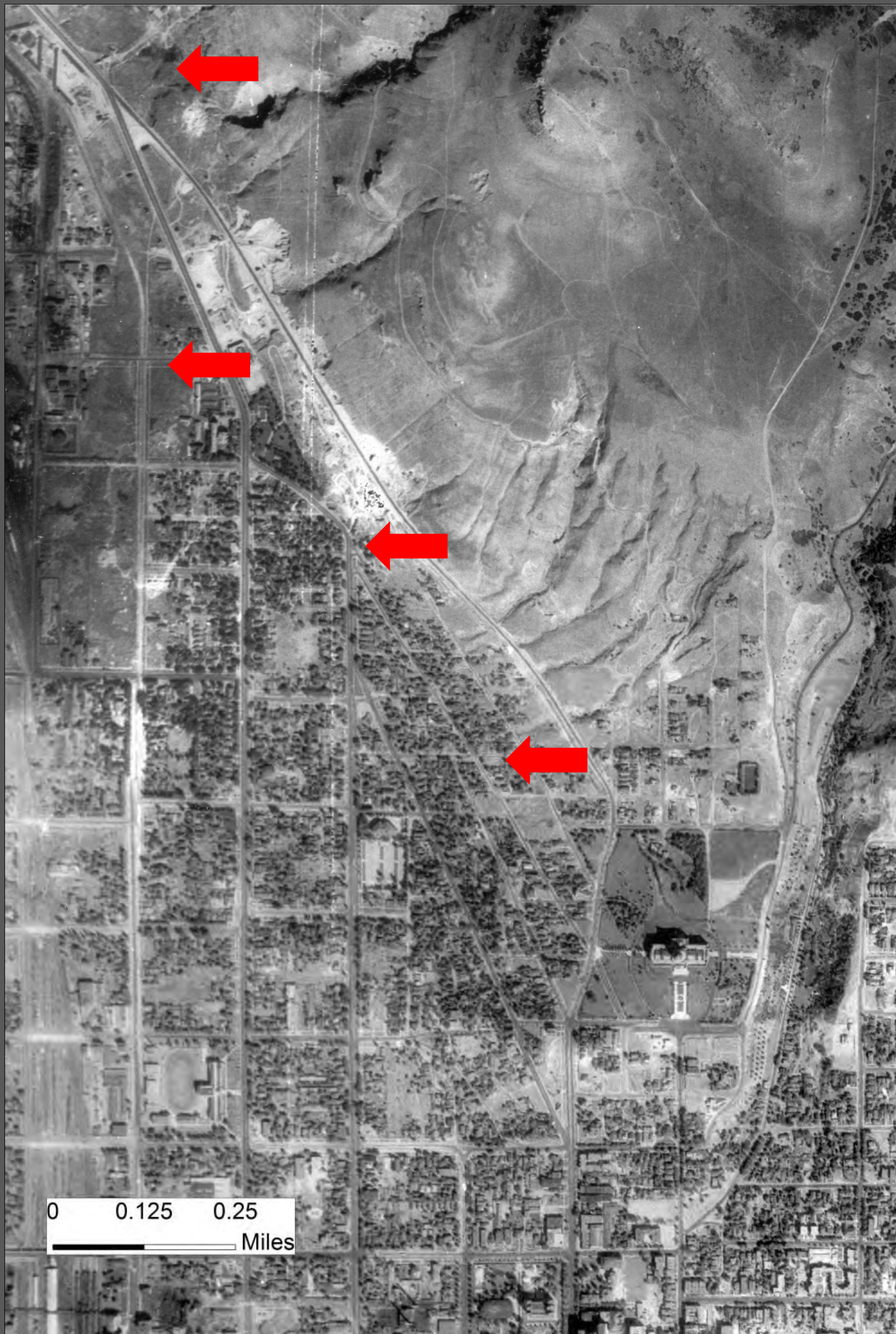

Scott and Shroba, 1985

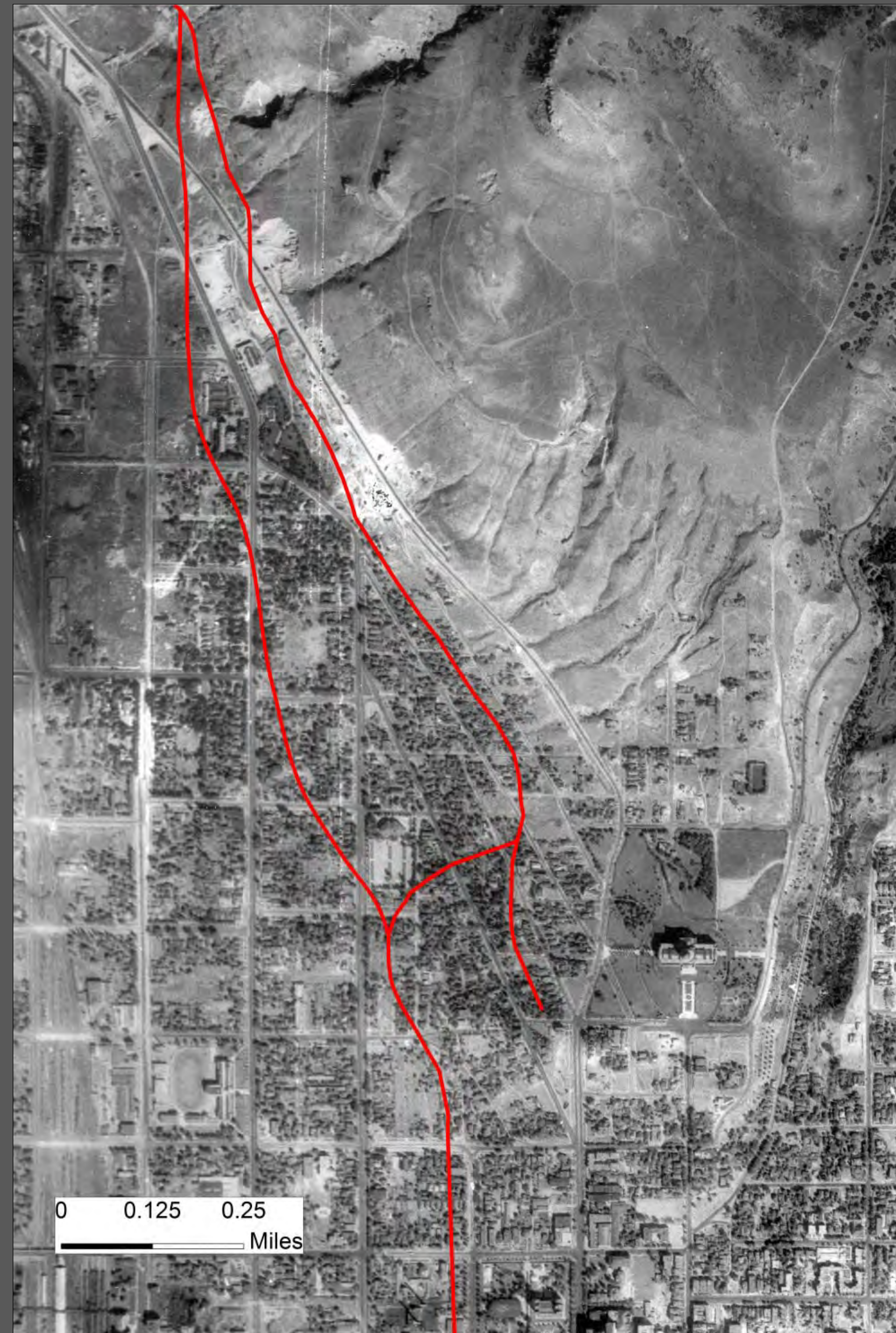

0 0.25 0.5
Miles


Personius and Scott, 1992

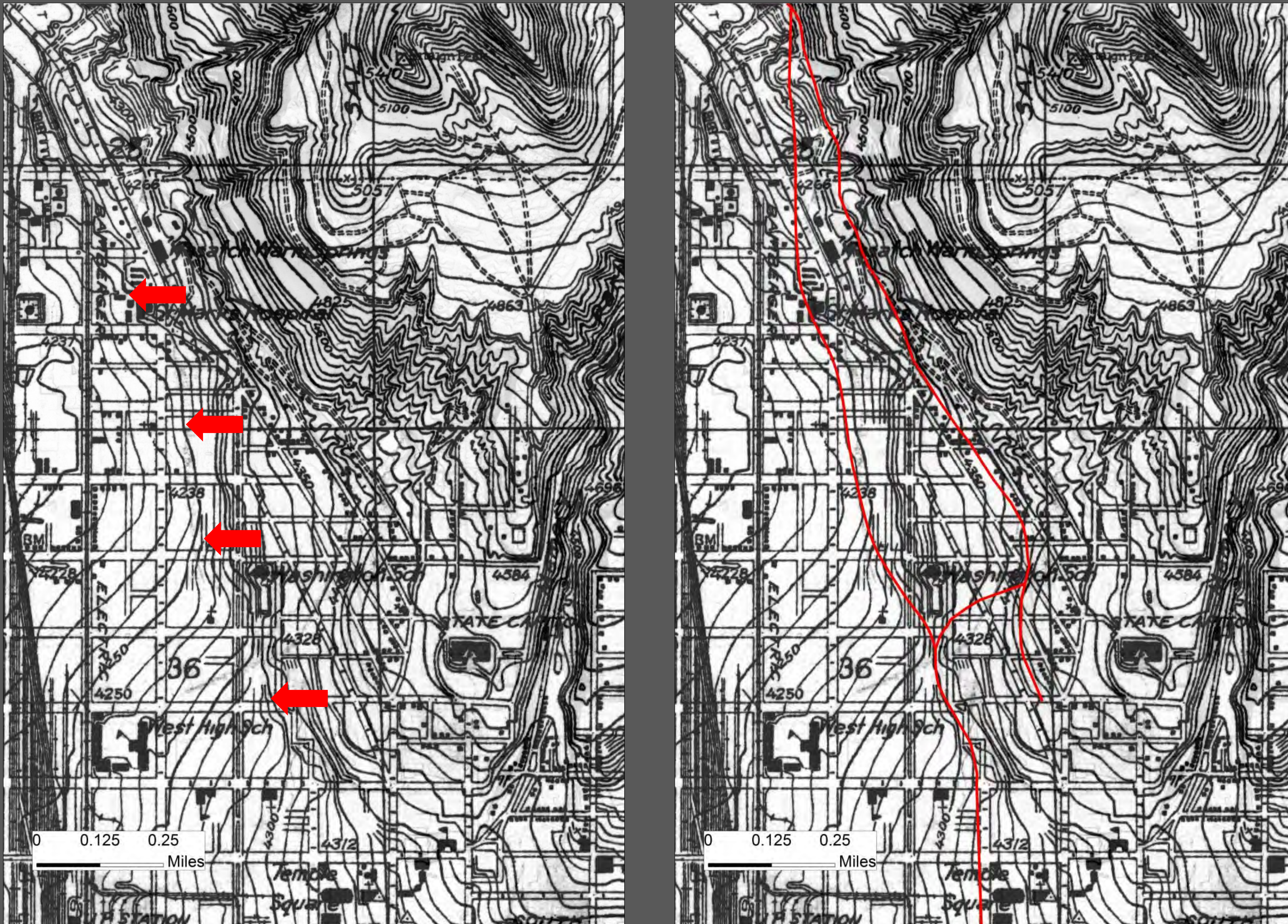

0
0.25
0.5
Miles


0 0.25 0.5
Miles



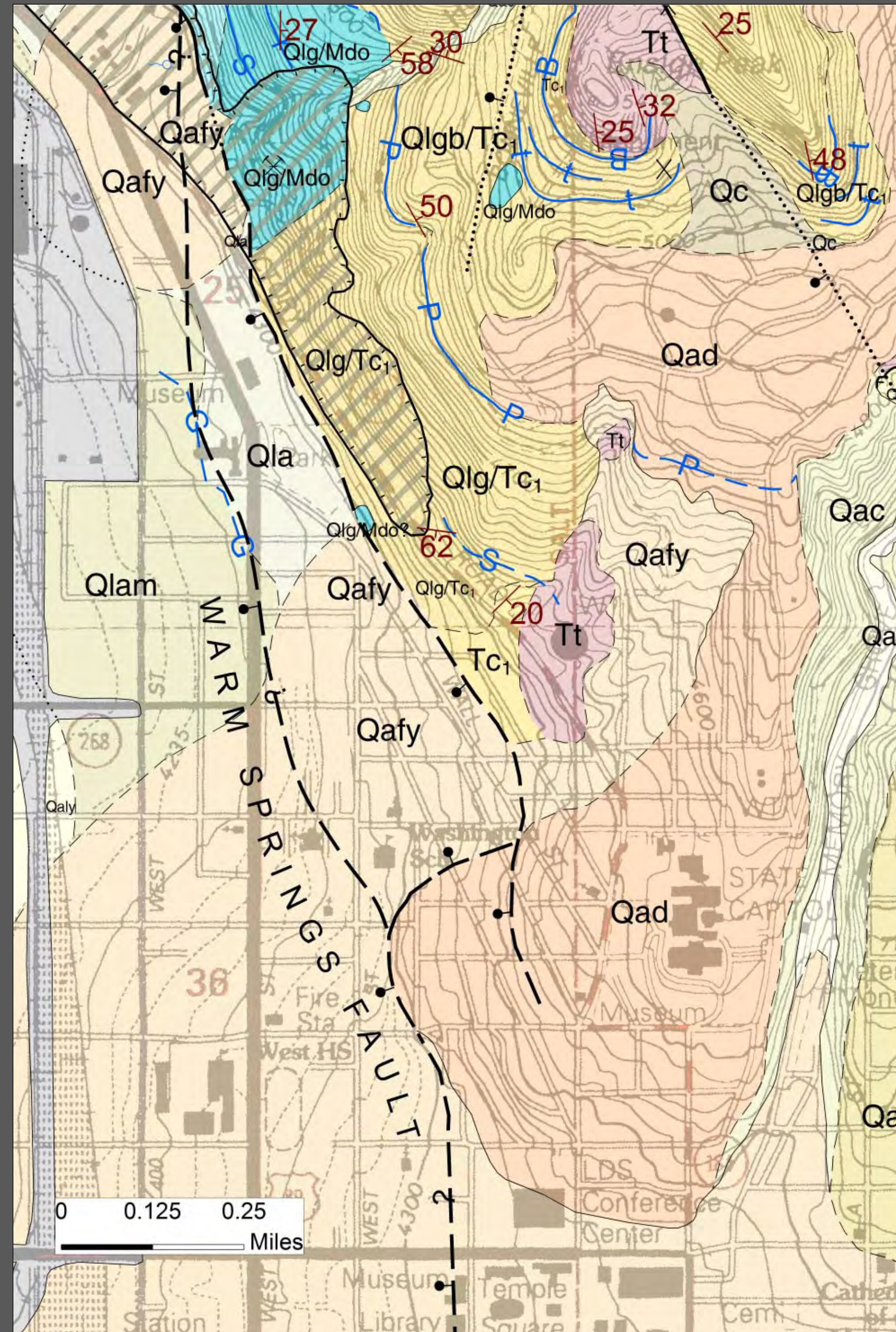


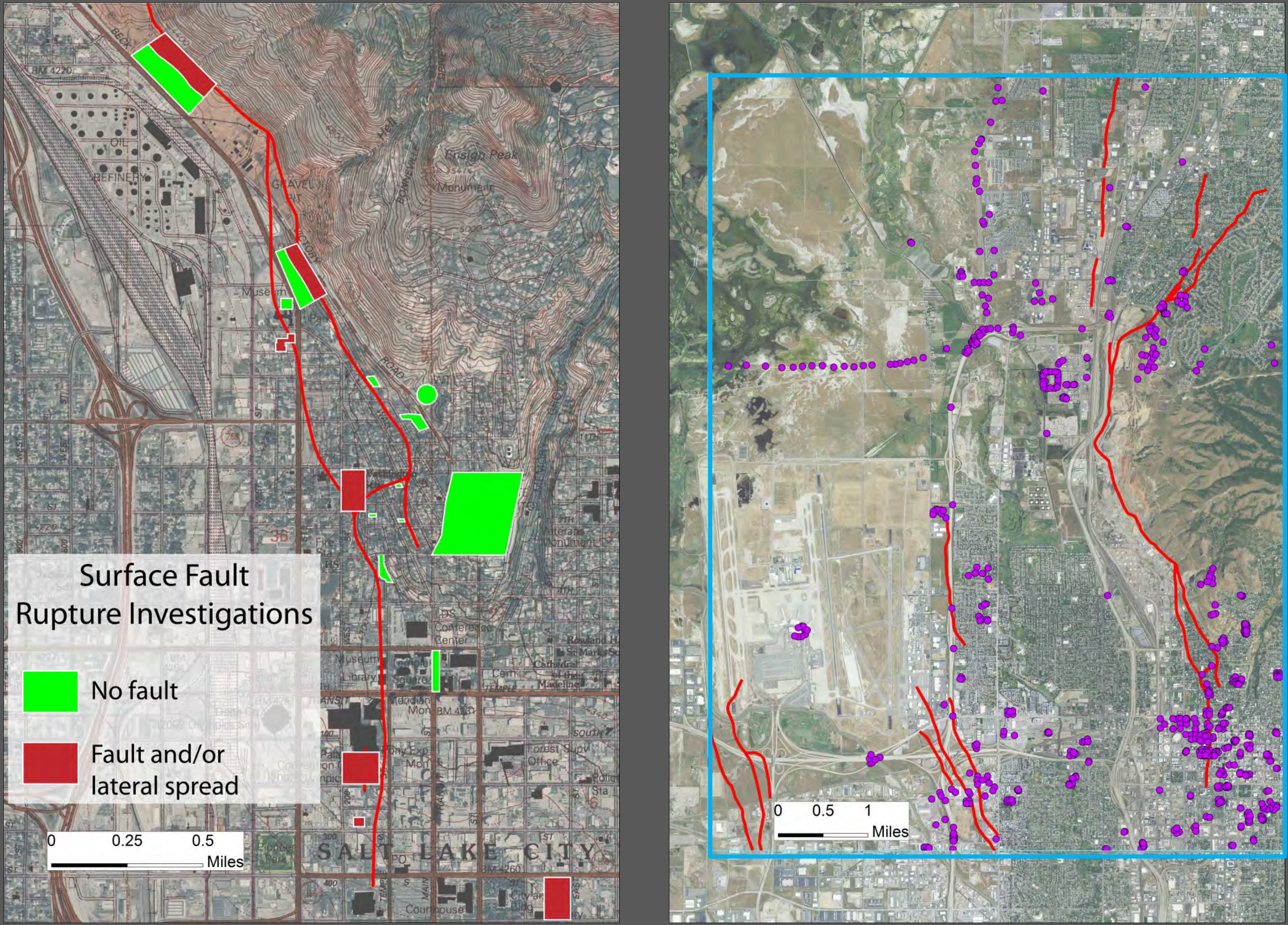
1937, USDA aerial photographs



1934 topographic map of Salt Lake City and Vicinity

0.5 m LiDAR, 2014

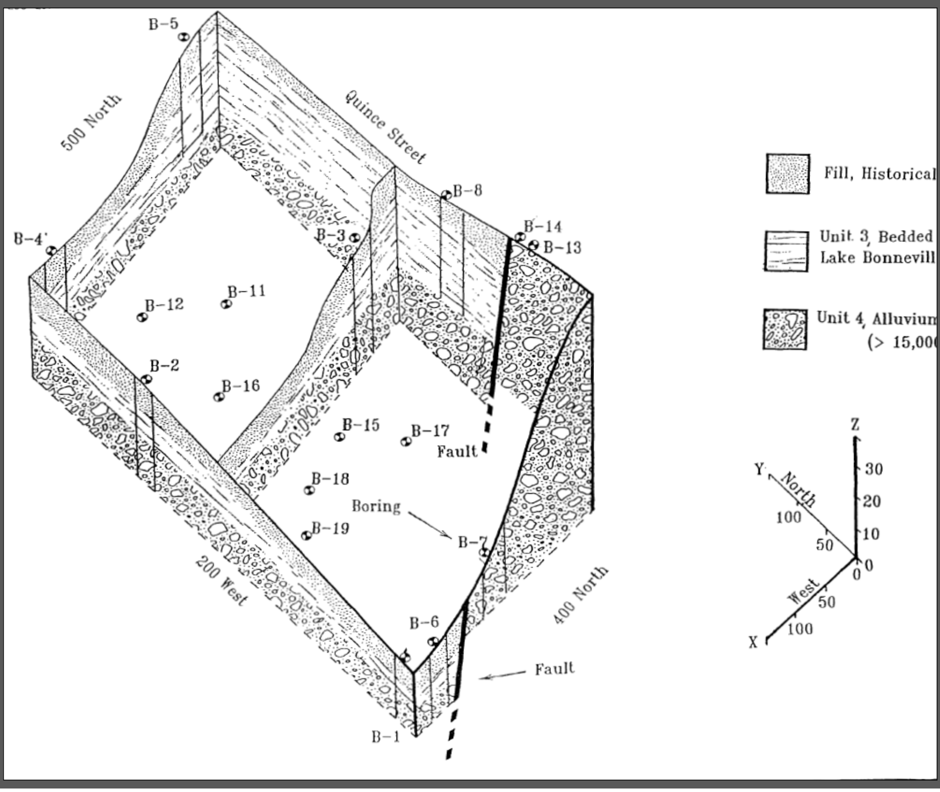


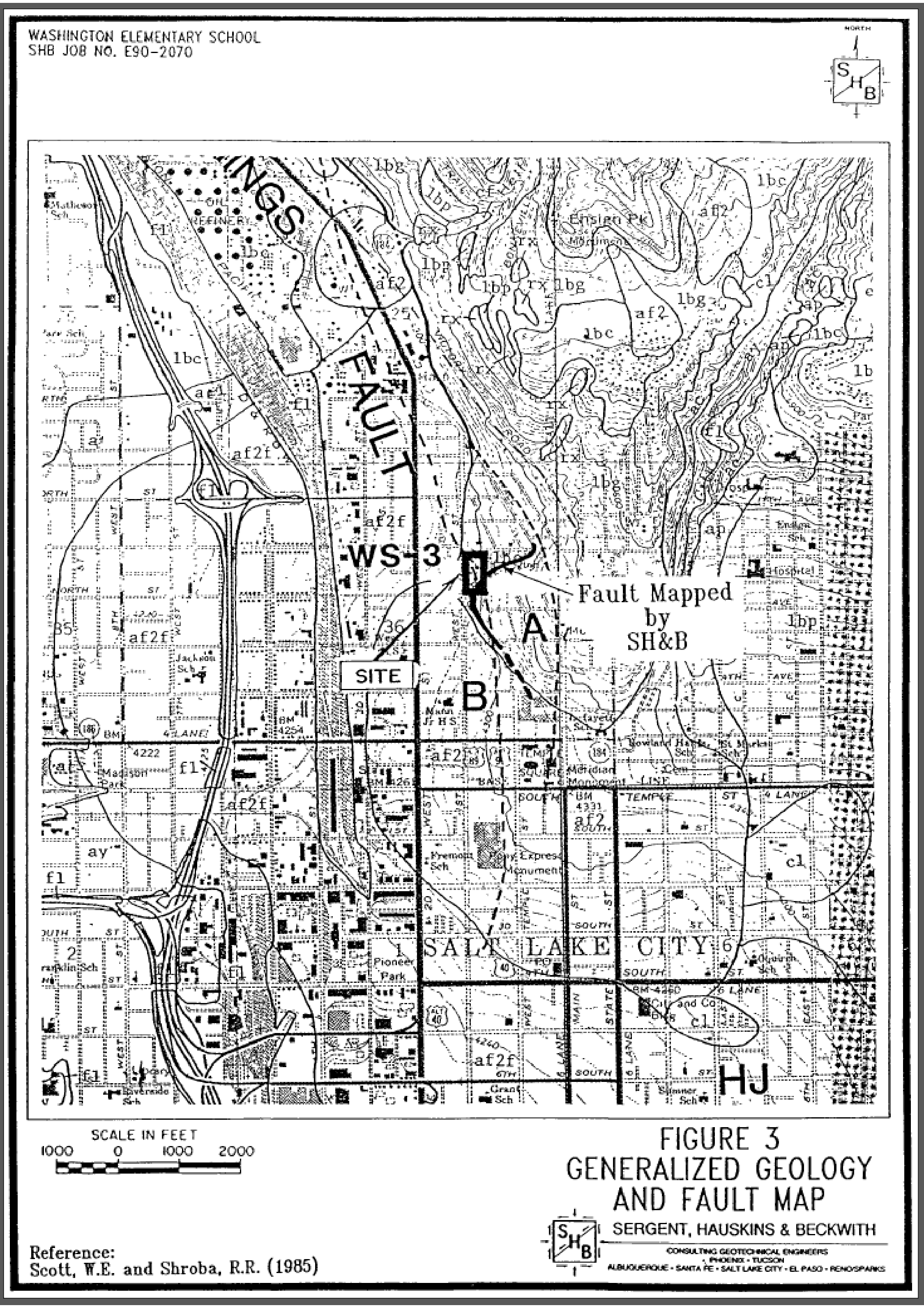

Surface Fault Rupture Investigations
No fault
Fault and/or lateral spread
0 0.25 0.5 Miles
SALT LAKE CITY
Ensign Peak
Monument
OIL REFINERY
GRAVEL PIT
Museum
LDS Conference Center
Museum Library
Temple Square
Cathedral of the Madeleine
Courthouse
0 0.5 1 Miles

Washington Elementary School

(Sergent, Hauskins & Beckwith, 1991)

- Confirm Warm Springs fault as far south as 400 N. and 200 W.
- Connection between "A" and "B" faults proposed





Salt Palace Convention Center Expansion

Salt Palace Convention Center Expansion

THURSDAY, JAN. 7, 1999

Deseret News

METRO

Fault causes suspension of Salt Palace expansion

Experts don't know if it extends under existing building

ing study, those options could range from abandoning the current Salt Palace expansion construction site to simply building around the fault.

The Salt Palace expansion was expected to be completed in July of 2000.

What is not certain is if the fault extends

The Salt Lake Tribune UTAH Wednesday, February 3, 1999

Consultants Say Salt Palace Faults Are Small, Safe

They recommend resumption of construction project, but county commissioners will wait a week

METRO

Section B

Salt Lake / Davis

FRIDAY, APRIL 16, 1999

• BOUNTIFUL • SALT LAKE CITY • MILLCREEK • HOLLADAY-COTTONWOOD • SANDY • MURRAY • WEST VALLEY CITY • TAYLORSVILLE • WEST JORDAN

Fault under site, geologist says

Report on Salt Palace project under dispute

concluded that a tectonic fault runs beneath the site.

In his final report given to the county late last month, David Simon of the geotechnical consulting firm Simon/ By-

tion, a much less serious condition than a fault and one whose consequences can be minimized or eliminated by structural modifications.

At worst, Kleinfelder and

County officials now find themselves in the position of choosing between conflicting opinions. They have chosen the one that will permit construction to go forward.

Simon's response was that rather than "changing his mind," as others have put it, the county asked for his preliminary conclusions and he gave them. He has repeatedly

The Salt Lake Tribune

UTAH

SECTION D SATURDAY

■ STATE OF THE STATE, D-4

APRIL 17, 1999

County Blasted on Palace Quake Safety

Expansion will proceed despite consultants' conflicting reports on whether a fault lurks under site

The Salt Lake Tribune UTAH/NATION Wednesday, May 26, 1999

Salt Palace Expansion Project Poised to Resume This Week

City waiting for confirmation that area is not in quake zone

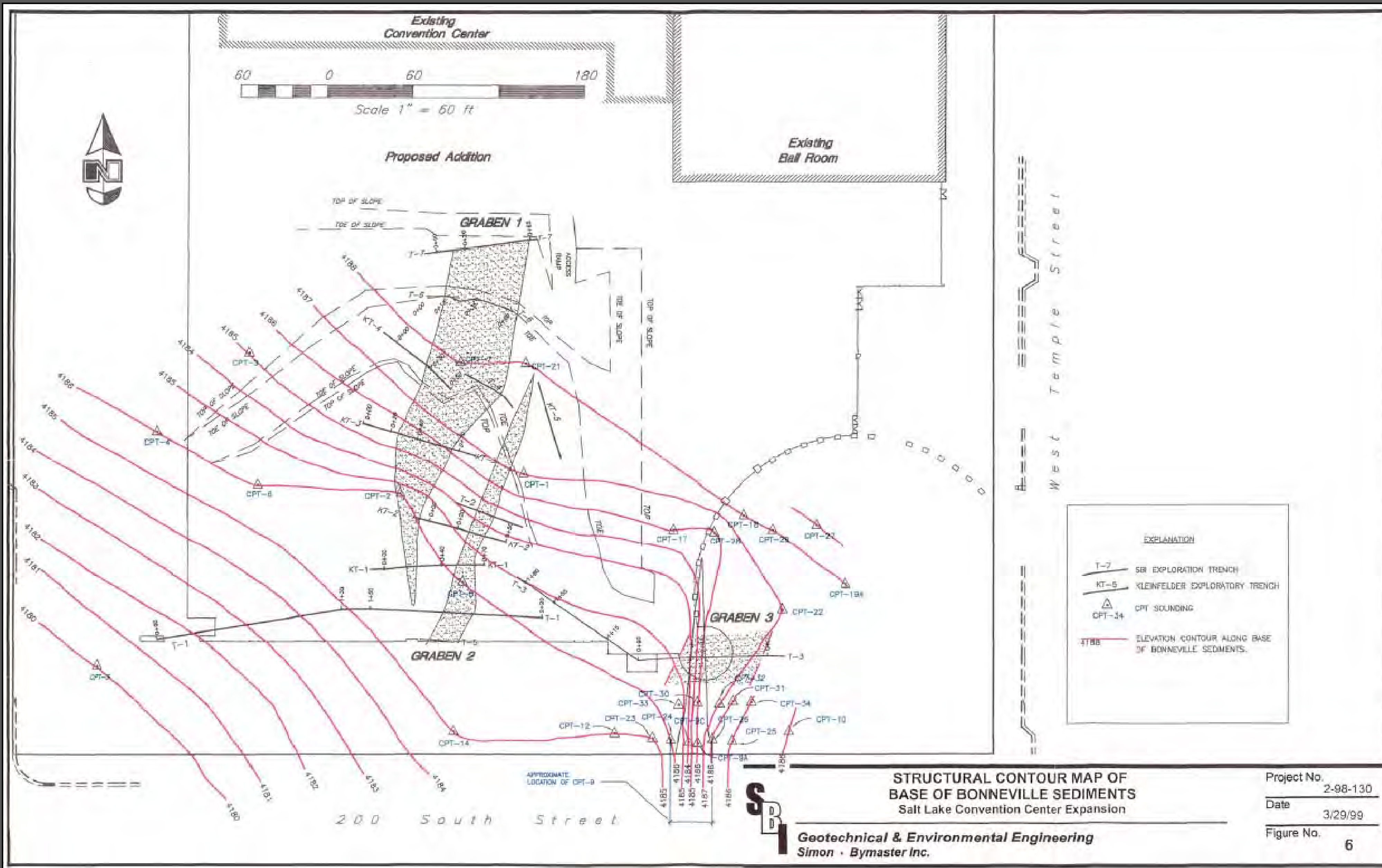
Wednesday, April 21, 1999

Geologists Muzzled On Salt Palace Fault

BY LEE SIEGEL

The Salt Lake Tribune UTAH/NATION Thursday, June 10, 1999

Salt Palace Expansion Work Gets Back on the Fast Track

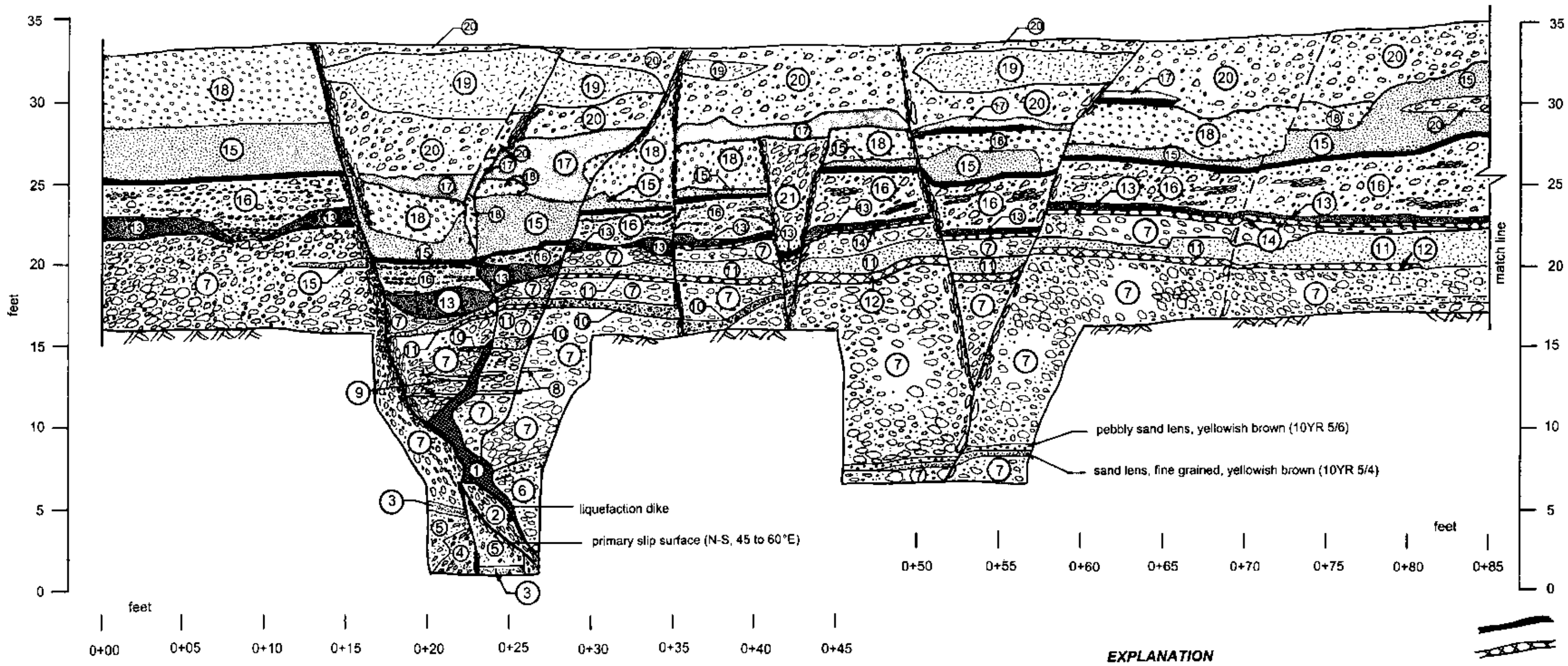


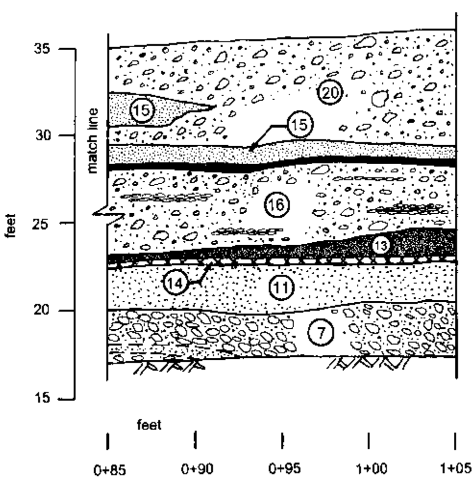
Simon Bymaster, Inc., March 29, 1999

west

TRENCH 6
North Wall

east





Iron oxide stained strata

Buried paleosol

EXPLANATION

1 Dike - Sand (SP), fine grained, brown (10YR 4/3), strike, N42°E, plunge 32°SW

2 Gravelly Sand (SP), fine to medium grained sand with subangular to subrounded clasts (approximately 20 to 30%) up to 6-inches in longest dimension, loose, slightly moist, dark grayish brown (10YR 4/2)

3 Sand (SP) lens, clayey, fine grained, brown (10YR 4/3)

4 Gravelly Sand (SP), fine grained sand with subangular to subrounded clasts (approximately 40%) up to 2-inches in longest dimension (average size ≤1-inch), medium dense, slightly moist, brown (10YR 4/3)

5 Gravelly Sand (SP), medium grained sand with subangular to subrounded clasts (approximately 20%) up to 6-inches in longest dimension, loose, slightly moist, dark yellowish brown (10YR 4/4)

6 Gravelly Sand (SP), fine grained sand with subangular to subrounded clasts (approximately 40%) up to 3-inches in longest dimension (average size ≤1-inch), medium dense, slightly moist, yellowish brown (10YR 5/4)

7 Sandy Gravel (GP), sub-angular to sub-rounded clasts in a medium to coarse grained pebbly sand matrix, medium dense to dense, slightly moist, poorly sorted, brown(10YR 5/3) to yellowish brown (10YR 5/4), clasts are coated with calcium carbonate, are approximately 60 to 70% by volume, and are ≤6-inches in longest dimension

8 Sand (SP) lens, fine grained, yellowish brown (10YR 5/4)

9 Sand (SP) lens, fine grained, dark yellowish brown (10YR 4/6)

10 Sand (SP), fine grained with scattered pebble-size clasts, dark yellowish brown (10YR 4/4)

11 Sand (SP), fine grained, yellowish brown (10YR 5/4)

12 *Buried Paleosol* - Silty Sand (SM) fine grained, with scattered pebble size clast (≤¼-inch), dark brown (7.5YR 5/2)

13 Sand (SP), fine grained with scattered pebble-size clasts (≤¼-inch), dark yellowish brown (10YR 4/4) to yellowish brown (10YR 5/4)

14 *Buried Paleosol* - Silty Sand (SM) fine grained, with scattered pebble size clast (≤¼-Inch), dark brown (7.5YR 5/2)

15 Sand (SP), fine grained, yellowish brown (10YR 5/4), with heavy iron-oxide staining along base

16 Sandy Gravel (GP), sub-angular to sub-rounded clasts in a coarse grained sand matrix, medium dense to dense, slightly moist, poorly sorted, yellowish brown (10YR 5/4),clasts are approximately 50% by volume, and are ≤2-inches in longest dimension; with some horizontal stratification and clast-supported layers

17 Sand (SP), fine grained, yellowish brown (10YR 5/4), with heavy iron-oxide staining along base

18 Sandy Gravel (GP), sub-angular to sub-rounded clasts in a fine to medium grained sand matrix, medium dense to dense, slightly moist, poorly sorted, yellowish brown (10YR 5/4); clast are approximately 40% by volume, and are ≤3-inches in longest dimension; with pebbly sand lenses and abundant scour and fill structures

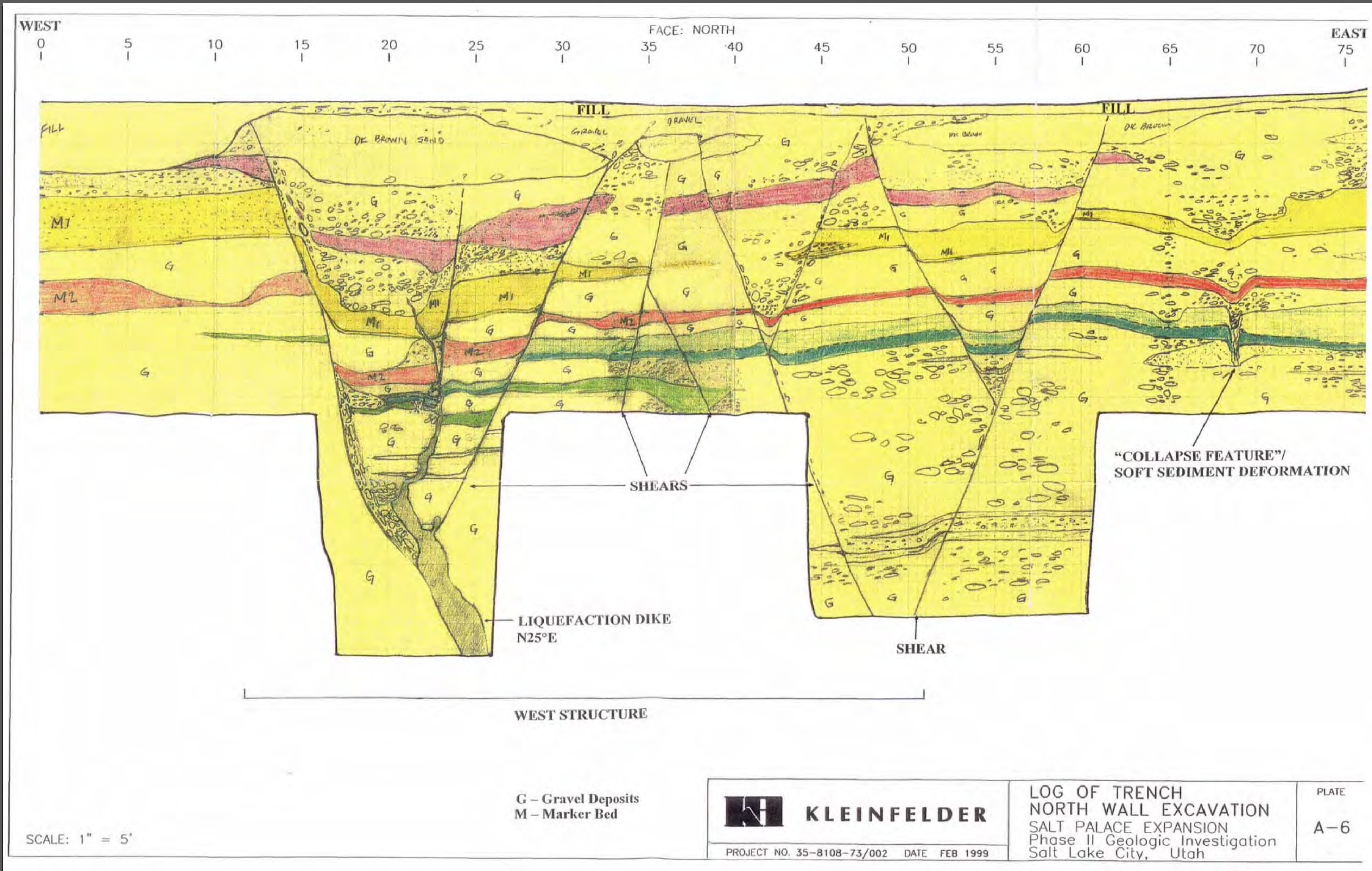
19 Silty Sand (SM), fine grained, dark yellowish brown (10YR 3/4)

20 Sandy Gravel (GP), sub-angular to sub-rounded clasts in a fine to medium grained sand matrix, medium dense to dense, slightly moist, poorly sorted, brown (10YR 4/3); clast are approximately 60% by volume, and are ≤6-inches in longest dimension

21 Sandy Gravel (GP), sub-angular to sub-rounded clasts in a fine to medium grained sand matrix, medium dense to dense, slightly moist, poorly sorted, yellowish brown (10YR 5/6); clast are approximately 40% by volume, and are ≤8-inches in longest dimension

TRENCH PROFILE T-6		
SCALE: as shown	APPROVED BY:	DRAWN BY DBS
DATE: 3/29/99	PROJECT NO. 2-98-130	REVISED
Salt Palace Convention Center Expansion 100 South West Temple Street Salt Lake City, Utah		
Simon • Bymaster Inc.		DRAWING NUMBER 4

Simon Bymaster, Inc., March 29, 1999



Kleinfelder, Inc. February 26, 1999

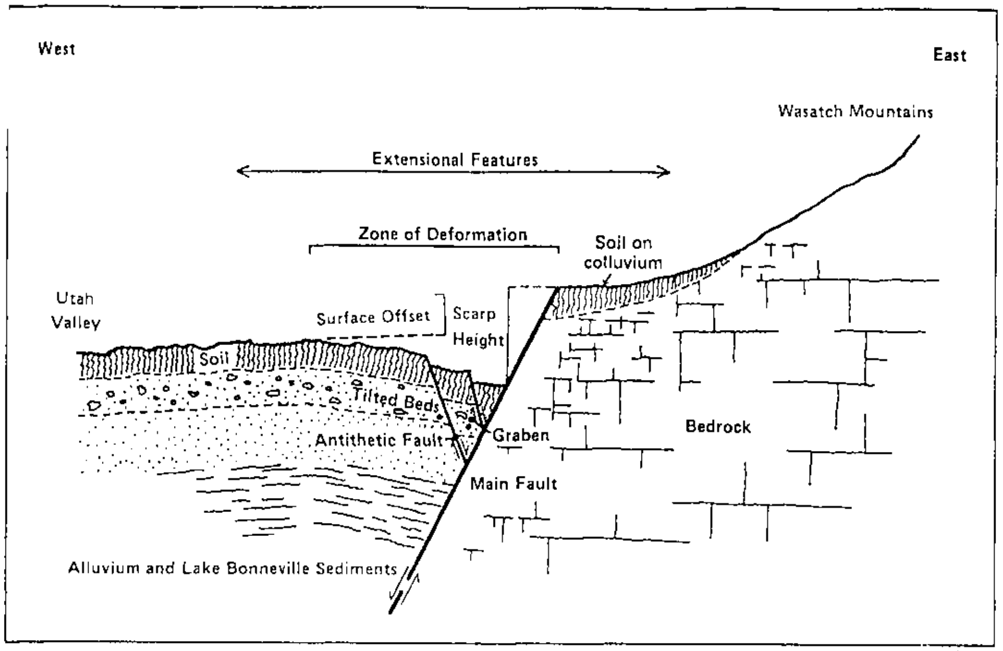


Figure 1. Sketch of Process by which Grabens Form as a Consequence of Normal Faulting (After Robison, 1993)

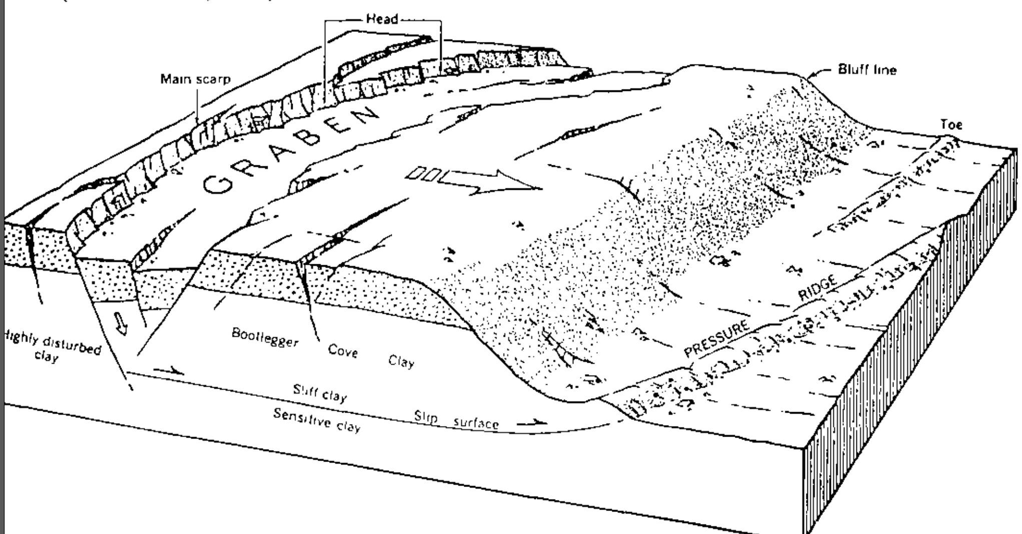


Figure 2. Sketch of Process by which Grabens Form as a Consequence of Lateral Spread (After Hansen, 1995)

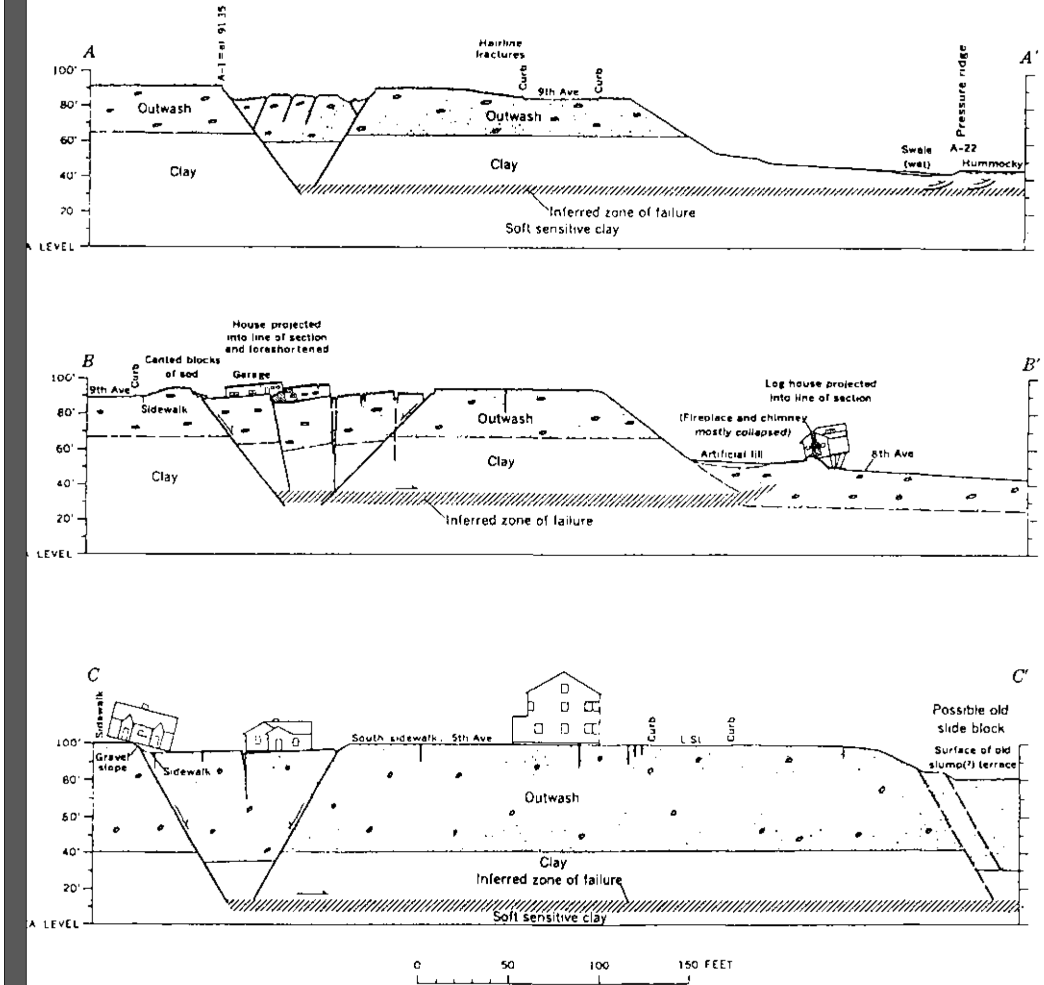
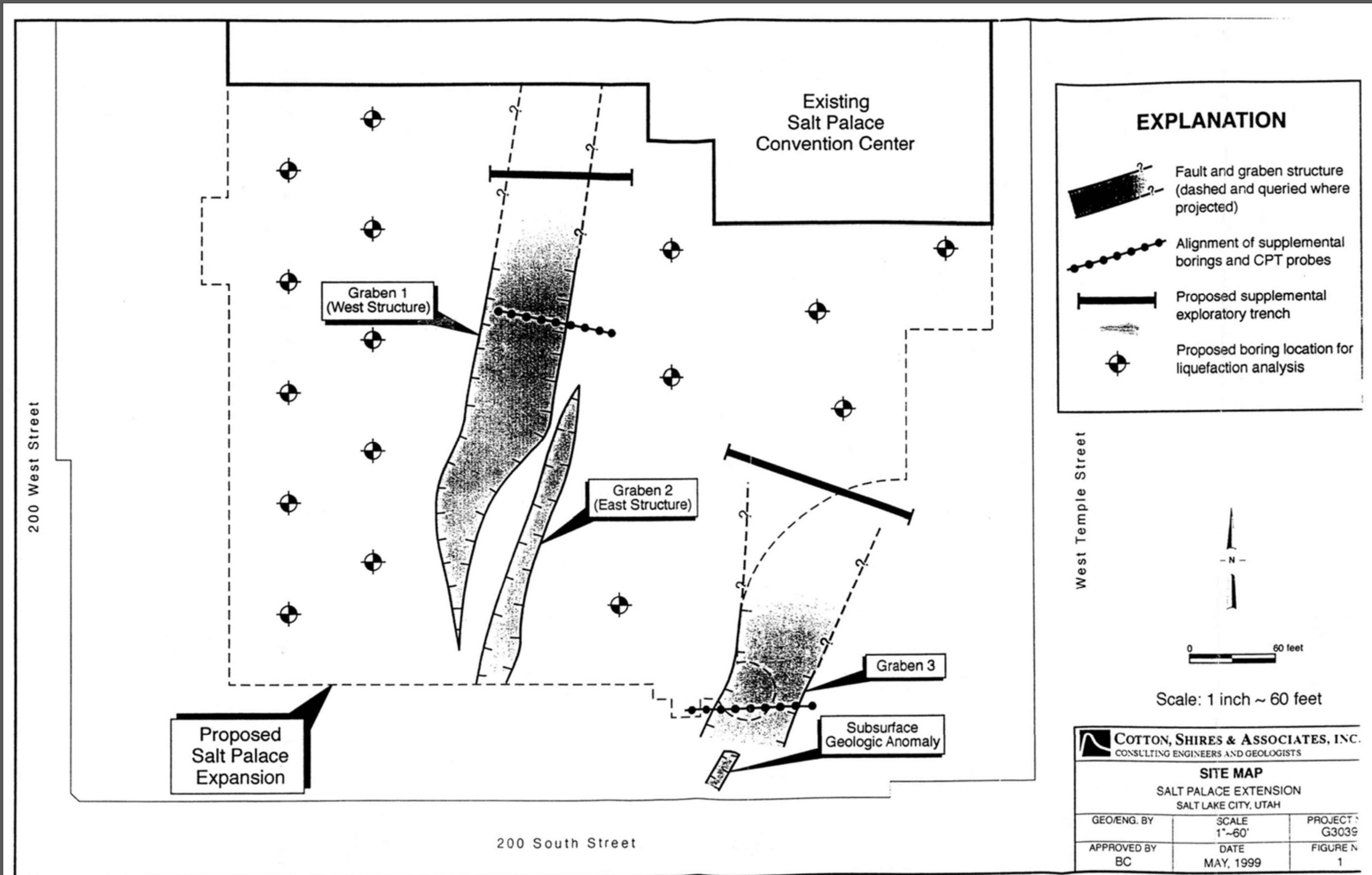


Figure 3. Geologic Section Through L-Street Slide (Lateral Spread) Showing Graben Features that Developed (After Hansen, 1995)



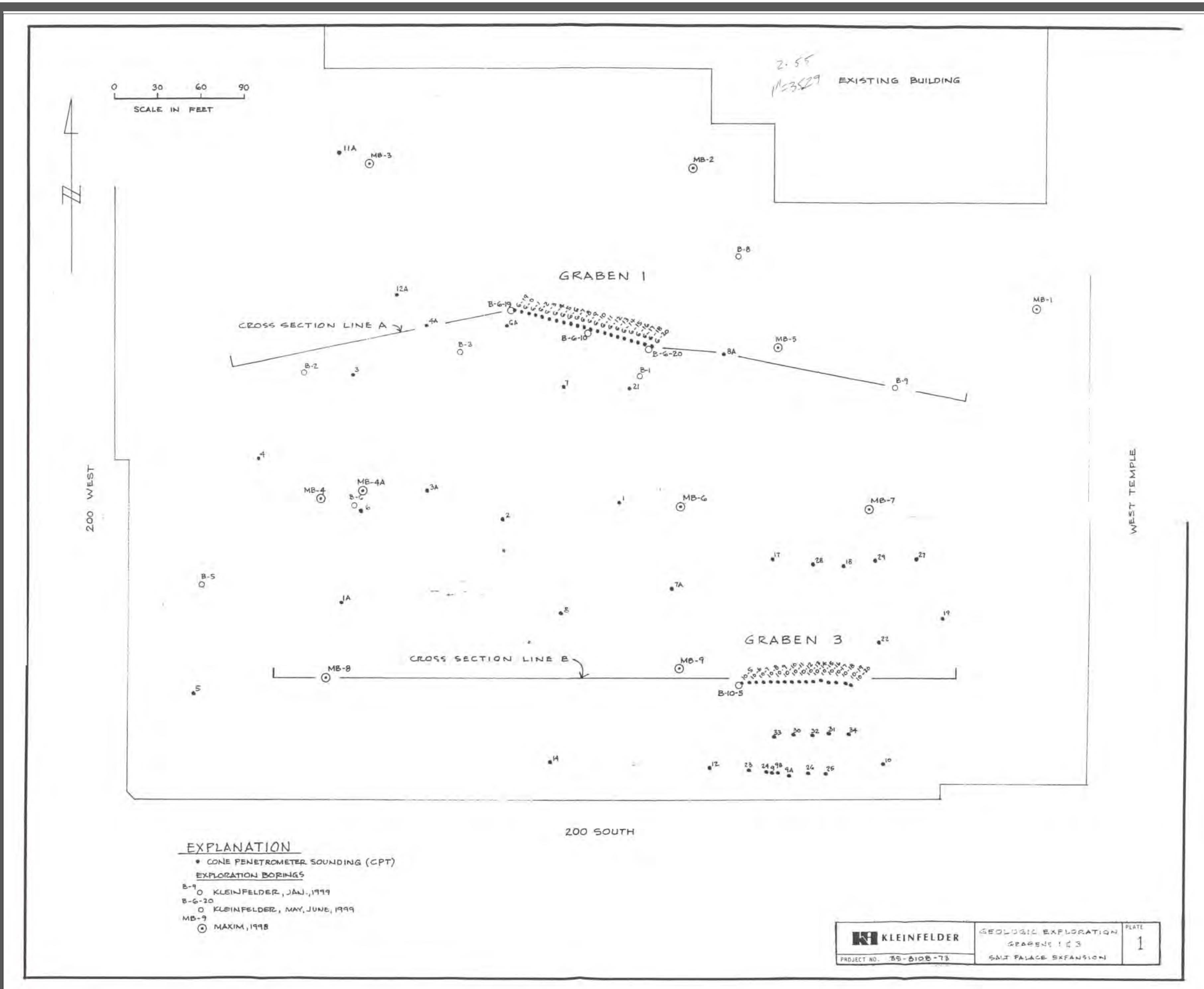
Cotton, Shires & Associates, Inc., July 30, 1999

The faults at the Salt Palace site are sufficiently well developed in that they were been traced across the site with reliable consistency. They generally trend to the northwest as a series of near parallel faults that form three graben structures. The nearly horizontal sedimentary layers of alluvium that underlie the site were displaced by these faults. In some exposures the offsets approximate five to six feet, while most faulting is generally measured in inches. In our opinion, the characteristics of the fault record did not allow a definitive judgement regarding their origin. It was simply not scientifically possible to determine exclusively from the surface exposures if the faults were the result of active tectonic ground faulting associated with a large magnitude earthquake that passed through the site, or lateral spreading due to strong ground shaking and liquefaction. Both phenomena are capable of producing the same paleoseismic record exhibited in the Salt Palace exposures.

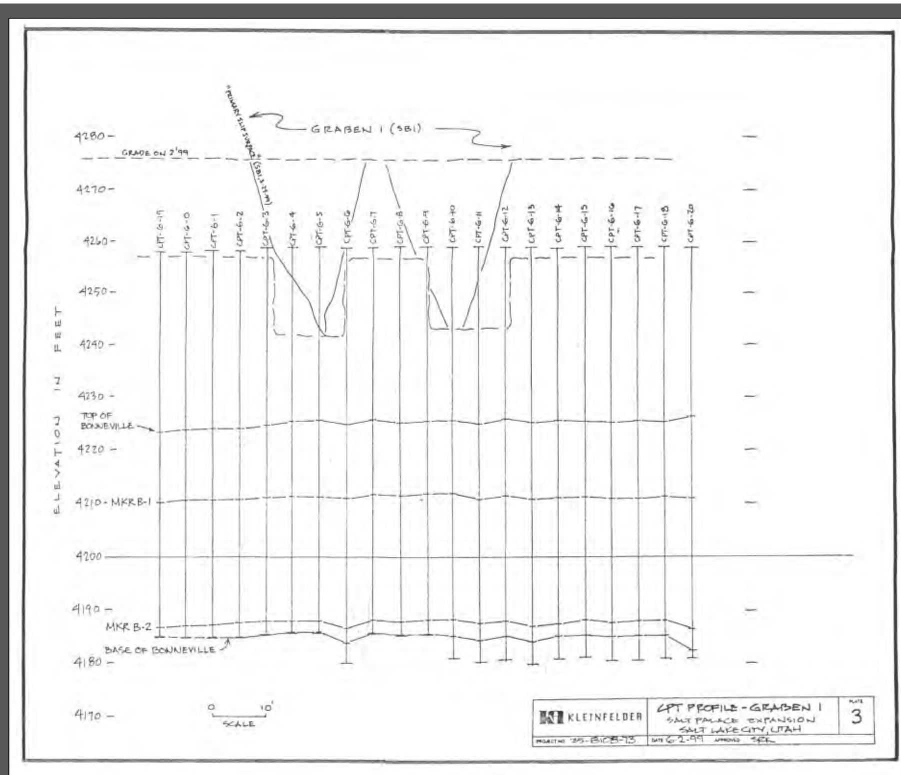
Cotton, Shires & Associates, Inc., July 30, 1999

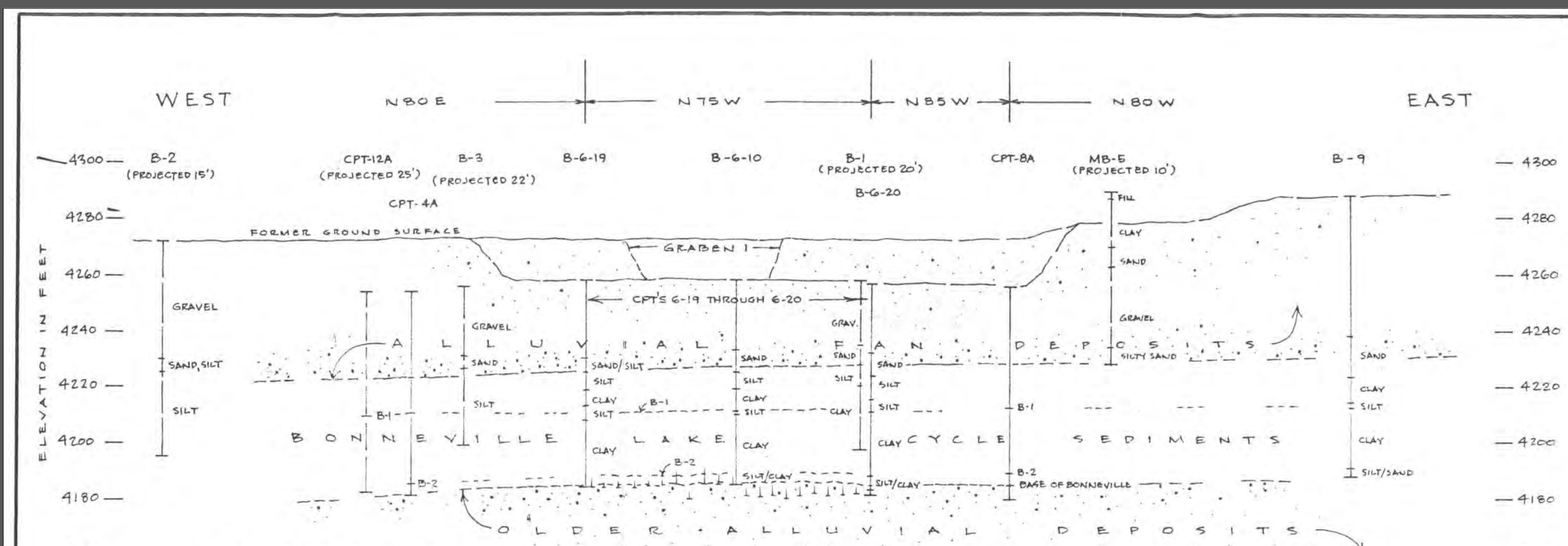
Borah Peak Earthquake, 1983

Great Alaska Earthquake, 1964



Kleinfelder, Inc. February 26, 1999





Kleinfelder, Inc. February 26, 1999

Summary of Investigation

- Simon Bymaster Inc.
  - Tectonic fault grabens
  - Liquefaction dikes
  - No large west-dipping fault
  - 3 colluvial wedges, on 3 separate faults
  - Vertically aligned (rotated) clasts along faults
  - Base of Bonneville displaced 3 to 9 feet
- Kleinfelder, Inc.
  - Liquefaction-induced lateral spread failures due to two seismic events
  - No large west-dipping fault
  - Lake Bonneville deposits not vertically offset
  - Mitigation for minor liquefaction recommended

Summary of Investigation

CONCLUSION AND RECOMMENDATION

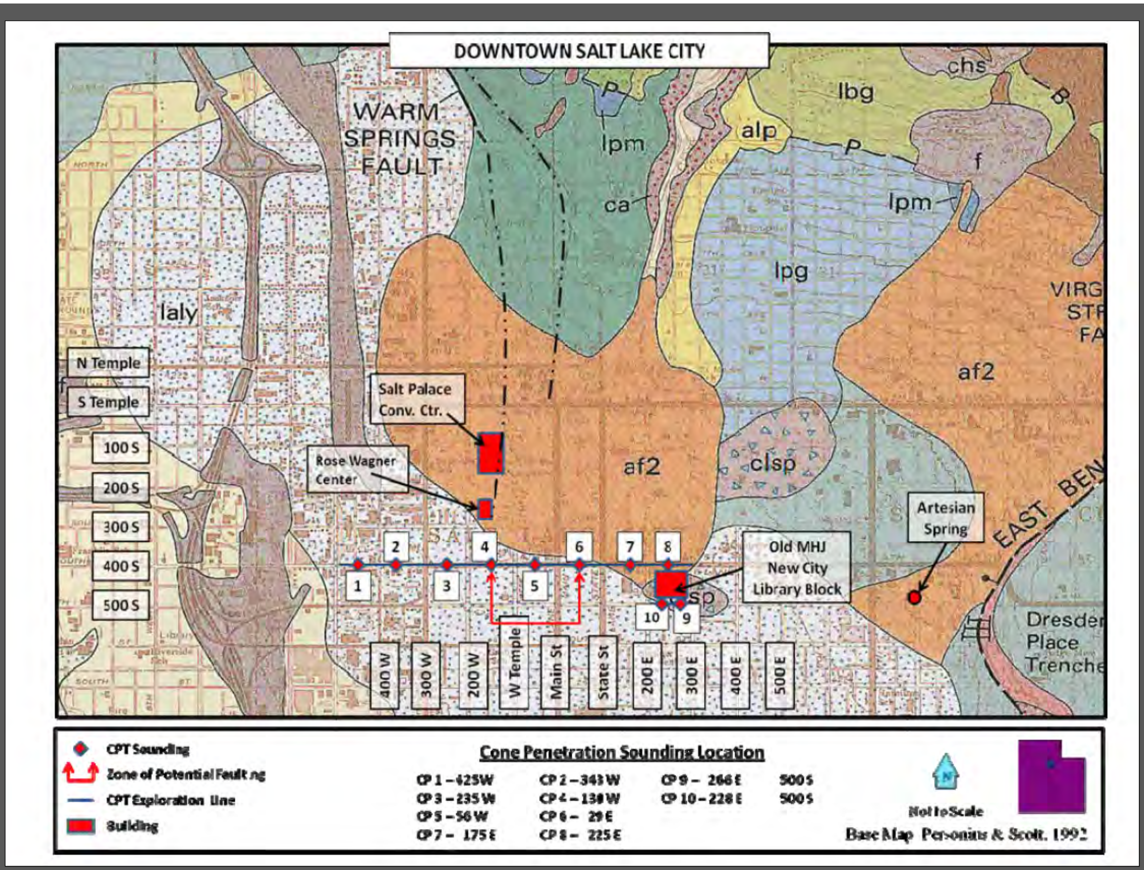
We are convinced that small vertical variations of the marker horizon (B-2) within the Bonneville Formation do exist, but inasmuch as they are significantly less than fault displacements seen in near surface exposures, it is unlikely that the near-surface faults are primarily of tectonic origin. We recognize that not every aspect of the faulted structures seen in the construction excavations can be easily attributed to a single mode of origin. We do find it compelling, however, that the faulting does not extend to the deep subsurface marker bed (B-2) of the Bonneville Formation. Significant faulting of the near-surface alluvial beds, without pronounced vertical offsets in older underlying geology, makes the non-tectonic origin more reasonable. Furthermore, we believe that analysis of the potentially liquefiable sediments by Dr. Youd is of sufficient scope to justify the conclusion that if defensive measures are taken to accommodate minor lateral spread and ground settlement at the Salt Palace site, adequate safety can be achieved.

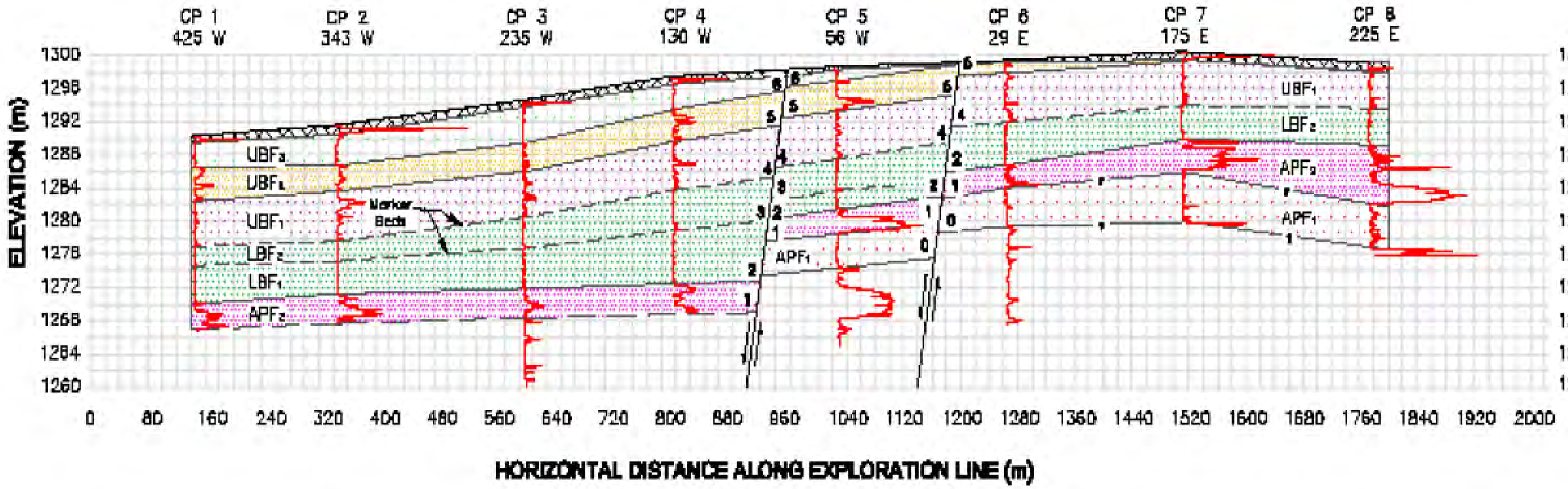
In light of our current understanding of the potential level of risk at this site to lateral spread and ground movement, we are concerned about the structural integrity of the existing Salt Palace Convention Center. In our opinion, the risk is high that ground settlement and spreading of "a few inches" could adversely impact the existing structure. We recommend that the project geotechnical and structural engineering consultants review this concern and provide the City with a report outlining their findings and recommendations.

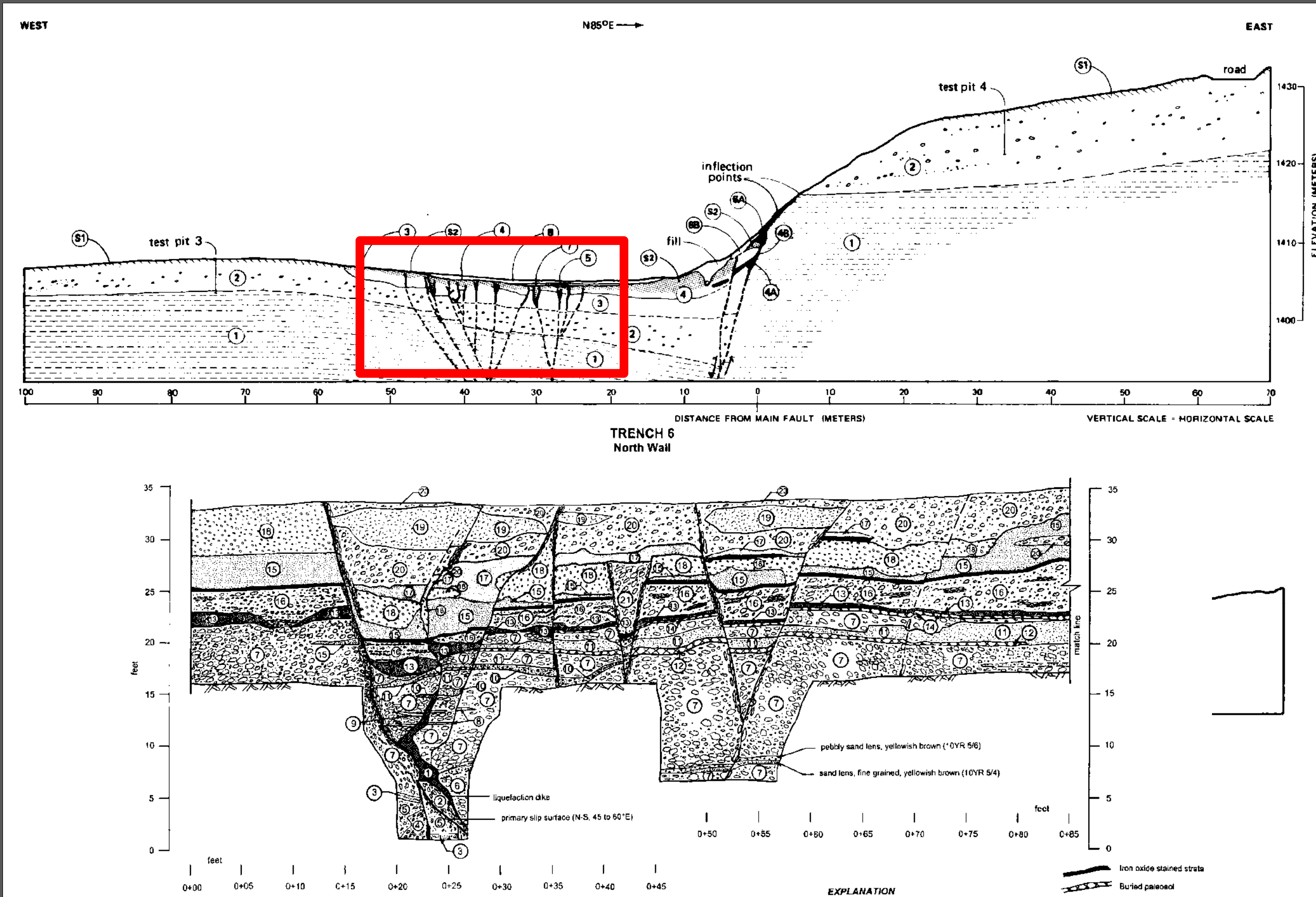
Cotton, Shires & Associates, Inc., July 30, 1999

Leeflang, 2008

- Found evidence for tectonic faulting
- CPT between 130 and 56 West shows approximately 8.7 meters (28.5 ft) of vertical offset of late Pleistocene lacustrine and alluvial deposits
- Even with about 240 meter (~780 ft) spacing, their interpreted vertical offset is significant

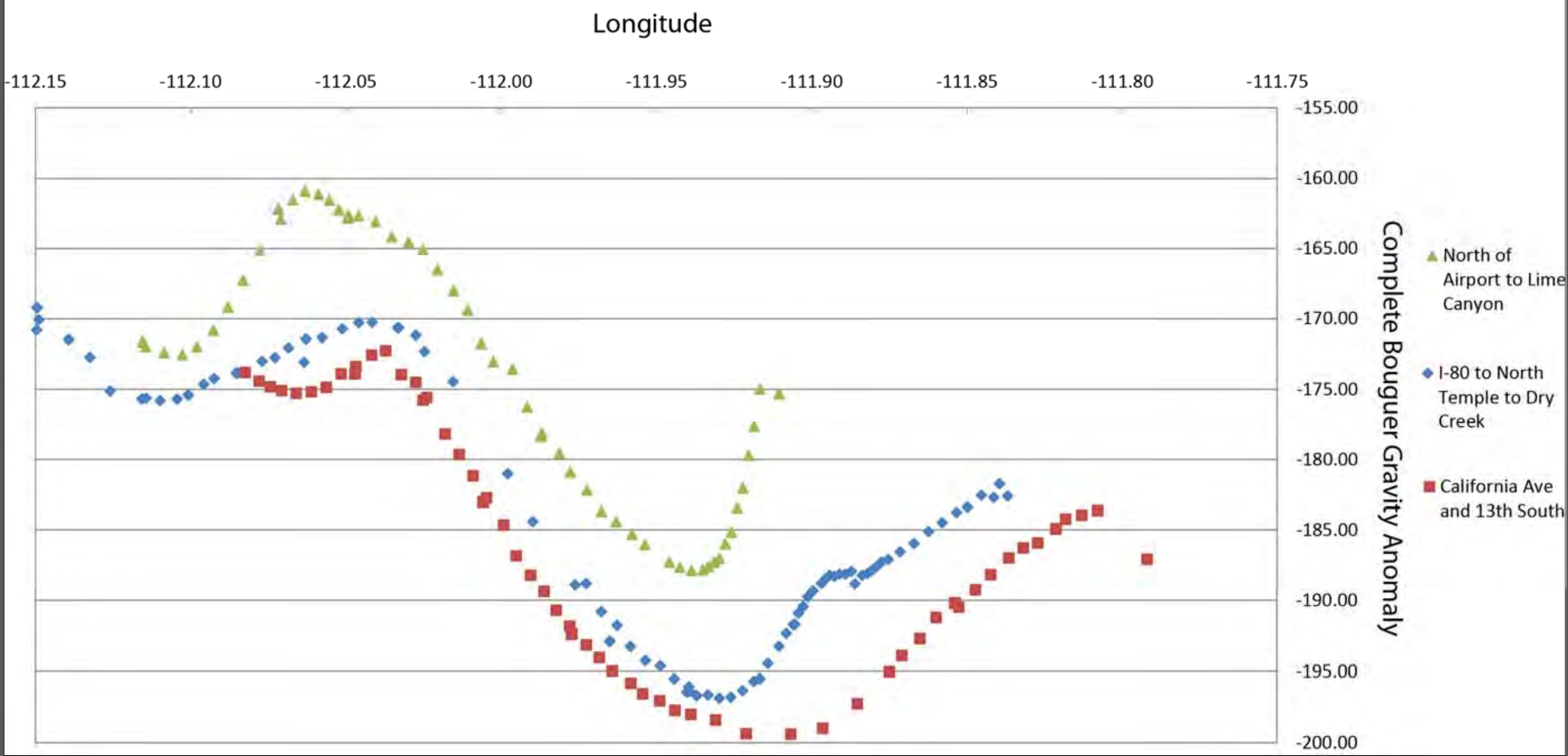


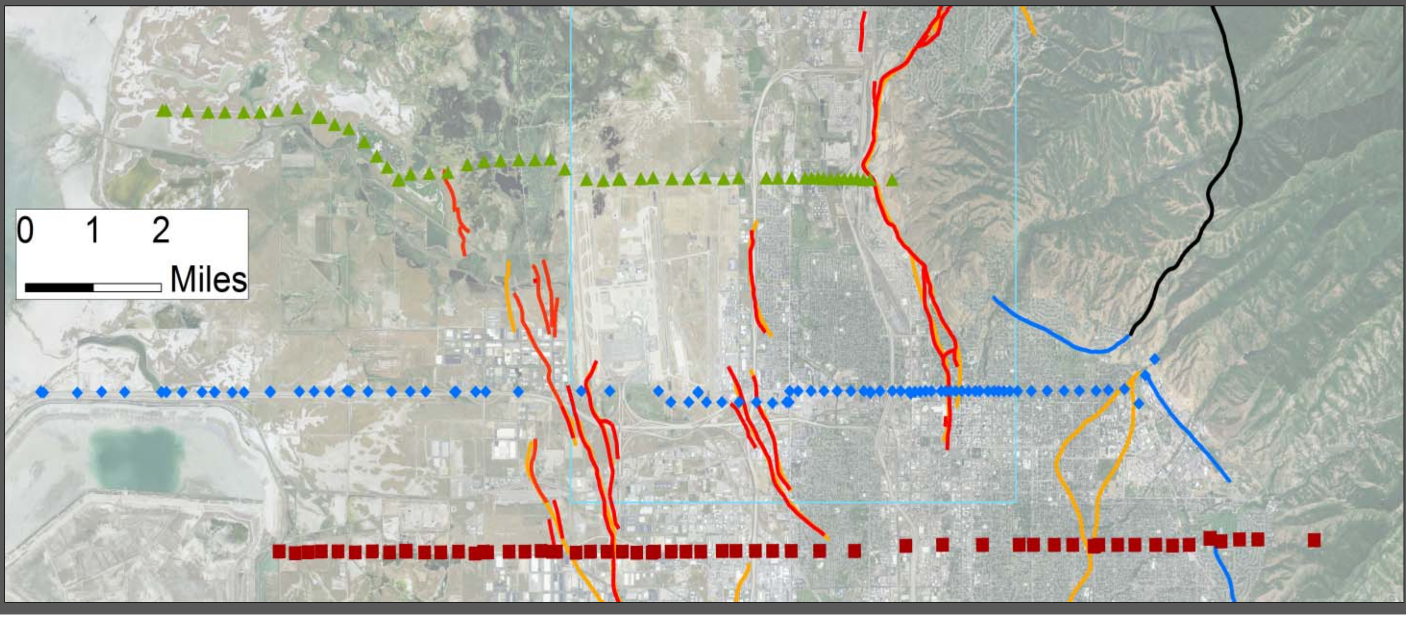


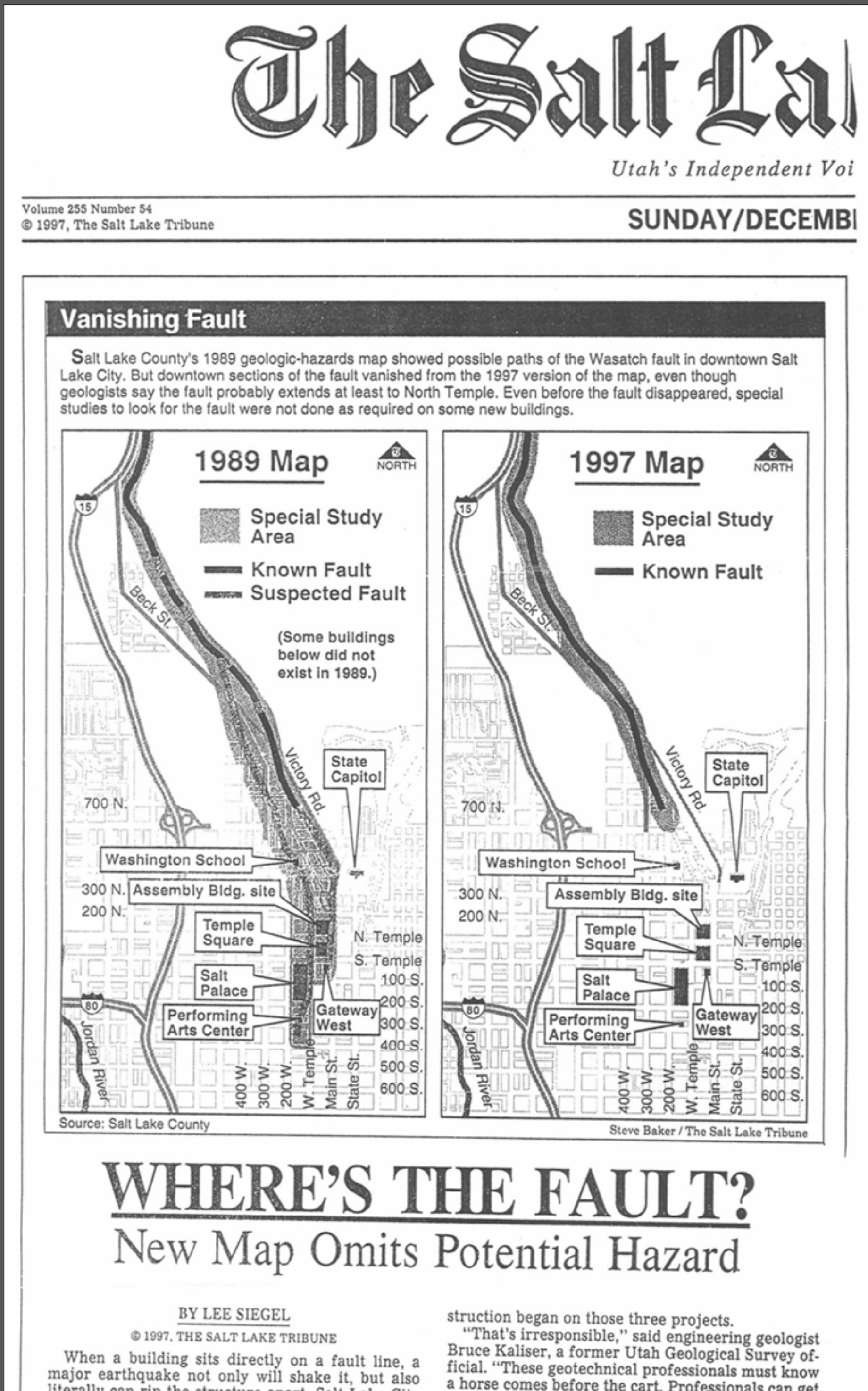


Swan and others, 1979

Gravity Profiles of the Salt Lake Valley Graben







The Salt La

Utah's Independent Voi

Volume 255 Number 54
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SUNDAY/DECEMB

Vanishing Fault

Salt Lake County's 1989 geologic-hazards map showed possible paths of the Wasatch fault in downtown Salt Lake City. But downtown sections of the fault vanished from the 1997 version of the map, even though geologists say the fault probably extends at least to North Temple. Even before the fault disappeared, special studies to look for the fault were not done as required on some new buildings.

Source: Salt Lake County

Steve Baker / The Salt Lake Tribune

WHERE'S THE FAULT?

New Map Omits Potential Hazard

BY LEE SIEGEL
© 1997, THE SALT LAKE TRIBUNE

When a building sits directly on a fault line, a major earthquake not only will shake it, but also literally can rip the structure apart. Salt Lake City

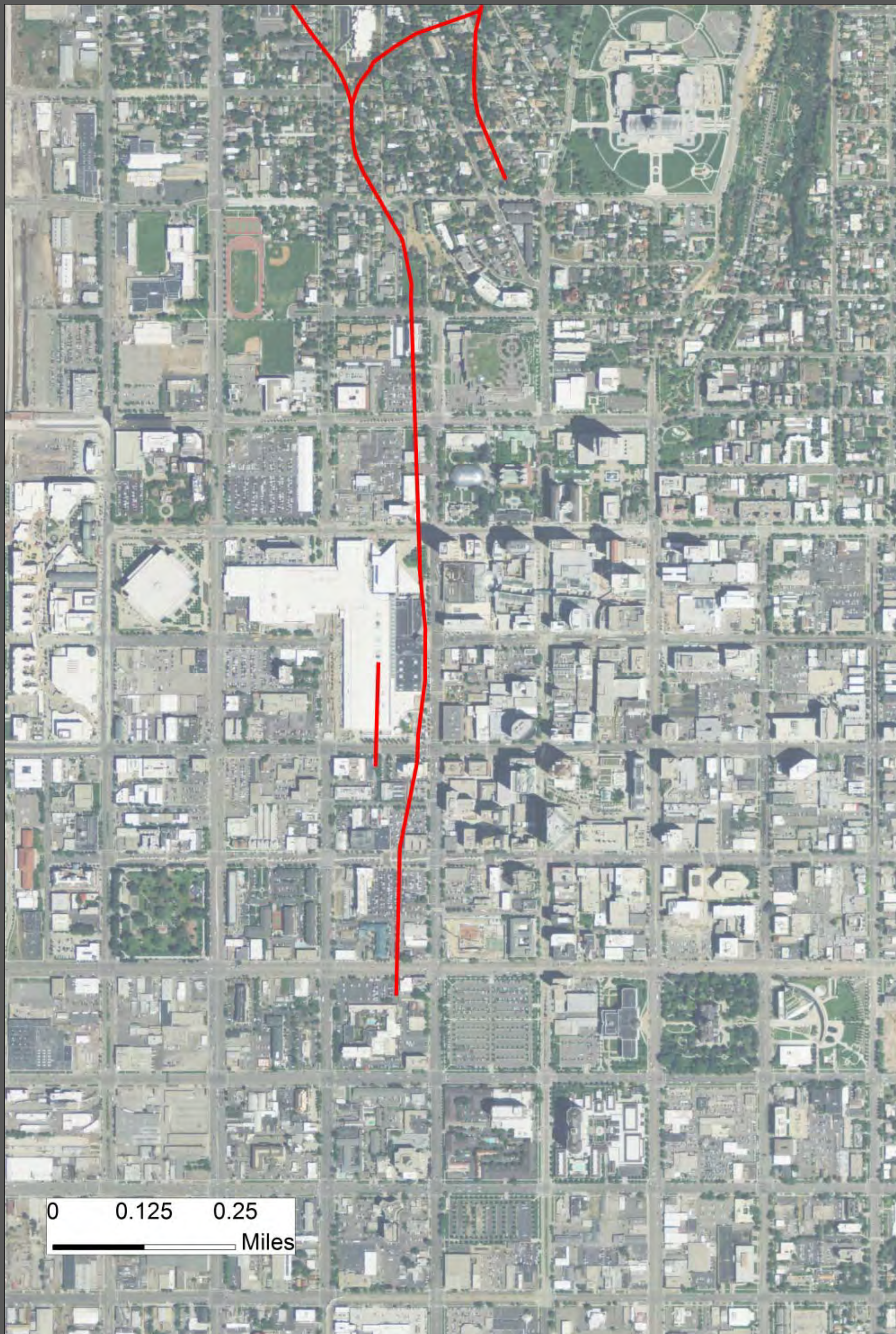
struction began on those three projects.

"That's irresponsible," said engineering geologist Bruce Kaliser, a former Utah Geological Survey official. "These geotechnical professionals must know a horse comes before the cart. Professionals can get

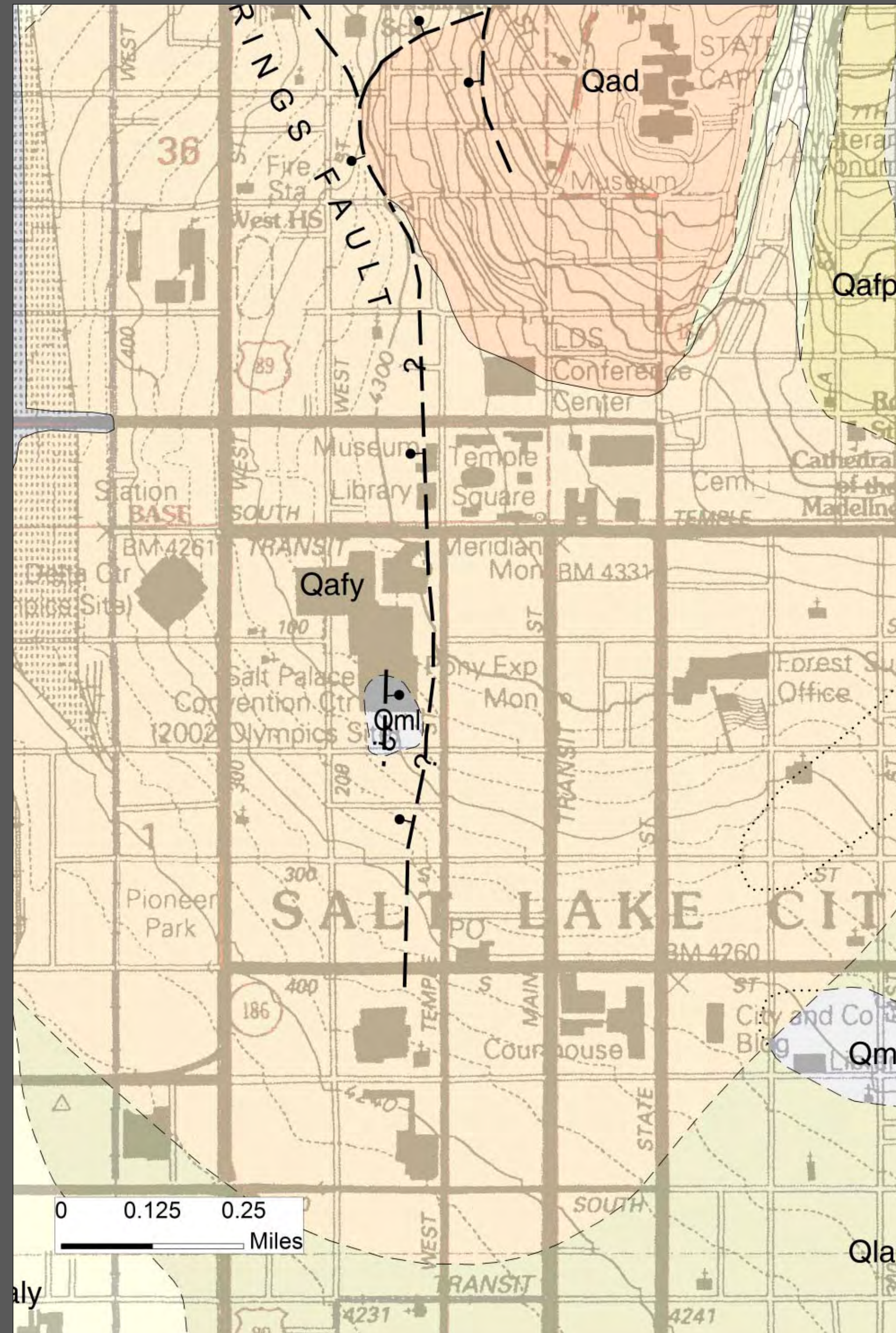
"To be, or not to be- that is the question"

The answer lies in the data

– The available data suggest continuing the western fault trace to at least 400 South



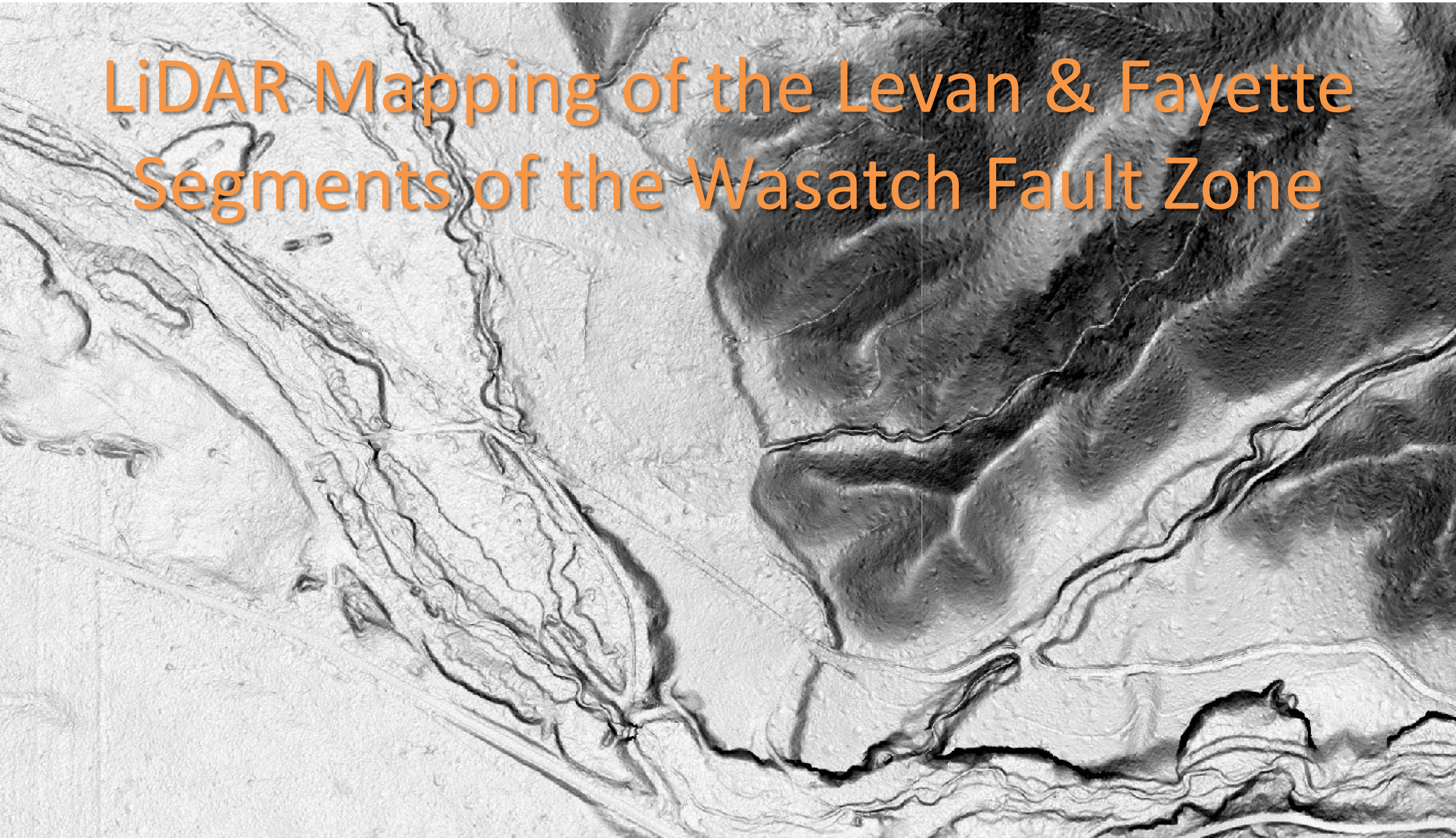
0
0.125
0.25
Miles



RINGS FAULT
Qad
Qafp
Qafy
Qml
Qlan
36
Fire Sta
West HS
LDS Conference Center
Museum
Temple Square
Library
Station
BASE
SOUTH
TEMPLE
BM 4261
Meridian Mon
BM 4331
Salt Palace Convention Ctr
2002 Olympics Site
Pony Exp Mon
Forest Sup Office
Pioneer Park
SALT LAKE CITY
PO
BM 4260
City and Co Bldg
Courthouse
STATE
MAIN
TRANSIT
Cathedral of the Madeline
4231
4241
0
0.125
0.25
Miles


Thank you

LiDAR Mapping of the Levan & Fayette Segments of the Wasatch Fault Zone



Adam I. Hiscock & Michael D. Hylland

Geologic Hazards Program

Levan/Fayette Segments

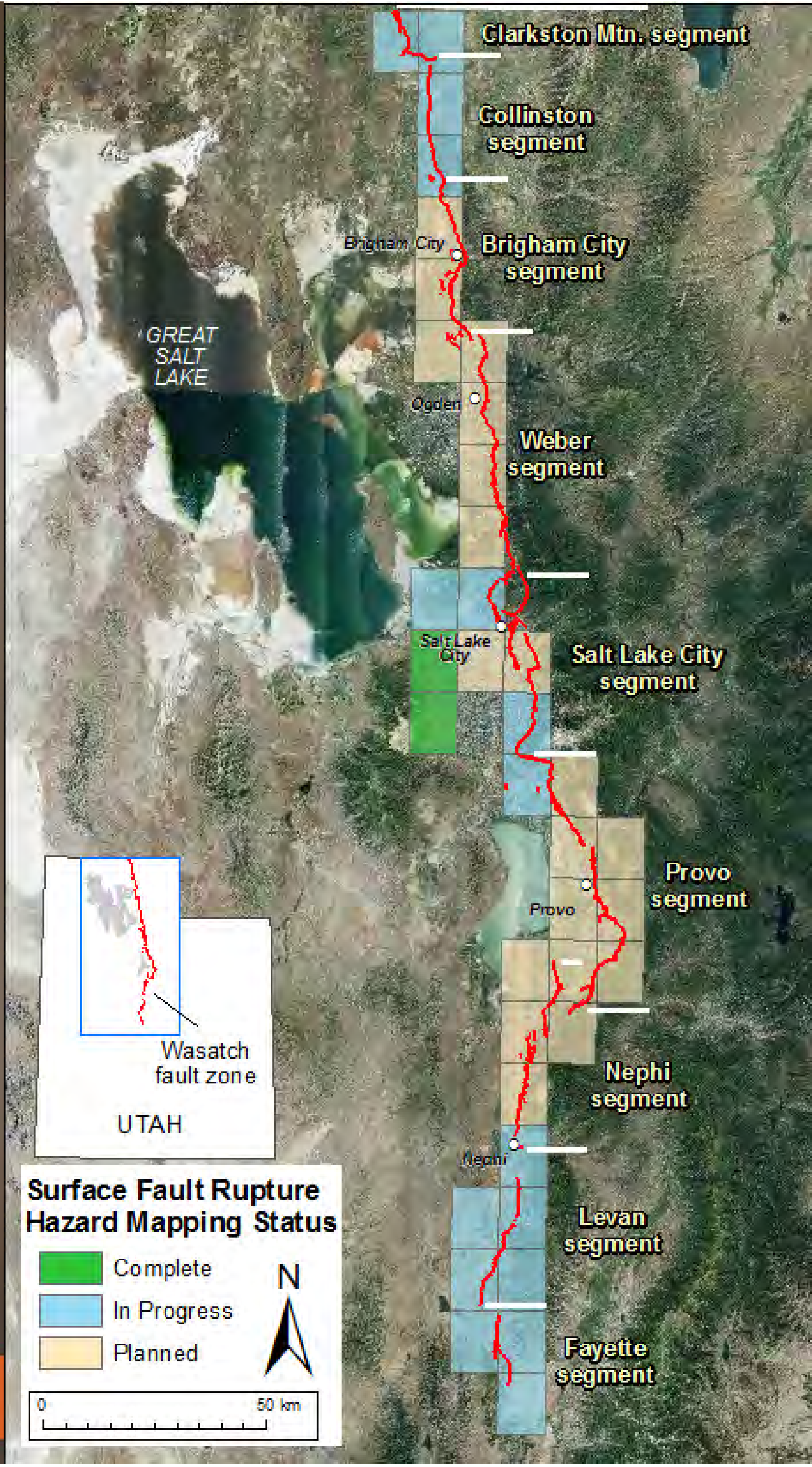
- Southernmost 2 segments of the Wasatch Fault Zone
- Levan – appx. 40 km long
- Fayette – appx. 22 km long
- Both show evidence for Holocene surface faulting
- 1 trench at Skinner Peaks on the Levan Segment, no trenching on Fayette segment.

UTAH DNR GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY

Wasatch Fault Zone Hazard Mapping Status

- Mapping quad-by-quad at 24K scale
- Publishing as Surface Fault Rupture Hazard Maps
- 16 quads in progress
- 20 quads planned



UTAH DNR GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY

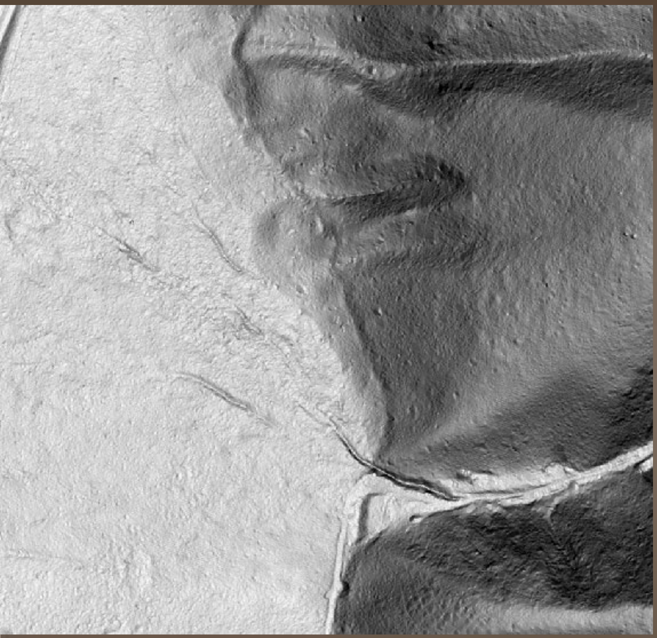
Objectives:

- Re-map Levan and Fayette segments of the WFZ at 1:10,000 or better scale. Identify previously un-mapped fault traces
- Use 2013-2014 0.5-meter LiDAR dataset, as well as historical aerial photos, previous geologic mapping, and field reconnaissance
- Create surface fault rupture hazard maps at 1:24,000 scale for land-use planning along the southern WFZ

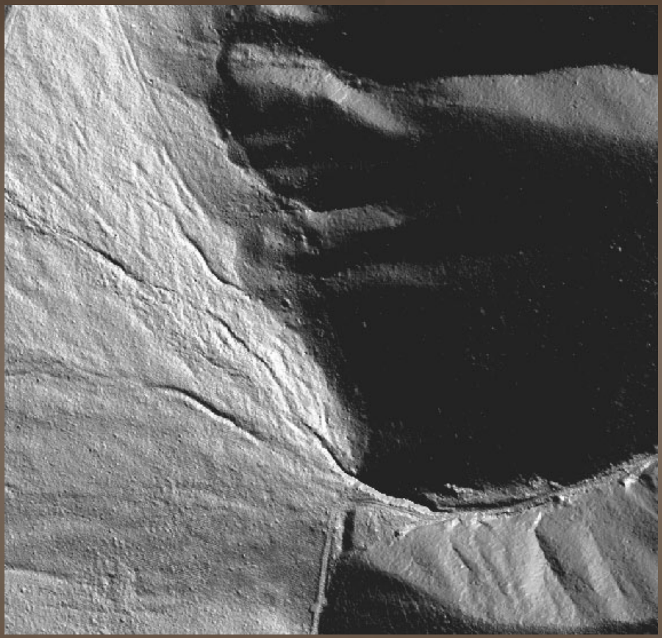
2013/2014 0.5-meter LiDAR Dataset

- Collected in 2013/2014 by a consortium of local, state, and federal government agencies, including UGS and USGS.
- Includes entire WFZ, from Fayette, Utah to north of Malad City, Idaho.
- Extremely high-resolution, great for mapping subtle fault scarps.
- Availability – Utah AGRC (point cloud data) & NSF OpenTopography (point cloud data, Google Earth DEM generation)
  - AGRC - gis.utah.gov
  - NSF OpenTopography - www.opentopography.org

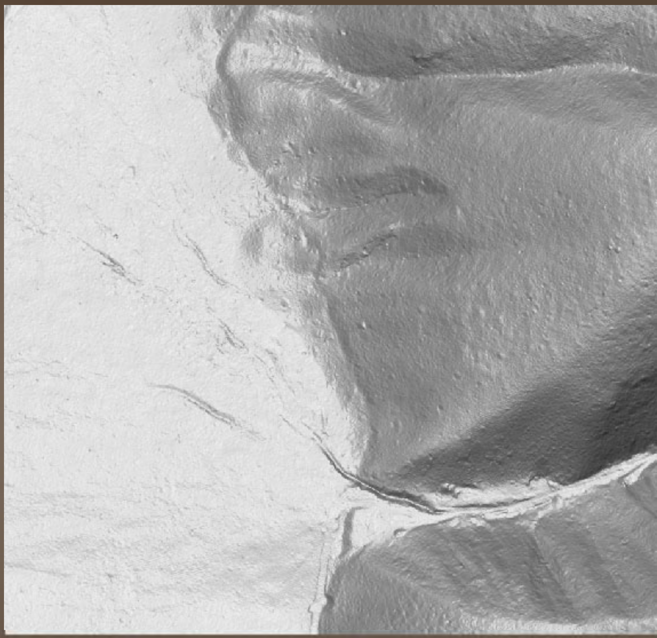
LiDAR Products Used



0-45° Slopeshade

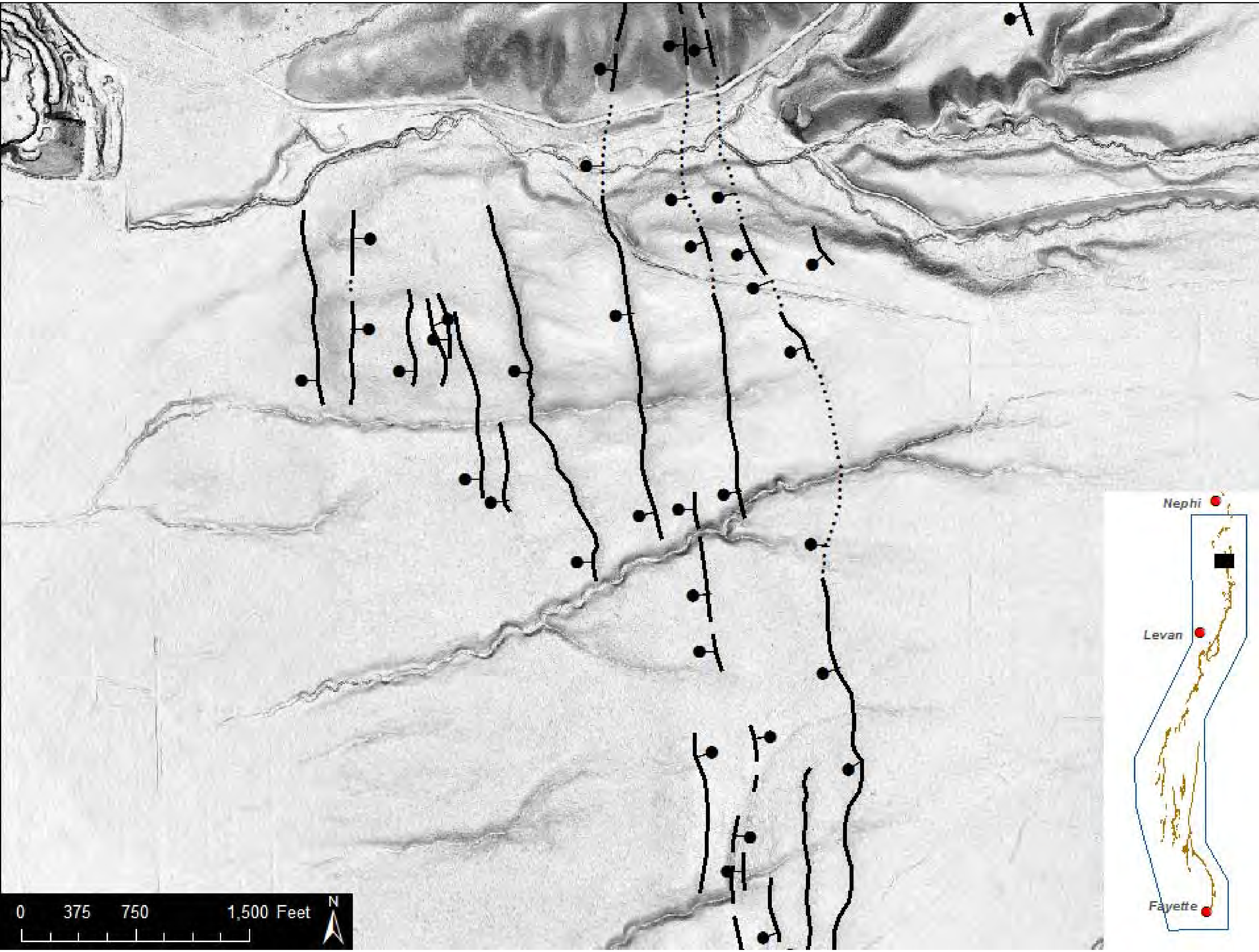


Altitude 50°, Azimuth 045° Hillshade

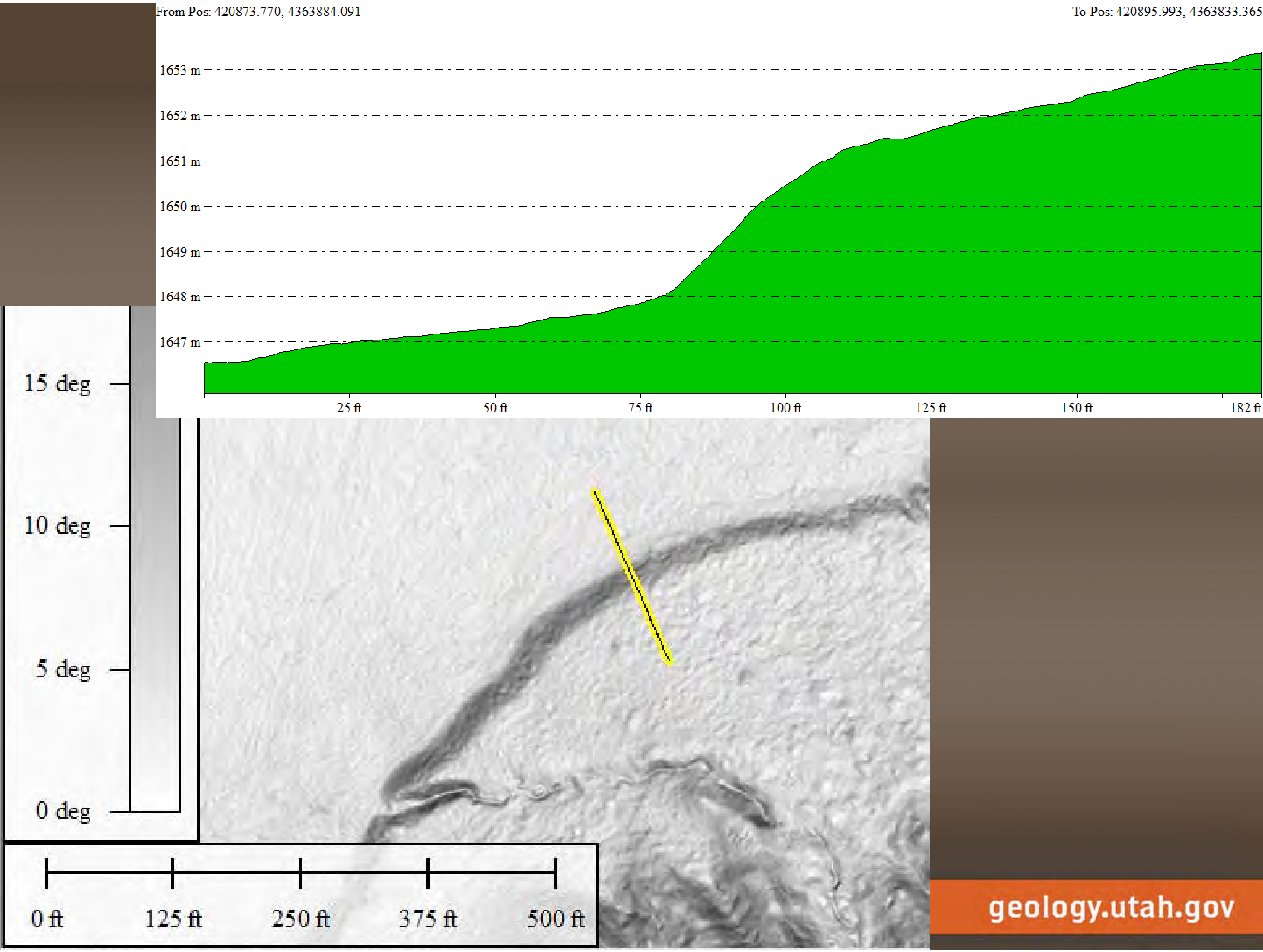


Altitude 80°, Azimuth 315° Hillshade

- All products created in GlobalMapper then brought into ArcGIS for mapping
- Variety of hillshades with different sun azimuth and altitude values used
- Contour lines generated from DEM also used
- Slopeshade product was the most useful for mapping fault scarps

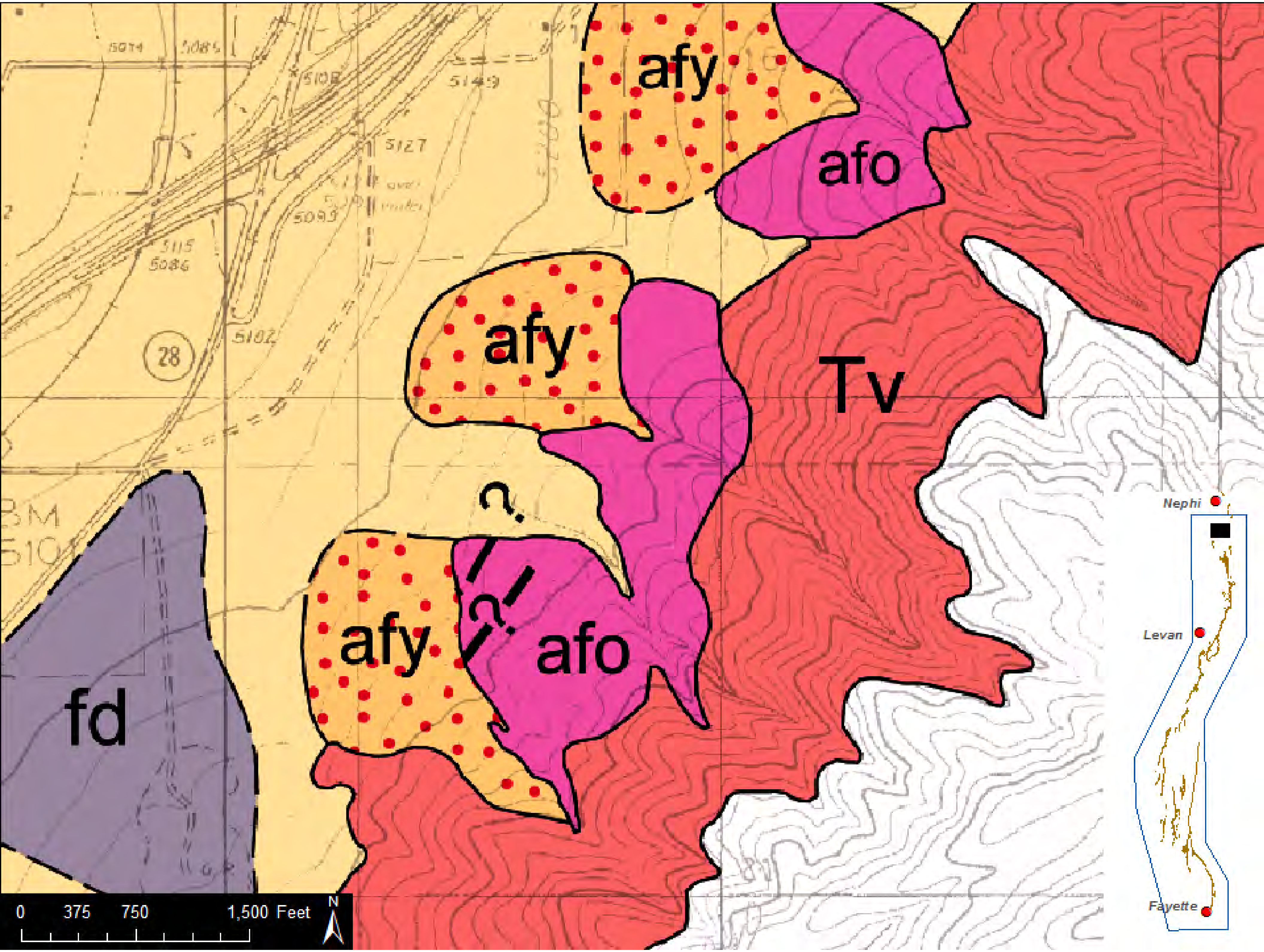


0 375 750 1,500 Feet
N
Nephi
Levan
Fayette

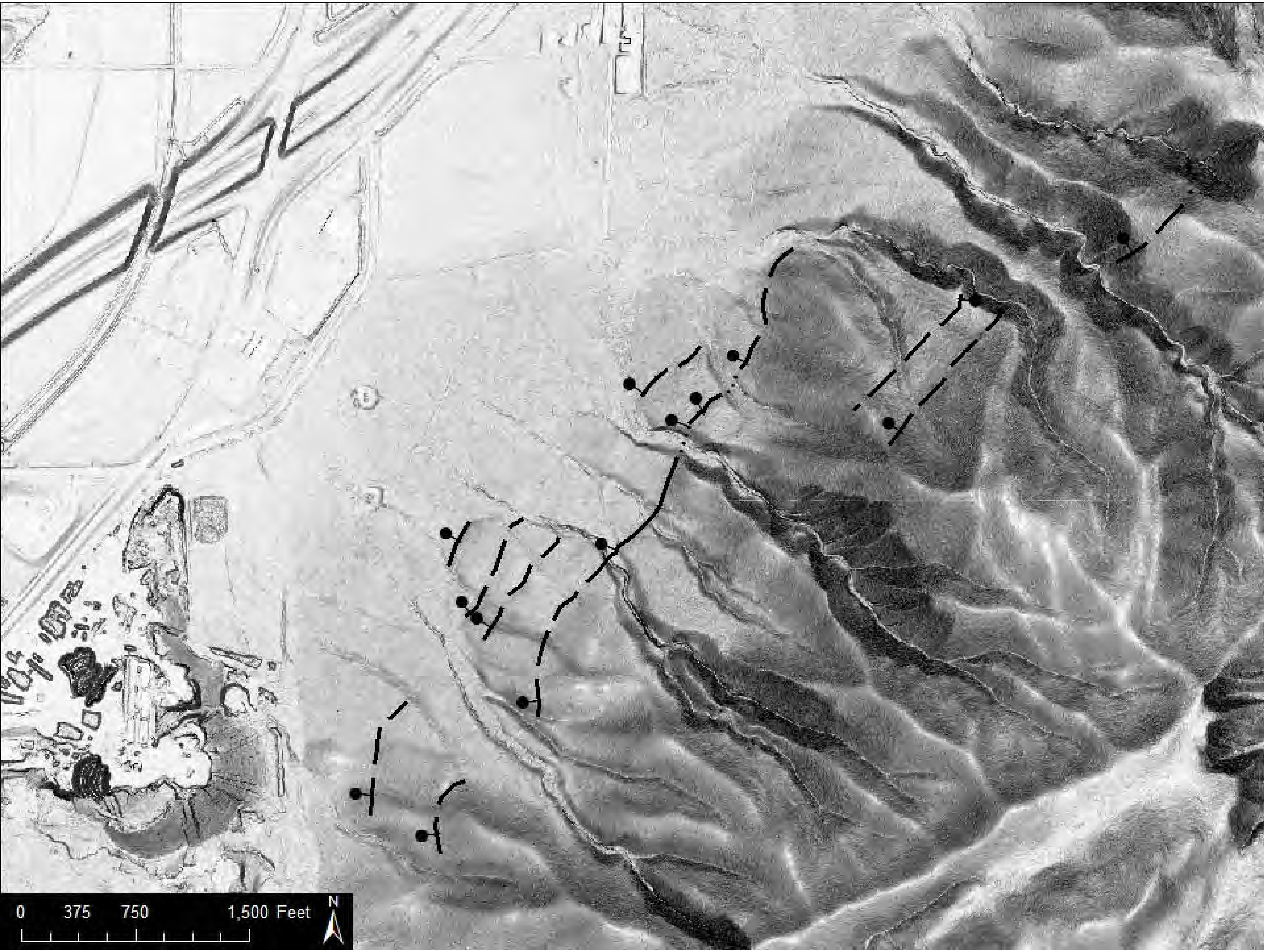

From Pos: 420873.770, 4363884.091
To Pos: 420895.993, 4363833.365
1653 m
1652 m
1651 m
1650 m
1649 m
1648 m
1647 m
25 ft
50 ft
75 ft
100 ft
125 ft
150 ft
182 ft
15 deg
10 deg
5 deg
0 deg
0 ft
125 ft
250 ft
375 ft
500 ft
geology.utah.gov

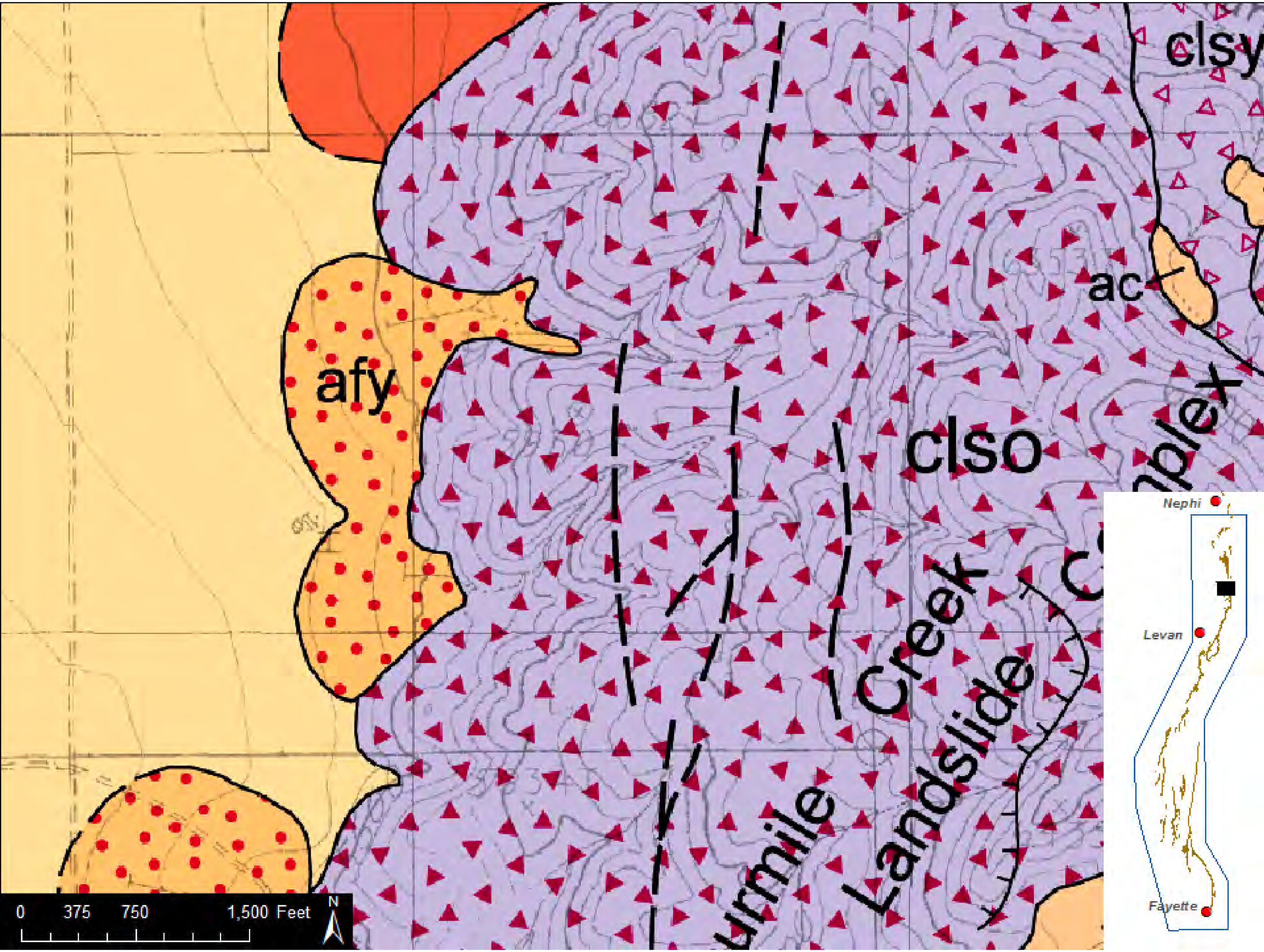
Other Data Used

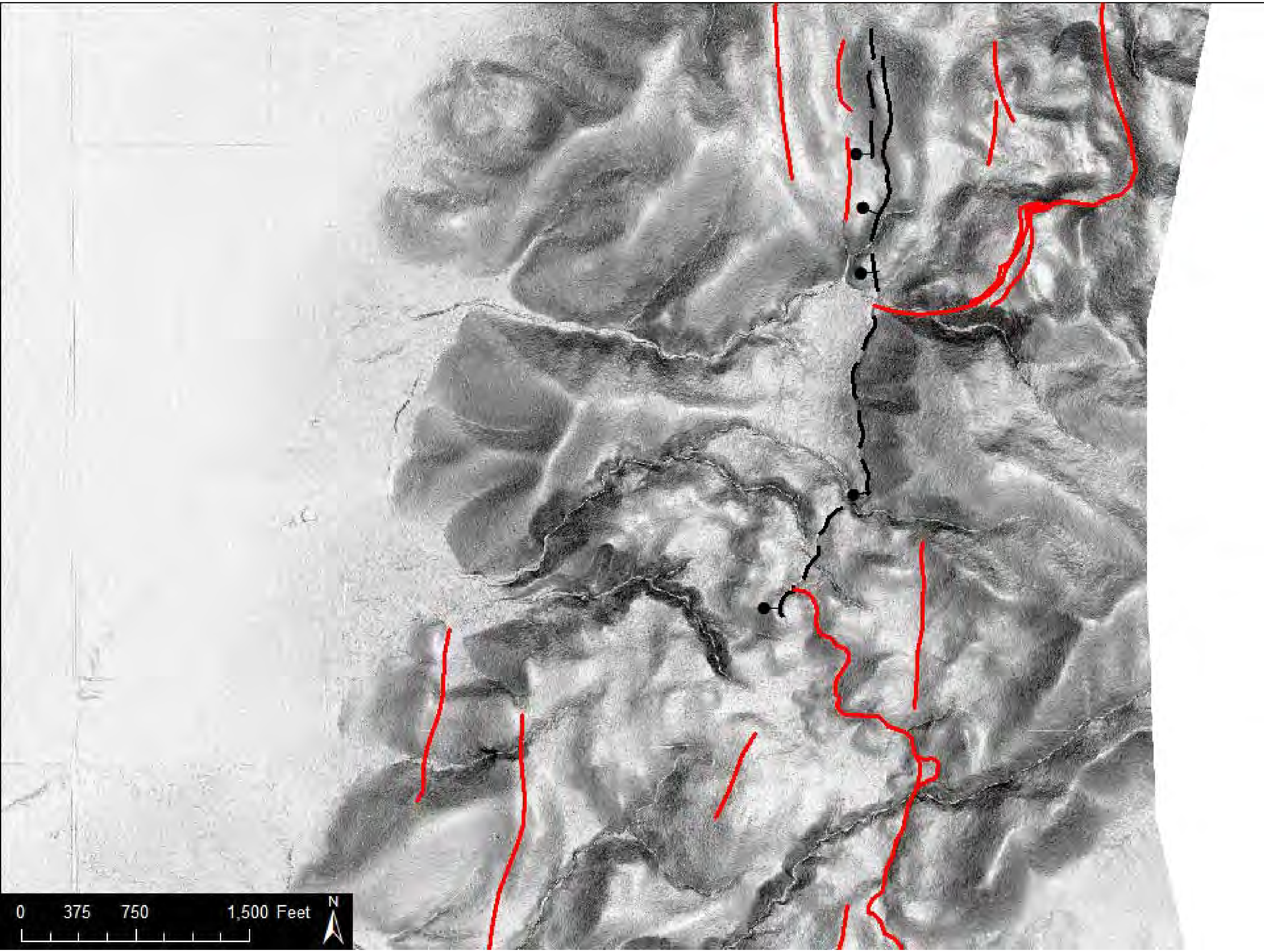
- Woodward-Lundgren & Associates 1970’s low-sun angle aerial photography
- Levan and Fayette Surficial Geologic Map, Hylland and Machette, 2008
- Existing geologic quad mapping
- Field reconnaissance of scarps

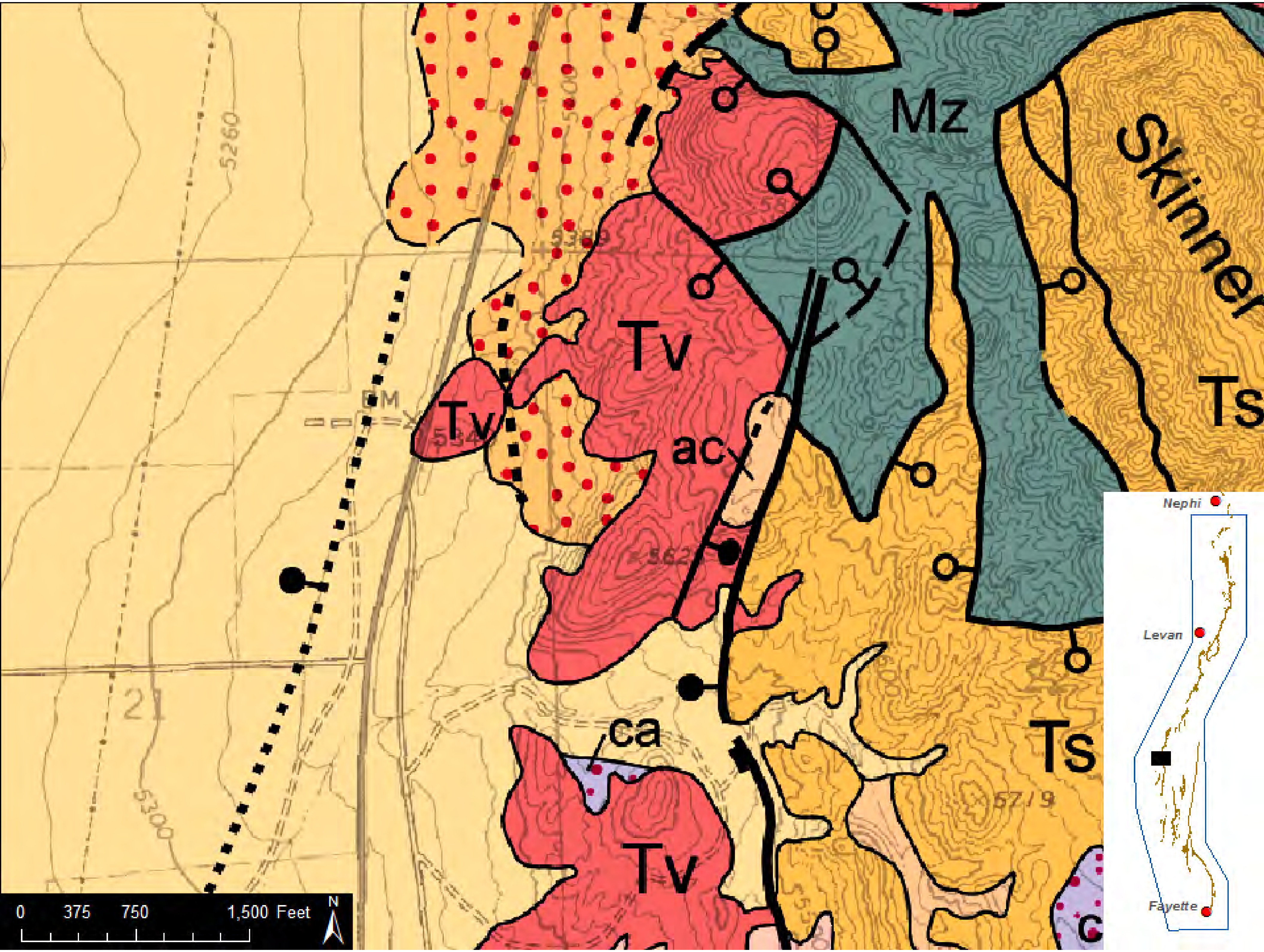


afy
afo
afy
Tv
afy
afo
fd
28
0 375 750 1,500 Feet
N
Nephi
Levan
Fayette


0
375
750
1,500 Feet
N

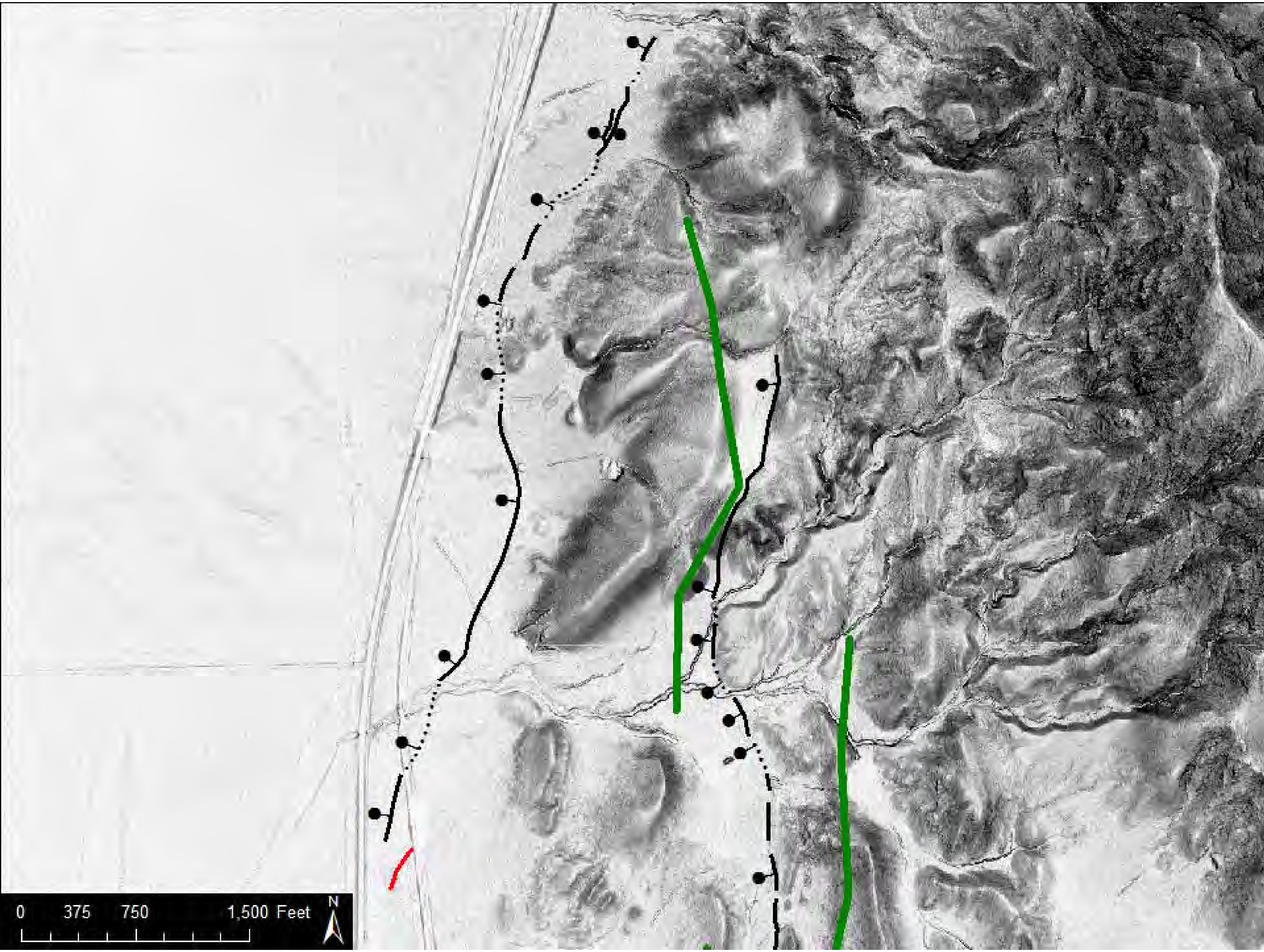

clsy
ac
afy
clso
Fourmile Creek Landslide Complex
0 375 750 1,500 Feet
N
Nephi
Levan
Fayette

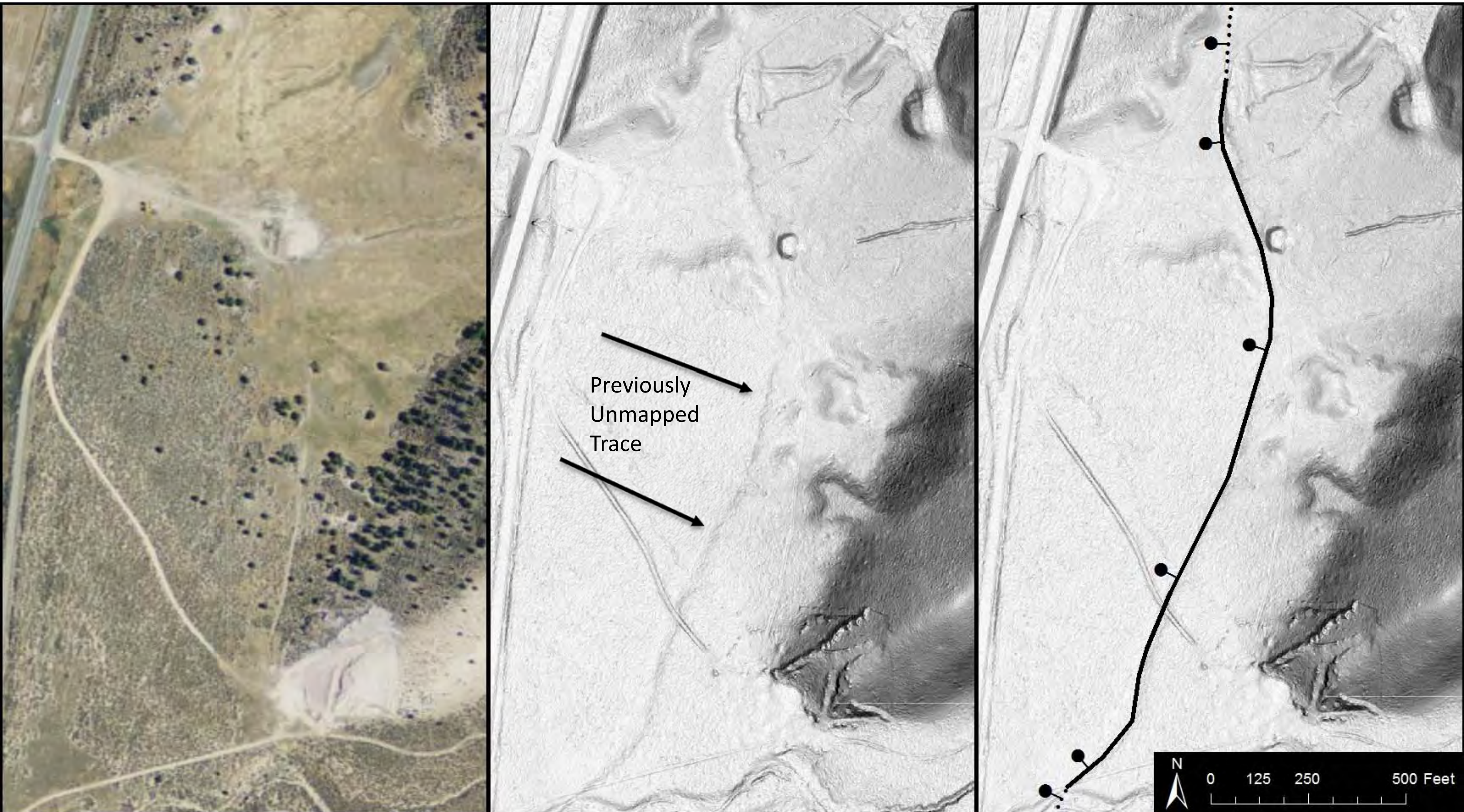

0 375 750 1,500 Feet
N



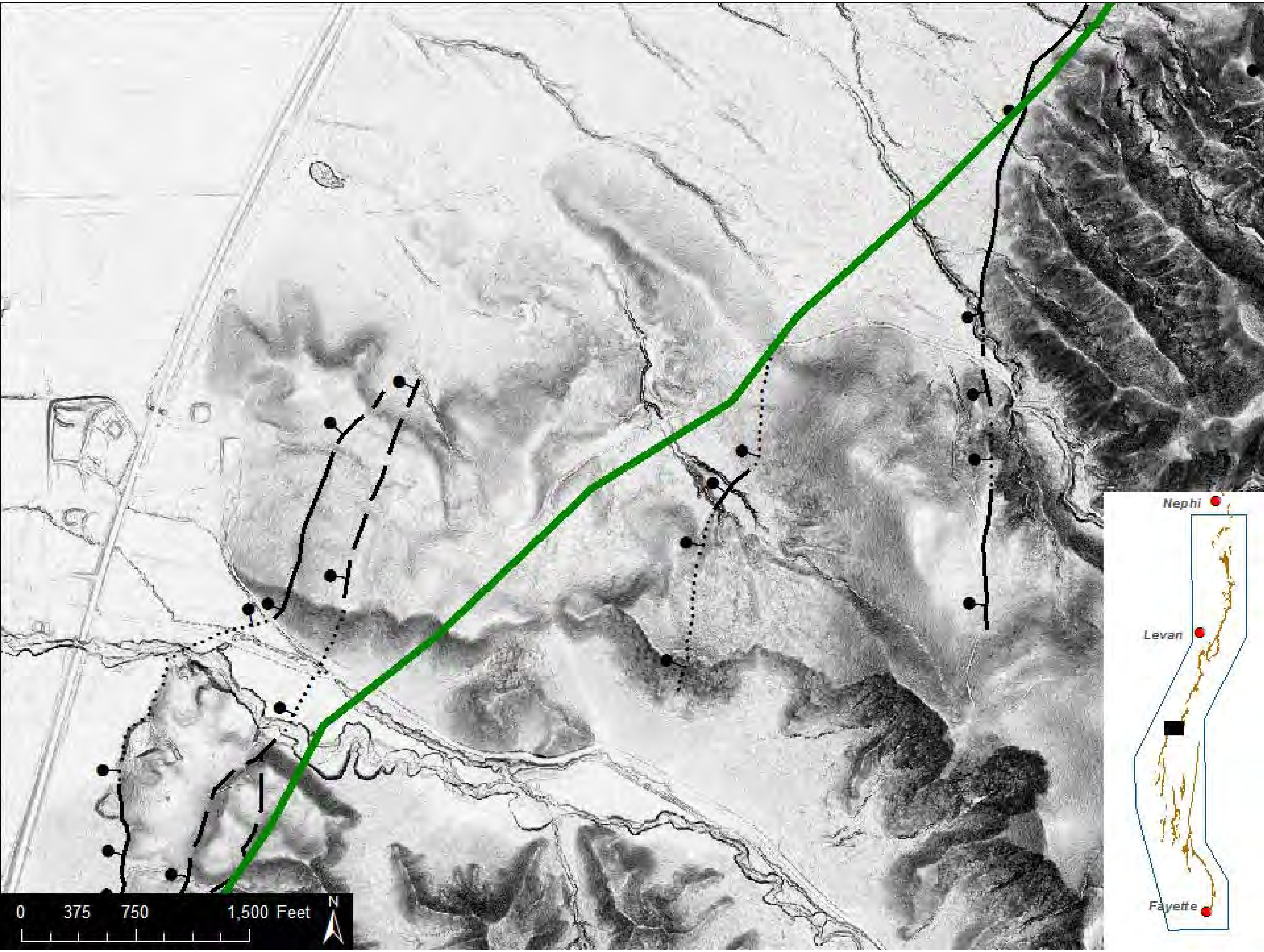
Mz
Skinner
Ts
Tv
ac
ca
Ts
Tv
Tv
Ts
c
5260
5300
5389
5534
5623
5779
21
BM
0
375
750
1,500 Feet
N
Nephi
Levan
Fayette


0 375 750 1,500 Feet
N

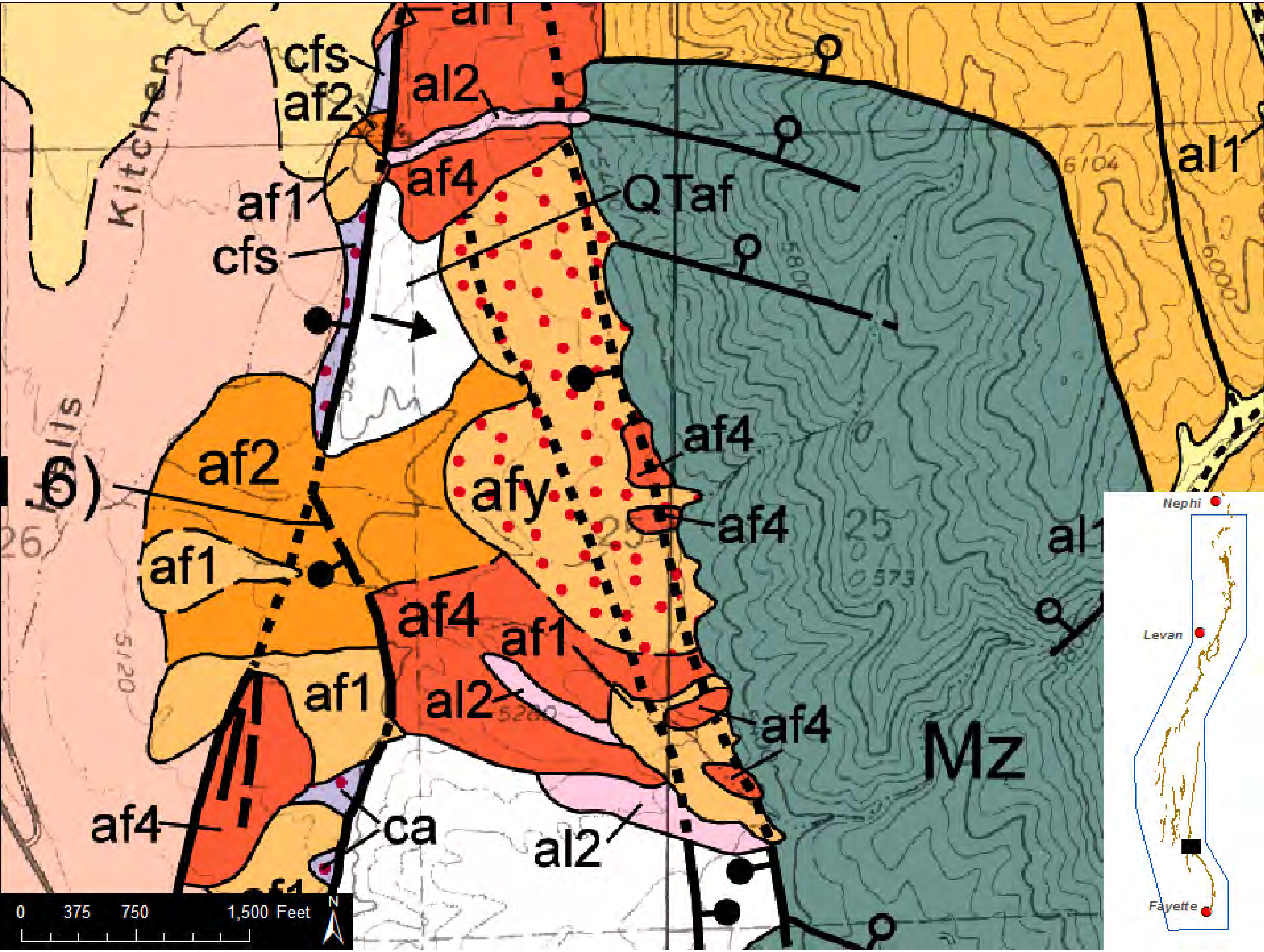

0
375
750
1,500 Feet
N

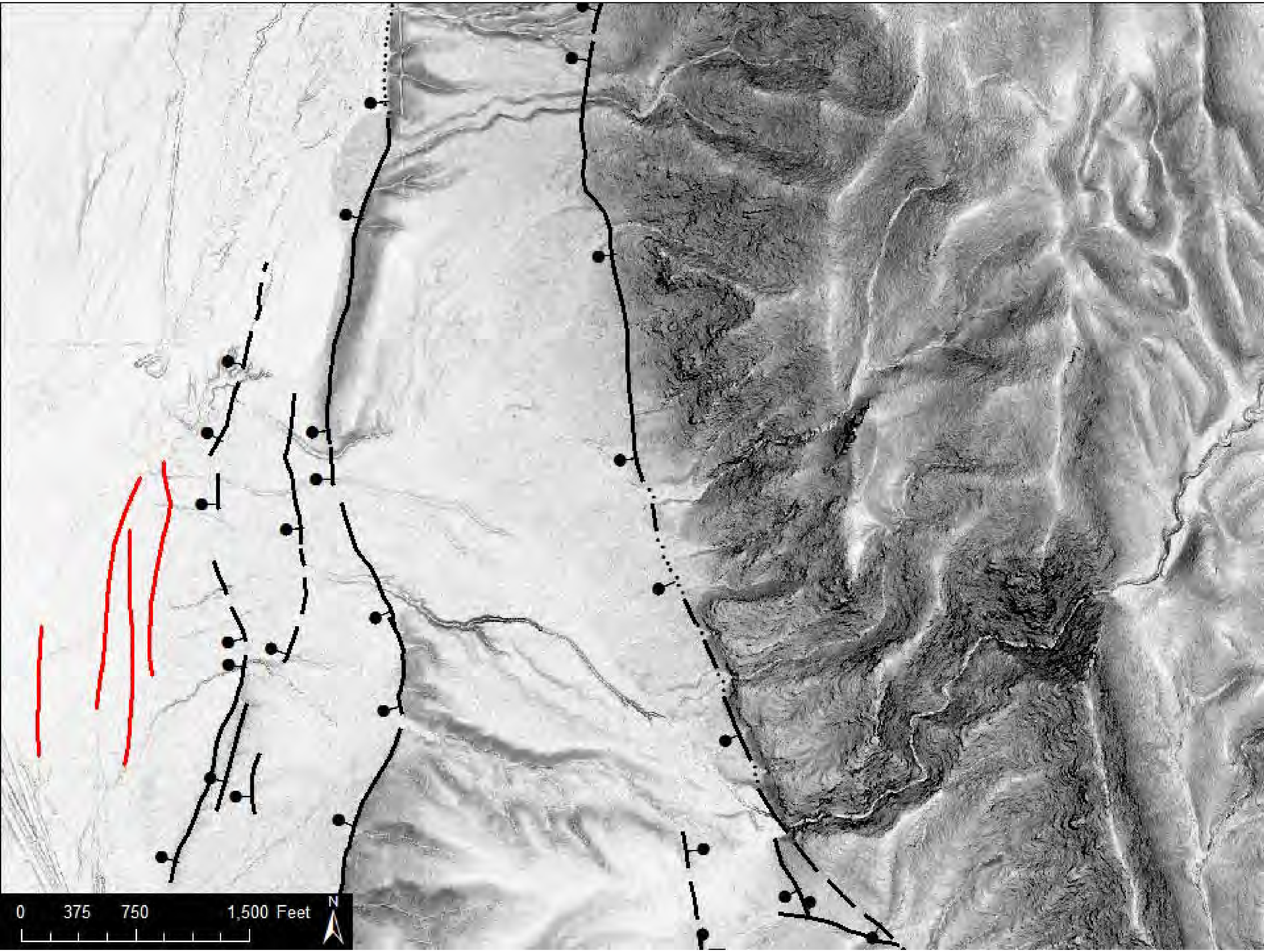


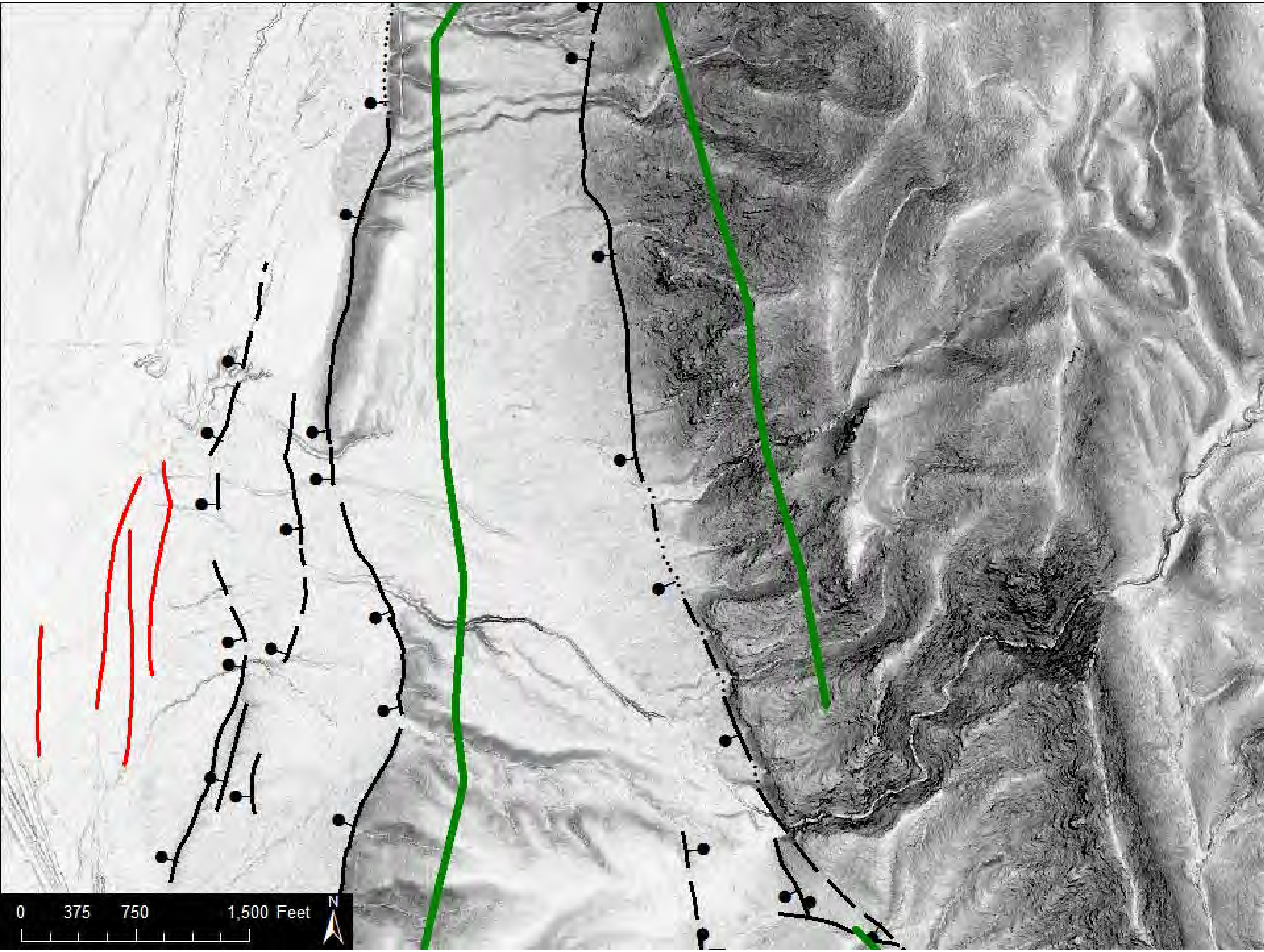
New Fault Trace Mapping



0 375 750 1,500 Feet
N
Nephi
Levan
Fayette

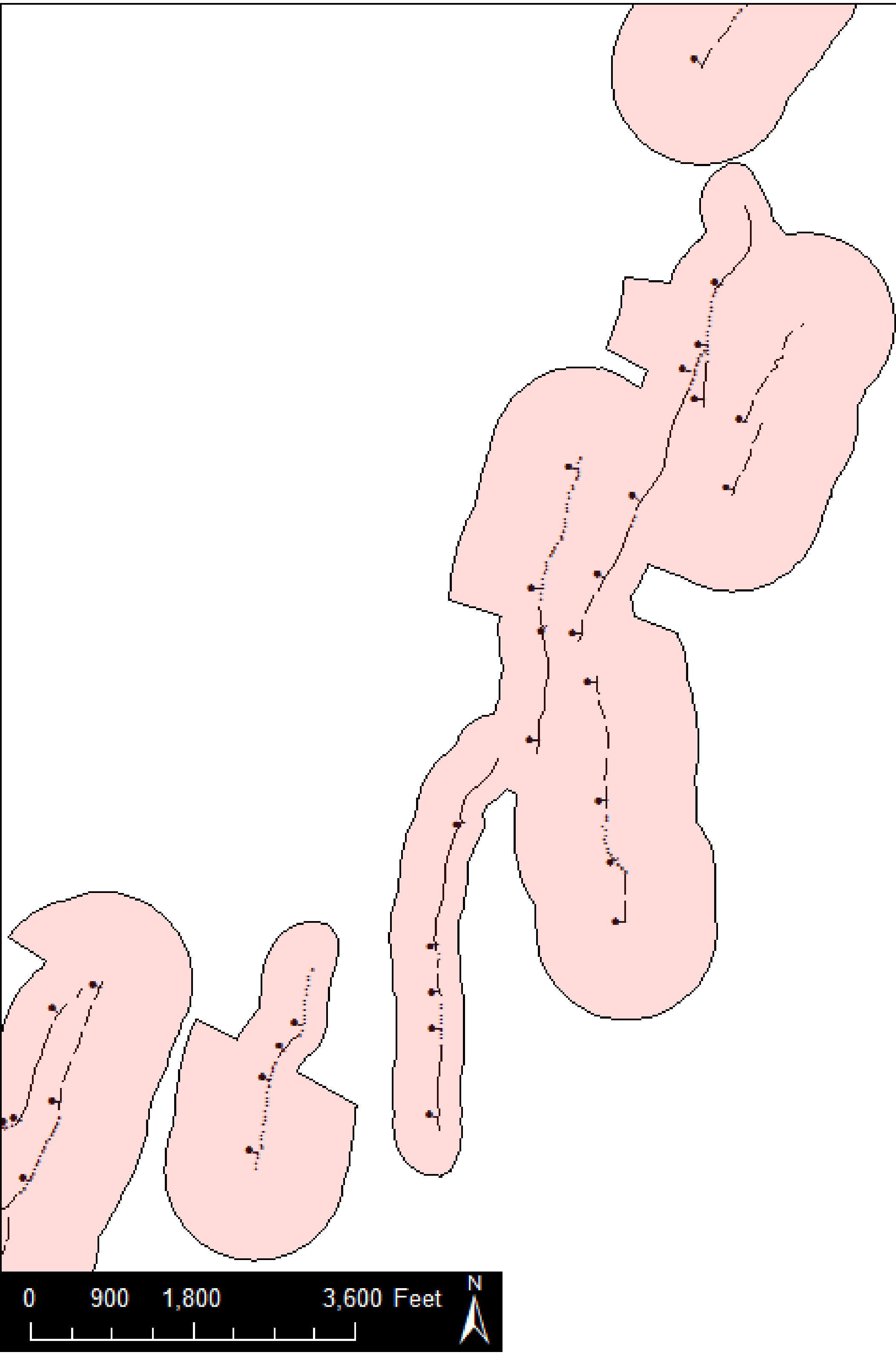

cfs
af2
al2
af4
af1
cfs
QTaf
al1
af2
afy
af4
af4
af1
25
al1
af4
af1
al2
af1
af4
Mz
af4
ca
al2
0 375 750 1,500 Feet
N
Nephi
Levan
Fayette
Kitchen

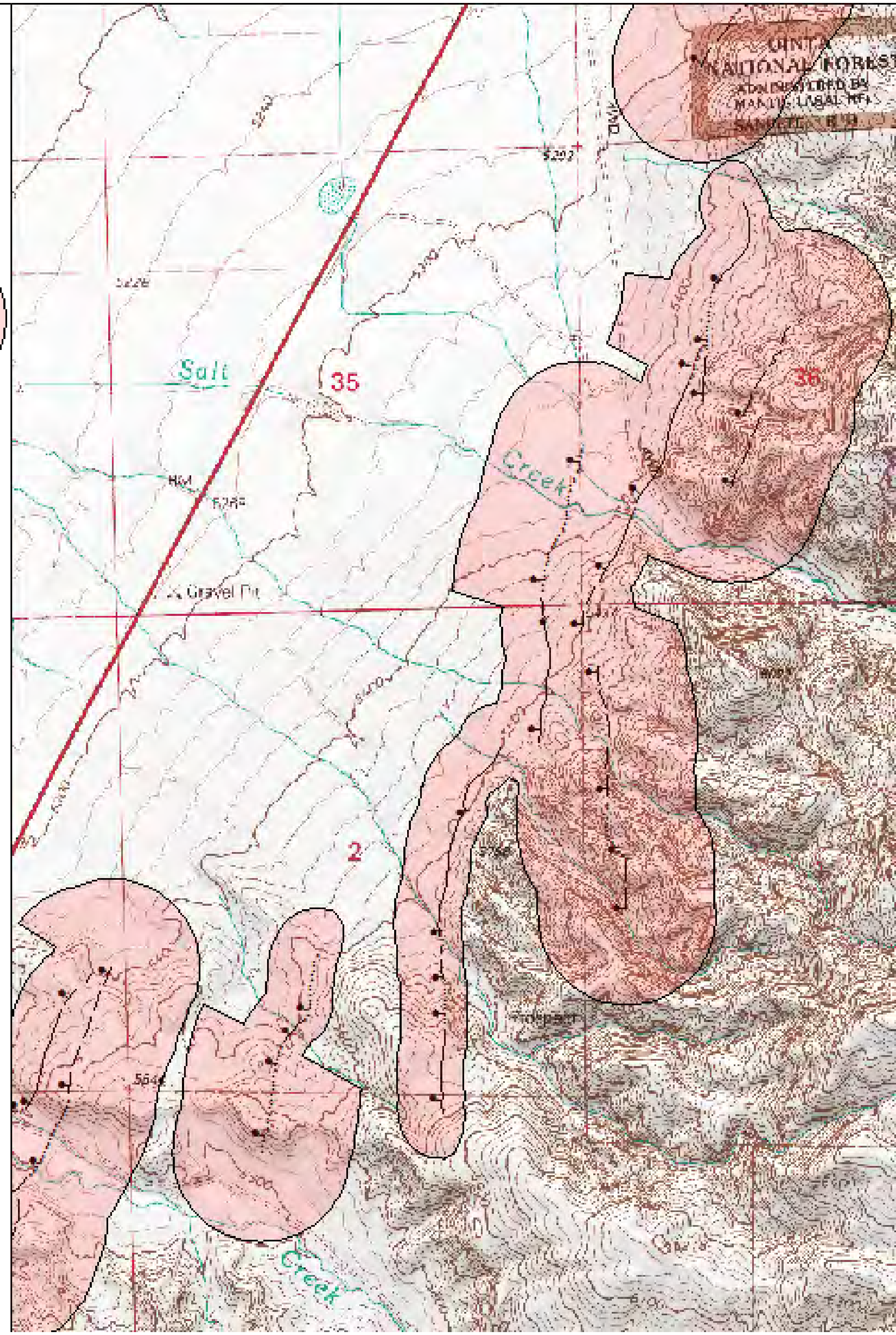

0 375 750 1,500 Feet
N


0 375 750 1,500 Feet
N

Special Study Zones

- For well-located faults, zone extends from the trace of the fault 250 feet on footwall, and 500 feet on hanging wall
- For moderately well-located and inferred faults, zone extends 1000 feet on either side of fault trace
- Mapper must use geologic knowledge and judgment while creating zones


0 900 1,800 3,600 Feet
N

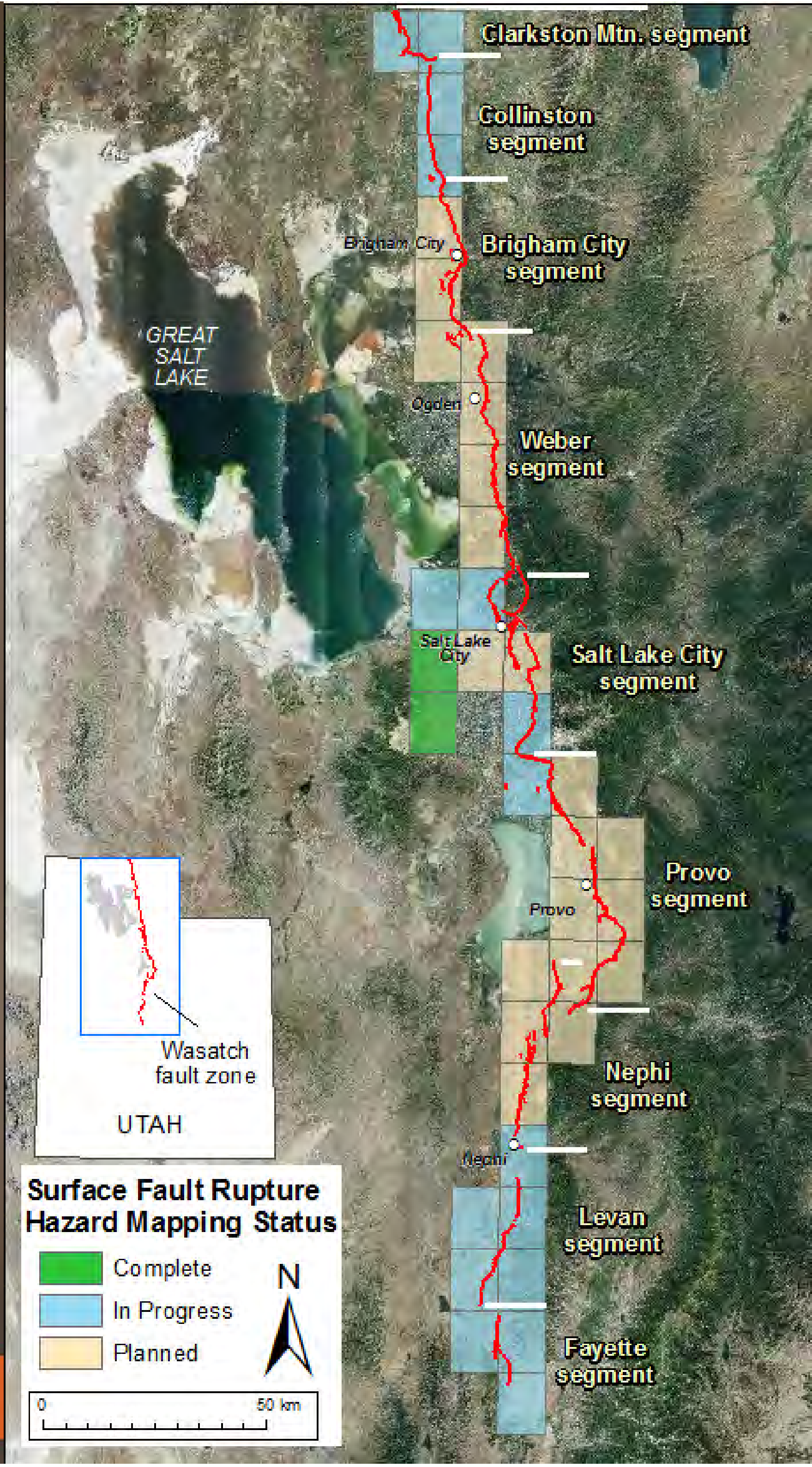

Salt
Creek
35
36
2
BM
Gravel Pit
Creek

Results

- Refined mapping of the Levan and Fayette segments of the Wasatch Fault Zone
- Added new fault traces as well as refined existing traces and complex faulting zones
- All new mapping will eventually be added to Utah Quaternary Fault Database
- Created a set of Surface Fault Rupture hazard maps for the southernmost Wasatch Fault – an area that will likely experience population growth in the future

Future Fault Mapping

- Continue working north from Levan – Nephi segment next
- Scott Bennett (USGS) – Provo segment fault trace mapping
- Adam McKean (UGS) – Salt Lake City & Brigham City segments fault trace mapping
- Kimm Harty and Adam McKean (UGS) – Collinston & Clarkston Mtn. segments fault trace mapping



UTAH GEOLOGICAL SURVEY

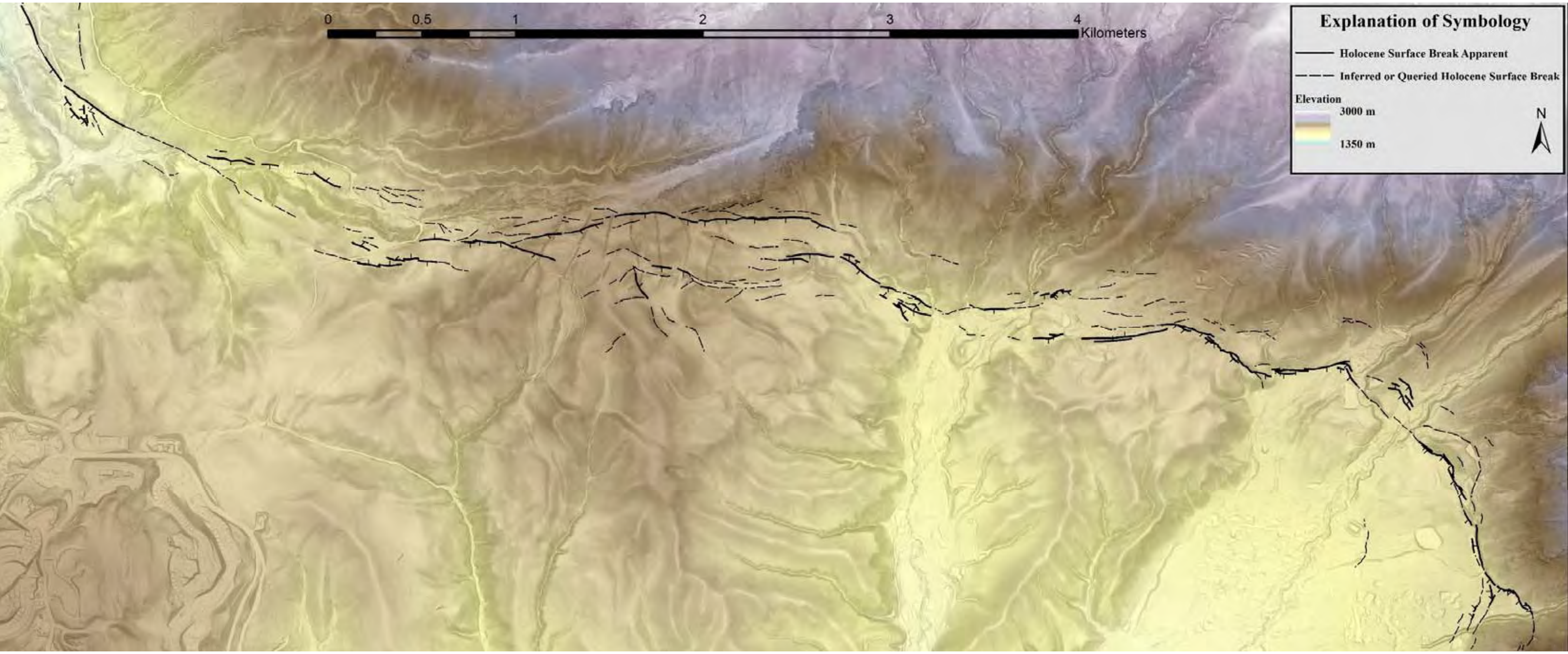
Summary

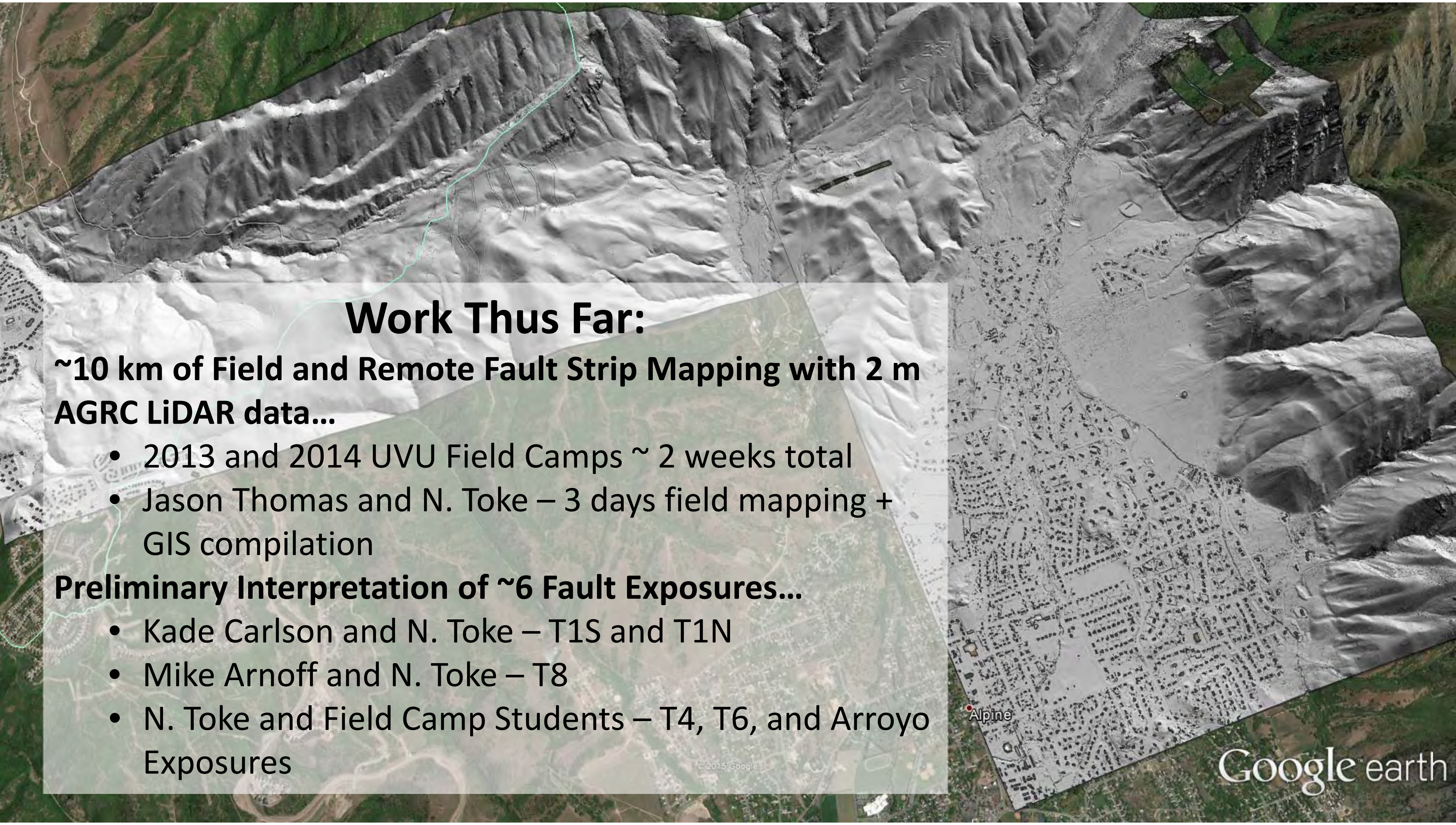
- 0.5-meter LiDAR data is a great tool for high-resolution mapping of fault scarps
- Allows us to more accurately map fault traces and generate better Hazard Maps for future development and planning

Fault strip mapping and continued exploration of existing Traverse Ridge Salient trenches and natural exposures along the Wasatch Fault

UTAH VALLEY UVU UNIVERSITY Department of EARTH SCIENCE

Utah Valley University's 2013-2014 summer field classes
N. Toké, M. Arnoff, K. Carlson, M. Bunds, and J. Thomas.





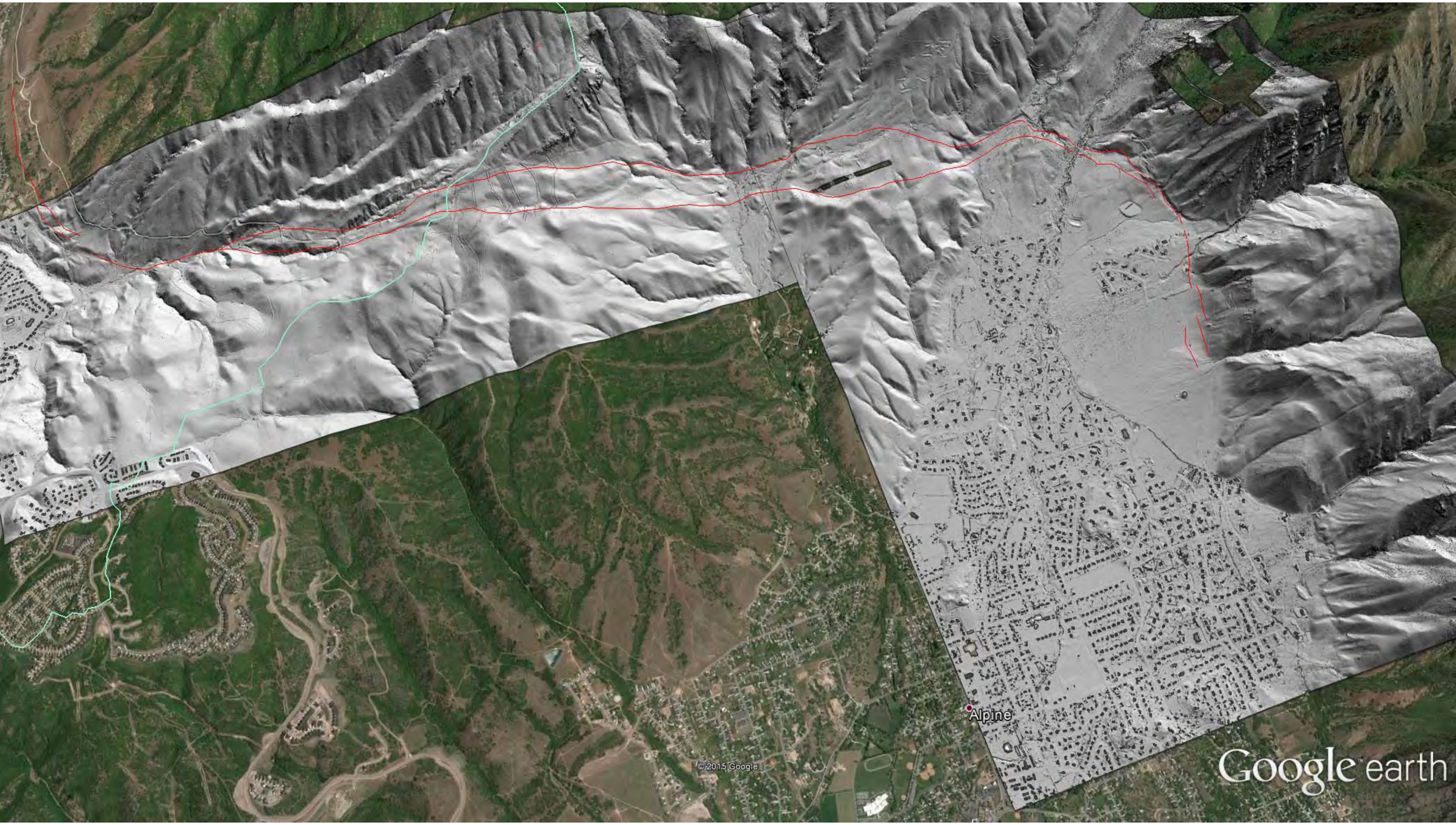
Work Thus Far:

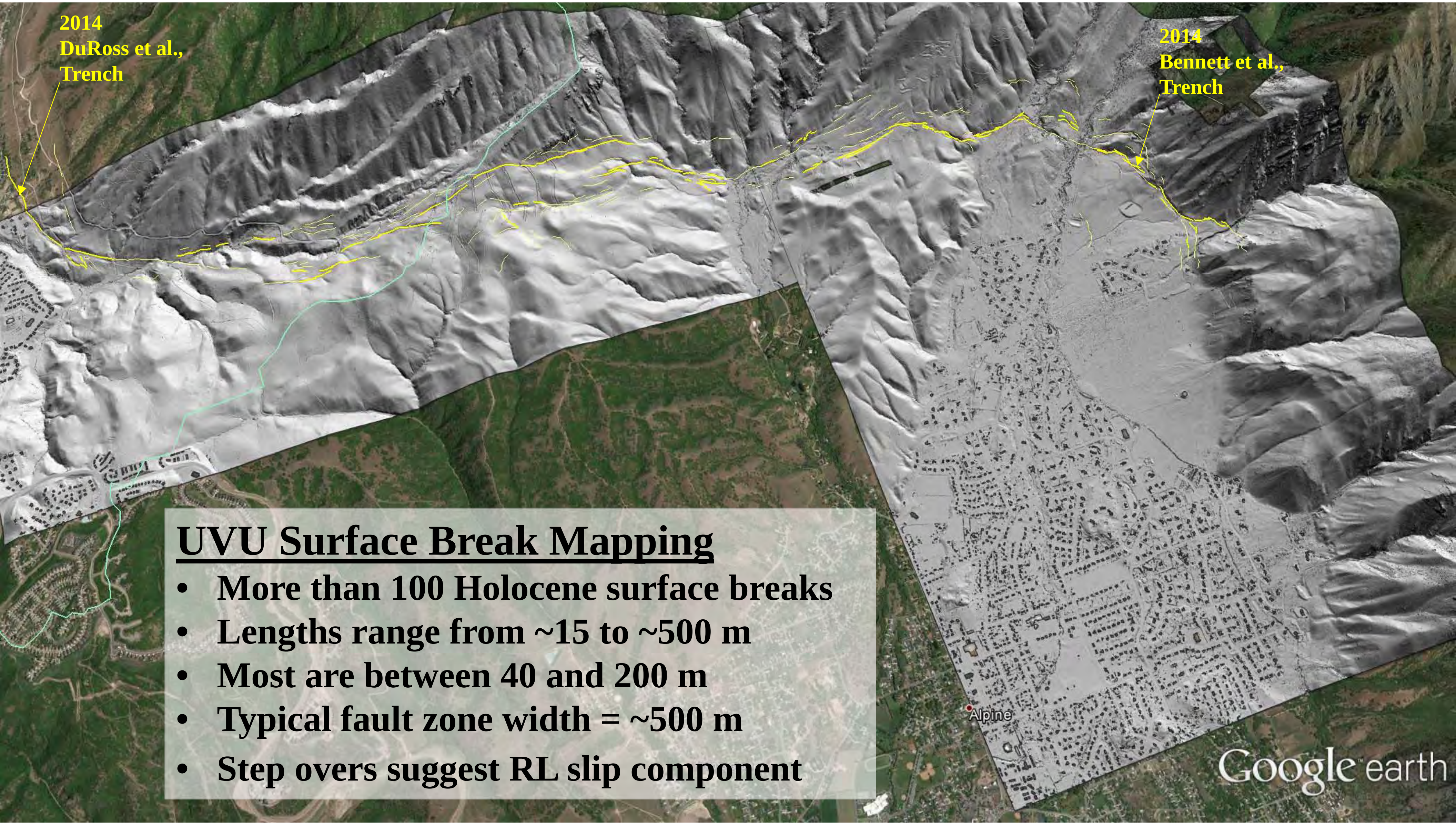
~10 km of Field and Remote Fault Strip Mapping with 2 m AGRC LiDAR data…

- 2013 and 2014 UVU Field Camps ~ 2 weeks total
- Jason Thomas and N. Toke – 3 days field mapping + GIS compilation

Preliminary Interpretation of ~6 Fault Exposures…

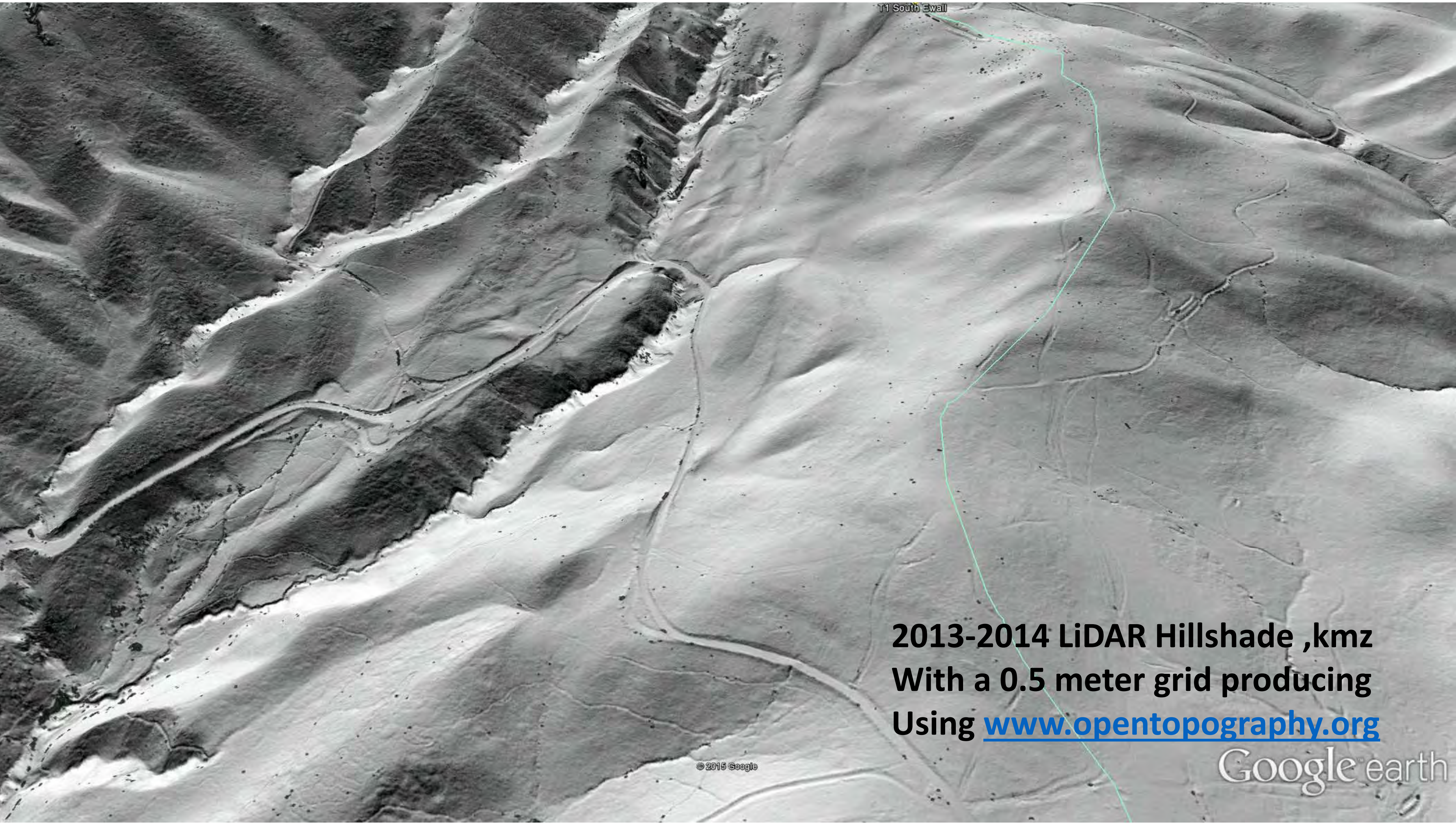
- Kade Carlson and N. Toke – T1S and T1N
- Mike Arnoff and N. Toke – T8
- N. Toke and Field Camp Students – T4, T6, and Arroyo Exposures

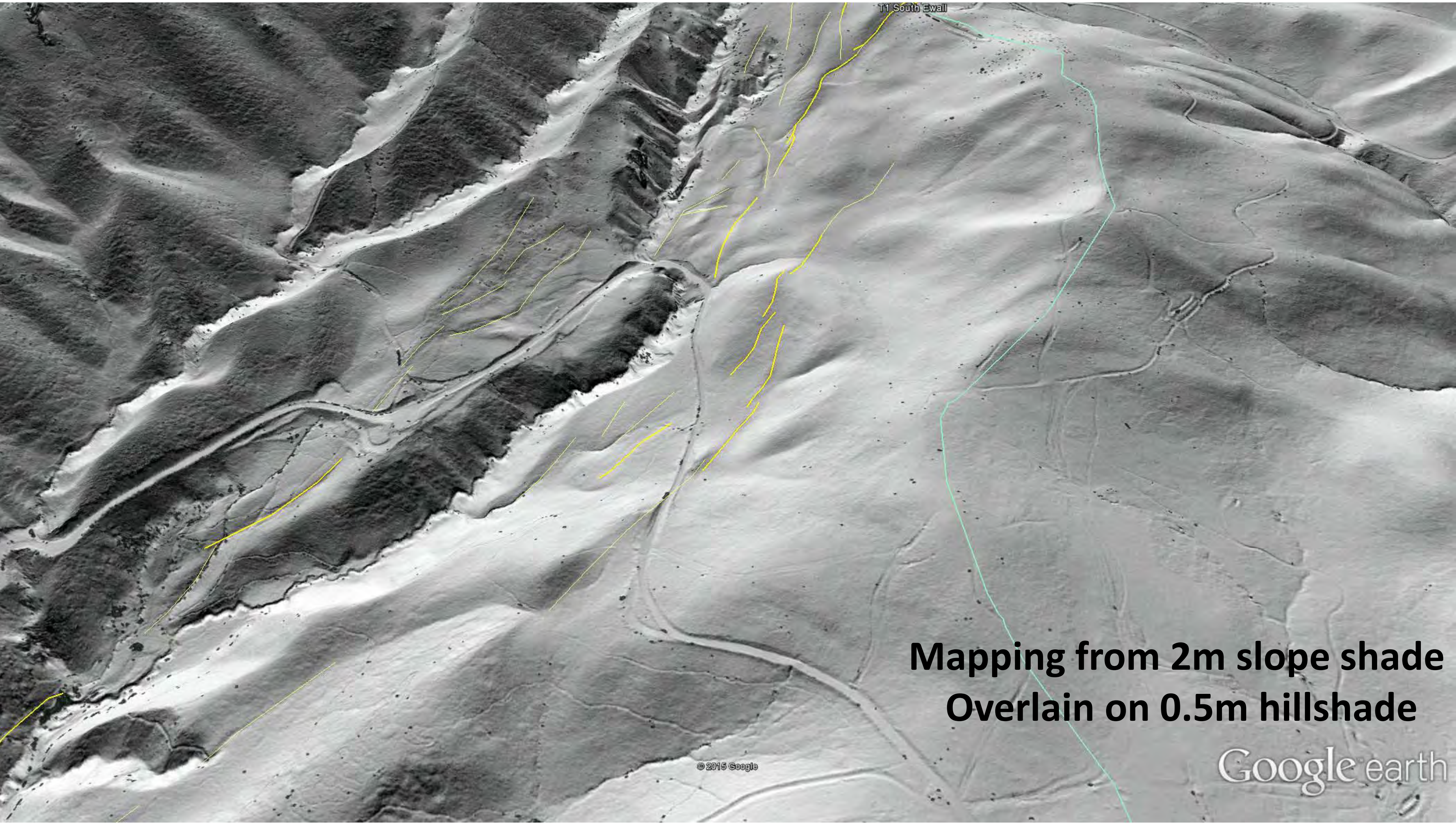

Alpine
©2015 Google
Google earth

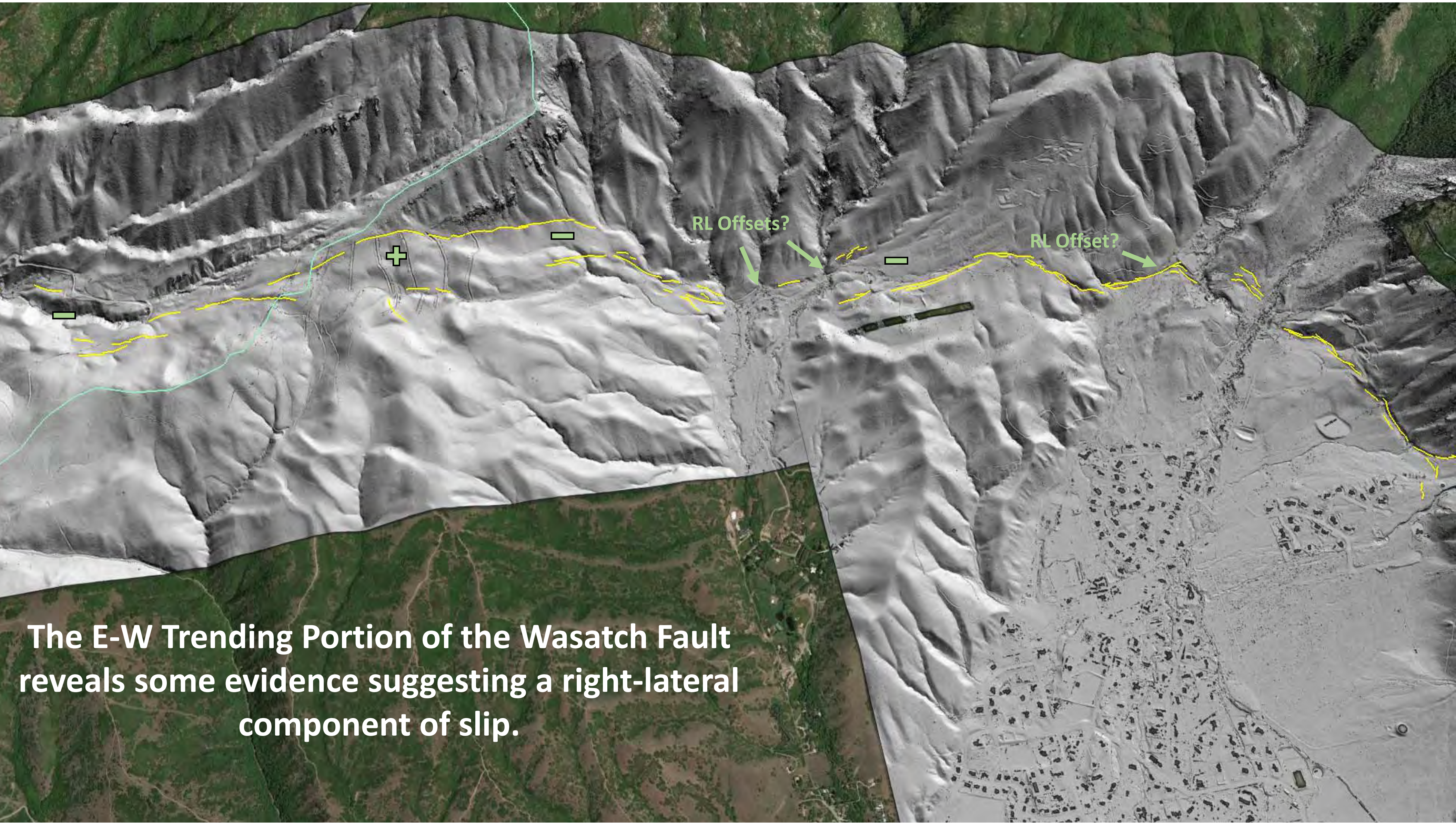


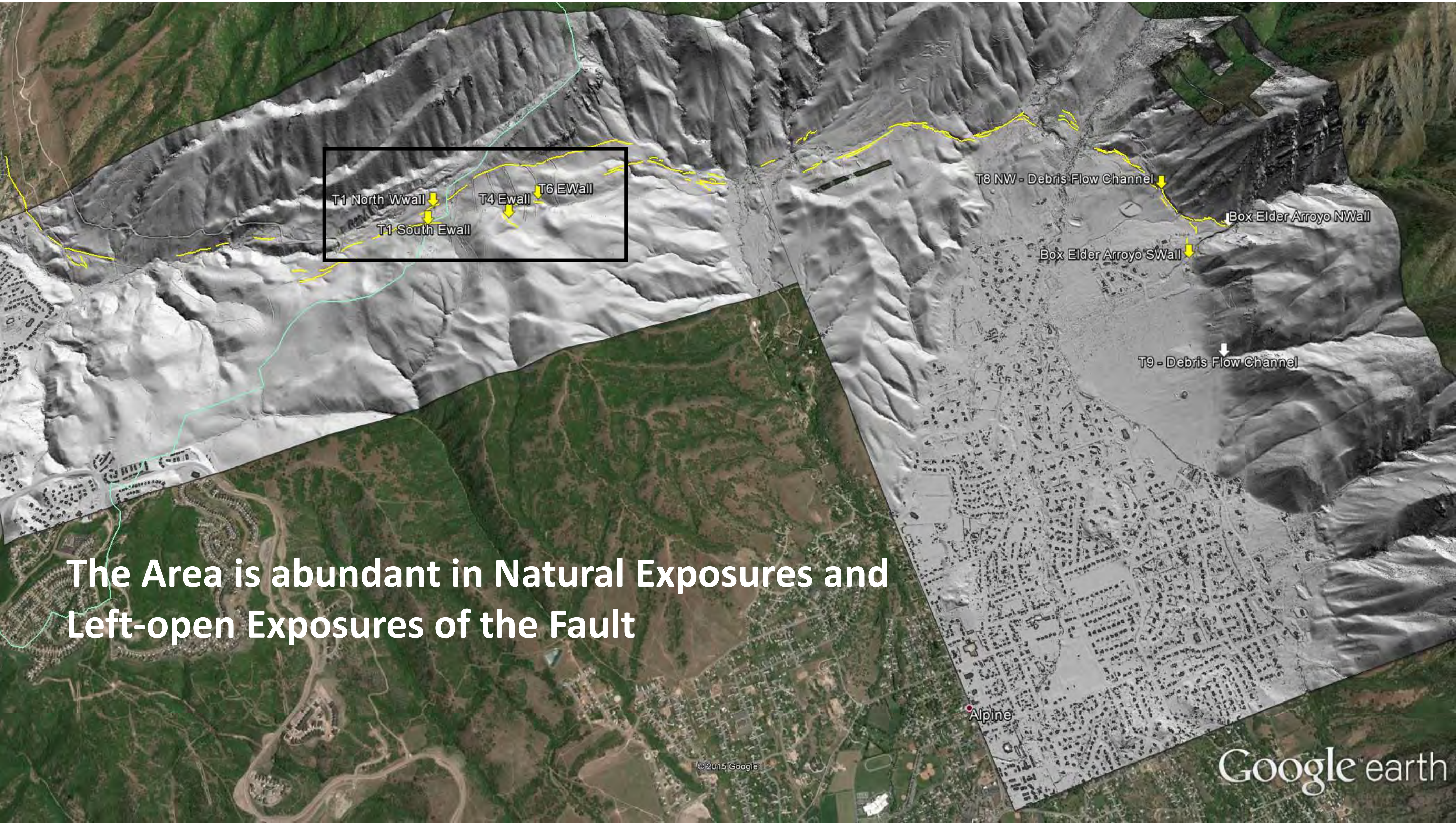
UVU Surface Break Mapping

- More than 100 Holocene surface breaks
- Lengths range from ~15 to ~500 m
- Most are between 40 and 200 m
- Typical fault zone width = ~500 m
- Step overs suggest RL slip component

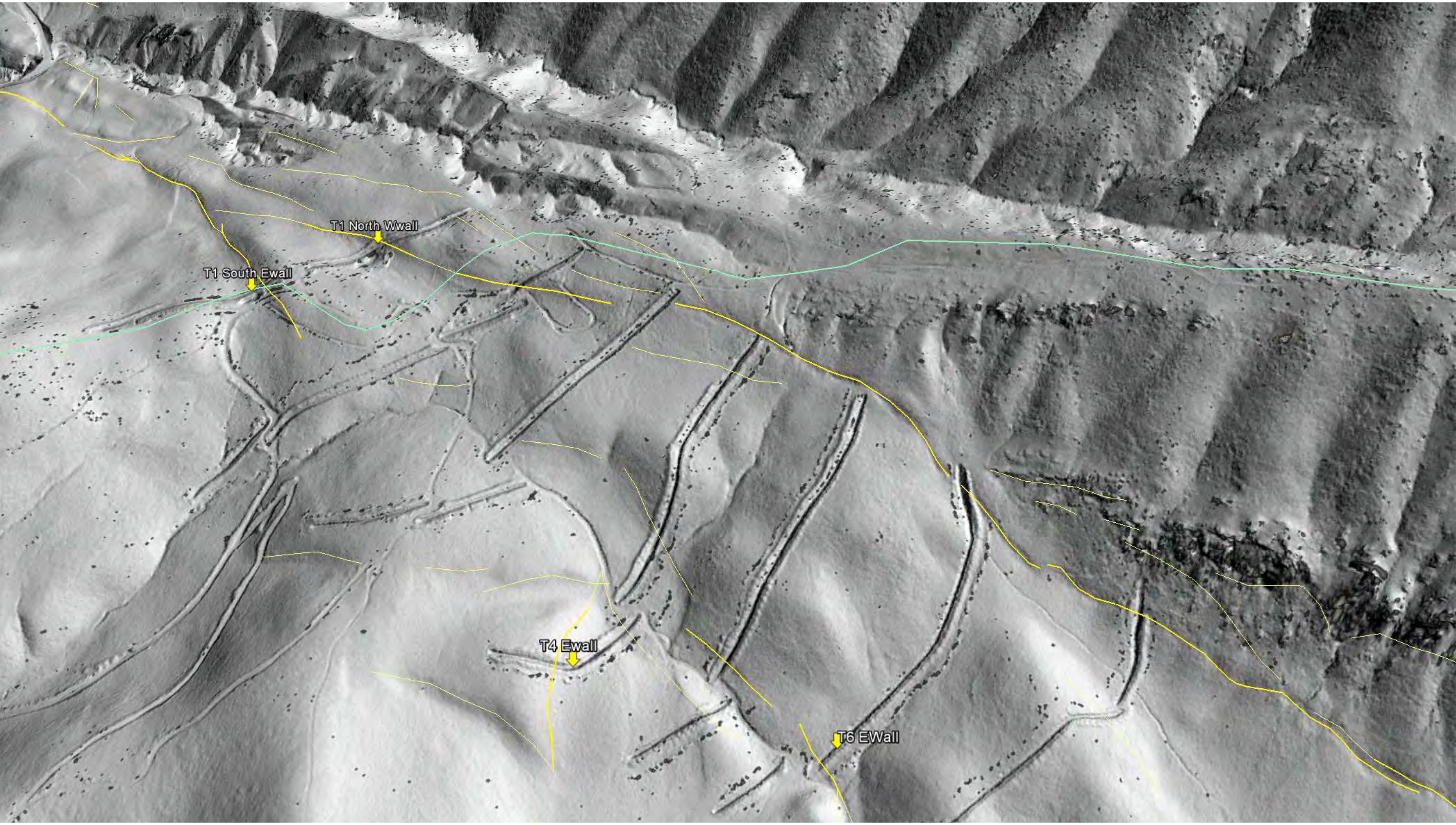

T1 South Ewall
2013-2014 LiDAR Hillshade ,kmz
With a 0.5 meter grid producing
Using www.opentopography.org
© 2015 Google
Google earth


T1 South Ewall
Mapping from 2m slope shade
Overlain on 0.5m hillshade
© 2015 Google
Google earth


RL Offsets?
RL Offset?
The E-W Trending Portion of the Wasatch Fault reveals some evidence suggesting a right-lateral component of slip.

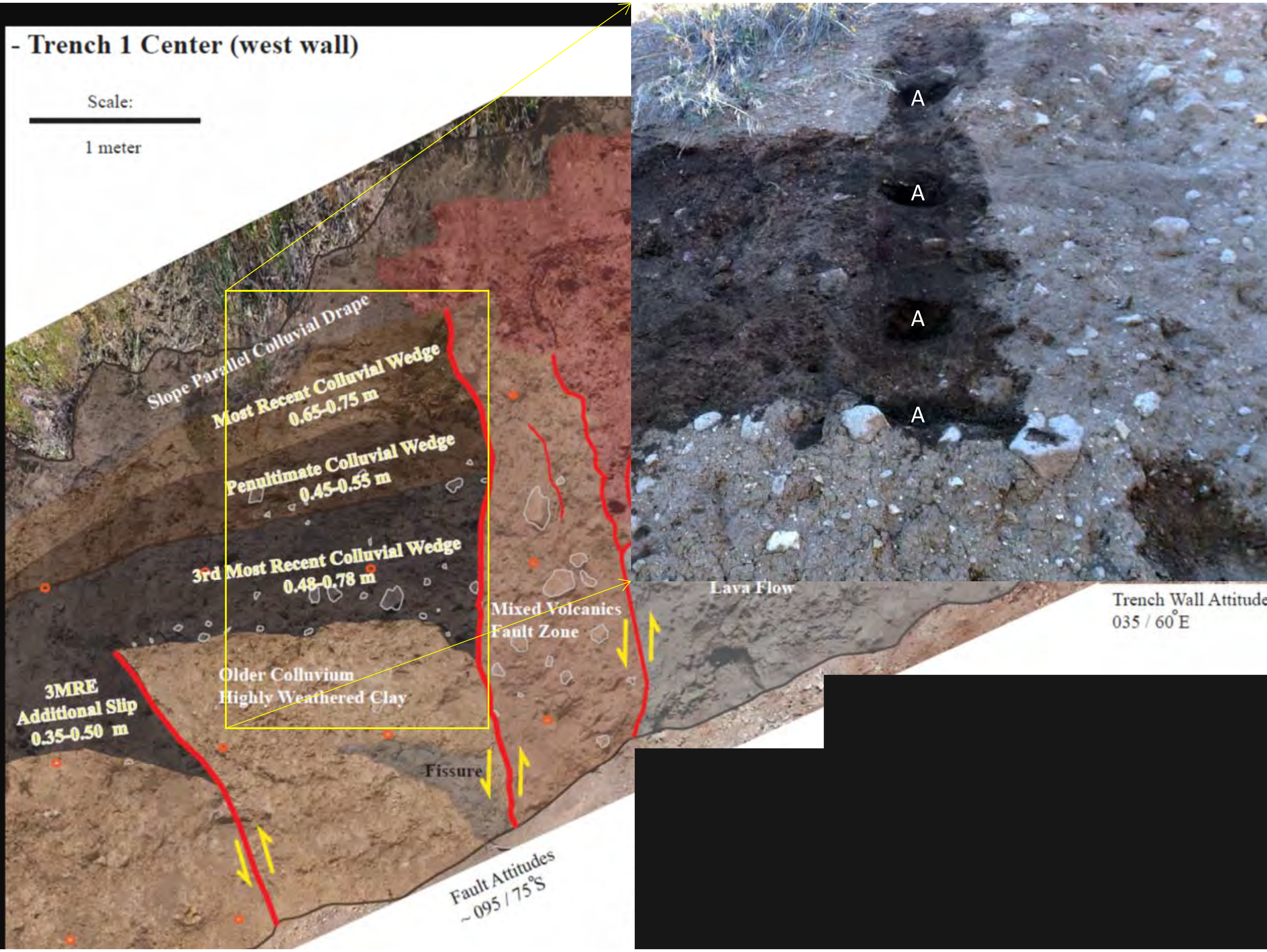


The Area is abundant in Natural Exposures and Left-open Exposures of the Fault

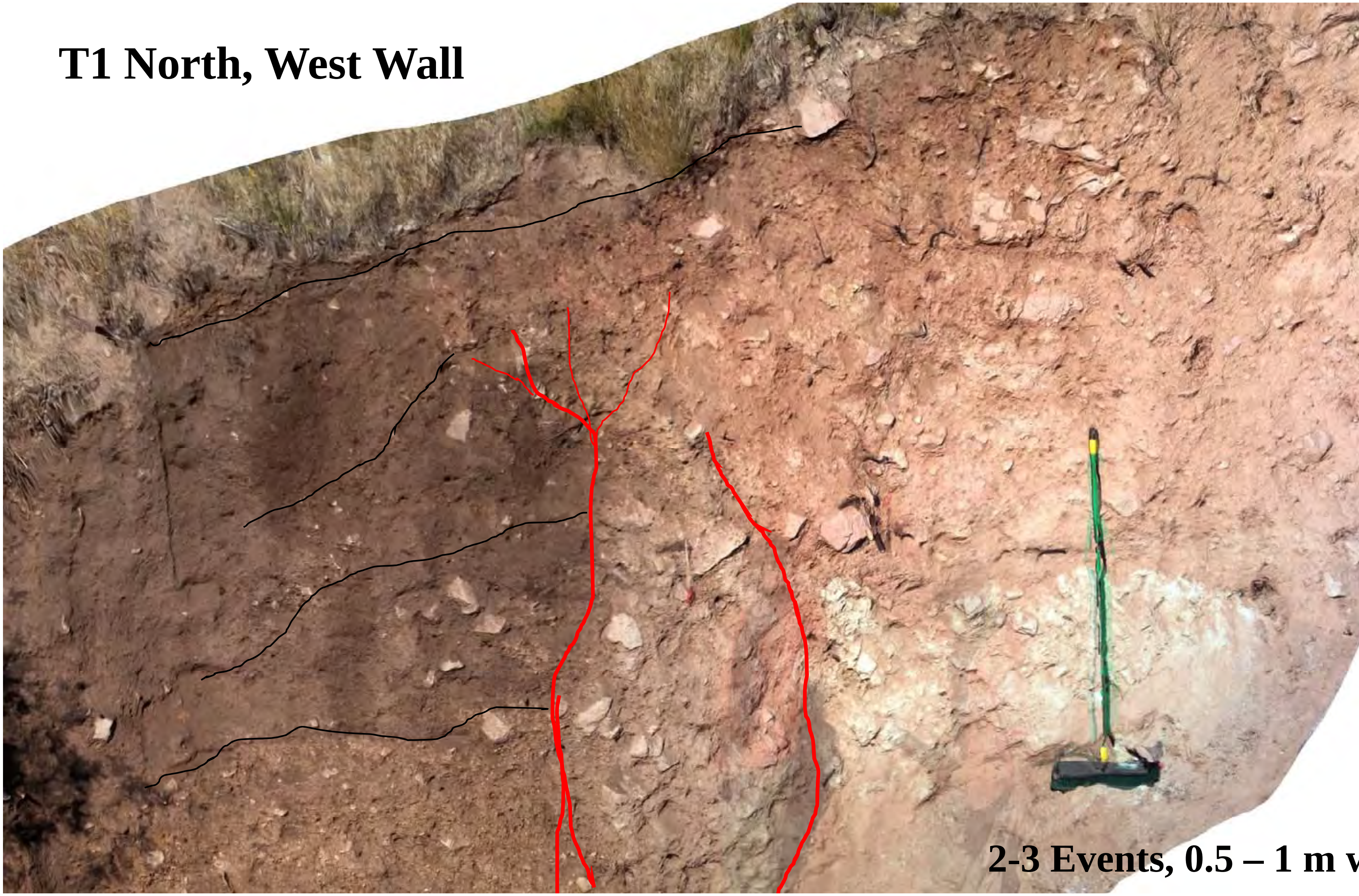


T1 North Wwall
T1 South Ewall
T4 Ewall
T6 EWall

T1 North, West Wall


- 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

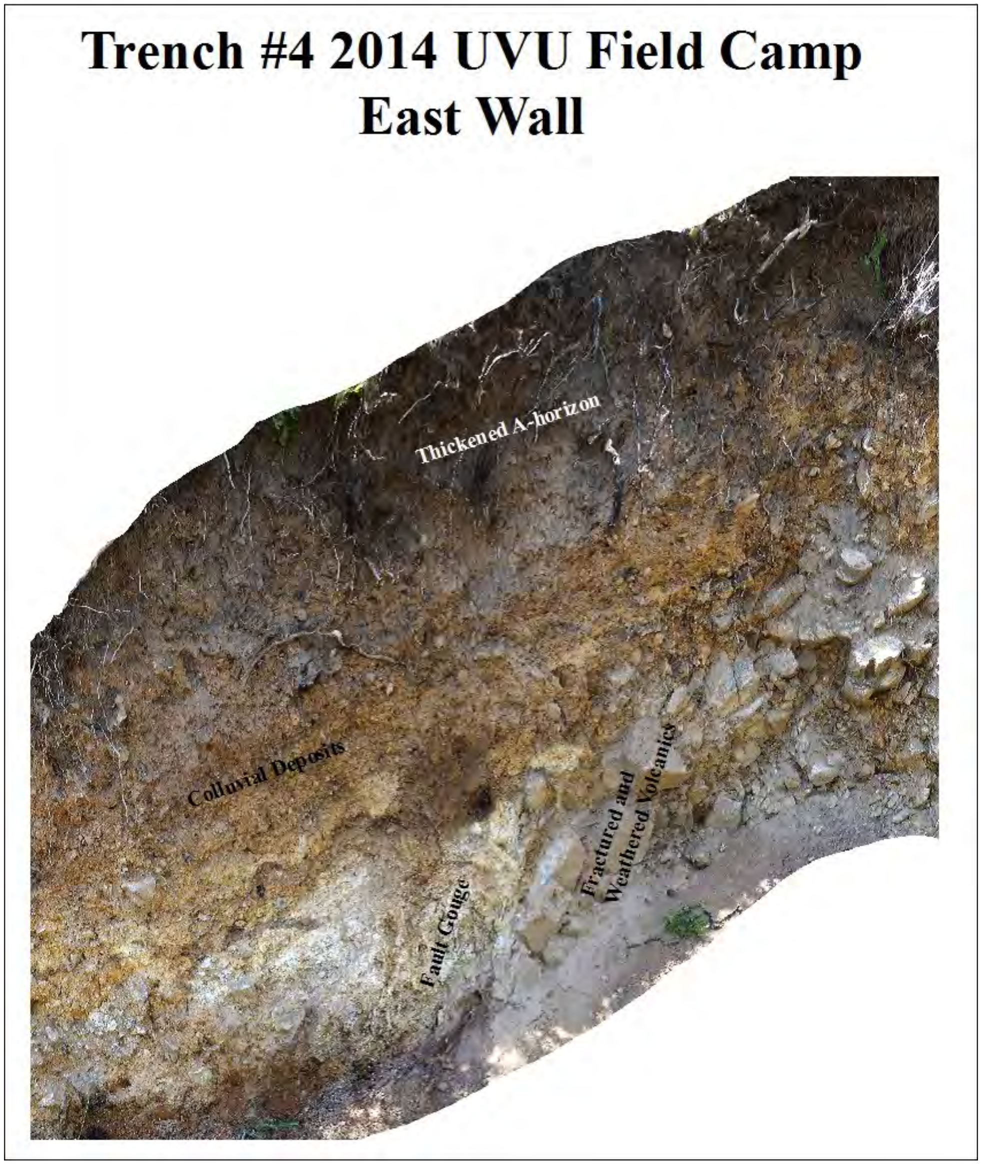
T1 North, West Wall



2-3 Events, 0.5 – 1 m wedges

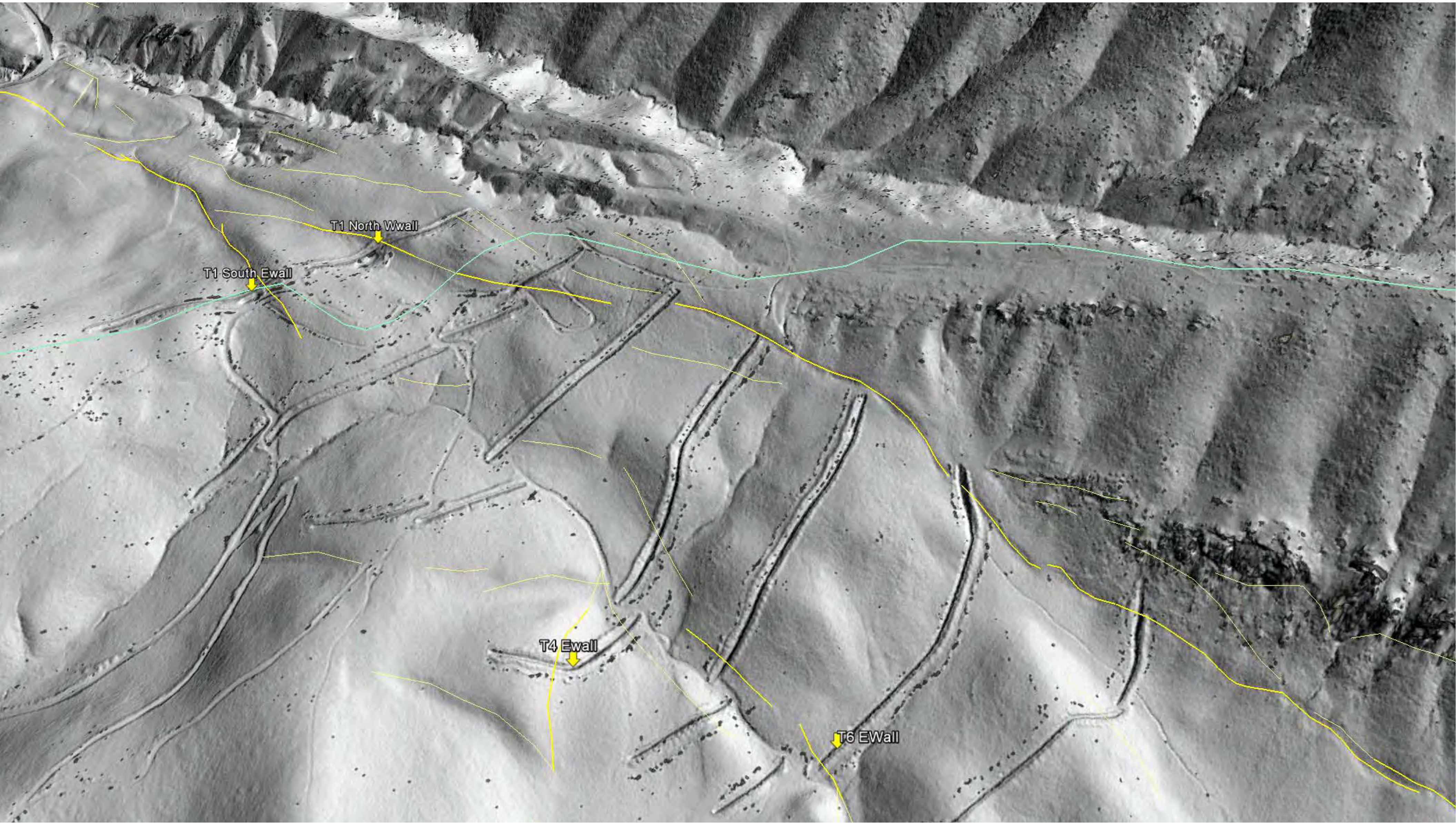
T1 South, East Wall

One Event with 1 - 1.5 m of displacement



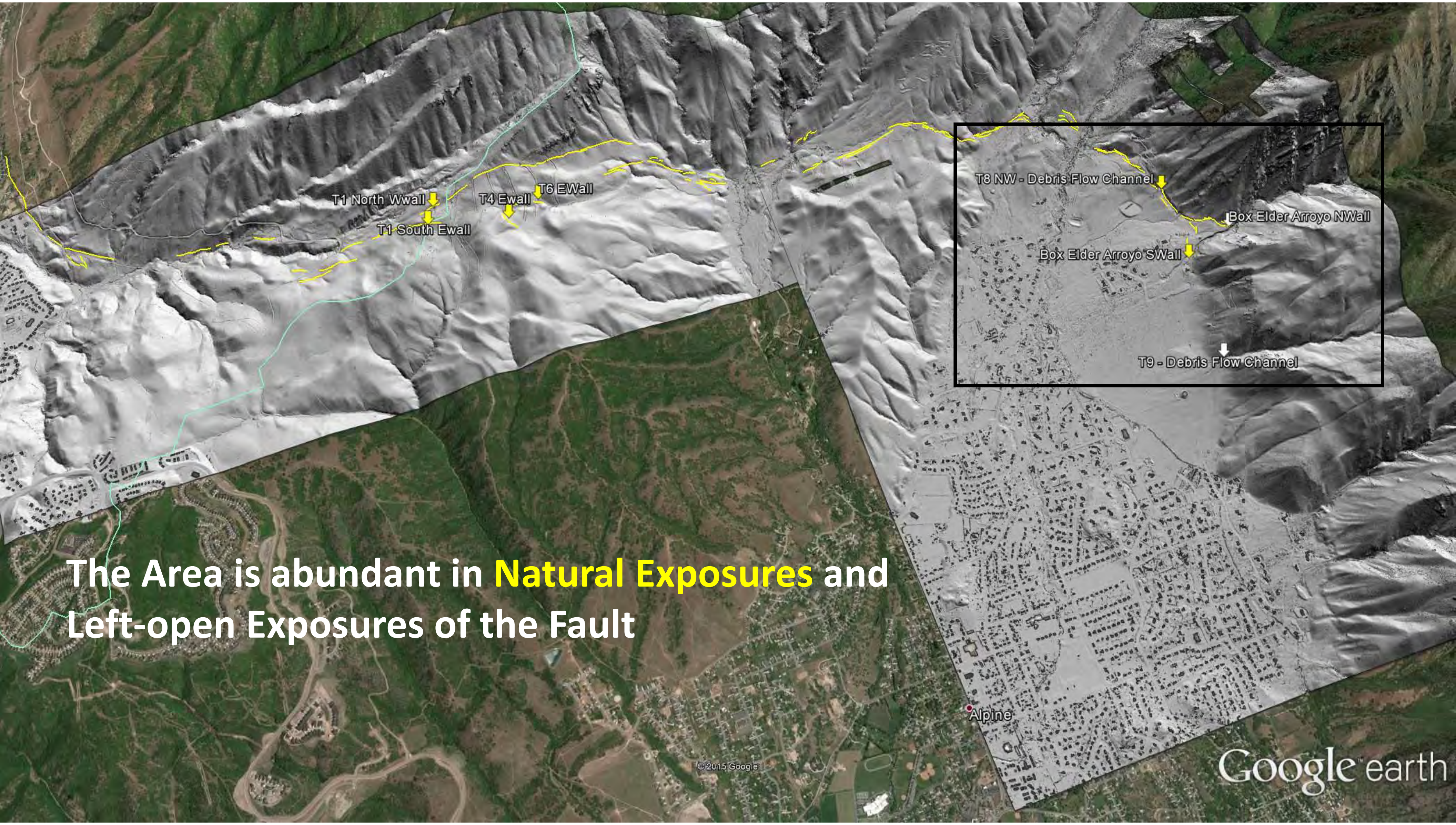
Evidence of Faulting

Fault Dip-Aligned Tertiary Volcanics
Fault Gouge with faulted fabric
Thickened present dayA-horizon
….1 Recent Event?

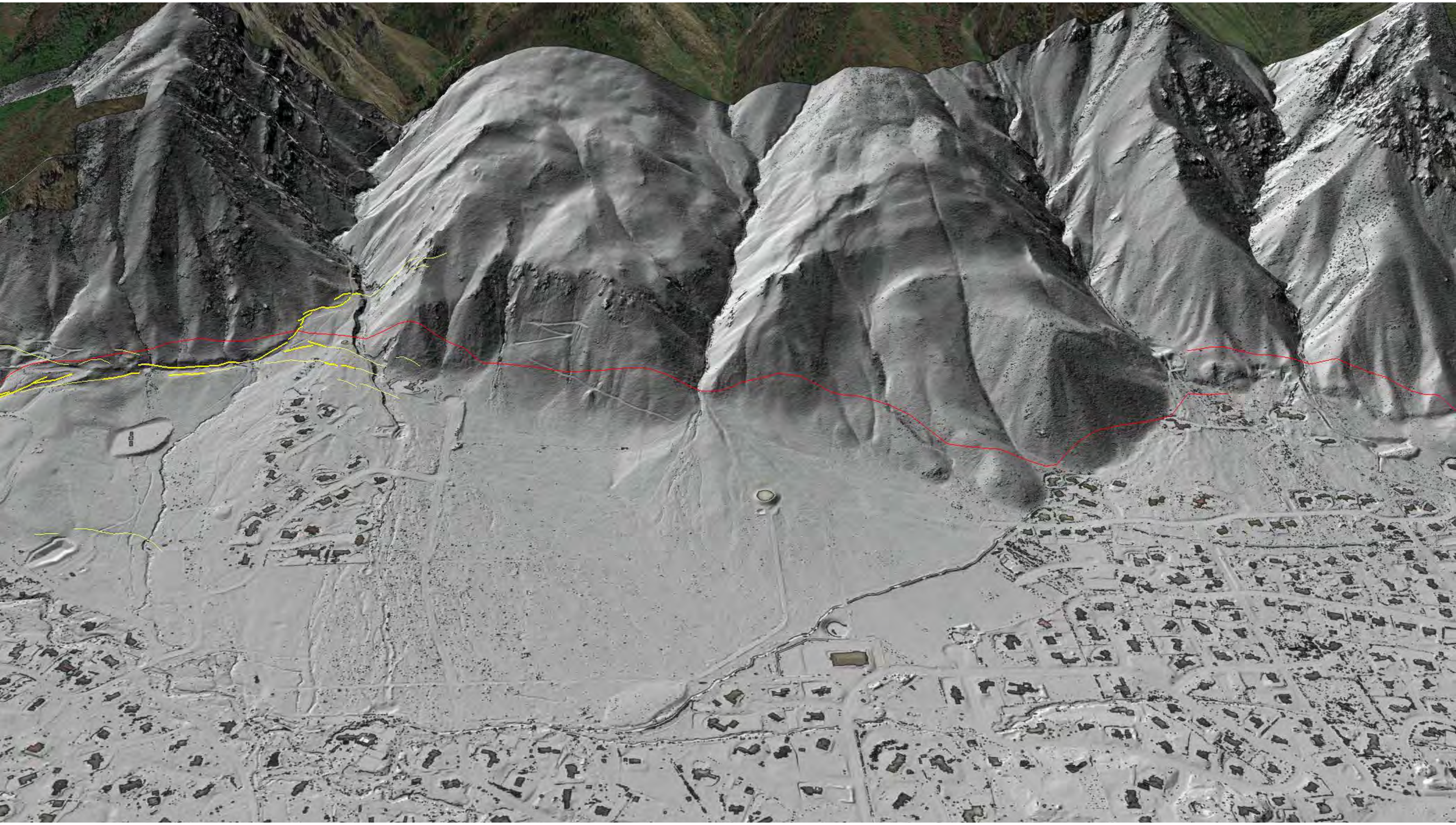

T1 North Wwall
T1 South Ewall
T4 Ewall
T6 EWall

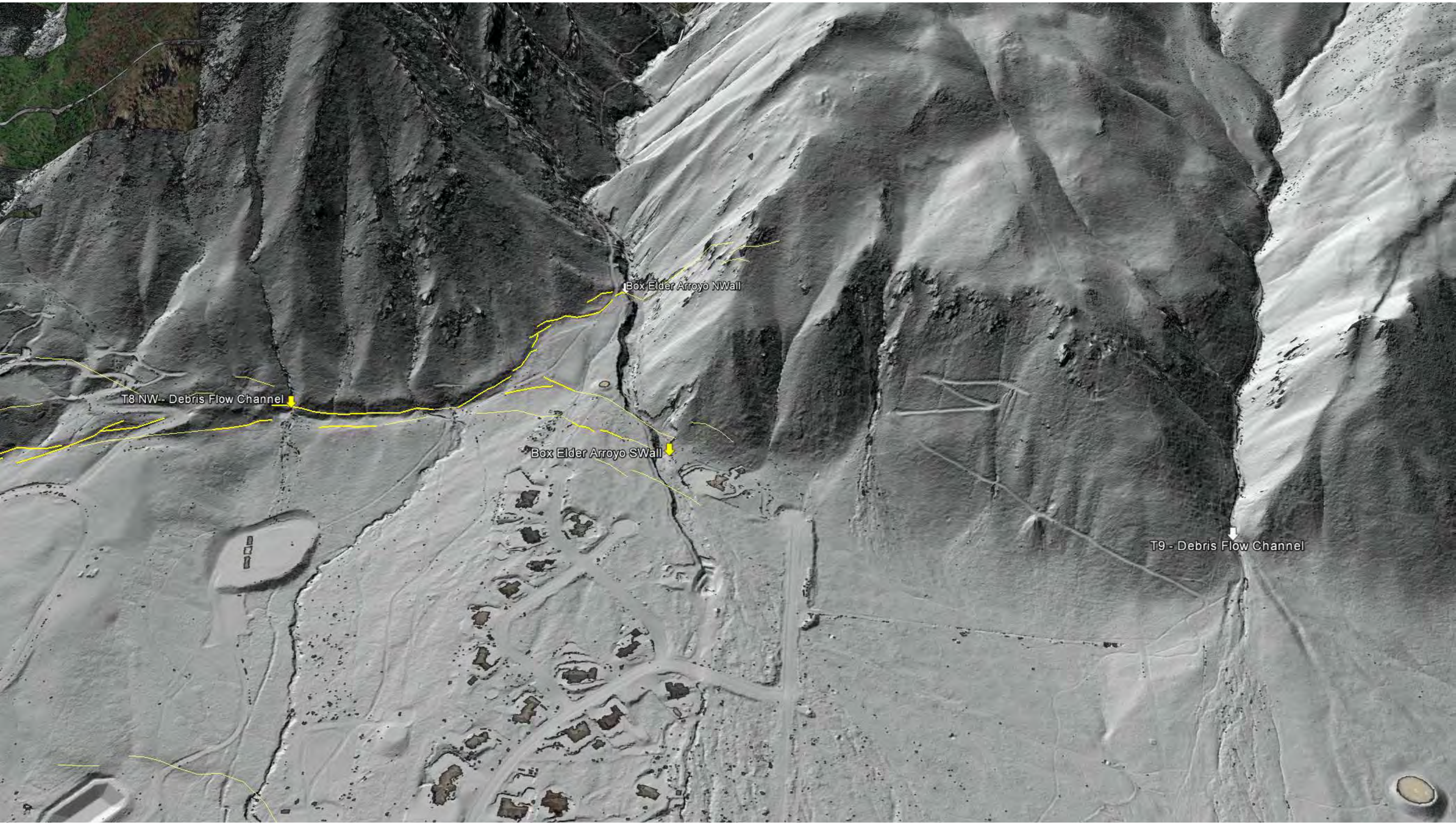
Trench #6 2014 UVU Field Camp - Southeast Wall

- **Deformed and displaced soil horizons.**
- **Buried A-horizon**
- **Possible, but unclear event evidence.**
- **Datable?**


T1 North Wwall
T1 South Ewall
T4 Ewall
T6 EWall
T8 NW - Debris Flow Channel
Box Elder Arroyo NWall
Box Elder Arroyo SWall
T9 - Debris Flow Channel
Alpine
©2015 Google
Google earth
The Area is abundant in Natural Exposures and
Left-open Exposures of the Fault


Thus far, our mapping has only
extended to Box Elder Canyon…




Box Elder Arroyo NWall
T8 NW - Debris Flow Channel
Box Elder Arroyo SWall
T9 - Debris Flow Channel

Debris Flow Channel Fault Exposure (Trench 8 North Wall)

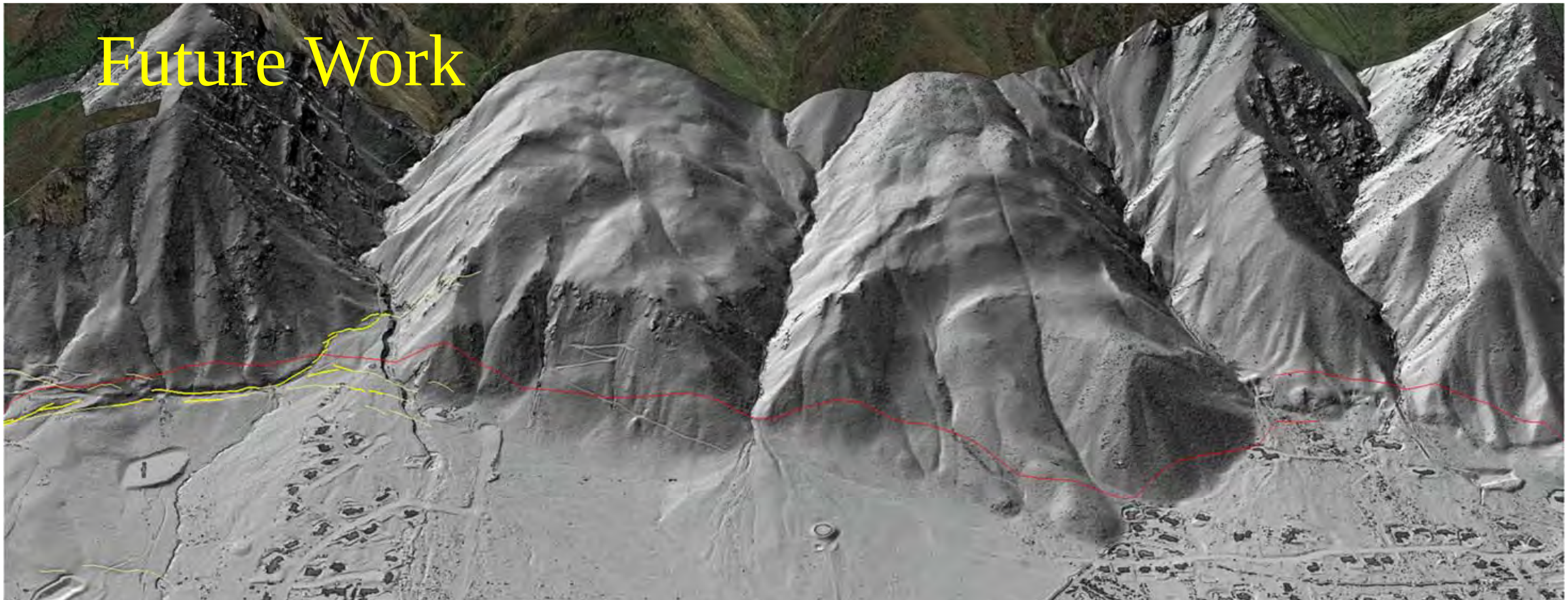
- Clear evidence of faulting
- Possible 0.5 m colluvial wedge

Box Elder Arroyo Fault Exposure (South Wall)

- Pronounced Wedge
- Meter-scale Event
- Datable Material…


Box Elder Arroyo NWall
Box Elder Arroyo SWall
© 2015 Google

Future Work



- **Get Ages for T1 Exposures**
- **Investigate T9 Exposure**
- **SFM of Box Elder Arroyo Walls – Ages?**
- **Revise Mapping with 0.5 m LiDAR**
- **Extend Mapping to American Fork Canyon**
- **Correlations with forthcoming USGS and UGS Results**

Applying Structure from Motion Techniques to Neotectonic Investigations: Methods, Error Analysis, and Examples

Michael Bunds, Nathan Toké, Suzanne Walther, Andrew Fletcher, Michael Arnoff and Brandon Powell

Department of Earth Science, Utah Valley University

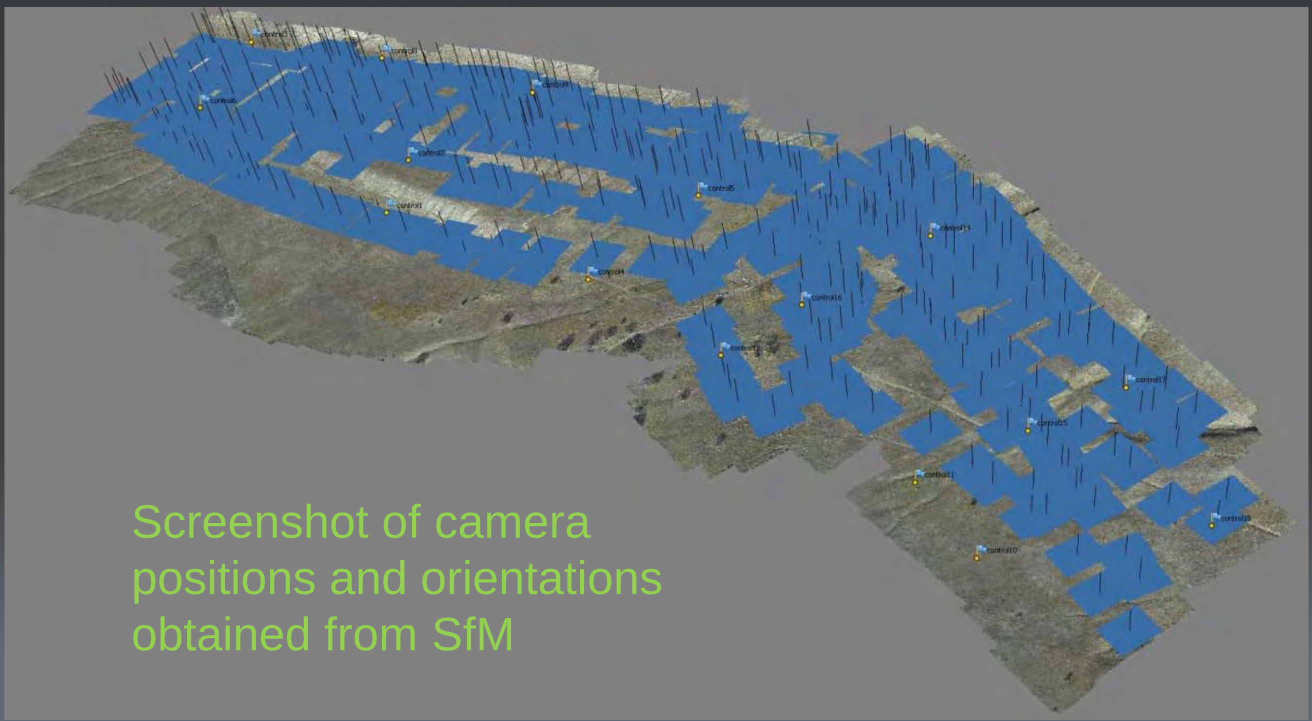
michael.bunds@uvu.edu

UTAH VALLEY UVU UNIVERSITY

Department of EARTH SCIENCE

What is Structure from Motion (SfM)?

- Broadly, a technique for producing a *point cloud* of a surface or surfaces from overlapping photographs taken from varying perspectives
  - Each point in cloud has x, y, z coordinates and RGB values if desired
- More formally, SfM is a technique to compute a *camera model* for each photograph:
  - No apriori information on cameras required (position, focal length, etc.)
  - Position and orientation of the camera relative to imaged surface
  - Lens parameters including distortion
  - Uses point matching between overlapping photos
- With camera models as input, *multi-view stereo* method, which uses parallax, is applied to solve for a *dense point cloud (similar to a LiDAR output)*
- Rasterized *DEM* can be produced from point cloud
- An *orthophoto* and a *3-d textured model* can also be produced



Screenshot of camera positions and orientations obtained from SfM

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What is SfM (cont'd)?

- Screenshots of 358 pt/m^2 point cloud

Uses of SfM in Earthquake Geology

Increasing complexity

- Quickly build photo-realistic 3-d models of features
- Accurately record trench walls; more information and less time-consuming than traditional panoramic merges (e.g., with Photoshop)
- Build DEMs from aerial imagery at accuracy approaching airborne LiDAR (ALS) and much finer resolution

Structure from Motion Software: *Agisoft Photoscan*

- Commonly used
- User friendly and science-capable
- Two versions
  - Standard
    - Builds 3-d models
    - Merges photos
    - Will not georeference, build DEMs, orthophotos, etc.
    - $179 ($59 educational license)
  - Professional
    - Georeferences models
    - Builds DEMs, orthophotos, etc.
    - $3499 ($549 educational license)

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3-d Images from SfM

- Simple to build 3-d models of features from several photos
- In the field, take overlapping photos from differing positions
- Process in software in minutes
- Photos are draped over 3-d model by Photoscan
- Easily transported as a pdf and viewed in Acrobat Reader
- What's required: digital camera, Agisoft Photoscan Standard (or equivalent)

Curb offset in M6.0 2014 Napa earthquake

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DEMs from SfM: Field Methods

- Place and survey ground control points (GCPs) for georeferencing
  - 15 to 20 points, we survey with Trimble R8 or 5700 RTK system.
  - Camera coordinates may be used instead, but are not high accuracy
- Record aerial photographs
  - Balloons and various UAVs have been successful
  - We've achieved accurate results with an entry-level hobbyist quadcopter and GoPro camera
- Optionally, measure checkpoints to validate model accuracy

Trimble R8 (VRS, or RTK mode)

DJI Phantom 2, Hero GoPro 3 Black, Zenmuse 3-axis gimbal

DEMs from SfM: Methods (cont'd)

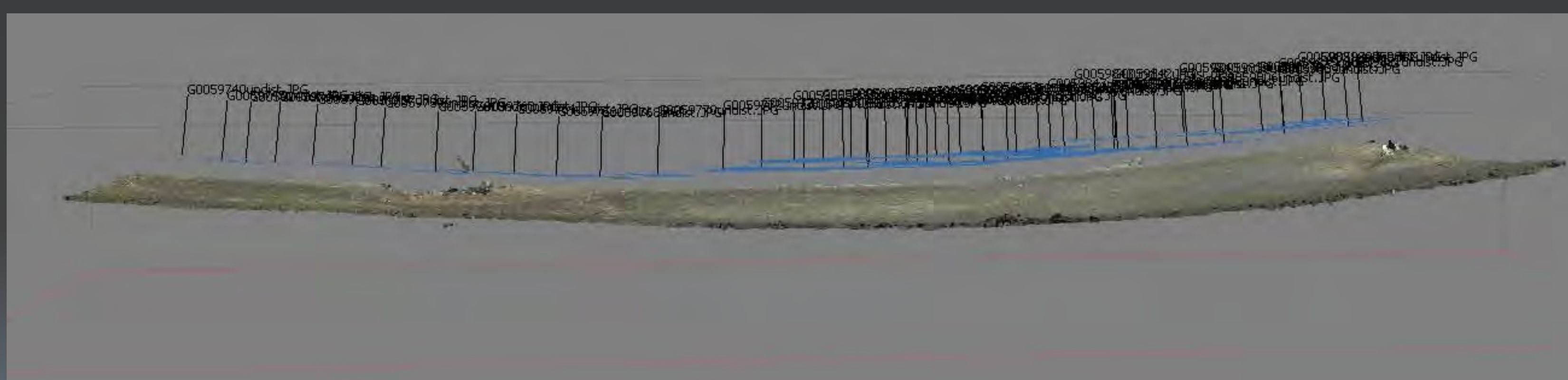
- Office
  - Process GCP data
  - Select photos for use in model.
    - We typically shoot 500 to 1000 photos, use 100 to 500 in model
    - GoPro photos must be pre-corrected for lens distortion
  - Process in Photoscan
    - Solve for camera model ('Align photos')
    - Incorporate GCPs and optimize camera model
    - Build 'dense' point cloud
    - Build high-resolution TIN and DEM in Agisoft or export point cloud for processing with LiDAR tools (e.g., lastools and/or GEON Points2grid)

Enhanced 'gaming' PC helpful (neon lights optional)

Model Doming (a word of warning)

- SfM cannot distinguish effectively between radial lens distortion and doming of ground surface
- Problem is pronounced for GoPro camera
- Issue is well mitigated with GCPs and/or proper radial distortion correction coefficients

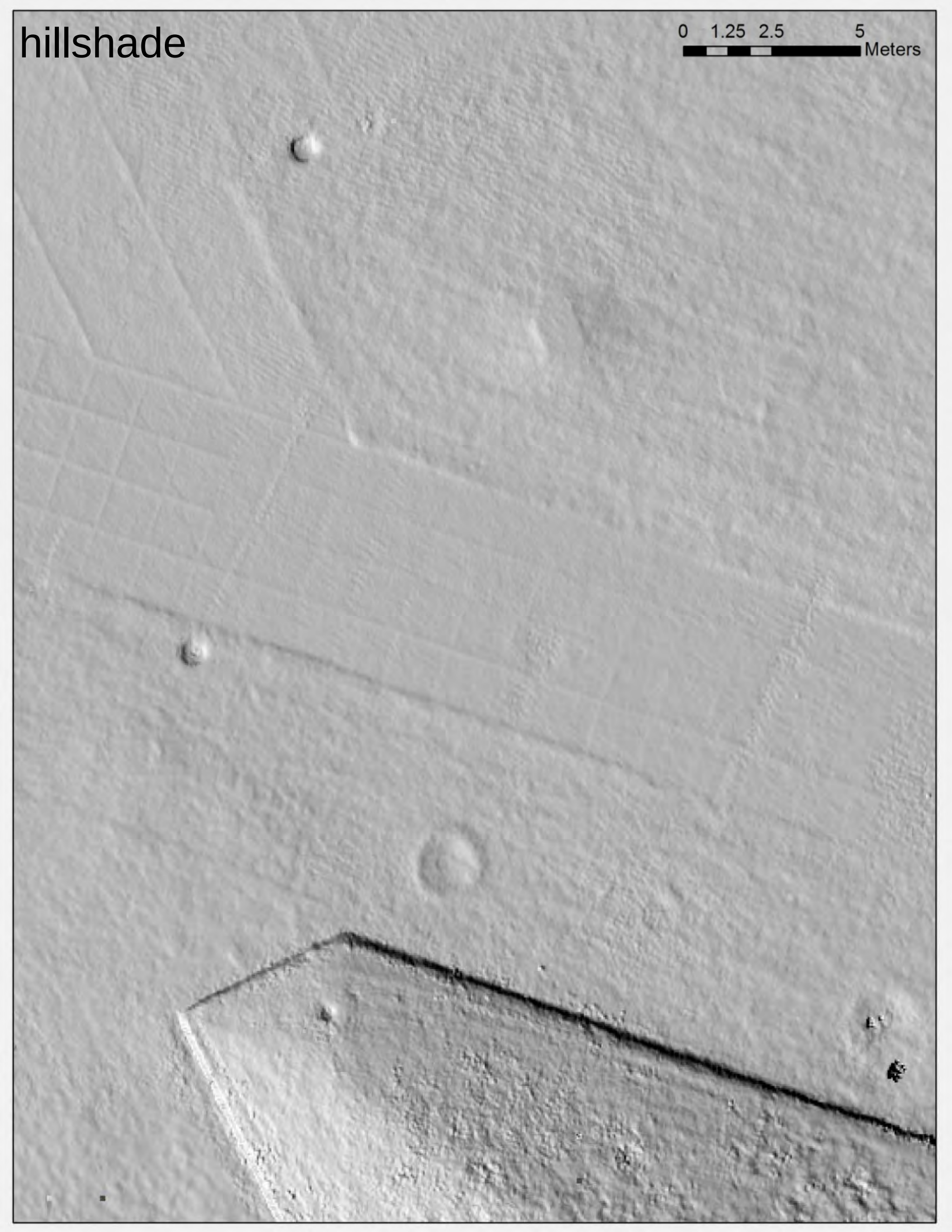
UVU test area; no GCPs, undercorrected radial distortion



San Andreas Fault; 2 GCPs, overcorrected radial distortion

Test Area, UVU Campus

- 2709 pt/m^2 (high setting)
- 92 photos, 20m average height but large range in heights
- Very high image overlap (ca. 35 images per GCP)
- 5 cm DEM
- 6300 m^2 map area
- 3.2 cm RMS misfit to LiDAR
- Noteworthy characteristics:
  - Fine detail visible
  - Sees under some trees
  - Shaded areas noisy
  - Some artifacts



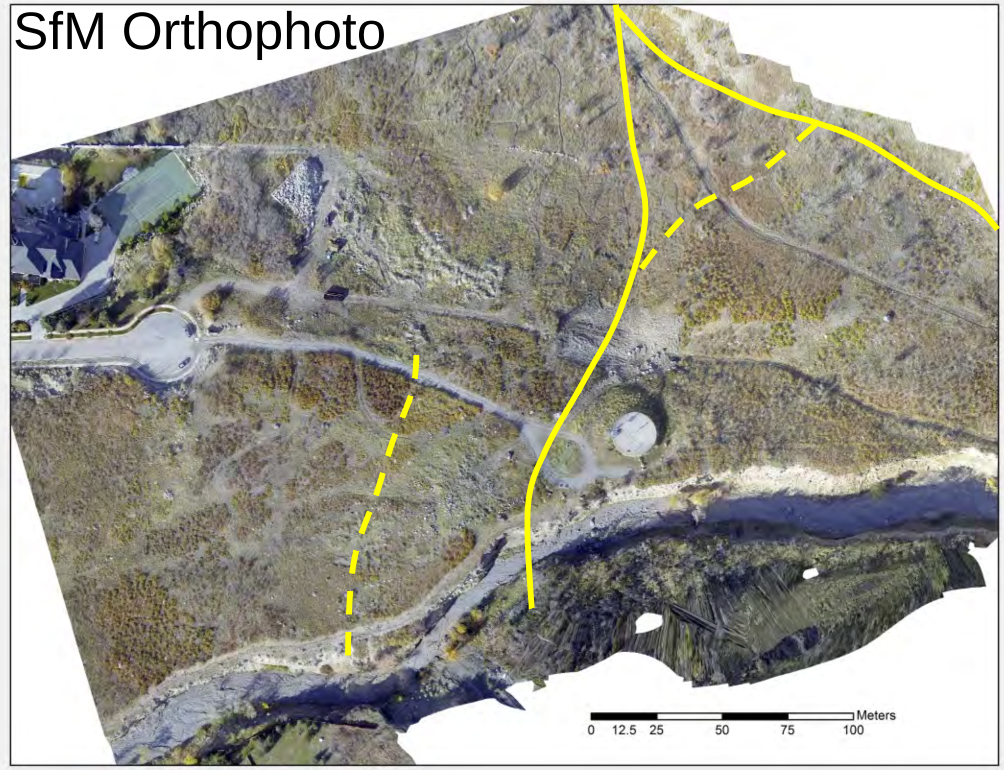
Wasatch Fault Near Box Elder Canyon

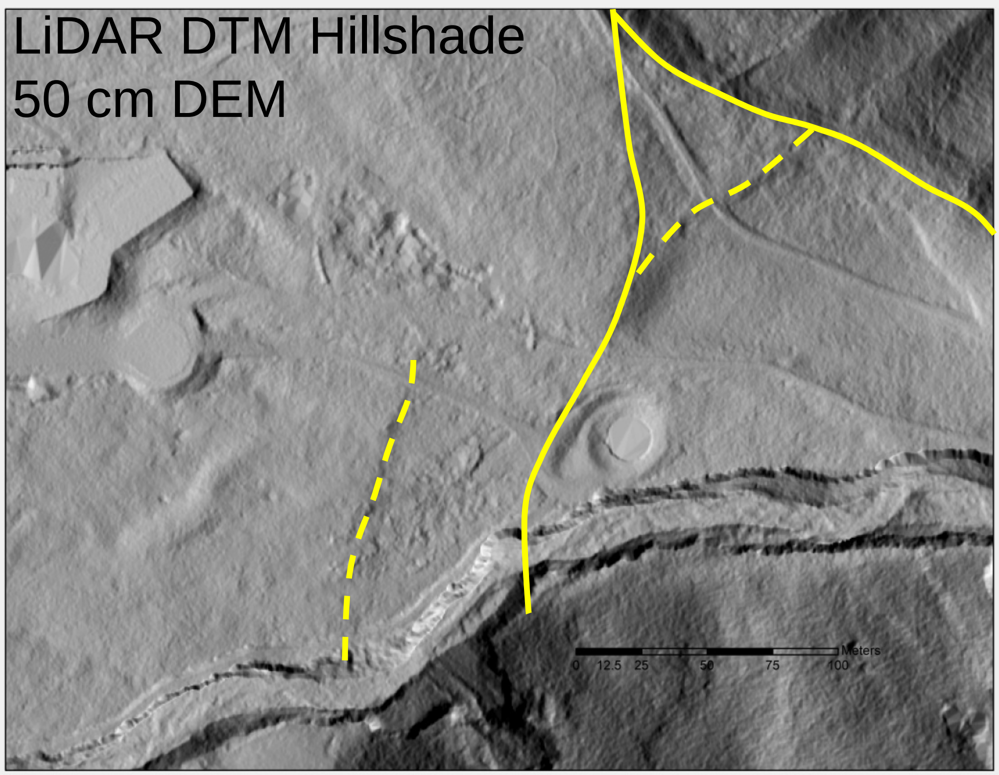
- Initiated as student class project by Mike Arnoff with Nate Toké
- Goal: Image Wasatch fault scarp(s)
- Significant scrub oak makes site somewhat SfM adverse

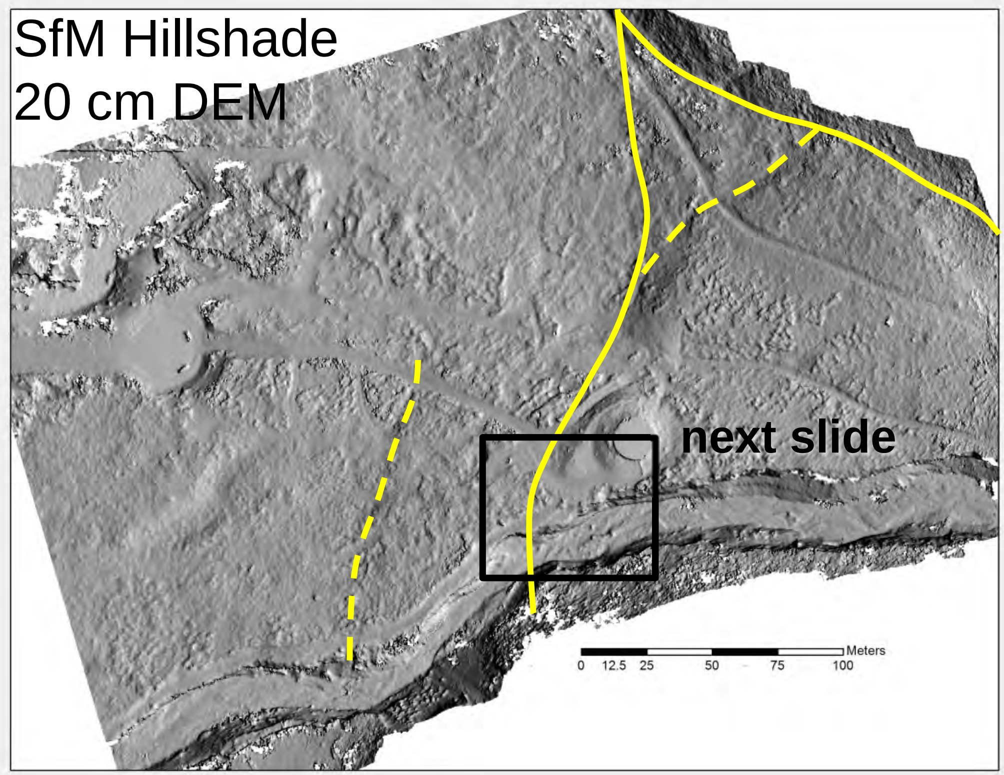
faults from USGS Quaternary fault database

Wasatch Fault Near Box Elder Canyon (cont'd)

- 149 photos, ave. altitude 51 m
- 9 GCPs
- 0.09 km^2 area mapped (90,000 m^2)
- Average photo overlap 21.1 images/GCP
- 91 pt/m^2 (medium setting) => 20 cm DEM
- 358 pt/m^2 (ultra high setting) => 6 cm DEM

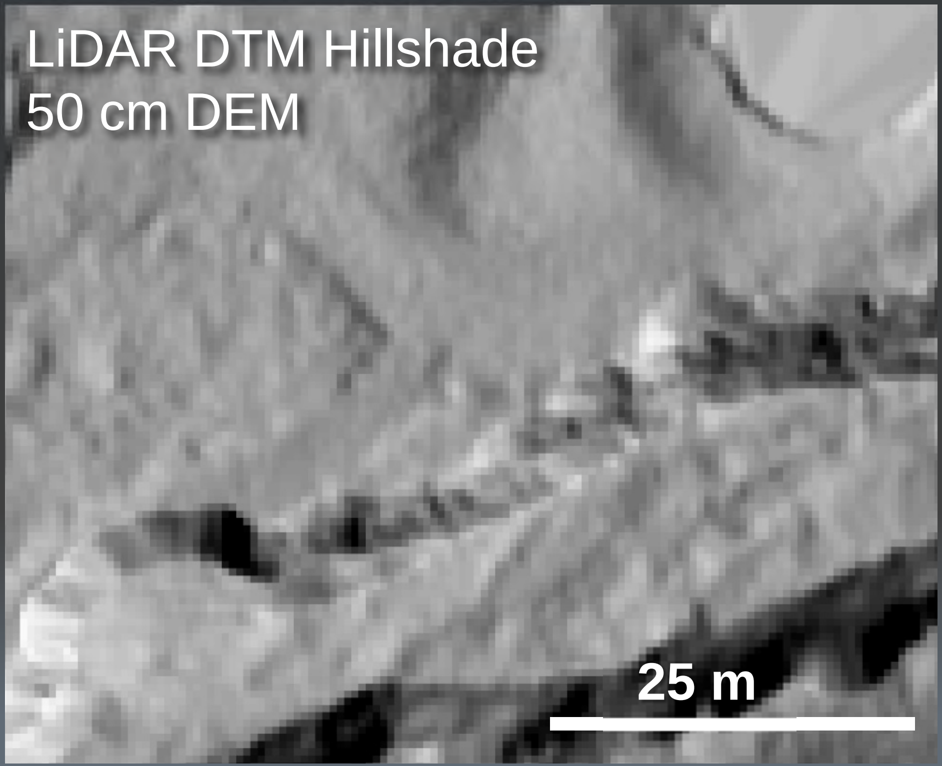


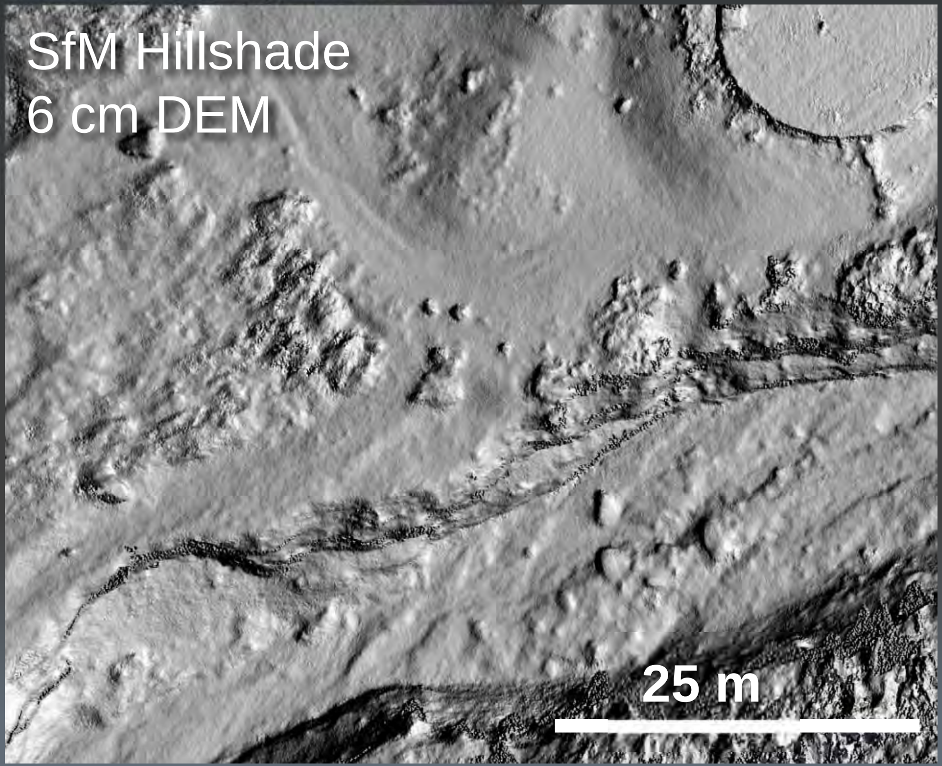




Wasatch Fault Near Box Elder Canyon: Detail

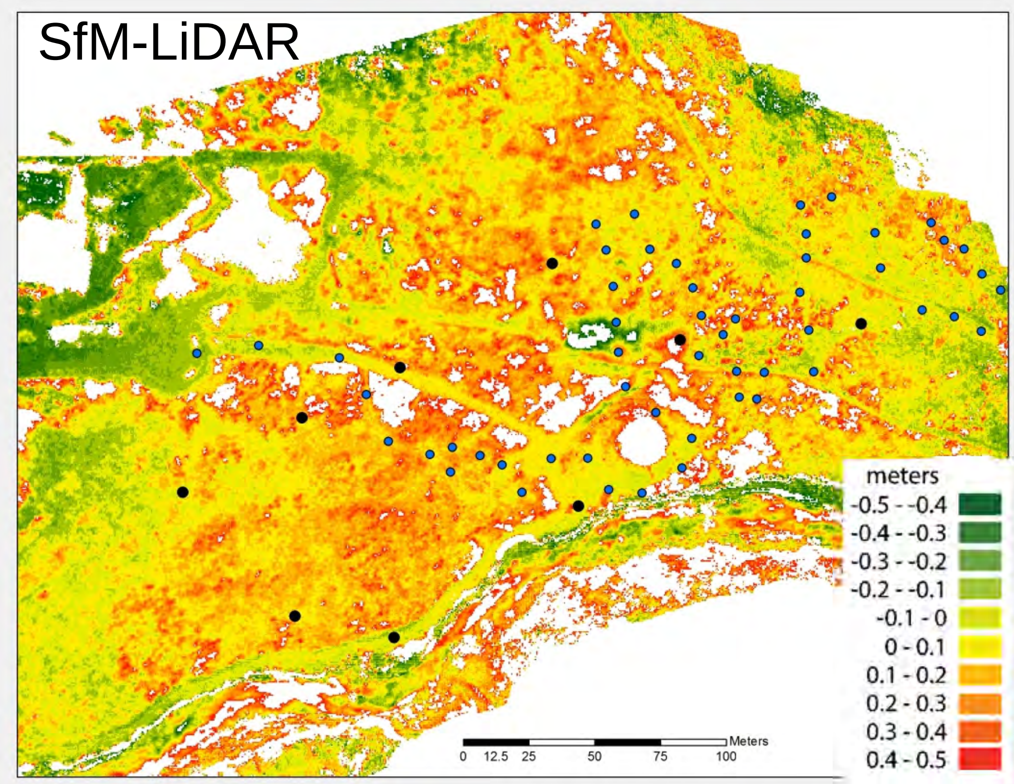
- 358 pt/m^2 (ultra high setting)
- 6 cm DEM

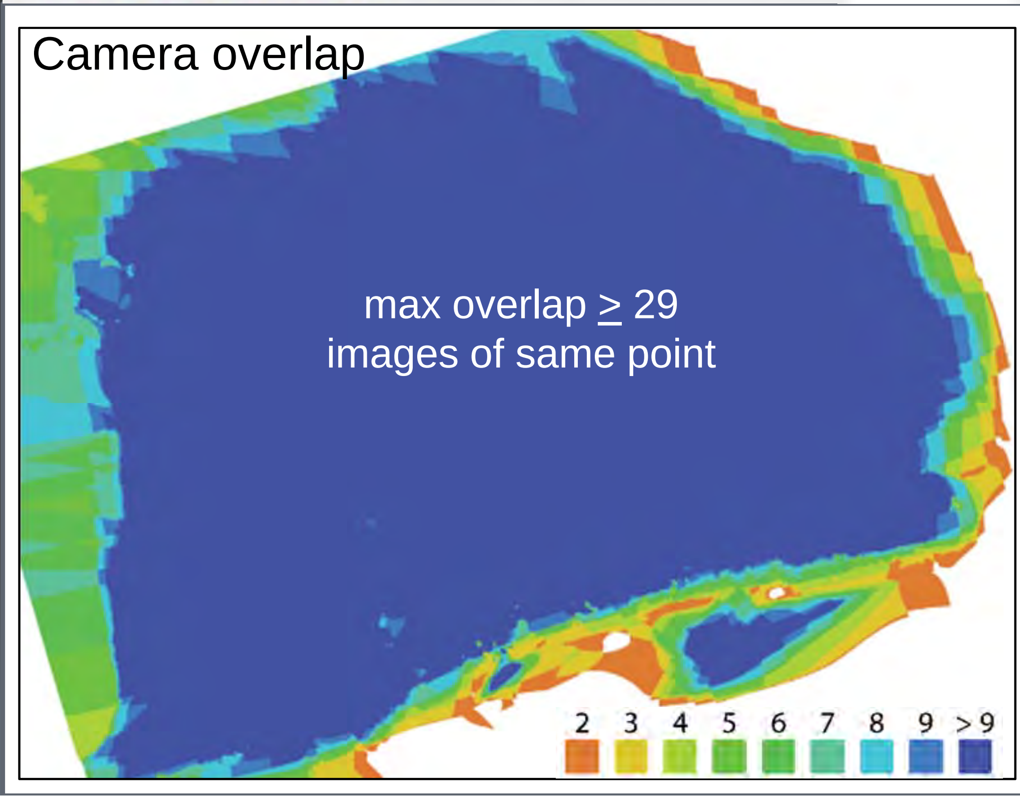


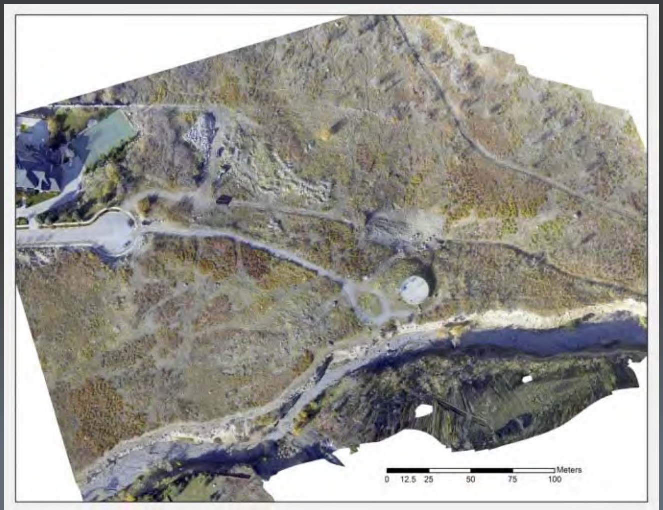


Wasatch Fault Near Box Elder Canyon: Accuracy

- 9.2 cm SfM RMS error based on 59 RTK GPS points on bare ground
- 9.8 cm LiDAR RMS error based on 59 RTK GPS points on bare ground
- SfM DEM shows good correspondence to LiDAR DTM
- SfM higher than DTM in areas of vegetation
- SfM shows some downwarping outside of control points and high camera overlap







Oquirrh Fault Near Stansbury Park

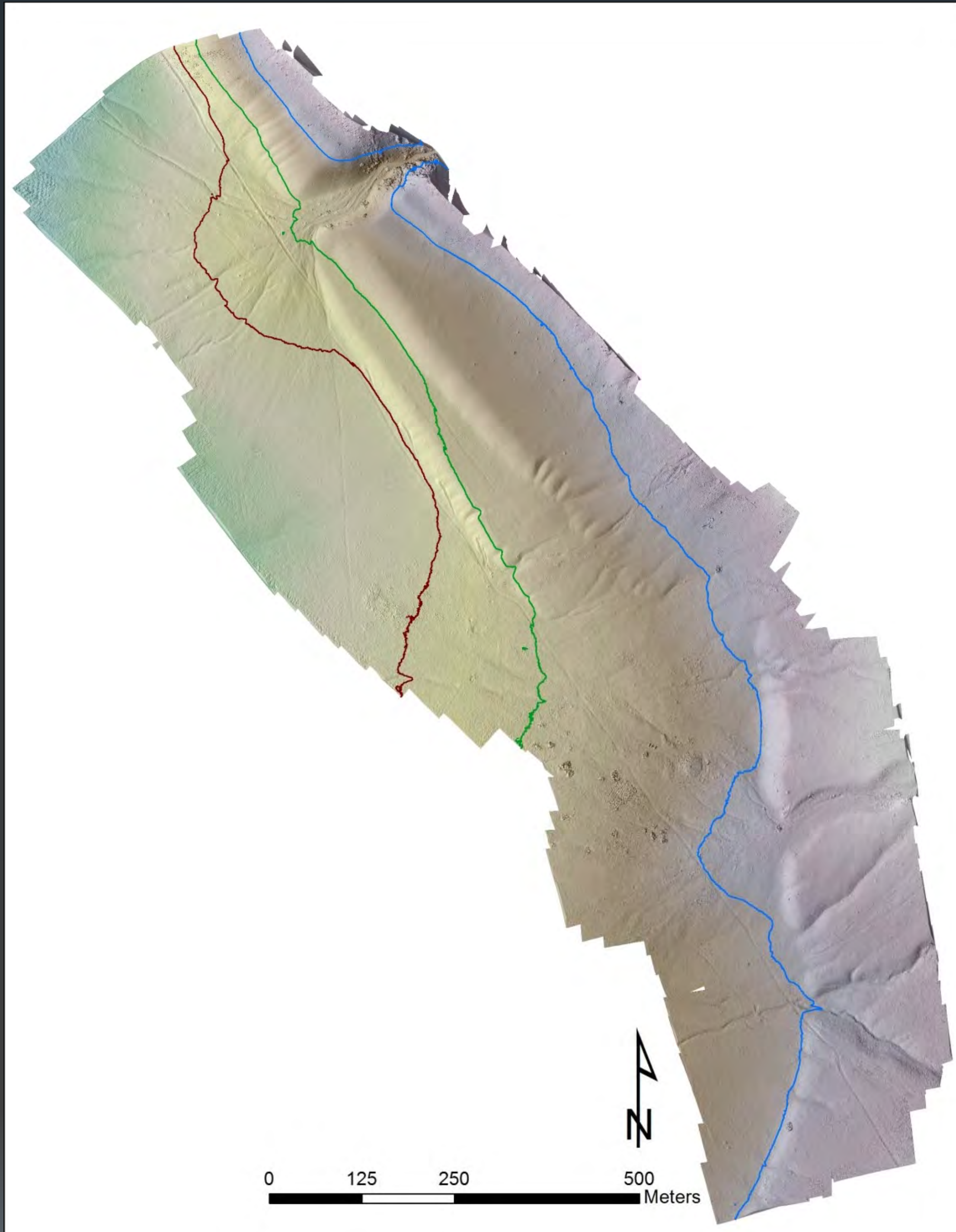
- Initiated as student class project by Andrew Fletcher
- Goal: determine offset of Bonneville bench across fault
- Vegetation mostly < 1 m grass/weeds – good for SfM

faults from USGS Quaternary fault database

Department of EARTH SCIENCE

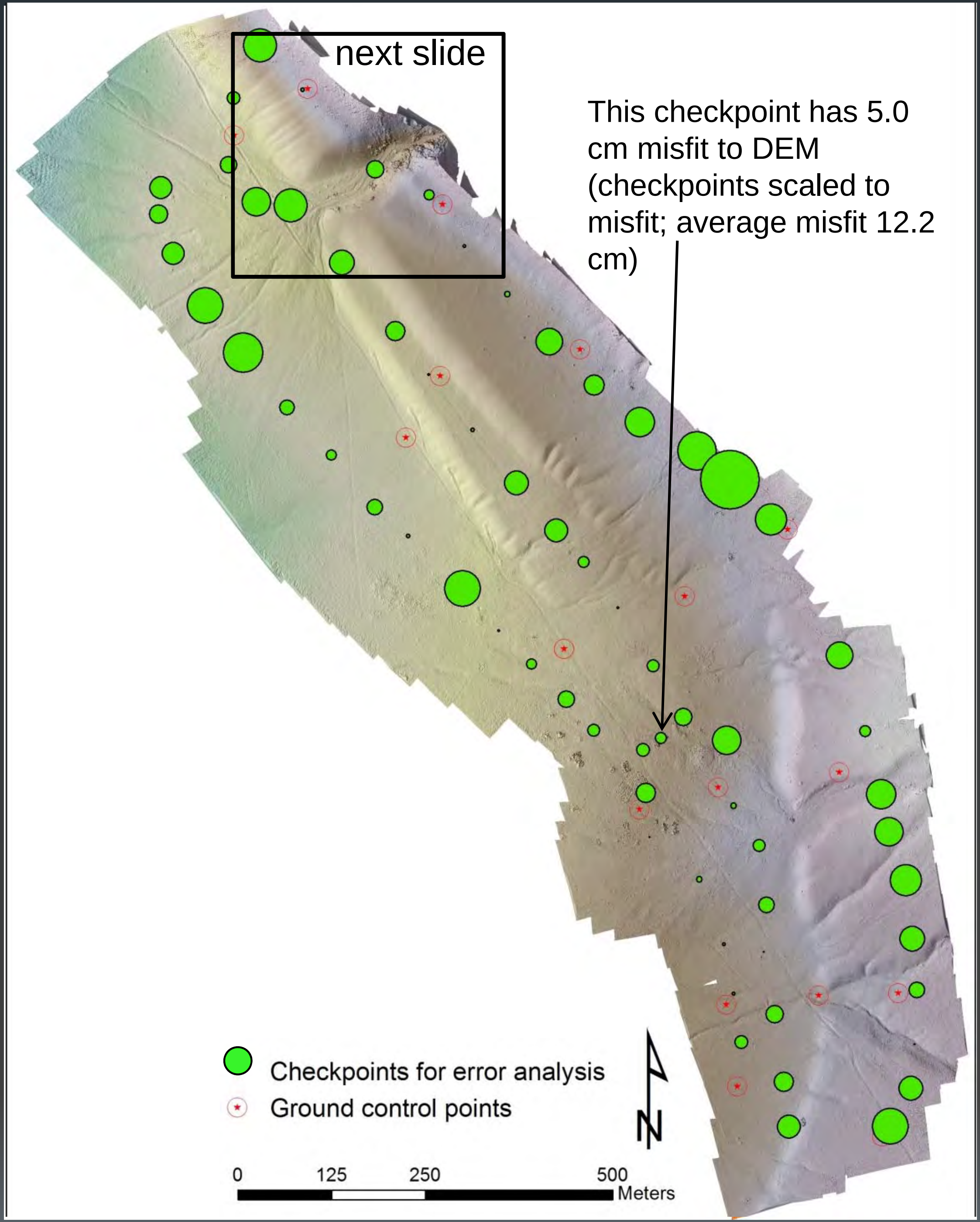
Oquirrh Fault Near Stansbury Park (cont'd)

- 334 images, average altitude 79.4 m
- 18 GCPs
- 0.82 km^2 area mapped
- Average camera overlap 8.9 GCPs/image
- 137.7 pt/m^2 point cloud density (high setting)
- 8.5 cm grid DEM
- Bonneville highstand shown by blue contour at 1590m asl



Oquirrh Fault Near Stansbury Park: Accuracy

- 12.2 cm SfM RMS error based on 67 RTK GPS points on bare ground
- No LiDAR for comparison
- Some noise and artifacts in areas of low camera overlap
- GPS checkpoints with large error explained by low camera overlap or absence of GCPs



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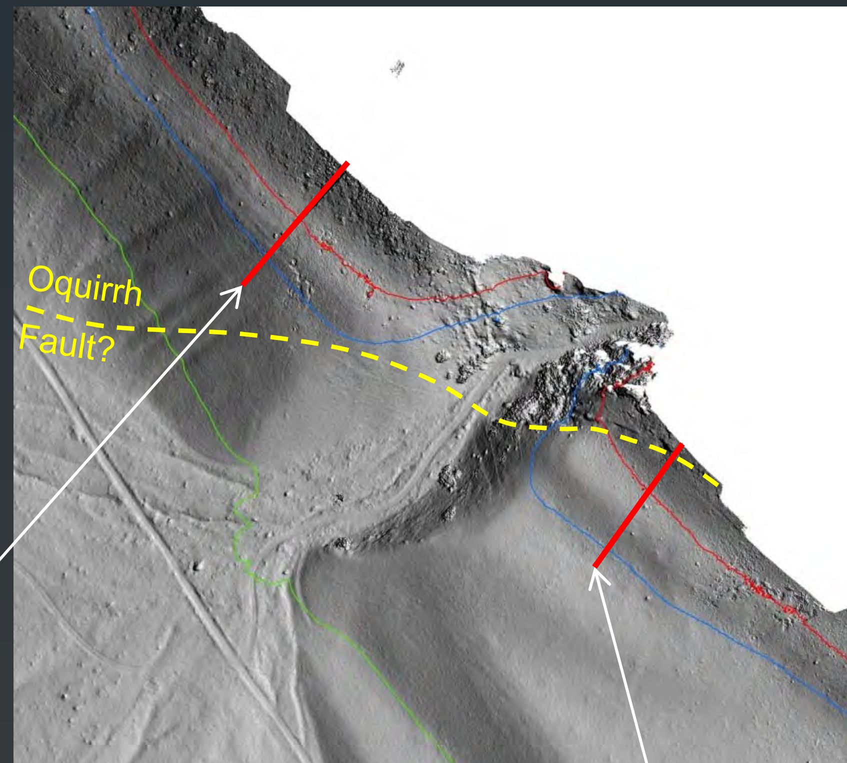
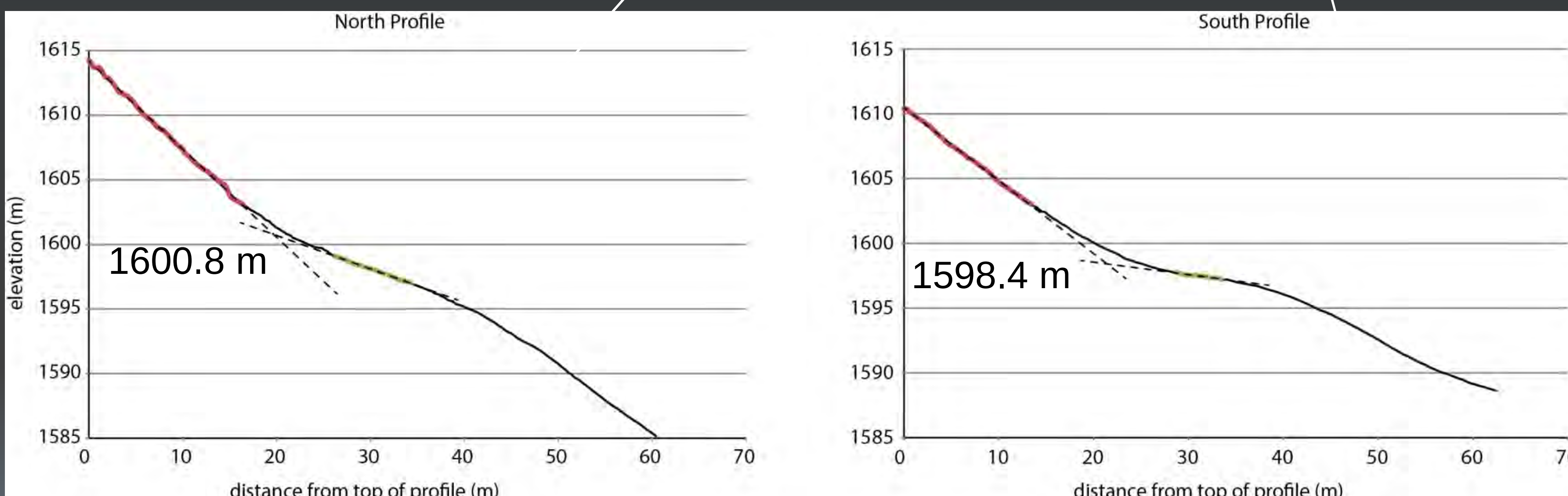
Oquirrh Fault Near Stansbury Park: Results

- Mapped area only includes offset pre-Bonneville(?) fan surface
- ~2.4 m offset
- Need to map further north

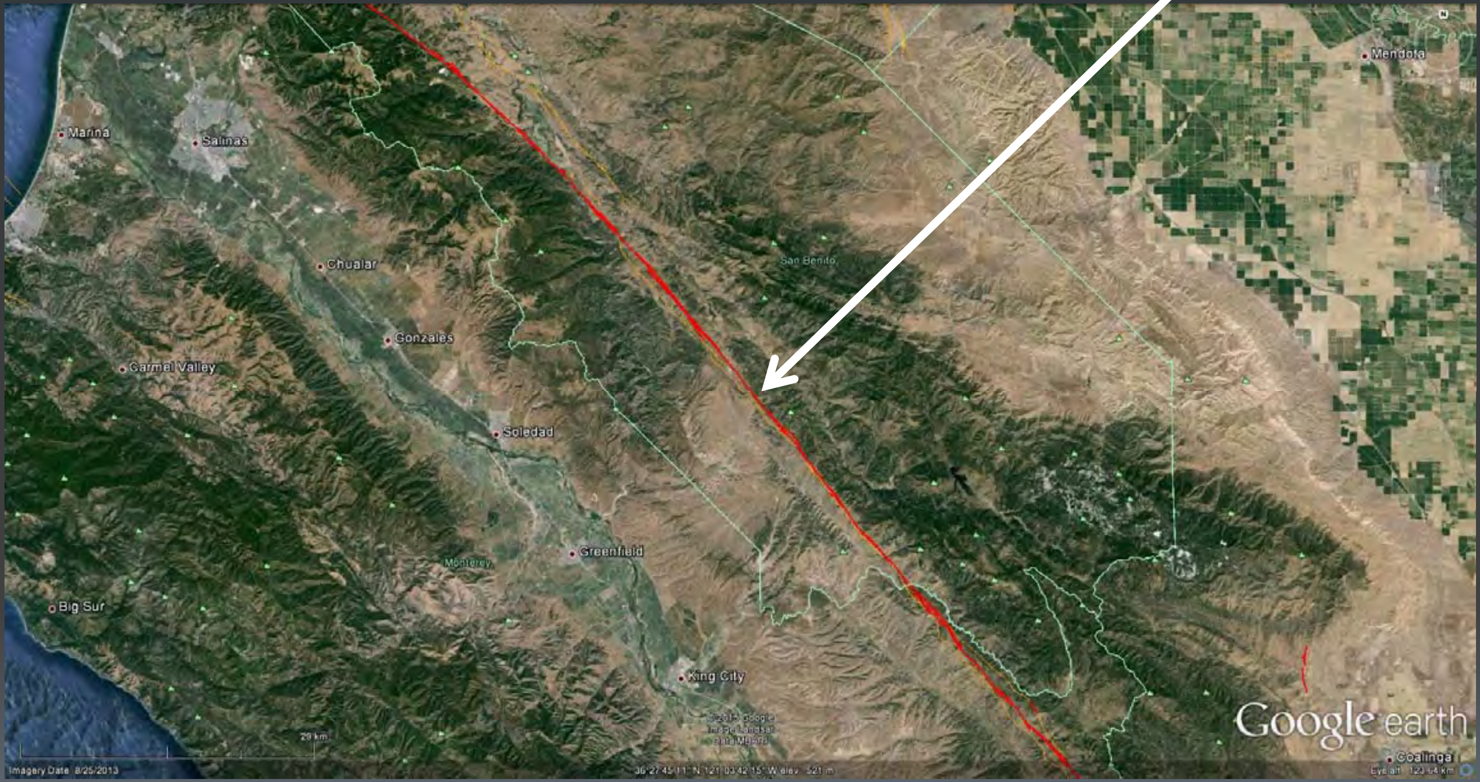




San Andreas Fault at Dry Lake Valley

- Creeping segment
- Goals: document creep-induced surface fractures in soil and prior trench sites

study site



faults from USGS Quaternary fault database

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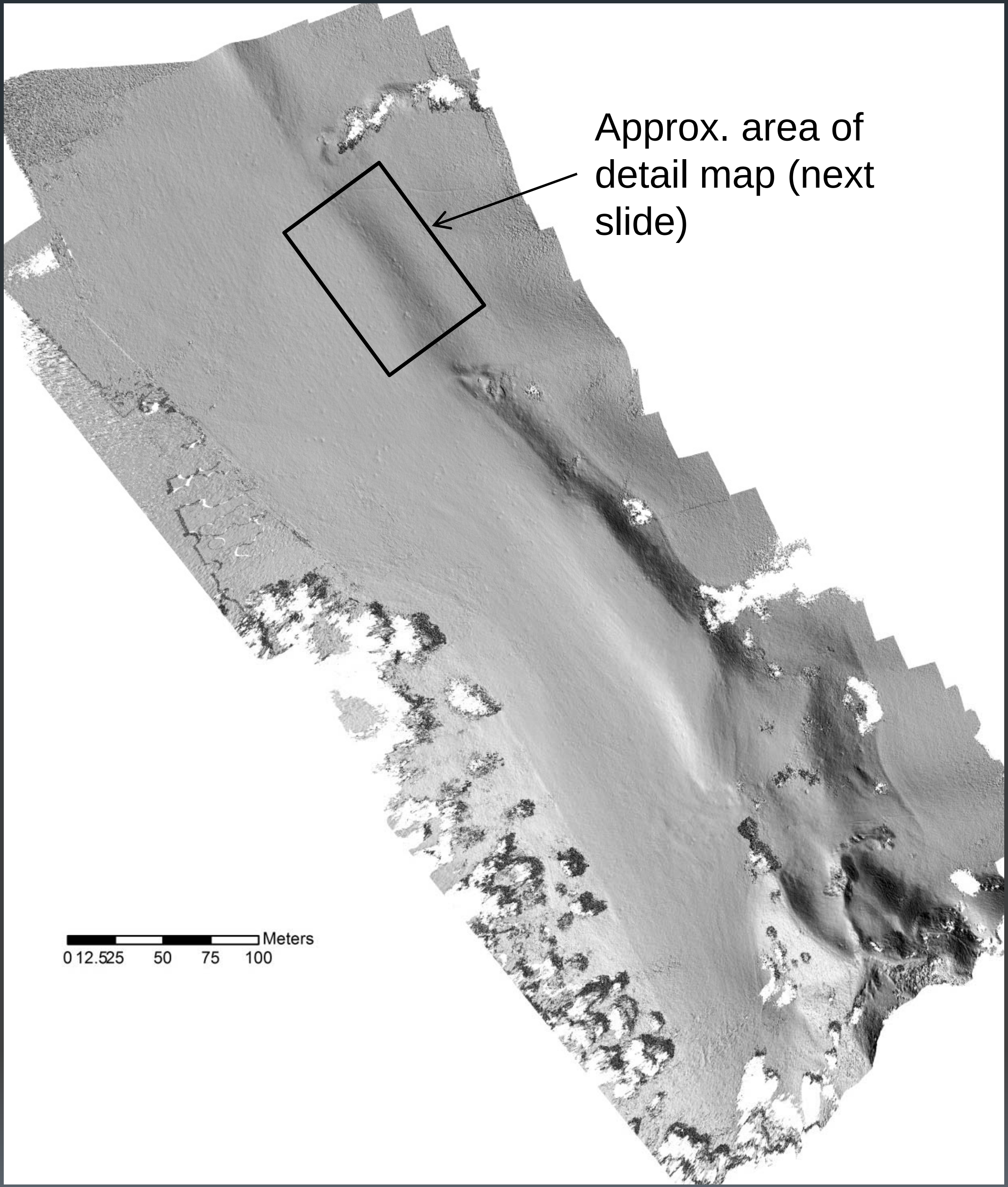
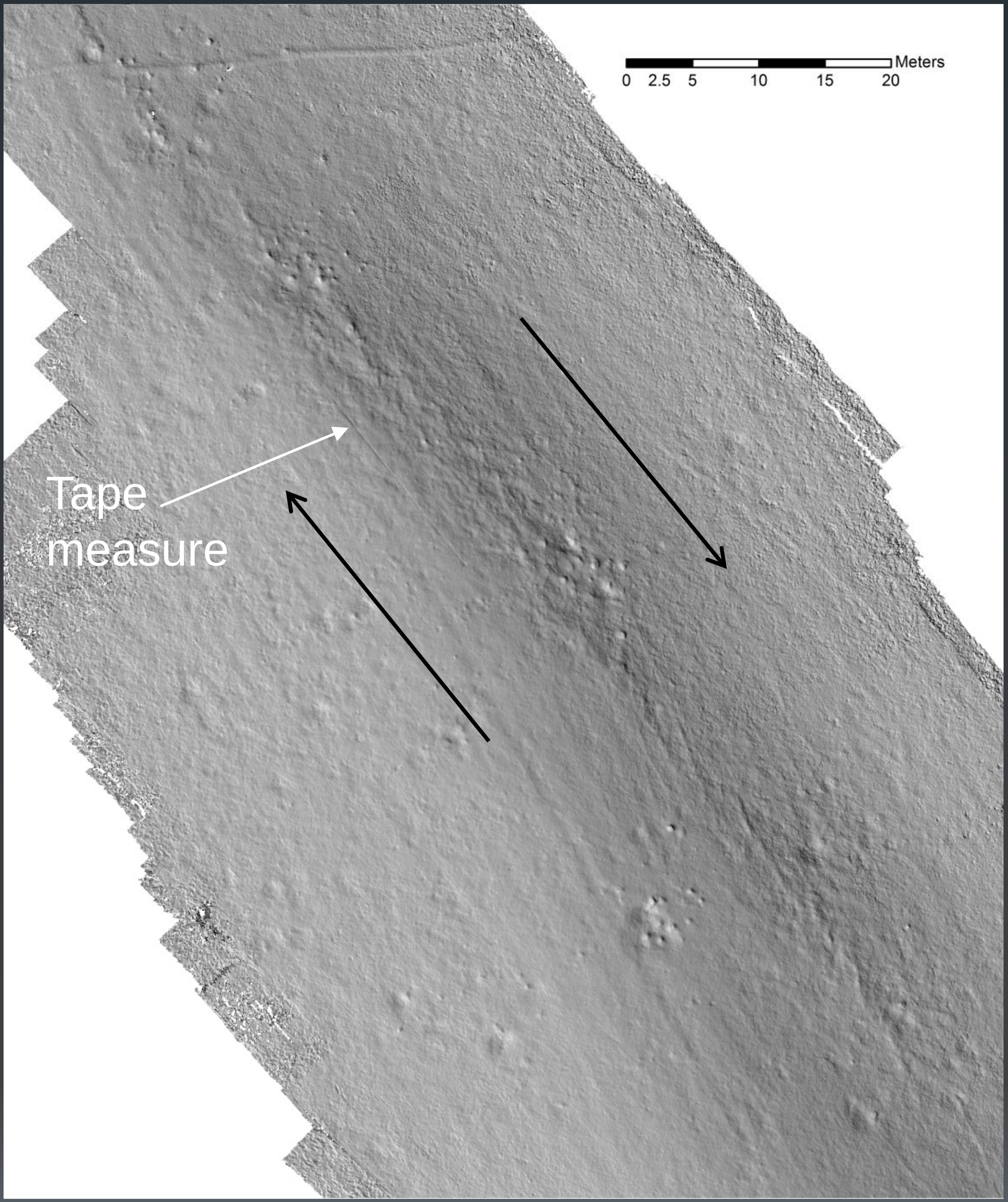
San Andreas Fault at Dry Lake Valley

- 2 maps, full area and fracture detail
- Full area map (right):
  - 62 images
  - 4 GCPs (not well georeferenced)
  - 635 pt/m^2 (ultra-high setting)
  - 5 cm DEM



San Andreas Fault at Dry Lake Valley

- Detail map (right):
  - 55 images
  - 3 cm DEM
  - captures en-echelon fracture sets
  - Also visible:
    - Gopher holes
    - Tape measure
    - Cattle trail



DEMs from SfM – Comparison to ALS

- Advantages of SfM relative to ALS
  - Low cost
  - Rapid deployment
  - High spatial resolution (e.g., < 5 cm DEM grid spacing)
  - Point cloud RGB information
- Disadvantages
  - Difficult to strip vegetation
  - Difficult to cover large areas, depending on aerial device and desired resolution
  - Accuracy may be reduced some
  - FAA permitting (Certificate of Authorization required for public agencies; virtually impossible for private under current rules; almost no regulations for hobbyists)

In Conclusion

- SfM works… Even with a DJI Phantom & GoPro

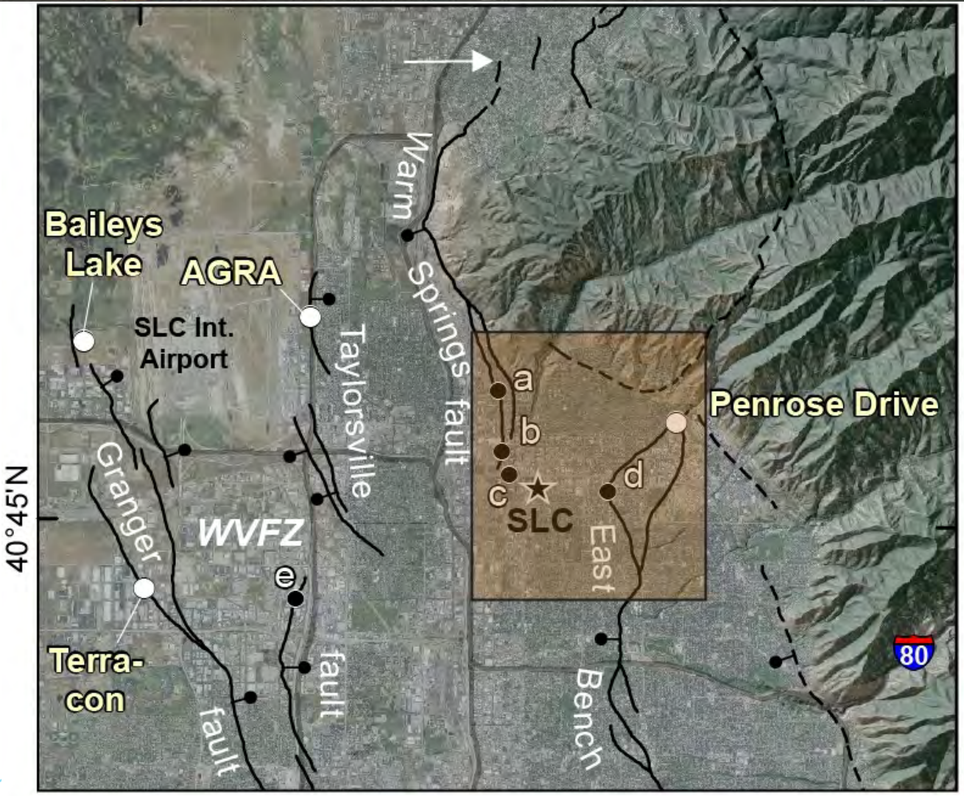
Wasatch fault seismic imaging project

Lee Liberty

Boise State University

Project objectives

- Identify and characterize active faults related to the Wasatch fault system through the downtown Salt Lake City corridor – p-wave reflection profiling to >100 m depth
- Provide earthquake site response (Vs30 or deeper) along each profile – Rayleigh wave imaging (MASW) to estimate shear wave (NEHRP-class) velocity distribution to 30-50 m depth
- Estimate depth to water table for liquefaction potential – p-wave refraction profiling to >20 m depth
- Identify shallow bedrock locations that may result in localized earthquake site amplification – p-wave reflection/refraction profiling
- Vp/Vs or Poisson's ratio to identify lithology (e.g., colluvial wedge deposits) – p-wave/s-wave tomography to 20 depth

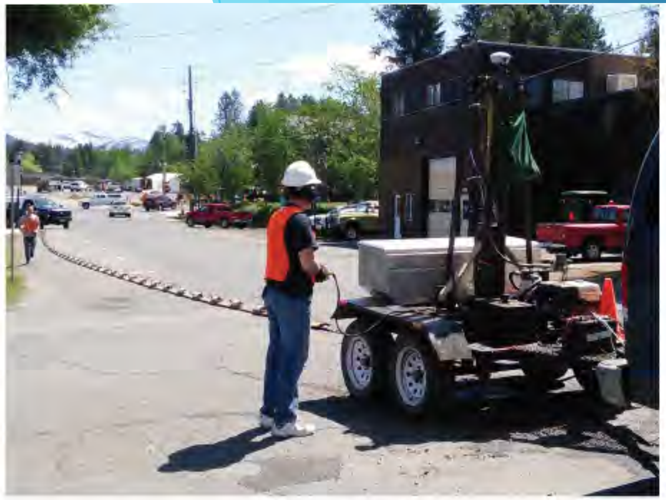


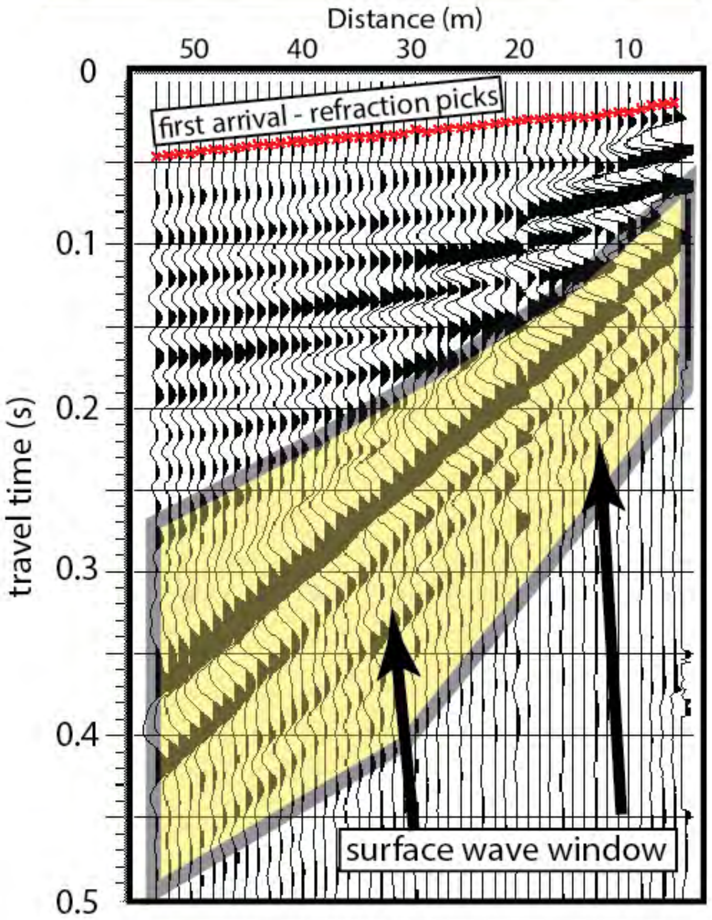
Land streamer technology

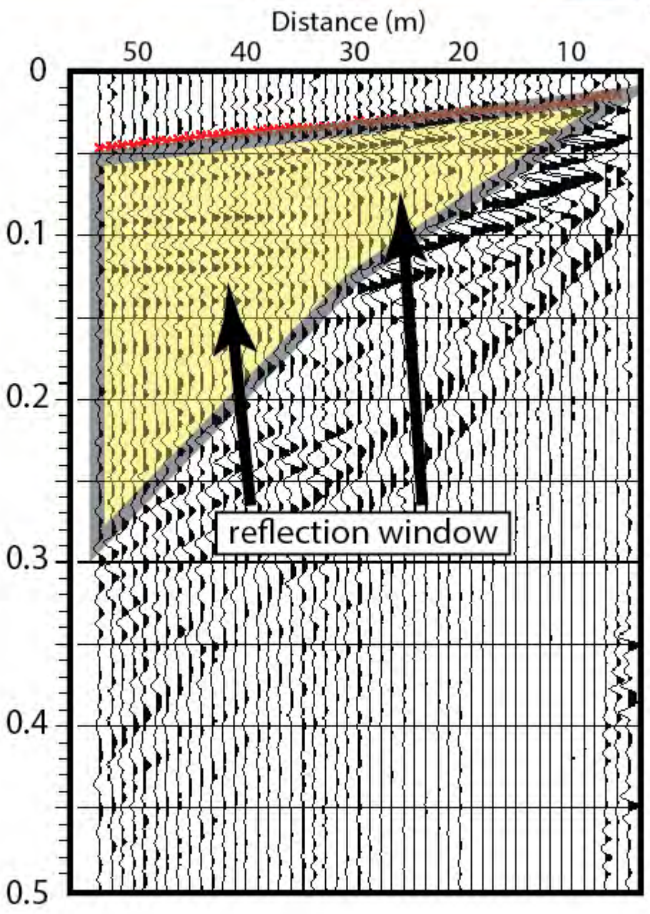
- 3-component 4.5 Hz geophones
- 48 shoes spaced 1 m apart (new design will result in 60 m aperture)
- Comparable data quality to planted geophones
- Operational along straight road or off-road traverses
- Accelerated weight drop used to rapidly collect wave data (every few seconds)

Simultaneous collection of

- P-wave or s-wave refraction data
- P-wave or s-wave reflection data
- Surface wave (Rayleigh or Love wave)
- Multicomponent data collection allows for a more robust analysis of surface and body waves

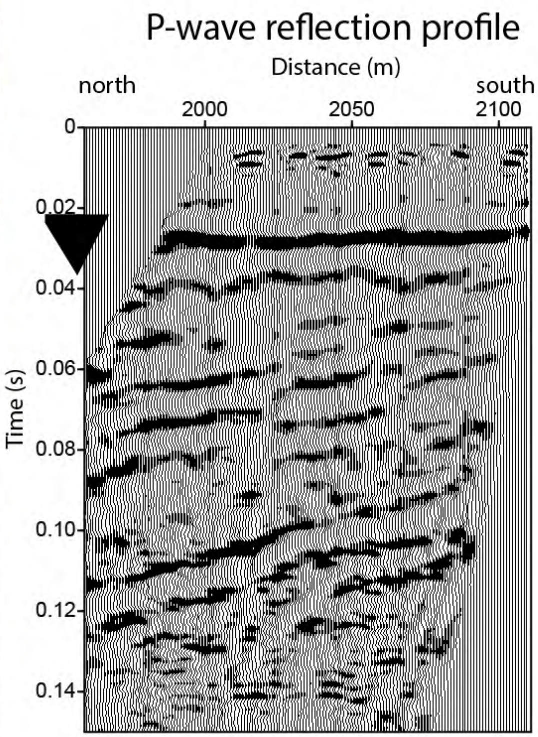


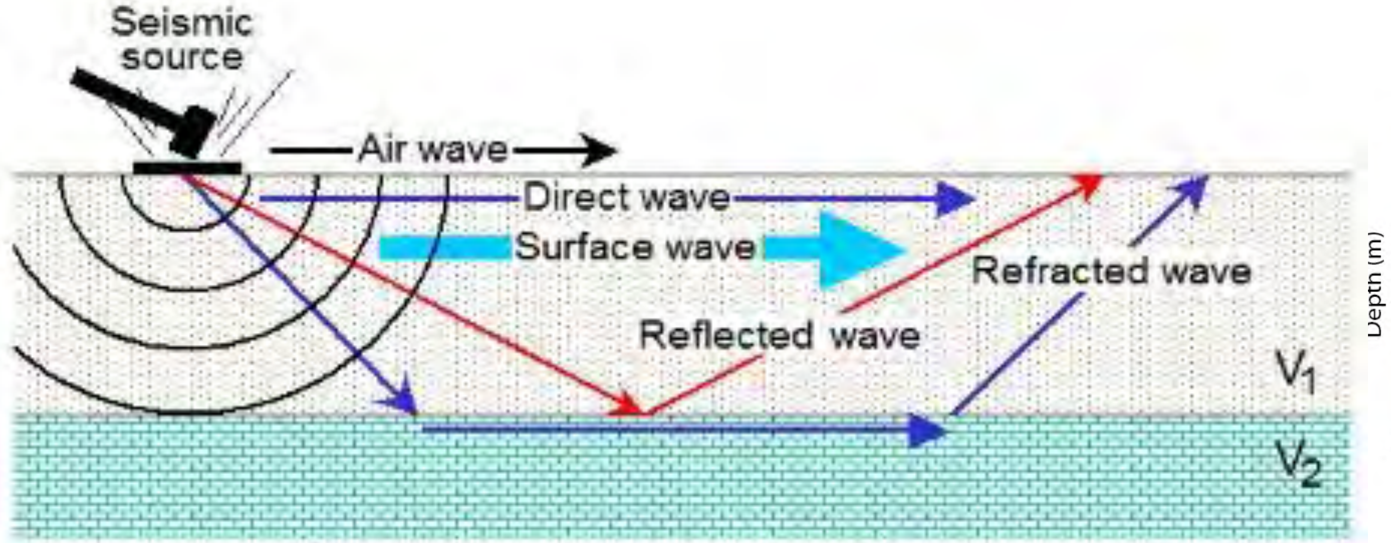


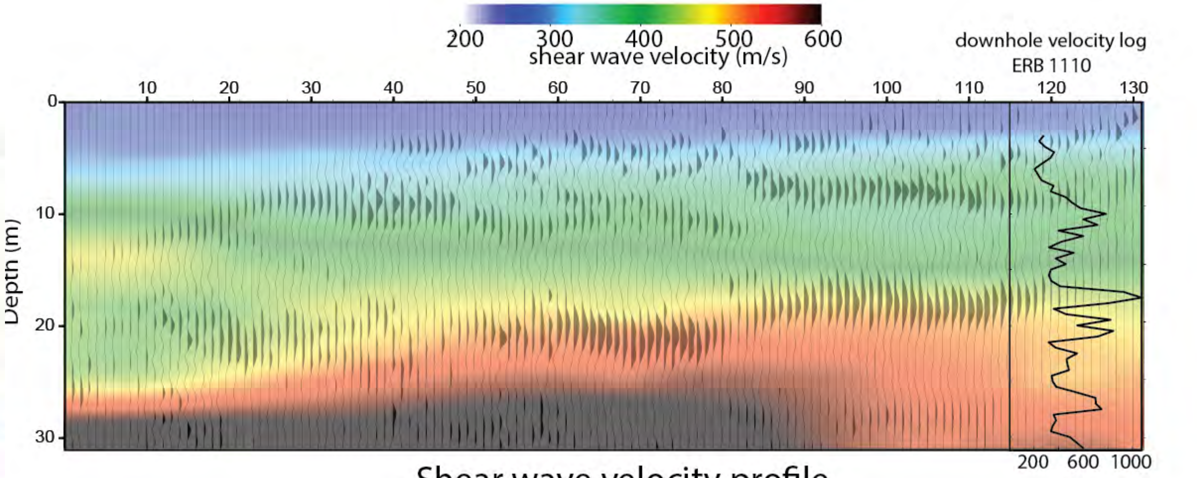


Body wave (seismic reflection & refraction profiling

- P-wave imaging to depths upwards of 200 m
- S-wave imaging to depth upwards of 50 m
- Compensate for high velocity asphalt surface (ray bending) via component rotation.
- Minimal statics effects due to smooth topography and uniform velocity near-surface (road) materials



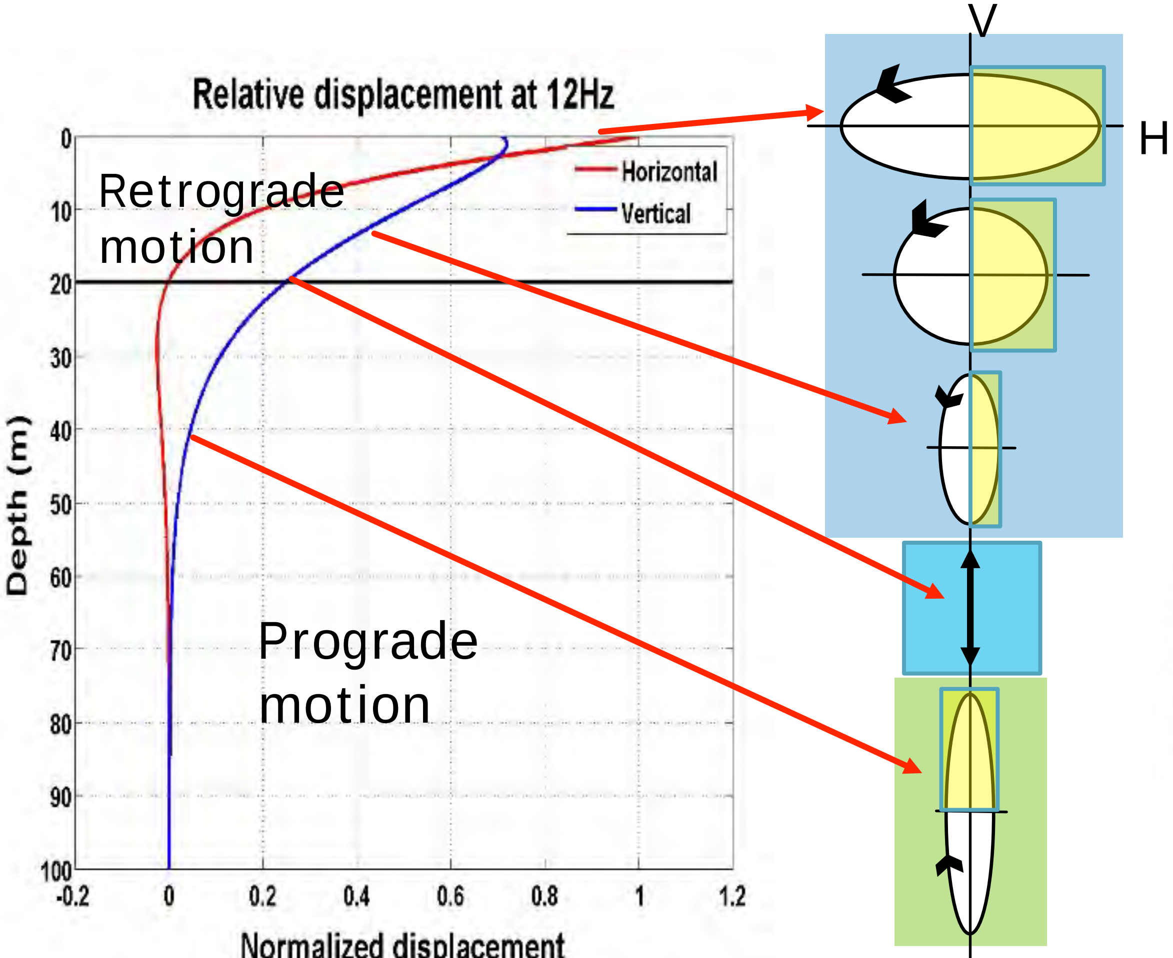


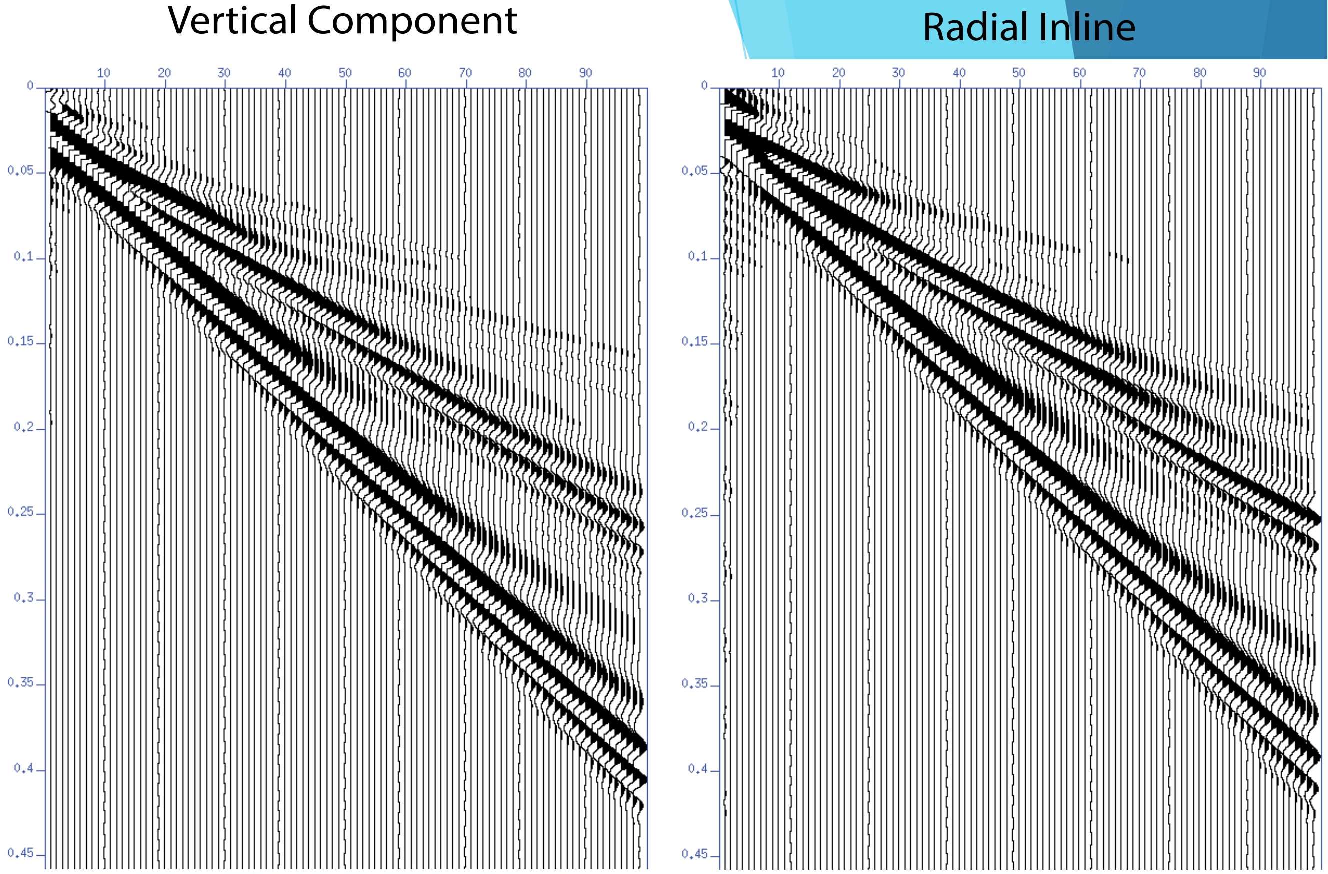


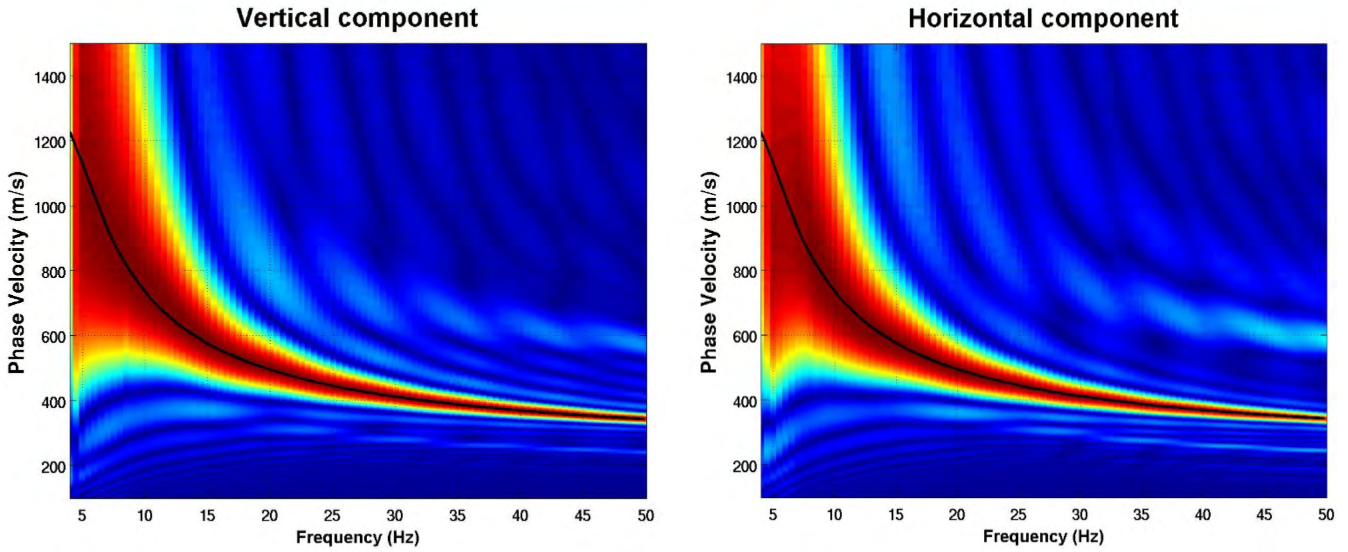
Shear wave velocity profile

Multicomponent surface wave approach

- Utilization of both radial and vertical sensors to improve shear wave velocity estimates from Rayleigh wave motion







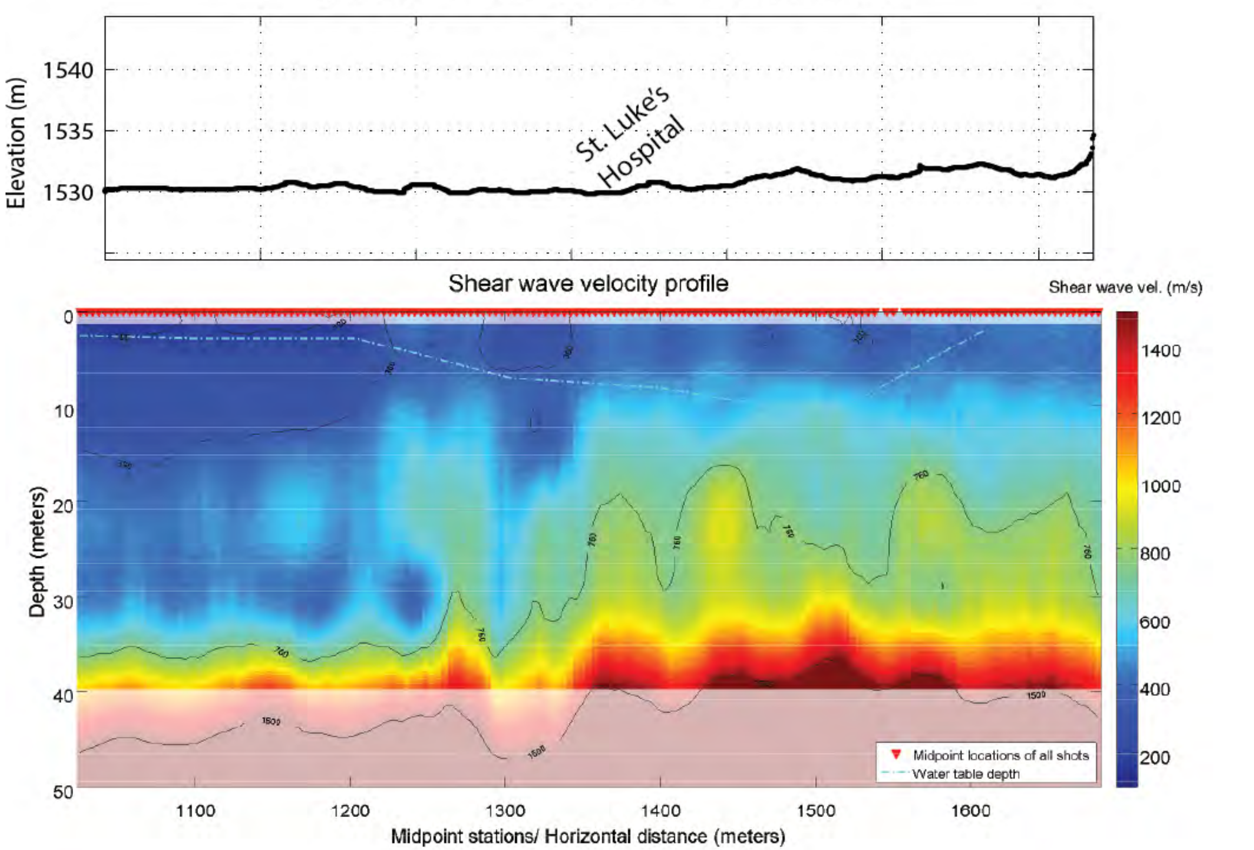
Integrative product

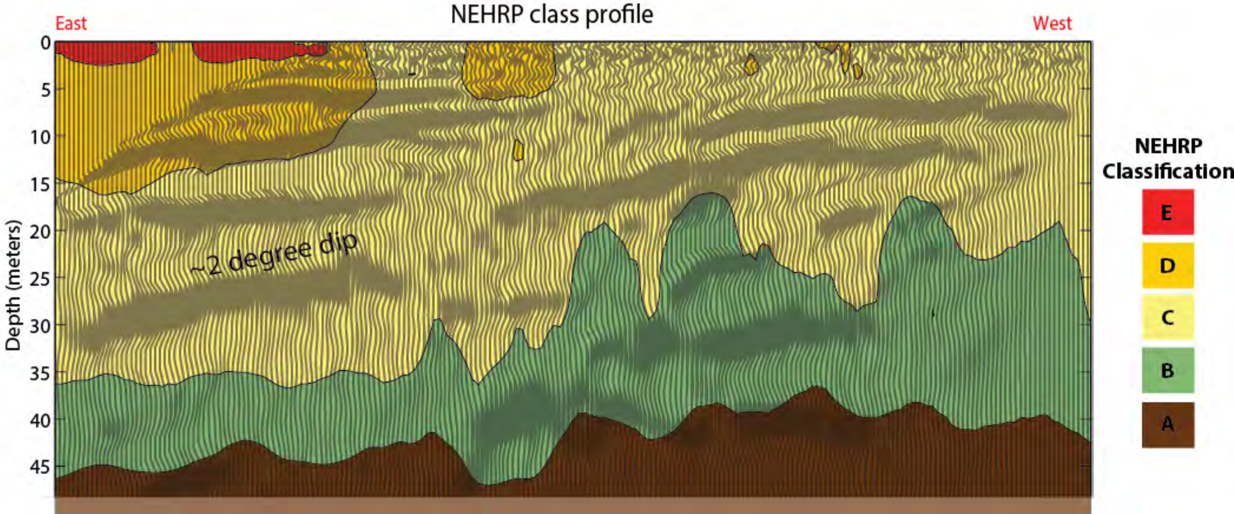
- Water table depth
- Vs profile
- Reflection profile
- NEHRP class for sediment type

McCall	Forest Street	Park Street	First Street	Lenora Street	Idaho Street	Second Street	Mill Street
Reference Station	1304	2122	3142	4118	5126	8042	
Vs 5	279	237	223	201	202		
Vs 10	322	264	244	234	234		
Vs 20	359	308	289	284	291		
Vs 30	432	318	340	298	323		
Vs 40	491		370		351		
Vs 30 NEHRP class	C1	D3	D3	D2	D3		
Average profile water table depth (meters)	7	3	2.7	7	3.5		
Max depth of shear wave velocity confidence (meters)	39	31	44	34	51	22	43

	NEHRP Class		Sediment Type
E	E		Soft soil
D	D	D1	Stiff soil
		D2	
		D3	
C	C	C1	Very dense soil/soft rock
		C2	
		C3	
B	B		Rock
A	A		Hard Rock

1) Forest Road- McCall, Idaho

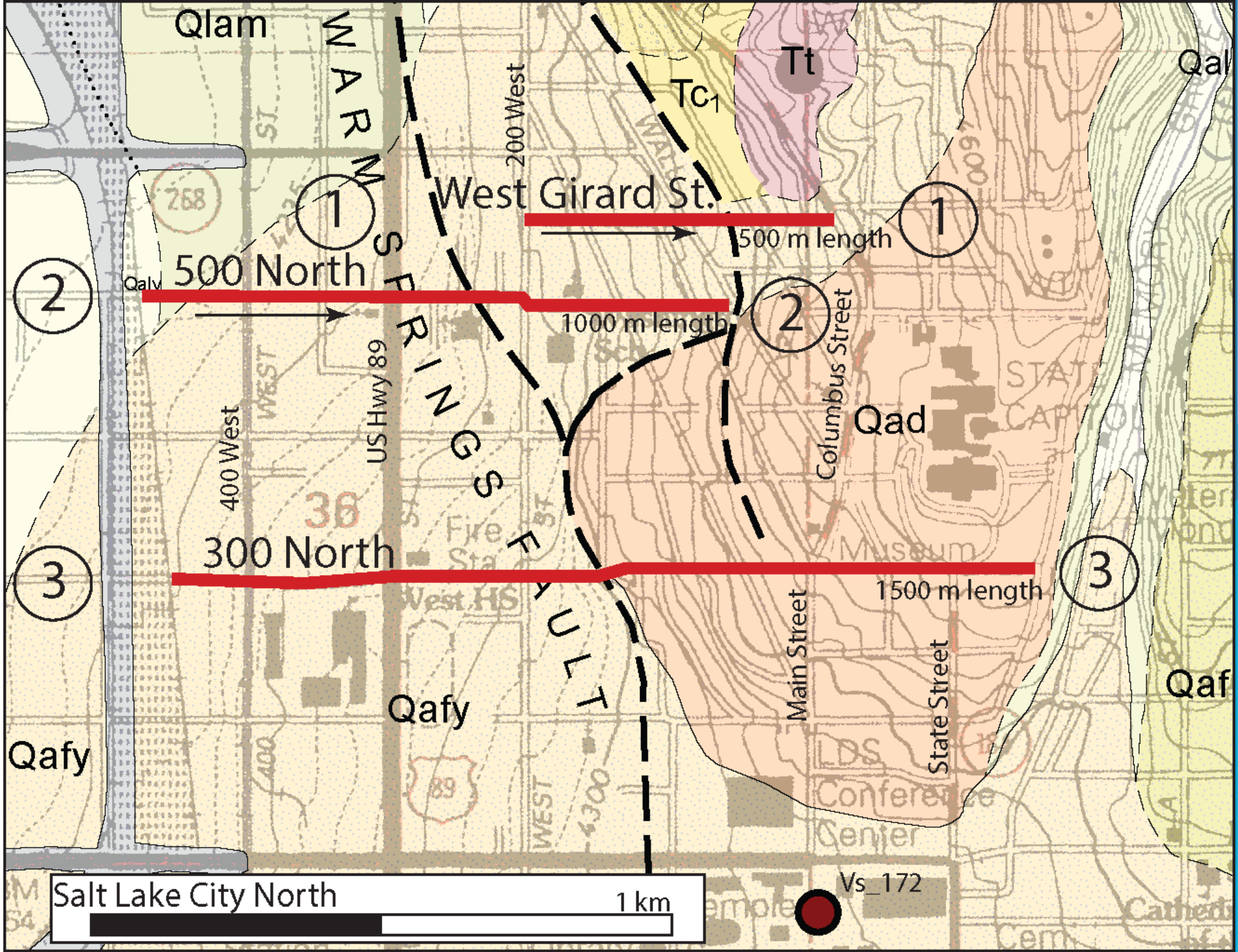




North Salt Lake City

- Locate and characterize the southern extension of the Warm Springs fault
- Three west – east profiles to identify two possible fault strands

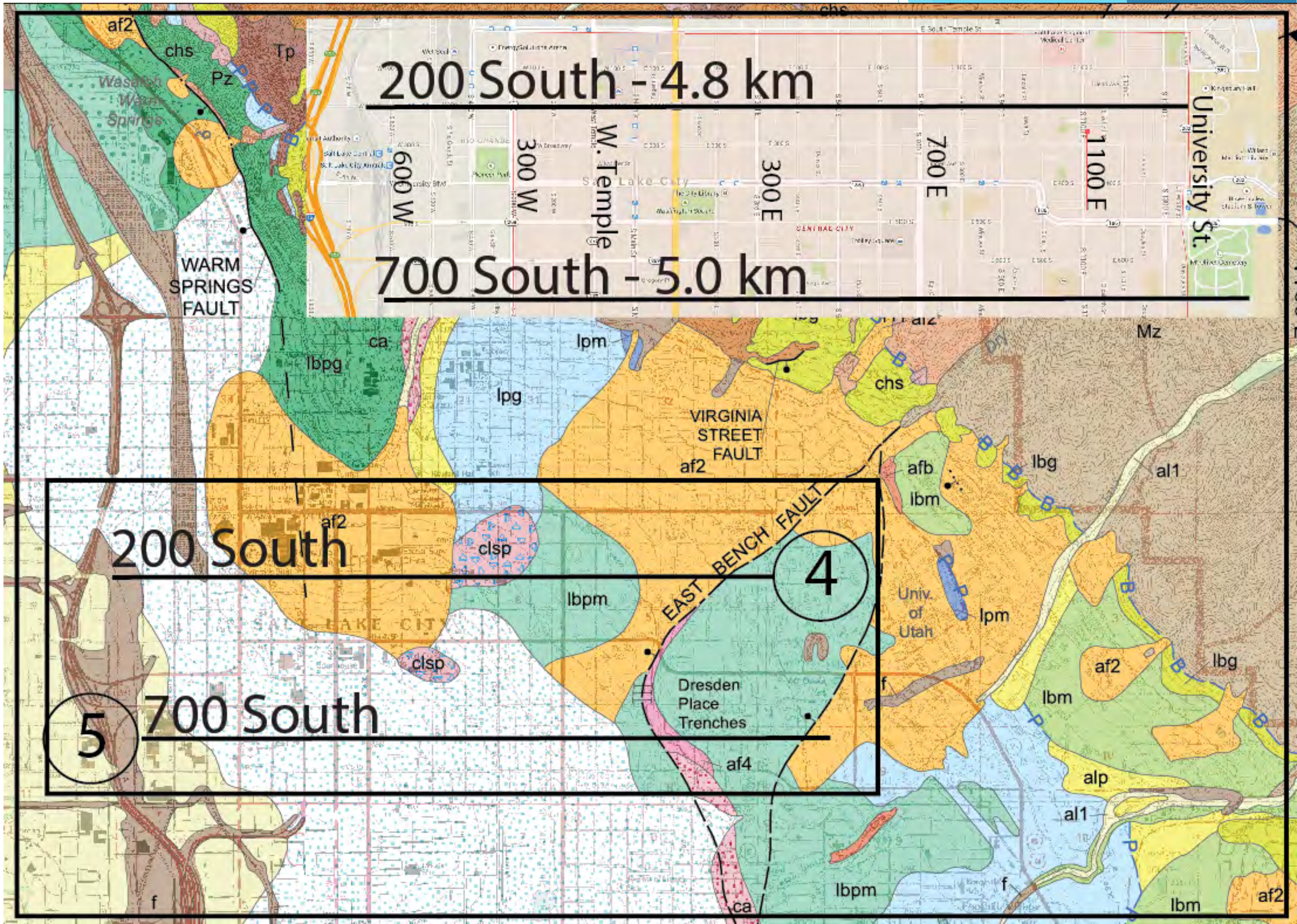
1. West Girard
2. 500 North
3. 300 North (RR Tracks to Capitol building)



Downtown Salt Lake City

- Locate and characterize the southern extension of the Warm Springs fault and northern extension of the East Bench fault
- Two west – east profiles

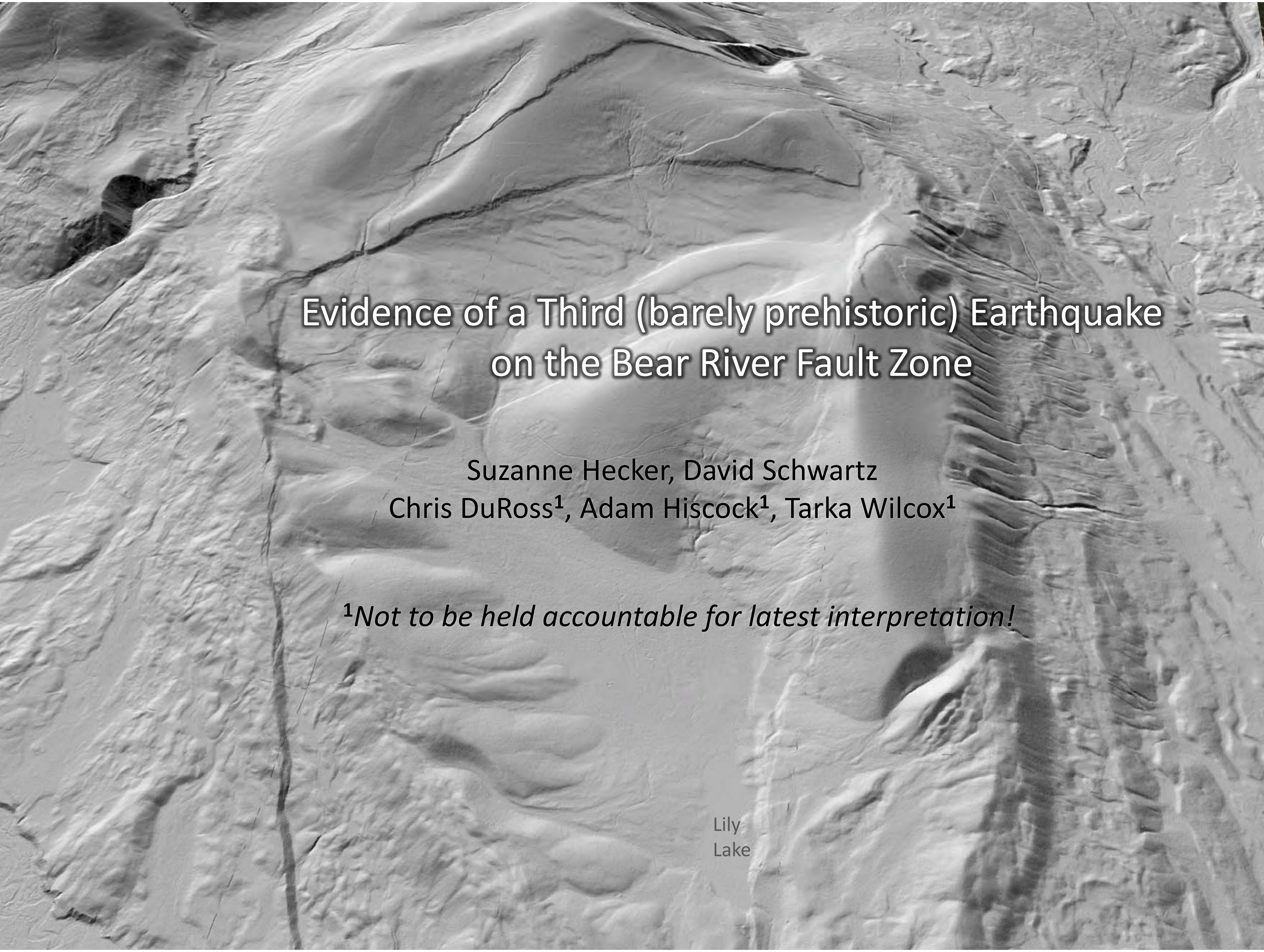
1. 200 South (across Salt Palace grounds to UU campus)
2. 700 South (Interstate to UU campus)



Evidence of a Third (barely prehistoric) Earthquake on the Bear River Fault Zone

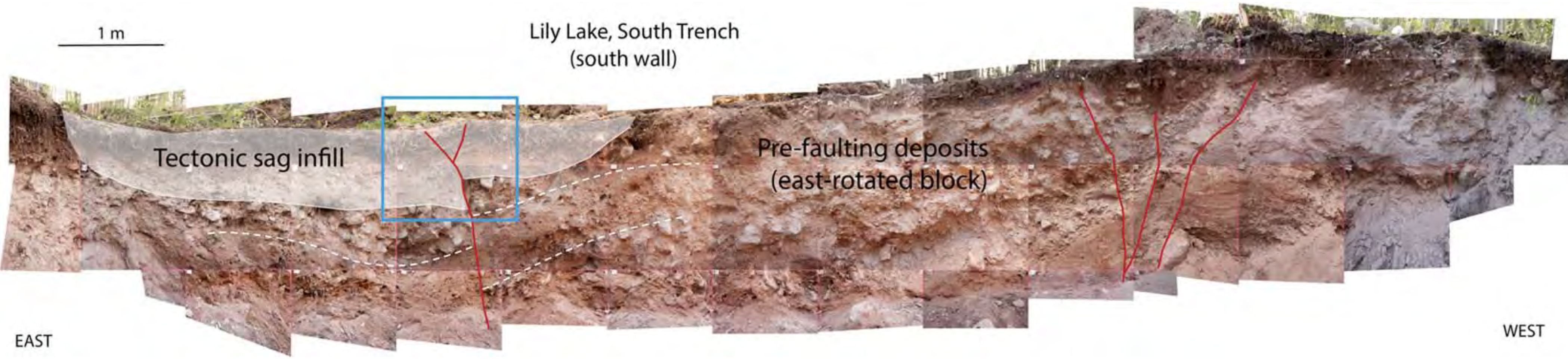
Suzanne Hecker, David Schwartz
Chris DuRoss[1], Adam Hiscock[1], Tarka Wilcox[1]

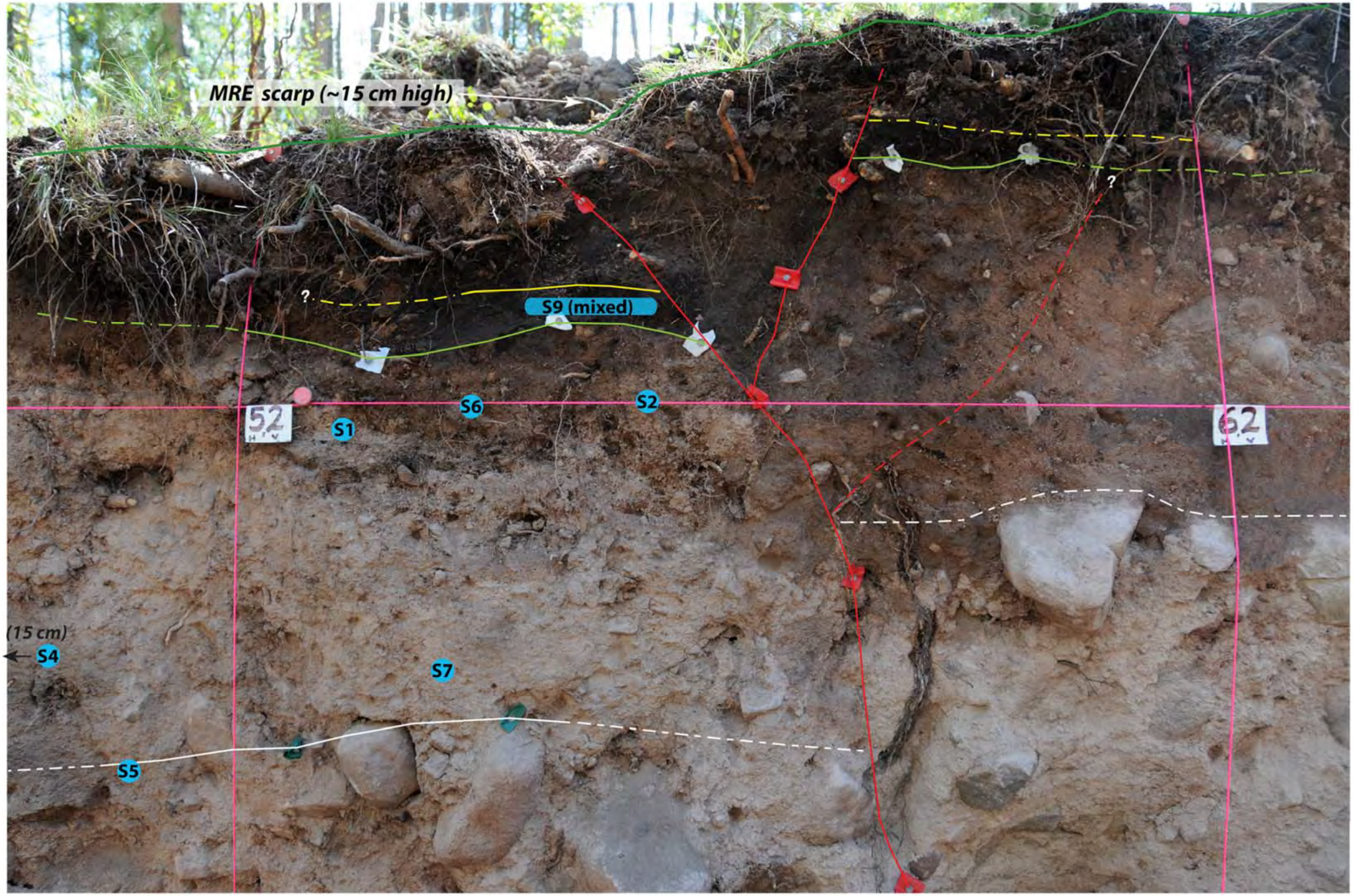
[1]*Not to be held accountable for latest interpretation!*

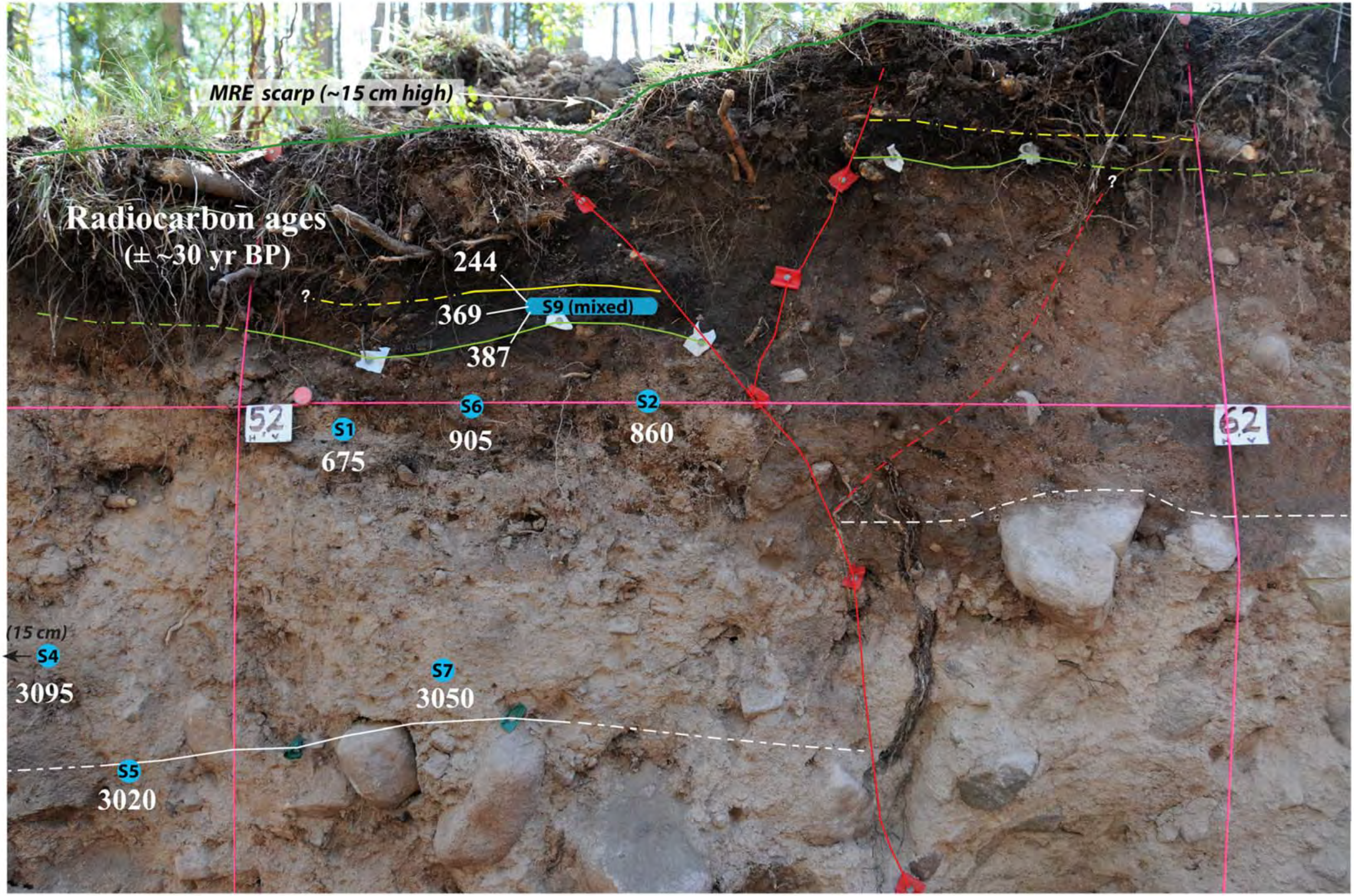


Wasatch fault zone
Provo
American Fork
Brighton
Sandy
Park City
Summit Park
Salt Lake City
Coalville
Morgan
Bear River fault zone
Lincoln Hwy
Evanston
Wyoming
Utah


N
0.5 km
Northward view-
uphill facing scarp
Lily
Lake
Lily Lake trench site
Big Burn site
Image USDA Farm Service Agency


1 m
Lily Lake, South Trench
(south wall)
Tectonic sag infill
Pre-faulting deposits
(east-rotated block)
EAST
WEST


MRE scarp (~15 cm high)
?
S9 (mixed)
?
52
S1
S6
S2
62
(15 cm)
S4
S7
S5

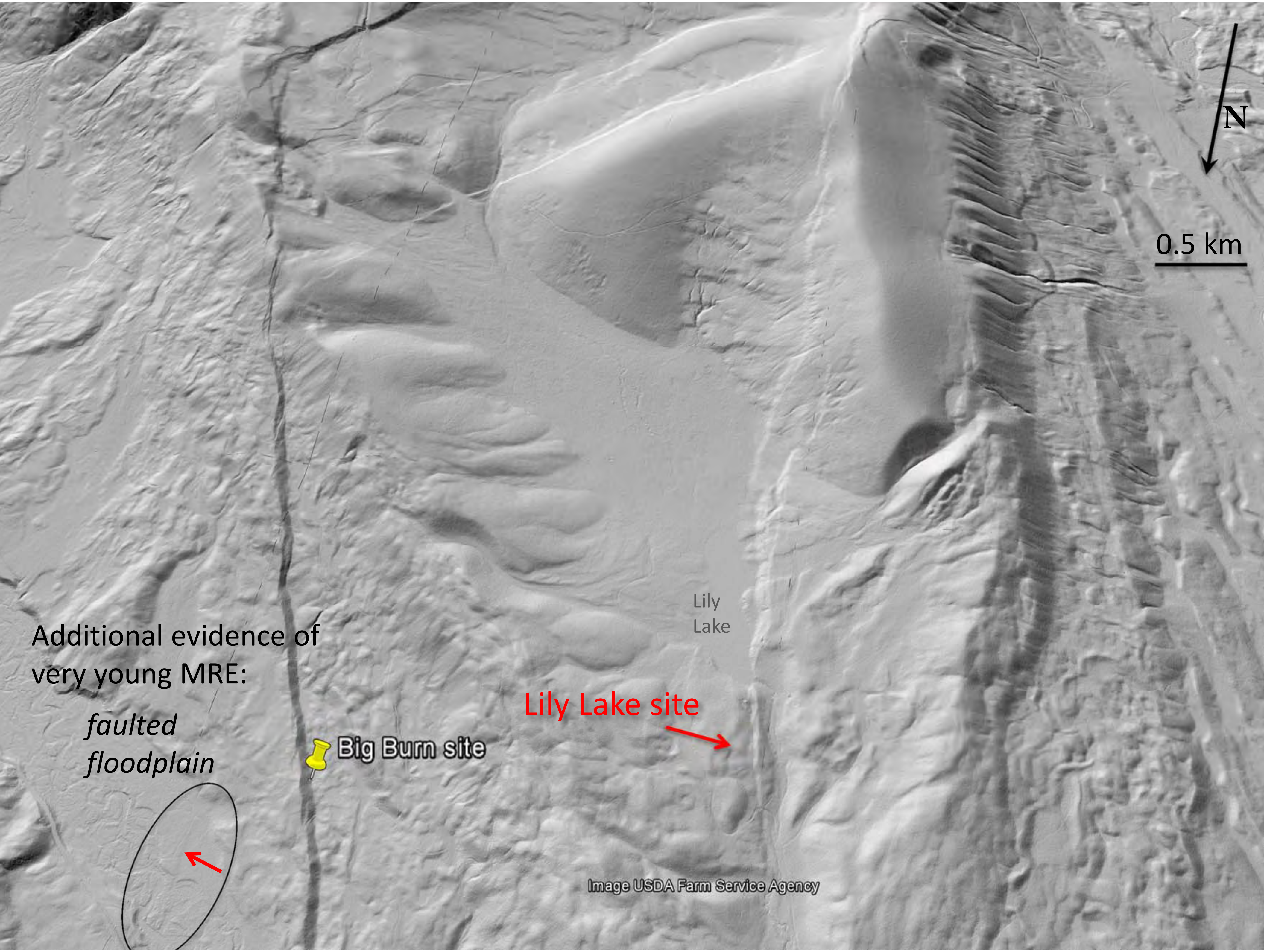


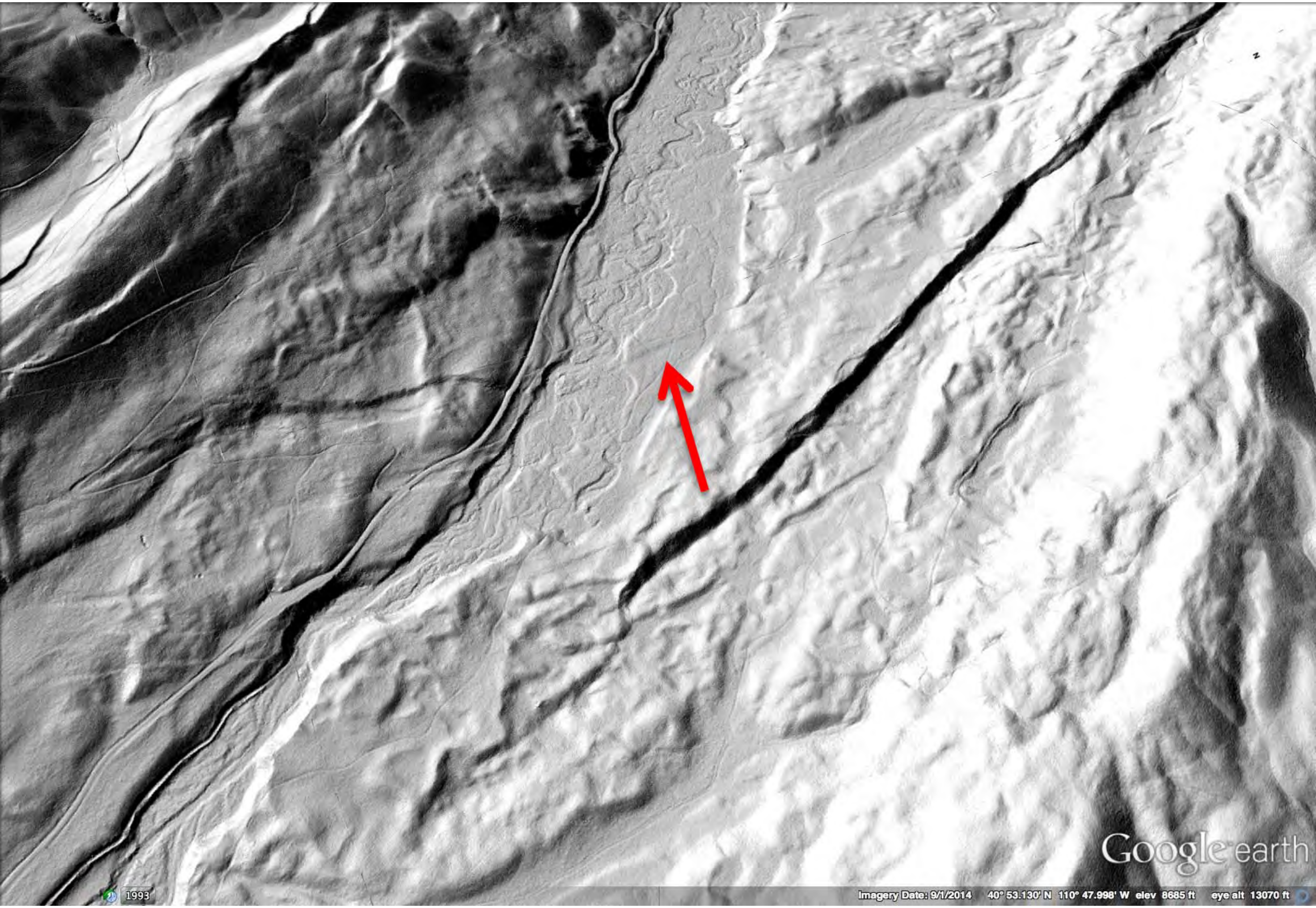
MRE scarp (~15 cm high)
Radiocarbon ages
(± ~30 yr BP)
244
369
S9 (mixed)
387
52
S1
675
S6
905
S2
860
62
(15 cm)
S4
3095
S7
3050
S5
3020

PaleoResearch Institute
RADIOCARBON RESULTS FOR MACROFLORAL REMAINS FROM BULK SOIL SAMPLE 9

Sample No.	Sample Identification	AMS ^{14}C Date*	1-sigma Calibrated Date (68.2%)	2-sigma Calibrated Date (95.4%)	* ^{13}C** ($^{o}/_{oo}$)
PRI-14-071-LLS-S-9-1	*Pinus* cone scale, charred	244 ± 22 RCYBP	310–280; 170–150 CAL yr. BP	320–280; 180–150; 10–(-11) CAL yr. BP	-23.6
PRI-14-071-LLS-S-9-2	*Pinus* cone scale, charred	369 ± 21 RCYBP	490–430; 360–330 CAL yr. BP	500–420; 400–310 CAL yr. BP	-24.3
PRI-14-071-LLS-S-9-3	*Pinus* needle, charred	387 ± 23 RCYBP	510–450; 350–330 CAL yr. BP	510–420; 380–320 CAL yr. BP	-25.7

Point of overlapping ages: ~320 CAL yr. BP
(**constraining the MRE to post ~1700 A.D.**)

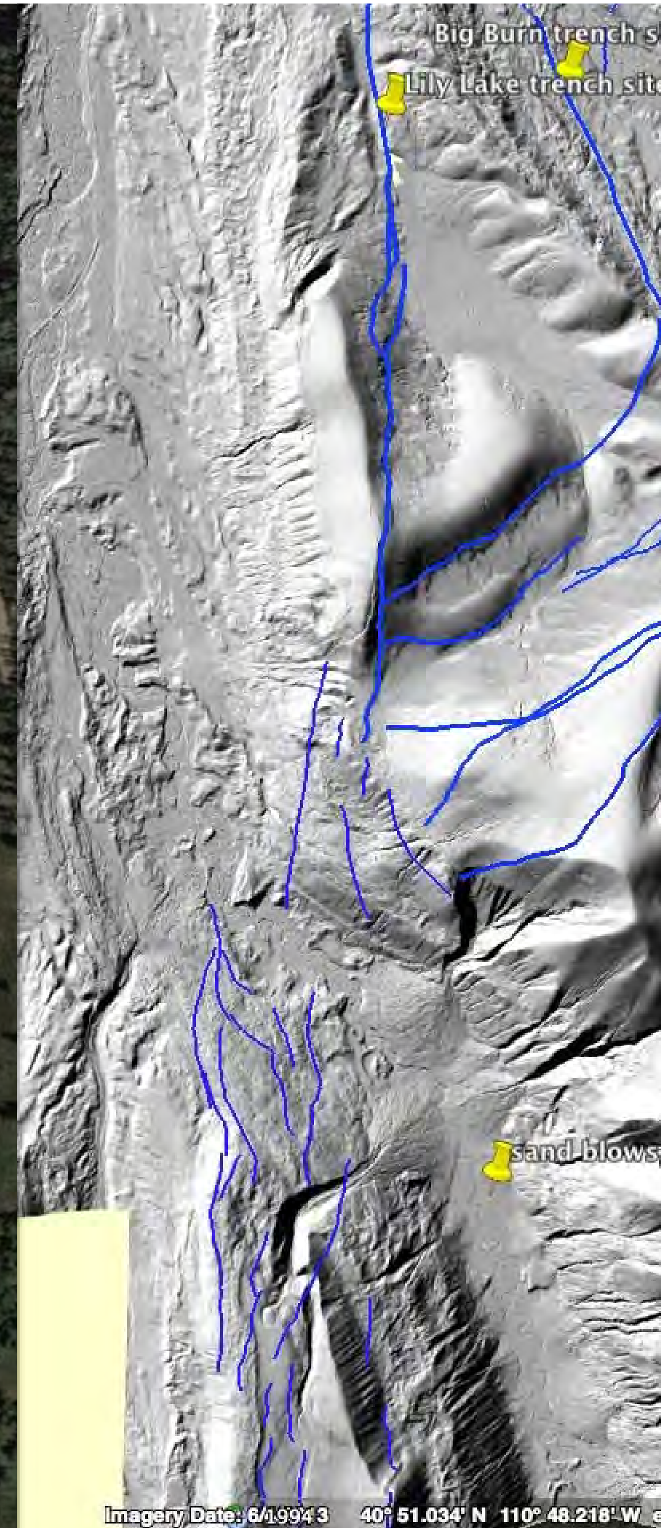

N
0.5 km
Lily
Lake
Additional evidence of
very young MRE:
faulted
floodplain
Big Burn site
Lily Lake site
Image USDA Farm Service Agency



Google earth
1993
Imagery Date: 9/1/2014 40° 53.130' N 110° 47.998' W elev 8685 ft eye alt 13070 ft

Additional evidence of very young MRE:

Sand blows (?) on Bear River floodplain

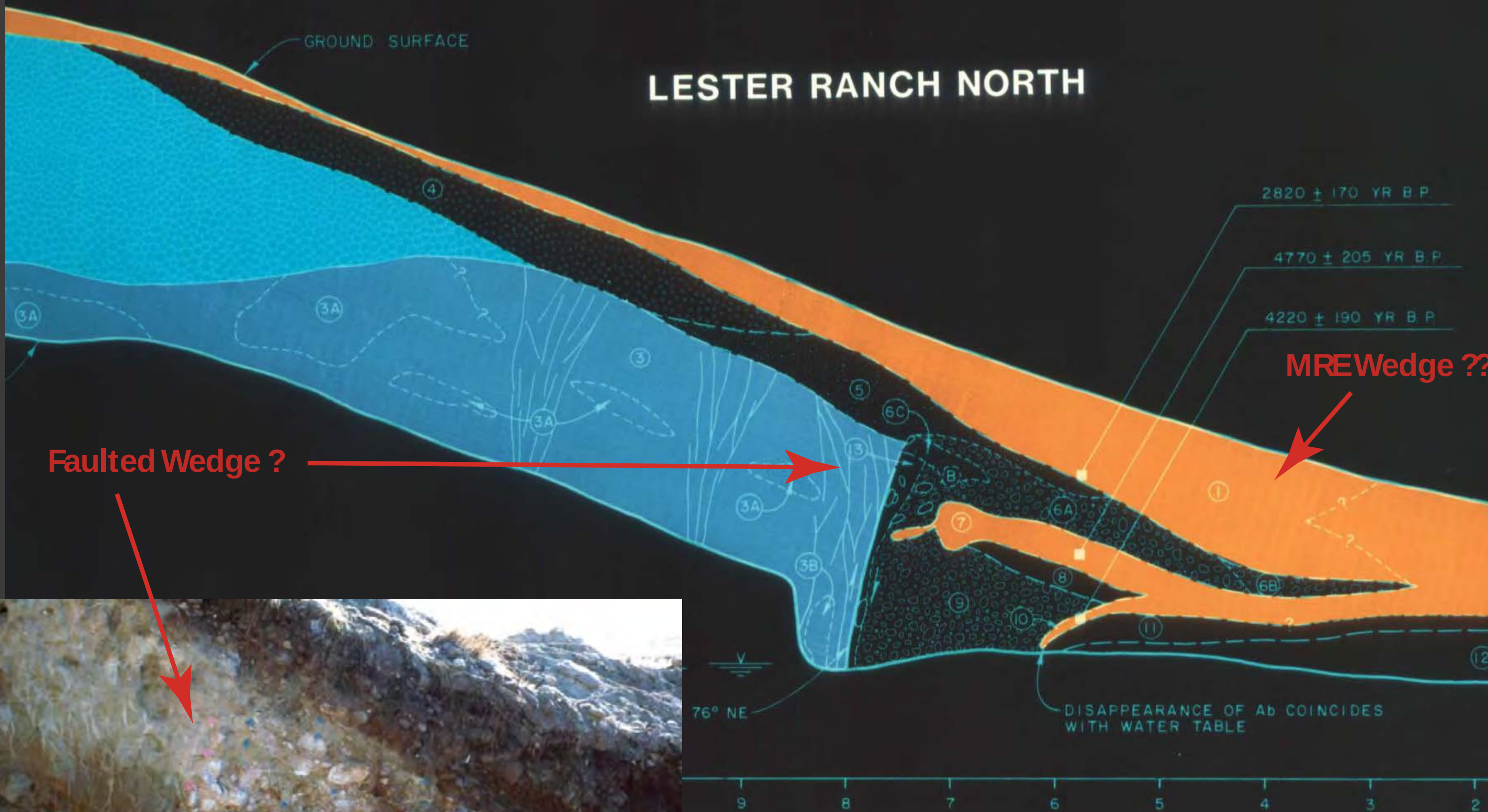


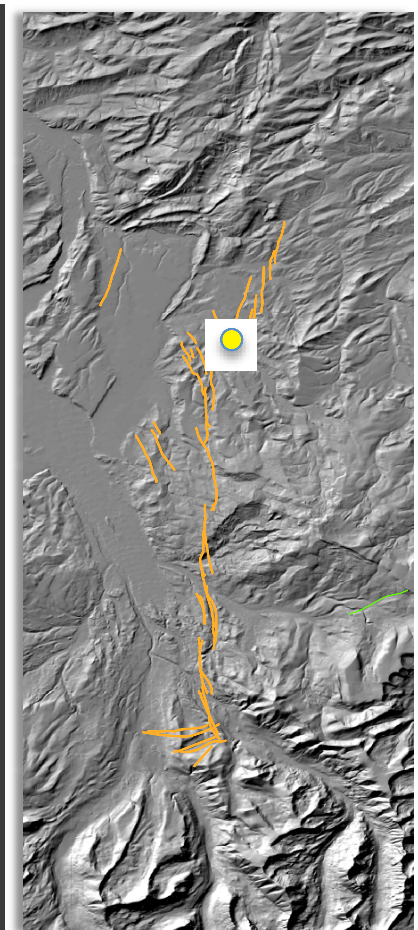
One of many circular depressions on Bear River floodplain

Circular depressions interpreted as sand blows: Bear River floodplain

Liquefaction-artesian fountain, Chilly Buttes, ID, 1983 Borah Peak earthquake

Possible Evidence of 3rd Event at North End of Fault....





(see West, 1993, 1994)

Lester Ranch North trench,
Bear River fault zone.

Geological Society of America

PENROSE CONFERENCE

June 22 – 29, 2015

American Association of Petroleum Geologists
American Geophysical Union
Association of Environmental & Engineering Geologists
Seismological Society of America
White Eagle Exploration

Extensional Reactivation of Thrust Faults, Coseismic Surface Rupture and Crustal Evolution at the Contemporary Margin, Basin and Range Province, Wyoming and Utah

http://www.geosociety.org/penrose/15wyoming.htm

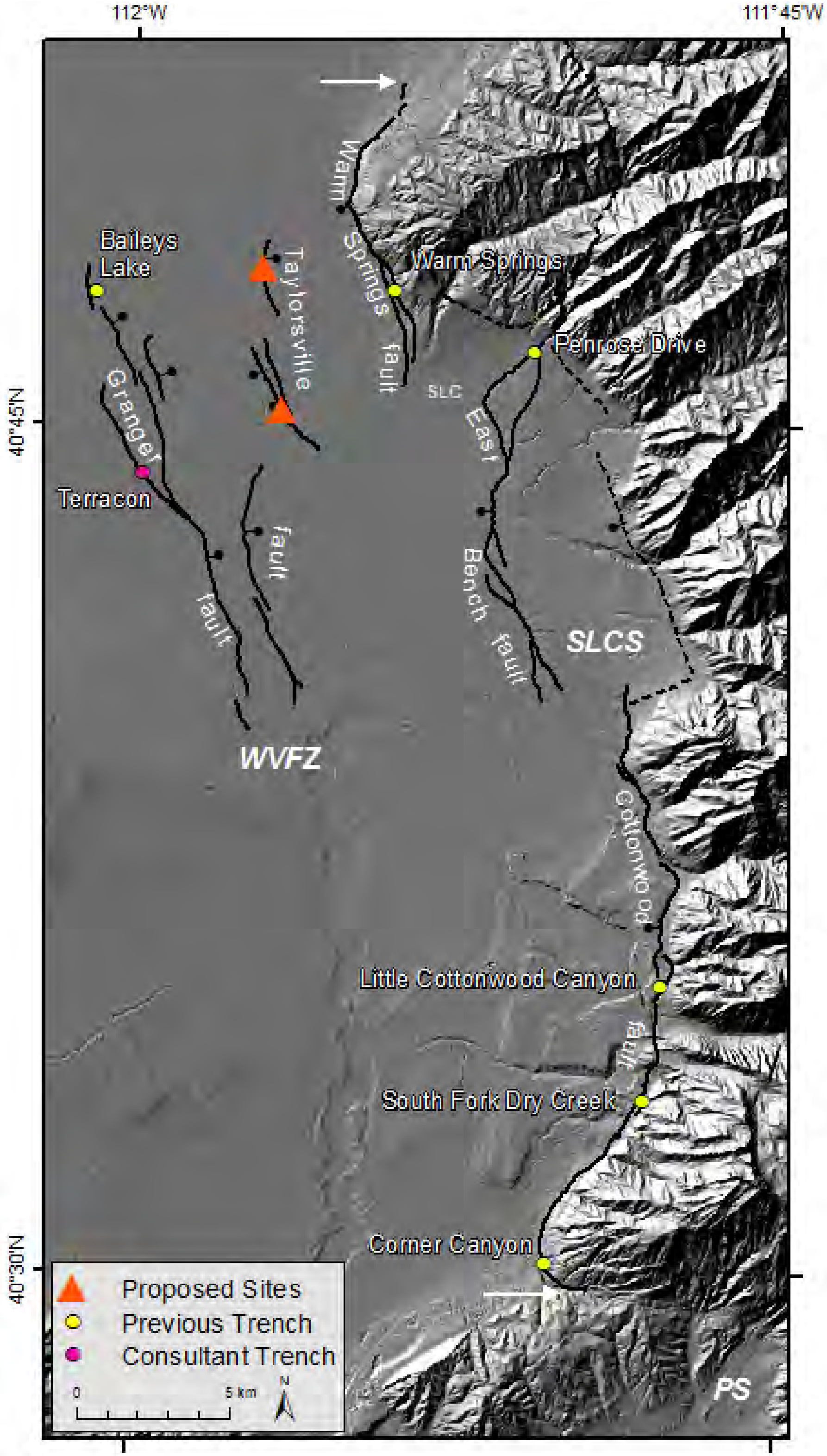
Update on planned trenching on the Taylorsville Fault

Overview

- UGS with assistance from the USGS Golden Office
- Tentative dates: August 24 – September 4th, 2015
- Currently working on site permissions

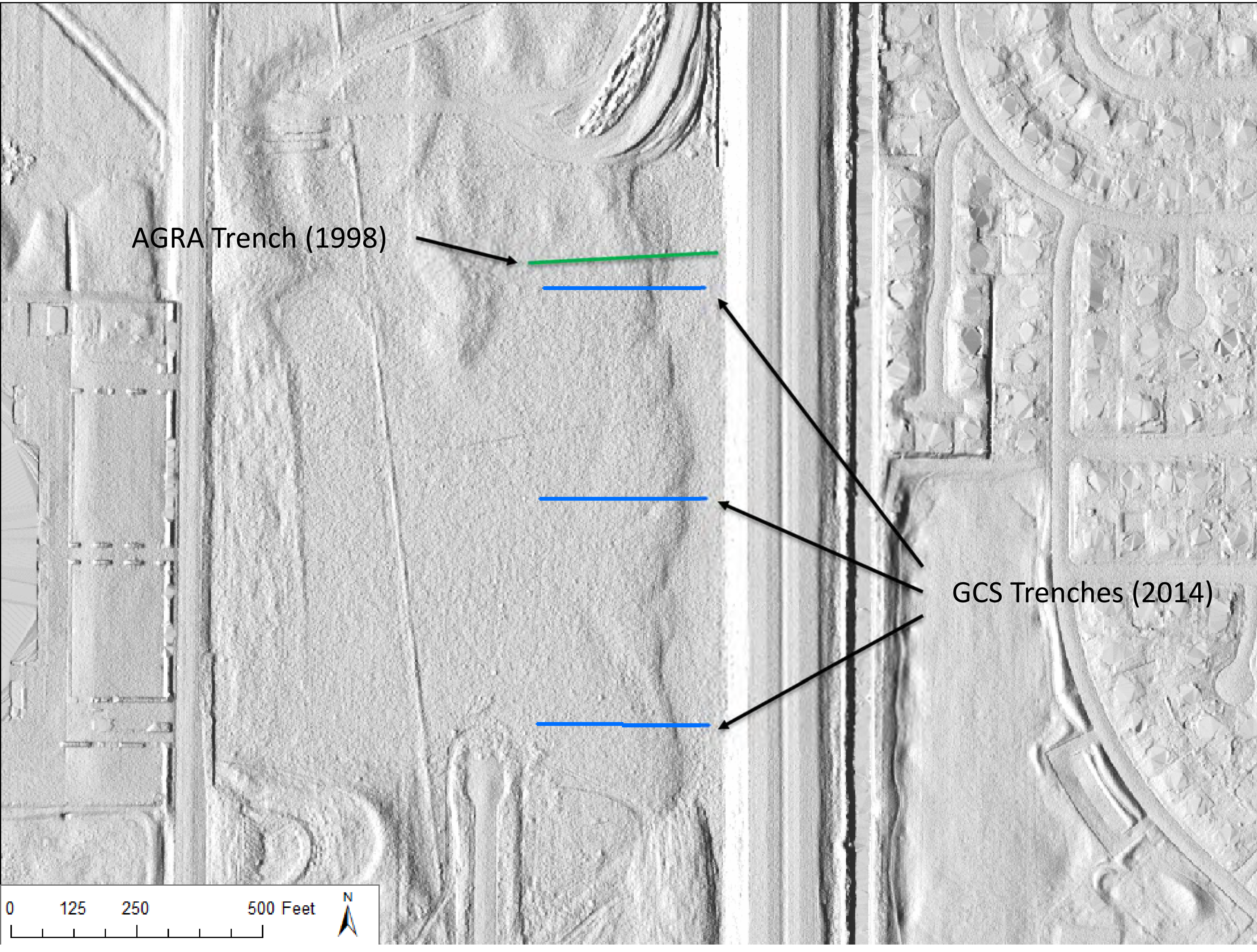
Site Location

- Taylorsville strand of the West Valley Fault Zone
- North site is primary site, south site is backup site
- North site – appx. 0.5m scarp, east dipping
- Backup site – appx. 1.5m scarp, west dipping

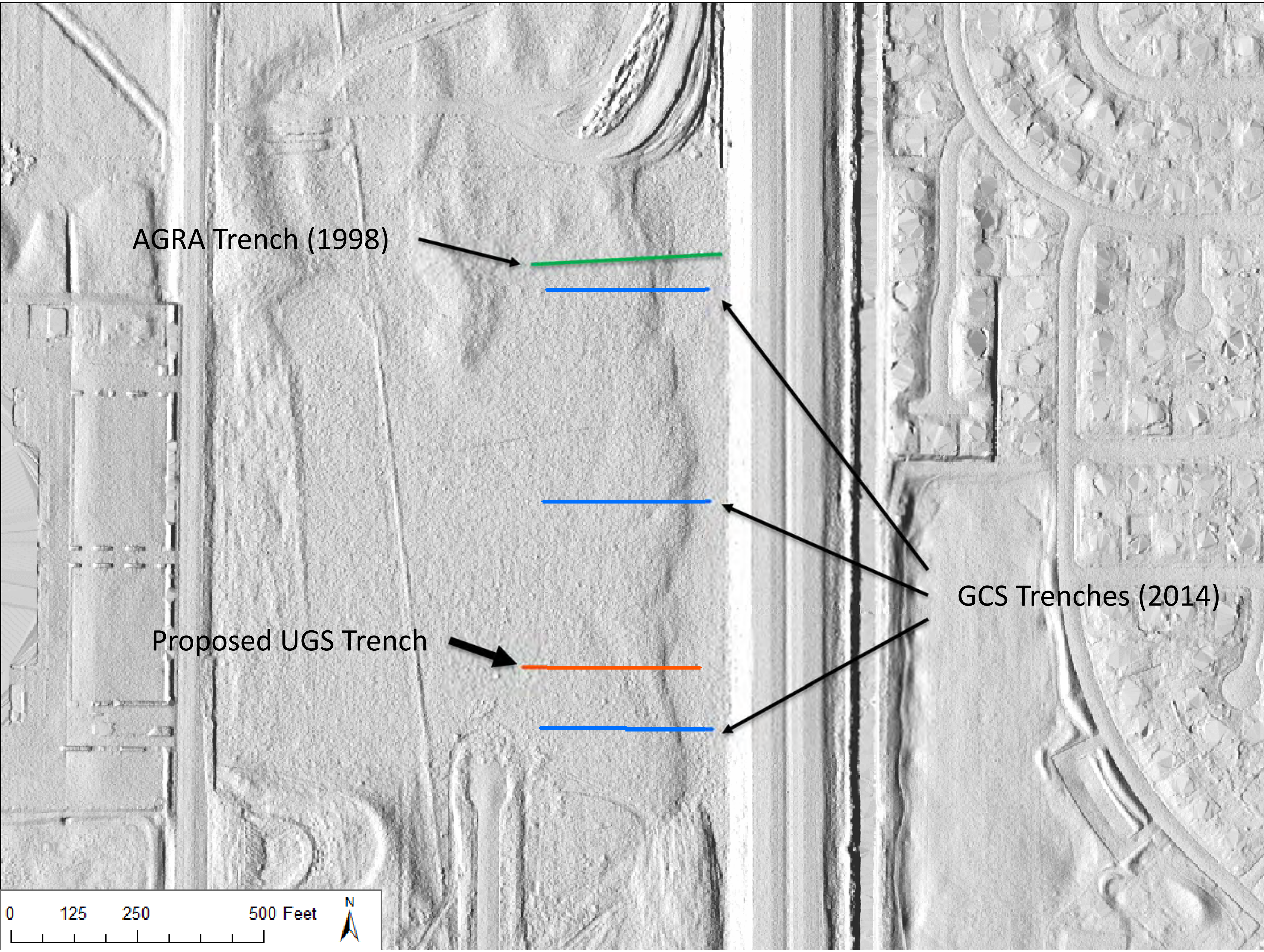


North Site – GCS Geoscience Trenches

- Trenched in August 2014 by Greg Schlenker of GCS Geoscience for industrial land pre-sale feasibility study
- Dug 3 trenches along scarp, encountered ground water at appx. 3 foot depth.
- North and South trenches showed good fault exposure, middle trench showed broad zone of down to east warping with a couple of possible small shears



AGRA Trench (1998)
GCS Trenches (2014)
0
125
250
500 Feet
N



AGRA Trench (1998)
GCS Trenches (2014)
Proposed UGS Trench
0
125
250
500 Feet
N


Airport

Backup Site

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

Chris DuRoss and Mike Hylland
Utah Geological Survey, Salt Lake City, UT

Walter Arabasz, James Pechmann, and Robert Smith
Department of Geology and Geophysics, University of Utah, Salt Lake City, UT

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

11 February 2015

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 and results will be released by end of 2015.

WGUEP Members

Ivan Wong, URS (Chair)
Bill Lund, UGS (Coordinator)
Mark Petersen, USGS (Sponsor)
Tony Crone, USGS (Sponsor)
Walter Arabasz, UUSS
Chris DuRoss, UGS
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, 6.5 and 6.75) in the Wasatch Front region for a range of intervals varying from 30 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 final forecast will be reviewed by the UGS, USGS, and NEPEC.
- There will be a media release of the WGUEP results. Project 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

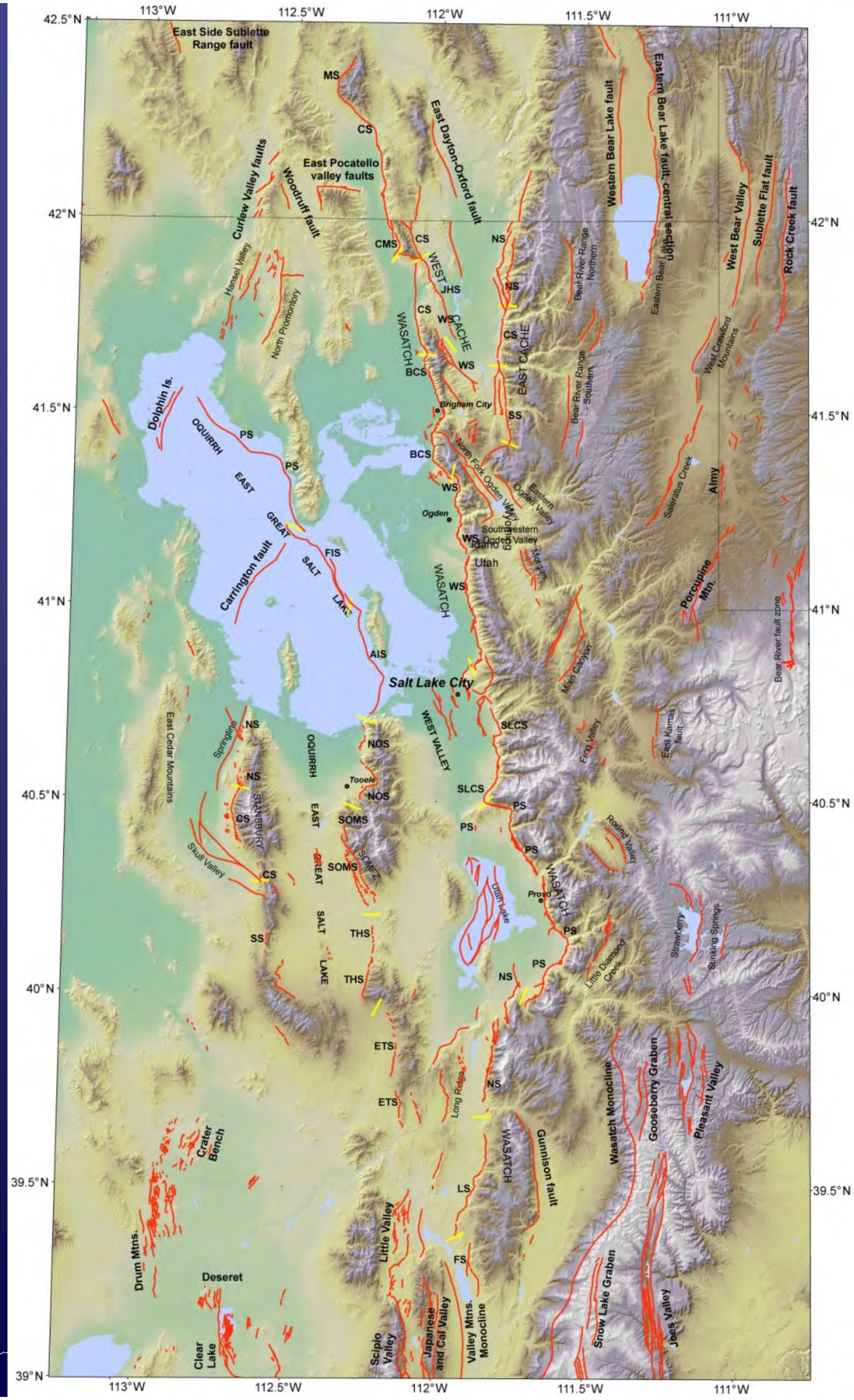
- Time-dependent probabilities were calculated for Wasatch and the Great Salt Lake fault zones where the data is available on the expected mean frequency of earthquakes and the elapsed time since the most recent large earthquake.

- 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.

WGUEP Wasatch Front



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

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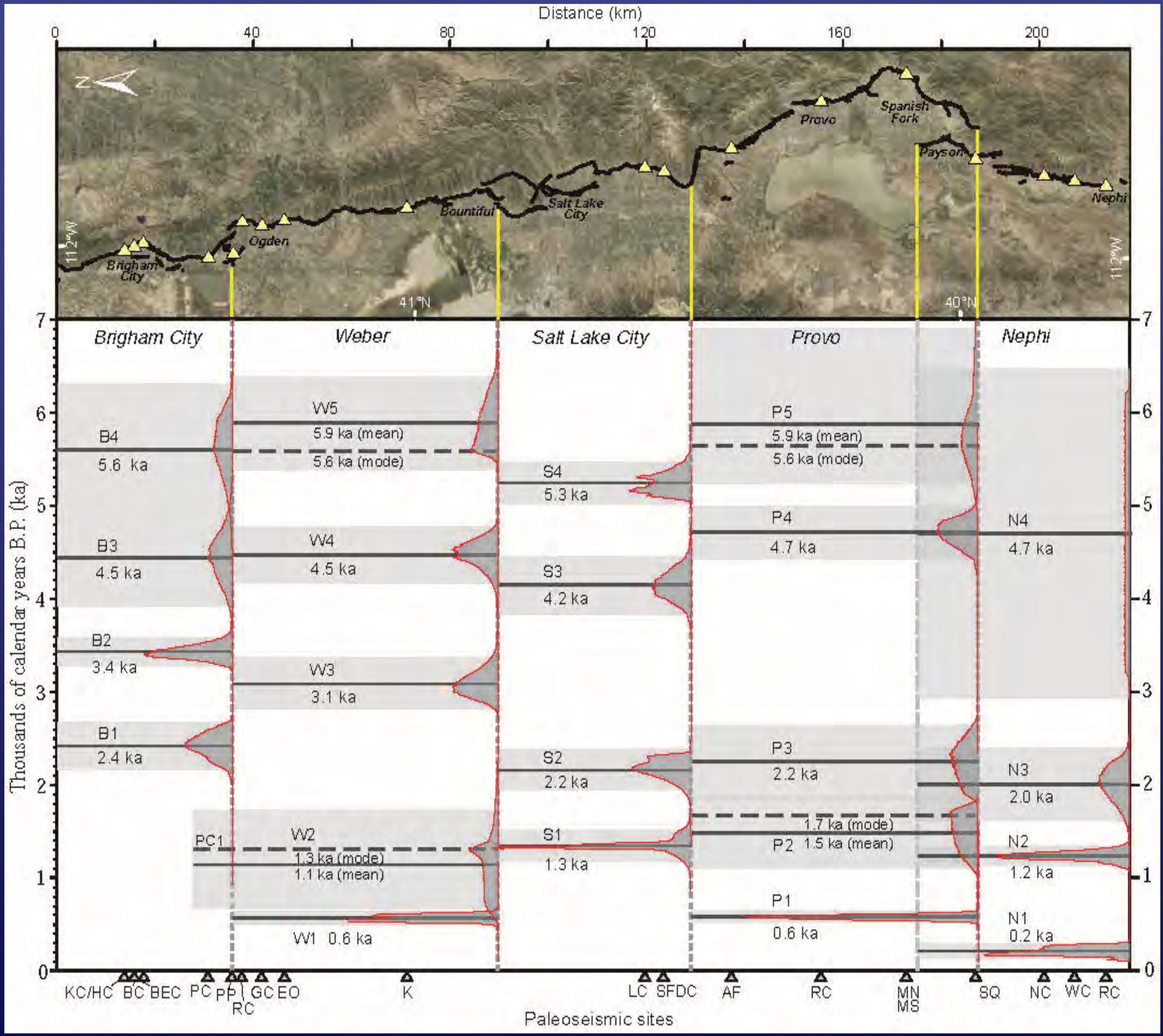
Single-Segment Rupture Model for the Central WFZ



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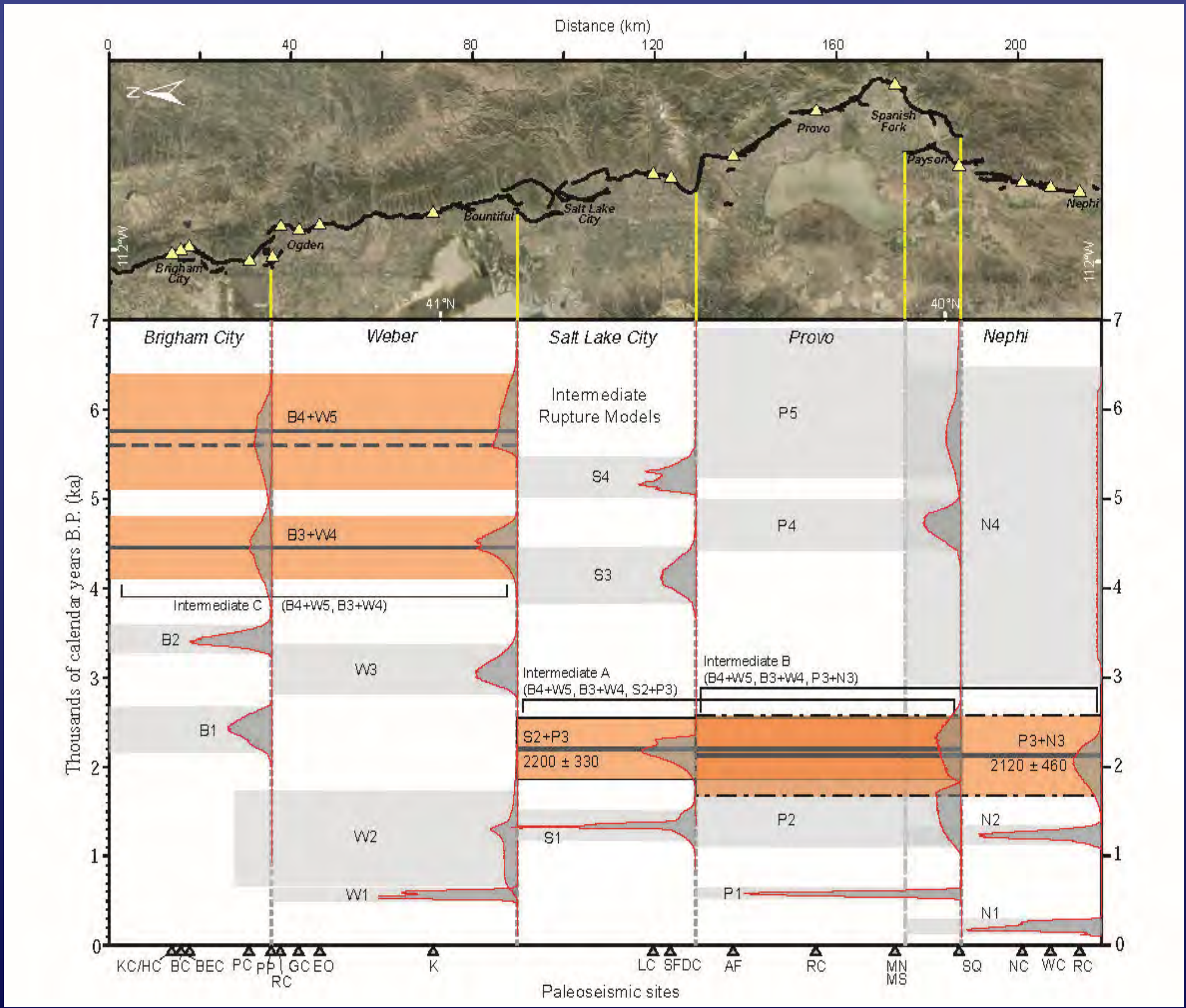
Intermediate Rupture Models for the Central WFZ

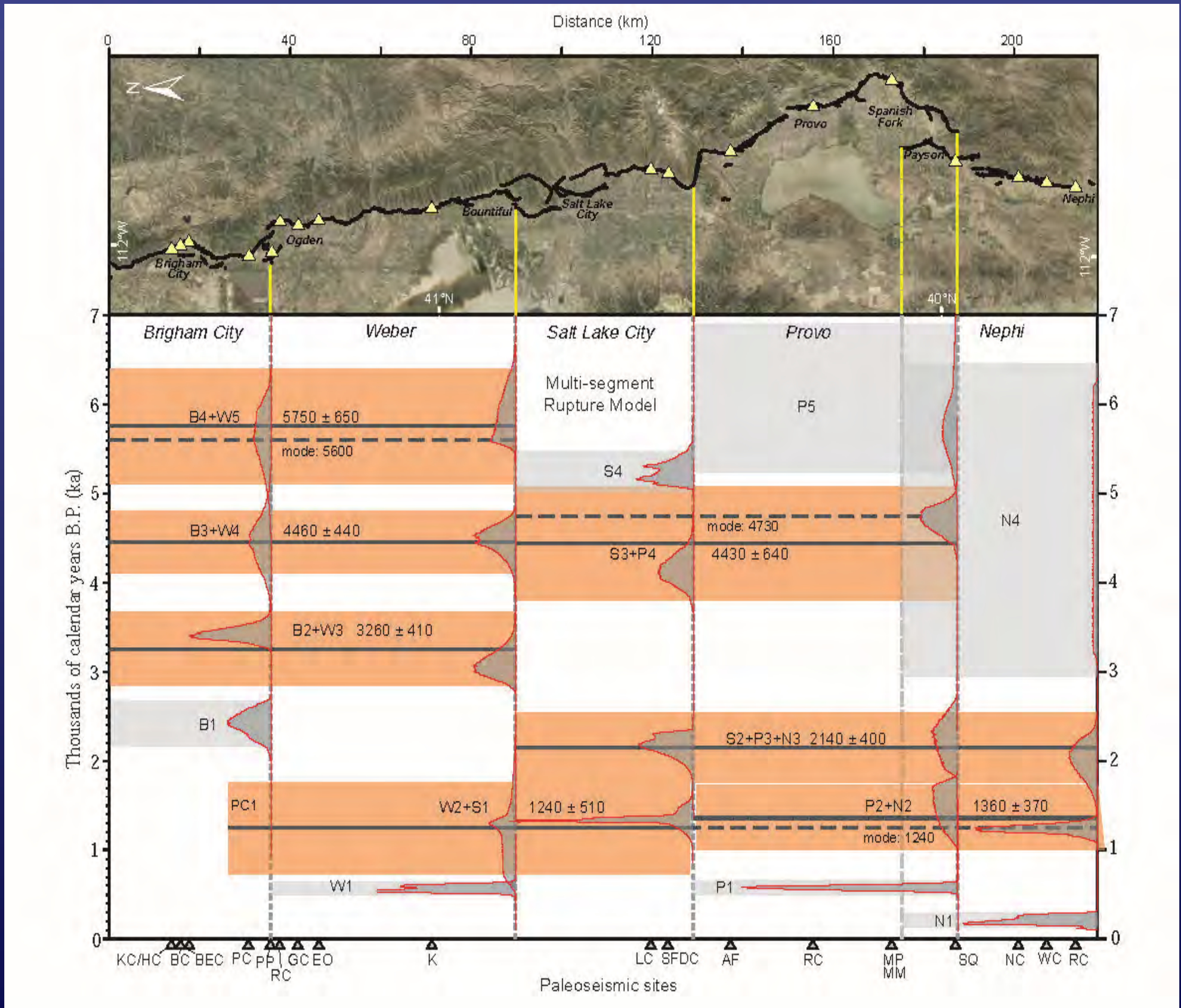
A – B4+W5, B3+W4 and S2+P3

B – P3+N3 in place of S2+P3

C – B4+W5 and B3+W4



Multi-Segment Rupture Models for the Central WFZ



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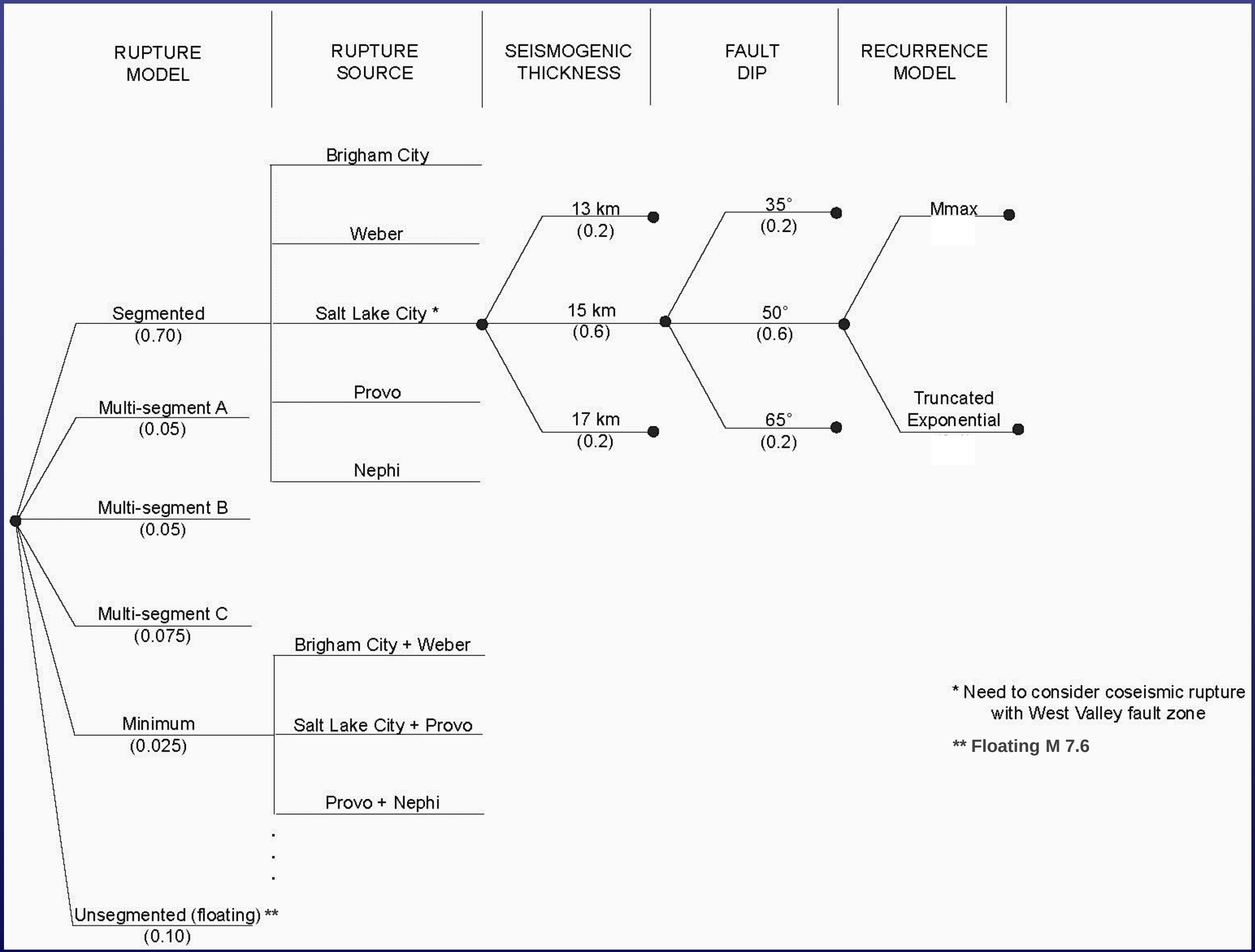
Generalized Logic Tree for Calculating the Recurrence of the Central Segments of WFZ



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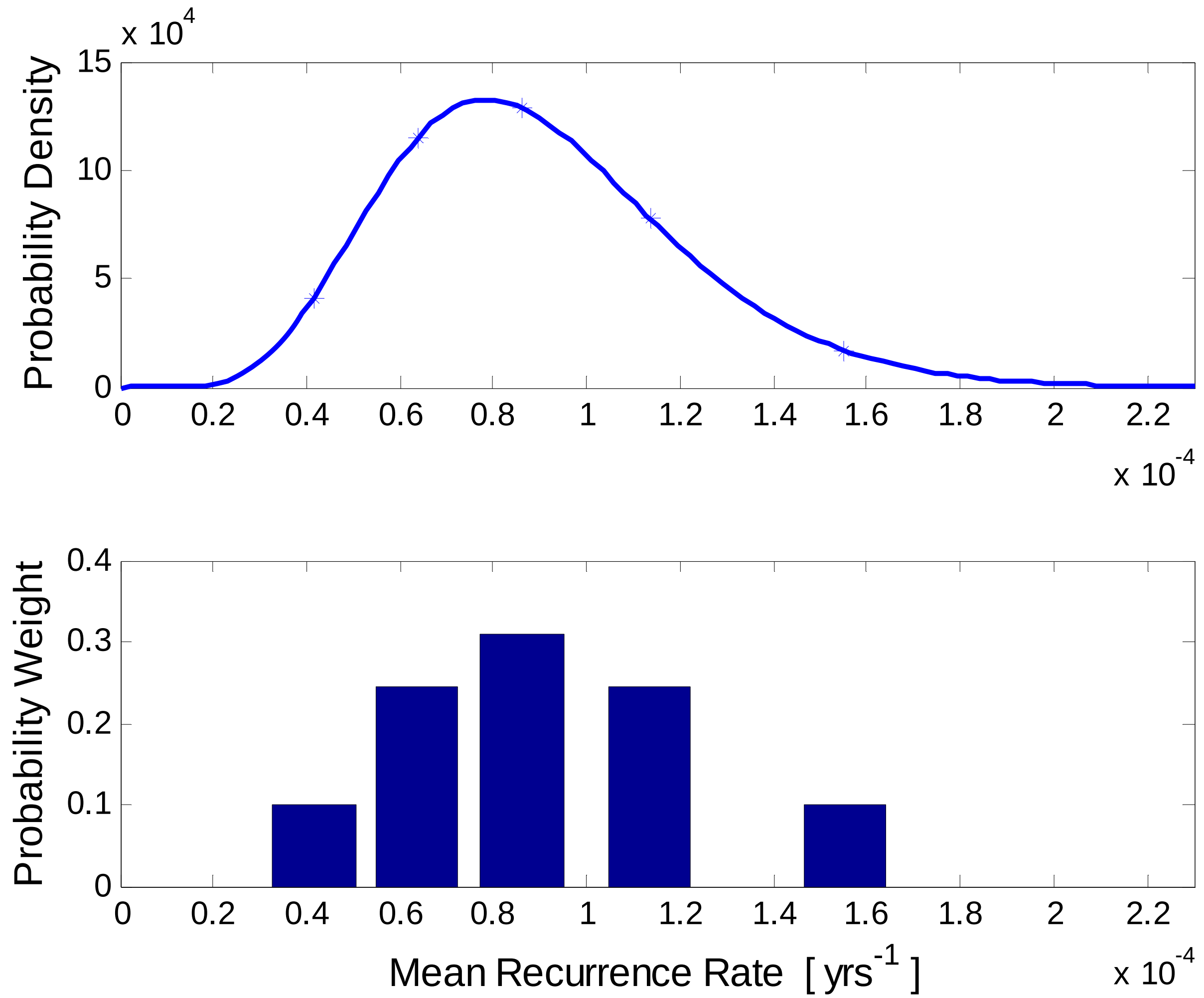
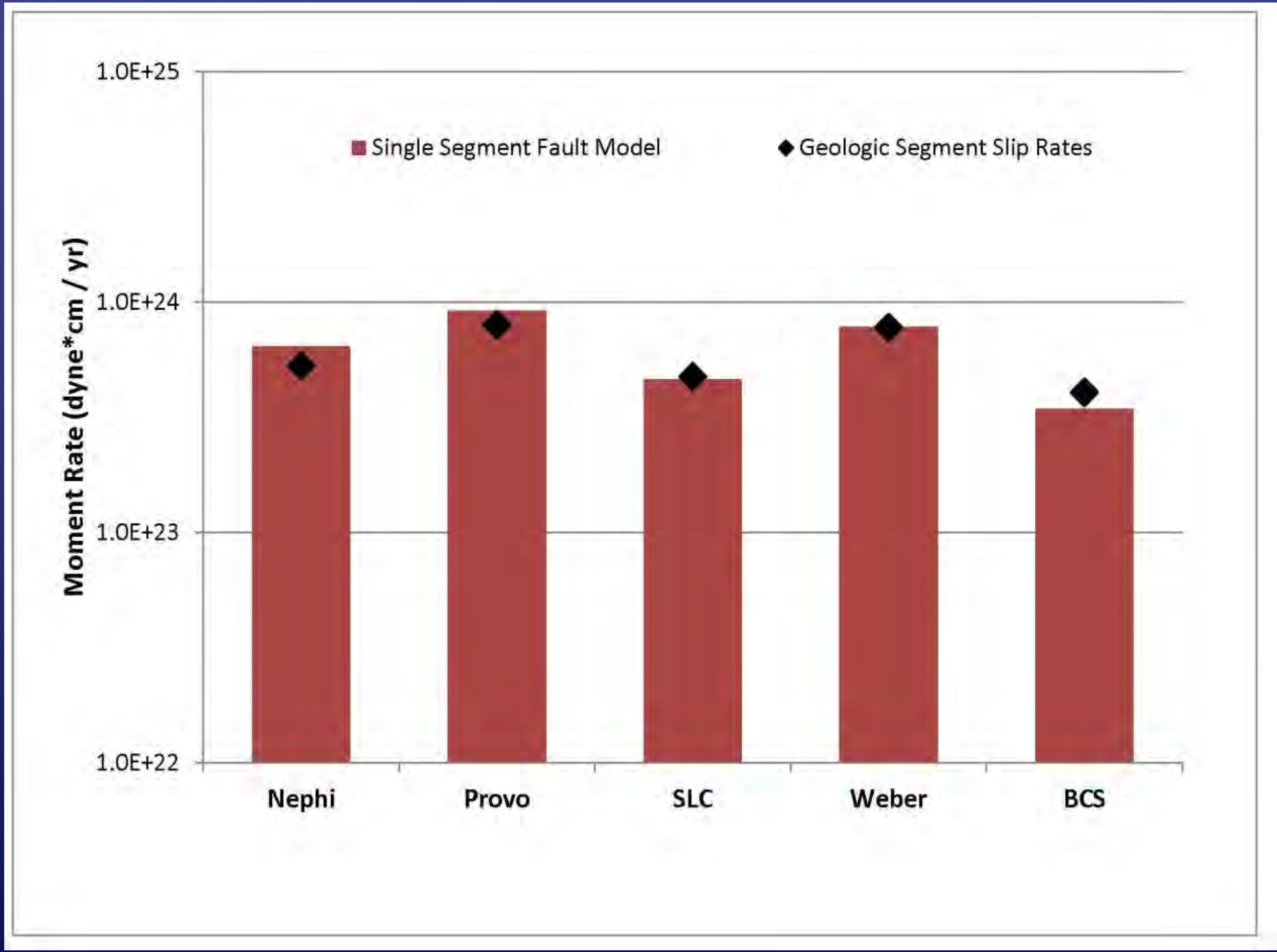
Calculating Recurrence Intervals



Ex. So. Oquirrh, 7 events in 89,011 yrs

Moment Rates for WFZ Central Segments – Preferred Rupture Model



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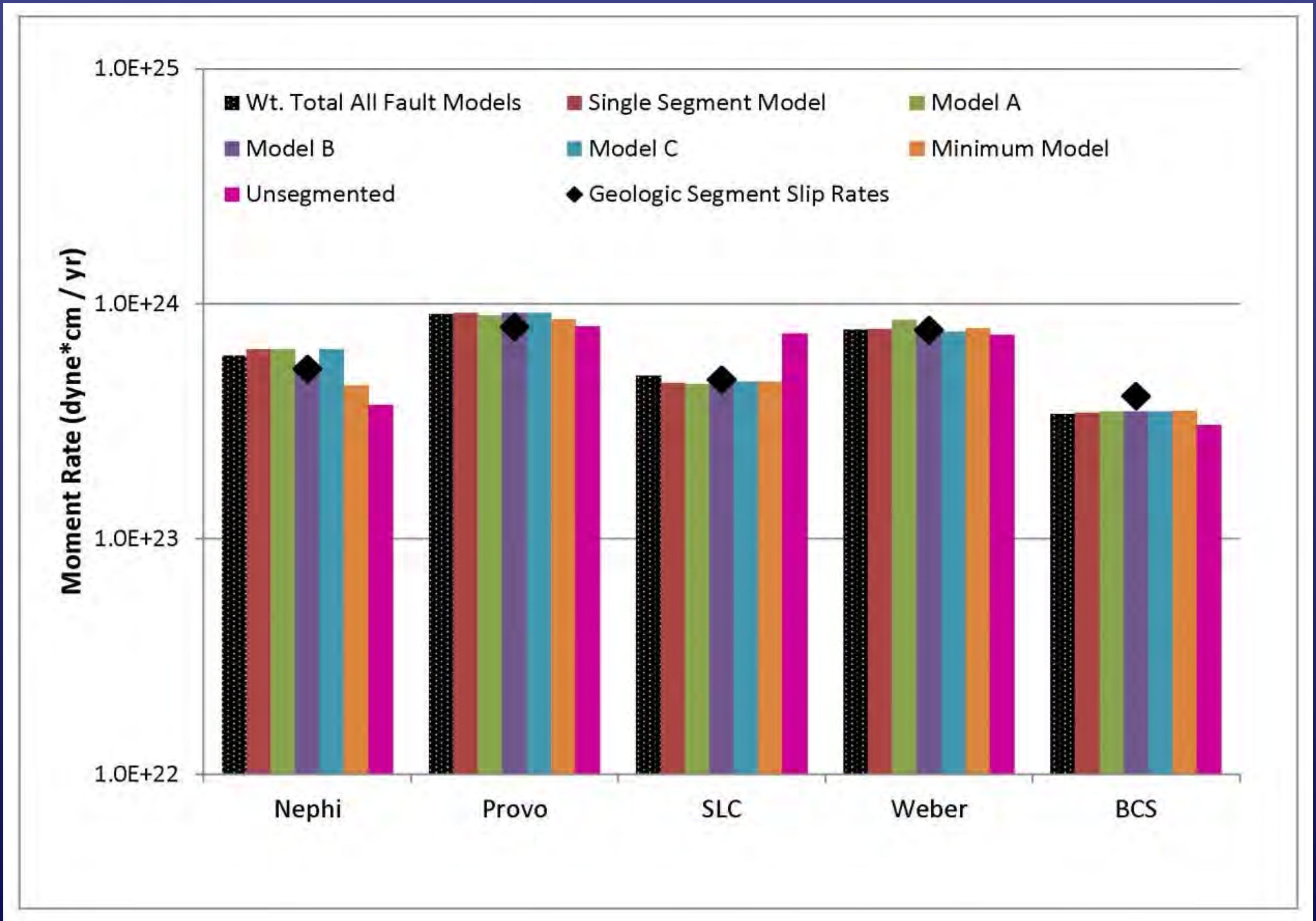
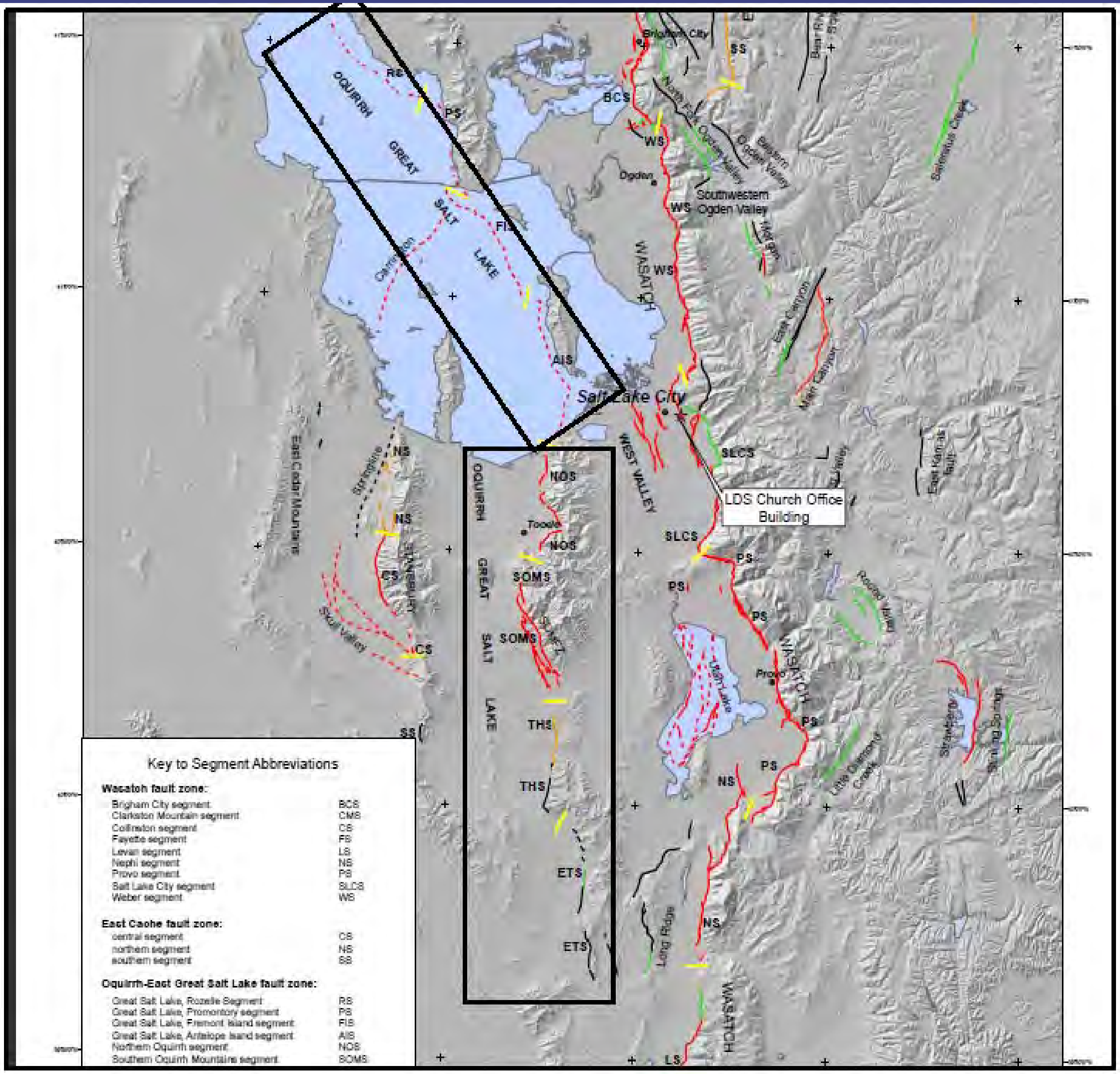
Moment Rates for WFZ central segments



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



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Proposed Rupture Models and Weights for the Oquirrh-Great Salt Lake Fault Zone

	Rupture Scenarios	Weights
1	RZ, PY, FI, AI, NO+S0, TH, ET	0.15
2	RZ, PY, FI, AI, NO, SO, TH, ET	0.4
3	RZ, PY, FI+AI, NO, SO, TH, ET	0.15
4	RZ, PY, FI, AI, NO, SO+TH, ET	0.1
5	Unsegmented (floating)	0.2

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“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

Recurrence Models

A and B faults (segmented faults):

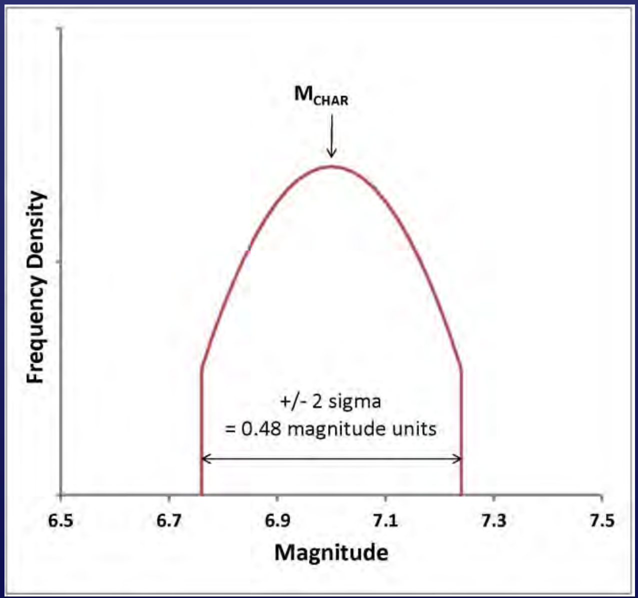
Segmented rupture models - M_{MAX}

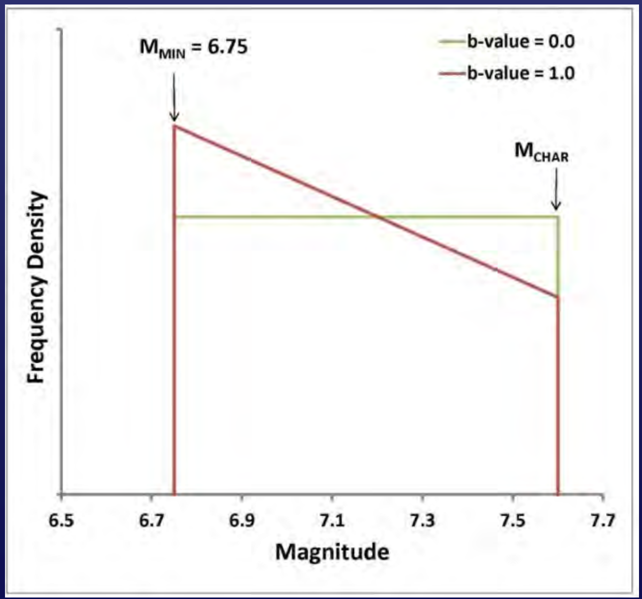
Unsegmented rupture models - Truncated Exponential (DTGR)

C faults (non-segmented):

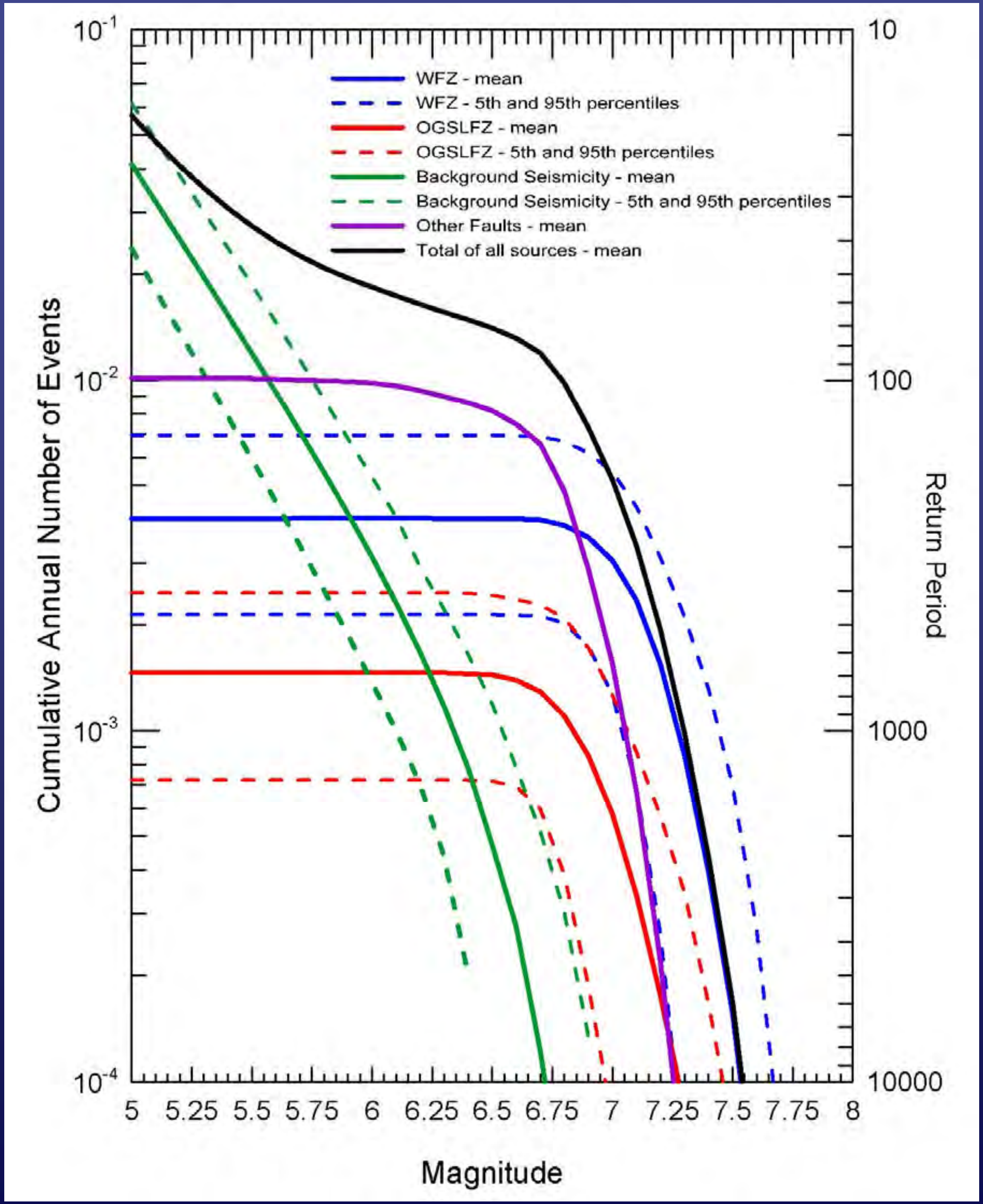
70% M_{MAX}

30% Truncated Exponential (DTGR)





Cumulative Magnitude-Frequency for the WFZ, OGSLFZ, Background Seismicity and Other Faults



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):
40% Mo (Hanks and Kanamori)
40% SRL-c (Stirling)
10% SRL (W&C-all)
10% W-SRL (Wesnousky)

C faults (not segmented, limited D data):
34% SRL-c (Stirling)
33% SRL (W&C-all)
33% W-SRL (Wesnousky)

Antithetic faults
50% RA (Stirling)
50% RA (W&C-all)

- We have adopted a background earthquake Mmax of M 6.75 ± 0.25.

- Fault dip uncertainty adopted is 50 ± 15 degrees.

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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)
- Considerable effort has been expended comparing moment rates derived from available geodetic, historical seismicity, and paleoseismic data. Moment rates were compared for the Wasatch region as a whole and for 4 subregions. The rates are consistent for 3 of the 4 subregions. There is a discrepancy in the rate for the subregion that encompasses the Levan and Fayette segments of the WFZ

Results

- Stay Tuned.

Basin and Range Province Seismic Hazards Summit III

Utah Geological Survey and Western States Seismic Policy Council

January 12 - 17, 2015

Salt Lake City, Utah

University of Utah Seismograph Stations
THE UNIVERSITY OF UTAH

Utah Department of Public Safety Division of Emergency Management

Utah DNR Geological Survey

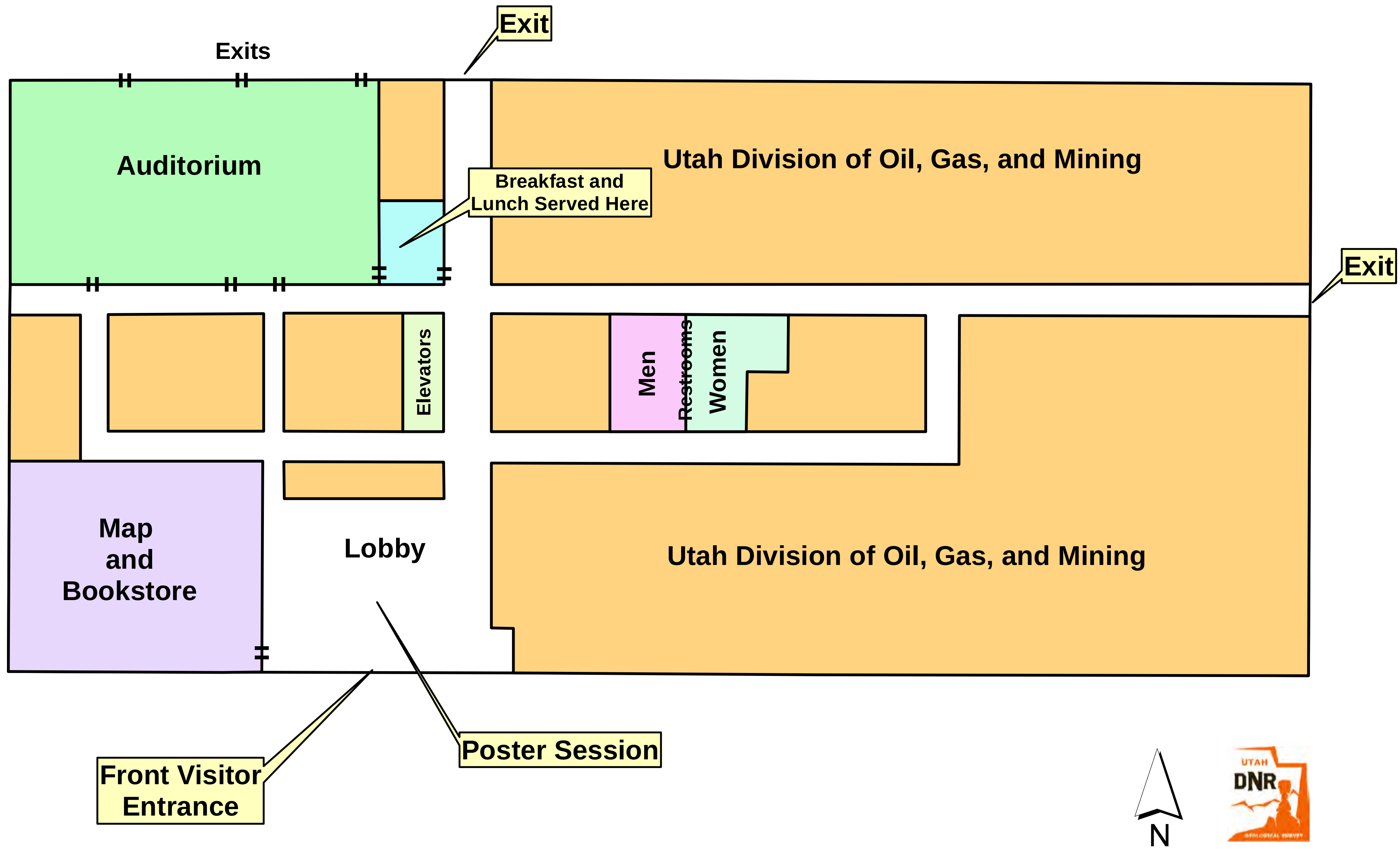
Environmental Engineering Geologists

USGS science for a changing world

WSSPC Western States Seismic Policy Council

Utah Seismic Safety Commission

Basin and Range Province Seismic Hazards Summit III
Utah Department of Natural Resources Building - First Floor Map



AGENDA
BASIN AND RANGE PROVINCE SEISMIC HAZARDS SUMMIT III
January 12 – 17, 2015
Utah Department of Natural Resources Building, Auditorium
Salt Lake City, Utah

The Utah Geological Survey and the Western States Seismic Policy Council, in conjunction with the Utah Division of Emergency Management, the Utah Professional Geologists Licensing Board, the Utah Professional Engineers and Land Surveyors Licensing Board, the U.S. Geological Survey (USGS), the Intermountain Section of the Association of Environmental and Engineering Geologists (AEG), the University of Utah Seismograph Stations, and the Utah Seismic Safety Commission will convene a Basin and Range Province Seismic Hazards Summit III (BRPSHSIII) to bring together geologists, seismologists, geodesists, engineers, emergency managers, and policy makers to present and discuss the latest earthquake-hazards research, and to evaluate research implications for hazard reduction and public policy in the Basin and Range Province.

Monday, January 12

7:30 a.m. Breakfast

8:00 a.m. **Short Course—Characterizing Hazardous Faults - Techniques, Data Needs, and Analysis**
Instructors: Christopher DuRoss, U.S. Geological Survey (formerly Utah Geological Survey) and others

The BRPSHSIII short course will describe and discuss the components of a successful paleoseismic investigation—from how to choose a site to interpreting and presenting data. Topics will include 1) site selection and trench design, 2) performing the field investigation, 3) radiocarbon and luminescence dating, 4) data analysis, and 5) reporting the results. The course will be geared toward students with no previous paleoseismic experience and consulting geologists with limited experience. However, more experienced geologists will benefit from discussions on the state and direction of the practice, such as probabilistic earthquake time determinations in OxCal. Participants will benefit from presentations from local experts on recent paleoseismic studies and specific tools and techniques, such as creating photomosaics and using and interpreting LiDAR data. Course materials will include hands-on materials (e.g., uninterpreted trench data) and exercises that will encourage discussion and collaboration. A breakfast, morning break, lunch, afternoon break, and short course booklet is provided as part of the registration fee.

8:00 a.m. **Workshop—U.S. Geological Survey Evaluation of Hazardous Faults in the Intermountain West (IMW) Region—2015 Update**
Leader: Richard Briggs, U.S. Geological Survey

In June 2008, a two-day workshop was convened at the USGS offices in Golden, Colorado, to identify important active faults in the IMW region for future studies. Knowledgeable state representatives and regional experts created a priority list that allows program managers to guide limited resources toward features that potentially pose the most serious hazard and/or risk in the IMW. The results of this workshop were published as USGS Open-File Report 2009-1140 (http://pubs.usgs.gov/of/2009/1140/).

This one-day workshop, led by the USGS Earthquake Hazards Program, will reexamine and update the priority list developed in 2008, to help maintain a balanced perspective of priorities throughout the entire IMW region. Because working groups have already been convened to specifically deal with Quaternary fault priorities in Utah and Nevada, this workshop will emphasize structures outside of these two states. A breakfast, morning break, lunch, and afternoon break are provided as part of the registration fee.

2:00 p.m. Registration/Poster Set Up

4:00 p.m. Short Course and Workshop Ends

6:00 p.m. **Off-Site Icebreaker**
Hosted by the Intermountain Section of the Association of Environmental and Engineering Geologists at Maxwell's East Coast Eatery, 357 South Main Street, Salt Lake City.

Tuesday, January 13

7:30 a.m. Registration/Breakfast
8:00 a.m. **Summit Opening (Welcome, Summit Objectives, and Overall Agenda)**

8:15 a.m. Keynote Address—Earthquake Early Warning in the Intermountain West: Keith Koper, Director, University of Utah Seismograph Stations

8:30 a.m. **First Session—Perspectives and Overview of User Needs**
Moderator: William Lund, Utah Geological Survey

8:30 a.m. Basin and Range Province Earthquakes—Low Probability High Consequences: Ivan Wong, URS Corporation
9:00 a.m. What Emergency Managers Need from Geoscientists: Bob Carey, Utah Division of Emergency Management
9:30 a.m. What Engineers Need from Geoscientists: George Ghusn, Jr., BJG Architecture+ Engineering

10:00 a.m. Break

10:30 a.m. What Local Governments Need from Geoscientists: David Dobbins, City Manager, Draper City
11:00 a.m. The National Seismic Hazard Maps in the Basin and Range Province—Thirty-Five Years in the Making: Mark Petersen, U.S. Geological Survey
11:30 a.m. Data and Tools for Seismic Hazard Investigations: Steve Bowman, Utah Geological Survey

12:00 p.m. Lunch

1:00 p.m. **Second Session—M_{max} Issues in the Basin and Range Province (BRP)**
Moderator: Ivan Wong, URS Corporation

1:00 p.m. Issues and Approaches for Estimating M_{max} for Earthquake Sources in the Basin and Range: Donald Wells, AMEC, Inc.
1:30 p.m. Analysis and Selection of M_{max} Relations for the Working Group on Utah Earthquake Probabilities: Christopher DuRoss, U.S. Geological Survey (formerly Utah Geological Survey)

2:00 p.m. Estimating Surface Lengths for Prehistoric Ruptures in the Basin and Range Province: Craig dePolo, Nevada Bureau of Mines and Geology

2:30 p.m. Fault Linkage, Complexity, and Earthquake Displacement: Glenn Biasi, University of Nevada, Reno

3:00 p.m. Break

3:30 p.m. Slip at a Point Variability—Implications for Earthquake-Magnitude Distributions Near M_{max}: Suzanne Hecker, U.S. Geological Survey

4:00 p.m. Estimating Magnitudes of Large Earthquakes from Geological Observations of Faults with Low Slip Rates: John Anderson, University of Nevada, Reno

4:30 p.m. M_{max} and the National Seismic Hazard Maps: Mark Petersen, U.S. Geological Survey

5:00 p.m. **First and Second Sessions Discussion**

6:30 p.m. **Intermountain Section of the Association of Environmental & Engineering Geologists and Utah Geological Association Joint Meeting**
Separate registration includes dinner, contact aegintermountain@gmail.com for details.

7:00 p.m. Natural Hazards Identification, Impact Analysis, and Risk Assessment for Community Disaster Mitigation Planning: Eldon Gath, President, Earth Consultants International and 2014-2015 AEG Richard H. Jahns Distinguished Lecturer in Applied Geology

Wednesday, January 14

7:30 a.m. Breakfast

8:00 a.m. **Opening (Objectives and Agenda for the Day)**

8:15 a.m. Keynote Address—Making Hazards Real: Using Scenarios to Spur Preparedness Before Disaster Strikes: David Applegate, Associate Director, U.S. Geological Survey

8:30 a.m. **Third Session—Ground Motions from Normal-Faulting Earthquakes**
Moderator: Jim Pechmann, University of Utah Seismograph Stations

8:30 a.m. Ground Motion Prediction Equations for the BRP—Current Status: Norm Abrahamson, Pacific Gas and Electric Company

9:00 a.m. Numerical Simulations of Wasatch Fault Earthquakes: Daniel Roten, University of California, San Diego

9:30 a.m. Numerical Simulations of Rupture Propagation and Ground Motions in Normal-Faulting Earthquakes: Ralph Archuleta, University of California, Santa Barbara

10:00 a.m. Break

10:30 a.m. Clark County and Reno/Tahoe: Advancing Earthquake Hazard Assessment with Physics and Geology: John Louie, University of Nevada, Reno

11:00 a.m. Rupture Direction and Near Fault Effects on Ground Motions in the Basin and Range Province: Jennie Watson-Lamprey, Watson-Lamprey Consulting

11:30 a.m. Precariously Balanced Rock Constraints on Seismic Hazard from Known Faults and from Smoothed “Background” Seismicity: Jim Brune, University of Nevada, Reno

12:00 p.m. Lunch

1:00 p.m. **Fourth Session—Fault Segmentation and Rupture Patterns in the BRP**
Moderator: David Schwartz, U.S. Geological Survey

- 1:00 p.m. Current Understanding and Issues Regarding Fault Segmentation in the BRP: David Schwartz, U. S. Geological Survey
- 1:30 p.m. Fault Linkage and Multisegment Ruptures—A Structural Prospective: Ron Bruhn, University of Utah, retired
- 2:00 p.m. UCERF-3 Fault Methodology—Is It Applicable to the BRP Seismic Hazard Analysis?: Ned Field/Morgan Page, U.S. Geological Survey

2:30 p.m. Break

- 3:00 p.m. Paleoseismic Trenching and LiDAR Analysis Supports Non-Persistent Rupture Terminations at Central Wasatch Fault Zone Segment Boundaries, Utah: Scott Bennett, U.S. Geological Survey
- 3:30 p.m. Rupture Patterns and Recurrence along the West Tahoe Fault System: California and Nevada: Gordon Seitz, California Geological Survey
- 4:00 p.m. Characterizing Ruptures of Normal Faults in Italy: Daniela Pantosti, National Institute of Geophysics and Volcanology, Italy

4:30 p.m. **Third and Fourth Sessions Discussion**

Thursday, January 15

7:30 a.m. Breakfast
8:00 a.m. **Opening (Objectives and Agenda for the Day)**

- 8:15 a.m. Keynote Address—Preparing for the Inevitable: Major General Jefferson S. Burton, Adjutant General, Utah National Guard

8:30 a.m. **Fifth Session—Earthquake Engineering and Risk Mitigation**
Moderator: Pete McDonough, Questar Gas Company

- 8:30 a.m. Current Strategies for Mitigating Surface Faulting in the Basin and Range Province: William Lund, Utah Geological Survey
- 9:00 a.m. Engineering Mitigation of Surface-Fault Rupture: Jonathan Bray, University of California, Berkeley
- 9:30 a.m. Geologic Data Needs for Engineering Mitigation of Earthquake Hazards: Ross Boulanger, University of California, Davis

10:00 a.m. Break

- 10:30 a.m. Reviewing Fault Surface-Rupture and Earthquake-Hazard-Mitigation Reports for Regulatory Compliance: Robert Larson, Los Angeles County Department of Public Works
- 11:00 a.m. Addressing Seismic Vulnerabilities to Natural Gas Systems: Pete McDonough, Questar Gas Company
- 11:30 a.m. Protection of Pipelines from Permanent Ground Deformation Using EPS Geofoam: Steve Bartlett, University of Utah

12:00 p.m. Lunch

1:00 p.m. **Sixth Session—Emergency Management and Public Policy**
Moderator: Bob Carey, Utah Division of Emergency Management

1:00 p.m. Case Study of the 2008 **M**6 Wells, Nevada Earthquake
- 1:00 p.m. Scientific Response to the 2008 **M**6 Wells, Nevada Earthquake: Craig dePolo, Nevada Bureau of Mines and Geology
- 1:30 p.m. Emergency Response - 2008 **M**6 Wells, Nevada Earthquake: Rich Harvey, Deputy State Forester, Nevada Division of Forestry
- 2:00 p.m. Engineering Considerations - 2008 **M**6 Wells, Nevada Earthquake: Barry Welliver, Structural Engineers Association of Utah
- 2:30 p.m. The Recovery of Wells, Nevada from the 2008 **M**6 Earthquake: Craig dePolo, Nevada Bureau of Mines and Geology

3:00 p.m. Break

3:30 p.m. Hazardous Faults in the BRP—What Constitutes Acceptable Risk: Roy Shlemon, R.J. Shlemon & Associates

4:00 p.m. Building Policy Considerations in Seismically Vulnerable Areas of the Basin and Range: Ron Lynn, Clark County, Nevada Department of Development Services

4:30 p.m. Modernizing the 1972 California Alquist-Priolo Act's Fault Zoning for the Performance-Based Millennium: Eldon Gath, Earth Consultants International

5:00 p.m. **Fifth and Sixth Sessions Discussion**

Friday, January 16

7:30 a.m. Breakfast

8:00 a.m. **Opening (Objectives and Agenda for the Day)**

8:15 a.m. Keynote Address—Kinematics of the Wasatch Fault Zone from GPS Measurements, Block Modeling, and Fault Modeling: Christine Puskas, UNAVCO.

8:45 a.m. **Seventh Session—Using Geodesy to Characterize Seismic Hazard in the BRP**
Moderator: Bill Hammond, University of Nevada, Reno

8:45 a.m. Fault Slip Rates in the Western Great Basin from Geodetic and Geologic Data: Bill Hammond, Corné Kreemer, Jayne Bormann, and Geoff Blewitt, University of Nevada, Reno

9:15 a.m. InSAR Analysis of the 2008 Reno-Mogul M4.7 Earthquake Swarm: Implications for Seismic Hazard in the Western Basin and Range: John Bell, Falk Amelung, and Christopher Henry, Nevada Bureau of Mines and Geology

9:45 a.m. Break

10:15 a.m. The Geodetic Strain Rate Field for the Colorado Plateau and Southern Basin and Range: Corné Kreemer, Geoff Blewitt, Bill Hammond, James Broermann, and Rick Bennett, University of Nevada, Reno

10:45 a.m. Update of Deformation Rates in the Snake River Plain: Suzette Payne, Rob McCaffrey, and Bob King, Idaho National Laboratory

11:15 a.m. Geodetic Constraints on Kinematics and Strain Rates in the Northern Basin and Range: Rebecca Bendick, Dylan Schmeelk, Yelebe Birhanu, and Cody Bomberger, University of Montana

11:45 a.m. **Seventh Session Discussion**

12:00 p.m. Lunch

1:00 p.m. **BRPSHSIII Wrap Up and Policy Discussion**
Moderators: William Lund, Utah Geological Survey and Craig dePolo, Nevada Bureau of Mines and Geology

1:00 p.m. Summit session topics review and policy discussion.

3:00 p.m. Break

4:30 p.m. Summit Close

Saturday, January 17

8:00 a.m. **Field Trip—Salt Lake City's Earthquake Threat and What Is Being Done About It**
Leader: Mike Hylland, Utah Geological Survey
Location: Meet in front of the Utah Department of Natural Resources Building, main visitor parking lot. The field trip bus will leave at 8:00 a.m.

The BRPSHSIII field trip will visit prominent fault scarps on the Salt Lake City segment of the Wasatch fault zone, review the Holocene surface-faulting history of the fault, discuss important fault issues, such as the potential for partial- and multiple-segment ruptures, consider Lake Bonneville deposits used for constraining timing of fault movement, observe earthquake risk reduction measures applied to several recent retrofit or new construction of buildings, and tour the University of Utah Seismograph Stations to discuss earthquake monitoring systems and ongoing seismological research. A morning break, lunch, afternoon break, and field trip booklet are provided as part of the registration fee.

4:00 p.m. Field trip bus returns to Utah Department of Natural Resources Building, main visitor parking lot.

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

PROCEEDINGS VOLUME CONTRIBUTIONS
BASIN AND RANGE PROVINCE SEISMIC HAZARDS SUMMIT III

January 12-17, 2015
Utah Department of Natural Resources Building, Auditorium
Salt Lake City, Utah

Posters

On display in the Utah Department of Natural Resources Building lobby Tuesday, January 13, 2015 to Friday, January 16, 2015, and will be included in the proceedings volume to be published after the summit.

A Unified Earthquake Catalog and Background Seismicity Rates for the Wasatch Front and Surrounding Utah Region: Walter Arabasz, James C. Pechmann, and Relu Burlacu

Applications of Structure from Motion Software for Use in Earthquake Geology Investigations—Examples from the Wasatch and San Andreas Faults: Nathan A. Toke, Michael P. Bunds, Andrew Fletcher, and Michael Arnoff

Comparison of Peak Ground Motions from the 2011 Japan Normal-Faulting Sequence with the Next Generation Attenuation-West2 Ground Motion Prediction Equations: Kevin M. McBean, John G. Anderson, and Hiroshi Kawase

Documenting Recent Rupture Traces and Paleoseismic Exposures Along the Traverse Ridge Salient Between the Provo and Salt Lake City Segments of the Wasatch Fault: Nathan A. Toke, Michael Arnoff, and Jason Thomas

LiDAR-Based Map of an Active, Normal Fault: Teton Fault, Wyoming: Chris L. Colwell, Jared J. Hanson, and Julie B. Willis

Morphotectonic Analysis of the Long-Term Surface Expression of the 2009 L'Aquila Earthquake Fault (Central Italy) Using Airborne LiDAR Data: Ricardo Civico, Stefano Pucci, Paolo Marco De Martini, and Daniela Pantosti

Near-Surface Geometric Evaluation of the Teton Fault Through Shallow Seismic Data Collection Methods, Grand Teton National Park, Wyoming: Mark Zellman, Glenn Thackray, Jason Altekruse, and Bruno Protti

New Paleoseismic Information Along the Kings Canyon Fault Zone, Carson City, Nevada: Craig dePolo, Rich Briggs, Ryan Gold, Anthony Crone, Shannon Mahan, and William Amidon

Ongoing Earthquake Swarm in Northwestern Nevada: Graham Kent

Paleoseismology of Utah Lake: Dave A. Dinter

Paleoseismology of the Northern Segments of the Great Salt Lake Fault: David A Dinter and Jim C. Pechmann

Preliminary Findings from a Paleoseismic Transect Across the Northwestern Basin and Range Province, Northwestern Nevada and Northeastern California: Steve Personius

The Washoe Shear Zone - A Newly Characterized Right-Lateral Strike-Slip Fault in Southwestern Reno: Craig dePolo, Ryan Gold, Rich Briggs, and Nadine Reitman

User Guide for Luminescence Sampling in Paleoseismic Contexts: Harrison J. Gray, Shannon A. Mahan, Tammy M. Rittenour, and Michelle S. Nelson

Technical Papers

Will be included in the proceedings volume to be published after the summit.

Engineering Mitigation of Surface-Fault Rupture: Jonathan D. Bray

Guide to Luminescence Dating Techniques and Their Application for Paleoseismic Research: Harrison J. Gray, Shannon A. Mahan, Tammy M. Rittenour, and Michelle S. Nelson

Seismic Vulnerabilities of Natural Gas Systems: Peter McDonough

Serving Professionals in Engineering Geology, Environmental Geology, and Hydrogeology Since 1957

January 2015 Newsletter

Intermountain Section of the Association of Environmental and Engineering Geologists

Table of Contents:

AEG/UGA Meeting Announcement

Eldon Gath: President of Earth Consultants International
2014-2015 Richard H. Jahns Distinguished Lecturer in Applied Geology

Presenting:

Natural Hazard Identification, Impact Analysis, and Risk Assessment for Community Disaster Mitigation Planning

Abstract:

This talk presents the methodology of hazard map preparation for use by city and county governments for land use planning, hazard mitigation, and loss prevention. Examples will be shown for several southern California cities and counties, including active fault and seismicity, landslide and slope instability, flooding, wildfire, liquefaction, tsunami, and other types of hazard maps. These maps provide the foundation for all public Safety Elements in California and for Disaster Mitigation Plans nationwide. Illustrating the hazard, communicating how hazard becomes risk, and helping our communities mitigate that risk is a critical skill set for engineering geologists to develop.

Biography:

Eldon, a consulting engineering geologist, has more than 30 years of experience in the identification, investigation, and remediation of geologic hazards, involving land use planning, environmental assessments, field exploration programs, and presentation of findings. He has particular experience with the evaluation of active faults for construction site planning, the development of seismic safety programs and policies, and is currently engaged in efforts to modernize California's 40-year old active fault zoning act.

Eldon is the President of Earth Consultants International, a geological consulting firm *[helping our clients solve complex earth-science problems around the world]* that he co-founded in 1997, following 12 years with Leighton Consulting in southern California. He has considerable international experience including field projects in Turkey, Panama, Mexico, Costa Rica and Papua New Guinea, as well as project involvement in many others.

Eldon is a graduate of the University of Minnesota, Institute of Technology, with a BS degree in Geology in 1978. Eldon has received several research grants and awards over the years and is frequently invited to speak to local southern California colleges.

Meeting Details

When: *Tuesday January 13, 2015*

Where: Department of Natural Resources: 1594 West North Temple, SLC, Utah, Room 1040.

What: AEG/UGA *Dinner/Social 6:30-7:00 PM-----Program Begins 7:00 PM*
Dinner: ***$15 Members w/RSVP***
$7 Student Members w/RSVP

How: *RSVP* ***aegintermountain@gmail.com or Call***
Jessica Castleton at 1-801-537-3381
by 12 Noon Friday Jan 9, 2015

Chair's Corner

Happy New Year!

Our year is off to a great start with AEG's Jahn's Lecturer Eldon Gath speaking at our January monthly meeting co-hosted with UGA during the Basin and Range Province Seismic Hazard Summit (BRPSHS III). There is still time to register and attended the BRPSHS III; see flyers attached for details. AEG is hosting the ice breaker for the BRPSHS III we hope to see you there.

The AEG Intermountain section is moving to a new email - aegintermountain@gmail.com. Please be patient with us and let us know of any problems during this transition.

February student night is right around the corner, please inform the geological students in your life of the opportunity to present. AEG will be giving out another student scholarship this year.

It is AEG membership renewal time. Please renew if you have not already and encourage others to join. Go to http://www.aegweb.org for more details and/or see membership form attached.

Joan Kester – Section Chair
Senior Geologist P.G./GIS Specialist

NEWS:

February 2015 AEG Professional Forum on Landslides

2015 Membership Renewal Due

UQFPWG 2014 Fault Study Priorities

Fault/Fault Segment	Original UQFPWG Priority (2005)
Nephi segment WFZ	1
West Valley fault zone	2
Weber segment WFZ – most recent event	3
Weber segment WFZ – multiple events	4
Utah Lake faults and folds	5
Great Salt Lake fault zone	6
Collinston & Clarkston Mountain segments WFZ	7
Sevier/Toroweap fault	8
Washington fault	9
Cedar City-Parowan monocline/ Paragonah fault	10
Enoch graben	11
East Cache fault zone	12
Clarkston fault	13
Wasatch Range back-valley faults	14
Hurricane fault	15
Levan segment WFZ	16
Gunnison fault	17
Scipio Valley faults	18
Faults beneath Bear Lake	19
Eastern Bear Lake fault	20
Bear River fault zone	2007
Brigham City segment WFZ – most recent event	2007
Carrington fault (Great Salt Lake)	2007
Provo segment WFZ – penultimate event	2007
Rozelle section – East Great Salt Lake Fault	2007
Salt Lake City segment WFZ – northern part	2009
Warm Springs fault/East Bench fault subsurface geometry and connection	2010
Brigham City segment WFZ rupture extent (north and south ends)	2011
Long-term earthquake record northern Provo segment WFZ	2011
West Valley fault zone – Taylorsville fault	2011
Hansel Valley fault	2011
Acquire new paleoseismic information in data gaps along the five central segments of the WFZ	2012

2014 Highest Priority Faults/Fault Sections For Study		
Fault/Fault Section[1]	**Investigation Status**	**Investigating Institution[2]**
Acquire new paleoseismic information for the five central segments of the Wasatch fault zone (WFZ) to address data gaps – e.g., (a) the displacement and rupture extent of earthquakes on the Brigham City, Weber, and Salt Lake City segments, (b) long-term (early Holocene and latest Pleistocene) earthquake records for the southern Brigham City, southern Weber, and northern Provo segments, and (c) the subsurface geometry and connection of the Warm Springs and East Bench faults on the Salt Lake City segment.	1. Provo segment Flat Canyon site, ongoing 2. Salt Lake City segment Corner Canyon site, ongoing 3. Provo segment Dry Creek and Maple Canyon sites, ongoing	1. USGS/UGS 2. UGS/USGS 3. USGS/UGS
Acquire long-term earthquake record for the West Valley fault zone – Taylorsville fault	NEHRP-funded study to commence in 2015	UGS
Improve the long-term earthquake record for Cache Valley (East and West Cache fault zones)	No activity	
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.	The UGS is currently mapping portions of the Wasatch and West Valley (Granger fault) fault zones	UGS

Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**
Cedar City-Parowan monocline/Paragonah fault[3]	10	No activity	
Enoch graben	11	No activity	
Clarkston fault[3] (West Cache fault zone)	13	Black and others (2000)	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Rozelle section, Great Salt Lake fault[4]	2007	No activity	

Studies of Priority Faults Complete or Ongoing			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status[5]**	**Investigating Institution**
Nephi segment WFZ	1	UGS Special Study 124 USGS Map 2966 UGS Special Study 151	UGS/USGS
West Valley fault zone (Granger fault)	2	UGS Special Study 149	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Contract deliverable FTR (UUGG investigation)	UUGG/BYU
Great Salt Lake fault zone	6	Contract deliverable FTR	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
Washington fault zone	9	Contract deliverable FTR	UGS
East Cache fault zone	12	UGS Miscellaneous Publication 13-3	USU
Wasatch Range back-valley fault (Main Canyon fault)	14	UGS Miscellaneous Publication 10-5	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Contract deliverable FTR	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north part	2009	Contract deliverable FTR	UGS/USGS
Hansel Valley fault[3]	2011	McCalpin (1985), Robinson (1986), McCalpin and others (1992), UUGG ongoing	UUGG
Long-term earthquake record Nephi segment WFZ – North Creek	2012	Contract deliverable FTR	UGS/USGS
Provo/Salt Lake City/Nephi segment Holocene fault segmentation – Flat Canyon, Alpine, Maple Canyon, and Corner Canyon trench sites	2012/2013	On going	USGS/UGS