2016 Utah Quaternary Fault Parameters Working Group (UQFPWG) Meeting

Wednesday, February 8, 2017

UTAH GEOLOGICAL SURVEY


Airport East Site (Taylorsville Fault)

Background

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

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

Agenda

8:00 Refreshments

8:15 – 8:30 Welcome, Overview of Meeting, and Review of Last Year’s Activities + U.S. Geological Survey Update

8:30 – 10:30 Technical Presentations (4)

10:30 Break (15 min)

10:45 – 12:00 Technical Presentations (5)

12:00 Lunch (1 hour, provided for those who have registered and paid)

1:00 – 2:15 Technical Presentations (5)

2:15 – 3:00 Update of Utah Consensus Quaternary Fault Parameters Discussion

3:00 Break (15 min)

3:15 – 4:30 Update of Utah Consensus Quaternary Fault Parameters Discussion

4:30 – 5:00 2018 Fault Investigation Priorities Discussion

See printed agenda for background information and last year’s priority list.

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

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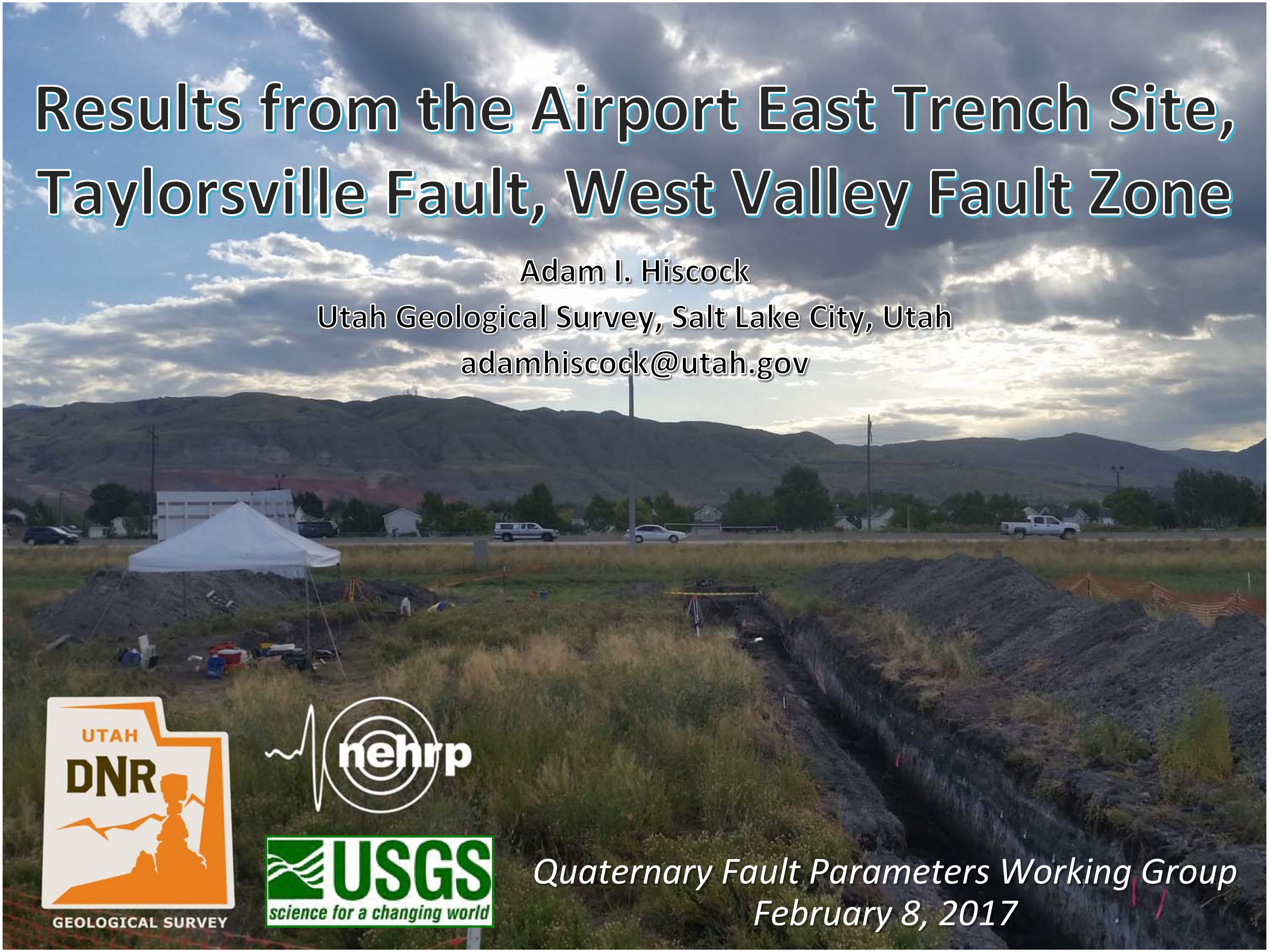


UTAH DNR GEOLOGICAL SURVEY

nehrp

USGS science for a changing world

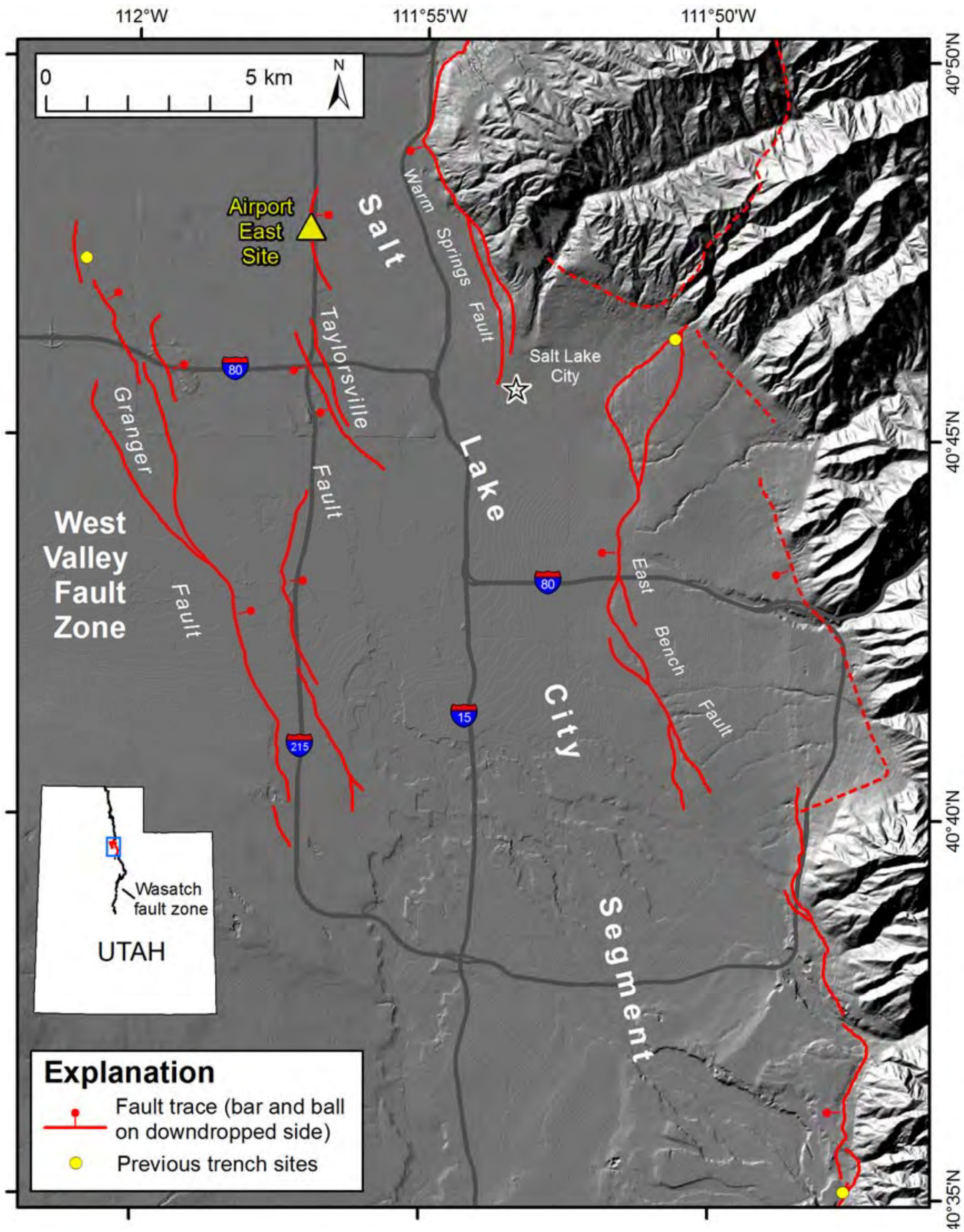
Quaternary Fault Parameters Working Group
February 8, 2017

Location & Purpose

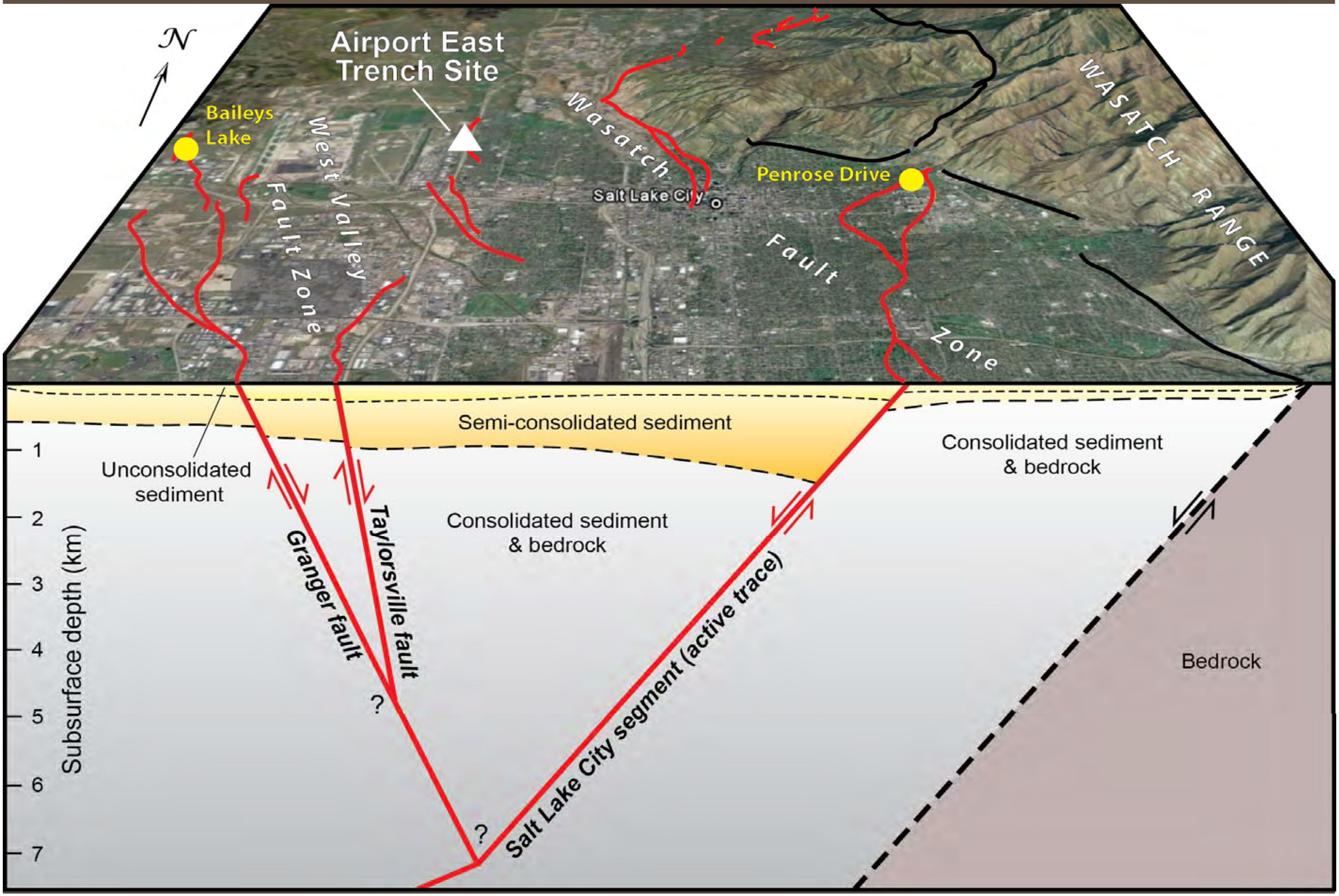
- Does earthquake timing compare with Baileys Lake Site?
- Does the WVFZ rupture with the SLCS (or other segments, i.e., Weber Segment) or independently?
- One of the last remaining sites on the Taylorsville fault for trenching – site is now under development.

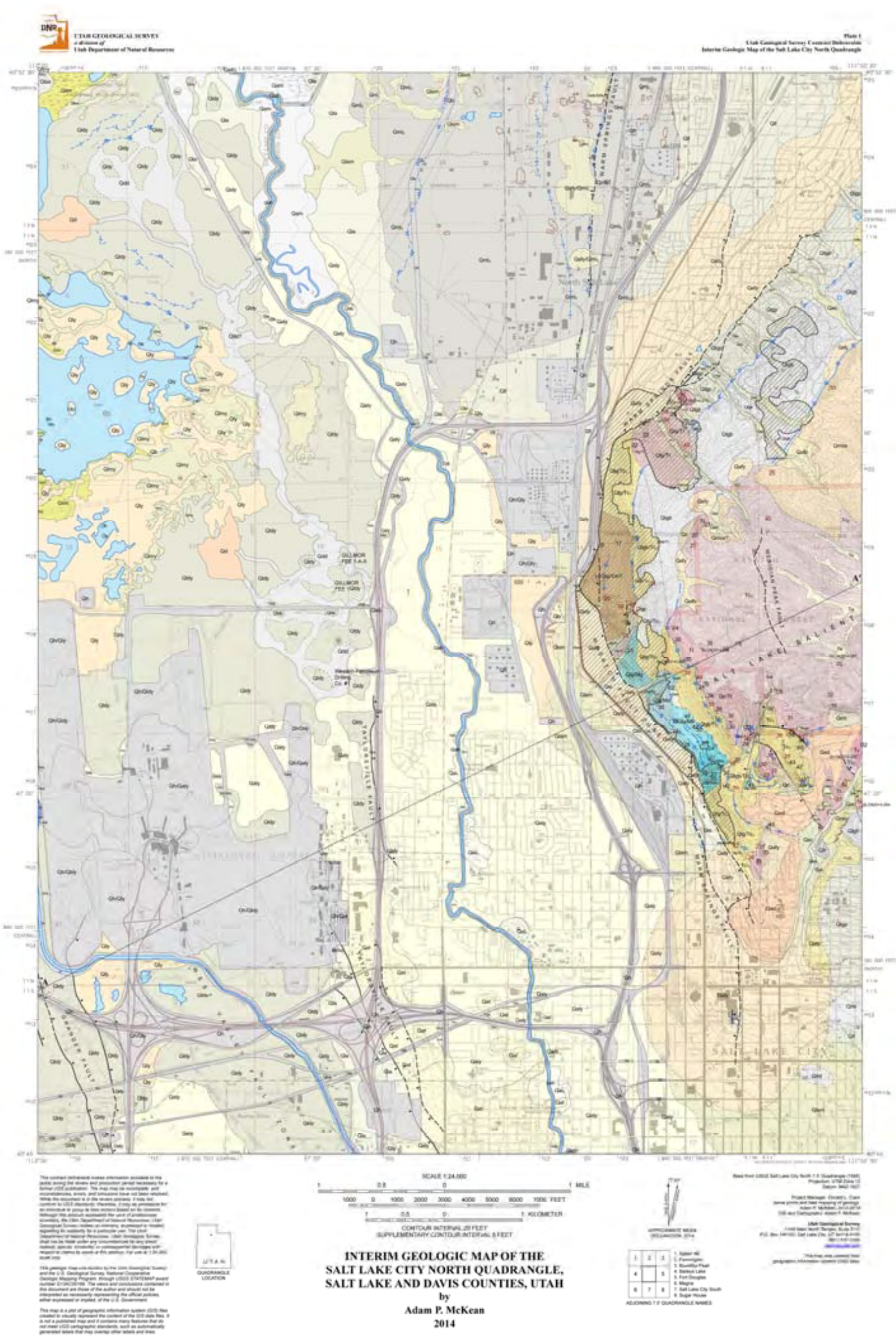
UTAH DNR GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY

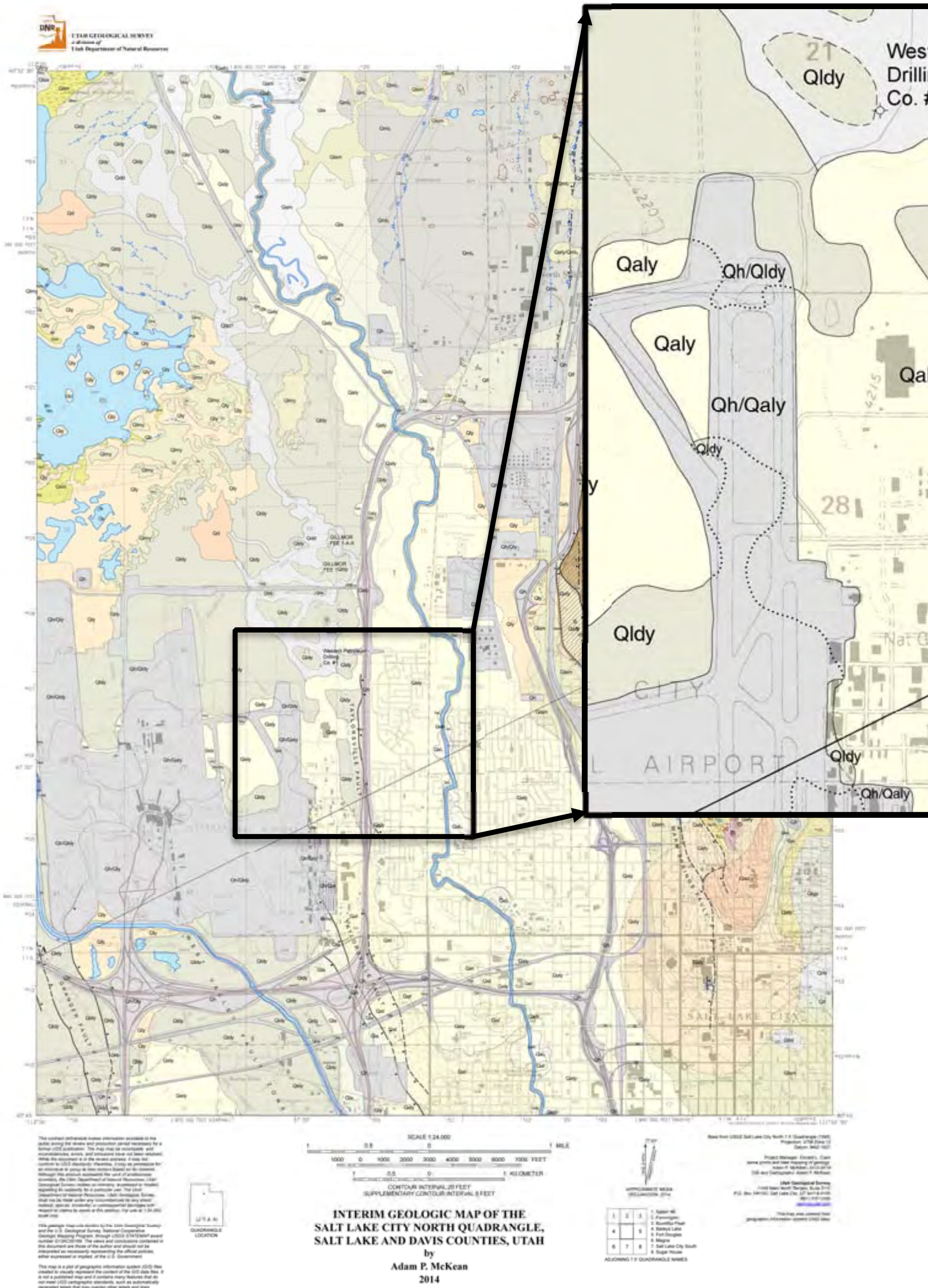


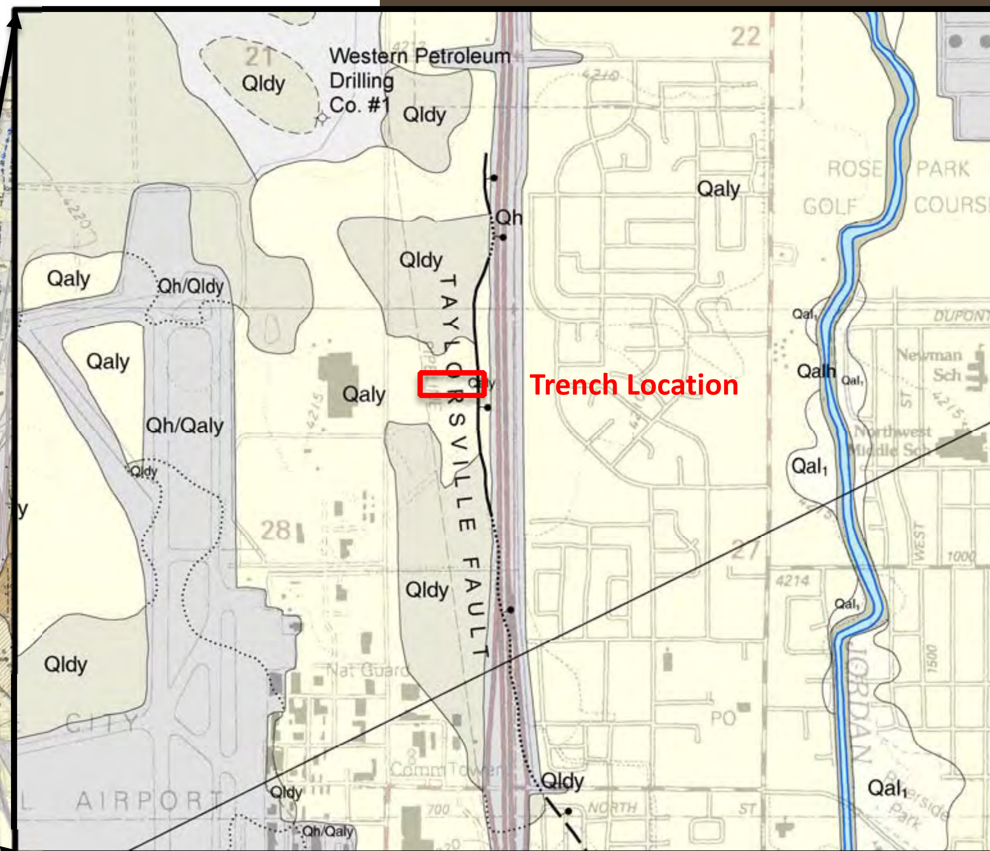
Location


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



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

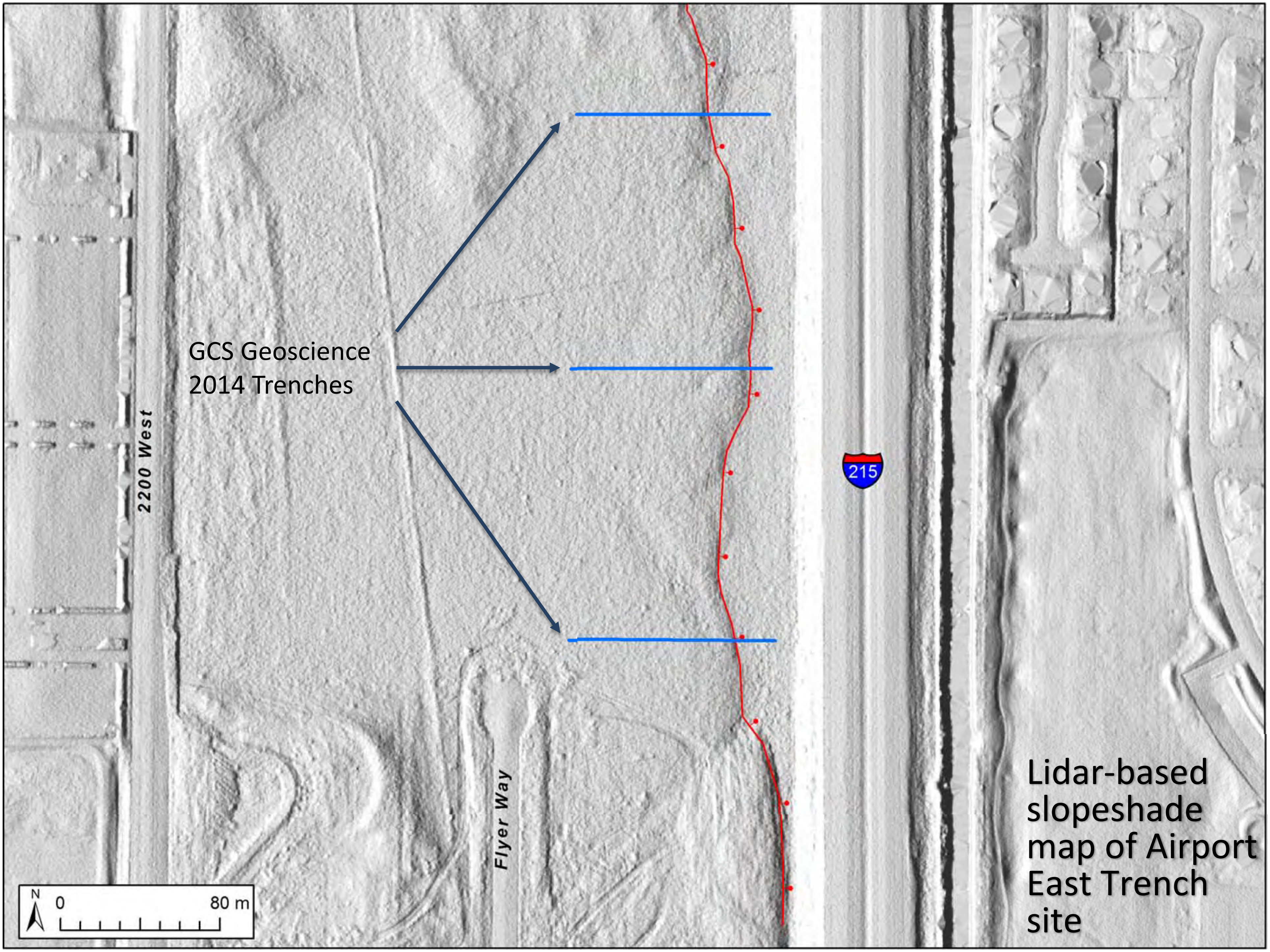


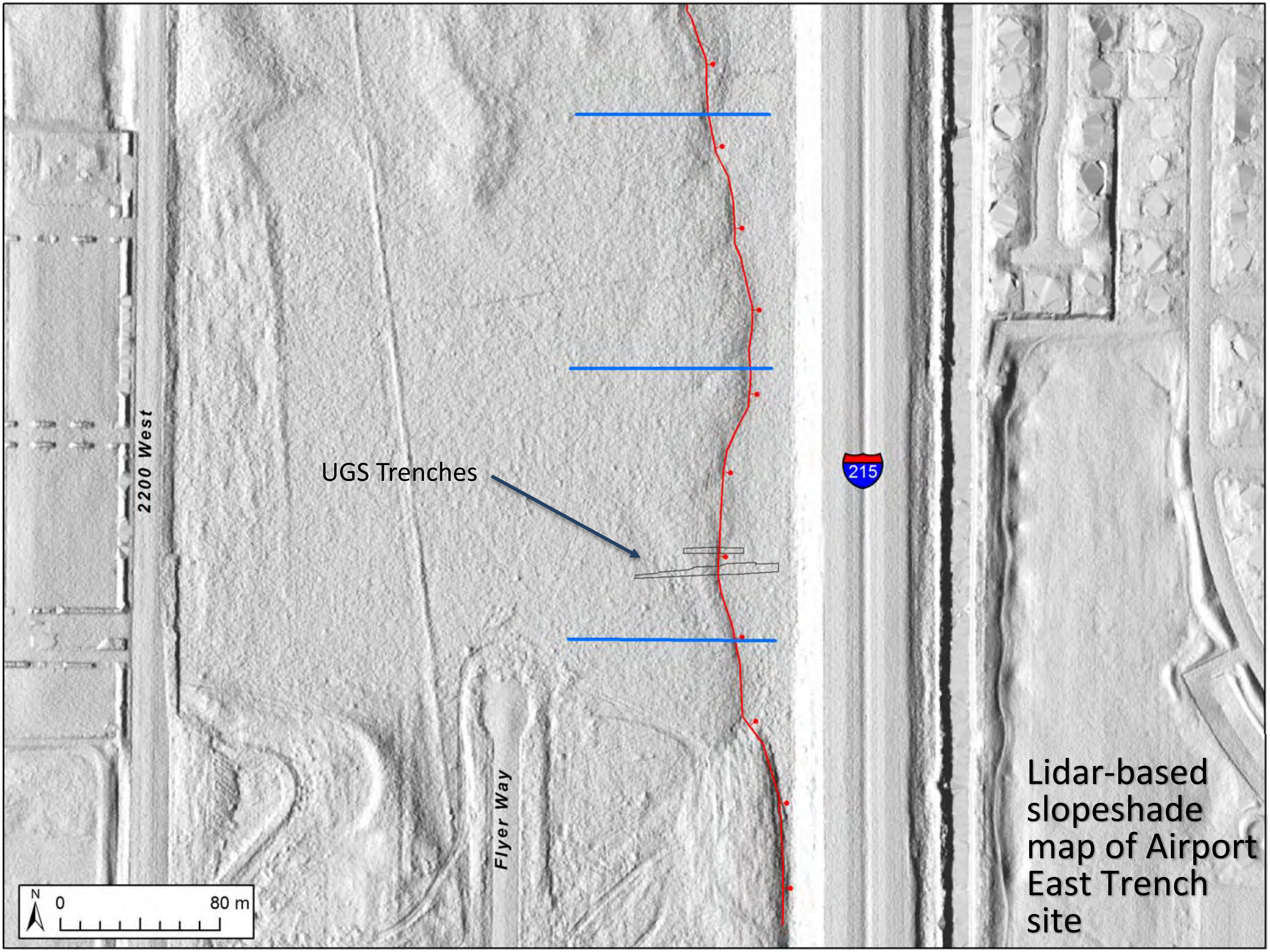


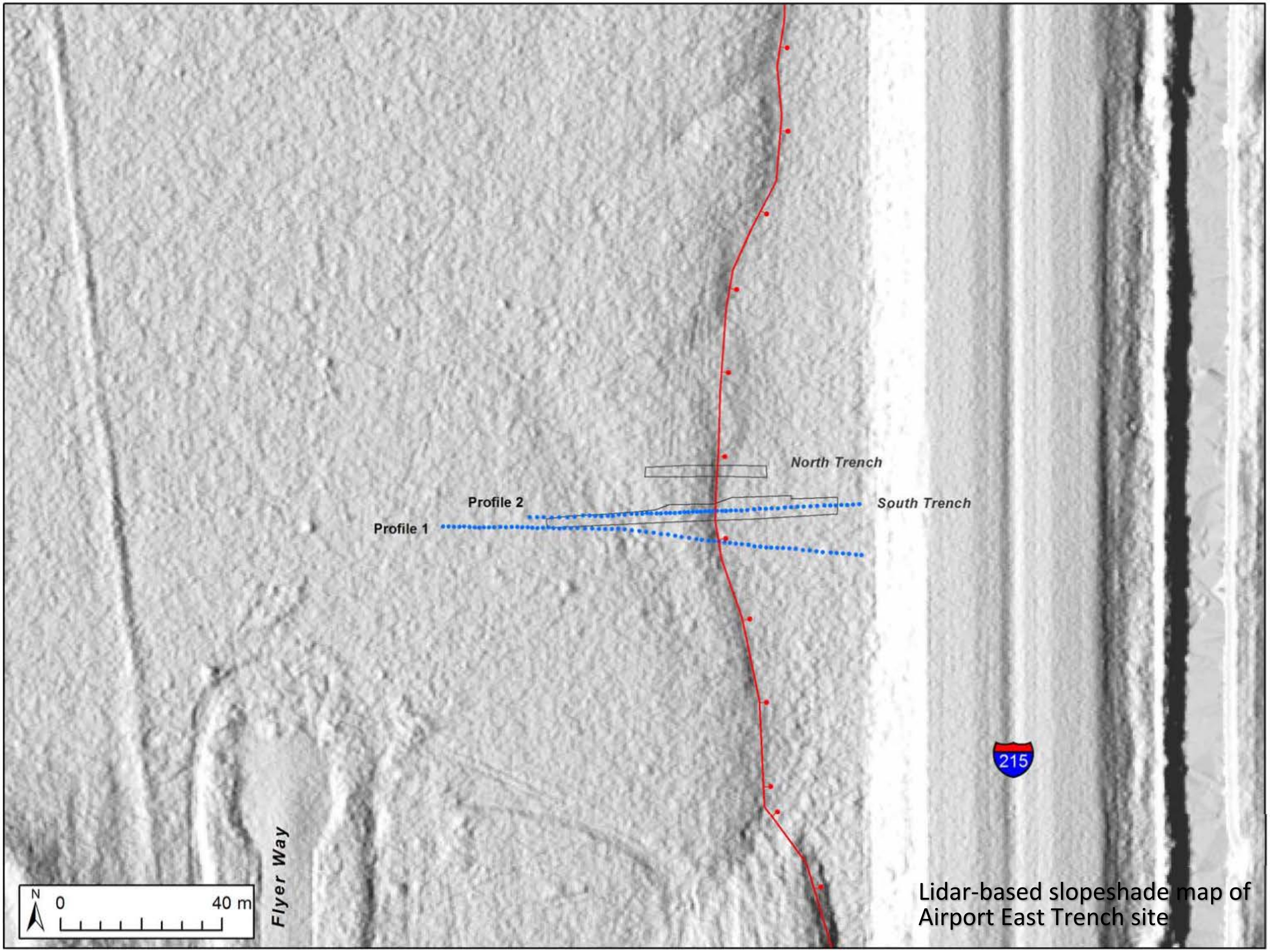
- Qaly – Holocene stream deposits associated with paleo-Jordan River channel
- Qldy – Holocene lacustrine and deltaic deposits
- Site is ~3m lower than the elevation of the Late Holocene highstand of the GSL
- Modern Jordan River channel lies 1 km east of the site


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

Lidar-based slopeshade map of Airport East Trench site

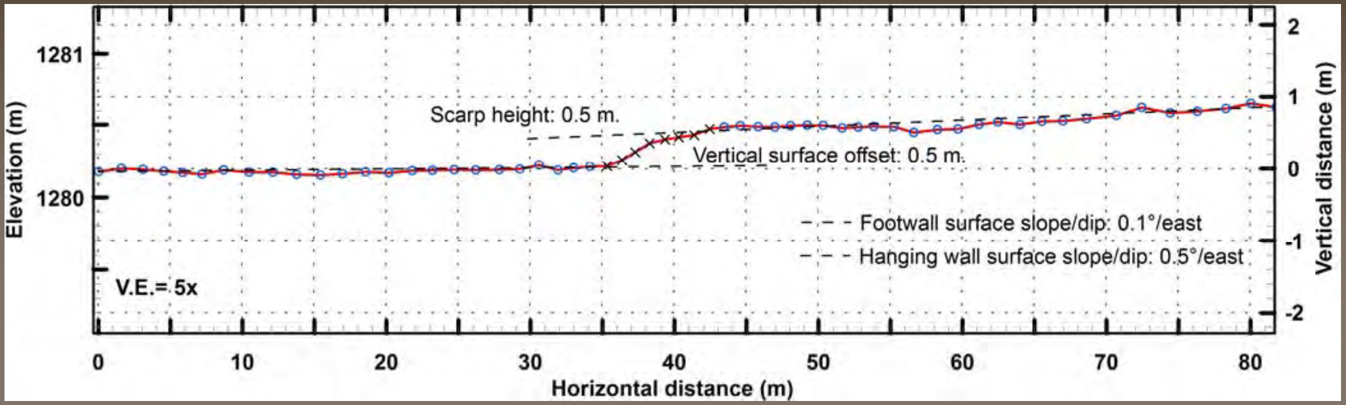

GCS Geoscience
2014 Trenches
2200 West
Flyer Way
215
N
0
80 m
Lidar-based slopeshade map of Airport East Trench site

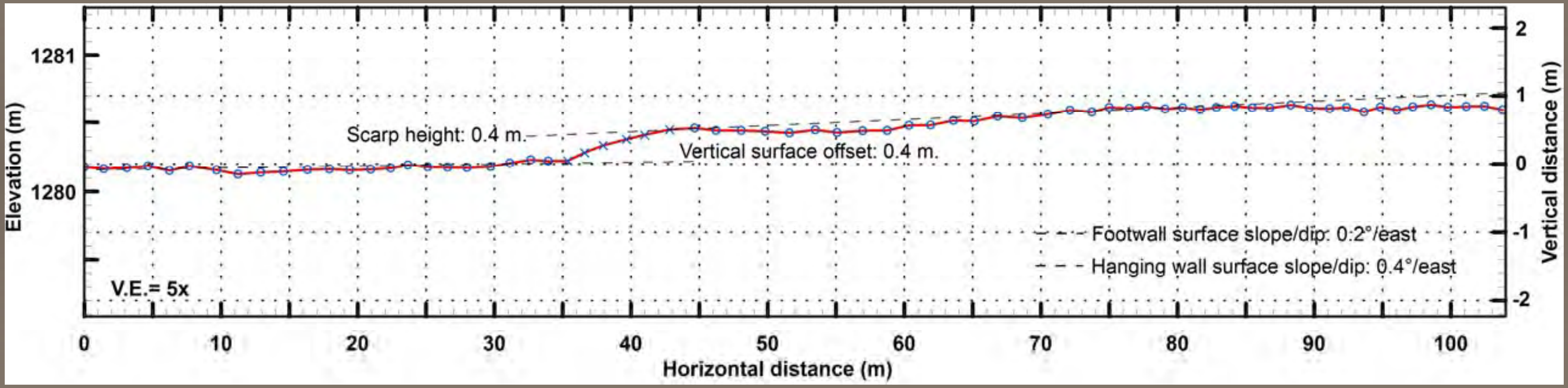

2200 West
UGS Trenches
215
Flyer Way
N
0
80 m
Lidar-based slopeshade map of Airport East Trench site



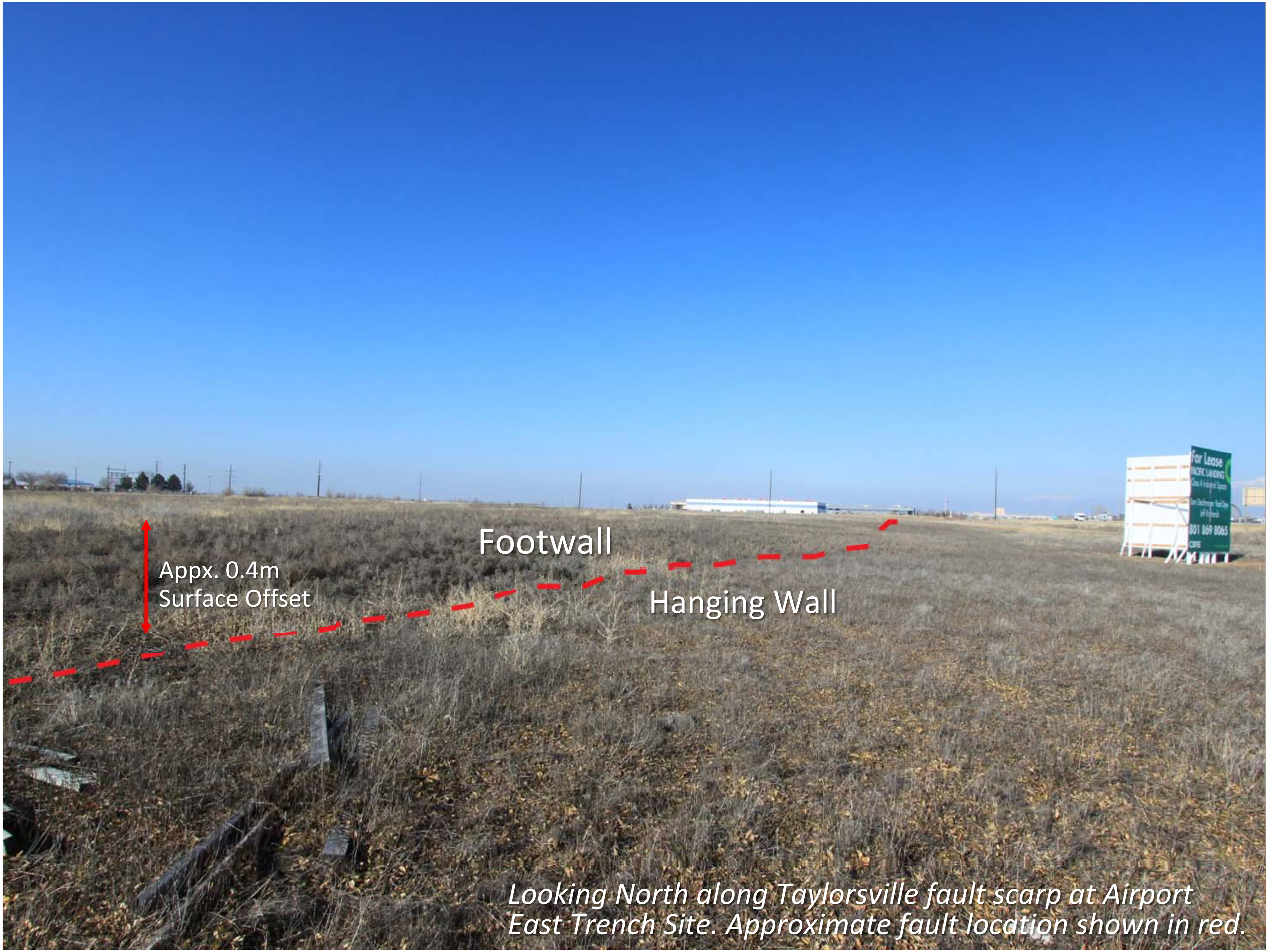
Lidar-based slopeshade map of Airport East Trench site

Profiles





- Vertical surface offset ~0.4 m
- Scarp height ~0.4m



Looking North along Taylorsville fault scarp at Airport East Trench Site. Approximate fault location shown in red.

Excavation – August 24, 2015


CAUTION — CUIDADO CAUTION — CUIDADO CAUTION

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

Stratigraphy

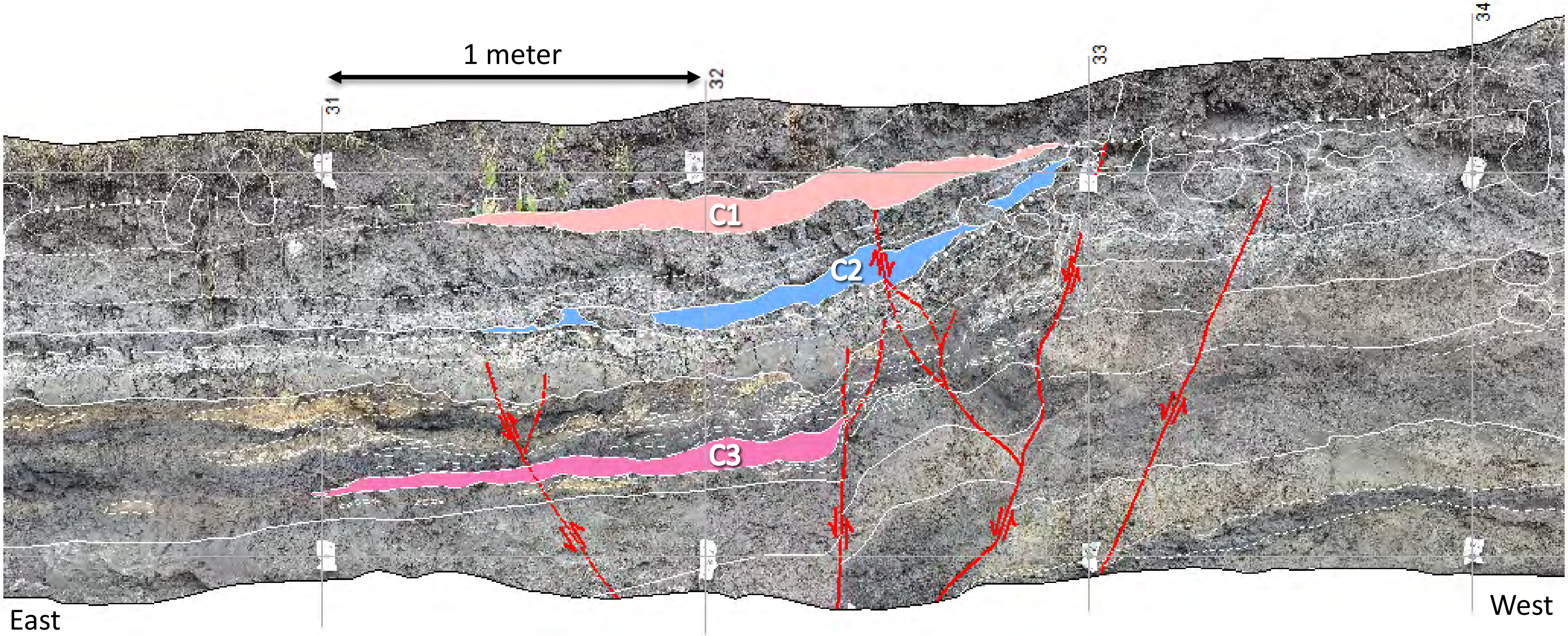
- Exposed fine-grained wetland, marsh, and fluvial overbank sediments, with lacustrine interbeds and scarp-derived colluvium
- Mapped 7 stratigraphic units
- Broad warping of units in footwall
- Several injected sand dikes correlated with areas of localized warping and deformation; probably liquefaction induced

deposited on Paleo-
argin marshes.

eas of localized
ion induced

Fault Zone

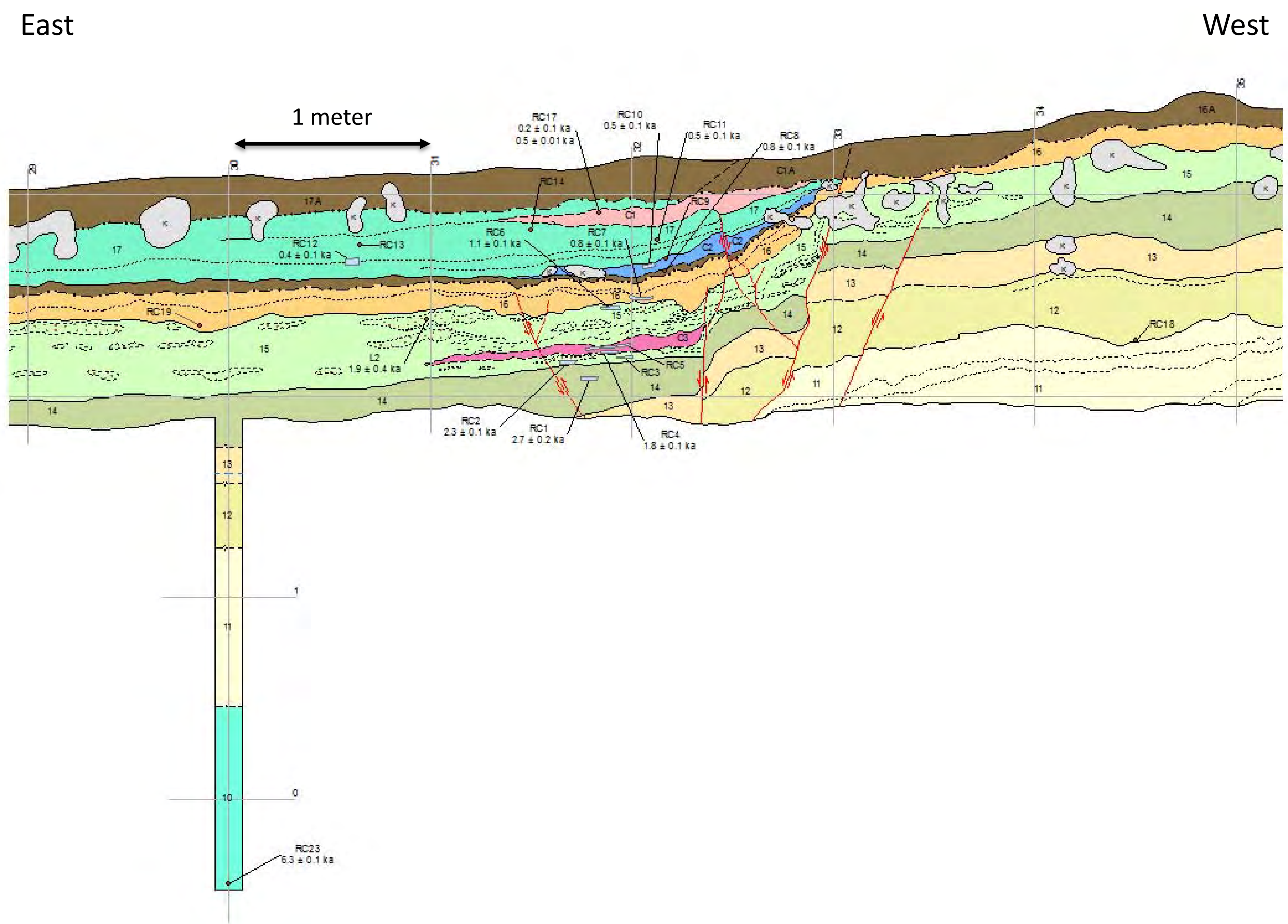
- Evidence for 3 surface faulting earthquakes; possibility of a 4th liquefaction related event shown by injected sand dikes and broad warping of footwall units.
- Complex rupture zone, spiderweb of faults
- Small events; 0.4 m total displacement exposed in trench



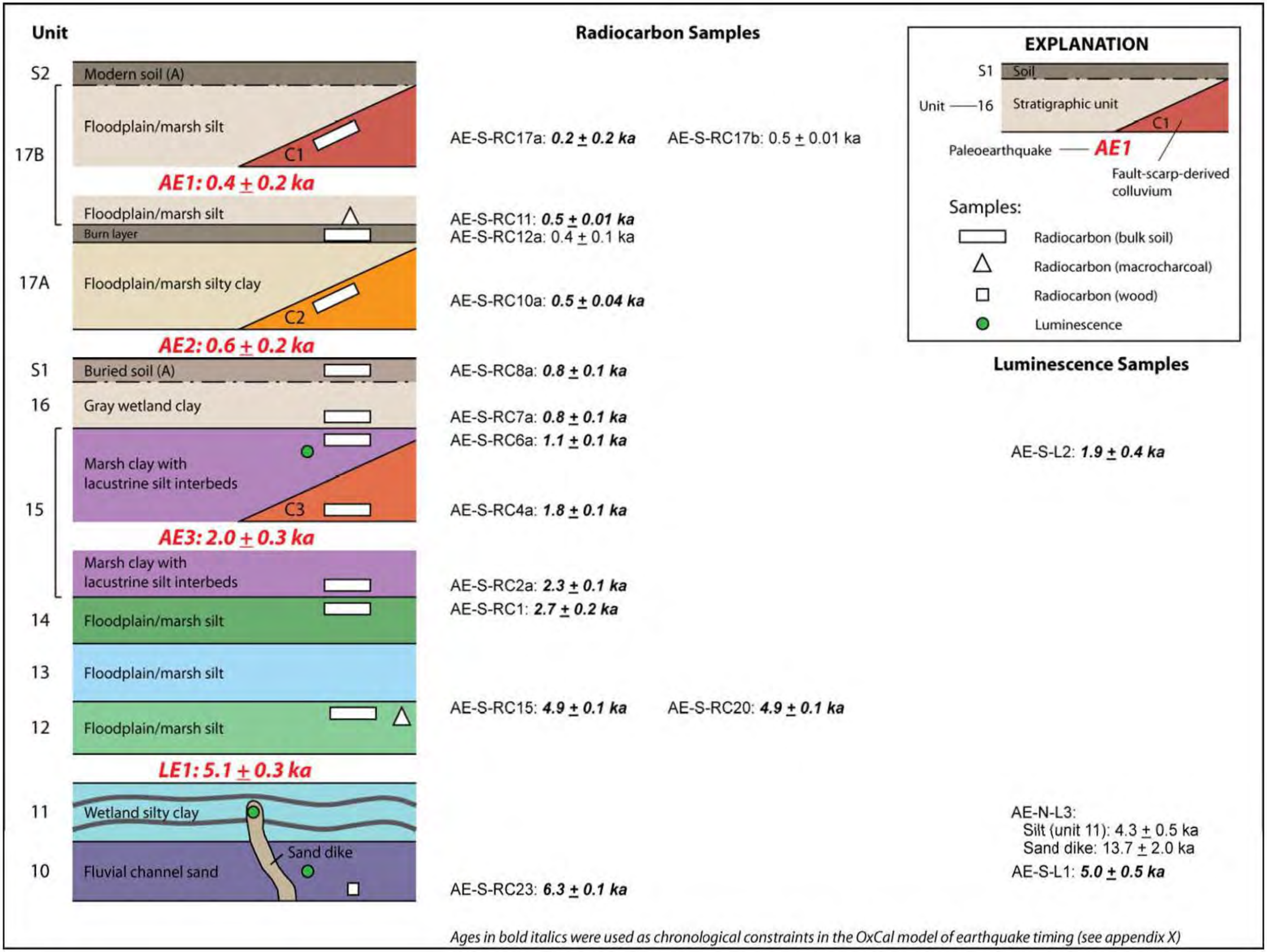
- Colluvial wedges:
  - Identified 3 wedges (C1-C3)
  - Thin wedges; maximum thickness: C1 ~ 10 cm; C2 ~ 12 cm; C3 ~ 10 cm
- Faulting:
  - Main trace dips 40-75° E.
  - ~ 27 cm of vertical displacement on main trace
  - ~ 7 synthetic/antithetic faults

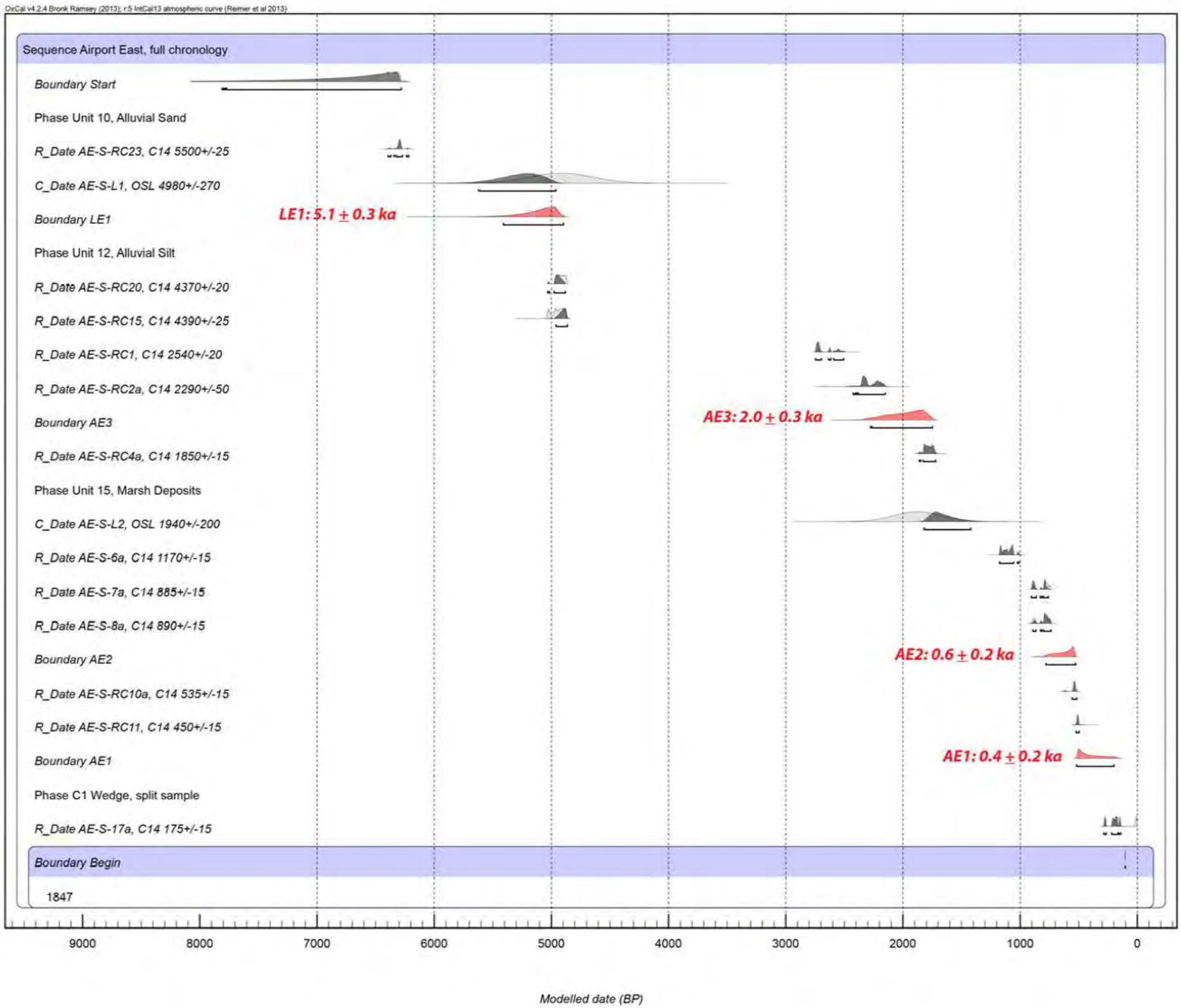
Sampling Strategy

- Radiocarbon (^{14}C)
  - 22 total samples collected in the field – 11 bulk soil, 10 discrete charcoal, 1 wood (collected from bottom of borehole)
  - 22 samples processed by PaleoResearch Institute (PRI), Golden, Colorado
  - 14 samples sent to Woods Hole Oceanographic Institution (Woods Hole, Massachusetts) for Accelerator Mass Spectrometry (AMS) dating.
- Optically Stimulated Luminescence (OSL)
  - 3 samples collected from sandy or silty lacustrine and alluvial sediments – processed by Shannon Mahan (USGS) in Lakewood, Colorado.

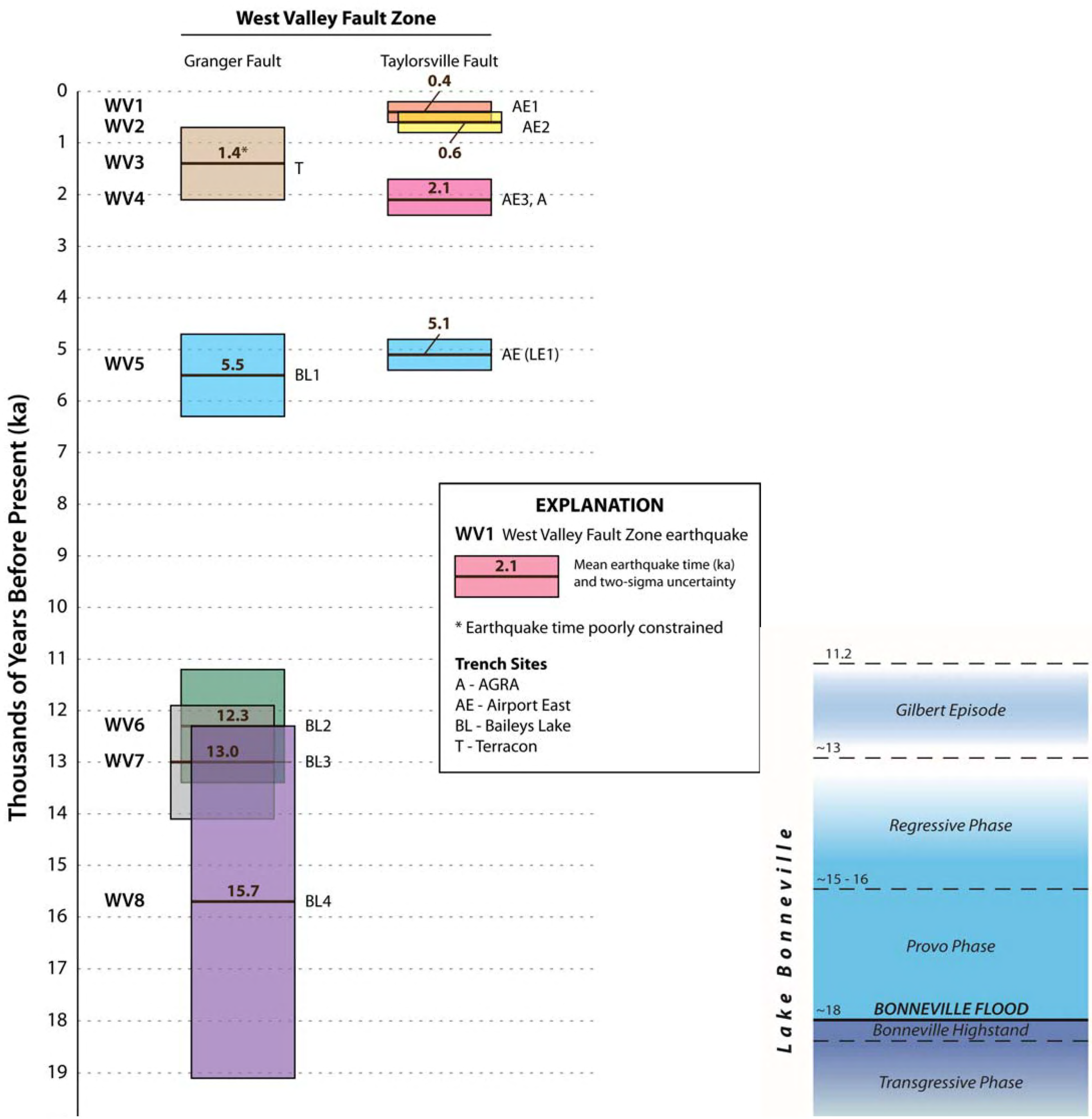


East
West
1 meter
RC17
0.2 ± 0.1 ka
0.5 ± 0.01 ka
RC10
0.5 ± 0.1 ka
RC11
0.5 ± 0.1 ka
RC8
0.8 ± 0.1 ka
RC14
RC9
RC12
0.4 ± 0.1 ka
RC13
RC6
1.1 ± 0.1 ka
RC7
0.8 ± 0.1 ka
RC19
RC18
L2
1.9 ± 0.4 ka
RC3
RC5
RC2
2.3 ± 0.1 ka
RC1
2.7 ± 0.2 ka
RC4
1.8 ± 0.1 ka
RC23
6.3 ± 0.1 ka
17A
16A
C1A
C1
C2
C3

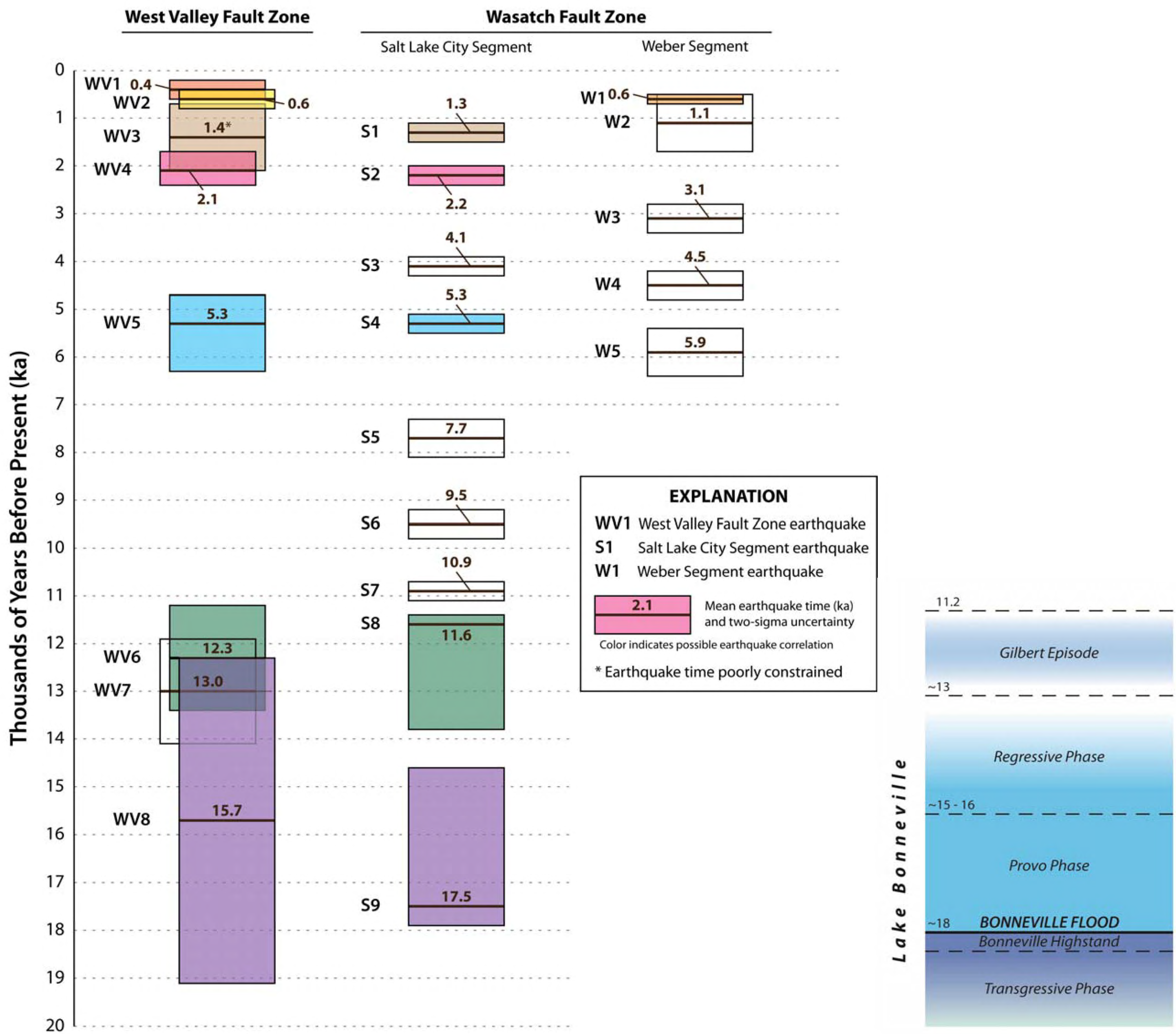

Unit
Radiocarbon Samples
EXPLANATION
S2
Modern soil (A)
17B
Floodplain/marsh silt
C1
AE-S-RC17a: 0.2 ± 0.2 ka
AE-S-RC17b: 0.5 ± 0.01 ka
AE1: 0.4 ± 0.2 ka
Floodplain/marsh silt
Burn layer
AE-S-RC11: 0.5 ± 0.01 ka
AE-S-RC12a: 0.4 ± 0.1 ka
17A
Floodplain/marsh silty clay
C2
AE-S-RC10a: 0.5 ± 0.04 ka
AE2: 0.6 ± 0.2 ka
S1
Buried soil (A)
AE-S-RC8a: 0.8 ± 0.1 ka
16
Gray wetland clay
AE-S-RC7a: 0.8 ± 0.1 ka
AE-S-RC6a: 1.1 ± 0.1 ka
15
Marsh clay with lacustrine silt interbeds
C3
AE-S-RC4a: 1.8 ± 0.1 ka
AE3: 2.0 ± 0.3 ka
Marsh clay with lacustrine silt interbeds
AE-S-RC2a: 2.3 ± 0.1 ka
AE-S-RC1: 2.7 ± 0.2 ka
14
Floodplain/marsh silt
13
Floodplain/marsh silt
12
Floodplain/marsh silt
AE-S-RC15: 4.9 ± 0.1 ka
AE-S-RC20: 4.9 ± 0.1 ka
LE1: 5.1 ± 0.3 ka
11
Wetland silty clay
10
Fluvial channel sand
Sand dike
AE-S-RC23: 6.3 ± 0.1 ka
S1
Soil
Unit
16
Stratigraphic unit
C1
Paleoearthquake
AE1
Fault-scarp-derived colluvium
Samples:
Radiocarbon (bulk soil)
Radiocarbon (macrocharcoal)
Radiocarbon (wood)
Luminescence
Luminescence Samples
AE-S-L2: 1.9 ± 0.4 ka
AE-N-L3:
Silt (unit 11): 4.3 ± 0.5 ka
Sand dike: 13.7 ± 2.0 ka
AE-S-L1: 5.0 ± 0.5 ka
Ages in bold italics were used as chronological constraints in the OxCal model of earthquake timing (see appendix X)



OxCal v4.2.4 Bronk Ramsey (2013); r:5 IntCal13 atmospheric curve (Reimer et al 2013)
Sequence Airport East, full chronology
Boundary Start
Phase Unit 10, Alluvial Sand
R_Date AE-S-RC23, C14 5500+/-25
C_Date AE-S-L1, OSL 4980+/-270
Boundary LE1
LE1: 5.1 ± 0.3 ka
Phase Unit 12, Alluvial Silt
R_Date AE-S-RC20, C14 4370+/-20
R_Date AE-S-RC15, C14 4390+/-25
R_Date AE-S-RC1, C14 2540+/-20
R_Date AE-S-RC2a, C14 2290+/-50
Boundary AE3
AE3: 2.0 ± 0.3 ka
R_Date AE-S-RC4a, C14 1850+/-15
Phase Unit 15, Marsh Deposits
C_Date AE-S-L2, OSL 1940+/-200
R_Date AE-S-6a, C14 1170+/-15
R_Date AE-S-7a, C14 885+/-15
R_Date AE-S-8a, C14 890+/-15
Boundary AE2
AE2: 0.6 ± 0.2 ka
R_Date AE-S-RC10a, C14 535+/-15
R_Date AE-S-RC11, C14 450+/-15
Boundary AE1
AE1: 0.4 ± 0.2 ka
Phase C1 Wedge, split sample
R_Date AE-S-17a, C14 175+/-15
Boundary Begin
1847
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Modelled date (BP)



West Valley Fault Zone
Granger Fault
Taylorsville Fault
Thousands of Years Before Present (ka)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
WV1
WV2
WV3
WV4
WV5
WV6
WV7
WV8
1.4*
T
0.4
AE1
AE2
0.6
2.1
AE3, A
5.1
AE (LE1)
5.5
BL1
12.3
BL2
13.0
BL3
15.7
BL4
EXPLANATION
WV1 West Valley Fault Zone earthquake
2.1
Mean earthquake time (ka) and two-sigma uncertainty
* Earthquake time poorly constrained
Trench Sites
A - AGRA
AE - Airport East
BL - Baileys Lake
T - Terracon
Lake Bonneville
11.2
Gilbert Episode
~13
Regressive Phase
~15 - 16
Provo Phase
~18
BONNEVILLE FLOOD
Bonneville Highstand
Transgressive Phase



West Valley Fault Zone
Wasatch Fault Zone
Salt Lake City Segment
Weber Segment
Thousands of Years Before Present (ka)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
WV1 0.4
WV2 0.6
WV3 1.4*
WV4 2.1
WV5 5.3
WV6 12.3
WV7 13.0
WV8 15.7
S1 1.3
S2 2.2
S3 4.1
S4 5.3
S5 7.7
S6 9.5
S7 10.9
S8 11.6
S9 17.5
W1 0.6
W2 1.1
W3 3.1
W4 4.5
W5 5.9
EXPLANATION
WV1 West Valley Fault Zone earthquake
S1 Salt Lake City Segment earthquake
W1 Weber Segment earthquake
2.1
Mean earthquake time (ka) and two-sigma uncertainty
Color indicates possible earthquake correlation
* Earthquake time poorly constrained
Lake Bonneville
11.2
Gilbert Episode
~13
Regressive Phase
~15 - 16
Provo Phase
~18
BONNEVILLE FLOOD
Bonneville Highstand
Transgressive Phase

Summary & Conclusions

- At least 3 earthquakes ruptured the Airport East site in the late Holocene.
  - EQ times are moderately well constrained by ^{14}C and OSL ages
  - Per-event displacements are very small, ~10 cm
  - The fourth even identified (LE1) cannot be directly attributed to slip on the Taylorsville fault
- Earthquakes at the Airport East site possibly correlate with both the SLCS and the Weber segment
  - Event AE3 possibly correlates with the second youngest event on the SLCS
  - Event AE2 possibly correlates with the youngest event on the Weber segment
- Next Steps:
  - Further integrate these results with data from SLCS and WS
  - Evaluate rupture models for the WVFZ utilizing this new data

UGS

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

USGS

Chris DuRoss
Rich Briggs
Steve Personius
Nadine Reitman
Shannon Mahan

Other

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

Paleoseismic Insight into the Normal Fault Segmentation of the Wasatch Fault Zone

Chris DuRoss

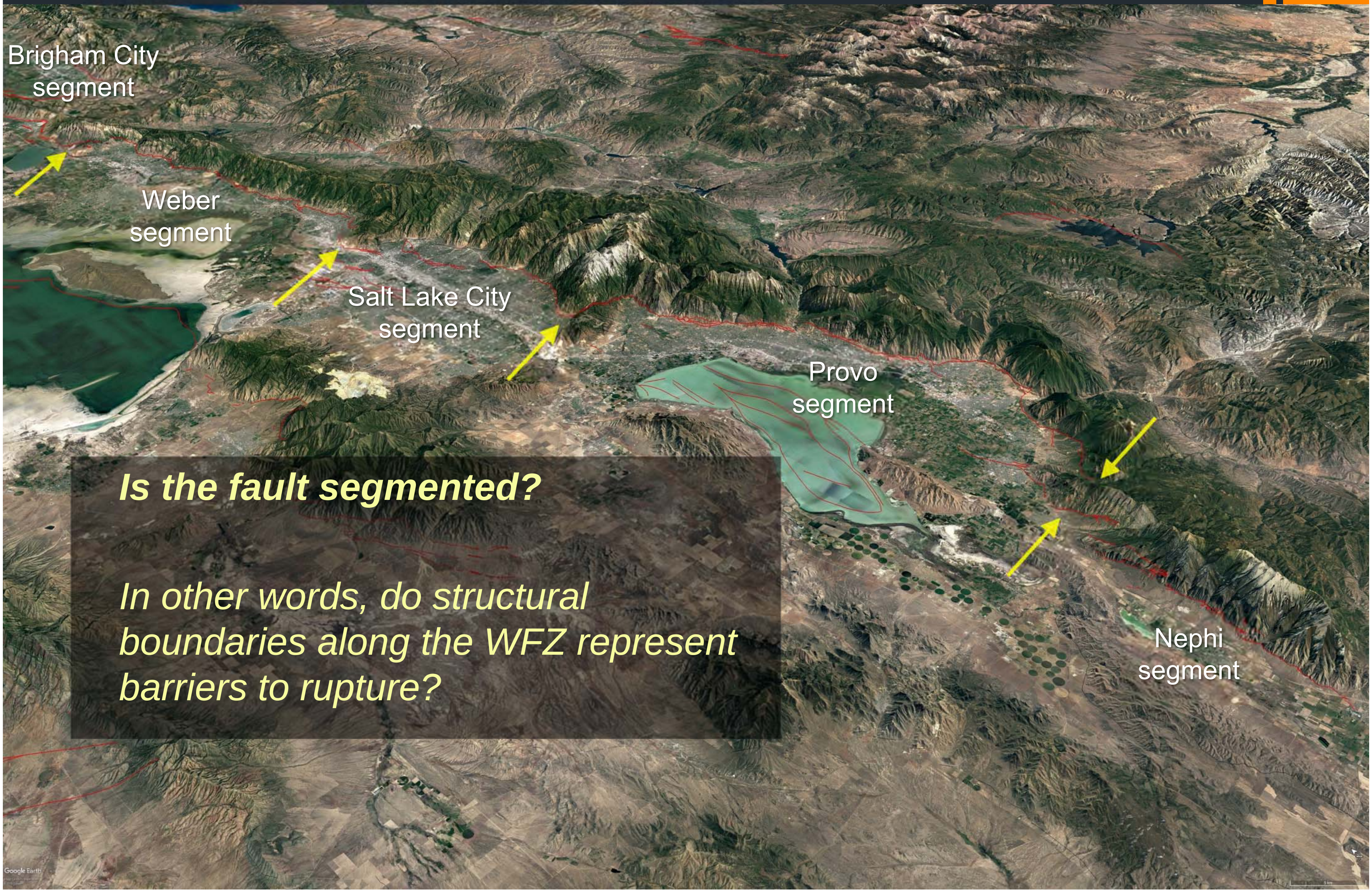
U.S. Geological Survey, Golden, Colorado

science for a changing world

Utah Quaternary Fault Parameters Working Group, February 10, 2017

UTAH DNR GEOLOGICAL SURVEY

Wasatch fault zone (WFZ)

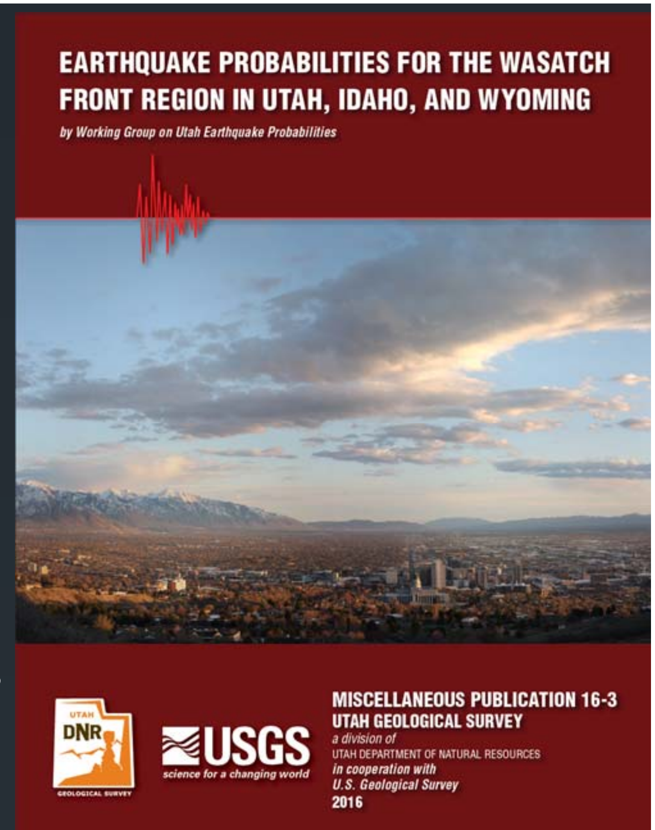


Is the fault segmented?

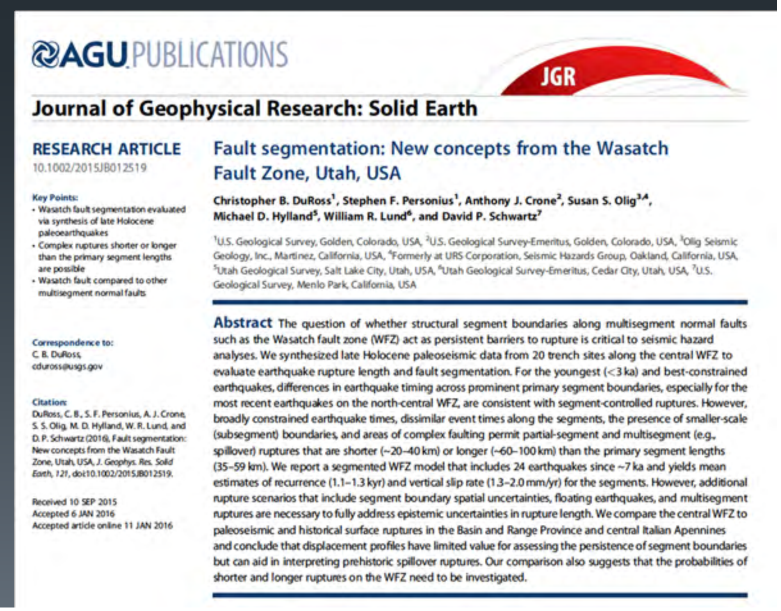
In other words, do structural boundaries along the WFZ represent barriers to rupture?

Topics

1. *Working Group on Utah Earthquake Probabilities (WGUEP) treatment of the WFZ*
2. *Stringing Pearls analysis (rupture building)*
3. *Update on recent trenching of the Nephi, Salt Lake City, and Provo segments*



WGUEP (2016 – UGS Misc. Pub 16-3)



AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Solid Earth

RESEARCH ARTICLE
10.1002/2015JB012519

Key Points:
- Wasatch fault segmentation evaluated via synthesis of late Holocene paleoearthquakes
- Complex ruptures shorter or longer than the primary segment lengths are possible
- Wasatch fault compared to other multisegment normal faults

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Fault segmentation: New concepts from the Wasatch Fault Zone, Utah, USA

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Abstract The question of whether structural segment boundaries along multisegment normal faults such as the Wasatch fault zone (WFZ) act as persistent barriers to rupture is critical to seismic hazard analyses. We synthesized late Holocene paleoseismic data from 20 trench sites along the central WFZ to evaluate earthquake rupture length and fault segmentation. For the youngest (<3 ka) and best-constrained earthquakes, differences in earthquake timing across prominent primary segment boundaries, especially for the most recent earthquakes on the north-central WFZ, are consistent with segment-controlled ruptures. However, broadly constrained earthquake times, dissimilar event times along the segments, the presence of smaller-scale (subsegment) boundaries, and areas of complex faulting permit partial-segment and multisegment (e.g., spillover) ruptures that are shorter (~20–40 km) or longer (~60–100 km) than the primary segment lengths (35–59 km). We report a segmented WFZ model that includes 24 earthquakes since ~7 ka and yields mean estimates of recurrence (1.1–1.3 kyr) and vertical slip rate (1.3–2.0 mm/yr) for the segments. However, additional rupture scenarios that include segment boundary spatial uncertainties, floating earthquakes, and multisegment ruptures are necessary to fully address epistemic uncertainties in rupture length. We compare the central WFZ to paleoseismic and historical surface ruptures in the Basin and Range Province and central Italian Apennines and conclude that displacement profiles have limited value for assessing the persistence of segment boundaries but can aid in interpreting prehistoric spillover ruptures. Our comparison also suggests that the probabilities of shorter and longer ruptures on the WFZ need to be investigated.

DuRoss et al. (2016 – JGR)

WGUEP Analysis

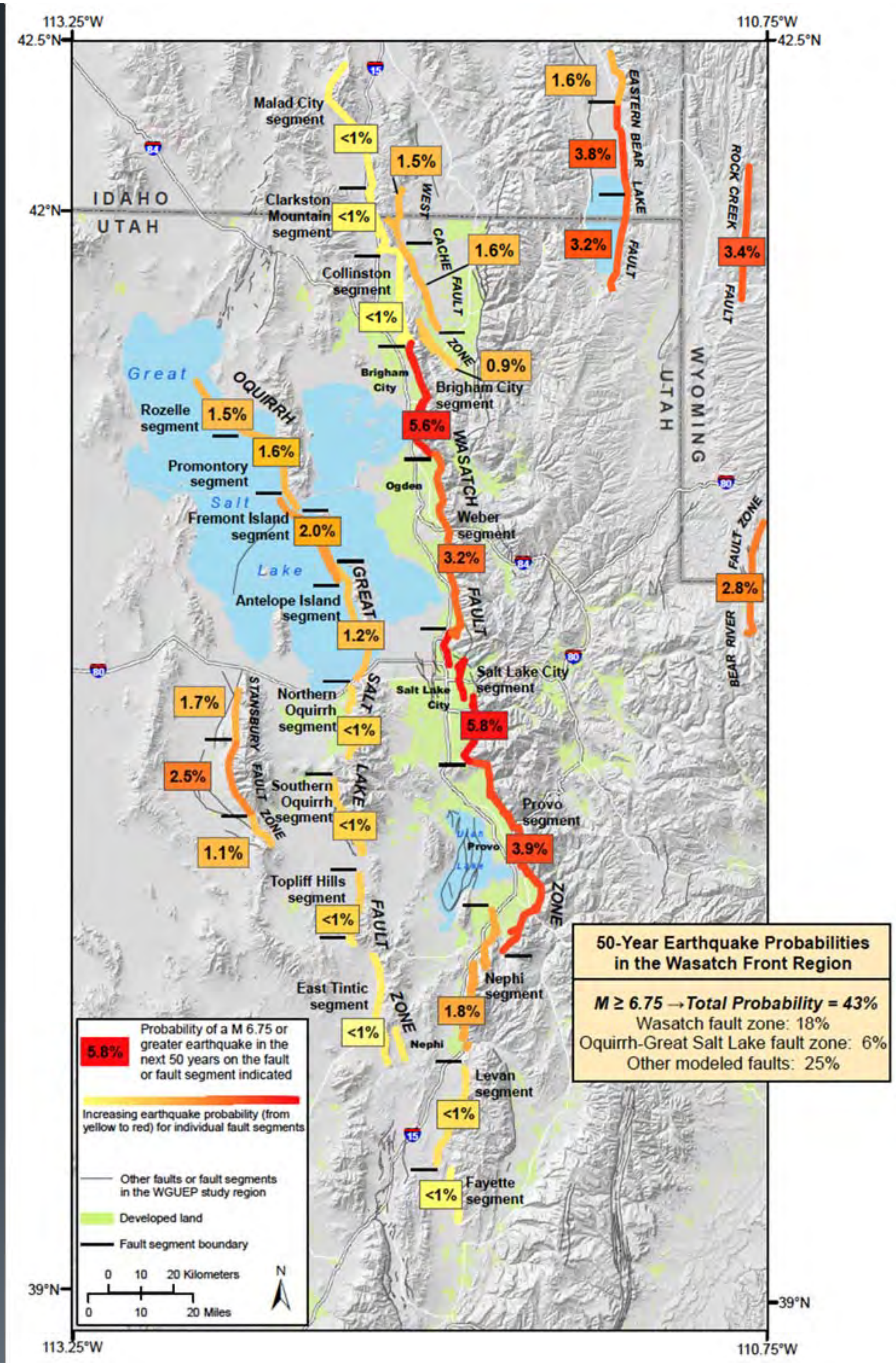
- Purpose: Update seismic source model for the central WFZ

- *Most significant work:*
  - *Synthesis of various paleoseismic datasets*
  - *Updated per-segment earthquake histories, recurrence intervals, and slip rates*
  - *Alternative rupture models (outside of the traditional segmentation model)*

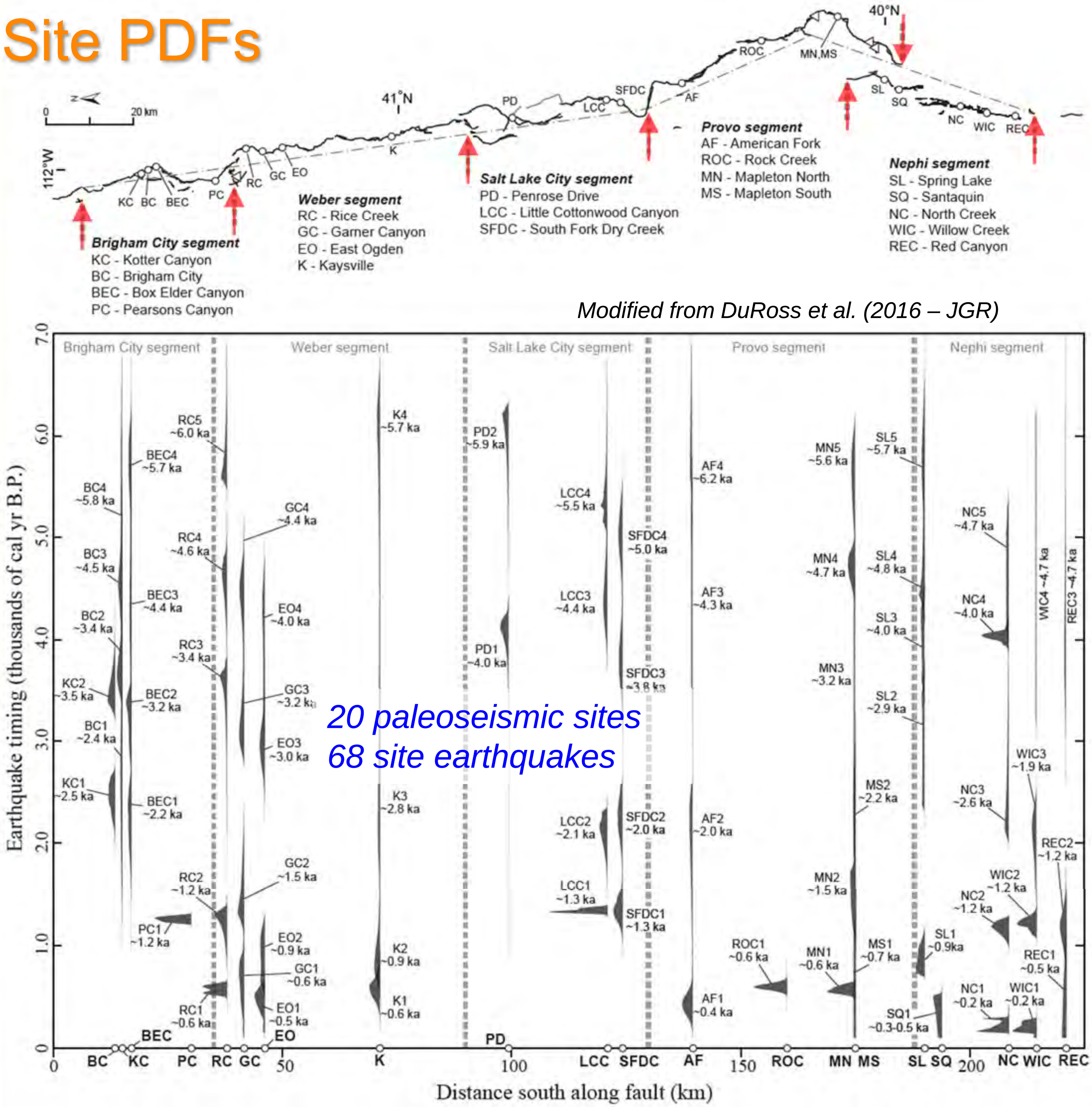
WGUEP Analysis

- *Wasatch Front Earthquake Forecast:*
  - *18% probability of at least one M6.75+ earthquake on the Wasatch fault in the next 50 years*
  - *43% probability of at least one M6.75+ earthquake in the region in the next 50 years*

WGUEP (2016)

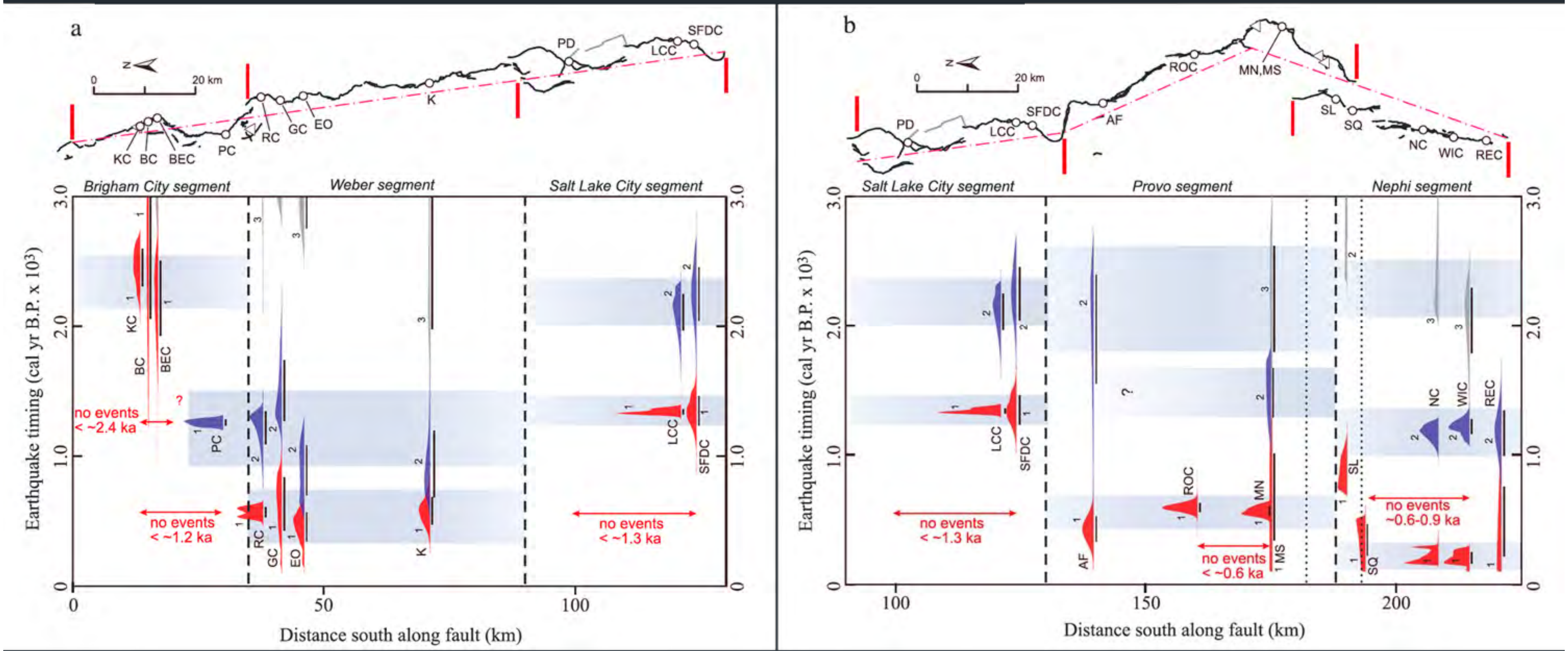


Site PDFs



Modified from DuRoss et al. (2016 – JGR)

Site Events → Segment Events



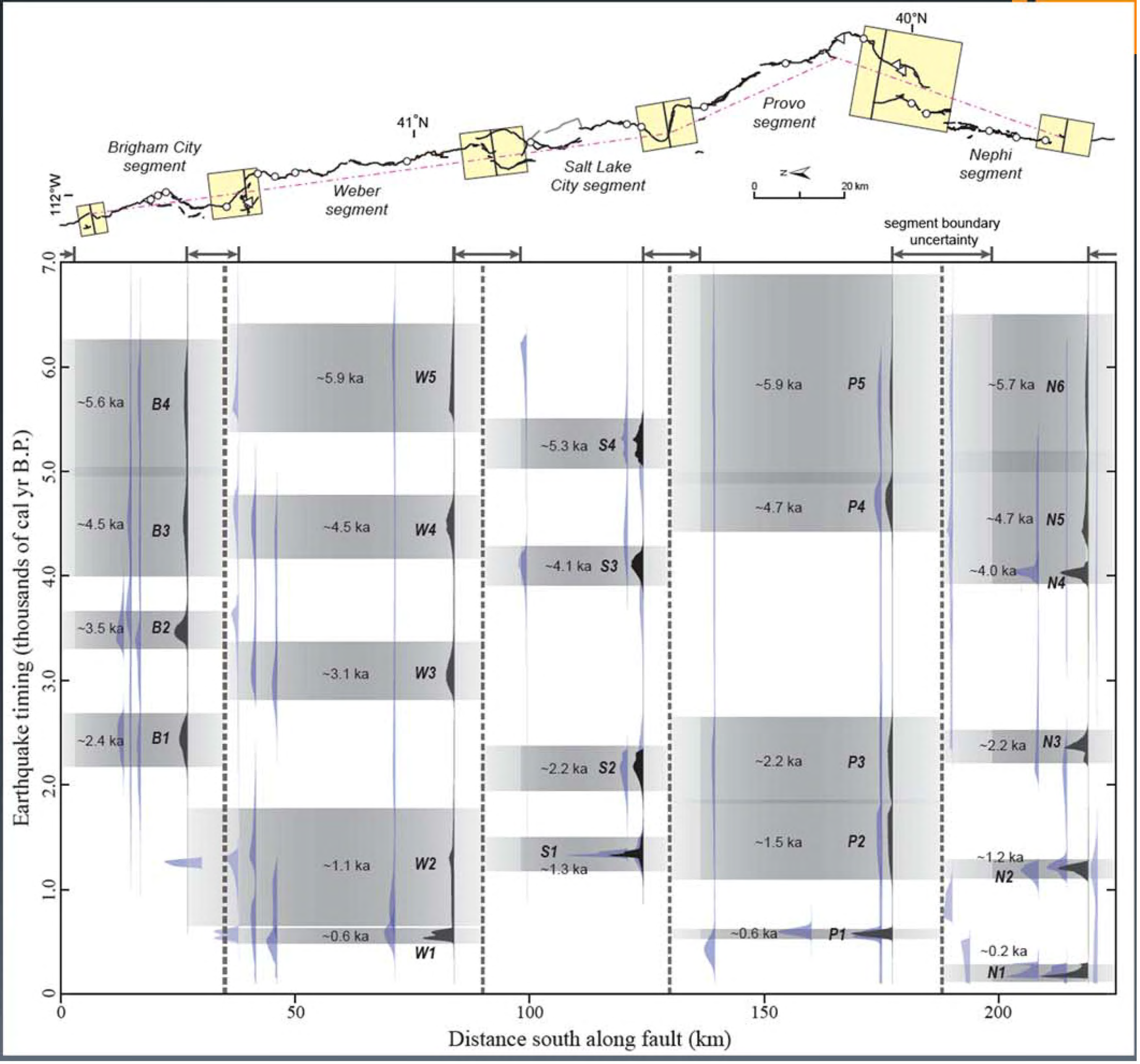
- *The youngest (<3 ka) earthquakes along the central WFZ provide the best evidence of ruptures limited (within reason) to the individual segments*

DuRoss et al. (2016 – JGR)

Single-Segment Rupture Model

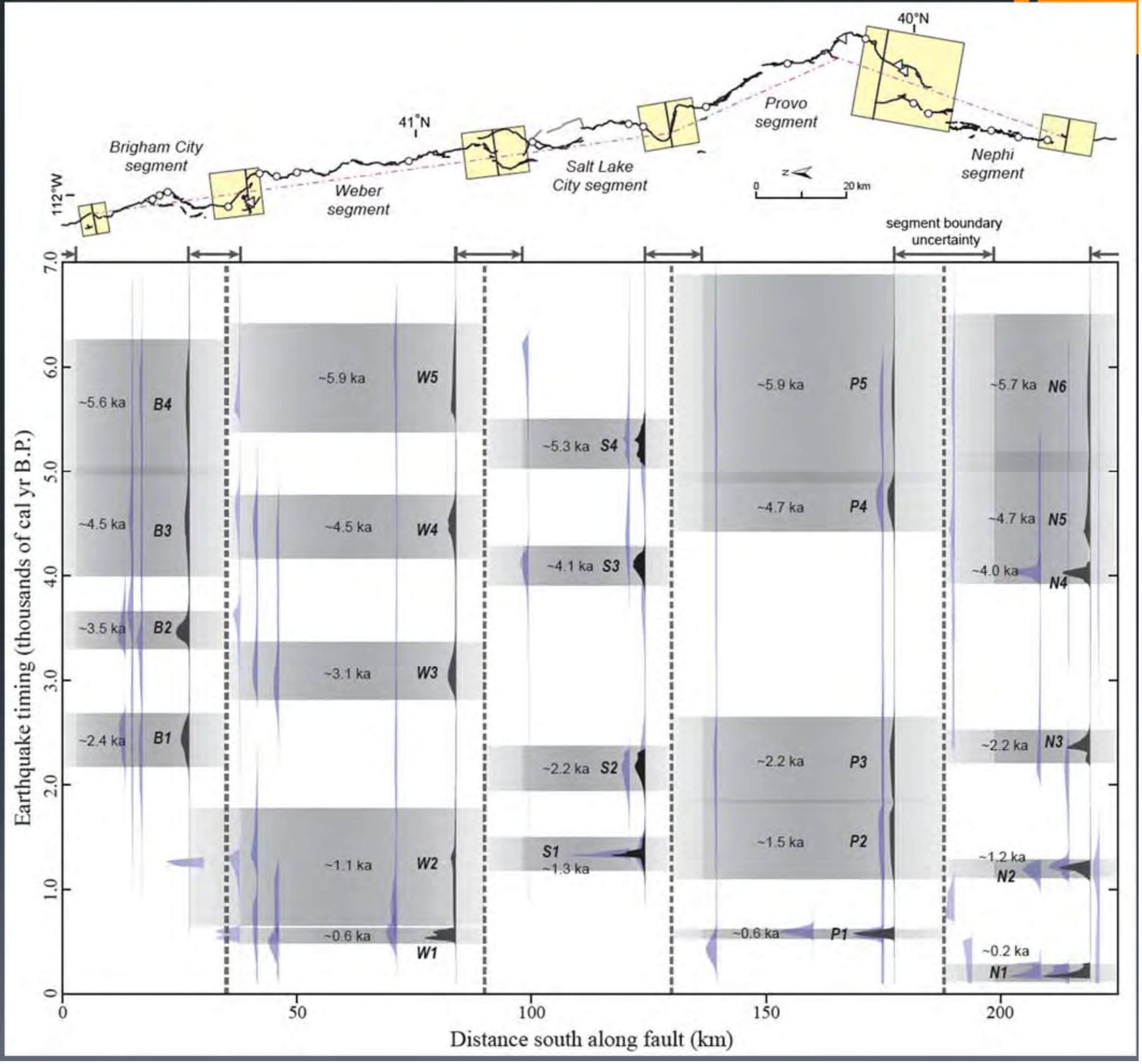
- 24 earthquakes since ~6 ka
- Mean recurrence: ~1.1–1.3 kyr per segment
- Mean slip rate: ~1.3–2.0 mm/yr per segment
- 3-17 km segment boundary uncertainties

Modified from DuRoss et al. (2016 – JGR)



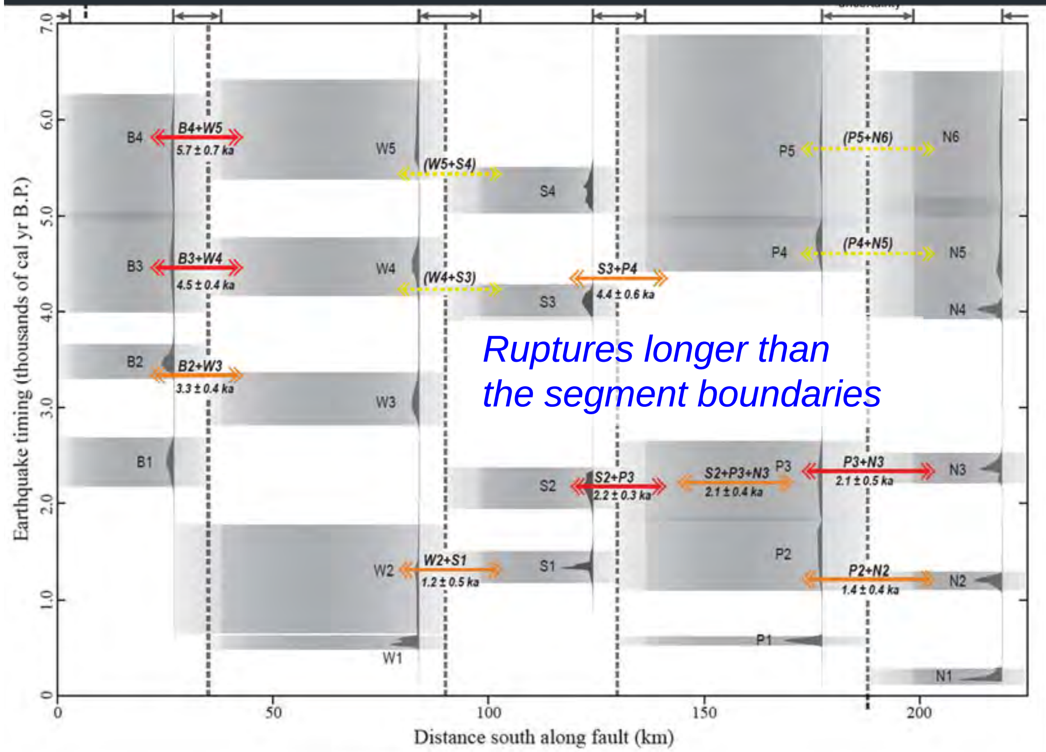
Single-Segment Rupture Model

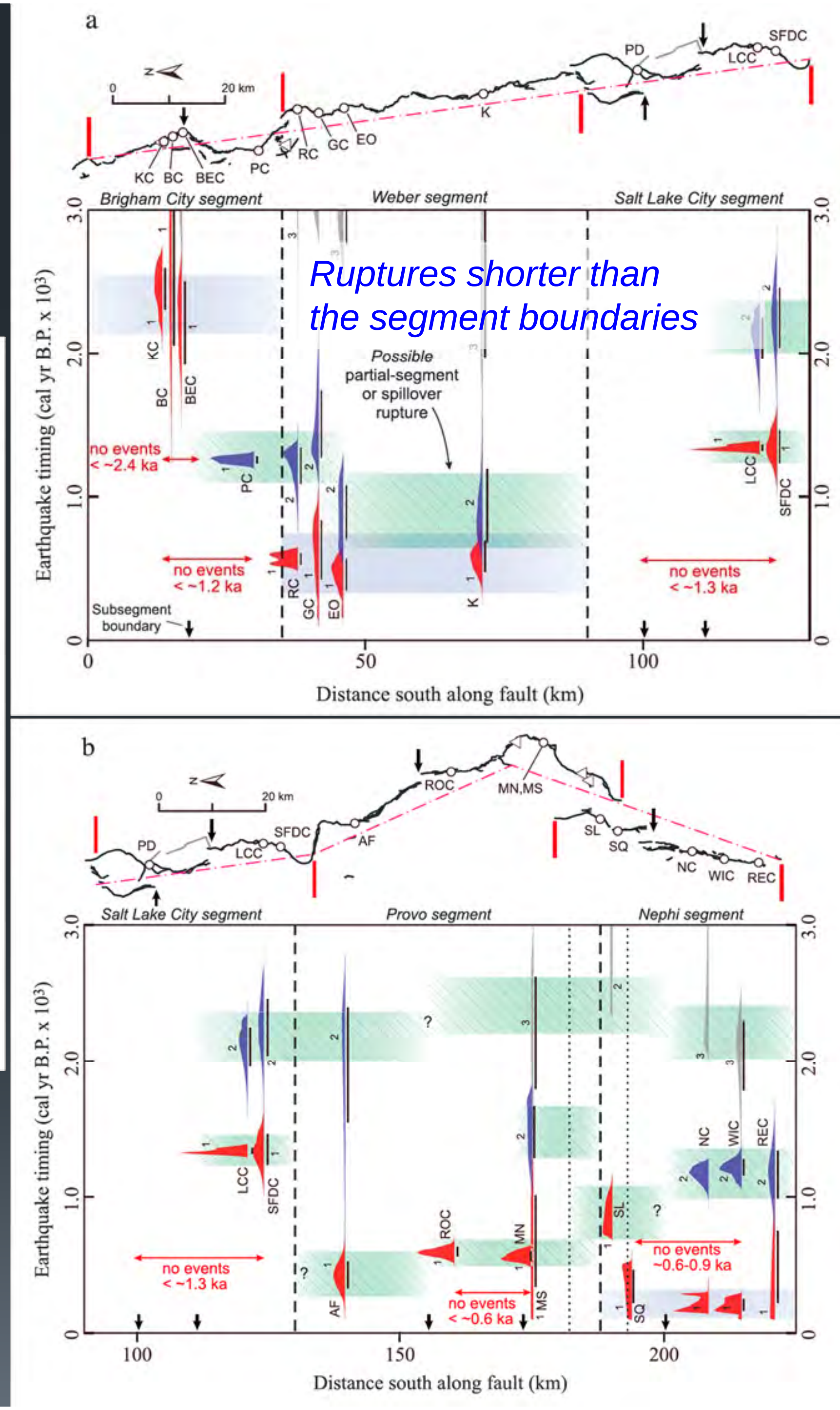
- **Pros**
  - Reasonable and reproducible
  - Segment boundary uncertainties account for some degree of spillover and partial segment rupture
- **Cons**
  - Limits complexity of allowable ruptures
  - Broad PDFs allow for multiple correlations



Alternative Rupture Models

Modified from WGUEP (2016)





- *WFZ paleoseismic data allow for multiple rupture modes*

DuRoss et al. (2016 – JGR)

Stringing Pearls

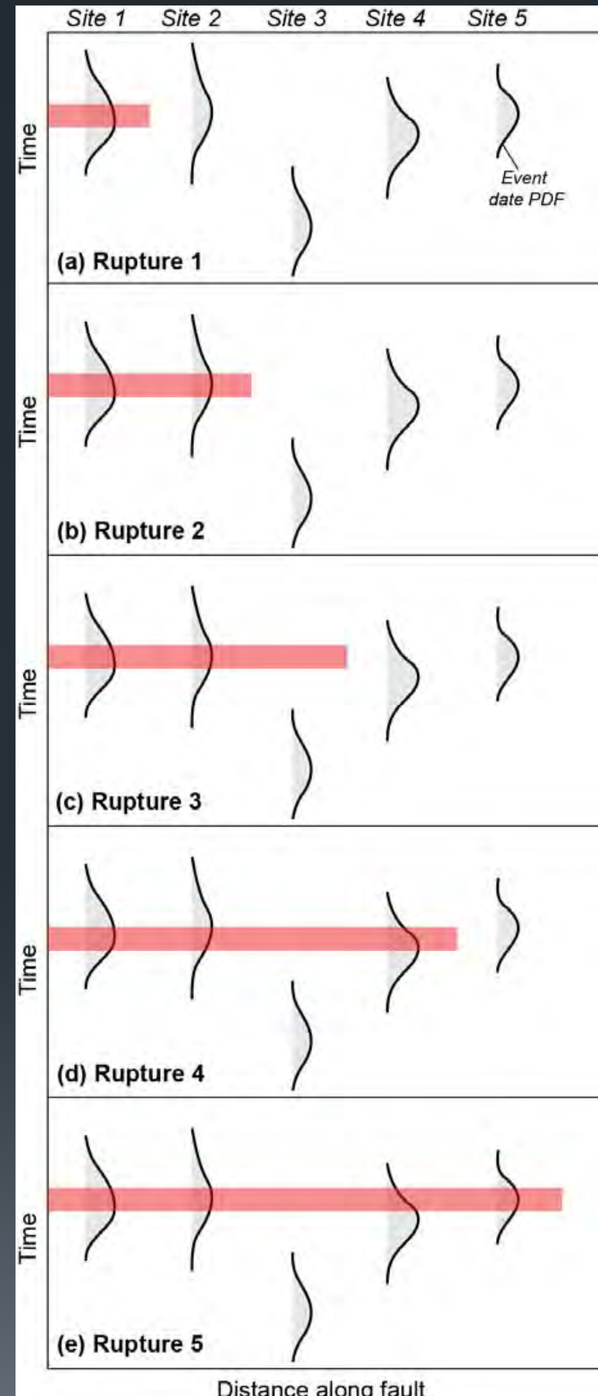
- Estimate hazard from multiple paleoseismic records by objectively exploring all potential event correlations

- Steps:
  1. Build possible ruptures based on correlations allowed by event dating

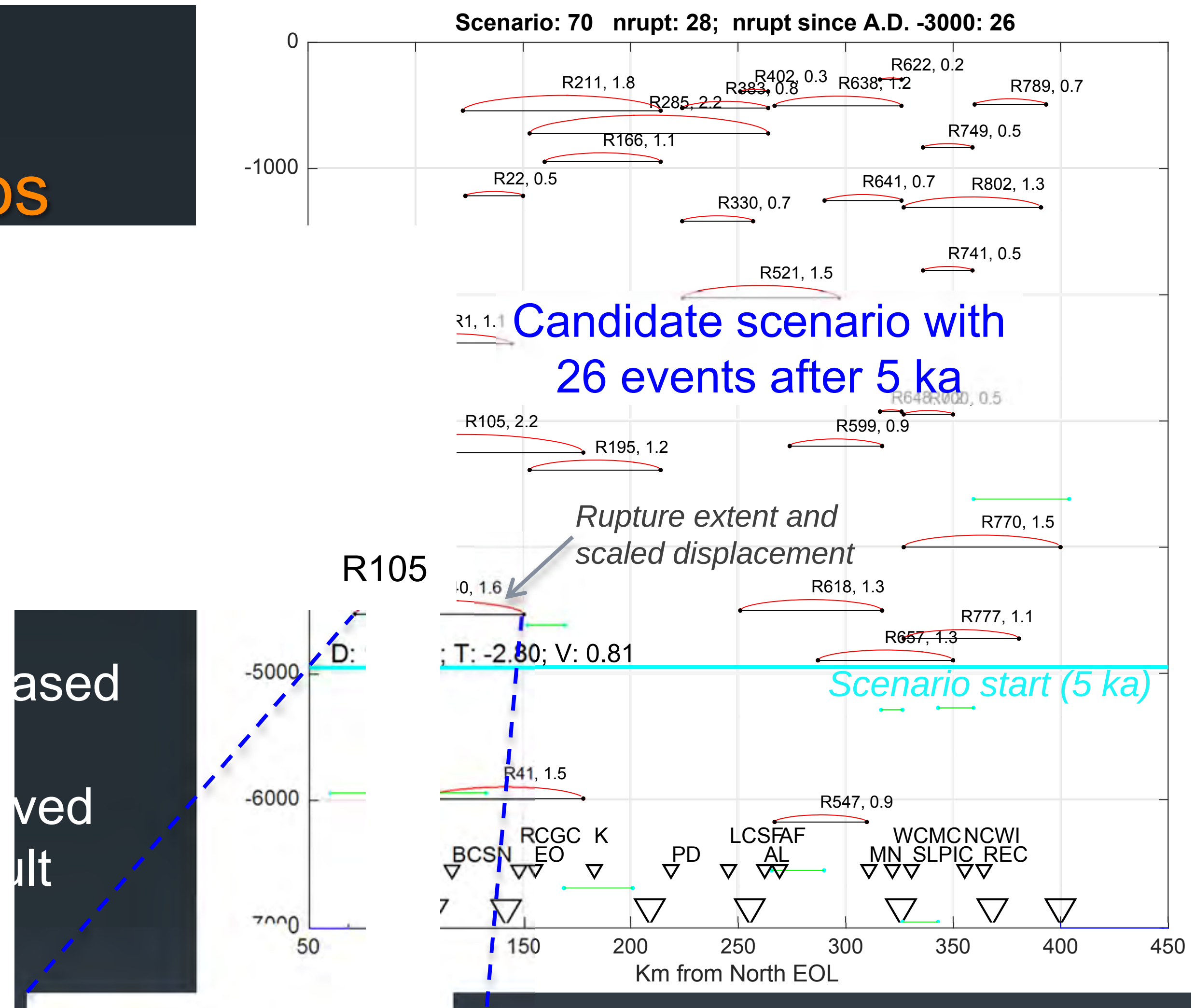
  1. Extend ruptures beyond ends of sites using displacement & scaling relations

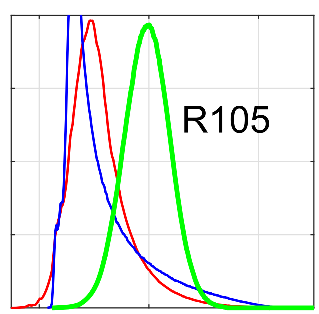
  1. Build "candidate rupture scenario" by selecting ruptures at random to account for each site observation

  1. Score scenarios for fit to fault displacement and dating agreement.



Ruptures Scenarios





Rupture 105, which combines events identified at three sites, is included in scenario 70

Ruptures Scenarios

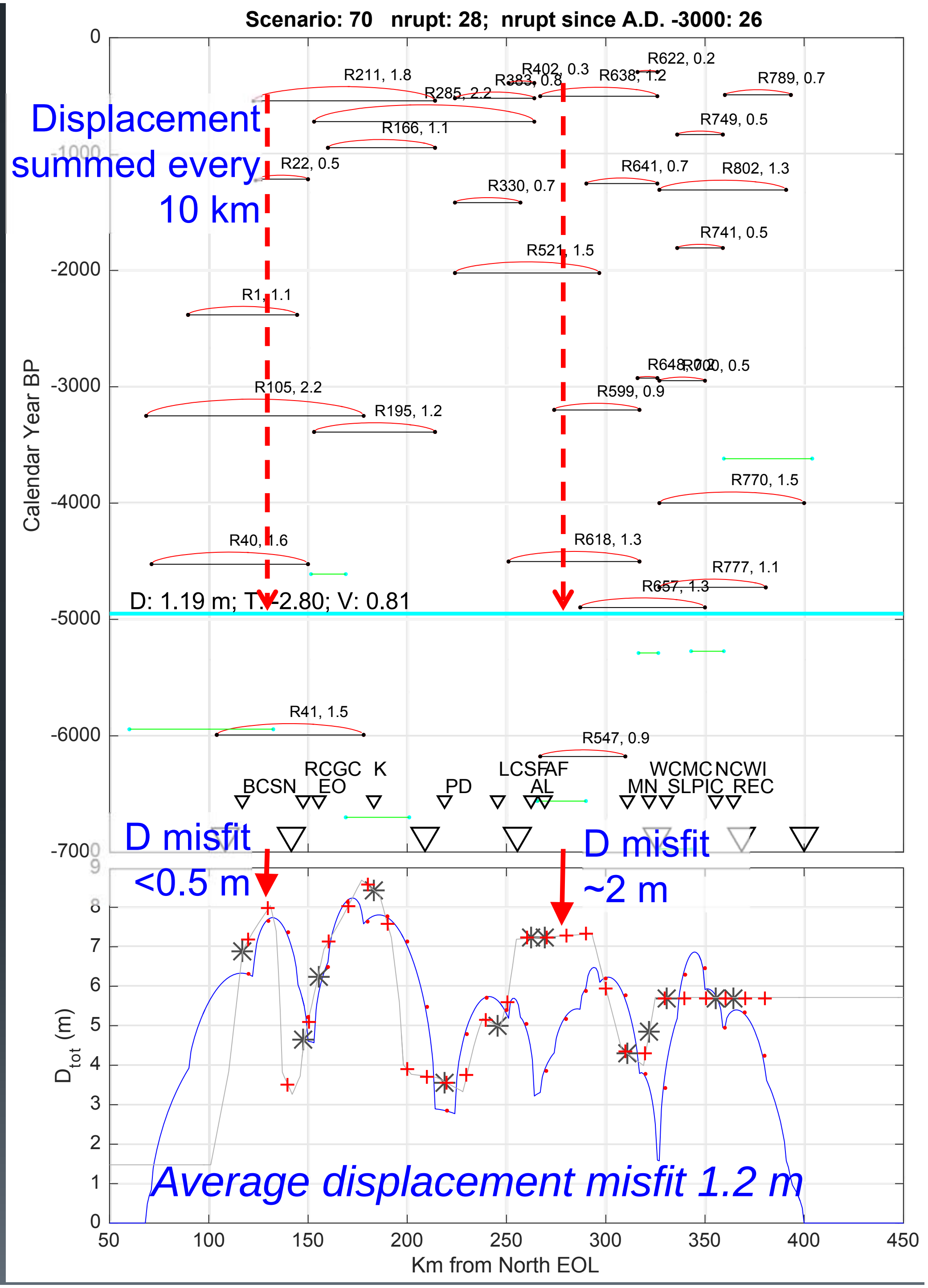
➢Displacement misfit and timing congruence used to grade scenarios

Displacement evaluated every 10 km:

All modeled ruptures (—▪—)

Latest Pleist. vert. offset (—+—)

Paleoseismic sites (“*”)



Ruptures Scenarios

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All modeled ruptures (—▪—)

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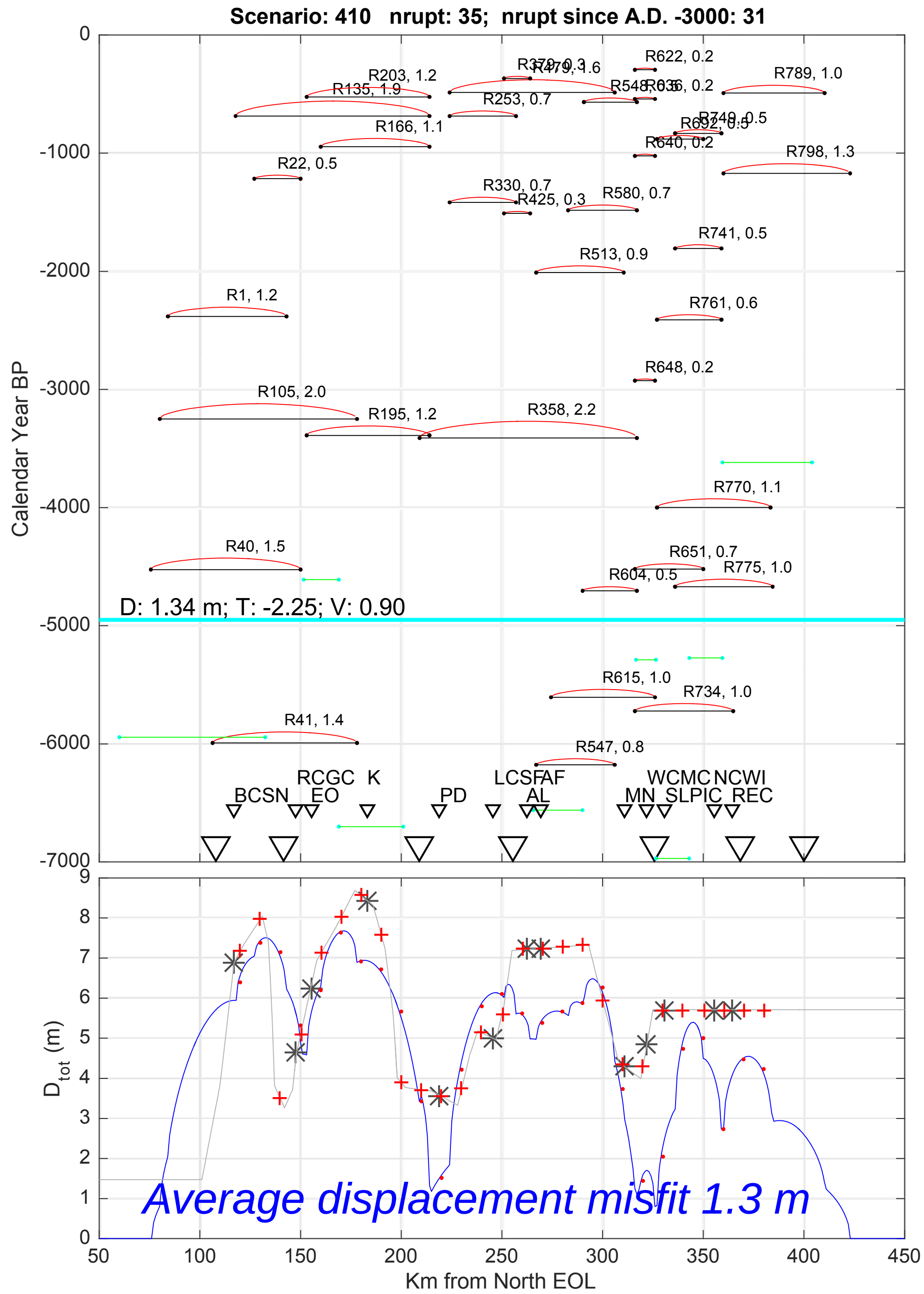
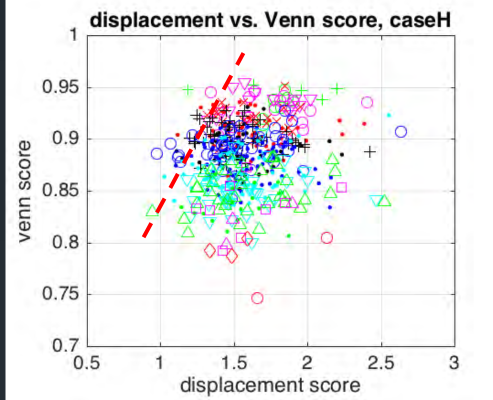
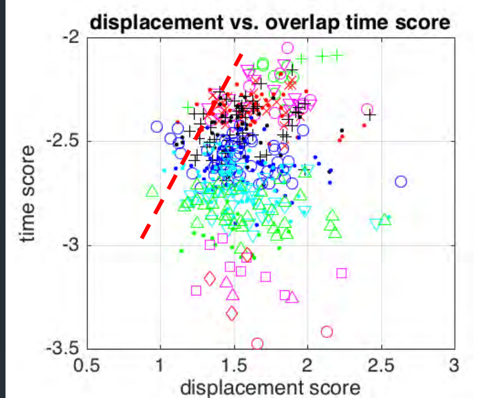


Evaluating Scenarios

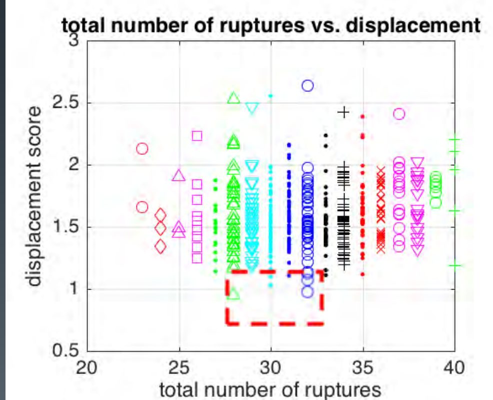
Time (overlap) vs. displacement scores

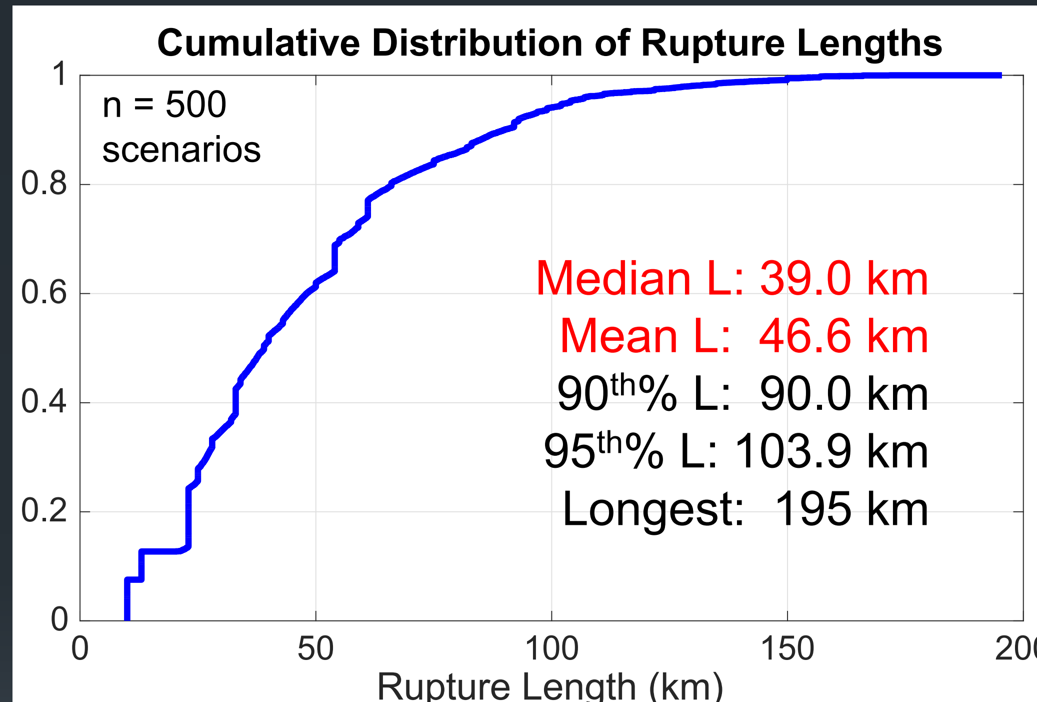


Time (product) vs. displacement scores



Displacement score vs. # of ruptures





Best displacement misfit for scenarios with 28 to 33 ruptures.

<u>In progress</u>: Magnitude-frequency distributions; analysis of segment boundary effectiveness

Salt Lake City, Provo, and Nephi Segment Trenching

- Purpose: Improve Holocene earthquake chronologies and address the question:

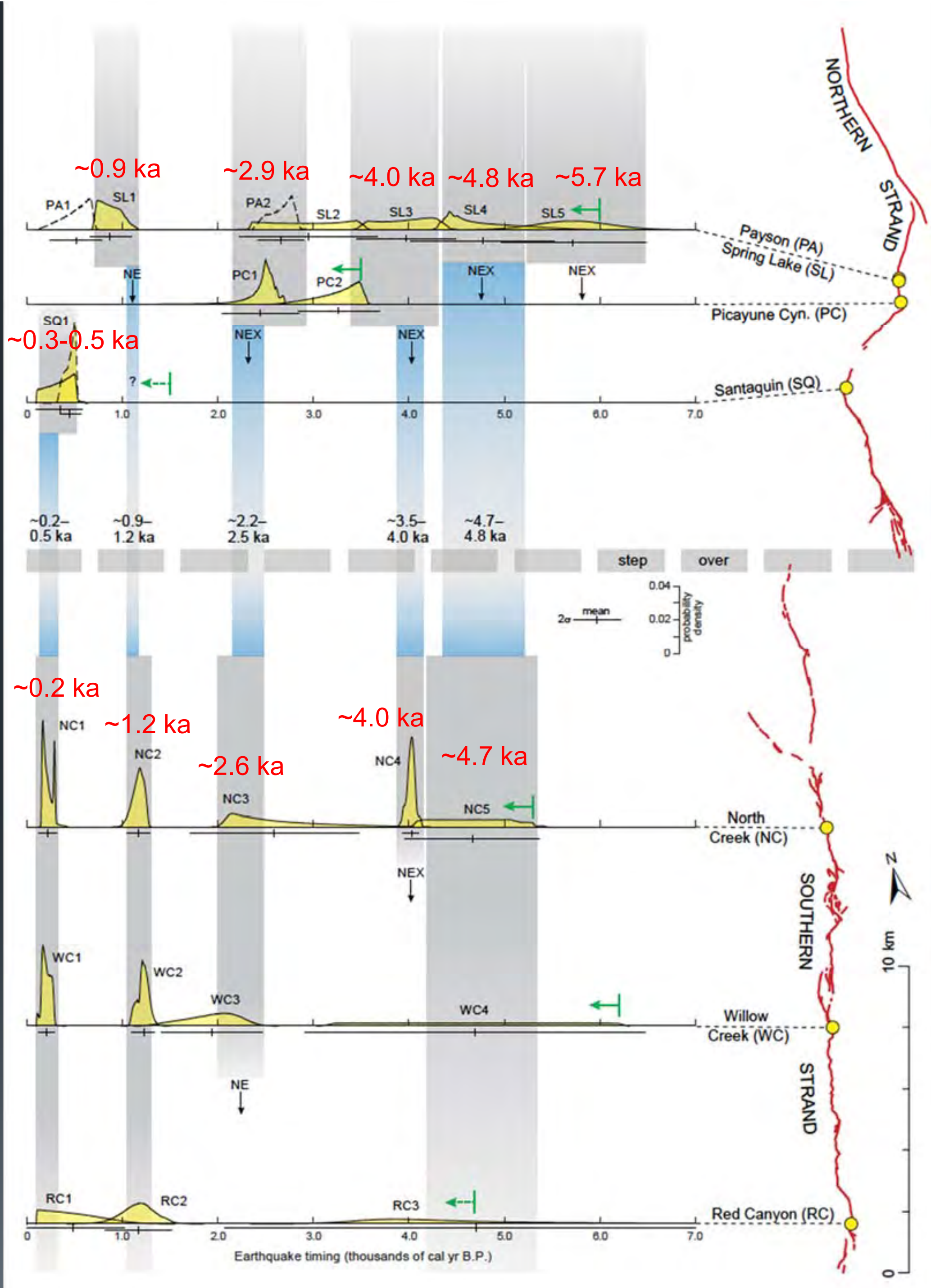
  Do prominent structural boundaries along the WFZ act as barriers to rupture propagation?

- *Sites:*
  - Corner Canyon: southern Salt Lake City
    (DuRoss et al., in review – EPSL)
  - Alpine: northern Provo
    (Bennett et al., in review – BSSA)
  - Spring Lake: northern Nephi
    (DuRoss et al., in press – UGS)
  - North Creek: southern Nephi
    (DuRoss et al., in press – UGS)

Nephi Segment Earthquake History

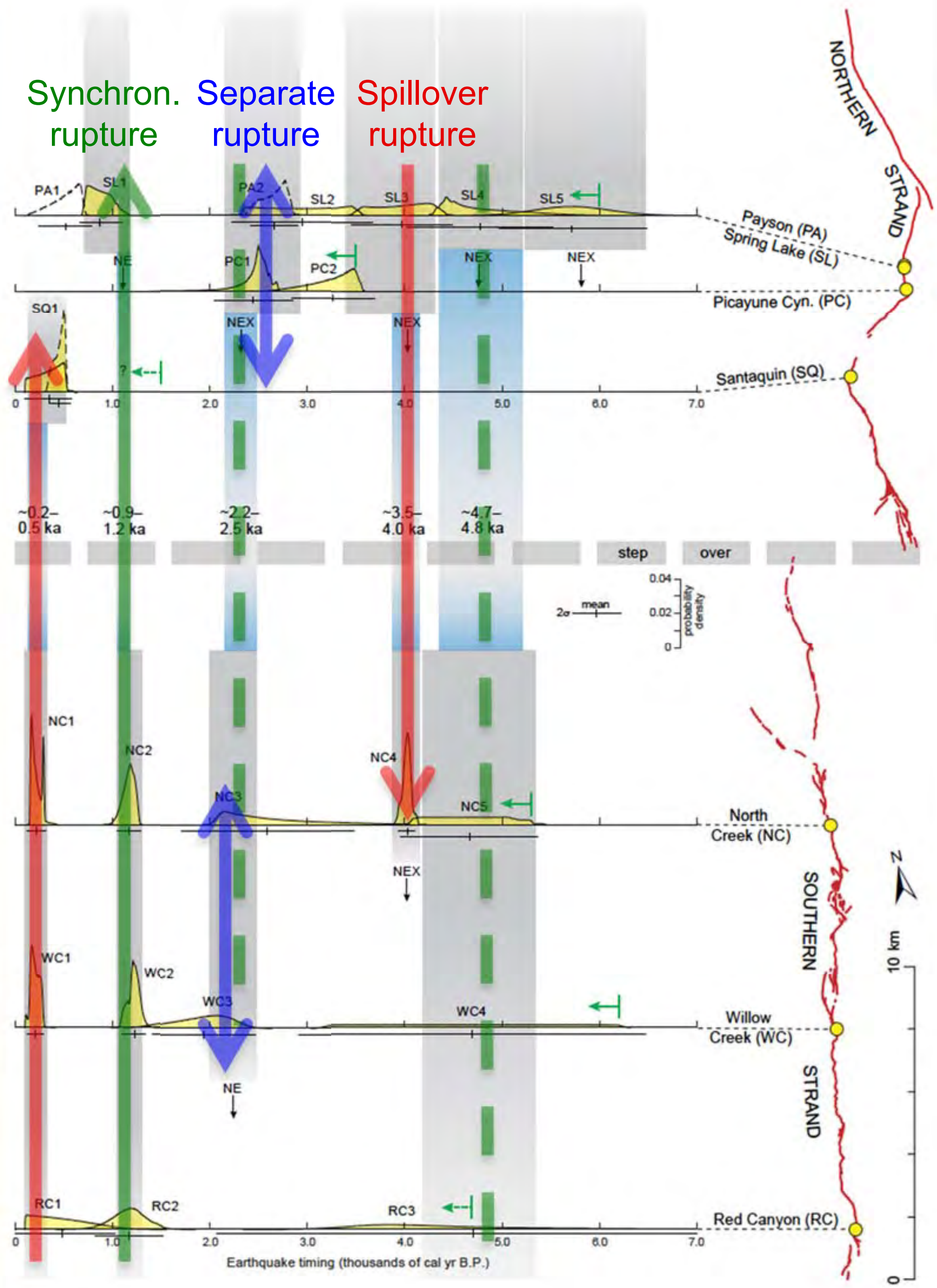
- ➢Similar earthquake histories on both fault strands
- ➢We interpret this timing overlap between strands as evidence of throughgoing (synchronous) rupture
- ➢However, we cannot rule out separate rupture of the strands
- ➢Per-event displacements are ~1–3 m and don't unequivocally support either rupture mode

DuRoss et al. (in press – UGS)



Nephi Segment Earthquake History

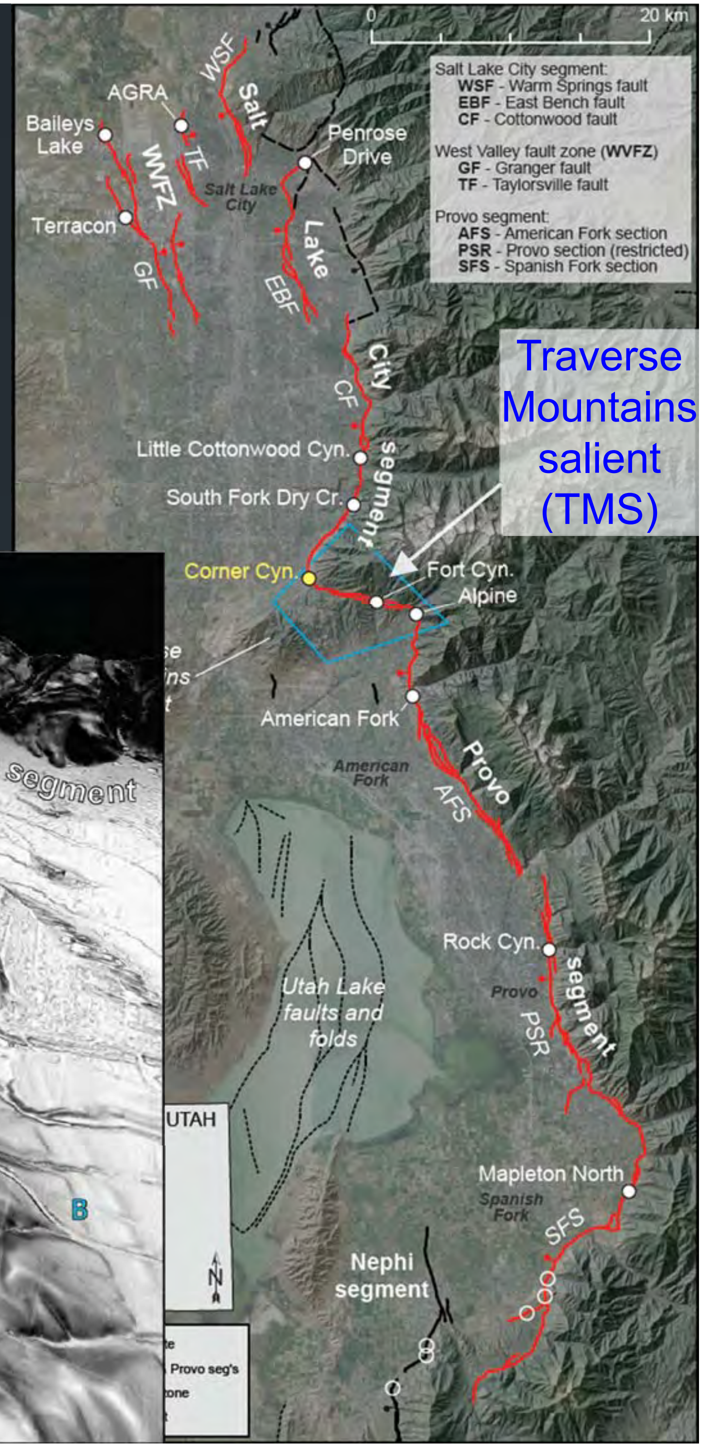
- We interpret a complex rupture history that may include:
  - Synchronous rupture of the strands
  - Spillover rupture
  - Separate rupture of the strands
- The 4-km step does not appear to be a significant barrier to rupture propagation

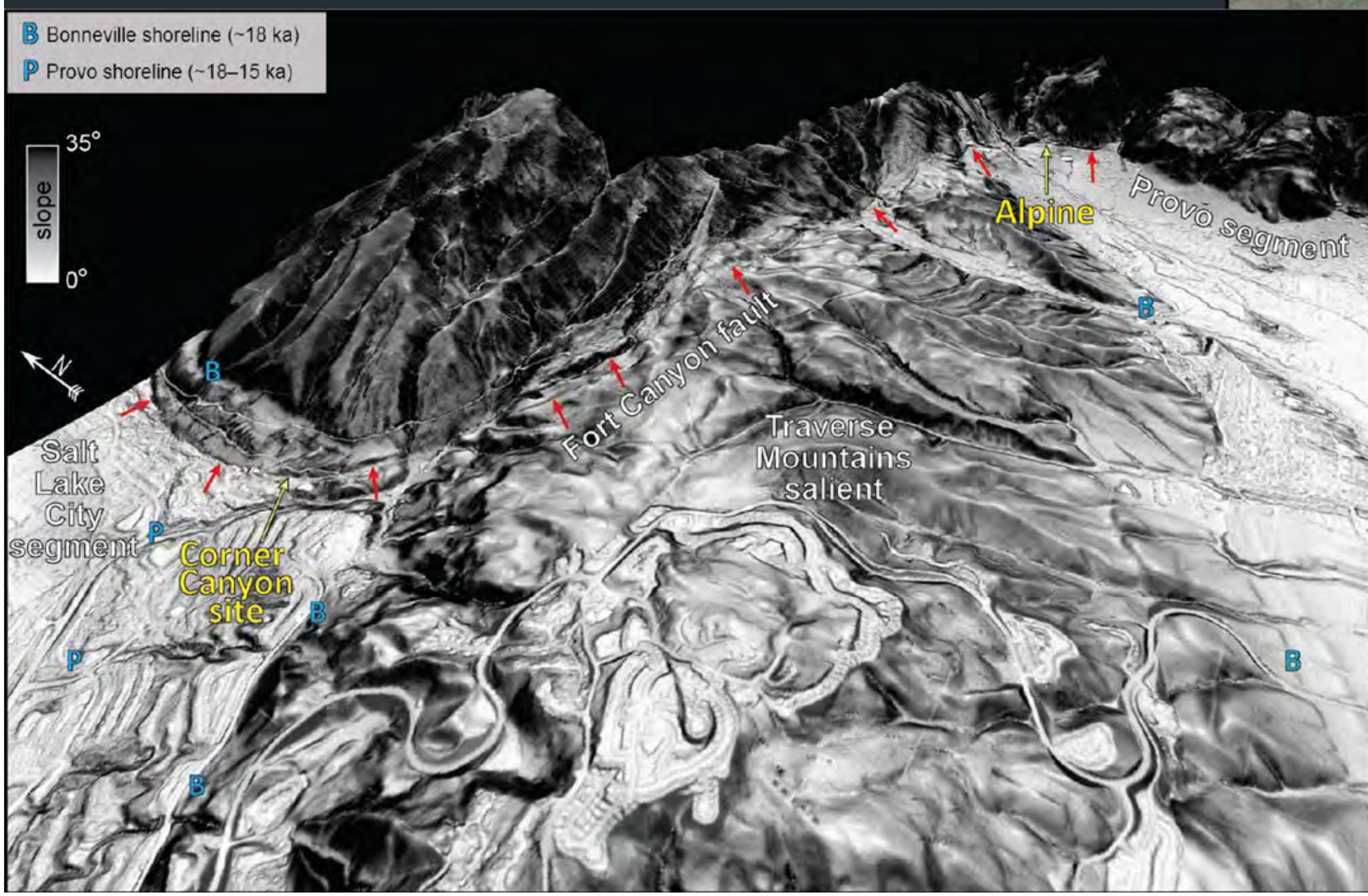


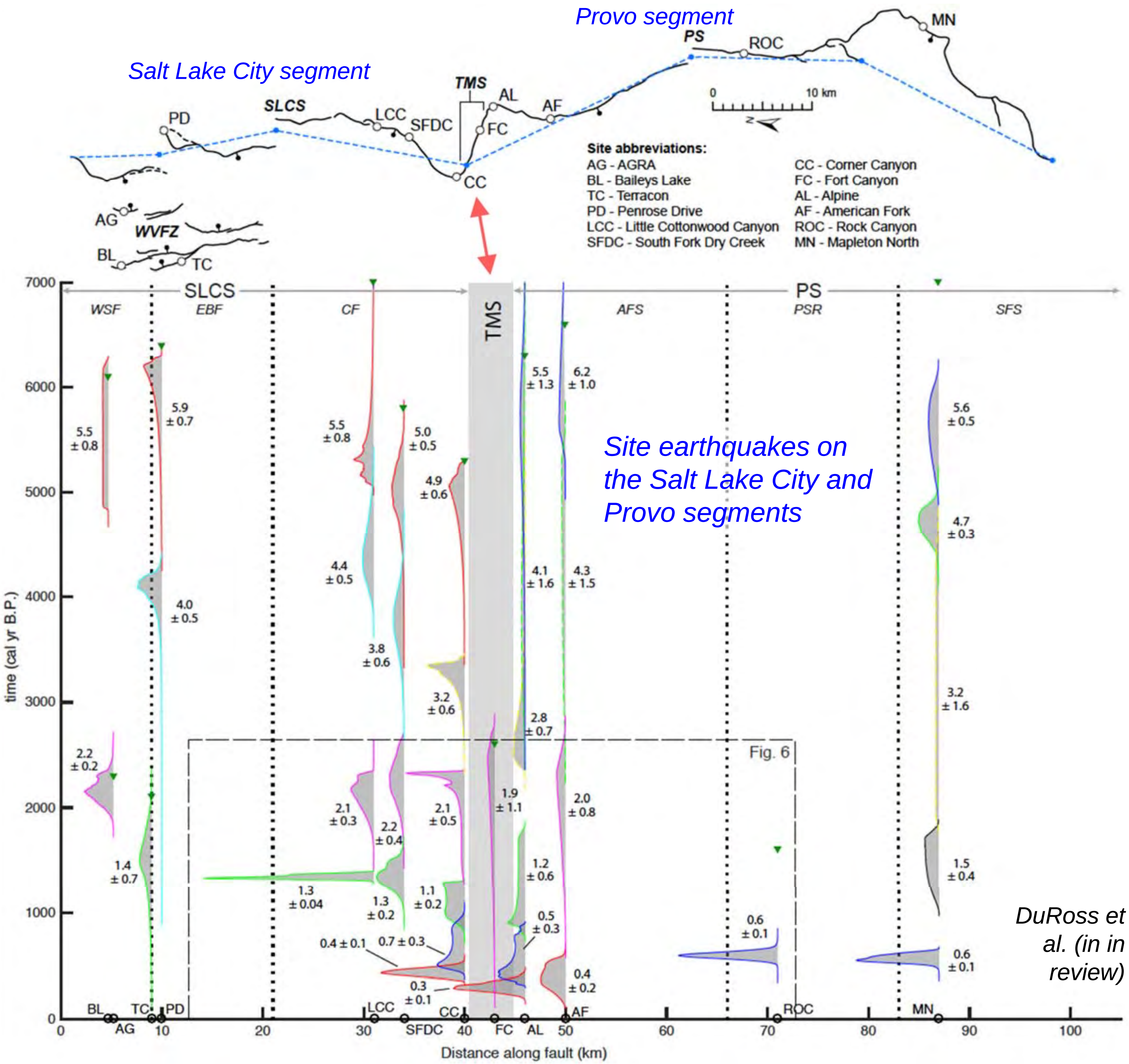
DuRoss et al. (in press – UGS)

Traverse Mountains salient (TMS) – structural boundary

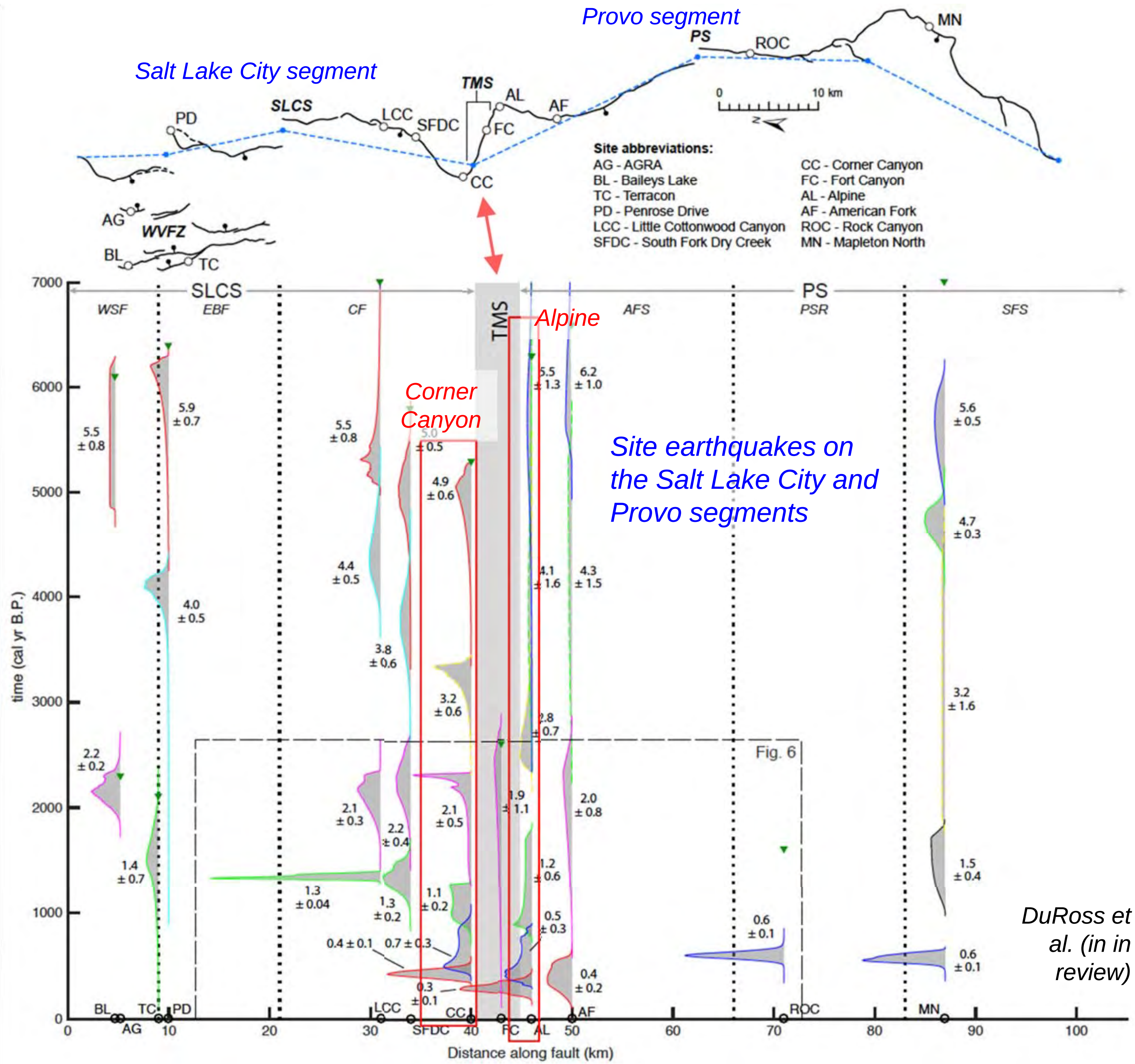
Has the TMS structural boundary arrested the propagation of recent (late Holocene) ruptures on WFZ?







Salt Lake City segment
Provo segment
Site abbreviations:
AG - AGRA
BL - Baileys Lake
TC - Terracon
PD - Penrose Drive
LCC - Little Cottonwood Canyon
SFDC - South Fork Dry Creek
CC - Corner Canyon
FC - Fort Canyon
AL - Alpine
AF - American Fork
ROC - Rock Canyon
MN - Mapleton North
Site earthquakes on the Salt Lake City and Provo segments
time (cal yr B.P.)
Distance along fault (km)
DuRoss et al. (in in review)


Provo segment
Salt Lake City segment
PS
ROC
MN
TMS
SLCS
AL
AF
PD
LCC
SFDC
FC
CC
0
10 km
Site abbreviations:
AG - AGRA
BL - Baileys Lake
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AL - Alpine
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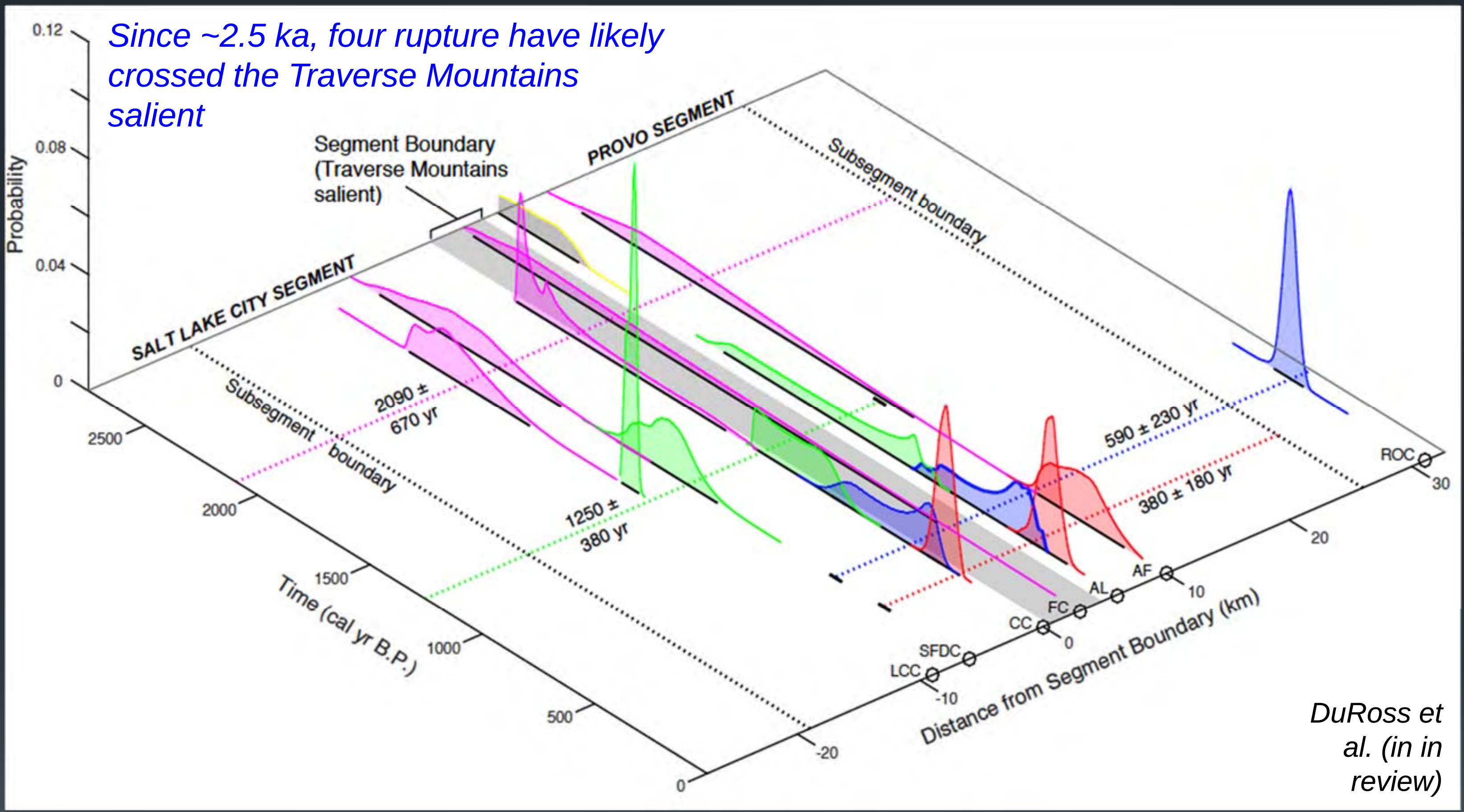
ROC - Rock Canyon
MN - Mapleton North
AG
WVFZ
BL
TC
Corner Canyon
Alpine
Site earthquakes on the Salt Lake City and Provo segments
WSF
EBF
CF
AFS
PSR
SFS
time (cal yr B.P.)
Distance along fault (km)
Fig. 6
DuRoss et al. (in in review)

Event Correlation & Rules



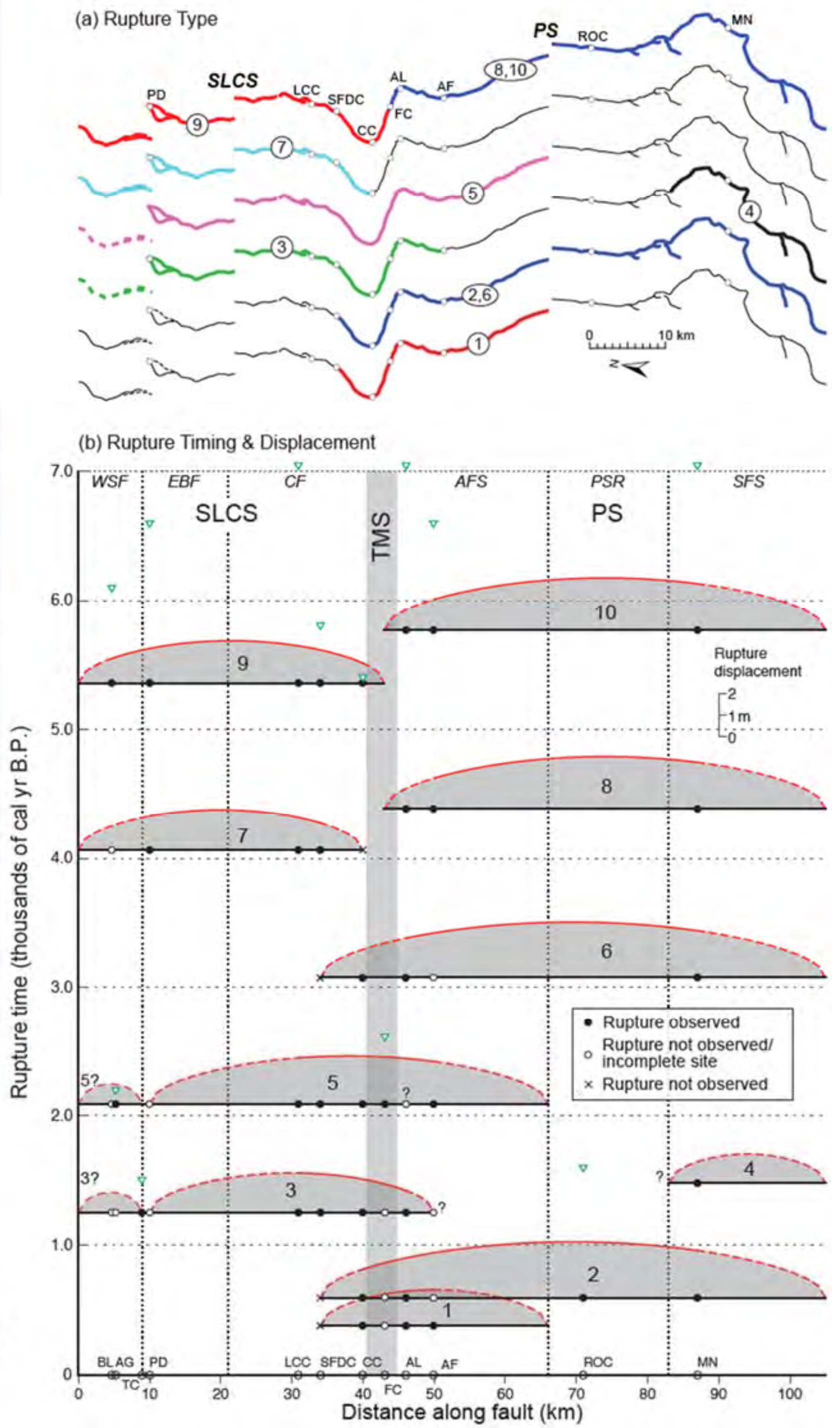
- Ruptures continued laterally from paleoseismic sites to:
  1. A paleoseismic site lacking evidence for the event, or
  2. A structural boundary, with no additional evidence for the event beyond

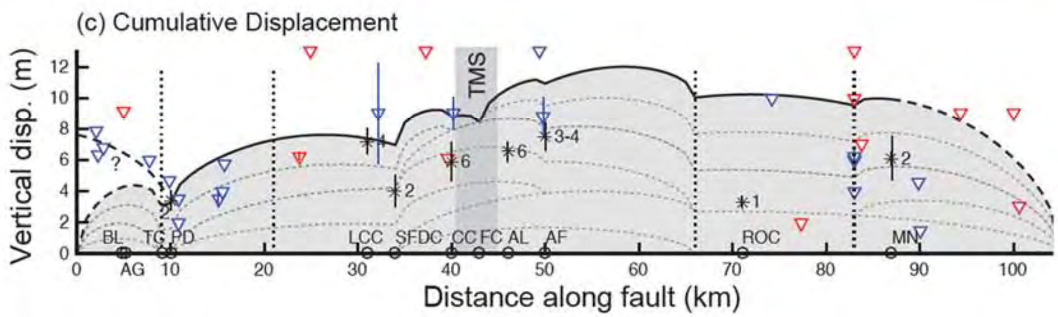
Preferred Rupture Model

- The TMS has influenced rupture extent, but cannot be considered a hard barrier to rupture
  - Spill over ruptures are common
  - We've identified at least one rupture of the segment boundary

- The complexity of ruptures in this area may have to do with the maturity of the boundary

DuRoss et al. (in in review)





Conclusions

1. Using a synthesis of paleoseismic data from 20 trench sites, we've updated the earthquake histories, recurrence intervals, and slip rates for the central WFZ segments

1. Recent data and analyses suggest that complex ruptures of the fault are possible:
   - Single-segment ruptures may still be a dominant mode of rupture on the central WFZ (based on earthquakes <3 ka)
   - Spillover ruptures appear to be common
   - Ruptures shorter than the segment lengths are possible, including those centered on the segment boundaries
   - Multi-segment ruptures are possible, but maybe less likely than other rupture modes

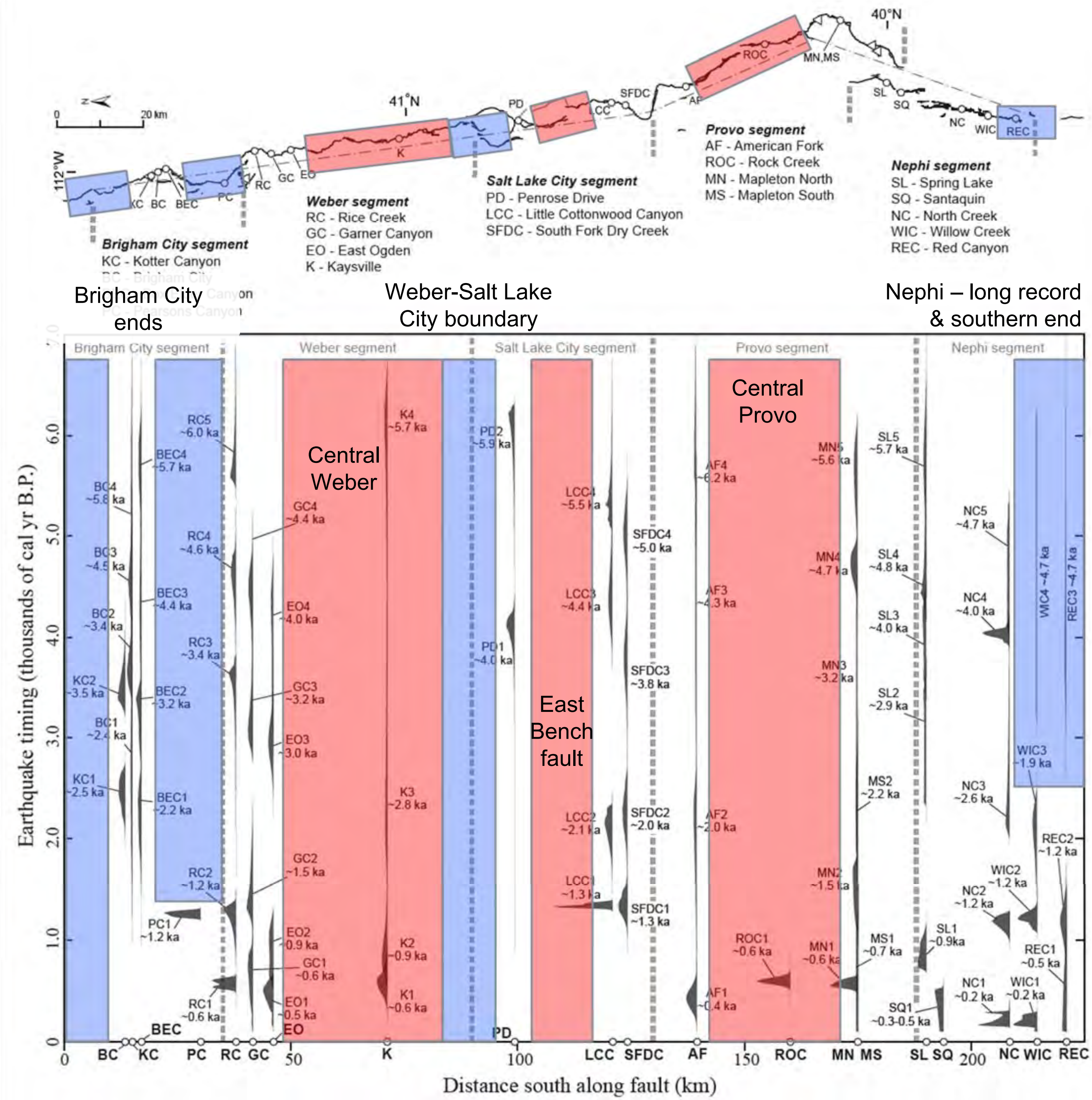
2. For probability/hazard analyses, multiple rupture modes and scenarios (weighted in a logic tree) help address epistemic uncertainties in rupture length and segmentation.

Future WFZ Paleoseismic Work?

1. Rupture length, segmentation, per-event displacement
   - Trenches focused on youngest (<3-5 ka) earthquakes along the fault, especially in data gaps and near structural boundaries
   - Well-constrained events essential for along-strike comparisons
   - Smaller scarps yield better per-event displacement data
   - Central-southern Weber segment, northern Salt Lake City segment, central Provo segment, northern Brigham City segment

1. Long(er)-term earthquake histories, recurrence, COV, and slip rate
   - Trenches across large, early Holocene–latest Pleistocene scarps
   - Complete records important; simple rather than complex faulting

2. Secondary faulting
   - West Valley fault zone, Utah Lake faults and folds


40°N
41°N
112°W
20 km
Brigham City segment
KC - Kotter Canyon
Weber segment
RC - Rice Creek
GC - Garner Canyon
EO - East Ogden
K - Kaysville
Salt Lake City segment
PD - Penrose Drive
LCC - Little Cottonwood Canyon
SFDC - South Fork Dry Creek
Provo segment
AF - American Fork
ROC - Rock Creek
MN - Mapleton North
MS - Mapleton South
Nephi segment
SL - Spring Lake
SQ - Santaquin
NC - North Creek
WIC - Willow Creek
REC - Red Canyon
Brigham City ends
Weber-Salt Lake City boundary
Nephi – long record & southern end
Central Weber
East Bench fault
Central Provo
Brigham City segment
Weber segment
Salt Lake City segment
Provo segment
Nephi segment
Earthquake timing (thousands of cal yr B.P.)
Distance south along fault (km)
BC KC PC RC GC 50 K 100 LCC SFDC AF 150 ROC MN MS SL SQ 200 NC WIC REC

SEISMIC IMAGING OF THE WASATCH FAULT BENEATH SALT LAKE CITY –
RESULTS AND NEW FIELD CAMPAIGN PLANS

Lee Liberty – Boise State University

BOISE STATE UNIVERSITY

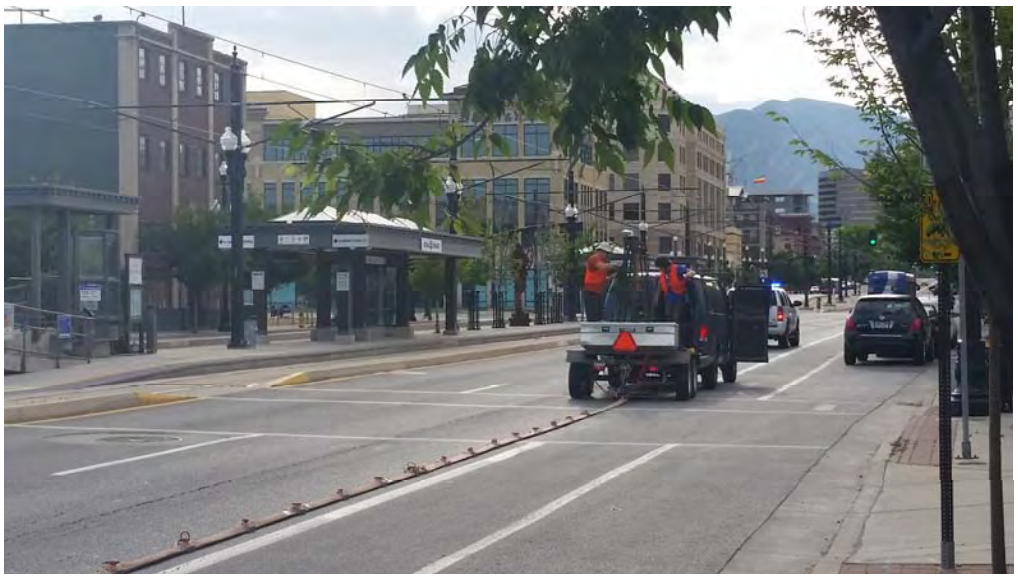
NEHRP-FOCUSED SEISMIC IMAGING OBJECTIVES

Earthquake hazard and risk assessments beneath urban centers

- Active fault mapping to identify and characterize "blind" faults – reflection profiling (upper 200-300 m)
- High frequency site response via Vs mapping (upper 30-50 m)
- Liquefaction susceptibility via Vp and Vs measurements
- Shallow bedrock mapping via Vp and reflection imaging
- Fault zone characterization via reflection, Vp and Vs (Vp/Vs) imaging

- USGS NEHRP #G15AP00054
- USGS NEHRP 2017 funding

BENEFITS OF SEISMIC LAND STREAMER COMPARED TO TRADITIONAL SEISMIC IMAGING

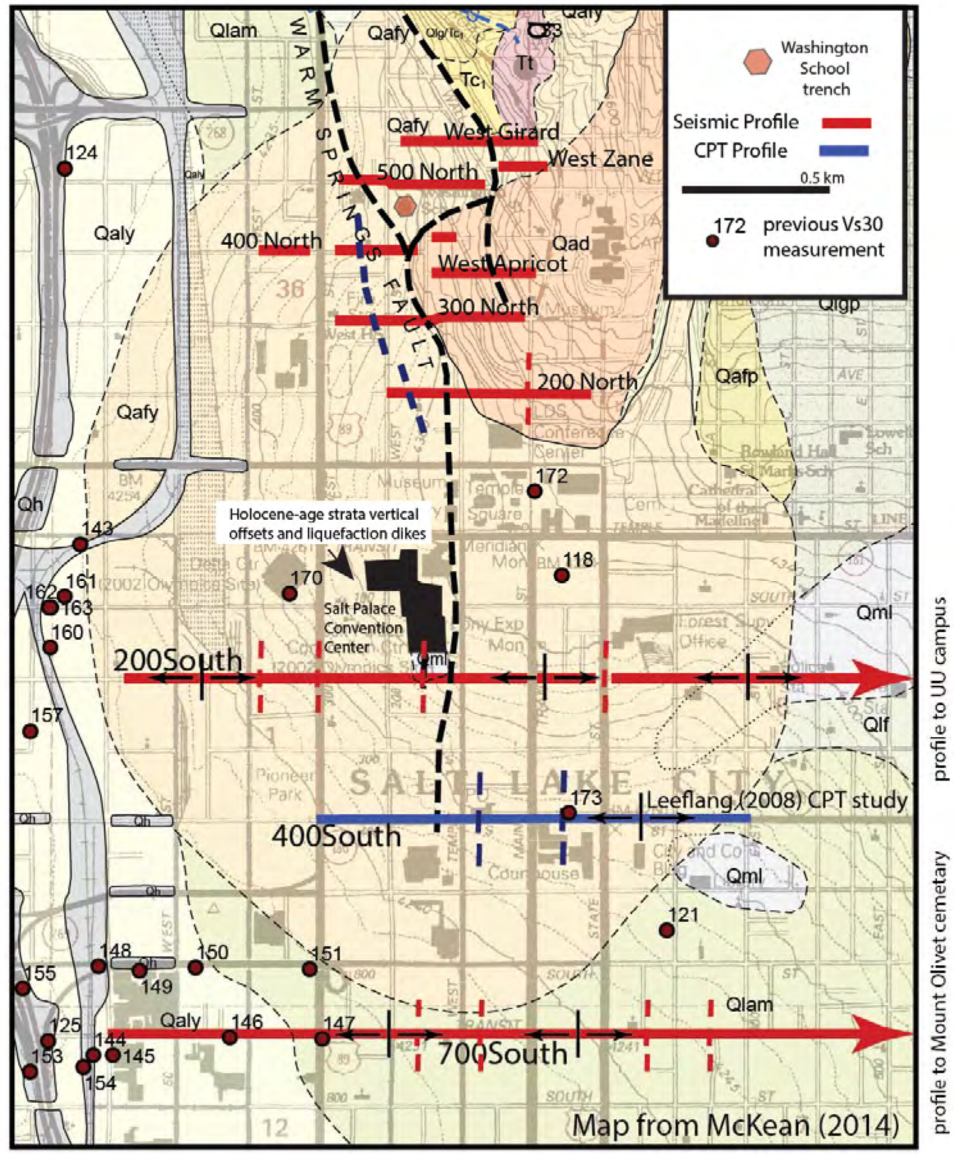


- Directly operate on city streets
- Predictable source/receiver geometry makes reflection processing simpler
- Real time GPS allows for simple geometry
- Physical properties of road and sub road are nearly uniform, thus near surface conditions are uniform
- Police or flagger assistance during off-hours to control traffic and provide near continuous profiling
- Large seismic source relative to imaging depths allows for traffic noise during data collection

SUMMARY OF 2015 FIELD CAMPAIGN

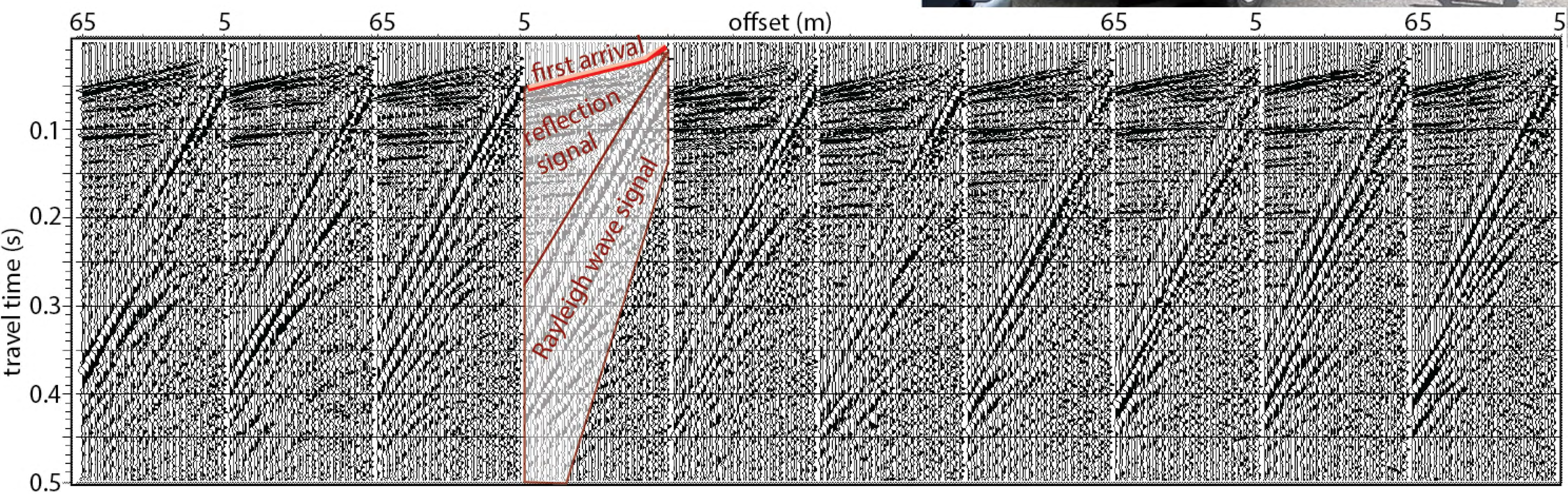
- Data collection - May, 2015 → USGS NEHRP #G15AP00054

- 5,576 shot gathers – 2 m spaced shots (gaps at major roads)
- About 15 km length along 9 west-east profiles
- Three field days @ 400 m/hour (~2 m shots every 15 seconds)
- Flagger crew in North Salt Lake City
- Police escort along 200 South and 700 South allowed near continuous profiling

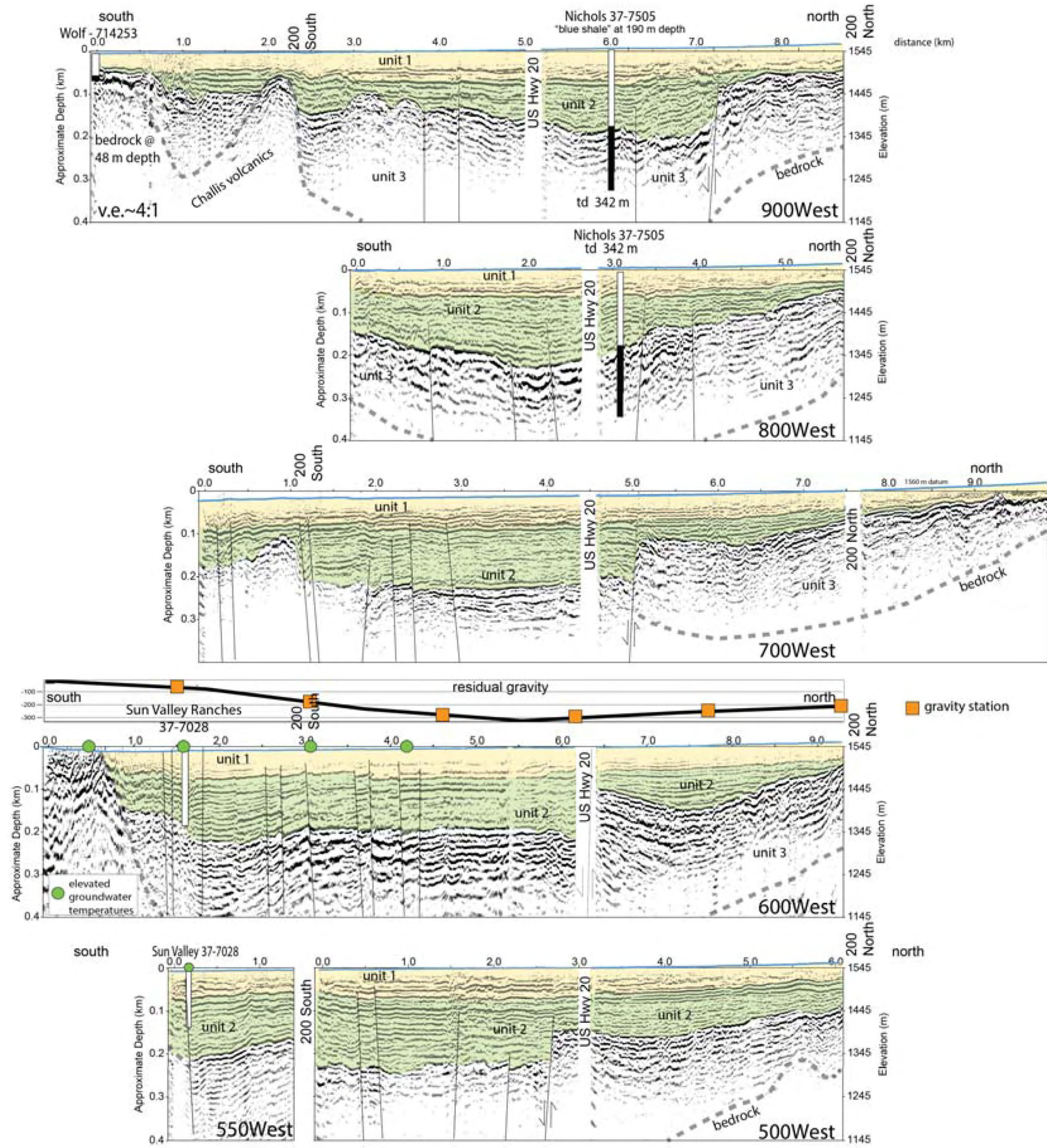


URBAN LAND STREAMER DESIGN

48 2-component shoes (vertical and in-line)
4.5 Hz geophones
1.25 m spaced geophones (60 m aperture)
(now optional 30 m segment to extend to 90 m aperture)
2 m nominal shot spacing
Accelerated weight drop source (now remotely controlled)



LAND STREAMER RESULTS FROM IDAHO – CAMAS PRAIRIE



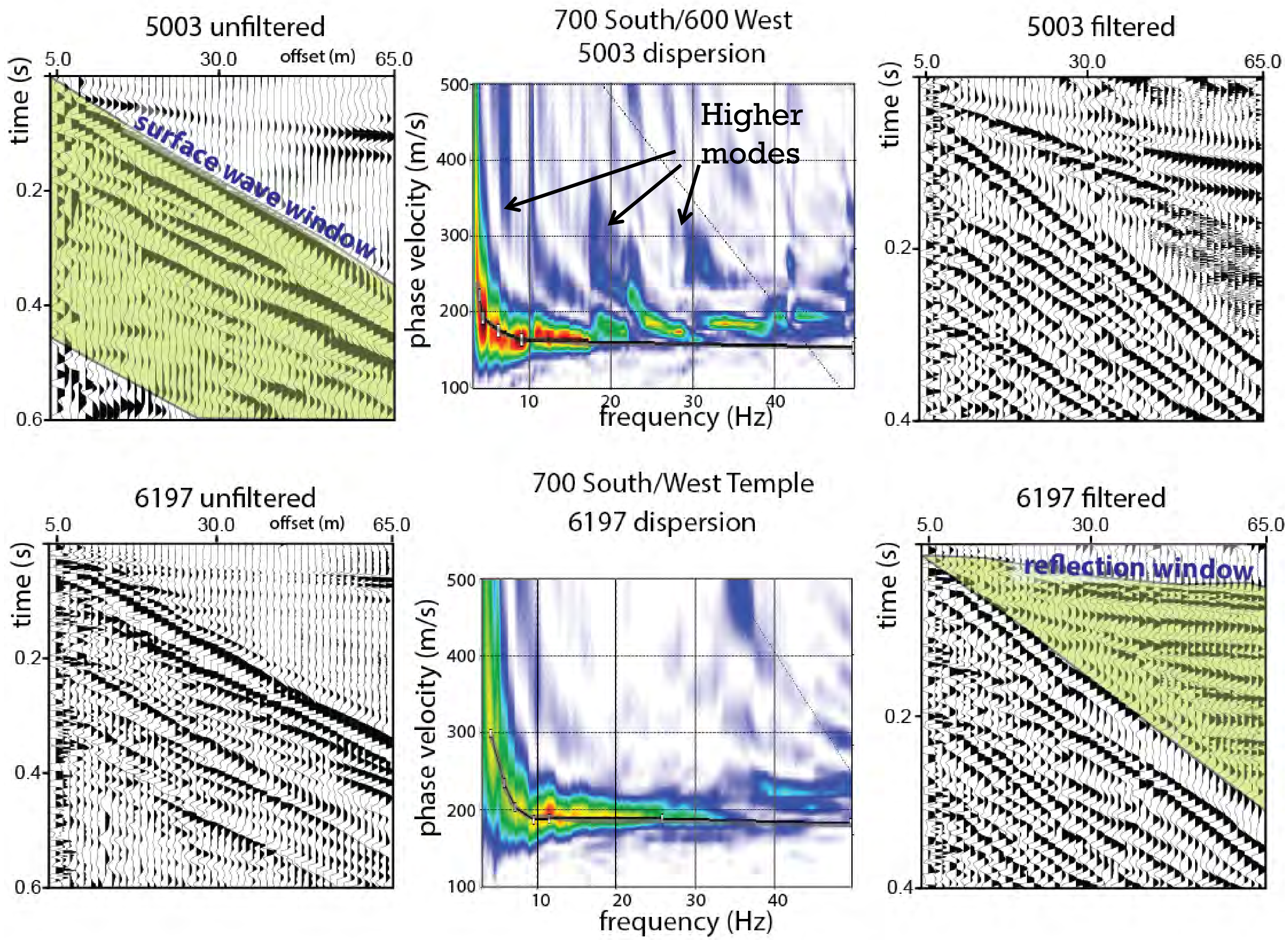
PHYSICAL PROPERTY ESTIMATES

From Bartlett, S., 2004 - UDOT

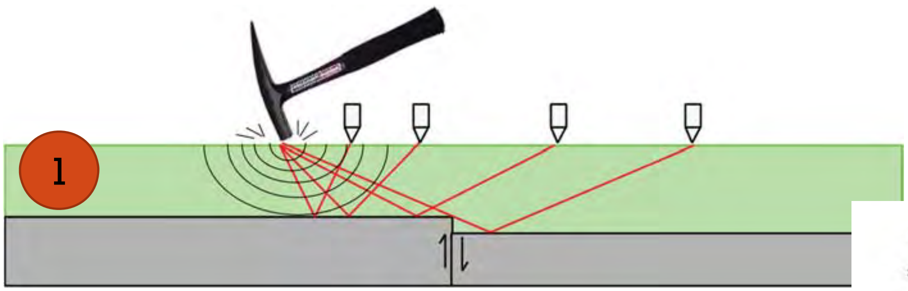
					Cone Penetrometer				Gardner alpha	0.3	
600 South					Vs	G	E		Gardner beta	0.25	
Depth	Depth	Soil Type	Unit Weight	bulk density	Shear wave Velocity	Shear Modulus	Modulus	Vp - dry	Vp/Vs - dry	Vp - from Gardner	Vp/Vs - wet
(m)	(m)		(kN/m3)	g/cc	(m/s)	(kPa)	(kPa)	(m/s)		wet, fcn of density	
0	5	Alluvium	19.2	1.96	146	41700	113000	293.3535	2.01	1818.9	12.46
5	12	Upper Bonneville	18.2	1.86	170	53600	161000	353.7999	2.08	1468.6	8.64
12	16	Interbeds	18.8	1.92	235	106000	318000	489.3258	2.08	1672.0	7.11
16	22	Lower Bonneville	18.2	1.86	201	75000	225000	418.33	2.08	1468.6	7.31
22	25	Pleistocene	19.5	1.99	237	112000	335000	493.3645	2.08	1935.3	8.17

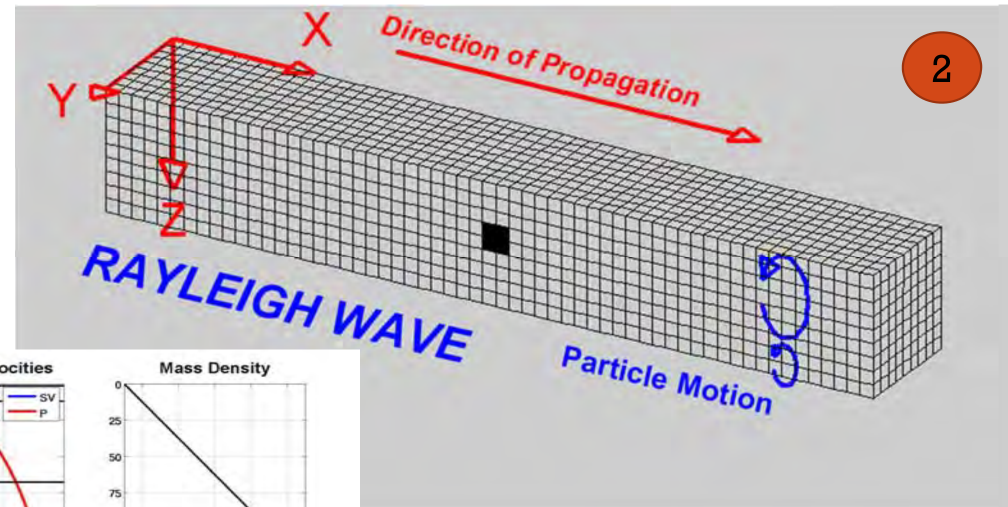
VS (MASW) PROFILING

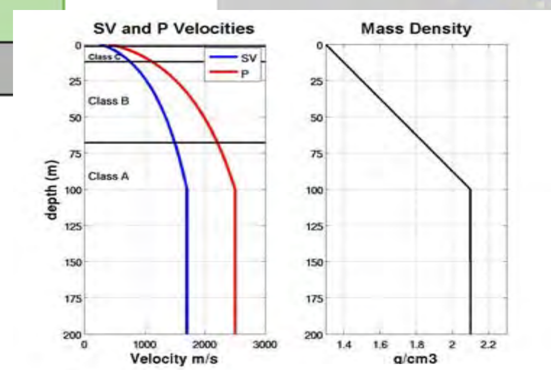
700 SOUTH SHOTS AND DISPERSION CURVES



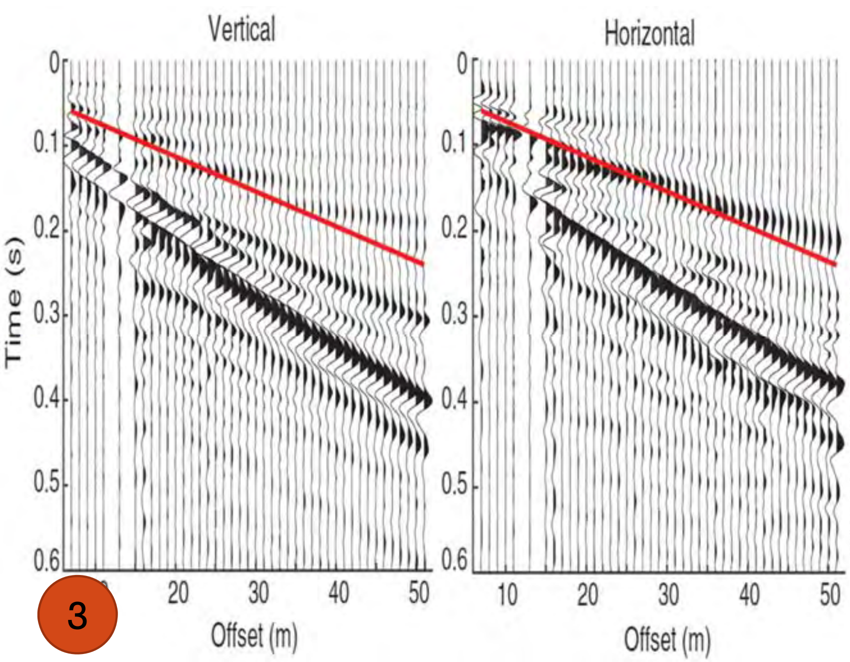
RAYLEIGH WAVES TO VS

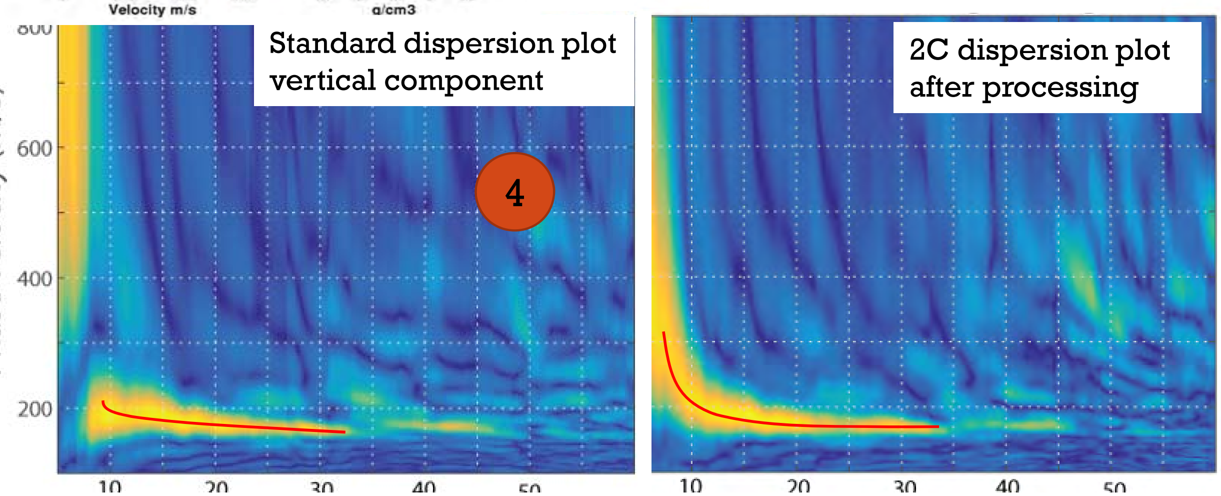






Multicomponent approach
Gribler et al. (2016)

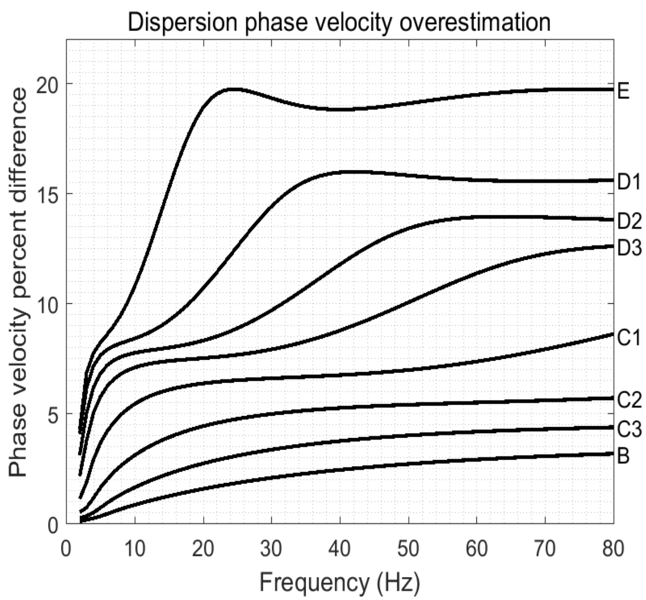




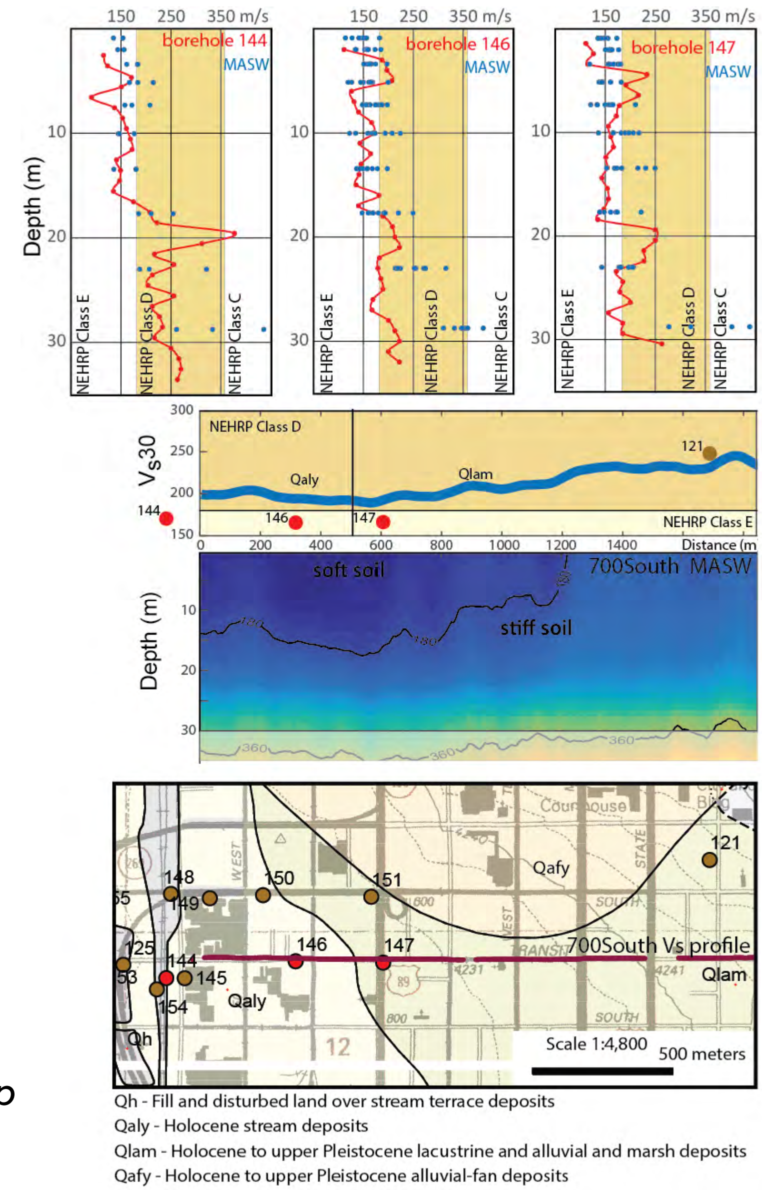
DOES THE ROAD SURFACE IMPACT SURFACE WAVE INVERSIONS?

- Site class dependent
  - When shear wave velocities match road surface velocities, the effect is minimal

  - Concrete (Vs=1500 m/s)

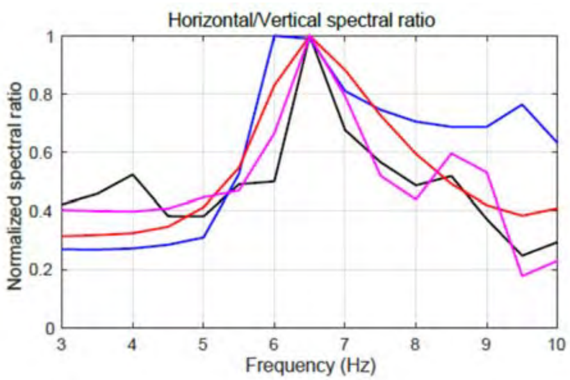


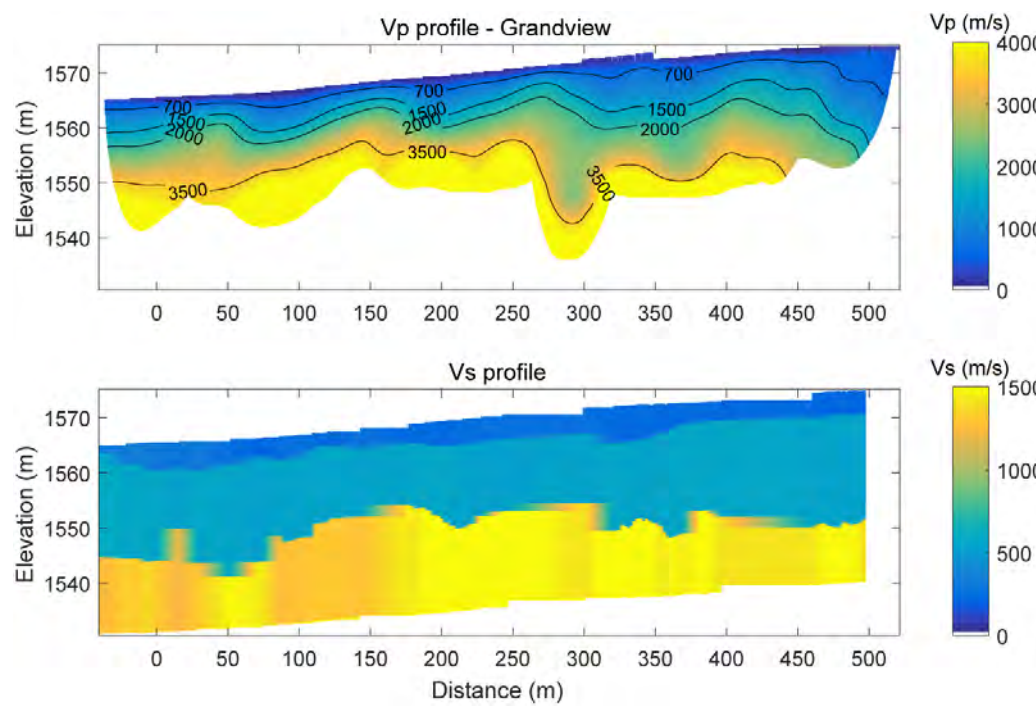
From Gribler et al., in prep



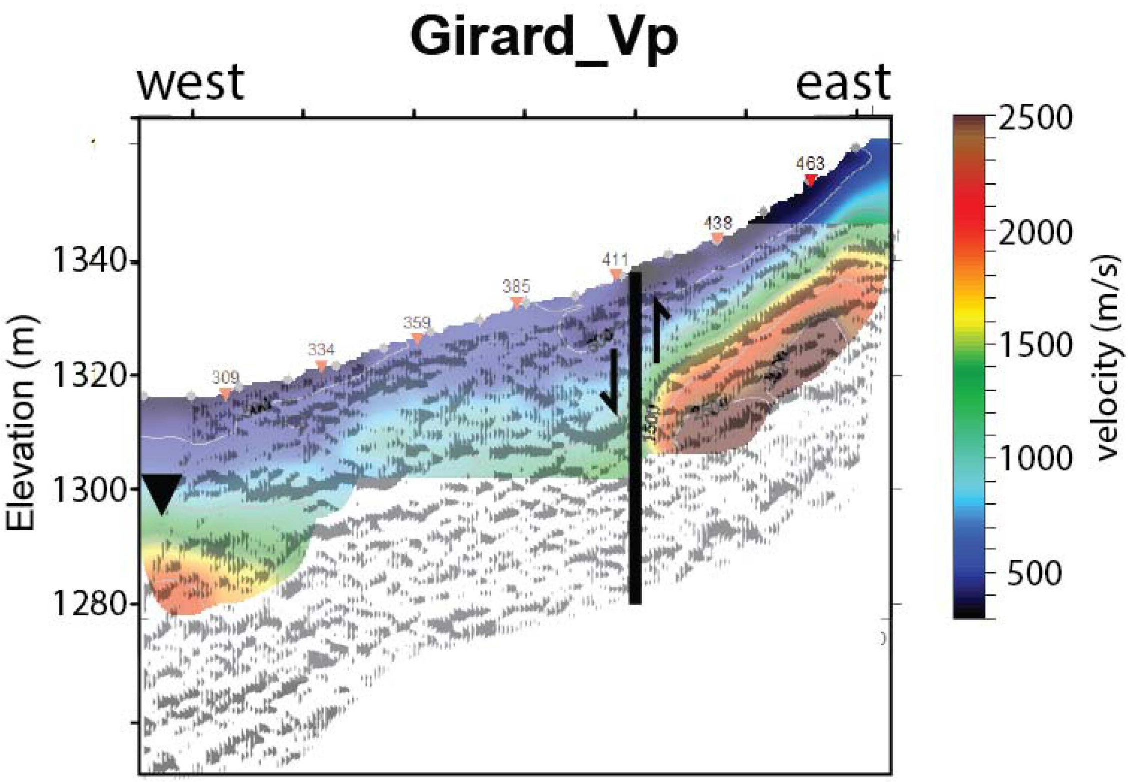
ACTIVE SOURCE H/V TO IDENTIFY LARGE V_S BOUNDARIES

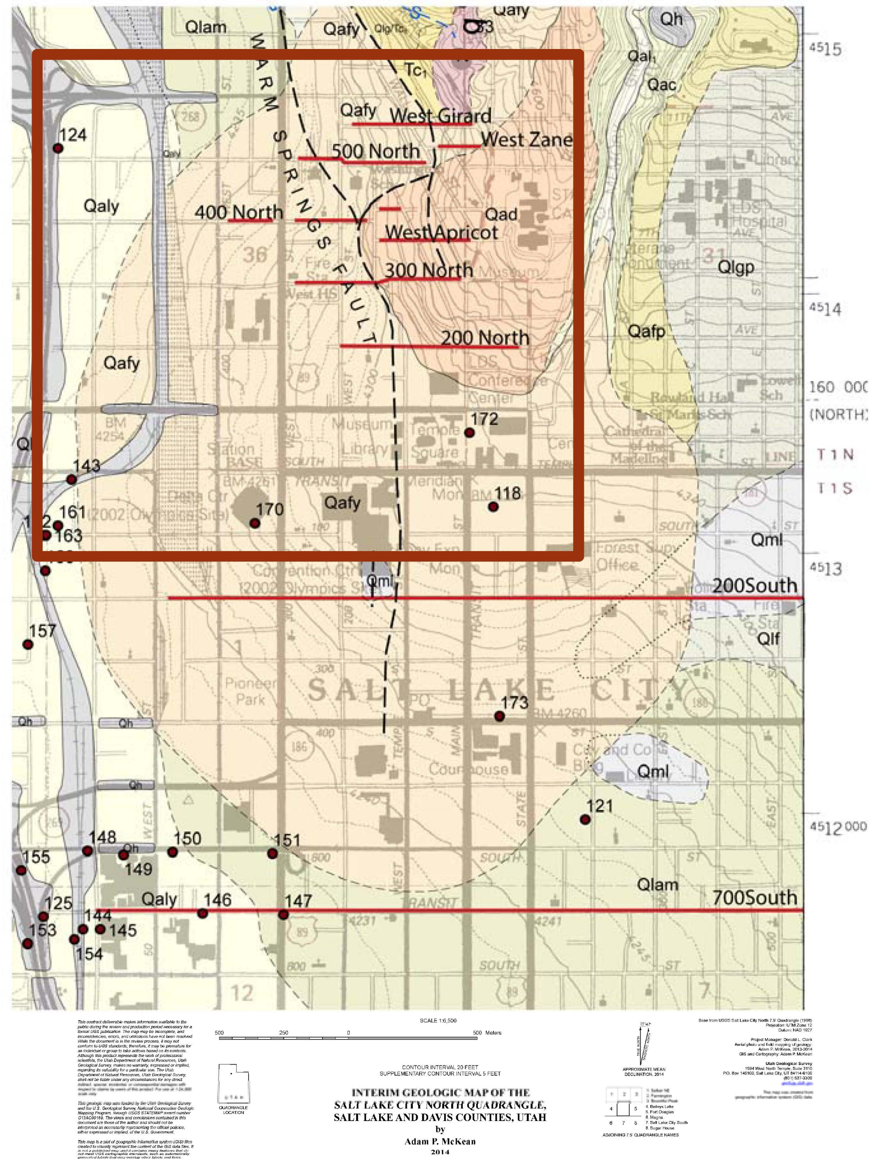
- "Joint inversion of H/V spectral ratios and phase-velocity dispersion with active seismic data" – SEG abstract



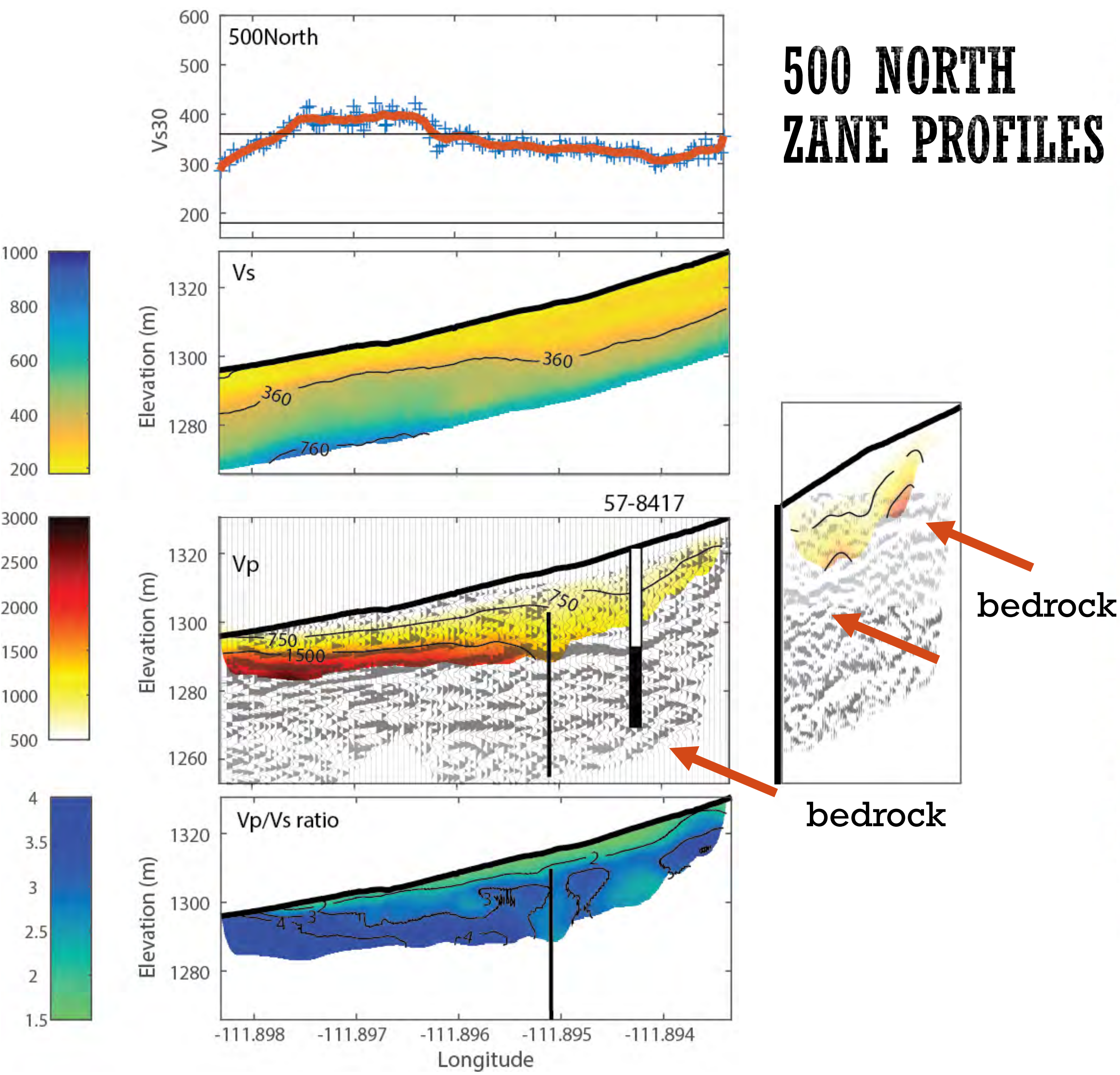


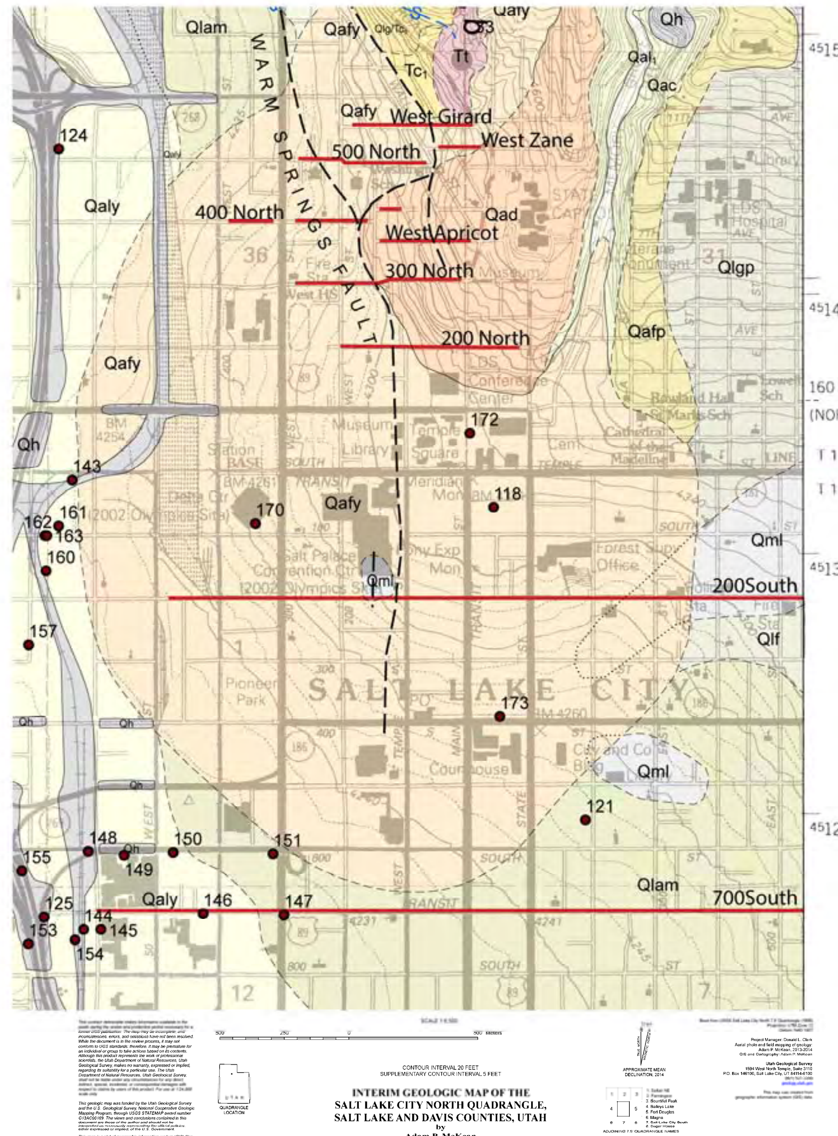
WEST GIRARD (20 M DEEP BEDROCK)





500 NORTH ZANE PROFILES

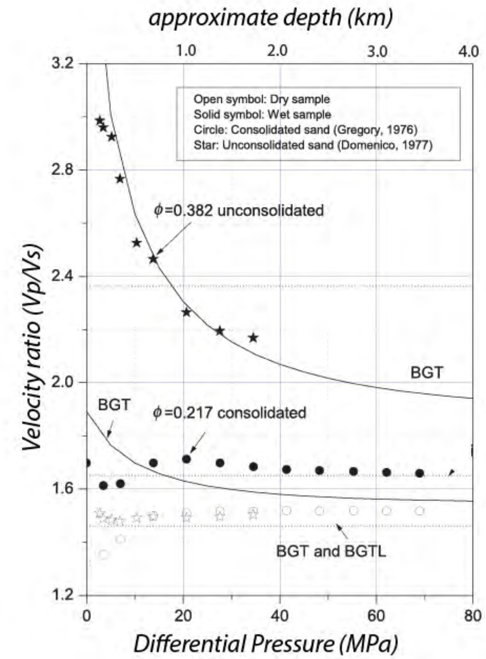




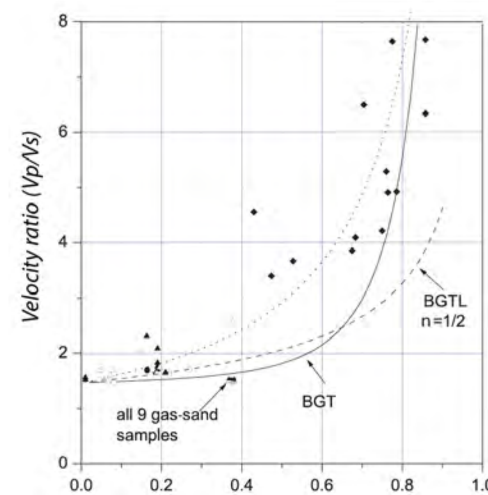
WHAT DOES V_P/V_S RATIO TELL US?

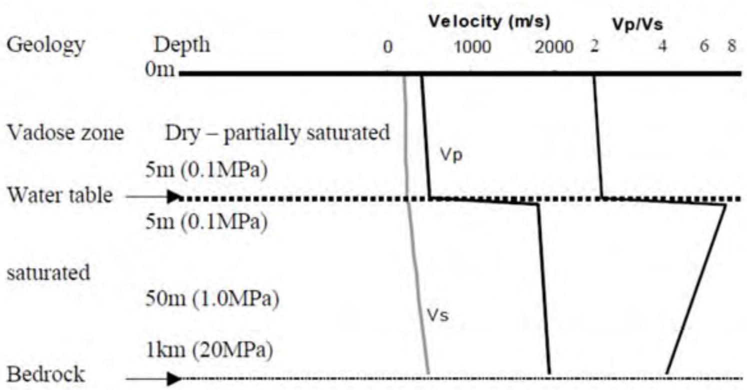
Mostly water saturation for unconsolidated seds

Soil Type	Shear wave Velocity	Vp - dry	Vp/Vs - dry	Vp - from Gardner	Vp/Vs - wet
	(m/s)	(m/s)		wet, fcn of density	
Alluvium	146	293.3535	2.01	1818.9	12.46
Upper Bonneville	170	353.7999	2.08	1468.6	8.64
Interbeds	235	489.3258	2.08	1672.0	7.11
Lower Bonneville	201	418.33	2.08	1468.6	7.31
Pleistocene	237	493.3645	2.08	1935.3	8.17



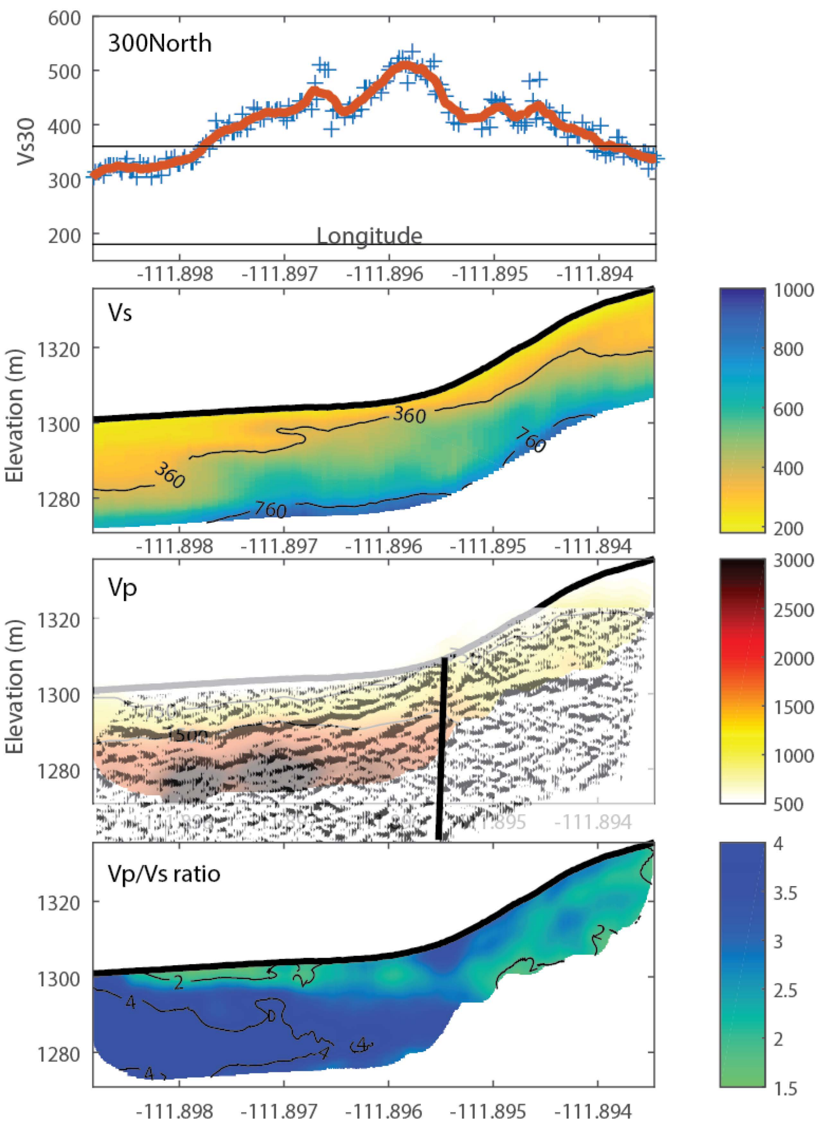
modified from Lee M.W. (2003)

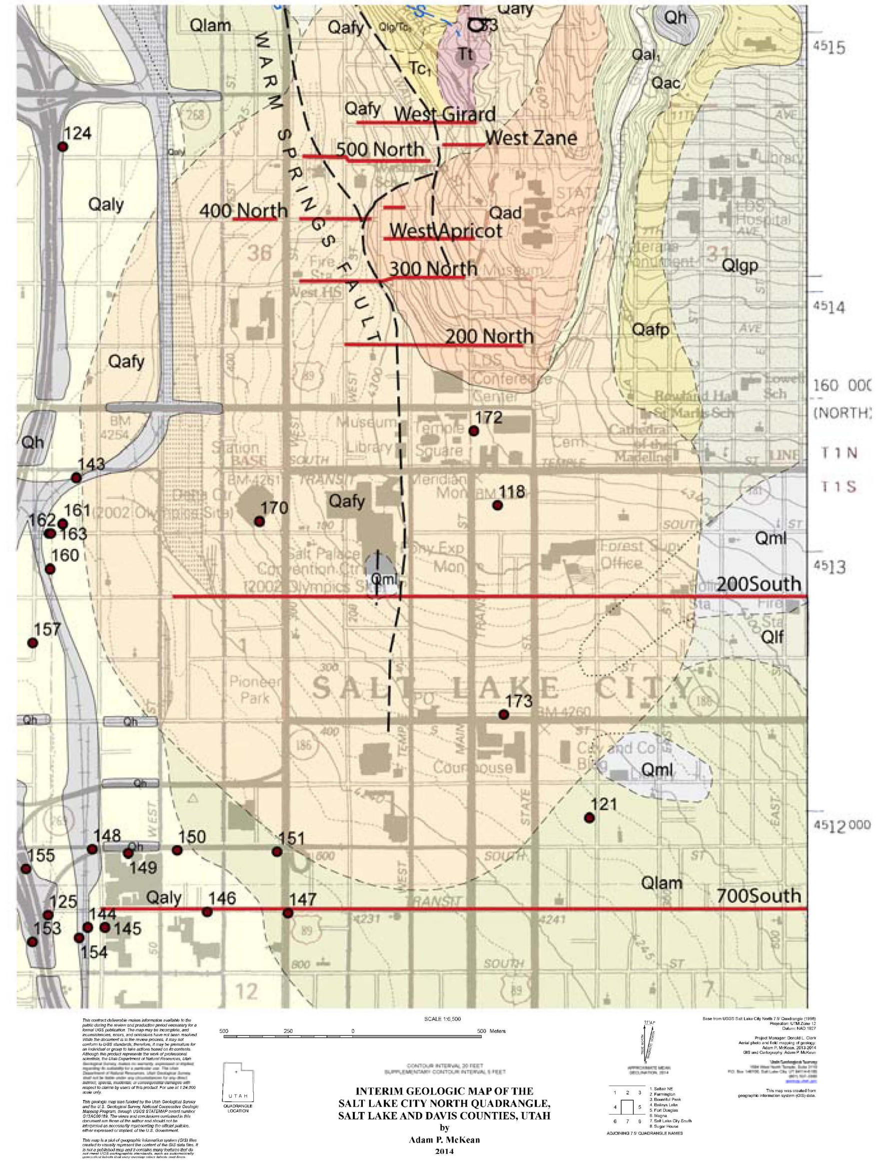


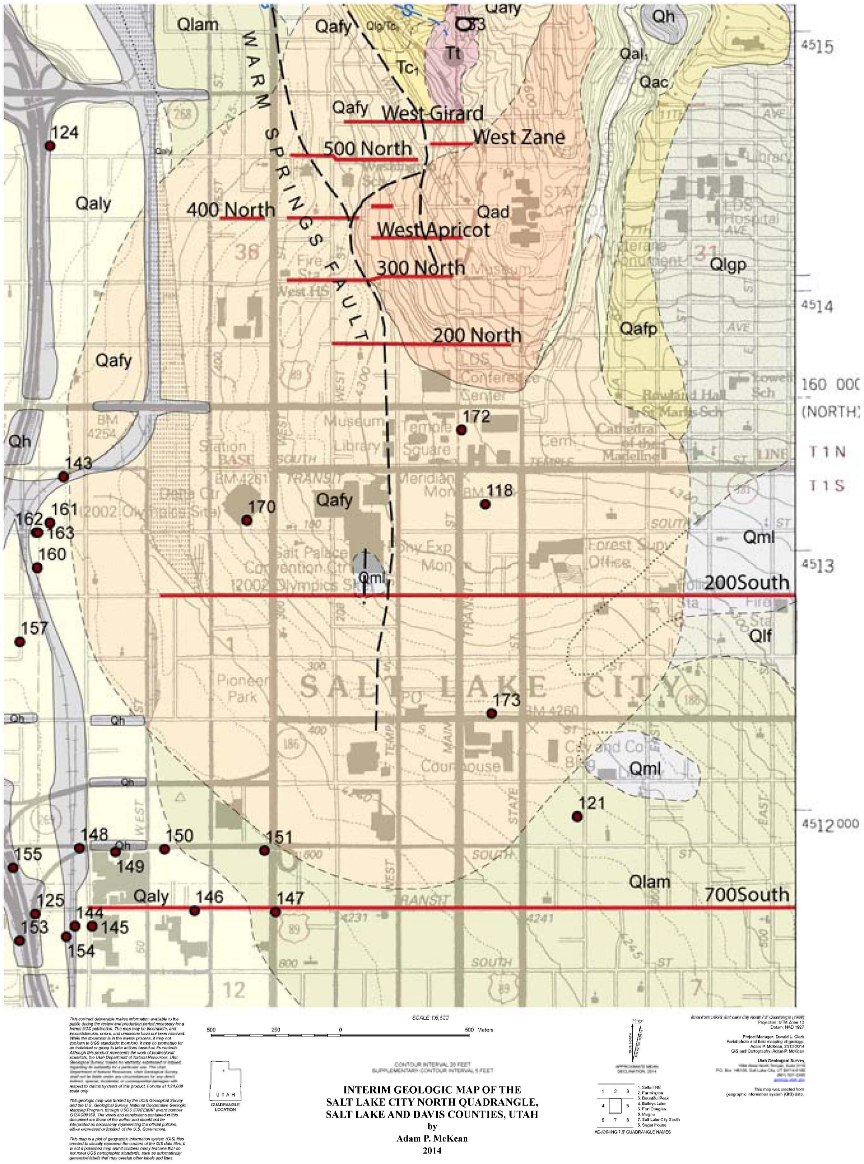


From Prassad, 2004

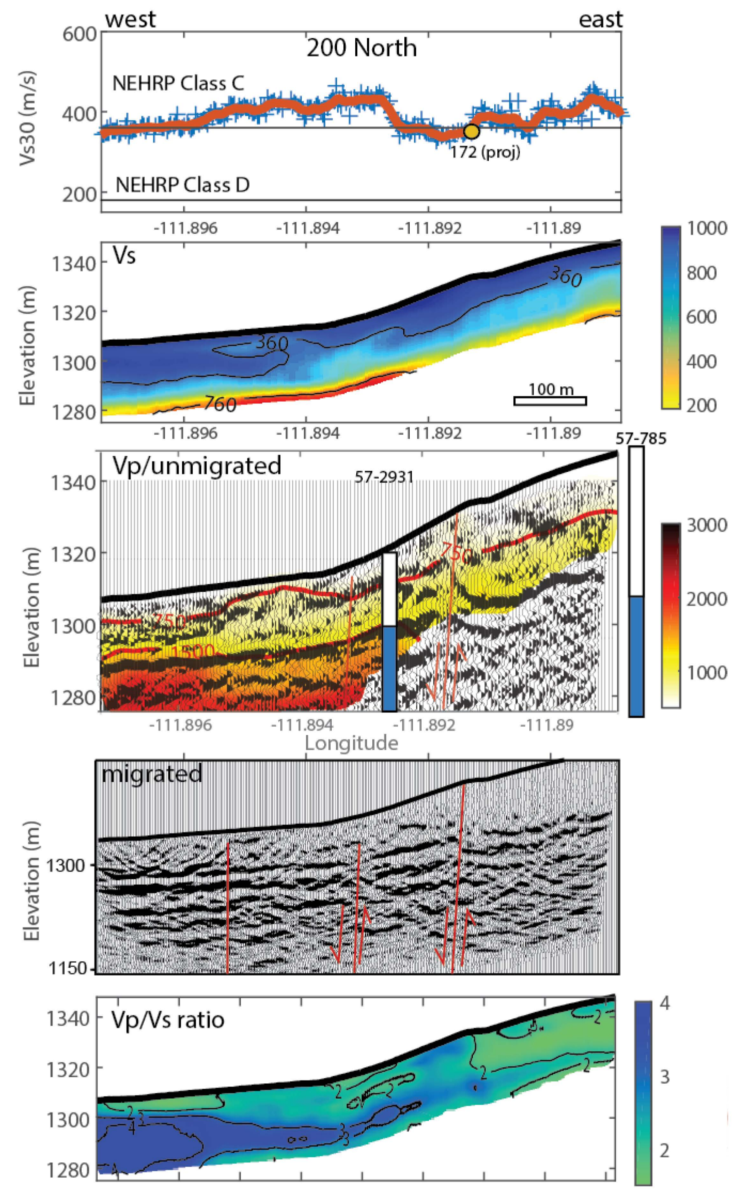
300 NORTH PROFILE

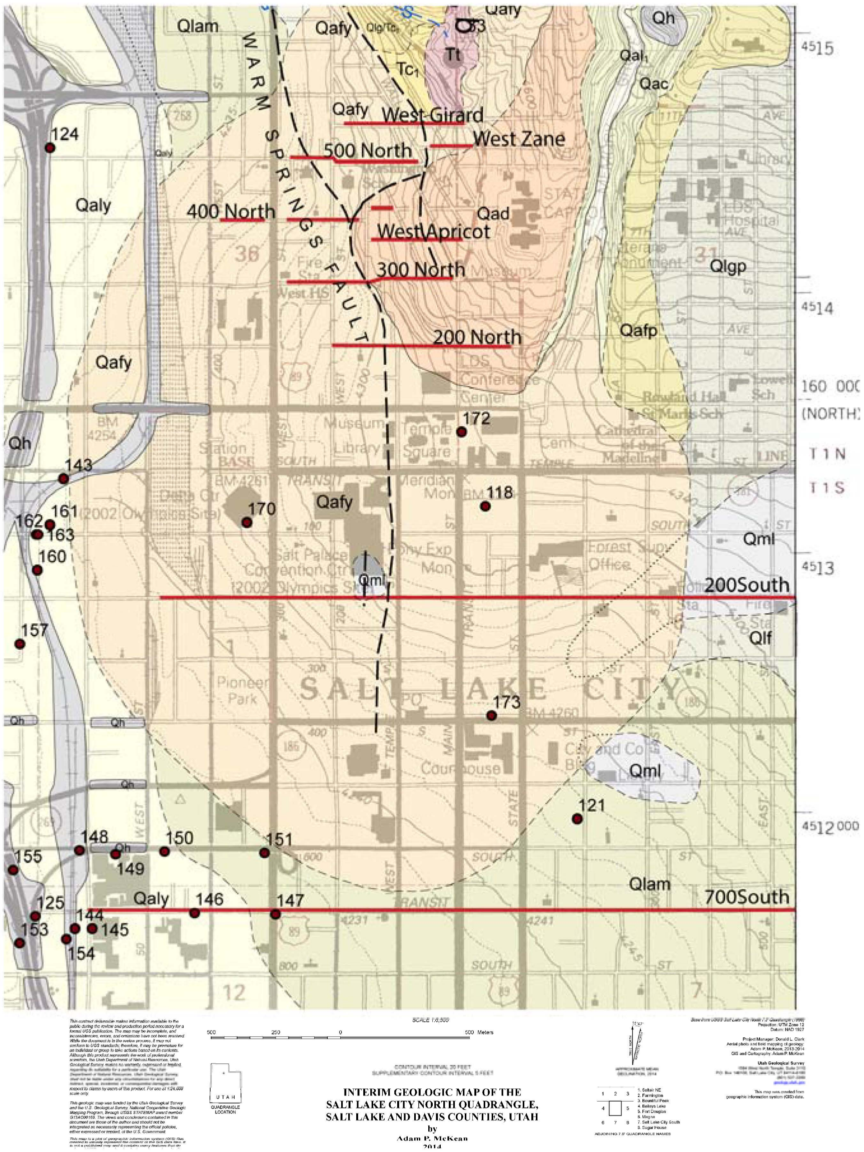




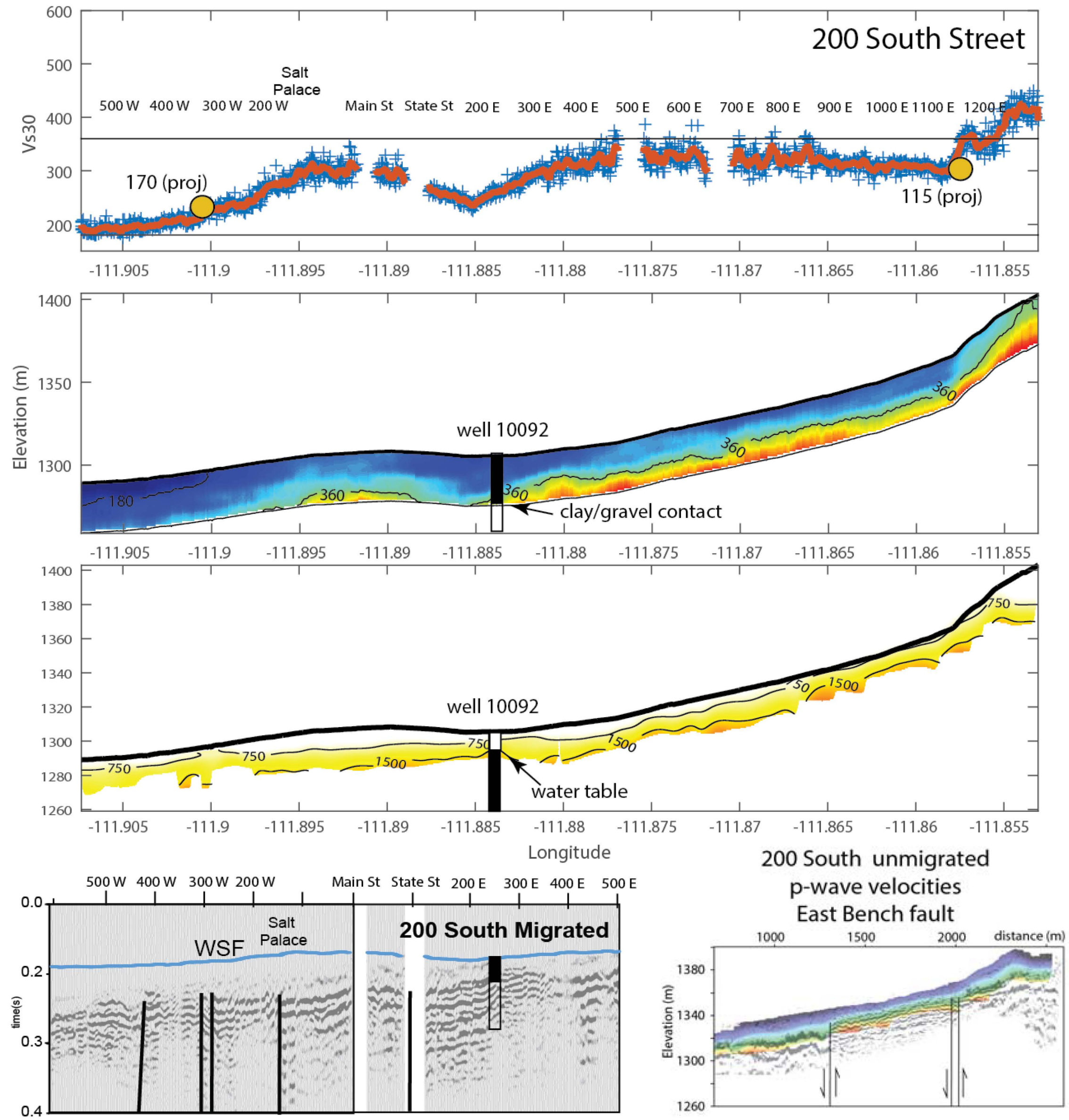


200 NORTH PROFILE





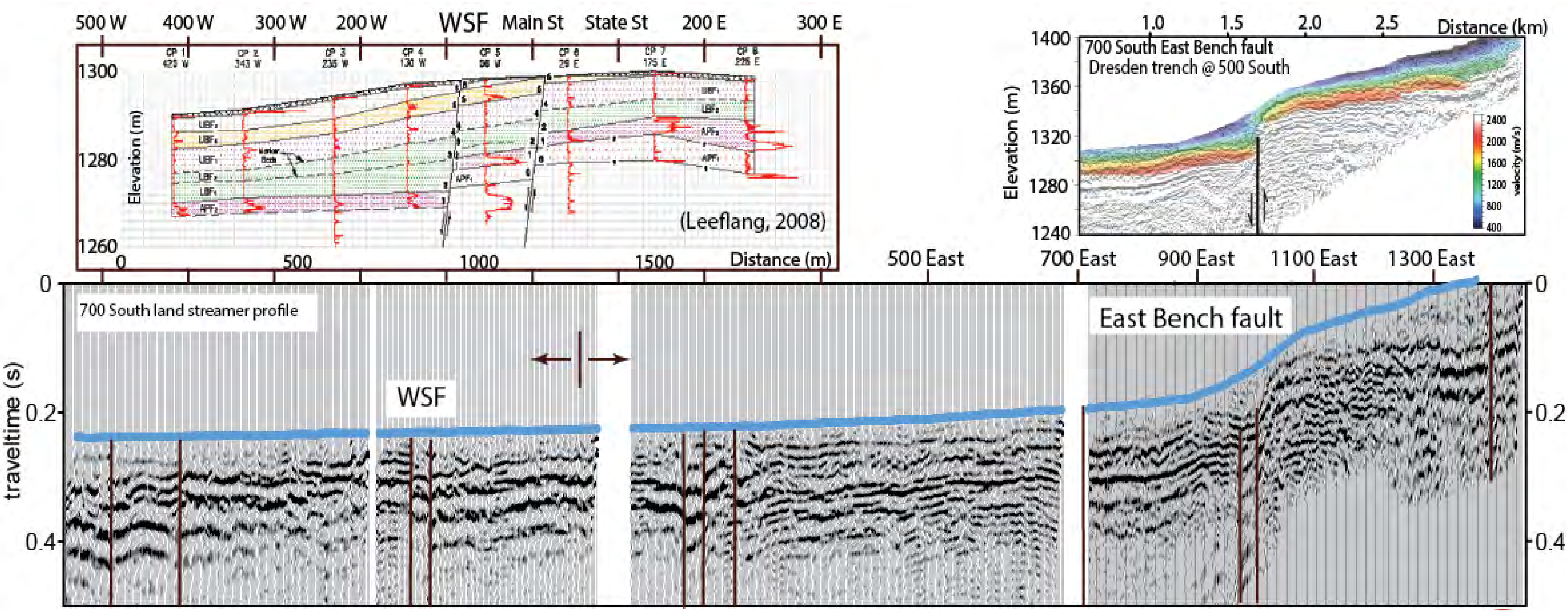
Qlam
Qafy
Qaly
Qh
Tt
Tc1
Qal1
Qac
Qad
Qafp
Qlgp
Qml
Qlf
WARM SPRINGS FAULT
West Girard
West Zane
500 North
400 North
West Apricot
300 North
200 North
200South
700South
SALT LAKE CITY
124
143
161
162
163
160
157
170
172
118
173
121
148
149
150
151
155
125
144
145
153
154
146
147
T 1 N
T 1 S
INTERIM GEOLOGIC MAP OF THE
SALT LAKE CITY NORTH QUADRANGLE,
SALT LAKE AND DAVIS COUNTIES, UTAH
by
Adam P. McKean
2014



200 South Street
Vs30
500 W 400 W 300 W 200 W
Salt Palace
Main St
State St
200 E 300 E 400 E 500 E 600 E 700 E 800 E 900 E 1000 E 1100 E 1200 E
170 (proj)
115 (proj)
Elevation (m)
well 10092
clay/gravel contact
180
360
water table
750
1500
Longitude
WSF
200 South Migrated
time(s)
200 South unmigrated
p-wave velocities
East Bench fault
distance (m)

700 SOUTH REFLECTION PROFILE (COMPARED TO 400S)

- **Dresden Place Trenches (1986):**
- ≥7 m deformation
- 3 m monoclinal warping—latest Pleistocene
- ≥4 m brittle deformation (fault offset)—Holocene

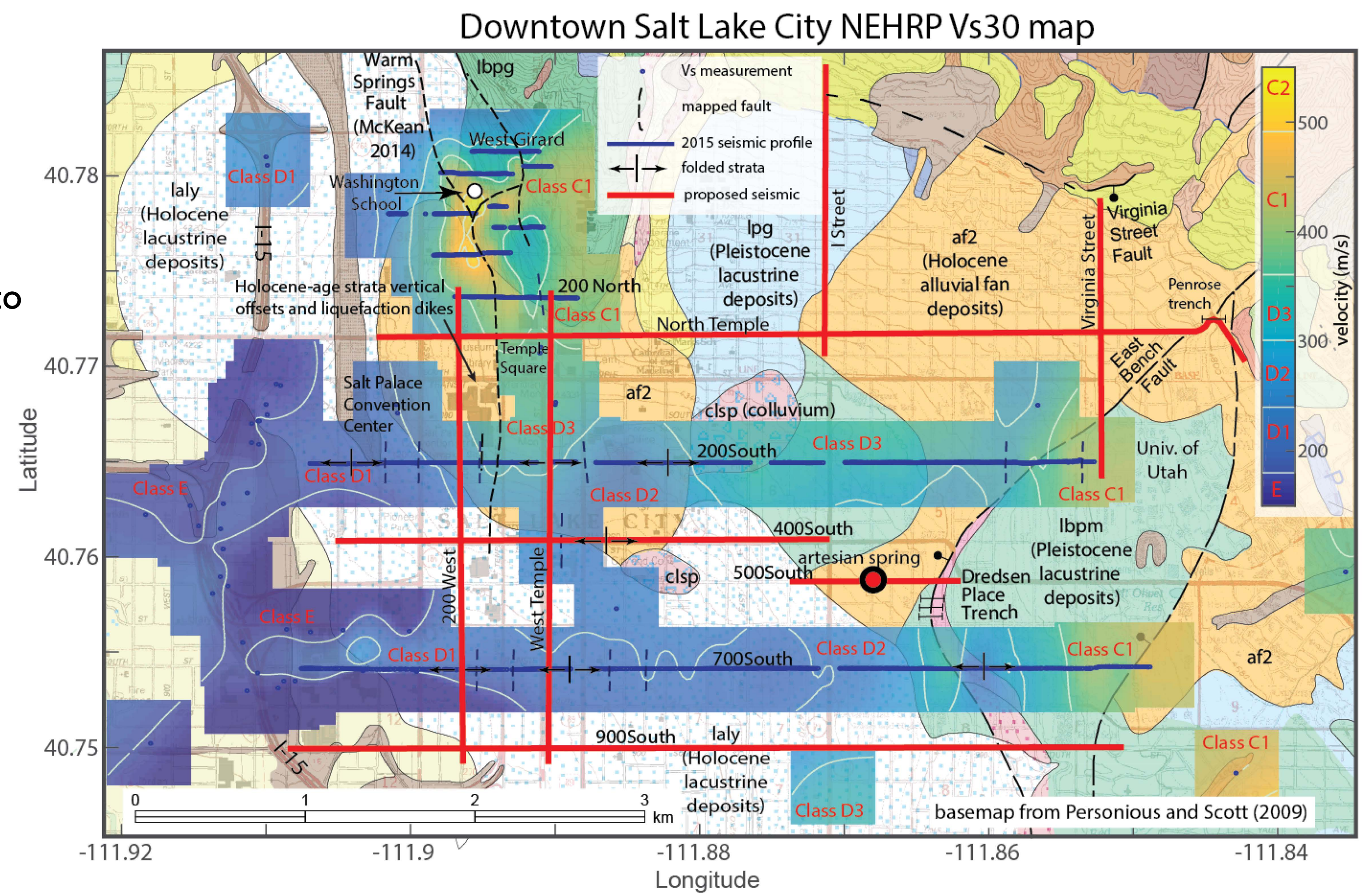


SALT LAKE CITY VS_{30} LAND STREAMER RESULTS WITH GEOLOGIC MAP

Low velocity Bonneville deposits beneath western portions of downtown Salt Lake City

Increase in Vs30 from west to east

High Vs in the fault zones



2017 PROJECT PLAN FOR IMAGING BENEATH SALT LAKE CITY

4 west-east seismic profiles

4 south-north profiles

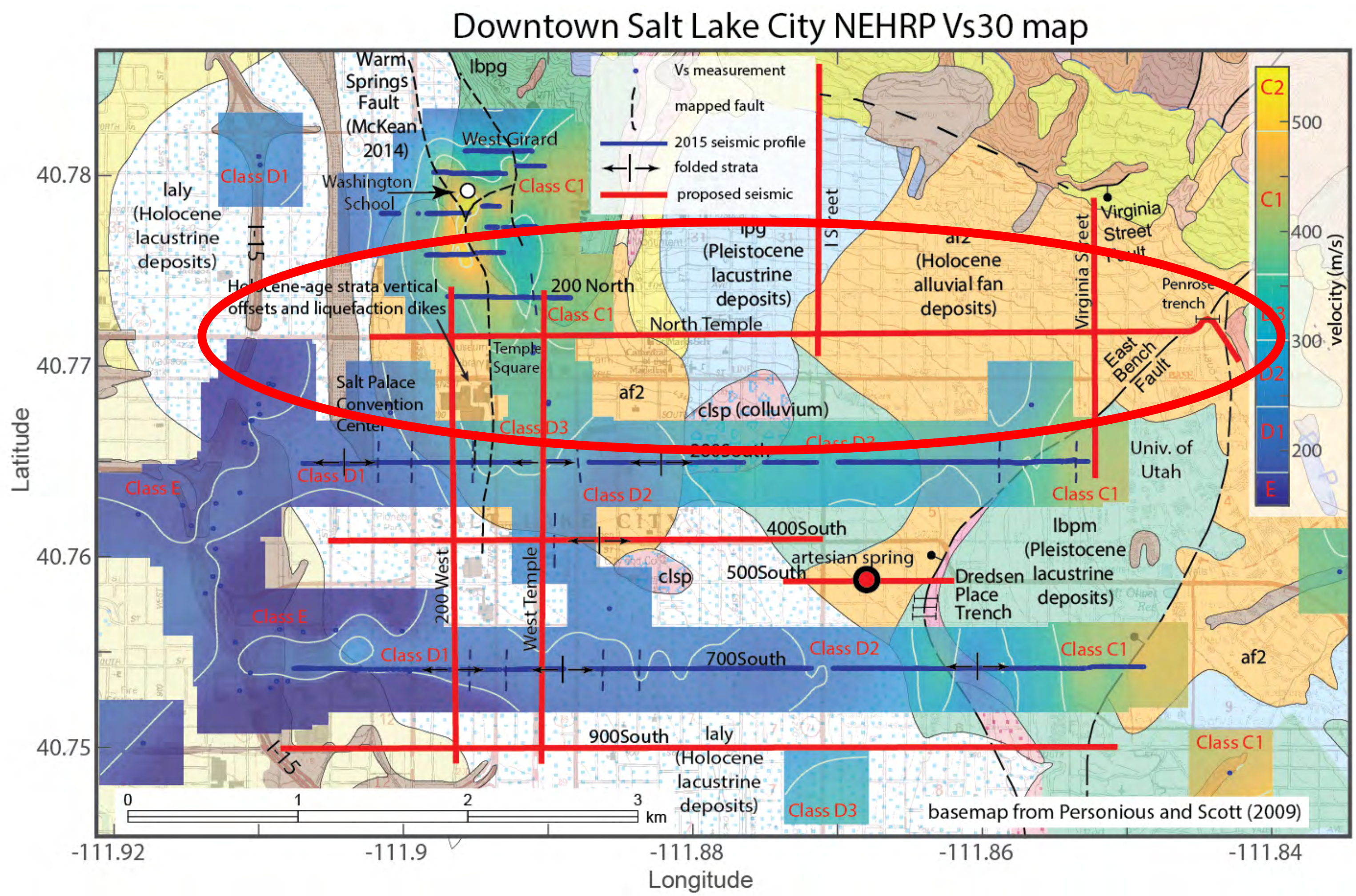
North Temple/2nd Avenue/Wasatch Drive

(5.25 km west-east)

400 West east to Penrose Drive/North Campus/Wasatch Drive

- Warm Springs fault north of downtown SLC.
- Trenches near the Temple Square suggest active faulting is not present.
- Cross the East Bench fault near Penrose trench

SALT LAKE CITY 2017 PROPOSED PLAN



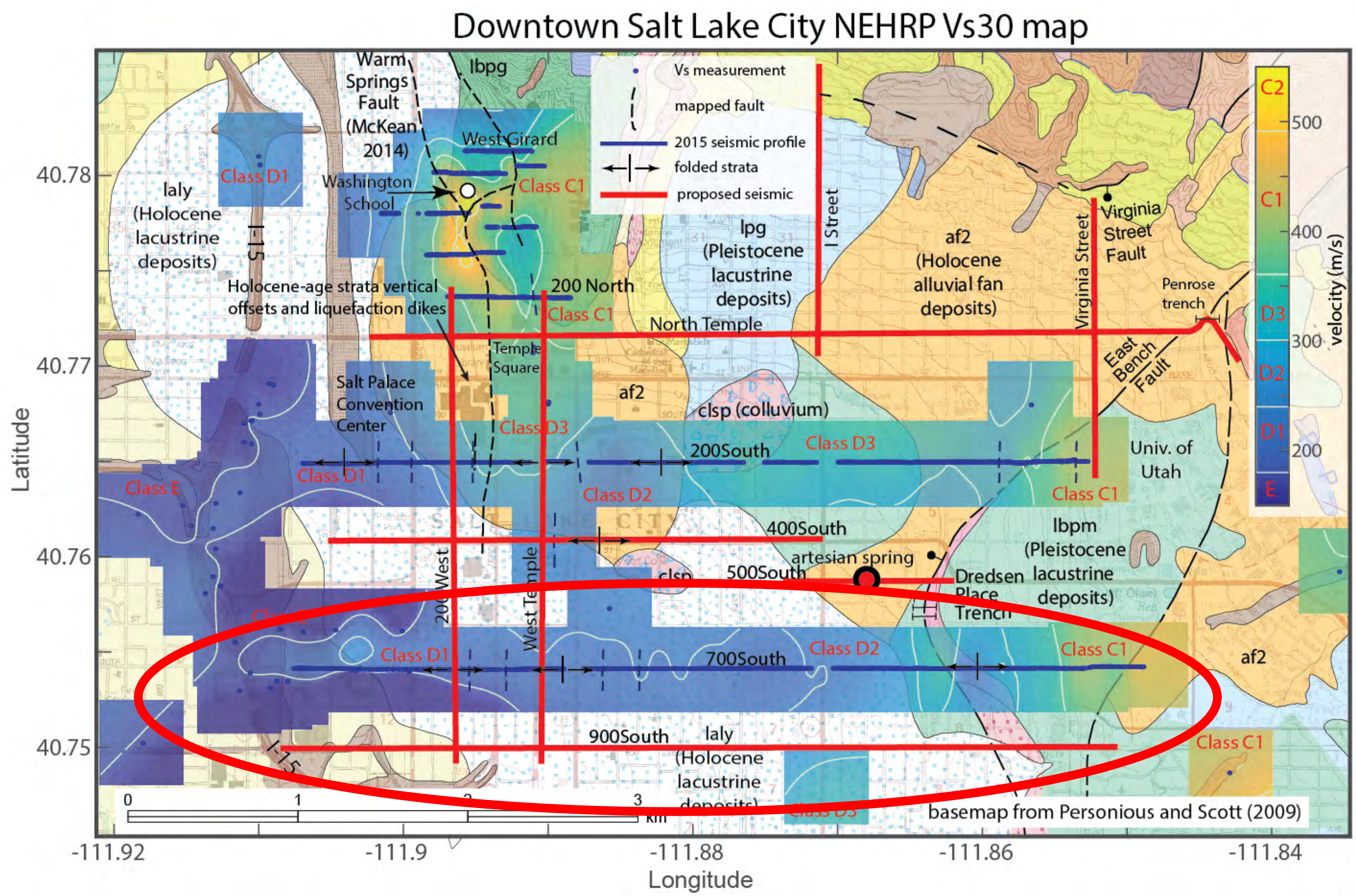
SALT LAKE CITY 2017 PROPOSED PLAN

900 South

(5 km east to west)

600 West east to 1500 East

- Southern extension of mapped strands of the Warm Springs fault through downtown
- Does folding observed on 700 South continue to the south?
- Antithetic faults related to the East Bench and Warm Springs faults?
- Cross both mapped strands of the East Bench fault.

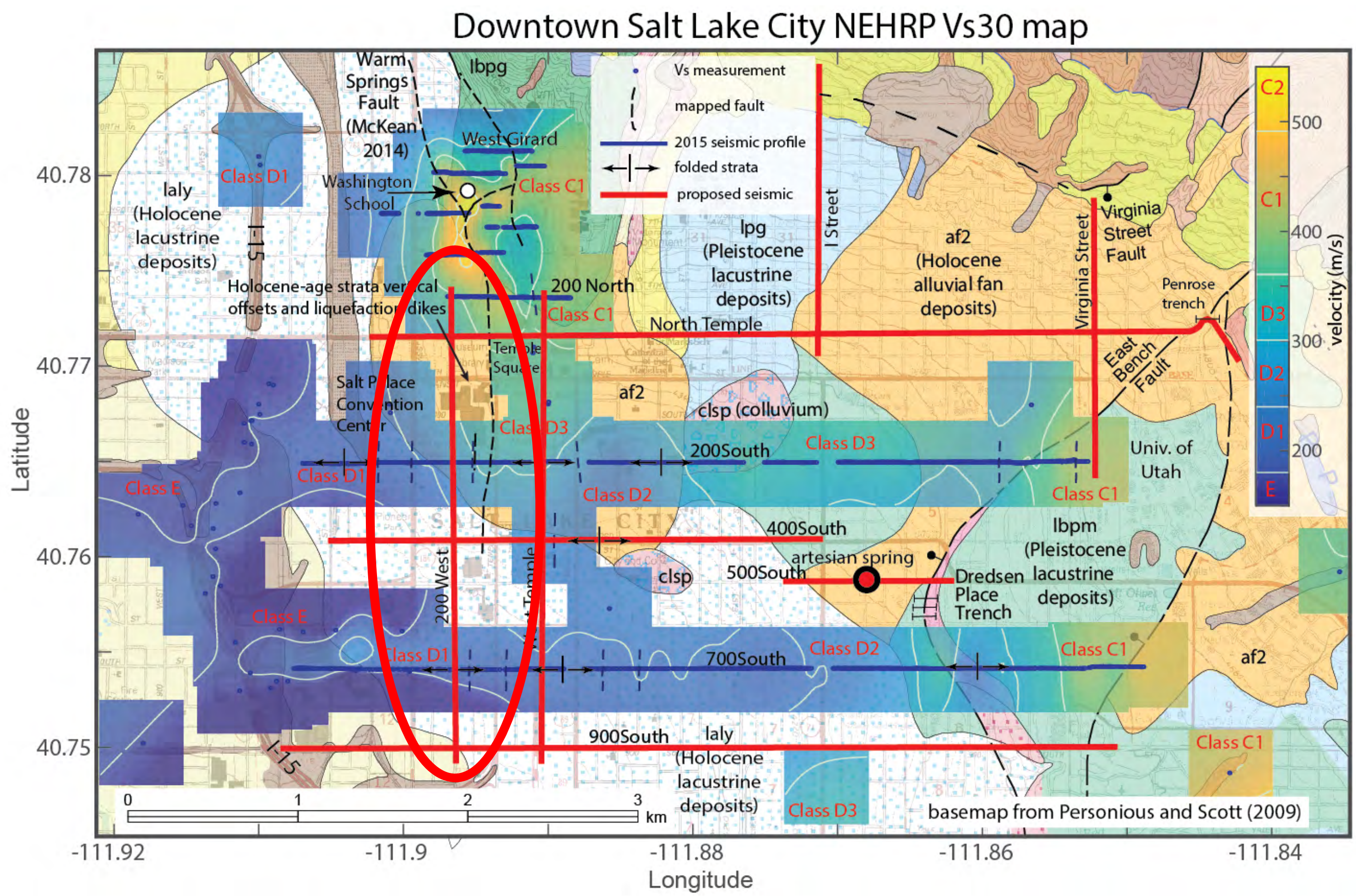


200 West

(2.5 km south to north)

- 900 South north to North Temple
- Stratigraphic continuity within/beneath Bonneville deposits
- Distinguish lateral (shallow) spreading from active (growth) faulting
- Identify any connecting faults
- Tie line for 2015 seismic survey.

SALT LAKE CITY 2017 PROPOSED PLAN



I Street

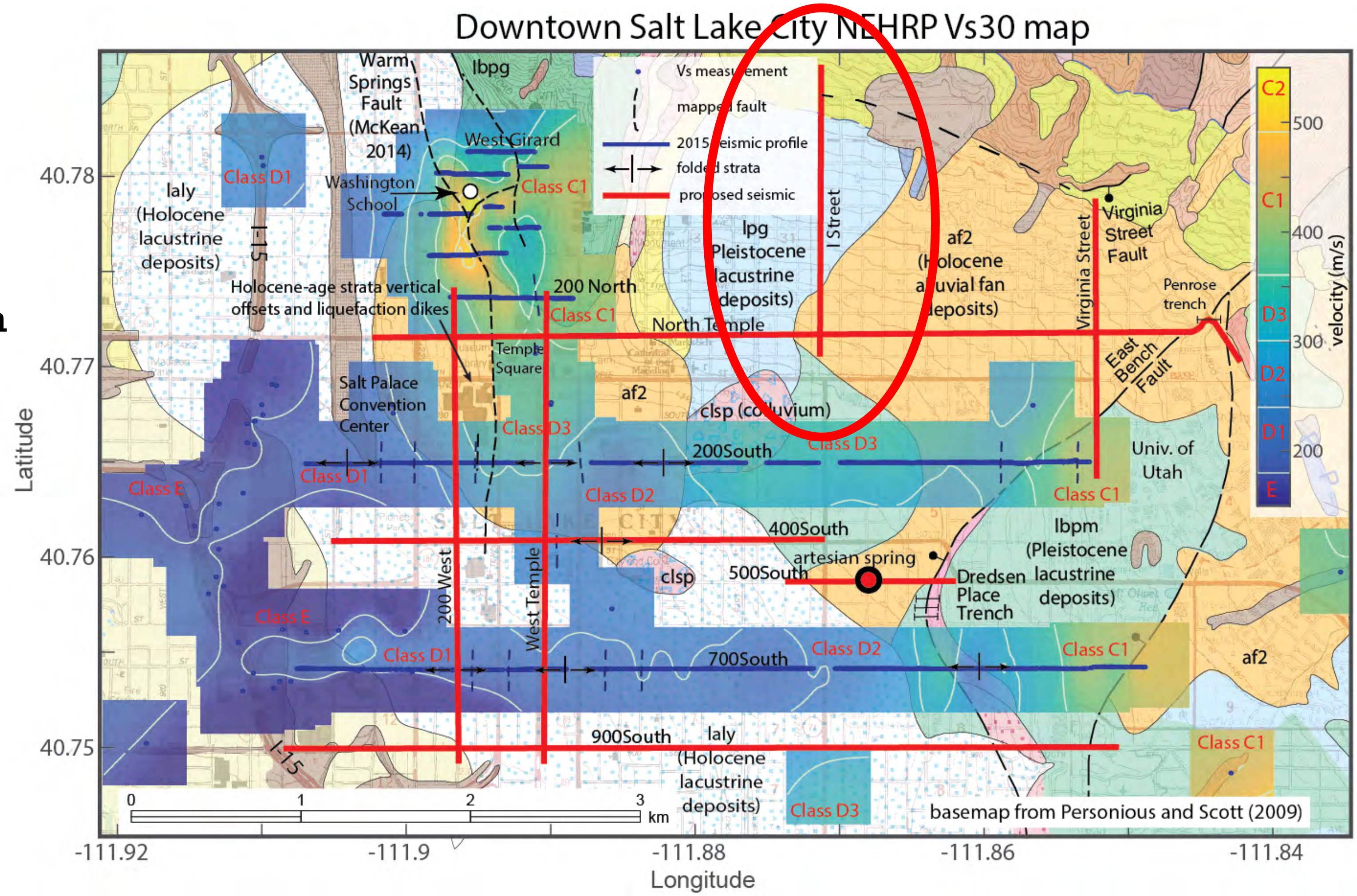
(1.75 km south to north)

South Temple north to North Hills Drive

Evidence for step-over structures related to the Wasatch fault system, westward extension/sense of motion of the Virginia Street (and related) faults.

Road crosses the presumed fault trace

SALT LAKE CITY 2017 PROPOSED PLAN



Virginia Street

(1.75 km south to north)

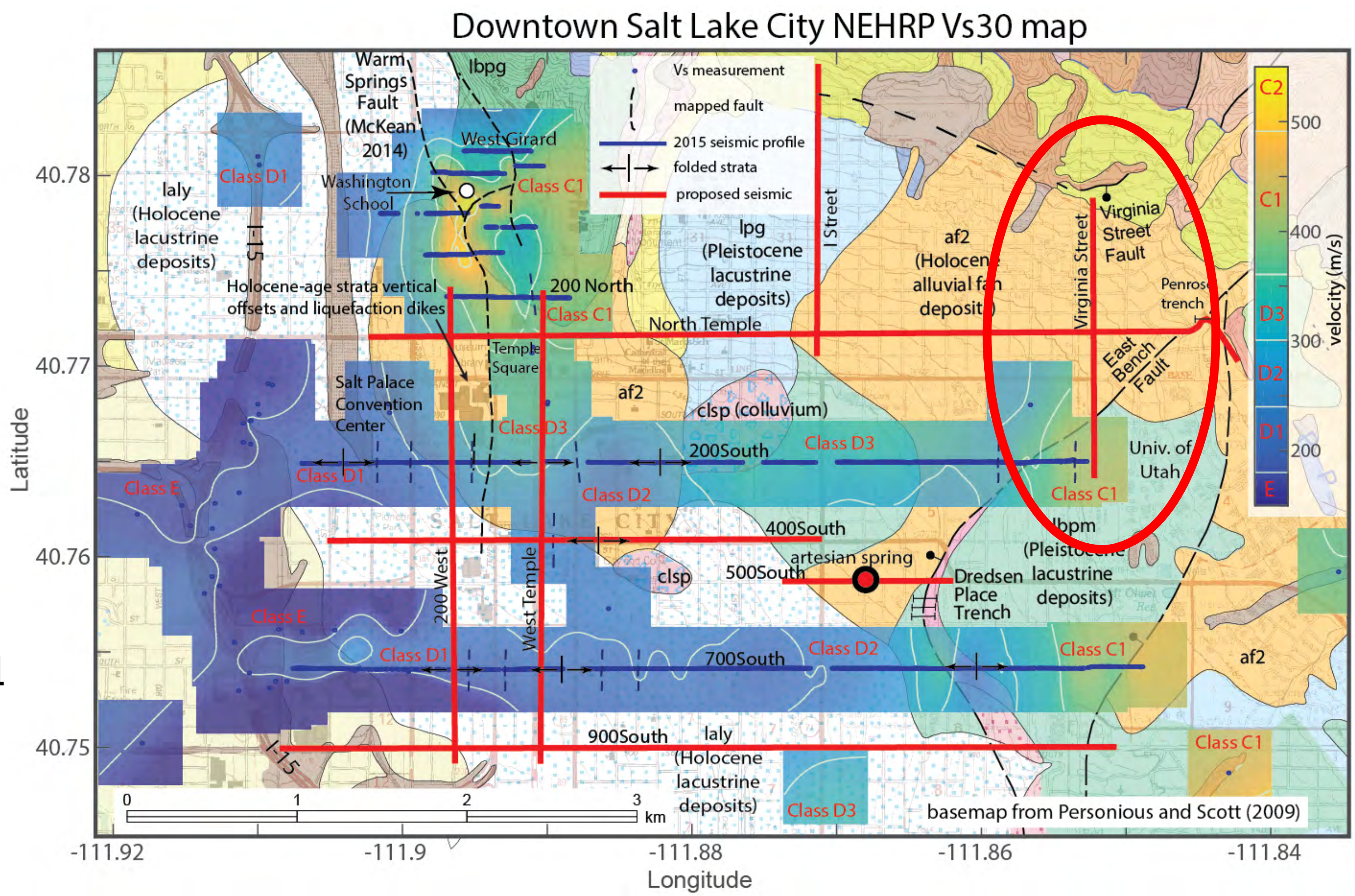
300 South north to bend in Virginia Street (at mapped fault trace).

Dip slip component to the Virginia Street fault, other accommodation faults, another crossing of the East Bench fault near Penrose trench.

Road ends at the mapped trace of the Virginia Street fault.

Look for additional road crossing fault near profile.

SALT LAKE CITY 2017 PROPOSED PLAN

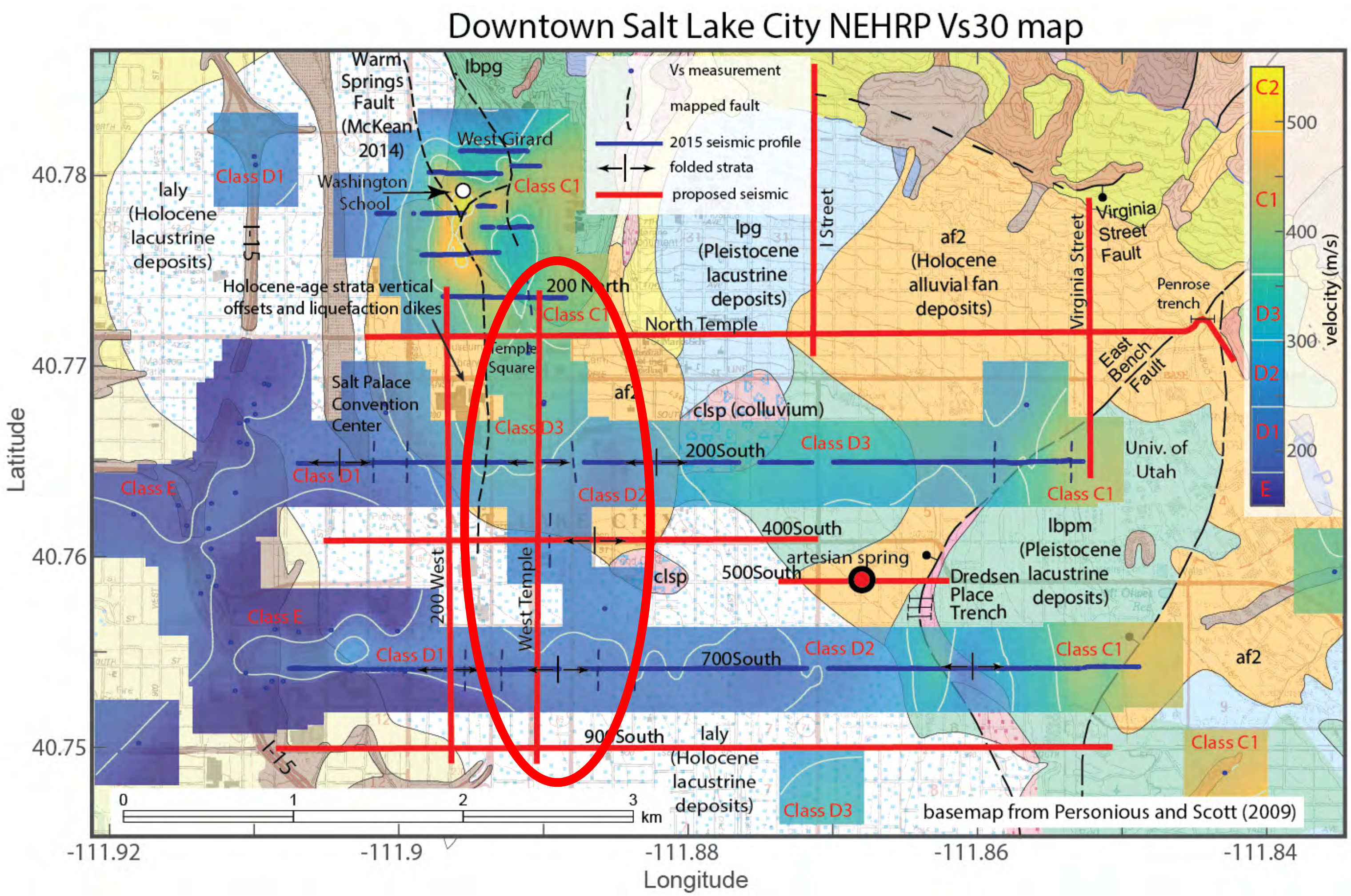


West Temple

(2.5 km south to north)

- 900 South north to North Temple
- Stratigraphic continuity within/beneath Bonneville deposits, distinguish shallow lateral spreading to active growth faulting via connecting faults;
- tie line for 2015 seismic survey.

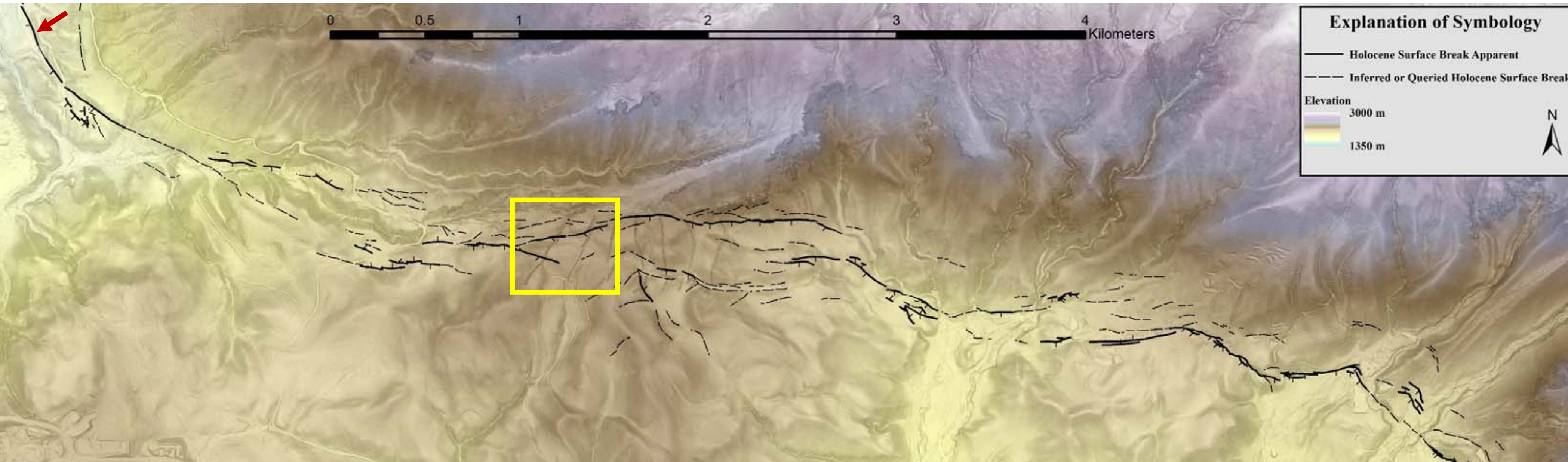
SALT LAKE CITY 2017 PROPOSED PLAN



Preliminary Results from the Traverse Ridge Paleoseismic Site

(40.492°, -111.805°)

Nathan Toké, Chris Langevin, Joe Phillips, Emily Kleber, Chris DuRoss,
Jack Wells, Daniel Horns, Greg McDonald, Adam Hiscock, and Kade Carlson



Key Findings

- **Two re-excavated trenches present evidence for at least 2 and up to 4 Holocene events**
- **Initial radiocarbon age results indicate two events between 1650 A.D. and 7300 B.C.E.**
- **Additional age results are pending…**

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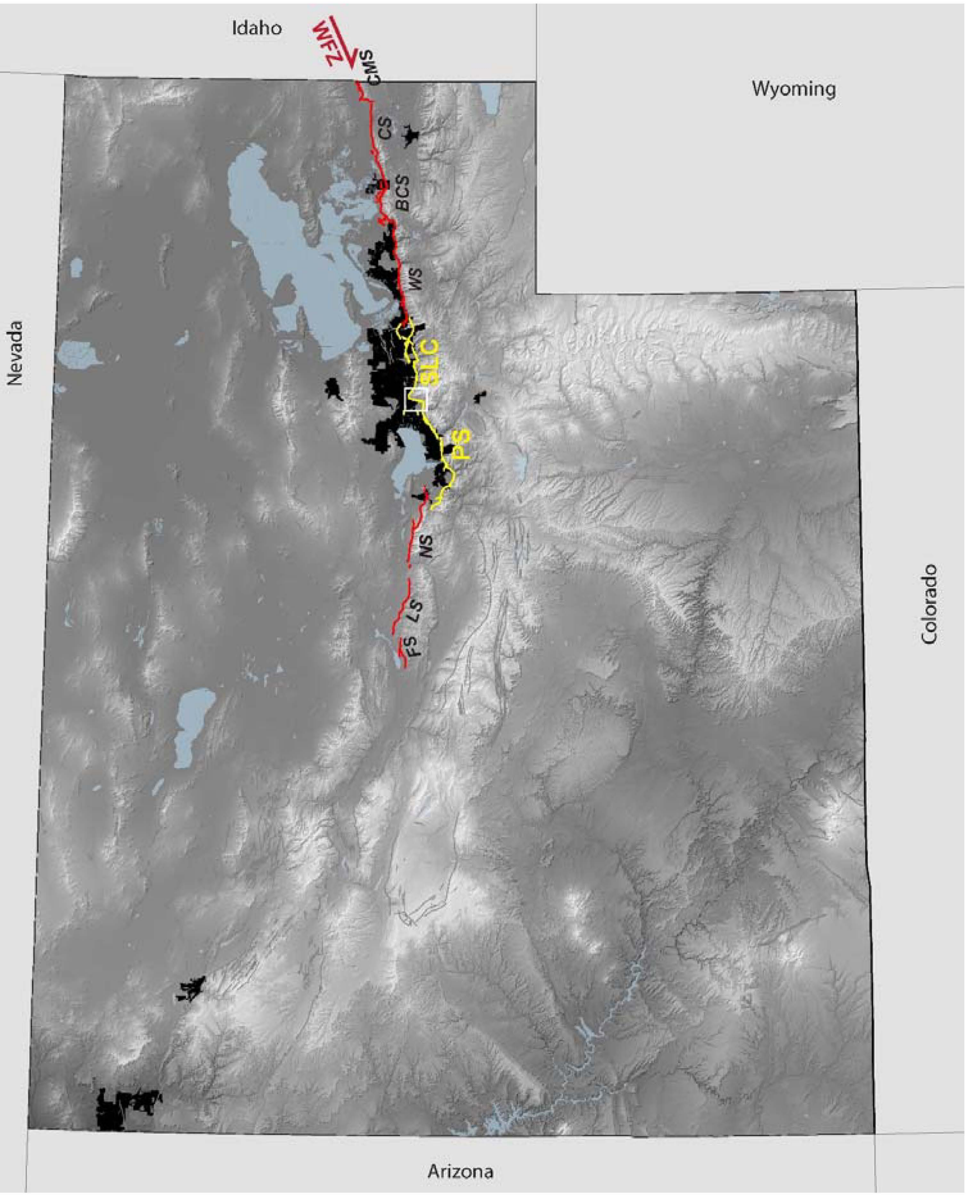
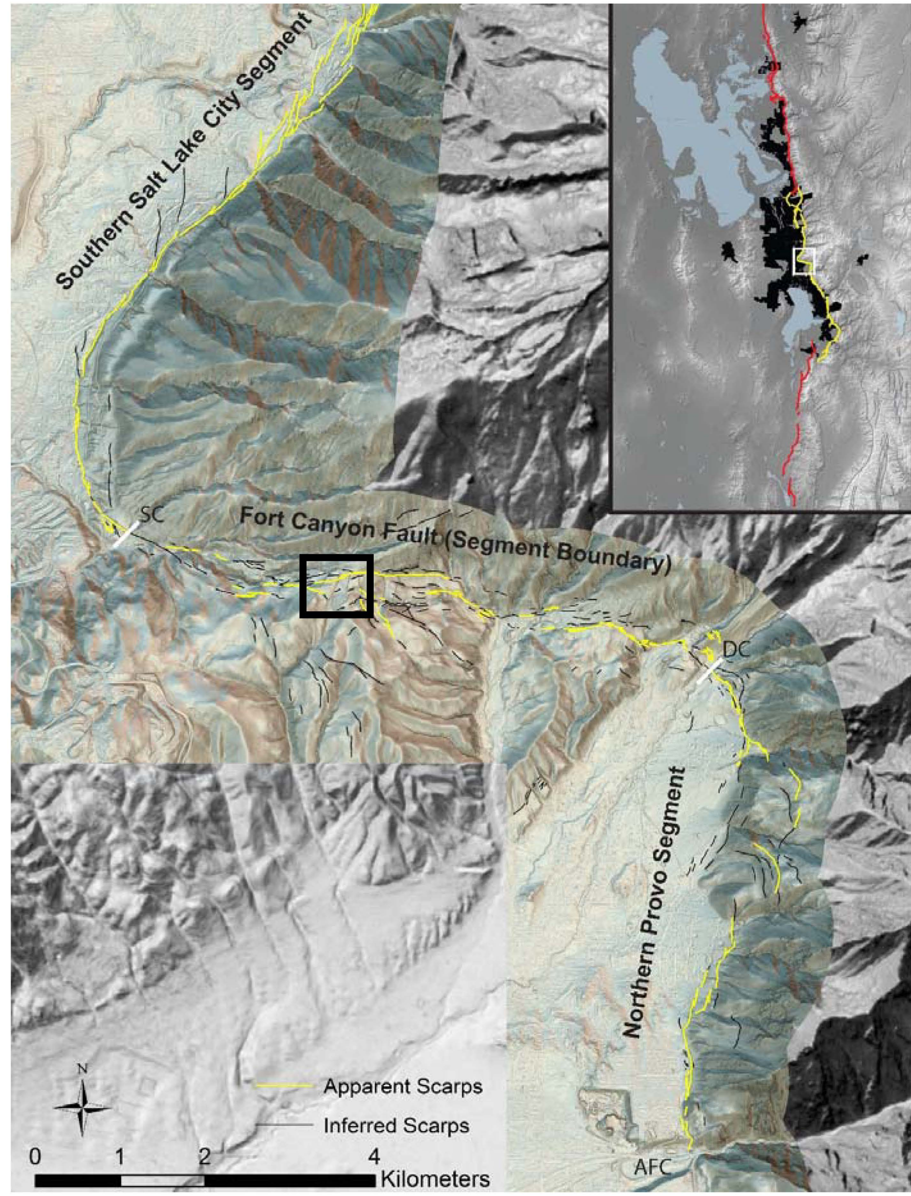
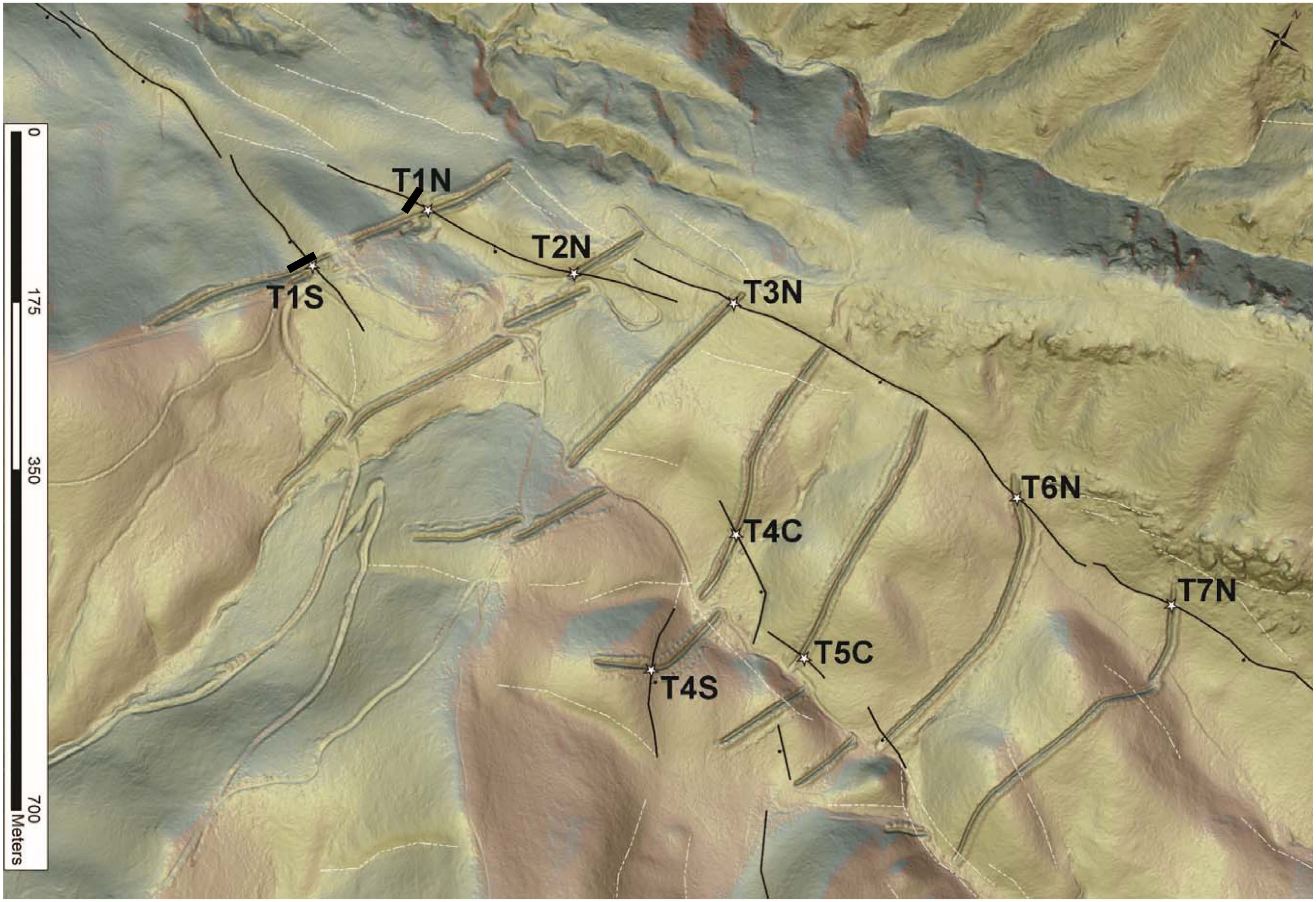
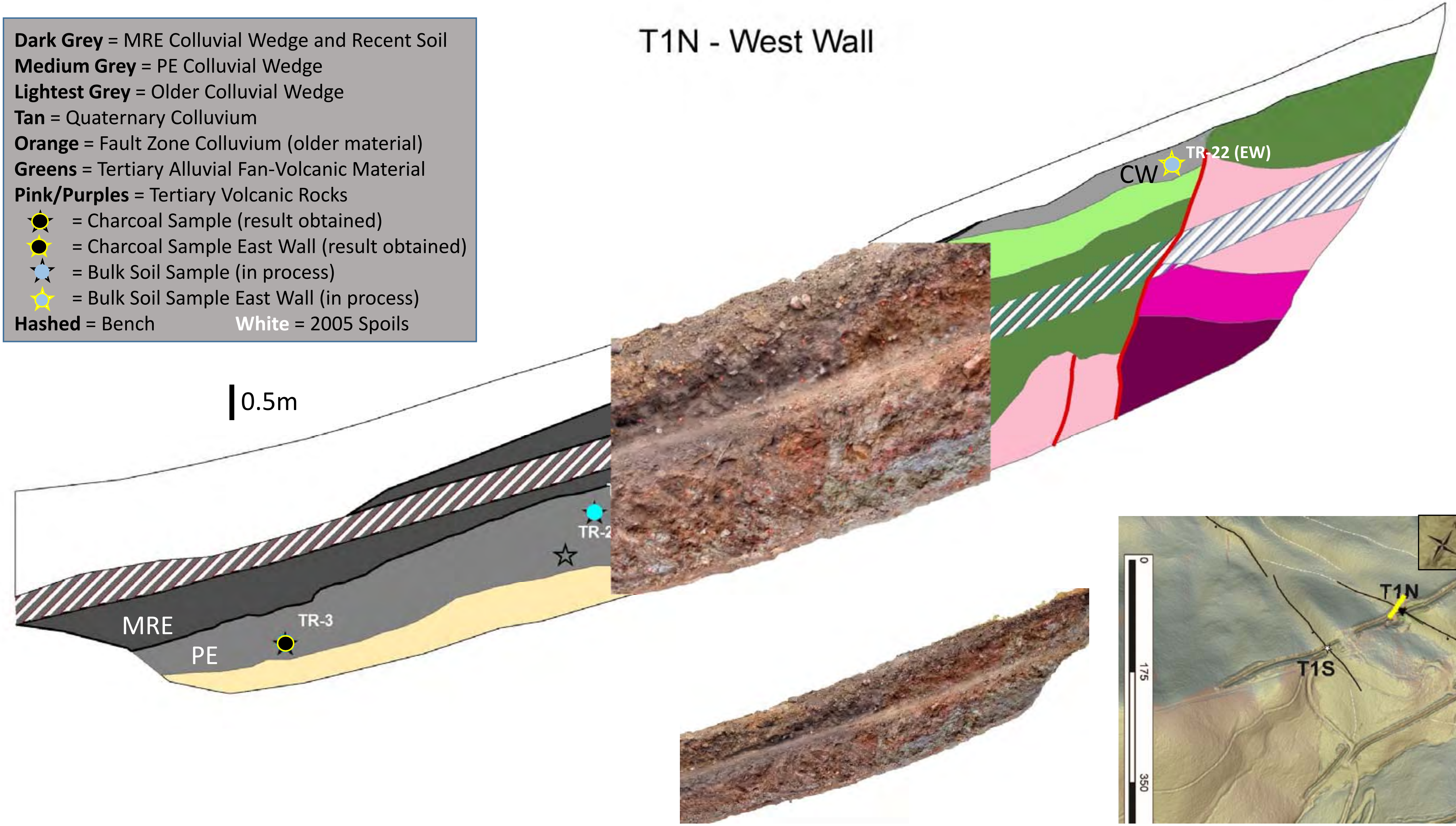

Idaho
WFZ
CMS
Wyoming
CS
BCS
WS
Nevada
SLC
PS
NS
Colorado
LS
FS
Arizona

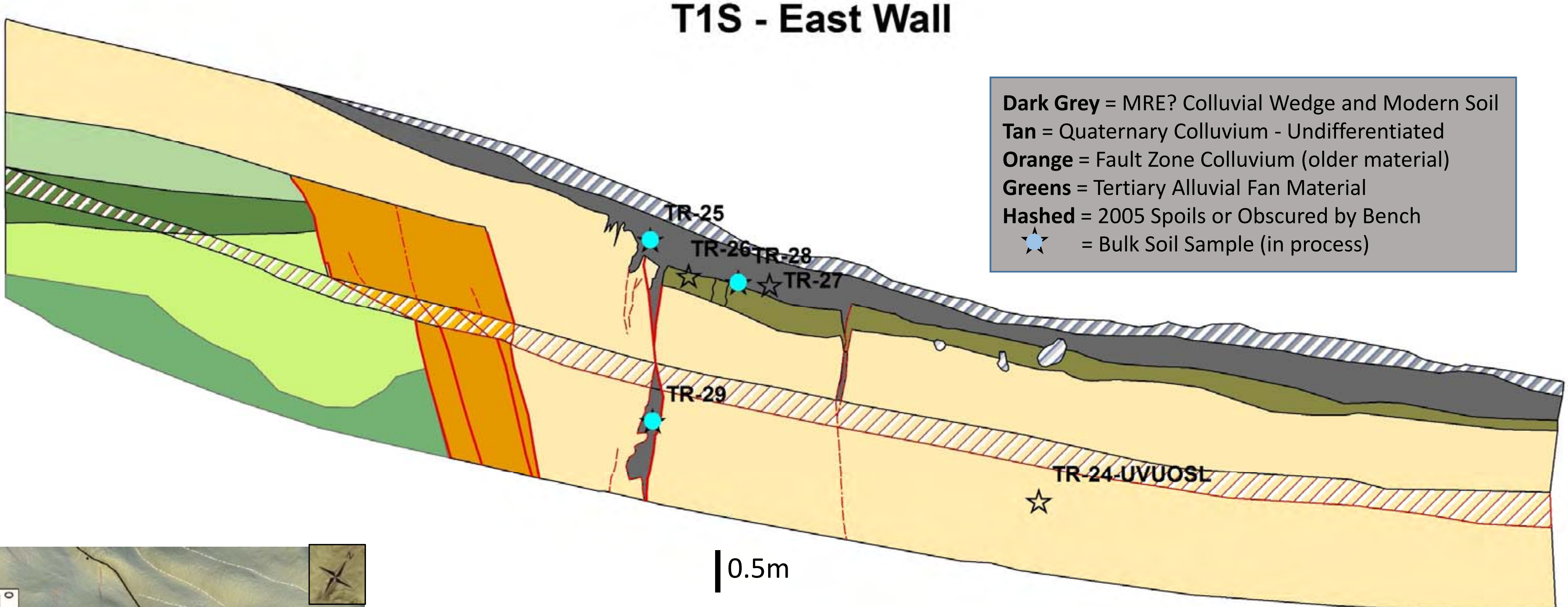

Southern Salt Lake City Segment
SC
Fort Canyon Fault (Segment Boundary)
DC
Northern Provo Segment
N
Apparent Scarps
Inferred Scarps
0 1 2 4
Kilometers
AFC

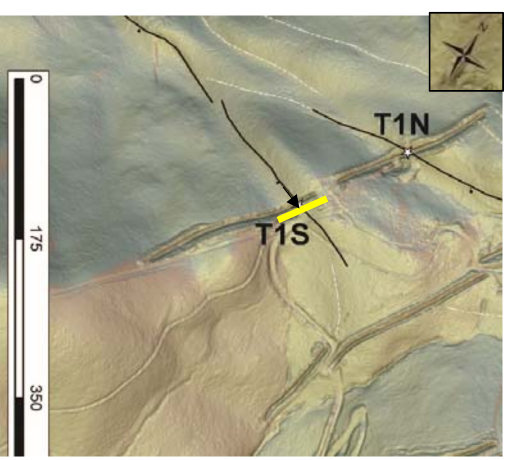


T1N
T1S
T2N
T3N
T4C
T4S
T5C
T6N
T7N
0
175
350
700
Meters

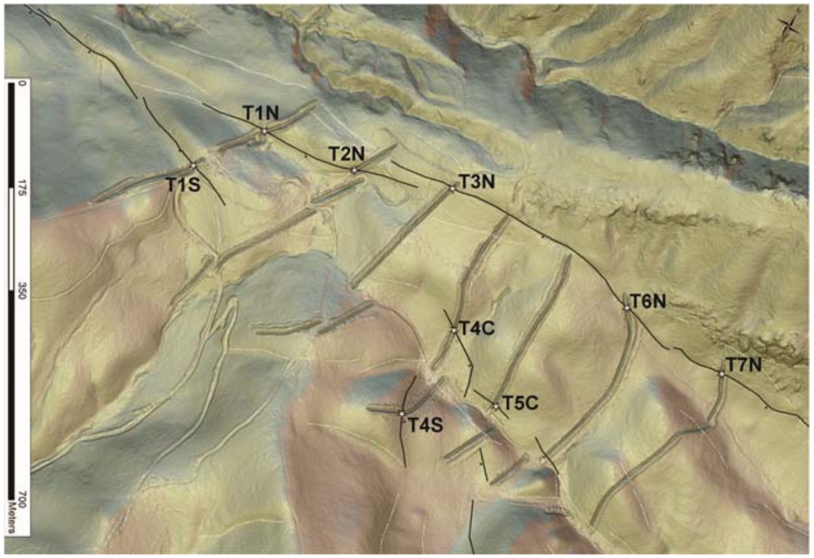

T1N - West Wall
Dark Grey = MRE Colluvial Wedge and Recent Soil
Medium Grey = PE Colluvial Wedge
Lightest Grey = Older Colluvial Wedge
Tan = Quaternary Colluvium
Orange = Fault Zone Colluvium (older material)
Greens = Tertiary Alluvial Fan-Volcanic Material
Pink/Purples = Tertiary Volcanic Rocks
= Charcoal Sample (result obtained)
= Charcoal Sample East Wall (result obtained)
= Bulk Soil Sample (in process)
= Bulk Soil Sample East Wall (in process)
Hashed = Bench
White = 2005 Spoils
0.5m
CW
TR-22 (EW)
MRE
PE
TR-3
T1N
T1S
0
175
350

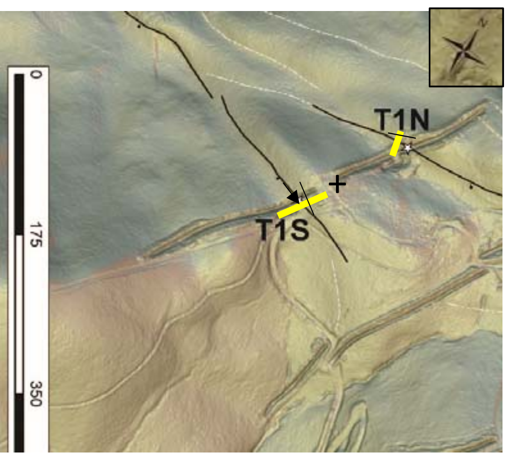
T1S - East Wall





Structural and slip-per-event Data





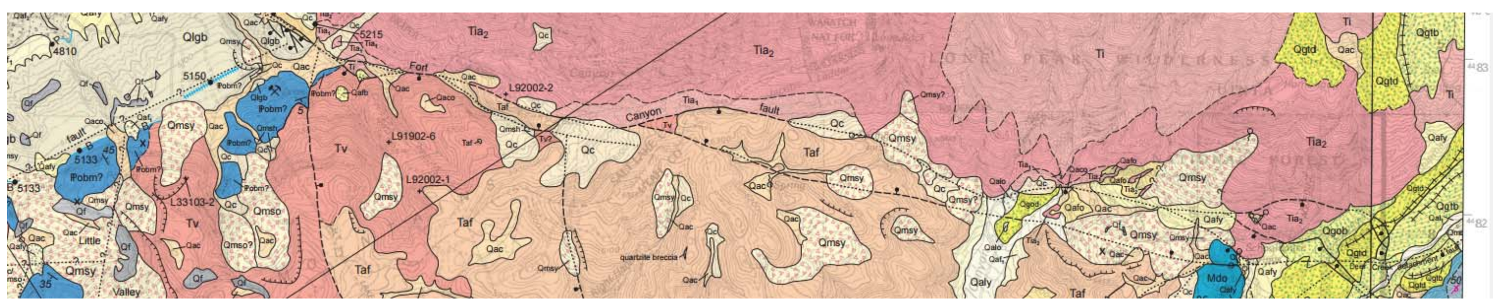
- Colluvial Wedge Heights Range from 0.5-1.0 m

  Slip Per Event of 1-2 m

- T1N Faults:
  - Strike: 277-288^{o} — FW Faults appear rotated CCW
  - Dip: 70-85^{o} S — FW Faults dip more steeply

- T1S Faults:
  - Strike: 294-308^{o} — FW Faults appear rotated CW
  - Dip: 64-89^{o} S — FW Faults dip more shallowly

- Left-step in fault trace with positive topography
- Possible offset ridgeline(s)



Initial Age Results

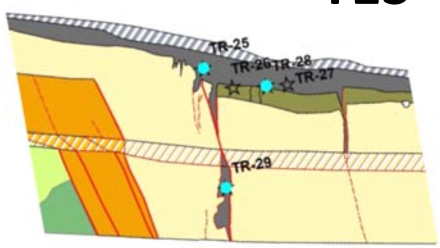
1. **MRE Prior to ~1650 AD**

T1S MRE?

2. **PE After ~7300 BCE**

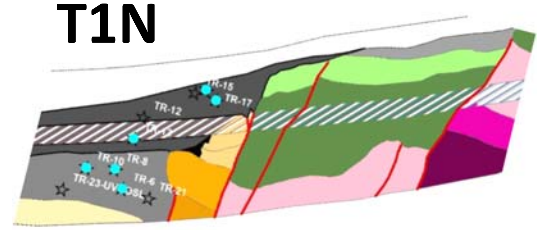
Older Event?

T1S



Trench1S Sample ID[1]	NSF-NOSAMS#	Sample Type	Trench and Coordinates (X,Y)[2]	Unit	Fraction Modern	+/- [3]	^{14}C age (years BP)	+/- [4]	2σ calibrated age (cal AD / BC)[5]
TR25_ UVU2016		Bulk ???	T1S - EW (9.90, 4.26)	MRE CW: Middle					
MRE? EVENT									
TR28_ UVU2016		Bulk ???	T1S - EW (8.99, 3.60)	MRE CW: Bottom					
TR29_ UVU2016		Bulk ???	T1S - EW (9.40, 2.30)	MRE Fissure					

T1N

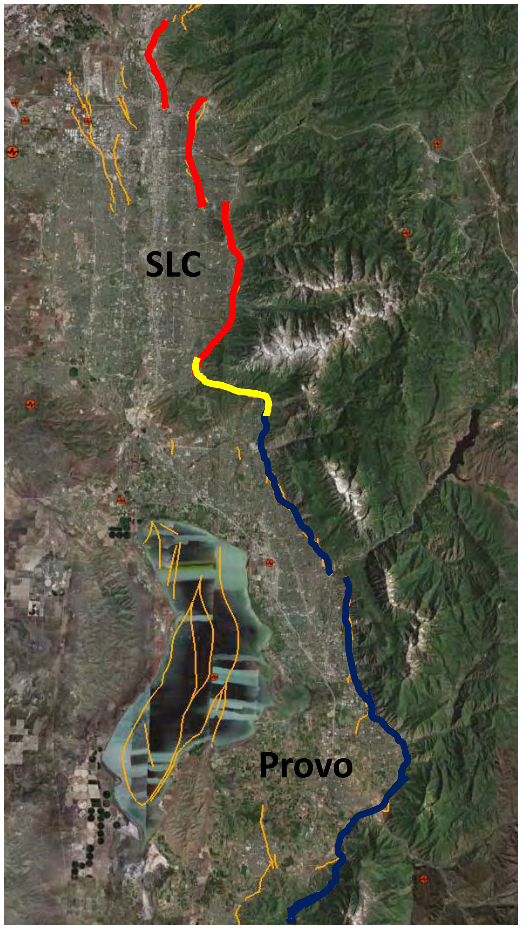


Trench 1N Sample ID[1]	NSF-NOSAMS#	Sample Type	Trench and Coordinates (X,Y)[2]	Unit	Fraction Modern	+/- [3]	^{14}C age (years BP)	+/- [4]	2σ calibrated age (cal AD / BC)[5]
TR7_ UVU2016	*142558*	*charcoal*	*T1N - EW (5.80, 3.47)*	*MRE CW: Middle*	*0.9519*	*0.0020*	*395*	*15*	1445-1495 AD (88.3%) 1601-1614 AD (7.1%)
TR16_ UVU2016	142559	charcoal	T1N - WW (6.05, 3.25)	MRE CW: Upper	0.9653	0.0020	285	15	**1522-1573 AD (51.8%) 1630-1654 AD (43.6%)**
TR17_ UVU2016	142560	charcoal	T1N - WW (6.25, 3.16)	MRE CW: Middle	0.9347	0.0020	545	15	**1325-1345 AD (17.5%) 1393-1426 AD (77.9%)**
MRE EVENT									
TR13_ UVU2016		Bulk ???	T1N - WW 5.00, 2.20)	MRE CW: Bottom					
TR10_ UVU2016		Bulk ???	T1N - WW (4.25, 1.80)	PE CW: Middle					
PE EVENT									
TR-A_ UVU2015	142561	charcoal	T1N-old	PE CW: Lower	0.4051	0.0020	7,260	40	**6222-6051 BC (95.4%)**
TR6_ UVU2016	142557	charcoal	T1N - WW (4.99, 1.86)	PE CW: Lower	0.3652	0.0021	8,090	45	**7287-6830 BC (95.4%)**
TR4_ UVU2016	142556	charcoal	T1N - EW (2.65, 1.43)	PE CW: Bottom	0.2202	0.0023	12,150	85	**12313-11812 BC (95.4%)**
TR3_ UVU2016	*142555*	*charcoal (root)*	*T1N - WW (0.80, 0.35)*	*PE CW Bottom*	*0.9573*	*0.0019*	*350*	*15*	*1470-1525 AD (43.6%) 1557-1633 AD (51.8%)*
Older EVENT									
TR22_ UVU2016		Bulk ???	T1N - EW (9.68, 5.4)	Foot Wall CW					

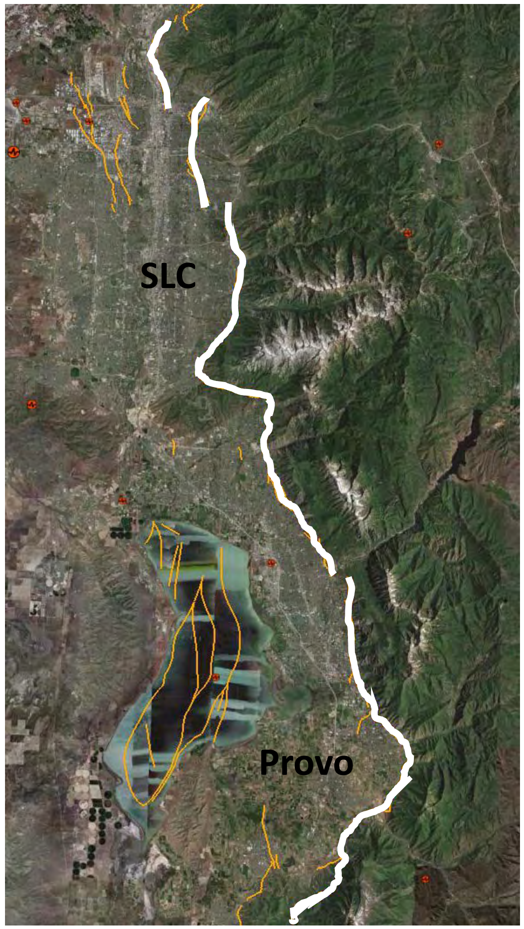
Rupture Models

from DuRoss, 2008

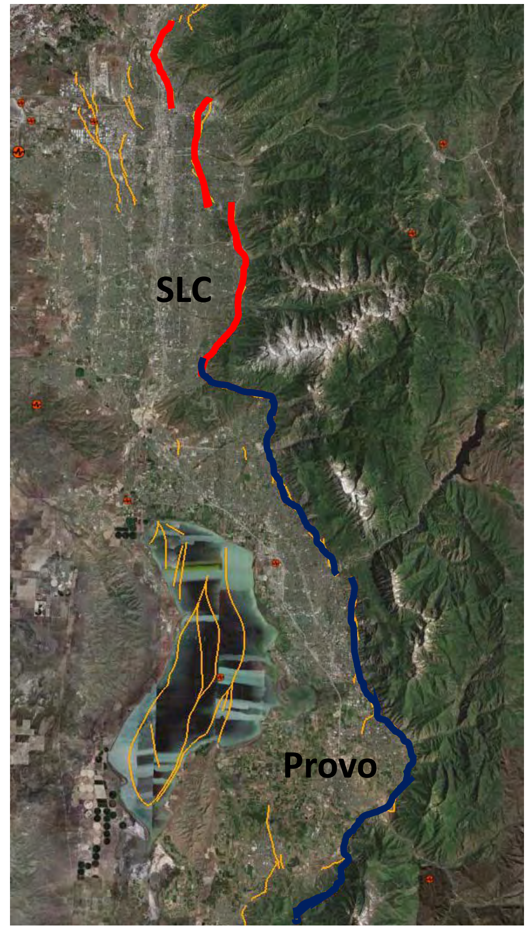
Segmented with In-fill Ruptures

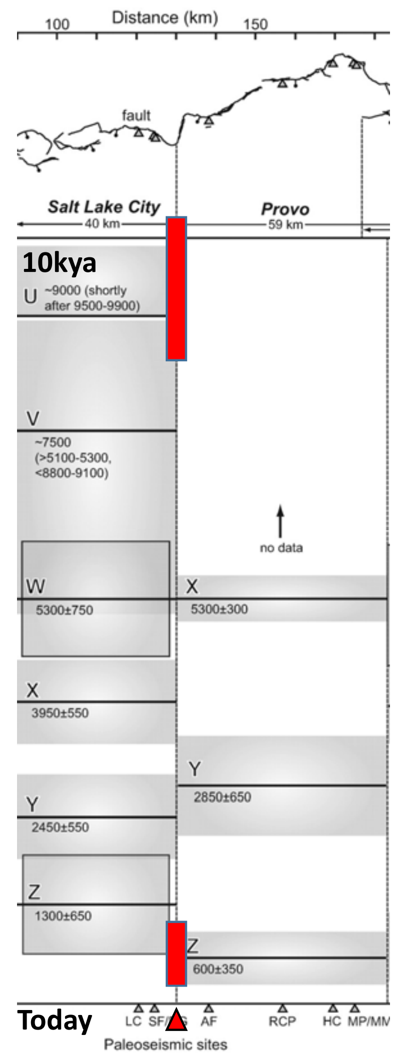


Multi-segment Ruptures



Spill-over Ruptures





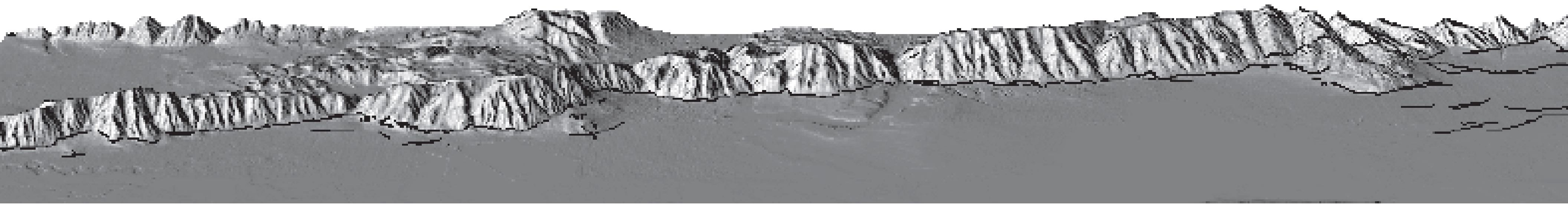
Work Remaining

- PaleoResearch Institute is processing 6 bulk soil samples resultant material to NOSAMS lab…
- Attempt to ascertain minimum throw on faults.

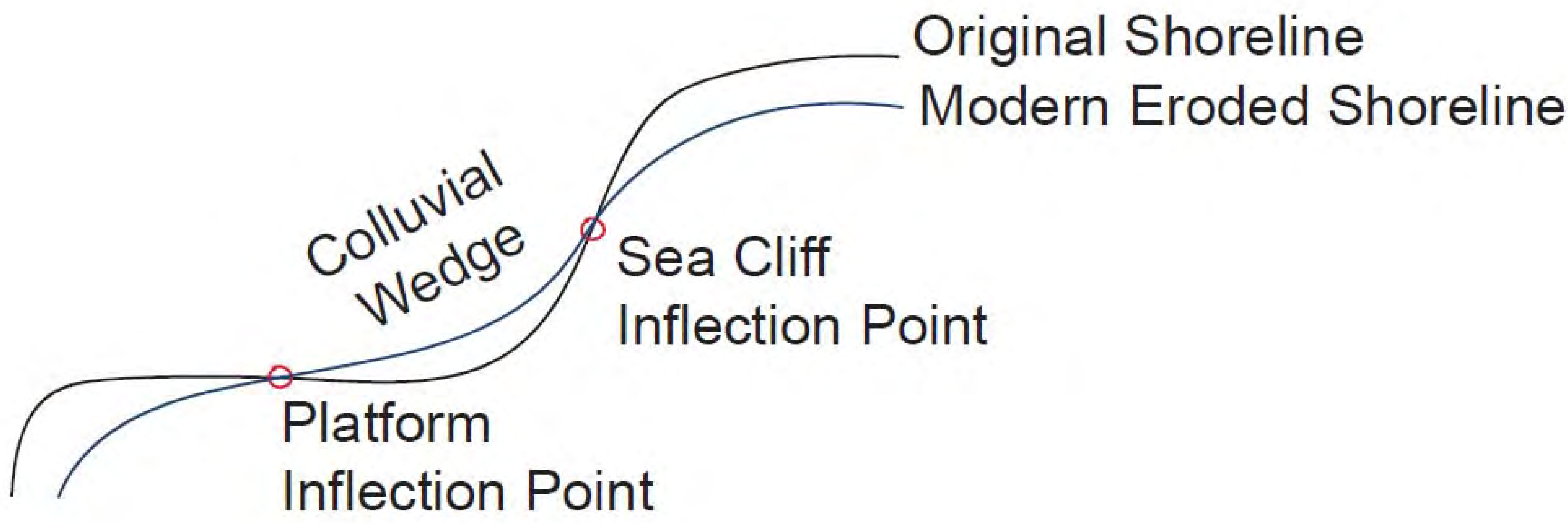
Characterization of Segmentation and Long-Term Slip Rates of the Wasatch Fault Zone, Utah

Brigham City and Weber Segments

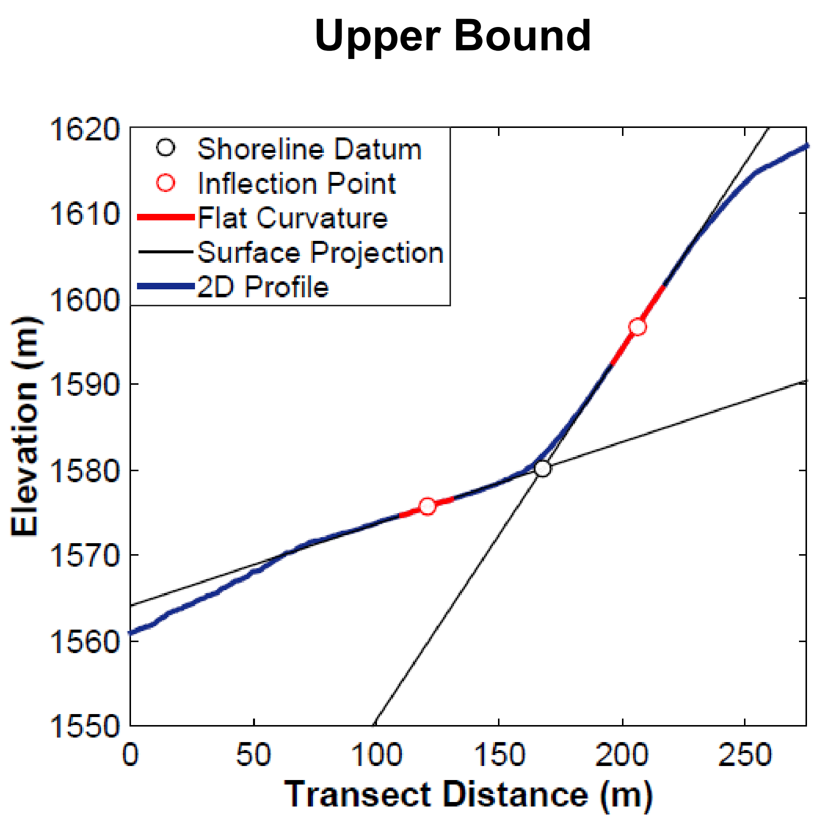
Julia Howe, MS Student
Paul Jewell, Ron Bruhn
University of Utah

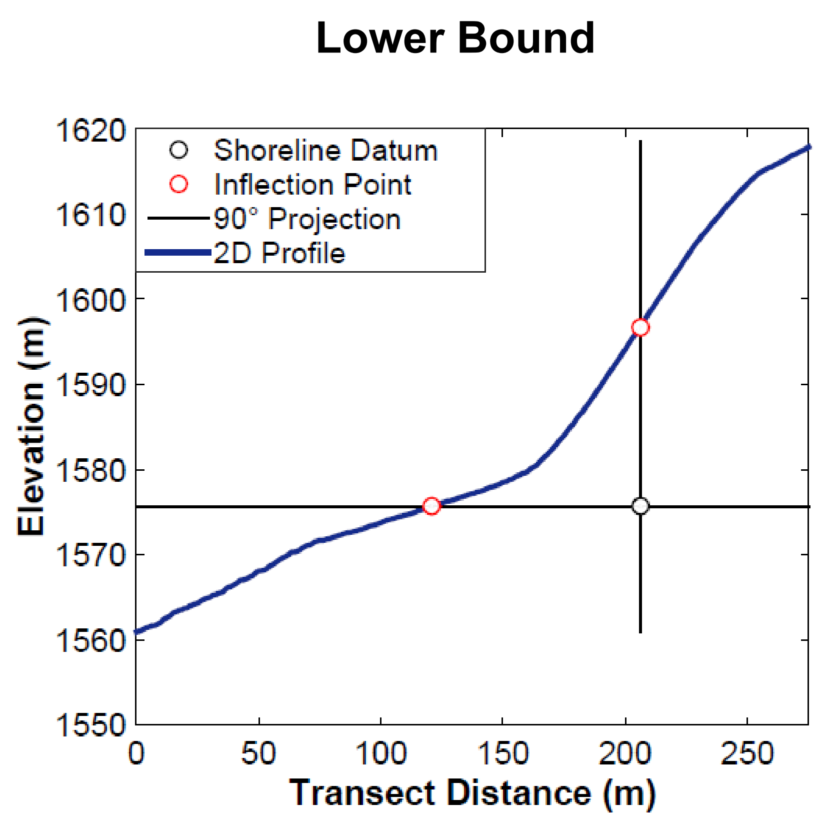


Methods - Concepts

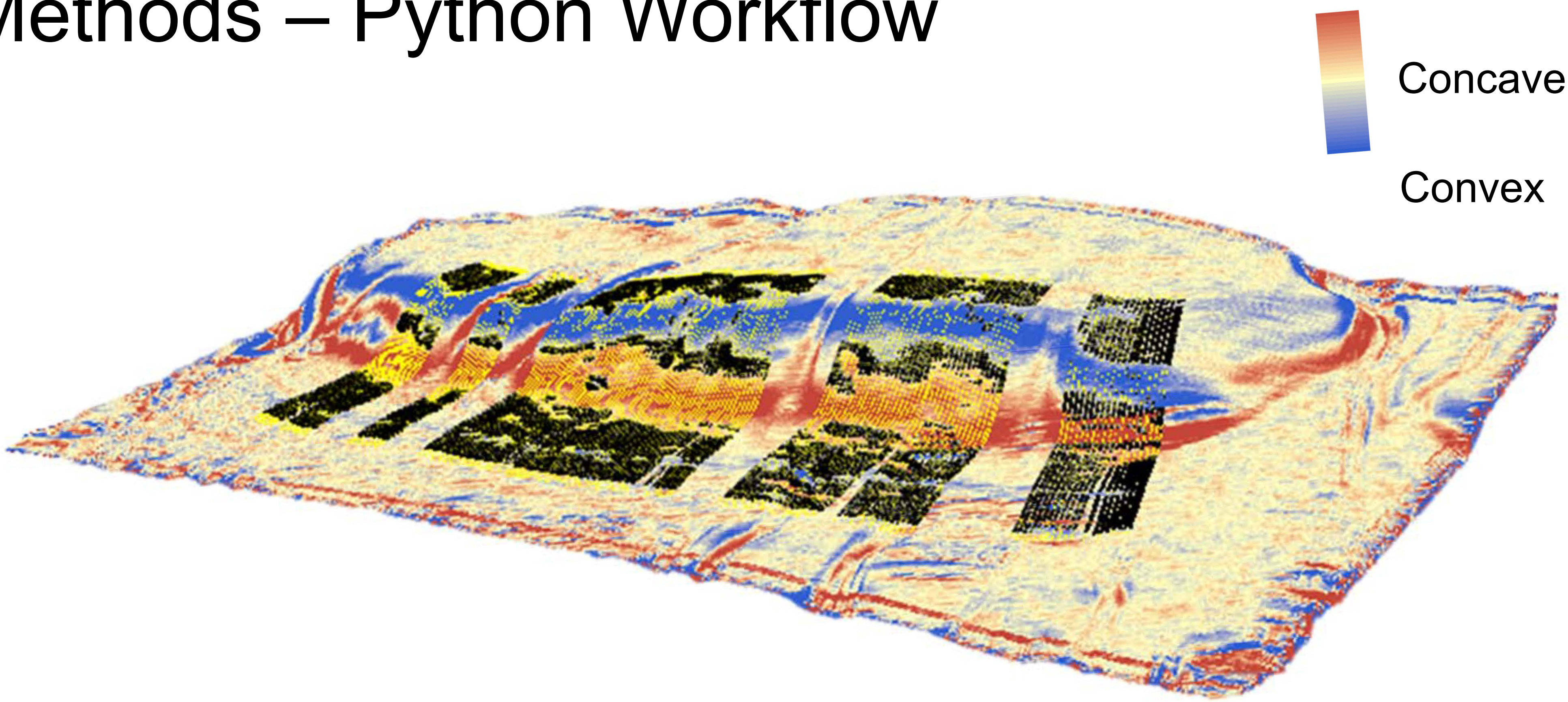


Methods - Concepts

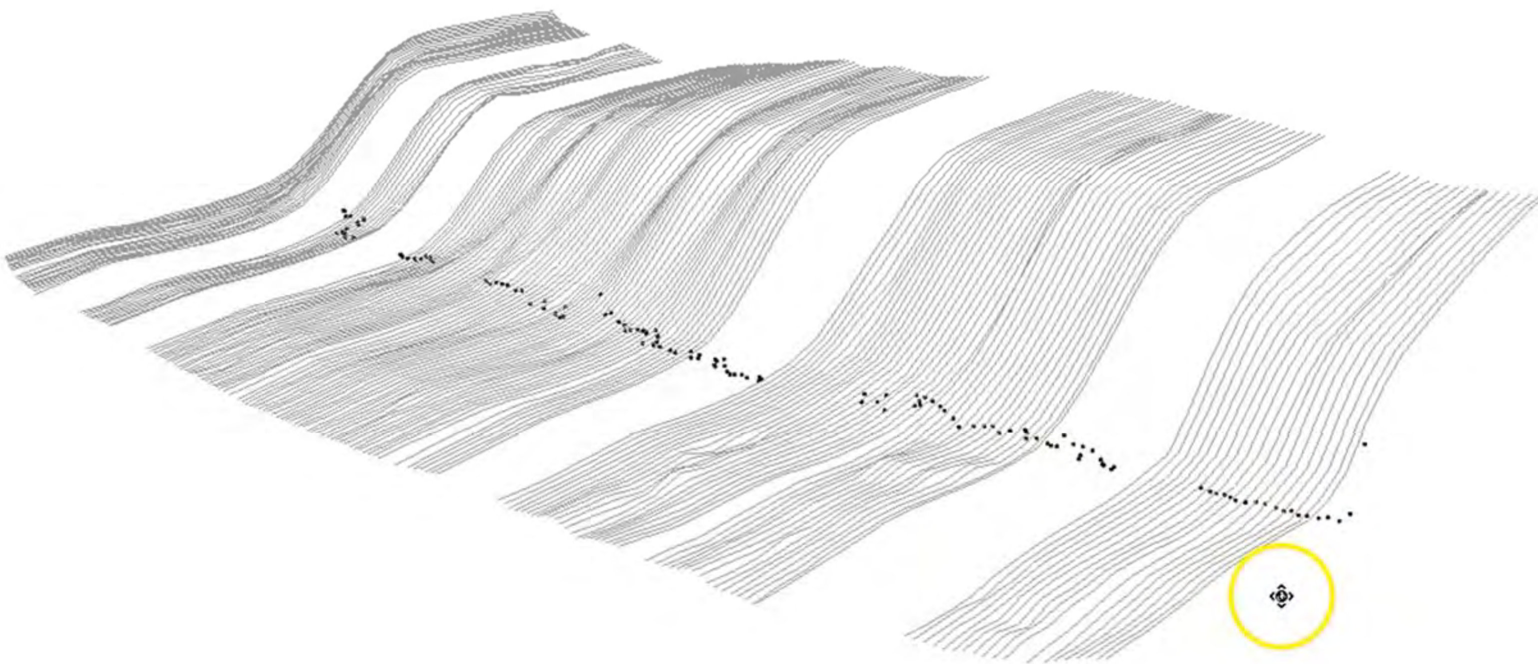




Methods – Python Workflow



Methods – Sample Results

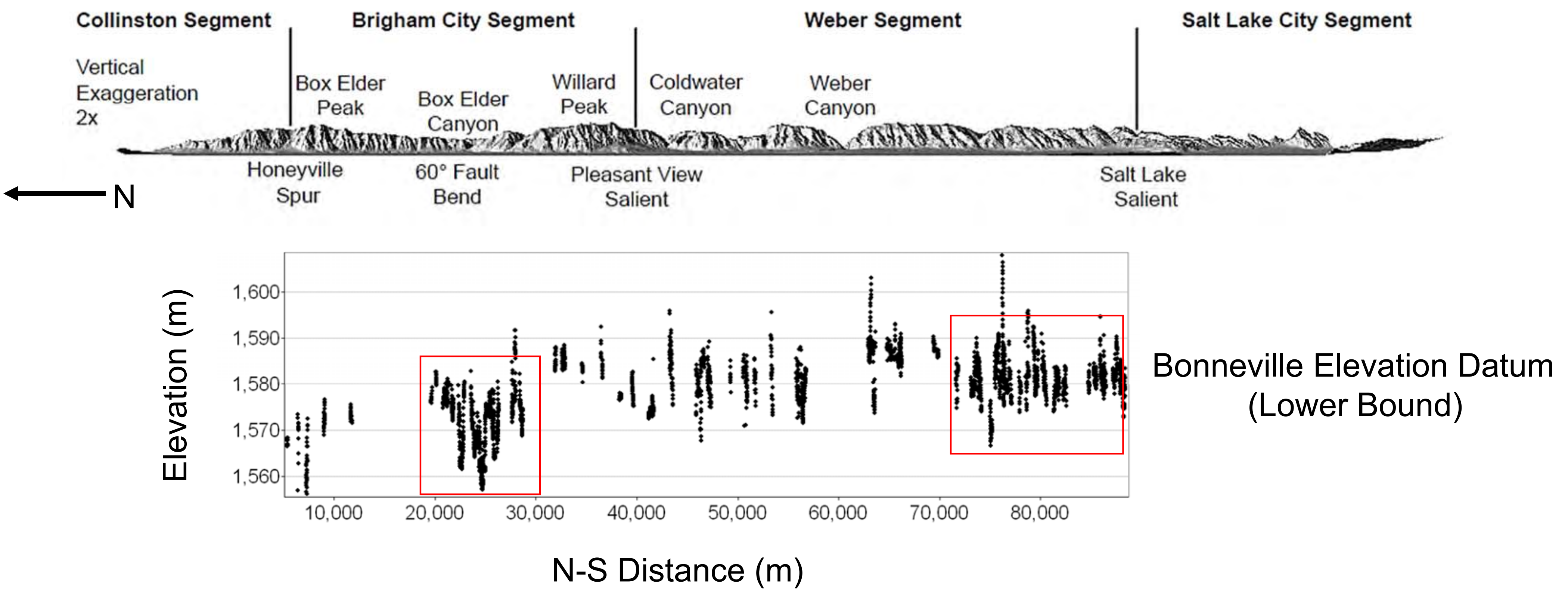


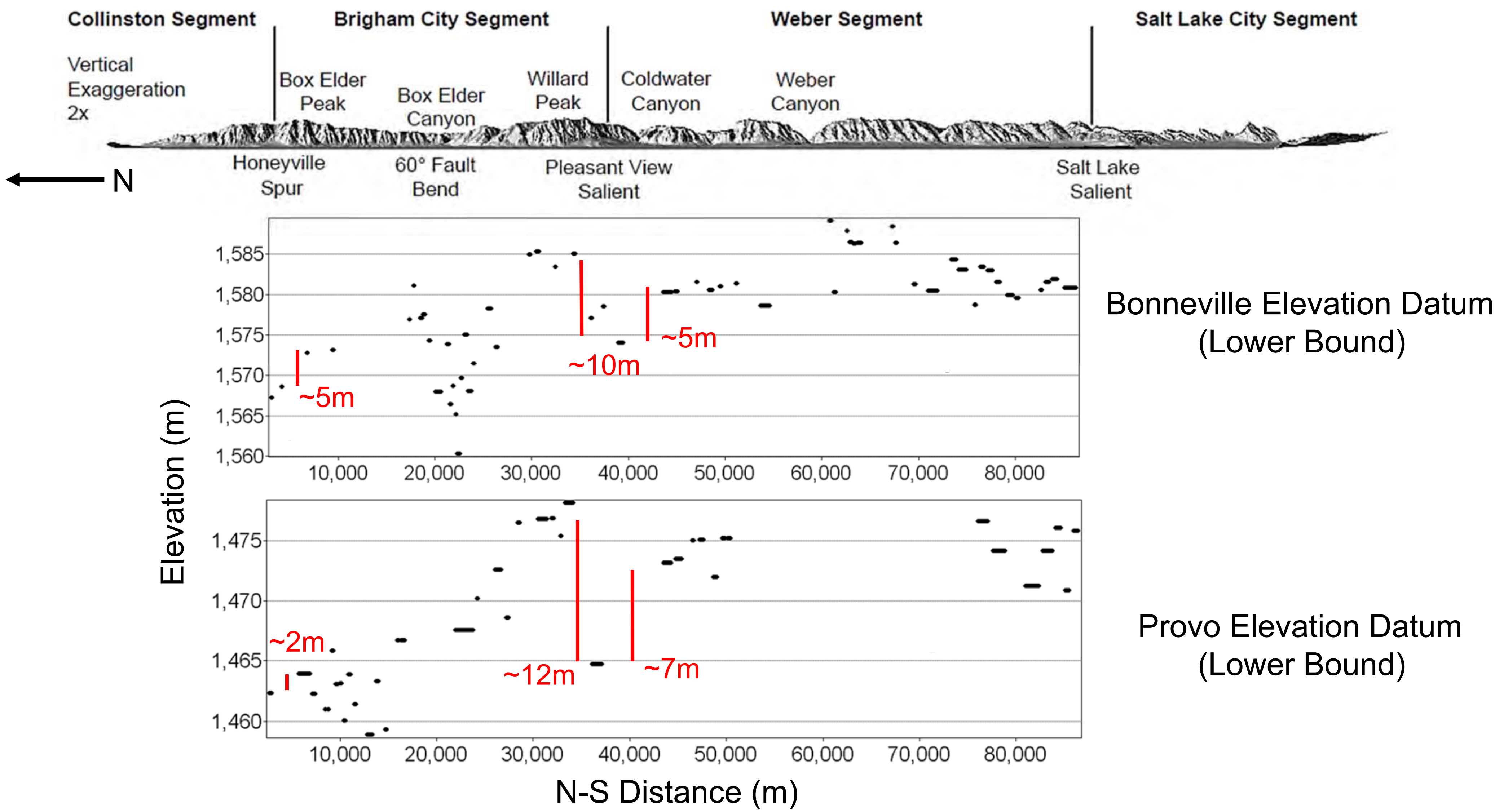
Coverage

Total Number of Elevation Datum Points
(Lower Bound)

	Bonneville	Provo
Brigham City Segment	1511	2153
Weber Segment	2259	1781
Total	**3770**	**3934**

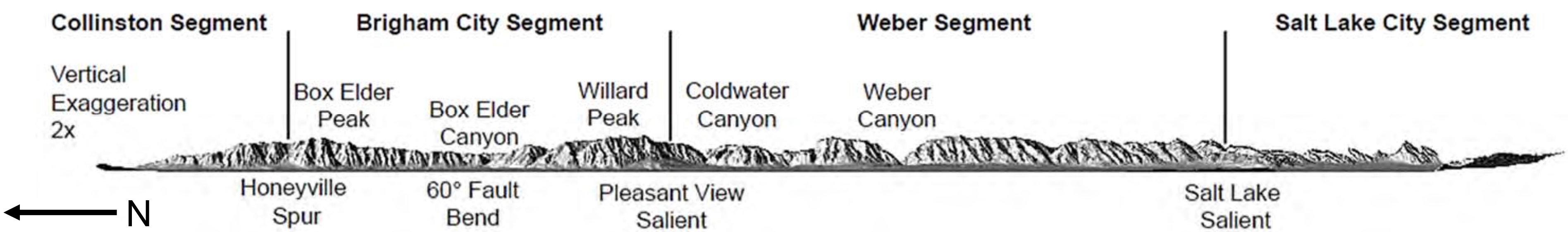
Raw Output – Surface Variability





Collinston Segment
Brigham City Segment
Weber Segment
Salt Lake City Segment
Vertical Exaggeration 2x
Box Elder Peak
Box Elder Canyon
Willard Peak
Coldwater Canyon
Weber Canyon
Honeyville Spur
60° Fault Bend
Pleasant View Salient
Salt Lake Salient
N
Bonneville Elevation Datum (Lower Bound)
Provo Elevation Datum (Lower Bound)
Elevation (m)
N-S Distance (m)
~5m
~10m
~5m
~2m
~12m
~7m
1,585
1,580
1,575
1,570
1,565
1,560
1,475
1,470
1,465
1,460
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000

Vertical Slip Rates



		Vertical Slip Rates (mm/yr)		
		Honeyville Spur	Pleasant View Salient	Coldwater Canyon
This Study (Minimum Rate)	Bonneville (18,000 yr)	0.28	0.56	0.28
	Provo (15-18,000 yr)	0.11 - 0.13	0.67 - 0.80	0.39 - 0.47
WGUEP Report (Open mean SR per segment)	< 6,000 yr	Brigham City Segment		Weber Segment
		0.9 - **1.2** - 1.3		01.2 - **1.7** - 2.3

Some Tentative Conclusions

- **Methods are new and improved**
  - Automated in python
  - Average of the landscape
  - Denser outputs
- **General elevation trends:**
  - Footwall elevation maximum at the published segment boundary
  - Footwall elevation minimum near the 60 degree bend in the fault
  - Displacement across the Weber River Canyon
- **Vertical slip rates are lower than Holocene vertical slip rates.**
  - Indicative of earthquake clustering in the Holocene
- **Find out more at my thesis defense!**

Constraints on the Timing, Surface Displacement, and Lateral Extent of the Oquirrh Fault's Most Recent Surface-Rupturing Event from High Resolution Topography

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

Department of Earth Science, Utah Valley University

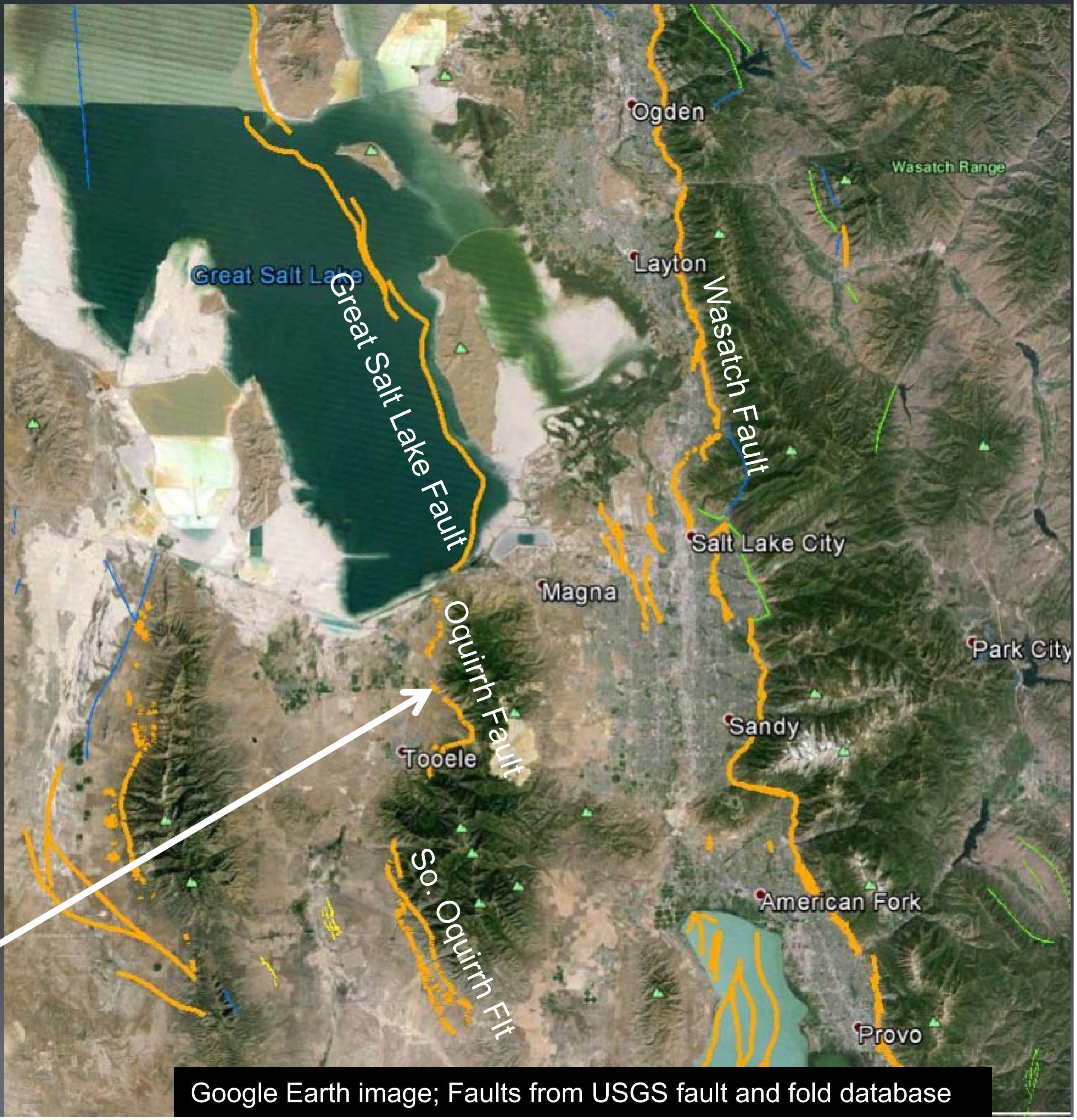
michael.bunds@uvu.edu

UTAH VALLEY UVU UNIVERSITY *Department of* EARTH SCIENCE

Oquirrh Fault Regional Setting

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

Study area



Oquirrh Fault Regional Setting

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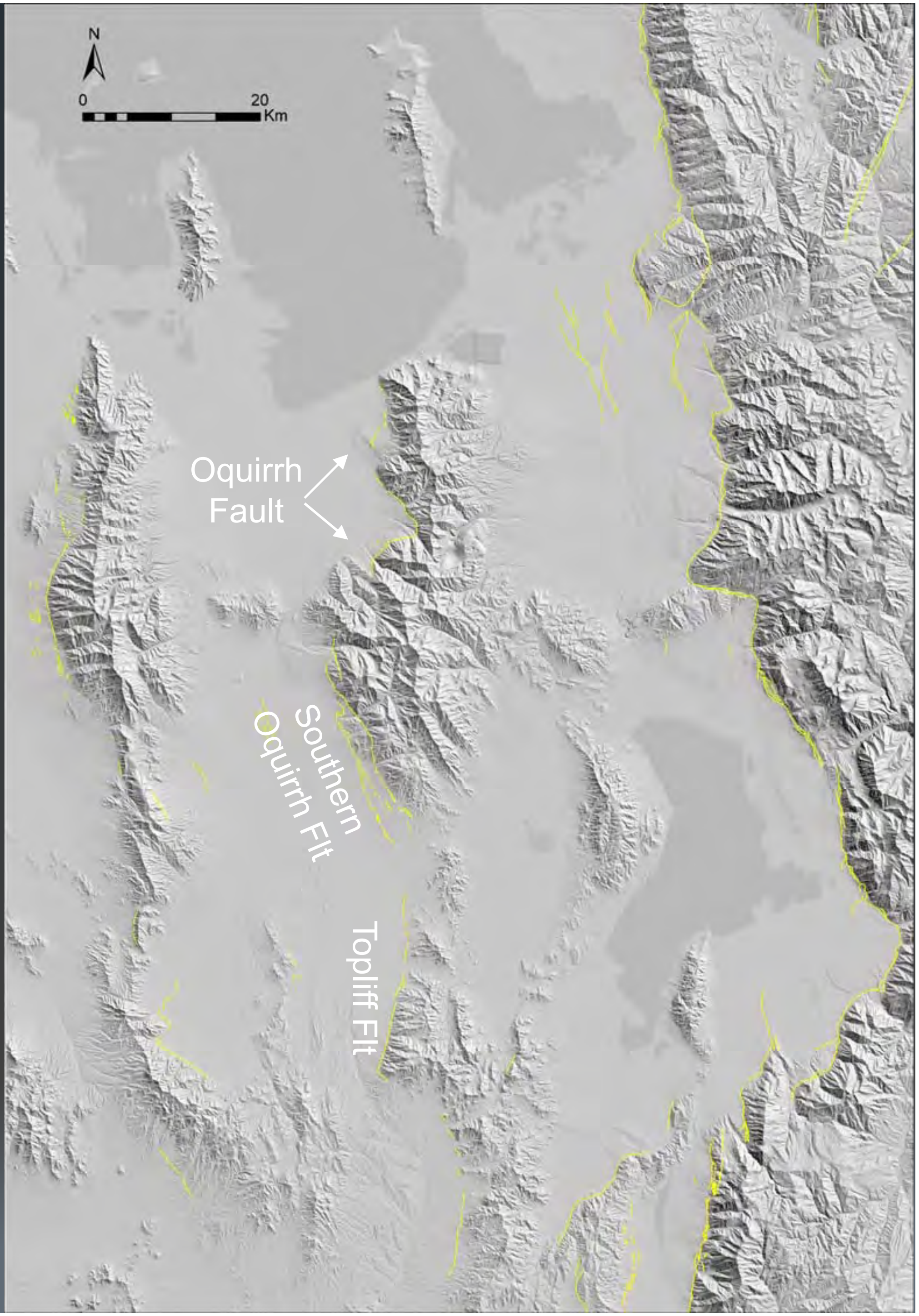

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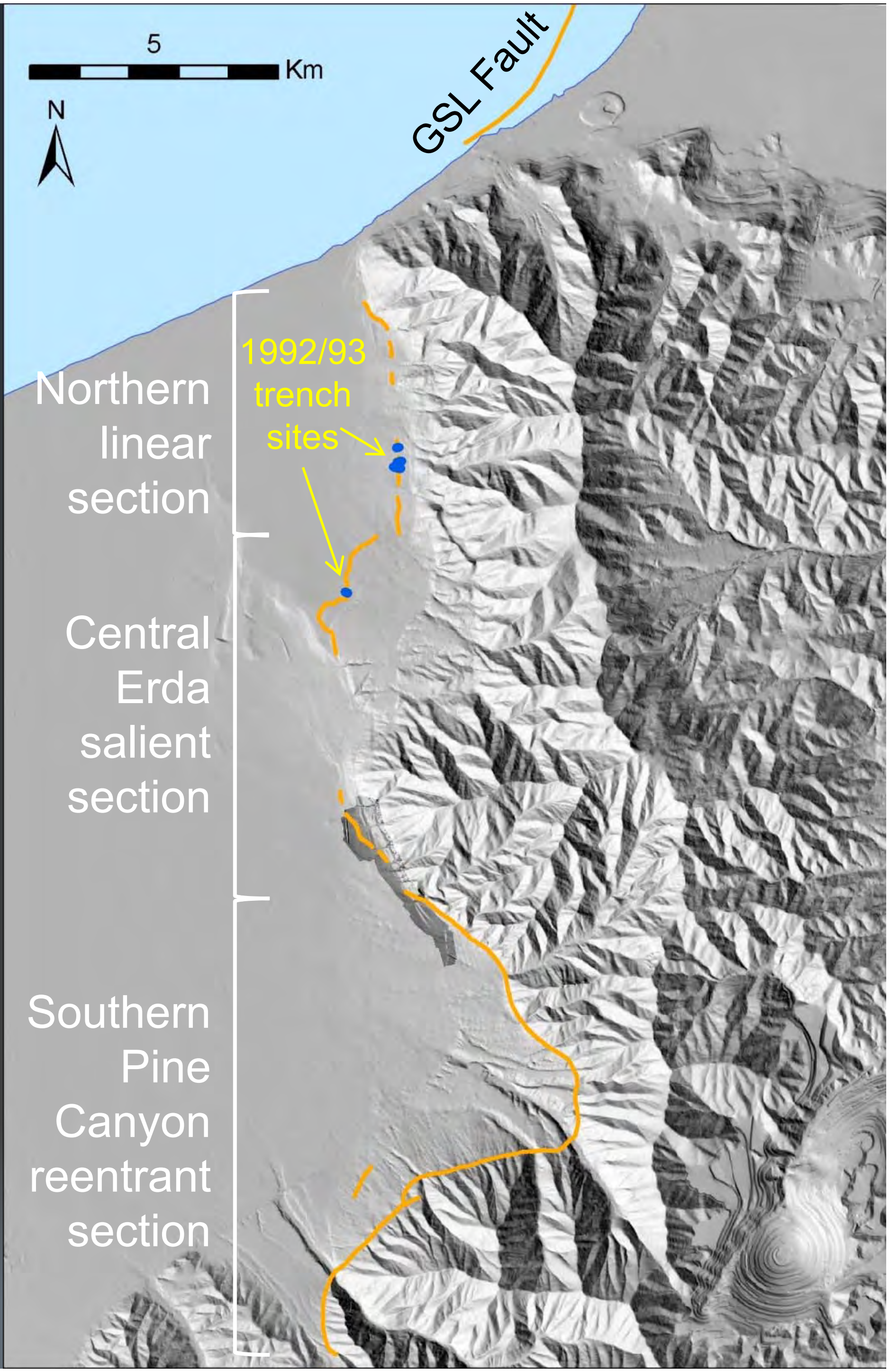
EARTH SCIENCE

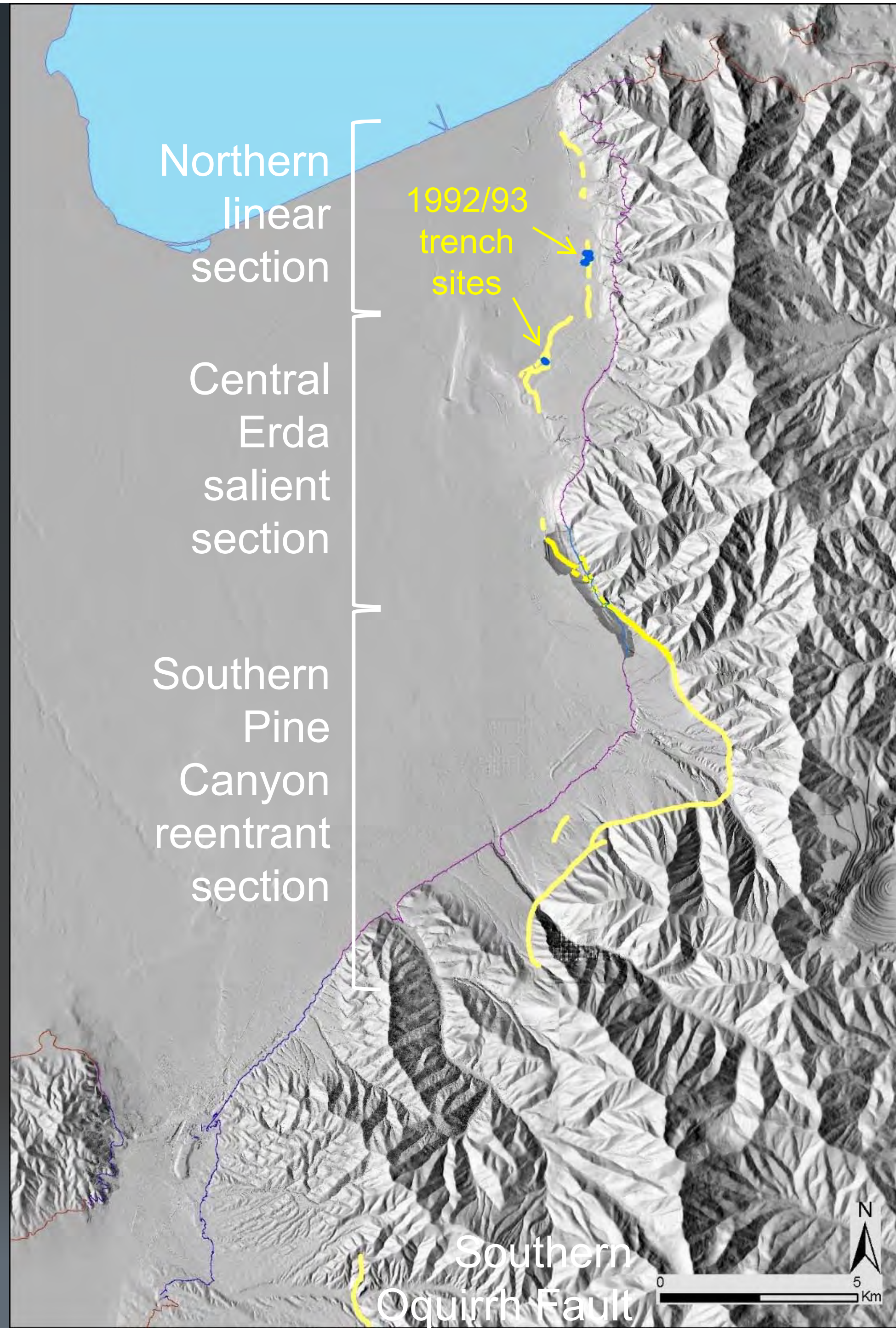
Oquirrh Fault

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



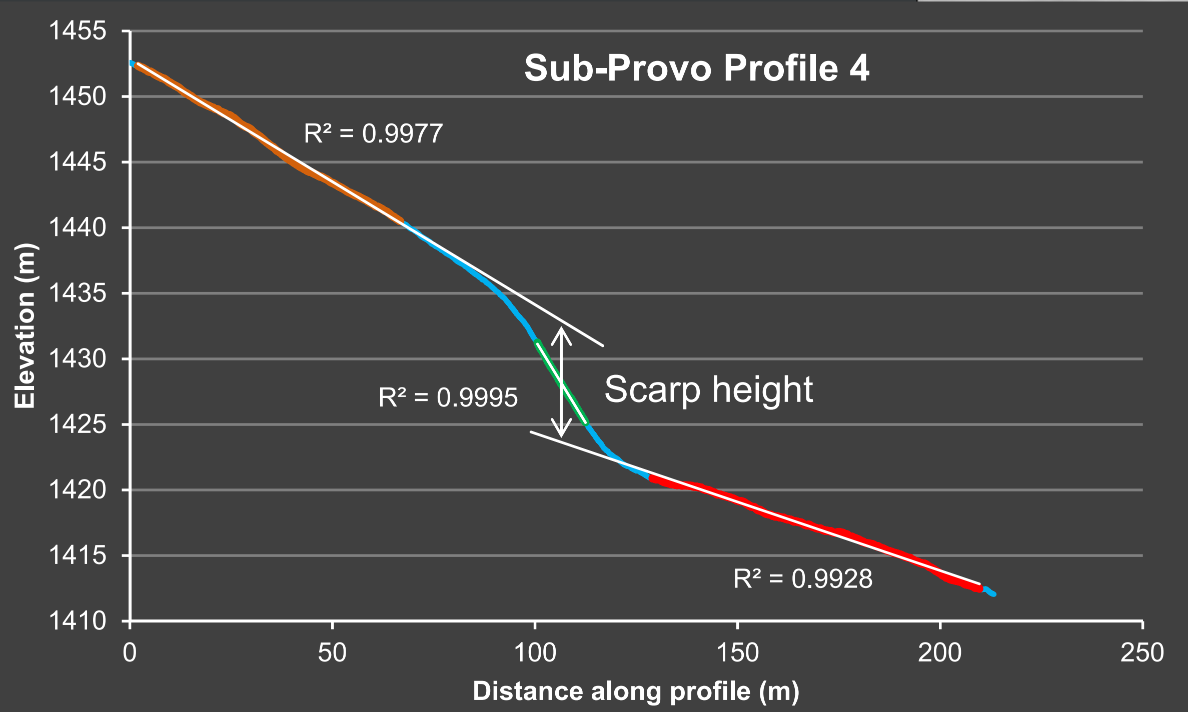
Project Goals

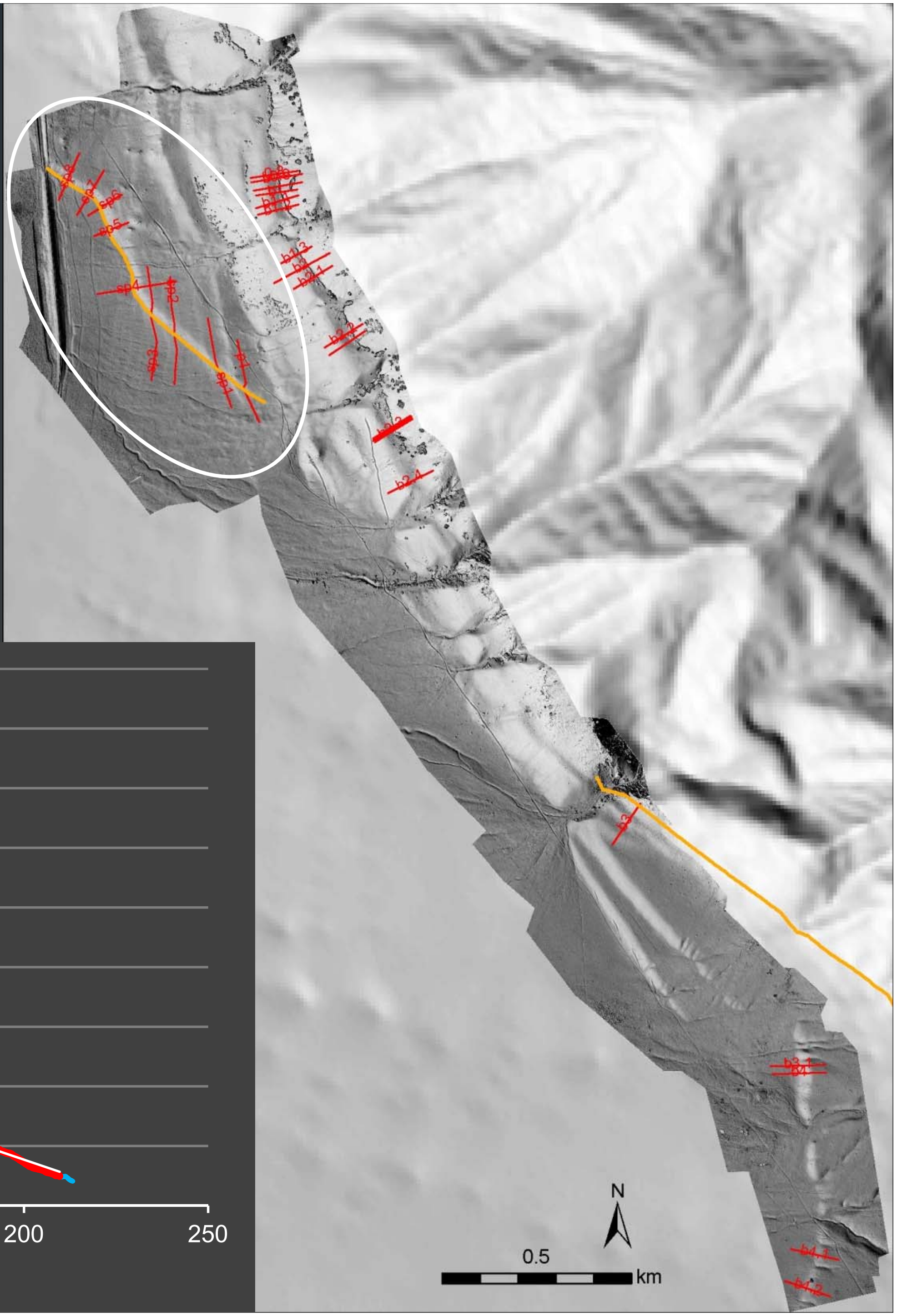
- Use scarp heights and Lk. Bonneville shoreline elevations along Oquirrh Flt to
  - Build on 1992/93 trenching results
  - Constrain extent of MRE surface rupture
- Develop SfM methods; student class projects



Scarp Height Measurement

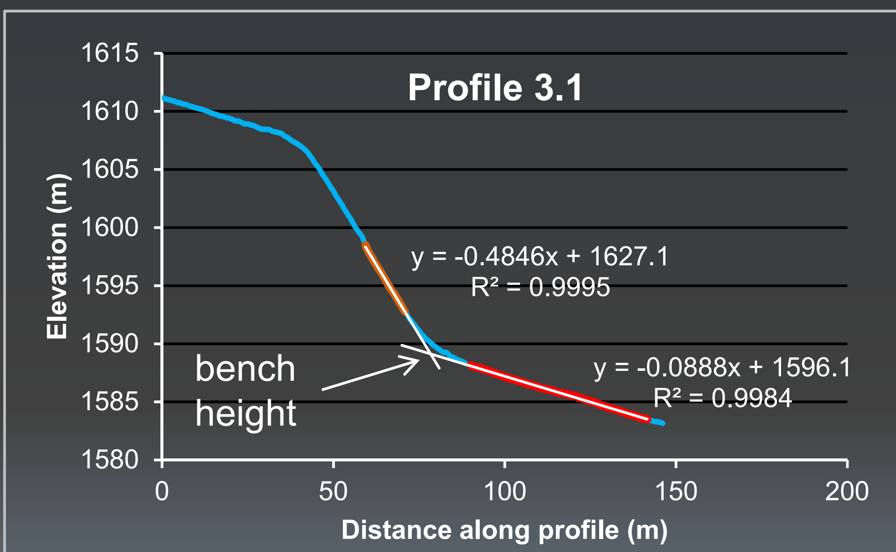
- On profiles, linear sections on footwall, hanging, and scarp face wall fit with lines
- Elevation difference between lines at midpoint of scarp is scarp height
    - Scarp height = net vertical displacement if fault dip is 90°

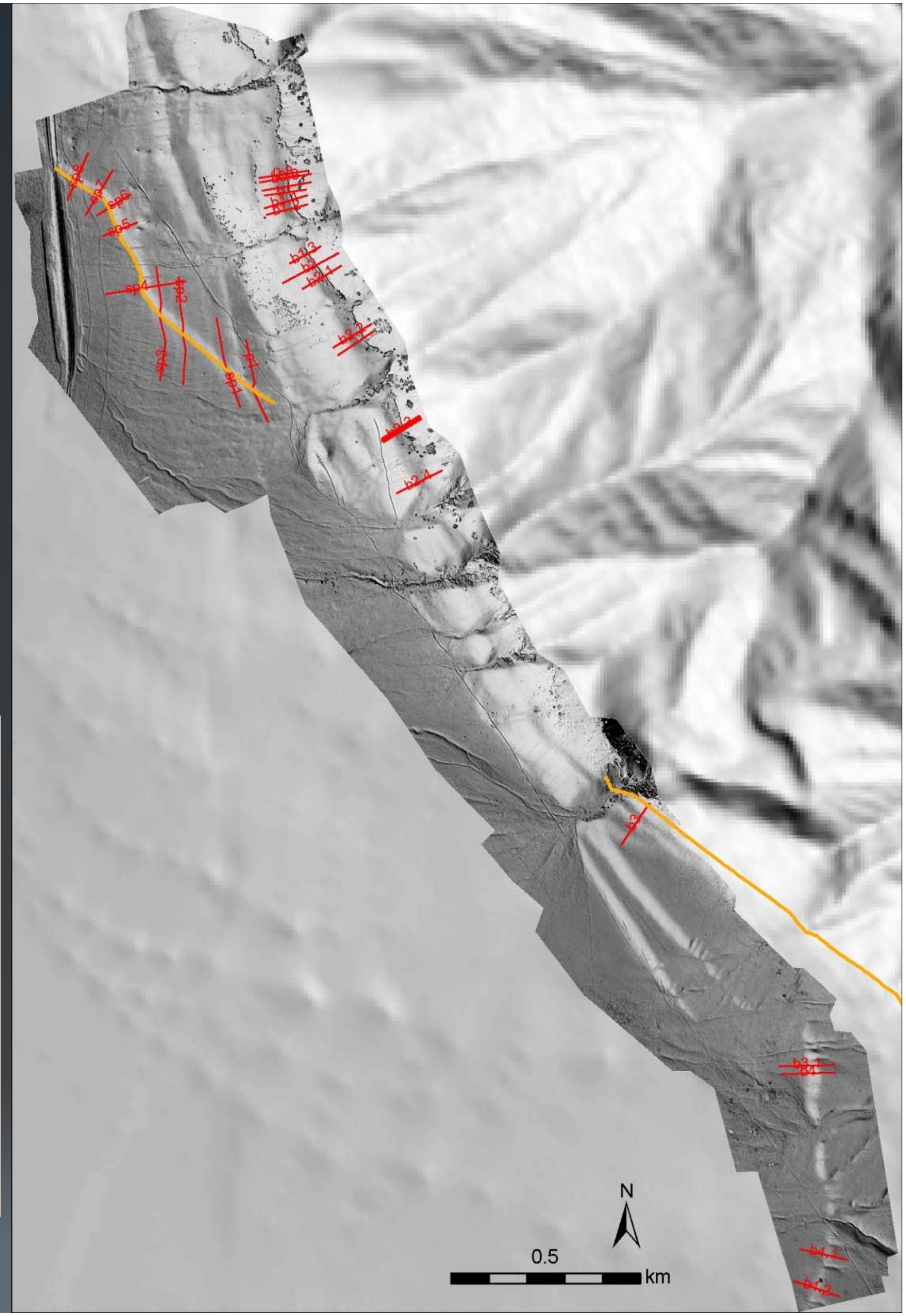




Shoreline Elevation Methods

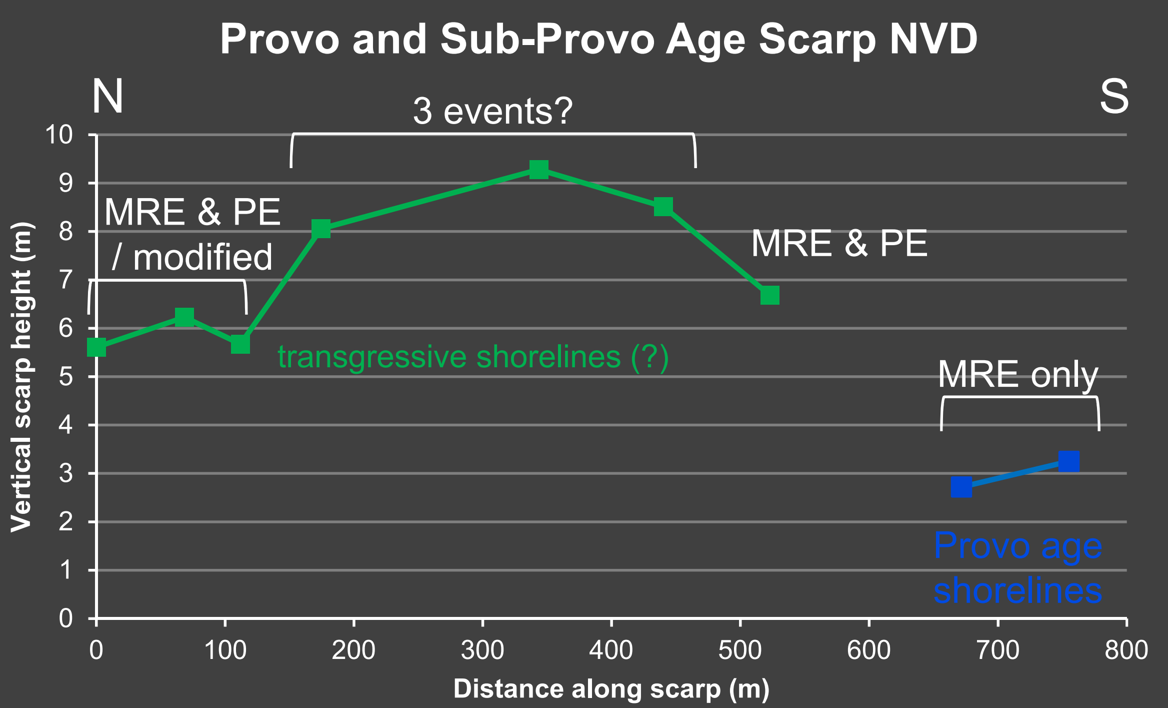
- Profiles carefully chosen to avoid culturally or geomorphologically modified areas
- Vegetation avoided or removed from profile
- On profiles, linear sections of wave-cut face and bench fit with lines
- Intersection of lines considered to be bench height

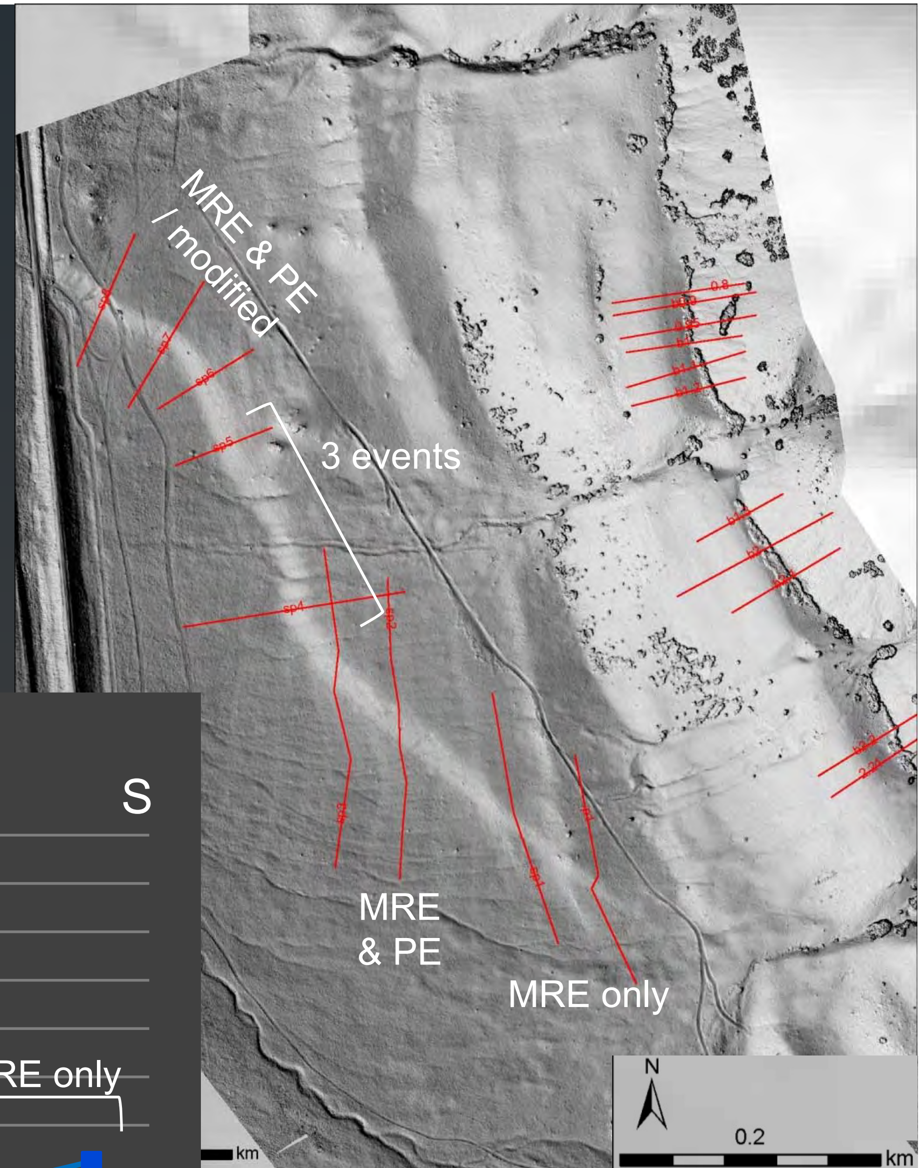




Scarp Heights

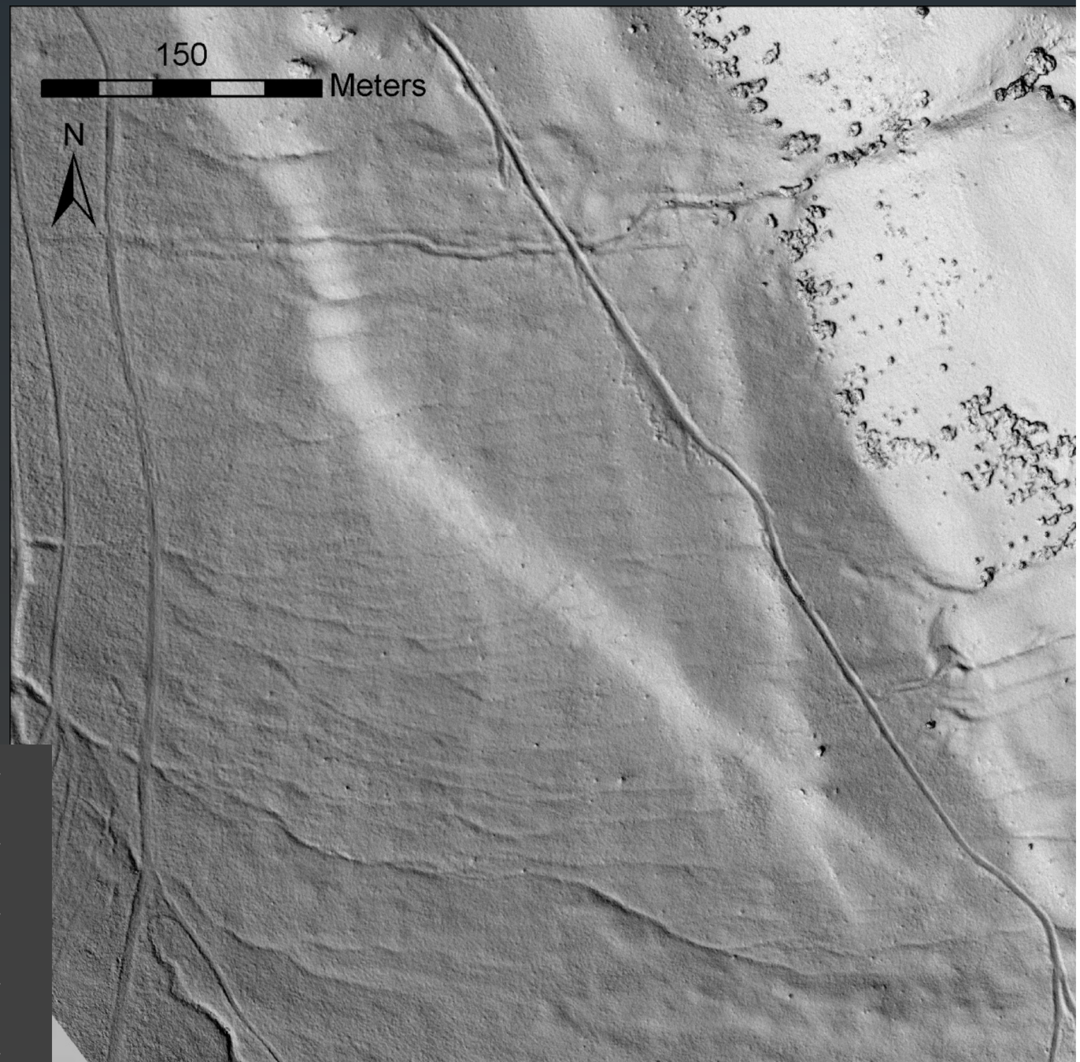
- Capturing MRE, PE and Antepenultimate event?

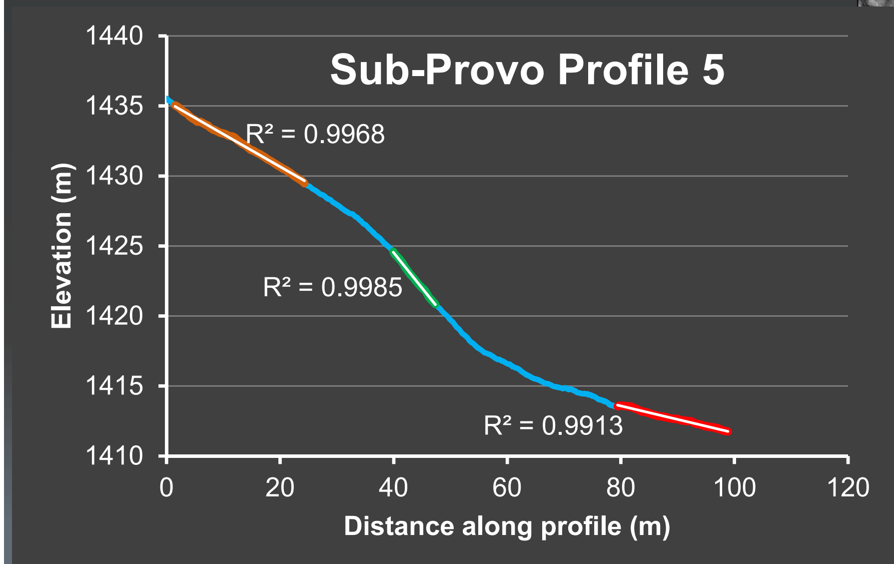




Scarp Heights

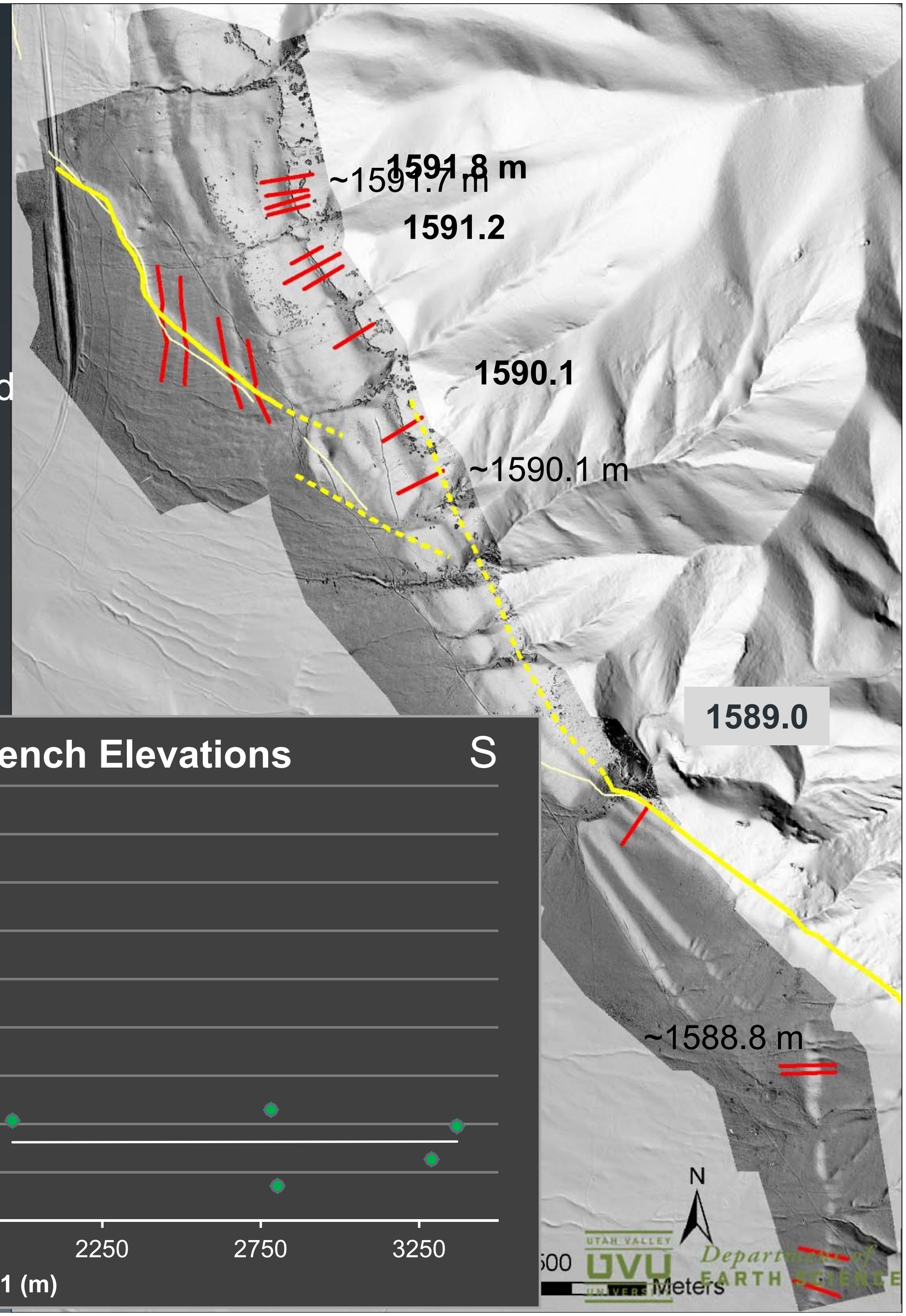
- Scarps across sub-Provo shorelines probably compound
    - Deflected shorelines
    - Scarp shape
- Inferred history:
    - Antepenultimate event
    - Early transgression
    - Penultimate event
    - Further transgression
    - Recession (post Provo, 14.4 Ka)
    - Most recent event

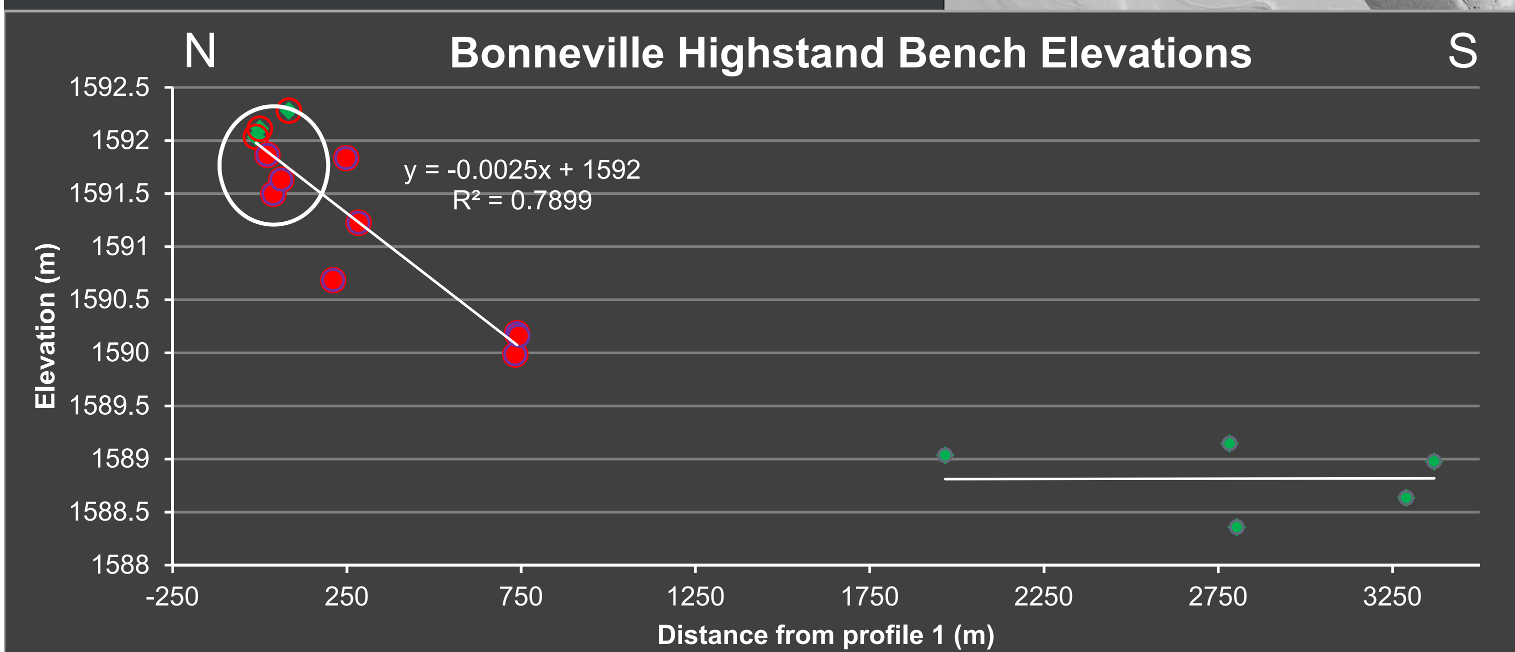




Highstand Bench

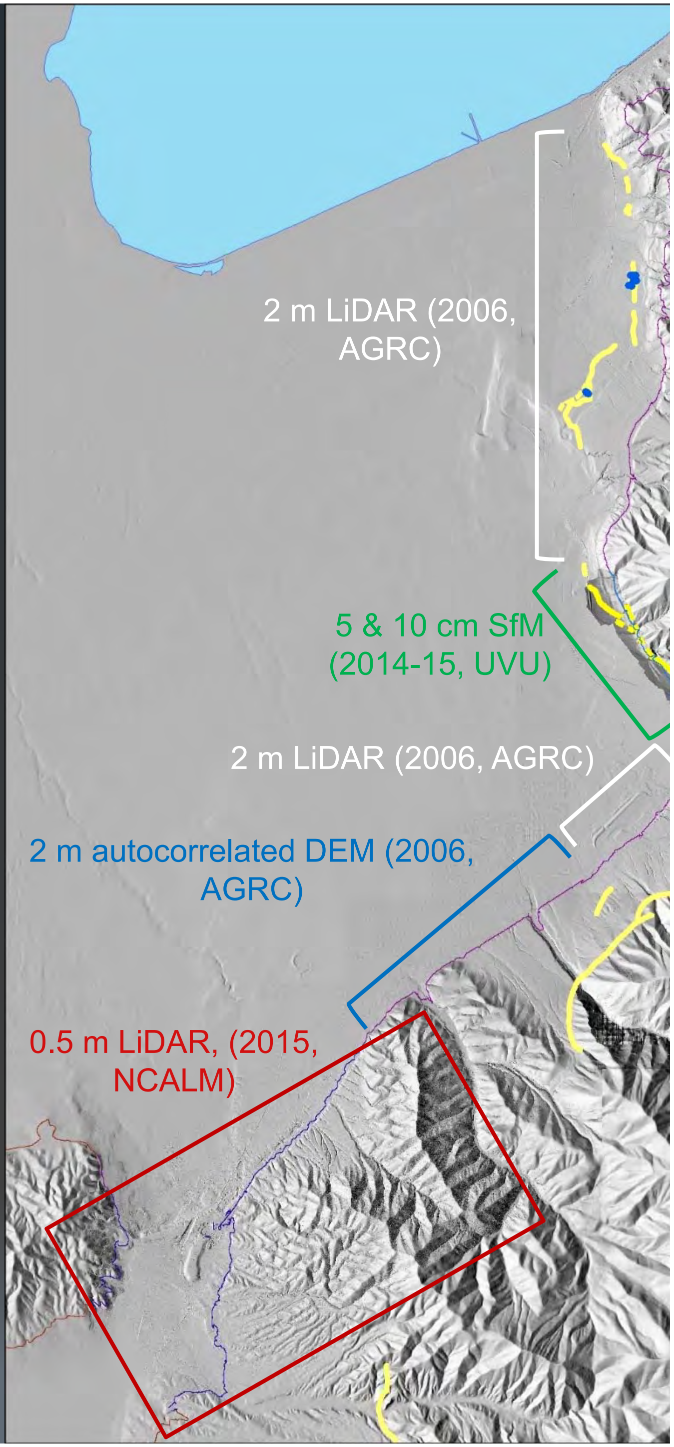
- Hanging wall average = 1588.83 m
- Footwall
  - Far north average = 1591.83 m
    - 1591.66 if three points are excluded (possible bench modification by deposition)
  - Gradient may reflect ramp, transfer of displacement to western scarp
- Post-highstand displacement = 2.83 – 3.0 m





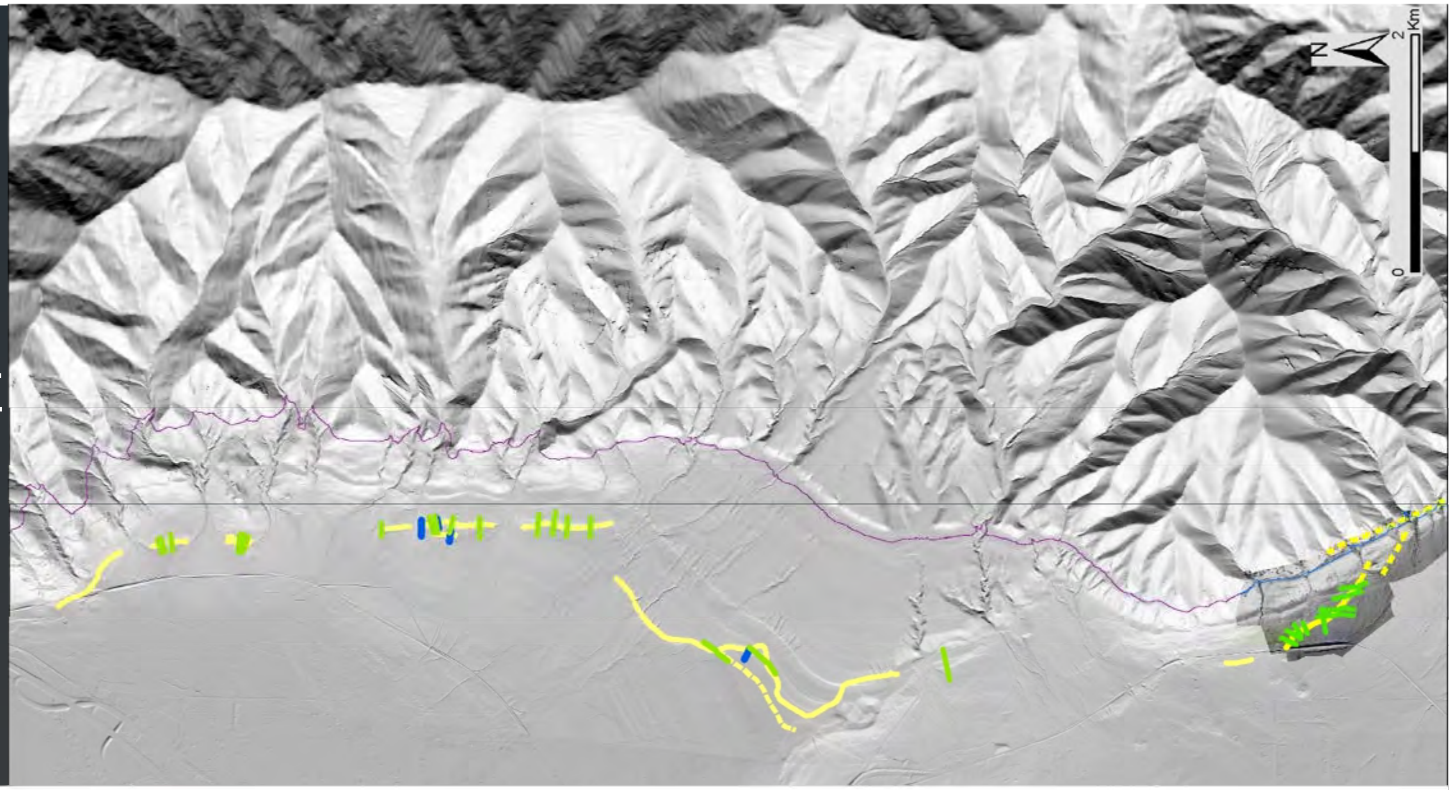
Searching for the Lateral Extent of Post-Provo Surface Rupture: Topographic Data Sources

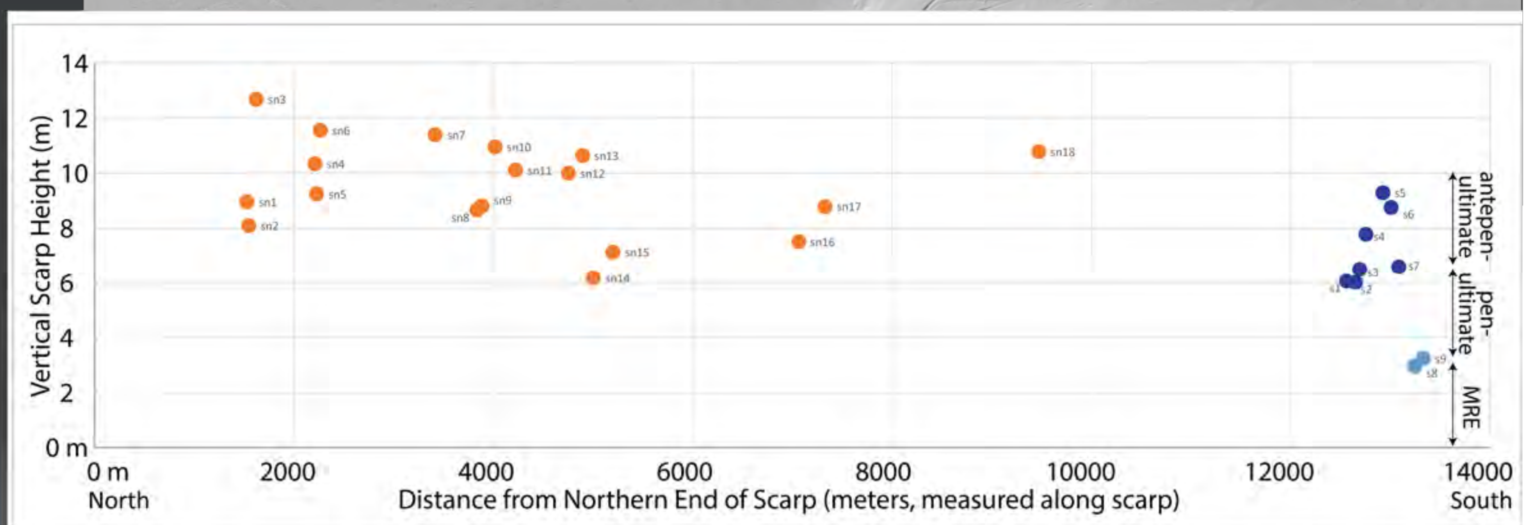
- 5 and 10 cm SfM – derived DSMs (2014-2015, UVU)
- 0.5 m LiDAR DEM (2015; NCALM / Larry Kellum U. of Utah)
- 2 m LiDAR – derived DTM (2006, AGRC)
- 2 m DEM, autocorrelated from 12.5 cm imagery (2006, AGRC)



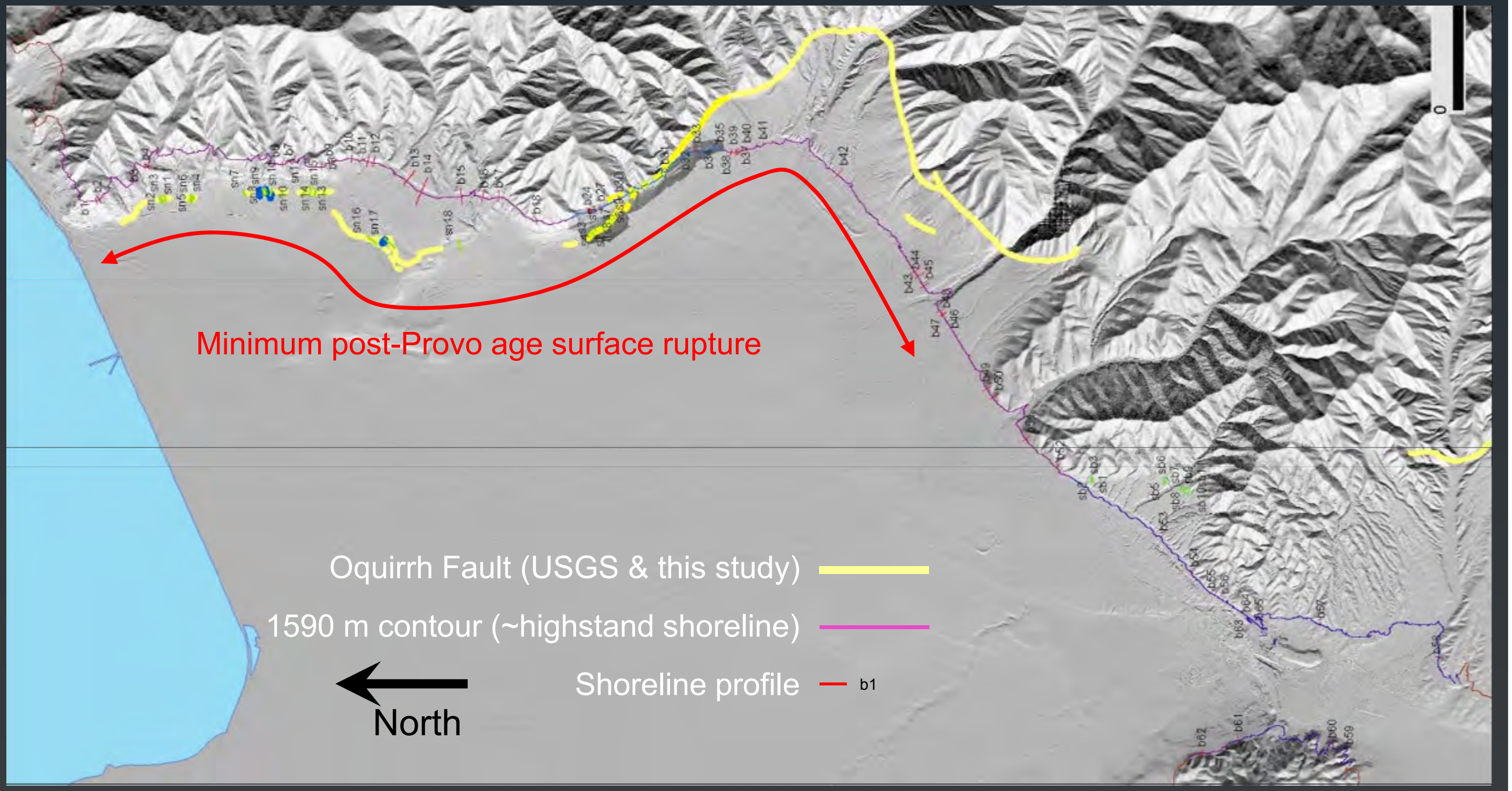
Scarp Heights

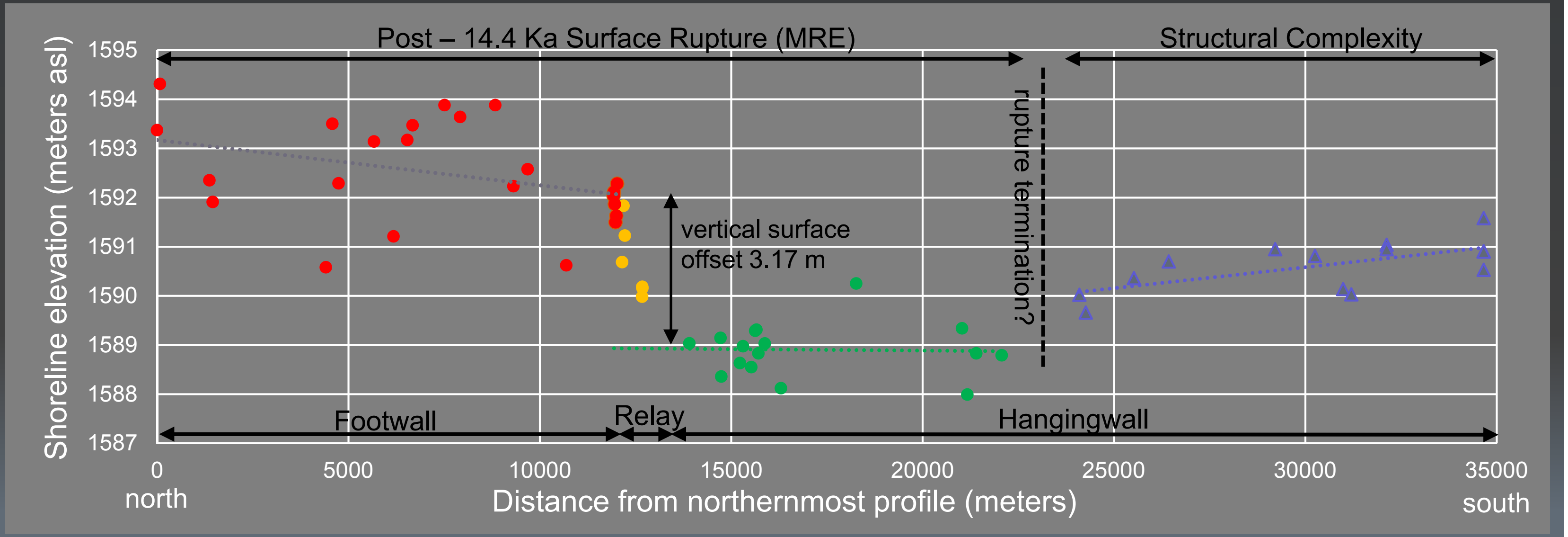
- Record MRE, PE and Antepenultimate events?



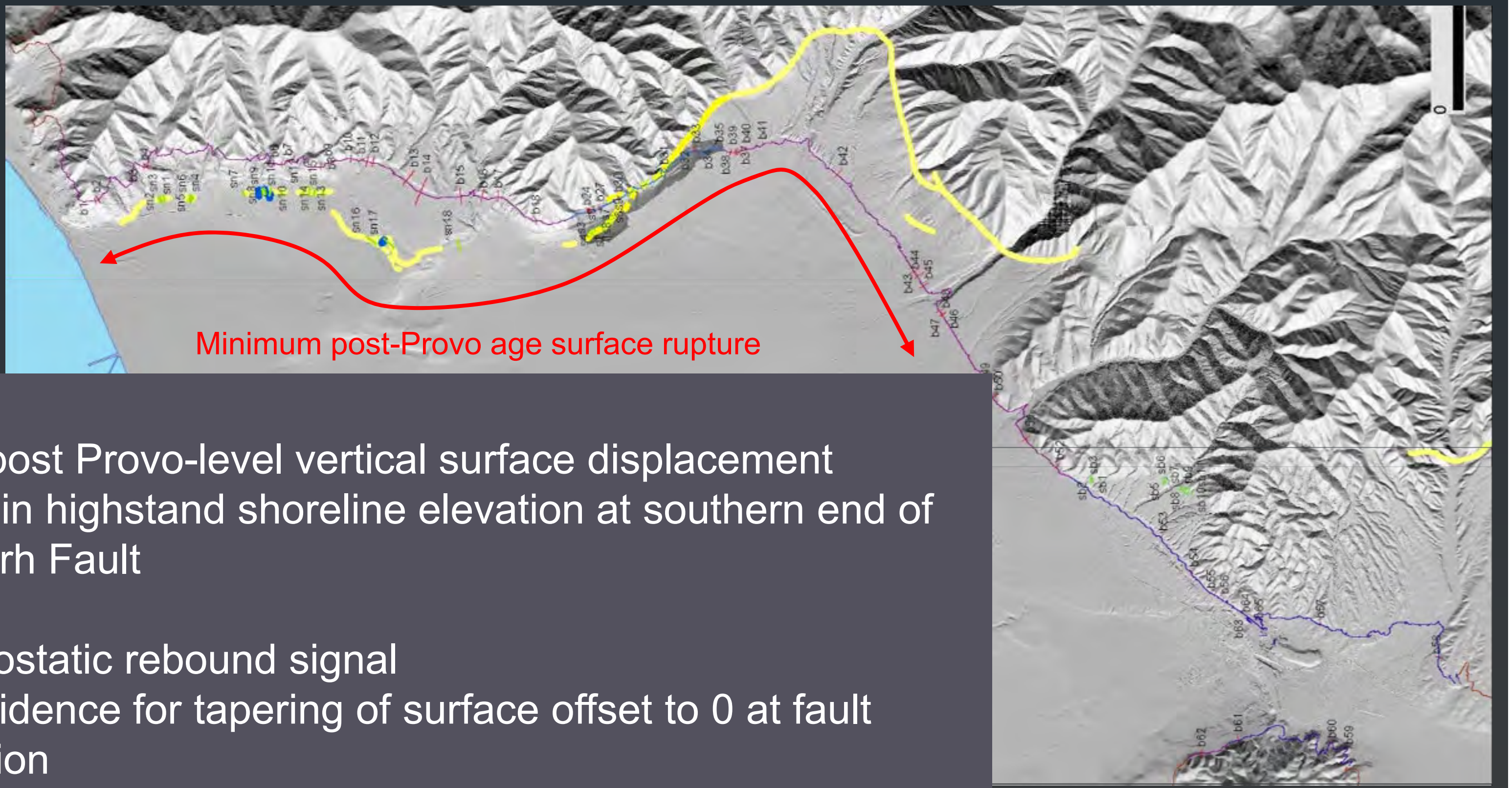


Highstand Shoreline Elevations

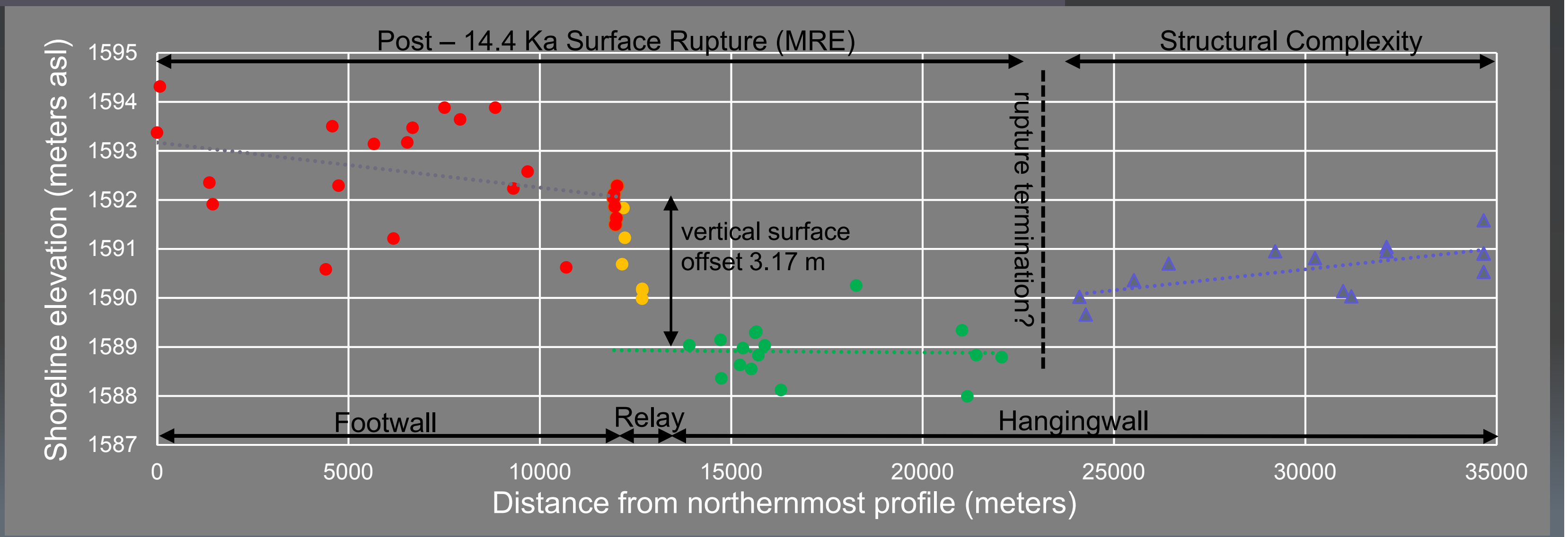




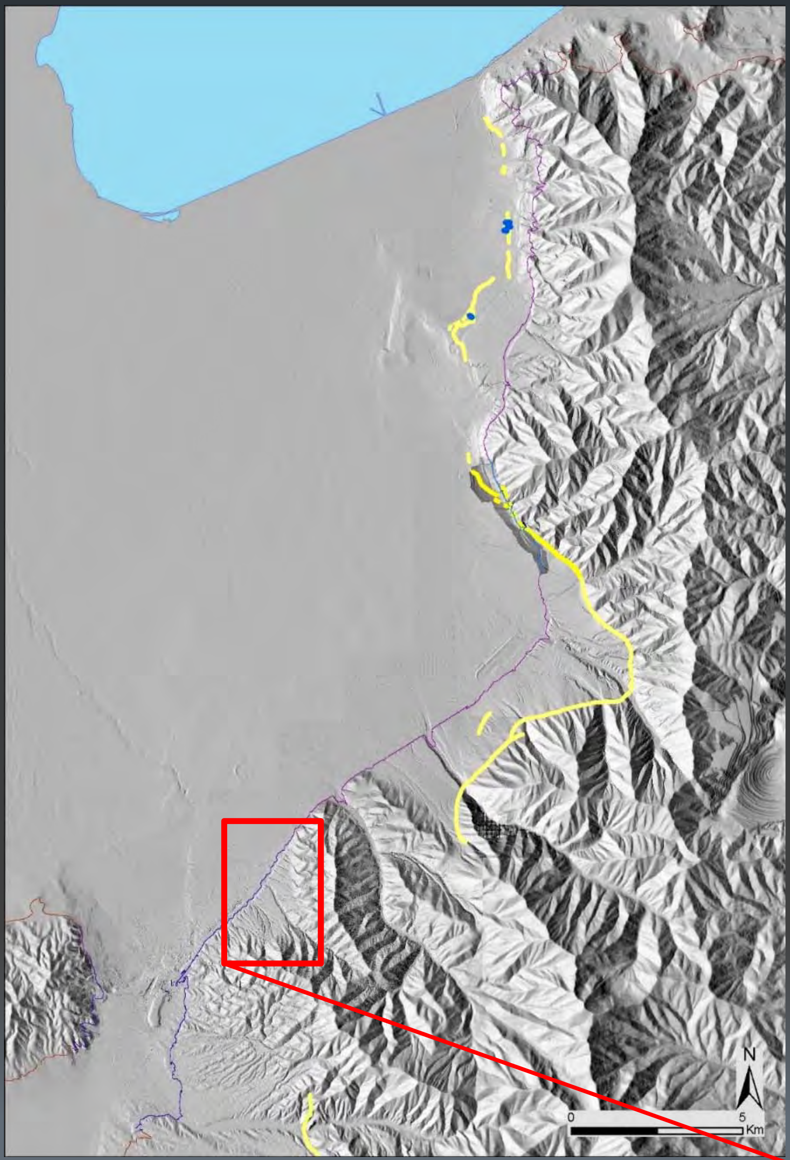
Highstand Shoreline Elevations

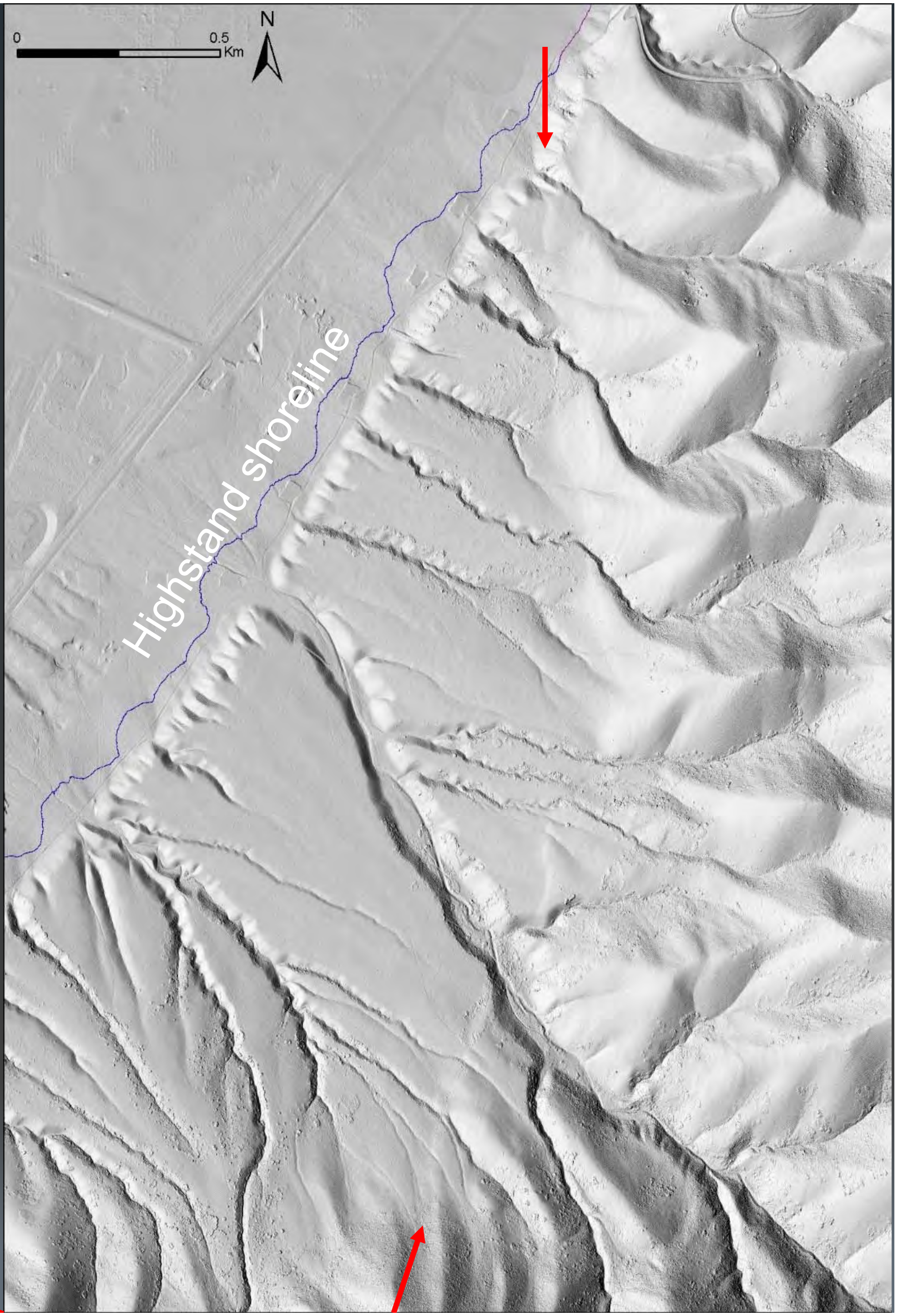


- Evident
  - ~3.2 m post Provo-level vertical surface displacement
  - Change in highstand shoreline elevation at southern end of N. Oquirrh Fault
- Not evident
  - Large isostatic rebound signal
  - Clear evidence for tapering of surface offset to 0 at fault termination

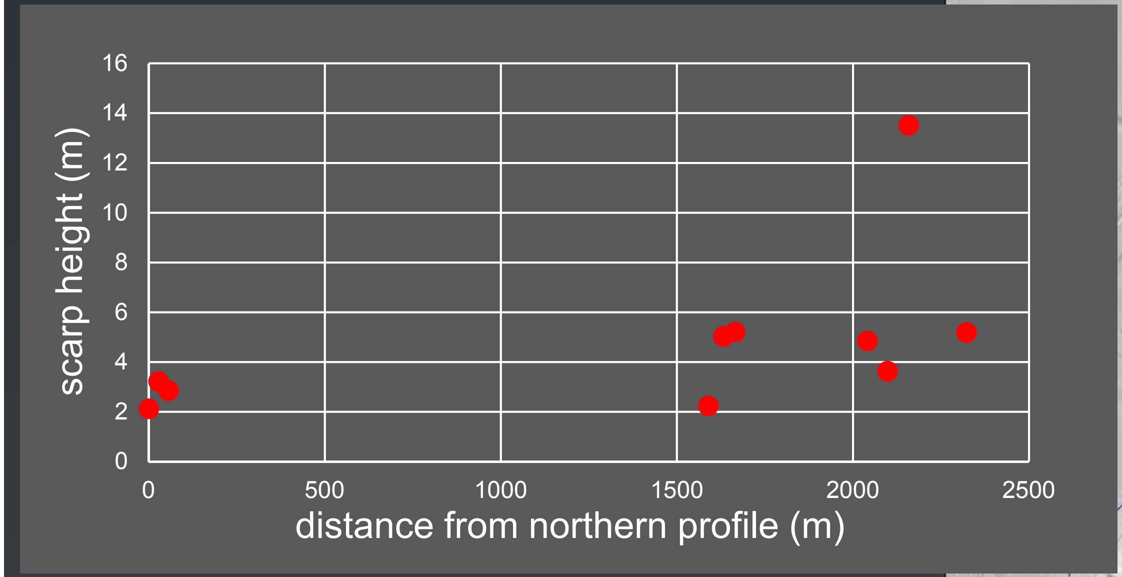


Possible Scarp North of Stockton Bar

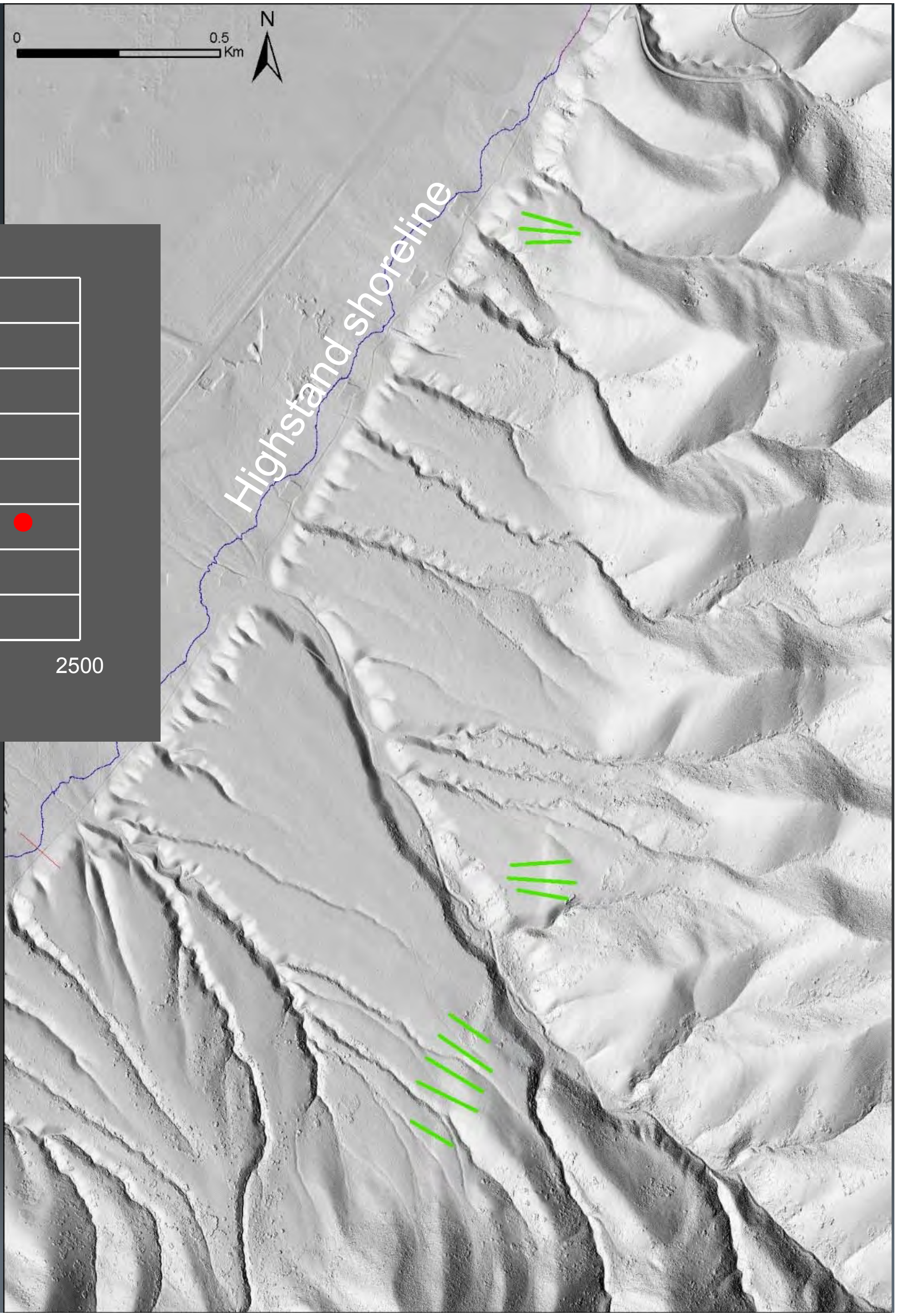




Possible Scarp North of Stockton Bar

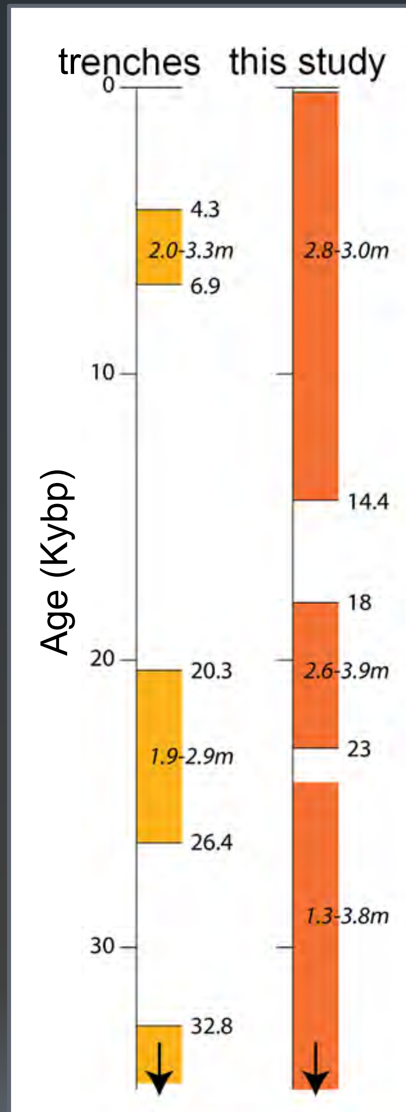


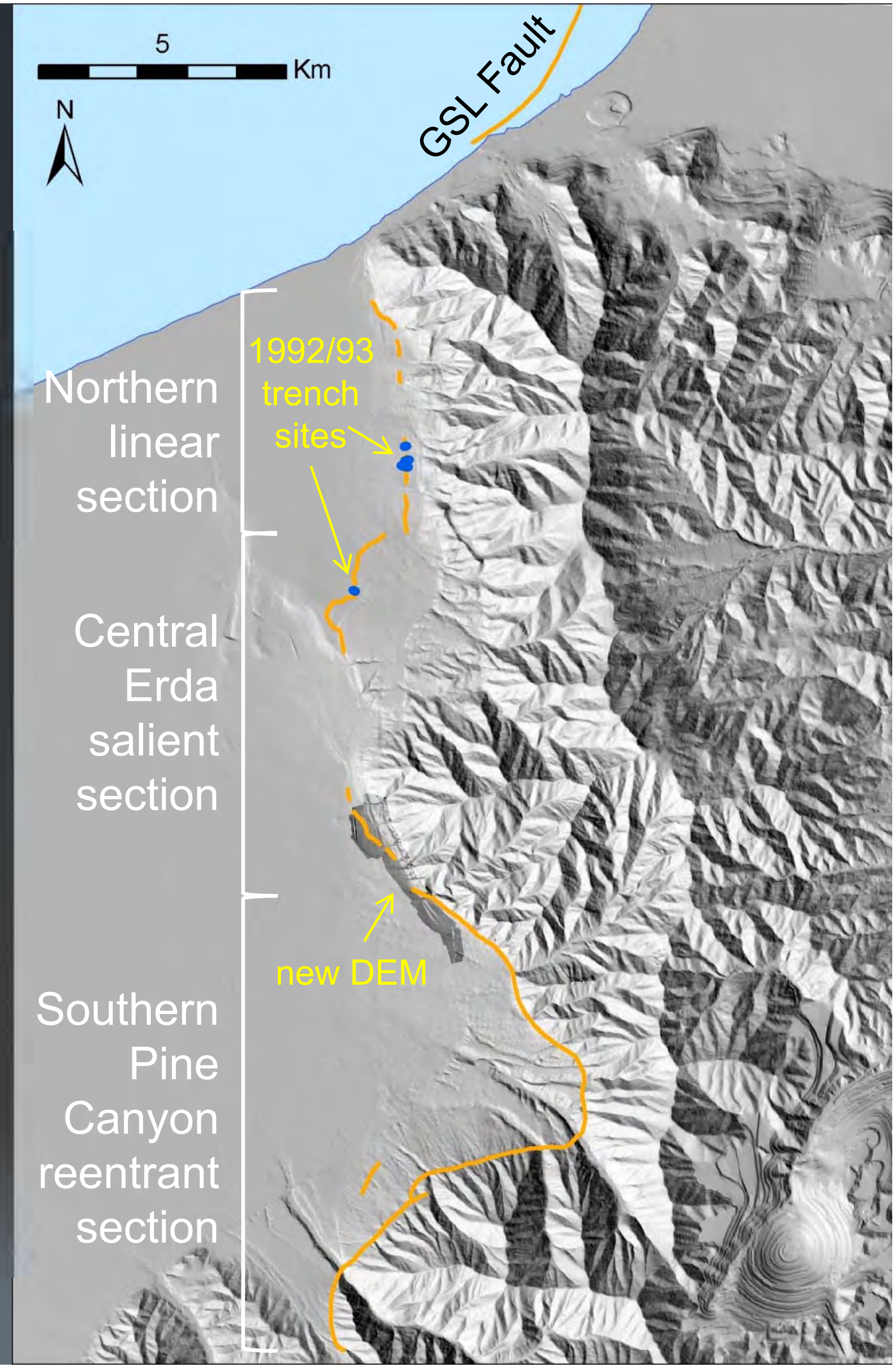
- Not field checked
- 2.1 to 5.2 (one 13.5?) m scarp heights
- One or two events?



Correlation with Trenching

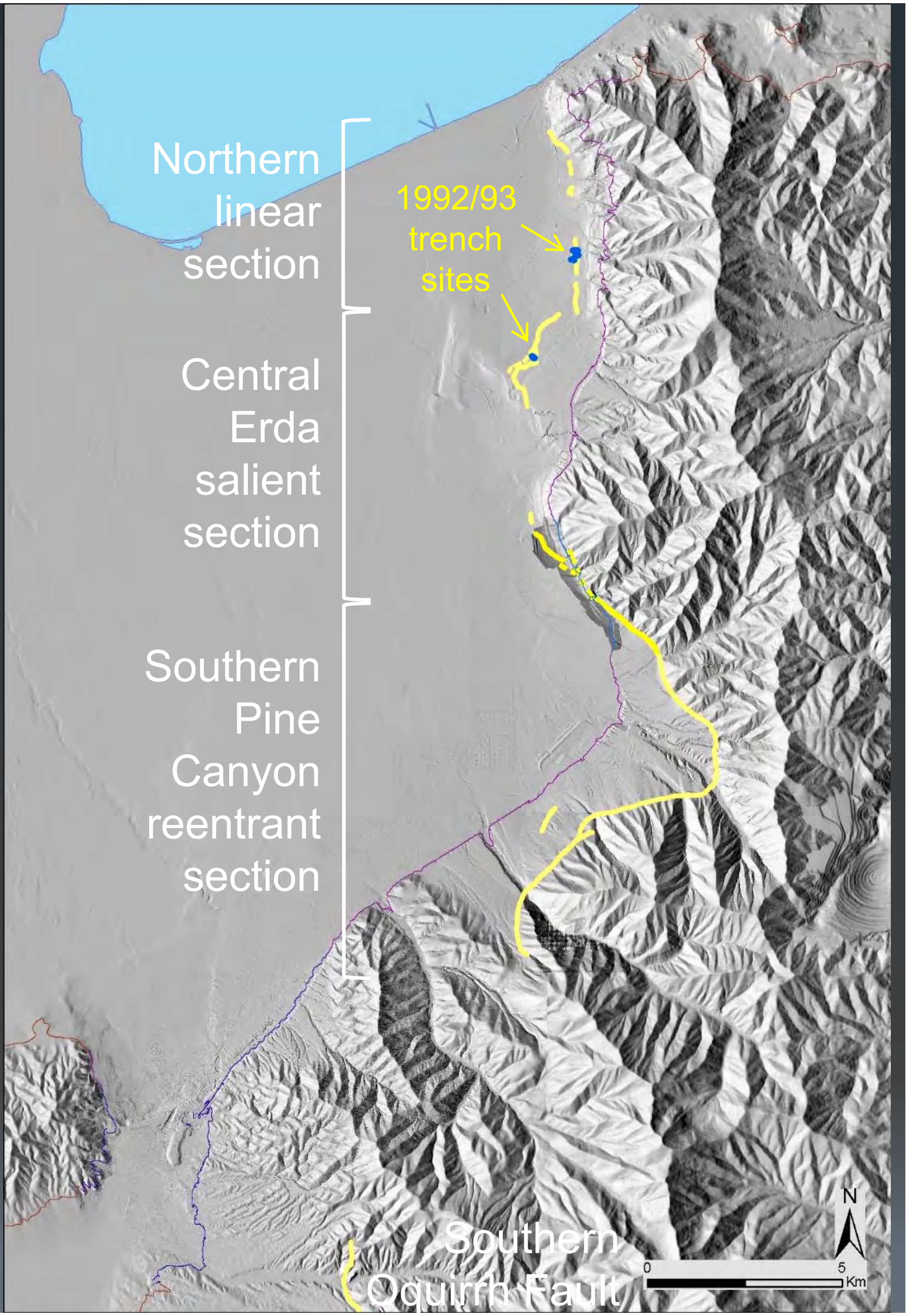
- Results are consistent with hypothesis that MRE in trench produced measured highstand shoreline elevation differences
- ~23 km minimum surface rupture in MRE





Conclusions

- Trench study results corroborated by scarp heights and shoreline elevations
- Minimum ~23 km MRE surface rupture
- Possible MRE surface rupture termination at southern end of reentrant section
- Shoreline elevations viable for extracting along-strike rupture information
- Higher resolution DEMs seemed to provide for more precise shoreline elevation measurement
- https://sketchfab.com/models/8a4d83f53f6a4de68be18a245c02c25e#



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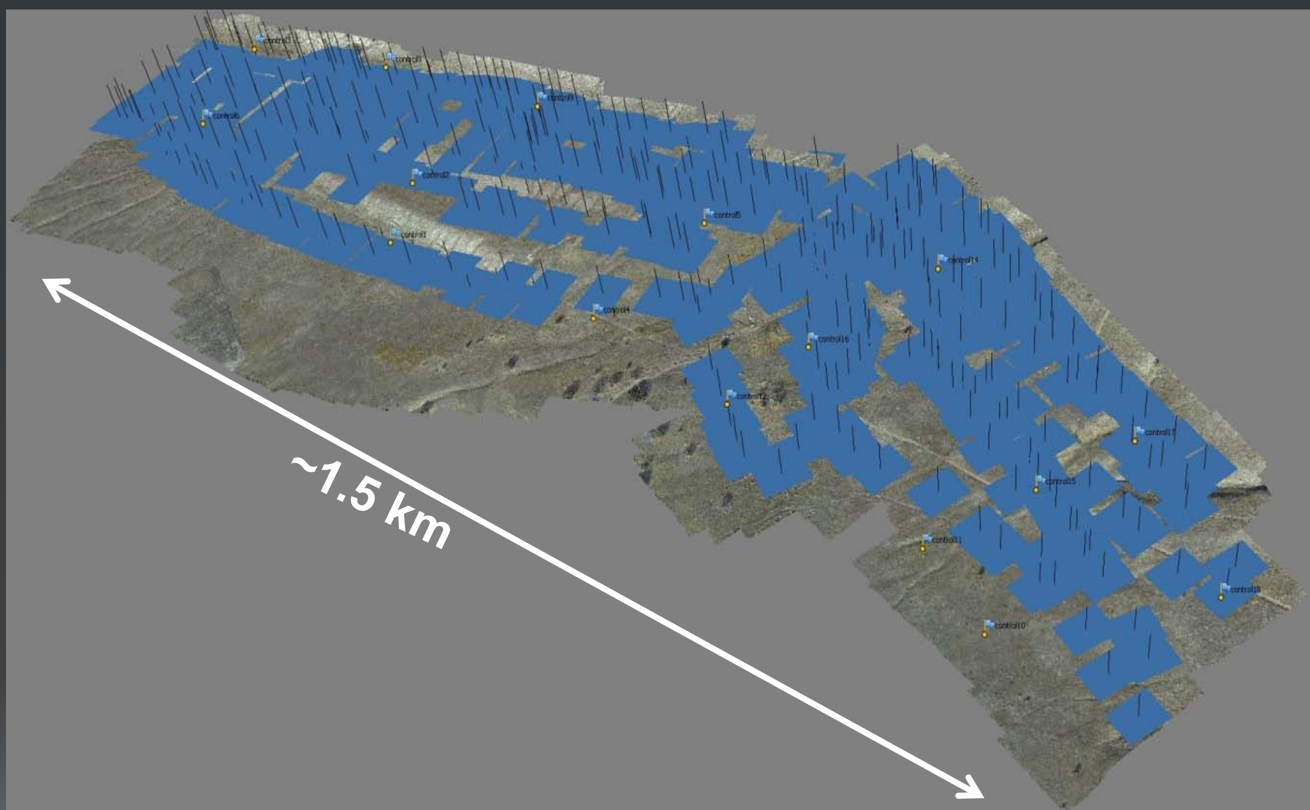
DEM Construction Methods: Aerial Imagery and Structure from Motion (SfM)

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

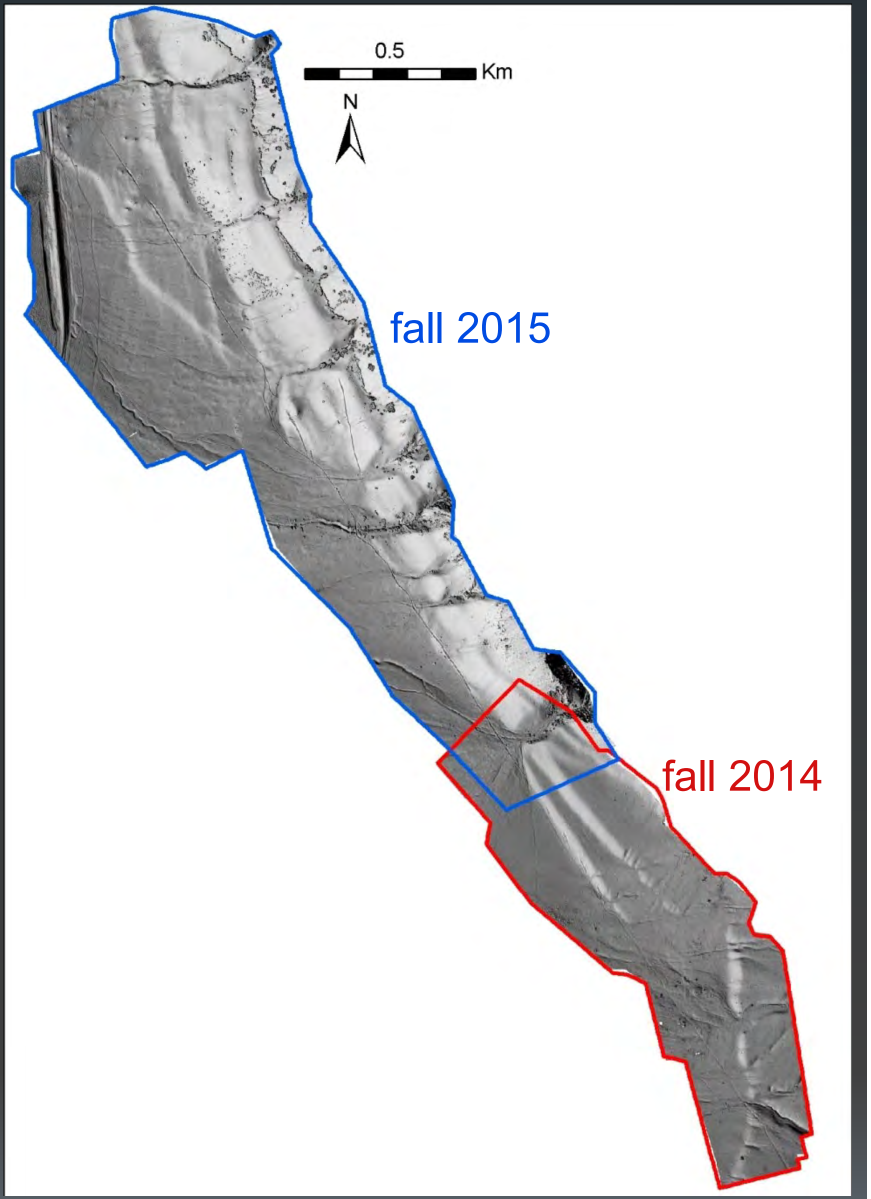


Blue squares are locations where photograph was taken from UAV.

SfM software determined locations of the photos.

Oquirrh Fault DEM

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



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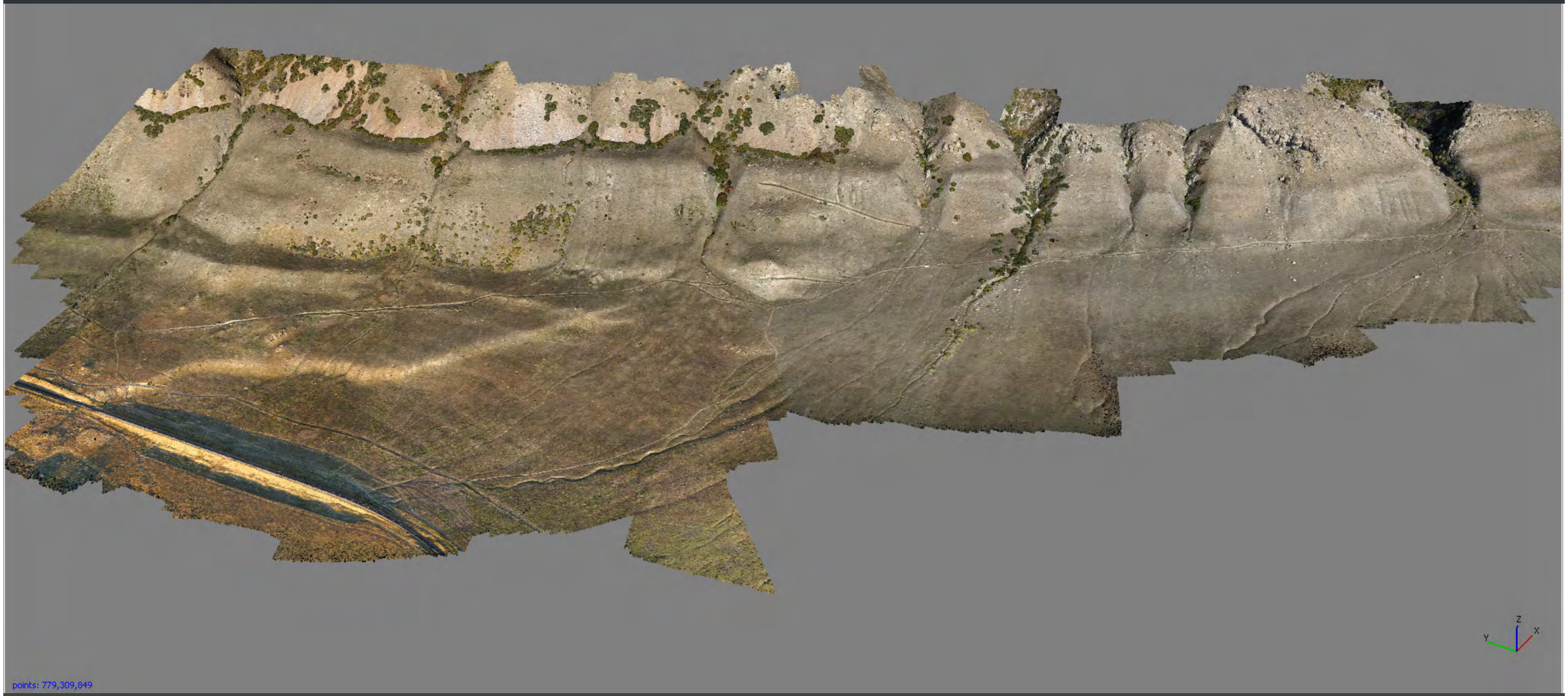
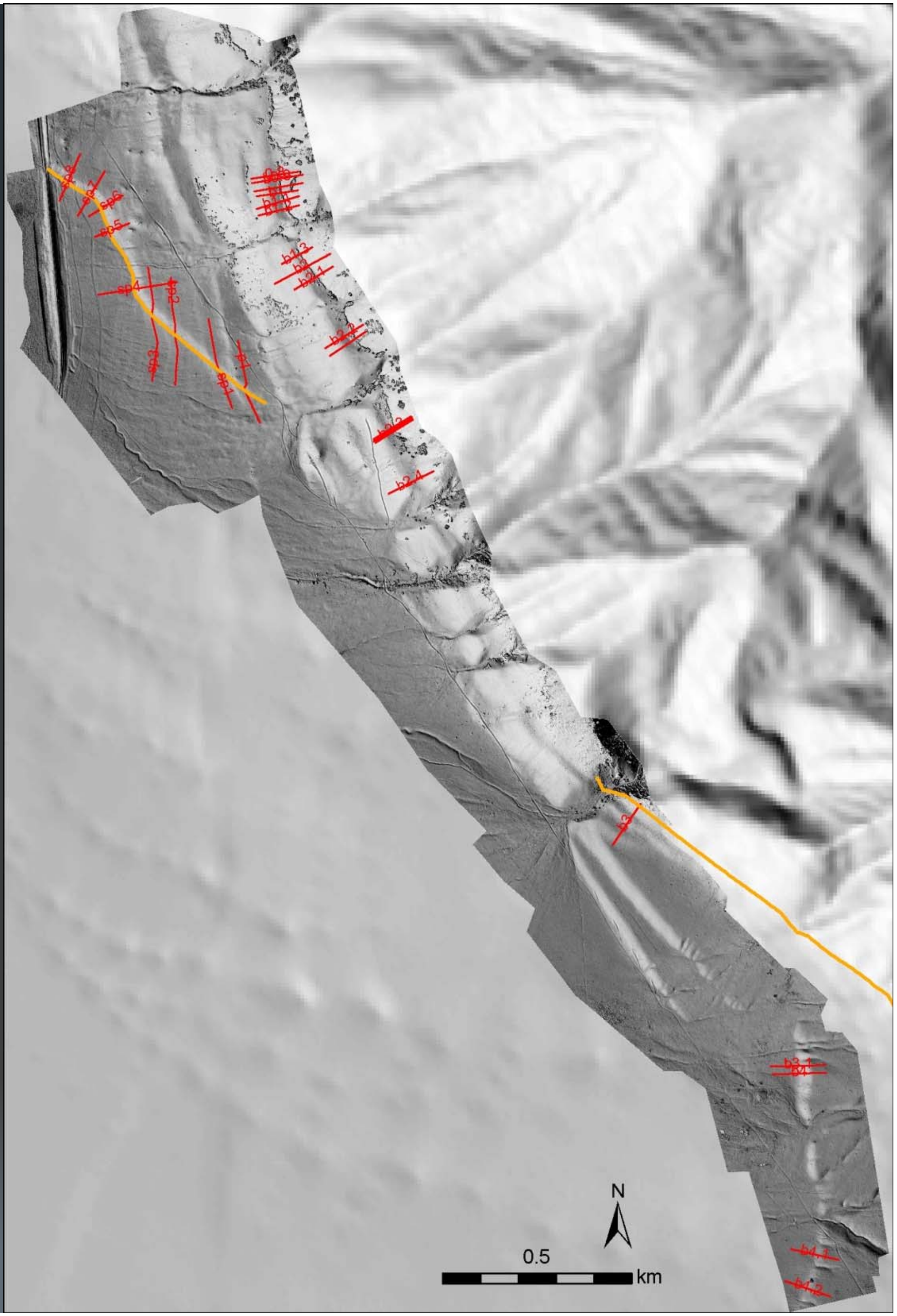
Northern Area Point Cloud Screenshot



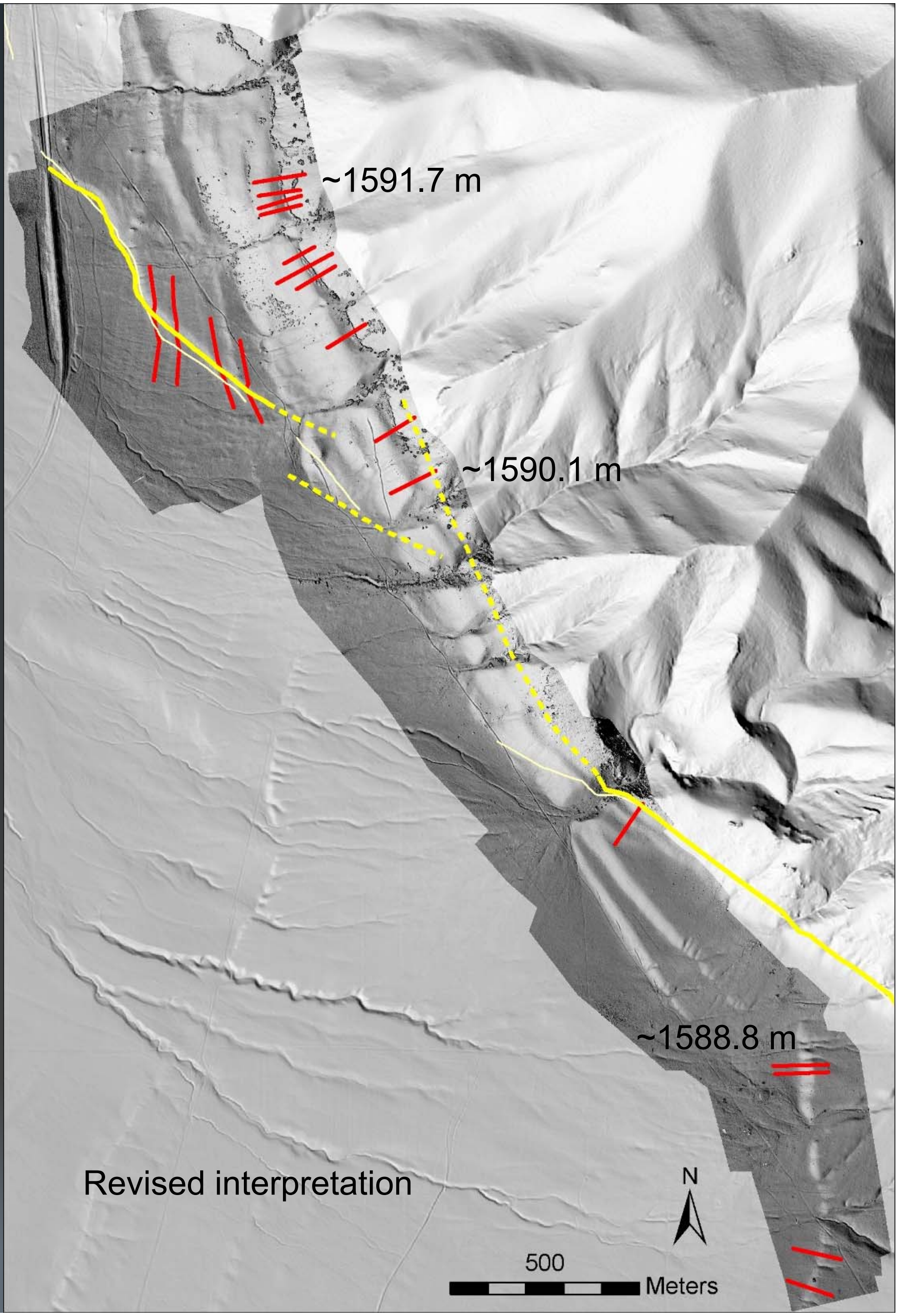
Oquirrh Fault DEM

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



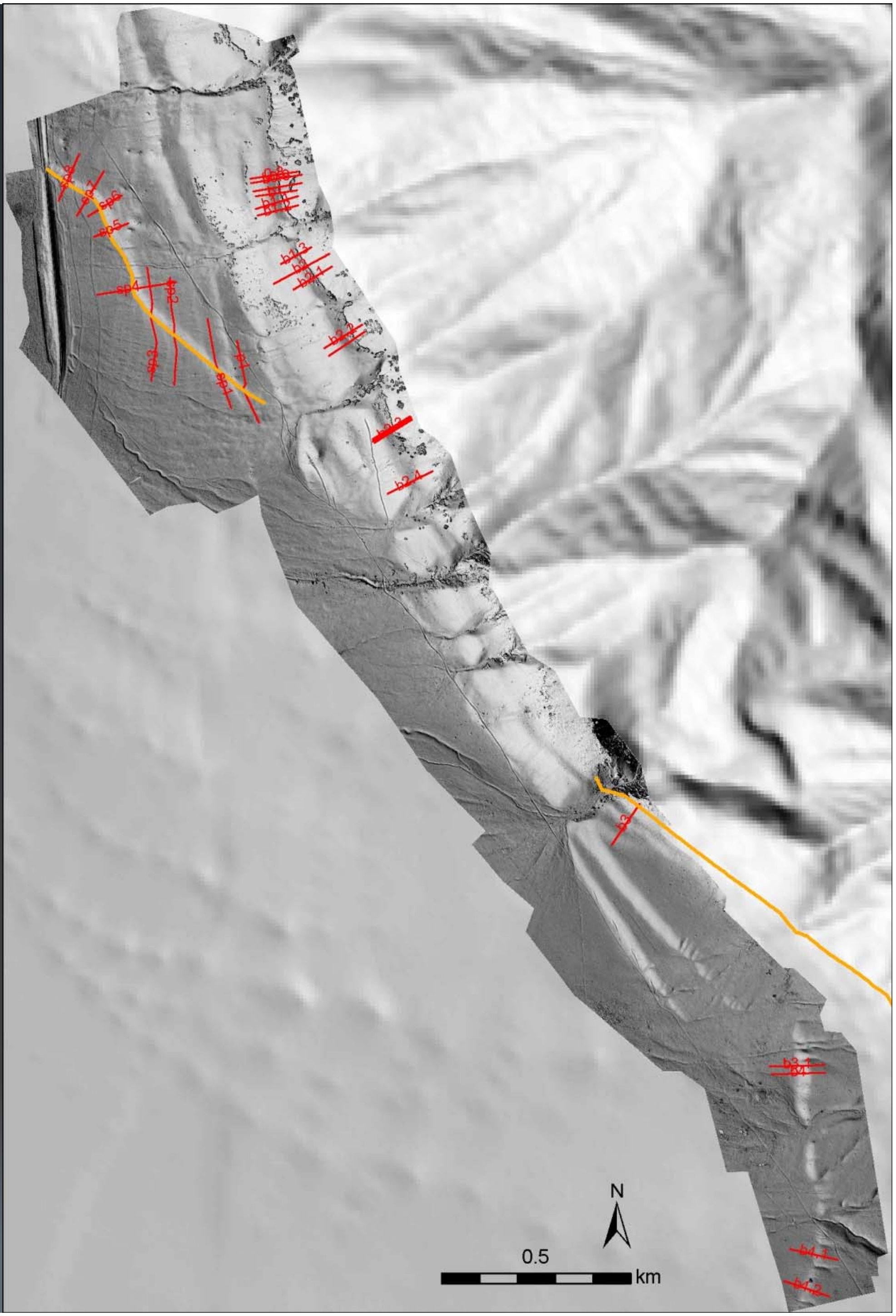
Structural Interpretation

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



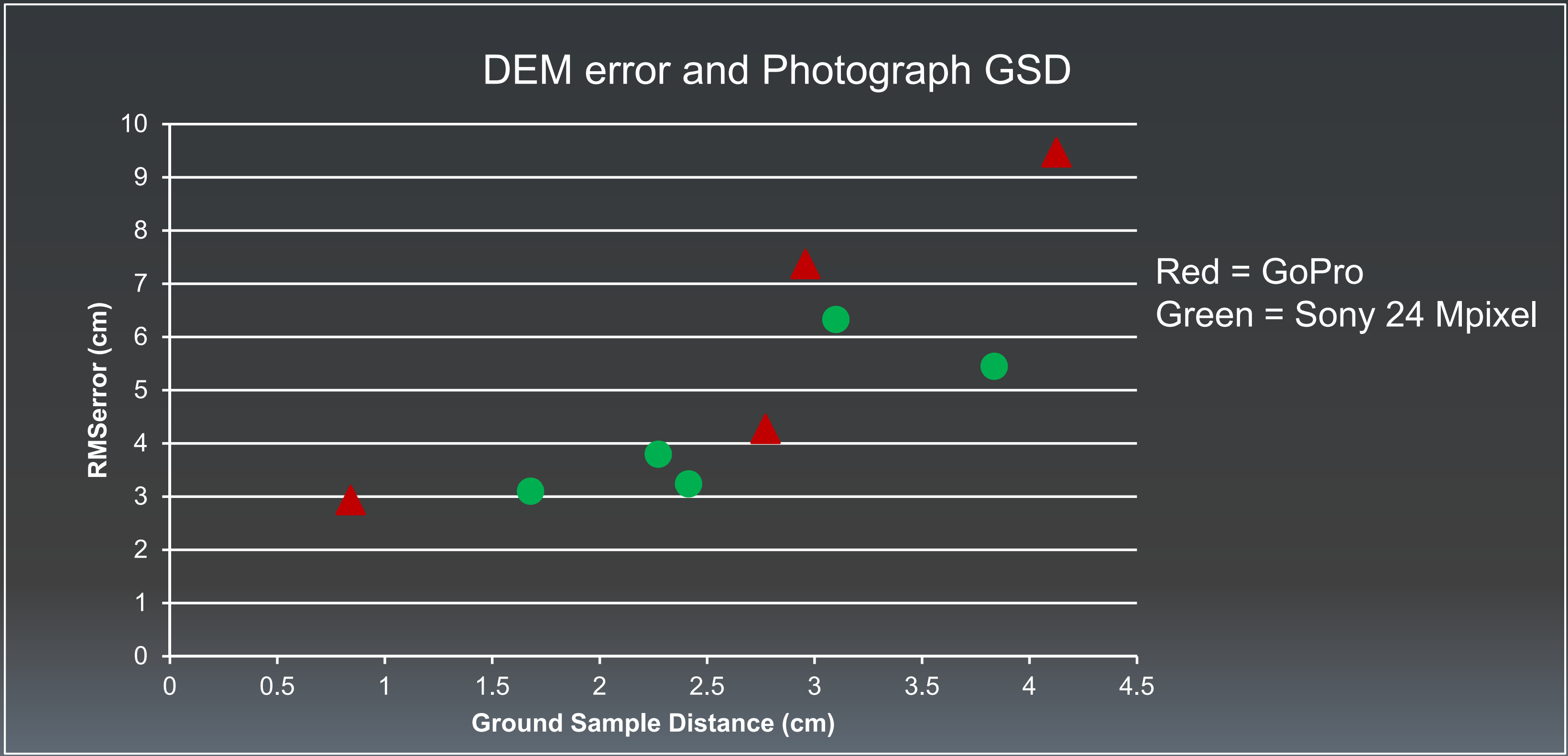
Displacement Summary

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



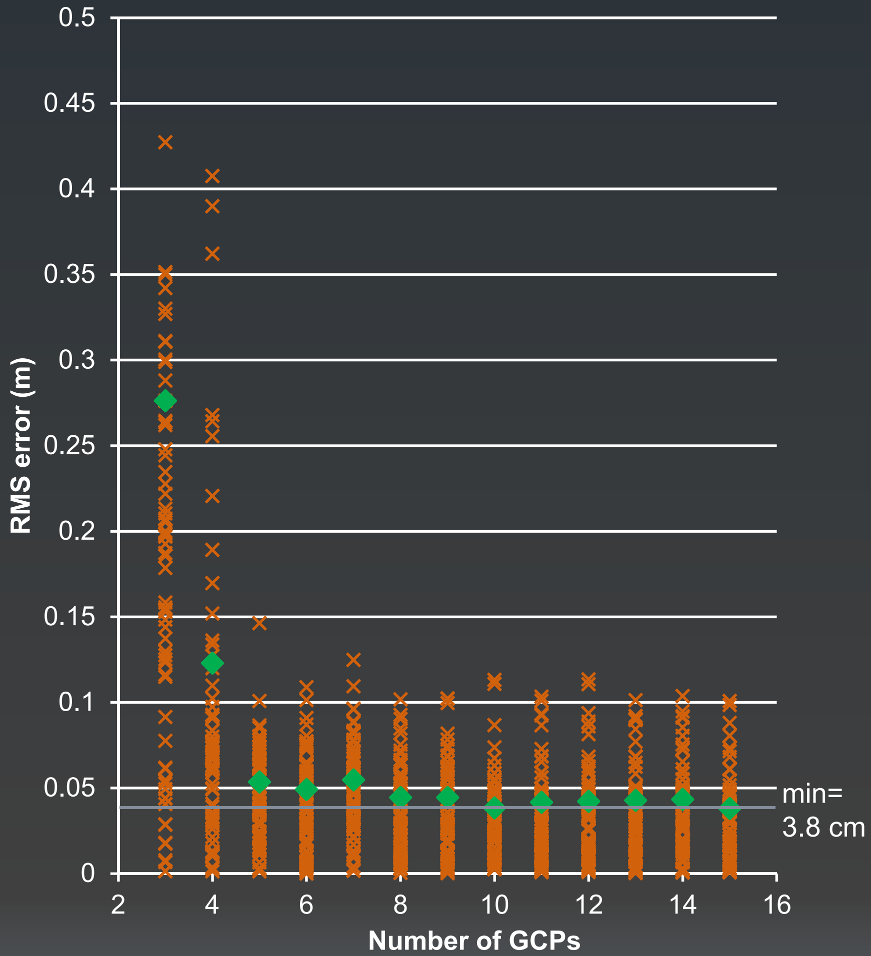
DEM Accuracy and Photograph Resolution

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



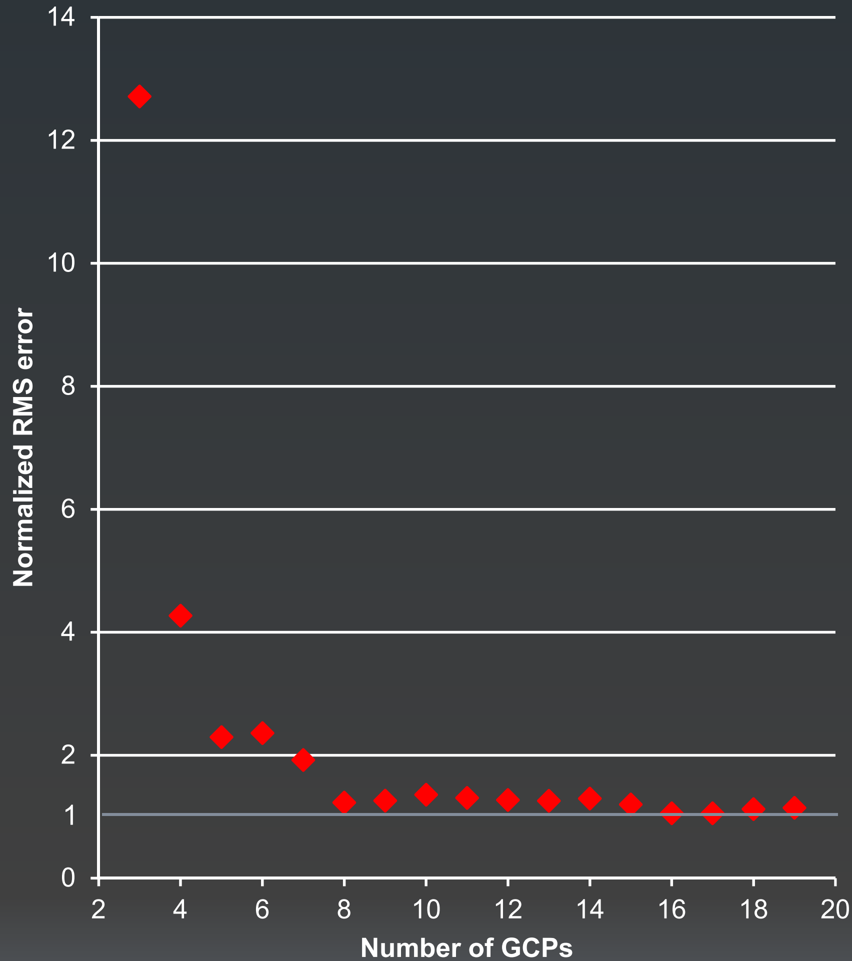
Number of GCPs and DEM Accuracy

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



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

Average normalized error for four test sites

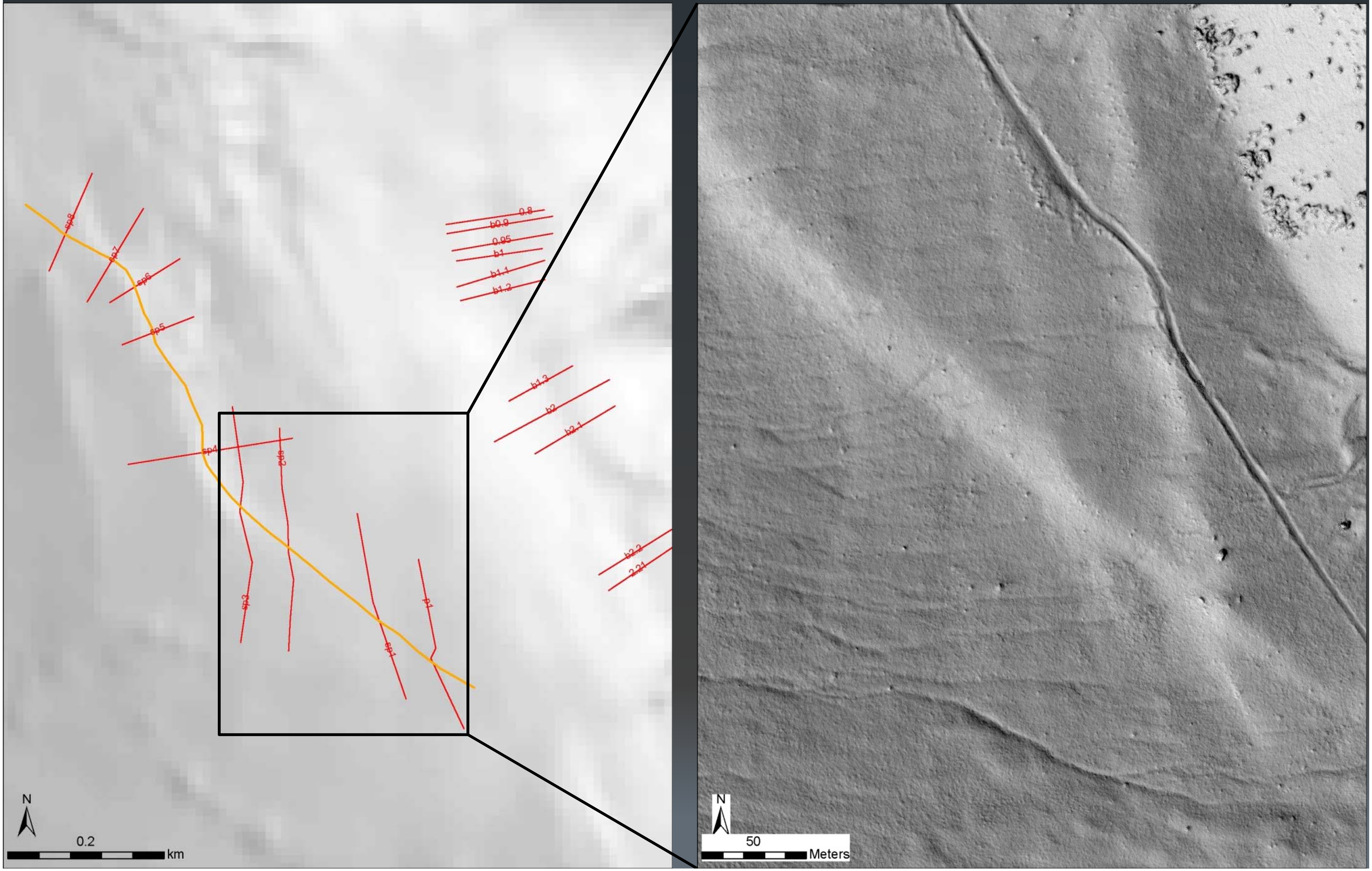


DEM Accuracy Summary

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

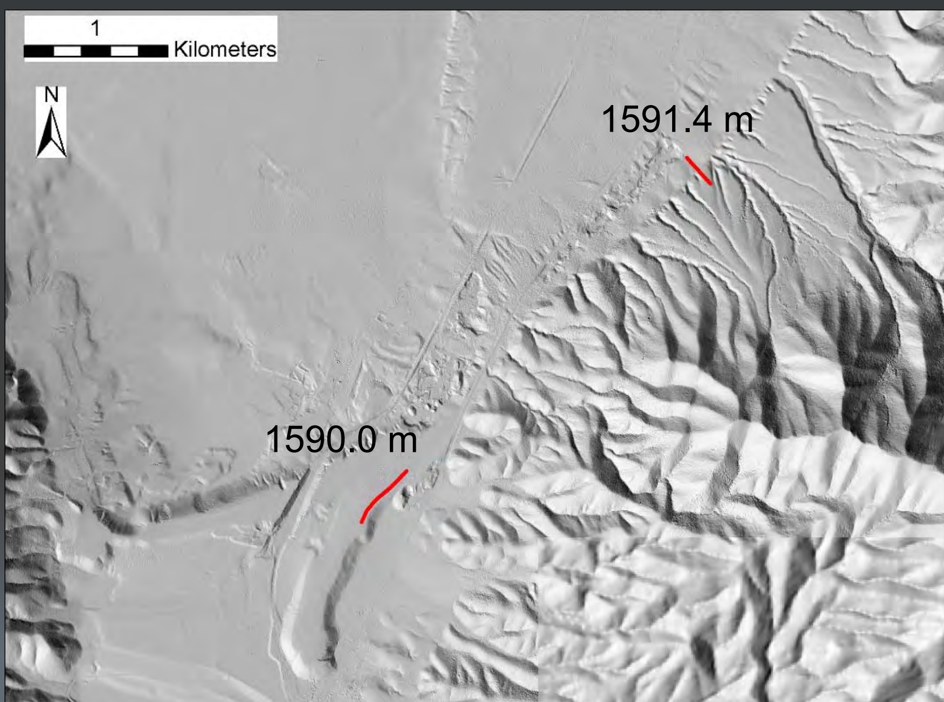
Oquirrh Fault DEM

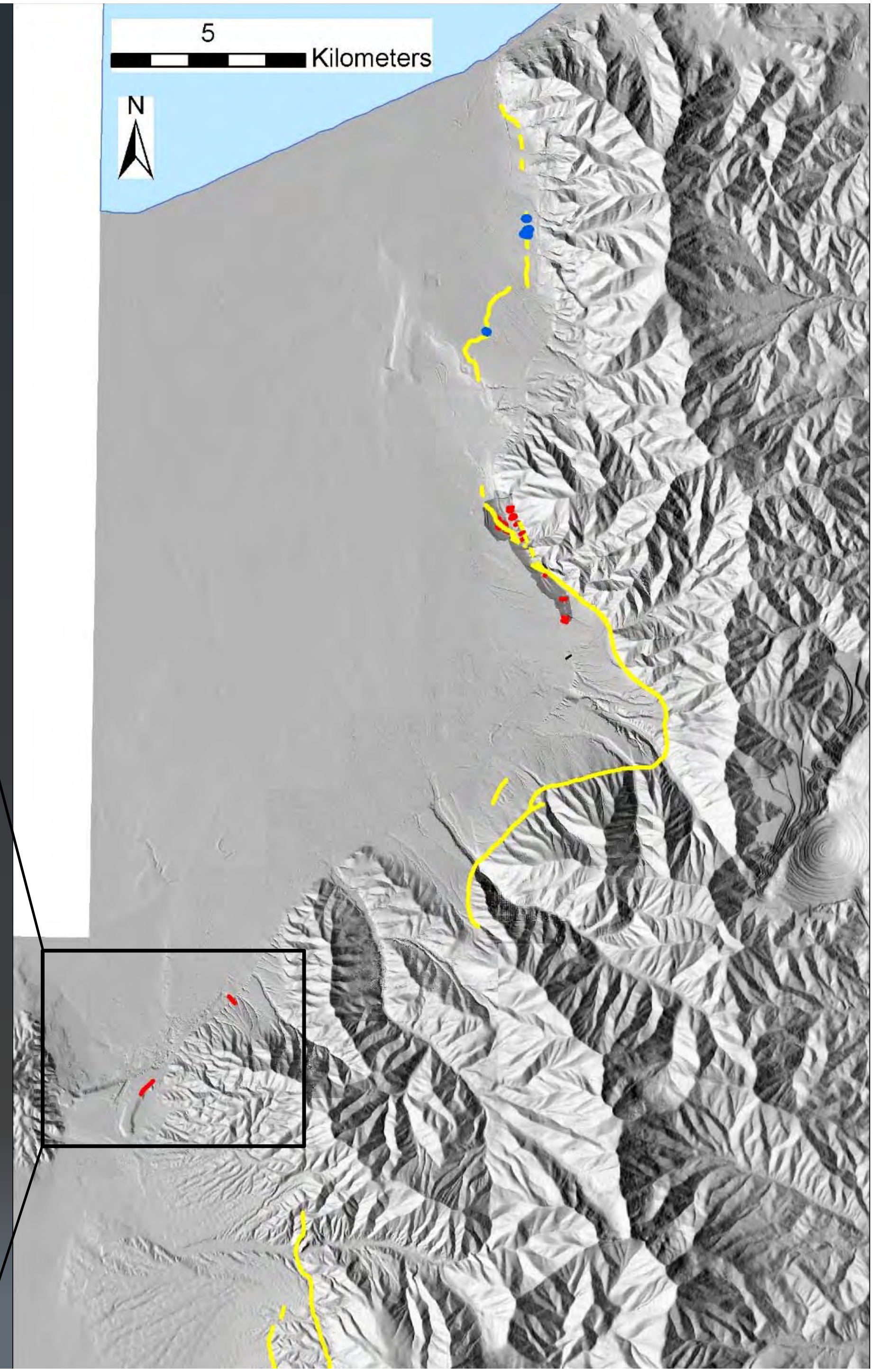
- 5 cm vs 5 m DEM



Looking South….

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





Equipment

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

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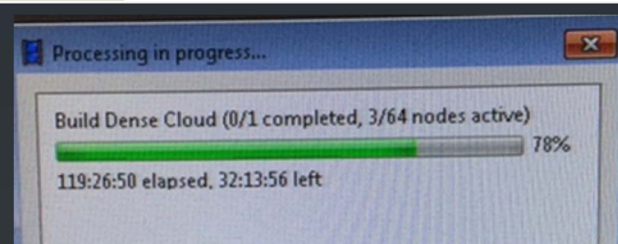
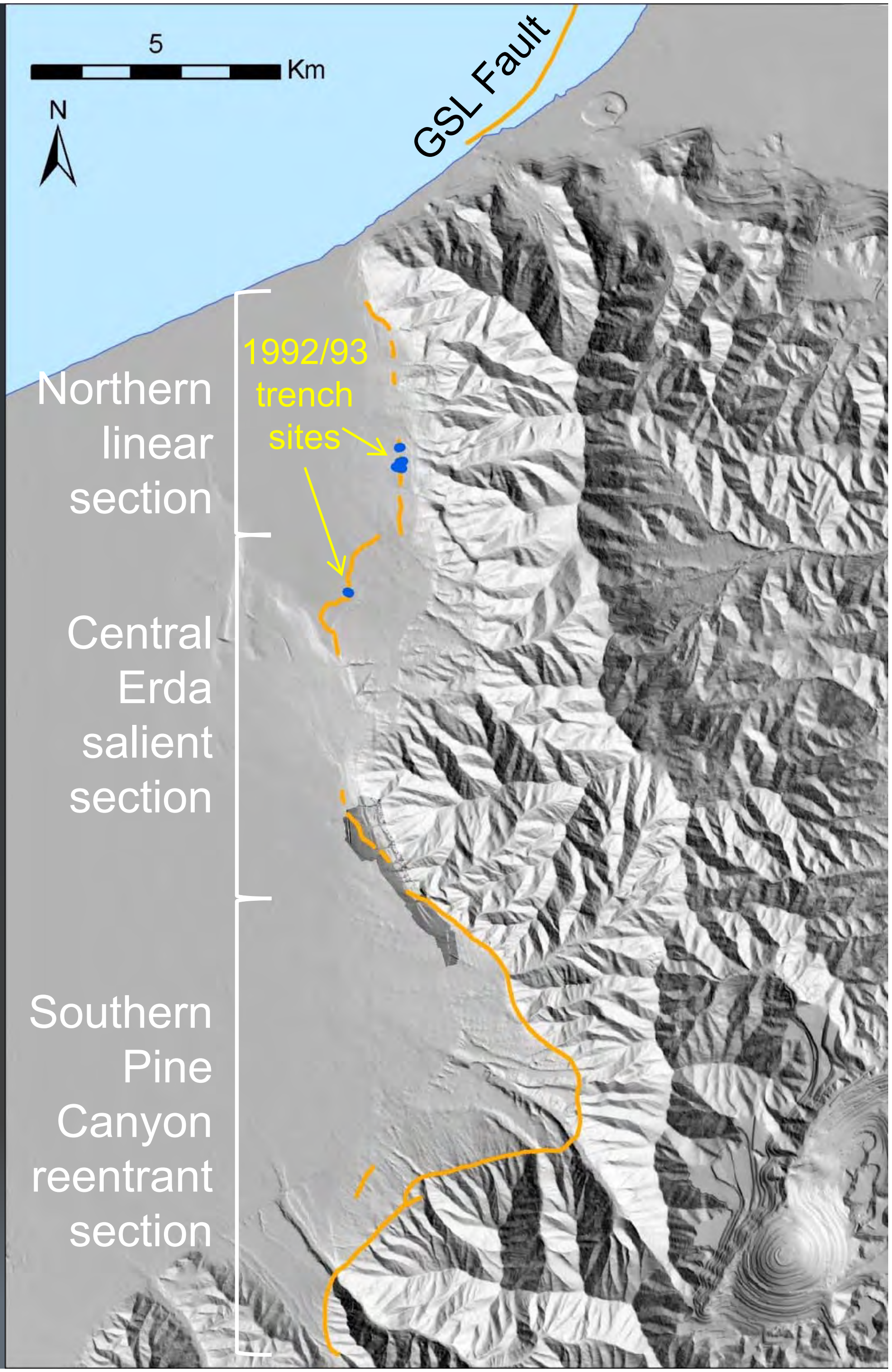


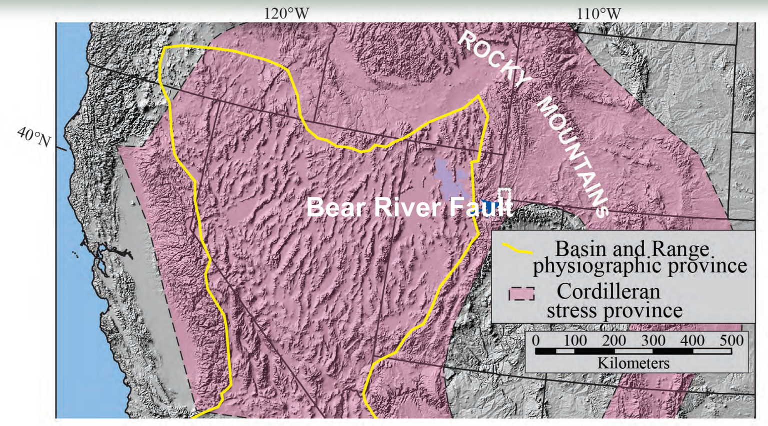
Future

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



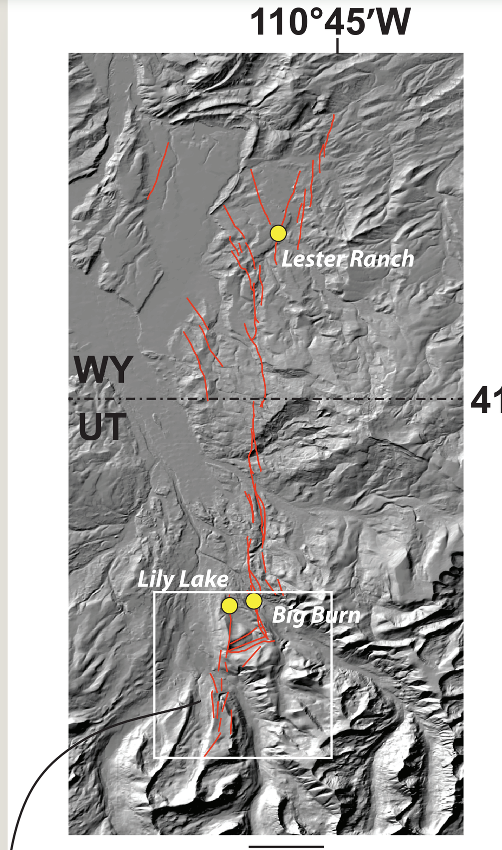
Investigating the Spatial Extent of a Barely Prehistoric Earthquake on the Bear River Normal Fault, Wyoming and Utah

S. Hecker, D.P. Schwartz, F.R. Cinti, R. Civico, M.W. West, A. Stoller, S.B. DeLong, and A.J. Pickering
shecker@usgs.gov



Abstract

To better constrain the length of a young prehistoric (significantly post-AD 1630) surface-rupturing earthquake recently discovered near the south end of the Bear River normal fault in Utah (Hecker and Schwartz, 2015, T31A-2823), we excavated a trench on a strand of the fault 25 km to the north in Wyoming, where previous work had found clear evidence of two older late Holocene events (West, 1993). These two events, which have been identified to the south as well, were interpreted as comprising the entire history of this very young fault. The new trench across the 5-m-high scarp at the northern site exposed a 6-m-wide zone of faulting and two packages of colluvial-wedge deposits, each tabular and 0.5-1 m thick. The colluvial deposits, which bury Pleistocene alluvial deposits that in turn overlie Eocene bedrock, appear correlative with West's two-event stratigraphy. In the latest trench, however, both wedges are faulted, with strands extending to the ground surface, evidence of a third, younger event. The amount of displacement in the most recent event (MRE) in the trench is small (few 10s of cm at most) and distributed and has resulted in only minor colluviation. The event record is complicated by a shallow slope failure in the soil A-horizon on the scarp that we interpret as possibly occurring during the MRE. The slide formed a head scarp at a location underlain by MRE faulting and built a low bench at least 100 m long on the surface below the scarp. We sampled buried in-place soil below the slide for radiocarbon analysis, which should allow age comparison with the earthquake identified farther south. Ultra-high-resolution topography from balloon photography and terrestrial lidar enable detailed morphologic study of surface processes and deformation at the site.



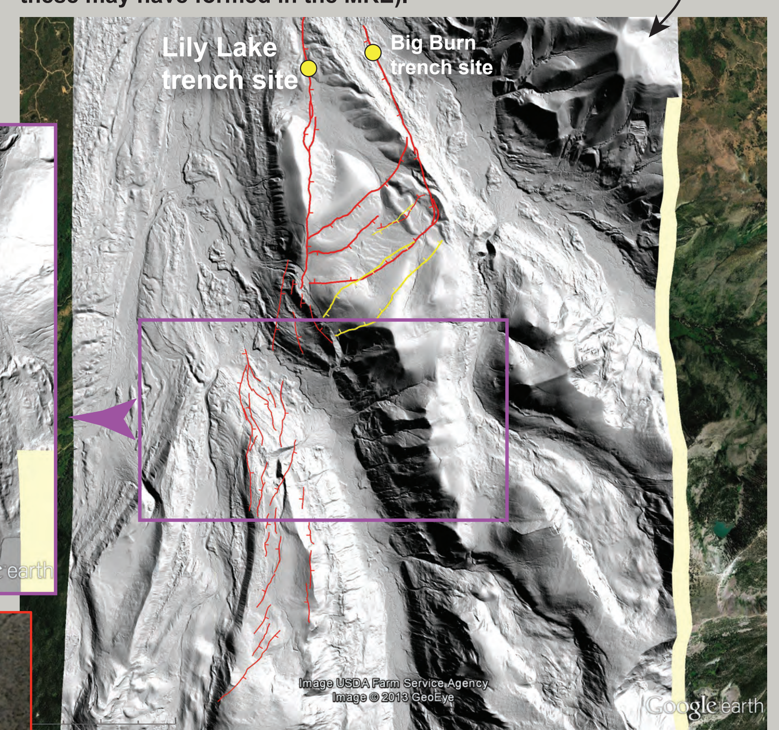
Simplified map of the Bear River fault (on 30-m DEM hillshade) showing paleoseismic trench sites. Outlined area is shown below.

View of scarp at location of 2016 Lester Ranch trench

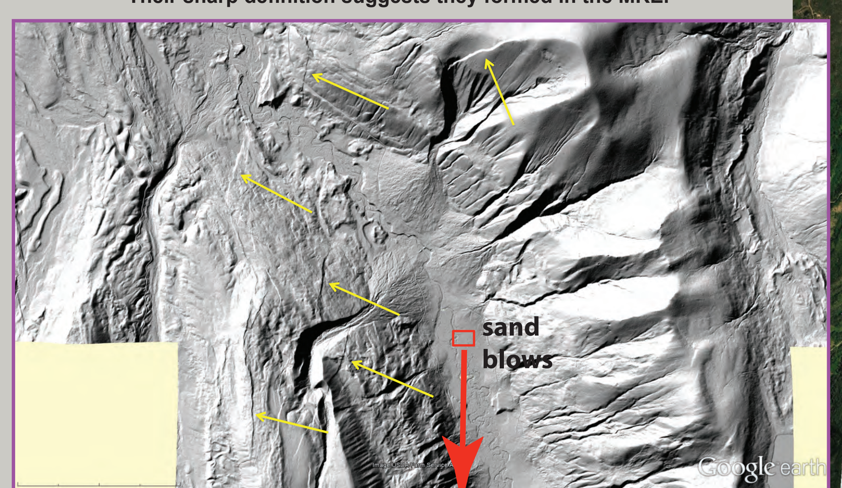
Evidence at Southern End of Fault of a Recent Earthquake

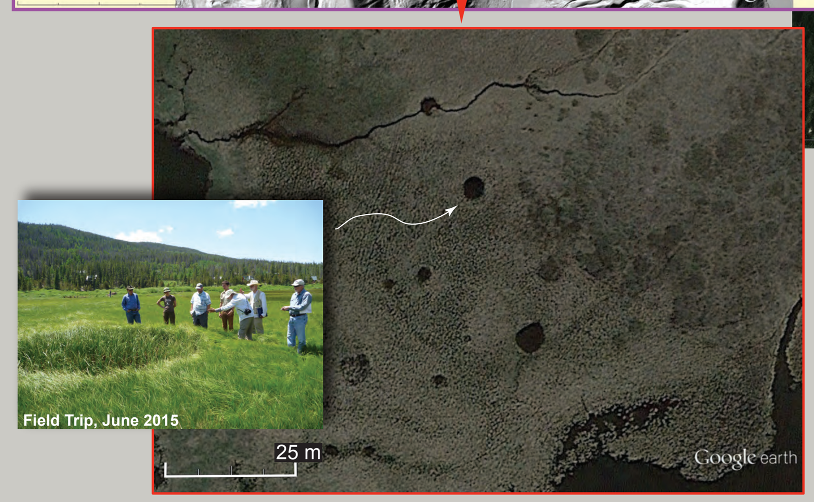
The MRE is best expressed at the Lily Lake trench, across a prominent antithetic strand of the fault; it is less well expressed in the trench at Big Burn on the main fault to the east of Lily Lake, where it's identified as a recent slope deposit at the toe of a large fold scarp.

Lidar hillshade derived from high-resolution (<0.5m) airborne dataset of the northwest flank of the Uinta Mountains in Utah. Fault scarps are delineated in red (yellow where cross cut older scarps, suggesting these may have formed in the MRE).

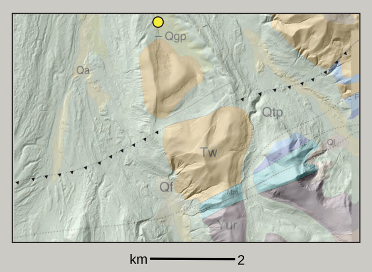


Yellow arrows point to distributed array of scarps at south end of the fault. Their sharp definition suggests they formed in the MRE.



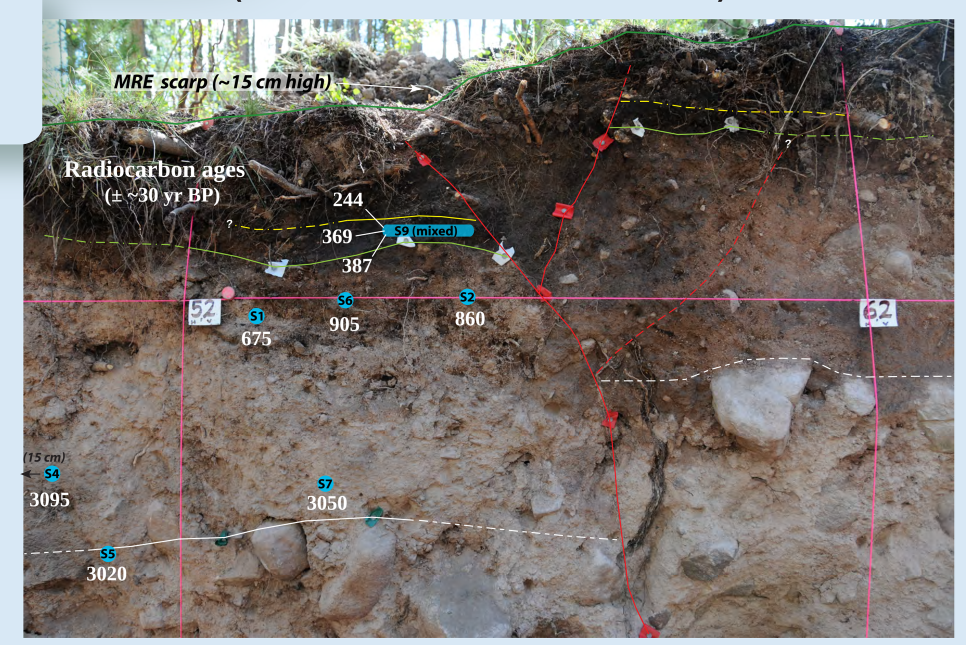


Google Earth image (June 2013) of water-filled depressions on the floodplain of the Bear River interpreted as liquefaction sand-blow craters. Their youthful morphology indicates they formed recently, likely during the MRE on the fault.



Geologic map overlain on hillshade showing the structural fabric (an northeast-trending overturned syncline and reverse faults) of the north flank of the Uinta Mountains, which strongly influences the rupture pattern of the BRF. Location of the northernmost reverse fault is emphasized. The Lily Lake site (yellow dot) is shown for reference.

Lily Lake Trench Site (antithetic strand of the BRF)



The most recent surface-rupturing event (MRE) at Lily Lake is identified from a fault that cuts up into the soil A horizon and forms a small scarp at the ground surface (shown here on south wall of trench). This newly-identified earthquake likely occurred in the 18th Century or later, recent enough that the modern A-horizon largely had formed and the scarplet on the forest floor is still preserved, but before the beginning of the historical record (c. 1850).

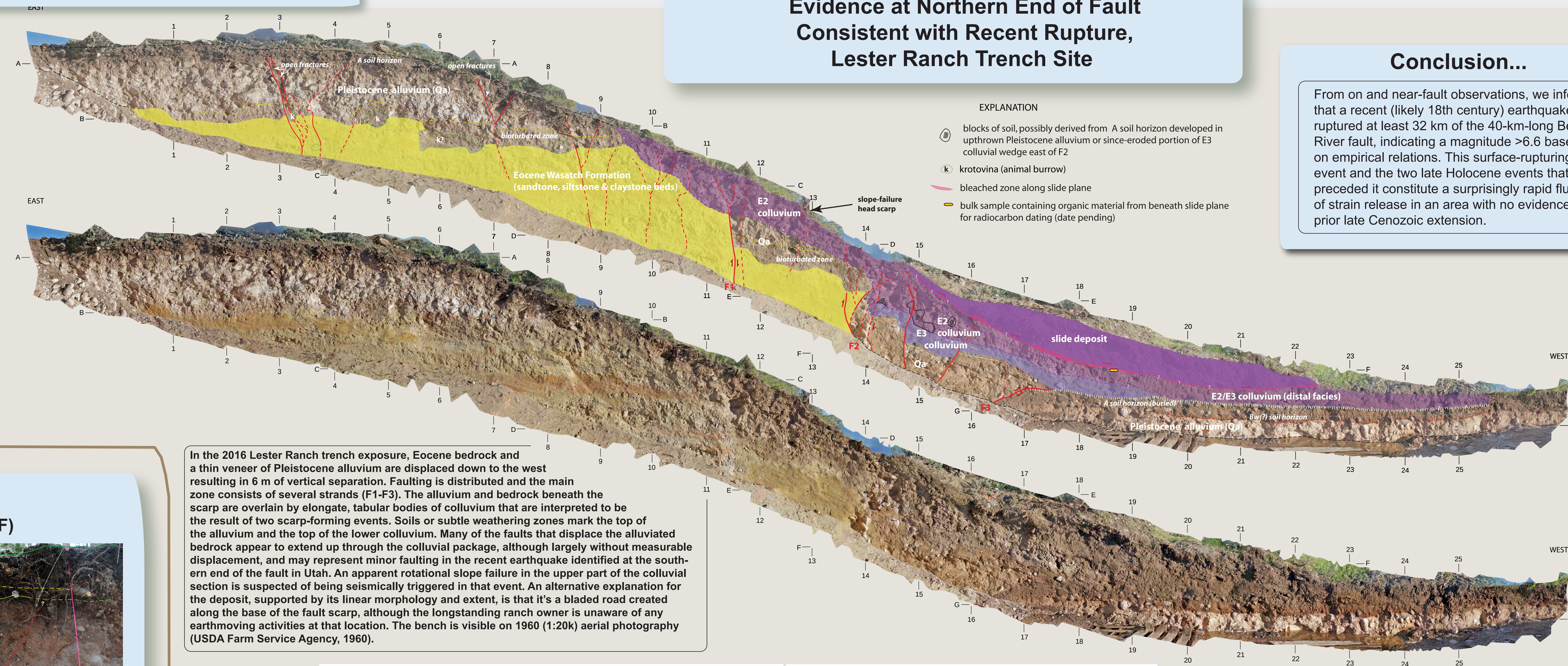
The location of C14-dated samples are indicated by blue ovals; white numbers are ages in radiocarbon years before present (RCYBP in table below). The material between the green and yellow contacts is an organic mat at the base of the A horizon from which macrofloral remains were collected and dated (see table); white contact is the base of a deposit that infills a depression formed in the penultimate event (~3 ka). Vertical pink string lines are 1 m apart.

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** (‰)
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

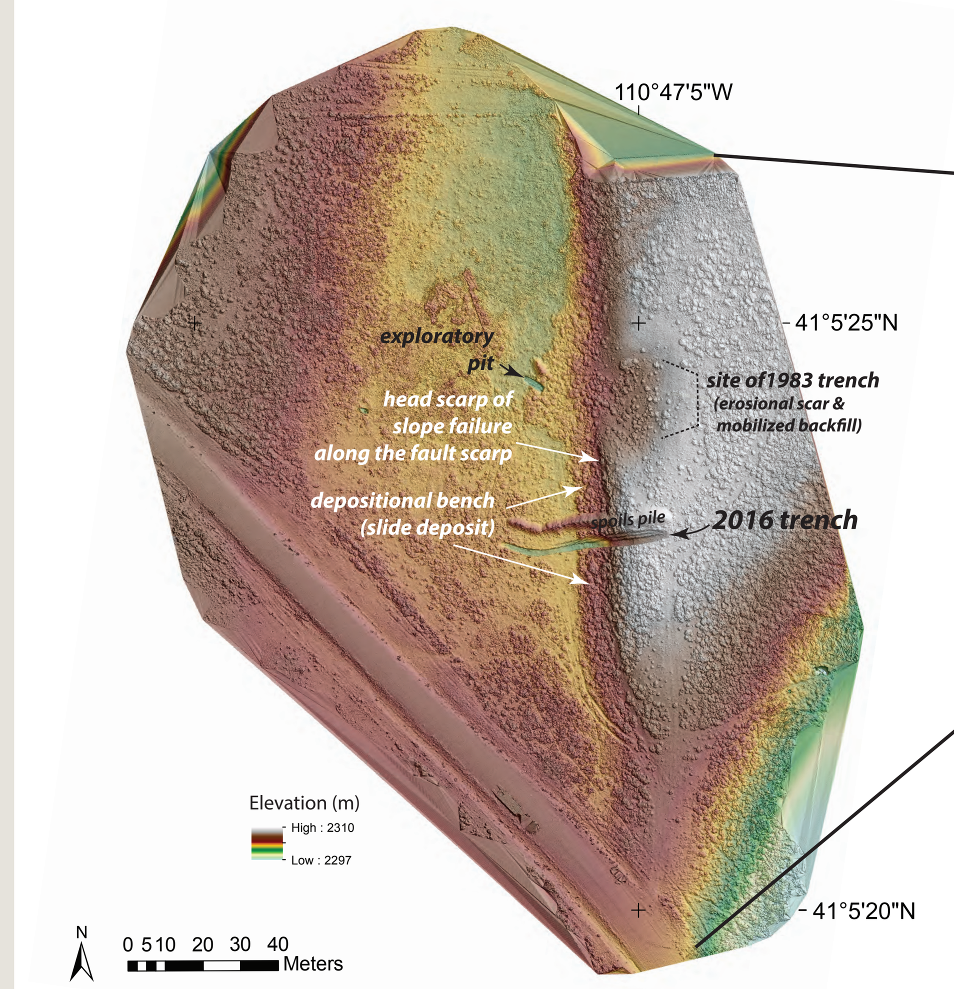
Similarity in age ranges among samples provide a constraint on the MRE of post 320 CAL yr. BP (post A.D. 1630)

Evidence at Northern End of Fault Consistent with Recent Rupture, Lester Ranch Trench Site

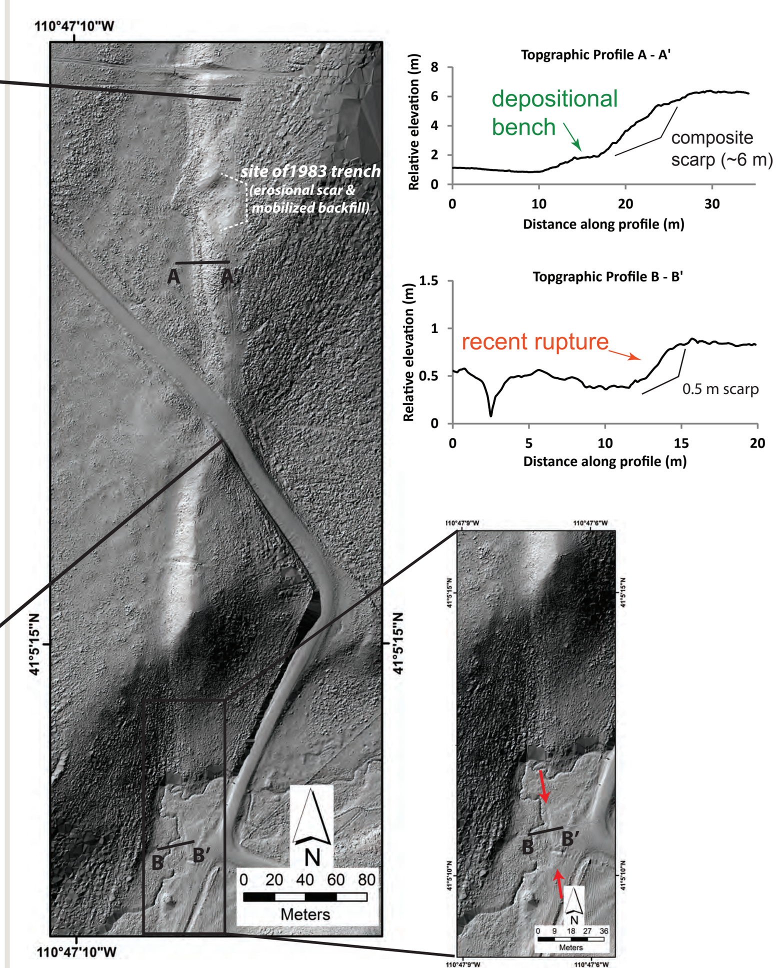


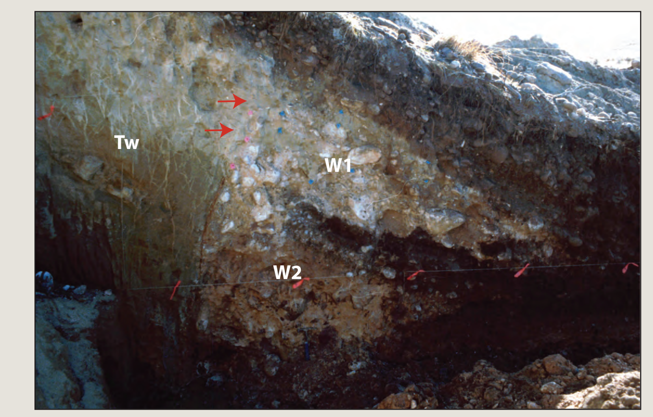
In the 2016 Lester Ranch trench exposure, Eocene bedrock and a thin veneer of Pleistocene alluvium are displaced down to the west resulting in 6 m of vertical separation. Faulting is distributed and the main zone consists of several strands (F1-F3). The alluvium and bedrock beneath the scarp are overlain by elongate, tabular bodies of colluvium that are interpreted to be the result of two scarp-forming events. Soils or subtle weathering zones mark the top of the alluvium and the top of the lower colluvium. Many of the faults that displace the alluviated bedrock appear to extend up through the colluvial package, although largely without measurable displacement, and may represent minor faulting in the recent earthquake identified at the southern end of the fault in Utah. An apparent rotational slope failure in the upper part of the colluvial section is suspected of being seismically triggered in that event. An alternative explanation for the deposit, supported by its linear morphology and extent, is that it's a bladed road created along the base of the fault scarp, although the longstanding ranch owner is unaware of any earthmoving activities at that location. The bench is visible on 1960 (1:20k) aerial photography (USDA Farm Service Agency, 1960).

Digital surface model (DSM) of the Lester Ranch trench site created using structure-from-motion (SfM) photogrammetry and balloon-based imagery (illustrated in right lower corner of poster).



Ground-based lidar hillshade image of the Lester Ranch site and area to the south. Topographic profiles are shown at future location of 2016 trench (A-A') and ~300 m to the south where the fault crosses a young floodplain (between red arrows; profile B-B'). The small (~0.5 m high) steep scarp on the floodplain is hypothesized to have formed entirely during the most recent event.



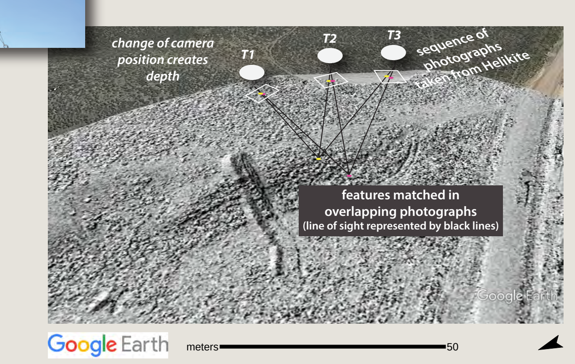


Original 1983 Lester Ranch trench exposure, located about 30 m north of the 2016 trench, showing deposits interpreted as a pair of stacked colluvial wedges (W2 and W1; West, 1993 and 1994); vertical-to-overturned normal fault juxtaposes colluvium against Wasatch Formation bedrock (Tw). Red arrows point to apparent shears cutting upper wedge (correlative with E2 colluvial wedge in 2016 trench), evidence of the third, youngest faulting event identified in the present study. Pink flags on string are 1 m apart.

Conclusion...

From on and near-fault observations, we infer that a recent (likely 18th century) earthquake ruptured at least 32 km of the 40-km-long Bear River fault, indicating a magnitude >6.6 based on empirical relations. This surface-rupturing event and the two late Holocene events that preceded it constitute a surprisingly rapid flurry of strain release in an area with no evidence of prior late Cenozoic extension.

Camera mounted on a Helikite (a tethered helium kite balloon) and perspective view of trench site illustrating image-collection technique for creating the photogrammetric DSM.



Updating Quaternary Fault Parameters for the Reno And Las Vegas Areas, Nevada

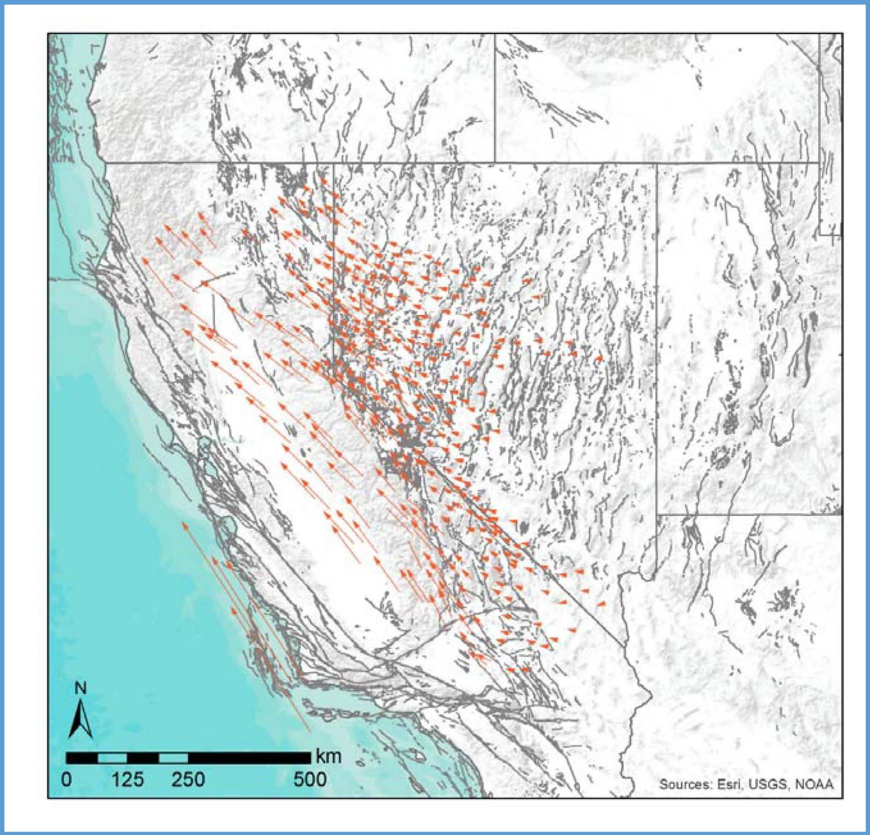
Rich D. Koehler
Nevada Bureau of Mines and Geology

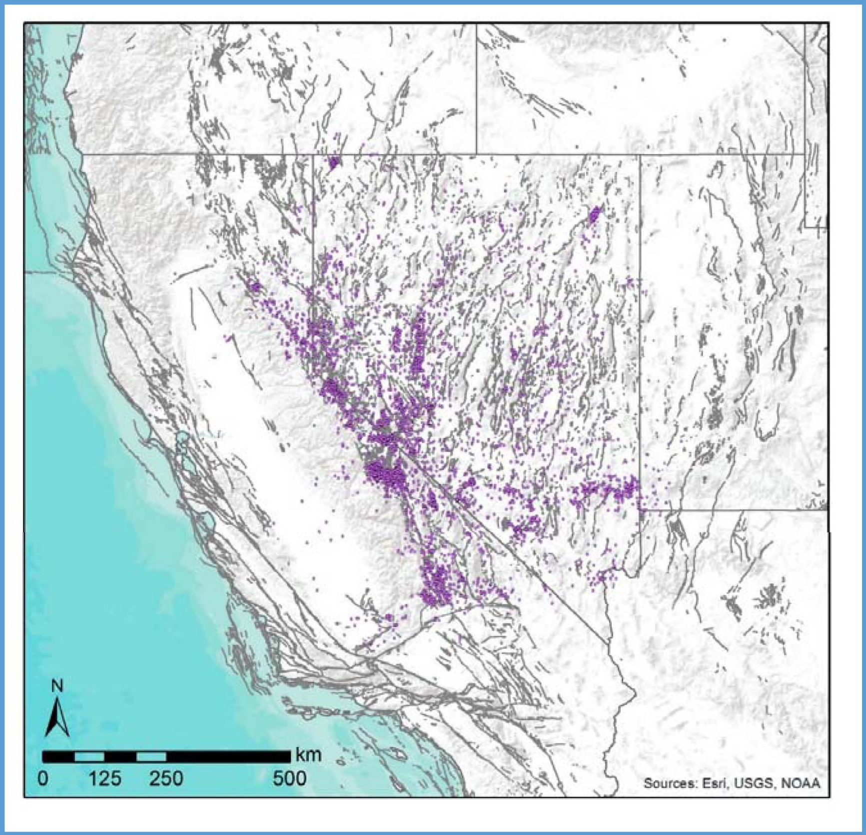
Presented at: 2017 Utah Quaternary Fault Parameters
Working Group, Salt Lake City, UT
February 8, 2017

Summary of topics

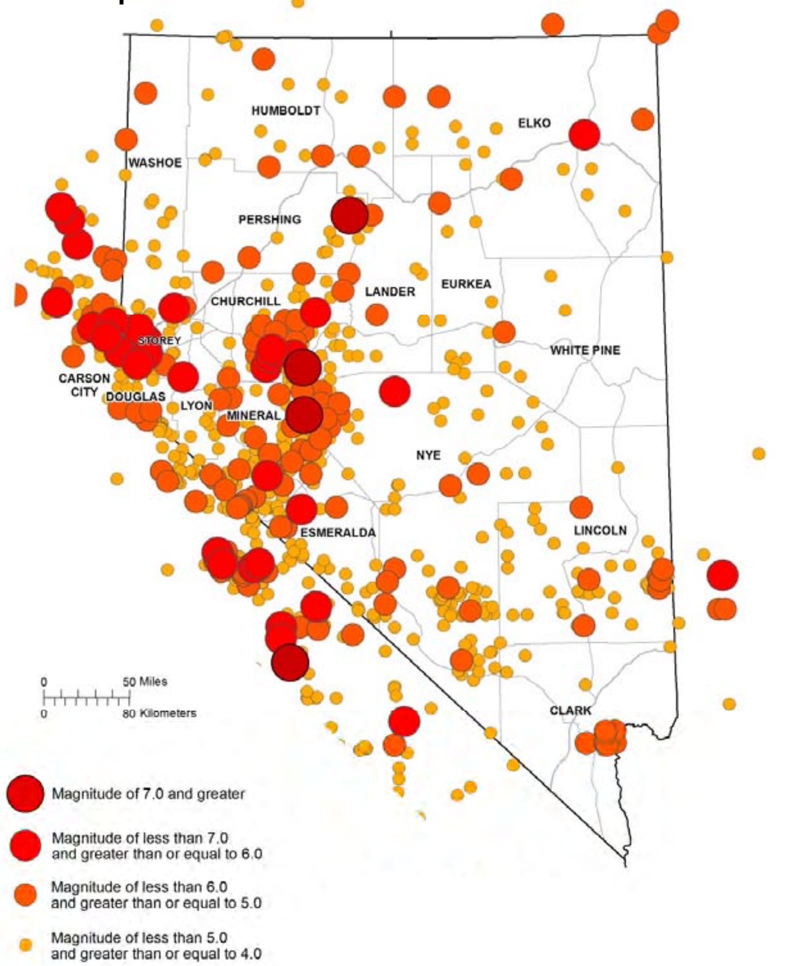
- Tectonic/geodetic setting of the Nevada
- Active faults, seismicity, and hazards of Nevada (Reno)
- National Seismic Hazards Map
- Efforts of the Nevada NBMG to update fault parameters
- Problems with using the QFF
- Additional products relevant to Nevada seismic hazard assessment
- The path forward

Active faults, seismicity, and geodesy



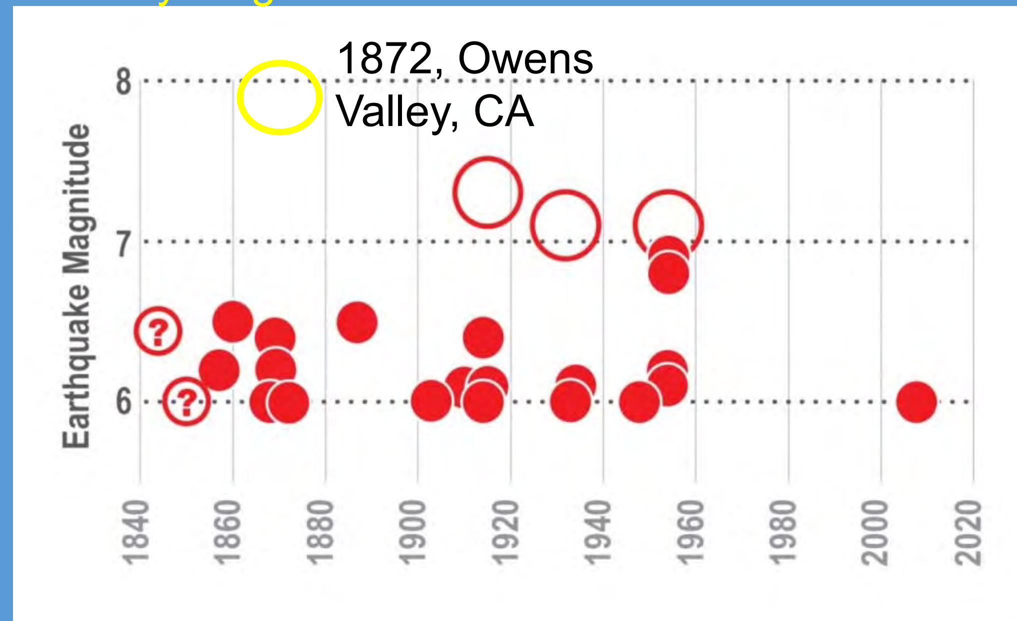


Earthquakes in Nevada 1840's-2012

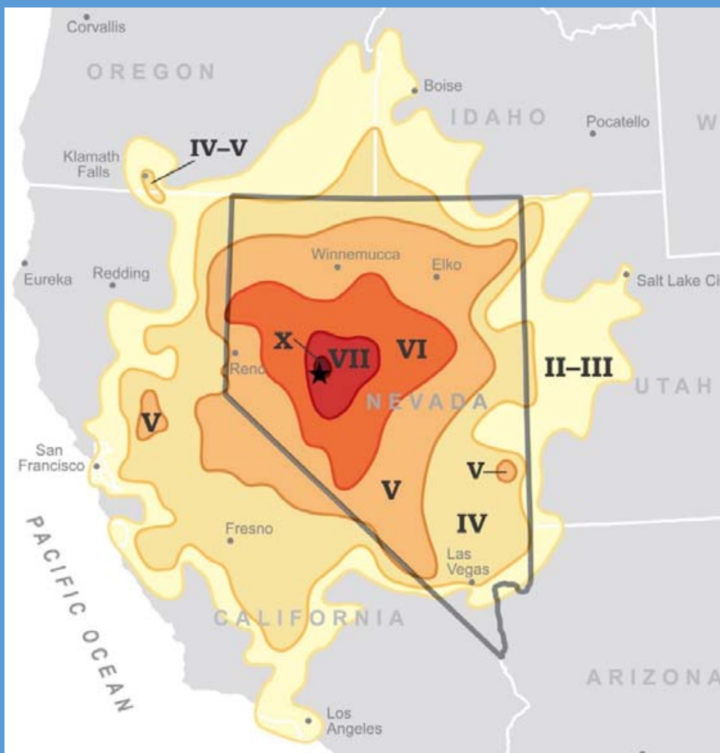


dePolo and dePolo, 2012

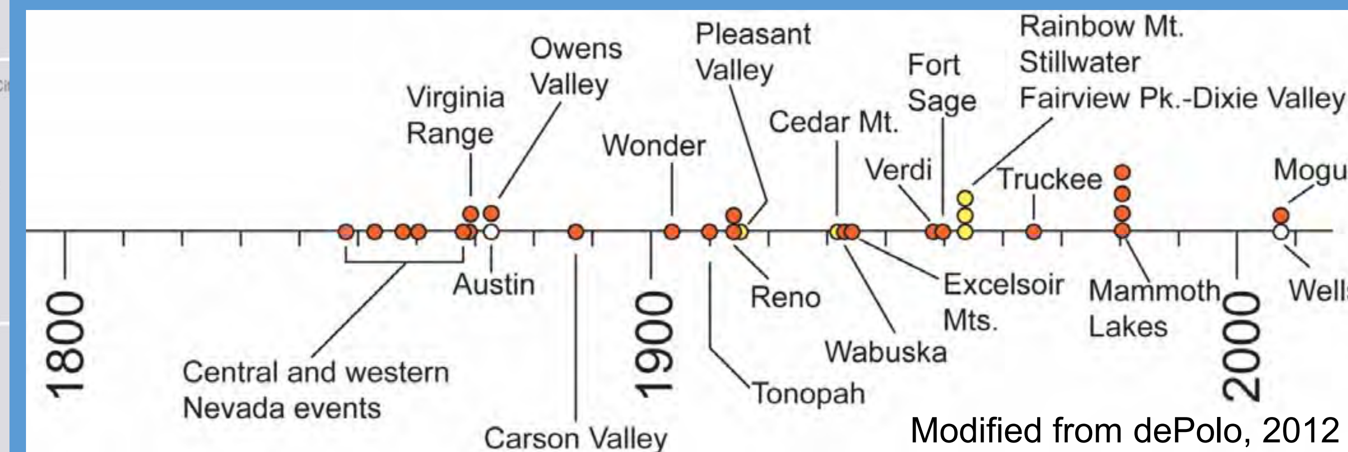
Major earthquakes in Nevada through time by magnitude



- over 35 M>6
- Magnitudes range from6.0-7.6



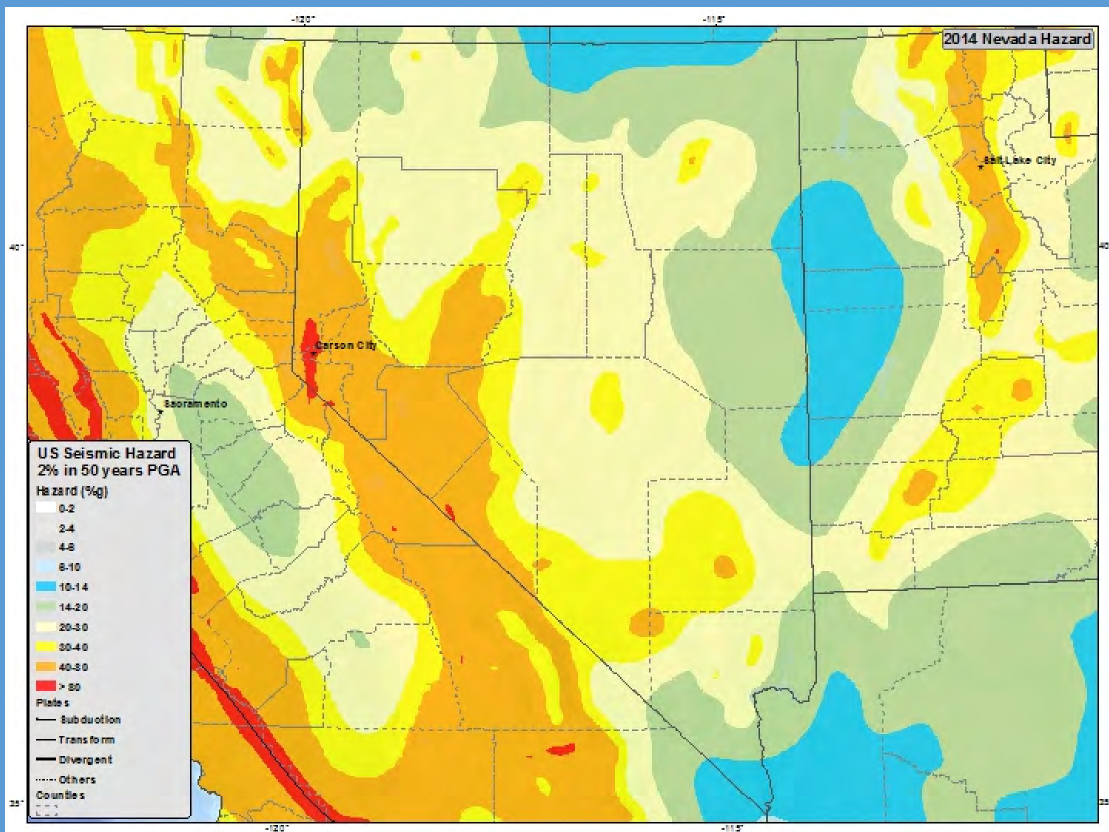
Nearly all major historic earthquakes have impacted the Reno area



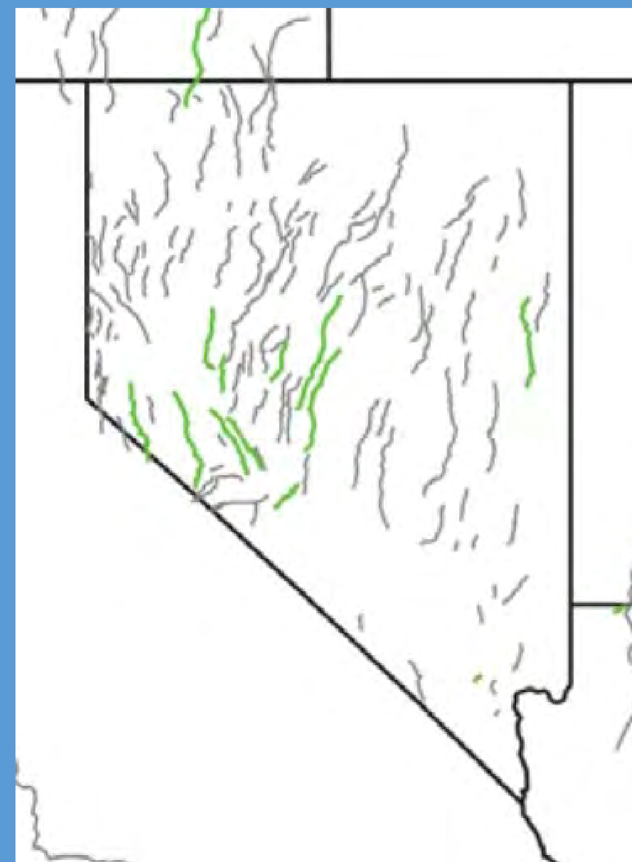
Primary and secondary effects
Surface fault rupture
Liquefaction, lateral spread
Rockfall, etc.

- Development pressures
- Railroad and highway freight interruptions will have national economic effects and impede rescue and recovery operations.

2014 USGS seismic hazard map
2% chance in 50 years of exceeding
PGA of 50% gravity.



Updated faults in green



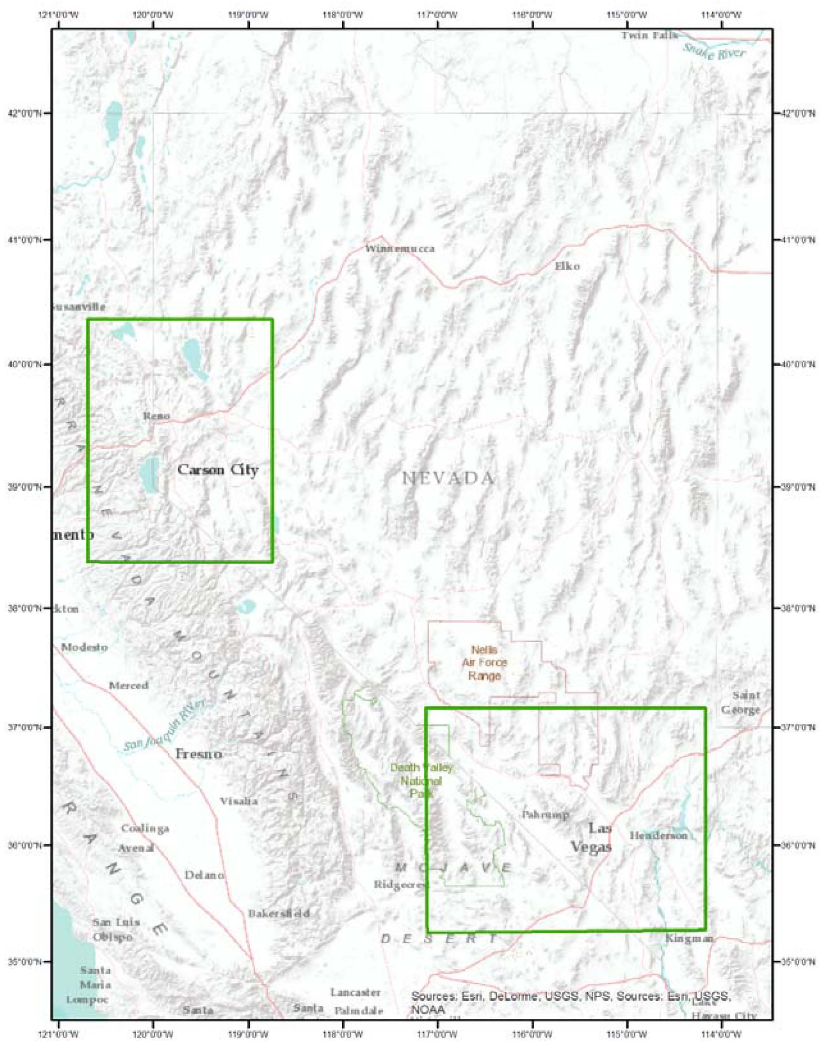
2014 update of NHM

- Generally only includes faults with repeated evidence of surface rupture
- Adjusted source characterization based on new literature (timing, amount of slip, slip rate)
- Used combined geodetic and geologic based slip rate models
- Source model is ~75% incomplete

Additional geologic work will

- Refine length of surface ruptures (Mag scaling relations M vs length)
- Document refined slip rates, age of most recent event, ages of paleoevents, recurrence.

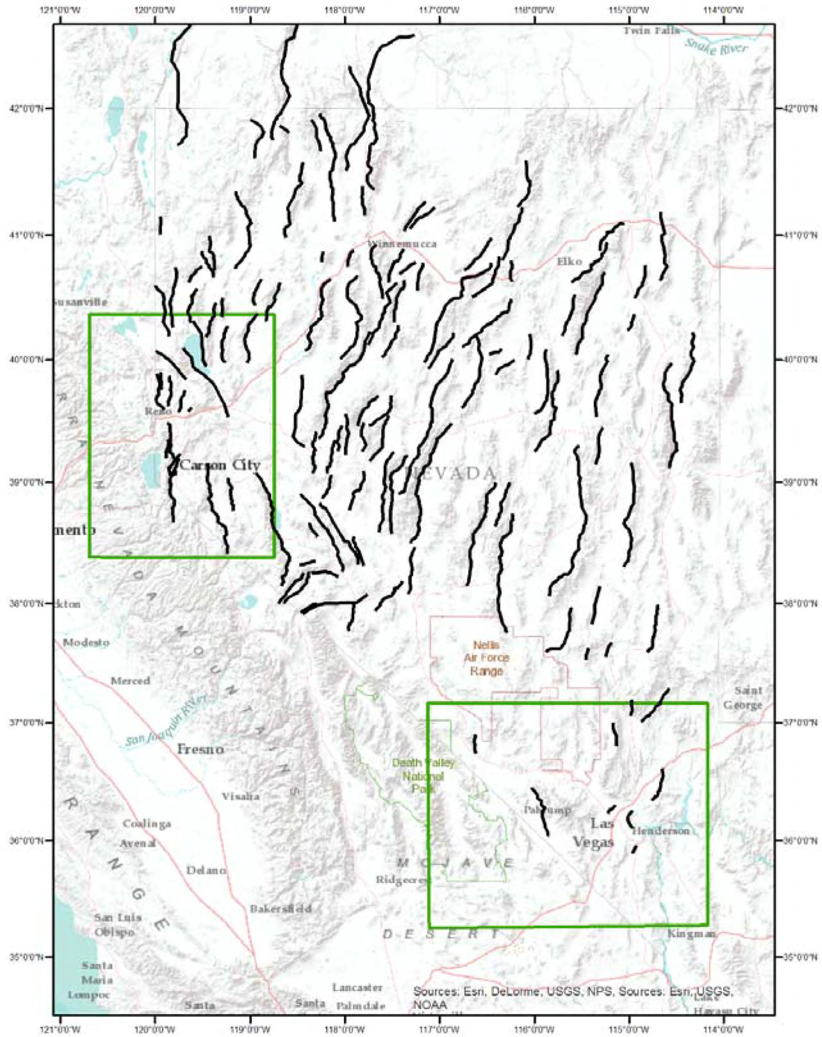
			2008	2014	
Benton Spring fault	Nevada	heave rate	0.27	0.5	Bell (1995); Wesnousky (2005).
Bettles Well-Petrified Springs fault	Nevada	heave rate		1.3	Wesnousky (2010).
Desatoya Mountains fault zone	Nevada	throw rate	0.1	0.04	Koehler and Wesnousky (2011).
Eglington fault	Nevada	constrain annual rate	0.000066	0.00044	C. dePolo (written commun., 2013
Lone Mountain fault zone	Nevada	throw rate	0.13	0.2	Hoeft and Frankel (2010).
Rainbow Mountain fault zone	Nevada	heave rate	0.15	0.2	Caskey and others (2004).
Sand Springs Range fault	Nevada	throw rate	0.1	0.2	Bell and others (2004).
Schell Creek Range fault system	Nevada	throw rate	0.01	0.1	Koehler and Wesnousky (2011).
Smith Valley fault	Nevada	throw rate	0.38	0.25	Hayes (1985); Wesnousky and Caffee (2011).
Toiyabe Range fault zone	Nevada	throw rate	0.22	0.06	Koehler and Wesnousky (2011).
Wassuk Range fault zone	Nevada	throw rate	0.55	0.7	Bormann and others (2012).
Western Toiyabe Range fault zone	Nevada	throw rate	0.2	0.07	Koehler and Wesnousky (2011).



NBMG is developing a new database to evaluate the current state of knowledge on Quaternary fault Rupture parameters.

New database includes:

- Available information from QFF
- Available information from NHM
- Updated references
- Consensus fault parameters



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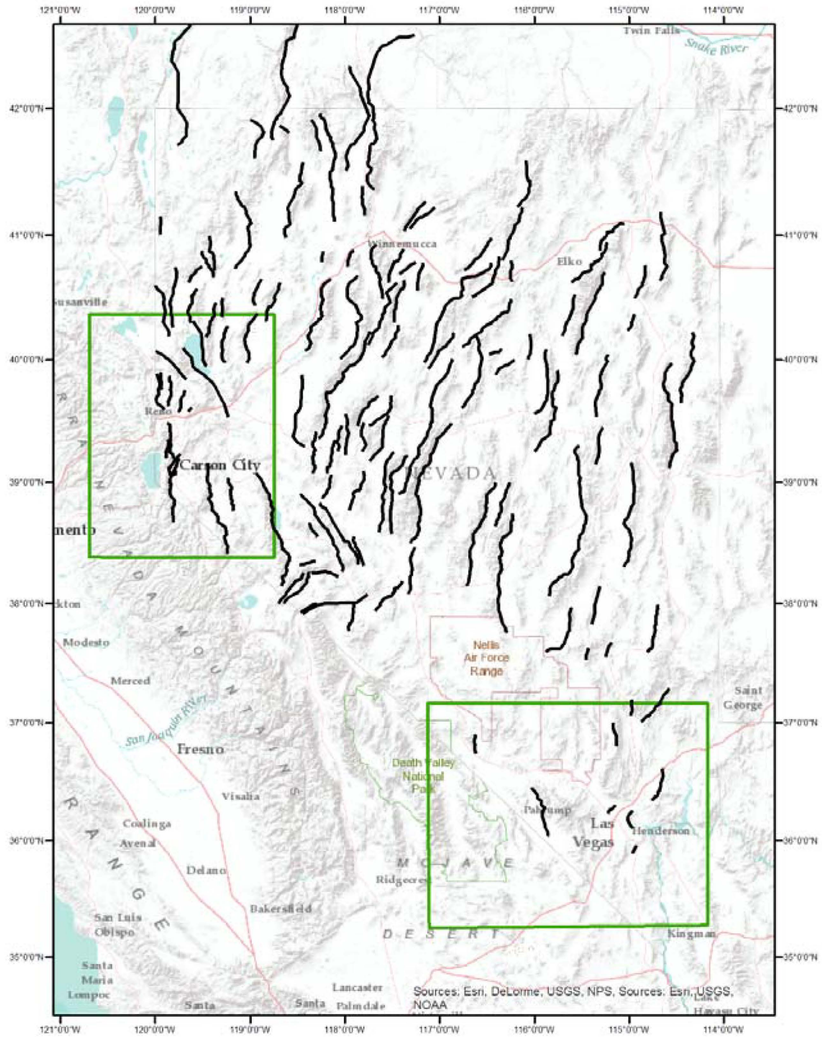
35°0'0"N
Twin Falls
Snake River
Winnemucca
Elko
Reno
Carson City
Modesto
Merced
San Joaquin River
Fresno
Visalia
Coalinga
Avenal
Delano
Bakersfield
San Luis Obispo
Santa Maria
Lompoc
Lancaster
Palmdale
Nellis Air Force Range
Death Valley National Park
Pahrump
Las Vegas
Henderson
Saint George
Kingman
Ridgecrest
MOJAVE DESERT
Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA



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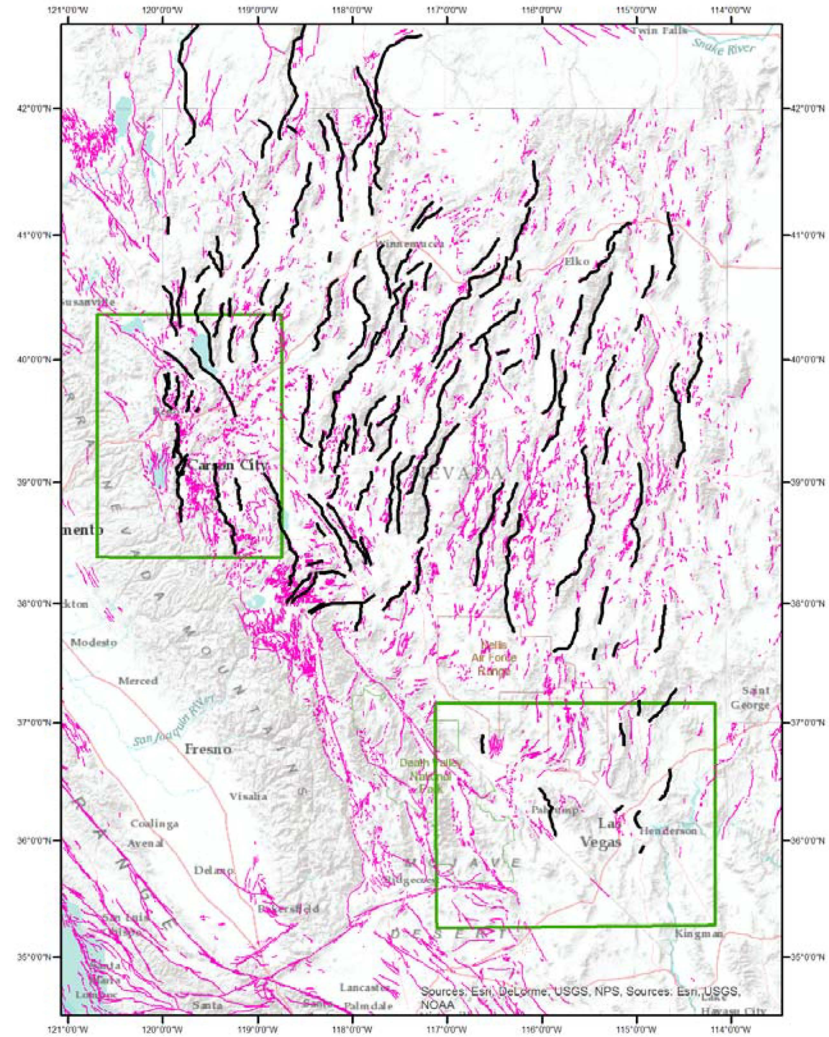
Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA



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Avenal
Las Vegas
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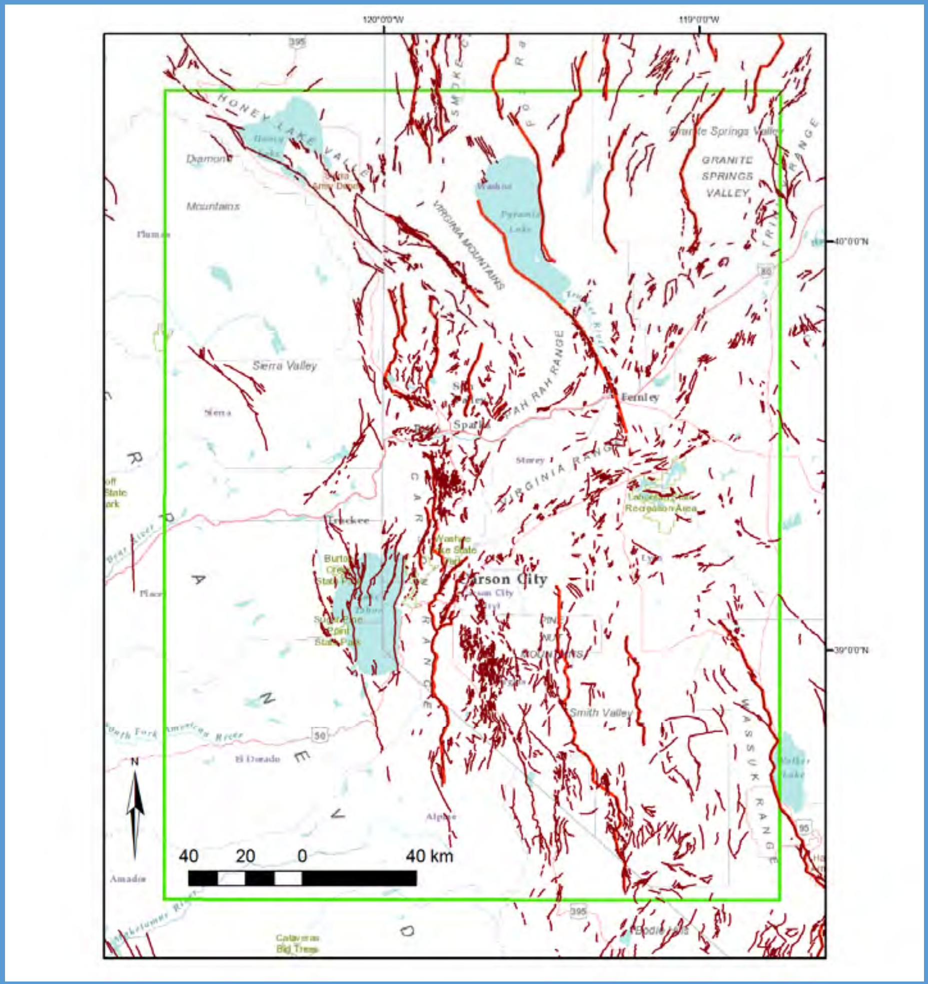
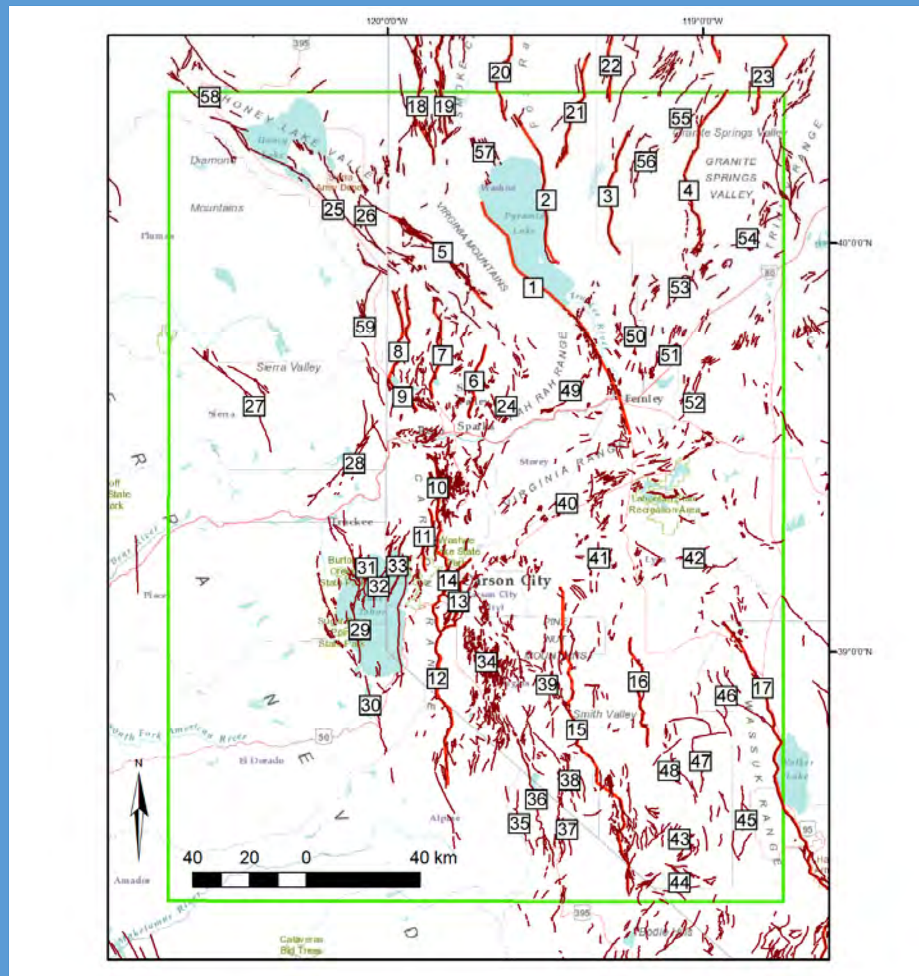
Saint George
Kingman
Lancaster
Palmdale
Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA

Reno focus area



Reno focus area

- 66 Q faults
- 23 included in NHM
- Data mining from QFF is completed.
- Most not updated since 1998/9



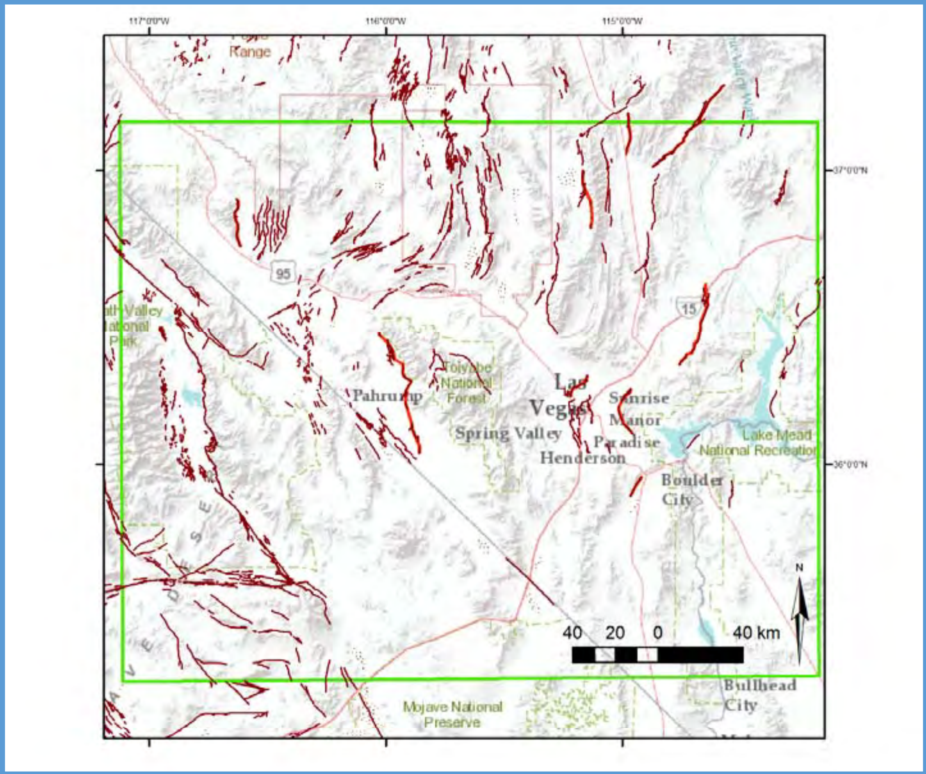
#of faults	slip rate
44	<0.2 mm/yr
10	0.2-1.0 mm/yr
4	1.0-5.0 mm/yr

Paleoseismic studies

10 faults in QFF

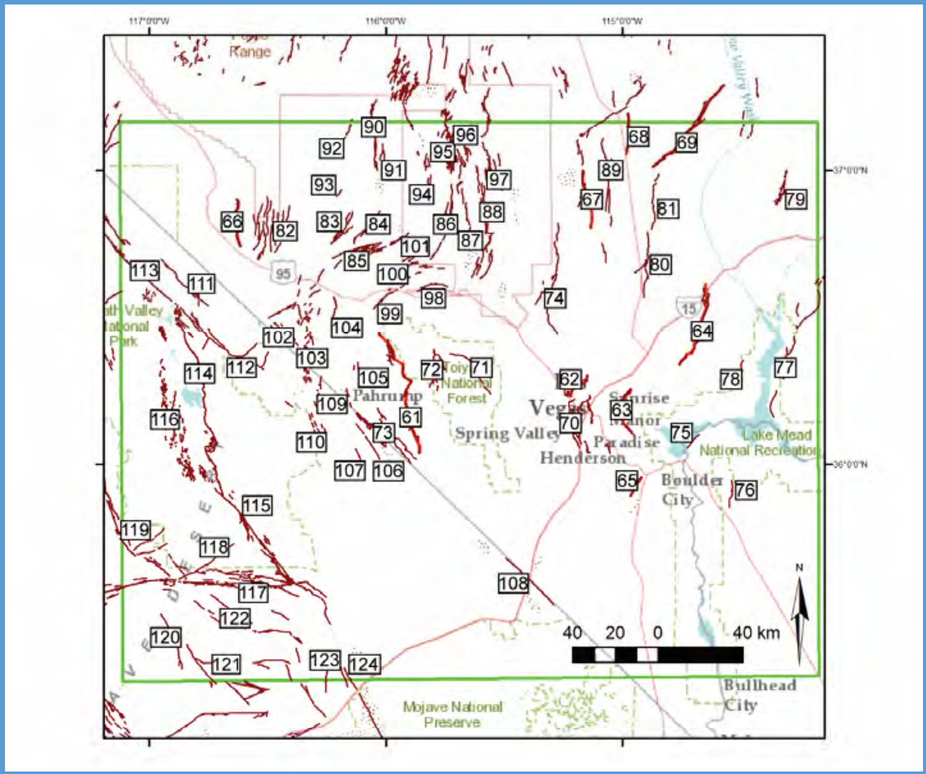
At least 6 faults have new studies

Las Vegas focus area



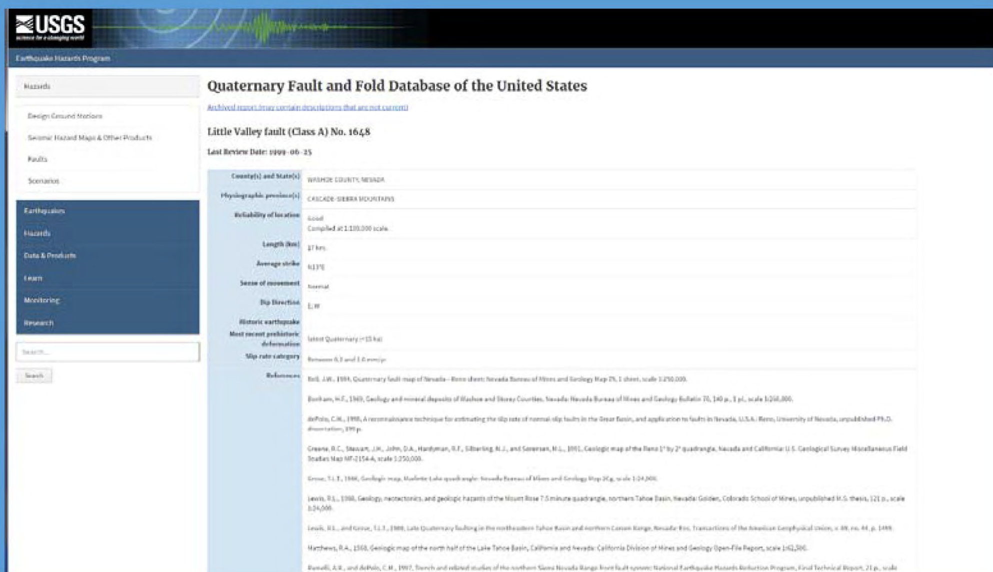
Las Vegas focus area

- 64 faults
- 9 included in NHM.
- Data mining from QFF not done yet.
- New fault assessment for Las Vegas Valley has started.



New project aimed at
- generating new geologic and fault maps of the Las Vegas Valley area;
- Paleoseismic investigations of earthquake sources (slip rate, recurrence)
- evaluation of fault source geometry, segmentation, and maximum magnitude potential

Quaternary fault and fold database of the U.S.



- Older info now archived, important info for evaluating Q parameters (geomorph expression, paleoseismic studies, etc.).
- Description pages not available for some faults.
- Some faults only accessible using text search others using interactive map.
- Ave. strike reported differently between pop up windows and desc. pages.
- Multiple entries for single faults (diffs. in strike and relative activity). Which to use?
- Back button results in full world extent (cumbersome).

Research Paper

GEOSPHERE

GEOSPHERE; v. 13, no. 1

doi:10.1130/GES01295.1

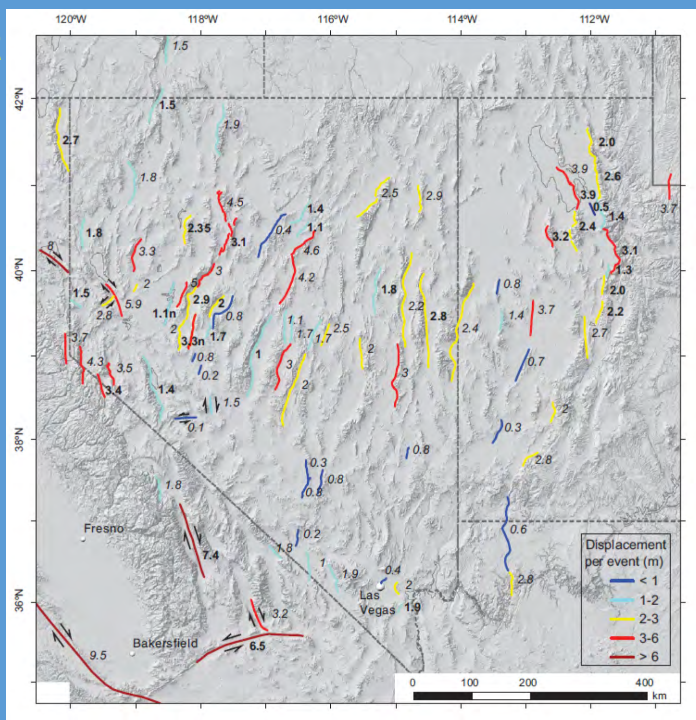
16 figures; 1 table; 1 supplemental file

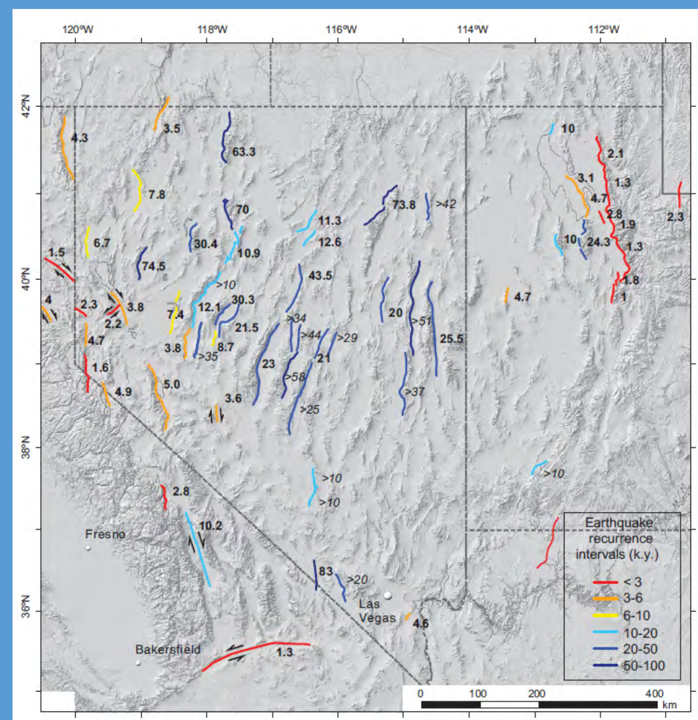
CORRESPONDENCE: eugenie.perouse@gmail.com

Spatiotemporal evolution of fault slip rates in deforming continents: The case of the Great Basin region, northern Basin and Range province

Eugénie Pérouse* and Brian P. Wernicke
Division of Geological and Planetary Sciences, California Institute of Technology, 1200 East California Boulevard, Pasadena, California 91125, USA

Displacement per event





Recurrence

Neotectonic database
Showing types of data and
Inferred displacement rate.


Research Paper

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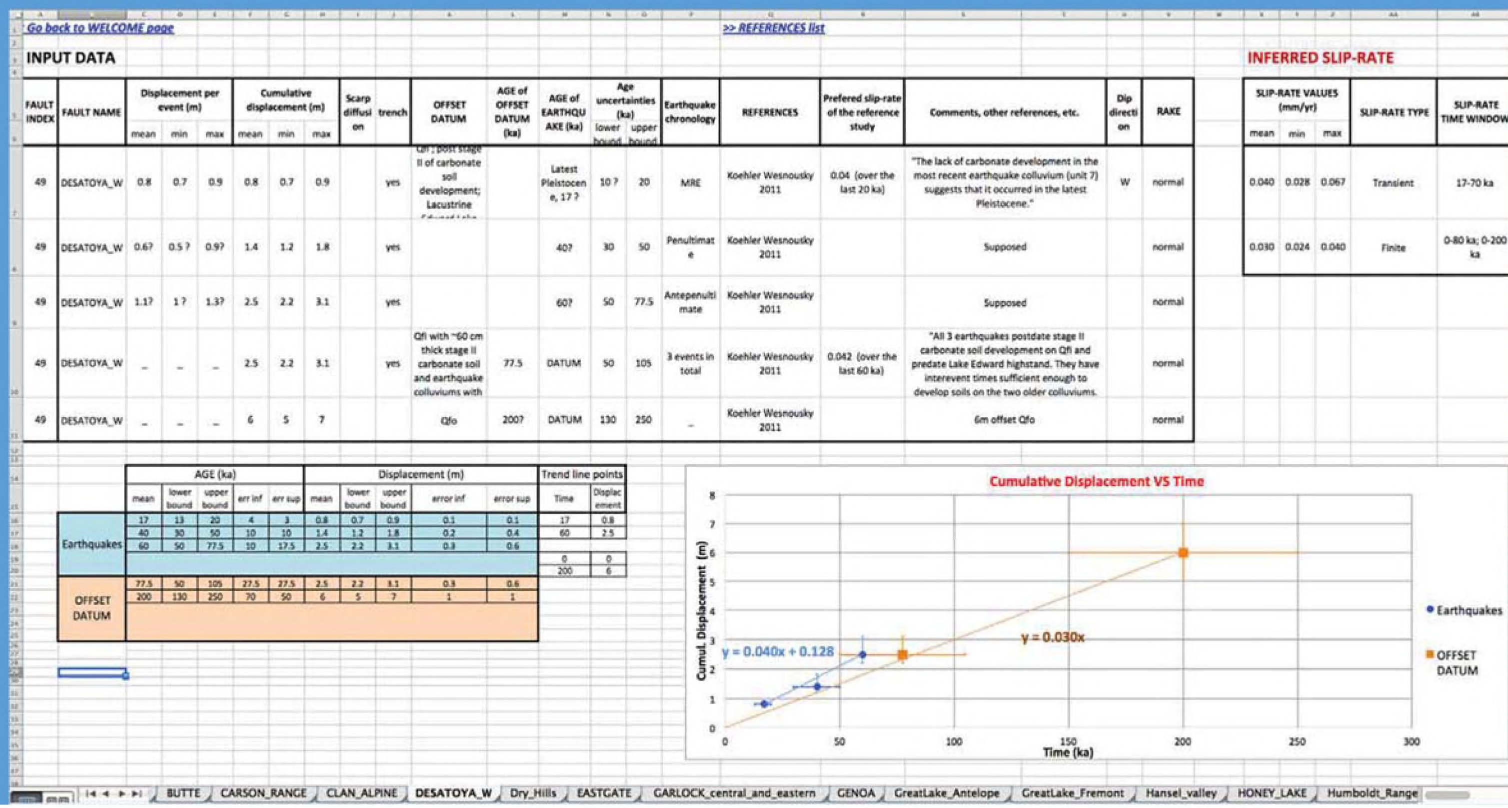

Go back to WELCOME page

>> REFERENCES list

INPUT DATA

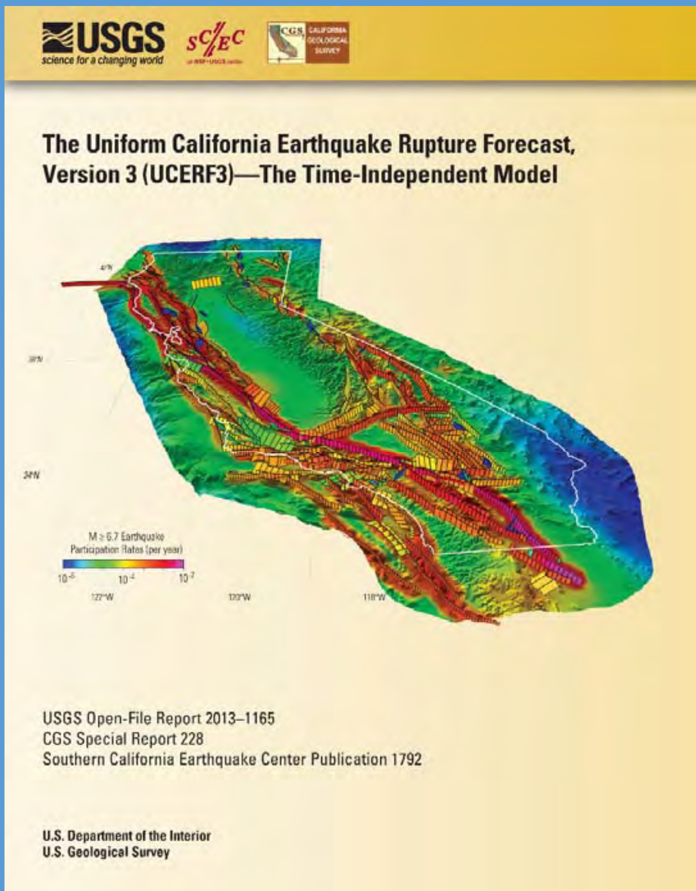
FAULT INDEX	FAULT NAME	Displacement per event (m)			Cumulative displacement (m)			Scarp diffusion	trench	OFFSET DATUM	AGE of OFFSET DATUM (ka)	AGE of EARTHQUAKE (ka)	Age uncertainties (ka)		Earthquake chronology	REFERENCES	Prefered slip-rate of the reference study	Comments, other references, etc.	Dip direction	RAKE
		mean	min	max	mean	min	max						lower bound	upper bound						
49	DESATOYA_W	0.8	0.7	0.9	0.8	0.7	0.9		yes	Qfi ; post stage II of carbonate soil development; Lacustrine		Latest Pleistocene, 17 ?	10 ?	20	MRE	Koehler Wesnousky 2011	0.04 (over the last 20 ka)	"The lack of carbonate development in the most recent earthquake colluvium (unit 7) suggests that it occurred in the latest Pleistocene."	W	normal
49	DESATOYA_W	0.6?	0.5 ?	0.9?	1.4	1.2	1.8		yes			40?	30	50	Penultimate	Koehler Wesnousky 2011		Supposed		normal
49	DESATOYA_W	1.1?	1 ?	1.3?	2.5	2.2	3.1		yes			60?	50	77.5	Antepenultimate	Koehler Wesnousky 2011		Supposed		normal
49	DESATOYA_W	_	_	_	2.5	2.2	3.1		yes	Qfi with ~60 cm thick stage II carbonate soil and earthquake colluviums with	77.5	DATUM	50	105	3 events in total	Koehler Wesnousky 2011	0.042 (over the last 60 ka)	"All 3 earthquakes postdate stage II carbonate soil development on Qfi and predate Lake Edward highstand. They have interevent times sufficient enough to develop soils on the two older colluviums.		normal
49	DESATOYA_W	_	_	_	6	5	7			Qfo	200?	DATUM	130	250	_	Koehler Wesnousky 2011		6m offset Qfo		normal

INFERRED SLIP-RATE

SLIP-RATE VALUES (mm/yr)			SLIP-RATE TYPE	SLIP-RATE TIME WINDOW
mean	min	max		
0.040	0.028	0.067	Transient	17-70 ka
0.030	0.024	0.040	Finite	0-80 ka; 0-200 ka

	AGE (ka)					Displacement (m)					Trend line points	
	mean	lower bound	upper bound	err inf	err sup	mean	lower bound	upper bound	error inf	error sup	Time	Displacement
Earthquakes	17	13	20	4	3	0.8	0.7	0.9	0.1	0.1	17	0.8
	40	30	50	10	10	1.4	1.2	1.8	0.2	0.4	60	2.5
	60	50	77.5	10	17.5	2.5	2.2	3.1	0.3	0.6		
											0	0
											200	6
OFFSET DATUM	77.5	50	105	27.5	27.5	2.5	2.2	3.1	0.3	0.6		
	200	130	250	70	50	6	5	7	1	1		

UCERF III



Applications of data in the CA/NV borderlands region

- Paleoseismic sites recurrence database
- Geologic-slip-rate data and geologic deformation model
- Incorporation of geodetic data
- Fault-to-fault rupture probabilities
- Applications of seismicity rate and mag-freq distribution

NBMG StateMAP Program

Text and references accompanying Nevada Bureau of Mines and Geology Open-File Report 16-6

Preliminary Geologic Map of the South Half of the Mount Rose NW Quadrangle, Washoe County, Nevada

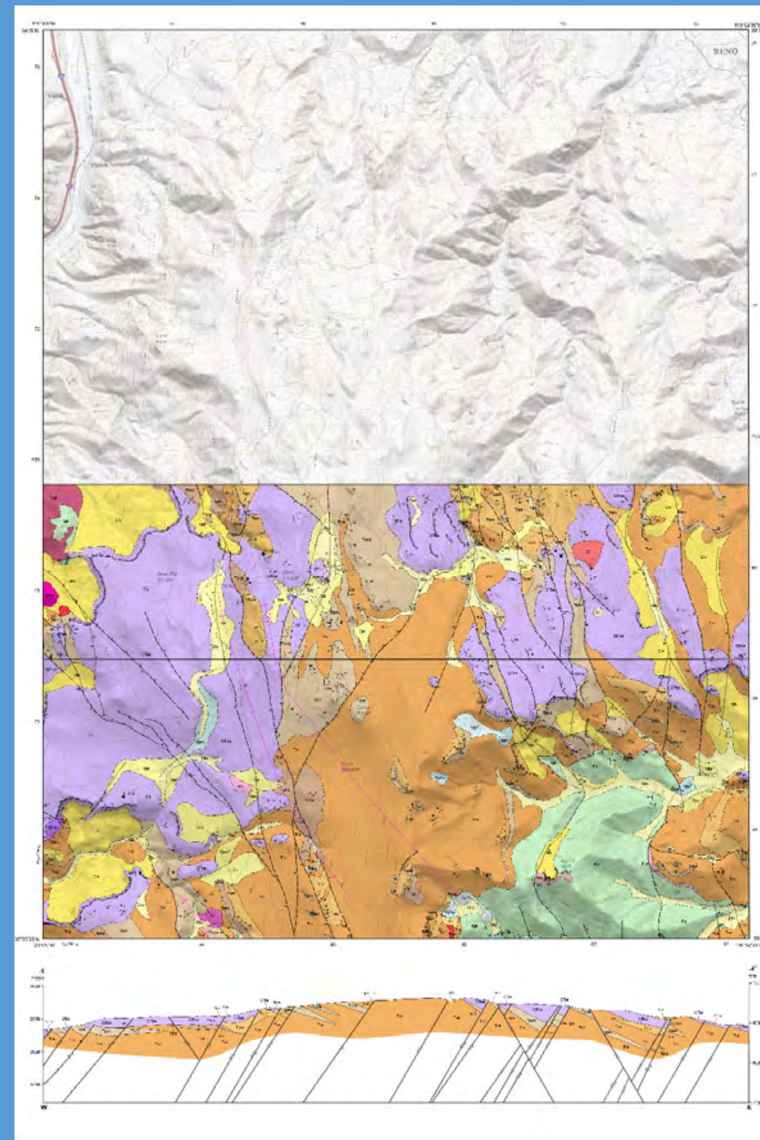
by

Nicholas H. Hinz and Alan R. Ramelli

Nevada Bureau of Mines and Geology, University of Nevada, Reno, NV

2016

- On-going annual mapping
- Discovery of new faults
- Revised structural models (dip, etc.)
- Documentation of Quaternary fault parameters



The Path Forward

- 2017 Working Group on Nevada Seismic Hazards
  workshop based on the Utah working group model.
- Continued collaboration between Nevada Seismological Laboratory
  NBMG, UNR & UNLV geology, Center for Neotectonic Studies (Nevada working group).
- Compile updates to knowledge based on recent literature (paleoseismology, geodesy, seismology).
- Review existing databases and methodologies (NHM, Perouse et al., UCERF III).
- Develop consensus UNR fault parameters within focus areas (slip rate, Mmax, dip, recurrence).
- Review key research directions aimed at reducing uncertainties and improving hazard estimates.
- Prioritize faults for additional study (annual update of priority list for NEHRP RFP).
- Communicate updates to USGS, NESC, WSSPC, and emergency management personnel
  (NHM updates, scenarios, building code officials, response and recovery, etc.).

Thanks!

Comparison of Geodetic and Geological/Seismological Moment Rates for the Wasatch Front Region, Utah

by

James C. Pechmann
University of Utah, Salt Lake City, Utah

Yuehua Zeng
U.S. Geological Survey, Golden, Colorado

Patricia A. Thomas
AECOM, Oakland, California

Mark D. Petersen
U.S. Geological Survey, Golden, Colorado

Utah Quaternary Fault Parameters Working Group
February 8, 2017

Objective

Test the Working Group on Utah Earthquake Probabilities Wasatch Front region source model by

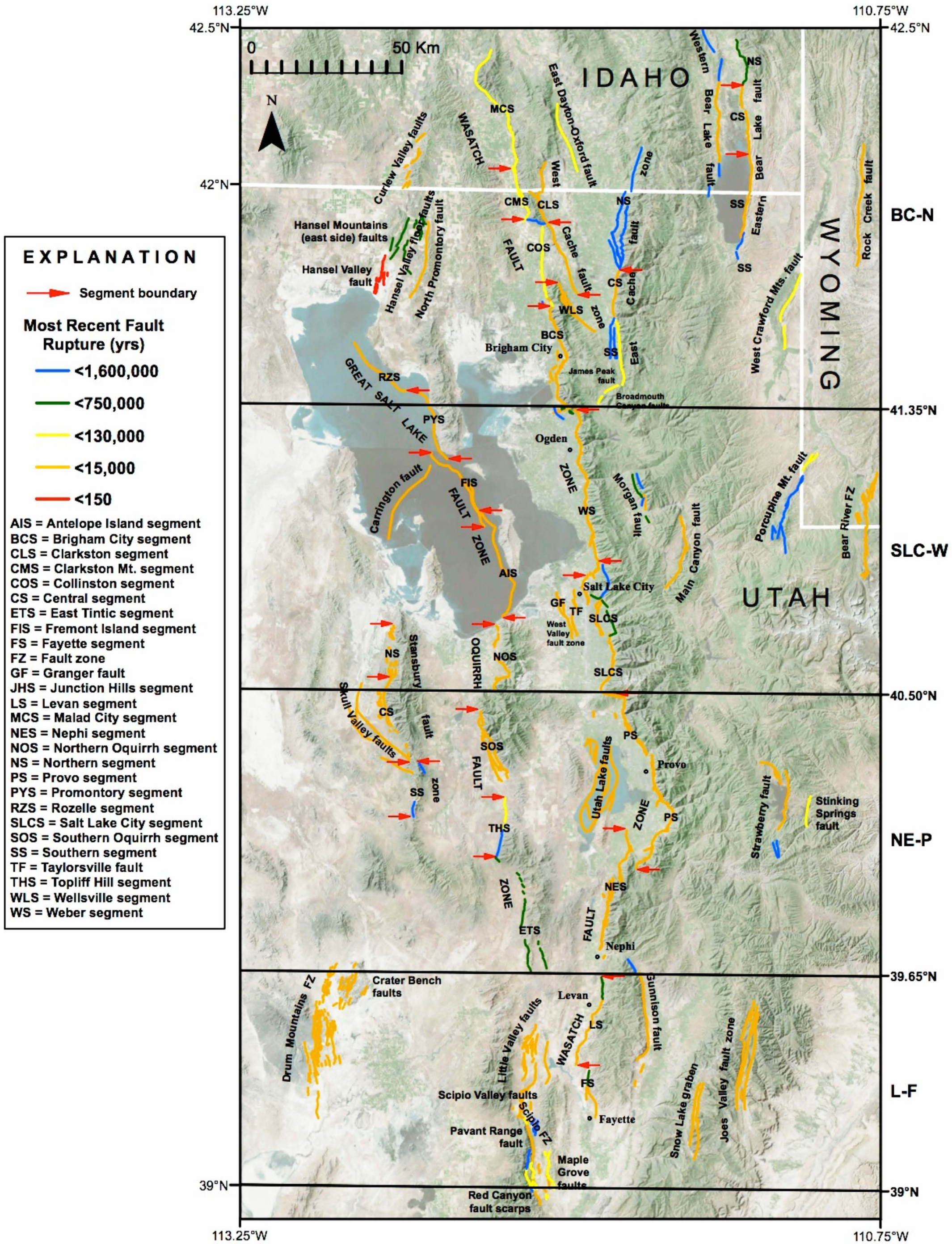
- **Comparing geological/seismological moment rates calculated from this model with**
- **"Geodetic moment rates" calculated from crustal deformation measurements.**

Results

- **The moment rates agree within uncertainties for the WF region as a whole and 3 of 4 subregions.**
- **In the 4th and southernmost subregion, the geodetic moment rate is 5X higher than the geological/ seismological moment rate.**

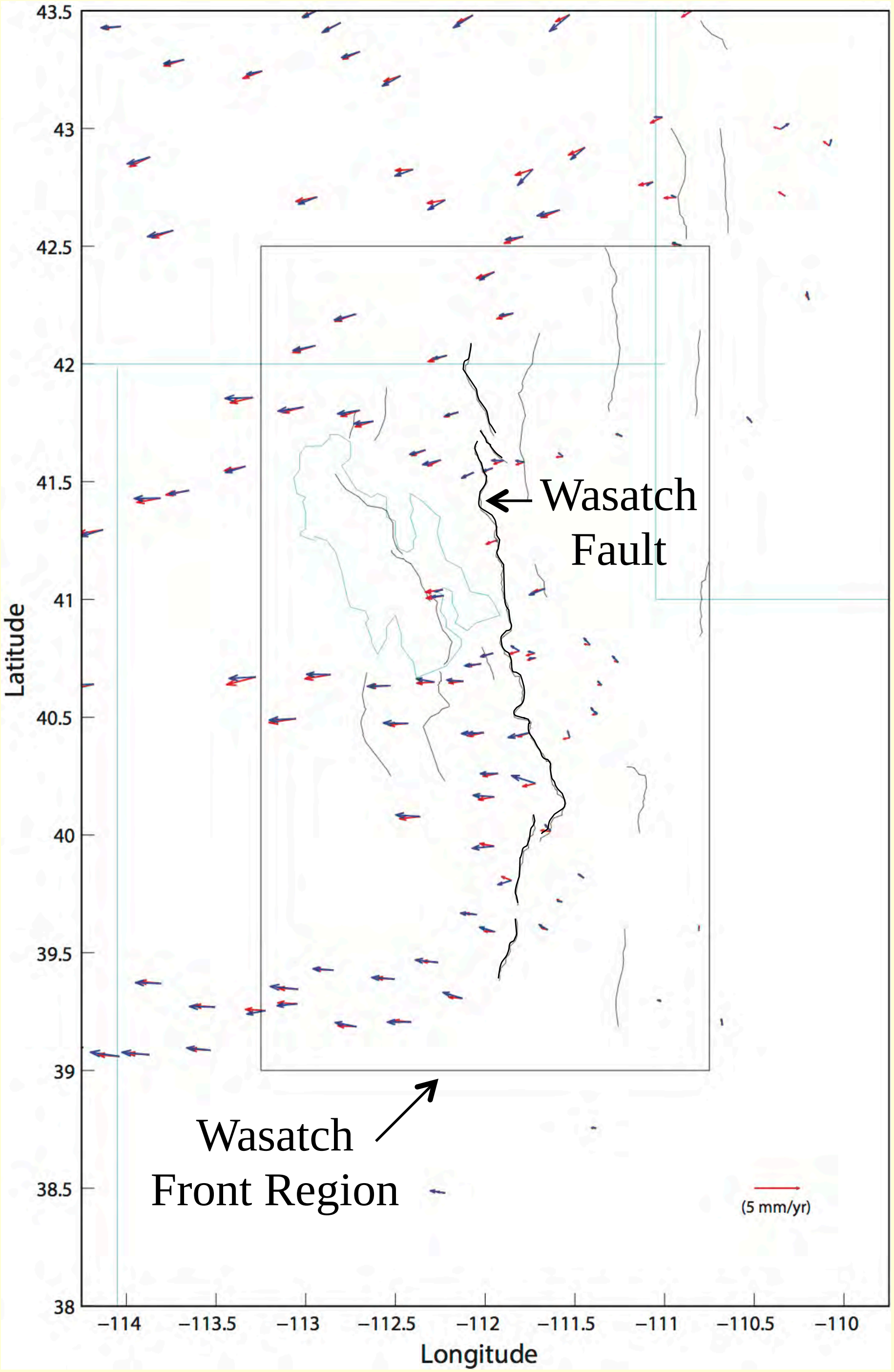
Wasatch Front Region

with faults considered in WGUEP earthquake forecast



Region divided into 4 subregions on Wasatch fault segment boundaries:

- BC-N; Brigham City & N
- SLC-W; SLC and Weber
- NE-P; Nephi and Provo
- L-F; Levan and Fayette



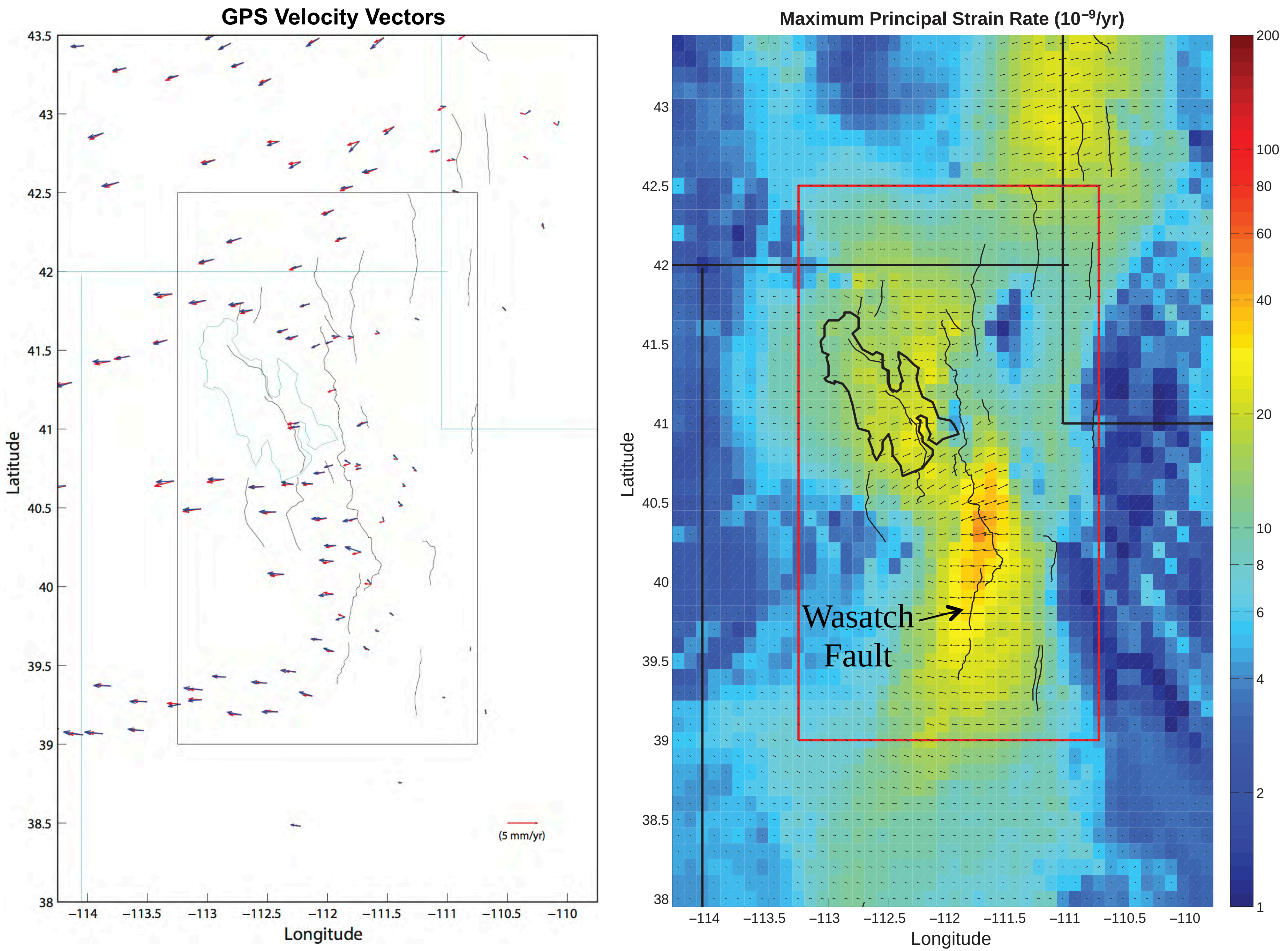
GPS Velocity Field

(Zeng and Shen, 2014; data set modified from McCaffrey et al., 2014)

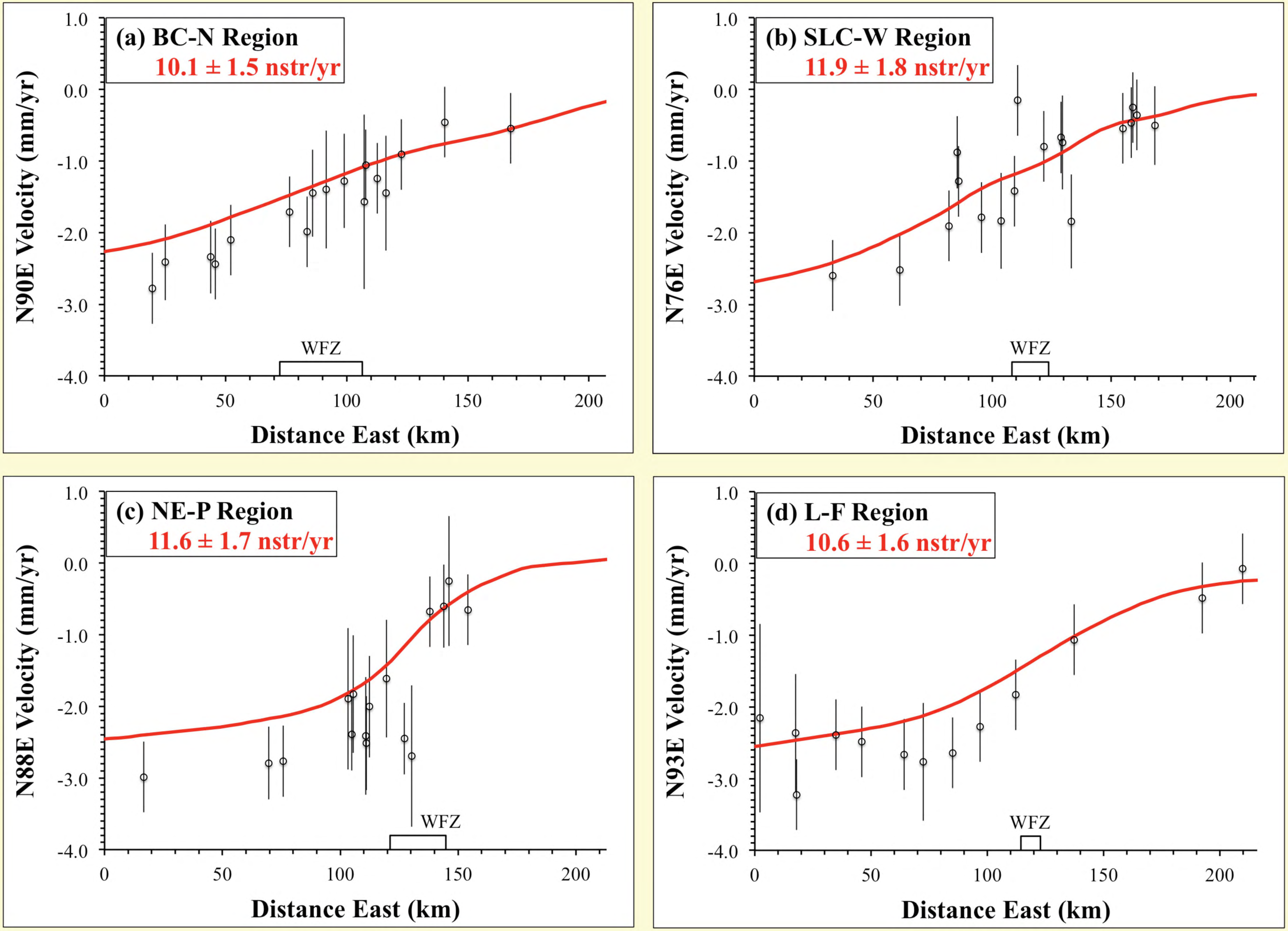
Blue: Observed

Red: Predicted by Zeng and Shen’s (2014) fault slip-rate inversion

Black lines: Faults used in the Zeng and Shen inversion



GPS Velocity Vectors
Latitude
Longitude
43.5
43
42.5
42
41.5
41
40.5
40
39.5
39
38.5
38
−114
−113.5
−113
−112.5
−112
−111.5
−111
−110.5
−110
(5 mm/yr)
Maximum Principal Strain Rate (10^{-9}/yr)
Wasatch Fault
200
100
80
60
40
20
10
8
6
4
2
1



(a) BC-N Region
10.1 ± 1.5 nstr/yr
N90E Velocity (mm/yr)
Distance East (km)
WFZ
1.0
0.0
-1.0
-2.0
-3.0
-4.0
0
50
100
150
200
(b) SLC-W Region
11.9 ± 1.8 nstr/yr
N76E Velocity (mm/yr)
Distance East (km)
WFZ
(c) NE-P Region
11.6 ± 1.7 nstr/yr
N88E Velocity (mm/yr)
Distance East (km)
WFZ
(d) L-F Region
10.6 ± 1.6 nstr/yr
N93E Velocity (mm/yr)
Distance East (km)
WFZ

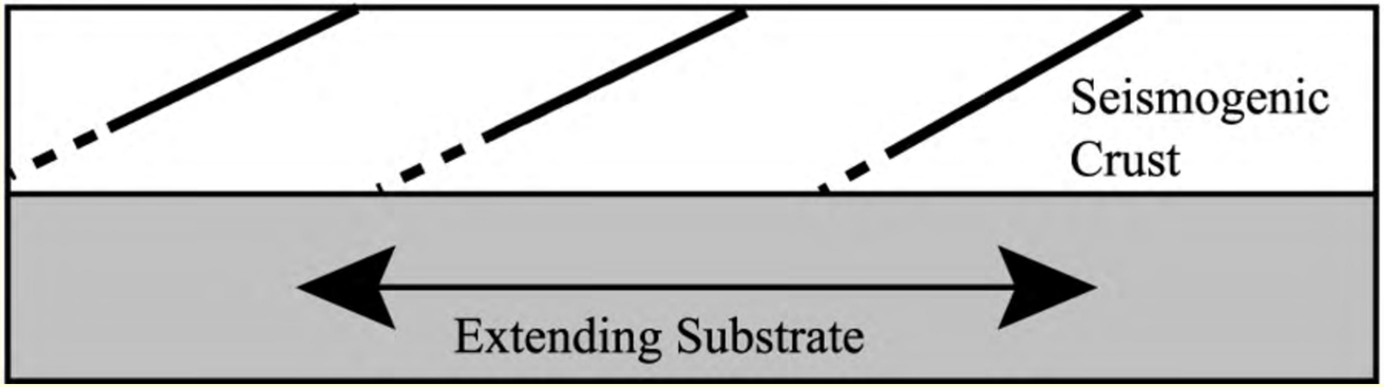
For a set of parallel normal faults, Kostrov's tensor equation reduces to the scalar equation

$$\dot{M}_0 = \frac{2\mu A H_s}{\sin 2\delta}\dot{\epsilon}_1$$

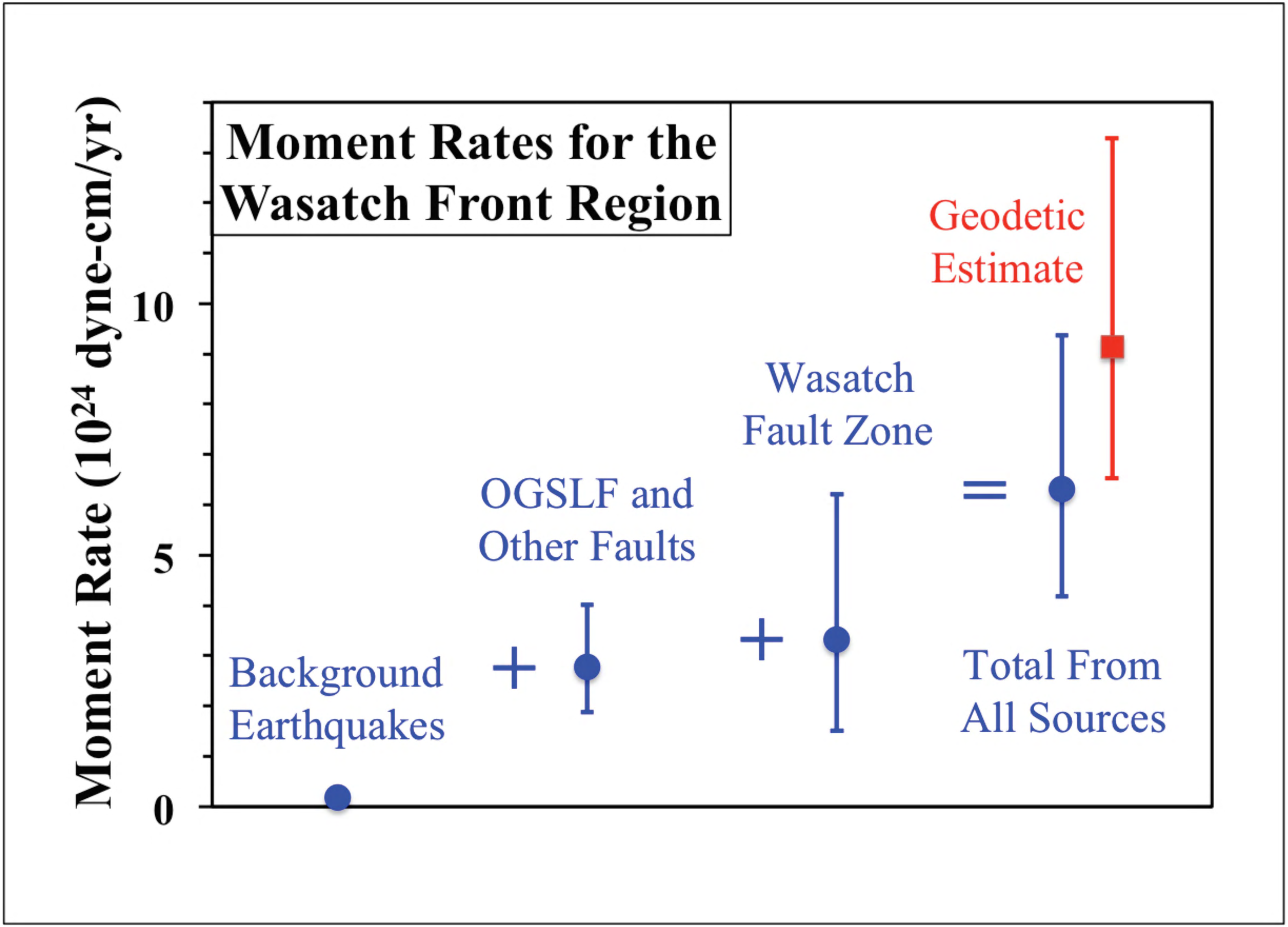
where $\dot{M}_0$ = seismic moment rate
= "geodetic moment rate"
μ = rigidity (= 3×10^{11} dynes/cm^2)
A = surface area of region
H_S = thickness of seismogenic layer (= 15 ± 3 km)
δ = fault dip (= 50° ± 15°)
$\dot{\epsilon}_1$ = extensional strain rate ⊥ to faults; assume = max principal strain rate

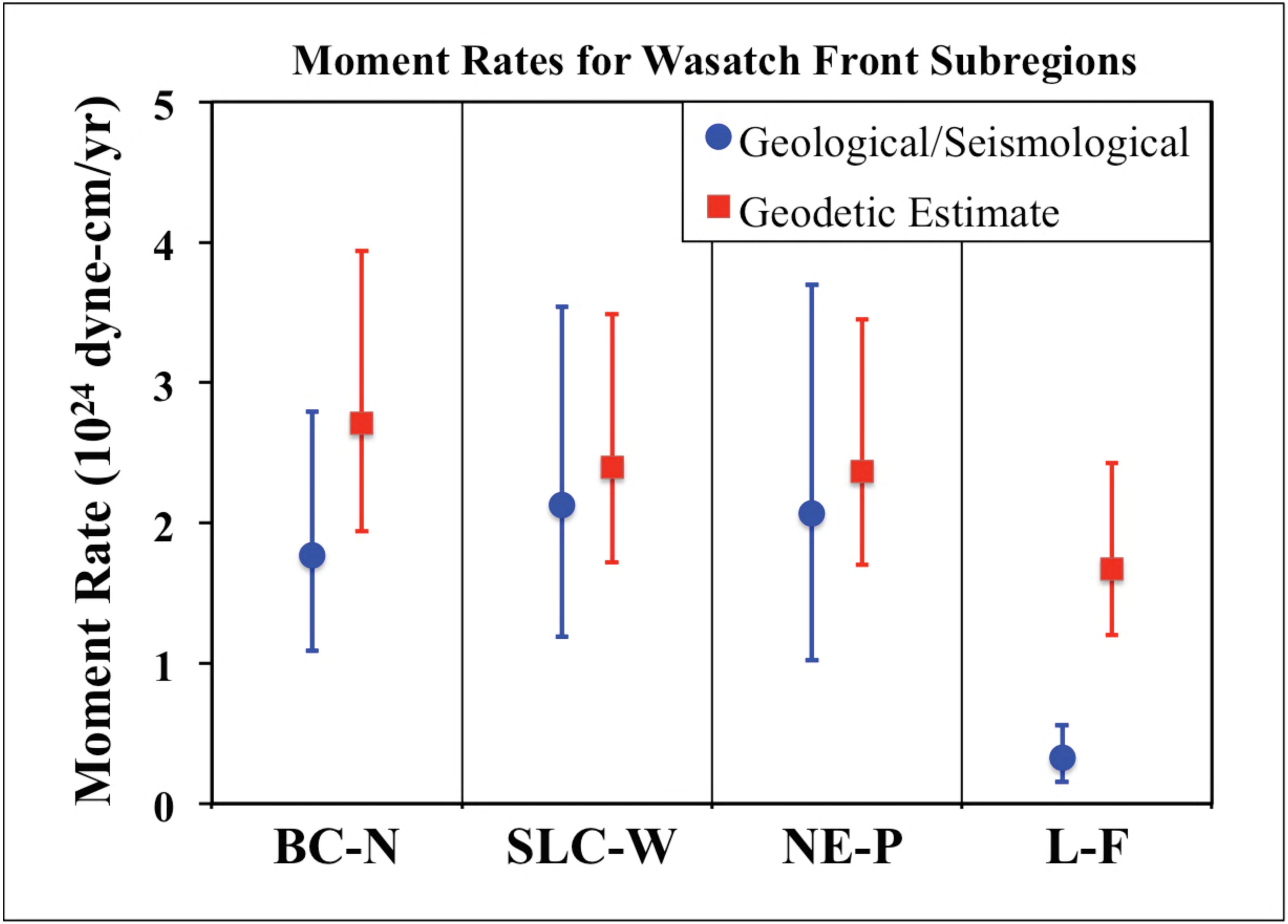
Why is Kostrov's Equation Applicable?

- Moment rate equation on the previous slide is the same as that of a 2-D block model
- By applying this equation, we are assuming that the short-term extension rate is equal to the long-term and large scale permanent extension rate caused by earthquakes.



Possible strain accumulation model (Niemi et al., 2004)


Moment Rates for the Wasatch Front Region
Moment Rate (10^{24} dyne-cm/yr)
10
5
0
Background Earthquakes
+
OGSLF and Other Faults
+
Wasatch Fault Zone
=
Total From All Sources
Geodetic Estimate



Moment Rates for Wasatch Front Subregions
Moment Rate (10^24 dyne-cm/yr)
0
1
2
3
4
5
Geological/Seismological
Geodetic Estimate
BC-N
SLC-W
NE-P
L-F

Slip Rates Needed to Explain Missing L-F Region Moment Rate

Faults or Fault Segments	Total Length (km)	Assumed Dip	Vertical Slip Rate (mm/yr)	Required Slip Rate (mm/yr)
Levan segment, WFZ	31	50°	~ 0.3	4.4
Fayette segment, WFZ	22		~ 0.175	2.5
Levan segment, WFZ	31	30°	~ 0.3	2.1
Fayette segment, WFZ	22		~ 0.175	1.2
12 Quaternary faults not in WGUEP Model	175	50°	< 0.2	1.0 (on all)
Unknown N/S-striking fault spanning region	72	50°	––	2.4
	72	30°	––	1.2

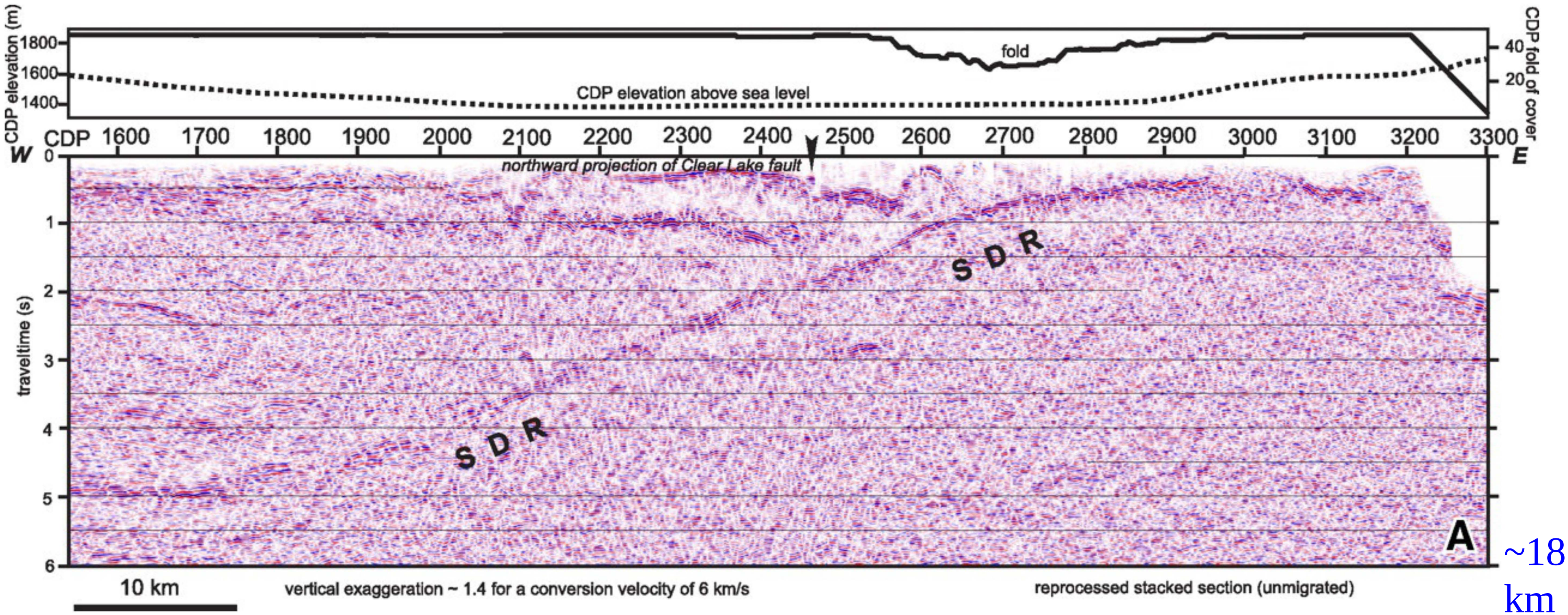
- For reference:
- Slip rates on 5 central WFZ segs. are 1.3 to 2.0 mm/yr (WGUEP).
- 1.0 mm/yr vertical slip rate –> 13 m post-Bonneville (13 ka) offset.

Conclusions

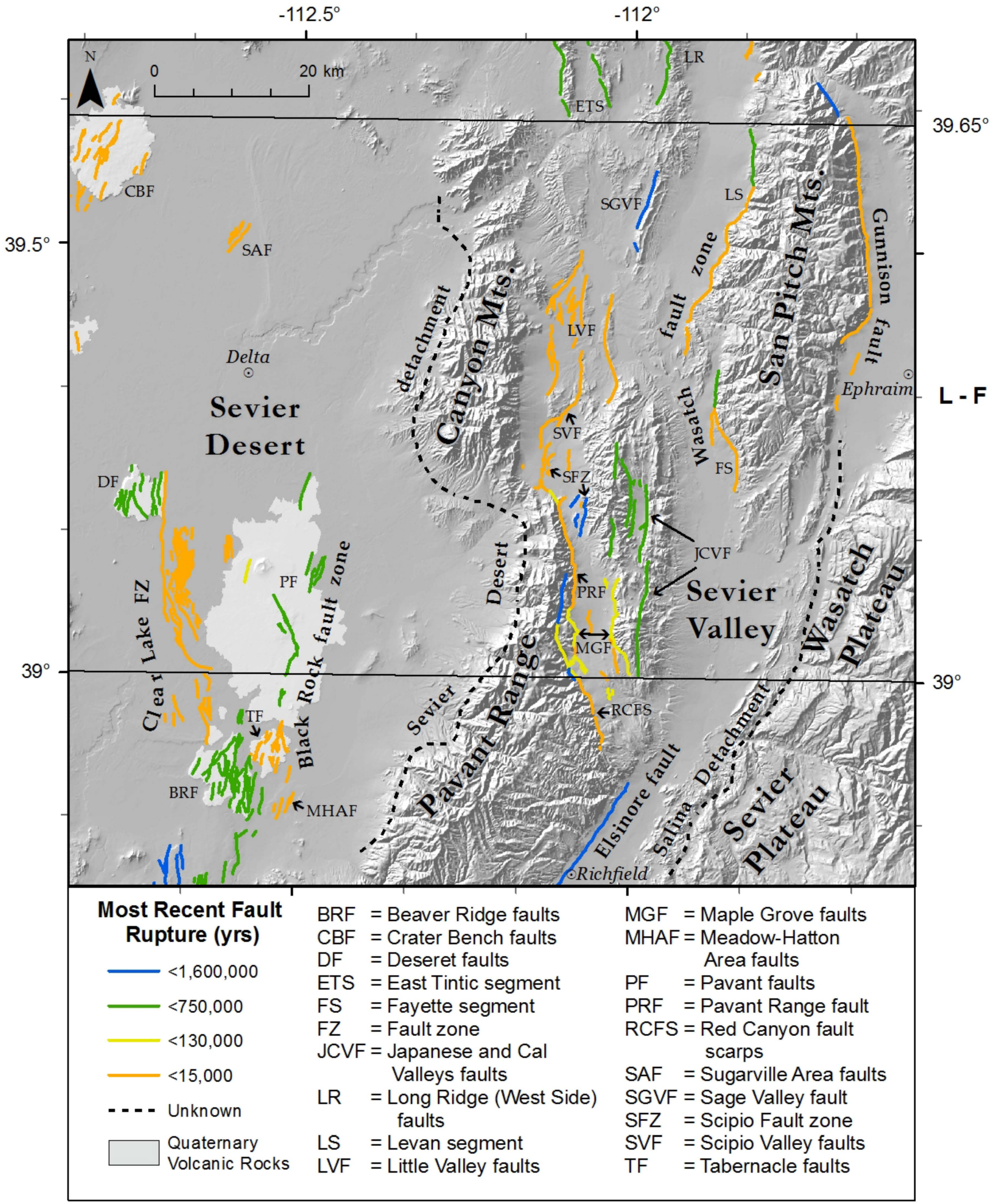
- **Geodetic moment rates agree with geological moment rates from the WGUEP model, within the uncertainties, for the Wasatch Front region as a whole and for 3 of 4 subregions.**
- **In the 4th and southernmost subregion, the geodetic moment rate is 5X larger than the geological moment rate.**
- **The unexplained moment rate is so large that it is unlikely that all of it is due to missing faults and/or underestimated earthquake rates on known faults.**
- **To the extent that it is due to strain accumulation on faults, it is possible that the WGUEP forecast underestimates earthquake probabilities in the southernmost Wasatch Front region and, to a much smaller extent, in the whole Wasatch Front region.**

Other Possible (Speculative) Explanations for the Moment Rate Discrepancy

- **Postseismic relaxation from a large, unrecognized prehistoric earthquake in the region?**
- **Aseismic deformation, perhaps related to salt tectonics?**
- **Magma movement? (Youngest volcanic rocks in the area are 660 ± 170 cal yr B.P.)**



- COCORP seismic reflection data (Allmendinger et al, 1983)
- Reprocessed by McBride et al. (2010); unmigrated
- SDR = Sevier Desert Reflector; average dip is 11° to 12°
- SDR extends 70 km west from near surface to 12-15 km depth.
- The SDR has been interpreted as a low-angle normal fault.
- Others interpret the eastern SDR as an unconformity and the western SDR as a Cretaceous thrust fault, fortuitously aligned.



Problems with interpretation of the Sevier Desert reflector as an active fault:

(1) It may be an unconformity, not a fault,

(2) It has a very low dip, 12°,

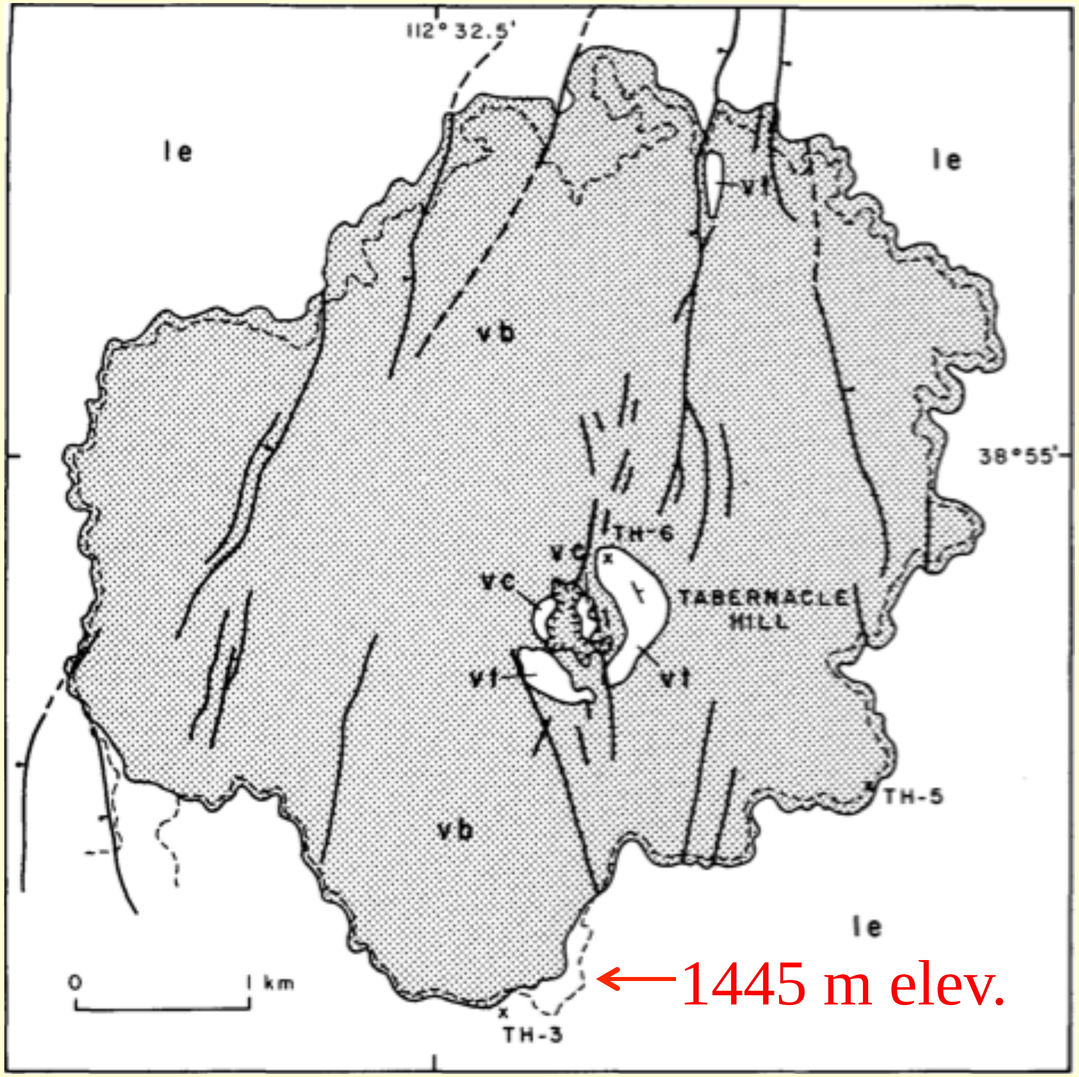
(3) There are no Quaternary scarps along its surface projection.

Unlikely that the Black Rock fault zone is the active trace of the Sevier Desert detachment because it:

(1) Has no significant topographic signature,

(2) Is only ~1/2 the length of the detachment, and

(3) Is closely associated with Quaternary volcanics.



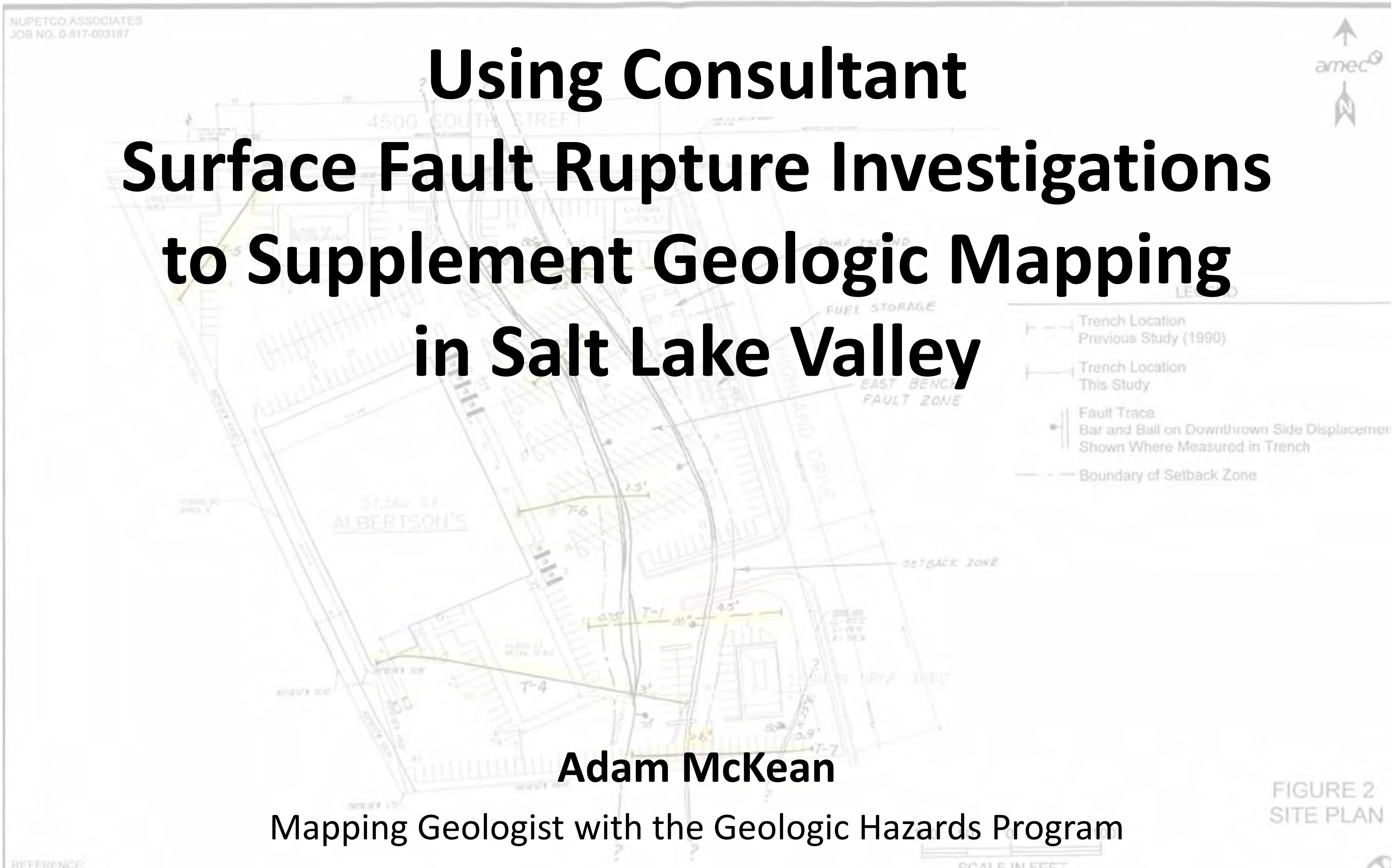
From Oviatt and Nash (1989)

Problems with Hoover's (1974) slip rate for the Tabernacle faults:

(1) Oviatt (1988) notes that the Tabernacle Hill flow appears to be draped over pre-existing fault scarps, and

(2) Hoover (1974) measured displacement on the "master fault," not the net vertical displacement across the whole fault zone.

Using Consultant Surface Fault Rupture Investigations to Supplement Geologic Mapping in Salt Lake Valley



Adam McKean

Mapping Geologist with the Geologic Hazards Program

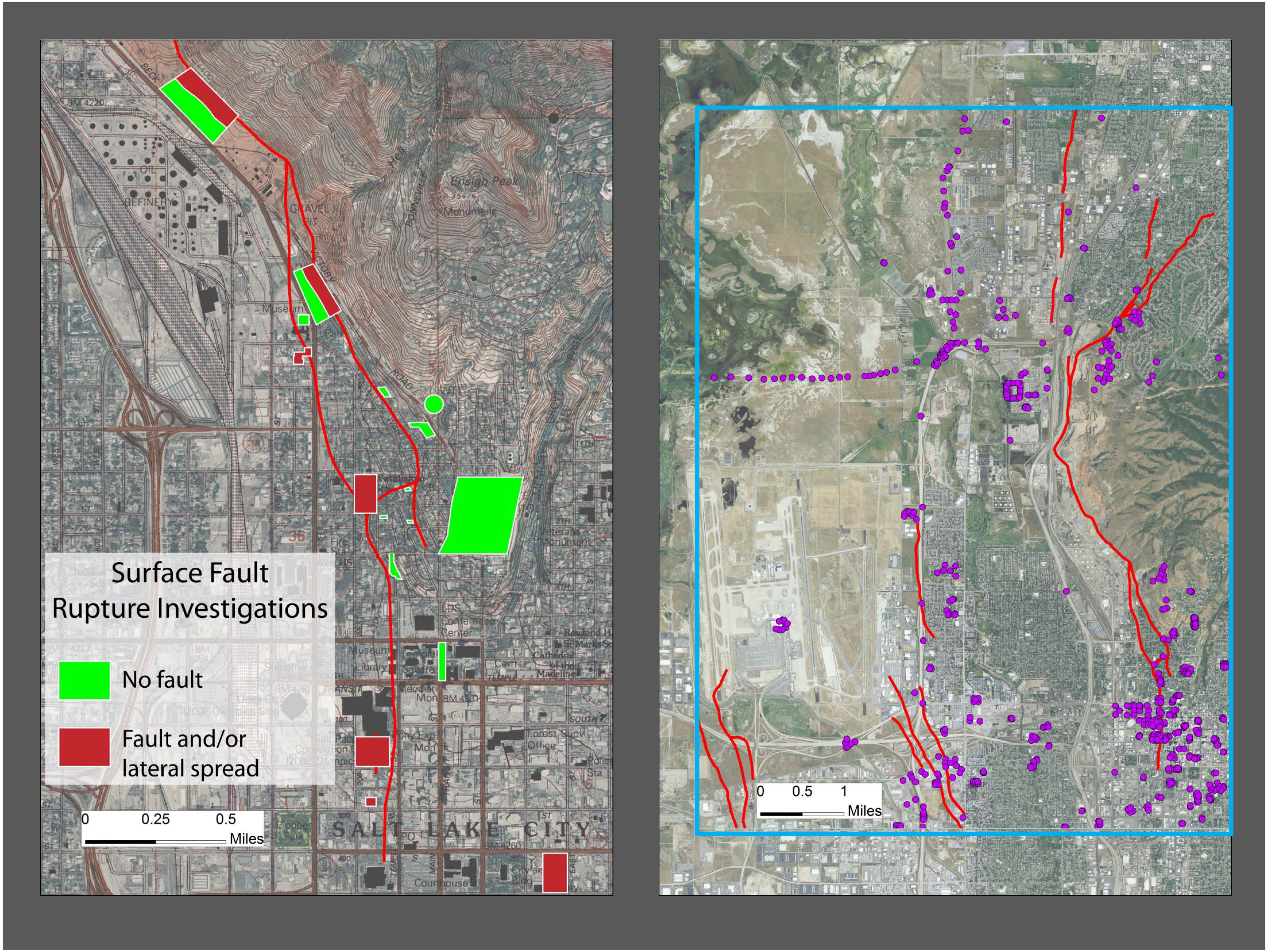
Tools in a Geologist Tool Belt

Traditional

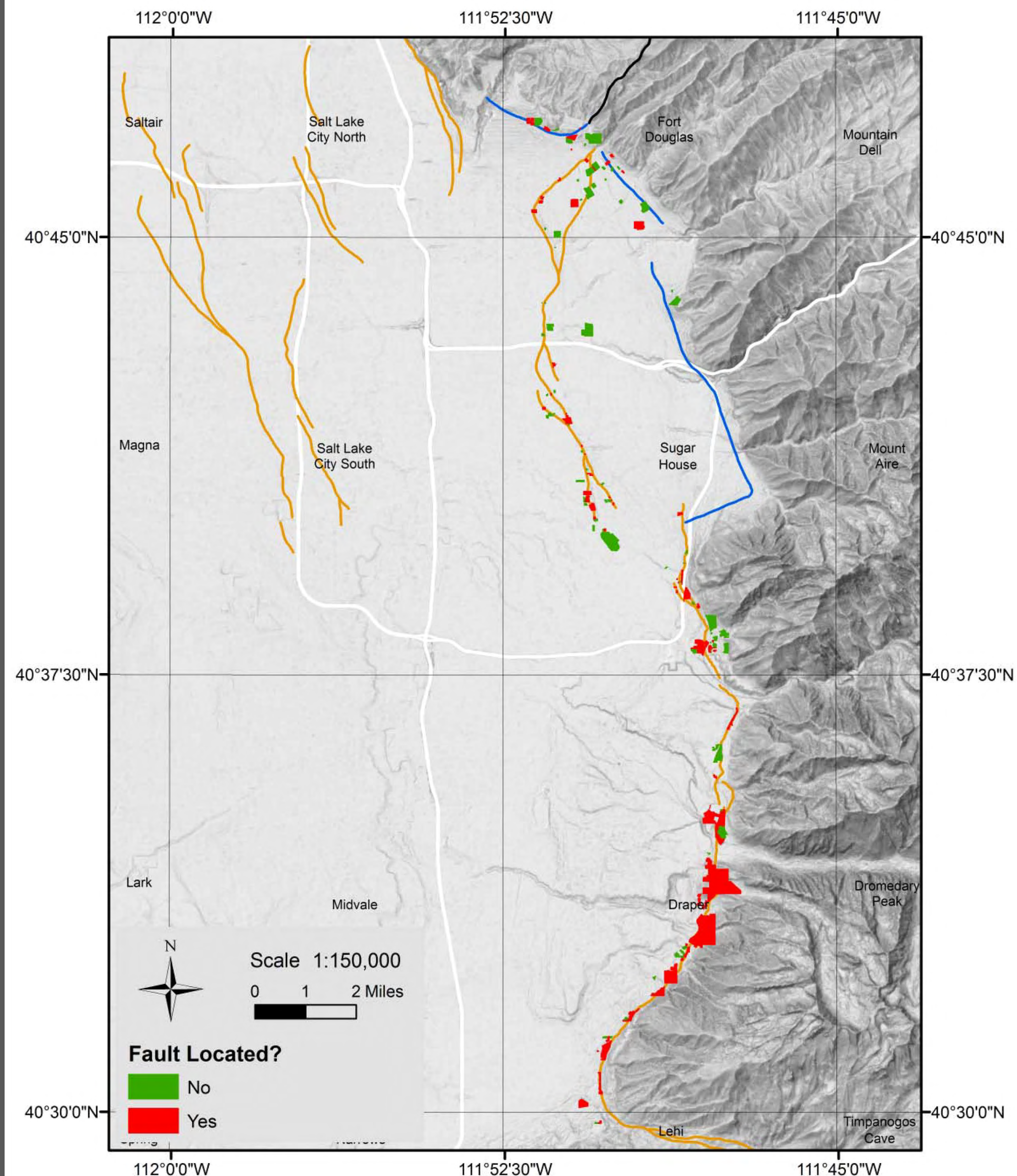
- Stereographic pairs of aerial photographs
- Topographic map
- Aerial imagery
- Rock hammer, hand lens, compass, GPS, acid bottle, etc.
- Gravity, aeromagnetic, GPR, seismic, etc.
- Water, oil, gas driller and electronic logs
- Lidar
- Publications and previous work

Nontraditional

- Historical accounts of geomorphology and geology
- Early photographs from predevelopment
- Consultant Reports:
  - Surface fault rupture investigations
  - Geotechnical investigations
  - Cone penetrometer test investigations
  - Other geologic and engineering investigations
- U.S. Natural Resources Conservation Service (NRCS) soil map data
- Structure from motion (SfM)



Surface Fault Rupture Investigations
No fault
Fault and/or lateral spread
0
0.25
0.5
Miles
SALT LAKE CITY
Ensign Peak
0
0.5
1
Miles



112°0'0"W
111°52'30"W
111°45'0"W
40°45'0"N
40°37'30"N
40°30'0"N
Saltair
Salt Lake City North
Fort Douglas
Mountain Dell
Magna
Salt Lake City South
Sugar House
Mount Aire
Lark
Midvale
Draper
Dromedary Peak
Lehi
Timpanogos Cave
N
Scale 1:150,000
0 1 2 Miles
Fault Located?
No
Yes

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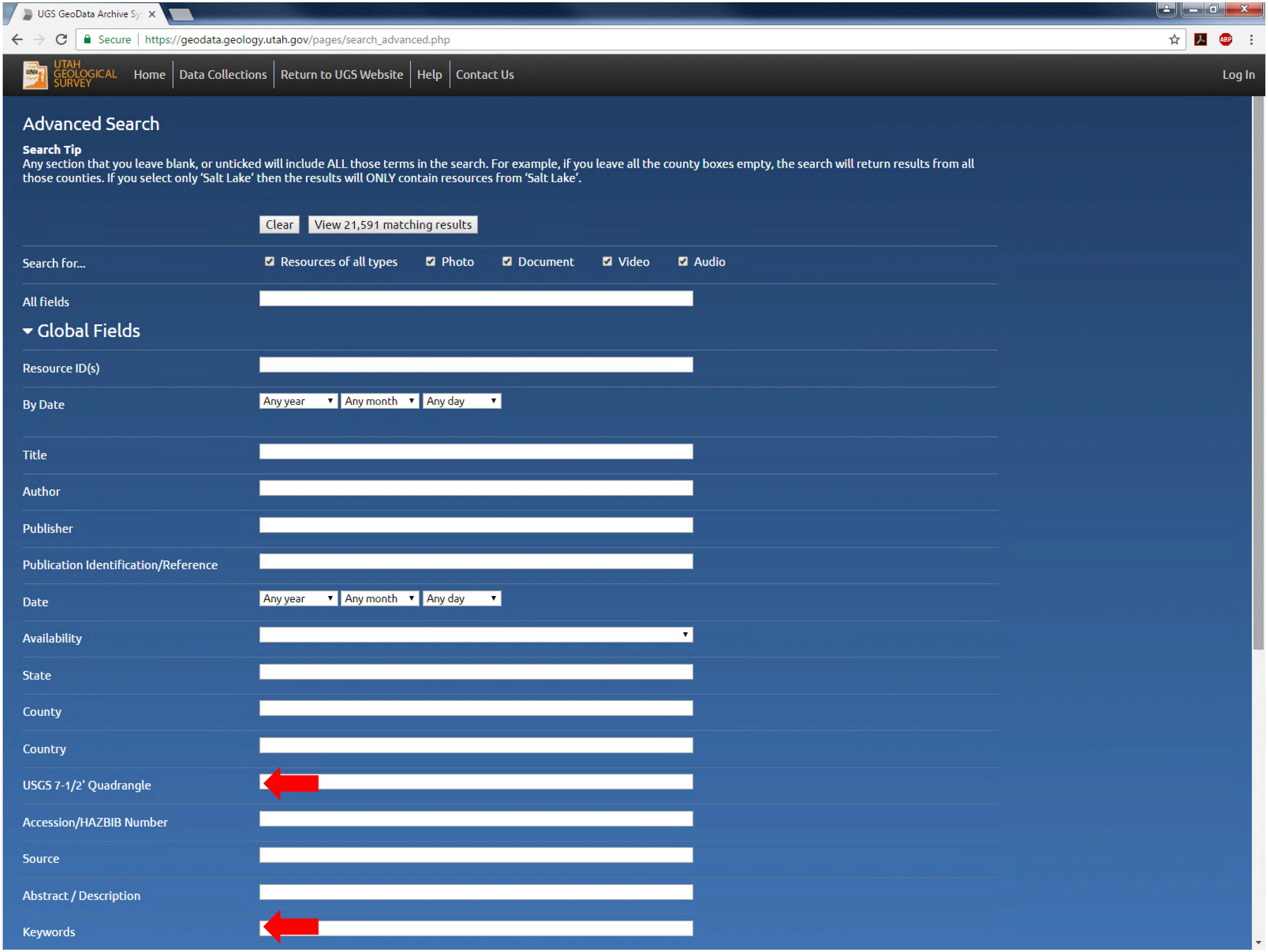
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Clear
View 21,591 matching results
Search for...
Resources of all types
Photo
Document
Video
Audio
All fields
Global Fields
Resource ID(s)
By Date
Any year
Any month
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Title
Author
Publisher
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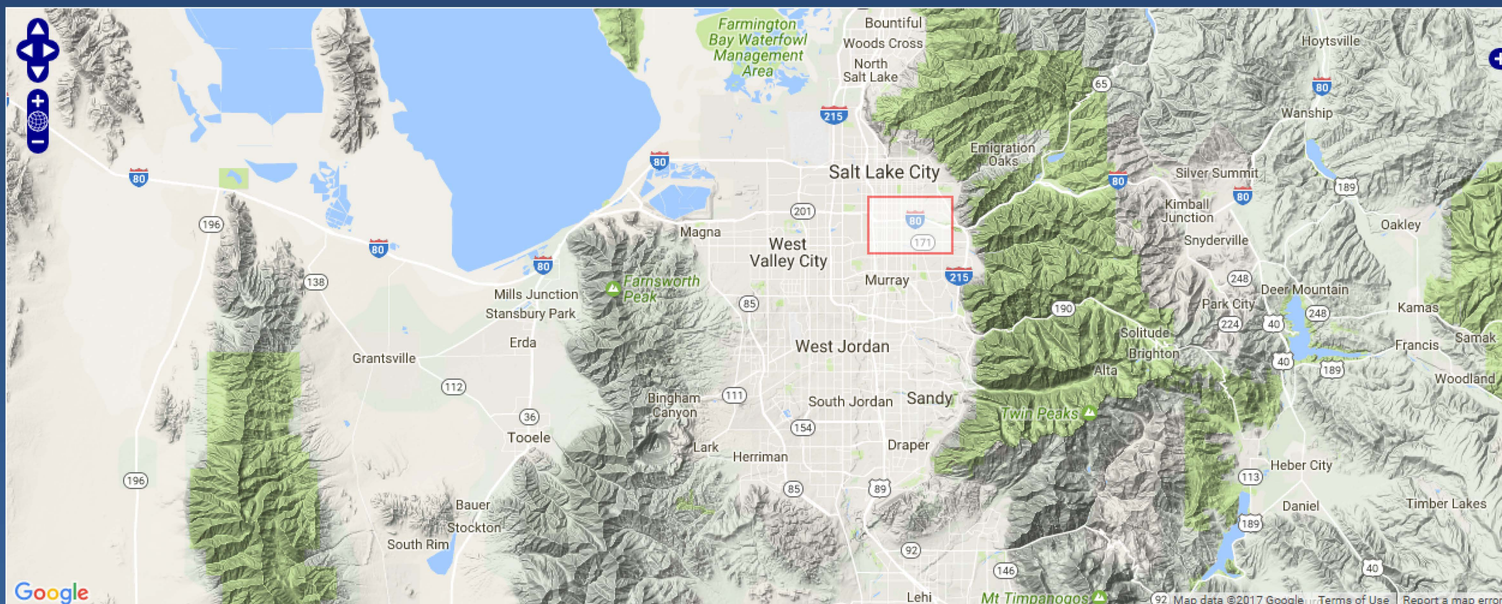
Drag mode: ◉ select search area ○ pan



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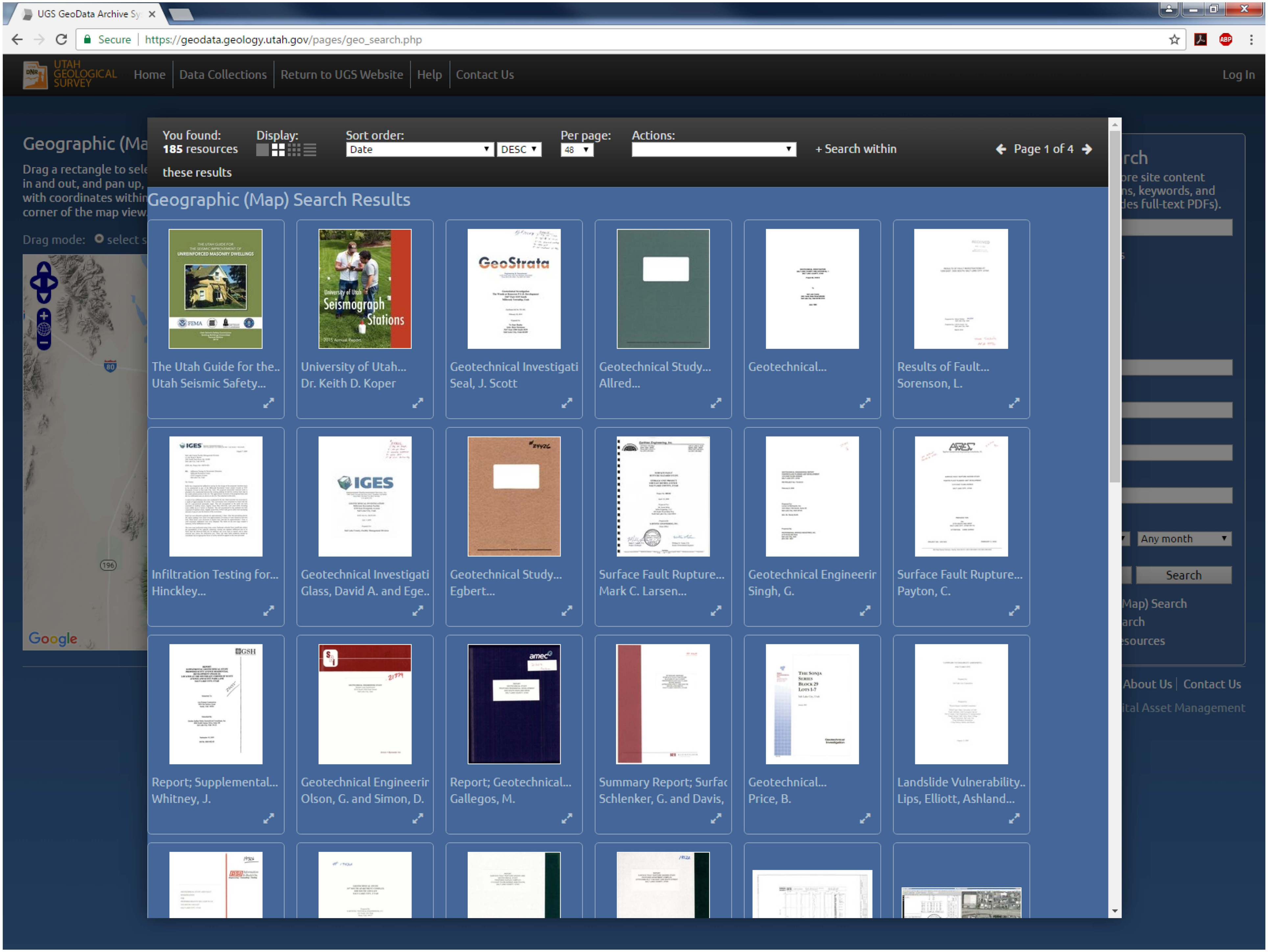
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Sugar House

Source
Salt Lake County

Keywords
surface fault rupture, paleoseismology

Original filename
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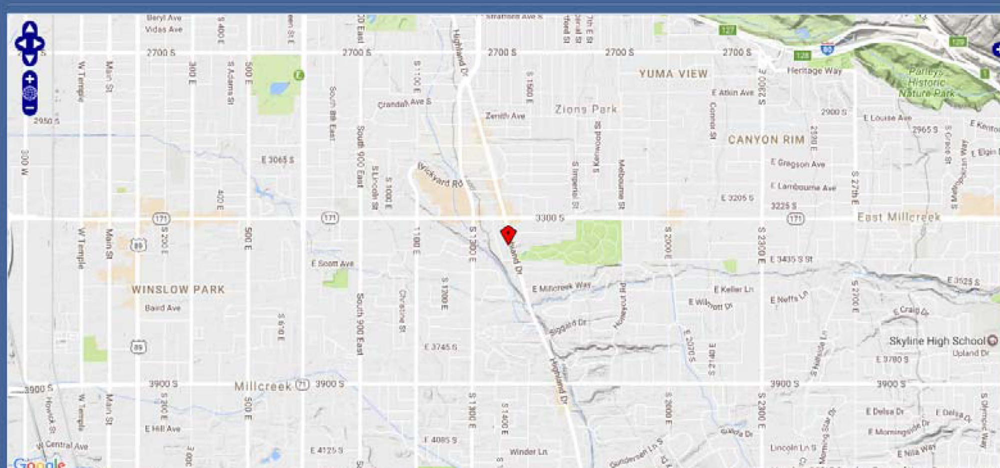
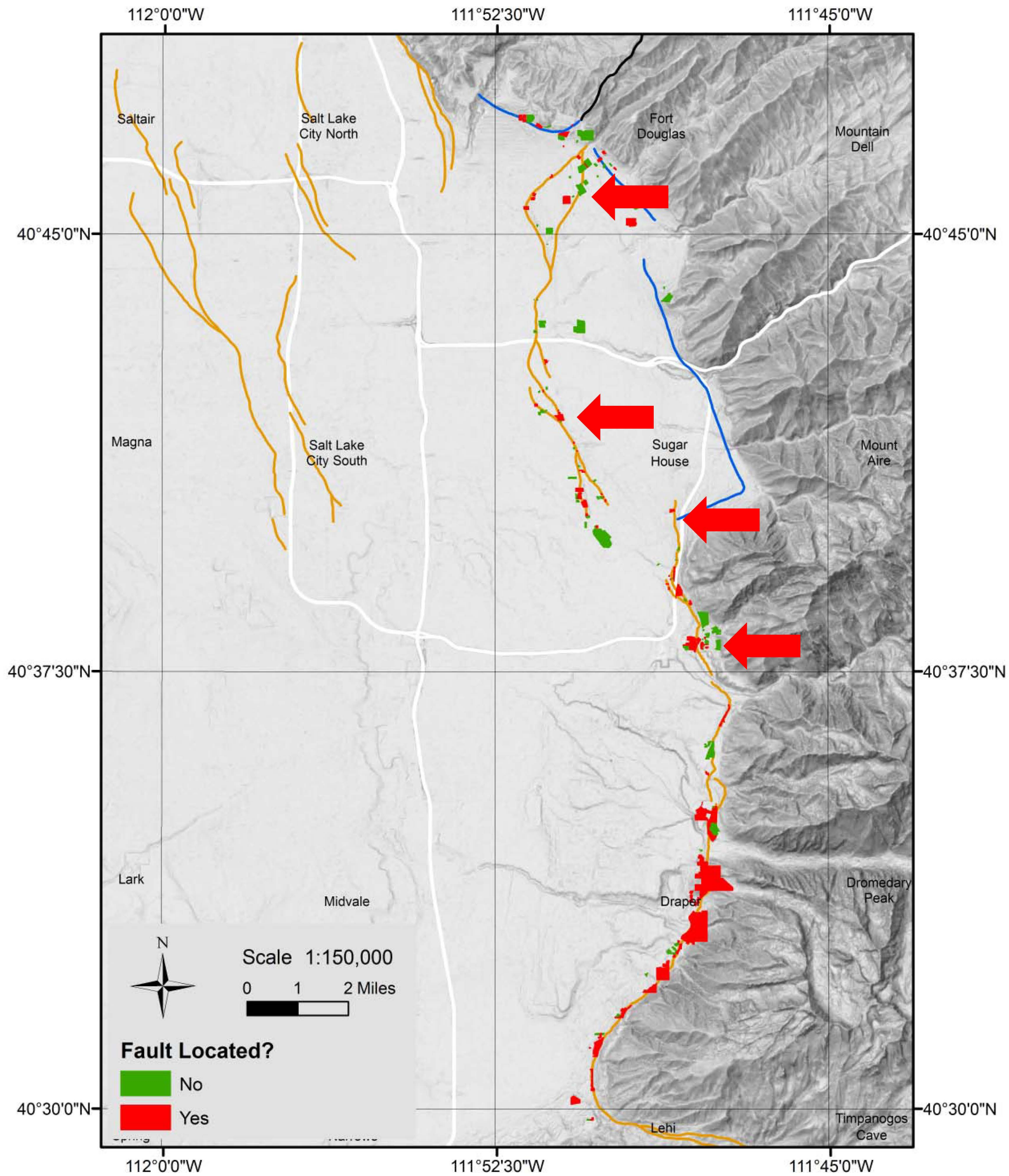
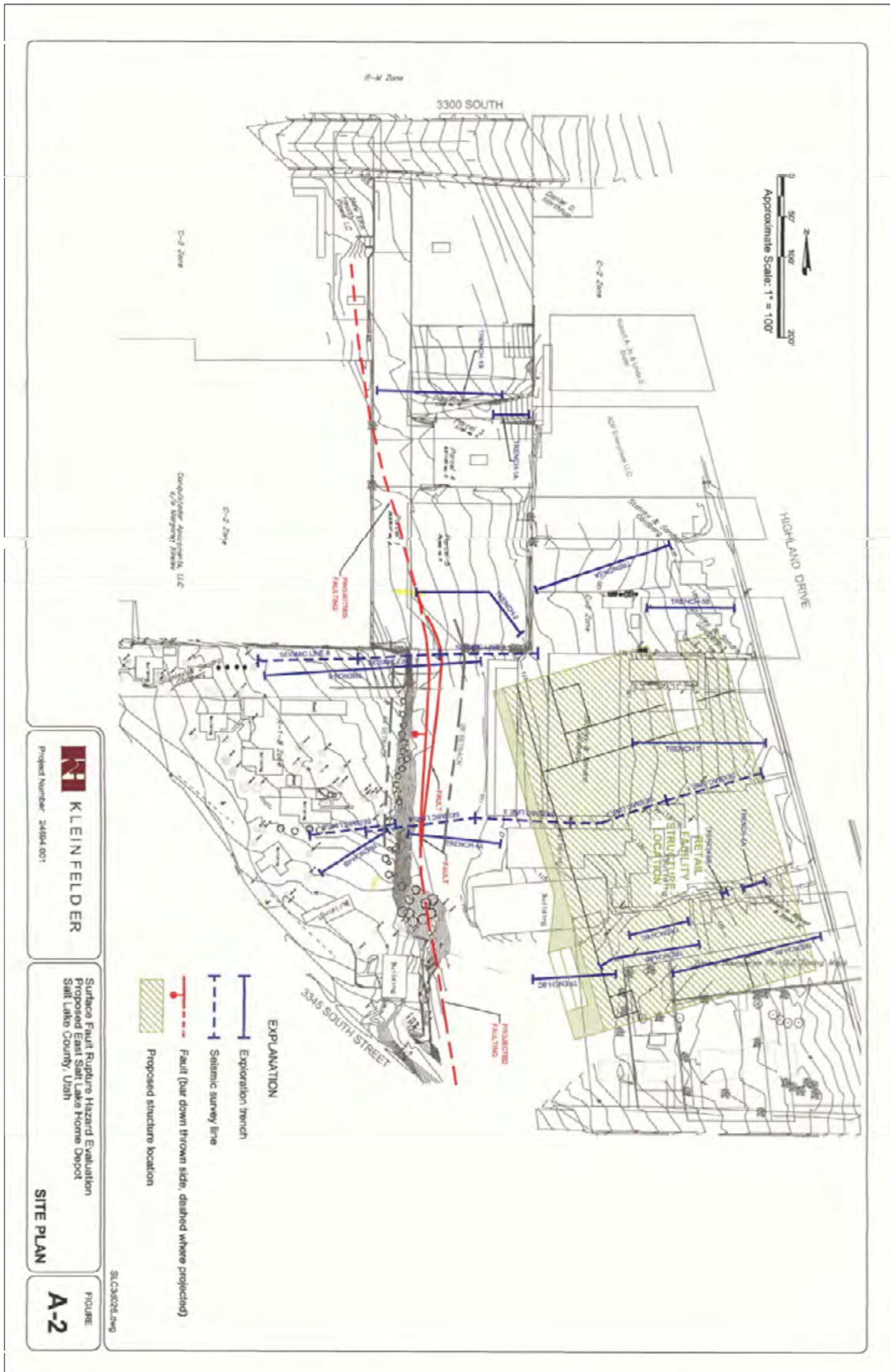
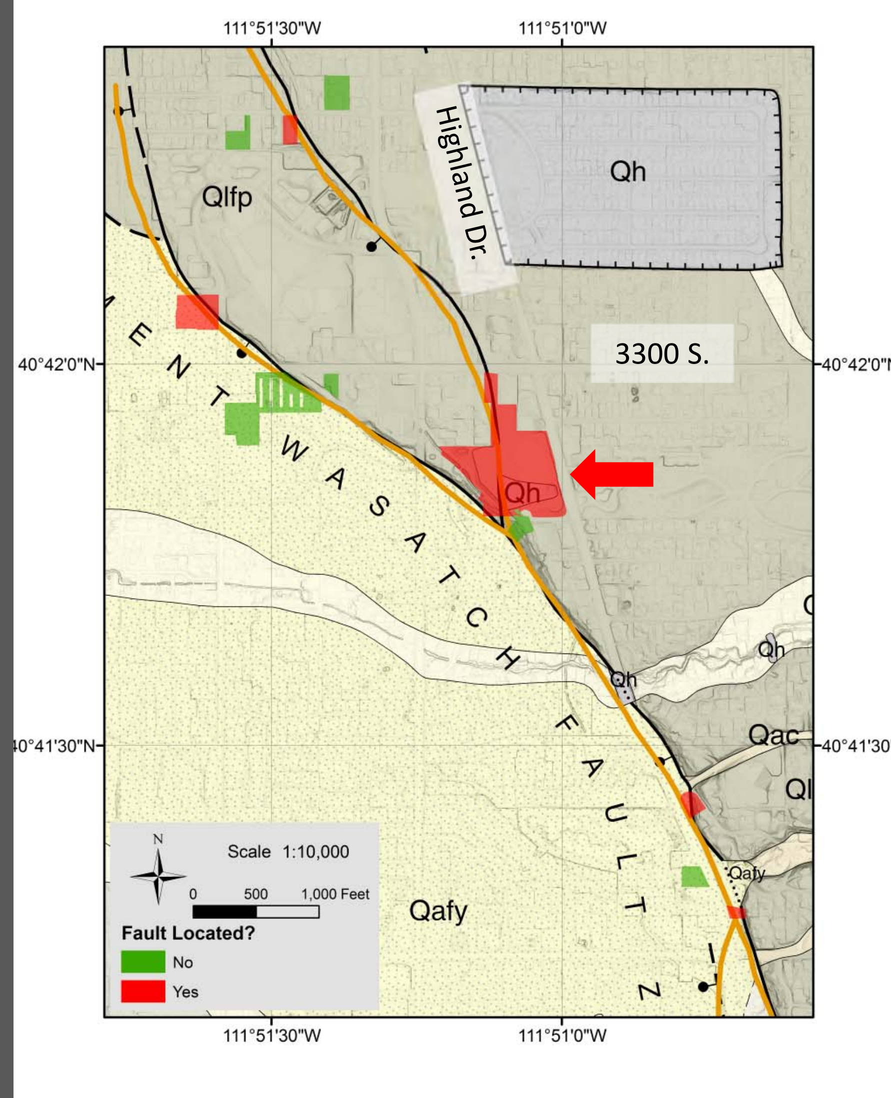




112°0'0"W
111°52'30"W
111°45'0"W
40°45'0"N
40°37'30"N
40°30'0"N
Saltair
Salt Lake City North
Fort Douglas
Mountain Dell
Magna
Salt Lake City South
Sugar House
Mount Aire
Lark
Midvale
Draper
Dromedary Peak
Lehi
Timpanogos Cave
N
Scale 1:150,000
0 1 2 Miles
Fault Located?
No
Yes

Home Depot
(3300 S and Highland Dr)





Rice Stadium
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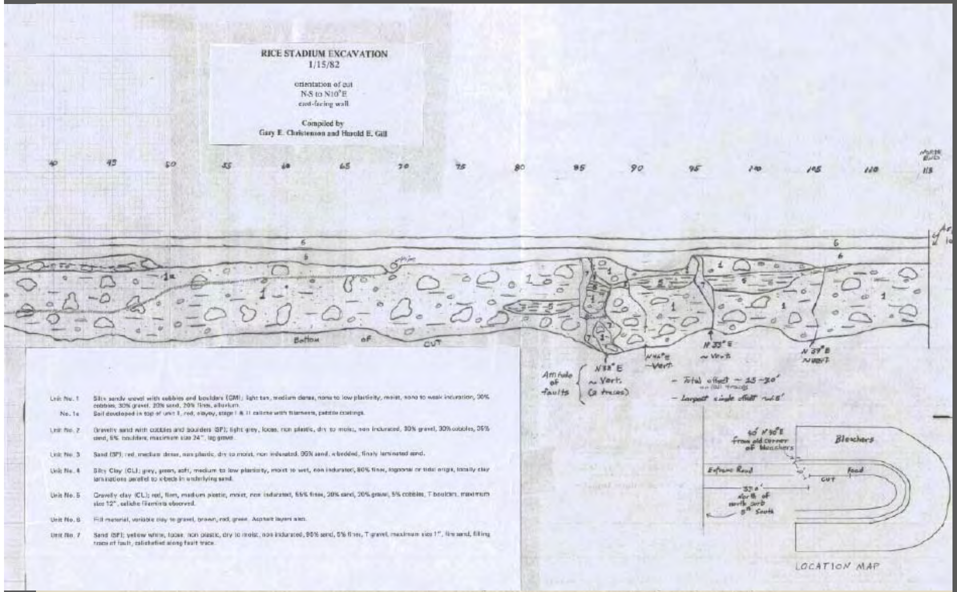
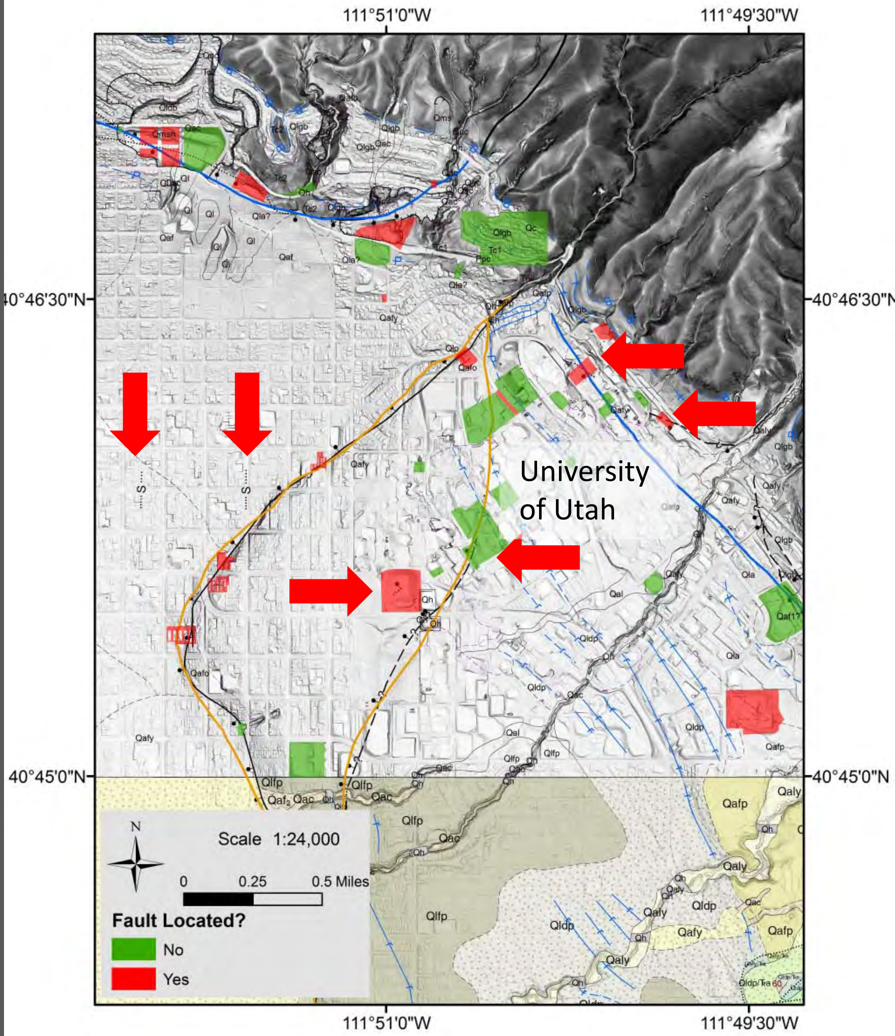
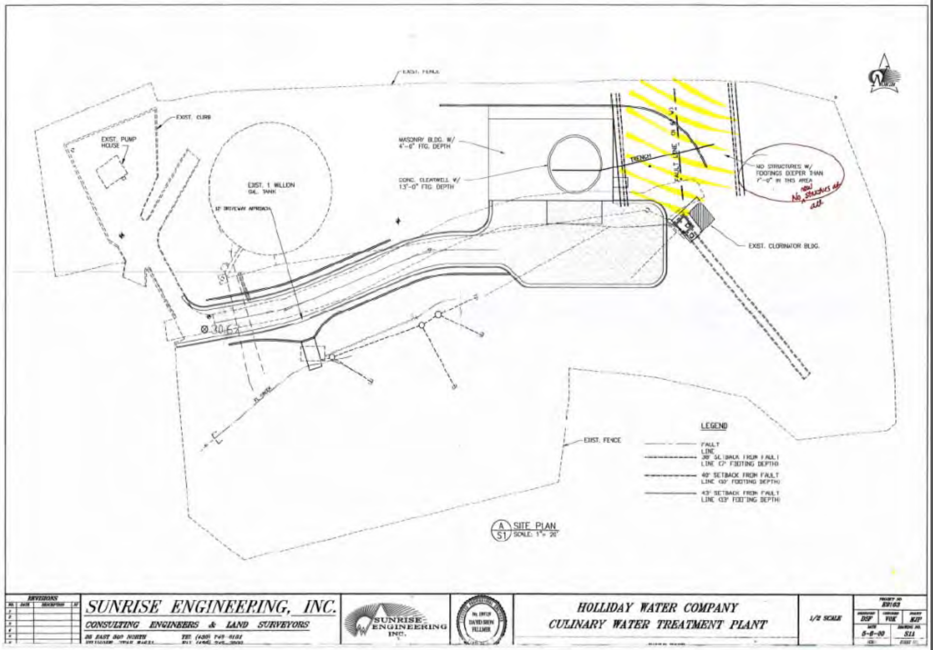


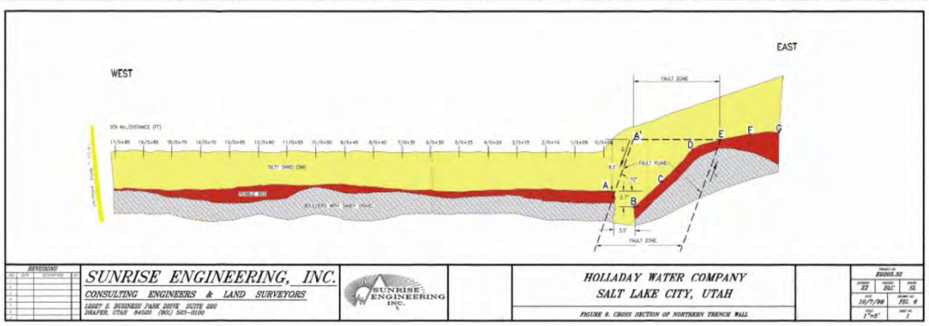
detailed inspection was performed by myself, William R. Lund and Gary E. Christenson. During the inspection, several faults were discovered and plans were made to return and prepare a detailed log of a portion of the east facing wall of the excavation. The detailed log was accomplished on January 15, 1982 by myself, Gary Christenson and Bill Case (see detailed log).

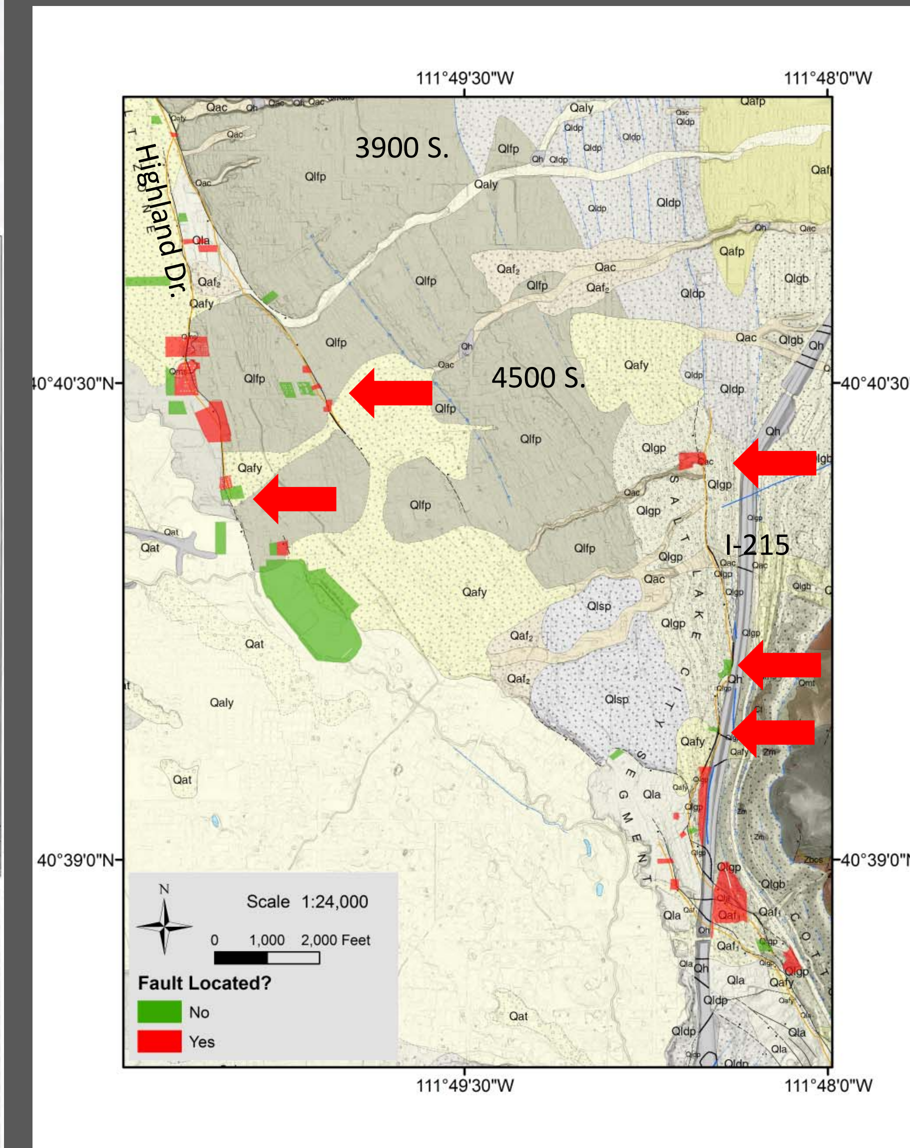
The following is a discussion concerning the stratigraphy and relative ages of the soil units within the U of U stadium excavation. Dr. Donald R. Currey, Dept. of Geography, University of Utah, believes that the alluvium (unit no. 1) is pre-Lake Bonneville with a soil development in the upper 2 feet. This soil horizon possibly can be correlated with the Dimple Dell and Promontory soil units found elsewhere in the Bonneville Basin; this would date the unit between 17,000 and 100,000 years before present. Dr. Currey feels that unit no. 2 is a lag gravel which represents a reworking of the top several inches or feet of the alluvium (unit no. 1) by a transgressing Lake Bonneville. Unit nos. 3 and 4 appear to be lacustrine sands and clays. The thinly laminated silty clay (unit no. 4) may have been a lagoonal or tidal deposit. Unit no. 5 appears to be a gravely clay lens within the alluvium (unit no. 1). Unit no. 6 consists of several layers of man-placed fill and asphalt.



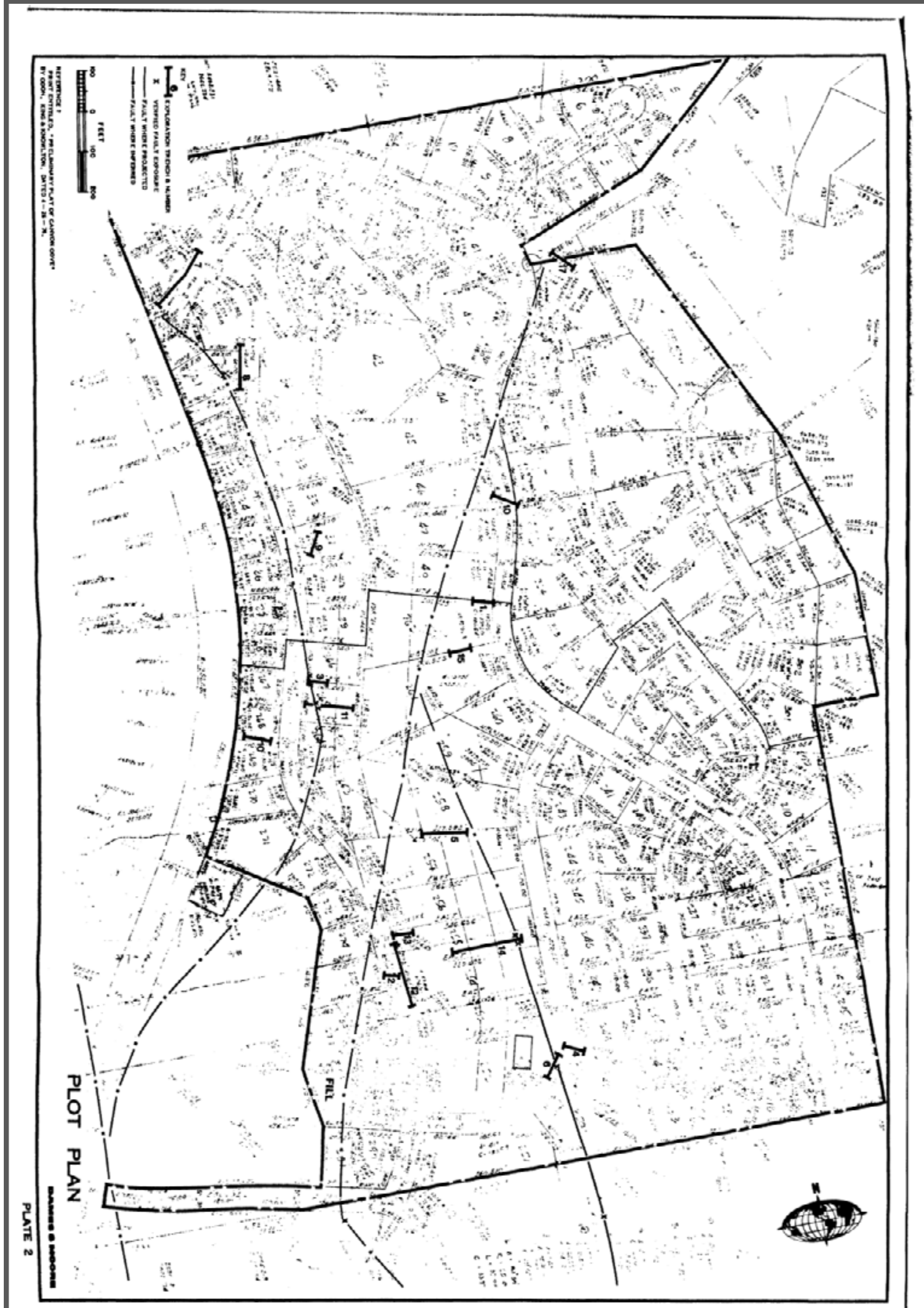
Spring Creek
Holladay

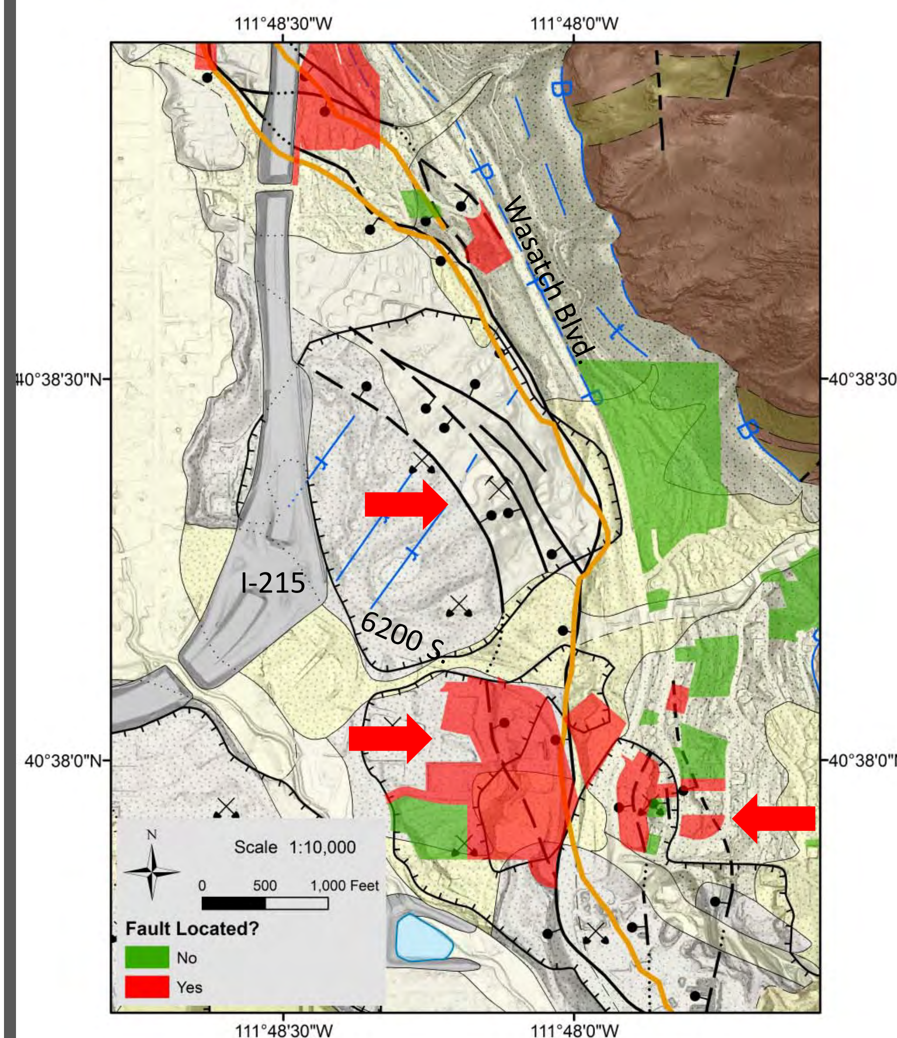




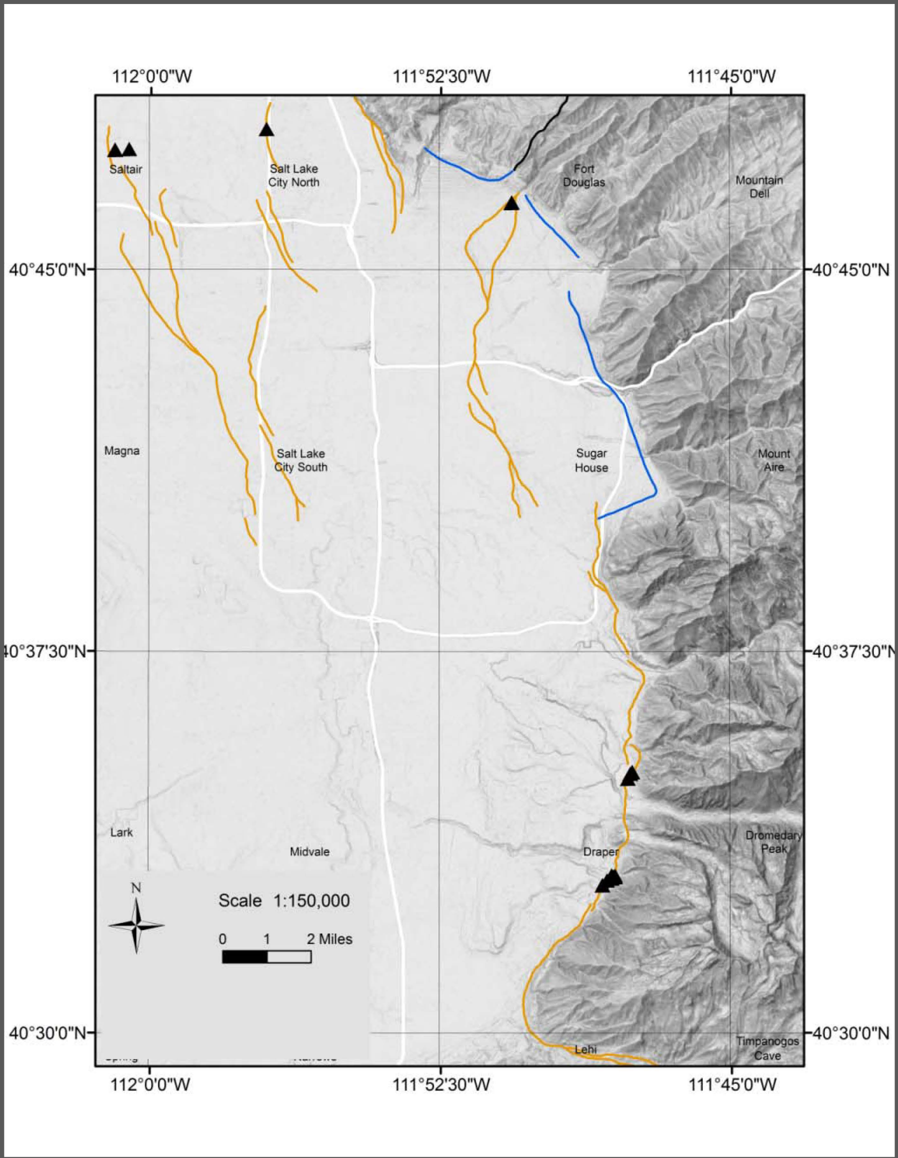


Canyon Cove (6500 S and Wasatch Blvd)

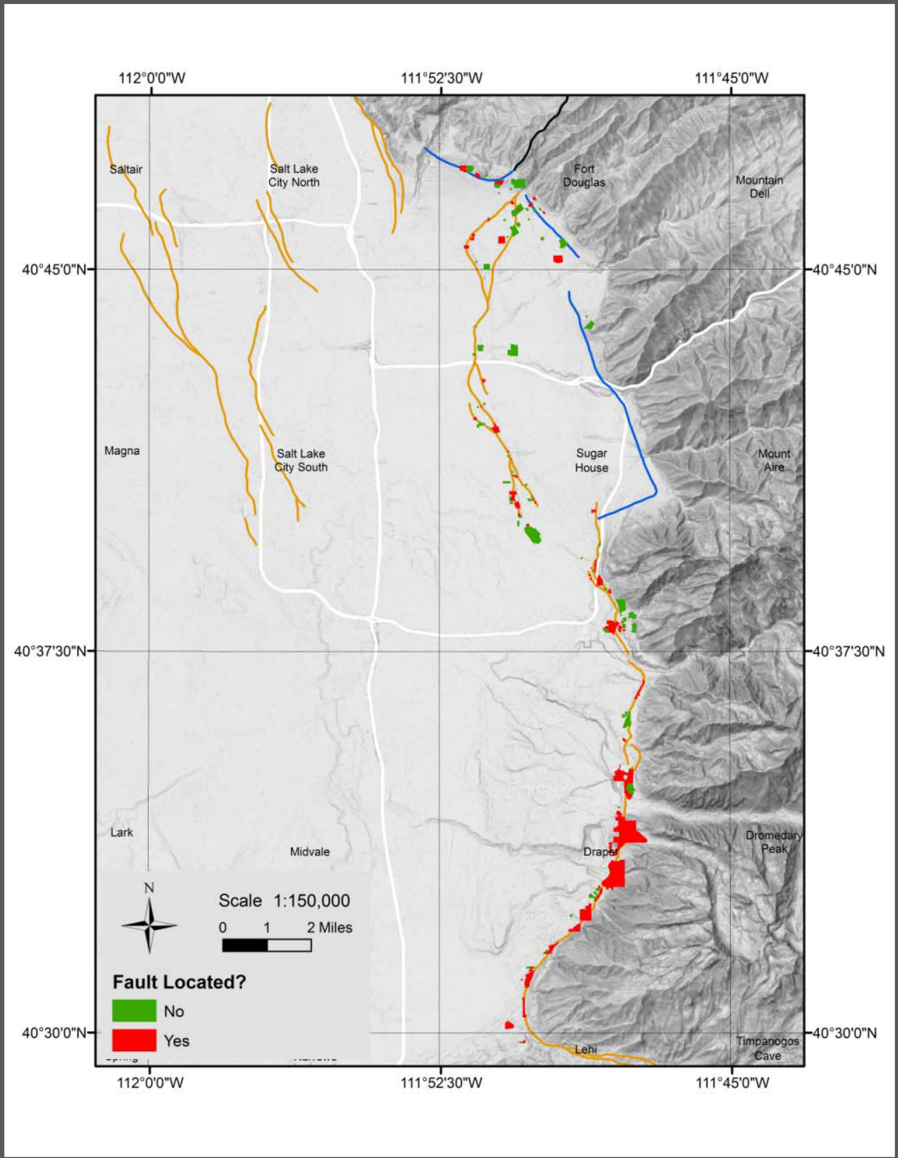




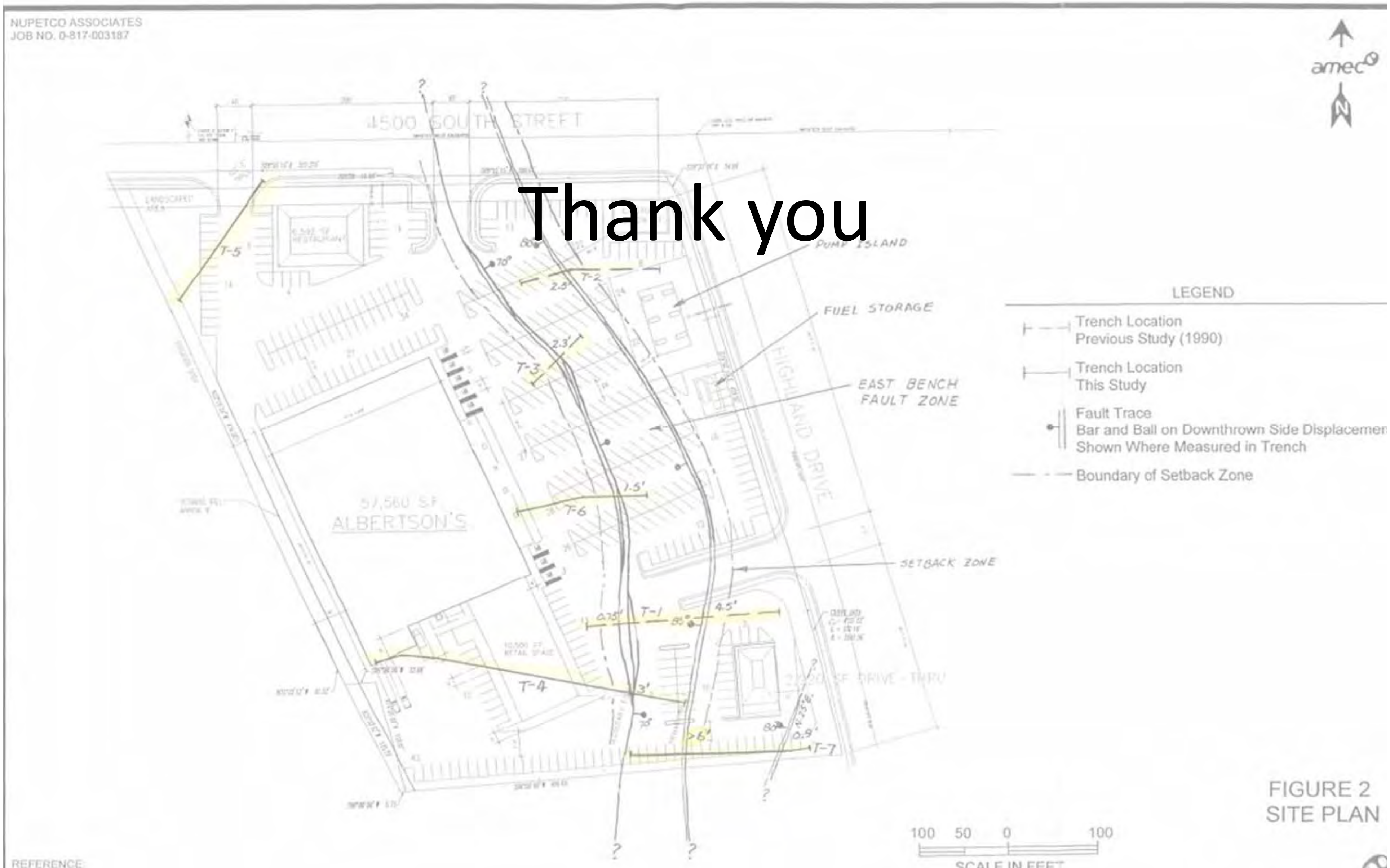
Paleoseismic Trenches
Paleoseismology of Utah Series



Consultant Surface Fault Rupture Investigations



Thank you



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4500 SOUTH STREET
PUMP ISLAND
FUEL STORAGE
EAST BENCH FAULT ZONE
SETBACK ZONE
HIGHLAND DRIVE
57,560 S.F. ALBERTSON'S
T-1
T-2
T-3
T-4
T-5
T-6
T-7
LEGEND
Trench Location Previous Study (1990)
Trench Location This Study
Fault Trace Bar and Ball on Downthrown Side Displacement Shown Where Measured in Trench
Boundary of Setback Zone
FIGURE 2
SITE PLAN
100 50 0 100
SCALE IN FEET
REFERENCE

Albertson's
(4500 S Highland Dr.)

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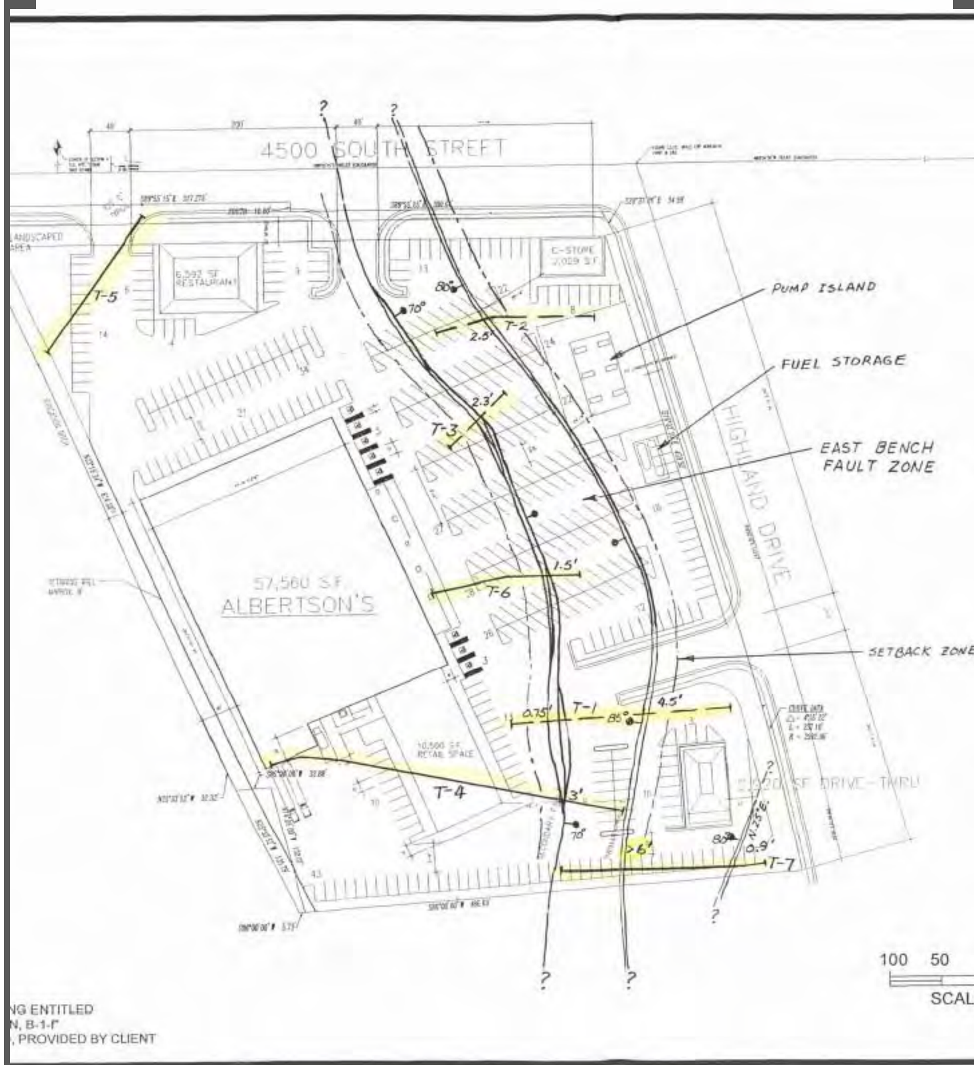

January 22, 2001

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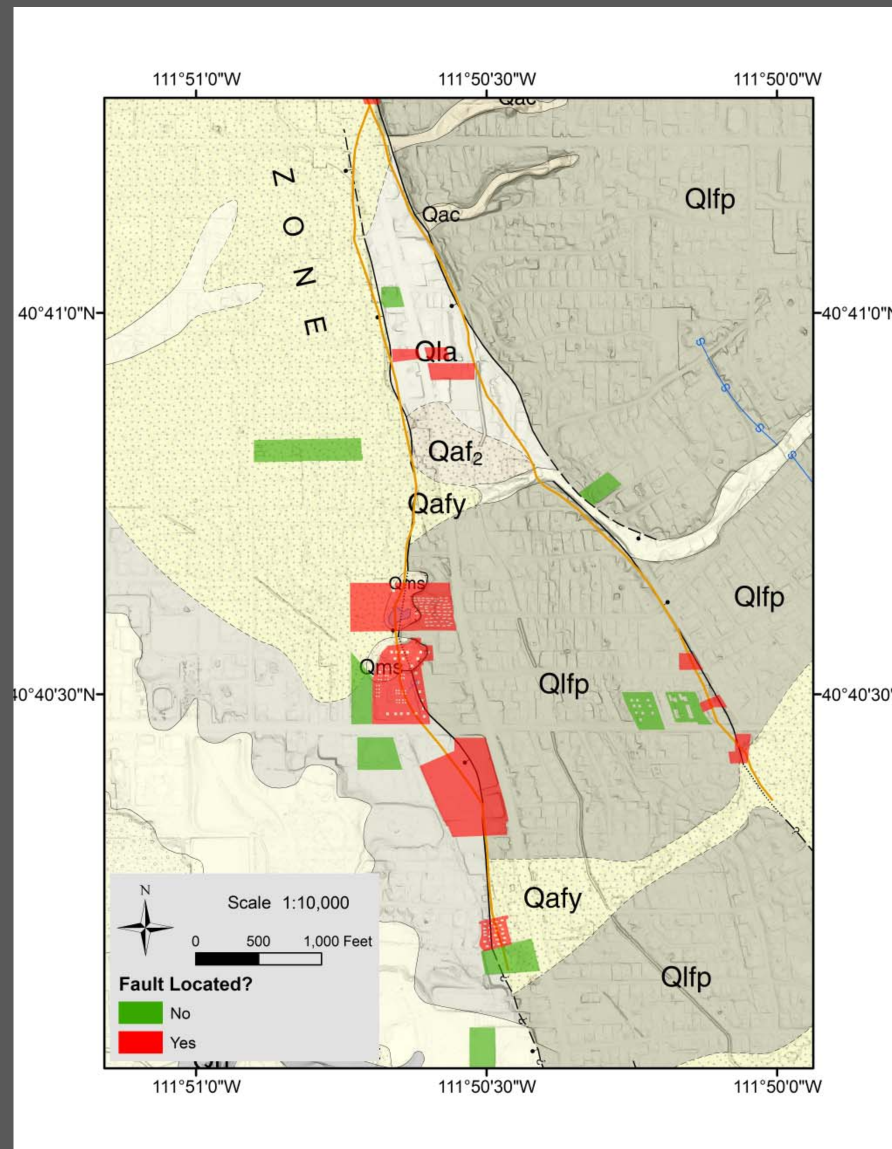
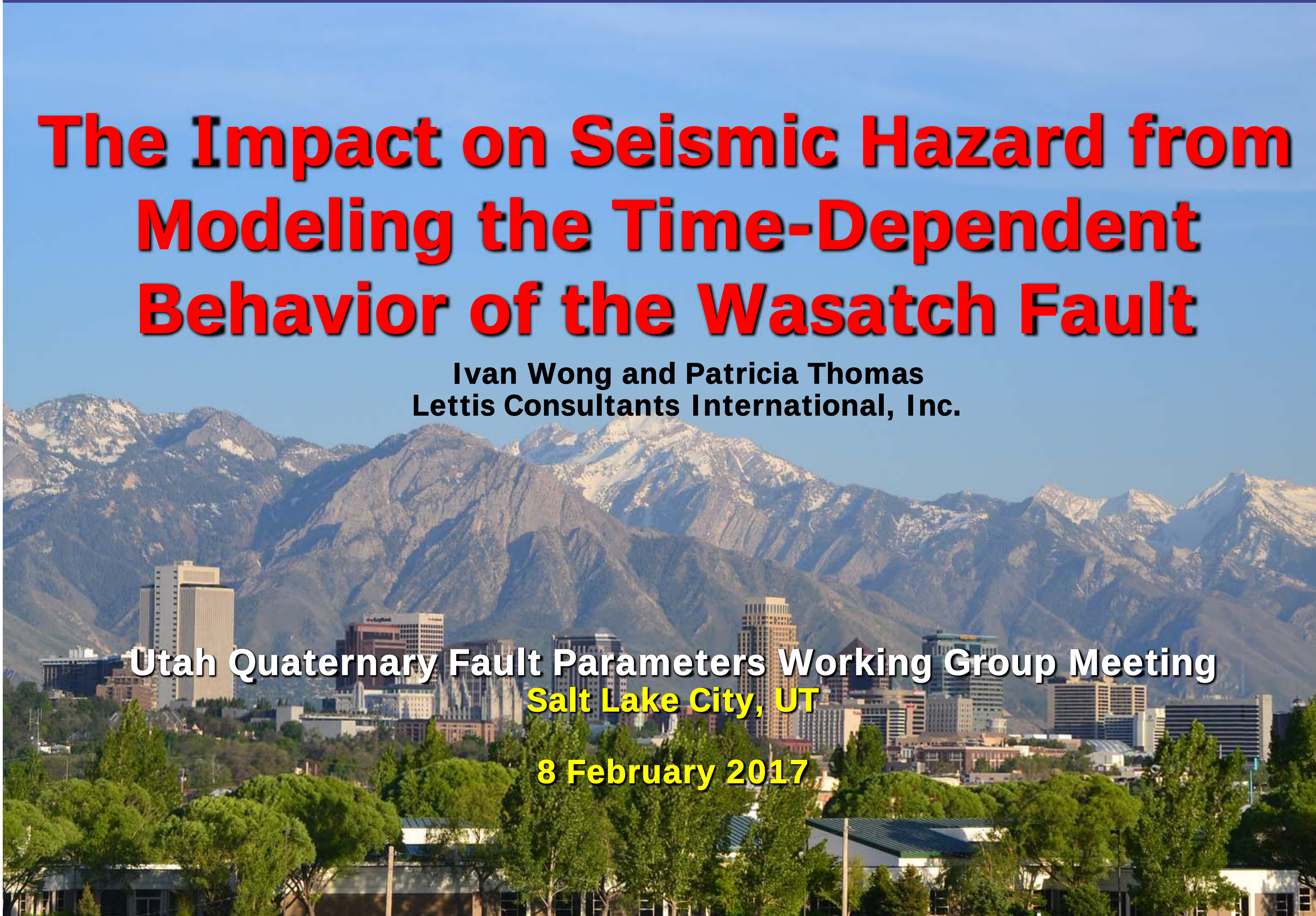


The Impact on Seismic Hazard from Modeling the Time-Dependent Behavior of the Wasatch Fault

Ivan Wong and Patricia Thomas
Lettis Consultants International, Inc.



Utah Quaternary Fault Parameters Working Group Meeting
Salt Lake City, UT

8 February 2017

WGUEP

- The Working Group on Utah Earthquake Probabilities was formed in late 2009.
- The WGUEP was funded by the USGS through the NEHRP external grants program to the UGS and URS Corporation the first 3 years and subsequently by the UGS and URS.
- The WGUEP process consisted of a 6+ year-effort of meetings, research, analyses, computations, and writing of the final report.

WGUEP Members

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

UUSS university of utah seismograph stations
USGS
UTAH DNR GEOLOGICAL SURVEY
THE UNIVERSITY OF UTAH Department of Geology & Geophysics
URS

Assistance from Steve Bowman, UGS and Rich Briggs, USGS

Scope of Work

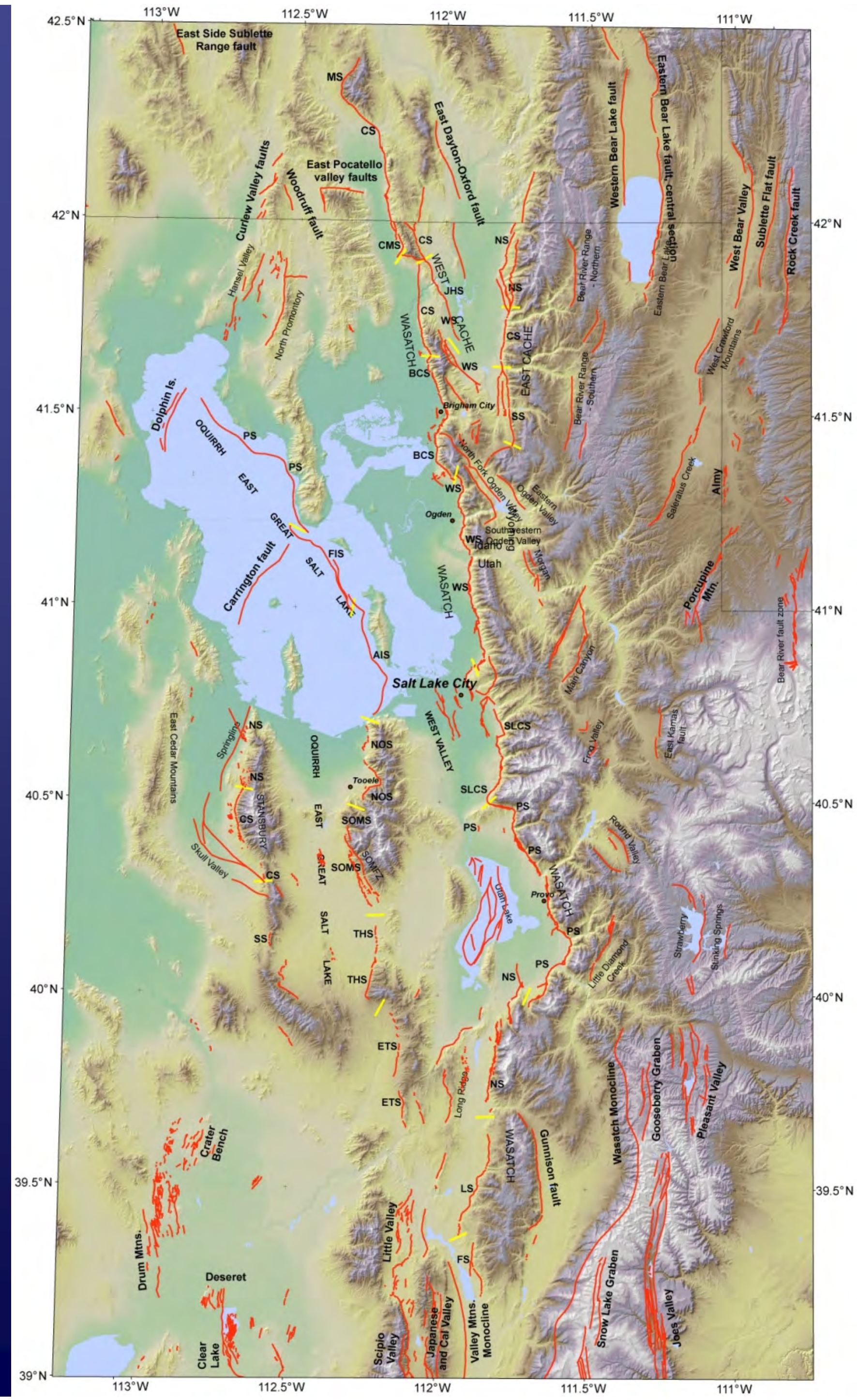
- Time-dependent probabilities were calculated for Wasatch and the Great Salt Lake fault zones where the data is available on the expected mean frequency of earthquakes and the elapsed time since the most recent large earthquake.
- Even for these faults, significant weight was given to the time-independent model.
- Where such information is lacking on less well-studied faults, time-independent probabilities were calculated.
- Uncertainties in all input parameters were explicitly addressed by the WGUEP using logic trees.

Objectives

- The WGUEP calculated the probability of moderate to large earthquakes (M $\geq$ 5.0) in the Wasatch Front region for a range of intervals varying from annually to 100 years.
- Time-dependent and time-independent earthquake probabilities that were estimated are:

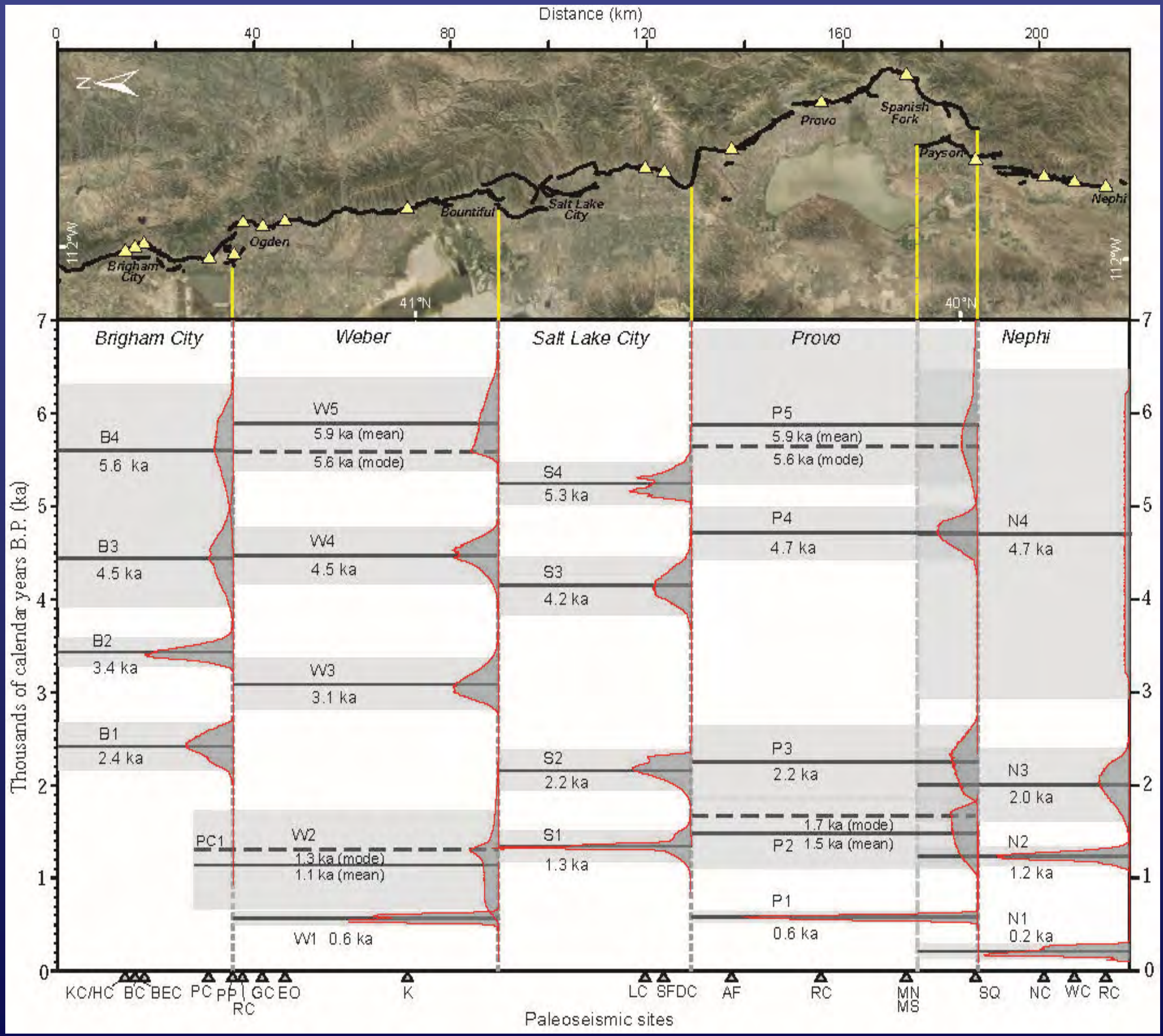
1. Segment-specific for the 5 central segments of the Wasatch fault.
2. Total for the Wasatch fault central segments and the whole fault including the end segments.
3. Segment-specific and fault-specific for the Oquirrh-Great Salt Lake fault.
4. Time-independent fault-specific for all other faults in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

Quaternary Faults and the Defined Wasatch Front Region



Segments of the Wasatch Fault Zone in Utah and Southernmost Idaho

Single-Segment Rupture Model for the Central WFZ

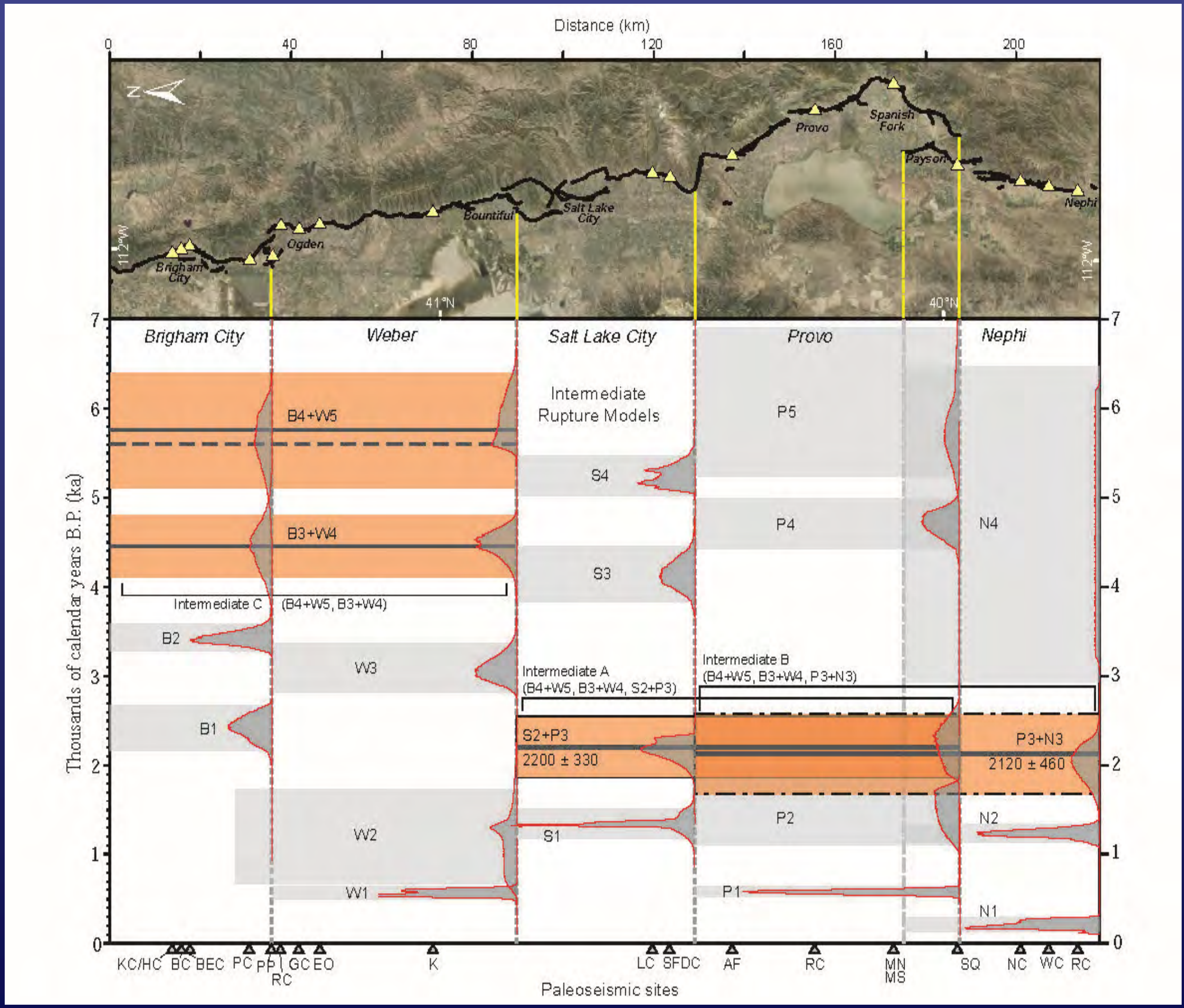


Intermediate Rupture Models for the Central WFZ

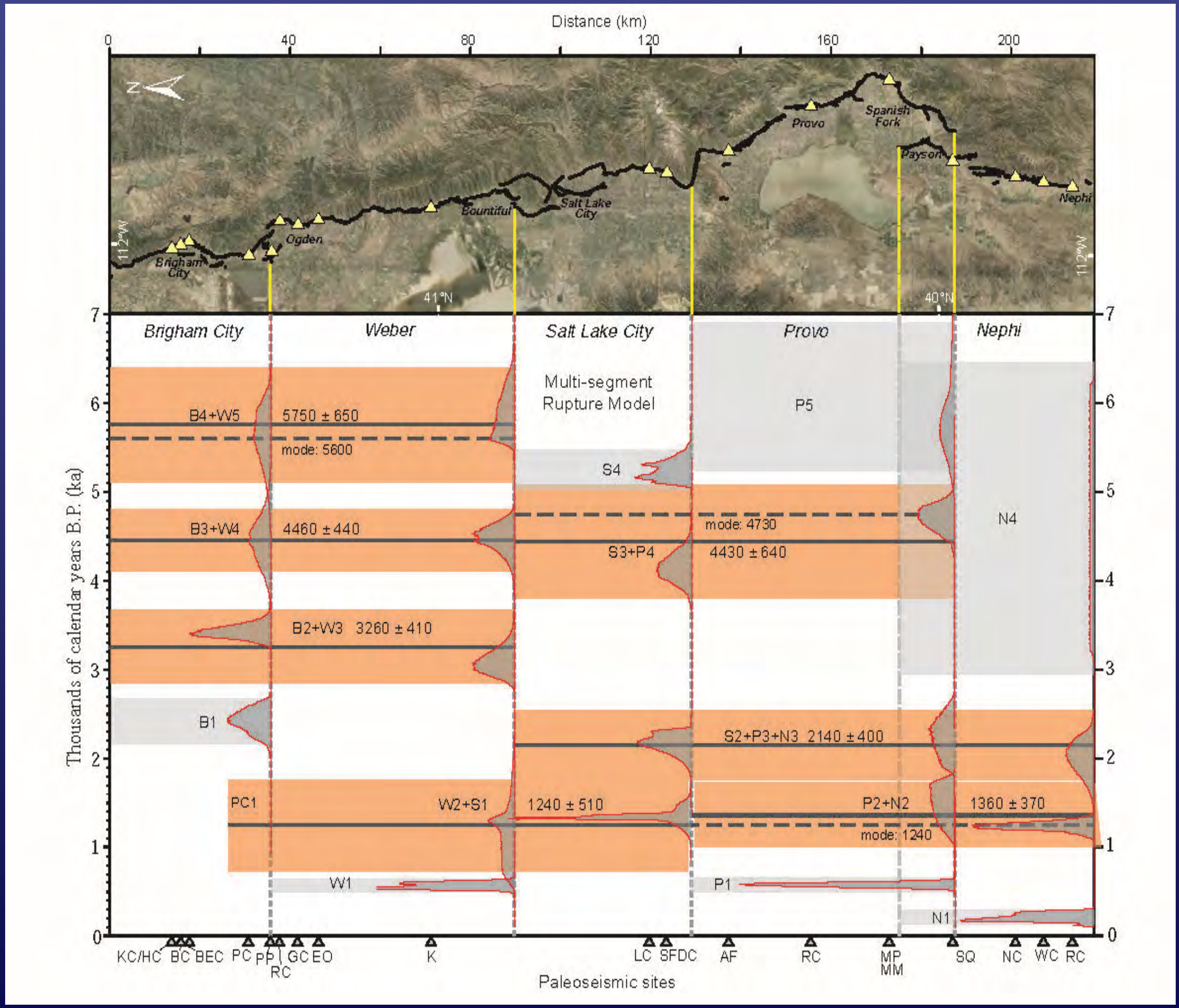
A – B4+W5, B3+W4 and S2+P3

B – P3+N3 in place of S2+P3

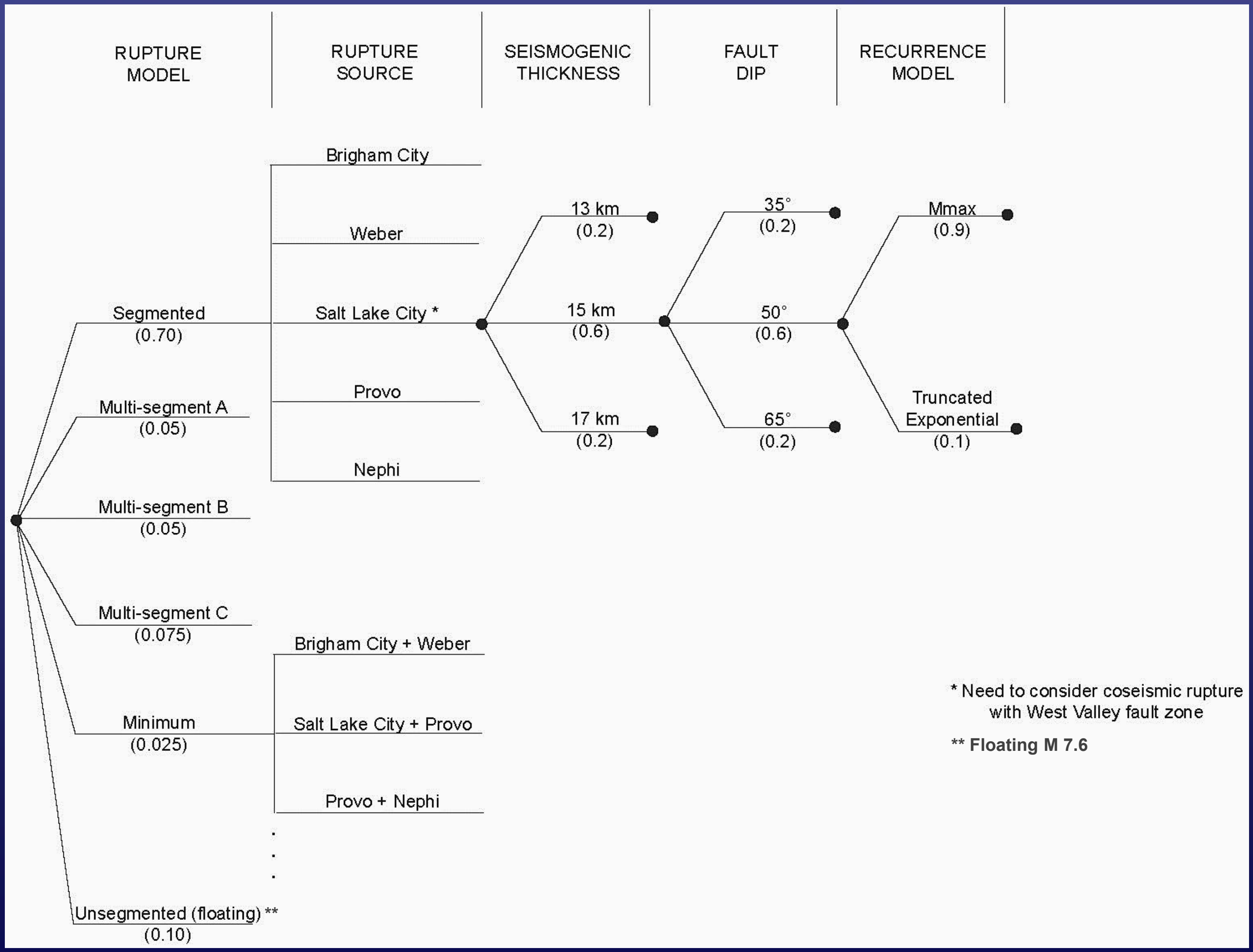
C – B4+W5 and B3+W4



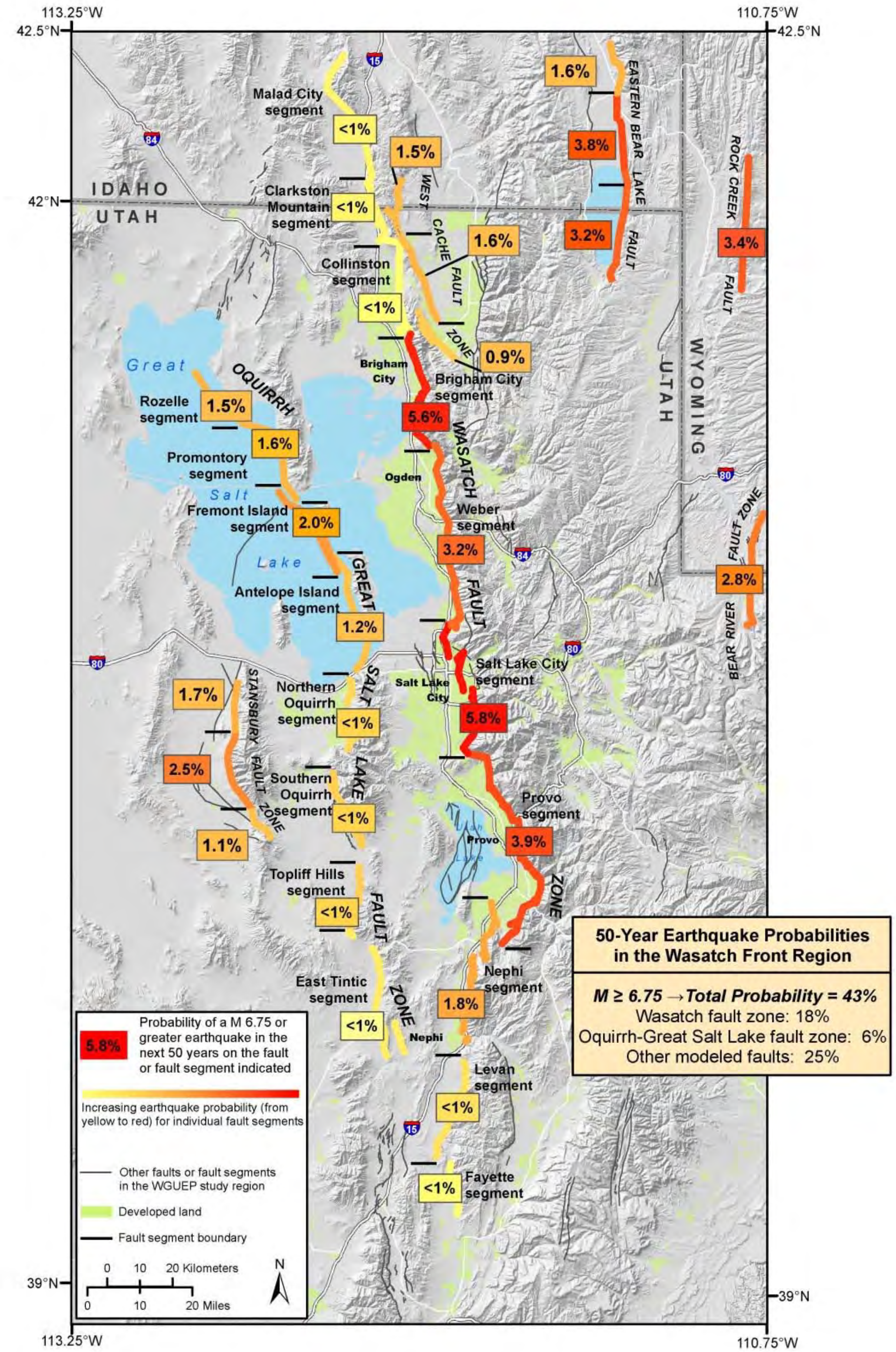
Multi-Segment Rupture Models for the Central WFZ



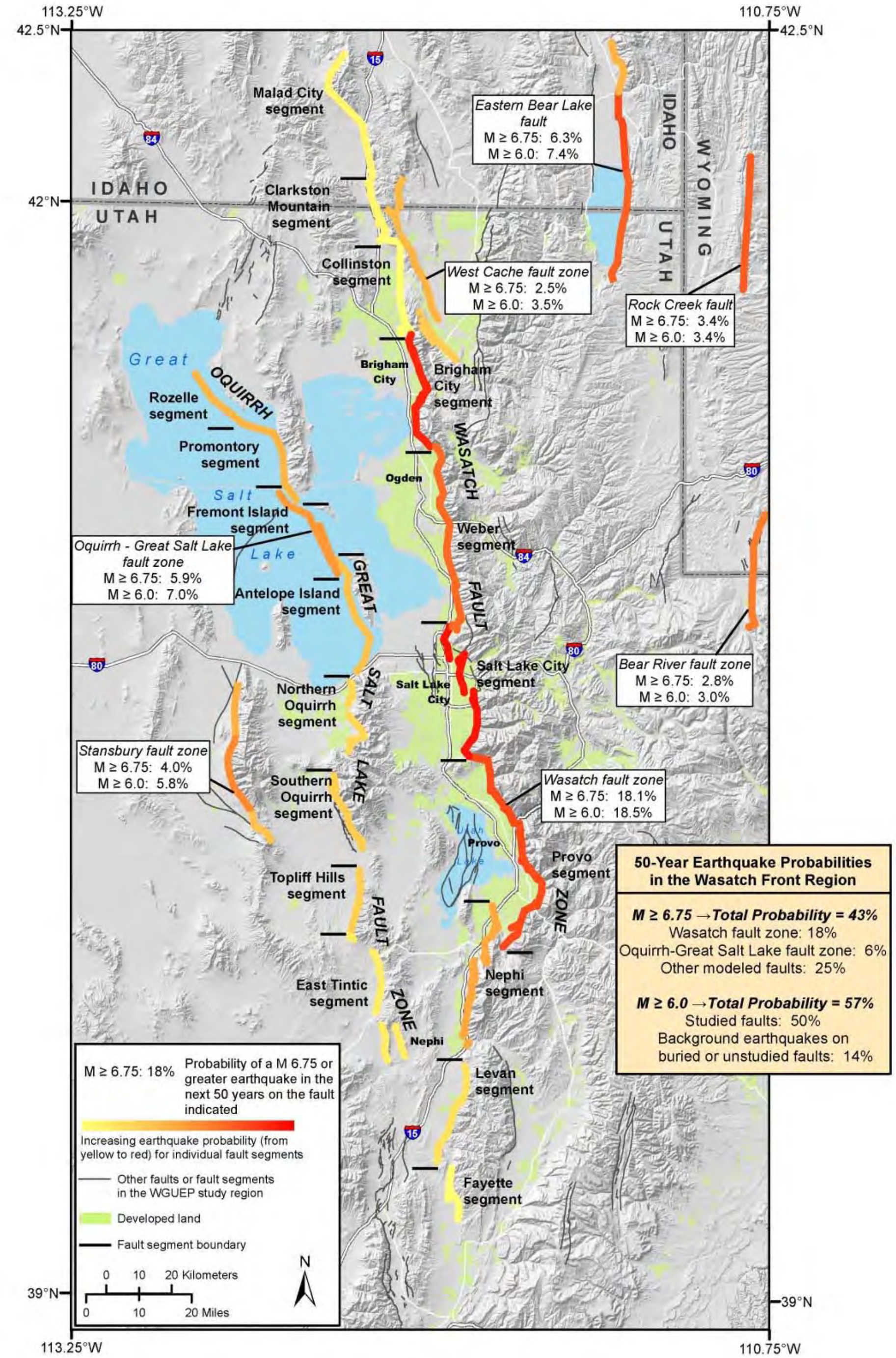
Generalized Logic Tree for Calculating the Recurrence of the Central Segments of WFZ



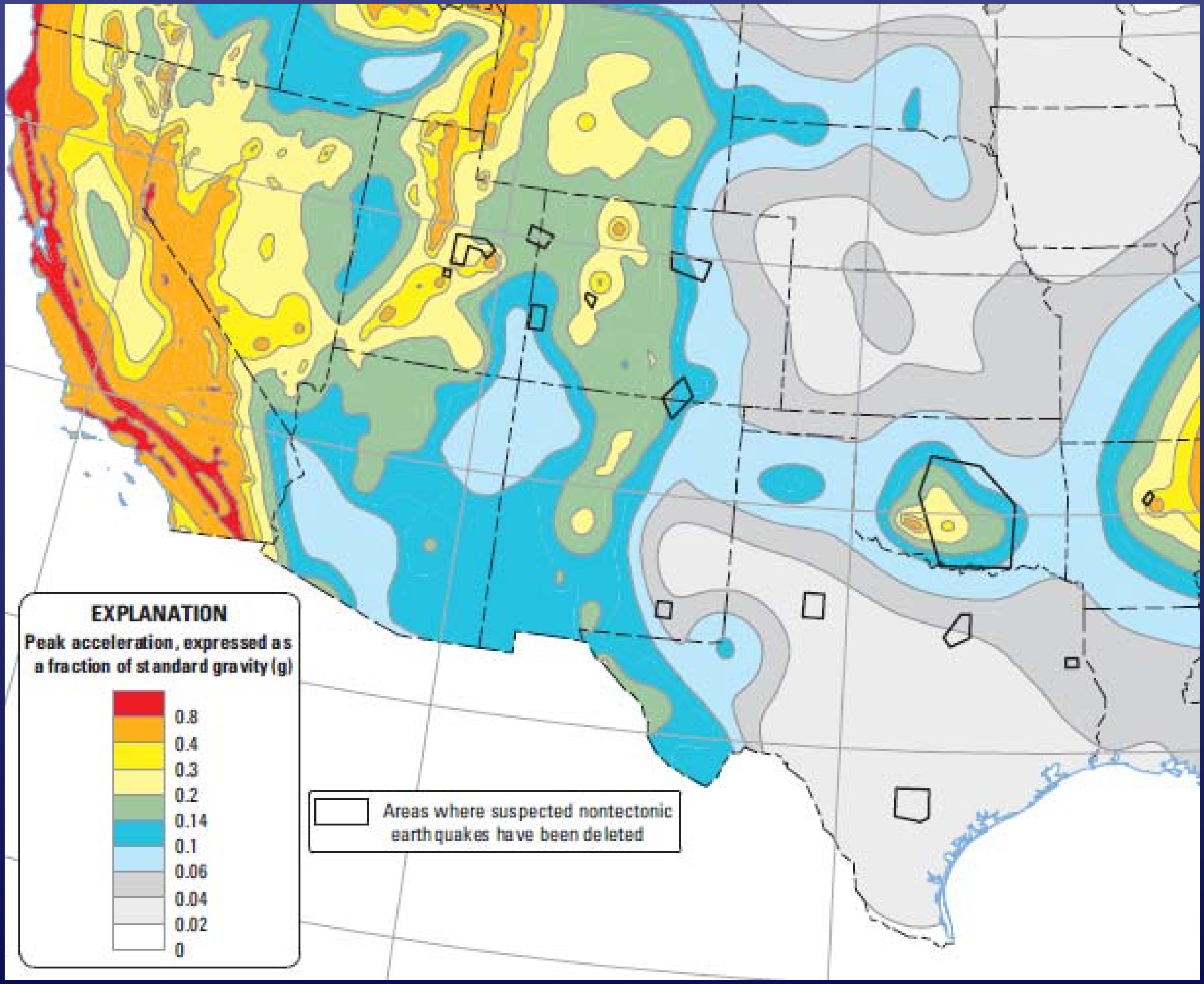
50-Year Probabilities for M≥6.75



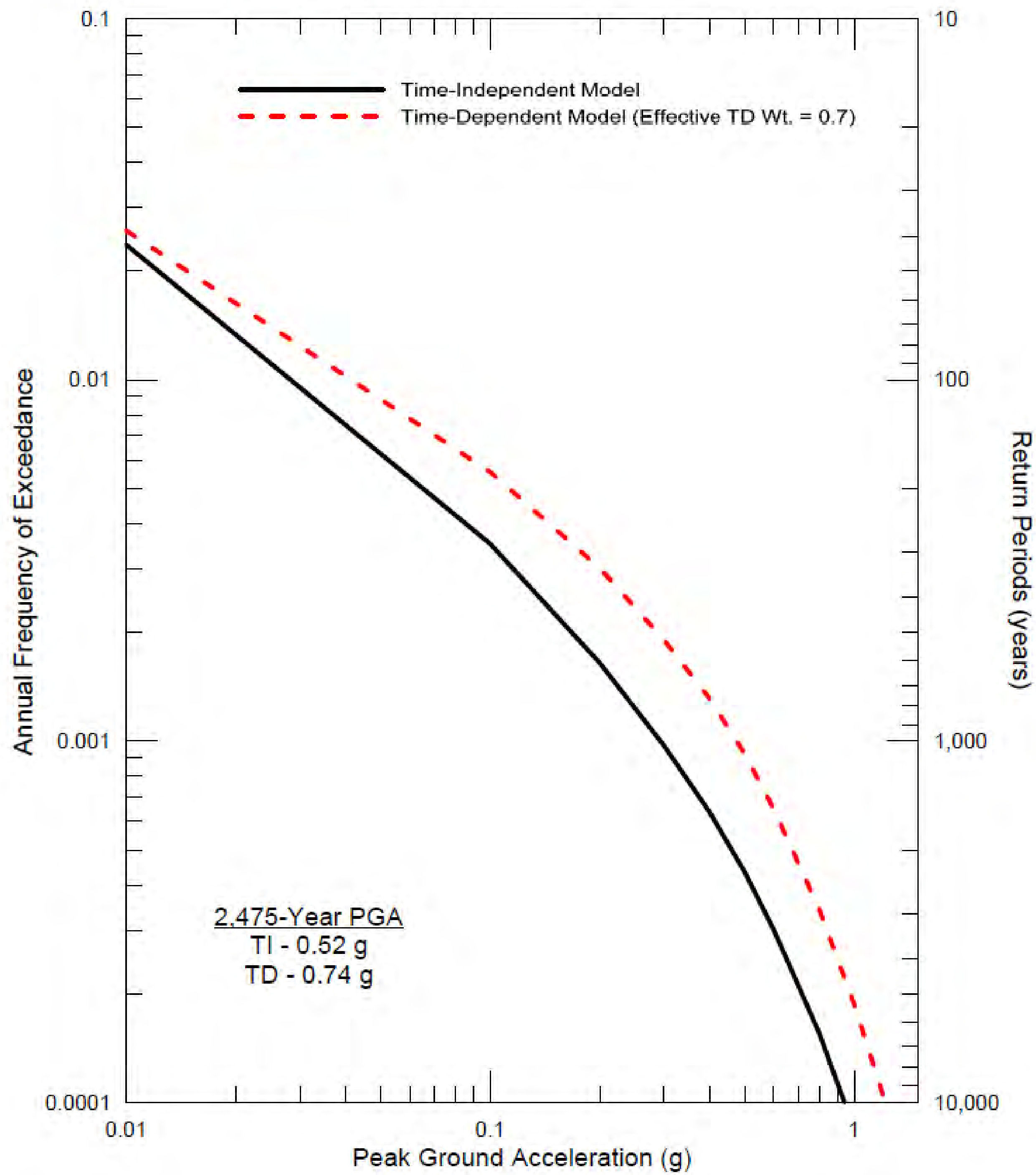
50-Year Probabilities for M≥6.75 and 6.0



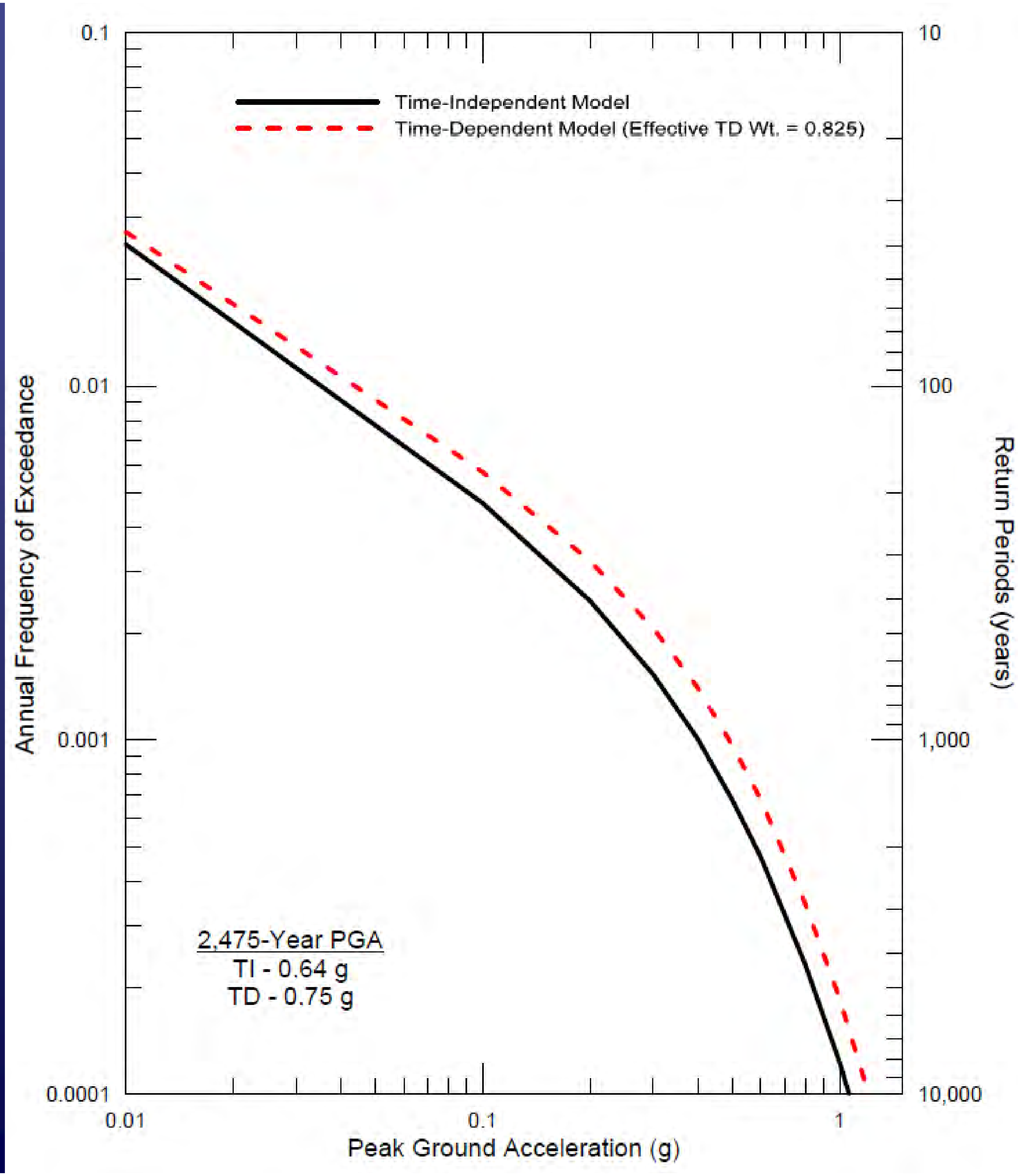
Two-Percent Probability of Exceedance in 50 Years Map of Peak Ground Acceleration



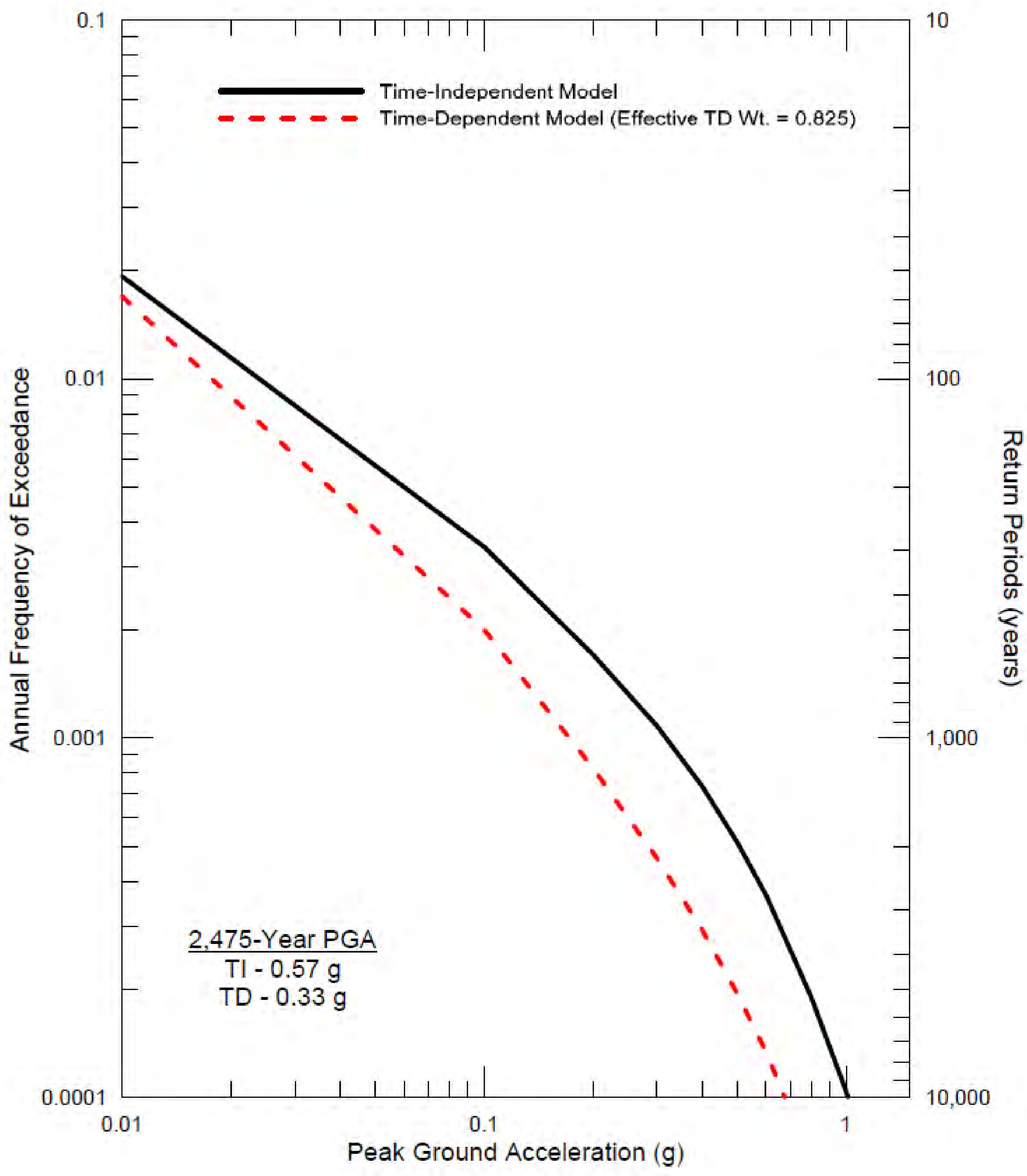
Comparison of Mean PGA Hazard in Brigham City



Comparison of Mean PGA Hazard in Salt Lake City



Comparison of Mean PGA Hazard in Nephi



Summary

- Comparison of the time-dependent and time-independent hazard at three cities along the Wasatch Front show significant differences at a 2475-yr return period.
- These differences are due primarily to how the elapsed time since the MRE compares to the average recurrence intervals of the rupture scenarios particularly the single segment ruptures.
- Note that because there is a time-independent component in the time-dependent recurrence intervals, the time-dependent hazard estimates have large uncertainties.
- However, even given those uncertainties, the time-dependent hazard estimates need to be given strong consideration in structural design and safety analyses.

RECLAMATION

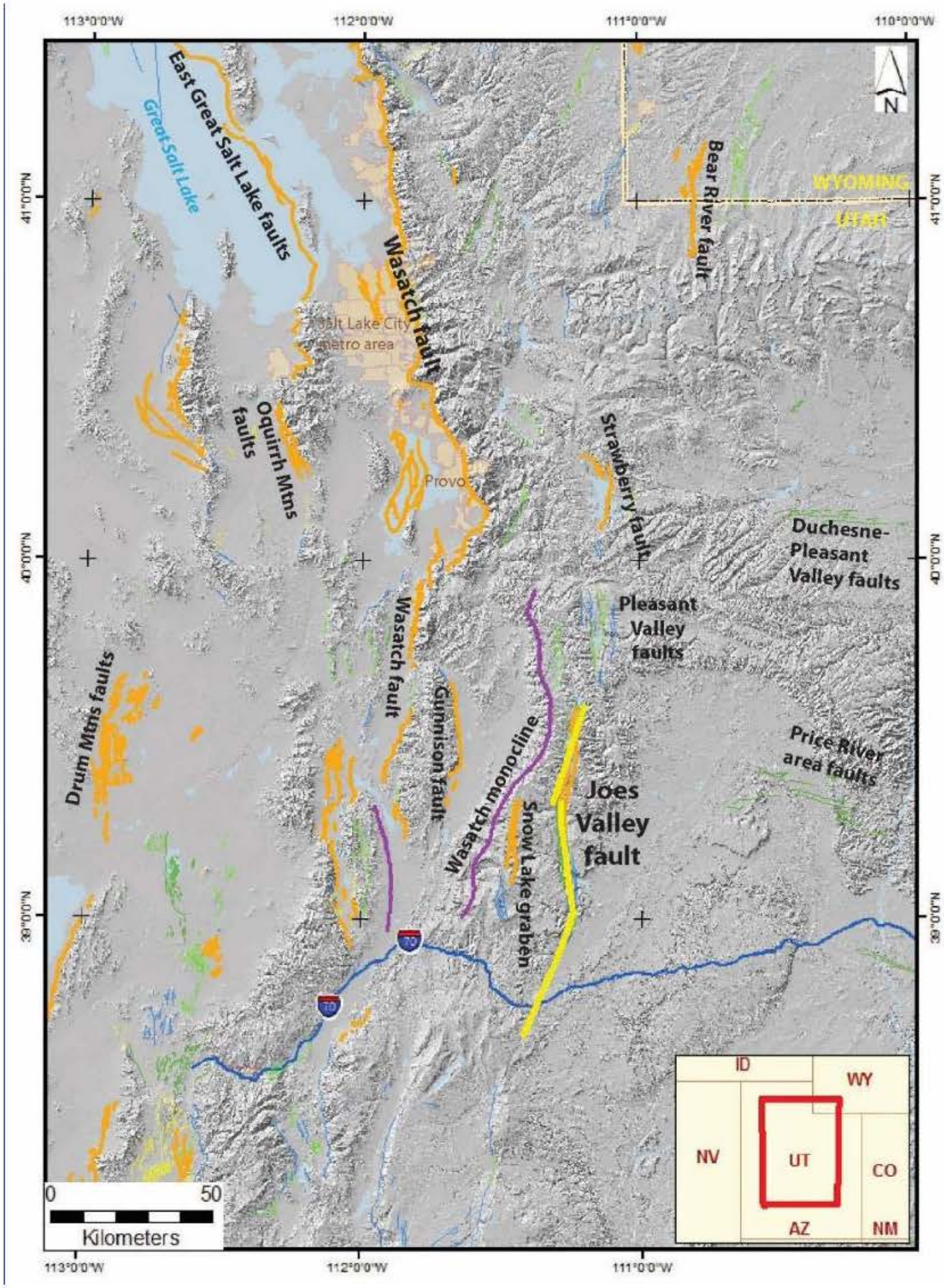
Managing Water in the West

Update of Ongoing Studies to Evaluate the Seismic Potential of the Joes Valley Fault Zone, East-central Utah

Lucy Piety, Vanessa King, and Joanna Redwine
Seismology, Geomorphology, and Geophysics Group
Bureau of Reclamation
Denver, Colorado

U.S. Department of the Interior
Bureau of Reclamation

February 2017

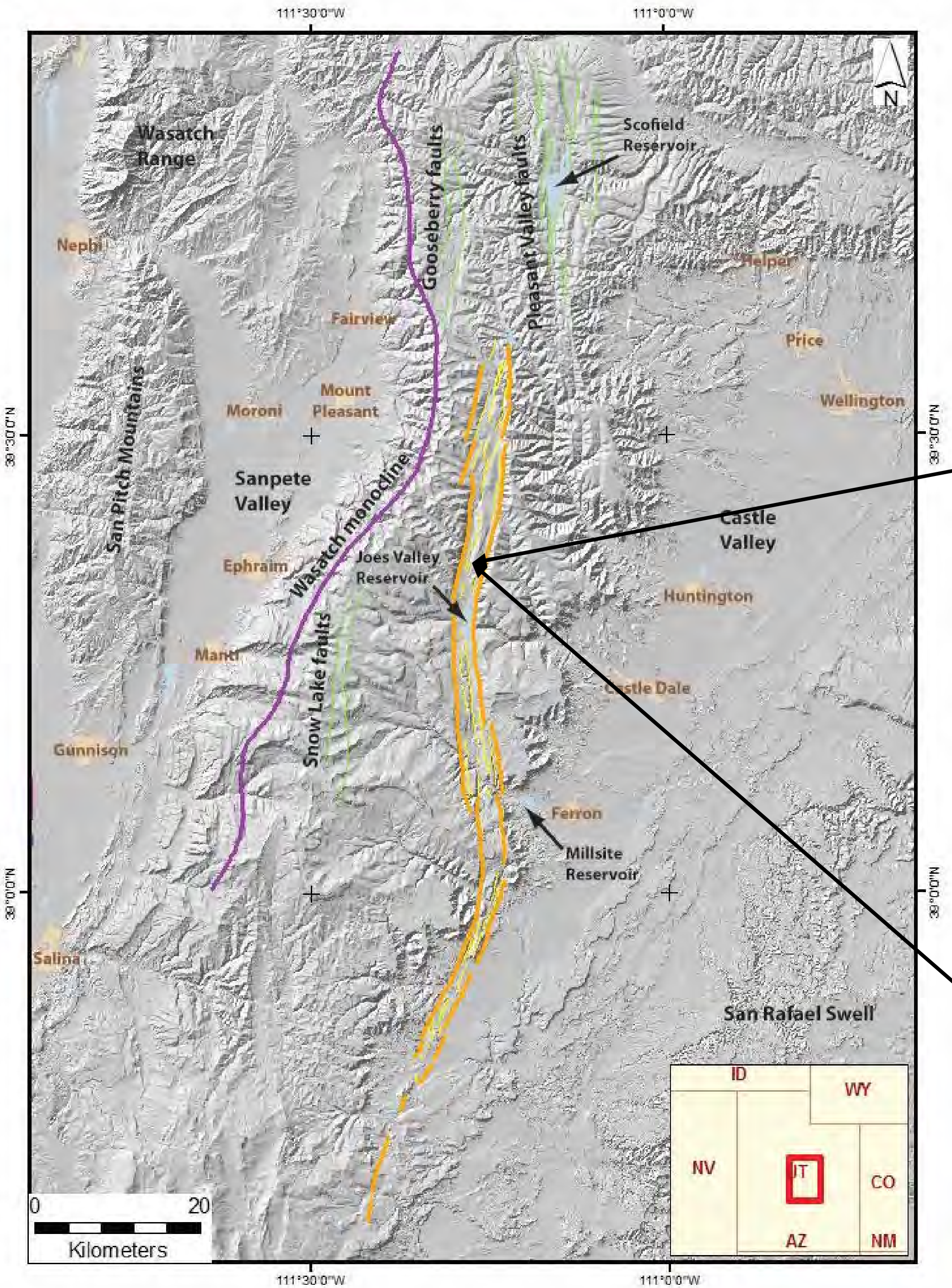


Joes Valley fault zone

- Within a zone of north-striking faults ~50 km east of Wasatch fault
- Most of the Joes Valley fault zone is through the Wasatch Plateau
- South part is along the west side of Castle Valley

RECLAMATION

Joes Valley fault zone



Looking north from north of Joes Valley Reservoir

Looking south from north of Joes Valley Reservoir

Background

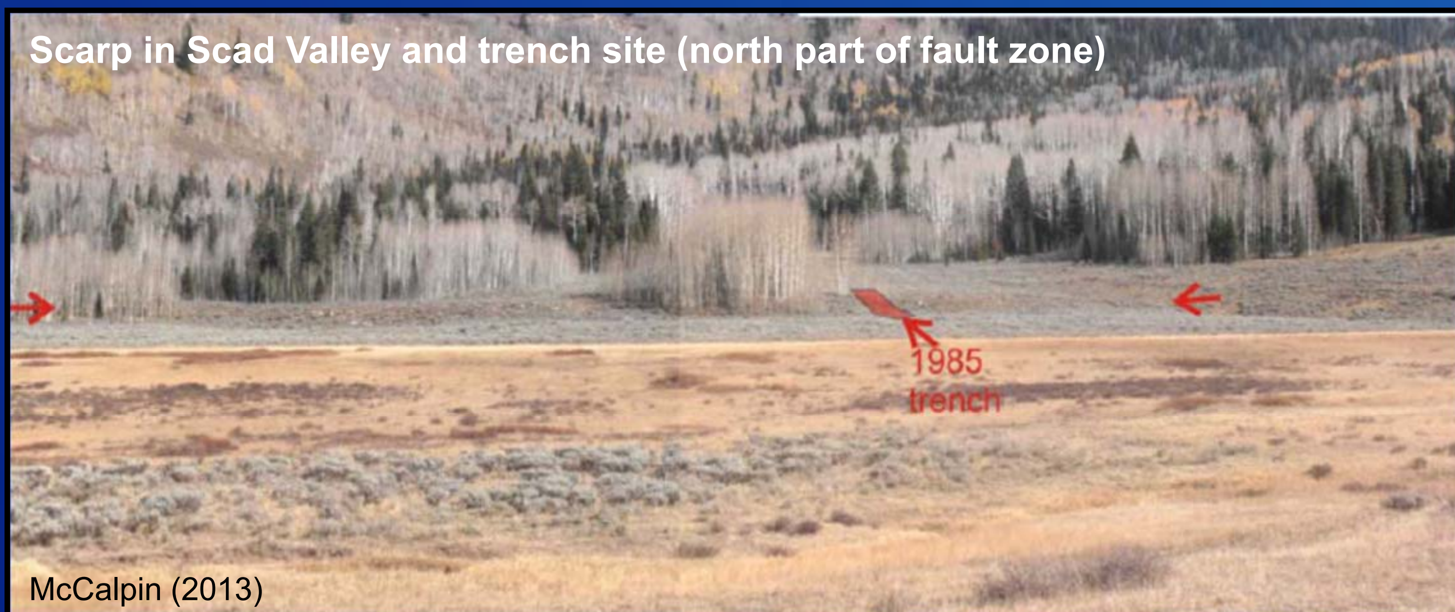
- Detailed geologic study of the Joes Valley fault (Lucy Foley and others, 1986, Reclamation report)

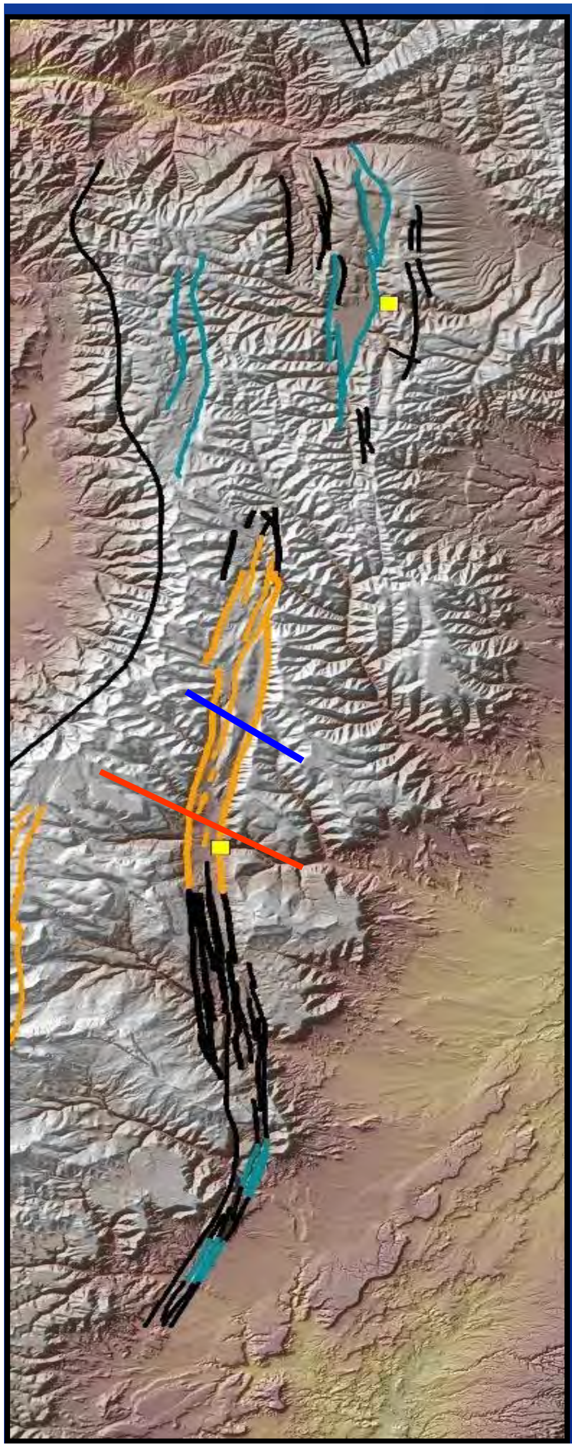
- Re-evaluation of the Joes Valley fault (Larry Anderson, 2008, Reclamation report)
  - Interpretation of two seismic reflection lines (Jim Cogan, Western State Colorado University, Gunnison, Colorado, contract report)

RECLAMATION

Main conclusions of Lucy Foley and others (1986)

- Recurrent late Quaternary (since 11 ka to 30 ka) surface displacements (northern Joes Valley faults)
- Youngest event in early Holocene (11 ka to 6.5 ka); no scarps on younger Holocene surfaces
- Faults extend to seismogenic depth of ~15 km and could generate large (7-7.5) earthquakes





Main conclusions of Jim Coogan's interpretation of two seismic reflection lines (~35 miles) and Larry Anderson (2008)

- Faults sole into weak rock of Carmel Formation and Arapien Shale (salt-bearing units) at depths of ~3 km
- Joes Valley faults do not extend to seismiogenic depths (10-20 km) so the faults are unlikely produce large (7-7.5) earthquakes

No resolution with conclusions of 1986 study

RECLAMATION

Present geologic studies—2 parts

- Subsurface studies
- Geomorphic studies

Goal: Integrate the two studies to better understand

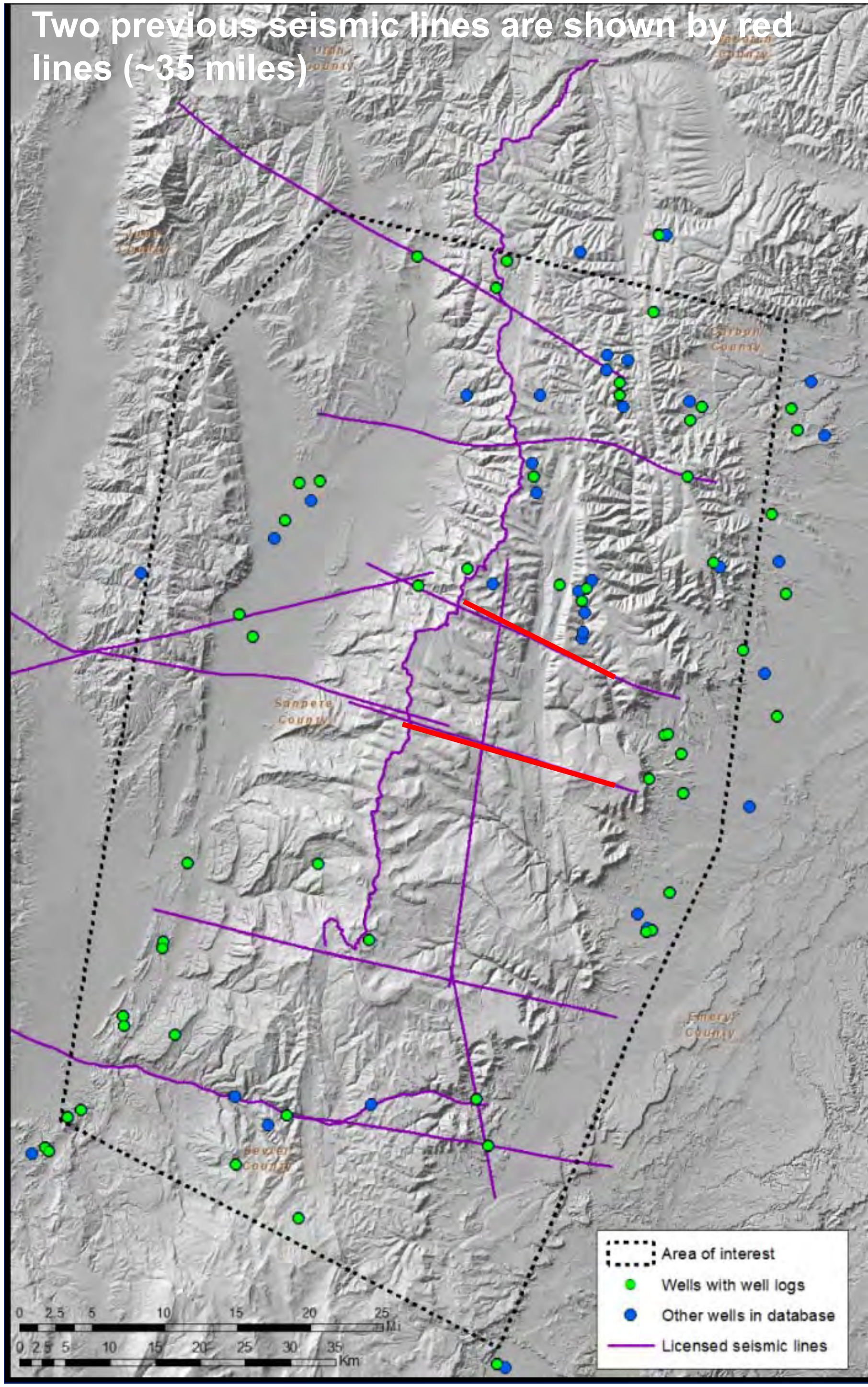
- **The origin and history of movement on the Joes Valley fault zone**
- **The potential for and type of tectonic activity on the fault zone**

RECLAMATION

Subsurface studies

- Licensed seismic reflection and well-log data
- Processing seismic reflection data with a common datum
- Interpretation of seismic reflection and well-log data
- Primary goals
  - Delineate subsurface geology, including presence of faults
  - Existence, extent, distribution, and depth of salt deposits beneath Joes Valley, Wasatch Plateau, and adjacent portions of Sanpete Valley and Castle Valley

RECLAMATION



Subsurface studies

About 385 miles of 2D seismic reflection data

Collected between late 1970s and 1980s

Wells shown in green are $\geq$10,000 feet deep and have sonic logs

Seismic interpretation is being done by contractors

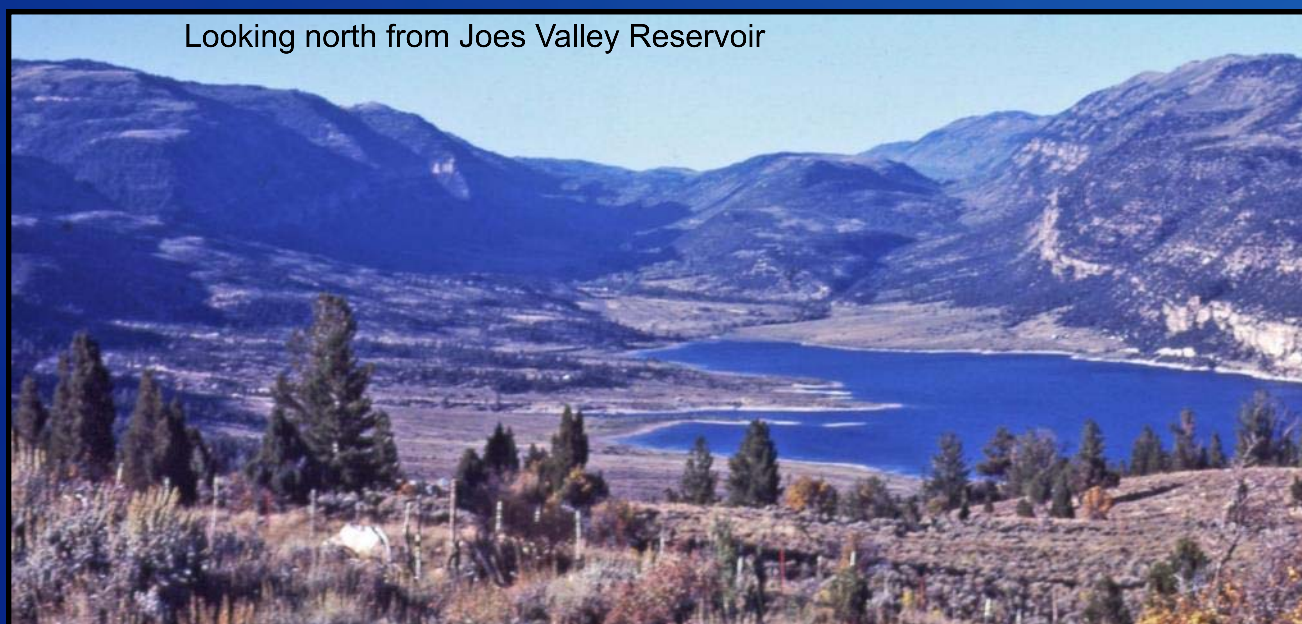
RECLAMATION

Geomorphic studies

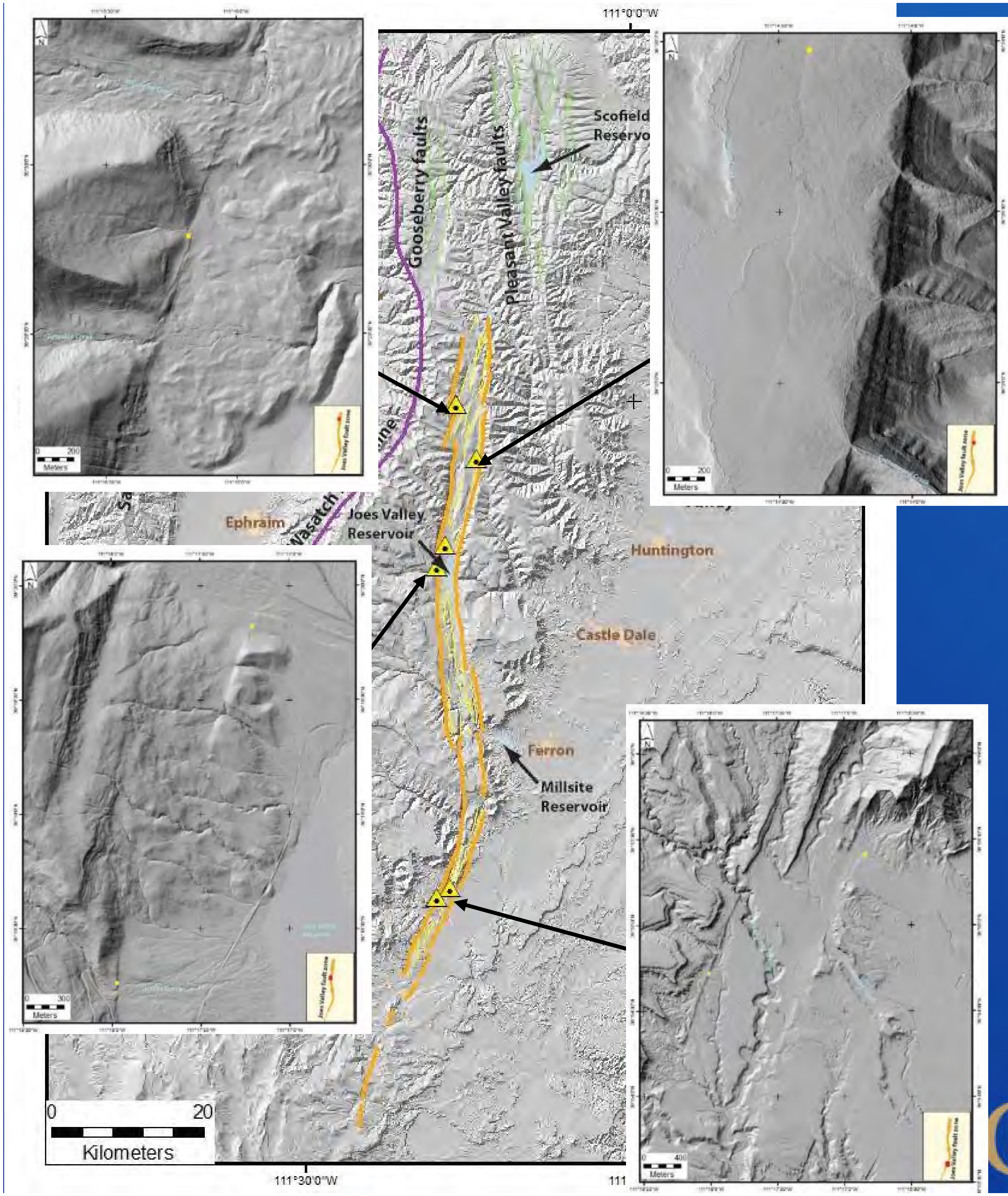
Primary goal

Refine the late Quaternary displacement history on several faults in the zone

- Mapping using lidar imagery
- Reconnaissance field mapping
- Excavate trenches if possible



Looking north from Joes Valley Reservoir



Trenches

6 possible sites

- 2 in north Joes Valley
- 2 in central Joes Valley
- 2 on southern end of fault zone

Locations

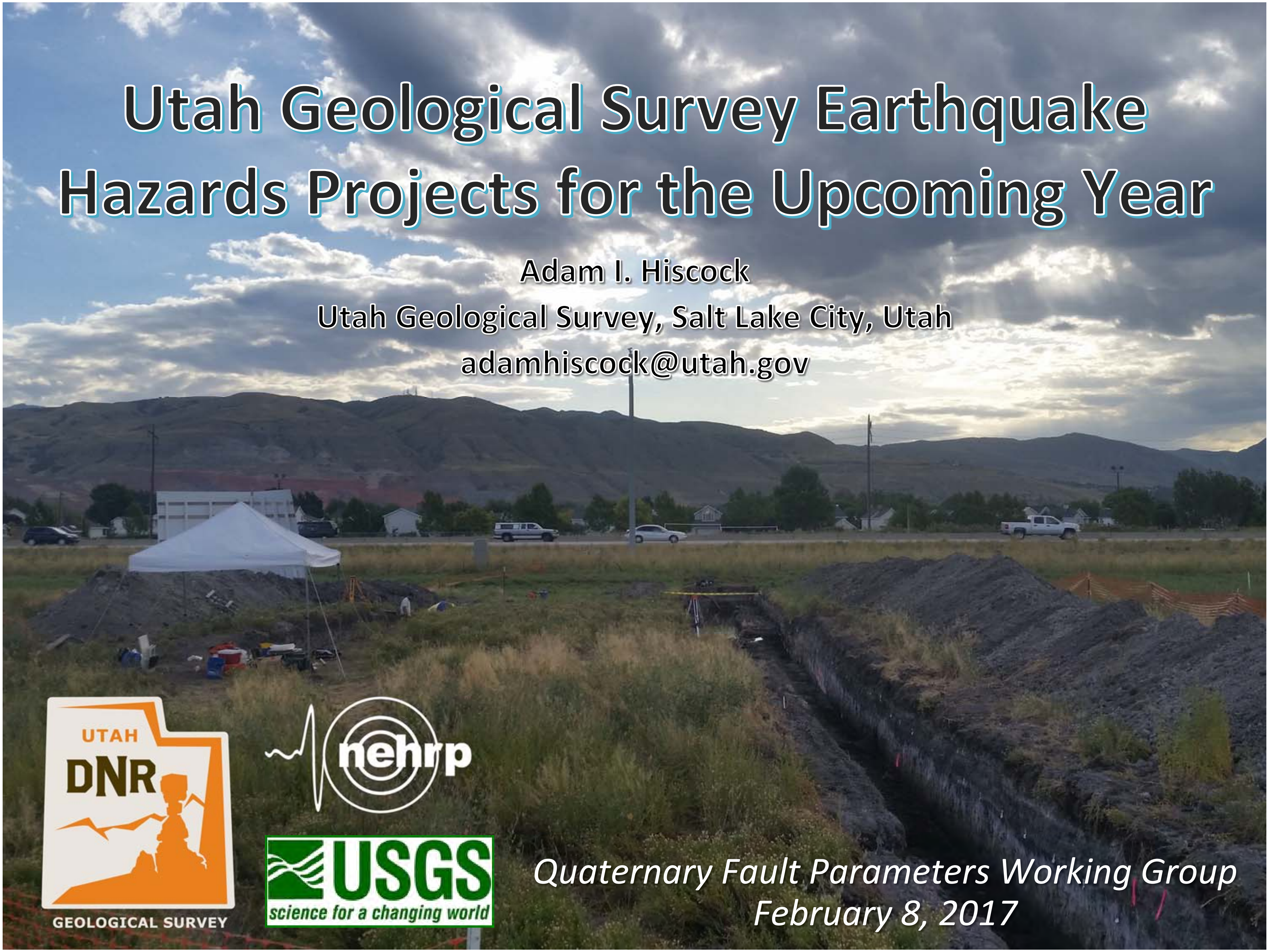
- 3 are on main west faults
- 3 are on faults within the fault zone

Excavations depend on ongoing efforts for permits from BLM and USFS and cultural/environmental surveys (Reclamation Provo office)

CLAMATION

Utah Geological Survey Earthquake Hazards Projects for the Upcoming Year

Adam I. Hiscock
Utah Geological Survey, Salt Lake City, Utah
adamhiscock@utah.gov



UTAH DNR GEOLOGICAL SURVEY

nehrp

USGS science for a changing world

Quaternary Fault Parameters Working Group
February 8, 2017

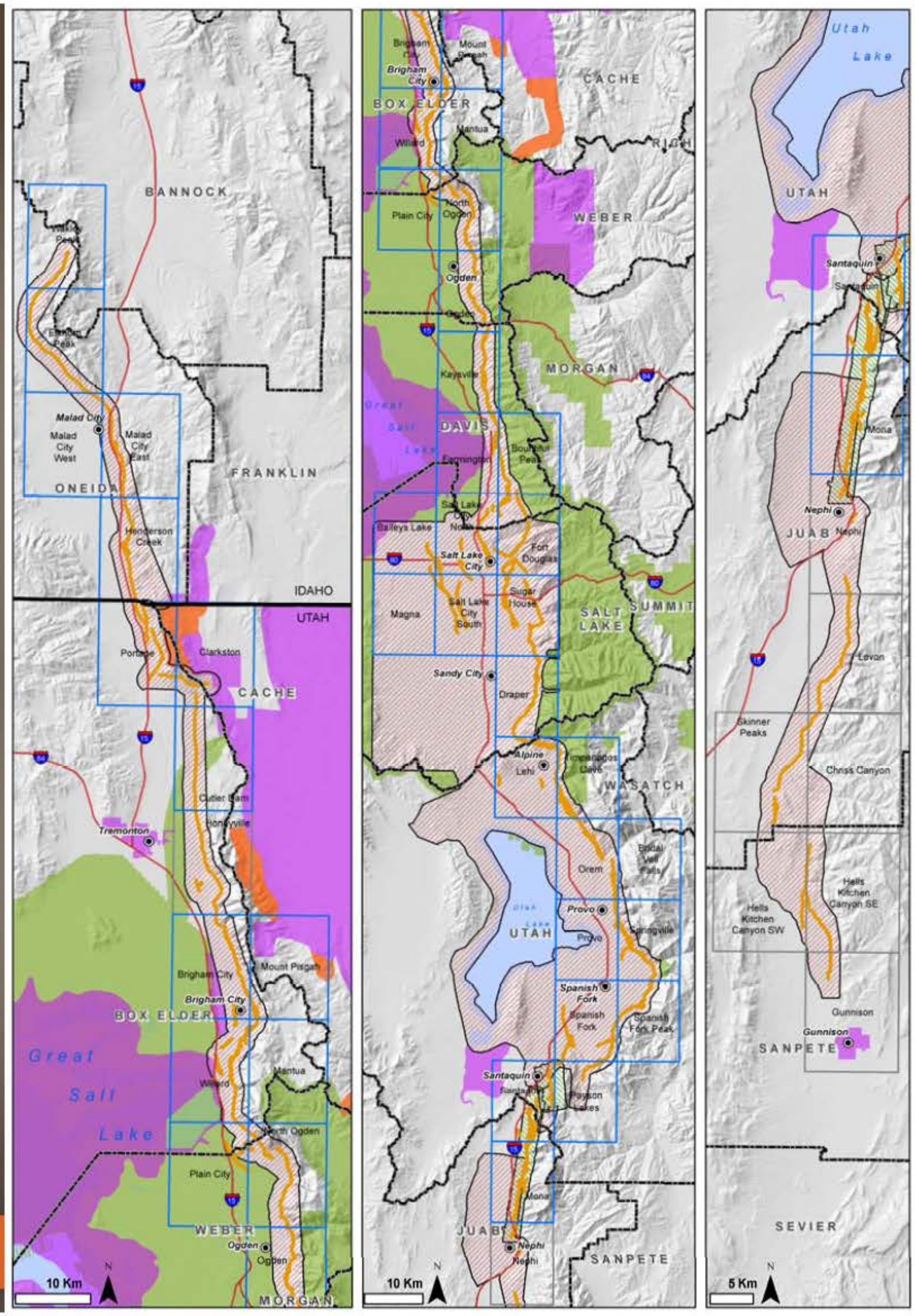
National Earthquake Hazards Reduction Program (NEHRP) Proposals

1. Detailed Mapping of the Wasatch Fault Zone, Utah and Idaho – Using New High-Resolution LiDAR Data to Reduce Earthquake Risk
   - Funded, 12/1/2016 – 12/1/2017
2. Paleoseismic Investigation of the Levan and Fayette Segments of the Wasatch Fault Zone, Juab and Sanpete Counties, Utah
   - Recommended for funding; on hold until April-May 2017
3. Detailed Mapping of the Holocene and Late Quaternary Active Traces of the East and West Cache Fault Zones, Cache Valley, Utah and Idaho – Using New High-Resolution LiDAR Data to Reduce Earthquake Risk
   - Recommended for funding; on hold until April-May 2017

WFZ LiDAR Mapping Project

- Map surface traces of the WFZ and WVFZ at 1:10,000
  - 2008 and 2013-2014 0.5-m LiDAR data, aerial photography, and field reconnaissance
- Delineate surface-fault-rupture hazard special study areas
- Identify future paleoseismic trench research sites

- Publish as 30 7-1/2 minute quadrangles in Utah; addition 5 7-1/2 minute quadrangles in Idaho in cooperation with the Idaho Geological Survey (IGS)
- GIS Data will be published at 1:10000 scale.
- Final mapping will be incorporated into the UGS *Utah Quaternary Fault and Fold Database* as needed.



UTAH GEOLOGICAL SURVEY

Quaternary Fault and Fold Database Update Presentation
February 8, 2017

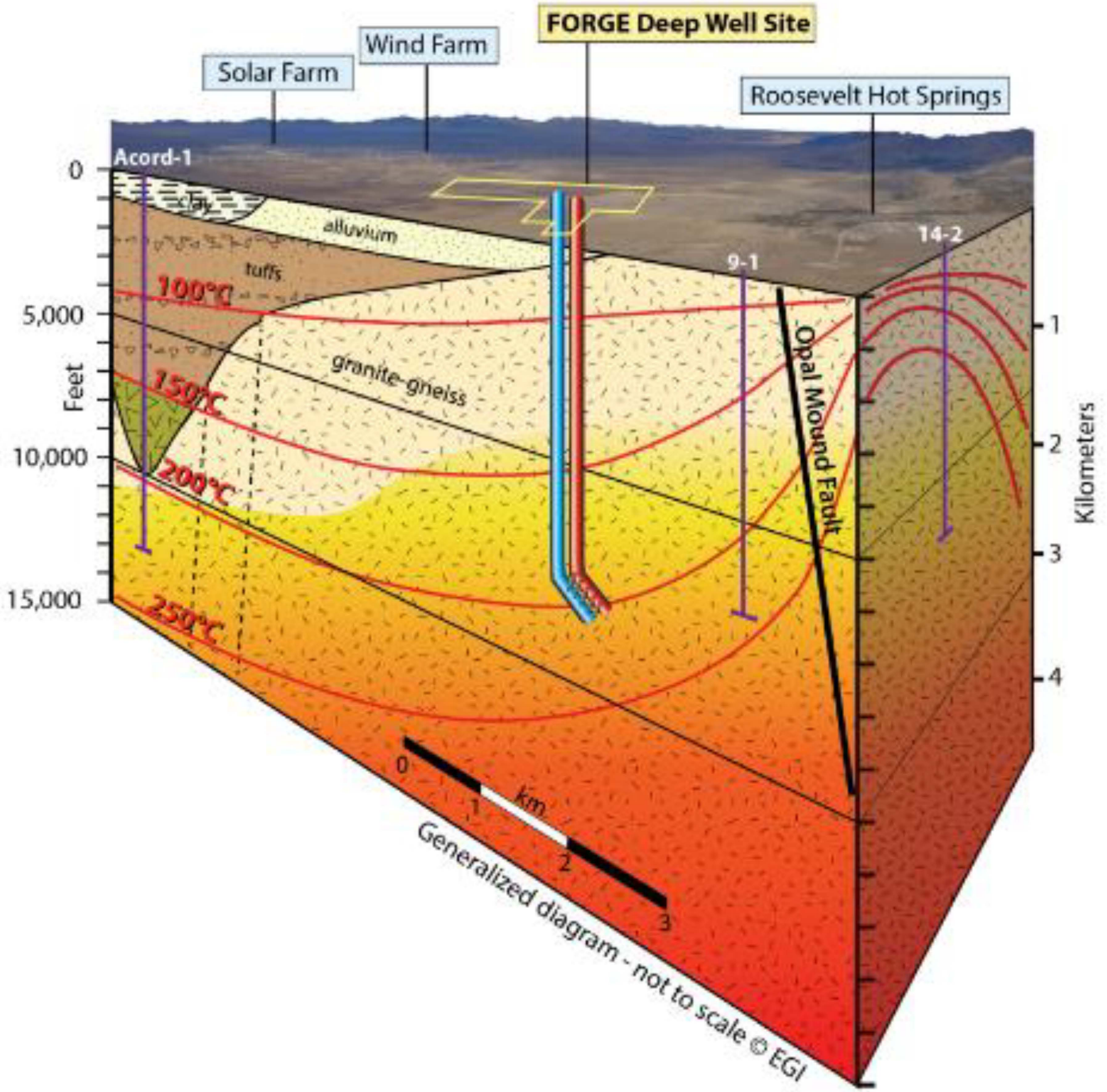
Visual 1: New USGS Q-faults page

- Brief update on new USGS changes
  - No longer updating reports
  - Emphasis on keeping citations up to date, and key attributes
- UGS Response
  - We like: elimination of the reports (much less work)
  - We don't like: not having the synopses be updated (useful for consultants), fault dip (is the dip angle relevant? How is it measured?)

Visual 2: UGS Q-faults page

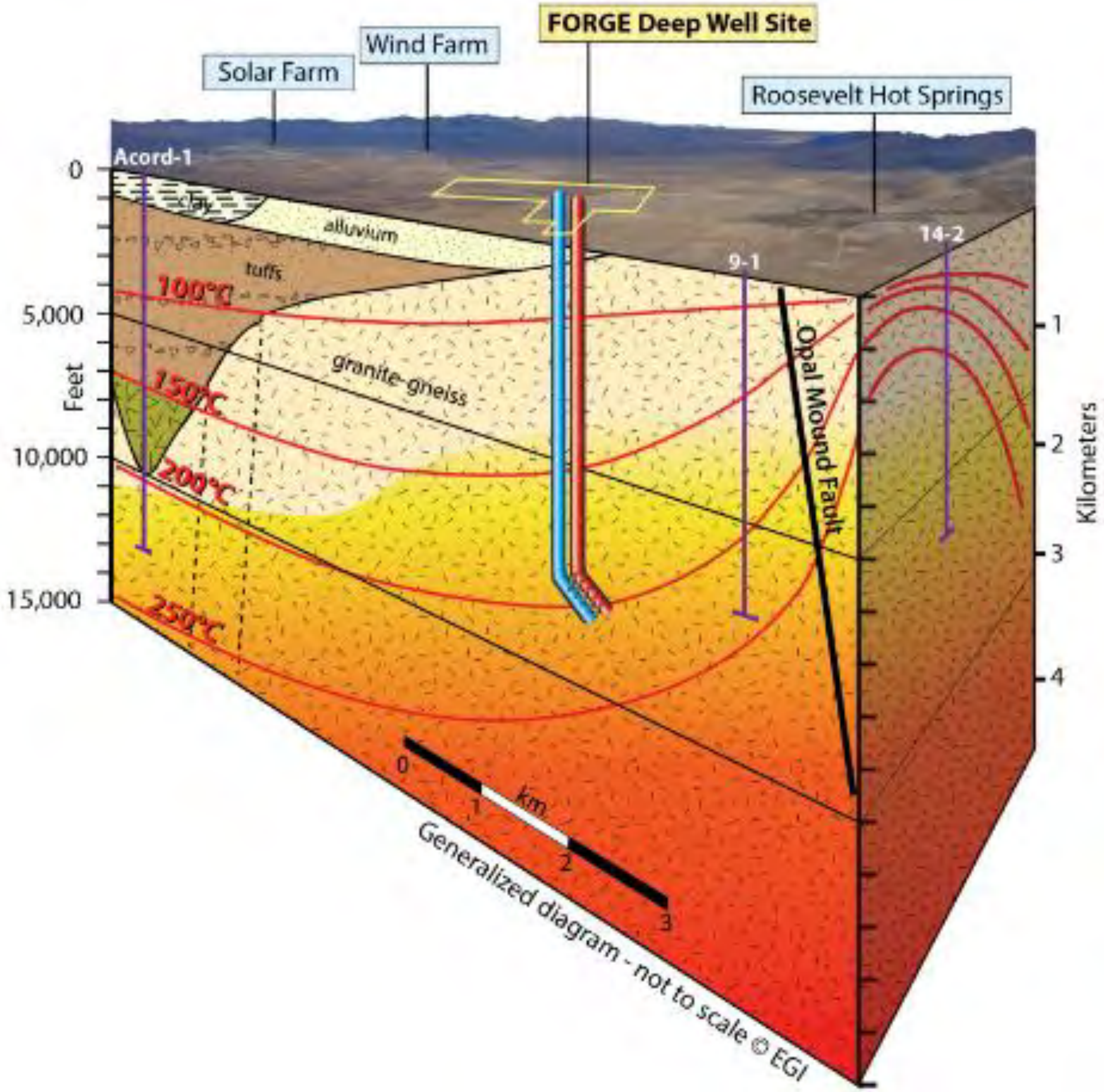
- Updated faults in the database:
  - New faults/sections: Great Salt Lake, Utah Lake, Carrington fault
  - Updated database to the AGRC.
  - Removal of Cedar City-Parowan Monocline, from discussion at 2016 meeting.
- Upcoming work
  - Updates coming up to get us completely updated (except unpublished work):
    - Number of faults that need attributes updates reviewed: 18
    - Number of faults that need geometry and attribute updates reviewed: 26
  - Response to USGS changes: new database fields
    - Paleoseismic recurrence interval (useful for consultants)
    - Last updated
    - Synopsis (useful for consultants)
  - "Paleoseismic Investigations" layer
    - Priority 1: Paleoseismology of Utah and other research projects
    - Priority 2: Consultant trenches
  - "Earthquake Database" (1850-2016)
    - Will get earthquake epicenters soon.

FORGE Experimental Geothermal Site



- Enhanced Geothermal System (EGS) field laboratory
- Testing fracking techniques from O&G in fractured bedrock.
- Granite and Gneiss basement rock 175 – 225°C
- FORGE site is adjacent to 300 MW wind farm and 240 MW solar plant (under construction)

FORGE Experimental Geothermal Site

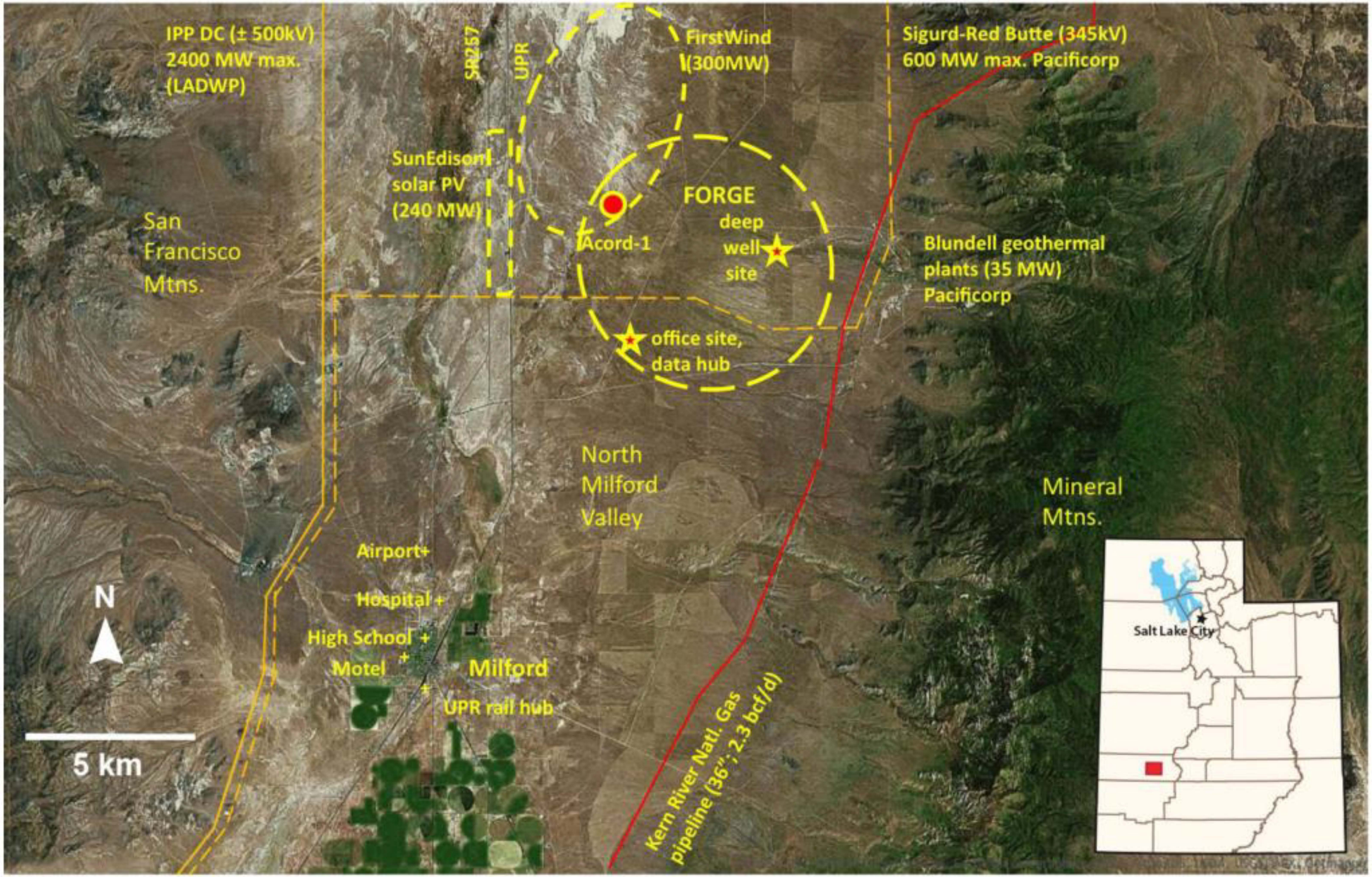


- 521 km^2 airborne lidar collected
- Surficial mapping underway
  - Constrain surface faulting relationships
  - Map Quaternary alluvial fans

<u>Mapping Goal</u>

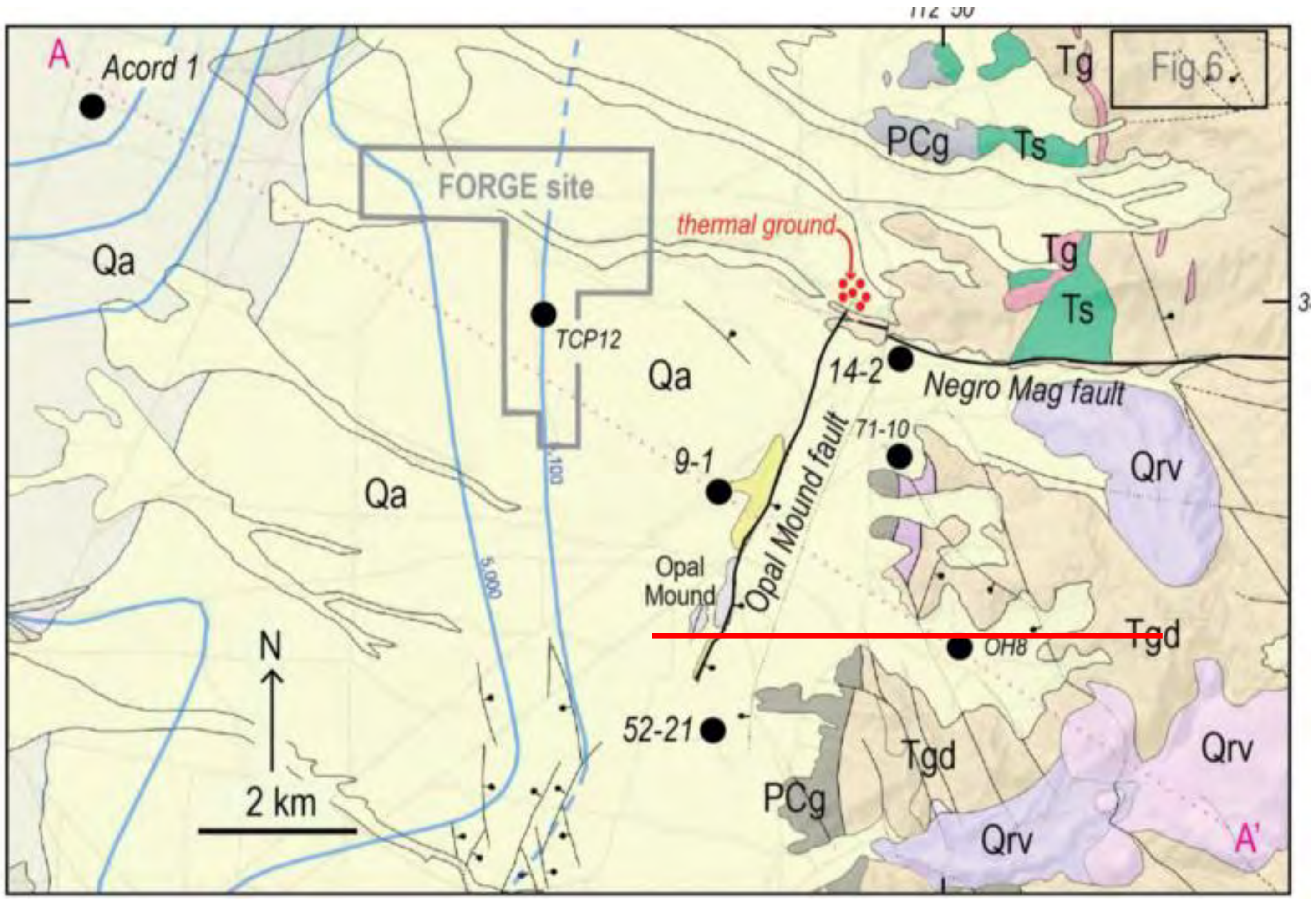
Understand the extent and characteristics of basement faulting.

More info www.forgeutah.com


IPP DC (± 500kV)
2400 MW max.
(LADWP)
SR257
UPR
FirstWind
(300MW)
Sigurd-Red Butte (345kV)
600 MW max. Pacificorp
SunEdison
solar PV
(240 MW)
FORGE
deep
well
site
Acord-1
San
Francisco
Mtns.
Blundell geothermal
plants (35 MW)
Pacificorp
office site,
data hub
North
Milford
Valley
Mineral
Mtns.
Airport+
Hospital +
High School +
Motel
Milford
UPR rail hub
N
5 km
Kern River Natl. Gas
pipeline (36"; 2.3 bcf/d)
Salt Lake City

Regional Geology

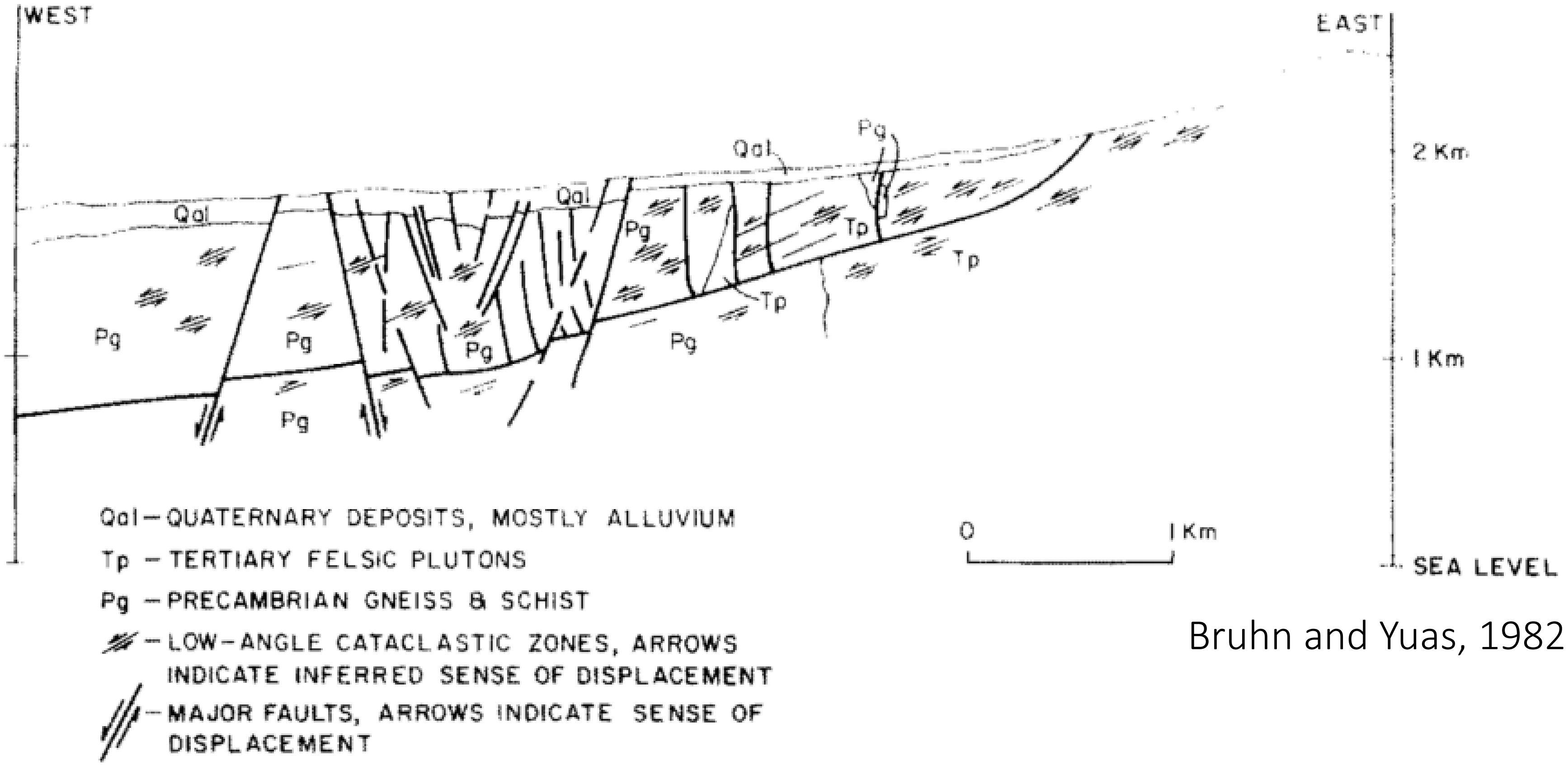
- Basement: Precambrian gneiss (~1720 Ma) and Tertiary plutonic rock (~25 Ma, ~18 Ma, 11-8 Ma)
- Low angle normal fault- Basin and Range extension
- High angle normal faults



Simmons et al., 2016

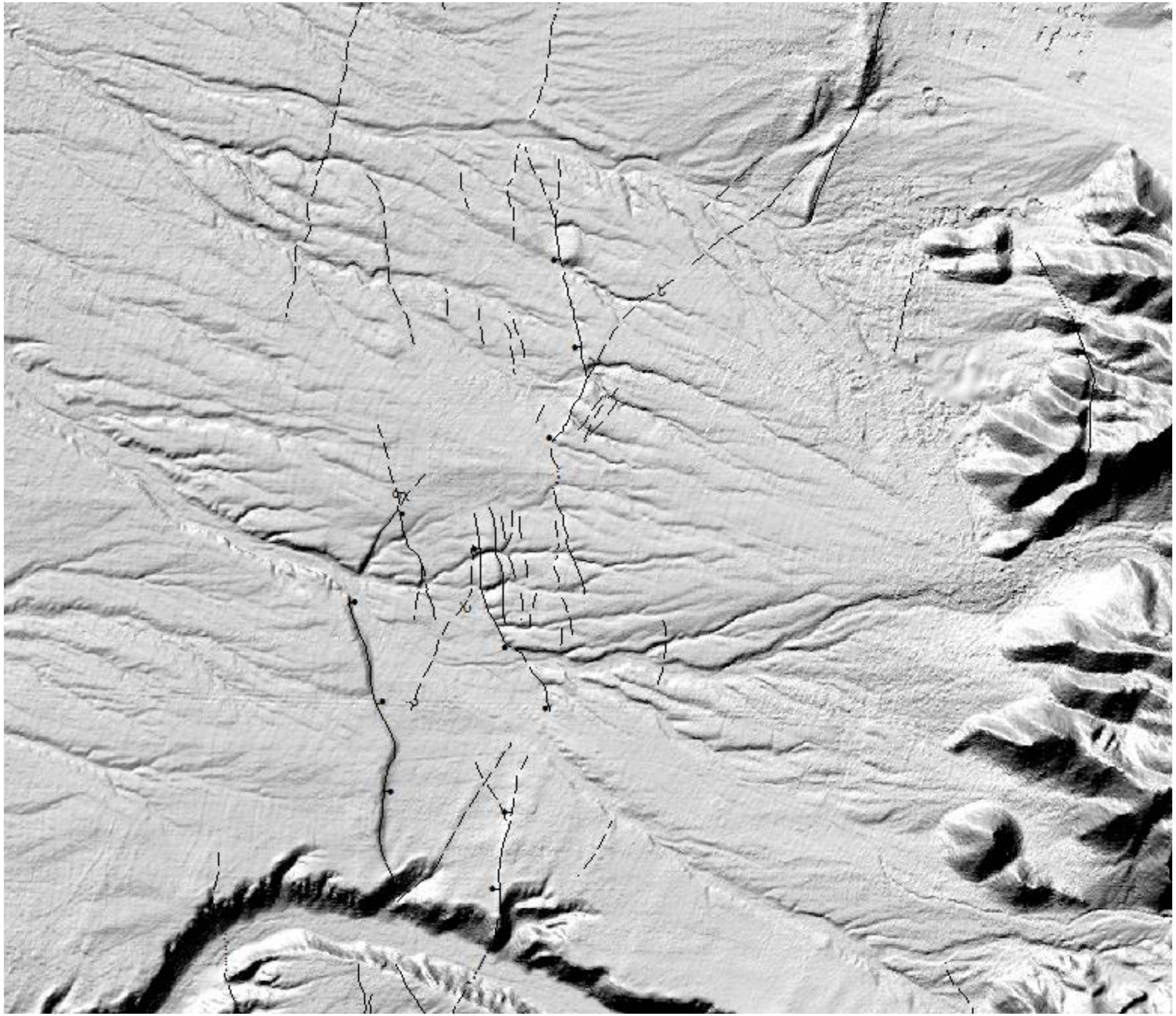
FORGE site

- Alluvial fans aggrading from the east (200-600m thick)
- Cut by high angle normal faults

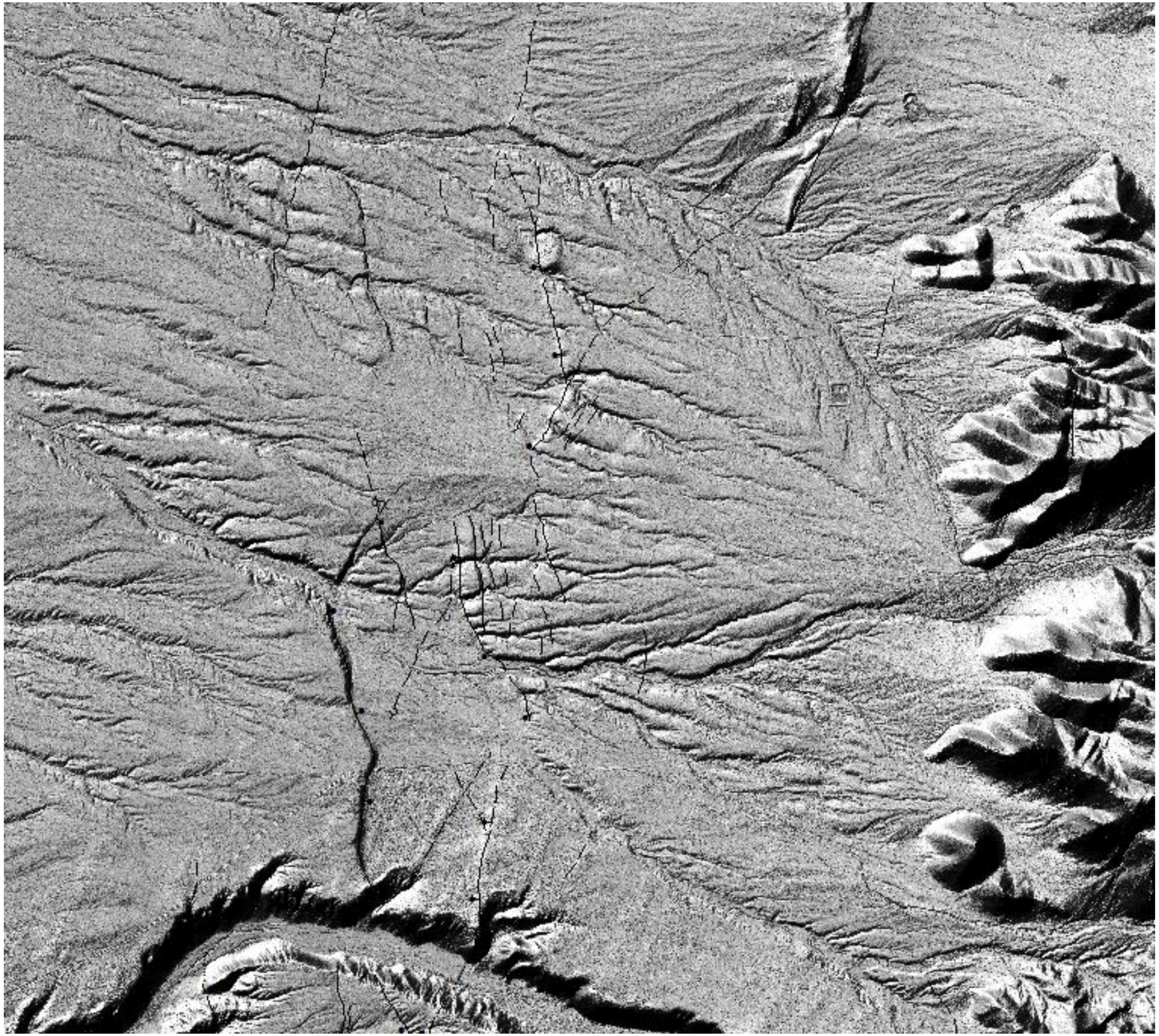


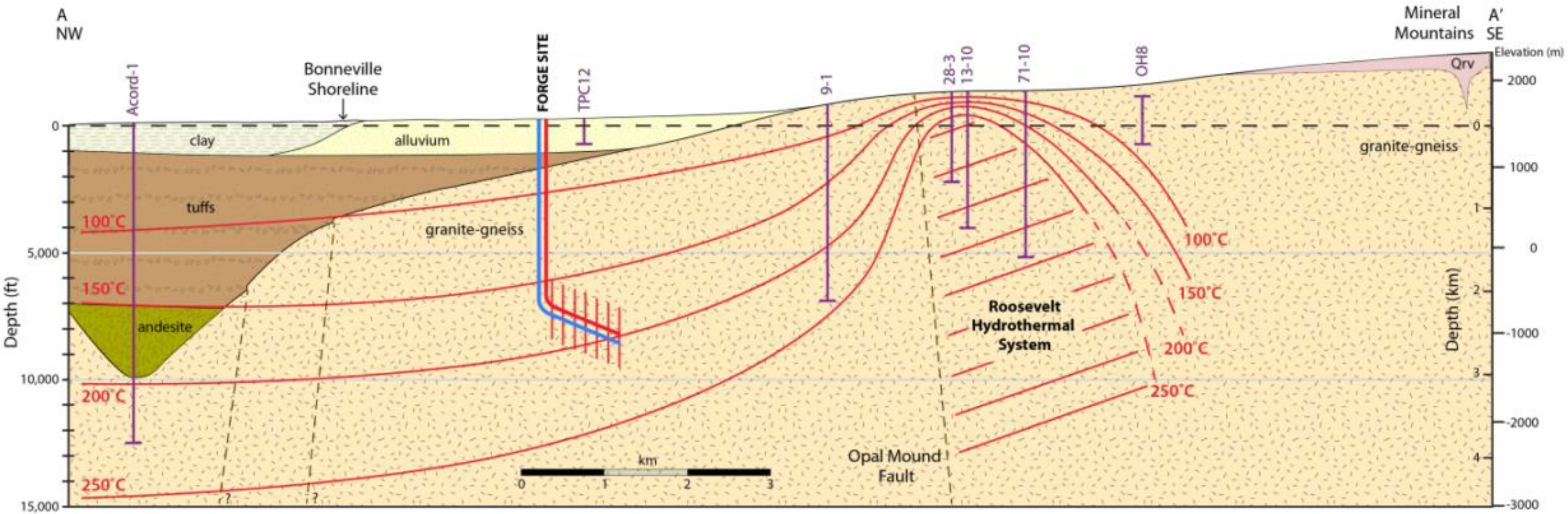
Bruhn and Yuas, 1982

5m Auto-corelated DEM



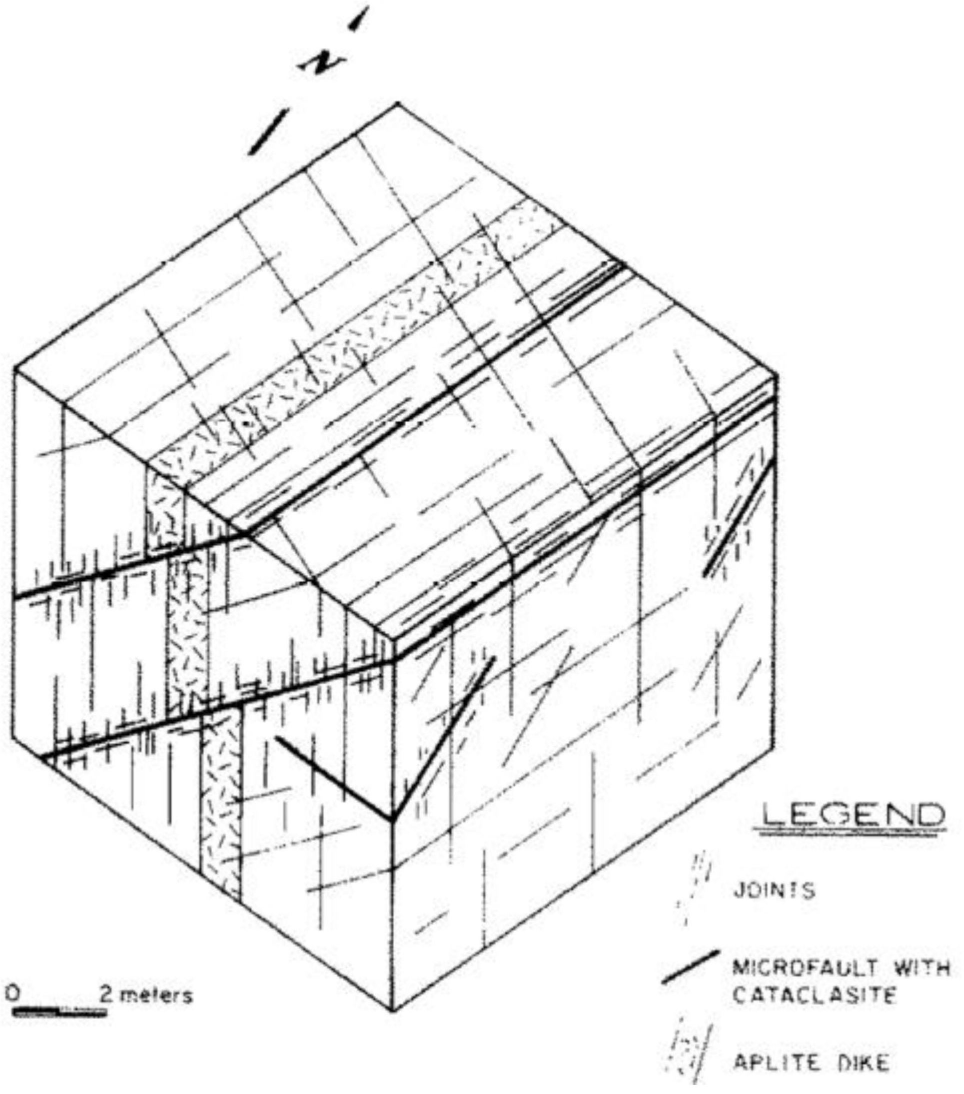
0.5m hillshade model





A
NW
A'
SE
Mineral Mountains
Bonneville Shoreline
FORGE SITE
Acord-1
TPC12
9-1
28-3
13-10
71-10
OH8
Qrv
clay
alluvium
tuffs
andesite
granite-gneiss
granite-gneiss
Roosevelt Hydrothermal System
Opal Mound Fault
100˚C
150˚C
200˚C
250˚C
100˚C
150˚C
200˚C
250˚C
Depth (ft)
0
5,000
10,000
15,000
Elevation (m)
2000
1000
0
-1000
-2000
-3000
Depth (km)
0
1
2
3
4
km
0
1
2
3

FRACTURE SYSTEM IN ROOSEVELT GEOTHERMAL AREA



Utah Quaternary Fault Parameters Working Group
Consensus Fault Parameters Update

Discussion Leader

William Lund
Utah Geological Survey

In The Beginning

The Utah Geological Survey (UGS) convened the first Utah Quaternary Fault Parameters Working Group (UQFPWG) in 2003

- NEHRP-funded, expert panel convened to evaluated the paleoseismic-trenching data then available for Utah's Quaternary faults in preparation for an update of the National Seismic Hazard Maps.
- Used experience and best professional judgment to assign preferred consensus earthquake timing, recurrence-interval (RI) and vertical slip-rate (VSR) estimates, and "best estimate" confidence limits for faults under review.
- Resulting RI and VSR estimates and associated confidence limits represented the then best available information regarding the faults/fault sections reviewed (Lund, 2005).

Lund, W.R., 2005, Consensus preferred recurrence-interval and vertical slip-rate estimates - review of Utah paleoseismic-trenching data by the Utah Quaternary Fault Parameters Working Group: Utah Geological Survey Bulletin 134, 109 p.

Utah Quaternary Faults with Paleoseismic-Trenching Data in 2003

- Wasatch fault zone
  - Brigham City segment
  - Weber segment
  - Salt Lake City segment
  - Provo segment
  - Nephi segment
  - Levan segment
- West Valley fault zone
- Joes Valley fault zone
- West Cache Valley fault zone
- East Cache Valley fault zone
- East Great Salt Lake fault zone
- Oquirrh fault zone
- Southern Oquirrh Mountains fault zone
- East Bear Lake fault
- Bear River fault zone
- Hogsback fault
- Hurricane fault zone
- Washington fault
- Morgan fault
- Strawberry fault
- James Peak fault
- Towanta Flat graben
- Bald Mountain fault
- Hansel Valley fault
- North Promontory fault
- Sugarville area faults
- Fish Springs fault

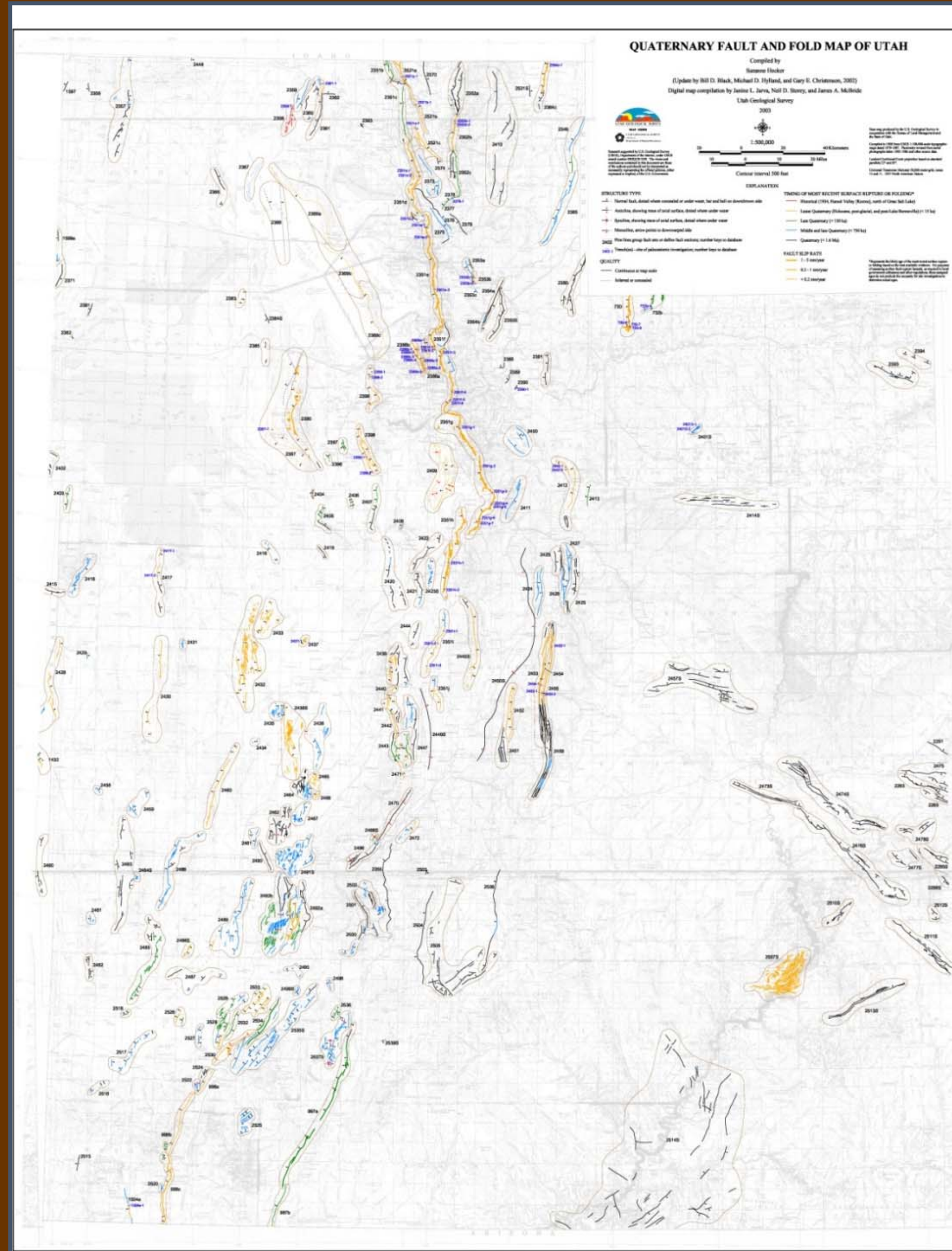
Example of UQFPWG Consensus Results

Parameter	Brigham City	Weber	Salt Lake City	Provo	Nephi	Levan
Earthquake Timing (cal yr B.P.)	Z 2100±800 Y 3450±300 X 4650±500 W 5950±250 V 7500±1000 U 8500±1500 T >14,800, <17,000	Za 0.5±0.3 ka Zb 1000±450 Y 3050±800 X 4400±700 W 6150±700	Z 1300±650 Y 2450±550 X 3950±550 W 5300±750 V ~7.5 ka U ~9 ka T ~ 17 ka S 17–20 ka (?)	Z 600±350 Y 2850±650 X 5300±300	Z <1±0.2 ka Y ~3.9±0.5 ka X >3.9±0.5, <5.3±0.7 ka	Z 1.0±0.2 ka
Preferred Recurrence Interval (yr)	2800 1300 500	2400 1400 500	2400 1300 500	3200 2400 1200	4800 2500 1200	12 ky 3ky
Preferred Vertical Slip Rate (mm/yr)	4.5 1.4 0.6	4.3 1.2 0.6	4.0 1.2 0.6	3.0 1.2 0.6	3.0 1.1 0.5	0.6 0.1

UQFPWG Process Produced a Disturbing Realization

Only 16% (33/212) of Utah's Q faults/fault segments had paleoseismic trenching data available for them, and much of those data had significant caveats associated with them.

UQFPWG was asked to identify additional Q faults/segments for which paleoseismic-trenching data are required to *"adequately characterize Utah's earthquake hazard to a minimally acceptable level."*



UQFPWG Originally Recommended 20 Faults in 2005 for Additional Study*

- Nephi segment WFZ
- West Valley fault zone
- Weber segment WFZ
- Weber segment "megatrench"
- Collinston & Clarkston Mountain segments WFZ
- Sevier/Toroweap fault
- Washington fault zone
- Cedar City/Parowan monocline
- Enoch graben/Red Hills faults
- Faults beneath Utah Lake
- East Cache fault zone
- Clarkston fault
- Wasatch Range back-valley fault
- Hurricane fault
- Levan segment WFZ
- Great Salt Lake fault zone
- Gunnison fault
- Scipio Valley faults
- Faults beneath Bear Lake
- Eastern Bear Lake fault

* Subsequently expanded in 2007, 2009, 2010, 2011, 2012,2013, 2014, 2015, and 2016 –see Table 3

So by 2005, Utah had consensus earthquake timing, SR, and RI parameters for 16 faults or fault/segments with trenching data, a list of 20 Quaternary faults that required further study to characterize the state's earthquake hazard to a minimally acceptable level, and a remaining ~176 Q faults scattered across the state about which little or nothing was known.

The Utah Geological Survey determined to make the UQFPWG permanent and added it to the already existing Utah Earthquake Working Groups (ground motion, liquefaction, slope stability). In 2005, the UQFPWG begin to systematically implement a process to spur study of the 20 Quaternary faults needing study on their list.

Annual Fault Study Priority Evaluation

AGENDA
QUATERNARY FAULT PARAMETERS WORKING GROUP
Wednesday, February 5, 2014
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

8:00 Continental breakfast

8:20 Welcome, overview of meeting, and review of last year's activities

8:30 Technical presentations of work completed or in progress
- 8:30 – Update on Nephi segment paleoseismic studies; Chris DuRoss, UGS
- 8:50 – Preliminary results from the Flat Canyon paleoseismic trench site, southern Provo segment, Wasatch fault—potential implications for Holocene fault segmentation along the Wasatch fault; Scott Bennett, USGS
- 9:10 – Geomorphic and paleoseismic evidence for multiple surface ruptures along structures between the Salt Lake City and Provo segments of the Wasatch fault; Nathan Toke, UVU
- 9:30 – Newly discovered Holocene-active basin floor fault in Goshen Valley, Utah County, Utah; Adam McKean, UGS
- 9:50 – U.S. Bureau of Reclamation Joes Valley fault study; Jim McCalpin, GEO-HAZ Consulting

10:10 Break

10:40 Technical presentations of work completed or in progress
- 10:40 – New observations from the Bear River fault zone; Dave Schwartz, USGS
- 11:00 – Clustered earthquakes during the Bonneville high stand–an update; Susanne Janecke, USU
- 11:20 – Contemporary deformation of the Wasatch Front, Utah, and its implication for the interseismic loading of the Wasatch fault zone; Wu-Lung Chang, UUGG
- 11:40 – New high-resolution LiDAR data for the Wasatch fault zone, and Salt Lake and Utah Counties, and hazard mapping; Steve Bowman, UGS

12:00 Lunch

1:00 Technical presentations of work completed or in progress
- 1:00 – Working Group on Utah Earthquake Probabilities, an update; Ivan Wong, URS Corporation
- 1:20 – Update on planned UGS & USGS trenching on the Salt Lake City and Provo segments of the Wasatch fault; Chris DuRoss, UGS and Scott Bennett, USGS
- 1:40 – Basin and Range Province Seismic Hazard Summit III; Bill Lund, UGS

2:00 UQFPWG 2014 fault study priorities (see table 1 for UQFPWG list of faults requiring additional study; see table 2 for UQFPWG 2013 fault priority list)

3:30 Adjourn

United States Geological Survey

Earthquake Hazards Program
External Research Support
http://earthquake.usgs.gov/research/external

USGS
science for a changing world

Proposals for Grants – Fiscal Year 2013
Program Announcement/Funding Opportunity G12AS20013

Closing Date: May 17, 2012

- **Utah: priority faults deemed to need further study have been identified by the Utah Quaternary Fault Parameters Working Group (UQFPWG). An updated list of these priorities as defined by the UQFPWG will be available in March 2012 at:** http://geology.utah.gov/ghp/workgroups/pdf/priorities2013.pdf. To learn more about activities of all of the Utah Working Groups, go to http://geology.utah.gov/ghp/workgroups/index.htm.

Table 3. Current status of paleoseismic investigations for Utah priority faults and fault segments identified by the UQFPWG as requiring additional investigation to adequately characterize Utah's earthquake hazard to a minimally acceptable level.

Fault or Fault Segment	UQFPWG Priority[1]	Investigations Status[2,3] (as of 12/2016)	Investigations Institution[4]
Nephi segment, Wasatch fault zone[5,6]	1	UGS Special Study 124 and 151 USGS SI Map 2966 UGS FTR Report	UGS/USGS
West Valley fault zone[5,6]	2	--	--
Granger fault		UGS Special Study 149	UGS/USGS
Taylorsville fault		Ongoing	UGS/USGS
Weber segment, Wasatch fault zone[5,6] – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment, Wasatch fault zone[5,6] – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds[6]	5	UUGG FTR Report	UUGG/BYU
Great Salt Lake fault zone[5,6]	6	UUGG FTR Report	UUGG
Collinston and Clarkston Mountain segments, Wasatch fault zone[6]	7	UGS Special Study 121 Map: UGS Open-File Report 638	UGS
Sevier and Toroweap faults[5,6]	8	UGS Special Study 122	UGS
Washington fault zone[6]	9	UGS Miscellaneous Publication 15-6	UGS
East Cache fault zone[5,6]	12	USU FTR Report	USU
Wasatch Range back-valley faults	14	No activity	--
Main Canyon fault[6]		UGS Miscellaneous Publication 10-5	USBR
Hurricane fault zone[5,6]	15	UGS Special Study 119	UGS
Levan segment, Wasatch fault zone[5,6]	16	UGS Map 229 Map: UGS Open-File Report 640 Proposal submitted, awaiting funding	UGS
Brigham City segment, Wasatch fault zone[5,6] – most recent event	2007	UGS Special Study 142	UGS/USGS
Bear River fault zone[5,6]	2007	AGU Abstracts: 2012 and 2013 USGS ongoing	USGS/UGS
Salt Lake City segment, Wasatch fault zone[5,6] – north part	2009	UGS Special Study 149	UGS/USGS
Hansel Valley fault zone[5,6]	2011	McCalpin (1985), Robinson (1986), McCalpin and others (1992) UUGG ongoing	UUGG
Nephi segment, Wasatch fault zone[5,6] – long-term earthquake record	2012	UGS FTR Report	UGS/USGS
Provo, Salt Lake City and Nephi segments, Wasatch fault zone[5,6] segmentation	2012	--	--
Flat, Maple, and Corner Canyons, and Alpine sites		USGS work ongoing UGS FTR Report	USGS/UGS
Fort Canyon fault, Traverse Mountains salient		Ongoing	UVU
Cottonwood fault, Corner Canyon site		UGS FTR Report	UGS/USGS
West Cache fault zone[5,6] – long-term earthquake record	2013	No activity	--
Using lidar[7] to map portions of the Hurricane[5,6], Wasatch[5,6], and West Valley[5,6] fault zones	2014	UGS Open-File Reports 638 and 640 Additional work ongoing	UGS
Northern segment of the Oquirrh fault zone[5,6]		No activity	--
Acquire high-resolution imagery (lidar, Structure from Motion, etc.)[7] and map Utah hazardous faults.	2015	Wasatch fault zone mapping proposal funded, awaiting award of East and West Cache fault zones mapping proposal.	UGS
		Lidar data for portions of the Bear Lake area, Cache Valley, and Great Salt Lake acquired fall 2016.	UGS/Others/ State of Utah
Refine the latest Quaternary earthquake chronology for the Topliff Hills fault[6].	2016	No activity	--
Acquire and analyze information on salt tectonics and its relation to the Main Canyon fault[6], Sevier detachment/Drum Mountains fault zone[6], Bear River fault zone[5,6], Spanish Valley (Moab area) faults, Joes Valley fault zone[5,6], Levan and Fayette segments[5,6] of the Wasatch fault zone, Scipio Valley faults[6], and the Gunnison fault[6].	2016	Levan and Fayette segments paleoseismic investigation proposal submitted, awaiting funding.	UGS

Fault Investigations Since 2005

(Table 3, 2017 UQFPWG agenda)

- **15 faults/fault segments studied**
- **21 new reports or maps (including NEHRP Final Technical Reports to the USGS)**
- **6 investigations and 1 map currently ongoing**
- **1 new investigation will begin in 2017**

Utah Paleoseismic Investigations Since 2005

- 2005- Segmentation and Holocene displacement history of the Great Salt Lake fault, Utah, Basin and Range Province Seismic Hazards Summit II
- 2006 - Holocene earthquake history of the northern Weber segment of the Wasatch fault zone, Utah – Paleoseismology of Utah, Volume 13
- 2007 - Paleoseismic investigation and long-term slip history of the Hurricane fault in southwestern Utah – Paleoseismology of Utah, Volume 14
- 2007 - Surficial-geologic reconnaissance and scarp profiling on the Collinston and Clarkston Mountain segments of the Wasatch Fault Zone, Box Elder County, Utah – paleoseismic inferences, implications for adjacent segments and issues for diffusion-equation scarp-age modeling – Paleoseismology of Utah, Volume 15
- 2008 - Paleoseismic reconnaissance of the Sevier fault, Kane and Garfield Counties, Utah – Paleoseismology of Utah, Volume 16
- 2008 - Paleoseismic investigation of the northern strand of the Nephi segment of the Wasatch fault zone at Santaquin, Utah – Paleoseismology of Utah, Volume 17, 2008
- 2009 - Paleoseismic investigation of the northern Weber segment of the Wasatch fault zone at Rice Creek trench site, North Ogden, Utah – Paleoseismology of Utah, Volume 18, 2009

Utah Paleoseismic Investigations Since 2005

- 2010 - Late Quaternary faulting in East Canyon Valley, Northern Utah – Paleoseismology of Utah, Volume 19
- 2011 - Extending the paleoseismic record of the Provo segment of the Wasatch fault zone, Utah: Final Technical Report to the U.S. Geological Survey,
- 2012 - Late Holocene earthquake history of the Brigham City segment of the Wasatch fault zone at the Hansen Canyon, Kotter Canyon, and Pearsons Canyon trench sites, Box Elder County, Utah − Paleoseismology of Utah, Volume 22
- 2012 - Determination of paleoearthquake timing and magnitudes on the southern segment of the East Cache fault, Utah: Final Technical Report to the U.S. Geological Survey
- 2014 - Evaluating surface faulting chronologies of graben-bounding faults in Salt Lake Valley, Utah – New paleoseismic data from the Salt Lake City segment of the Wasatch fault zone and the West Valley fault zone – Paleoseismology of Utah, Volume 24
- 2014 - History of late Holocene earthquakes at the Willow Creek site and on the Nephi segment, Wasatch fault zone – Paleoseismology of Utah, Volume 25

Utah Paleoseismic Investigations Since 2005

- 2014 – Paleoseismology of the Promontory segment, East Great Salt Lake fault: Final Technical Report to the U.S. Geological Survey
- 2014 - Paleoseismic investigation to determine the mid-Holocene chronology of surface-faulting earthquakes on the Nephi segment of the Wasatch fault zone, Utah and Juab Counties, Utah: Final Technical Report to the U.S. Geological Survey
- 2014 – Paleoseismology of faults submerged beneath Utah Lake: Final Technical Report to the U.S. Geological Survey
- 2015 – Paleoseismic investigations of Holocene earthquakes on the Provo segment, Wasatch fault zone, Utah: Final Technical Report to the U.S. Geological Survey
- 2015 - Geologic mapping and paleoseismic investigations of the Washington zone, Washington County, Utah, and Mohave County, Arizona − Paleoseismology of Utah, Volume 27
- 2016 - Late Holocene chronology of surface-faulting earthquakes at the Corner Canyon site on the Salt Lake City segment of the Wasatch fault zone, Salt Lake County, Utah: Final technical report to the U.S. Geological Survey

*Note that not all of these investigations produced new trenching data.

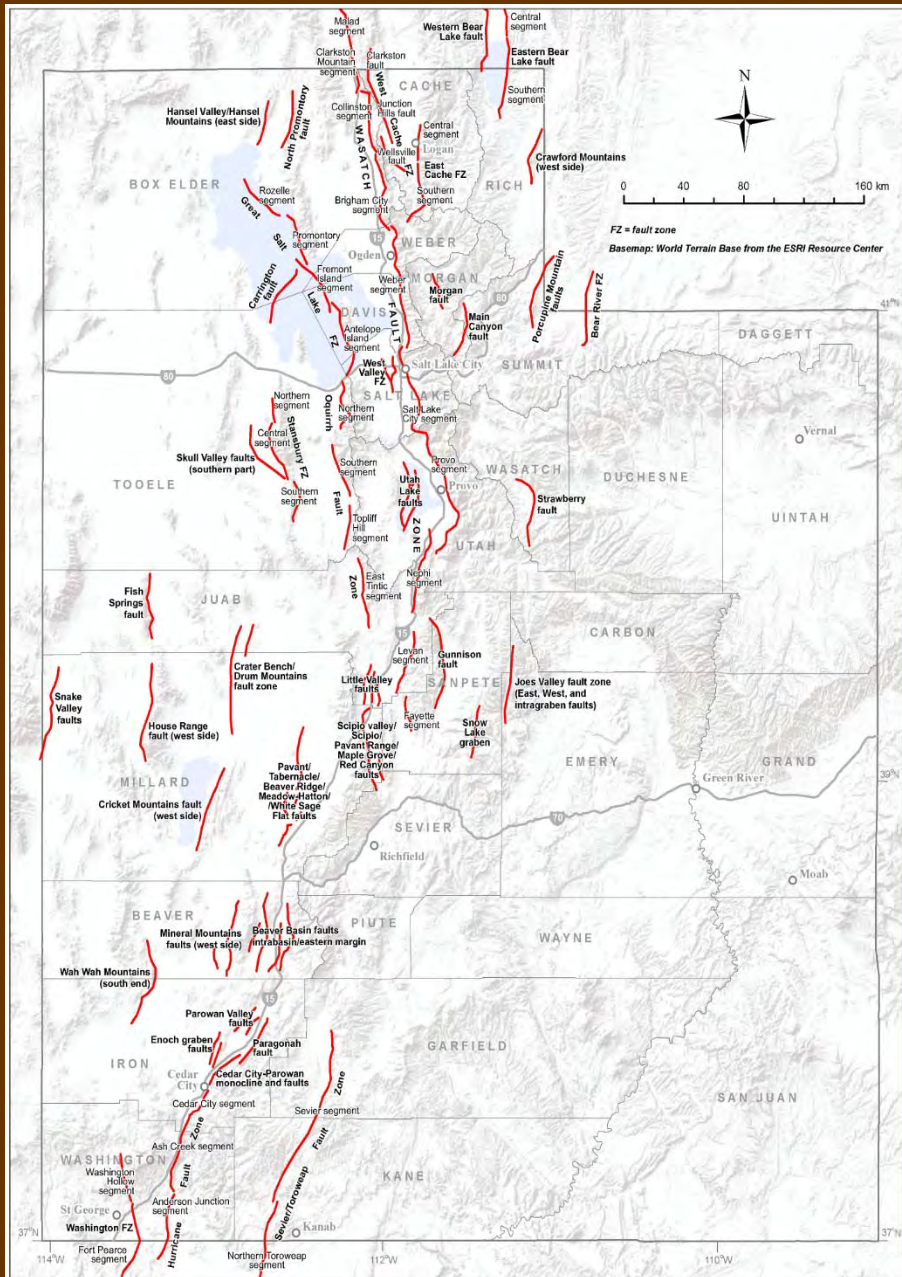
Updating Utah's Consensus Paleoseismology Database

It has been UQFPWG's intent to maintain a database of consensus paleoseismic data for Utah Quaternary faults and fault segments – currently Lund (2005).

- **Since the initial UQFPWG review in 2004 and publication of Lund (2005), there have been at least 21 paleoseismic investigations (not all involving trenching) undertaken in Utah that have produced new paleoseismic data on Utah Quaternary faults/fault segments — in particular on the six Holocene-active segments of the Wasatch fault zone.**
- **Additionally two summary papers regarding Utah's Quaternary faults recently have been published by the UGS:**

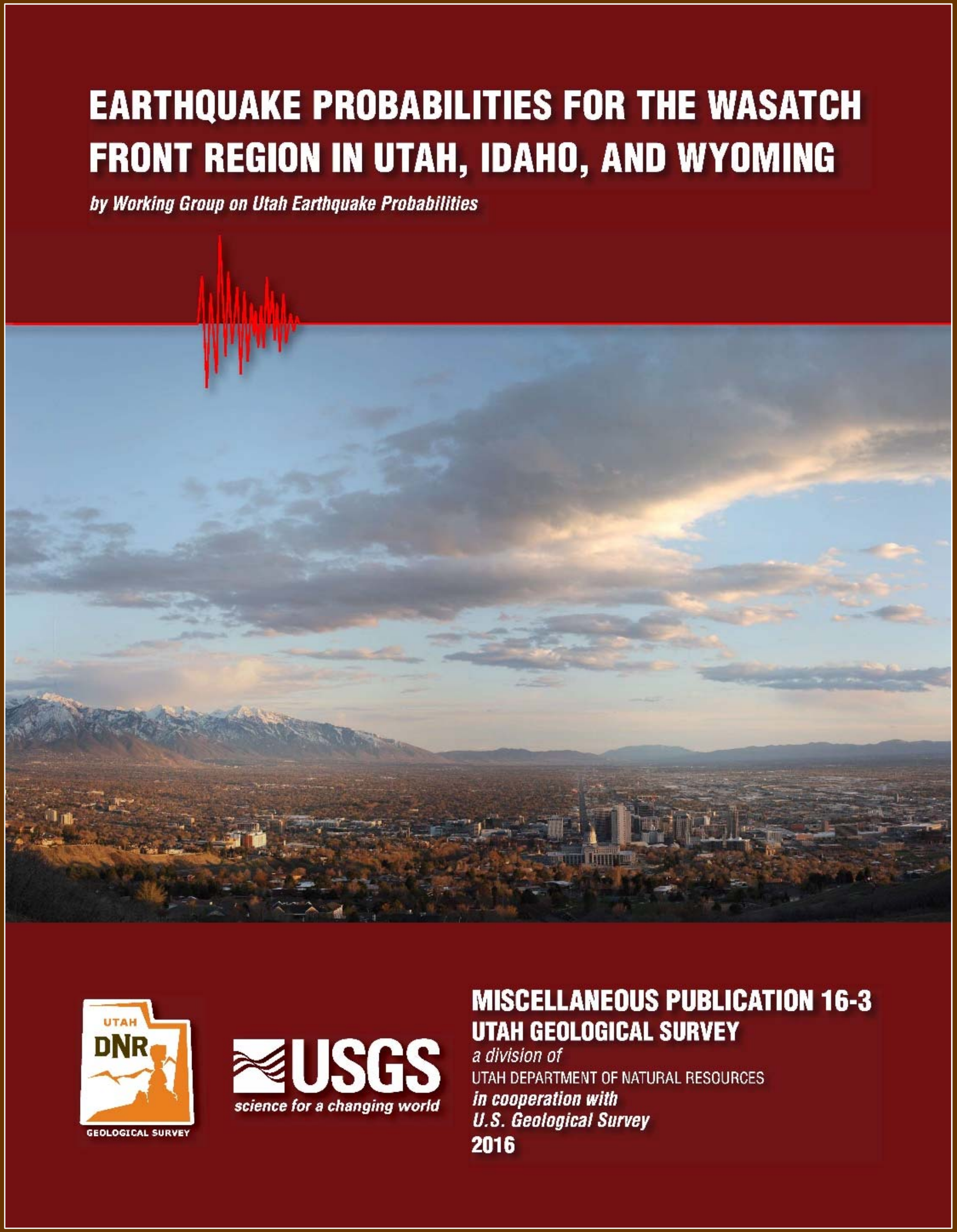
Lund, W.R., 2014, Hazus loss estimation software earthquake model revised Utah fault database, updated through 2013: Utah Geological Survey Open-File Report 631

Working Group on Utah Earthquake Probabilities, 2016, Earthquake probabilities for the Wasatch Front region in Utah, Idaho, and Wyoming: Utah Geological Survey Miscellaneous Publication 16-3



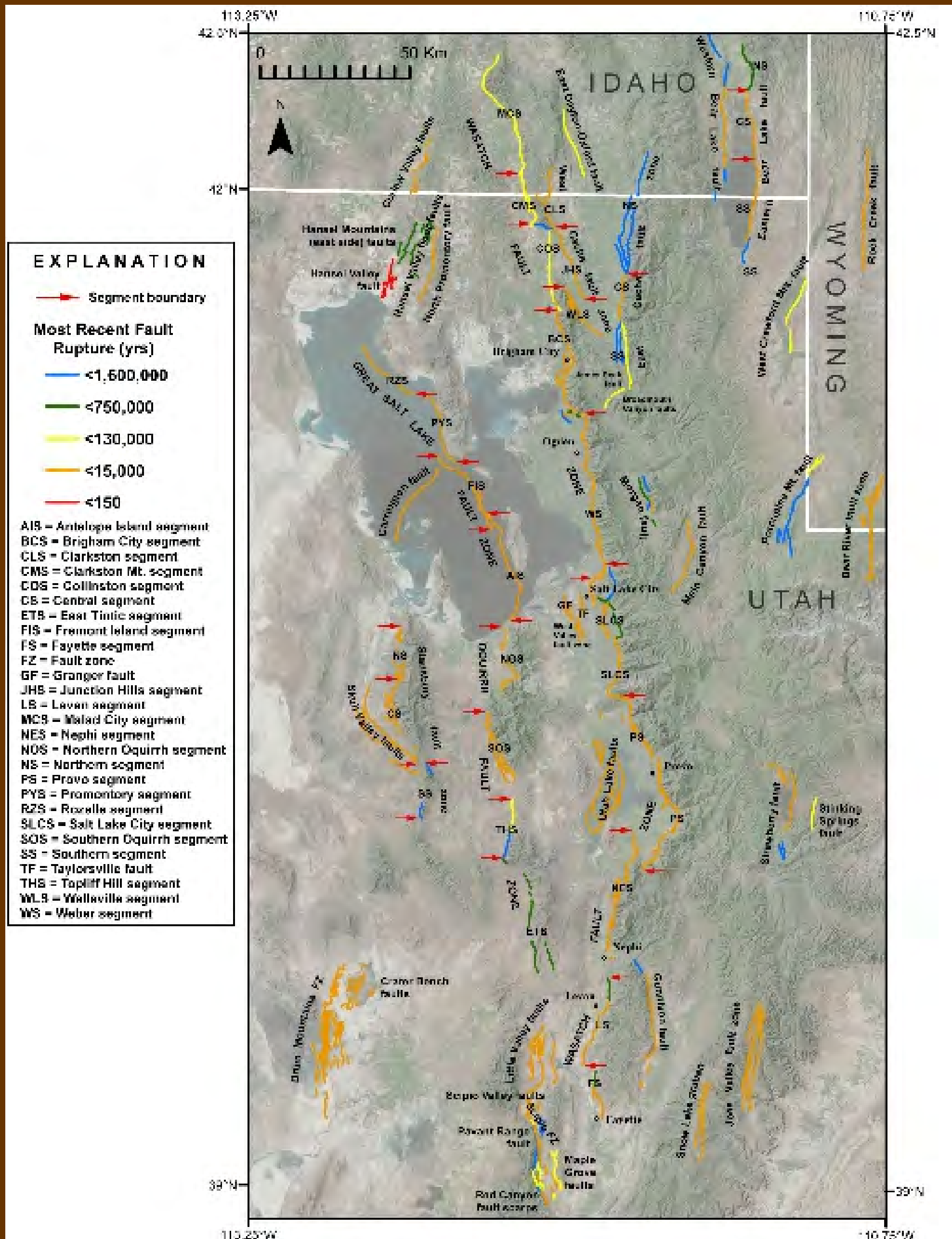
Utah Hazus Fault Database Update

- **Completed before the Working Group on Utah Earthquake Probabilities (WGUEP) report was published.**
- **Used WGUEP criteria to identify faults considered most likely to generate surface-faulting earthquakes.**
- **Used WGUEP criteria to estimate earthquake magnitudes.**
- **Resulted in no new fault parameter data.**



Working Group on Utah Earthquake Probabilities

- **Expert panel charged with developing a probabilistic earthquake forecasts for the Wasatch Front region for the next 30, 50, and 100 years.**
- **Paleoseismology subcommittee analyzed available fault-parameter data for faults within the Wasatch Front Region considered capable of generating future large earthquakes.** **(DuRoss, Crone, Hylland, Lund, Olig, Personious, and Schwartz)**



WGUEP Paleoseismic Analysis

- **WGUEP Chapter 4 - Characteristics of Wasatch Front Region Faults**
  - **4.1 - Wasatch Fault Zone Central Segments**
  - **4.2 - Wasatch Fault Zone End Segments**
  - **4.3 - Oquirrh – Great Salt Lake Fault Zone**
  - **4.5 - Other Modeled Faults**
- **Appendix B – Holocene Paleoseismology of the Central Segments of the Wasatch Fault Zone, Utah**
- **Appendix C – Oquirrh – Great Salt Lake Fault Zone**
- **Appendix D – Other Fault Parameter Database**

WGUEP Paleoseismic Review

Wasatch Fault Zone Central Segments:

- Systematic analysis of all existing paleoseismic data
- OxCal modeling of individual earthquake timing data
- Correlation of site earthquake timing data to develop segment-wide surface-faulting earthquake histories
- Calculated open and closed mean recurrence intervals for each segment
- Compiled vertical displacement data per trench site to estimate mean vertical displacement per earthquake along each segment
- Used new timing and displacement data to calculate mean segment slip rates

WGUEP Paleoseismic Review

Wasatch Fault Zone End Segments:

- Paleoseismic data are very limited for the WFZ end segments – only the Levan segment has been trenched (2 surface-faulting earthquakes identified).
- Paleoseismic subcommittee compiled and analyzed existing earthquake timing data (chiefly from geologic relations) and displacement data (scarp profiles and/or geologic relations)
- WGUEP estimated consensus slip rate ranges for each end segment.

WGUEP Paleoseismic Review

Oquirrh – Great Salt Lake Fault Zone:

- The WGUEP formally defined the Oquirrh – Great Salt Lake fault zone (OGSLFZ) as consisting of eight segments, four sub-lacustrine segment on the Great Salt Lake fault zone (GSLFZ) and four terrestrial segments on the Oquirrh fault zone (OFZ).
- Paleoseismic data for the OGSLFZ are from geophysics and drilling data for the Fremont Island and Antelope Island segments on the GSLFZ, and from limited trenching data for the Northern Oquirrh (NO) and Southern Oquirrh (SO) segments of the OFZ.
- The earthquake timing data for the NO and SO segments were modeled using OxCal (see WGUEP appendix C).
- Earthquake timing data were used to determine Poisson RI ranges for the FI, AI, NO, SO segments and SR ranges for the remaining segments.
- Vertical displacement estimates calculated for the NO and SO segments

WGUEP Paleoseismic Review

Other Modeled Faults:

- There are 105 faults/fault segments in the WGUEP Wasatch Front Region exclusive of the WFZ and OGSLFZ.
- The WGUEP established screening criteria to identify faults unlikely to affect the WGUEP earthquake forecast. Sixty faults were identified and removed from further consideration.
- Used available paleoseismic information to characterize the remaining 45 fault/fault segments retained in the WGUEP earthquake forecast.
  - Lund (2005)
  - URS Corporation proprietary data
  - USGS and UGS Quaternary Fault and Fold Databases
  - Geologic literature
- Fault characterization reports RI or SR (sometimes both) depending on paleoseismic data available. No earthquake timing.

New Paleoseismic Data Outside of the WGUEP Wasatch Front Region

- Hurricane fault zone – slip rates from displaced basalt flows
- Sevier fault – slip rates from displaced basalt flows
- Washington fault – trench data (earthquake timing and recurrence; slip rates from displaced basalt flows.

Discussion Questions

1. Should UQFPWG accept and incorporate the WGUEP fault parameter data for the faults in the Wasatch Front Region into the fault parameter database?
   - Most thoroughly reviewed paleoseismic data in Utah
   - Incorporates new paleoseismic data through ~ 2014
   - Includes Utah's most active faults and covers an area where ~80% of Utah residents live
   - Thoroughly vetted by the USGS during the WGUEP review process
2. Should UQFPWG continue to limit the fault parameter database to data from trenched faults only, or expand the database to include paleoseismic information obtained from geologic relations (e.g., slip rates determined from displaced Lake Bonneville deposits or dated lava flows)? What about including displacement, fault length, etc. data where available?
3. Should the database continue to be limited to data from published sources only? How gray is permissible? Is an FTR to the USGS an acceptable source, how about a UGS memo to file, or a meeting abstract or poster?
4. What format should the updated database take – bulletin, circular, open-file report?

Central Segments Wasatch Fault Zone

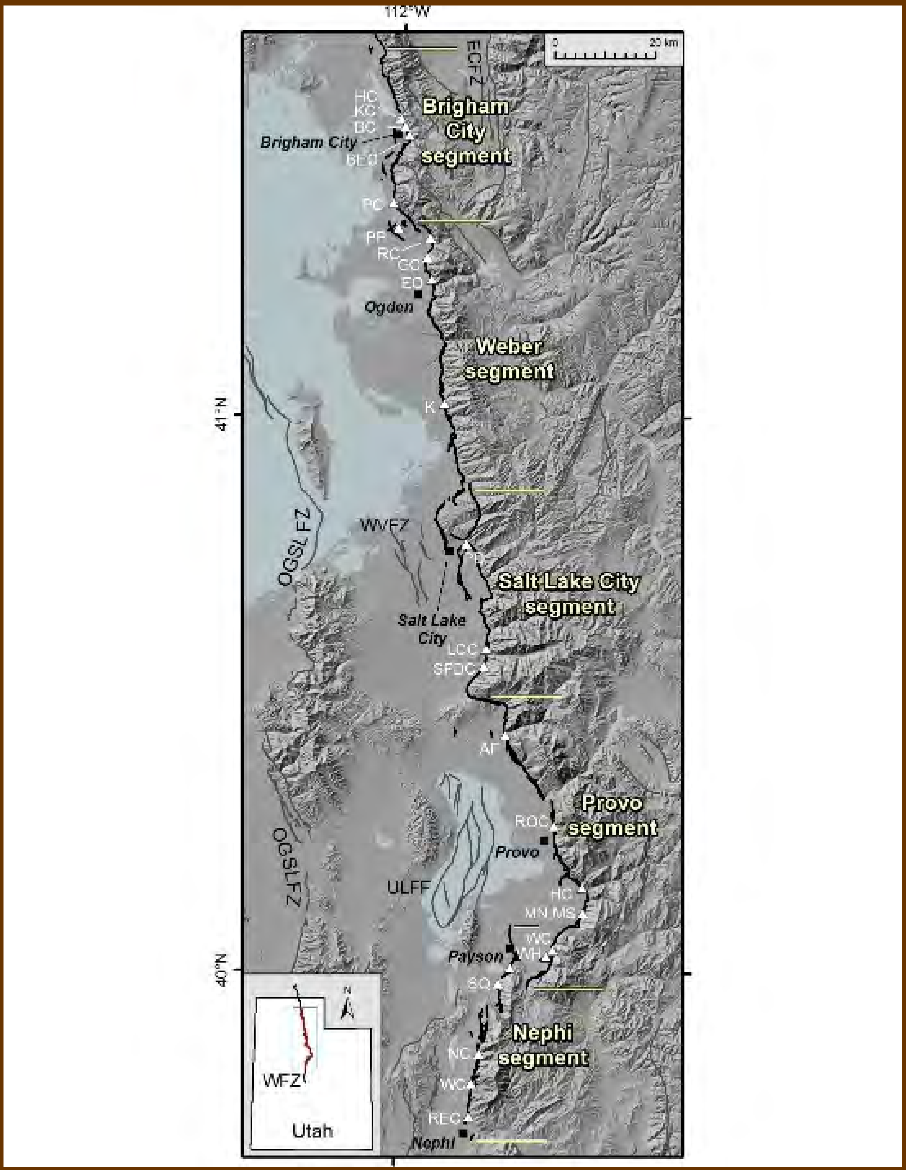


Table 4.1-1. Summary of earthquake timing data for the central WFZ.

Rupture[1]	Earthquake Timing[2] (ka)		Inter-event recurrence[3] (kyr)
	Mean ± 2σ	5th–50th–95th [mode]	
B1	2.4 ± 0.3	2.2–2.4–2.6 [2.4]	-
B2	3.5 ± 0.2	3.4–3.5–3.7 [3.4]	1.1 (B2–B1)
B3	4.5 ± 0.5	4.1–4.5–5.0 [4.5]	1.0 (B3–B2)
B4	5.6 ± 0.6	5.0–5.6–6.1 [5.6]	1.1 (B4–B3)
W1	0.6 ± 0.1	0.5–0.6–0.6 [0.5]	--
W2	1.1 ± 0.6	0.7–1.2–1.7 [1.3]	0.7 (W2–W1)
W3	3.1 ± 0.3	2.9–3.1–3.3 [3.1]	1.9 (W3–W2)
W4	4.5 ± 0.3	4.2–4.5–4.7 [4.5]	1.4 (W4–W3)
W5	5.9 ± 0.5	5.6–5.9–6.4 [5.6]	1.4 (W5–W4)
S1	1.3 ± 0.2	1.2–1.3–1.5 [1.3]	-
S2	2.2 ± 0.2	2.0–2.2–2.3 [2.2]	0.8 (S2–S1)
S3	4.1 ± 0.3	3.9–4.1–4.4 [4.1]	2.0 (S3–S2)
S4	5.3 ± 0.2	5.1–5.2–5.5 [5.2]	1.1 (S4–S3)
P1	0.6 ± 0.05	0.5–0.6–0.6 [0.6]	-
P2	1.5 ± 0.4	1.2–1.5–1.8 [1.7]	0.9 (P2–P1)
P3	2.2 ± 0.4	1.9–2.3–2.6 [2.3]	0.8 (P3–P2)
P4	4.7 ± 0.3	4.5–4.7–4.9 [4.7]	2.5 (P4–P3)
P5	5.9 ± 1.0	5.2–5.8–6.9 [5.6]	1.2 (P5–P4)
N1	0.2 ± 0.1	0.1–0.2–0.3 [0.2]	-
N2	1.2 ± 0.1	1.2–1.2–1.3 [1.2]	1.0 (N2–N1)
N3	2.0 ± 0.4	1.7–2.0–2.3 [2.0]	0.8 (N3–N2)
N4	4.7 ± 1.8	3.3–4.7–6.1 [5.8]	2.7 (N4–N3)

[1] Numerical values indicate youngest (e.g., B1) and progressively older earthquakes (e.g., B2–B4).
[2] Summary statistics based on integration of per-site earthquake-timing PDFs (derived from OxCal models; Appendix B) following the method of DuRoss *et al.* (2011). See Appendix B for PDF integration method and site PDFs contributing to the segment-wide rupture times. Earthquake times are in thousands of years before 1950.
[3] Individual recurrence interval (RI) is mean recurrence time between earthquakes (e.g., B4–B3 time); see Appendix B for uncertainties.

Table 4.1-2. Mean recurrence intervals for the central WFZ.

Segment	Closed mean RI[1] (kyr)	Open mean RI (*N*-in-*T*)[1] (kyr)	Time since MRE[2] (kyr)
BCS	1.1 ± 0.2 (B4–B1)	1.5 ± 0.1; 4 events < 5.9 ± 0.4 ka	2.5 ± 0.3
WS	1.3 ± 0.1 (W5–W1)	1.4 ± 0.3; 5 events < 7.1 ± 1.4 ka	0.6 ± 0.07
SLCS	1.3 ± 0.1 (S4–S1)	1.3 ± 0.09; 4 events < 5.2 ± 0.4 ka	1.4 ± 0.2
PS	1.3 ± 0.2 (P5–P1)	1.2 ± 0.03; 5 events < 6.1 ± 0.2 ka	0.6 ± 0.05
NS	0.9 ± 0.2 (N3–N1)	1.1 ± 0.04; 3 events < 3.2 ± 0.1 ka	0.3 ± 0.09

[1] Closed mean recurrence is elapsed time between oldest and youngest earthquakes per segment (e.g., B4–B1) divided by the number of closed intervals. Open mean recurrence is the time from the maximum constraining age on the oldest event (e.g., 5.9 ± 0.4 ka for B4) to the present (2011) divided by number of events. Recurrence values do not account for sample-size uncertainties (see Section 3.5). See text and Appendix B for additional discussion.

[2] Time (to the present; 2011) since the most recent earthquake (MRE).

Table 4.1-3. Summary of displacement per rupture source on the central WFZ.

Rupture Source[1]	Obs. D[2] (m)	Modeled D (displacement curves)[3] (m)			EQs obs.[4]	Disp. obs.[4]
	μ	μ	min	max		
BCS	2.0	1.7	1.2	2.1	4	6
WS	2.1	2.4	1.1	4.1	5	16
SLCS	1.7	1.7	1.2	2.2	4	8
PS	2.5	2.6	1.3	3.6	4	6
NS	1.8	2.0	1.5	2.7	3	5-6
BCS+WS	2.2	2.0	1.7	2.4	3	13
WS+SLCS	1.9	2.7	2.4	2.9	1	6
SLCS+PS+NS	2.1	1.7	1.6	1.9	1	3
SLCS+PS	2.0	1.6	1.3	2.0	2	6
PS+NS	2.1	2.8	1.2	4.2	2	4

[1] Vertical displacement (D) for single-segment rupture sources, e.g., the BCS or WS, and multiple-segment rupture sources, e.g., the BCS and WS combined (BCS+WS). Multi-segment rupture sources are discussed in Section 4.1.5; see Appendix B for additional discussion.

[2] Mean (μ) of observed displacement per earthquake on the source (Appendix B). For example, mean observed displacement for BCS is mean of displacement estimates for B1, B2, B3, and B4 (Appendix B).

[3] Mean (μ) and minimum-maximum range of modeled displacement per earthquake on the source, using analytical displacement curves (Appendix B).

[4] EQs. obs. is total number of earthquakes on the source. Disp. obs. is the total number of site observations of displacement for the source.

Table 4.1-4. Summary of vertical slip rates for the central WFZ.

Slip Rate (SR):	BCS	WS	SLCS	PS	NS
	mm/yr [wt.]	mm/yr [wt.]	mm/yr [wt.]	mm/yr [wt.]	mm/yr [wt.]
Closed mean SR per segment[1]	1.6 (1.0–2.4) [0.2]	1.9 (1.1–2.9) [0.35]	1.3 (1.0–1.8) [0.35]	2.0 (1.2–3.0) [0.35]	1.7 (1.1–3.2) [0.2]
Open mean SR per segment[2]	1.2 (0.9–1.3) [0.2]	1.7 (1.2–2.3) [0]	1.3 (1.0–1.6) [0]	2.1 (1.9–2.4) [0]	1.5 (1.3–1.8) [0.2]
Composite closed mean SR[3]	1.7 (0.9–2.7) [0.3]	1.7 (0.9–2.7) [0.35]	1.7 (0.9–2.7) [0.35]	1.7 (0.9–2.7) [0.35]	1.7 (0.9–2.7) [0.3]
Composite long-term SR[4]	1.0 (0.6–1.4) [0.3]	1.0 (0.6–1.4) [0.3]	1.0 (0.6–1.4) [0.3]	1.0 (0.6–1.4) [0.3]	1.0 (0.6–1.4) [0.3]
Weighted mean SR [5]	**1.3 (0.8–2.0)**	**1.5 (0.9–2.4)**	**1.3 (0.8–2.0)**	**1.6 (0.9–2.4)**	**1.4 (0.9–2.2)**

[1] Closed-interval slip rate (SRs) are the average of mean, minimum, and maximum SRs based on (1) average displacement and recurrence and (2) elapsed time and total displacement.
[2] Open-interval SRs are based on the total displacement since the maximum limiting age for the oldest earthquake on the segment.
[3] The composite closed mean SR is based on the mean displacement per event and the composite closed recurrence interval for the central WFZ. See text and Appendix B for discussion.
[4] The composite long-term SR is based on long-term SRs per segment, which are based on the total net vertical tectonic displacement of latest Pleistocene-age geomorphic surfaces related to the Provo phase and highstand of Lake Bonneville and reported in Appendix B.
[5] Weighted mean SRs per segment are based on weighting scheme for per-segment and composite SRs (weights shown in brackets); see Appendix B for discussion.

End Segments Wasatch Fault Zone

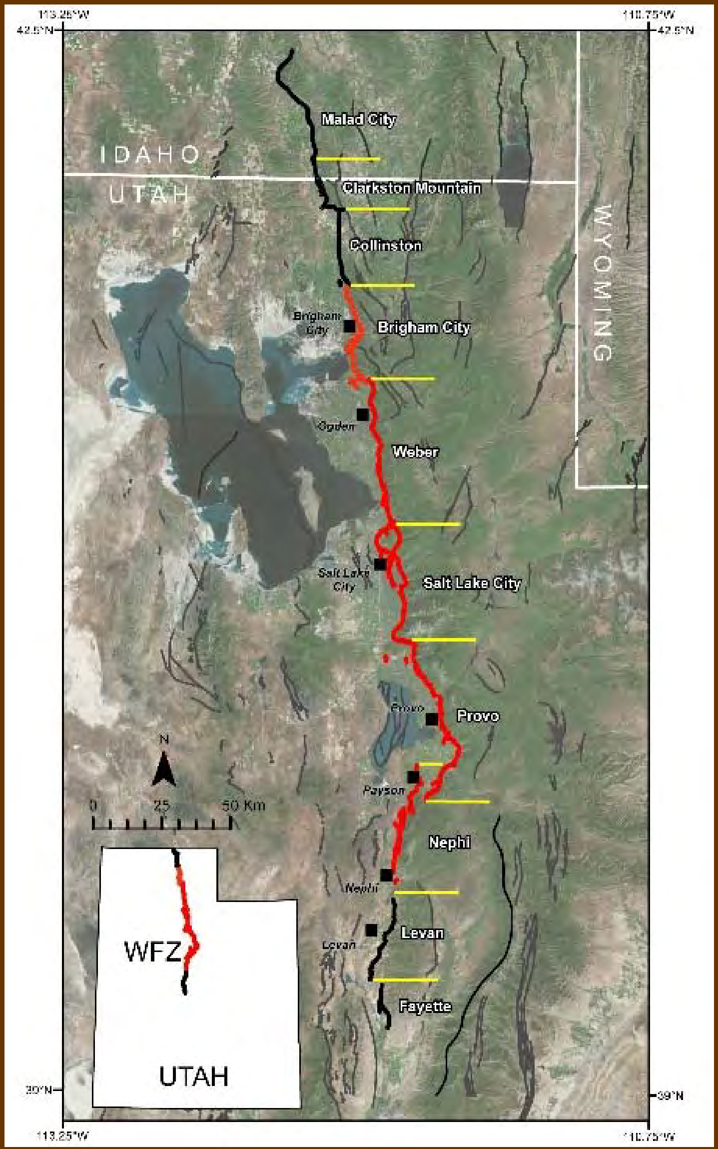


Table 4.2-1. Displacement, slip rate, and recurrence for the WFZ end segments.

Segment	Timing of Most Recent Surface Faulting	Net Displ. or Surface Offset (m)	Time Interval (kyr)	Slip Rate (mm/yr)	WGUEP Slip Rate Consensus Range (mm/yr)	Recurrence Interval (kyr)
MCS[1]	Late Pleistocene	≤ 1.5 (est.)	> 18	< 0.08	0.01–0.1	NA
CMS[2]	Late Pleistocene	2.0	> 18	< 0.1	0.01–0.1	NA
CS[3]	Late Pleistocene	2 (est.)	> 18	< 0.1	0.01–0.1	NA
	Long term[4]:	≤ 12	300	≤ 0.04		
LS[5]	≤ 1.0 ± 0.2 ka	1.8	> 4.8–9.8	< 0.2–0.4	0.1–0.6	> 3 & < 12**
	1.0–1.5 ka	1.8–3.0	> 1.3–3.3	< 0.5–2.3		
		–	–	< 0.3±0.1*		
		–	–	0.1–0.6**		
	Long term[4]:	≤ 4.8	100–250	≤ 0.02–0.05		
FS[6]	Early(?) Holocene (SW strand)	0.8–1.6	< 11.5	> 0.07–0.1	0.01–0.1	NA
	Latest Pleistocene (SE strand)	0.5–1.3	< 18	> 0.03–0.07		
	Early(?) or middle (?) Pleistocene (N strand)	No data	> 250	NA		
	Long term[4]:	≤ 3.0	100–250	≤ 0.01–0.03		

NA, not applicable.

[1] Data from Machette *et al.* (1992), this report.
[2] Data from Hylland (2007a).
[3] Data from Personius (1990), Hylland (2007a).
[4] Long-term slip rate based on maximum measured scarp heights and estimated age of soil developed on faulted deposits.
[5] Data from Jackson (1991), Hylland (2007b), Hylland and Machette (2008); * – Preferred value of Hylland and Machette (2008), ** – Utah Quaternary Fault Parameters Working Group consensus range (Lund, 2005).
[6] Data from Hylland (2007b), Hylland and Machette (2008).

Table 4.2-2. Slip-rate model distributions for the WFZ end segments.

Segment	WGUEP Slip Rate Consensus Range[1] (mm/yr)	Slip Rate Distribution (5th–50th–95th percentile) (0.2–0.6–0.2 weight)
Malad City (MCS)	0.01 – 0.1	0.01 – 0.05 – 0.1
Clarkston Mountain (CMS)	0.01 – 0.1	0.01 – 0.05 – 0.1
Collinston (CS)	0.01 – 0.1	0.01 – 0.05 – 0.1
MCS+CMS[2]	–	–
MCS+CMS+CS[3]	–	–
Levan (LS), single-segment	–	0.05 – 0.15 – 0.3
Fayette (FS), single-segment	–	0.005 – 0.025 – 0.05
LS+FS	–	0.005 – 0.15 – 0.3
LS total; single-segment + (LS+FS)	0.1 – 0.6[4]	0.055 – 0.3 – 0.6[5]
FS total; single-segment + (LS+FS)	0.01 – 0.1[4]	0.01 – 0.175 – 0.35[5]

[1] See Table 4.2-1 for slip-rate data.
[2] Used for floating rupture length in multi-segment model.
[3] Cumulative length for multi-segment model; not modeled rupture length.
[4] Total slip rates (single-segment + multi-segment rupture); see text for discussion.
[5] Summed 5th, 50th, and 95th percentile values (single-segment + multi-segment rupture) for comparison with WGUEP consensus ranges only; values not used in model.

Oquirrh – Great Salt Lake Fault Zone

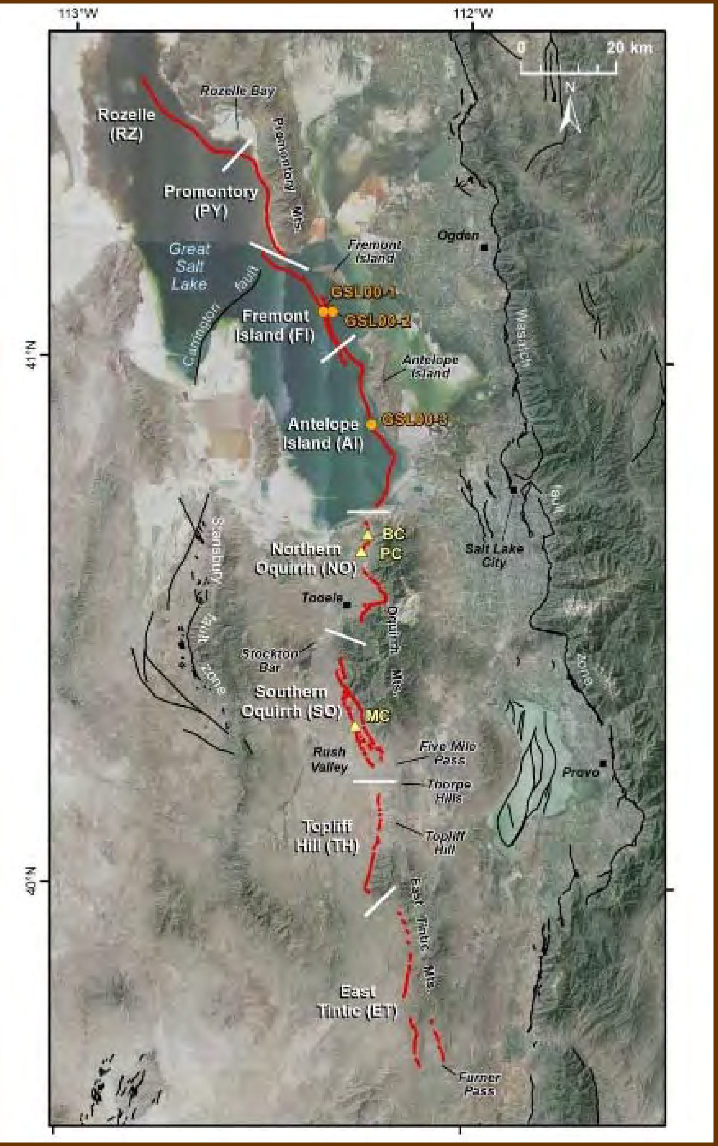


Table 4.3-1. Paleoearthquake times and estimated earthquake recurrence intervals for the Great Salt Lake fault[1].

Earthquake Pairs	Timing (terrestrially calibrated[2], residence corrected[3], cal yr B.P.[4])[5]	Recurrence Interval (yr)[5]
Antelope Island segment		
EH-A3	586 +201/-241	5584 +219/-172
EH-A2	6170 +236/-234	
EH-A2	6170 +236/-234	3728 +223/-285
EH-A1	9898 +247/-302	
Fremont Island segment		
EH-F3	3150+235/-211	3262 +151/-184
EH-F2	6412 +209/-211	
EH-F2	6412 +209/-211	<5015 +587/-424
EH-F1	<11,427 +605/-449	
Average single-segment recurrence interval = 4200 ± 1400 years[6]		

[1] Dinter and Pechmann (2005).

[2] Radiocarbon years converted to calendar years using Stuiver *et al.* (1998) terrestrial calibration (CALIB v. 4.3; Stuiver and Reimer, 1993).

[3] Correction for carbon residence time in provenance area prior to deposition = 321+191/-171 cal yr, the difference between the terrestrially calibrated ^{14}C date of Mazama ash interval at Site GSL00-3 (=7994+170/-128 cal yr B.P.) and terrestrial calibration (=7673+113/-86 cal yr B.P.) of published Mazama ^{14}C age (6845±50 ^{14}C yr B.P.; Bacon [1983]).

[4] Calendar years before 1950.

[5] 2σ confidence limits.

[6] The mean, with 2σ confidence limits, for the three closed recurrence intervals.

Table 4.3-2. Timing of surface-faulting earthquakes on segments of the OGSLFZ[1].

	Fault Segment	Youngest Event	Penultimate Event	Older Events
Great Salt Lake fault[2]	Rozelle (RZ)	Holocene (?)	unknown	unknown
	Promontory (PY)	Holocene (?)	unknown	unknown
	Fremont Island (FI)	3150 (+240, -210)	6410 (±210)	> 7410[3] < 11,430 (+610, -450)
	Antelope Island (AI)	590 (+200, -240)	6170 (+240, -230)	9,900 (+250, -300)
	Northern Oquirrh (NO)[4]	6320 (±1600) [4970 to 7640]	27,600 (±3840) [24,430 to 30,800]	>> 33,000
	Southern Oquirrh (SO)[5]	3030 (±1880) [1460 to 4580]	Roughly 5 to 31 ka	Two additional events since about 75 ka; or three to five additional events since about 92 ka
	Topliff Hills (TH)	> 18,000[6] or < 18,000[7]	unknown	unknown
	East Tintic (ET) [8]	middle and late Pleistocene (?)	unknown	unknown

[1] Updated from Olig *et al.* (2001) as noted. Mean ages in calendar calibrated radiocarbon years before 1950 (cal yr B.P.), rounded to the nearest decade, with 2-σ errors in parentheses and 5th and 95th percentiles in brackets, except as noted.

[2] Timing data from Dinter and Pechmann (2005), except as described in footnote 3.

[3] The antepenultimate event occurred within a 12-m-thick salt and sapropel unit. The maximum age for this event is from radiocarbon dating of charcoal from sediments immediately underlying the salt and sapropel unit (Dinter and Pechmann, 2005). The minimum age comes from a conservative time estimate of at least 1000 yrs between the penultimate event horizon and the top of the salt and sapropel unit, based on measurements of sediment thicknesses between these two horizons and sedimentation rates estimated for the overlying sediments.

[4] From analysis in Appendix C, using data from previous studies of the Big Canyon and Pole Canyon trench sites (Olig *et al.*, 1994; 1996). For comparison, previously the 5th and 95th percentiles of the youngest and penultimate events on the NO segment were respectively estimated to be 4800 to 7900 cal yr B.P., and 20,300 to 26,400 ^{14}C yr B.P. Note that a mean age of 30,910 cal yr B.P. was calculated for sample OFPC-RC3 (Table C-1) and used in rate calculations for the NO segment (Table 4.3-7).

[5] From analysis in Appendix C, using previous timing data for the Mercur fault from Mercur Canyon trench site (Olig *et al.*, 2001) and an additional unpublished IRSL age (see text for discussion). For comparison, previously the 5th and 95th percentiles of the youngest event on the SO segment were estimated to be 1300 to 4830 cal yr B.P. Note that the mean of the combined age for the Unit 2a loess of 88,950 cal yr B.P. (Table C-2) was used as the maximum age constraint in rate calculations for the SO segment (see Table 4.3-7).

[6] Modified from Barnhard and Dodge (1988) based on Lake Bonneville highstand age from Reheis *et al.* (2014).

[7] Modified from Everitt and Kaliser (1980) based on Lake Bonneville highstand age from Reheis *et al.* (2014); see text for discussion.

[8] From Bucknam and Anderson (1979).

Table 4.3-7. Poisson rate distributions for OGSLFZ rupture sources.[1]

Source	Approach (weight)	Recurrence (in yrs) or Vertical Slip Rate (in mm/yr)[2]	Notes
RZ segment	Recurrence Intervals (1.0)	14,103 (0.101) 6300 (0.244) 3724 (0.310) 2377 (0.244) 1468 (0.101)	No segment-specific slip rate or event timing data available. Assumed similar rates to the AI segment.
PY segment	Recurrence Intervals (1.0)	14,103 (0.101) 6300 (0.244) 3724 (0.310) 2377 (0.244) 1468 (0.101)	No segment-specific slip rate or event timing data available. Assumed similar rates to the AI segment.
FI segment[3]	Recurrence Intervals (1.0)	13,680 (0.101) 6024 (0.244) 3521 (0.310) 2222 (0.244) 1348 (0.101)	From approach 2 with $N = 3$ and $T = 11,488$ yrs (Table 4.3-1).[4]
AI segment[3]	Recurrence Intervals (1.0)	14,103 (0.101) 6300 (0.244) 3724 (0.310) 2377 (0.244) 1468 (0.101)	From approach 2 with $N = 3$ and $T = 9959$ yrs (Table 4.3-1).
NO segment	Recurrence Intervals (0.6)	106,538 (0.101) 36,153 (0.244) 18,453 (0.310) 10,613 (0.244) 5983 (0.101)	From approach 2 with $N = 2$ and $T = 30,971$ yrs (Appendix C-2 and Table 4.3-2).
	Slip Rates (0.4)	***0.05 (0.2)*** ***0.2 (0.6)*** ***0.4 (0.2)***	Consensus slip rates from the UQFPWG (Lund, 2005).

Table 4.3-7. Continued.

Source	Approach (weight)	Recurrence (in yrs) or Vertical Slip Rate (in mm/yr)[2]	Notes
SO segment	Recurrence Intervals (0.6)	37,291 (0.101) 22,366 (0.244) 15,698 (0.310) 11,433 (0.244) 8004 (0.101)	From approach 1 with $N = 5$ and $T = 89{,}011$ yrs (Appendix C-2 and Table 4.3-2). This alternative of five events is weighted 0.5.
		24,106 (0101) 15,704 (0.244) 11,606 (0.310) 8817 (0.244) 6441 (0.101)	From approach 1 with $N = 7$ and $T = 89{,}011$ yrs (distribution weighted 0.5) (see Appendix C-2 and Table 4.3-2). This alternative of seven events is weighted 0.5.
	Slip Rates (0.4)	***0.05 (0.2)*** ***0.2 (0.6)*** ***0.4 (0.2)***	Consensus slip rates from the UQFPWG (Lund, 2005).
TH segment	Slip Rates (1.0)	***0.05 (0.2)*** ***0.2 (0.6)*** ***0.4 (0.2)***	No segment-specific paleoseismic data. Assumed rates similar to the NO and SO segments based on descriptions of scarps and arguments in Everitt and Kaliser (1980).
ET segment	Slip Rates (1.0)	***0.025 (0.3)*** ***0.1 (0.4)*** ***0.2 (0.3)***	Assumed half the rates of the NO and SO segments, but with broader weights due to larger uncertainties, based on relatively poor geomorphic expression for this end segment (Black and Hecker, 1999b).
FI+AI segments	Recurrence Intervals (1.0)	14,103 (0.101) 6300 (0.244) 3724 (0.310) 2377 (0.244) 1468 (0.101)	Used rate distribution of AI segment as it is better constrained and rate distributions are similar.

Methodology from WGUEP

For faults with paleoseismic data (namely the WFZ central segments and the OGSLFZ), we calculated mean recurrence intervals/rates via the approaches described in the Central and Eastern U.S. (CEUS) Seismic Source Characterization (SSC) for Nuclear Facilities (EPRI/DOE/NRC, 2012). The CEUS-SSC approaches resulted in discrete five-point approximations to continuous probability distributions of mean recurrence intervals and rates that define weighted branches of the WGUEP logic tree. As discussed in the CEUS-SSC report and below, these probability distributions quantify the uncertainty in the mean recurrence intervals/rates that arise from relatively small samples sizes (i.e., small numbers) of past earthquakes.

Other Modeled Faults

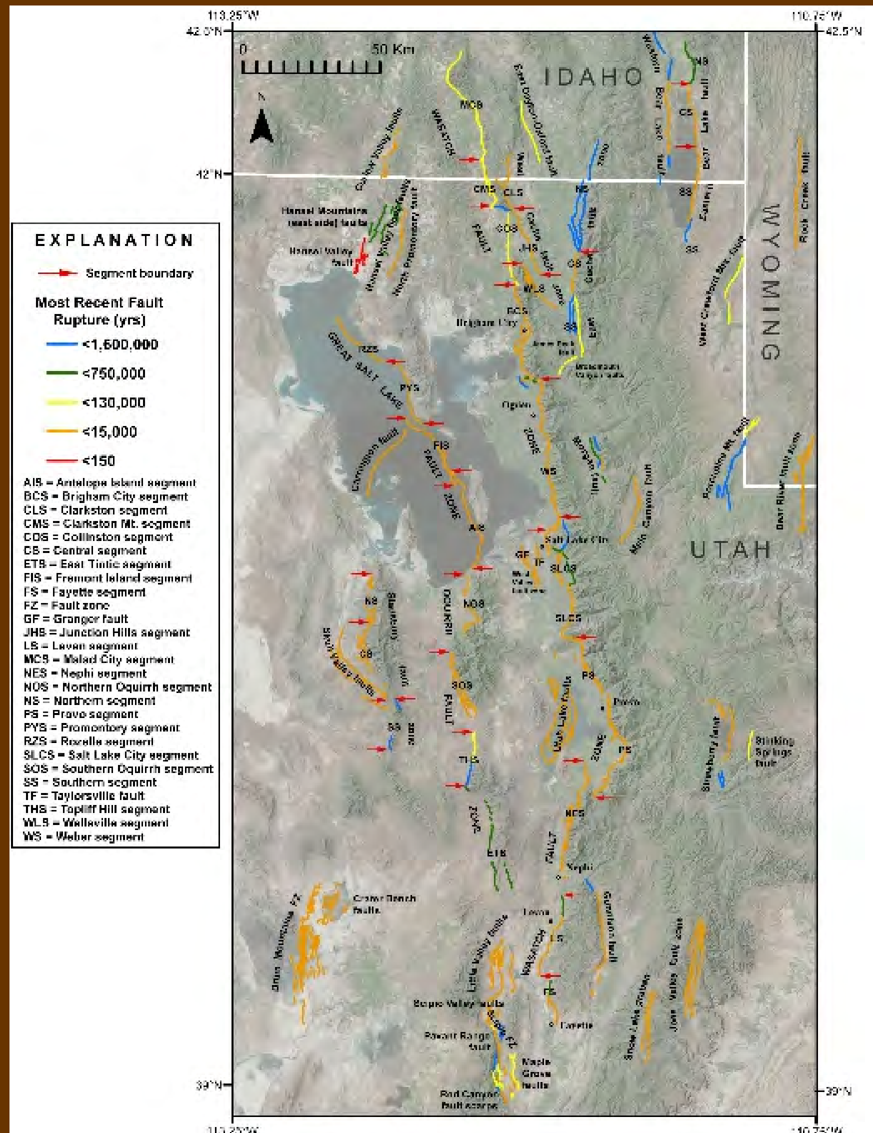


Table 4.5-2 Other modeled faults—Quaternary-active faults/fault segments in the Wasatch Front region, other than the WFZ and OGSLFZ, retained in the WGUEP fault model. Superscripts indicate linked faults.

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 Mountains (east side) faults[3]
Hansel Valley (valley floor) faults[3]
James Peak fault[1]
Joes Valley fault zone
Little Valley faults
Main Canyon fault
Maple Grove faults[4]
Morgan fault
North Promontory fault
Pavant Range fault[4]
Porcupine Mountain fault
Red Canyon fault scarps[4]
Rock Creek fault
Scipio fault zone[4]
Scipio Valley faults[4]
Skull Valley (mid valley) faults
Snow Lake graben
Stansbury fault
  Northern segment
  Central segment
  Southern segment
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[5]
  Taylorsville fault[5]
Western Bear Lake fault

Table 4.5-3. Fault/fault segment parameters from USGS (2013) for Quaternary-active faults/fault segments other than the WFZ and OGSLFZ in the Wasatch Front region.

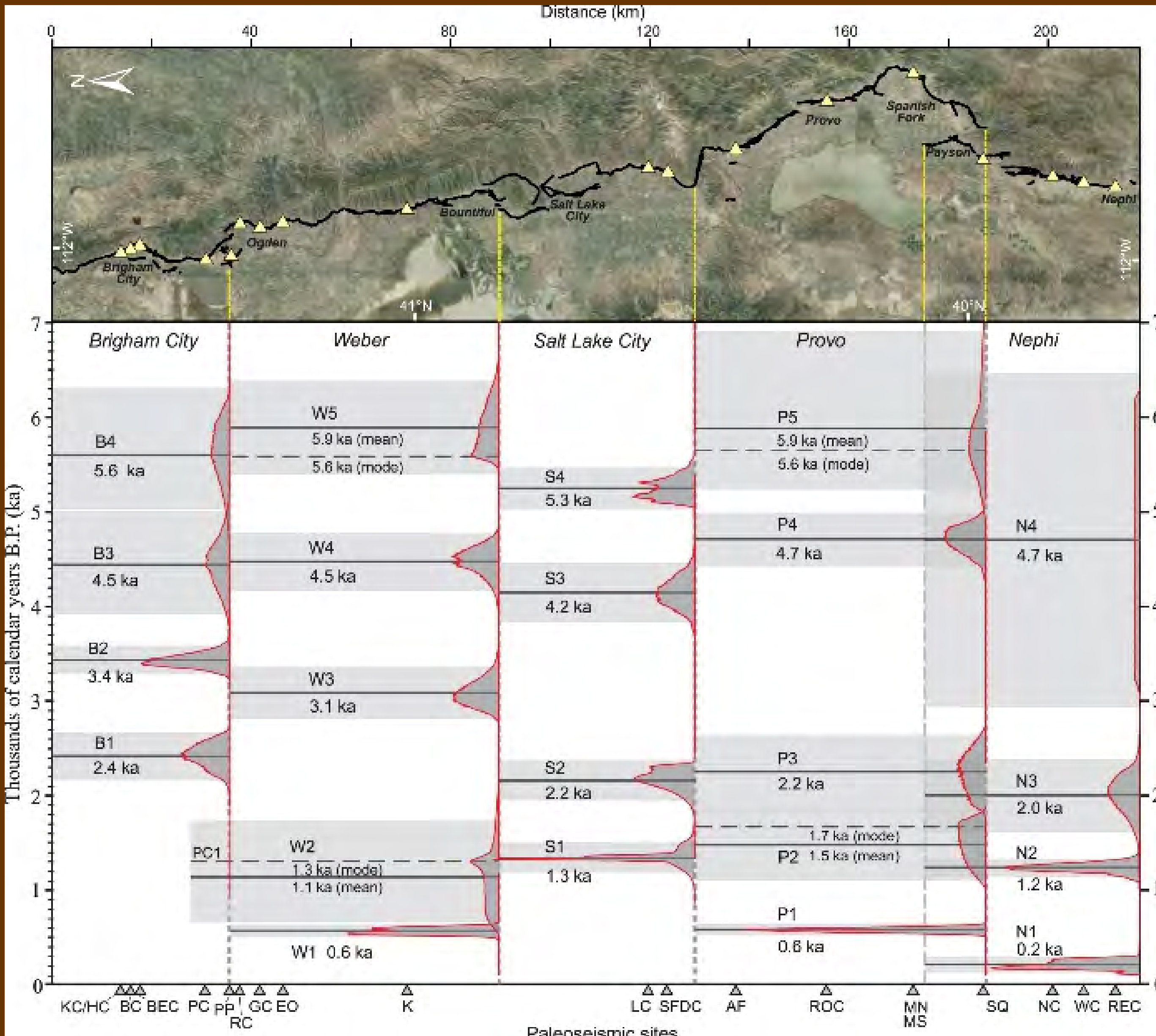
Parameters		Retained Faults	Excluded Faults
Total[1]	105	45	60
Slip Rate			
< 0.2 mm/yr		37	59
> 0.2 mm/yr < 1.0 mm/yr		7	1
> 1.0 mm/yr < 5.0 mm/yr		1	0
Timing of Most Recent Movement			
Historical		1	0
Latest Quaternary < 15 ka		32	4
Late Quaternary < 130 ka		7	5
Late and Middle Quaternary < 750 ka		3	21
Quaternary < 1.6 Ma		2	30
Length			
0 – 10 km		4	29
11 – 20 km		15	17
21– 30 km		11	6
31 – 40 km		6	5
> 40 km		9	3

[1] Excludes the WFZ and OGSLFZ.

Table D-1. Parameters for Other Wasatch Front Faults

Fault Name	Rupture Model[1]	Probability of Activity[2]	Fault Category[3]	SRL (km)[4]	Dip Degrees)[5]	Seismogenic Depth (km)[6]	M_{char}[7]	Vertical Slip Rate (mm/yr)	Recurrence Interval (yr)	Comments
Bear River fault zone (Holocene)	Independent (1.0)	1.0	C	35	50±15	15±3 (E)	6.96	—	1000 (0.2) 2300 (0.6)[8] 3500 (0.2)	Detailed trenching and mapping by West (1994) revealed evidence for two large, late Holocene surface-faulting earthquakes on this apparently geologically young normal fault with no associated range front. This west-dipping fault may merge into a ramp of the Laramide-age Darby-Hogsback thrust fault at a depth of about 5-7 km (West, 1994). There is no evidence, at this time, that the fault zone has discrete rupture segments.
Carrington fault (Latest Quaternary)	Independent (1.0)	1.0	C	~30[9]	50 ± 15	15 ± 3 (W)	6.89	—	1800 (0.2)[10] 4200 (0.6) 6600 (0.2)	Dinter and Pechmann (2005) first identified the Carrington fault based on displacements observed in high-resolution seismic reflection profiles in the Great Salt Lake. The northeast-striking, ~30-km-long, down-to-the-northwest normal fault, which is northwest of Carrington Island, is clearly visible on a recent bathymetry map of Great Salt Lake (Baskin and Allen, 2005). This scarp is as high as 1.5 m, and likely has experienced multiple Holocene surface-faulting events, similar to the Antelope and Fremont Island segments of the Great Salt Lake fault zone. However, earthquake times remain unconstrained (D. Dinter, University of Utah, written communication, 2010). Based on the apparent similarities of the lakebed scarps, we assigned a recurrence interval distribution similar to the Antelope Island segment of the Great Salt Lake fault zone.
Crater Bench faults and Drum Mountains fault zone (Latest Quaternary and Holocene)	Linked (1.0)	0.5	C	Drum Mountains fault zone - 52 Crater Bench faults - 16 The two fault zones completely overlap	50 ± 15	15 ± 3 (W)	7.13	0.01 (0.2) 0.04 (0.6) 0.2 (0.02)	—	Comments from Tony Crone (U.S. Geological Survey [USGS]): "In the absence of better data, I'd favor leaving the linked Drum Mountains/Crater Bench fault zone in their current low slip rate category (<0.2 mm/yr) for two reasons. First our knowledge of the actual net slip across the entire complex zone is imperfect. The net slip could actually be very small. With current Global Positioning System technology we have an opportunity to efficiently and

Fault Name	Rupture Model[1]	Probability of Activity[2]	Fault Category[3]	SRL (km)[4]	Dip Degrees)[5]	Seismogenic Depth (km)[6]	M_{char}[7]	Vertical Slip Rate (mm/yr)	Recurrence Interval (yr)	Comments
Eastern Bear Lake fault	Unsegmented (0.3)	1.0	B	rupture length = 39)	50 ± 15	15 ± 3 (E)	7.10	1.6 (0.2)	—	Southern segment (Lund, 2005) due to the presence of large scarps on likely Holocene and latest Pleistocene deposits. The Northern segment lacks compelling evidence for latest Quaternary movement and consequently is assigned a lower slip rate (one half the UQFPWG's Southern segment consensus value).
				Northern segment - 19 (Middle - Late Quaternary)			6.76	0.1 (0.2) 0.3 (0.6) 0.8 (0.2)	—	
				Central segment - 24 (Latest Quaternary)			6.87	0.2 (0.2) 0.6 (0.6) 1.6 (0.2)	—	
				Southern segment - 35 (Holocene)			7.05	**0.8** 0.2 (0.2)[15] 0.6 (0.6) 1.6 (0.2)	**0.2** 3000 (0.2)[15] 8000 (0.6) 15,000 (0.2)	
Faults along the western edge of Scipio Valley and eastern base of the Pavant Range (from south to north includes the Red Canyon fault scarps, Maple Grove faults, Pavant Range fault, Scipio fault zone, and Scipio Valley faults). (Latest Quaternary to Late Quaternary)	Linked (1.0)	1.0	C	Total length - 45	50 ± 15	15 ± 3 (W)	7.06	0.02 (0.2)[18] 0.1 (0.6) 0.4 (0.2)	—	Several north-striking, individually short faults along the north side of the Pavant Range and the western side of Scipio Valley that are in close alignment and show evidence for late Quaternary surface faulting (Anderson and Bucknam, 1979; Bucknam and Anderson, 1979). Therefore, we link these faults to form a single unsegmented fault zone. Scarps vary from 2 to 11 m on unconsolidated deposits, but ages are not well constrained. The preferred slip rate assumes 3 to 4 m of slip since 30 ka, whereas the minimum slip rate assumes 2 m of slip since 130 ka, and the maximum rate assumes 11 m of slip since 30 ka.
Gunnison fault (Latest Quaternary)	Independent (1.0)	0.8	C	42	50 ± 15	15 ± 3 (W)	7.04	0.02 (0.2) 0.1 (0.6) 0.4 (0.2)	—	Little is known about rates of activity, but scarps and location are similar to the faults along the north side of the Pavant Range and the western side of Scipio Valley. Therefore a slip-rate distribution similar to the Scipio Valley faults was assigned to this fault. This structure may be related to salt tectonics and therefore was given a reduced probability of activity.
Hansel Valley fault (includes Hansel Mountains [east side] faults and Hansel Valley [valley floor] faults) (Historic - Mid- to	Linked (1.0) Independent (0.6) Coseismic (0.4)	1.0	AFP	30	50 ± 15	Antithetic fault truncated against the North Promontory fault.	6.49	0.06 (0.2)[15] 0.1 (0.6) 0.2 (0.2)	—	Both the number and timing of surface-faulting earthquakes on the Hansel Valley fault(s) are unknown. The fault exhibits an irregular pattern of surface faulting with inter-event intervals ranging from possibly as little as 1-2 kyr to more than 30 kyr, indicating that earthquake recurrence has been highly variable through

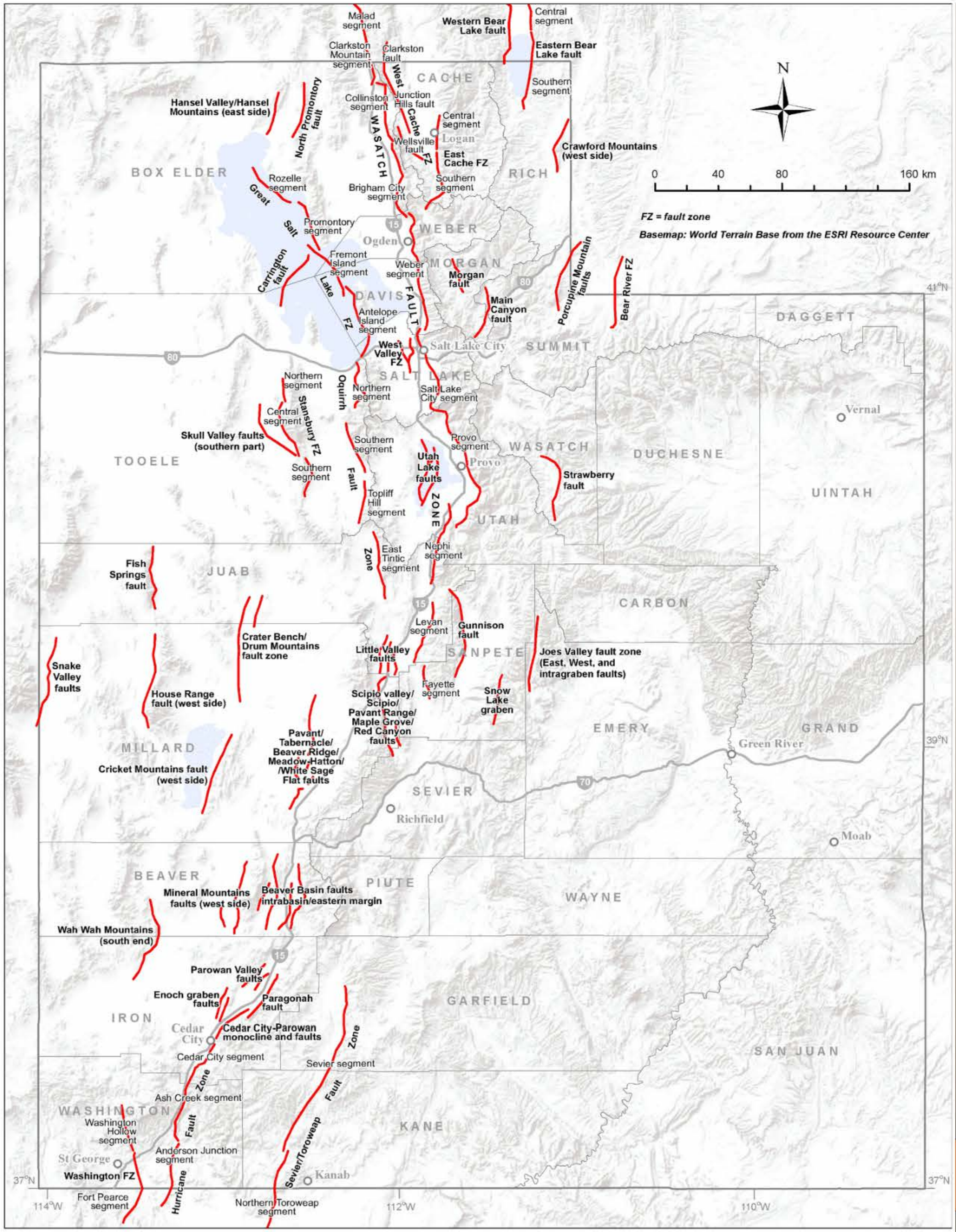


Distance (km)
Brigham City
Ogden
Bountiful
Salt Lake City
Provo
Spanish Fork
Payson
Nephi
41°N
40°N
112°W
Brigham City
Weber
Salt Lake City
Provo
Nephi
Thousands of calendar years B.P. (ka)
B4 5.6 ka
B3 4.5 ka
B2 3.4 ka
B1 2.4 ka
PC1
W5 5.9 ka (mean) 5.6 ka (mode)
W4 4.5 ka
W3 3.1 ka
W2 1.3 ka (mode) 1.1 ka (mean)
W1 0.6 ka
S4 5.3 ka
S3 4.2 ka
S2 2.2 ka
S1 1.3 ka
P5 5.9 ka (mean) 5.6 ka (mode)
P4 4.7 ka
P3 2.2 ka
P2 1.7 ka (mode) 1.5 ka (mean)
P1 0.6 ka
N4 4.7 ka
N3 2.0 ka
N2 1.2 ka
N1 0.2 ka
KC/HC BC BEC PC PP RC GC EO K LC SFDC AF ROC MN MS SQ NC WC REC
Paleoseismic sites

2018 Fault Investigation Priorities Discussion

Utah Fault or Fault Segment	UQFPWG Priorities	
	2005[1]	Additions
Nephi segment, Wasatch fault zone[2,3]	1	--
West Valley fault zone[2,3]	2	--
Weber segment, Wasatch fault zone[2,3] – most recent event	3	--
Weber segment, Wasatch fault zone[2,3] – multiple events	4	--
Utah Lake faults and folds[3]	5	--
Great Salt Lake fault zone[2,3]	6	--
Collinston and Clarkston Mountain segments, Wasatch fault zone[3]	7	--
Sevier and Toroweap faults[2,3]	8	--
Washington fault zone[3] (includes Dutchman Draw fault[2])	9	--
Cedar City-Parowan monocline (removed 2016)[3,4] and Paragonah fault[2,3]	10	--
Enoch graben[3]	11	--
East Cache fault zone[2,3]	12	--
Clarkston fault[2,3]	13	--
Wasatch Range back-valley faults (includes Morgan fault[2] and Main Canyon fault[3])	14	--
Hurricane fault zone[2,3]	15	--
Levan segment, Wasatch fault zone[2,3]	16	--
Gunnison fault[3]	17	--
Scipio Valley faults[3]	18	--
Faults beneath Bear Lake	19	--
Eastern Bear Lake fault zone[2,3]	20	--
Bear River fault zone[2,3]	--	
Brigham City segment, Wasatch fault zone[2,3] – most recent event	--	
Carrington fault, Great Salt Lake fault zone[3]	--	2007
Provo segment, Wasatch fault zone[2,3] – penultimate event	--	
Rozelle section, East Great Salt Lake fault[3]	--	
Salt Lake City segment, Wasatch fault zone[2,3] – northern part	--	2009
Warm Springs fault/East Bench fault[2,3] subsurface geometry and connection	--	2010
Brigham City segment, Wasatch fault zone[2,3] rupture extent (north and south ends)	--	
Northern Provo segment, Wasatch fault zone[2,3] – long-term earthquake record	--	2011
Hansel Valley fault[2,3]	--	
Acquire new paleoseismic information to address paleoseismic data gaps for the five central segments of the Wasatch fault zone.	--	2012
West Cache fault zone[2,3] – long-term earthquake record	--	2013
Use recently acquired lidar[5] data to more accurately map the traces of the Wasatch, West Valley, and Hurricane fault zones, and search for and map as appropriate previously undiscovered mid-valley Quaternary faults.	--	2014
Acquire high-resolution aerial imagery (lidar, Structure from Motion, etc.)[5] and map high-risk (chiefly urban) Utah hazardous faults. Identify future paleoseismic trench sites.	--	2015
Northern segment of the Oquirrh fault zone[2,3]	--	
Acquire and analyze information on salt tectonics and its relation to the Main Canyon fault[3], Sevier detachment/Drum Mountains fault		

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



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2017 List of Highest Priority Faults or Fault Segments

Fault or Fault Segment (Not in Priority Order)	Investigations	
	Status (as of 12/2016)[1,2]	Institution
Acquire paleoseismic information to address paleoseismic data gaps for (1) the five central segments of the Wasatch fault zone[3,4], (2) the Oquirrh fault zone[3,4], (3) refining the latest Quaternary earthquake chronology for the Topliff Hills fault, and (4) the East and West Cache fault zones[3,4]. Examples of paleoseismic data to acquire include extent of surface-faulting rupture, earthquake timing, displacement, and subsurface fault geometry.	Nephi segment, Spring Lake and North Creek sites: UGS FTR Report, Special Study ongoing	UGS/USGS
	Provo segment, Flat Canyon site: USGS ongoing, UGS FTR Report	USGS/UGS
	Salt Lake City segment, Corner Canyon site: UGS FTR Report	UGS/USGS
	Provo segment, Dry Creek and Maple Canyon sites: USGS ongoing, UGS FTR Report	USGS/UGS
	Fort Canyon fault, Traverse Mountains salient: ongoing	UVU
	Southern segment, East Cache fault zone: FTR Report	USU/GEO-HAZ
Use recently acquired lidar[5] data to more accurately map the traces of the Wasatch[3,4], West Valley[3,4], and Hurricane[3,4] fault zones, and search for and map as appropriate previously undiscovered mid-valley Quaternary faults.	UGS Open-File Reports 638 and 640 The UGS is mapping portions of the Hurricane, Wasatch, and West Valley fault zones.	UGS
Acquire earthquake timing information for the Utah Lake faults[3] to investigate the relation of earthquakes on that fault system to large earthquakes on the adjacent Provo segment of the Wasatch fault zone[2,3] (independent or coseismic ruptures, fault pairs?).	No activity	--
Acquire high resolution aerial imagery (lidar, Structure from Motion, etc.)[5] and map high-risk (chiefly urban) Utah hazardous faults. Identify future paleoseismic trench sites.	Wasatch fault zone mapping proposal funded, awaiting possible award of East and West Cache fault zones mapping proposal.	UGS
	Lidar data for portions of the Bear Lake area, Cache Valley, and Great Salt Lake acquired fall 2016, data to be publicly available summer 2017.	UGS/Others/ State of Utah
Acquire and analyze information on salt tectonics and its relation to the Main Canyon fault[3], Sevier detachment/Drum Mountains[4] faults, Bear River fault zone[3,4], Spanish Valley (Moab area) faults, Joes Valley fault zone[3,4], Levan[3,4] and Fayette segments of the Wasatch fault zone, Scipio Valley faults[4], and the Gunnison fault[4].	Levan and Fayette segments paleoseismic investigation proposal submitted, awaiting funding.	UGS

2017 List of Other Priority Faults or Fault Segments

Fault or Fault Segment	UQFPWG Priority[1]	Investigations	
		Status (as of 12/2016)[2]	Institution
Paragonah fault[3,4]	10[5]	No activity	--
Enoch graben[4]	11	Map: UGS Open-File Report 628	UGS
Clarkston fault, West Cache fault zone[3,4]	13	UGS Special Study 98 Mapping proposal submitted, awaiting funding	UGS
Gunnison fault[4]	17	No activity	--
Scipio Valley faults[4]	18	No activity	--
Faults beneath Bear Lake	19	No activity	--
Eastern Bear Lake fault zone[4]	20	No activity	--
Carrington fault, Great Salt Lake fault zone[4]	2007	No activity	--
Rozelle section, Great Salt Lake fault zone[4,6]	2007	No activity	--