2018 Utah Quaternary Fault Parameters Working Group (UQFPWG) Meeting

Wednesday, February 14, 2018

UTAH DNR GEOLOGICAL SURVEY

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.

Agenda

8:00 Refreshments

8:00 – 8:30 Welcome, Overview of Meeting, and Review of Last Year's Activities, UGS Paleoseismology Update, and U.S. Geological Survey Update

8:45 – 10:00 Technical Presentations (4)

10:00 Break (15 min)

10:15 – 12:00 Technical Presentations (6)

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

1:00 – 3:00 Technical Presentations (5)

3:00 Break (15 min)

3:15 – 3:45 Discussion – Surface-Fault-Rupture Investigations & Urban Geologic Mapping

3:45 – 5:00 Discussion – 2019 Fault Investigation Priorities

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

Update on the USGS External Grants program (and more)

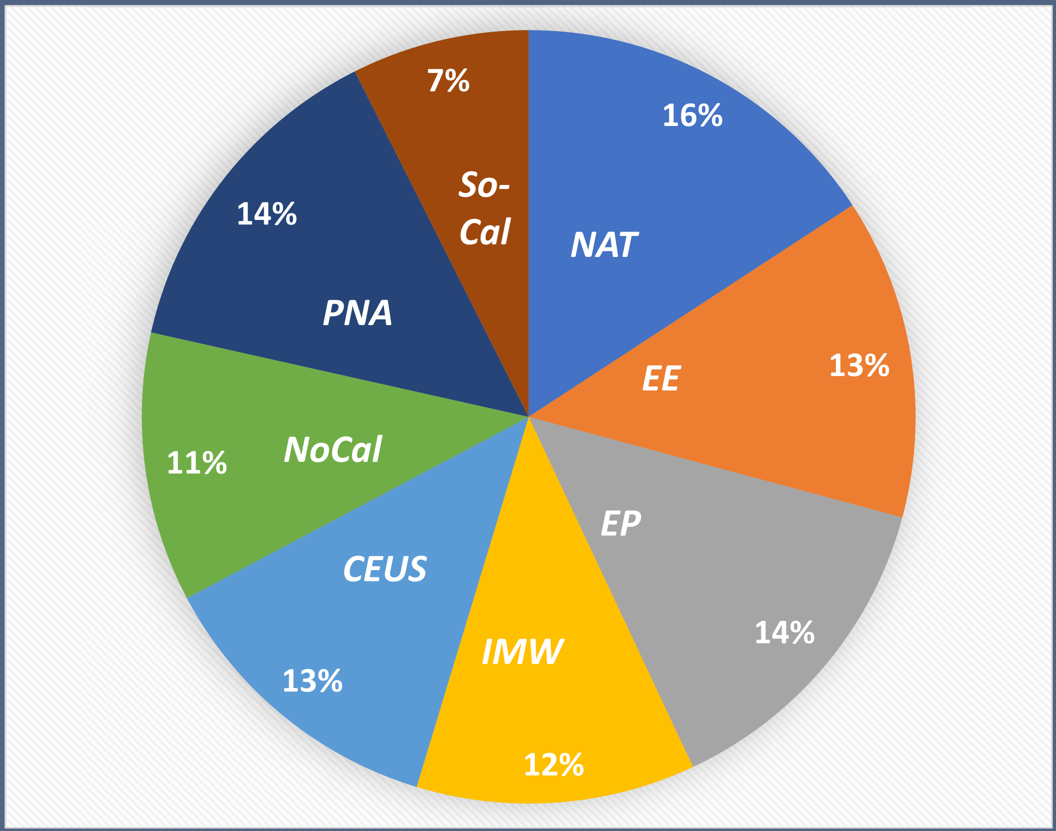
Ryan Gold, USGS Intermountain West Regional Coordinator

USGS
science for a changing world

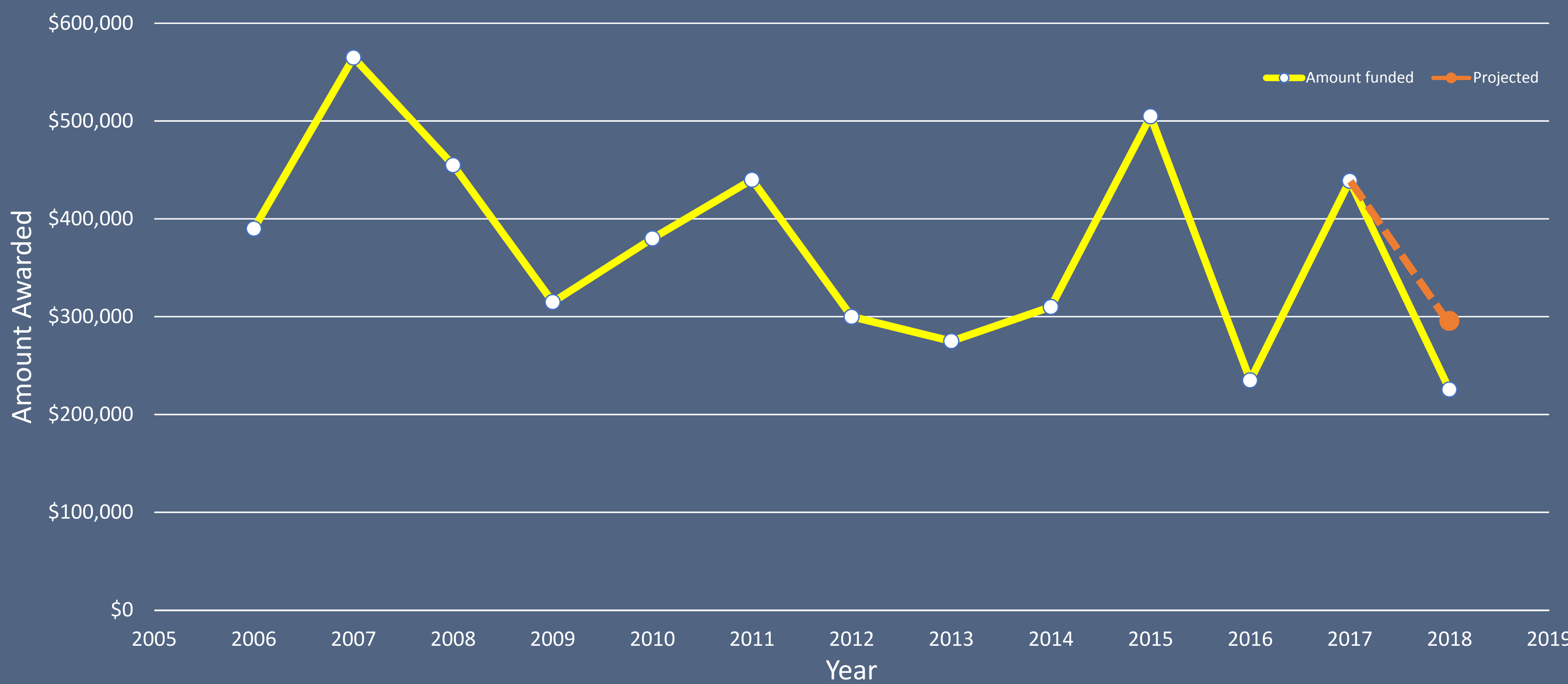
Intermountain West Region

USGS External Grants Program, FY2017 (last year)

- $3.57M competitive research grants funded - FY17
- 212 Proposals received, 62 funded (~29% success rate) - FY17
- IMW funded 12 proposals ($438.9k) in FY17
  (Utah – 4 proposals, ~$247k)
- Additional ~$15.4 M in additional external USGS funding (seismic & geodetic regional monitoring, SCEC, EEW etc.) – FY17



Intermountain West External Grants funding

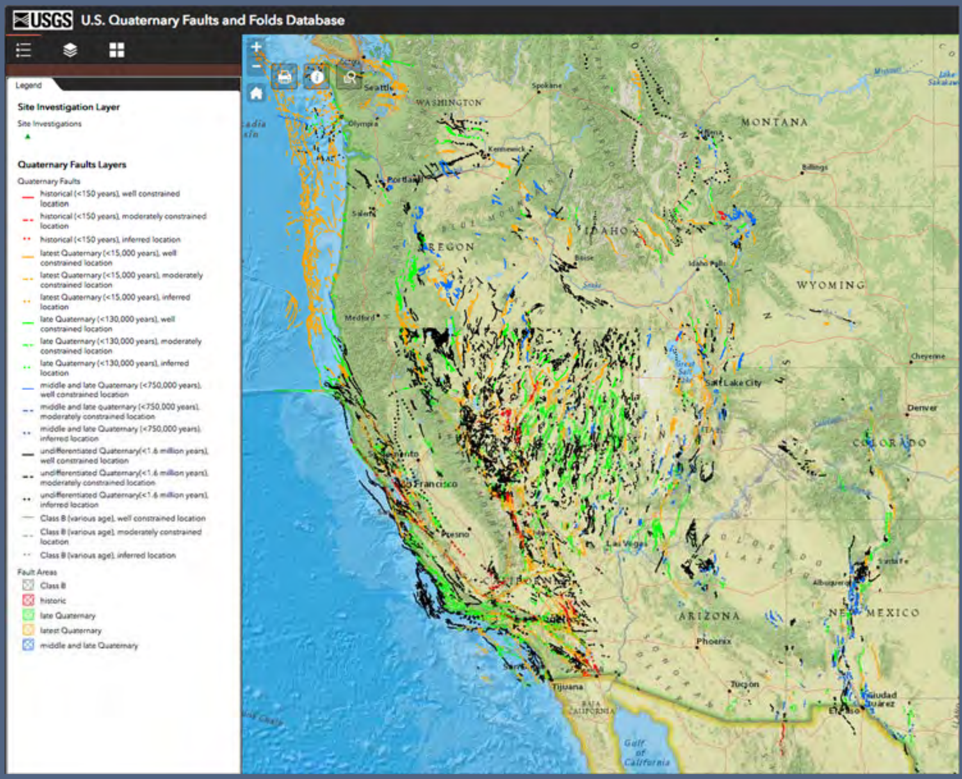


Looking forward

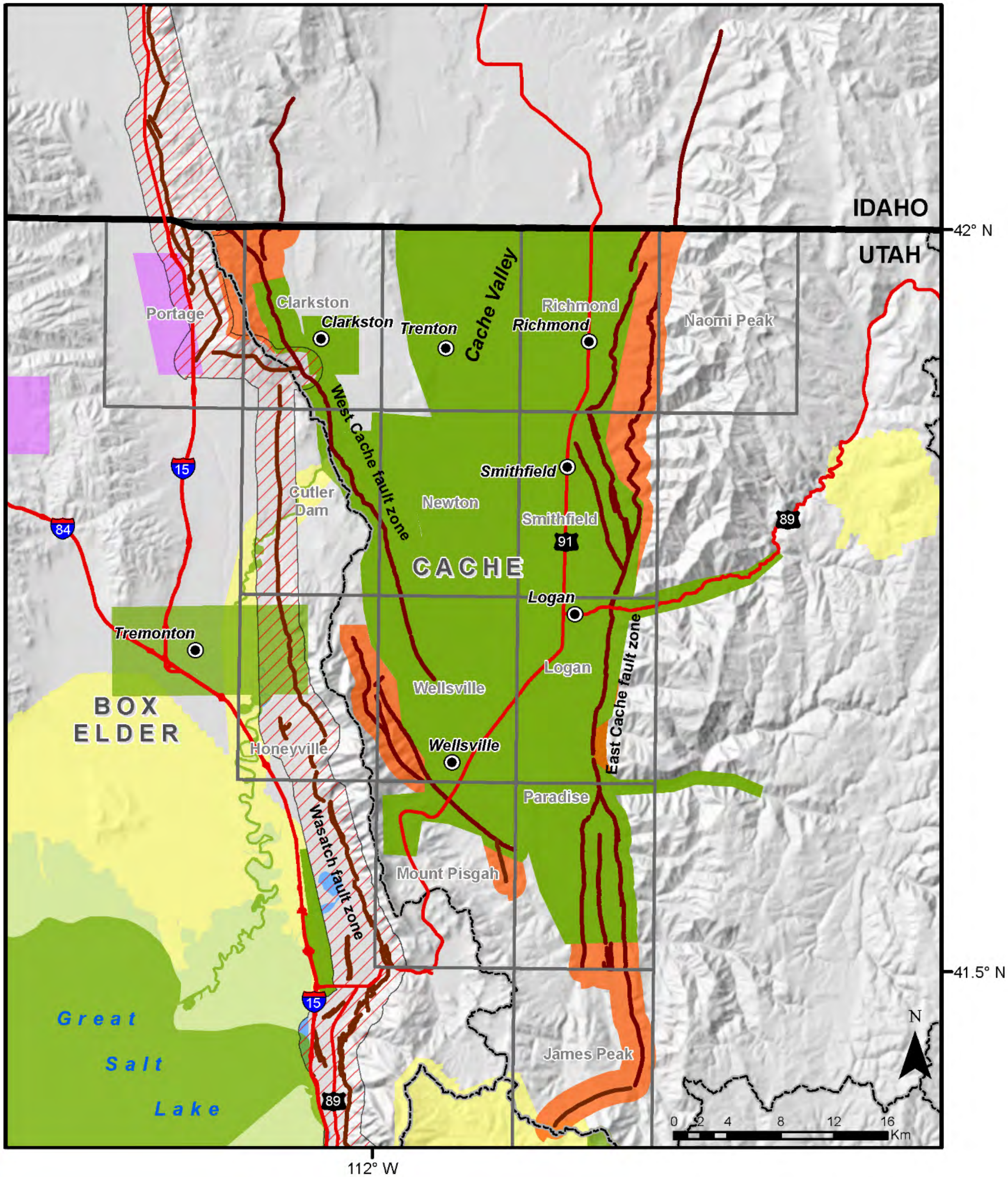
- FY18 (current) – additional funding dependent on passage of federal appropriations bill.
  - Only one proposal submitted for Utah-based research.
- FY19 (details & tips)
  - Look for program announcement in March 2018.
  - Proposal dues in May 2018.
  - Panel meets in August – please send me an email if you'd be interested in serving and won't have conflict of interest (e.g., submitting a proposal this year).
  - *FYI - Start date can be used to guide funding decisions.*
  - Increased scrutiny on out-of-cycle proposals. *Everything should be competitive.*
  - For FY18, average funded proposal in IMW requested ~$49k. Cost sharing a plus.
  - Panels increasingly scrutinizing history of publishing USGS-funded research.

USGS Quaternary Fault and Fold database

- USGS will only maintain limited metadata fields (long-format reports still accessible)
- Online interface updated late 2017 (thanks for your input/review!)
- Significant database updates completed for:
  - Utah
  - Arizona
  - California
  - New Mexico
  - Alaska
  - Washington
  - Oregon
- Due for update
  - Colorado (underway)
  - Nevada (tbd)
- Kathy Haller retired (IMW POC: Ryan Gold)

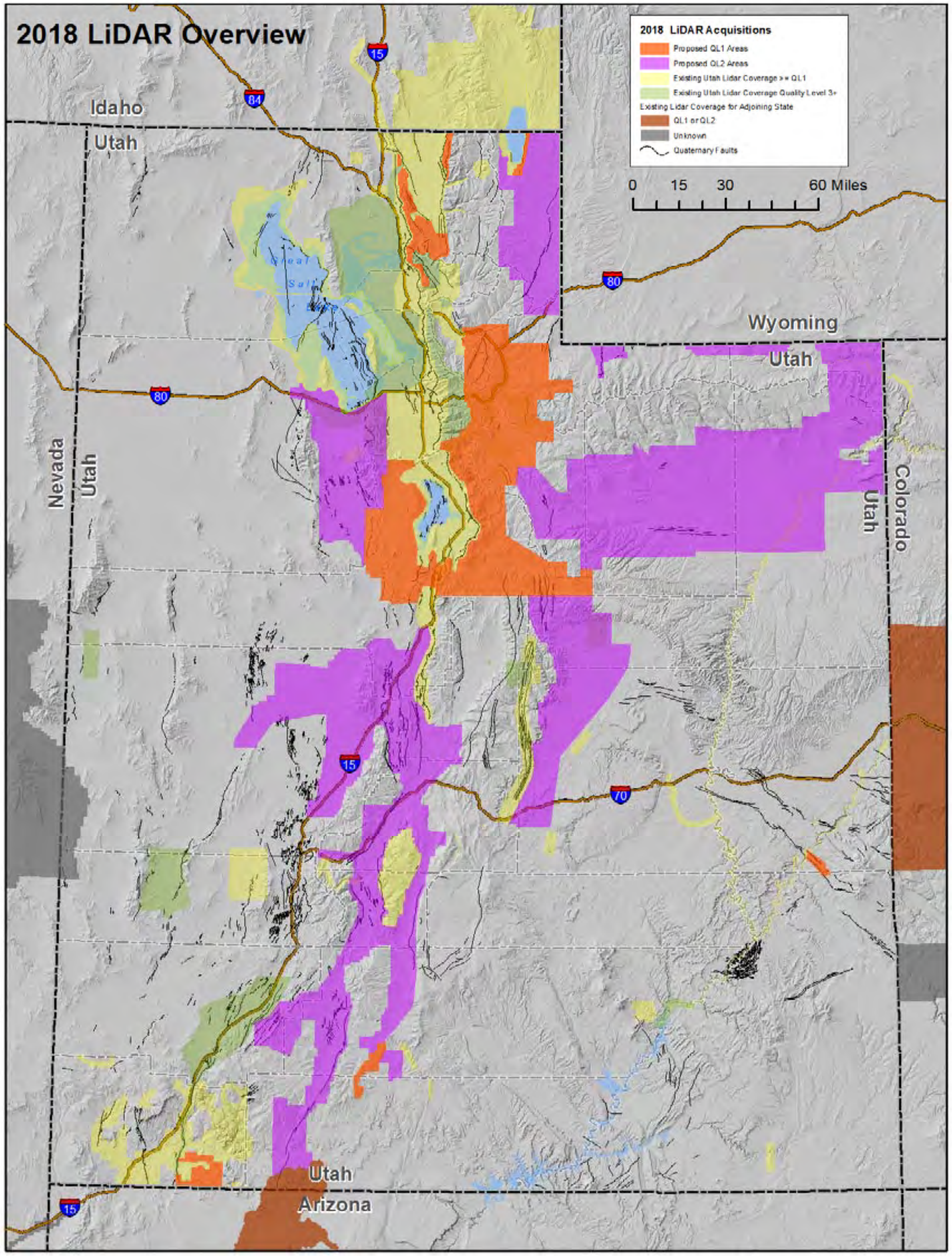


https://earthquake.usgs.gov/hazards/qfaults/



Cache Valley Fault Trace Mapping

geology.utah.gov

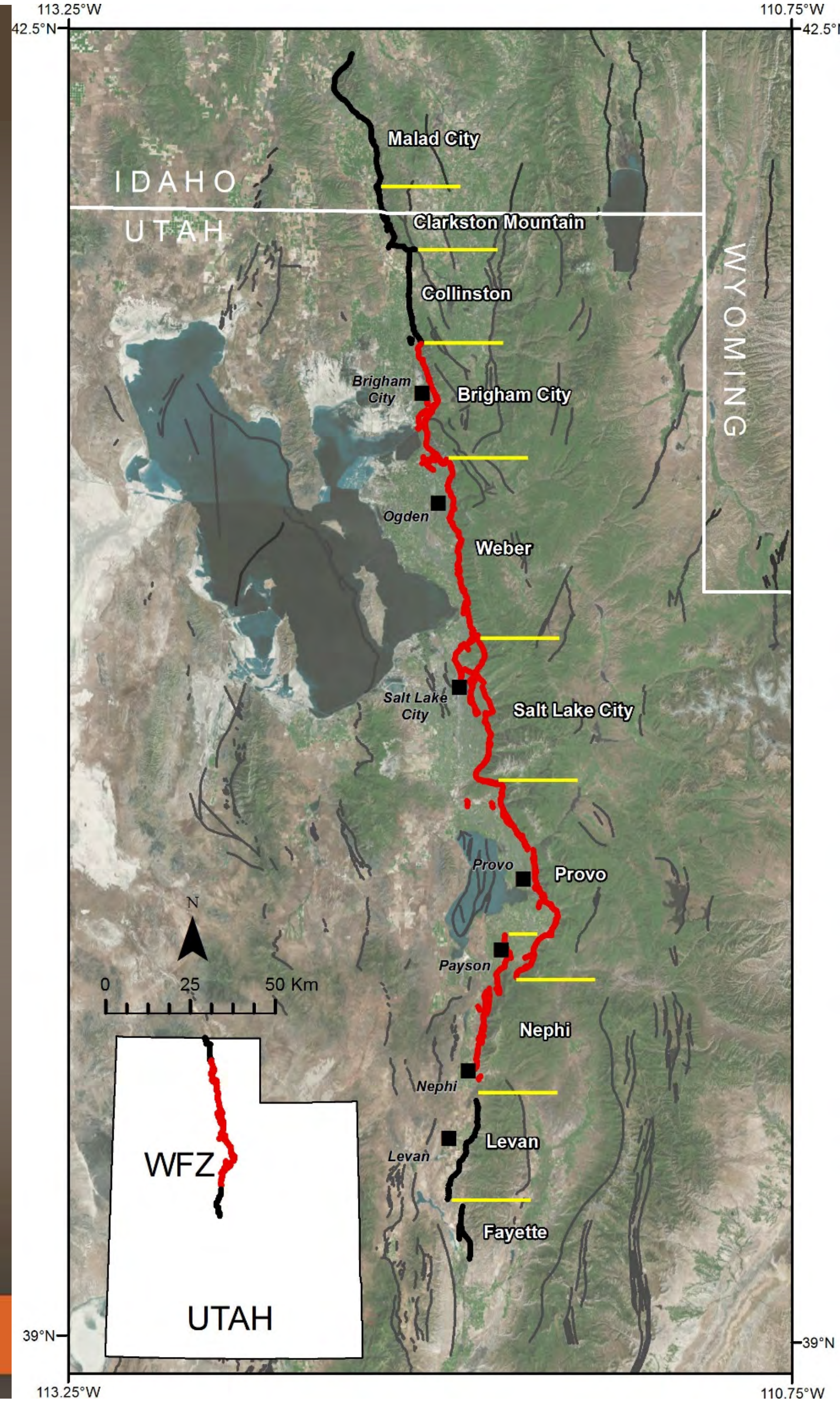


UGS LIDAR Acquisition

geology.utah.gov

Future UGS Trenching Projects

- Additional trenching on northern WFZ end segments
- No to very little data exists
- New mapping has identified potential trench sites



UTAH DNR
GEOLOGICAL SURVEY
UTAH GEOLOGICAL SURVEY

SEISMIC LAND STREAMER IMAGING BENEATH SALT LAKE CITY

UTAH FAULT PARAMETERS WORKING GROUP – 2/14/18

Lee Liberty – Boise State University

Gabe Gribler, James St. Clair, Thomas Harper, Thomas Otheim

BOISE STATE UNIVERSITY

SEISMIC IMAGING OBJECTIVES

Earthquake hazard and risk assessments beneath urban centers

- Identify and characterize the Warm Springs fault beneath downtown SLC
- Identify and characterize the northern portions of the East Bench fault
- Identify and characterize faults within the step-over region of the Salt Lake front
- Generate a Vs_{30} map for Salt Lake City
- Liquefaction susceptibility via Vp and Vs measurements

  (map low Vs zones and identify shallow water table areas)
- Depth to bedrock/key boundaries via gravity, Vp, Vs, and reflection imaging

- Funding sources

USGS NEHRP #G15AP00054 – 2015 field campaign

USGS NEHRP #G17AP00052 – 2017 field campaign – in progress

BENEFITS OF SEISMIC LAND STREAMER COMPARED TO TRADITIONAL SEISMIC IMAGING

- Rapid data collection – 4-5 km/day
- Minimal field crew – one person operation
- Directly operate on city streets
- Predictable source/receiver geometry makes processing more simple
- Real time GPS allows for simple geometry
- Physical properties of road and sub road make for a uniform near surface
- Police or flagger assistance to control traffic and provide near continuous profiling
- Large seismic source relative to imaging depths allows for traffic noise during data collection

SUMMARY OF 2015/2017 FIELD CAMPAIGNS

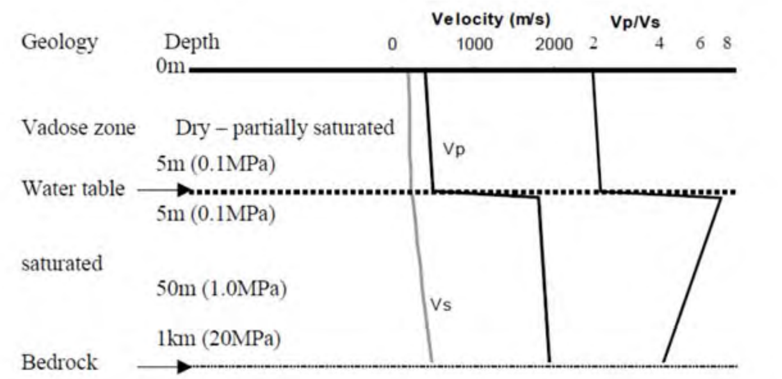
May, 2015 → 3 field days
5,576 48 channel shot gathers
2 m spaced shots (gaps at major roads)
15 km length along 9 west-east profiles
Police escort along most roads allowed near continuous profiling
Offsets: 5-65 m

May, 2017 → 5 field days
9839 shot gathers
20 km length along 13 profiles
Offsets: 10-70 m

Total:
35 km along 22 streets
2m spaced shots, 1.25 m spaced receivers
400 m/hour or a shot every 15 seconds
15,419 hammer hits

PHYSICAL PROPERTY ESTIMATES SALT LAKE CITY

Low Vs & Vp for Bonneville deposits
Higher Vs & Vp for alluvial fan deposits
High Vp for water saturated sediments
Good reflectivity in lake deposits, shallow groundwater
Poor reflectivity in alluvial fans, deeper water table

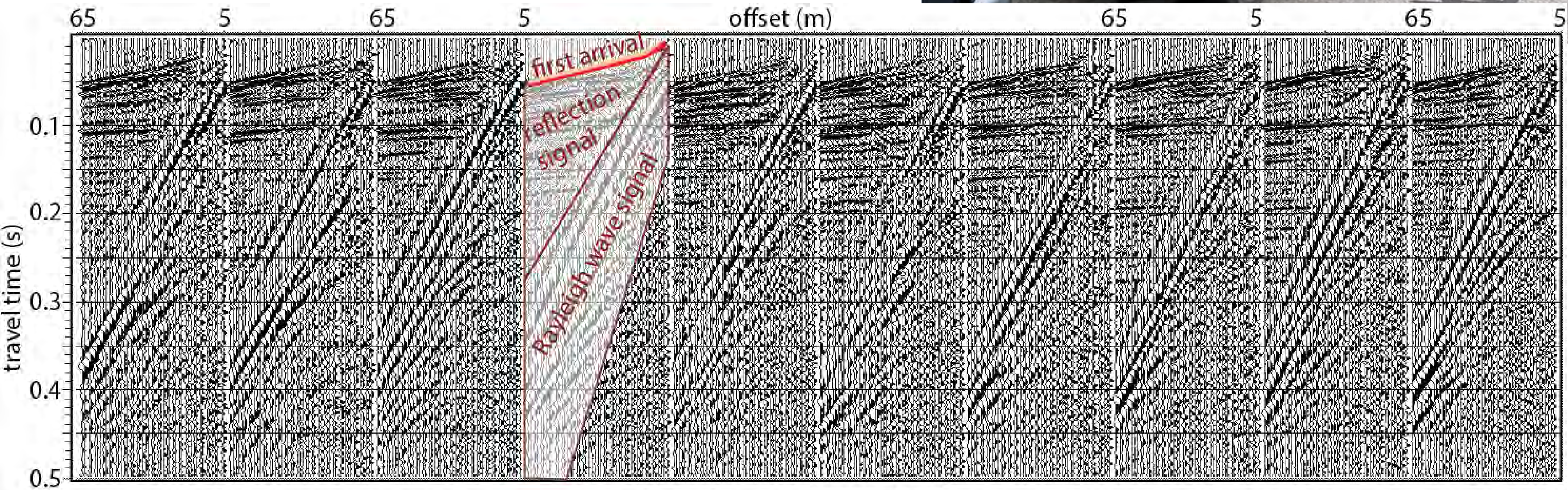


From Bartlett, S., 2004 - UDOT

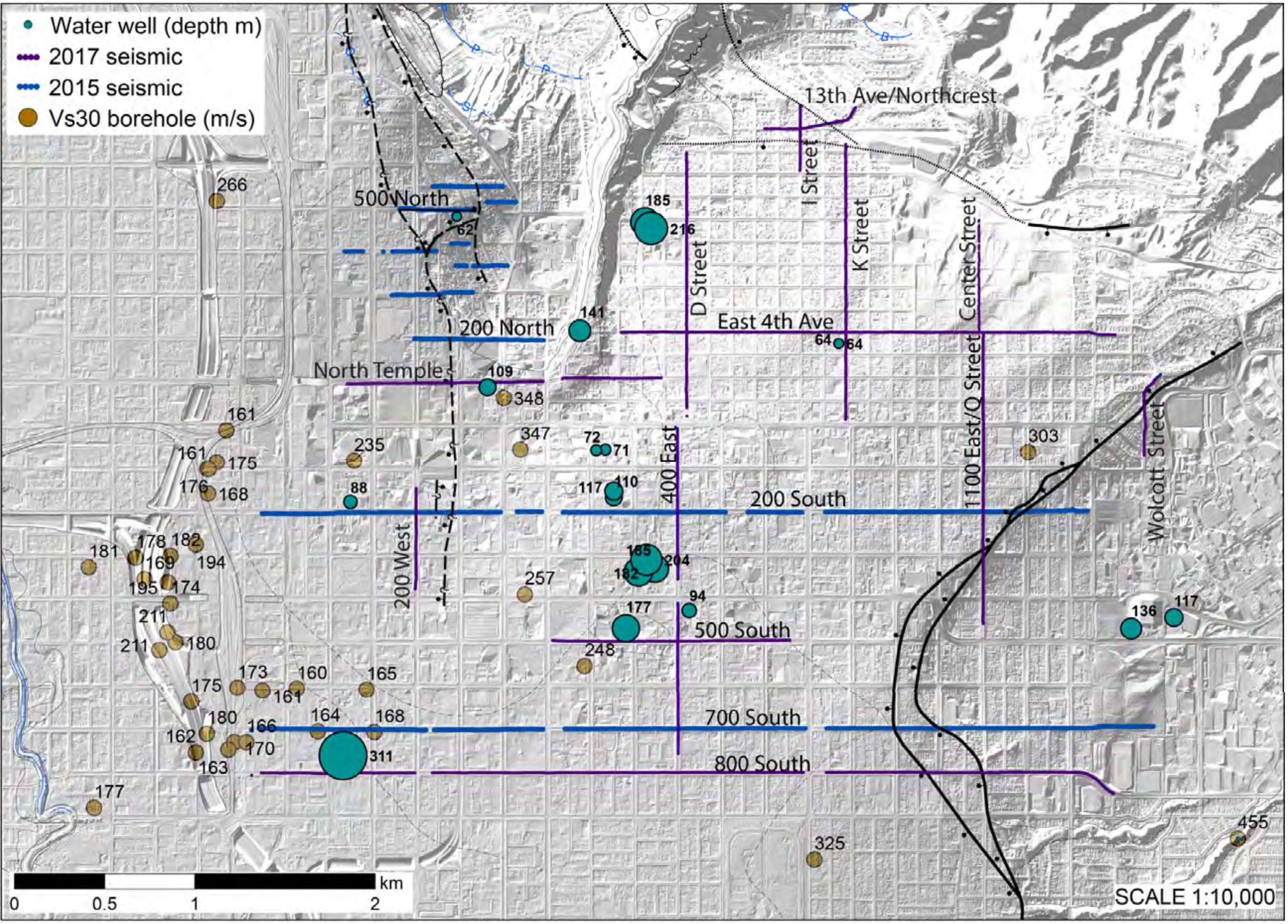
					Cone Penetrometer				Gardner alpha	0.3	
600 South					Vs	G	E		Gardner beta	0.25	
Depth	Depth	Soil Type	Unit Weight	bulk density	Shear wave Velocity	Shear Modulus	Modulus	Vp - dry	Vp/Vs - dry	Vp - from Gardner	Vp/Vs - wet
(m)	(m)		(kN/m3)	g/cc	(m/s)	(kPa)	(kPa)	(m/s)		wet, fcn of density	
0	5	Alluvium	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

URBAN LAND STREAMER DESIGN

48 2-component shoes (vertical and in-line)
4.5 Hz geophones (interchangeable to 10, 40 Hz)
1.25 m spaced geophones (60 m aperture)
(now additional 30 m segment to extend to 90 m aperture)
2 m nominal shot spacing
Accelerated weight drop source (Arduino controlled)
One person performs all operations



DOWNTOWN SALT LAKE CITY LIDAR MAP WITH SEISMIC AND BOREHOLE LOCATIONS



36 Vs measurements

McDonald and Ashland (2008)

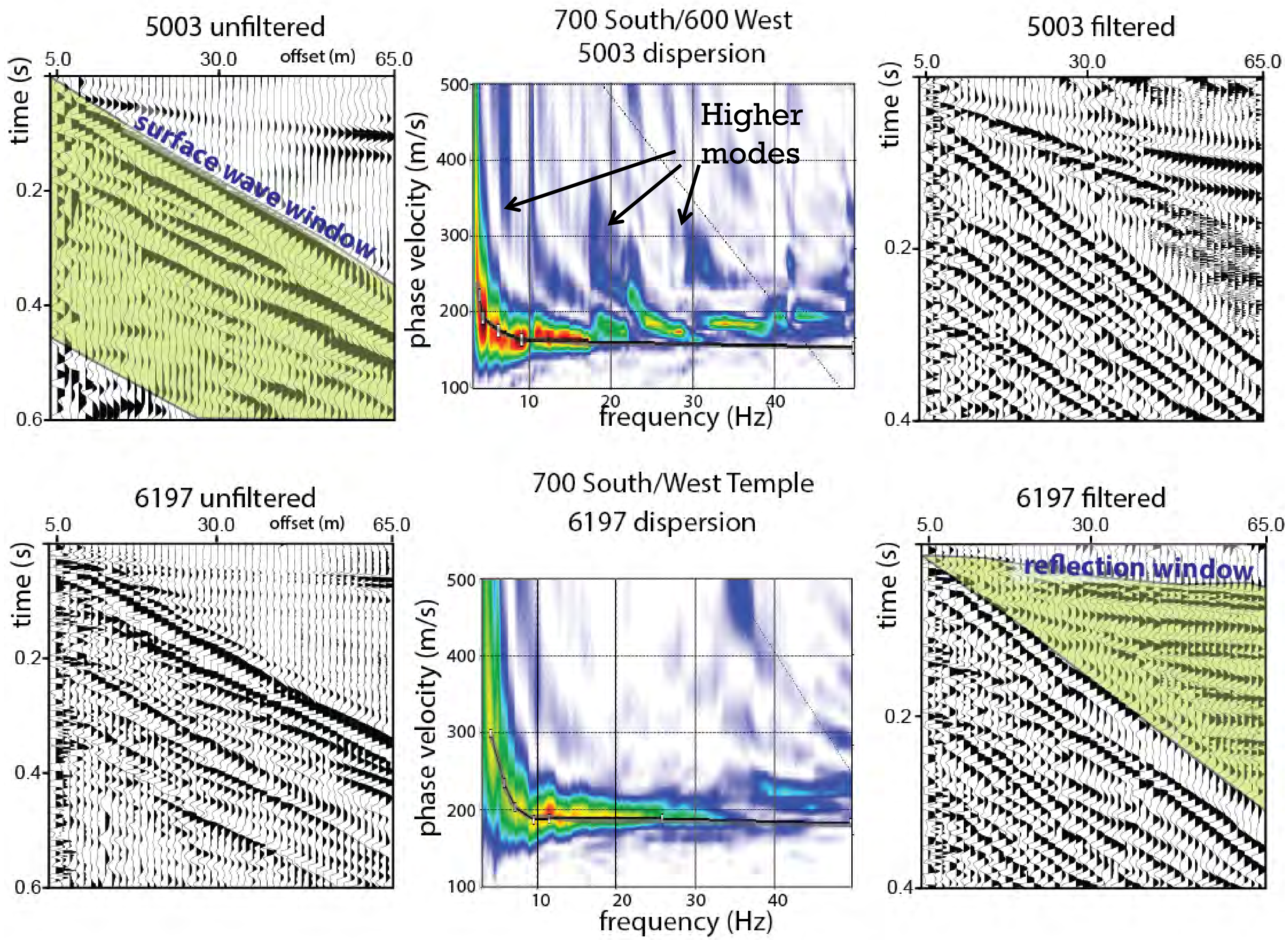
Mapped faults
McKean (2014)
Personious and Scott (2009)

VS (MASW) PROFILING

700 SOUTH SHOTS AND DISPERSION CURVES

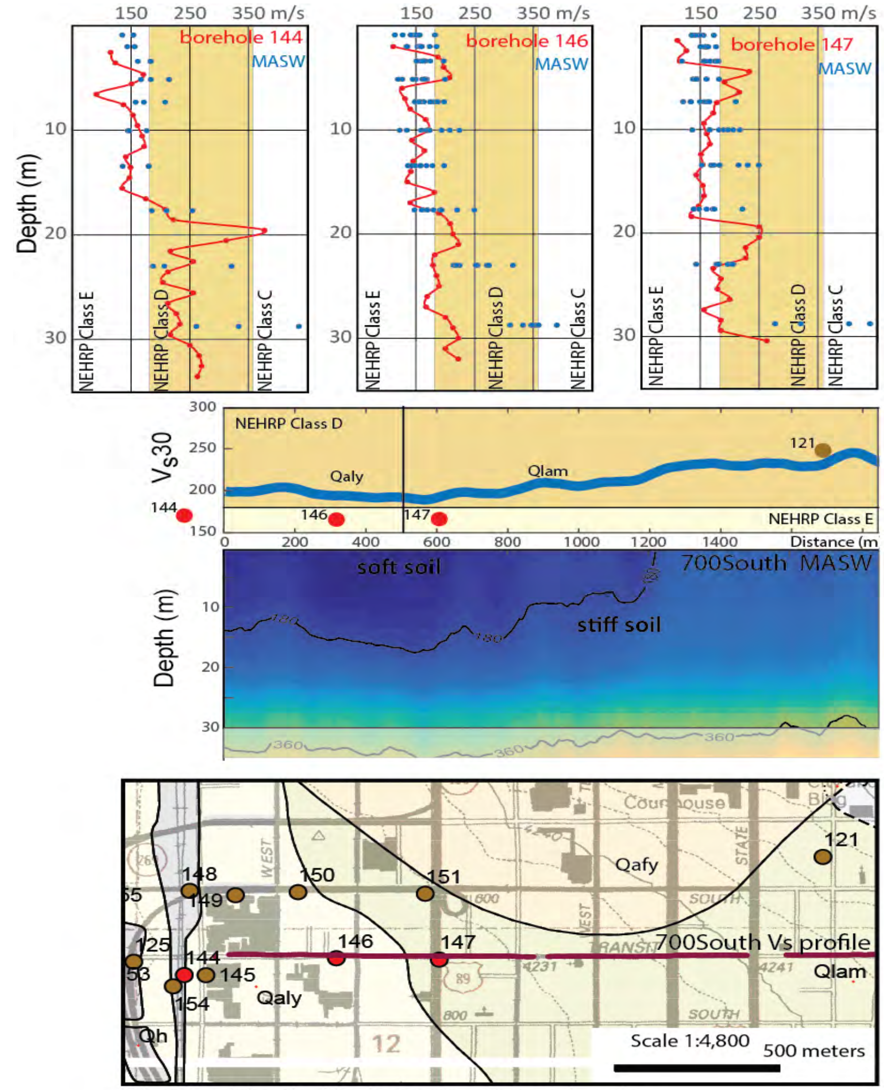
$$VS30M = \sum DI / \sum TI = 30 / \sum (DI/VSI)$$

SUMMATION OF THICKNESS (DI) DIVIDED BY VELOCITY (VSI) OF EACH LAYER



DO ROAD SURFACE/UTILITIES IMPACT SEISMIC MEASUREMENTS?

USUALLY NO – BUT CONCRETE ROADS AND TUNNELS ARE BAD

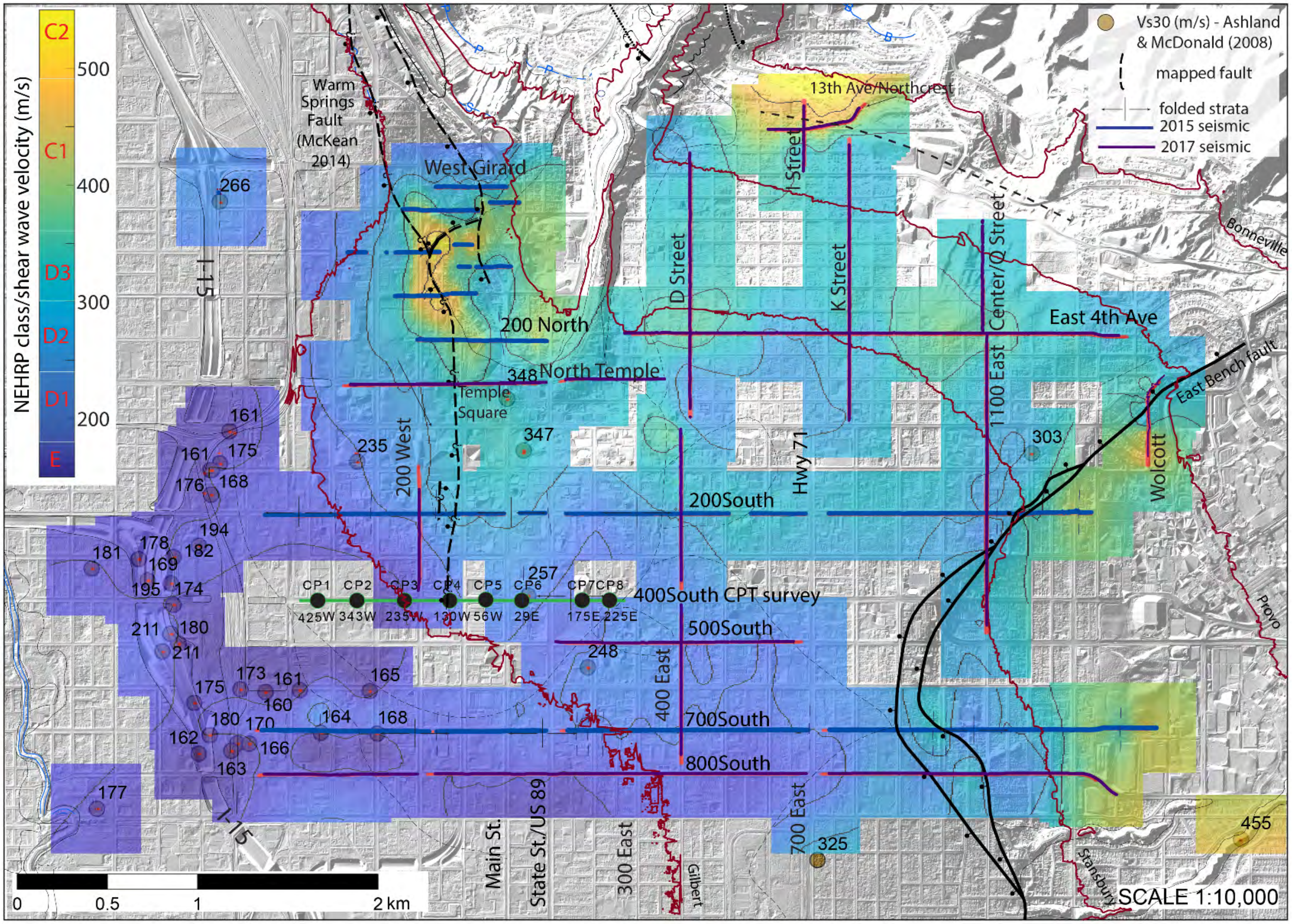


Qh - Fill and disturbed land over stream terrace deposits
Qaly - Holocene stream deposits
Qlam - Holocene to upper Pleistocene lacustrine and alluvial and marsh deposits
Qafy - Holocene to upper Pleistocene alluvial-fan deposits

VS$_{30}$ MAP FOR DOWNTOWN SALT LAKE CITY

36 Vs measurements
McDonald and Ashland (2008)

15,000 additional Vs measurements
via seismic land streamer

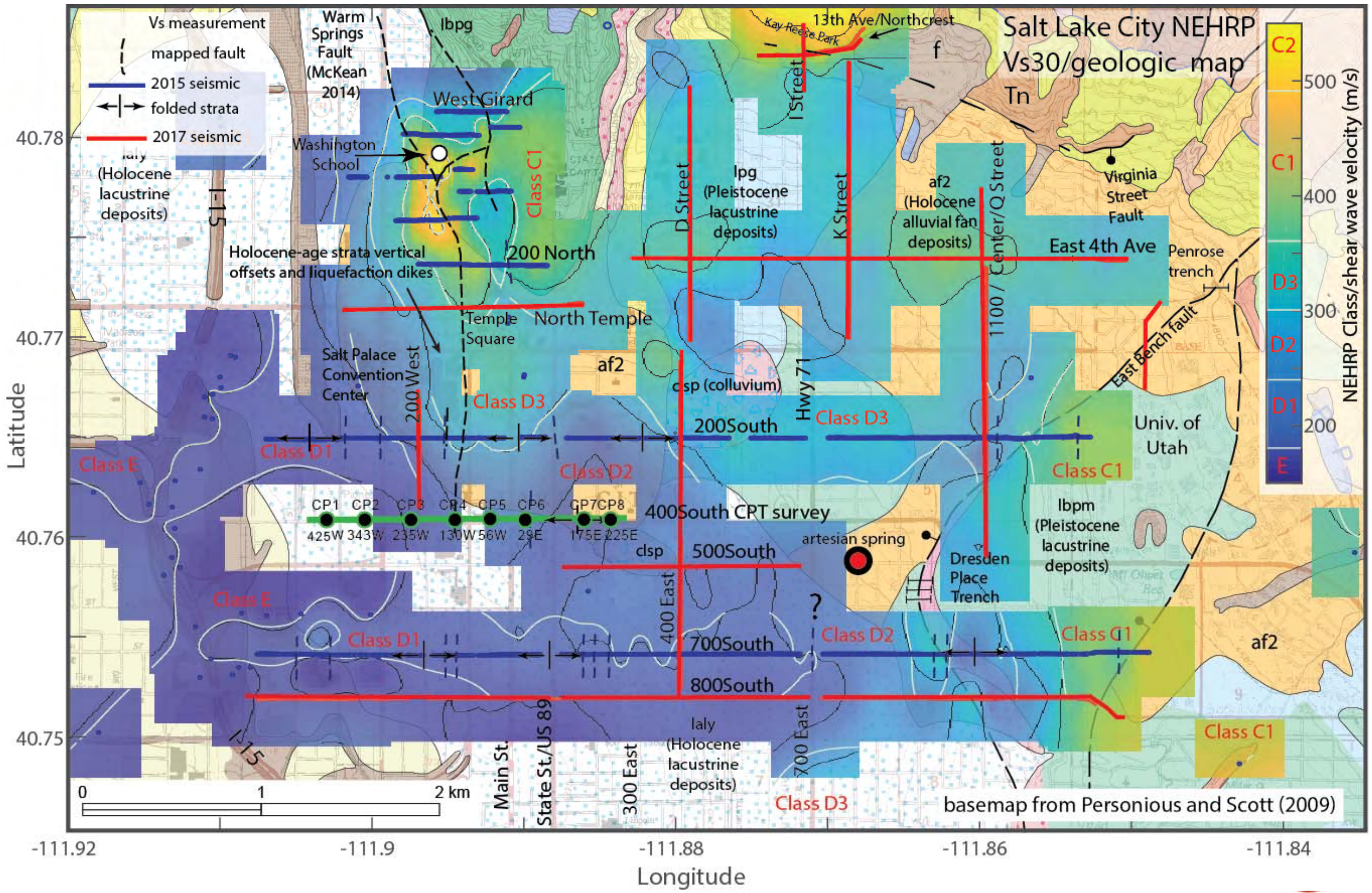


SALT LAKE CITY VS$_{30}$ LAND STREAMER RESULTS WITH GEOLOGIC MAP

Low Vs for Bonneville deposits beneath western portions of downtown Salt Lake City

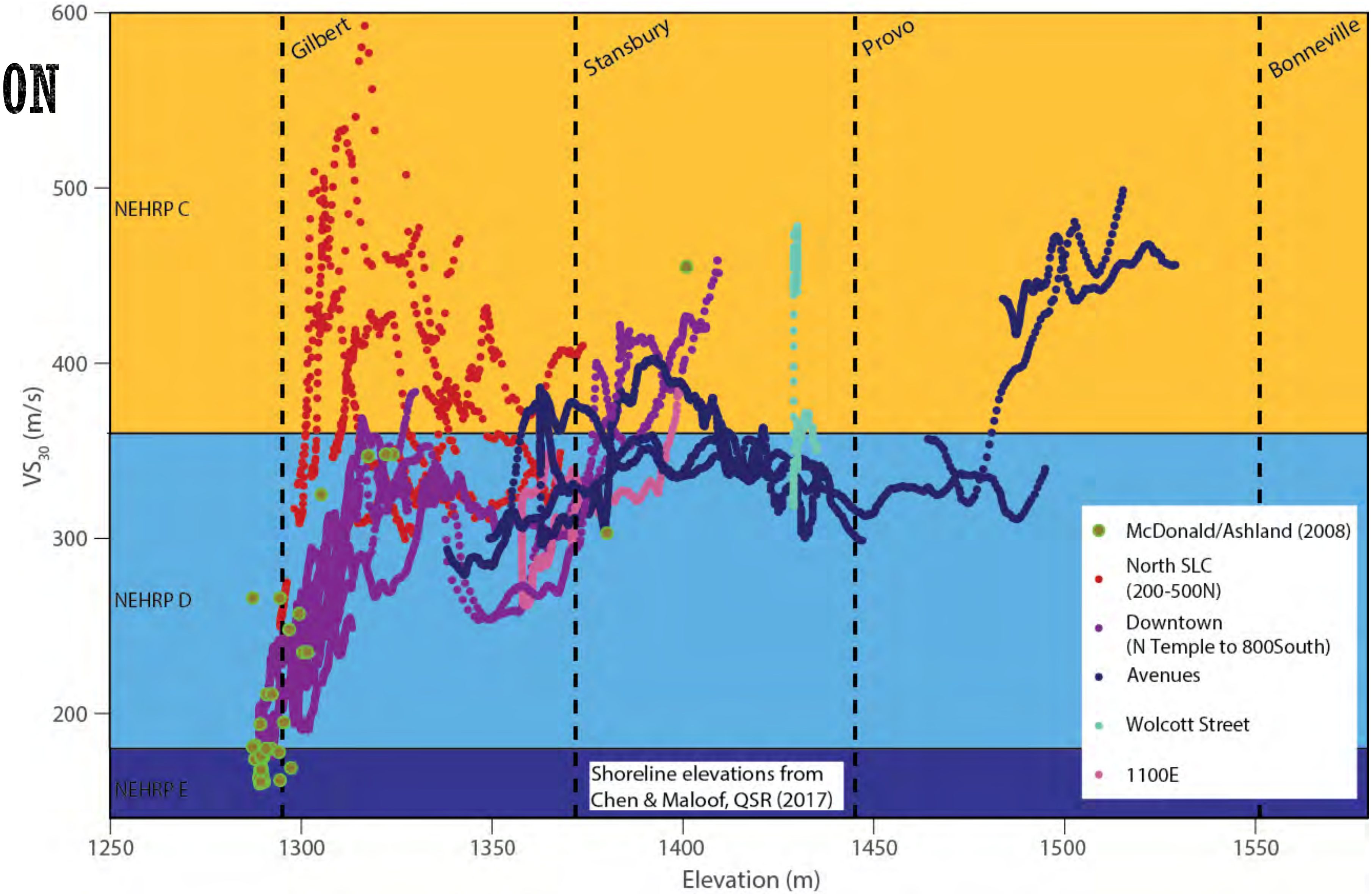
Increase in Vs30 from west to east

High Vs in the footwall or in fault zones



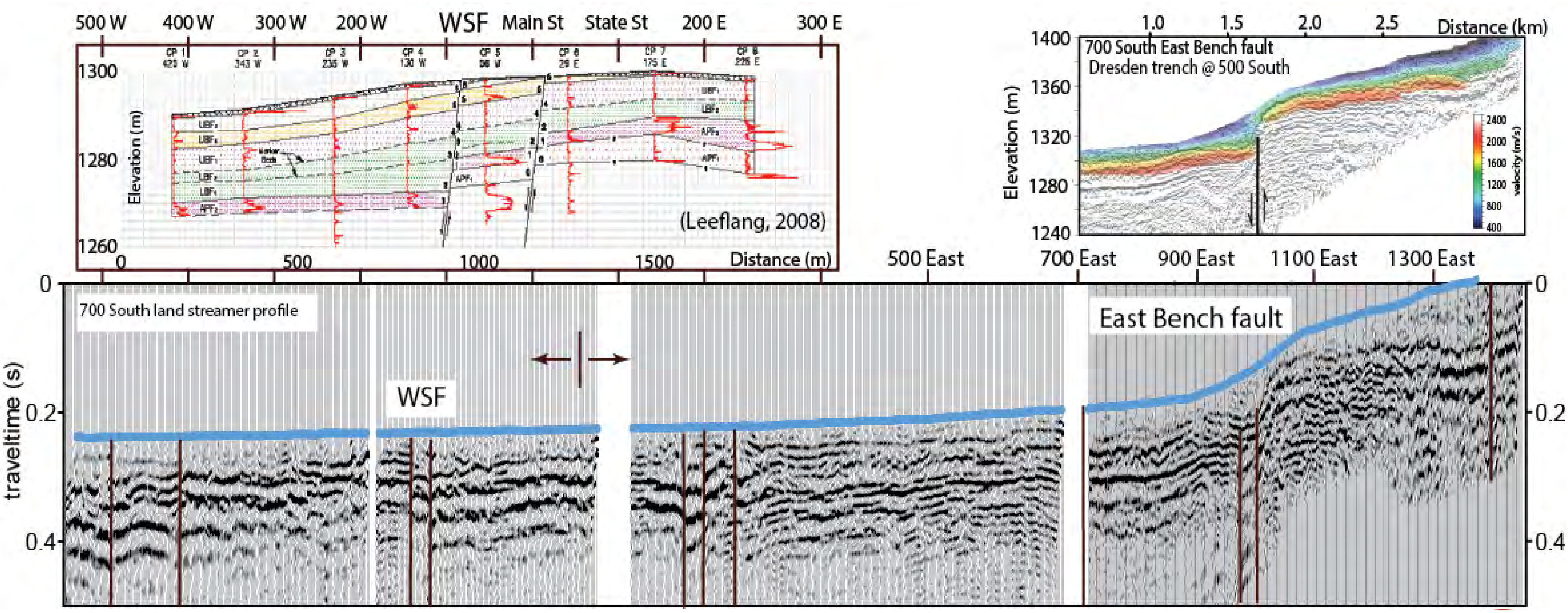
ELEVATION VS. VS_{30}

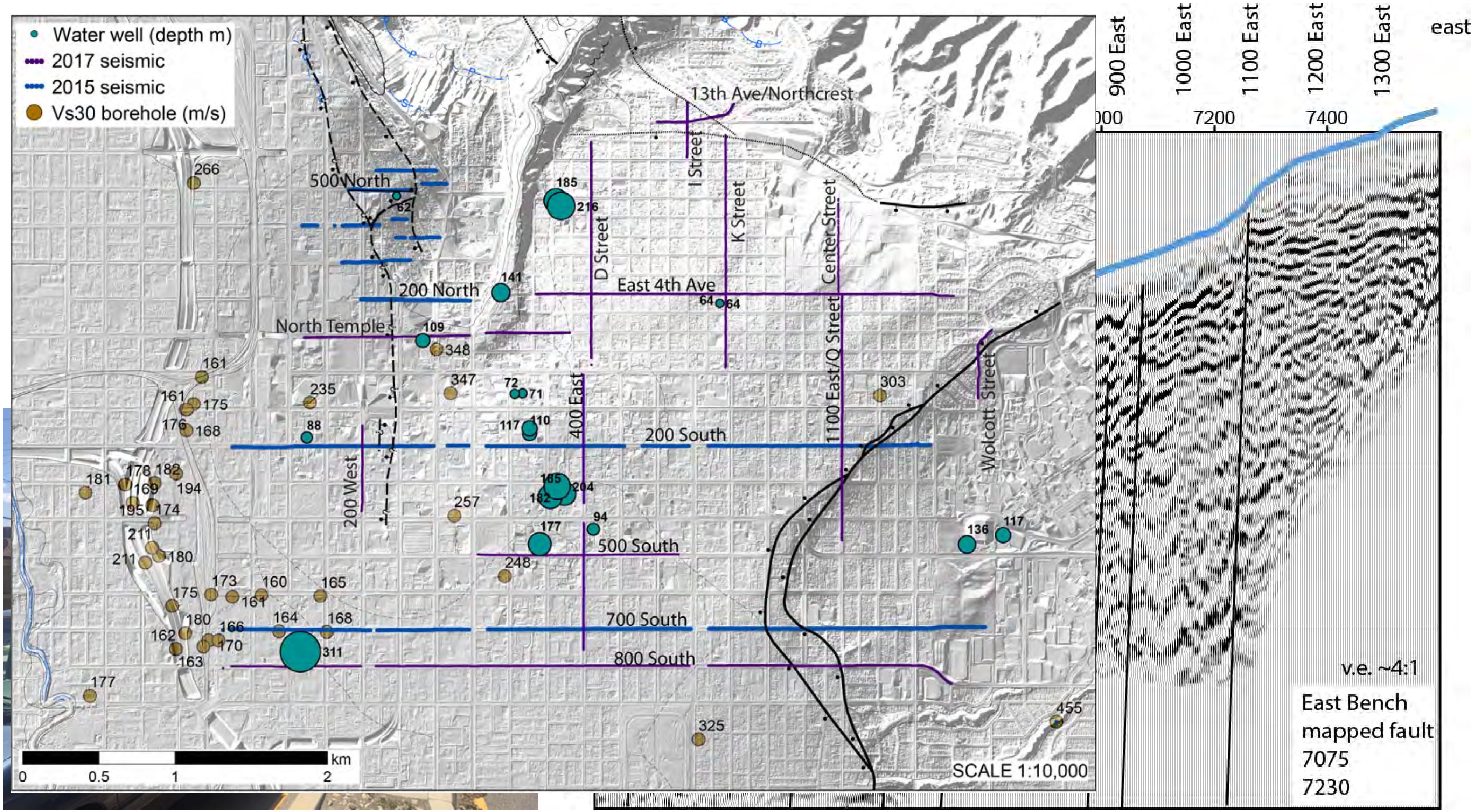
Linear Vs/elevation relationship at low elevations



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

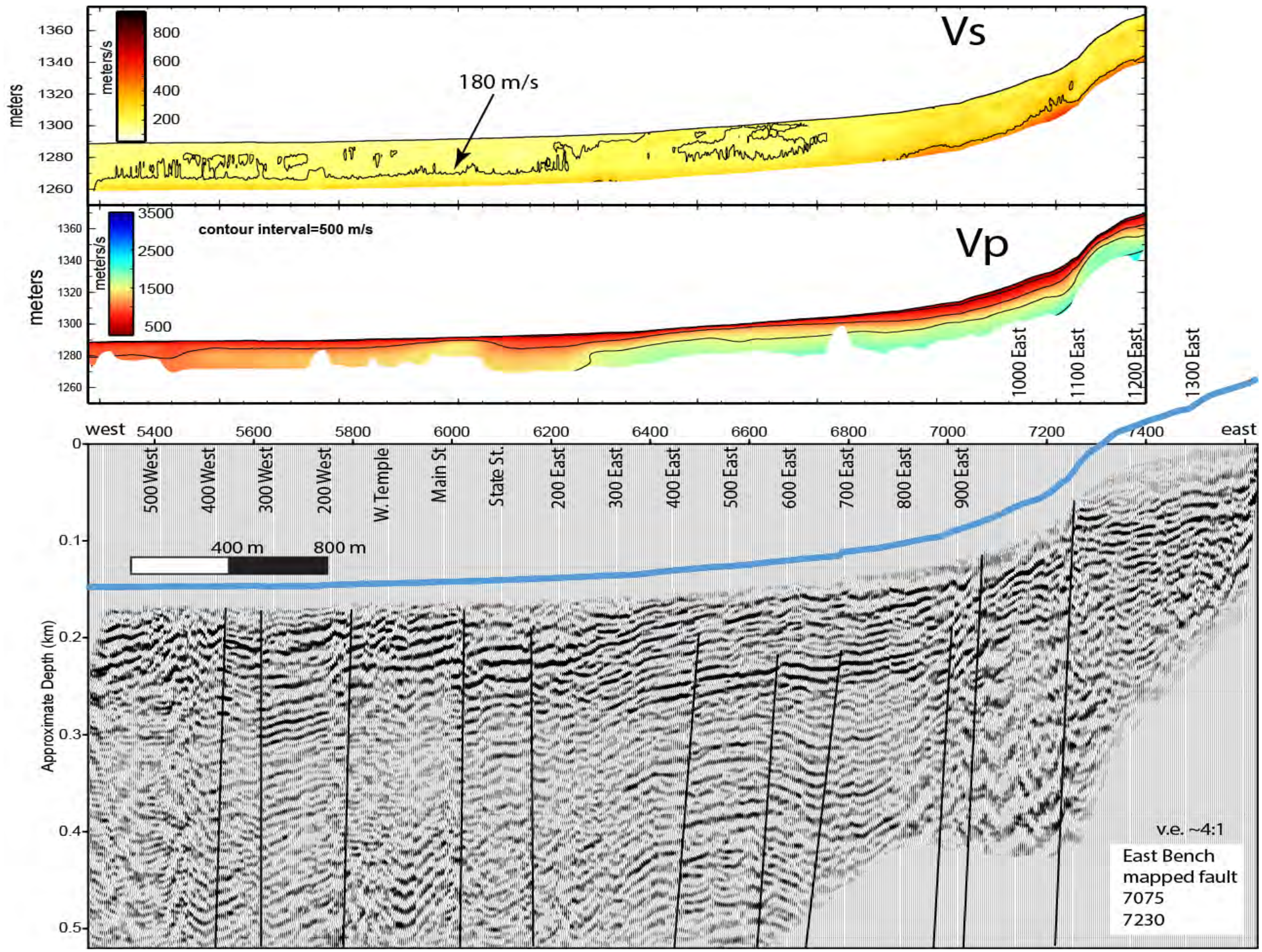



Water well (depth m)
2017 seismic
2015 seismic
Vs30 borehole (m/s)
13th Ave/Northcrest
500 North
200 North
North Temple
East 4th Ave
D Street
I Street
K Street
Center Street
1100 East/O Street
400 East
200 South
200 West
Wolcott Street
500 South
700 South
800 South
SCALE 1:10,000
km
0
0.5
1
2
900 East
1000 East
1100 East
1200 East
1300 East
east
7200
7400
v.e. ~4:1
East Bench
mapped fault
7075
7230

800 SOUTH

Vs and Vp velocities slow to the west

Seismic character is more chaotic to the west



VS_{30} MAP FOR DOWNTOWN SLC

36 Vs measurements

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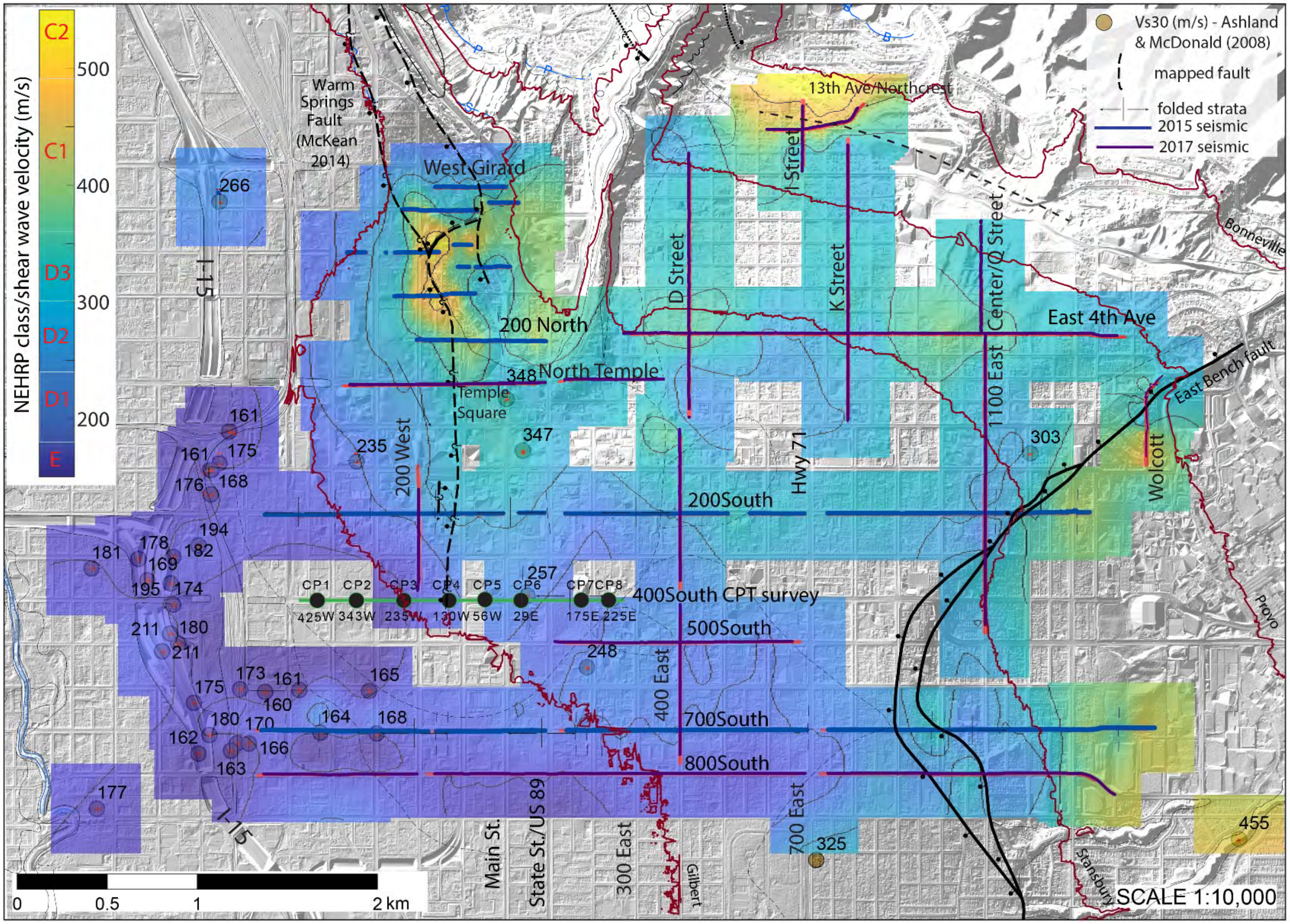
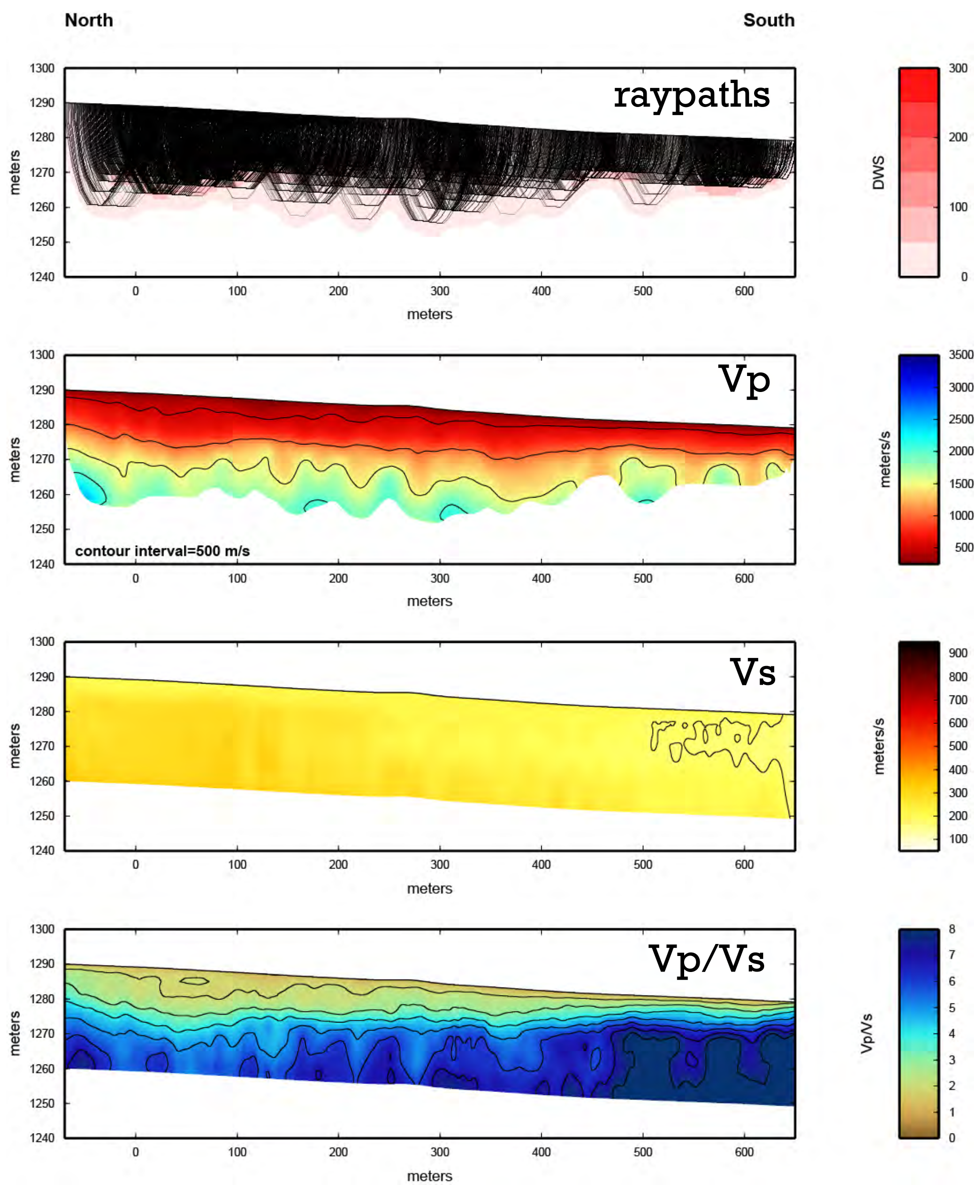
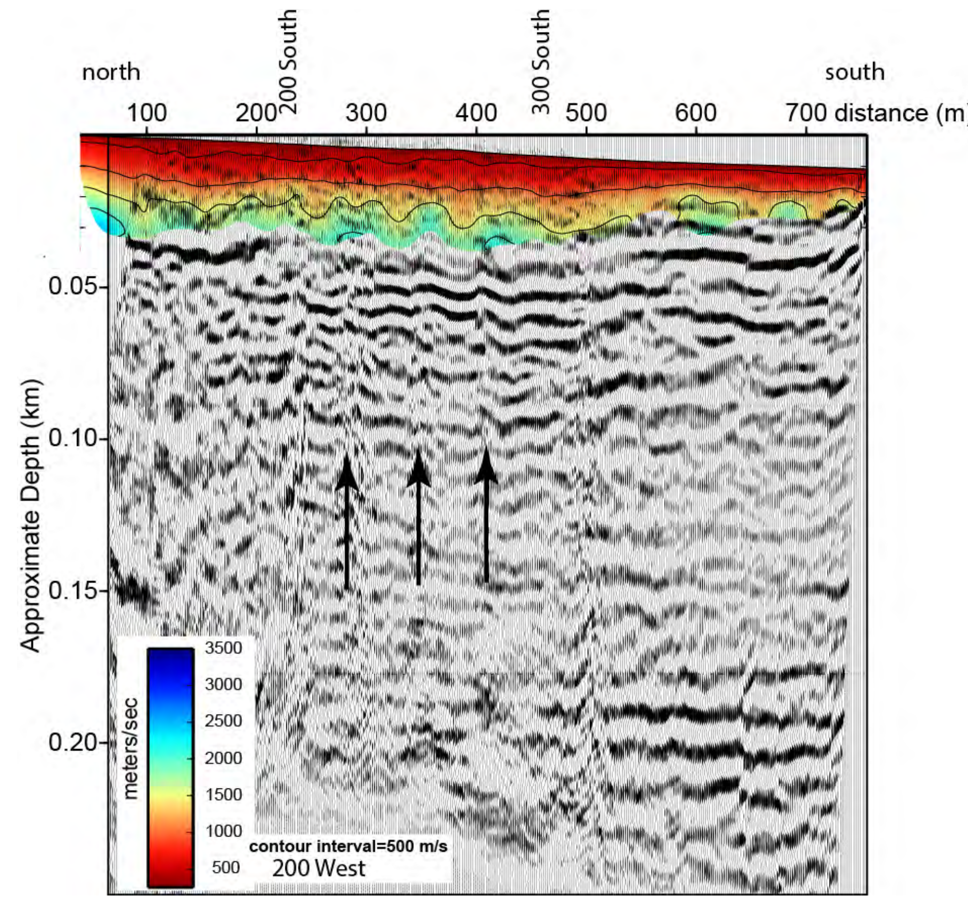
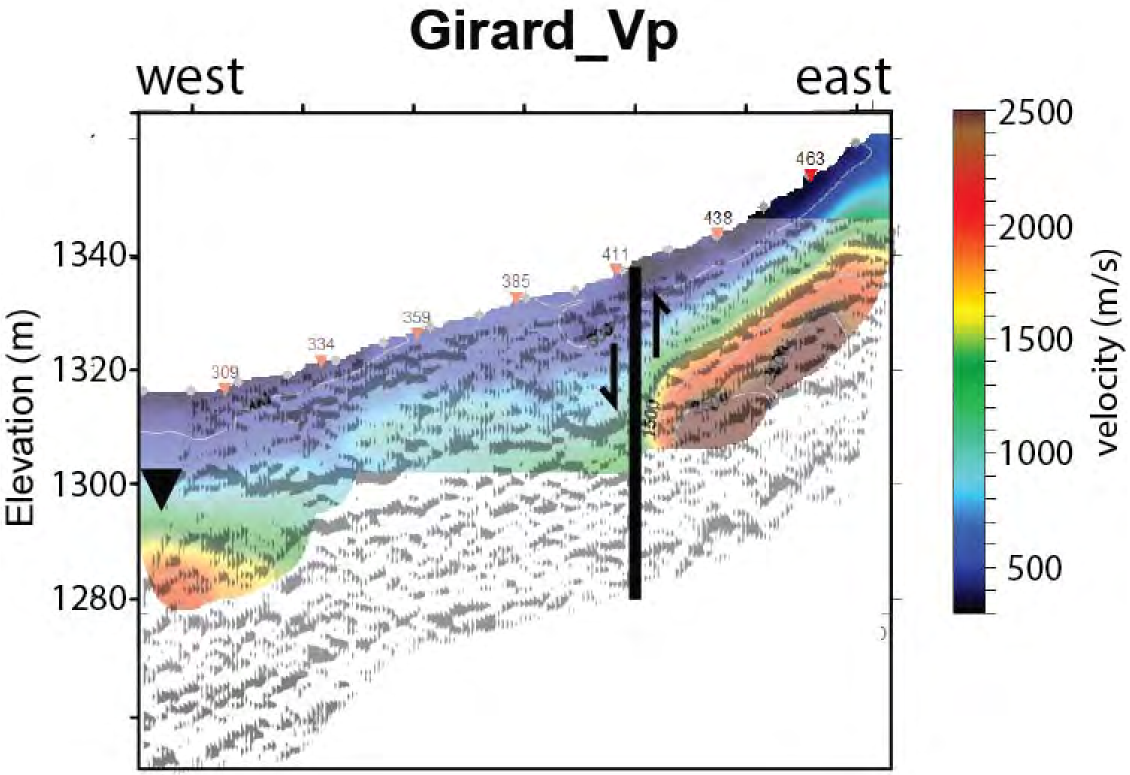


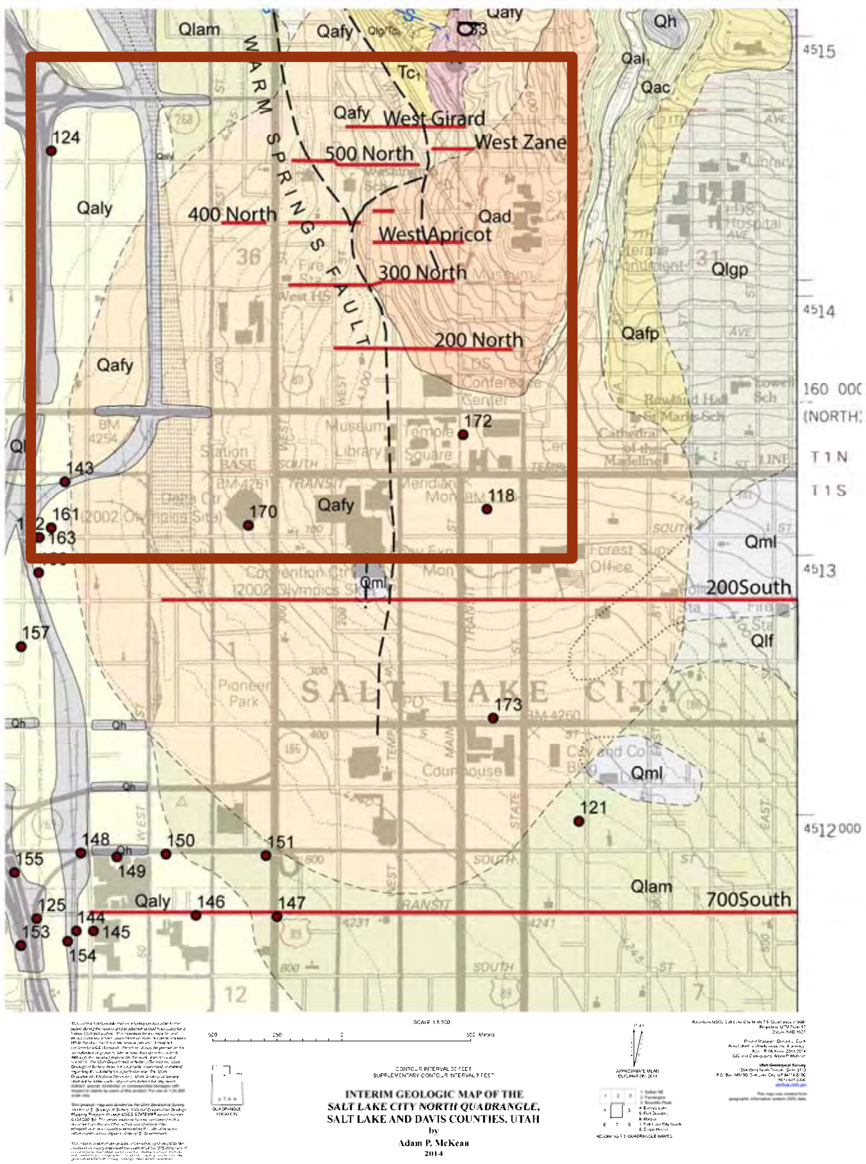
200 WEST SEISMIC REFLECTION/REFRACTION



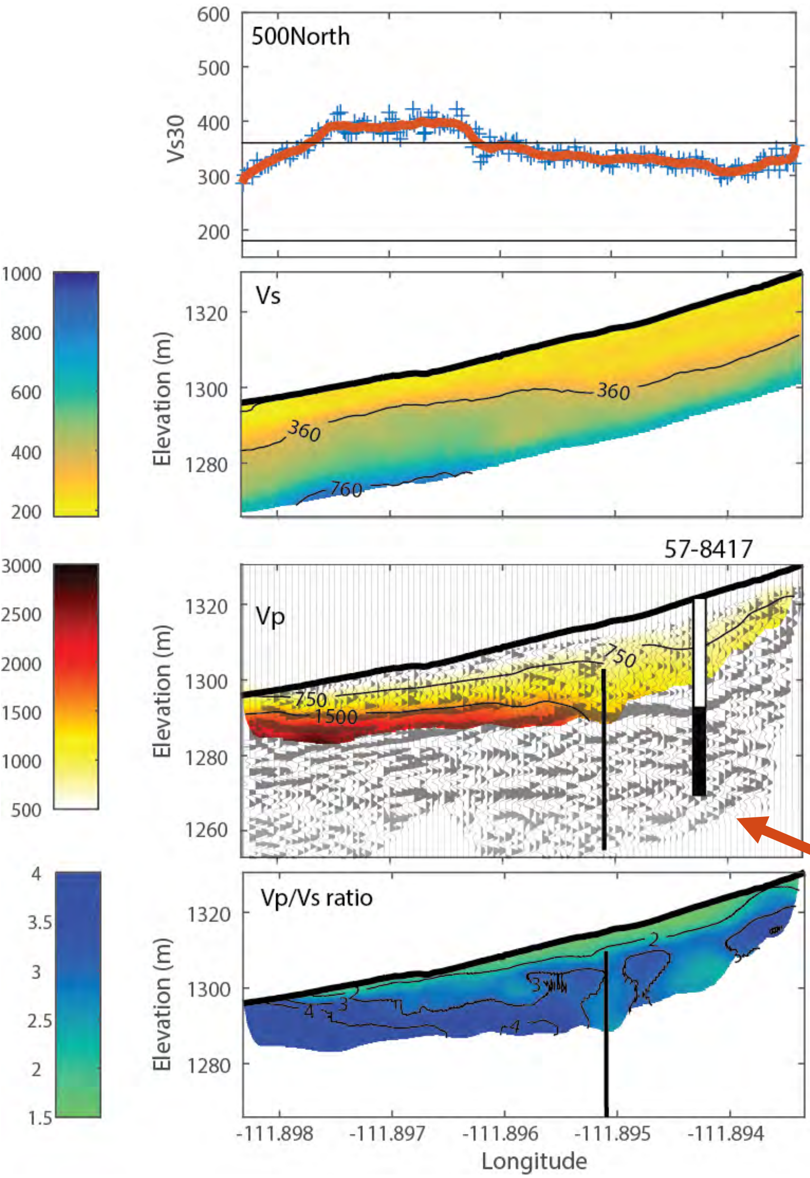


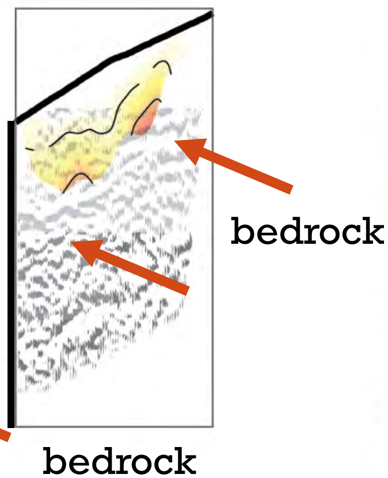
WEST GIRARD (20 M DEEP BEDROCK)

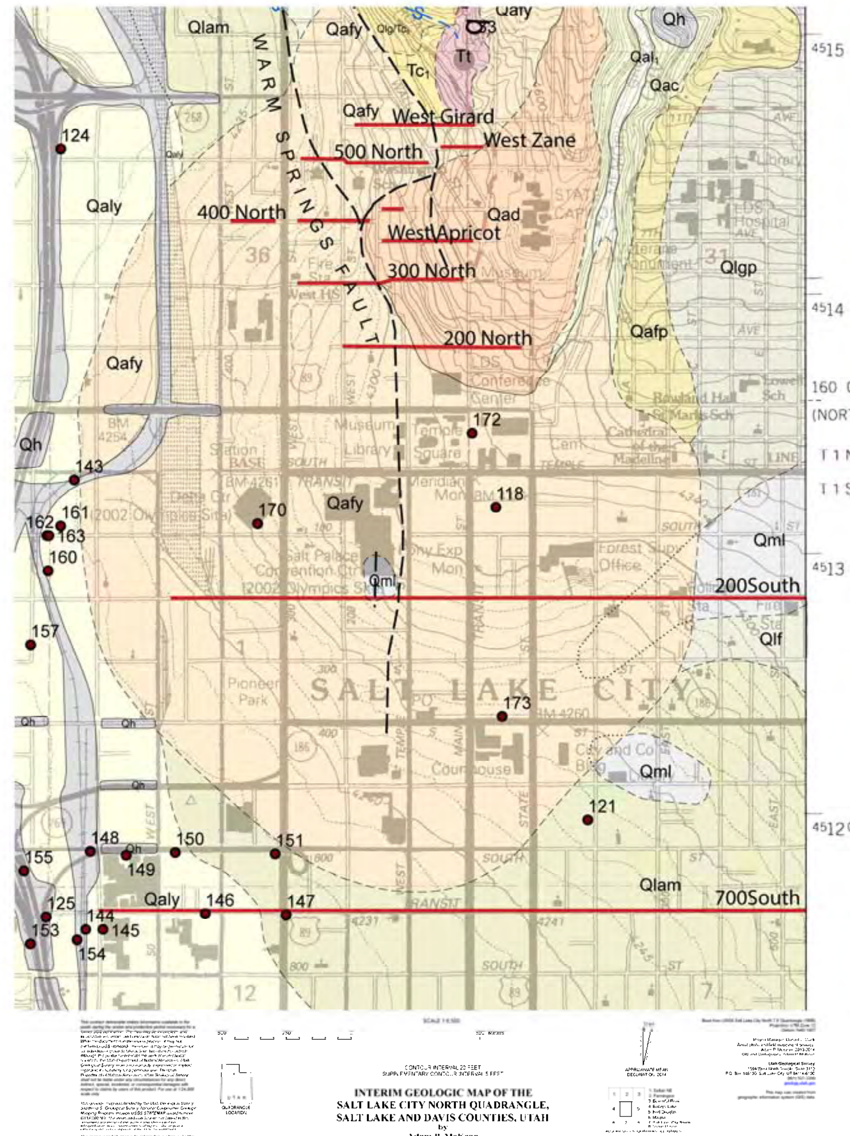




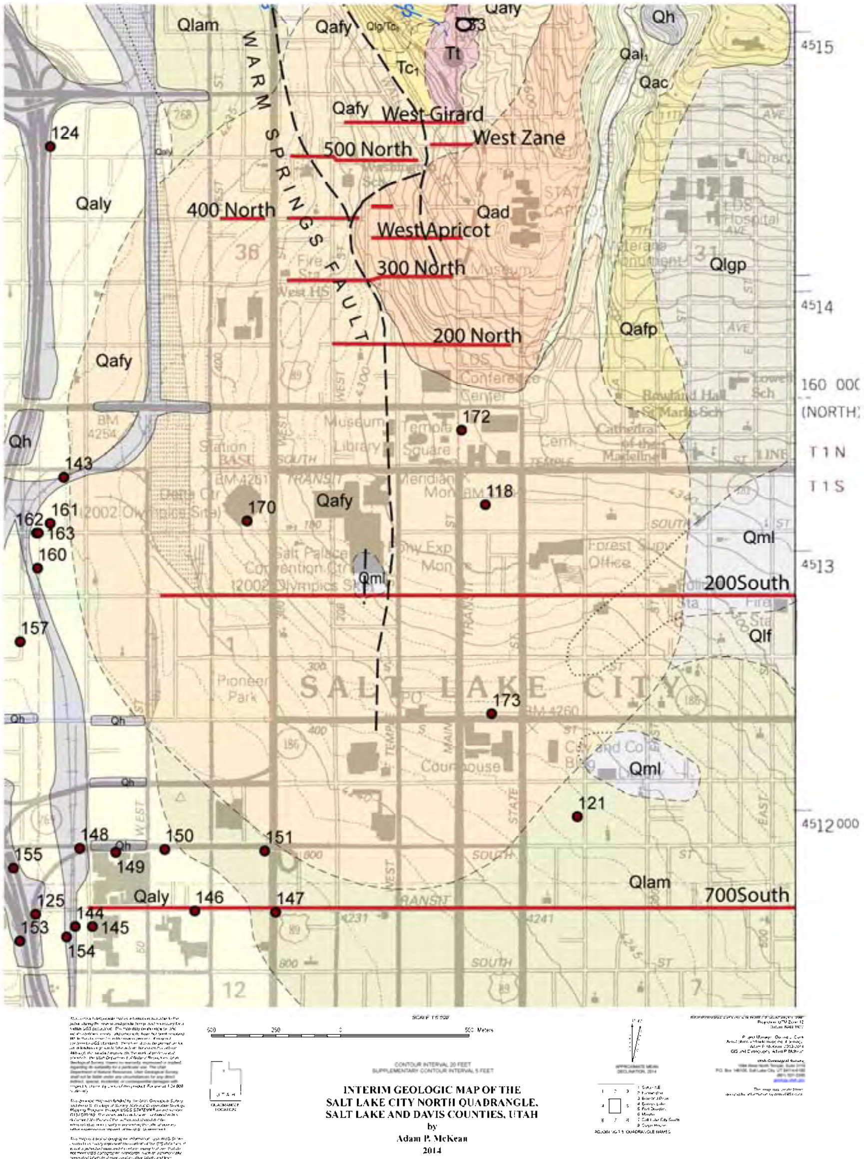
500 NORTH ZANE PROFILES

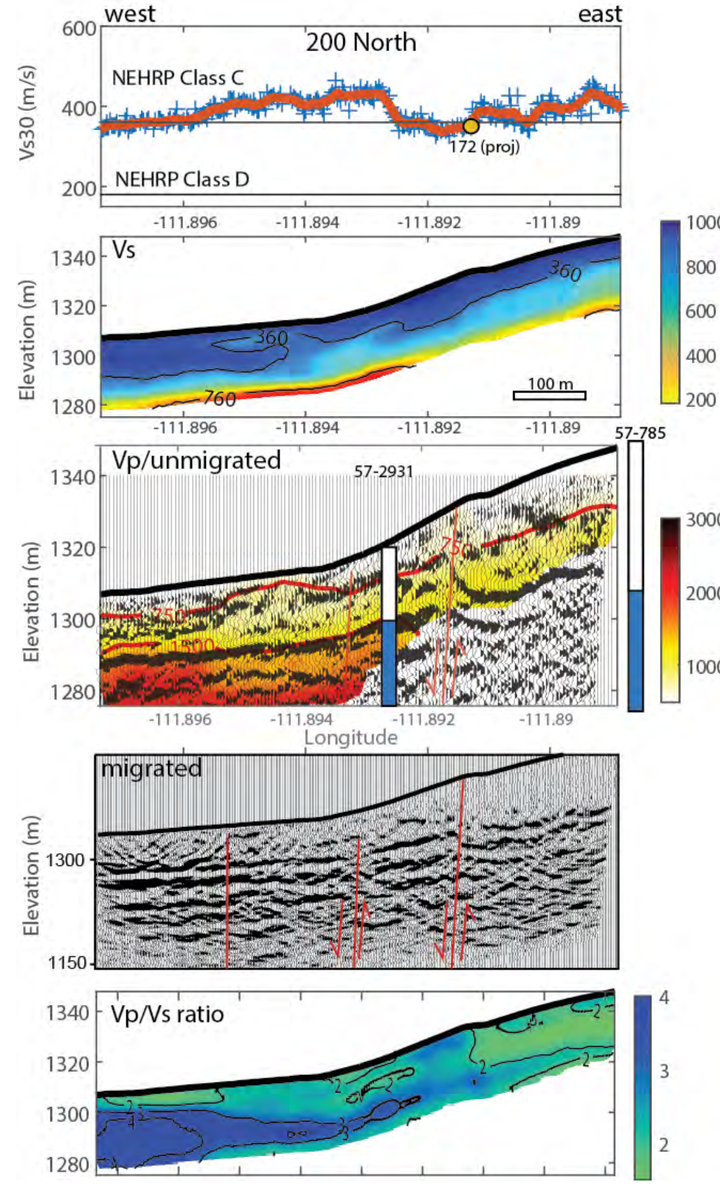




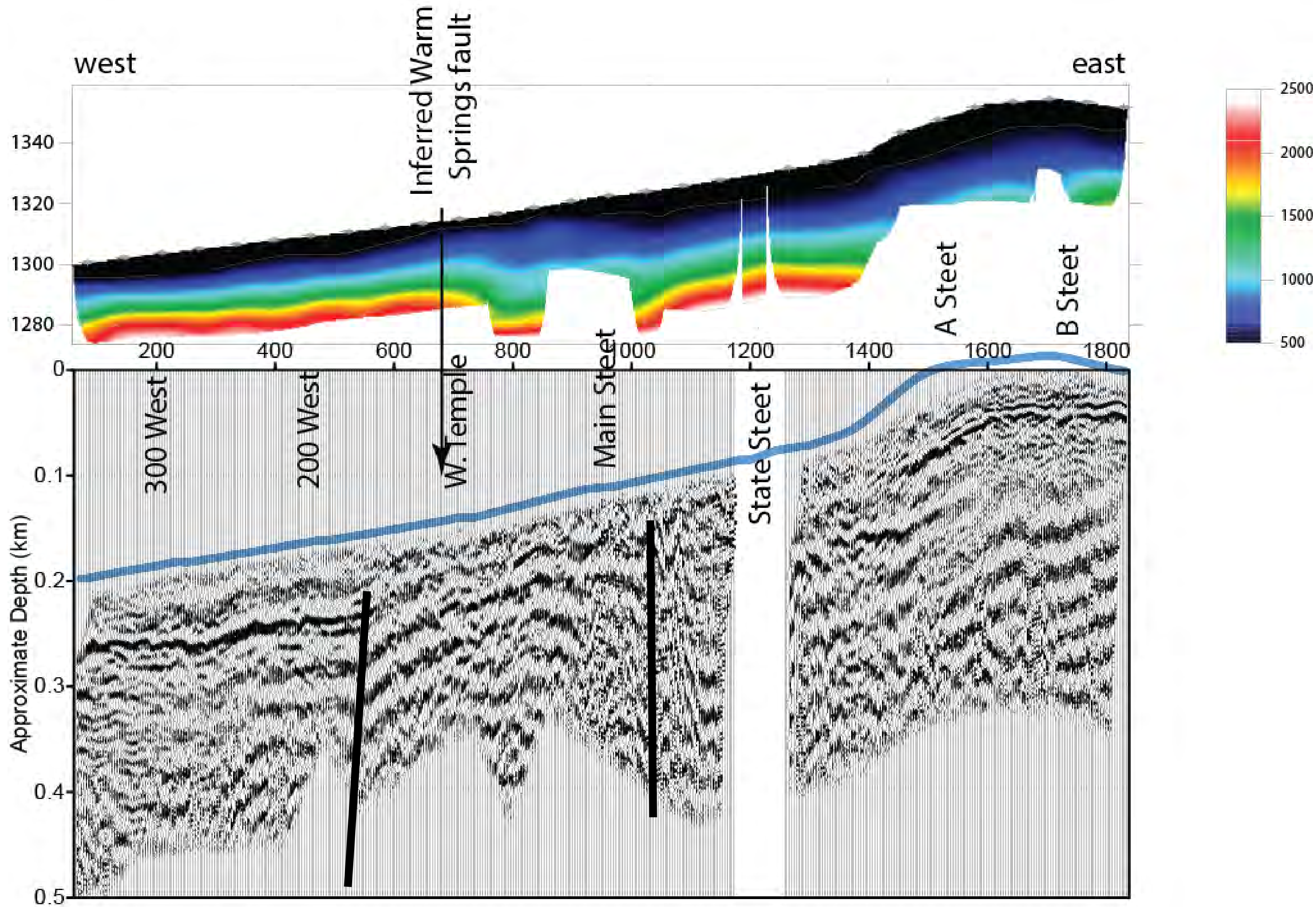


200 NORTH PROFILE





NORTH TEMPLE

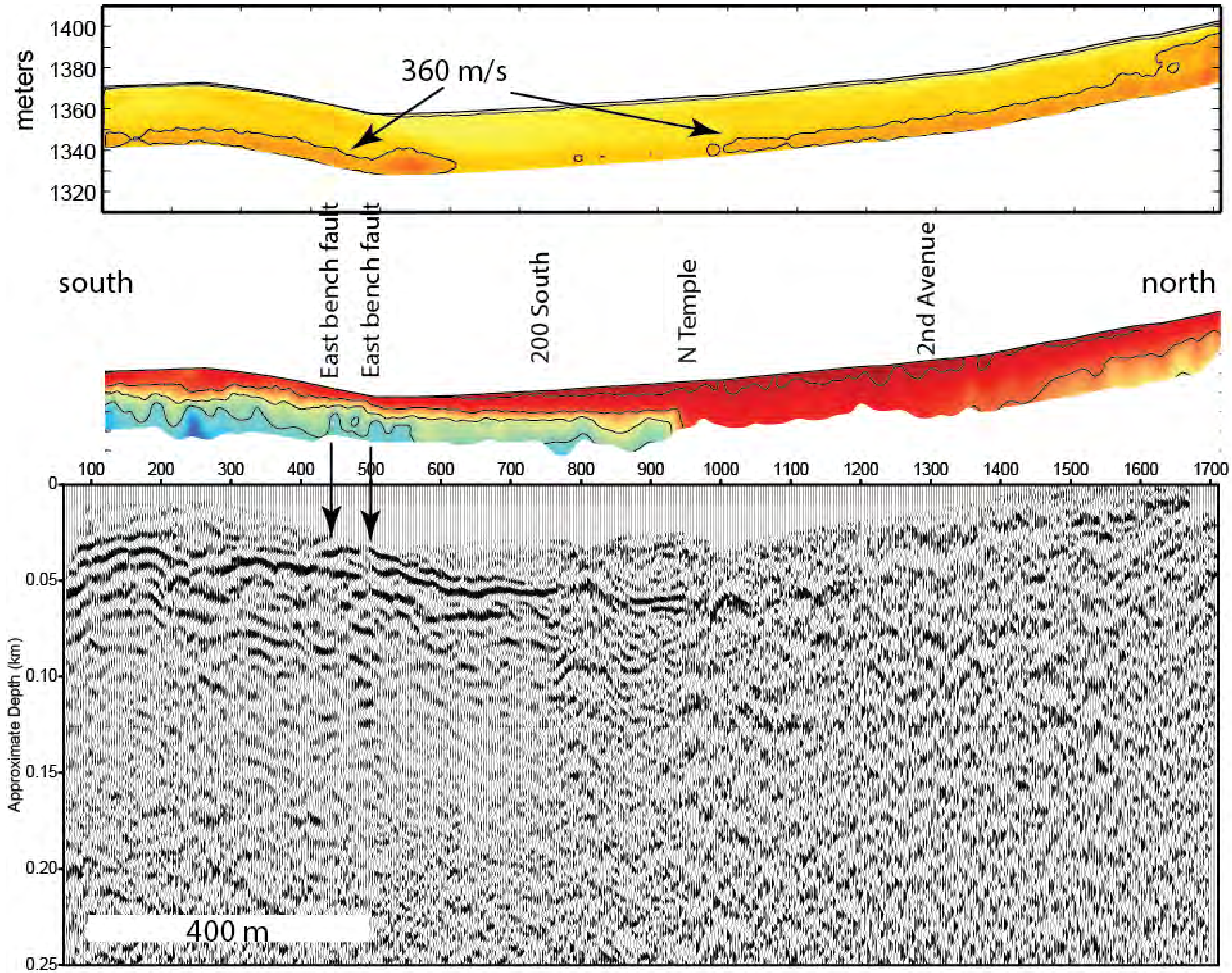


Step in water table beneath West Temple

Fault beneath Main Street

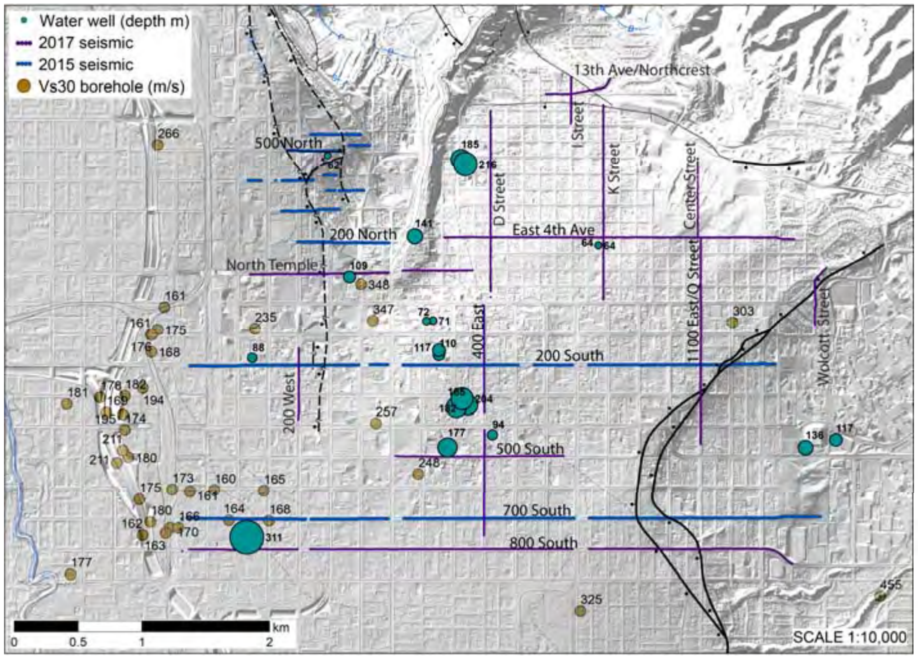
1100 EAST

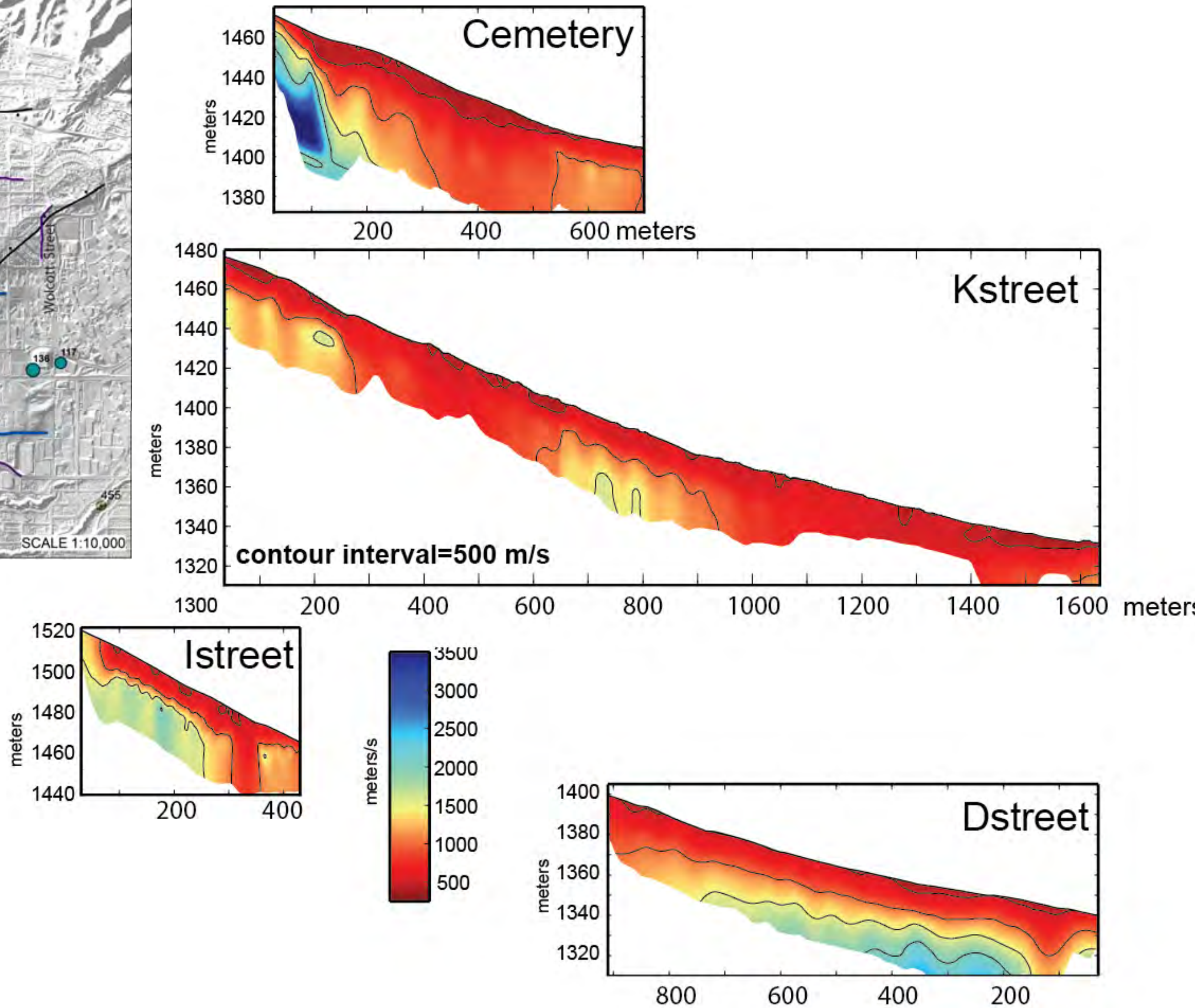
Vp



Seismic character changes beneath North Temple (fault?)

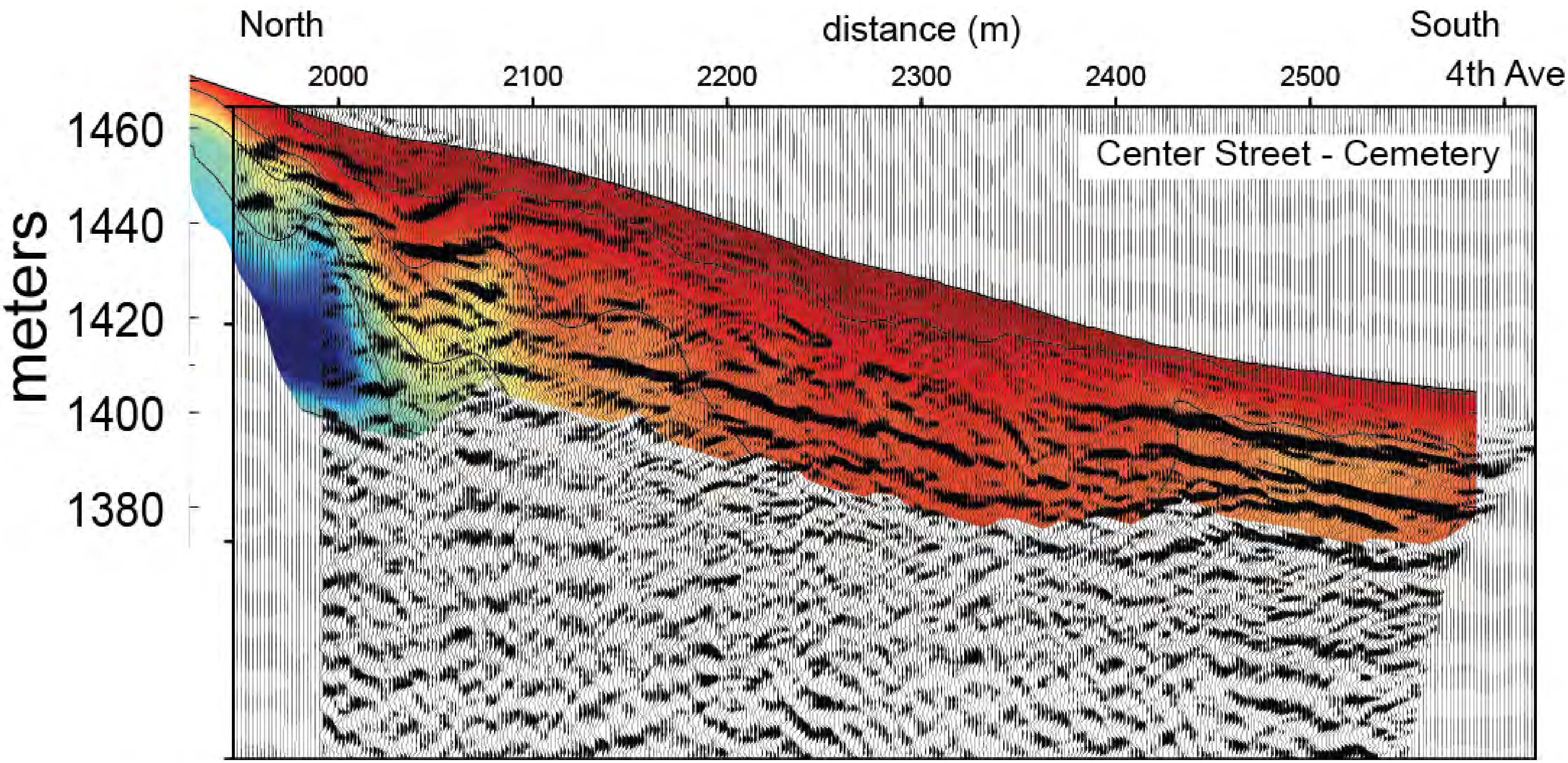
Shallow water table to the south
Deeper water table to the north



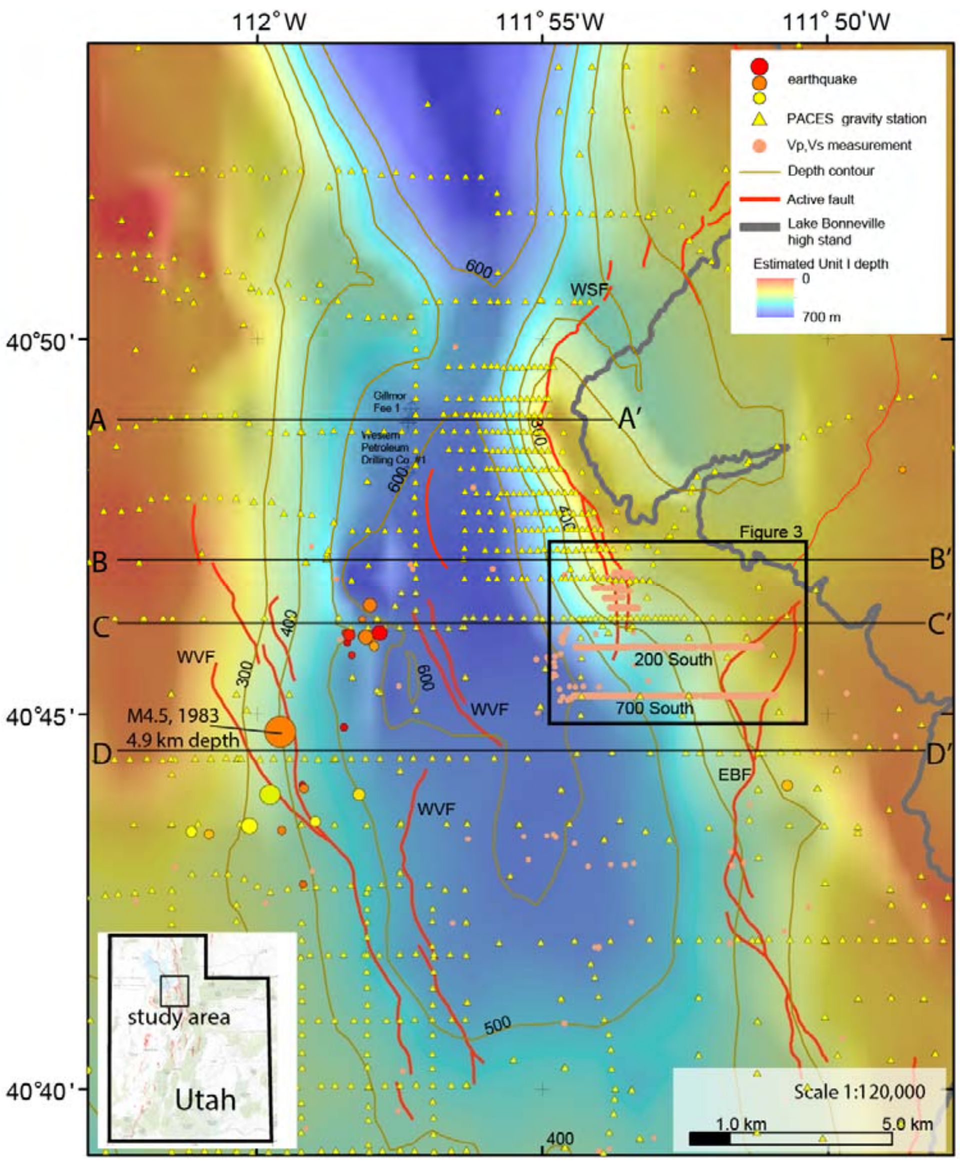


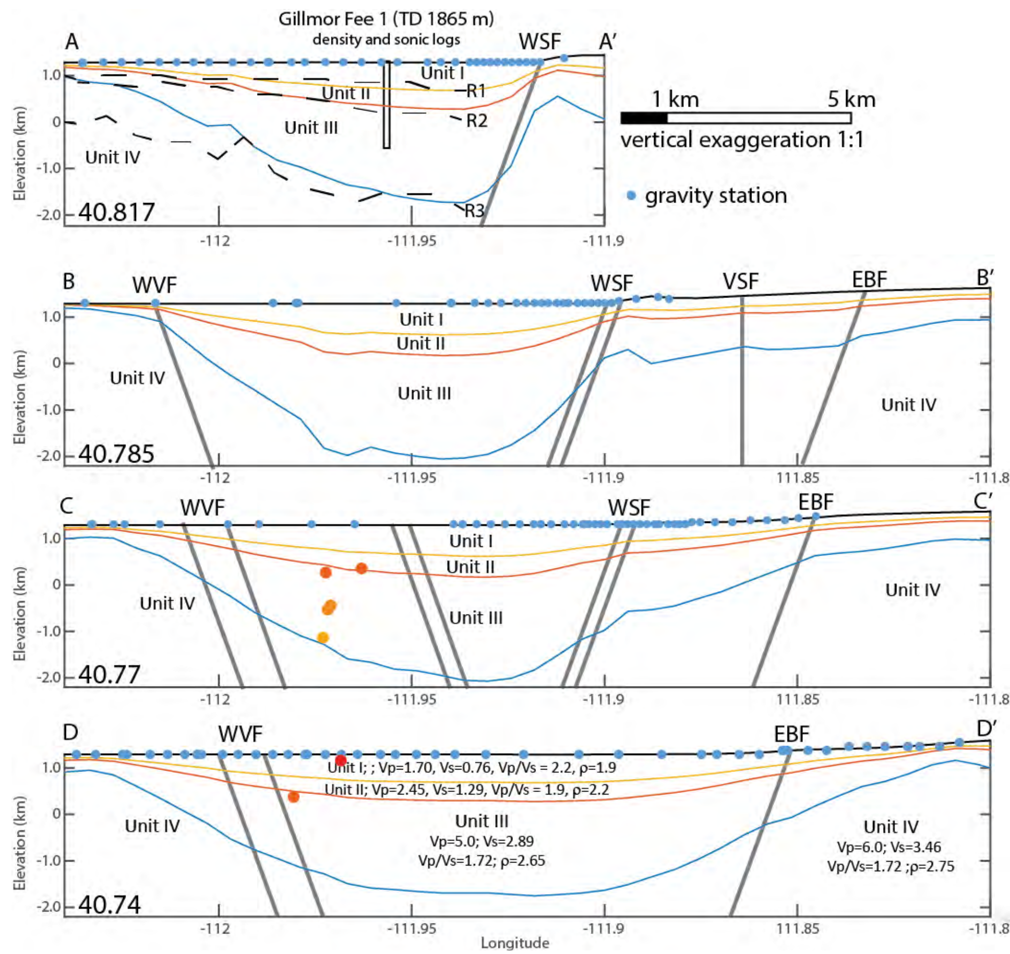
SEISMIC REFRACTION THE AVENUES

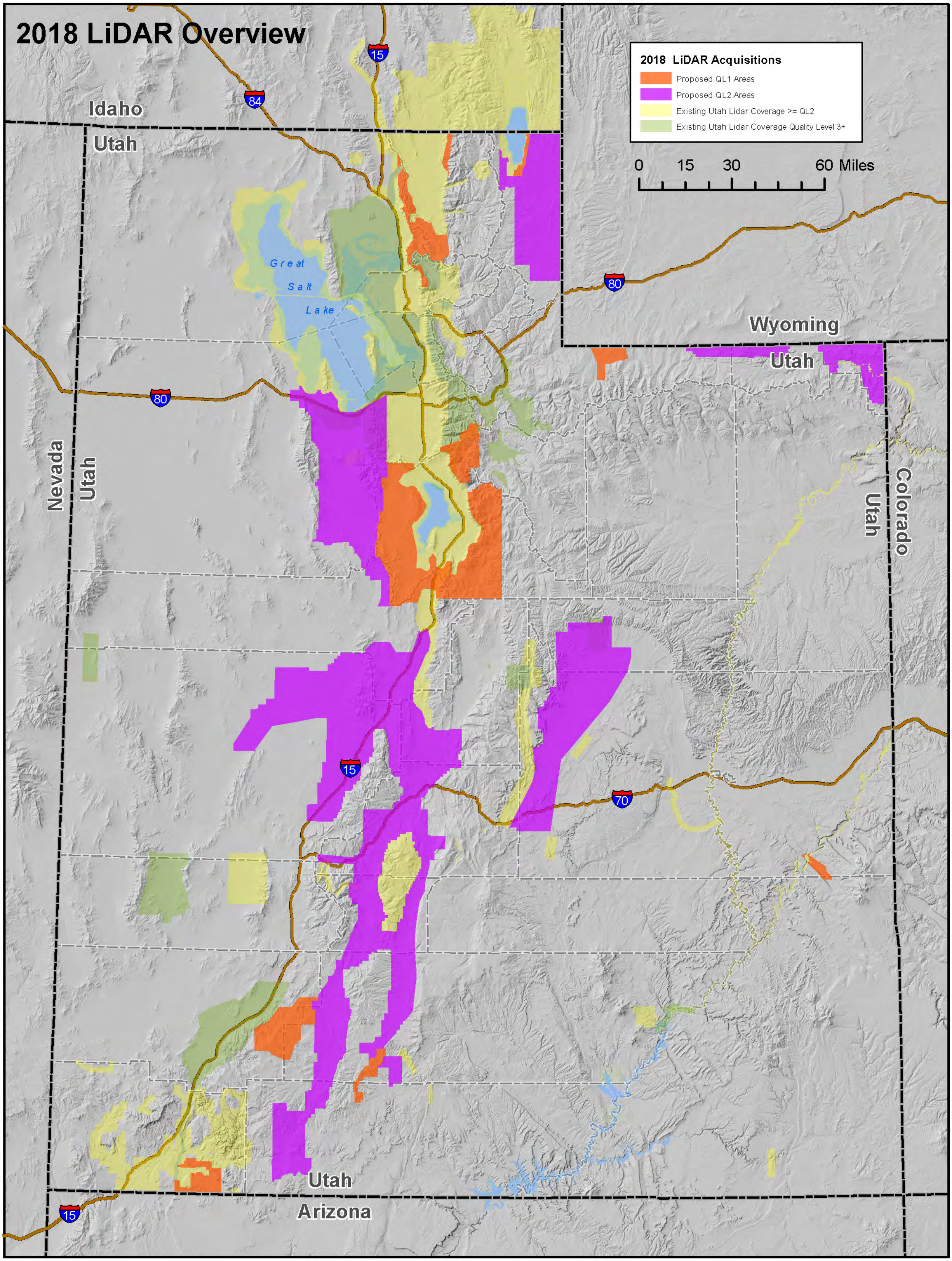
CEMETERY PROFILE

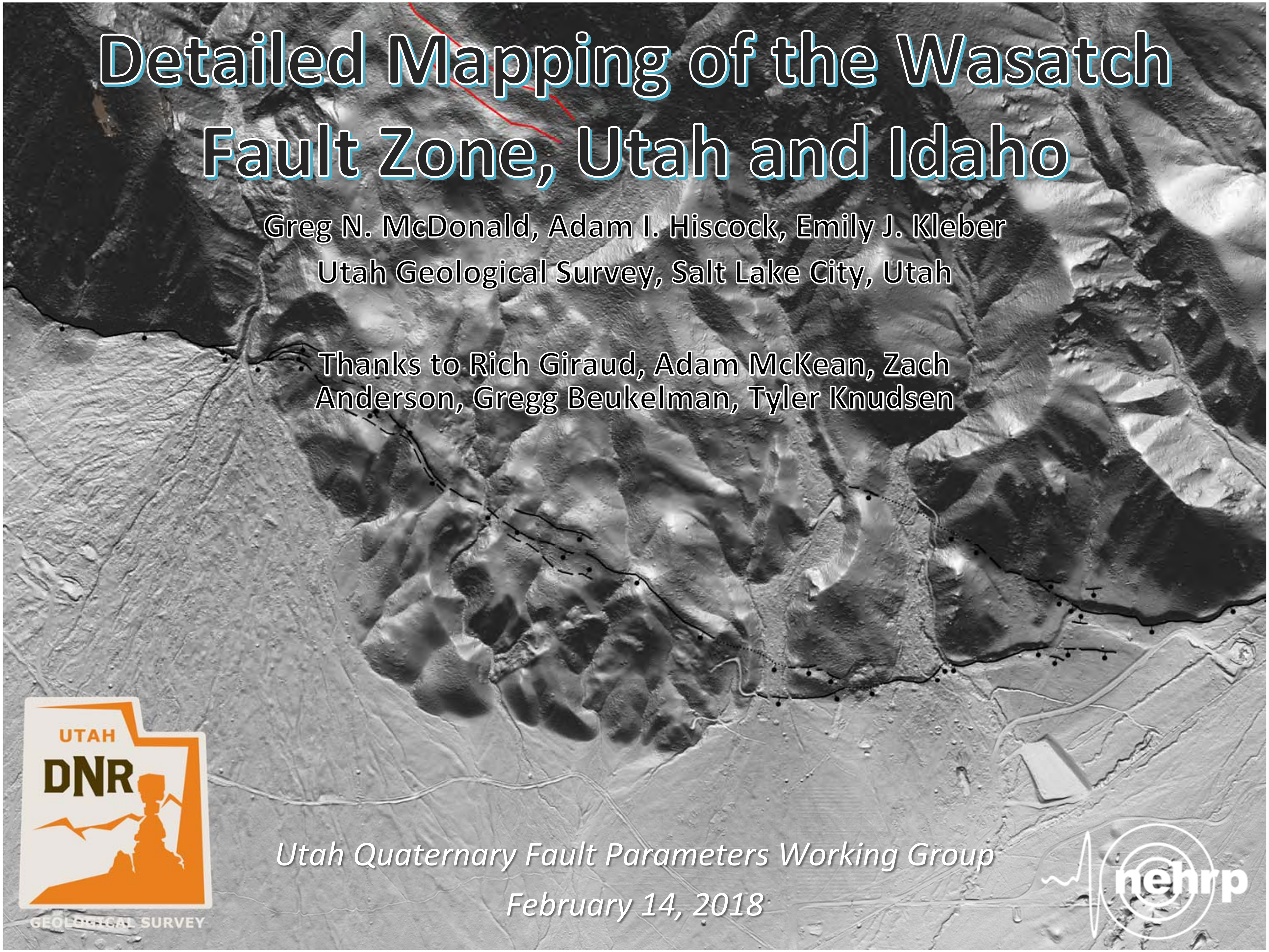


GRAVITY MODELS FOR WASATCH FRONT






2018 LiDAR Overview
2018 LiDAR Acquisitions
Proposed QL1 Areas
Proposed QL2 Areas
Existing Utah Lidar Coverage >= QL2
Existing Utah Lidar Coverage Quality Level 3+
0 15 30 60 Miles
Idaho
Utah
Wyoming
Utah
Nevada
Utah
Colorado
Utah
Utah
Arizona
Great Salt Lake
15
84
80
80
15
70
15



Detailed Mapping of the Wasatch Fault Zone, Utah and Idaho

Greg N. McDonald, Adam I. Hiscock, Emily J. Kleber

Utah Geological Survey, Salt Lake City, Utah

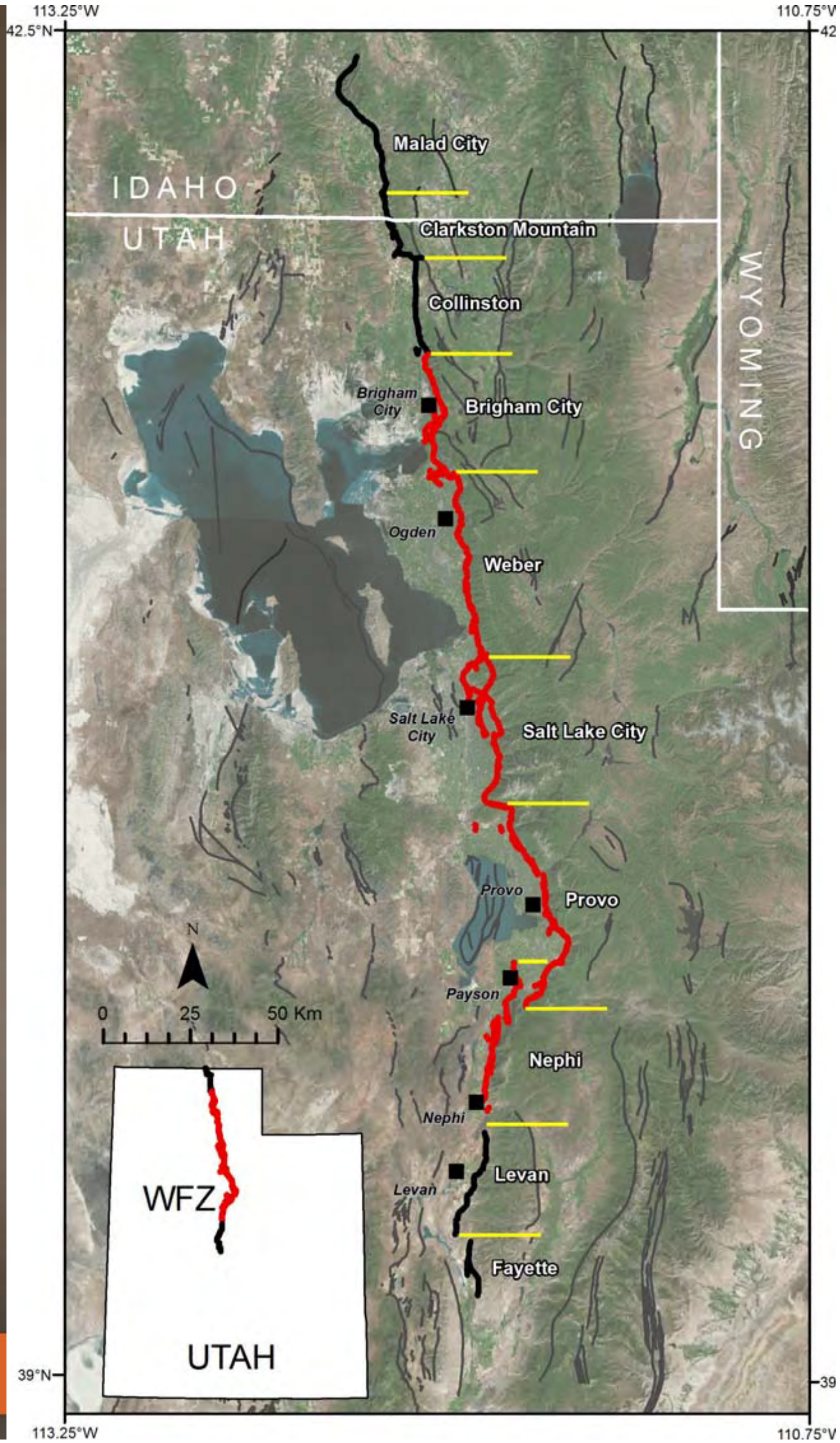
Thanks to Rich Giraud, Adam McKean, Zach Anderson, Gregg Beukelman, Tyler Knudsen

Utah Quaternary Fault Parameters Working Group

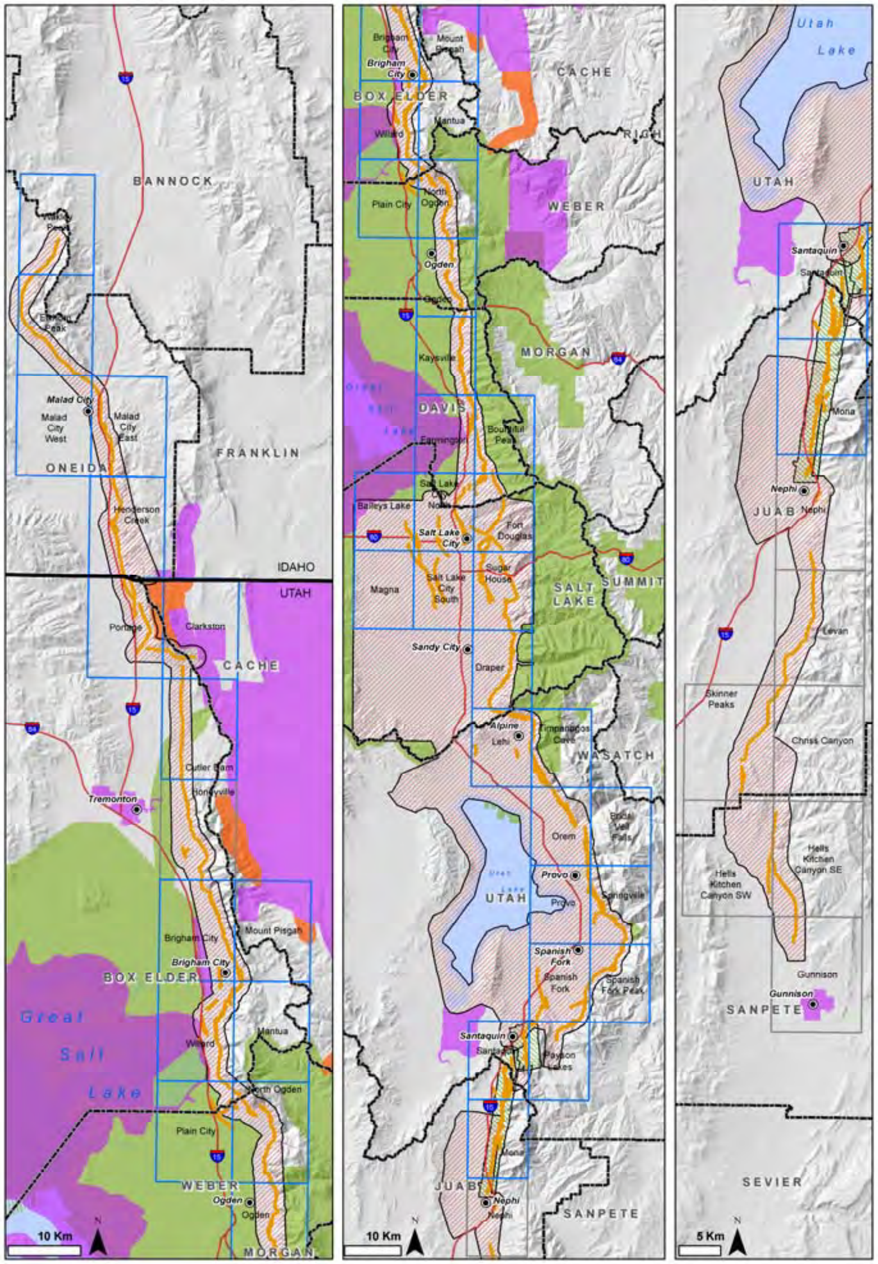
February 14, 2018

- NEHRP-funded
- Detailed mapping using high-resolution lidar
  - supplemented with aerial photos and some field reconnaissance
  - Previous mapping
- Levan and Fayette segments (south end) mapped in 2014-15 by Hiscock and Hylland
- This project
  - Remaining 8 segments
  - 35 7.5-minute quadrangles in Utah; additional 5 quads in Idaho
  - Delineate surface-fault-rupture hazard special study areas
  - Identify potential paleoseismic investigation sites
- Mapping will be incorporated into the UGS *Utah Quaternary Fault and Fold Database*

UTAH GEOLOGICAL SURVEY

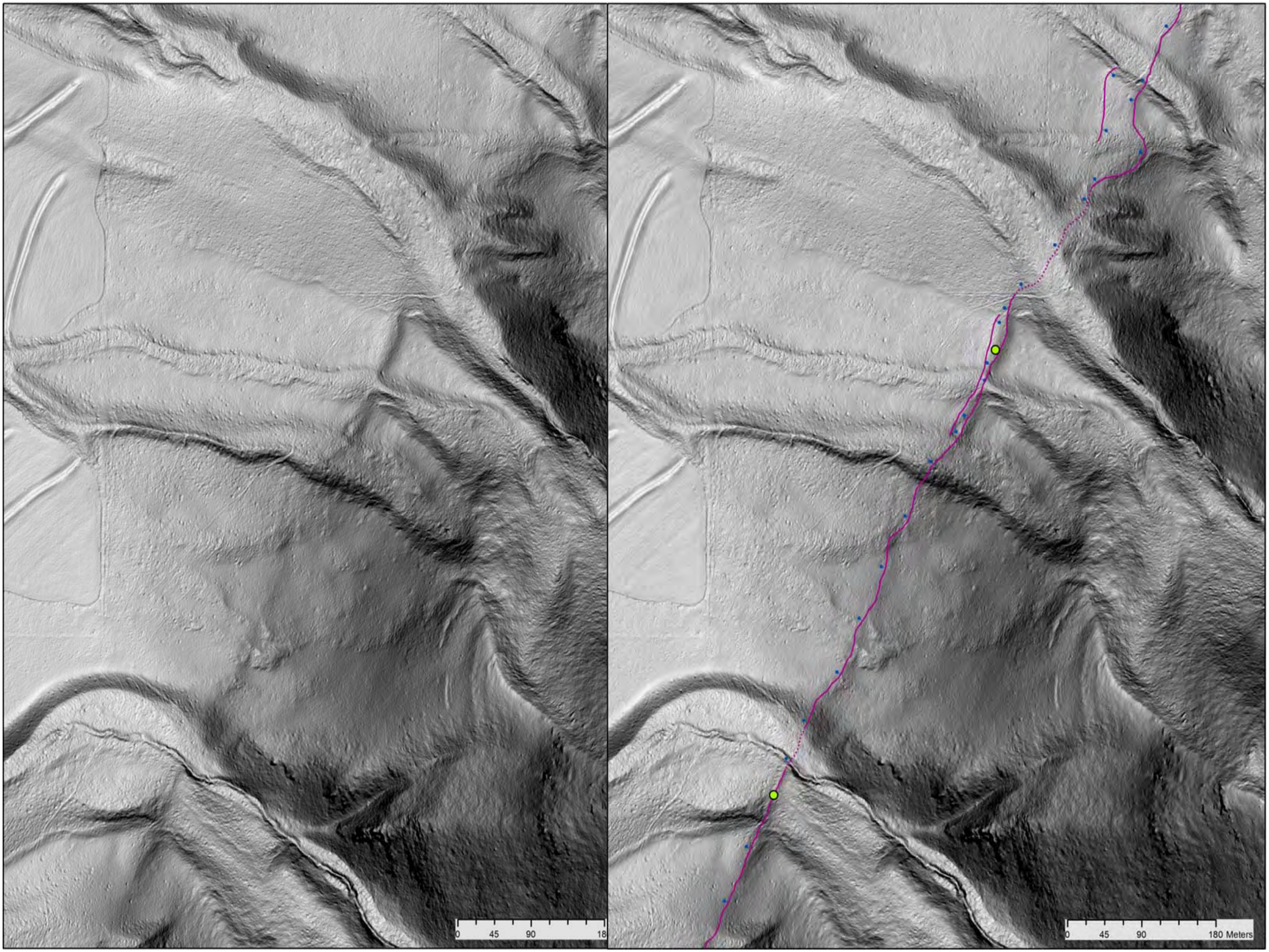


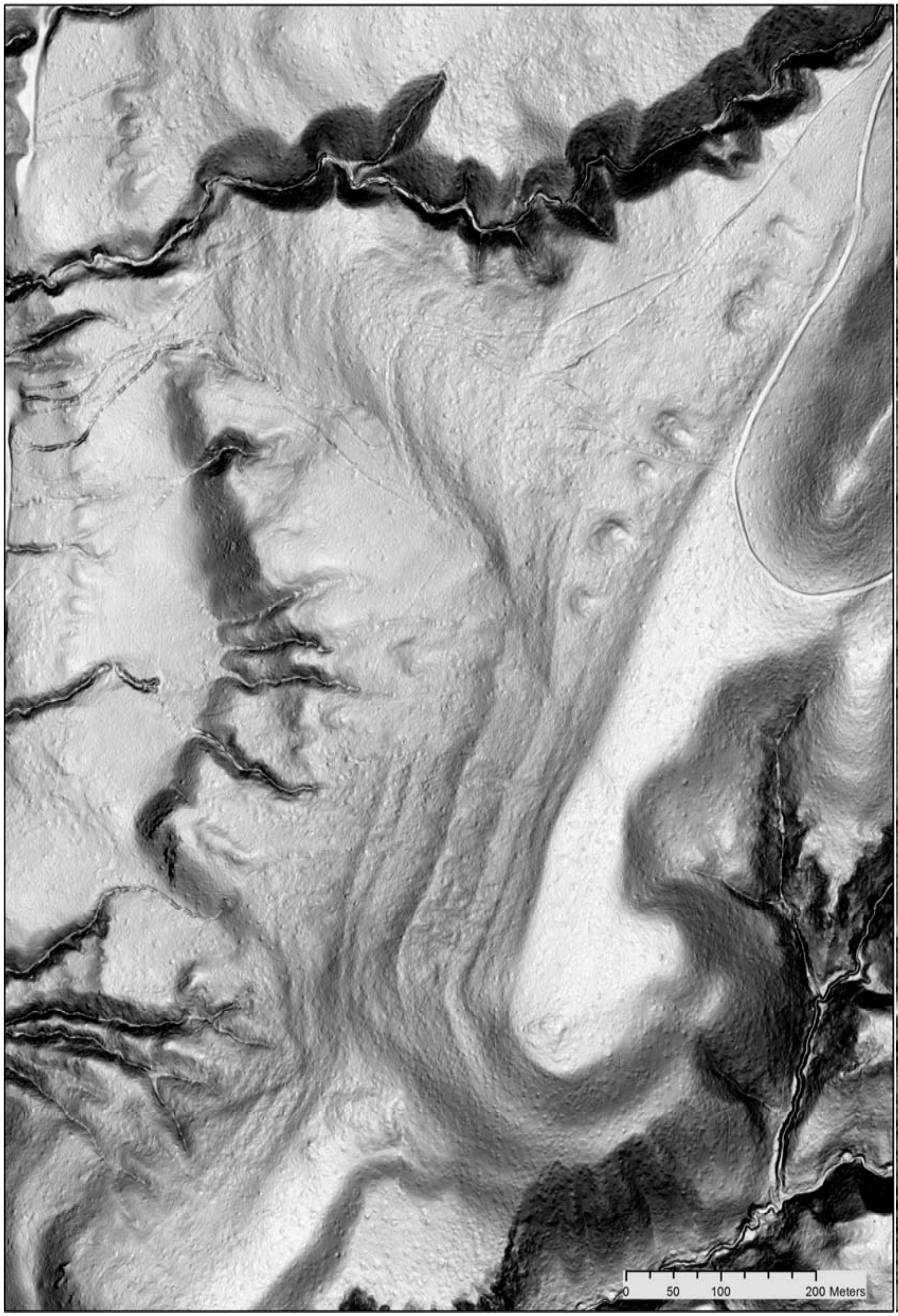
High Resolution LiDAR Wasatch Fault Zone

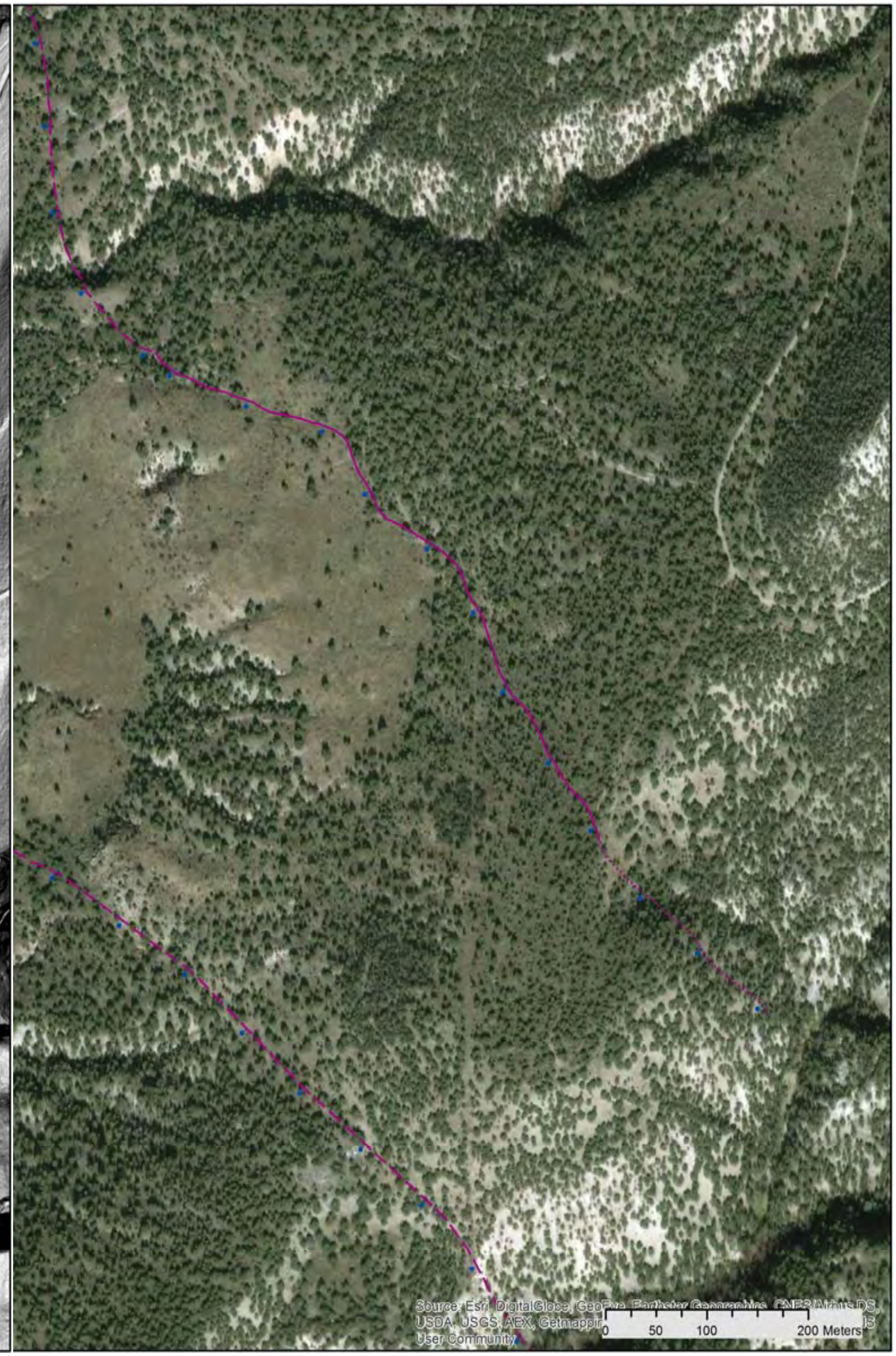


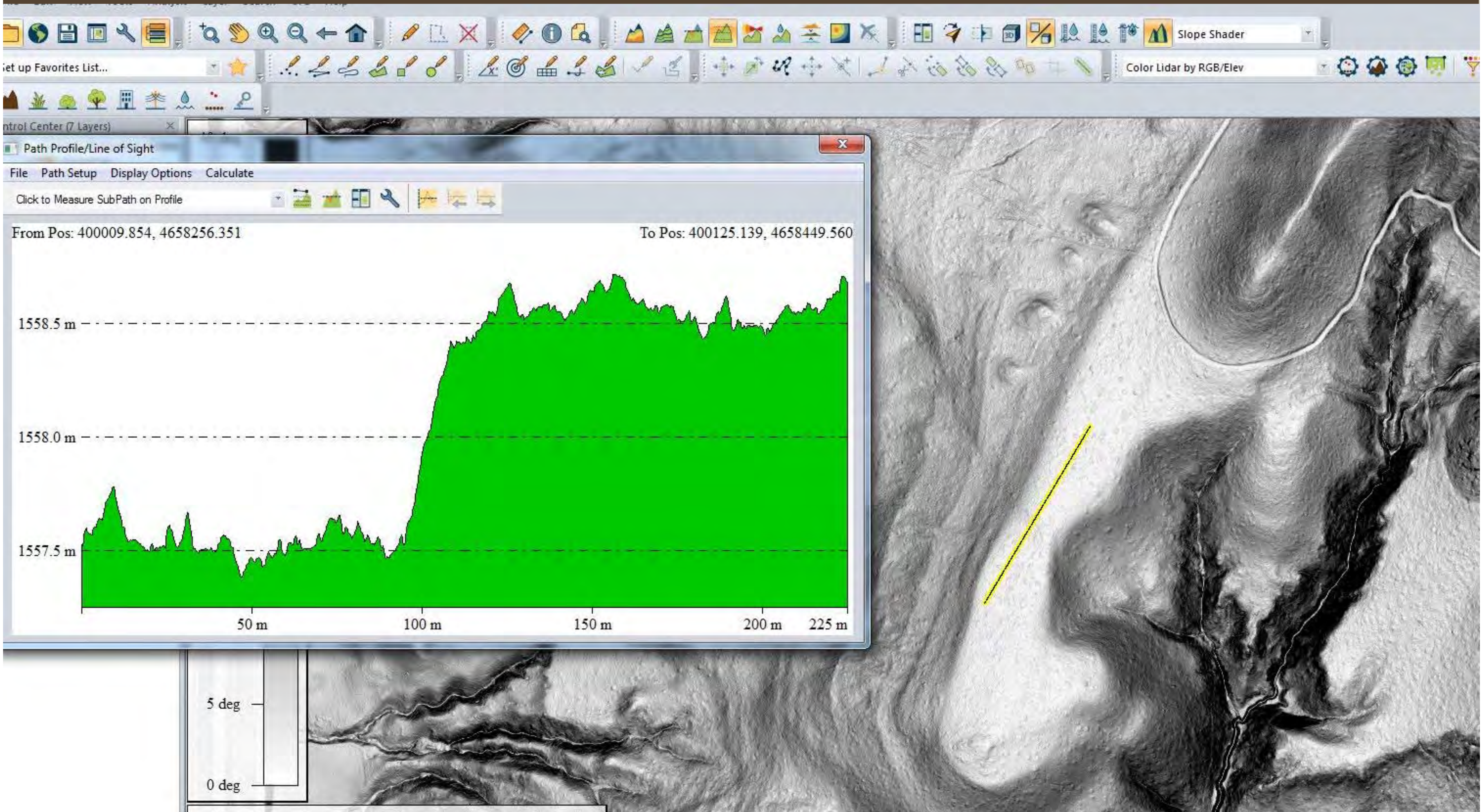
Mapping Datasets

- 2013/2014 UGS WFZ 0.5-meter LIDAR data
  - Entire WFZ: Fayette, UT north to Malad City, ID
  - High-Resolution - great for subtle features/scarps
  - Available through Utah AGRC & NSF OpenTopography
- 2008 EarthScope Intermountain Seismic Belt LIDAR – Nephi Segment area
- Historical Aerial Photography -1970 Woodward-Lundgren & Associates low-sun angle aerial photography, 1930s-60s
- Existing geologic mapping
- Field Reconnaissance

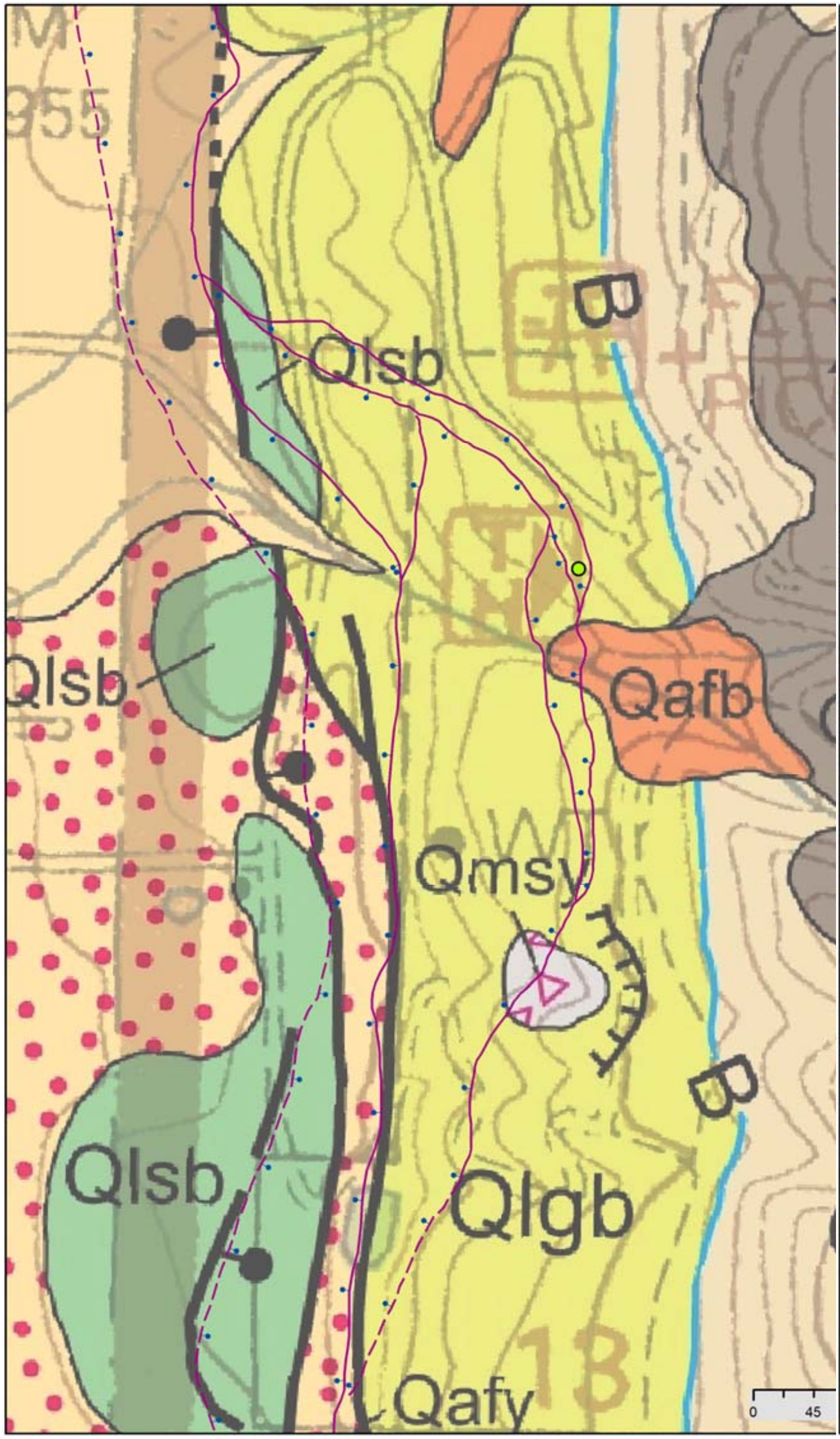
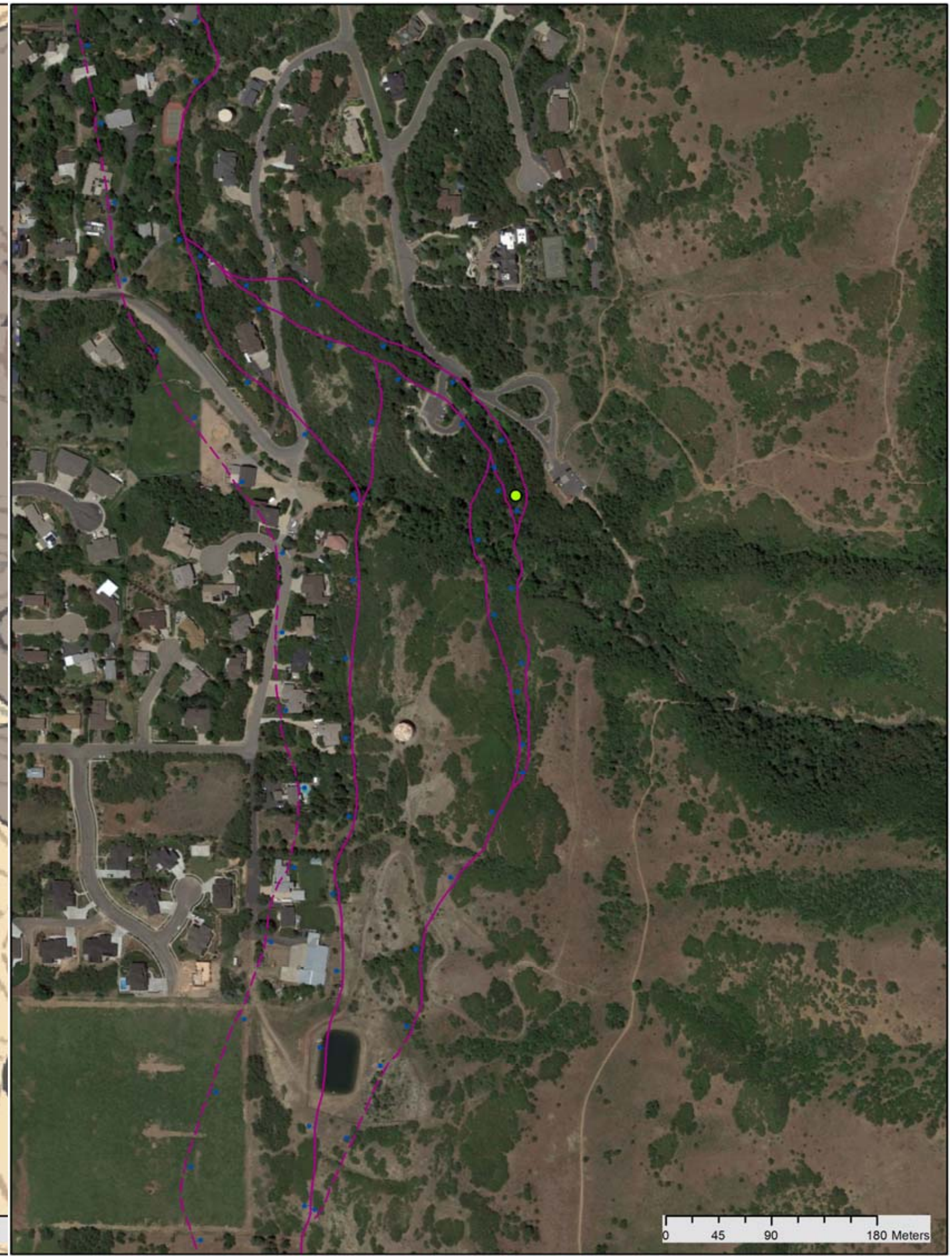

0 45 90 18
0 45 90 180 Meters

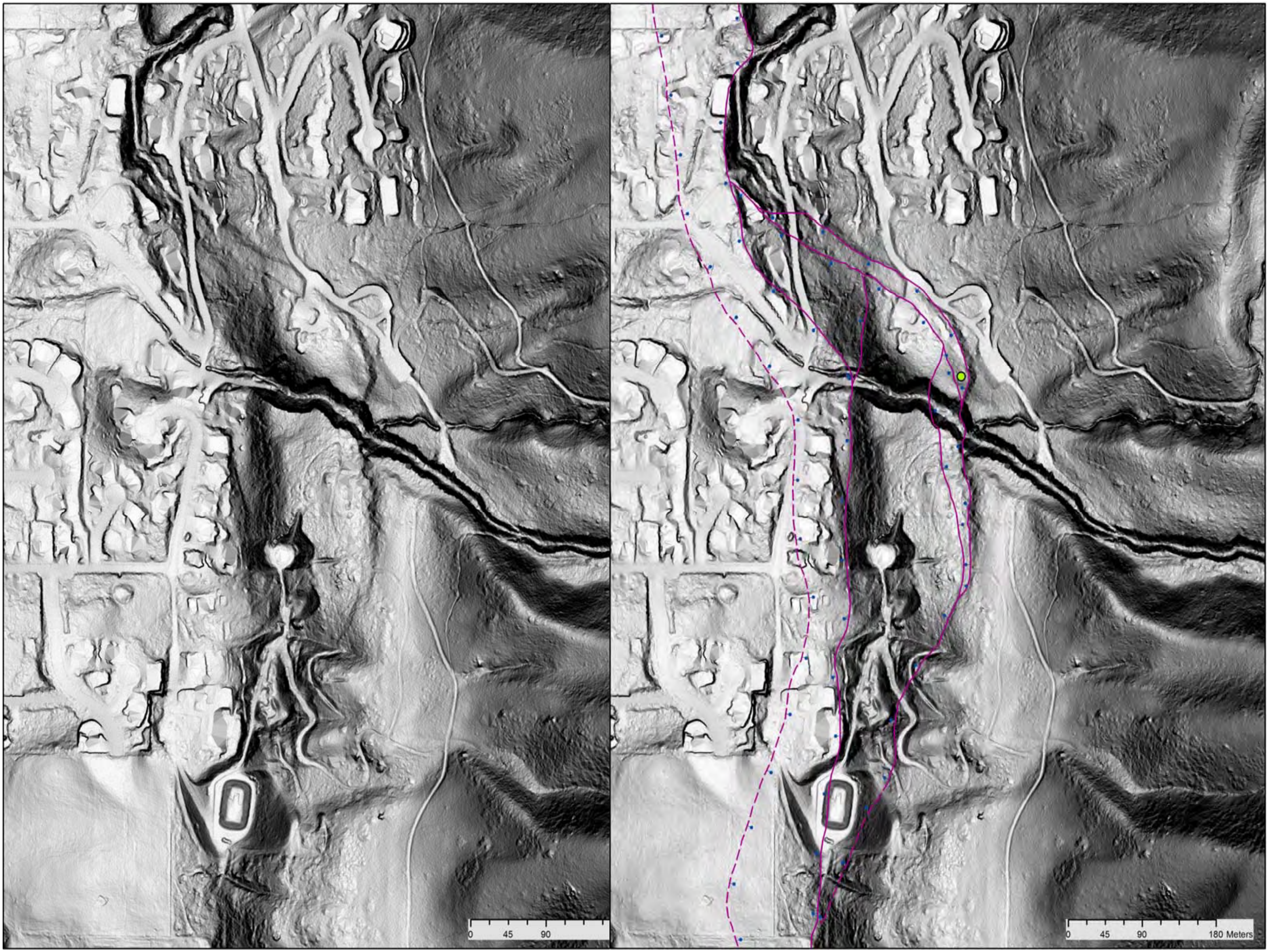

0 50 100 200 Meters


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmappin
User Community
0 50 100 200 Meters



Slope Shader
Set up Favorites List...
Color Lidar by RGB/Elev
Control Center (7 Layers)
Path Profile/Line of Sight
File
Path Setup
Display Options
Calculate
Click to Measure SubPath on Profile
From Pos: 400009.854, 4658256.351
To Pos: 400125.139, 4658449.560
1558.5 m
1558.0 m
1557.5 m
50 m
100 m
150 m
200 m
225 m
5 deg
0 deg

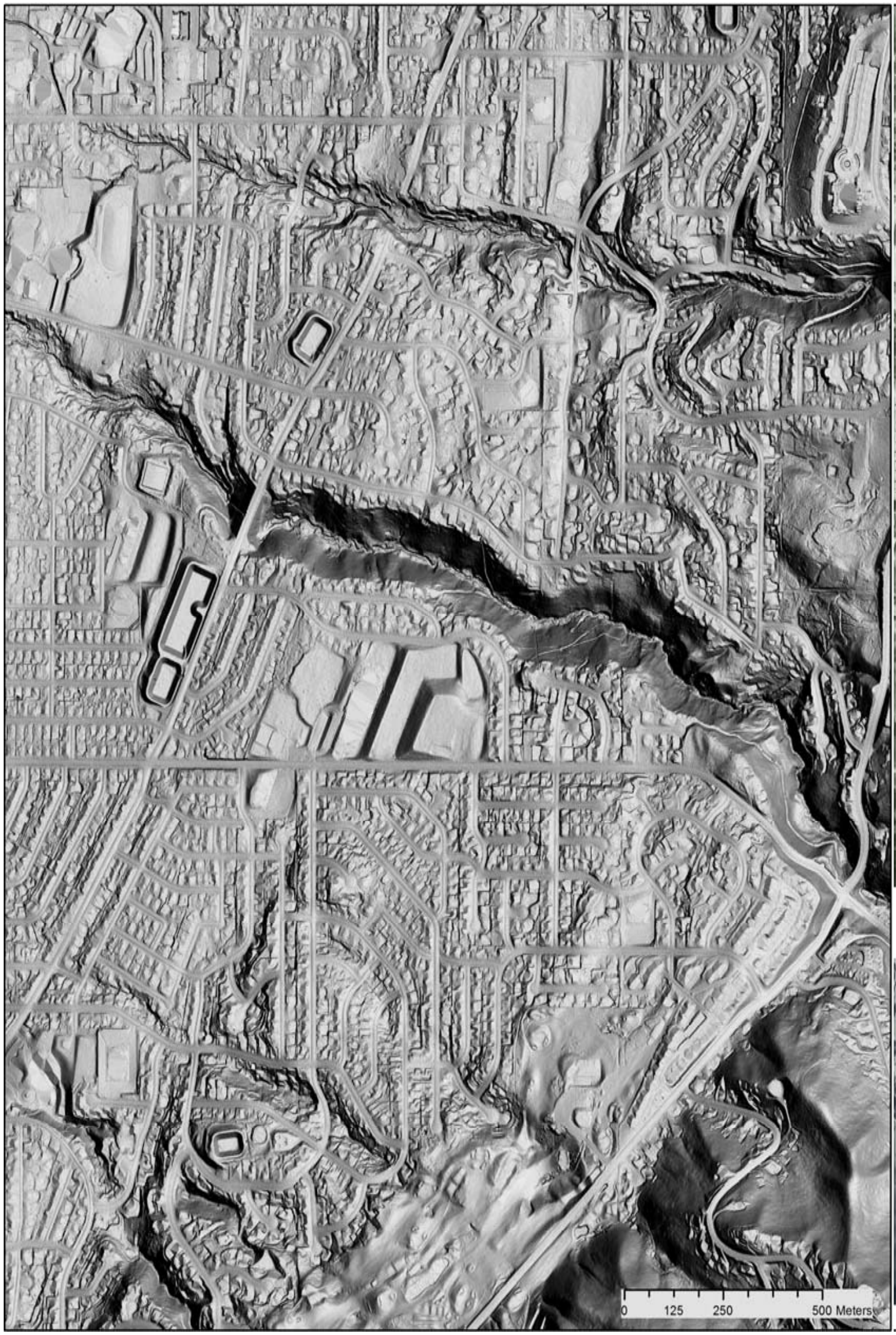

Qlsb
Qlsb
Qafb
Qmsy
Qlsb
Qlgb
Qafy
B
B
0 45

0 45 90 180 Meters



0 45 90
0 45 90 180 Meters


0 45 90 180 Meters

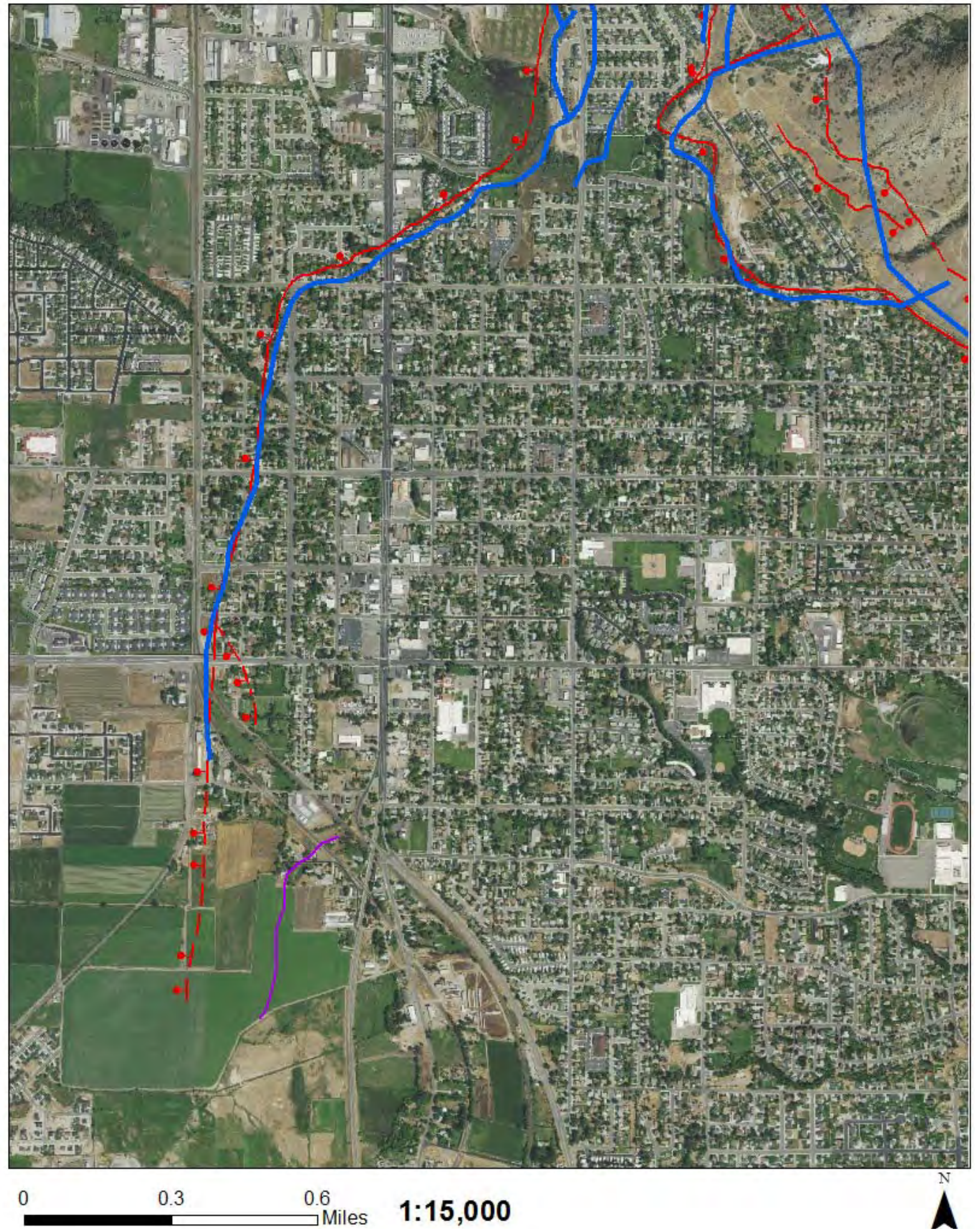
0 45 90 180 Meters


0 125 250 500 Meters


0 125 250 500 Meters

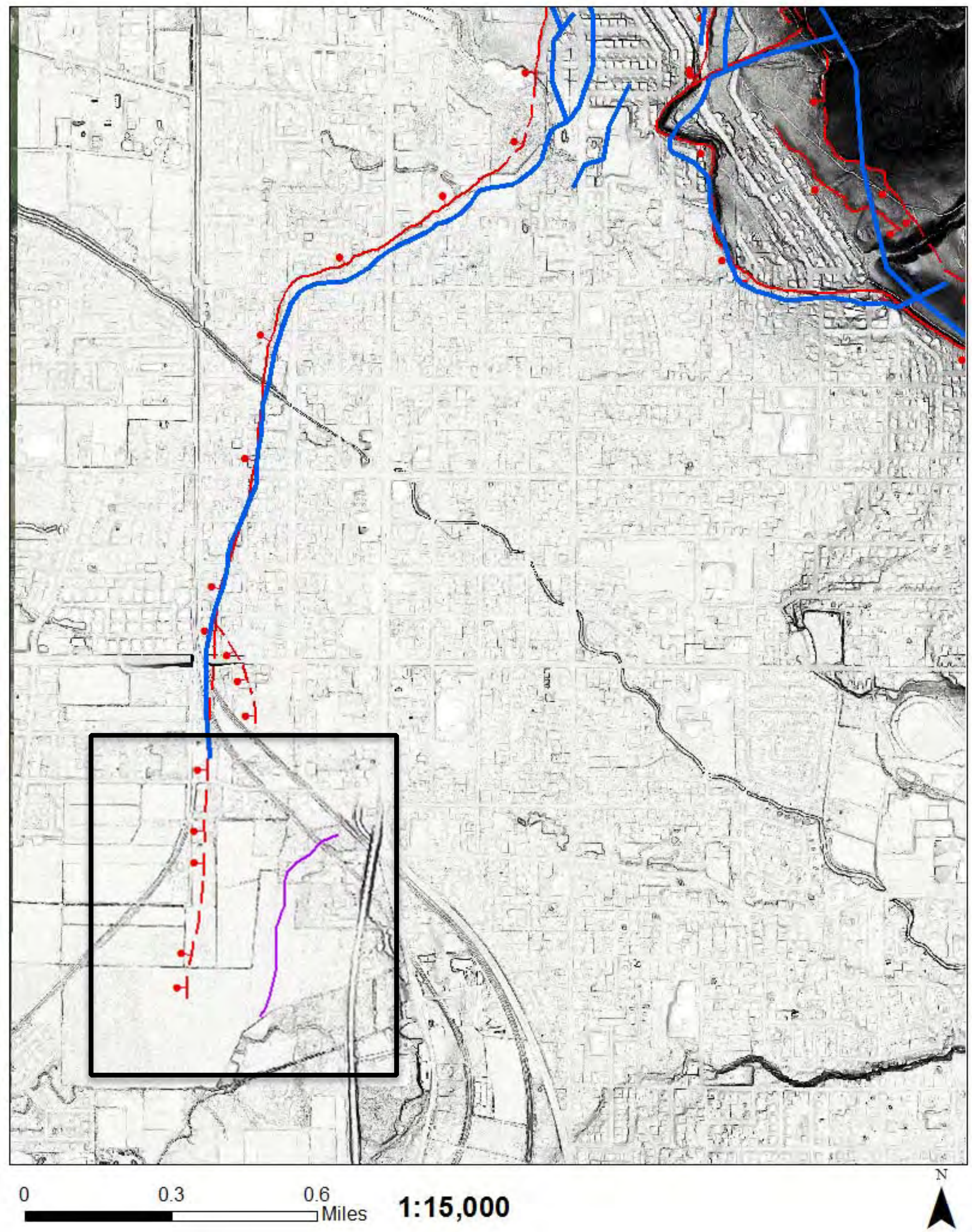
Provo Segment

- Springville Fault
- 2014 NAIP imagery
- Blue = old mapping
- Red = new lidar mapping



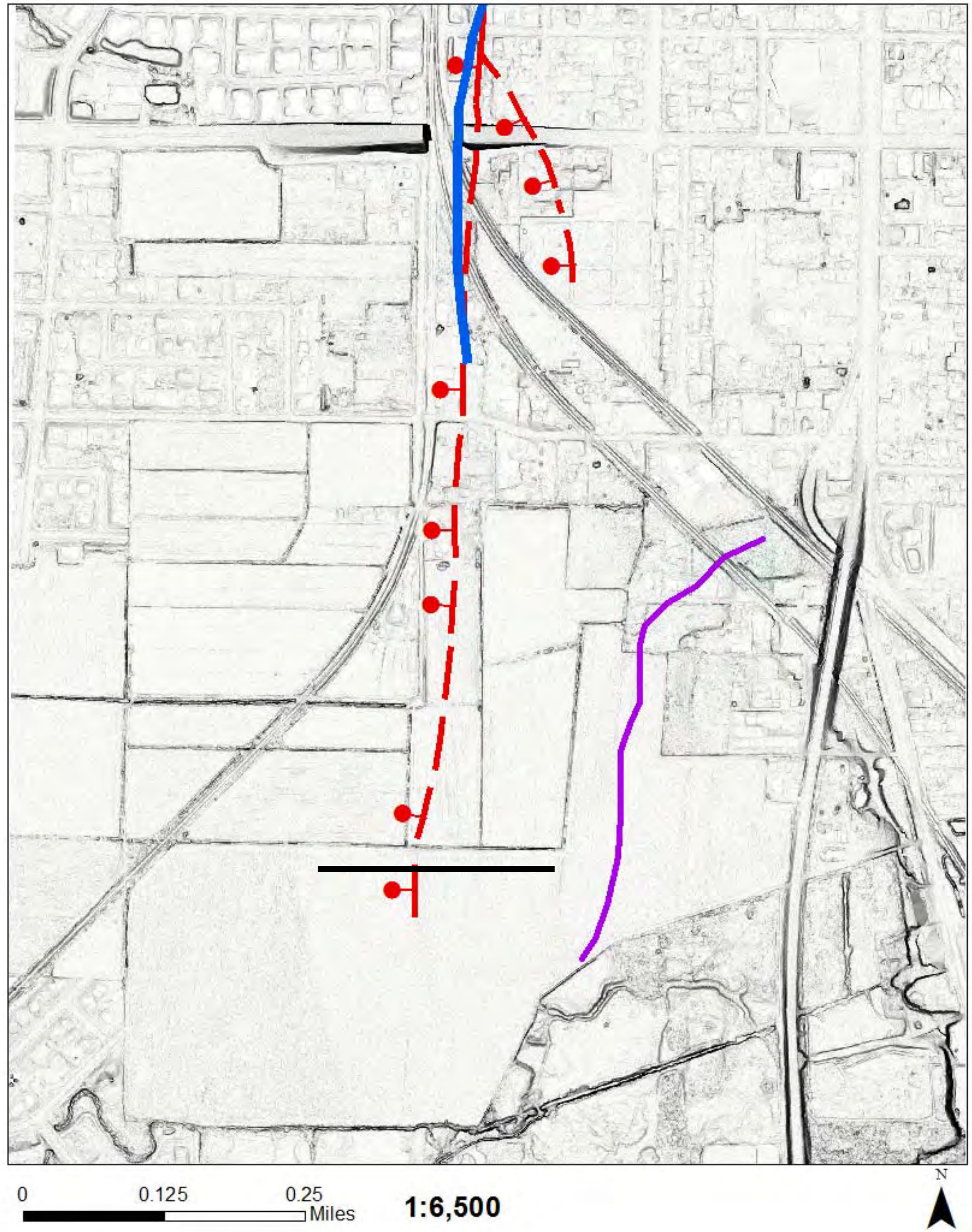
Provo Segment

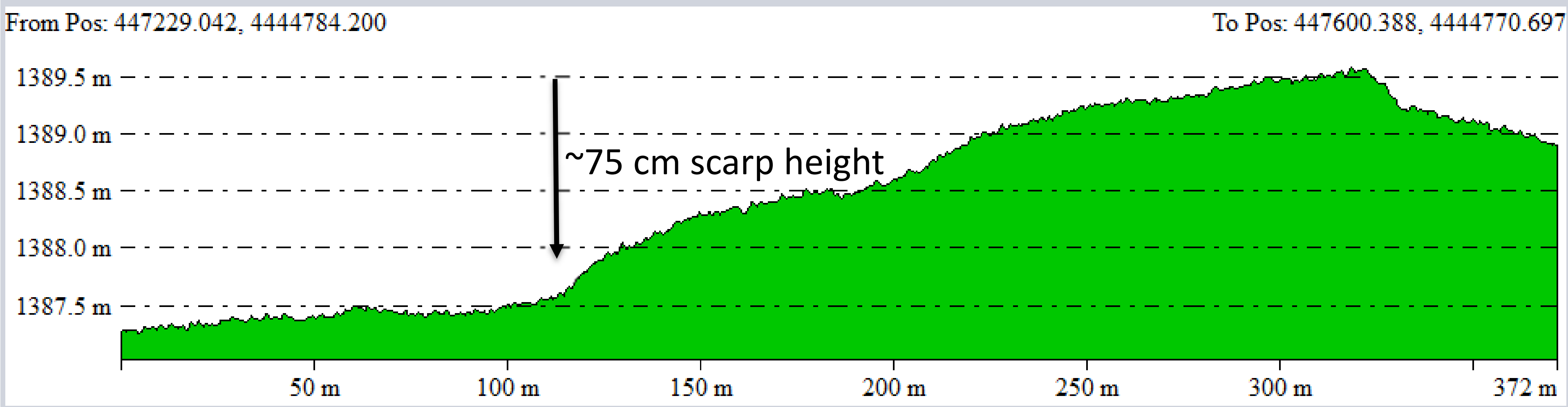
- Springville Fault
- Slope shade
- Blue = old mapping
- Red = new lidar mapping



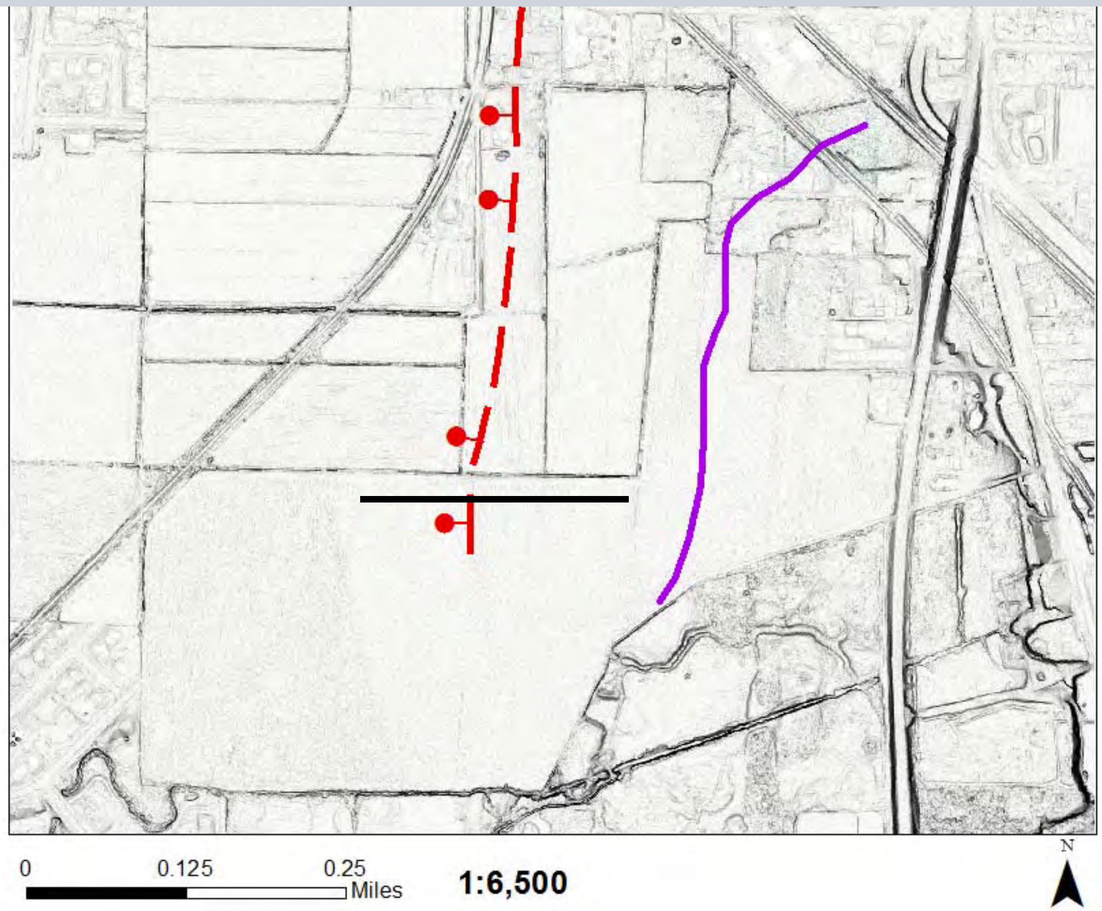
Provo Segment

- Springville Fault
- Slope shade
- Blue = old mapping
- Red = new lidar mapping
- Purple = lineament/still deciding what it is…





- Blue = old mapping
- Red = new lidar mapping
- Purple = lineament/still deciding what it is…

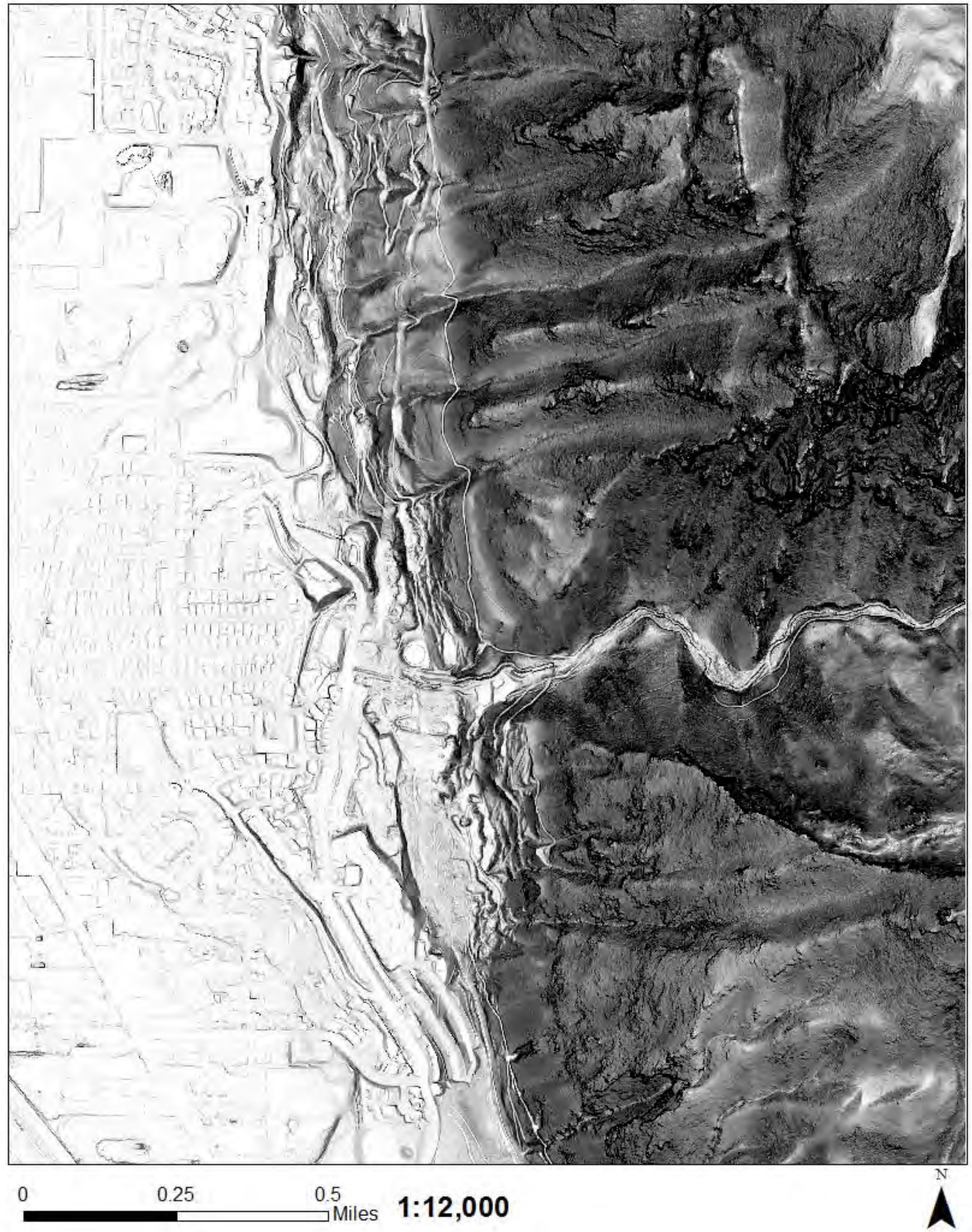


Provo Segment

- Just north of Springville
- 2014 NAIP imagery

Provo Segment

- 0.5 m slope shade image
- Extensive development in quarry and residential areas

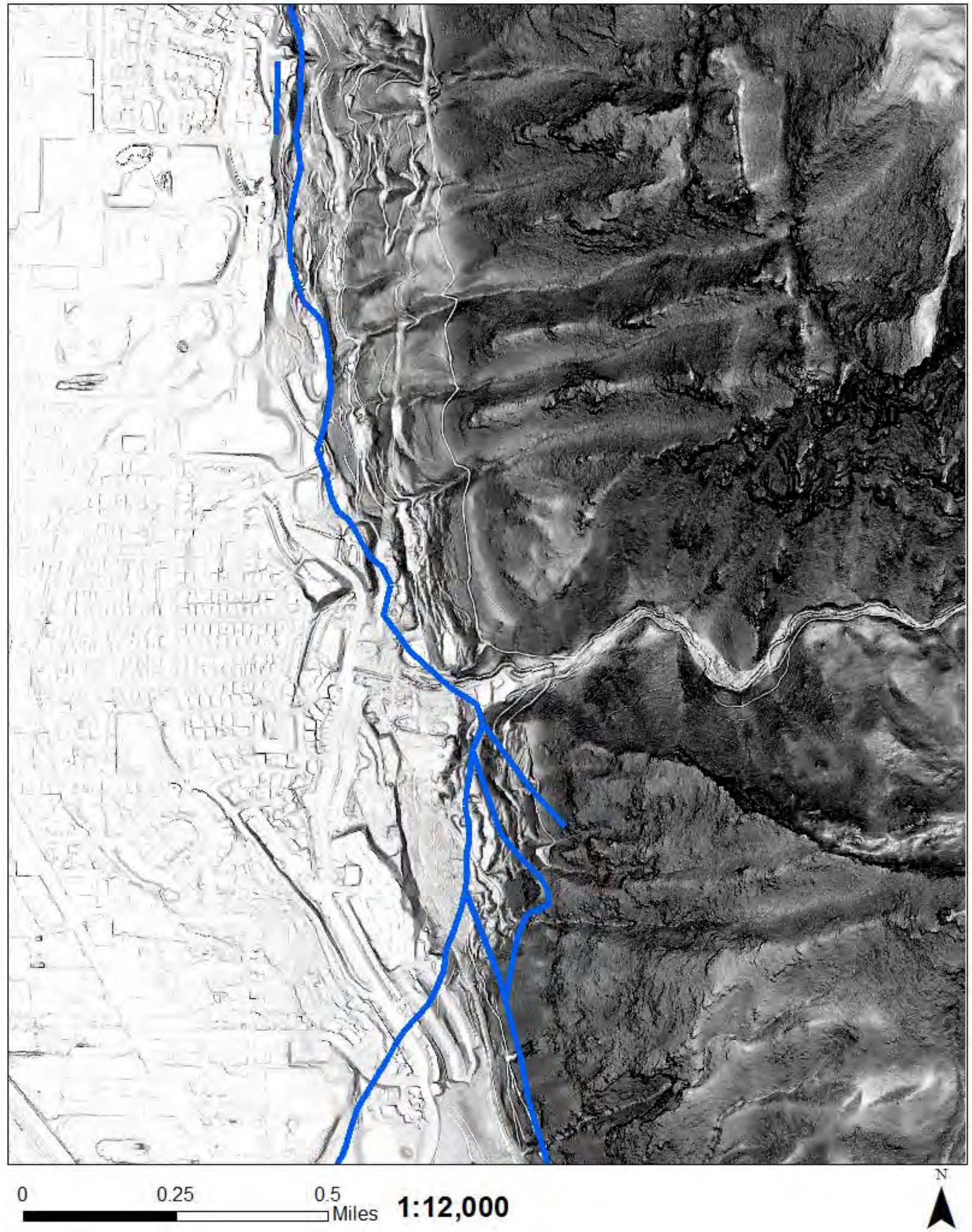


Provo Segment

- 1970s low sun angle photos.
- Still extensive development…

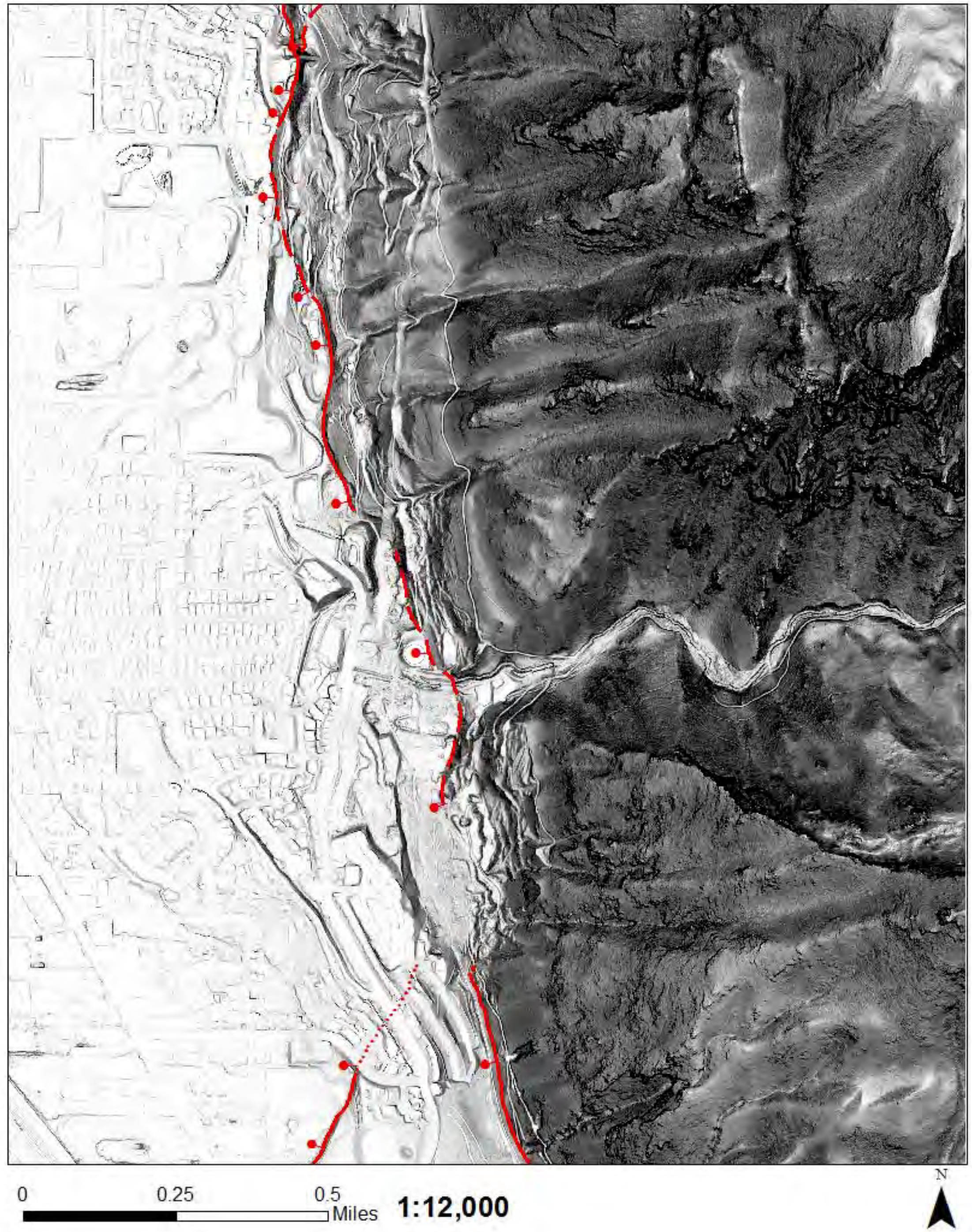
Provo Segment

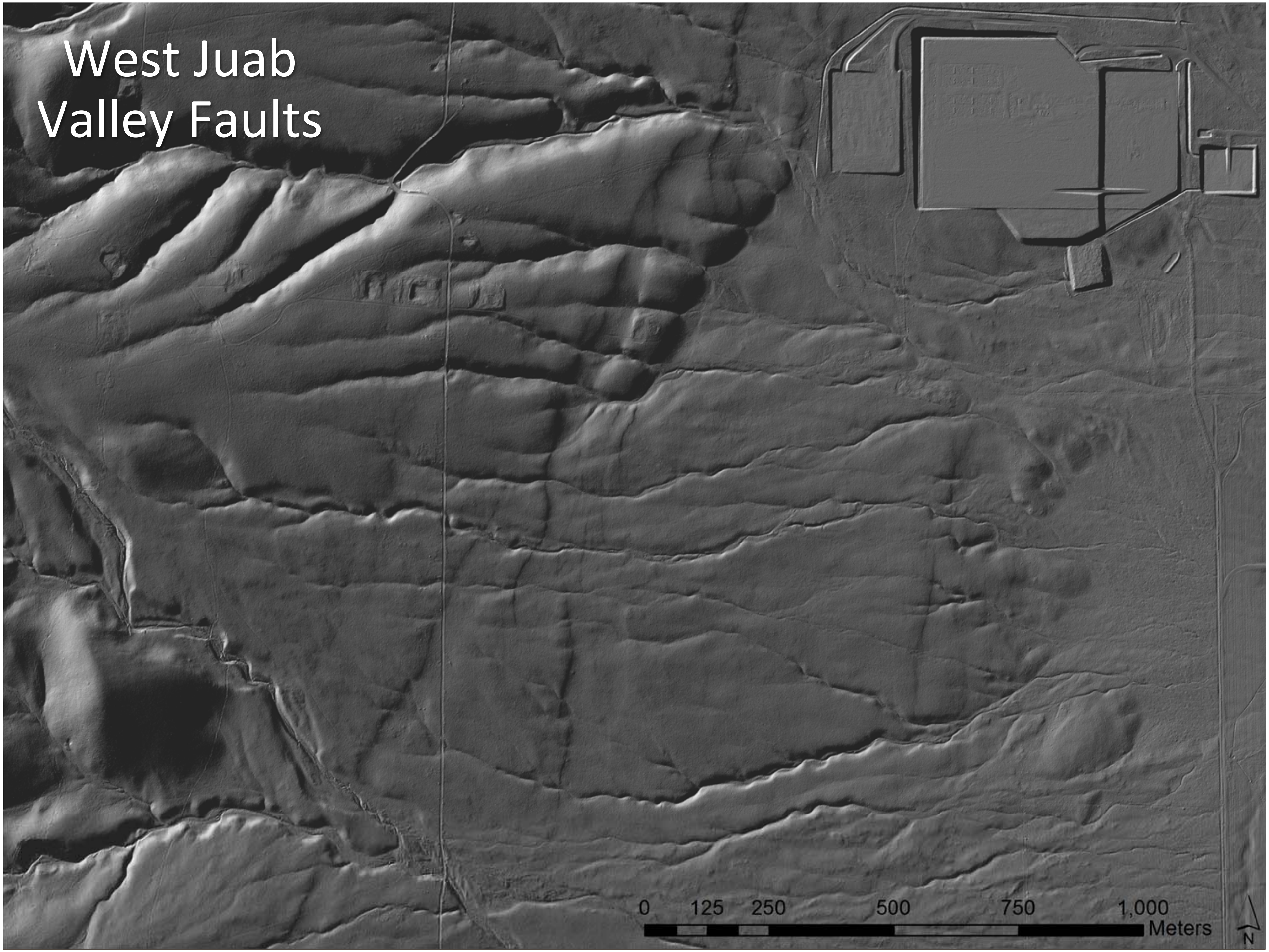
- Previous Q-fault mapping

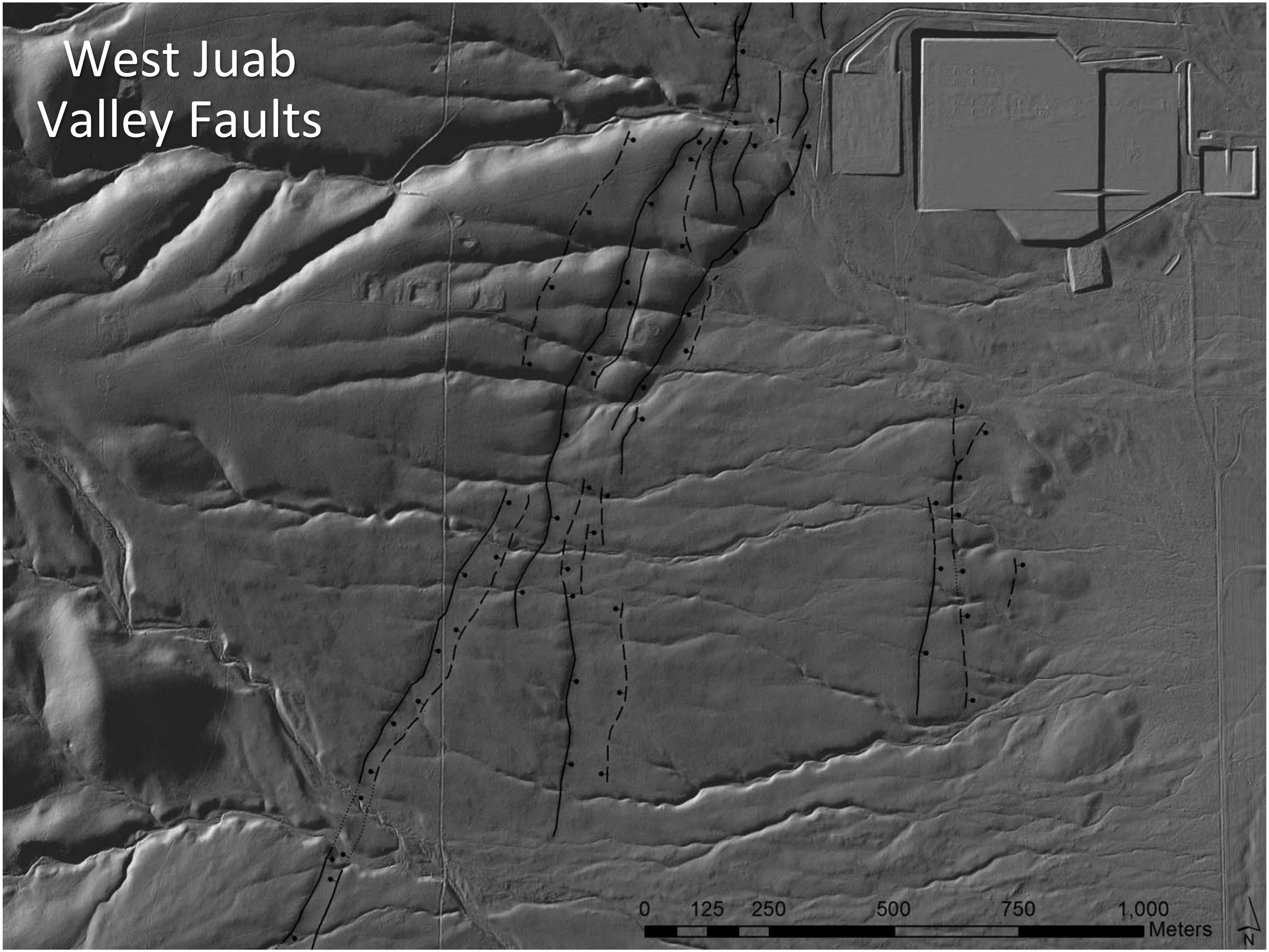


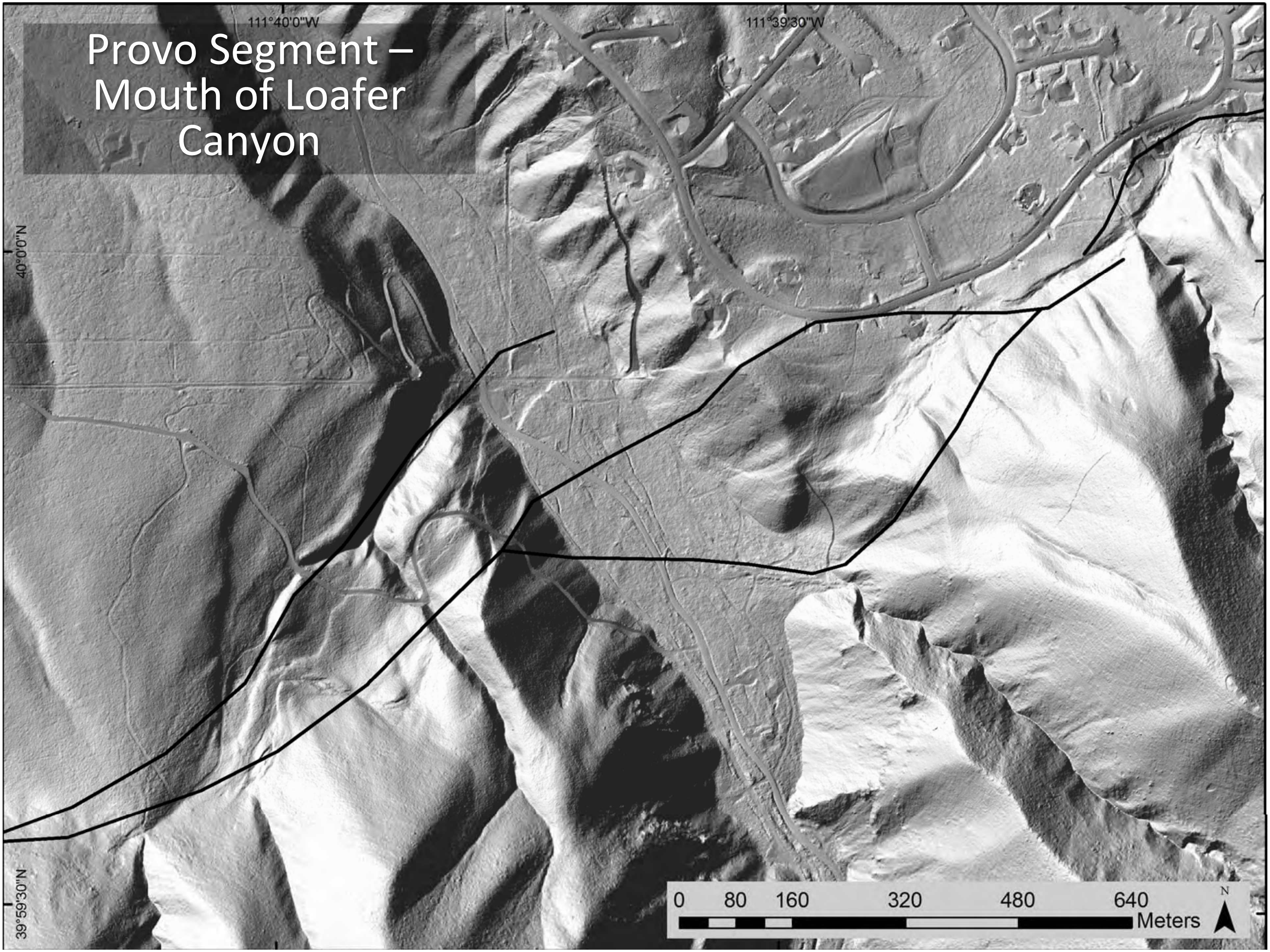
Provo Segment

- Draft Q-fault mapping
- Given deposits, there is probably more detail.
- Lidar and air photos require more scrutiny and may fall short.

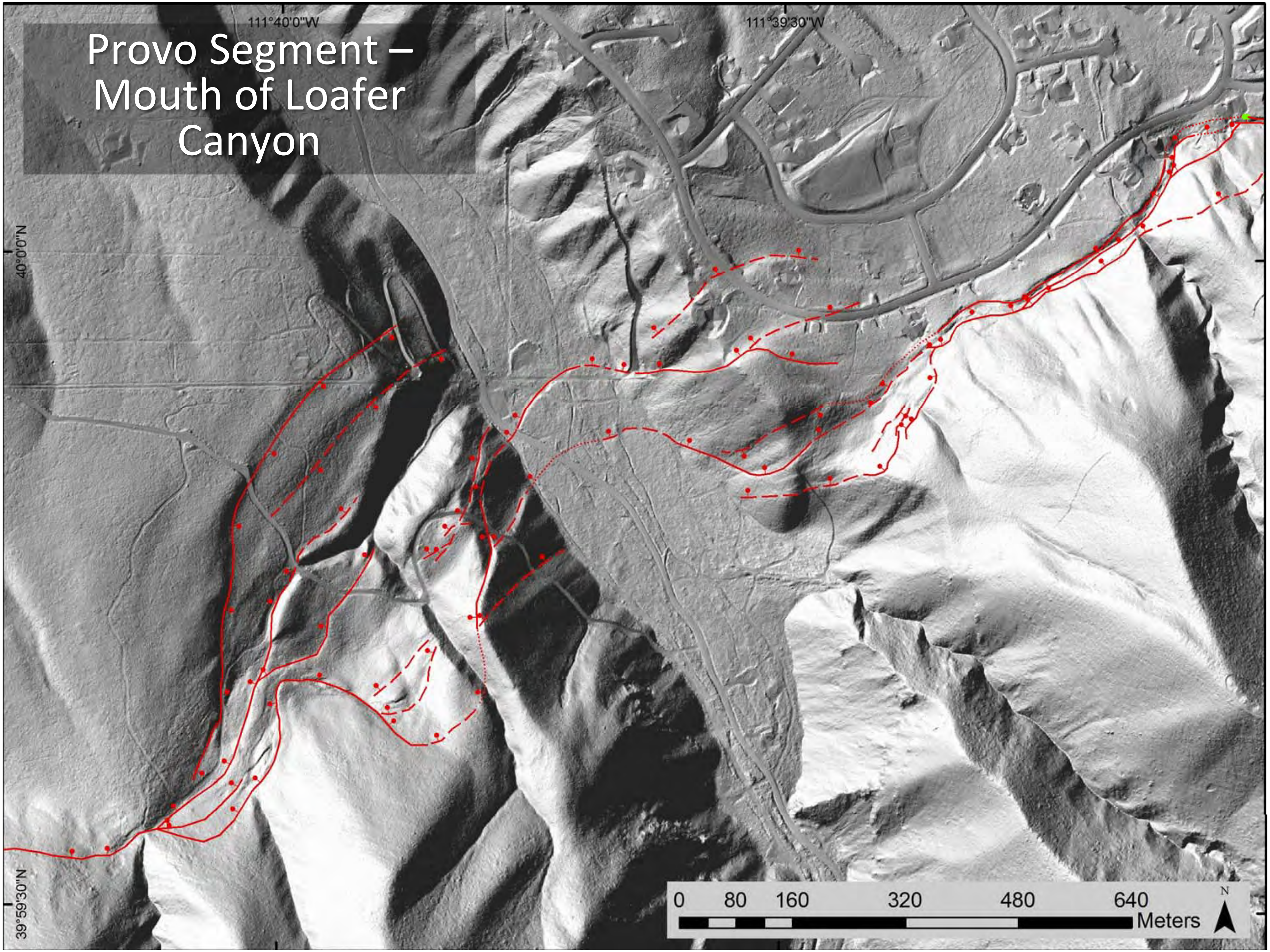



West Juab
Valley Faults
0
125
250
500
750
1,000
Meters
N

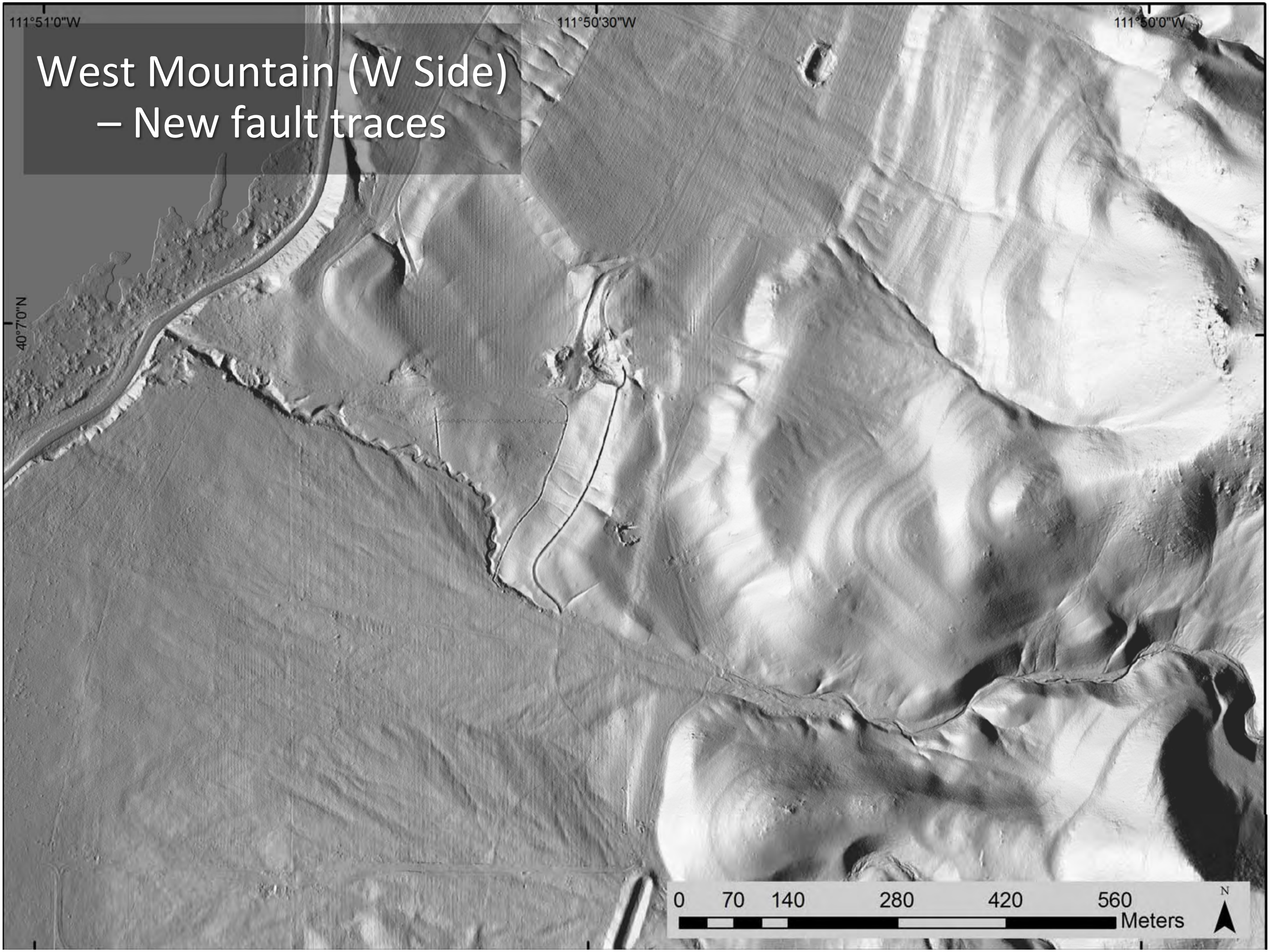

West Juab
Valley Faults
0
125
250
500
750
1,000
Meters
N

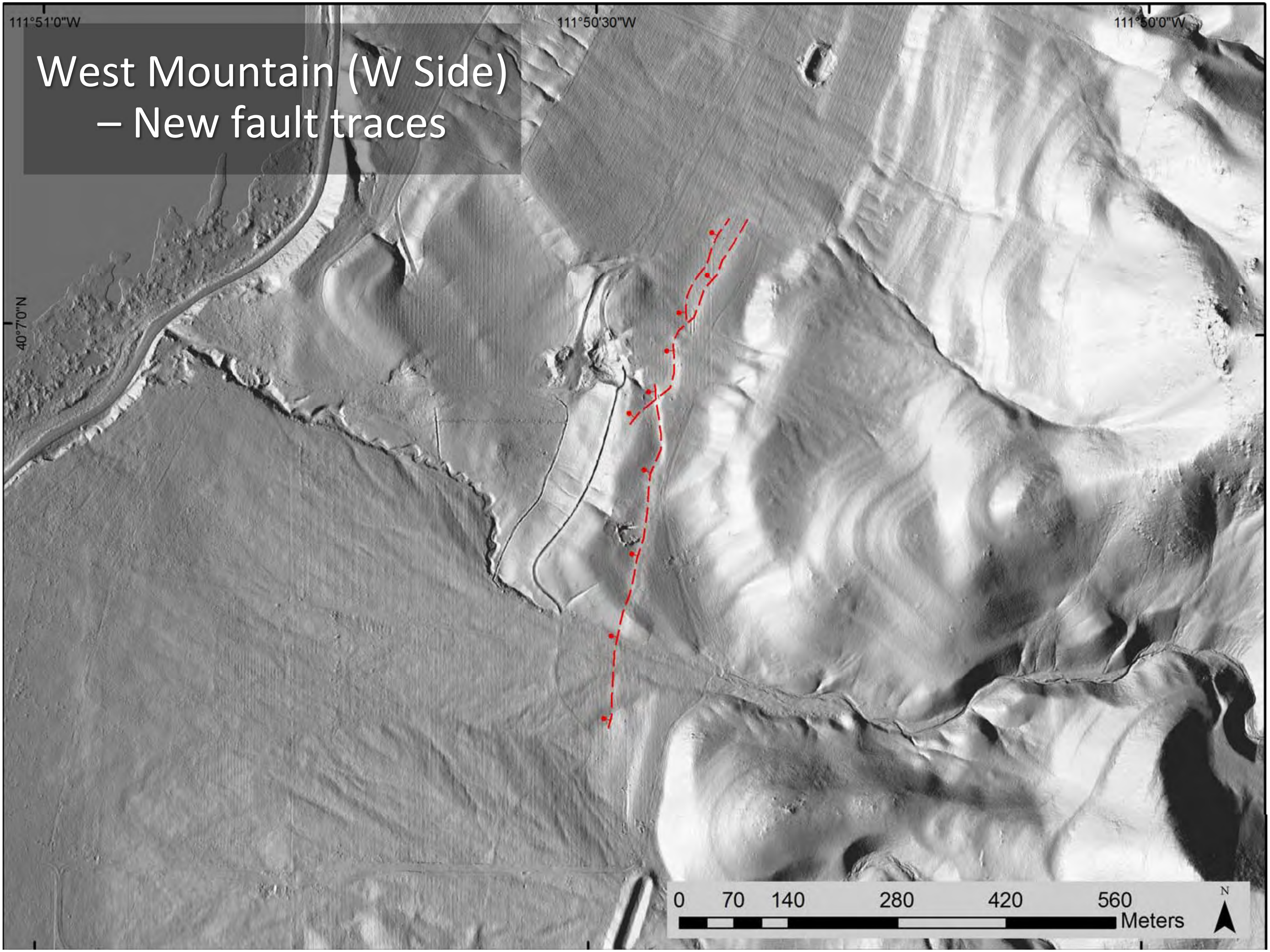

Provo Segment – Mouth of Loafer Canyon
111°40'0"W
111°39'30"W
40°0'0"N
39°59'30"N
0
80
160
320
480
640
Meters
N

Provo Segment – Mouth of Loafer Canyon



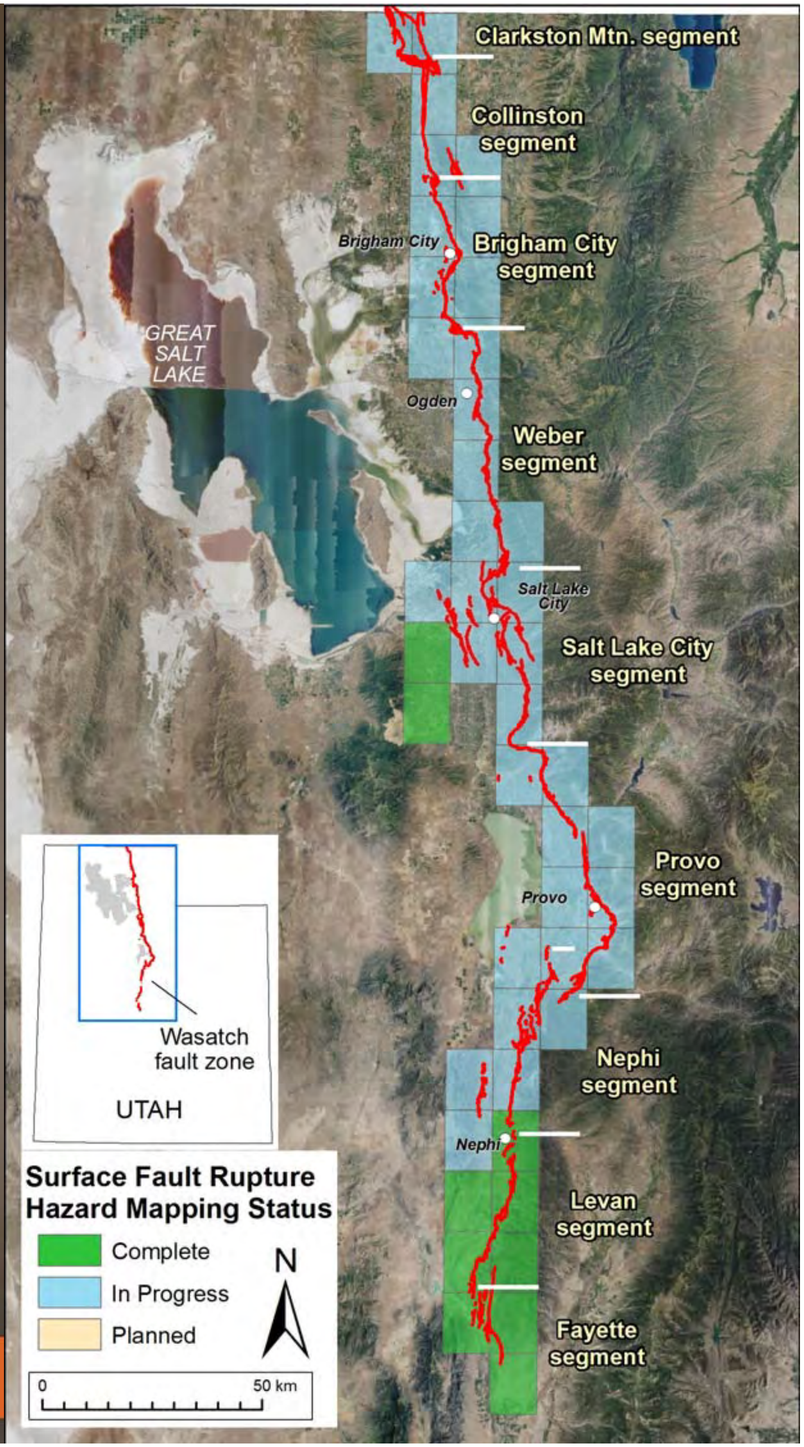
West Mountain (W Side) – New fault traces




West Mountain (W Side)
– New fault traces
111°51'0"W
111°50'30"W
111°50'0"W
40°7'0"N
0
70
140
280
420
560
Meters
N

Wasatch Fault Zone Hazard Mapping Status

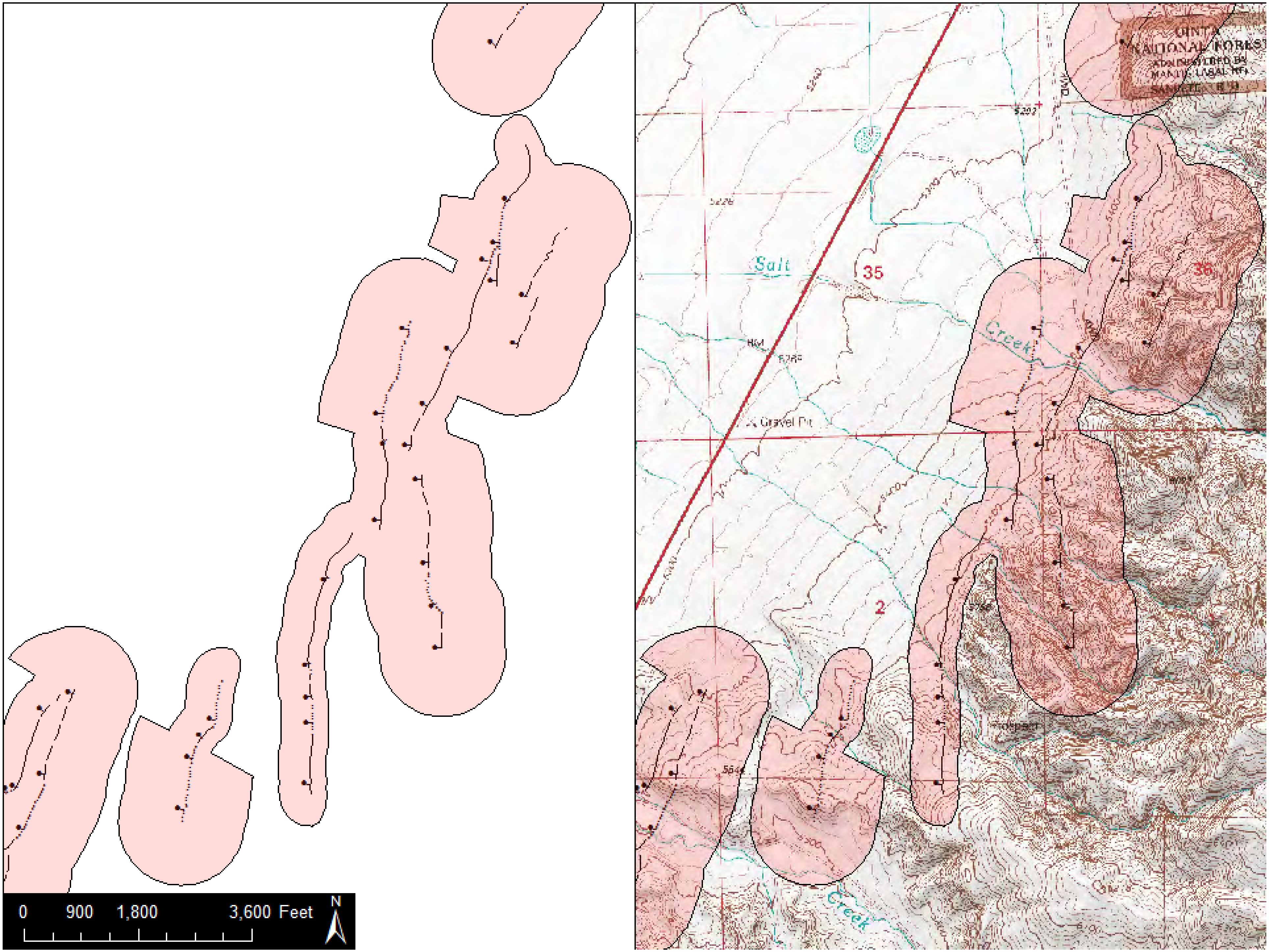
- Publishing quad-by-quad at 24K scale, surface-fault rupture hazard maps
- 37 quads in Utah (UT)
- Additional 5 quads in Idaho

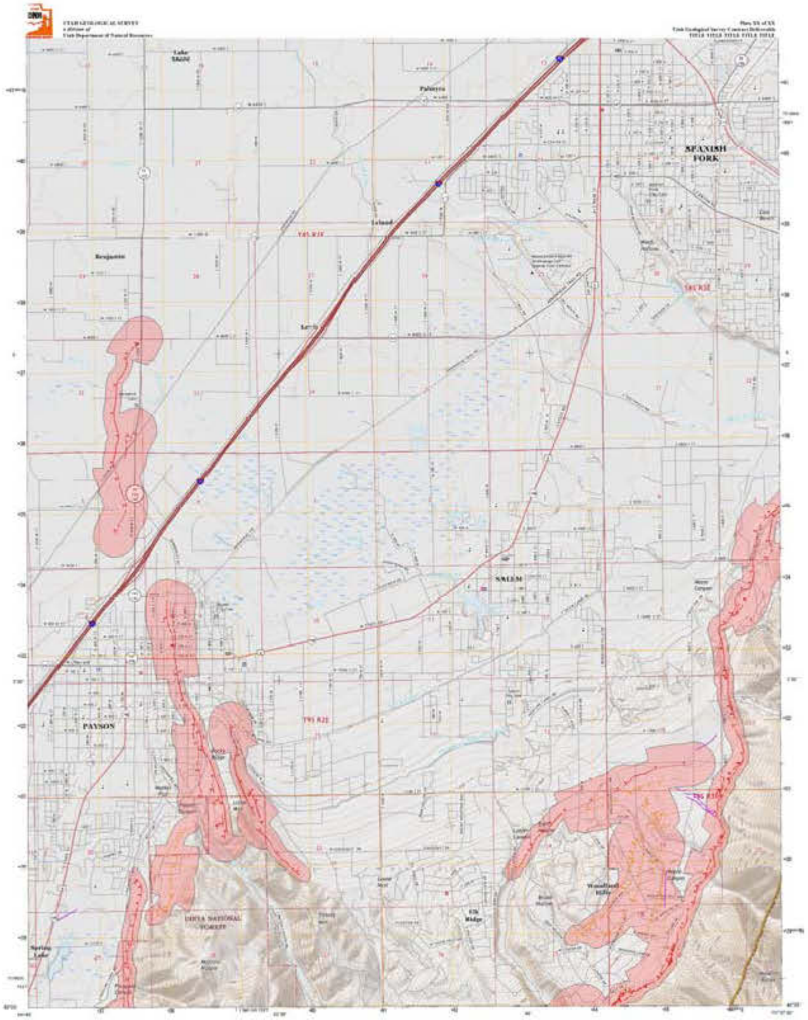


UTAH GEOLOGICAL SURVEY

Surface – Fault Rupture Hazard Maps

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


0 900 1,800 3,600 Feet
N
Salt
Creek
35
36
2
Gravel Pit
Creek



SCALE 1:24,000

CONTOUR INTERVAL 20 FEET

SURFACE FAULT RUPTURE HAZARD MAP OF THE SPANISH FORK QUADRANGLE, UTAH COUNTY, UTAH

by

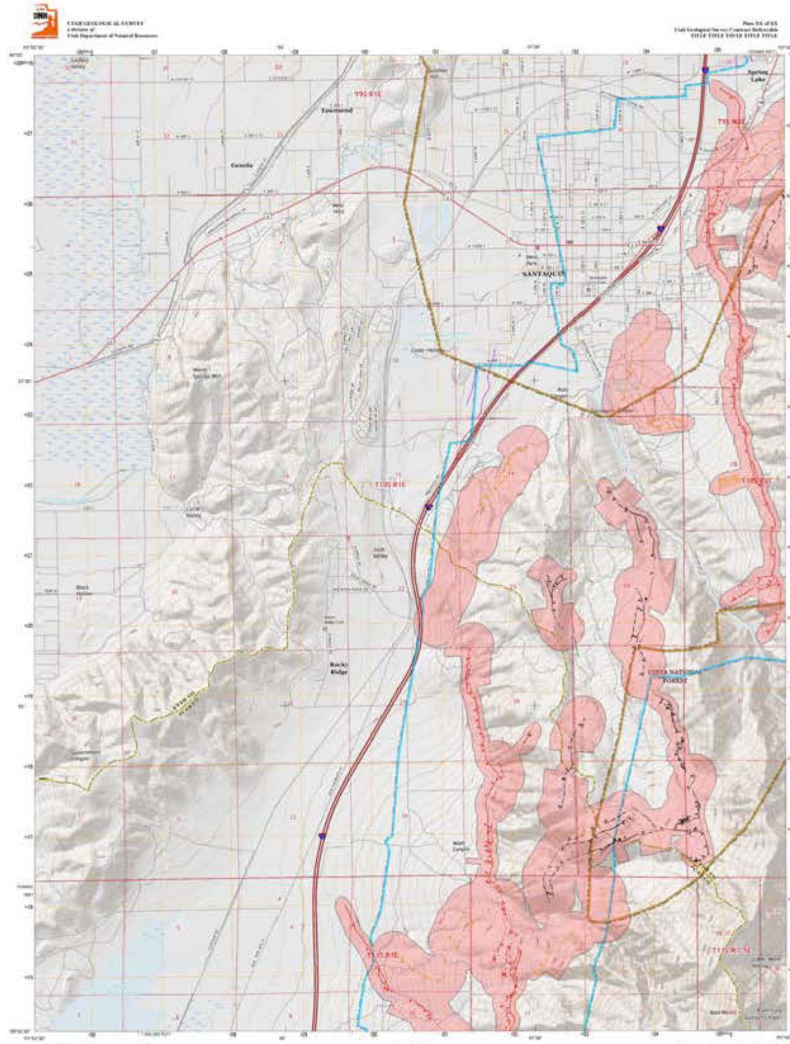
Adam I. Hiscock and Michael D. Hylland

2018

EXPLANATION

USING THIS MAP

REFERENCES



SCALE 1:24,000

CONTOUR INTERVAL 40 FEET

SURFACE FAULT RUPTURE HAZARD MAP OF THE SANTAQUIN QUADRANGLE, UTAH AND JUAB COUNTIES, UTAH

by

Adam I. Hiscock

2018

EXPLANATION

USING THIS MAP

REFERENCES

Results

- Refined mapping of the entire Wasatch Fault Zone
- Added new fault traces as well as refined existing traces and complex faulting zones
- All new mapping will eventually be added to Utah Quaternary Fault Database
- Created a set of Surface Fault Rupture hazard maps for the entire Wasatch Fault – a metropolitan area which is experiencing rapid population growth.

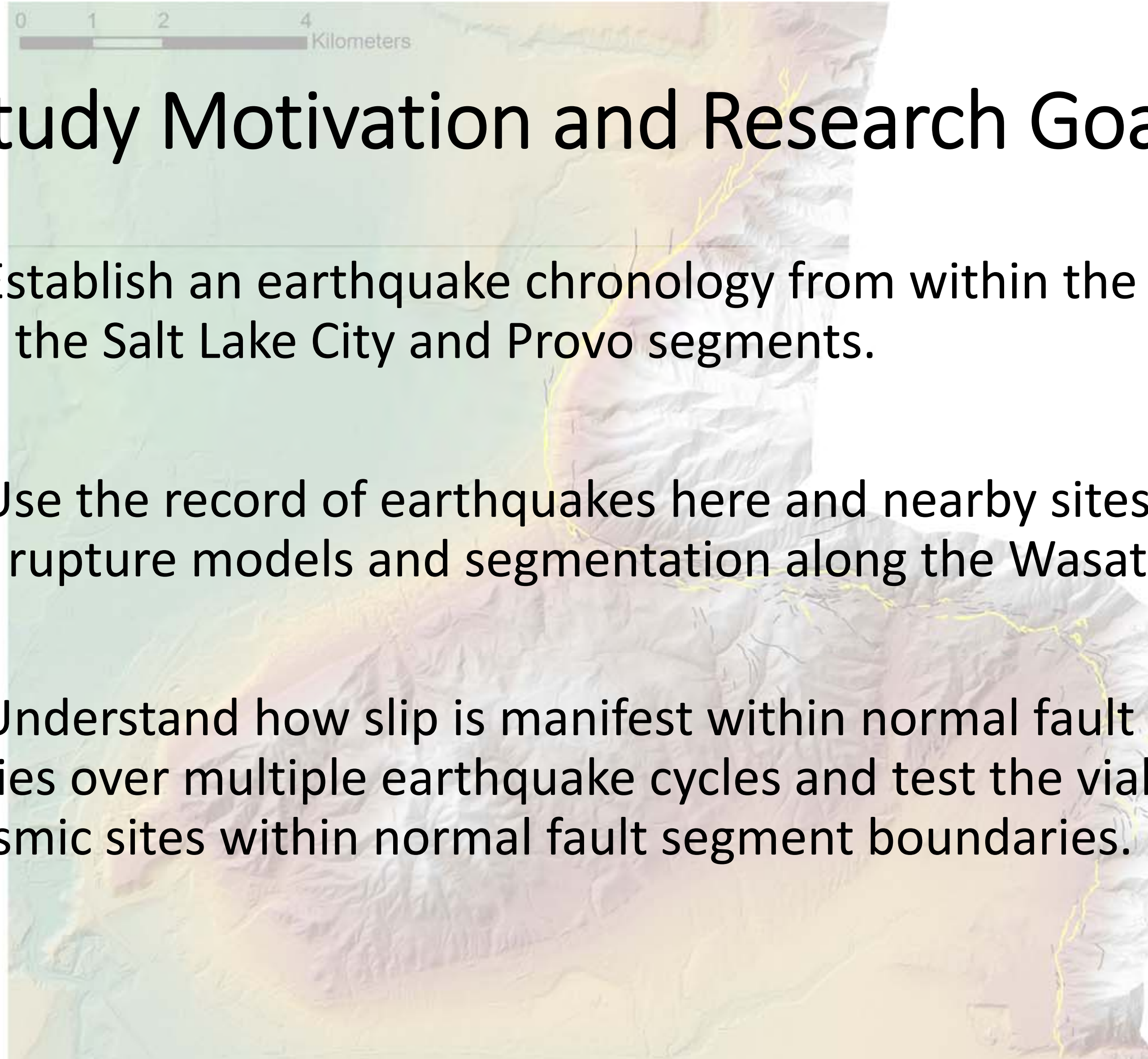

AIH PHOTOGRAPHY

Technical Summary of the Traverse Ridge Paleoseismic Site

UTAH VALLEY UVU UNIVERSITY Department of EARTH SCIENCE

Joseph Phillips, N. Toke, C. Langevin, J. Wells, D. Horns (UVU); E. Kleber, G. McDonald, A. Hiscock (UGS), C. DuRoss (USGS).

Support: 2016 NEHRP, UVU-SAC, NOSAMS, PaleoResearch, UGS student interns, Todd Nelson, Draper City, and David Simon

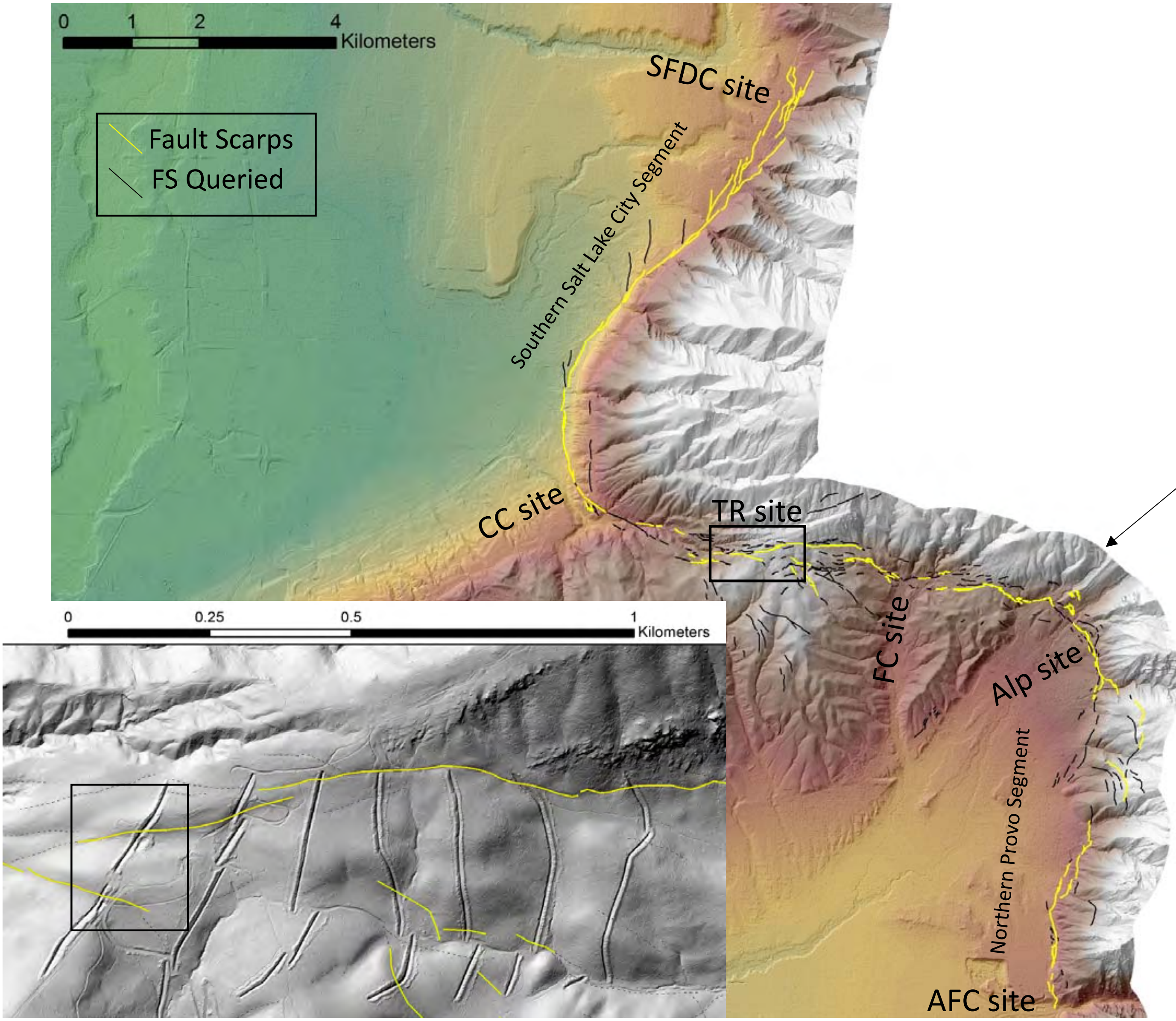


Study Motivation and Research Goals

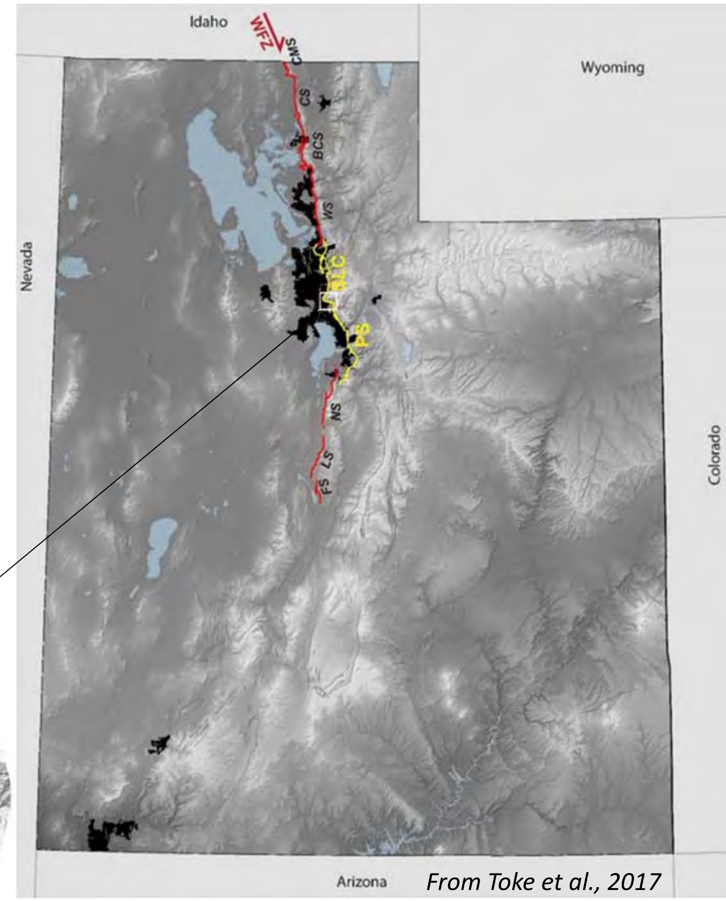
- **Goal 1.** Establish an earthquake chronology from within the boundary between the Salt Lake City and Provo segments.

- **Goal 2.** Use the record of earthquakes here and nearby sites to evaluate rupture models and segmentation along the Wasatch Fault.

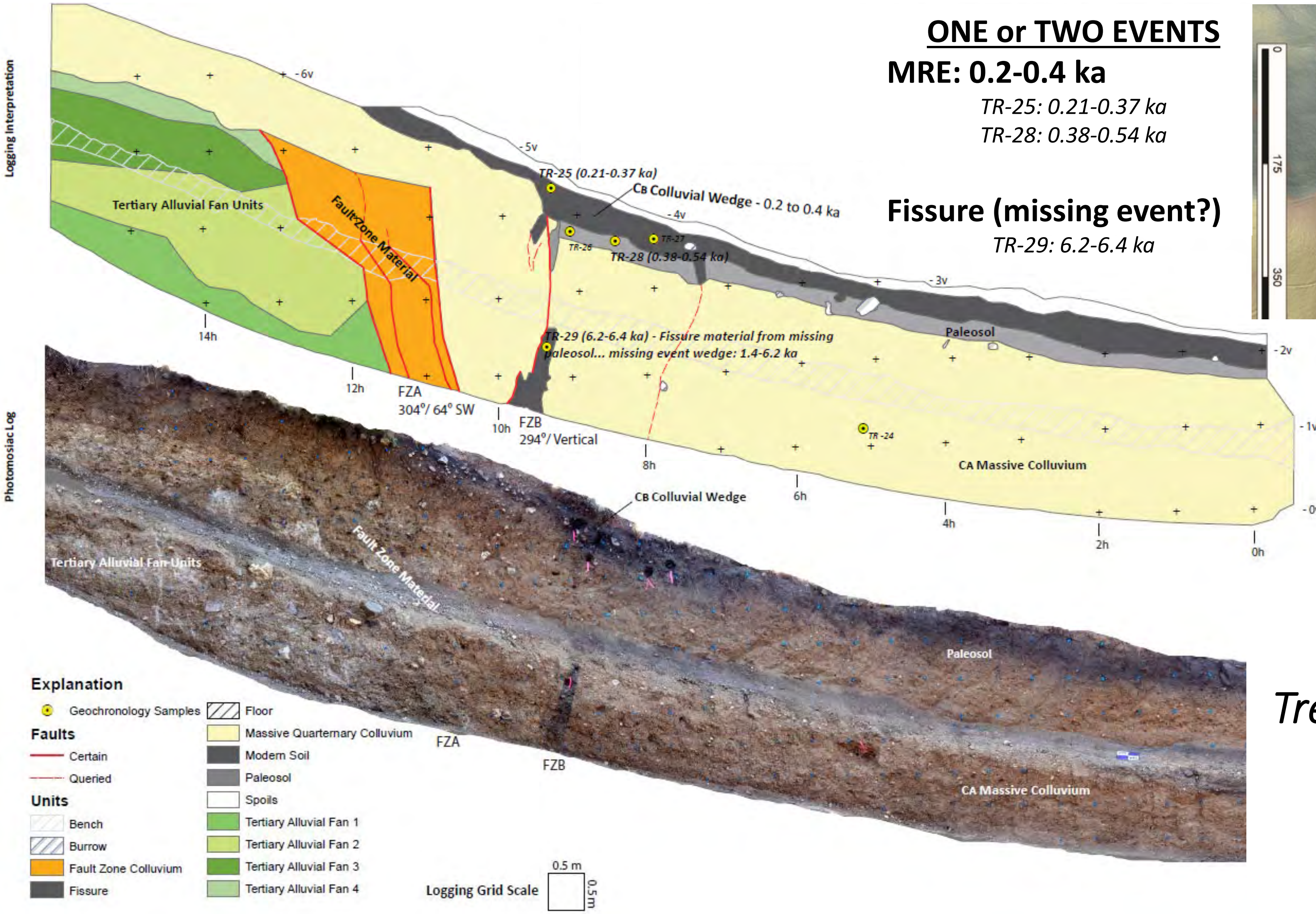
- **Goal 3.** Understand how slip is manifest within normal fault segment boundaries over multiple earthquake cycles and test the viability of paleoseismic sites within normal fault segment boundaries.



0 1 2 4
Kilometers
Fault Scarps
FS Queried
SFDC site
Southern Salt Lake City Segment
CC site
TR site
FC site
Alp site
Northern Provo Segment
AFC site
0 0.25 0.5 1
Kilometers



Idaho
WFZ
CMS
CS
BCS
WS
SLC
PS
NS
LS
FS
Wyoming
Nevada
Colorado
Arizona
From Toke et al., 2017



ONE or TWO EVENTS

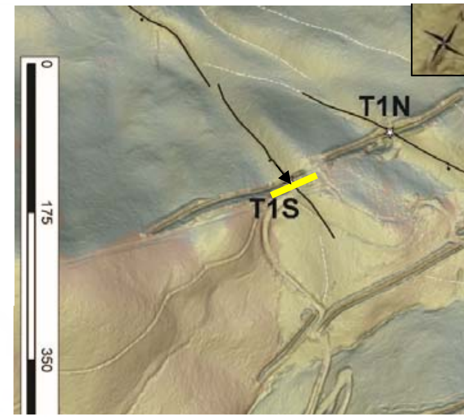
MRE: 0.2-0.4 ka

TR-25: 0.21-0.37 ka

TR-28: 0.38-0.54 ka

Fissure (missing event?)

TR-29: 6.2-6.4 ka



Trench 1 South – East Wall

Trench 1 North – West Wall

TWO EVENTS

Upper CW: 0.6-3.4 ka

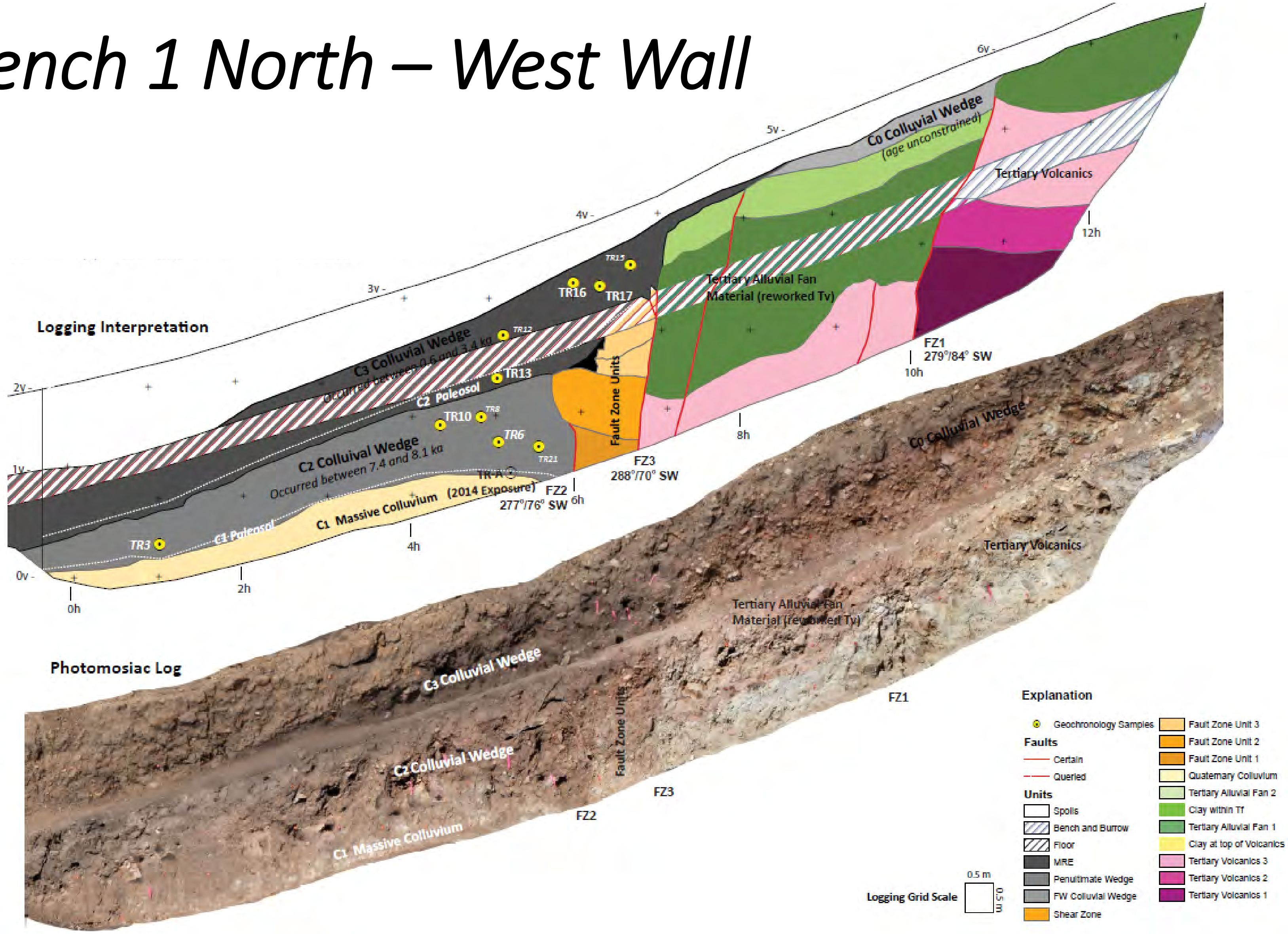
TR 16: 0.4-0.5 ka

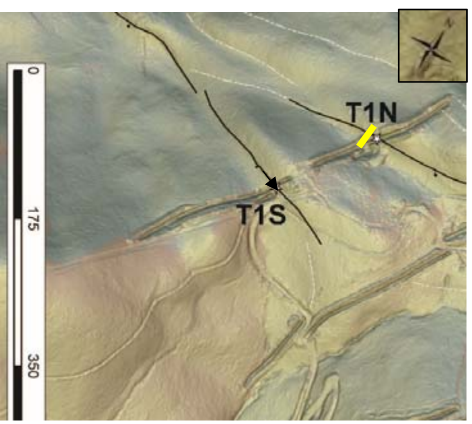
TR-13a: 3.4-3.5 ka

Lower CW: 7.4-8.1 ka

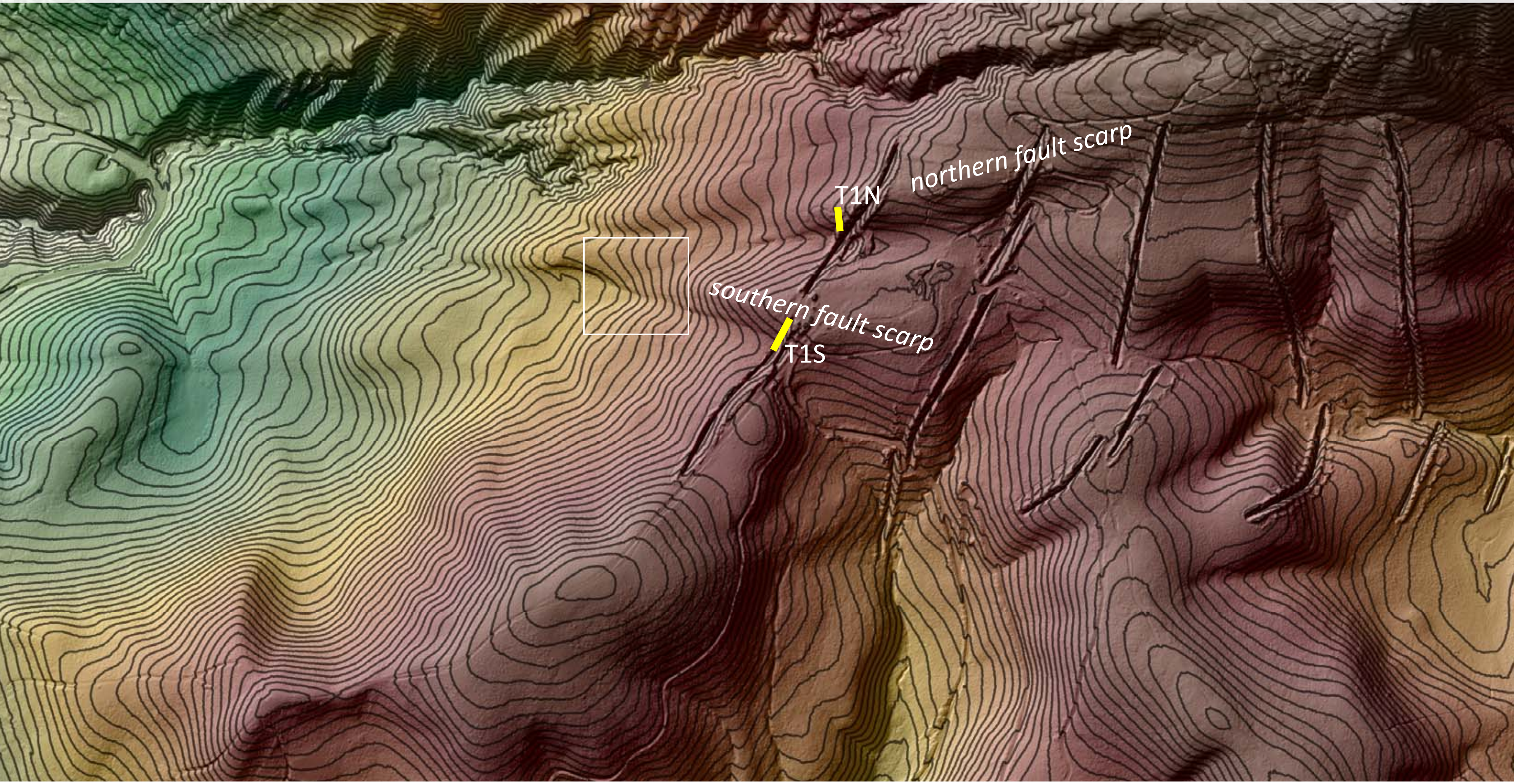
TR-10: 7.4-7.5 ka

TR-A: 8.1-8.2 ka

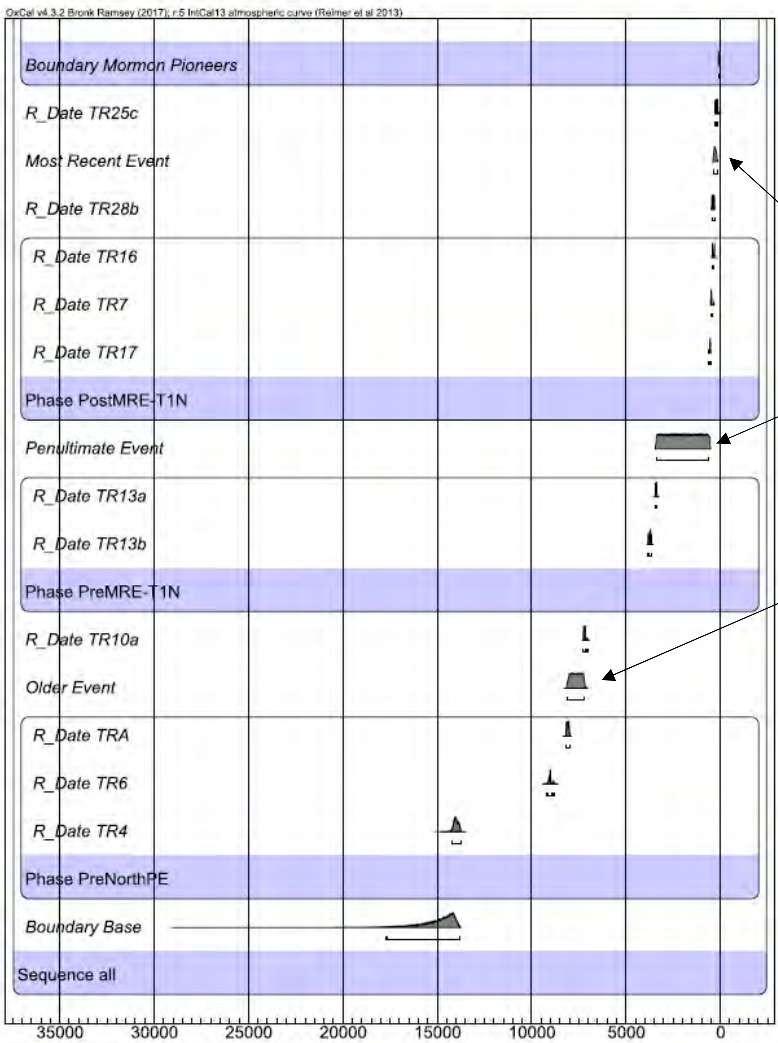




Cross-Cutting Fault Scarps?

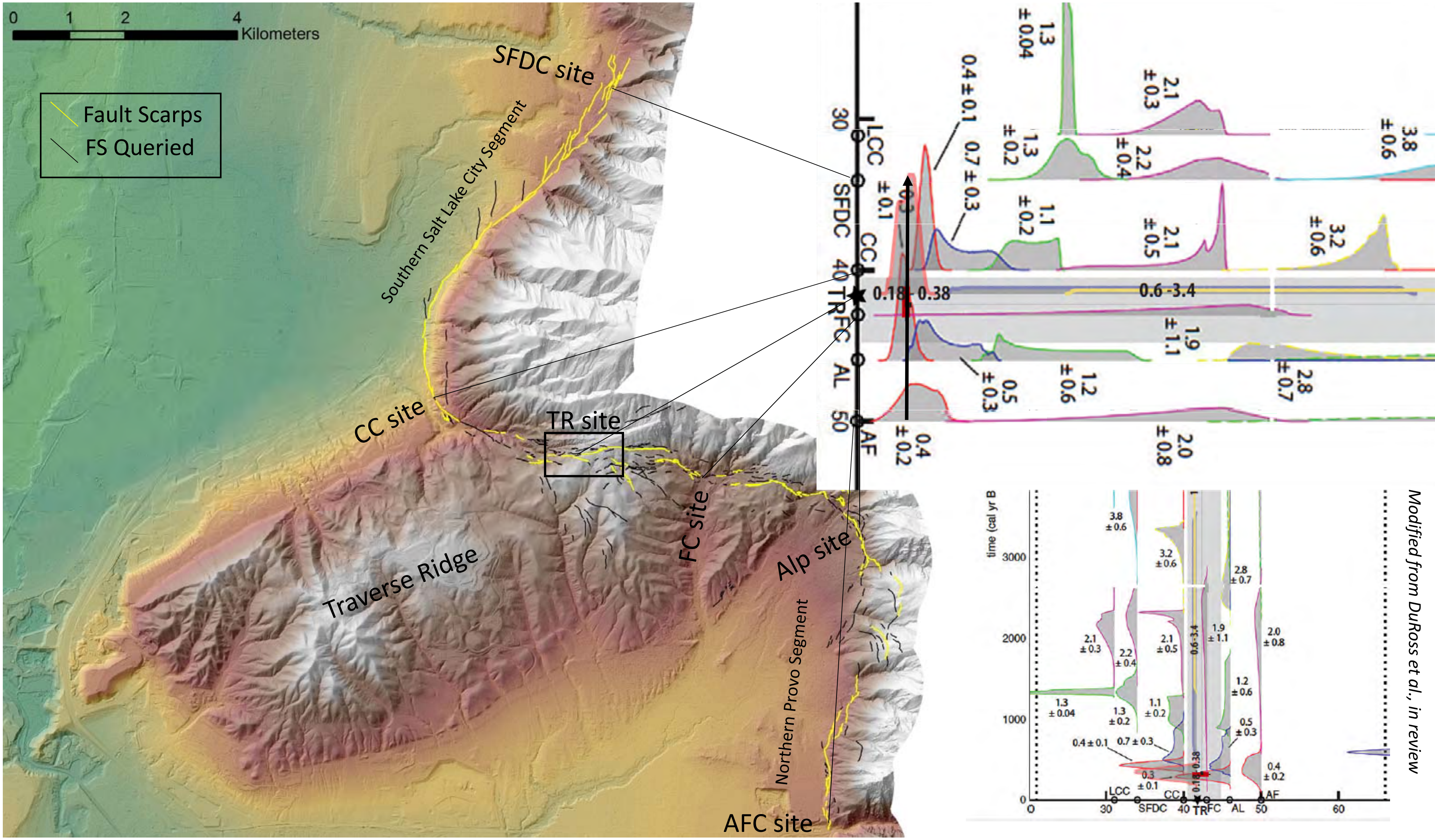


Summary of Events at the Traverse Ridge Site



	(2 Sigma) Age Constraint	Trench Observed	Colluvial Wedge	Wedge Height	Fault Zone	Rupture Length[1]	Mw Empirical[2]
Most Recent Event (MRE)	**0.2-0.4 ka**	**T1S**	$\mathbf{C_B}$	**0.7**	**FZb**	**15 km**	**6.7**
Penultimate Event (PE)	**0.6-3.4 ka**	**T1N**	$\mathbf{C_3}$	**1.2**	**FZ3**	**44 km**	**7.0**
Missing Event	*1.4-6.2 ka*	*T1S*	*eroded*	*?*	*FZb*	*?*	*?*
Older Event	**7.4-8.1 ka**	**T1N**	$\mathbf{C_2}$	**1.1**	**FZ2**	**33 km**	**6.9**
Unconstrained Event	*Pre Holocene*	*T1N*	C_0	*0.5*	*FZ1*	*8 km*	*6.6*

1- Rupture lengths (L) calculated using the empirical equation related to displacement (D) from the instrumental data of Stirling et al., 2002: Log (L) = -0.81 + 0.56*Log(D), displacement is assumed to be the colluvial wedge heights presented here which are minimum estimates.
2- Moment magnitudes (Mw) calculated following the empirical equation for average displacement along normal faults: Mw = 6.45 + 0.65*Log(AD), Wells and Coppersmith, (1994)



Modified from DuRoss et al., in review

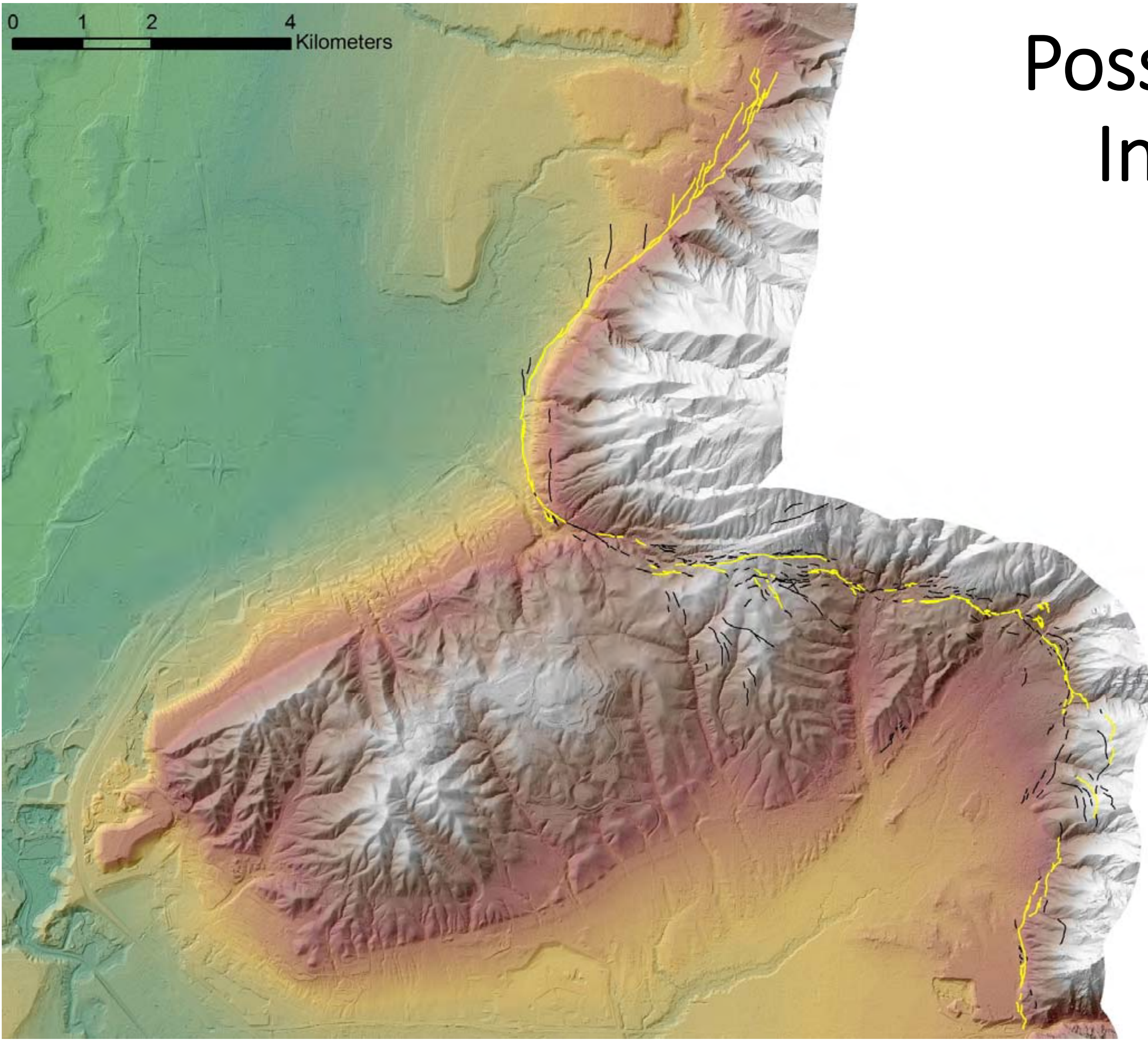
Conclusions

- 3-4 events have ruptured the Traverse Ridge site during the Holocene.

- The MRE event provides evidence for ruptures extending into and possibly spilling over the segment boundary.

- The penultimate event at this site is not well constrained

- Fewer events are captured at this site than other nearby sites
  (i.e., Corner Canyon and Alpine).



Possible Reasons for an Incomplete Record

- Surface slip may be less (or absent) through the segment boundary.
- Modest colluvial wedge evidence could be lost to erosion (e.g., *Missing event soil material in fissure*).
- Distributed slip: some events may be expressed on scarps that are less prominent or distributed among many faults

References

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The State of Utah, Utah Automated Geographic Reference Center, Utah Geological Survey, Utah Division of Emergency Management, Salt Lake County, Federal Emergency Management Agency, U.S. Geological Survey, and the U.S. Environmental Protection Agency, 2013-2014 State of Utah Acquired Lidar Data – Wasatch Front, downloaded from OpenTopography: http://opentopo.sdsc.edu/datasetMetadata?otCollectionID=OT.122014.26912.1, DOI: 10.5069/G9TH8JNQ

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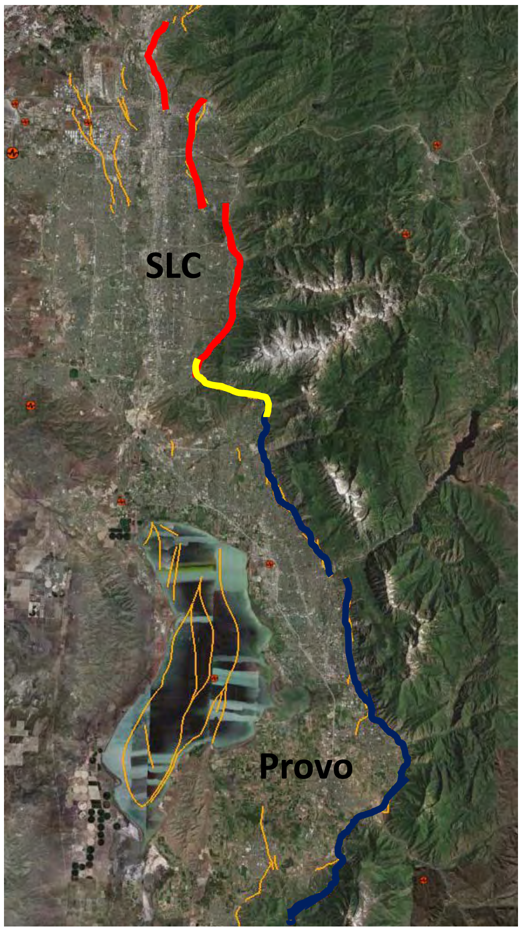
Acknowledgments

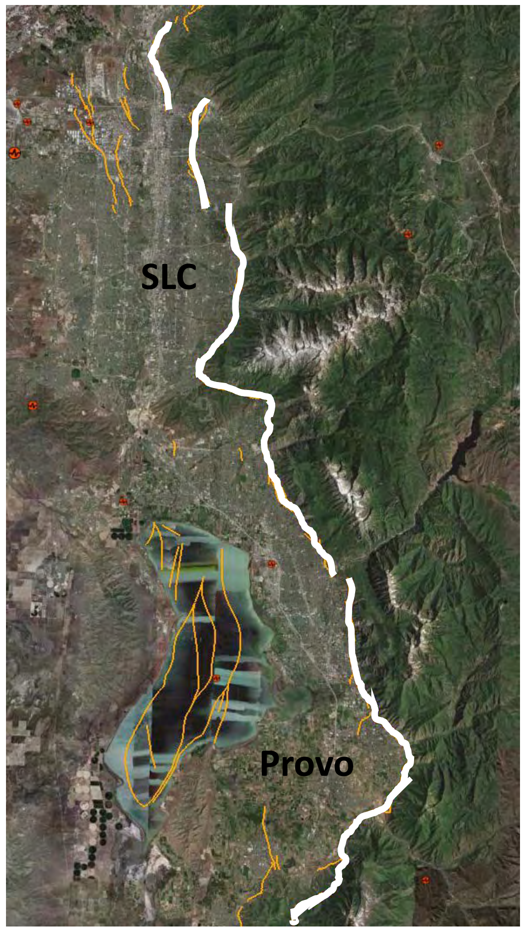
This research was supported by a USGS NEHRP Award #2016-05 and a UVU College of Science and Health SAC Award. We thank the city of Draper and David Simon for assistance in gaining access to the study site. Todd Nelson provided professional excavation service. We received significant field support from Mike Hylland, Greg Bukleman, UGS interns from Weber State and Carlton College, Shannon Fell, Christopher Bross, and Paul Bushman. Jim McCalpin shared preliminary logging interpretations from the seven existing consultant trenches near this site. UVU Department of Earth Science field camp students from 2013 and 2014 helped reconnaissance these sites. Radiocarbon analyses were run by the Woods Hole Oceanographic Institute NOSAMS lab. Bulk Soil charcoal extractions were processed at PaleoResearch Institute in Golden, CO.

Rupture Models

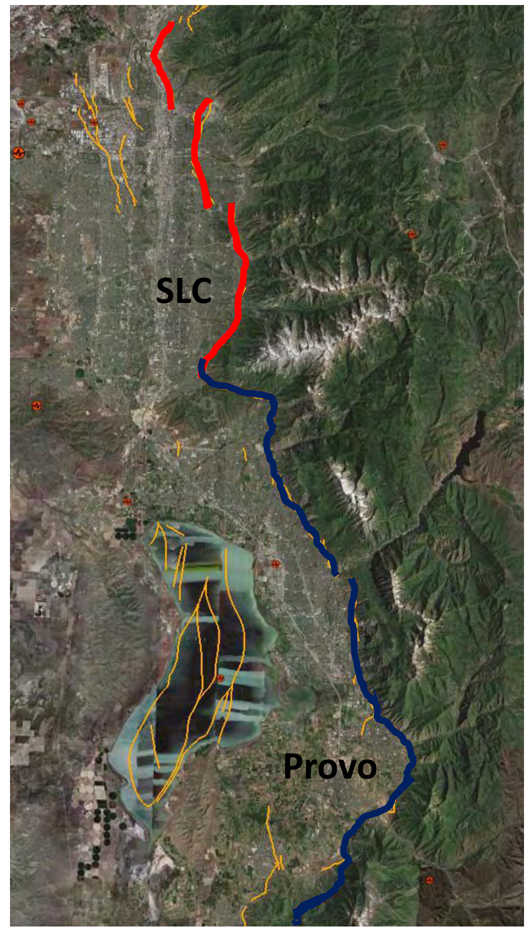
Segmented with In-fill Ruptures

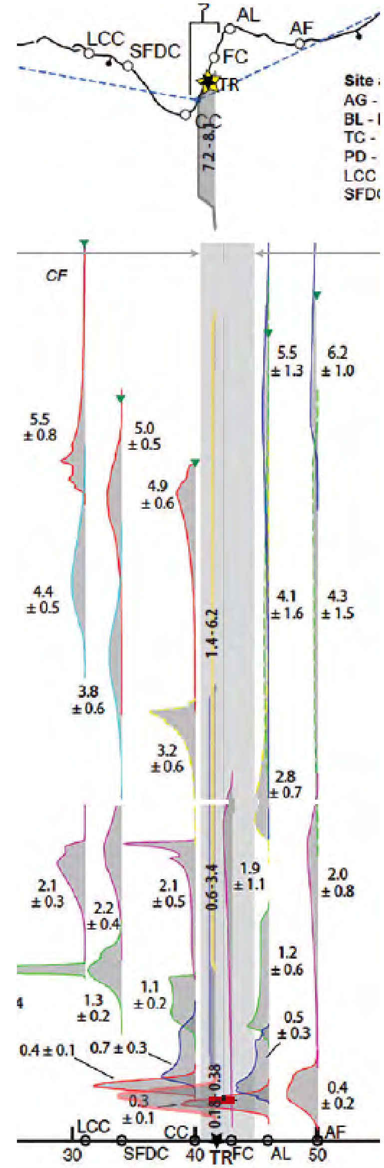


Multi-segment Ruptures



Spill-over Ruptures

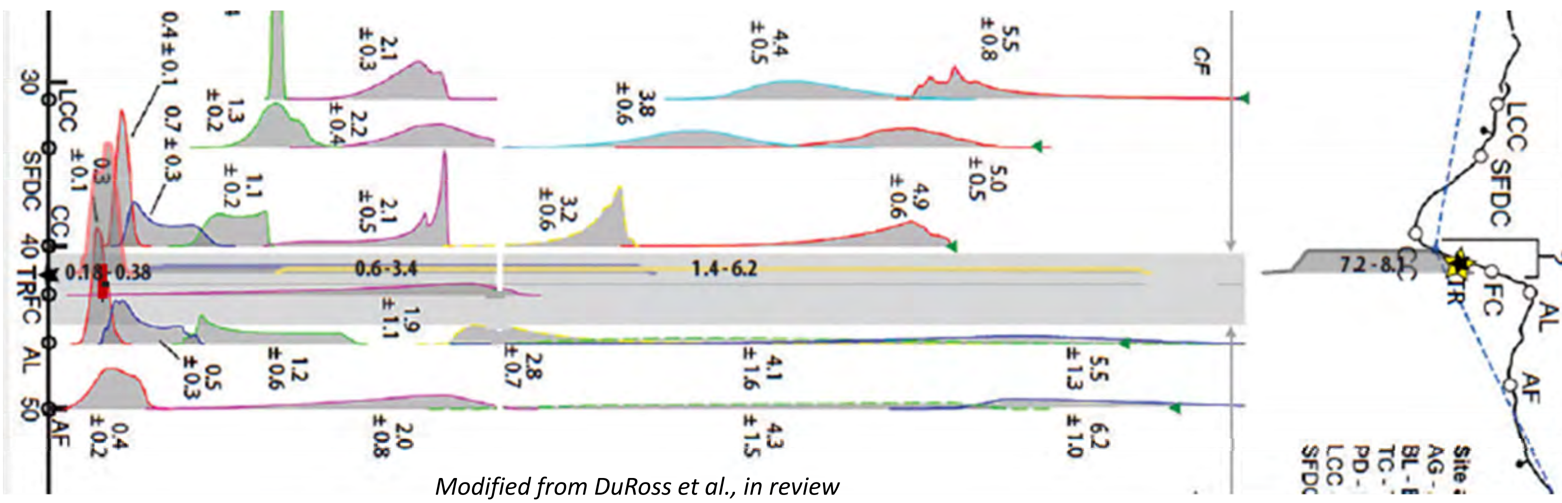




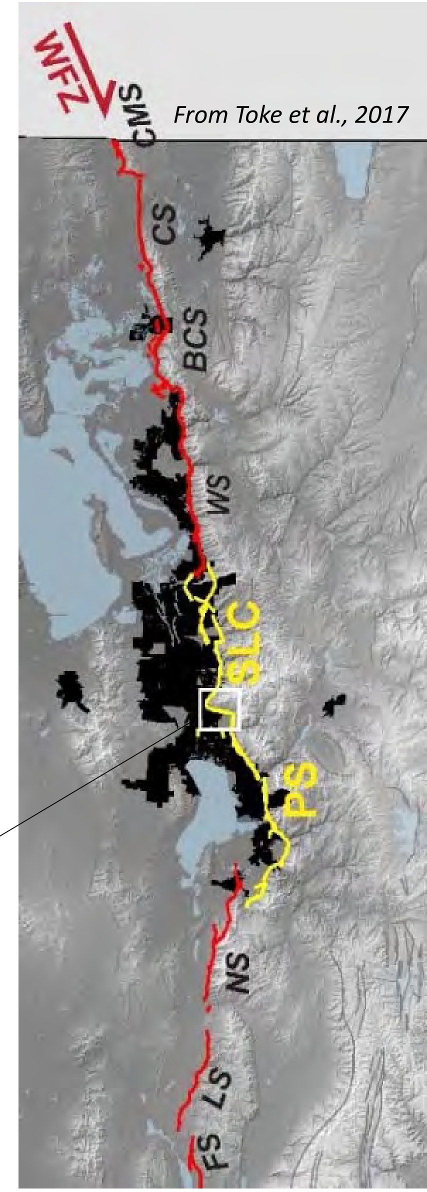
Traverse Ridge Site, Wasatch Fault Segment Boundary

- **Slip-per-event**: 0.5 – 2 m
- **MRE:** 0.2-0.4 ka **E2(PE):** 0.6-3.4 ka **E3?:** 0.6 – 6.2 ka **E4:** 7.2-8.1 ka
- **Earthquake Frequency:** apparently low… 3-4 events since ~8 ka at TR Site
  - ➢ Distributed rupture through boundary?
  - ➢ Discontinuous in places (i.e., sub surface)?
  - ➢ Small vertical displacements, not preserved?

Present 7 ka



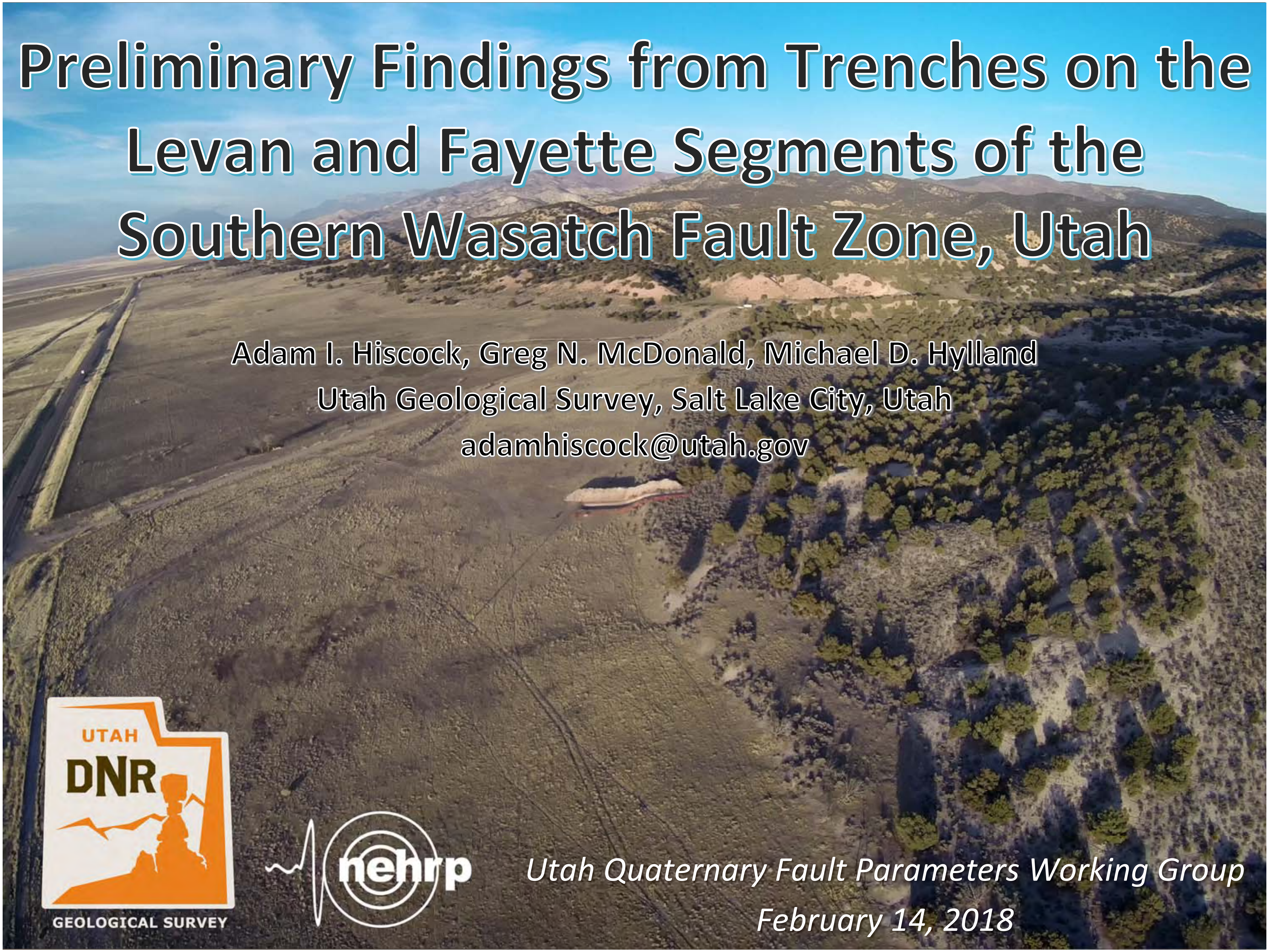
Modified from DuRoss et al., in review



From Toke et al., 2017

Preliminary Findings from Trenches on the Levan and Fayette Segments of the Southern Wasatch Fault Zone, Utah

Adam I. Hiscock, Greg N. McDonald, Michael D. Hylland
Utah Geological Survey, Salt Lake City, Utah
adamhiscock@utah.gov



UTAH DNR GEOLOGICAL SURVEY

nehrp

Utah Quaternary Fault Parameters Working Group

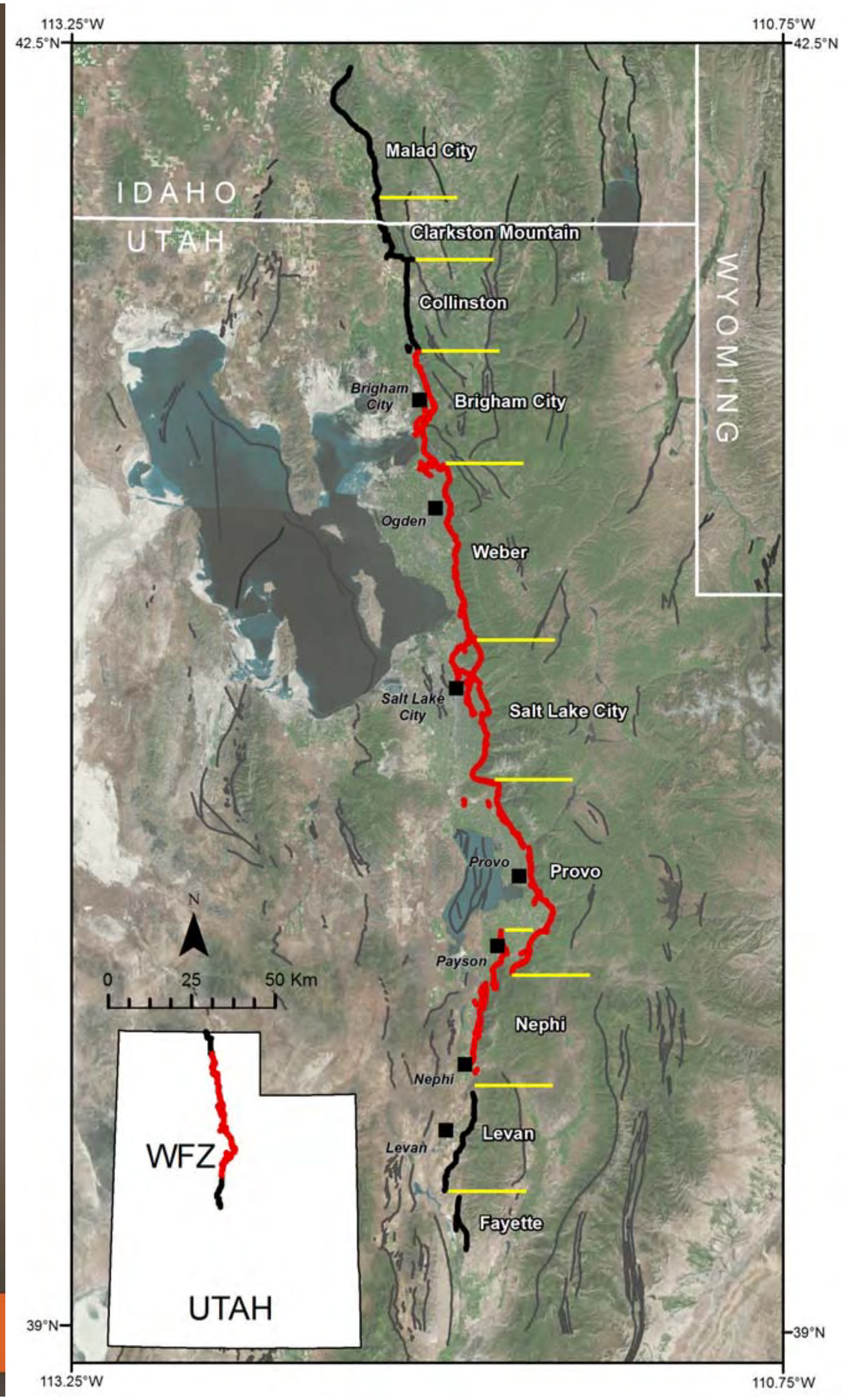
February 14, 2018

Purpose

- Southernmost 2 segments of the WFZ – Levan (LS) and Fayette (FS) segments
- Very little paleoseismic data – earthquake timing poorly constrained on LS, non existent on FS
- Both segments show evidence of Holocene rupture
- Data will provide insights into segment boundary evolution
- Large discrepancy between geodetic and geologic strain rates in southern WFZ
- Does salt dissolution play a role in faulting on the LS and FS?

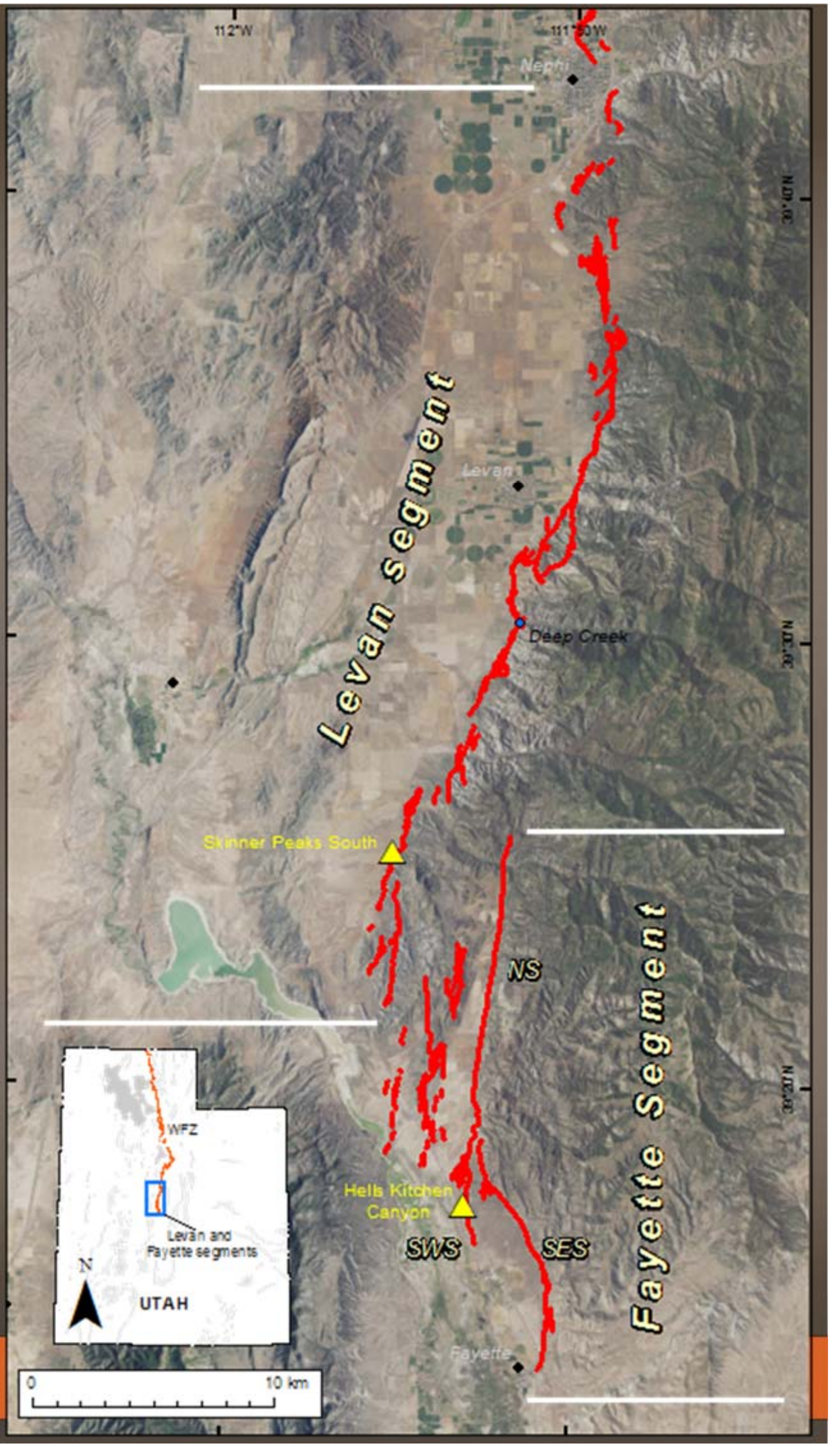
UTAH DNR GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY



Location

- Selected 2 sites – Skinner Peaks South and Hells Kitchen South
- Sites on private and public land (BLM)
- Excavated 1 trench at each site on October 10, 2017; backfilled on November 1, 2017



Previous Work on Levan Segment

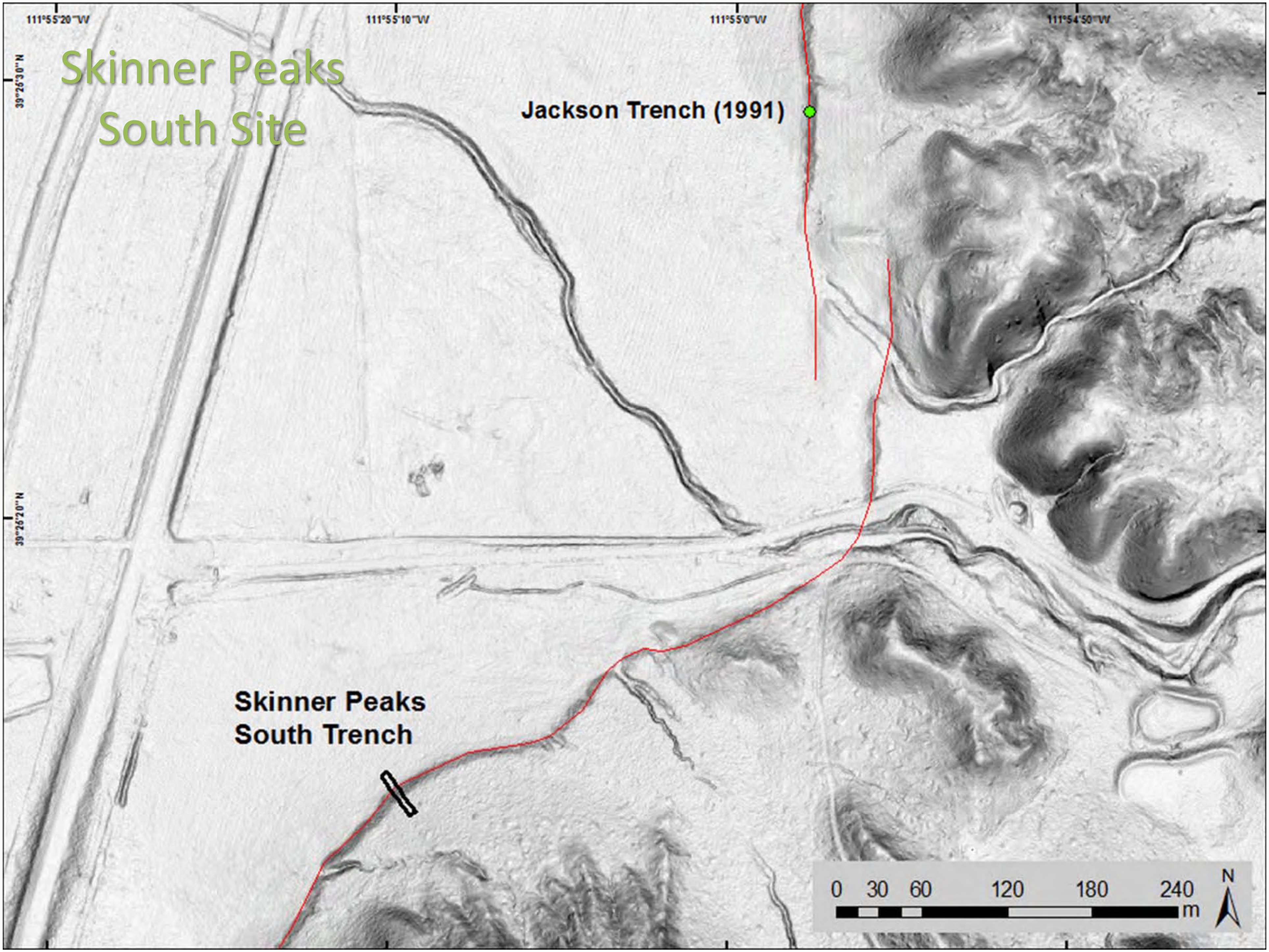
- Jackson (1991) – single trench excavated near Skinner Peaks
  - Evidence for 2 surface-faulting EQ's
  - MRE around 1.0 to 1.5 ka, PE prior to 3.1-3.9 ka
  - Shallow bedrock encountered in footwall – unable to correlate deposits across the fault
- Additionally, Jackson logged Deep Creek natural exposure and constrained MRE age
- Hylland and Machette (2008) – collected C-14 samples from Deep Creek natural exposure as well as faulted fan alluvium near Skinner Peaks
  - Ages consistent with MRE timing of around 1 ka

Previous Work on Levan/Fayette Segments

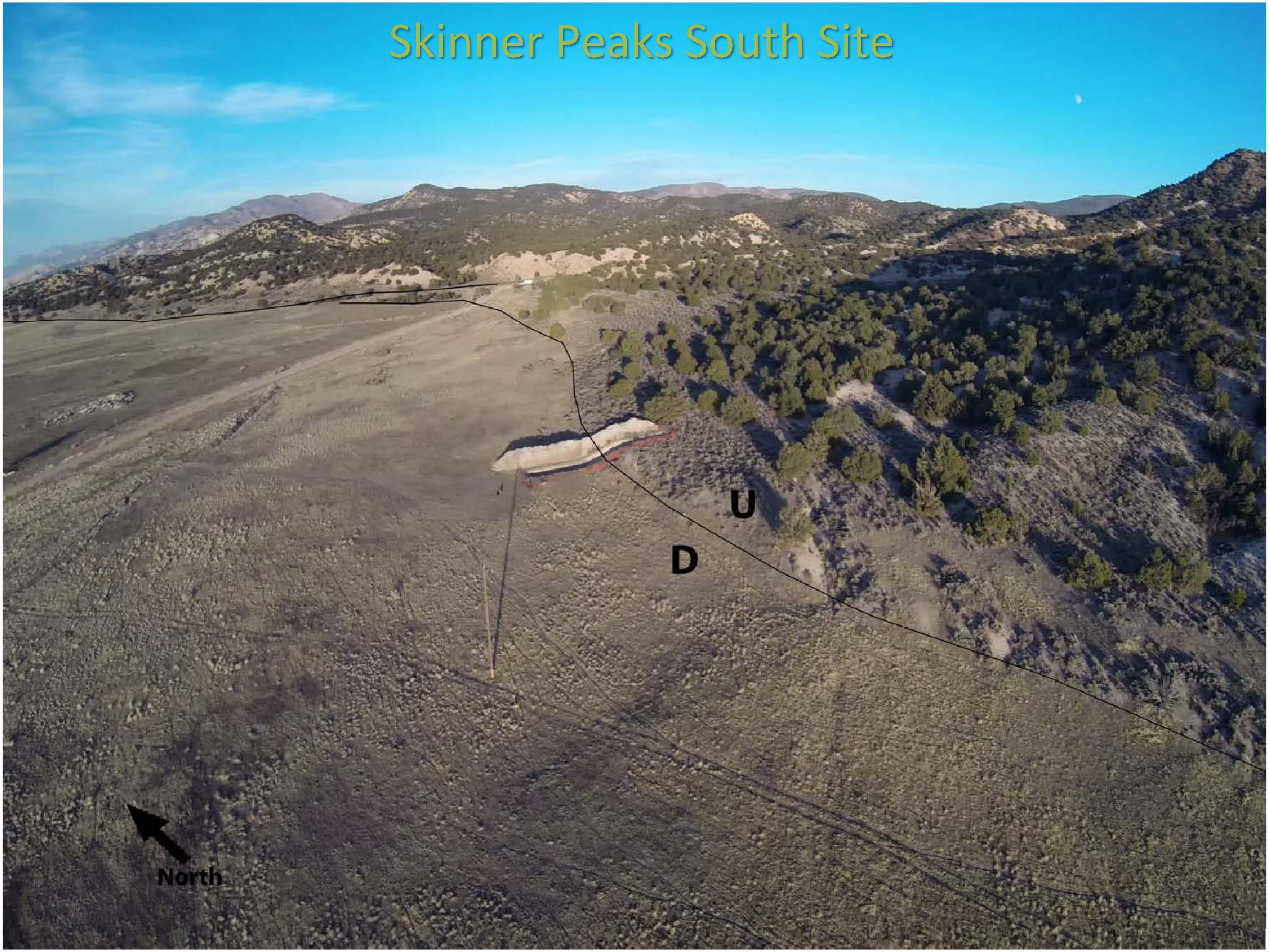
- Hylland and Machette (2008) – completed 31 fault-scarp profiles on the LS, 21 profiles on the FS
  - Indicated composite scarp morphology on Holocene deposits on the southern LS vs. simple scarp morphology on the northern LS (single-event scarps).
  - Speculated the LS PE may represent spill-over rupture from a FS surface-faulting earthquake
- Hiscock and Hylland (2015) – completed detailed fault-trace mapping for the LS and FS using 0.5-m LIDAR data

Skinner Peaks South Site

- 3-4 meter scarp
- Coarse, volcanic derived fan material
- Local bedrock: Tertiary Formation of Painted Rocks, Member 5 – volcanic conglomerate & welded tuff

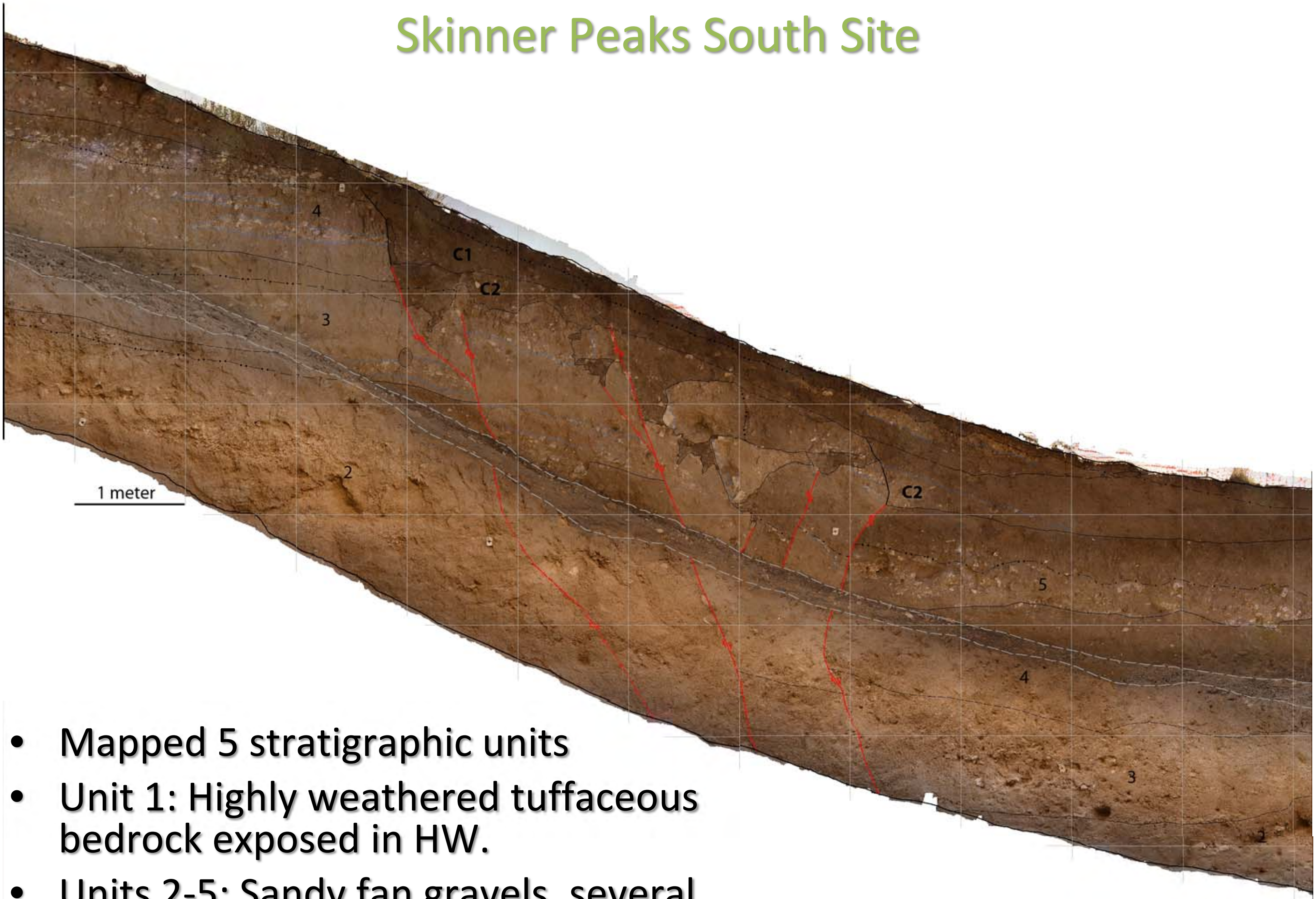

Skinner Peaks South Site
111°55'20"W
111°55'10"W
111°55'0"W
111°54'50"W
39°26'3.0"N
39°26'2.0"N
Jackson Trench (1991)
Skinner Peaks South Trench
0 30 60 120 180 240 m
N


Skinner Peaks South Site
North


Skinner Peaks South Site
U
D
North

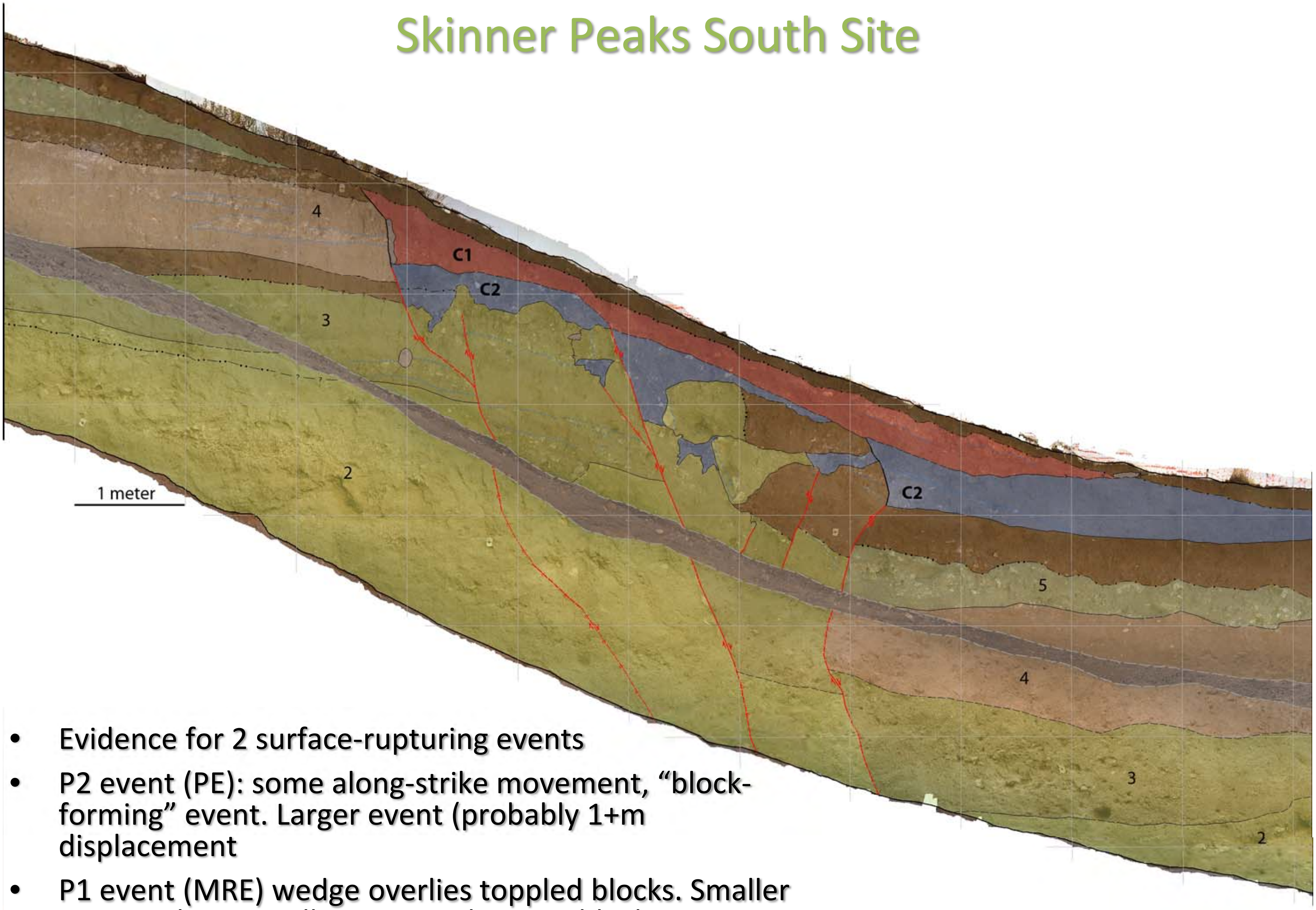

Skinner Peaks South Site

Skinner Peaks South Site



- Mapped 5 stratigraphic units
- Unit 1: Highly weathered tuffaceous bedrock exposed in HW.
- Units 2-5: Sandy fan gravels, several prominent buried soil horizons.

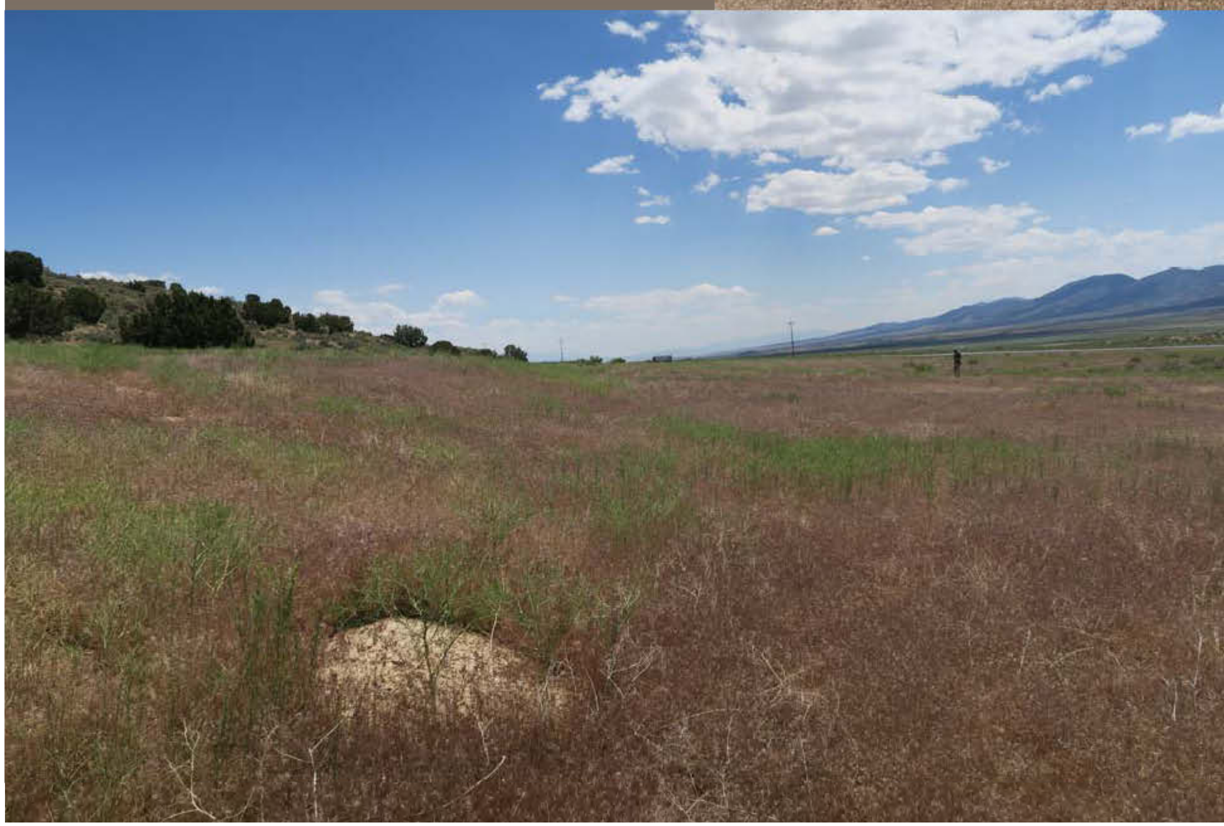
Skinner Peaks South Site



- Evidence for 2 surface-rupturing events
- P2 event (PE): some along-strike movement, “block-forming” event. Larger event (probably 1+m displacement
- P1 event (MRE) wedge overlies toppled blocks. Smaller event – thinner colluvium overlying P2 blocks.

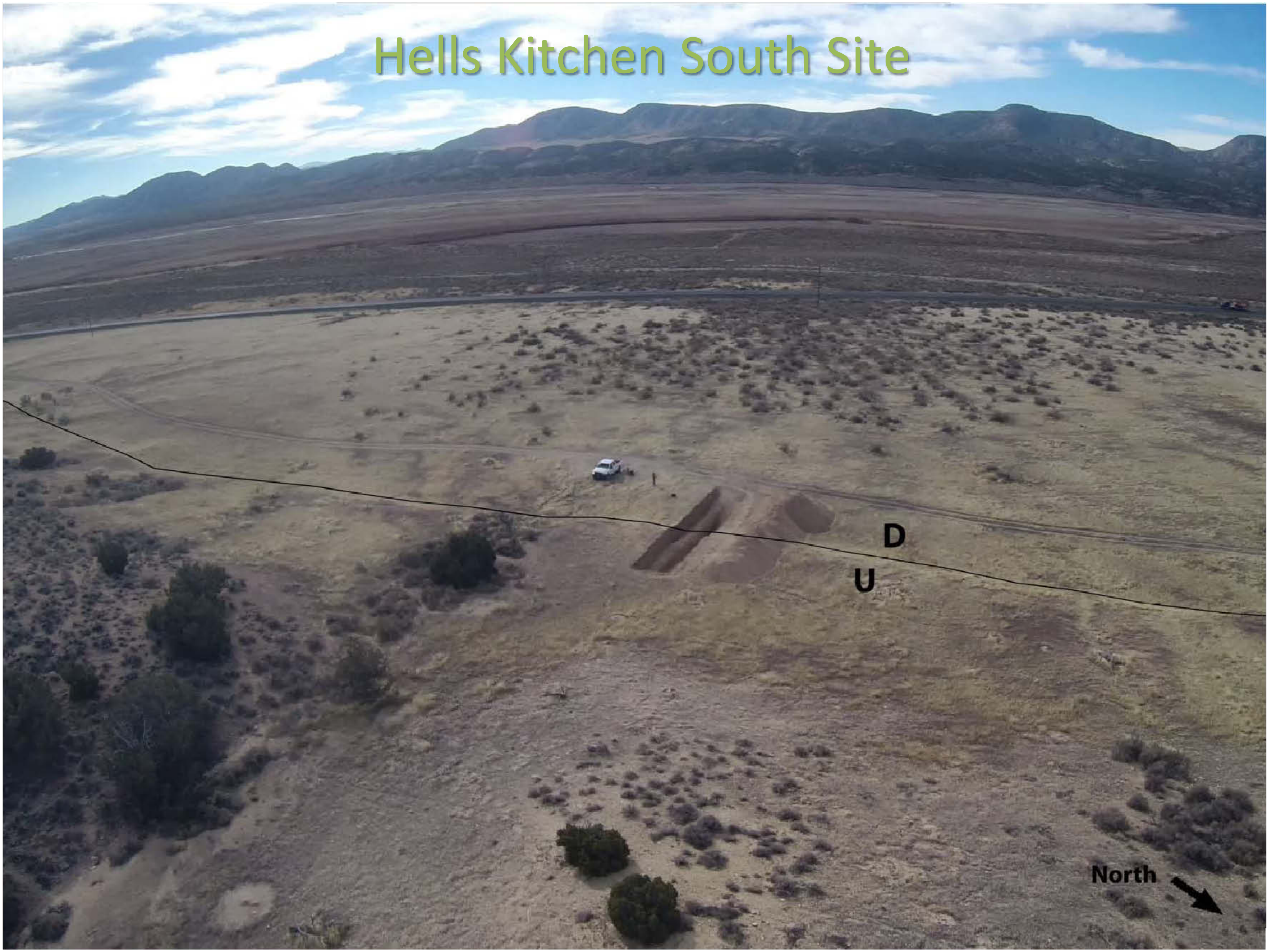
Hells Kitchen South Site

- 1-2 meter scarp
- Carbonate-derived fan material
- Local bedrock: Tertiary units (North Horn, Flagstaff, Colton, Green River formations), Cretaceous Indianola Group



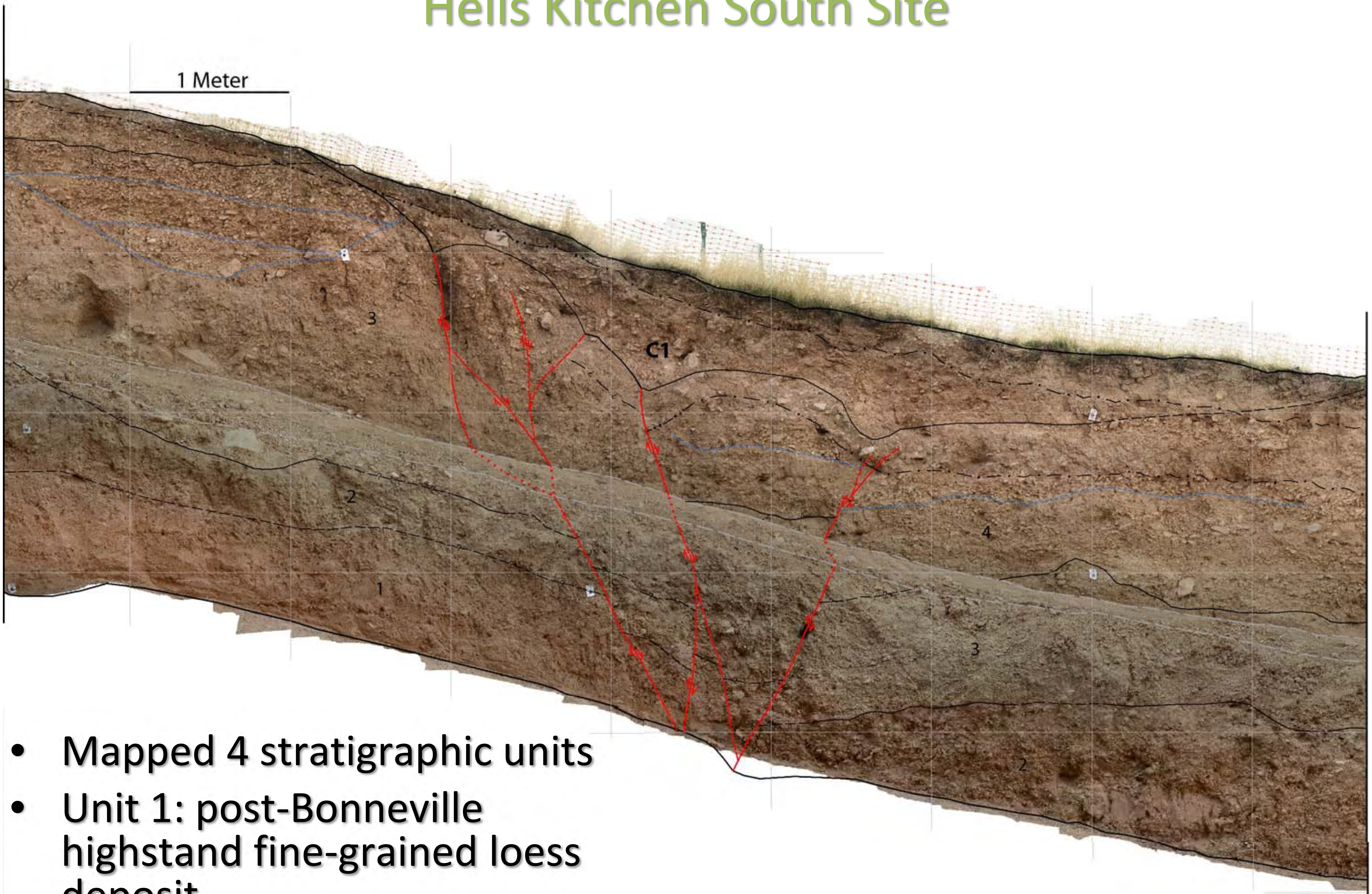
Hells Kitchen South Site


Hells Kitchen South Site
North


Hells Kitchen South Site
D
U
North

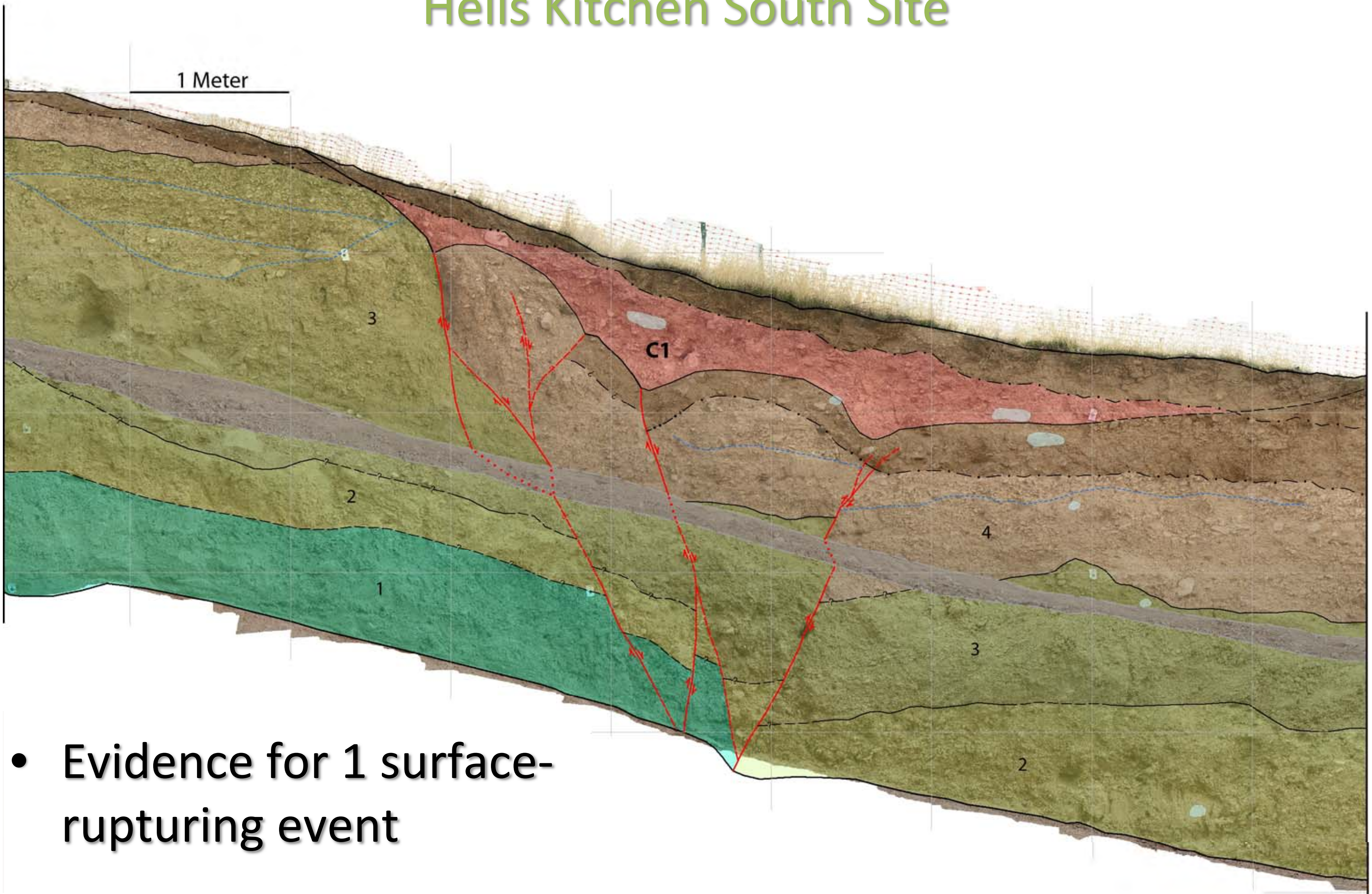

Hells Kitchen South Site

Hells Kitchen South Site



- Mapped 4 stratigraphic units
- Unit 1: post-Bonneville highstand fine-grained loess deposit
- Units 2-4: Coarse fan deposits

Hells Kitchen South Site



- Evidence for 1 surface-rupturing event

Sampling Strategy

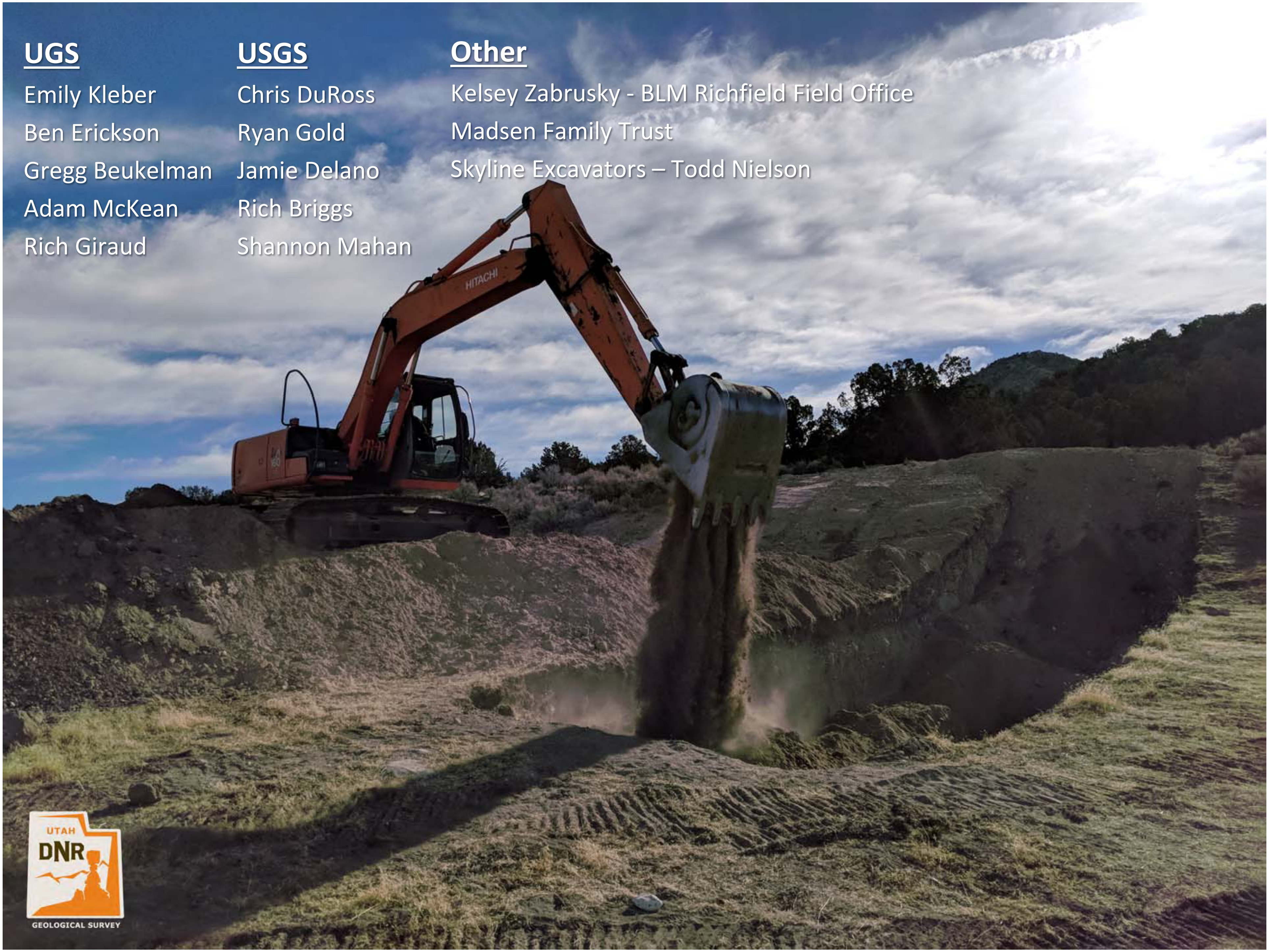
- Collected 20 C-14 samples (4 macro, 16 bulk-soil)
  - 15 sent to PRI for macrofloral analysis
  - NOSAMS for AMS dating
  - Expected dates: Late summer/fall 2018
- Collected 15 OSL samples
  - 10 samples with Shannon Mahan (USGS) for dating

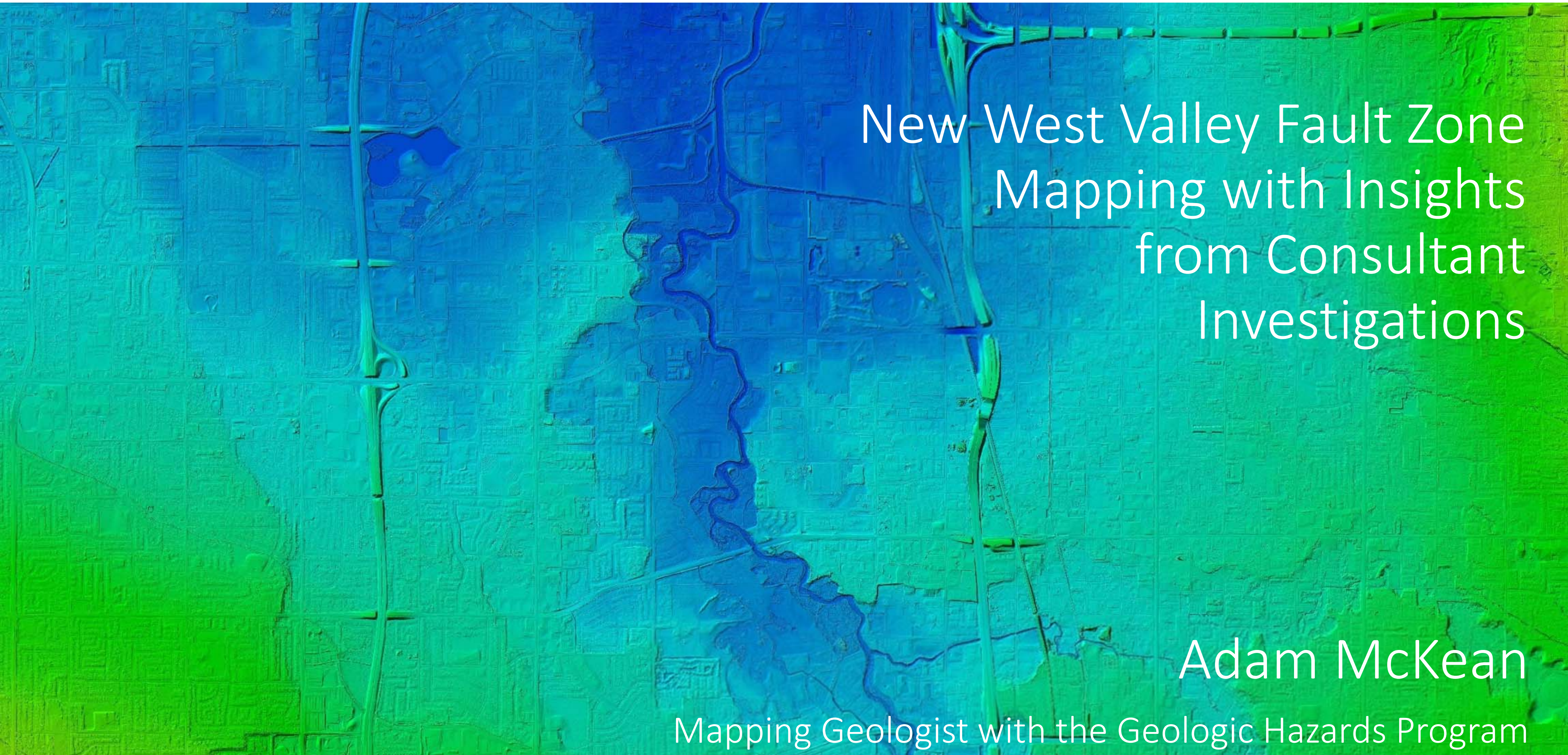
Summary & Conclusions

- Evidence for 2 earthquakes at the Skinner Peaks Site (Levan Segment)
  - MRE potential correlation with 1.0 ka event from Deep Creek natural exposure
  - Potential for PE event to correlate to MRE on FS
- Evidence for 1 earthquake at the Hells Kitchen Canyon Site (Fayette Segment)

Next Steps

- Process C-14 and OSL samples for deposit ages
- Model earthquake rupture timing using OxCal software
- Evaluate rupture models Levan and Fayette segments utilizing this new data
  - Explore segment boundary issues (i.e. spill-over rupture from LS to FS)
  - Explore the issue of salt-dissolution vs. tectonic faulting on the LS and FS using new data


UGS
Emily Kleber
Ben Erickson
Gregg Beukelman
Adam McKean
Rich Giraud
USGS
Chris DuRoss
Ryan Gold
Jamie Delano
Rich Briggs
Shannon Mahan
Other
Kelsey Zabrusky - BLM Richfield Field Office
Madsen Family Trust
Skyline Excavators – Todd Nielson
HITACHI
UTAH
DNR
GEOLOGICAL SURVEY

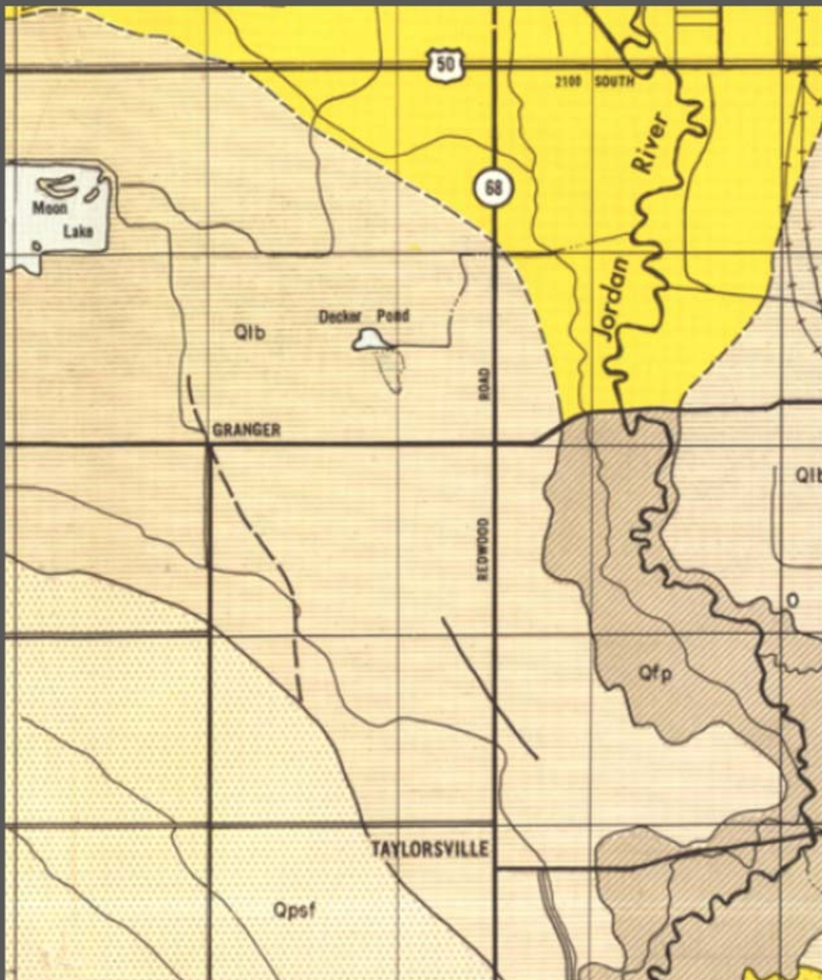


New West Valley Fault Zone Mapping with Insights from Consultant Investigations

Adam McKean

Mapping Geologist with the Geologic Hazards Program

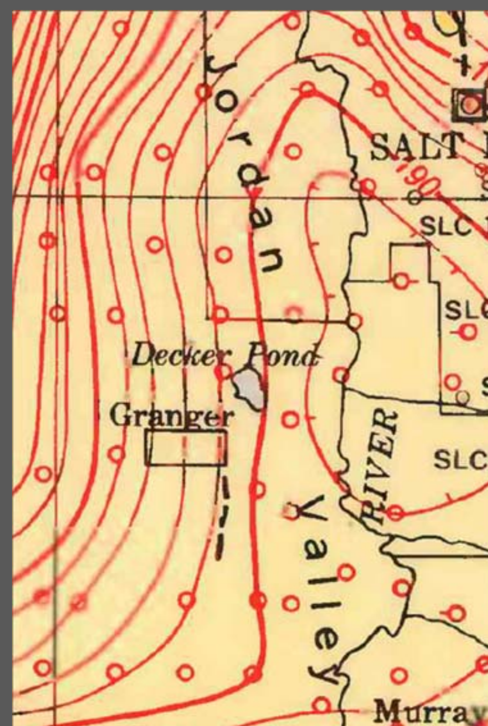
West Valley Fault Zone: History

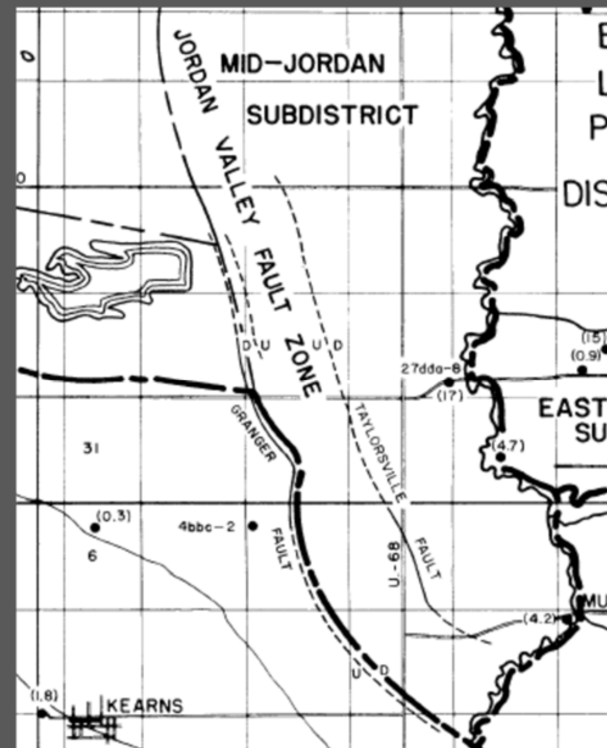


1st shown as faults by Marsell and Threet (1960)

Cook and Berg (1961)

Correlated the faults to their steep gravity gradient in what they called the Jordan Valley graben

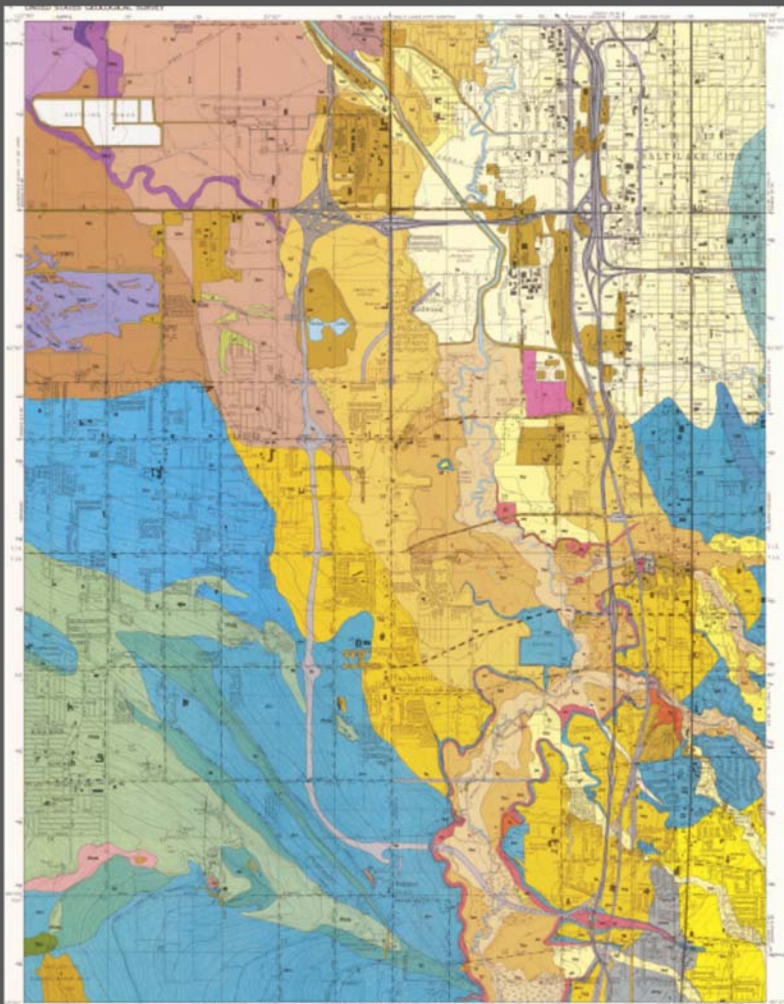




Marine and Price (1964)

Named the faults Granger and Taylorsville faults of the Jordan Valley fault zone, and provided drill hole data for displacement minimums across the faults

West Valley Fault Zone: History



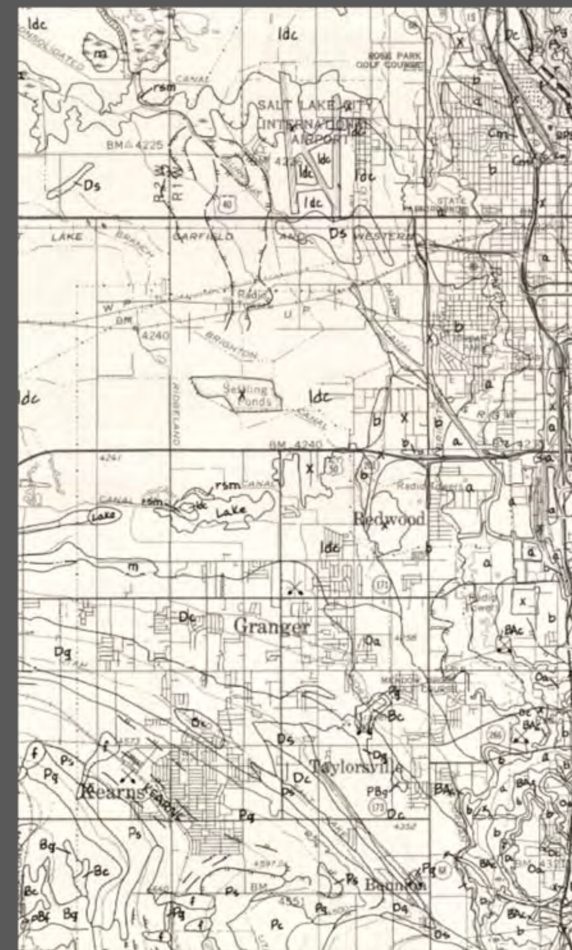
Van Horn’s (1979 and 1982)

Did not show the fault zone

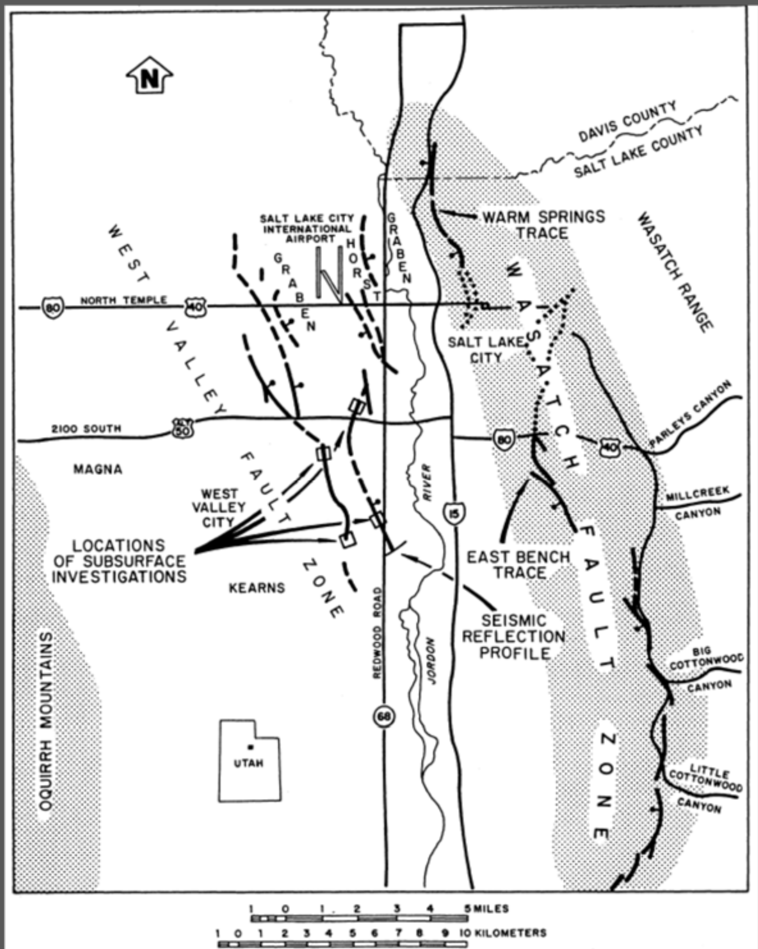
Attributed the scarps to differential erosion of distinct stratigraphic units (Van Horn, 1986, personal communication in Keaton and others, 1987)

Miller’s (1980)

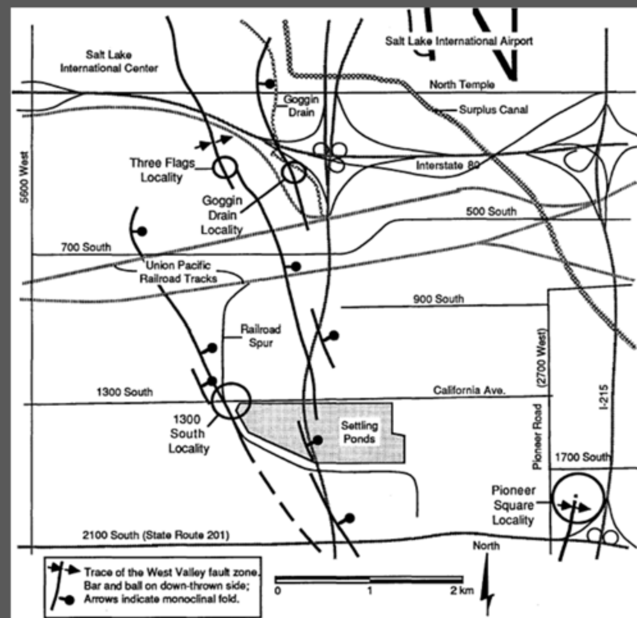
Included the northern part of the Granger fault as scarps with uncertain origin.



West Valley Fault Zone: History



Keaton, Currey, and Olig (1987)
(published in 1993 as UGS Contract Report 93-8)



Keaton and Currey (1989)
(published in 1993 as UGS Contract Report 93-7)

Keaton and others (1987)
Keaton and Currey (1989)

Conducted the first detailed investigations of the fault zone using:

- Geomorphic mapping
- Trenches
- Borings

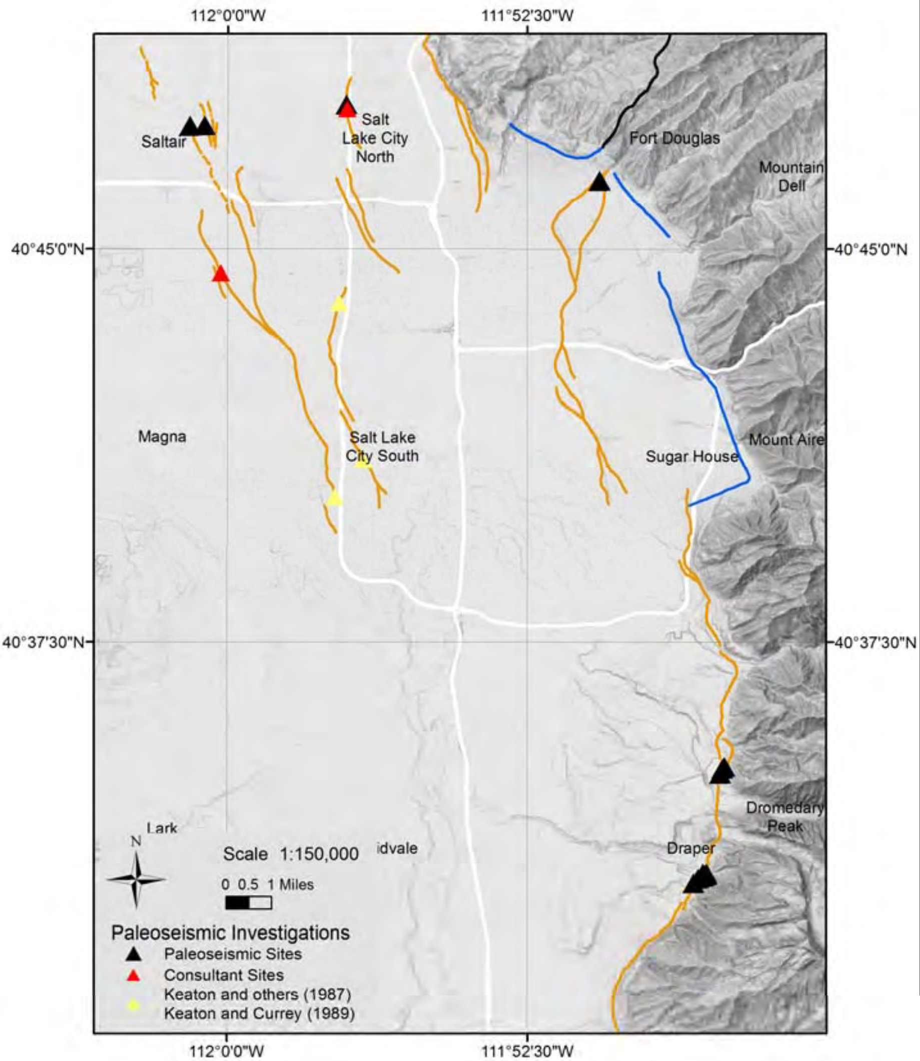
Provided definitive evidence for surface-fault ruptures on the Granger and Taylorsville faults

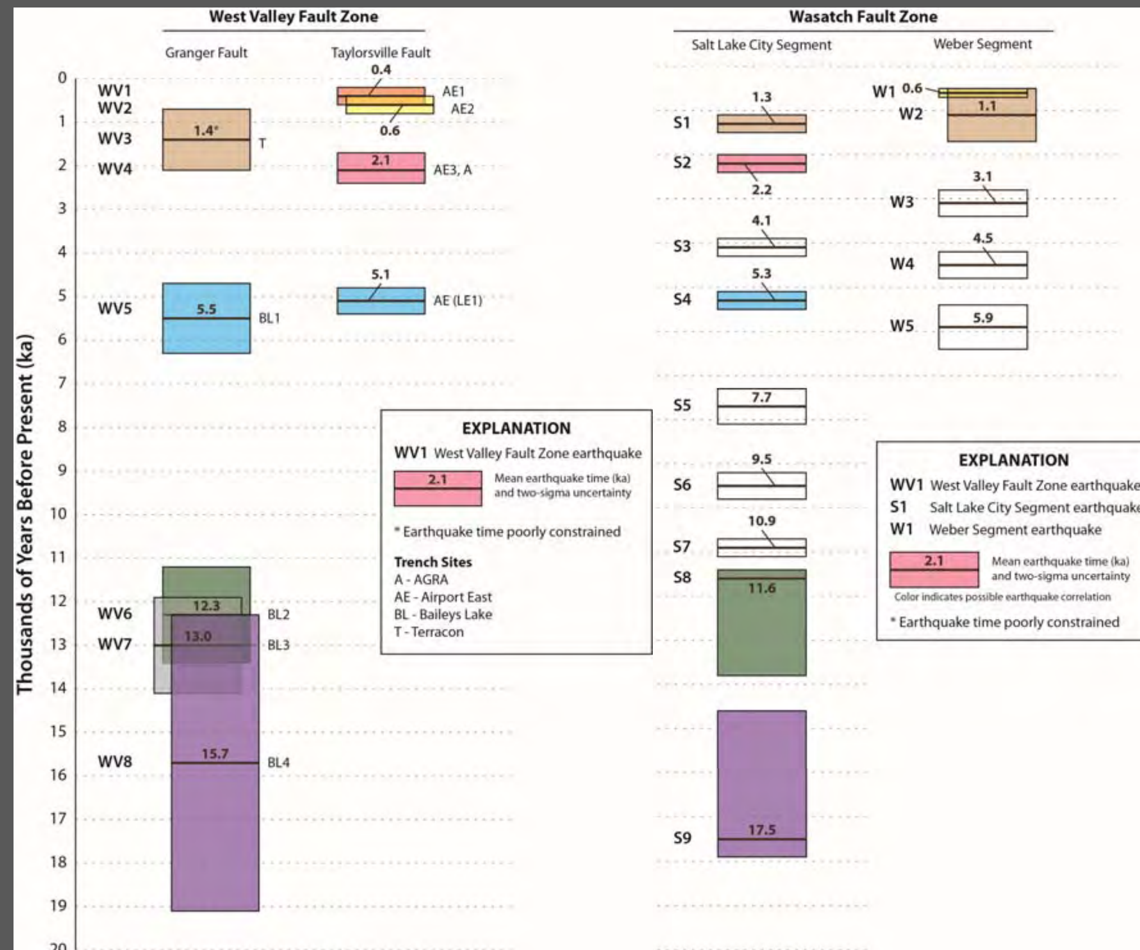
Proposed the West Valley fault zone name

Provided long-term (140 kyr) cumulative displacements and slip rates for the West Valley fault zone

However, they were unable to provide individual earthquake timing and displacement data

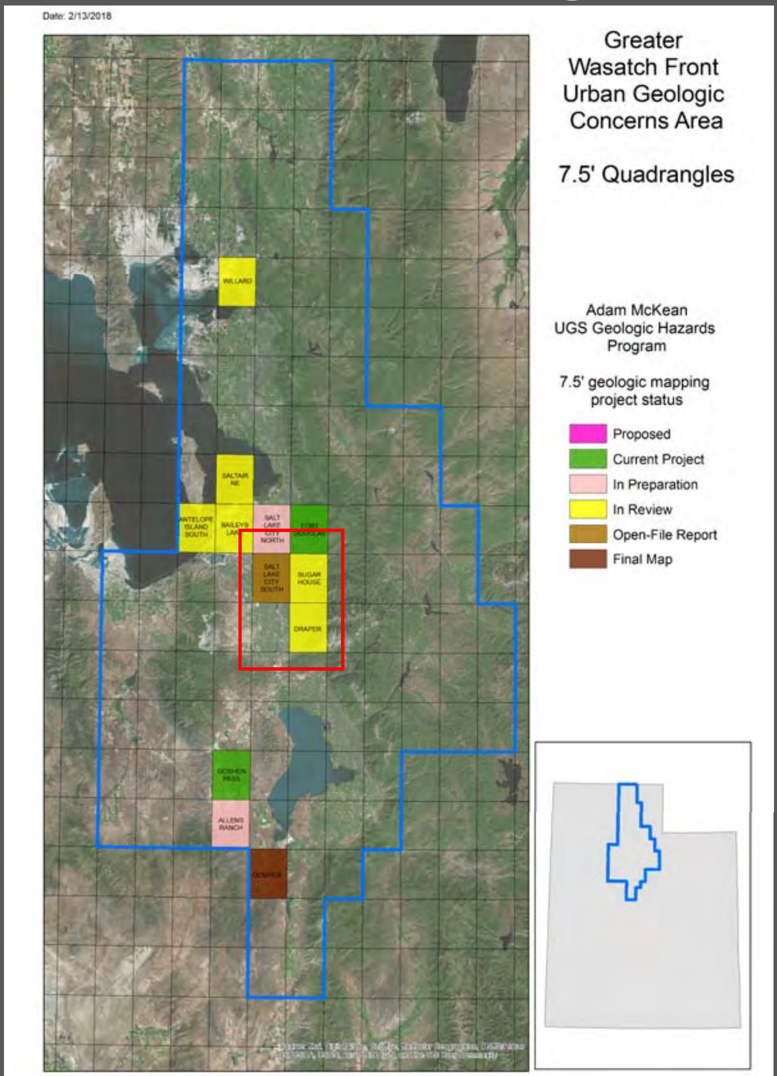
West Valley Fault Zone: Recent Work



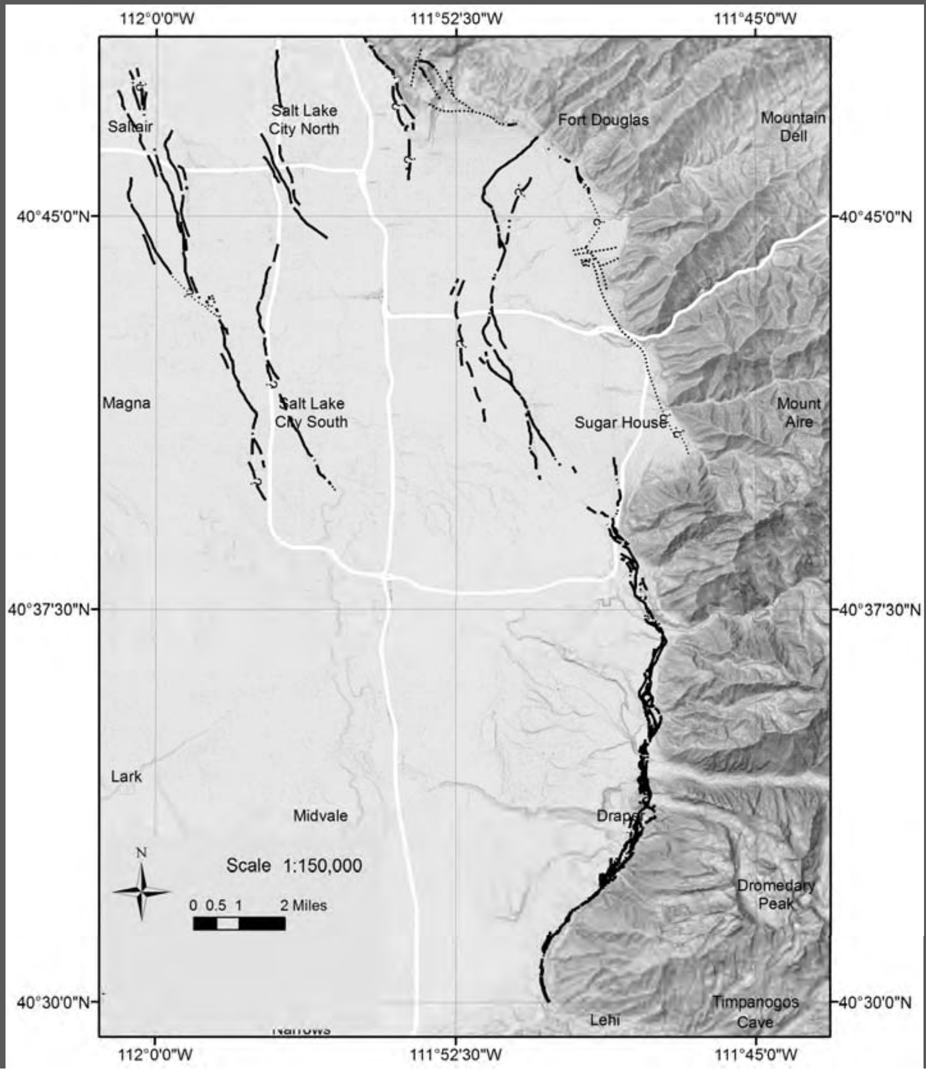


Hylland and others, 2017

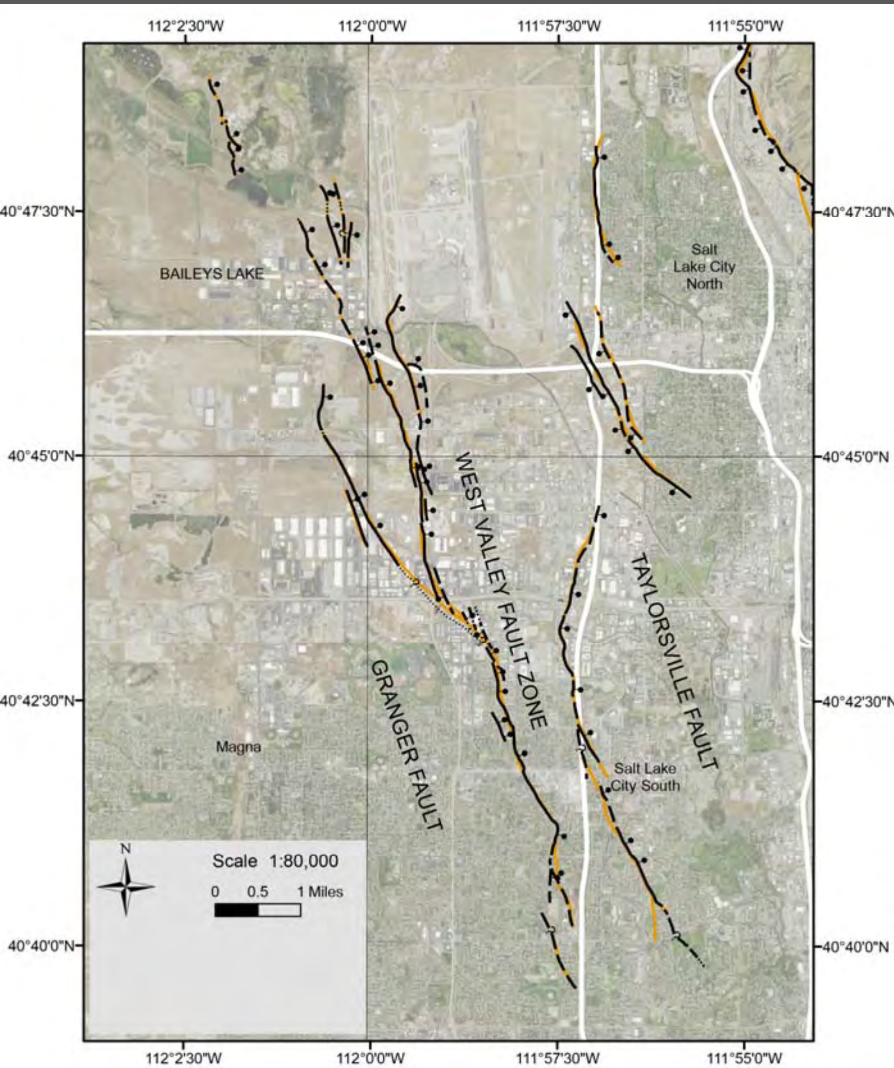
STATEMAP Progress



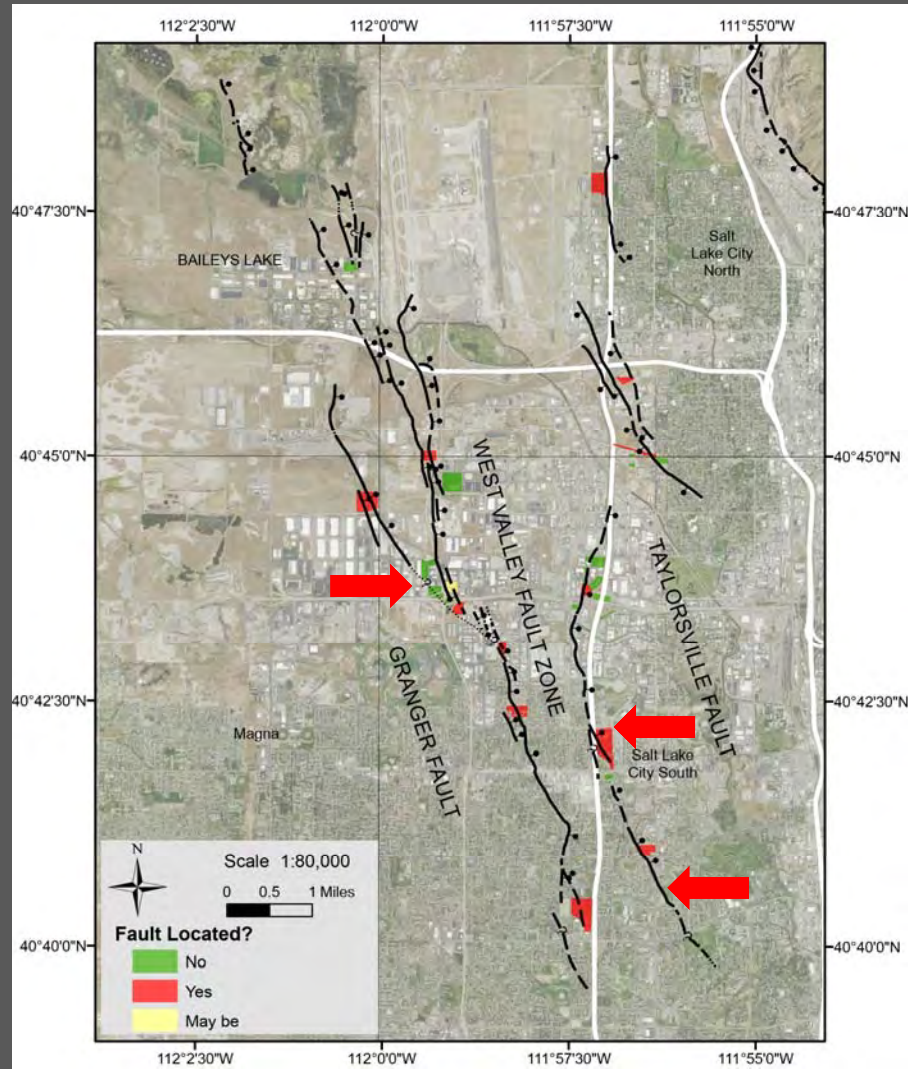
New Mapping

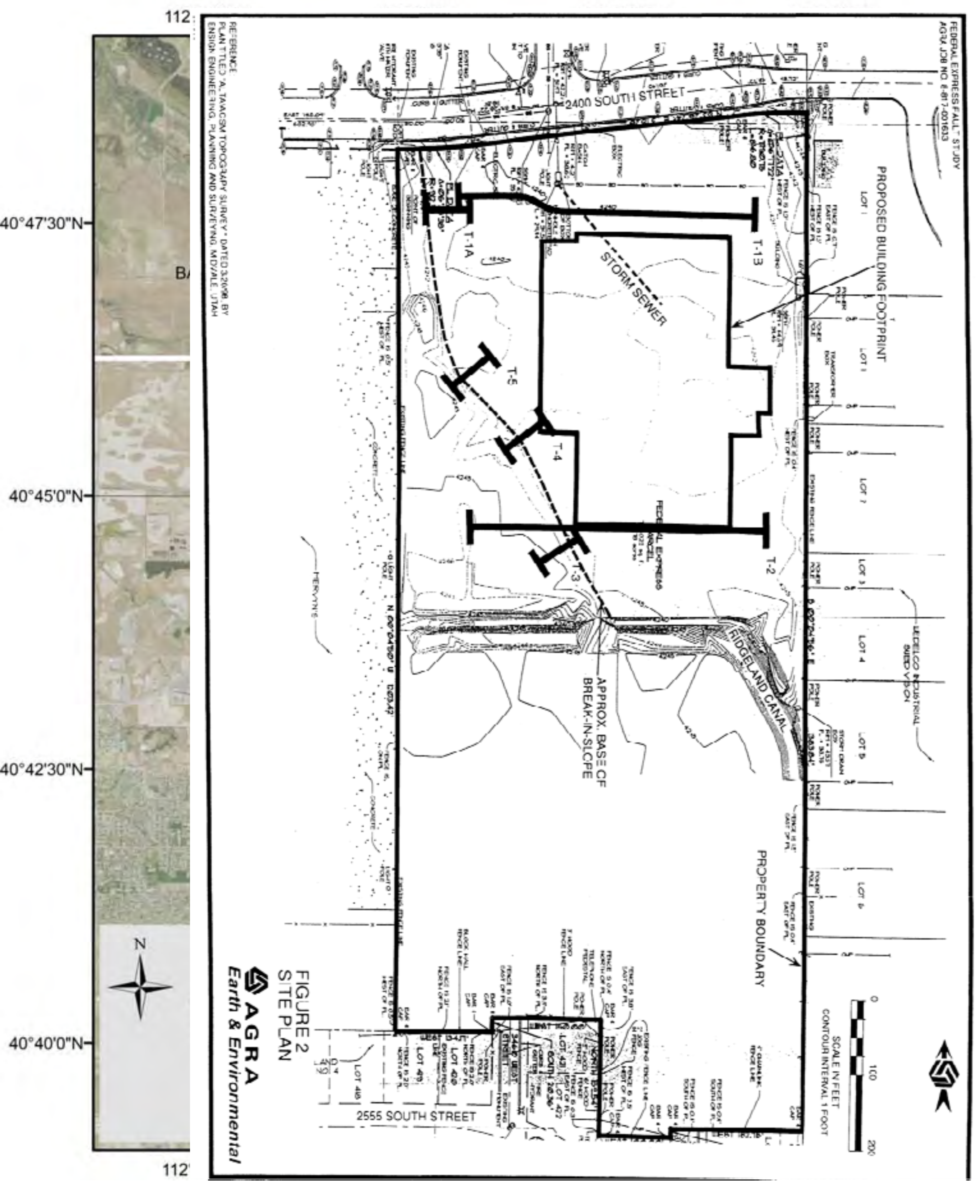


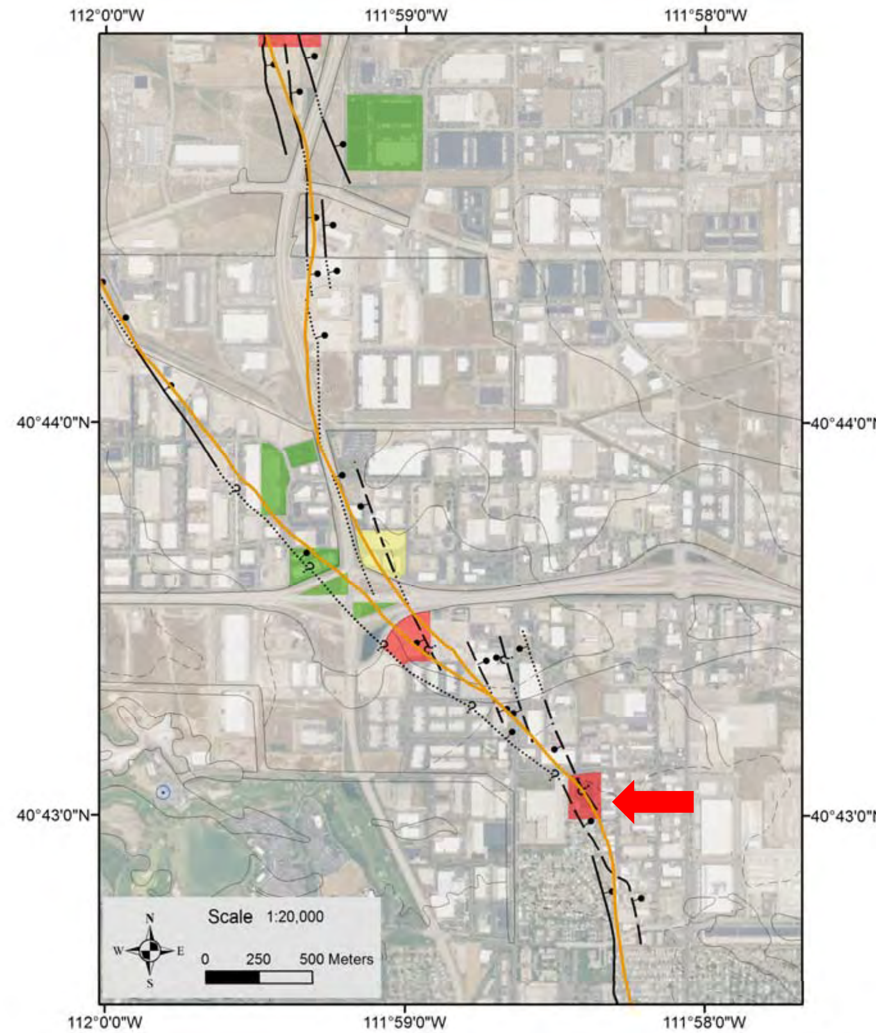
New Mapping



Consultant Investigations




40°47'30"N
40°45'0"N
40°42'30"N
40°40'0"N
2400 SOUTH STREET
2555 SOUTH STREET
STORM SEWER
PROPOSED BUILDING FOOTPRINT
RIDGELAND CANAL
APPROX. BASE OF BREAK-IN-SLOPE
PROPERTY BOUNDARY
FIGURE 2
SITE PLAN
AGRA
Earth & Environmental


112°0'0"W
111°59'0"W
111°58'0"W
40°44'0"N
40°43'0"N
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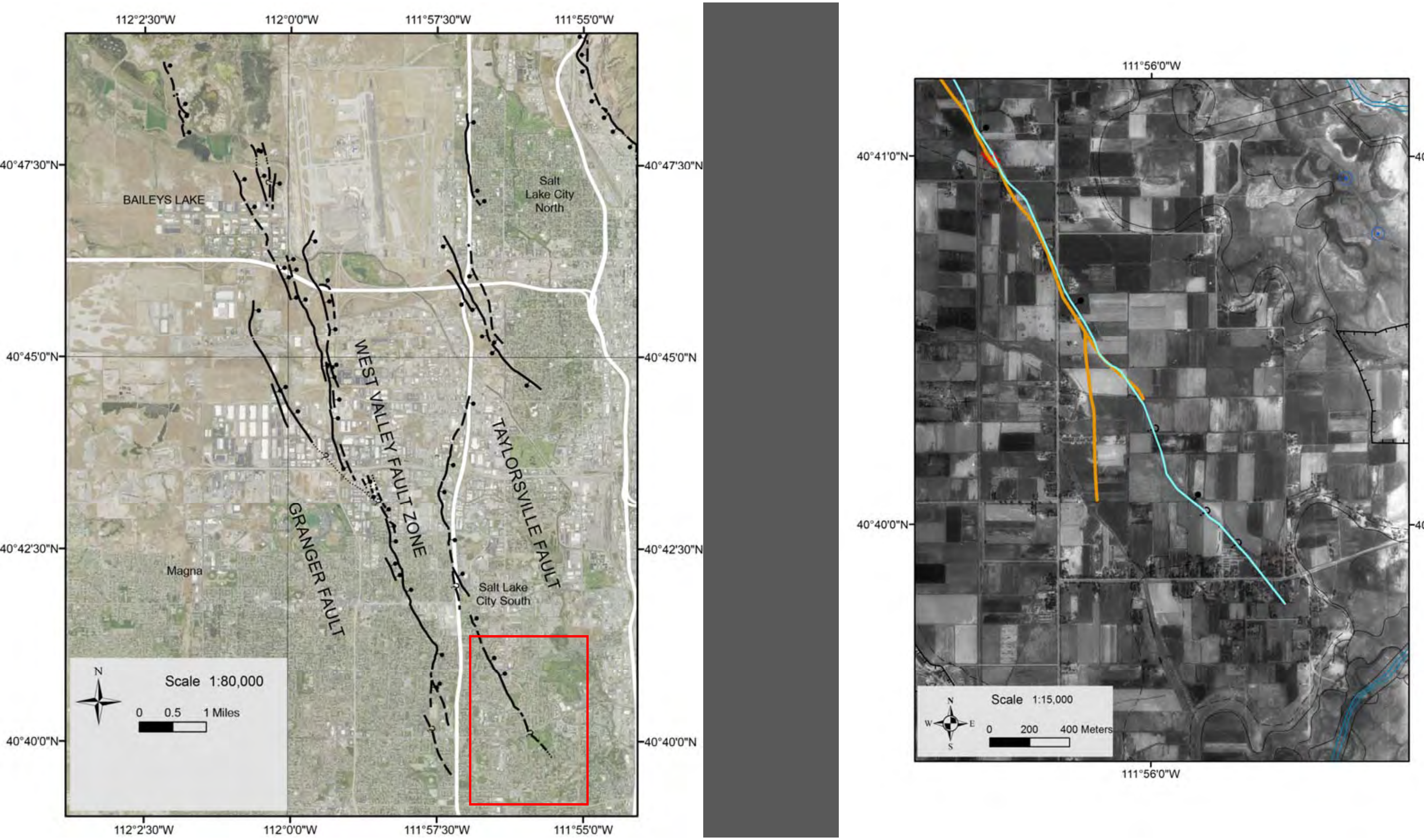
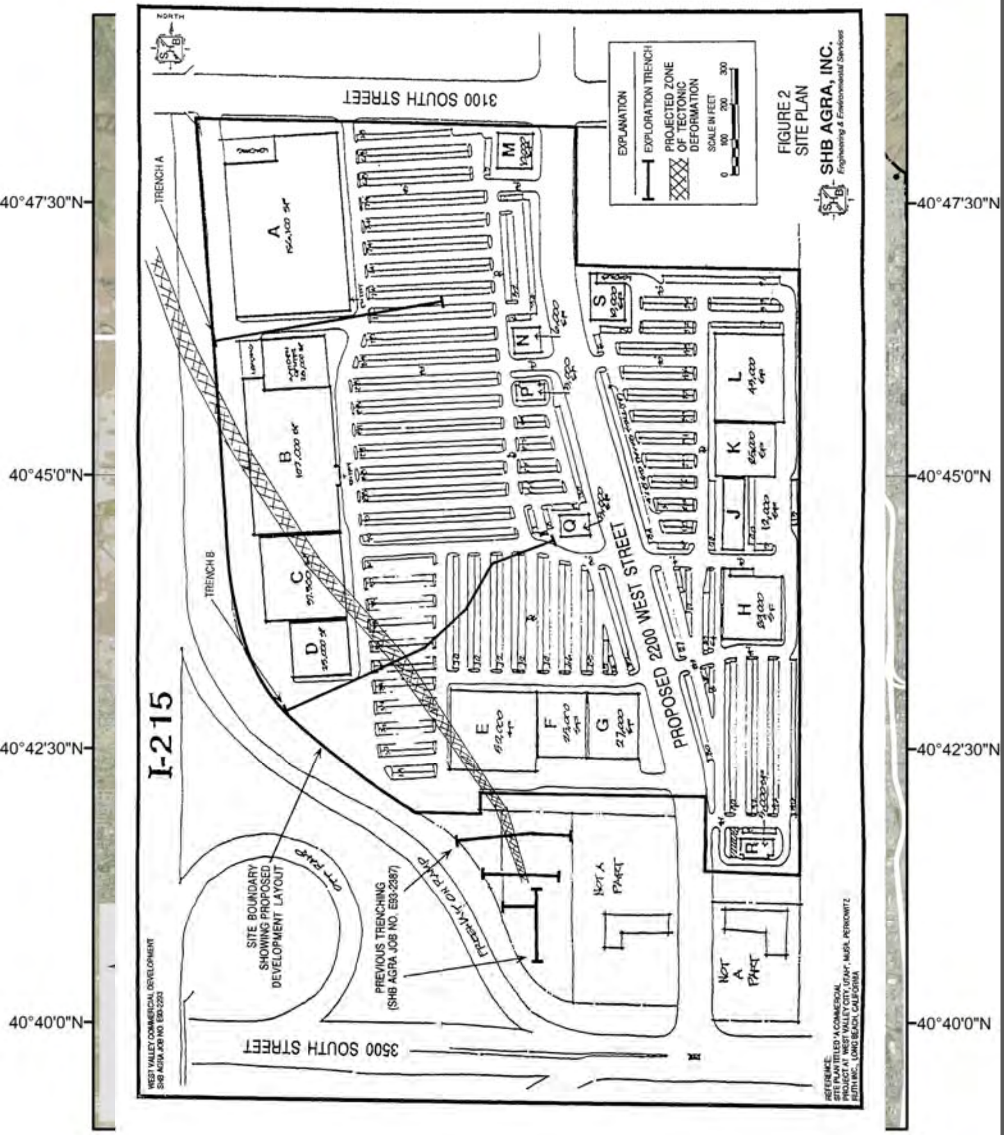
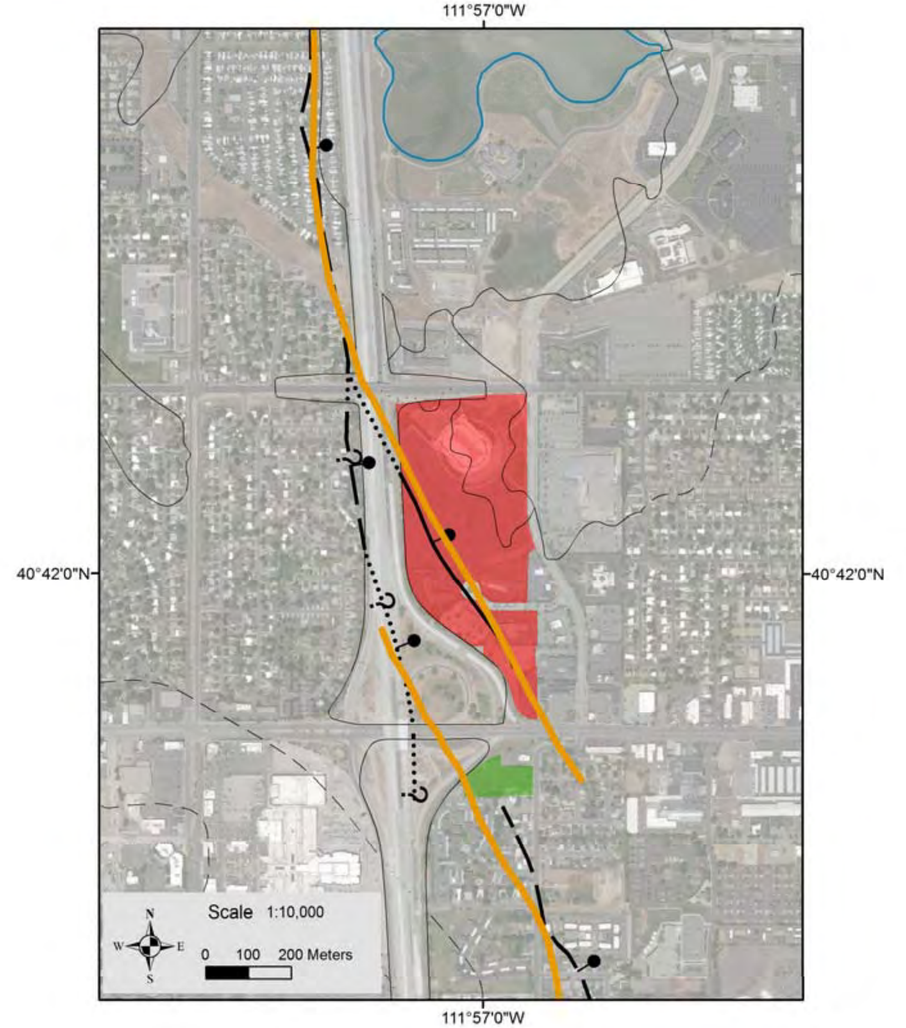
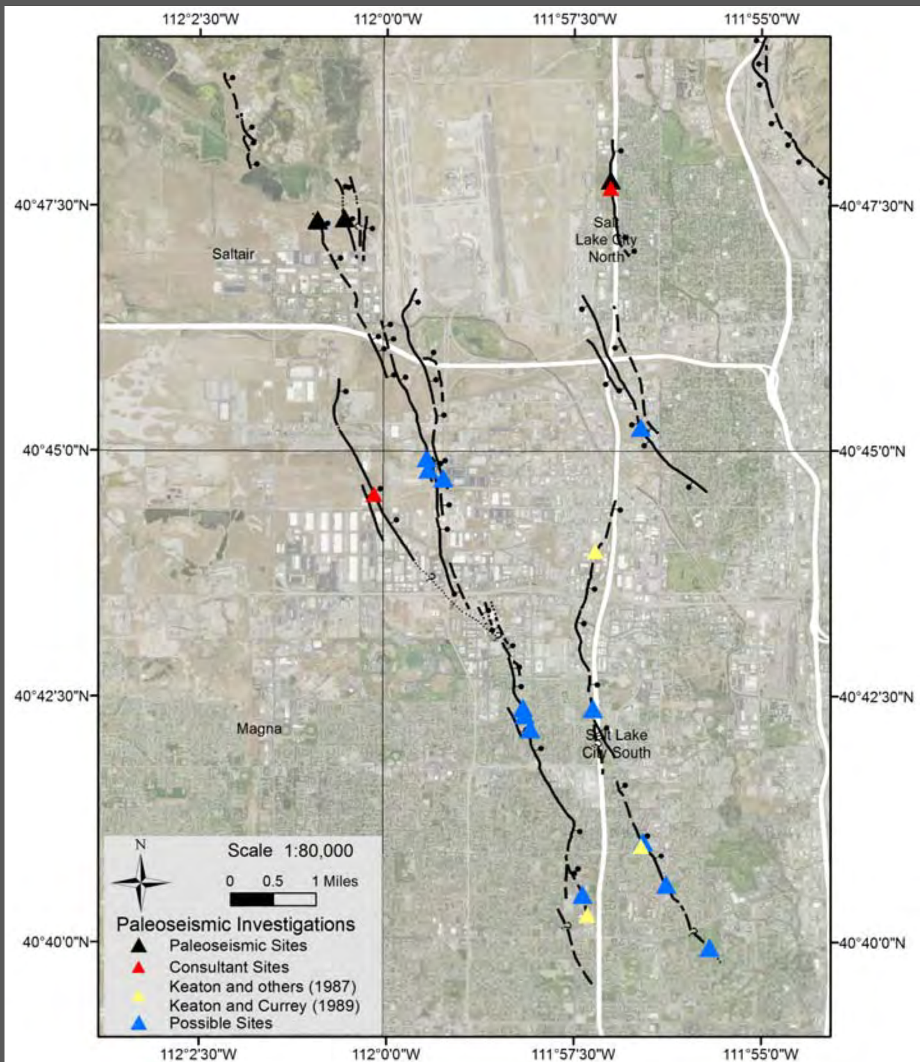
0 250 500 Meters

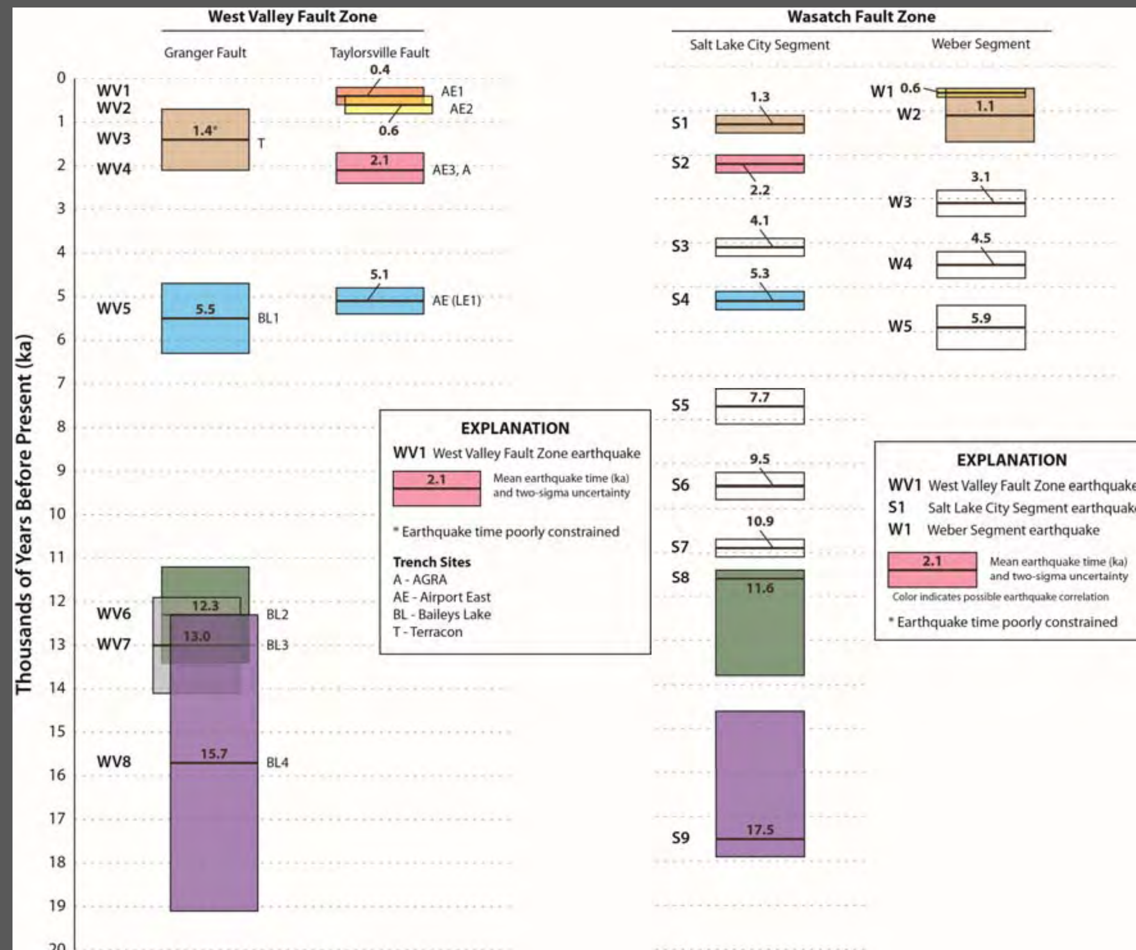

112°2'30"W
112°0'0"W
111°57'30"W
111°55'0"W
40°47'30"N
40°45'0"N
40°42'30"N
40°40'0"N
BAILEYS LAKE
Salt Lake City North
WEST VALLEY FAULT ZONE
TAYLORSVILLE FAULT
GRANGER FAULT
Magna
Salt Lake City South
N
Scale 1:80,000
0 0.5 1 Miles
111°56'0"W
40°41'0"N
40°40'0"N
N
W
E
S
Scale 1:15,000
0 200 400 Meters


40°47'30"N
40°45'0"N
40°42'30"N
40°40'0"N
3100 SOUTH STREET
3500 SOUTH STREET
I-215
PROPOSED 2200 WEST STREET
TRENCH A
TRENCH B
EXPLANATION
EXPLORATION TRENCH
PROJECTED ZONE OF TECTONIC DEFORMATION
SCALE IN FEET
FIGURE 2
SITE PLAN
SHB AGRA, INC.
Engineering & Environmental Services
SITE BOUNDARY SHOWING PROPOSED DEVELOPMENT LAYOUT
PREVIOUS TRENCHING (SHB AGRA JOB NO. E93-2387)
NOT A PART

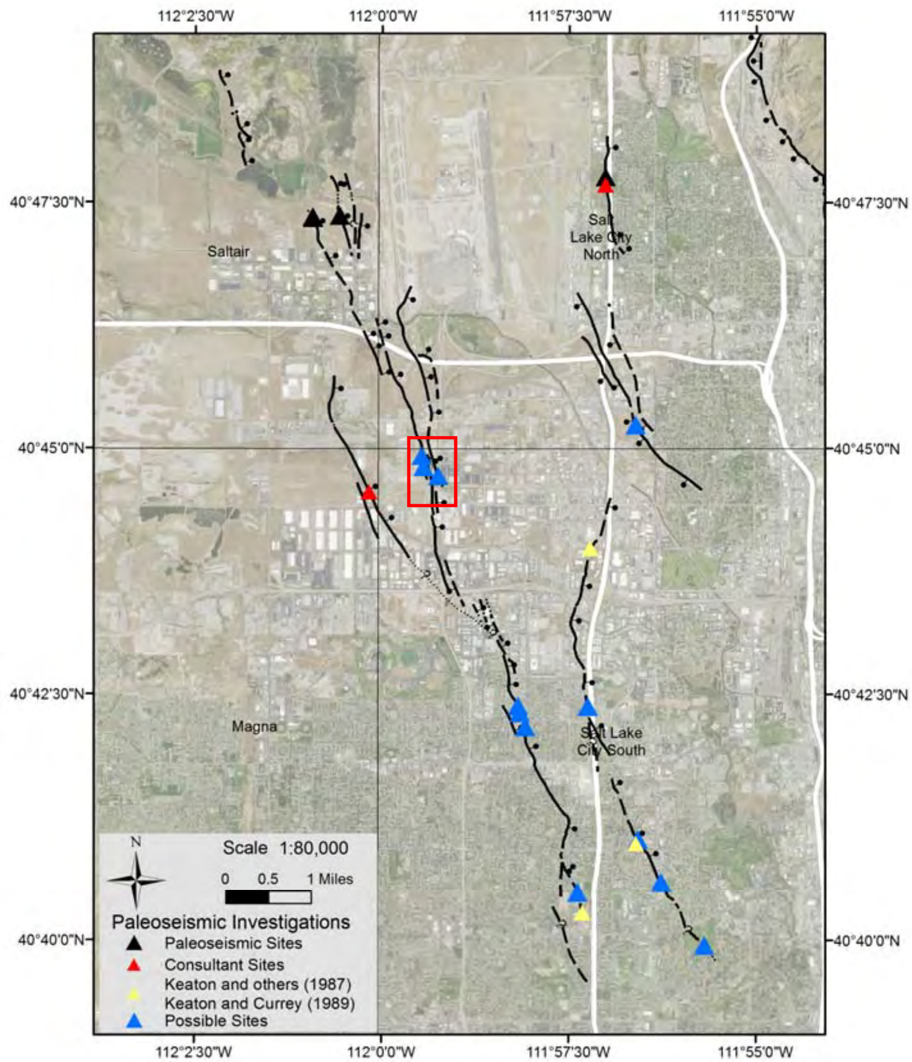

111°57'0"W
40°42'0"N
Scale 1:10,000
N
S
E
W
0 100 200 Meters

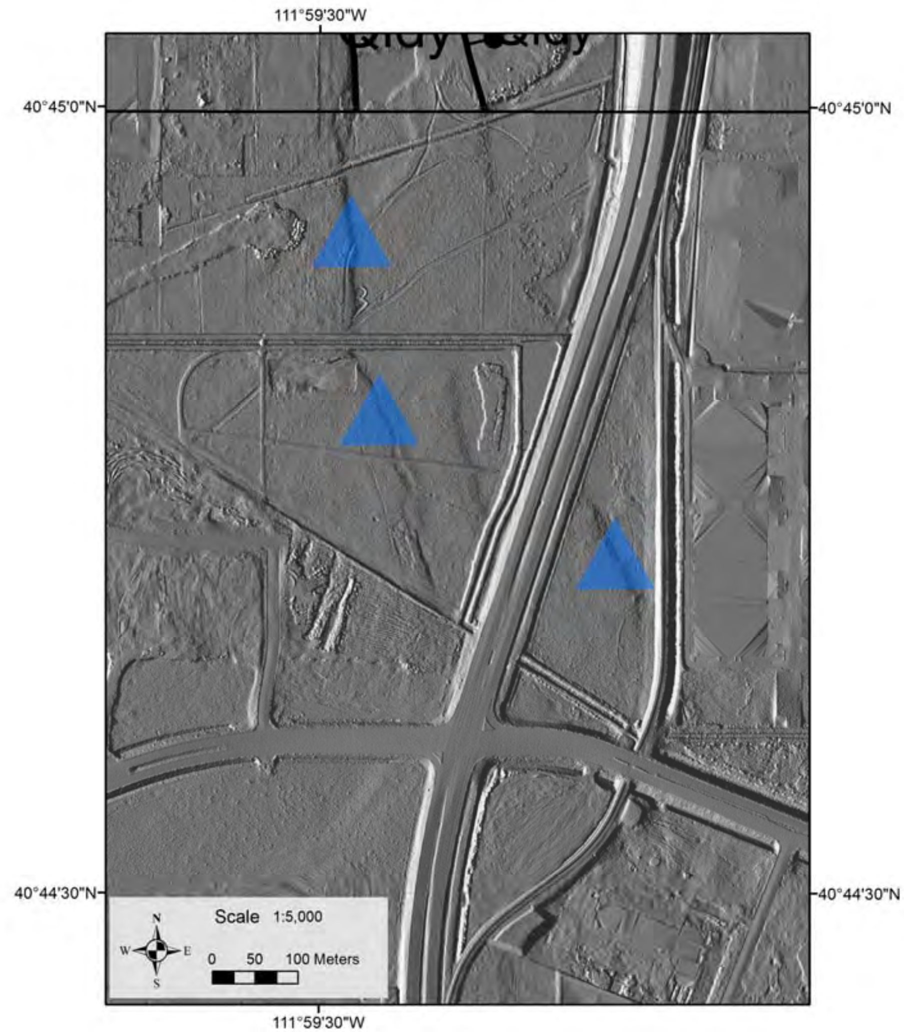
Potential Paleoseismic Sites

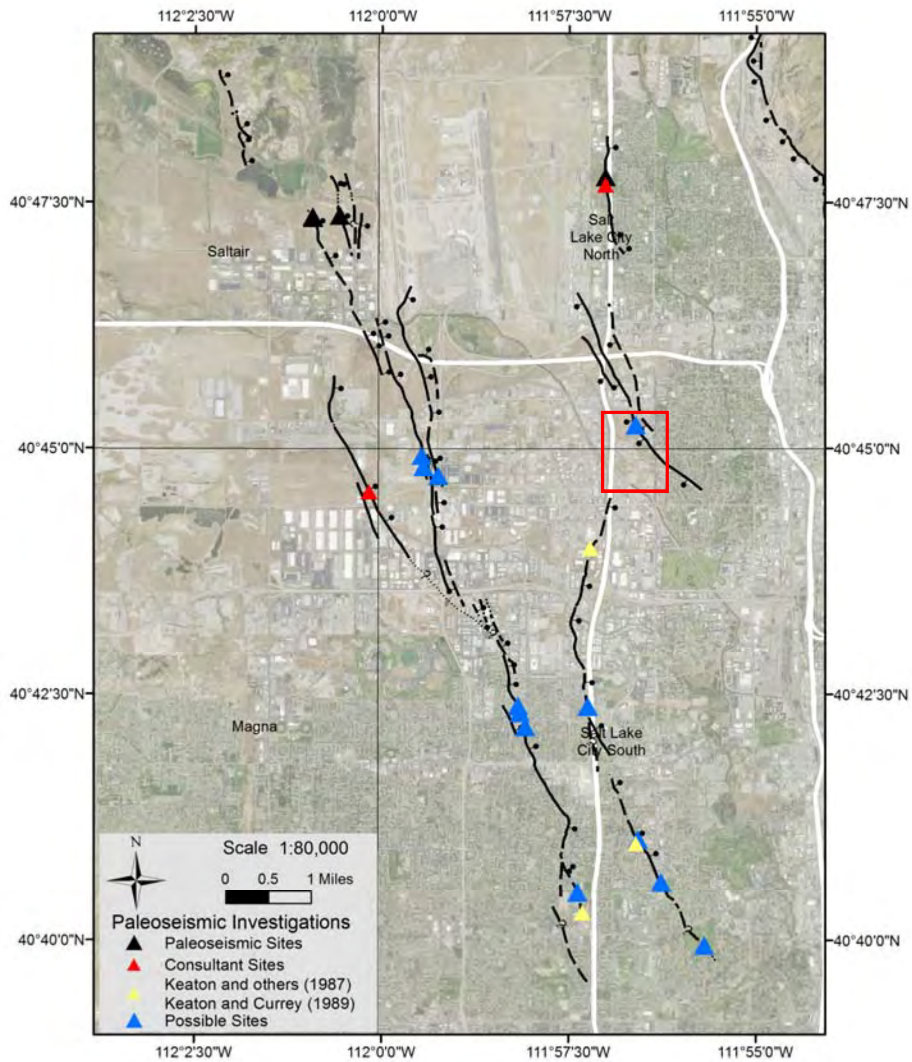




Hylland and others, 2017


112°2'30"W
112°0'0"W
111°57'30"W
111°55'0"W
40°47'30"N
40°45'0"N
40°42'30"N
40°40'0"N
Saltair
Salt Lake City North
Magna
Salt Lake City South
Scale 1:80,000
0 0.5 1 Miles
N
Paleoseismic Investigations
Paleoseismic Sites
Consultant Sites
Keaton and others (1987)
Keaton and Currey (1989)
Possible Sites


111°59'30"W
40°45'0"N
40°44'30"N
Scale 1:5,000
N
W
E
S
0 50 100 Meters



112°2'30"W
112°0'0"W
111°57'30"W
111°55'0"W
40°47'30"N
40°45'0"N
40°42'30"N
40°40'0"N
Saltair
Salt Lake City North
Magna
Salt Lake City South
Scale 1:80,000
0 0.5 1 Miles
N
Paleoseismic Investigations
Paleoseismic Sites
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Keaton and others (1987)
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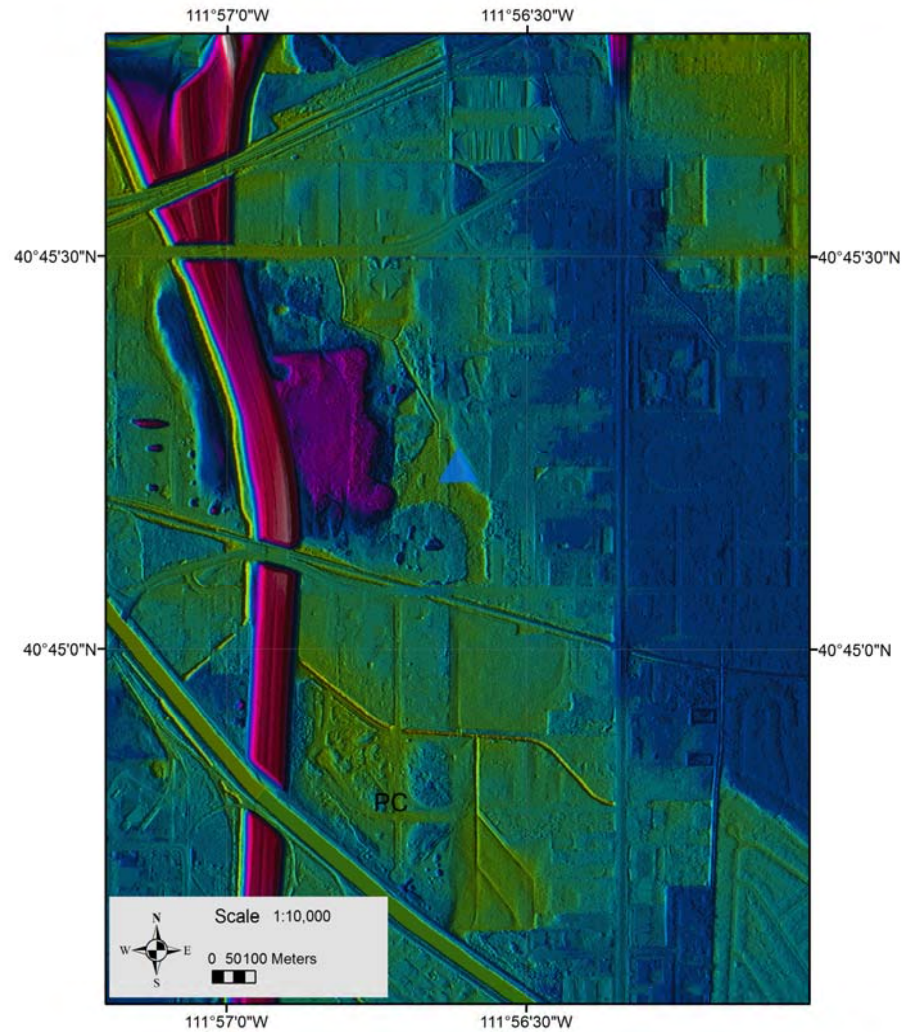
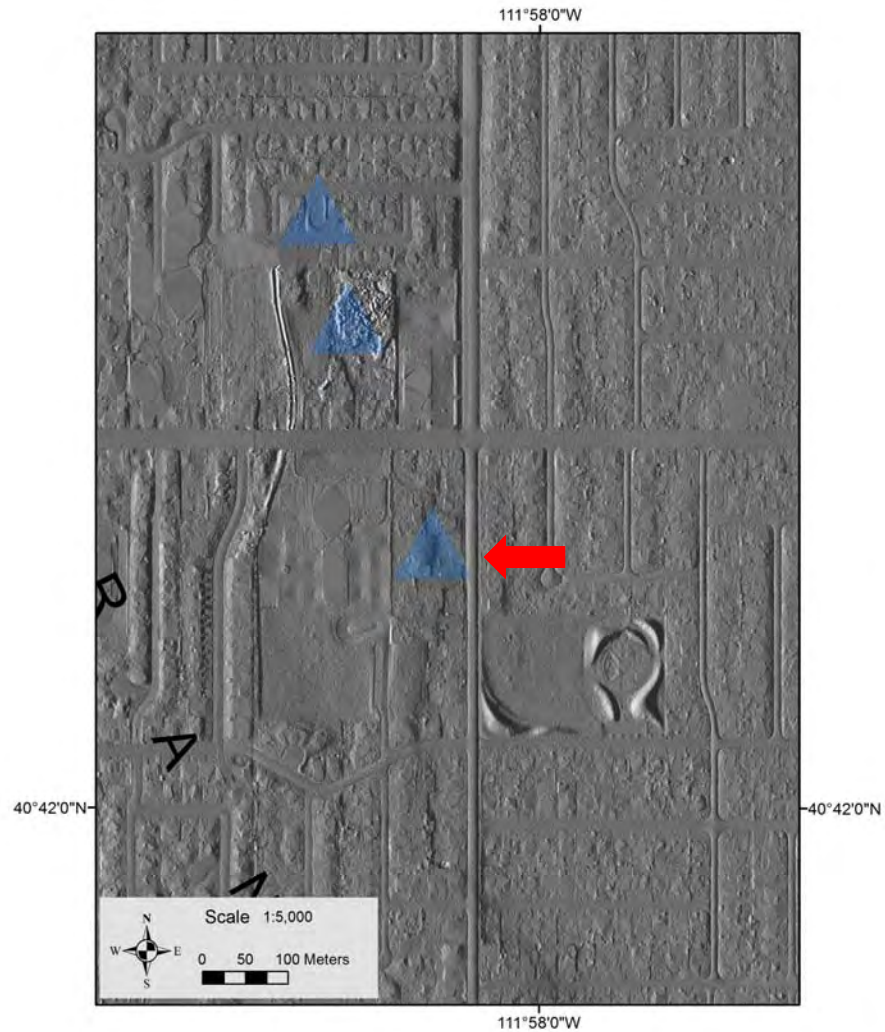
Possible Sites



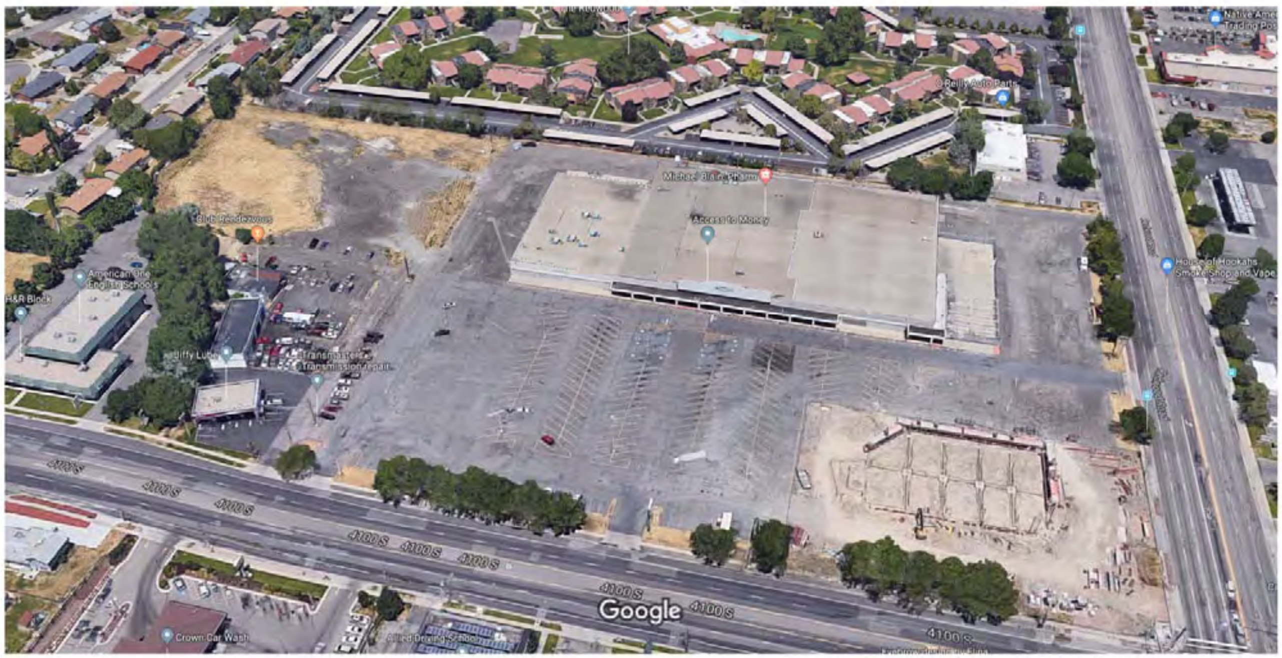
111°57'0"W
111°56'30"W
40°45'30"N
40°45'0"N
PC
Scale 1:10,000
N
W
E
S
0 50100 Meters


Google Maps
3166 32nd W
Google
Image capture: Jun 2017
© 2018 Google

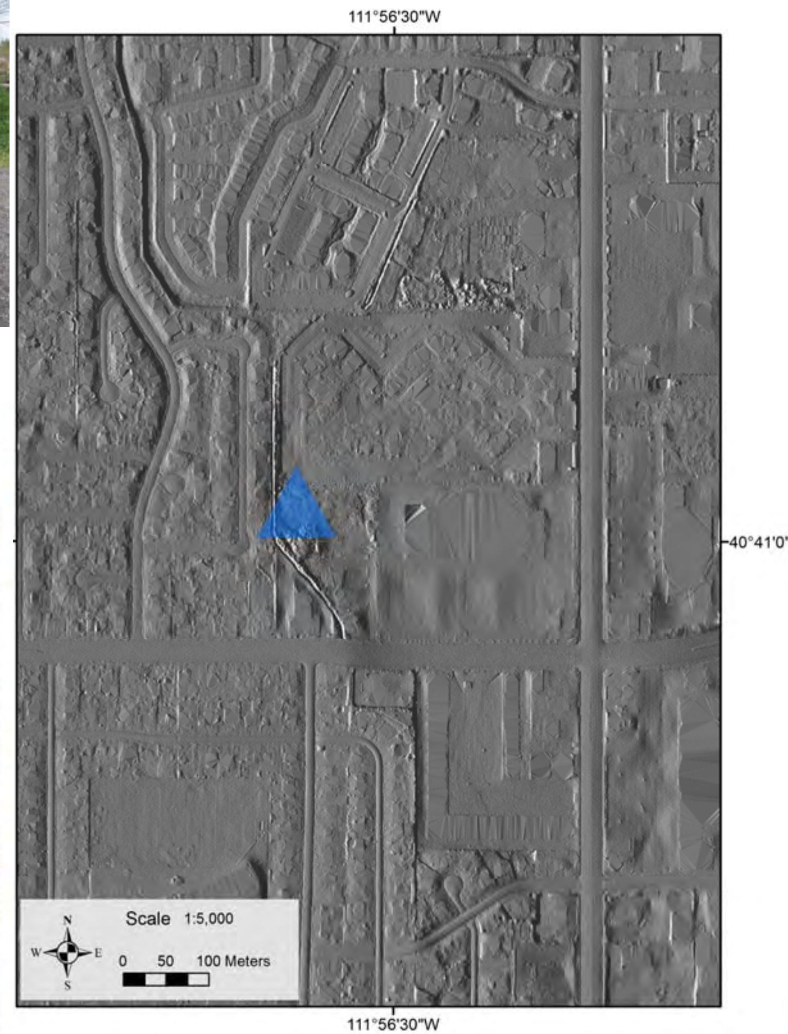

40°42'30"N
40°40'0"N
N
Pal


111°58'0"W
40°42'0"N
40°42'0"N
111°58'0"W
Scale 1:5,000
N
W
E
S
0 50 100 Meters

Google Maps



Imagery ©2018 Google, Map data ©2018 Google 50 ft



Thank you

1924 Topographic Map

Assessing the possible co-seismic nature of paleo-rock avalanches in the intermountain seismic belt, Utah

Brendon J. Quirk, Jeff Moore, Benjamin Laabs, Patricia Pedersen, Nathaniel Lifton , Marc Caffee, UGS Hazards Group

Hazard chains

<u>Primary</u> / Secondary / Tertiary hazards…

- Example 1: The 2008 M8.0 Wenchuan Earthquake

69,200 deaths, 18,195 missing, 374,216 injured, and more than 5 million people homeless

Severe ground shaking

Hazard chains

Primary / Secondary / Tertiary hazards…

- Example 1: The 2008 M8.0 Wenchuan Earthquake

Landslides responsible for ~20,000 casualties

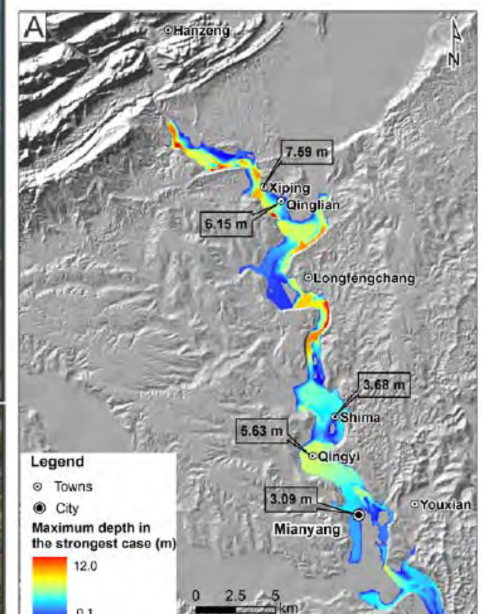
Hazard chains

Primary / Secondary / <u>Tertiary</u> hazards…

- Example 1: The 2008 Wenchuan Earthquake

2.5 million people threatened by flooding

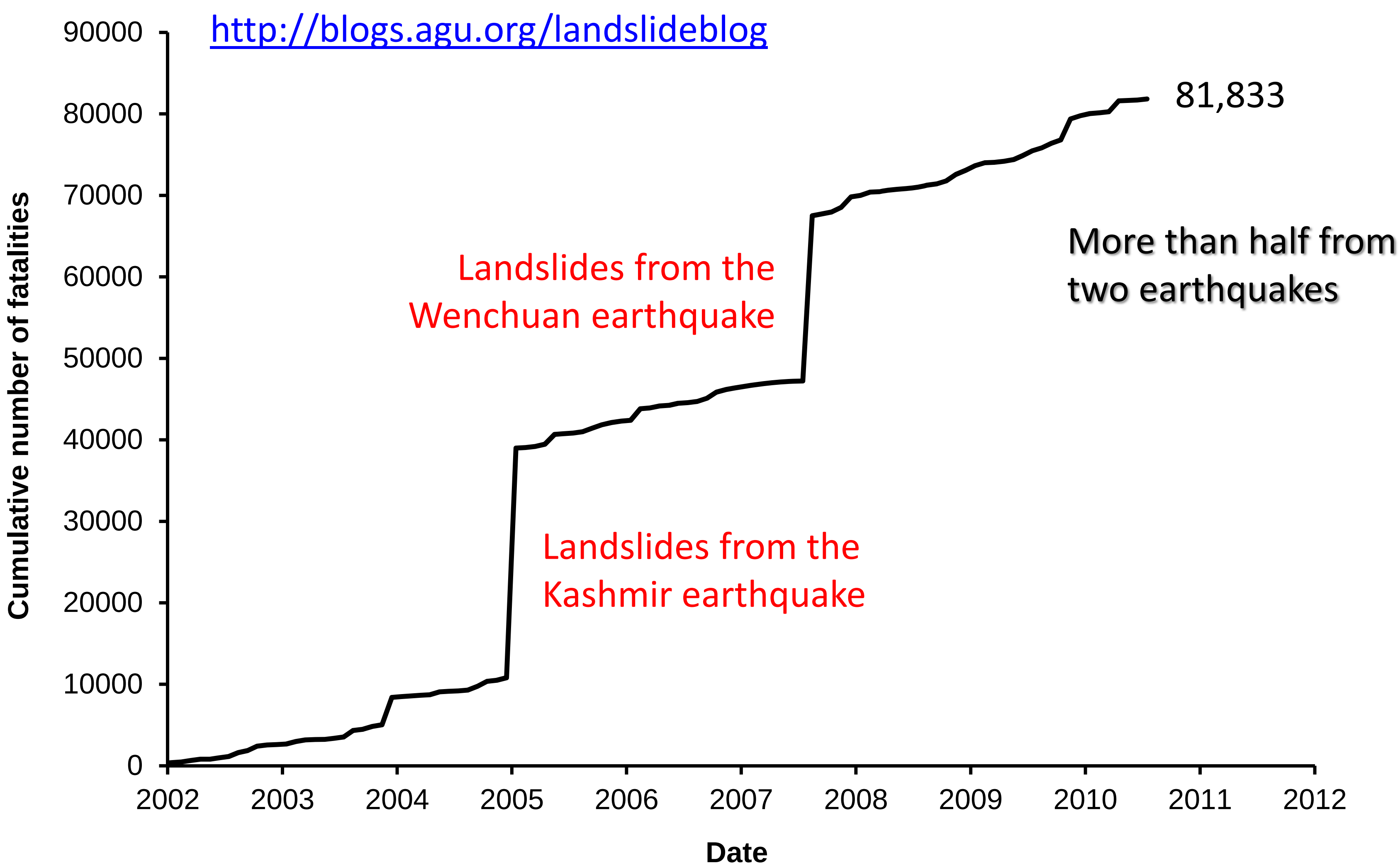
Landslide dammed lakes and flooding: 66 new lakes formed



Tangjiashan

The human cost of landslides

Dave Petley, 10 years of data collection via internet and news sources



Research Question and Work Plan

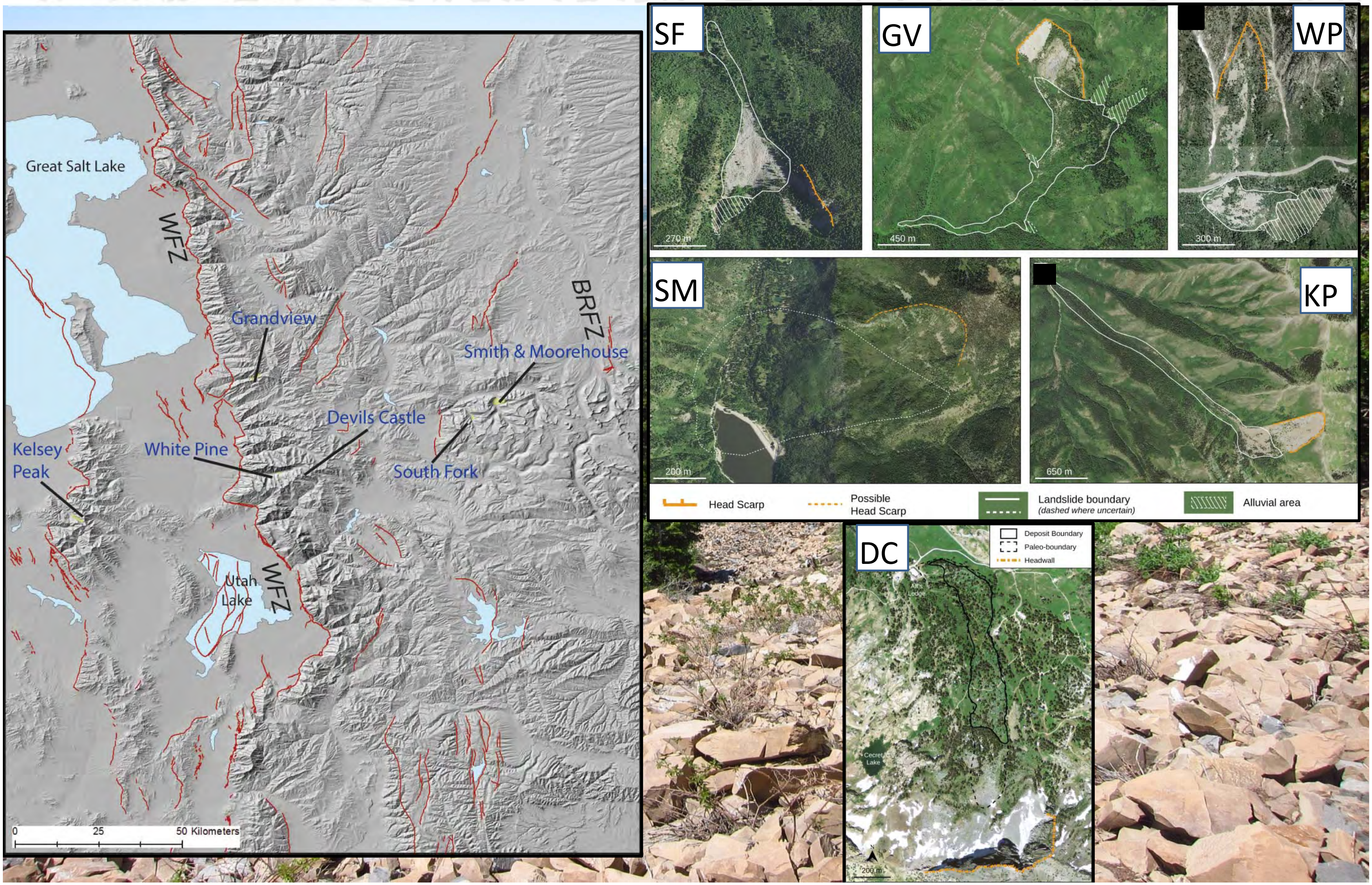
There is a need to evaluate this understudied potential hazard in this region.

Fundamental Question: *Were six of Utah's largest paleo-rock avalanches trigged by earthquakes along the Wasatch, Bear River, or other Quaternary faults?*

We make the assumption that if we can establish that paleo-earthquakes and rock avalanches were **coeval** then the former likely triggered the latter.

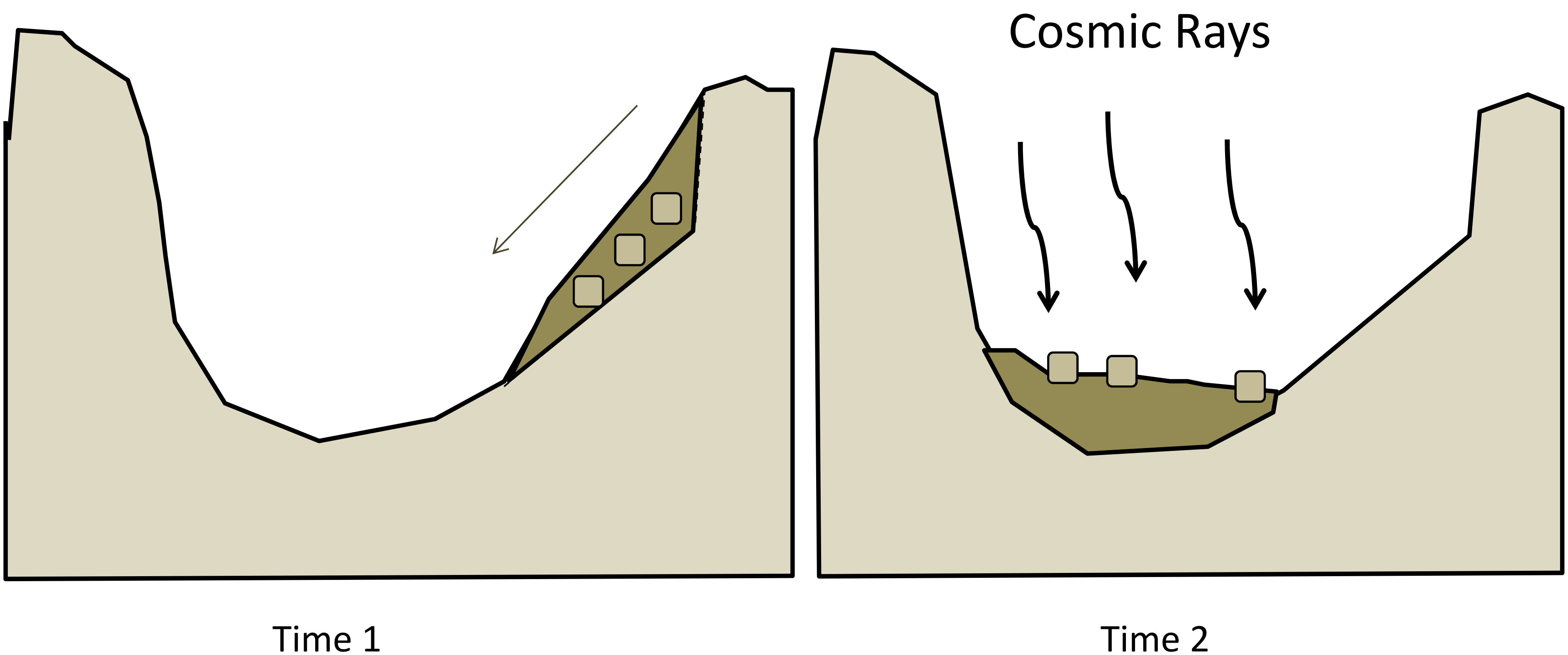
Therefore we look to establish **rock avalanche chronologies** using ***cosmogenic exposure dating*** (both ^{10}Be, and ^{36}Cl).

Study Area



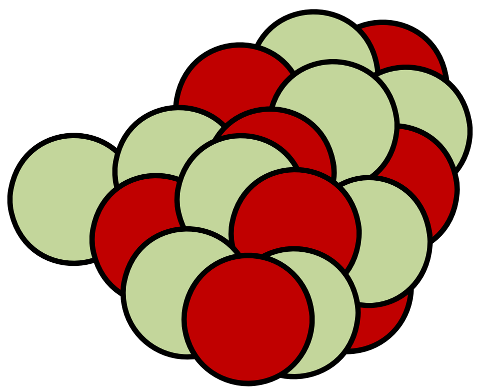
Great Salt Lake
WFZ
Grandview
BRFZ
Smith & Moorehouse
Devils Castle
Kelsey Peak
White Pine
South Fork
Utah Lake
WFZ
0
25
50 Kilometers
SF
270 m
GV
450 m
WP
300 m
SM
200 m
KP
650 m
Head Scarp
Possible Head Scarp
Landslide boundary
(dashed where uncertain)
Alluvial area
DC
Deposit Boundary
Paleo-boundary
Headwall
200 m

Cosmogenic Exposure Dating

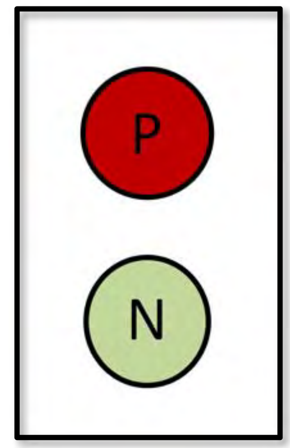


Cosmogenic Exposure Dating

^{16}O in SiO_2 is the primary target for production, via spallation, of cosmogenic ^{10}Be at a known rate.



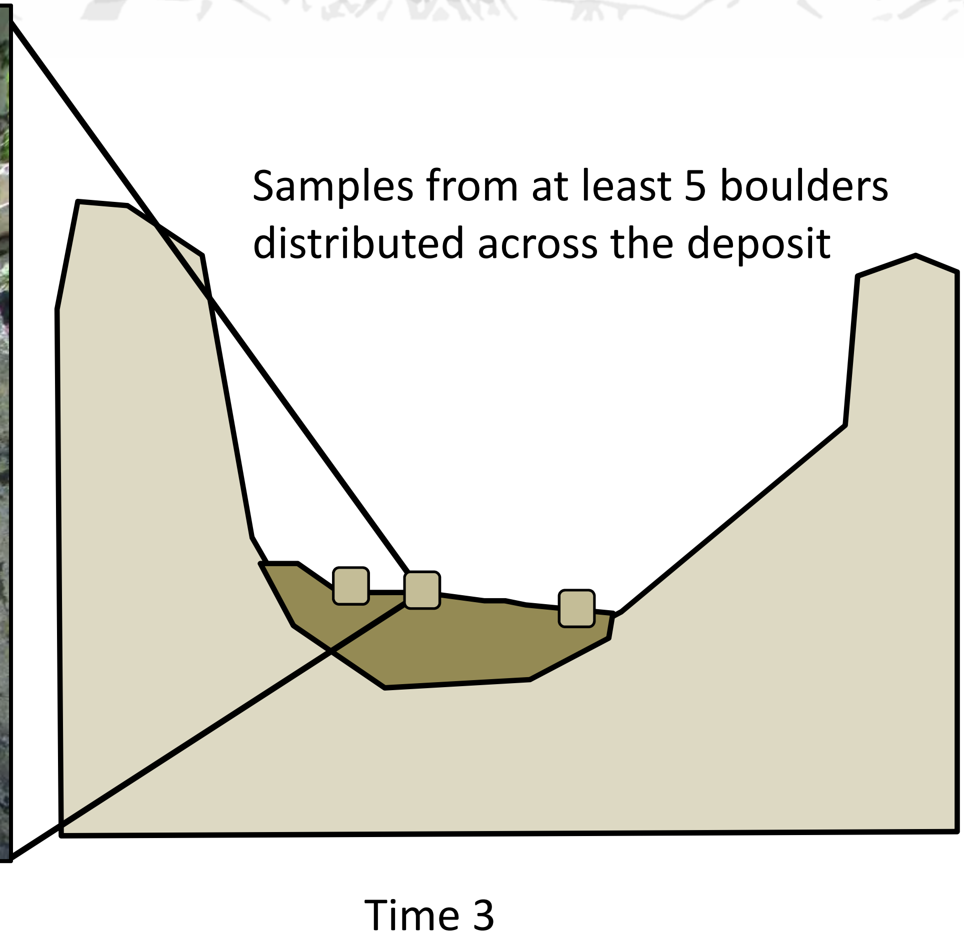
^{10}Be



Therefore if we measure the concentration of ^{10}Be:

$$\text{Exposure Age} = \frac{^{10}Be\ Concentration}{^{10}Be\ Production\ Rate}$$

Cosmogenic Exposure Dating



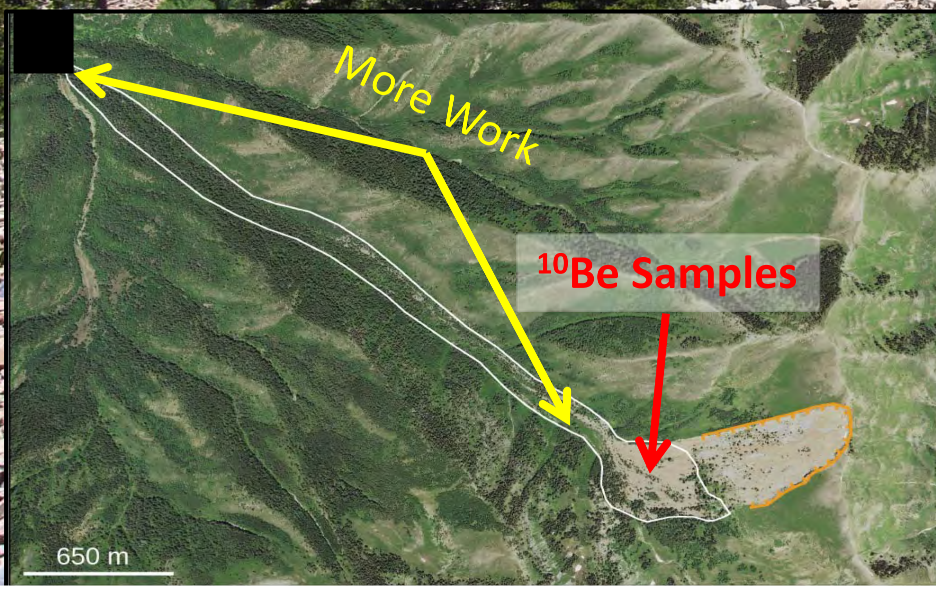
$$\text{Landform (Event) Age} \approx \text{Exposure Age} = \frac{^{10}Be\ Concentration}{^{10}Be\ Production\ Rate}$$

Kelsey Peak – Settlement Canyon, Oquirrh Mts.

Fahrboshchung - 21°; Estimated Volume – 3.1 M m^3 ; Butterfield Peaks Formation quartzite ;Boulder-block field in upper deposit; lower deposit characterized by levee type deposits

Kelsey Peak – Settlement Canyon, Oquirrh Mts.

Fahrboshchung - 21°; Estimated Volume – 3.1 M m^3 ; Butterfield Peaks Formation quartzite ; super-elevation; Boulder-block field in upper deposit; lower deposit characterized by levee type deposits

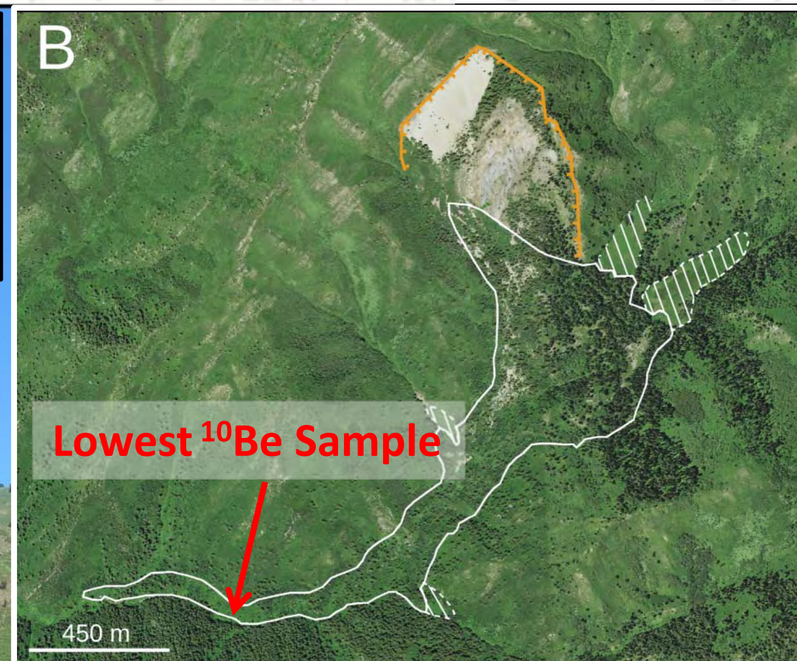


Grandview – City Creek Canyon, SLC

Fahrboshchung - 10°; Estimated Volume – 8.5 M m^3

Weber Sandstone; Super-elevation

Recent Previous Work – Ashland & McDonald, 2008



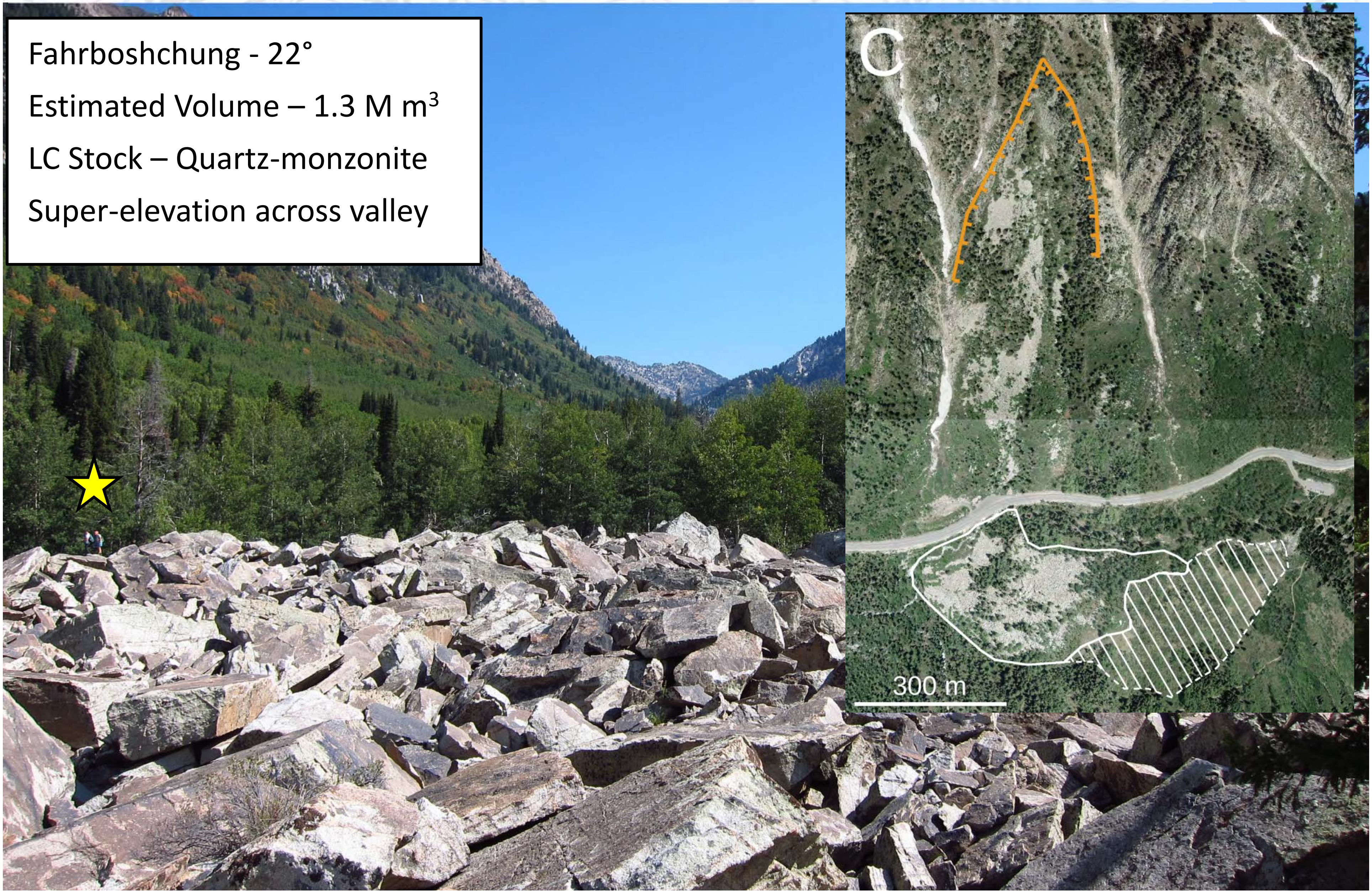
White Pine – Little Cottonwood Canyon

Fahrboshchung - 22°

Estimated Volume – 1.3 M m^3

LC Stock – Quartz-monzonite

Super-elevation across valley



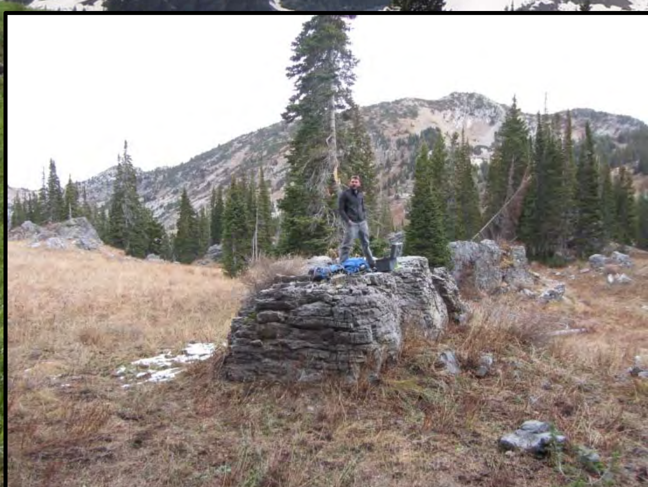
Devils Castle – Albion Basin, LCC

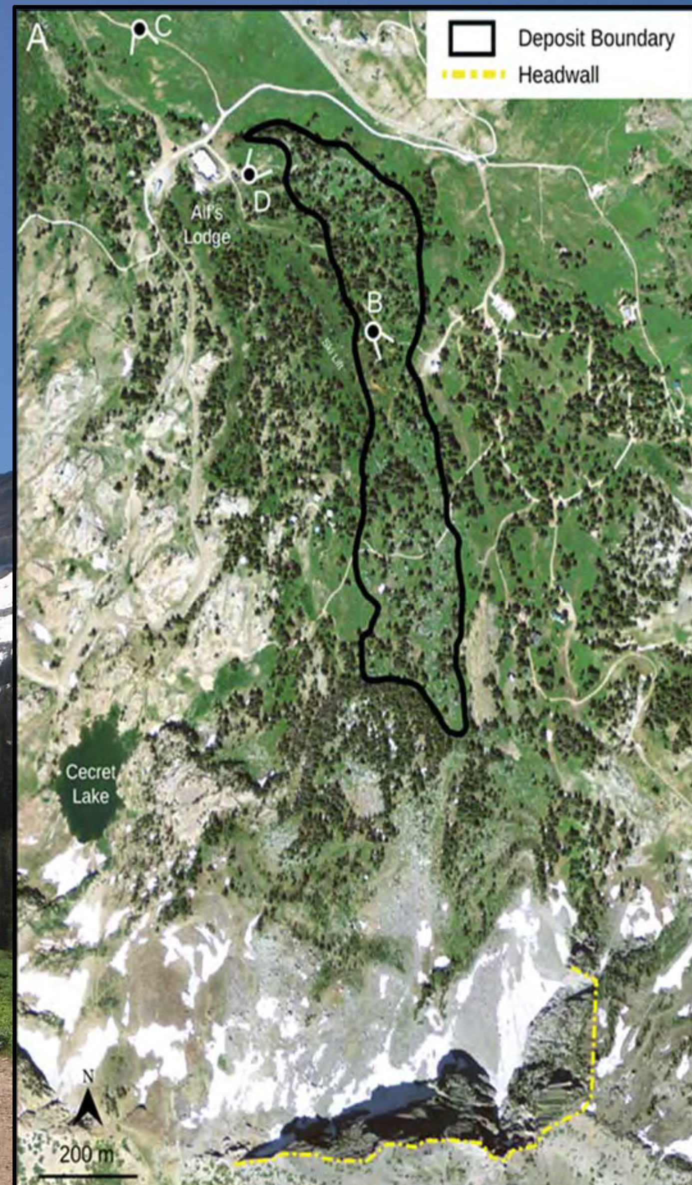
Fahrboshchung - 14°; Appx. Volume – 1.8 M m^3

Deseret Limestone; Relatively Old Deposit

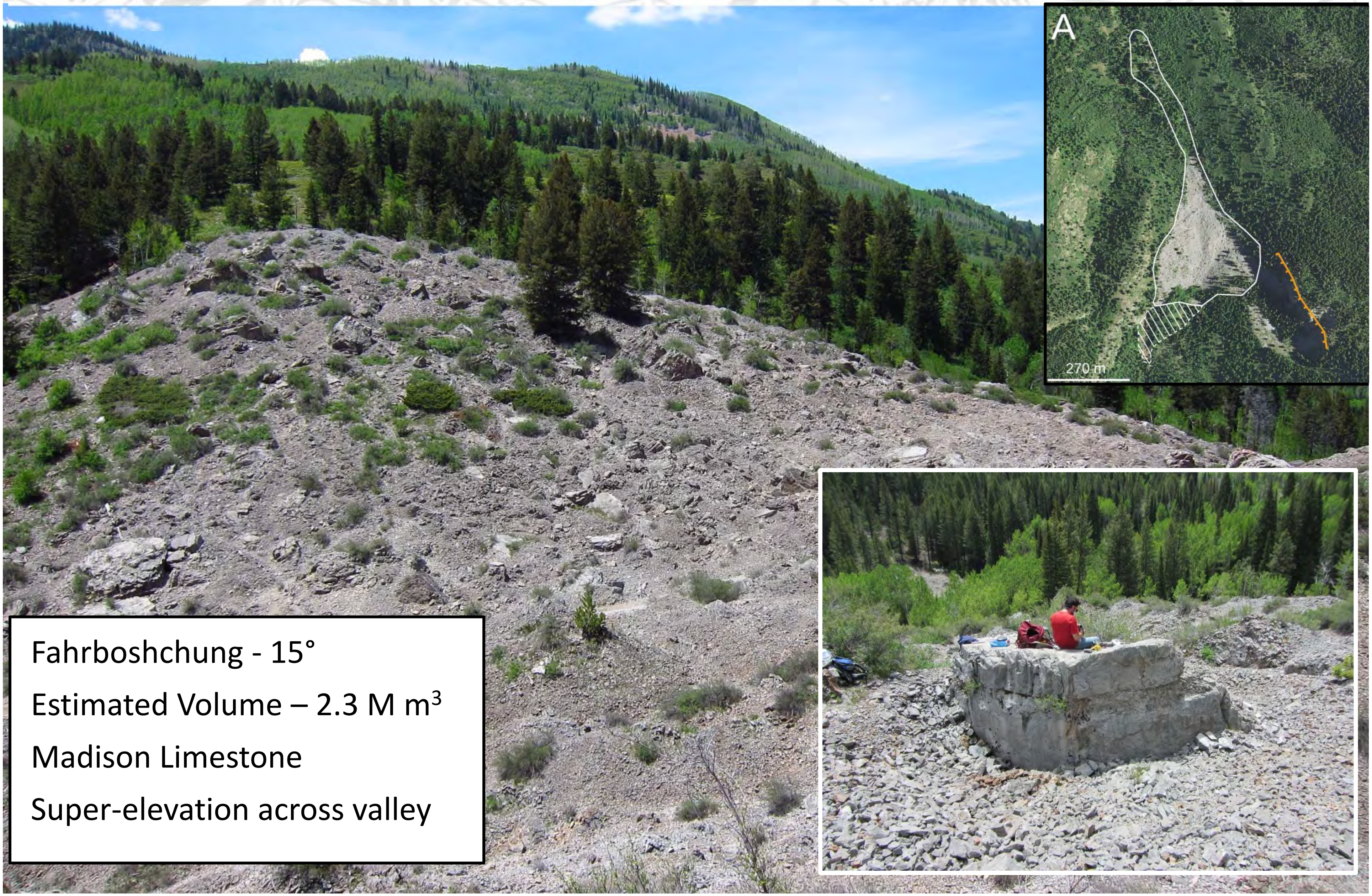
Interesting cross cutting relationships with glacial and rock glacier deposits

Velocity Estimates – 15 to 27 m/s





South Fork Weber – Western Uinta



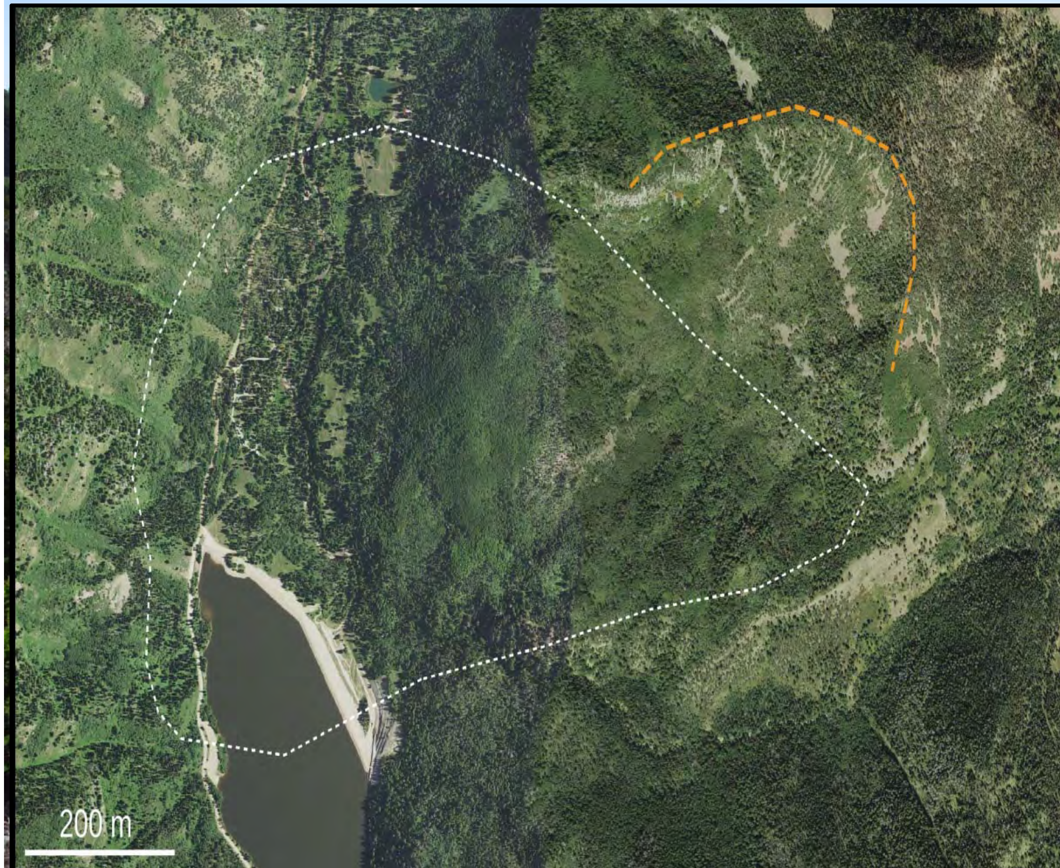
Fahrboshchung - 15°

Estimated Volume – 2.3 M m^3

Madison Limestone

Super-elevation across valley

Smith & Moorehouse – Western Uinta

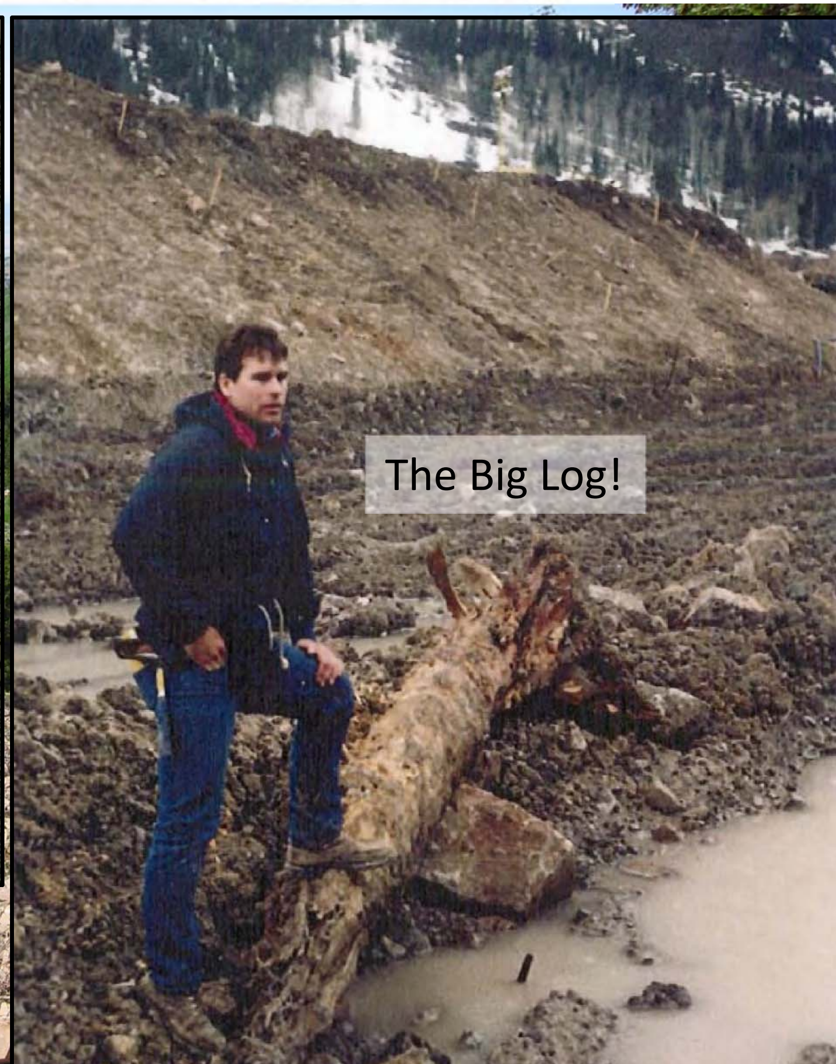


Fahrboshchung - 14°

Estimated Volume – 43 M m^3

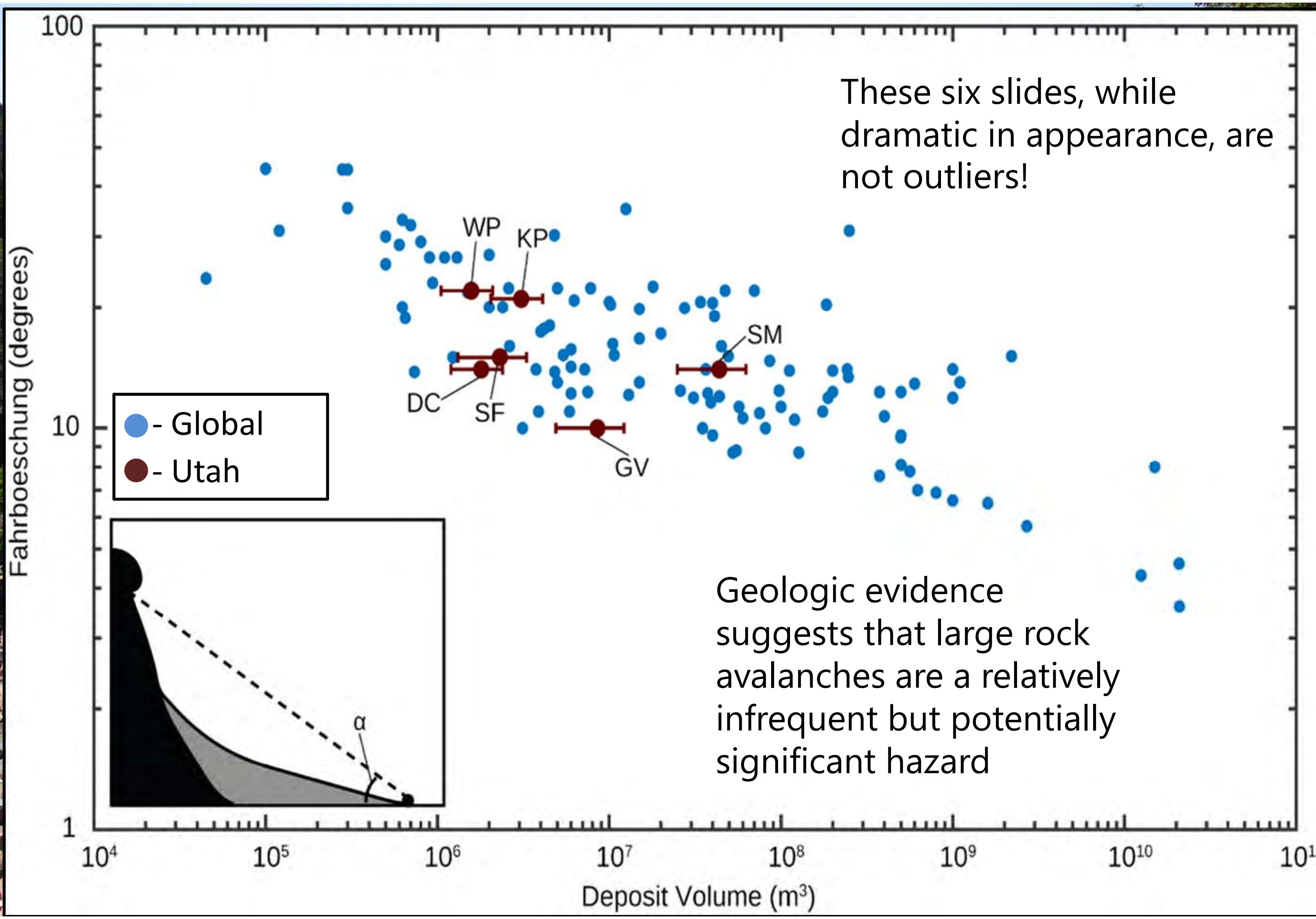
The “Big Log” Radiocarbon age – ca. 4.0 ^{14}C ka BP

Red Till reinterpreted as rock avalanche deposit



Utah Department of Natural Resources, 1986

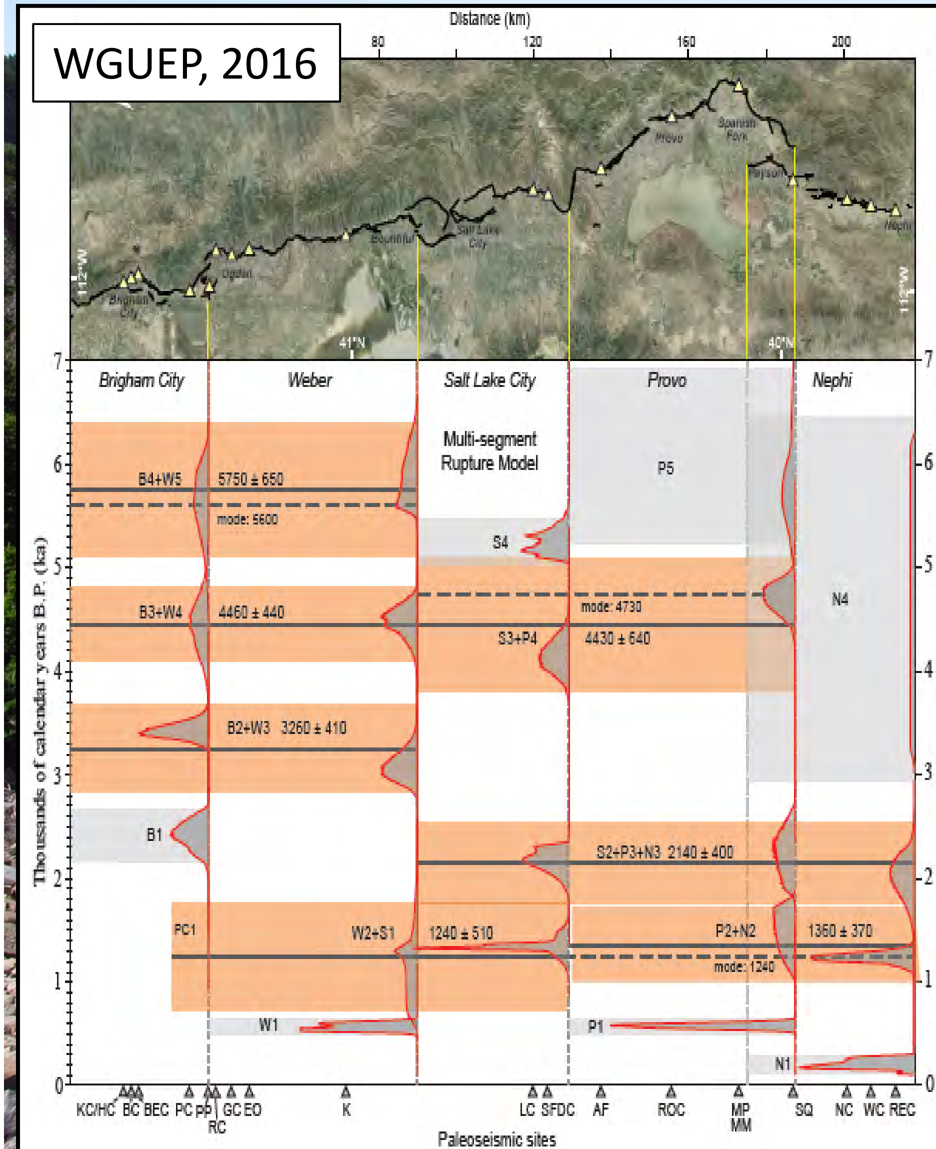
Global Context

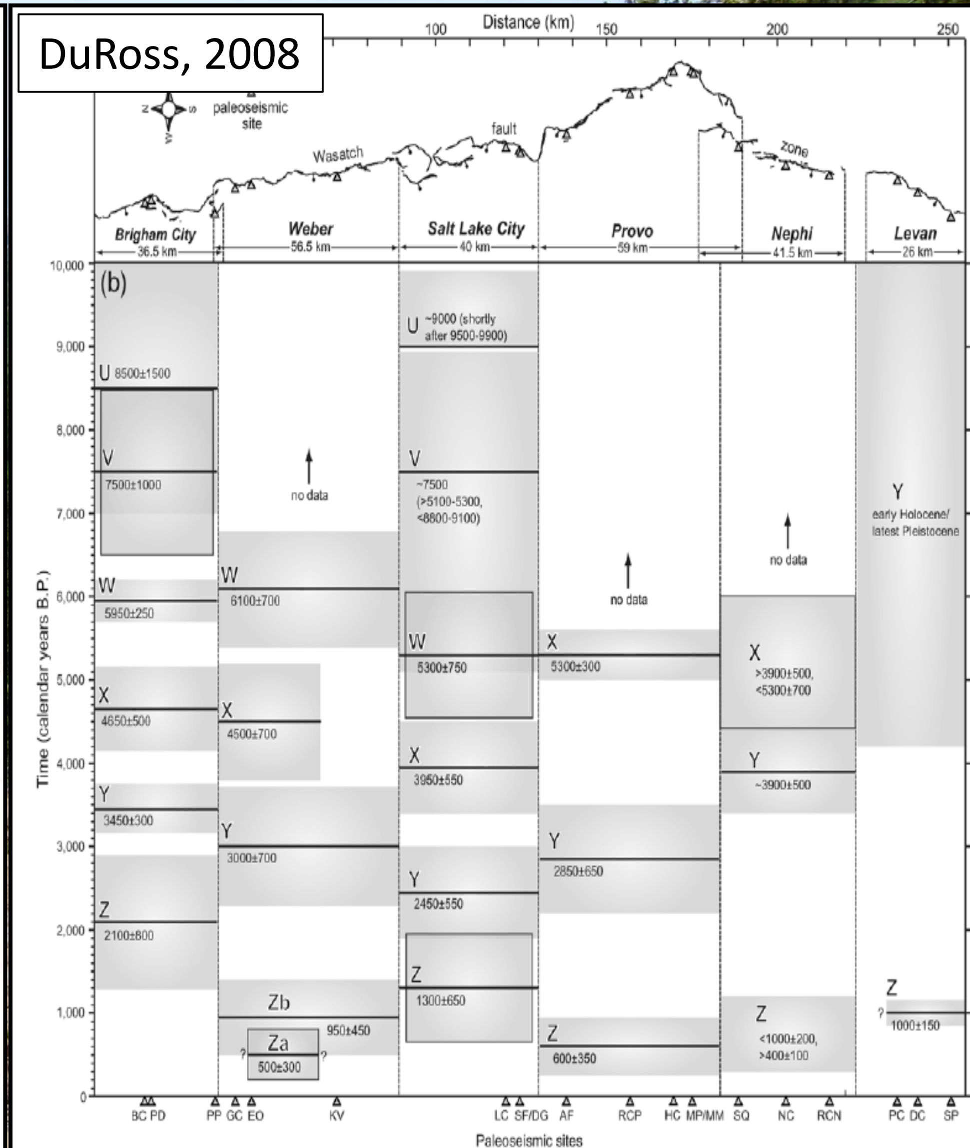


These six slides, while dramatic in appearance, are not outliers!

Geologic evidence suggests that large rock avalanches are a relatively infrequent but potentially significant hazard

Paleoseismic Comparison





Thank You!

A Special Thank You to: Patricia Pedersen ,Jeff Moore, Nathaniel Lifton, Benjamin Laabs Marc Caffee, Rich Giraud, Greg McDonald, Paul Geimer, Grant Rea-Downing Emily Kleber

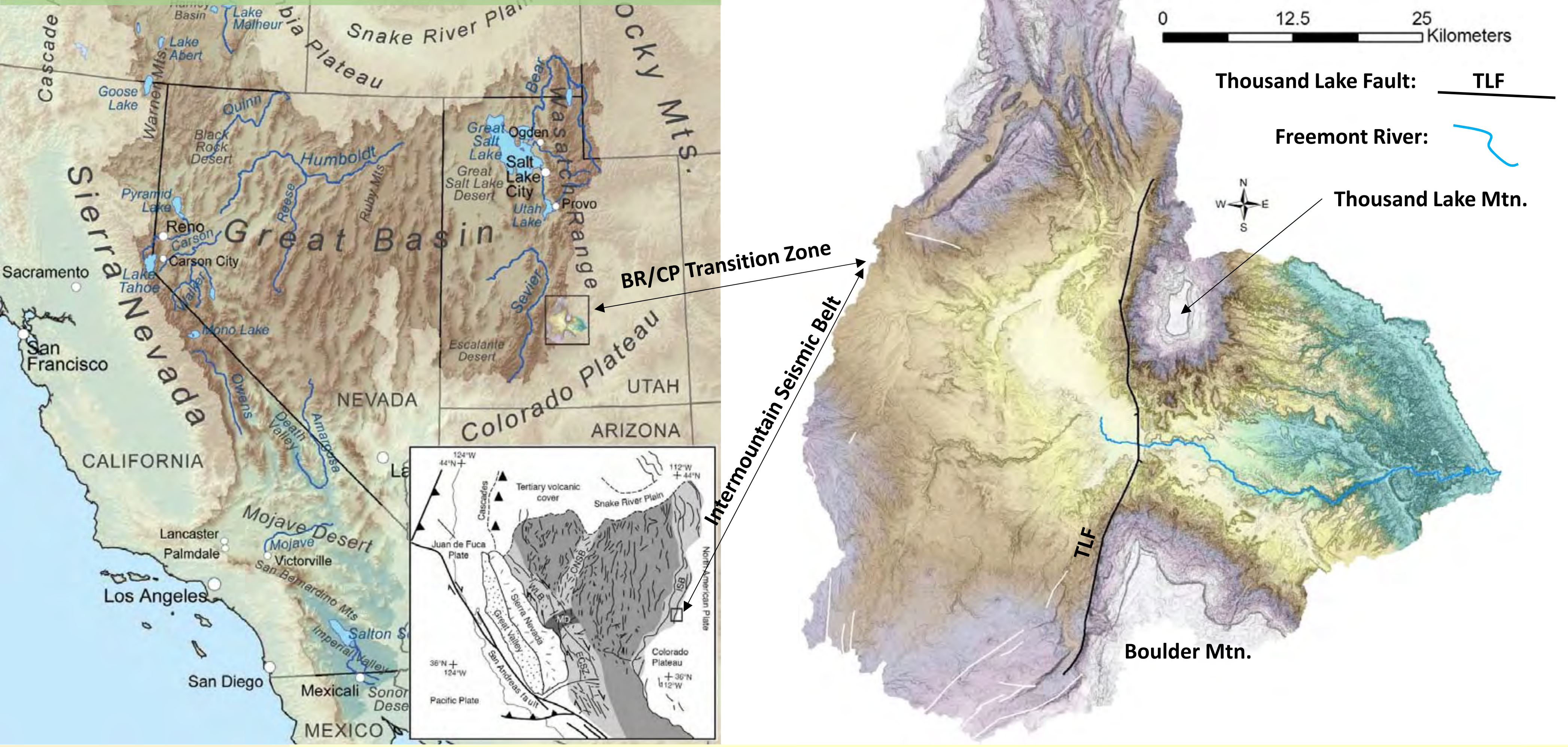
"This material is based upon work supported by the National Science Foundation under Grant Nos. EAR-1358514, 1358554, 1358401, 1358443, and 1101100 (EarthScope National Office). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. Thanks to the EarthScope program for its support."

Reconnaissance Investigation of the Thousand Lake Fault near Bicknell, Utah

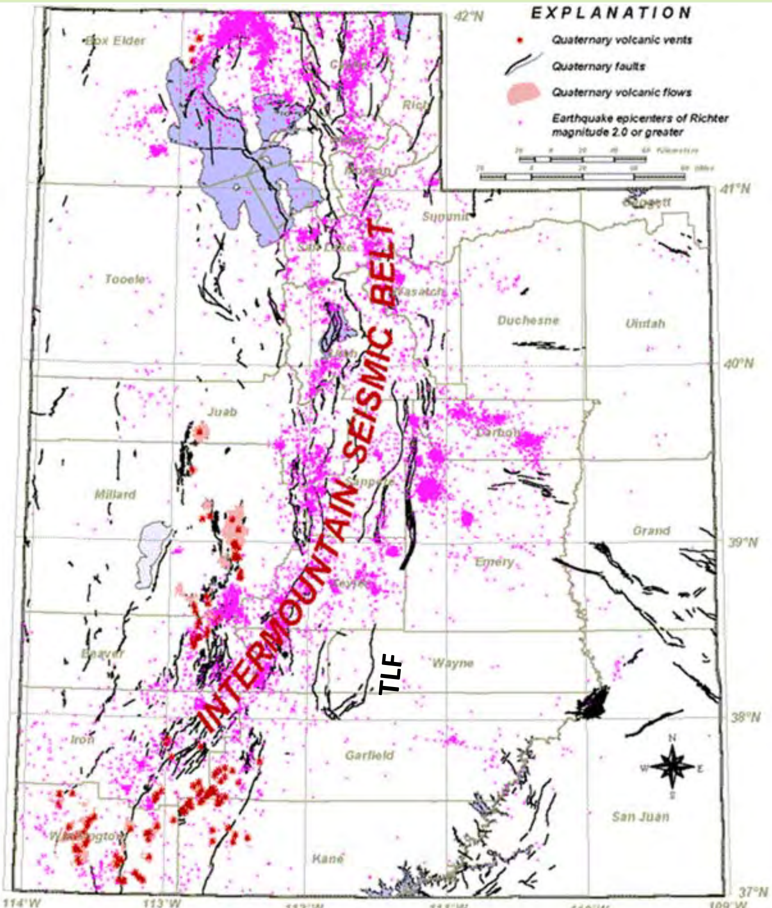
Dr. Nathan Toké, Associate Professor of Earth Science, Utah Valley University
Plus: Joseph Phillips and Students from the 2015-2017 UVU Geology Field Camps

Tectonic and Geomorphic Setting

Freemont River Basin



Prior Information about the Thousand Lake Fault



From Utah Geological Survey: http://files.geology.utah.gov/emp/geothermal/quaternary_faults.htm

Earthquake epicenters and Quaternary tectonic features in relation to the Intermountain seismic belt (after Smith and Sbar, 1974; Hecker, 1993; and Black and others, 2000).

Quaternary Activity?

- **Last Activity since 750 ka** *(Utah Q Fault Database)*
  - ***- faulted terraces that formed since start of Mid Quaternary***
- **Last Active before 125 ka** *(Marchetti et al., 2007)*
  - ***- undisturbed landslide deposits covering TLF on Boulder Mtn.***

Earthquake Size?

- **Fault Length ~ 49 km**

Slip Rate?

- **< 0.2 mm/yr** *(Utah Q Fault Database)*

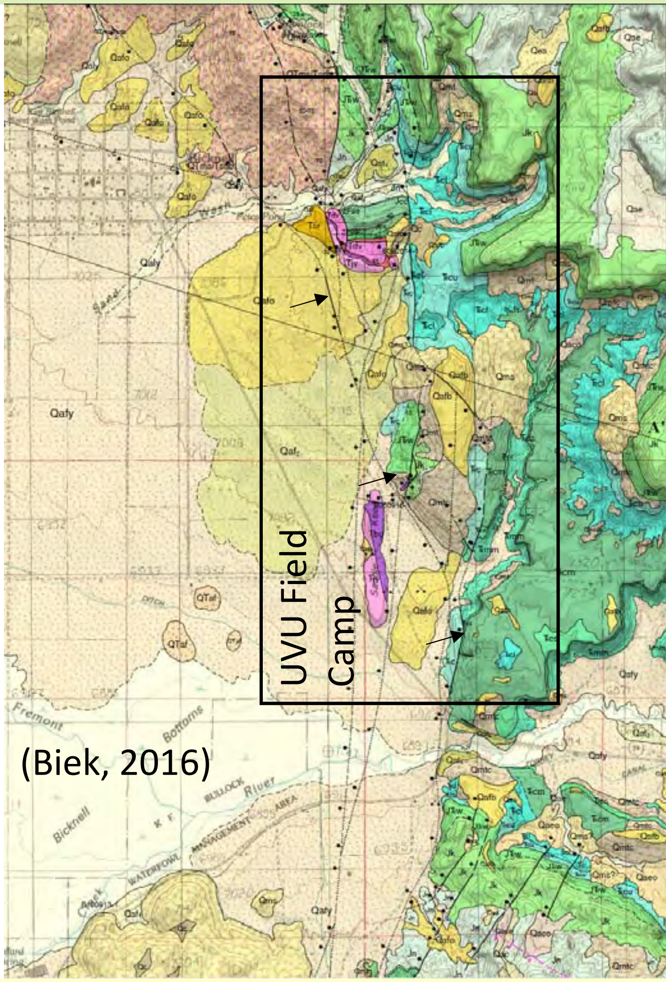
What more can we say today?

Methods: Mapping, Paleoseismic Recon, and Spatial Analysis

What's the character of faulting

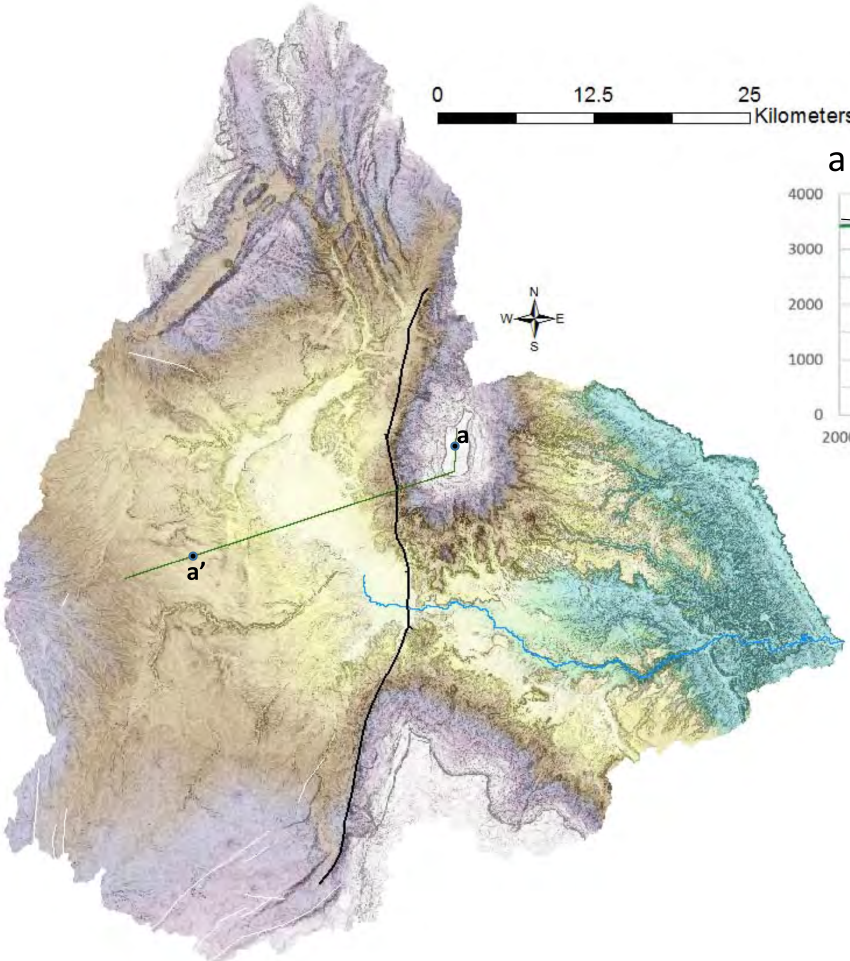
- Fault zone width?
- Seek out Paleoseismic outcrops.
- Displacement per event?
- Most recent activity?
- Slip rate?

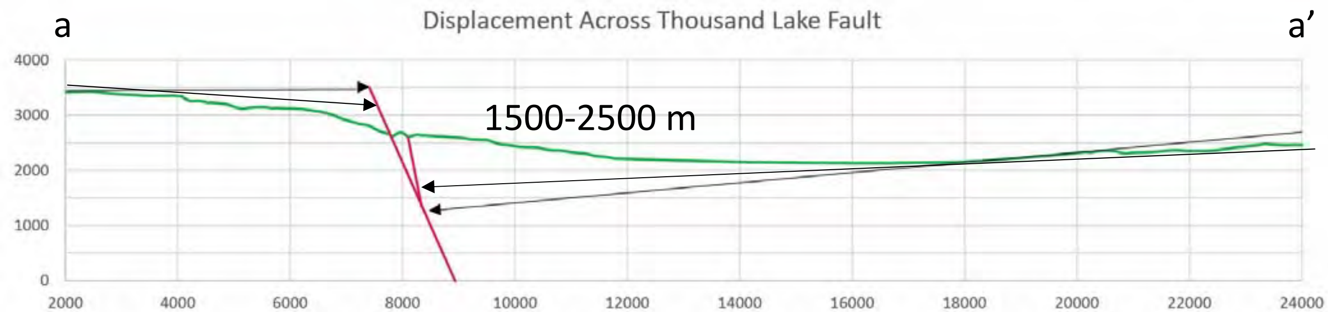
-Mapped/Recon. about 5 x 2.5 km
-Used GIS to determine LT Slip Rate
-Documented paleoseismic outcrops
-Measured displacement of surfaces
-Explored Freemont R. terraces in GIS



(Biek, 2016)

Total Displacement and Long Term Slip Rate





- Age of Displaced Volcanics ~24.5 Mya (e.g., Mattox, 1991)
- Tectonic Initiation 10-16 Mya (e.g., McQuarrie and Warnicke, 2005)

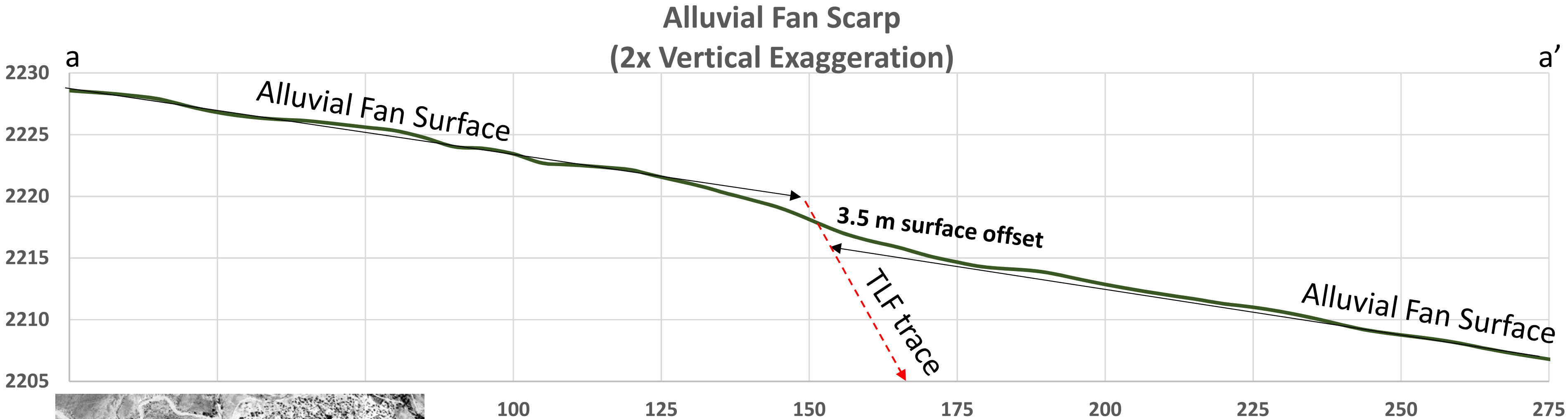
Near Fault Center

Minimum Long Term Slip Rate ~ 0.1 mm/yr

Maximum Long Term Slip Rate ~ 0.25 mm/yr

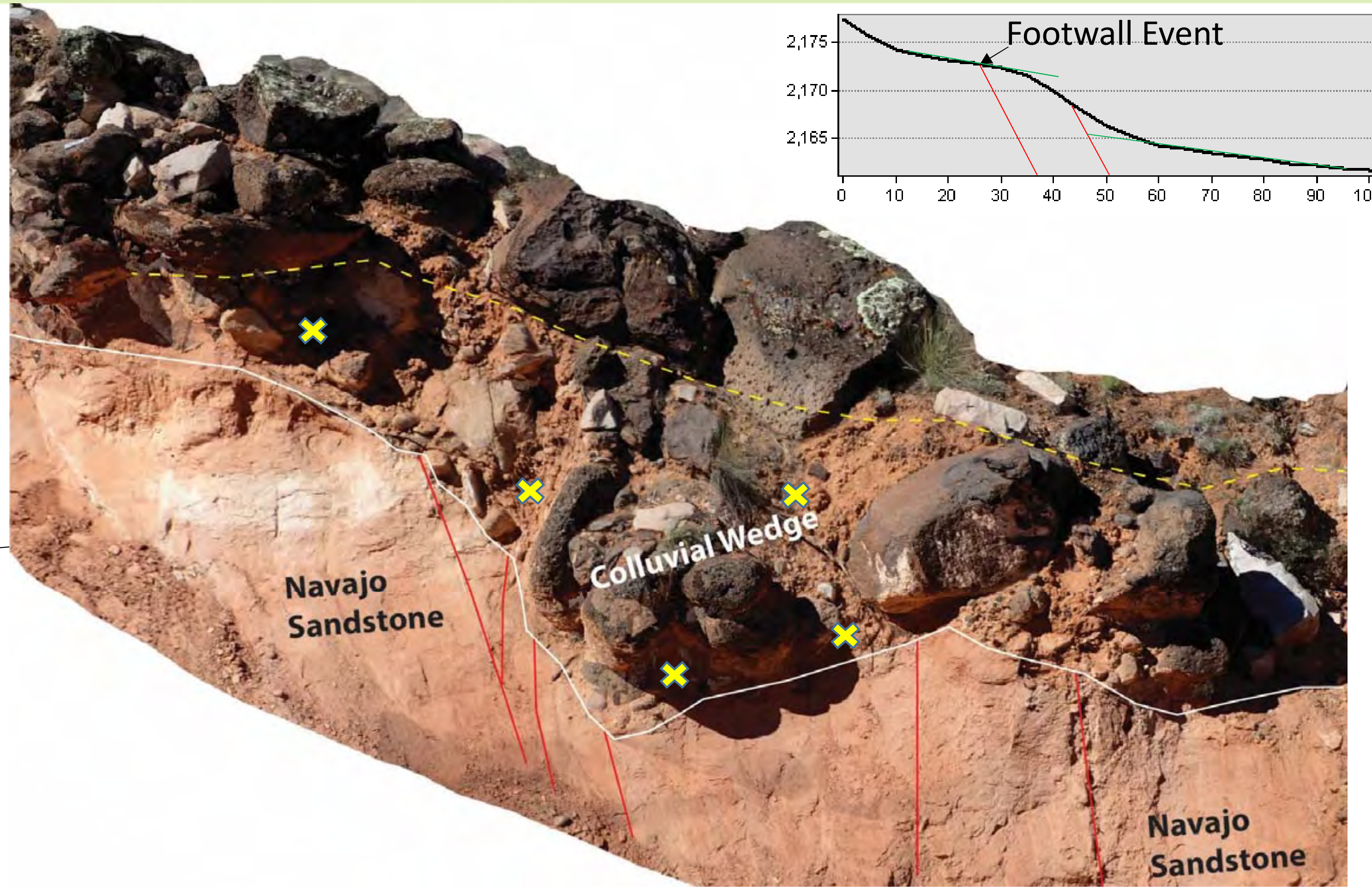
Earthquake Evidence – Fault Scarps

Fault Scarp Displacement Analysis

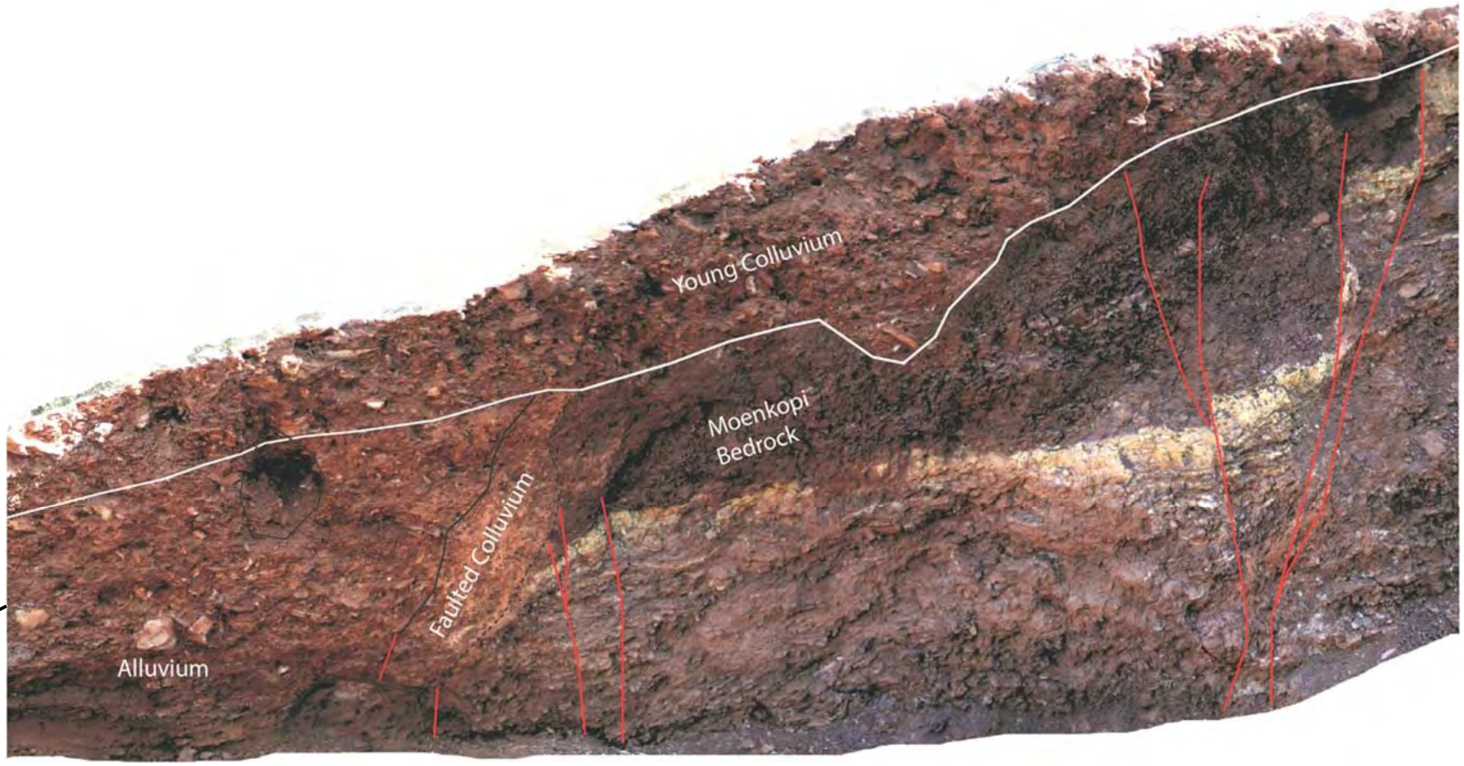


~ 4 m fault displacement (since fan abandonment)

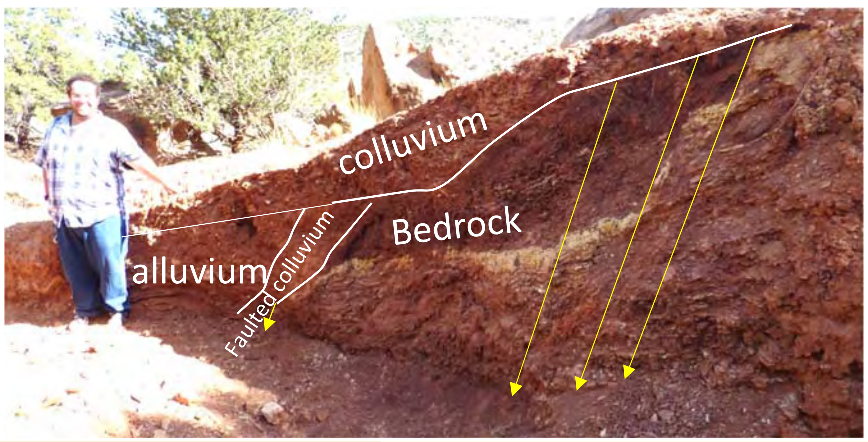
Earthquake Evidence – Footwall Colluvial Wedge



Earthquake Evidence – Fault-derived Colluvium



Paleoseismic Reconnaissance Recap

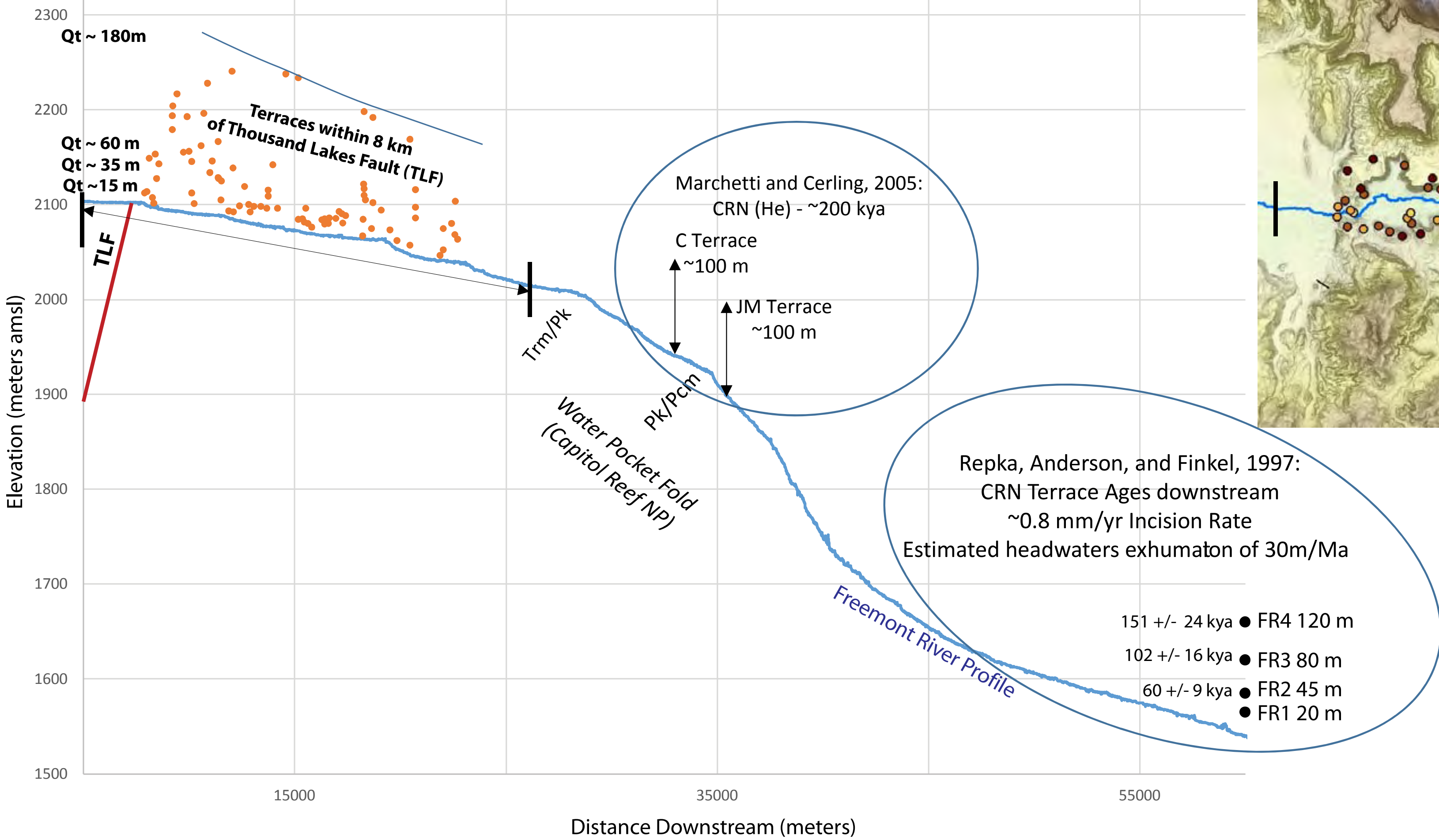


- Footwall faulting in Terrace 10-12 m above local base level: **Slip-per-event = ~ 1+ m/event**
  Expected recurrence rate
  - **1m/0.25 mm/yr = 4,000 yrs**
  - **2m/0.1 mm/yr = 20,000 yrs**

- **Alluvial Fan surface with 4 m displacement**
  - **Given slip rate, possibly a surface associated with end of Last Glacial Maximum (15-25 kya)**
  - **2-4 events since surface abandonment.**

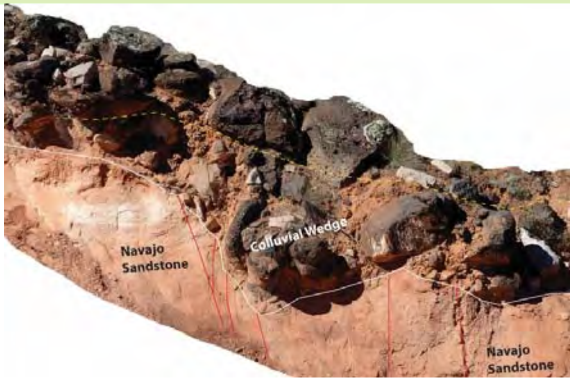
- **Anticipated Mw: 6.8 - 7.2**
  (30-50 km-long ruptures, 1-2 m displacement, 20 km depth)

Pleistocene Activity Evidence – Terrace Warping



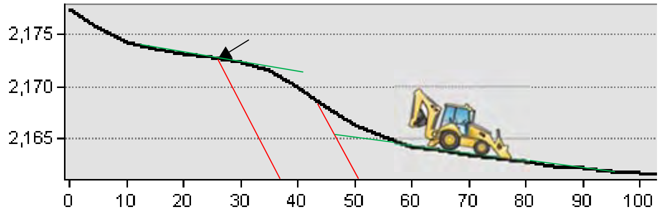
Preliminary Findings Thousand Lake Fault

- **Geologic Slip Rate 0.1-0.25 mm/year**
- **Probably Active During the Late Pleistocene**
- **Anticipated Recurrence 4,000 – 20,000 yrs/event**
- **Anticipated Moment Magnitude: 6.8-7.2**



What's next?:

- *C-14 Ages from Footwall Colluvial Wedge Material*
- *Possibly trench adjacent displaced terrace or fan*
- *Further analyses of terrace warping…*



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- Utah Quaternary Fault and Fold Database: https://geology.utah.gov/resources/data-databases/qfaults/
- Utah Geological Survey Aerial Imagery Collection: 1950 DKT, 1958 EEZ, and 1966 EEZ https://geodata.geology.utah.gov/imagery/

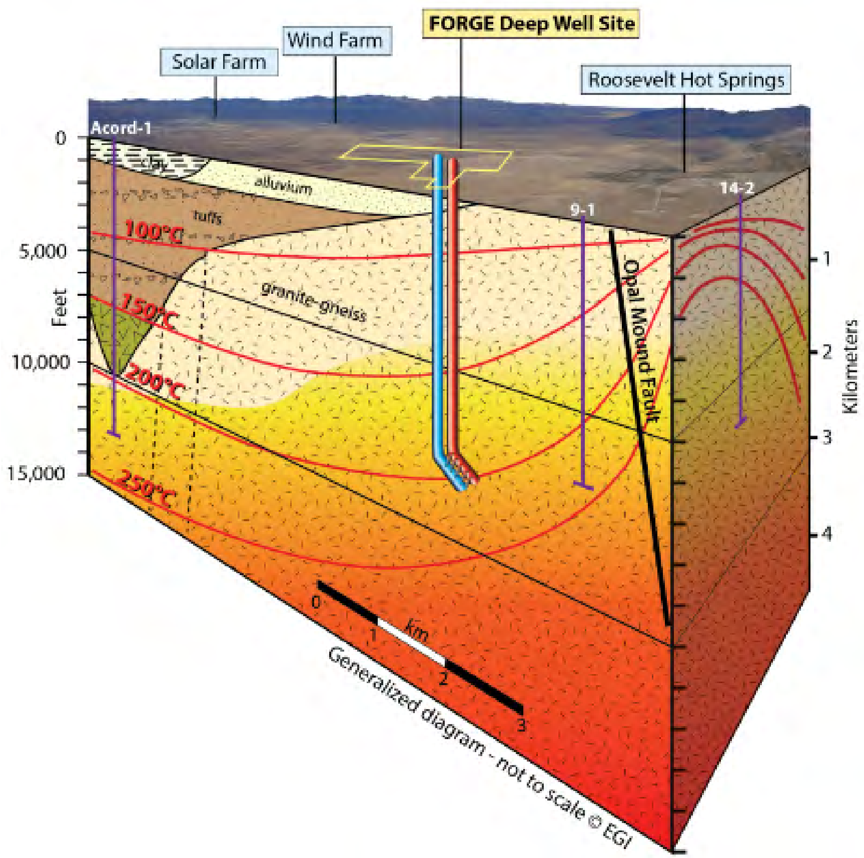
Utah FORGE Quaternary Geology and Quaternary Fault Activity

Emily Kleber, Tyler Knudsen, Stefan Kirby, and Adam Hiscock

Outline

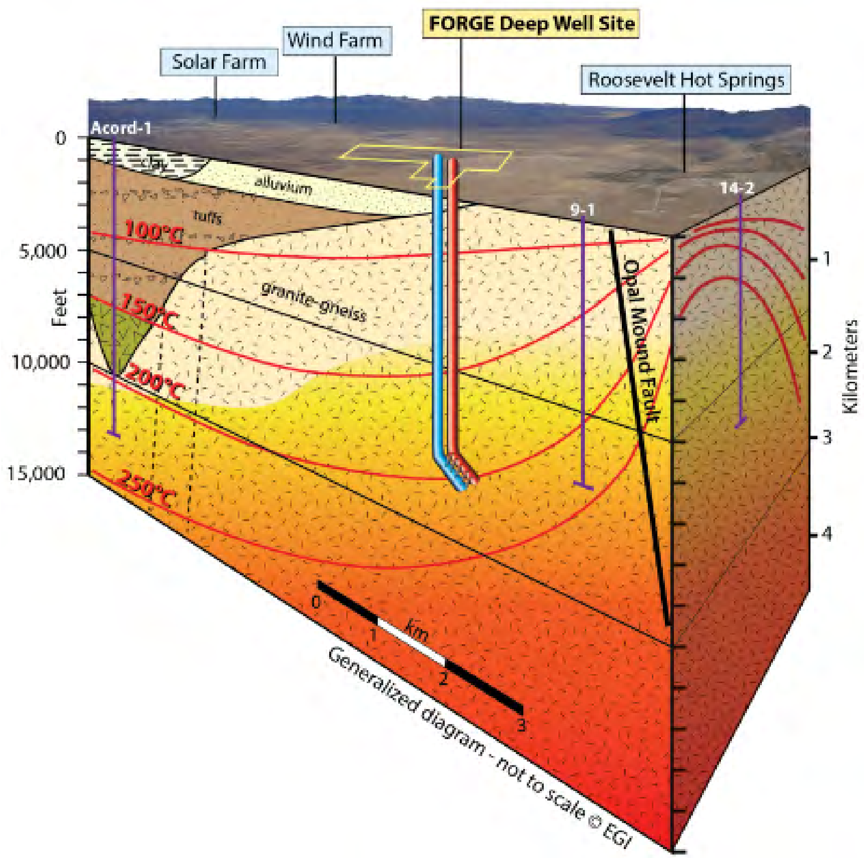
- Introduction to the FORGE project
- Regional overview
- Quaternary mapping
- Opal Mound fault
- Mineral Mountains west faults
- Geochronology of offset alluvial fans
- Preliminary interpretations

FORGE Experimental Geothermal Site



- FORGE – Frontiers Observatory for Research in Geothermal Energy
- Aim to develop an Enhanced Geothermal System (EGS) field laboratory
- Testing fracking techniques from O&G in fractured bedrock to create geothermal reservoir
- Granite and Gneiss basement rock 175 – 225°C

FORGE Experimental Geothermal Site

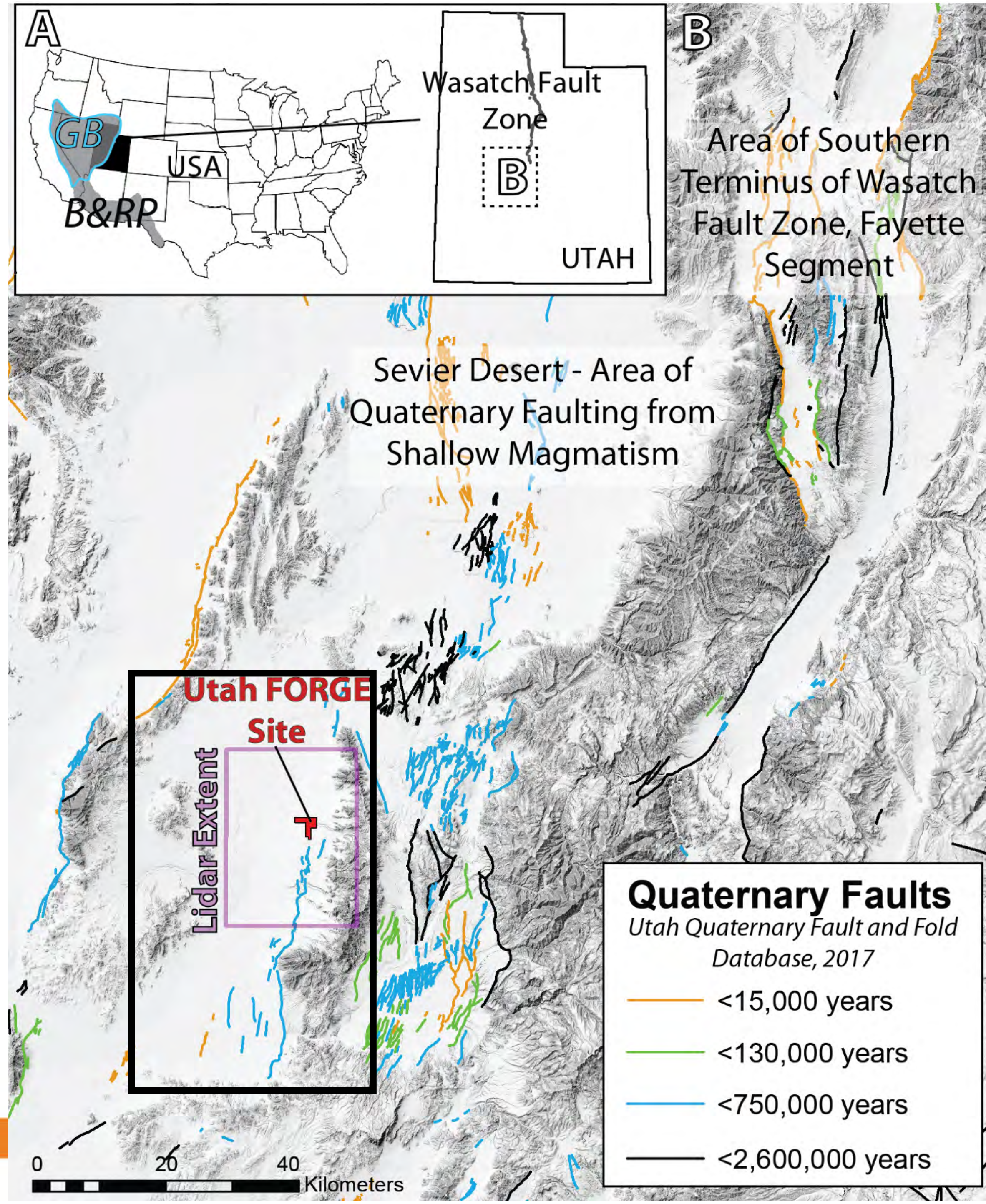


Goals

- Detailed Quaternary geologic and fault mapping.
- Constrain timing of faulting.

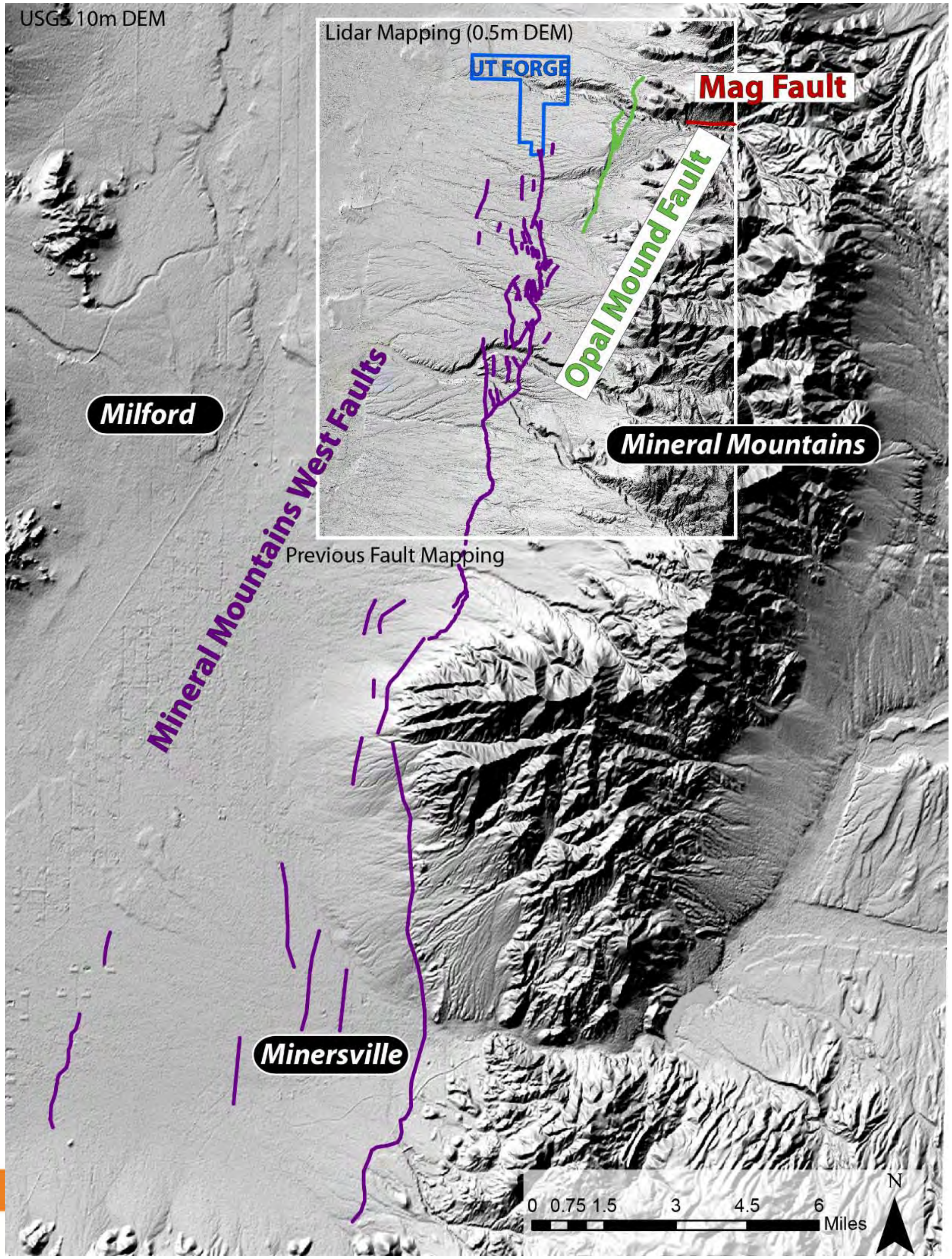
Methods

- Quaternary geologic mapping.
- Geomorphic characterization of fault scarps.
- Infrared Stimulated Luminescence (IRSL) burial dating.


A
Wasatch Fault
Zone
GB
USA
B&RP
B
UTAH
B
Area of Southern
Terminus of Wasatch
Fault Zone, Fayette
Segment
Sevier Desert - Area of
Quaternary Faulting from
Shallow Magmatism
Utah FORGE
Site
Lidar Extent
Quaternary Faults
Utah Quaternary Fault and Fold
Database, 2017
<15,000 years
<130,000 years
<750,000 years
<2,600,000 years
0
20
40
Kilometers

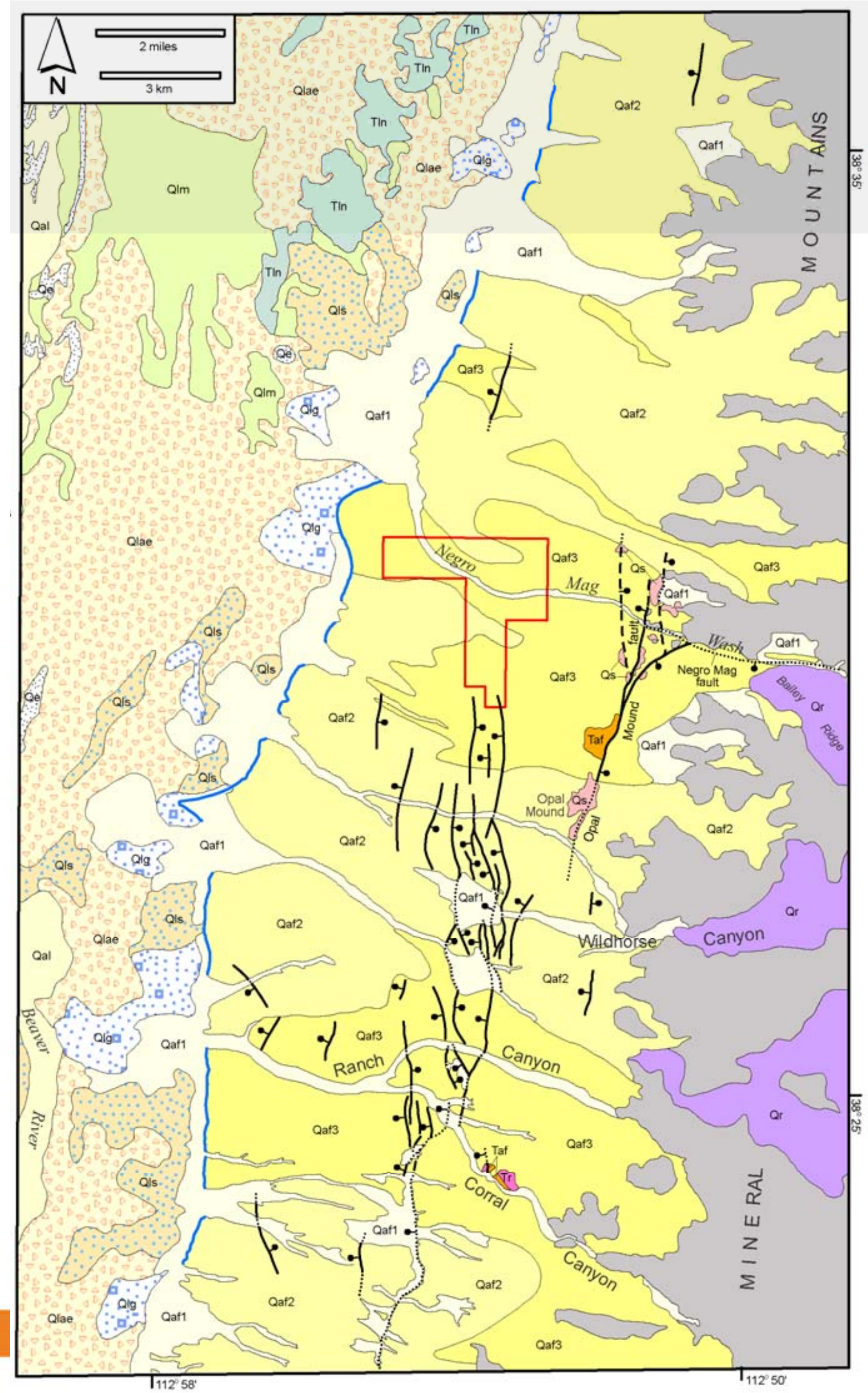
FORGE area Faults

- **Red – N. Mag fault**
- Green – Opal Mound fault
- Purple – Mineral Mountains West faults



Quaternary Mapping

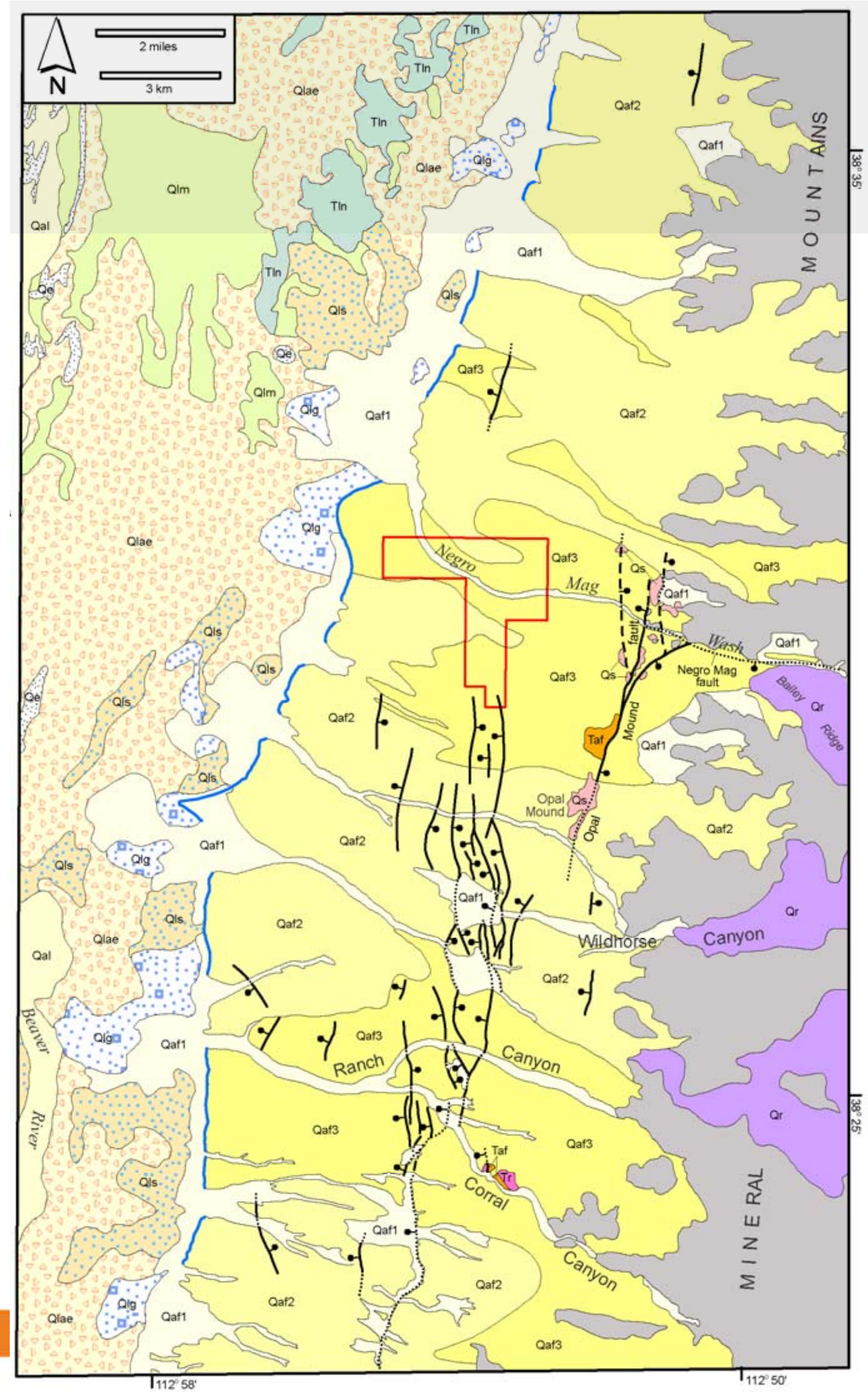
- Using 2016 half-meter lidar (330 square miles)
- Mapped at 1:10,000
- Historic and recent aerial photos.
- Field mapping
- Observations from 5 soil pits
- Final IRSL results received 1/31/18



Quaternary Mapping

BEDROCK

Qr	Quaternary rhyolite (middle Pleistocene) - Rhyolite flows and domes with K-Ar ages ranging from ~0.5 to ~0.8 Ma (Lipman and others, 1978).
Tr	Tertiary rhyolite (Miocene) - About 7.9 Ma (Lipman and others (1978) rhyolite deposited on Taf in Corral Canyon.
	Other bedrock - Mostly granitic intrusive rocks intruded into Precambrian banded gneiss.



Quaternary Mapping

LACUSTRINE DEPOSITS

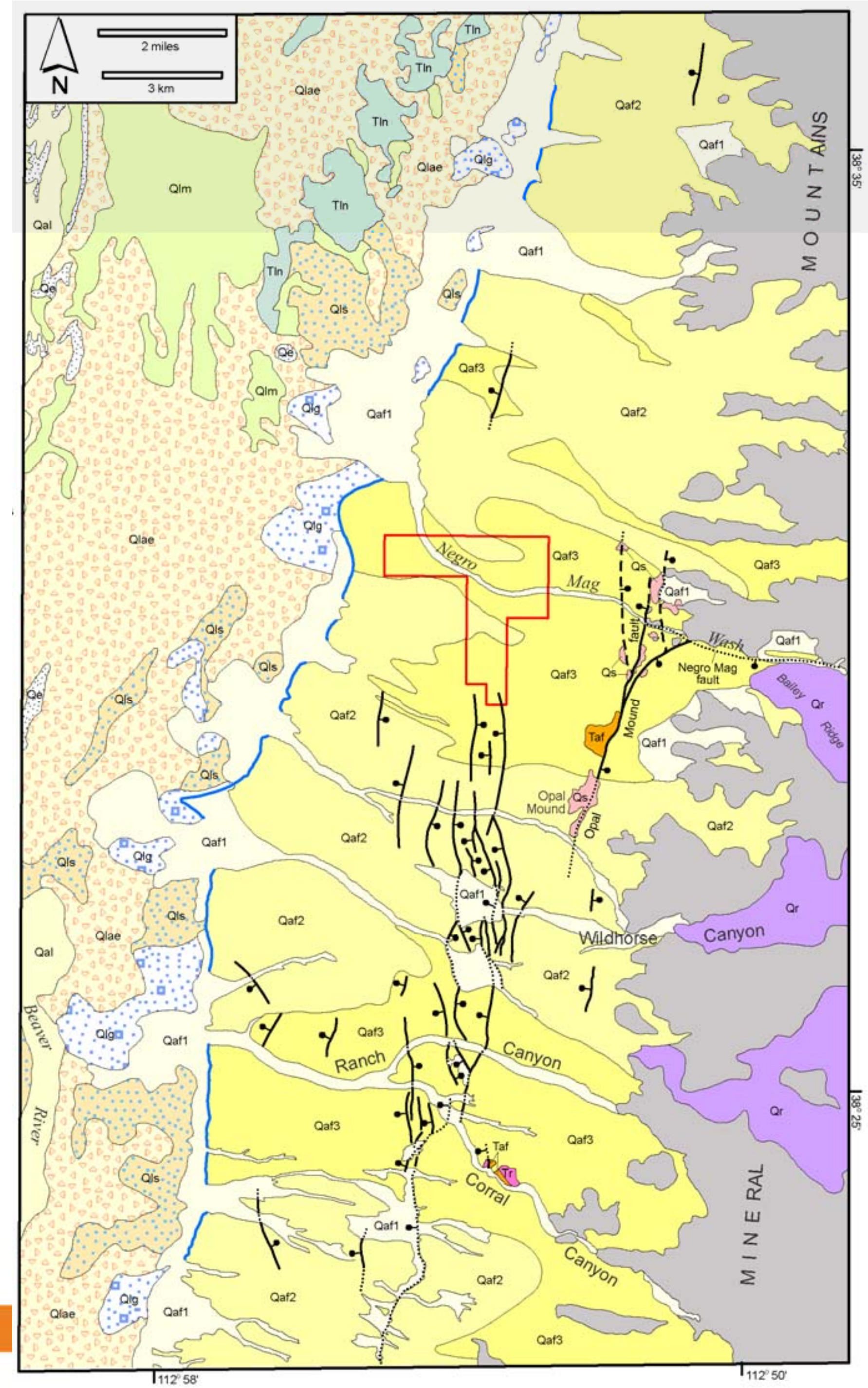
Qlae — Lacustrine, alluvial, and eolian deposits, undivided (Holocene to upper Pleistocene)

Qlg — Lacustrine gravel (upper Pleistocene) - Sandy beach and spit gravel deposited in Lake Bonneville.

Qls — Lacustrine sand (upper Pleistocene) - Sand and pebbly sand deposited in Lake Bonneville.

Qlm — Lacustrine mud (upper Pleistocene) - silt, marl, clay and minor sand that are deep-water sediments of Lake Bonneville.

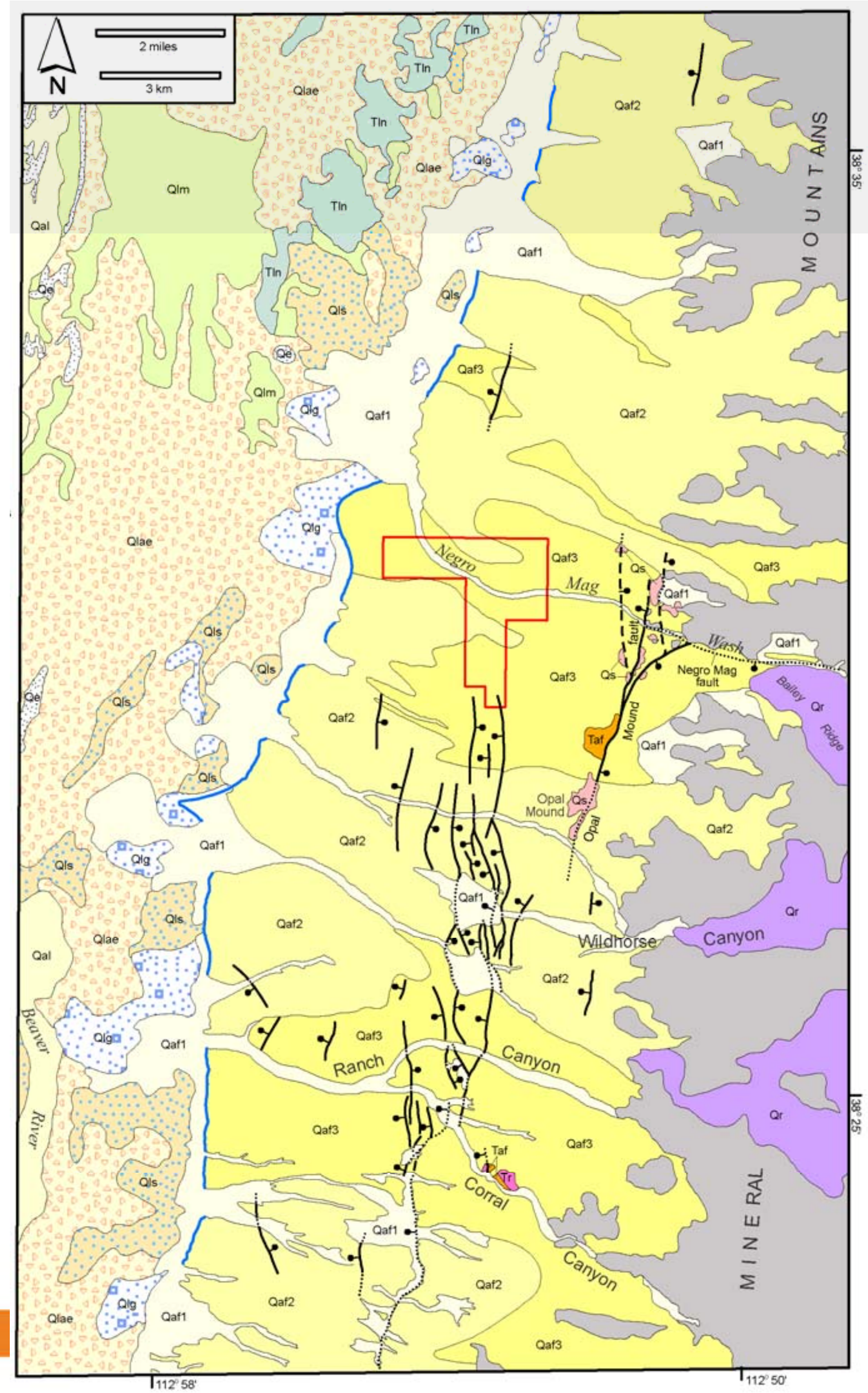
Tln — Freshwater limestone (late Pliocene? to middle Pleistocene?) - Massive freshwater limestone tentatively correlated with Hintze and Davis's (2003) pre-Lake Bonneville Limestone of Twin Peaks.



Quaternary Mapping

EOLIAN DEPOSITS

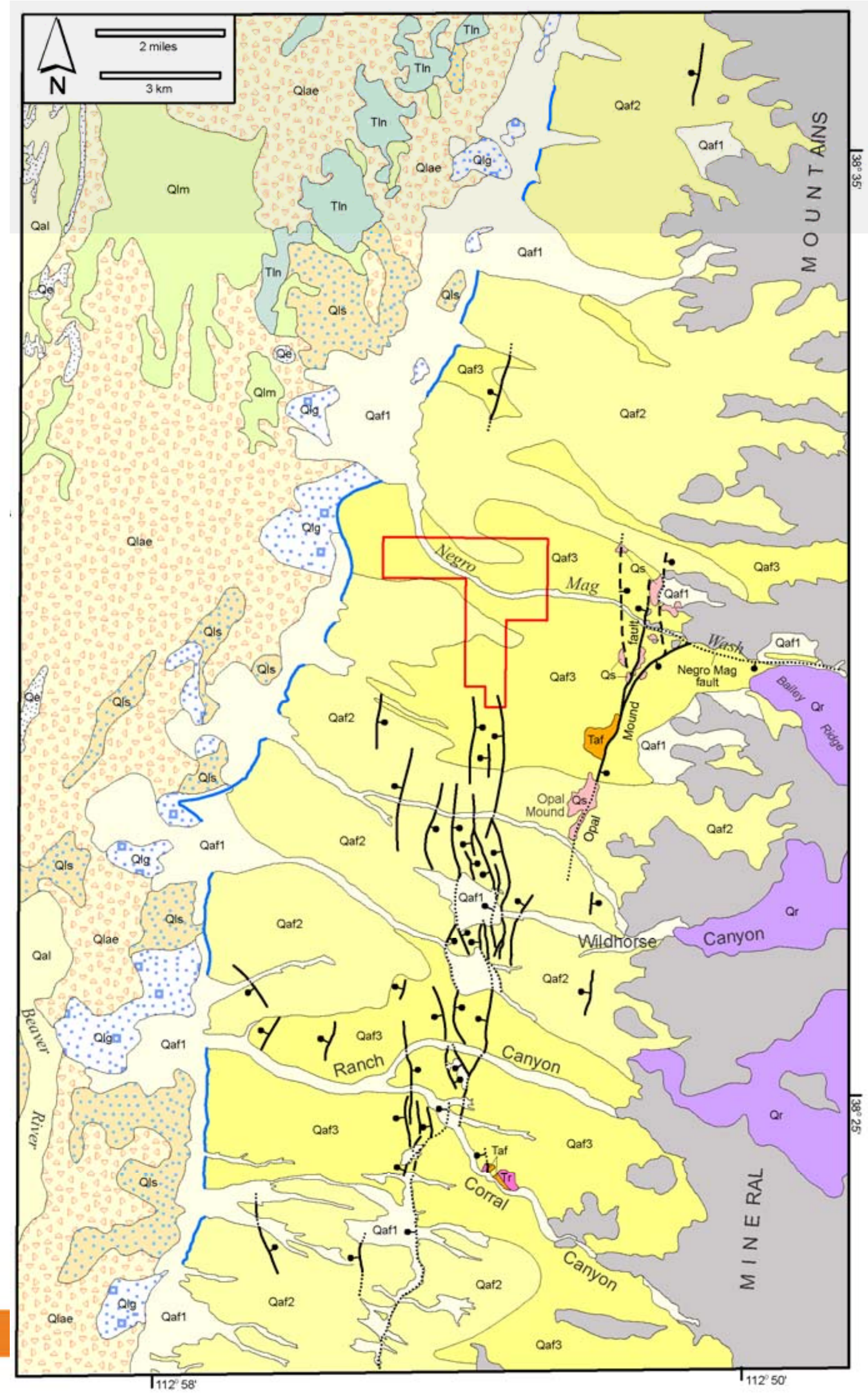
Qe — Eolian sand (Holocene) - well-sorted silt and sand deposited in sheets, mounds, and dunes.



Quaternary Mapping

SPRING DEPOSITS

Qs	Hot spring deposits (Holocene to upper Pleistocene) - Sinter-cemented alluvial deposits and primary opaline sinter deposited along strands of the Opal Mound fault.



Quaternary Mapping

ALLUVIAL DEPOSITS

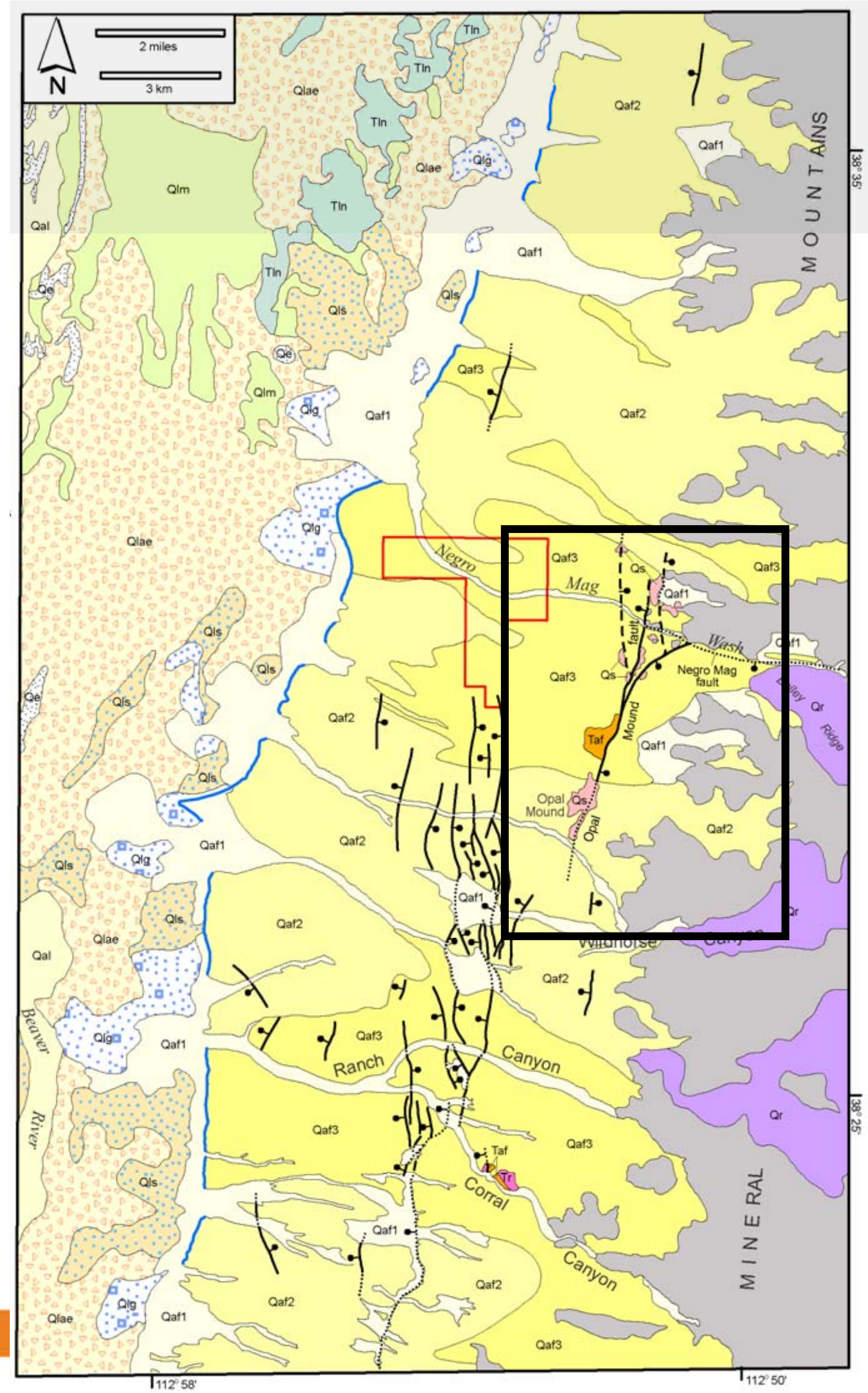
Qal Stream alluvium (Holocene) - Clay, silt, and sand deposited along the Beaver River channel.

Qaf1 Level-1 fan alluvium (Holocene to latest Pleistocene) - Post-Lake Bonneville sediment deposited principally as debris flows and debris floods.

Qaf2 Level-2 fan alluvium (Holocene to upper Pleistocene) - Mostly pre-Bonneville sediment similar to Qaf1 but is incised by active drainages as much as 30 feet (9 m).

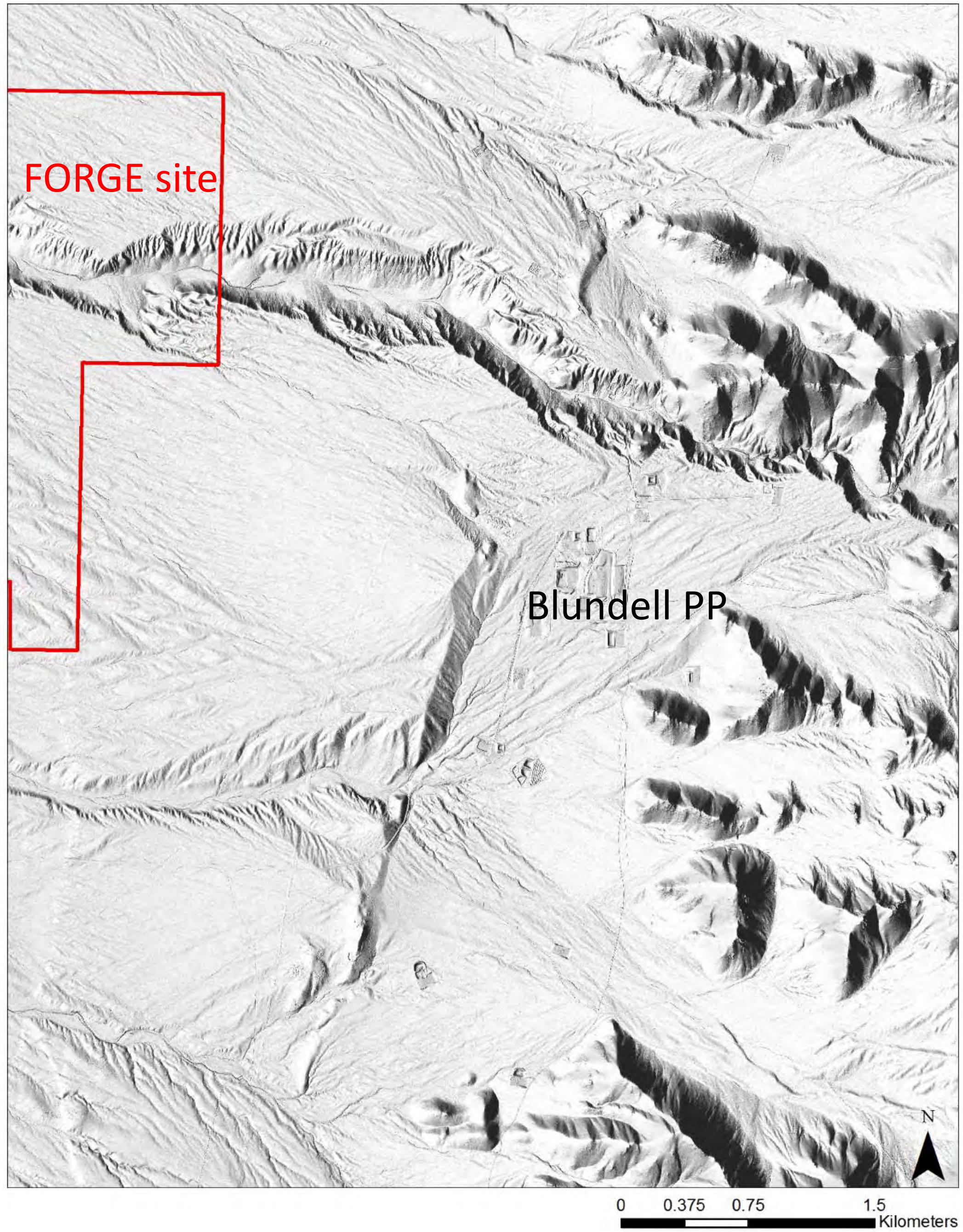
Qaf3 Level-3 fan alluvium (upper Pleistocene) - Pre-Bonneville sediment similar to Qaf1 but incised by active drainages as much as 200 feet (60 m).

Taf Basin-fill deposits (Pliocene? to Miocene) - Coarse debris with clasts as large as 15 feet (5 m) in long dimension interpreted to have been shed off of the ancestral Mineral Mountains.



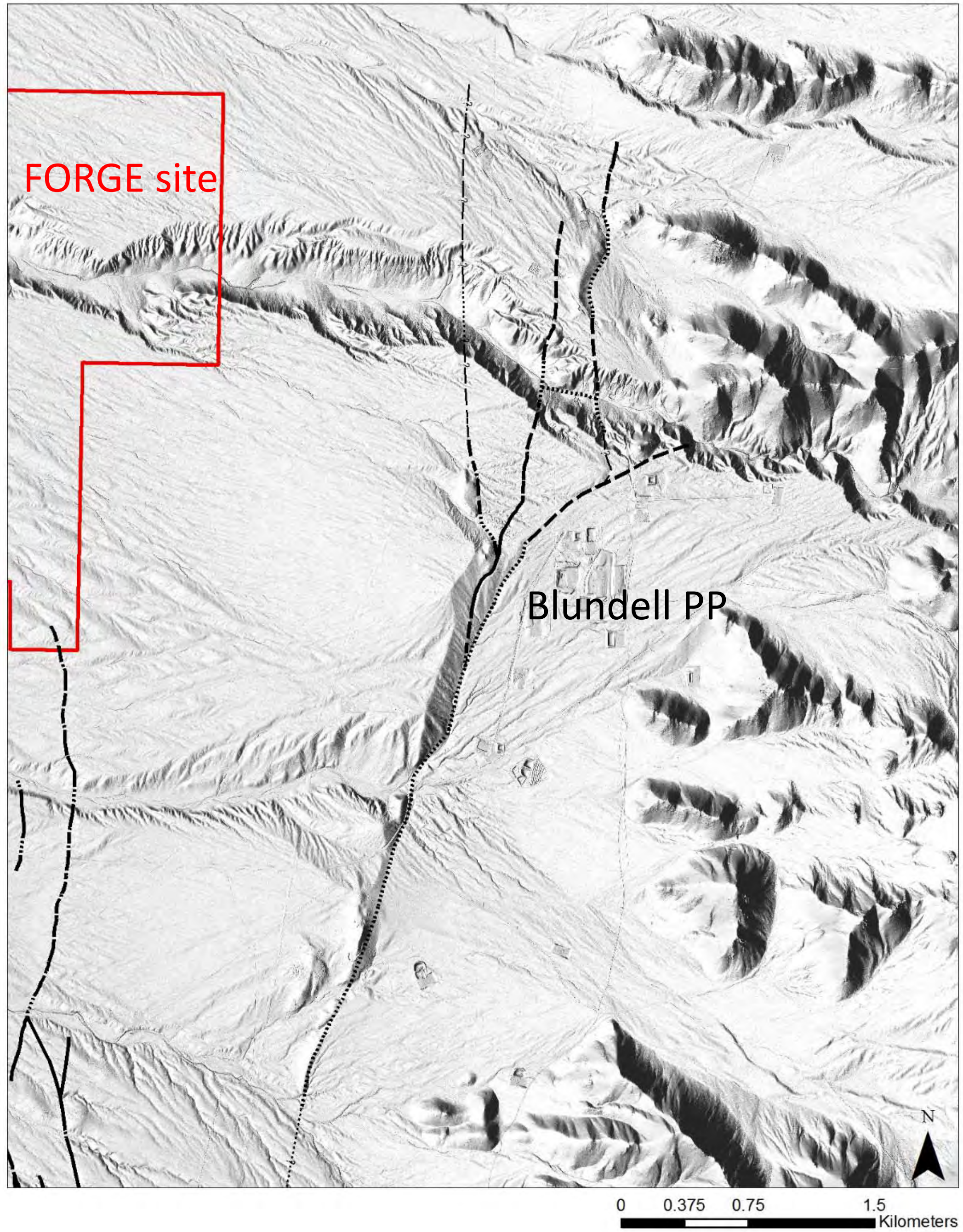
Opal Mound fault

- East-dipping
- Cut by 2 major drainages.
- Sinter/Opal armoring



Opal Mound fault

- East-dipping
- Cut by 2 major drainages.
- Sinter/Opal armoring
- Length: 7 km
- Scarp height: 13 -18 m
- Average slope: 4° – 7°



Opal Mound Fault

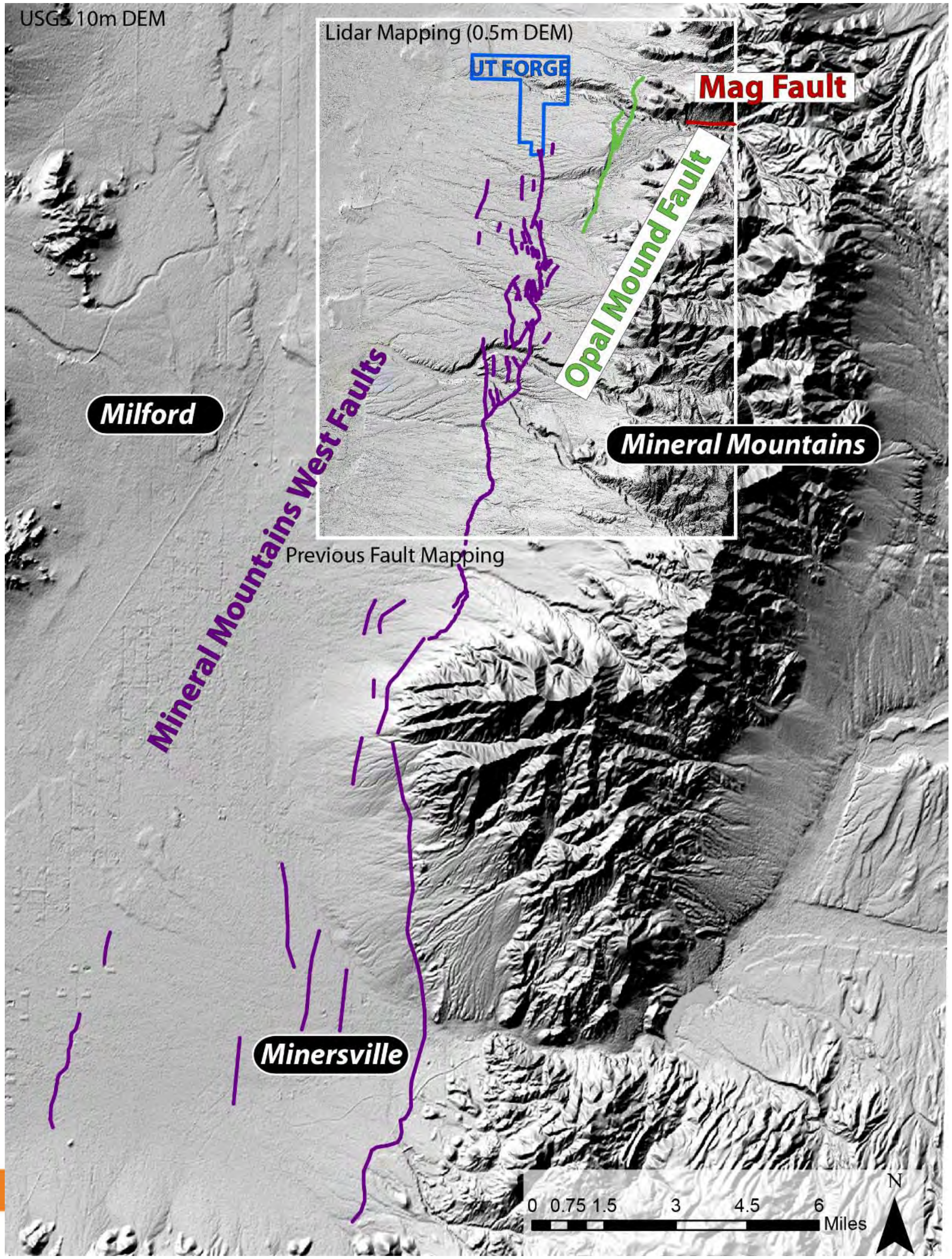
Southward view of a spring vent on Opal Mound. White arrow points to hammer placed in the vent neck, where banded opal is vertical. Note that additional opal laminations dip gently away from either side of the vent.

South-directed view of east-dipping (~20°) sinter-cemented alluvium south of NM wash.

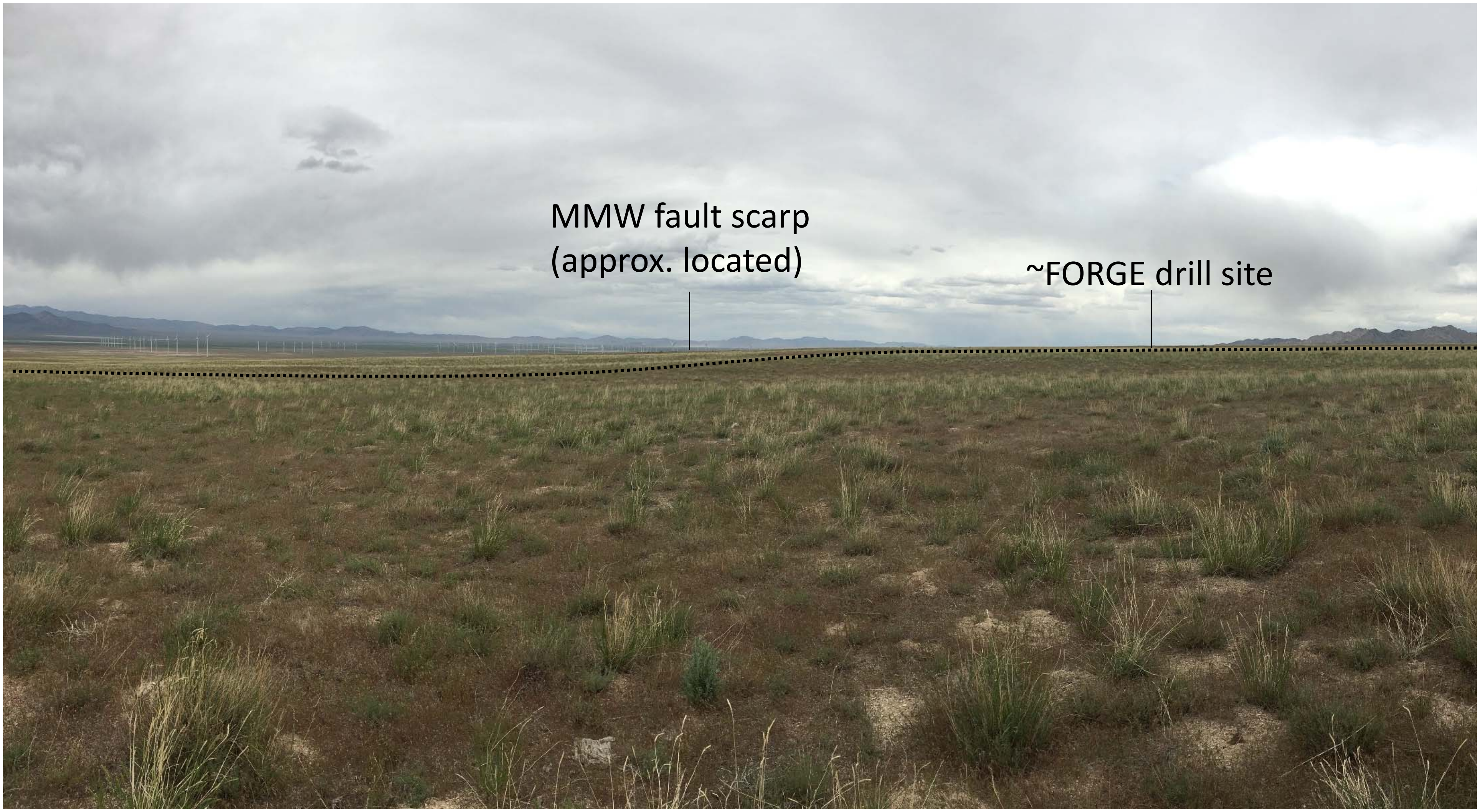
Photos from T.Knudsen

Mineral Mountains West faults

- ~40 km long
- Predominantly west dipping
- Northernmost terminus is 8 km graben
  - Graben faults: <1m – 8m high, average ~3.1m
  - 5° - 7°

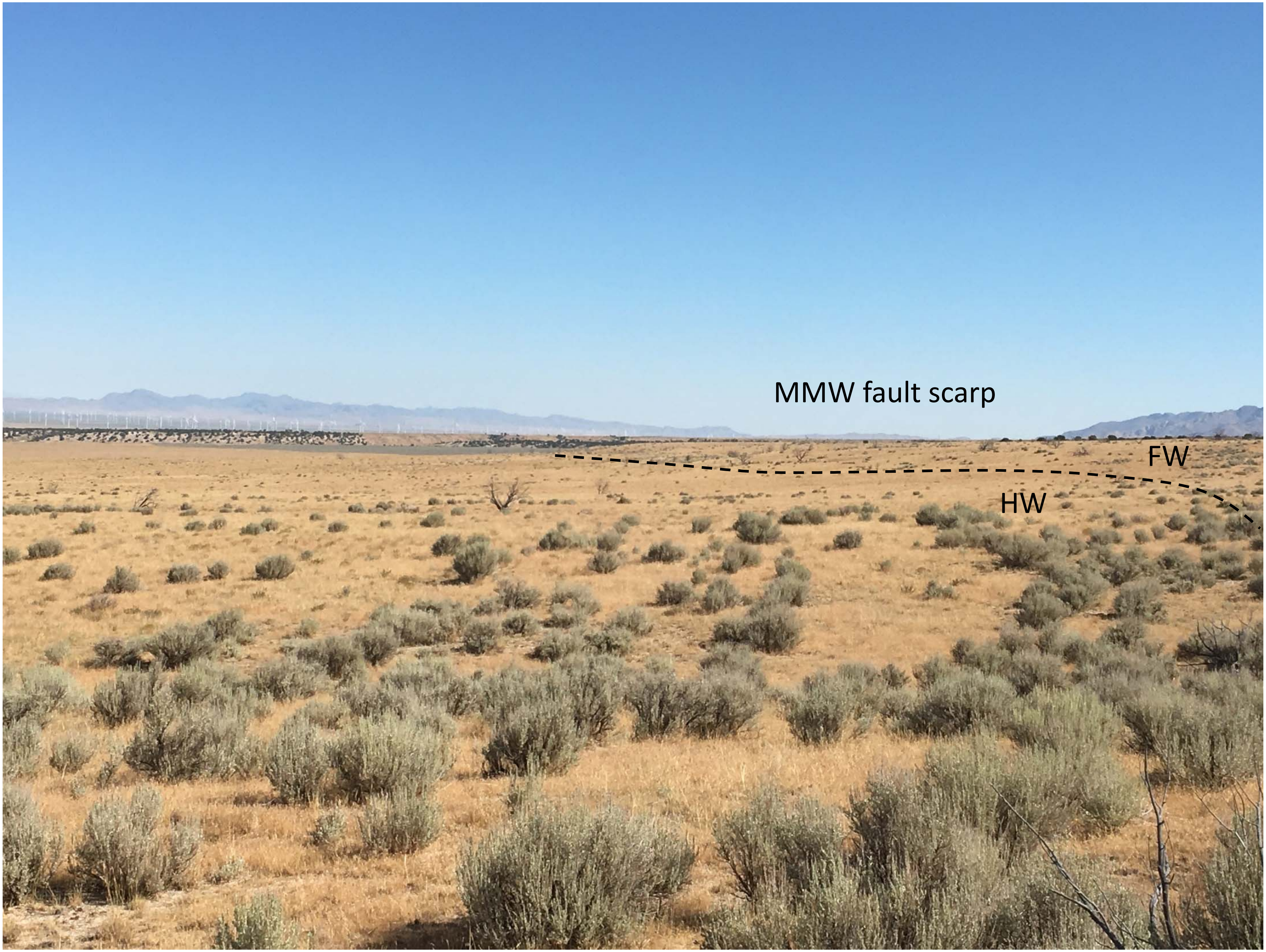


Mineral Mountains West (MMW) faults –Field photos from north to south



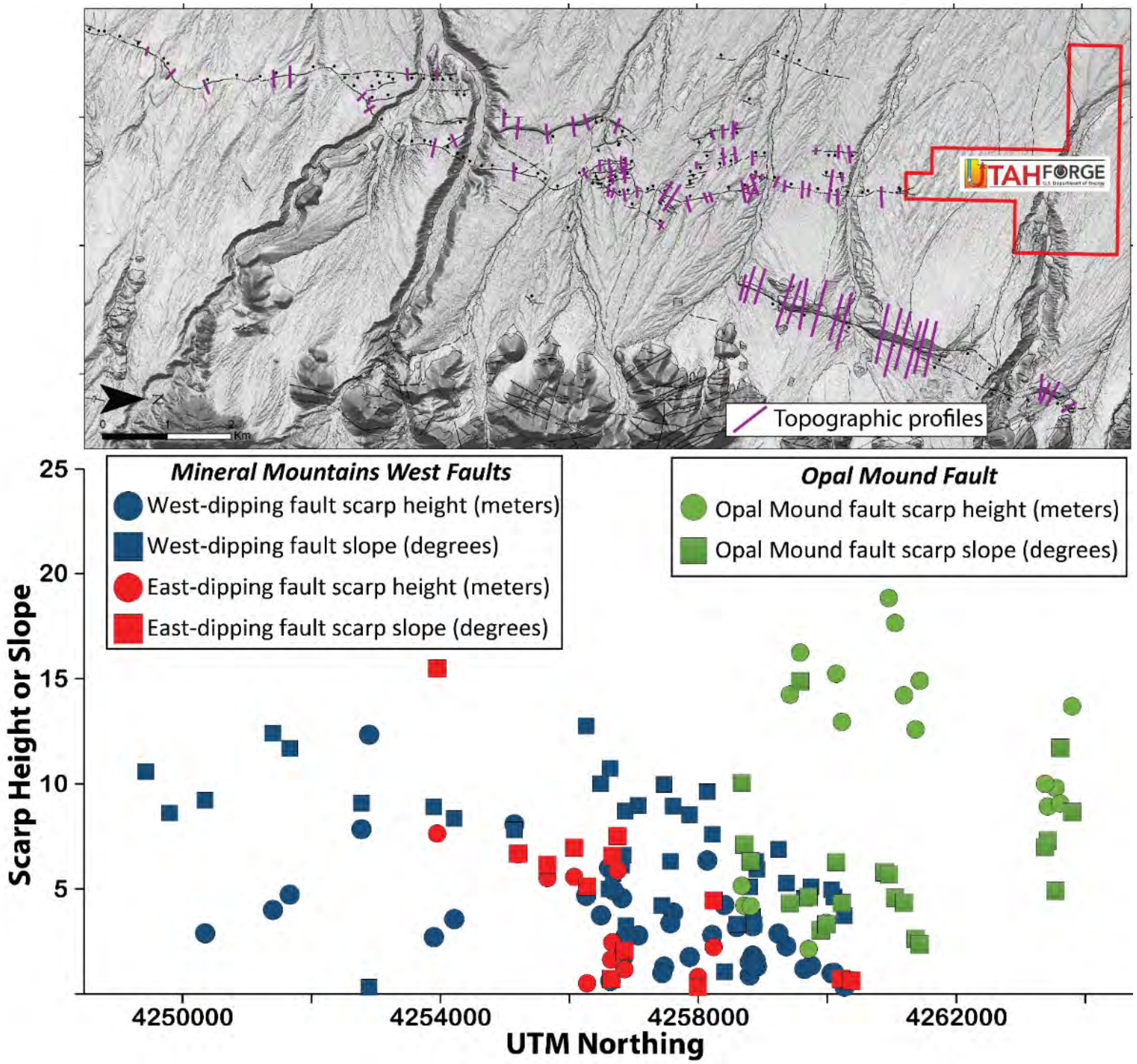
Low-sun angle (am) photo of a low MMW fault scarp (15 ft [5 m] high) formed on late Pleistocene alluvial-fan deposits north of Ranch Canyon.

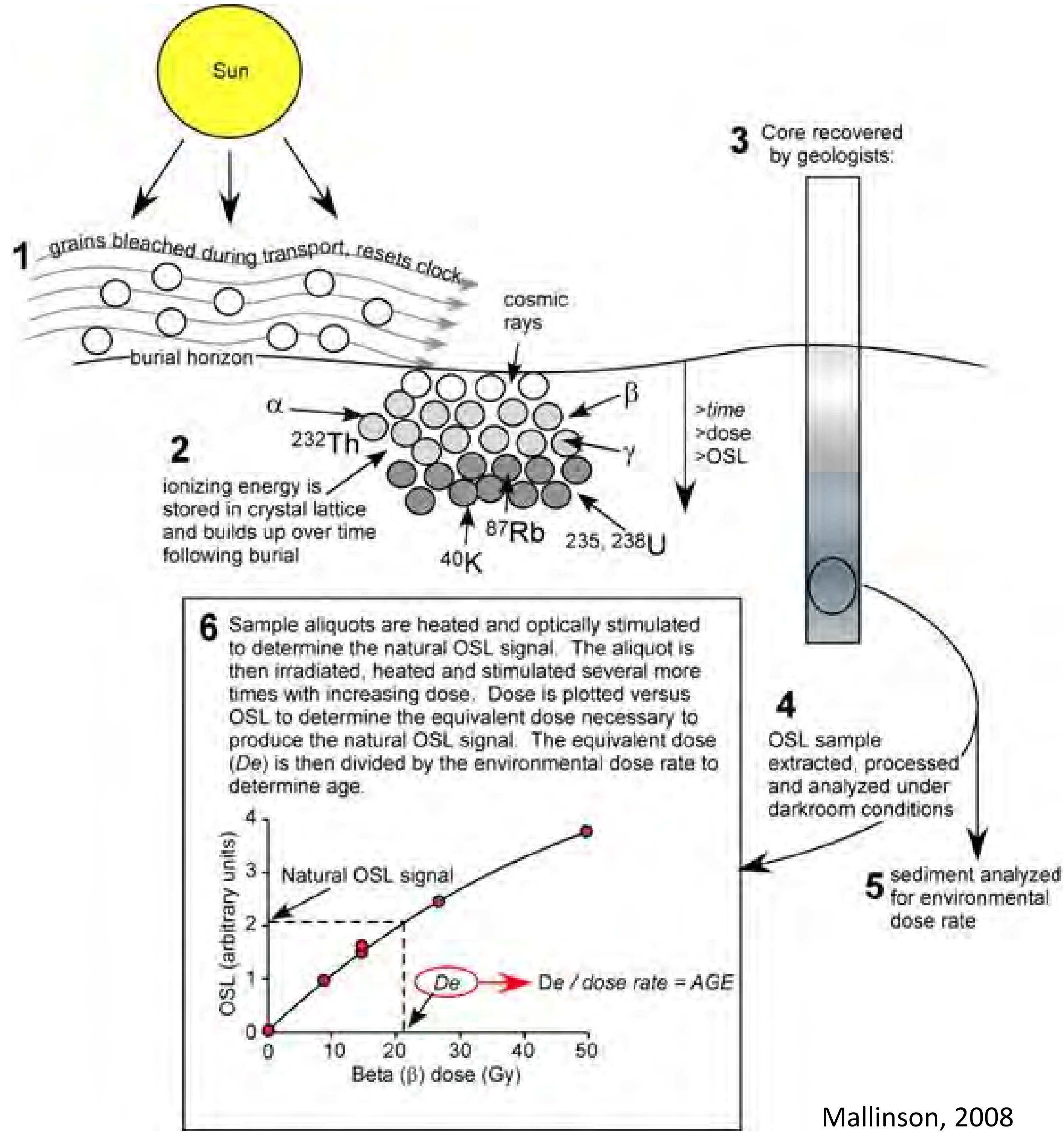

MMW fault scarp
HW
FW


MMW fault scarp
FW
HW

Geomorphic characterization of MMW fault scarps

- Scarp topographic profile analysis within lidar extent.
- Scarp slope and height decrease to the north, even within the graben.





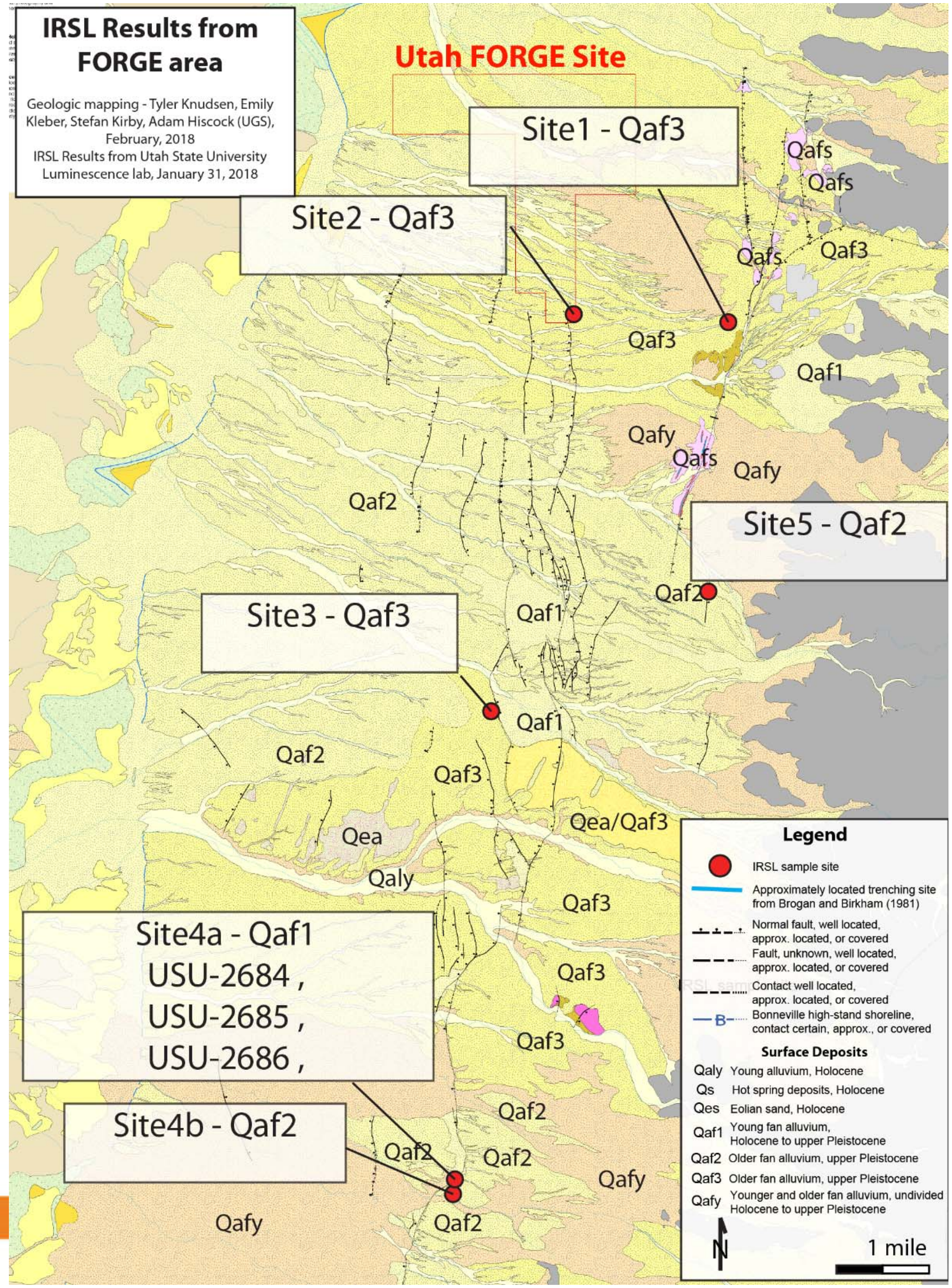
Mallinson, 2008

OSL/IRSL dating

- GOAL: constrain ages of faulted Quaternary deposits.
- Infrared Stimulated luminescence (IRSL) of feldspar grains at Utah State University with Dr. Tammy Rittenour.
- 5 sites

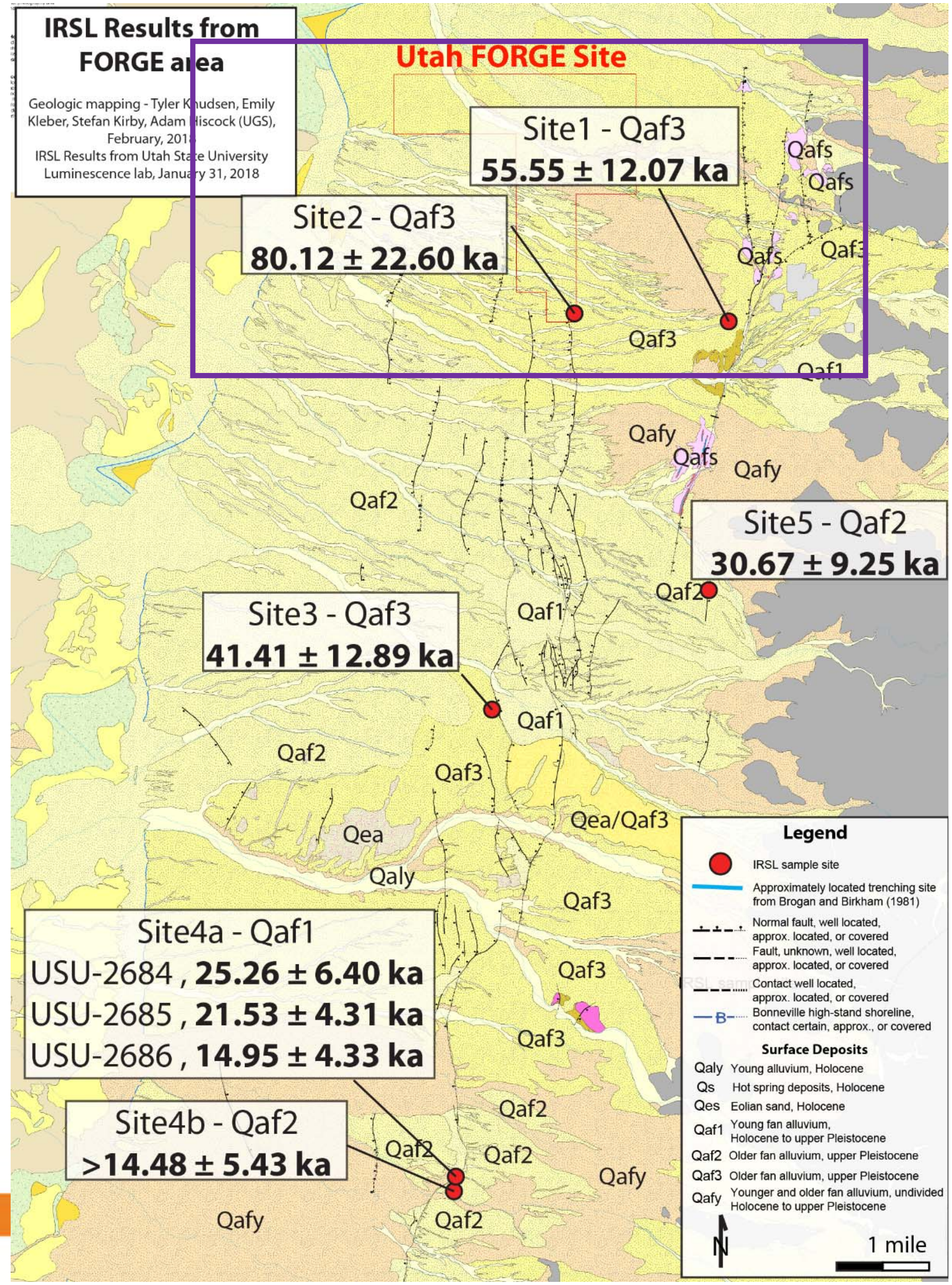
USU LUMINESCENCE LABORATORY
http://usu.edu/geo/luminlab
1770 North Research Parkway, Suite 123, North Logan, Utah 84341

UTAH DNR GEOLOGICAL SURVEY



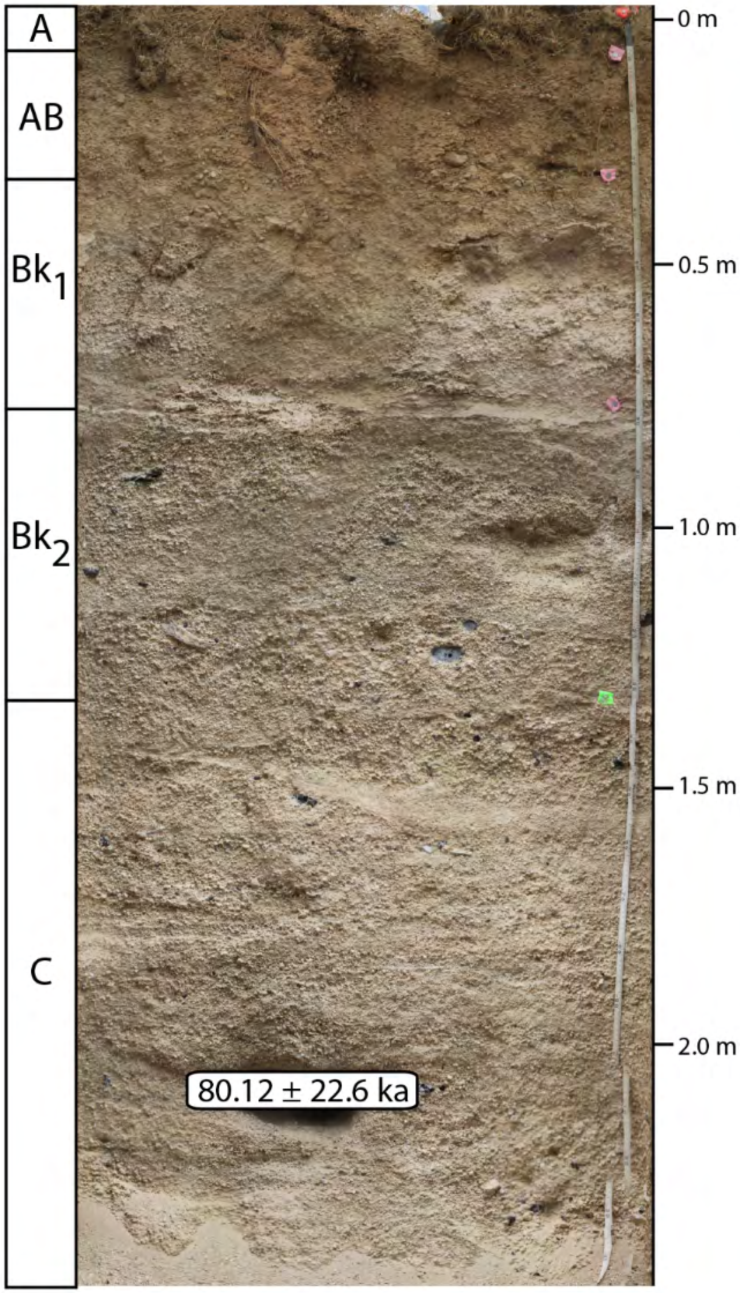
OSL/IRSL dating

- Results

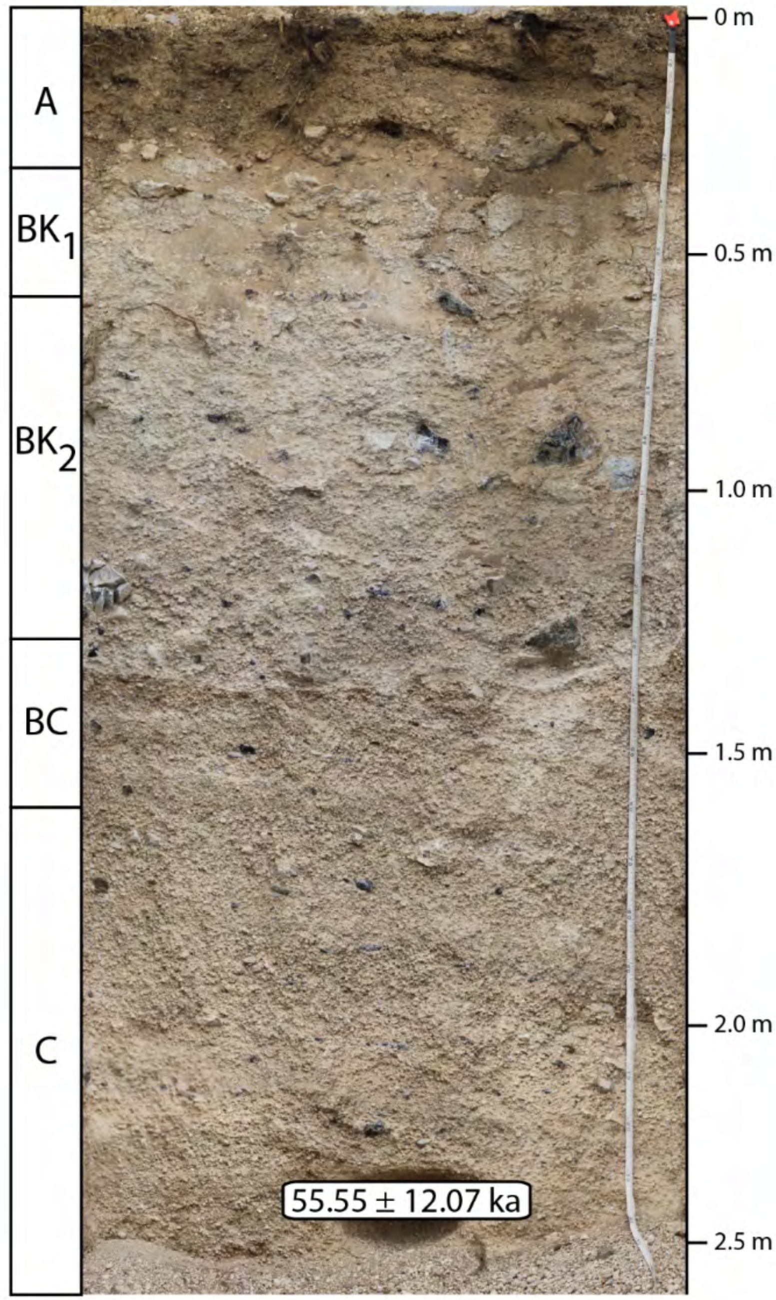


Site 1

IRSL Site 2 (USU-2681)
Sampled August 23, 2017
N 38.48514, W 112.88897, 1703 m ASL

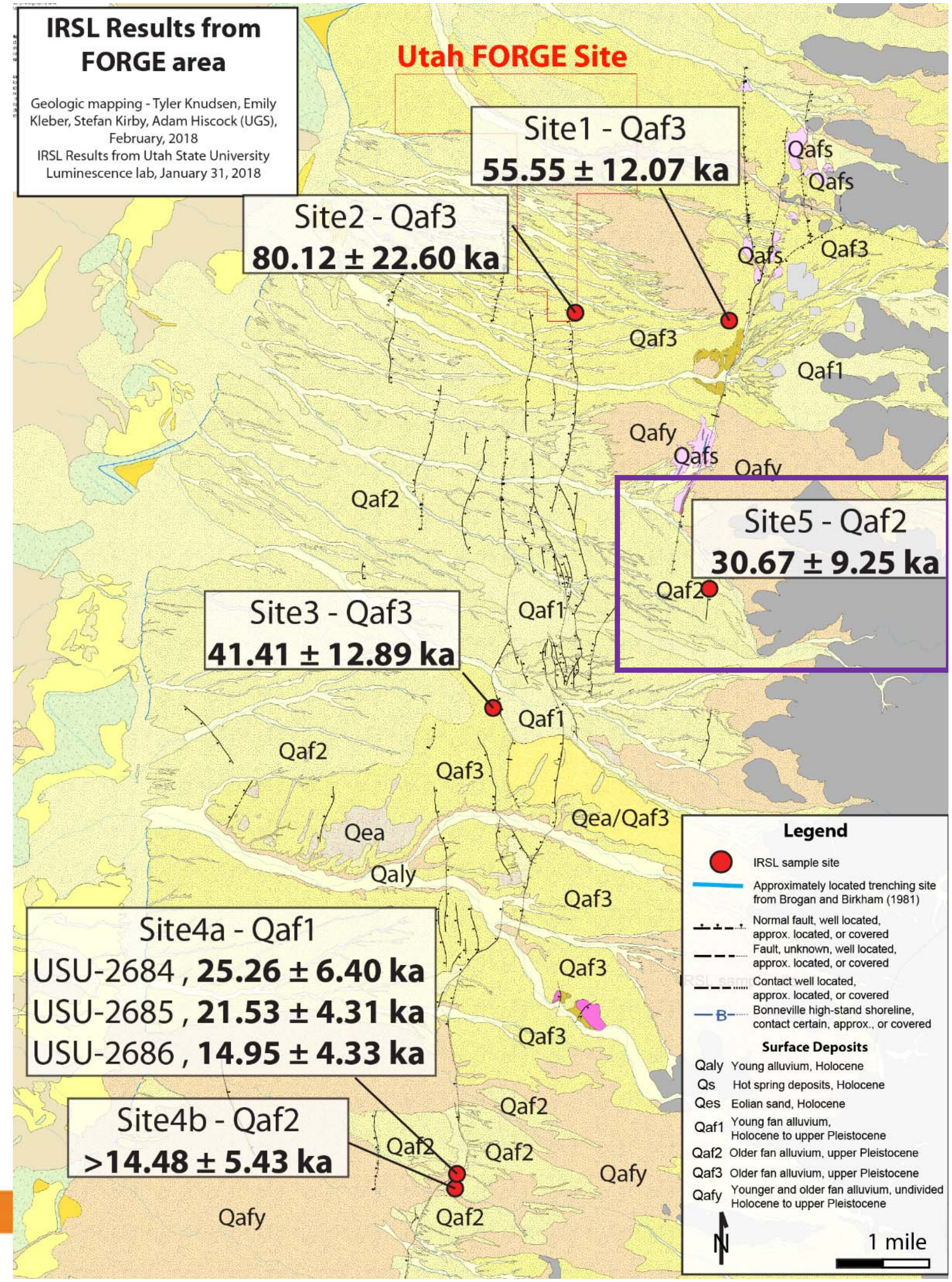


IRSL Site 1 (USU-2680)
Sampled August 23, 2017
N 38.48468, W 112.86554, 1800 m ASL



OSL/IRSL dating

- Results



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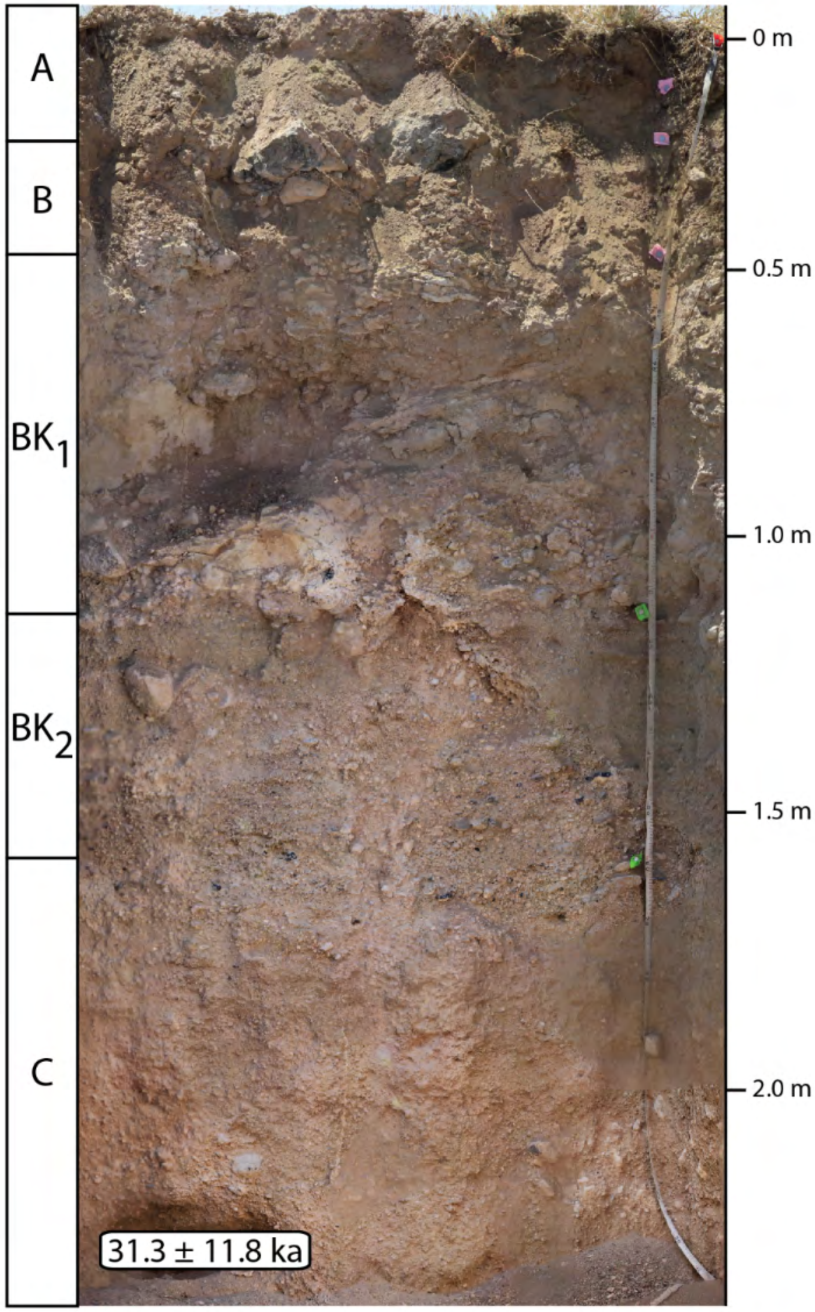
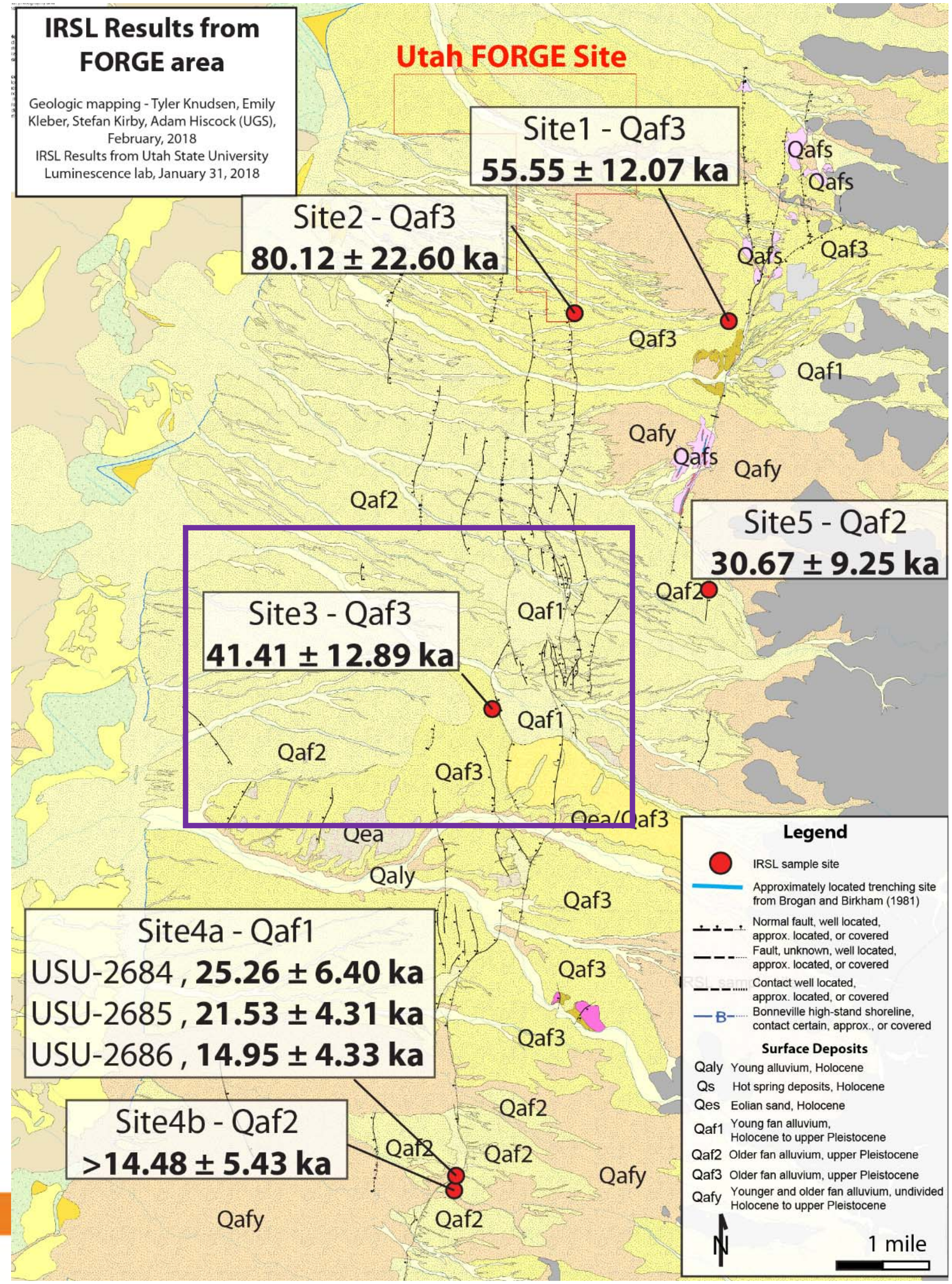
UTAH DNR GEOLOGICAL SURVEY

IRSL Site 5 (USU-2682)
Sampled August 23, 2017
N 38.45210, W 112.86866, 1791 m ASL



OSL/IRSL dating

- Results



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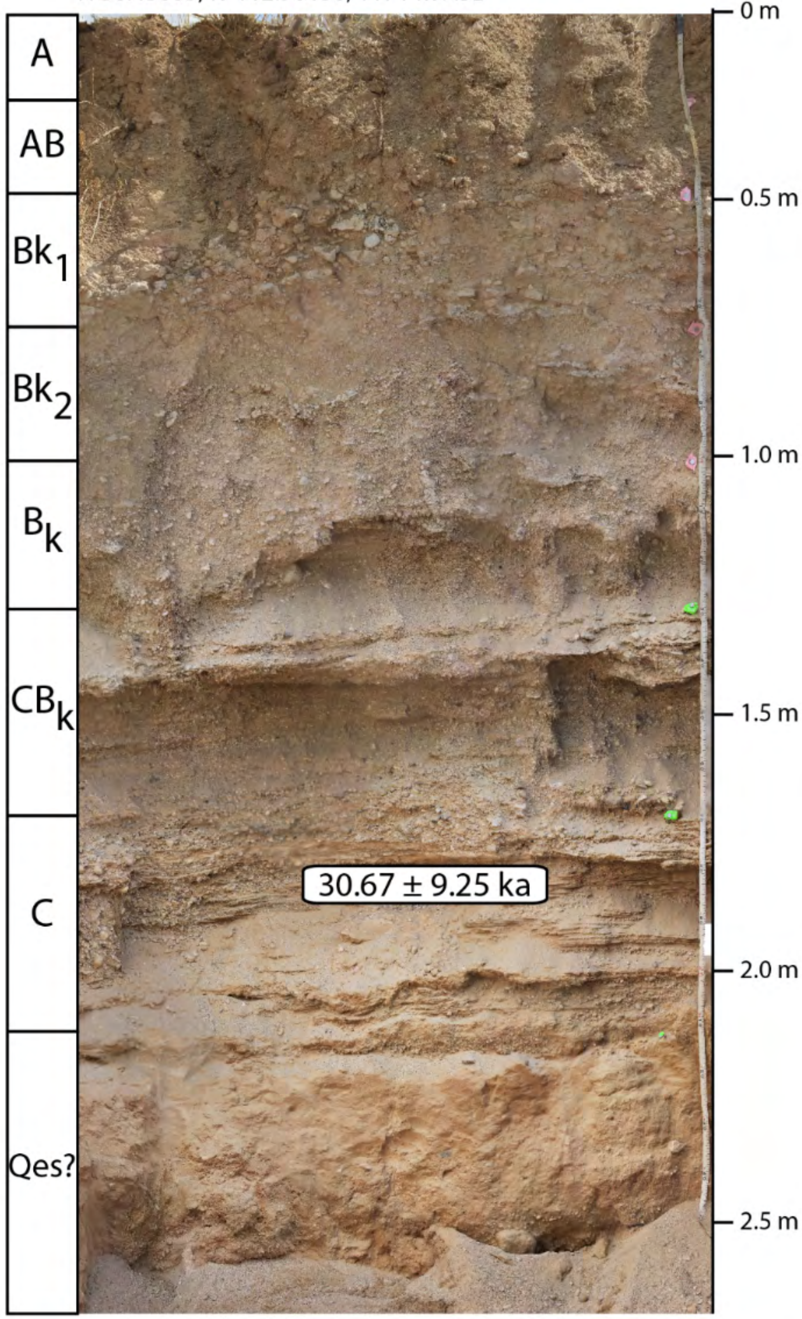
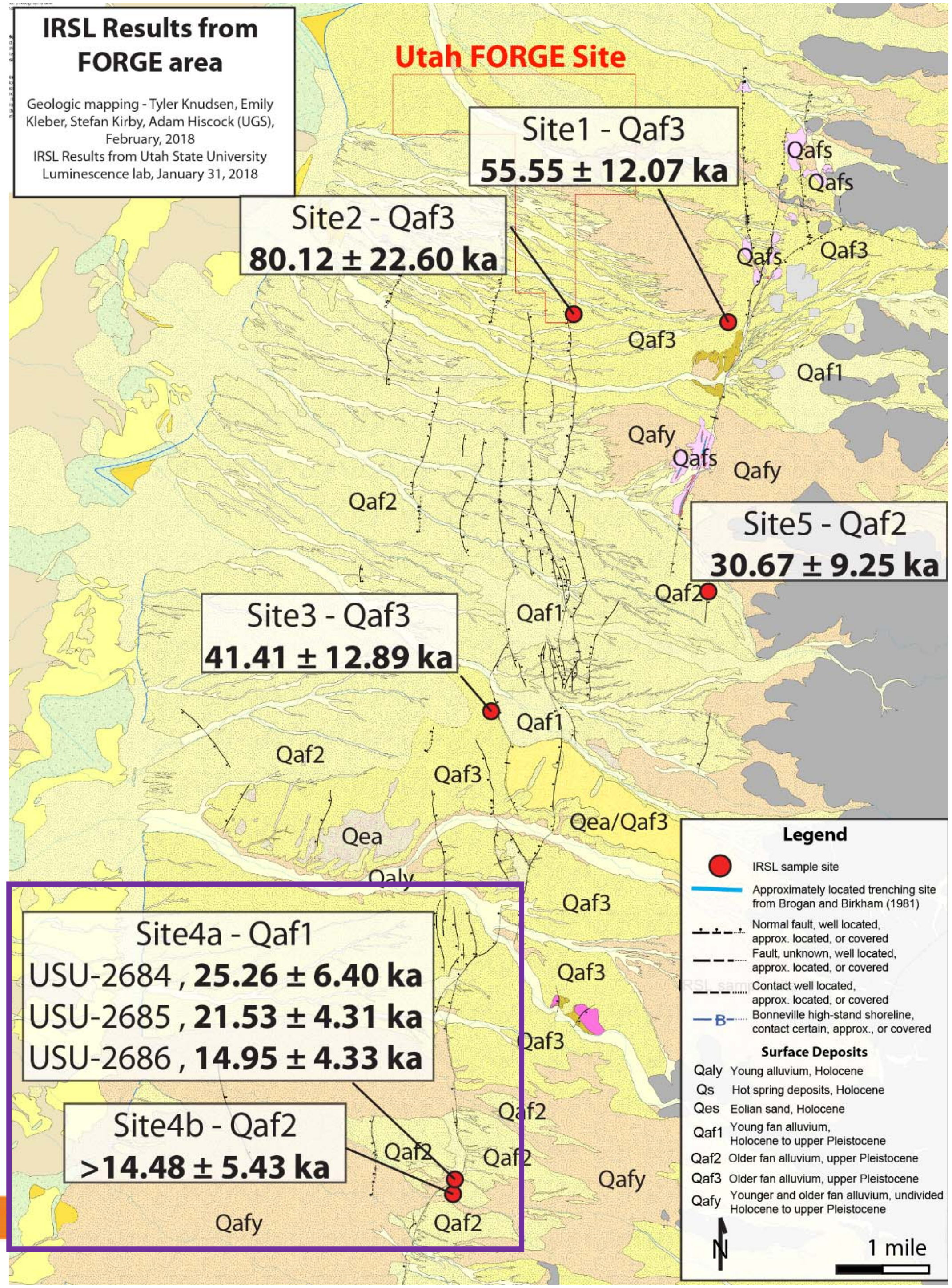
USU LUMINESCENCE LABORATORY
1770 North Research Parkway, Suite 123, North Logan, Utah 84341

IRSL Site 3 (USU-2683)
Sampled August 23, 2017
N 38.43803, W 112.90150, 1171 m ASL



OSL/IRSL dating

- Results



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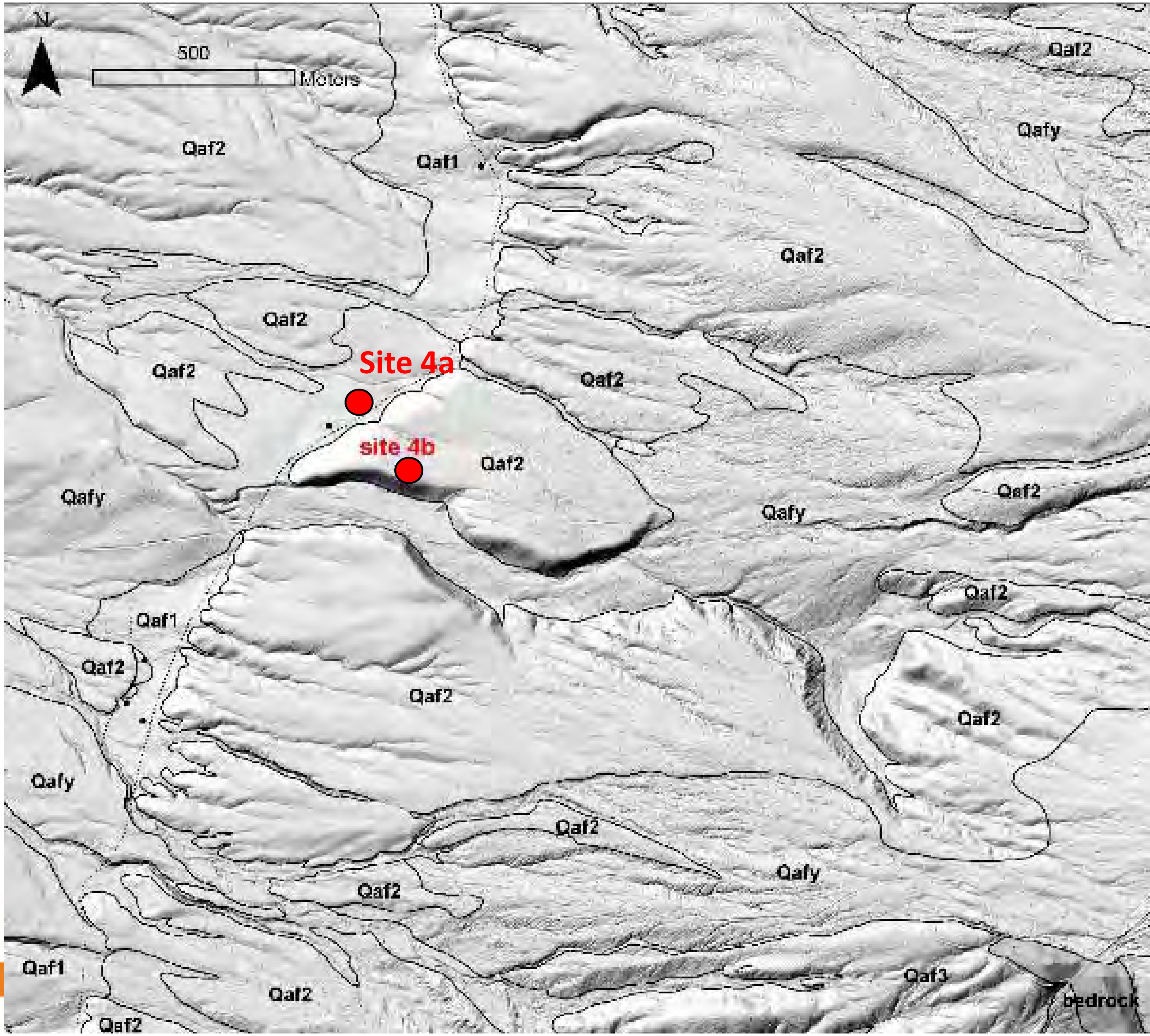
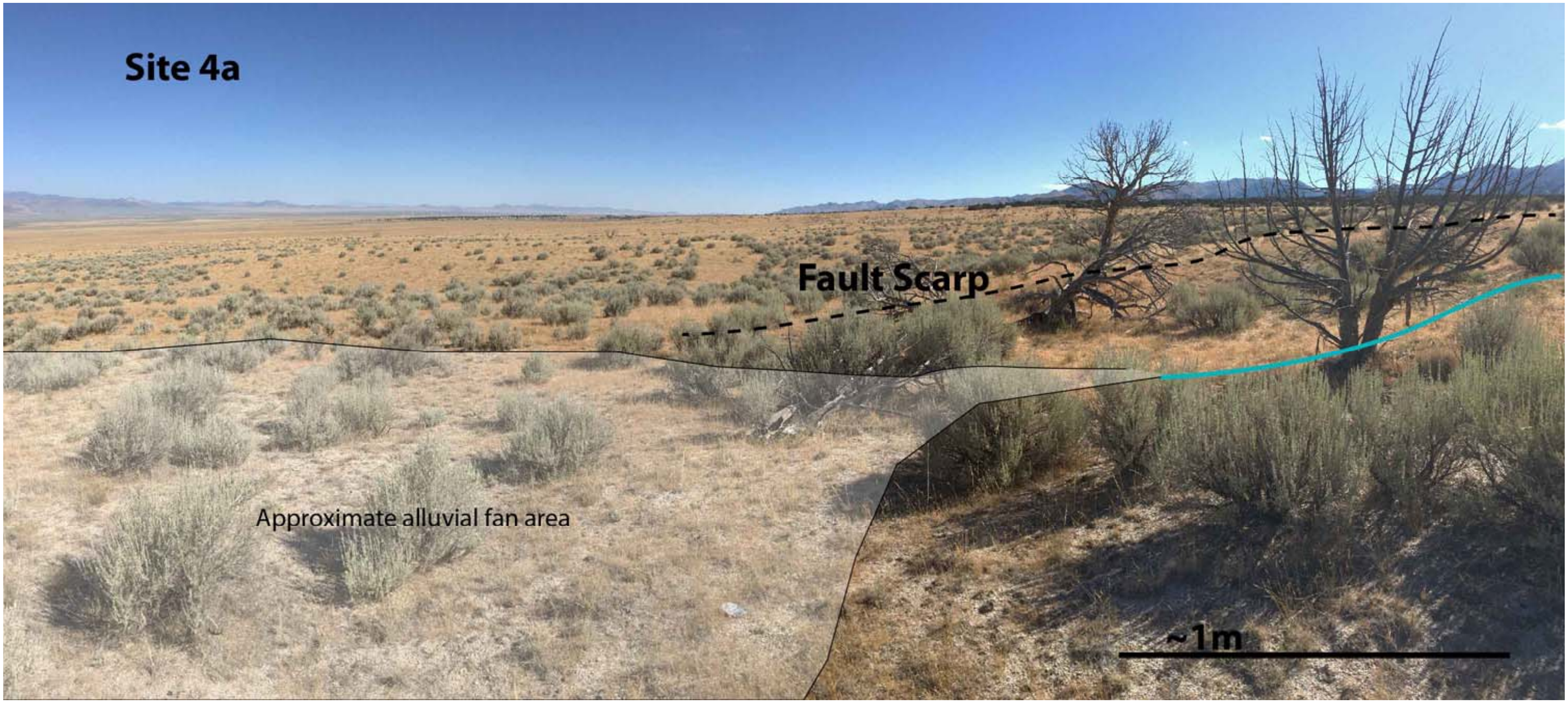
1770 North Research Parkway, Suite 123, North Logan, Utah 84341

UTAH DNR GEOLOGICAL SURVEY

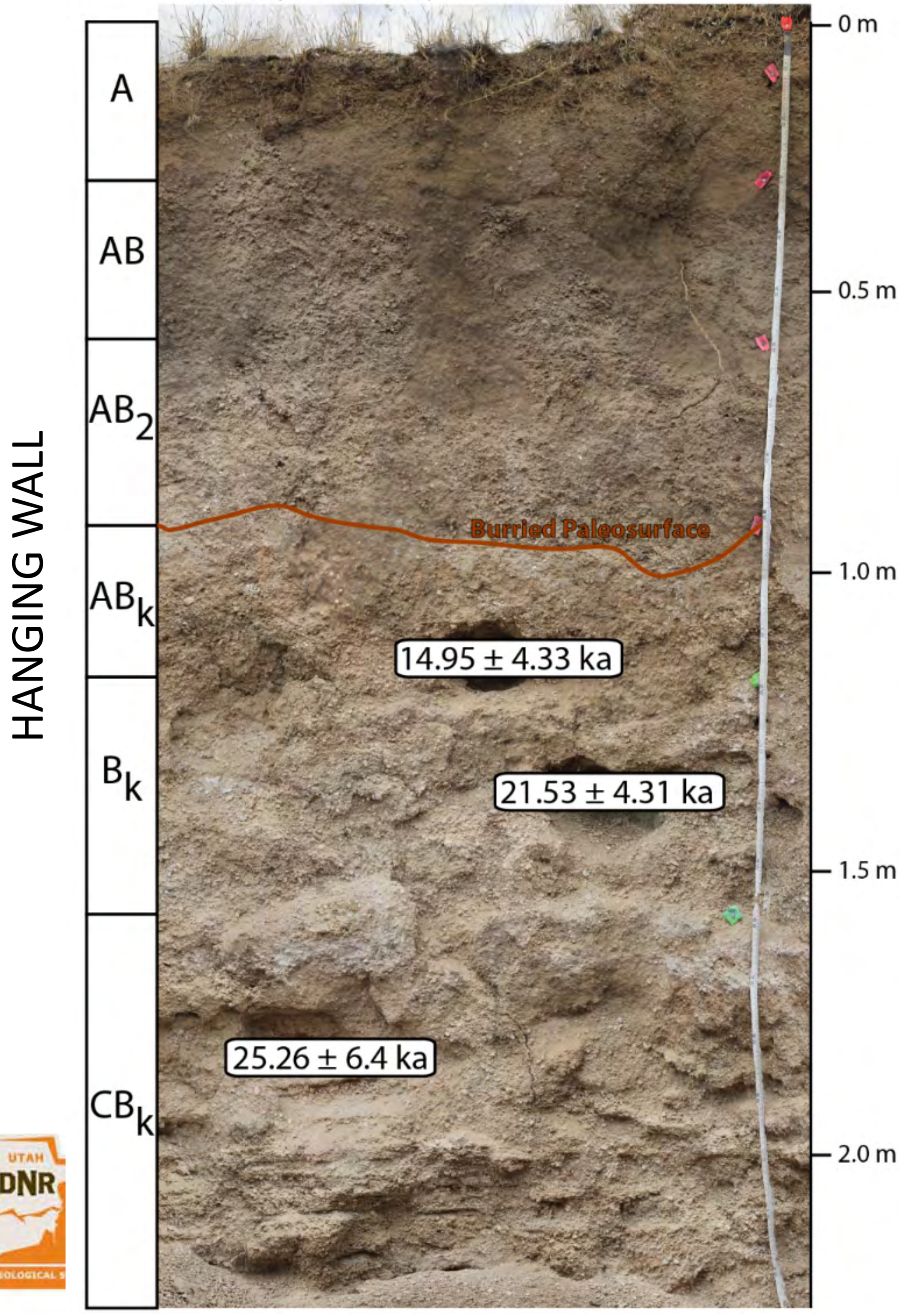


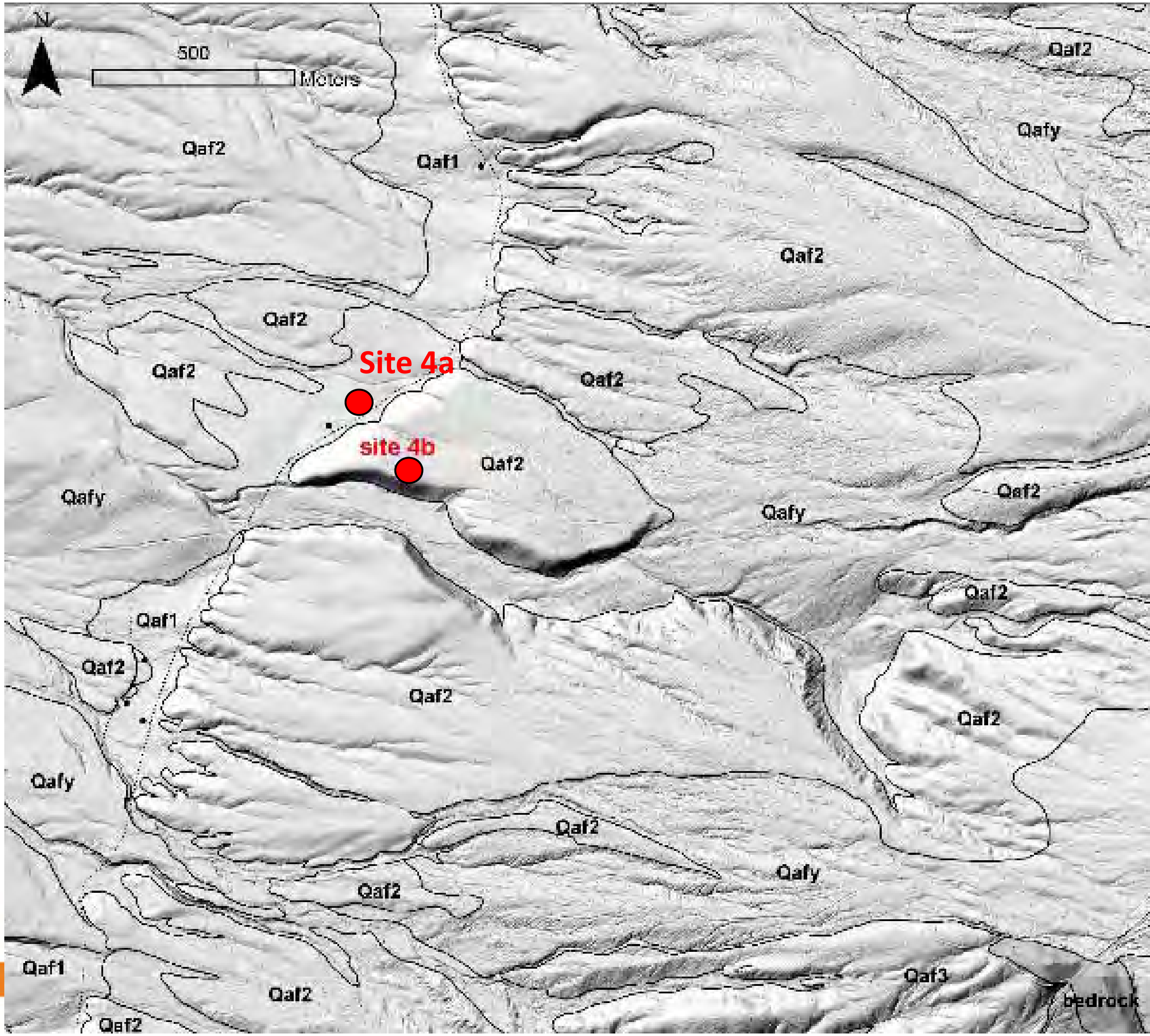
UTAH DNR GEOLOGICAL SURVEY

…tah.gov


Site 4a
Fault Scarp
Approximate alluvial fan area
~1m

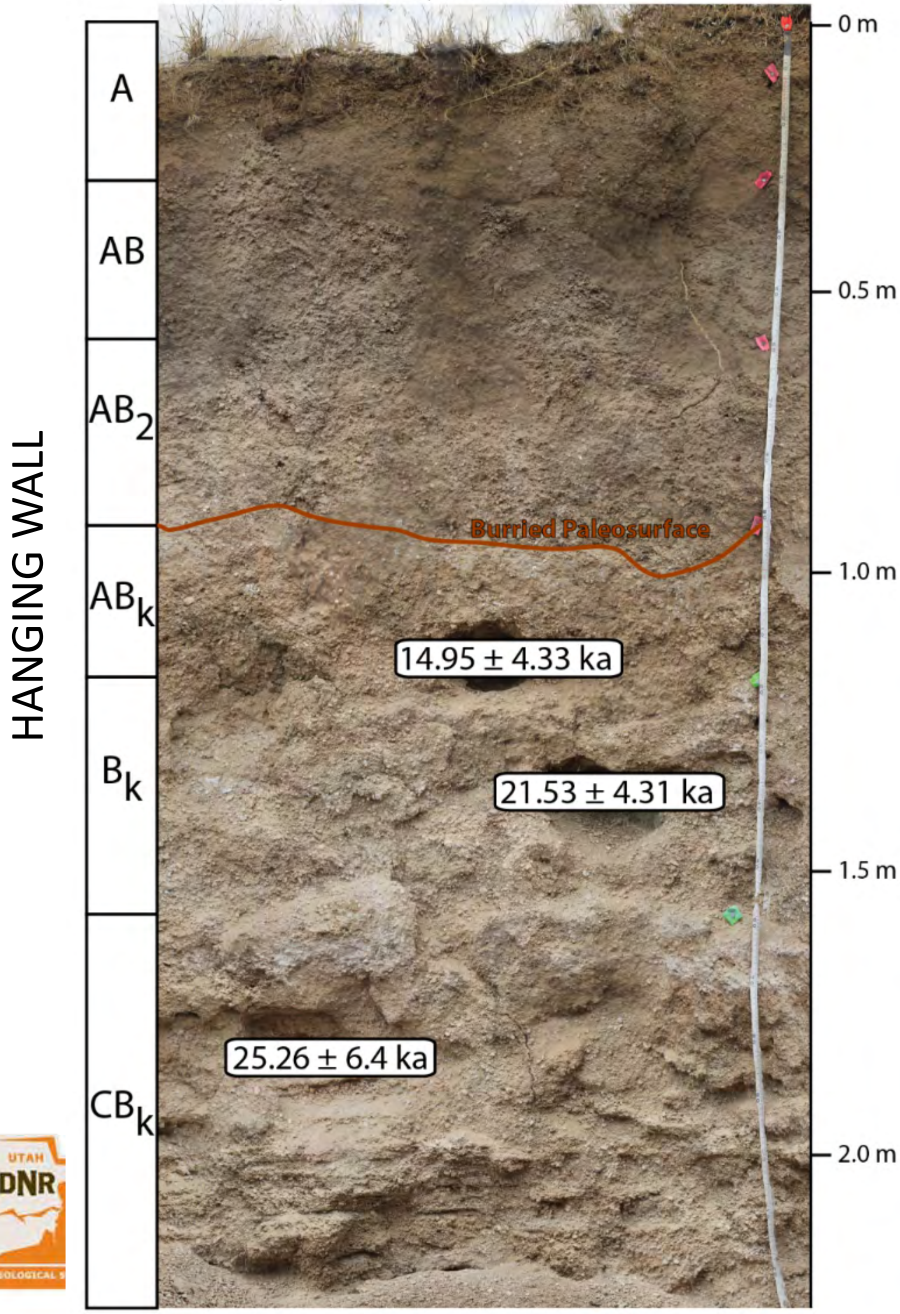
IRSL Site 4a (USU-2684, 2685, 2686)
Sampled August 23 and 24, 2017
N 38.38123, W 112.90760, 1744 m ASL



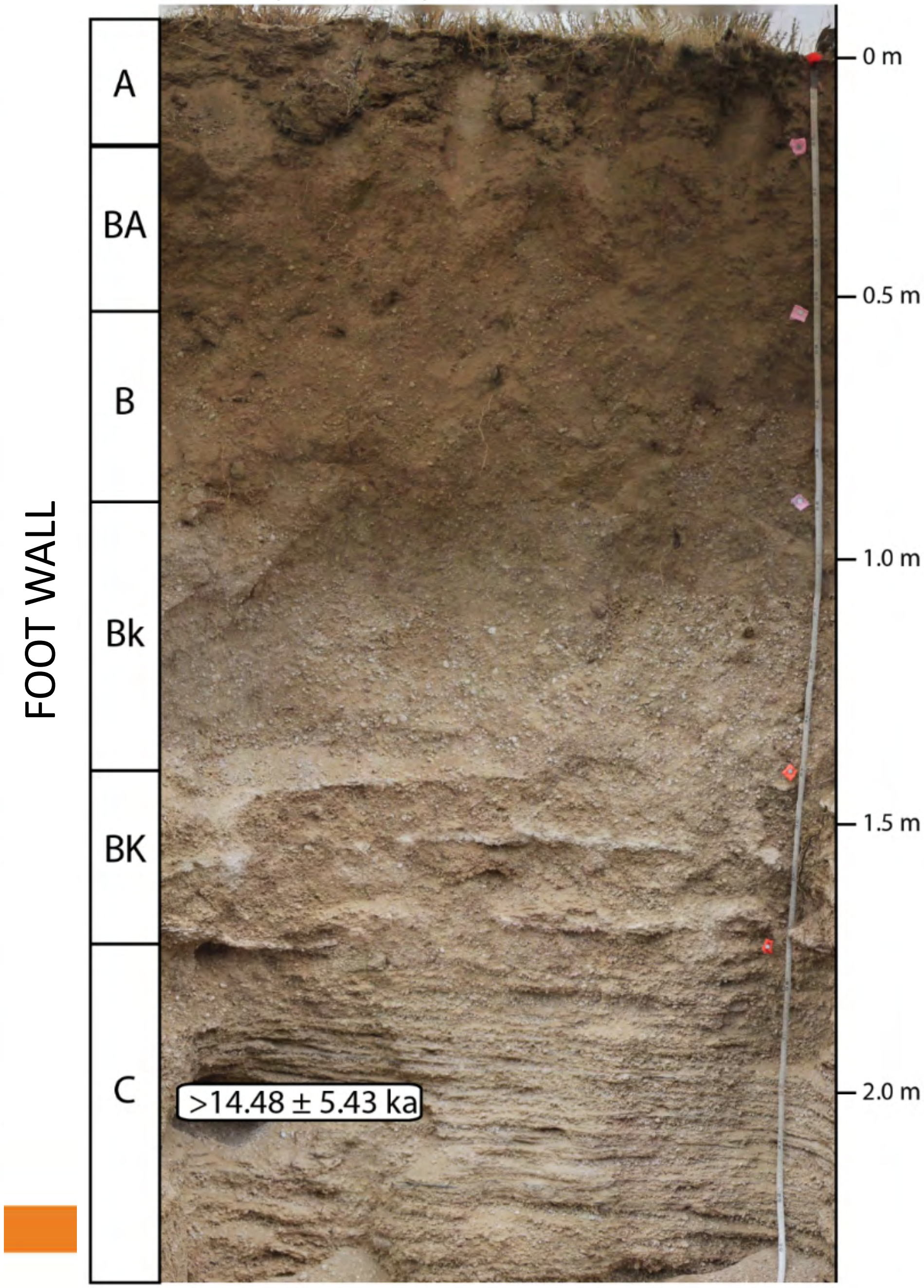


N
500
Meters
Qaf2
Qaf1
Qaf2
Qafy
Qaf2
Qaf2
Site 4a
Qaf2
Qaf2
site 4b
Qaf2
Qafy
Qafy
Qaf2
Qaf2
Qaf1
Qaf2
Qaf2
Qaf2
Qafy
Qaf2
Qafy
Qaf2
Qaf1
Qaf2
Qaf3
bedrock
Qaf2

IRSL Site 4a (USU-2684, 2685, 2686)
Sampled August 23 and 24, 2017
N 38.38123, W 112.90760, 1744 m ASL



IRSL Site 4b (USU-2684)
Sampled August 24, 2017
N 38.37970, W 112.90788, 1738 m ASL



Preliminary Interpretations

If geology is right:

- Lots of soil development at site 4b (FW)
- Surface texture/roughness is similar to other Qaf2 surfaces
- Qaf2 surface is ~ 30 ka
- More complex alluvial fan aggradation may have reset IRSL grain.

If IRSL age is right (and interpretation):

- > 14ka is a minimum, but more or less correct
- Doesn't look like a flood deposit (ie. not reset)
- Matching ~14ka age from site $a to 4b
- Indicated faulting could have initiated >14 ka

Preliminary Interpretations – Implications for Quaternary fault and fold database

Currently in Q-faults DB

- Structure Age <750,000
- Slip rate category: <0.2 mm/yr

Preliminary Interpretations – Implications for Quaternary fault and fold database

If geology is right:

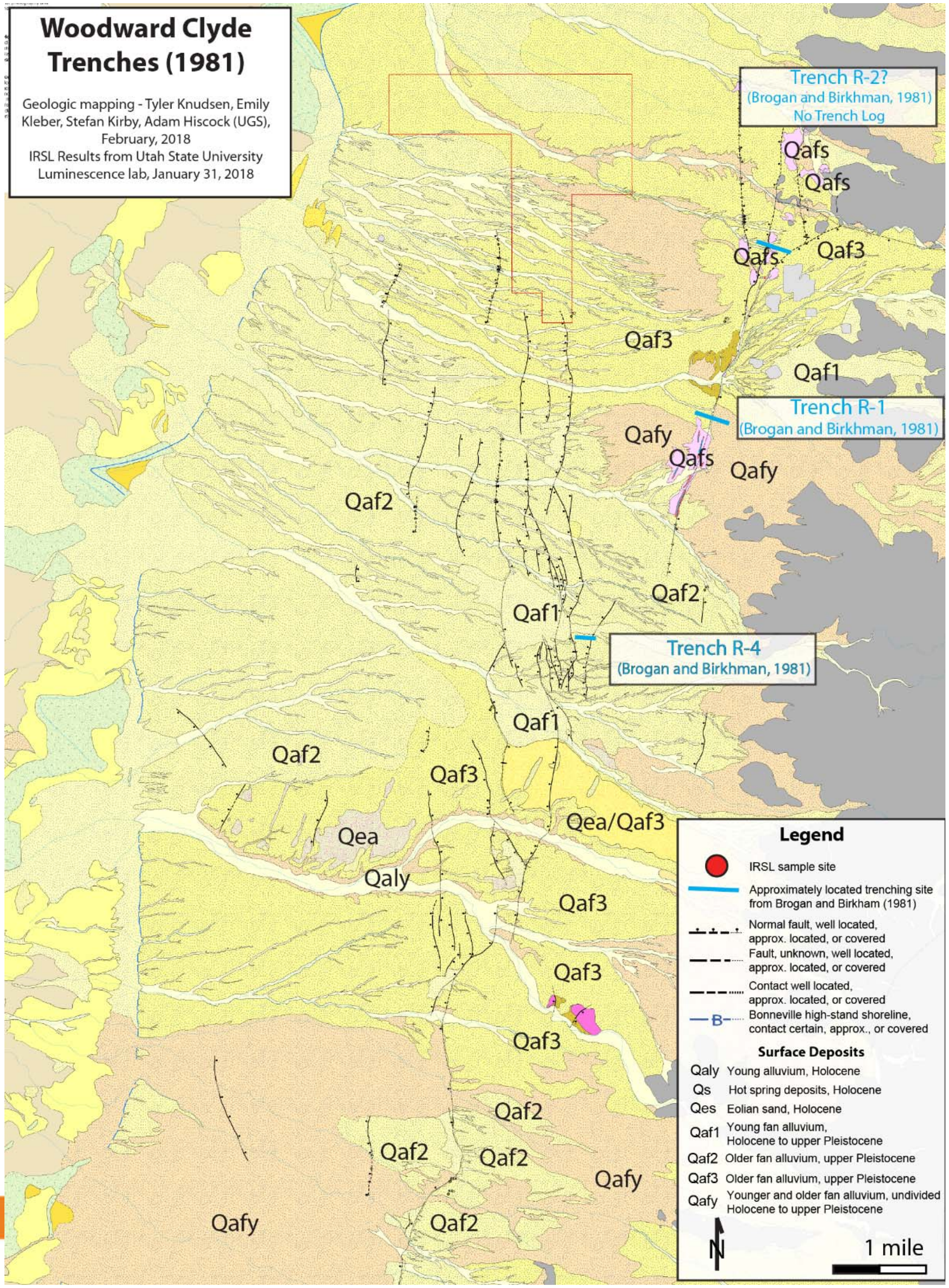
- Structure Age ~~<750,000~~
  - <130,000
- Slip rate category: <0.2 mm/yr

If IRSL age is right (and interpretation):

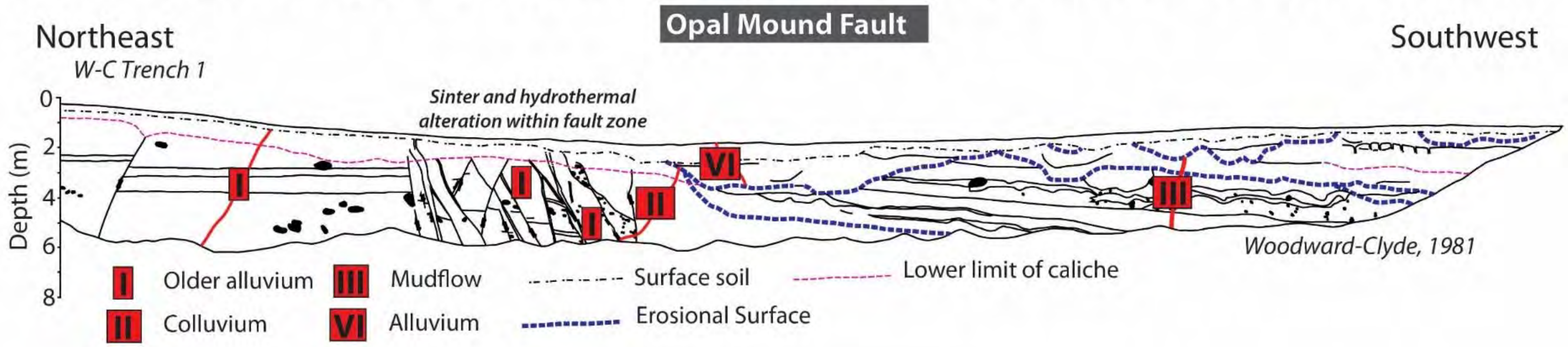
- Structure Age ~~<750,000~~
  - <130,000 ? <15,000
- Slip rate category: <0.2 mm/yr
  - 0.2 – 1 mm/yr

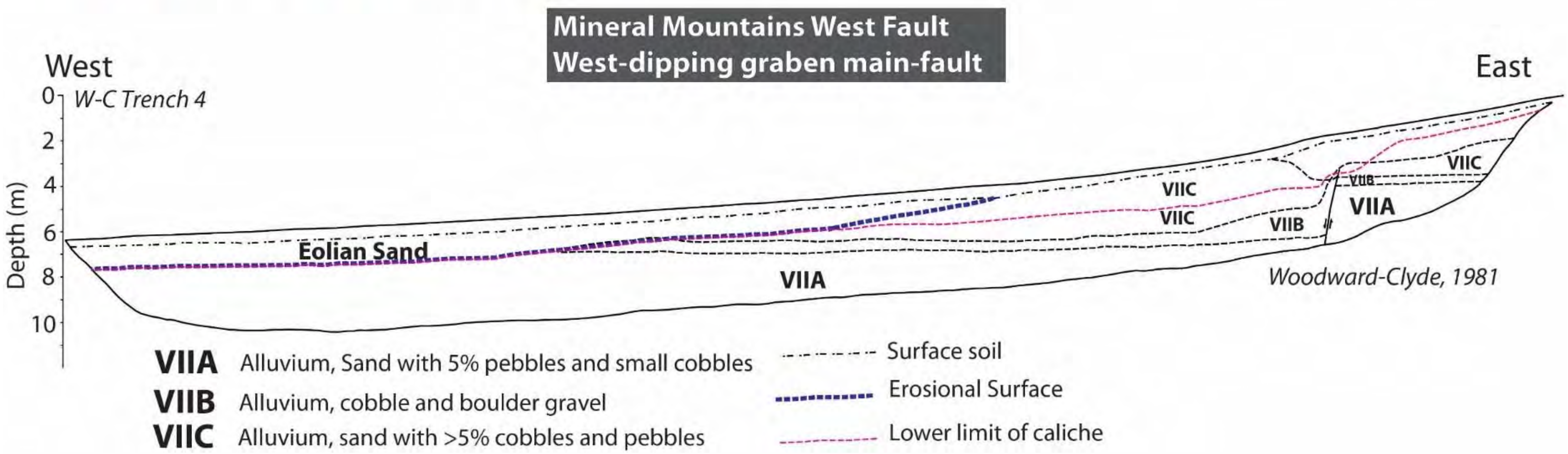
Woodward-Clyde Trenches (1981)

- Dug in late 1970s, when Paleoseismology was a developing discipline.
- Useful observations, but very little quantitative data available from these trenches.

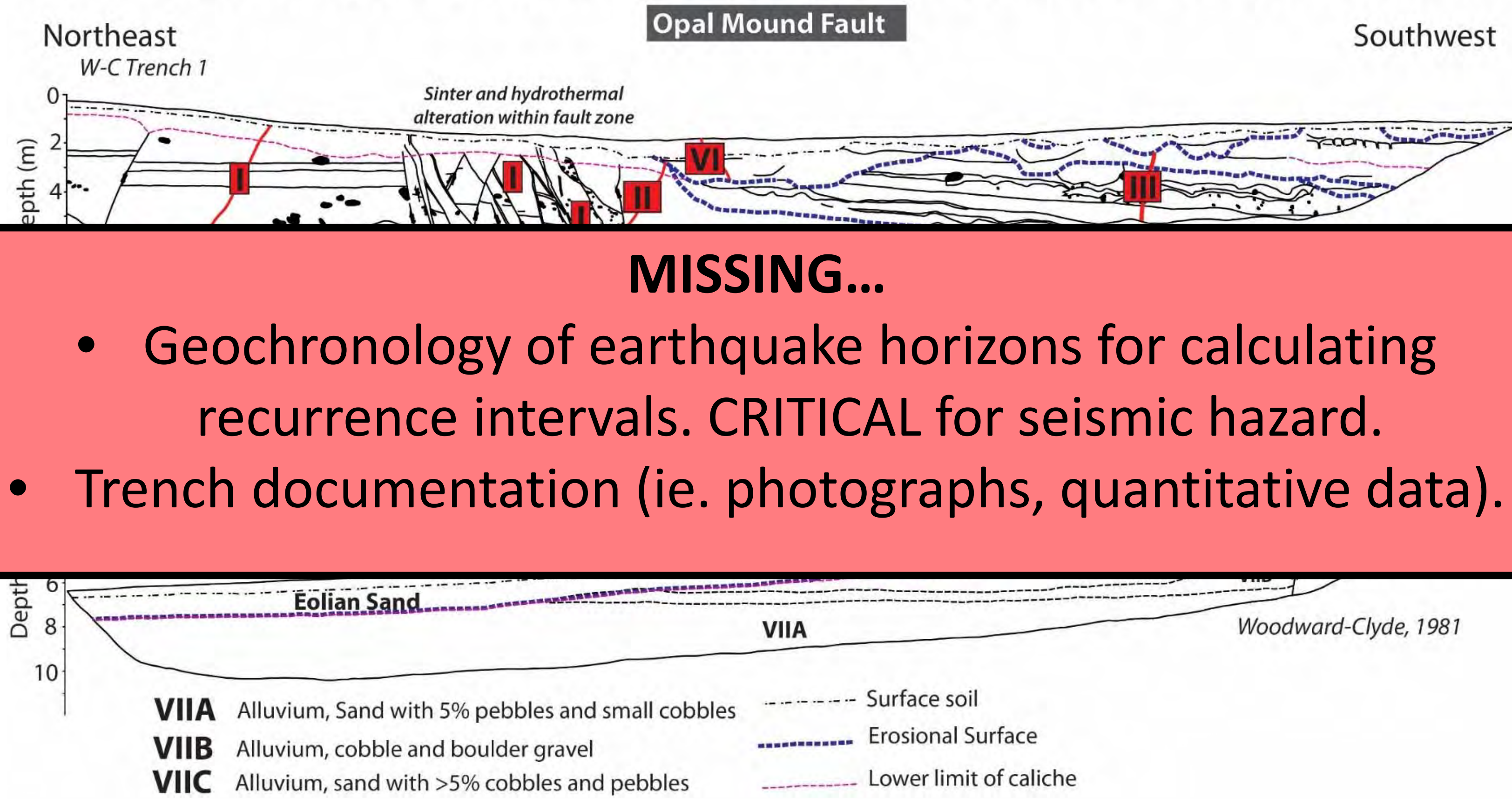


Paleoseismic Trenching Data from Woodward Clyde Report "Faults and Geothermal Anomalies" (1981)





Paleoseismic Trenching Data from Woodward Clyde Report "Faults and Geothermal Anomalies" (1981)



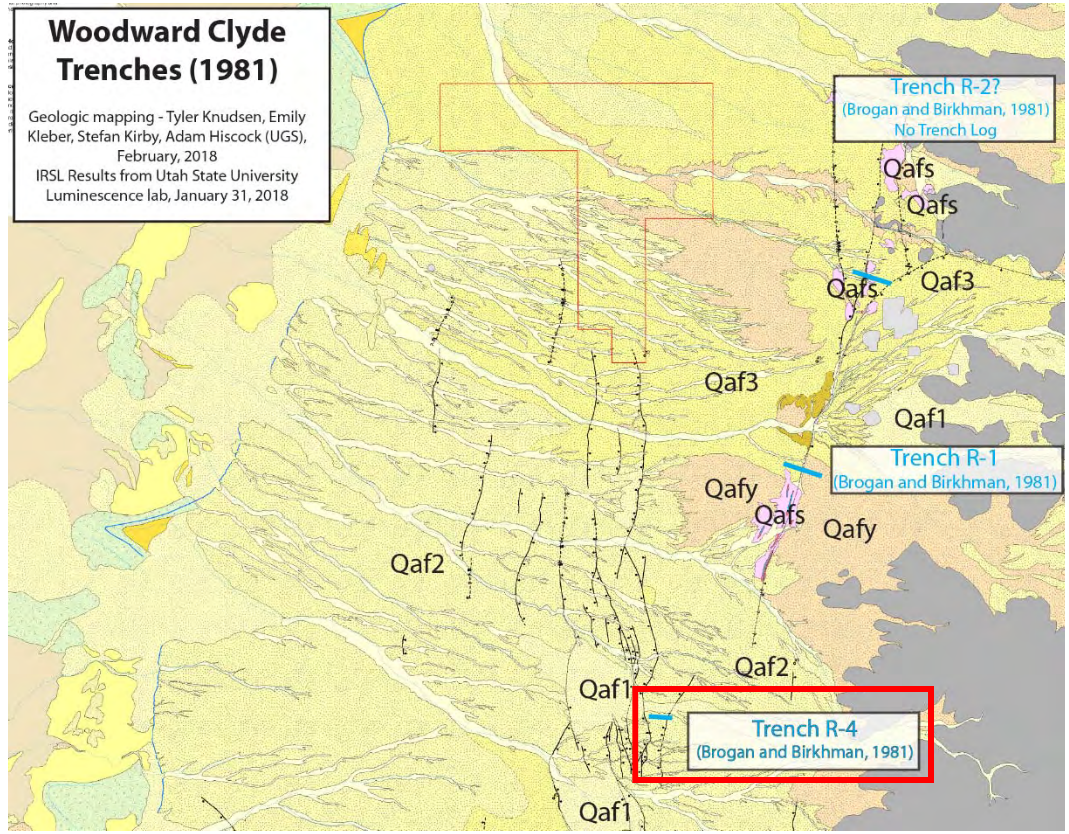
MISSING…

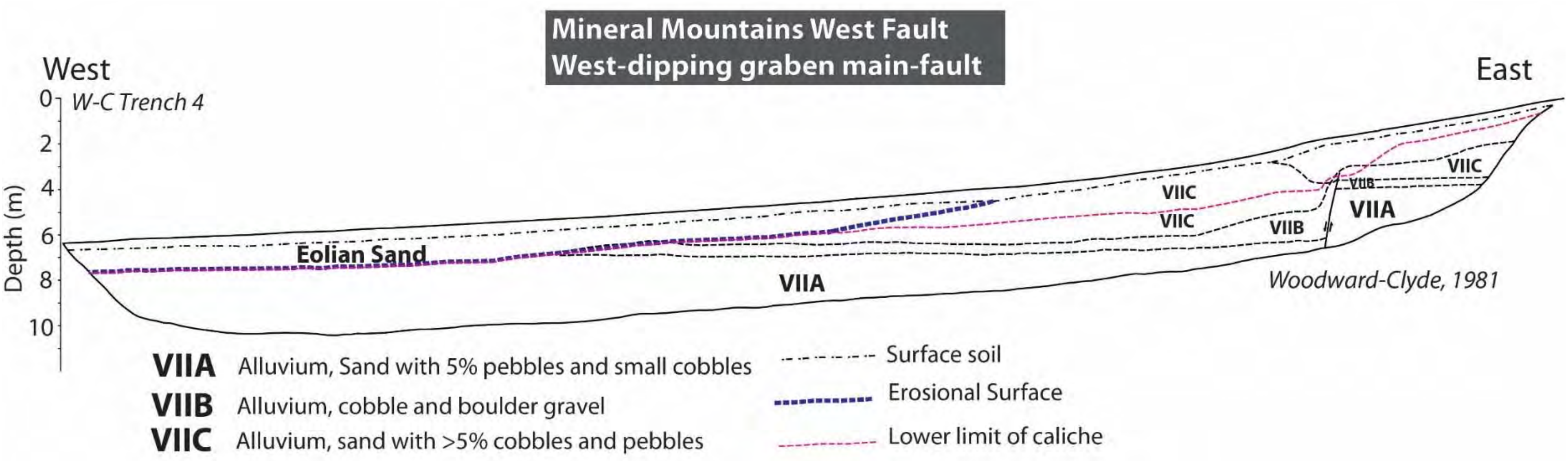
- Geochronology of earthquake horizons for calculating recurrence intervals. CRITICAL for seismic hazard.
- Trench documentation (ie. photographs, quantitative data).

Thank you

- Utah Geological Survey – Rick Allis, Steve Bowman, Tyler Knudsen, Stefan Kirby,, Adam Hiscock
- University of Utah – John Bartley, Kris Pankow
- EGI – Joe Moore, Stuart Simmons, Gosia Skowron
- Utah State University Luminescence Laboratory – Tammy Rittenour, Michelle Nelson, Carlie Ideker

Woodward-Clyde Trenches (1981)

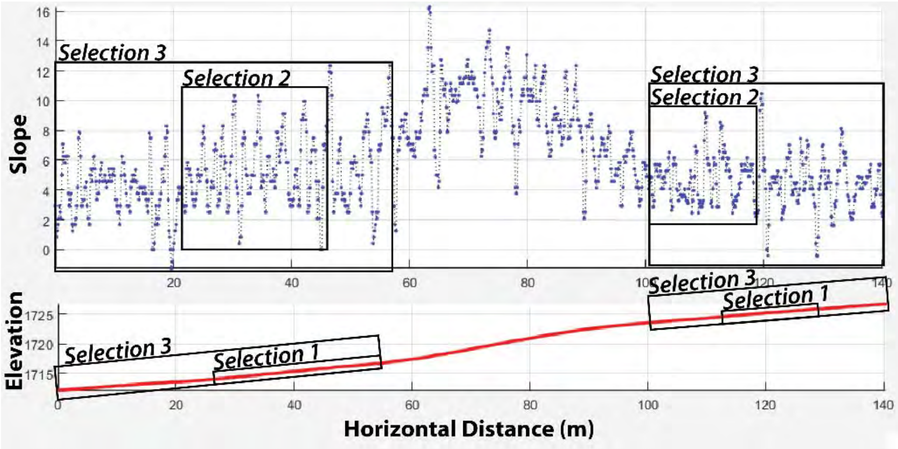




Ongoing and future work

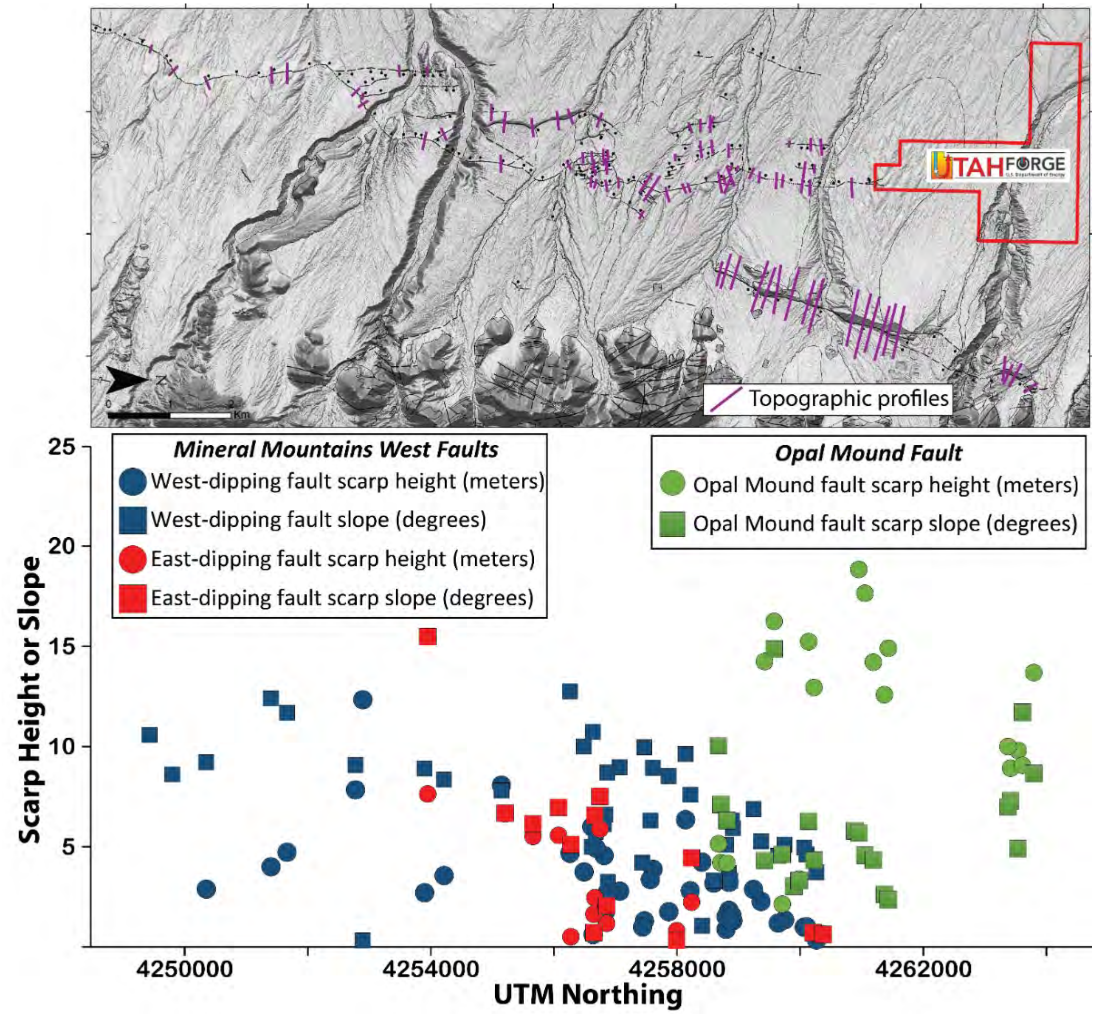
- Figure out our ages!
- Paleoseismic trenching of MMW faults?

Geomorphic Characterization



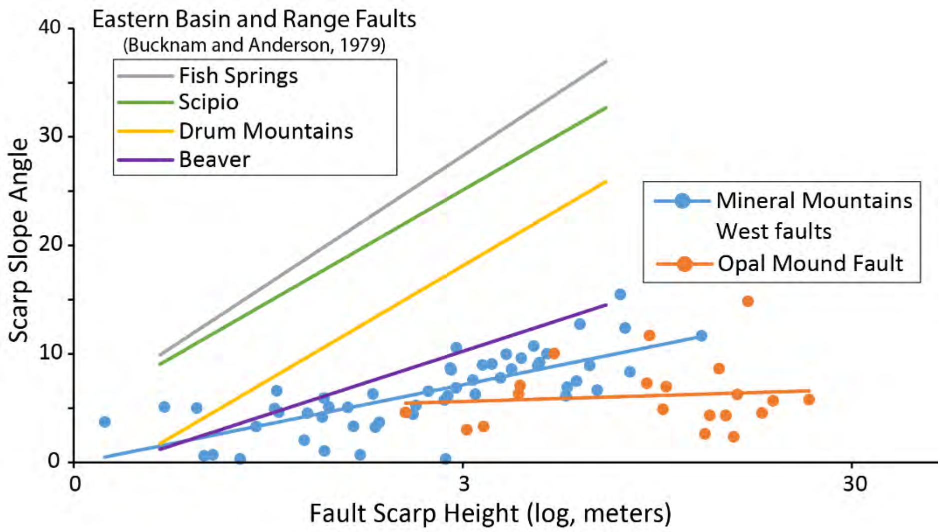
Geomorphic characterization of fault scarps

- N. Mag fault
  - Geomorphic expression is insufficient for this analysis (north facing on south aggrading slope).
- Opal Mound
  - Hard to discern pattern likely due to opal/sinter deposits interacting with erosional surface processes.



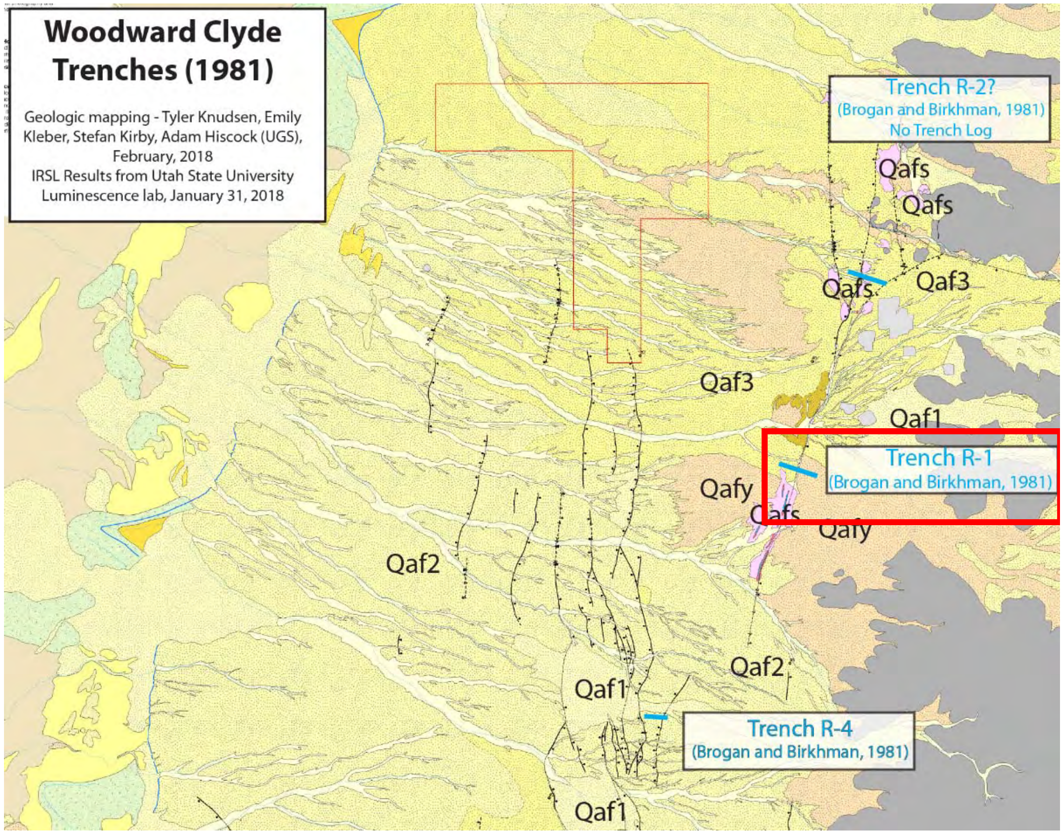
Geomorphic characterization of fault scarps

- Compared to other active fault scarps in the Basin and Range/Sevier Desert area from Bucknam and Anderson (1979).
- Lower regression slope = less activity OR less slip/event.
- MMW faults do not appear as active as other Eastern B&R/Sevier Desert faults.
- Recent work (Stahl and Niemi, 2017) indicate extension is related to shallow magmatic processes in the Sevier Desert (Drum Mountains).
    - How do the MMW faults fit in?

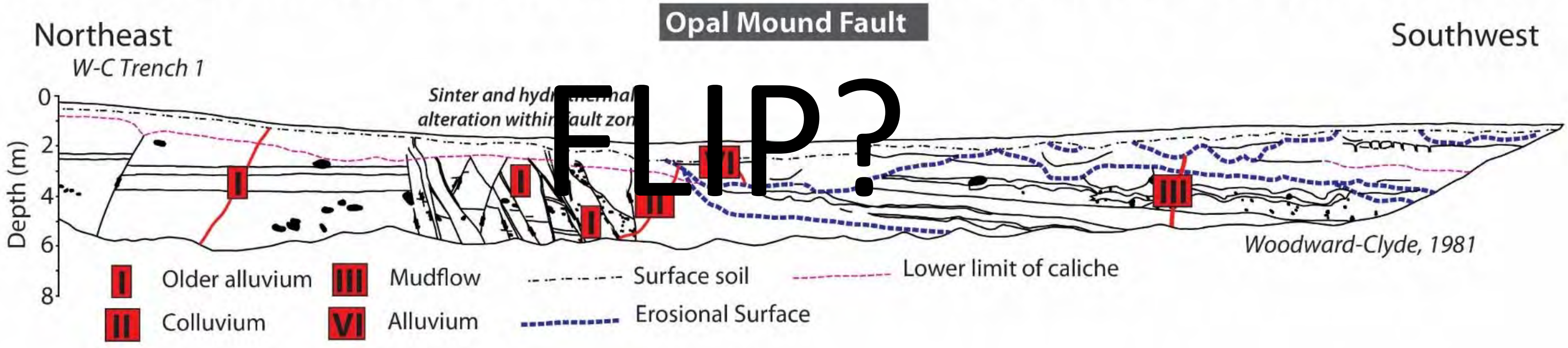


Caveats to dating offset alluvial deposits

Woodward-Clyde Trenches (1981)



Paleoseismic Trenching Data from Woodward Clyde Report "Faults and Geothermal Anomalies" (1981)



FLIP?

RECLAMATION

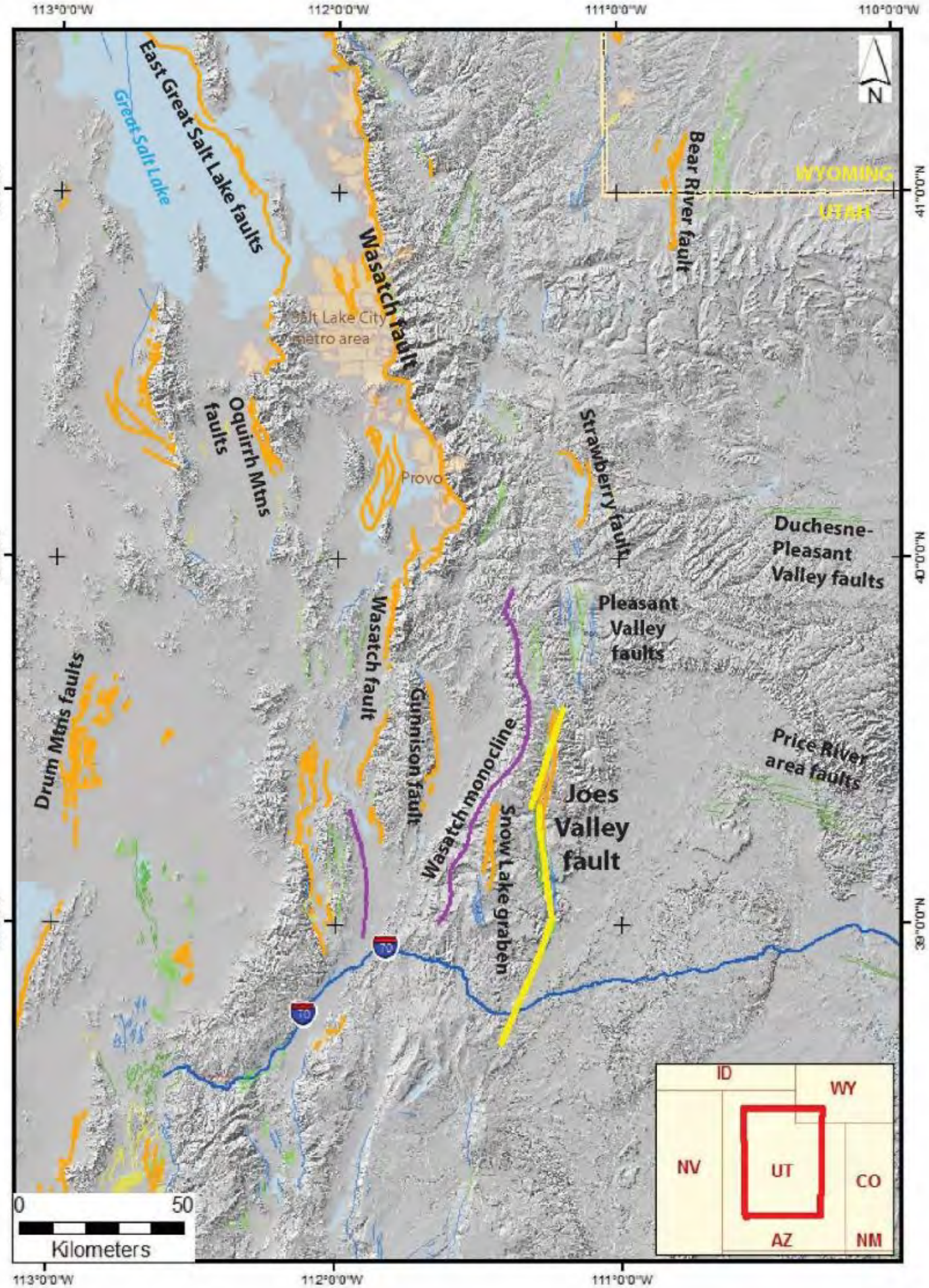
Managing Water in the West

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

Lucy Piety, Julia Howe, Ralph Klinger, Ryan Levinson, Joanna Redwine, and Kris Hornsby
Seismology, Geomorphology, and Geophysics Group
Bureau of Reclamation
Denver, Colorado

U.S. Department of the Interior
Bureau of Reclamation

February 2018



JVFZ Seismic Investigation

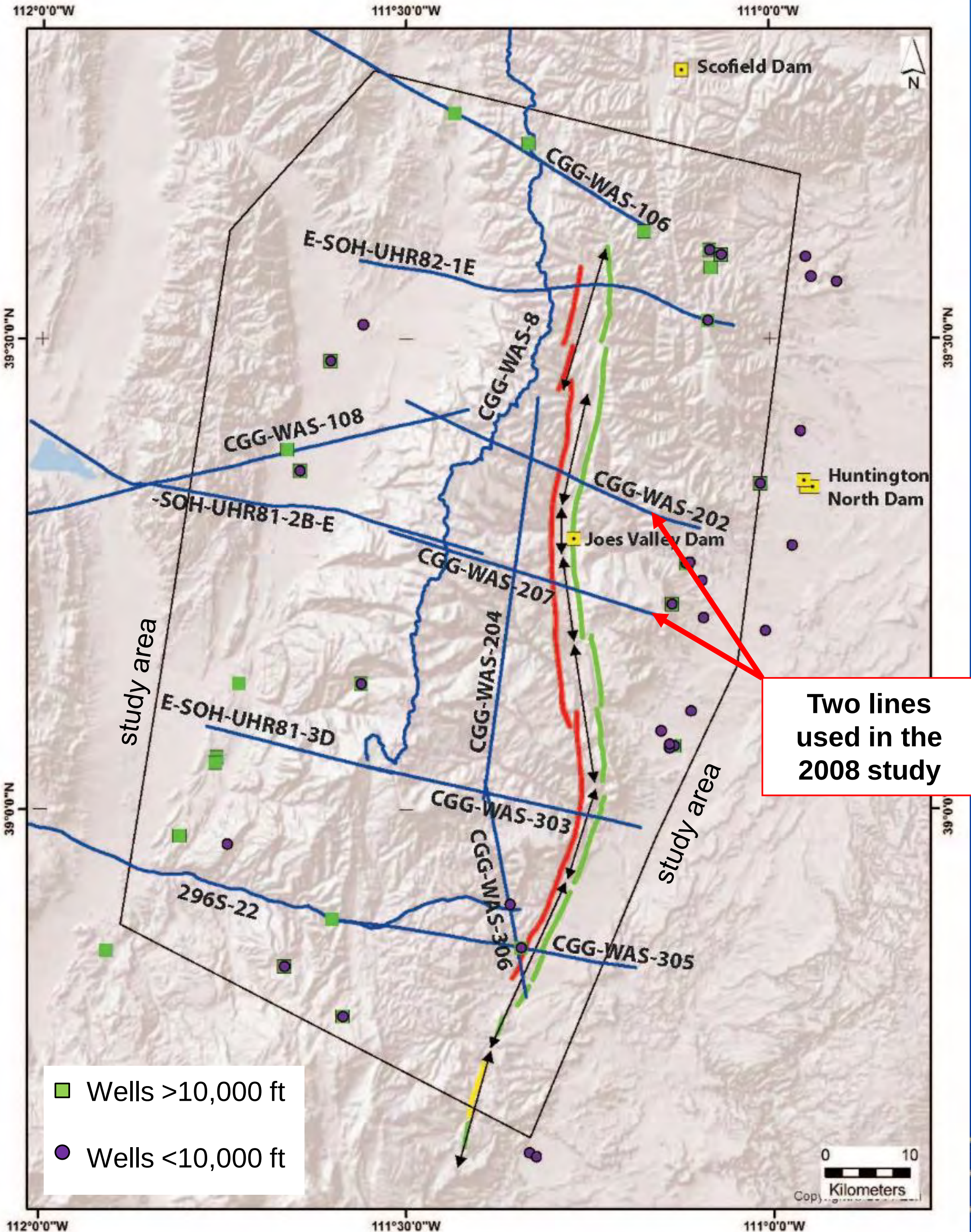
The Fault Zone:

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

2017 Work:

- Subsurface Investigation
- Compilation of state-wide stress data
- 1 of 6 paleoseismic trenches excavated

RECLAMATION



Subsurface Investigation

Scope:

- 13 2D seismic lines (350 miles) licensed, reprocessed, and interpreted
- ~9,170 km^2 area covered
- Digital well log data from 95 wells

Seismic data reprocessed by Seimax Technologies LP (Houston, Texas)

Geologic interpretations by Dave List of David List Consulting, Inc.

Seismic interpretations by John Arestad of Excel Geophysics Services and International Reservoir Technologies, Inc.

ECLAMATION

Subsurface Investigation - Results

CGG-WAS-202

Redacted

CGG-WAS-207

Redacted

Figures modified from Arestad (2017)

Redacted

Figure modified from Sturm (2017)

Compilation of Stress Data

Scope:

- Original – 60 km radius from the dam
- 75 data points throughout Utah
    - 40 data points within 60 km of the dam

Types of Data Collected:

- Drilling-induced fracture analysis from image logs
- Orientation of face cleats (21 coal mines)
- Orientation of lateral wells (drilled in minimum horizontal stress orientation)
- World stress map project
- Hydrofrac or minifrac data

Data collected and interpreted by Stephen Sturm
303 PetroImages, Denver

Stress Data Results

Least principal horizontal stress azimuth for the State of Utah

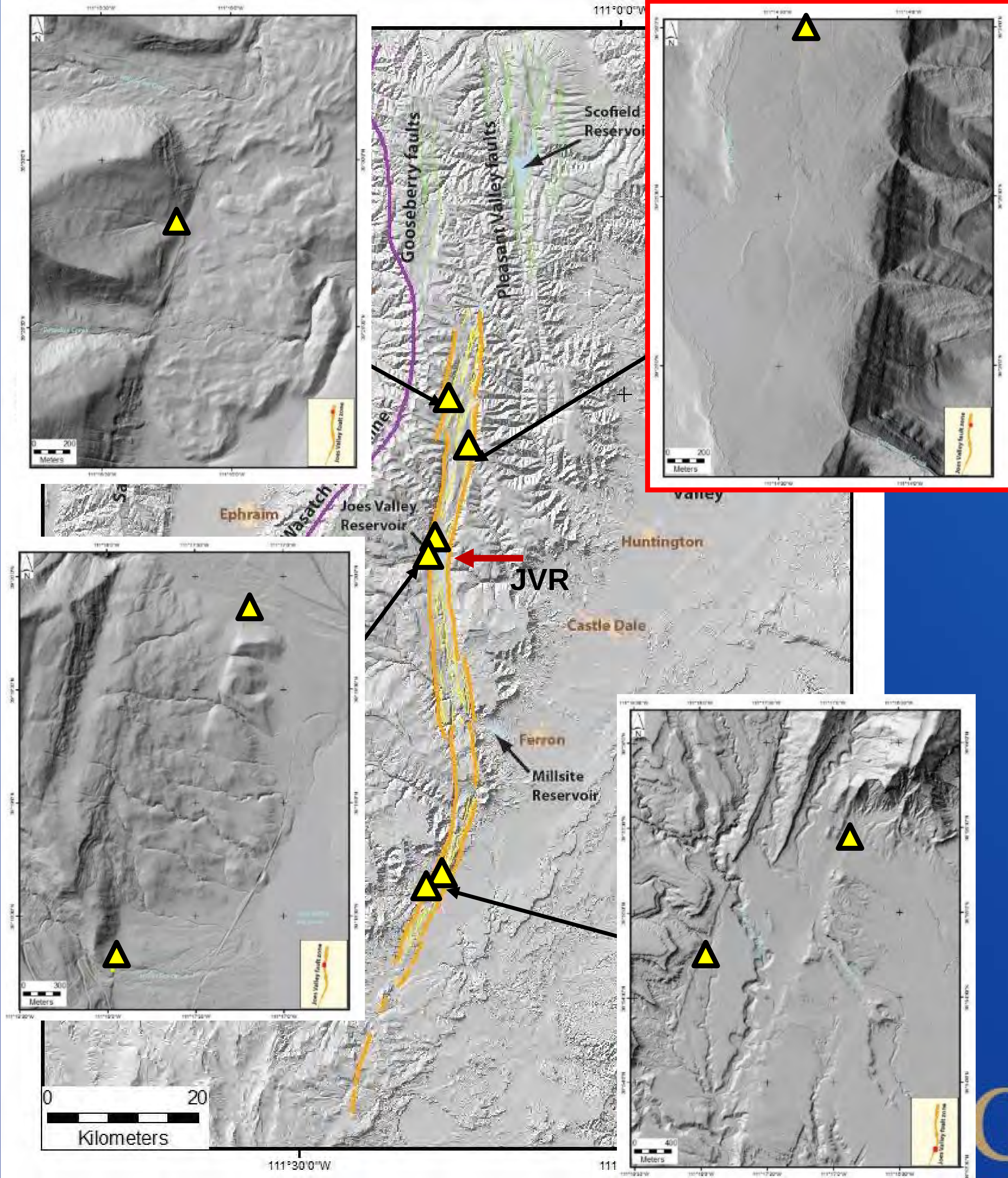
Redacted

Least principal horizontal stress azimuth for area near Joes Valley Dam

Redacted

Figures modified from Sturm (2017)

RECLAMATION



Trench Locations

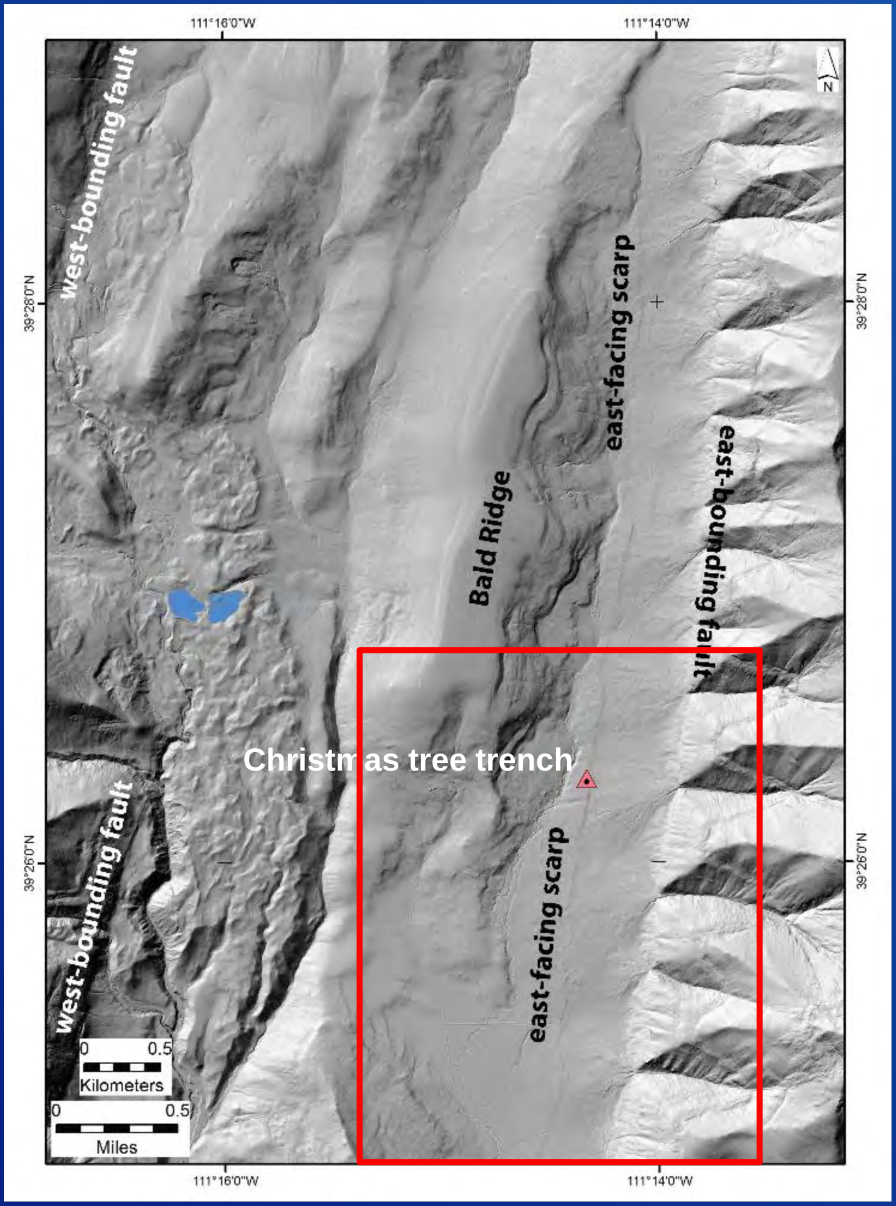
6 Total Sites:

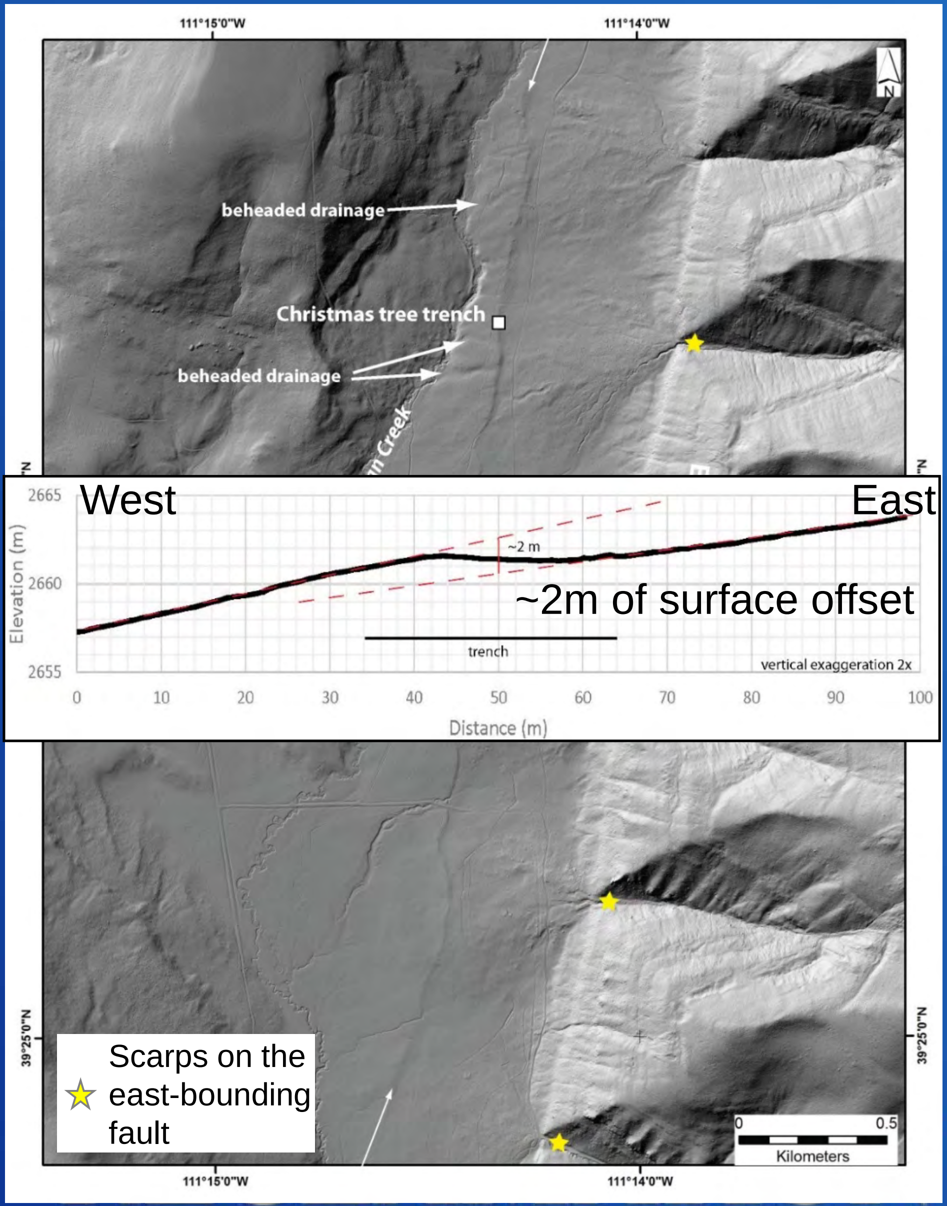
- 2 in north Joes Valley
- 2 in central Joes Valley
- 2 on southern end of fault zone

Locations:

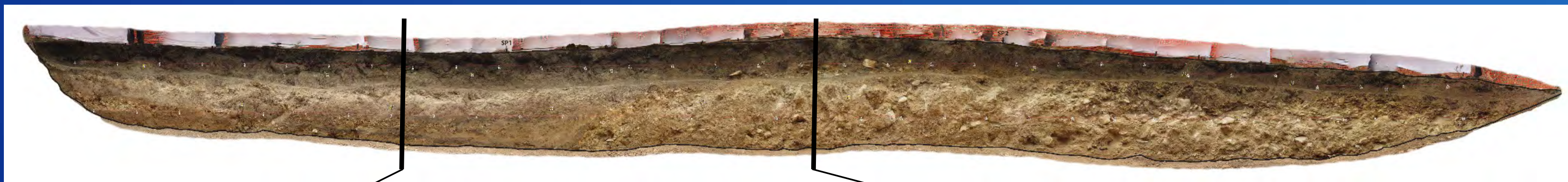
- 3 are on main west faults
- 3 are on faults within the fault zone
- No sites on the main east faults

Christmas Tree Trench – Excavated September 2017





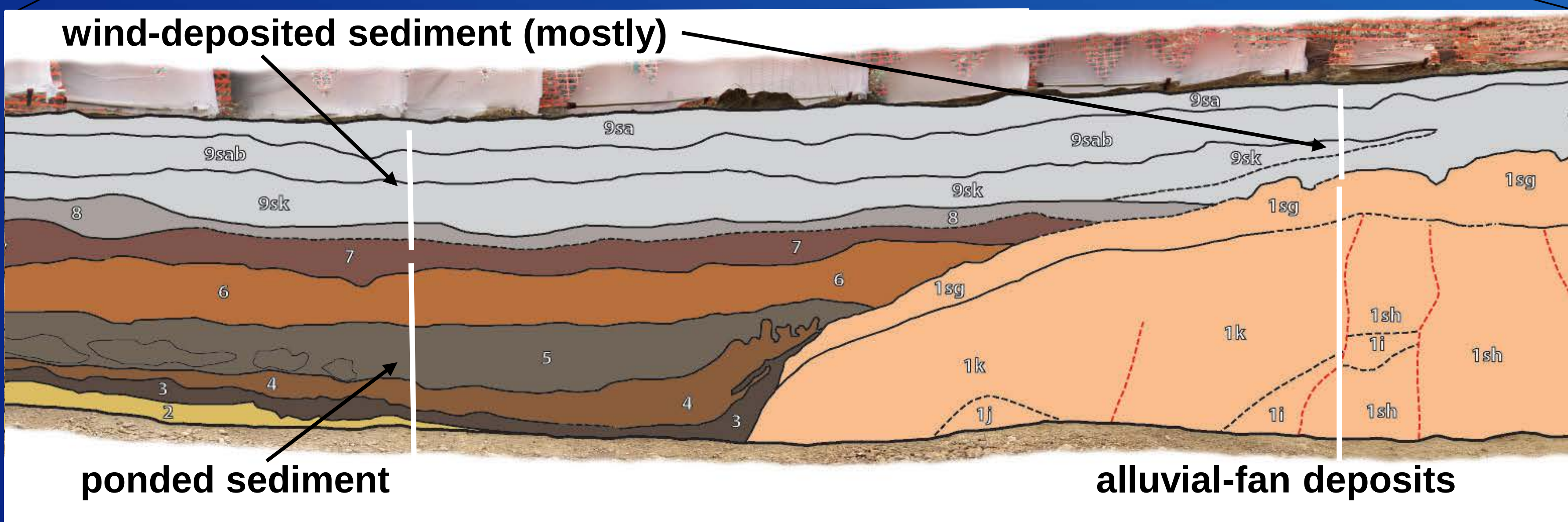
South Wall Trench Log – Under Review



East

West

Drainage Direction →



Zone of Deformation (~10 m)

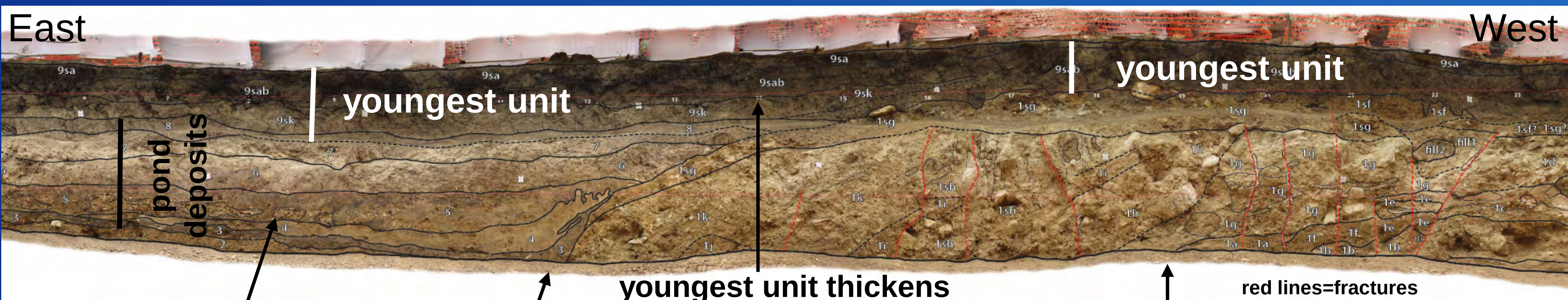
RECLAMATION

Photomosaic by J. Buck (TrenchScan)

Working hypothesis – Style of Deformation

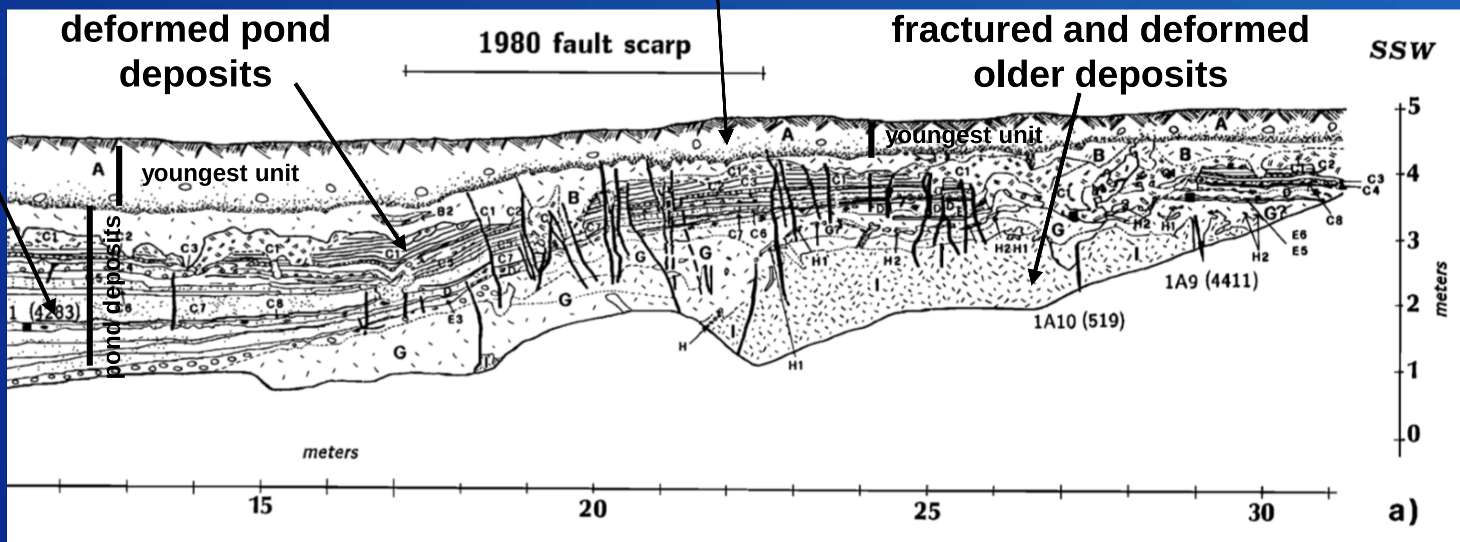
South Wall

topographic scarp



youngest unit thickens across the scarp

pond deposits



Surface deformation on Irpinia fault, Italy
After 1980 M_S 6.9 earthquake

Figure modified from Pantosti and others (1993)

RECLAMATION

Working hypothesis – Mechanism of Deformation

Conceptual Model

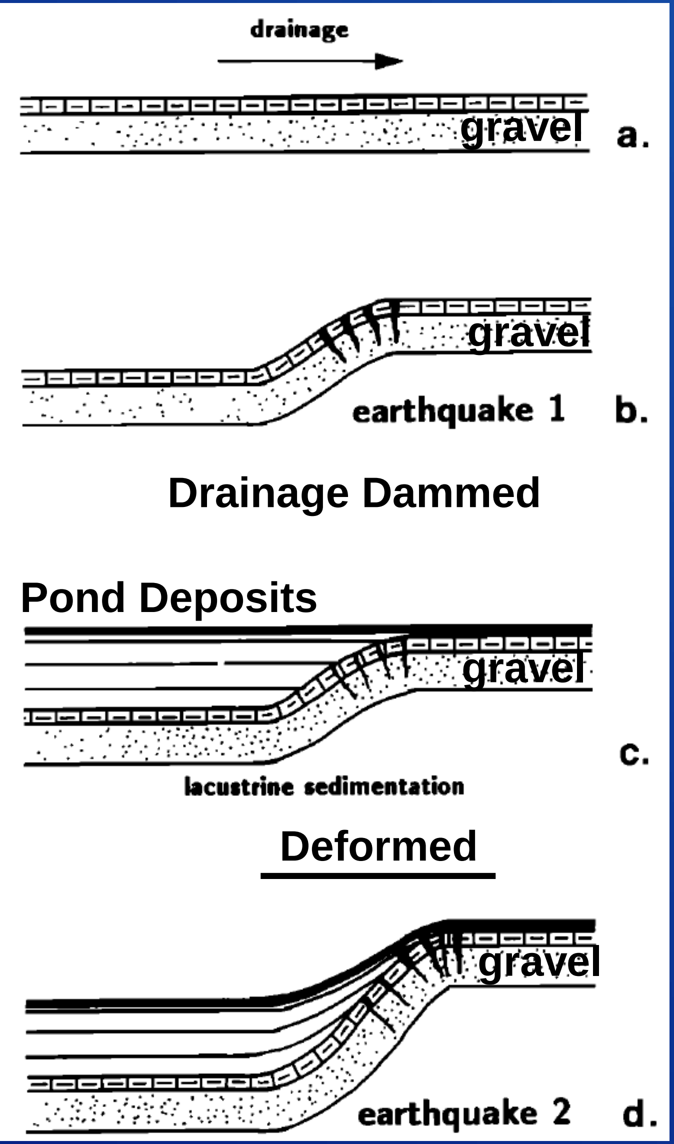


Figure modified from Pantosti and others (1993)

Observed in Christmas Tree Trench

a.

- Existing alluvial fan

b.

- Minor fracturing through gravelly alluvial fan deposits
- Deformation (rotation) of beds within the alluvial fan deposits

c.

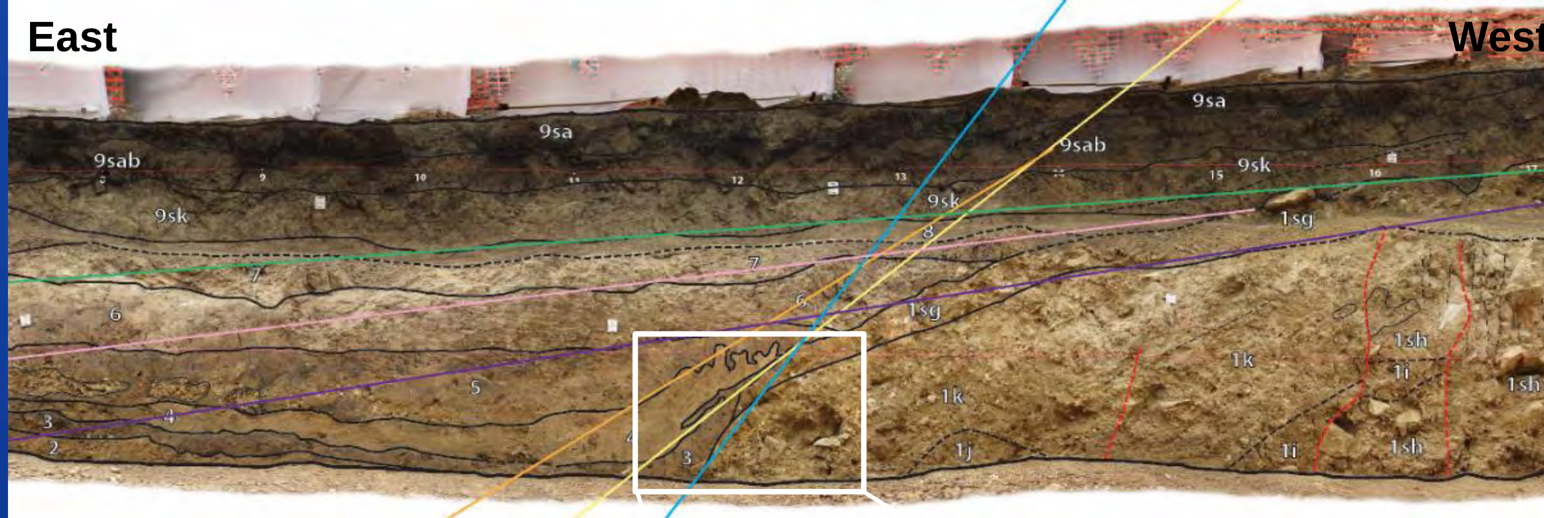
- Ponding on the east side of the scarp

d.

- Primary style of deformation: warping of fine-grained lacustrine/pond deposits
- Zone of deformation ~10 m wide

RECLAMATION

South wall



How many earthquakes?

Top of unit	Deformation (degrees) south wall	Deformation (degrees) north wall
9		
8	4 (green)	5
7	4	not in deformed zone
6	7 (pink)	not in deformed zone
5	9 (purple)	12-14
4	33 (orange)	23
3	43-45	28
1	(blue)	33
1 bevel	22	28

11,324 – 11,215 cal BP

younger EQ cannot be ruled out

EQ3

EQ2

EQ??

EQ1

Initial radiocarbon age

Initial OSL age

Convoluted bedding along upper and lower contacts of unit 4 could be the result of liquefaction

Current Status of the JVFZ Investigation

Preliminary Interpretations:

- The Joes Valley faults extend to seismogenic depths
- The JVFZ is located at a stress boundary – unclear if it is favorably oriented for fault rupture
- Minimum of 3 earthquake events on the east-bounding antithetic fault since ~11 ka

Future Work:

- Excavation of 5 additional trenches between late April and early September
- Additional interpretation of seismic lines
- Geomechanical modeling – deformation analysis

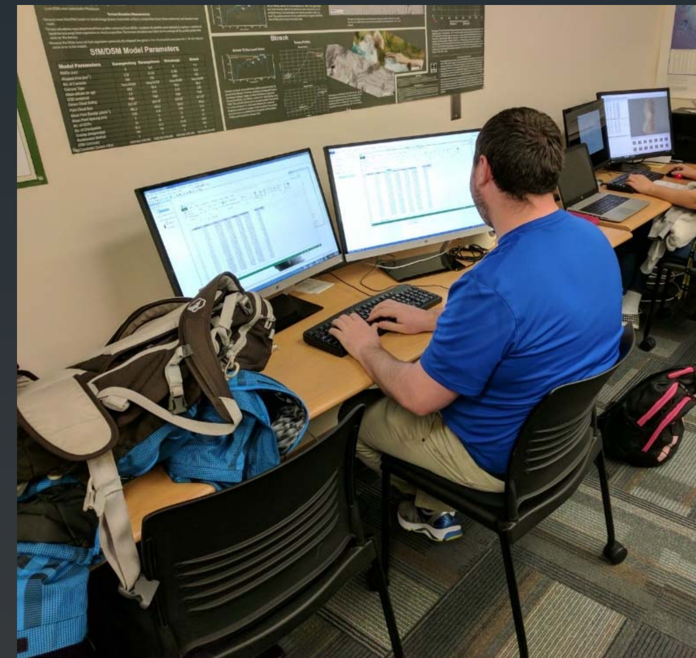
Preliminary Look at Topliff Hills Fault History (and a review of the Oquirrh Fault)

Michael Bunds, Nathan Toké, Marissa Keck, and Serena Smith

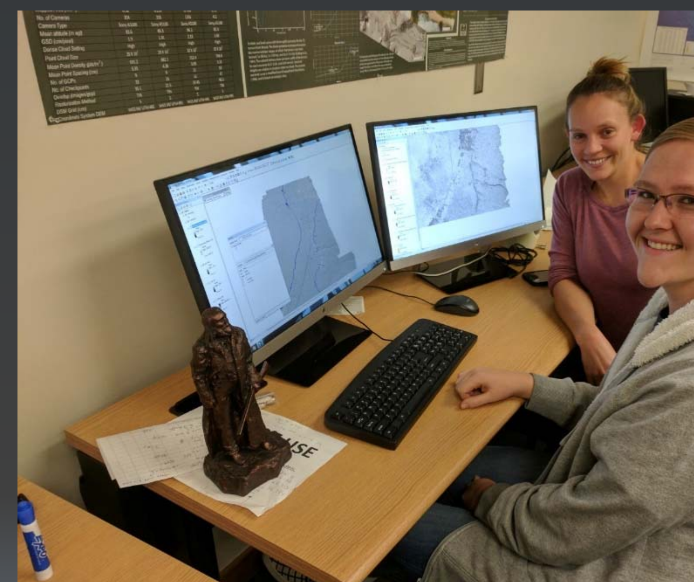
Department of Earth Science, Utah Valley University

michael.bunds@uvu.edu

UTAH VALLEY UVU UNIVERSITY Department of EARTH SCIENCE



Student Collaborators



ew Fletcher (GEOG 4100, Fall 2014)

y Larsen, Mike Arnold, Jeremy Andreini, Wells, Bret Huffaker (GEOG 4100, Fall)

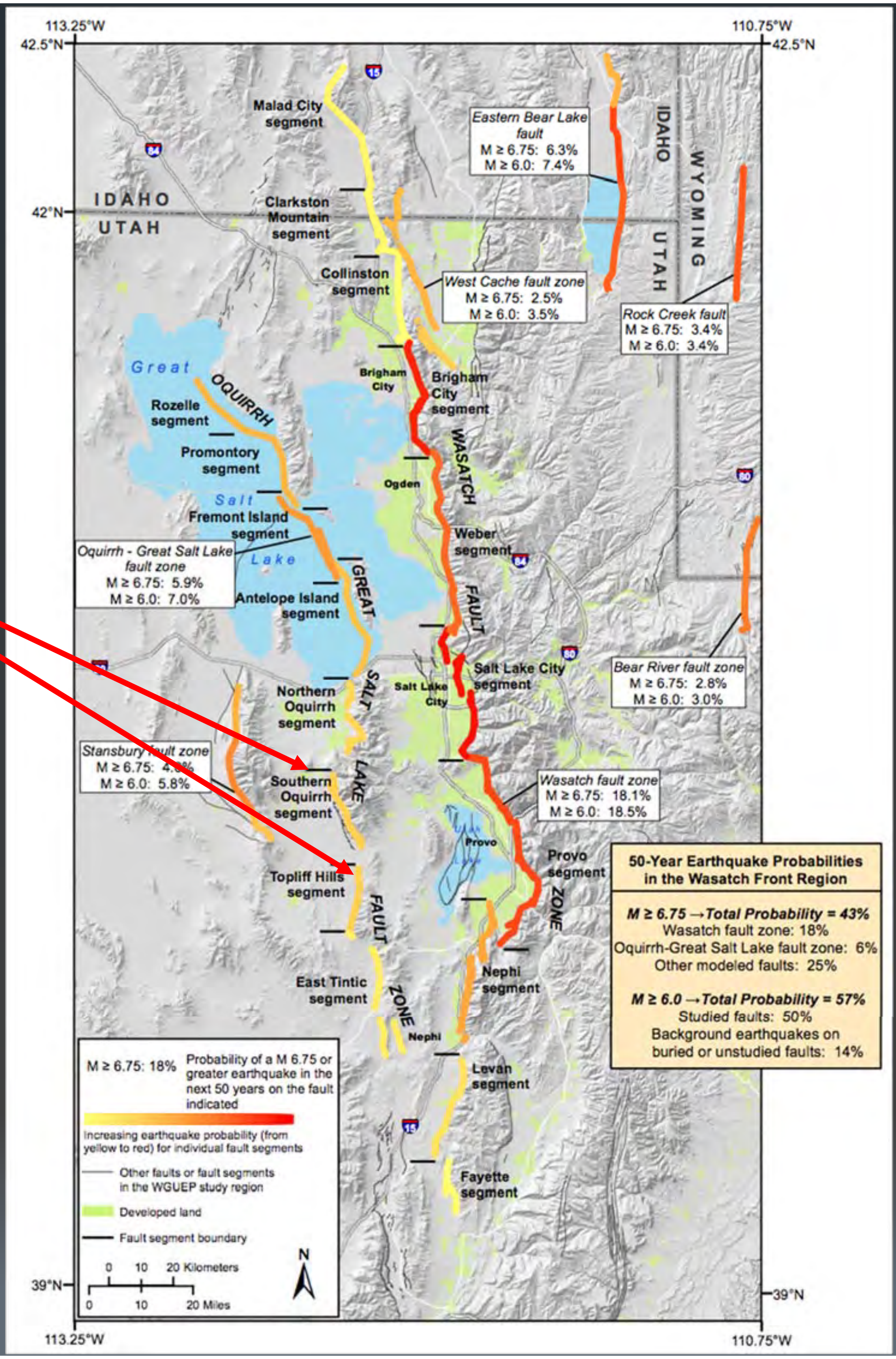
ssa Keck, Serena Smith, McKenzie ey, Joe Phillips, Logan Woolstenhulme, my Saldivar (GEOG 4100, Fall, 2017)

UTAH VALLEY UVU UNIVERSITY

Departm EARTH

Oquirrh and Topliff Faults

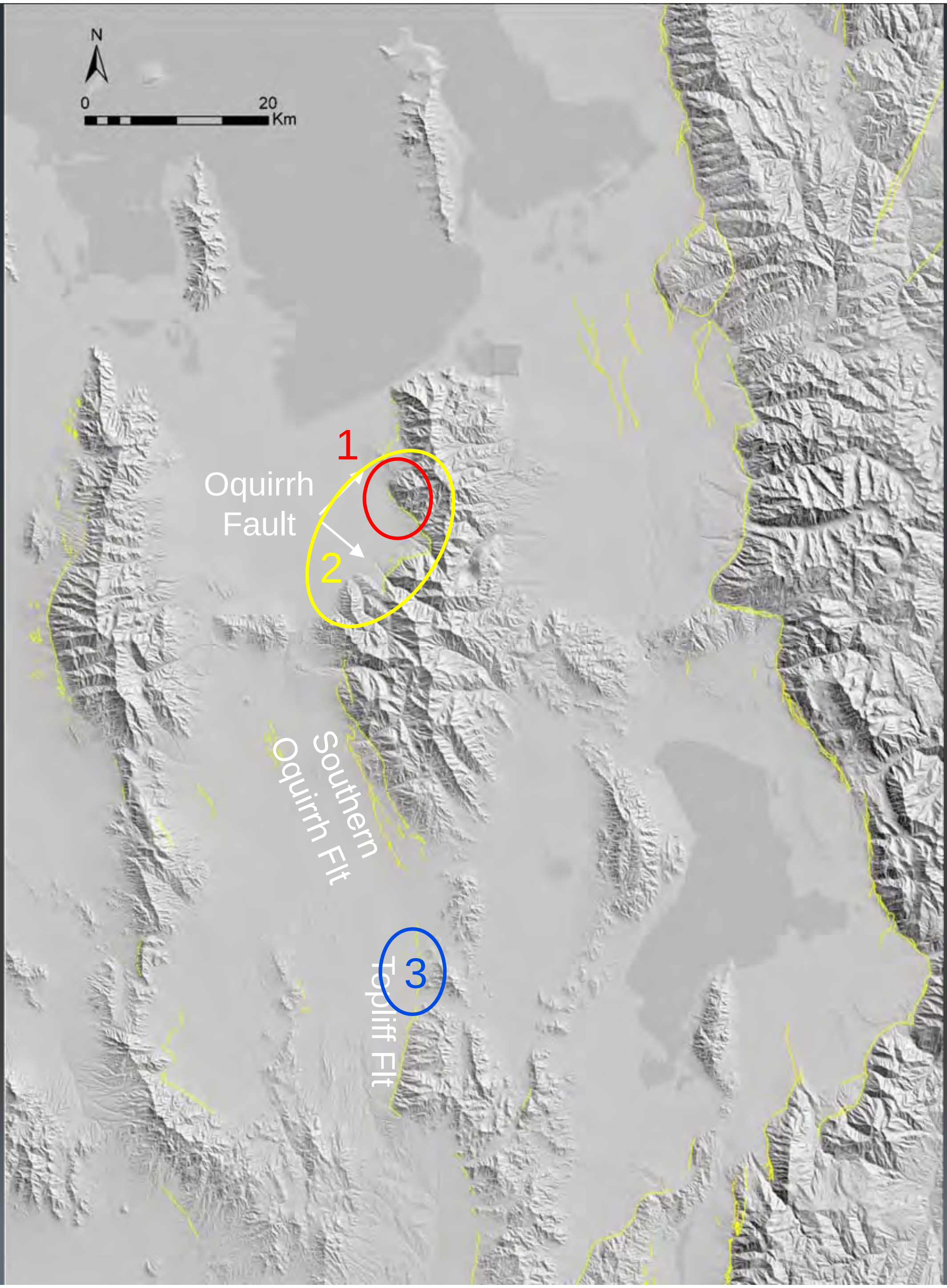
- Oquirrh and Topliff Faults are part of the second longest fault system in the state
- Potential **risk** to Tooele and Utah County



Hazardous Faults near the Wasatch Front, color-coded by future earthquake probability (Figure UGS)

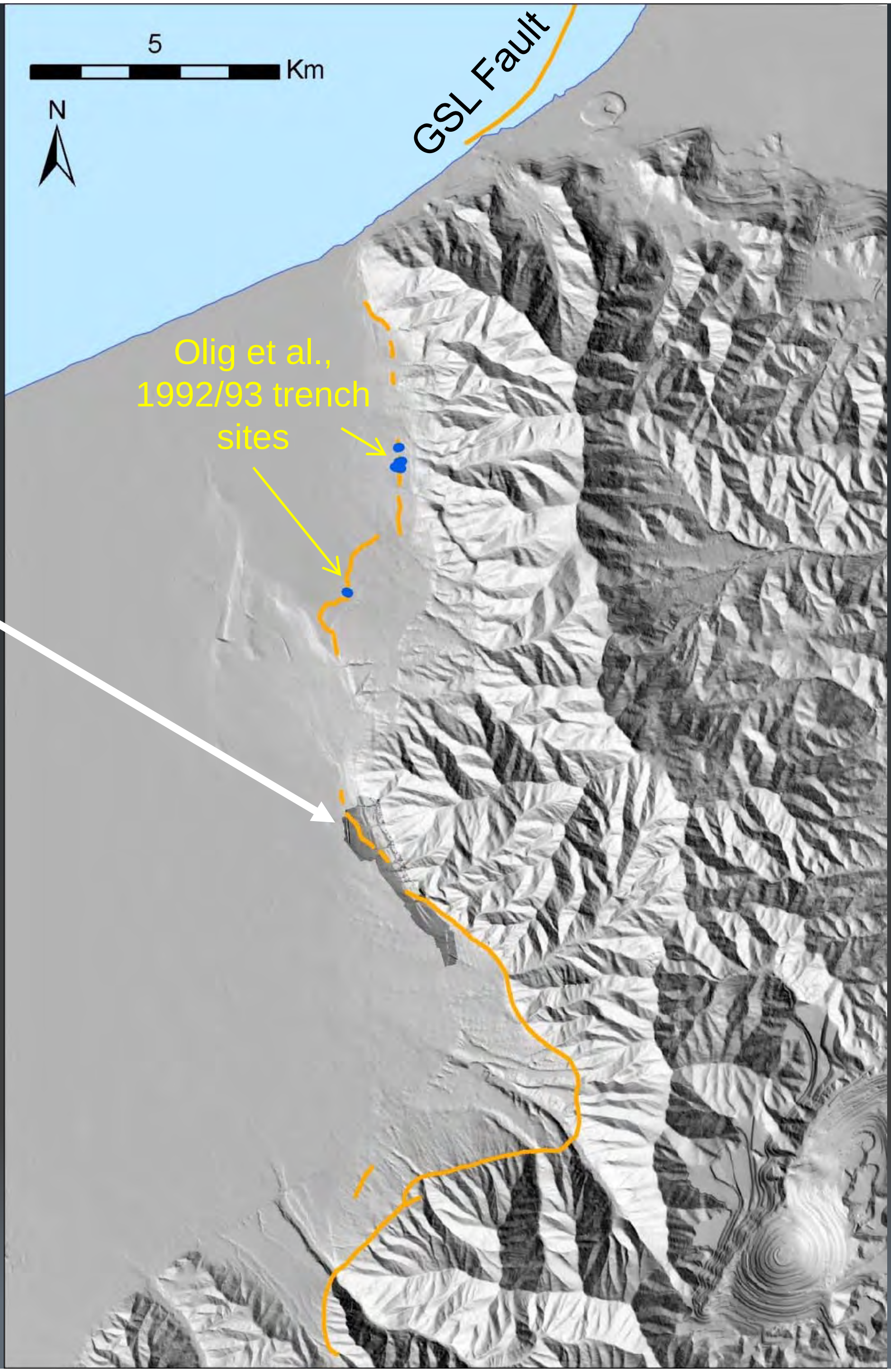
tudy Sites and esearch Questions

1. Oquirrh Fault slip rate, earthquake recurrence interval (frequency)
2. Length of surface rupture, last earthquake on Oquirrh Fault
3. Topliff Fault slip rate, date of last earthquake



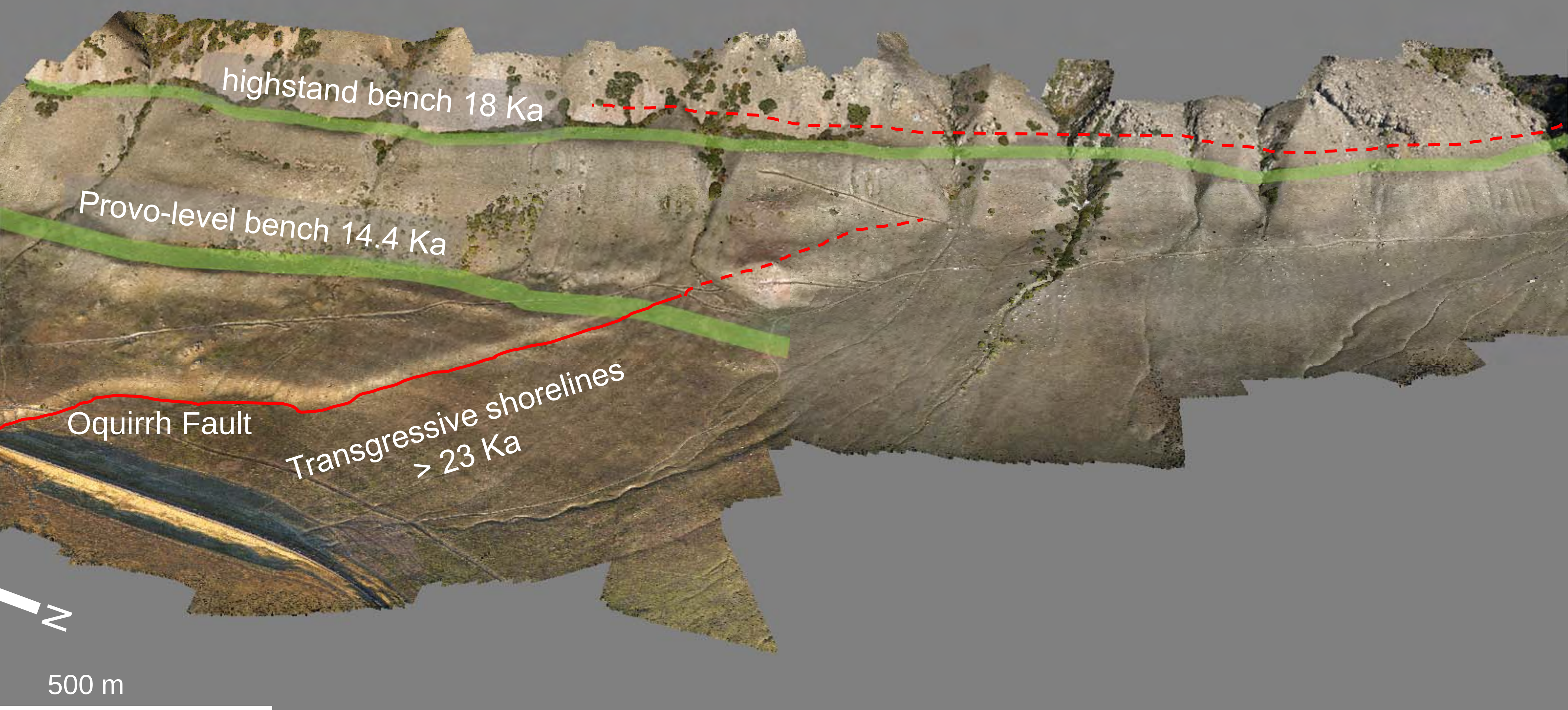
Oquirrh Fault

Constructed DEMs of ~ 3km of fault and Lake Bonneville shoreline in 2014 and 2015



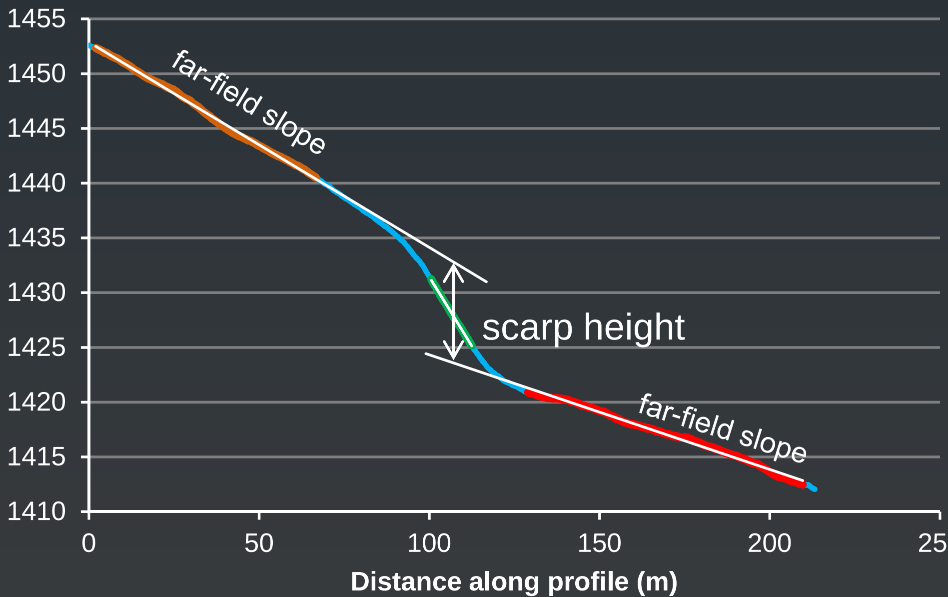
-D Model of Northern Portion of Study Area 1

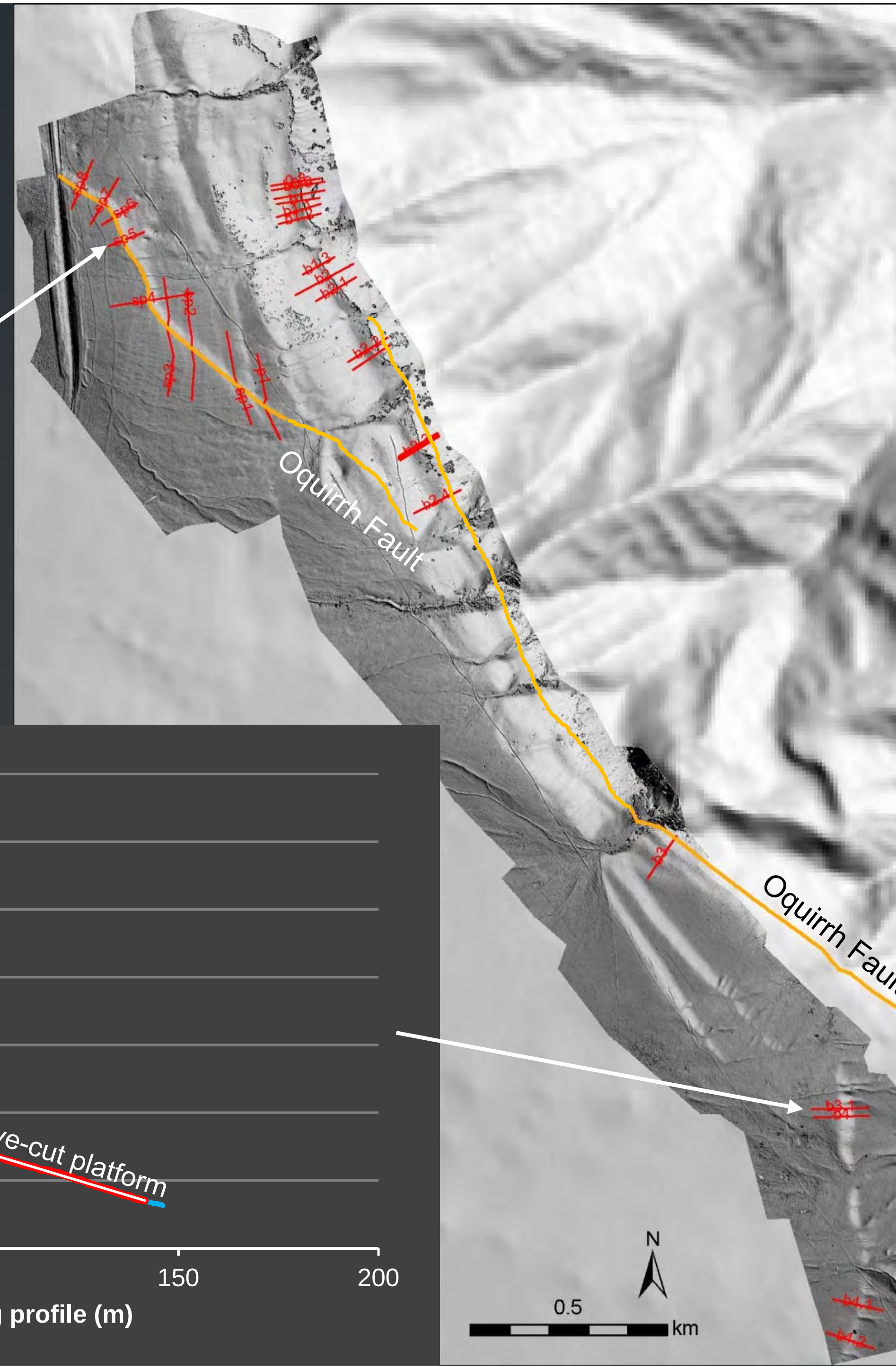
- Fault offsets Pluvial Lake Bonneville shorelines of known age



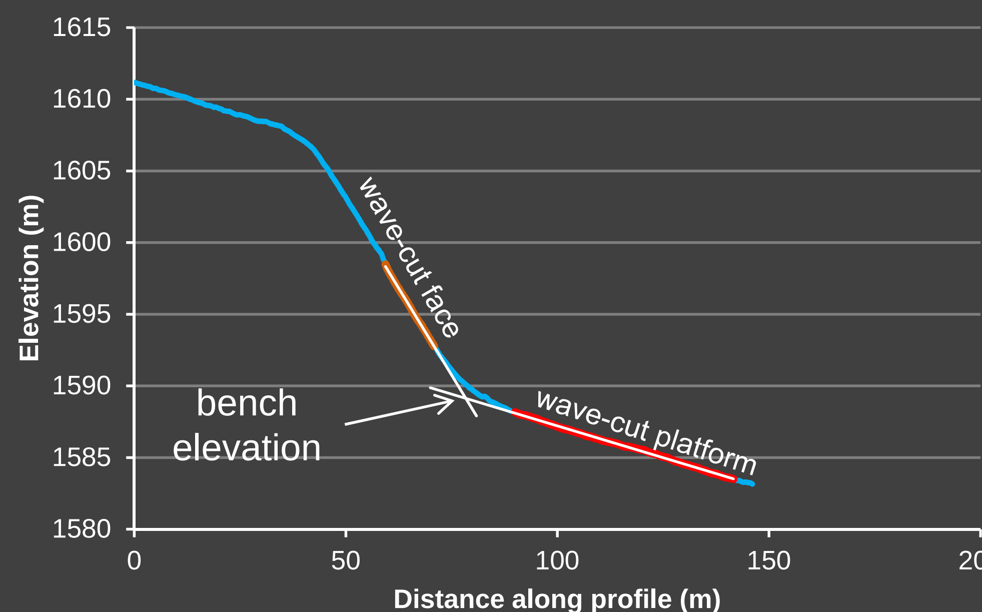
Point cloud (779,309,000 points) screen shot

race and Scarp Profiling Methods





- locations are carefully ed
- data are extracted EM using ArcMAP
- script used to:
  - : lines to far field opes & scarp face or ave cut platform & face
  - alculate scarp height bench elevation



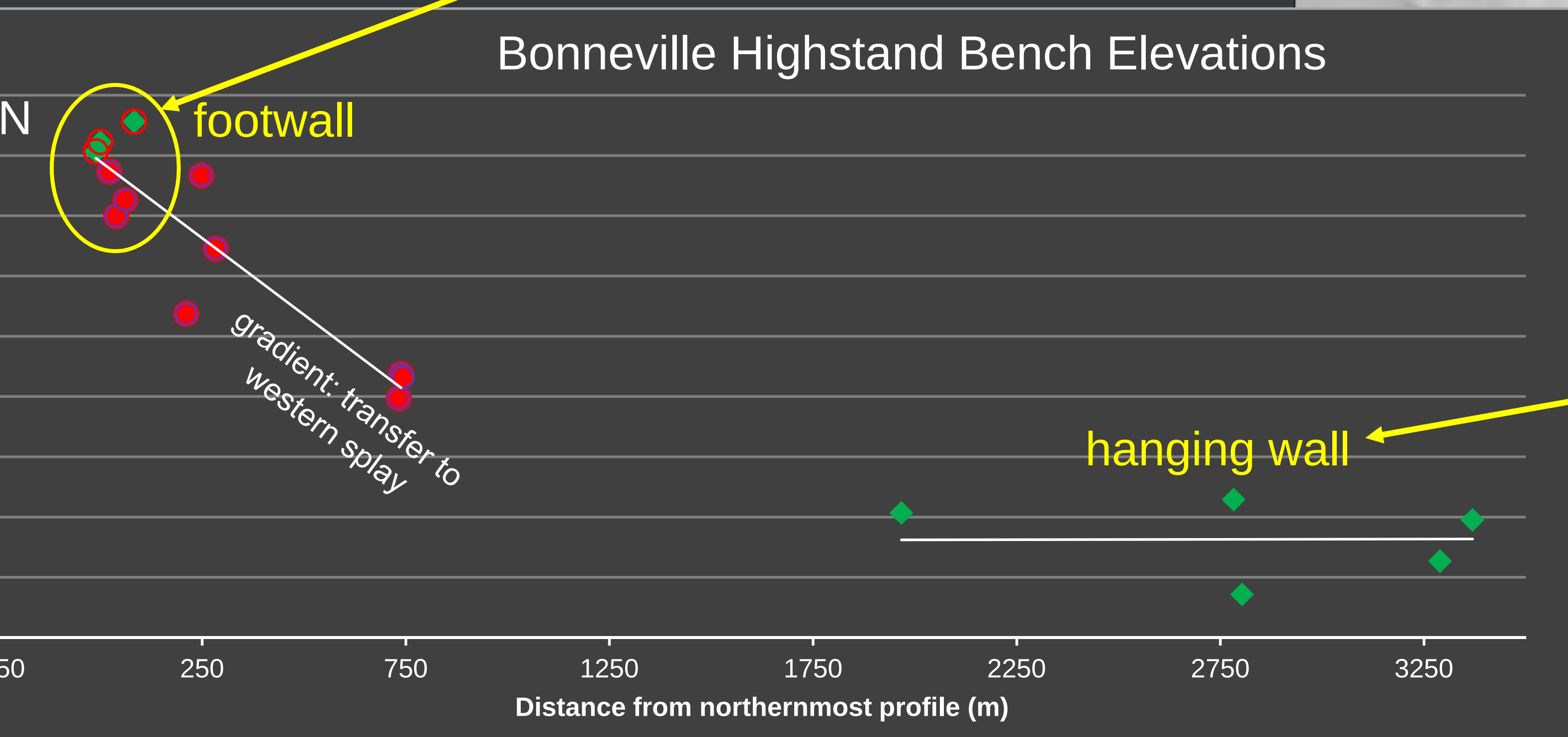
. Bonneville Highstand Bench evations

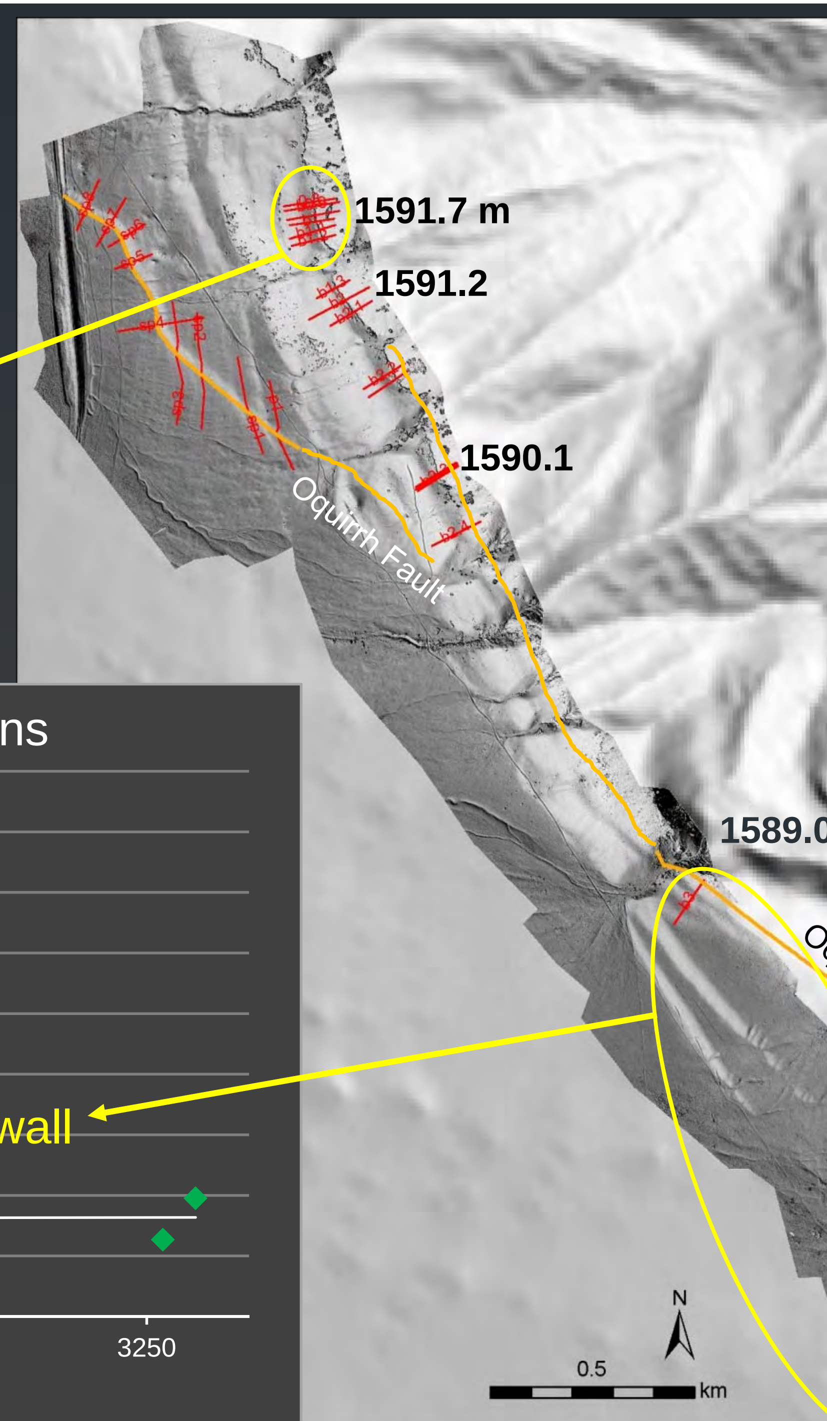
wall average = 1591.7 m

Gradient interpreted as ramp / transfer to western splay

ging wall average = 1588.8 m

-highstand displacement = 2.8 – 3.0 m



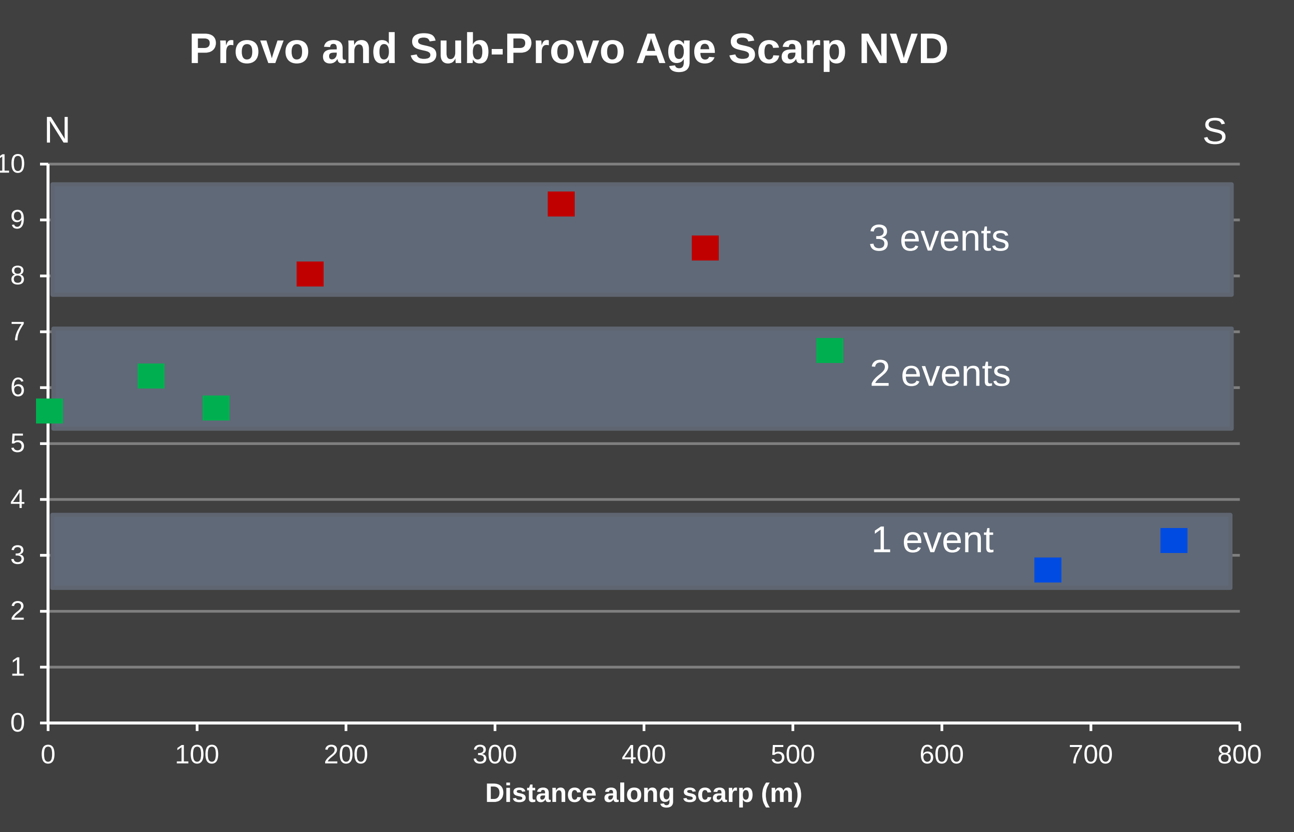


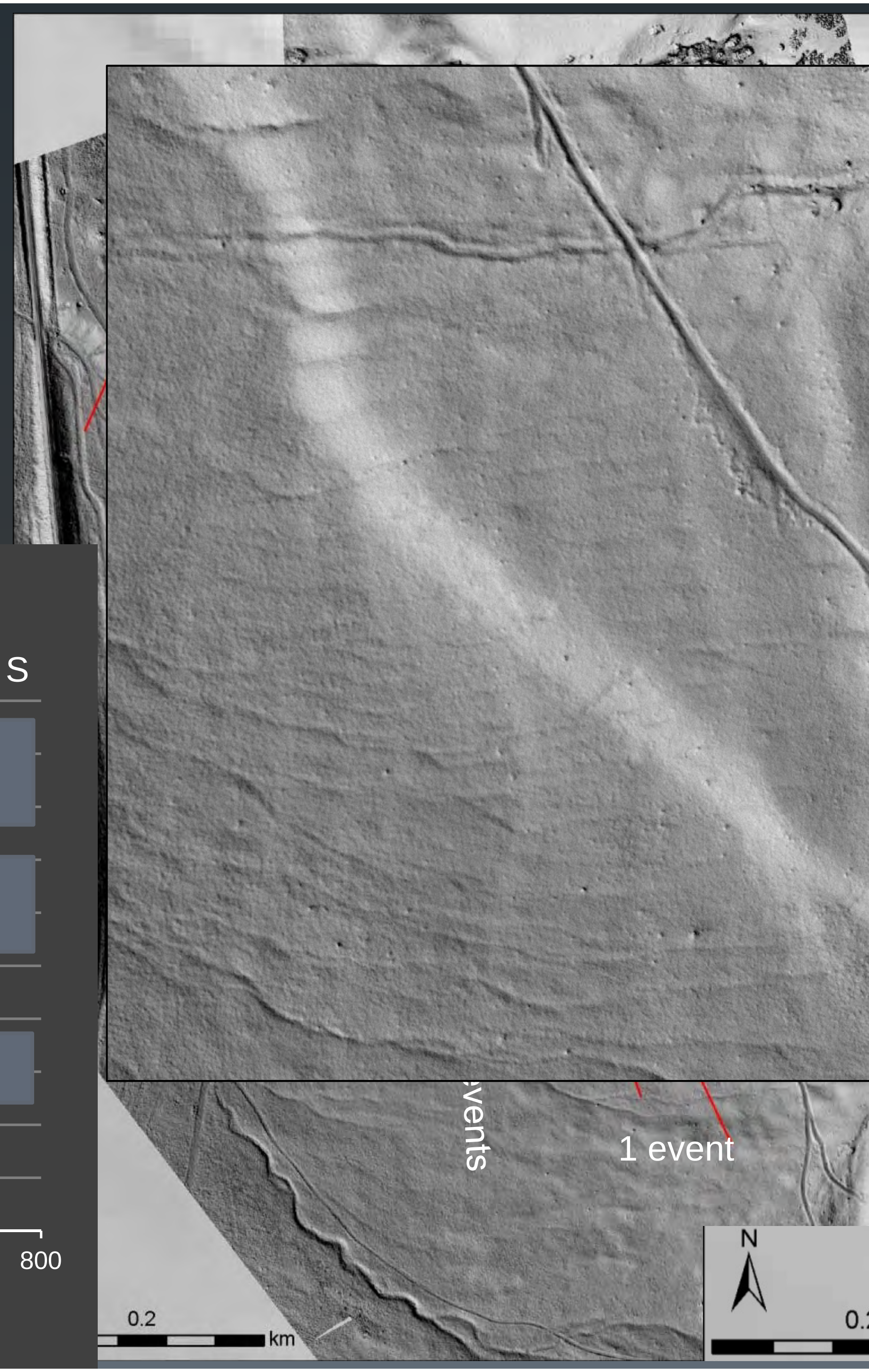
Scarp Heights

- Inferred History:
  - Most recent event occurs
  - Highstand & Provo shorelines form
  - Penultimate event occurs
  - Transgressive shorelines form
  - Antepenultimate event occurs

younger

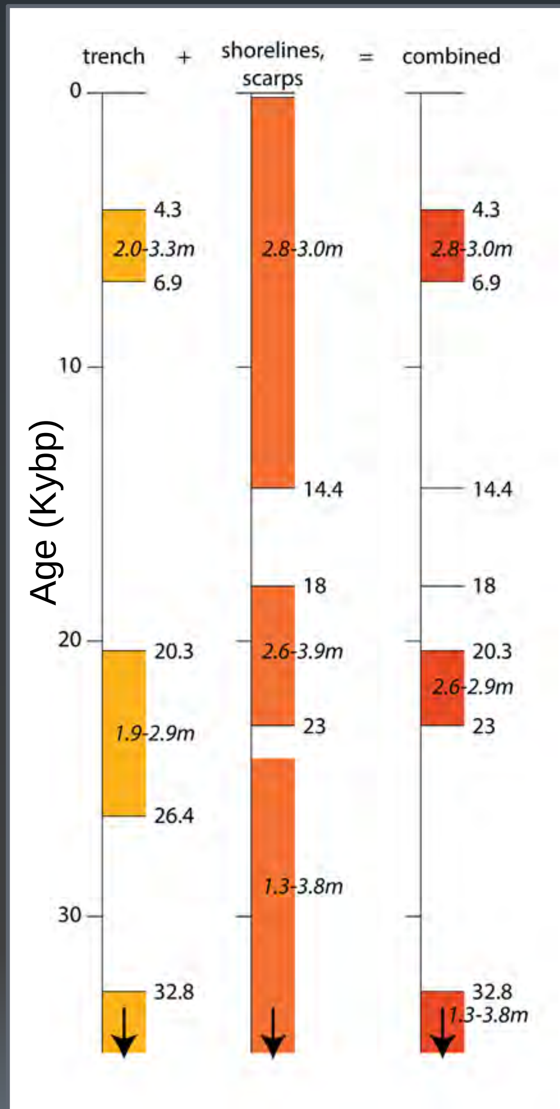
older

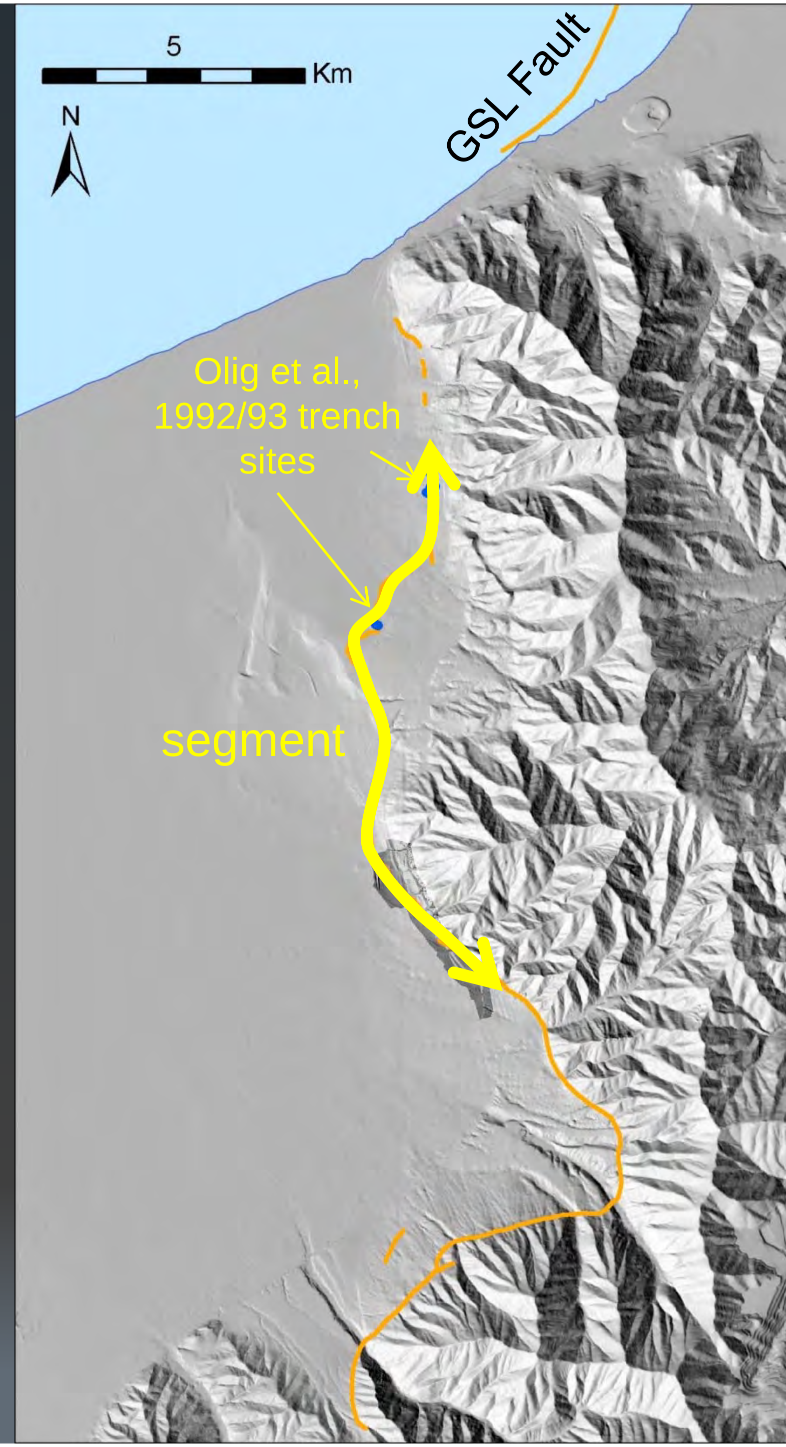




quirrh Fault Parameters

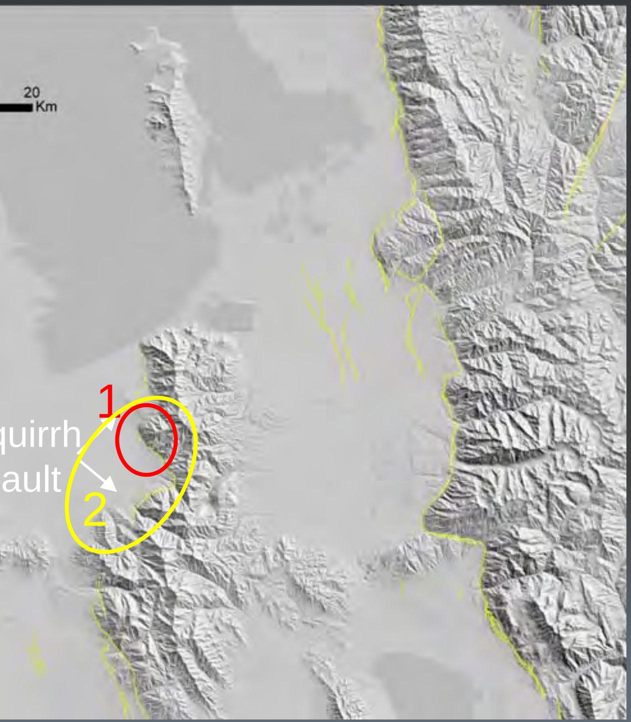
- rate 0.26 to 0.33 mm/yr
  n in 18-23Ka)
- urrence interval
  ,000 years (3
  hquakes in >33,000 yrs)
- per earthquake ~ 3 m
- gruence with trenching
  ults suggests single
  ment
- ger recurrence interval
  n 4200 $\pm$ 1400 yrs Dinter
  echmann found for GSL
  lt

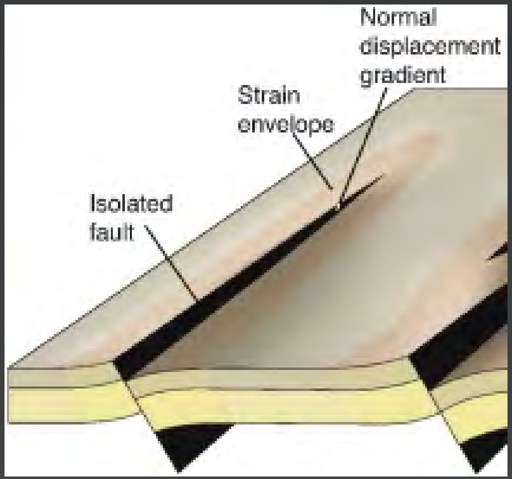


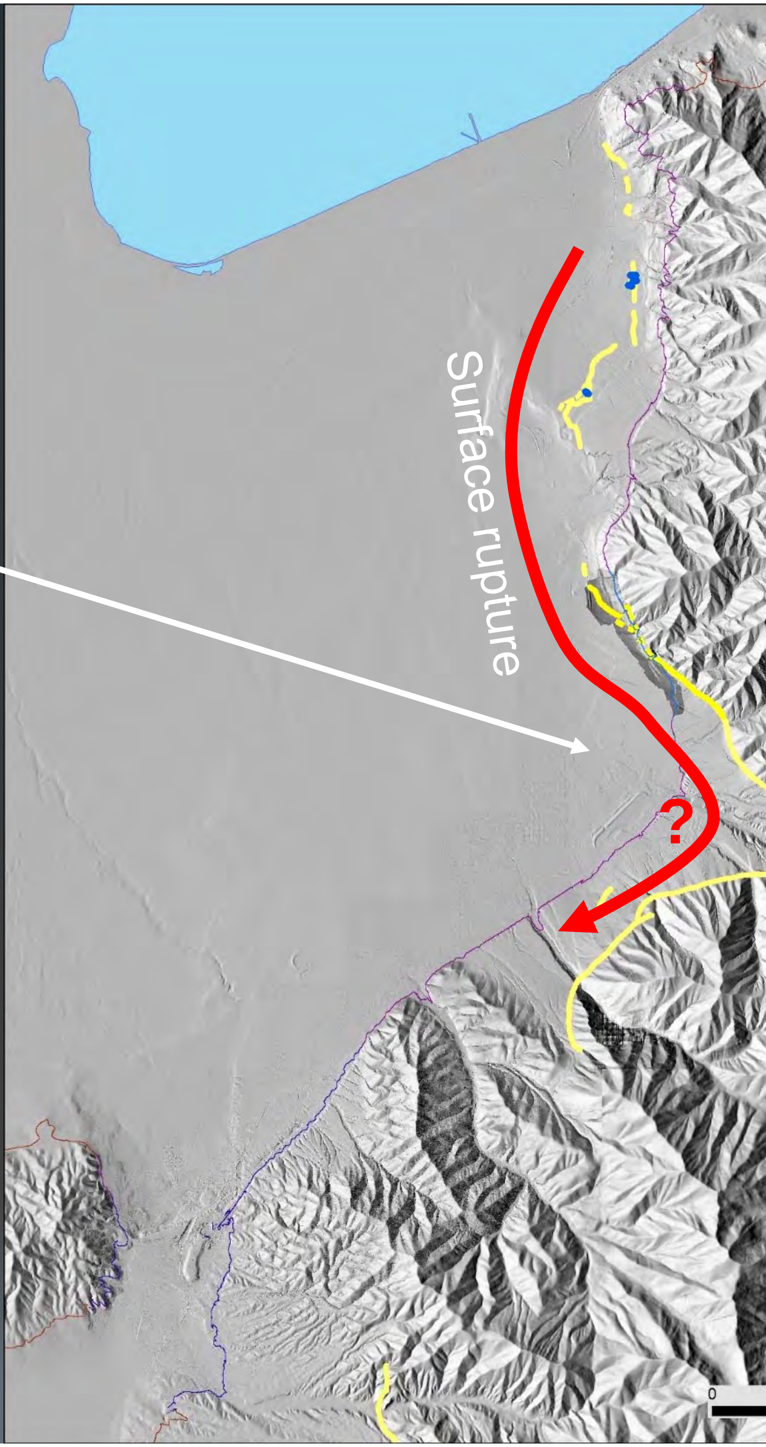


thern Extent of Surface Rupture
Most Recent Oquirrh Flt
thquake

Where rupture ended, elevation of Lk. Bonneville Highstand bench in hanging wall should increase

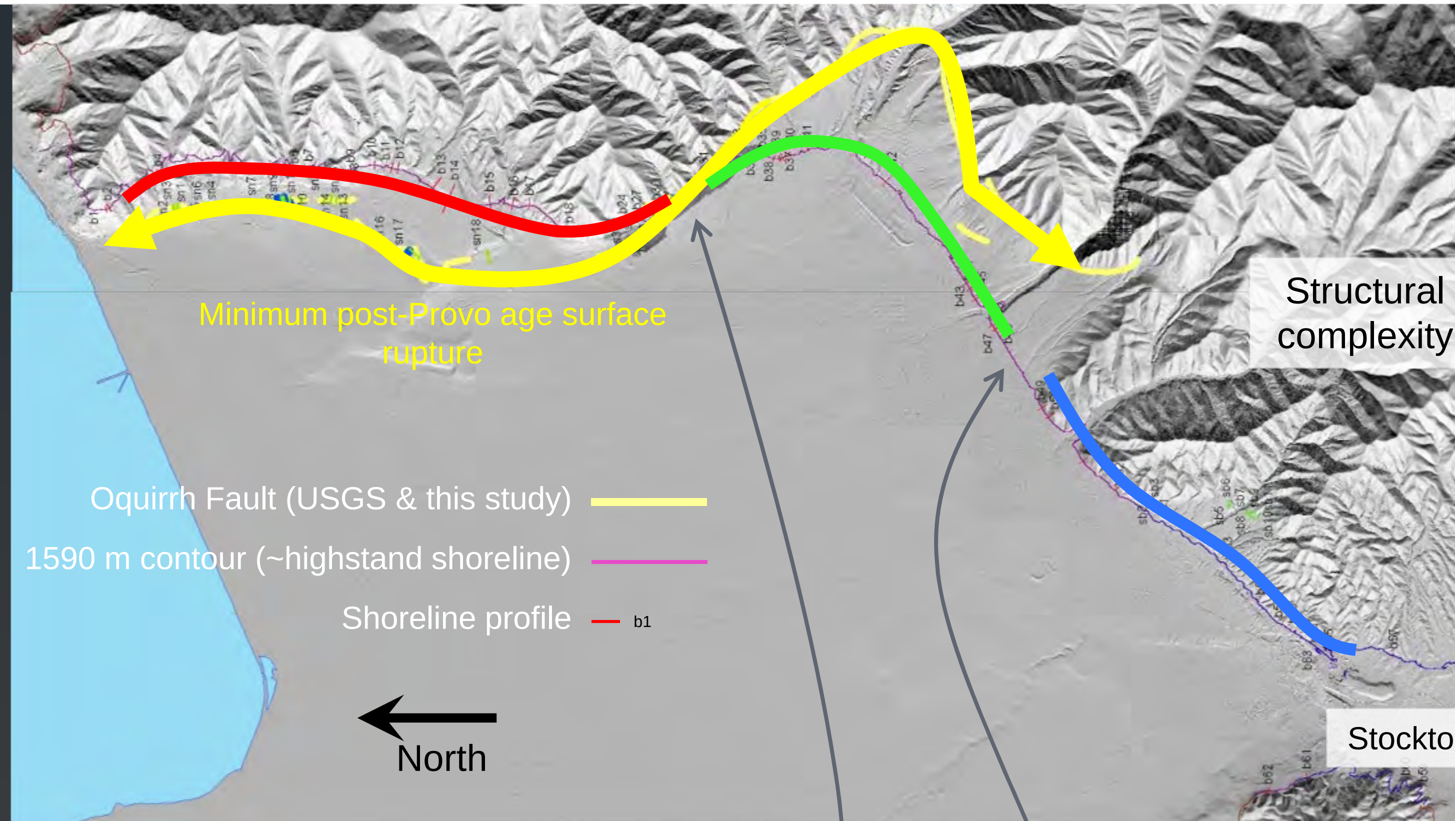


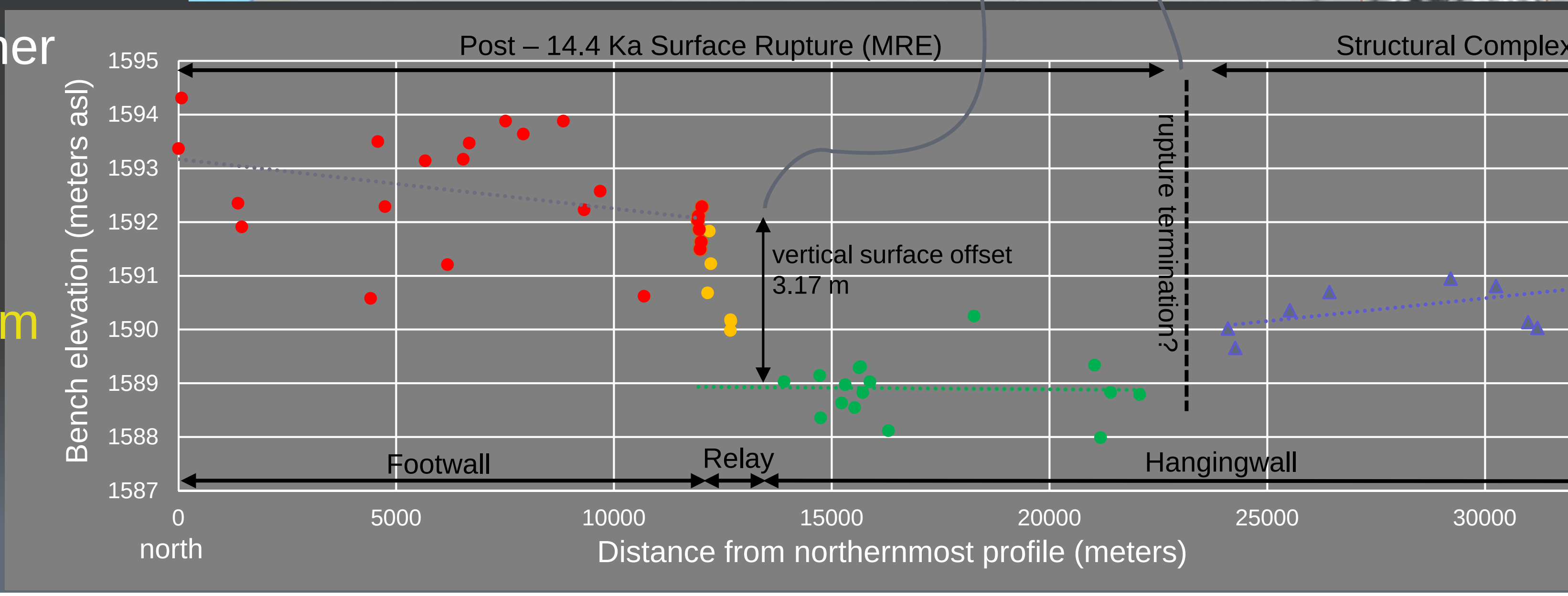




hstand Bench Elevations

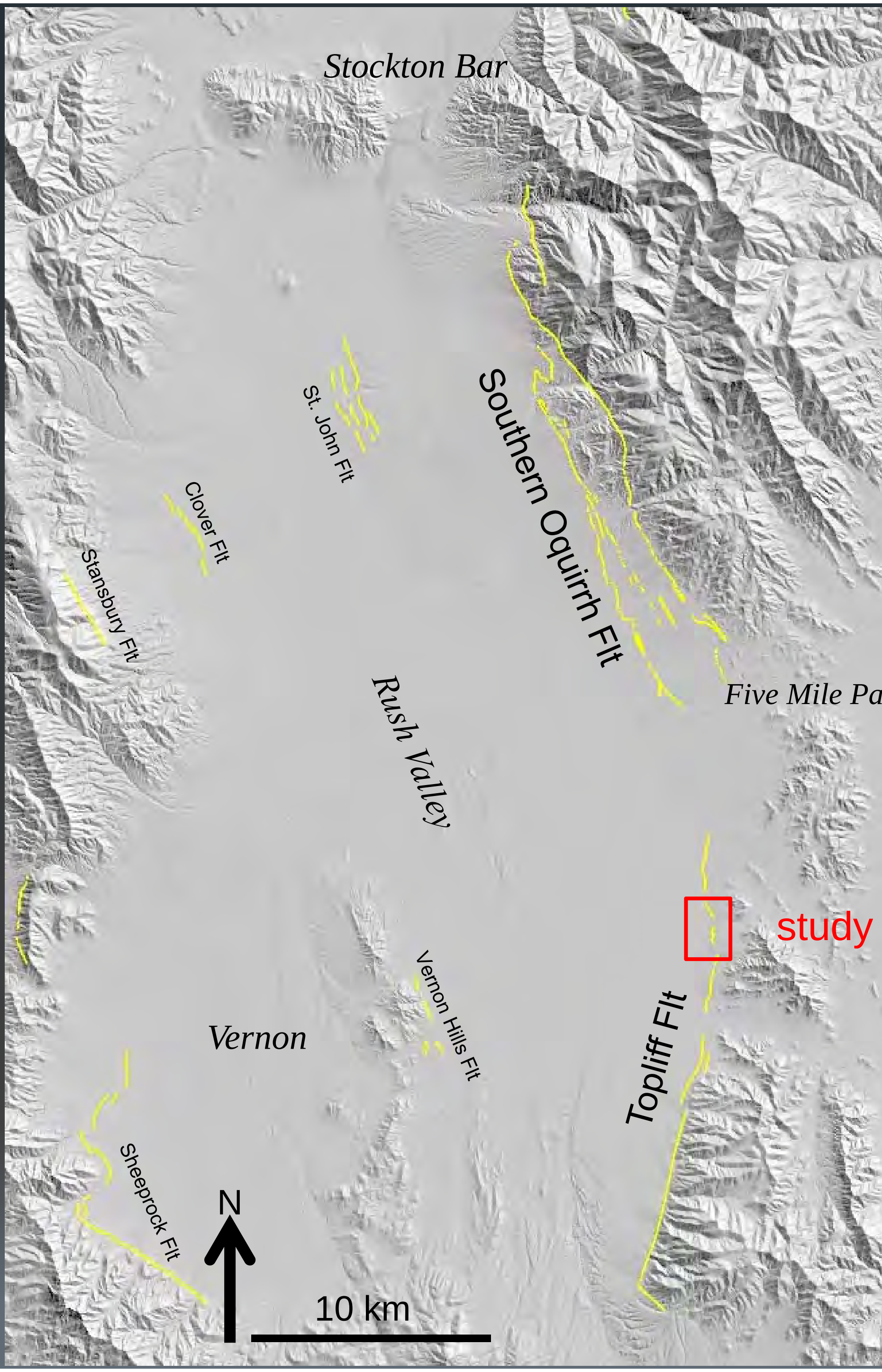
- t wall consistent from L to where cut by fault tudy site 1
- nging wall bench vation consistent ards south, to ctural complexity
- nging wall ~ 1 m higher thwest of structural nplexity
- ggests most recent thquake ruptured from ctural complexity at st to GSL





pliff Fault

- Background
  - West-dipping normal fault
  - No previous formal earthquake hazard studies
- Research Plan
  - Build DEM from SfM
  - Map fault and shoreline(s)
  - Measure Bonneville highstand bench in foot wall and hanging wall to estimate post-highstand displacement
  - Measure scarp heights



emotely Piloted Aerial Systems

- JI Phantom 2, modified to carry 24.3 Mpixel Sony camera
- JI Mavic Pro, ultra small quadcopter
- hantom 4 Pro, small quadcopters
- JI Matrice 100, quadcopter, modified:
  - On-board, high accuracy GPS
  - 24.3 Mpixel Sony camera
- ensefly eBee Plus, fixed-wing, enterprise survey-pecific
  - On-board, high accuracy GPS
  - Automated flight

Matrice 100

Phantom 2

Phantom 4 Pro

eBee Plus

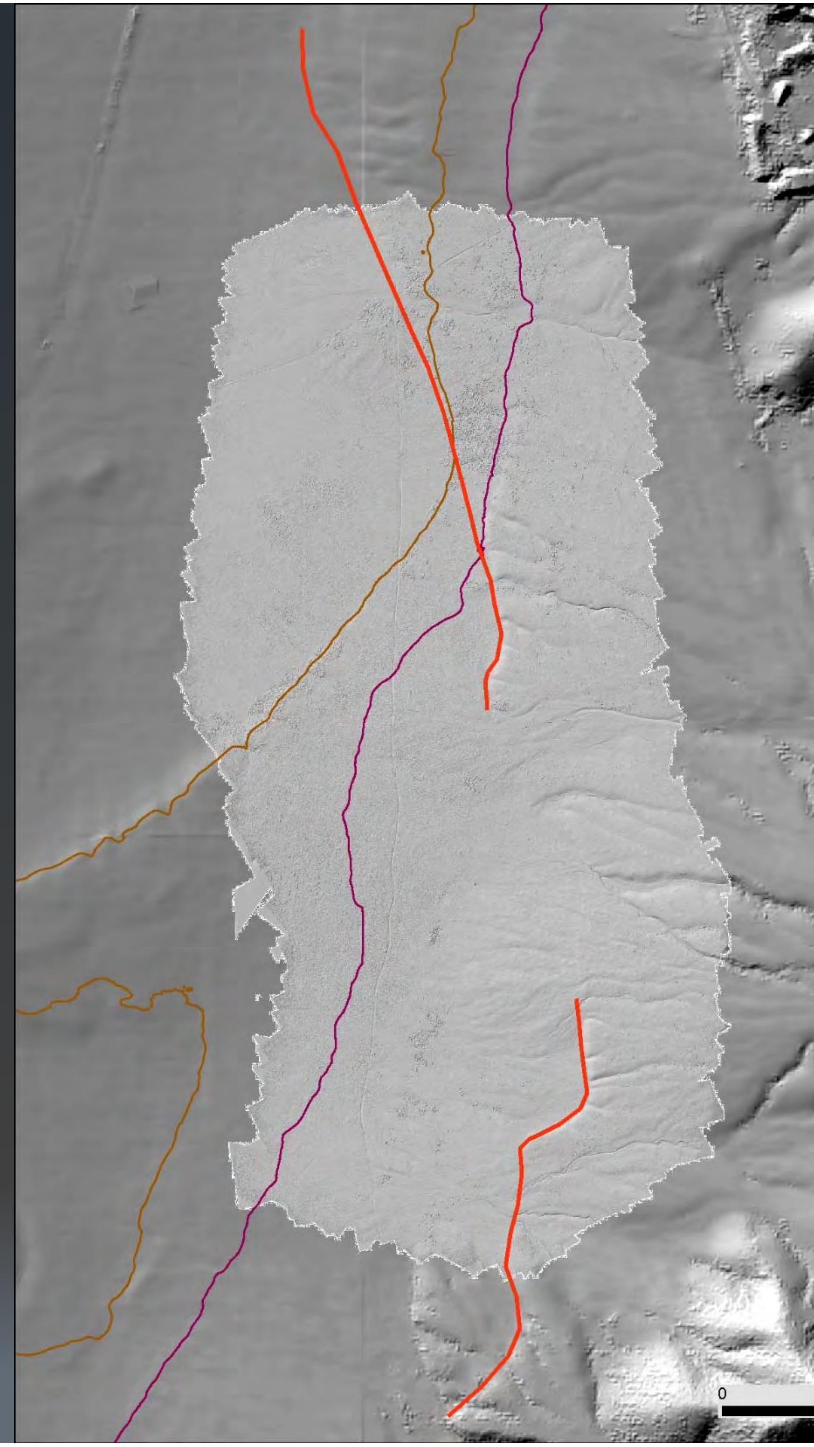
apping the
pliff Fault

nsefly eBee Plus

Plus

pliff SfM – Derived DEM

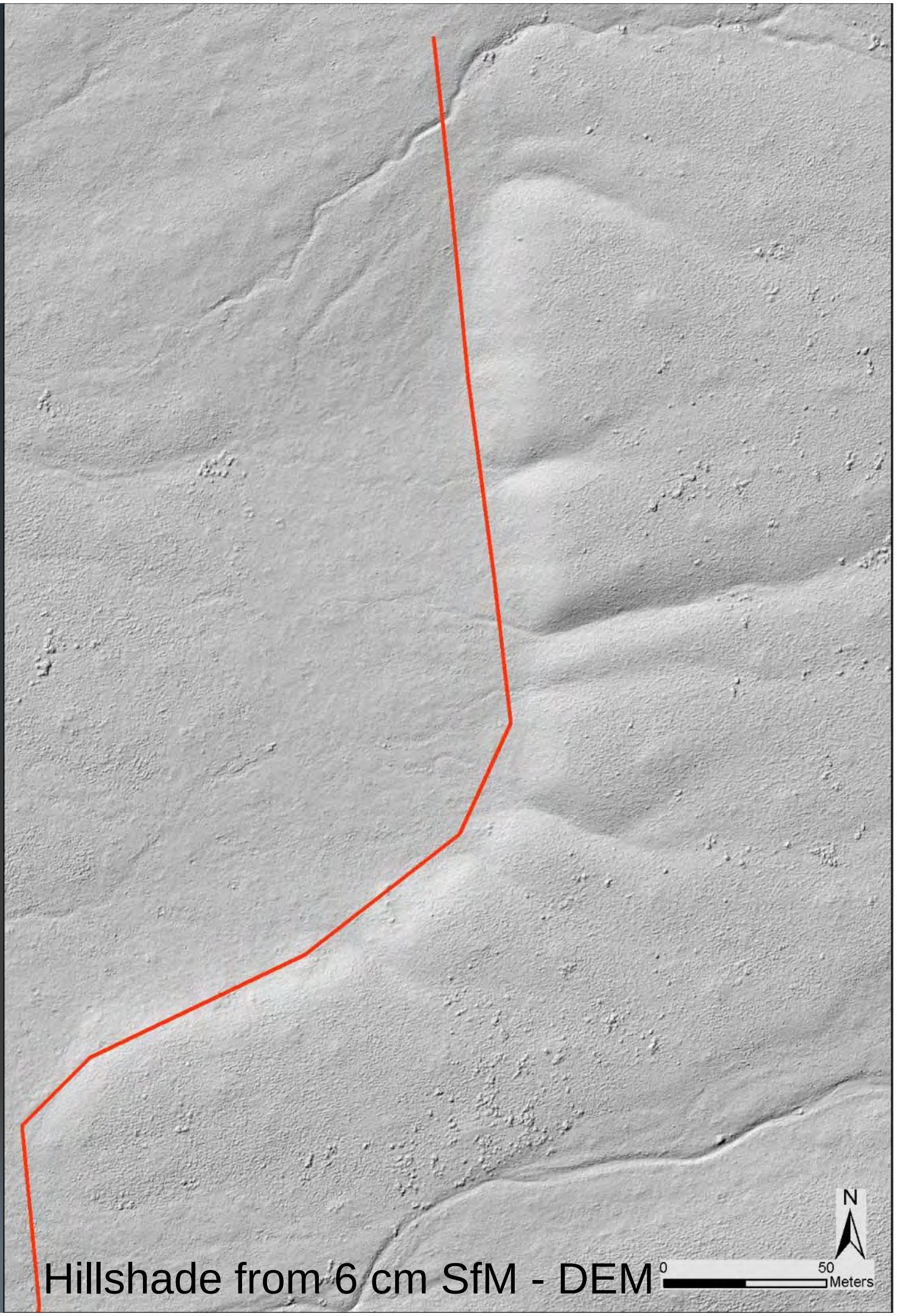
- Made by Marissa Keck, Serena Smith and McKenzie Ranney, with crucial field help from Logan Woolstenhulme, Joe Phillips, Jeremy Saldivar (Fall GEOG 4100 class)
- eBee Plus platform
- 1923 photographs
- Georeferenced using on-board GPS and GCPs
- Point cloud 720 million points
- 6 cm pixel DEM
- DEM accuracy: ~4.4 cm RMSerror relative to checkpoints
- One day of field work to fly area with 3 UAS (for comparison)



6 cm hillshade for this study with
2 m hillshade background

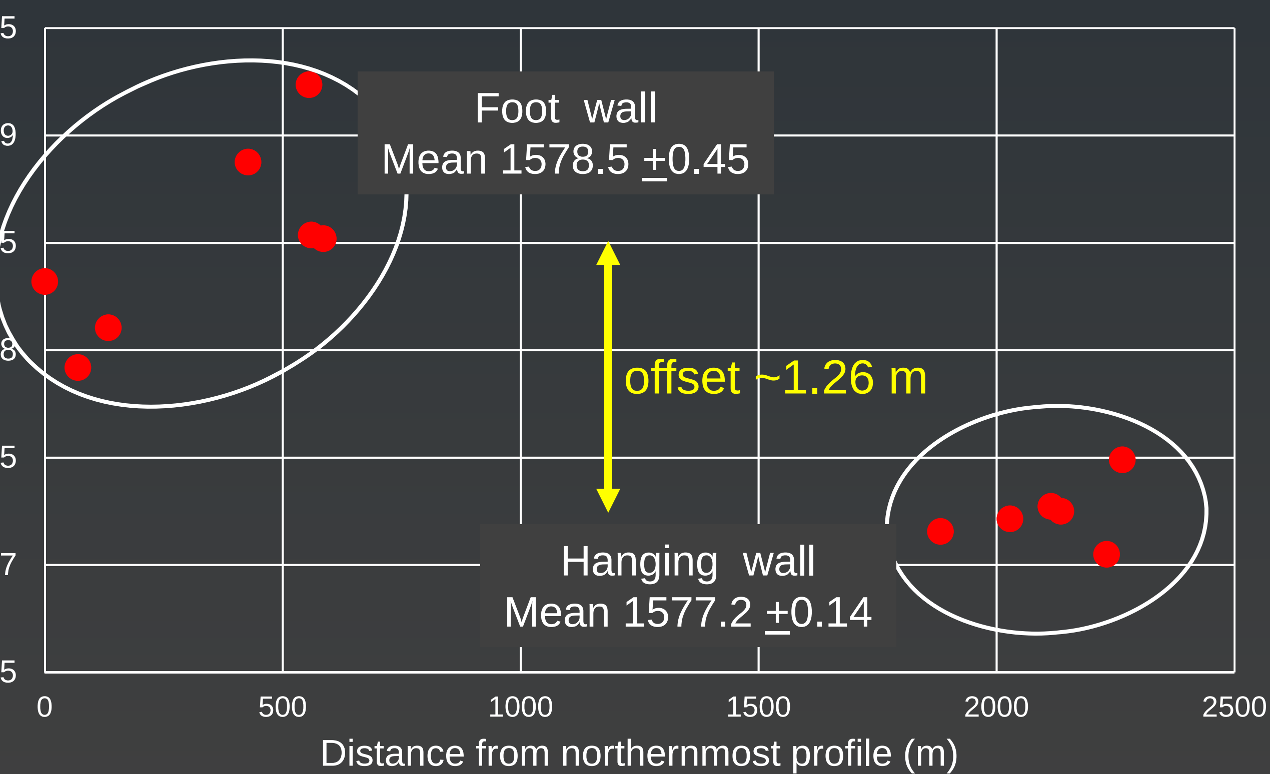
EM Comparison

- 2 m autocorrelated DEM vs 6 cm SfM-derived DEM
- Greatly increased resolution
- Improved accuracy
- Cannot resolve nor accurately measure scarps and other smaller features without high resolution topography

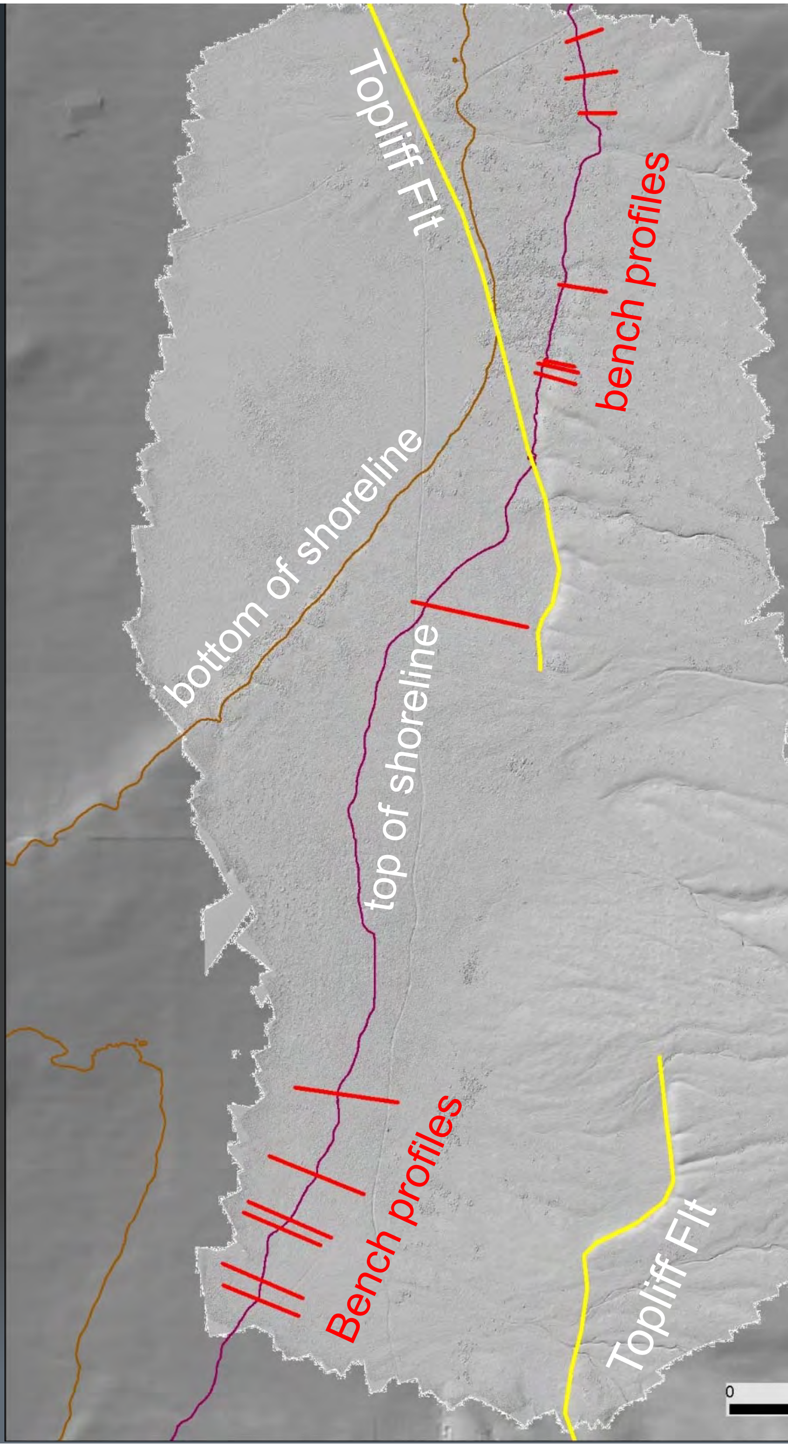


Hillshade from 6 cm SfM - DEM

oreline Bench Elevations



Post highstand offset = 1.26 m ± 0.6 m

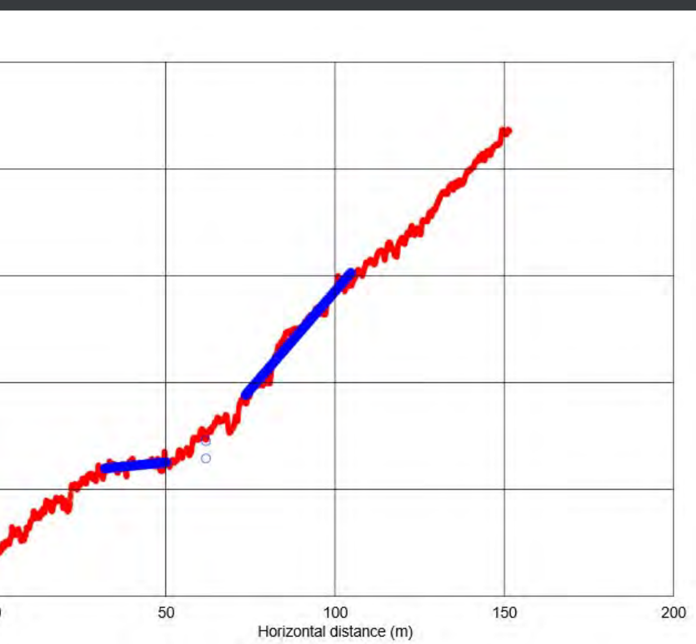


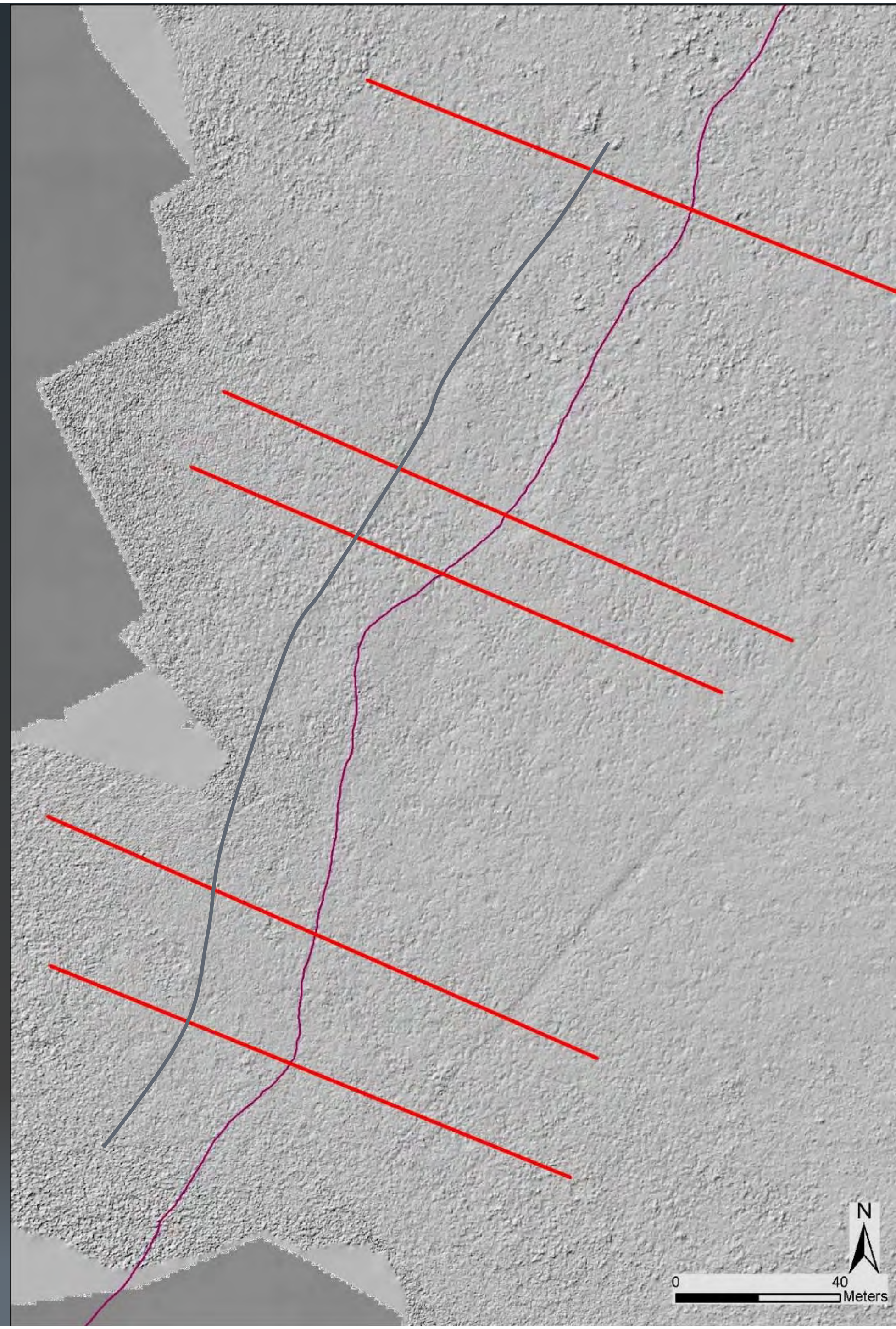
6 cm hillshade
2 m hillshade background

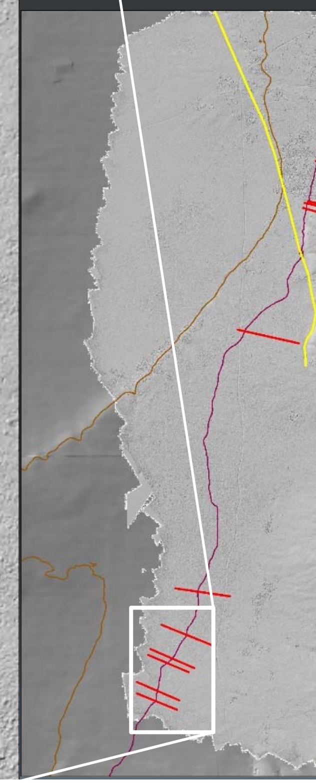
oreline Bench vations, cont’d

e bench is not well defined
hanging wall, so results
equivocal

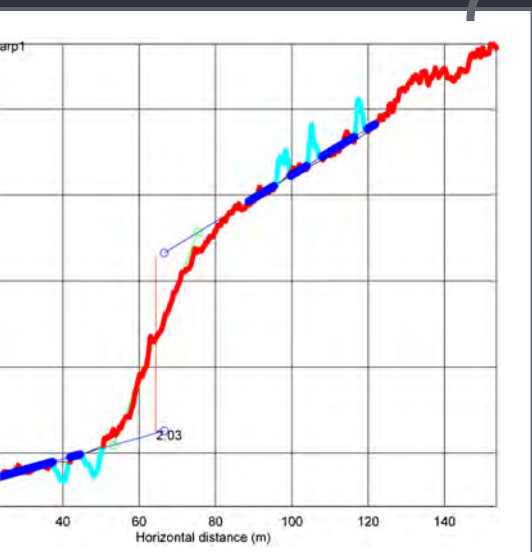
Offset 1.26 m + 0.6 m ?

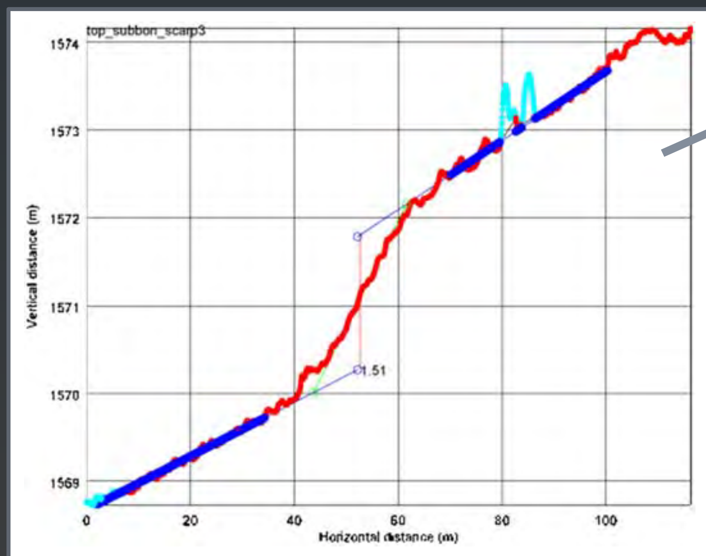


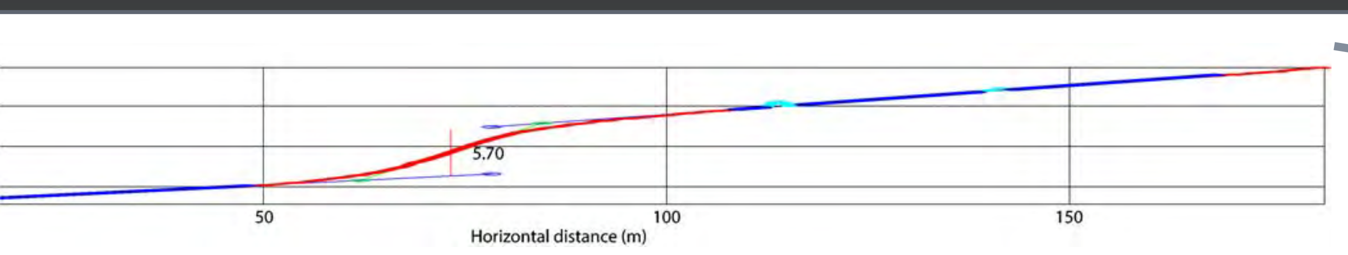


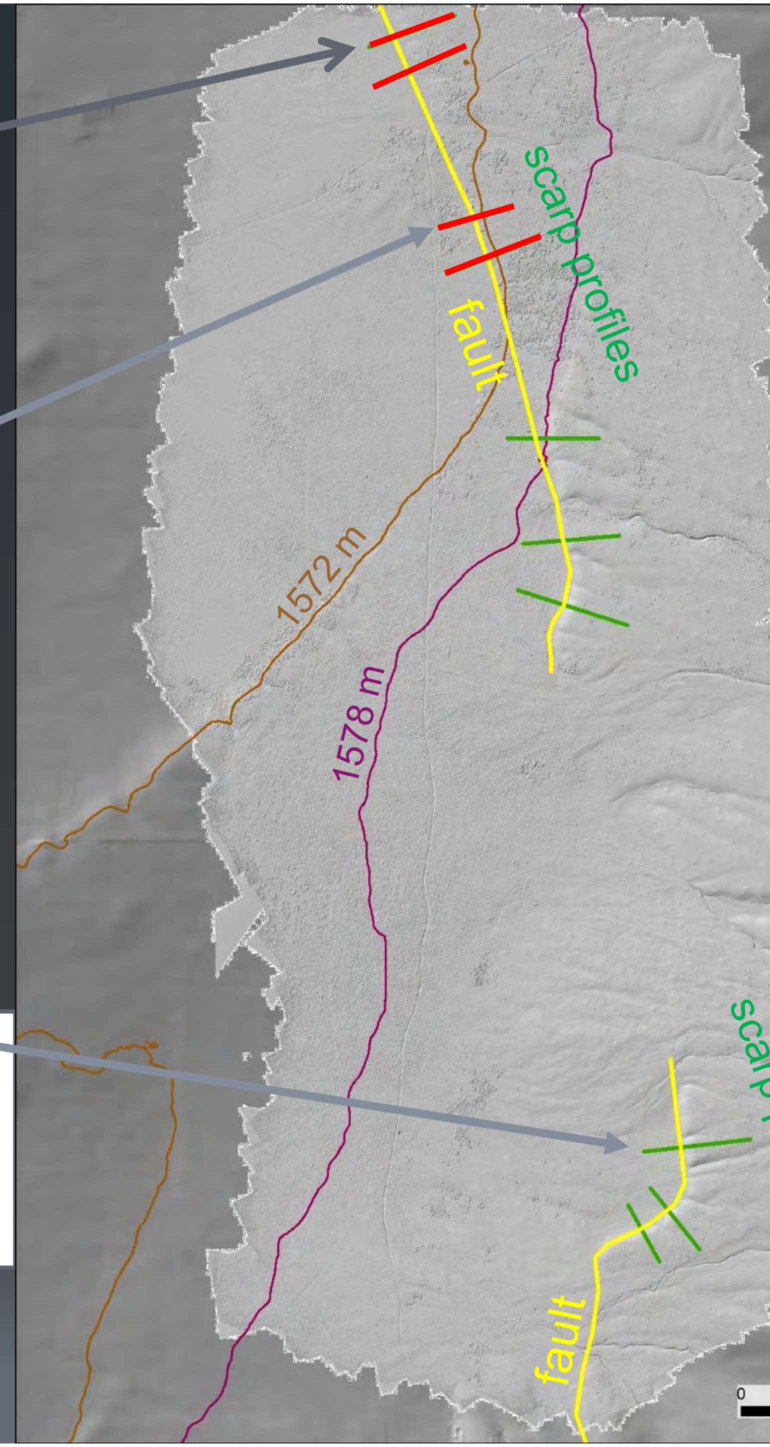


pliff Fault Scarps

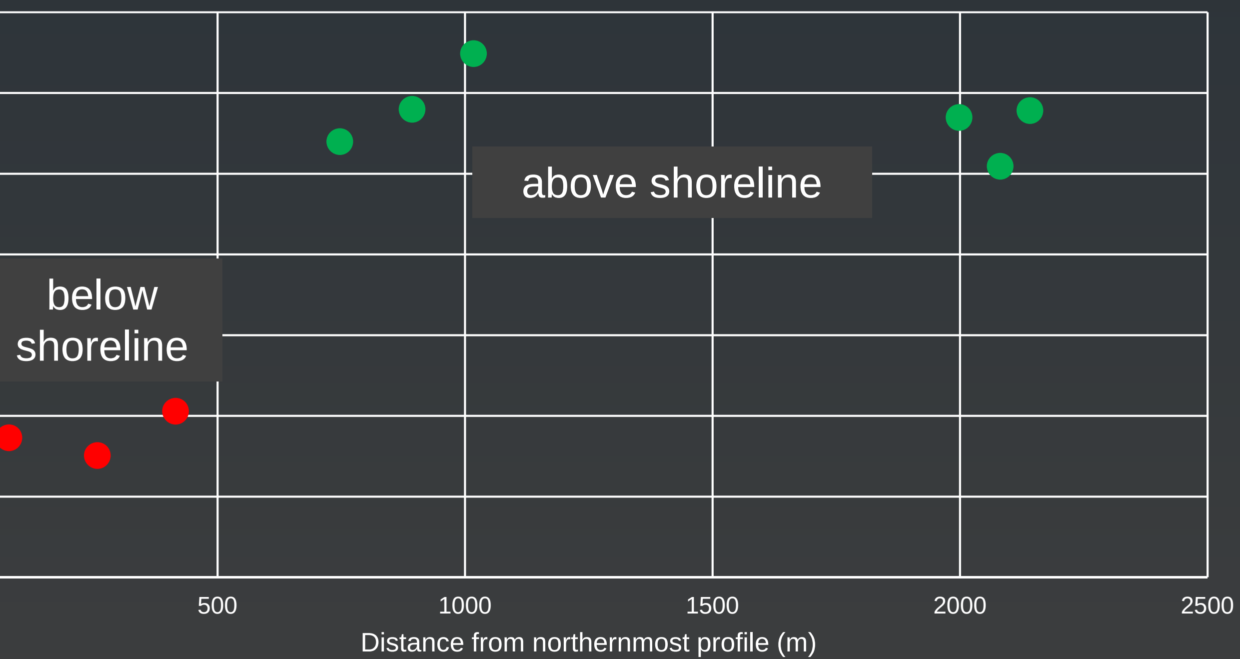


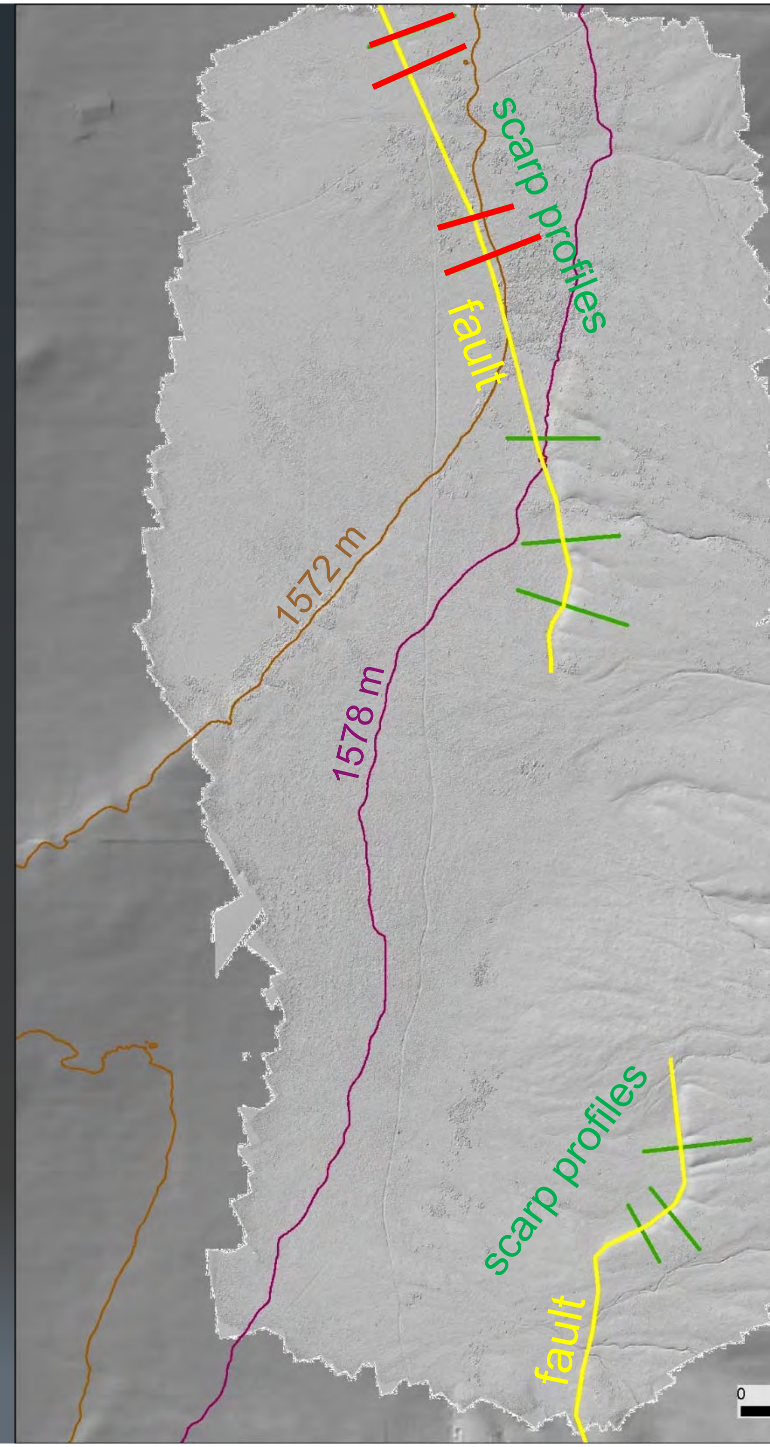






pliff Fault Scarp Heights

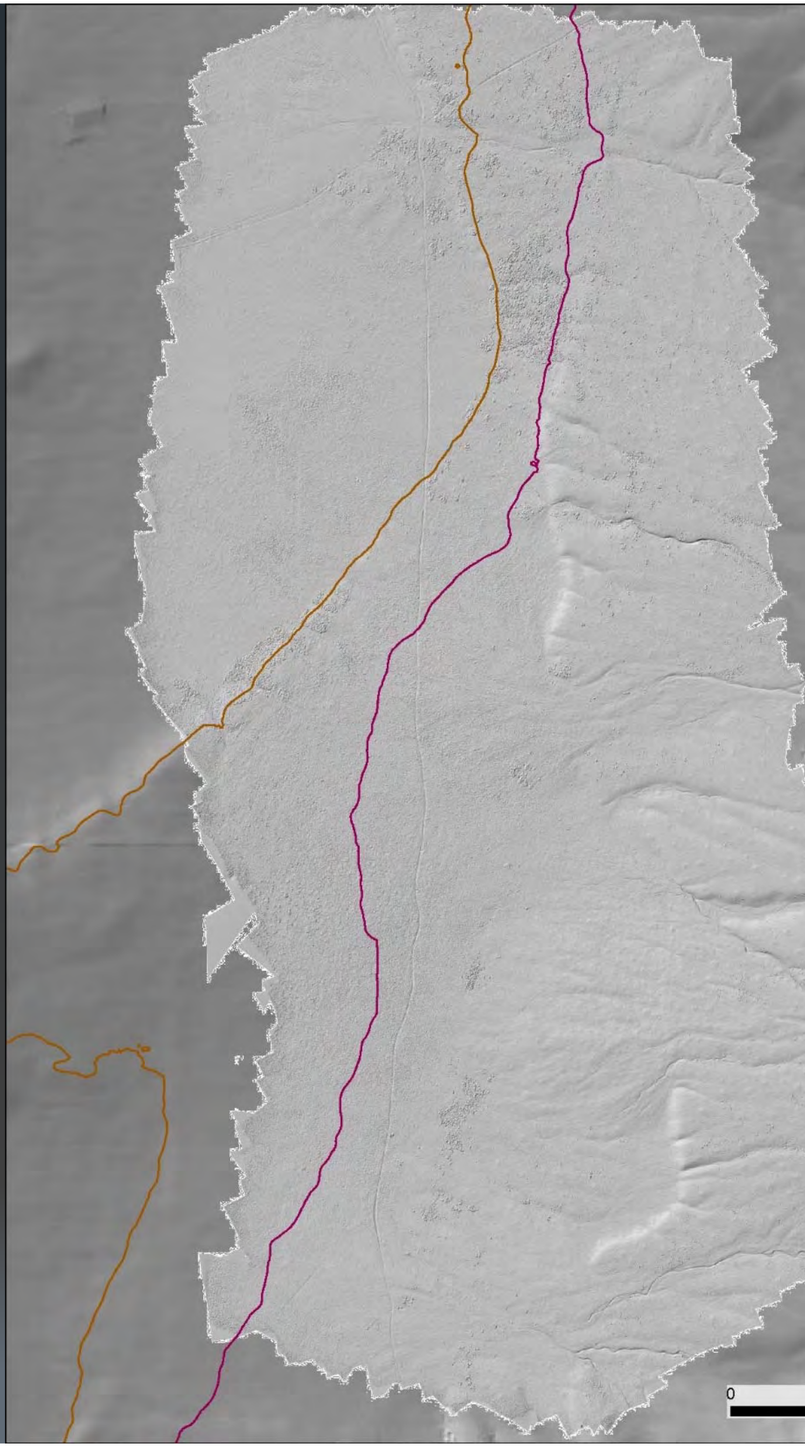




- ne(?) earthquake preserved in scarp below oreline, offset = 1.8 m + 0.3 m
- vo to three earthquakes preserved in scarp ove shoreline. Surface age unknown.

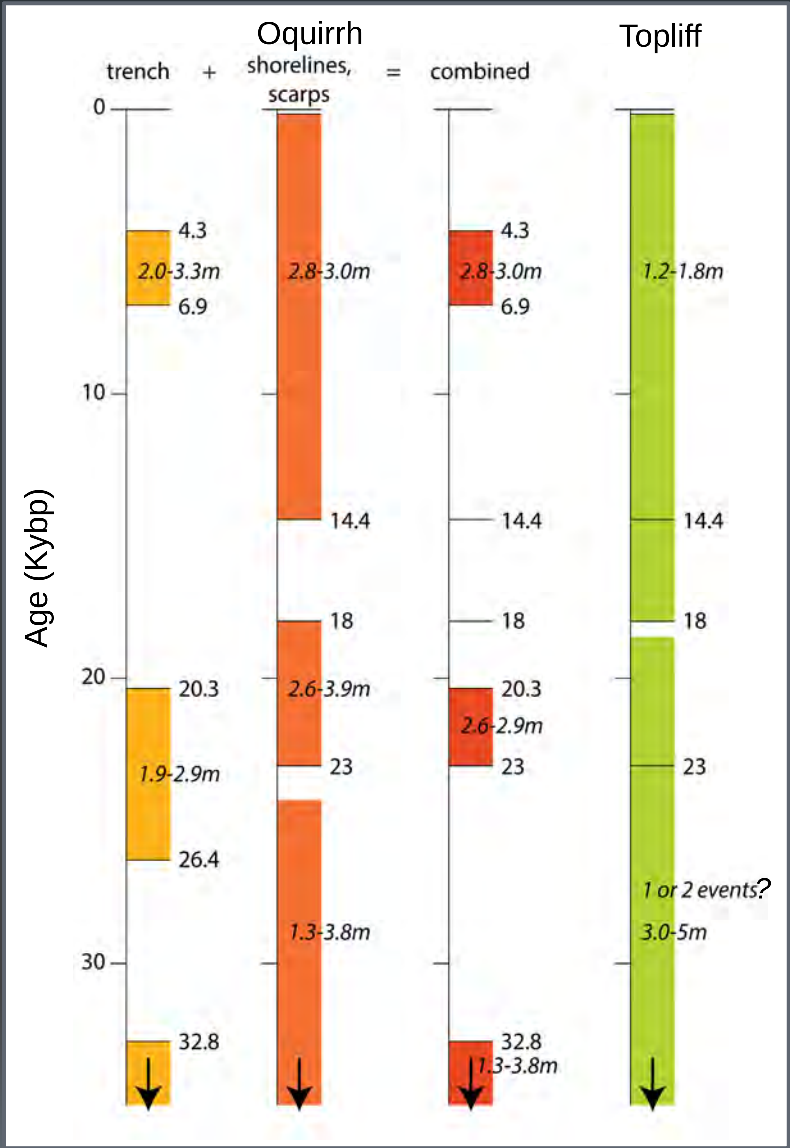
pliff Summary

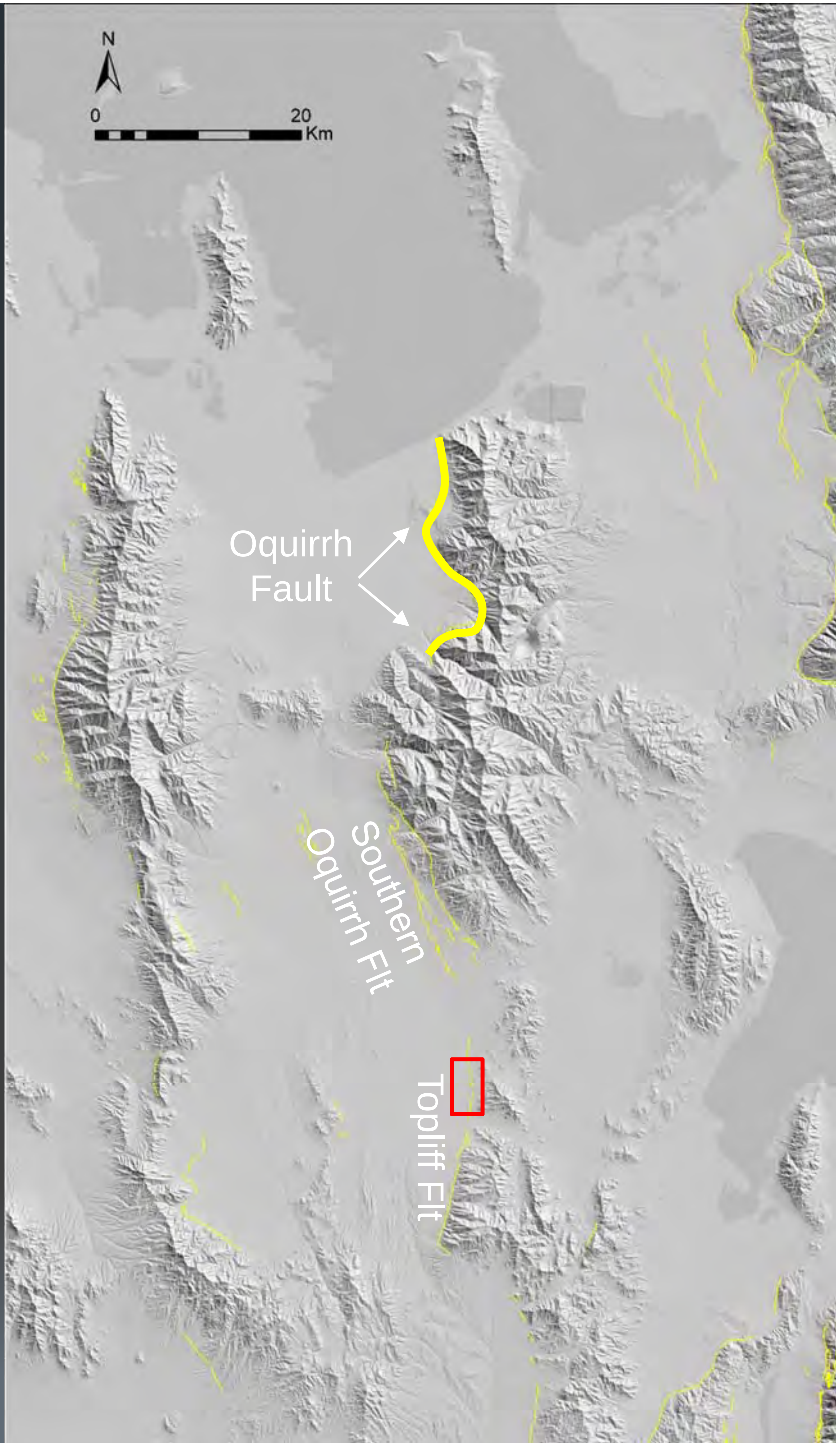
- Possibly one earthquake post-highstand (18 Ka)
  - 1.2 to 1.8 m offset
  - Yields 0.07 to 0.1 mm / yr slip rate estimate
- One or two (?) additional earthquakes in older surface of unknown age



Together

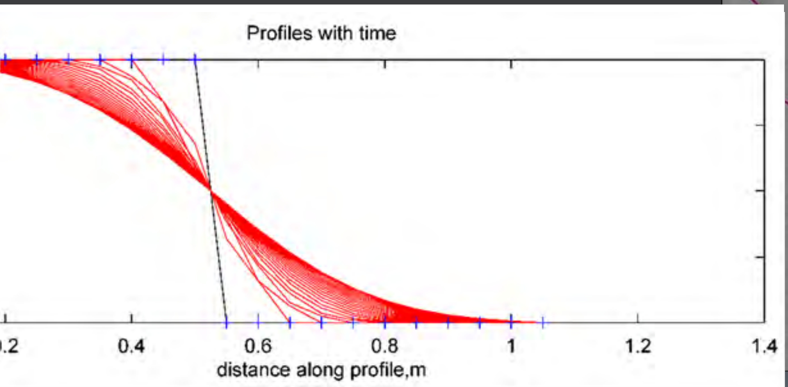
- irrh Fault
  - 1 event post-Lk. Bonneville north of Stockton Bar. ~ 3 m offset
  - 1 event post transgression, pre-highstand
  - 1 event pre-transgression
- liff Fault
  - 1 event post-Lk. Bonneville possible. 1.2 – 1.8 m offset
  - 1 or 2 events pre-highstand

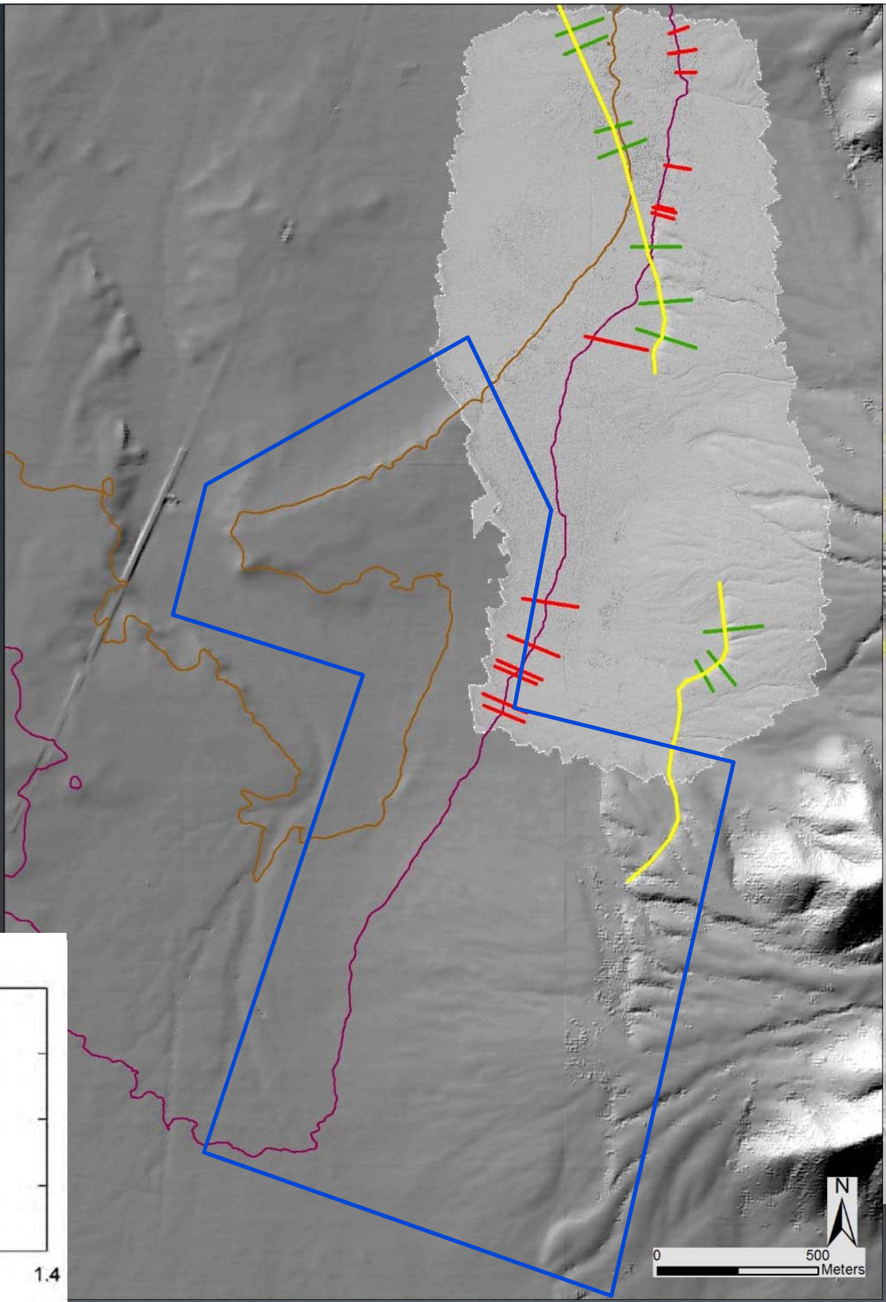


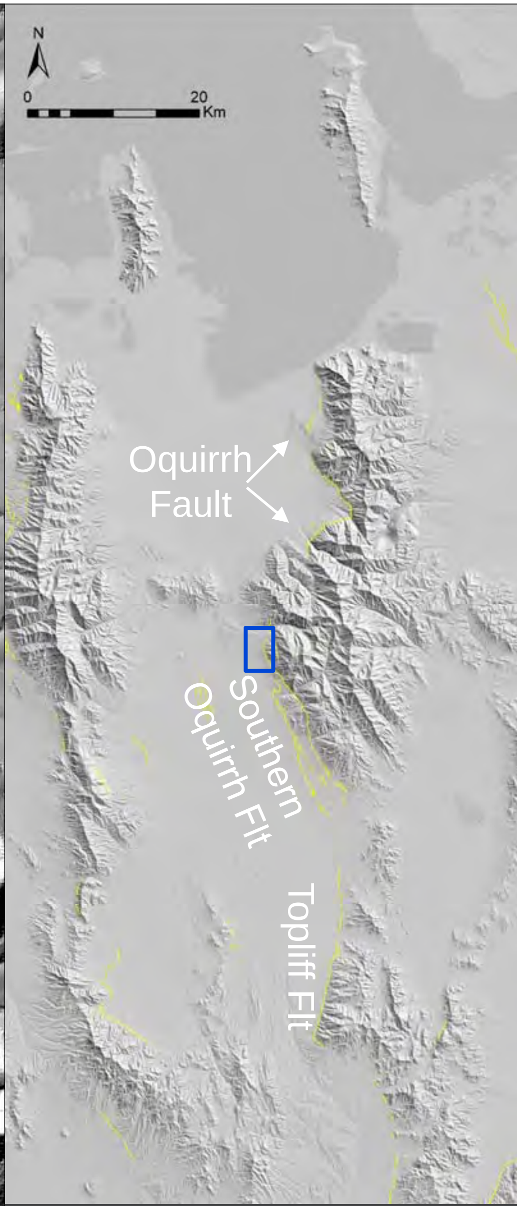


hat Next?

- oper geomorphic mapping of site
- carp diffusion modeling?
- nlarge DEM coverage at existing
  pliff study site?
- enerate DEM at alternative site,
  ssibly on Southern Oquirrh Fault?
- ench Topliff at existing site?
- ate older fan surfaces??

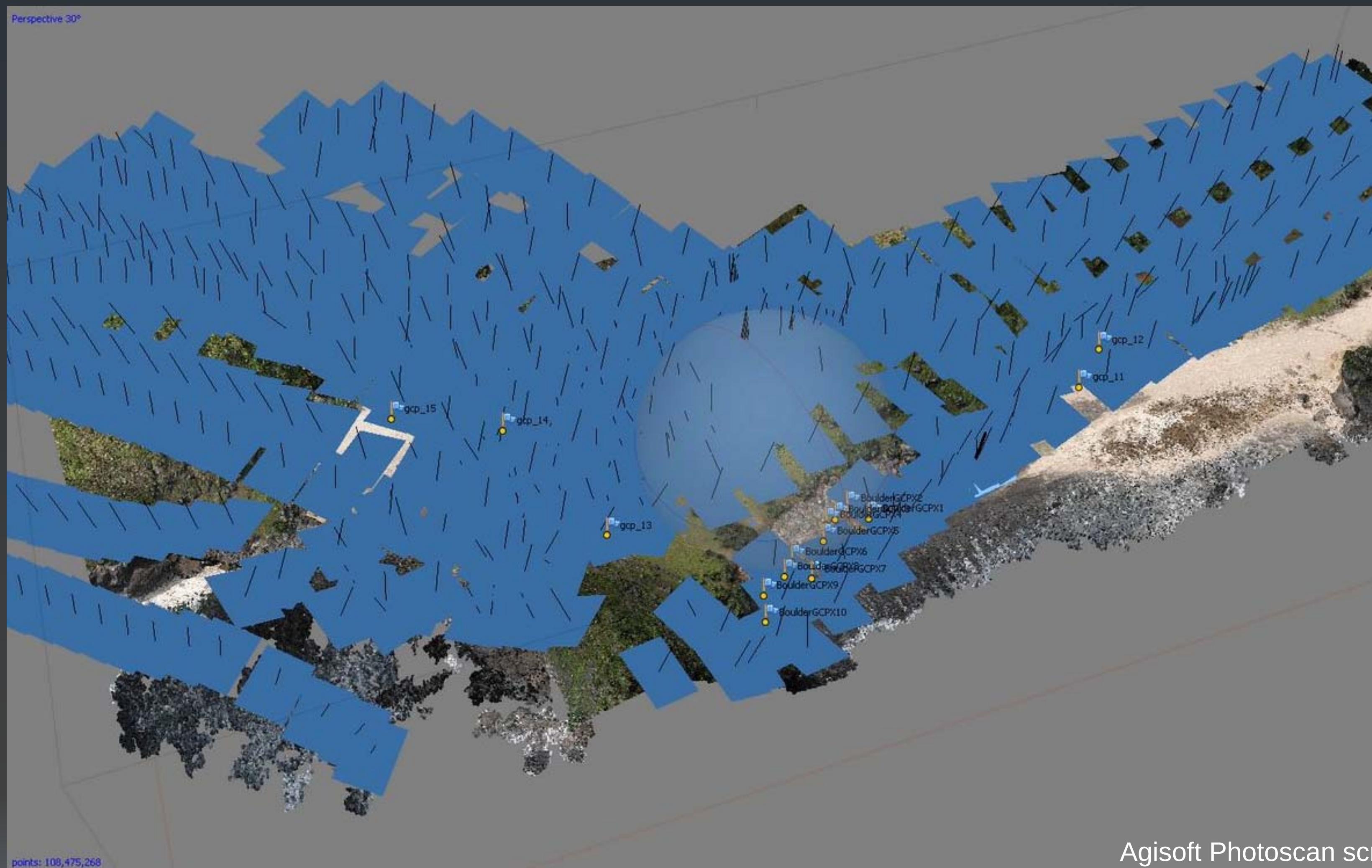






uilding Topographic Maps from UAV Photographs: Structure from otion (SfM)

- I is a method for king a 3-d model of a face from overlapping tos taken from erent perspectives
- del can be accurately led, oriented, and referenced
- mmercial software ., Agisoft Photoscan)
- mary product is a point ud
- nt clouds can be terized into digital vation models (DEMs)

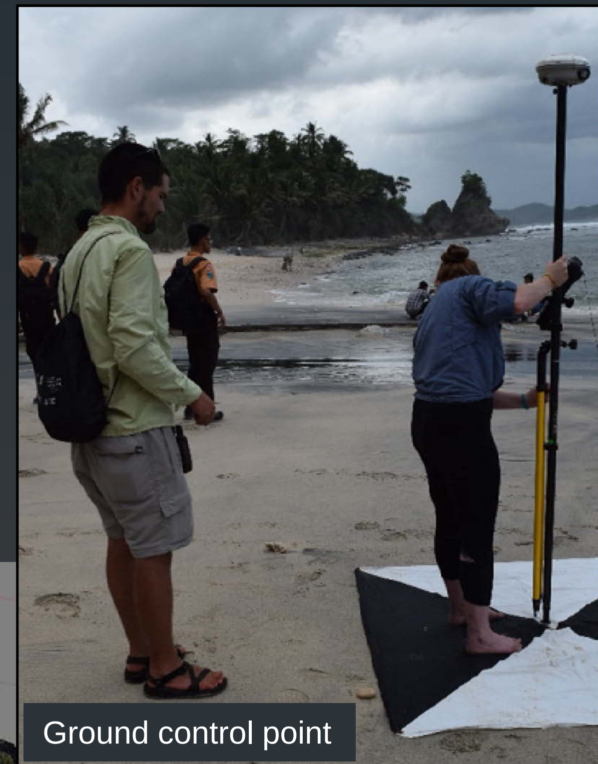


Agisoft Photoscan sc

Blue squares are locations where photographs were taken from UAV.

eoreferencing Point Clouds and DSMs

- 5 to 20 Ground control points (GCPs) are arrayed across mapping area (9 usually sufficient) and measured using RTK GPS
- And/or: Survey-grade GPS on-board UAV accurately records camera position for each photograph

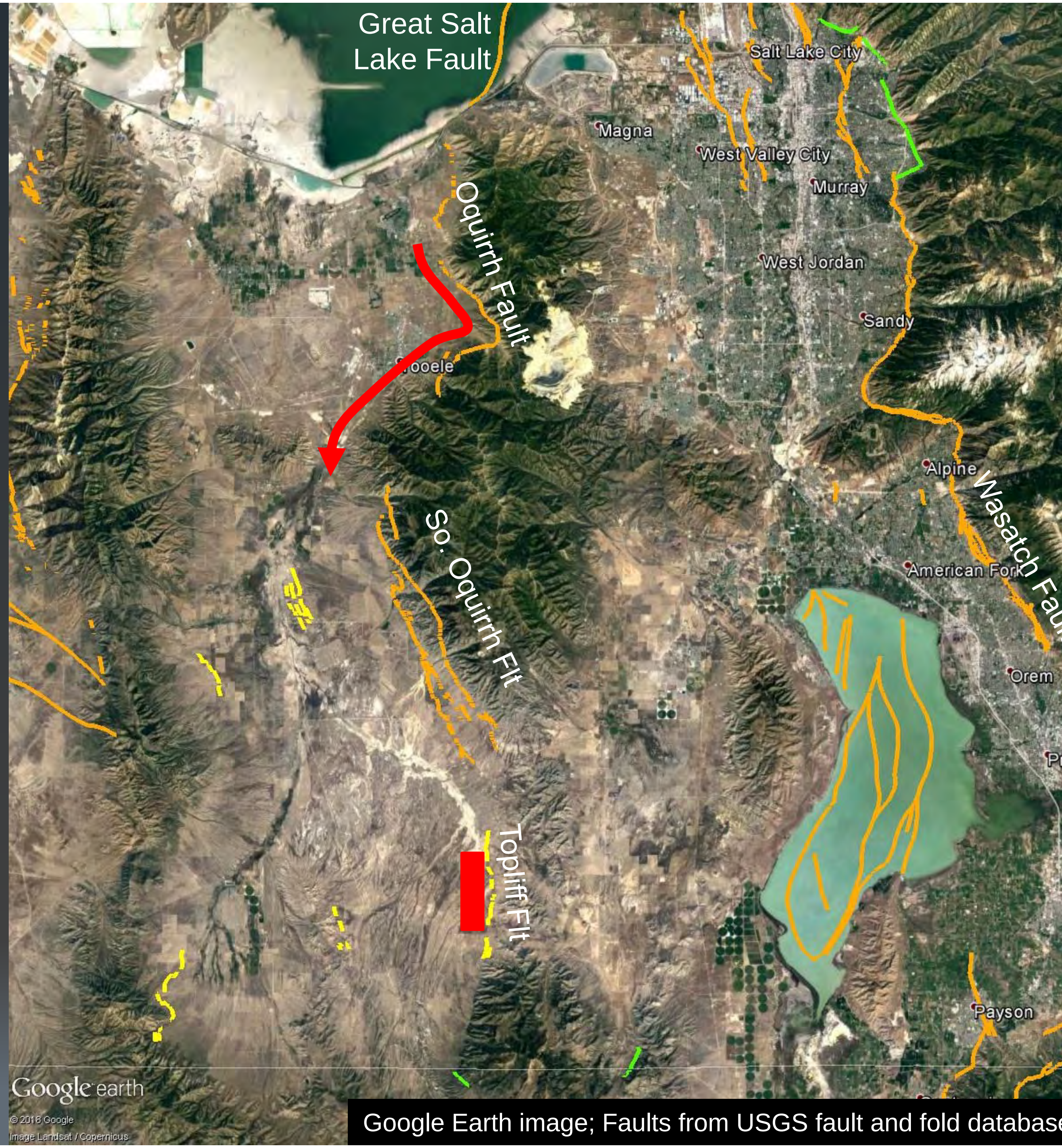


Ground control point

Ground control point locations

ack to) Oquirrh d Topliff Faults

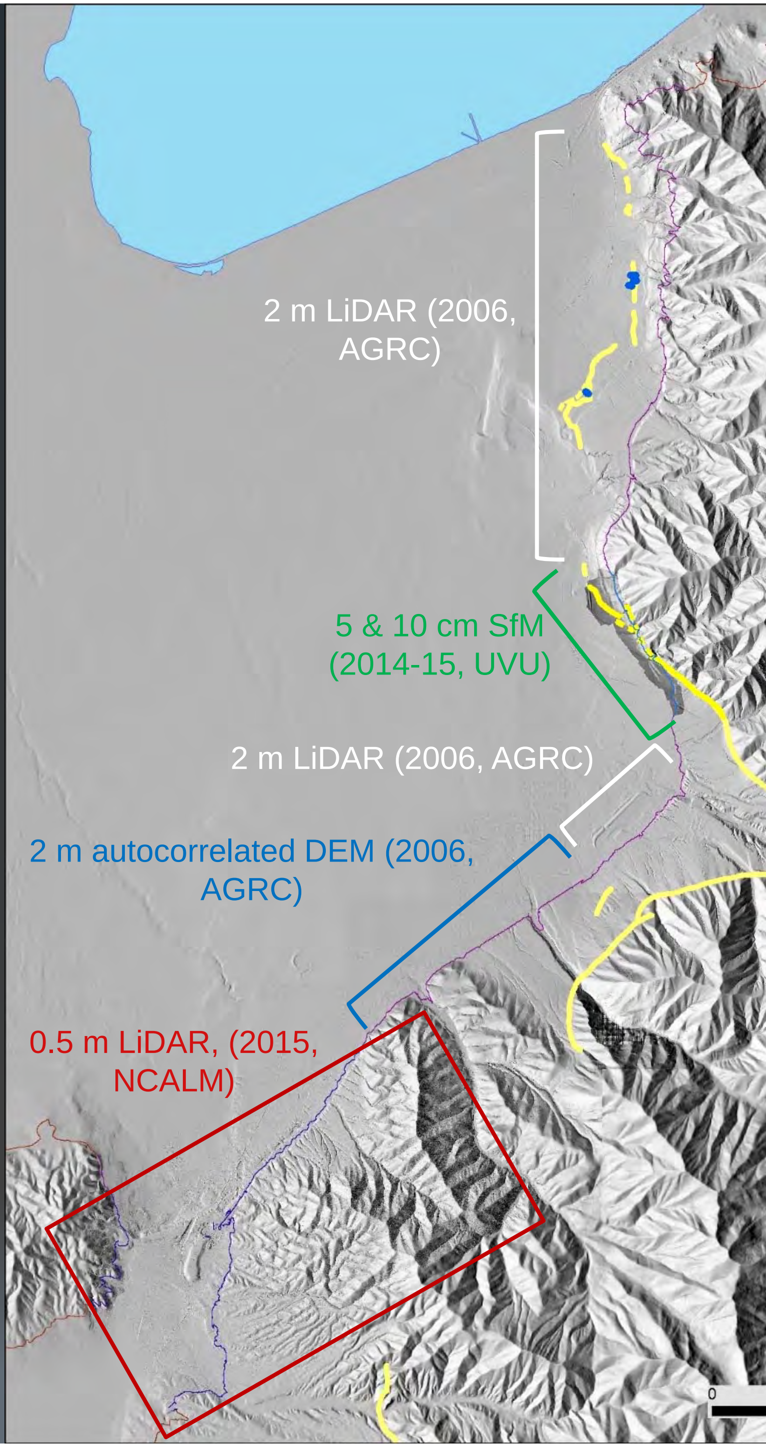
- est-dipping normal faults west side of Oquirrh / ntic Mountains
- obably contiguous with eat Salt Lake Fault, aking second longest ult system in Utah



Google Earth image; Faults from USGS fault and fold database

earching for the Extent of Post-ovo Surface Rupture on Oquirrh ault: Topographic Data Sources

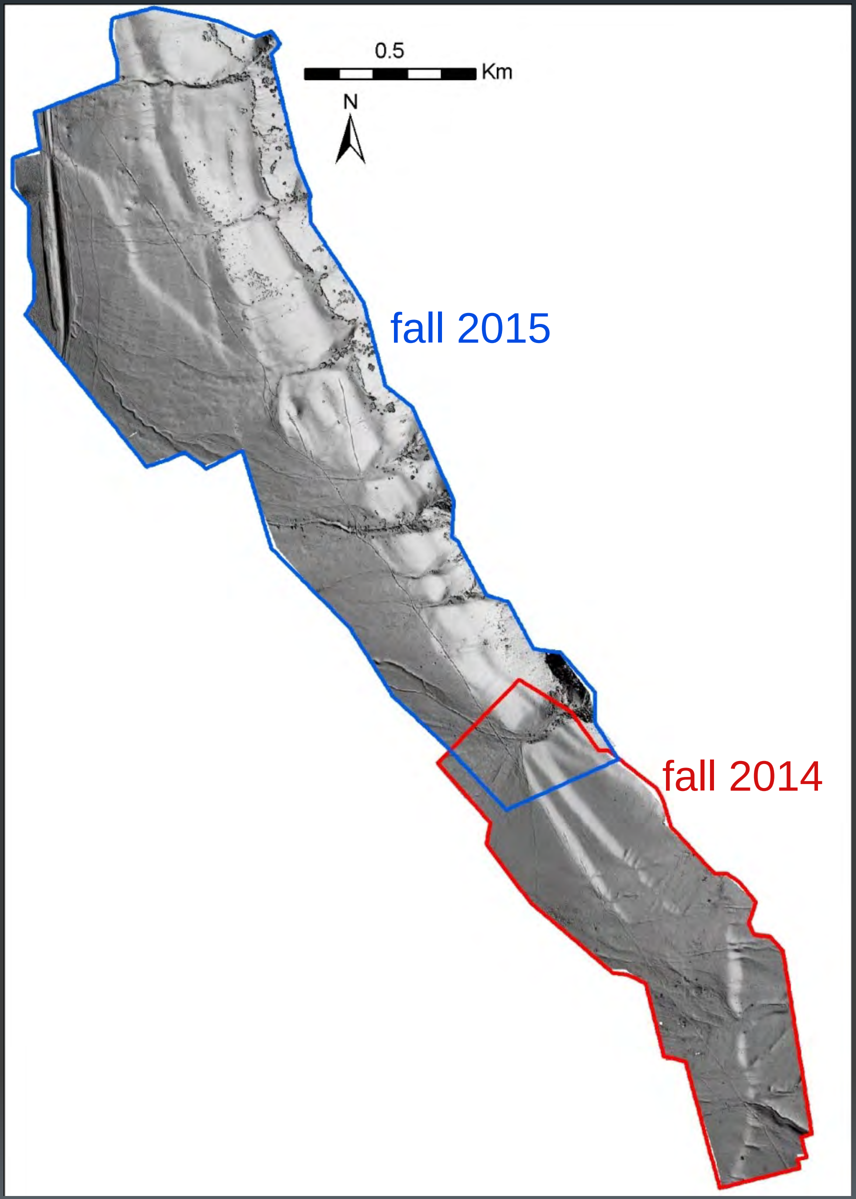
- 5 and 10 cm SfM – derived DSMs (2014-2015, UVU)
- 0.5 m LiDAR DEM (2015; NCALM / Larry Kellum U. of Utah)
- 2 m LiDAR – derived DTM (2006, AGRC)
- 2 m DEM, autocorrelated from 12.5 cm imagery (2006, AGRC)



UVU Department of Earth Science

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

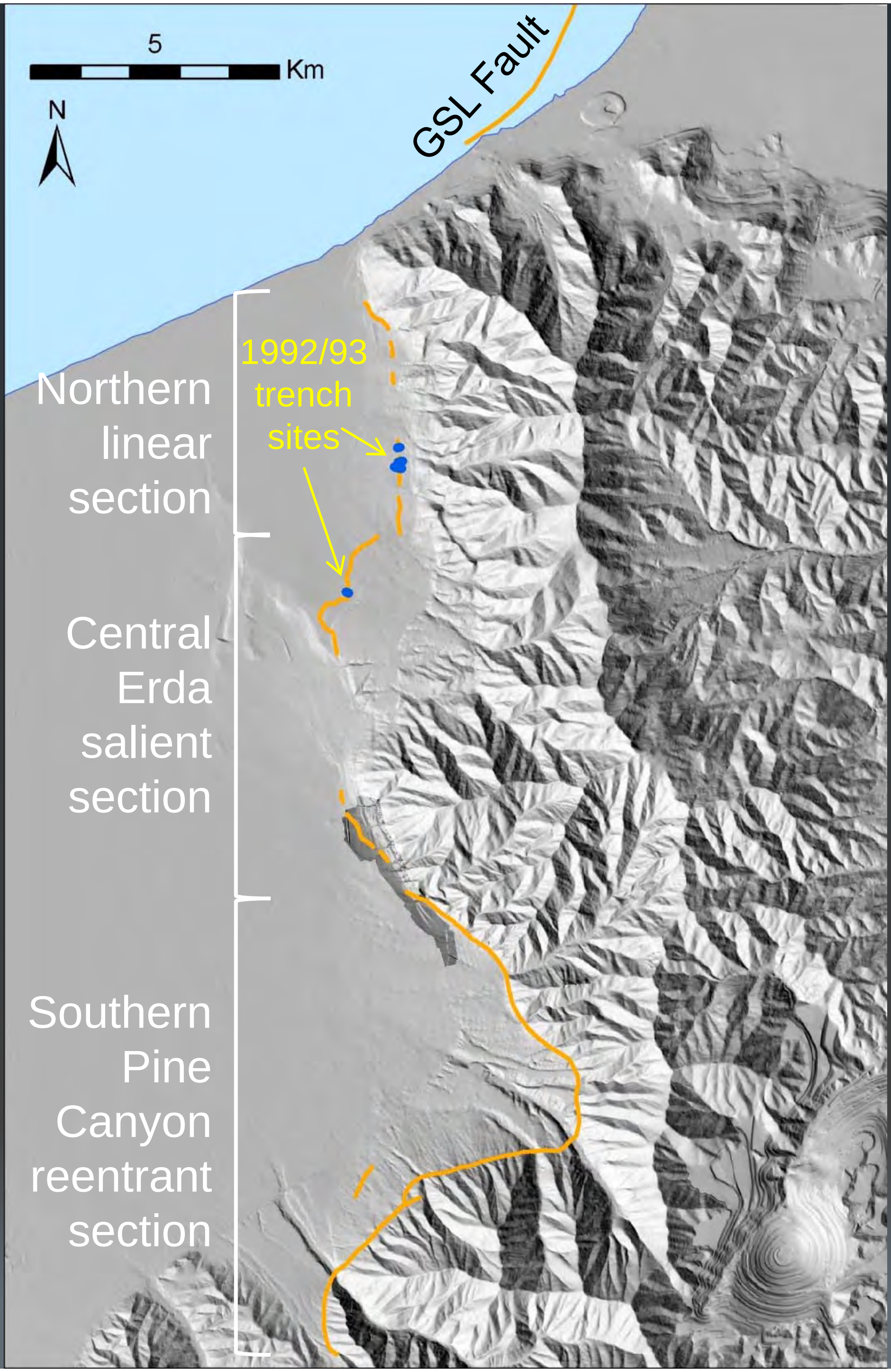


DEM Accuracy Summary

- 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

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?



THE CALIFORNIA SMGB GEOHAZARDS COMMITTEE ALQUIST-PRIOLO PROGRAM TECHNICAL ADVISORY COMMITTEE

2007-2016: GREAT EXPECTATIONS, GOOD WORK, AND ULTIMATE FAILURE

Robert E. Tepel

February 14, 2018

Utah Earthquake Working Group Meeting

Salt Lake City, Utah

Utah Geological Survey

DISCLAIMER

- This presentation consists only of the personal recollections of the author. Given the passage of time these recollections might not be complete or correct; others might have differing recollections and opinions. My purpose is to note some of the procedural requirements and decisions that ultimately led this effort astray. Some simple lessons were learned about the optimal way to administer the work of a science-based technical working group charged with recommending potential improvements to a law that requires science-based investigation and reporting. ---Robert E. Tepel

What is the SMGB?

The California State Mining and Geology Board.

Resides in the Department of Conservation

9 members

WHAT DOES THE SMGB DO?

- *Administers the Surface Mining and Reclamation Act (SMARA) by adopting regulations.*
- *Adopts regulations to administer the Alquist-Priolo Earthquake Fault Zoning Act (A-P Act).*
- *Additional functions; not enumerated here.*

THE A-P ACT STARTED WITH CLARENCE ALLEN

- Idea sparked by his testimony before a legislative committee after the Sylmar Earthquake of February 9, 1971 (I was there.) (Allen was a Professor of Geology at Caltech and a consultant.)
- Signed into law on December 22, 1972;
- purpose: to mitigate the hazards of surface faulting to structures for human occupancy (Wikipedia).

THE A-P TAC STARTED WITH THE CAMARILLO LETTER (1)

Development proposal for a stripped site (no natural soil remained that might show fault offsets and help in dating the age of displacement)…but there were A-P zoned faults on either side of the property, and extension across the property could be visualized.

THE A-P TAC STARTED WITH THE CAMARILLO LETTER (2)

The City of Camarillo asked SMGB for advice on how to administer the A-P Act in this case. Discussion brought up some long-standing concerns with the scope, administration, and scientific criteria of the regulations adopted pursuant to the Act. Were they consistent with the current state of scientific knowledge and engineering practice?

This triggered the creation of the A-P TAC (Technical Advisory Committee) by the SMGB as a working group that was to report to the SMGB's Geohazards Committee.

CHARGE TO THE 2007 A-P TAC (simplified)

- Review the A-P program and its effectiveness
- Consider state of the science
- Recommend technical/scientific avenues of improvement for further consideration
- (It was recognized that the ultimately recommended changes might require legislative and regulatory action, and would require additional public discussion.)

FIRST MISSTEP

- The Camarillo issue was lost in the blossoming scope of a review of the A-P Program
- It probably would have been resolved if the work of the A-P TAC was carried to completion.

SECOND MISSTEP

- As a creature of the SMGB, the A-P TAC was subject to the open meeting requirements of state law.
- Published agendas and open meetings of the full TAC were required. Normally, this process would be routine, but…
- For the first few meetings of the full A-P TAC an amateur videographer set up his video camera and recorded the meeting. While this would not bother experienced board members in a formal board meeting, it stifled discussion among the TAC members.

LESSON LEARNED

- A group of scientist accustomed to informal "free, frank, and open" discussion of complex (and perhaps controversial) issues in the application of scientific knowledge is not comfortable carrying out their discussion in a public forum, especially one that is being video-recorded.
- As it happened, the videographer (a geologist) reportedly found distant employment after the first few TAC meetings and did not return.
- Conclusion: a science-based working group of the nature of the A-P TAC works best in an informal setting.

EARLY REVIEW OF THE A-P PROGRAM

- The “Reitherman Report” was the first review of the A-P program. Citation: The Reitherman Company, 1991, A Study of the Effectiveness of the Alquist-Priolo Program. 131 p. California Division of Mines and Geology Open File Report 90-18.
- Authors: Robert Reitherman and David J. Leeds.

GOAL IN POPULATING THE A-P TAC of 2007

- Include members who were practicing geologists and engineers who had direct field experience in A-P exploration and A-P report writing.
- Include CGS staff
- Include reviewing/regulatory geologists, both agency employees and consultants to agencies
- Include change protagonists (was this a misstep?)
-

A-P TAC MEMBERSHIP (1)

- Stephen Testa, Executive Officer of the SMGB, was assigned Secretary duties, including compiling the output of the working groups into a report using standard SMGB formatting.
- Robert E. Tepel, SMGB Geohazards Committee, Chair.
- JC Isham, SMGB member, Vice-Chair
- Candidates for additional members proposed by CGS and SMGB staff and the names A-P TAC Chair and Vice-Chair

A-P TAC MEMBERSHIP (2)

- Jerry Treiman, CEG, CGS
- William Bryant, CEG, CGS
- Glenn Borchardt, soil scientist
- Thomas Blake, CEG, consultant
- David Jones, CEG, regulatory geologist
- R. Rexford Upp, CEG, PE, consultant
- Allan Kropp, PE, consultant

A-P TAC MEMBERSHIP (3)

- Tali Tucker, PE, City Engineer, City of Camarillo
- Jonathan Bray, PE, Professor of Civil Engineering, UC Berkeley
- John Baldwin, CEG, consultant
- William Fraser, CEG, California Division of Safety of Dams
-

A-P TAC MEMBERSHIP (4)

- Charles Nestle, CEG, City of Los Angeles, regulatory geologist
- Kerry Cato, Ph.D., CEG, consultant
- Roy Shlemon, Ph.D., CEG, consultant
-

Almost a Misstep

- Unbeknownst to me, two A-P TAC members had recently been opposing experts in a civil litigation.
- Although I was confident that a cordial relationship would be maintained, I guided these two people to different working groups within the A-P TAC.

A-P TAC WORKING GROUPS

- Working Group 1-2: Qualifications and Practice
- Working Group 3: Characterization of Faults
- Working Group 4: Avoidance versus Mitigation
- Working Group 5-6: Authority and Jurisdiction

OUTREACH EFFORTS

- Some A-P TAC and GeoHazards Committee meetings were held around the state to receive comments from the consulting and regulatory communities.

MY BEST IDEA

- Survey jurisdictions affected by the A-P Act to determine how well they understand and apply the A-P Act.
- The data were compiled and analyzed by Bill Bryant (CGS) in a highly useful form.
- Working conclusion: the staff at many lead agencies would benefit from workshop-level training in the administration of their responsibilities under the A-P Act.

CHUGGING ALONG TO D-DAY

– With interest building in the profession and CGS, a Geohazards Committee hearing was scheduled for September 30, 2015, in Sacramento

– I was unable to attend because of two medical appointments that could not be changed.

– Instead of a full draft report being released, the agenda package included only an Executive Summary chapter.

HUGE MISTAKE!!!!!!!!

- With no supporting data, examples, discussion, or analysis, the reader saw only bare conclusions and recommendations.
- Naturally, they were highly critical. Some critics viewed the report as proposed instructions from the SMGB to the CGS…instructions that were inapplicable because they required the CGS to take actions not authorized in the A-P Act. Actually…

The Misunderstanding

- The A-P TAC report was (merely) a report to the Geohazards Committee of the SMGB.
- Any action by the Geohazards Committee or the SMGB that would lead to changes in A-P criteria or regulations would require public hearings and either legislative action or regulatory rulemaking.

The Demise of the A-P TAC

- Criticism of the work of the A-P TAC was largely already addressed by the full report in preparation.
- Priority for finalizing the A-P TAC report was apparently lost. (JC Isham and I were no longer on the SMGB at the time of the September 30, 2015 meeting.)
- A 2016 attempt by JC Isham and I to produce a compact version of the full A-P TAC report could not be accomplished within the time allowed by the board.
- We requested the SMGB to terminate the A-P TAC.
- A-P TAC working files and progress reports are archived by the State Mining and Geology Board.

CONCLUSIONS, LIMITATIONS, AND ACKNOWLEDGMENTS

- The 2007-16 A-P TAC was a proper attempt by the State Mining and Geology Board to carry out its responsibilities.
- This attempt did not produce useful results, largely because of the administrative and procedural missteps noted.
- This presentation is merely my personal (and likely imperfect) recollection and is not an official or authorized document of the California State Mining and Geology Board or the California Geological Survey. Responsibility for errors or omissions is mine alone. Corrections are welcome.
- I thank all the A-P TAC members and SMGB staff participants in the work of the A-P TAC for their sincere dedication to accomplishing the charge to the A-P TAC.

Progress Towards an Updated Nevada Seismic Hazards Model

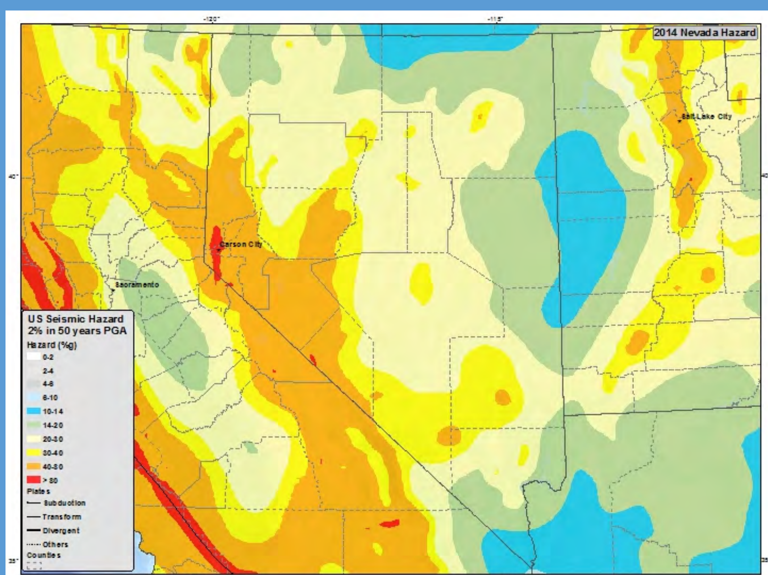
Rich D. Koehler
Nevada Bureau of Mines and Geology
University of Nevada, Reno

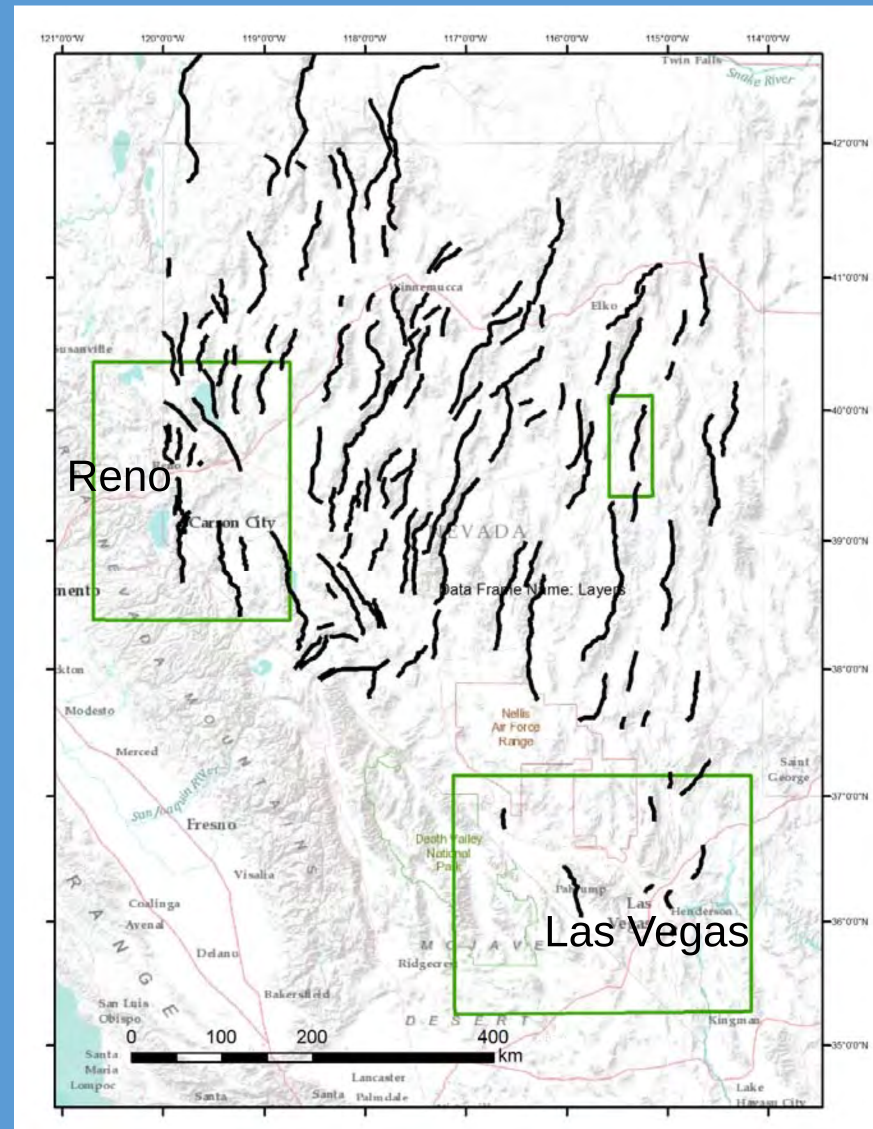
2018 Utah Quaternary Fault Parameters Working Group
Wednesday, February 14, 2018
Salt Lake City, Utah

Faults included in the National Seismic Hazard map for Nevada

2014 update included modification of parameters for 12 faults including:

- In Reno area: Smith Valley and Wassuk Range faults; adjustment to throw rate.
- In Vegas area: Eglington fault; throw rate.



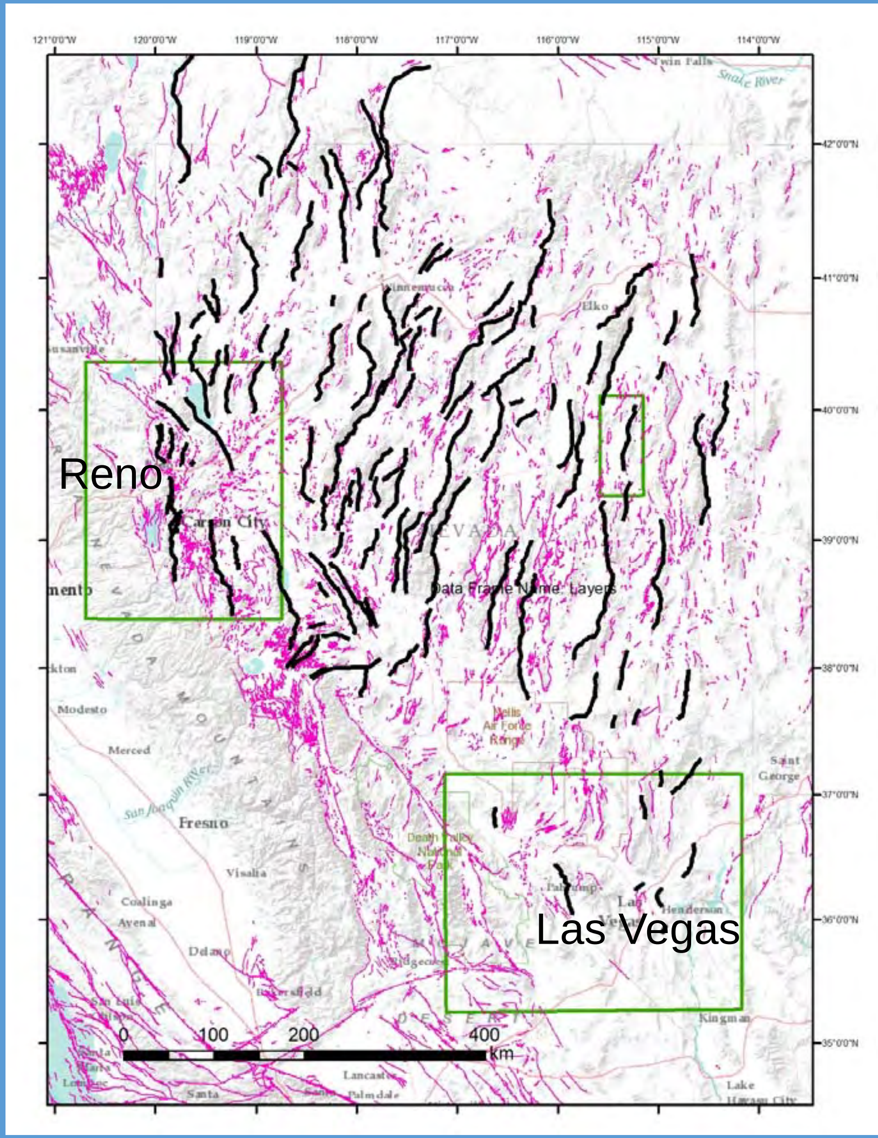


Faults included in the National Seismic Hazard map for Nevada and all faults from Quaternary database

- 2014 NSHM depicts most major sources
- Some sources not included, but have good evidence of Quaternary deformation

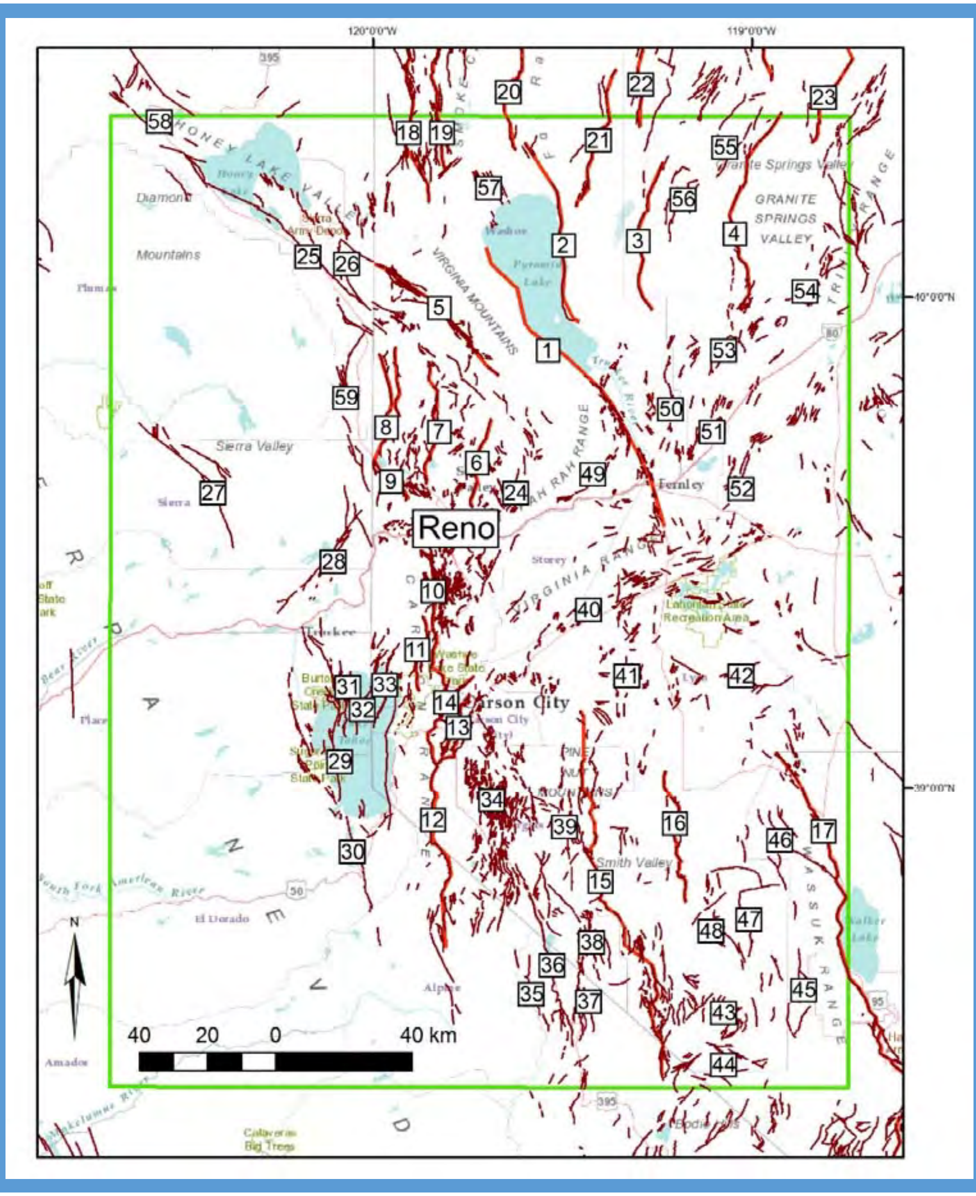
    Toquima and Monitor ranges
    Carson lineament
    East Carson fault zone

- Faults of the North Valleys are included (not all), but are associated with uncertain parameters.



Efforts to qualitatively assess research priorities that will benefit future updates of the NSHM

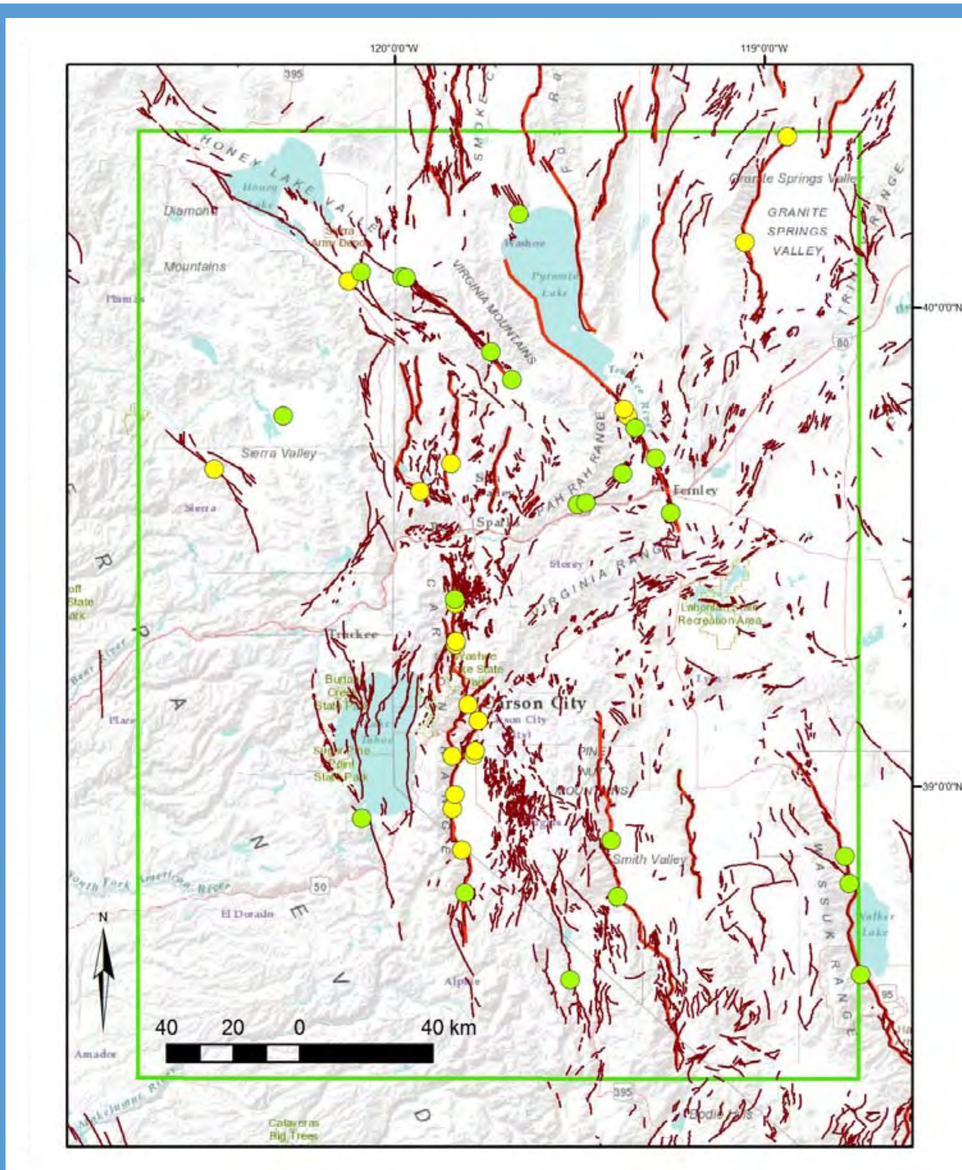
- Inventory of faults in proximity to Reno
- At least 50 Quaternary faults
- 24 faults included in NSHM
- Review Quaternary fault and fold database
- Review new literature (paleoseismic studies)
- Develop criteria for prioritization.



Fault data currently not cited in Quaternary database

Does the NSHM reflect this data?

Fault name	Slip rate	Earthquake Timing	reference
Olinghouse fault		MRE<1935 ka; 2 EQ < 19,800 ka	Briggs and Wesnousky, 2005
Olinghouse fault		3 EQ after 3,360 +/- 190 cal. yr B.P.	Briggs and Wesnousky, 2005
Warm Springs Valley fault		6 EQ betw 11.6 and 21 ka; 2 EQ <11.6 ka	dePolo and Ramelli, 2004
Warm Springs Valley fault	0.3-2.2 mm/yr; s.s		dePolo, 2006
North Pyramid lake fault	0.04 mm/yr; s.s/normal	MRE <3,640 yr B.P.	Vice, 2008 M.S. thesis
Fort Sage Mountains fault		3 EQs – 1950; ~5.6 ka; 20.5 ka	Briggs et al., 2013
Wassuks Range fault zone	~1.0–1.5 mm/yr, v.; ~1.1 ± 0.4 mm/yr, s.s.		Dong et al., 2014
Wassuks Range fault zone	>0.3–0.4 mm/yr late Pleistocene; v. 0.7 +/- 0.1 mm/yr Holocene; v.	2 events since 9.4 ka; MRE < 2,810 cal B.P.	Bormann et al., 2012
Antelope Valley fault zone	~0.7 mm/yr	MRE ~1,350 cal yr B.P.; penult >6,250 cal yr B.P.	Sarmiento et al., 2011
West Tahoe-Dollar Point fault	Post Tahoe, <0.5 ± 0.1 mm/yr; Post Tioga, ~1.4 ± 0.7 mm/y		Pierce et al., 2017
Pyramid Lake fault zone	0.5 and 1:6 mm/yr, s.s.		Angster et al., 2016
Smith Valley fault zone	0.125-0.33 mm/yr, v.	MRE ~3,530 +/- 80 cal yr B.P.	Wesnousky and Caffee, 2011
Pyramid Lake fault zone	~2.6 ± 0.3 mm/yr	MRE <1,705 ka; 4 EQ since 15.5 ka	Briggs and Wesnousky, 2004
Warm Springs Valley fault zone	1.8-2.4 mm/y late Pleistocene; 0.2 mm/y Holocene		Gold et al., 2013a
Grizzly Valley fault zone			Gold et al., 2013b



Qualitative criteria for evaluating priority

Included in the model (yes = 0, no = 1)

Length (<8km = 0, 8-25 km = 1, >25 km = 2)

Slip rate data quality (well constrained = 0, moderately constrained = 1, no data = 2)

Slip rate (<0.2 = 0, 0.2-1 = 1, 1-5 = 2)

Recurrence/timing data (yes = 0, no = 1)

Age of most recent deformation (older than latest Pleistocene = 0, latest Pleistocene = 1, <15 ka = 2)

Distance to Reno (>30 km = 0, <30 km =1)

Table 1. Faults within the Reno focus area.

Fault number	Fault name	geologic slip rate (mm/yr) QFF	Geologic slip rate (mm/yr) NSHM	Timing data	length (km)	Most recent activity	Comment and Score based on qualitative criteria defined in this presentation.
INCLUDED IN NSHM							
1	Pyramid Lake fault zone	1-5	2	Yes	77	<15	6
2	Eastern Pyramid Lake/Lake Range fault zone	<0.2	0.131	no	44	<130	6
3	Nightingale Mountains fault zone	<0.2	0.131	no	35	<1600	5
4	Granite Springs Valley fault zone	0.2-1	0.261	yes	50	<15	7
5	Warm Springs Valley fault zone	<0.2	0.5	yes	70	<15	6
6	Spanish Springs Valley fault zone	<0.2	0.131	no	23	<15	7
7	Freds Mountain fault	<0.2	0.131	yes	28	<130	7
8	Petersen Mountain fault	<0.2	0.131; 0.065	no	25	<130	6
9	Peavine Peak fault zone	<0.2	NA	yes	15	<15	6
10	Mount Rose fault zone	1-5	1.958	yes	38	<15	9
11	Little Valley fault	0.2-1	0.261	no	17	<15	8
12	Carson Range-Kings Canyon fault (Genoa fault)	1-5	2.61	yes	36	<15	8
13	Indian Hill fault	<0.2	0.131	yes	8	<15	5
14	Carson City fault	<0.2	0.131	yes	16	<15	6
15	Smith Valley fault	0.2-1	0.326	yes	96	<15	5
16	Singatse Range fault zone	<0.2	0.131	no	40	<130	6
17	Wassuk Range fault zone	0.2-1	0.914	yes	116	<15	5
18	Dry Valley-Smoke Creek Ranch fault zone	<0.2	0.131	no	48	<15	7
19	Bonham Ranch fault zone	0.2-1	0.261	no	54	<15	8
20	Fox Range fault zone	<0.2	0.131	no	31	<15	7
21	San Emidio fault zone	0.2-1	0.261	yes	32	<15*	7 *New age (Ramelli)
22	Selenite Range fault zone	<0.2	0.131	no	18	<1600	4
23	Seven Troughs Range fault zone	<0.2	0.131	no	37	<1600	5
24	Spanish Springs Peak fault zone	<0.2	0.1	no	13	<1600	5
NOT INCLUDED IN 2014 NSHM							
25	Honey Lake fault zone	1-5		yes	98	<15	6 CA
26	Fort Sage fault	<0.2		yes	17	<15	6 CA
27	Mohawk Valley fault zone	0.2-1		yes	42	<15	6 CA
28	Dog Valley fault zone	NA		no	28	<1600	7 CA
29	West Tahoe-Dollar Point fault zone	0.2-1		yes	51	<15	6 CA
30	Tahoe-Sierra frontal fault zone	NA		no	50	<1600	6 CA
31	Agate Bay fault	NA		no	17	<1600	6 CA
32	North Tahoe fault	0.2-1		no	25	<15	8 CA and NV
33	Incline Village fault	0.2-1		yes	20	<15	7
34	East Carson Valley fault zone	<0.2		no	48	<15	9
35	Slinkard Valley fault zone	NA		no	25	<130	6 CA
36	Antelope Valley fault zone	0.2-1		yes	12	<15	6 CA and NV
37	East Antelope Valley fault zone	<0.2		no	18	<15	7 CA and NV
38	Unnamed faults west of Wellington Hills	<0.2		no	28	<1600	6

Fault number	Fault name	geologic slip rate (mm/yr) QFF	Geologic slip rate (mm/yr) NSHM	Timing data	length (km)	Most recent activity	Comment and Score based on qualitative criteria defined in this presentation.
NOT INCLUDED IN NSHM							
39	Unnamed faults in the Pine Mountains	<0.2		no	42	<1600	6
40	Carson lineament	<0.2		no	72	<15	9
41	Unnamed fault zone in Pine Mountains	<0.2		no	18	<1600	5
42	Unnamed fault zone in Desert Mountains	<0.2		no	30	<1600	6
43	Unnamed fault zone in Pine Grove Hills	<0.2		no	21	<1600	5
44	Unnamed faults near East Walker River	<0.2		no	29	<1600	6
45	Unnamed faults west of Pike Peak	<0.2		no	20	<1600	5
46	Unnamed faults west of Wassuk Range	<0.2		no	24	<130	6
47	Cambridge Hills fault	<0.2		no	15	<1600	5
48	Unnamed fault zone near Pine Grove Flat	<0.2		no	33	<1600	6
49	Olinghouse fault zone	<0.2		yes	18	<15	7
50	Unnamed fault zone near Little Valley	<0.2		no	26	<1600	5
51	Unnamed fault zone southeastern Truckee Range	<0.2		no	34	<15	8
52	Hot Springs Mountain fault zone	<0.2		yes	43	<15	7
53	Unnamed fault zone near North Valley	<0.2		no	17	<1600	5
54	Unnamed fault zone on northwest side of Trinity Range	<0.2		no	34	<15	8
55	Unnamed fault zone along Sahwave Mountains	<0.2		no	14	<1600	5
56	Unnamed fault zone between Kumive and Sage Hen Valleys	<0.2		no	17	<130	6
57	Terraced Hills fault zone	<0.2		yes	13	<15	6 Age from Vice, 2008
58	Unnamed faults in Susanville-Eagle Lake area	NA		no	20	<1600	4 CA
59	Last Chance/Upper Long Valley fault zone	NA		no	33	<15	9 CA and NV

Prioritization based on these criteria

Score = 9

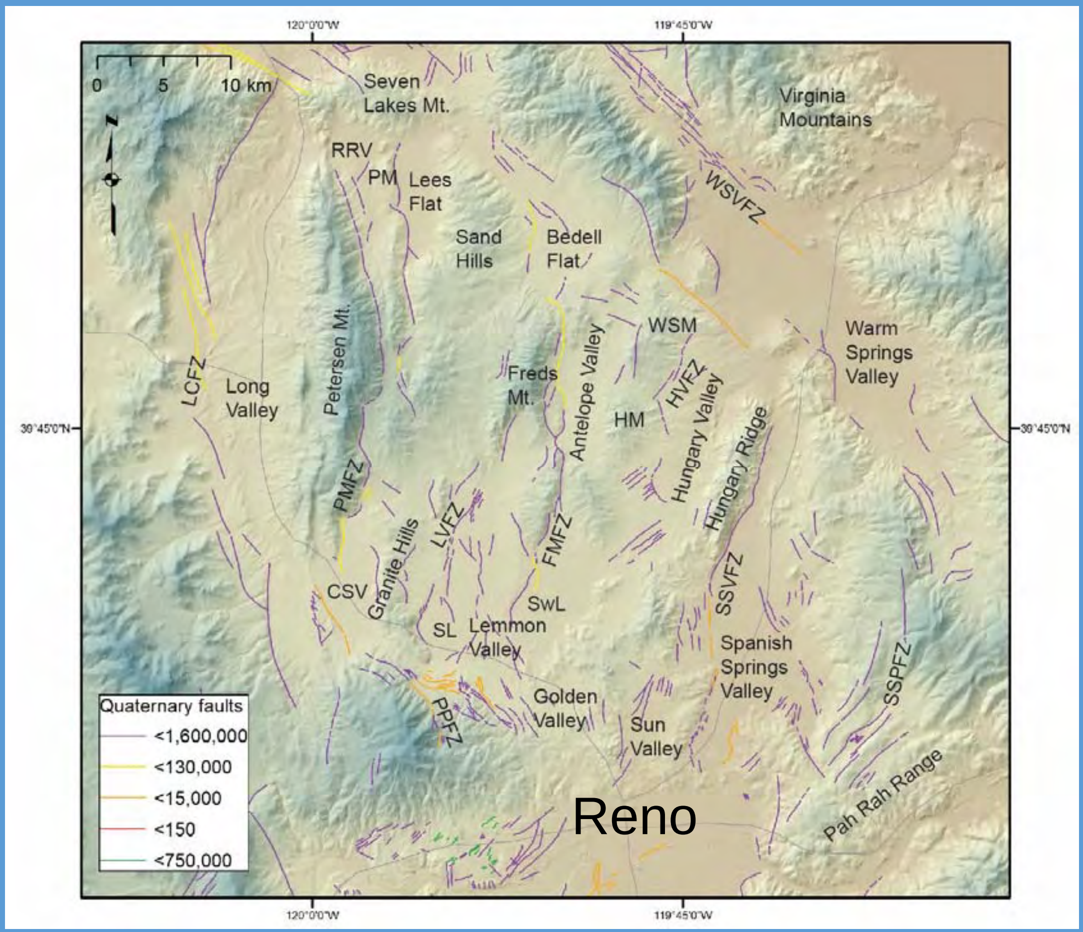
Mount Rose fault zone
East Carson Valley fault zone
Carson lineament
Last Chance/Upper Long Valley fault

Score = 8

Little Valley fault
Genoa fault
Bonham Ranch fault zone
North Tahoe fault
Unnamed - southeastern Truckee Range
Unnamed - northwest side of Trinity Range

Score = 7

Granite Springs Valley fault zone
Spanish Springs Valley fault zone
Fred’s Mountain fault
Dry Valley-Smoke Creek Ranch fault zone
Fox Range fault zone
San Emidio fault zone
Dog Valley fault zone
Incline Village fault
East Antelope Valley fault zone
Olinghouse fault zone
Hot Springs Mountain fault zone



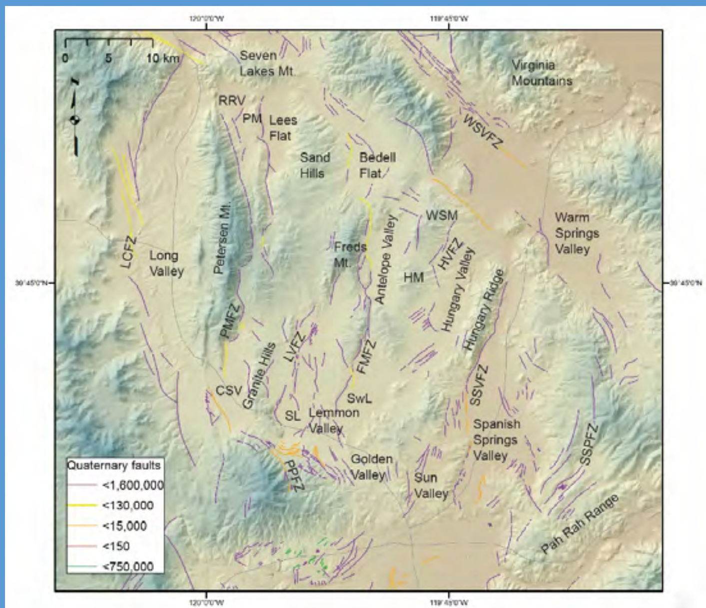
The North Valleys sit between the Walker Lane and the Sierra Nevada Range front.

North and northeast trending normal faults.

Moderate geomorphic expression, discontinuous scarps in Pleistocene deposits, triangular facets.

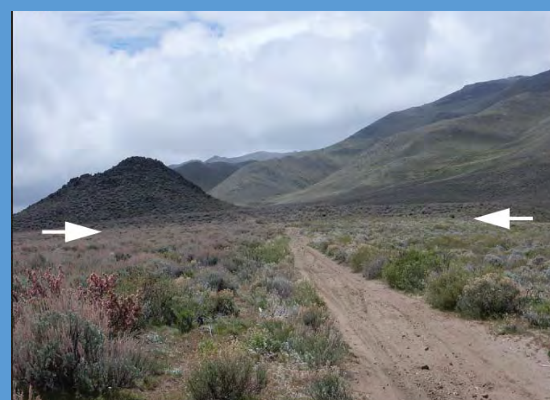
Faults include Last Chance/Long Valley, Petersen Mt., Fred’s Mountain, Spanish Springs Valley, Spanish Springs Peak faults and unnamed faults in Hungary and Lemmon valleys.

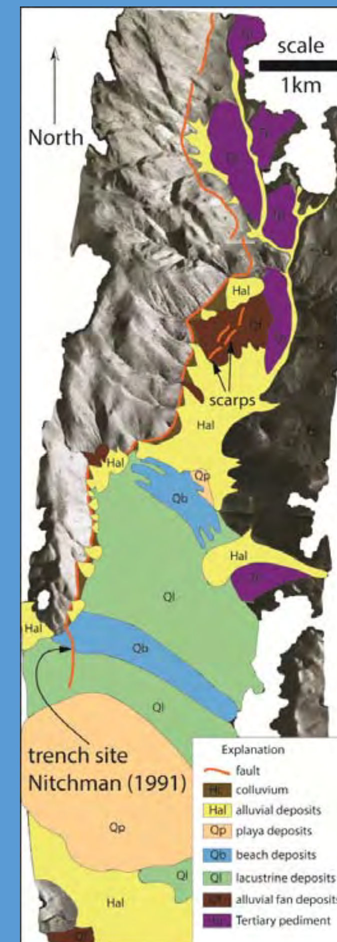
collectively accommodate 0.9-1.2 mm/yr of extension and <0.3 mm/yr of dextral slip.

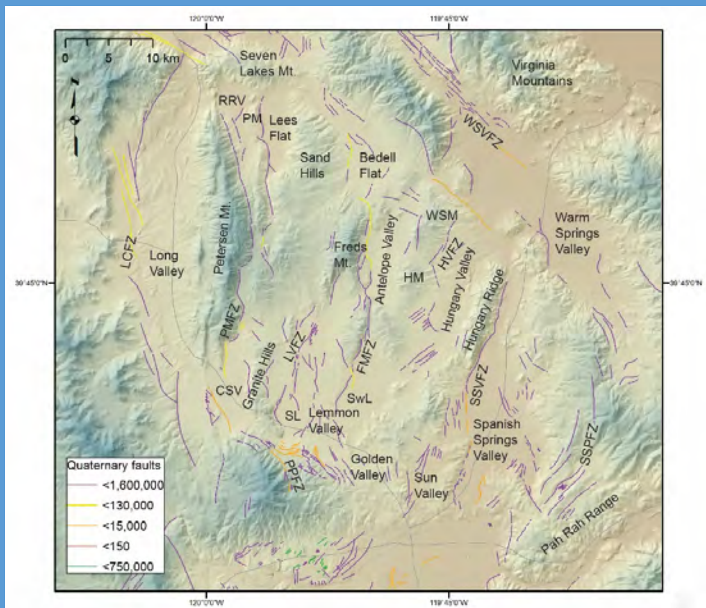


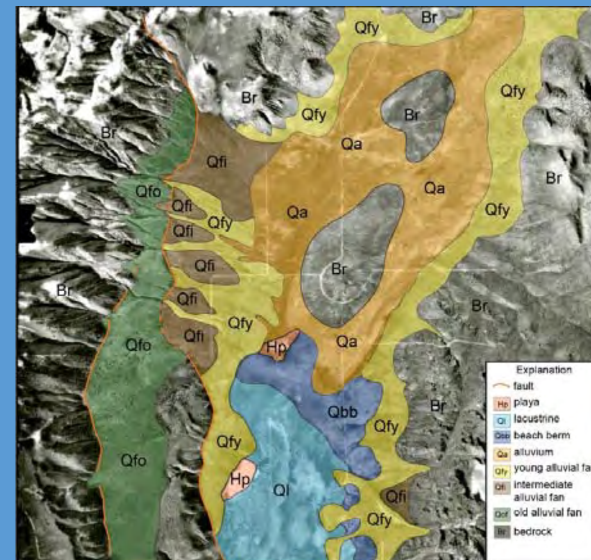
Petersen Mountain fault zone

- Earthquake timing
- Slip rate
- Active length
- Relative activity of two strands



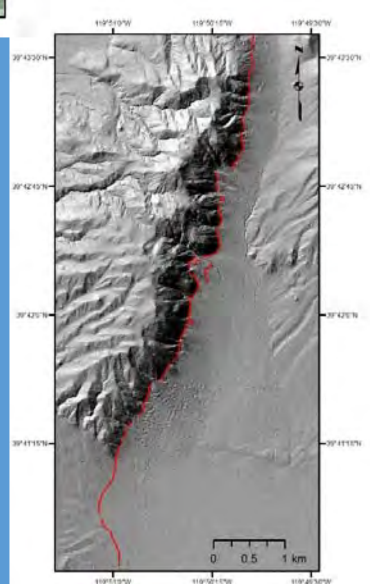


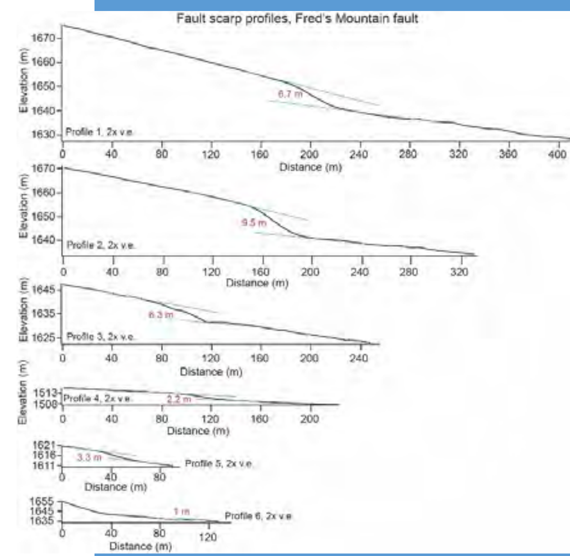


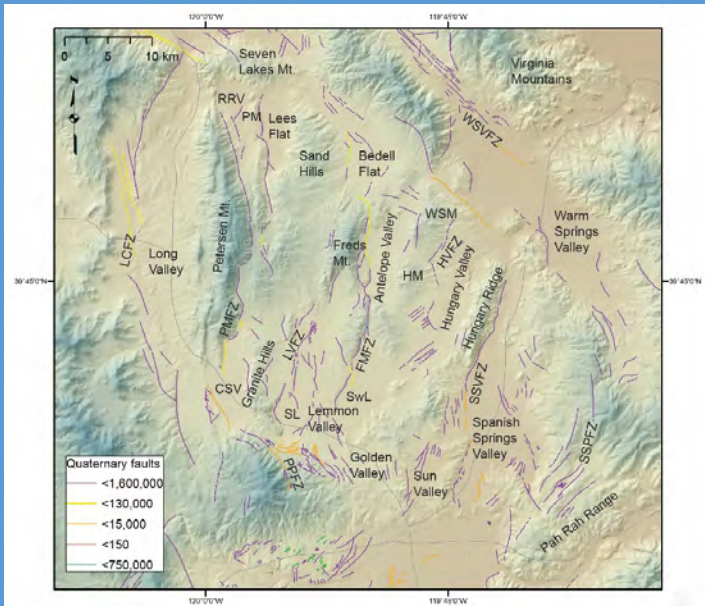


Fred's Mountain fault zone

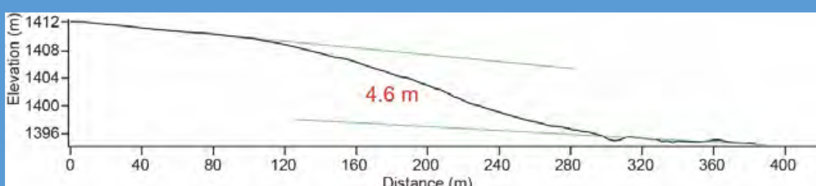
- Age of offset surfaces
- Slip rate
- Continuity of young rupture

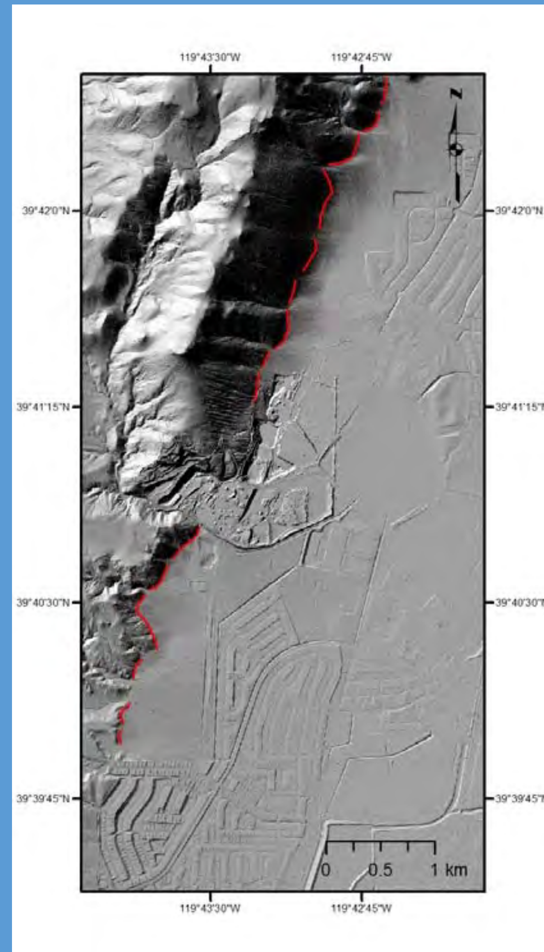


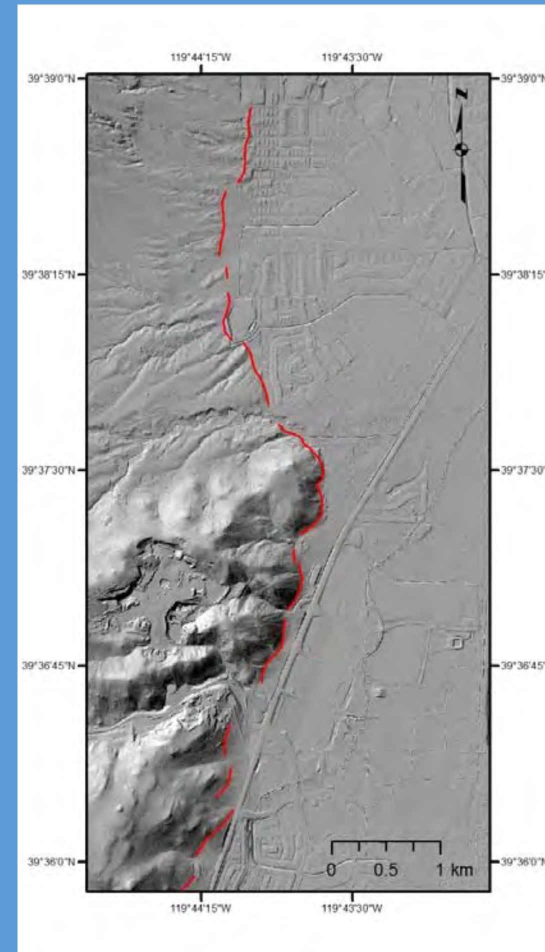


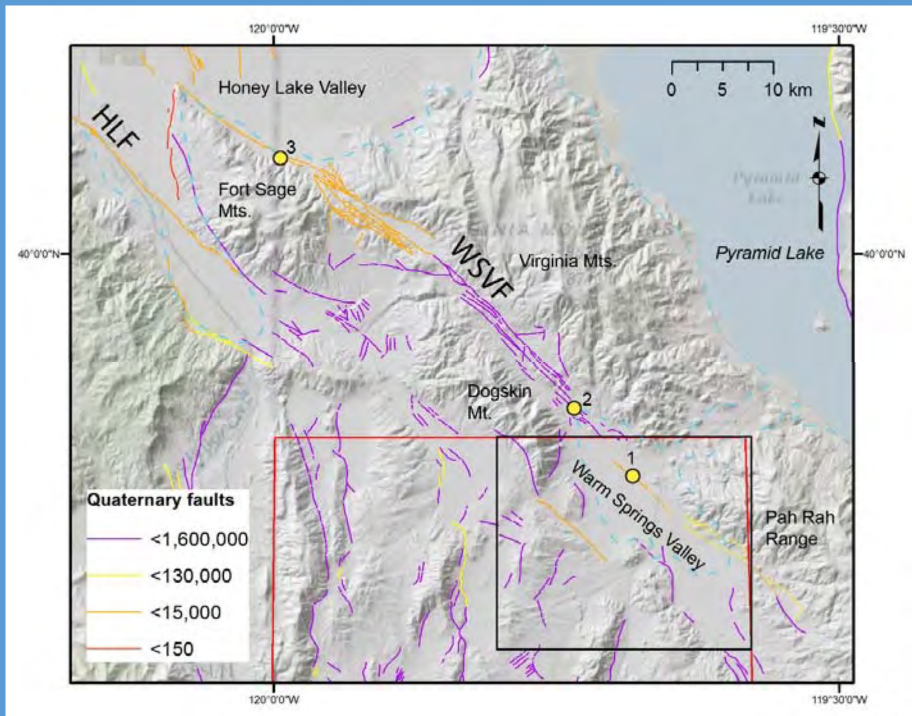


Spanish Springs Valley fault zone





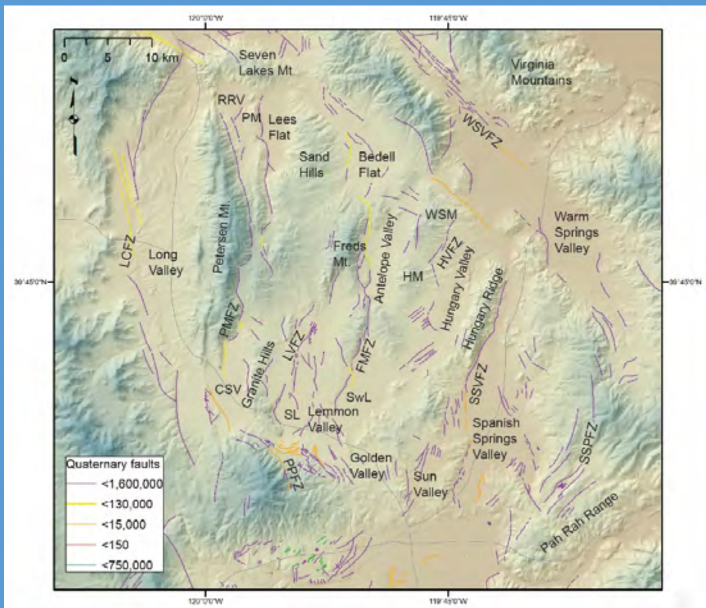




Warm Springs Valley fault zone

- Earthquake timing
- Temporal patterns in slip rate
- Deformation along adjacent faults

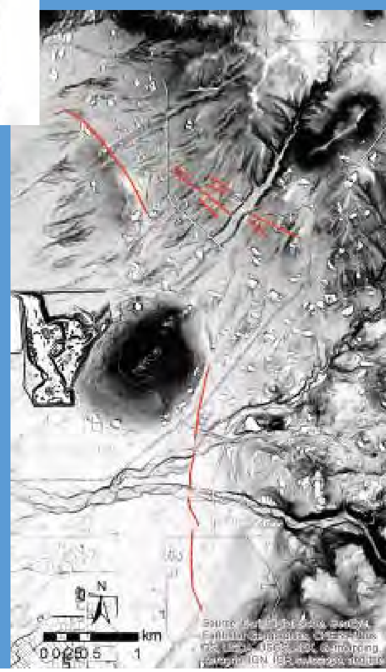


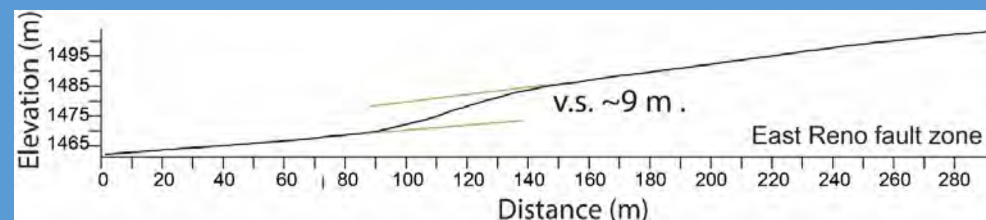


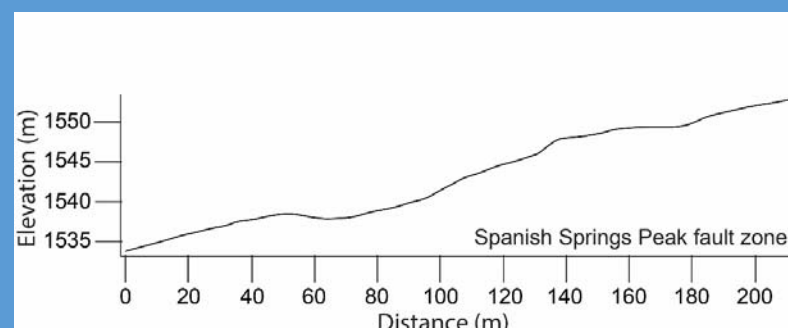
East Reno fault zone

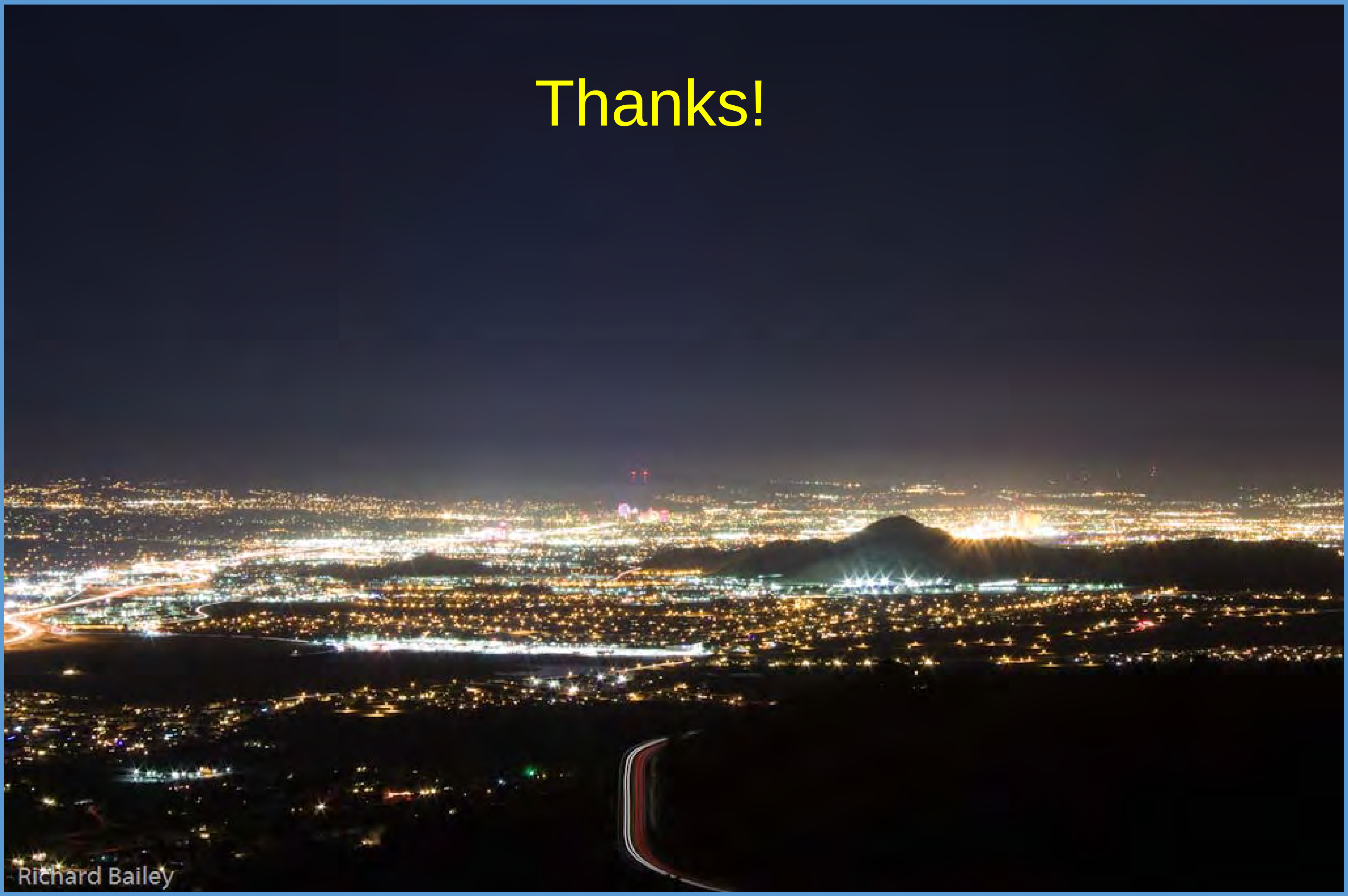
Spanish Springs Peak fault zone

- Basic characterization
- Future projects








Thanks!
Richard Bailey

PATA DAYS 2017: 8th International Workshop on Paleoseismology, Active Tectonics and Archeoseismology

Blenheim, New Zealand

November 13 – 19, 2017

PATA Days 2017

- Focused on the ground effects from November 2016 M7.8 Kaikōura Earthquake.
- 300th anniversary of AD 1717 (+/- 5 yrs) M ~8.0 Alpine Fault Earthquake.

Photo from Koji Okumura

PATA Days 2017

- 130 participants
- 21 countries represented
- 2 field trips
- 3 days of talk/poster sessions
- 1 public lecture

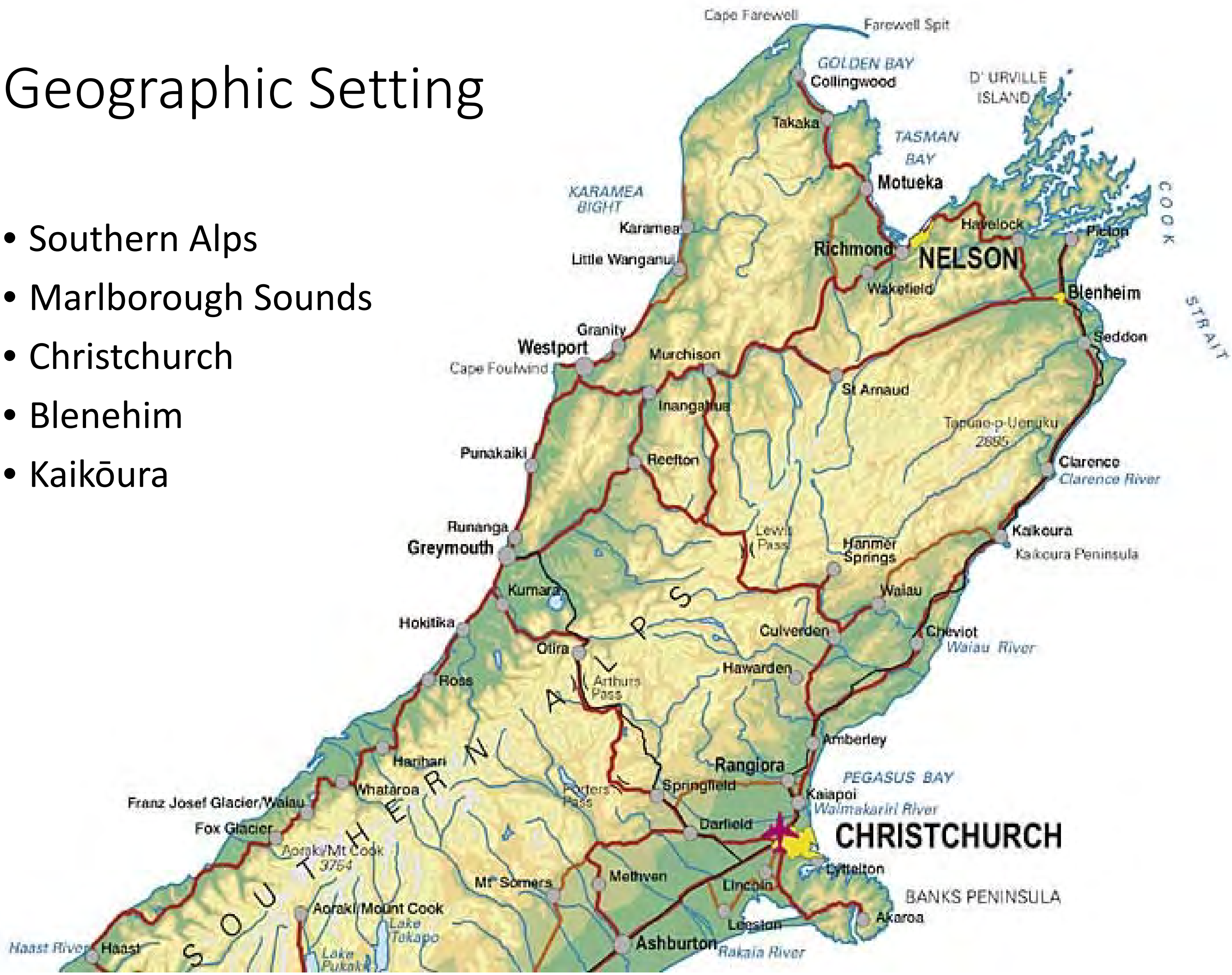
Photo from Koji Okumura

Geographic Setting

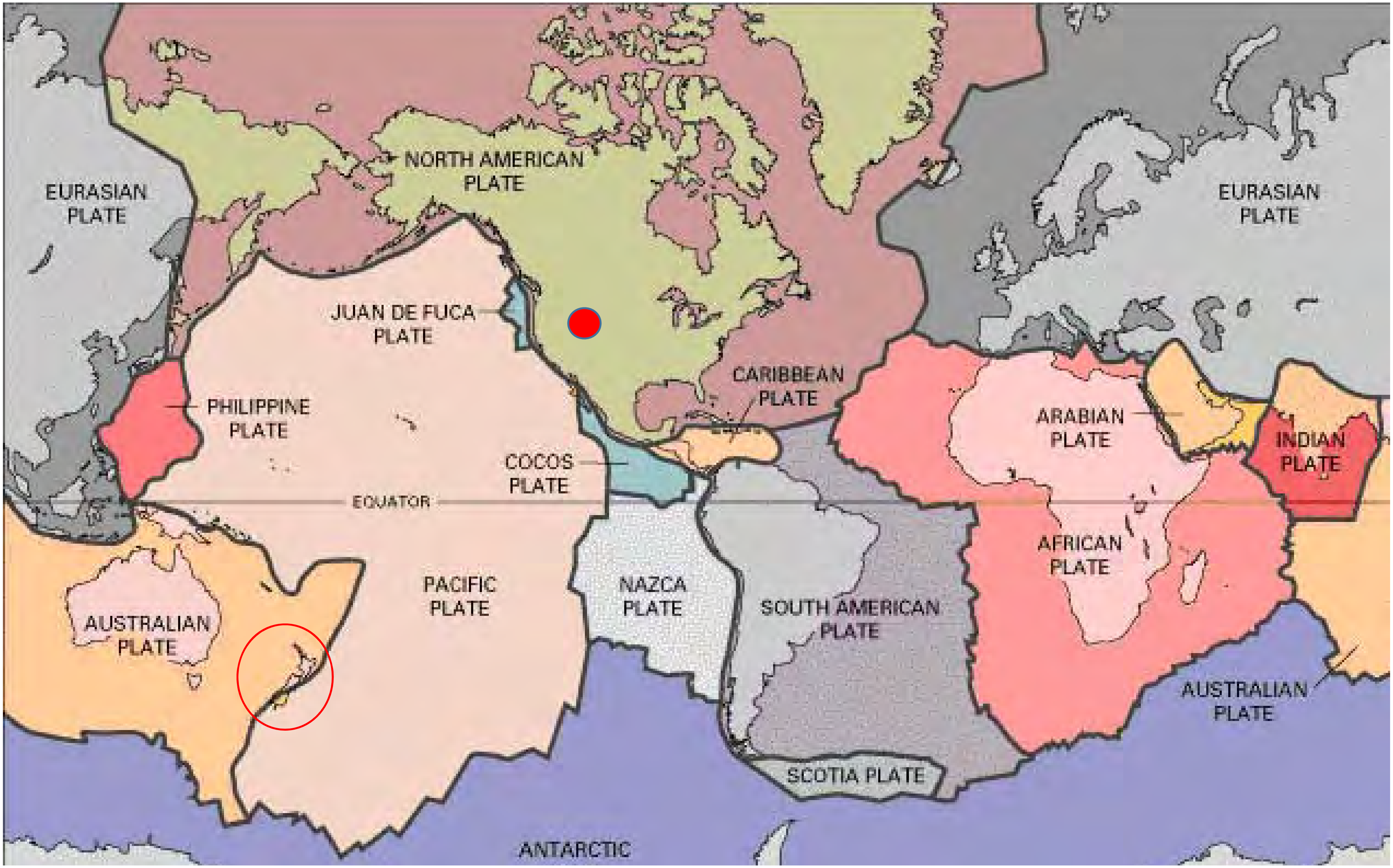
- North Island
  - Auckland
  - Wellington
  - Mt. Doom
- South Island
  - Southern Alps
  - Christchurch
  - Blenheim
  - Kaikōura

Geographic Setting

- Southern Alps
- Marlborough Sounds
- Christchurch
- Blenehim
- Kaikōura

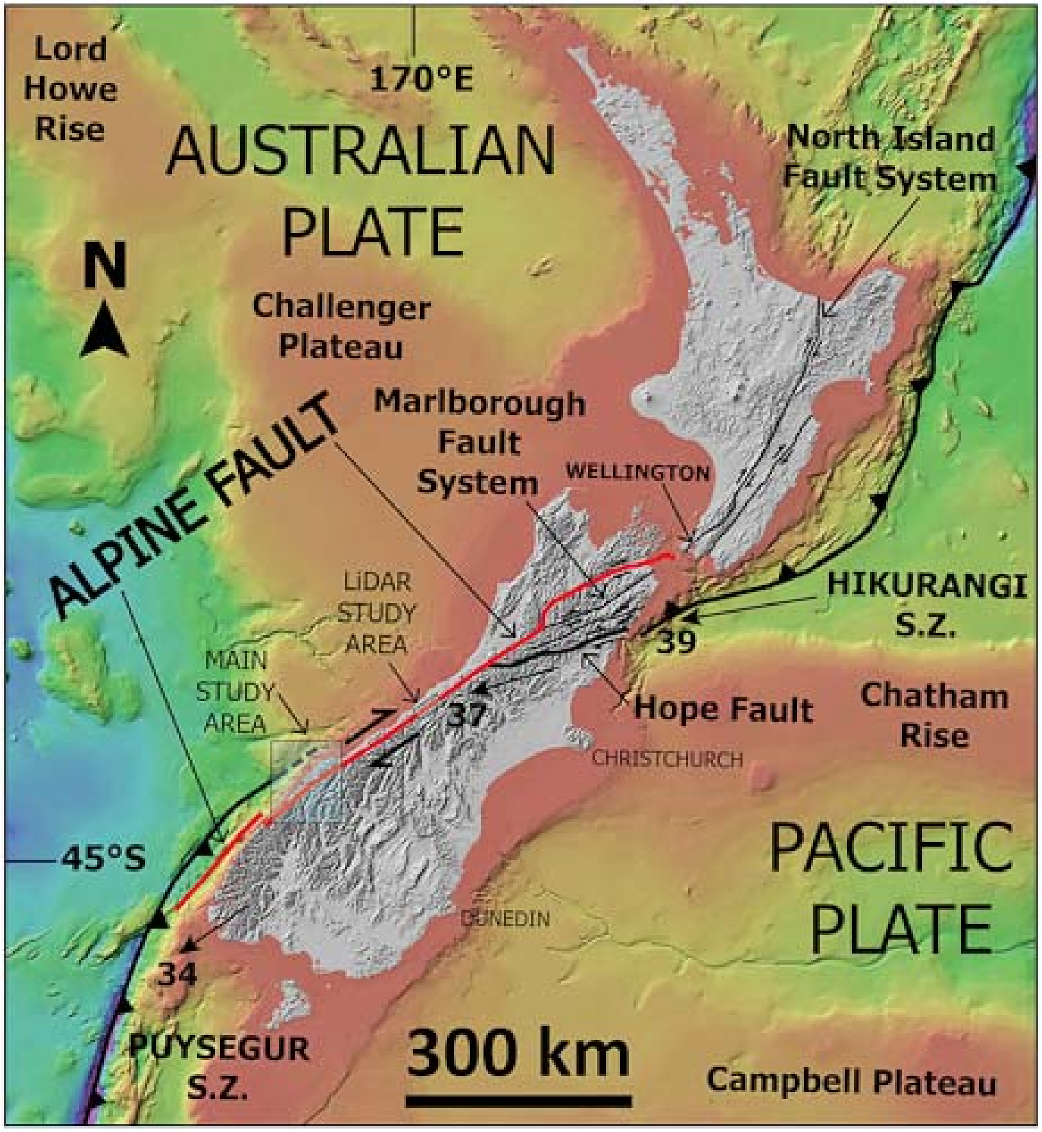


Tectonic Setting



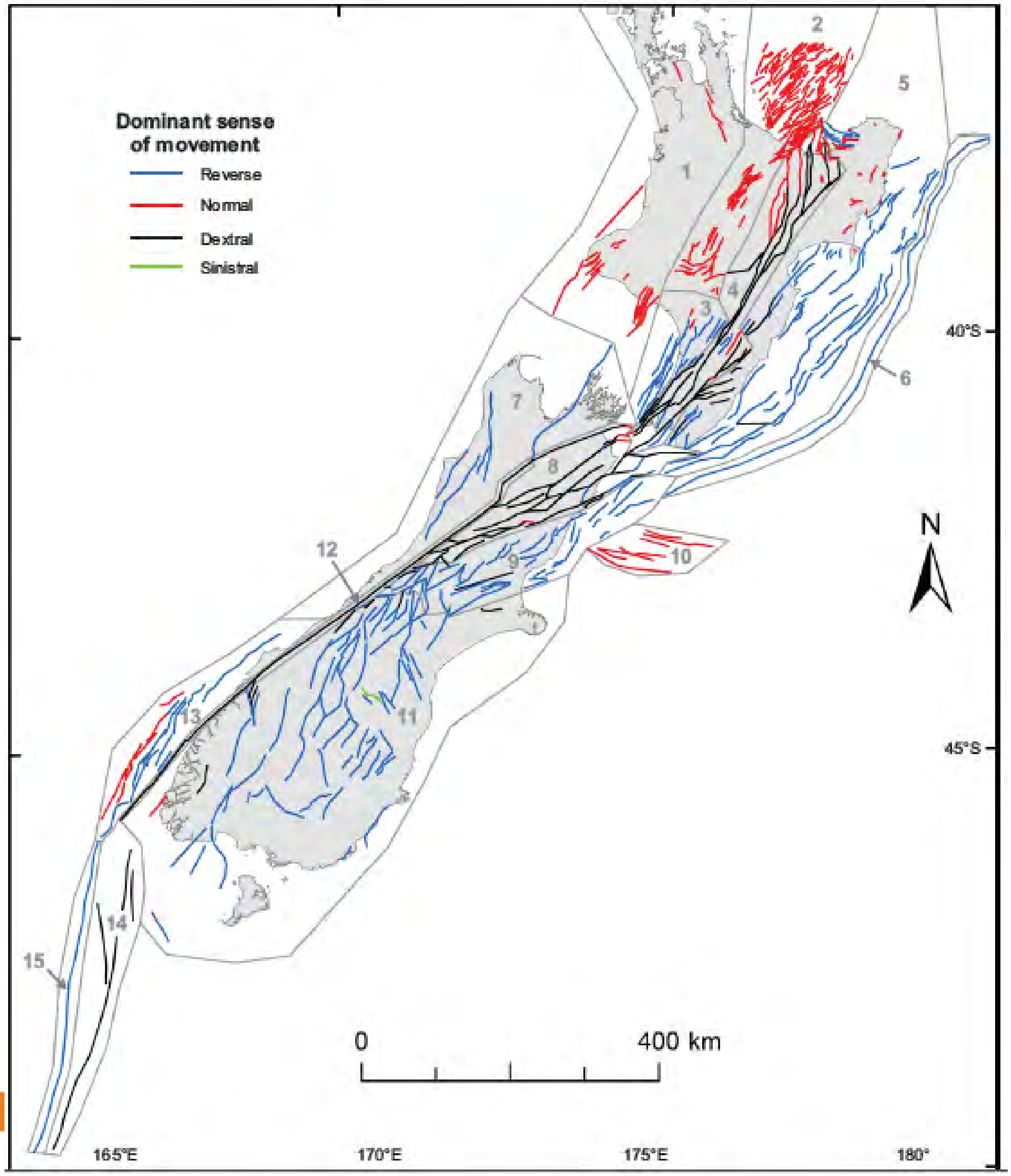
Tectonic Setting

- Hikurangi Subduction Zone
  - Dense Pacific oceanic plate subducting under buoyant Australian continental plate.
- Alpine Fault- Dextral strike-slip fault
- Puysegur Subduction Zone
  - Dense Australian plate subducting under continental Pacific Plate (Zealandia)



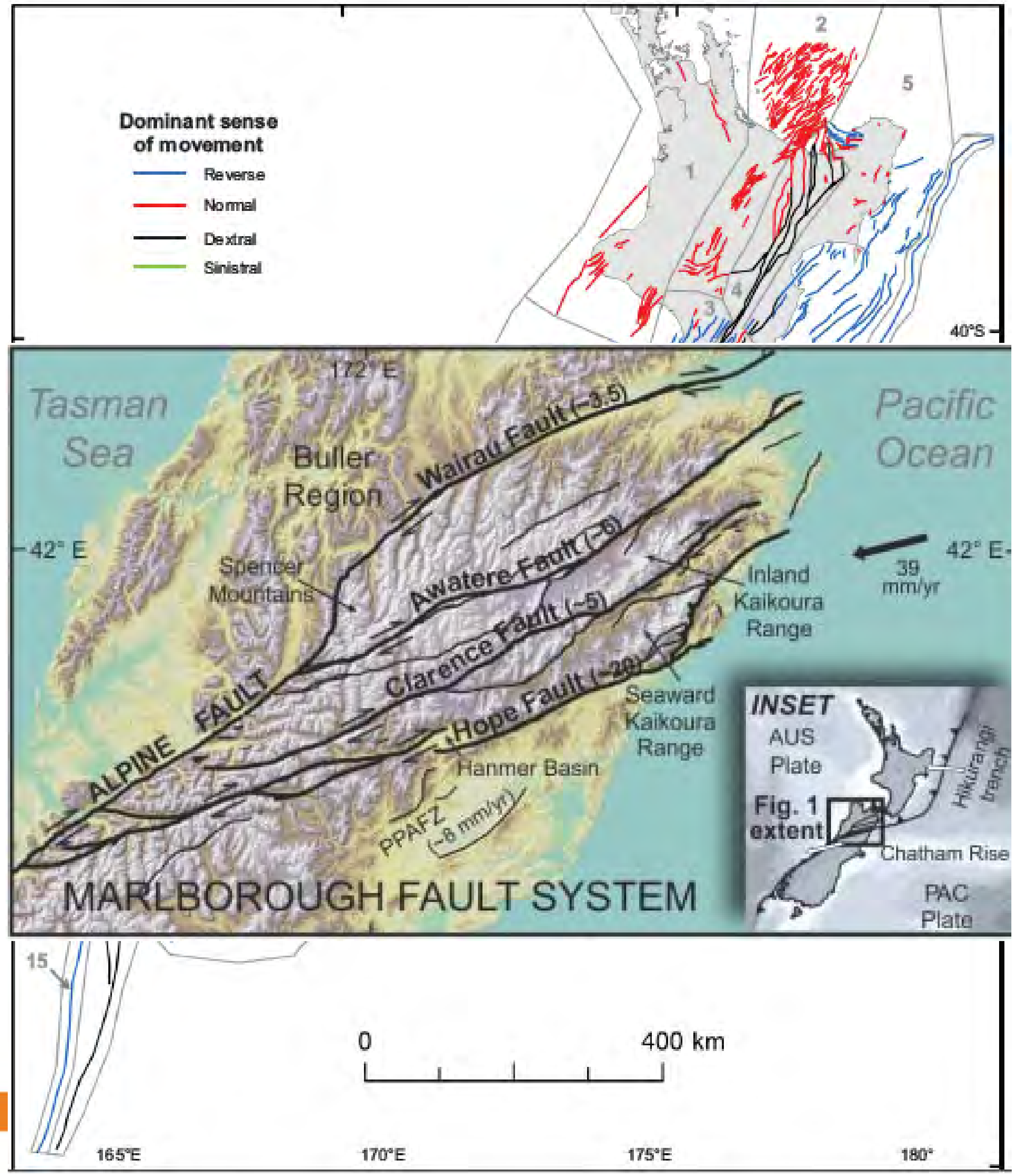
Tectonic Setting

- Alpine Fault- right-lateral strike slip plate boundary fault.
  - 30 mm/yr of dextral movement
  - 7mm of uplift



Tectonic Setting

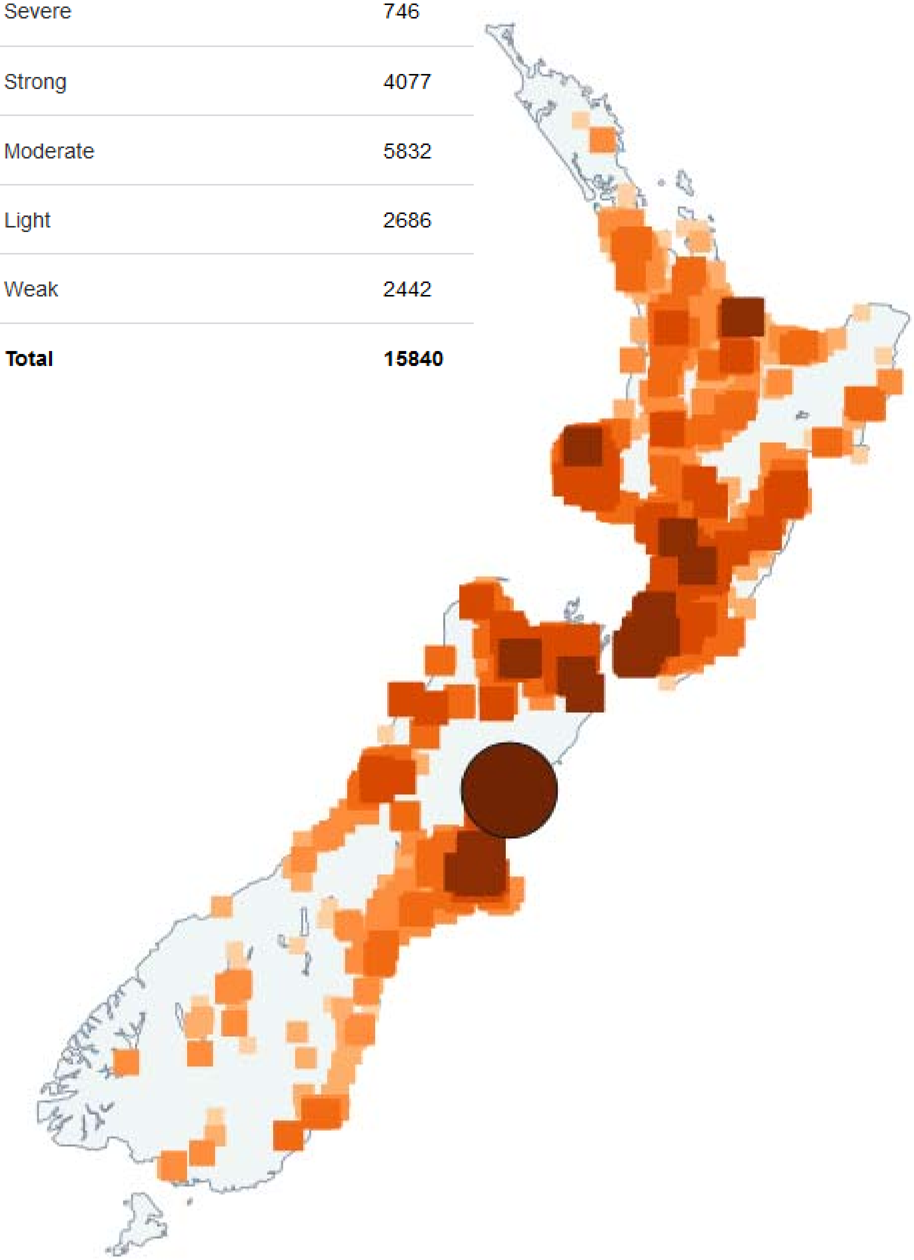
- Marlborough Fault System (MFS)- Oblique-slip faults.
  - Connect the Alpine Fault to the Hikurangi Subduction Zone.
  - Hikurangi Subduction zone is ~25 km below the MFS
  - 4 large dextral faults
    - Hope Fault- 20-25 mm/yr
    - Clarence Fault- 3.5-5 mm/yr
    - Awarere Fault- 4.4 mm/yr
    - Wairau Fault- 3-5 mm/yr



M 7.8 Kaikōura Ea

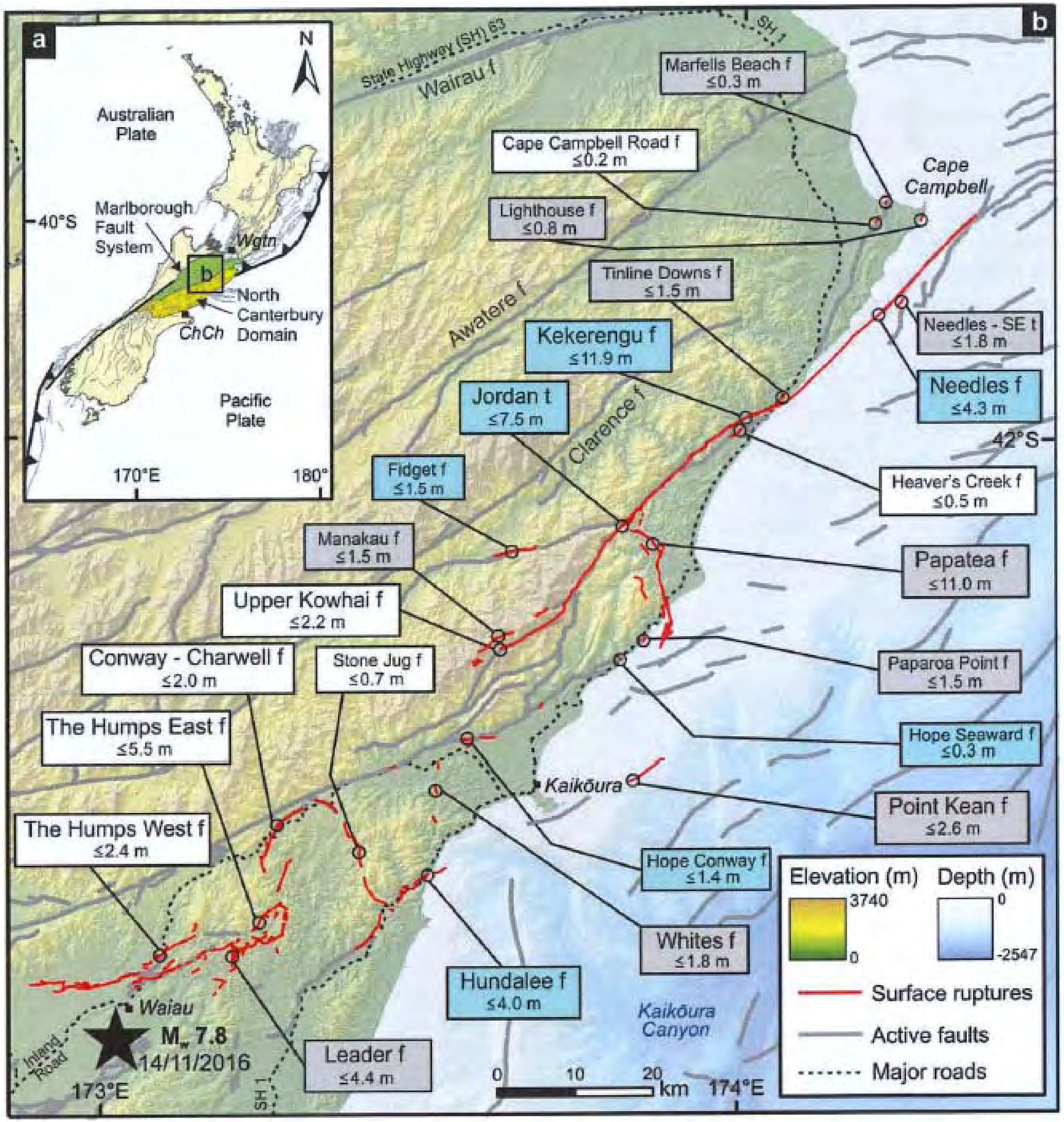
	Extreme	57
	Severe	746
	Strong	4077
	Moderate	5832
	Light	2686
	Weak	2442
	Total	**15840**

- At 12.02 a.m., on Monday 14 November 2016 NZDT
- 15 km depth.
- Surface rupture on the northeast coast of the south island, and submarine faults.
- Strong ground motion effects in Wellington Harbor.



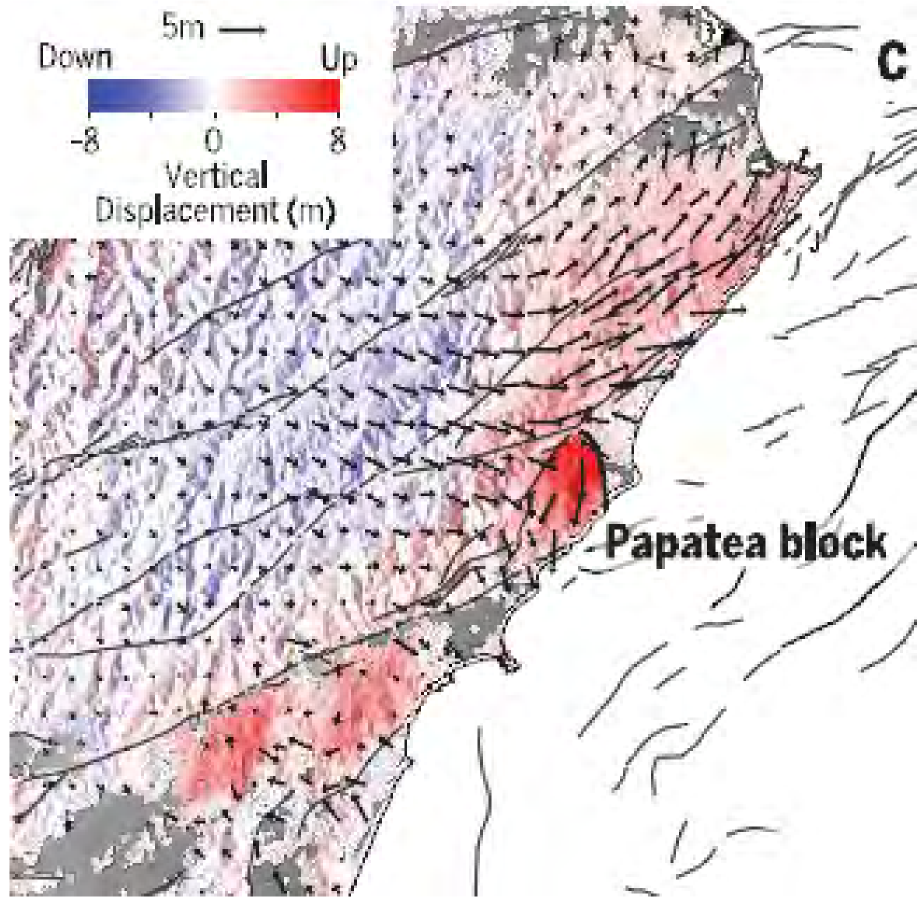
M 7.8 Kaikōura Earthquake Effects

- 2+ minutes of strong shaking at epicenter.
- Rupture propagated to the north at ~2km/second
- 100 km of coastline uplifted.

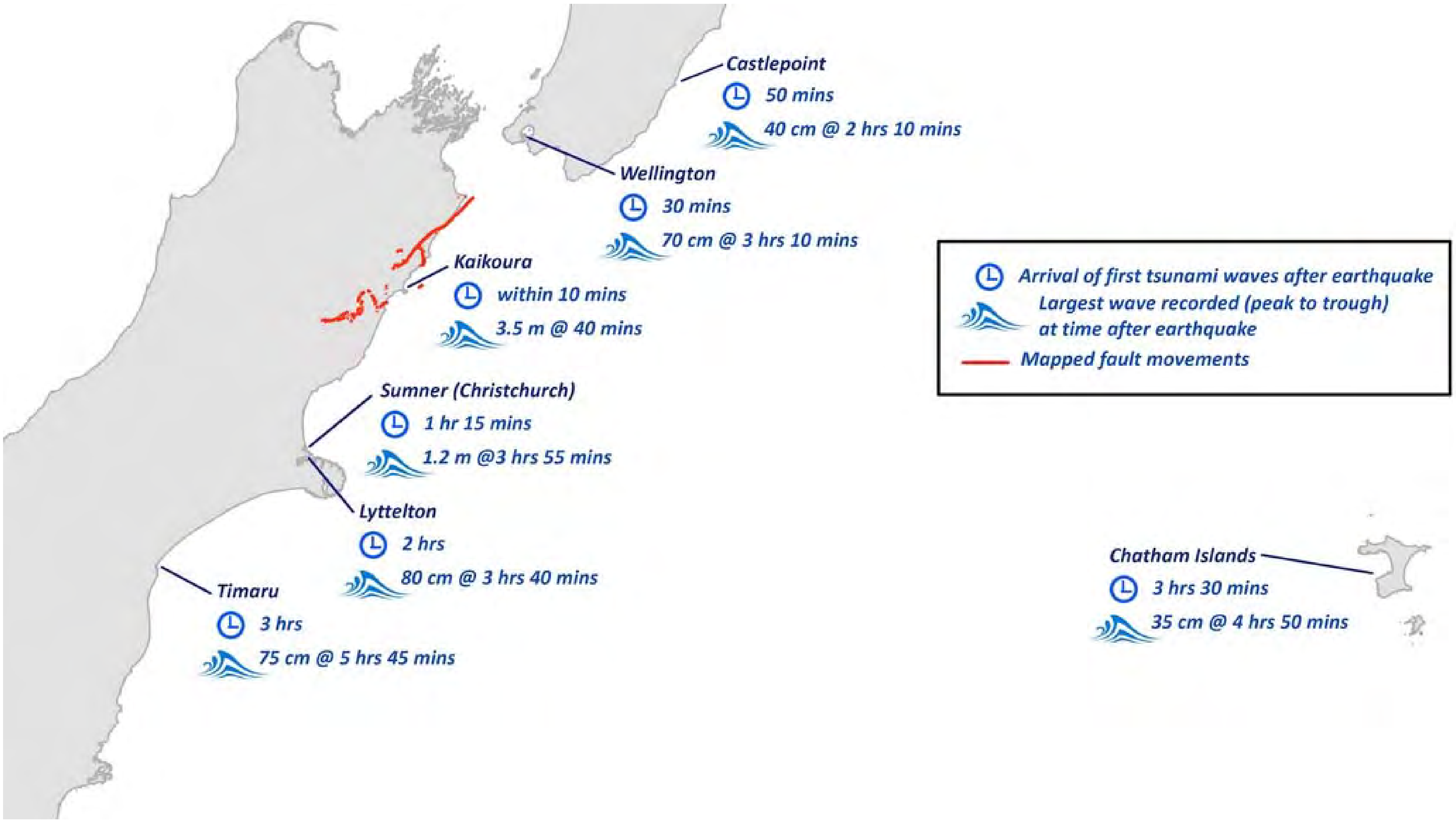


M 7.8 Kaikōura Earthquake Effects

- One of the most complex surface fault rupturing earthquakes ever recorded.
- 180 km of surface rupture on 12+ major crustal faults.
- Papatea block uplifted 8 m and translated to the south by 4 -5 meters.
- Seismic hazard models for NZ did not have this complex of a rupture accounted for.

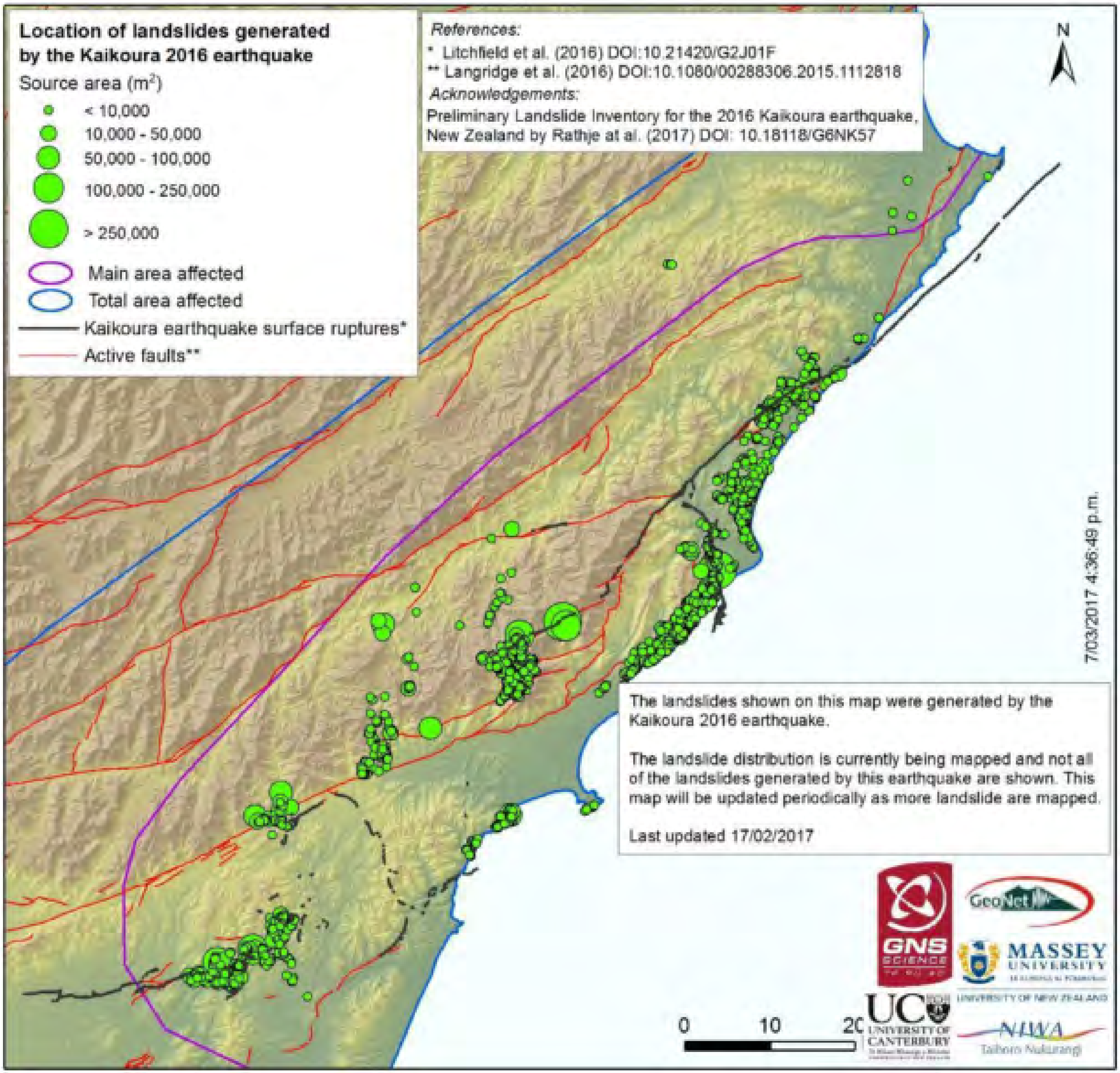


M 7.8 Kaikōura Earthquake Effects



M 7.8 Kaikōura Earthquake Effects

- 100,000 + landslides triggered as a result of ground shaking.
- 200+ valley blocking landslides.
- Very little liquefaction.



M 7.8 Kaikōura Earthquake Effects

- State highway 1 closed for more than 1 year- tourism re-directed.
- Estimated economic loss for New Zealand - $465 million over 2 years.
- Fishing industry outside Kaikōura - Massive shellfish and fish deaths and harbor damages.

Site 14, south of Kaikoura

January 2017

November 2017

New Zealand Government

NZ TRANSPORT AGENCY WAKA KOTAHI / KiwiRail

North Canterbury Transport Infrastructure Recovery

Slippy McSlip Face, north of Kaikoura

March 2017

September 2017

November 2017

New Zealand Government

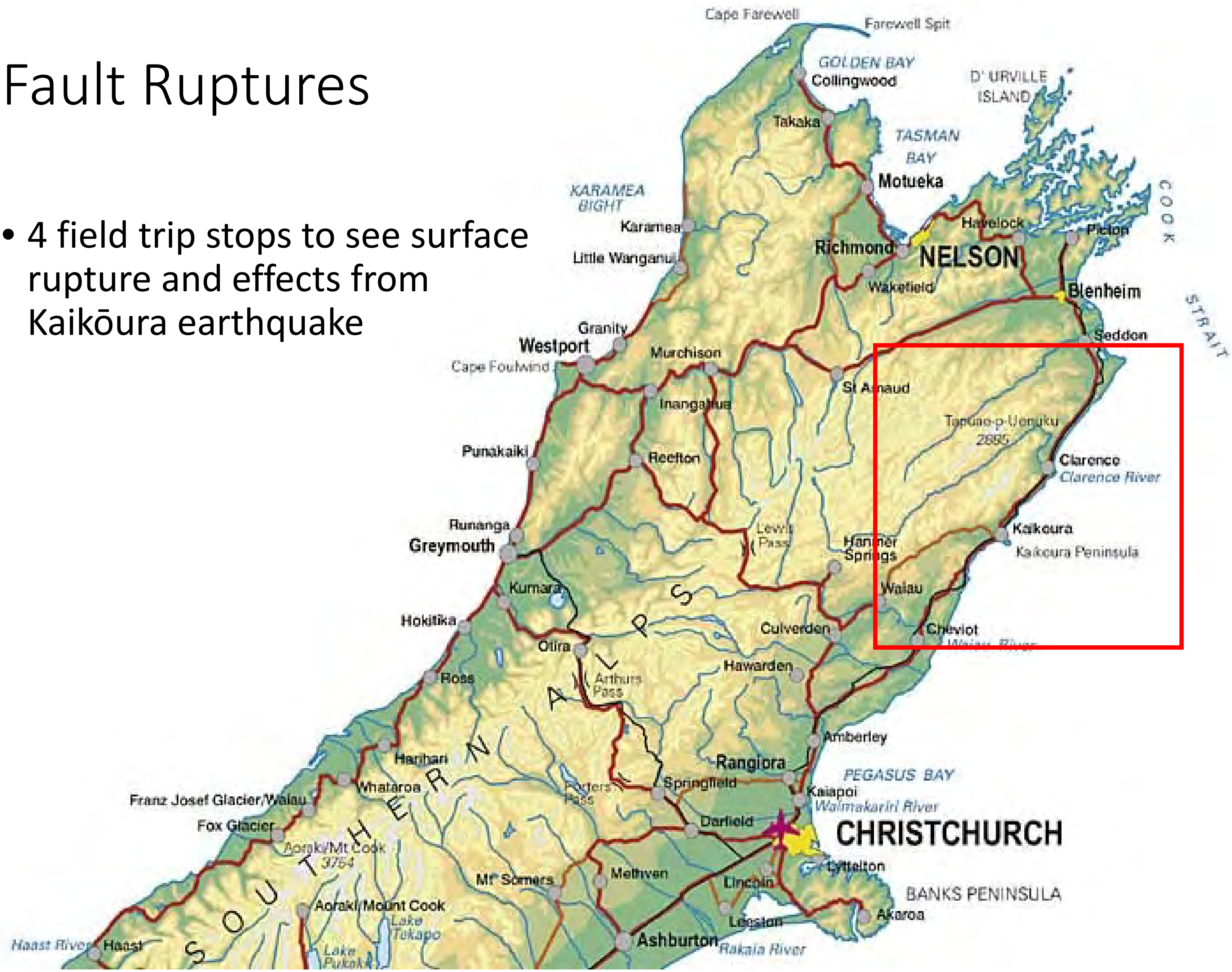
NZ TRANSPORT AGENCY WAKA KOTAHI / KiwiRail / North Canterbury Transport Infrastructure Recovery

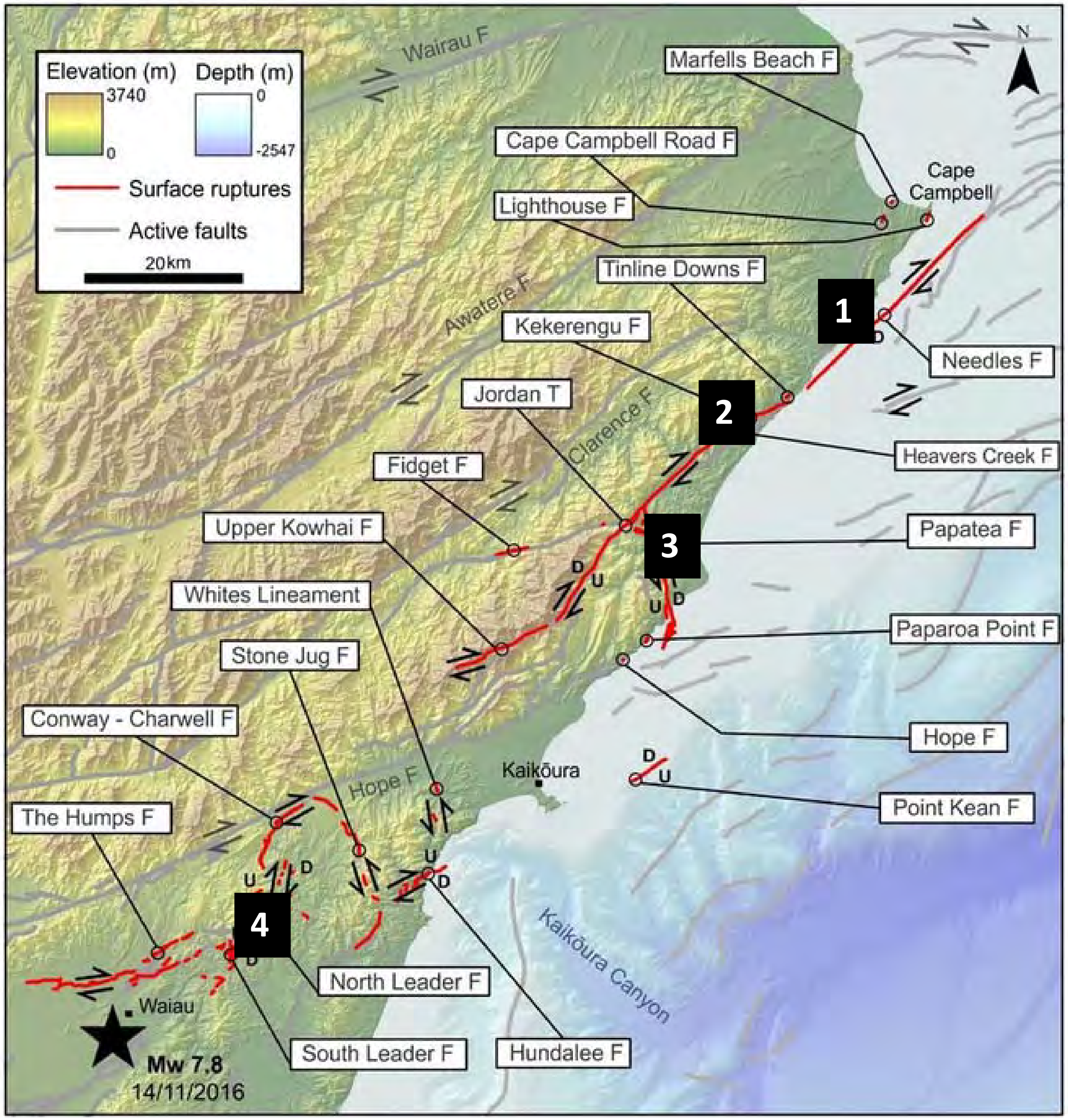
M 7.8 Kaikōura Earthquake Effects

- Psychological – Many New Zealanders lived through 2011 Canterbury earthquake sequence in Christchurch.
- Insecurity, uncertainty, **loss of trust in scientific information**, continued hyper-vigilance, and poor sleep.
- Scientists became "first responders."

Fault Ruptures

- 4 field trip stops to see surface rupture and effects from Kaikōura earthquake





Elevation (m)
3740
0
Depth (m)
0
-2547
Surface ruptures
Active faults
20km
N
Wairau F
Awatere F
Clarence F
Hope F
Marfells Beach F
Cape Campbell Road F
Lighthouse F
Cape Campbell
Tinline Downs F
Kekerengu F
Needles F
Jordan T
Heavers Creek F
Fidget F
Upper Kowhai F
Papatea F
Whites Lineament
Paparoa Point F
Stone Jug F
Conway - Charwell F
Hope F
Kaikōura
Point Kean F
The Humps F
North Leader F
Waiau
South Leader F
Hundalee F
Kaikōura Canyon
Mw 7.8
14/11/2016
1
2
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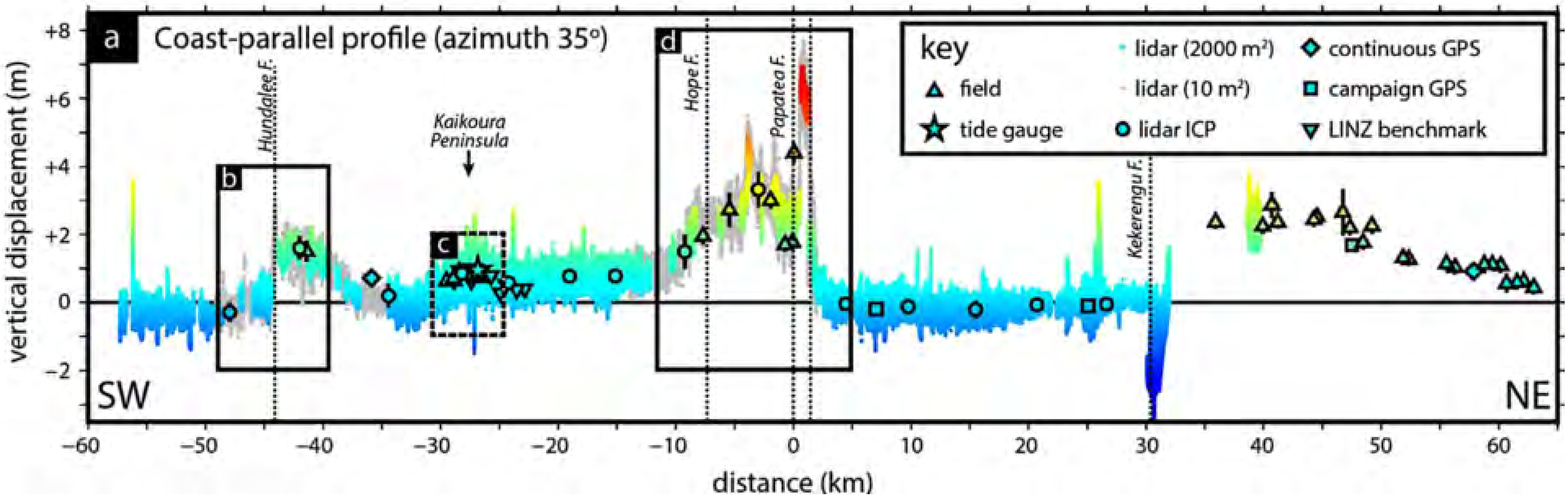
4

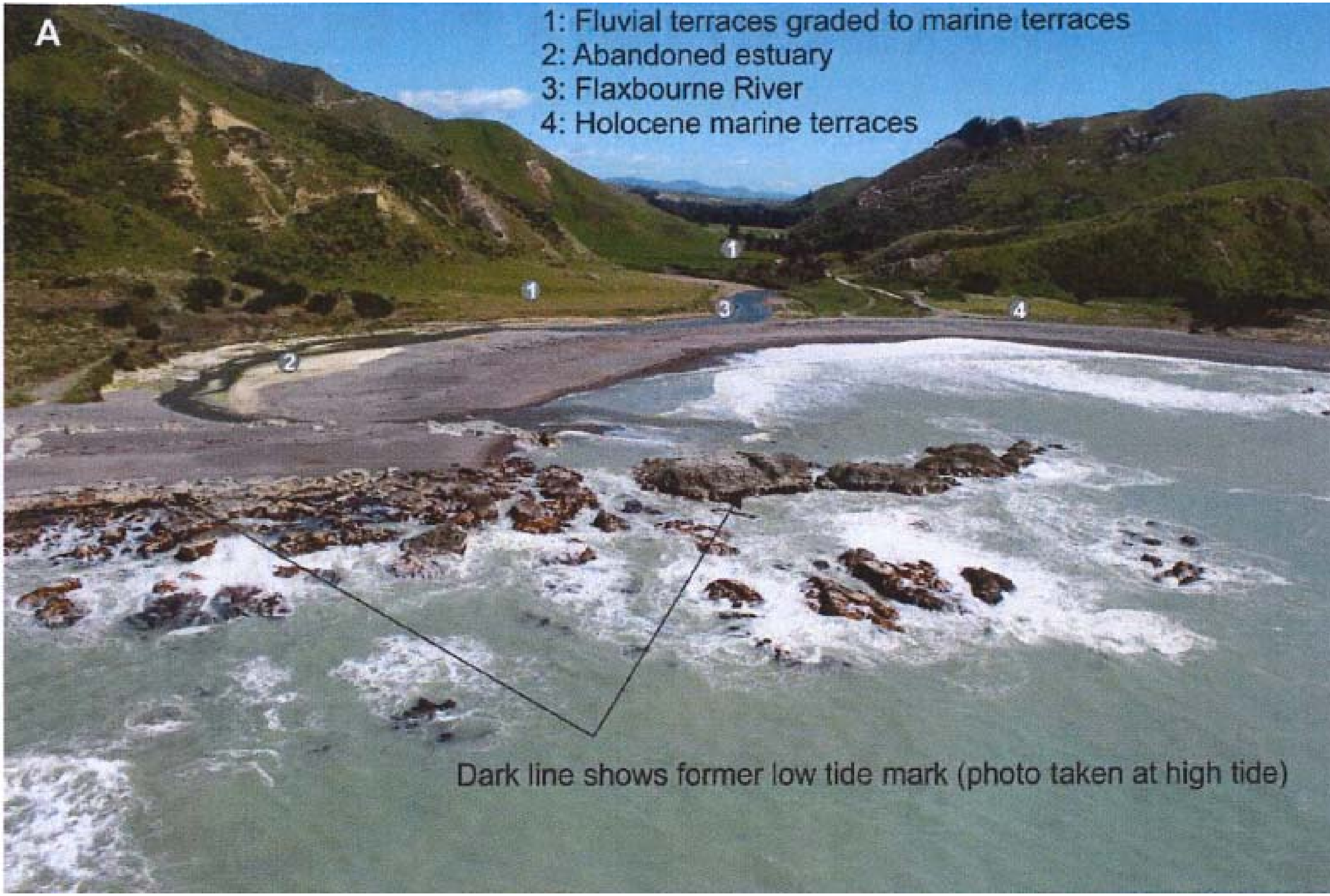
Stop 1- Needles Fault and Ward Beach

- Impacts of coastal uplift on offshore faults
- Highly variable vertical displacements along the coast, -2.5 m to 6.5 m (Clark et al., 2017)
- At Ward Beach, ~2.2 to 2.6 m of uplift.
- Uplift tracked by correlating uplifted tidal species to their habitable depth.

Stop 1- Needles Fault and Ward Beach

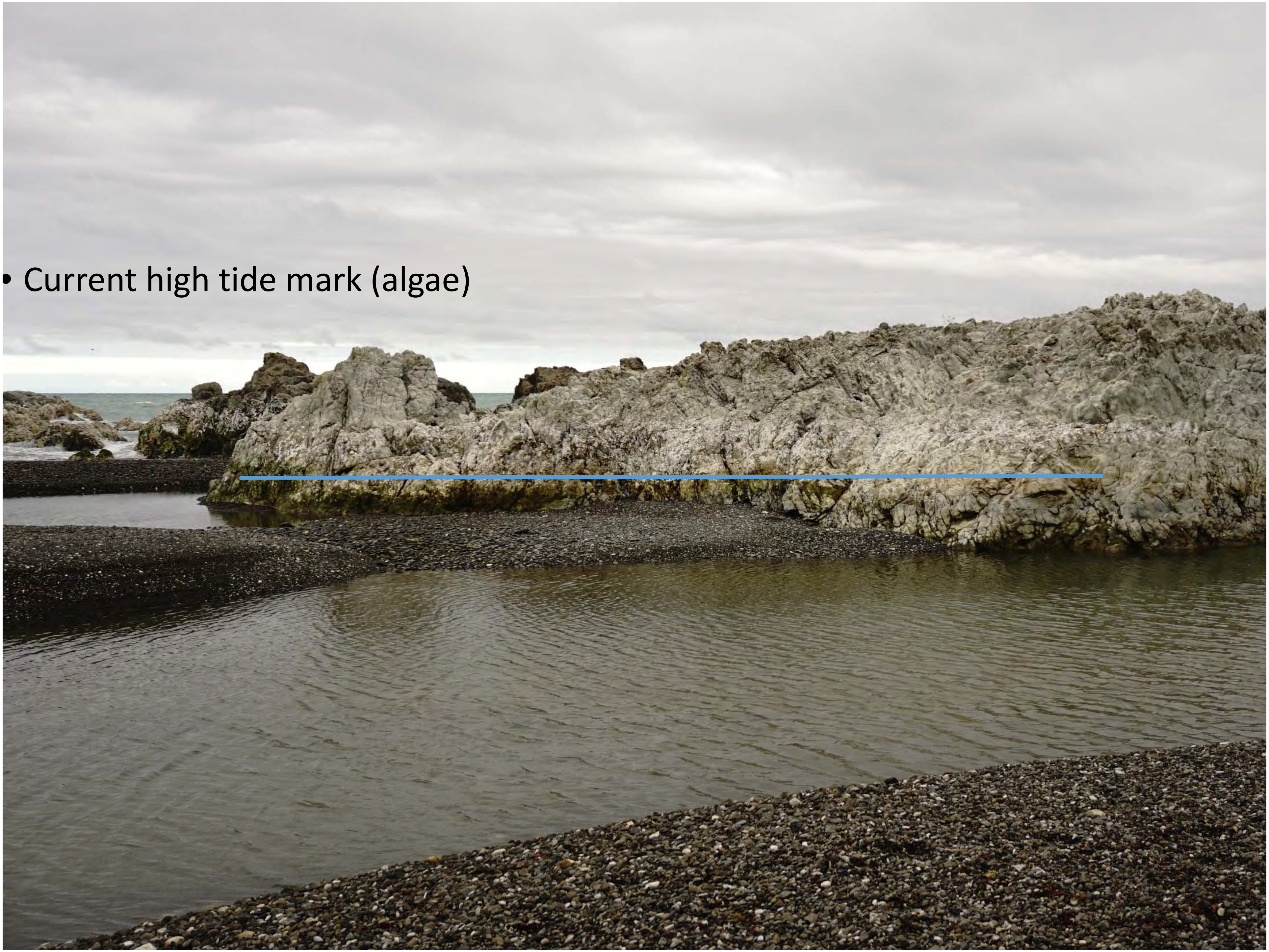


Stop 1- Needles Fault and Ward Beach

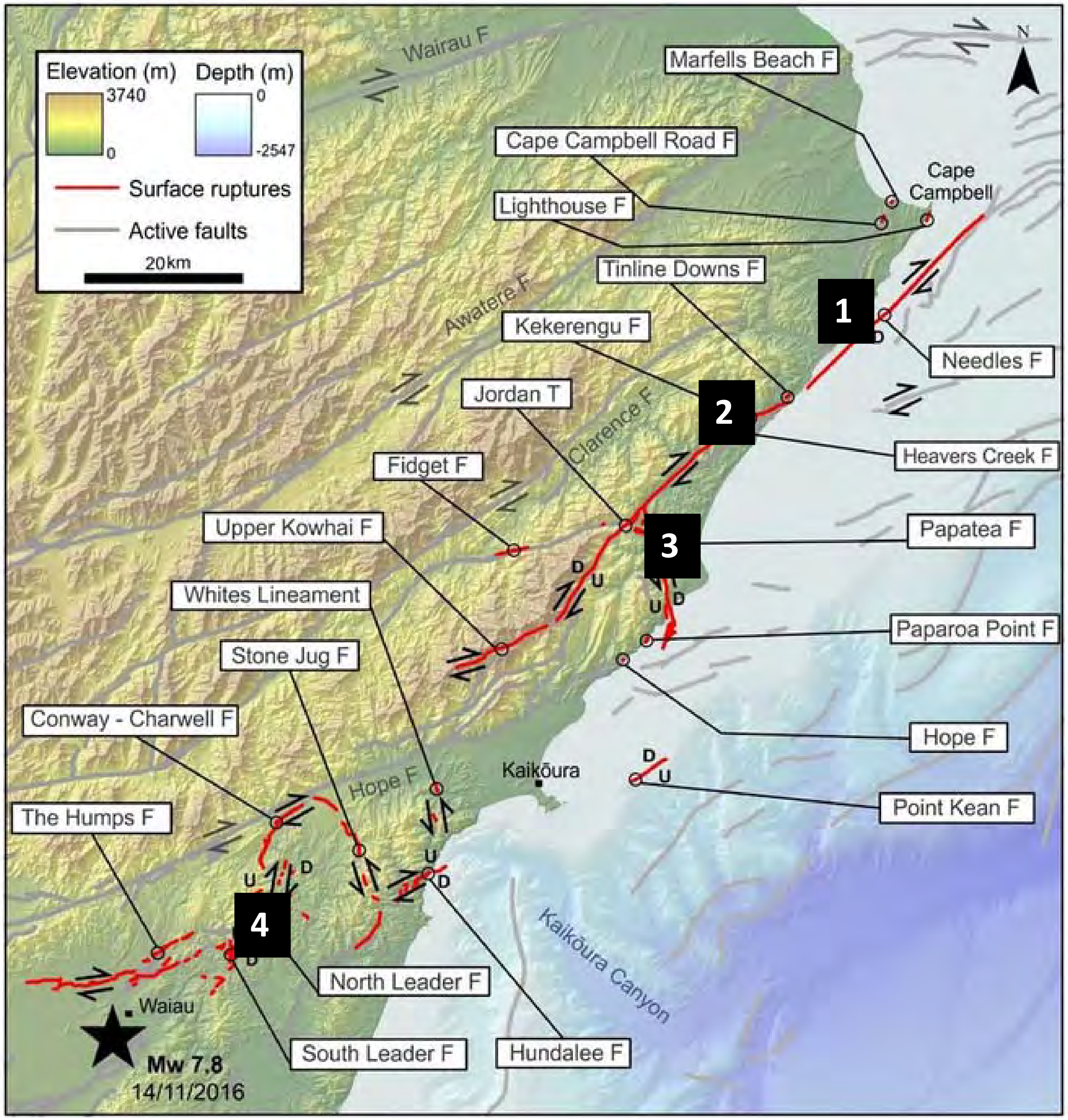


Stop 1- Needles Fault and Ward Beach

- Current high tide mark (algae)



- Pervious high tide mark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Kaikōura Canyon
Waiau
South Leader F
Hundalee F
Mw 7.8
14/11/2016
1
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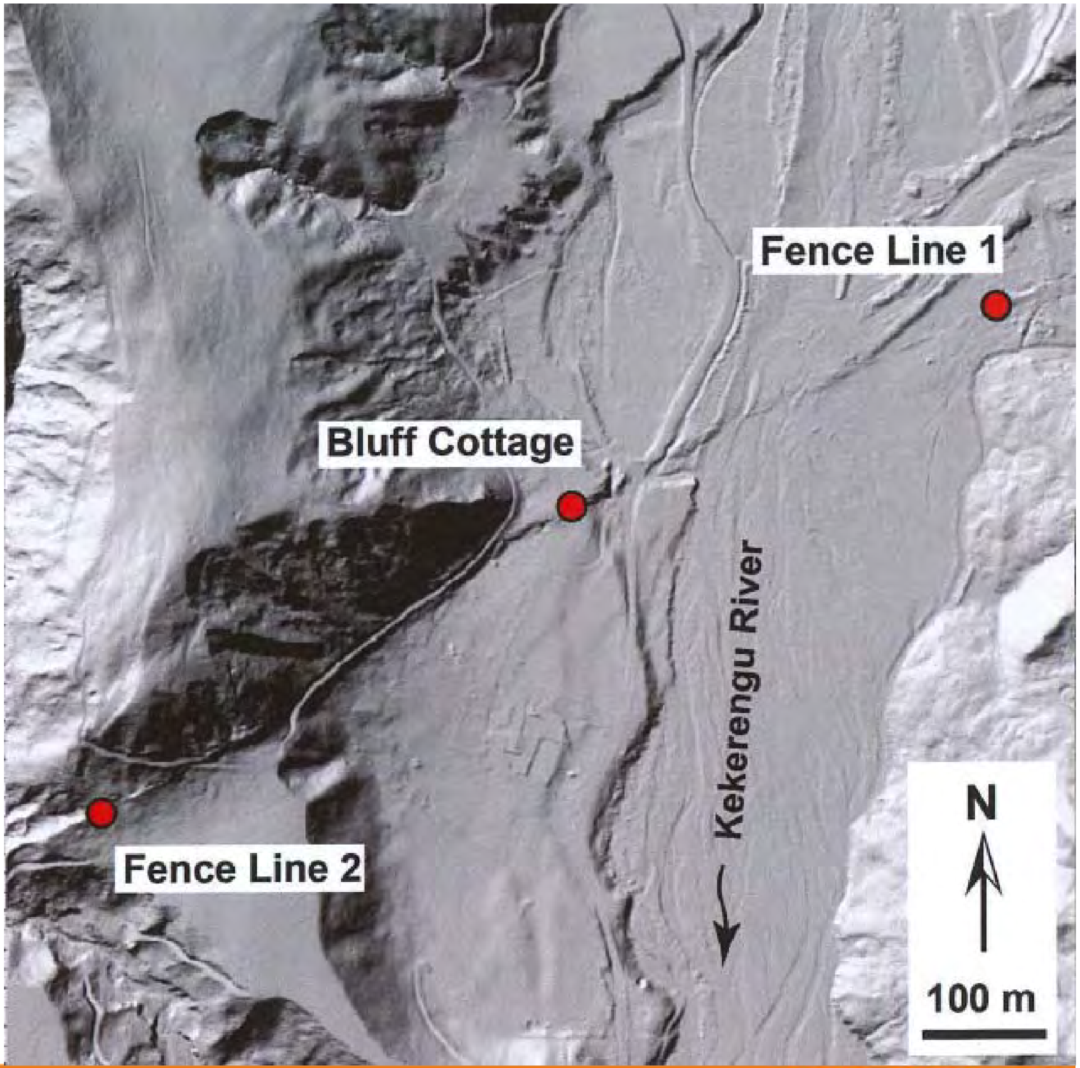
4

Stop 2- Kekerengu Fault

- Slip rate ~20-26 mm.yr (Van Dissen et al., 2016)
- Recurrence interval ~380 $\pm$ 30 years (Little et al., in press)
- Predominantly strike-slip, right lateral.
- Kekerengu fault system had longest continuous ruptures (85km) from the earthquake.
- Maximum vertical displacement ~12m
  - One of the largest co-seismic surface ruptures ever observed.

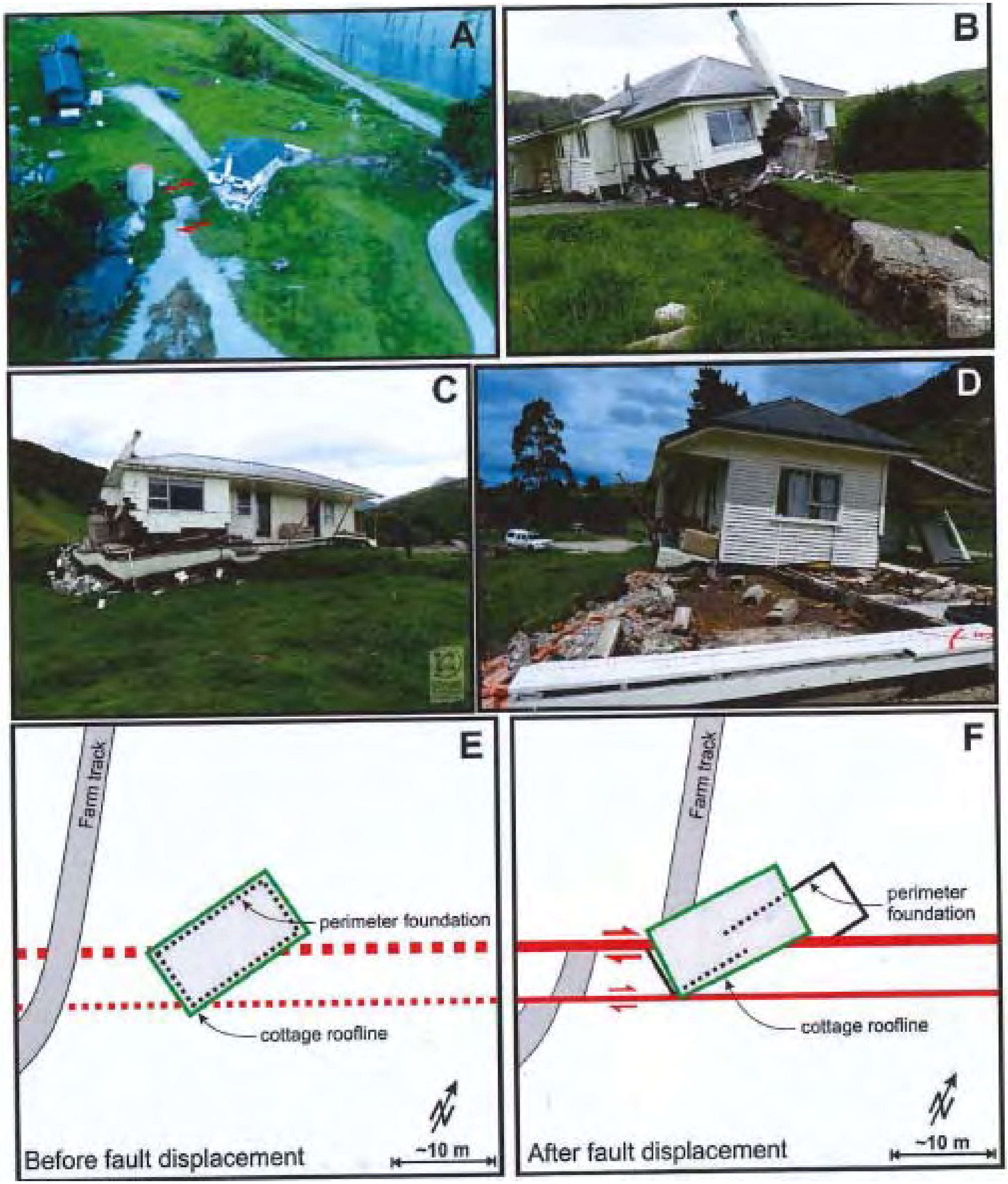
Stop 2- Kekerengu Fault

- Offset man-made features
- Fences and a cottage

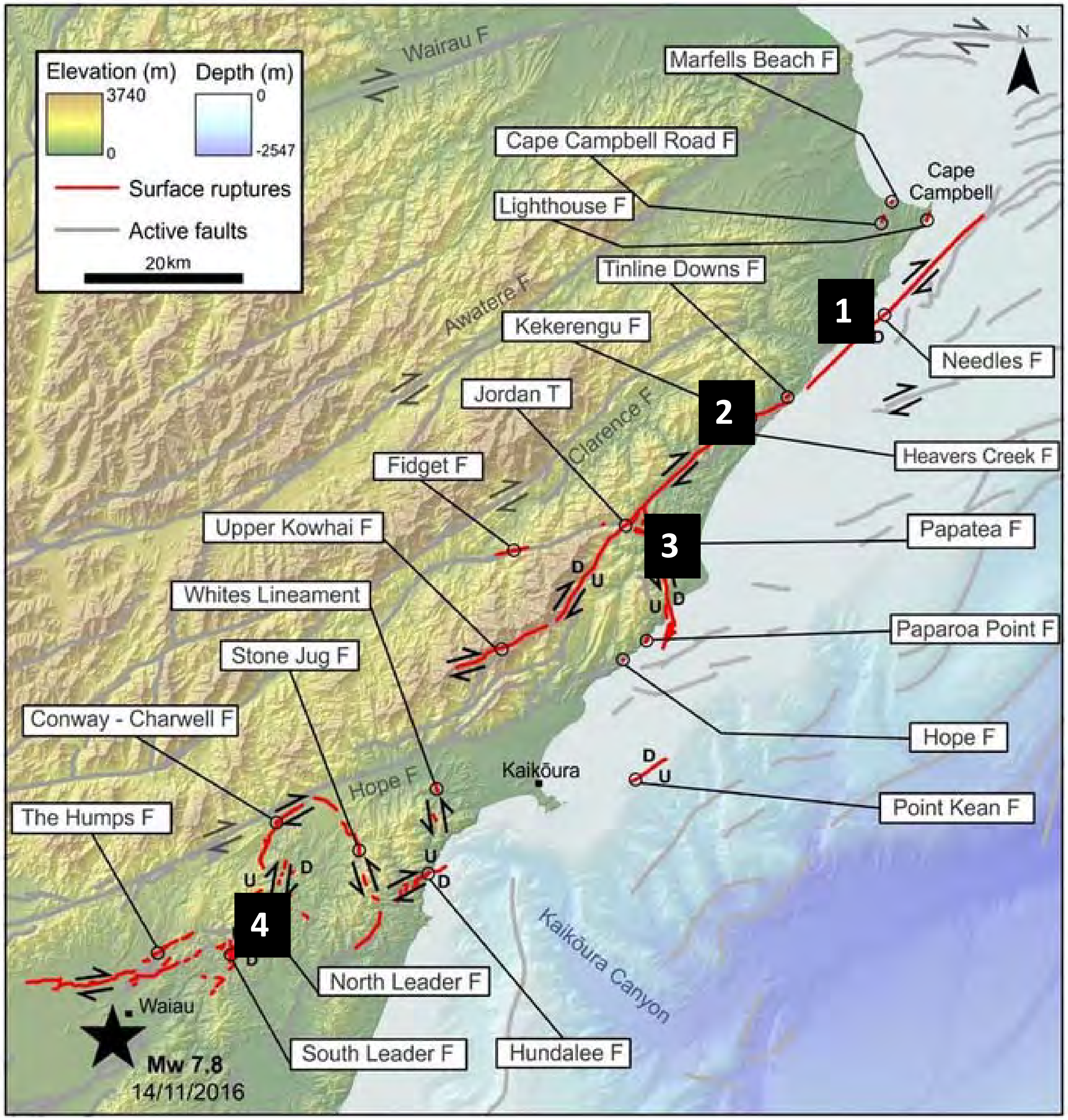


Stop 2- Kekerengu Fault Bluff Cottage

10 meters of localized horizontal fault displacement extended through the cottage.


A
B
C
D
E
Farm track
perimeter foundation
cottage roofline
~10 m
Before fault displacement
F
Farm track
perimeter foundation
cottage roofline
~10 m
After fault displacement


10.8 ± 0.6 m offset fence



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Kaikōura
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The Humps F
North Leader F
Kaikōura Canyon
Waiau
South Leader F
Hundalee F
Mw 7.8
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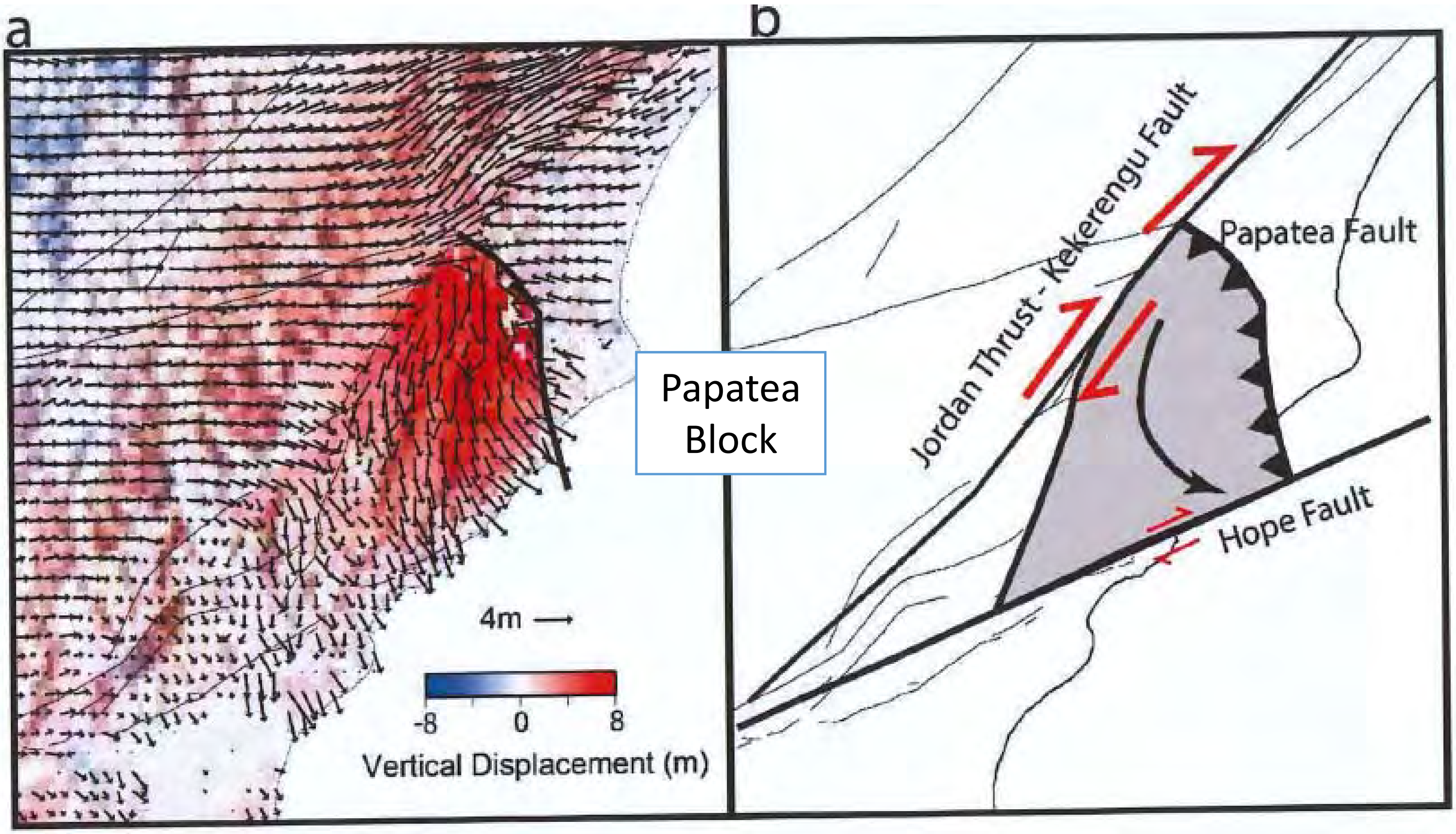
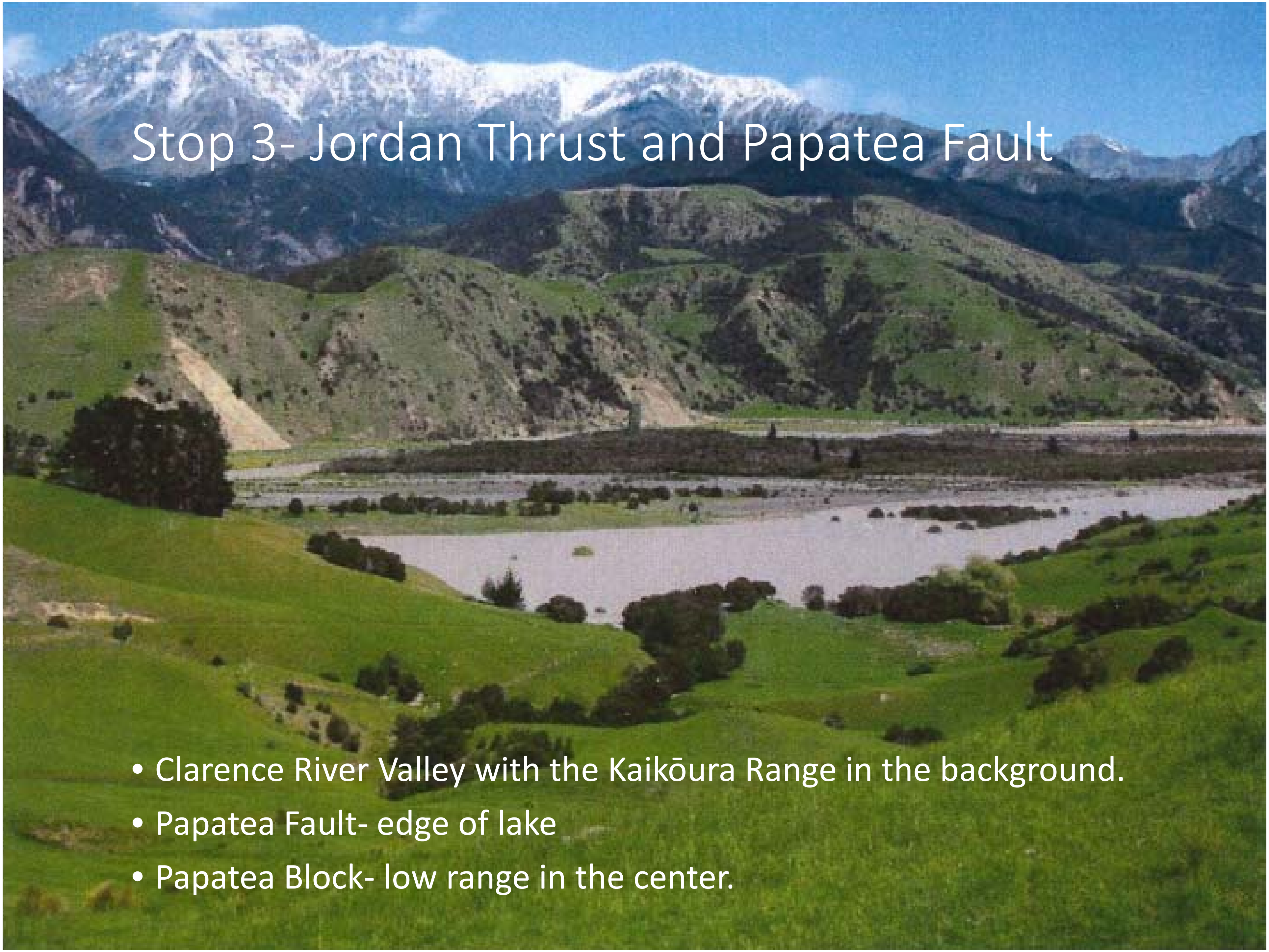
Stop 3- Jordan Thrust and Papatea Fault

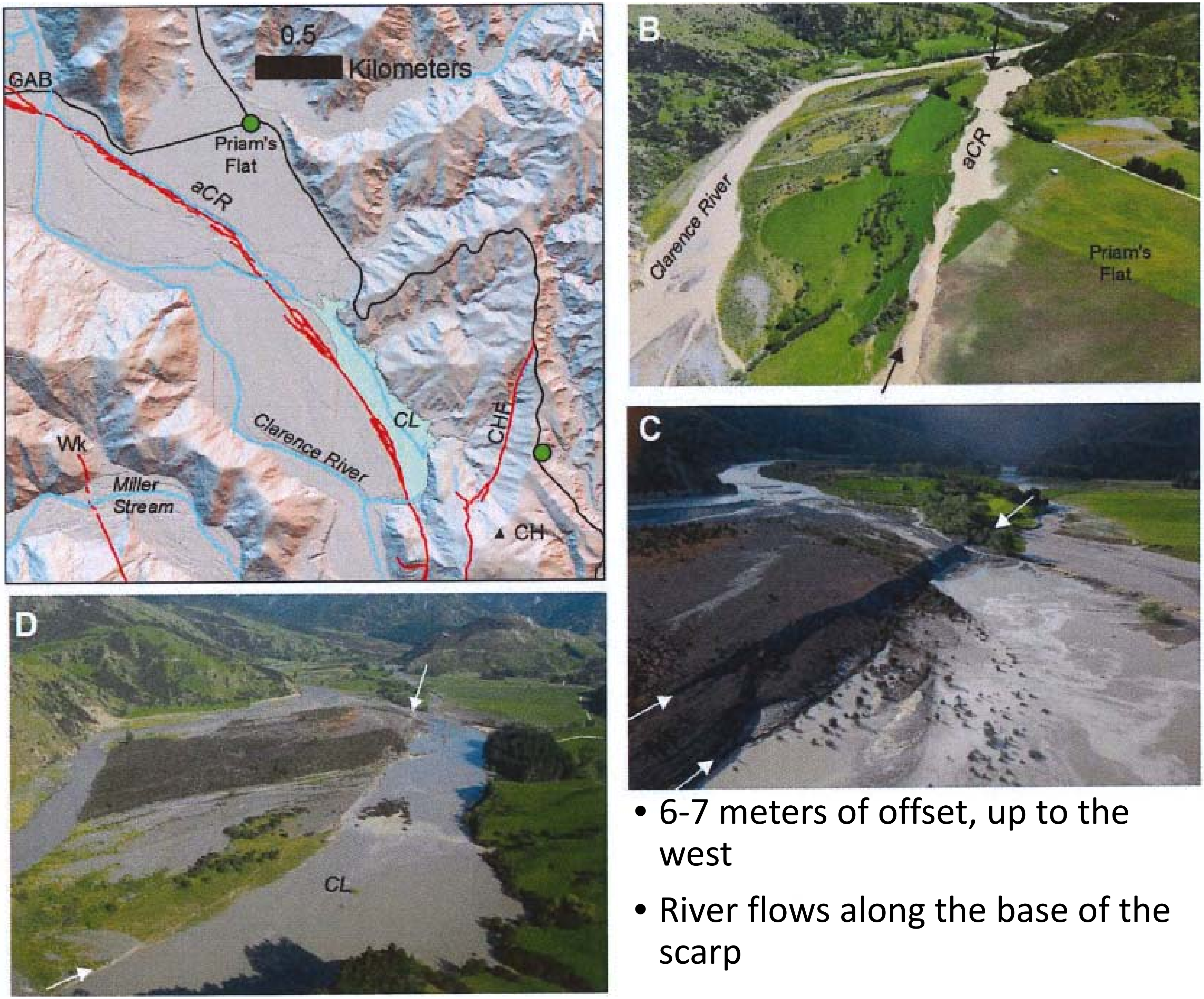


- Prior to Kaikoura EQ, Papatea fault not in fault database



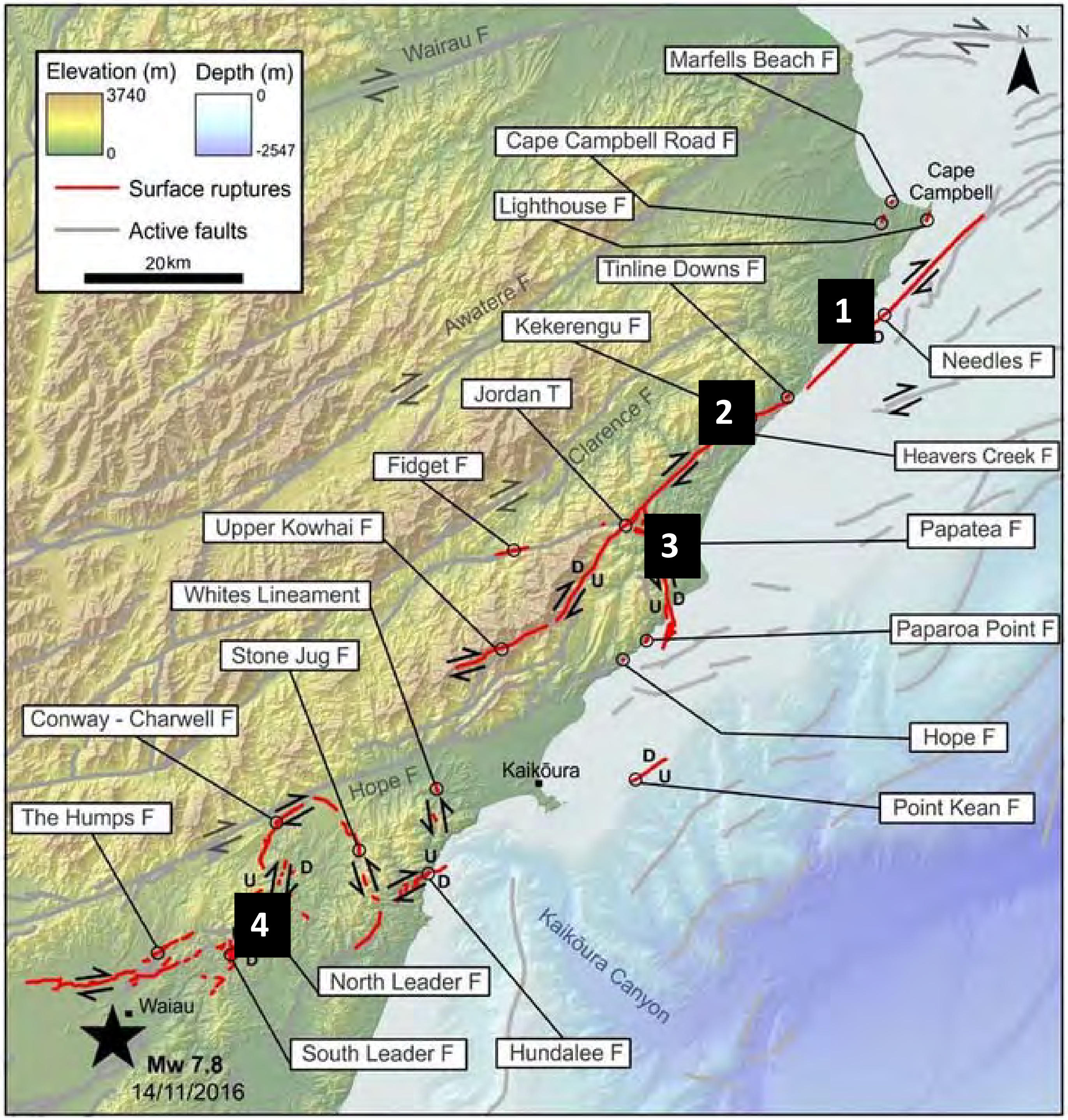
Stop 3- Jordan Thrust and Papatea Fault

- Clarence River Valley with the Kaikōura Range in the background.
- Papatea Fault- edge of lake
- Papatea Block- low range in the center.



- 6-7 meters of offset, up to the west
- River flows along the base of the scarp

Stop 3- Papatea Fault in the Clarence River Valley



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North Leader F
South Leader F
Hundalee F
Kaikōura Canyon
Waiau
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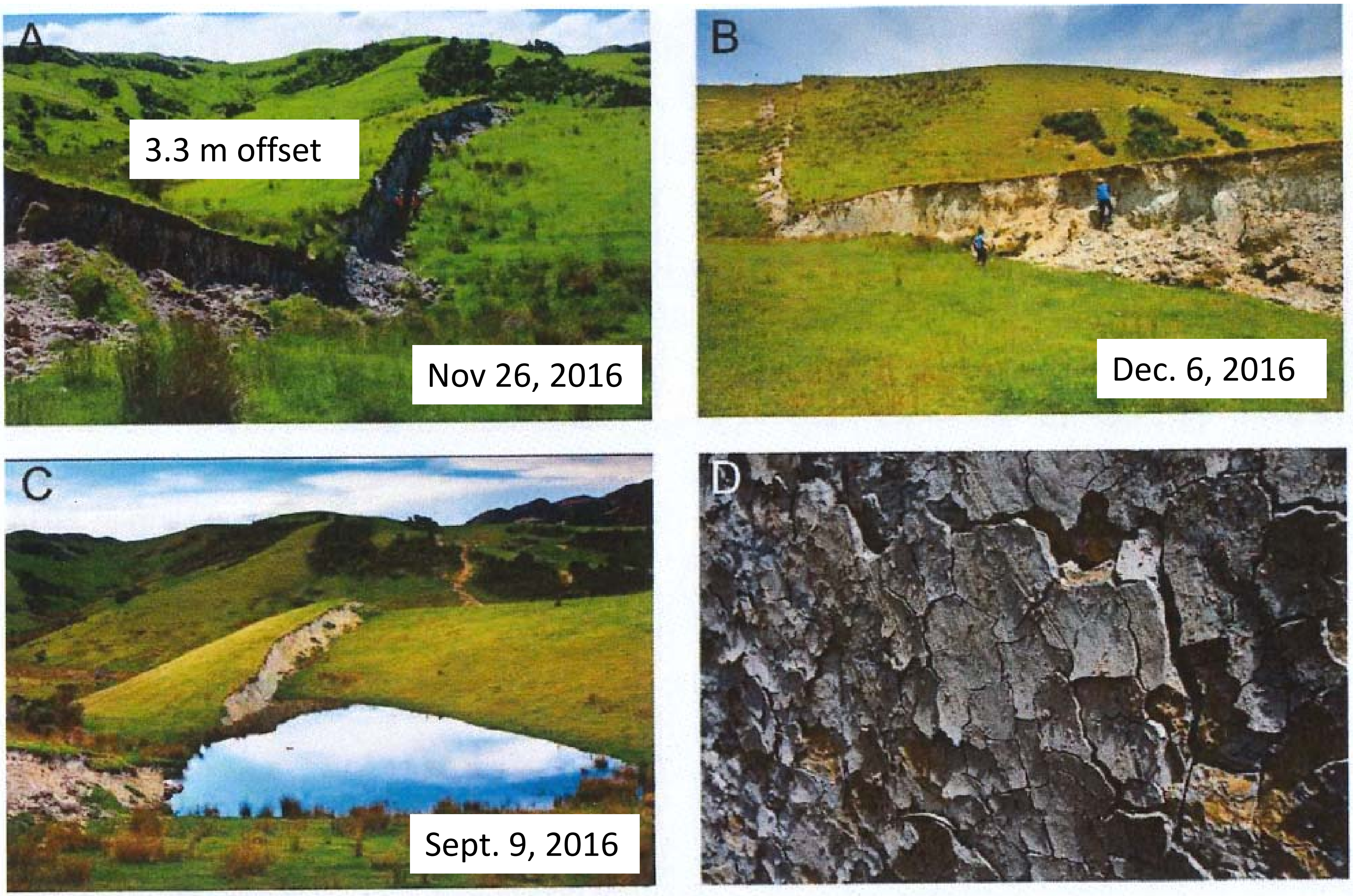
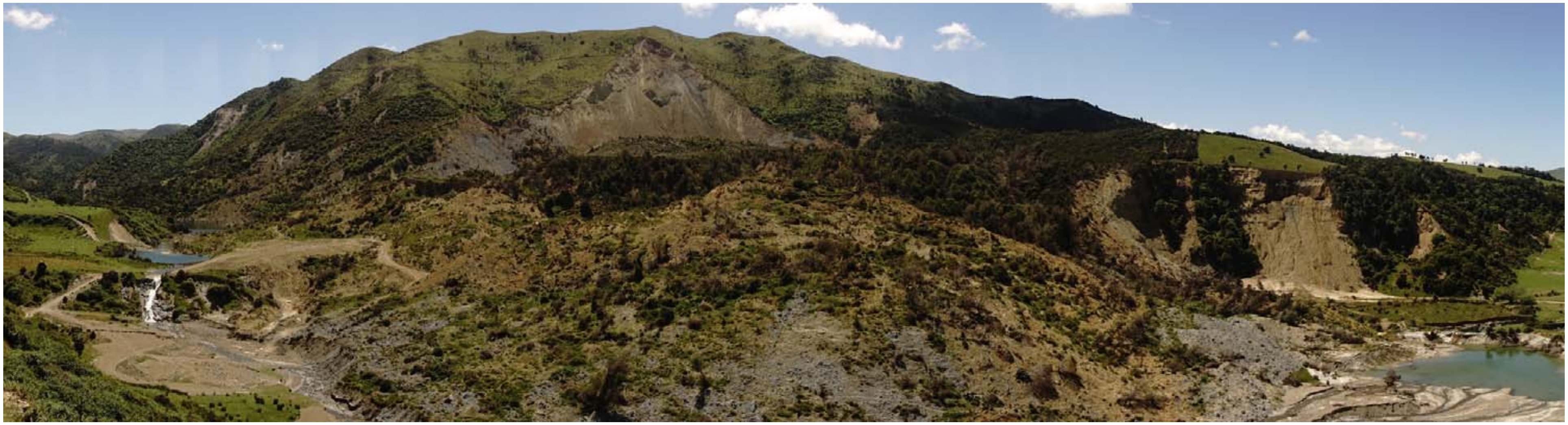
Stop 4- South Leader Fault Zone




Nov. 19, 2017

Stop 4- Leader River Landslide



- Slump/block landslide that moved in a single event
- Landslide dam formed and was partially breached Feb. 13/14, 2017
- Considered to currently be stable.
- The Humps/Leader fault zone come together close to this location.
- Fault mapped at the top of the headscarp.

Stop 4- Leader River landslide

Stop 4- Leader River landslide

Lessons Learned from 2016 M7.8 Kaikōura Earthquake

- The Kaikōura earthquake defies many conventional assumptions about fault segmentation.
- Paleoseismology
  - An event of this complexity could be interpreted as multiple events in the paleoseismic record.
- Segment boundary ruptures
  - Kaikōura earthquake had multiple segment ruptures over great distances.
  - Numerical models for seismic hazard commonly will halt a rupture propagation if it has to step across a fault greater than 5 km away.
- Seismic Hazard models
  - Could not capture the complexity of this faulting sequence.

Lessons Learned from 2016 M7.8 Kaikōura Earthquake, and 2011 Canterbury EQ sequence

- As scientists, we must be sensitive to the disaster.
- Scientists can sometimes be the "first responders."
- Making post-event data available online is incredibly valuable and important to the public.
- Authentic collaboration with local communities goes far.
    - Farmers/landowners know more about what their land looked like before an event.

Final Note- The Alpine Fault!?

Isn't it nice to be a geologist in the desert?

Discussion: Benefits of Incorporating Consultant Surface-Fault-Rupture Investigations into Urban Geologic Mapping

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
- Excavations, road cuts, utility trenches, auger holes, and natural erosion surfaces

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)

Where do all the reports come from?

- Cities, Counties, State Agencies, University of Utah, private donations, etc.
- Funded by UGS and Geologic Data Preservation Project Grant (USGS)

- Utah Correctional Industries scan the reports and enter metadata
- Additional metadata and geolocations added by UGS staff

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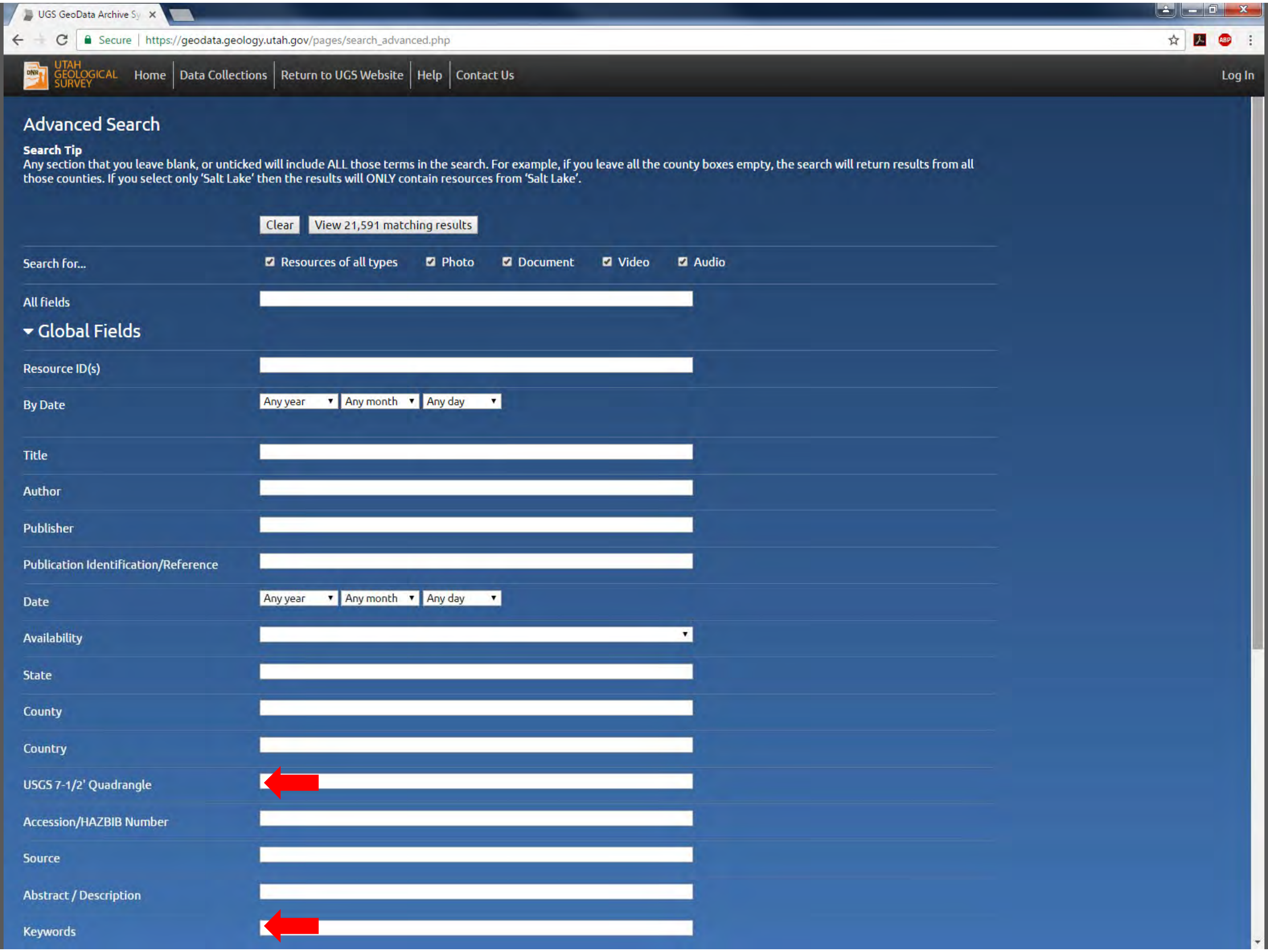
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View 21,591 matching results
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Resources of all types
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Video
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All fields
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By Date
Any year
Any month
Any day
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Publication Identification/Reference
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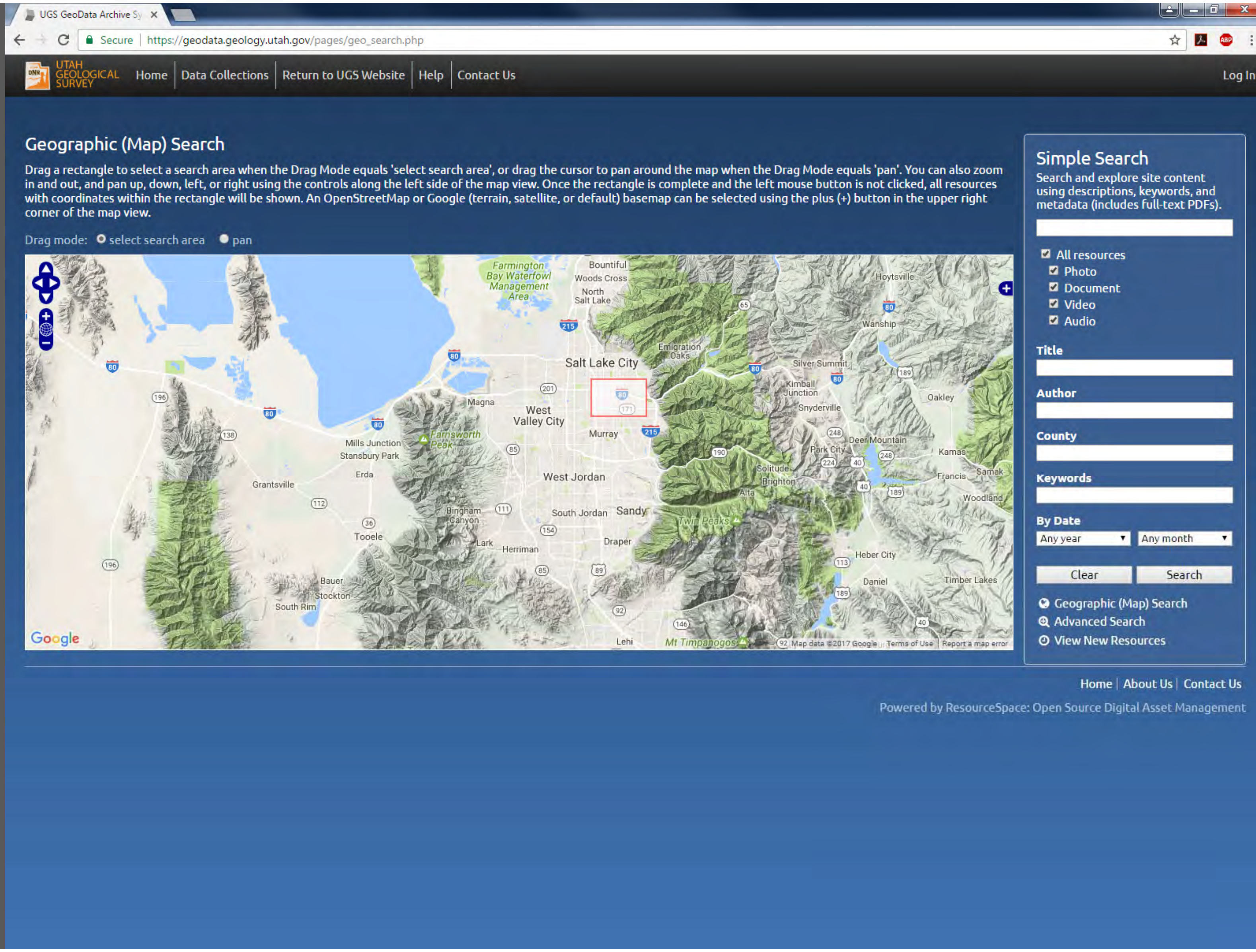
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Drag mode: select search area pan
Salt Lake City
West Valley City
West Jordan
Murray
South Jordan
Sandy
Draper
Magna
Tooele
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Kamas
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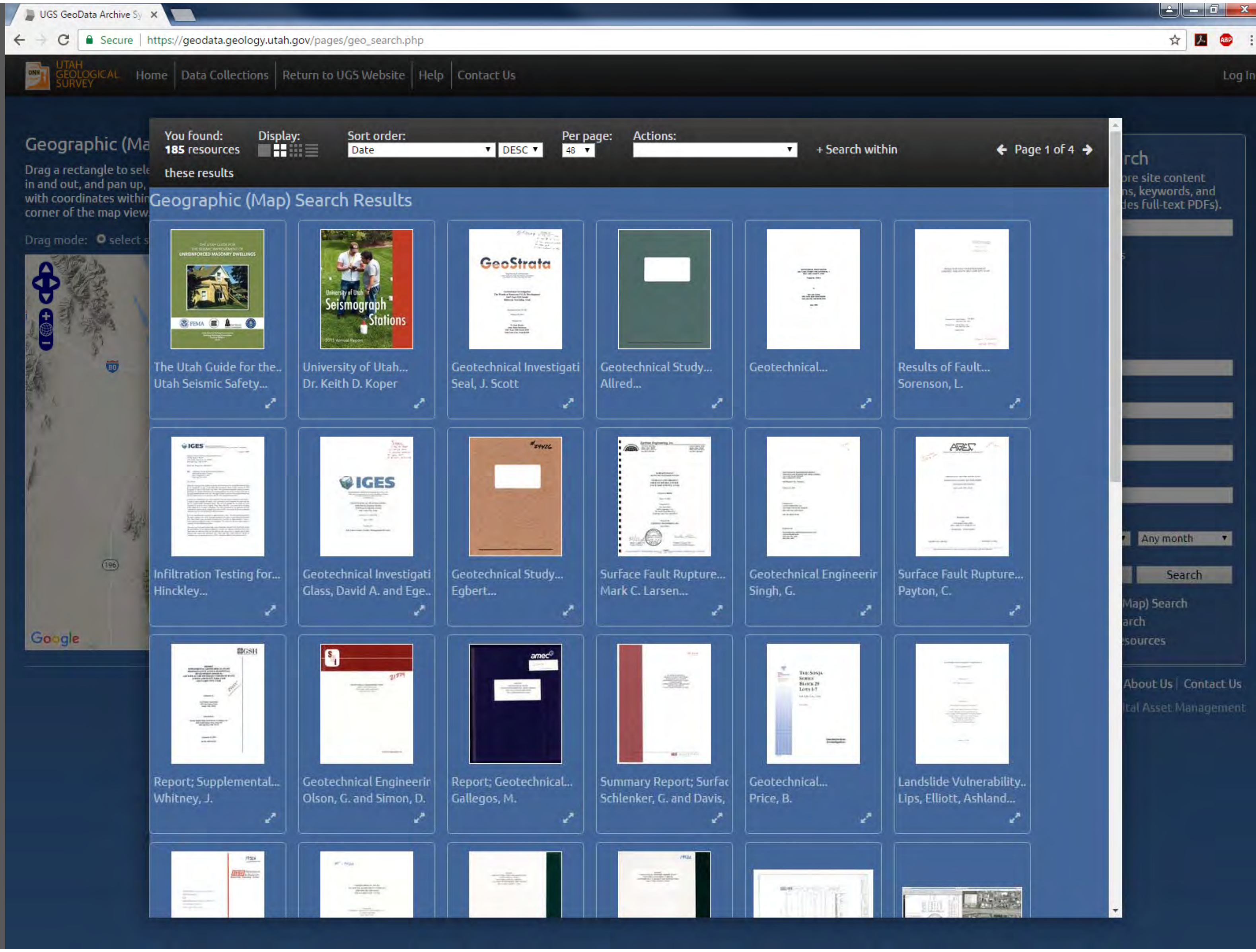
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Summary Report; Surface Fault Rupture Hazard Evaluation; Proposed East Salt Lake Home Depot; Approximately 3500 South Highland Drive; Salt Lake County, Utah

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Resource Type
Document

Title
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Author
Schlenker, G. and Davis, S.

Date
February 19 2003

County
Salt Lake

Keywords
surface fault rupture, paleoseismology

Publisher
Kleinfelder, Inc.

Availability
Public Domain

USGS 7-1/2' Quadrangle
Sugar House

Original Filename
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Document Date
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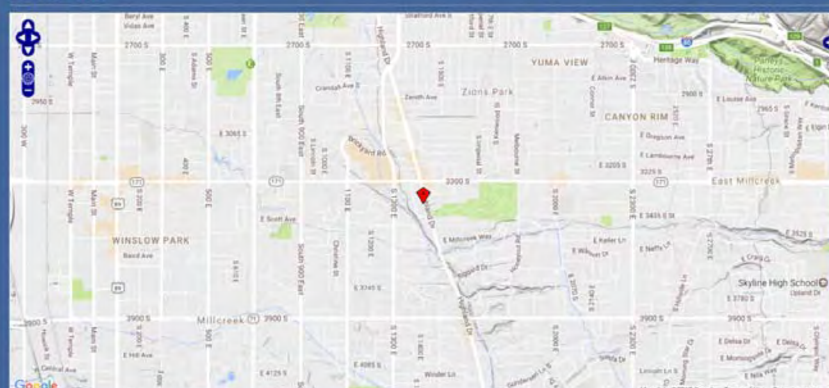

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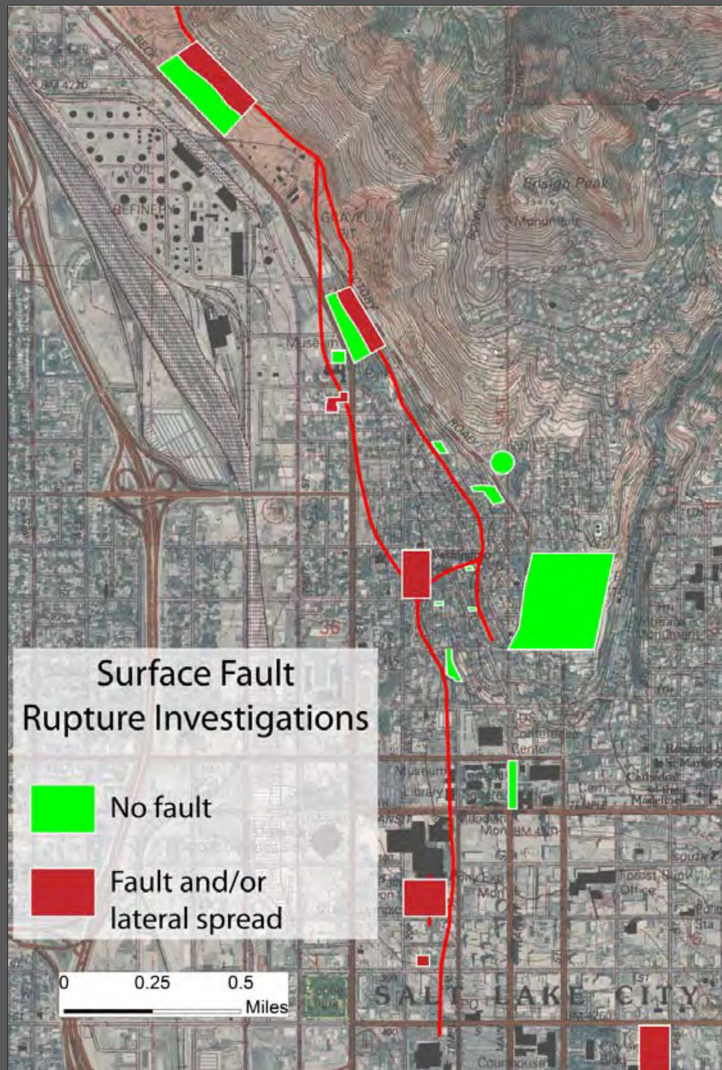
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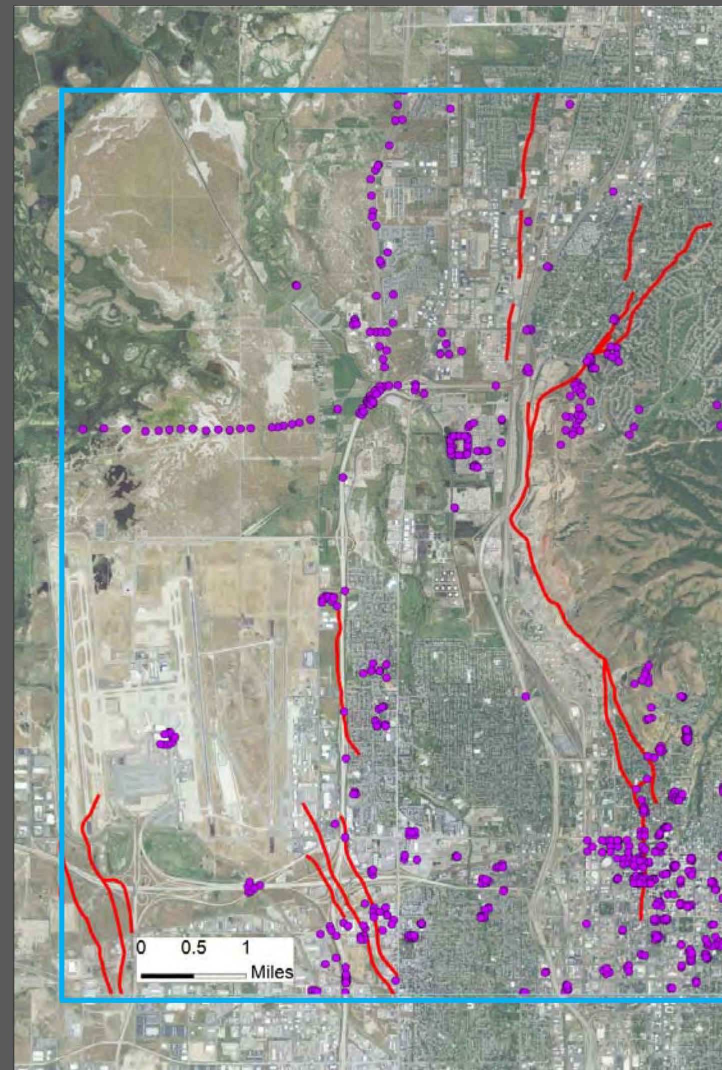
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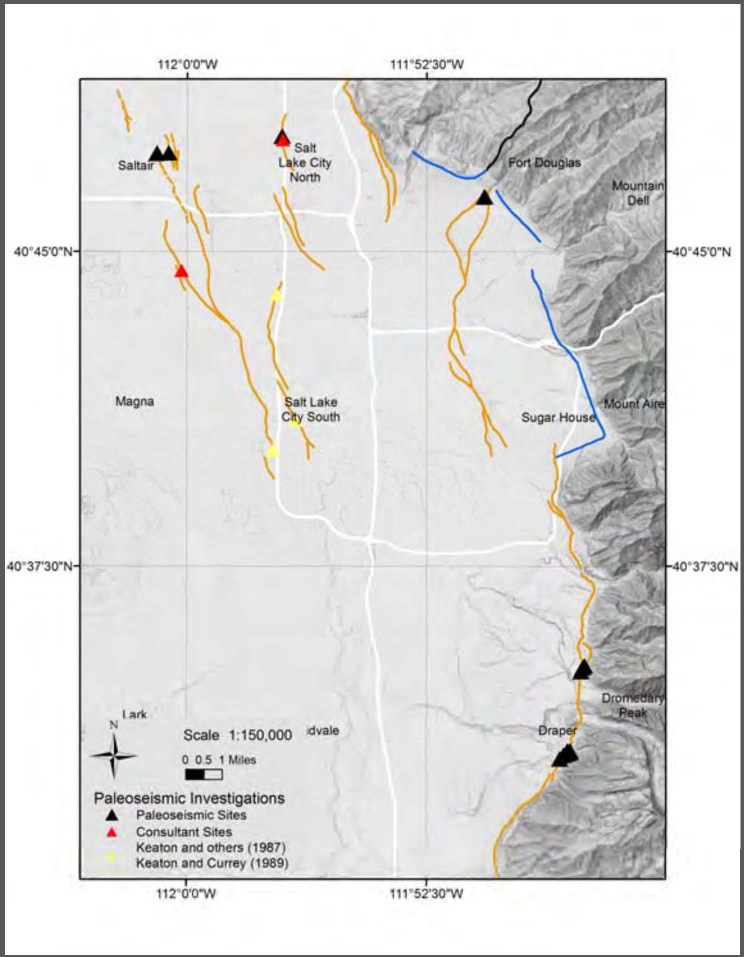
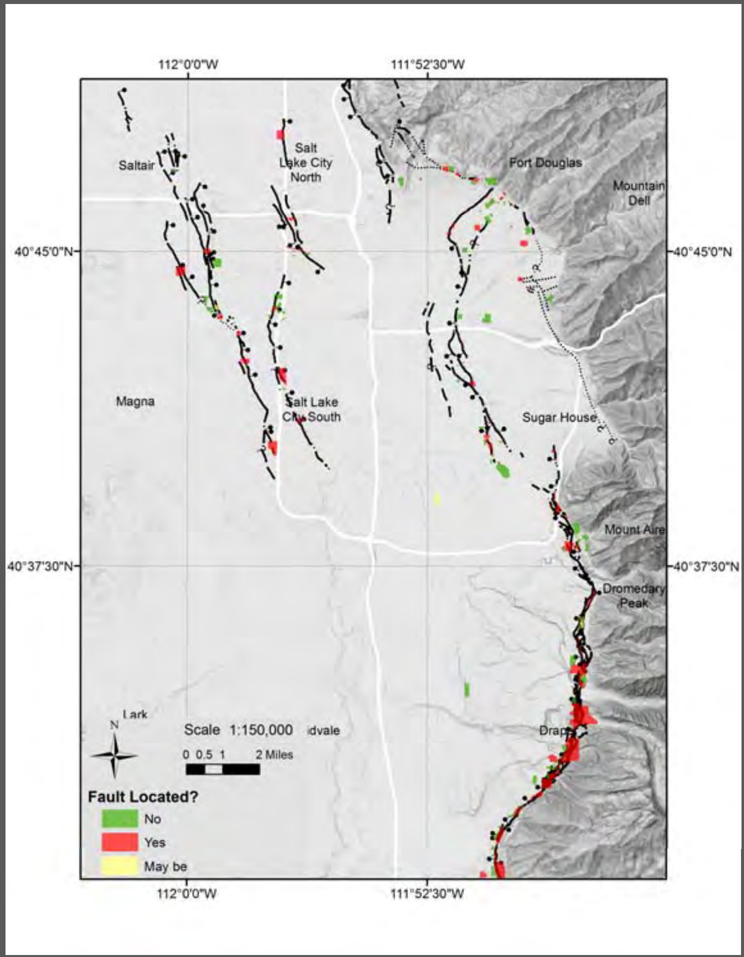
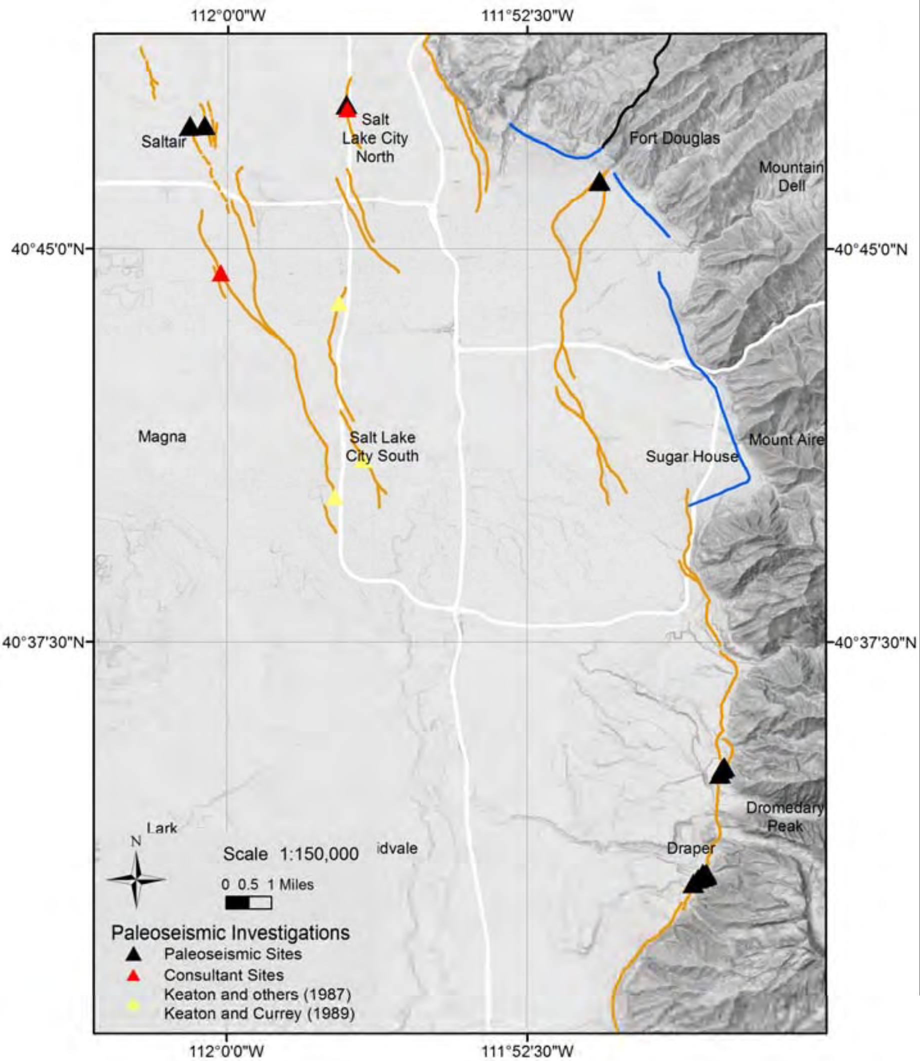
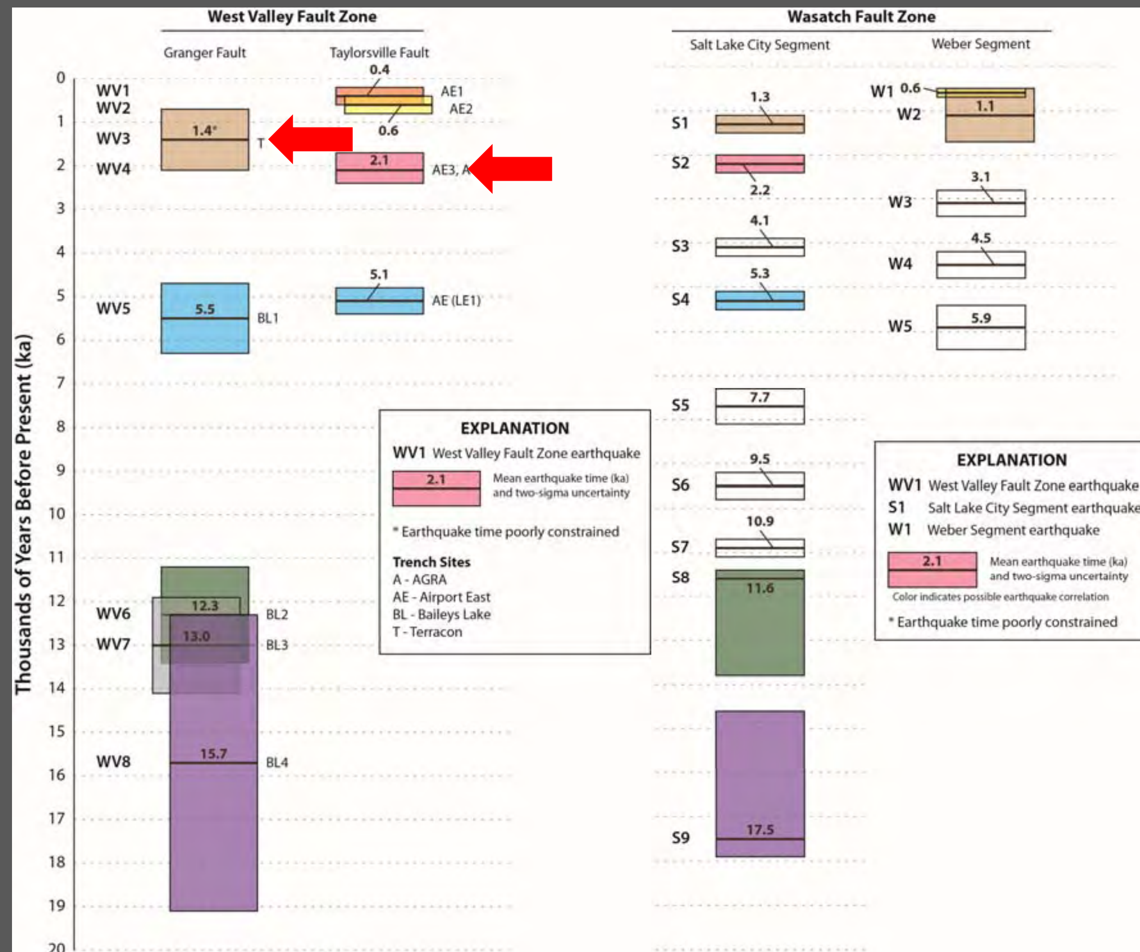


Consultant Surface-Fault-Rupture Investigations



West Valley Fault Zone: Recent Work





Hylland and others, 2017

Discussion

Benefits

- Builds relationships of mutual collaboration and cooperation
- Improve
  - Fault mapping
    - Accuracy and detail
    - Saving money on future work
  - Earthquake timing
  - Surficial geologic units and descriptions
  - Available data not just in Salt Lake Valley but in surrounding valleys and faults away from the Wasatch fault zone
- Reports are a data source for the UGS Comprehensive Geologic Hazard Map Sets (ALL of THEM)
- UGS can provide opinions on field exposures during reviews

Difficulties

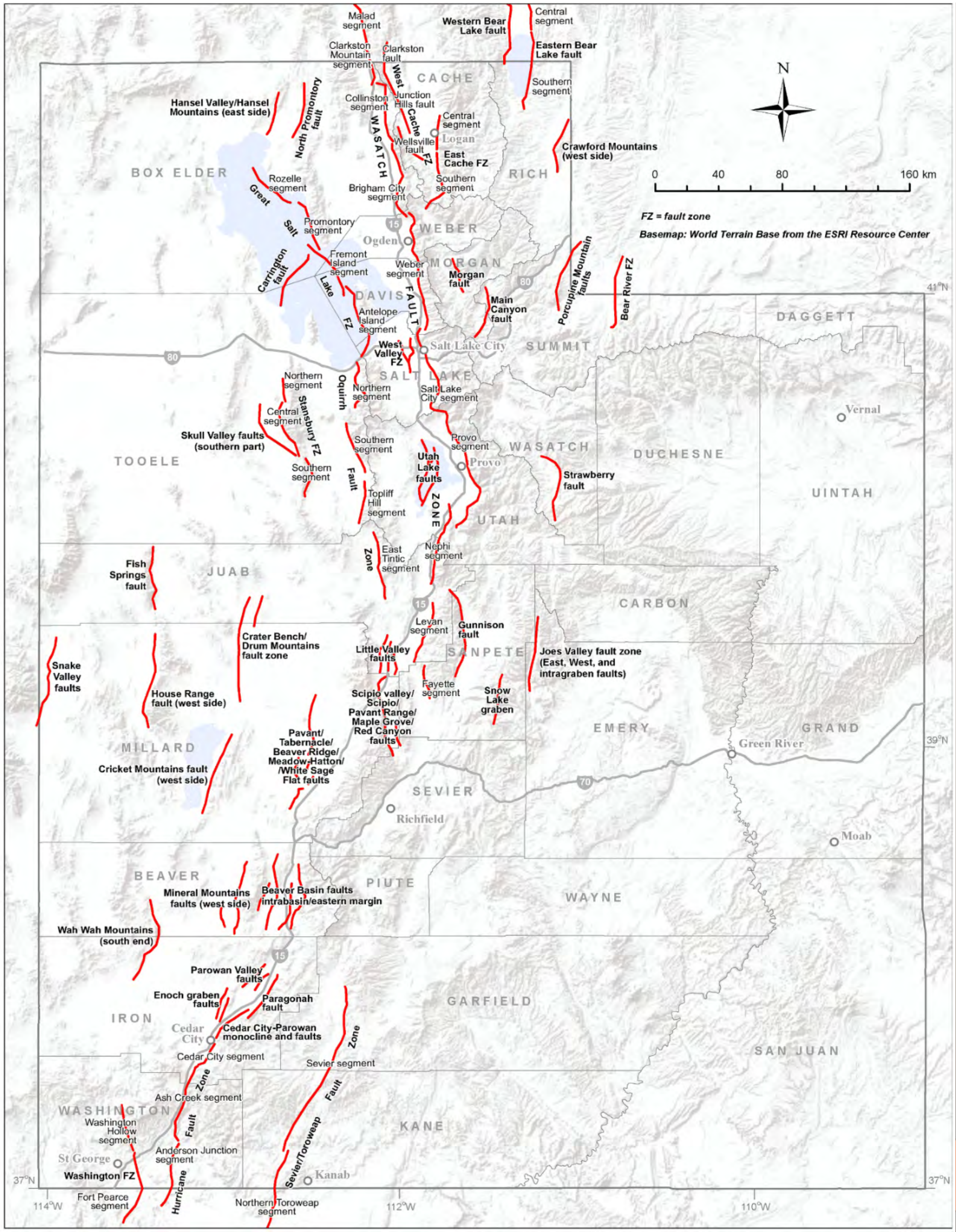
- UGS no longer in an official review position as in the past for the counties or cities
- Client privilege necessitates the consultant requesting client permission for visitors
- Surface-fault-rupture investigations trenches only open for a short time open
- Limited candidate sites for future paleoseimic sites
  - Perishable data along developed faults in urban areas
- Communication between UGS and consultant community
  - UGS Hazard webpage, updated project lists
  - Attendance at local association meetings
- Reports limited to publicly available reports from the regulatory agencies
  - Some reports come in from consultants, but this limited
  - Access with some cities is limited

2019 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]	--	2007
Brigham City segment, Wasatch fault zone[2,3] – most recent event	--	
Carrington fault, Great Salt Lake fault zone[3]	--	
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

Utah Fault or Fault Segment	2005[1]	Additions
Northern Provo segment, Wasatch fault zone[2,3] – long-term earthquake record	--	2011
Taylorsville fault, West Valley fault zone[3]	--	
Hansel Valley fault[2,3]	--	
Acquire new paleoseismic information to address data gaps for the five central segments of the Wasatch fault zone.	--	2012
Focus on the youngest earthquakes (3-5 ka); large, early Holocene–latest Pleistocene scarps; and secondary faulting (West Valley fault zone[1,2,3] and Utah Lake faults and folds[1,3]).	--	Modified 2017
Improve the long-term earthquake record for Cache Valley (East[1,2,3] and West Cache[2,3] fault zones).	--	2013
Use recently acquired lidar data to more accurately map the traces of the Wasatch, West Valley, and Hurricane fault zones, and search for and map as appropriate previously undiscovered mid-valley Quaternary faults[5].	--	2014
East[1,2,3] and West Bear Lake, East and West Cache[1,2,3], and Hurricane[1,2,3] fault zones	--	Modified 2017
Acquire earthquake timing information for the Utah Lake faults[1,3] to investigate the relation of earthquakes to large earthquakes on the adjacent Provo segment of the Wasatch fault zone[3,4].	--	2015
Acquire new paleoseismic information to address data gaps for the northern Oquirrh fault zone[3].	--	
Acquire high resolution aerial imagery (Lidar, Structure from Motion, etc.) and map high-risk (chiefly urban) Utah hazardous faults[5]. Identify future paleoseismic trench sites.	--	
East[1,2,3] and West Bear Lake, East and West Cache[1,2,3], Oquirrh[2,3], and Hansel Valley[2,3] fault zones	--	Modified 2017
Acquire and analyze information on salt tectonics and its relation to the Main Canyon fault[1,3], Sevier detachment/Drum Mountains fault zone[3], Bear River fault zone[2,3], Spanish Valley (Moab area), Joes Valley fault zone[2,3], Levan[1] and Fayette segments[2,3] of the Wasatch fault zone, Scipio Valley faults[3], and the Gunnison fault[1,3].	--	2016
Refine the latest Quaternary earthquake chronology for the Topliff Hills fault[3].	--	

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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2018 List of Highest Priority Faults or Fault Segments

Fault or Fault Segment (Not in Priority Order)	Investigations	
	Status (as of 1/2018)[1,2]	Institution
Acquire new paleoseismic information to address data gaps for (a) the five central segments of the Wasatch fault zone[3,4] (including focusing on the youngest earthquakes [3-5 ka]; large, early Holocene–latest Pleistocene scarps; and secondary faulting [West Valley fault zone[3,4] and Utah Lake faults and folds[4]]), (b) the northern segment of the Oquirrh fault zone[3,4], (c) refining the latest Quaternary earthquake chronology for the Topliff Hills fault[4], and (d) the East and West Cache[3,4] fault zones. Examples of paleoseismic data to acquire include extent of surface-faulting rupture, earthquake timing, displacement, and subsurface fault geometry.	Nephi segment, Spring Lake and North Creek sites: UGS Special Study 159	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 East[3,4] and West[4] Bear Lake, East and West Cache[3,4], and Hurricane[3,4] fault zones, and search for and map as appropriate previously undiscovered mid-valley Quaternary faults.	Hurricane and East and West Cache fault zones lidar and mapping ongoing.	UGS
Acquire earthquake timing information for the Utah Lake faults[4] to investigate the relation of earthquakes on that fault system to large earthquakes on the adjacent Provo segment of the Wasatch fault zone (independent or coseismic ruptures, fault pairs?).	No activity	--
Acquire high-resolution aerial imagery (lidar[5], Structure from Motion, etc.), map high-risk (chiefly urban) Utah hazardous faults (including the East[3,4] and West[4] Bear Lake, East and West Cache[3,4], Oquirrh[3,4], and Hansel Valley[3,4] fault zones), and identify new paleoseismic trench sites.	Mapping: East and West Cache fault zones ongoing.	UGS
	Lidar: Remaining portions of the East and West Bear Lake, East and West Cache, and Oquirrh fault zones planned in 2018.	State of Utah/UGS
Acquire and analyze information on salt tectonics and its relation to the Main Canyon fault[4], Sevier detachment/Drum Mountains faults[4], Bear River fault zone[3,4], Spanish Valley (Moab area), Joes Valley fault zone[3,4], Levan[3,4] and Fayette[4] segments of the Wasatch fault zone, Scipio Valley faults[4], and the Gunnison fault[4].	Levan and Fayette segments paleoseismic investigation ongoing.	UGS
	Moab quadrangle salt-tectonics-related ground subsidence hazard mapping ongoing.	UGS
	Lidar: Most of Moab/Spanish Valley planned in 2018.	UGS/State of Utah

2018 List of Other Priority Faults or Fault Segments

Fault or Fault Segment	UQFPWG Priority[1]	Investigations	
		Status (as of 1/2018)[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 ongoing	UGS
Gunnison fault[4]	17	No activity	--
Scipio Valley faults[4]	18	Lidar: planned in 2018.	State of Utah/UGS
Faults beneath Bear Lake	19	No activity	--
Eastern Bear Lake fault zone[4]	20	Lidar: planned in 2018.	State of Utah/UGS
Carrington fault, Great Salt Lake fault zone[4]	2007	No activity	--
Rozelle section, Great Salt Lake fault zone[4,6]	2007	Janecke and Evans (2017)	USU