2018 Basin and Range Province Earthquake Working Group (BRPEWG) Meeting

Thursday, February 15, 2018


Airport East Site (Taylorsville Fault)

UTAH GEOLOGICAL SURVEY

Background

- The Utah Geological Survey reactivated the Basin and Range Province Earthquake Working Group (BRPEWG), due to the general lack of other Basin and Range Province (BRP)/ Intermountain West (IW) state earthquake working groups and the need for effective communication and collaboration in applied earthquake-hazard research within the region.

- BRPEWG was previously convened in 2006 and 2011, in response to U.S. Geological Survey (USGS) National Seismic Hazard Map update issues, and was hosted by the UGS.

- Part of the highly successful Utah Earthquake Working Groups framework that consist of three standing committees created to help set coordinate earthquake-hazard research in Utah.

- Working group intended to be focused on the Intermountain West, not just Utah, and help all states deal with earthquake hazards. We are all in this problem together.

Agenda

8:00 Refreshments

8:00 – 8:30 Welcome and Overview of Meeting

8:30 – 10:00 State Presentations on Technical Issues (3)

10:00 Break (15 min)

10:15 – 11:45 Technical Presentations (3)

11:45 Lunch (1 hour, provided for those who have registered and paid)

12:45 – 2:45 Technical Presentations (4)

2:45 Break (15 min)

3:00 – 3:30 Special Presentations (2)

3:30 – 5:00 Discussion – BRP Earthquake Hazard Issues and Investigation Priorities

See printed agenda for background information.

The State of Seismic Hazard Assessment in Arizona

Basin and Range Province

Earthquake Working Group

February 2018

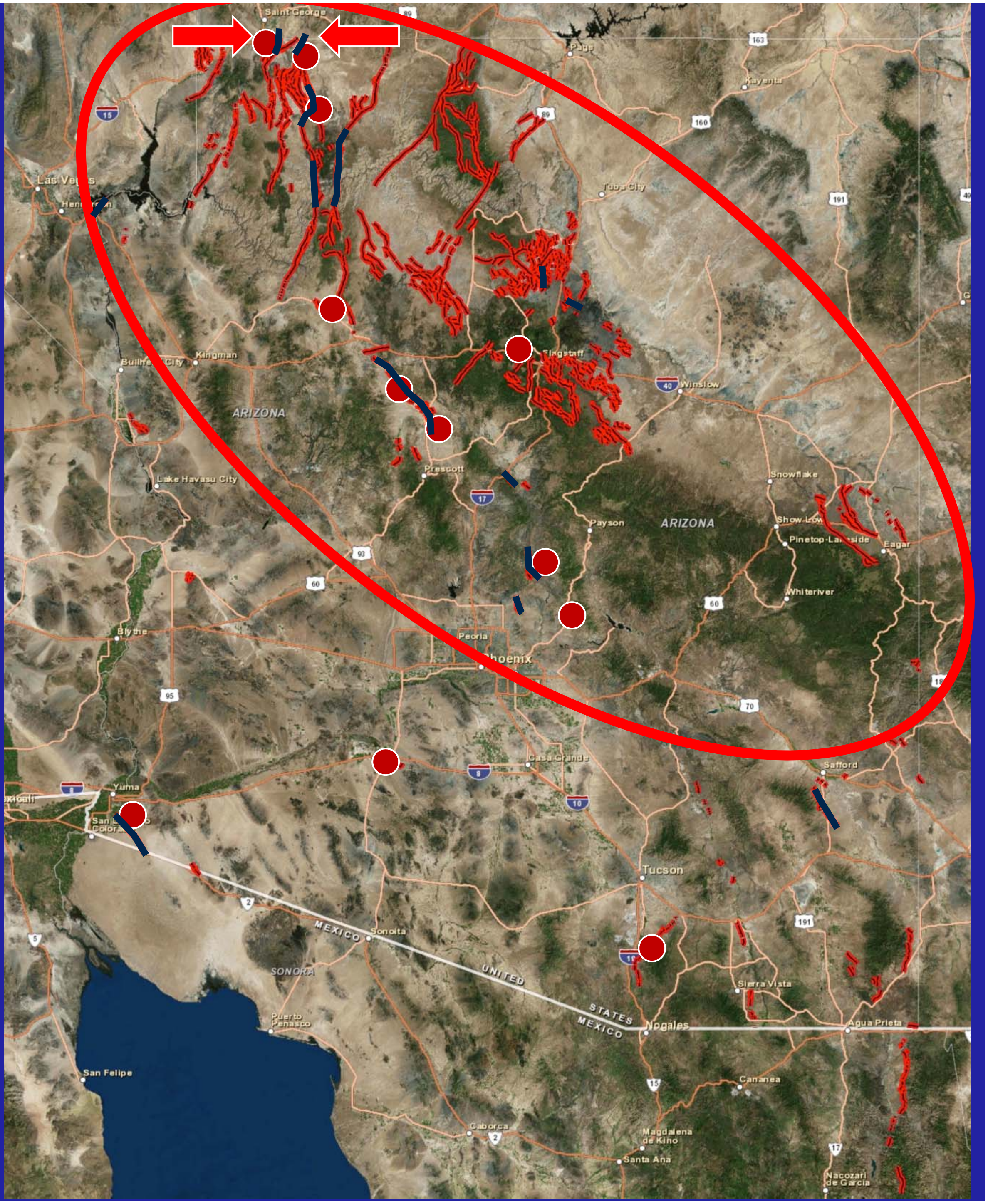
Philip A. Pearthree

Arizona Geological Survey

- Briefly review historical seismicity and Quaternary faults across AZ
- Consider some key issues for seismic hazard assessments
  - Quaternary faulting
    - Mead Slope, Big Chino+, Lake Mary, Hurricane
    - Many low-slip-rate faults in the Flagstaff area - cumulative impact on probabilistic assessments?
  - Historical seismicity
    - Evolving detection thresholds, what events included, current broad-band seismic network
  - Geodetic strain rates
    - Complications from large plate boundary earthquakes
    - Similar rates across northern and southern AZ; Weird!

Quaternary Faults in AZ

- ~100 faults active since 2.6 Ma
- concentrated along Colorado Plateau margin
- highest known slip rate ~0.2 m/kyr
- ~14 active since 15 ka
- ~12 faults trenched - most barely studied



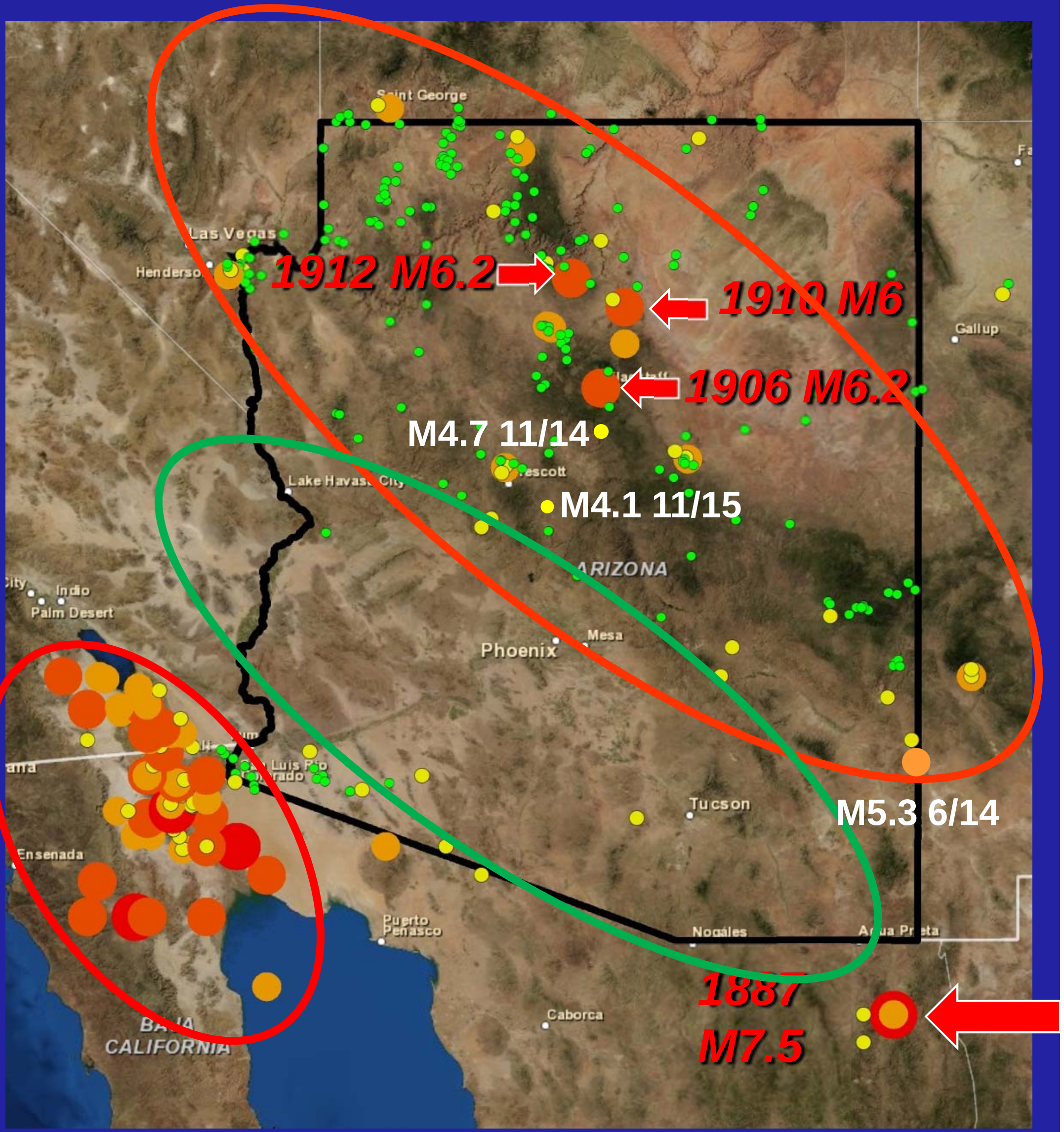
Historical Seismicity in Arizona

~1850 to 1900

- lots of action in N Mexico, S California
- *a big earthquake in the southern Basin and Range*

1900 to present

- Flagstaff area cluster
- Moderate seismicity mainly in northern AZ since then
- Absence of seismicity in much of SW AZ
- Recent earthquakes shook all major pop centers

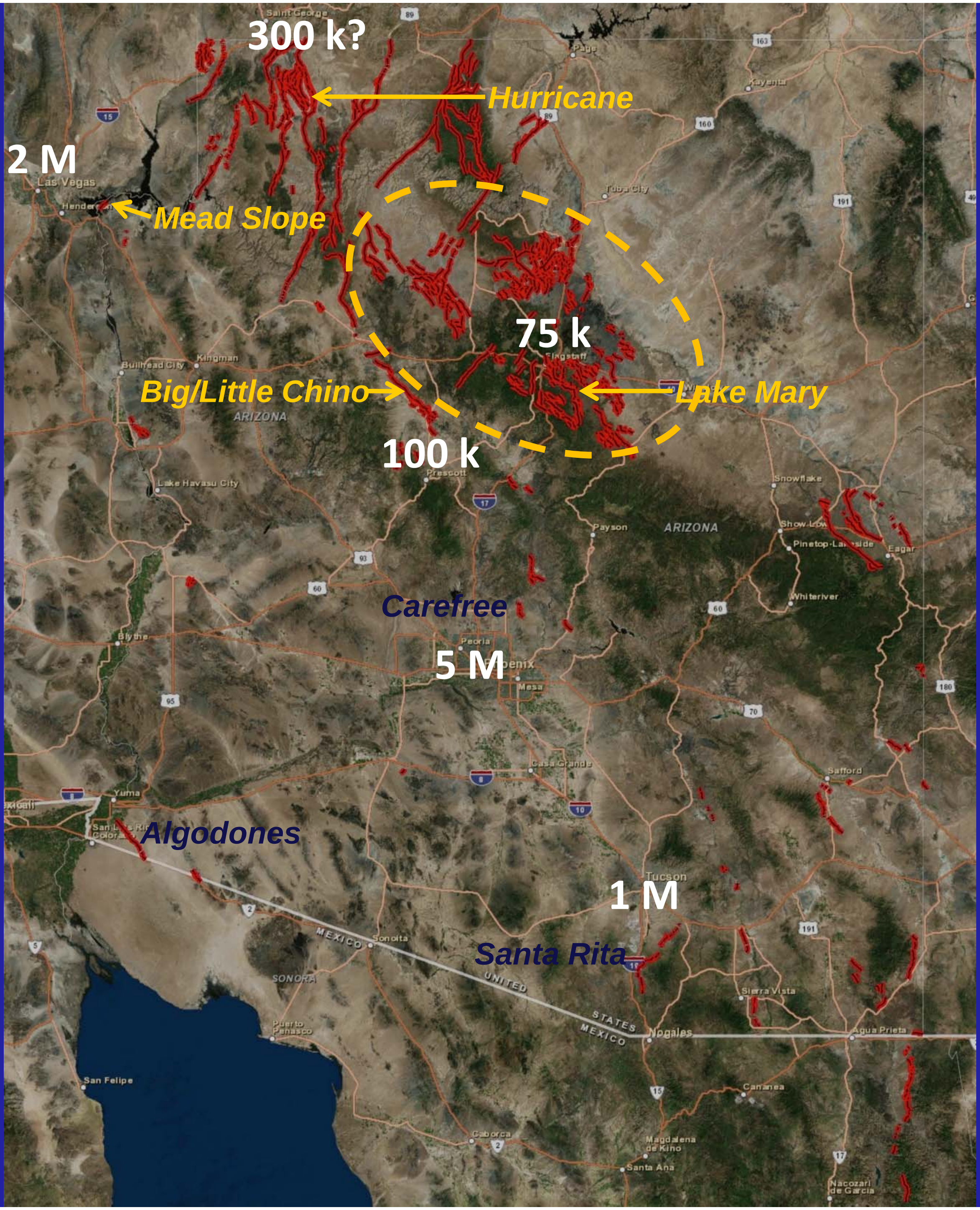


What is [fairly] new?

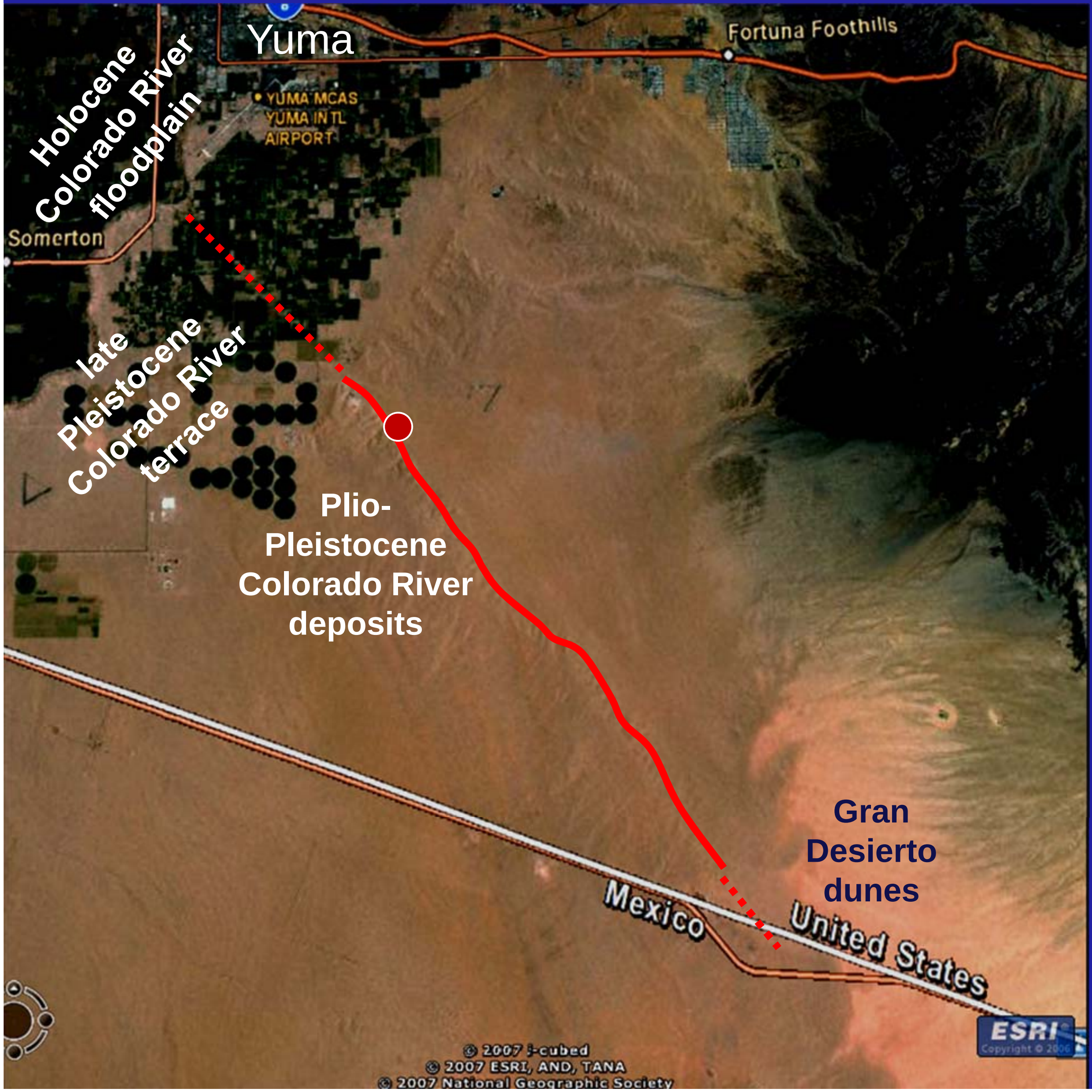
- On-going geologic mapping of areas including Q fault zones
  - Found one new set of faults,
  - More thoroughly characterized several other fault zones
- New project – Mead Slope fault zone
- Geodesy
  - Measurements over past ~20 yrs
  - Complications from large plate boundary earthquakes
  - Surprisingly similar extension rates across southern and northern AZ
- Enhanced broadband seismic network
  - Better coverage to more uniformly detect m~2.5 or greater events
  - More accurate locations for moderate events

Most hazardous faults in AZ

- Populations centers – *Phoenix, Tucson*
- Mead Slope - *Las Vegas, Hoover Dam*
- Lake Mary - *Flagstaff*
- Big/Little Chino - *Prescott*
- Hurricane - *Southwest UT*
- Many distributed faults, NC AZ
- *Honorable mention*
  - *Algodones, Santa Rita, Carefree*



Algodones fault



- NW-trending; margin of plate boundary system?
- Near Yuma metro area
- Trenched in early 1970's; evidence of multiple 0.5 – 1.5 m surface ruptures
- Youngest event 11-15 ka
- At least 15 m vertical displacement of ***Plio-Pleistocene*** river deposits
- *Minimal detectable deformation of 50-100 ka Colorado R deposits*
- ***Much lower slip rate than previously inferred***

Mead Slope Fault

- Apparently pretty short but ends are buried or submerged
- Offsets a variety of Pleistocene fans by increasing amounts
- Essentially in Lake Mead, near Las Vegas and very near Hoover Dam
- Many other Q faults in Las Vegas area, few in AZ

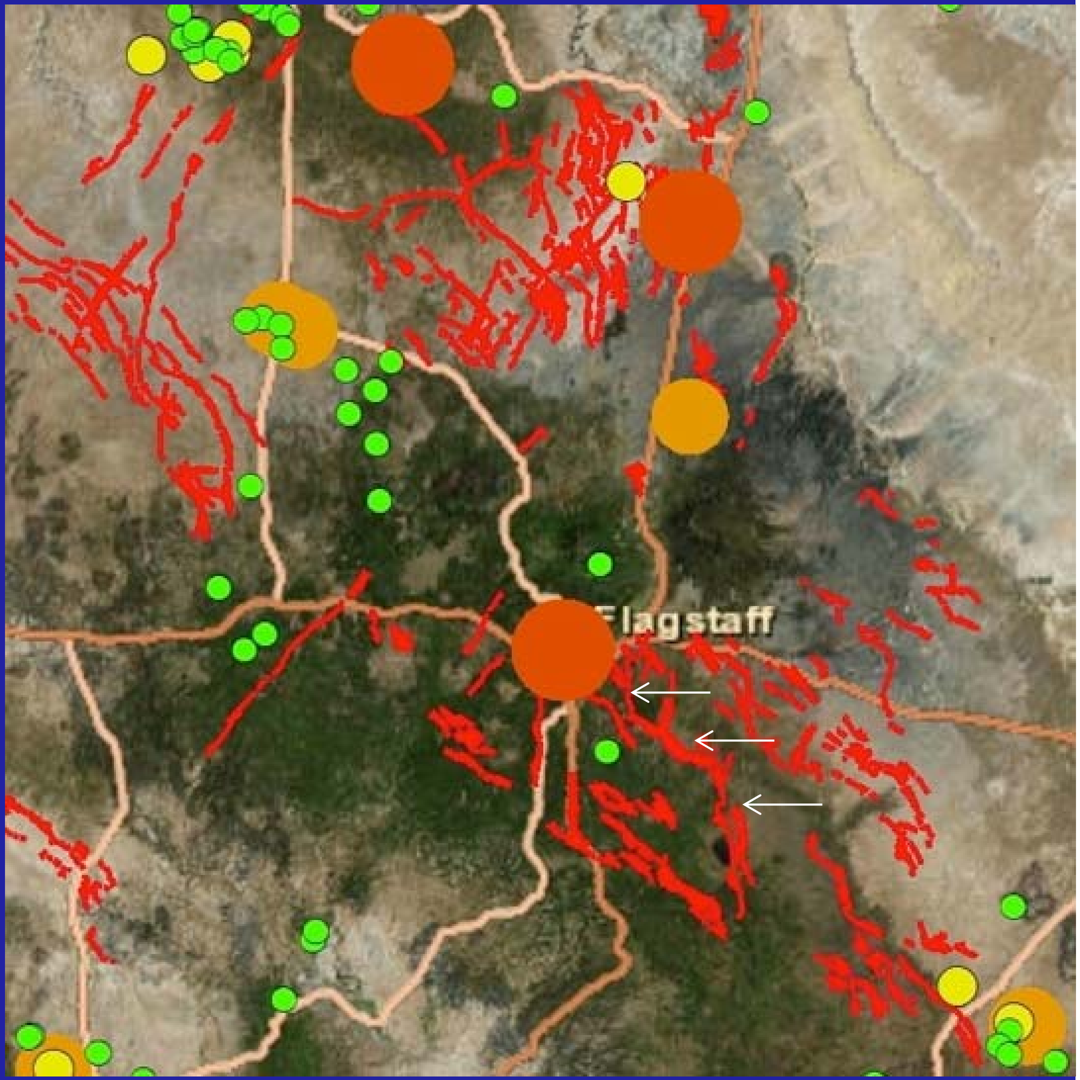
Las Vegas

Mead Slope Fault

- Offsets of latest Pleistocene and older Pleistocene fan by increasing amounts
- Displaces young fan deposits
- Primarily left-lateral displacement, near vertical fault

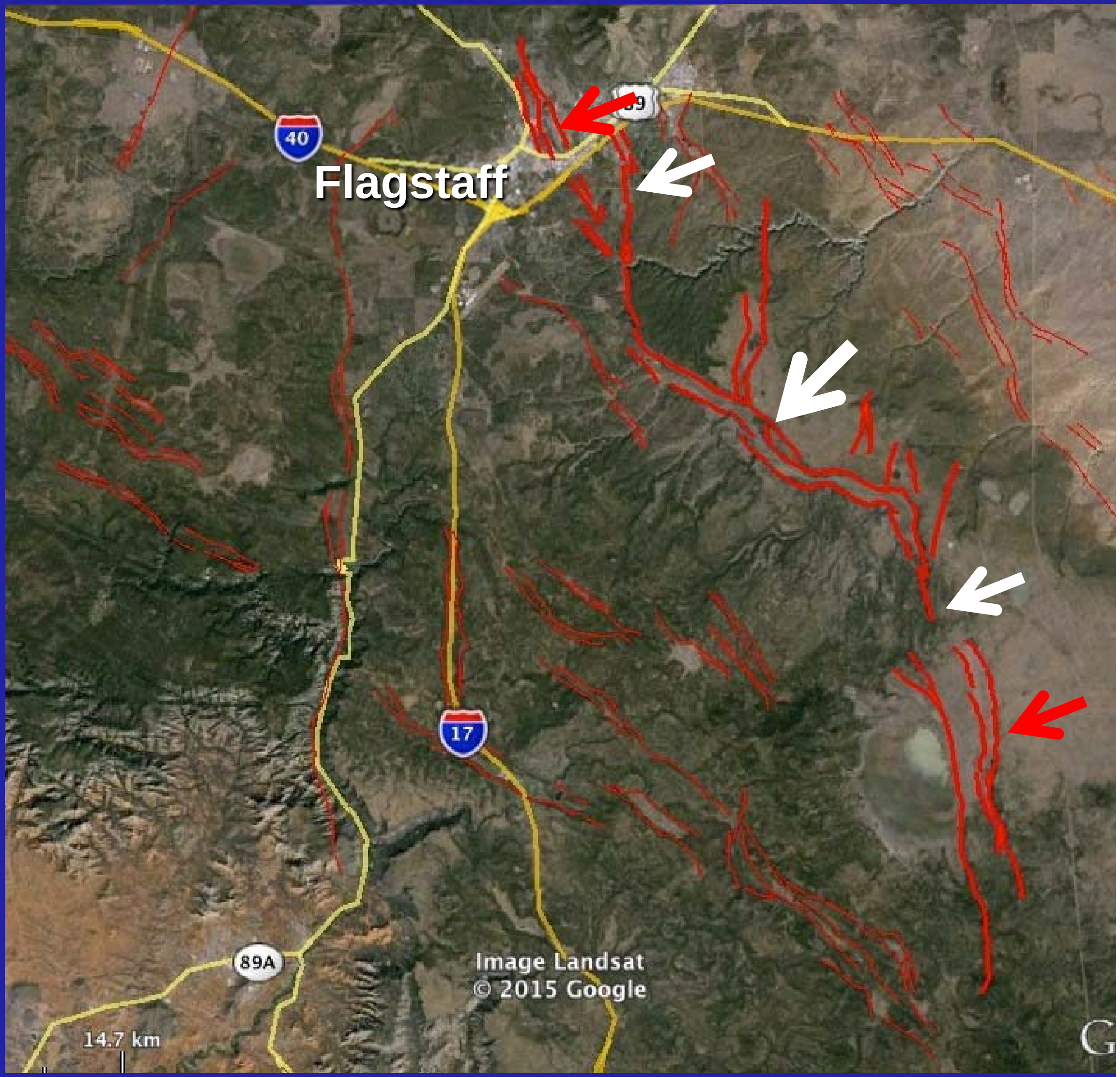
Lake Mary fault zone

- Fairly high regional seismic hazard?
  - historical seismicity
  - abundant young faults
- Lake Mary fz
  - potentially longest, length very uncertain, most displacement of any fault zone in area
- Close to Flagstaff pleasantly expanding urban area



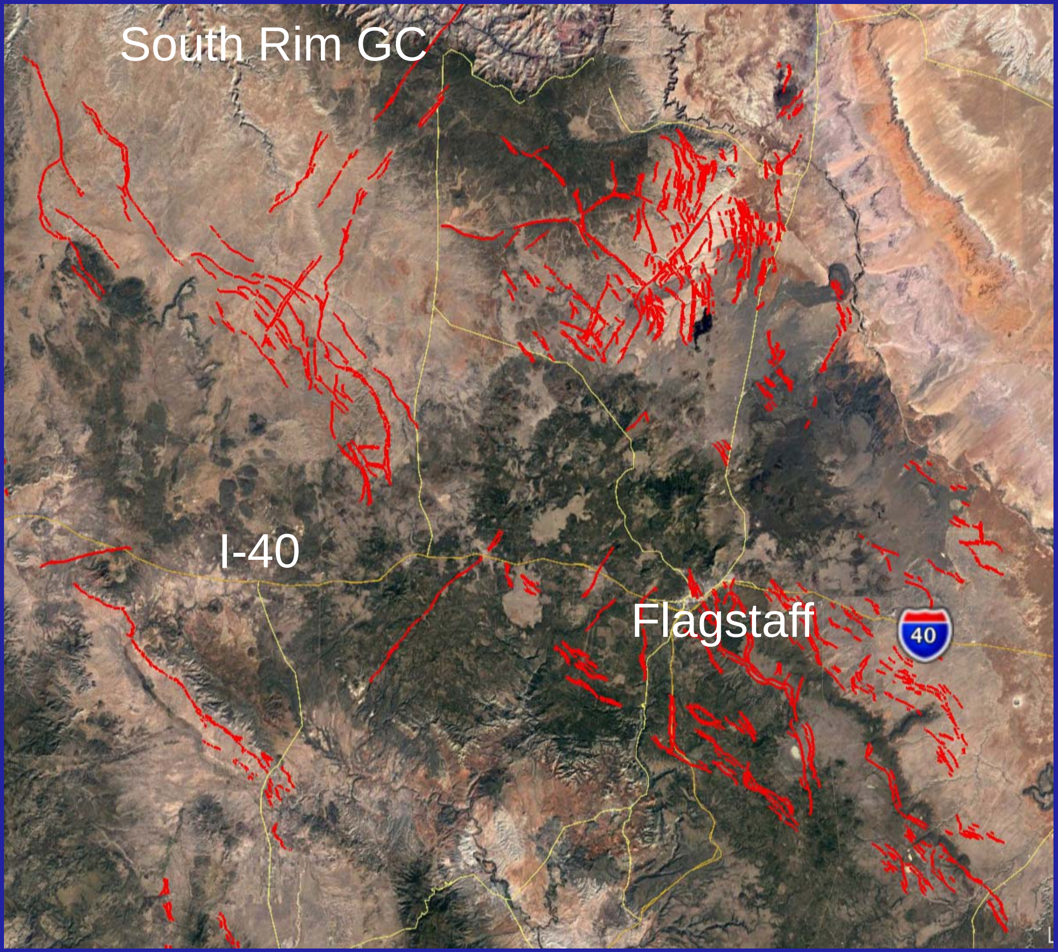
Lake Mary+ Fault Zone

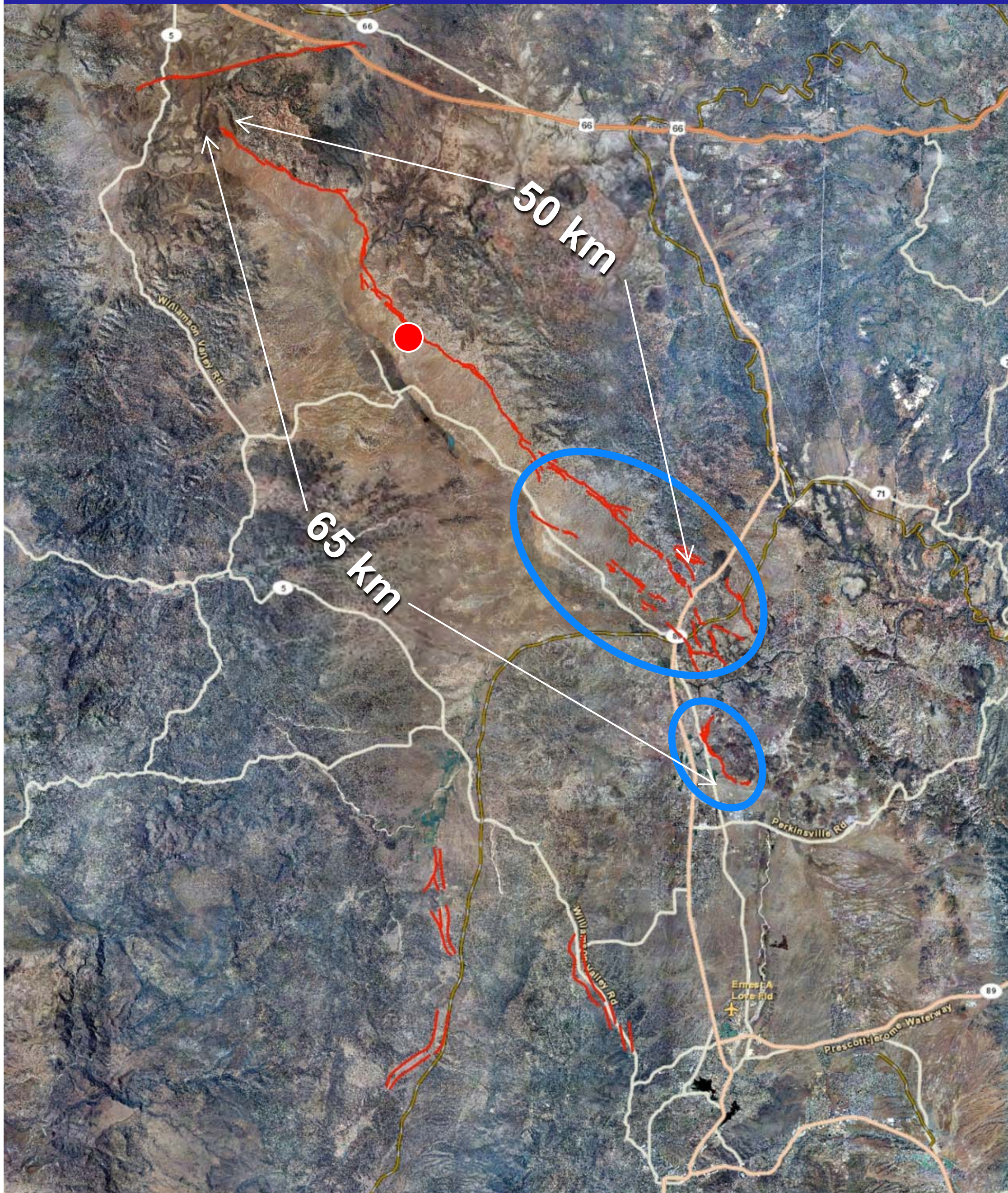
- 25-km-long impressively sharp bedrock escarpment
- ~130 m vertical displacement of ~6 Ma basalt, >0.02 m/kyr rate
- Could link with other adjacent fault zones, into Flagstaff?
- Max rupture length of 50 km is reasonable
- ***Age and length of youngest rupture unknown***



Many faults in northern AZ

- Some cut Q basalt flows
- More form bedrock scarps
- Faulted alluvium not common
- All likely low slip rates
- But poorly characterized
- Cumulative effect on regional seismic hazard?





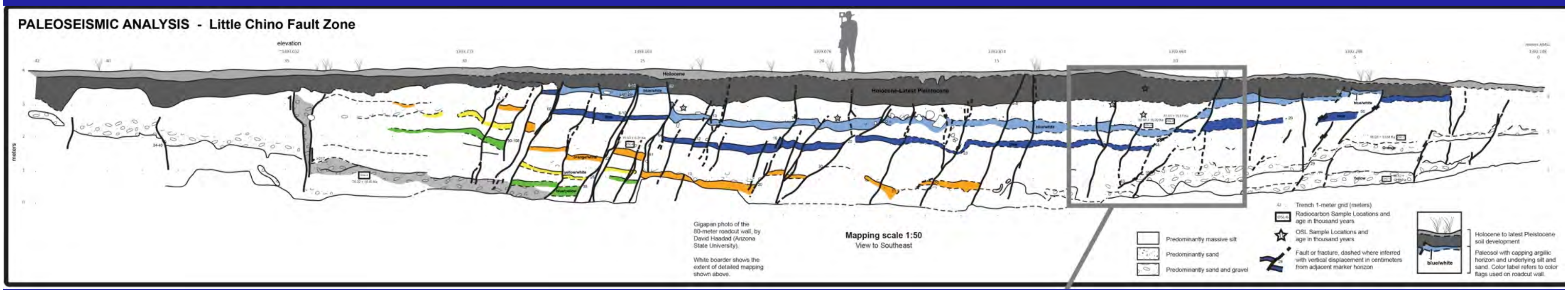
Big Chino Fault Zone

- ~ 50 km fault zone along SW margin of Colorado Plateau
- Geomorph analysis and trenching in 1980's and 1990's indicated latest Pleistocene faulting, slip rate ~0.1m/kyr
- New geologic mapping revealed more young faulting at SE terminus
- Length increase to 65 km? implications for M estimates

Big Chino Fault Zone

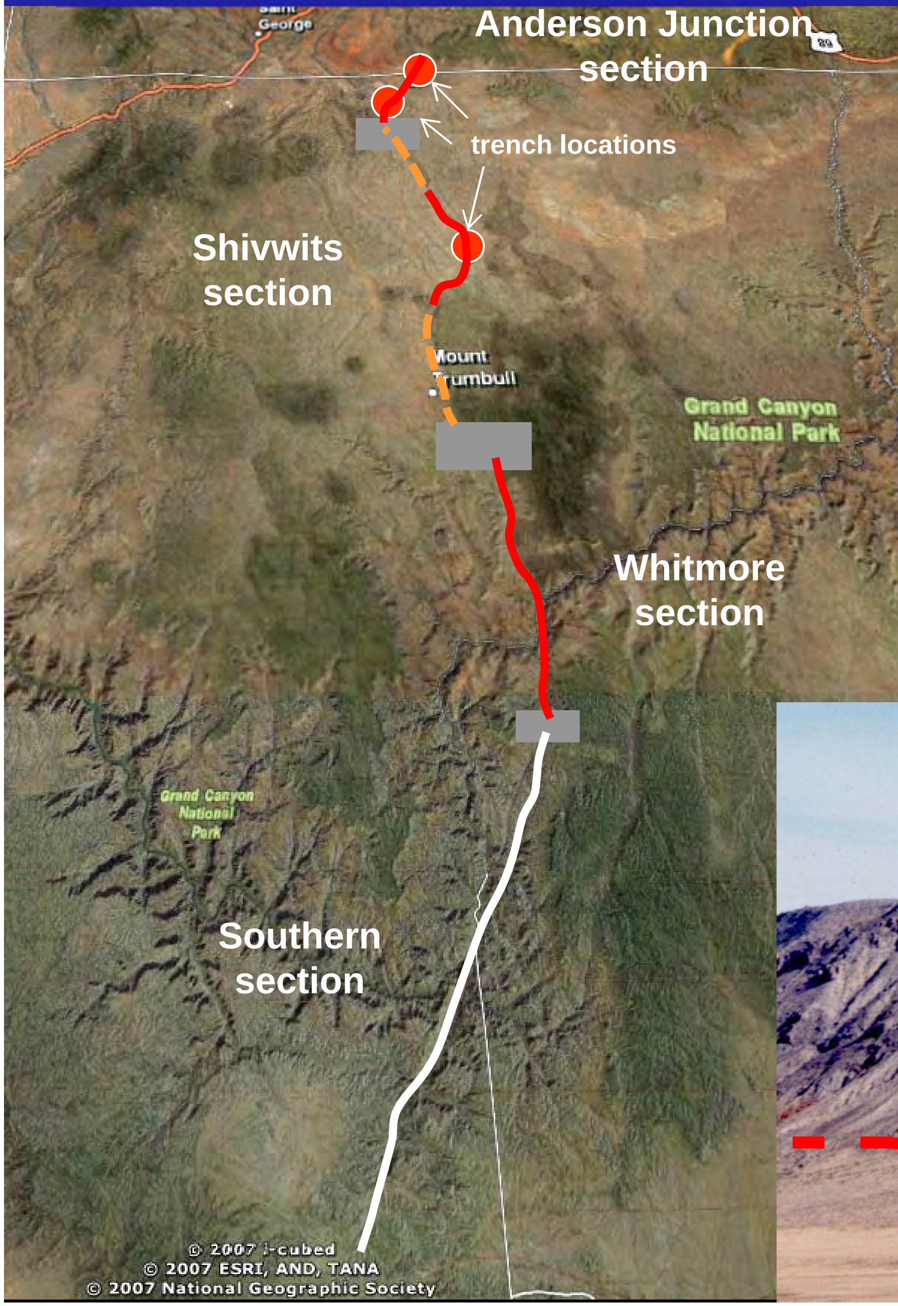
- 20+ m high fault scarps common, probably middle Pleistocene alluvial fans
- Trenching suggests 3 surface ruptures in past ~100 ky, youngest rupture ~latest Pleistocene

Little Chino addition



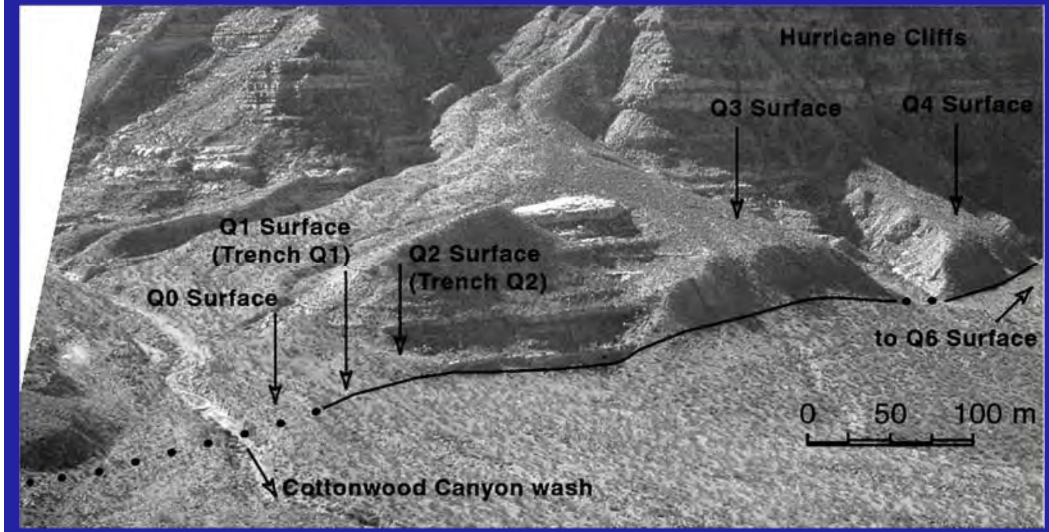
- Roadcut fortuitously discovered during geologic mapping
- Complex faults cut Quaternary deposits, nice buried soils
- Clear evidence for recurrent faulting, most recent event may be early Holocene
- ***Fault interactions uncertain; need for better constraints on age of youngest movement on Big Chino fz***

Hurricane fault

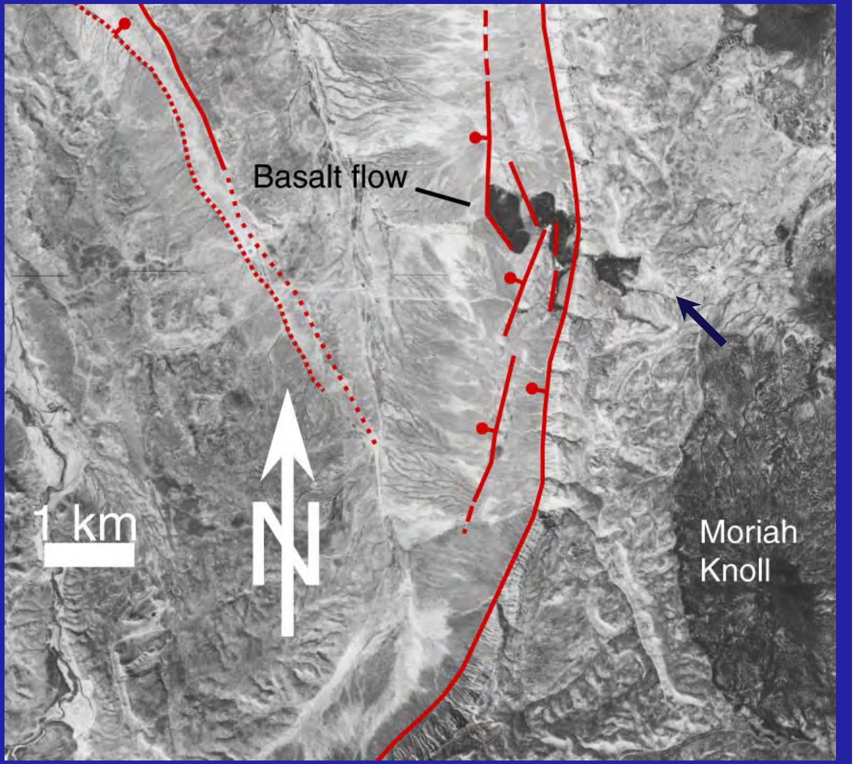


- 250 km long fault shared by Arizona and Utah
- Impressive fault escarpment, late Quaternary faulting
- Primary hazard in bourgeoning southern Utah

Hurricane fault



- Displacement of early Holocene and Pleistocene alluvial surfaces
- 20 m vertical displacement of ~100 ka Q3 surface
- Slip rate of ~0.2 mm/yr



- Basalt erupted ~850,000 yrs ago
- Displaced ~200 m
- Long-term slip rate of ~0.2 mm/yr

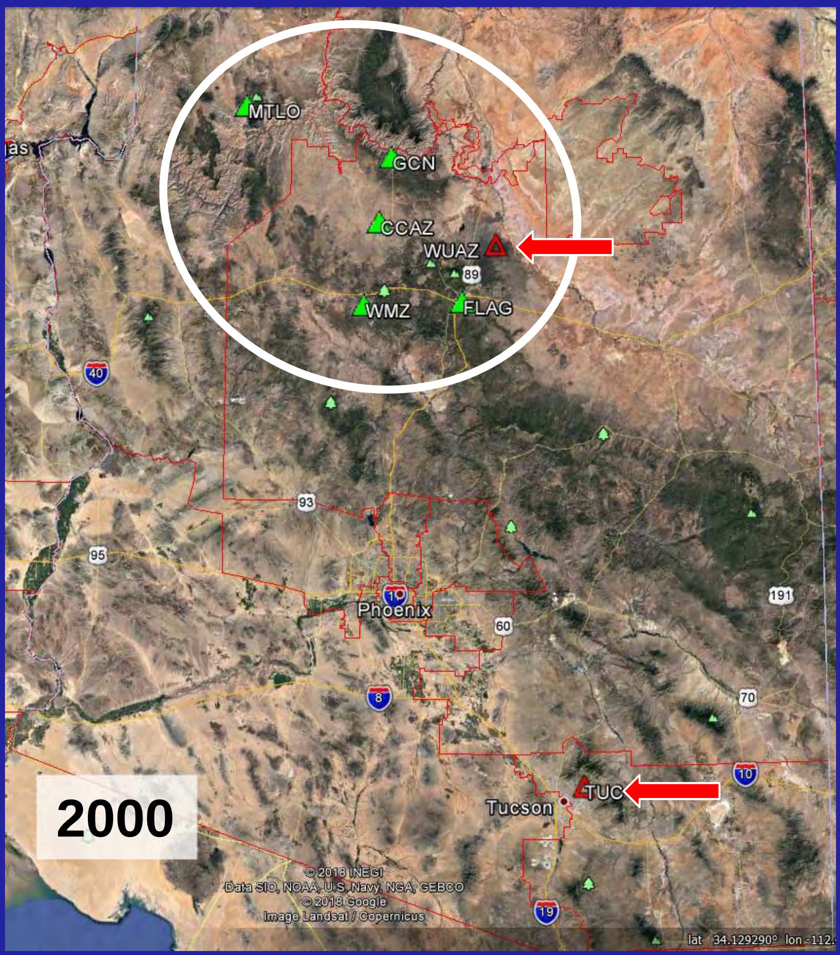
Hurricane fault seismic hazard

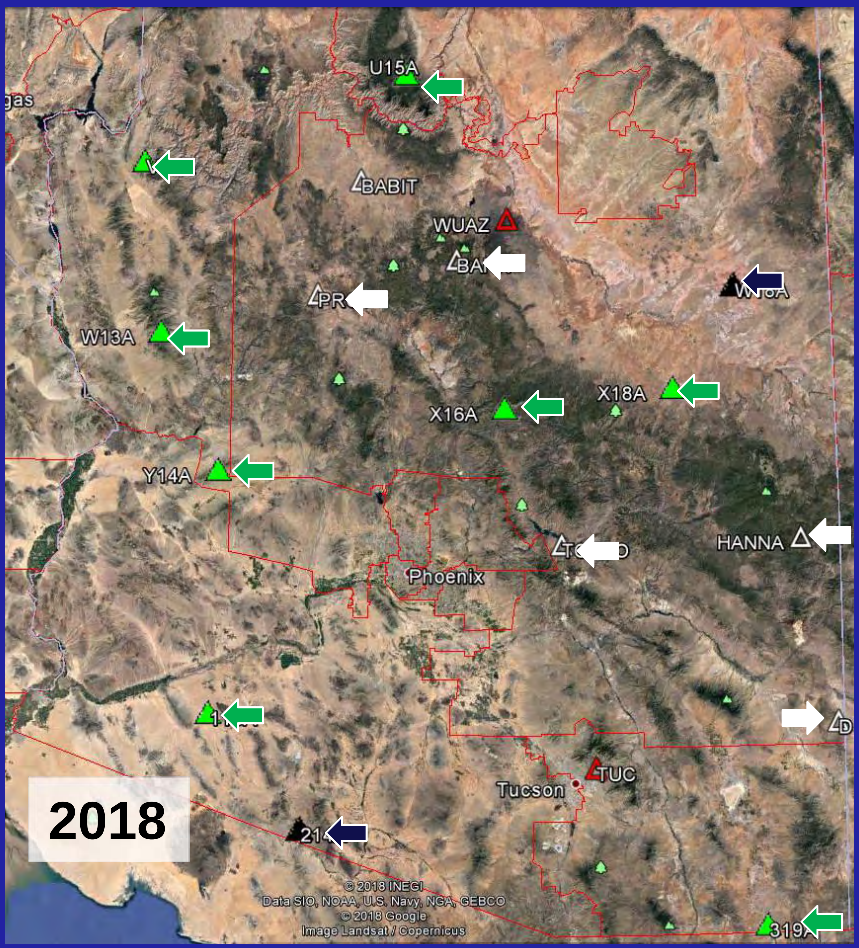
- **At least 3 sections of Hurricane fault likely ruptured in large earthquakes in past 20,000 yrs**
- **Trenching data and long-term slip rates suggest recurrence intervals of 10,000 to 30,000 yrs for individual segments**
- ***Individual rupture lengths poorly defined***
- ***Substantial uncertainty for hazard assessments***

Enhanced Seismic Network

- Major increase in the number of seismometers in AZ since 2000
- All broadband
- Calibrating autodetect methods
- Legacy analog network in northern AZ operated by NAU/AEIC

Added seismic stations

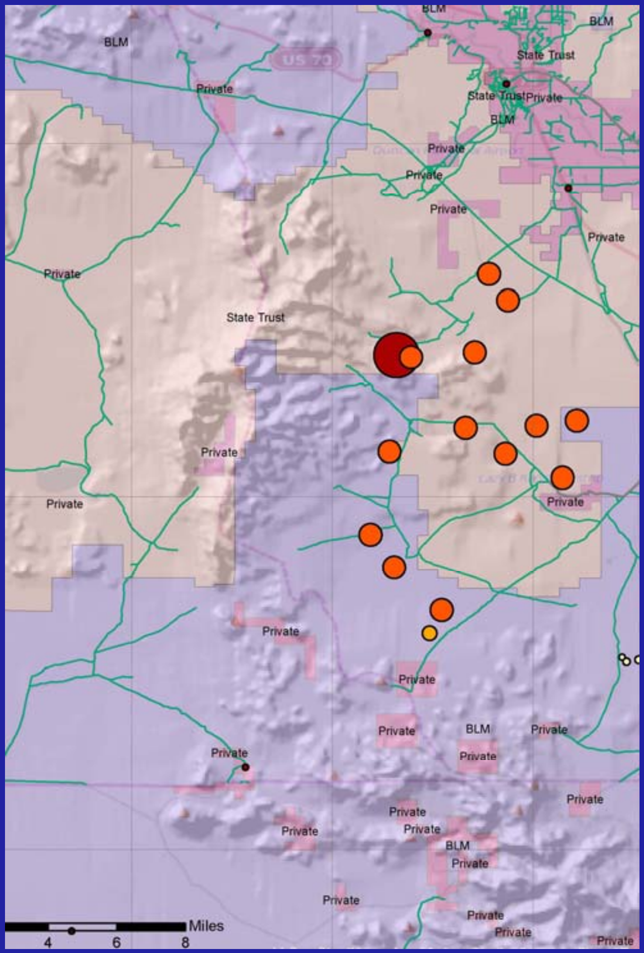




Probably detect all EQs >M2.5

Temporary networks – Duncan sequence

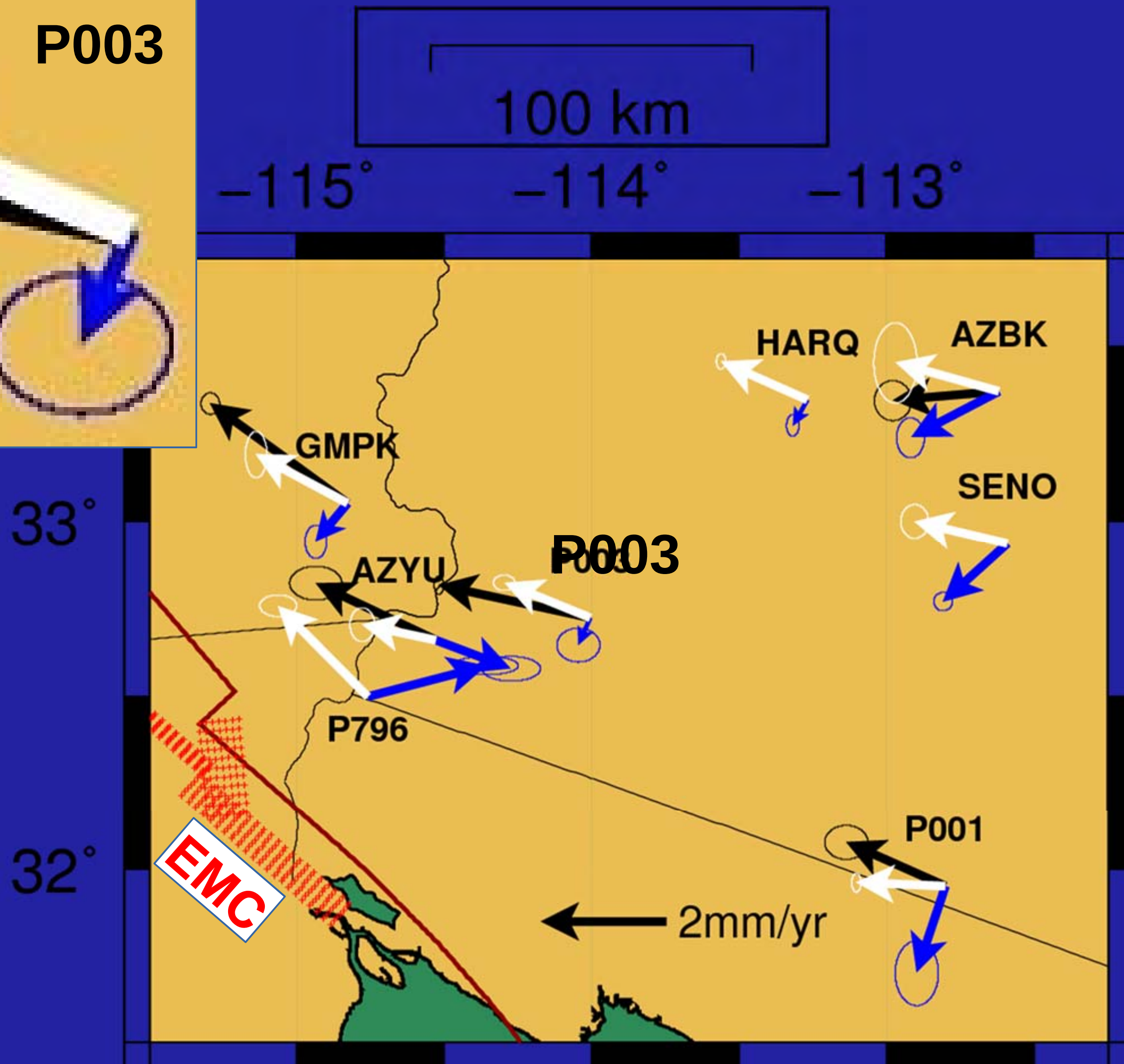
- M 5.3 event 30 Jun 2014
- Temporary network deployment for ~3 months
- Assistance from PASSCAL
- Delineating structure(s)?



Geodesy

- Rick Bennett, Austin Holland, James Broermann, UA
- Corne Kreemer, Bill Hammond, UNR
- Several networks and campaigns
- Regional measurements over past ~20 yrs, and active monitoring

Observed Time-Varying Velocities southwest AZ

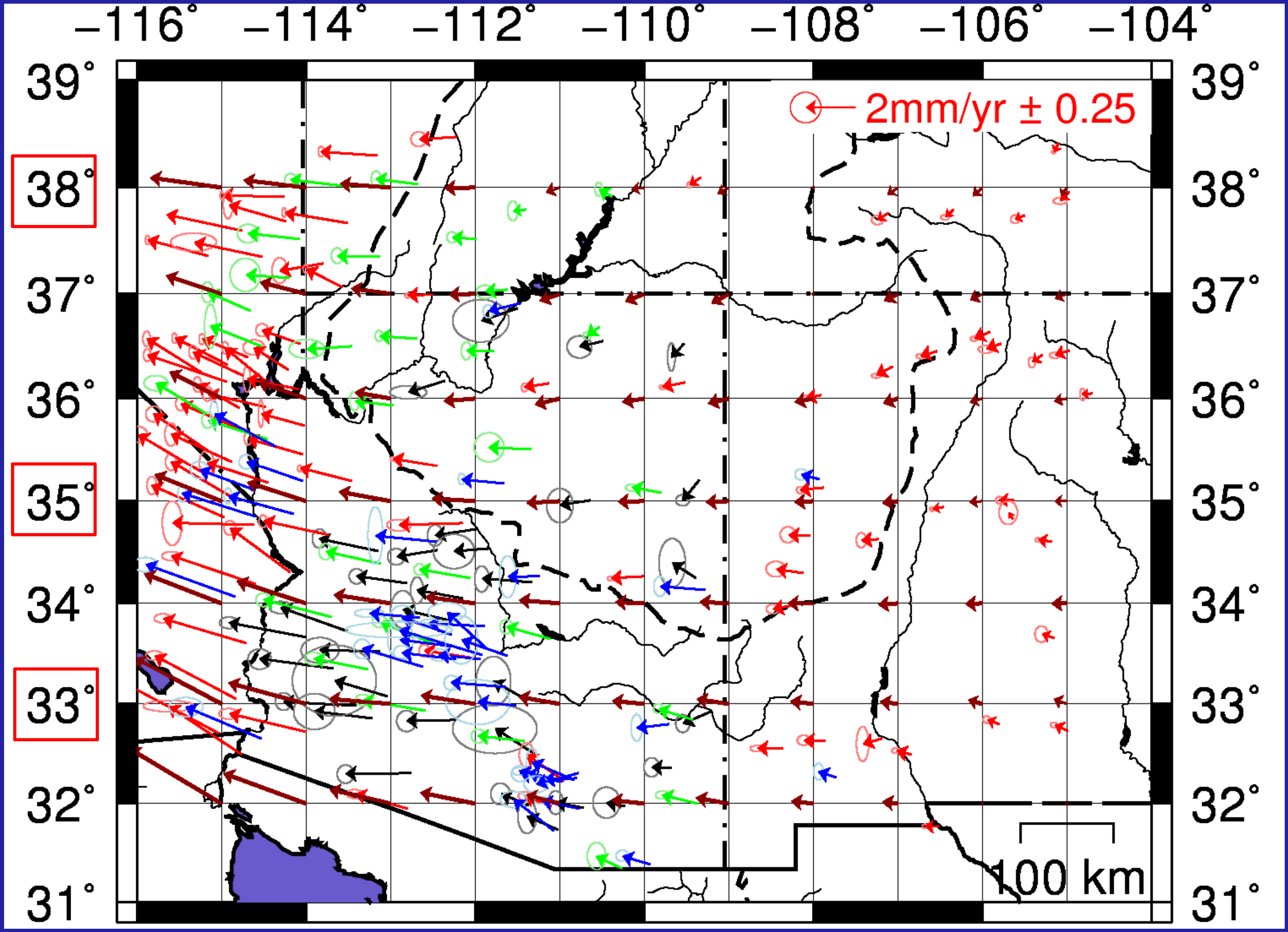


Pre-EMC black
2011-2013 blue
2014-2016 white

El Mayor-Cucapah
4 April, 2010 (EMC)
Mw 7.2

Time-invariant velocities used to calculate strain

ES sites (this study)   PBO   CORS   Campaign



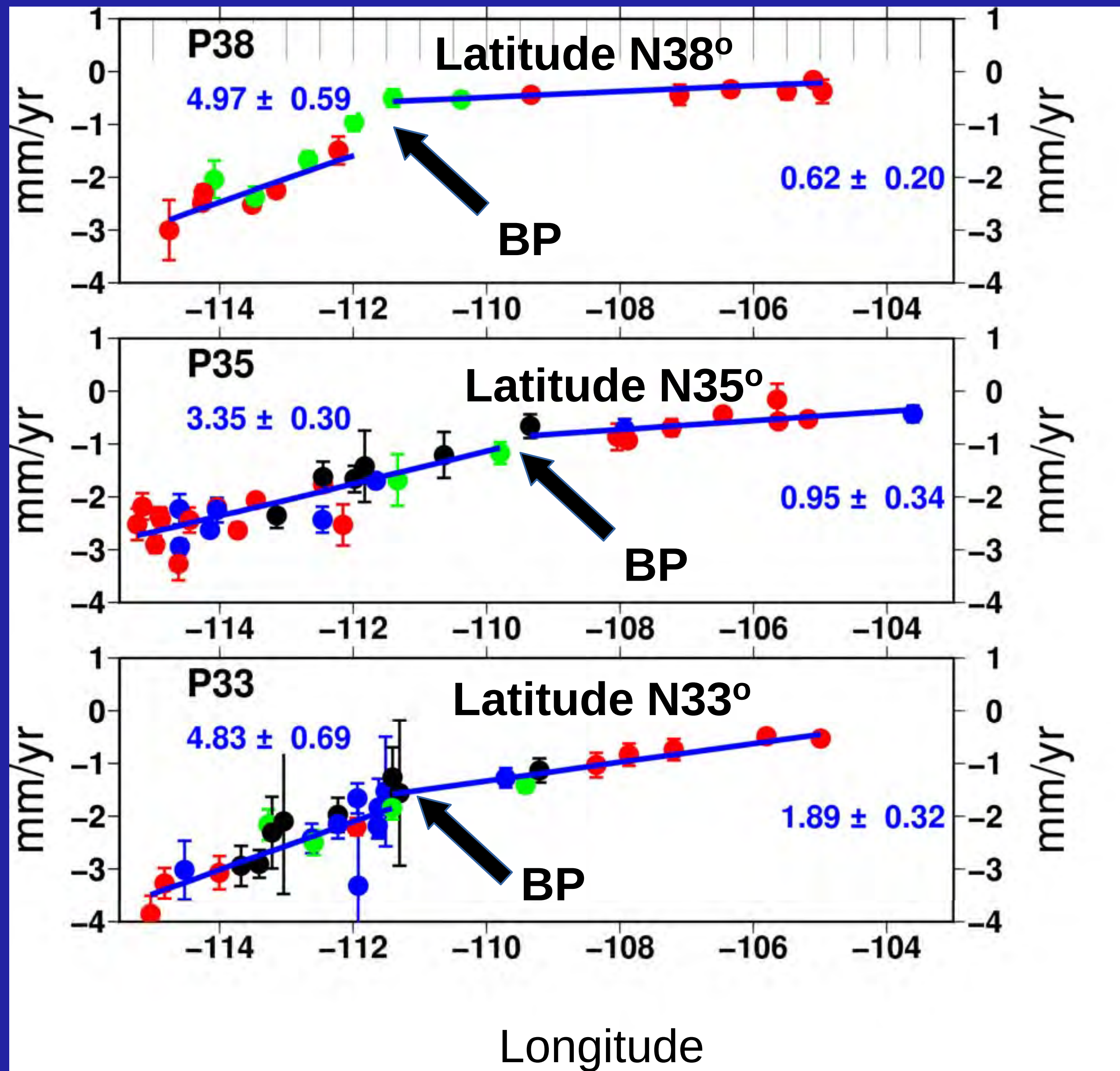
East component of velocity along lines of latitude

Velocities:

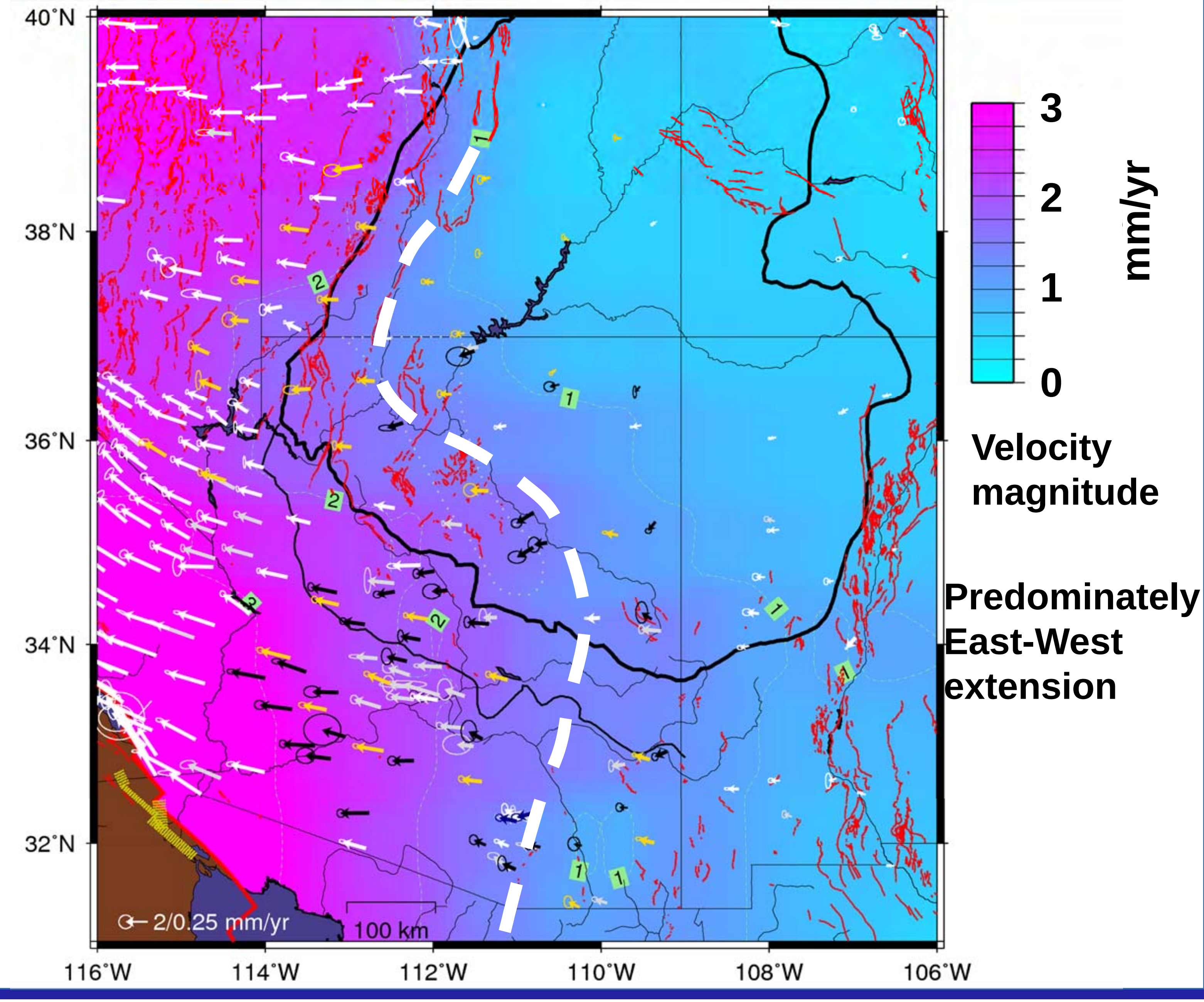
ES sites (this study)
PBO **Campaign**
CORS

Blue numbers are velocity gradients in nanostrains/year.

Break point between segments is used to define deformation boundary zone.



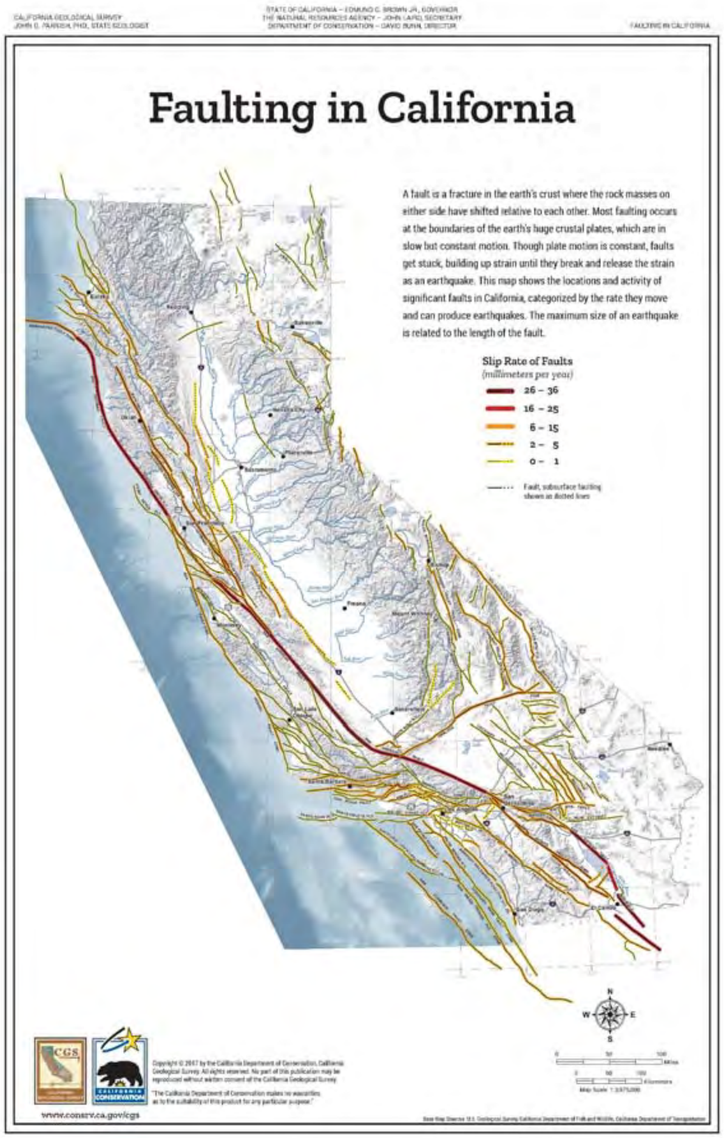
Time-invariant velocity field



Predominately East-West extension

Geodetic interpretations

- Earthquakes along the plate boundary can change the surface velocity field in the Southern Basin and Range.
- Time-varying velocities can lead to brief periods of shortening and longer term reduction in rates of extension in the Southern Basin and Range.
- Time-invariant velocities indicate two deformation domains, a relatively lower strain rate eastern domain and relatively higher strain rate western domain.
- It is not clear at this time why the discrepancy exists.
- **This introduces some significant uncertainty into previous seismic hazard interpretations**



Technical Issues for the Basin and Range:

Gordon Seitz, California Geological Survey

Major Revision to California Guide for Assessing Fault Rupture Hazards Publication 42

Selected Fault Zoning Issues
Examples –

Napa 2014 Earthquake and West Napa Fault

West Tahoe Fault

SPECIAL PUBLICATION 42
Revised 2018

EARTHQUAKE FAULT ZONES

A GUIDE FOR GOVERNMENT AGENCIES, PROPERTY OWNERS / DEVELOPERS, AND GEOSCIENCE PRACTITIONERS FOR ASSESSING FAULT RUPTURE HAZARDS IN CALIFORNIA

CALIFORNIA GEOLOGICAL SURVEY

DEPARTMENT OF CONSERVATION
CALIFORNIA GEOLOGICAL SURVEY

STATE OF CALIFORNIA
EDMUND G. BROWN, JR.
GOVERNOR

THE NATURAL RESOURCES AGENCY
JOHN LAIRD
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
DAVID BUNN
DIRECTOR

CALIFORNIA GEOLOGICAL SURVEY
JOHN G. PARRISH, *PH.D.*
STATE GEOLOGIST

In 2016, the California Geological Survey convened an expert panel to focus on the development of an update to Special Publication 42. The intent was to prepare a guidance document for fault rupture hazards similar to CGS Special Publication 117A, which addresses hazards from soil liquefaction and earthquake-triggered landslides. This panel was composed of geoscience researchers, consultants and reviewers, as well as representatives of state, regional and local government agencies. Their willing participation in the preparation of this document significantly improved its quality and is greatly appreciated.

2016 to 2017 California Geological Survey Special Publication 42 Advisory Panel

- Robert Anderson – Alfred E. Alquist Seismic Safety Commission
- Dana Brechwald – Association of Bay Area Governments
- Dr. Alan Hull – Golder Associates Inc.
- Dr. Tom Rockwell - San Diego State University, Department of Geological Sciences
- Scott Lindvall – Lettis Consultants International, Inc.
- Sandra Potter – County of Sonoma; Chair, Geohazards Committee, State Mining and Geology Board
- Ted Sayre – Cotton, Shires and Associates, Inc.
- Dr. David Schwartz – U.S. Geological Survey

2016 to 2017 California Geological Survey Staff

- Timothy Dawson – Senior Engineering Geologist
- Timothy McCrink – Supervising Engineering Geologist
- Ron Rubin – Engineering Geologist
- Dr. Gordon Seitz – Engineering Geologist
- Eleanor Spangler – Engineering Geologist
- Christopher Tran – Student Assistant

SPECIAL PUBLICATION 42

EARTHQUAKE FAULT ZONES

A GUIDE FOR GOVERNMENT AGENCIES, PROPERTY OWNERS / DEVELOPERS, AND GEOSCIENCE PRACTITIONERS FOR ASSESSING FAULT RUPTURE HAZARDS IN CALIFORNIA

Revised 2018

California Department of Conservation
California Geological Survey
801 K Street, MS 12-31
Sacramento, CA 95814

Photo: Cottage destroyed by surface fault rupture on the Kekerengu Fault during the Mw 7.8 2016 Kaikoura earthquake, New Zealand. Approximately 10 meters of right-lateral fault displacement occurred under this house, tearing it from its foundation. Photo credit: VML 190573, Julian Thomson, GNS Science / Earthquake Commission

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ILLUSTRATIONS

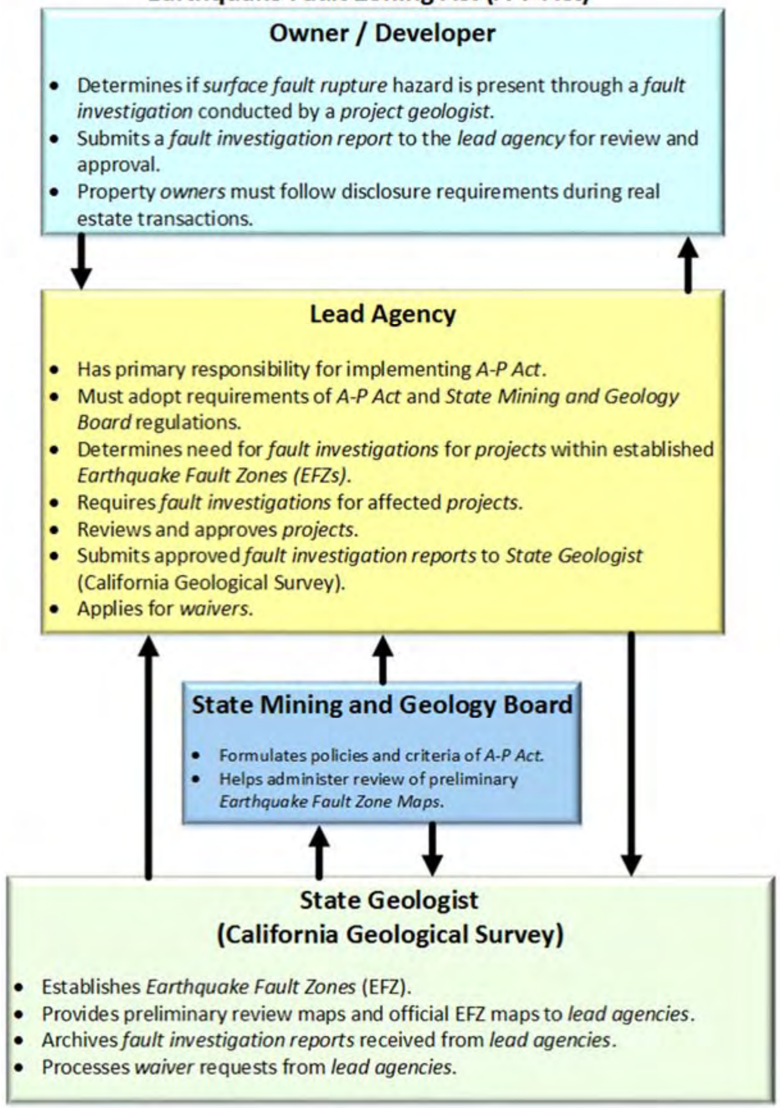
Figures

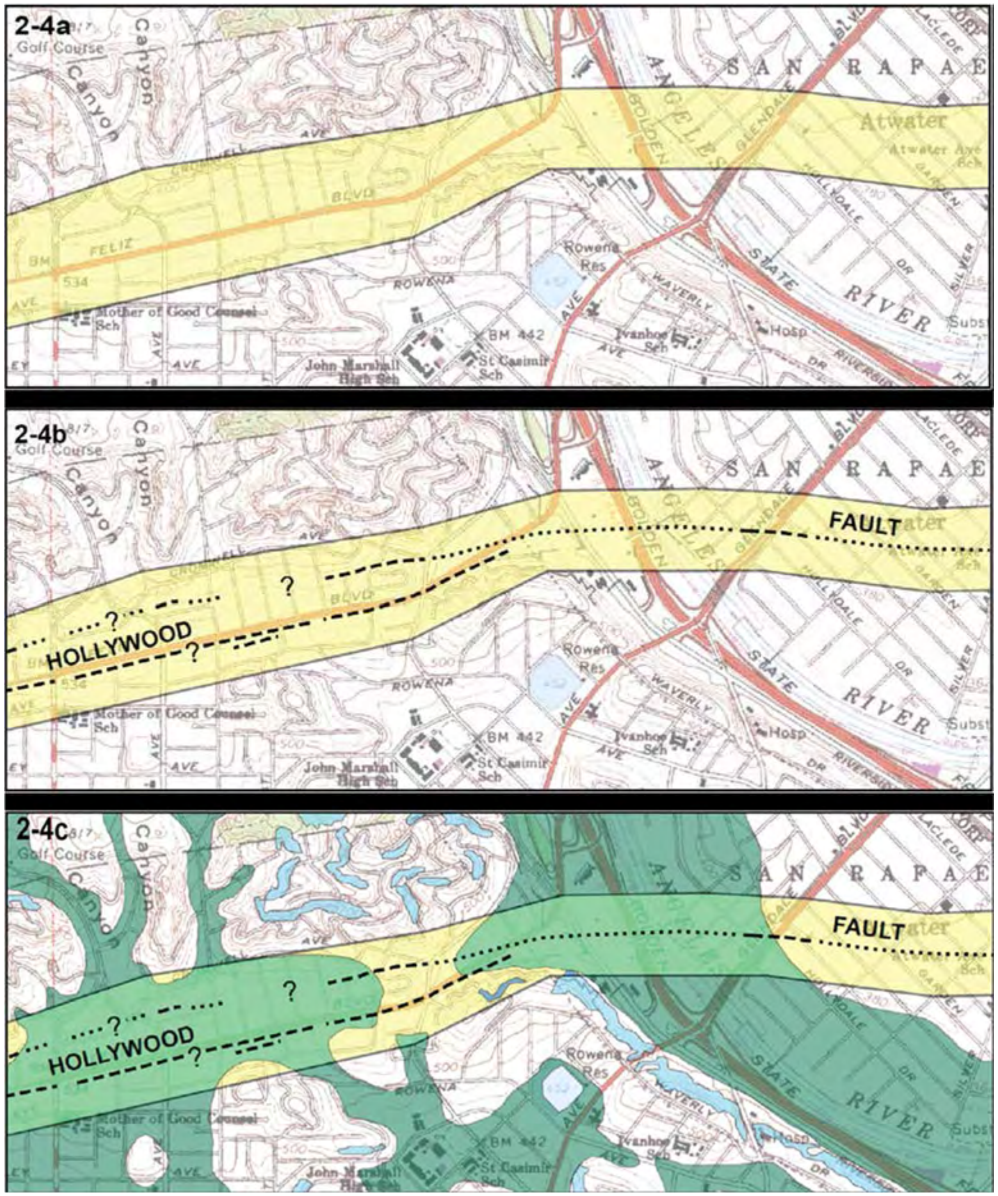
Plates

Example of surface fault rupture from the M 6.0 August 24, 2014 South Napa earthquake. Displacement at this location was about 0.5 meters (1.6 feet).

Impact of surface fault rupture on a home during the November 14, 2016 M 7.8 Kaikoura earthquake, New Zealand. Fault displacement at this location was about 10 meters (33 feet) of horizontal offset. Photo credit: Pilar Villamor, GNS Science / Earthquake Commission. 2b. House damaged by surface rupture during the August 14, 2014 M 6.0 South Napa earthquake. Total displacement on the fault was less than 1 foot, yet even relatively modest amounts of fault offset required expensive (>$100,000) repairs including the replacement of the foundation of the house. Red arrows show relative trend of faulting and sense of horizontal movement.

Roles and responsibilities under the Alquist – Priolo Earthquake Fault Zoning Act (A-P Act)




2-4a
2-4b
2-4c
Golf Course
Canyon
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Atwater
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FELIZ
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Mother of Good Counsel Sch
BM 442
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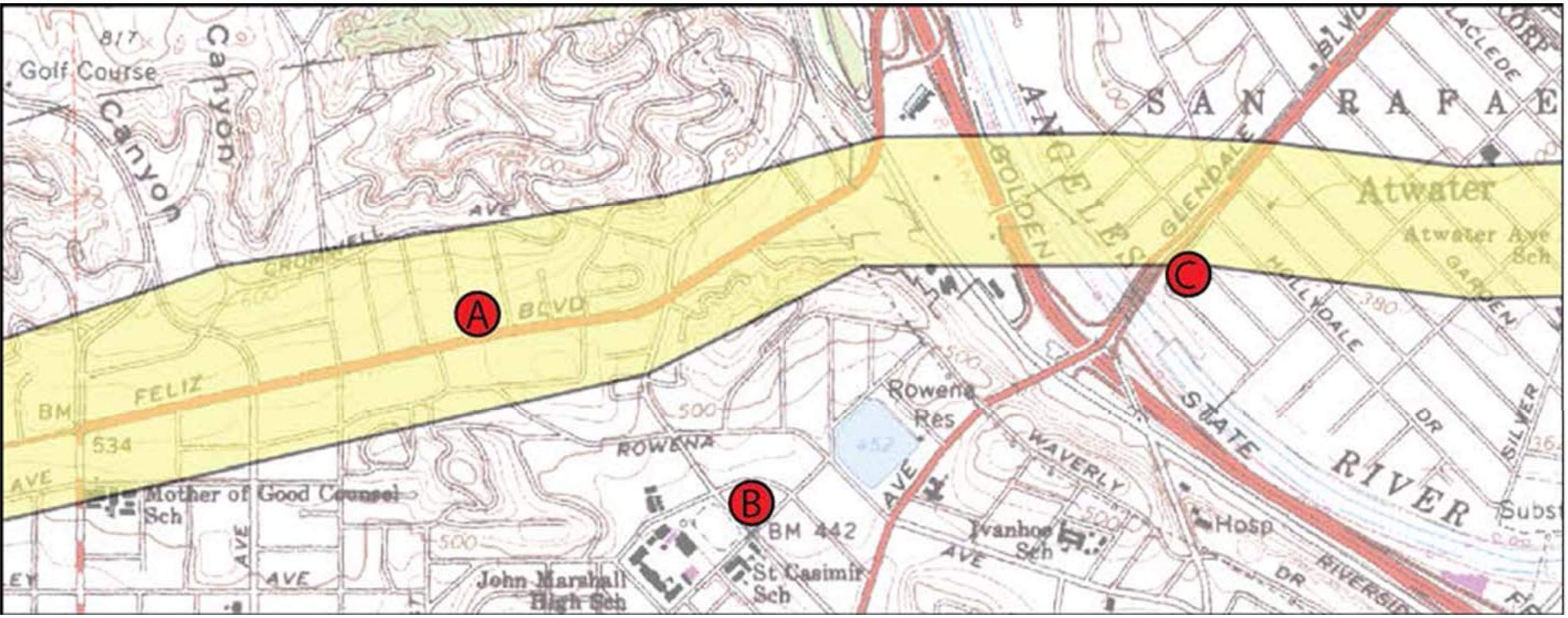


Illustration of *projects* (red circles) in, outside, or near, an *Earthquake Fault Zone (EFZ),* shown as the yellow shaded area. Site A (red circle with letter A) is within the *EFZ*, Site B is outside of the *EFZ* and Site C is near the *EFZ*. In this example, Site A would be regulated by the *A-P Act* and Site B is not regulated by the *A-P Act*. For Site C the *lead agency* should be consulted to determine if the *project* is located within the *EFZ*. The *EFZ* map is a portion of the Hollywood 7.5-minute Quadrangle *Earthquake Zones of Required Investigation Map*.

It is worth reiterating that a *project* located outside of an *Earthquake Fault Zone* is still regulated by the *A-P Act* if a *Holocene-active fault* is found at that site. This can happen if a *lead agency* has established its own regulatory zone requiring an assessment of *surface fault rupture* hazard or in a situation where a *Holocene-active fault* is discovered during a geologic investigation for that *project*. If located outside of an *Earthquake Fault Zone*, *age-undetermined faults* are not regulated by the *A-P Act*. However, the *project geologist* may want to consider all available data and provide recommendations regarding whether *setbacks* or other engineered solutions should be considered in the placement or design of a structure crossing these faults.

The following concepts are provided to help focus the *fault investigation*:

1. The fact that a *project* lies within a designated *Earthquake Fault Zone* does not necessarily indicate that a hazard requiring *mitigation* is present at that site. Instead, it indicates that regional (that is, not site-specific) information suggests that the probability of a hazard is great enough to warrant a site-specific investigation. However, the working premise for the planning and execution of a site investigation within an *Earthquake Fault Zone* (EFZ) is that ***the suitability of the site must be demonstrated***. This premise will persist until either: (a) the *fault investigation* satisfactorily demonstrates the absence of *surface fault rupture* hazard, or (b) the site investigation satisfactorily defines the *surface fault rupture* hazard and provides a suitable *setback* recommendation for its *mitigation*.

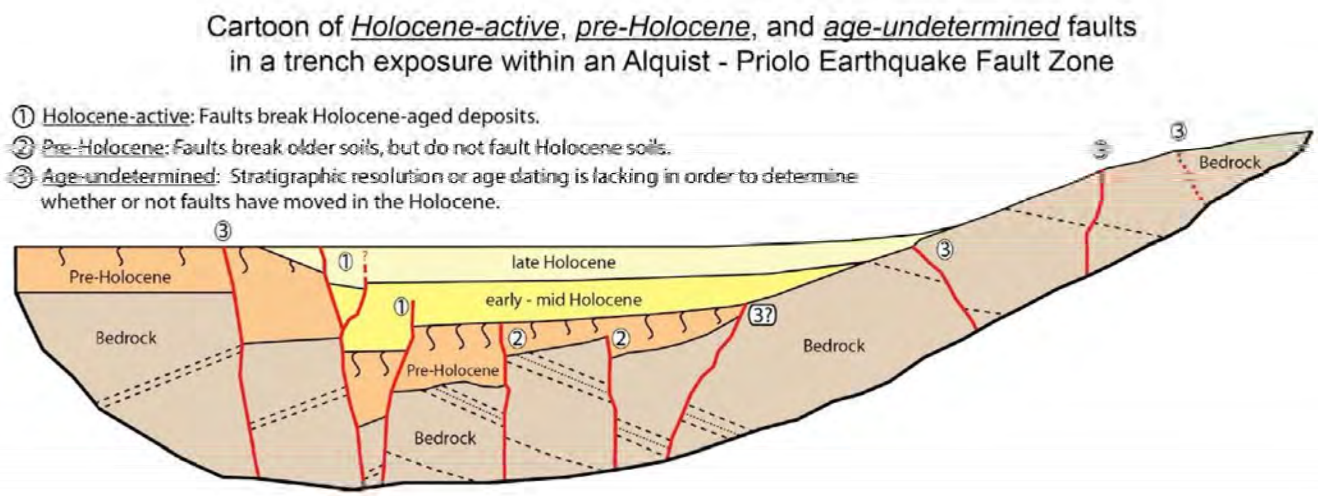
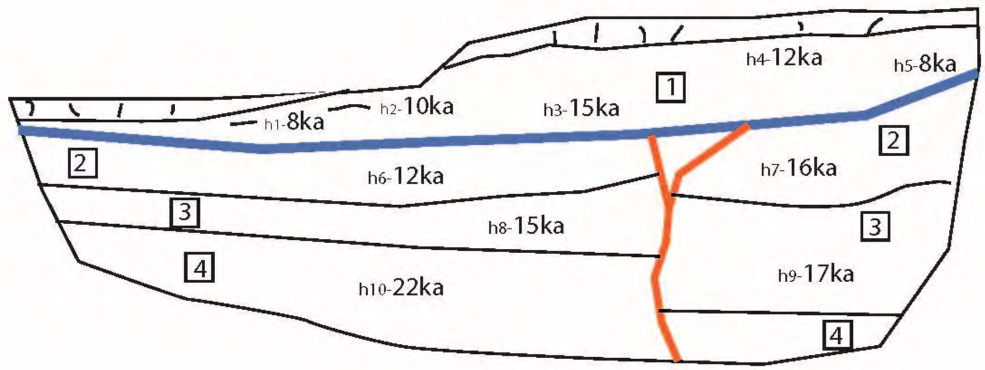


Figure 5-1. Fault classifications in a hypothetical trench log where *Holocene-active faults* break Holocene-age deposits and *pre-Holocene faults* break pre-Holocene age deposits, but not Holocene age deposits. The recency of movement for *age-undetermined faults* are unconstrained due to a lack of overlying deposits to determine the timing of the most recent fault displacement.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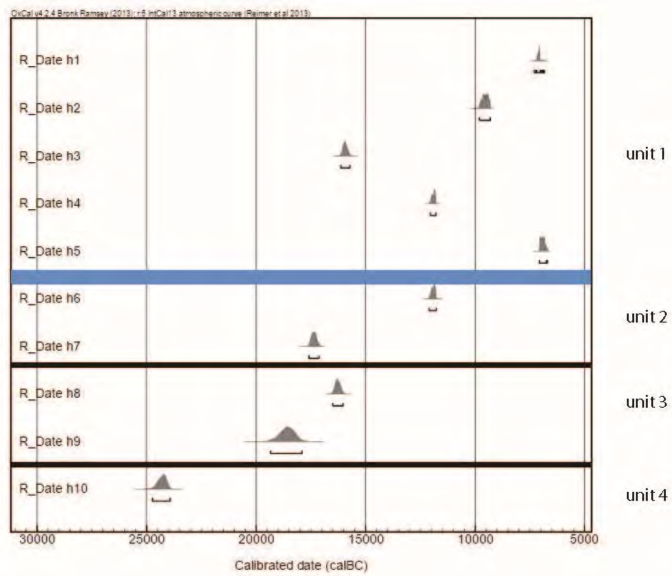
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Fault Zoning Criteria

- A major objective of CGS's continuing Fault Evaluation and Zoning Program is to evaluate the hundreds of remaining potentially active faults in California for zoning consideration. However, it became apparent as the program progressed that there are so many potentially active (i.e., Quaternary) faults in the state (Jennings, 1975) that it would be meaningless to zone all of them. In late 1975, the State Geologist made a policy decision to zone only those potentially active faults that have a relatively high potential for ground rupture. To facilitate this, the terms "sufficiently active" and "well-defined," from Section 2622 of the Act, were defined for application in zoning faults other than the four named in the Act. These two terms constitute the present criteria used by the State Geologist in determining if a given fault should be zoned under the Alquist-Priolo Act.

Sufficiently active. A fault is deemed sufficiently active if there is evidence of Holocene surface displacement along one or more of its segments or branches. Holocene surface displacement may be directly observable or inferred; it need not be present everywhere along a fault to qualify that fault for zoning.

Well-defined. A fault is considered well-defined if its trace is clearly detectable by a trained geologist as a physical feature at or just below the ground surface. The fault may be identified by direct observation or by indirect methods (e.g., geomorphic evidence or geophysical techniques). The critical consideration is that the fault, or some part of it, can be located in the field with sufficient precision and confidence to indicate that the required site-specific investigations would meet with some success.

APPENDIX C: THE CALIFORNIA GEOLOGICAL SURVEY'S FAULT EVALUATION AND ZONING PROGRAM

C.1 Fault Evaluation and Zoning Program

The Fault Evaluation and Zoning Program was initiated in early 1976 for the purpose of evaluating those "other faults" identified in the Act as "sufficiently active and well-defined" (see definitions below) after it was recognized that effective future zoning could not rely solely on the limited fault data of others. Justification of this program is discussed in more detail in Special Publication 47 of the Division of Mines and Geology (1976; also see Hart, 1978).

The program originally was scheduled over a 10-year period. The state was divided into 10 regions or work areas, with one region scheduled for evaluation each year. However, the work in some regions was extended because of heavy workloads. Fault evaluation work includes interpretation of aerial photographs and limited field mapping, as well as the use of other geologists' works. A list of faults to be evaluated in a target region was prepared and priorities assigned. The list included potentially active faults not yet zoned, as well as previously zoned faults or fault-segments that warranted zone revisions (change or deletion). Faults also were evaluated in areas outside of scheduled regions, as the need arose (e.g., to map fault rupture immediately after an earthquake). The fault evaluation work was completed in early 1991. The work is summarized for each region in Open-File Reports (OFR) 77-8, 78-10, 79-10, 81-3, 83-10, 84-52, 86-3, 88-1, 89-16, and 91-9.

For each fault evaluated by CGS since 1976 a Fault Evaluation Report (FER) has been prepared, summarizing data on the location, recency of activity, sense and magnitude of displacement, and providing recommendations for or against zoning. FERs that resulted in *Earthquake Fault Zones (EFZ)* are available through the Information warehouse on the CGS web page (http://maps.conservation.ca.gov/cgs/informationwarehouse/). FERs that did not recommend *EFZs* be delineated are available from CGS by request.

Faults zoned since 1976 are considered to meet the criteria of "sufficiently active and well-defined" (see Definitions below). Many other faults do not appear to meet the criteria and have not been zoned. It is important to note that it is sometimes difficult to distinguish between slightly active faults and inactive ones, because the surface features formed as a result of minor, infrequent rupture are easily obliterated by geologic processes (erosion, sedimentation, mass wasting) or human activities. Even large scale fault-rupture can be obscured in complex geologic terranes or high-energy environments. Recent fault-rupture is challenging to detect where it is distributed as numerous breaks or warps in broad zones of deformation. As a consequence of these problems, it is not possible to identify and zone all active faults in California. For the most part, rupture on faults not identified as active is expected to be minor.

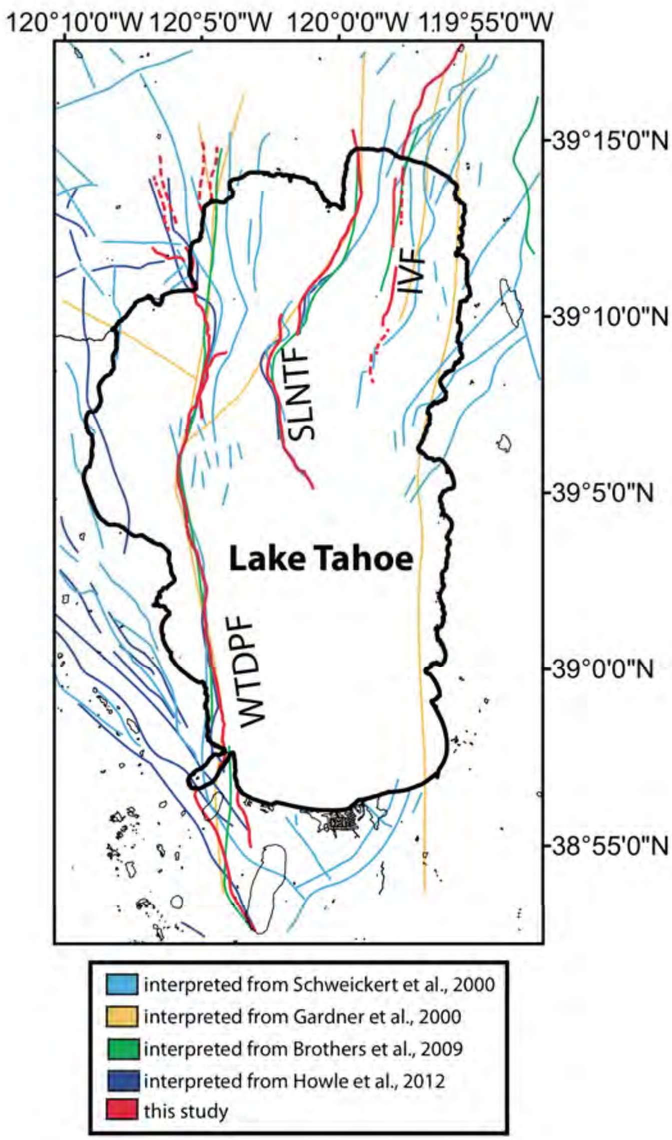
Under the AP Act (Sec. 2622), the State Geologist has an on-going responsibility to review "new geologic and seismic data" in order to revise *EFZ* and to delineate new zones

Table 5-1. Most Applicable Age Dating Methods for Fault Activity Investigations.

Method	Age Range / Uncertainty Range	Property Measured / Sample Materials	Application Criteria
Radiocarbon Dating	0 to 50,000 years 2 to 5%	^{14}C Organic matter	Most favored method due to its proven reliability to provide objective results. • multiple sample analyses allow an increase in confidence and accuracy • fast turn around • single dates can be misleading due to the difficulty in evaluating the context uncertainty
Luminescence	100 to 100,000 years Greater than 10%	Luminescence Quartz or Feldspar Crystals	Often suitable where sand-size material exists and when little C-14 dateable material can be found. Often requires research level effort to properly integrate all aspects of the method. Can provide reliable age estimate if done correctly. • strict sampling protocol • may complement ^{14}C well, as it can help assess context uncertainty
Cosmogenic nuclide	1,000 to 2,000,000 years Greater than 10%	^{10}Be, ^{26}Al, ^{36}Cl Quartz Feldspars Carbonates	Unique for its ability to date surfaces or burial events. Often requires research level effort to properly integrate all aspects of the method. Can provide reliable age estimate if done correctly. • strongly influenced by sampling protocol • accurate results are model dependent
Soil Profile Development Index (SDI)	500 to 500,000 Greater than 30%	Numerous Alteration of parent material	Requires quantitative dating of similar soil profiles in the area as calibration. Significant expertise is required for SDI age estimates.

Tahoe Basin Fault Behavior and Surface Rupture Zoning of the West Tahoe Fault

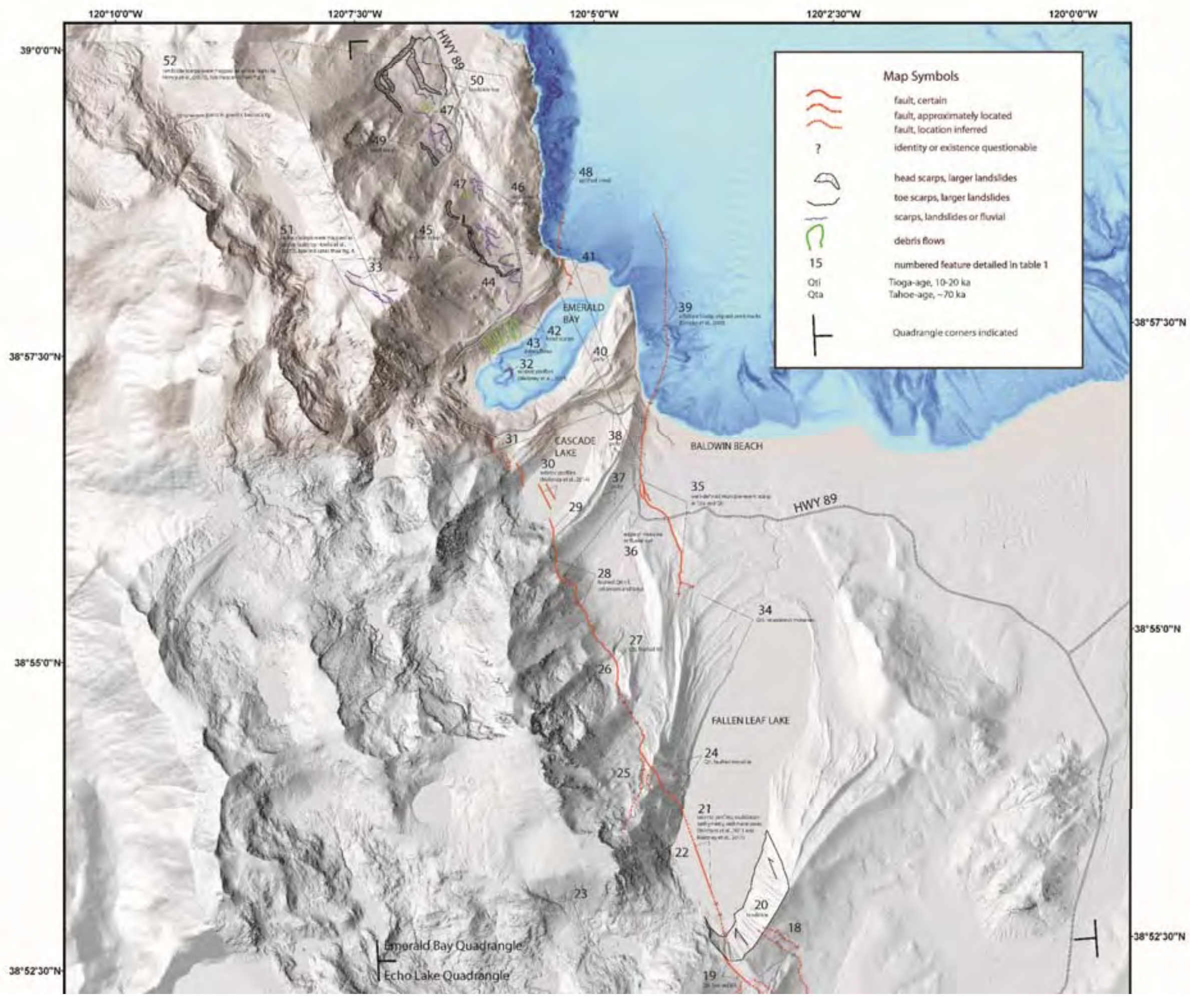
Gordon Seitz, CGS, Menlo Park

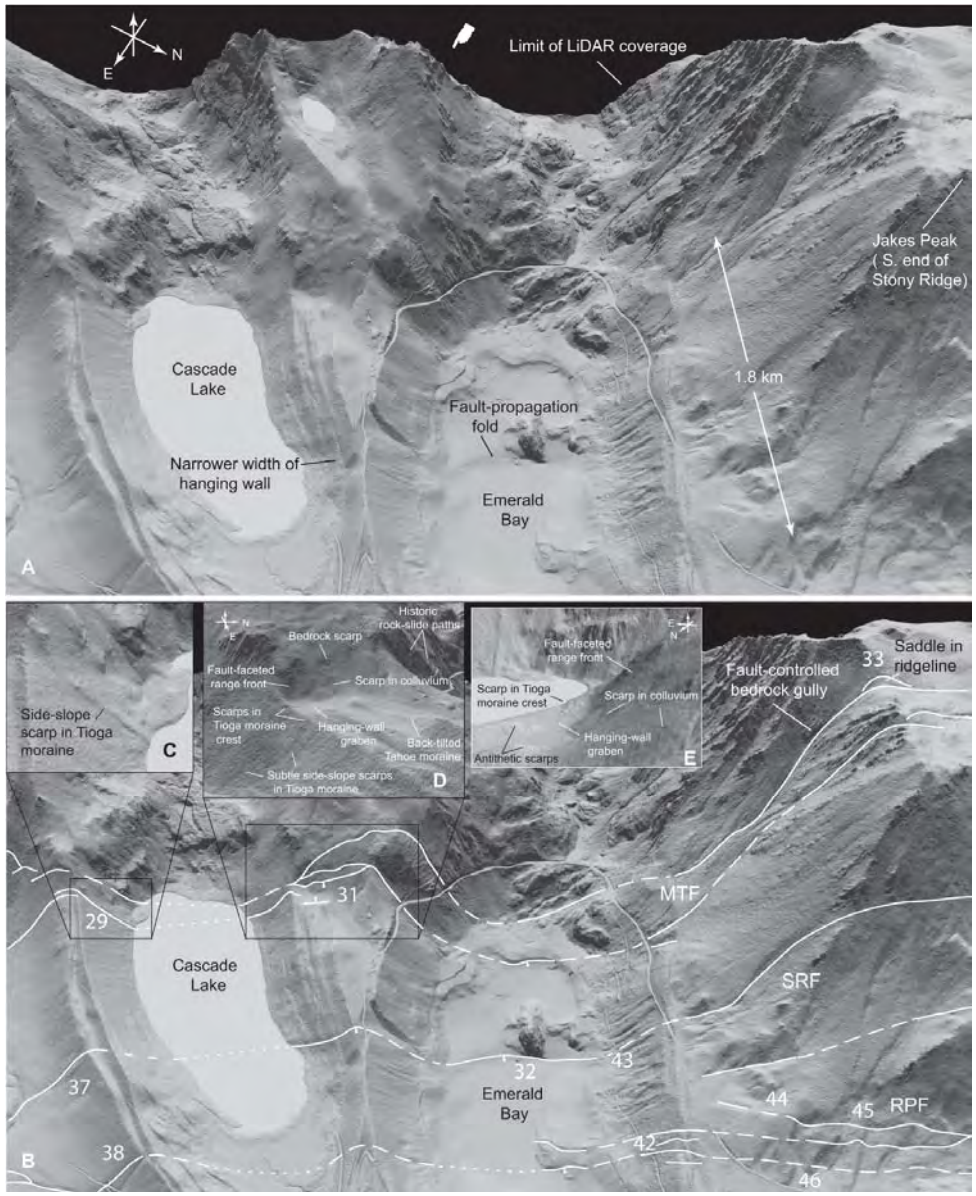


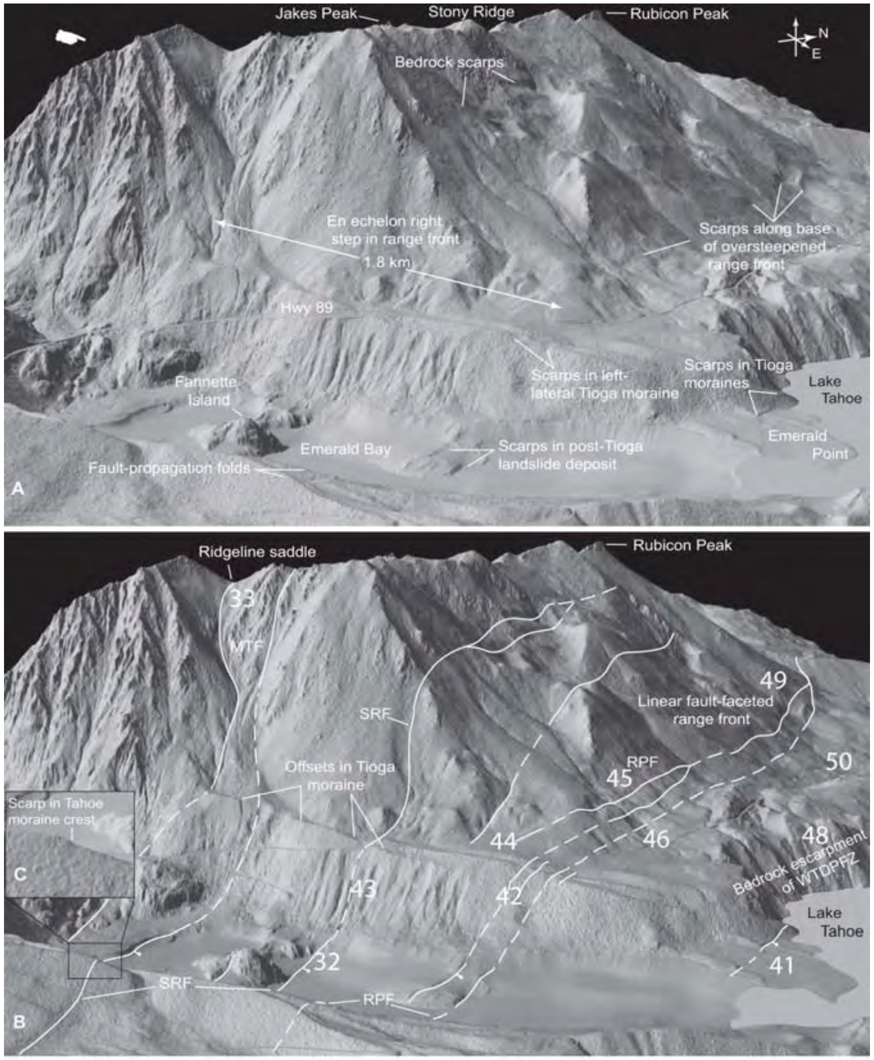
Reevaluating Late-Pleistocene and Holocene Active Faults in the Tahoe Basin, California-Nevada

Graham Kent
Nevada Seismological Laboratory, University of Nevada, Reno, Reno, Nevada 89557-0174, USA
Gretchen Schmauder
Nevada Seismological Laboratory, University of Nevada, Reno, Reno, Nevada 89557-0174, USA Now at: Geometrics, 2190 Fortune Drive, San Jose, California 95131, USA
Jillian Maloney
Department of Geological Sciences, San Diego State University, San Diego, California 92018, USA
Neal Driscoll
Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, California 92093, USA
Annie Kell
Nevada Seismological Laboratory, University of Nevada, Reno, Reno, Nevada 89557-0174, USA
Ken Smith
Nevada Seismological Laboratory, University of Nevada, Reno, Reno, Nevada 89557-0174, USA
Rob Baskin
U.S. Geological Survey, West Valley City, Utah 84119, USA
Gordon Seitz
California Geological Survey, 345 Middlefield Road, MS 520, Menlo Park, California 94025, USA

- Is more data always better ?
- Yes, but ....
- Not all data contributes equally to zoning
- lidar and to some degree seismic profiles add objectivity

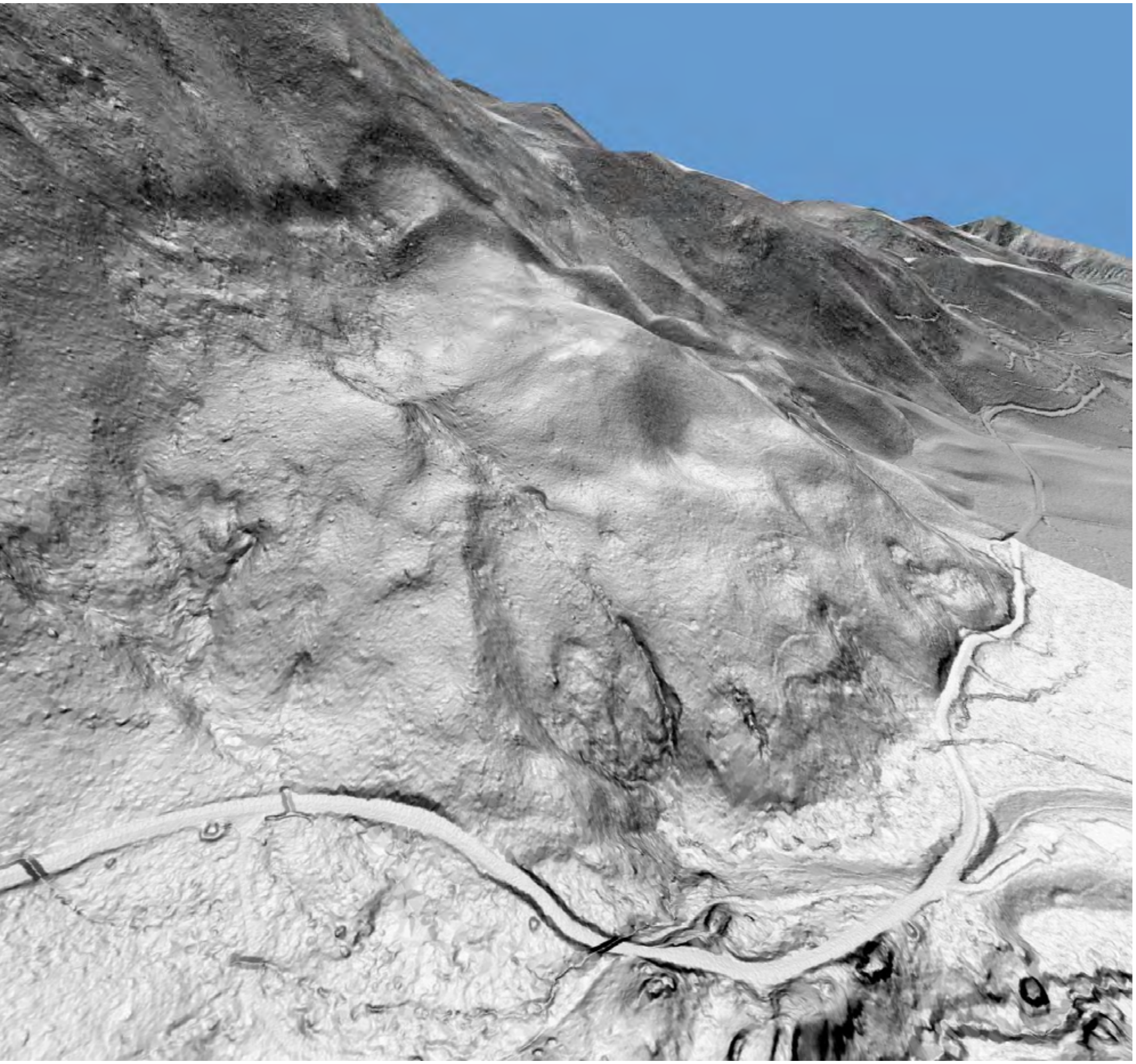

120°10'0"W
120°7'30"W
120°5'0"W
120°2'30"W
120°0'0"W
39°0'0"N
38°57'30"N
38°55'0"N
38°52'30"N
HWY 89
EMERALD BAY
CASCADE LAKE
BALDWIN BEACH
FALLEN LEAF LAKE
Emerald Bay Quadrangle
Echo Lake Quadrangle
Map Symbols
fault, certain
fault, approximately located
fault, location inferred
?
identity or existence questionable
head scarps, larger landslides
toe scarps, larger landslides
scarps, landslides or fluvial
debris flows
15
numbered feature detailed in table 1
Qti
Tioga-age, 10-20 ka
Qta
Tahoe-age, ~70 ka
Quadrangle corners indicated


E
N
Limit of LiDAR coverage
Jakes Peak (S. end of Stony Ridge)
1.8 km
Cascade Lake
Fault-propagation fold
Narrower width of hanging wall
Emerald Bay
A
Side-slope scarp in Tioga moraine
C
Historic rock-slide paths
Bedrock scarp
Fault-faceted range front
Scarp in colluvium
Scarps in Tioga moraine crest
Hanging-wall graben
Back-tilted Tahoe moraine
Subtle side-slope scarps in Tioga moraine
D
Fault-faceted range front
Scarp in Tioga moraine crest
Scarp in colluvium
Hanging-wall graben
Antithetic scarps
E
Saddle in ridgeline
33
Fault-controlled bedrock gully
MTF
29
31
Cascade Lake
SRF
43
32
37
Emerald Bay
44
45
RPF
42
38
46
B



40	**Gully on the south slope of the right-lateral moraine (Qti) of Emerald Bay. This gully has formed along a low of the moraine crest. Merging of crests focusing the flow of surface drainage and or primary glacial deposition is interpreted to have formed this limited extent feature. Moraine crests to the north are continuous. Long profiles along the moraine crest are consistent with primary glacial deposition. Howle et al. (2012) interpreted this feature as a Quaternary active fault.**
41	Well-defined east-facing scarp in Qti till and across three moraine crests. This fault may extend into Emerald Bay, however it was not observed in a 3d seismic grid (Maloney et al. 2014) and the Emerald Bay right-lateral moraines do not exhibit faulting along this trend. To the north this fault trends offshore and may connect with the primary WTF (Dingler et al., 2009), though the primary strand may well be further east.
42	Older generation of debris slides of Qti moraines, truncating the moraine crests.
43	Debris flows on the south slope of the left-lateral Qti moraines , some postdating 42.
44	Inset alluvial/colluvial range front apron or debris cone between bedrock highs. The relatively low angle slope of the inset surface combined with a possible head scarp is also consistent with an old landslide at least pre Qti. The possible head scarp elevation matches the adjacent large slides to the north fairly well (45 and 49).
45	Well-defined large rotational slide scarps. Characteristic arcuate shaped scarp with an inset down-dropped slide mass. Howle et al. (2012) indicates these scarps as:" scarps along base of over-steepened range front" and attributes them to active faults (Howle et al.2012; fig 5).
46	Multiple smaller rotational slides within the larger slide mass.
47	Debris flows
48	Elevated shelf is consistent with an offshore West Tahoe Fault north of the section 2 to section 3 step over.

Fig. modified from Howle et al. 2012

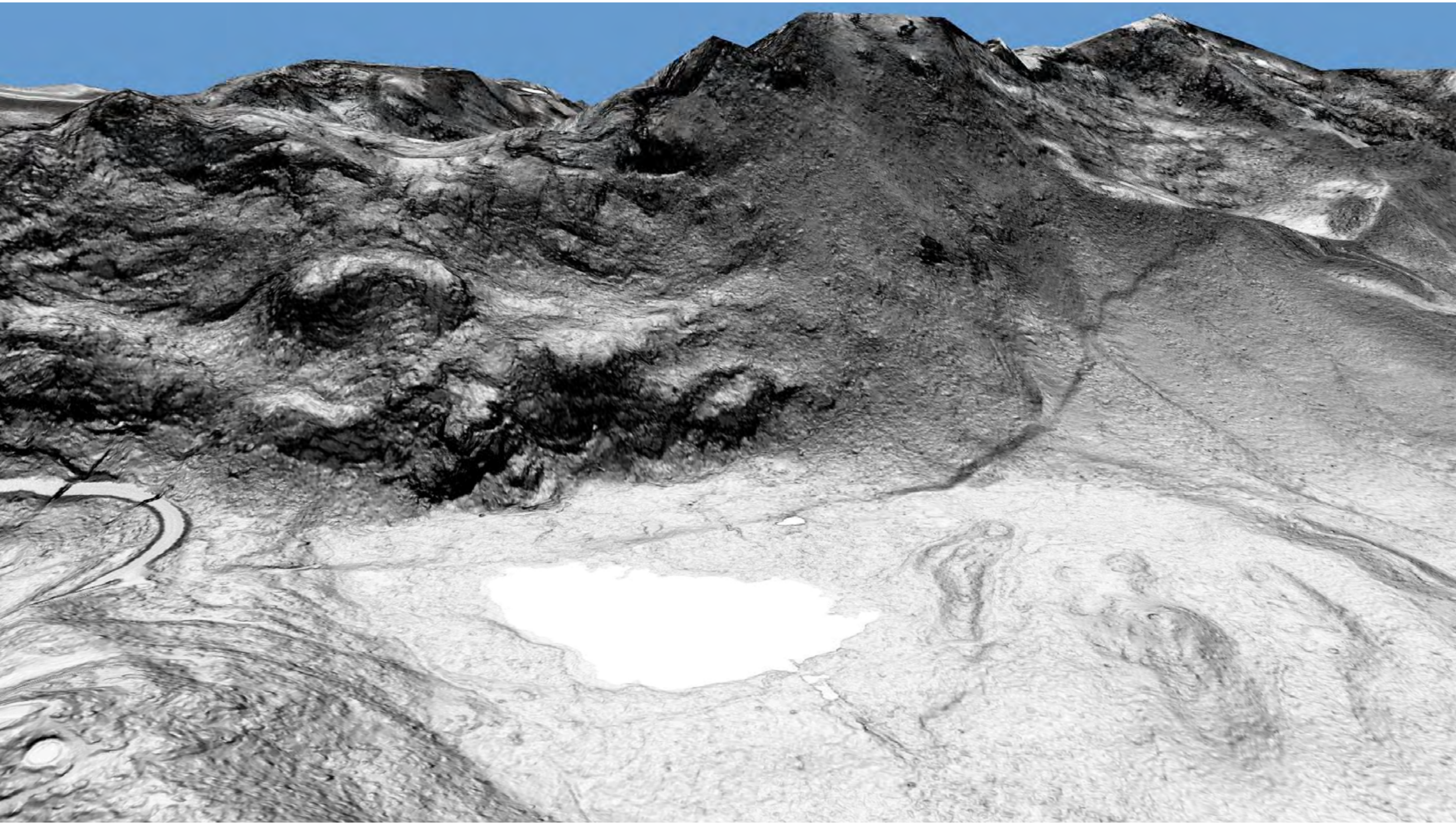


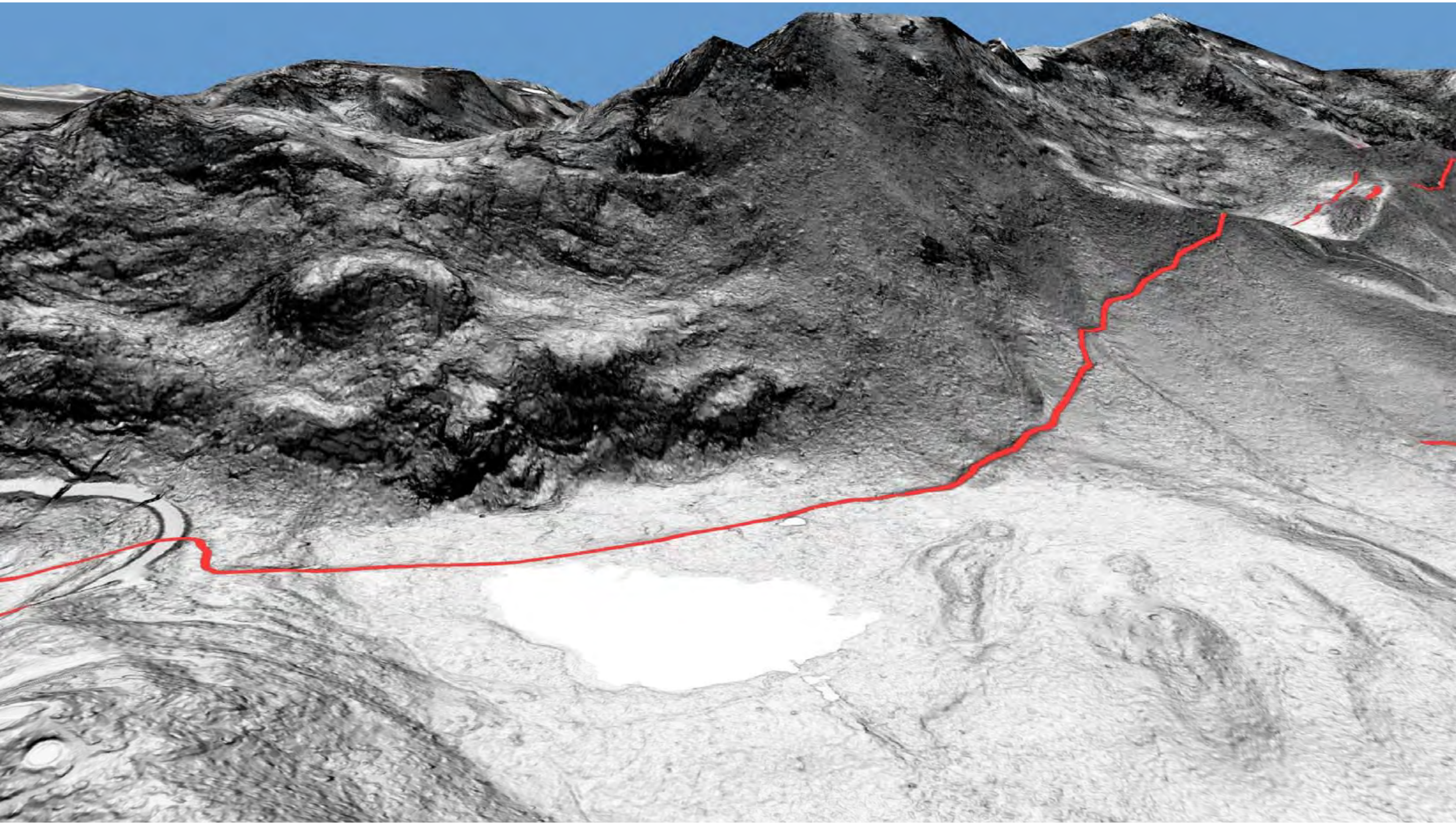
Feature #49 in Fault Evaluation Report

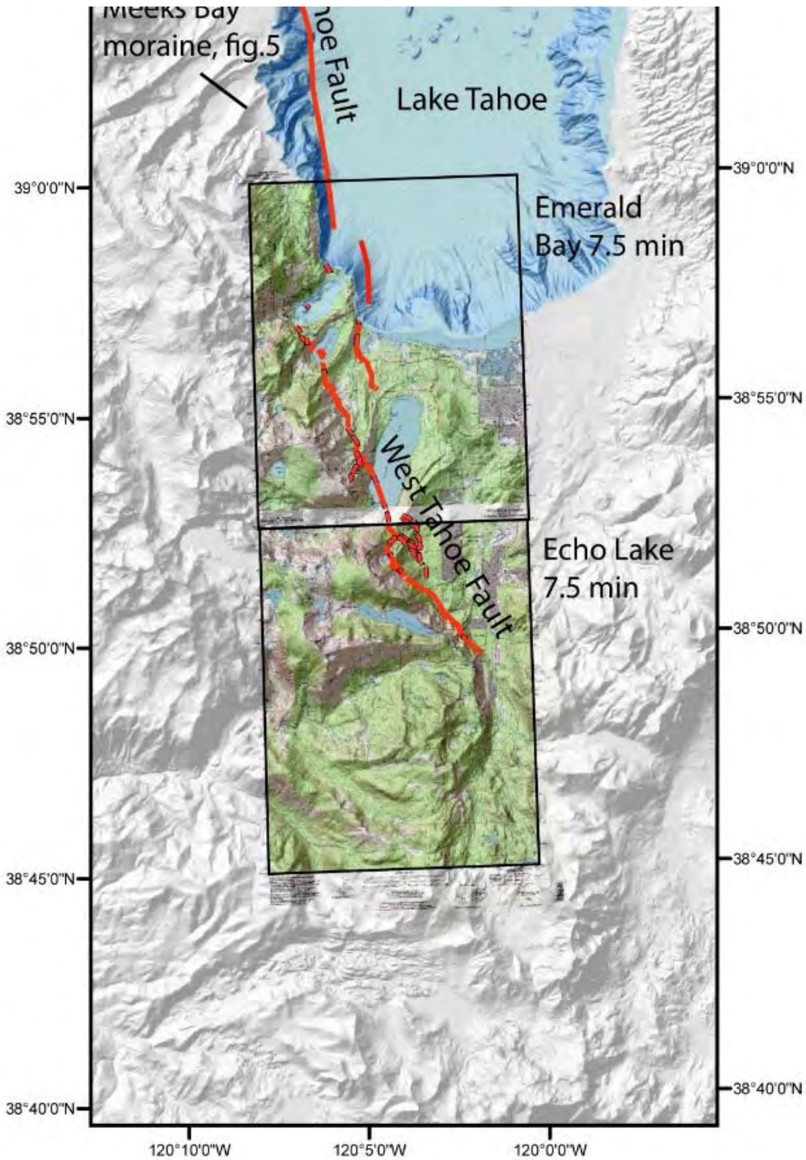
- was previously mapped and interpreted to be an active fault (Howle et al., 2012).

- CGS evaluation concludes it does not meet the State active fault criteria, in fact it's a landslide and not a fault.

- In our fault evaluation we used the latest higher resolution Lidar data set.





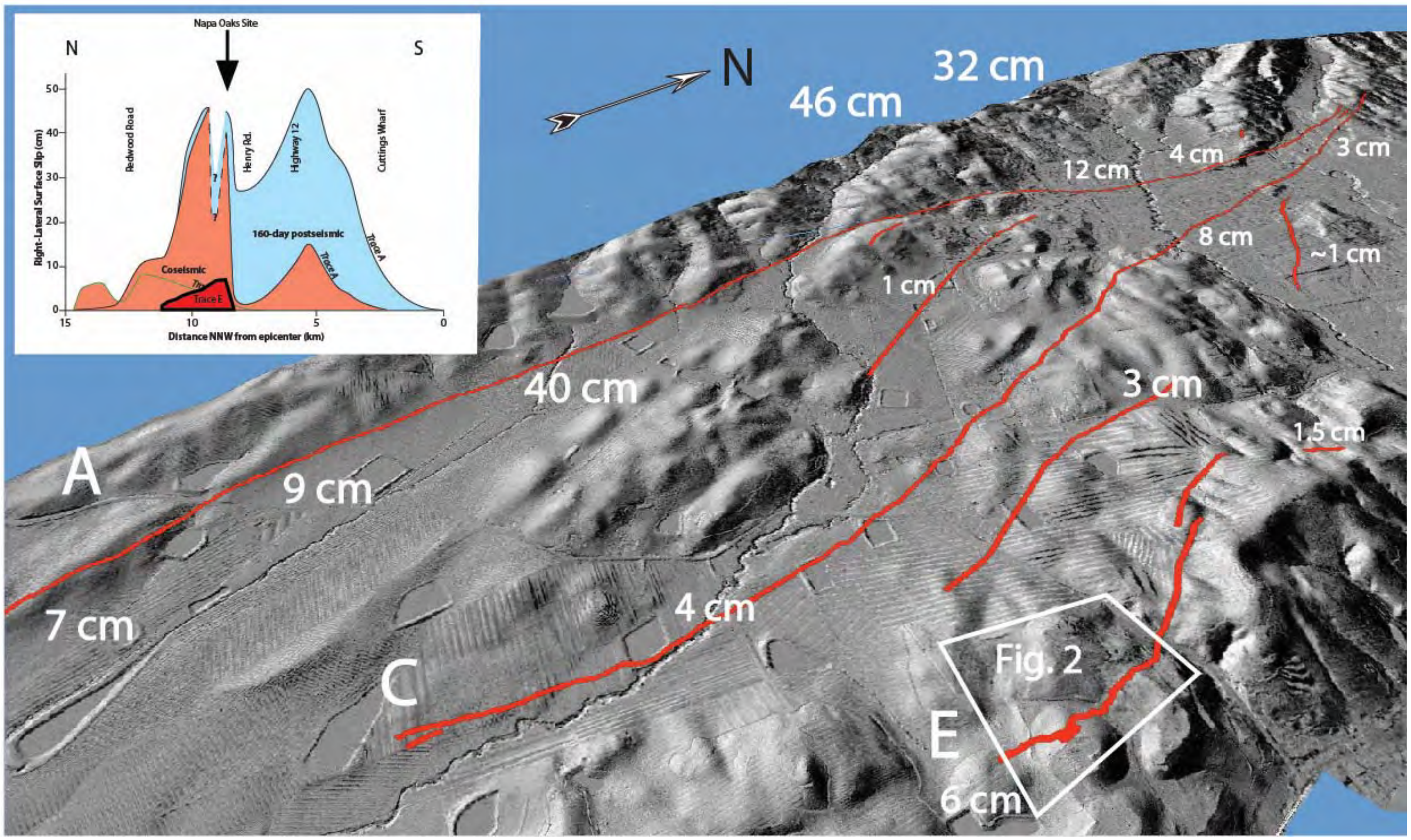


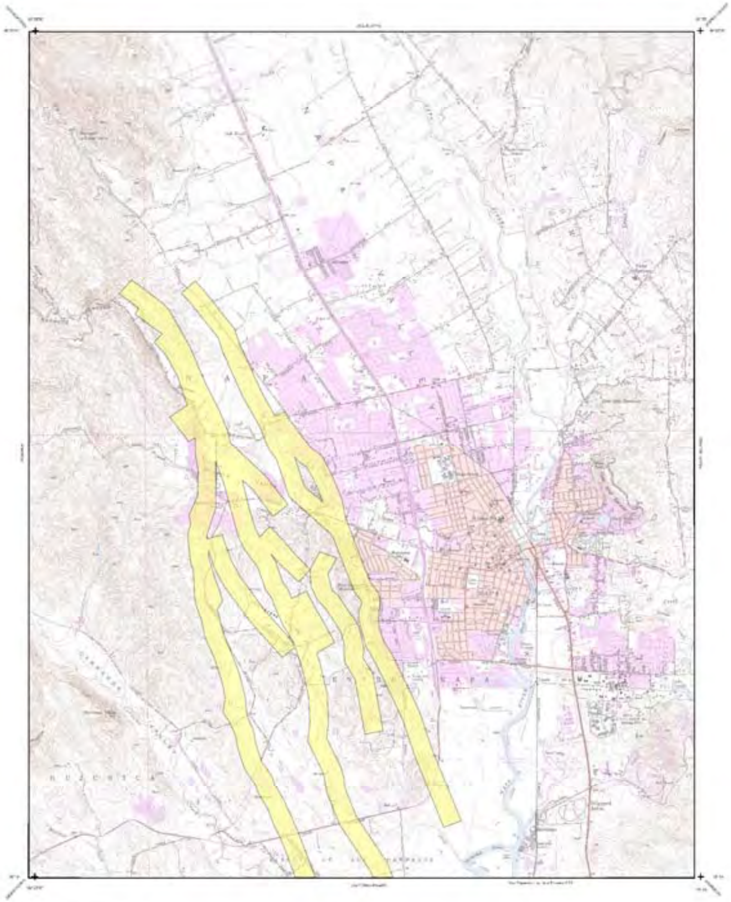
Meeks Bay
moraine, fig.5
Tahoe Fault
Lake Tahoe
Emerald
Bay 7.5 min
West Tahoe Fault
Echo Lake
7.5 min
39°0'0"N
38°55'0"N
38°50'0"N
38°45'0"N
38°40'0"N
120°10'0"W
120°5'0"W
120°0'0"W

PRELIMINARY
EARTHQUAKE FAULT ZONES
FOR REVIEW PURPOSES ONLY
DRAFT

Multiple Holocene-Age Events on the Easternmost Surface Rupture of the August 24, 2014 South Napa Earthquake

Gordon Seitz, California Geological Survey, Menlo Park; Carla Rosa, United States Geological Survey, Menlo Park; Kevin Ryan, Ryan Consulting, Orinda, California.
Gordon.Seitz@conservation.ca.gov





Earthquake Zones of Required Investigation
Napa Quadrangle

California Geological Survey

This Map Shows Alquist-Priolo Earthquake Fault Zones
Seismic Hazard Zones Have Not Been Prepared For The Napa Quadrangle

MAP EXPLANATION

Earthquake Fault Zones

Active Fault Traces

ADDITIONAL INFORMATION

IMPORTANT

NAPA QUADRANGLE

EARTHQUAKE FAULT ZONES

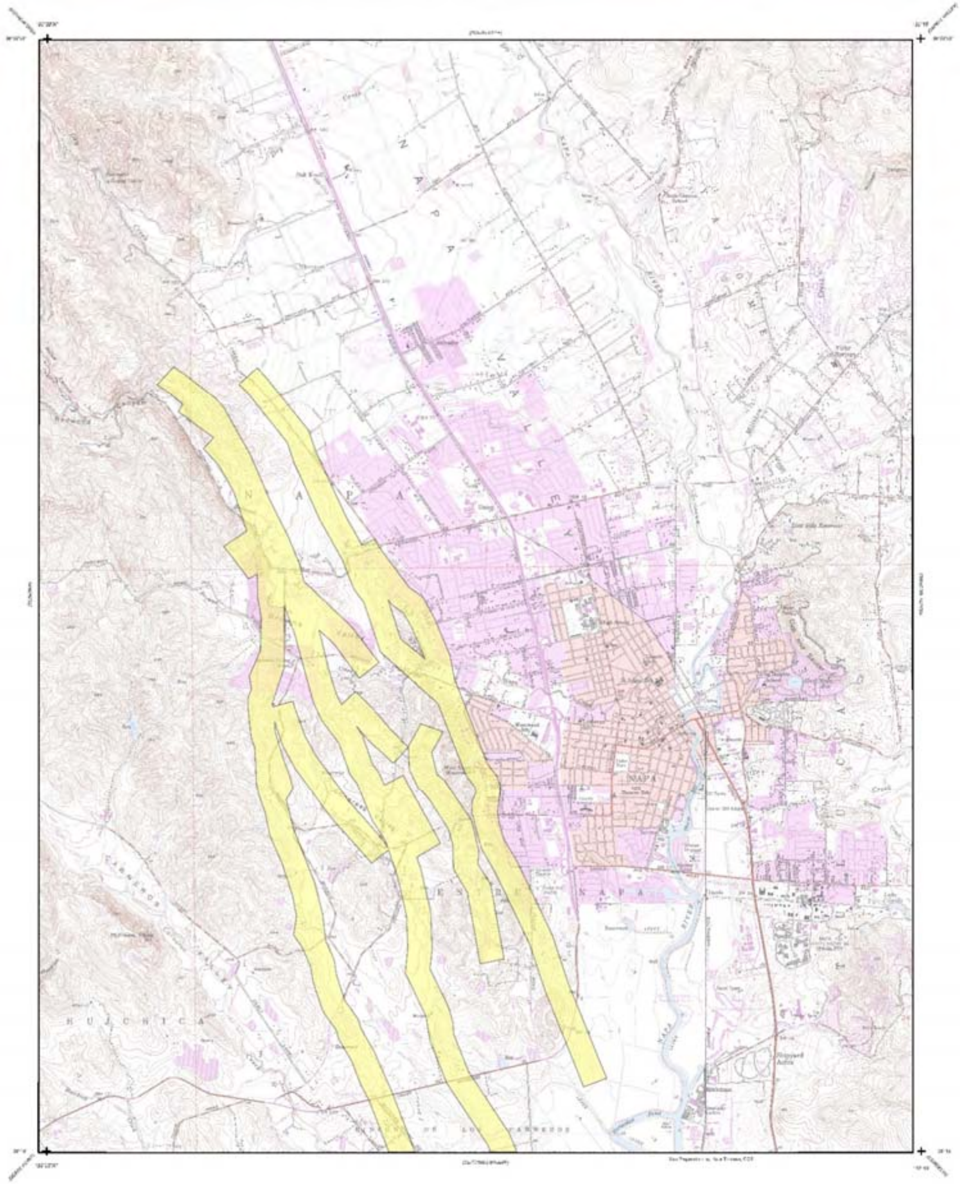
Delineated in compliance with Chapter 7.5,
Division 2 of the California Public Resources Code
(Alquist-Priolo Earthquake Fault Zoning Act)

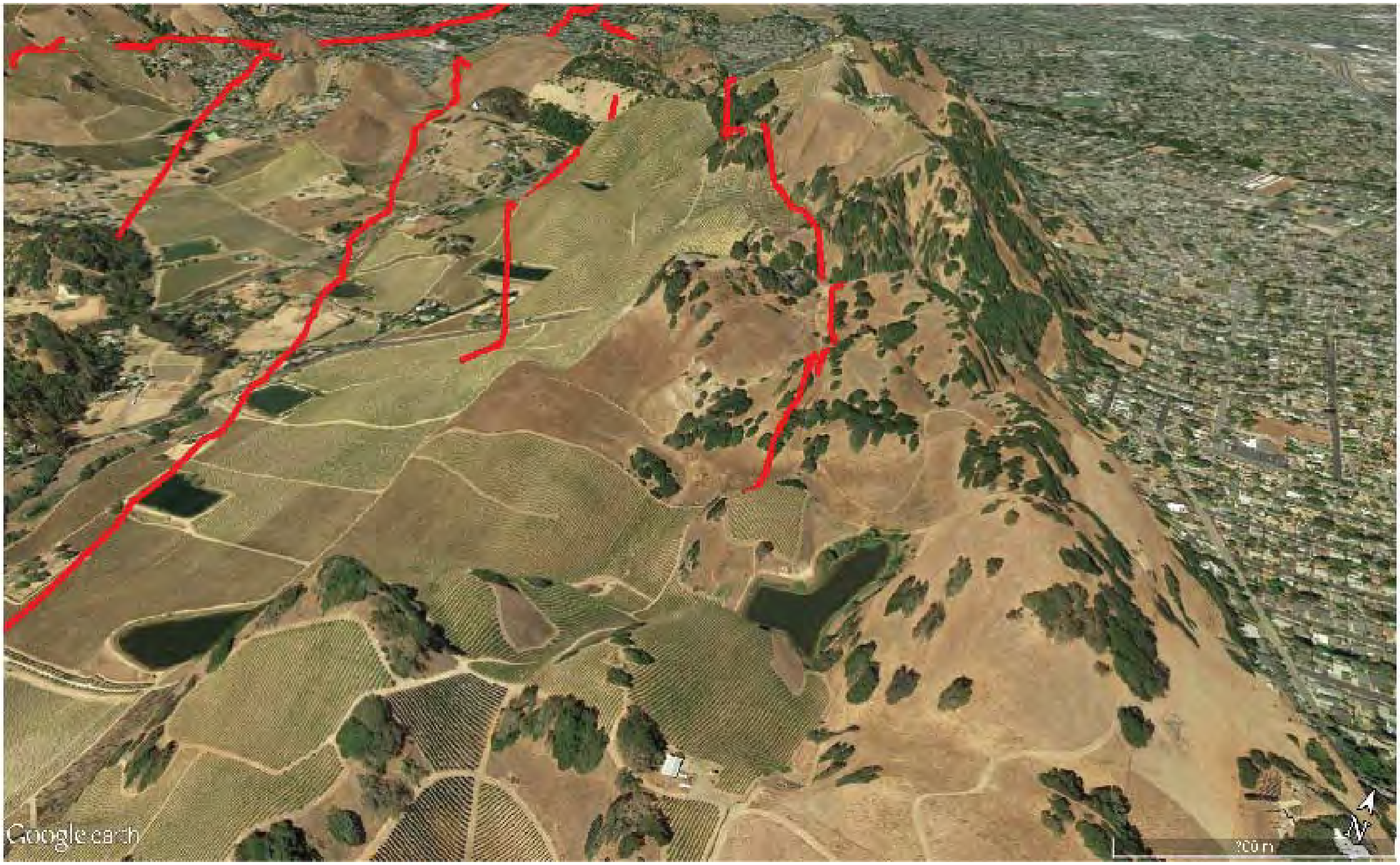
OFFICIAL MAP

Released: January 11, 2018

STATE GEOLOGIST

JOHN G. PARRISH


NAPA


Google earth

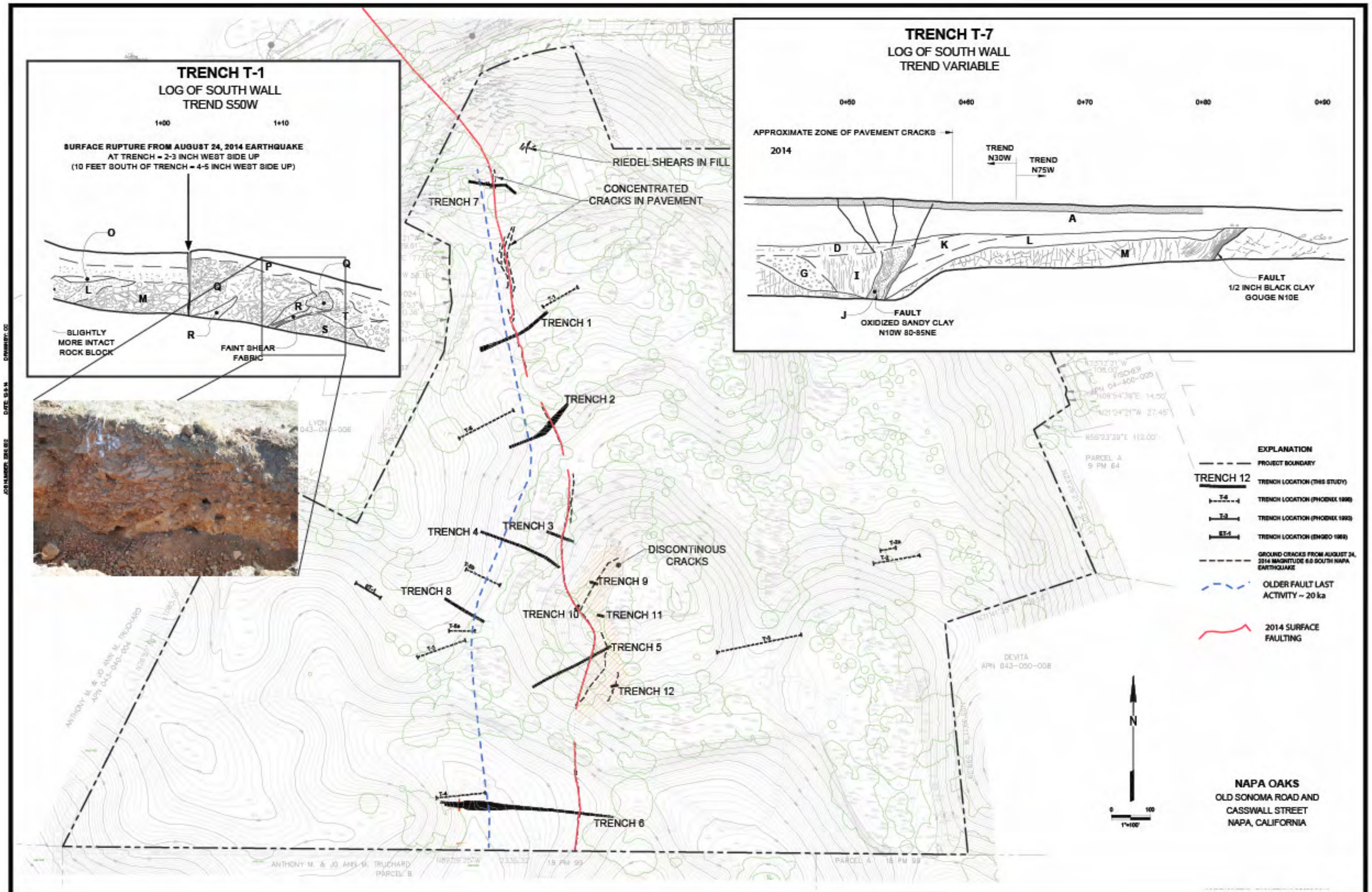
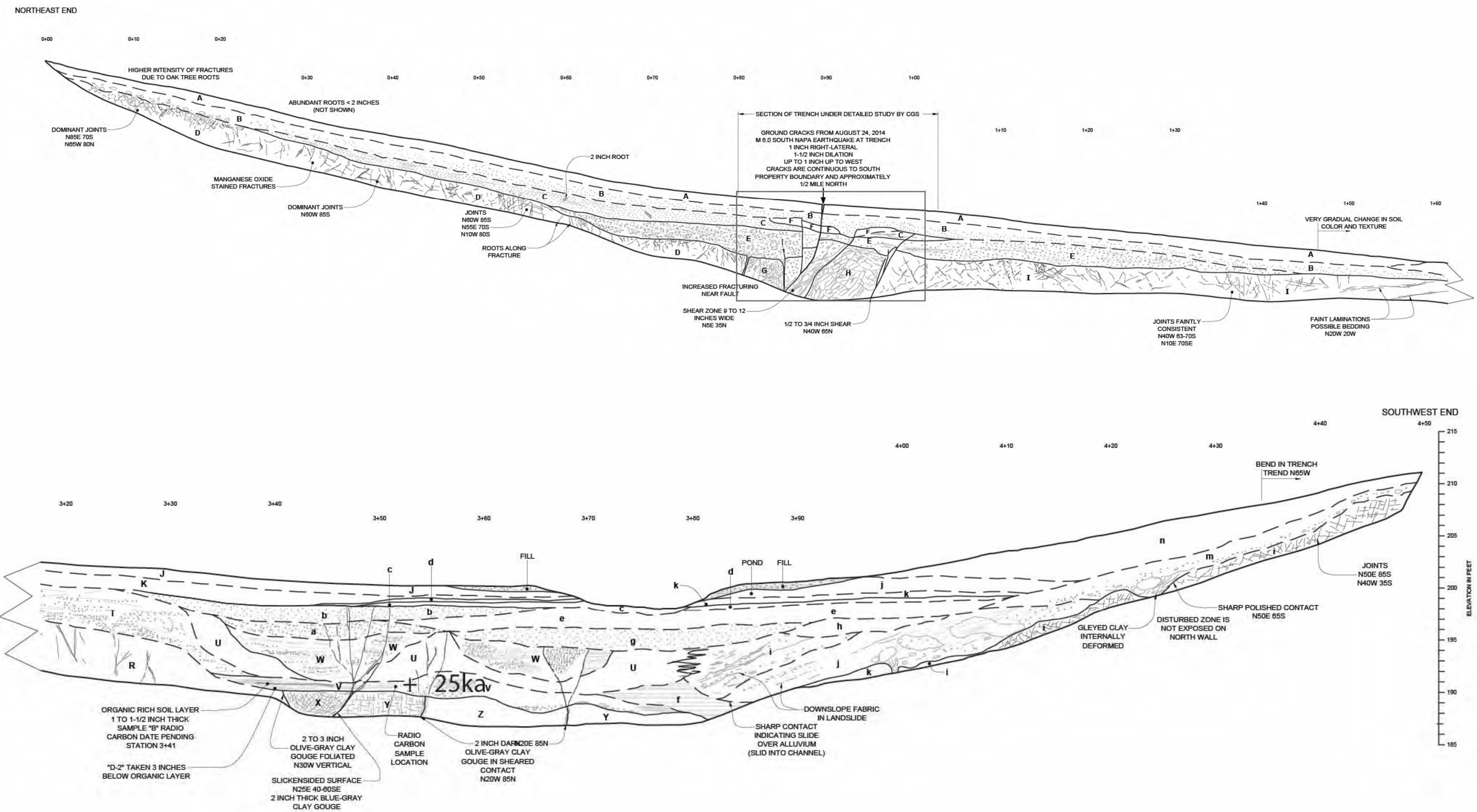
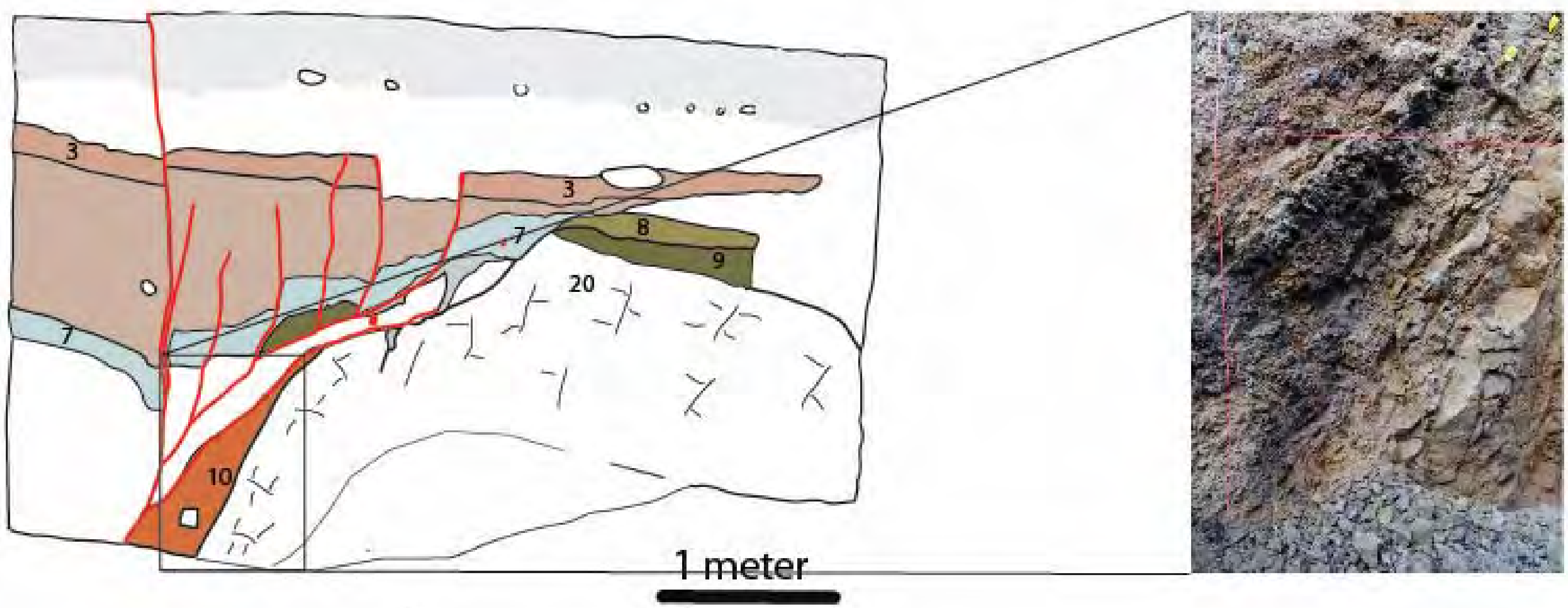
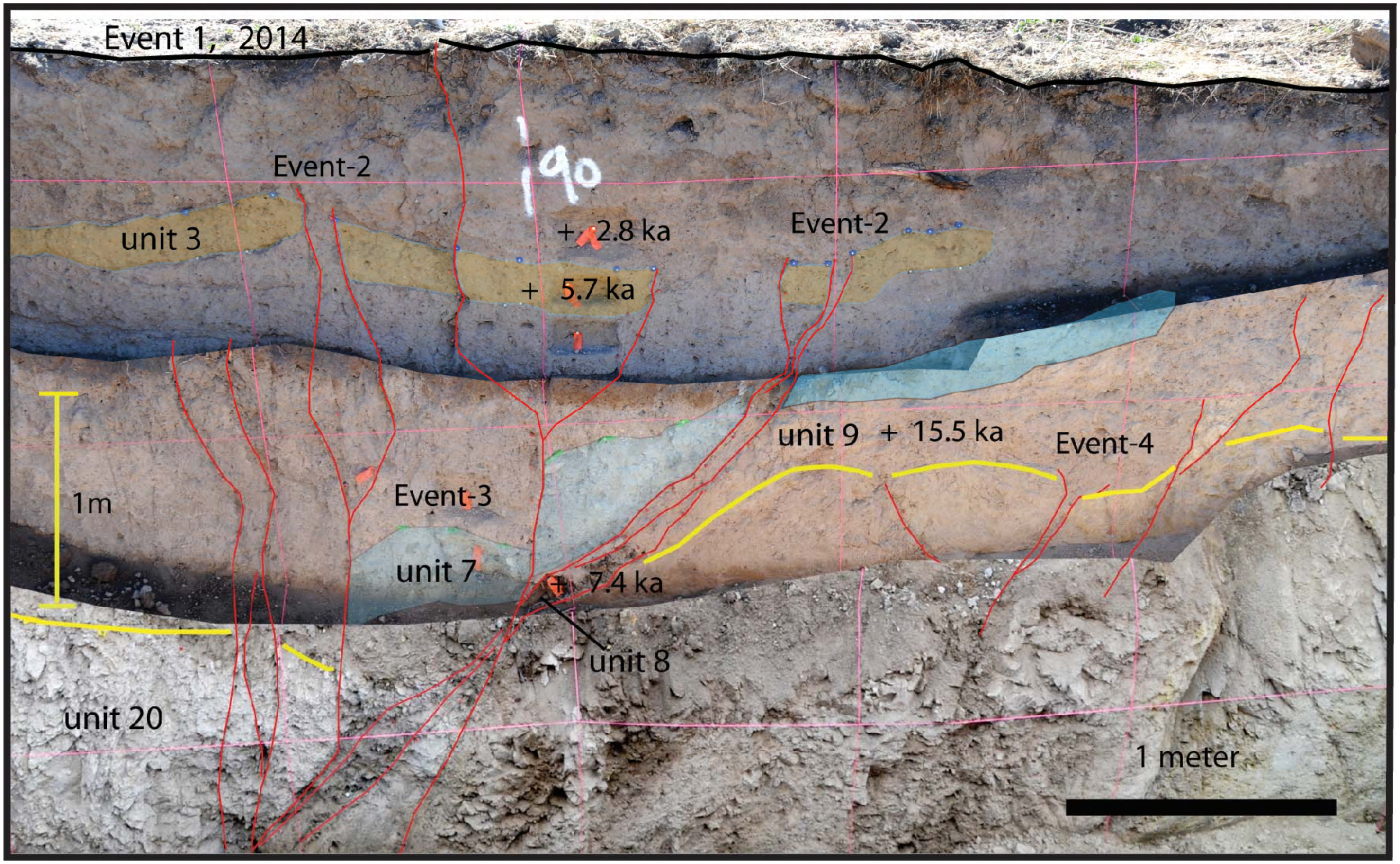

TRENCH T-1
LOG OF SOUTH WALL
TREND S50W
1+00
1+10
SURFACE RUPTURE FROM AUGUST 24, 2014 EARTHQUAKE
AT TRENCH = 2-3 INCH WEST SIDE UP
(10 FEET SOUTH OF TRENCH = 4-5 INCH WEST SIDE UP)
O
L
M
Q
P
R
S
T
SLIGHTLY
MORE INTACT
ROCK BLOCK
FAINT SHEAR
FABRIC
TRENCH T-7
LOG OF SOUTH WALL
TREND VARIABLE
0+50
0+60
0+70
0+80
0+90
APPROXIMATE ZONE OF PAVEMENT CRACKS
2014
TREND
N30W
TREND
N75W
A
D
K
L
M
G
I
J
FAULT
OXIDIZED SANDY CLAY
N10W 80-85NE
FAULT
1/2 INCH BLACK CLAY
GOUGE N10E
RIEDEL SHEARS IN FILL
CONCENTRATED
CRACKS IN PAVEMENT
TRENCH 7
TRENCH 1
TRENCH 2
TRENCH 3
TRENCH 4
DISCONTINOUS
CRACKS
TRENCH 8
TRENCH 9
TRENCH 10
TRENCH 11
TRENCH 5
TRENCH 12
TRENCH 6
EXPLANATION
PROJECT BOUNDARY
TRENCH 12
TRENCH LOCATION (THIS STUDY)
TRENCH LOCATION
TRENCH LOCATION
TRENCH LOCATION
GROUND CRACKS FROM AUGUST 24, 2014 MAGNITUDE 6.0 SOUTH NAPA EARTHQUAKE
OLDER FAULT LAST ACTIVITY ~ 20 ka
2014 SURFACE FAULTING
N
NAPA OAKS
OLD SONOMA ROAD AND
CASSWALL STREET
NAPA, CALIFORNIA

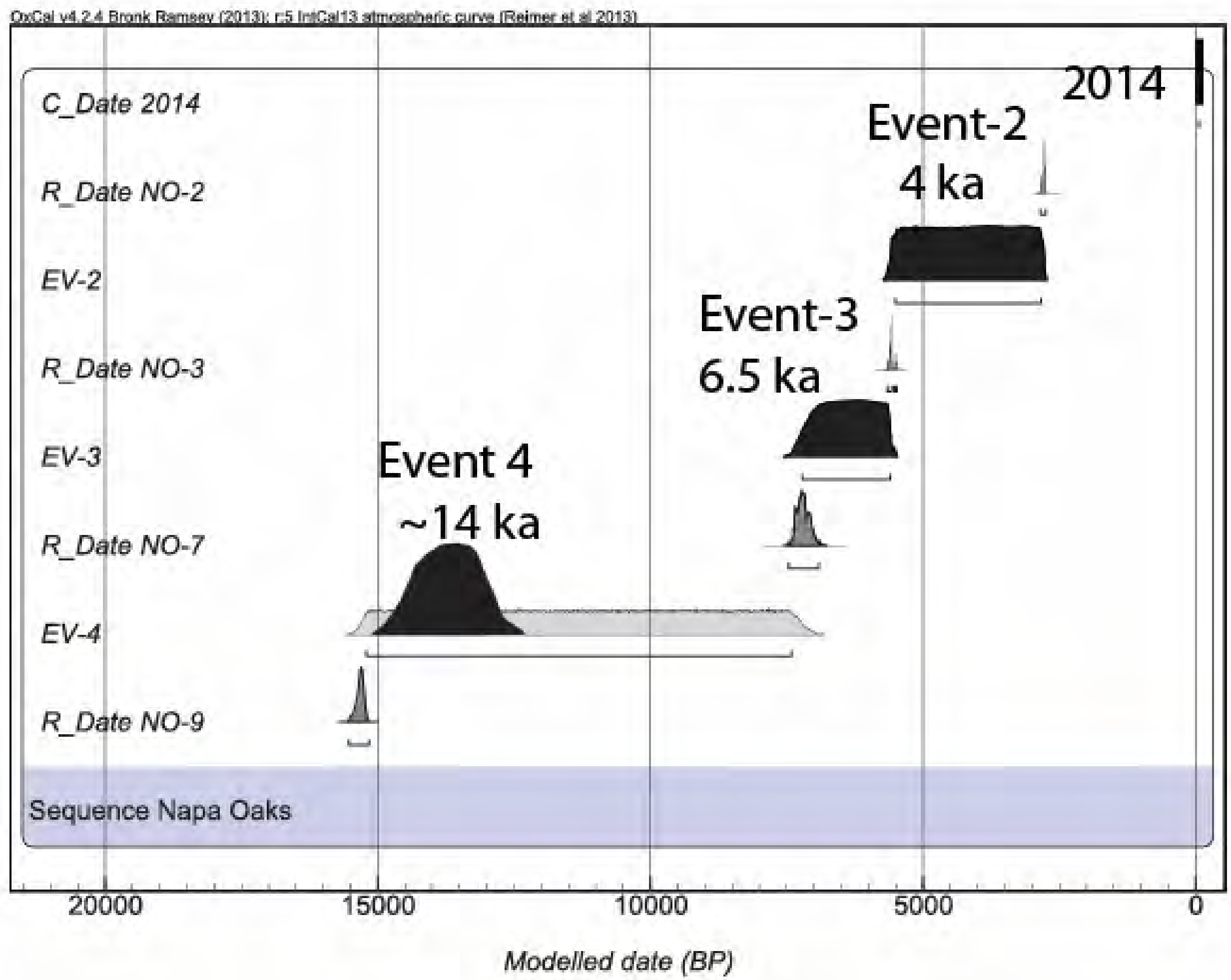
PLATE 4


NORTHEAST END
HIGHER INTENSITY OF FRACTURES DUE TO OAK TREE ROOTS
ABUNDANT ROOTS < 2 INCHES (NOT SHOWN)
DOMINANT JOINTS N85E 70S N65W 80N
MANGANESE OXIDE STAINED FRACTURES
DOMINANT JOINTS N60W 85S
2 INCH ROOT
JOINTS N60W 85S N55E 70S N10W 80S
ROOTS ALONG FRACTURE
SECTION OF TRENCH UNDER DETAILED STUDY BY CGS
GROUND CRACKS FROM AUGUST 24, 2014 M 6.0 SOUTH NAPA EARTHQUAKE AT TRENCH 1 INCH RIGHT-LATERAL 1-1/2 INCH DILATION UP TO 1 INCH UP TO WEST CRACKS ARE CONTINUOUS TO SOUTH PROPERTY BOUNDARY AND APPROXIMATELY 1/2 MILE NORTH
INCREASED FRACTURING NEAR FAULT
SHEAR ZONE 9 TO 12 INCHES WIDE N5E 35N
1/2 TO 3/4 INCH SHEAR N40W 65N
VERY GRADUAL CHANGE IN SOIL COLOR AND TEXTURE
JOINTS FAINTLY CONSISTENT N40W 63-70S N10E 70SE
FAINT LAMINATIONS POSSIBLE BEDDING N20W 20W
SOUTHWEST END
BEND IN TRENCH TREND N65W
FILL
POND
FILL
25ka
JOINTS N50E 85S N40W 35S
SHARP POLISHED CONTACT N50E 65S
DISTURBED ZONE IS NOT EXPOSED ON NORTH WALL
GLEYED CLAY INTERNALLY DEFORMED
DOWNSLOPE FABRIC IN LANDSLIDE
SHARP CONTACT INDICATING SLIDE OVER ALLUVIUM (SLID INTO CHANNEL)
ORGANIC RICH SOIL LAYER 1 TO 1-1/2 INCH THICK SAMPLE "B" RADIO CARBON DATE PENDING STATION 3+41
"D-2" TAKEN 3 INCHES BELOW ORGANIC LAYER
2 TO 3 INCH OLIVE-GRAY CLAY GOUGE FOLIATED N30W VERTICAL
SLICKENSIDED SURFACE N25E 40-60SE 2 INCH THICK BLUE-GRAY CLAY GOUGE
RADIO CARBON SAMPLE LOCATION
2 INCH DARK N20E 85N OLIVE-GRAY CLAY GOUGE IN SHEARED CONTACT N20W 85N
ELEVATION IN FEET
215
210
205
200
195
190
185



3
3
7
7
8
9
20
10
1 meter


Event 1, 2014
Event-2
190
unit 3
+ 2.8 ka
Event-2
+ 5.7 ka
unit 9 + 15.5 ka
Event-4
1m
Event-3
unit 7
+ 7.4 ka
unit 8
unit 20
1 meter



OxCal v4.2.4 Bronk Ramsey (2013); r:5 IntCal13 atmospheric curve (Reimer et al 2013)
C_Date 2014
R_Date NO-2
EV-2
R_Date NO-3
EV-3
R_Date NO-7
EV-4
R_Date NO-9
Sequence Napa Oaks
2014
Event-2
4 ka
Event-3
6.5 ka
Event 4
~14 ka
20000
15000
10000
5000
0
Modelled date (BP)

Conclusions

- On this easternmost surface rupture trace E, previous displacements during the past 15 ka were significantly larger.

- 3 events predating 2014 were recognized: Event 2: 4 ka, Event 3: 6.5 ka, and Event 4: ~14 ka.

- The 2014 right lateral displacement was 6 cm with 1 cm down to the east. Using this ratio the cumulative slip is about 6 m, which results in single event offsets in the few meter range, larger than any 2014 displacements along the primary tectonic trace A.

- The slip rate over 15 ka is 0.4 mm/yr.

- The weak tectonic geomorphic fault signature, apparently inconsistent with the paleoseismic rate may be due to low cumulative displacement. A related older sub parallel fault to the west may have been the more active structure in the past.

- This study has important implications for surface rupture hazard assessments, and helps place limits on the ability to recognize surface rupture potential. It also highlights the value of post-earthquake investigations including the mapping of minor cracks as indicators of active faults.

Update and Issues Facing Earthquake Research in Colorado

Matt Morgan

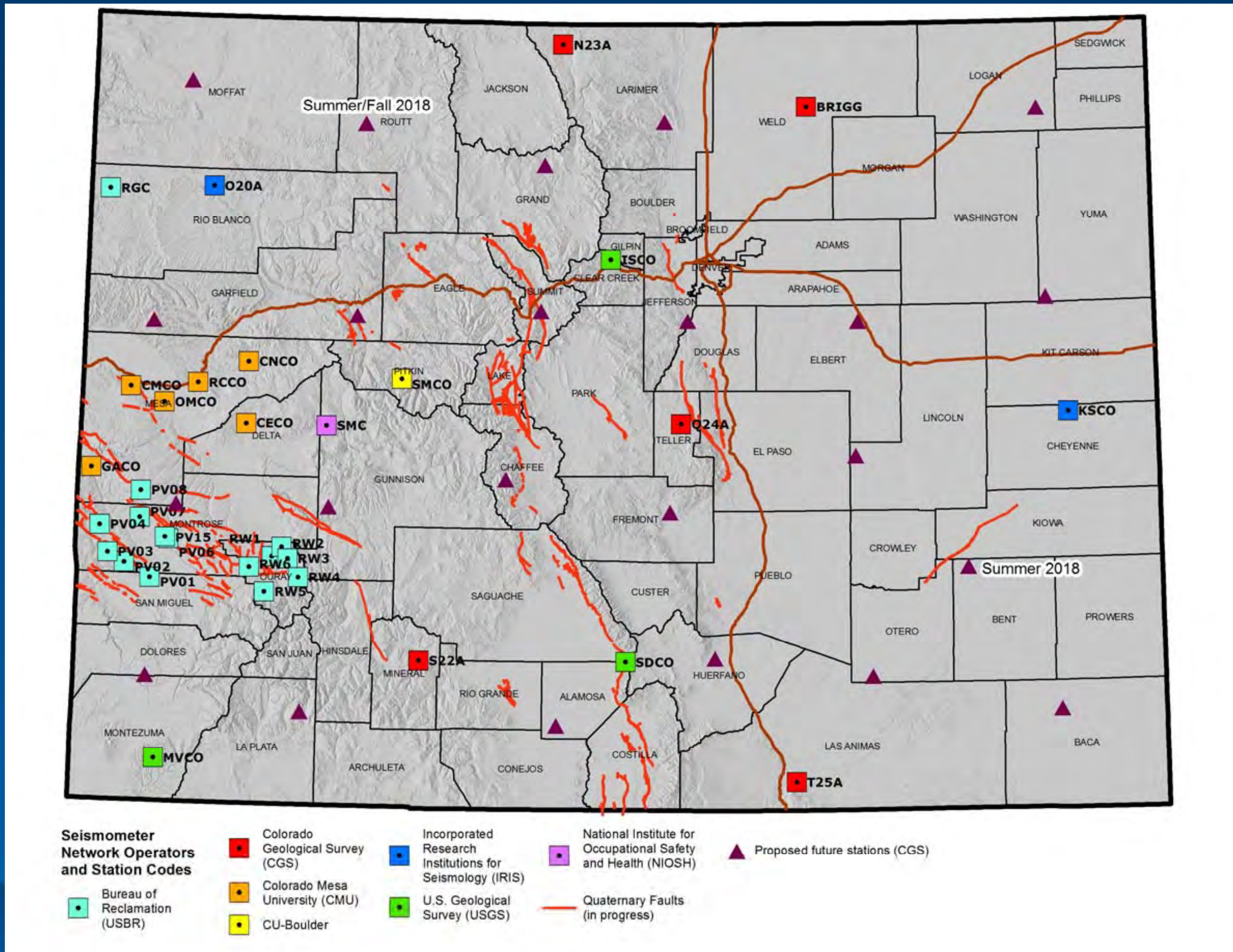
Deputy Director

Geologic Hazard, Mineral Resources and Geologic Mapping Program Manager

COLORADO SCHOOL OF MINES

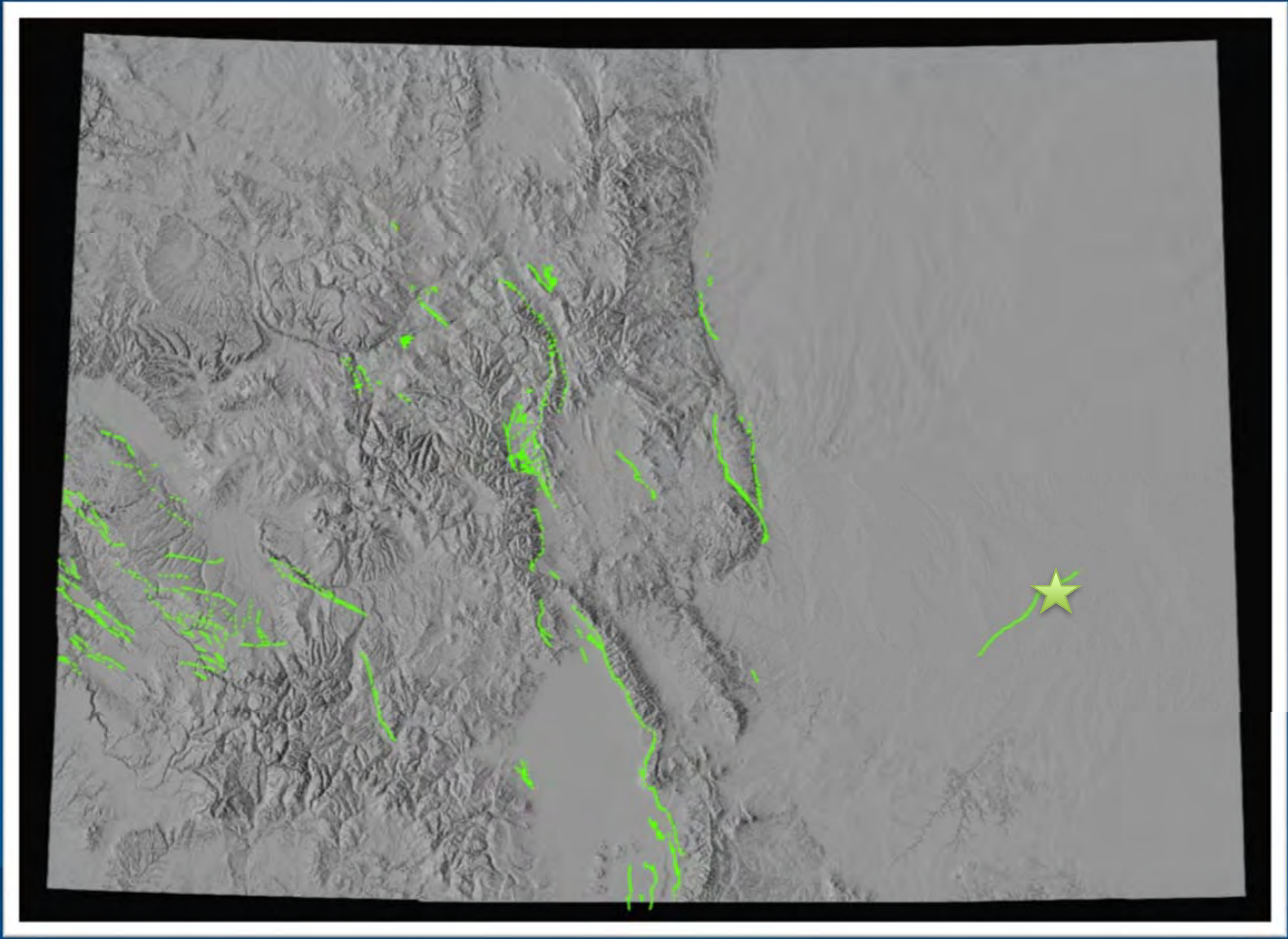
COLORADO GEOLOGICAL SURVEY

Seismometer Locations

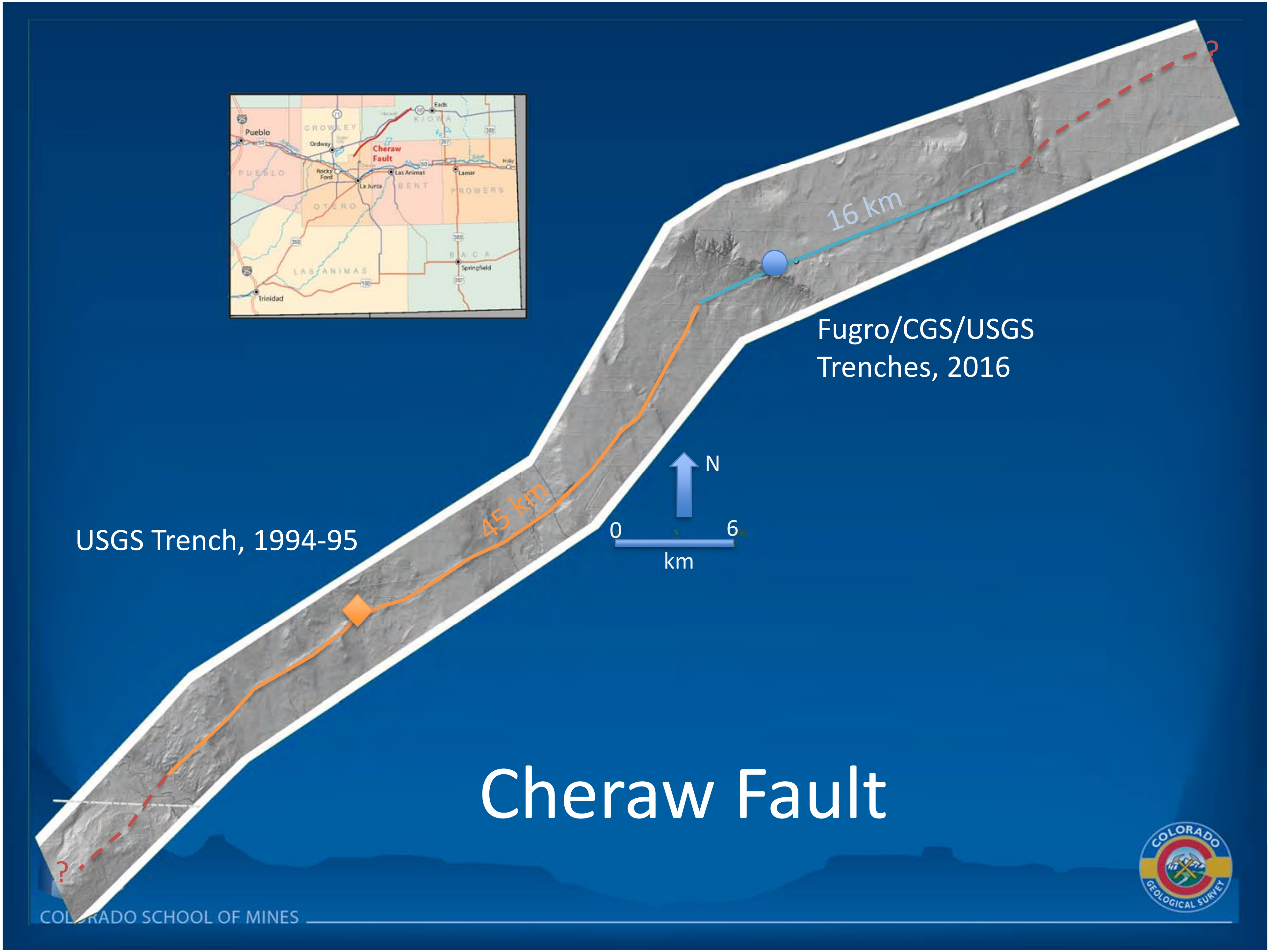


Seismometer Installation

Cheraw Fault Trenching



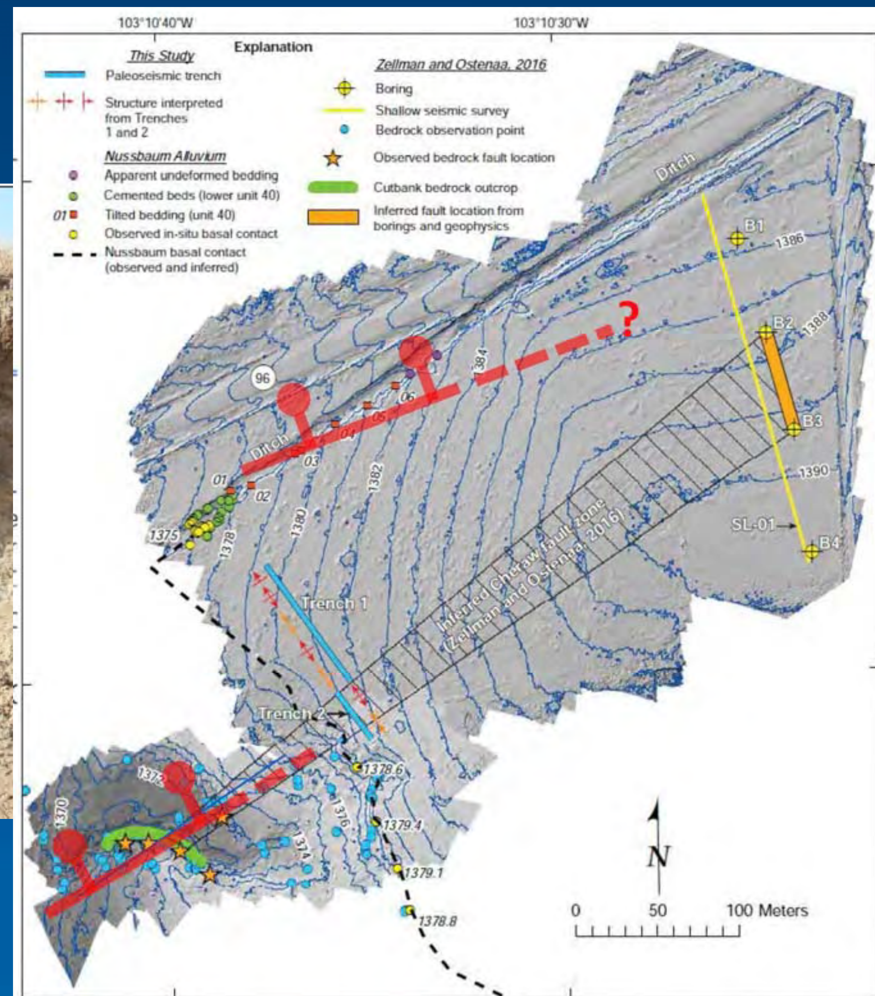
COLORADO SCHOOL OF MINES


Cheraw Fault
USGS Trench, 1994-95
Fugro/CGS/USGS
Trenches, 2016
45 km
16 km
?
?
N
0
6
km
Pueblo
Ordway
Rocky Ford
La Junta
Las Animas
Lamar
Eads
Springfield
Trinidad
Cheraw Fault
CROWLEY
KIOWA
PUEBLO
OTERO
BENT
PROWERS
BACA
LAS ANIMAS
COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES

Cheraw Fault Trenching

Mark Zellman, BGC Engineering

Cheraw Fault Trenching

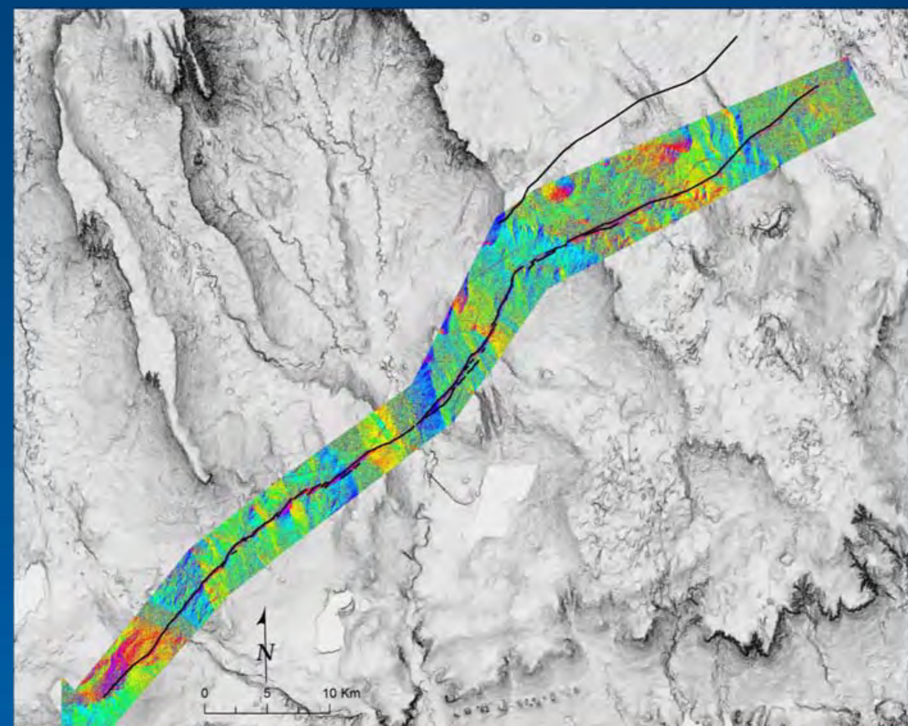


Mark Zellman, BGC Engineering

Cheraw Fault Findings

- Increased length of fault to ~60 km; additional segments may exist
- Complex fault, multiple steps; deformation in recent trenches on left-stepping ramp
- Nussbaum Alluvium at the Haswell site is deformed and its basal contact is vertically offset at least 5 to 6 m, and most likely about 9 m
- New ages, deformed sediments are much younger than previously known - deposition of units within the Nussbaum Alluvium spanned an age range from at least 126 ka to >>160 ka
- Deformed stratigraphy and age constraints from luminescence dating suggest that this slip on the Cheraw fault occurred after ~126 to 159 ka, yielding a minimum vertical slip rate of ~0.06 to 0.07 mm/yr since that time

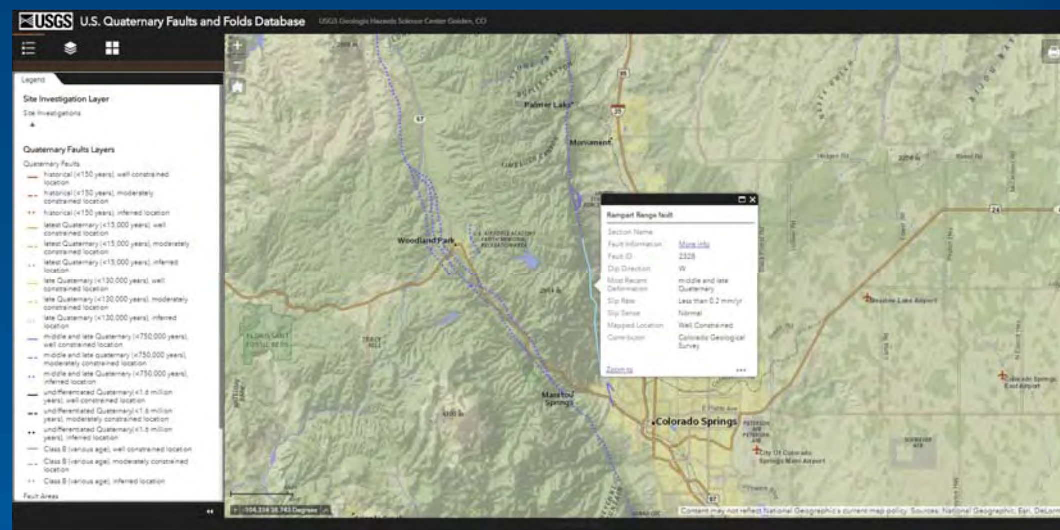
-Zellman and Ostenaa, 2018



Mark Zellman, BGC Engineering

Quaternary Fault Database Update

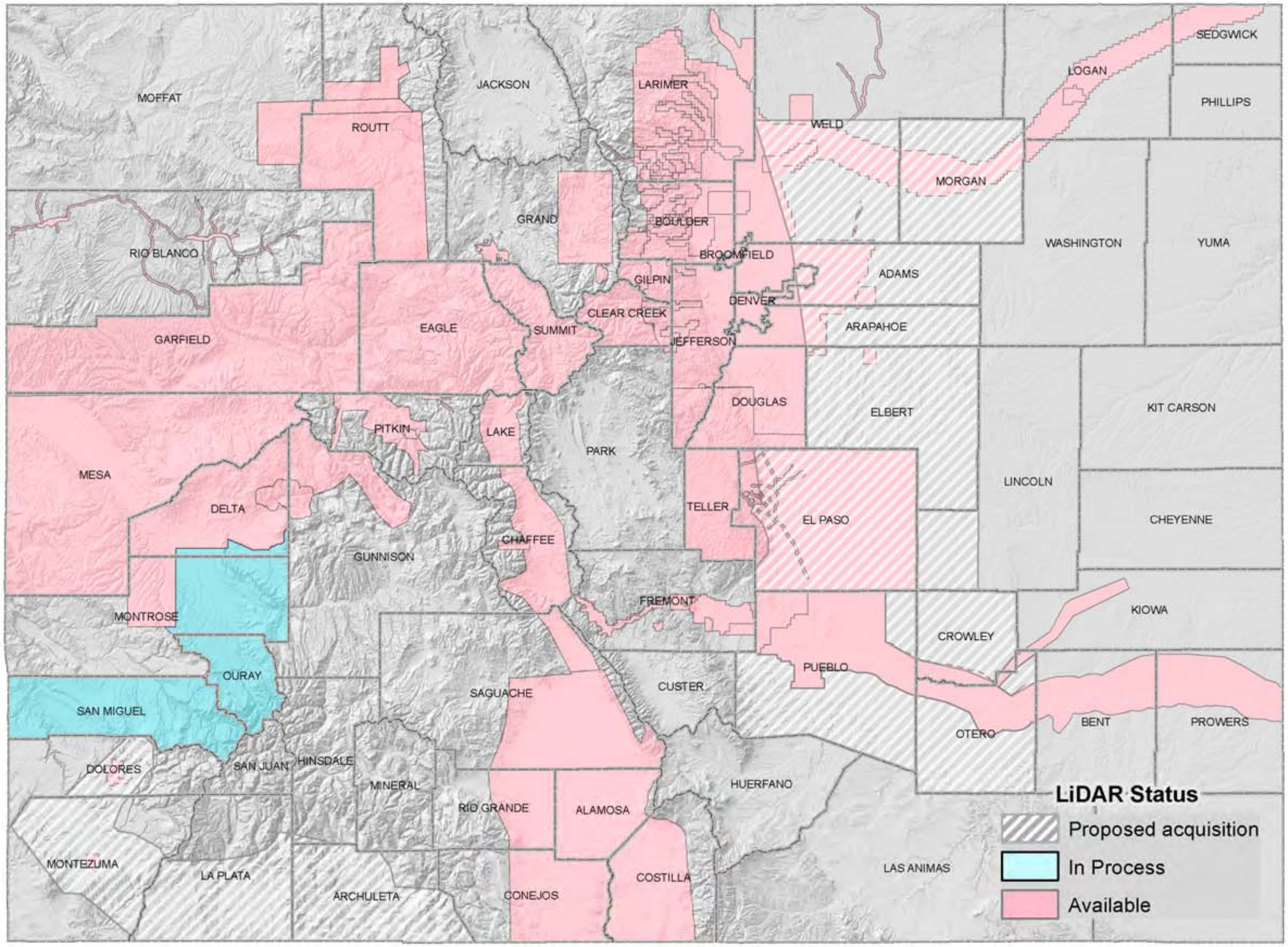
- USGS funded
- Last updated in 1998
- Fault traces using 24k and 100k maps, LiDAR
- Updating the full "legacy" database – CGS could take ownership



Earthquake Reference Collection (ERC)

- Contains 550 papers, consultant reports, abstracts, maps, theses
- Search by Author, Title, Year
- Will be updated with more user-friendly interface, keyword search, and index map

Lidar Acquisition in Colorado
September 2017



Technical Issues

- Q-Faults are not fully characterized
  - Mapped in the 70s-90s, only a handful have reliable absolute ages, most ages assigned by soils and height in landscape
  - Paucity of trenches
  - Poorly constrained ages of Q deposits
- More ages are needed
- Lidar coming, but slowly, 32% of the state is covered
- Cross-border coordination, could help on Lidar collection, geo mapping, proposals for funding
- Things move S-L-O-W

Non-Technical Issues

- Funding-Little (none) internally; externally, money available for outreach but not science
- More pressing projects (Debris flows, Landslides, Hydro, Minerals)
- Lack of available technical staff

Conclusions

- A small amount (<20k) of funding goes a long way in Colorado
- Lidar and geochron are first steps to make faster progress > larger, detailed projects
- More public outreach, make our science understandable
- Cross-border coordination

Technical Issues Facing Idaho

2018 Basin and Range Province Earthquake Working Group

February 15, 2018

Zach Lifton

Idaho Geological Survey

Idaho Fault Priorities

- Lost River*
- Squaw Creek*-Jakes Creek-Big Flat
- E & W Bear Lake
- Sawtooth*-Boulder Front
- Owyhee
- Beaverhead*
- Lemhi*

*Priority faults suggested at BRPSHS III (2014)

Idaho Fault Database

- Current ID database vs USGS database
  - USGS is more up-to-date
  - USGS line work is more detailed
  - ID includes some faults that are not included in USGS
- What standard to meet to include in USGS database?
- IGS is working on updating the fault database
  - Better imagery (Google Earth, etc.)
  - More LiDAR available and more coming soon
  - Working toward a more modern model (perhaps following UCERF3 database)
    - More parameters
    - Defined uncertainties

22-25 October
Seattle, Washington, USA

THE GEOLOGICAL SOCIETY OF AMERICA®

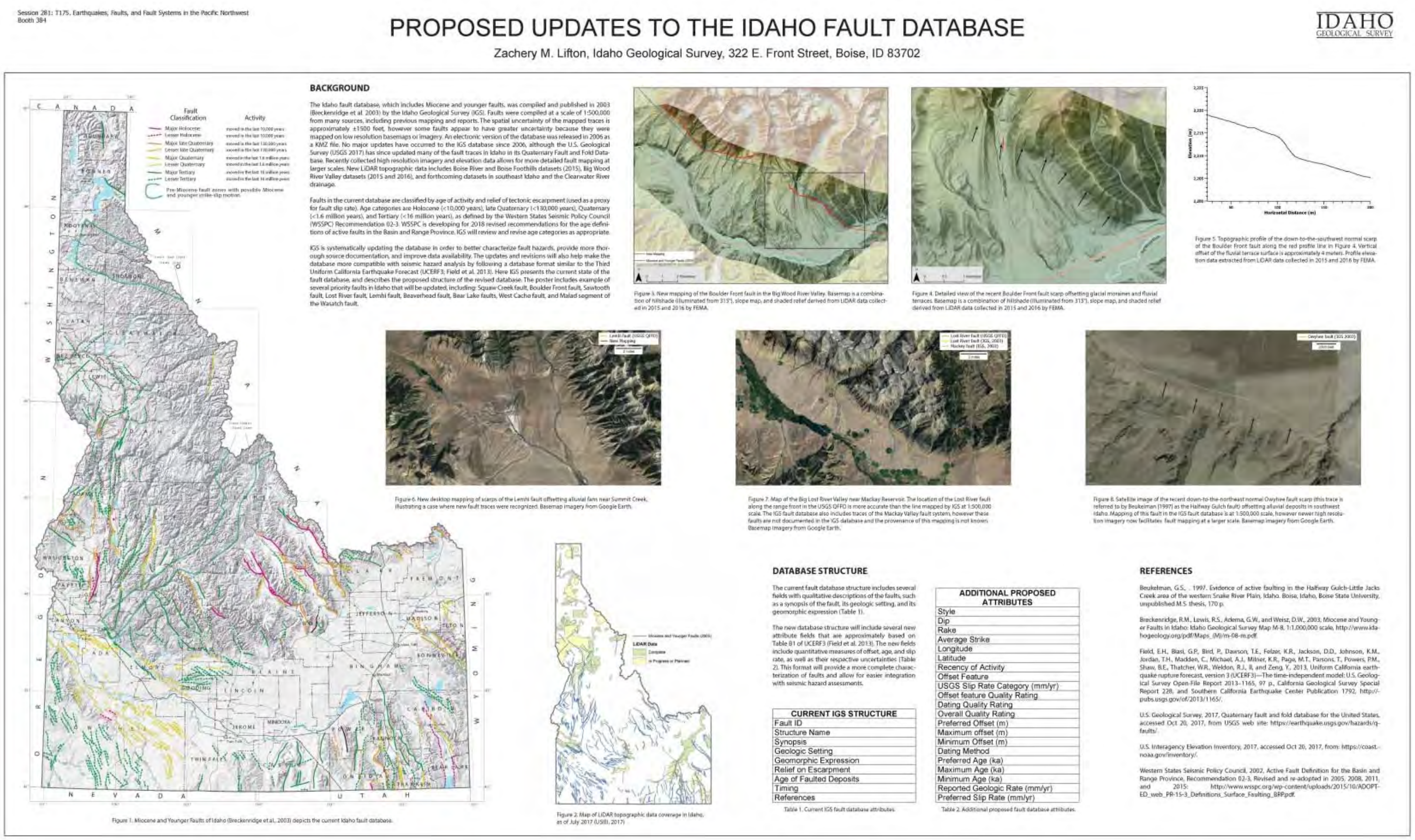
GSA Annual Meeting in Seattle, Washington, USA - 2017

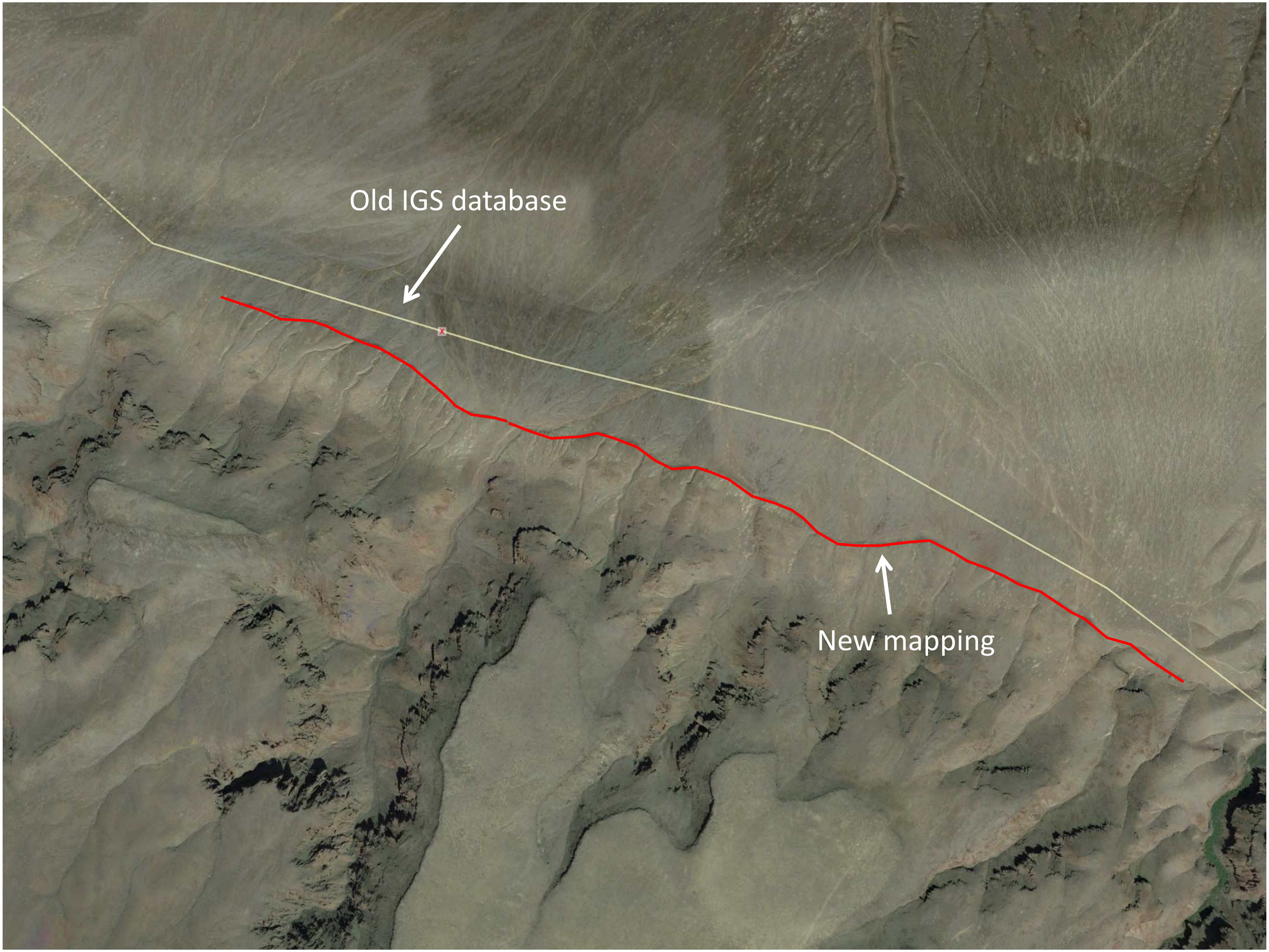
Paper No. 281-13
Presentation Time: 9:00 AM-6:30 PM

PROPOSED UPDATES TO THE IDAHO FAULT DATABASE

LIFTON, Zachery M., Idaho Geological Survey, 322 E. Front Street, Suite 201, Boise, ID 83702, zlifton@uidaho.edu

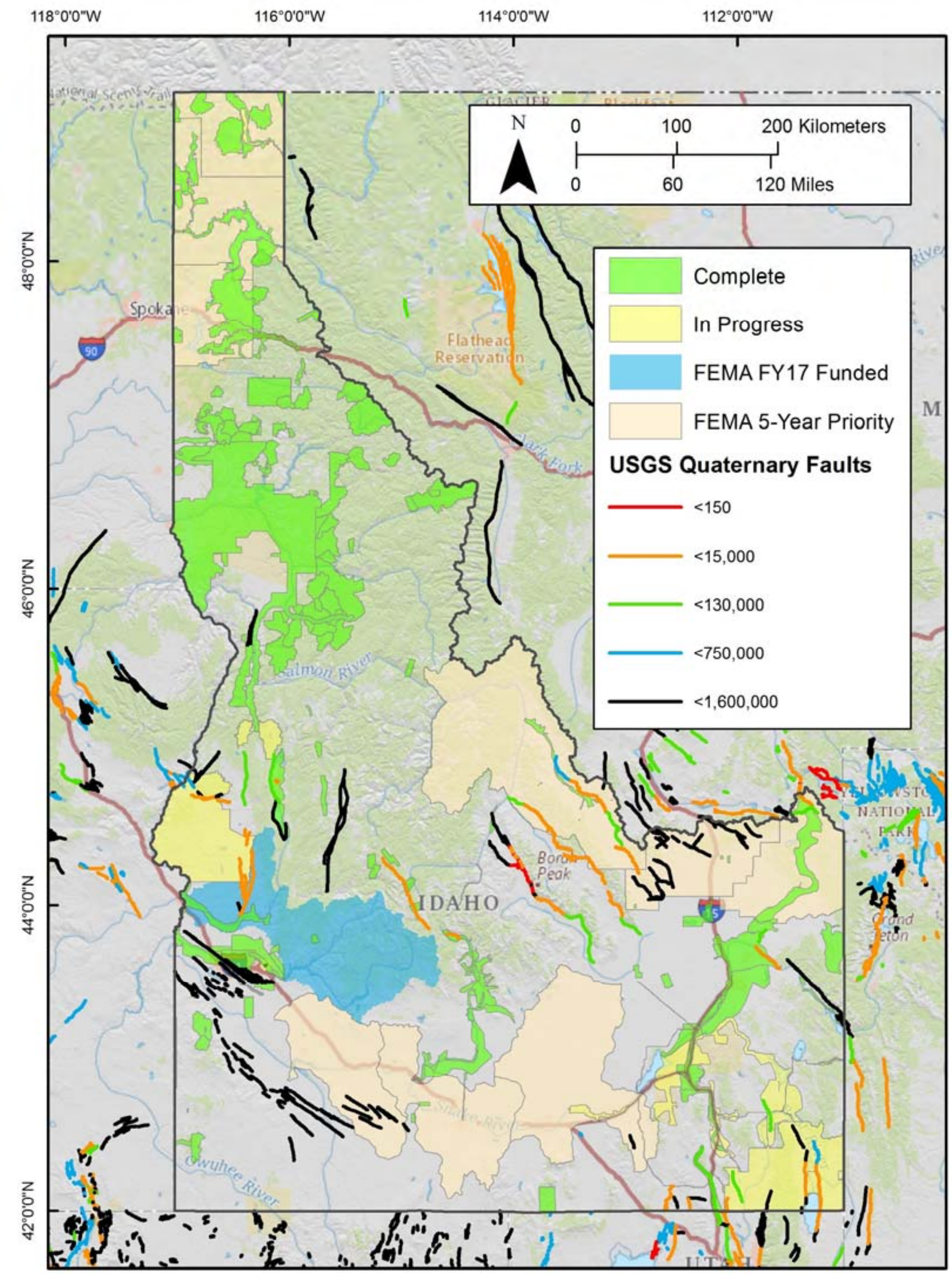
The Idaho fault database, which includes Miocene and younger faults, was compiled and published in 2003 (Breckenridge et al. 2003) by the Idaho Geological Survey (IGS). An electronic version of the database was released in 2006 and it has since been updated sporadically. IGS is systematically updating the database in order to better characterize fault hazards, provide more thorough source documentation, and improve data availability. Recently collected high resolution imagery and elevation data allows for more detailed fault mapping at larger scales. The updates and revisions will also help make the database more compatible with seismic hazard analysis by following a database format similar to the Third Uniform California Earthquake Forecast (UCERF3; Field et al. 2013). This poster presents the current state of the fault database, and describes the proposed structure of the revised database. The poster will also highlight several priority faults in Idaho, including: Squaw Creek fault, Boulder Front fault, Sawtooth fault, Lost River fault, Lemhi fault, Beaverhead fault, Bear Lake faults, West Cache fault, and Malad segment of the Wasatch fault.




Old IGS database
New mapping

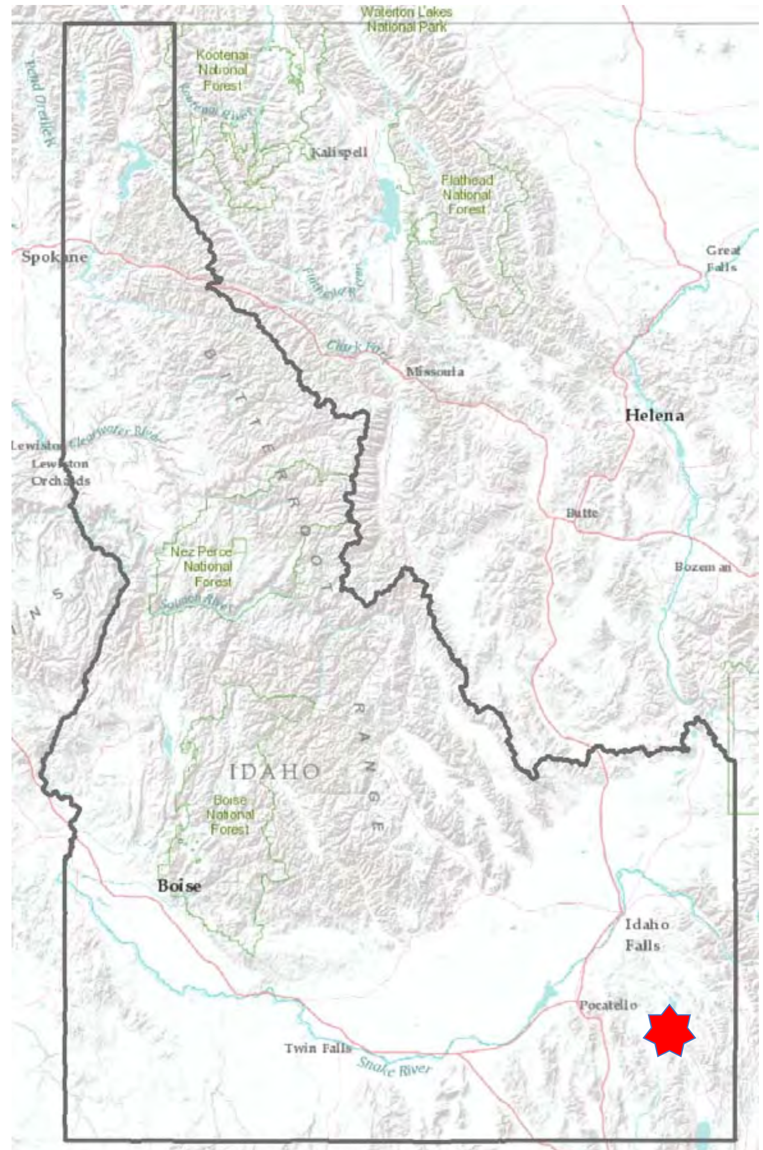
LiDAR Data Availability

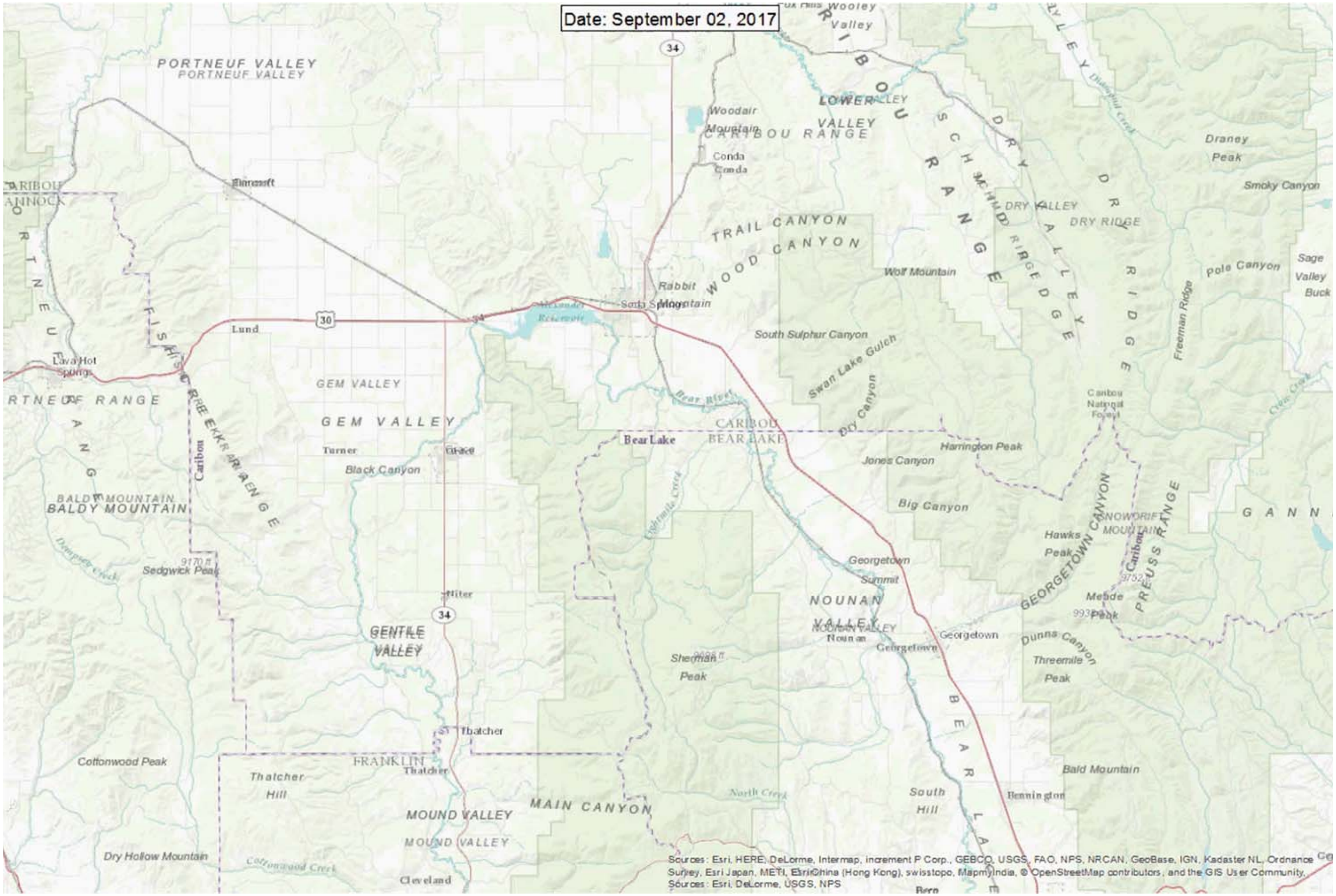
- Current coverage
- New datasets
- Forthcoming datasets

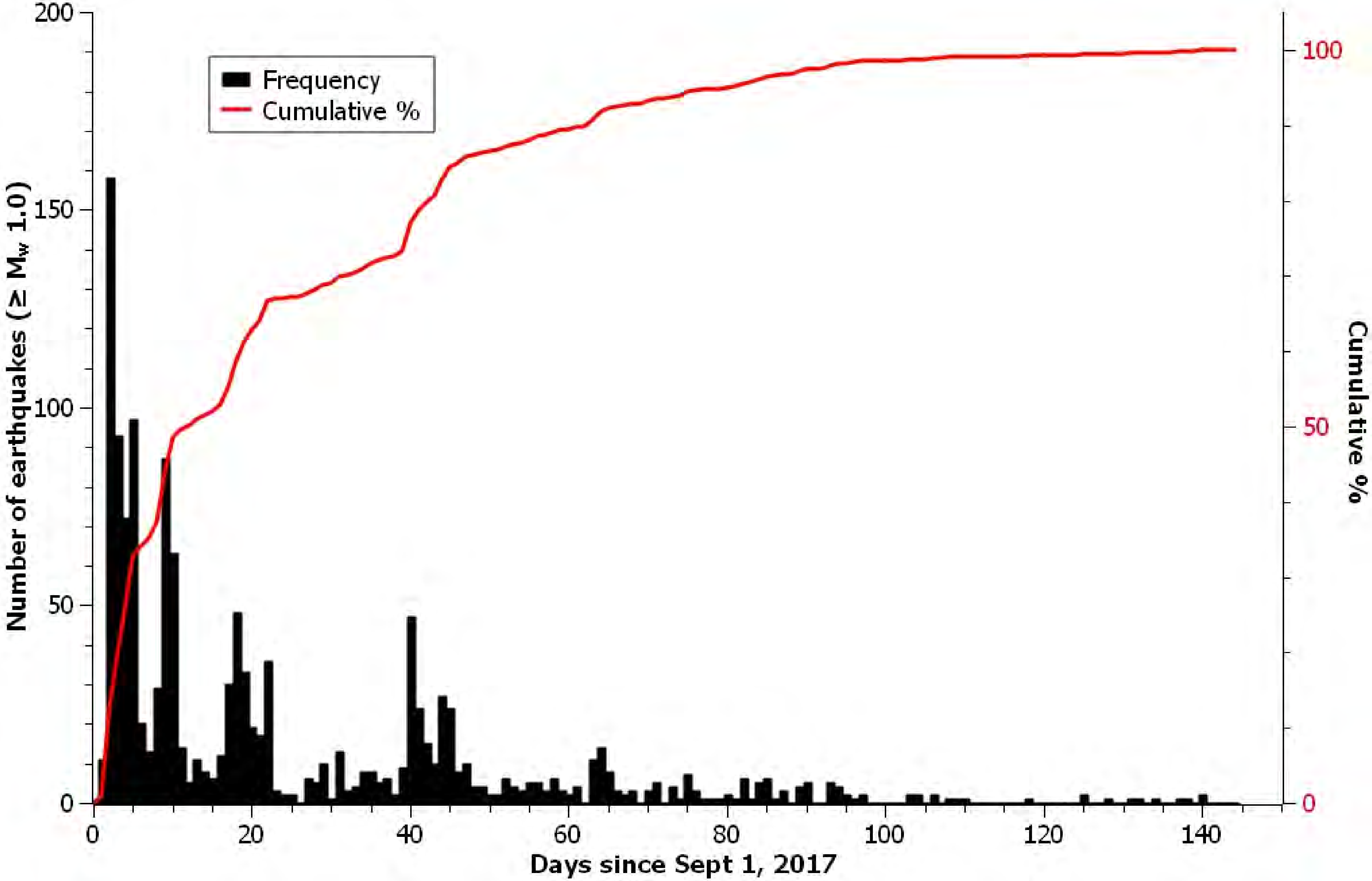


Soda Springs Earthquake Sequence

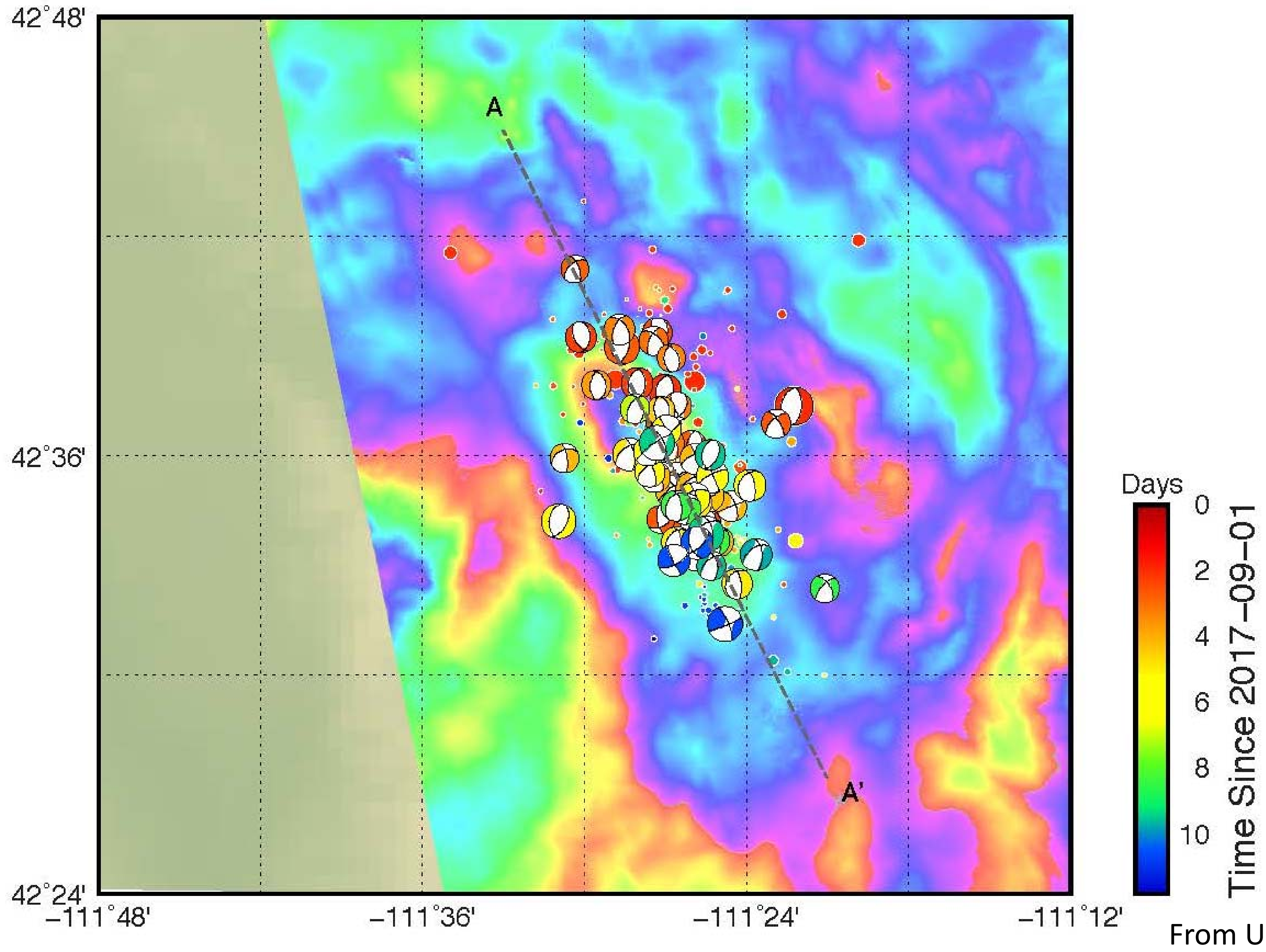
- Began Sept. 2, 2017
- 9 foreshocks up to M4.1 in preceding 30 min
- M5.3 mainshock
- >1900 locatable aftershocks:
  - 26 > M4.0
- UUSS and USGS deployed 8 temporary stations
- Source fault is not clearly known




Date: September 02, 2017
PORTNEUF VALLEY
Woodair
Mountain
LOWER VALLEY
CARIBOU RANGE
Conda
Draney
Peak
Smoky Canyon
TRAIL CANYON
WOOD CANYON
DRY VALLEY
DRY RIDGE
Wolf Mountain
Pole Canyon
Sage
Valley
Buck
Freeman Ridge
Rabbit
Mountain
Lund
Lava Hot
Springs
South Sulphur Canyon
Swan Lake Gulch
GEM VALLEY
Bear River
Dry Canyon
Caribou
National
Forest
BALDY MOUNTAIN
Bear Lake
Turner
Black Canyon
Harrington Peak
Jones Canyon
Big Canyon
GEORGETOWN CANYON
Hawks
Peak
Sedgwick Peak
9170 ft
Georgetown
Summit
NOUNAN VALLEY
Niter
GENTILE
VALLEY
Georgetown
Meade
Peak
Dunns Canyon
Threemile
Peak
Sherman
Peak
Thatcher
Cottonwood Peak
FRANKLIN
Thatcher
Hill
MOUND VALLEY
MAIN CANYON
Bald Mountain
South
Hill
Bennington
Dry Hollow Mountain
Cleveland
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community,
Sources: Esri, DeLorme, USGS, NPS


Frequency
Cumulative %
Number of earthquakes (≥ Mw 1.0)
Cumulative %
Days since Sept 1, 2017
200
150
100
50
0
100
50
0
0
20
40
60
80
100
120
140

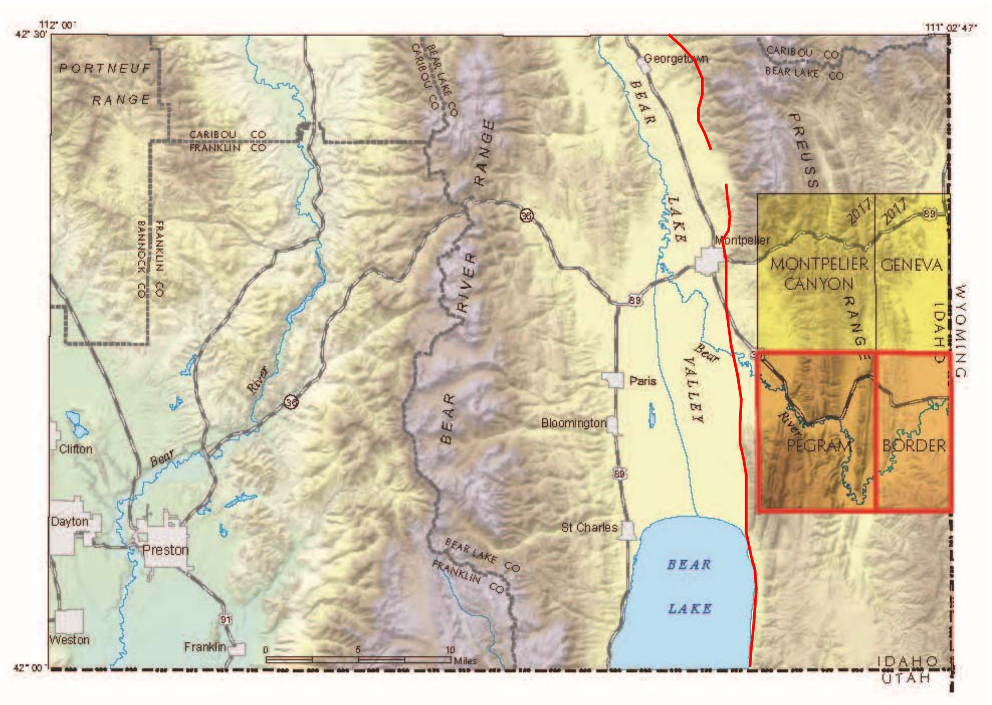
InSAR interferogram



From USGS, 2017

New Mapping in SE Idaho

- STATEMAP funded
- Covers part of E. Bear Lake fault
- Additional work being done by UGS on north end of Wasatch
- Current FEMA proposal to map active faults with new lidar



Paleoseismology

- Older trenches:
  - Lost River fault: 12 trenches (1969-1995)
  - Lemhi fault: 11 trenches (1969-1992)
  - Squaw Creek and Jakes Flat: 1 trench each (1983)
  - Owyhee fault: 1 trench (1997)
  - West Bear Lake fault: 1 trench (1989)
  - East Bear Lake fault: 2 trenches on Utah side (1990)

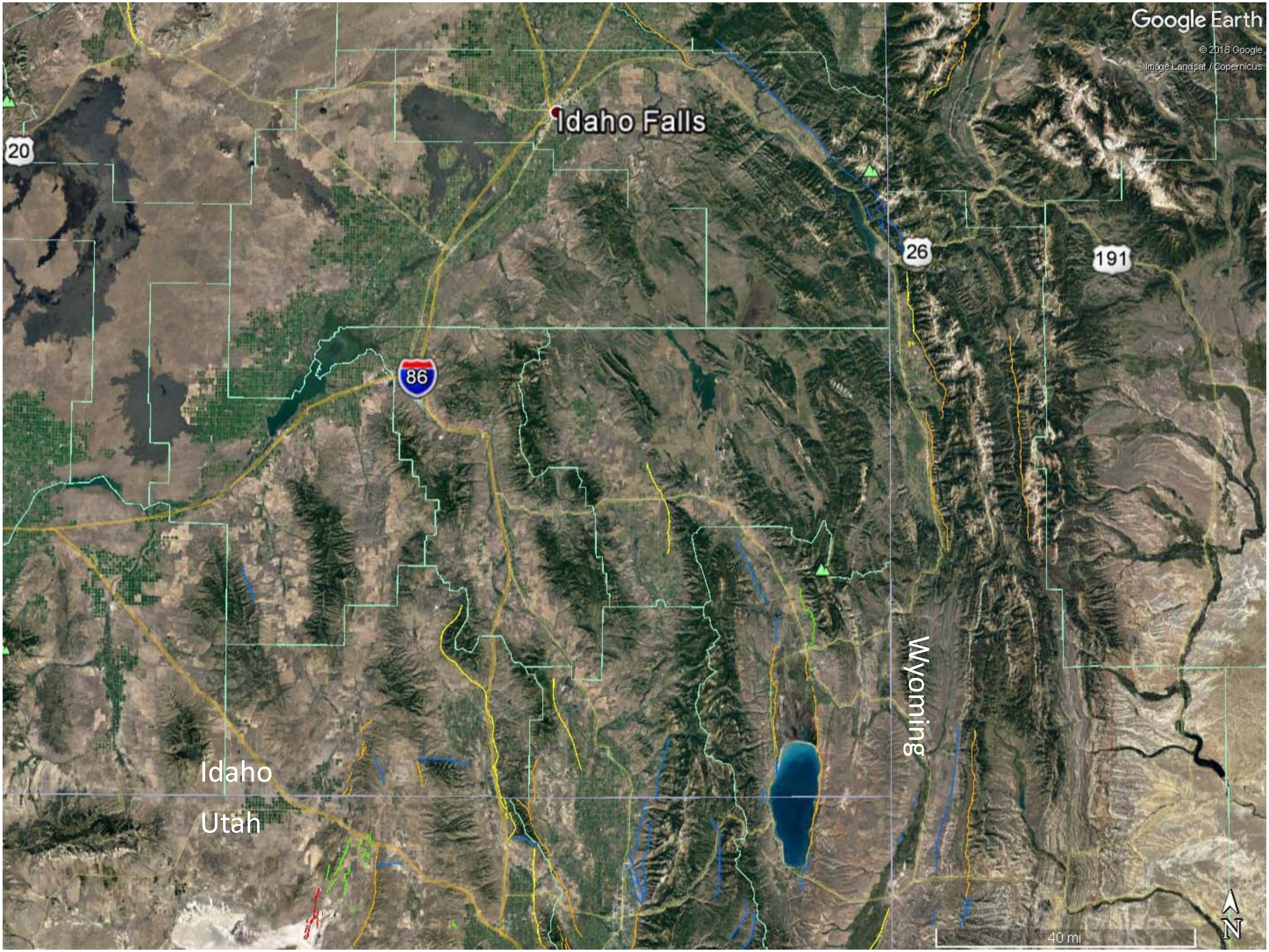
- Sawtooth fault:
  - Glenn Thackray and others at ISU (Thackray et al. 2013 Geology; Johnson 2009 thesis) have done mapping, hand trenching, and lake coring
  - Small portions of fault covered by lidar; fault is not completely mapped
  - Length of rupture, possible segmentation is unknown
  - Relatively high slip rate: 0.5-0.9 mm/yr
  - 2-3 post-14 ka events; ~4100 yr BP and ~7500 yr BP

Idaho Cross-Border Fault Issues

- Washington
  - Spokane fault
- Montana
  - Several faults on either side of the border that may affect the other state (e.g. Beaverhead fault, Bitterroot fault)
  - Seismicity in Helena and Kalispell areas
  - Lewis Clark fault zone (including Hope fault)

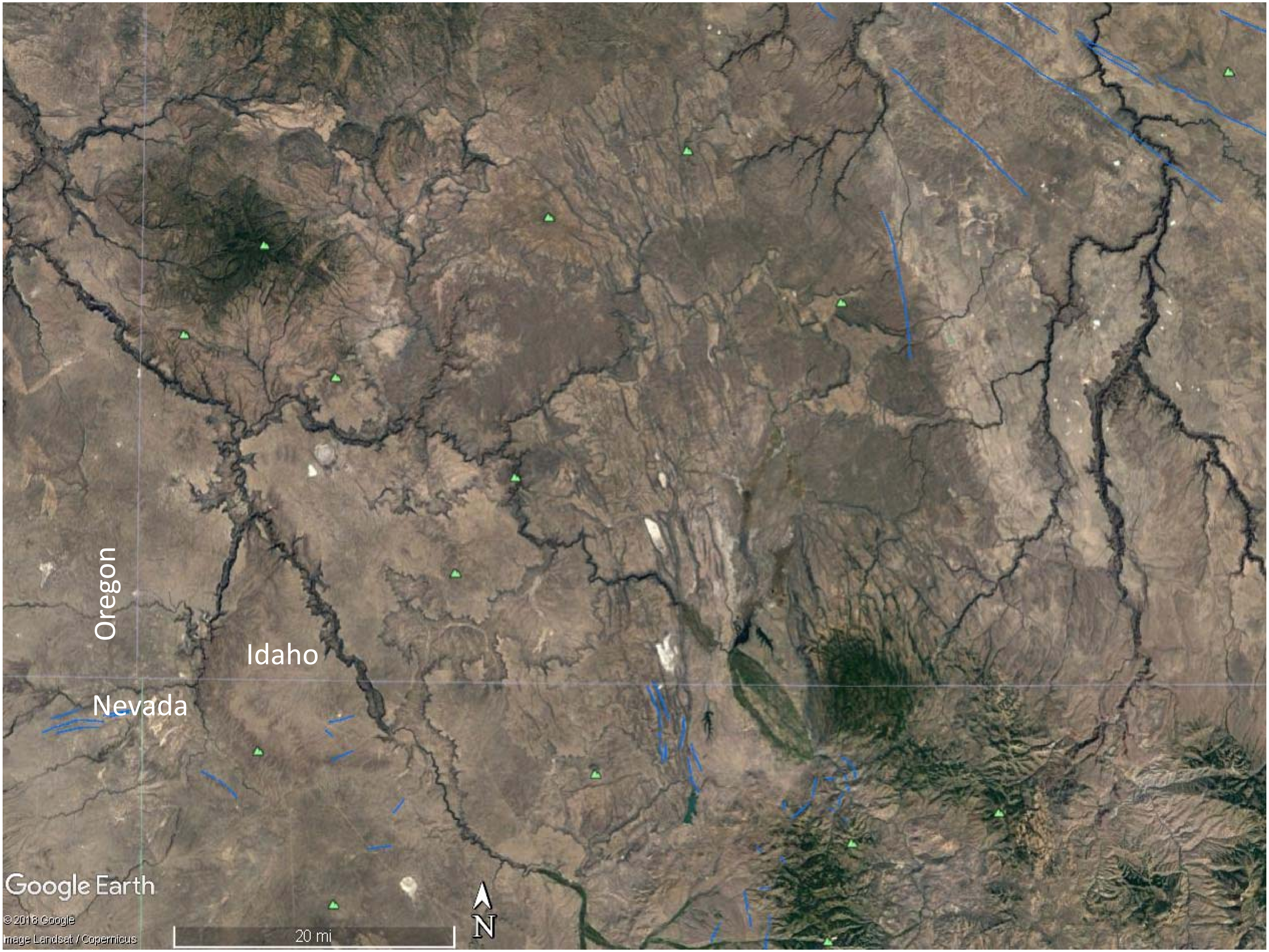
Idaho Cross-Border Fault Issues

- Wyoming
  - Teton and Grand Valley faults
- Utah
  - Bear Lake faults
  - Cache Valley faults
  - Northern end of Wasatch fault
  - Large EQ may have more impact on Utah than Idaho


Google Earth
© 2018 Google
Image Landsat / Copernicus
Idaho Falls
20
86
26
191
Wyoming
Idaho
Utah
40 mi
N

Idaho Cross-Border Fault Issues

- Nevada
  - M5.9 Wells EQ was widely felt in southern Idaho
  - Many faults in Nevada have not been mapped on the Idaho side of the border
- Oregon
  - Pine Valley fault
  - Cottonwood Mountain fault


Oregon
Idaho
Nevada
Google Earth
© 2018 Google
Image Landsat / Copernicus
20 mi
N

Update and Issues Facing Earthquake Research in Colorado

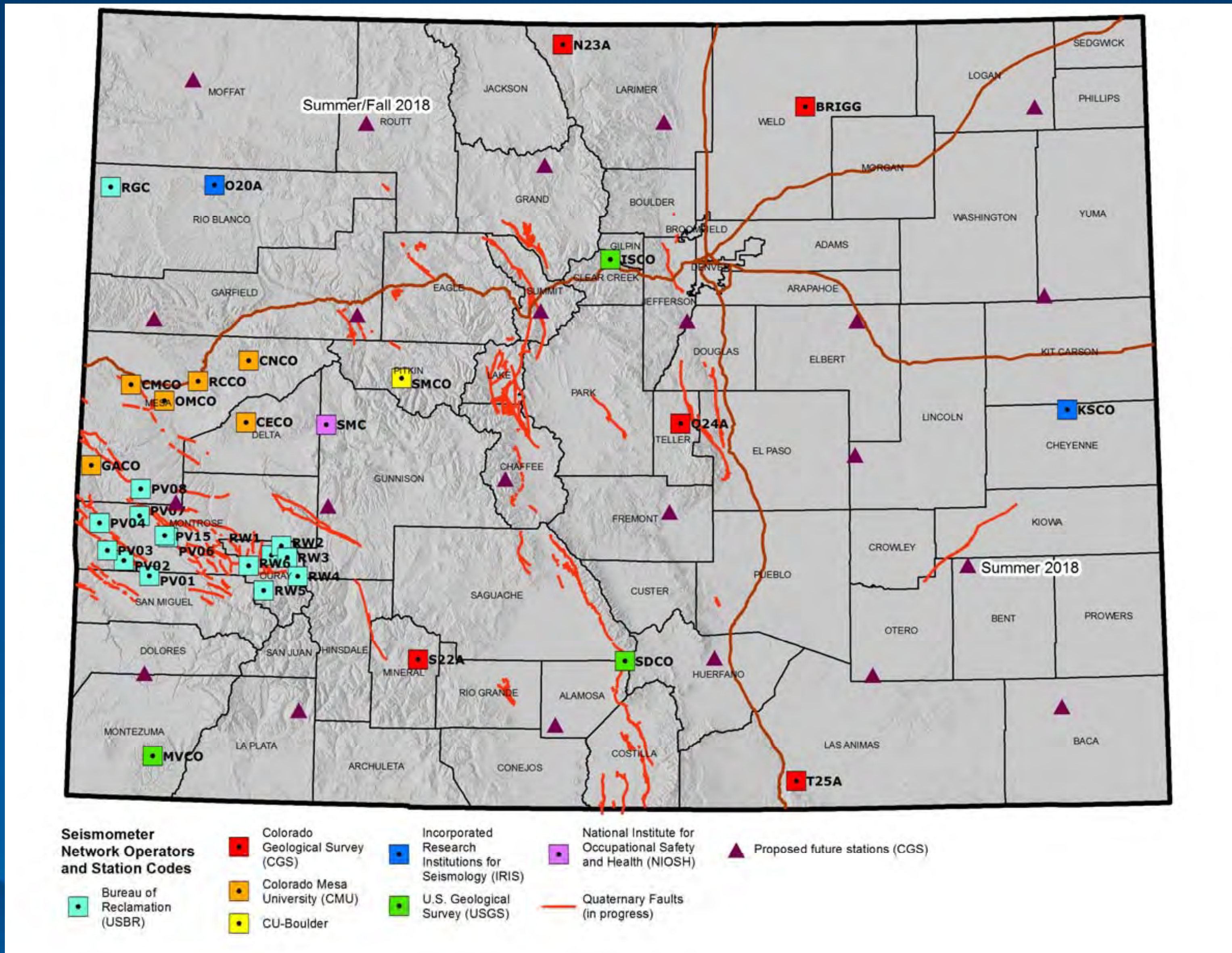
Matt Morgan

Deputy Director

Geologic Hazard, Mineral Resources, and Geologic Mapping Program Manager

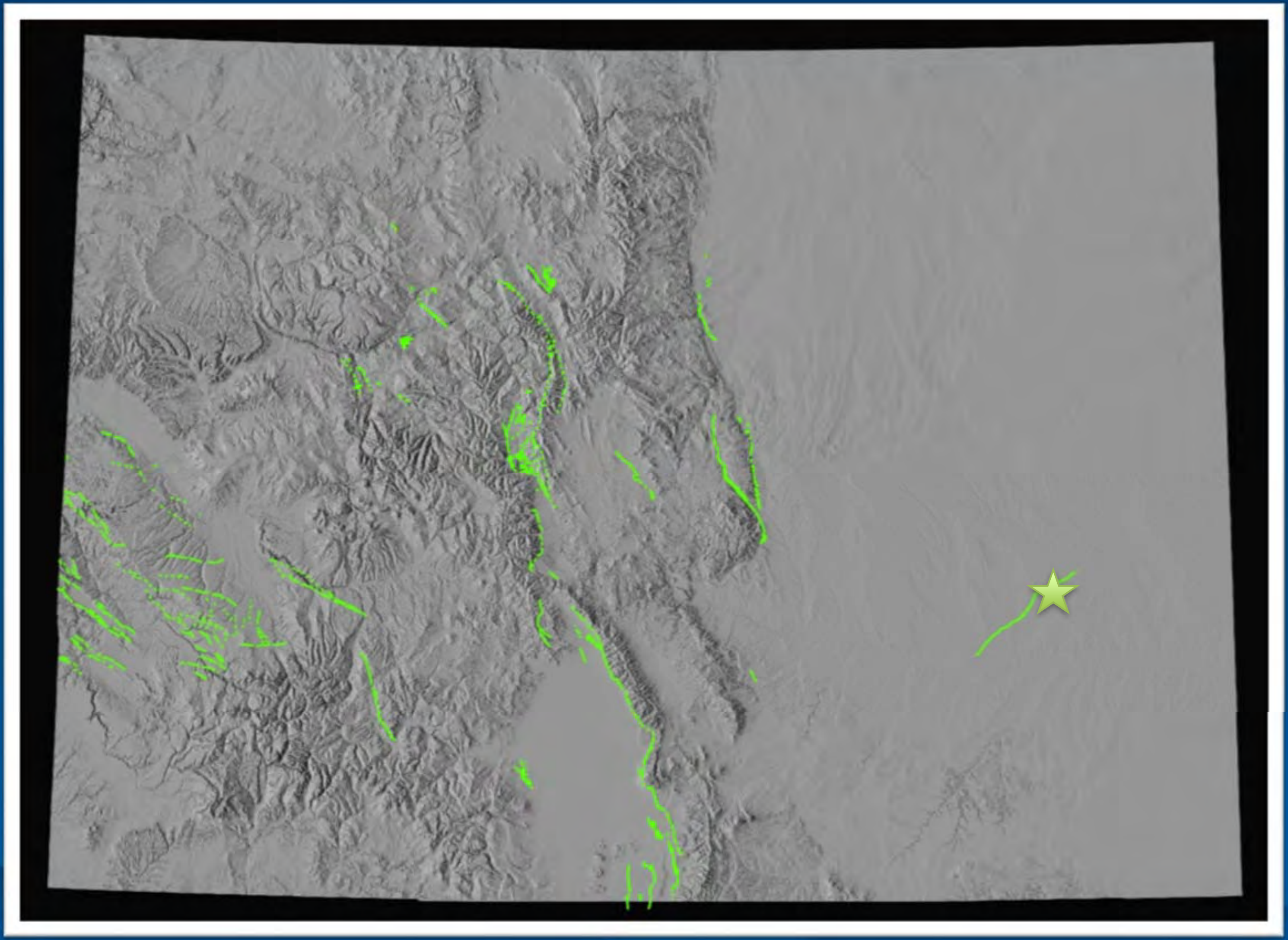
COLORADO SCHOOL OF MINES

Seismometer Locations

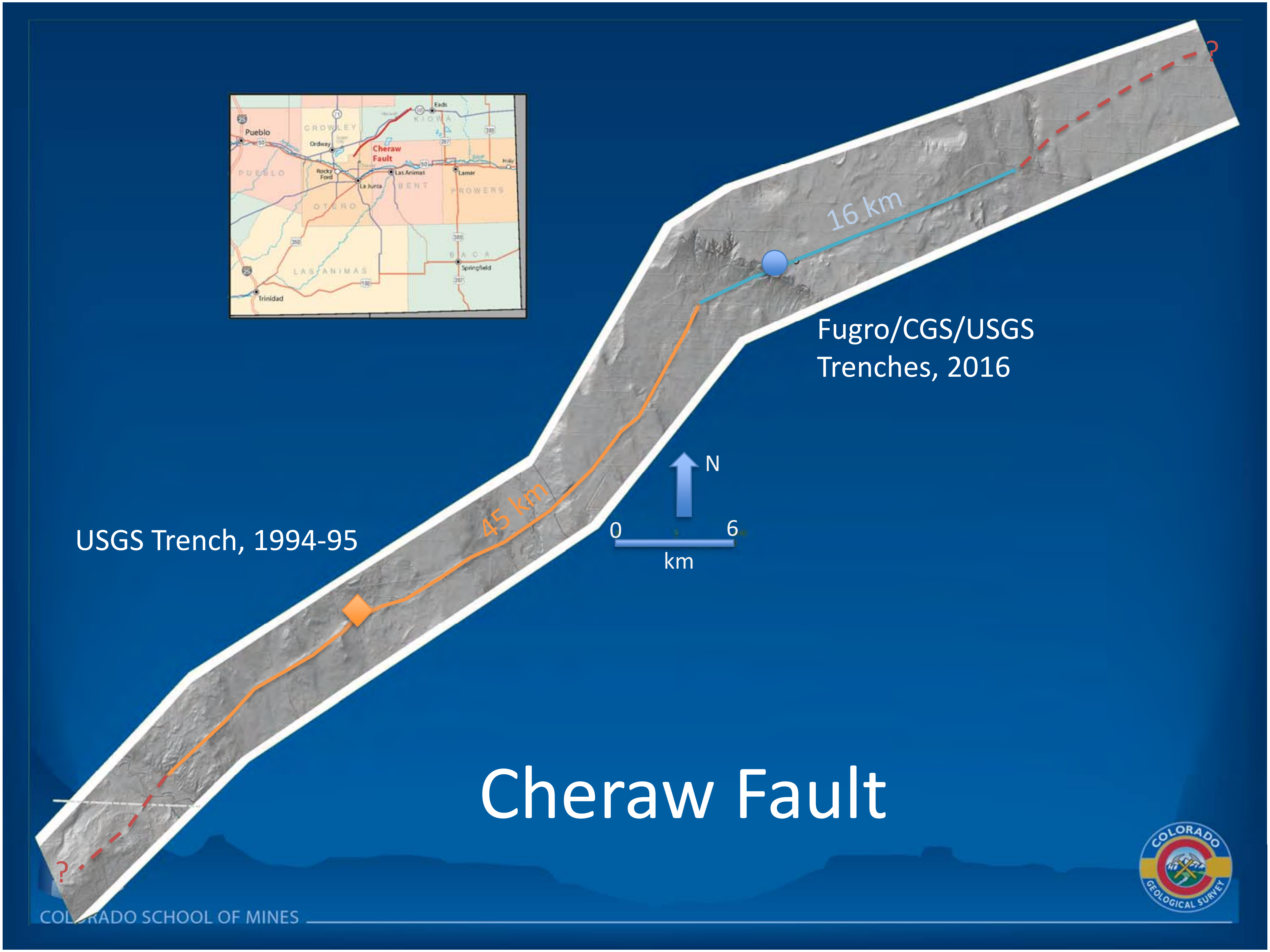


Seismometer Installation

Cheraw Fault Trenching



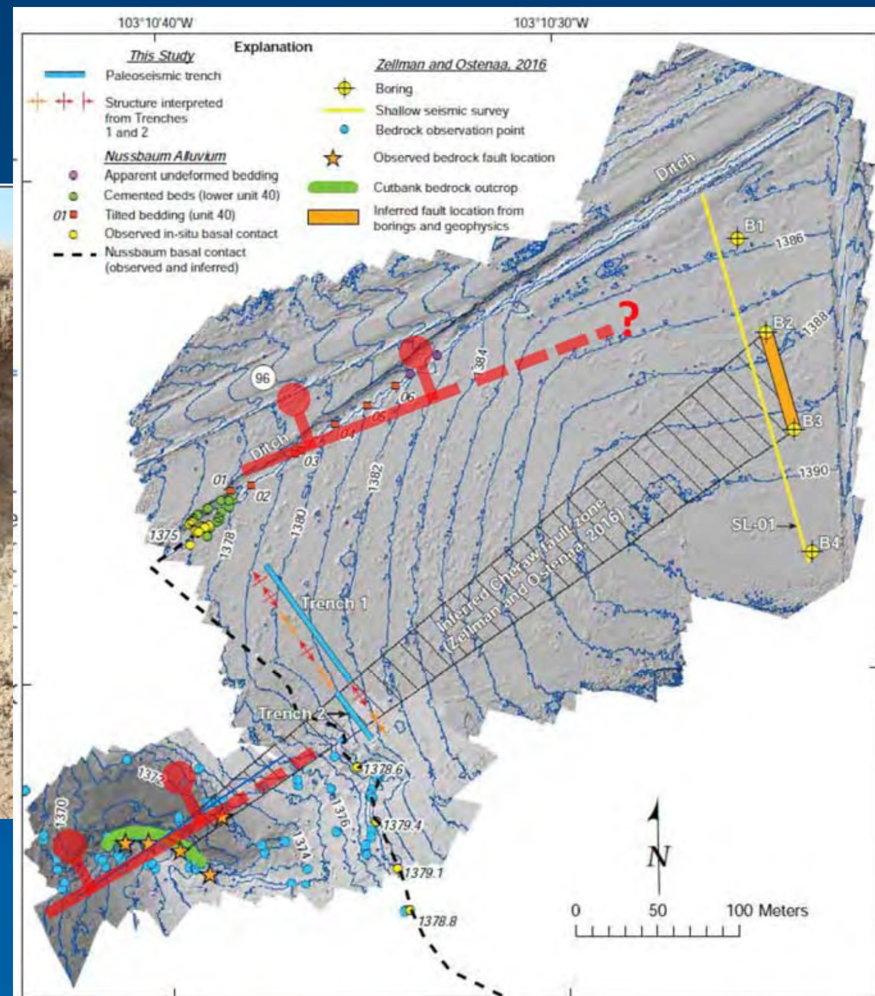
COLORADO SCHOOL OF MINES


Pueblo
Cheraw Fault
Las Animas
Lamar
Trinidad
Springfield
16 km
Fugro/CGS/USGS
Trenches, 2016
N
0
6
km
45 km
USGS Trench, 1994-95
?
?
Cheraw Fault
COLORADO SCHOOL OF MINES
COLORADO GEOLOGICAL SURVEY

Cheraw Fault Trenching

Mark Zellman, BGC Engineering

Cheraw Fault Trenching

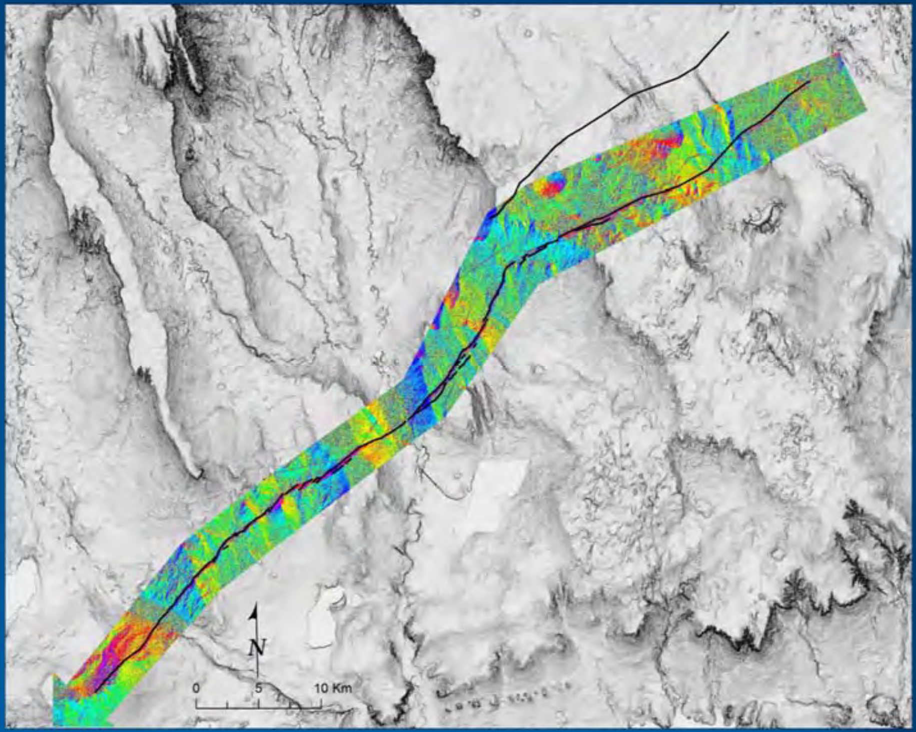


Mark Zellman, BGC Engineering

Cheraw Fault Findings

- Increased length of fault to ~60 km; additional segments may exist and increase length to 80 km
- Complex fault, multiple steps; deformation in recent trenches on left-stepping ramp
- Nussbaum Alluvium at the Haswell site is deformed and its basal contact is vertically offset at least 5 to 6 m, and most likely about 9 m
- New ages, deformed sediments are much younger than previously known - deposition of units within the Nussbaum Alluvium spanned an age range from at least 126 ka to >>160 ka
- Deformed stratigraphy and age constraints from luminescence dating suggest that this slip on the Cheraw fault occurred after ~126 to 159 ka, yielding a minimum vertical slip rate of ~0.06 to 0.07 mm/yr since that time

-Ostenaa and Zellman, 2018



Mark Zellman, BGC Engineering; Lidar CGS

Quaternary Fault Database Update

- USGS funded
- Last updated in 1998
- Update fault traces and trenches using 24k and 100k maps, LiDAR, consultant reports
- Updating the full “legacy” database – CGS could take ownership

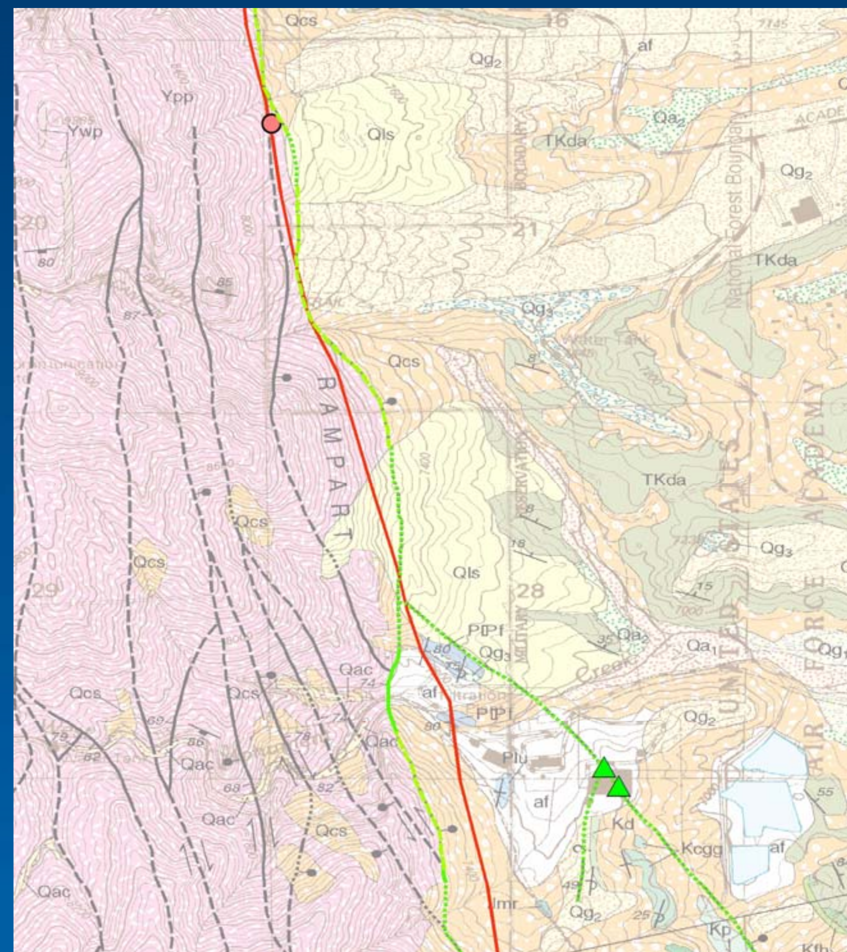
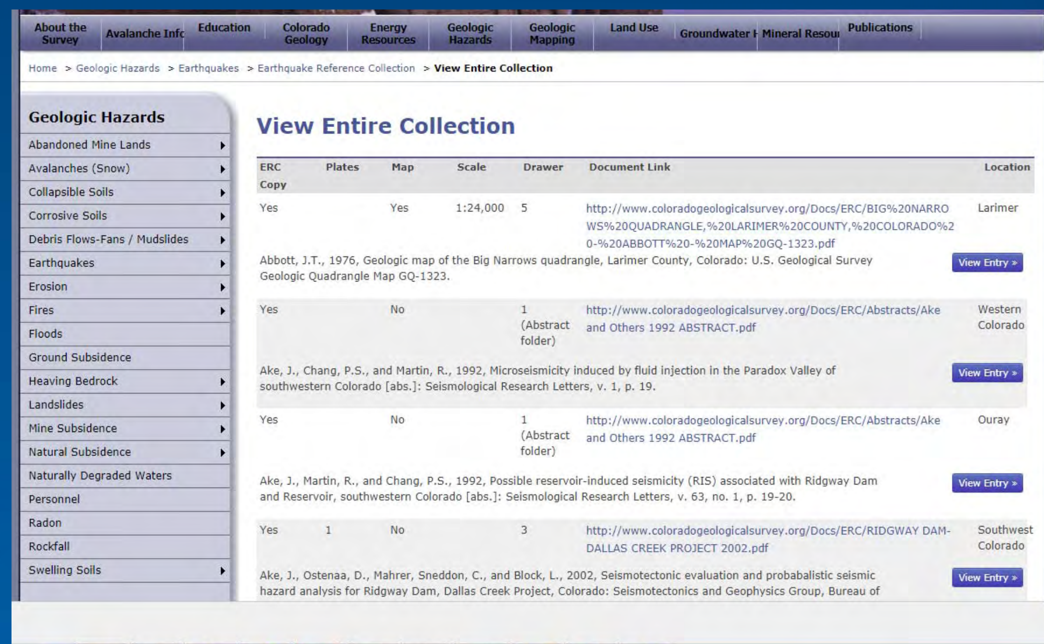


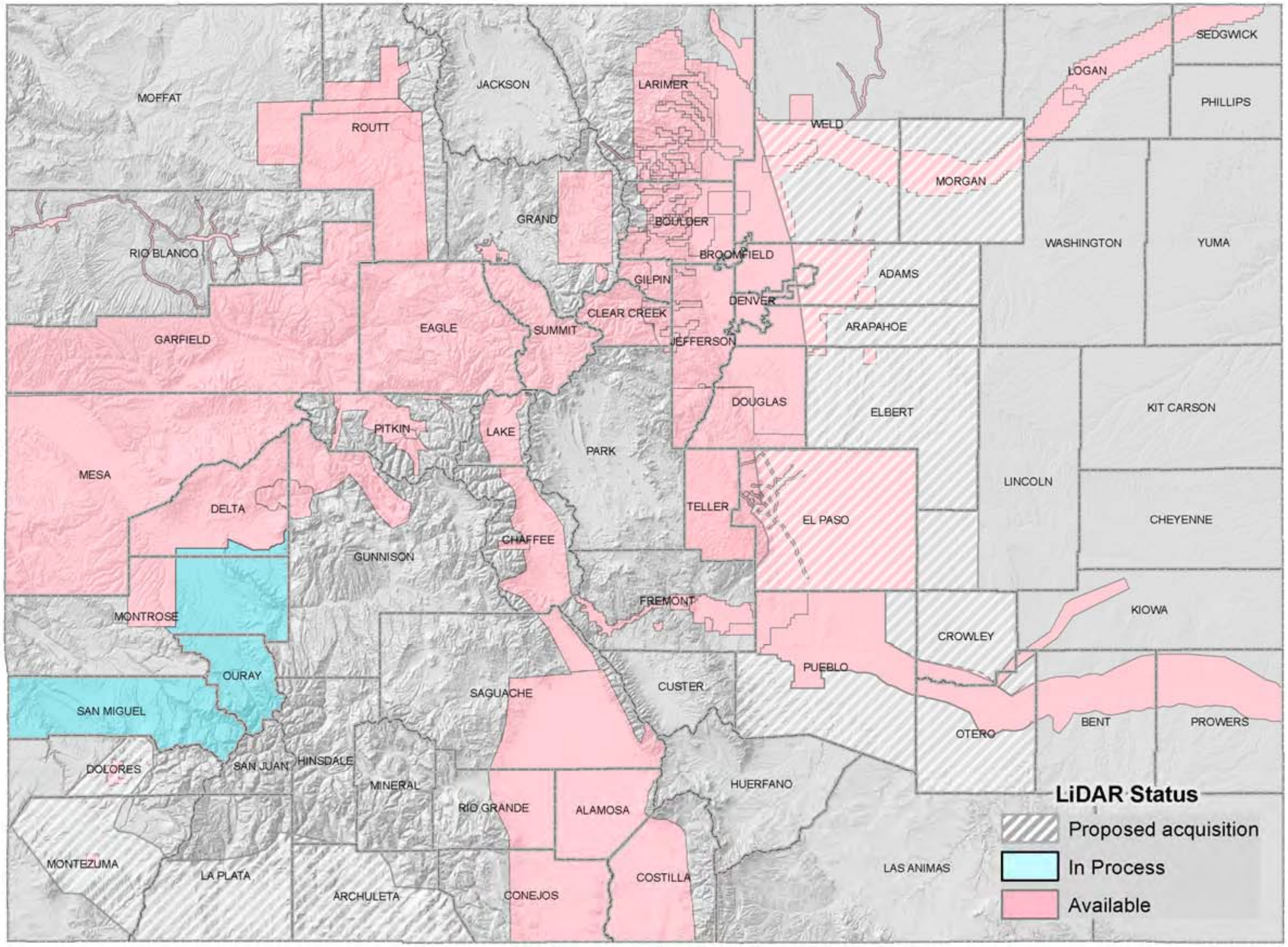
Image at right: 24k geologic map showing Rampart Range fault (green lines) compared to trace of fault from 250k map (red line). Green triangles are relocated trench locations; compare to prior location (red dot).

Earthquake Reference Collection (ERC)

- Contains 550 papers, consultant reports, abstracts, maps, theses
- Search by Author, Title, Year
- Will be updated with more user-friendly interface, keyword search, and index map



Lidar Acquisition in Colorado
September 2017



Technical Issues

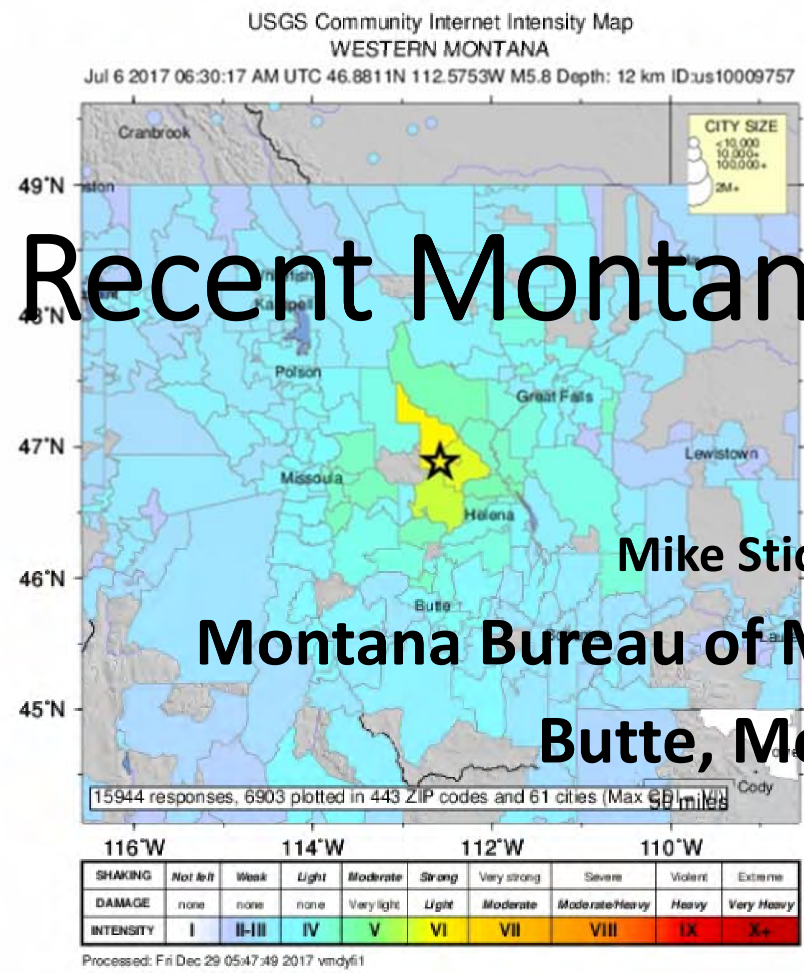
- Q-Faults are not fully characterized
  - Mapped in the 70s-90s, only a handful have reliable absolute ages, most ages assigned by soils and height in landscape
  - Paucity of trenches
  - Poorly constrained ages of Q deposits; need more ages!
- Faults of priority: Williams Fork, Frontal, Ute Pass, Rampart Range, Golden
- Lidar coming, but slowly, 32% of the state is covered
- Cross-border coordination, could help on Lidar collection, geo mapping, proposals for funding

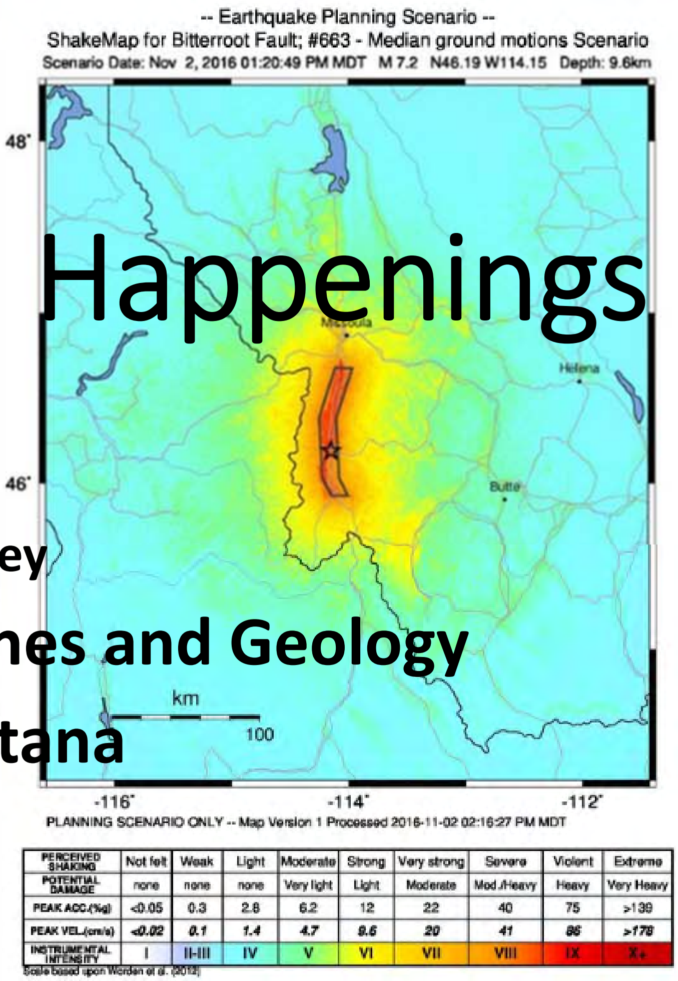
Non-Technical Issues

- Funding-Little internally; externally, money available for outreach but not science
- More pressing projects (Debris flows, landslides, hydrology, minerals)
- Lack of available technical staff

Conclusions

- A small amount (<20k) of funding goes a long way in Colorado
- Installing additional seismometers
- Lidar and geochron are first steps to make faster progress, start small > larger, detailed projects
- More work needed on Williams Fork, Frontal, Ute Pass, Rampart Range, Golden faults; Cheraw study on-going
- More public outreach, make our science understandable and research funding easier to justify
- Cross-border coordination very important



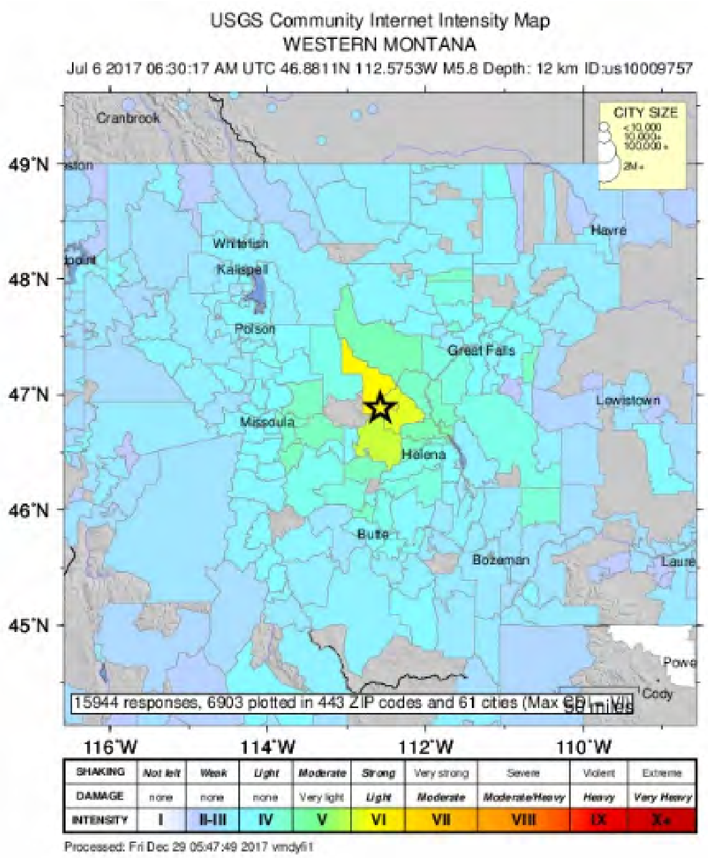


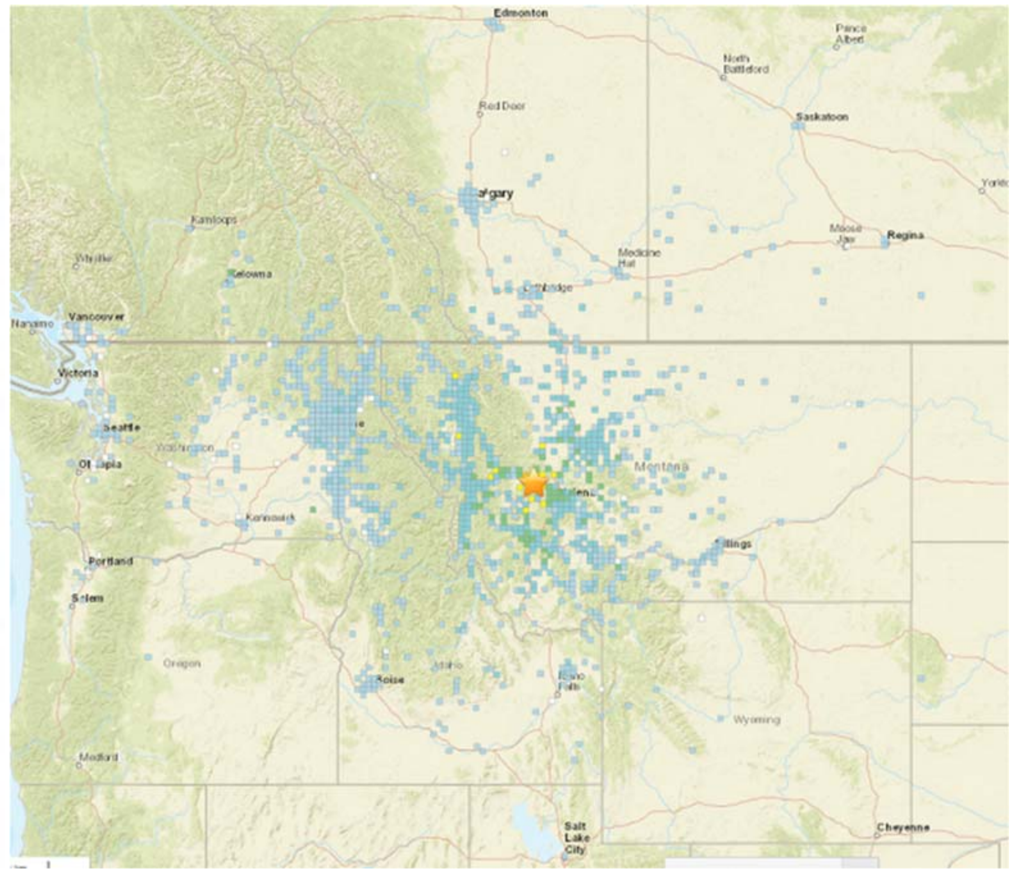
Recent Montana Happenings

Mike Stickney

Montana Bureau of Mines and Geology

Butte, Montana

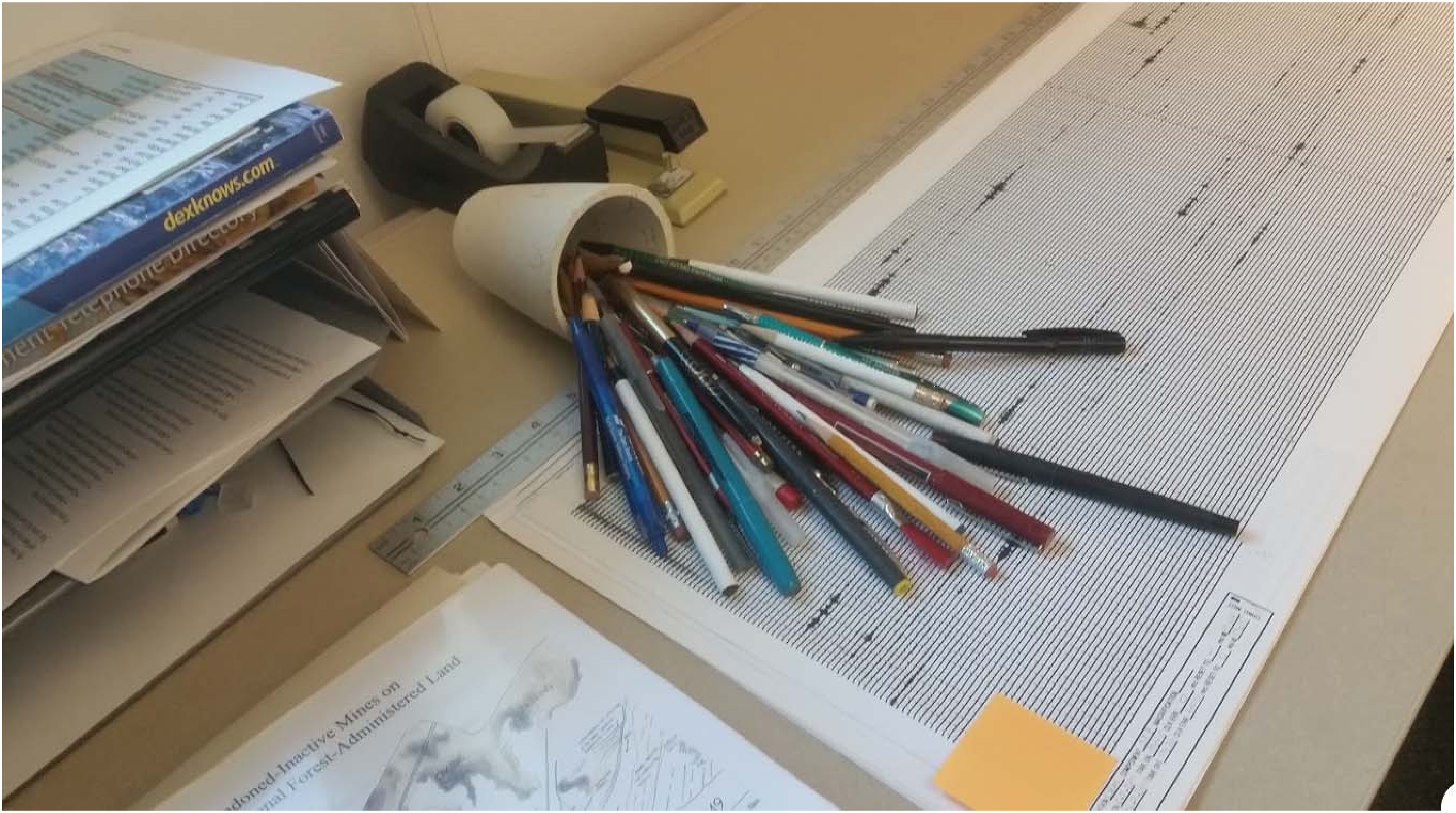

USGS Community Internet Intensity Map
WESTERN MONTANA
Jul 6 2017 06:30:17 AM UTC 46.8811N 112.5753W M5.8 Depth: 12 km ID:us10009757
CITY SIZE
Cranbrook
Whitefish
Kalispell
Polson
Havre
Great Falls
Lewistown
Missoula
Helena
Butte
Bozeman
Cody
49°N
48°N
47°N
46°N
45°N
116°W
114°W
112°W
110°W
15944 responses, 6903 plotted in 443 ZIP codes and 61 cities
SHAKING
Not felt
Weak
Light
Moderate
Strong
Very strong
Severe
Violent
Extreme
DAMAGE
none
none
none
Very light
Light
Moderate
Moderate/Heavy
Heavy
Very Heavy
INTENSITY
I
II-III
IV
V
VI
VII
VIII
IX
X+
Processed: Fri Dec 29 05:47:49 2017

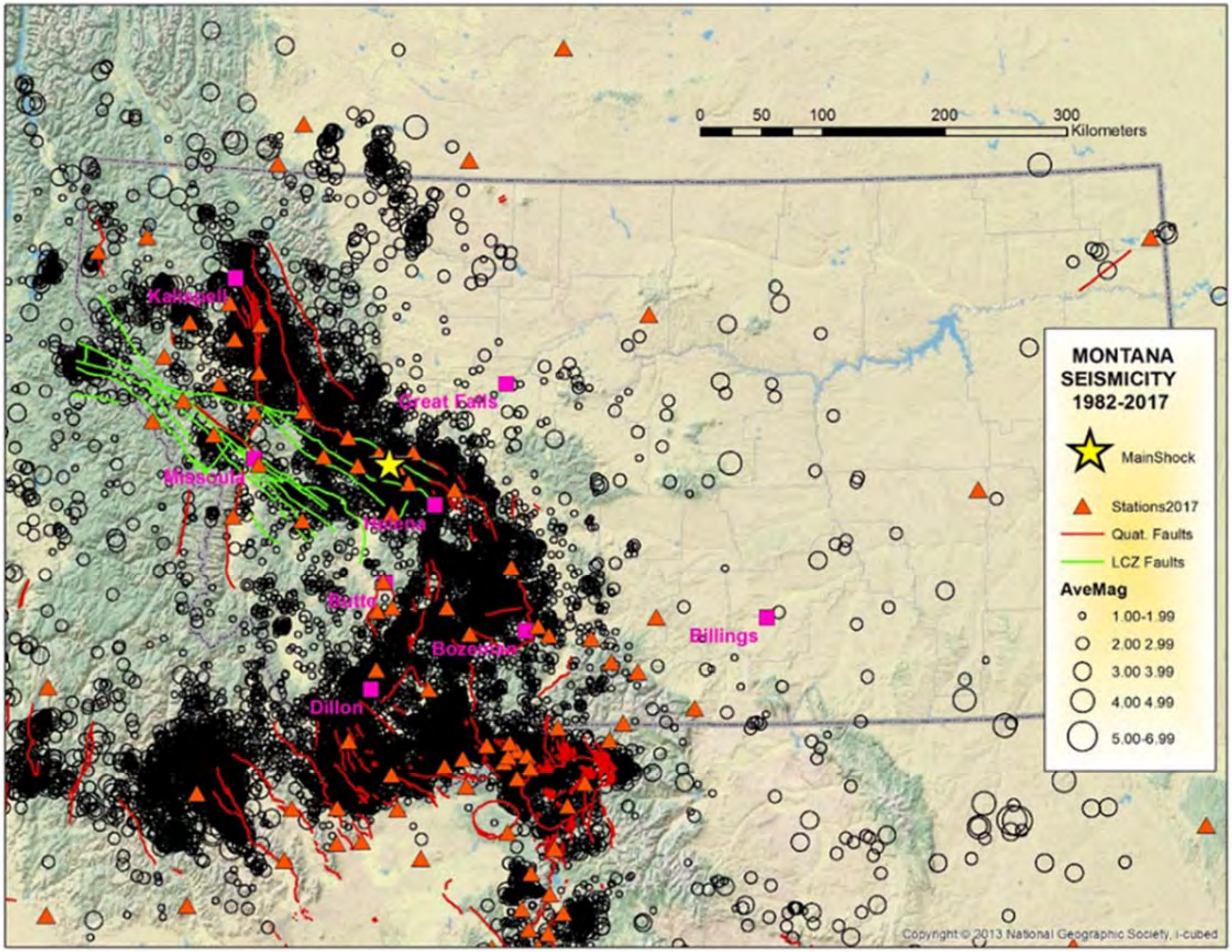

Edmonton
Red Deer
Saskatoon
Kamloops
Kelowna
Vancouver
Victoria
Seattle
Portland
Salem
Boise
Montana
Billings
Wyoming
Oregon
Regina
Medicine Hat
Salt Lake City
Cheyenne

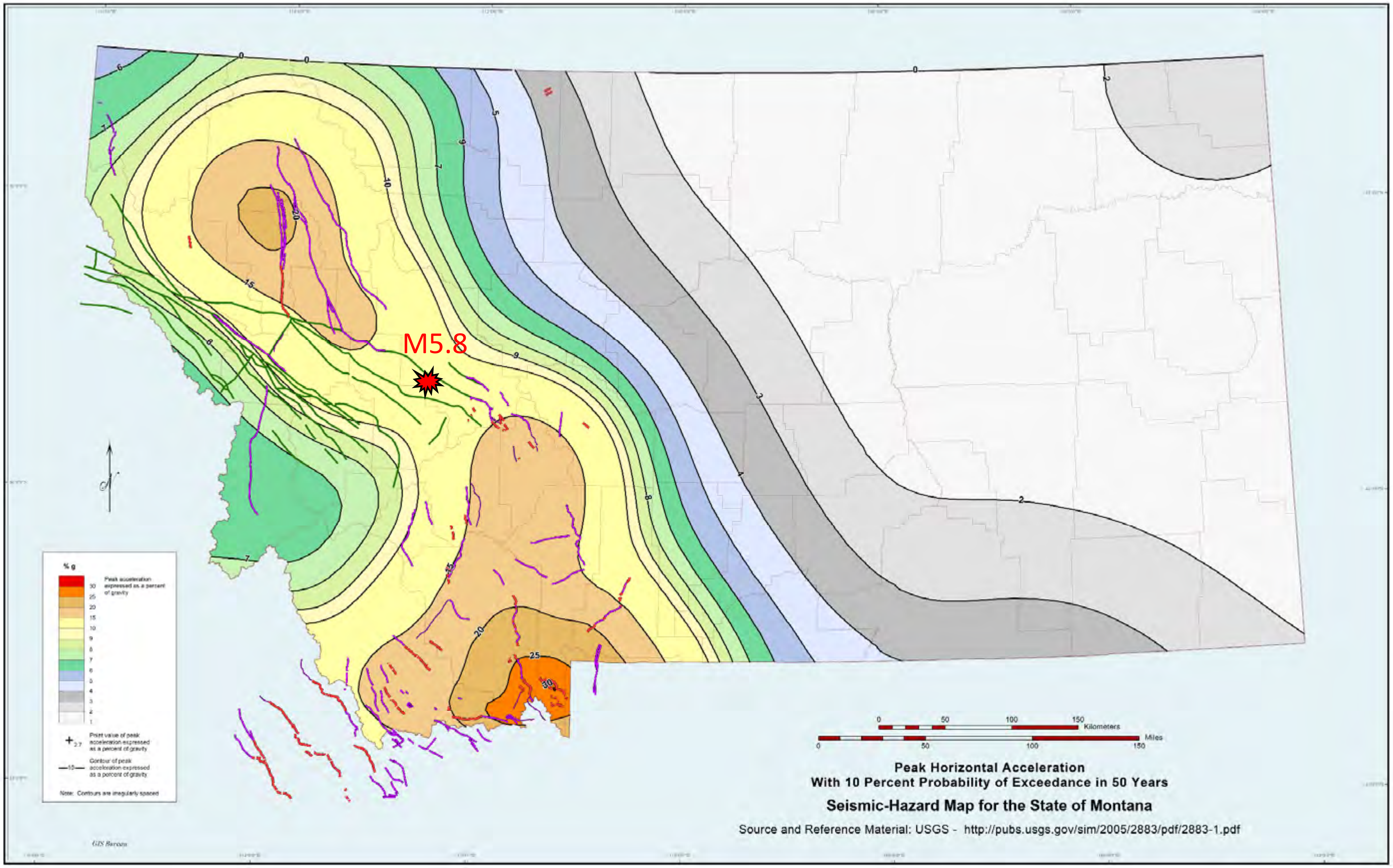
Walmart in Helena Montana after the earthquake

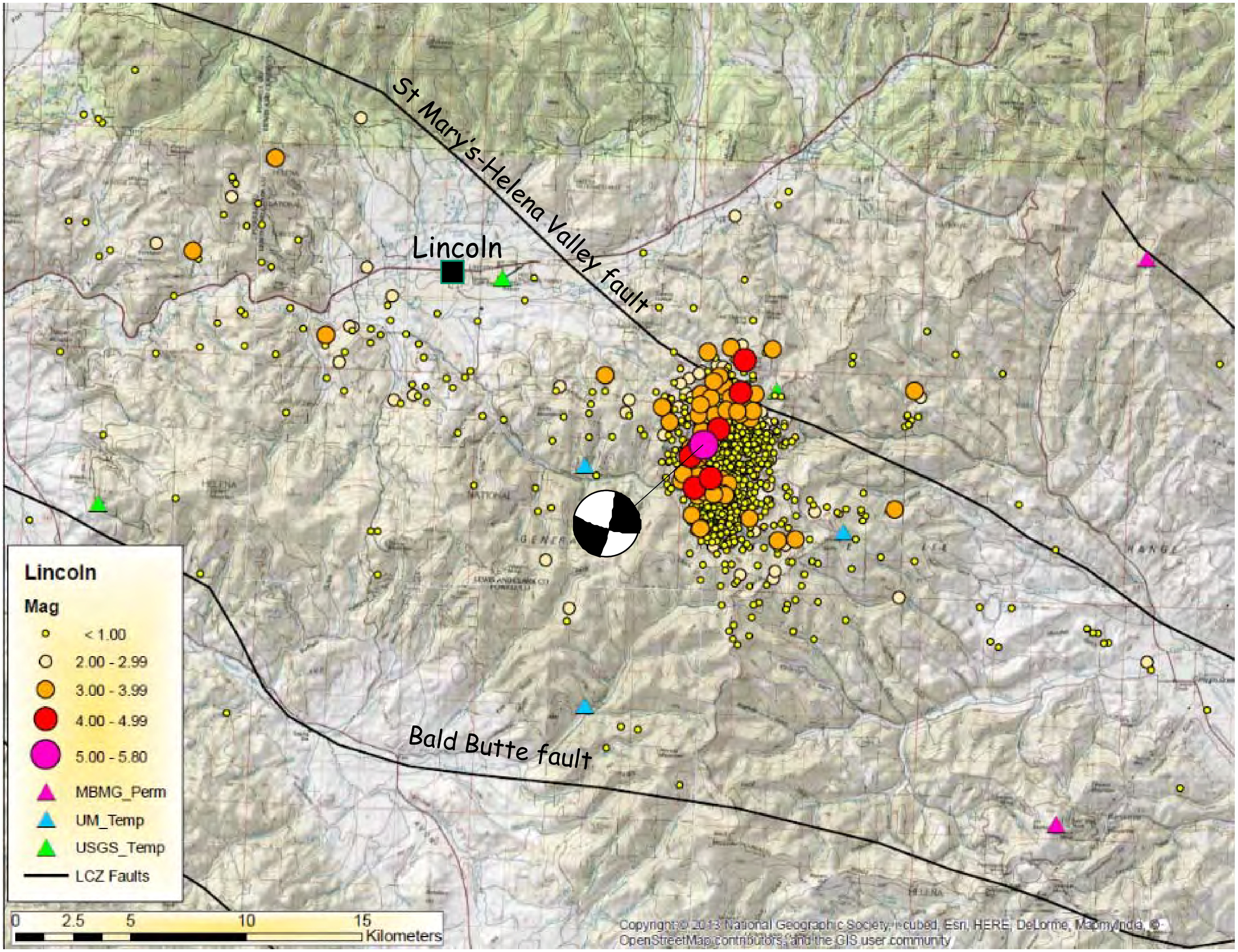
●●●○○ Verizon 3G 1:35 AM 93%

facebook.com

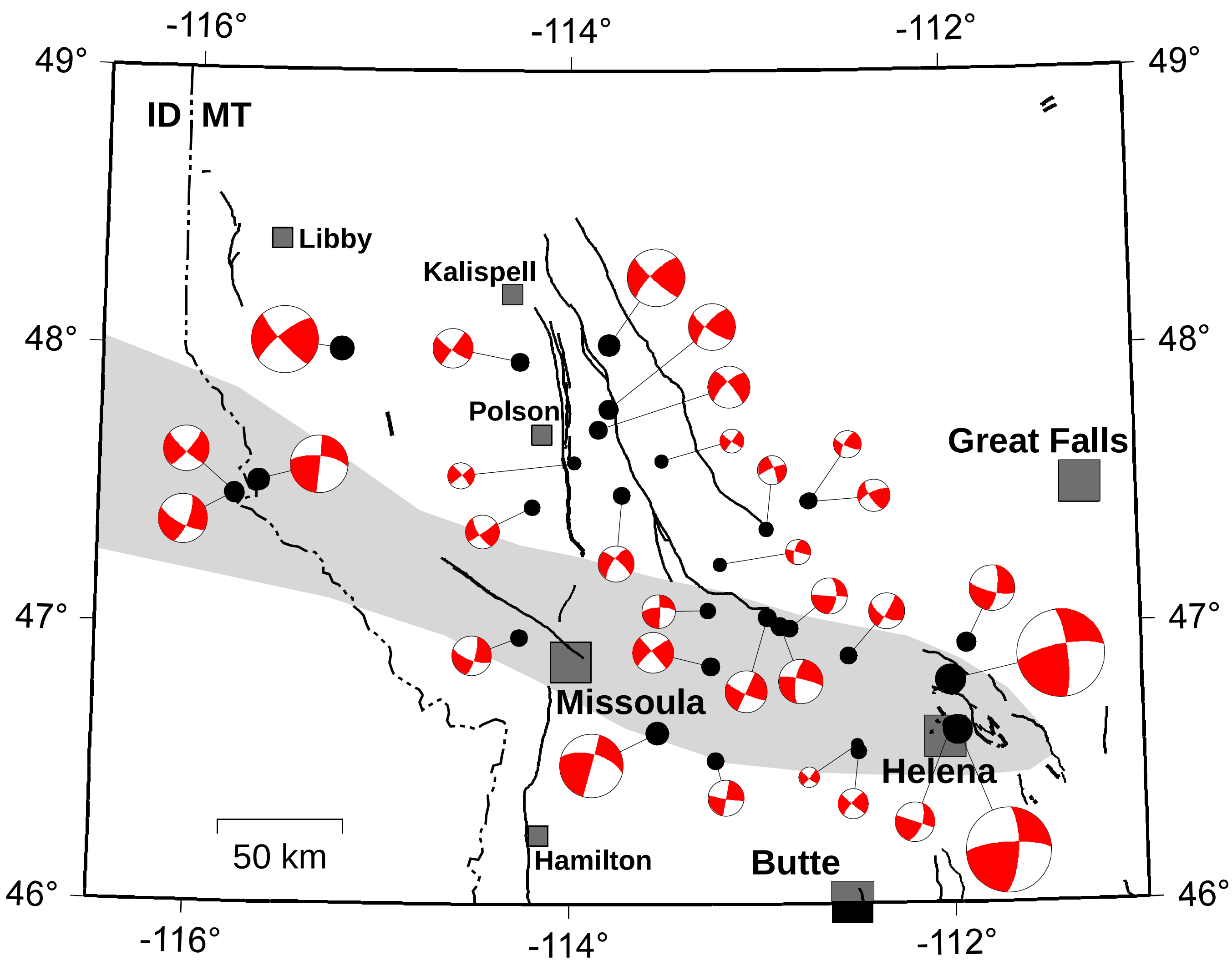

dexknows.com
Telephone Directory

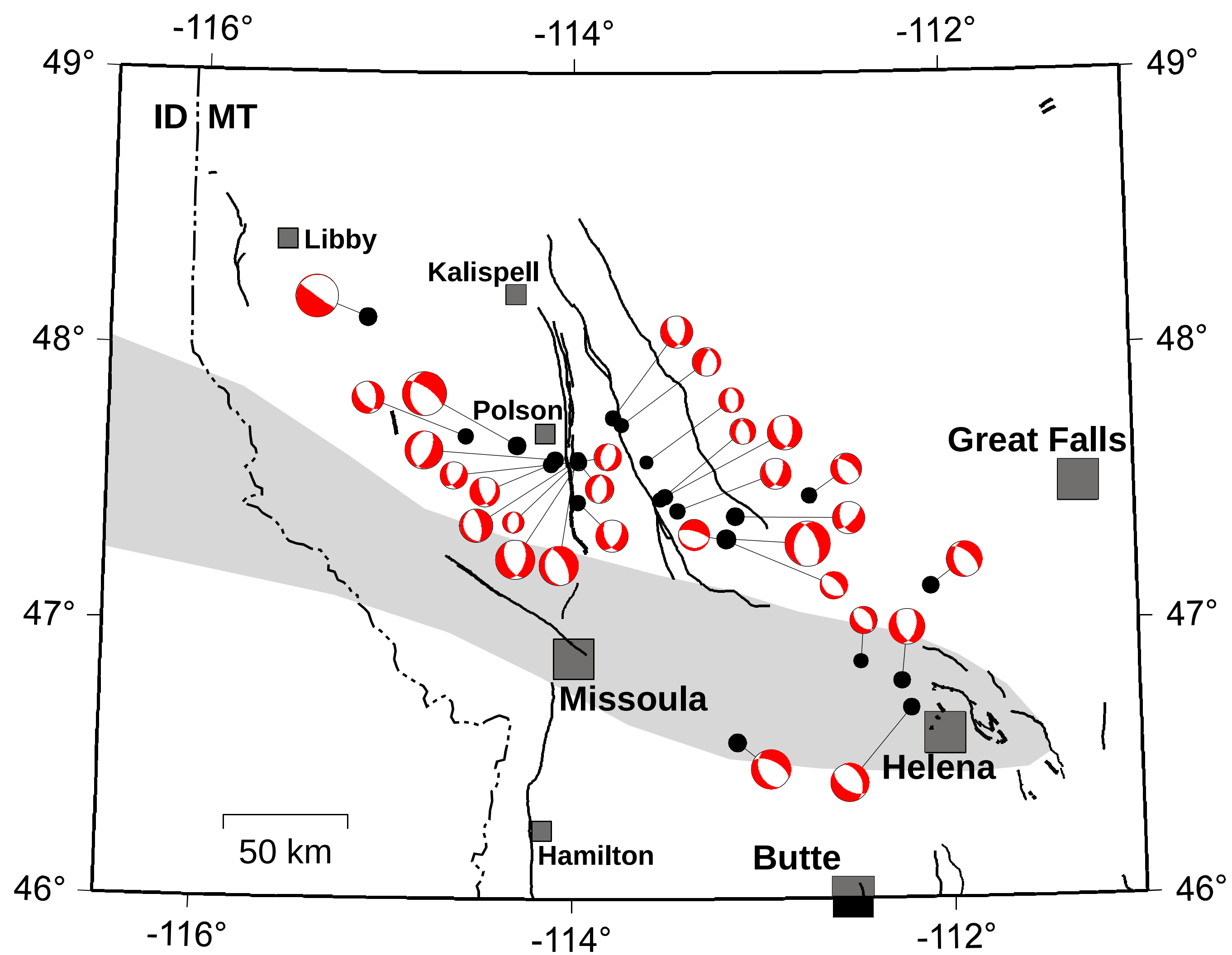

MONTANA SEISMICITY 1982-2017
MainShock
Stations2017
Quat. Faults
LCZ Faults
AveMag
1.00-1.99
2.00 2.99
3.00 3.99
4.00 4.99
5.00-6.99
0 50 100 200 300 Kilometers
Kalispell
Great Falls
Missoula
Helena
Butte
Bozeman
Billings
Dillon
Copyright © 2013 National Geographic Society, i-cubed


M5.8
% g
Peak acceleration expressed as a percent of gravity
Point value of peak acceleration expressed as a percent of gravity
Contour of peak acceleration expressed as a percent of gravity
Note: Contours are irregularly spaced
GIS Bureau
Kilometers
Miles
Peak Horizontal Acceleration
With 10 Percent Probability of Exceedance in 50 Years
Seismic-Hazard Map for the State of Montana
Source and Reference Material: USGS - http://pubs.usgs.gov/sim/2005/2883/pdf/2883-1.pdf



St Mary's-Helena Valley fault
Lincoln
Bald Butte fault
Lincoln
Mag
< 1.00
2.00 - 2.99
3.00 - 3.99
4.00 - 4.99
5.00 - 5.80
MBMG_Perm
UM_Temp
USGS_Temp
LCZ Faults
0 2.5 5 10 15
Kilometers
Copyright © 2013 National Geographic Society, i-cubed, Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community


-116°
-114°
-112°
49°
49°
48°
48°
47°
47°
46°
46°
ID
MT
Libby
Kalispell
Polson
Great Falls
Missoula
Helena
Hamilton
Butte
50 km
-116°
-114°
-112°



-116°
-114°
-112°
49°
48°
47°
46°
ID
MT
Libby
Kalispell
Polson
Great Falls
Missoula
Helena
Hamilton
Butte
50 km

MBMG

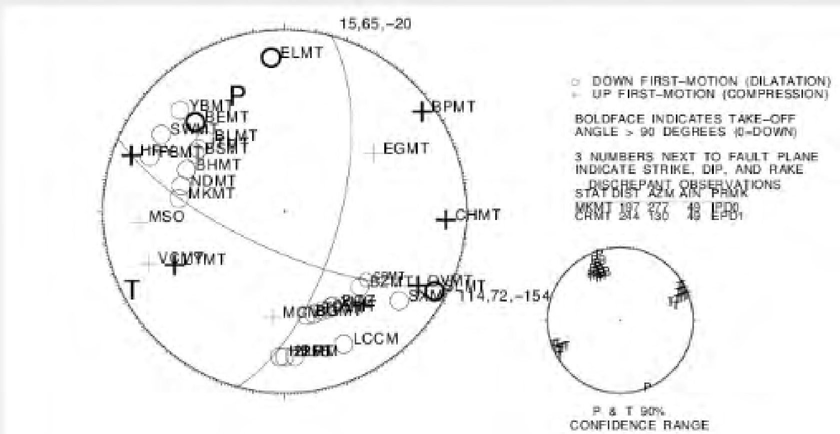
USGS

First-Motion Focal Mechanism for Event mb80223569

The focal mechanism shown below graphically portrays the orientation of the fault plane on which the ea
detailed explanation describes how to interpret a focal mechanism. If more than one mechanism exists for

```
MB First Motion Mechanism
 P FIRST-MOTION FOCAL MECHANISM
 (double-couple source assumed)

 Event Date & Time            : 07/06/2017 06:30:17 GMT = Thu Jul 06 00:30:17 MDT 2017
 Location                     : 46.8908 N, 112.5375 W
                              : (46 deg. 53.45 min. N, 112.deg. 32.25 min. W)
 Depth                        : 13.4 km. deep (  8.4 miles)
 Magnitude                    : 5.8 MH
 # P First motions            :  33
 Strike uncertainty           :   3 deg.
 Dip    uncertainty           :  15 deg.
 Rake   uncertainty           :  10 deg.
```



W-phase Moment Tensor (Mww)

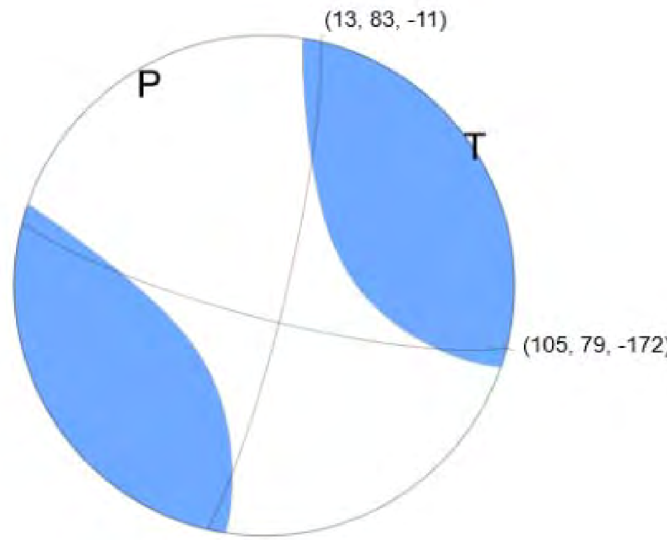
Moment	6.407e+17 N-m
Magnitude	5.8 Mww
Depth	19.5 km
Percent DC	45 %
Half Duration	1.97 s
Catalog	US
Data Source	US[1]
Contributor	US[1]

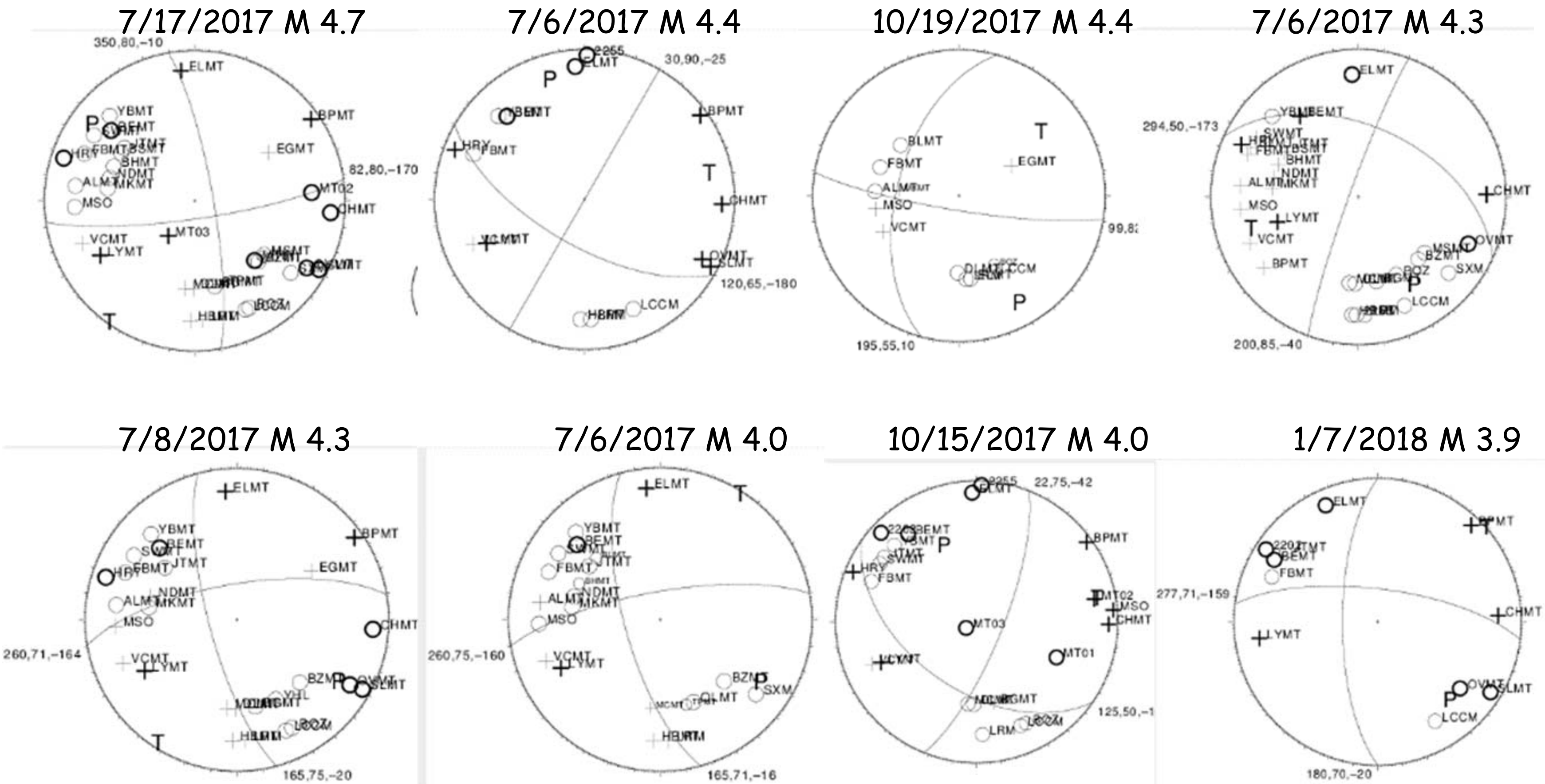
Nodal Planes

Plane	Strike	Dip	Rake
NP1	13°	83°	-11°
NP2	105°	79°	-172°

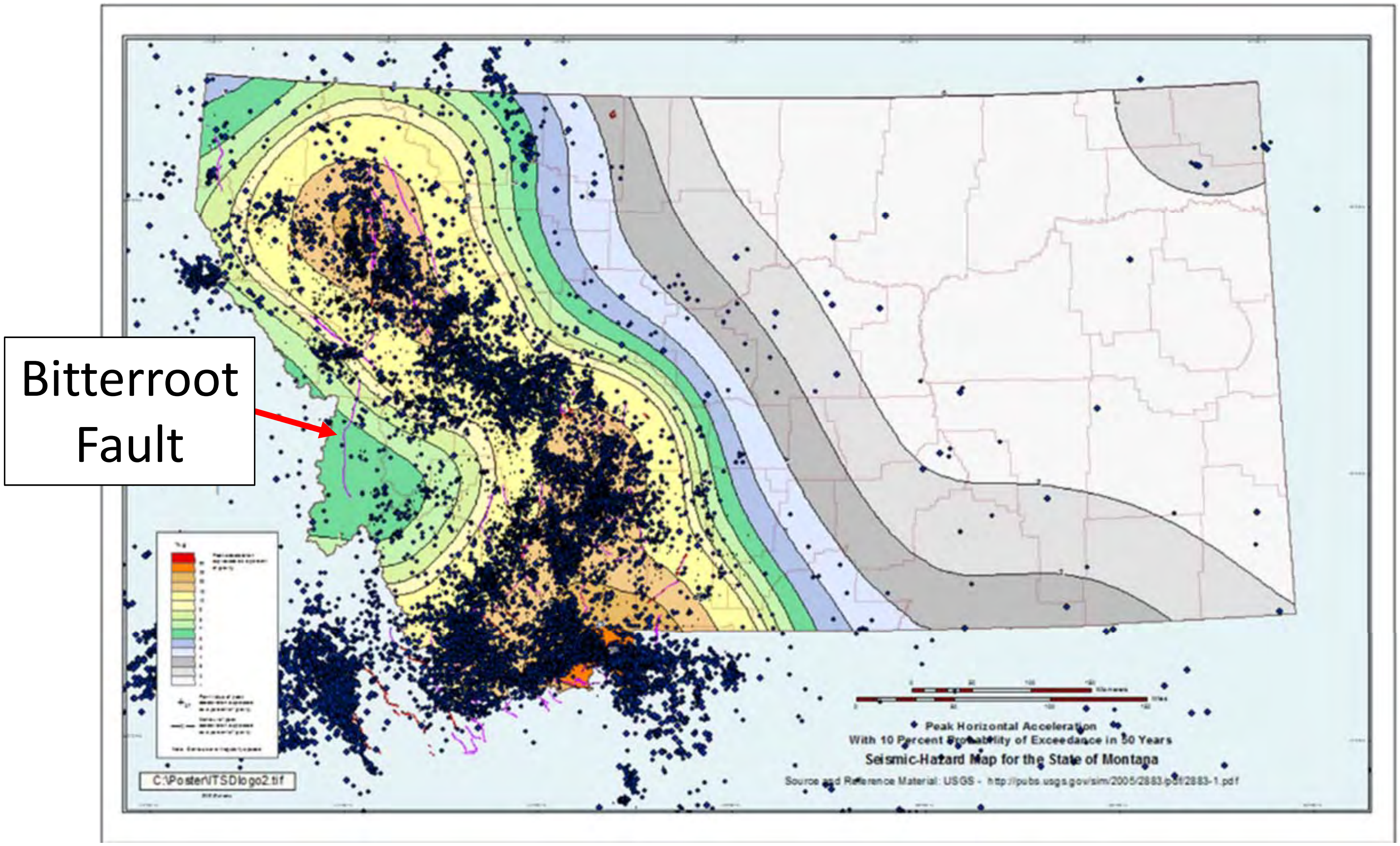
Principal Axes

Axis	Value	Plunge	Azimuth
T	7.161e+17 N-m	2°	59°
N	1.971e+17 N-m	77°	159°
P	-5.190e+17 N-m	13°	329°

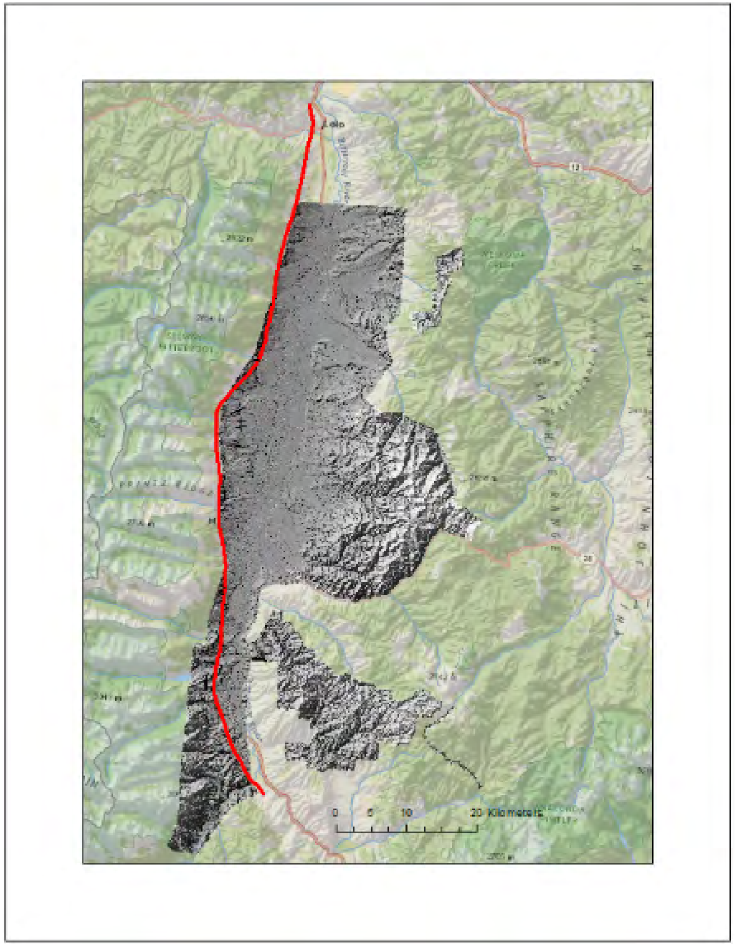



7/17/2017 M 4.7
350,80,-10
82,80,-170
7/6/2017 M 4.4
30,90,-25
120,65,-180
10/19/2017 M 4.4
195,55,10
7/6/2017 M 4.3
294,50,-173
200,85,-40
7/8/2017 M 4.3
260,71,-164
165,75,-20
7/6/2017 M 4.0
260,75,-160
165,71,-16
10/15/2017 M 4.0
22,75,-42
1/7/2018 M 3.9
277,71,-159
180,70,-20

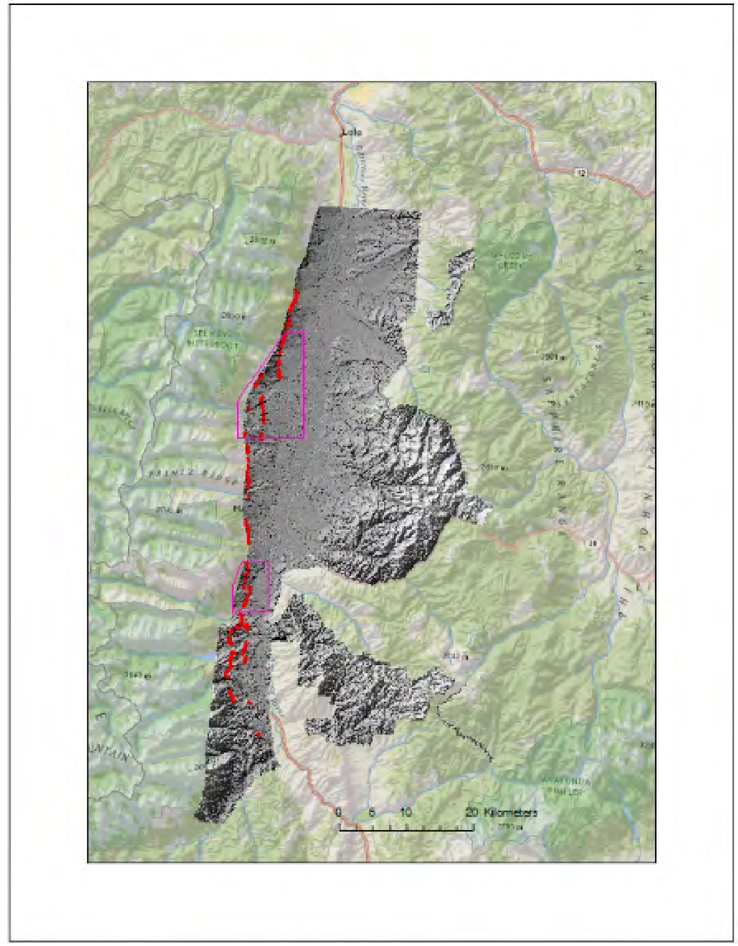
Seismic hazard (USGS) and earthquakes since 1982 (MBMG)

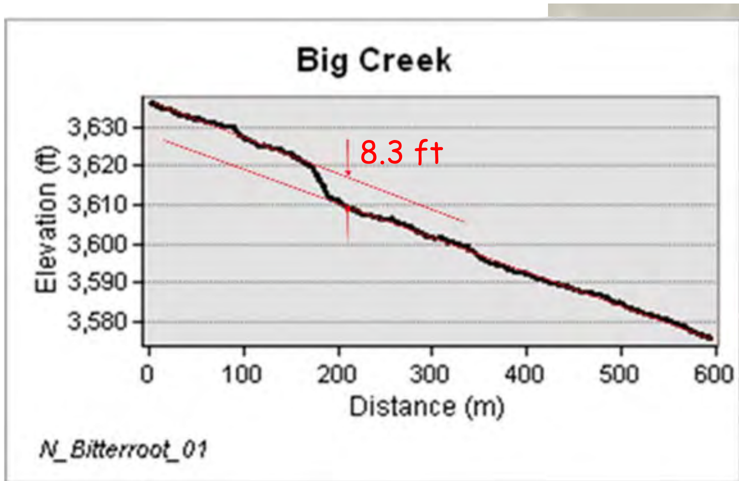


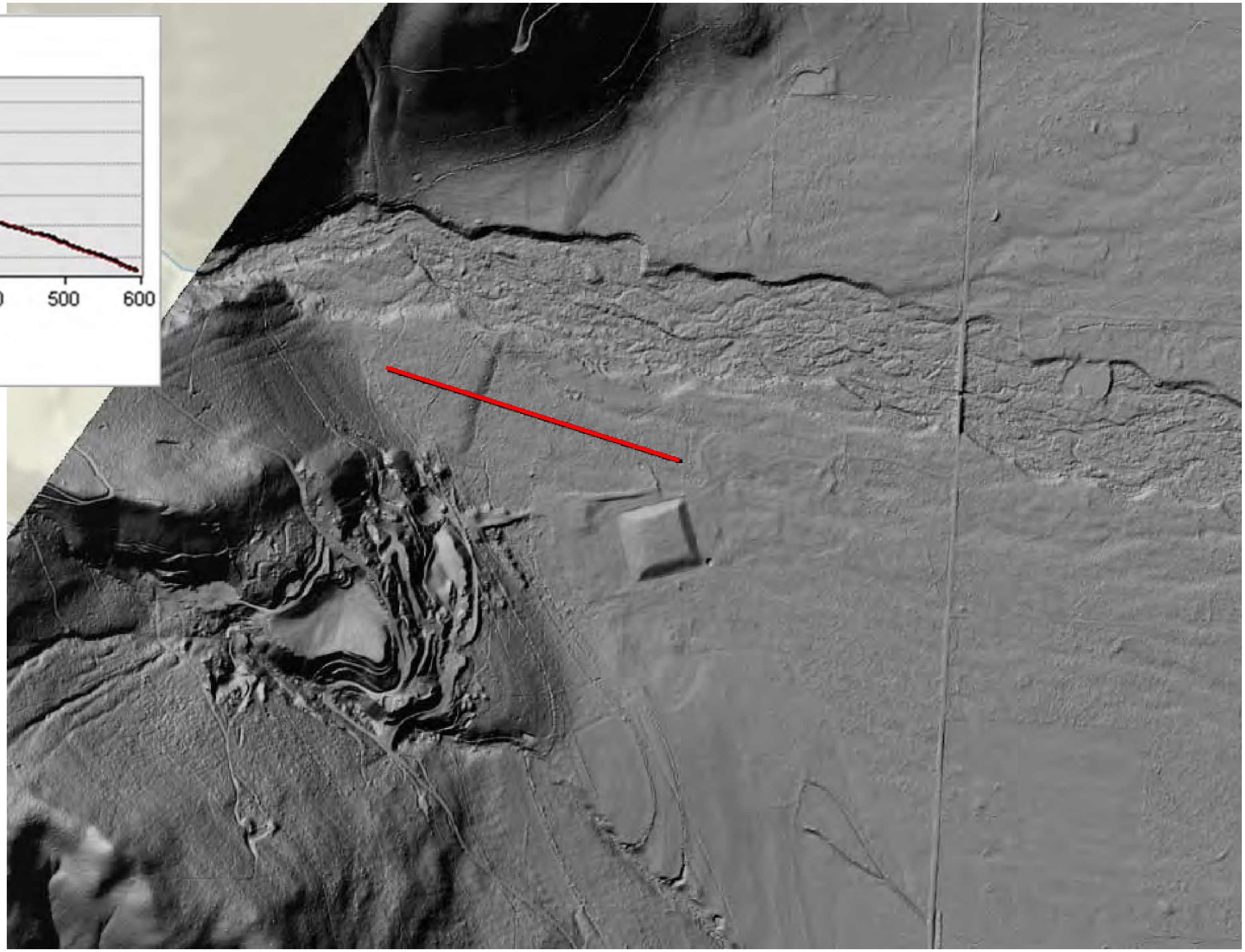
USGS Quaternary Fault and Fold Database

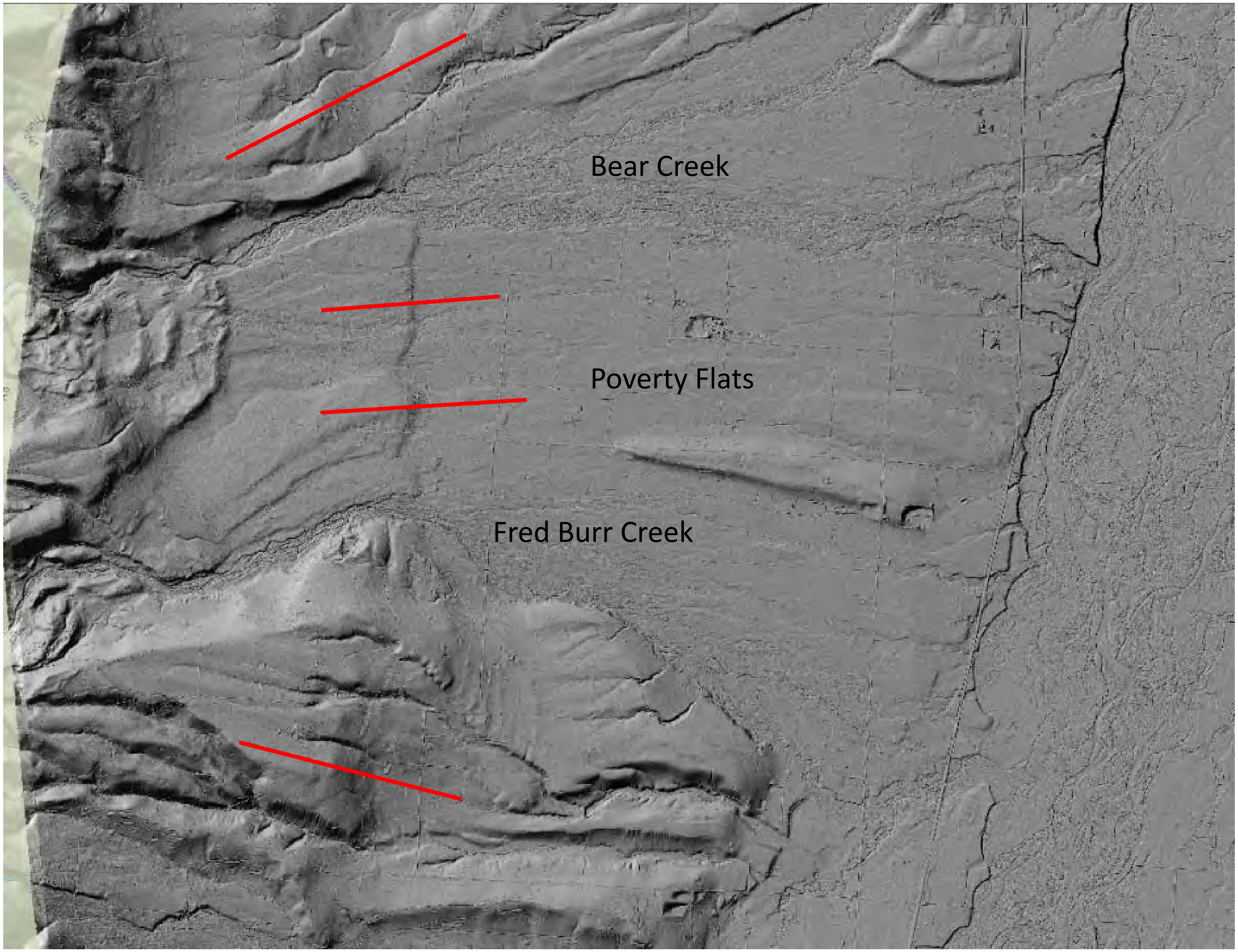


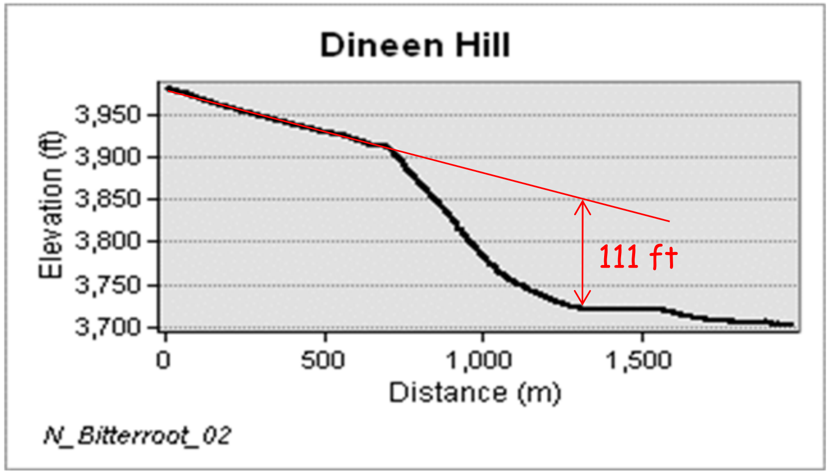
MBMG scarp mapping from LiDAR

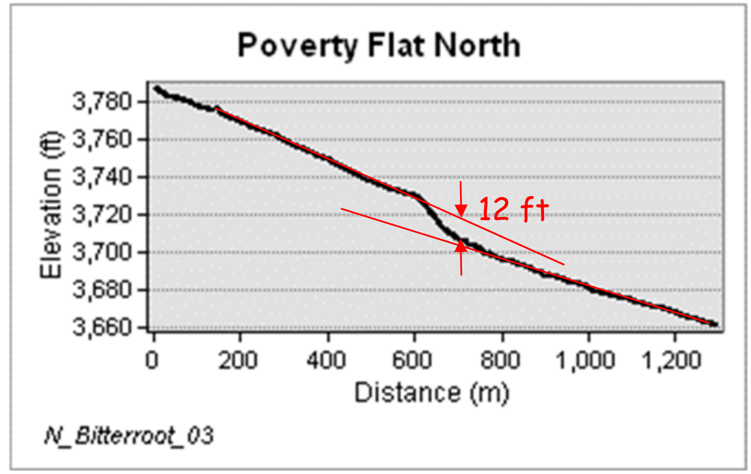


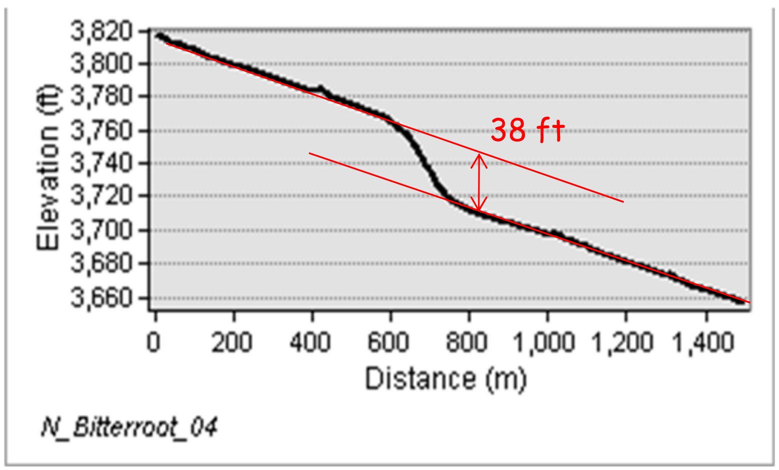

Big Creek
Elevation (ft)
3,630
3,620
3,610
3,600
3,590
3,580
8.3 ft
0
100
200
300
400
500
600
Distance (m)
N_Bitterroot_01

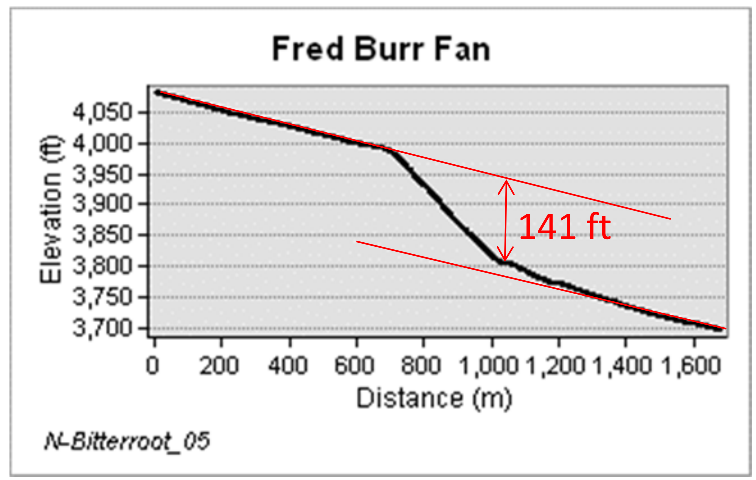


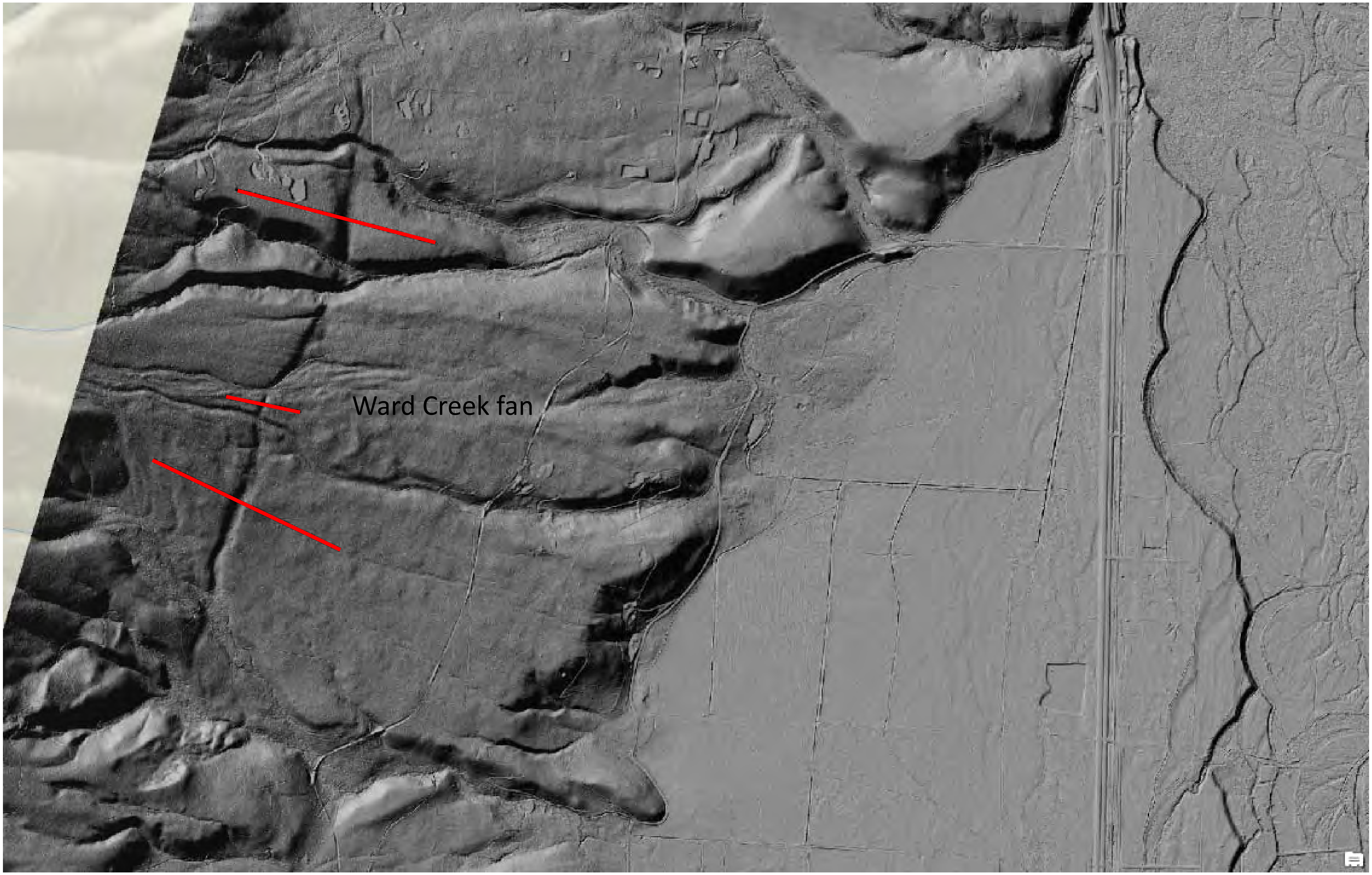

Bear Creek
Poverty Flats
Fred Burr Creek

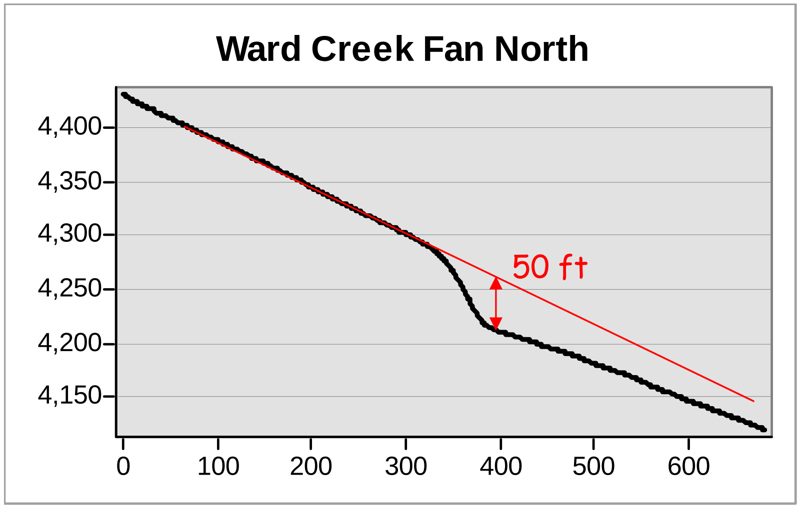

Dineen Hill
Elevation (ft)
3,950
3,900
3,850
3,800
3,750
3,700
0
500
1,000
1,500
Distance (m)
111 ft
N_Bitterroot_02

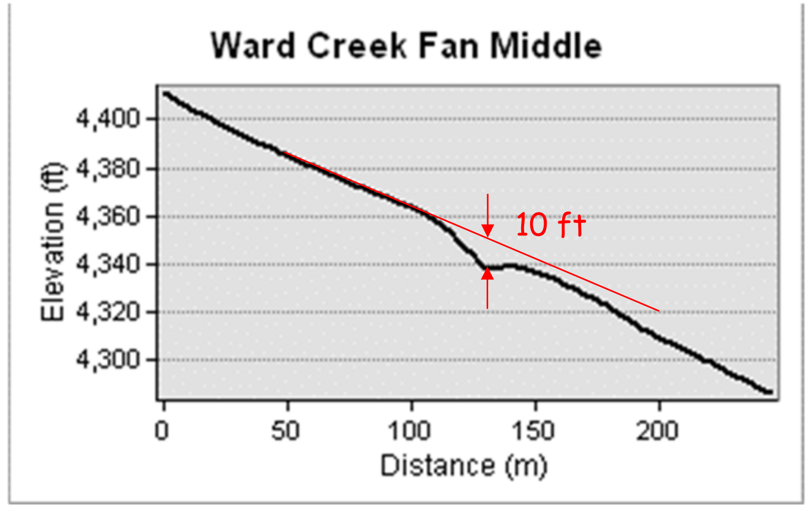

Poverty Flat North
Elevation (ft)
3,780
3,760
3,740
3,720
3,700
3,680
3,660
0
200
400
600
800
1,000
1,200
Distance (m)
12 ft
N_Bitterroot_03

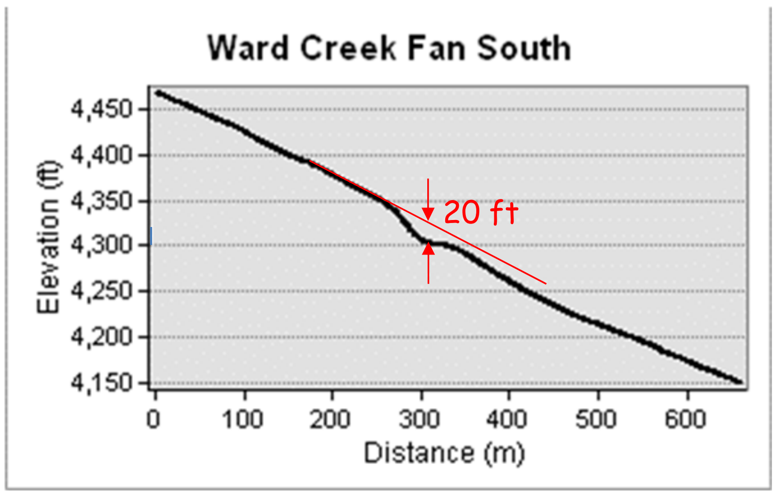

Elevation (ft)
3,820
3,800
3,780
3,760
3,740
3,720
3,700
3,680
3,660
0
200
400
600
800
1,000
1,200
1,400
Distance (m)
38 ft
N_Bitterroot_04

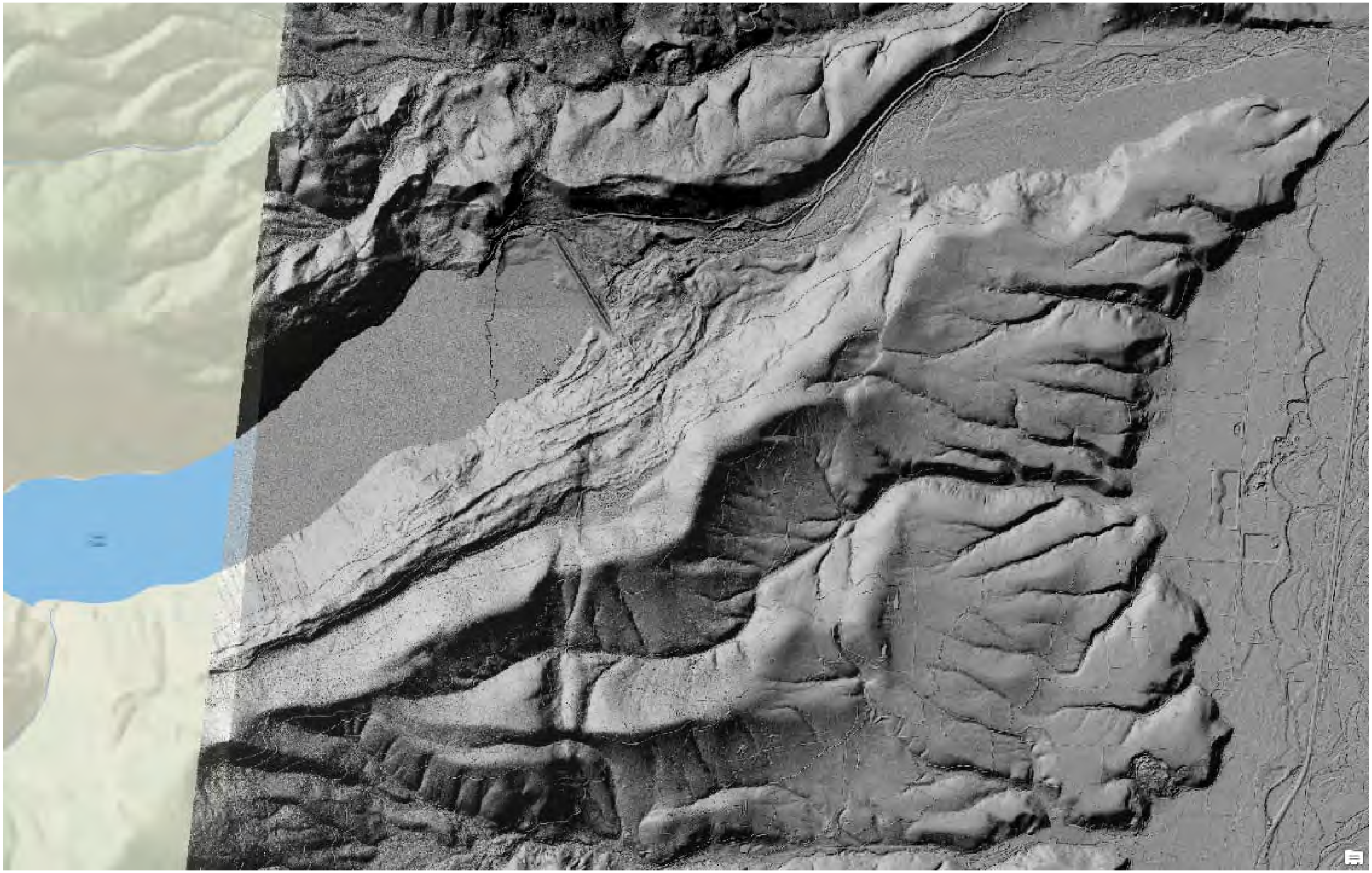

Fred Burr Fan
Elevation (ft)
4,050
4,000
3,950
3,900
3,850
3,800
3,750
3,700
0
200
400
600
800
1,000
1,200
1,400
1,600
Distance (m)
141 ft
N-Bitterroot_05

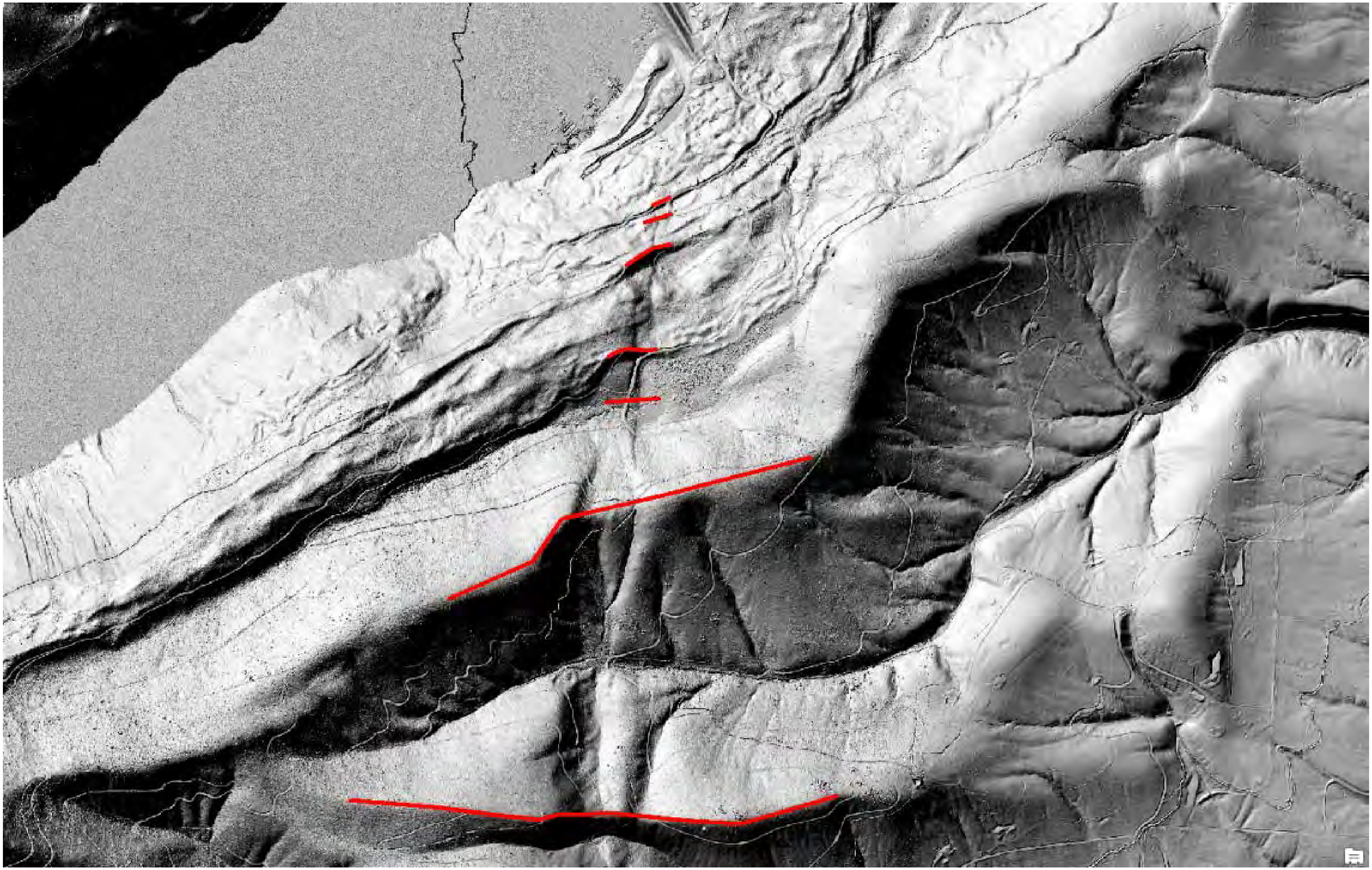

Ward Creek fan

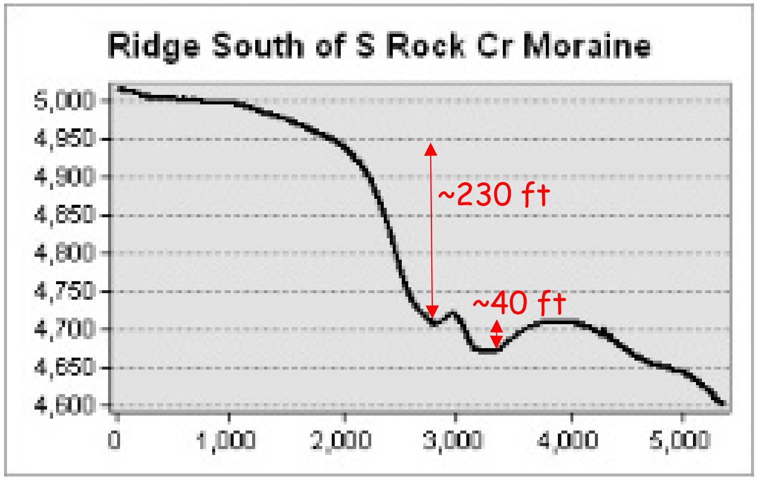

Ward Creek Fan North
4,400
4,350
4,300
4,250
4,200
4,150
0
100
200
300
400
500
600
50 ft

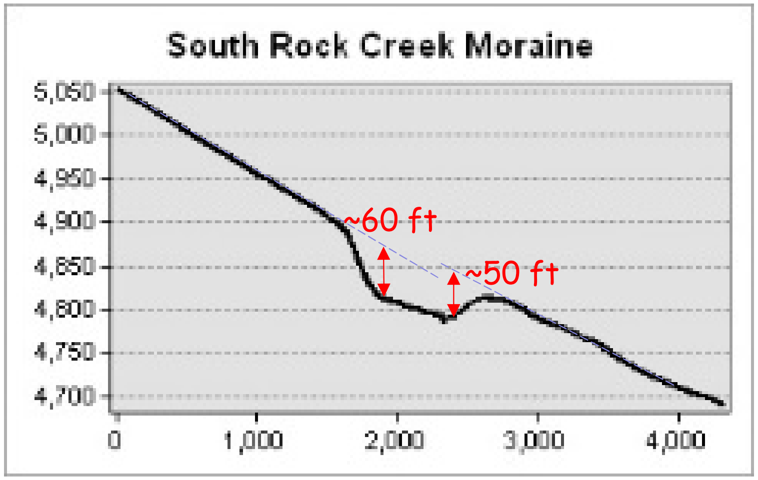

Ward Creek Fan Middle
Elevation (ft)
4,400
4,380
4,360
4,340
4,320
4,300
0
50
100
150
200
Distance (m)
10 ft

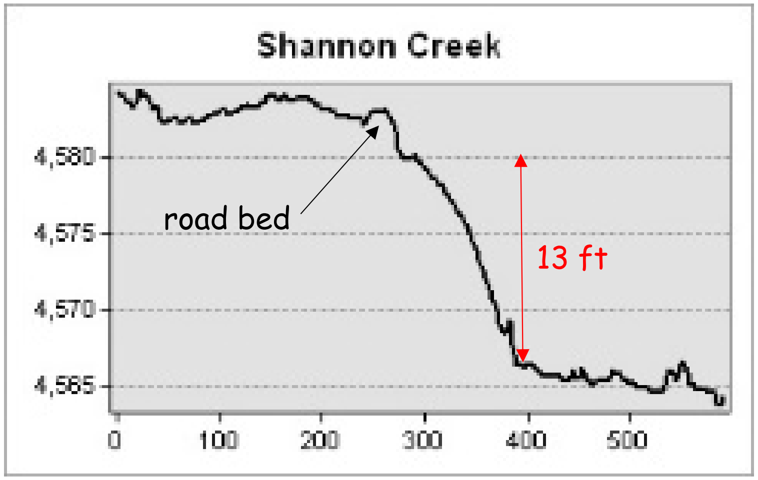

Ward Creek Fan South
Elevation (ft)
4,450
4,400
4,350
4,300
4,250
4,200
4,150
0
100
200
300
400
500
600
Distance (m)
20 ft

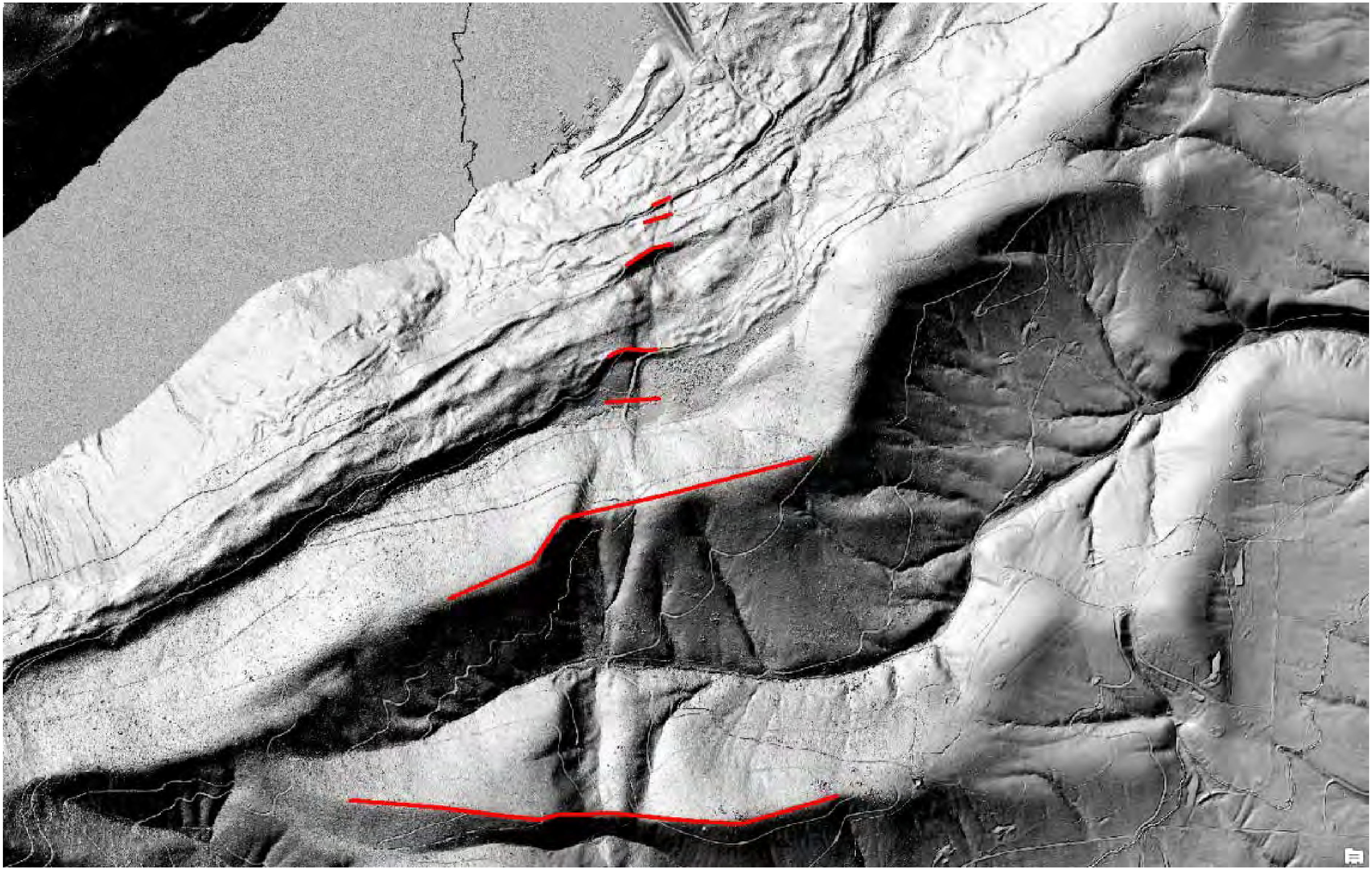


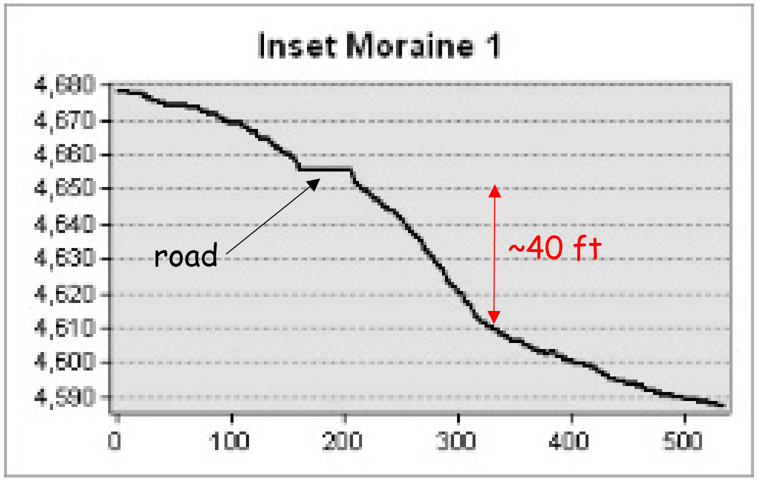


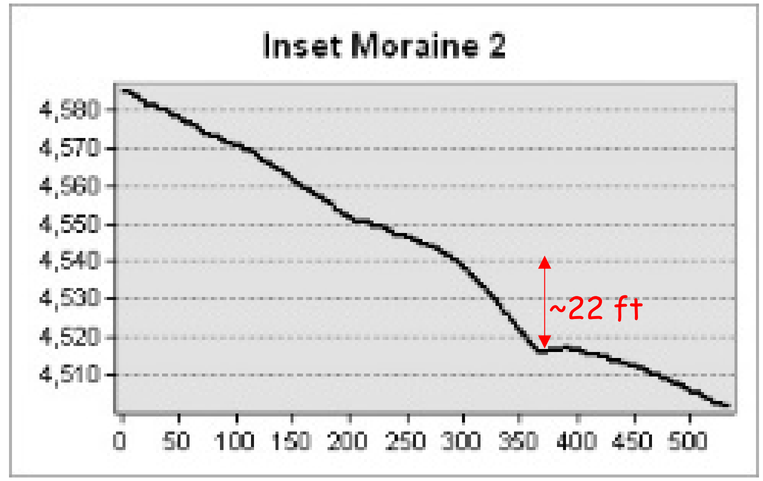

Ridge South of S Rock Cr Moraine
5,000
4,950
4,900
4,850
4,800
4,750
4,700
4,650
4,600
0
1,000
2,000
3,000
4,000
5,000
~230 ft
~40 ft

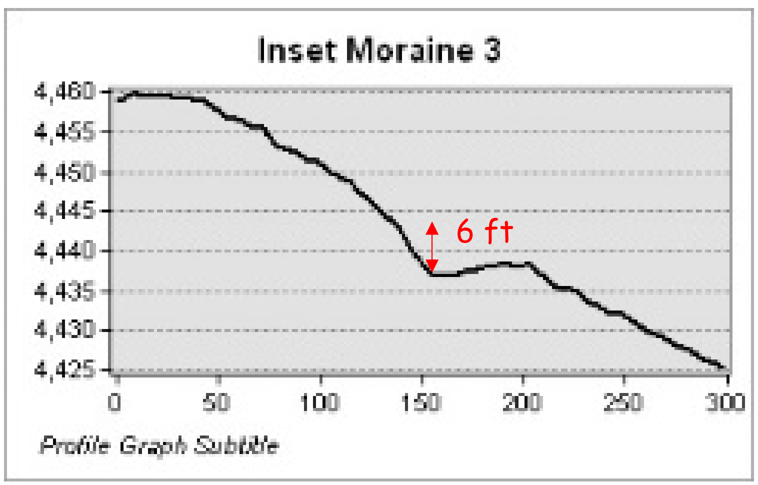

South Rock Creek Moraine
5,050
5,000
4,950
4,900
4,850
4,800
4,750
4,700
0
1,000
2,000
3,000
4,000
~60 ft
~50 ft

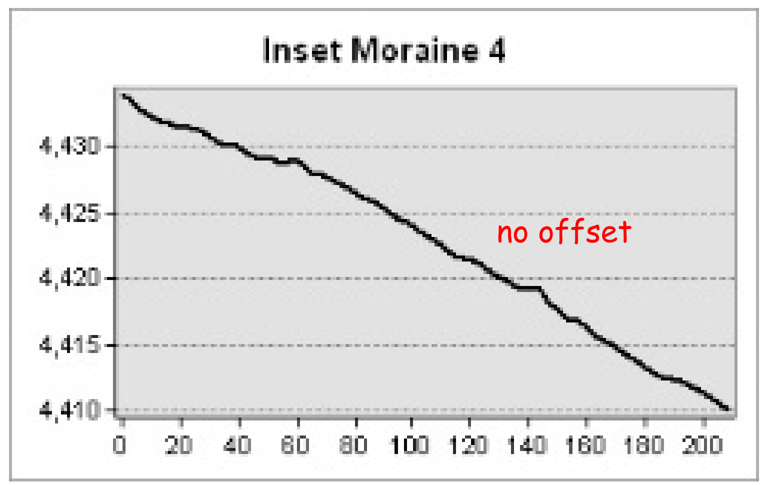

Shannon Creek
4,580
4,575
4,570
4,565
0
100
200
300
400
500
road bed
13 ft

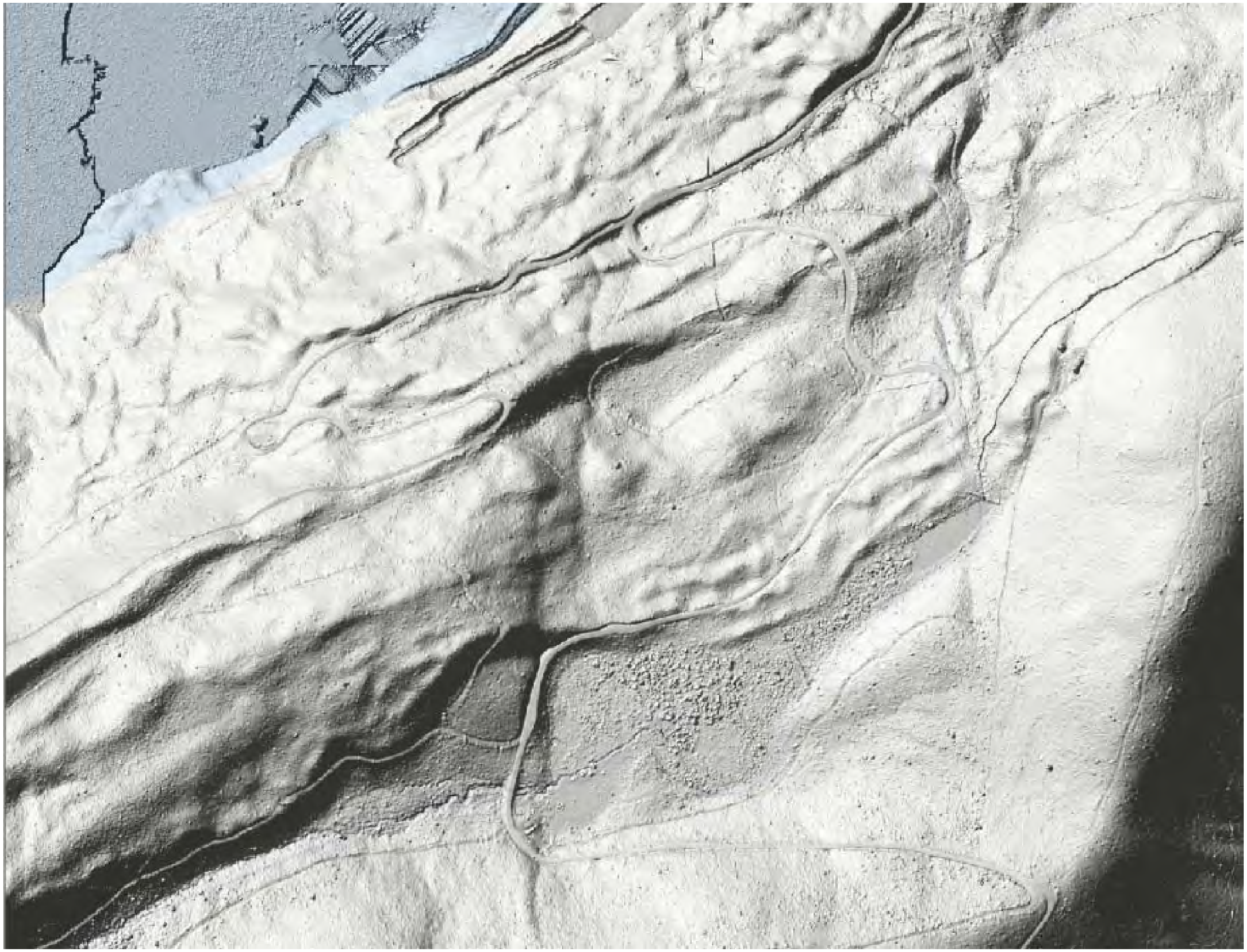


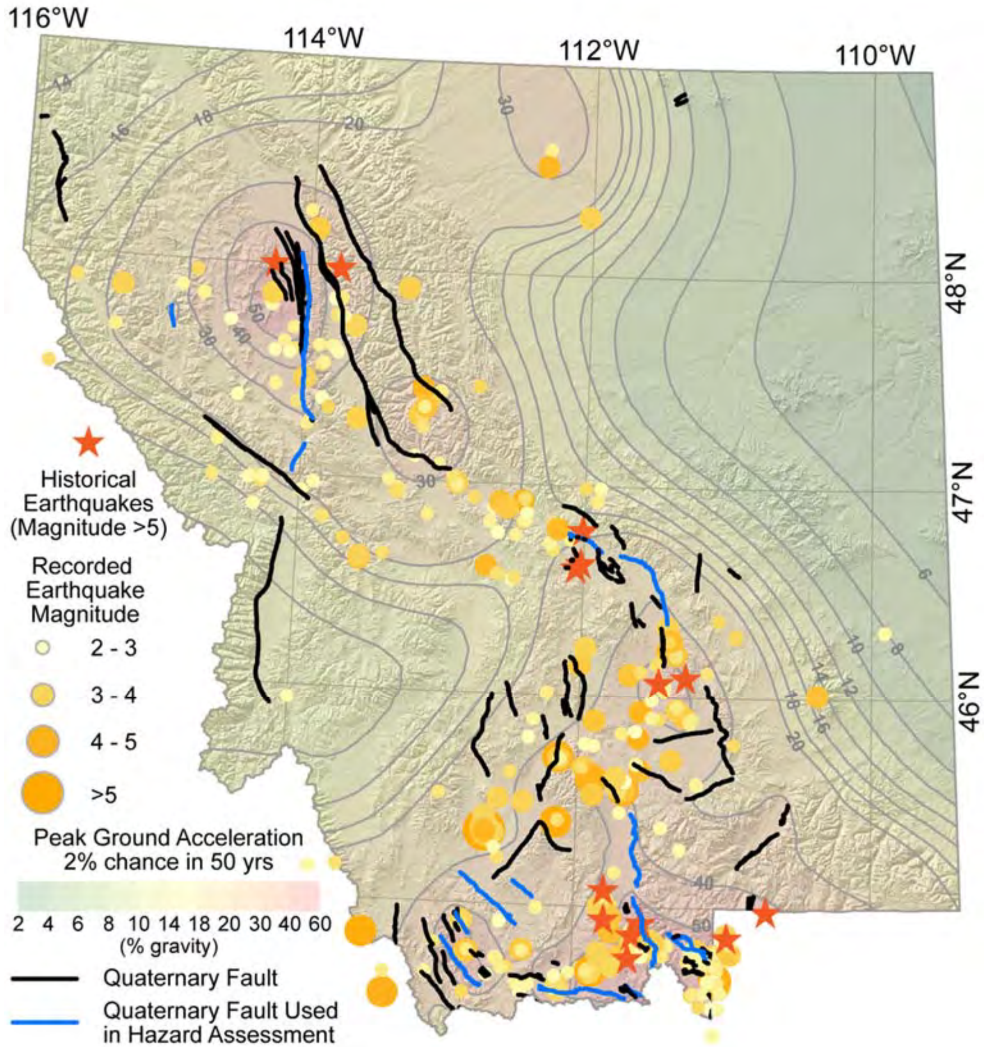

Inset Moraine 1
4,680
4,670
4,660
4,650
4,640
4,630
4,620
4,610
4,600
4,590
0
100
200
300
400
500
road
~40 ft


Inset Moraine 2
4,580
4,570
4,560
4,550
4,540
4,530
4,520
4,510
0
50
100
150
200
250
300
350
400
450
500
~22 ft

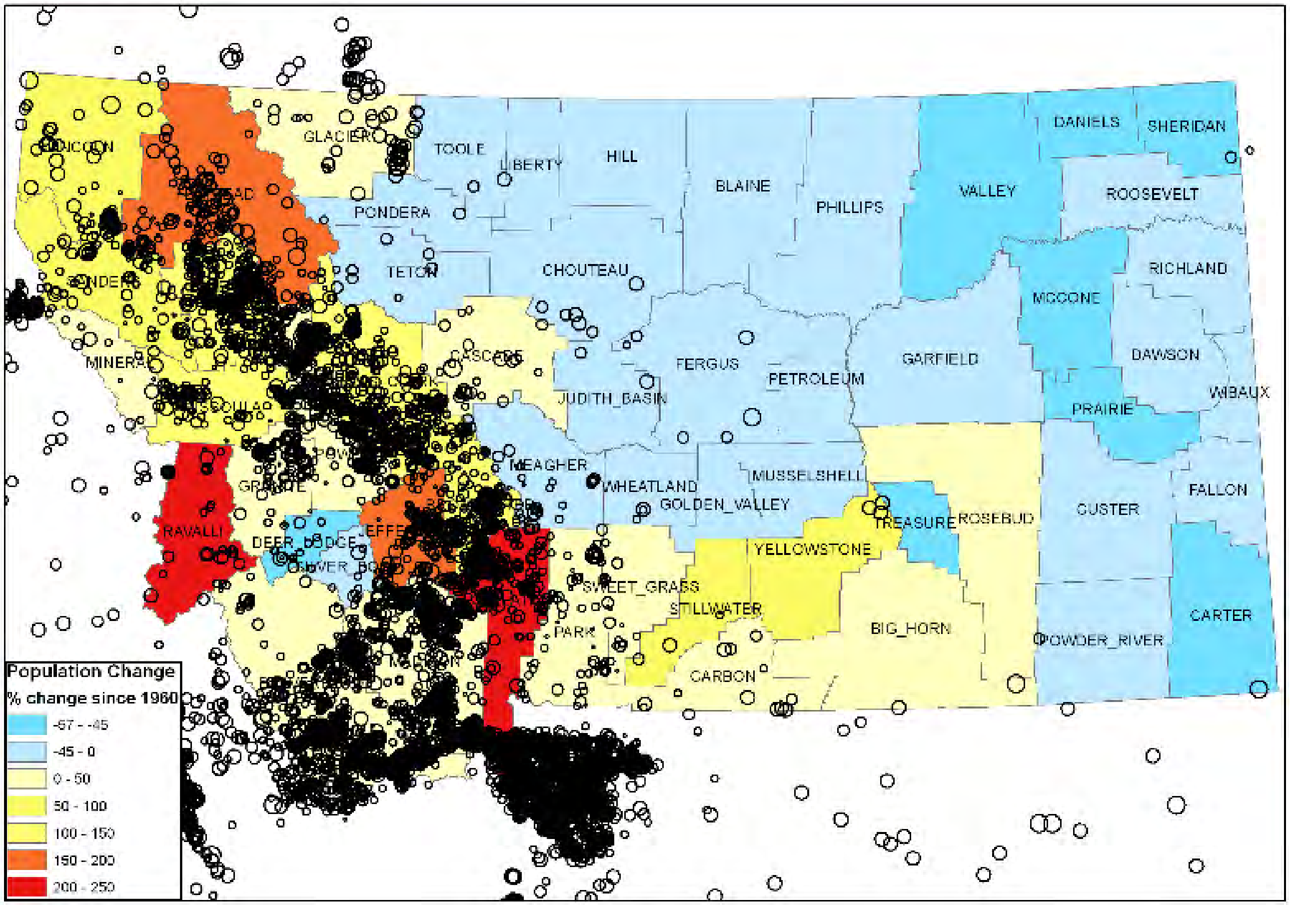

Inset Moraine 3
4,460
4,455
4,450
4,445
4,440
4,435
4,430
4,425
0
50
100
150
200
250
300
6 ft
Profile Graph Subtitle

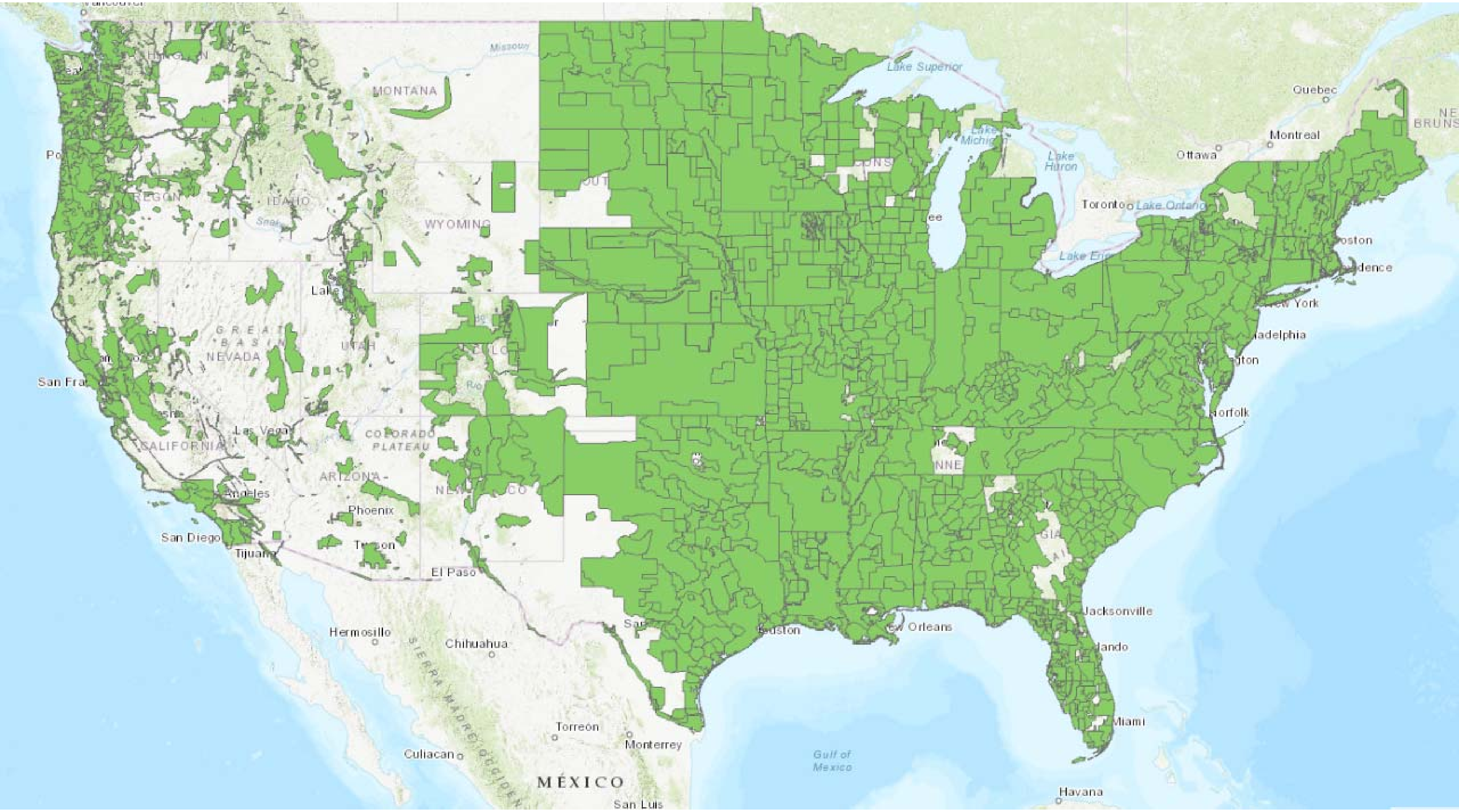

Inset Moraine 4
4,430
4,425
4,420
4,415
4,410
0
20
40
60
80
100
120
140
160
180
200
no offset




116°W
114°W
112°W
110°W
48°N
47°N
46°N
Historical Earthquakes (Magnitude >5)
Recorded Earthquake Magnitude
2 - 3
3 - 4
4 - 5
>5
Peak Ground Acceleration 2% chance in 50 yrs
2 4 6 8 10 14 18 20 30 40 60
(% gravity)
Quaternary Fault
Quaternary Fault Used in Hazard Assessment

Change in County Population 1960-2010



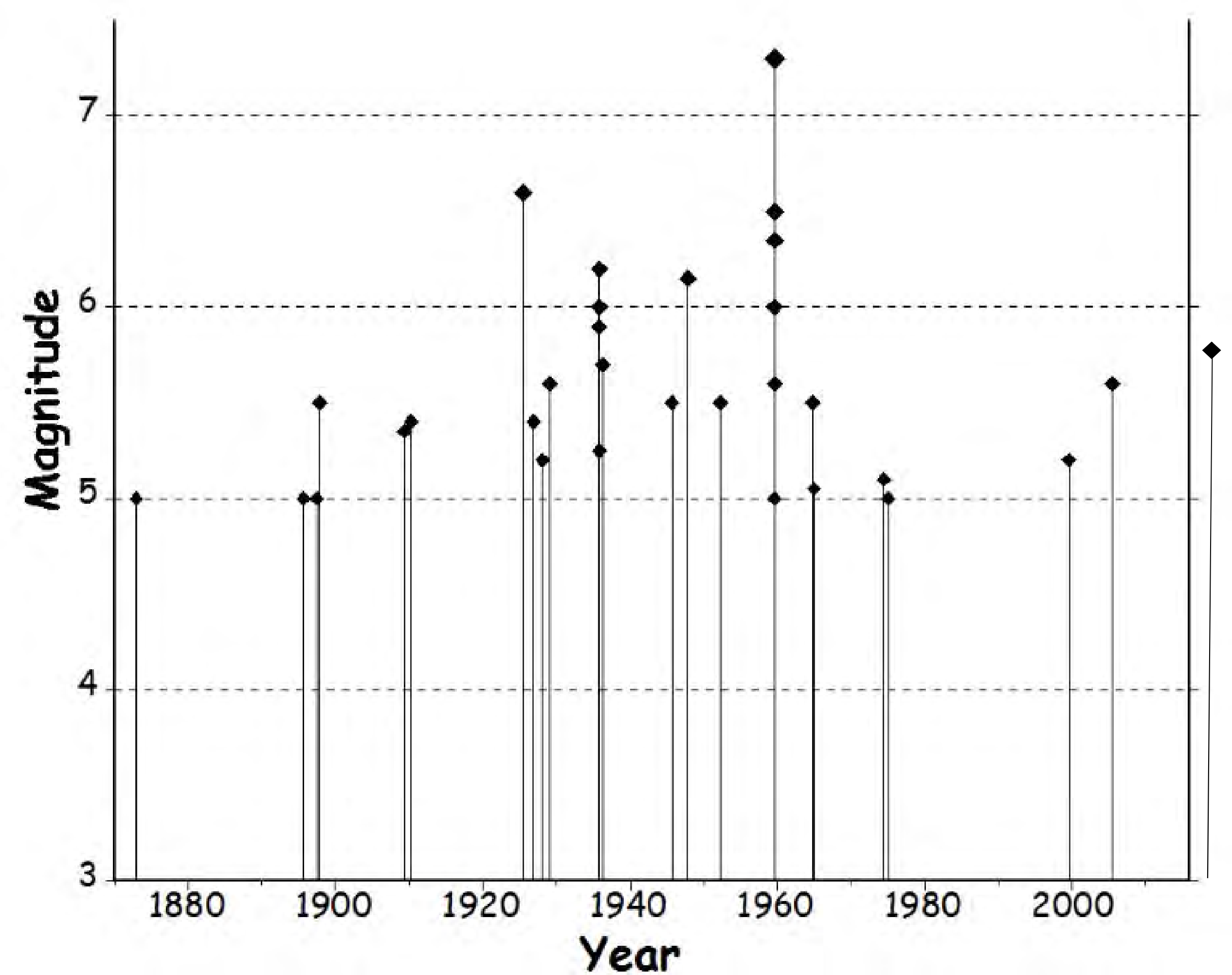


MONTANA
WYOMING
IDAHO
NEVADA
UTAH
COLORADO
PLATEAU
ARIZONA
Missouri
Lake Superior
Lake Huron
Quebec
Montreal
Ottawa
Toronto
Lake Ontario
New York
Norfolk
Jacksonville
Miami
Havana
Gulf of
Mexico
New Orleans
El Paso
Phoenix
San Diego
Tijuana
Hermosillo
Chihuahua
Torreón
Monterrey
Culiacan
MÉXICO
San Luis


Questions / Comments

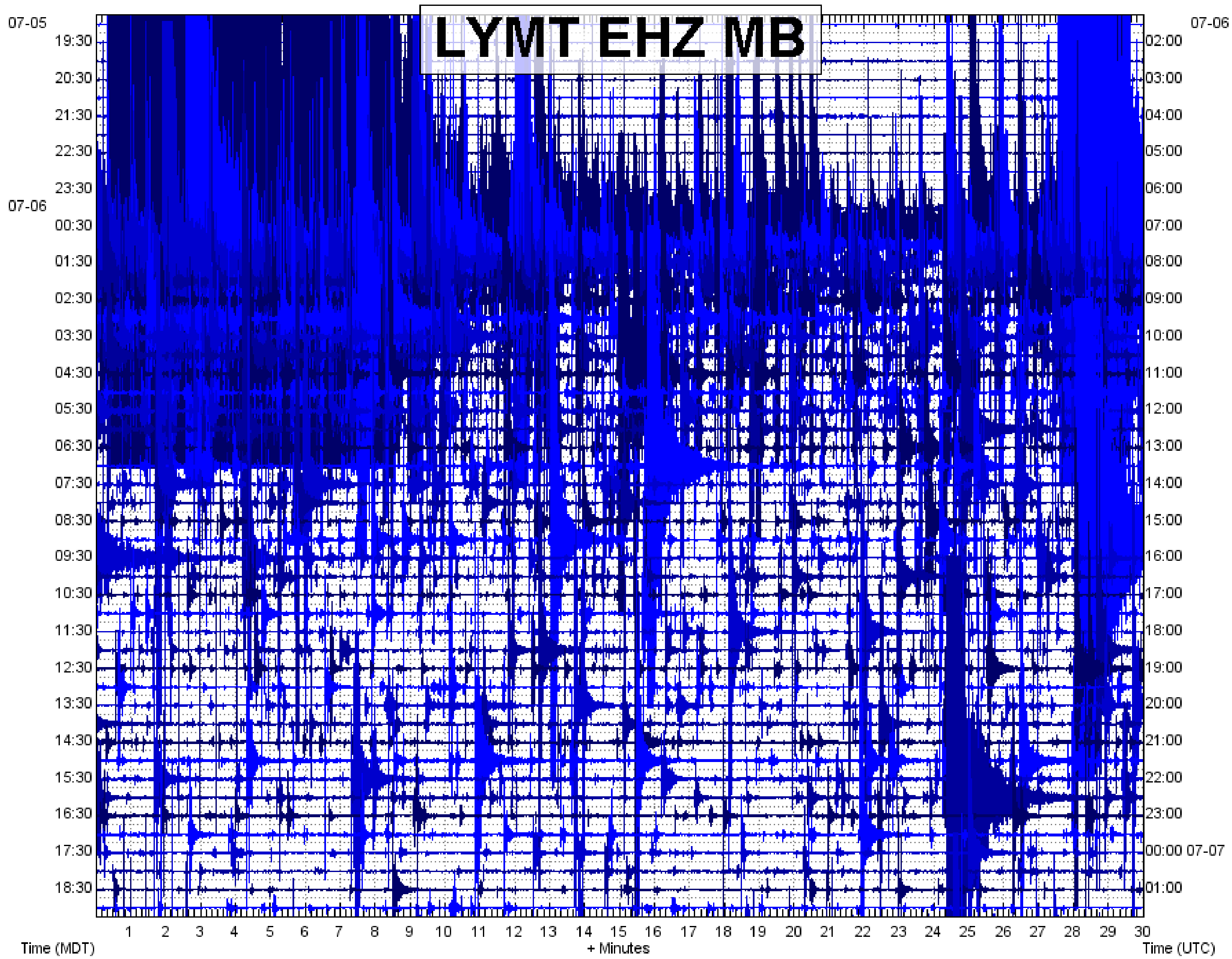

7/2016
Tour Guide
Imagery Date: 7/30/2016
lat 46.054646° lon -114.230686°

Montana Earthquakes M ≥ 5

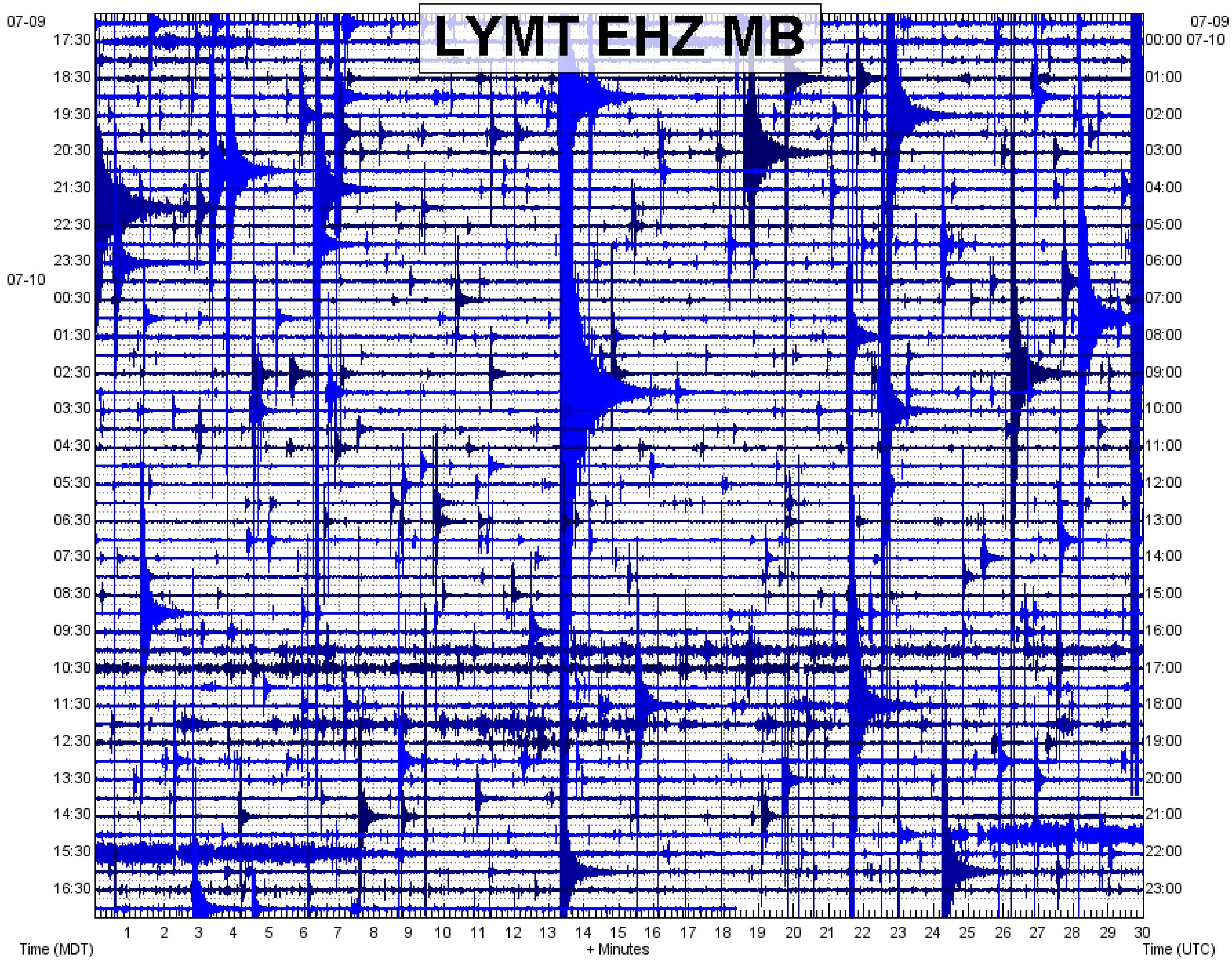


Bitterroot Fault looking south

98 km long



LYMT EHZ MB
07-05
19:30
20:30
21:30
22:30
23:30
07-06
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
07-06
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00 07-07
01:00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Time (MDT)
+ Minutes
Time (UTC)



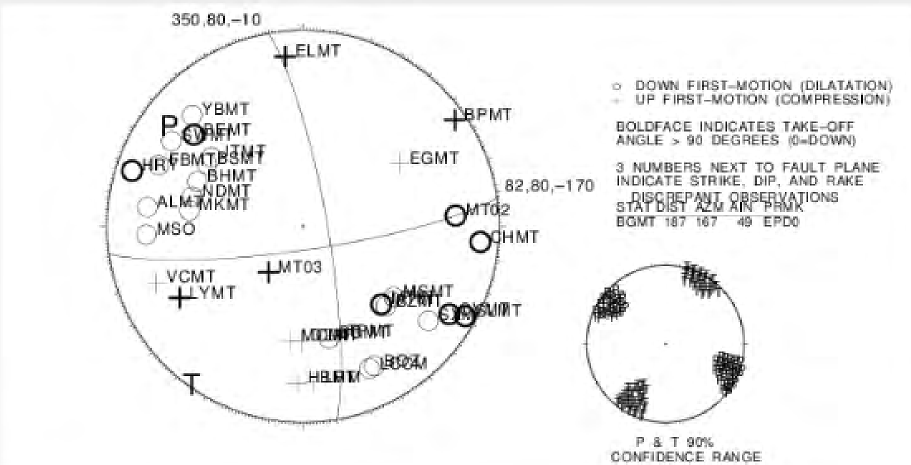
LYMT EHZ MB
07-09
17:30
18:30
19:30
20:30
21:30
22:30
23:30
07-10
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
07-09
00:00 07-10
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Time (MDT)
+ Minutes
Time (UTC)

First-Motion Focal Mechanism for Event mb80232594

The focal mechanism shown below graphically portrays the orientation of the fault plane on which the ear
detailed explanation describes how to interpret a focal mechanism. If more than one mechanism exists for

```
MB First Motion Mechanism
 P FIRST-MOTION FOCAL MECHANISM
 (double-couple source assumed)

 Event Date & Time          : 07/17/2017 08:49:50 GMT = Mon Jul 17 02:49:50 MDT 2017
 Location                   : 46.8742 N, 112.5418 W
                            : (46 deg. 52.45 min. N, 112.deg. 32.51 min. W)
 Depth                      : 11.5 km. deep (  7.2 miles)
 Magnitude                  : 4.7 ML
 # P First motions          :  35
 Strike uncertainty         :   8 deg.
 Dip    uncertainty         :  25 deg.
 Rake   uncertainty         :  30 deg.
```

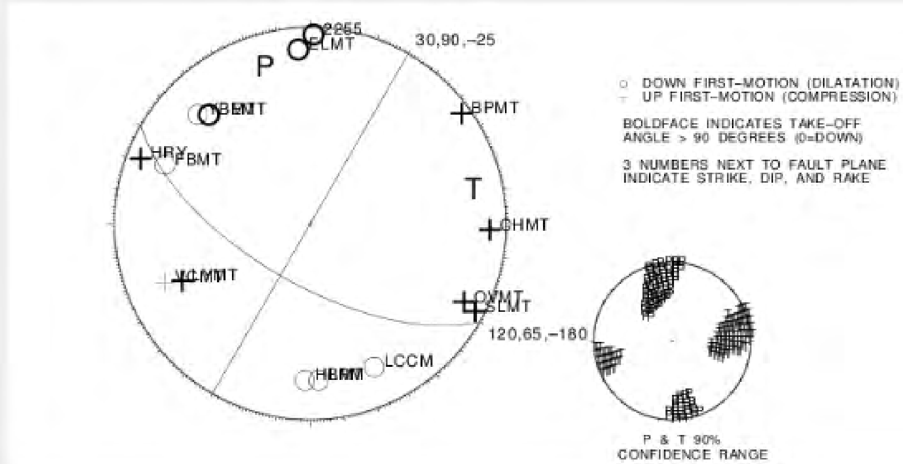


First-Motion Focal Mechanism for Event mb80223609

The focal mechanism shown below graphically portrays the orientation of the fault plane on which the e
detailed explanation describes how to interpret a focal mechanism. If more than one mechanism exists f

```
MB First Motion Mechanism
 P FIRST-MOTION FOCAL MECHANISM
 (double-couple source assumed)

 Event Date & Time          : 07/06/2017 07:02:28 GMT = Thu Jul 06 01:02:28 MDT 201
 Location                   : 46.8973 N, 112.5295 W
                            : (46 deg. 53.84 min. N, 112.deg. 31.77 min. W)
 Depth                      : 10.9 km. deep (  6.8 miles)
 Magnitude                  : 4.4 ML
 # P First motions          :  15
 Strike uncertainty         :  13 deg.
 Dip    uncertainty         :  33 deg.
 Rake   uncertainty         :  40 deg.
```

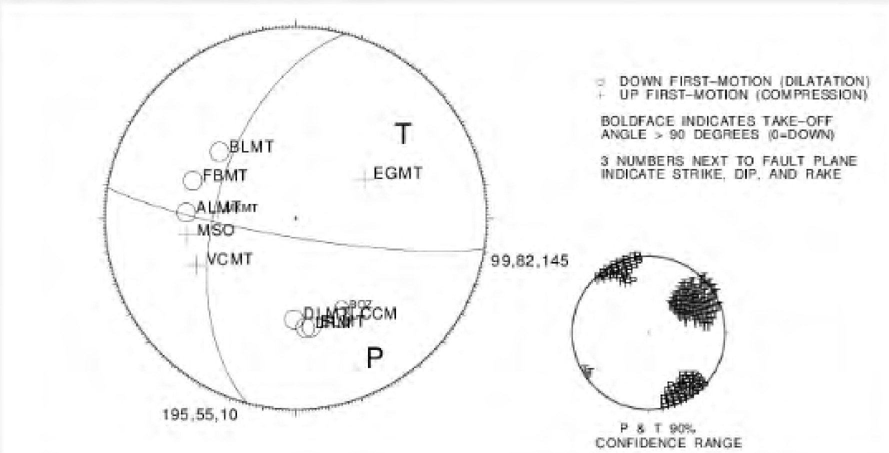


First-Motion Focal Mechanism for Event mb80263274

The focal mechanism shown below graphically portrays the orientation of the fault plane on which the ear
detailed explanation describes how to interpret a focal mechanism. If more than one mechanism exists for

```
MB First Motion Mechanism
 P FIRST-MOTION FOCAL MECHANISM
 (double-couple source assumed)

 Event Date & Time             : 10/19/2017 22:18:16 GMT = Thu Oct 19 16:18:16 MDT 2017
 Location                      : 46.9857 N, 112.5798 W
                               : (46 deg. 59.14 min. N, 112.deg. 34.79 min. W)
 Depth                         : -3.1 km. deep ( -1.9 miles)
 Magnitude                     : 4.4 ML
 # P First motions             :  12
 Strike uncertainty            :  15 deg.
 Dip    uncertainty            :  25 deg.
 Rake   uncertainty            :  15 deg.
```

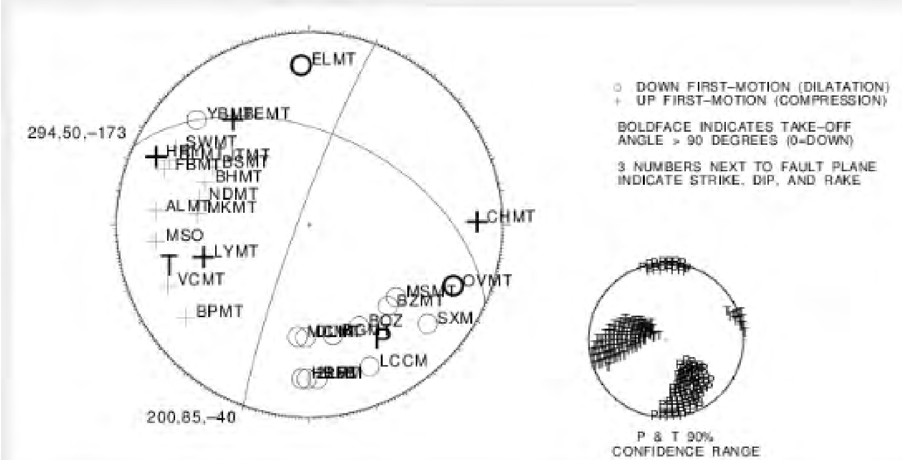


First-Motion Focal Mechanism for Event mb80224574

The focal mechanism shown below graphically portrays the orientation of the fault plane on which the ear
detailed explanation describes how to interpret a focal mechanism. If more than one mechanism exists for

```
MB First Motion Mechanism
 P FIRST-MOTION FOCAL MECHANISM
 (double-couple source assumed)

 Event Date & Time             : 07/06/2017 15:27:59 GMT = Thu Jul 06 09:27:59 MDT 2017
 Location                      : 46.9245 N, 112.5162 W
                               : (46 deg. 55.47 min. N, 112.deg. 30.97 min. W)
 Depth                         : 15.7 km. deep (  9.8 miles)
 Magnitude                     : 4.3 ML
 # P First motions             :  30
 Strike uncertainty            :  20 deg.
 Dip    uncertainty            :  25 deg.
 Rake   uncertainty            :  25 deg.
```

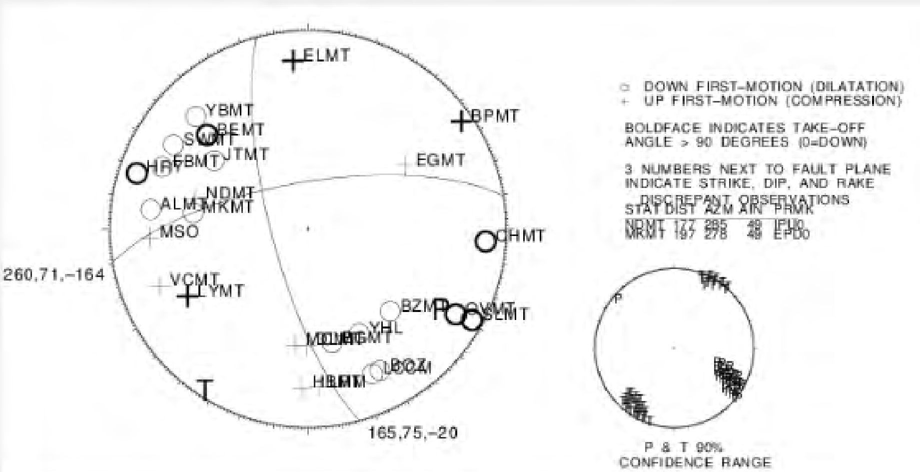


First-Motion Focal Mechanism for Event mb80227349

The focal mechanism shown below graphically portrays the orientation of the fault plane on which the ea
detailed explanation describes how to interpret a focal mechanism. If more than one mechanism exists fo

```
MB First Motion Mechanism
 P FIRST-MOTION FOCAL MECHANISM
 (double-couple source assumed)

 Event Date & Time            : 07/08/2017 12:38:24 GMT = Sat Jul 08 06:38:24 MDT 2017
 Location                     : 46.8782 N, 112.5330 W
                              : (46 deg. 52.69 min. N, 112.deg. 31.98 min. W)
 Depth                        : 12.5 km. deep (  7.8 miles)
 Magnitude                    : 4.3 ML
 # P First motions            :  27
 Strike uncertainty           :   5 deg.
 Dip    uncertainty           :  13 deg.
 Rake   uncertainty           :  15 deg.
```

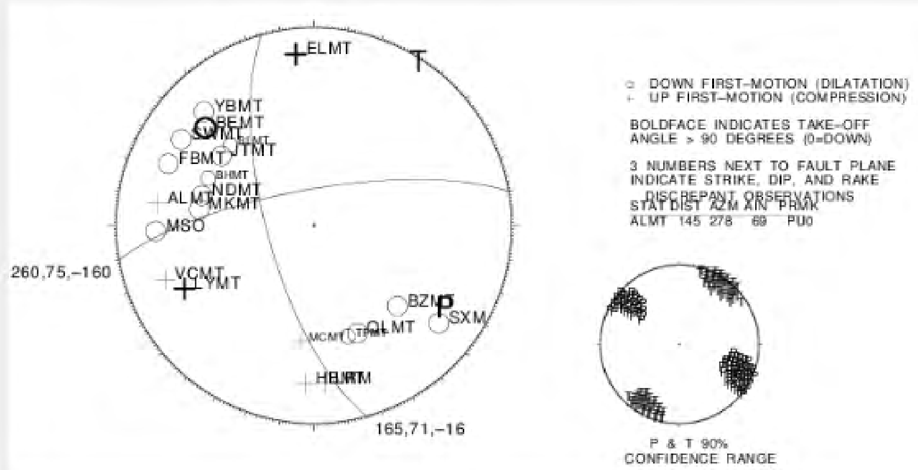


First-Motion Focal Mechanism for Event mb80225209

The focal mechanism shown below graphically portrays the orientation of the fault plane on which the ea
detailed explanation describes how to interpret a focal mechanism. If more than one mechanism exists for

```
MB First Motion Mechanism
 P FIRST-MOTION FOCAL MECHANISM
 (double-couple source assumed)

 Event Date & Time            : 07/06/2017 22:24:15 GMT = Thu Jul 06 16:24:15 MDT 2017
 Location                     : 46.8858 N, 112.5475 W
                              : (46 deg. 53.15 min. N, 112.deg. 32.85 min. W)
 Depth                        : 11.5 km. deep (  7.2 miles)
 Magnitude                    : 4.0 ML
 # P First motions            :  21
 Strike uncertainty           :  10 deg.
 Dip    uncertainty           :  23 deg.
 Rake   uncertainty           :  25 deg.
```



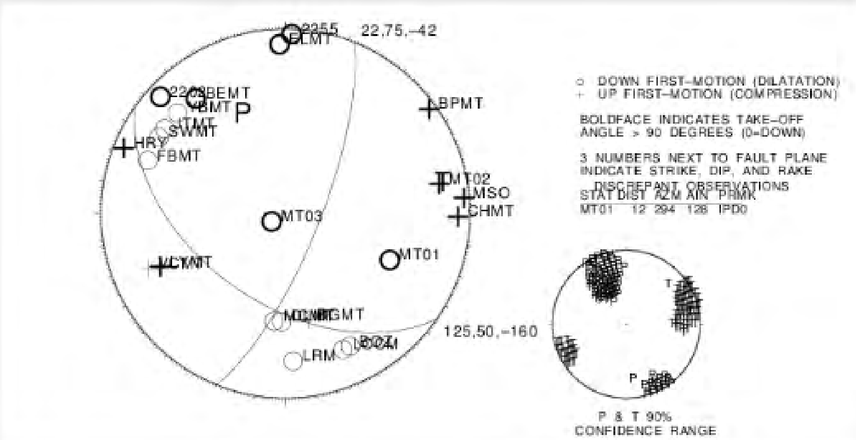
First-Motion Focal Mechanism for Event [mb80261624]

The focal mechanism shown below graphically portrays the orientation of the fault plane on which the ear
detailed [explanation] describes how to interpret a focal mechanism. If more than one mechanism exists for

---

```
MB First Motion Mechanism
 P FIRST-MOTION FOCAL MECHANISM
 (double-couple source assumed)

 Event Date & Time          : 10/15/2017 01:41:52 GMT = Sat Oct 14 19:41:52 MDT 2017
 Location                   : 46.9075 N, 112.5117 W
                            : (46 deg. 54.45 min. N, 112.deg. 30.70 min. W)
 Depth                      :  9.4 km. deep (  5.9 miles)
 Magnitude                  : 4.0 ML
 # P First motions          :  23
 Strike uncertainty         :  10 deg.
 Dip    uncertainty         :  25 deg.
 Rake   uncertainty         :  30 deg.
```



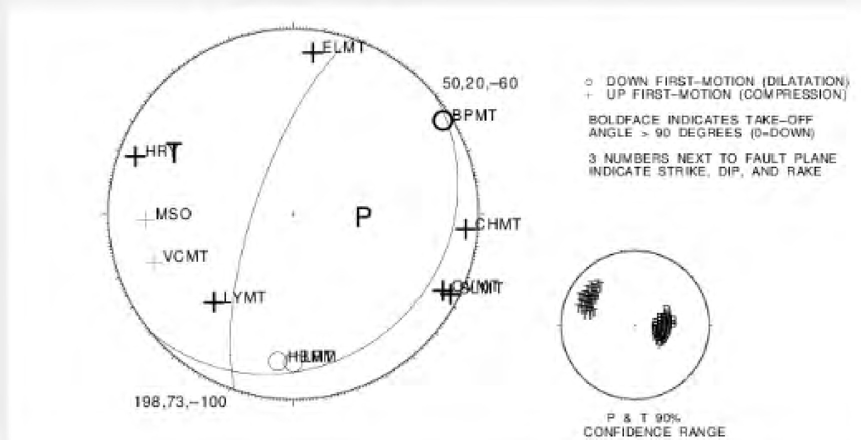
First-Motion Focal Mechanism for Event [mb80223669]

The focal mechanism shown below graphically portrays the orientation of the fault plane on which the ear
detailed [explanation] describes how to interpret a focal mechanism. If more than one mechanism exists for

---

```
MB First Motion Mechanism
 P FIRST-MOTION FOCAL MECHANISM
 (double-couple source assumed)

 Event Date & Time          : 07/06/2017 07:31:49 GMT = Thu Jul 06 01:31:49 MDT 2017
 Location                   : 46.8685 N, 112.4278 W
                            : (46 deg. 52.11 min. N, 112.deg. 25.67 min. W)
 Depth                      : 10.8 km. deep (  6.8 miles)
 Magnitude                  : 3.9 ML
 # P First motions          :  11
 Strike uncertainty         :  20 deg.
 Dip    uncertainty         :  10 deg.
 Rake   uncertainty         :  15 deg.
```

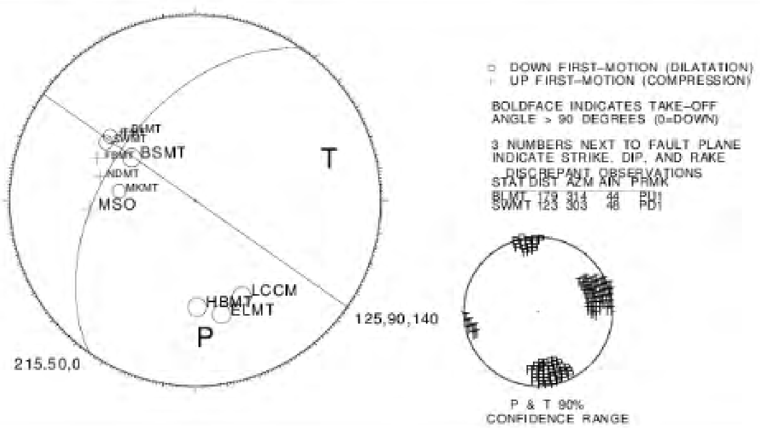


First-Motion Focal Mechanism for Event mb80223624

The focal mechanism shown below graphically portrays the orientation of the fault plane on which the ea
detailed explanation describes how to interpret a focal mechanism. If more than one mechanism exists for

```
MB First Motion Mechanism
 P FIRST-MOTION FOCAL MECHANISM
 (double-couple source assumed)

 Event Date & Time           : 07/06/2017 07:08:60 GMT = Thu Jul 06 01:09:00 MDT 2017
 Location                    : 46.9213 N, 112.6183 W
                             : (46 deg. 55.28 min. N, 112.deg. 37.10 min. W)
 Depth                       : -3.4 km. deep ( -2.1 miles)
 Magnitude                   : 3.3 MD
 # P First motions           :  11
 Strike uncertainty          :  10 deg.
 Dip    uncertainty          :  23 deg.
 Rake   uncertainty          :  10 deg.
```

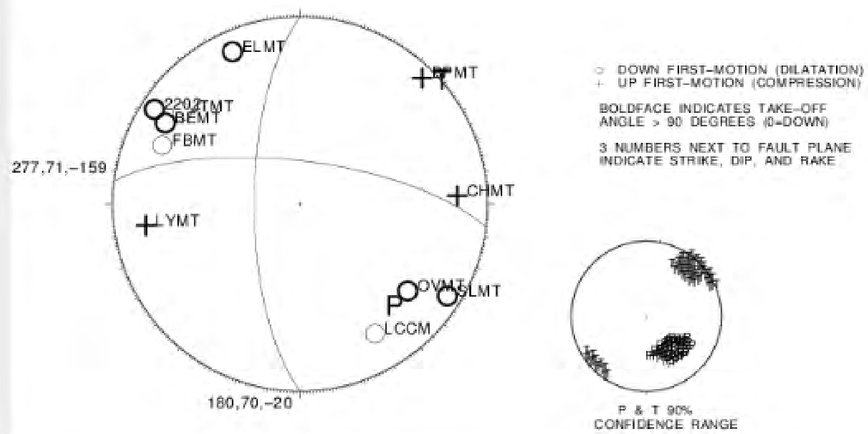


First-Motion Focal Mechanism for Event mb80277059

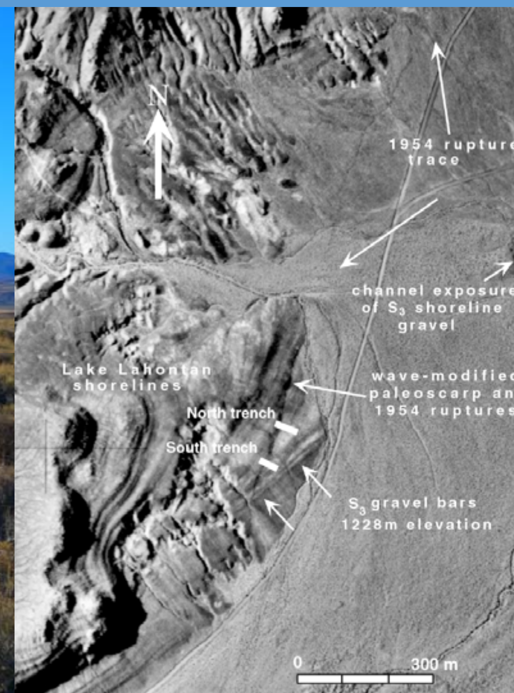
The focal mechanism shown below graphically portrays the orientation of the fault plane on which the ea
detailed explanation describes how to interpret a focal mechanism. If more than one mechanism exists fo

```
MB First Motion Mechanism
 P FIRST-MOTION FOCAL MECHANISM
 (double-couple source assumed)

 Event Date & Time           : 01/07/2018 19:29:42 GMT = Sun Jan 07 12:29:42 MST 2018
 Location                    : 46.9278 N, 112.7547 W
                             : (46 deg. 55.67 min. N, 112.deg. 45.28 min. W)
 Depth                       : 12.5 km. deep (  7.8 miles)
 Magnitude                   : 3.9 ML
 # P First motions           :  11
 Strike uncertainty          :  18 deg.
 Dip    uncertainty          :  20 deg.
 Rake   uncertainty          :  10 deg.
```



State Presentations on technical Issues facing the Basin & Range
Nevada



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

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

The main focus of natural hazards studies and outreach at NBMG

- Earthquake geology and paleoseismic research
- Quaternary research (alluvial fan timing)
- Engineering geology
- Participation in Nevada Earthquake Safety Council (NESC)
- Participation in the Western States Seismic Policy Council (WSSPC)
- Earthquake awareness talks to the public
- Rapid response to hazardous geologic events (floods, earthquakes, landslides)

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Efforts to further the goals of the program and contribute to the mission of NBMG

- A new Quaternary geology and Geologic Hazards laboratory is being established
- Collaborations with the Nevada Seismological Laboratory
- Collaborations with the E.L. Cord Luminescence Laboratory at Desert Research Institute
- Sponsoring new graduate student research (Fall, 2017)
- Teaching in the Department of Geological Sciences and Engineering (field methods, field camp)

Continuous or cyclic fan deposition?

Implications for:
Earthquake hazards
Debris flow frequency
Evaluation of climate change

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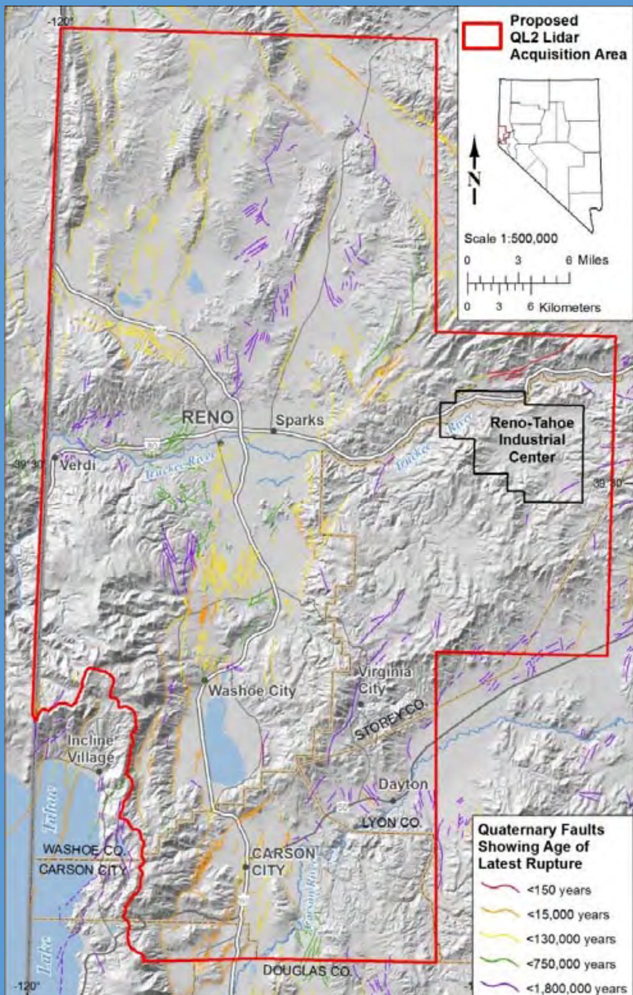

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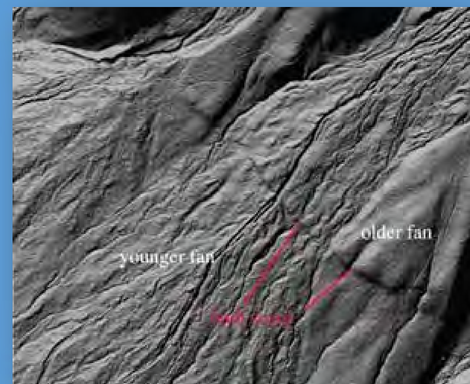
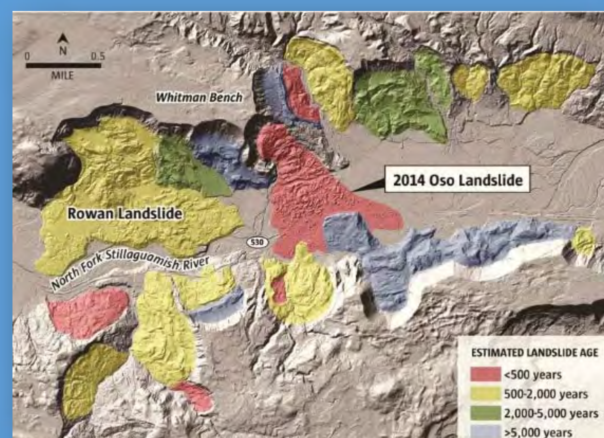
New 3DEP lidar will greatly benefit the natural hazards program

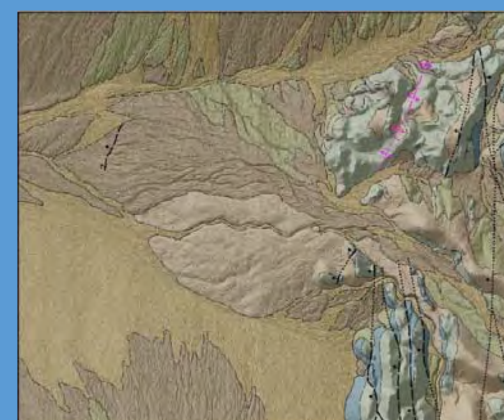


Earthquake hazards

Flood Risk Management



Landslide Mapping

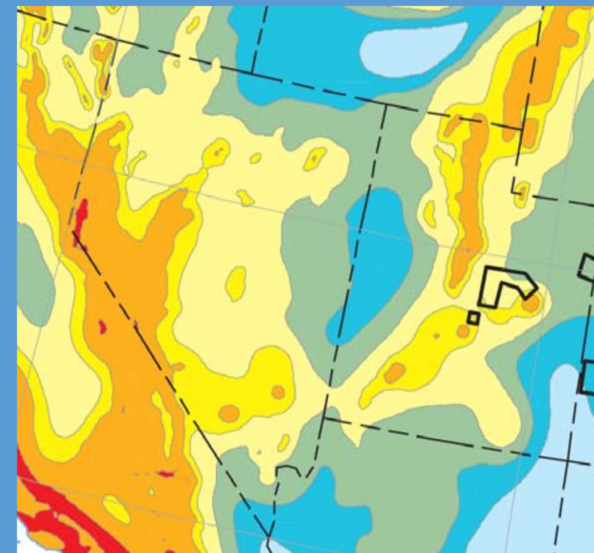


Geologic Mapping

2018 Working Group on Nevada Seismic Hazards

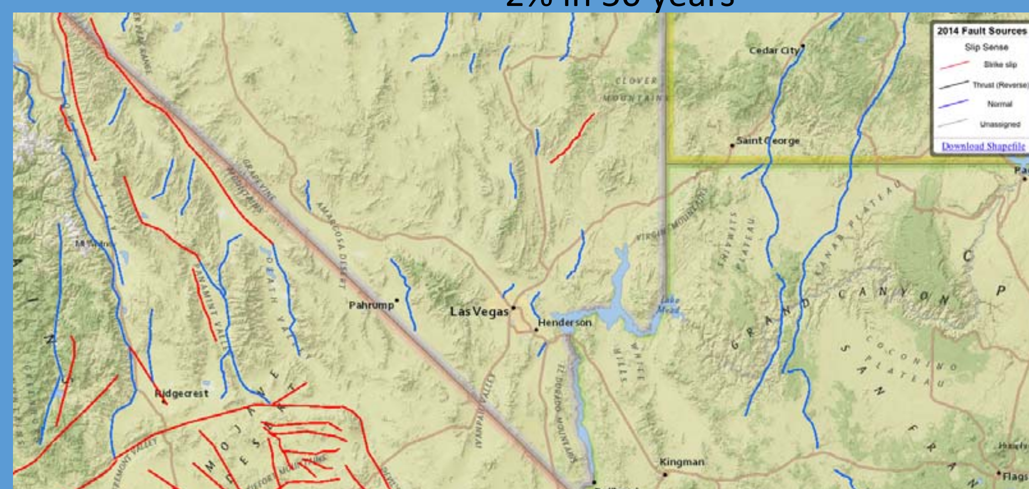
Main objectives

- review earthquake hazard research
- provide insight related to technical issues and uncertainties
- identify priorities for future research benefit the National Seismic Hazard Map
- improve time-independent forecasts of future earthquake occurrence
- improve estimates of the ground motions



Peak ground acceleration
2% in 50 years

Faults included in the 2014 National Seismic Hazards map



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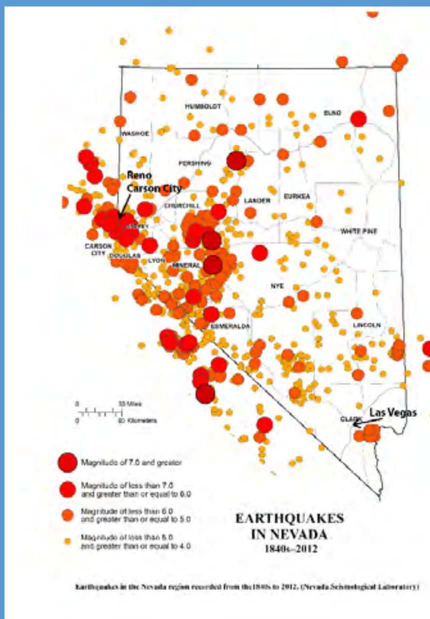
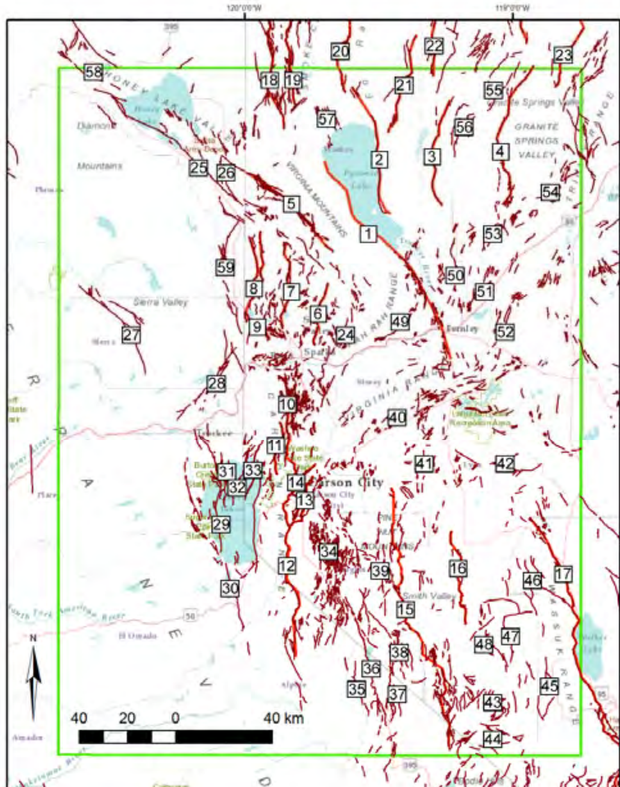
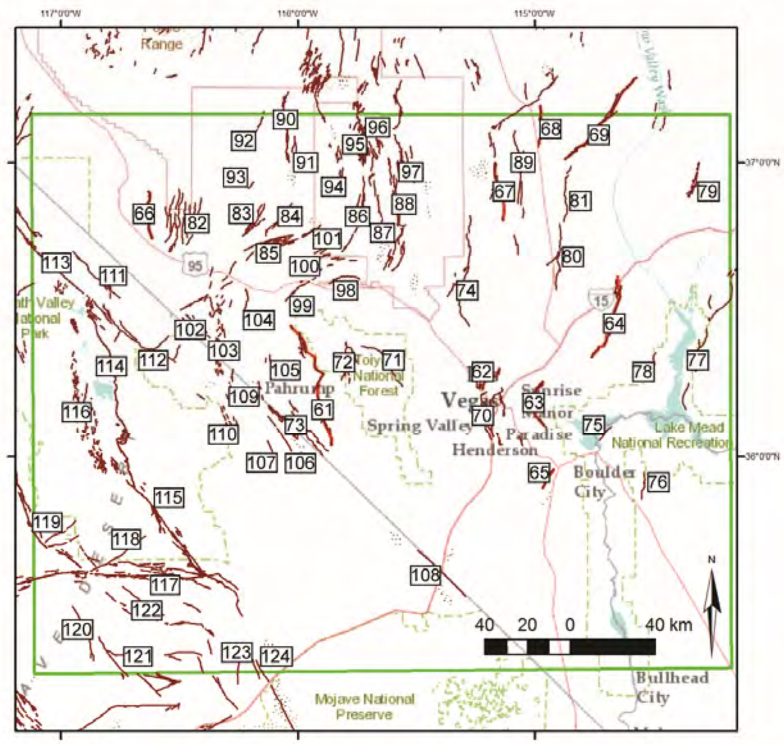
2018 Working Group on Nevada Seismic Hazards



Reno focus area



Las Vegas focus area



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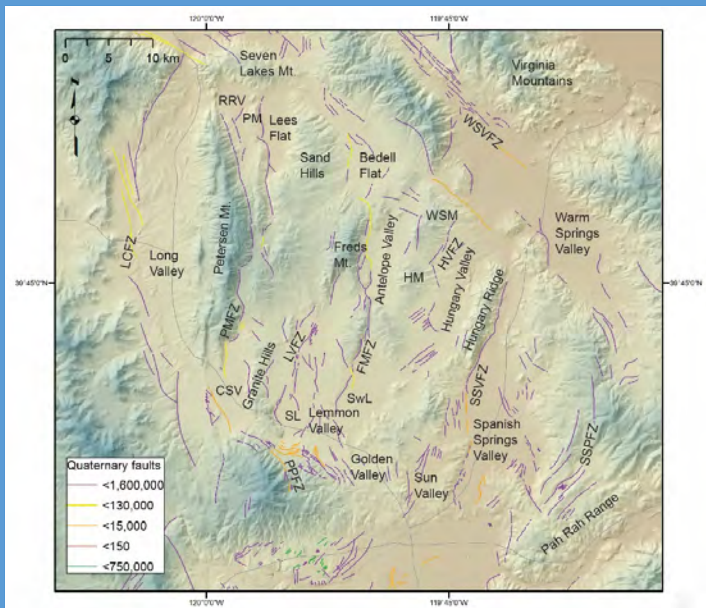
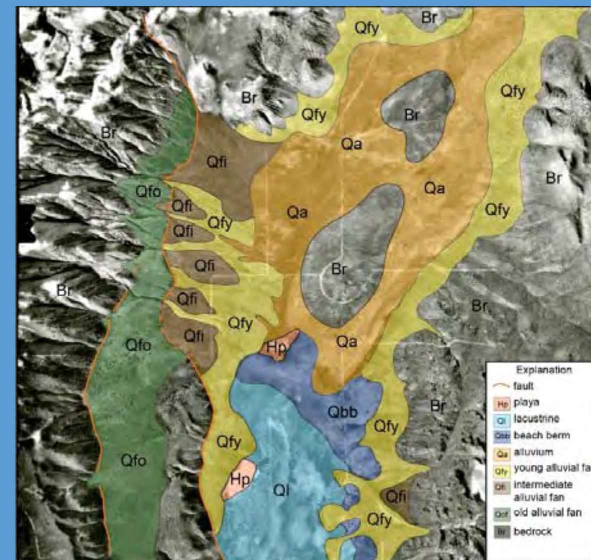
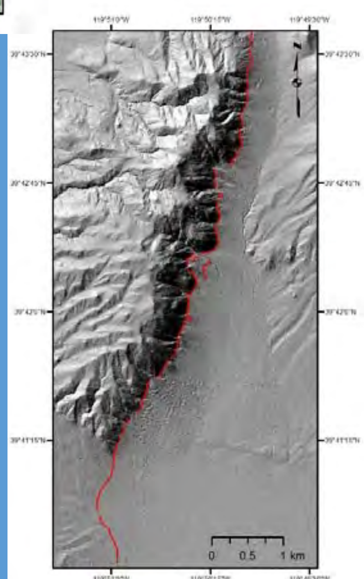
Additional studies in Vegas (dePolo)

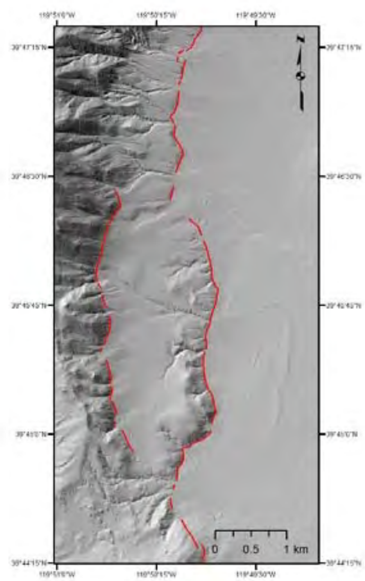


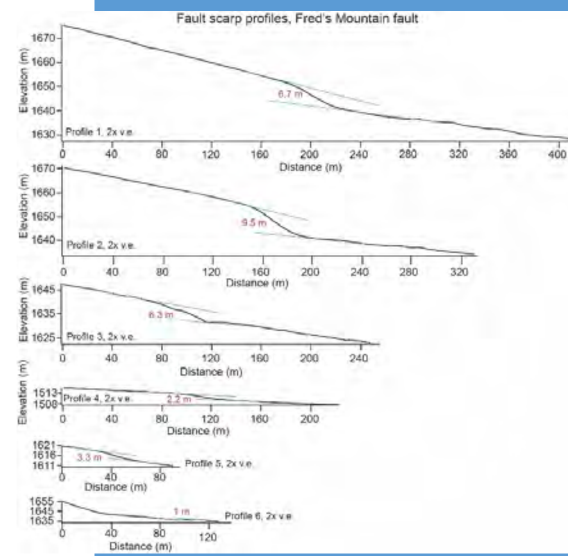


Fred's Mountain fault zone

- Age of offset surfaces
- Reconnaissance slip rate
- Calibration of rates used in the NSHM

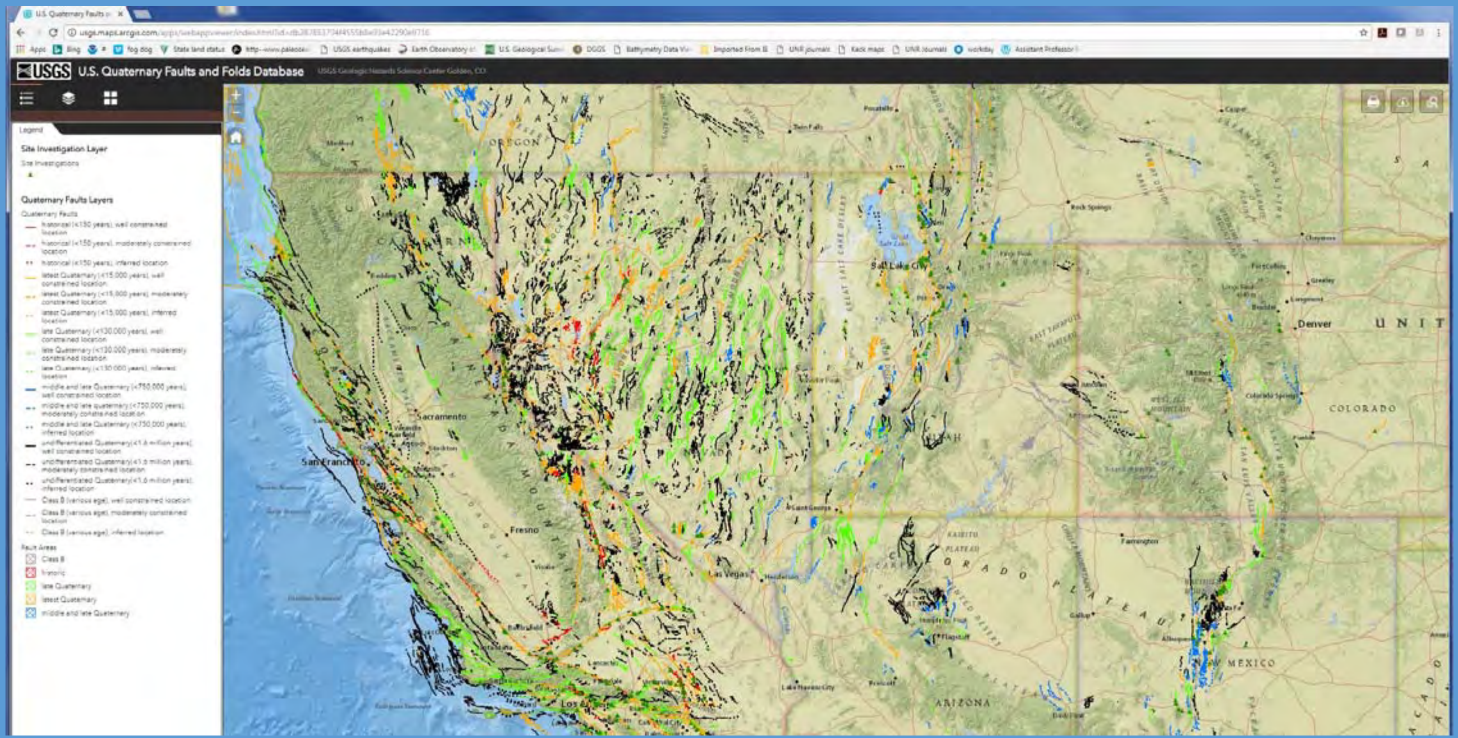






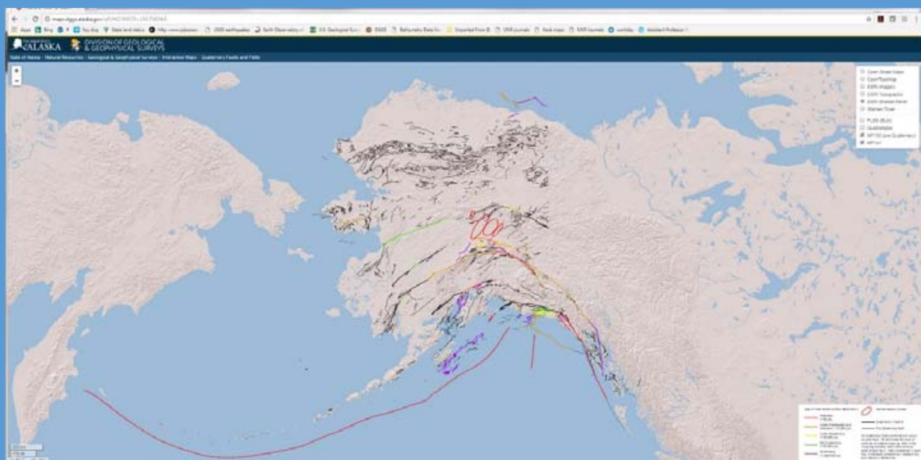
Statewide Challenges

- Resolving border faults
- Developing a Nevada database
- Database maintenance

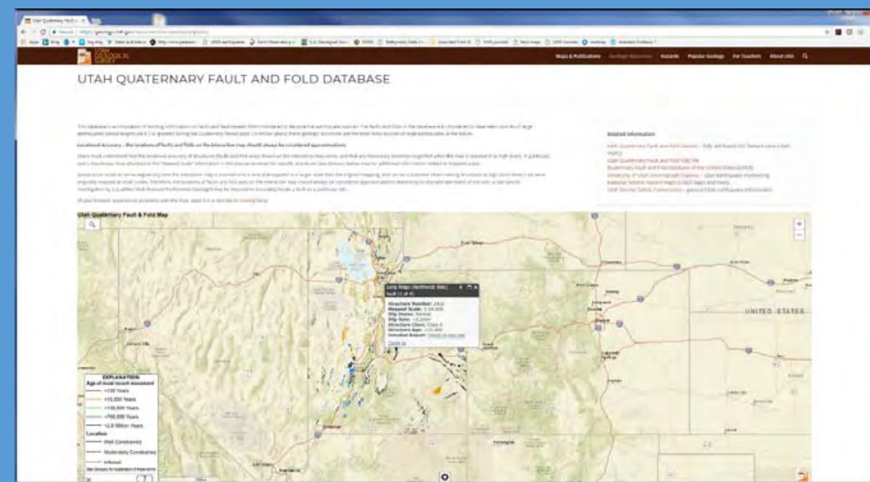


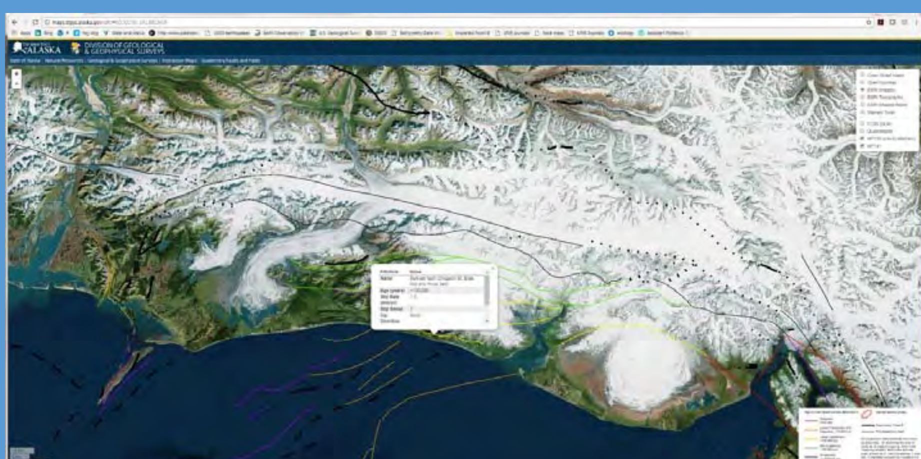
Quaternary fault databases

Alaska

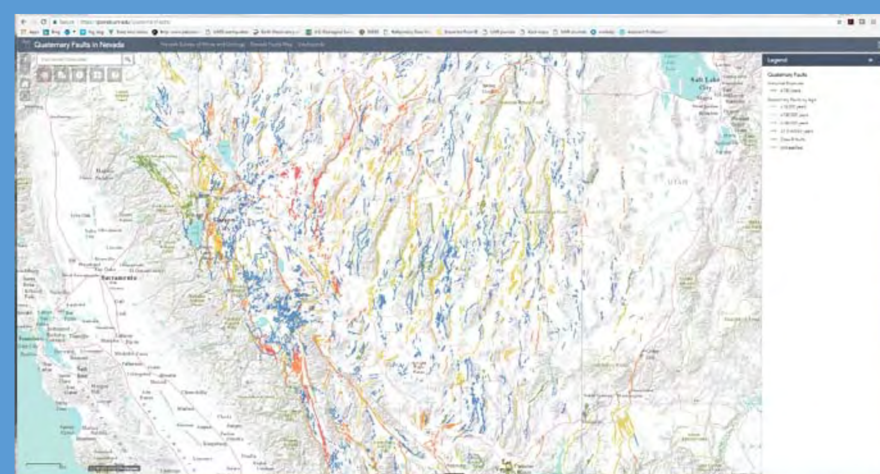


Utah

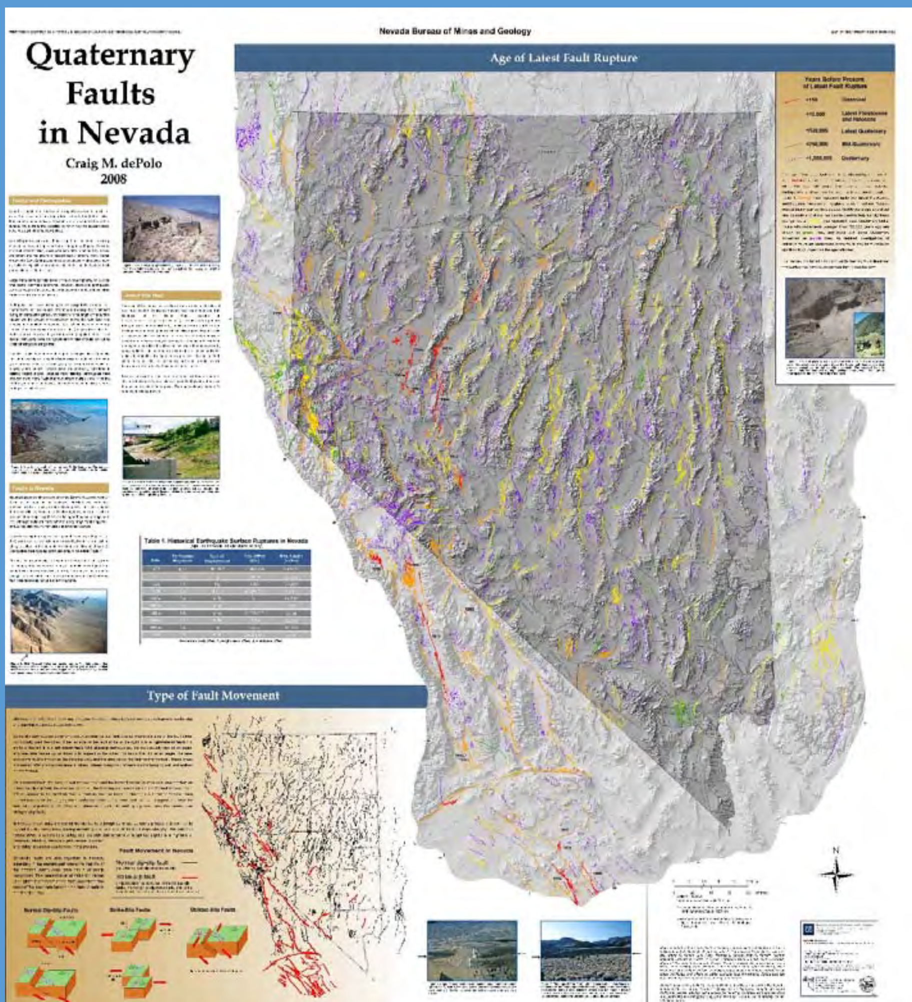


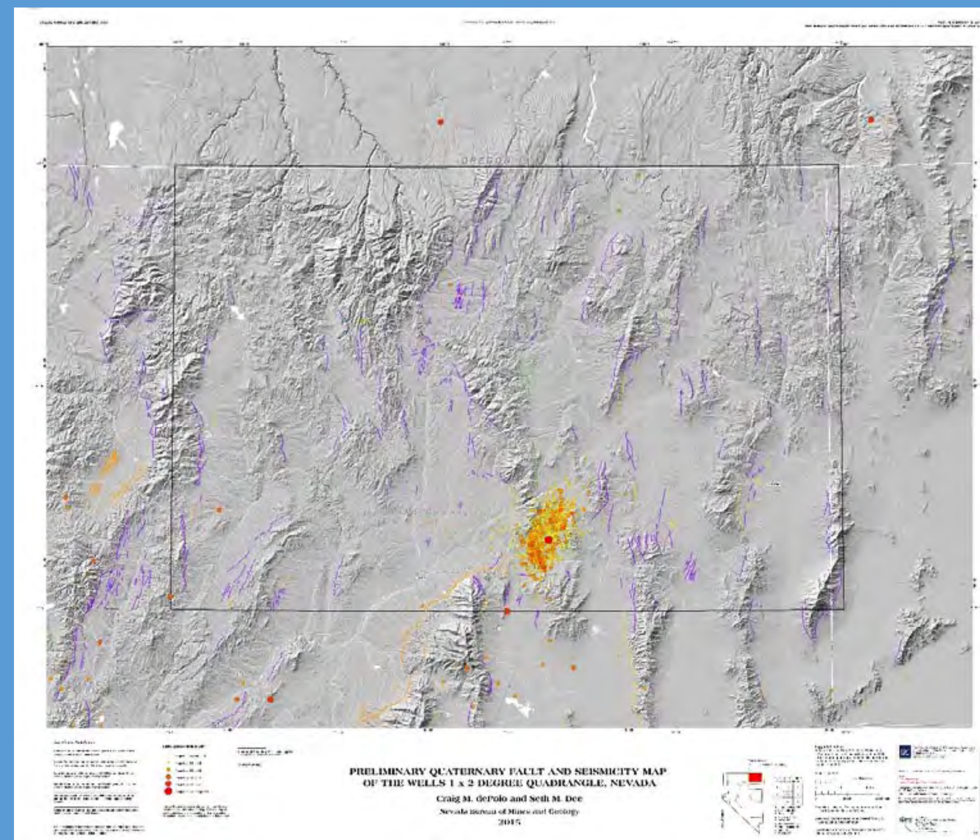


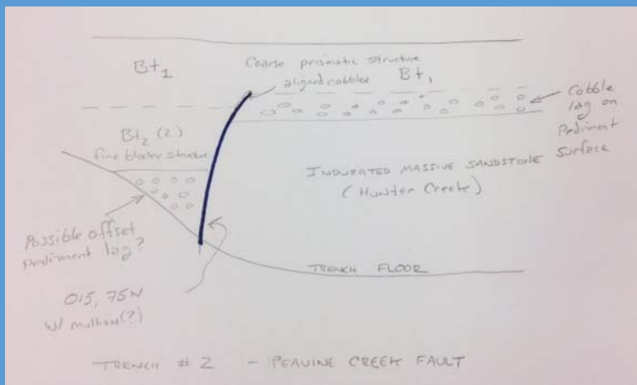
Nevada



Continuity between paper products and digital database



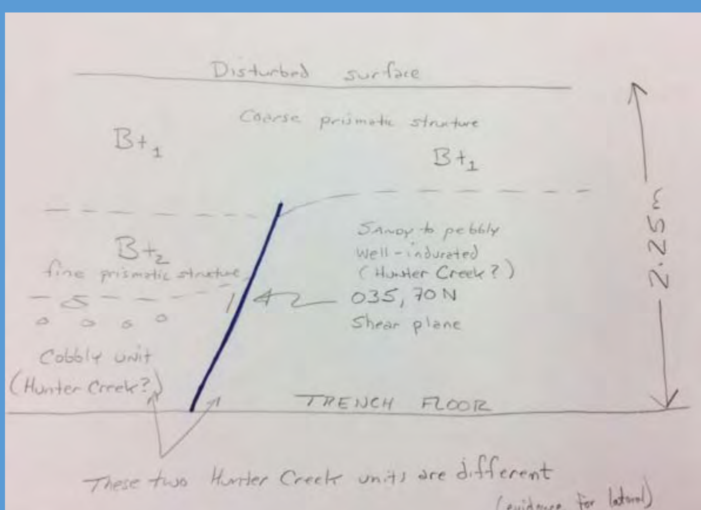


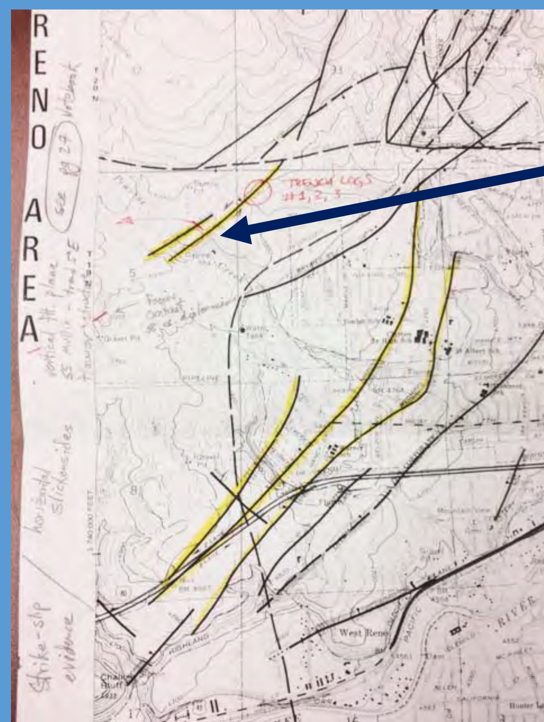


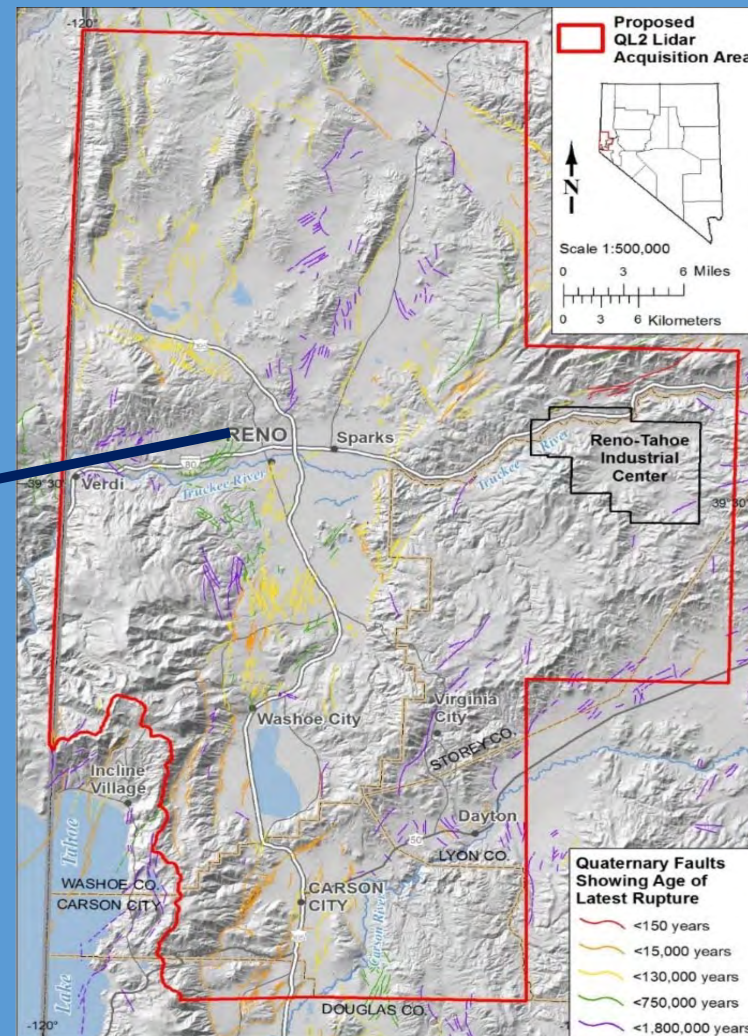
Review of unpublished archival data form NBMG files

New lidar 2018

Peavine Creek fault







Other challenges

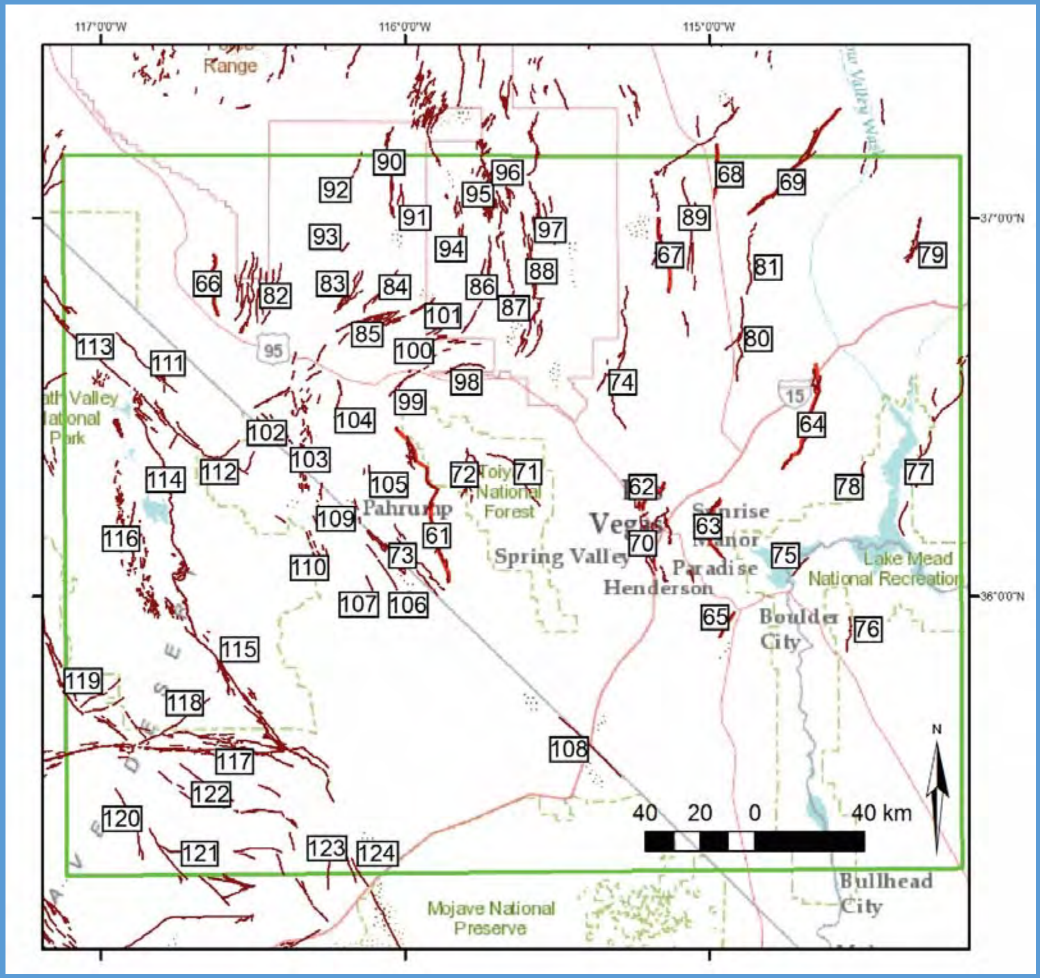
- Low rates of deformation
- Encroaching development

Faults in proximity to Las Vegas

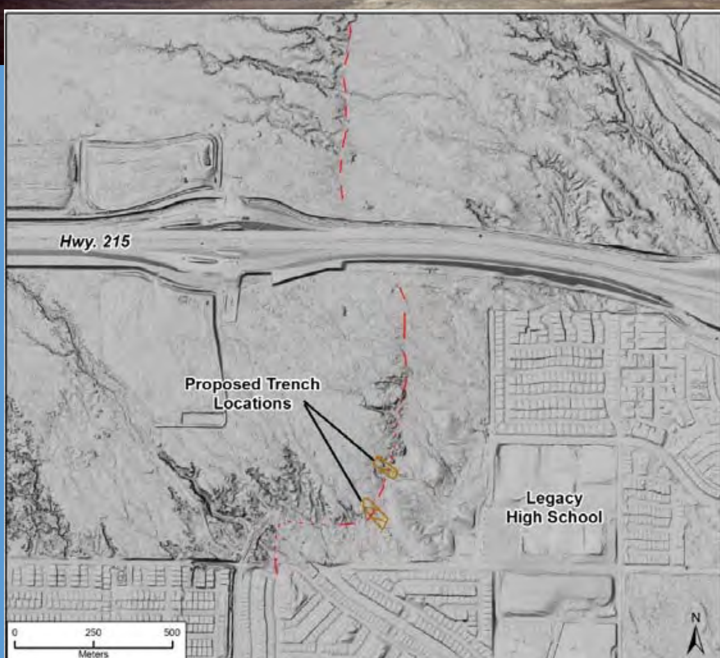
9 faults included in NSHM

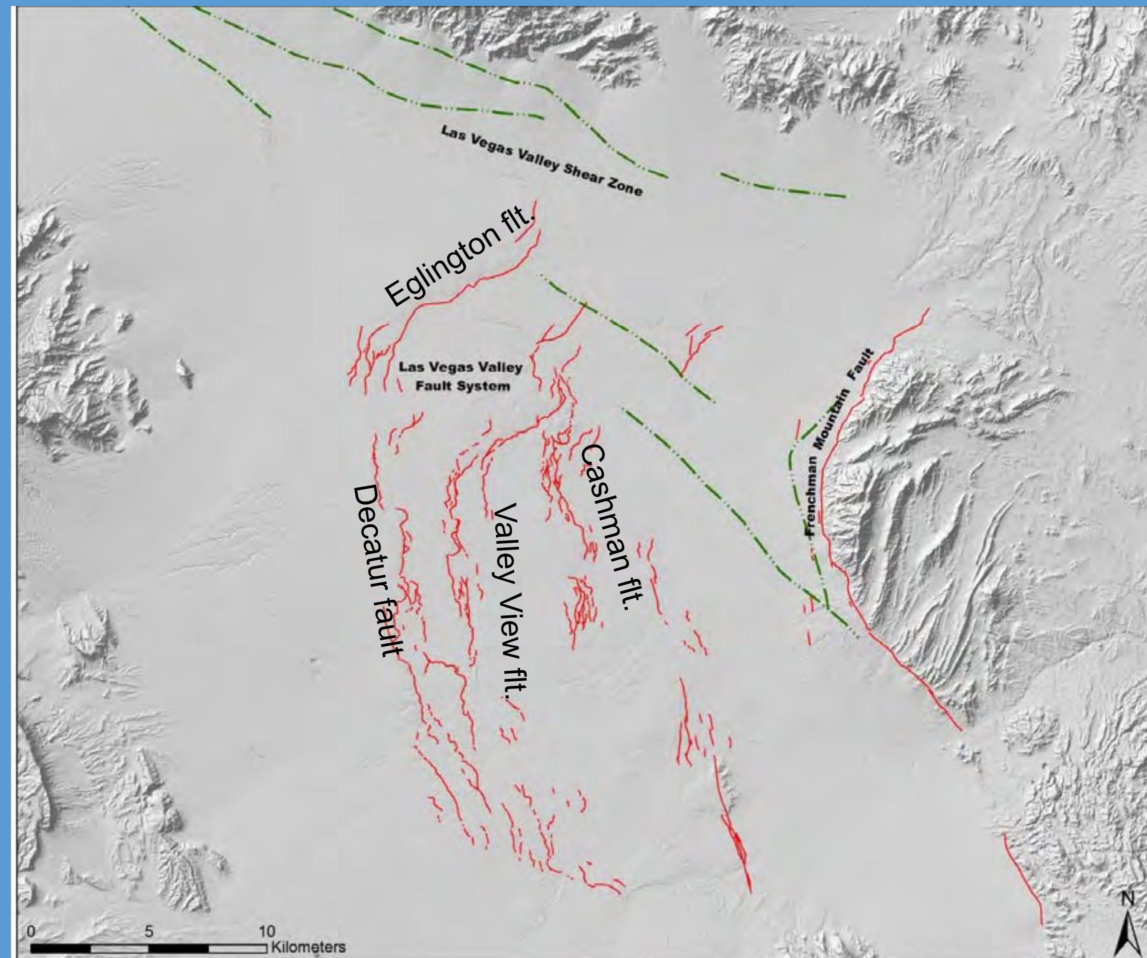
Challenging faults currently being investigated:

- Frenchman Mountain fault
- Eglington fault
- Las Vegas Valley fault system



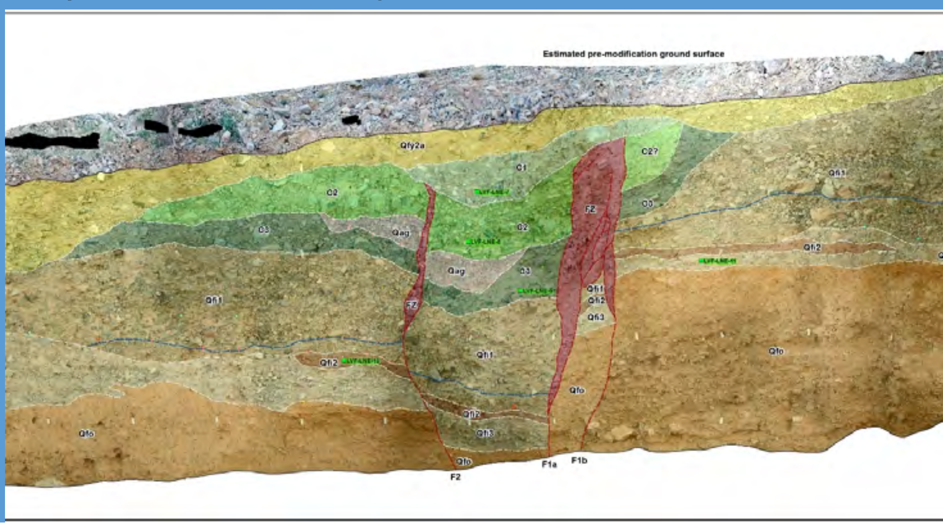

Eglington fault

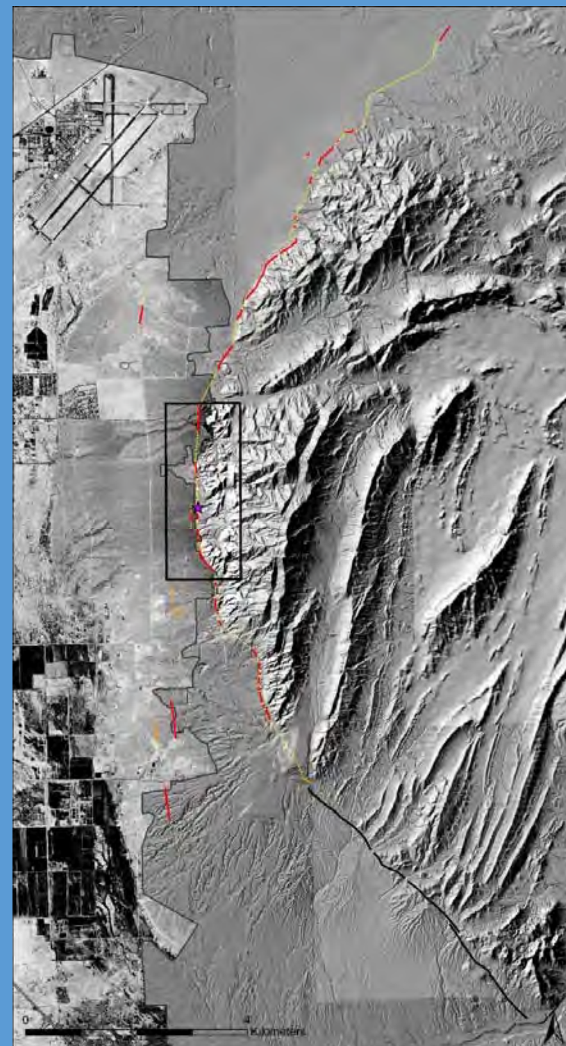

Hwy. 215
Proposed Trench
Locations
Legacy
High School
N
0
250
500
Meters


Las Vegas Valley Shear Zone
Eglington flt.
Las Vegas Valley
Fault System
Frenchman Mountain Fault
Cashman flt.
Decatur fault
Valley View flt.
0
5
10
Kilometers
N

Frenchman Mountain fault

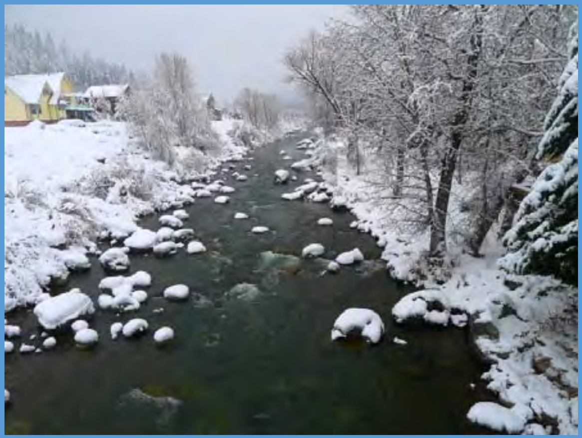
EQ3: 43.3 – 53.5 ka; EQ2 : 24.6 – 28.8 ka; MRE: ??
Slip rate: ~0.03 mm/yr





Rapid response to emergencies

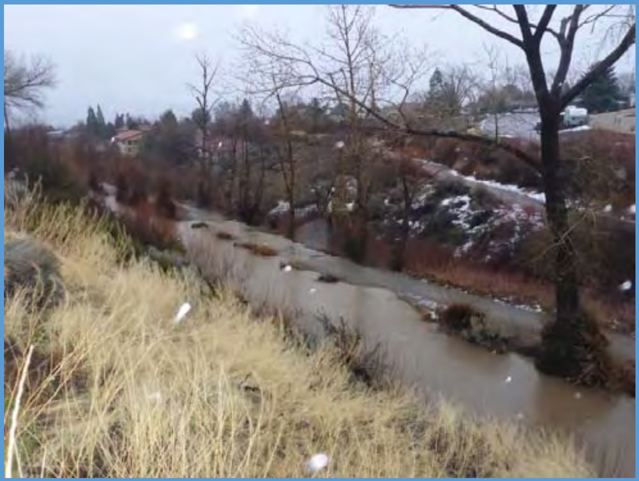
The night before



Morning of the flood

Rain on snow flood, January 2017

Communication of the location of damage and safety concerns to local officials, USGS, FEMA



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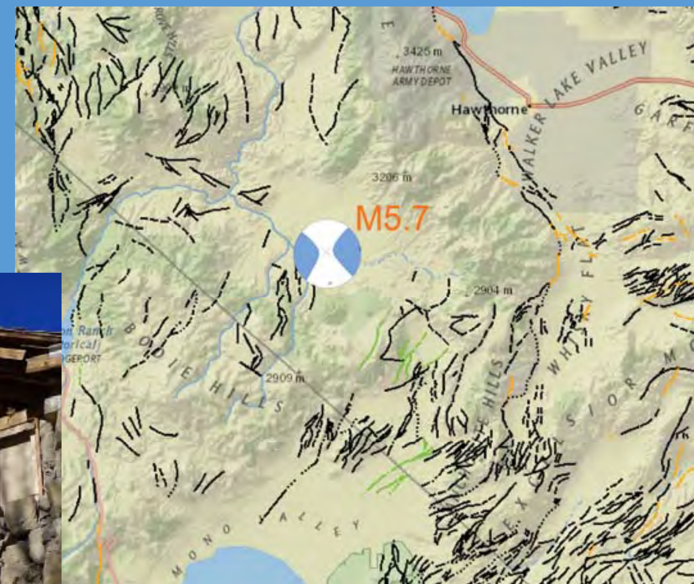
Rapid response to emergencies

Hawthorne earthquake, 2017

Nine-mile ranch



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Rapid response to emergencies

Hawthorne earthquake, 2017

Geologic effects include rock fall, sand blows, and lateral spread. No surface rupture.

Nevada Bureau of Mines and Geology
University of Nevada, Reno


Thanks!

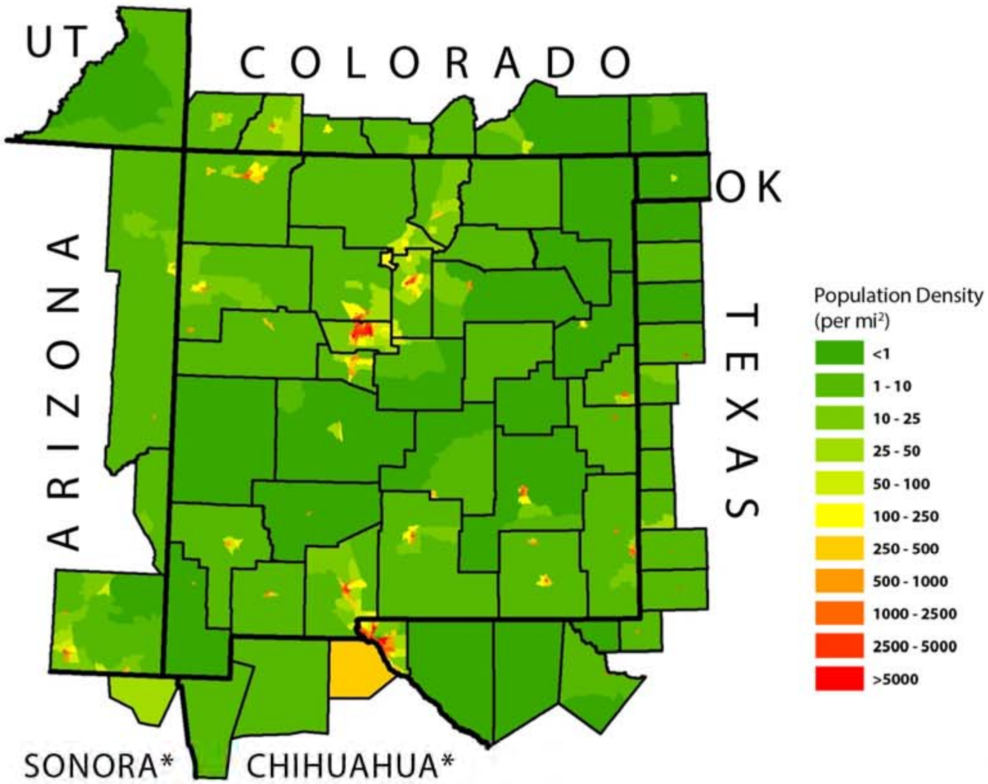
EARTHQUAKE HAZARDS IN NEW MEXICO

Cross-border fault issues and investigative priorities

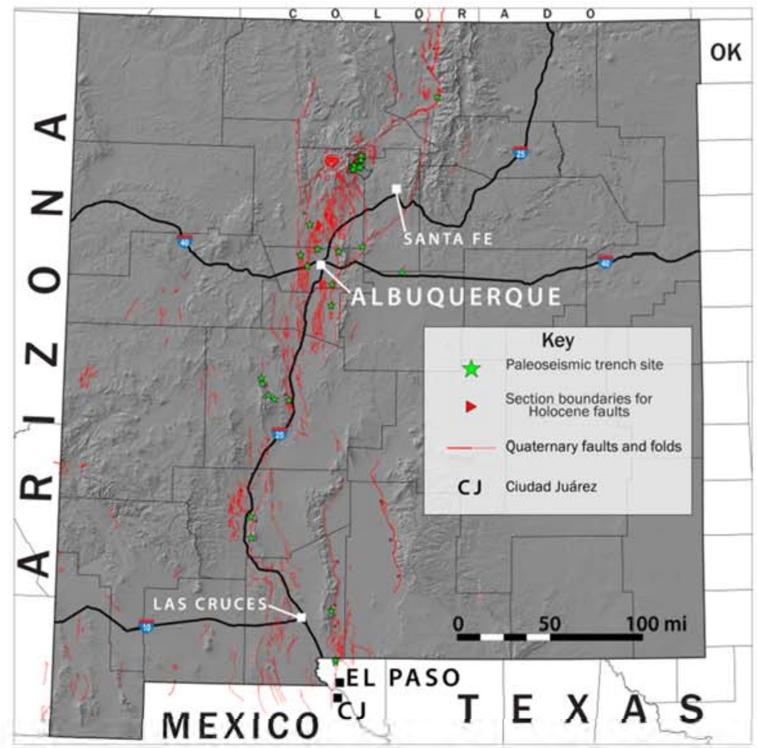
Andy Jochems, Dan Koning, and Dave Love

New Mexico Bureau of Geology & Mineral Resources
New Mexico Institute of Mining & Technology

Population density and Quaternary faults



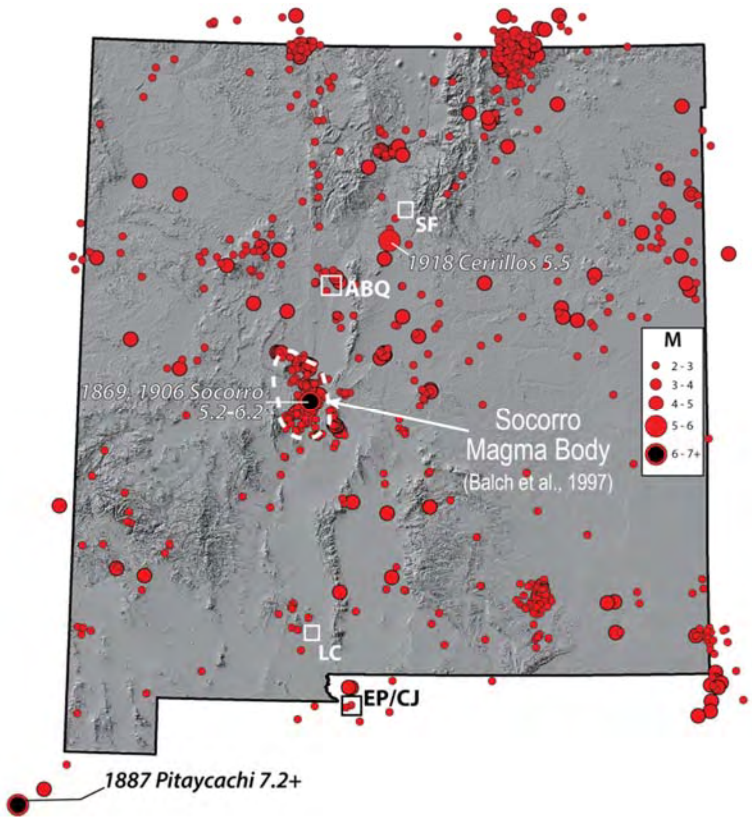
U.S. Census Bureau, 2010
Columbia Univ., 1999
*Mexico population data from 1990 census



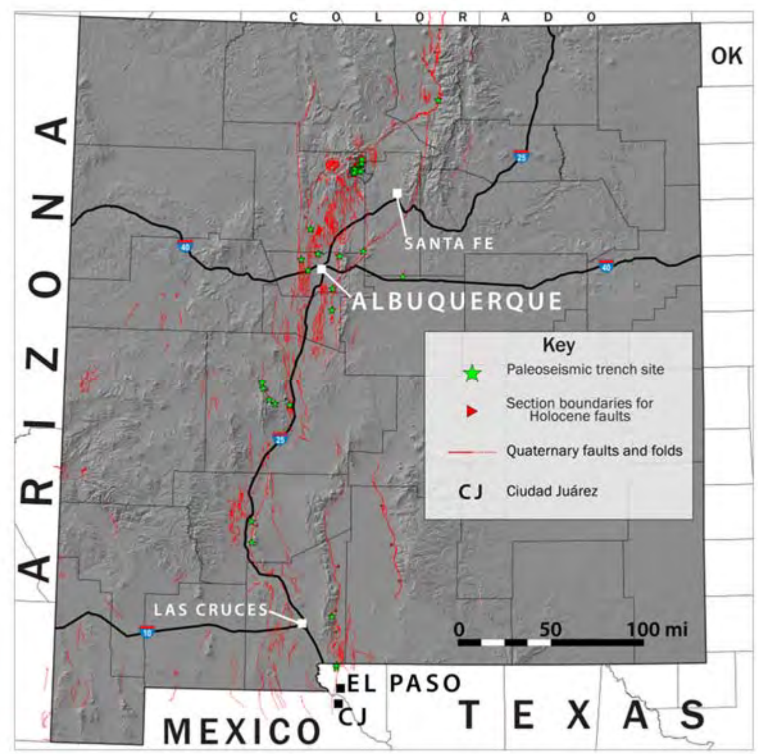
162 Quaternary faults (Class A+B)
- **19 Latest Quat. (<15 ka) faults**

35 trench sites (16 faults)

Historical seismicity in relation to faults



Instrumental record (1962-2009) + select older events
(Pearthree et al., 1990; Sanford et al., 2002; Pursley et al., 2013)

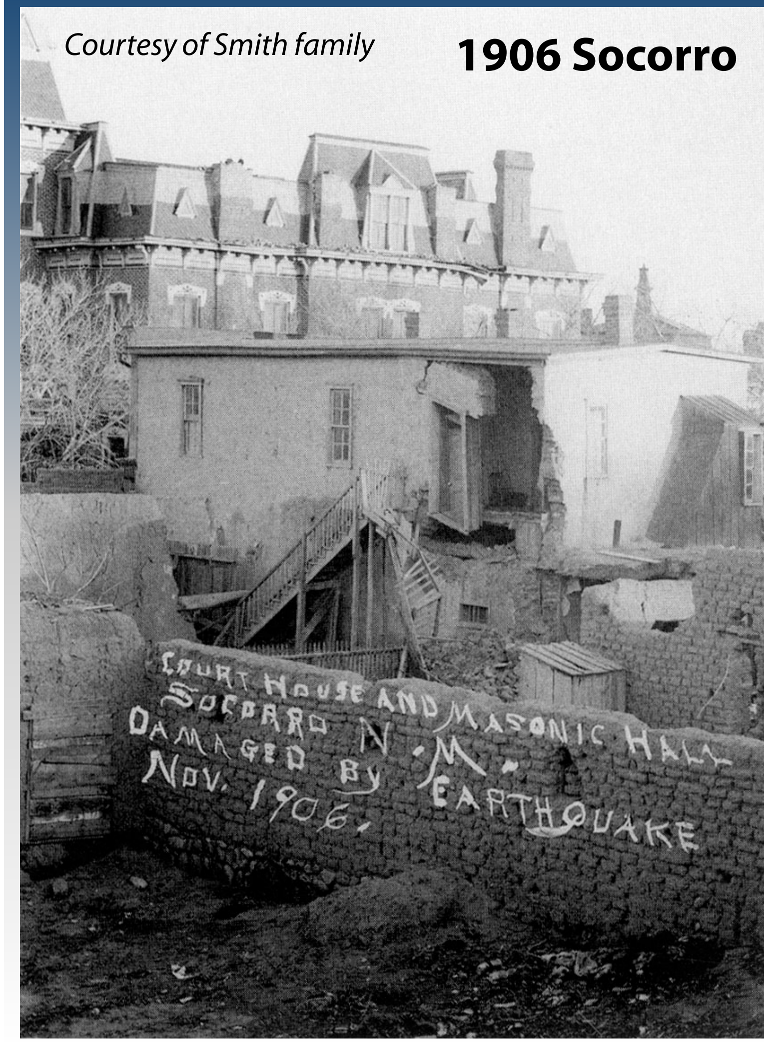


162 Quaternary faults (Class A+B)
- **19 Latest Quat. (<15 ka) faults**

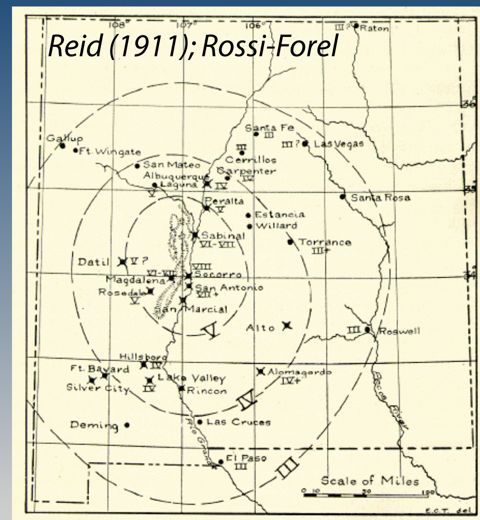
35 trench sites (16 faults)

Courtesy of Smith family

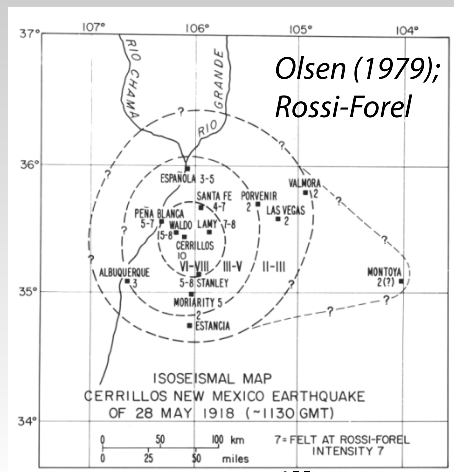
1906 Socorro



Reid (1911); Rossi-Forel

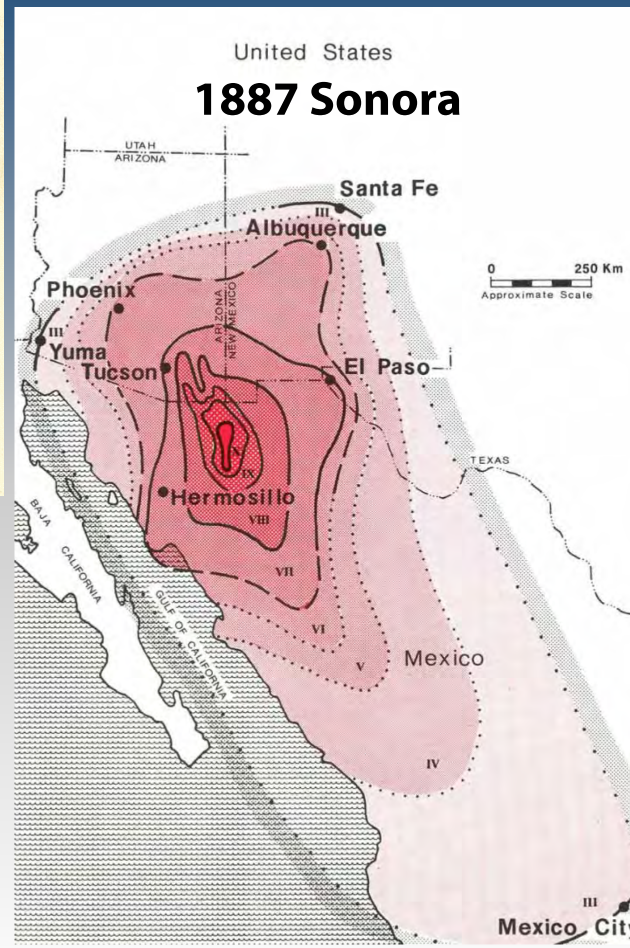


Olsen (1979); Rossi-Forel

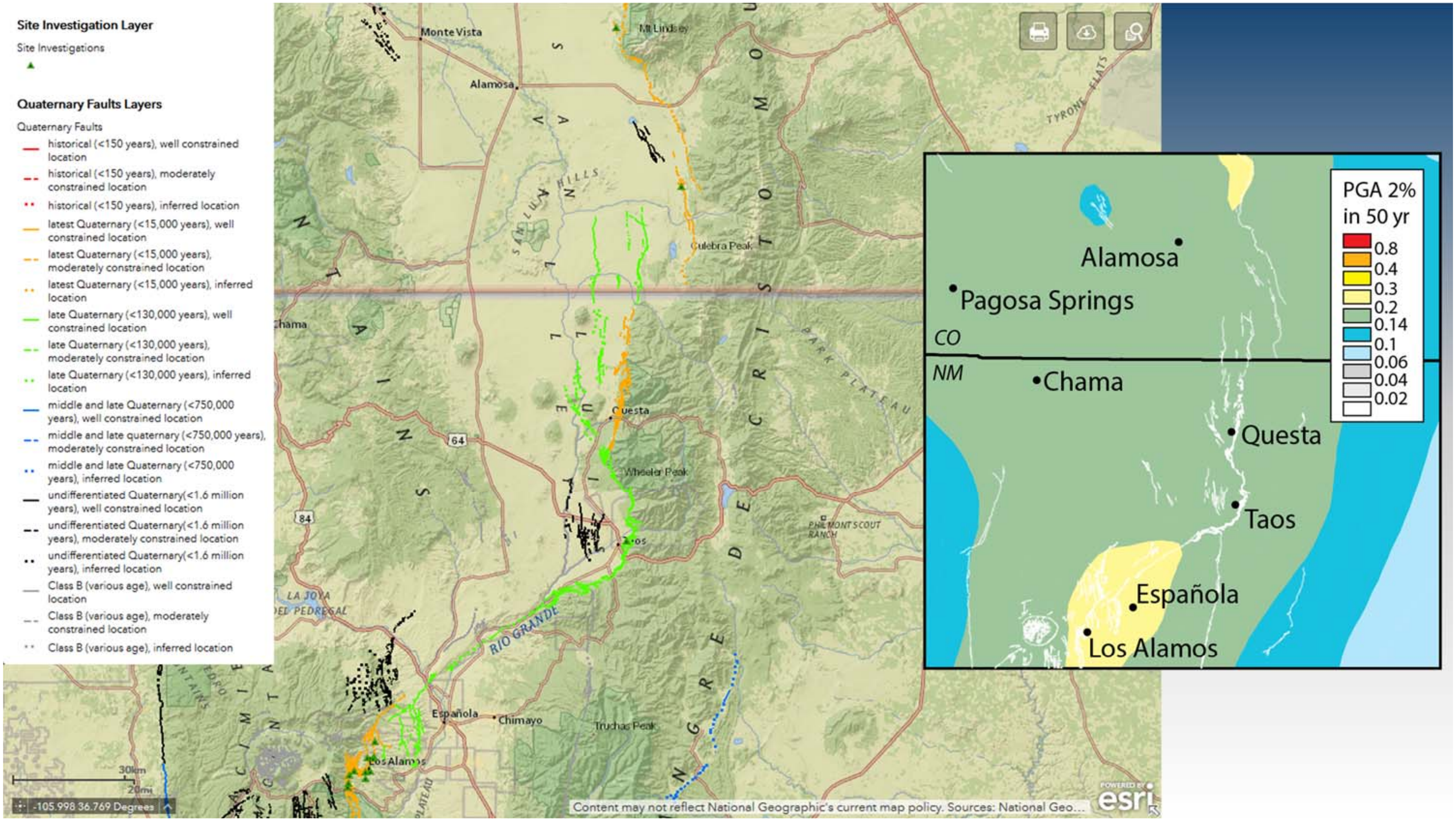


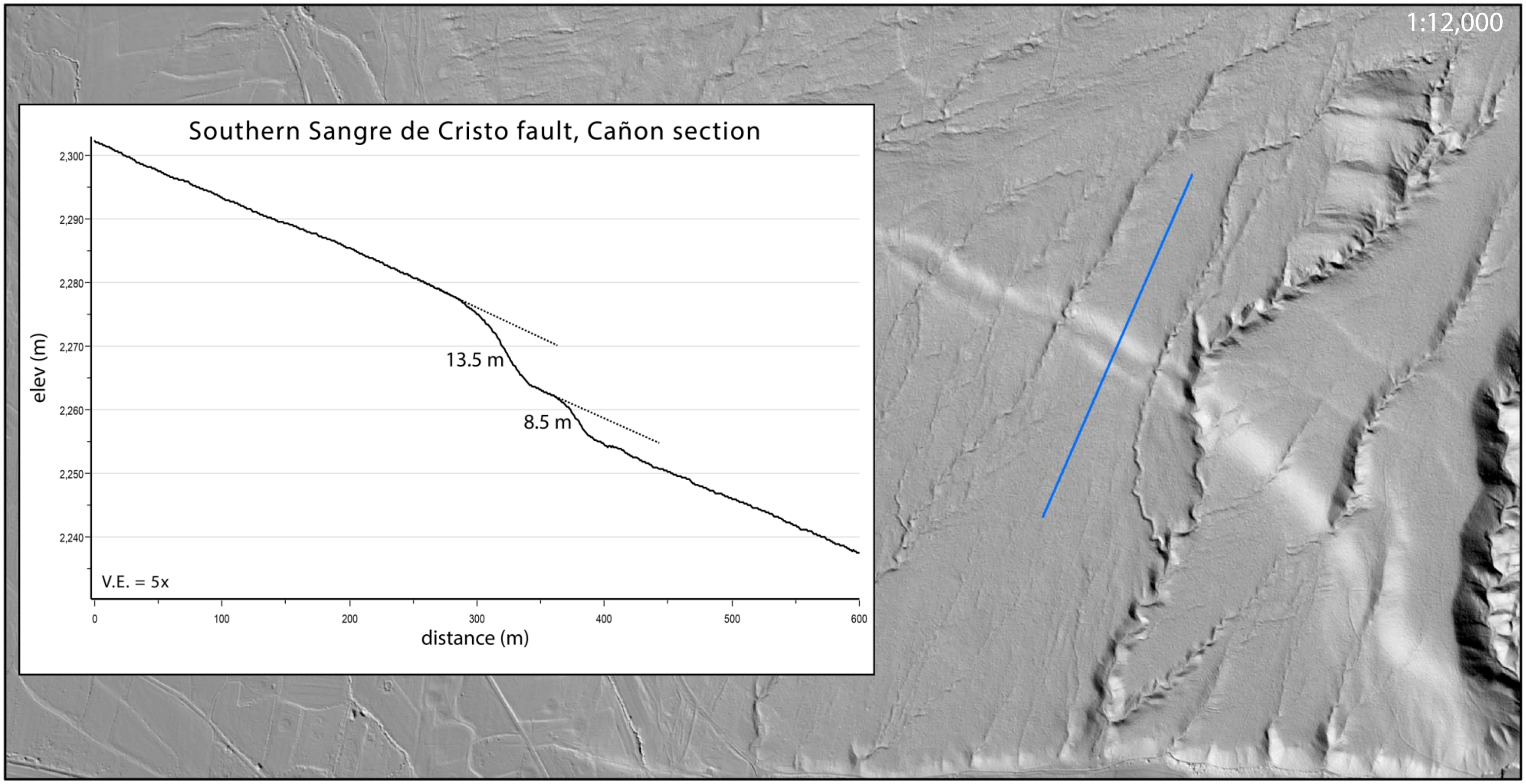
1918 Cerrillos

1887 Sonora

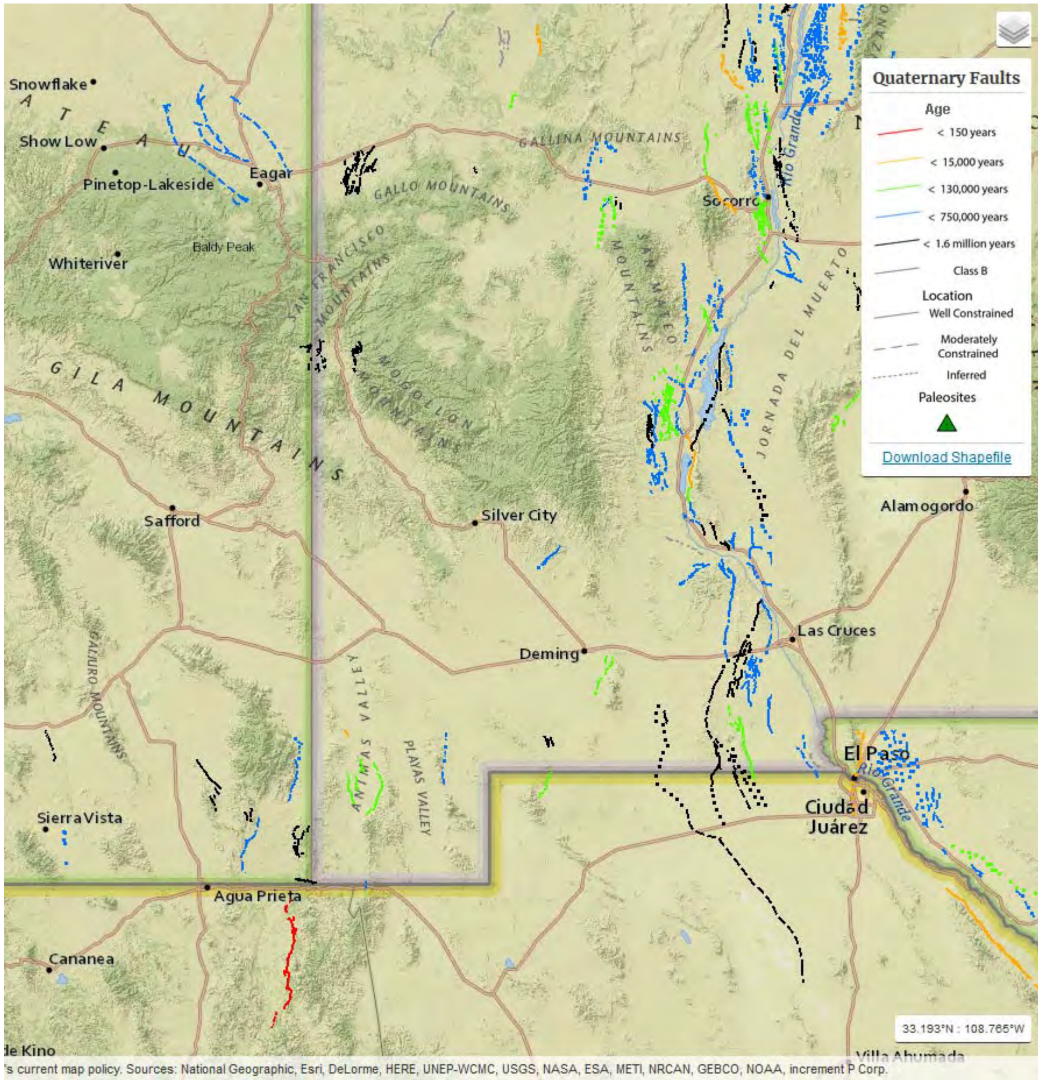


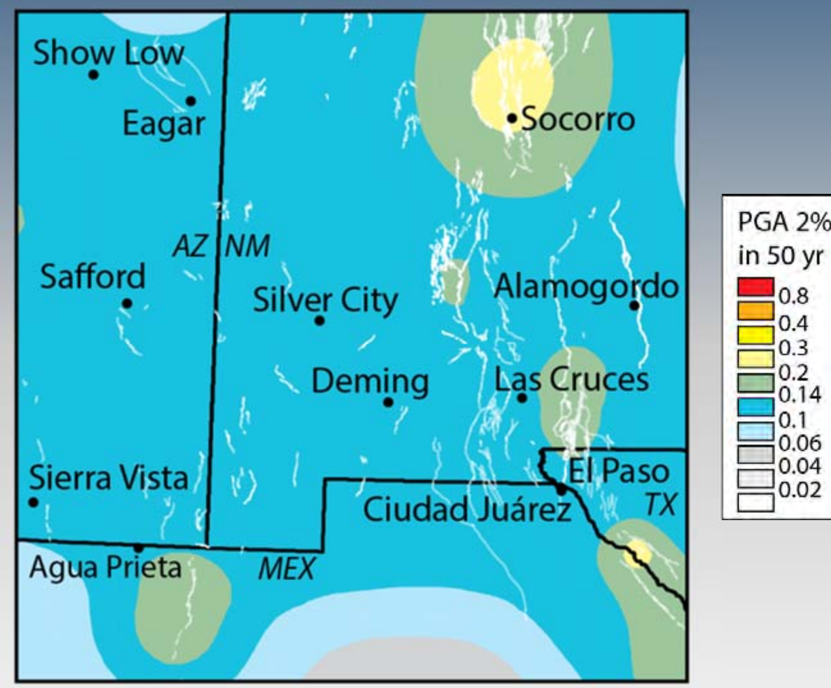
DuBois and Smith (1980); MMI

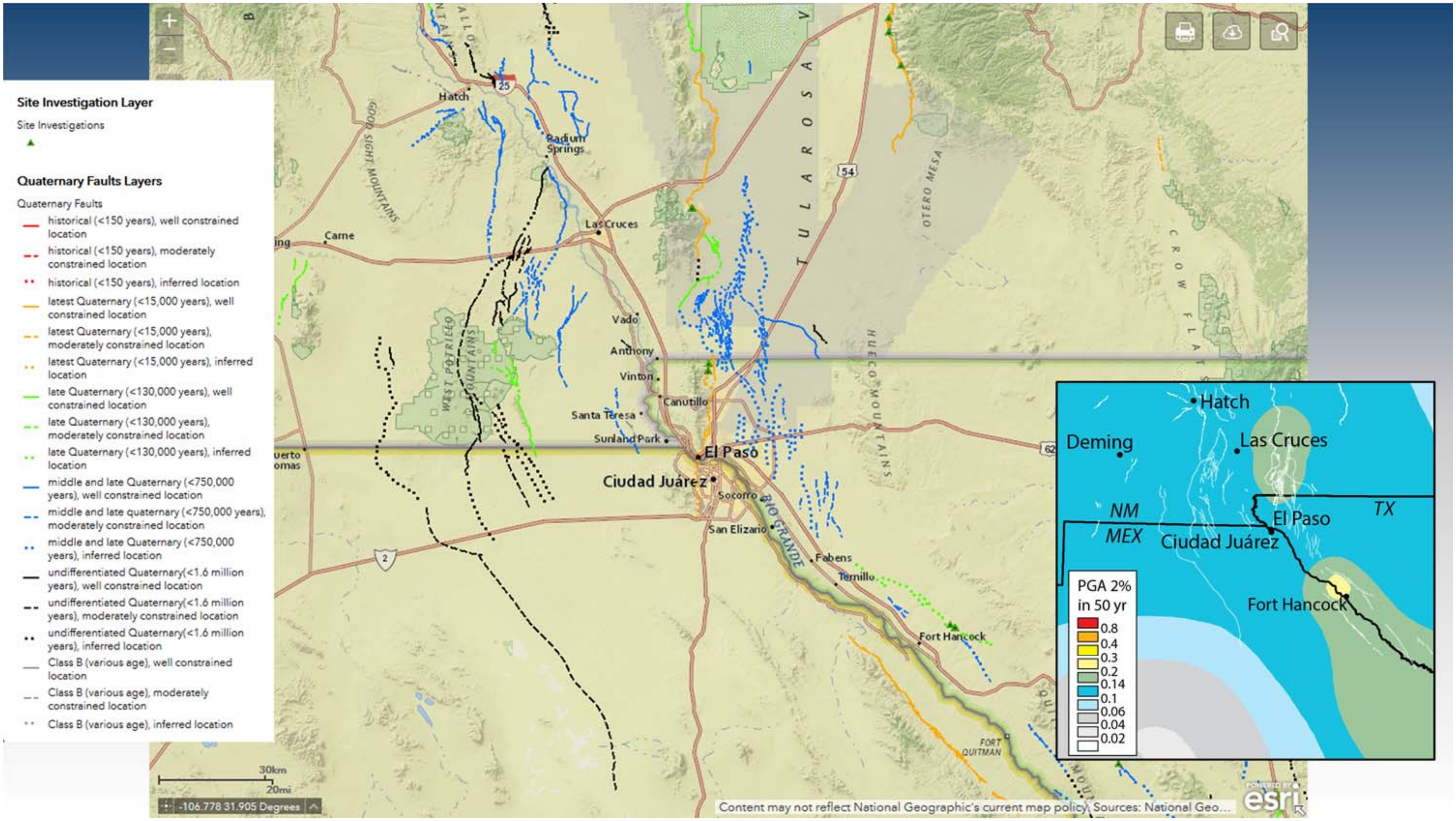

Site Investigation Layer
Site Investigations
Quaternary Faults Layers
Quaternary Faults
historical (<150 years), well constrained location
historical (<150 years), moderately constrained location
historical (<150 years), inferred location
latest Quaternary (<15,000 years), well constrained location
latest Quaternary (<15,000 years), moderately constrained location
latest Quaternary (<15,000 years), inferred location
late Quaternary (<130,000 years), well constrained location
late Quaternary (<130,000 years), moderately constrained location
late Quaternary (<130,000 years), inferred location
middle and late Quaternary (<750,000 years), well constrained location
middle and late quaternary (<750,000 years), moderately constrained location
middle and late Quaternary (<750,000 years), inferred location
undifferentiated Quaternary(<1.6 million years), well constrained location
undifferentiated Quaternary(<1.6 million years), moderately constrained location
undifferentiated Quaternary(<1.6 million years), inferred location
Class B (various age), well constrained location
Class B (various age), moderately constrained location
Class B (various age), inferred location
Monte Vista
Alamosa
Mt Lindsey
Culebra Peak
Chama
Questa
Wheeler Peak
Española
Chimayo
Los Alamos
Truchas Peak
RIO GRANDE
64
84
30km
20mi
-105.998 36.769 Degrees
Content may not reflect National Geographic's current map policy. Sources: National Geo...
esri
PGA 2% in 50 yr
0.8
0.4
0.3
0.2
0.14
0.1
0.06
0.04
0.02
Alamosa
Pagosa Springs
CO
NM
Chama
Questa
Taos
Española
Los Alamos



1:12,000
Southern Sangre de Cristo fault, Cañon section
elev (m)
2,300
2,290
2,280
2,270
2,260
2,250
2,240
13.5 m
8.5 m
V.E. = 5x
0
100
200
300
400
500
600
distance (m)


Snowflake
Show Low
Pinetop-Lakeside
Eagar
Baldy Peak
Whiteriver
GILA MOUNTAINS
GALLINA MOUNTAINS
GALLO MOUNTAINS
SAN FRANCISCO MOUNTAINS
MOGOLLON MOUNTAINS
SAN MATEO MOUNTAINS
JORNADA DEL MUERTO
Rio Grande
Socorro
Safford
Silver City
Alamogordo
Las Cruces
Deming
GALIURO MOUNTAINS
ANIMAS VALLEY
PLAYAS VALLEY
El Paso
Ciudad Juárez
Sierra Vista
Agua Prieta
Cananea
Quaternary Faults
Age
< 150 years
< 15,000 years
< 130,000 years
< 750,000 years
< 1.6 million years
Class B
Location
Well Constrained
Moderately Constrained
Inferred
Paleosites
Download Shapefile
33.193°N : 108.765°W
's current map policy. Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.


Show Low
Eagar
Socorro
AZ
NM
Safford
Silver City
Alamogordo
Deming
Las Cruces
Sierra Vista
El Paso
Ciudad Juárez
TX
Agua Prieta
MEX
PGA 2% in 50 yr
0.8
0.4
0.3
0.2
0.14
0.1
0.06
0.04
0.02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undifferentiated Quaternary(<1.6 million years), well constrained location
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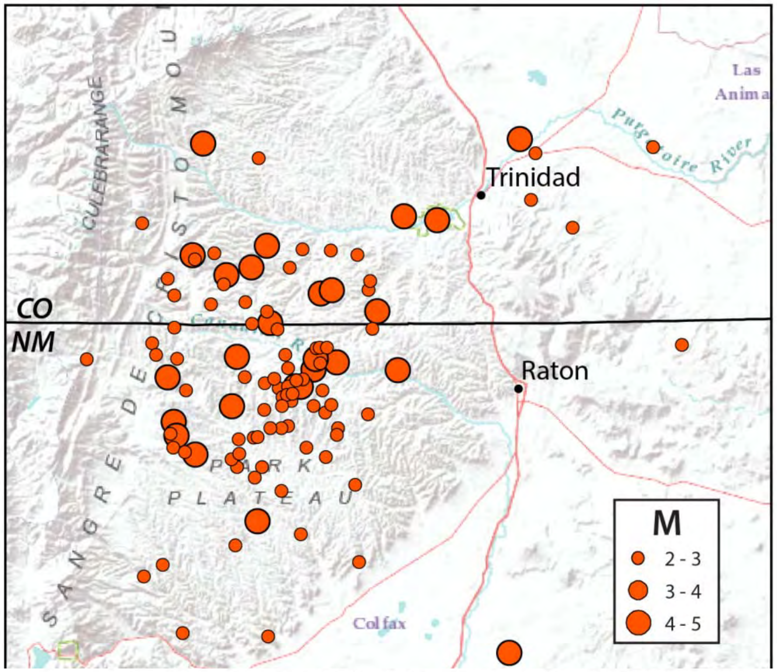
Class B (various age), well constrained location
Class B (various age), moderately constrained location
Class B (various age), inferred location
Hatch
Radium Springs
Las Cruces
Carne
Vado
Anthony
Vinton
Canutillo
Santa Teresa
Sunland Park
El Paso
Ciudad Juárez
Socorro
San Elizario
Fabens
Tornillo
Fort Hancock
TULAROSA
OTERO MESA
HUECO MOUNTAINS
WEST POTRILLO MOUNTAINS
GOOD SIGHT MOUNTAINS
CROW FLATS
RIO GRANDE
FORT QUITMAN
30km
20mi
-106.778 31.905 Degrees
Content may not reflect National Geographic's current map policy. Sources: National Geo...
esri
Hatch
Deming
Las Cruces
NM
MEX
TX
El Paso
Ciudad Juárez
Fort Hancock
PGA 2% in 50 yr
0.8
0.4
0.3
0.2
0.14
0.1
0.06
0.04
0.02

Fault or fault zone	Length (km)	Most recent rupture	Recurrence interval	Slip rate (mm/yr)	Refs
Arizona-New Mexico					
Alma Mesa	15	Early Pleist (?)	?	≤ 0.02	Houser et al. (1994) Menges & Pearthree (1983)
Guadalupe Canyon	5	Early Pleist (?)	?	≤ 0.02	Machette et al. (1986) Menges & Pearthree (1983)
Rimrock	10	Late Pleist	?	≤ 0.025	Machette et al. (1986)
Colorado-New Mexico					
Mesita	29	15-25 ka	?	≤ 0.1	Personius & Machette (1984) Thompson & Machette (1989)
Southern Sangre de Cristo *(San Pedro Mesa sect.)*	24	Late Pleist	?	0.075-0.1	Ruleman & Machette (2007) Thompson & Machette (1989)
Texas-New Mexico					
East Franklin Mountains	45	8-17 ka	9-22 kyr	0.1-0.3	Keaton & Barnes (1996) McCalpin (2006)
Hueco	116	Mid Pleist	?	≤ 0.05	Collins & Raney (1991, 1997)

Fault or fault zone	Length (km)	Most recent rupture	Recurrence interval	Slip rate (mm/yr)	Refs
Mexico-New Mexico					
Camel Mountain	47	Mid-Late Pleist (?)	?	≤ 0.04	Reeves (1969) Seager (1995)
East Potrillo	31	Late Pleist	?	≤ 0.1	Cervera (2006) Seager & Mack (1994)
Lang Canyon	1	Mid Pleist	?	≤ 0.01	Vincent & Krider (1997)
Mastodon	14	Mid Pleist	?	≤ 0.01	Hawley & Lozinsky (1992)
Mount Riley	37	Early-Mid Pleist (?)	?	<< 0.2	Seager (1995) Seager & Mack (1994)
Sierra Palomas	14	Mid Pleist (?)	?	≤ 0.01	Seager (1995) Seager & Clemons (1988)
West Robledo	103	Early-Mid Pleist (?)	?	≤ 0.01	Seager (1995) Seager et al. (1987)

Induced seismicity in NM

Raton Basin

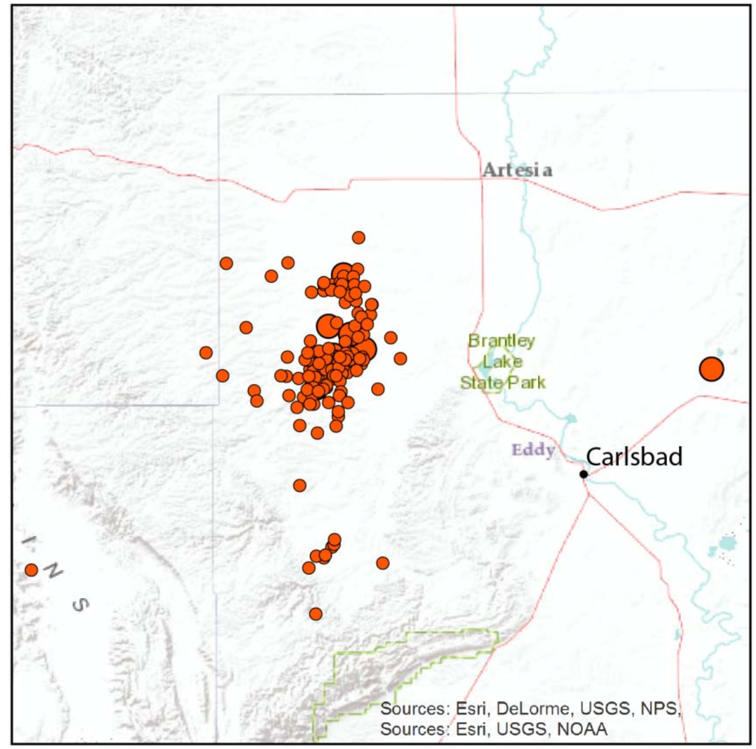


Bulletin of the Seismological Society of America, Vol. 104, No. 5, pp. –, October 2014, doi: 10.1785/0120140009

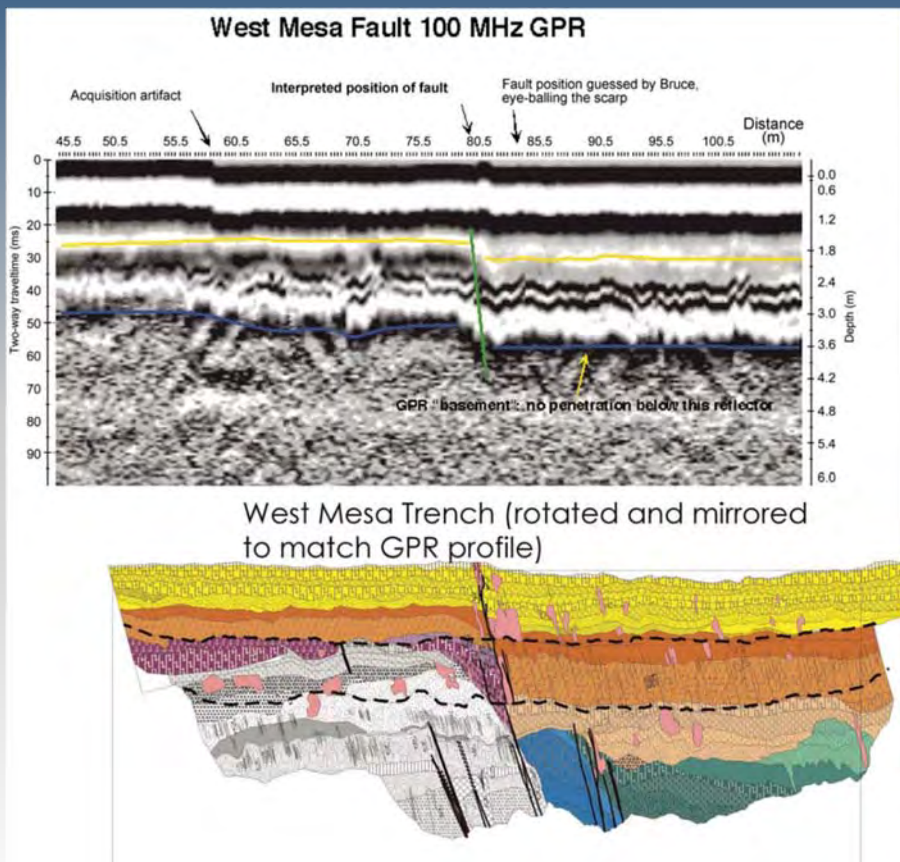
The 2001–Present Induced Earthquake Sequence in the Raton Basin of Northern New Mexico and Southern Colorado

by Justin L. Rubinstein, William L. Ellsworth, Arthur McGarr, and Harley M. Benz

Dagger Draw



Recent paleoseismic studies



<u>Calabacillas Fault, Albuquerque Basin</u>

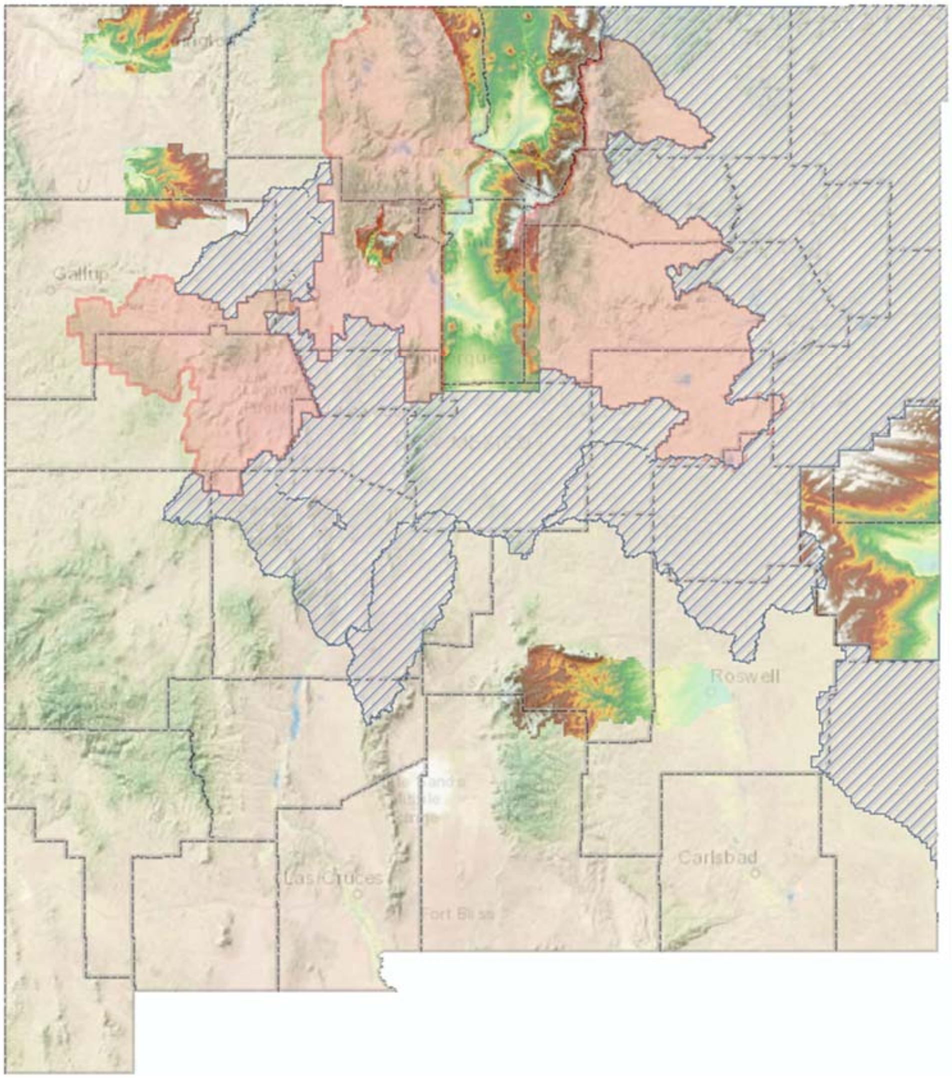
McCalpin et al. (2011)–GSA Special Paper 479

- 34 km long
- MRE ~14 ka
- RI 9-20 kyr
- Potential for GPR to locate faults buried by Holocene sediment

Recent paleoseismic studies

• In 2016, two paleoseismic trenches were excavated across an antithetic fault of the Pajarito fault system (PFS). The Pajarito fault system serves as the master fault for a Rio Grande rift basin called the Espanola Basin. The fault lies directly adjacent to the Los Alamos National Laboratories (LANL).

- LANL has commissioned a multi-year paleoseismic investigation of the Pajarito fault system
- LANL PFS project team includes Emily Schultz-Fellenz (LANL PM), Rick Kelley, Richard Lee, and Giday WoldeGabriel among others.
- The paleoseismic effort is spear-headed by Lettis Consultants International, Inc. (LCI) – LCI's includes a notable group of paleoseismologists working with the LANL PFS Team spearheaded by Robert Givler.
- The 2016 trenches exposed middle to late Pleistocene to mid-Holocene deposits.
- Geochronology (OSL and paleomagnetic samples), coupled with pedogenic analysis, indicates limited Holocene deposition, consistent with local geologic mapping.
- Based on the trench exposures and initial age-dating information, the PFS Team preliminarily interprets several Pleistocene events as well as a single Holocene event on the antithetic fault zone of the PFS. In 2018, the project team plans to excavate additional paleoseismic trenches at separate locations along the PFS.



LiDAR Acquisition

- Shaded relief: flown, available
- Red shade: flown, available spring 2018
- Hachured: to-be-flown, available spring 2019 (FEMA, MRCoG, NRCS, USFS)

>50% of state will have LiDAR coverage by 2020 (mostly QL2)

rgis.unm.edu

New Mexico fault priorities

Ranking (previous)	Fault or fault zones*	Most Recent Rupture	Slip rate (mm/yr)	Estimated Affected Population (min)
1 (2)	Rincon	(Mid?) Holo	<0.4	~1 million
2 (2)	Other Albuquerque-area faults *(incl. Hubbell Spring system)*	Mid Pleist-Holocene	<0.2 - 1	~1 million
3 (nr)	Mesilla Basin	Late Pleist	<0.2	100-150k
4 (nr)	San Andres Mountains (southern section)	5-15 ka?	<0.2	100-150k
5 (nr)	Alamogordo (Three Rivers section)	Holocene?	<0.2	50-150k
Other priorities	(a) Pursue funding (b) Refine mapping using new LiDAR datasets (c) Update seismic array			

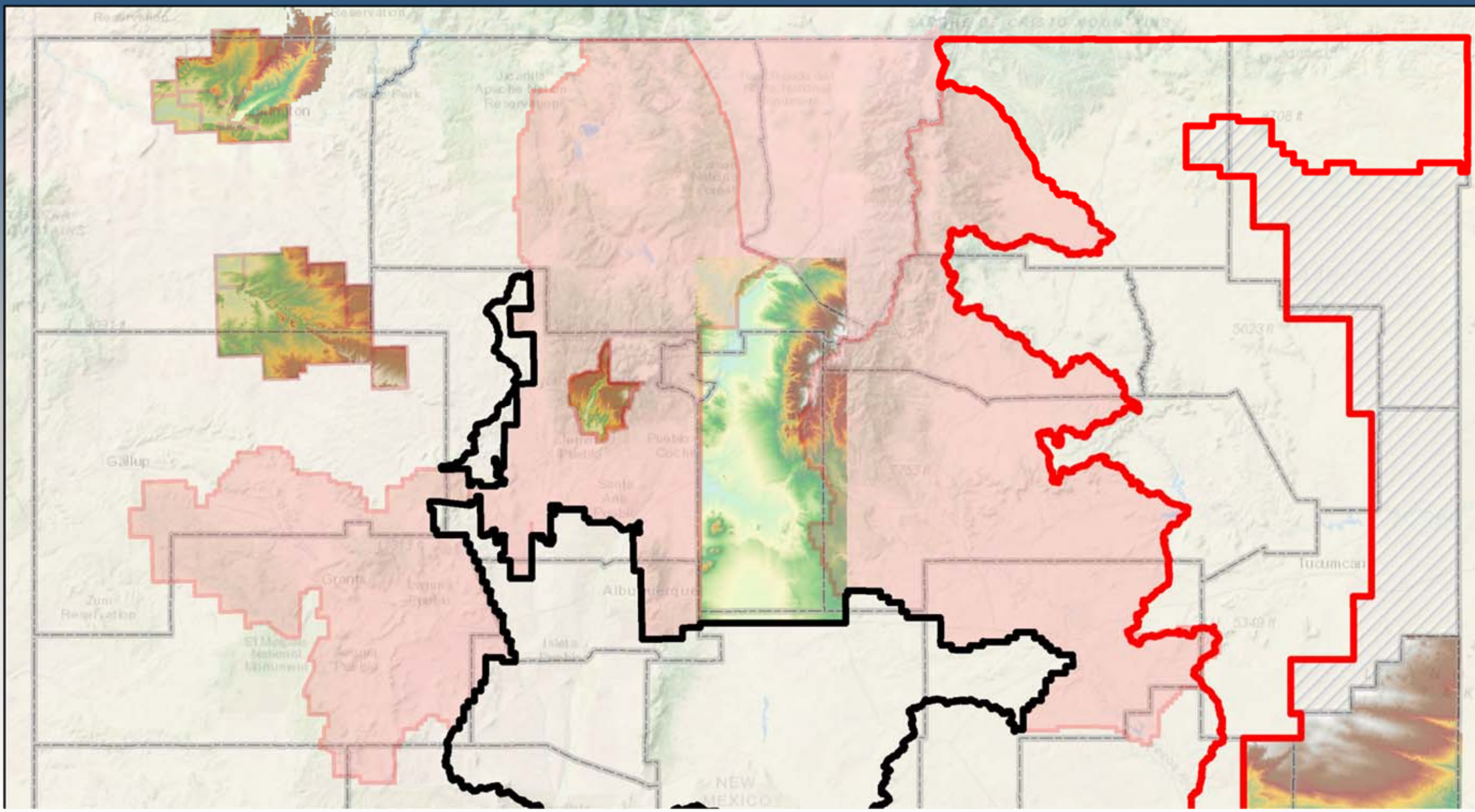
*In addition to proximity to population corridors, all faults are near military and/or national lab facilities.

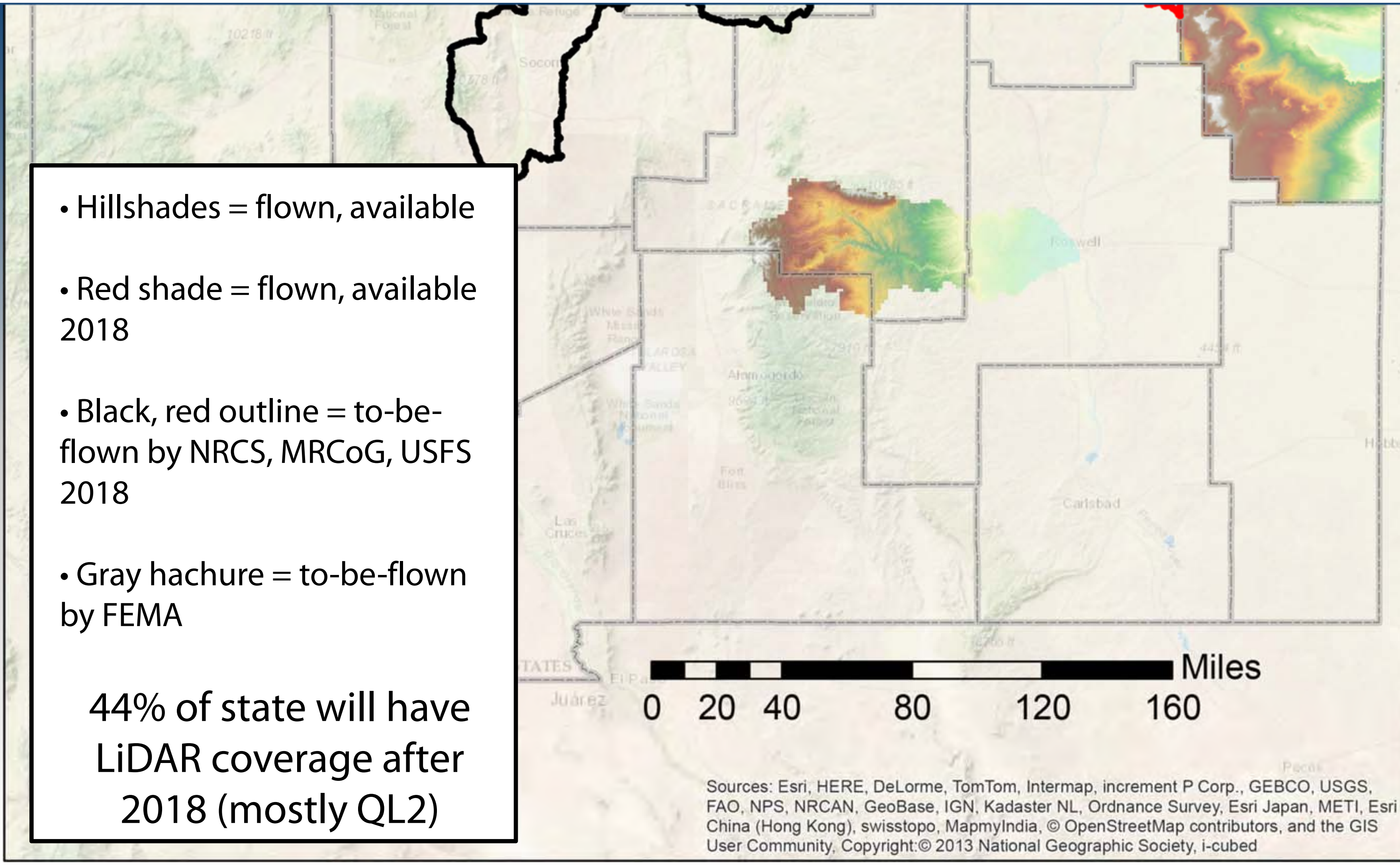
Issues and challenges

- Personnel / expertise
- Land access
- $$$
- Public awareness

Thank You—Questions?

Andy Jochems
NM Bureau of Geology & Mineral Resources
(575) 835-6213
Andy.Jochems@nmt.edu


Gallup
Grants
Tucumcari
NEW
MEXICO



- Hillshades = flown, available
- Red shade = flown, available 2018
- Black, red outline = to-be-flown by NRCS, MRCoG, USFS 2018
- Gray hachure = to-be-flown by FEMA

44% of state will have LiDAR coverage after 2018 (mostly QL2)

Earthquake Hazards Lessons From DOGAMI

Bill Burns, Ian Madin, and Jason McClaughry

Oregon Department of Geology and Mineral Industries

OUTLINE

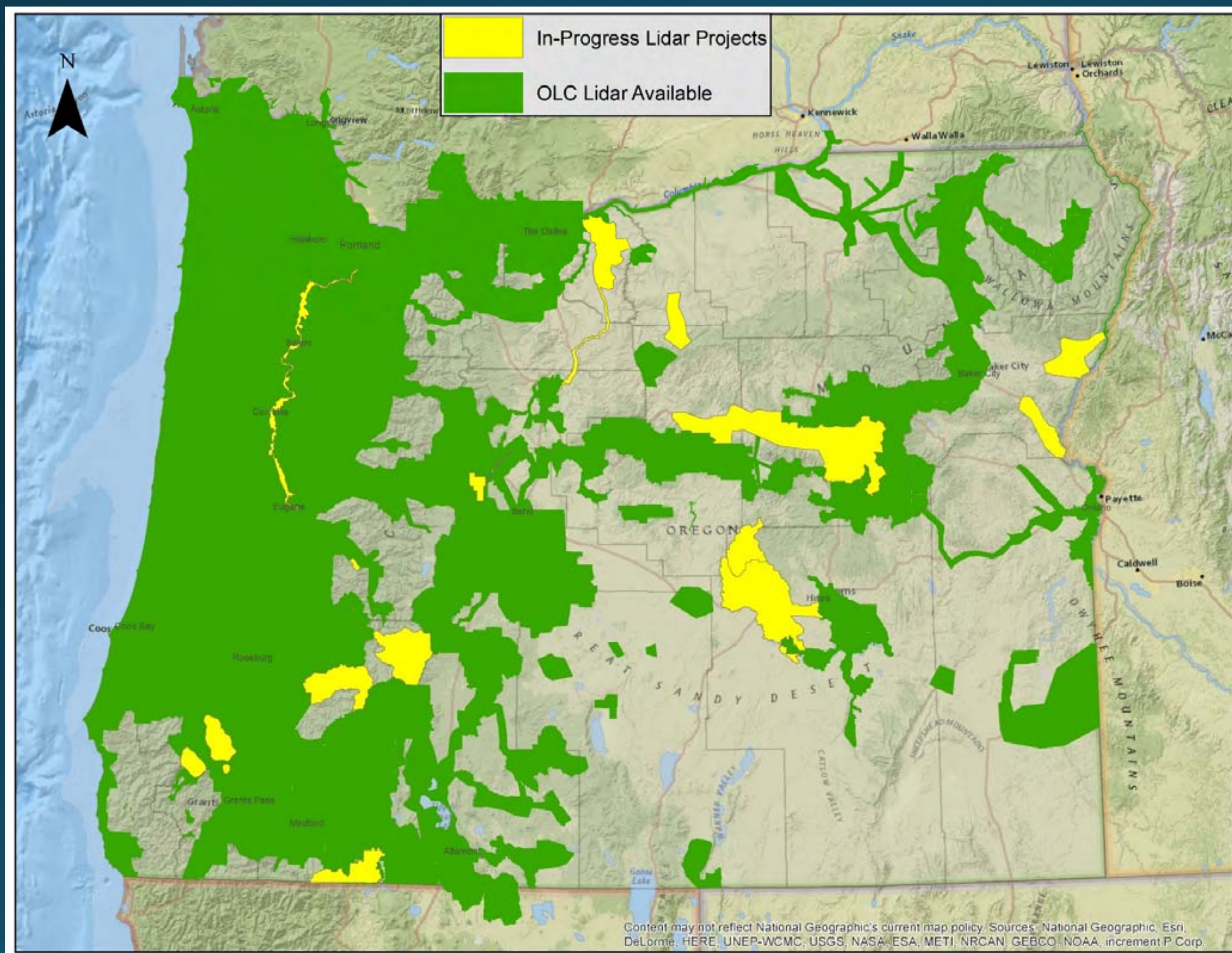
1) Use lidar to map young fault features

2) No lidar? Use regional/air photo structure from motion (SFM)

3) Coseismic landslides

4) EQ Damage and loss analysis

1) Young Faults Using Lidar – Lidar Coverage



OLC lidar project areas are defined by the shared interest of Consortium funding partners.

Virtually none of the data were collected primarily to support geologic research or to target young faulting.

Ian Madin, GSA 2017 Session 210-11, 10/24/17

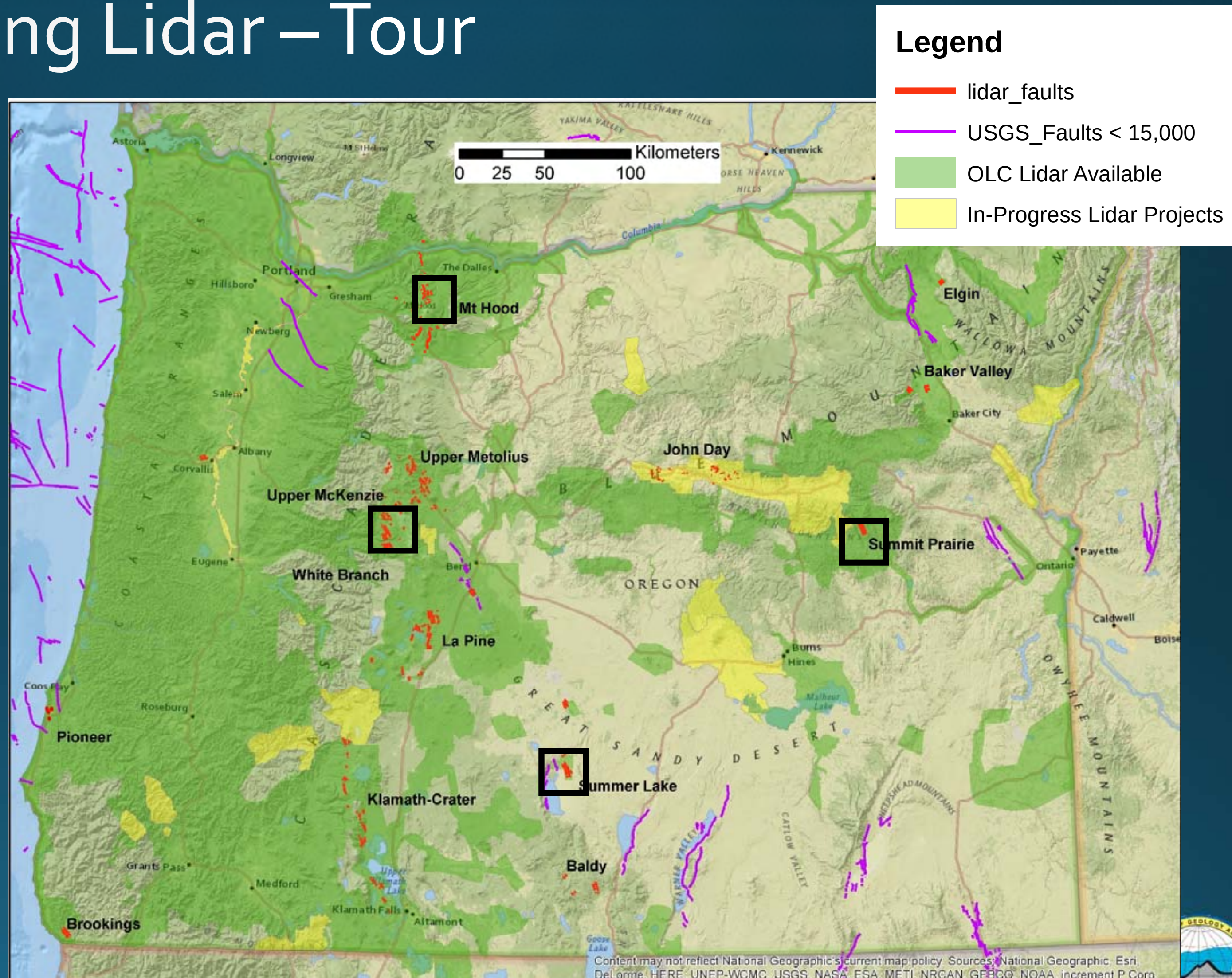
Bill Burns, 2018

1) Young Faults Using Lidar – Tour

This map shows all of the young fault features mapped to date during review of OLC lidar data. In virtually all cases, previous studies had not identified young fault features in these areas.

We mapped scarps that cut young surficial materials, or that had a sharp appearance in bedrock or older surficial materials. The majority of the areas have been visited briefly in the field to confirm the presence of young faulting.

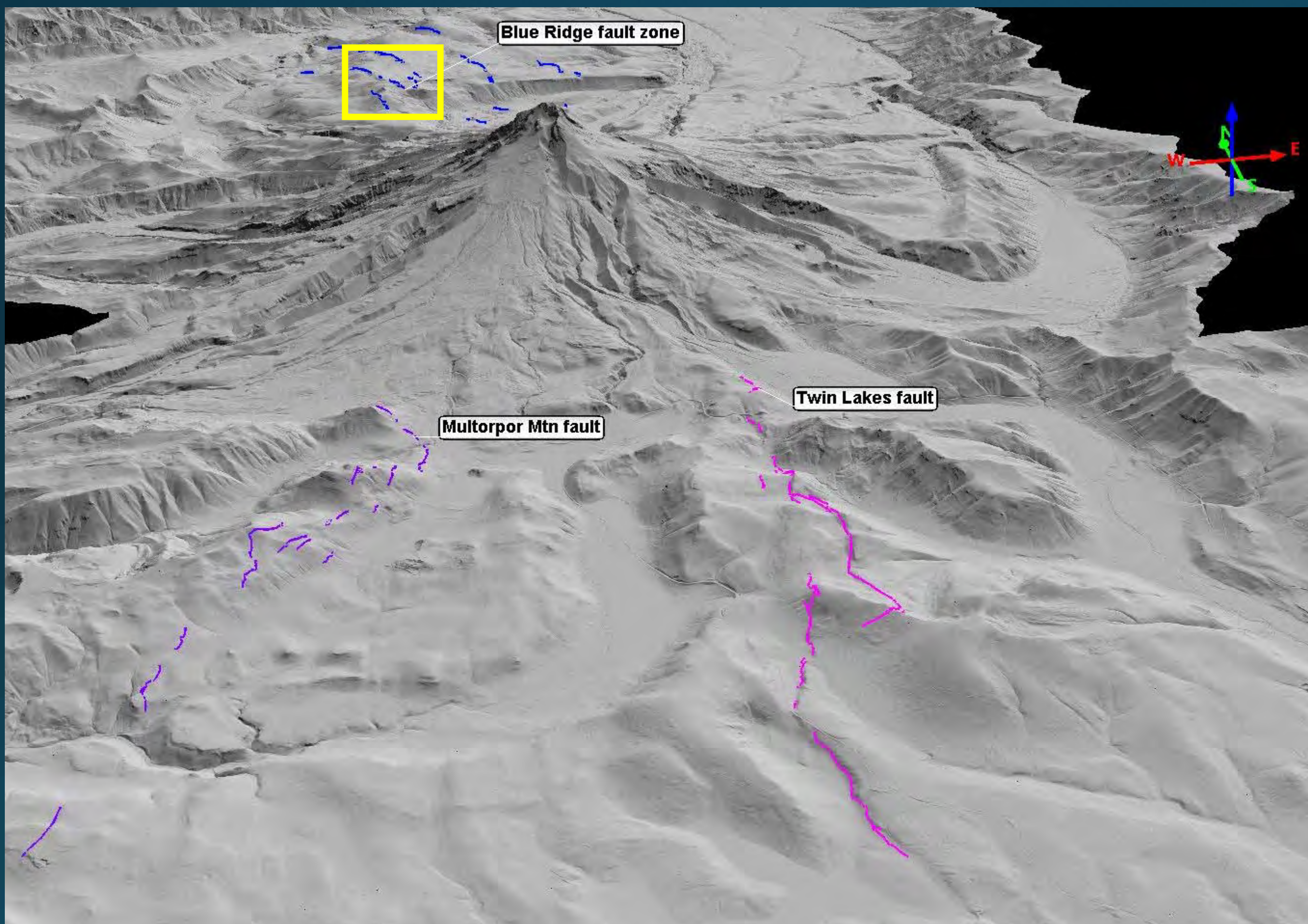
The lidar also covers several faults listed in the USGS database as < 15ka in age, but none of those shows any evidence for recent faulting.



Ian Madin, GSA 2017 Session 210-11, 10/24/17

Bill Burns, 2018

1) Young Faults Using Lidar – Mt Hood Fault Zone



Multorpor Mountain Fault

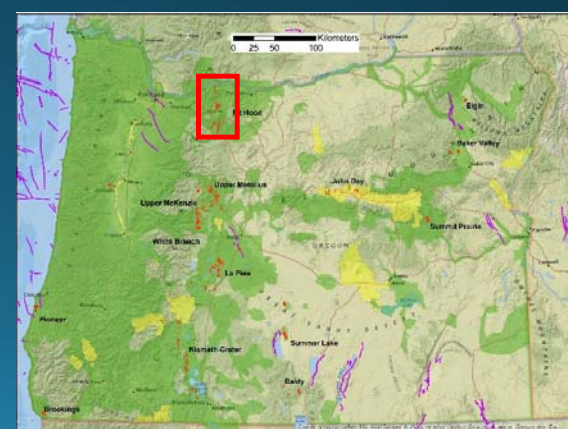
•Scarps extend 12 km and offset 20 ka glacial deposits 8-9 m. Defines a graben with the Twin Lakes Fault.

Twin Lakes Fault

• Extends 17 km with scarps 1-2 m high in post glacial colluvium

Blue Ridge Fault

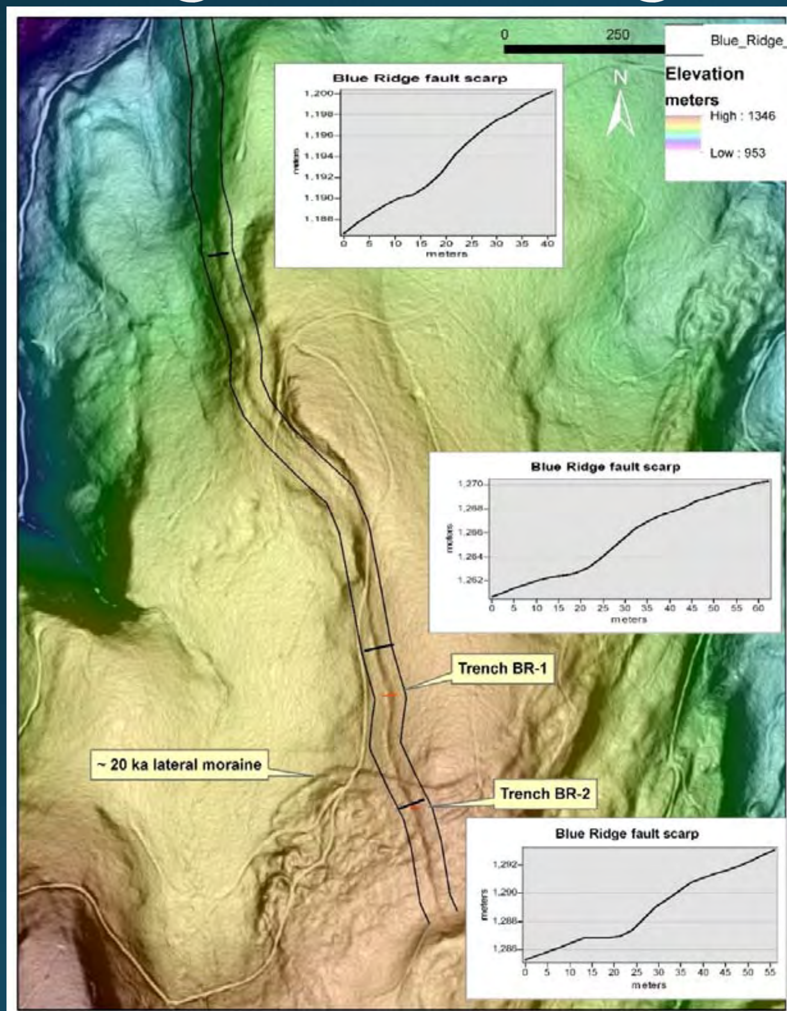
- Extends over 12 km in steep glaciated terrain with scarps 1-2 m high in glacial deposits.



Ian Madin, GSA 2017 Session 210-11, 10/24/17

Bill Burns, 2018

1) Young Faults Using Lidar – Blue Ridge Trench



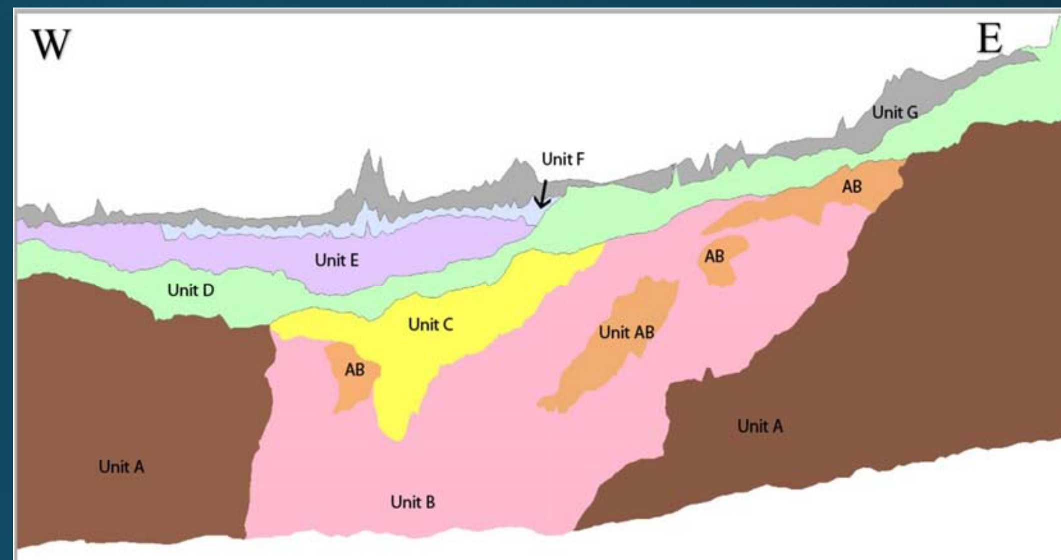


Table 1. Accelerator mass spectroscopy radiocarbon age data for samples from trench BR-1 (figs. 3, 4).

[All ages in years before present. Analyses by Beta Analytic]

Sample	Unit	Conventional radiocarbon age	2σ calibrated age
BR1_10/3-8	F	1,330 ± 30	1,300–1,240
			1,200–1,180
BR1_10/3-9	E	2,050 ± 30	2,040–2,020
			2,010–1,920
			1,920–1,900
BR1_10/3-2	D	8,830 ± 40	10,160–9,980
			9,970–9,700
BR1_MC-4	C	11,640 ± 50	13,600–13,380
BR1_MC-8	C	11,670 ± 50	13,640–13,400
BR1_MC-9	C	11,720 ± 50	13,710–13,430

Blue Ridge fault trench shows single event with 1.8 m of slip at about 13.5 ka

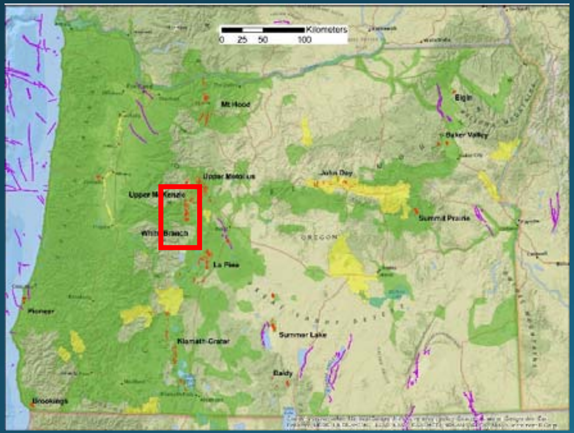
Ian Madin, GSA 2017 Session 210-11, 10/24/17

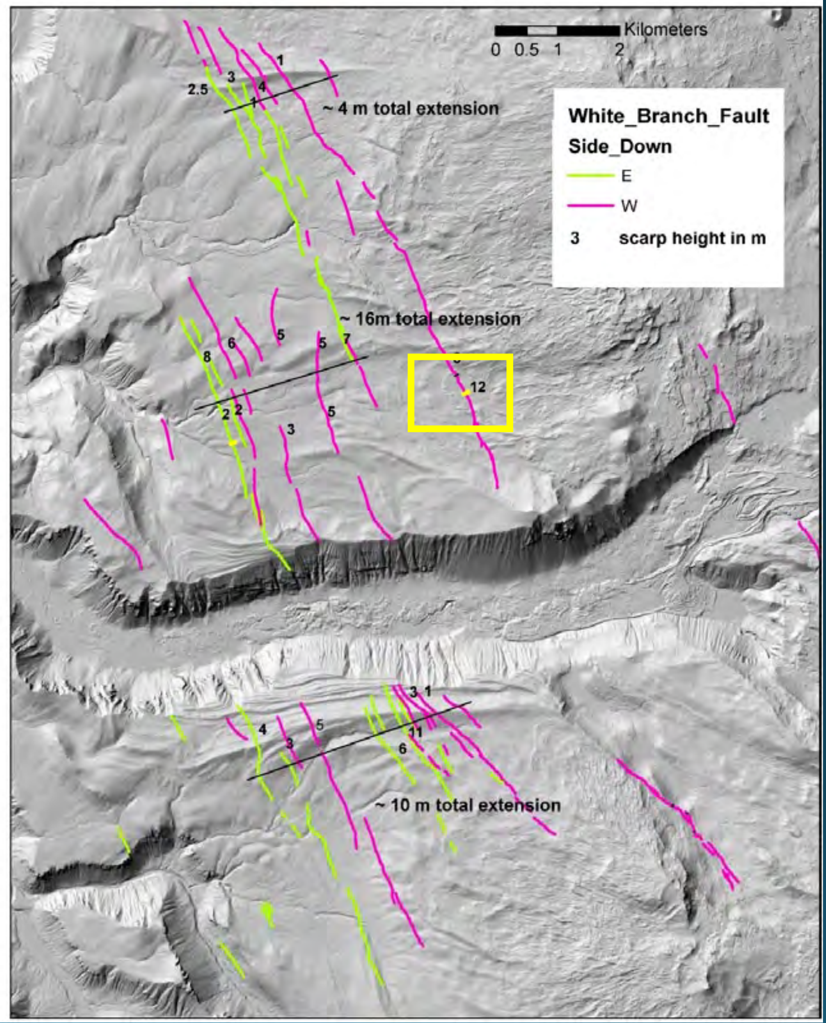
Bill Burns, 2018

1) Young Faults Using Lidar – White Branch Fault Zone

The White Branch fault zone consists of dozens of scarps which range up to 12 m in height and which cut moraines of Suttle Lake age, approximately 20,000 years old.

The scarps define a complex graben, which extends at least 18 km N-S and 10 km E-W. Based on the height of scarps across several transects, the estimated normal fault extension for this system ranges from 4 to 16 m.



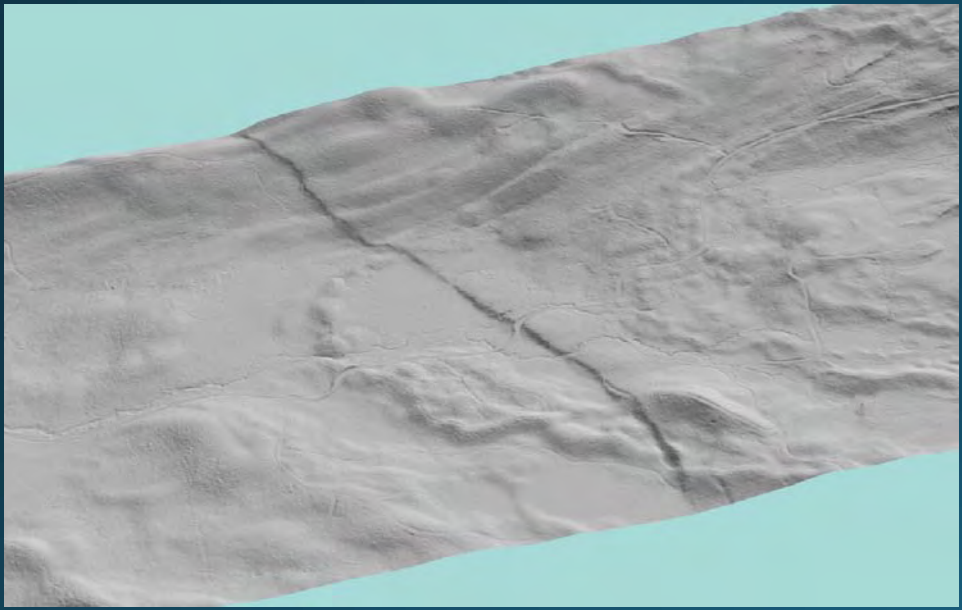


Ian Madin, GSA 2017 Session 210-11, 10/24/17

Bill Burns, 2018

1) Young Faults Using Lidar – White Branch Fault Zone

E and W-facing scarps in southern portion of White Branch fault zone



Lidar view and photo of 12 m high scarp in ~ 20 ka recessional moraines

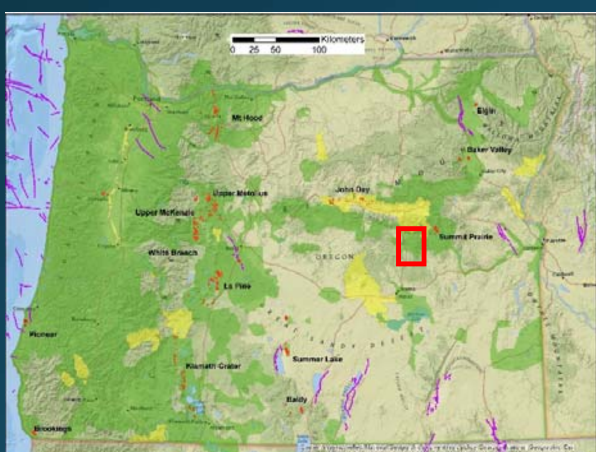
Ian Madin, GSA 2017 Session 210-11, 10/24/17

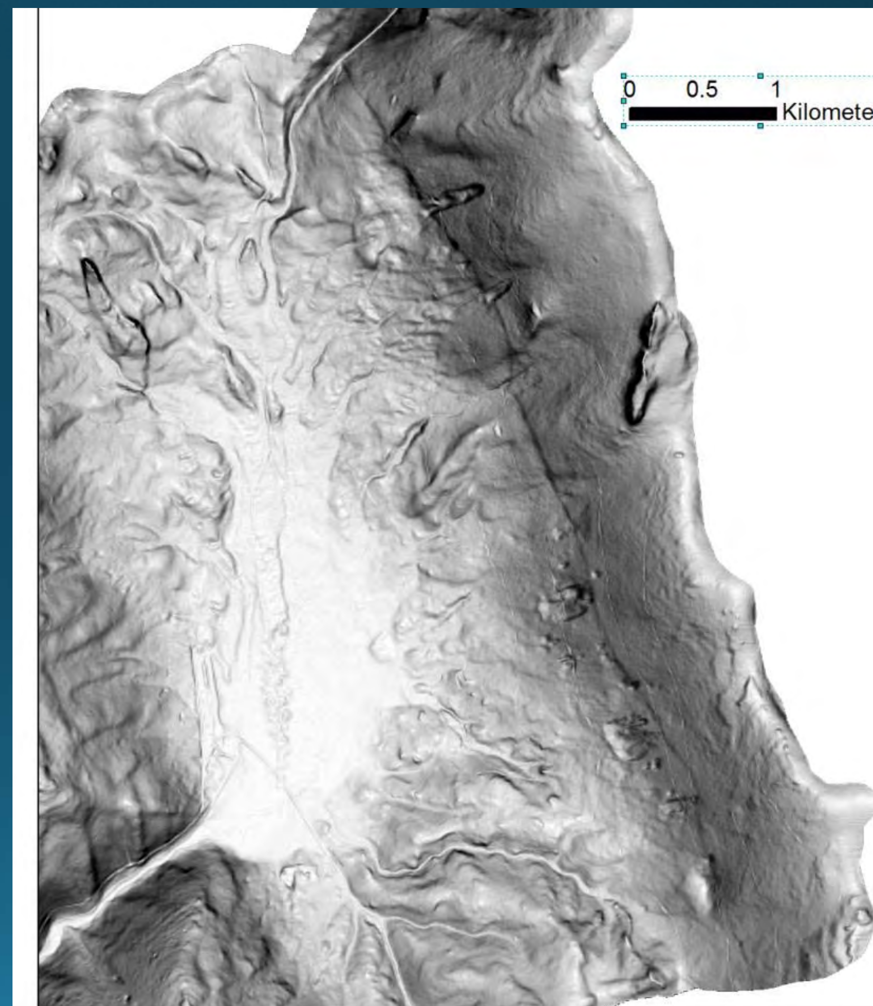
Bill Burns, 2018

1) Young Faults Using Lidar – Summit Prairie Fault

•NW-trending west-side-down normal fault extends > 7km across lidar coverage

•2-3m offset in colluvium on 20 degree slope

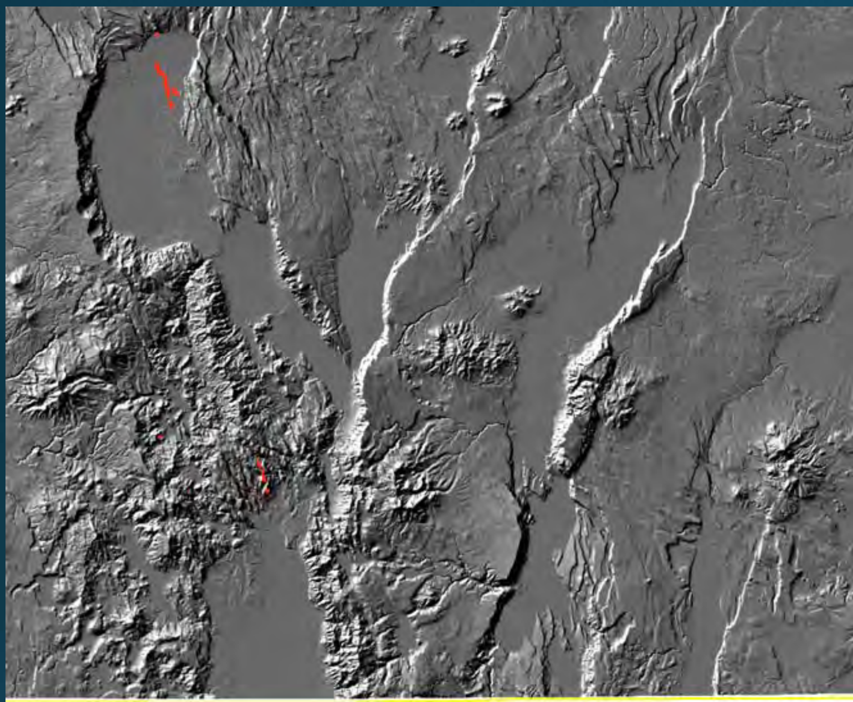


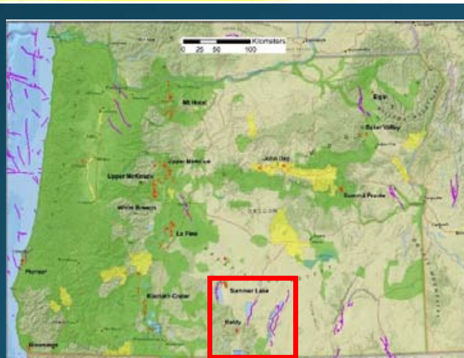


Ian Madin, GSA 2017 Session 210-11, 10/24/17

Bill Burns, 2018

1) Young Faults Using Lidar – Summer Lake Fault

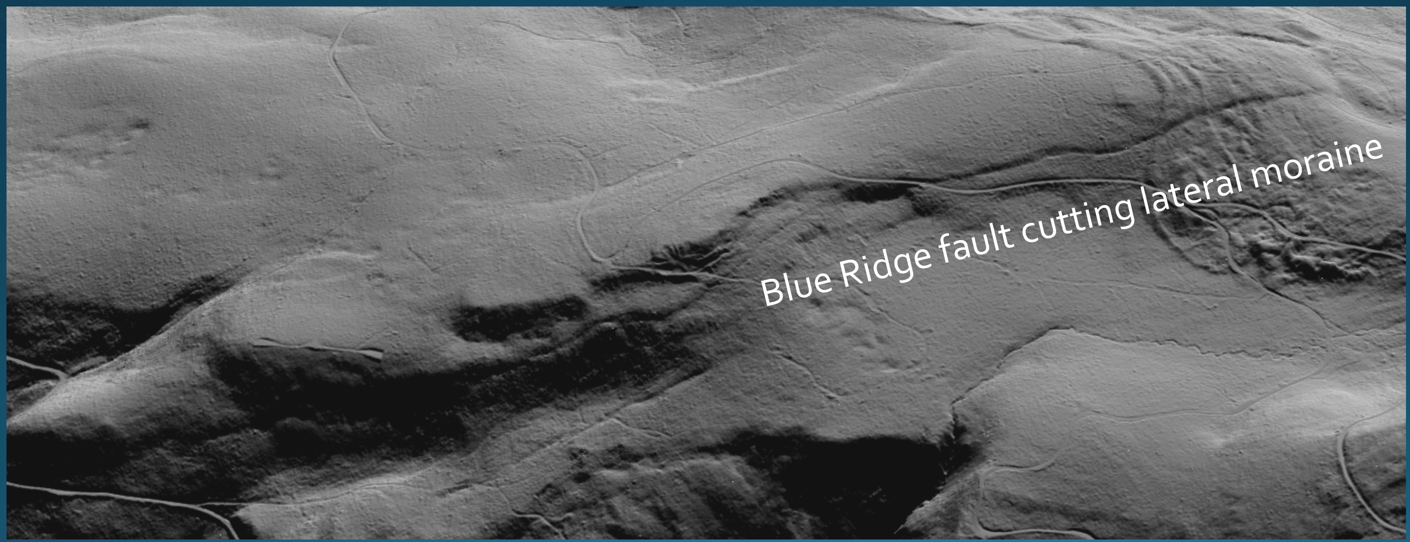




Bill Burns, 2018

1) Young Faults Using Lidar – Summary

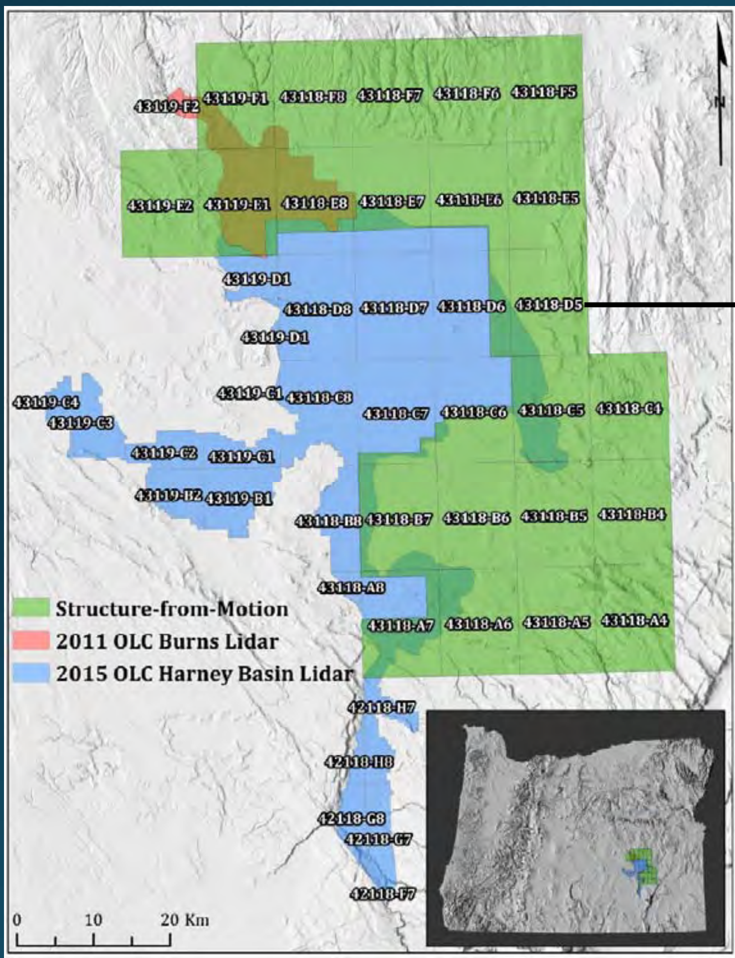
- Cursory review of the large, high quality lidar dataset collected by the Oregon Lidar Consortium has identified dozens of previously unrecognized young faults.
- None have been studied in significant detail.
- Somebody ought to do that, it could be you!
- View and download lidar data at http://www.oregongeology.org/lidar/index.htm
- Email Ian.Madin@Oregon.gov for fault GIS data.



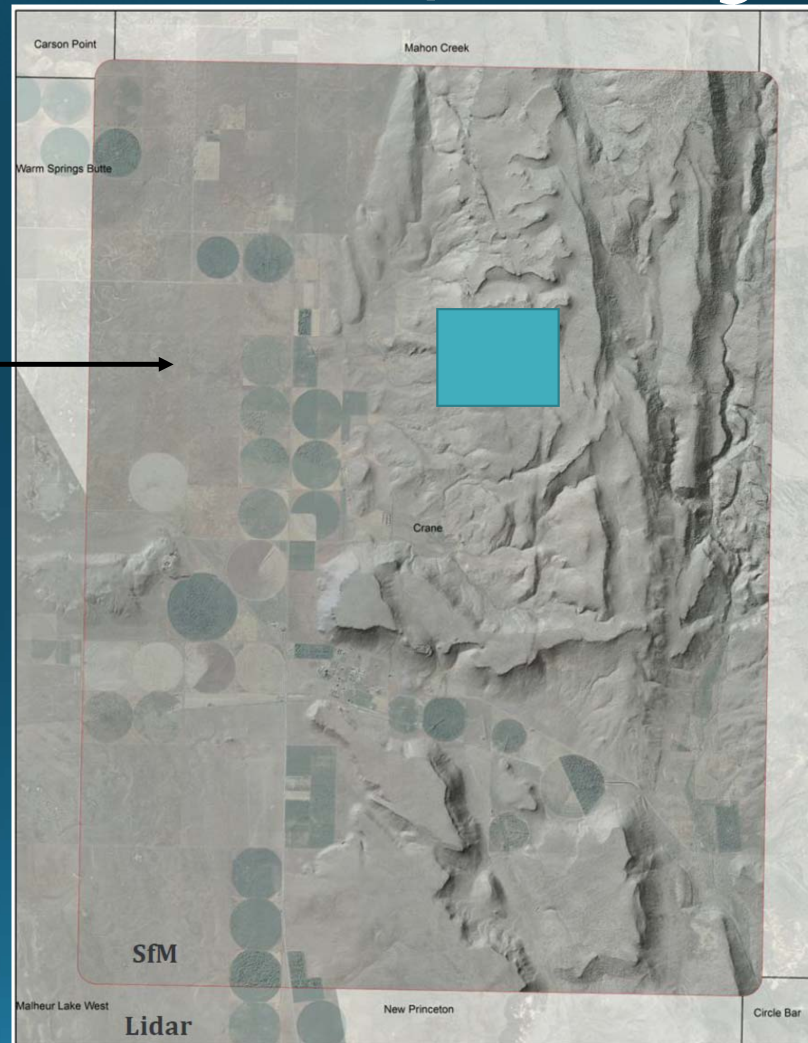
Ian Madin, GSA 2017 Session 210-11, 10/24/17

Bill Burns, 2018

2) Structure From Motion– Crane Quad, SE Oregon



Jason McClaughry, Draft, 2018



Bill Burns, 2018

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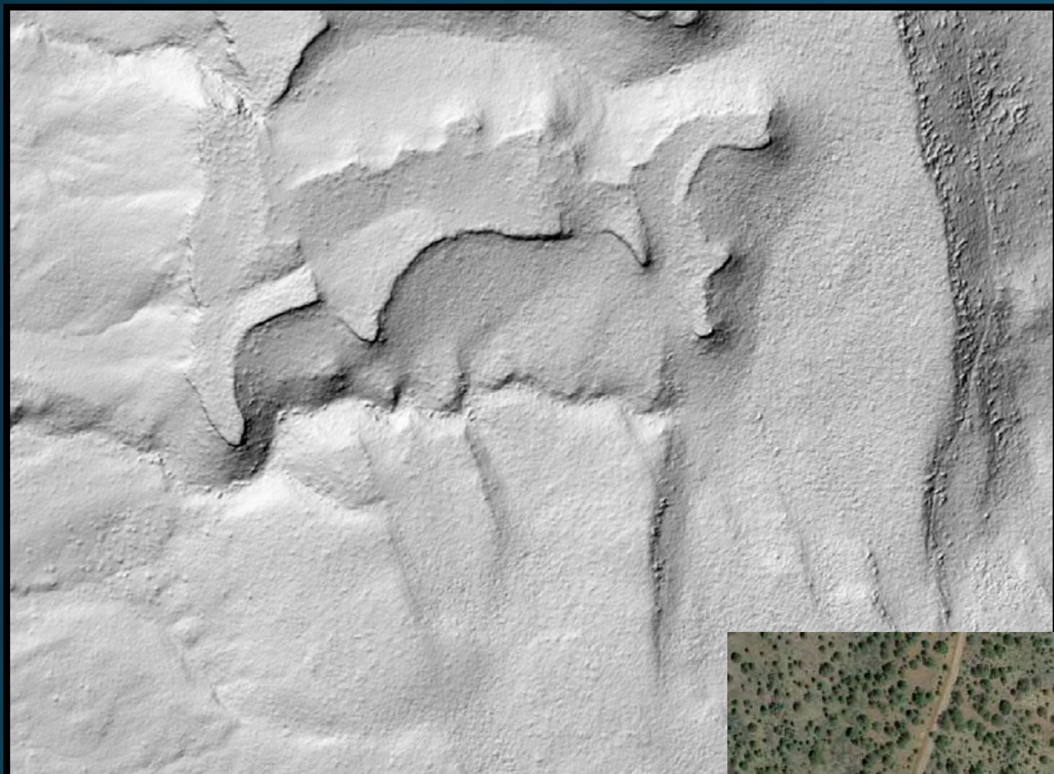
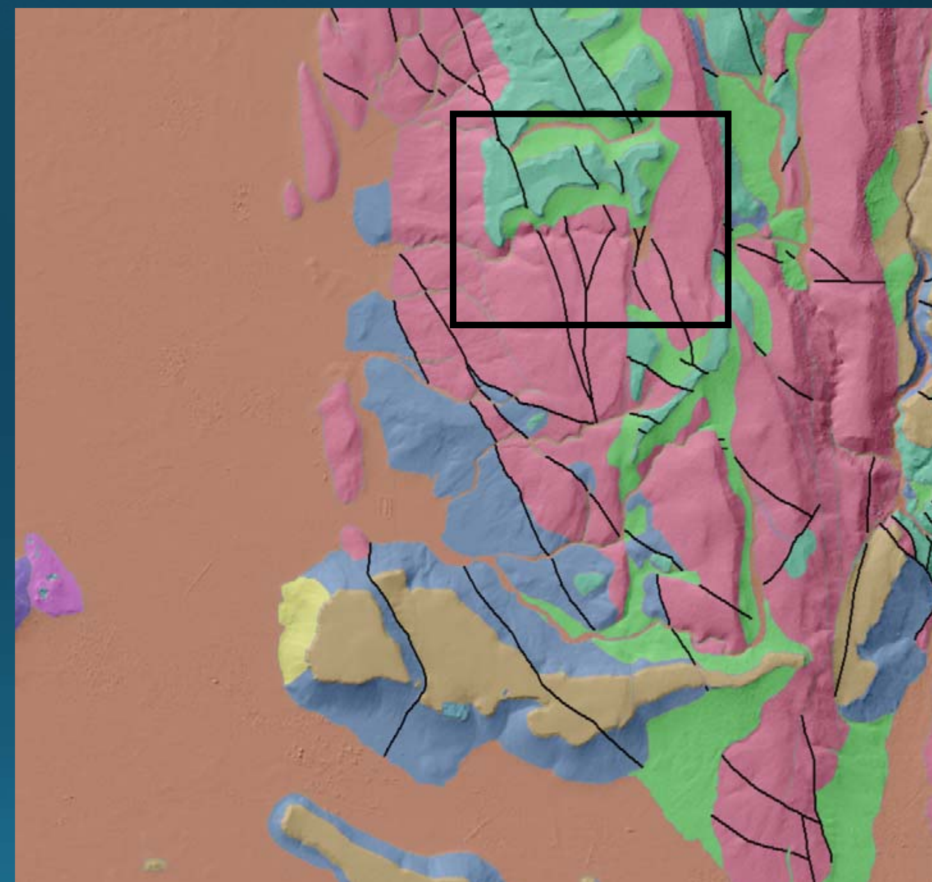




Jason McClaughry, Draft, 2018

Bill Burns, 2018

3) Coseismic Landslides

Comparing Remote Sensing Data for Landslide Mapping

	Dataset	USGS 10m DEM	City PDX Data	Stereo-Pair Aerial Photograph (1973)	LIDAR
Single Person	Time (hours)	6	10	21	37
	Smallest Landslide (Square Feet)	1,151,610	57,373	21,730	862
	Smallest Landslide (Square Meters)	106,988	5,330	2,019	80
	Largest Landslide (Square Feet)	77,593,943	77,682,394	65,109,813	64,511,123
	Largest Landslide (Square Meters)	7,208,710	7,216,927	6,048,897	5,993,277
	Total Number of Landslides	**11**	**34**	**31**	**211**
Individual People	Time (hours)	8	11	10	39
	Smallest Landslide (Square Feet)	373,428	18,231	87,308	298
	Smallest Landslide (Square Meters)	34,693	1,694	8,111	28
	Largest Landslide (Square Feet)	3,328,046	32,837,973	10,322,765	997,173
	Largest Landslide (Square Meters)	309,185	3,050,746	959,016	92,640
	Total Number of Landslides	**6**	**69**	**18**	**151**

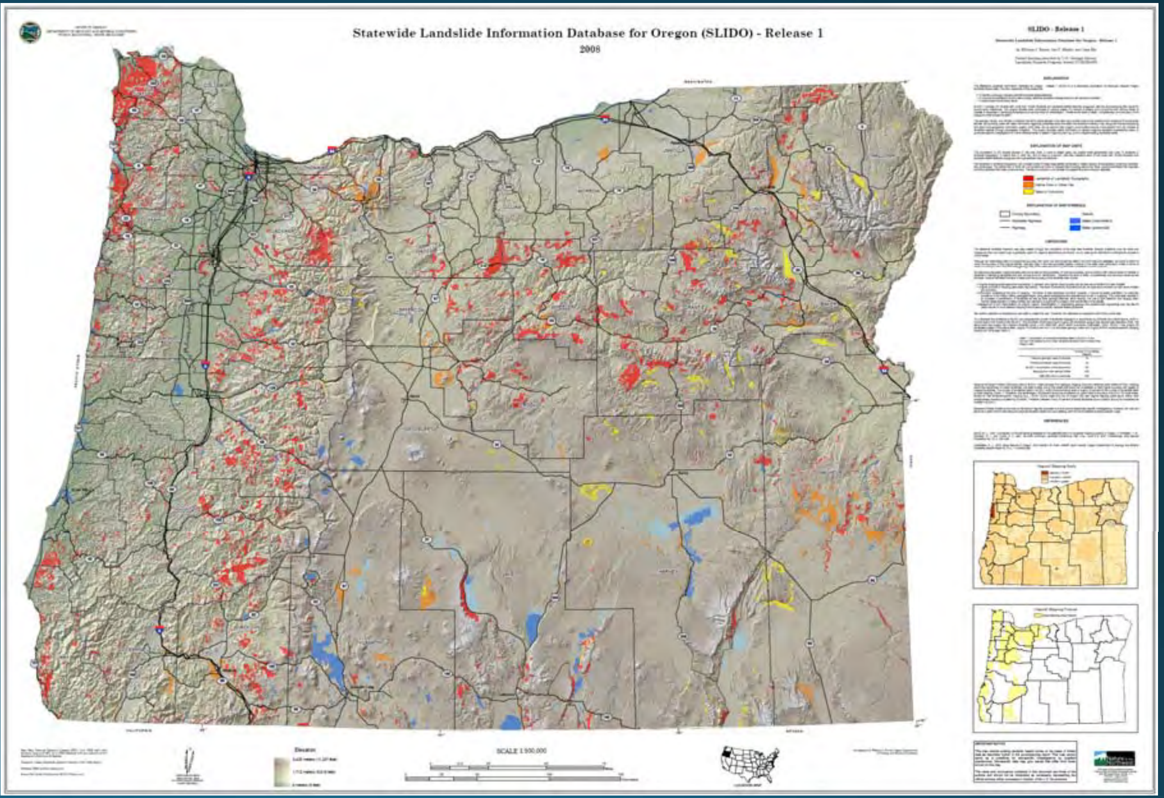
Burns, W. J., 2007, Comparison of remote sensing datasets for the establishment of a landslide mapping protocol in Oregon. AEG Special Publication 23: Vail, Colo., Conference Presentations, 1st North American Landslide Conference.

Bill Burns, 2018

3) Coseismic Landslides

Comparison Conclusions

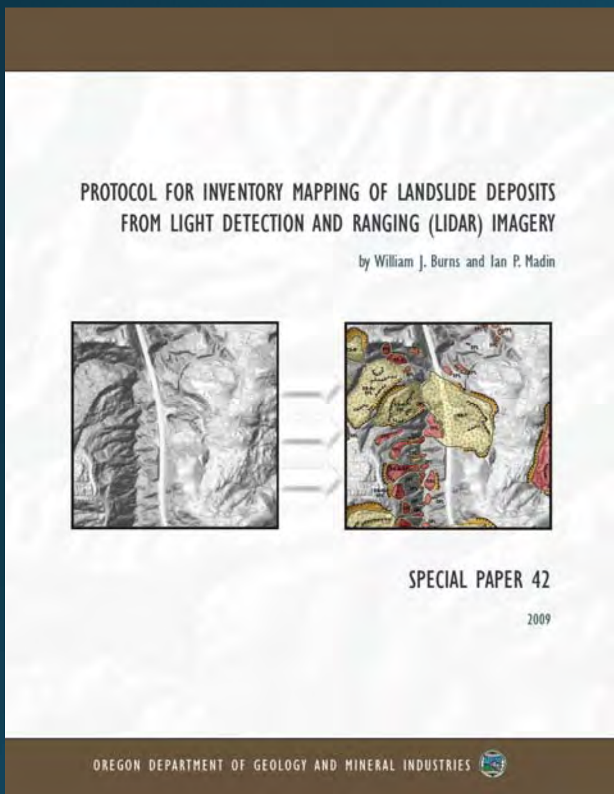
- Use Lidar
- Compile all previously mapped landslides
  - SLIDO R1 (2009)
  - 1952-2008 (~60 years)
  - 257 studies
  - 15,093 landslides



Burns, W. J., 2007, Comparison of remote sensing datasets for the establishment of a landslide mapping protocol in Oregon. AEG Special Publication 23: Vail, Colo., Conference Presentations, 1st North American Landslide Conference.

Bill Burns, 2018

3) Coseismic Landslides – Mapping Methods

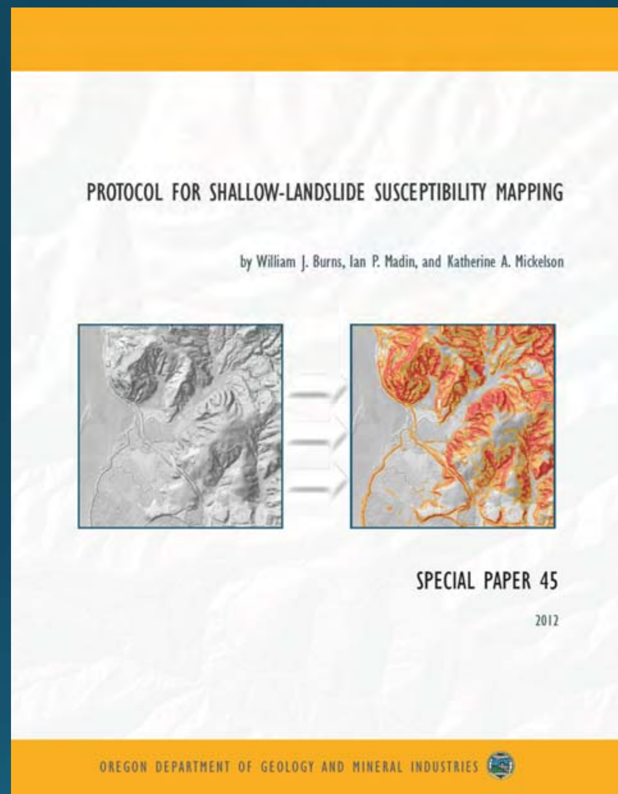

PROTOCOL FOR INVENTORY MAPPING OF LANDSLIDE DEPOSITS FROM LIGHT DETECTION AND RANGING (LIDAR) IMAGERY

by William J. Burns and Ian P. Madin

SPECIAL PAPER 42

2009

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

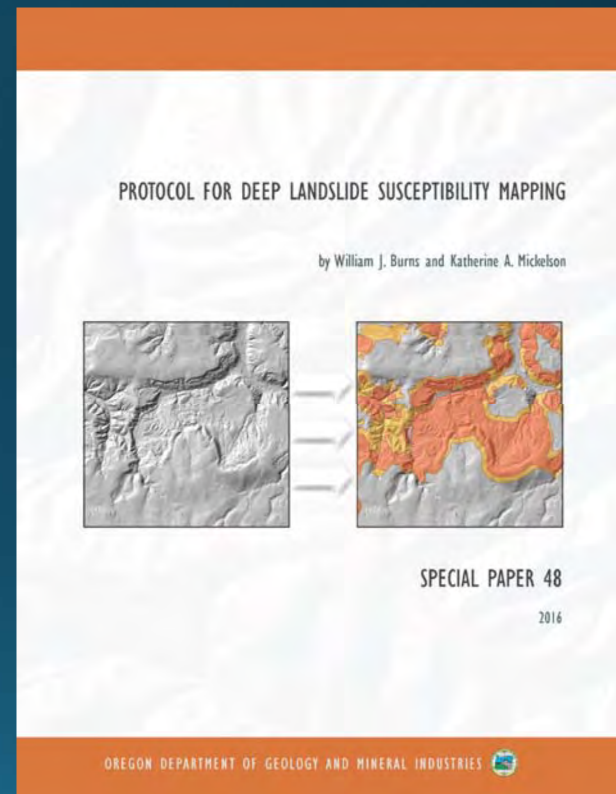

PROTOCOL FOR SHALLOW-LANDSLIDE SUSCEPTIBILITY MAPPING

by William J. Burns, Ian P. Madin, and Katherine A. Mickelson

SPECIAL PAPER 45

2012

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES


PROTOCOL FOR DEEP LANDSLIDE SUSCEPTIBILITY MAPPING

by William J. Burns and Katherine A. Mickelson

SPECIAL PAPER 48

2016

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

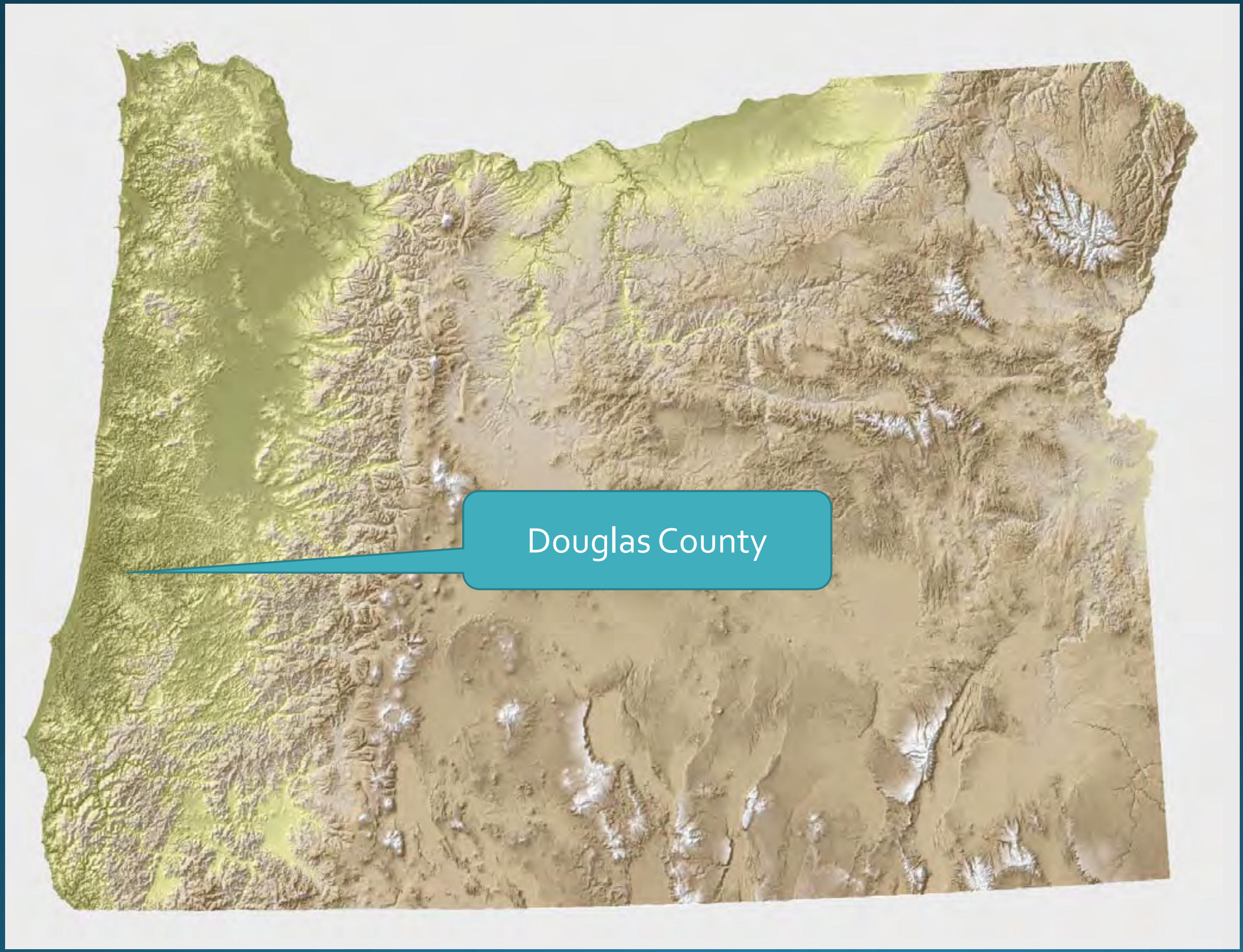
Past Landslides

Future Shallow Landslide Areas

Future Deep Landslide Areas

Bill Burns, 2018

3) Coseismic Landslides – Example in Western Oregon



Burns, W.J., Herinckx, H.H., and Lindsey, K.O., 2017. Landslide inventory of portions of northwest Douglas County, Oregon, Oregon Department of Geology and Mineral Industries, Open-File Report O-17-04.

Bill Burns, 2018

3) Coseismic Landslides – Example in Western Oregon

Douglas County

BLM Land, North of the Umpqua River

2009 photo

Burns, W.J., Herinckx, H.H., and Lindsey, K.O., 2017. Landslide inventory of portions of northwest Douglas County, Oregon, Oregon Department of Geology and Mineral Industries, Open-File Report O-17-04.

Burns, 2017

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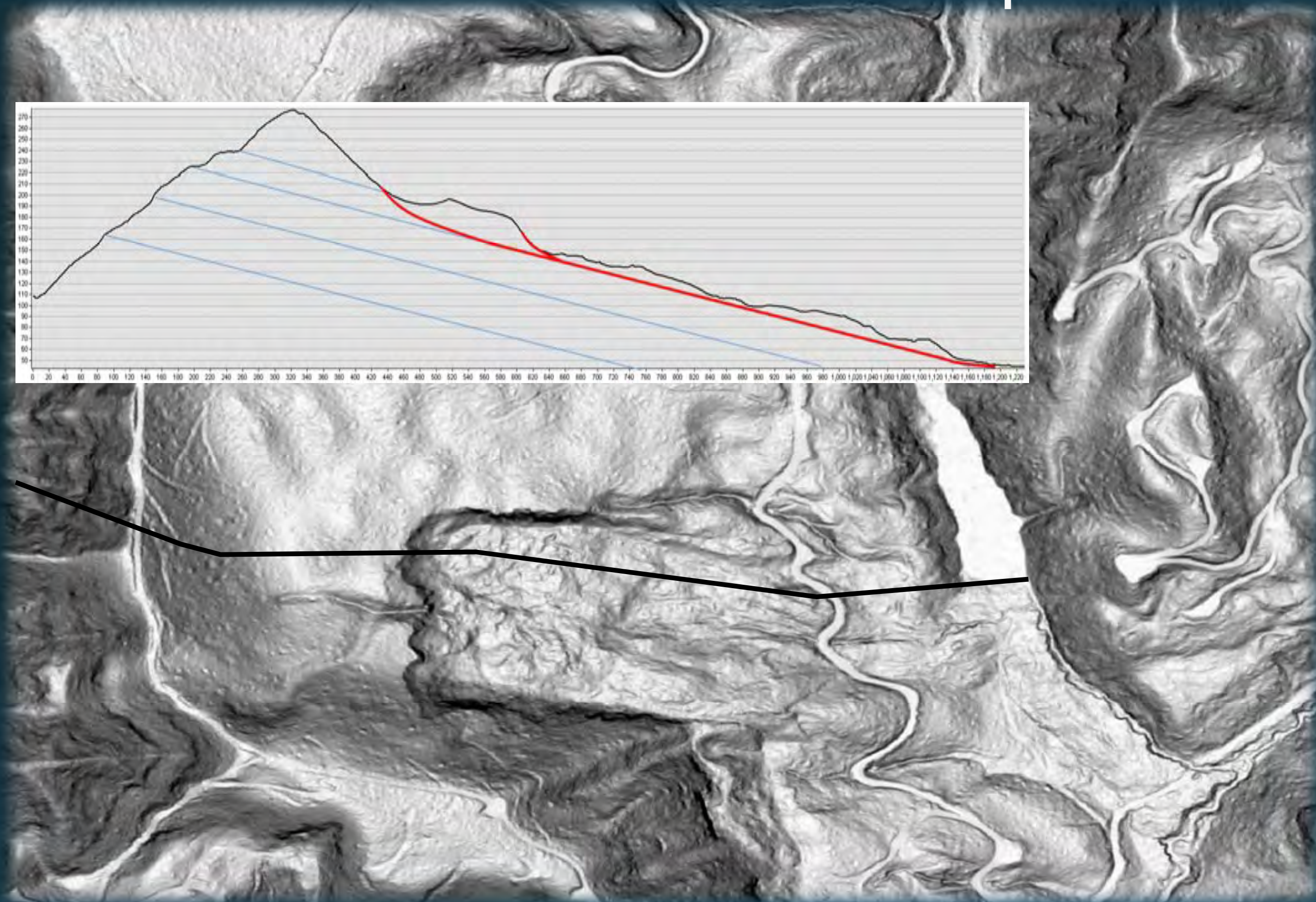


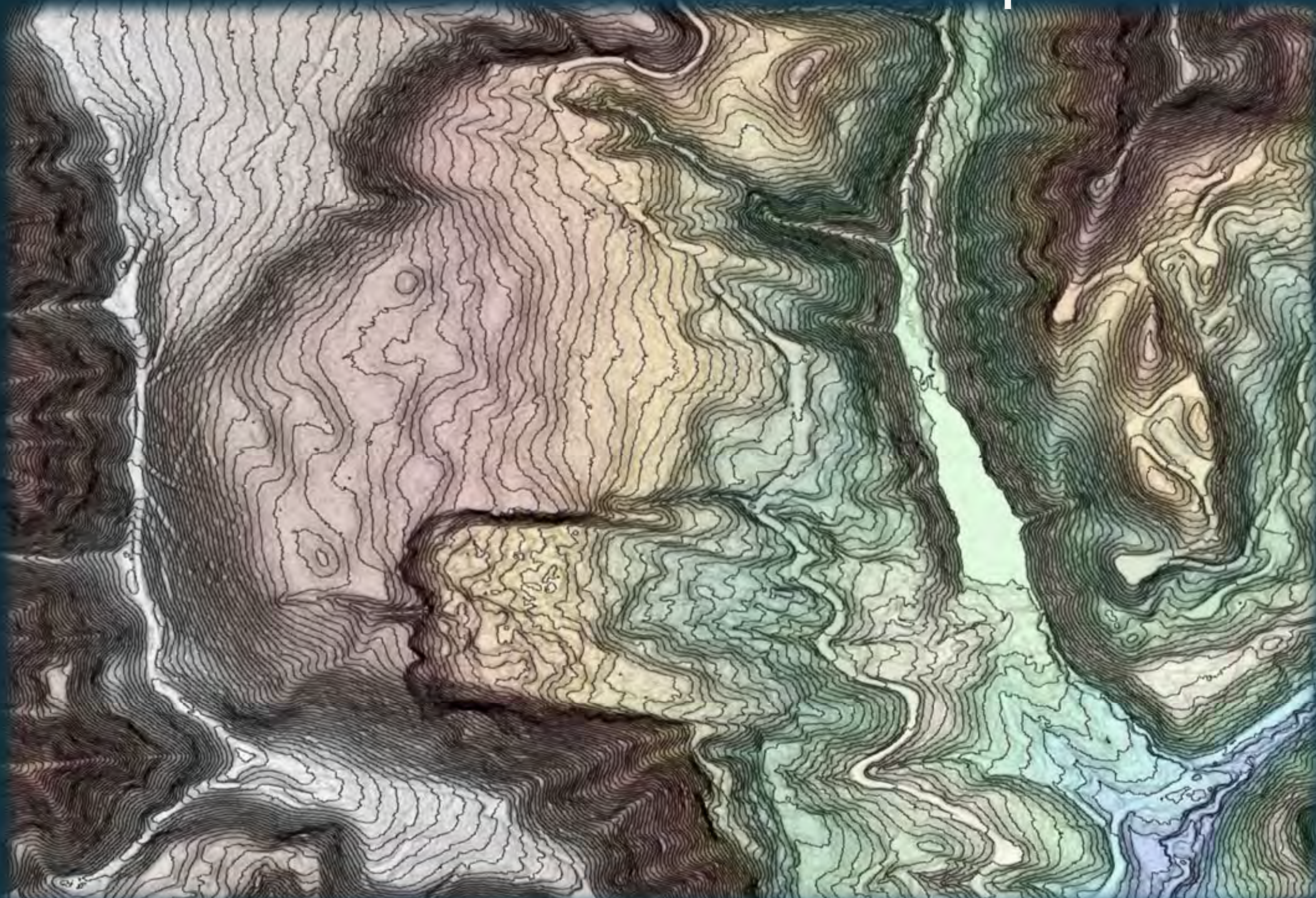
Douglas County

Lidar 1m Bare Earth Slope

Burns, W.J., Herinckx, H.H., and Lindsey, K.O., 2017. Landslide inventory of portions of northwest Douglas County, Oregon, Oregon Department of Geology and Mineral Industries, Open-File Report O-17-04.

Burns, 2017

3) Coseismic Landslides – Example in Western Oregon



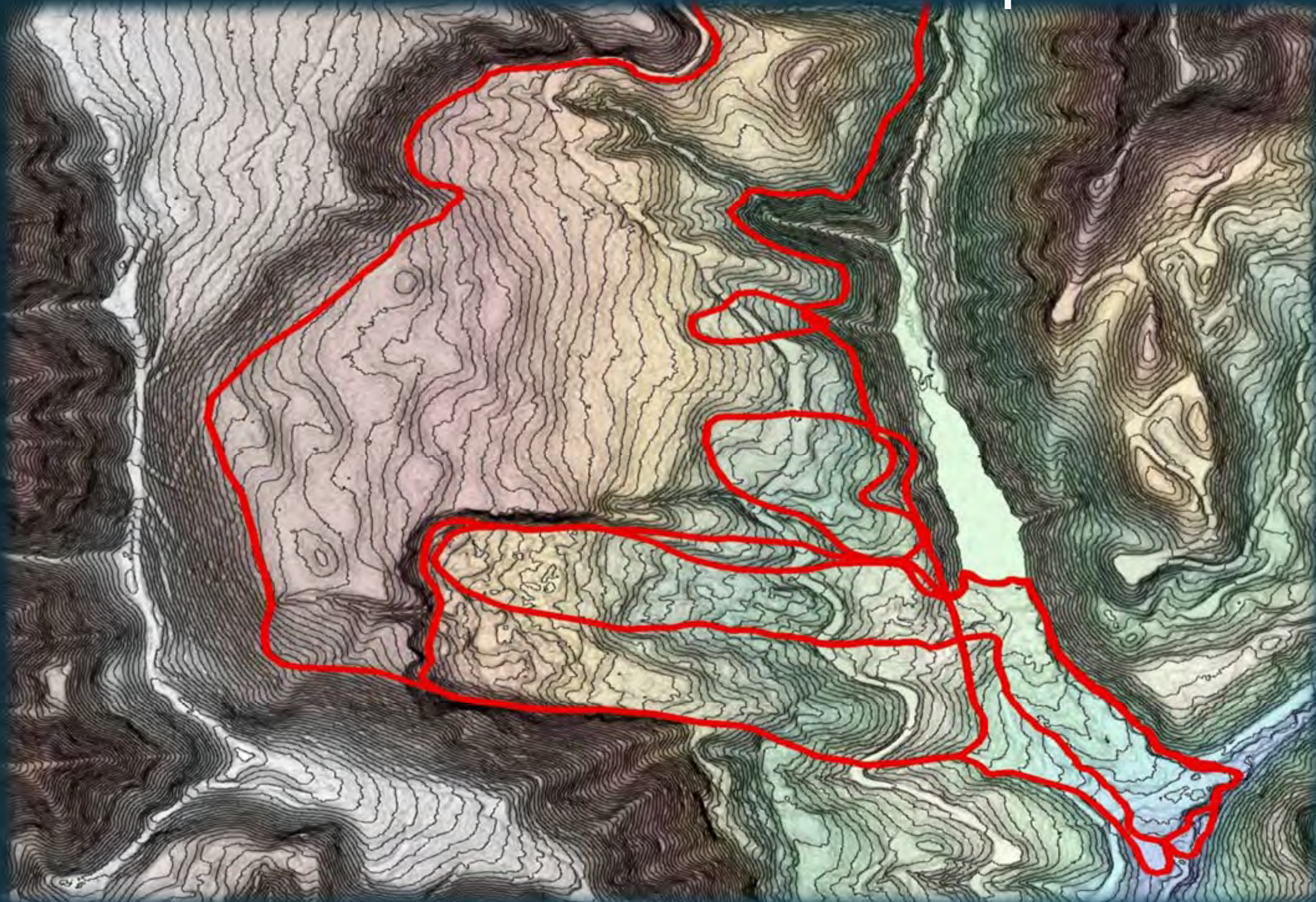
Douglas County

Bare Earth Slope & DEM Elevation Color Ramp & 3ft Contours

Burns, W.J., Herinckx, H.H., and Lindsey, K.O., 2017. Landslide inventory of portions of northwest Douglas County, Oregon, Oregon Department of Geology and Mineral Industries, Open-File Report O-17-04.

Burns, 2017

3) Coseismic Landslides – Example in Western Oregon



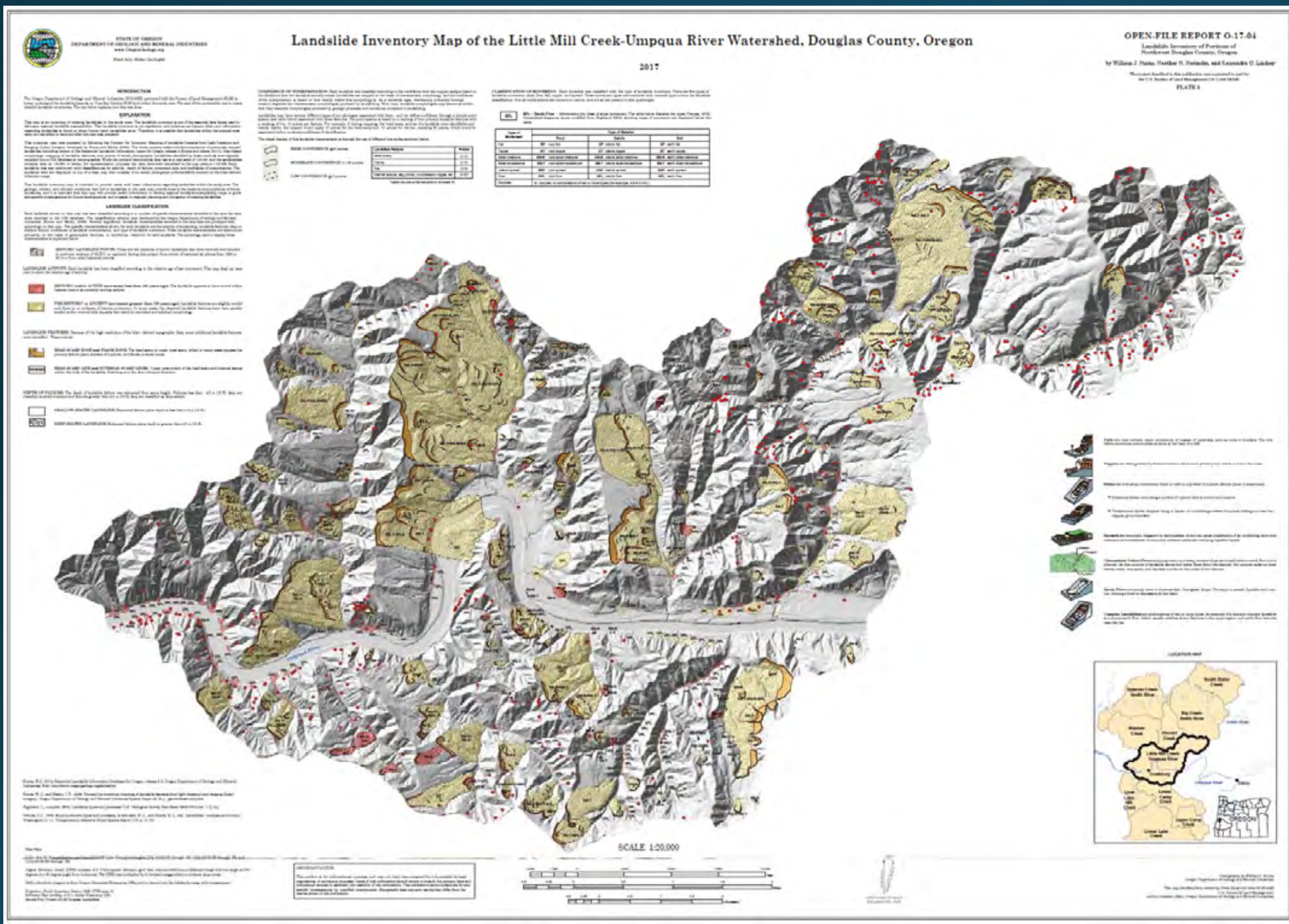
Douglas County

Bare Earth Slope & DEM
Elevation Color Ramp & 3ft
Contours & Landslides

Burns, W.J., Herinckx, H.H., and Lindsey, K.O., 2017. Landslide inventory of portions of northwest Douglas County, Oregon, Oregon Department of Geology and Mineral Industries, Open-File Report O-17-04.

Burns, 2017

3) Coseismic Landslides – Example in Western Oregon



- 21 previously mapped
- 2,981 new mapped landslide polygons

Burns, W.J., Herinckx, H.H., and Lindsey, K.O., 2017. Landslide inventory of portions of northwest Douglas County, Oregon, Oregon Department of Geology and Mineral Industries, Open-File Report O-17-04.

Bill Burns, 2018

3) Coseismic Landslides – 24 Attributes - Landslide Age

QUADNAME
Text; 7.5-minute quadrangle name. Example: Oregon City

UNIQUE_ID
*Text; unique identification number: concatenation of QUADNAME_ID. * Example:* Oregon City_1

CONFIDENCE
Text; confidence of identification.
- High (≥30)
- Moderate (20-30)
- Low (≤20)

AGE
Text; estimated age.
- Historic (<150 years)
- Pre-Historic (>150 years)

DATE_MOVE
Text; date of last known movement or movements. Examples: 10/6/1996, 2/12/1997

DEEP_SHAL
Text; deep or shallow seated: 4.5 m (15 ft) is the boundary value.
- Deep
- Shallow

NAME
Text; landslide name. Example: Spady Landslide

GEOL
Text; geologic unit. Example: Troutdale Formation

SLOPE
Float; adjacent slope angle, 0 to 90. Units: degrees. Example: 32

HS_HEIGHT
Float; change in elevation from bottom to top of head scarp. Units: feet. Example: 16

FAIL_DEPTH
Float; estimated calculated depth of failure. Units: feet. Example: 14

FAN_HEIGHT
Float; change in elevation from bottom to top of fan. Units: feet. Example: 35

TYPE_MOVE *Text; type of movement.*	MOVE_CLASS *Text; movement classification.*	MOVE_CODE *Text; movement classification code.*
Slide	Debris Slide - Rotational	DS-R
	Debris Slide - Translational	DS-T
	Earth Slide - Rotational	ES-R
	Earth Slide - Translational	ES-T
	Rock Slide - Rotational	RS-R
	Rock Slide - Translational	RS-T
Flow	Debris Flow	DFL
	Earth Flow	EFL
	Rock Flow	RFL
Spread	Debris Spread	DSP
	Rock Spread	RSP
	Rock Spread	RSP
Fall	Debris Fall	DF
	Rock Fall	RF
	Rock Fall	RF
Topple	Debris Topple	DT
	Earth Topple	ET
	Rock Topple	RT
Complex	Complex	C
	Complex Earth Slide - Rotational & Earth Flow	ES-R>EFL

FAN_DEPTH
Float; estimated calculated fan depth. Units: feet. Example: 33

HS_IS1
Float; horizontal distance from head scarp (HS) to internal scarp no. 1 (IS1). Units: feet. Example: 5

IS1_IS2
Float; horizontal distance from internal scarp no. 1 (IS1) to internal scarp no. 2 (IS2). Units: feet. Example: 5

IS2_IS3
Float; horizontal distance from internal scarp no. 2 (IS2) to internal scarp no. 3 (IS3). Units: feet. Example: 5

IS3_IS4
Float; horizontal distance from internal scarp no. 3 (IS3) to internal scarp no. 4 (IS4). Units: feet. Example: 5

HD_AVE
Float; calculated average horizontal distance between scarps. Units: feet. Example: 5

DIRECT
Float; direction of movement, in increments of 22.5. Units: degrees.
0
22.5
45
76.5
90
112.5
135
157.5
180
202.5
225
247.5
270
292.5
315
337.5
360

AREA
Float; size of landslide deposit. Units: square feet. Example: 500

VOL
Float; volume of landslide deposit. Units: cubic feet. Example: 7000

Known Date or Estimated Age

- If a date of movement is known, enter it in the field.
- Estimation of the age of a landslide can be very difficult. However, as age is often an important attribute for hazard assessments, an estimate should be attempted.
  - Historic or active (movement <150 years): The landslide appears to be currently moving or to have moved within historic time or historic data has identified the landslide as having moved in the last 150 years. Landslide features generally sharp and clear
  - Prehistoric or ancient (movement >150 years): Landslide features are slightly to strongly eroded or covered with younger deposits. Features may be subdued and indistinct

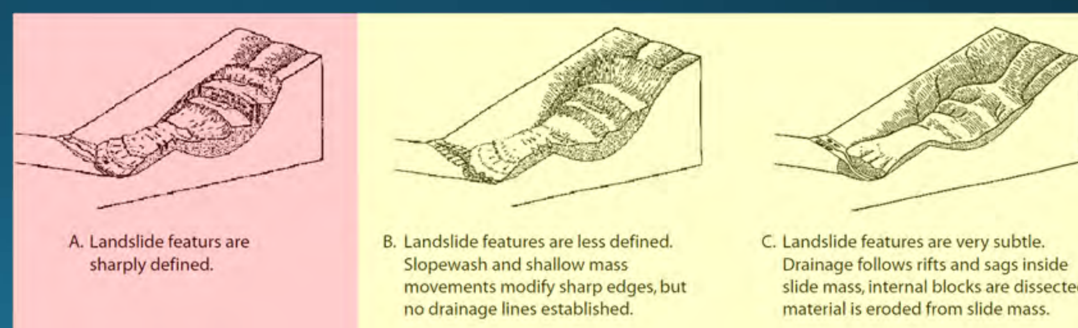


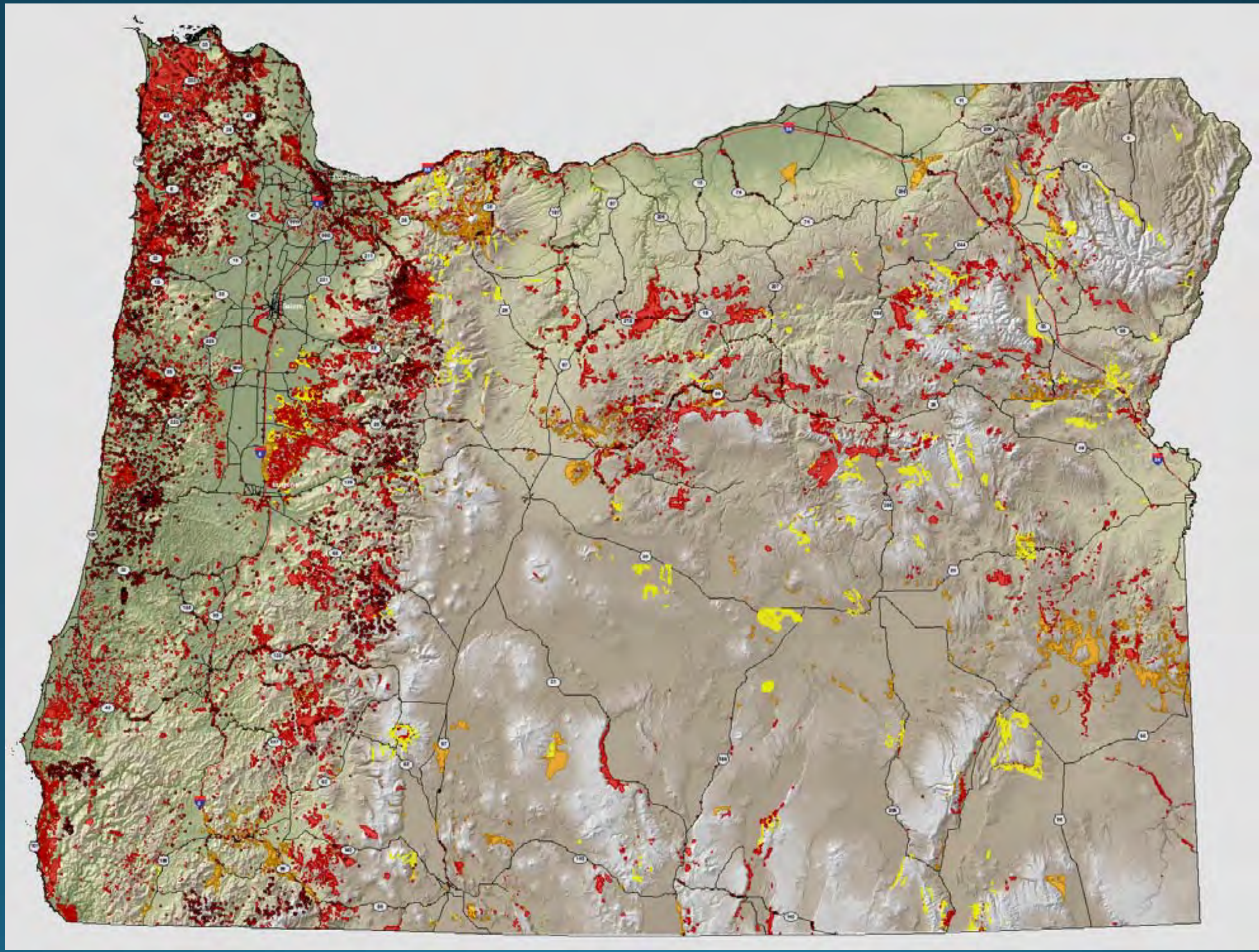
Figure 16. Geomorphic changes in surface morphology of a landslide with time (McCalpin, 1974).

Burns, W.J., Madin, I.P., 2009. Protocol for Inventory Mapping of Landslide Deposits from Light Detection and Ranging (lidar) Imagery, Oregon Department of Geology and Mineral Industries, Special Paper 42

Bill Burns, 2018

3) Coseismic Landslides

~53,000 Landslides
SLIDO Database



Burns, W.J., 2014, Statewide Landslide Information Database for Oregon, release 3.2: Oregon Department of Geology and Mineral Industries

Bill Burns, 2018

3) Coseismic Landslides

SLIDO – Statewide Landslide Information Database for Oregon

SLIDO v1 – No lidar-based mapping, No historic points

- 1952-2008 (~60 years) = **15,093** landslide polygons

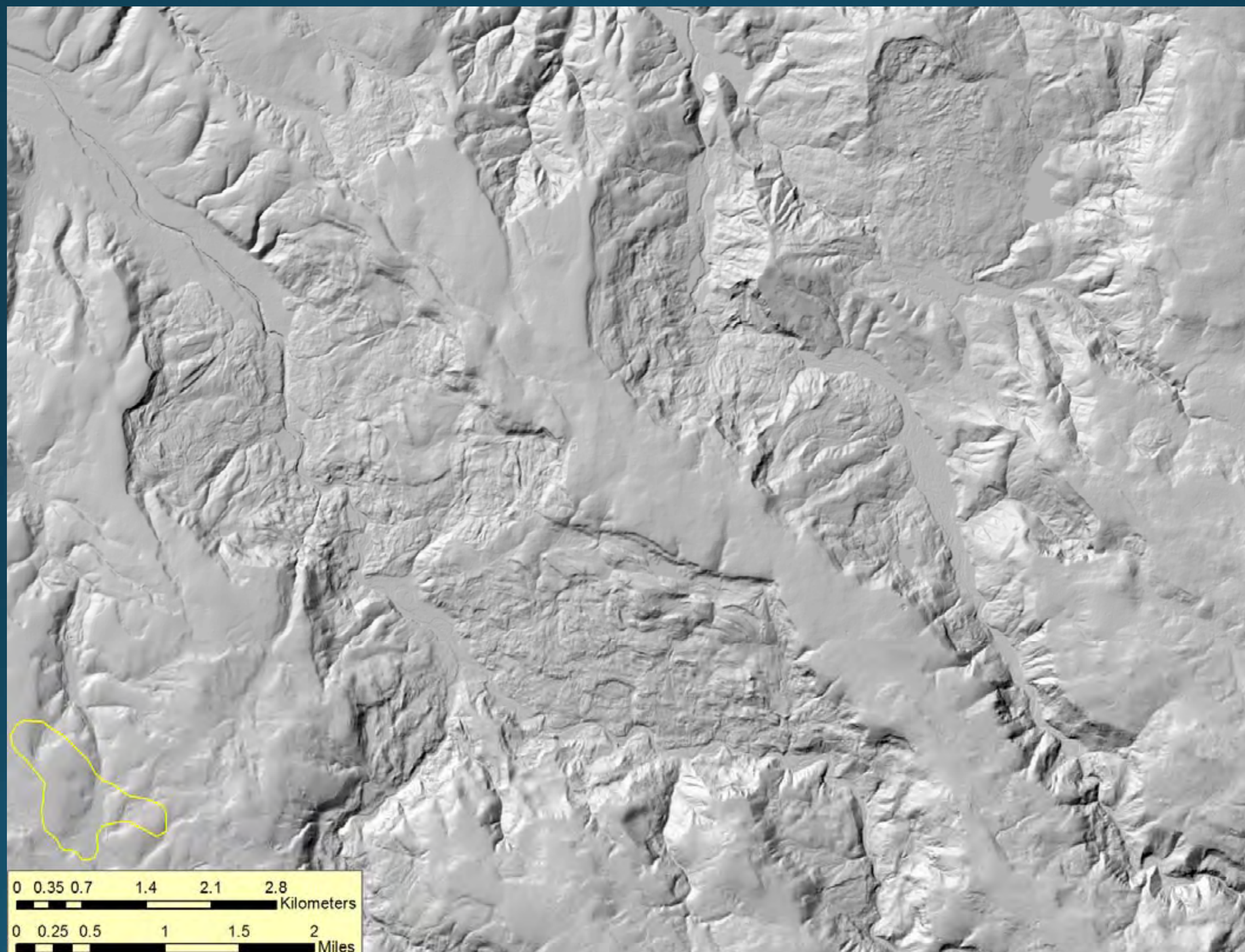
SLIDO v3.2

- 2009-2014 (5 years) = 25,936 (total **41,029**)
- +**12,095** historic landslide points

- Mapped more in 5 years than previous ~60!

Burns, W.J., 2014, Statewide Landslide Information Database for Oregon, release 3.2: Oregon Department of Geology and Mineral Industries

3) Coseismic Landslides



Clackamas County, Oregon

Bill Burns, 2018

4) Risk Analysis – Exposure and HAZUS

1. Exposure (at-risk)

EQ, Flood, Wind

2. FEMA's HAZUS
   - Earthquake induced landslide risk assessment
     - Scenario 1: No landslide hazard (0 out of 10)
     - Scenario 2: Detailed landslide hazard
     - Difference the 2 scenarios and get the landslide portion only

Bill Burns, 2018

4) Risk Analysis – Exposure and HAZUS

Buildings Exposed to Deep Landslide Inventory SE Portland Metro

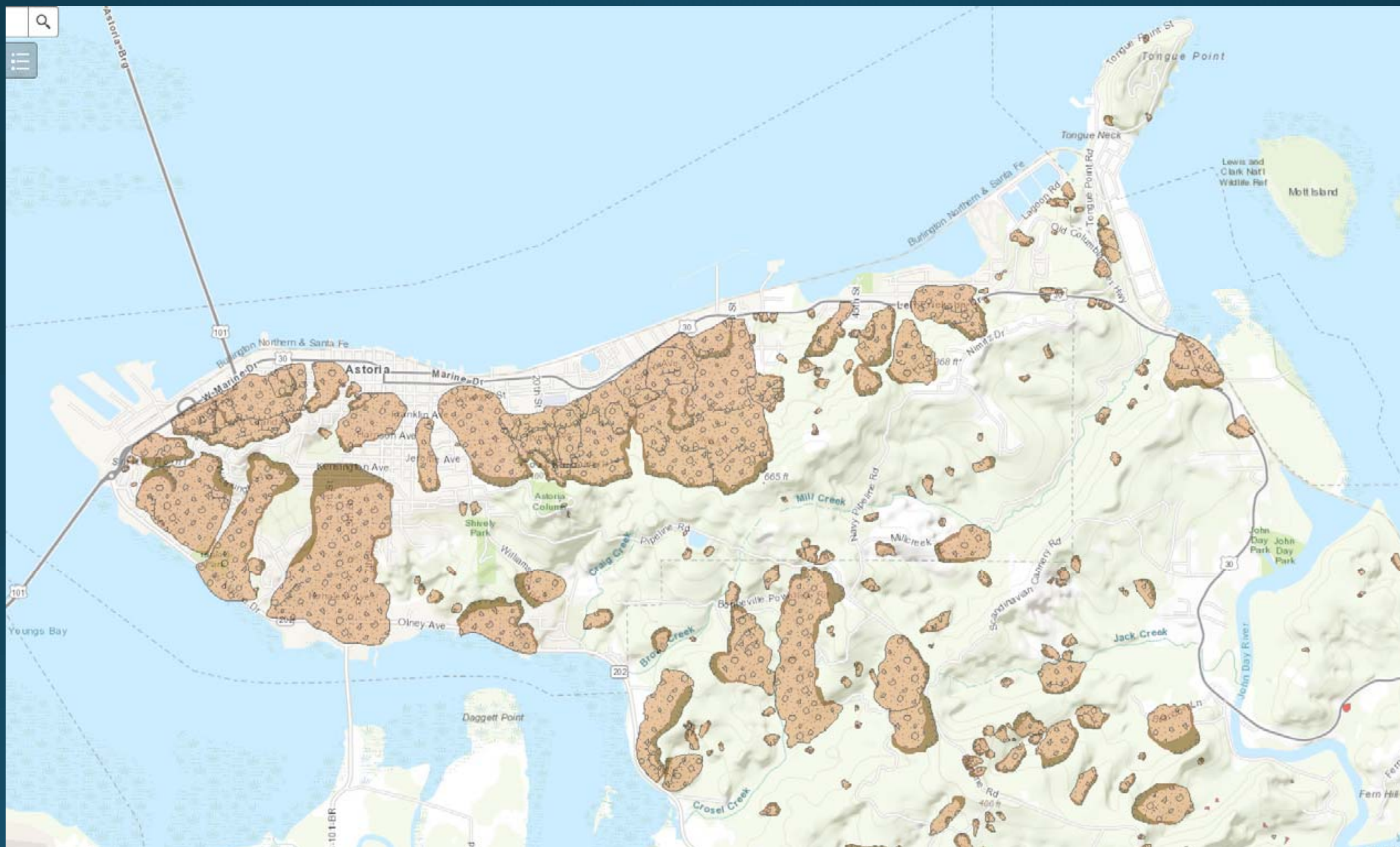
	Permanent Population	Building Count		Building Value Value
Shallow Landslides	227	123	$	16,809,407
Deep Landslides	7,247	3128	$	416,470,782
Fans	487	412	$	32,543,039

Purple=Commercial
Green=Public
Yellow=Residential

Burns, W.J., Mickelson, K.A., Jones, C.B., Pickner, S.G., Hughes, K.L., Sleeter, R., 2013. Landslide hazard and risk study of northwestern Clackamas County, Oregon: Oregon Department of Geology and Mineral Industries, Open-File Report O-13-08

Bill Burns, 2018

4) Risk Analysis – Exposure and HAZUS



Burns, W.J. and Mickelson, K.A., 2013. Landslide Inventory, Susceptibility Maps, and Risk Analysis for the City of Astoria, Clatsop County, Oregon: Oregon Department of Geology OFR O-13-05

Bill Burns, 2018

4) Risk Analysis – Exposure and HAZUS

	Expected Damage Count (Complete Damage)	Ratio (Complete Damage / Inventory)	Functionality (Total % After 1 Day)	Losses	Loss Ratio	Total Losses (Buildings and Lifelines)	Total Loss Ratio
***Hazus-MH, Scenario 1 Results** (landslide hazards set to 0 out of 10)*							
Buildings (Total)	69	2%		$203,040,000	22%	$341,030,000	12%
Residential	51	2%		$104,900,000	15%		
Commercial	14	14%		$75,770,000	42%		
Critical Facilities							
Hospital			13%				
Schools			29%				
Fire stations			27%				
Police stations			28%				
Infrastructure							
Highway				$99,670,000	6%		
Waste water				$14,330,000	19%		
Potable water				$8,481,000	21%		
Natural gas				$156,000	14%		
Communication				$73,000	22%		
***Hazus-MH, Scenario 2 Results** (landslide hazards derived from detailed lidar-based mapping performed as part of this project)*							
Buildings (total)	188	5%		$360,060,000	38%	$601,190,000	21%
Residential	142	4%		$178,071,450	26%		
Commercial	34	34%		$138,801,390	77%		
Critical facilities							
Hospital			3%				
Schools			15%				
Fire stations			14%				
Police stations			14%				
Infrastructure							
Highway				$188,183,000	11%		
Waste water				$20,673,000	27%		
Potable water				$12,026,000	30%		
Natural gas				$402,000	37%		
Communication				$102,000	30%		

No Landslides

Landslides

HAZUS Method Results

Loss ratio nearly doubled!

Landslides induced by earthquake cause as much damage as earthquake itself

Bill Burns, 2018

Burns, W.J. and Mickelson, K.A., 2013. Landslide Inventory, Susceptibility Maps, and Risk Analysis for the City of Astoria, Clatsop County, Oregon: Oregon Department of Geology OFR O-13-05

Conclusions

- Use lidar to map faults
  - Need to be studied after we find them
- Use SFR where you don't have lidar
  - Works great, especially in low density vegetation areas
- Coseismic landslides
  - Inventory getting good, but relationship to EQ not well understood
- Risk Analysis
  - Even if the risk analysis is simple, it demonstrates the potential for damage and loss
  - Risk encourages people to put science into action
  - Earthquake triggered hazards maybe as important as the earthquake itself, but are not studied at the same level

BASIN AND RANGE PROVINCE EARTHQUAKE WORKING GROUP
Utah Update

Thursday, February 15, 2018

Utah Geological Survey

Geologic Hazards Program

- **Wasatch Front**
  - Nearly 80% of Utah's population lives within 15 miles of the Wasatch fault
  - More than 75% of Utah's economy is concentrated in Salt Lake, Utah, Davis, and Weber counties
- **Infrastructure**
  - Numerous utilities and transportation corridors cross, or are very near to the fault
  - Many brick or block buildings are unreinforced masonry and susceptible to considerable damage or collapse

Utah Geological Survey (UGS)

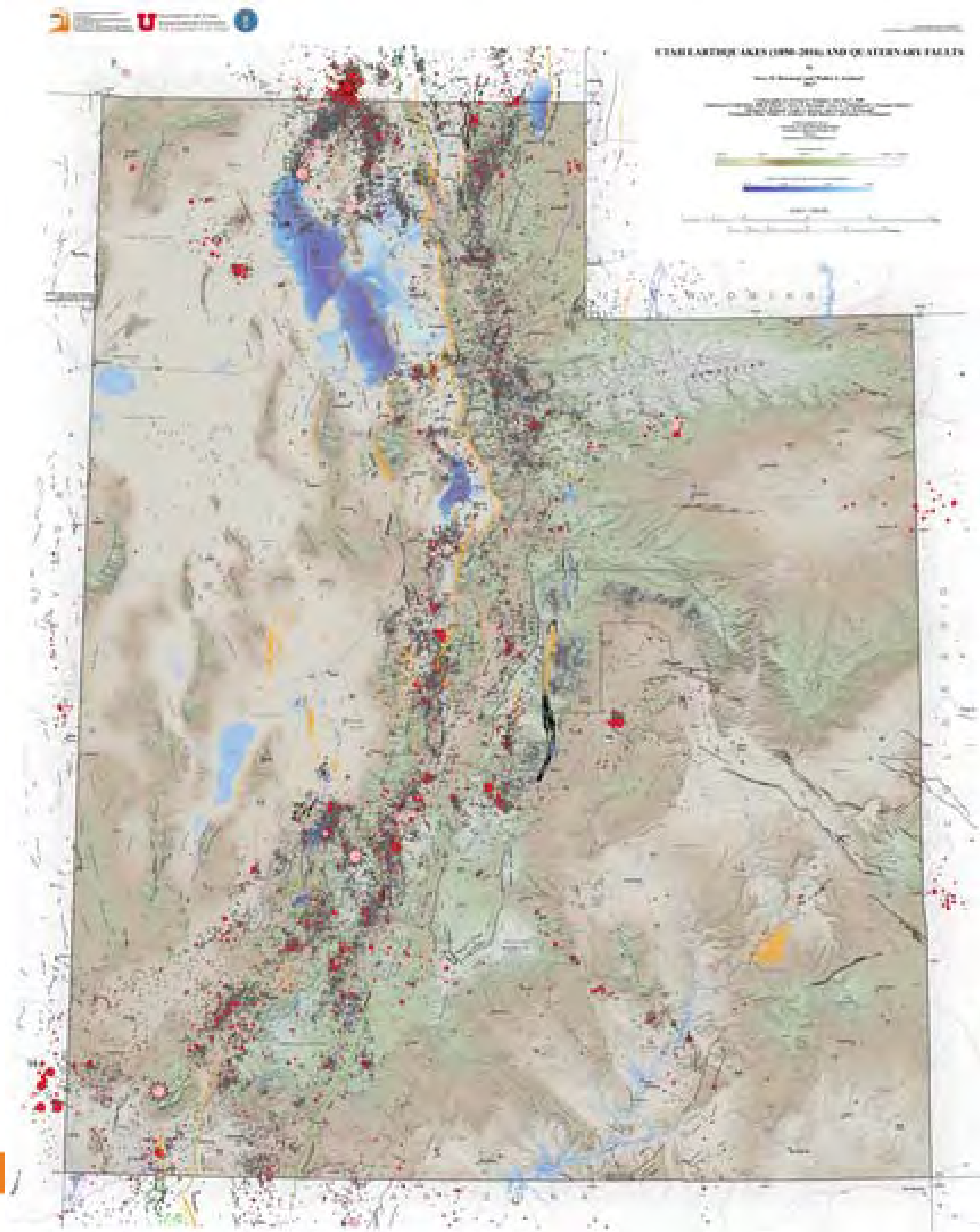
- UGS is ~70 full time employees
- 2 offices: Salt Lake City and Cedar City
- Where does our funding come from?
  - State general funds
  - Mineral severance taxes on Federal land
  - Grants/contracts
    - Federal agencies, state agencies, local government

Our main office at 1594 N. Temple, Salt Lake City

Utah Geological Survey (UGS)

- Programs within UGS:
  - Geologic Hazards Program (10 FTE)
  - Geologic Mapping Program
  - Groundwater and Paleontology Program
  - Energy and Minerals Program
  - Geologic Information and Outreach Program

Our main office at 1594 N. Temple, Salt Lake City


UTAH EARTHQUAKES (1850-2016) AND QUATERNARY FAULTS

Earthquake Mainshocks of Measured or Estimated Moment Magnitude (M) 4.9 or Greater

(labeled by number on map)

No.	Date (GMT)	Epicenter Location	M
1	11/14/1901	Tushar Mountains	6.6
2	11/17/1902	Pine Valley	6.3
3	10/06/1909	Hansel Valley	5.6
4	05/22/1910	Salt Lake City	5.3
5	09/29/1921	Elsinore	5.5
6	03/12/1934	Hansel Valley	6.6
7	11/19/1937	Idaho-Nevada-Utah border area	5.4
8	01/18/1950	Northwestern Uinta Basin	5.3
9	07/21/1959	Arizona-Utah border	5.6
10	08/30/1962	Cache Valley	5.8
11	09/05/1962	Magna	4.9
12	07/07/1963	Juab Valley	5.1
13	08/16/1966	Nevada-Utah border	5.2
14	10/04/1967	Marysvale	5.1
15	03/28/1975	Pocatello Valley, Idaho	6.0
16	08/14/1988	San Rafael Swell	5.0
17	01/30/1989	Southern Wasatch Plateau	5.2
18	09/02/1992	St. George	5.5

Utah Geological Survey – Geologic Hazards Program

- **Respond** to geologic hazard emergencies and provide unbiased, scientific advice to local governments and incident commanders.
- **Investigate** and map geologic hazards in urban and other areas (publish and distribute PDFs and GIS spatial data).
- **Provide** geologic hazard related technical outreach, educational outreach, and information to inform Utah about hazards.

1999/2011+ Sherwood Hills Landslide

February 2010 Rockville Rock Fall

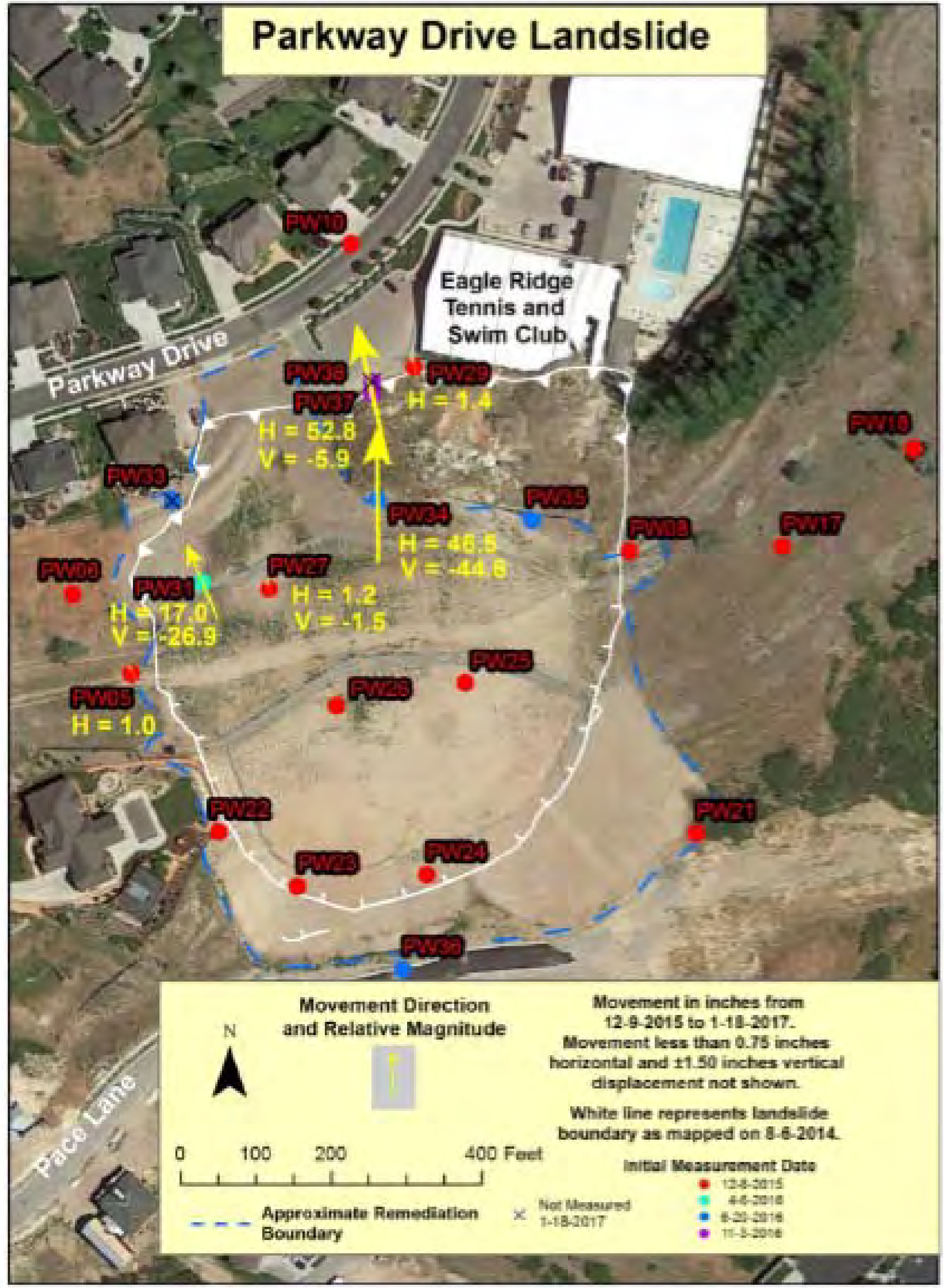
Hazards Response

Response

- Urban landslides
- Debris flows
- Rock falls
- Flooding

Monitoring

- GPS monitoring
- Groundwater well database
- Field invesigations

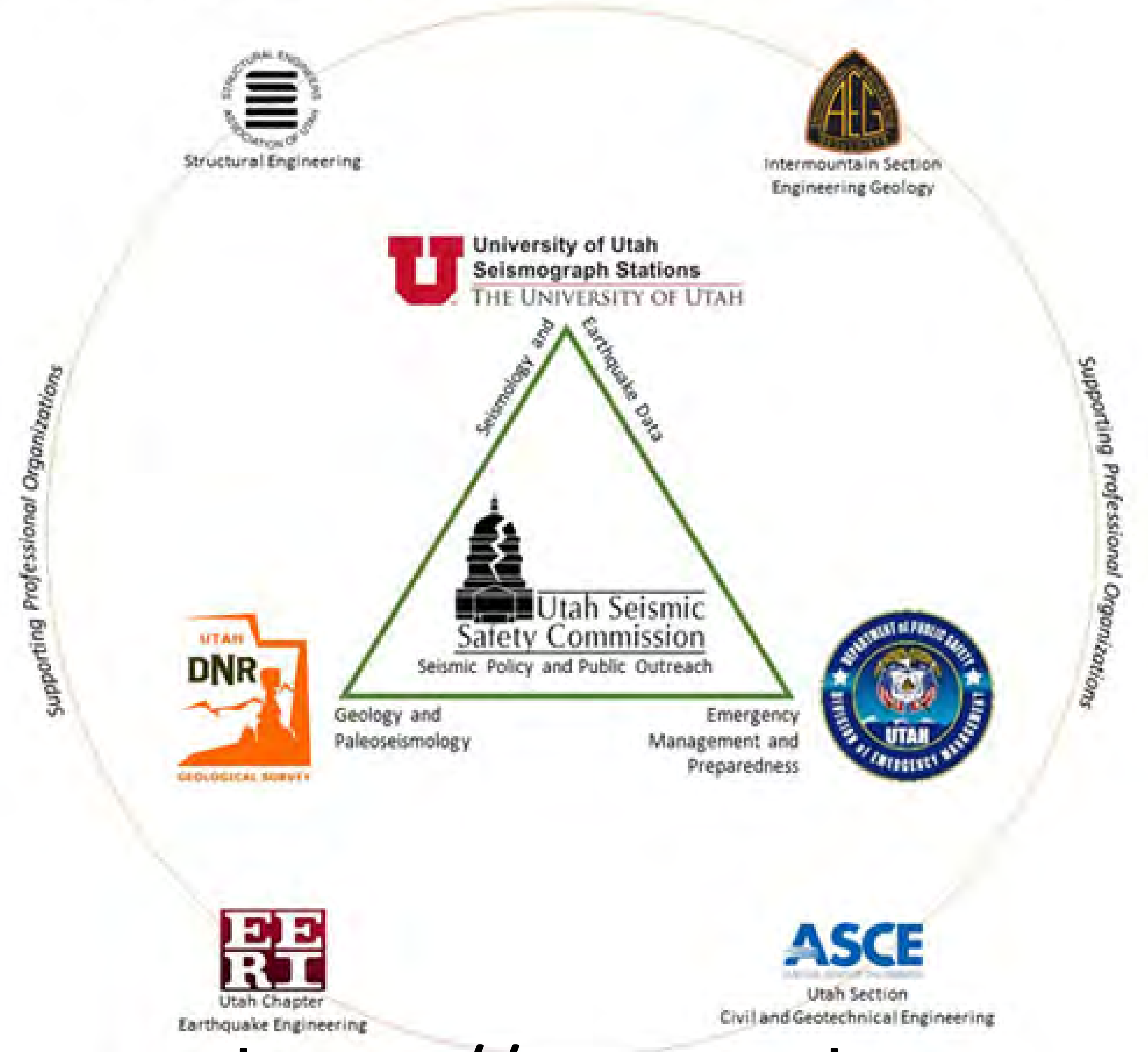


368 West Main Street, Rockville Residence September 29, 2010, Before Fatal December 21, 2013, Rock Fall

December 12, 2013 Rockville Rock Fall (With Two Deaths)

Utah Earthquake Program

an integrated Utah state agency and professional organization partnership to reduce earthquake risk



https://ussc.utah.gov

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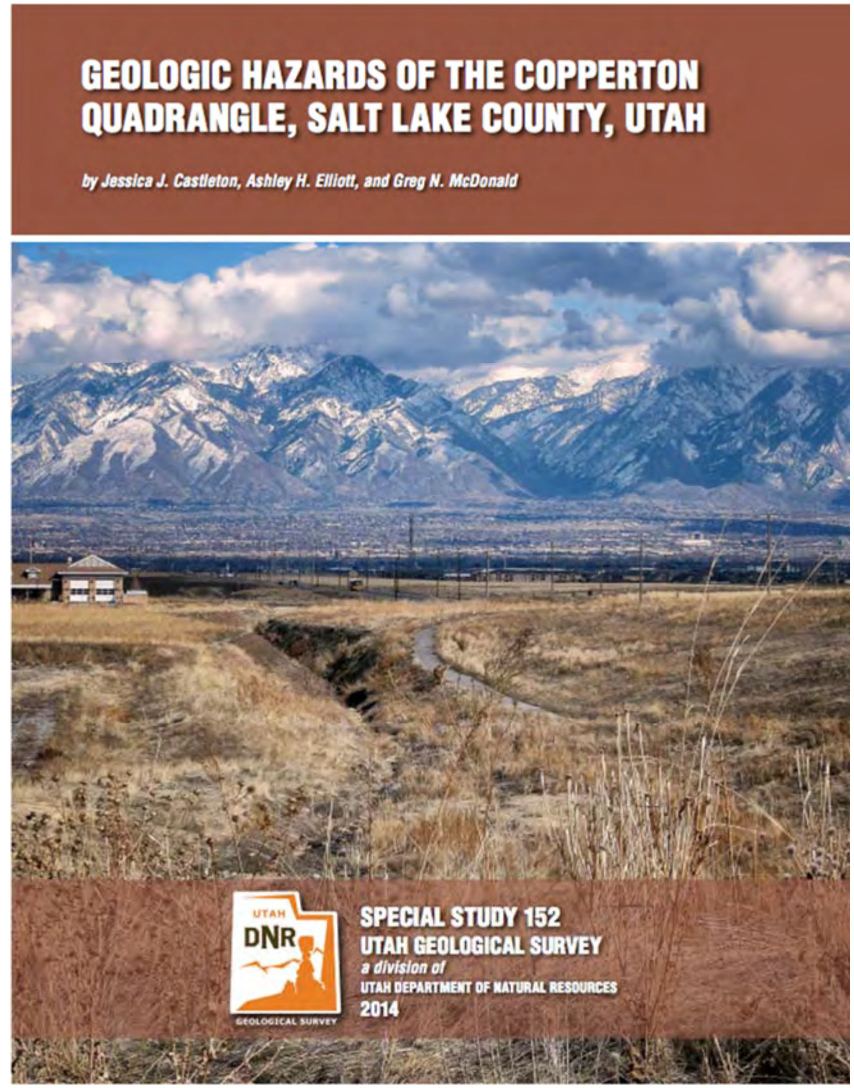
1999/2011+ Sherwood Hills Landslide

February 2010 Rockville Rock Fall

Geologic Hazard Mapping Program

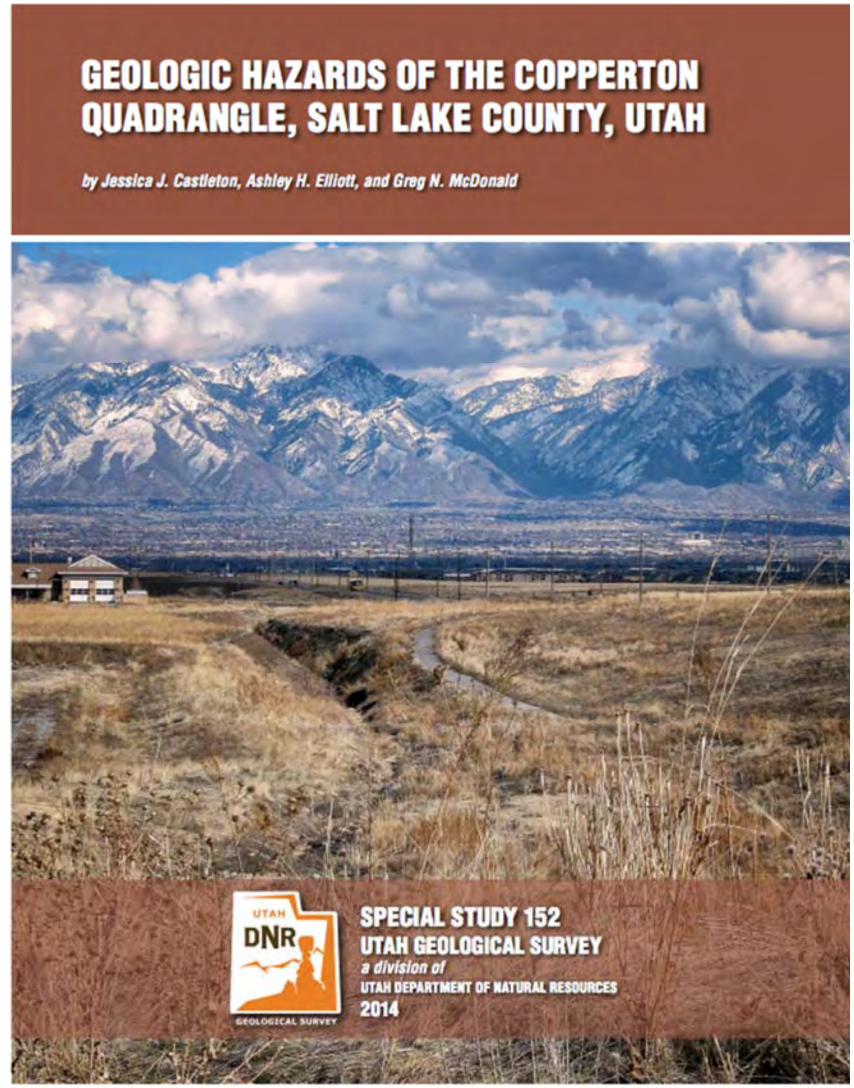
- Intend to provide information on the type and location of critical geologic hazards that may impact existing and future development.
- Incorporate available site-specific geotechnical consultant investigation reports, previous UGS geologic-hazard studies, new UGS mapping, Natural Resources Conservation Service soil data, and field data.



Geologic Hazard Mapping Program

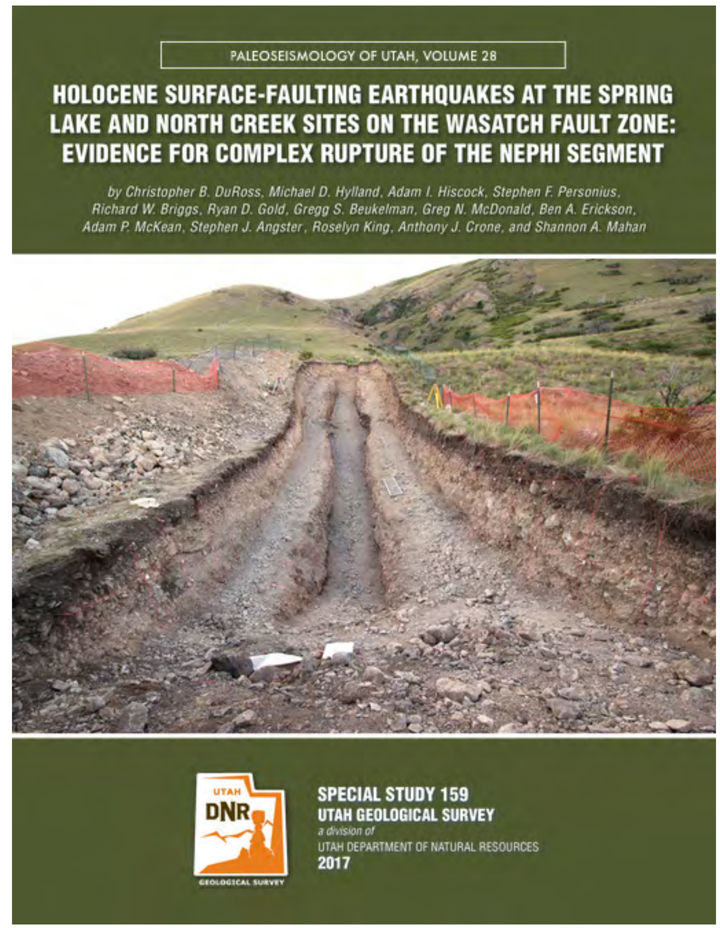
Finish report includes

- Detailed write up of process.
- 1:24,000 scale maps highlighting hazard potential based on geologic deposits and interpretation.
- GIS data for each map.

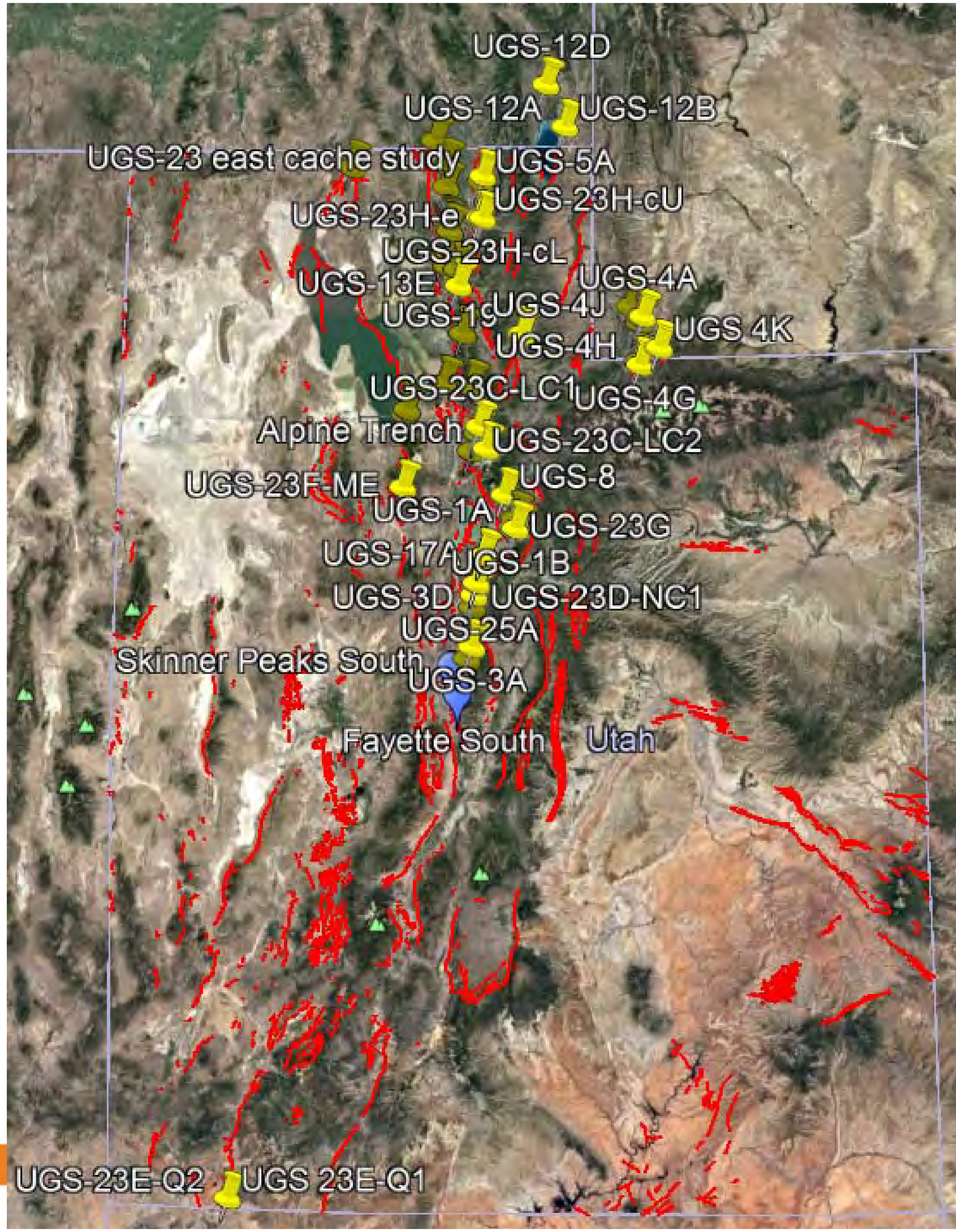


UGS Paleoseismology of Utah Series

- Many NEHRP Final Technical Reports (FTR) are not easily accessible.
  - 2000-current: Available on USGS website
  - Prior to 2000: Very limited availability
- 28 paleoseismic related report and report compilations

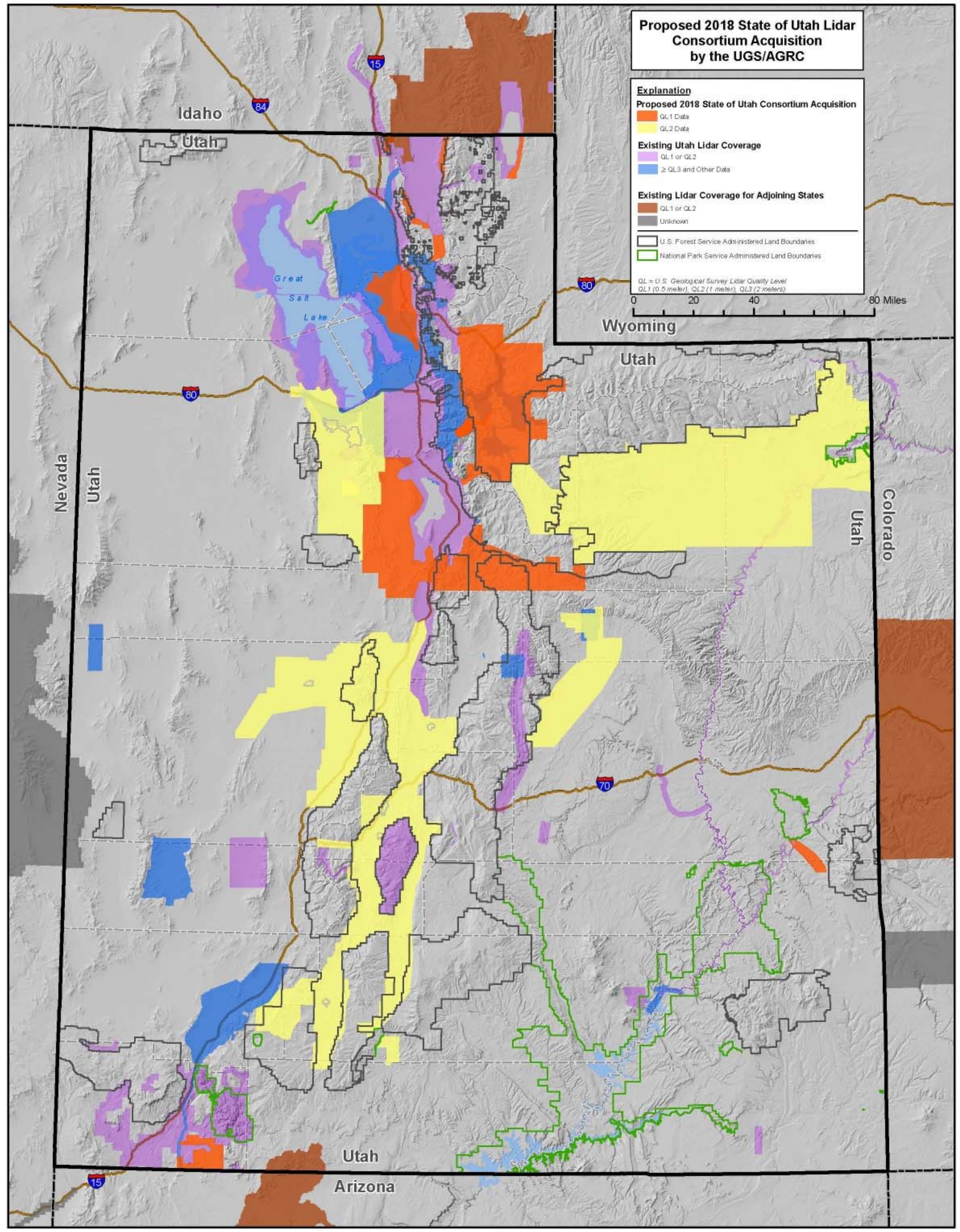


Volume 28
(most recent)


UGS-12D
UGS-12A
UGS-12B
UGS-23 east cache study
UGS-5A
UGS-23H-cU
UGS-23H-e
UGS-23H-cL
UGS-13E
UGS-4A
UGS-19
UGS-4J
UGS 4K
UGS-4H
UGS-23C-LC1
UGS-4G
Alpine Trench
UGS-23C-LC2
UGS-8
UGS-23F-ME
UGS-1A
UGS-23G
UGS-17A
UGS-1B
UGS-3D
UGS-23D-NC1
UGS-25A
Skinner Peaks South
UGS-3A
Fayette South
Utah
UGS-23E-Q2
UGS 23E-Q1

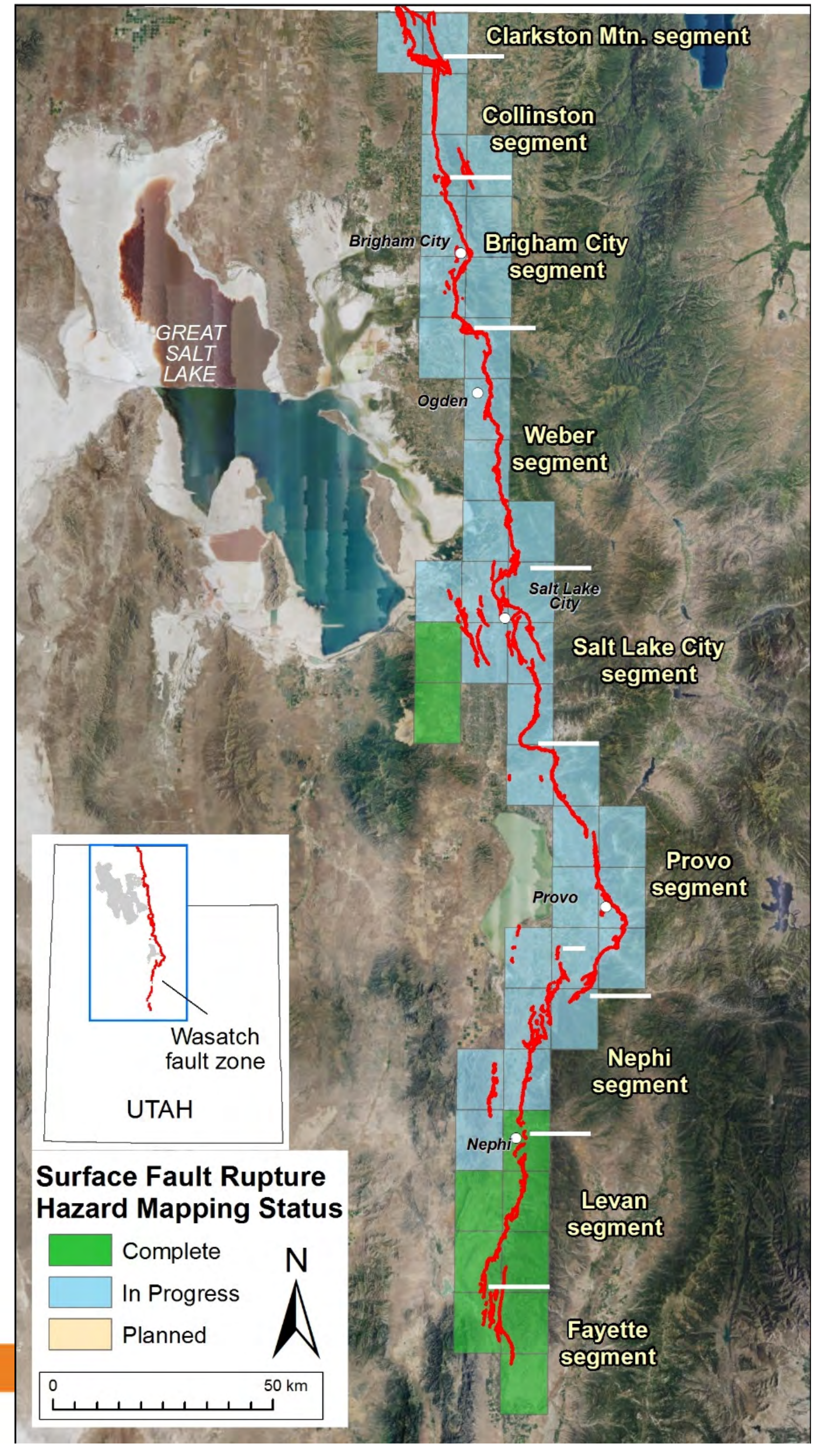
Lidar in Utah

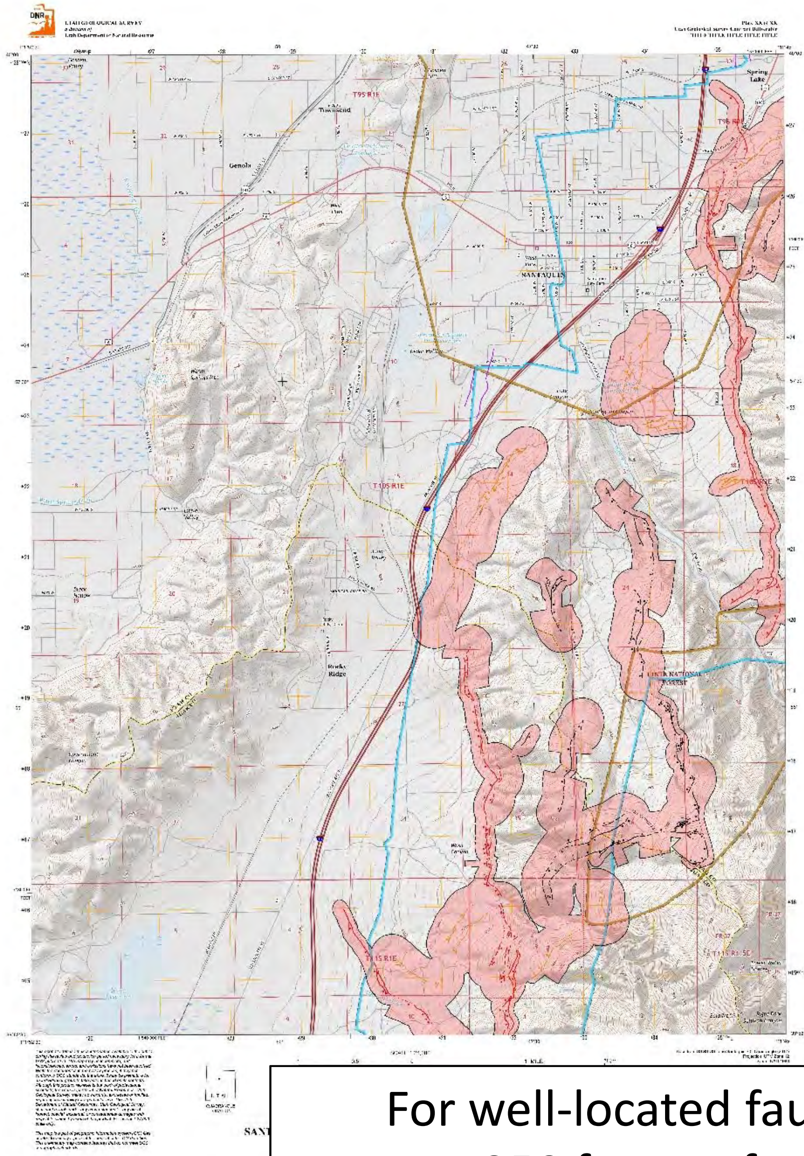
- 2011 to 2017- 6848 sq. mi.
- 2018: ~15,000 sq. mi
- **Multi-agency partnerships are key to lidar acquisition success in Utah.**
- Data is extensively reviewed in house.

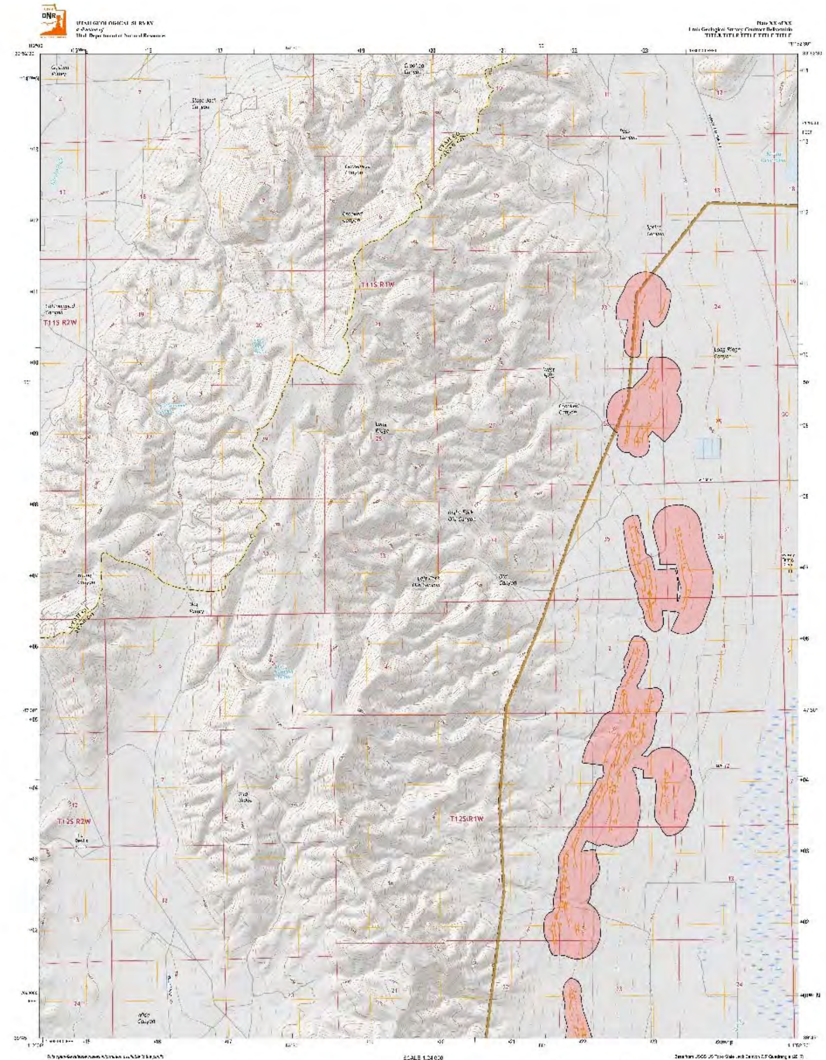


NEHRP funded Wasatch Fault Zone Mapping

- Detailed mapping using high-resolution lidar
- 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*







For well-located faults

250 feet on footwall

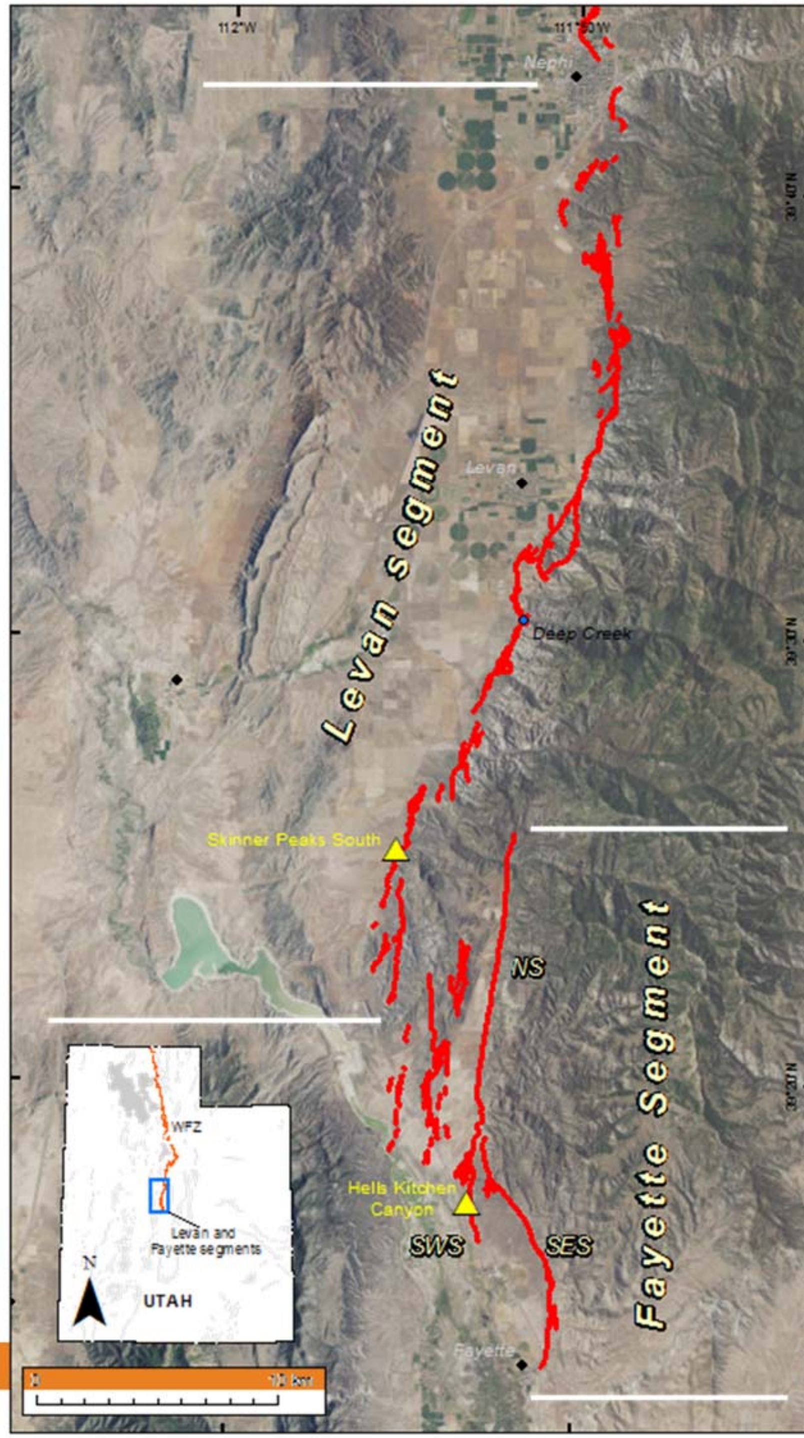
500 feet on hanging wall

For moderately well-located and inferred faults

1000 feet on either side of fault trace

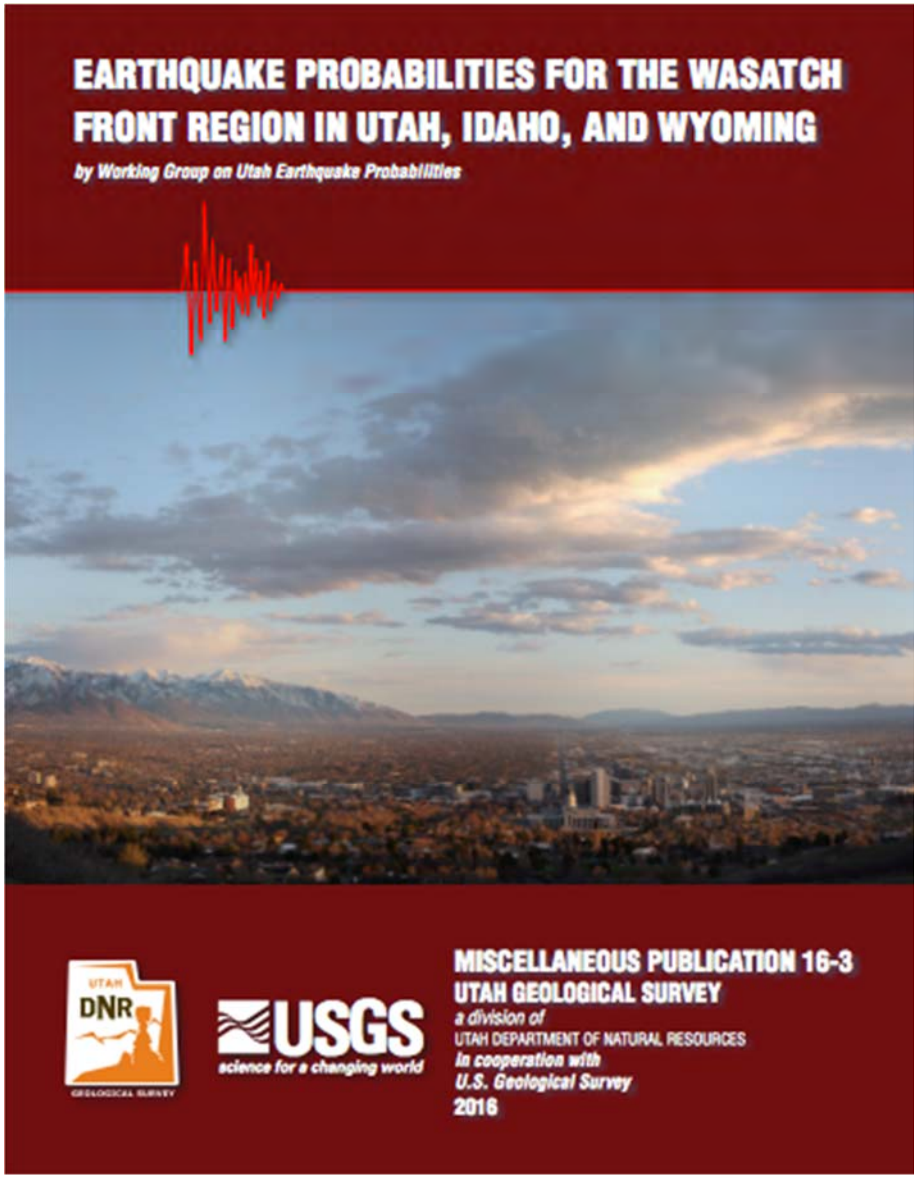
NEHRP Funded
Levan/Fayette Trenches

- Evidence for 2 earthquakes at the Skinner Peaks Site (Levan Segment)
- Evidence for 1 earthquake at the Hells Kitchen Canyon Site (Fayette Segment)



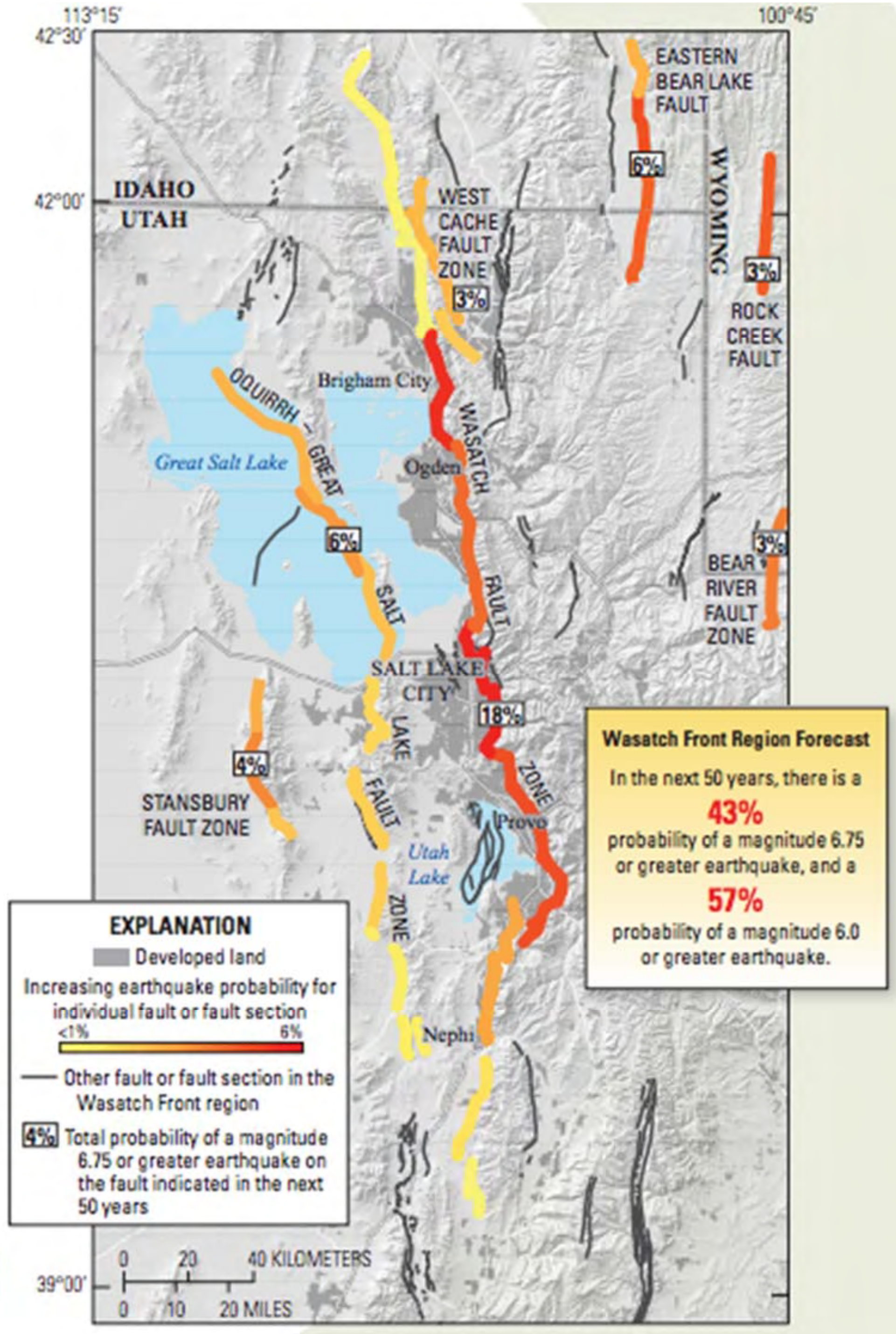
Earthquake Probabilities

- Probabilistic earthquake forecast from the working group for Utah earthquake probabilities (WGUEP).
- (1) combined time-dependent and time-independent probabilities of large earthquakes for the five central segments of the WFZ and two segments of the Great Salt Lake fault zone
- (2) time independent probabilities for less well-studied faults.
- (3) estimates of the time-independent probabilities of background earthquakes not associated with known or mapped faults in the moment magnitude (M) 5.0 to 6.75 range.



Earthquake Probabilities

- Result of the working group for Utah earthquake probabilities (WGUEP).
- 43% probability of at least one M6.75 or greater earthquake in the next 50 years.
- At least 22 surface fault rupturing earthquakes between Brigham City and Nephi in the last 6,000 years.



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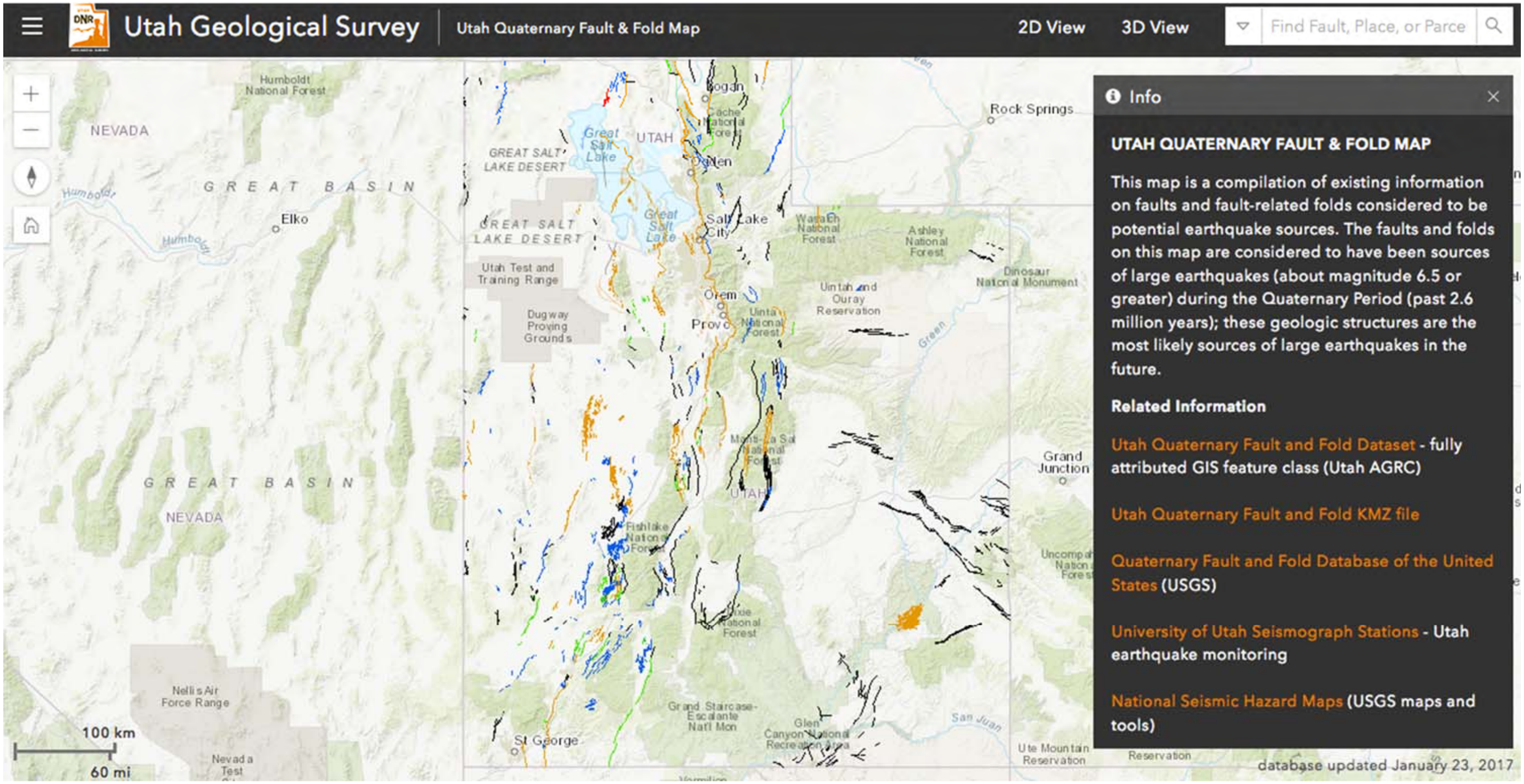
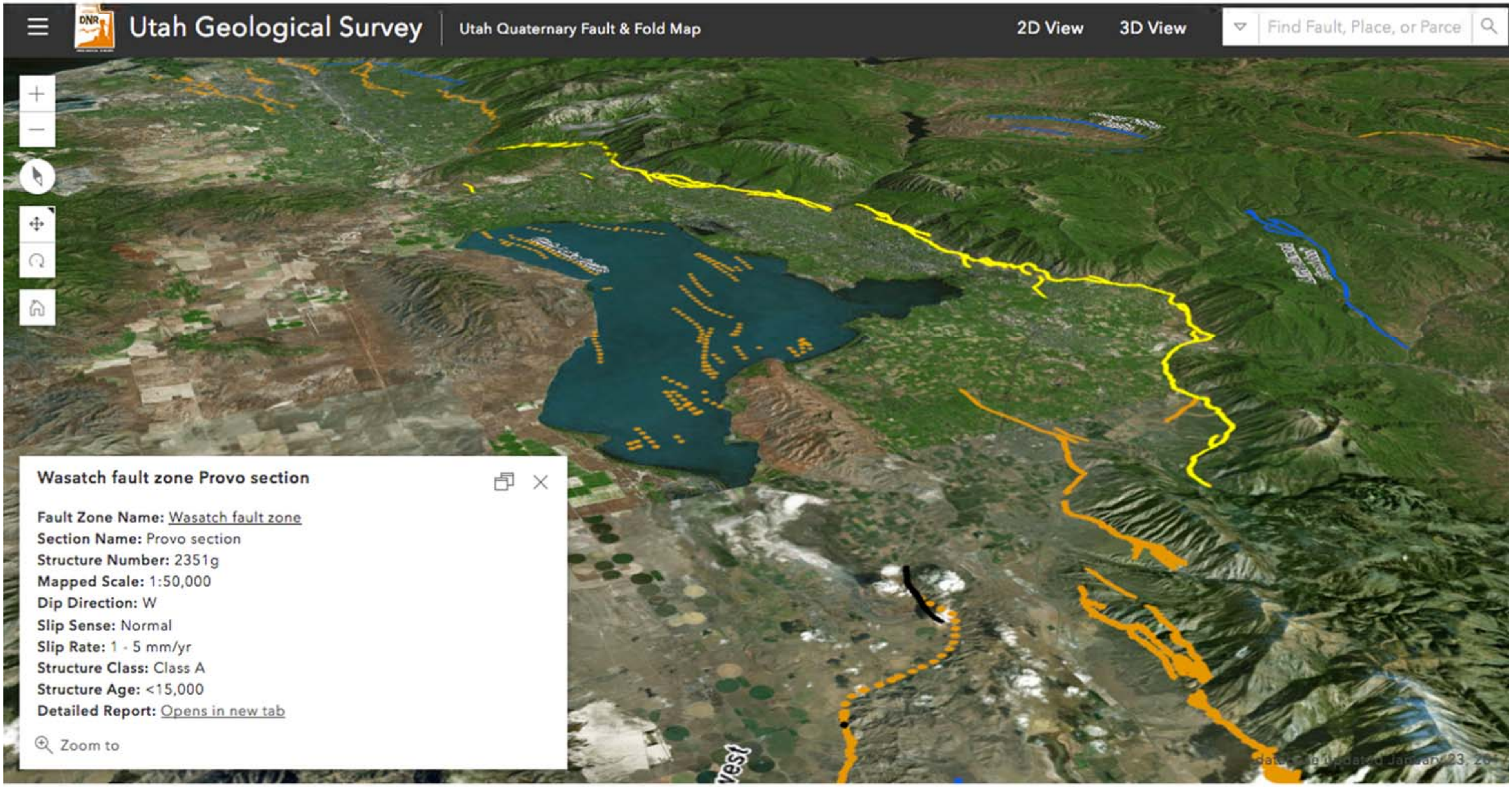
February 2010 Rockville Rock Fall

https://geology.utah.gov

New Q-faults Database interface



New Q-faults Database interface



https://geodata.geology.utah.gov/

UTAH GEOLOGICAL SURVEY | Home | Data Collectio | Log In

Utah Geological Survey GeoData Archive System

The UGS GeoData Archive System, part of our Geologic Data Preservation Project, contains Utah geologic- and wetlands-related scanned documents, photographs (except aerial), and other digital materials (resources) from our files and those gathered from other agencies or organizations in one easy-to-use web-based system. Resources available to general users are all in the public domain and may contain reports submitted to state and local governments as part of permit reviews (and as a result are in the public domain). Metadata describing each resource is searchable, along with spatial searching for resources that are local or site-specific in nature (Geographic Search link in Simple Search pane). Resources representing counties, regional areas, or a larger area are not spatially searchable at this time and must be searched using text-based metadata (Simple or Advanced Search). Individual data collections are accessible using the Data Collections links. Users are also encouraged to search the UGS Library for books and similar materials.

If you find metadata for an resource that is incorrect or missing, you can suggest metadata corrections by clicking on the *Find an Error in the Metadata?* link in the Resource Download and Tools box on the resource view page for each resource. Submissions will be reviewed and updated as needed.

Upon searching for specific resources, they may be viewed directly, or downloaded to your local device. Documents are predominately in text-searchable PDF format. Authorized users may log in for more functionality and resource viewing. Not all resources may be available to all users due to copyright and/or distribution restrictions. Adobe Reader 9 or greater, is needed to view the PDF files. Firefox 9 or greater is recommended for best web browser performance.

Data Collections
Select...
View all

Map Search
Search for resources using an OpenStreetMap or Google basemap and bounding box area.

Air Photo/Imagery Indexes
Scanned aerial photography and imagery indexes of Utah.

Simple Search
Search and explore site content using descriptions, keywords, and metadata (includes full-text PDFs).

- All resources
  - Photo
  - Document
  - Video
  - Audio

Title

Author

County

Keywords

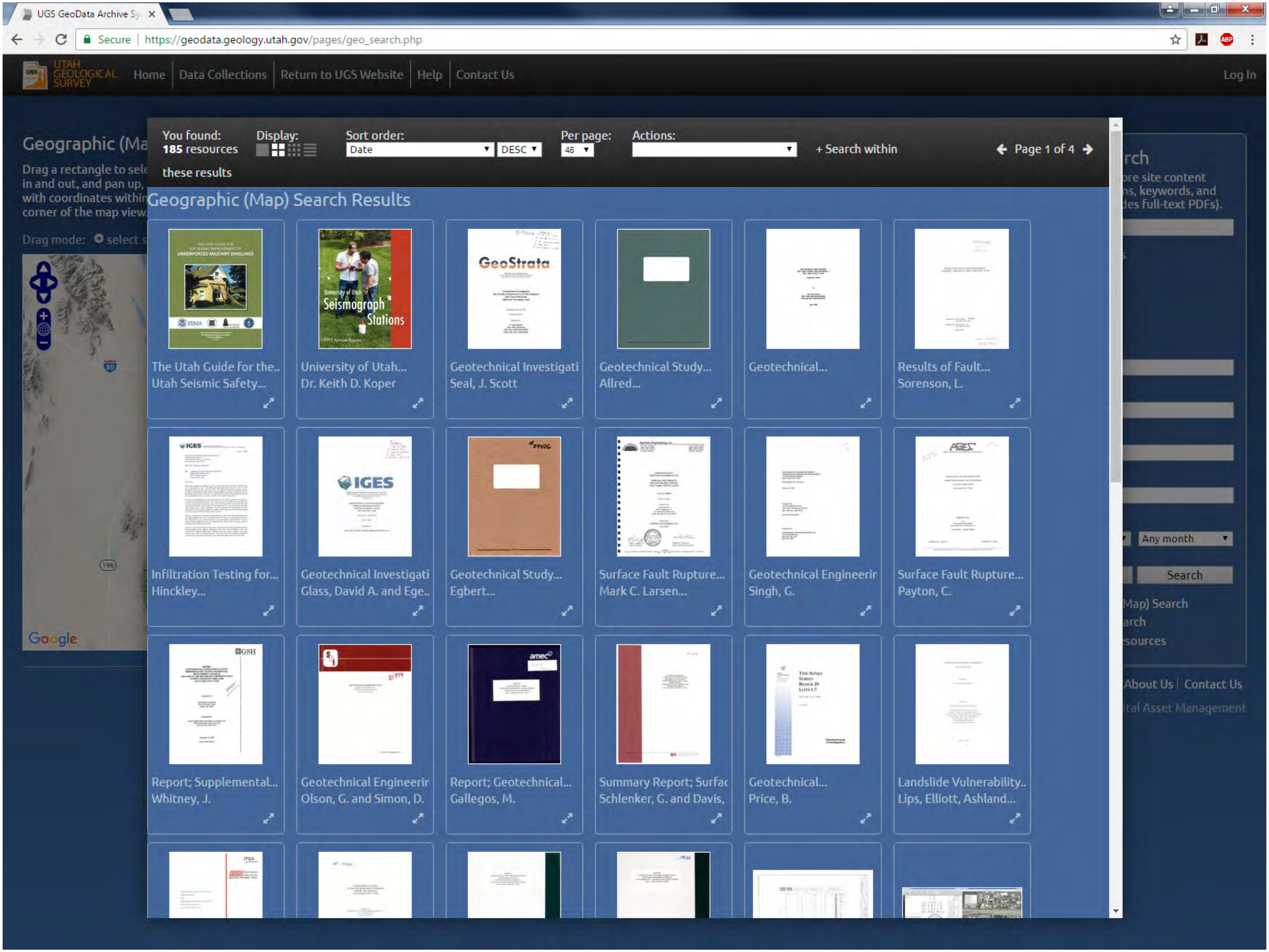
By Date
Any year | Any month

Clear | Search

- Geographic (Map) Search
- Advanced Search
- View New Resources

Announcements
>Metadata Download

>New Items Being Added Weekly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Data Collections
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in and out, and pan up,
with coordinates within
corner of the map view
Drag mode:
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You found:
185 resources
Display:
Sort order:
Date
DESC
Per page:
48
Actions:
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these results
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Utah Seismic Safety...
University of Utah...
Dr. Keith D. Koper
Seismograph Stations
GeoStrata
Geotechnical Investigati
Seal, J. Scott
Geotechnical Study...
Allred...
Geotechnical...
Results of Fault...
Sorenson, L.
IGES
Infiltration Testing for...
Hinckley...
Geotechnical Investigati
Glass, David A. and Ege..
Geotechnical Study...
Egbert...
Surface Fault Rupture...
Mark C. Larsen...
Geotechnical Engineerir
Singh, G.
Surface Fault Rupture...
Payton, C.
Report; Supplemental...
Whitney, J.
Geotechnical Engineerir
Olson, G. and Simon, D.
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Report; Geotechnical...
Gallegos, M.
Summary Report; Surfac
Schlenker, G. and Davis,
Geotechnical...
Price, B.
Landslide Vulnerability..
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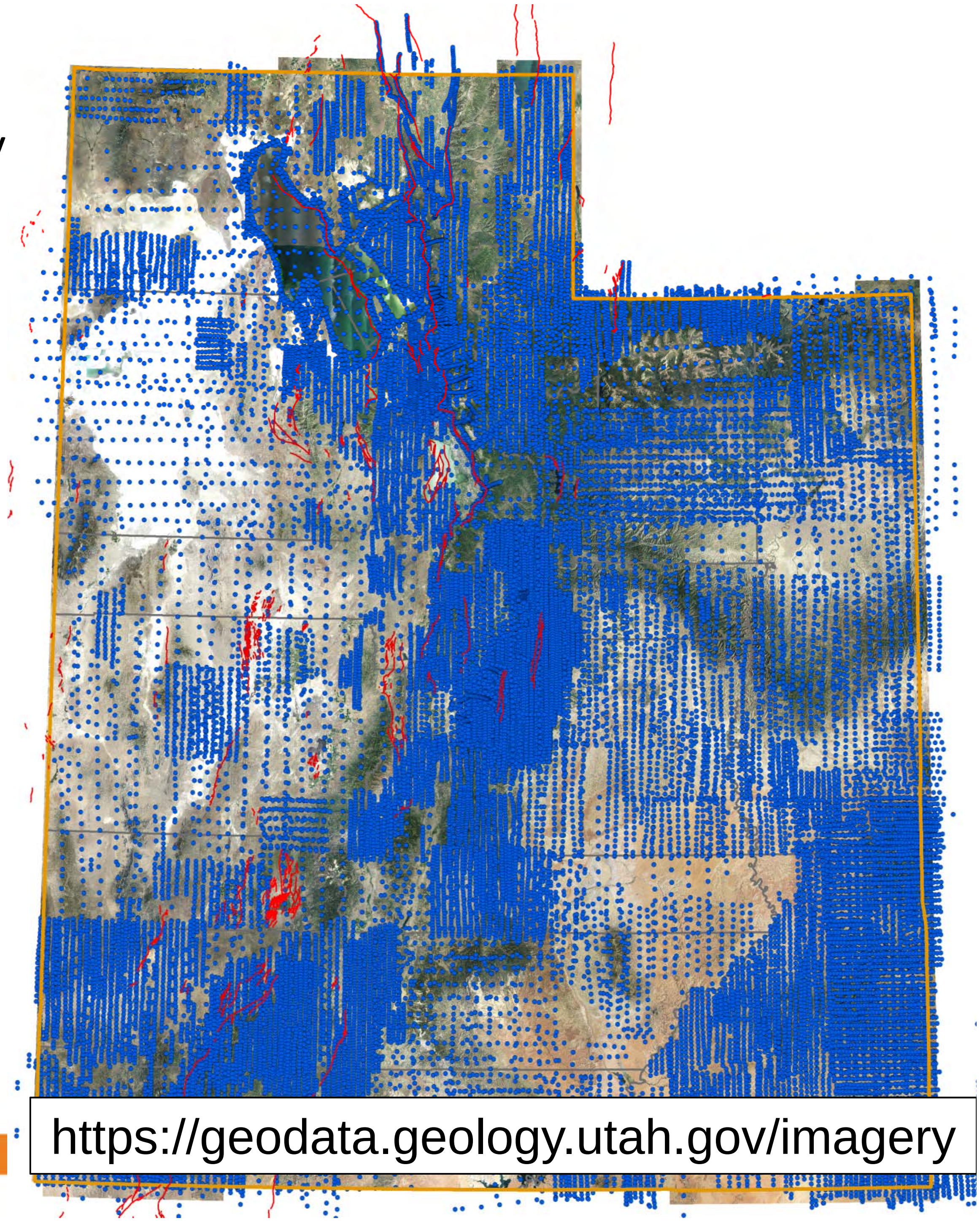
UGS Aerial Imagery Collection

- 96,443 individual photographs.
- Over 230 datasets.
- 1935 to present



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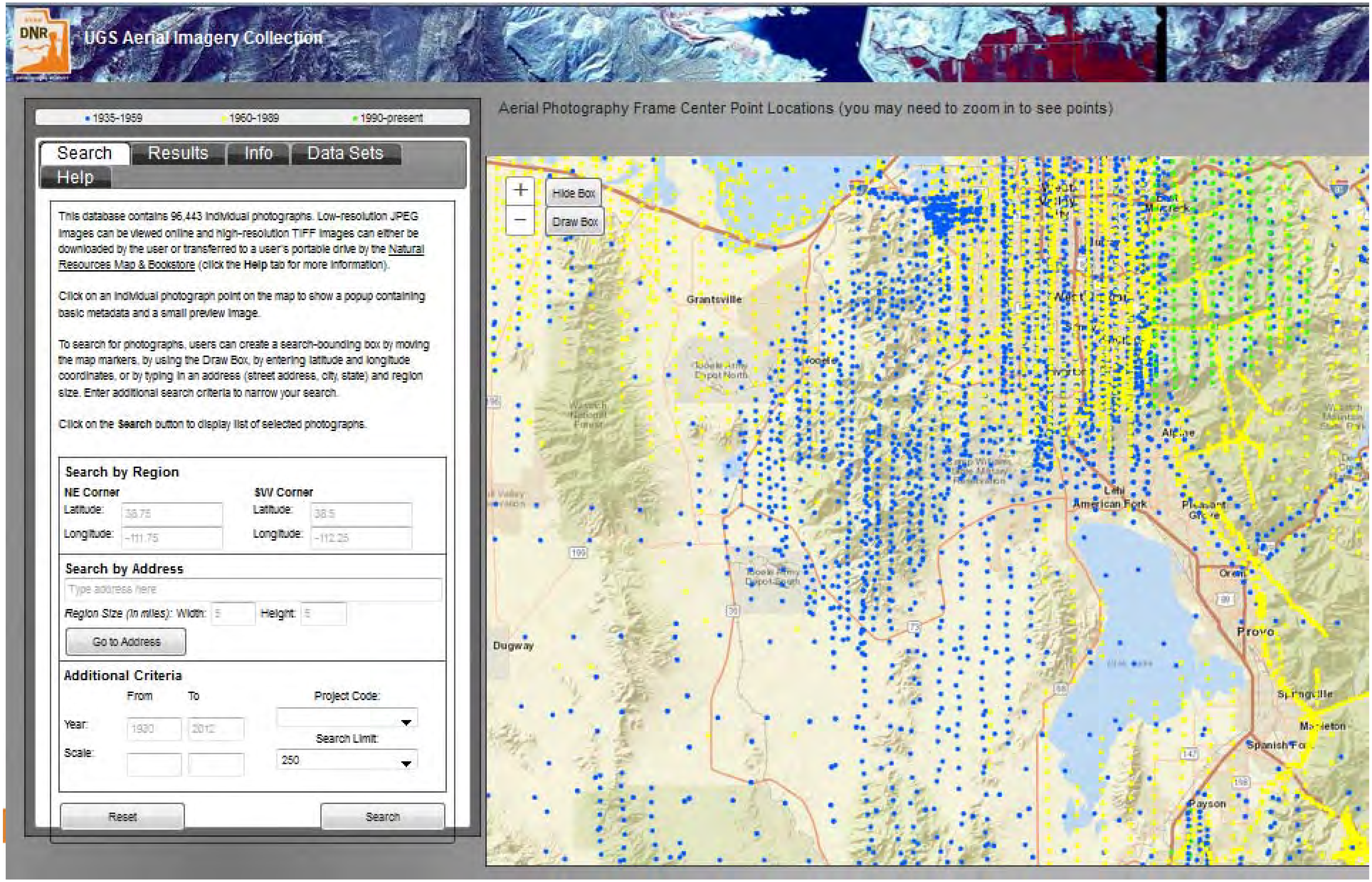


https://quake.utah.edu

U of U Seismograph Stations

Reducing the risk from earthquakes in Utah through research, education, and public service

RECENT EARTHQUAKES

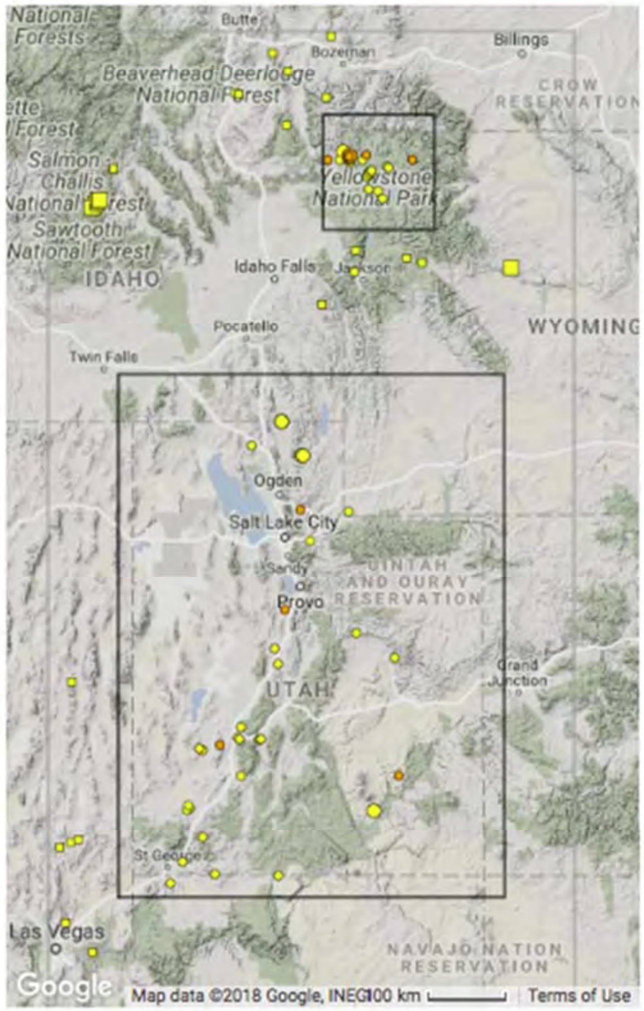
UUSS NETWORK

MAGNITUDE

1
2
3
4
5
6

Last 2 Hours
Last 2 Days
Last 2 Weeks

University of Utah Seismograph Stations



Recent Posts

Magnitude 4.3 near Soda Springs, ID January 26, 2018

Earthquake database for Utah Geological Survey Map 277: Utah earthquakes (1850–2016) and Quaternary faults: Utah Geological Survey Open-File Report 667 November 8, 2017

Sulphur Peak Earthquake Information October 3, 2017

Magnitude 3.4 earthquake near Monroe, UT September 25, 2017

Magnitude 3.3 near Park City, UT September 18, 2017

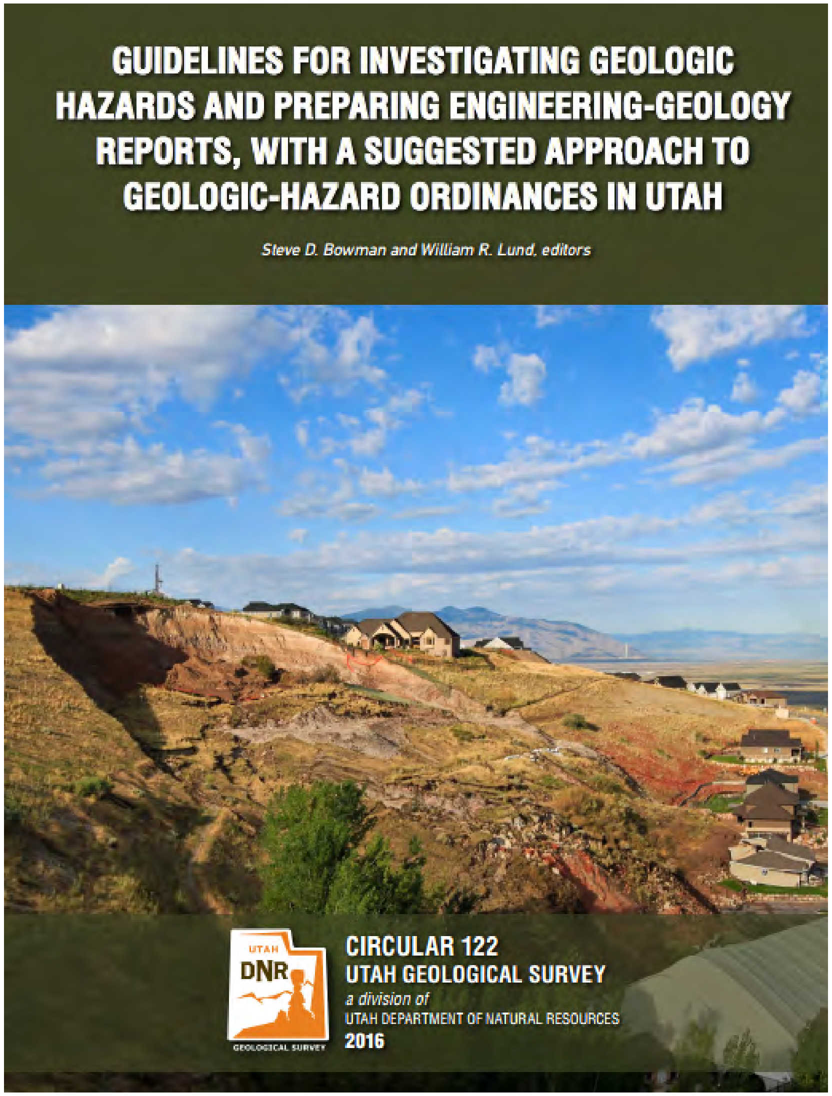
Tweets by @UUSS_Quake_Info

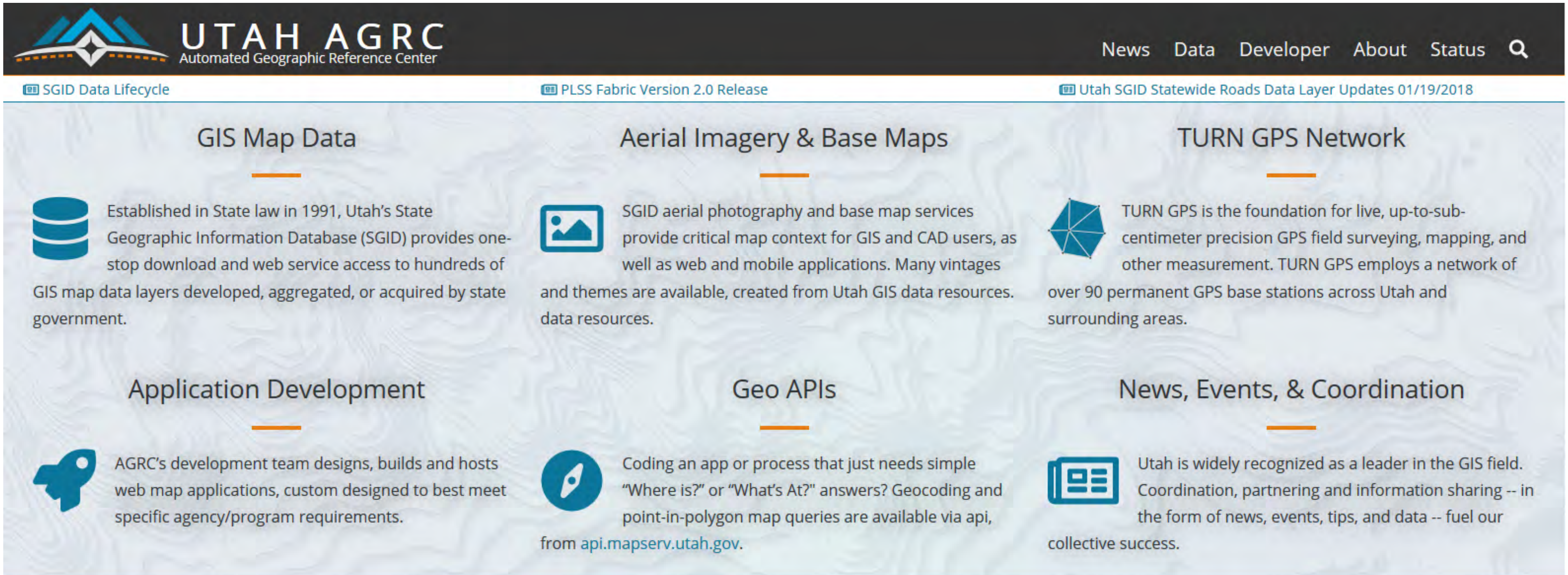
UTAH DNR GEOLOGICAL SURVEY

.utah.gov

Geologic Hazards Guidelines (2016)

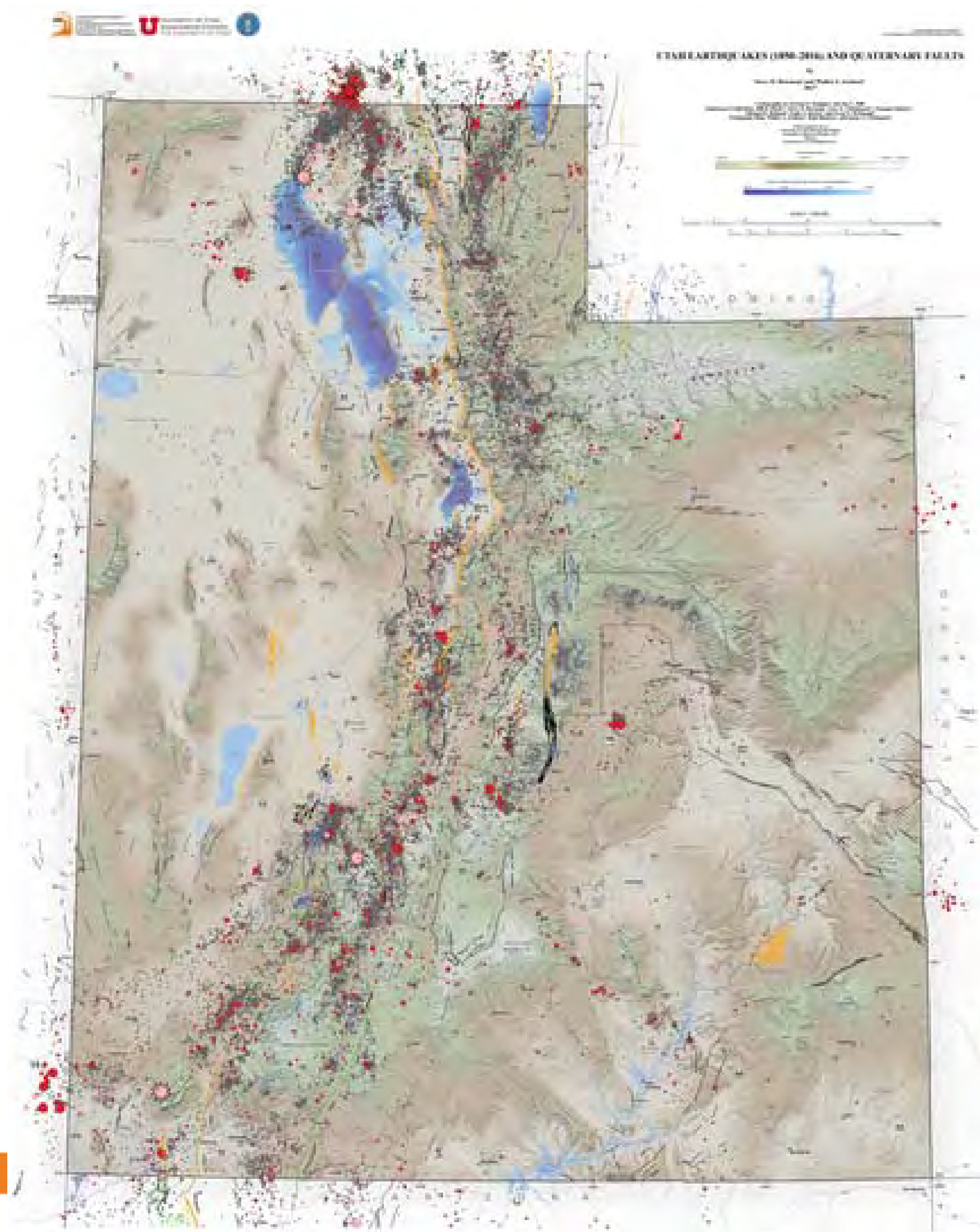
- Engineering Geology Reports (2016)
- Surface-Fault-Rupture (2003)-
- Debris Flows and Alluvial Fans (2005)
- Geologic Hazard Ordinances (1987)
- Rock Fall (new)
- Ground Subsidence and Earth Fissures (new)





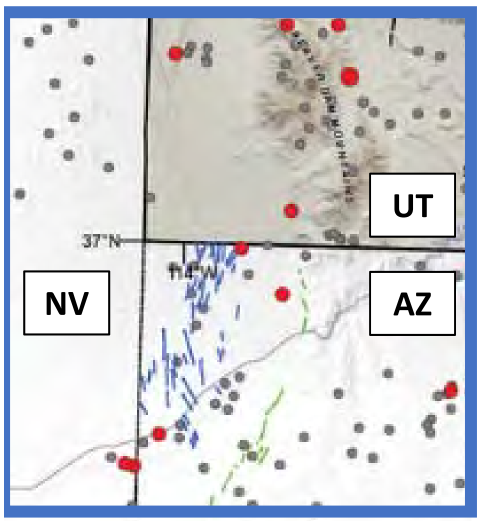
- Utah Automated Geographic Reference Center (AGRC)
- State of Utah's map technology coordination office.
- Started 1984

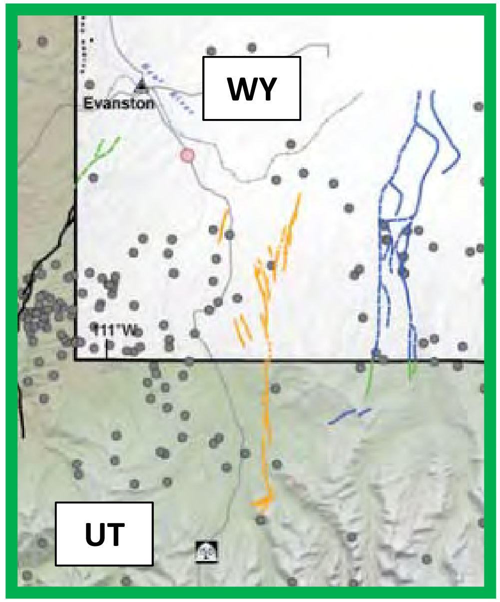
Discussion Point 1- Cross Border Faults

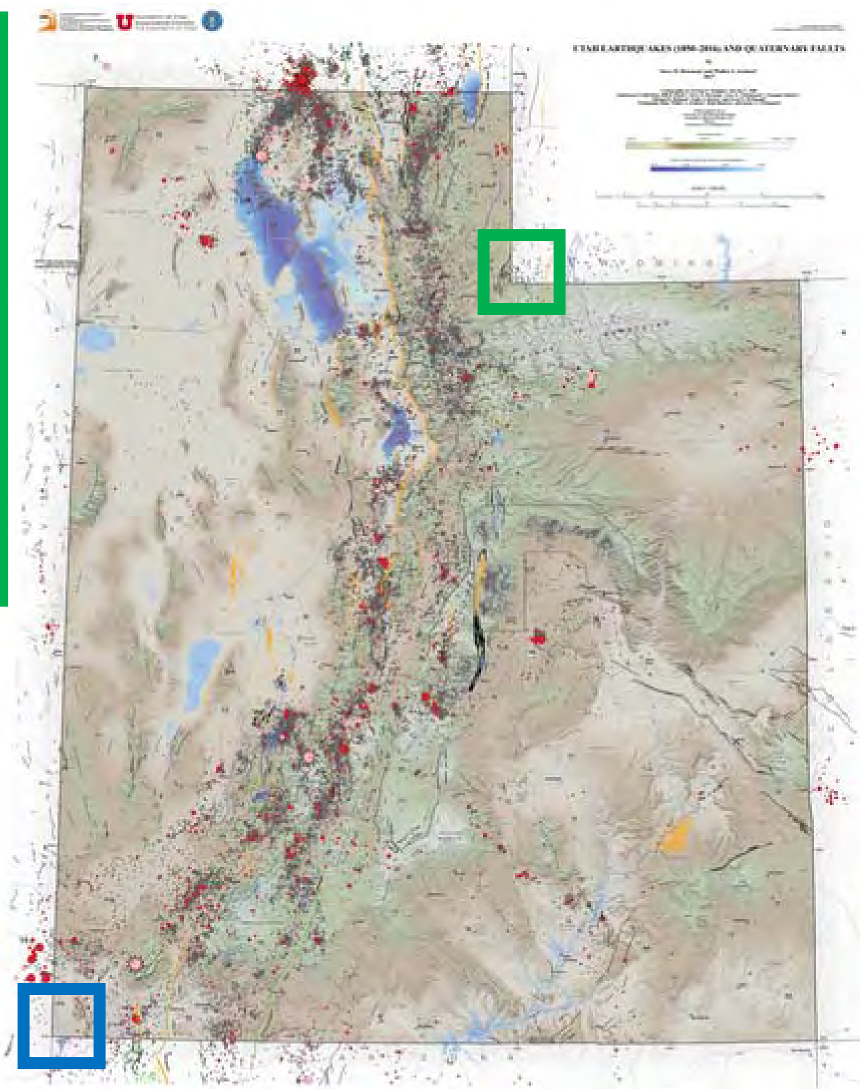


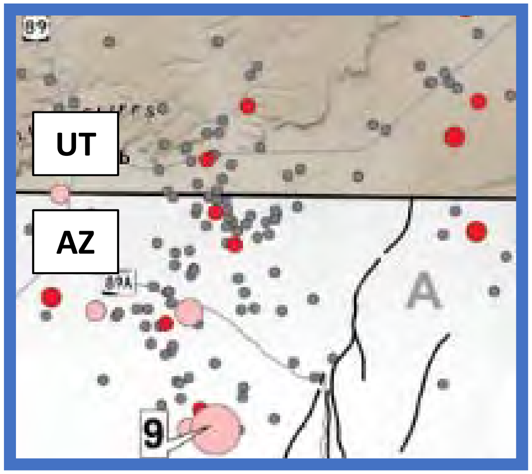
UTAH
DNR
GEOLOGICAL SURVEY

Littlefield Mesa faults

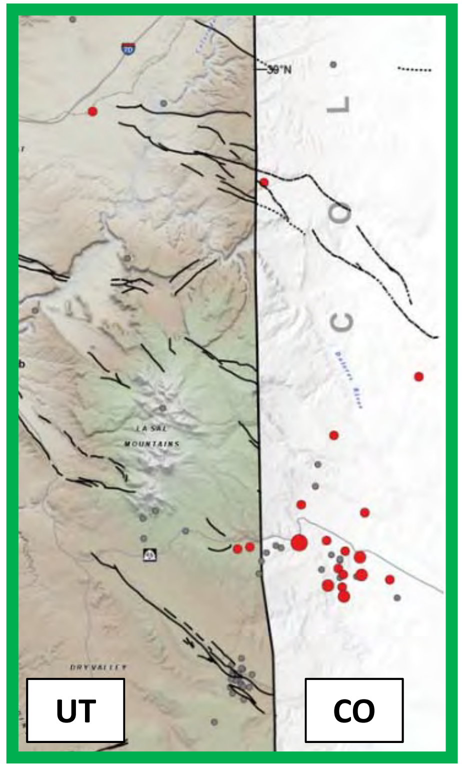




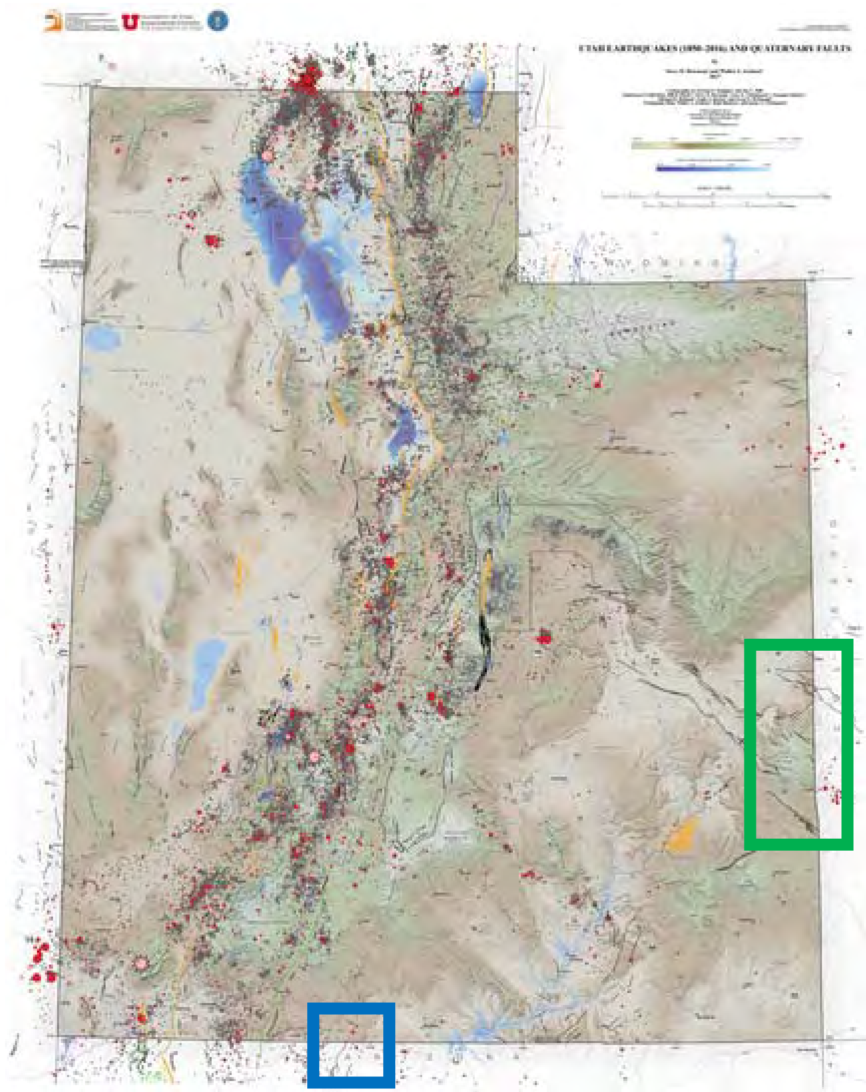




West Kaibab fault system

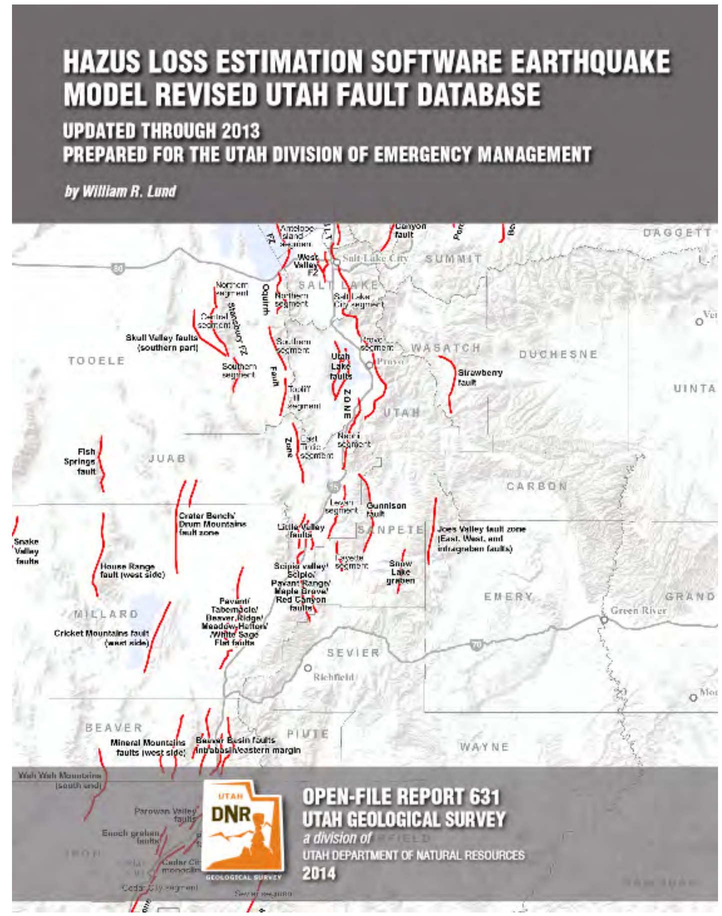


Lisbon Valley fault zone
Simbad Valley Graben
Paradox Valley Graben
Ryan Creek Fault zone



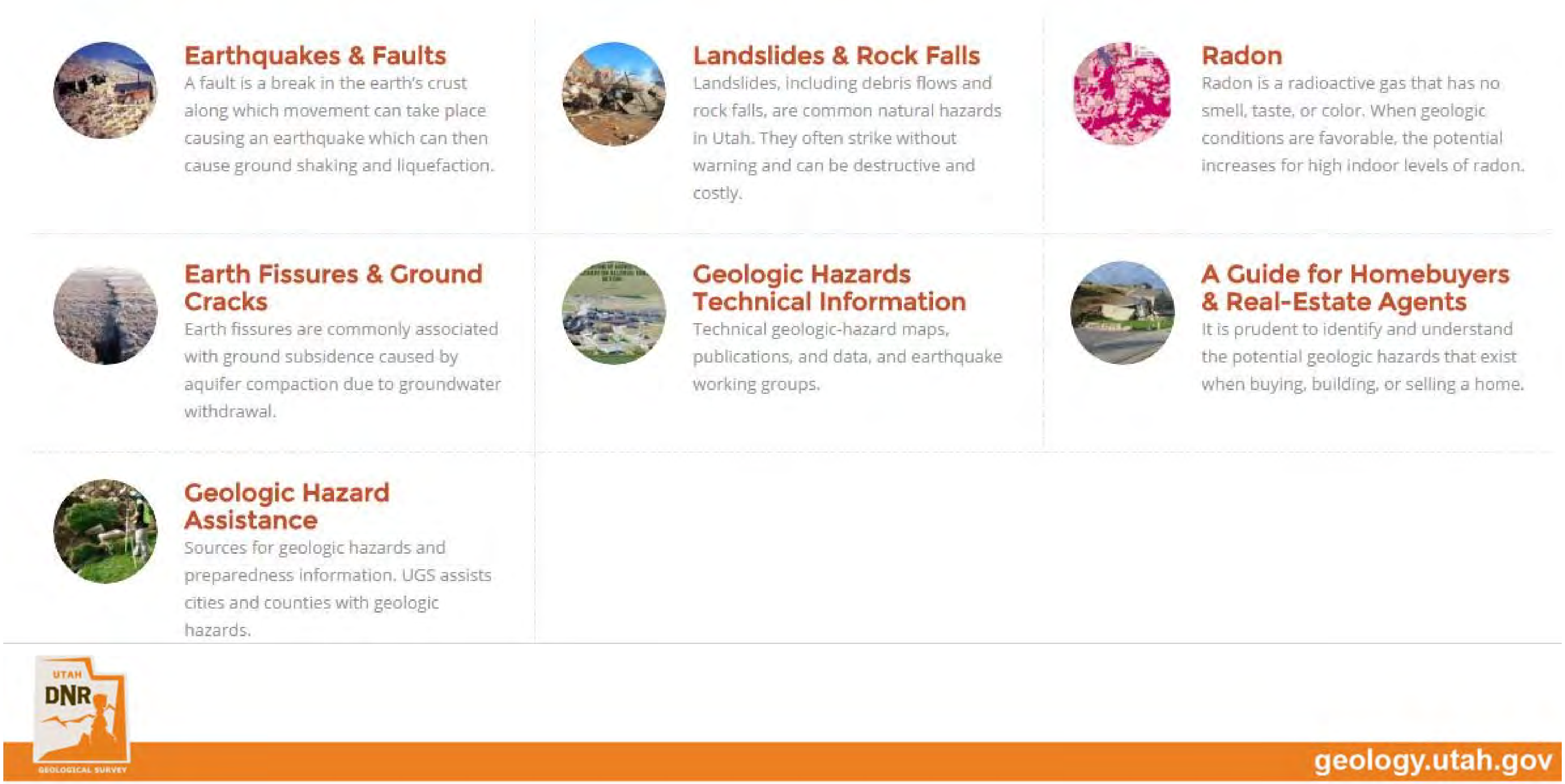
Discussion Point 2- Cross Border Fault Parameters Consensus

- Already have parameters for HAZUS and probabilities working group
  - East and west Bear faults
  - East and West Cache Valley Faults
  - Washington Fault
  - Hurricane Fault
- Other faults for consensus?



Thank you.

geology.utah.gov/hazards/

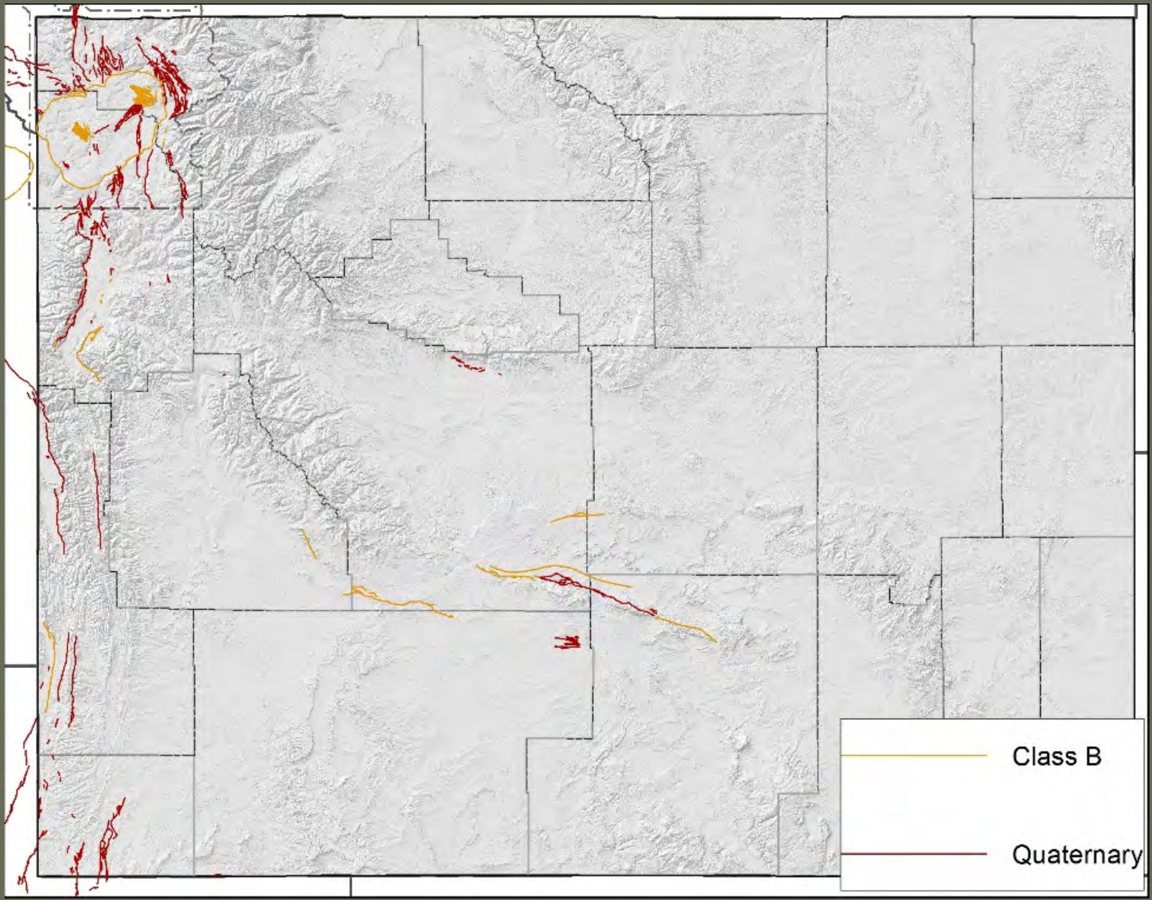


Updates and Highlights from Wyoming

Seth Wittke
Wyoming Geological Survey
BRPEWG - 2018

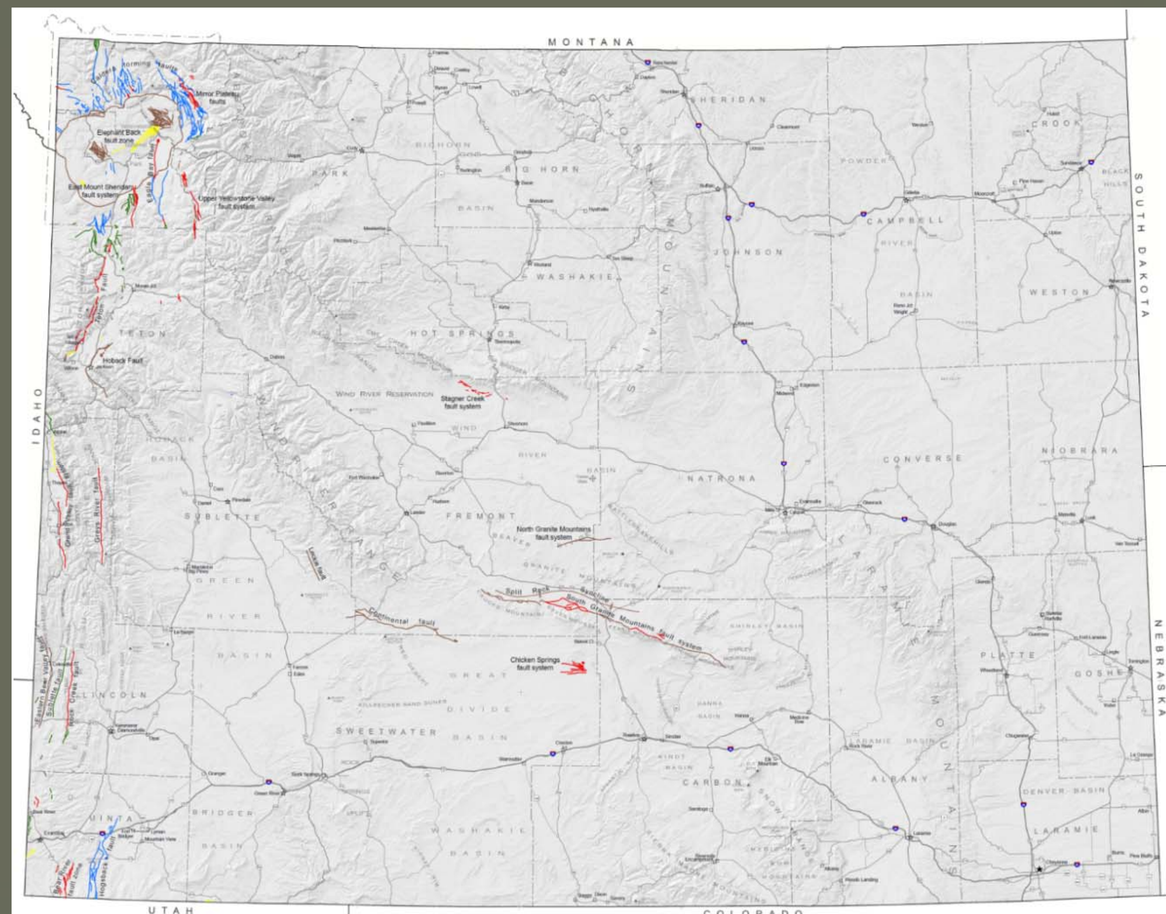
Quaternary-aged faults in Wyoming

- ~ 60 faults
  - Includes Class B
  - Primarily in BRP
  - Some outliers
- Few actually cross state lines
  - Events carry multi-state consequences



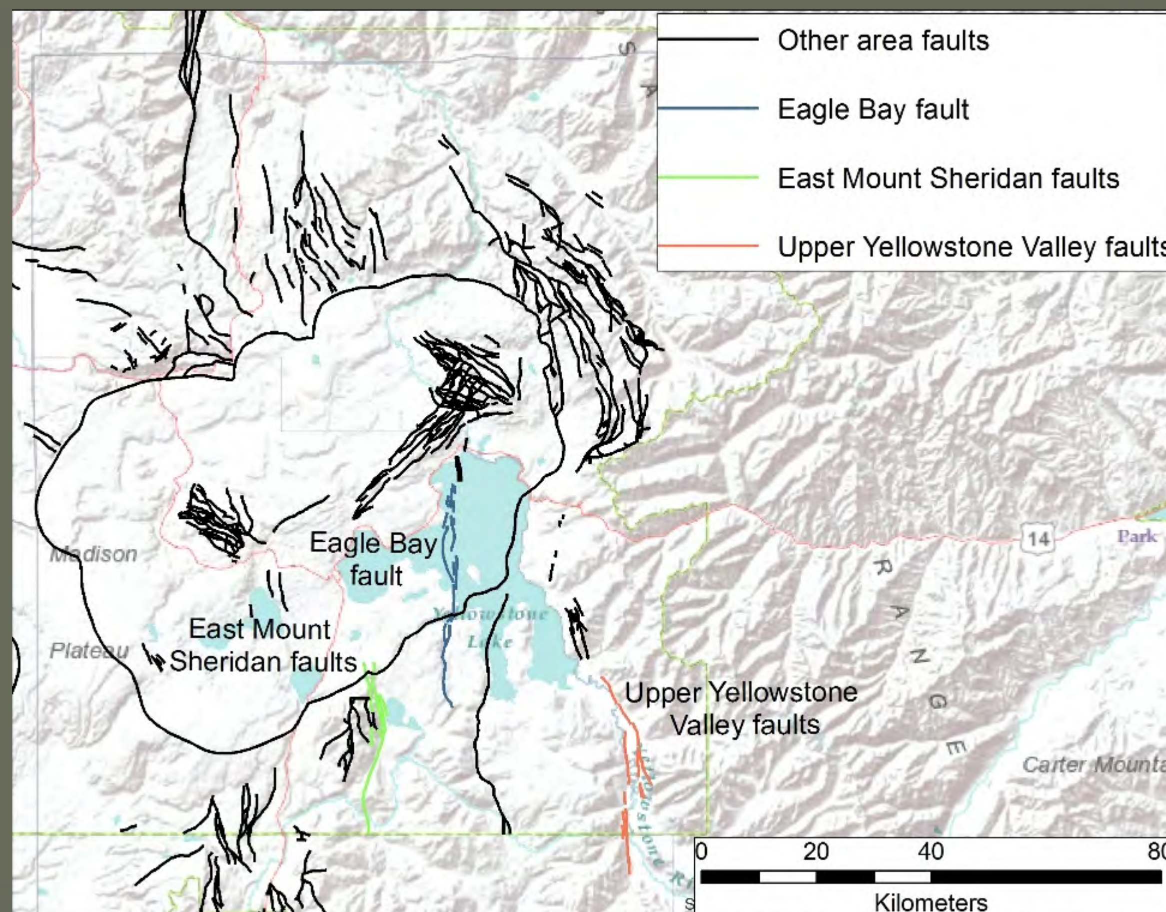
Priorities

- 2015 BRPSHS II meeting
  - Teton
  - Grand Valley
  - Rock Creek
  - South Granite
  - Everything else



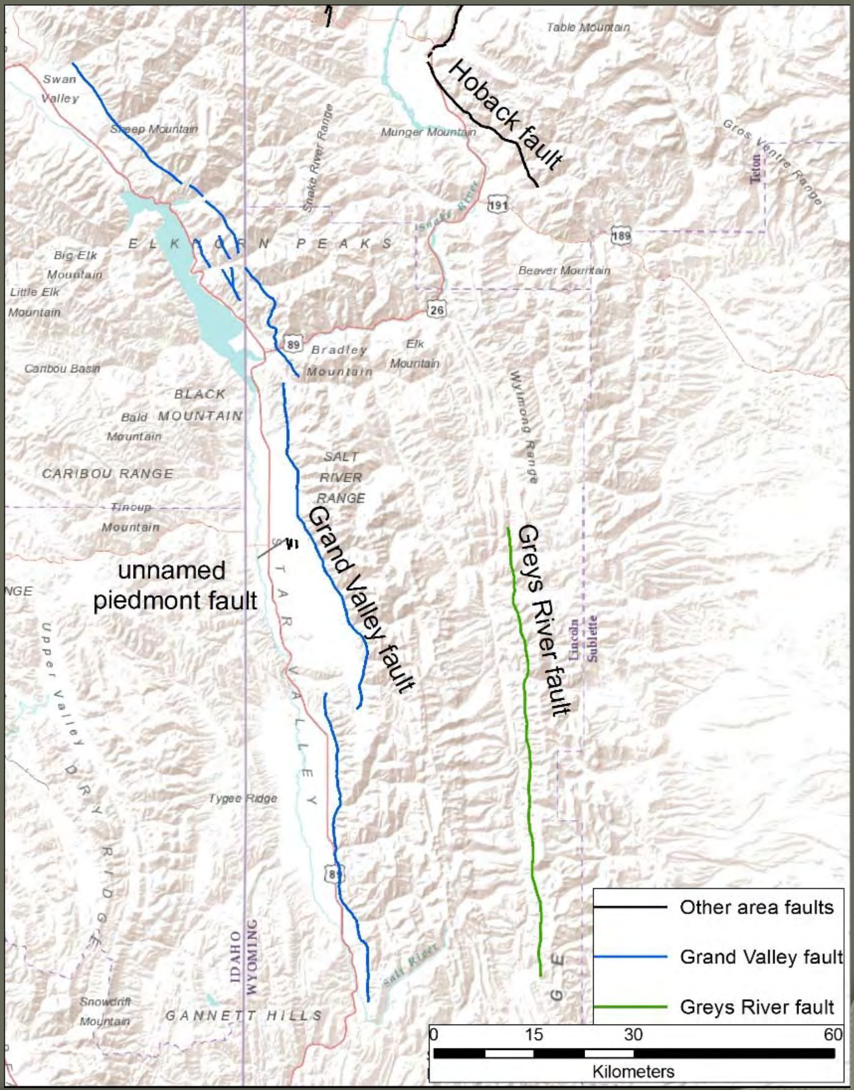
Yellowstone faults

- Three "main" systems
- Remote
- Multi-agency involvement
  - YVO



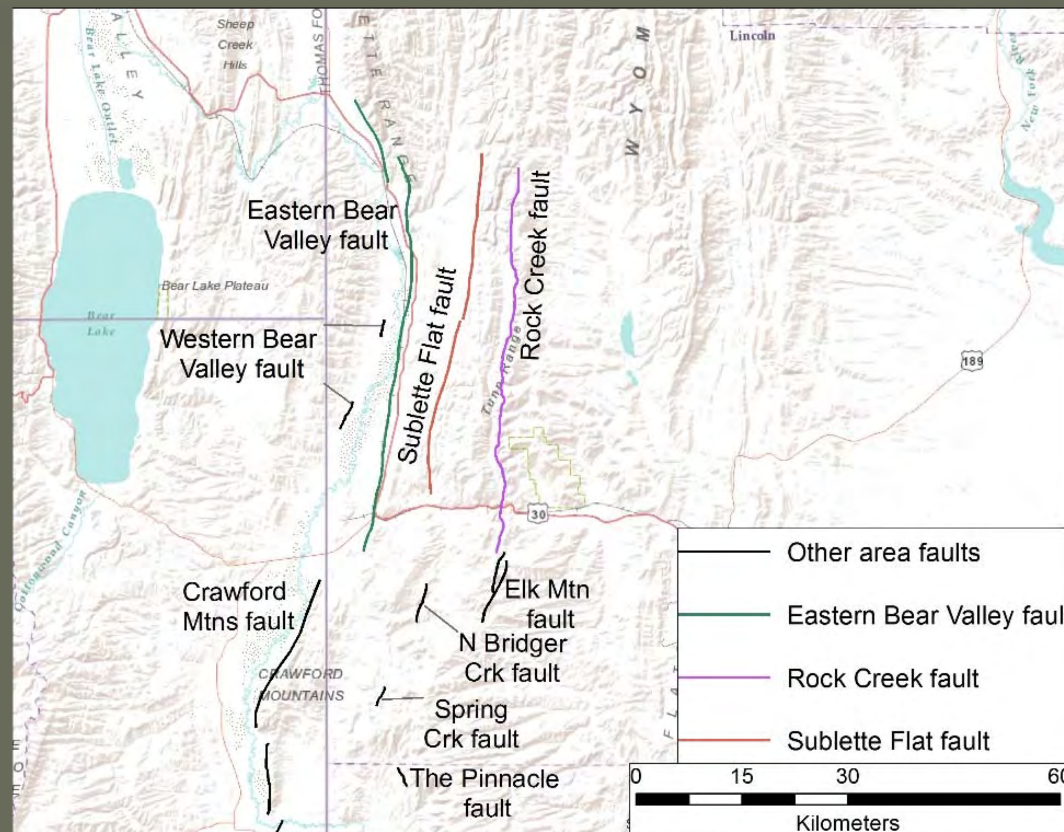
Grand Valley system

- Shared with Idaho
  - Grand and Swan valley (northern) sections considered less active
  - Not as obvious as Prater Mtn and Star Valley to the south



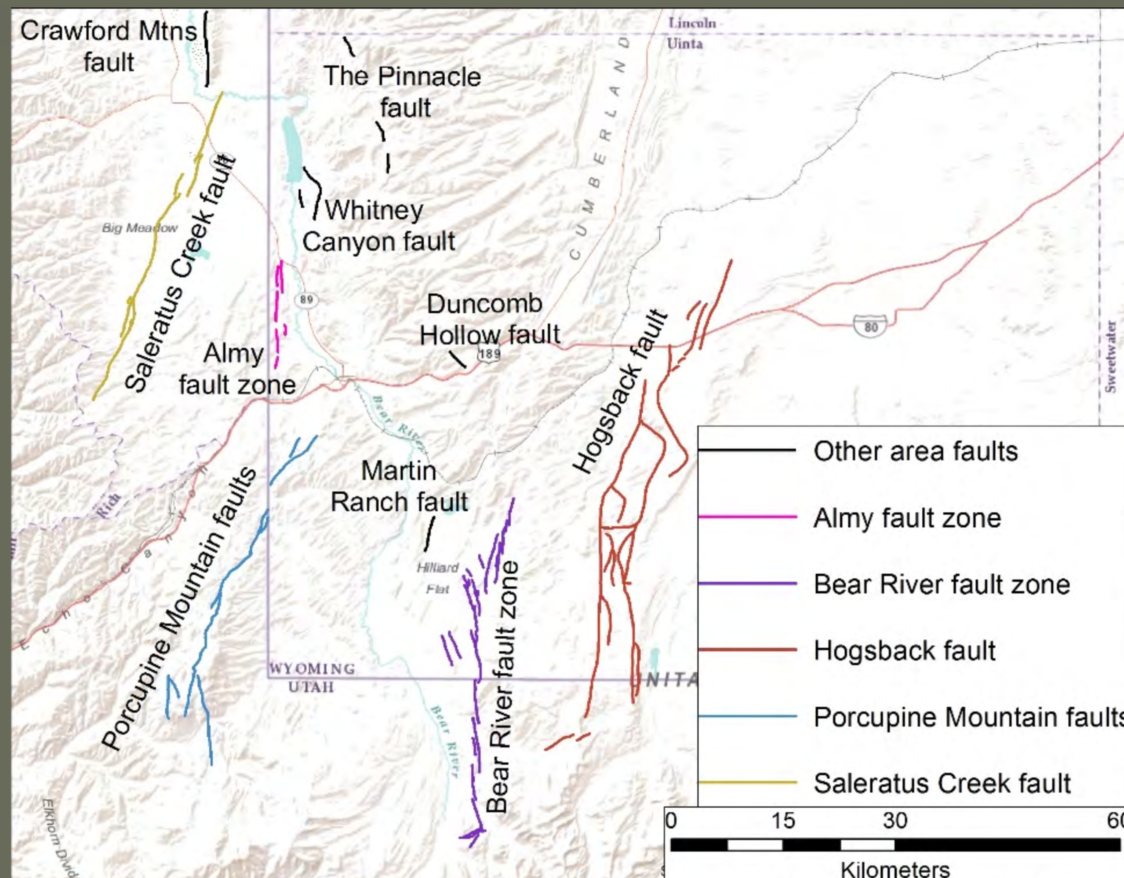
Tunp Range area

- Rock Creek fault
  - Northern extend coincides with Afton 30x60 boundary
  - Relationship to other area faults unclear
- Sublette Flat and Bear Valley faults are less obvious
  - However the relationship to Crawford Mtns is also unclear



Southwest Wyoming

- Numerous crossing, or near-crossing faults
  - Highly variable level of understanding

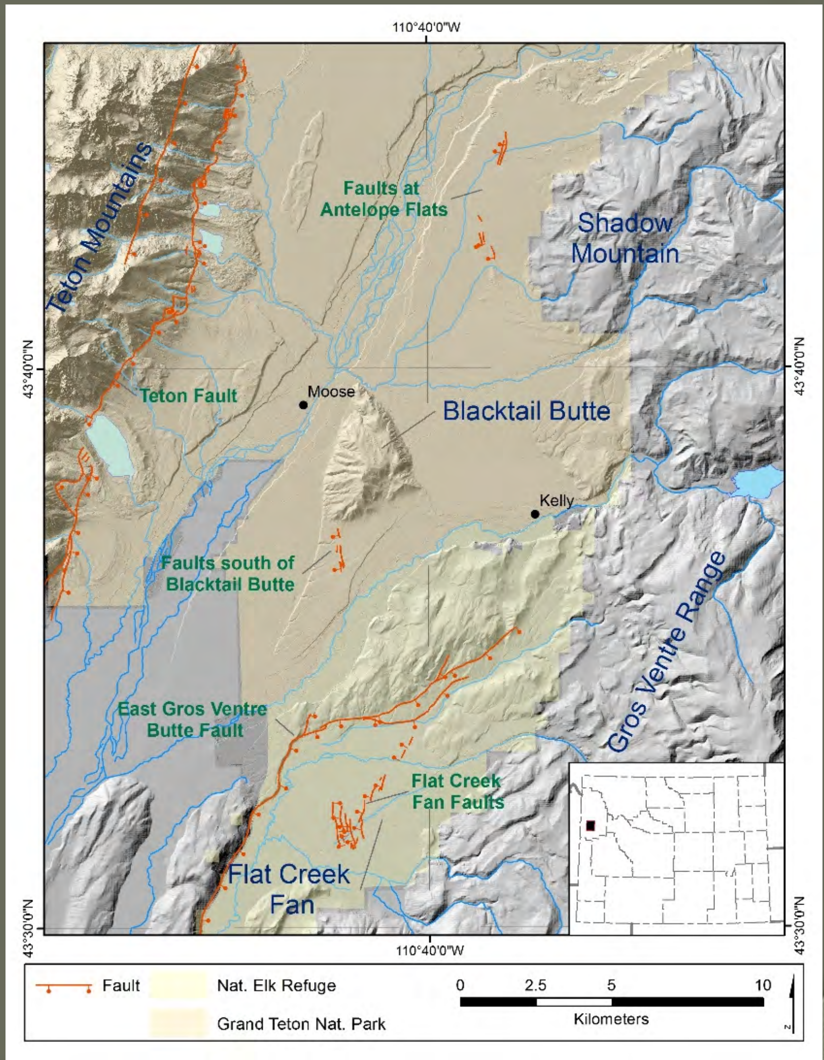


Current paleoseimic work

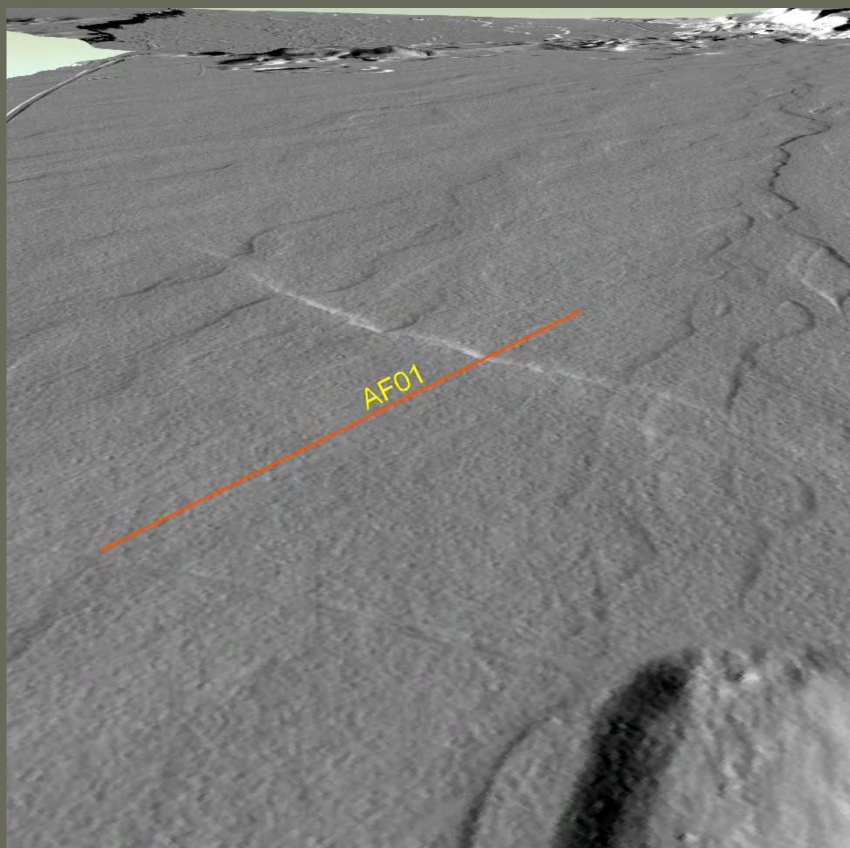
- Buffalo Bowl
  - Fall 2017
- Leigh Lake and Steamboat Mtn
  - ISU
  - USBOR
  - Zellman and others
- Jenny Lake
  - Oxidental

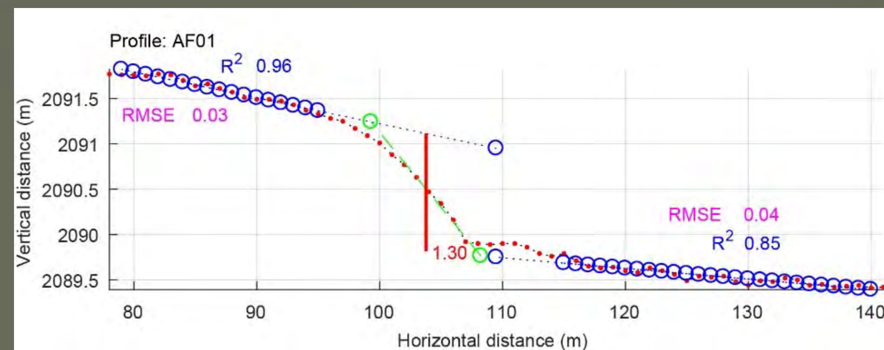
Recent work

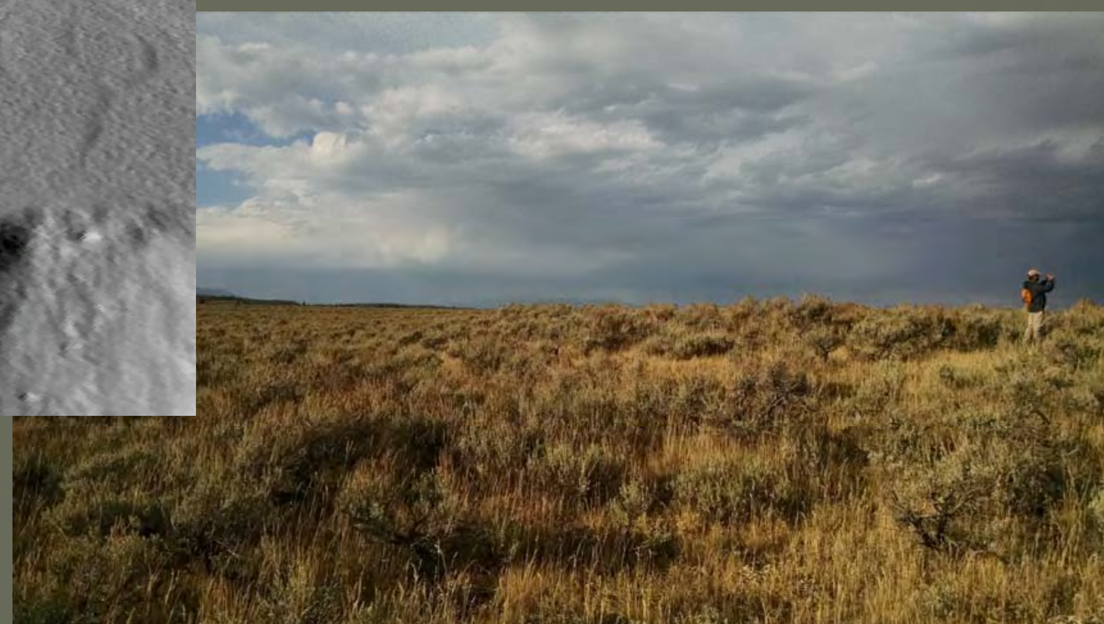
- Eastern Jackson Hole faults - 2017
- Three fault groups
  - Antelope Flats
  - Blacktail Butte
  - Flat Creek
- Partially funded through USGS



Recent work


AF01


Profile: AF01
R^2 0.96
RMSE 0.03
RMSE 0.04
R^2 0.85
1.30
Vertical distance (m)
2091.5
2091
2090.5
2090
2089.5
80
90
100
110
120
130
140
Horizontal distance (m)



Teton fault map

- Zellman and others
  - WSGS will publish

Other work

- WSGS is working on surface investigations
  - Chicken Springs
  - Muddy Gap
  - Rock Creek

- USGS, USBOR
  - Teton
  - Antelope Flats
  - South Granite

Summary

- A number of multi-state faults exist
  - Many could use a fresh look
- Relationship of main faults to small discontinuous faults is unclear
- A lot of new work is being done in the state

Thank You

Questions?

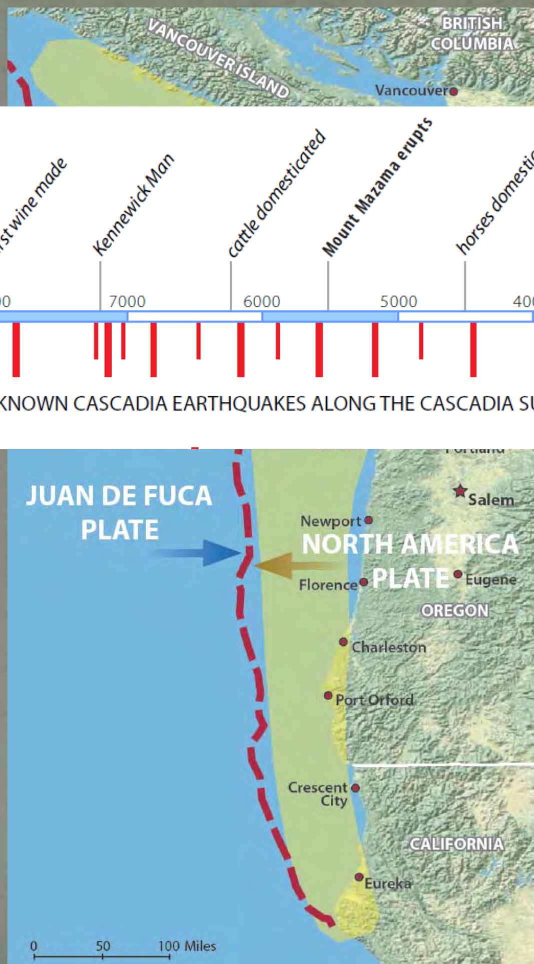
Investigation of Cascadia Triggered Landslides

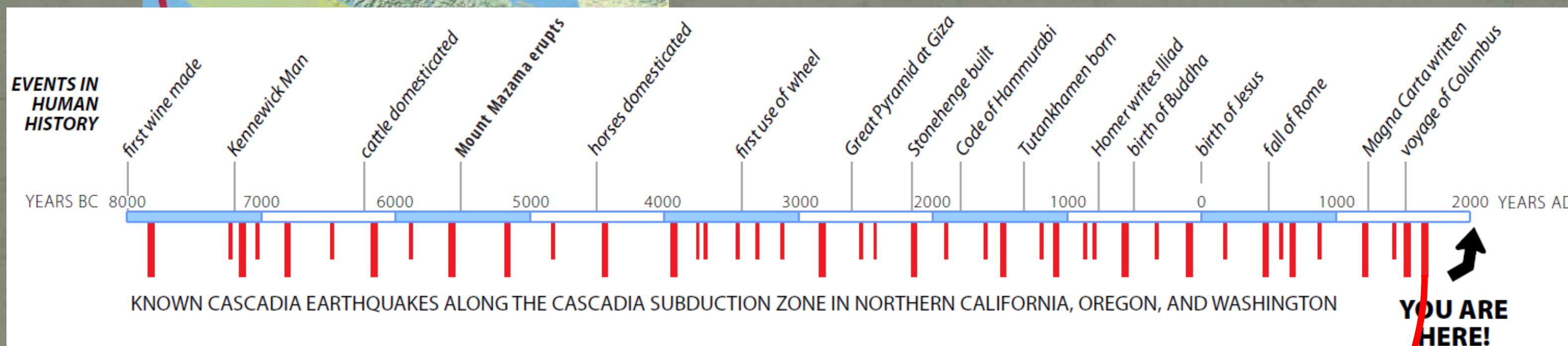
Bill Burns & Nancy Calhoun

Bryan Black

Josh Roering & Will Struble

The Problem - Cascadia Subduction Zone



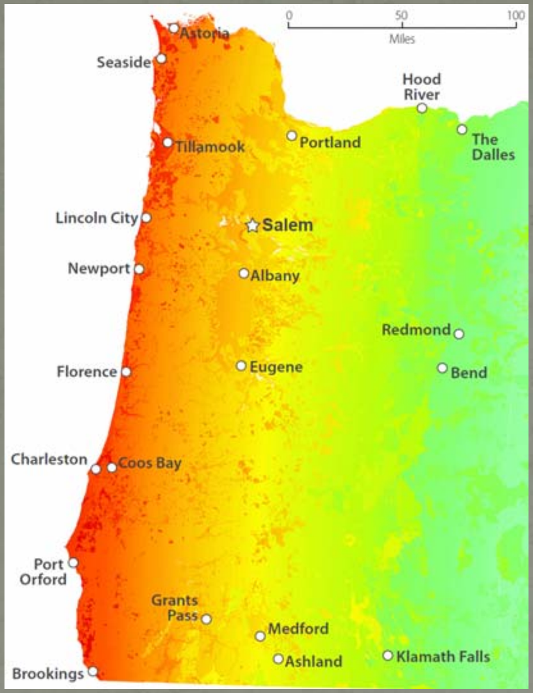


January 1700

Cascadia, Winter 2012 and Winter 2010; USGS (https://soundwaves.usgs.gov/2008/01/awards2.html)

Burns, 2017

It Is Going to Shake

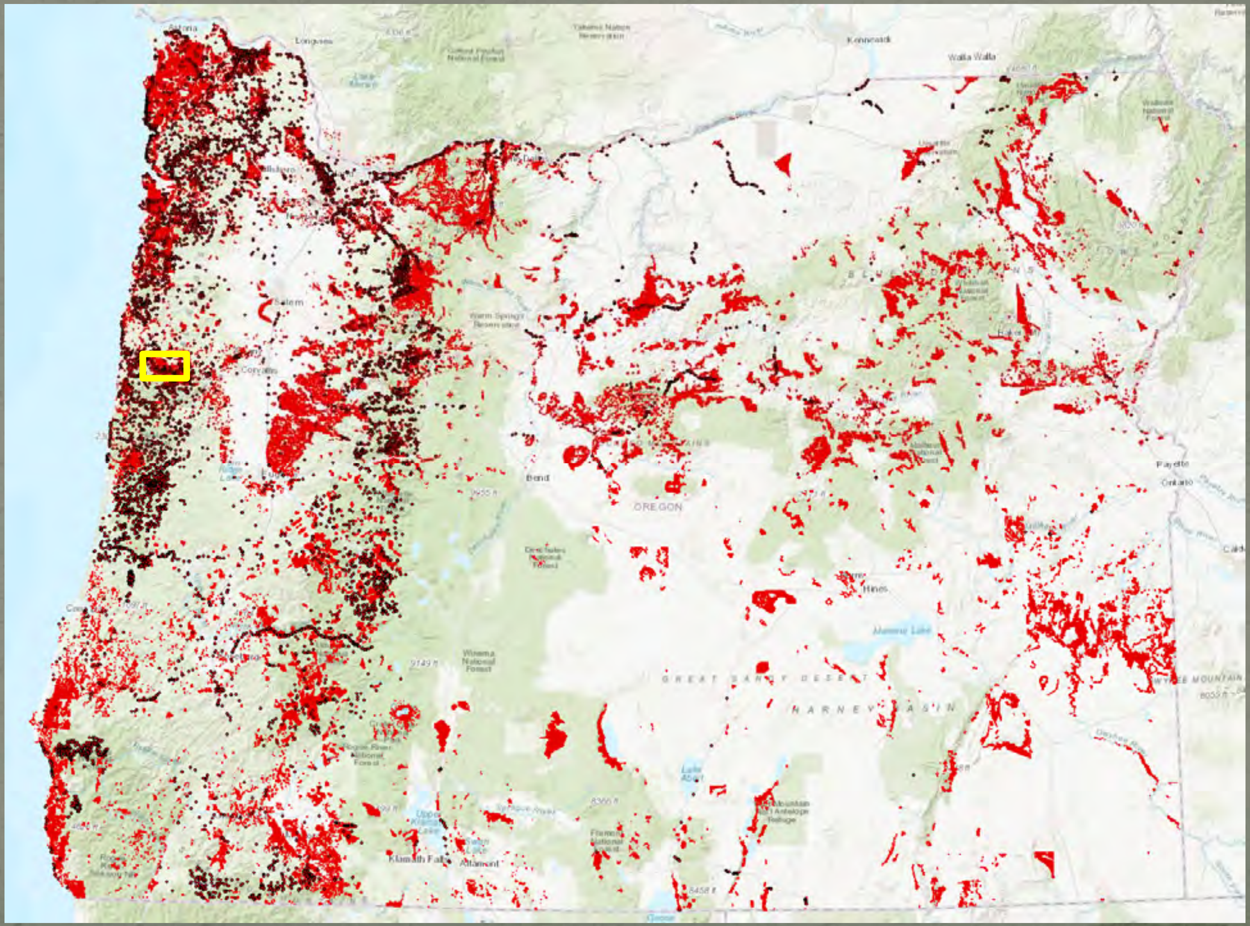


- M9 Cascadia Scenario
- Ground shaking with site soil class

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

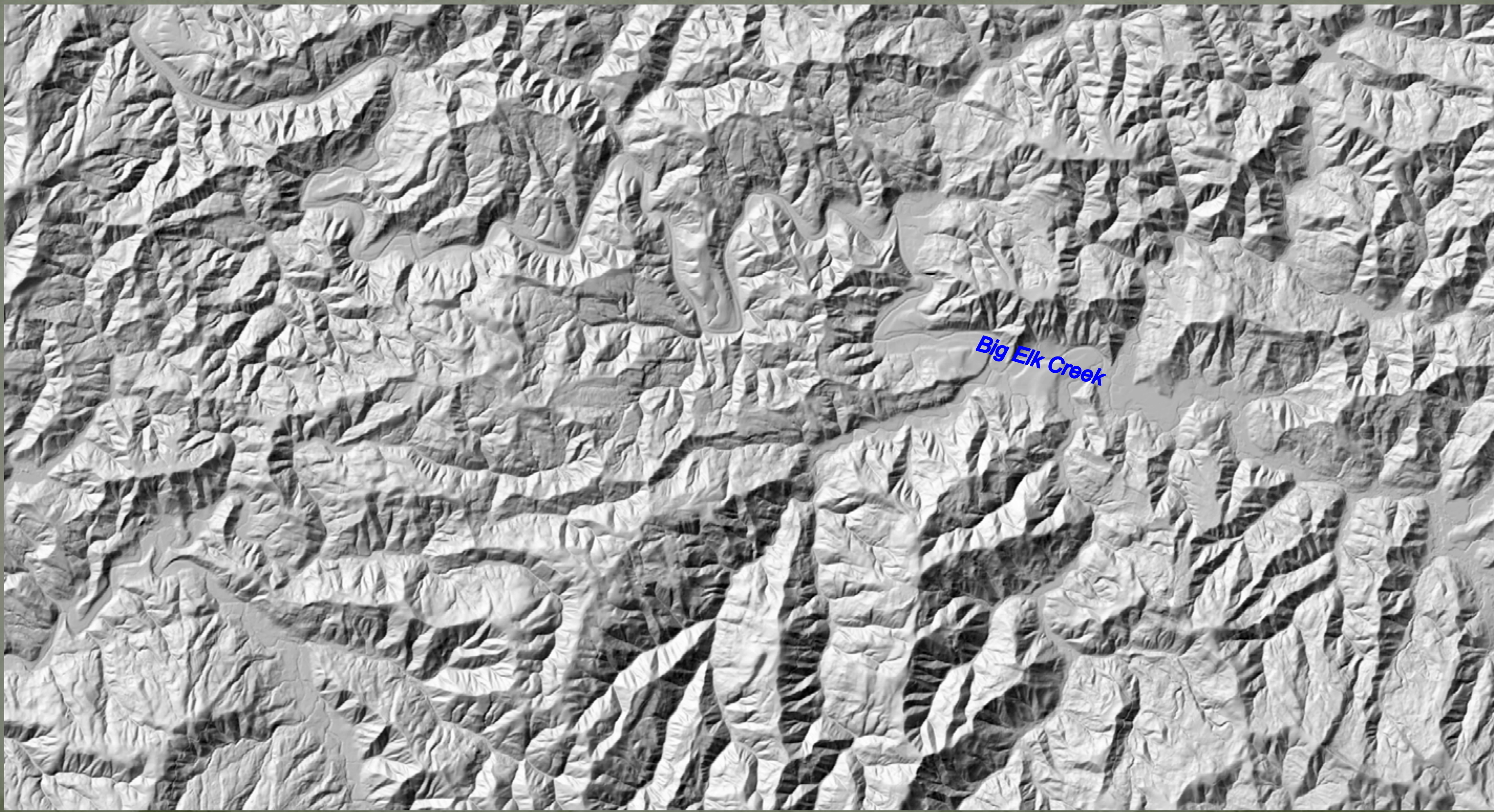
There Are A Lot of Landslides

- SLIDO 3.3
- 2017
- 55,959 landslides



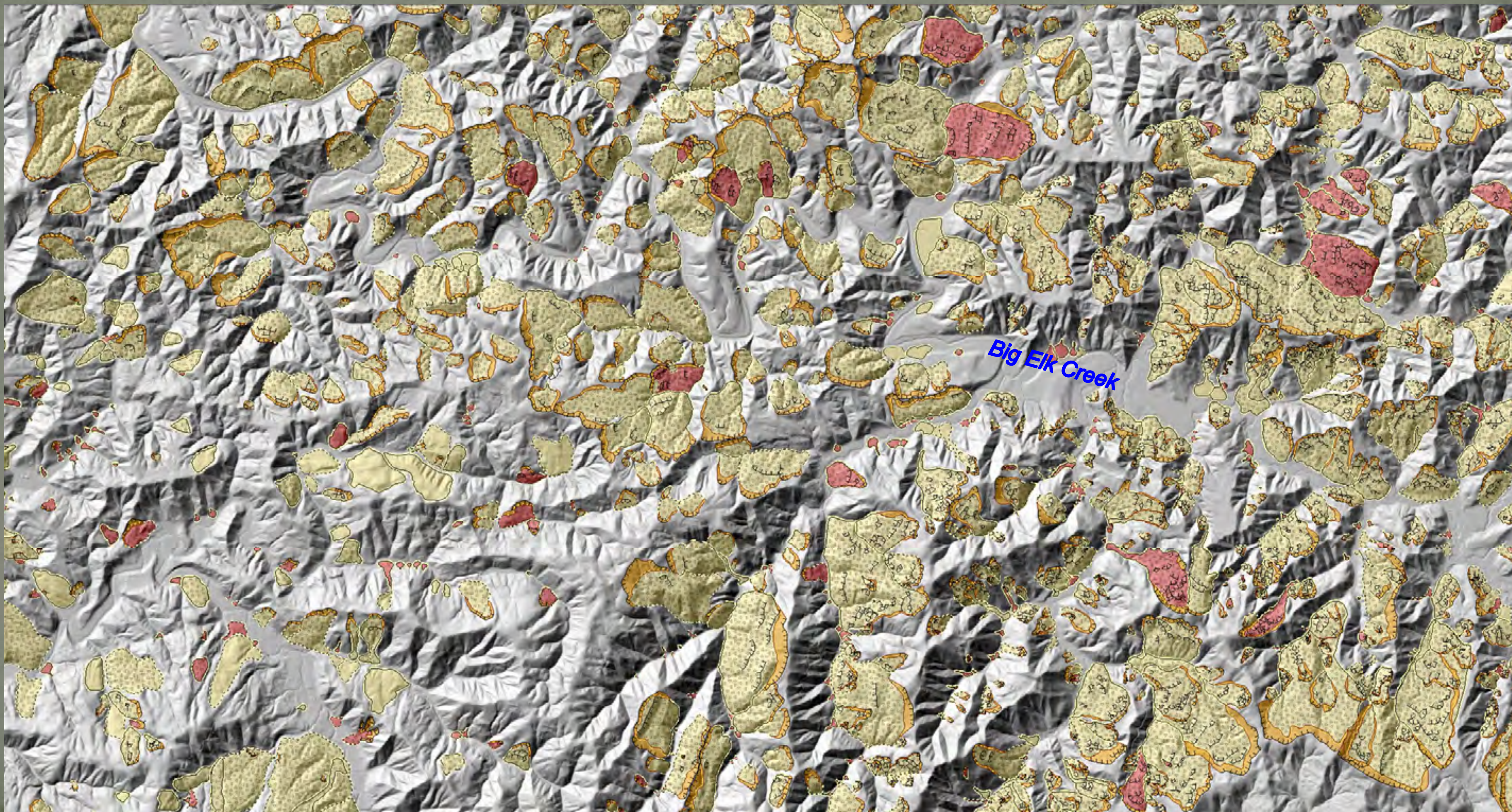
Burns, 2017

Oregon Coast Range - Lidar Hillshade



Burns, 2017

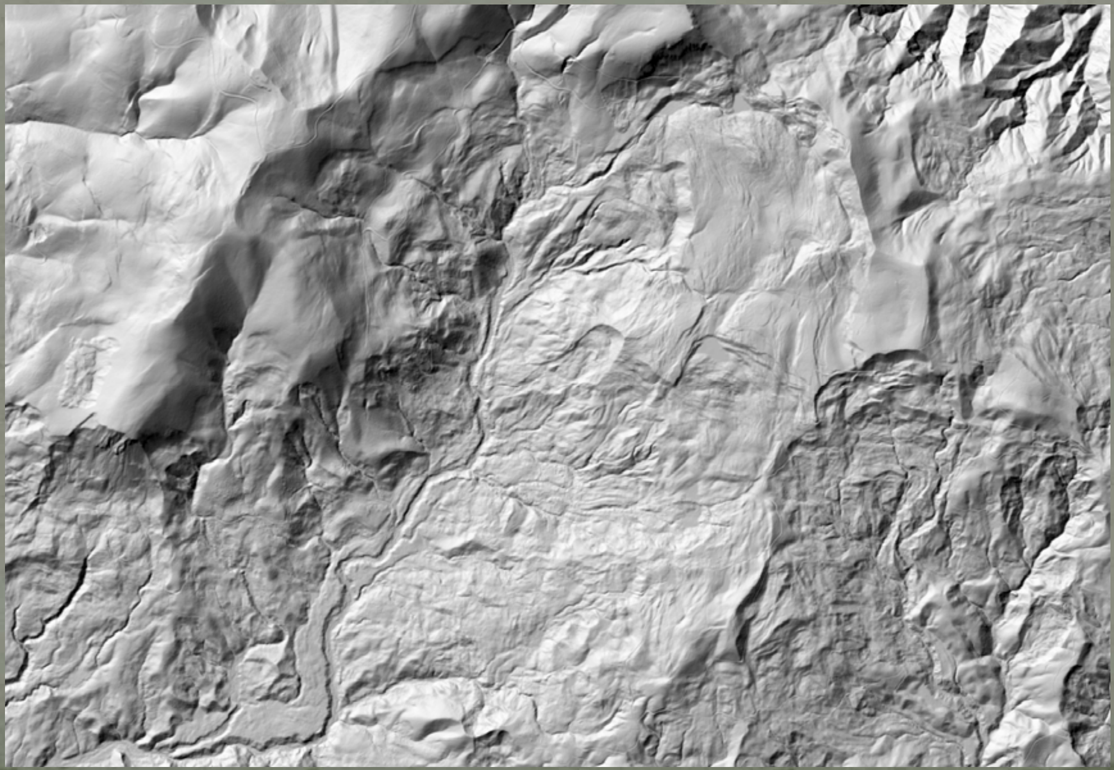
1,146 Landslides – 6 mi x 12 mi



Burns, 2017

Investigation of Cascadia Triggered Landslides

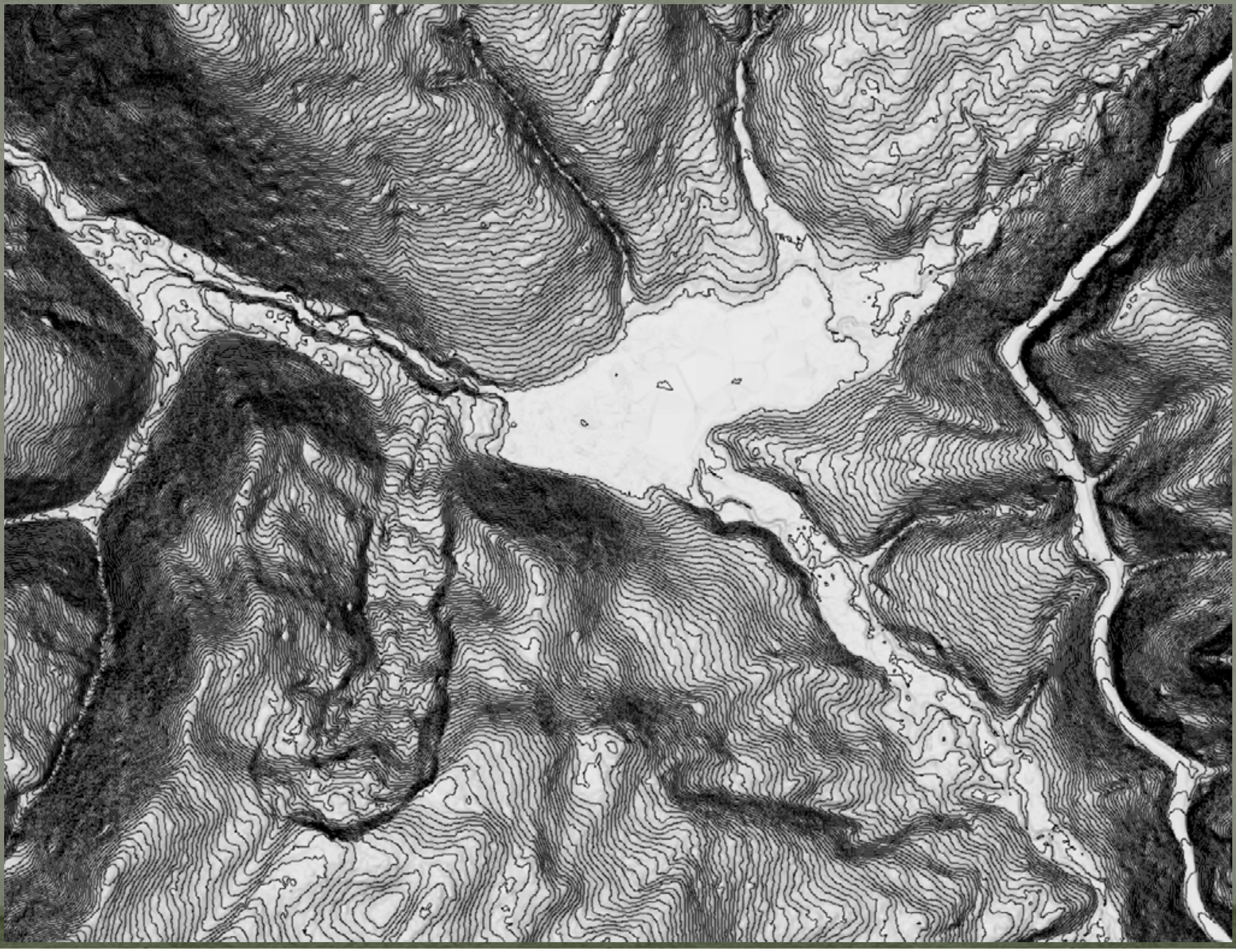
- Find a way to date landslides in the Oregon Coast Range
- Specifically, find landslides that occurred during the 1700 event
- Landslide process is very complicated…



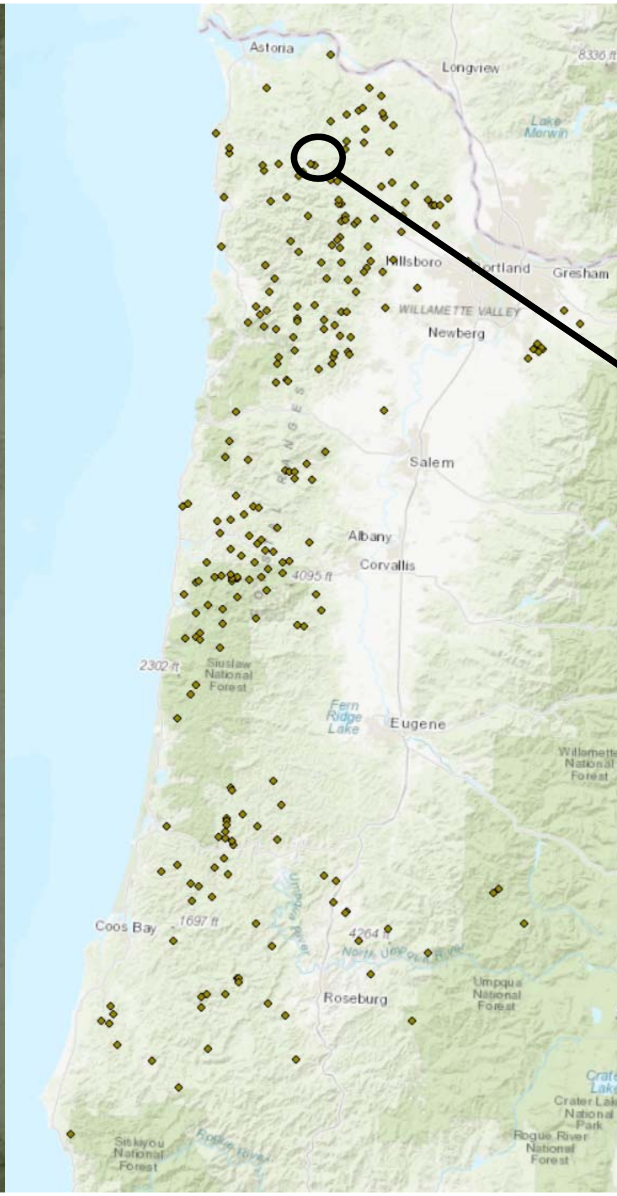
Burns, 2017

Landslide Dam Sites!

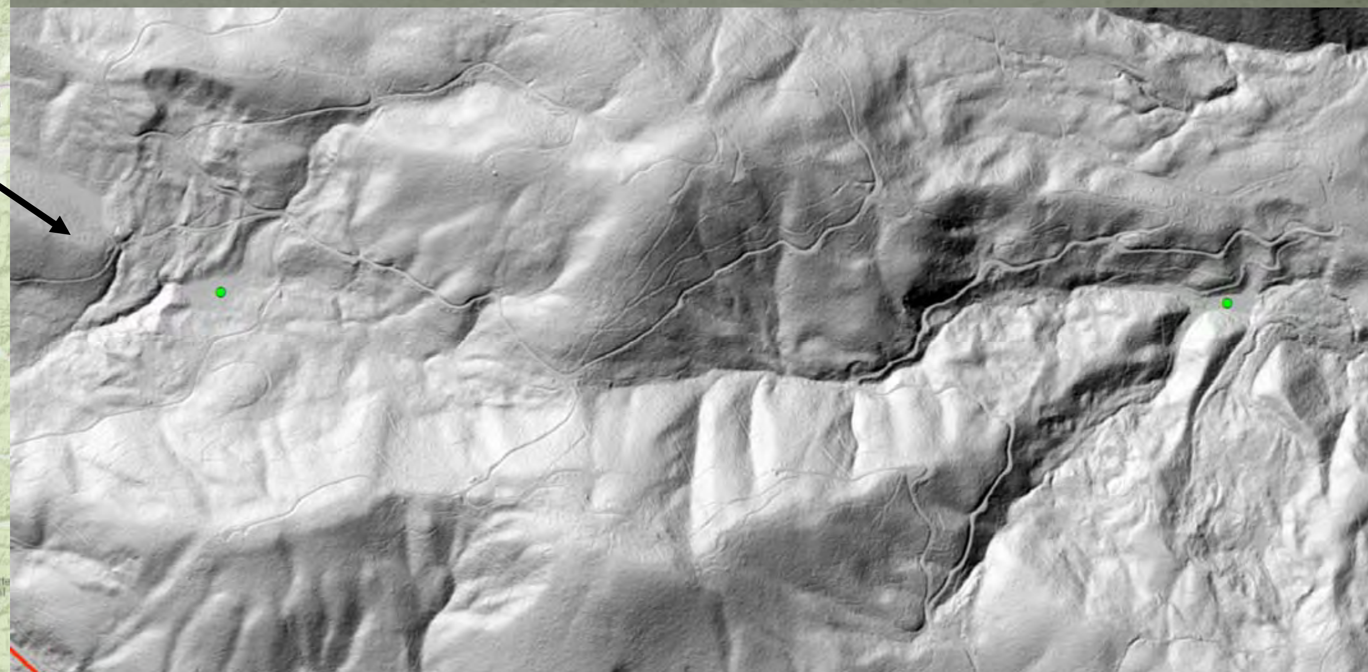
Wasson Lake



Burns, 2017

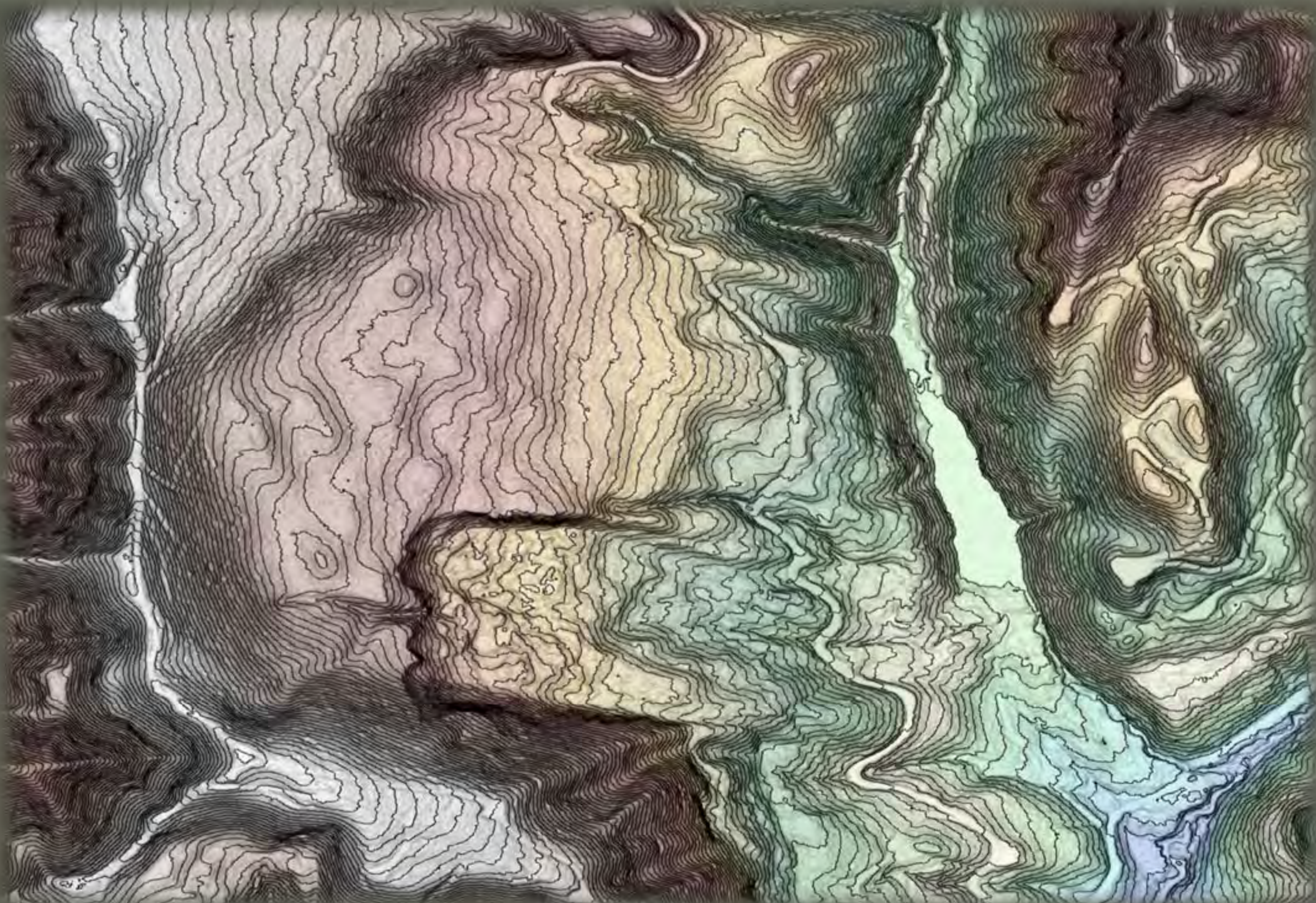


219 Possible Sites



- Identified 25 sites and visited ~20
  - Land ownership
  - Sharp landslide morphology
  - Ease of access
  - Lake

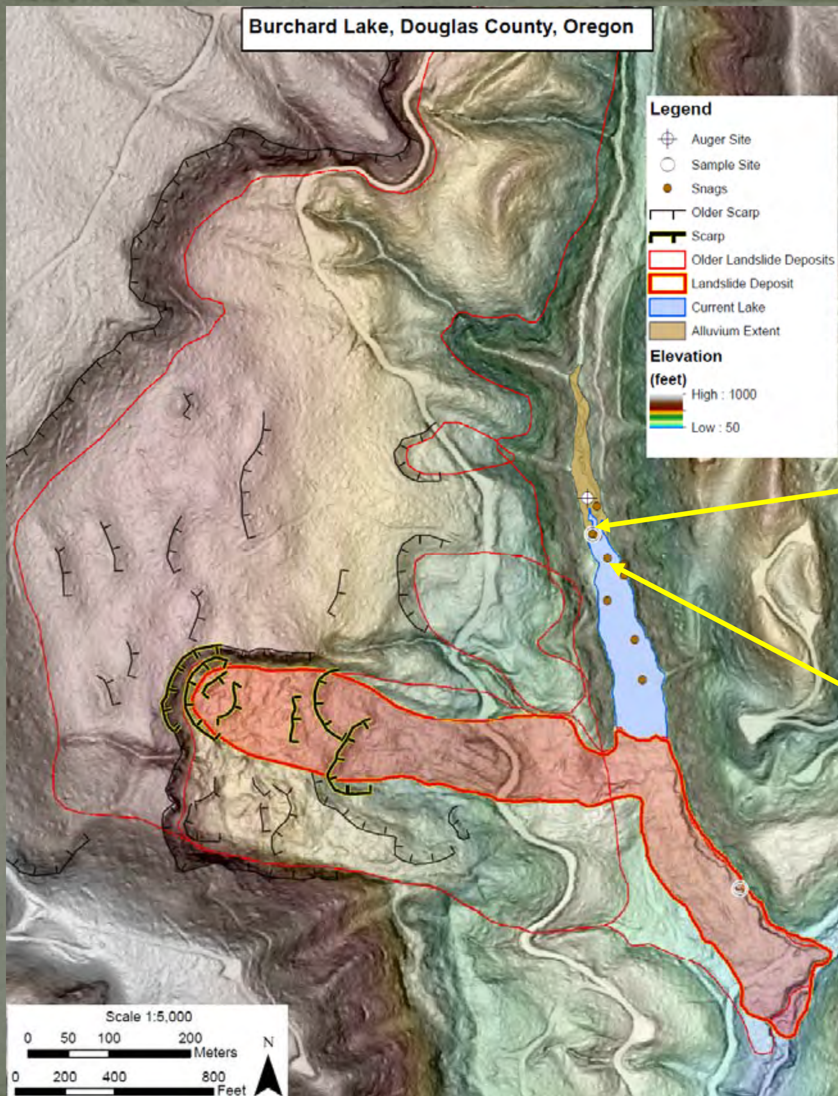
Burns, 2017



Burchard Lake

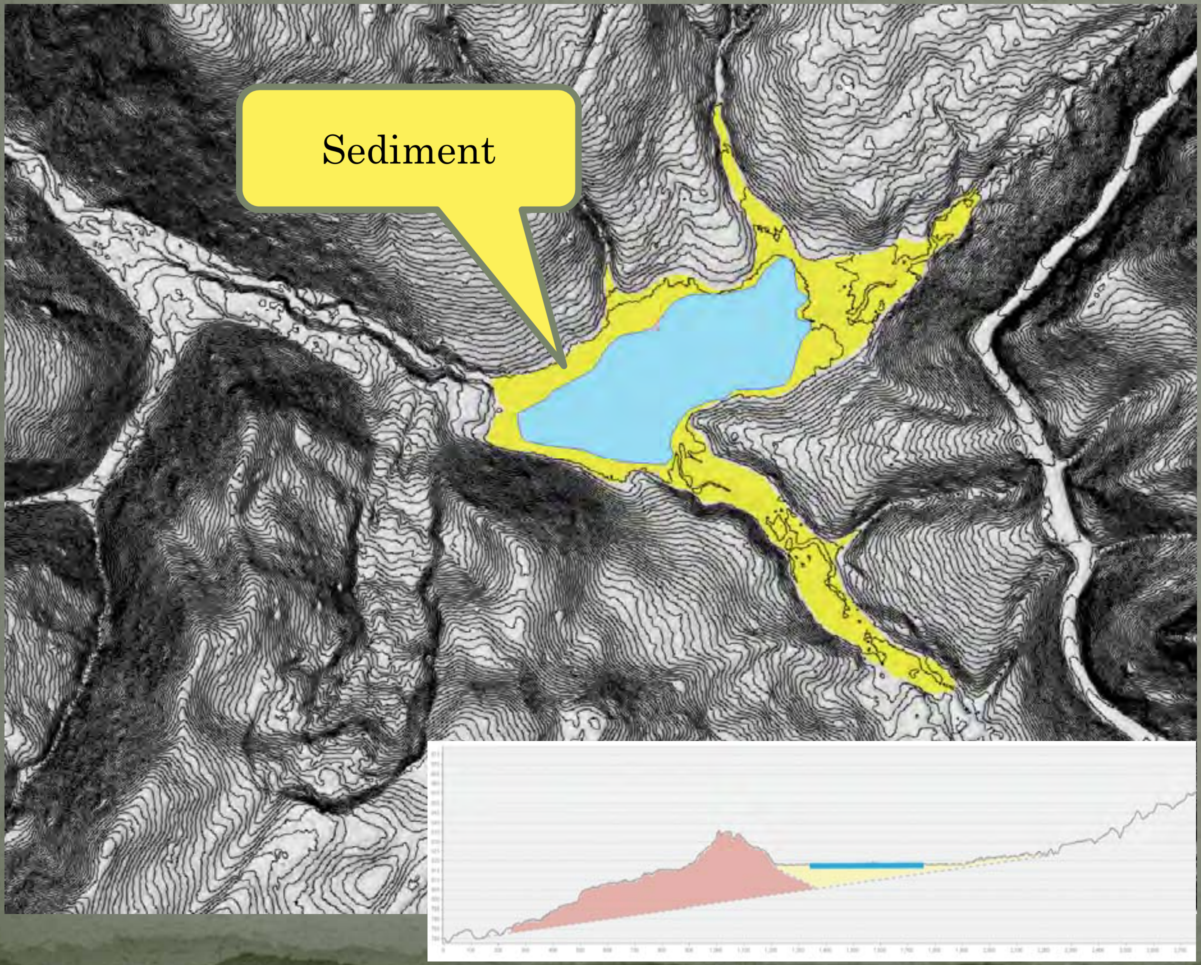
Bare Earth Slope & DEM Elevation Color Ramp & 3ft Contours

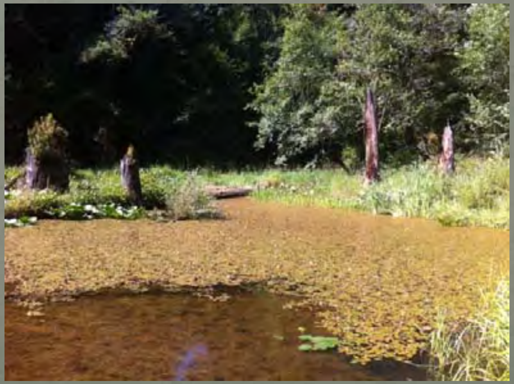
Burns, 2017


Burchard Lake, Douglas County, Oregon
Legend
Auger Site
Sample Site
Snags
Older Scarp
Scarp
Older Landslide Deposits
Landslide Deposit
Current Lake
Alluvium Extent
Elevation
(feet)
High : 1000
Low : 50
Scale 1:5,000
0 50 100 200
Meters
0 200 400 800
Feet
N

Burns, 2017

Wasson Lake





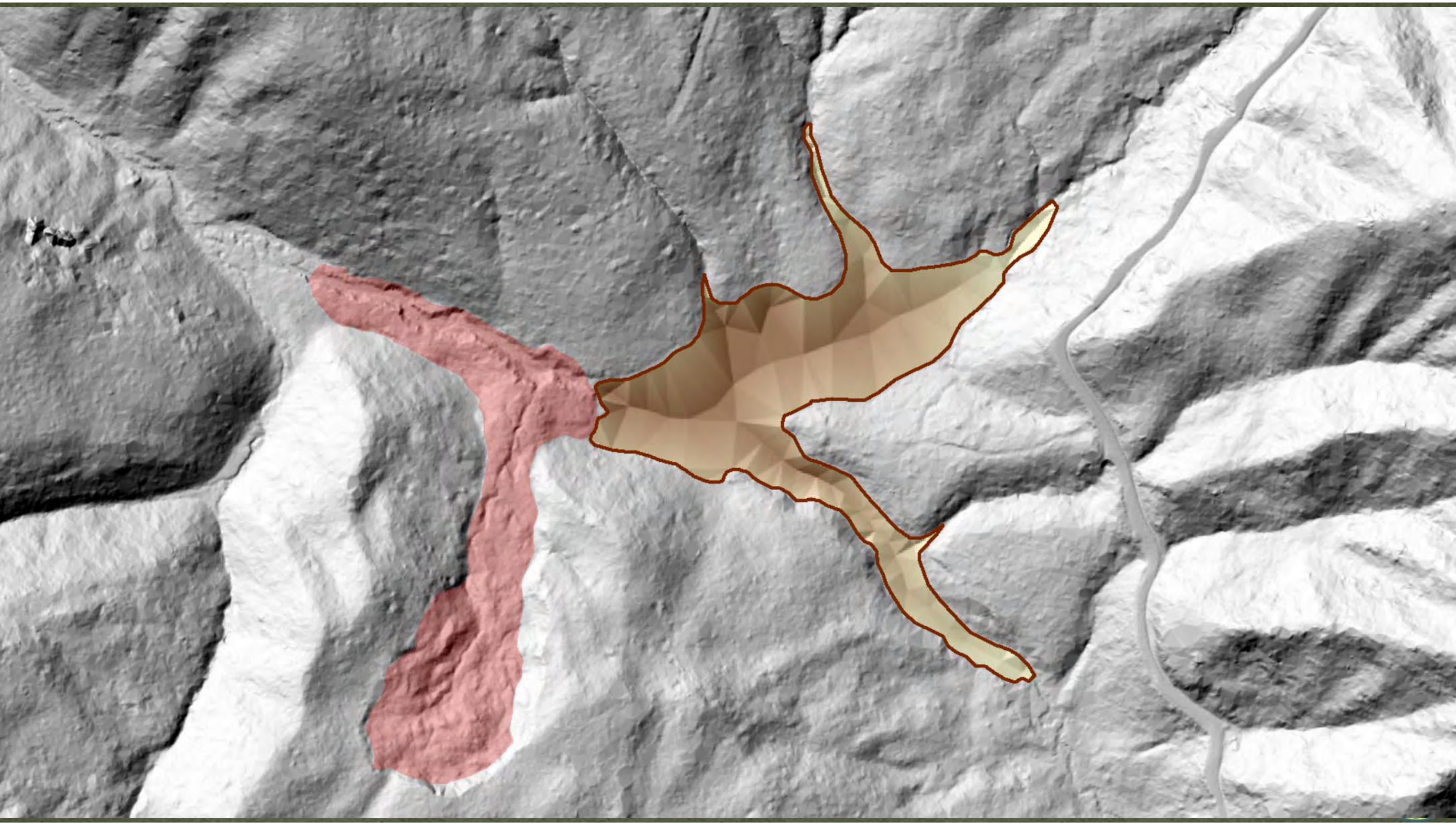
Burns, 2017

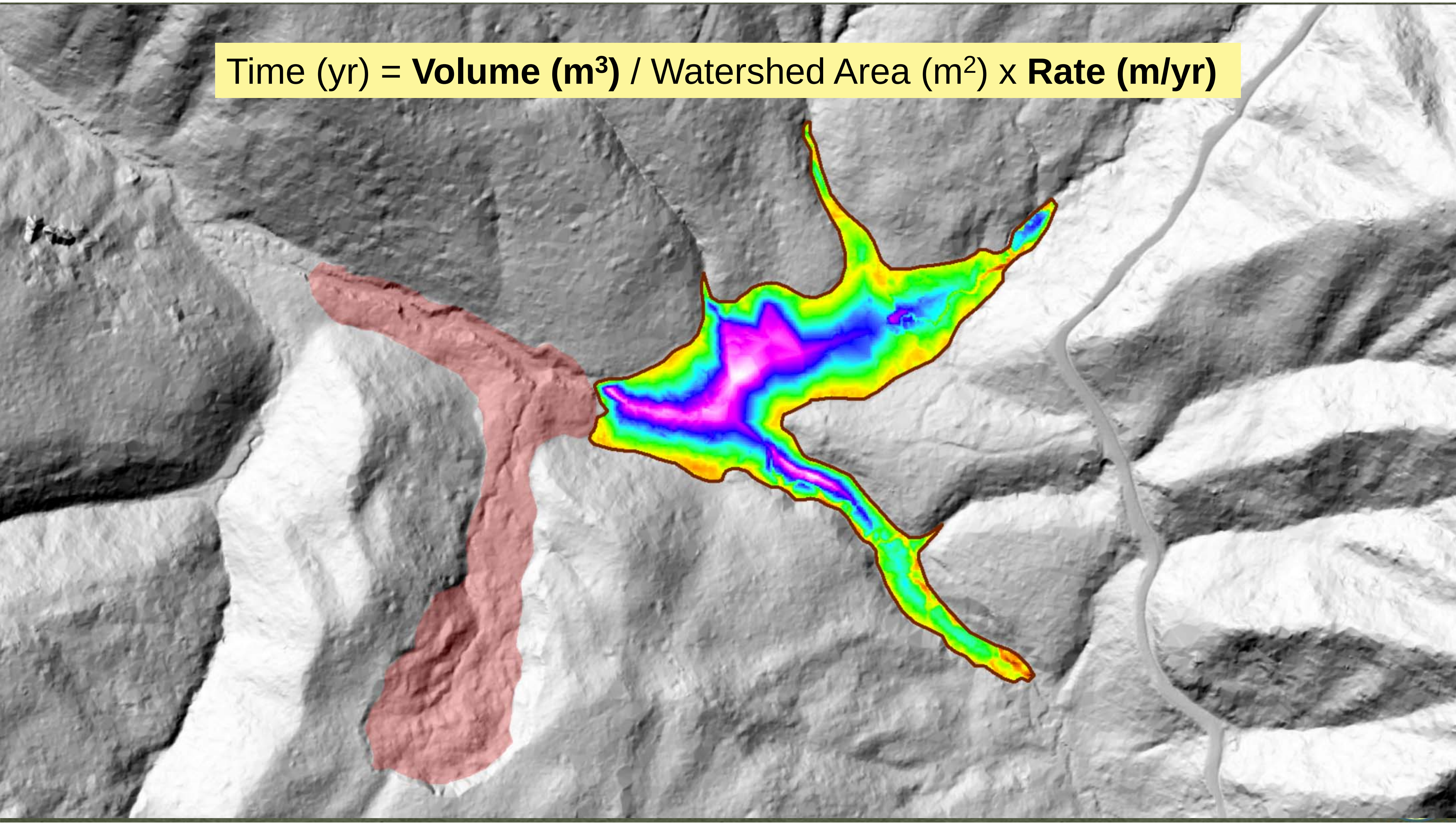
Sediment Volume

Time (yr) = Volume (m^3) / Watershed Area (m^2) x Rate (m/yr)

- Oregon Coast Range - Erosion Rate Range
  - Low 0.05 mm/yr
  - High 0.2 mm/yr

http://geog.uoregon.edu/amarcus/geog607w09/Readings/Roering,2008,OCRbackground2008.pdf;
Butterfield, Nicholas J.F., Bunds, Michael P., Zanazzi, Alessandro and Toke, Nathan A., A PRELIMINARY LOOK AT GEOMORPHIC IMPACTS AND TIMING OF TWO LARGE, DRAINAGE-DAMMING LANDSLIDES IN THE CENTRAL WASATCH, GSA 2015 Annual Meeting

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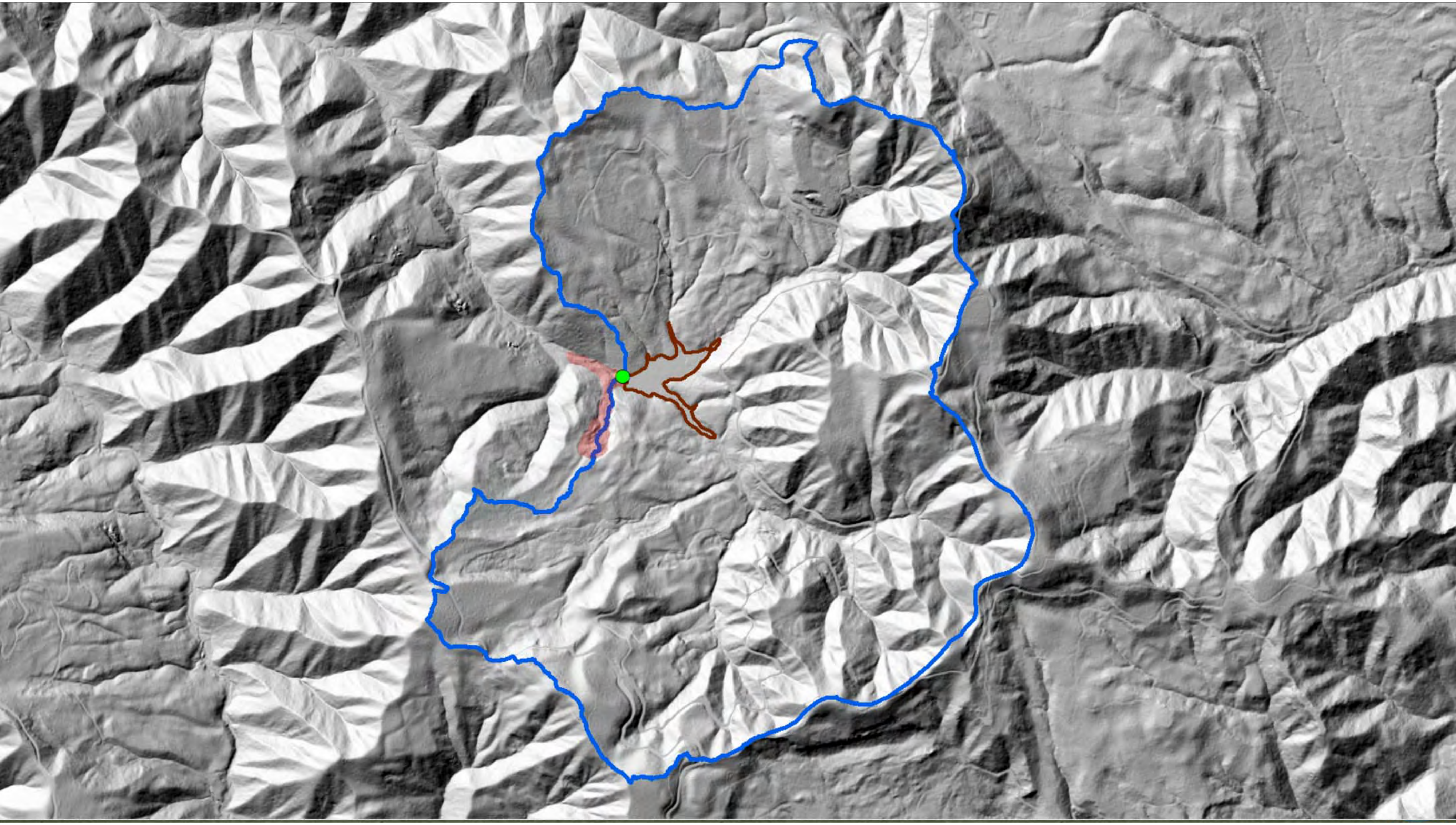

Sediment Volume Hourglass

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  - High 0.2 mm/yr

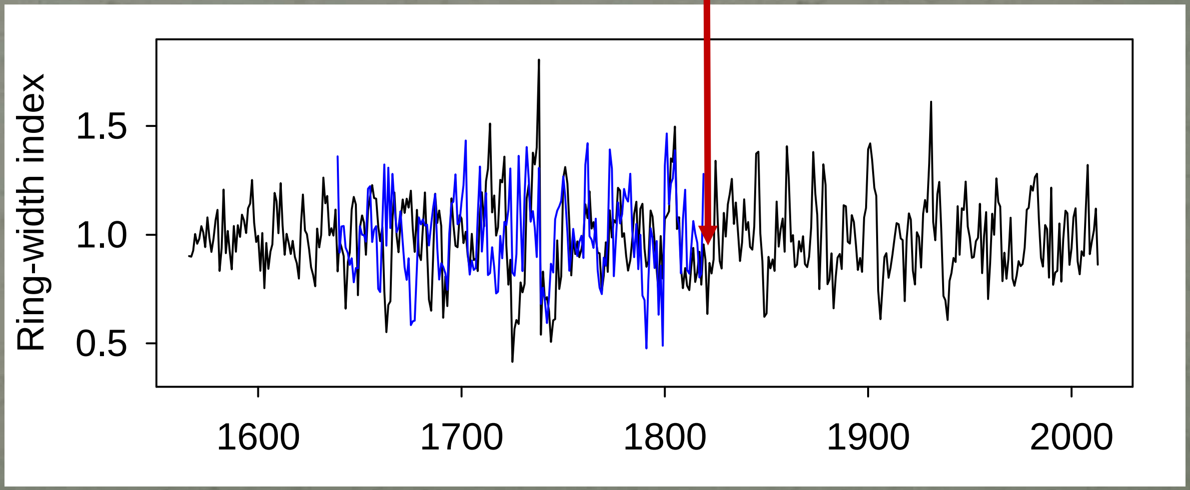
- Low 549 yrs ago - 1467 AD
- High 137 yrs ago - 1879 AD

January 1700 !

http://geog.uoregon.edu/amarcus/geog607w09/Readings/Roering,2008,OCRbackground2008.pdf;
Butterfield, Nicholas J.F., Bunds, Michael P., Zanazzi, Alessandro and Toke, Nathan A., A PRELIMINARY LOOK AT GEOMORPHIC IMPACTS AND TIMING OF TWO LARGE, DRAINAGE-DAMMING LANDSLIDES IN THE CENTRAL WASATCH, GSA 2015 Annual Meeting

Dendrochronology

Tree Died
198 yrs ago
or 1819 AD



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~~January 1700 !~~

1819 AD

http://geog.uoregon.edu/amarcus/geog607w09/Readings/Roering,2008,OCRbackground2008.pdf;
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Burns, 2017

Method Works!

- Lidar landslide mapping to find potential sites
- Site reconnaissance
- Sediment rate
- Carbon dating
- Detailed site mapping and sampling
- Dendrochronology

Burns, 2017

June 2017 Workshop

- UW, USGS, DOGAMI, WADNR, PSU, UO, UT, Humbolt
- Facilitate, coordinate, and expand collective efforts
  - Characterize the complex coseismic landslide history and hazards in the Cascadia region
- Primary future research topics developed by the workgroup are:
  - Better understanding earthquake effects on landscape
  - Compilation current knowledge landslides triggered by subduction zone EQs
  - Use landslide data to assist constraining earthquake recurrence intervals
  - Use landslides to constrain ground motion.

Burns, 2017

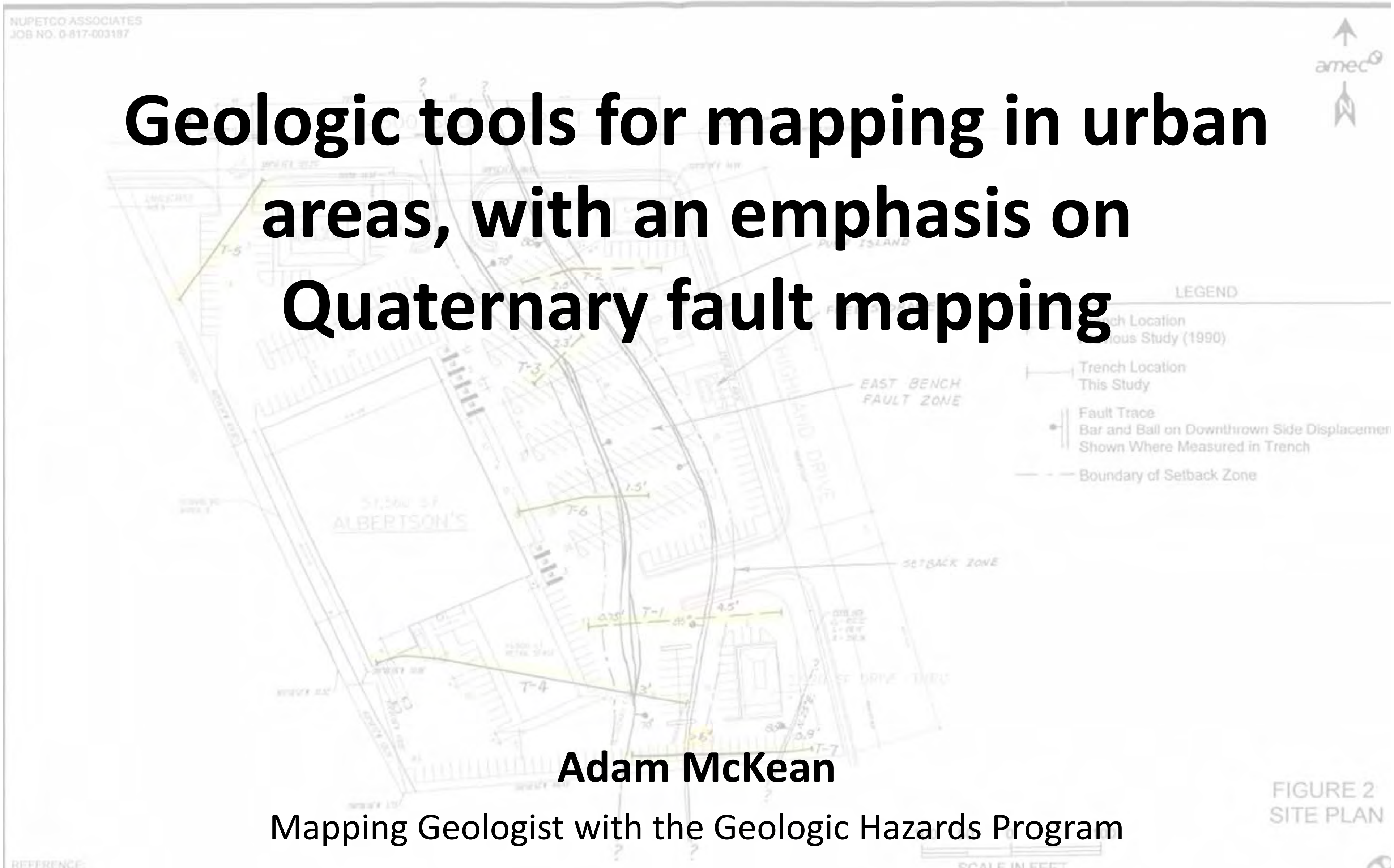
Thank You to the USGS For Funding!

Questions

Research supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award number G16AP00170 & G17AP00171. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Burns, 2017

Geologic tools for mapping in urban areas, with an emphasis on Quaternary fault mapping



Adam McKean

Mapping Geologist with the Geologic Hazards Program

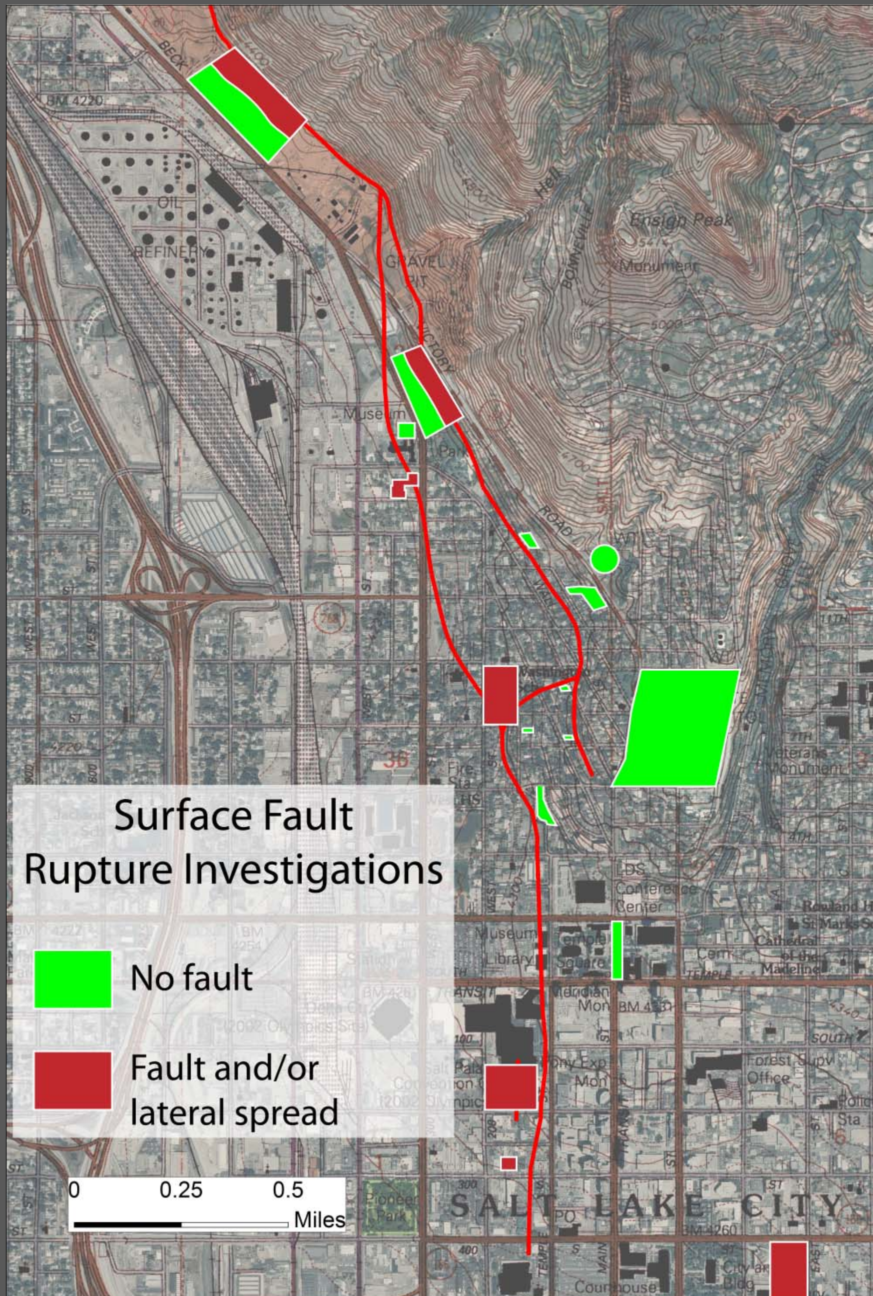
Tools in a Geologist Tool Belt

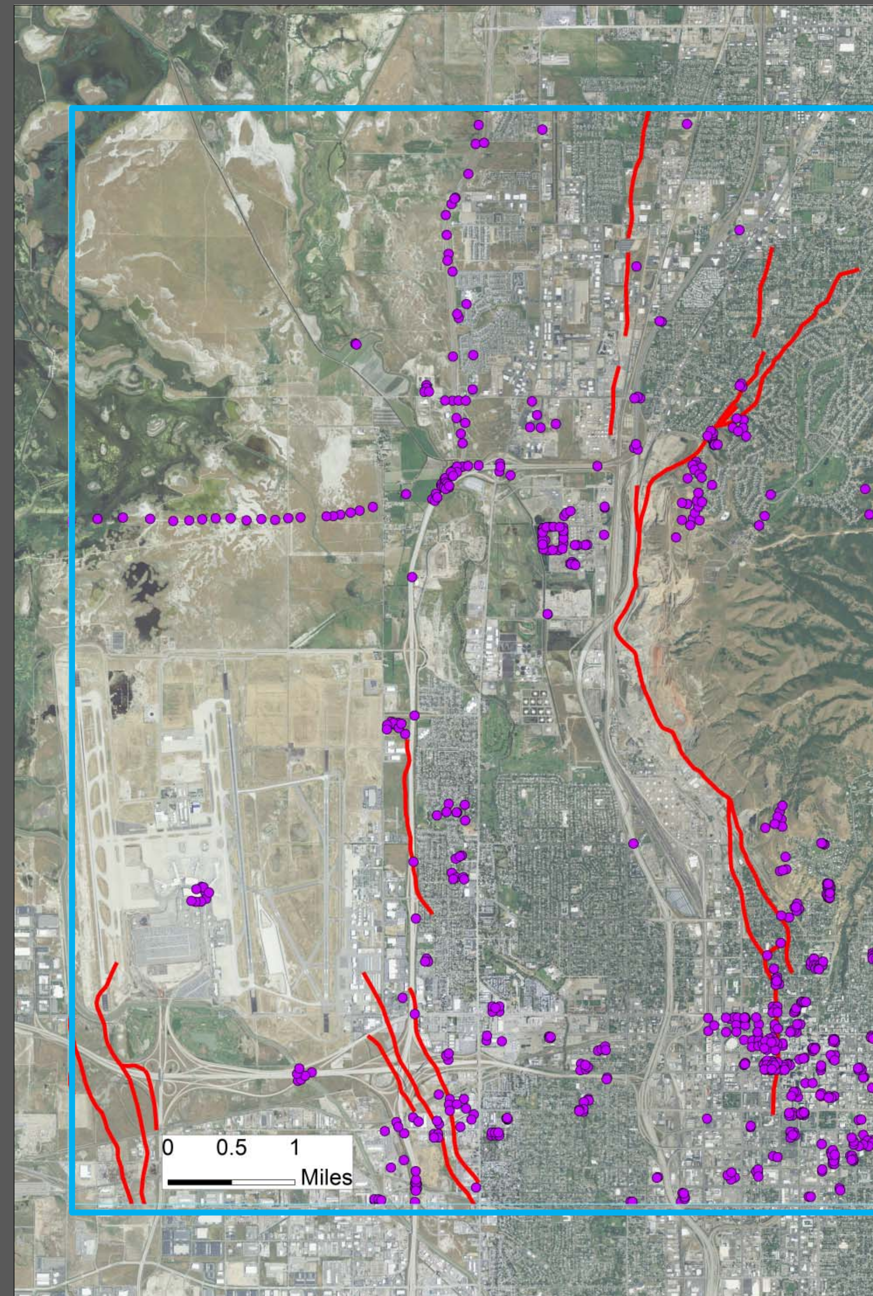
Traditional

- 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)


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


0
0.5
1
Miles

Where do all the reports come from?

- Cities, Counties, State Agencies, University of Utah, 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

UGS GeoData Archive Sy

Secure | https://geodata.geology.utah.gov/pages/home.php

UTAH GEOLOGICAL SURVEY | Home | Data Collections | Return to UGS Website | Help | Contact Us | Log In

Utah Geological Survey GeoData Archive System

The UGS GeoData Archive System, part of our Geologic Data Preservation Project, contains Utah geologic- and wetlands-related scanned documents, photographs (except aerial), and other digital materials (resources) from our files and those gathered from other agencies or organizations in one easy-to-use web-based system. Resources available to general users are all in the public domain and may contain reports submitted to state and local governments as part of permit reviews (and as a result are in the public domain). Metadata describing each resource is searchable, along with spatial searching for resources that are local or site-specific in nature (Geographic Search link in Simple Search pane). Resources representing counties, regional areas, or a larger area are not spatially searchable at this time and must be searched using text-based metadata (Simple or Advanced Search). Individual data collections are accessible using the Data Collections links. Users are also encouraged to search the UGS Library for books and similar materials.

If you find metadata for an resource that is incorrect or missing, you can suggest metadata corrections by clicking on the *Find an Error in the Metadata?* link in the Resource Download and Tools box on the resource view page for each resource. Submissions will be reviewed and updated as needed.

Upon searching for specific resources, they may be viewed directly, or downloaded to your local device. Documents are predominately in text-searchable PDF format. Authorized users may log in for more functionality and resource viewing. Not all resources may be available to all users due to copyright and/or distribution restrictions. Adobe Reader 9 or greater, is needed to view the PDF files. Firefox 9 or greater is recommended for best web browser performance.

Data Collections

Select...

View all

Map Search

Search for resources using an OpenStreetMap or Google basemap and bounding box area.

Air Photo/Imagery Indexes

Scanned aerial photography and imagery indexes of Utah.

Simple Search

Search and explore site content using descriptions, keywords, and metadata (includes full-text PDFs).

- ☑ All resources
  - ☑ Photo
  - ☑ Document
  - ☑ Video
  - ☑ Audio

Title

Author

County

Keywords

By Date

Any year | Any month

Clear | Search

- Geographic (Map) Search
- Advanced Search
- View New Resources

Announcements

>Metadata Download

>New Items Being Added Weekly

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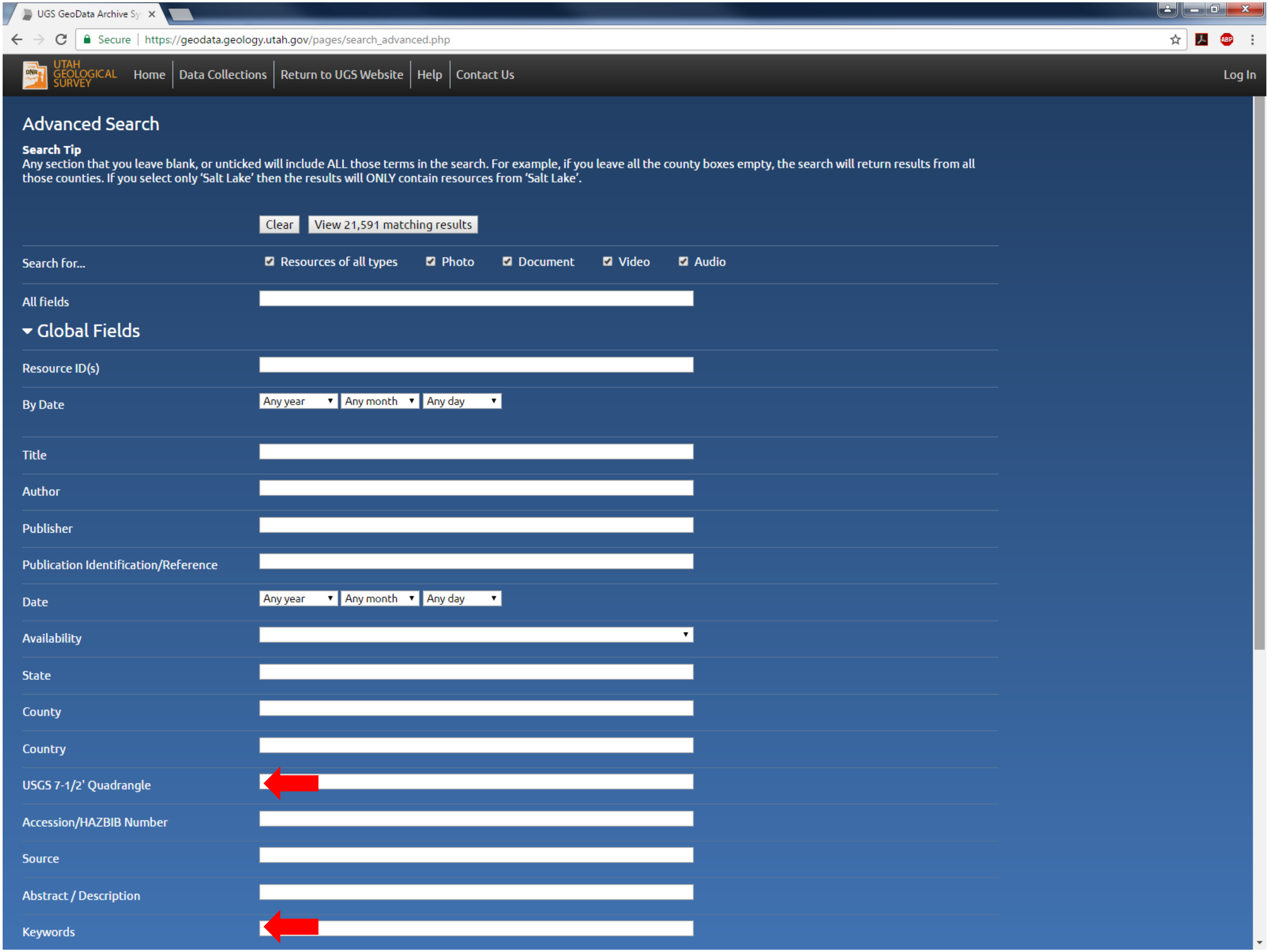
UGS GeoData Archive Sy
Secure https://geodata.geology.utah.gov/pages/search_advanced.php
UTAH GEOLOGICAL SURVEY
Home
Data Collections
Return to UGS Website
Help
Contact Us
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Advanced Search
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USGS 7-1/2' Quadrangle
Accession/HAZBIB Number
Source
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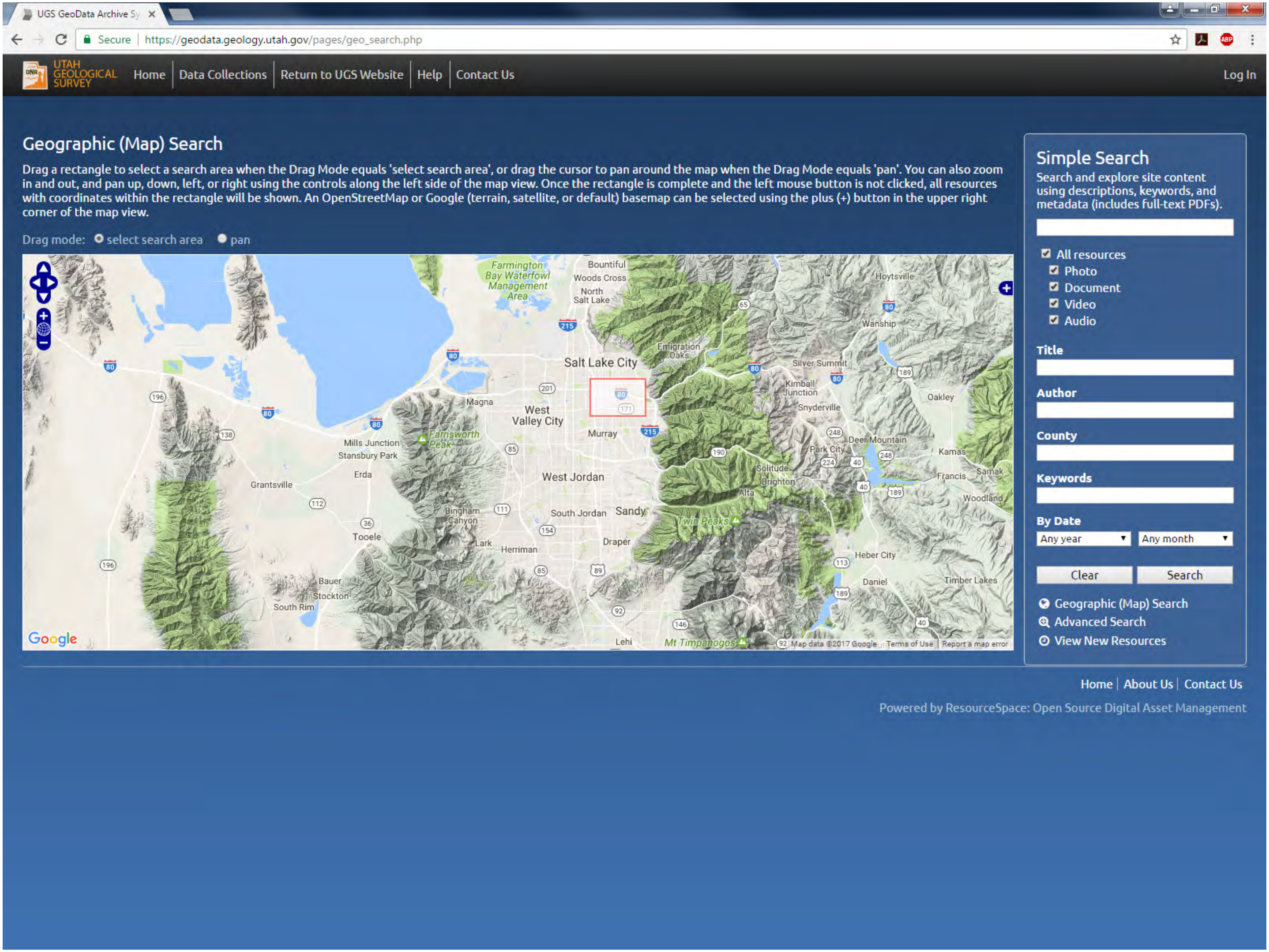
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Drag a rectangle to select a search area when the Drag Mode equals 'select search area', or drag the cursor to pan around the map when the Drag Mode equals 'pan'. You can also zoom in and out, and pan up, down, left, or right using the controls along the left side of the map view. Once the rectangle is complete and the left mouse button is not clicked, all resources with coordinates within the rectangle will be shown. An OpenStreetMap or Google (terrain, satellite, or default) basemap can be selected using the plus (+) button in the upper right corner of the map view.
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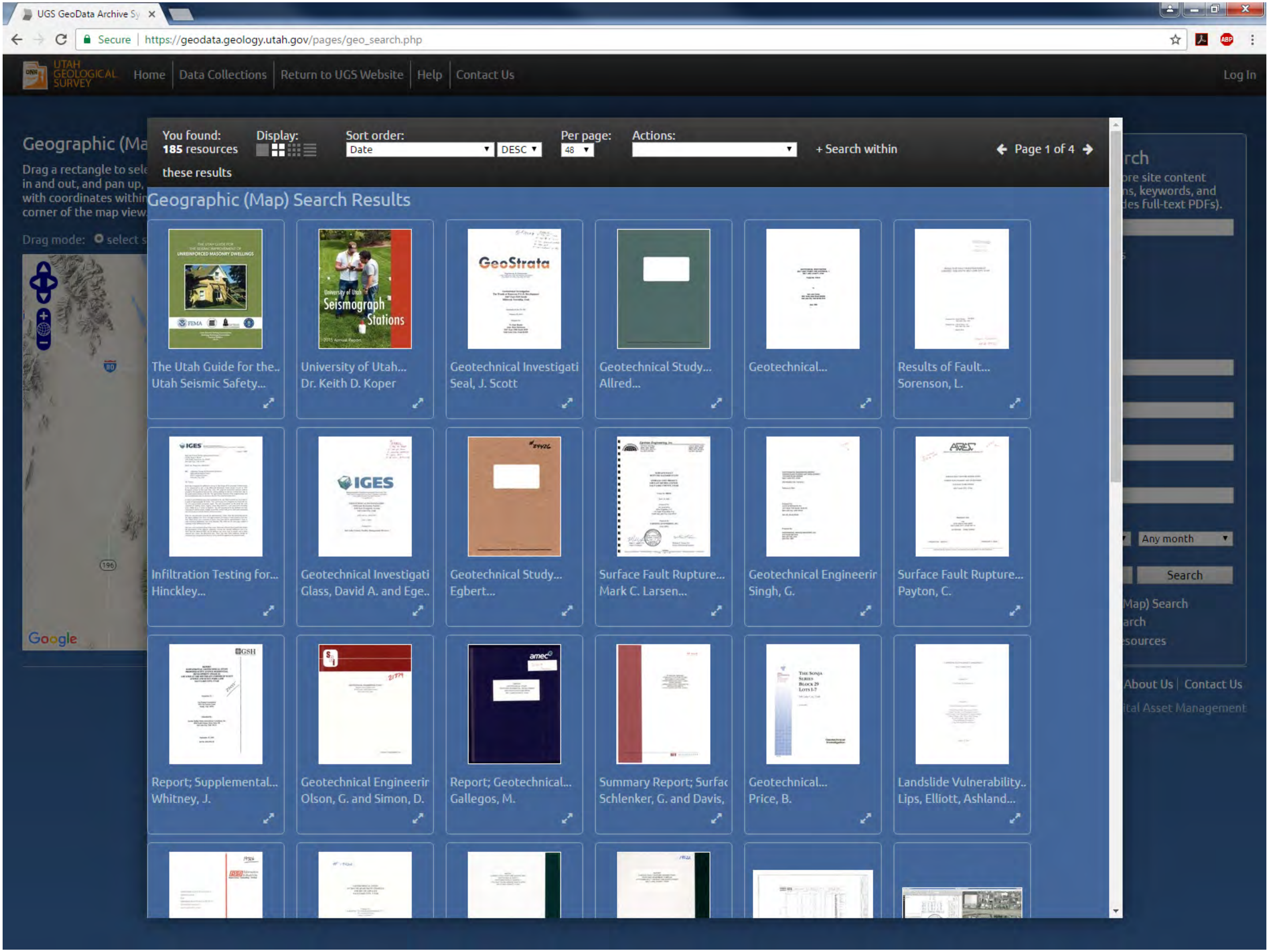
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Summary Report; Surface Fault Rupture Hazard Evaluation; Proposed East Salt Lake Home Depot; Approximately 3500 South Highland Drive; Salt Lake County, Utah

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Resource Details

Resource ID	638
Resource Type	Document
Title	Summary Report; Surface Fault Rupture Hazard Evaluation; Proposed East Salt Lake Home Depot; Approximately 3500 South Highland Drive; Salt Lake County, Utah
Author	Schlenker, G. and Davis, S.
Publisher	Kleinfelder, Inc.
Publication Identification/Reference	Kleinfelder File No. 24694.001
Date	February 19 2003
Availability	Public Domain
State	Utah
County	Salt Lake
USGS 7 1/2' Quadrangle	Sugar House
Source	Salt Lake County
Keywords	surface fault rupture, paleoseismology
Original filename	24694.001.pdf
Program	Hazards
Document Date	02/19/2003
Published For/Client	Home Depot U.S.A., Inc.
Document Type	Report
Media Type	Bound Report
Scan Type	Original

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Search and explore site content using descriptions, keywords, and metadata (includes full-text PDFs).

quad:sugar quad:house

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  - ☑ Photo
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Author

County

Keywords: paleoseismology

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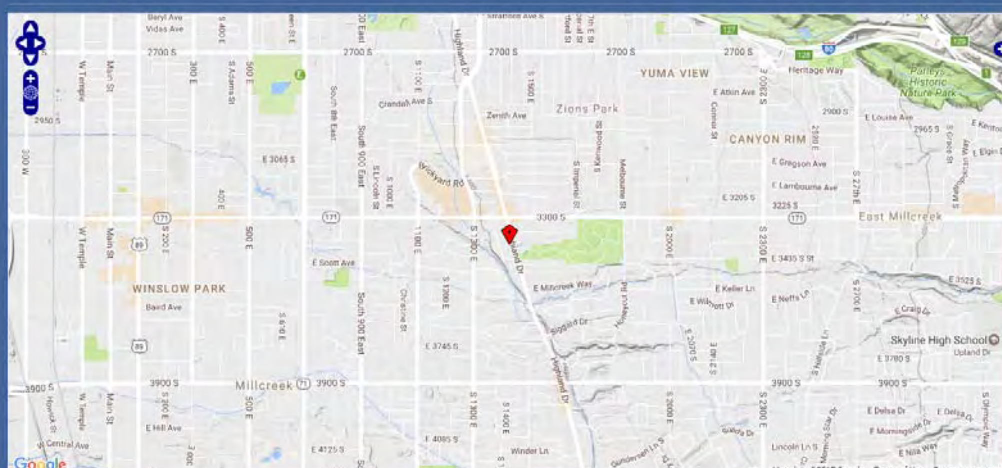
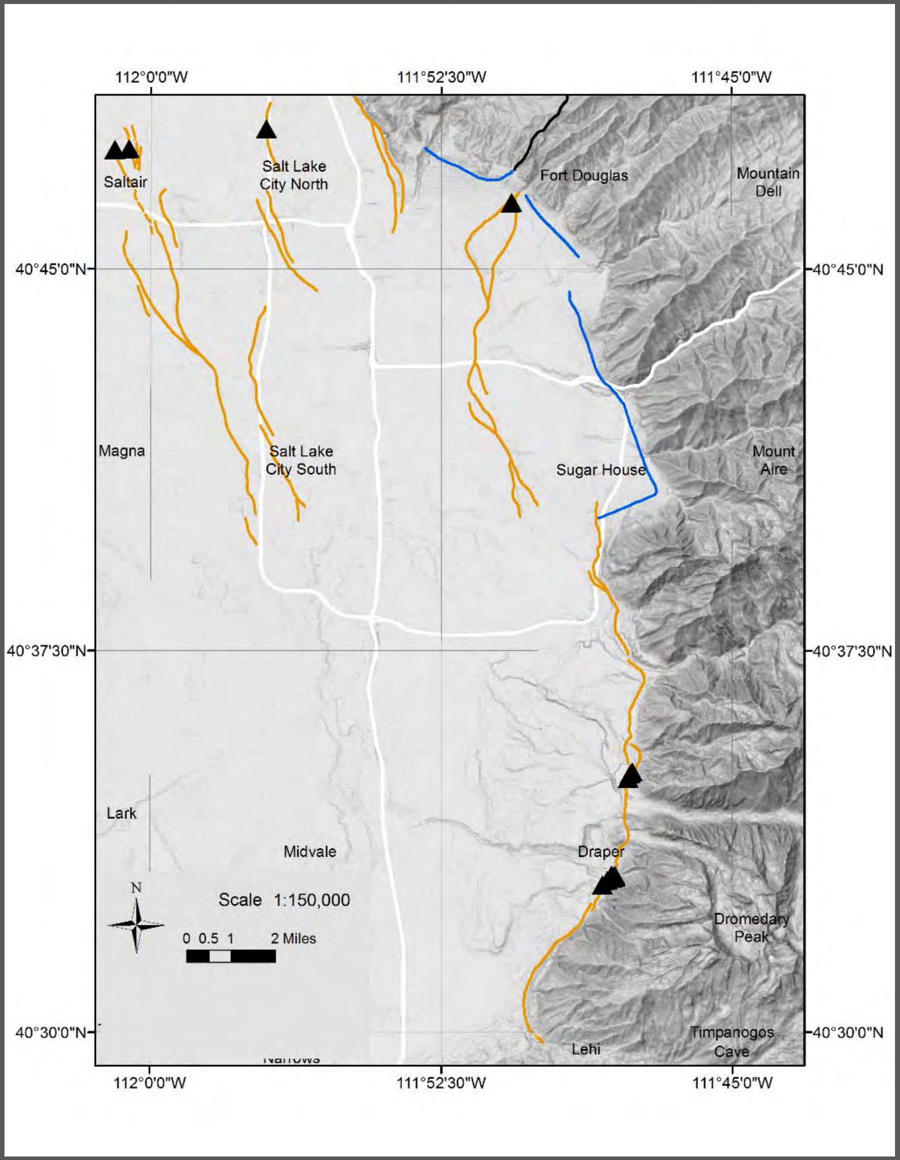
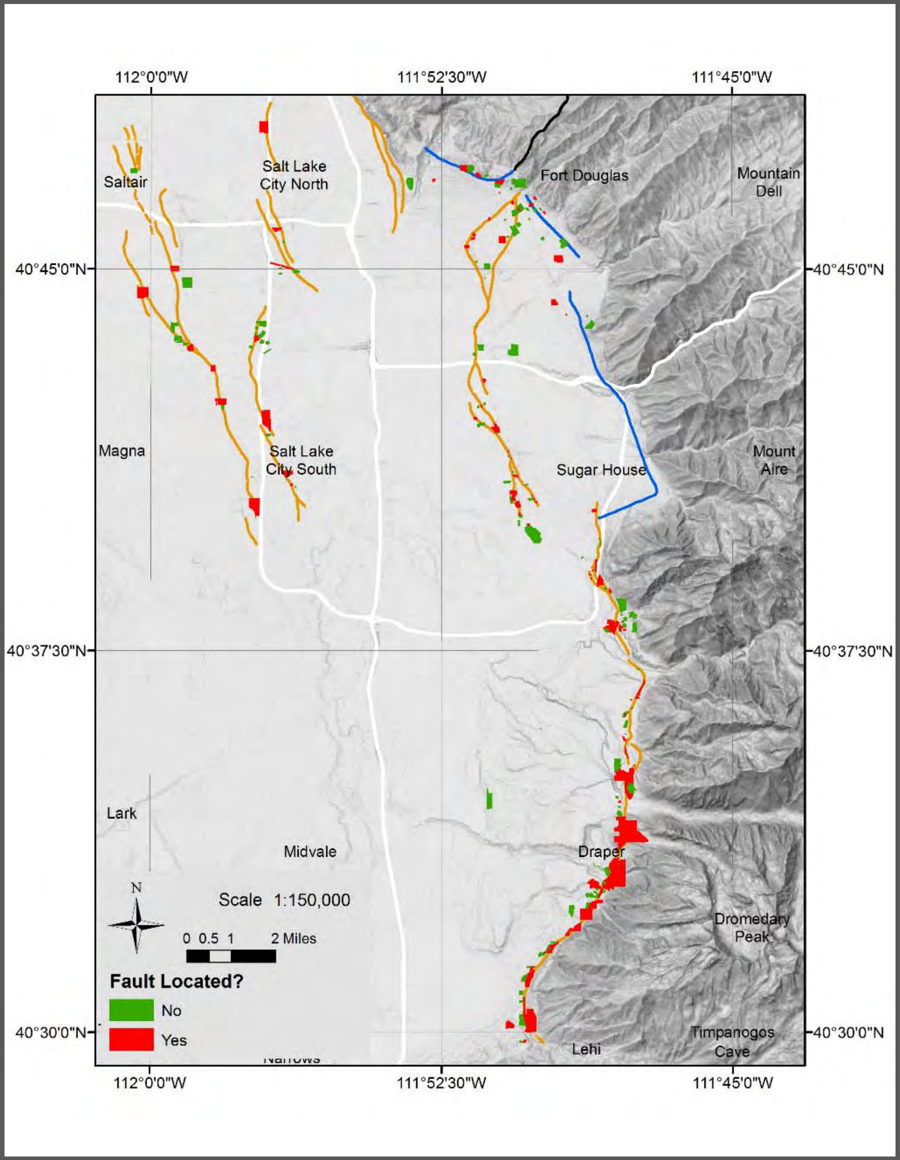
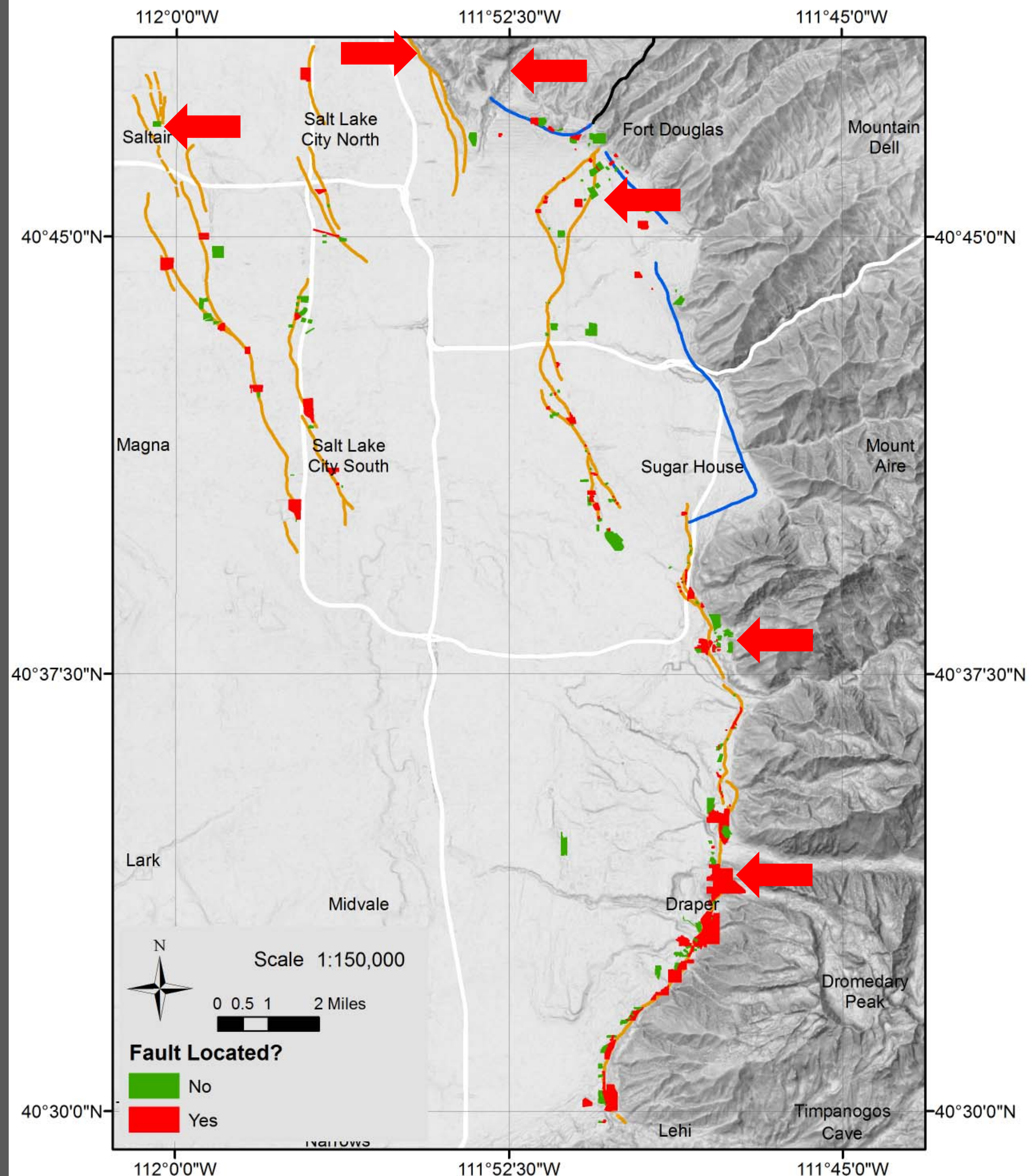


Paleoseismic Trenches
Paleoseismology of Utah Series

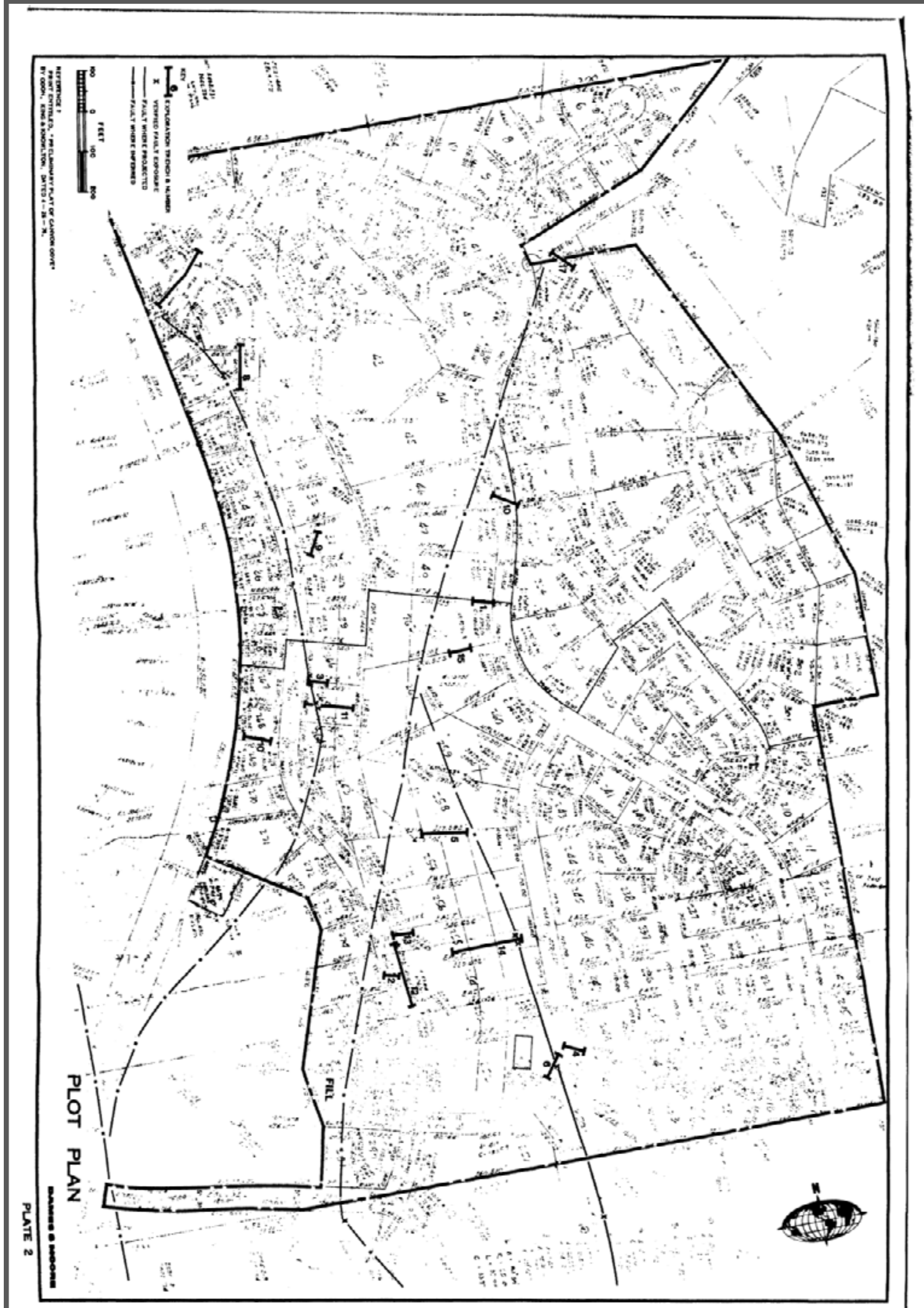


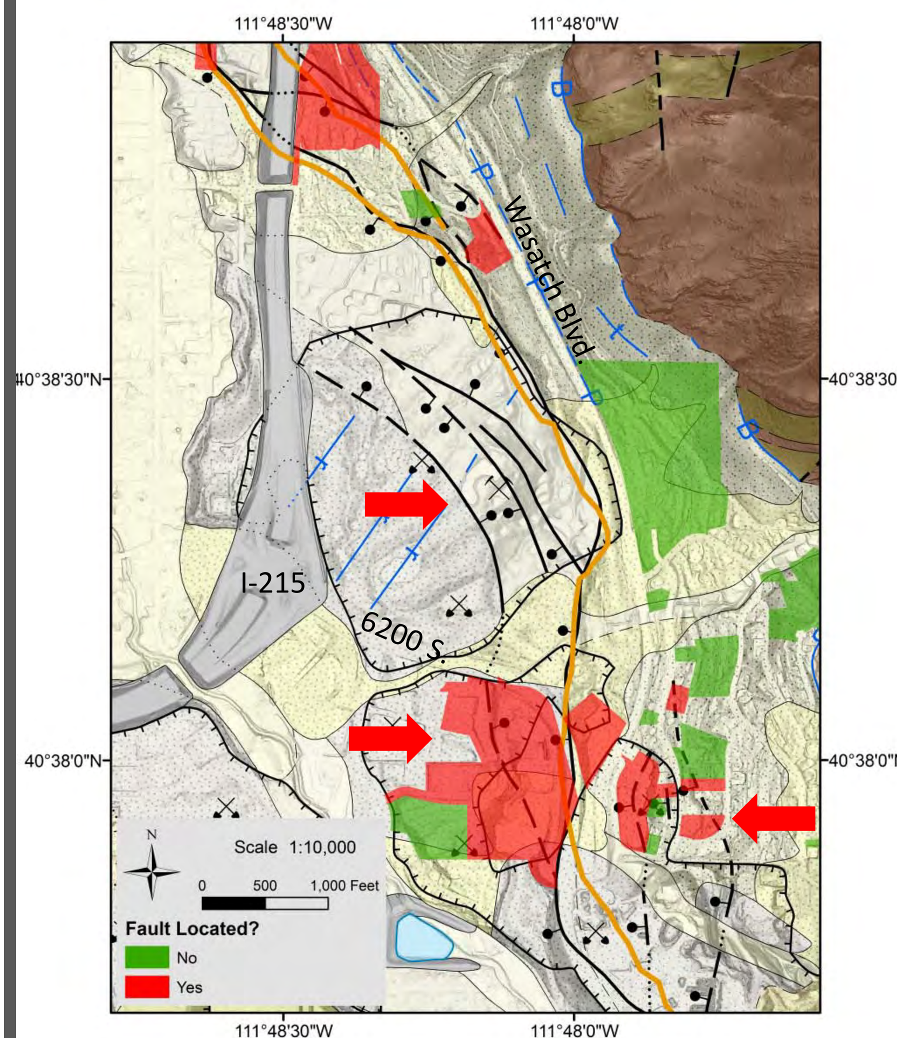
Consultant Surface Fault Rupture Investigations



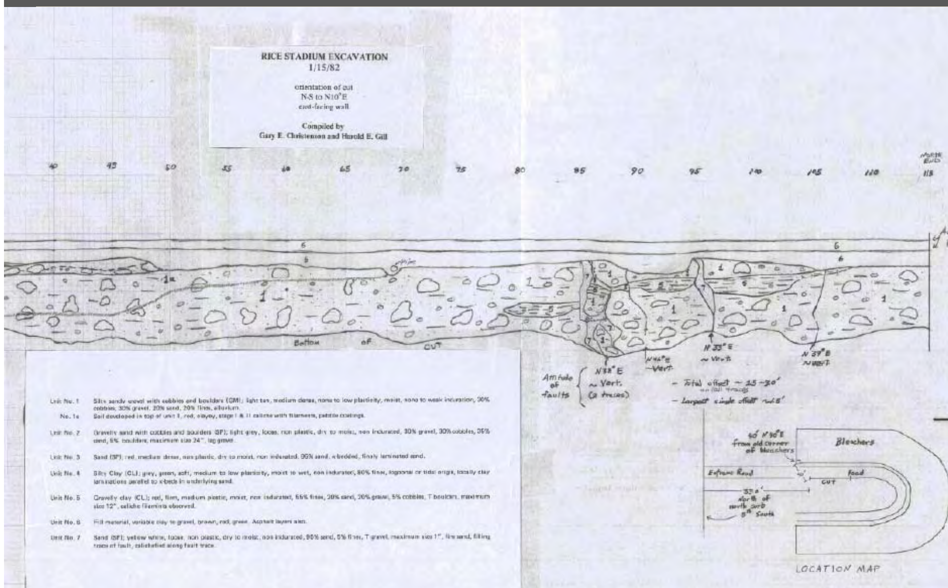

112°0'0"W
111°52'30"W
111°45'0"W
40°45'0"N
40°37'30"N
40°30'0"N
Saltair
Salt Lake City North
Fort Douglas
Mountain Dell
Magna
Salt Lake City South
Sugar House
Mount Aire
Lark
Midvale
Draper
Dromedary Peak
Lehi
Timpanogos Cave
Scale 1:150,000
0 0.5 1 2 Miles
N
Fault Located?
No
Yes

Canyon Cove
(6500 S and Wasatch Blvd)



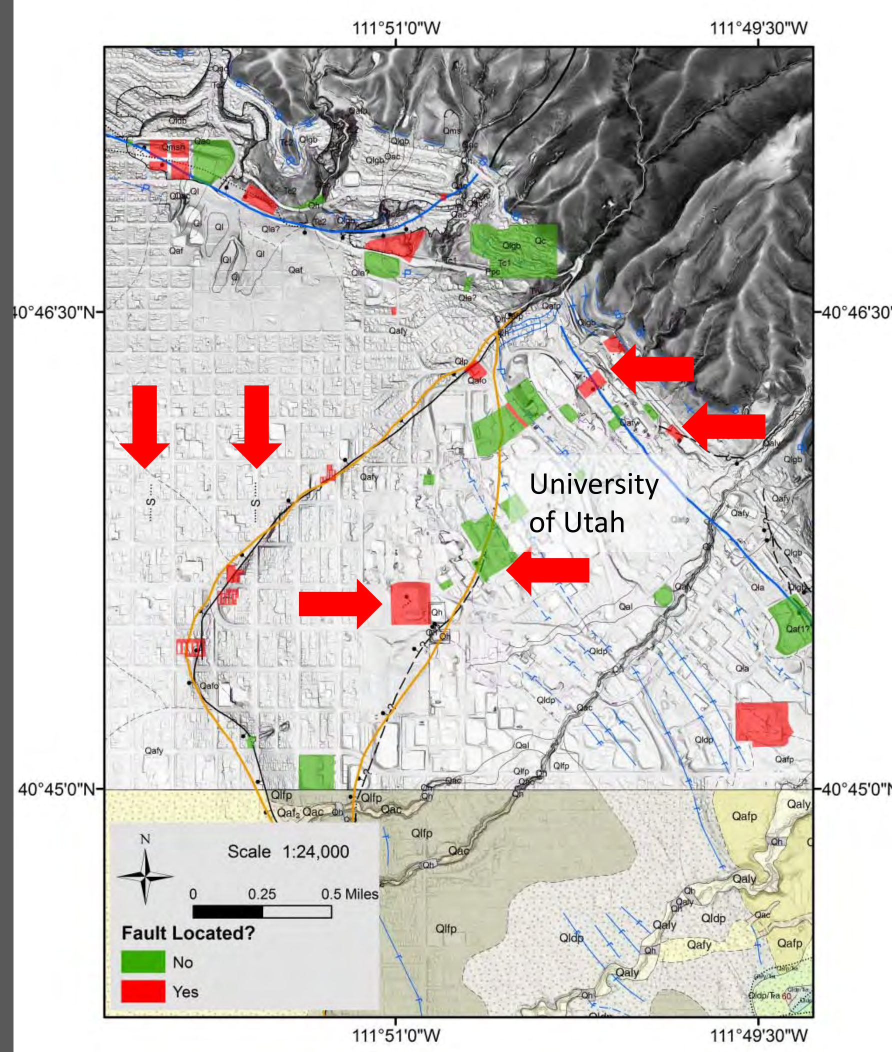


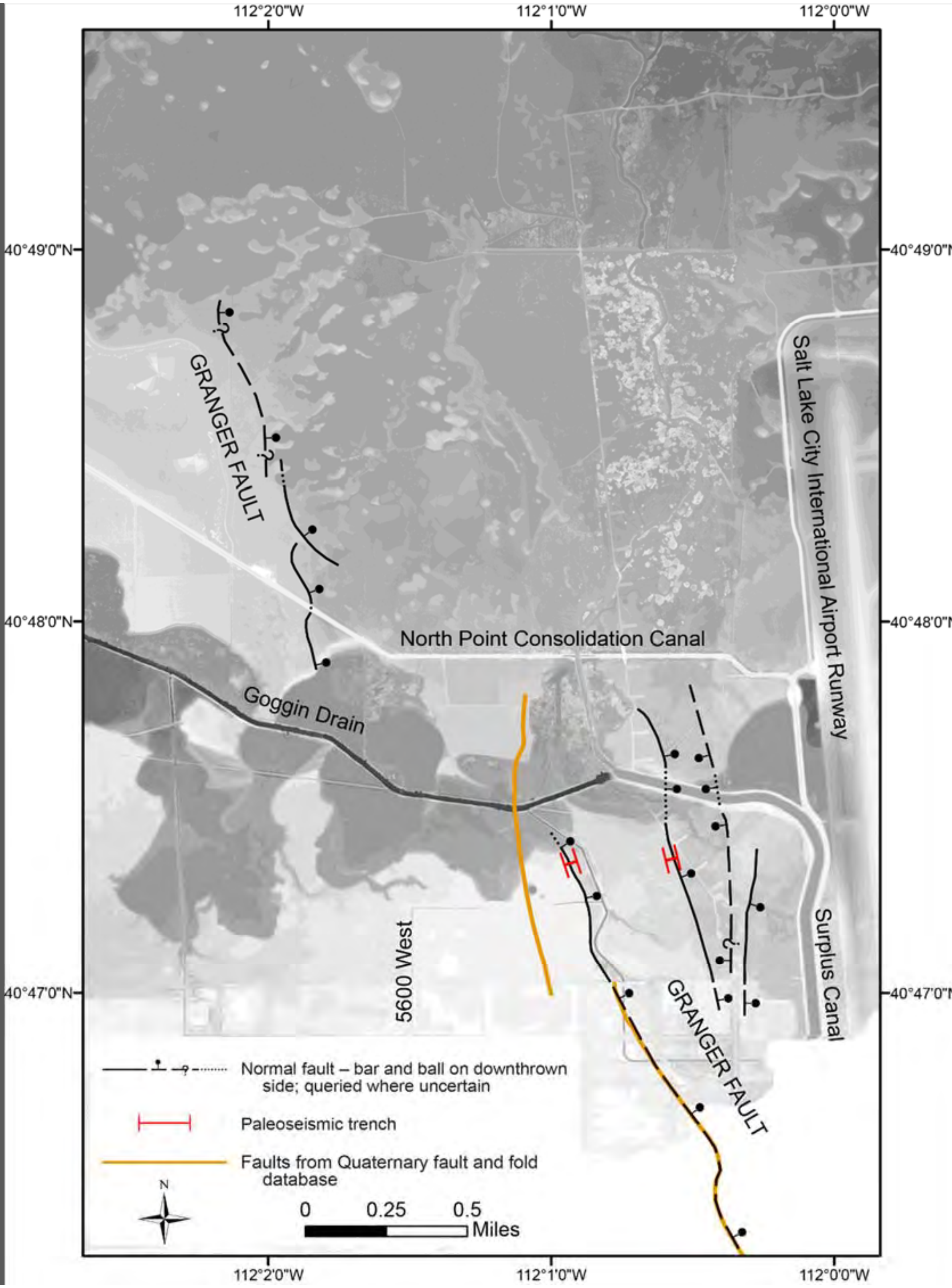
Rice Stadium
University of Utah



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

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

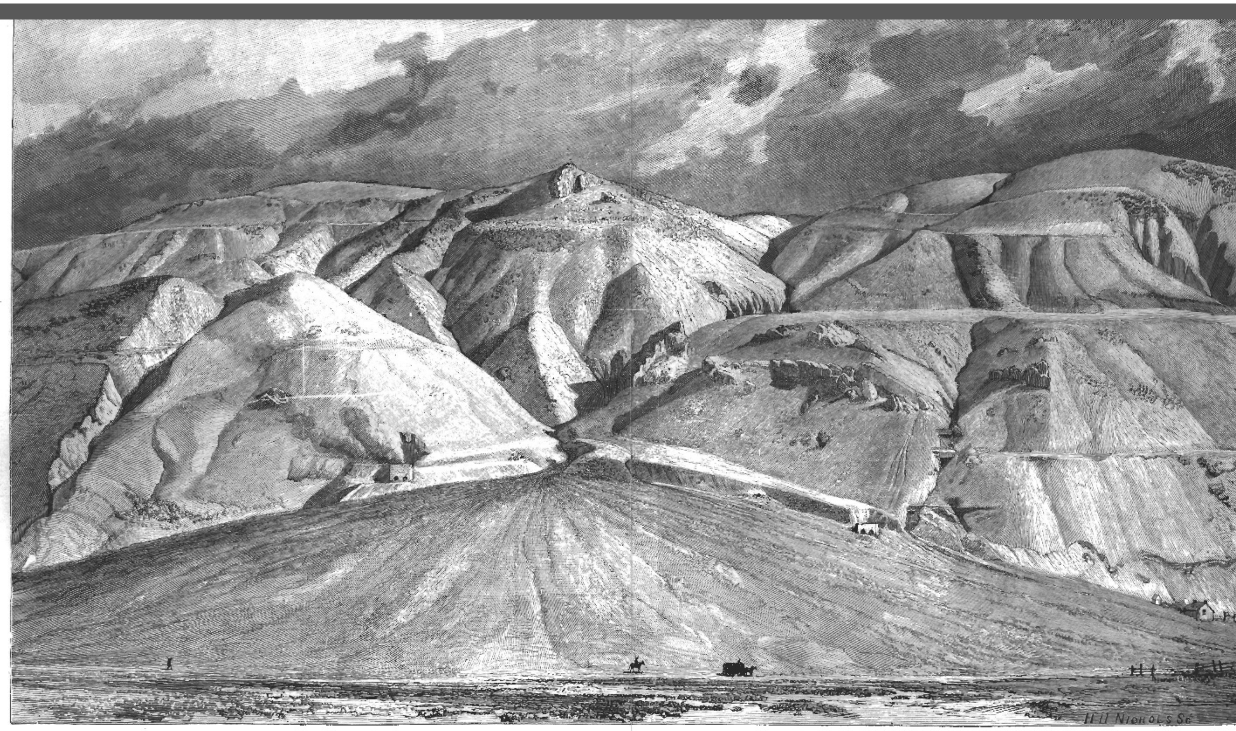




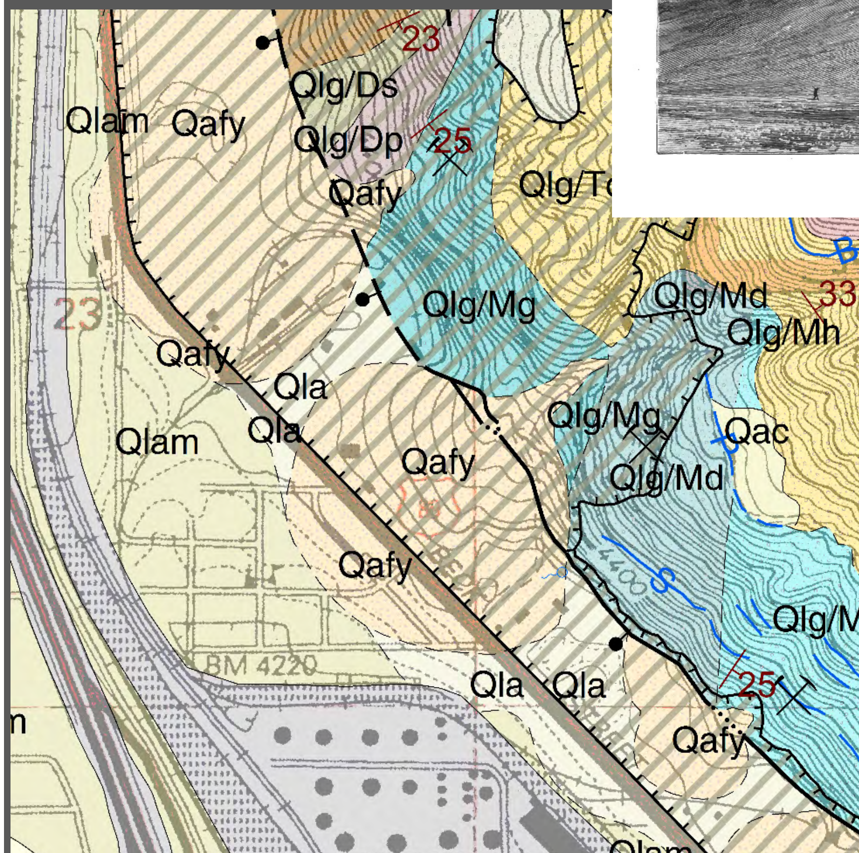
Granger Fault

- Newly mapped Granger fault strands in black (McKean and Hylland, 2013)
- Compared with Quaternary fault and fold database faults in orange (USGS and UGS, 2006)
- UGS paleoseismic trenches located in red (Hylland and others, 2014).
- Base map is a 1 m lidar digital elevation model

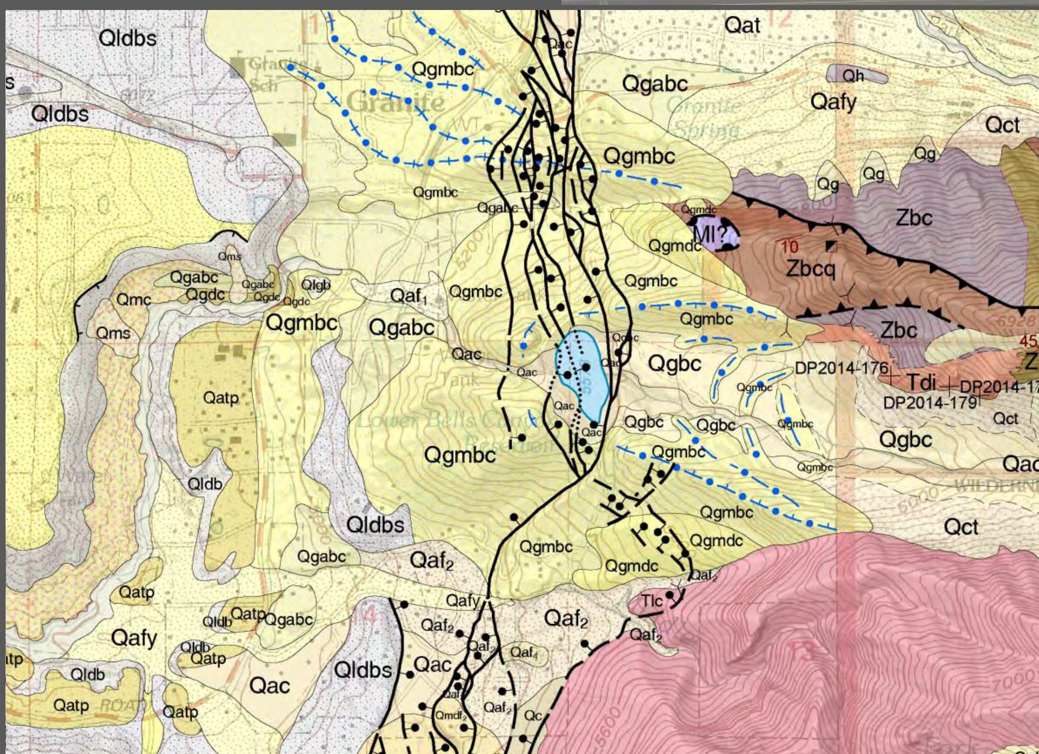
Warm Springs Fault

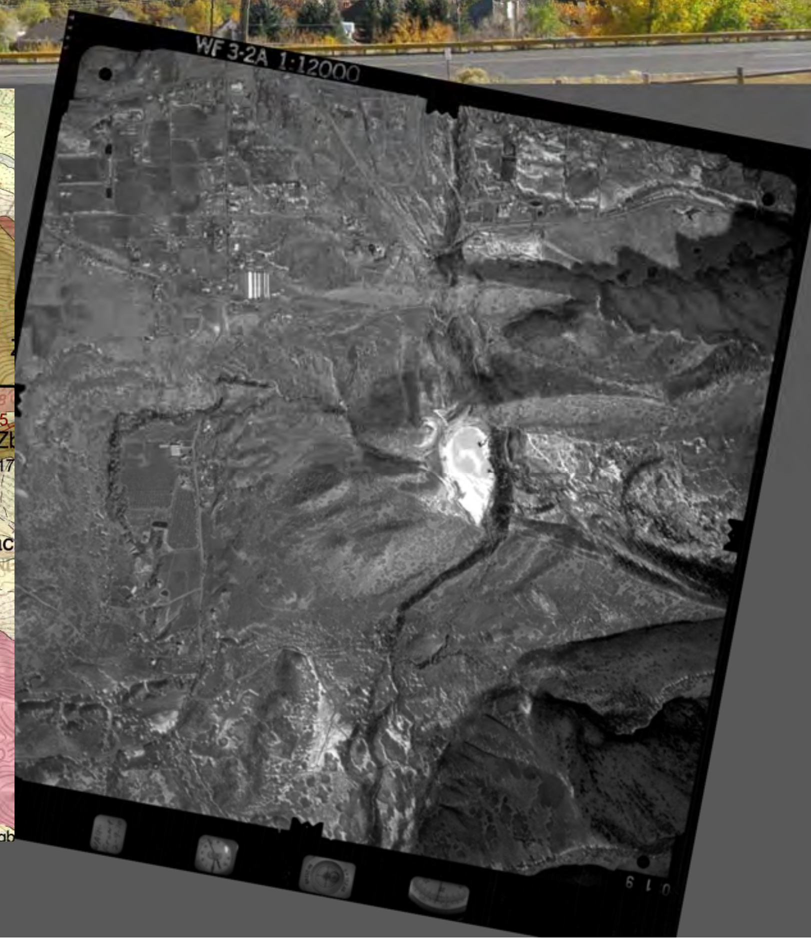


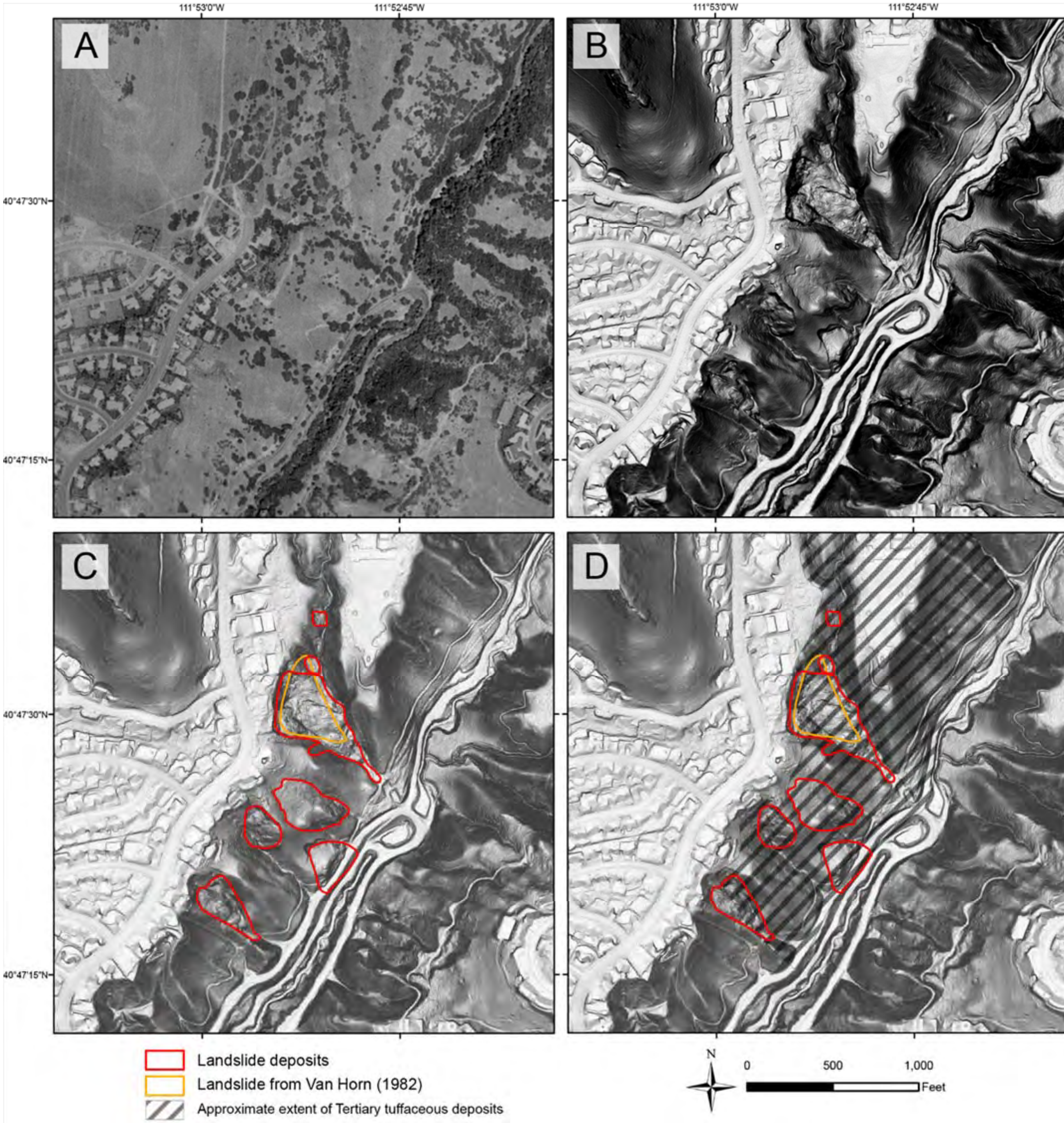
FAULT SCARP CROSSING ALLUVIAL CONE, NEAR SALT LAKE CITY.
Drawn by W. H. Holmes.



Little Cottonwood Fault







City Creek Canyon Landslides

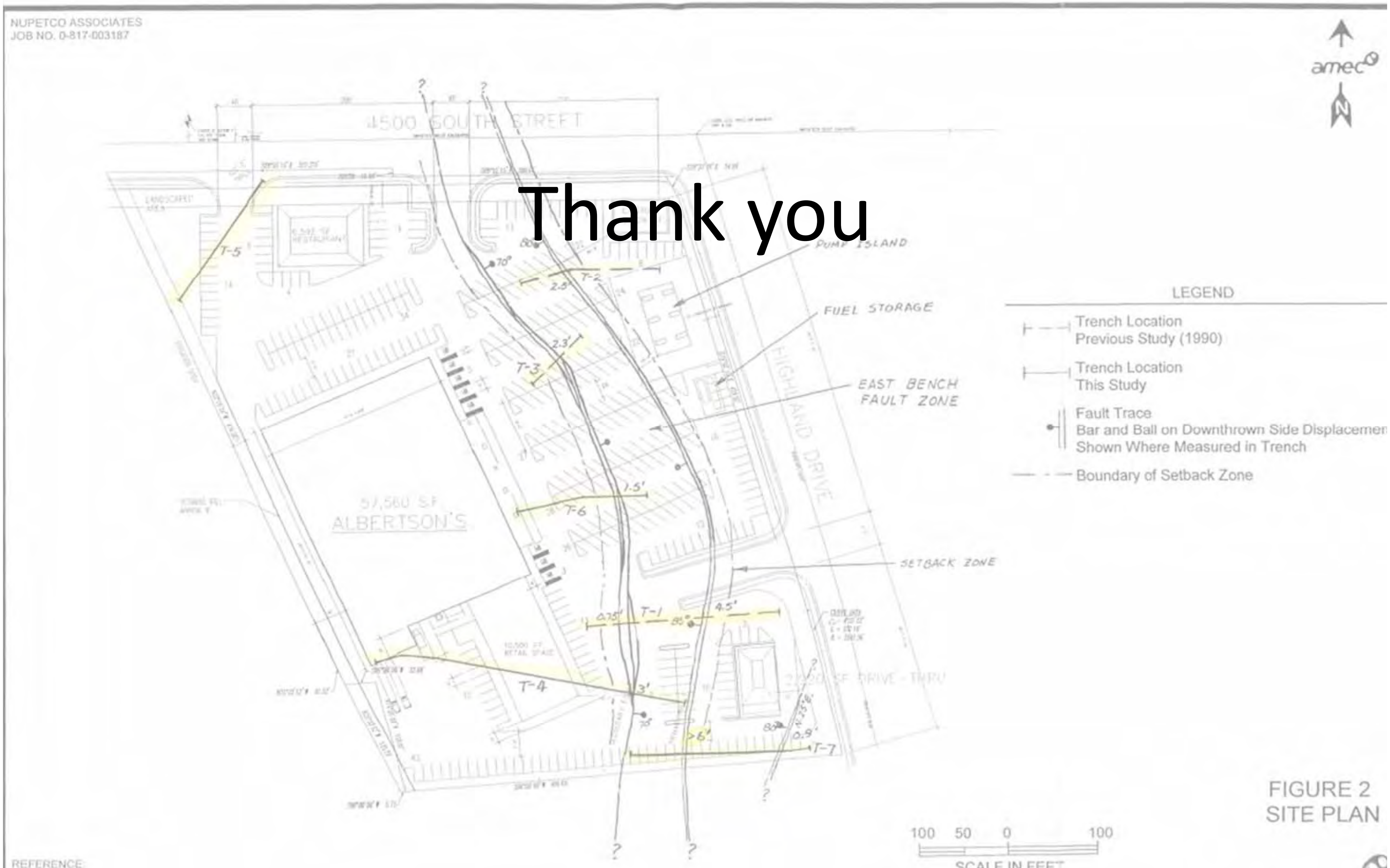
A. 1997 black and white aerial image (AGRC, 1977)

B. 2013–2014 0.5 m lidar (AGRC, 2013–2014) slope shade

C. Outlines of new landslide mapping shown in red, compared with Van Horn (1982) in orange

D. Tertiary tuffaceous deposits, approximate extent shown with gray crosshatch

Thank you


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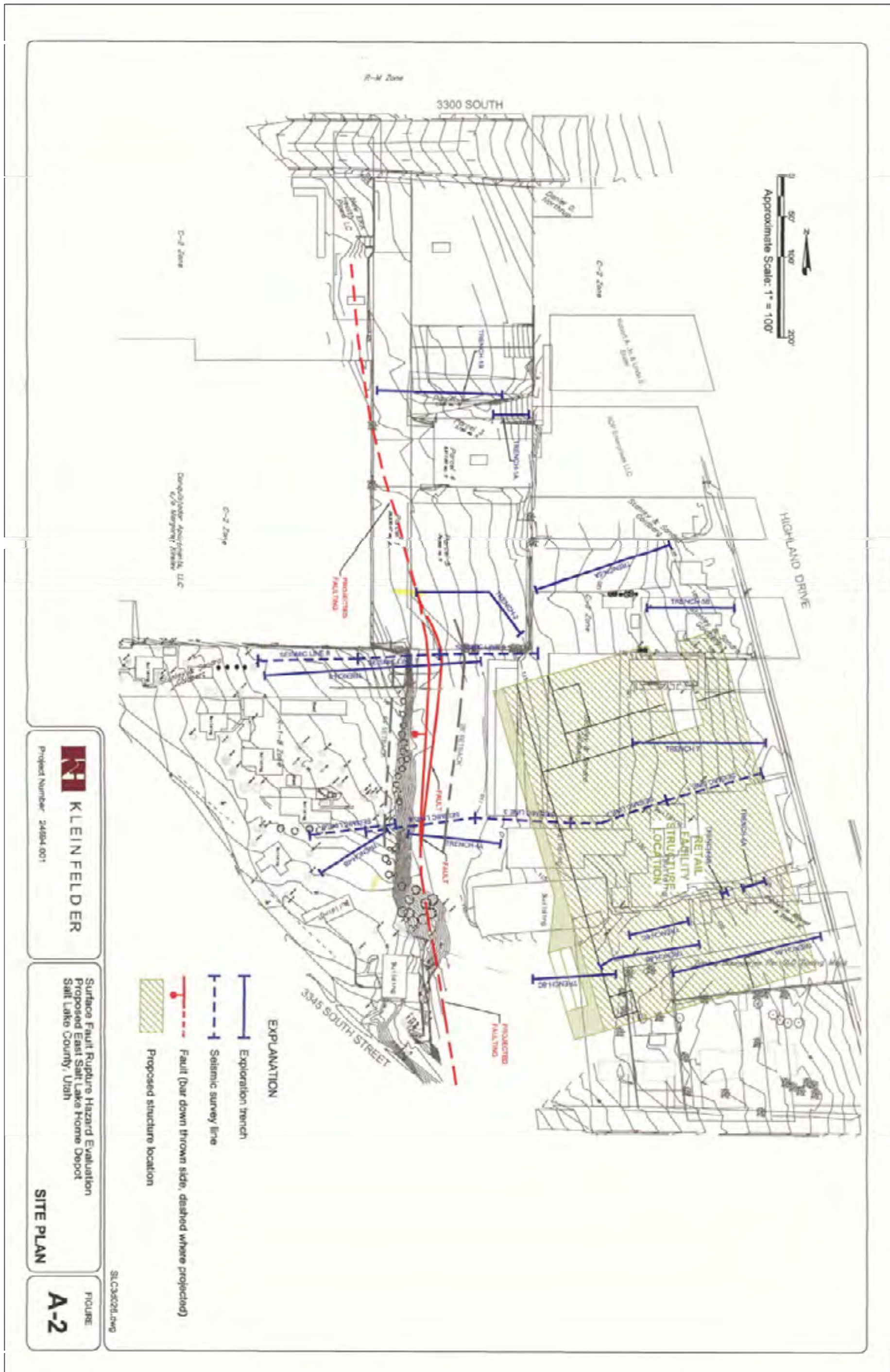
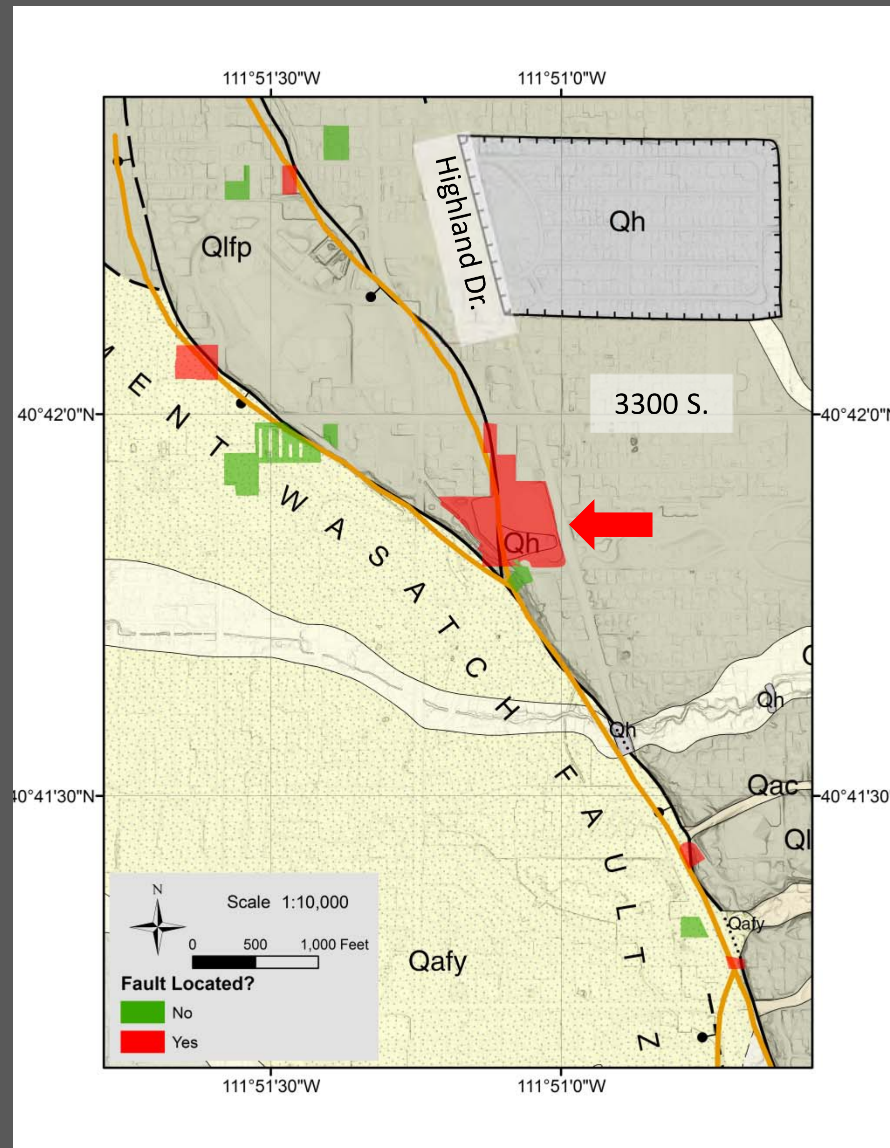
amec
4500 SOUTH STREET
PUMP ISLAND
FUEL STORAGE
EAST BENCH FAULT ZONE
SETBACK ZONE
HIGHLAND DRIVE
57,560 S.F.
ALBERTSON'S
T-1
T-2
T-3
T-4
T-5
T-6
T-7
LEGEND
Trench Location Previous Study (1990)
Trench Location This Study
Fault Trace
Bar and Ball on Downthrown Side Displacement Shown Where Measured in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



Home Depot
(3300 S and Highland Dr)



Discussion – Basin and Range Province Earthquake Hazards Issues and Investigation Priorities

- How do we want to move forward as a working group?
    - Suggest meeting yearly in February with the Utah Earthquake Working Groups.
    - Future topics or focused meetings?

- Cross-border Quaternary fault issues (fault trace mapping discrepancies, lack of mapping, fault parameter discrepancies, and poorly defined or lack of parameter data).
  - o Determine fault trace issues (mapped fault ends, offsets, etc.) at state borders and collaboratively work to resolve?
  - o When consensus-based Quaternary fault parameters exist in one state for faults crossing into another, can agreement be made to adopt the parameters for the entire fault, if relevant? Examples: East Bear Lake, East and West Cache, Hurricane, Washington, and Wasatch fault zones (Utah parameters).

- Quaternary fault investigation priorities in the region outside Utah.
  - Existing state priorities for Nevada and Utah.
  - Other states?

- Possible development of consensus-based Quaternary fault slip-rate and recurrence interval parameters for the region modeled after the Utah consensus parameters.
    - Consensus parameters exist for Utah.
    - Other states?

- Coordination and funding opportunities for acquiring new lidar?
    - USGS 3DEP?
    - Multi-state/multi-agency partnerships?

- Interest in paleoseismic investigation best practices to assist those states with limited expertise?
  - Short course(s)?
  - Online resources?