Basin and Range Province Seismic Hazards Summit III

Utah Geological Survey and Western States Seismic Policy Council

USGS Workshop

USGS Evaluation of Hazardous Faults in the Intermountain West (IMW) Region—2015 Update

Workshop convened by Rich Briggs and Ryan Gold, U.S. Geological Survey

U.S. Geological Survey Workshop Summary: Evaluation of Hazardous Faults in the Intermountain West Region—2015 Update

In conjunction with the Basin and Range Province Seismic Hazard Summit III, January 12, 2015, Salt Lake City, Utah

Workshop convened by Rich Briggs and Ryan Gold, U.S. Geological Survey

SUMMARY

The goal of this workshop was to gather representatives from Intermountain West (IMW) states to present their top five faults of concern and to create strategies to prioritize and fund active fault studies. The workshop focused on states outside Utah and Nevada, but workshop participation was open to all.

This gathering built on a similar exercise in 2008 (Crone and others, 2009) that ranked active faults by research priority in the IMW.

Representatives from Arizona, Colorado, Idaho, Montana, Oregon (in absentia), New Mexico, and Wyoming presented faults considered priorities for further study. Texas declined to send a representative. Workshop participants also offered suggestions for improving the IMW region portion of the USGS solicitation for External Research Grants; these suggestions and the list of each state's top five priority faults were included in the Fiscal Year (FY) 2016 U.S. Geological Survey (USGS) External Research Grants Program Announcement.

WORKSHOP AGENDA

7:30 AM — A la carte breakfast

8:00 AM — Welcome from the conveners and logistics

Goals and product for the workshop

Rich Briggs, USGS

Ryan Gold, USGS

8:10 AM — Review of the 2008 workshop results and a summary of external IMW work (NEHRP) funded by the USGS since 2006

Rich Briggs, USGS

8:30 AM — The Utah Working Groups: Where they started, and where they are now

Bill Lund, Utah Geological Survey

9:00 AM — Faults of concern: Arizona

Phil Pearthree, Arizona Geological Survey

9:30 AM — Faults of concern: Colorado

Matt Morgan, Colorado Geological Survey

10:00 AM — BREAK

10:15 AM Faults of concern: Montana

Mike Stickney, Montana Bureau of Mines and Geology

10:45 AM Faults of concern: Idaho

Bill Phillips, Idaho Geological Survey

11:15 AM Faults of concern: Oregon

Rich Briggs, USGS

11:45 AM Discussion

12:00 AM LUNCH

1:00 PM Faults of concern: Wyoming

Mort Larsen, Wyoming Geological Survey

1:30 PM Faults of concern: New Mexico

Dave Love, New Mexico Bureau of Geology

2:00 PM Faults of concern: Texas

Rich Briggs, USGS

2:30 PM The 2014 National Seismic Hazard Map update: Focus on IMW faults

Ryan Gold, USGS

3:00 PM BREAK

3:15 PM Data gaps and research targets: Summary of 2015 faults of concern to help guide future state work and USGS External Grants (NEHRP) funding

Rich Briggs, USGS

Ryan Gold, USGS

3:45 PM Open discussion

Possible topics include:

- Balancing hazard and risk in the IMW: How to best prioritize studies?
- Challenges faced by State surveys in conducting active fault studies.
- IMW External Grants (NEHRP) funding: Status quo or changes required?
- Induced seismicity: How does this affect priorities?

4:30 PM End

WORKSHOP ATTENDEES

Attendee	Affiliation
Phil Pearthree	Arizona Geological Survey
Matt Morgan	Colorado Geological Survey
Mike Stickney	Montana Bureau of Mines and Geology
Susan Olig	URS Corporation
Bill Lund	Utah Geological Survey
Dean Ostenaa	Fugro Consultants
Bill Phillips	Idaho Geological Survey
Craig dePolo	Nevada Bureau of Mines and Geology
Mort Larsen	Wyoming State Geological Survey
Dave Love	New Mexico Bureau of Geology
Michael Fazio	City of Bluffdale, Utah
Rich Reed	unspecified
James Bela	Oregon Earthquake Awareness
Glen Boyle	Eagle Engineering
Sarah Derouin	U.S. Bureau of Reclamation
Glenda Besana-Ostman	U.S. Bureau of Reclamation
Susanne Janecke	Utah State University
Ivan Wong	URS Corporation

MOTIVATION FOR WORKSHOP

The IMW region spans the Rocky Mountains to the Sierra Nevada and encompasses most of the broadly deforming western United States. Relatively low slip rates and a multitude of distributed active faults present challenges for seismic hazard studies in this region. These challenges are compounded by rapid development and the urban character of IMW population centers, which tend to be concentrated along active faults.

The workshop was motivated by the need to balance fault studies across the broad IMW region, and to support state efforts to prioritize active faults for further study. This effort took a slightly different approach than previous prioritization attempts. Rather than create a ranked list of faults for the entire IMW region (Crone and others, 2009), a list was presented for each state by representatives of that state's geological survey. Also, by focusing on ”faults of concern,” each state set their own criteria for inclusion, such as population at risk, potential hazard, or current lack of information.

BACKGROUND MATERIAL FOR PARTICIPANTS

Bill Lund of the Utah Geological Survey presented a short history of the Utah Quaternary Fault Parameters Working Group (UQFPWG, http://geology.utah.gov/hazards/earthquakes-faults/utah-earthquake-working-groups/quaternary-fault-parameters/). Strong collective action in Utah has resulted in unparalleled success in identifying, prioritizing, and acting on active fault characterization. Although no single approach will suit each state, the systematic progress made by the UQFPWG in Utah was discussed as a powerful way to make measureable progress on active fault problems.

Ryan Gold outlined the criteria for inclusion of active faults as sources in the USGS National Seismic Hazard Map (NSHM) (Petersen and others, 2014). He also discussed the changes between the 2008 and 2014 versions of the NSHM in the IMW. The goal of this presentation was to foster conversation on the inclusion, or lack thereof, of faults deemed important by the states in the NSHM.

Top Five Faults of Concern

The faults highlighted by each state are summarized here. More detailed discussion for each state is included in the corresponding state presentations:

Arizona: Lake Mary, Big/Little Chino, Mead Slope, Hurricane, and Needles faults

Colorado: Golden, Rampart Range, Ute Pass, Williams Fork Mountains, and Frontal faults

Idaho: Lost River, Squaw Creek, Sawtooth, Beaverhead, and Lemhi faults

Montana: Swan, Centennial/Madison, Continental, Bitterroot, and Brockton-Froid fault zones

New Mexico: Rincon Ridge, Northern Alamogordo, Mesilla Basin, Albuquerque Basin, and Southern San Andres Mountains faults

Oregon (IMW portion): Goose Lake Graben, West Klamath fault zone, La Pine Graben, Sisters-Metolius fault zone, Grande Ronde Valley faults

Wyoming: Teton, Grand Valley, Rock Creek, Greys River, and East Gros Ventre faults

DISCUSSION PERIOD

The workshop culminated in a discussion that revolved around two main themes: criteria used to select the faults of concern, and the future direction of active fault research in the IMW region. The discussion ended with collective ideas on why research on active faults in the IMW region remains important in the face of many other pressing national needs.

The main points of each main thread of this conversation are paraphrased below in bullet form.

Criteria Used to Select Faults of Concern

- At present, the "faults of concern" list has little consistency because the framework is different for each state.
- Similarly, the degree of vetting for faults listed by each state varies dramatically. Each state is at a different stage of developing a structure for identifying and ranking priority faults.
- Do the criteria employed by each state for evaluating priority faults need to be uniform? Is the present list too highly dependent on the individuals who created the priorities?
- Neighboring states may consider working together to develop lists—science and uniformity of mapping win.
- Five faults per state is perhaps too many—would three be better?
- A working group approach by each state, or by groups of states, would help to make the framework for highlighting faults of concern more consistent.
- The current disconnect between the faults represented in the USGS Quaternary Fault and Fold Database, the faults seen as important by the states, and the faults included in the NSHM is confusing and needs to be addressed by the USGS.

Future Direction of Active Fault Research in the IMW Region

- The IMW portion of the USGS External Grants Program Announcement should explicitly include state priorities (this recommendation was acted upon for the FY16 External Grants Program Announcement).

- A science path toward funding is needed: The IMW portion of the USGS External Grants Program Announcement should include a list of purely scientific issues important to hazard that can be studied on any fault, not just in high-risk areas (this recommendation was acted upon for the FY16 External Grants Program Announcement).

- A few attendees would prefer that USGS External Research funding go to a single location or problem each year until that issue is resolved; their message to USGS is to focus. Others prefer that funding be divided equally between the states, because funding at present is unequal; their message to the USGS is to diversify. Most attendees agree that a mix of hazard, risk, and scientific interest as vetted by outside panels should direct USGS external funding. This is more or less the current model.

- Will UCERF3-style (Field and others, 2013) fault networks, rather than isolated sources, become standard in future NSHM updates? If so, the entire approach used now, which focus on high-slip-rate faults, will need to be reconsidered. All the low-slip-rate faults now ignored will become important.

- There is a perception that the USGS is only concerned with faults with maximum perceived risk, and thus most lightly populated IMW states feel neglected by the USGS. One attendee remarked, "If it's only population multiplied by probability, it's the Wasatch." As a counter to the view that only population matters, another attendee pointed out one significant earthquake could be devastating for many lower-population states in the context of the state's economy.

- As the NSHM moves toward time-dependent hazard, faults near urban areas will become critical. We do not have the urban paleoseismic chronologies we need.

Why Study Faults in the IMW Region?

- Participants recognize that the IMW lags behind other regions if annualized losses alone are the metric for evaluating hazard and risk. But the consensus of the group is that this limited perspective misses larger truths about the region:

    - The IMW region hosts the highest relative concentration of urban populations in the country.

    - Most people in the IMW region live near mountains for water, thus usually on the hanging wall of and near to an active fault.

    - Construction in the IMW region is often old and/or substandard, with many unreinforced masonry structures due to history and climate, and not designed for potential ground shaking intensities.

    - There have been nearly as many M7+ earthquakes in the IMW region since the late 1800s as in California over the same time period. We cannot count on the next IMW M7+ earthquake occurring in a sparsely populated area.

    - Infrastructure (including energy) in the IMW region is distributed, and so high environmental impacts may result from a large earthquake outside a populated area. Evaluations centered solely on cities miss an important source of risk in the IMW region.

REFERENCES

Crone, A.J., Haller, K.M., and Maharrey, J.Z., 2009, Evaluation of hazardous faults in the Intermountain West region—Summary and recommendations of a workshop: U.S. Geological Survey Open-File Report 2009-1140, 72 p.

Field, E.H., Biasi, G.P., Bird, P., Dawson, T.E., Felzer, K.R., Jackson, D.D., Johnson, K.M., Jordan, T.H., Madden, C., Michael, A.J., Milner, K.R., Page, M.T., Parsons, T., Powers, P.M., Shaw, B.E., Thatcher, W.R., Weldon, R.J., II, and Zeng, Y., 2013, Uniform California earthquake rupture forecast, version 3 (UCERF3)—The time-independent model: U.S. Geological Survey Open-File Report 2013–1165, 97 p., California Geological Survey Special Report 228, and Southern California Earthquake Center Publication 1792, http://pubs.usgs.gov/of/2013/1165/.

Petersen, M.D., Moschetti, M.P., Powers, P.M., Mueller, C.S., Haller, K.M., Frankel, A.D., Zeng, Y., Rezaeian, S., Harmsen, S.C., Boyd, O.S., Field, N., Chen, R., Rukstales, K.S., Luco, N., Wheeler, R.L., Williams, R.A., and Olsen, A.H., 2014, Documentation for the 2014 update of the United States National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2014–1091, 243 p.

Basin and Range Province Seismic Hazards Summit III

Utah Geological Survey and Western States Seismic Policy Council

USGS Workshop Presentations

USGS Evaluation of Hazardous Faults in the Intermountain West (IMW) Region—2015 Update

The following is a PDF version of the workshop PowerPoint presentations.

USGS Evaluation of Hazardous Faults in the Intermountain West (IMW) Region-2015 Update

in conjunction with the Basin and Range Province Seismic Hazard Summit III (BRPSHSIII)

January 12, 2015, Salt Lake City, Utah

Conveners: Rich Briggs (rbriggs@usgs.gov)
Ryan Gold (rgold@usgs.gov)

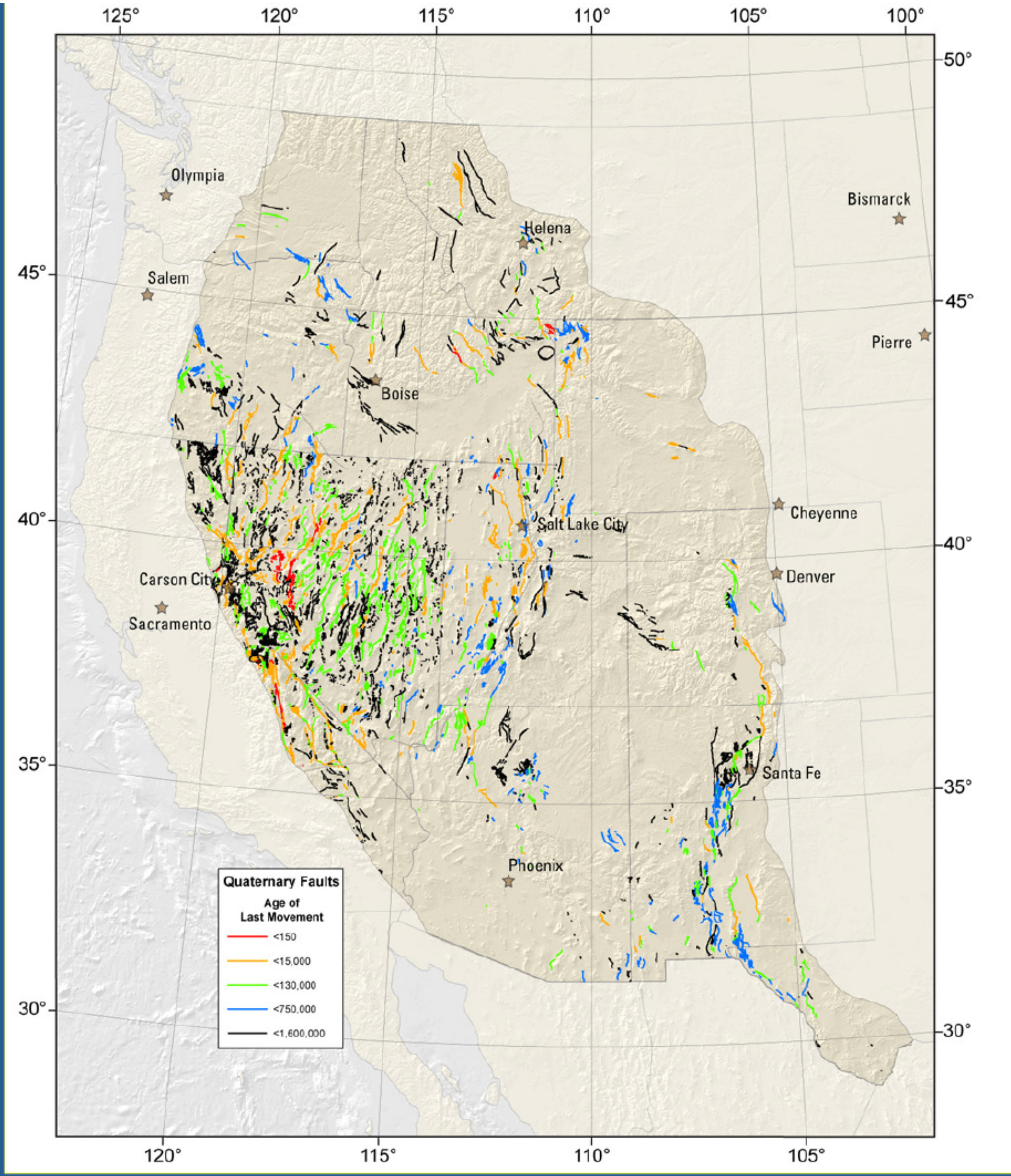
USGS

Overview

1. **Welcome and logistics**
2. **Review agenda**
3. **Workshop goals and product**
4. **Review of the 2008 workshop results and a summary of recent USGS External Grants (informally known as 'NEHRP') work in the Intermountain West**

USGS

IMW Region



USGS

Workshop goals and product

Goal: Top 5 faults of concern from IMW states outside Nevada and Utah.

We want to put a spotlight on high-priority faults in advance of the next updates to the National Seismic Hazard Maps, tentatively scheduled for 2017.

Product: Workshop report and update to USGS External Grant solicitation that can be used to guide future work.

Faults of Concern

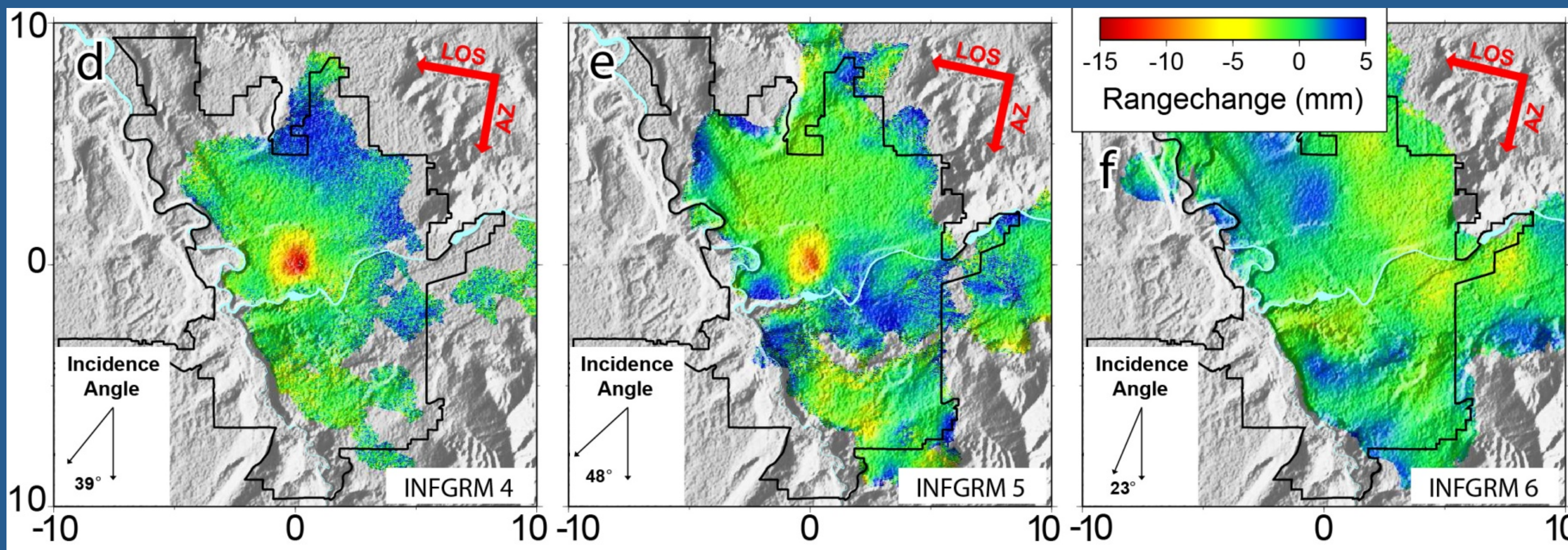
The concept "faults of concern" is meant to capture hazardous and/or high risk faults, especially faults for which little is known.

It is meant to strike a balance between hazard, risk, and knowledge, a particular challenge in the IMW region.

These are priority faults, important faults, understudied faults, etc.

USGS

Example Fault of Concern (outside IMW): The Spokane Fault



Wicks, C., C. Weaver, P. Bodin, and B. Sherrod (2013), InSAR Evidence for an active shallow thrust fault beneath the city of Spokane Washington, USA, *Journal of Geophysical Research: Solid Earth*, *118*(3), 1268-1276.

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Review of the 2008 workshop results

USGS

Review of 2008 workshop results

Supported by the USGS Earthquake Hazards Program

Evaluation of Hazardous Faults in the Intermountain West Region—
Summary and Recommendations of a Workshop

By Anthony J. Crone, Kathleen M. Haller, and Joseph Z. Maharrey

Open-File Report 2009–1140

U.S. Department of the Interior
U.S. Geological Survey

http://pubs.er.usgs.gov/publication/ofr20091140

2008 fault ranking system (proposed, not used)

Table 3. A proposed numerical rating system for IMW Quaternary faults.

[System was proposed by J. McCalpin as a possible methodology to apply to IMW faults]
Rating= W_1**P**+W_2**SR**+W_3**R**+W_4**U**+W_5**I**+W_6**D**
Where: W_x are weights (integers between 1 and 10; 1 indicates low importance and 10 indicates high importance)
Bold letters are the Class values for each input parameter, where Class 1=1, Class 2=2, Class 3=3

Input Parameter	Class 1	Class 2	Class 3
P=population of close city (<100 km) or critical facility type	<20,000	20,000–200,000	>200,000
SR=slip rate (mm/yr)	<0.1	0.1–0.2	>0.2
R=rapid urbanization of fault trace	low	med	high
U=uncertainty in current source parameters	low	med	high
I=impact on National Map of changing fault's parameters (or of adding a fault)	low	med	high
D=distance from fault to city/critical facility (km)	>100 km	20–100 km	<20 km

Subjective relative weights:
W_1=10 (population)
W_2=1 (Slip rate)
W_3=4 (rapid urbanization)
W_4=3 (uncertainty in parameters)
W_5=5 (impact of change)
W_6=7 (distance fault to city)

Example 1: high-rated fault, East Franklin Mountains, Texas
Rating= 10P+1SR+4R+3U+5I+7D
= 10(3)+1(2)+4(3)+3(2)+5(2)+7(3)= **84**

Example 2; low-rated fault, Rock Creek fault, Wyoming
Rating= 10P+1SR+4R+3U+5I+7D
= 10(1)+1(3)+4(1)+3(3)+5(3)+7(1)= **48**

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2008 fault rankings (1/2)

	Structure name	Cumulative Points from the sum of "Top ten rankings"
1.	E. Franklin Mtns. fault, NM and TX	147
2.	Albuquerque area faults, NM	115
3.	Golden fault, CO	68
4.	Algodones fault, AZ	56
5.	Hurricane fault, AZ and UT	52
6.	Centennial fault, MT	47
7.	Rampart Range fault, CO	46
8.	Teton fault, WY	43
9.	Metolius-Sisters faults, OR	38
10.	Squaw Creek fault, ID	36
11.	Klamath graben faults, OR	34
12.	Washington fault, AZ and UT	29
13.	Mission fault, MT	27
14.	Rocky Mtn. Arsenal fault, CO	26
15.	Beaverhead fault, ID	24
16.	Sawtooth fault, ID	20
17.	Long Valley fault, ID	18
18.	Canyon Ferry fault, MT	17
19.	Madison fault, MT	16
20.	Wallula fault, OR	15
21.	Embudo-Santa Clara fault, NM	13
22.	Hebgen/Red Canyon fault, MT	13
23.	Powder River Peninsula fault, OR	9

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2008 fault rankings (2/2)

24	East Mt. Sheridan fault, WY	8
25.	Williams Fork fault, CO	8
26.	Grays River fault, WY	7
27.	Pajarito fault, NM	6
28.	Big Chino, AZ	5
29.	Heise-Grand Valley faults, ID	4
30.	Amargosa fault, northern Mexico	3
31.	Lake Mary fault zone, AZ	2
32.	Bear River fault, WY	1
33.	Needles graben and fold, AZ	1
34.	Star Valley fault, WY	1
35.	Red Rock fault, MT	1
36.	Hoback fault, WY	1
37.	Eagle Bay fault, WY	0
38.	Grande Ronde Valley fault, OR	0
39.	Ute Pass fault, CO	0
40.	Rock Creek fault, WY	0
41.	Hubble Springs fault system, NM	0
42.	Lobo Valley fault, TX	0

USGS

Summary of externally-funded work in the Intermountain West

External Research Support

Funded Research - Grants & Cooperative Agreements

The Earthquake Hazards Program funds research in order to provide earth science data and information essential to mitigate earthquake losses.

View Projects:

Award Year: All Years

Region: Intermountain West

Journal Publication: ☐

Search Projects:

PI:

Award No.:

Keyword in Title:

Institution:

Find Projects

For reports from awards made prior to 2000, use the advanced search of the USGS Library Catalog.

Award No.	Principal Investigator(s)	Region	Project Title	Institution	Final Report	Journal Publication(s)	Year
02HQGR0105	David Dinter and James Pechmann	Intermountain West	Paleoseismology of the Promontory Segment,	University of Utah	download		2002

Information available at http://earthquake.usgs.gov/research/external/research.php

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USGS External Funding: Two main points

1) IMW panels have overwhelmingly supported proposals for work in Nevada and Utah.

2) The average funded proposal since 2006 is a $46k, one year study focusing on a previously-identified problem near an urban area with immediate impact on the National Seismic Hazard Maps. There are important exceptions – but they are exceptions.

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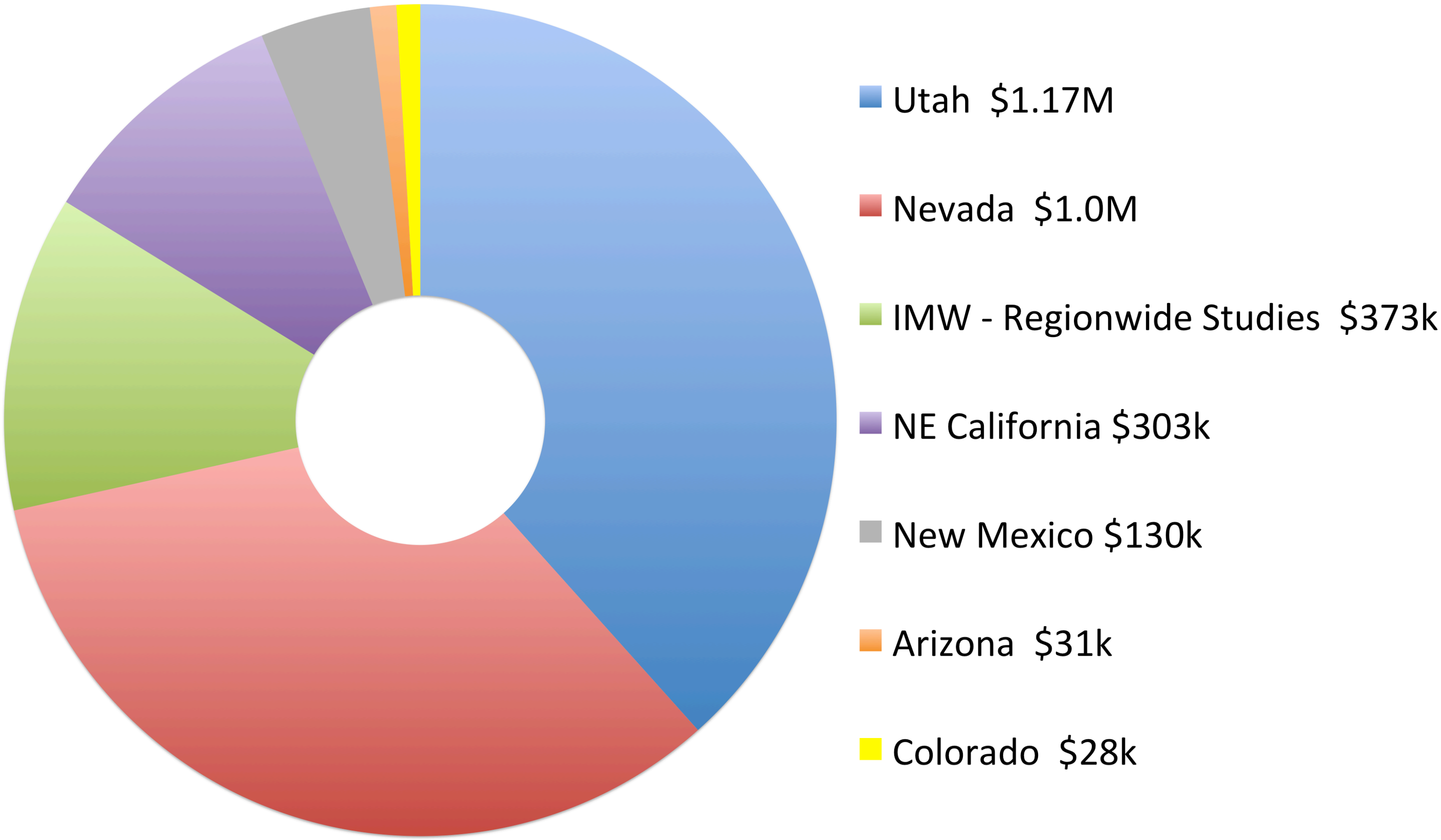
USGS Competitive IMW External Funding: ~$3.0 million since 2006-2013



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USGS External Research Support: Success Rate

Earthquake Hazards Program Grant Proposal Success Rate

Year	Proposals reviewed by panels	Proposals NOT recomm. for support by panels	Proposals recomm. for support by panels, but not funds available	Proposals funded
2009	162	56	26	80
2010	237	106	66	65
2011	208	85	47	76
2012	187	70	44	73
2013	221	94	71	56

40% successful

25% successful

IMW generally tracks the overall External Research Program statistics

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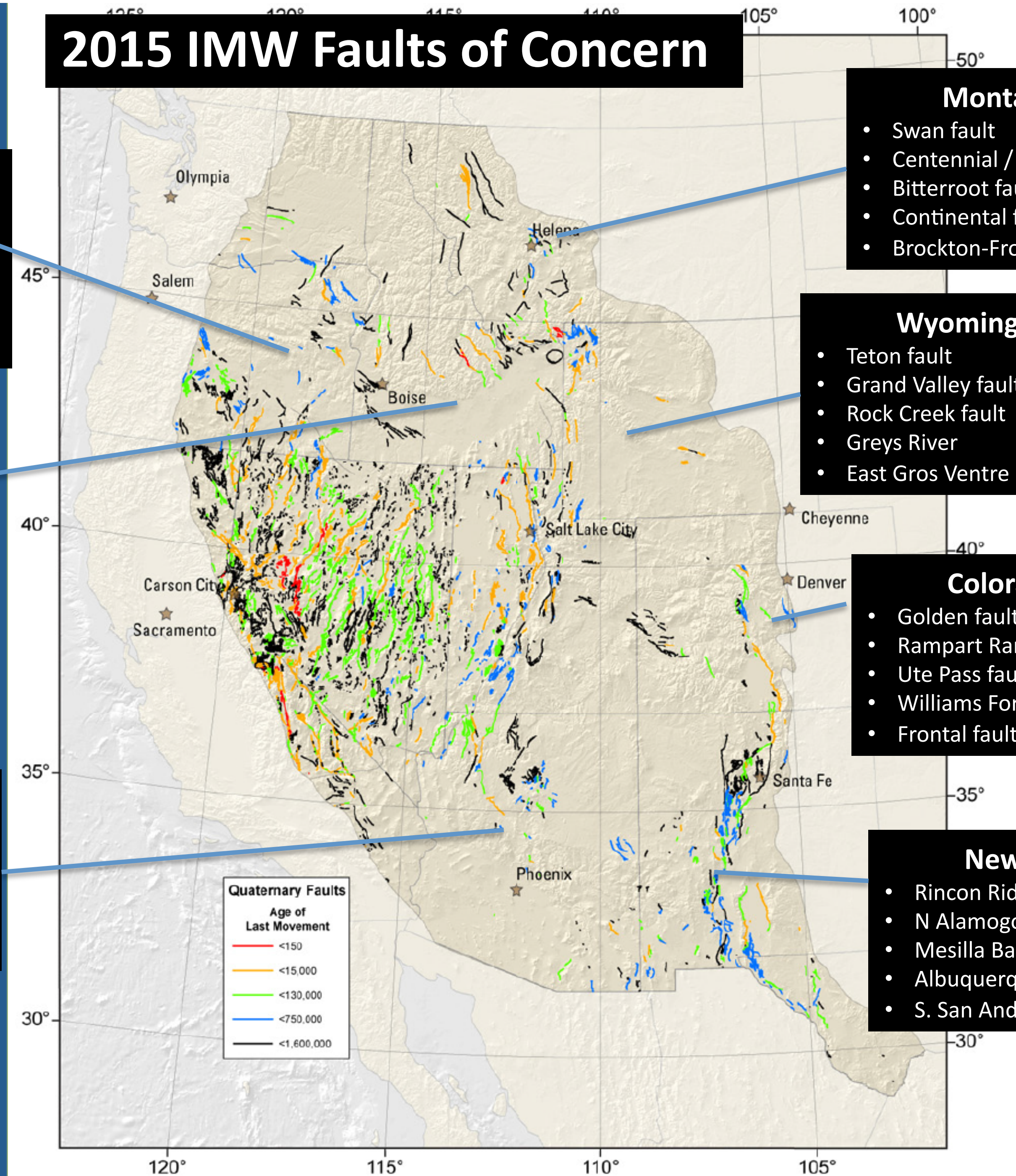
2015 IMW Faults of Concern



Oregon

- Goose Lake Graben
- West Klamath Fault Zone
- La Pine Graben
- Sisters Metolius fault zone
- Grande Ronde Valley faults

Idaho

- Lost River fault
- Square Creek fault
- Sawtooth fault
- Beaverhead fault
- Lemhi fault

Arizona

- Lake Mary fault
- Big/Little Chino fault
- Hurricane fault
- Mead Slope fault
- Needles fault complex

Montana

- Swan fault
- Centennial / Madison faults
- Bitterroot fault
- Continental fault
- Brockton-Froid

Wyoming

- Teton fault
- Grand Valley fault
- Rock Creek fault
- Greys River
- East Gros Ventre

Colorado

- Golden fault
- Rampart Range fault
- Ute Pass fault
- Williams Fork Mountains
- Frontal fault

New Mexico

- Rincon Ridge fault
- N Alamogordo fault
- Mesilla Basin faults
- Albuquerque Basin faults
- S. San Andres Mtns faults

Prioritizing Utah's Potentially Hazardous Quaternary Faults

The Utah Quaternary Fault Parameters Working Group: Where It Started and Where It Is Now

William Lund
Utah Geological Survey

In The Beginning

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

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

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

Original UQFPWG Members

GROUP A

Suzanne Hecker – USGS

Michael Hylland – UGS

William Lund – UGS

Michael Machette – USGS

James McCalpin – GEO-HAZ

Alan Nelson – USGS

Susan Olig – URS Corp.

Dean Ostenaa – USBR

Stephen Personius – USGS

David Schwartz – USGS

GROUP B

Craig dePolo – NBMG

Kathleen Haller – USGS

Philip Pearthree – AZGS

James Pechmann – UofU

Mark Peterson – USGS

Robert Smith – UofU

Ivan Wong – URS Corp.

Utah Quaternary Faults with Paleoseismic-Trenching Data in 2003

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

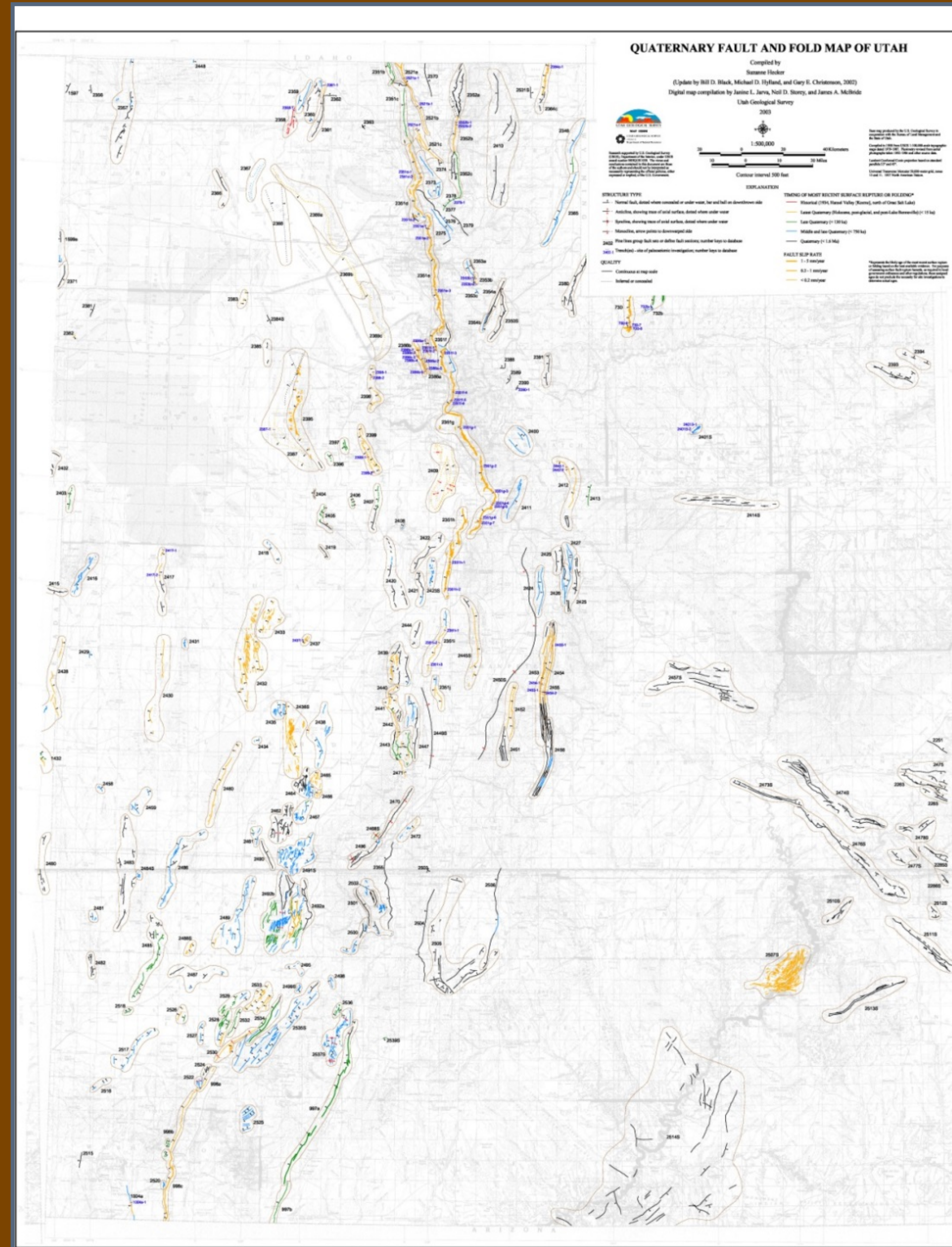
Example of UQFPWG Consensus Results

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

UQFPWG Process Produced a Disturbing Realization

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

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



UQFPWG Originally Recommended 20 Faults for Additional Study*

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

* Subsequently expanded in 2007, 2009, 2010, 2011, and 2012

So, in 2004 that's where things stood, Utah had a consensus list of 20 Quaternary faults that required further study to characterize the state's earthquake hazard to a "minimally acceptable level."

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

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Utah Quaternary Fault Parameters Working Group

The main goal of the Utah Quaternary Fault Parameters Working Group (UQFPWG) is to characterize active fault sources in Utah.

The working group began by developing consensus slip-rate and recurrence-interval data for all Utah trenched faults (Lund, 2005) in 2003 and 2004. The working group also developed an initial priority list of faults requiring additional study and, based on each year's paleoseismic investigations, has updated the list annually.

As new paleoseismic data became available, the working group modified its consensus slip-rate and recurrence-interval values as necessary. The UQFPWG started annual meetings in 2005.

Annual Meeting Results	Annual Meeting Agendas	Annual Meeting Presentations
2005	2005	2005
2006	2006	2006
2007	2007	2007
2008	2008	2008
2009	2009	2009
2010	2010	2010
2011	2011	2011
2012	2012	2012
2013	2013	2013
2014	2014	2014

Publications

Paleoseismic studies that developed out of the UQFPWG meetings and published by the UGS are found in the Paleoseismology of Utah Series.

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

Contact

Working Group Facilitator and UGS Liaison - William Lund [(435) 865-9034], billlund@utah.gov

1594 W. North Temple, PO 146100, Salt Lake City, UT 84114-6100, 801.537.3300, Fax 801.537.3400
Hours: Monday - Friday 8:00 a.m. to 5:00 p.m.

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

8:00 Continental breakfast

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

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

10:10 Break

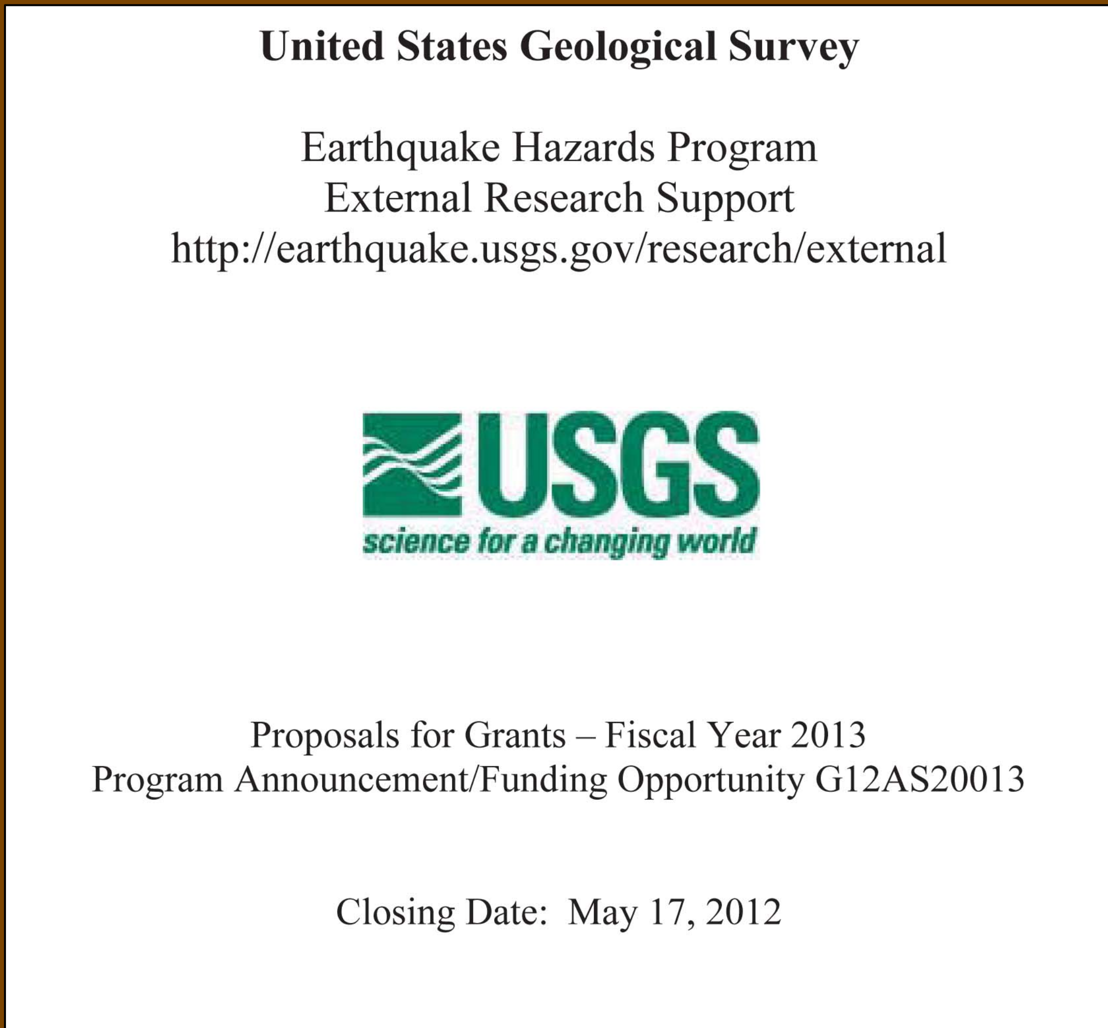
10:40 Technical presentations of work completed or in progress
- 10:40 – New observations from the Bear River fault zone; Dave Schwartz, USGS
- 11:00 – Clustered earthquakes during the Bonneville high stand–an update; Susanne Janecke, USU
- 11:20 – Contemporary deformation of the Wasatch Front, Utah,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

12:00 Lunch

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

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

3:30 Adjourn


United States Geological Survey

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

USGS
science for a changing world

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

Closing Date: May 17, 2012

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

Table 2. UQFPWG 2014 list of highest priority Quaternary faults/fault segments requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level, and status of current paleoseismic investigations for all currently identified Utah priority faults/fault segments.

2014 Highest Priority Faults/Fault Sections For Study

Fault/Fault Section[1]	Investigation Status	Investigating Institution[2]
Acquire new paleoseismic information for the five central segments of the Wasatch fault zone to address data gaps – e.g., (a) the rupture extent of earthquakes on the Brigham City and Salt Lake City segments, (b) long-term earthquake records for the northern Provo, southern Weber, and Salt Lake City segments, and (c) the subsurface geometry and connection of the Warm Springs and East Bench faults on the Salt Lake City segment	UGS/USGS trenching (see below) BYU Utah Lake sediment study	UGS/USGS BYU
Acquire long-term earthquake record for the West Valley fault zone – Taylorsville fault	Consultant's trench of opportunity	UGS
Improve the long-term earthquake record for Cache Valley (East and West Cache fault zones)	No activity	

Other Priority Faults/Fault Sections Requiring Further Study

Fault/Fault Section	Original UQFPWG Priority	Investigation Status	Investigating Institution[2]
Cedar City-Parowan monocline/Paragonah fault[3]	10	No activity	
Enoch graben	11	No activity	
Clarkston fault[3] (West Cache fault zone)	13	Black and others (2000)	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Rozelle section, Great Salt Lake fault[4]	2007	No activity	

Faults/Fault Sections Studies Complete or Ongoing

Fault/Fault Section	Original UQFPWG Priority	Investigation Status	Investigating Institution[2]
Nephi segment WFZ	1	UGS Special Study 124 USGS Map 2966 UGS Special Study 151 North Creek investigation ongoing	UGS/USGS
West Valley fault zone (Granger fault)	2	UGS Special Study 149	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Ongoing	UUGG/BYU
Great Salt Lake fault zone	6	Contract Deliverable FTR[5]	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
Washington fault zone	9	Contract deliverable FTR[5]	UGS
East Cache fault zone	12	UGS Miscellaneous Publication 13-3	USU
Wasatch Range back-valley fault (Main Canyon fault)	14	UGS Miscellaneous Publication 10-5	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	UGS Special Study 142	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north part	2009	Special Study 149	UGS/USGS
Hansel Valley fault[3]	2011	McCalpin, (1985), Robinson (1986), McCalpin and others (1992), UUGG ongoing	UUGG
Long-term earthquake record Nephi segment WFZ – North Creek	2012	Contract deliverable FTR[5]	UGS/USGS
Provo/Salt Lake City/Nephi segment Holocene fault segmentation – Flat Canyon, Alpine, Maple Canyon, and Corner Canyon trench sites	2012/2013	On going	USGS/UGS

[1]Not in priority order; [2]UGS (Utah Geological Survey), USU (Utah State University), USGS (U.S. Geological Survey), UUGG (University of Utah Department of Geology & Geophysics), USBR (U.S. Bureau of Reclamation); [3]Earthquake source on the USGS National Seismic Hazard Maps; [4]Previous highest priority fault/fault segment; [5]FTR (Final Technical Report).

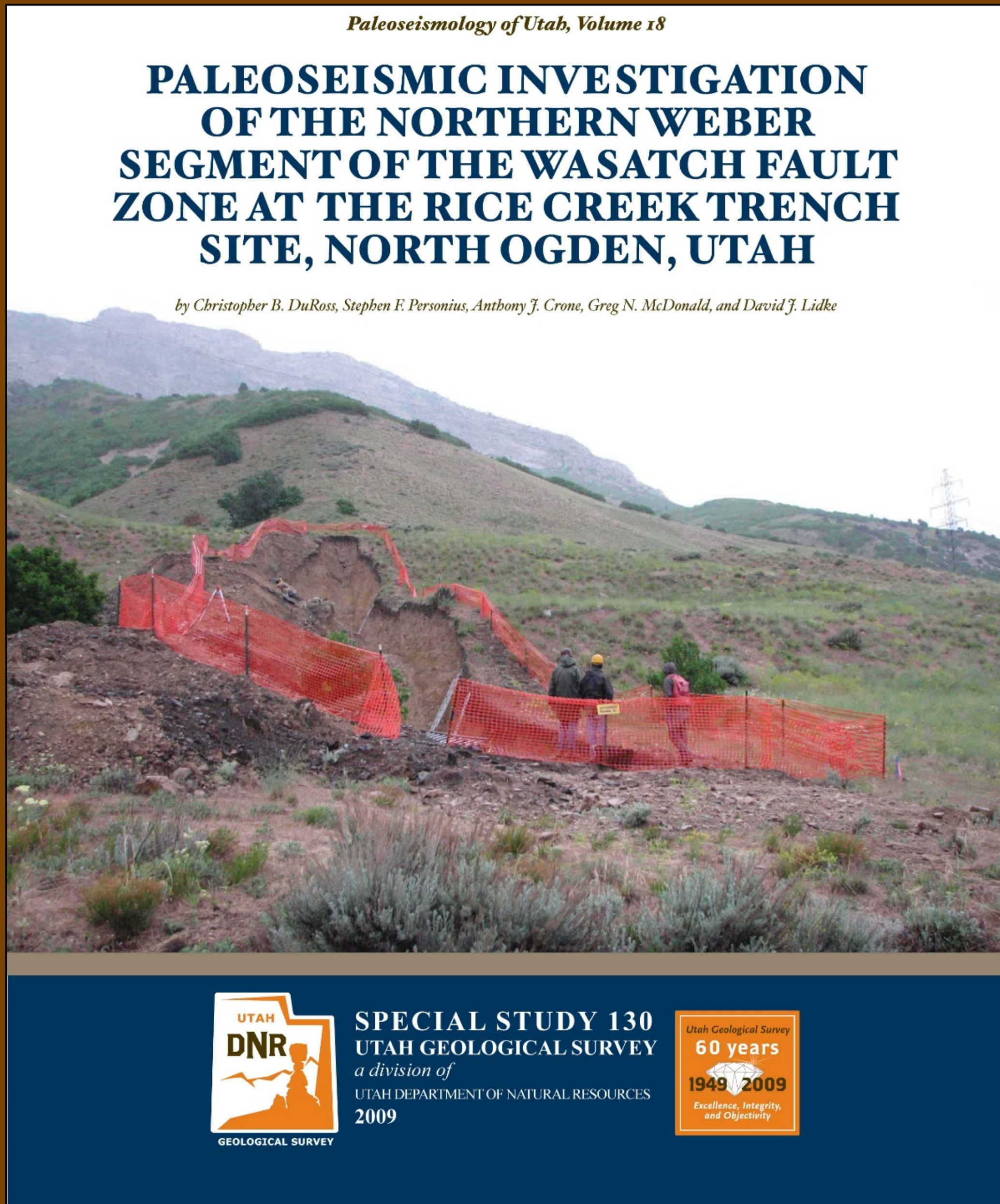
Bottom Line

Since 2005

- 15 faults or fault segments studied
- 14 new published reports or maps
- 6 studies and 1 map currently in preparation or review
- 2 new investigations will begin in 2015

Updating Utah's Consensus Paleoseismology Database

- It is the UQFPWG's responsibility to maintain a database of consensus paleoseismic data for Utah Quaternary faults and fault segments – currently Lund (2005).
  - Since the UQFPWG review in 2004, there have been at least 15 research paleoseismic trenching investigations undertaken in Utah that have or will soon produce new paleoseismic data on several Utah Quaternary faults — in particular the six Holocene-active segments of the Wasatch fault zone.
  - The Working Group on Utah Earthquake Probabilities (WGUEP) has for the past five years been developing a consensus earthquake forecast for the Wasatch Front region. The forecast includes a rigorous re-evaluation of all Utah "legacy" (pre 2004) paleoseismic data and incorporates new data up to 2012.
  - The new paleoseismic data and release of the WGUEP report later in 2015 will trigger a review and update of the Utah consensus paleoseismology database in 2016 .



Paleoseismology of Utah, Volume 18

PALEOSEISMIC INVESTIGATION OF THE NORTHERN WEBER SEGMENT OF THE WASATCH FAULT ZONE AT THE RICE CREEK TRENCH SITE, NORTH OGDEN, UTAH

by Christopher B. DuRoss, Stephen F. Personius, Anthony J. Crone, Greg N. McDonald, and David J. Lidke

UTAH DNR GEOLOGICAL SURVEY

SPECIAL STUDY 130
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2009

Utah Geological Survey 60 years 1949 2009 Excellence, Integrity, and Objectivity

Questions?

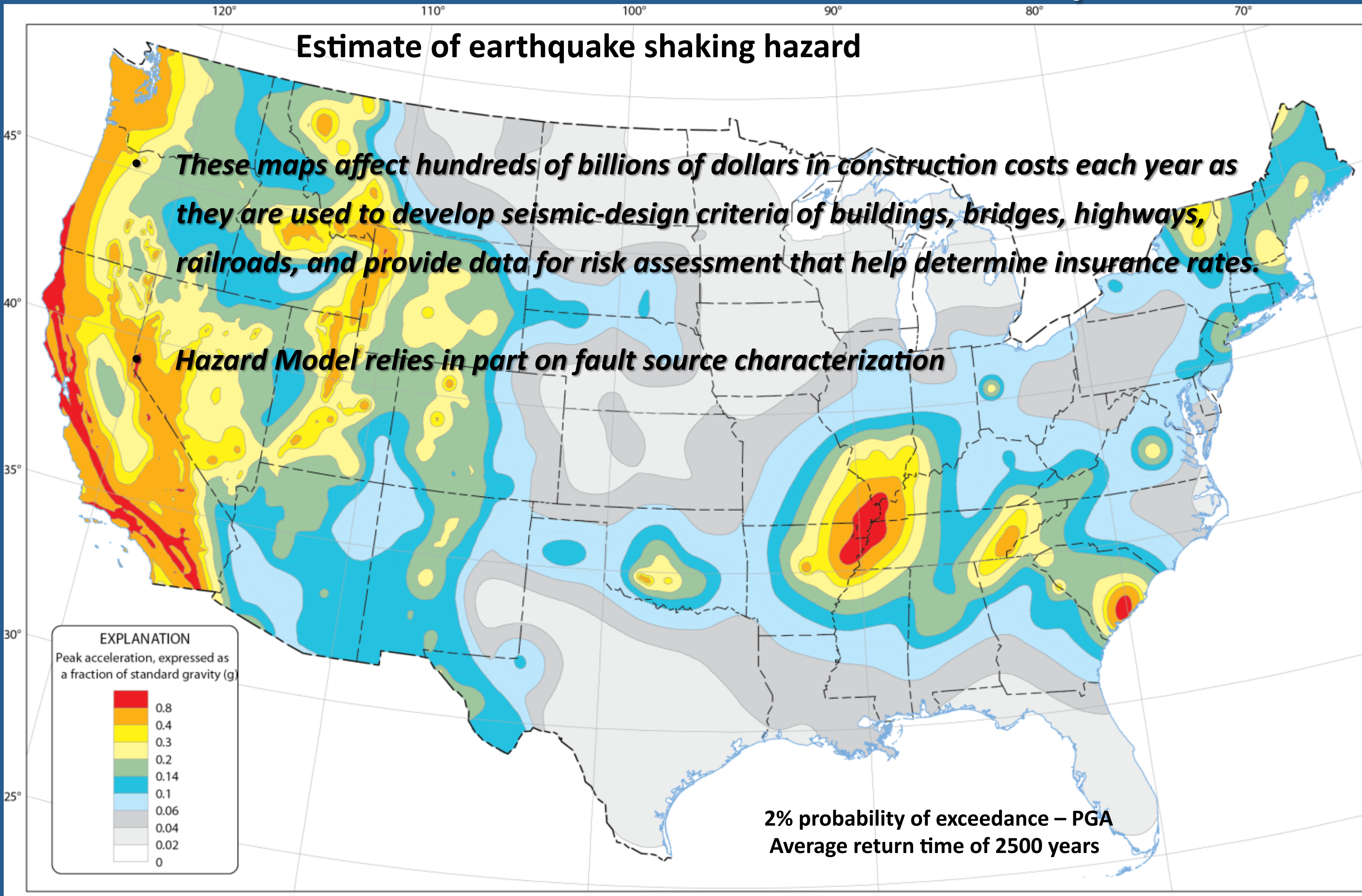
2014 U. S. National Seismic Hazard Map update: Focus on IMW

Ryan Gold

Slide contributions from Rob Williams and Mark Petersen

USGS

2014 U. S. National Seismic Hazard Map



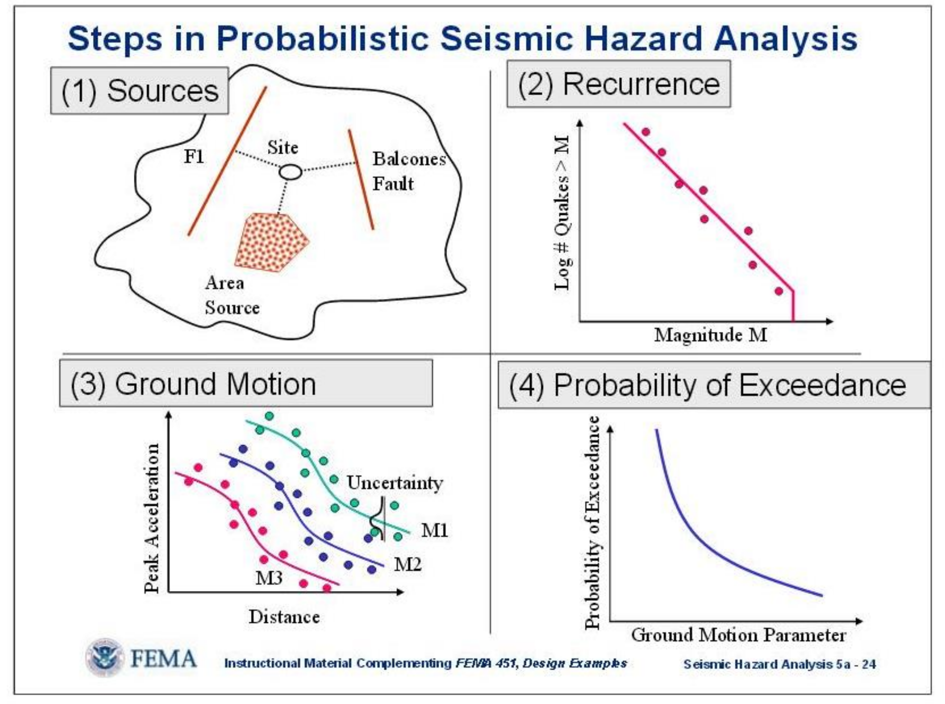
- ***These maps affect hundreds of billions of dollars in construction costs each year as they are used to develop seismic-design criteria of buildings, bridges, highways, railroads, and provide data for risk assessment that help determine insurance rates.***
- ***Hazard Model relies in part on fault source characterization***

USGS

Elements of Probabilistic Seismic Hazard Analysis

Geologic fault studies may contribute most to:

1. Where will earthquakes occur in the future?
2. How often will they happen and how large can they get?
3. How hard will they shake the ground?
4. When answers are available for Steps 1-3: Add up all of the sources to find the probability of exceeding damaging shaking.



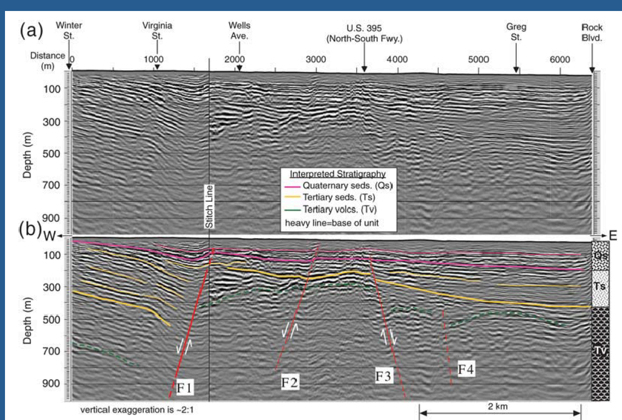
(after FEMA 451, Ellsworth 2014).

USGS

Criteria for including faults in the hazard model

1. **Shown to be active in the Quaternary**
2. **Fault geometry (length, dip; to constrain magnitude)**
3. **Slip rate or recurrence interval data**
4. **Results vetted in a peer-reviewed publication**

Geophysics

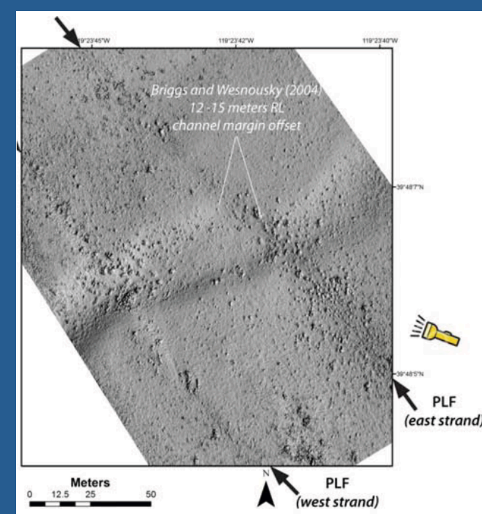


Stephenson et al., 2013

Paleoseismology

Gold, unpublished

Mapping



Angster et al., 2014

USGS

2014 U. S. National Seismic Hazard Map

2008
NSHM

2014
NSHM

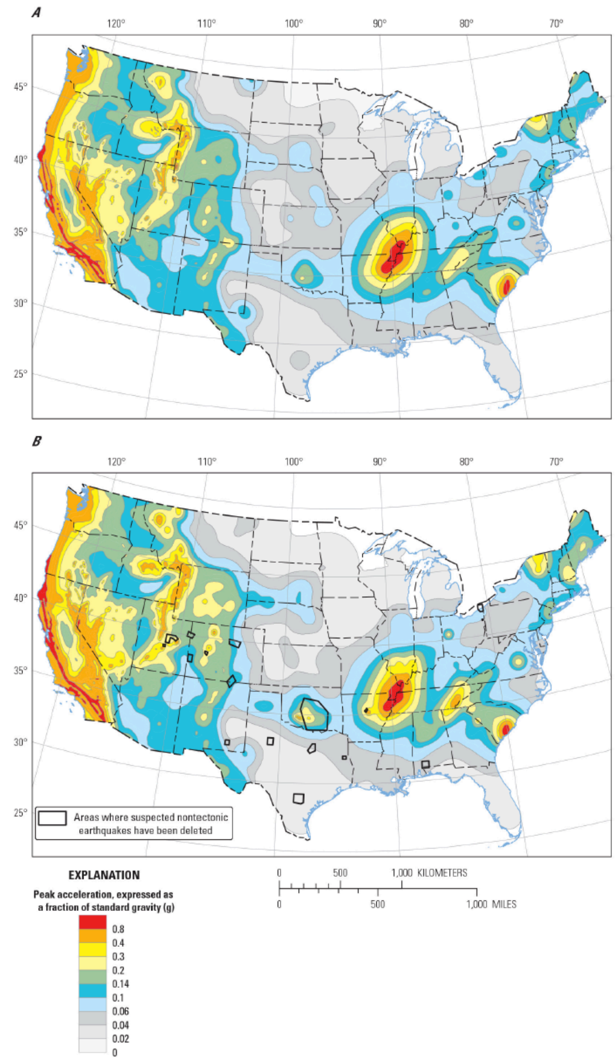


Figure 1. Maps showing peak ground acceleration for 2-percent probability of exceedance in 50 years and V_{S30} site condition of 760 meters per second. *A*, 2008 version of the national seismic hazard maps and *B*, 2014 version.

2014
minus
2008
(difference)

2014:2008
(ratio)

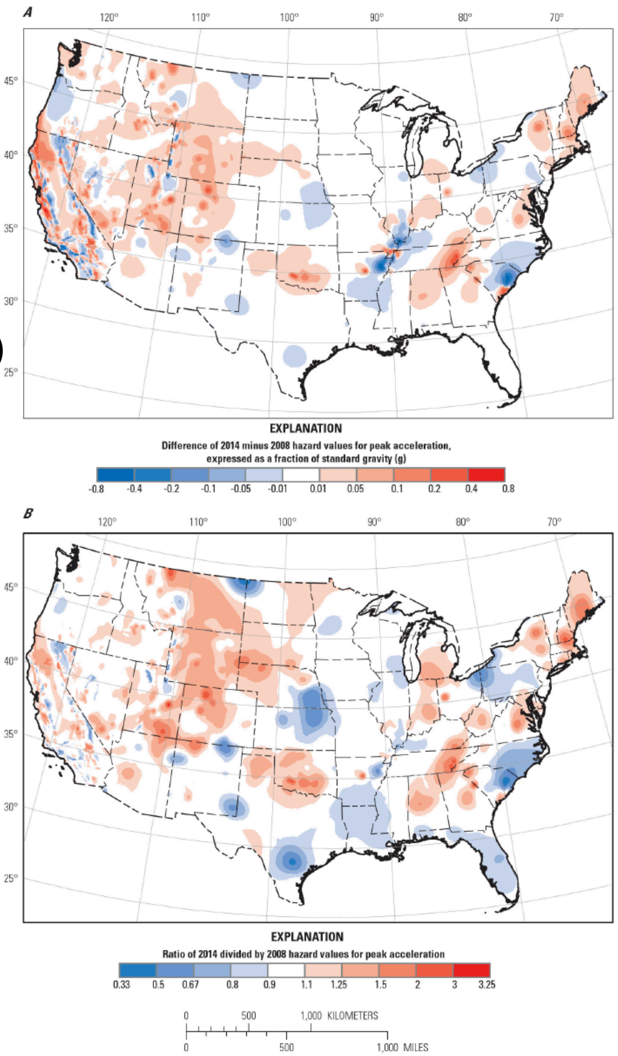


Figure 7. Maps comparing change in peak ground acceleration for 2-percent probability of exceedance in 50 years and V_{S30} site condition of 760 meters per second. *A*, Difference between the 2014 and 2008 versions of the national seismic hazard maps and *B*, ratio between the 2014 and 2008 versions.

USGS

Petersen et al., 2014

2014 U. S. National Seismic Hazard Map (new & updated sources)

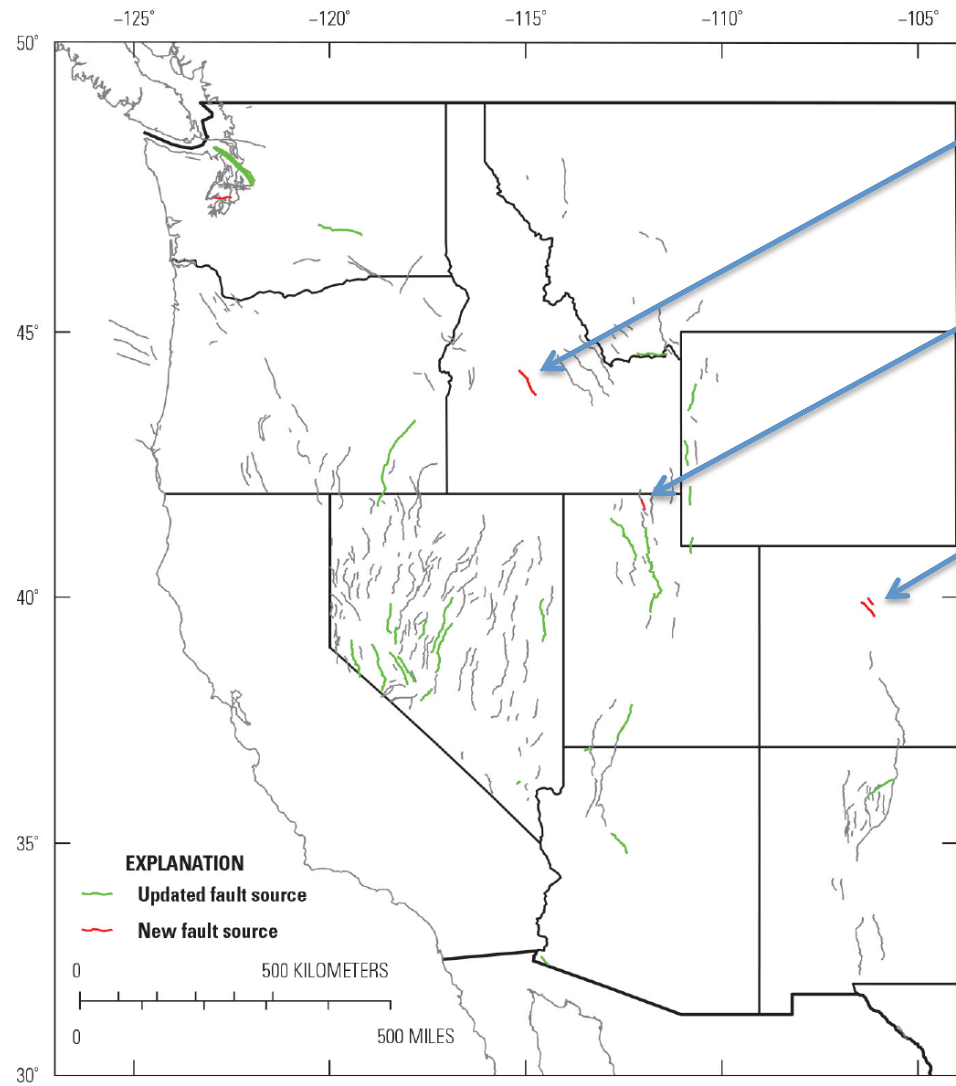


Figure 48. Map of crustal fault sources in the Intermountain West and Pacific Northwest. Fault sources in California are not shown.

Sawtooth fault

West Cache fault

Gore Range frontal fault & Williams Fork Mtns fault

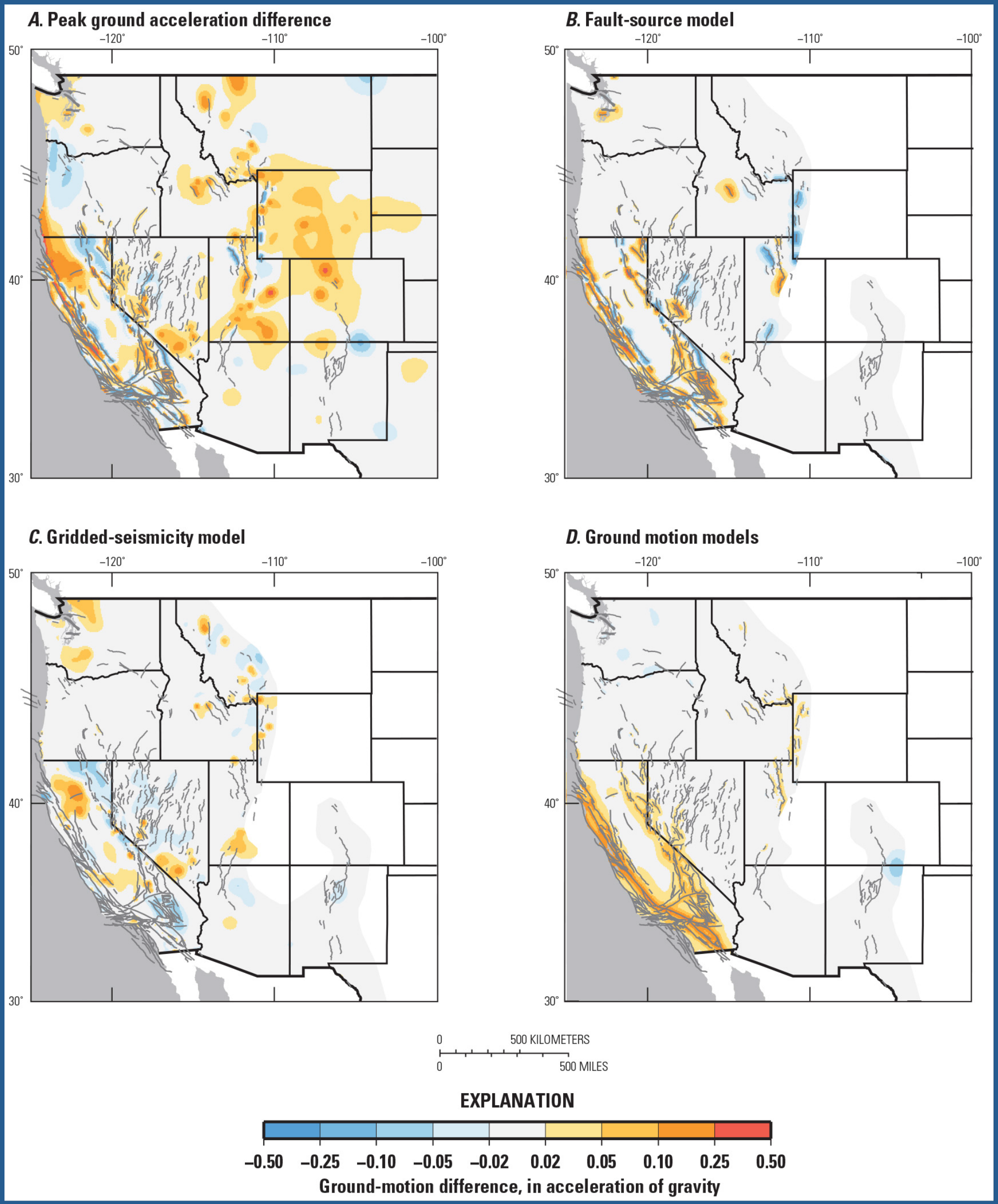
USGS

Petersen et al., 2014

Western US - 2014 U. S. National Seismic Hazard Map (2014 minus 2008)

Peak Ground acceleration difference

Gridded seismicity model



Fault source model (difference)

Ground motion models

USGS

Petersen et al., 2014

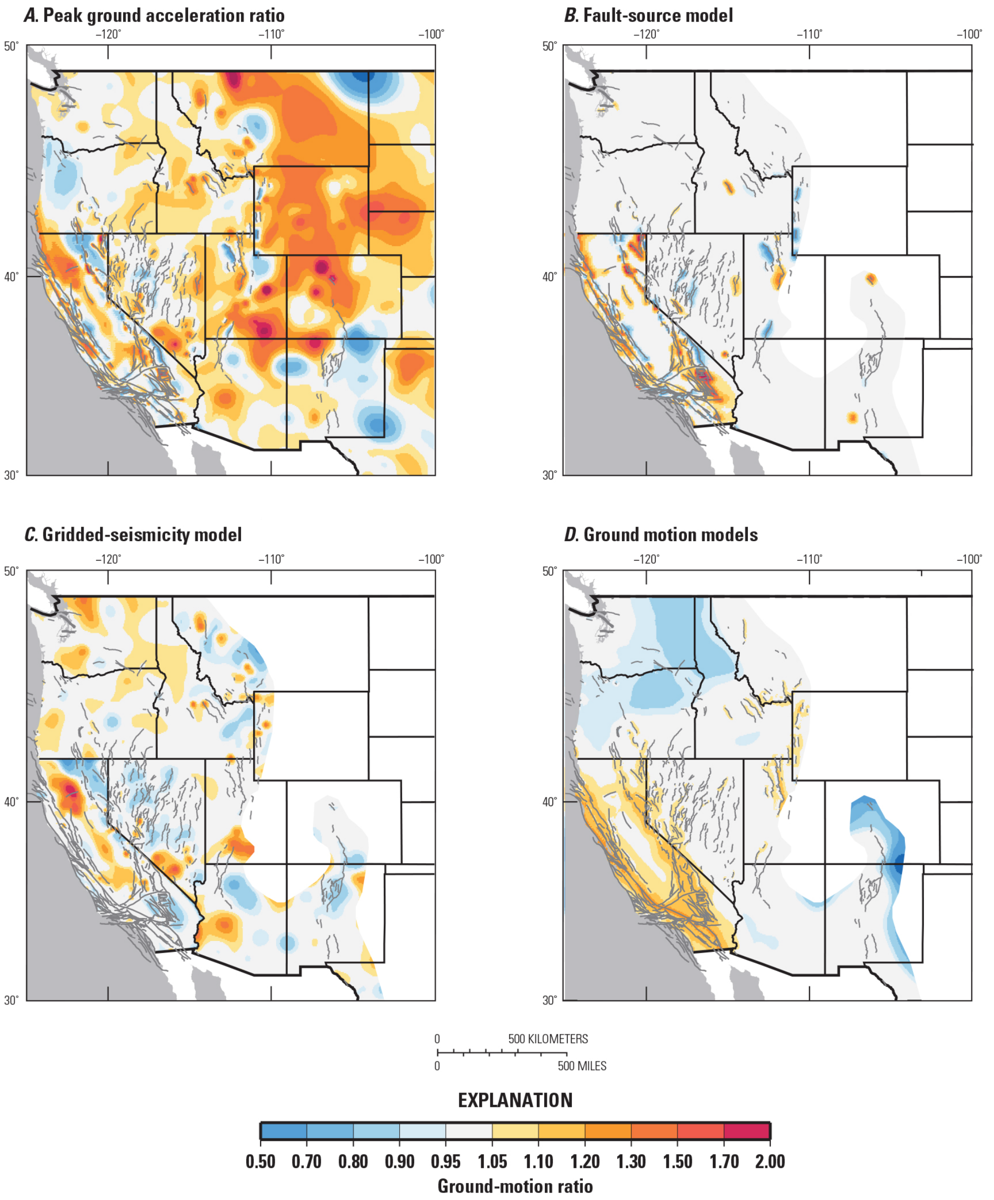
Western US - 2014 U. S. National Seismic Hazard Map (ratio 2014:2008)

Peak Ground acceleration difference

Fault source model (difference)

Gridded seismicity model

Ground motion models



Petersen et al., 2014

USGS

Particularly Hazardous Quaternary Faults in Arizona

USGS Intermountain West Workshop

January 2015

Philip A. Pearthree
Research Geologist
Arizona Geological Survey

The Plan

- Review historical seismicity and Quaternary faults across AZ
- Identify 5 most hazardous faults in state based on slip rate / recurrence info, proximity to urban areas, what is and is not known about their behavior
- Briefly summarize salient features and what is and isn't known about these faults

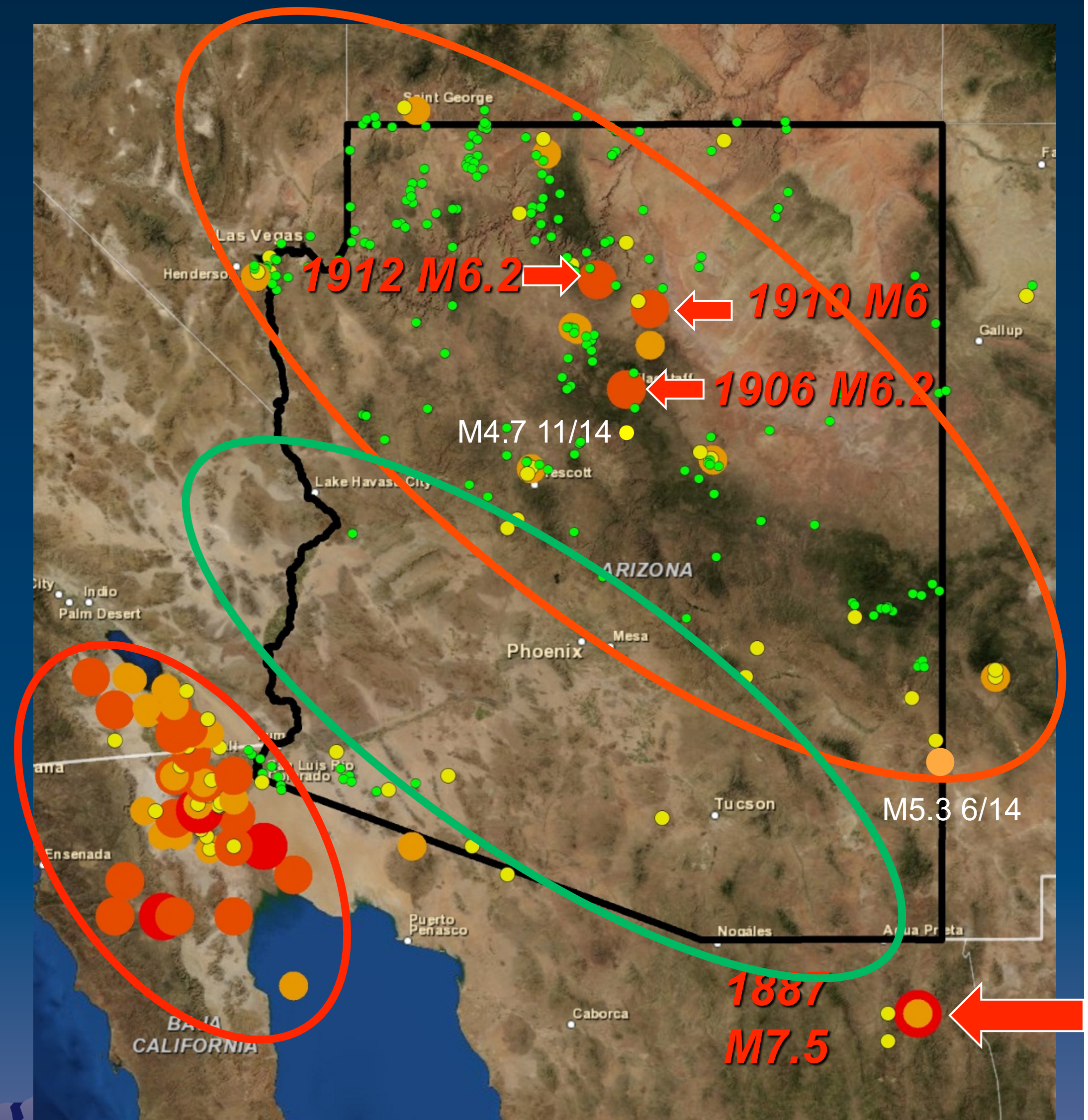
Historical Seismicity in Arizona

~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



Quaternary Faults in AZ

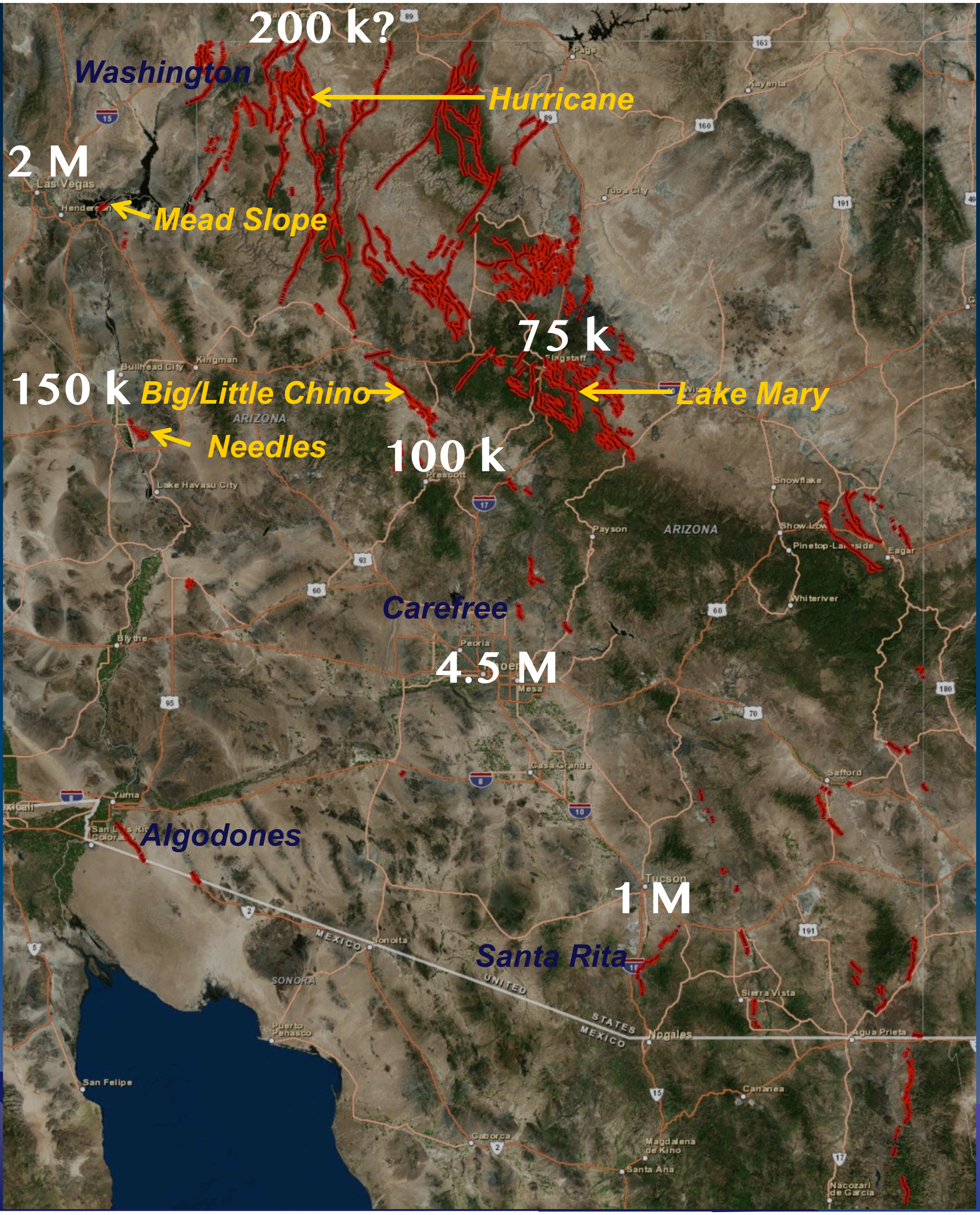
- ~100 faults active since 2.6 Ma
- concentrated along Colorado Plateau margin
- highest slip rate ~0.2 m/kyr
- ~13 active since 15 ka
- ~12 faults trenched - most barely studied

What is new since 2008?

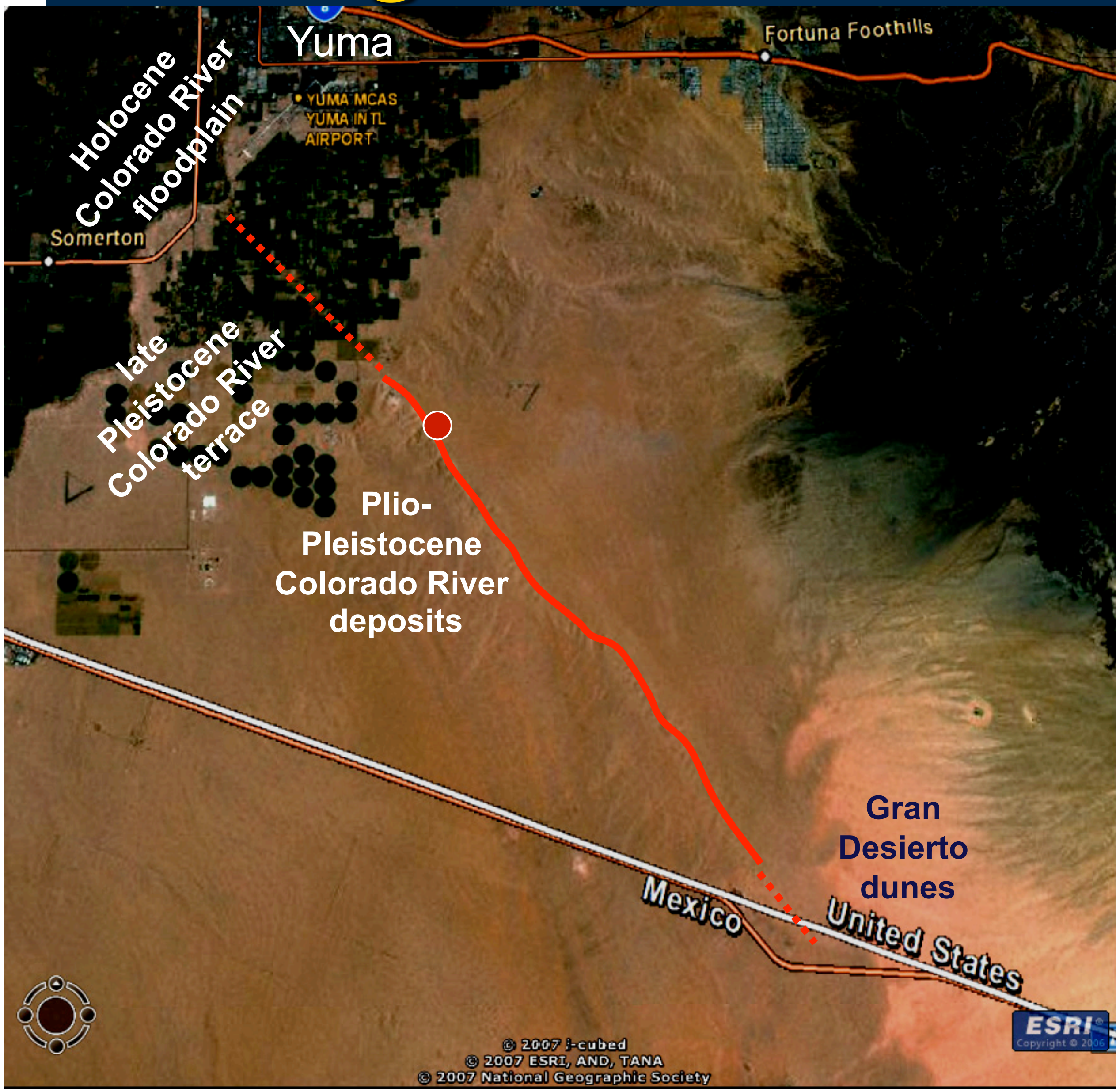
- Detailed geologic mapping of areas including Q fault zones
  - mostly Statemap projects
  - more thoroughly characterized some fault zones
  - some new temporal constraints
- Trenching and detailed analysis of the Washington fault zone – UGS
  - much more detailed mapping and structural analysis
  - evidence for 2 Holocene surface ruptures near AZ-UT border
- Incipient geodesy
  - measurements over past ~15 yrs
  - surprisingly similar extension rates across southern and northern AZ
  - complications from large plate boundary earthquakes

Most hazardous faults in AZ

- Populations centers – *Phoenix, Tucson*
- Lake Mary etc - *Flagstaff*
- Big/Little Chino - *Prescott*
- Hurricane - *Southwest UT*
- Mead Slope - *Las Vegas*
- Needles - *Mohave Valley*
- *Honorable mention*
  Washington, Algodones, Santa Rita, Carefree



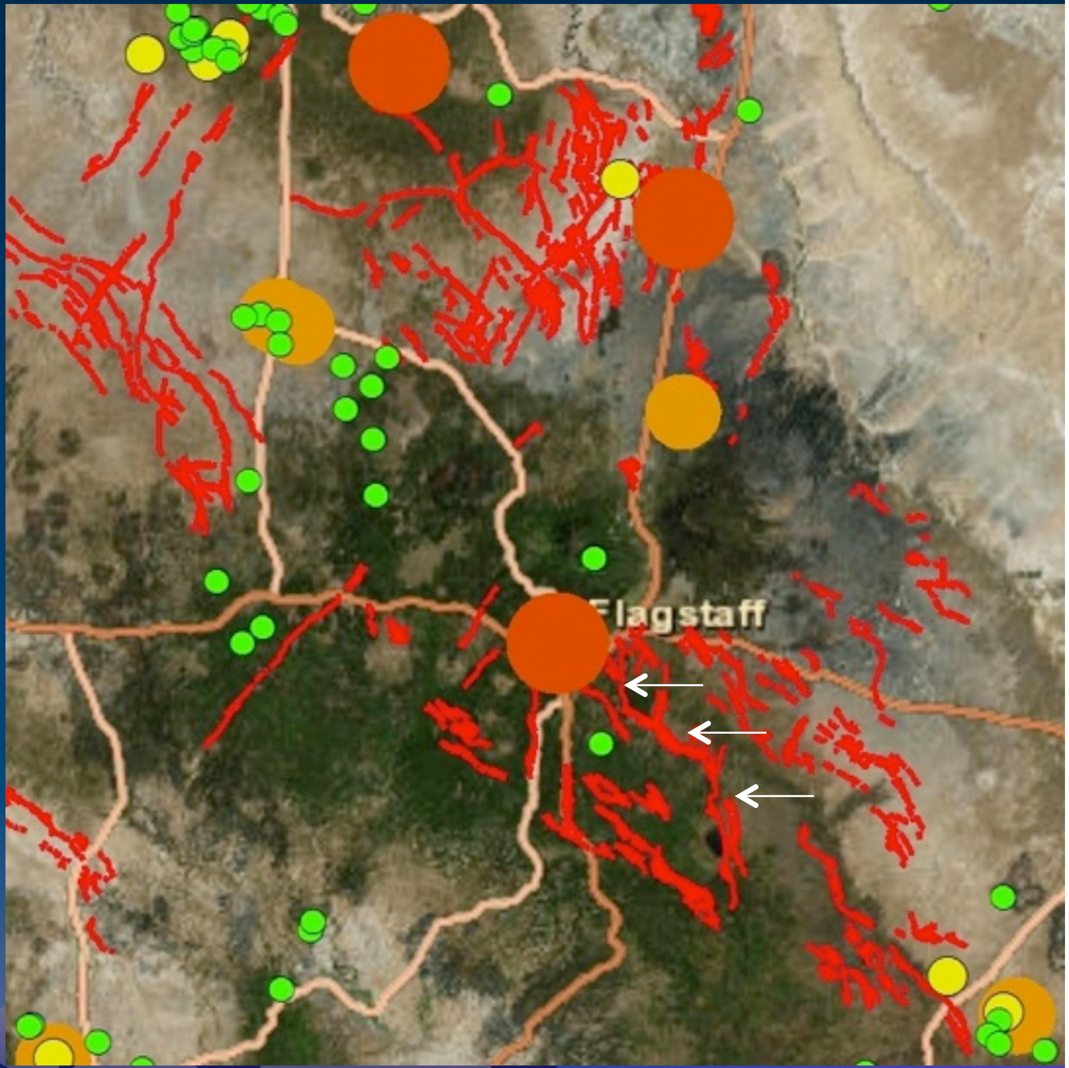
Algodones fault



- 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***

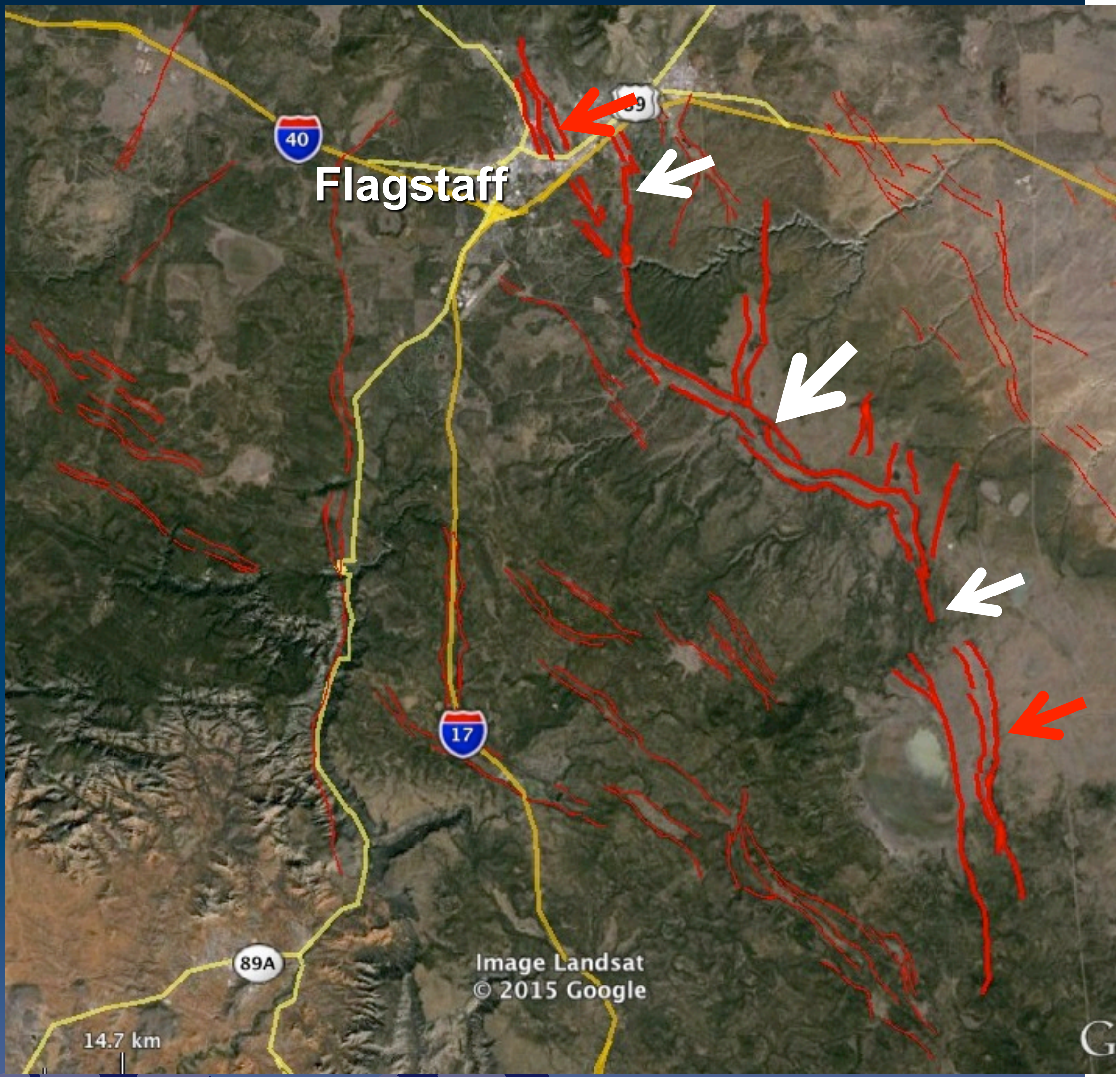
Lake Mary fault zone - Flagstaff area

- 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

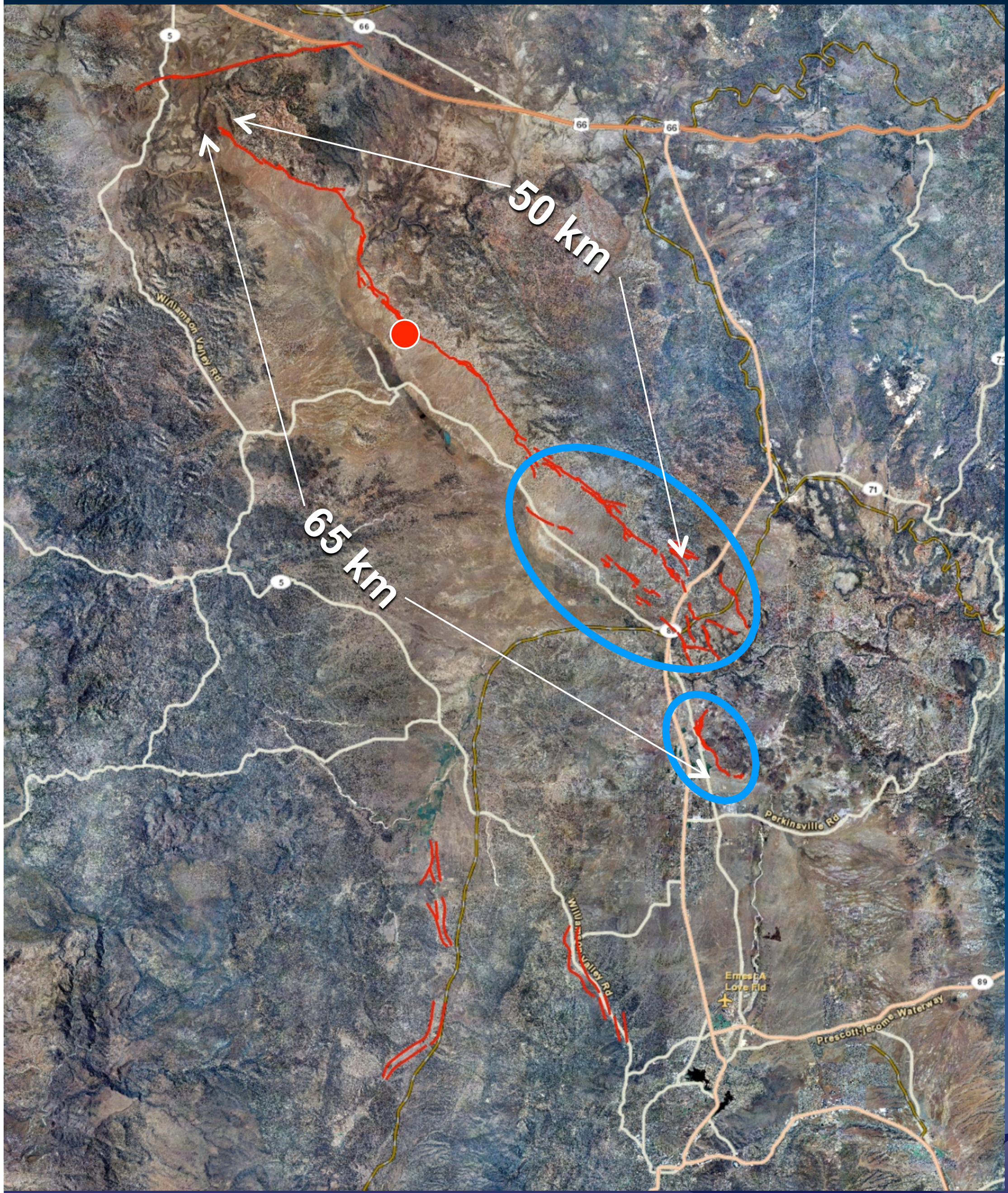


Lake Mary+ Fault Zone

- 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***



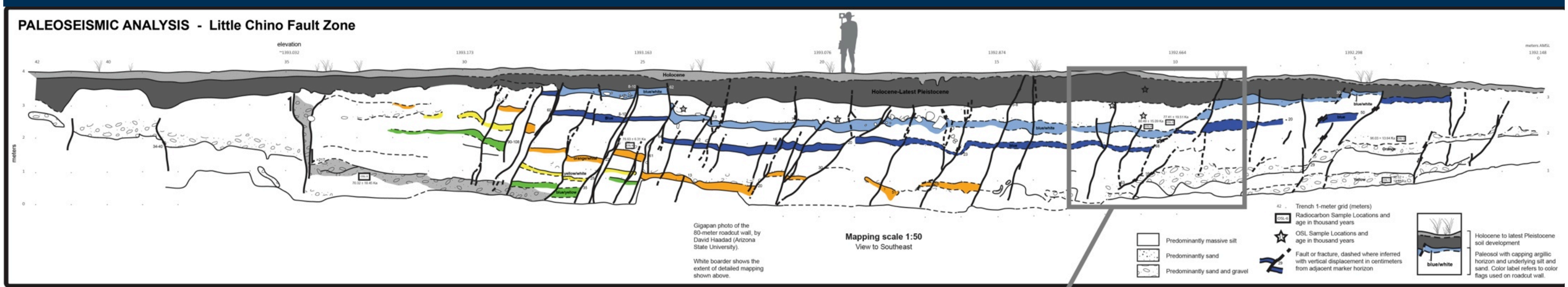
Big Chino Fault Zone



- ~ 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

ARIZONA GEOLOGICAL SURVEY AZGS

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***

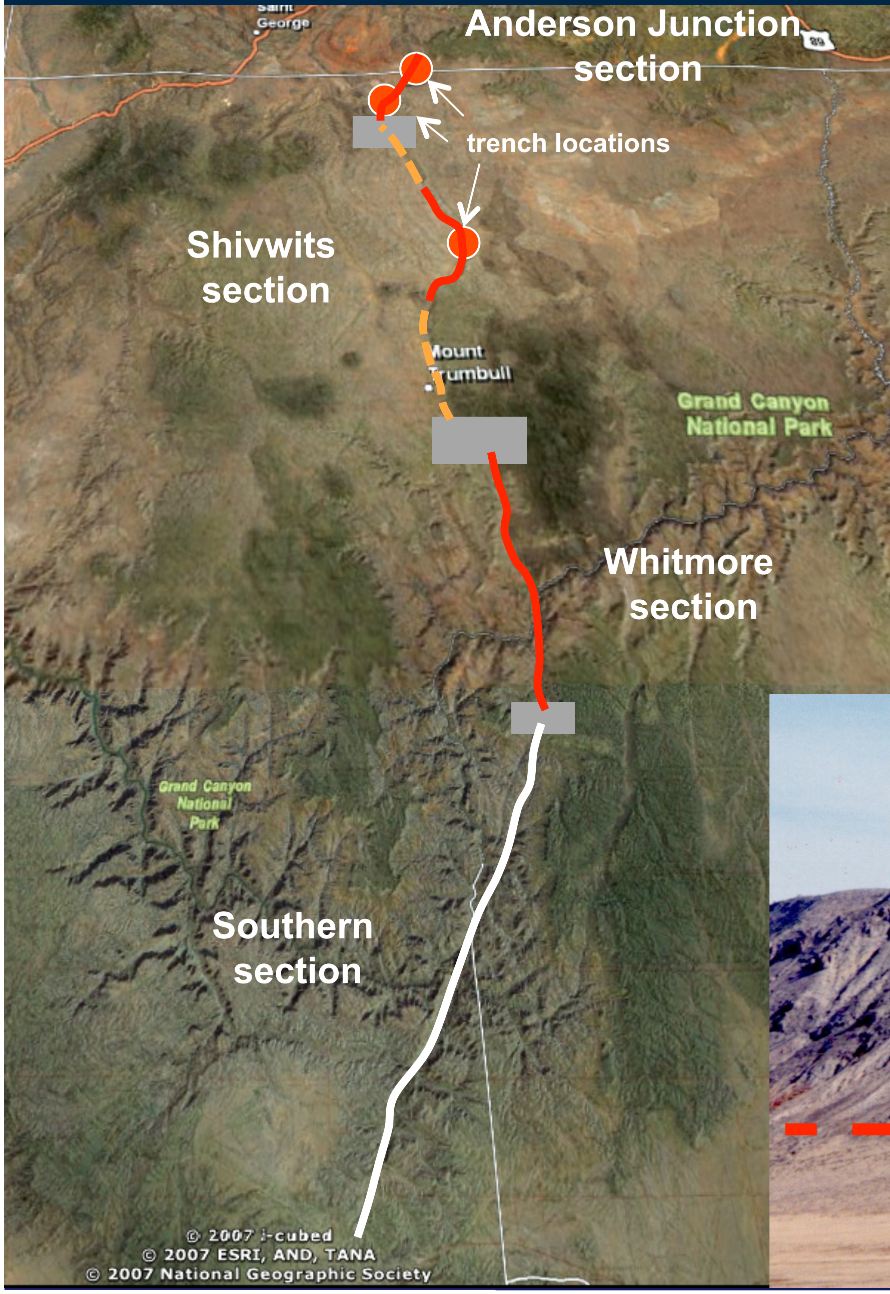
Mead Slope Fault

- Apparently pretty short
- 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

Mead Slope Fault

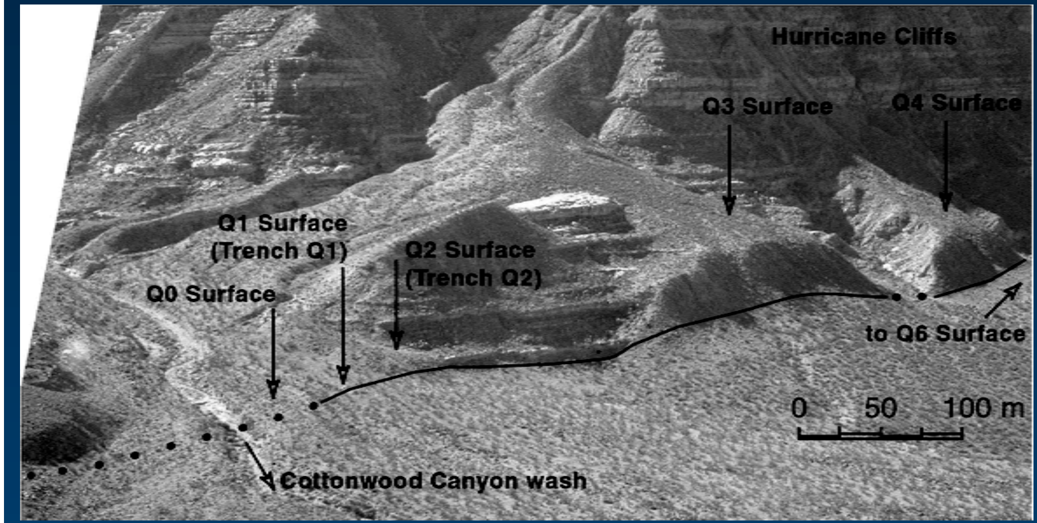
- Offsets of latest Pleistocene and older Pleistocene fan by increasing amounts
- Displaces young fan deposits
- Primarily left-lateral displacement, near vertical fault (Stewart and dePolo)
- ***Fault zone length? More precise dating?***

Hurricane fault

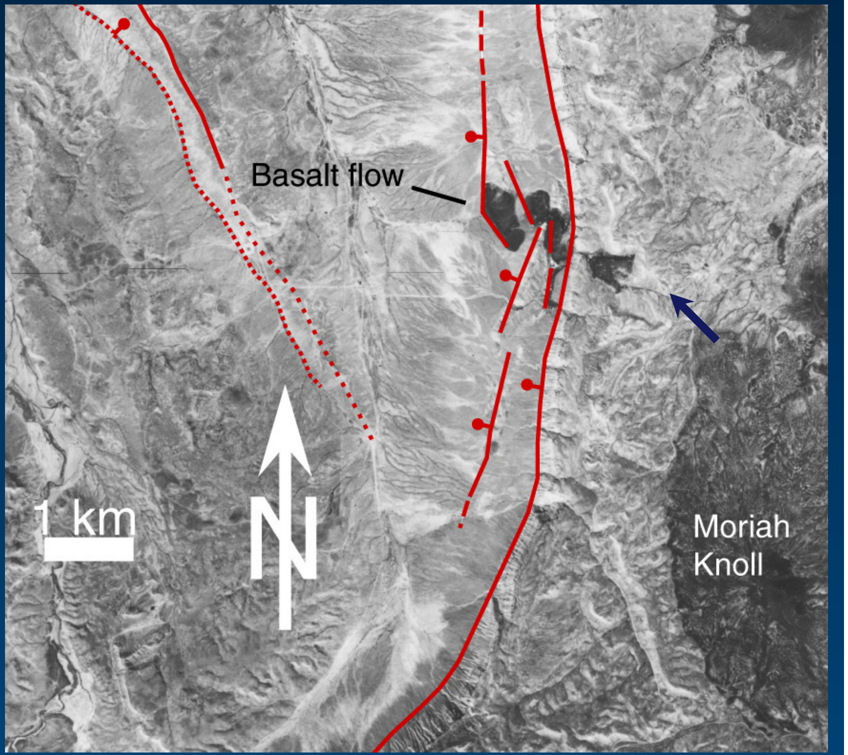


- 250 km long fault shared by Arizona and Utah
- Impressive fault escarpment, late Quaternary faulting
- Primary hazard in bourgeoning southern Utah

Hurricane fault



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

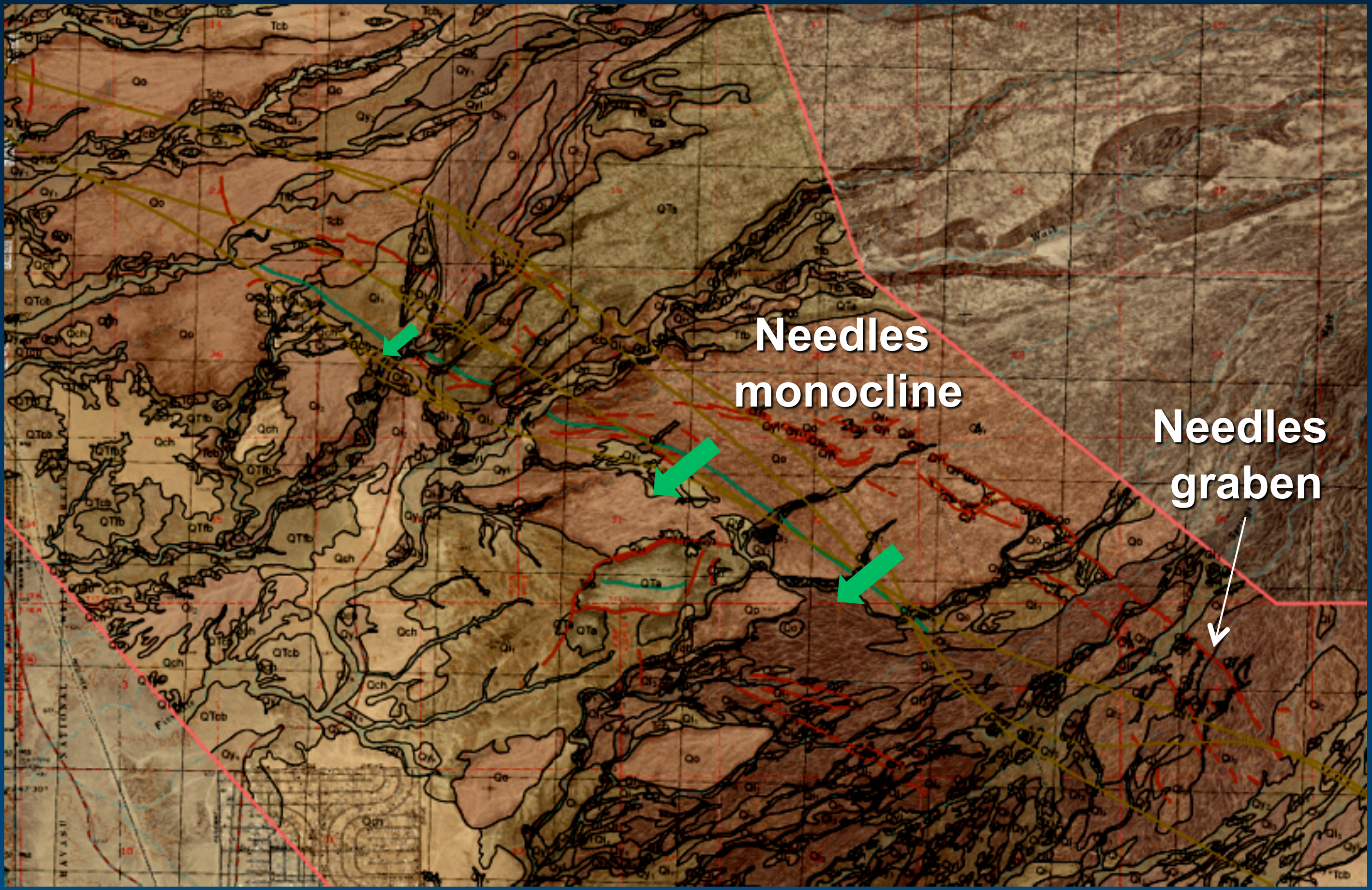


- Basalt erupted ~850,000 yrs ago
- Displaced ~200 m
- Long-term slip rate of ~0.2 mm/yr

Hurricane fault seismic hazard

- At least 3 sections of Hurricane fault likely ruptured in large earthquakes since 15 ka
- 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, segmentation speculative at this time*
- *Substantial uncertainty for hazard assessments*

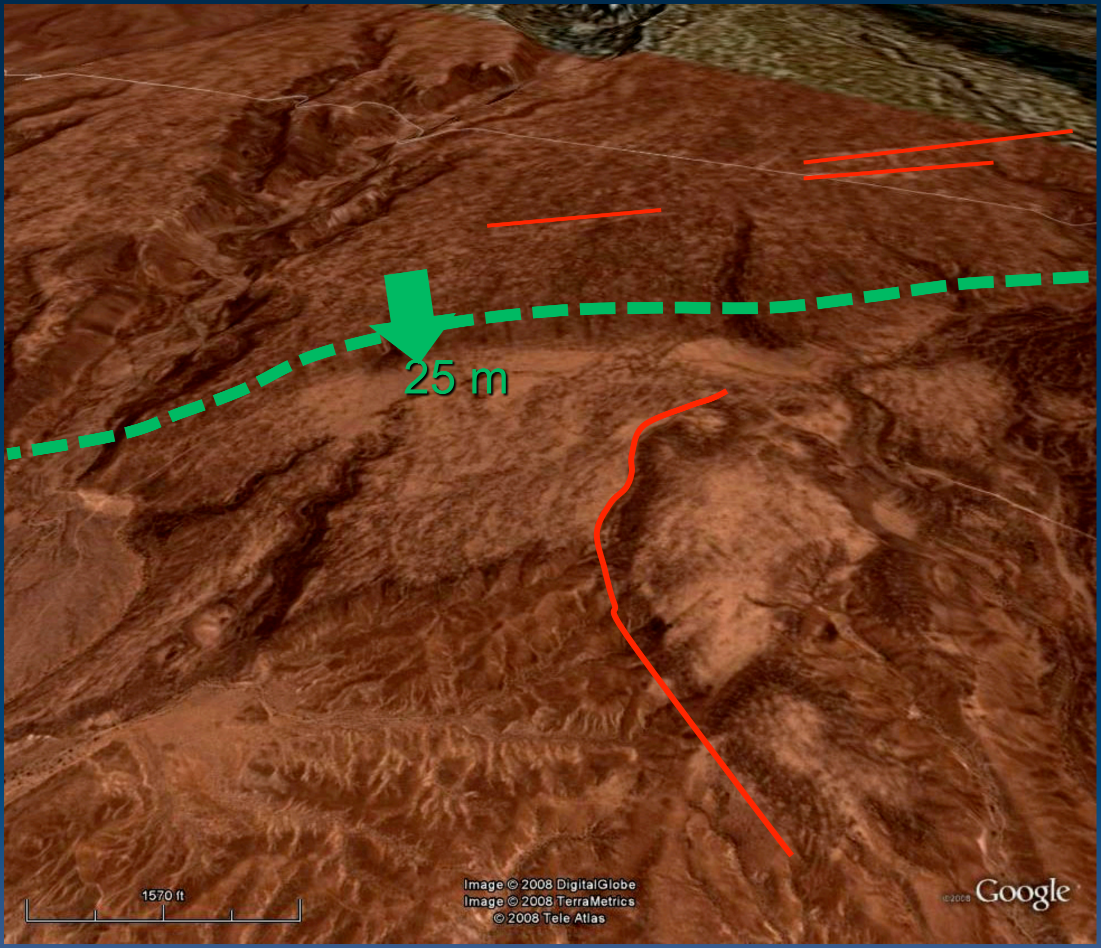
Needles graben and fold



- Small-offset graben formed on Pleistocene fan recognized in 1970's
- Much larger monoclinal fold and more faults recognized more recently
- In rapidly populating Bullhead City / Laughlin / Needles area

Needles graben and fold

- Graben is wrinkle on back of larger ~fold
- > 25 m vertical displacement of middle Pleistocene alluvial fan
- Substantially greater tilting of Pliocene river deposits
- More faulting than previously recognized total zone length at least 20 km
- ***Better constraints on age of youngest movement***



Summary

Fault zone	Length (km)	Youngest rupture	Slip rate (m/ky)	Population exposure
Lake Mary	25-50	Late Pleist?	>0.02	75,000
Big/Little Chino	55-70	Latest Pleist-early Holoc	0.1	100,000
Mead Slope	7+	Holocene	?	2 million
Hurricane	250*	Early Holocene	0.2	150,000
Needles	20	Late Pleist	0.05	150,000

*includes fault length in Utah

Colorado's Potentially Hazardous Quaternary Faults

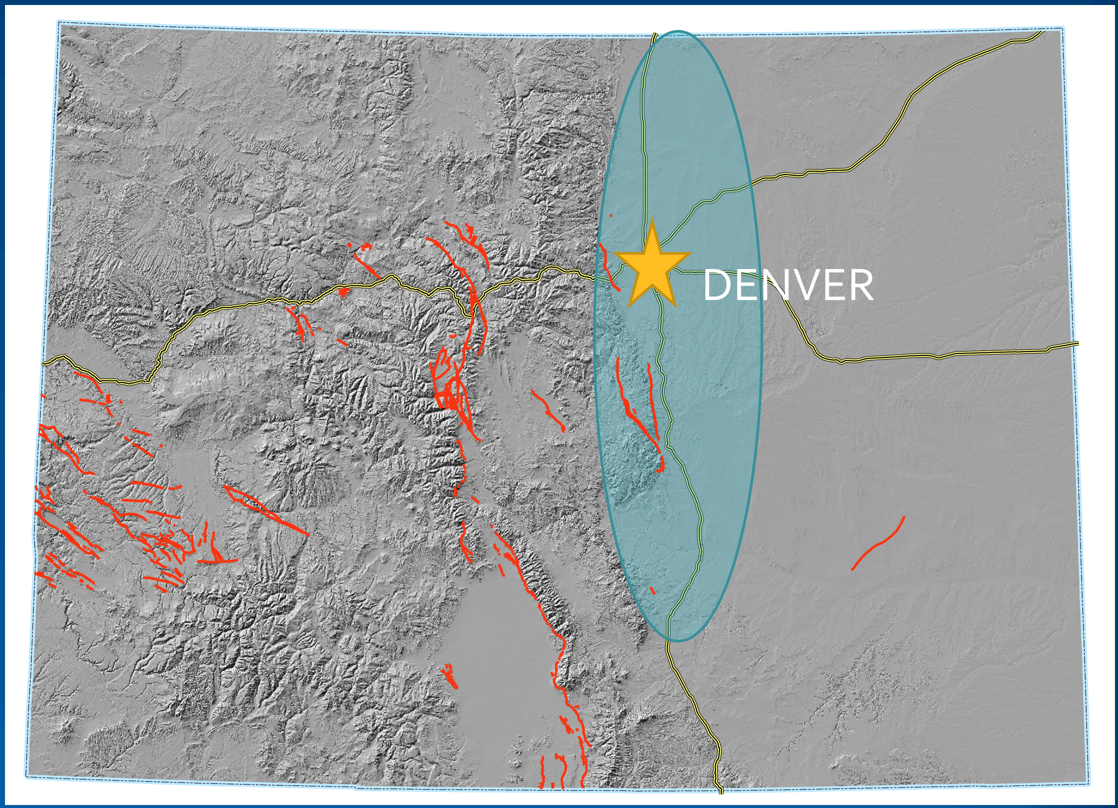
Matt Morgan

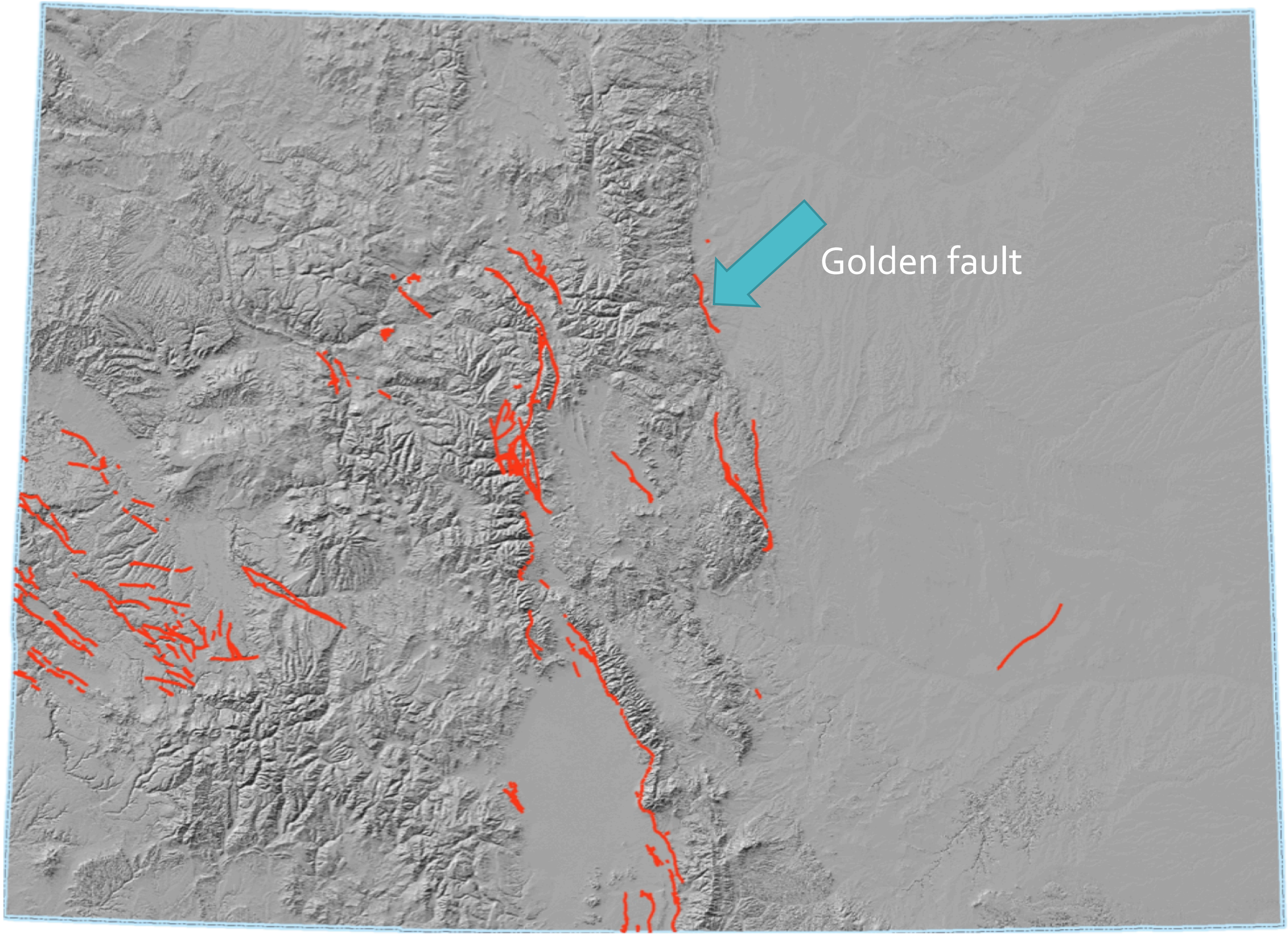
Colorado Geological Survey at the Colorado School of Mines
Golden, Colorado
mmorgan@mines.edu

COLORADO SCHOOL OF MINES

Colorado is GROWING

- Colorado is the 2nd most populated state in the IMW
- 3rd fastest growing state in US
- 85% of population in Front Range Urban Corridor
- 90 documented or suspect Quaternary faults




Golden fault


Denver

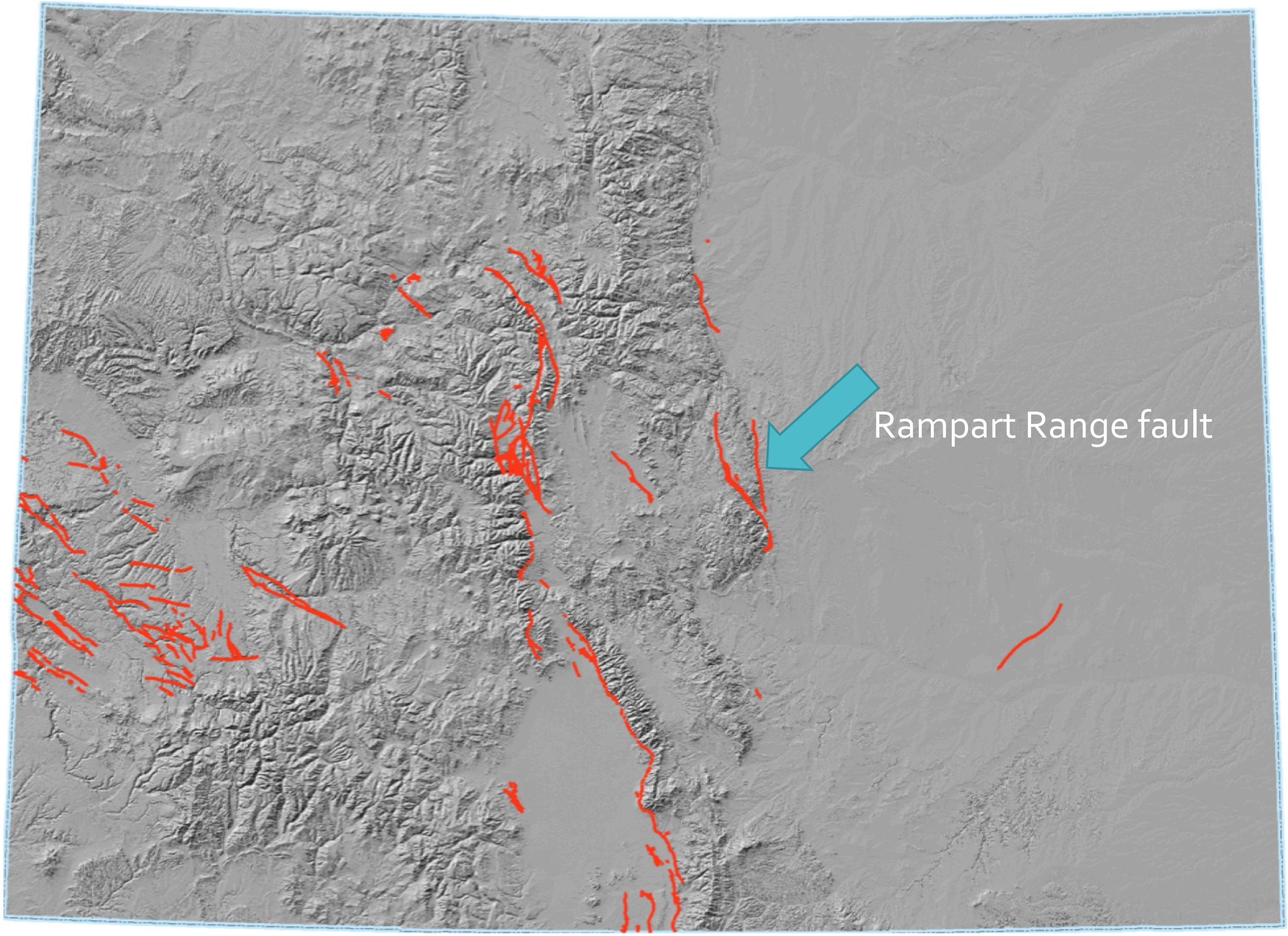
Golden fault

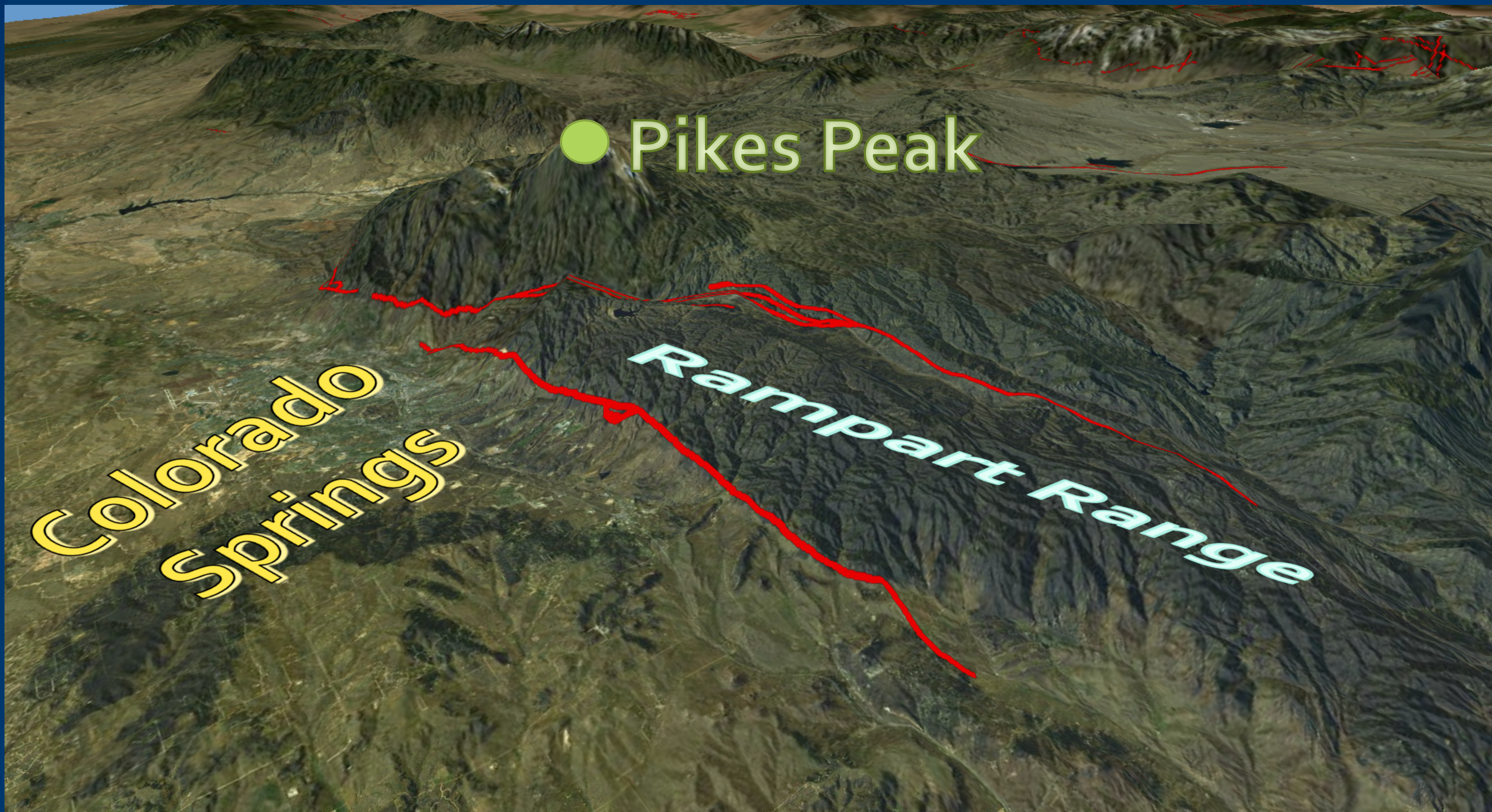
- Lies along the eastern margin of the Front Range
- Most densely populated area of Colorado
- HAZUS M6.5 event
  - $45 billion total economic loss
- First suggested to have Quaternary displacement by Scott (1970)
  - Cited ~8000 feet of stratigraphic throw near Golden
  - Two vertical shear zones in trench that "displace" Verdos alluvium and colluvium by 2 m
- Kirkham (1977)
  - *2 trenches; youngest offset ~700 ka (soils)*
  - "Shear zones" which rotated clasts and displace colluvium and ash
  - Thickening of soil on downthrown side
- Dames and Moore (1981) disputed studies by Scott and Kirkham
  - 6 trenches and a quarry exposure
  - Observed faults and fractures in Quaternary deposits-related to creep
  - Bedrock tongues protrude into alluvium-creep
  - "no compelling evidence for tectonic activity of Golden fault was identified".

Golden fault

ISSUES:

- Trace and dip direction are poorly located
- Quaternary sediments are predominantly gravels
- Unknown absolute ages of surficial deposits
- Prevalence of landslide deposits
- Likely segmented; where to trench?

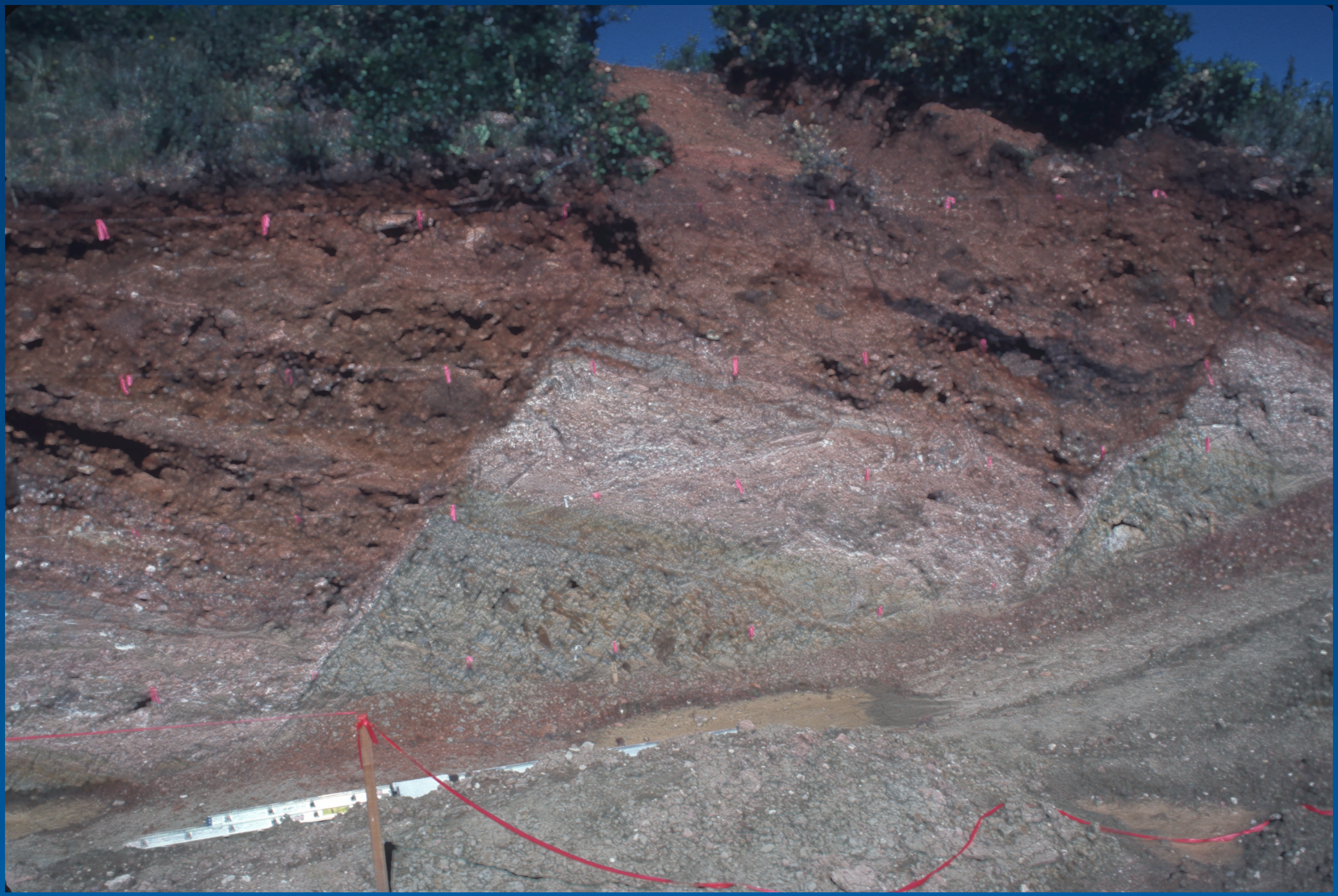

Rampart Range fault


Pikes Peak
Rampart Range
Colorado Springs

Rampart Range fault

- Located few miles west of Colorado Springs
- Second largest city in Colorado (>440,000 residents)
- Trends N-S along east side of the Front Range for ~50 km
- Experienced reverse movement during the Laramide, but normal movement during the late Cenozoic
- Marked by topographic breaks and vegetation lineaments.
- Scott (1970) reported approximately 8 m of down-to-the-west Quaternary displacement
- Trenching by Dickson (1986) demonstrated the fault offset the Douglass Mesa gravel (postulated to be ~600 ka) 29.3 m sometime between 600 and 30 to 50 ka.
- In April 1991, Microgeophysics (1991) located a swarm sequence with magnitudes 2.6 to 2.8 on the south end of this fault system.
- Benjamin and Associates (1994) calculated slip rates of 0.01 to 0.07 mm/yr
- HAZUS M7.0 event
  - $28 billion total economic loss

COLORADO SCHOOL OF MINES

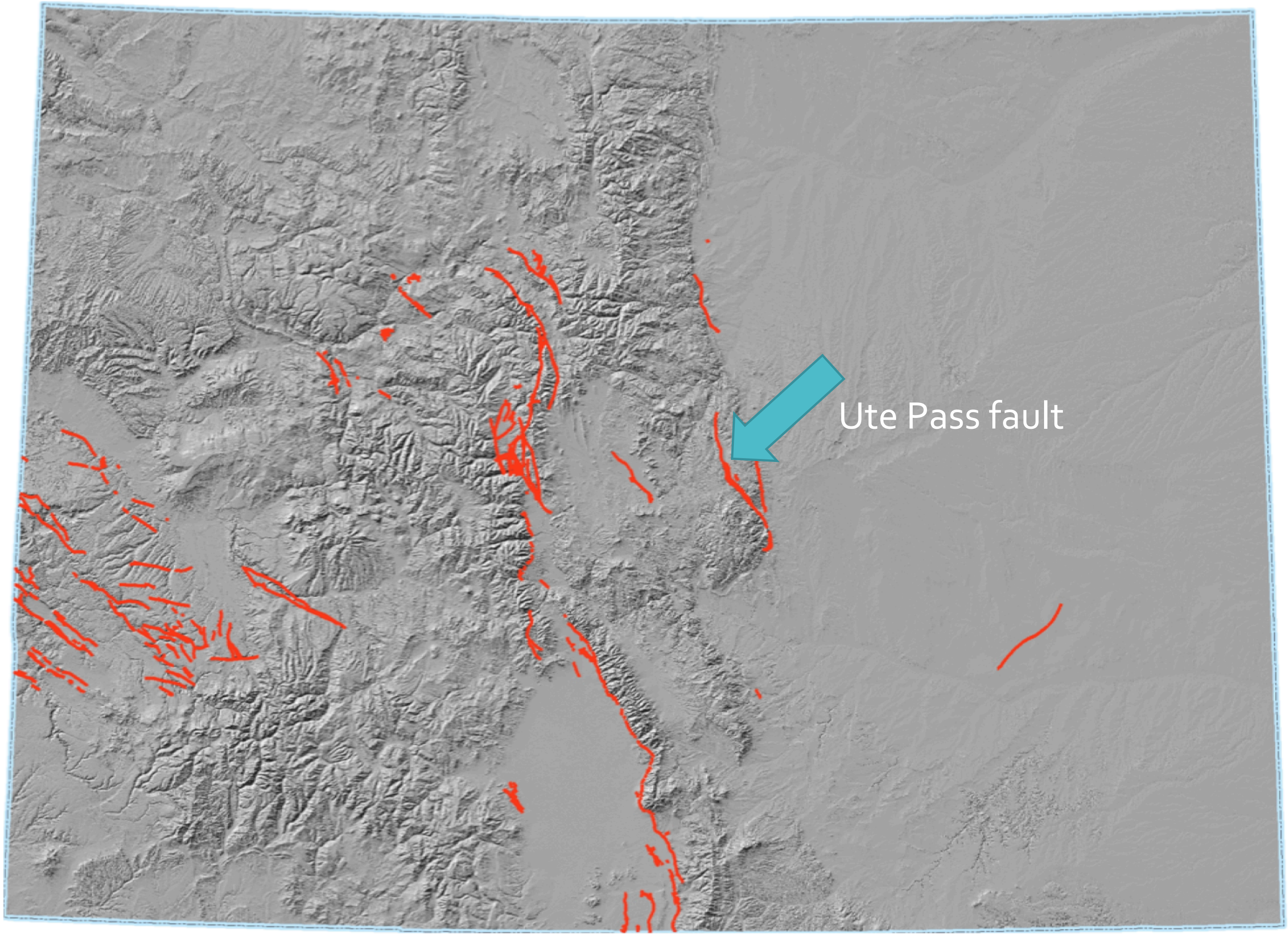


COLORADO SCHOOL OF MINES

Rampart Range fault

ISSUES:

- Lack of reliable absolute ages of offset sediments
- Segmented-which segment do we trench?
- Landslide deposits flank the fault
- Trenched segment now has a reservoir constructed


Ute Pass fault


Pikes Peak
Cheynne Mtn.
Colorado
Springs

Ute Pass fault zone

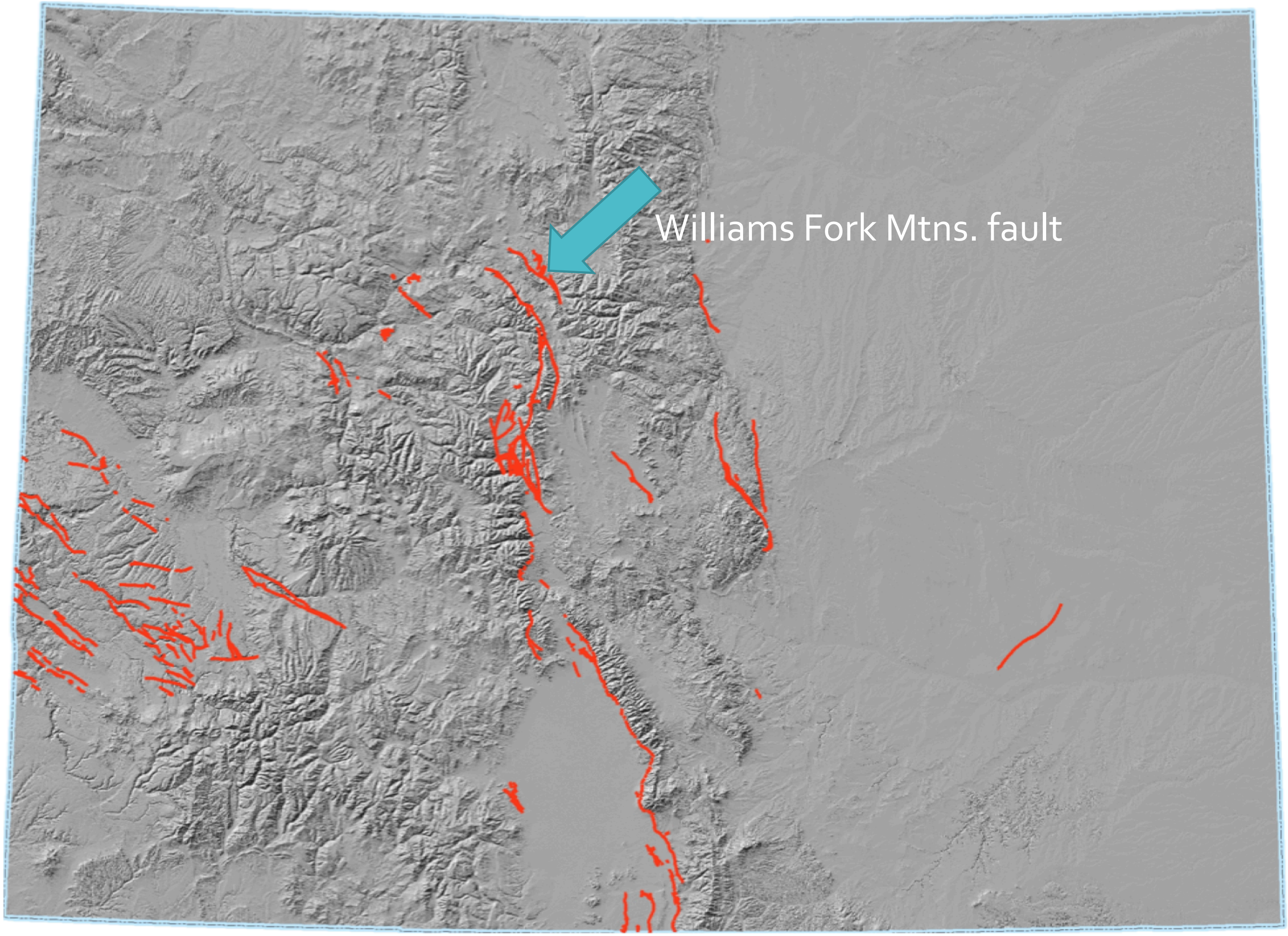
- Defined by a series of about 5 generally northwest-striking faults west of Colorado Springs
- Trends N-S along east side of Cheyenne Mtn (~9 km) then bends NW for 30 km, then N for 32 km
- Tonal and vegetation lineaments and bedrock scarps are discontinuous along the southern trace of the fault but are lacking along the northern trace.
- Late Cenozoic movement on the fault is strongly supported along the length of the fault (e.g., Taylor, 1975; Scott and others, 1978; Kirkham and Rogers, 1981; Dickson, 1986).
- Quaternary deposits do not appear to be offset across the north end of the fault (Bryant and others, 1981; Dickson and others, 1986; Unruh and others, 1994).
- Scarps developed in middle to late Quaternary alluvium and rockfall deposits are cited as evidence for recent fault activity on the south end of the fault by Scott and Wobus (1973) and Kirkham and Rogers (1981).
- Unruh and others (1994) did not recognize any evidence to support mid-Pleistocene to Holocene displacement. However, they did not address the scarps in rockfall deposits as previously presented by Scott and Wobus (1973) and Kirkham and Rogers (1981).
- Two events; the most recent paleoevent on this fault is *tentatively* classified as having occurred during the middle to late Quaternary.
- Slip rate <0.2 mm/yr
- Recent CGS mapping of the fault was inconclusive
- HAZUS M7.0 event
  - $22 billion total economic loss

COLORADO SCHOOL OF MINES

Ute Pass fault zone

ISSUES:

- Lack of reliable absolute ages of offset sediments; bedrock on bedrock in places
- No trenches have been excavated along the fault
- Landslide and rockfall deposits flank the fault


Williams Fork Mtns. fault


Kremmling
Williams Fork Mtns.

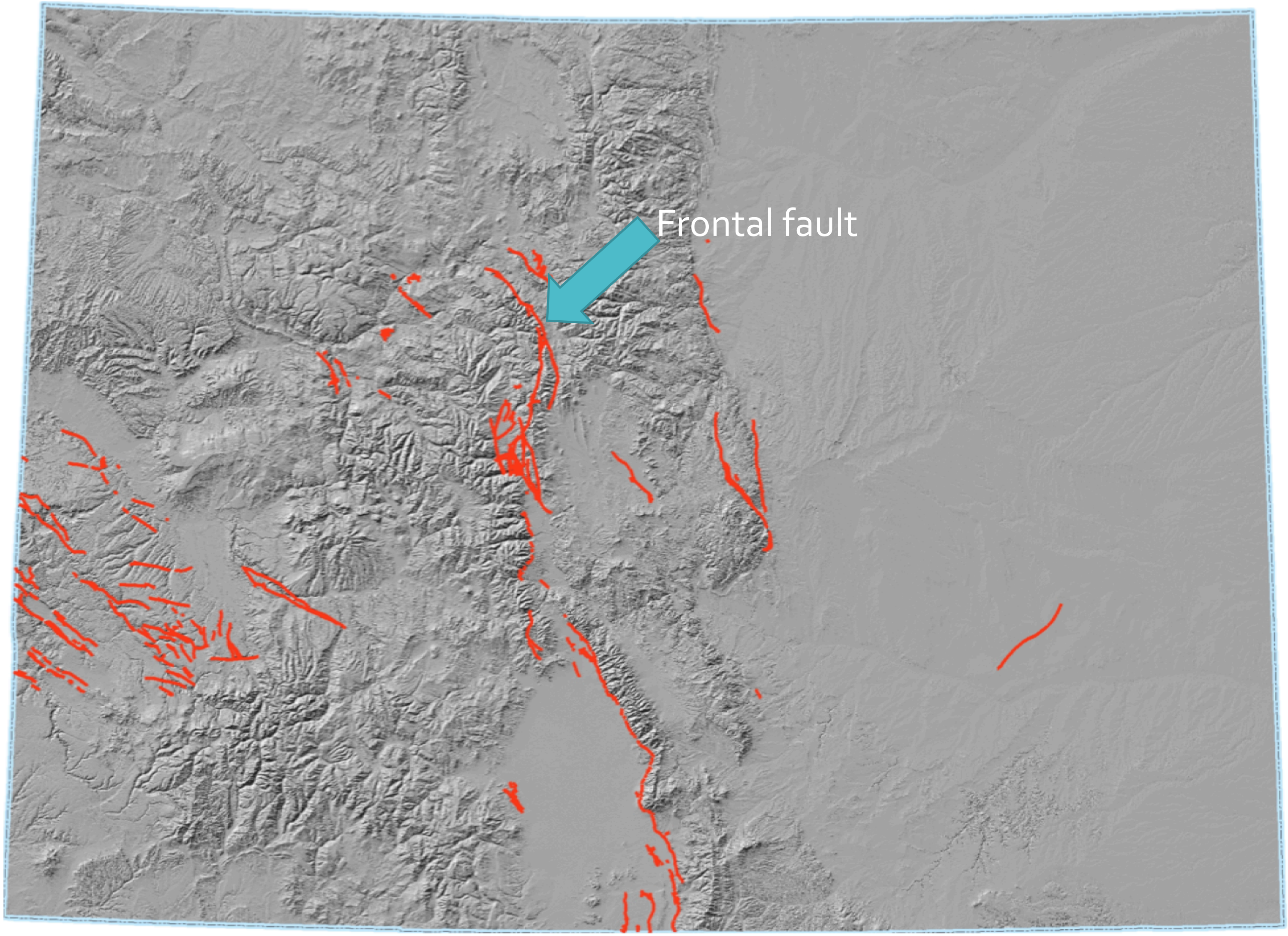
Williams Fork Mountains fault

- Series of three northwest-striking faults on the E flank of the Williams Fork Mountains and the west margin of the Neogene Williams Fork Valley graben, southeast of Kremmling ; total 50 km long
- Marked by an east-facing topographic break and by vegetation and topographic lineaments
- Unruh and others (1993, 1996) studied a northeast-facing scarp in Pinedale age alluvial fan deposits with down-to-the-east displacement of about 13 m.
  - A bevel on the scarp in the fan deposits was interpreted as indicating two episodes of movement since the last 10 to 40 ka.
- Strong evidence of late Quaternary deformation, primarily tectonic scarps in surficial deposits, is present along most of the 18-km-long northern section (Kirkham, 2004)
- No conclusive evidence of Quaternary activity was discovered on the 18-km-long southern section of the Williams Fork Mountains fault or on faults that form the eastern margin of the graben.
- Tectonic fault scarps are present in Holocene and late Pleistocene alluvium in many of the tributary valleys that cross the northern section.
- At two sites - Holocene deposits are offset over 1 m.
  At a third site a scarp displaces likely early Holocene or latest Pleistocene deposits by 2 m
- The greatest measured surface offset of 9.5 m was in a deposit that may be age equivalent with the Bull Lake glaciation.
- Estimated slip rate for the northern section of the Williams Fork Mountains fault is 0.1 to 0.3 mm/year
- HAZUS M6.75 event
  - $4 billion total economic loss

Williams Fork Mountains fault

ISSUES

- Ages of the faulted deposits are poorly constrained; no datable organic materials were recovered in the six soil pits of Kirkham (2004).
- Additional studies are required to better establish the chronologic framework
- The only trenching occurred along a "subsidiary" fault to the main fault by Kirkham and others in 2005. This trench revealed folding in Miocene mudstones; however, no ruptures in younger deposits were given by Kirkham (2005).
- Lack of adequate trenching locations and poor access make trenching problematic.


Frontal fault

Gore Range
Breckenridge
Silverthorne

Frontal fault

- Range-front fault that forms the east margin of the Gore and Tenmile Ranges; 75 km long
- Marked by an east-facing topographic break and by vegetation and topographic lineaments
- Tweto and others (1970) –
  - faulting in middle to early glacial deposits
  - historic movement on the fault based on a 1920 earthflow that created scarps and a ridge top stream north of Boulder Creek.
- West (1977; 1978) - all of the geomorphic features that Tweto and others (1970) attributed to young faulting are the result of normal alpine fluvial and colluvial processes
- Tweto (1979) - movement on the fault as recently as the Quaternary
- Kirkham and Rogers (1981) - during the early Quaternary
- Howard and others (1978) and Colman (1985) - during the Quaternary
- Unruh and others (1993) - Pinedale glacial deposits are offset by the fault (7m)
- Anderson and Piety (2007); Derouin and others (2009) - LiDAR and field studies – 2 to 10-m-high scarps result of recurrent late(?) Quaternary activity
- HAZUS M7.0 event
  - $9 billion total economic loss

Frontal fault

ISSUES

- Deposits not dated
- Need more trenches but access is an issue
- What is the age of the most recent surface-rupturing event?
- Is it segmented?
- Slip rate and/or recurrence interval?

COLORADO SCHOOL OF MINES

Idaho –Faults of Concern

USGS Workshop on Evaluation of Hazardous Faults
in the Intermountain West Region – 2015 Update

Bill Phillips
Idaho Geological Survey
University of Idaho
Moscow, Idaho

Salt Lake City, Utah
January 12, 2015

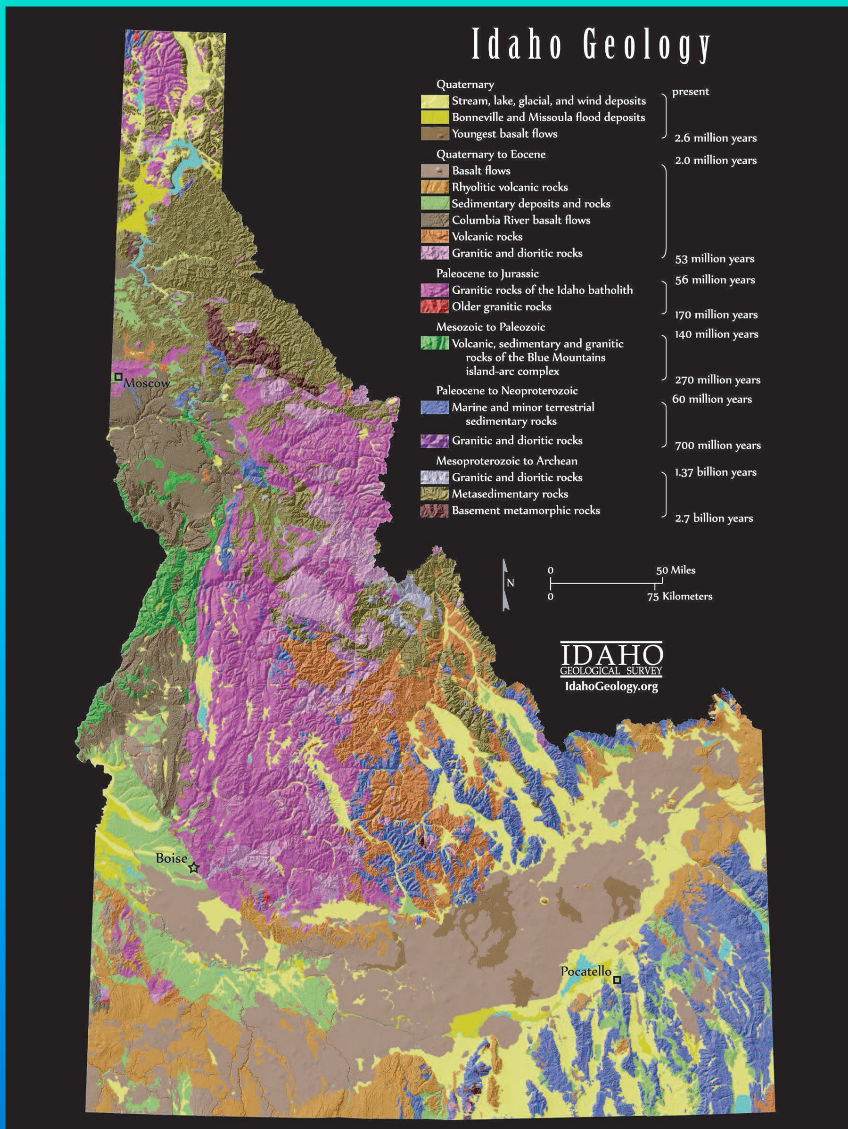
Talk Outline

- Procedure for Identifying Faults of Concern
- Neotectonic Framework of Idaho
- Idaho Faults of Concern
- Suggestions for Further Work

Procedures for Identifying Faults of Concern

1. Evaluate all Idaho faults in USGS fault database with **Holocene-latest Quaternary** class
2. Remove faults lacking evidence for <15ka deformation
3. Assign **Risk** score based upon population and infrastructure
4. Assign **Hazard** score as measured by slip rate
5. Assign **Data Quality and Completeness** score
6. Add **interesting and poorly understood** structures

Neotectonic Framework of Idaho

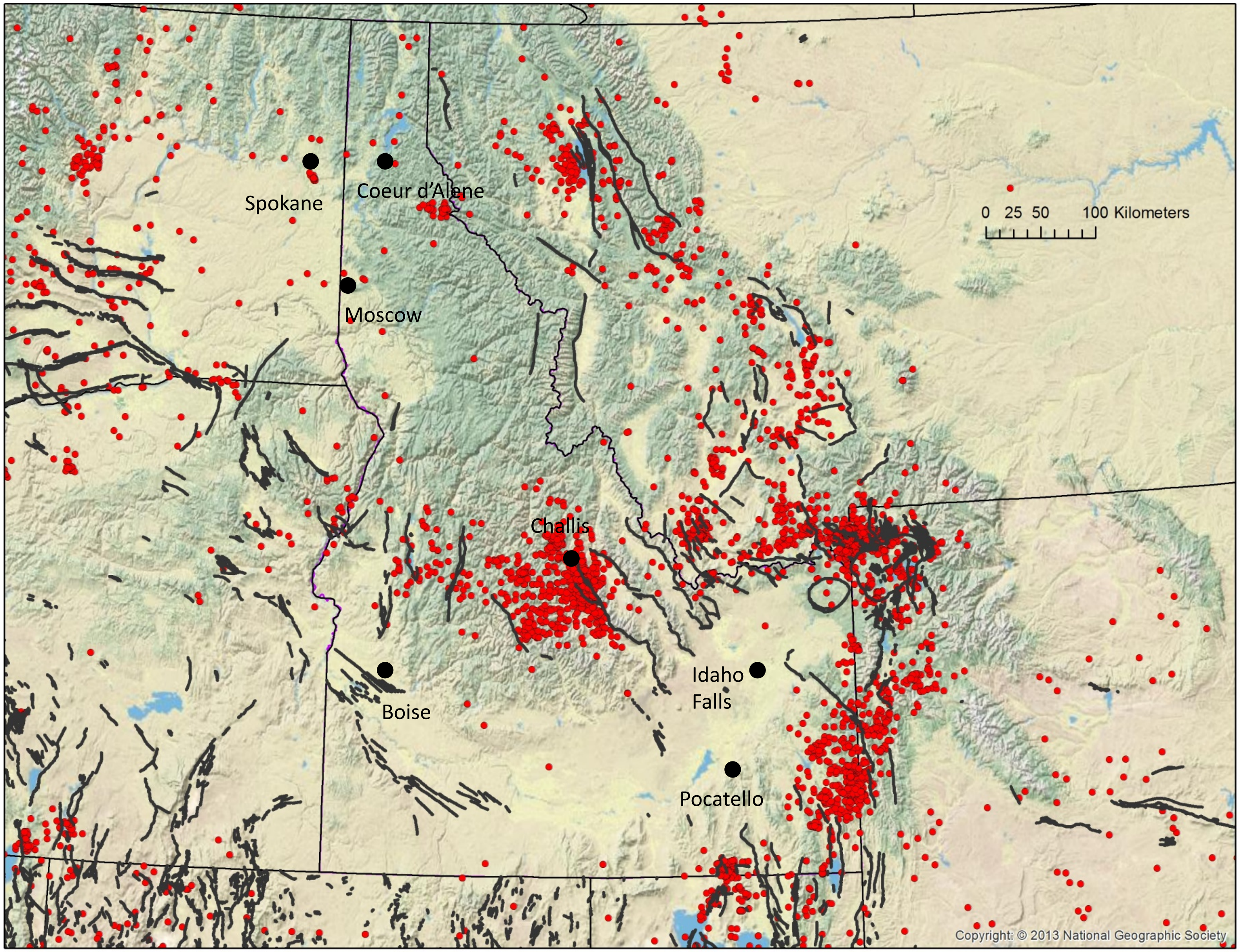


Idaho Geologic Map Postcard by L. Stanford (IGS 2014)

Idaho Geologic Provinces

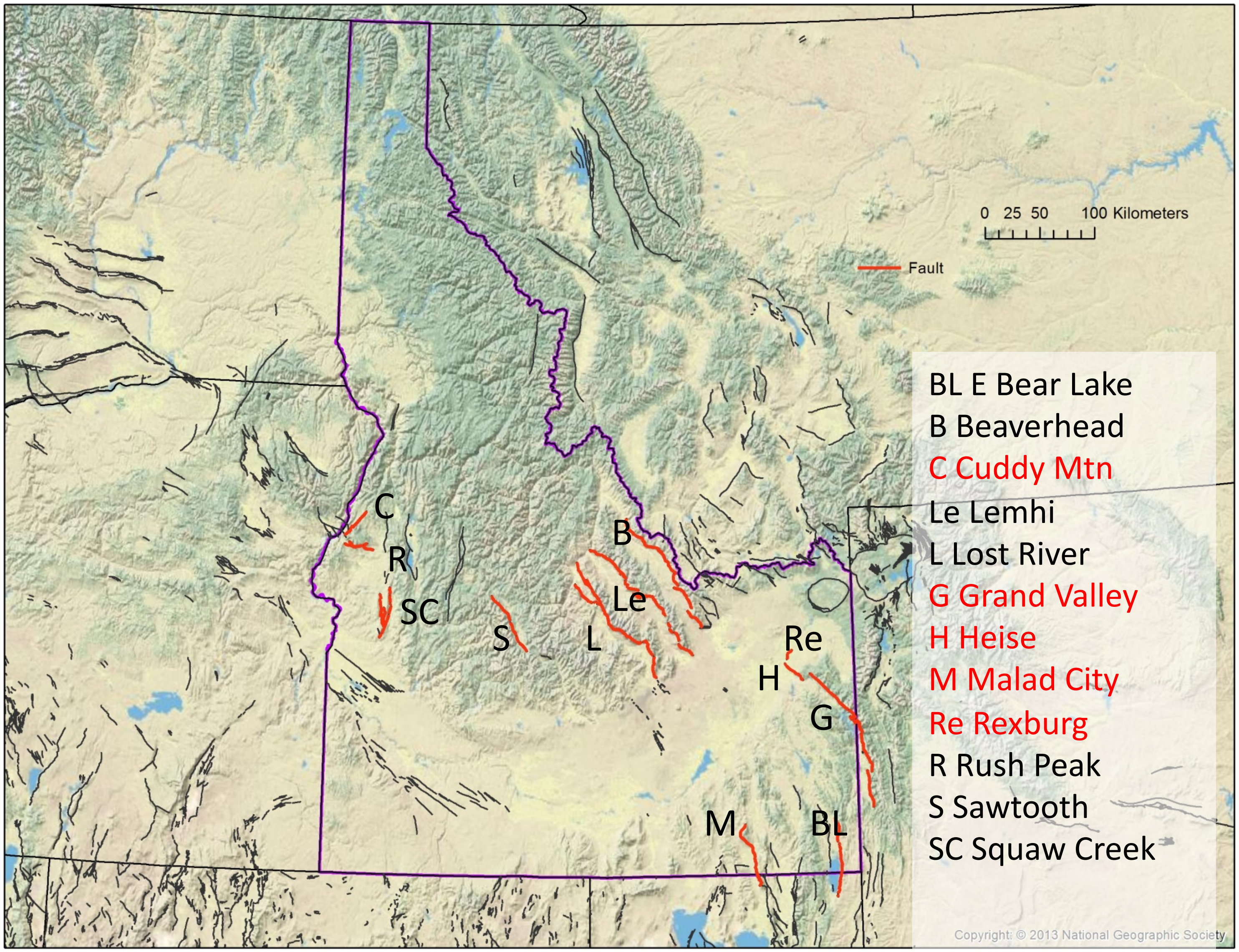
- Snake River Plain – Yellowstone
  - ESRP
  - WSRP
- Columbia River Basalt Group
- Basin and Range
- Challis Volcanic Province
- Idaho Batholith
- WY-ID Thrust Belt
- Accreted Terranes
  - Idaho Shear Zone
- North American Craton

Regional Seismicity and Quaternary Faults



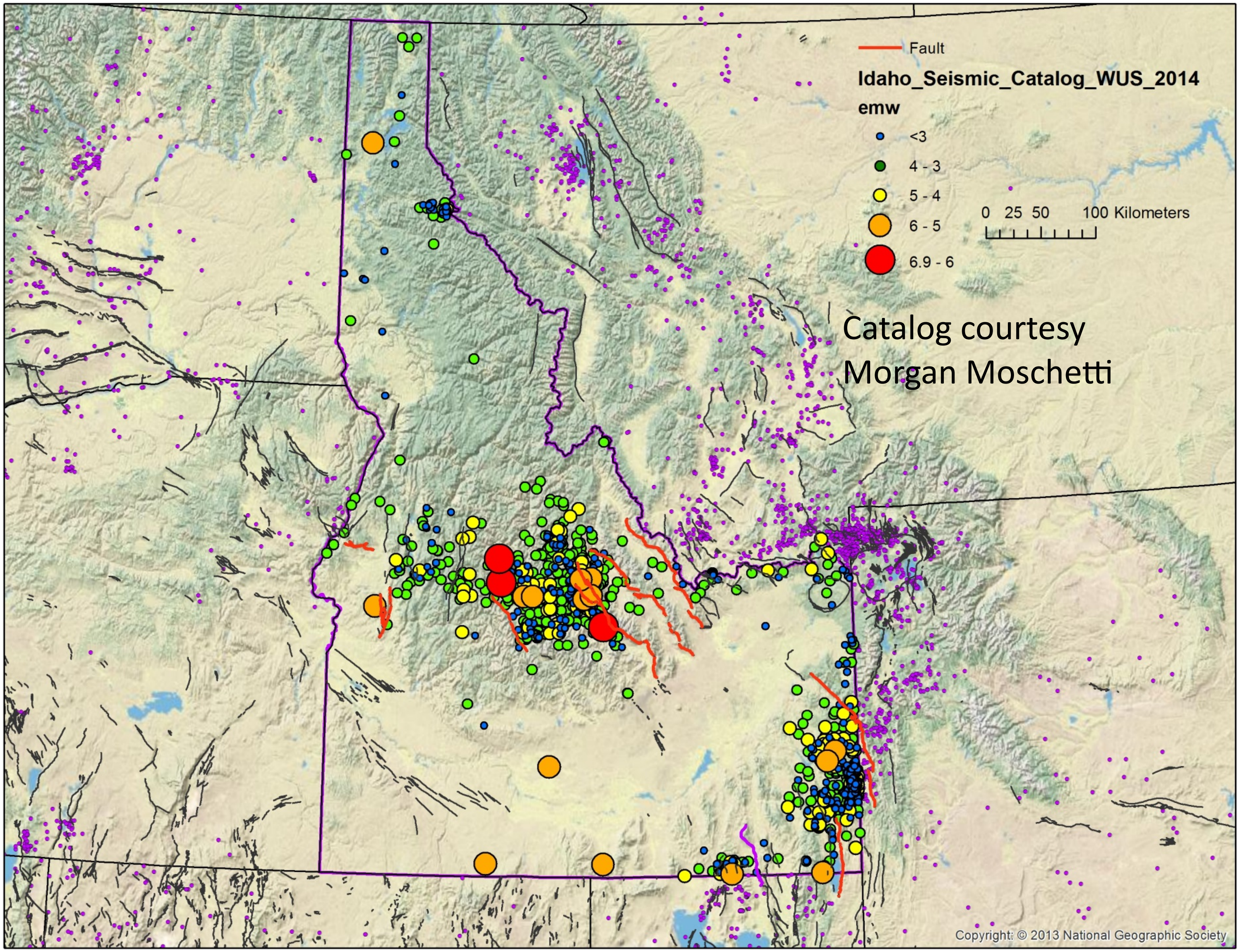
Sources: WUS Seismic Catalog 2014 Un-Declustered; USGS Fault Database, All Quaternary Faults

Candidate Idaho Faults of Concern (mostly <15ka Deformation)



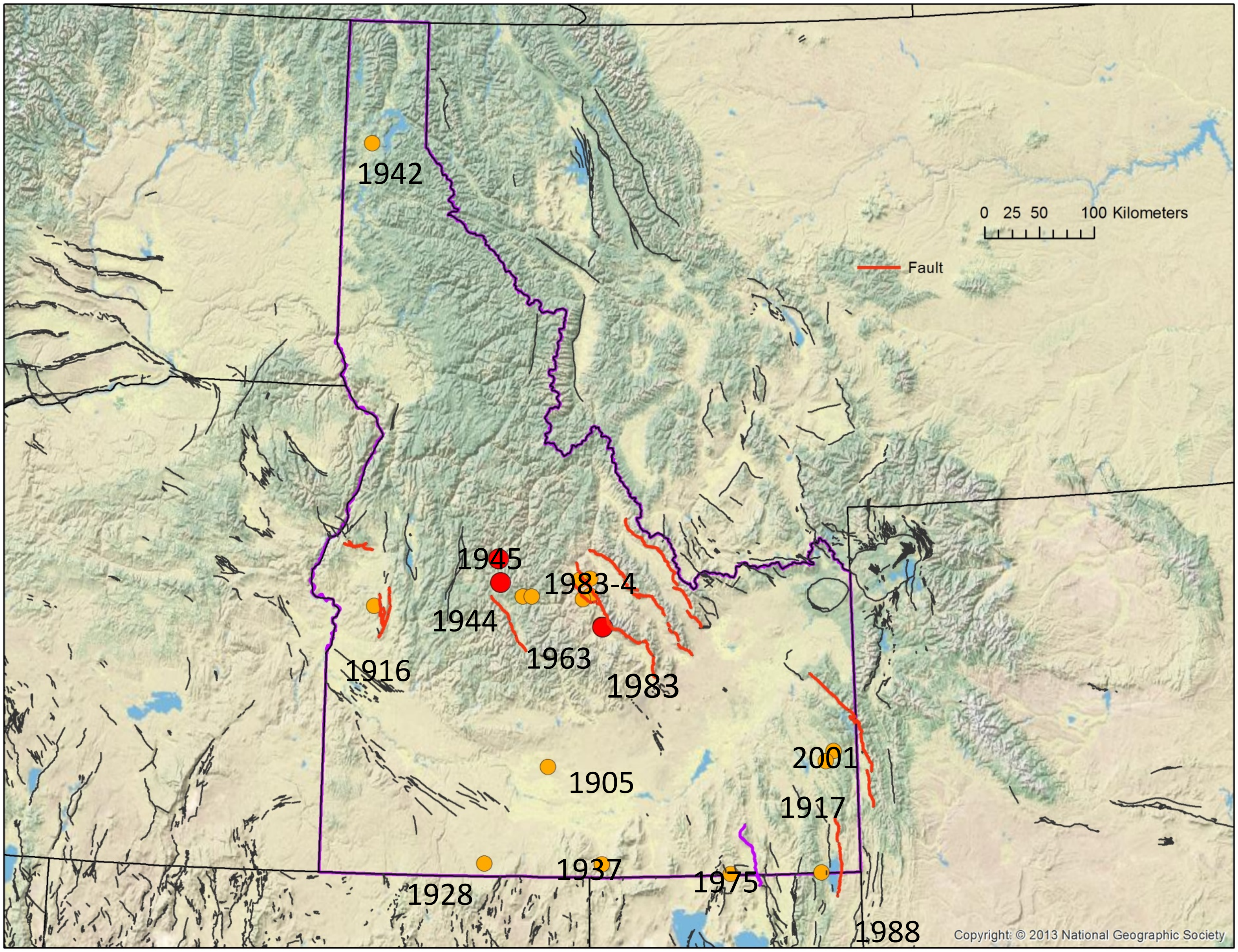
Source: USGS Fault Database, accessed 1/2015

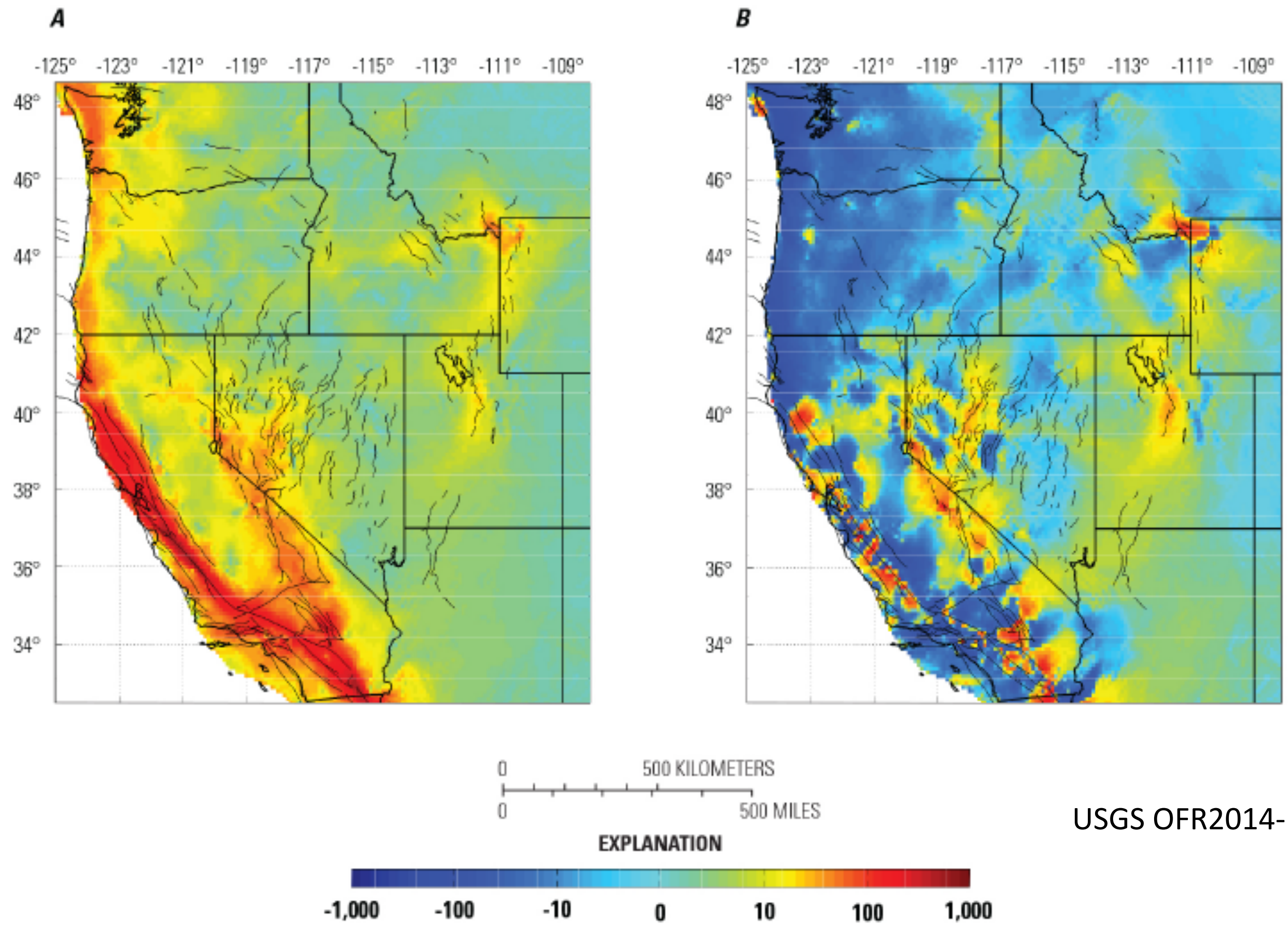
Idaho Seismic Catalog



Catalog courtesy Morgan Moschetti

Idaho Historical Seismicity Mw>=5

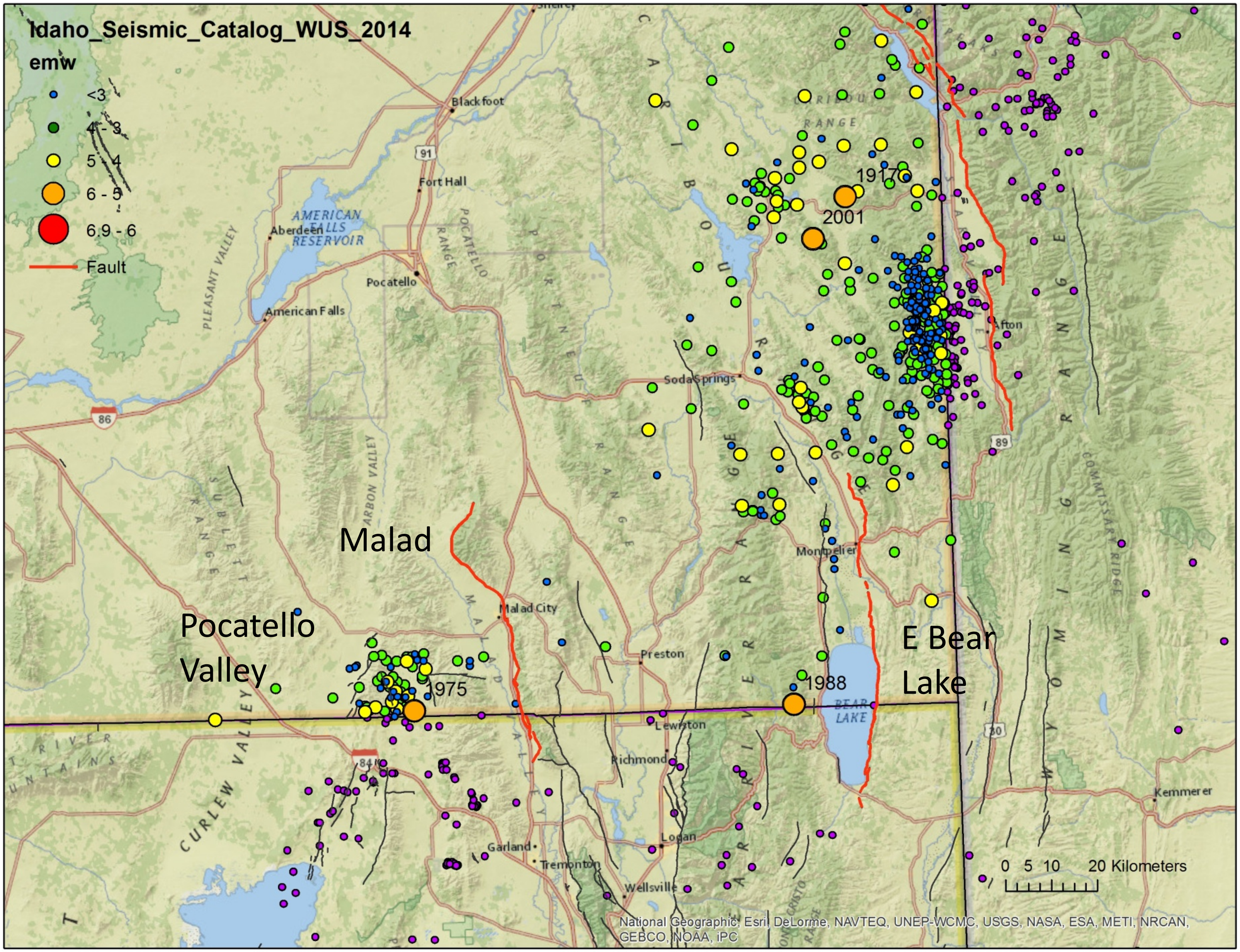




USGS OFR2014-1091

Figure 50. Strain-rate maps of the Western United States calculated using the global positioning system (GPS) dataset collected for the combined-inversion models showing *A*, maximum shear and *B*, dilatational strain. Fault sources are shown (black lines).

SE Idaho

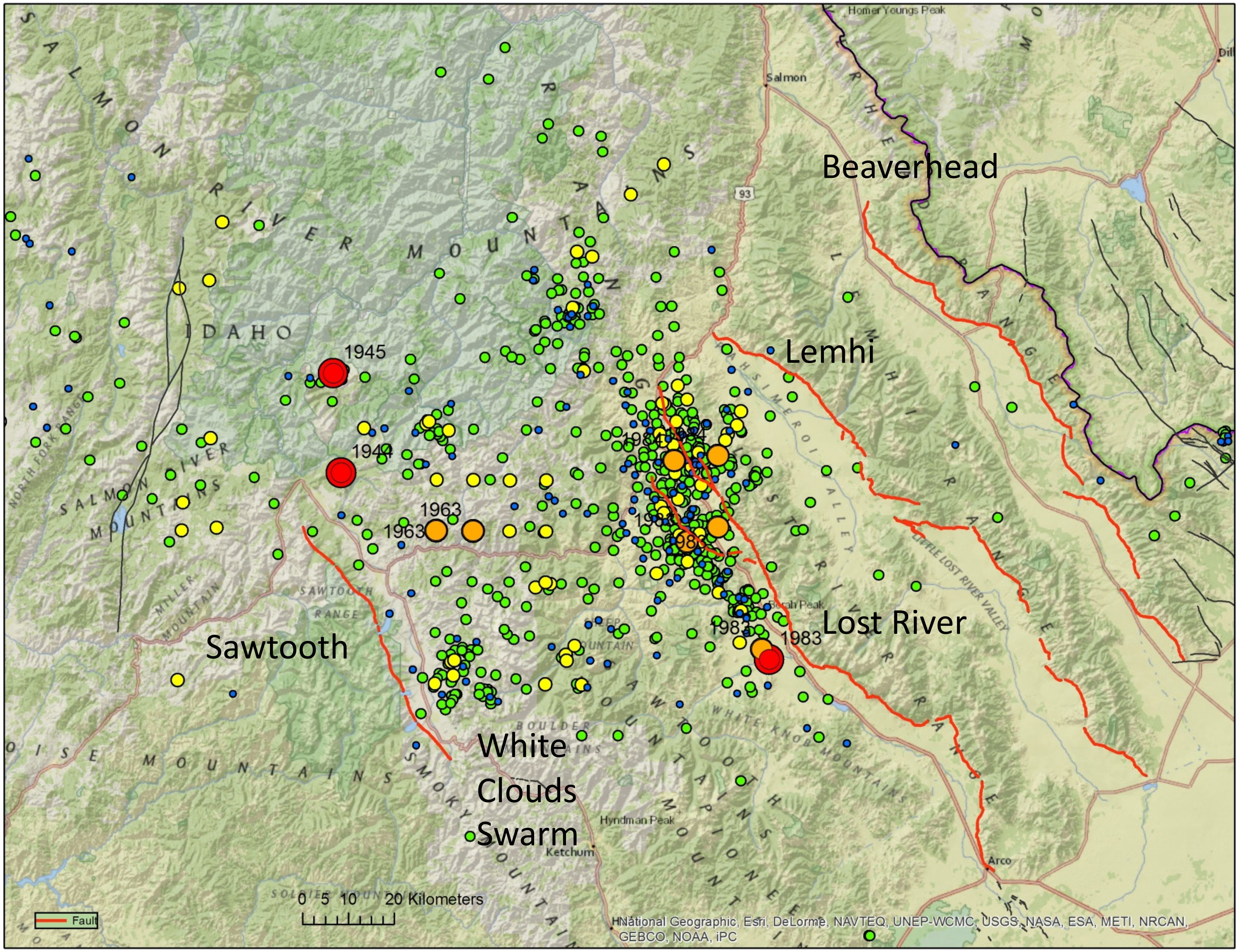


Idaho_Seismic_Catalog_WUS_2014
emw
<3
4 - 3
5 - 4
6 - 5
6.9 - 6
Fault
Malad
Pocatello
Valley
E Bear
Lake
1975
1988
2001
1917
Blackfoot
Fort Hall
Aberdeen
American Falls
Pocatello
Soda Springs
Montpelier
Malad City
Preston
Lewiston
Richmond
Logan
Garland
Tremonton
Wellsville
Afton
Kemmerer
0 5 10 20 Kilometers
National Geographic, Esri, DeLorme, NAVTEQ, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, iPC

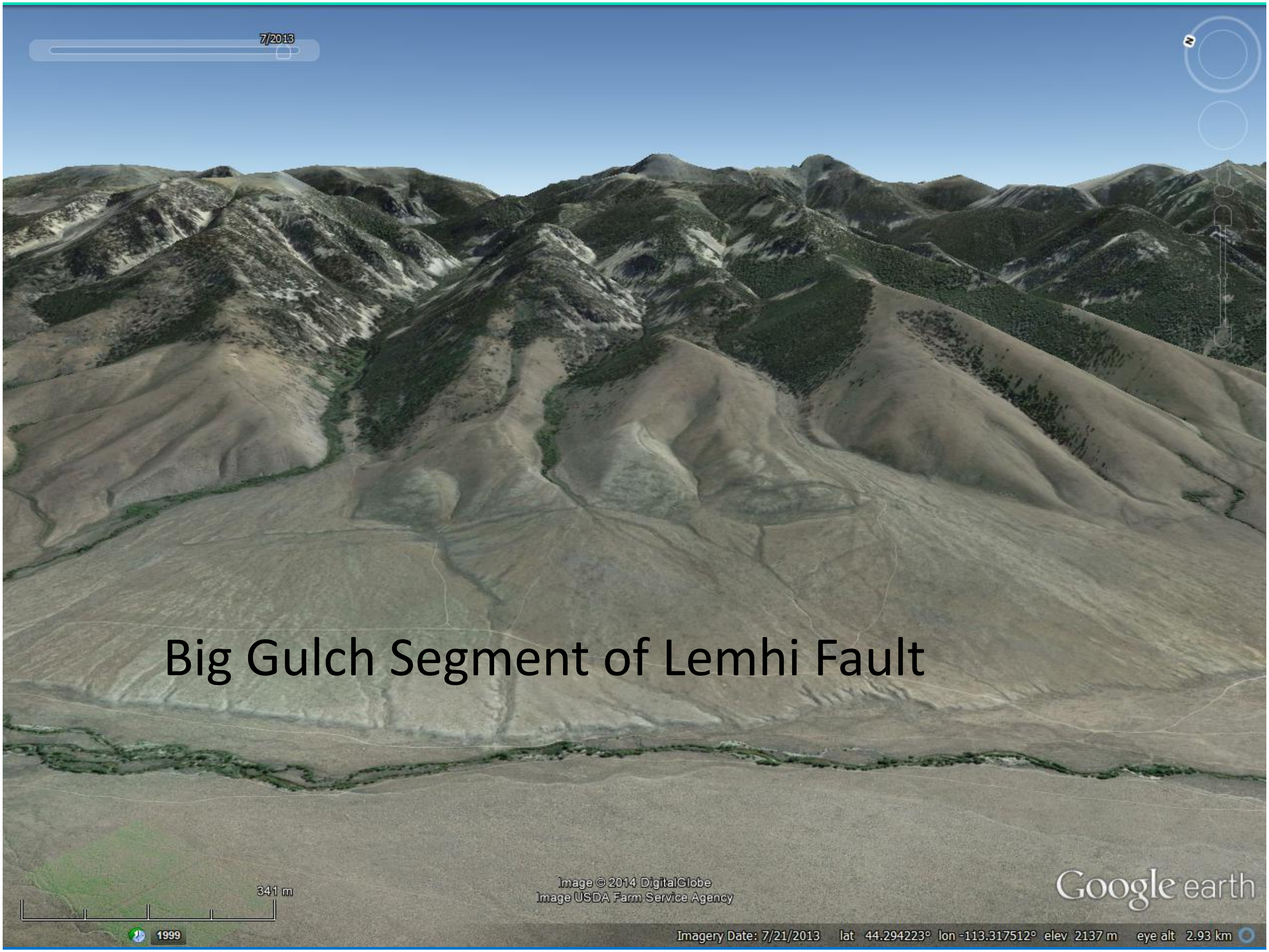
Malad City Segment of Wasatch Fault
Poorly Studied (But Important?) Fault

Image by Bill Phillips courtesy UGS and Mike Hylland

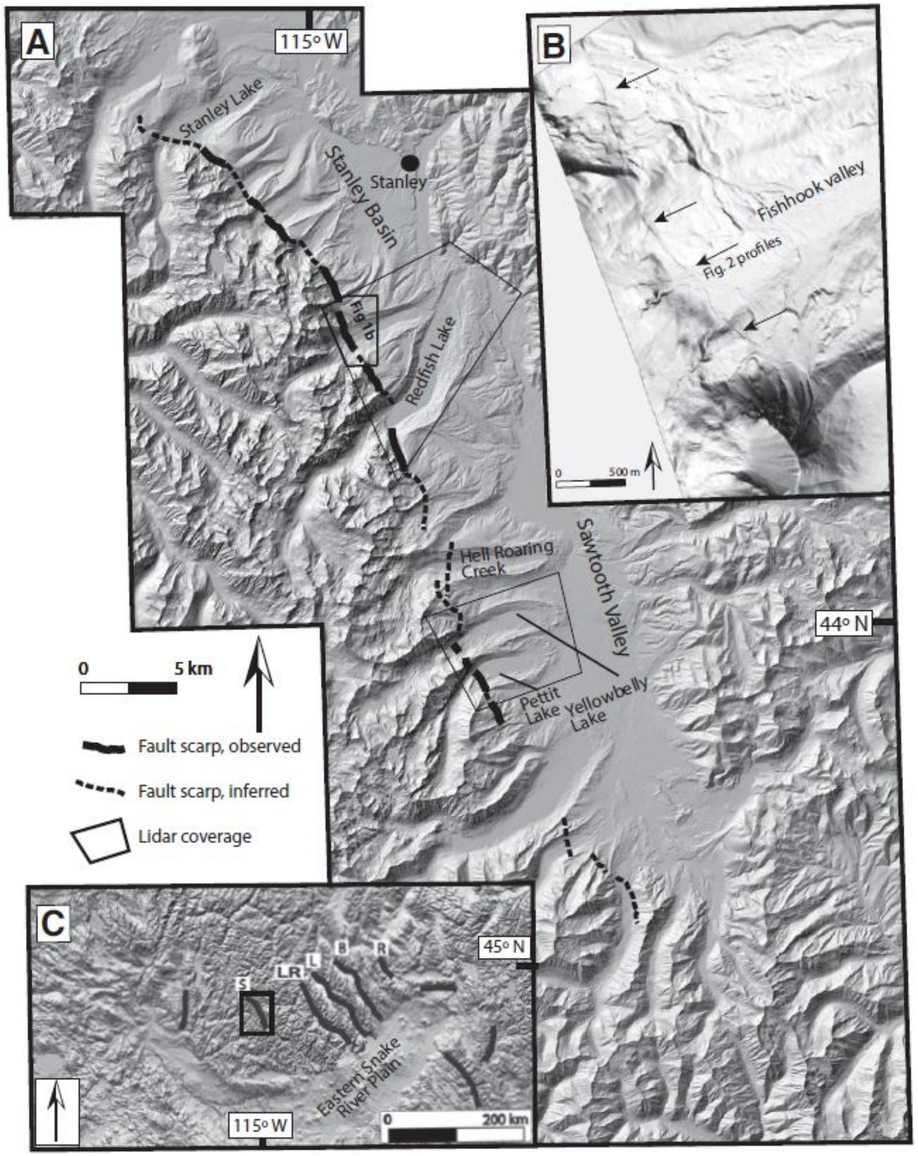
Central Idaho

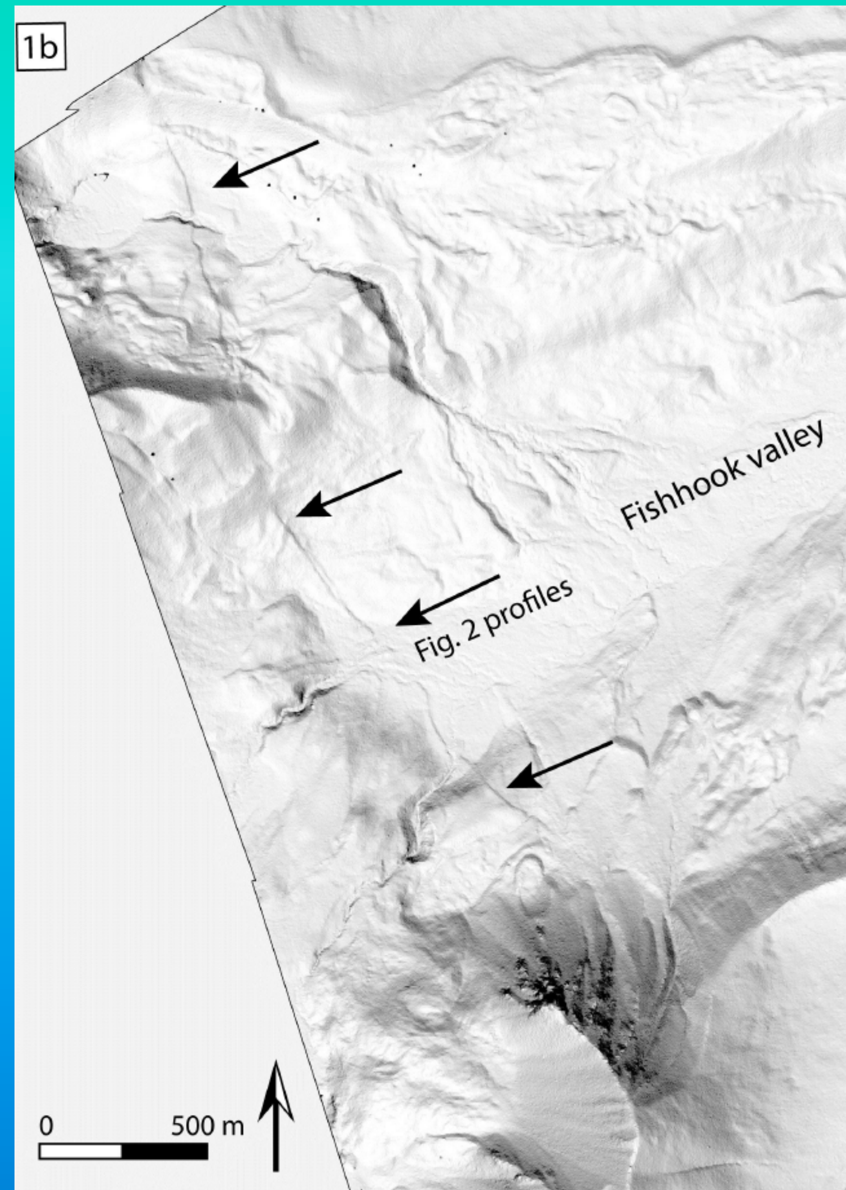



Beaverhead Fault
6/2013
179 m
1999
Image USDA Farm Service Agency
Image © 2014 DigitalGlobe
Imagery Date: 6/8/2013 lat 44.268955° lon -112.917064° elev 2229 m eye alt 2.72 km
Google earth


7/2013
Big Gulch Segment of Lemhi Fault
341 m
Image © 2014 DigitalGlobe
Image USDA Farm Service Agency
Google earth
1999
Imagery Date: 7/21/2013 lat 44.294223° lon -113.317512° elev 2137 m eye alt 2.93 km

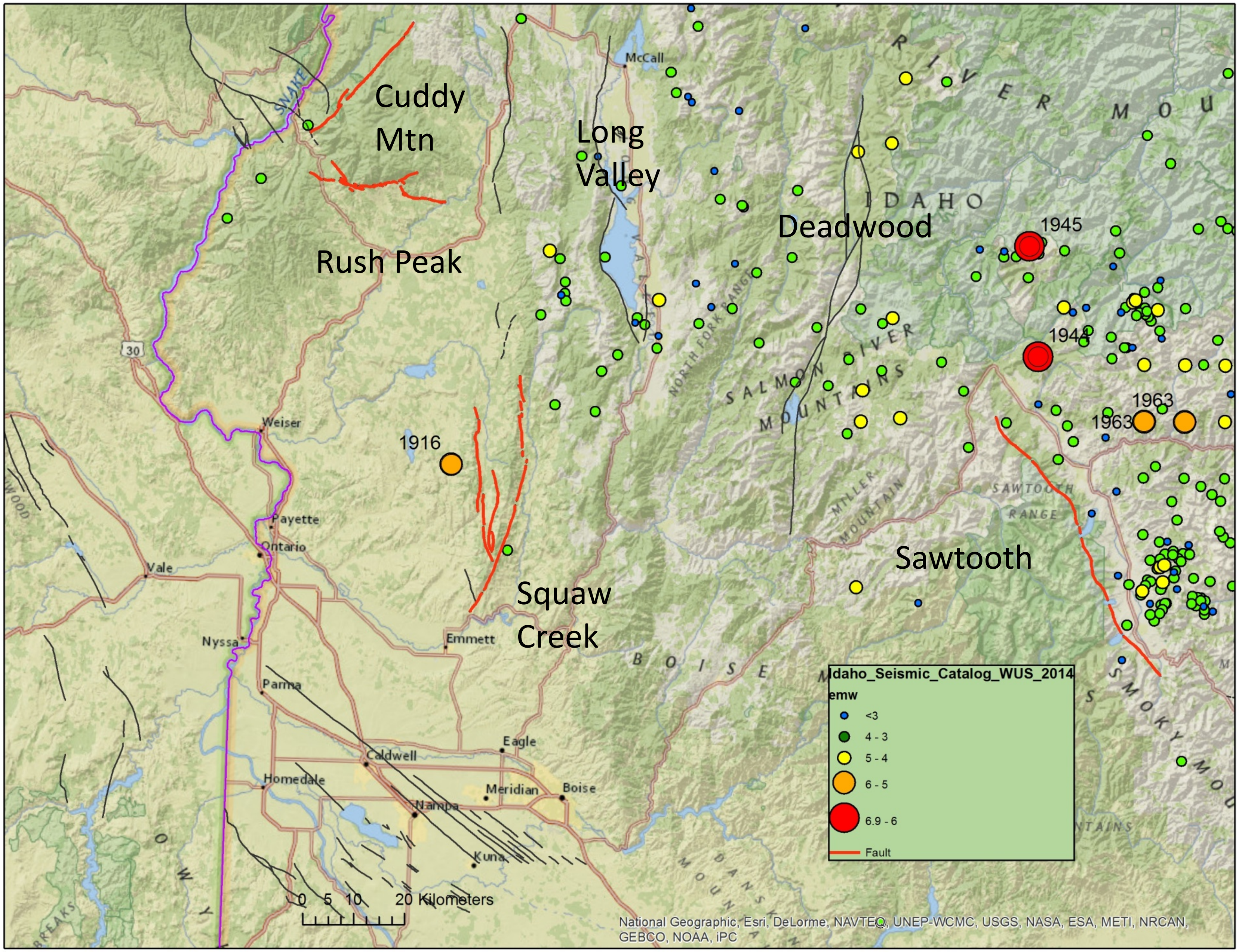
Sawtooth Fault





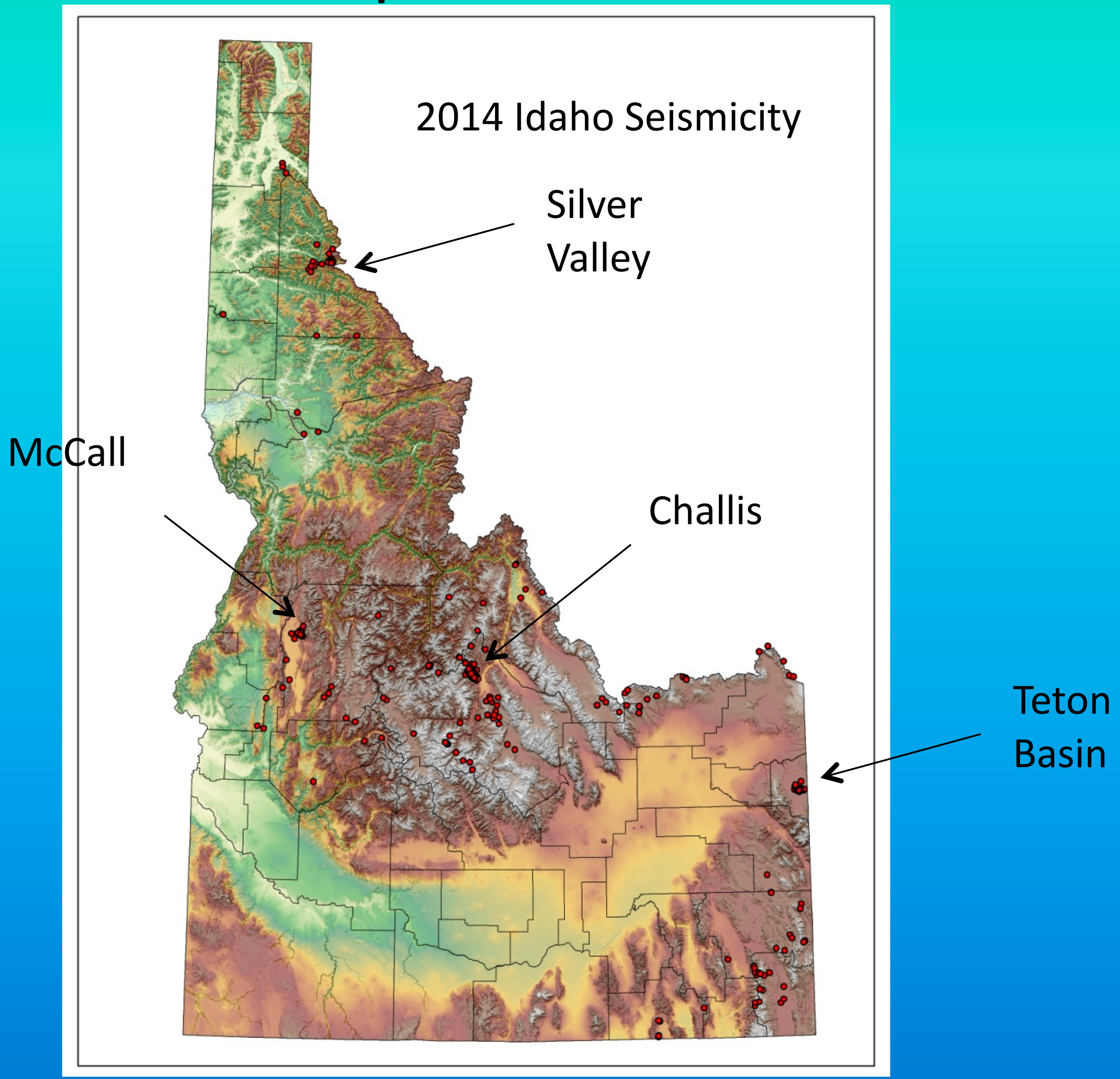
Images from Thackray et al.,, 2013

SW Idaho

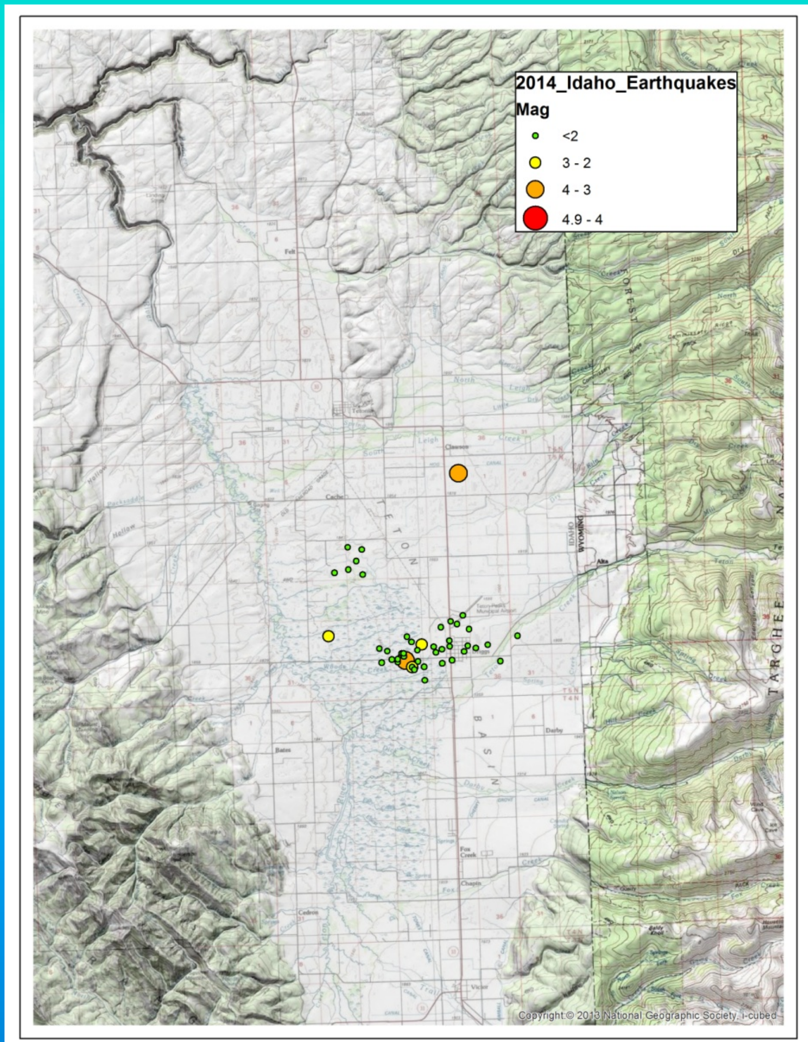


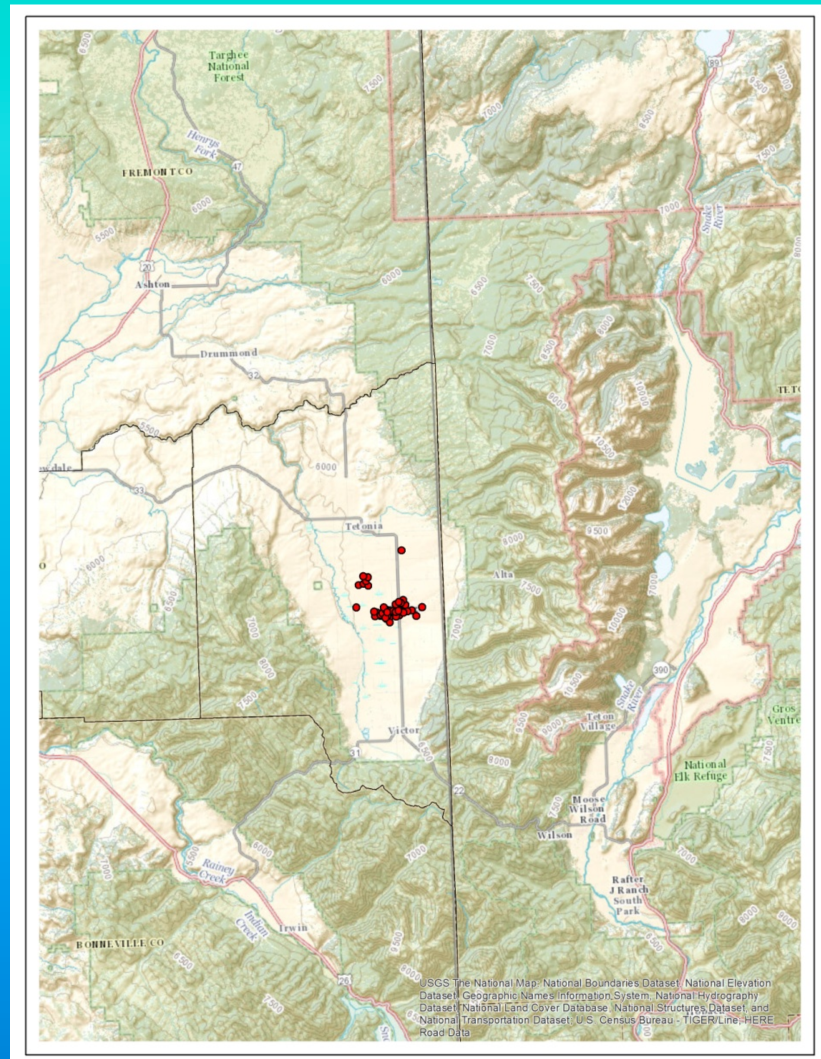
Cuddy Mtn
Long Valley
Rush Peak
Deadwood
1945
1944
1963
1963
1916
Squaw Creek
Sawtooth
McCall
Weiser
Payette
Ontario
Vale
Nyssa
Parma
Emmett
Eagle
Caldwell
Homedale
Meridian
Boise
Nampa
Kuna
IDAHO
SALMON RIVER MOUNTAINS
SAWTOOTH RANGE
BOISE
0 5 10 20 Kilometers
Idaho_Seismic_Catalog_WUS_2014
emw
<3
4 - 3
5 - 4
6 - 5
6.9 - 6
Fault
National Geographic, Esri, DeLorme, NAVTEQ, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, iPC

Earthquake Swarms



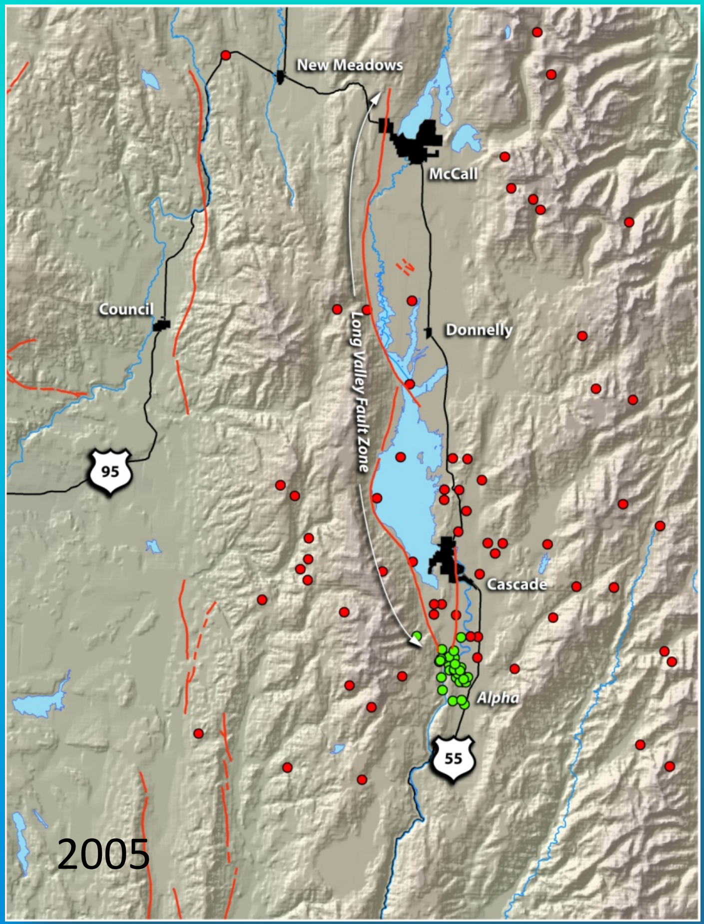
Teton Basin Earthquake Swarm 2013-2014

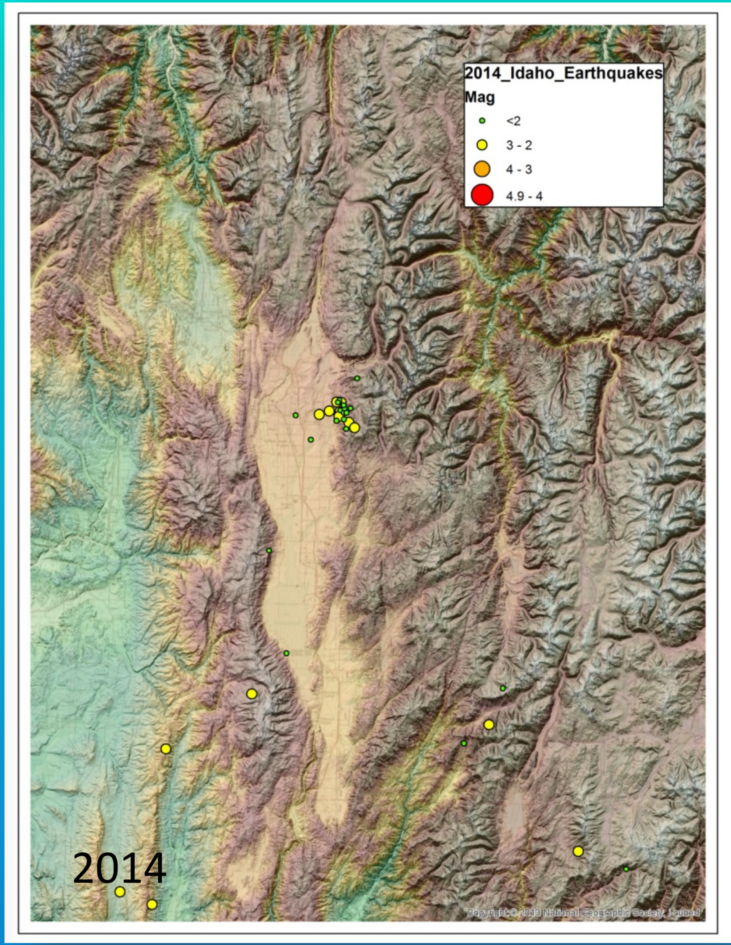




Earthquake locations by Mike Stickney

Long Valley Earthquake Swarms

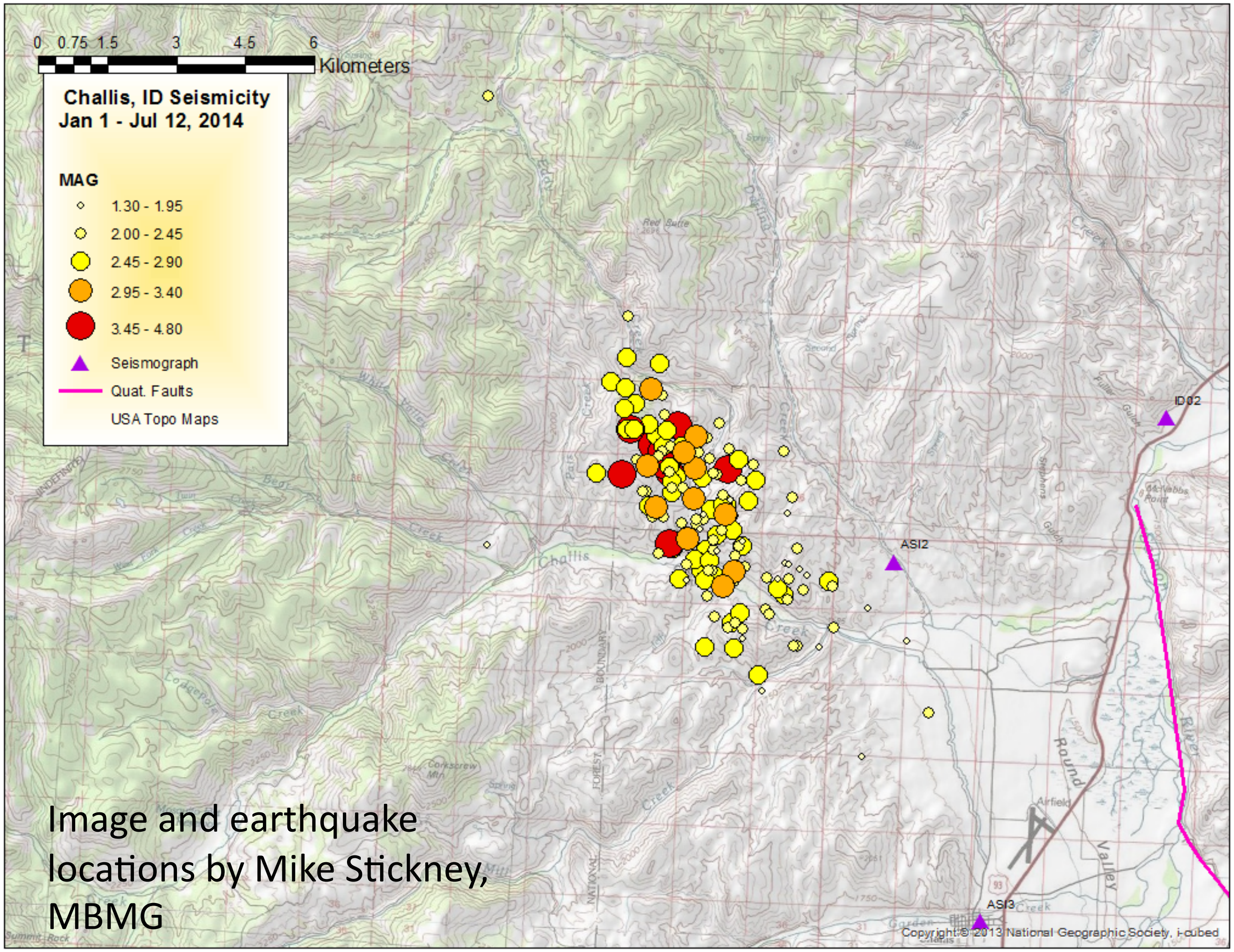




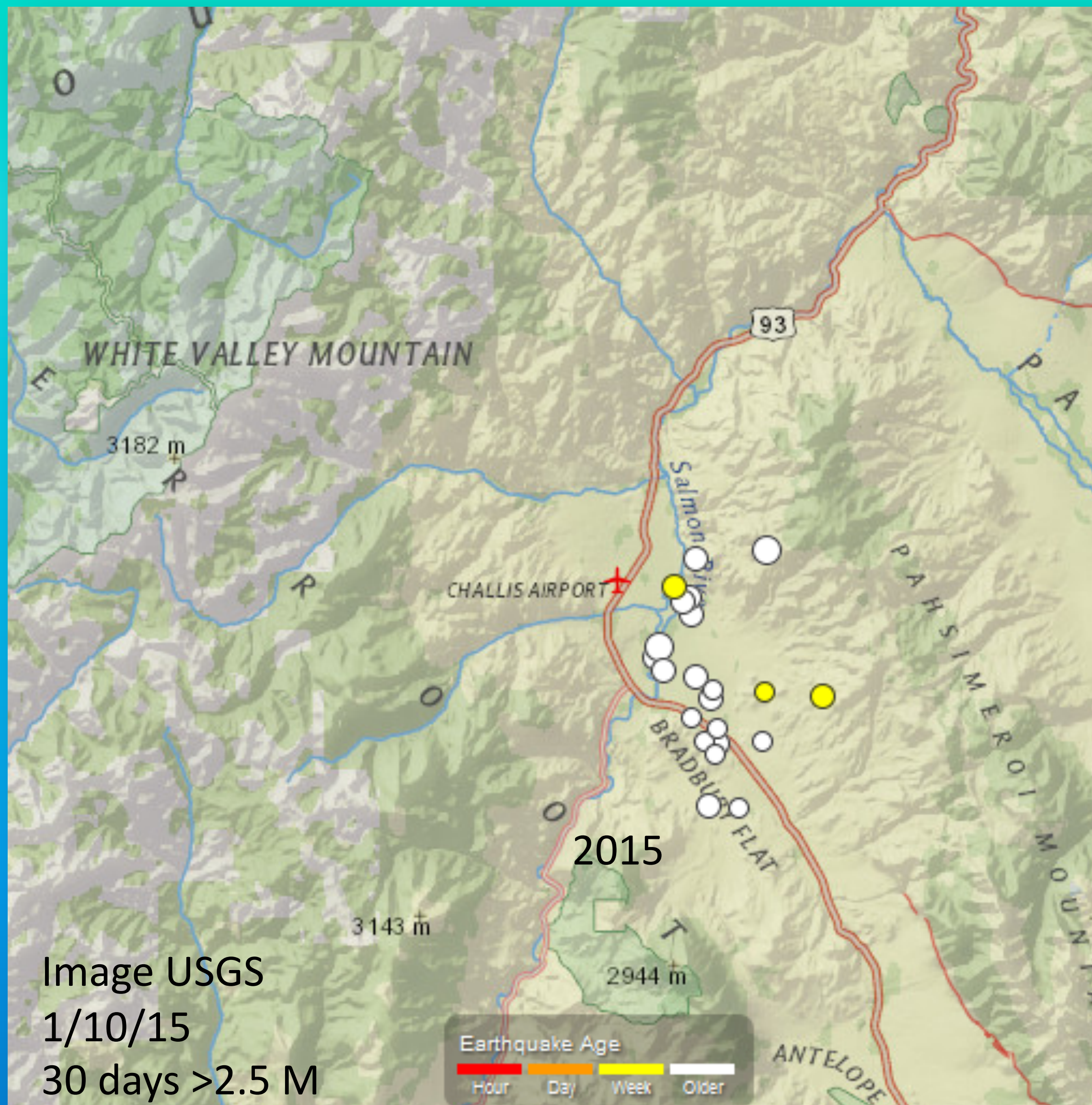
Alpha

McCall

Challis Earthquake Swarm 2014 (Mmax = 4.8)



Challis 2015 Earthquake Swarm (Mmax 4.9)



Relationship Challis Swarm with Aftershocks of Borah Peak 1983 Mw 6.9

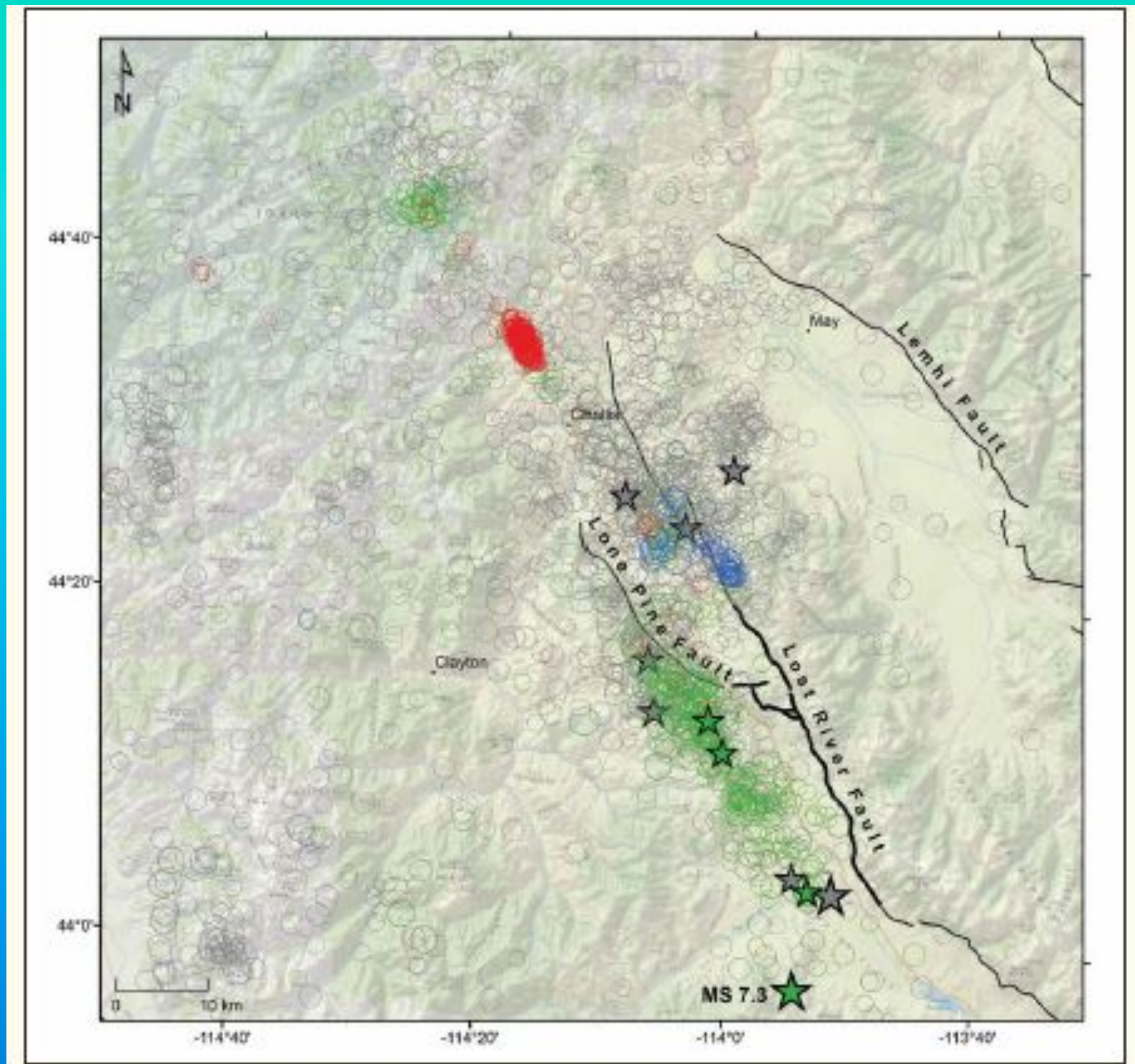
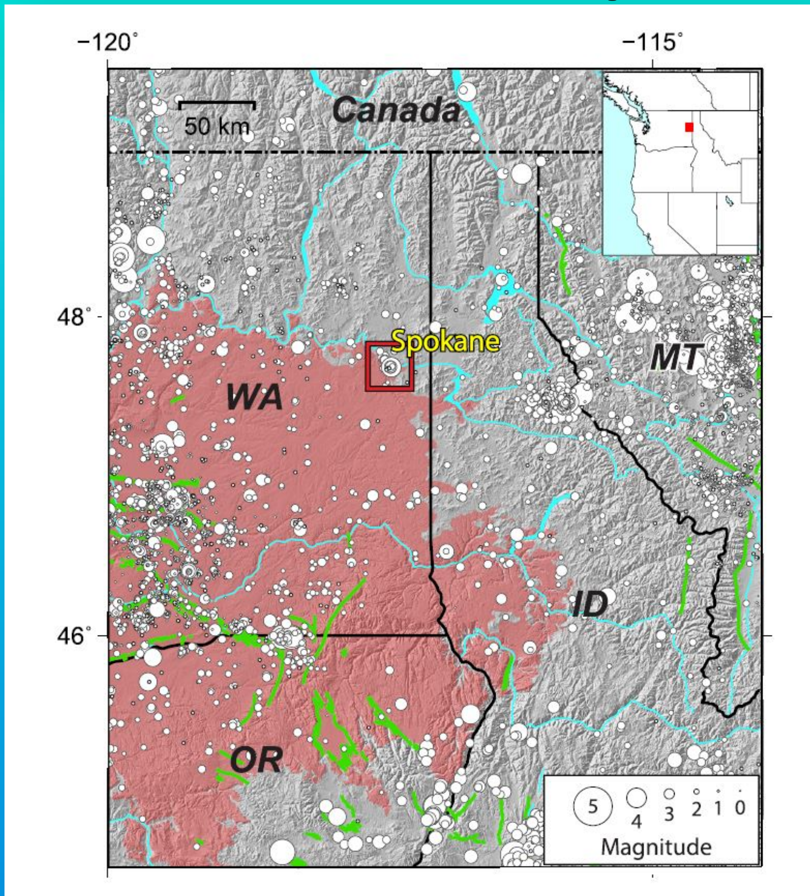
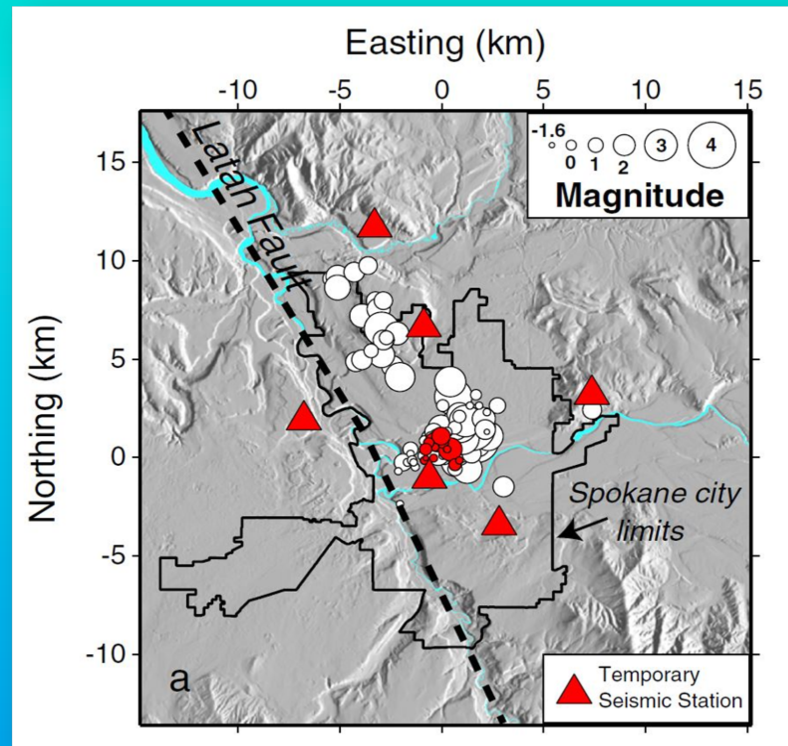


Image from Stickney et al. 2014, AGU

Spokane Fault





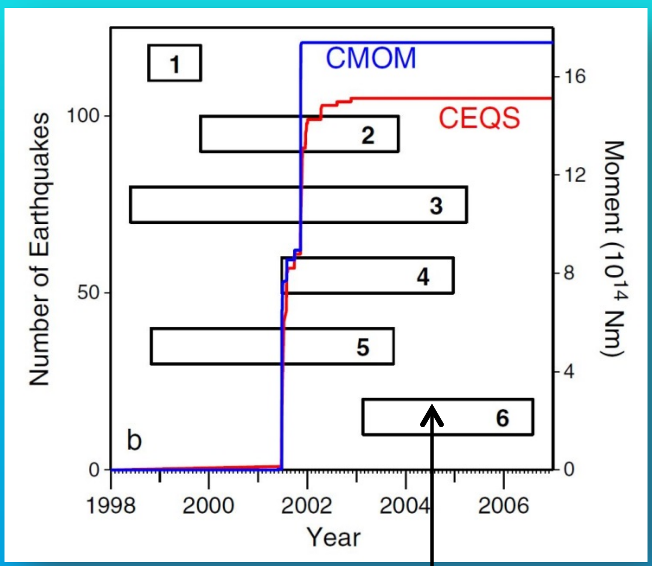
Figures from Wicks et al., 2013

- Swarm May – Nov 2001
- 105 earthquakes recorded
- Mmax = 4.0
- No known Quaternary faults

- Temporary seismic array deployed PNSN (Wright et al., 2002)
- Widely reported by regional news media

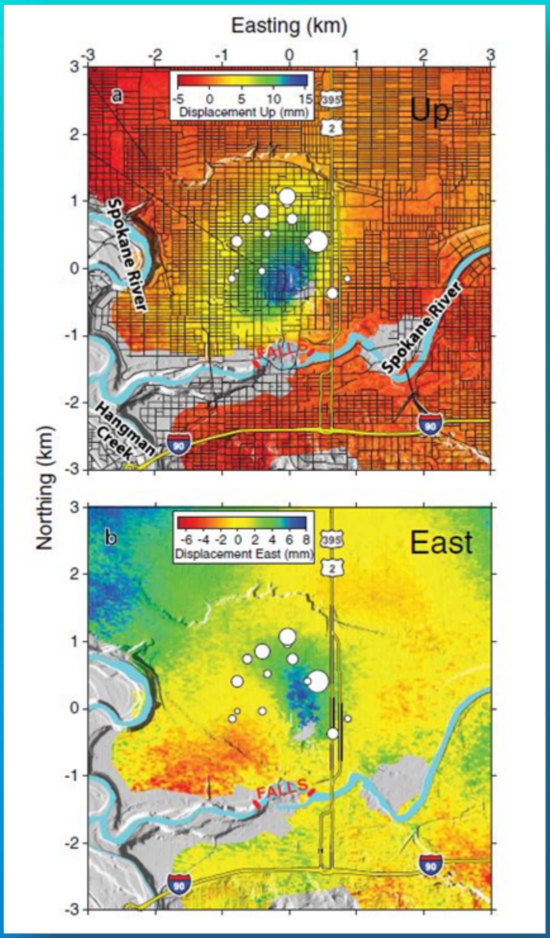
Spokane Swarm – Use of InSAR to Identify Fault

CMOM cumulative moment
CEQS cumulative seismicity

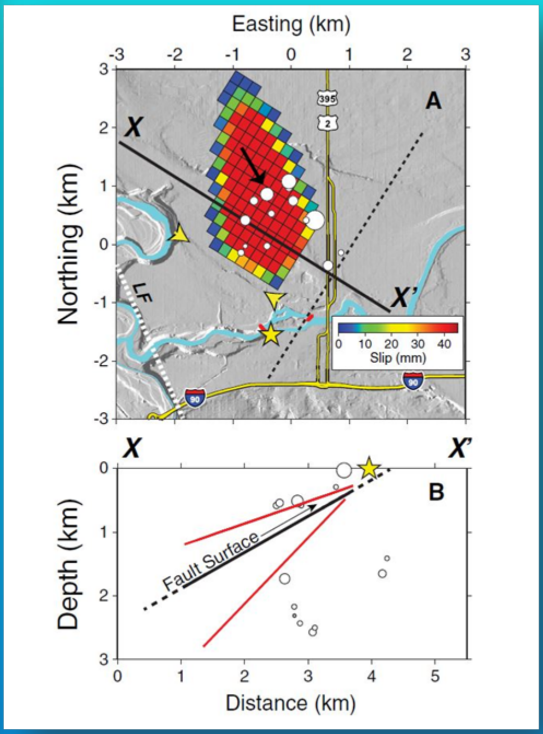


Interferogram time span

Figures from Wicks et al., 2013



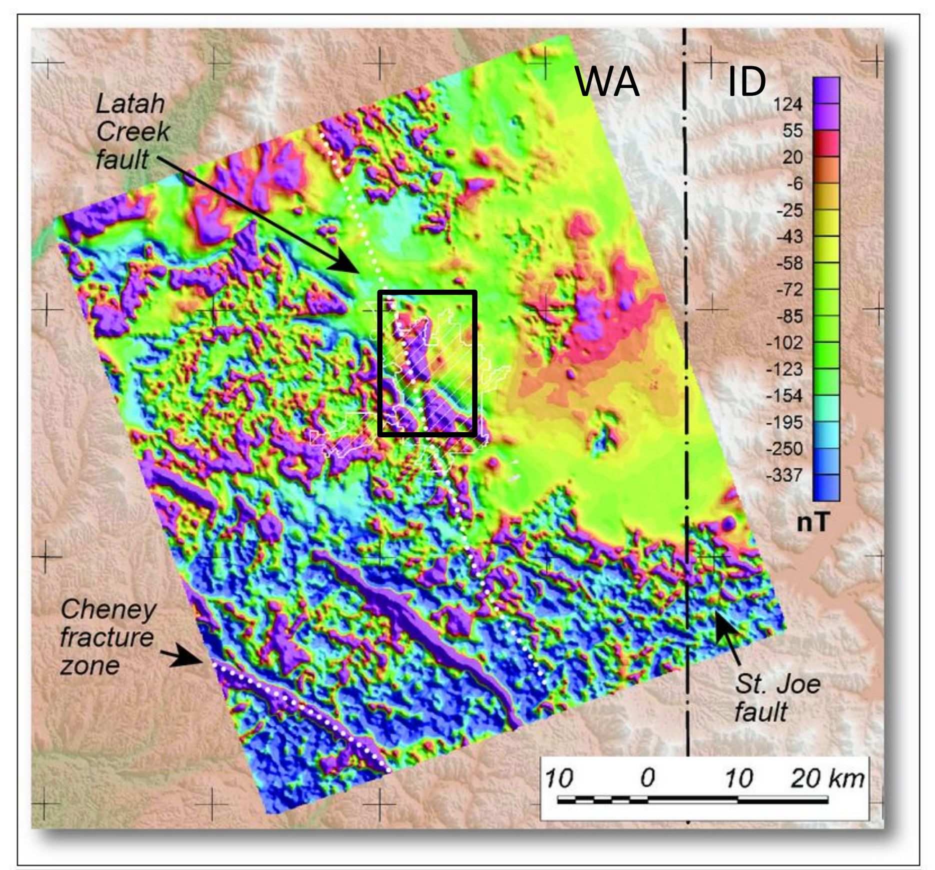
Deformation detected by InSAR



Best fit model: NE-trending thrust fault

Spokane Fault

- Other work
  - Aeromagnetic Survey
    - Magnetic anomaly coincides with Spokane fault?
  - LiDAR
  - Seismic Reflection
  - Community Workshops
- Lessons Learned
  - Swarms in high risk-low hazard areas may motivate new research (and funding)
  - Imperative to deploy temporary arrays in poorly monitored areas
  - InSAR was "game-changer"



Richard Blakely, USGS Press Release 1/3/2014

Idaho Faults of Concern - 2015

- Candidate Faults*
  – Beaverhead
  – Eastern Bear Lake
  – Lemhi
  – Lost River
  – Malad City
  – Sawtooth
  – Squaw Creek
  – Swarms
    - Long Valley
    - Spokane
    - Teton Basin

*alphabetical order

5 Idaho Faults of Concern

1. Lost River (science + people)
2. Squaw Creek (close to Boise)
3. Sawtooth (new data + people)
4. Beaverhead (science + INL)
5. Lemhi (science + INL)

Runner Ups:

- E Bear Lake (highest slip rate + people)
- Long Valley (swarms + people)
- Malad City (science + people)

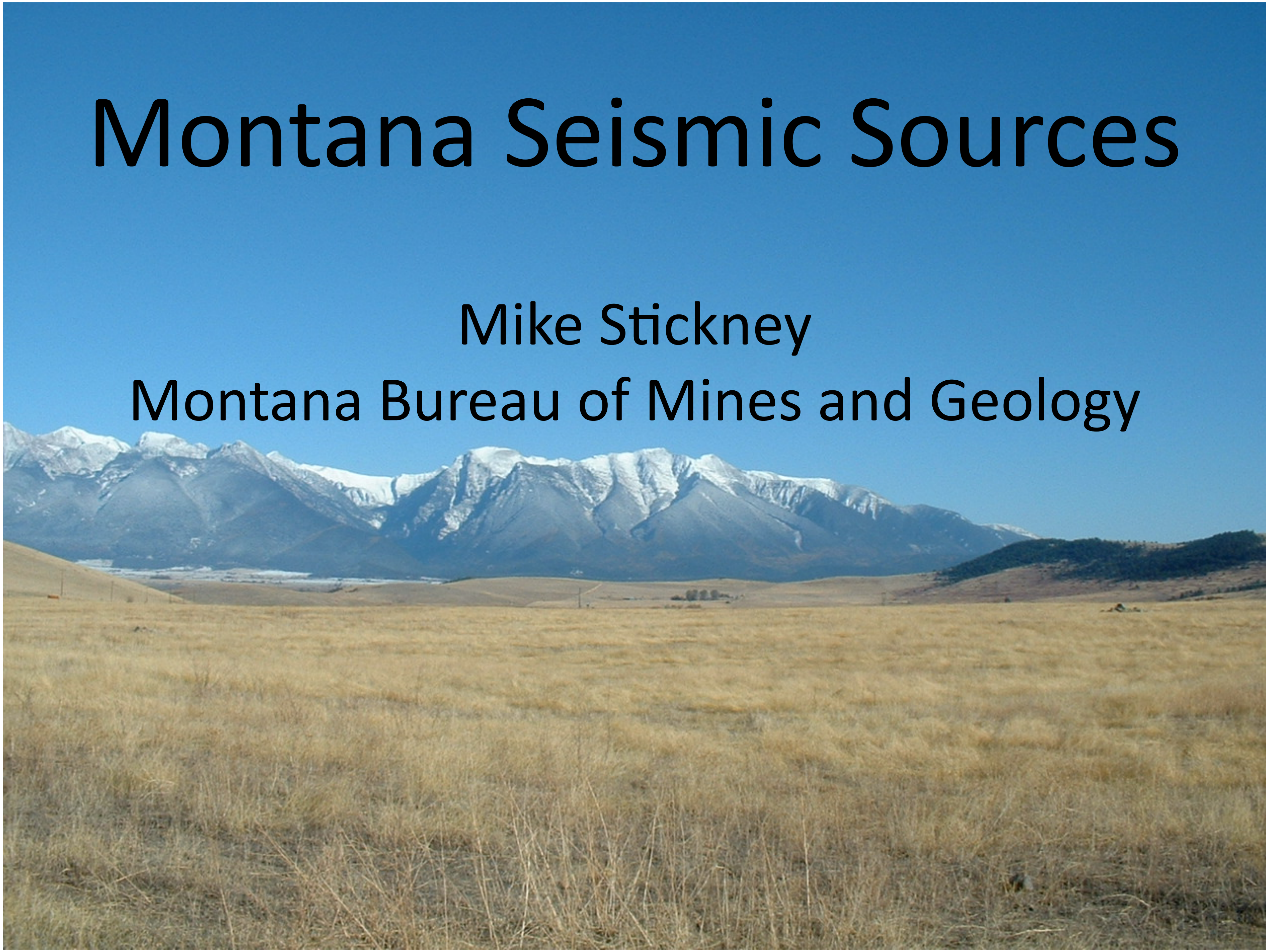
Acknowledgments

Mike Stickney (MBMG)

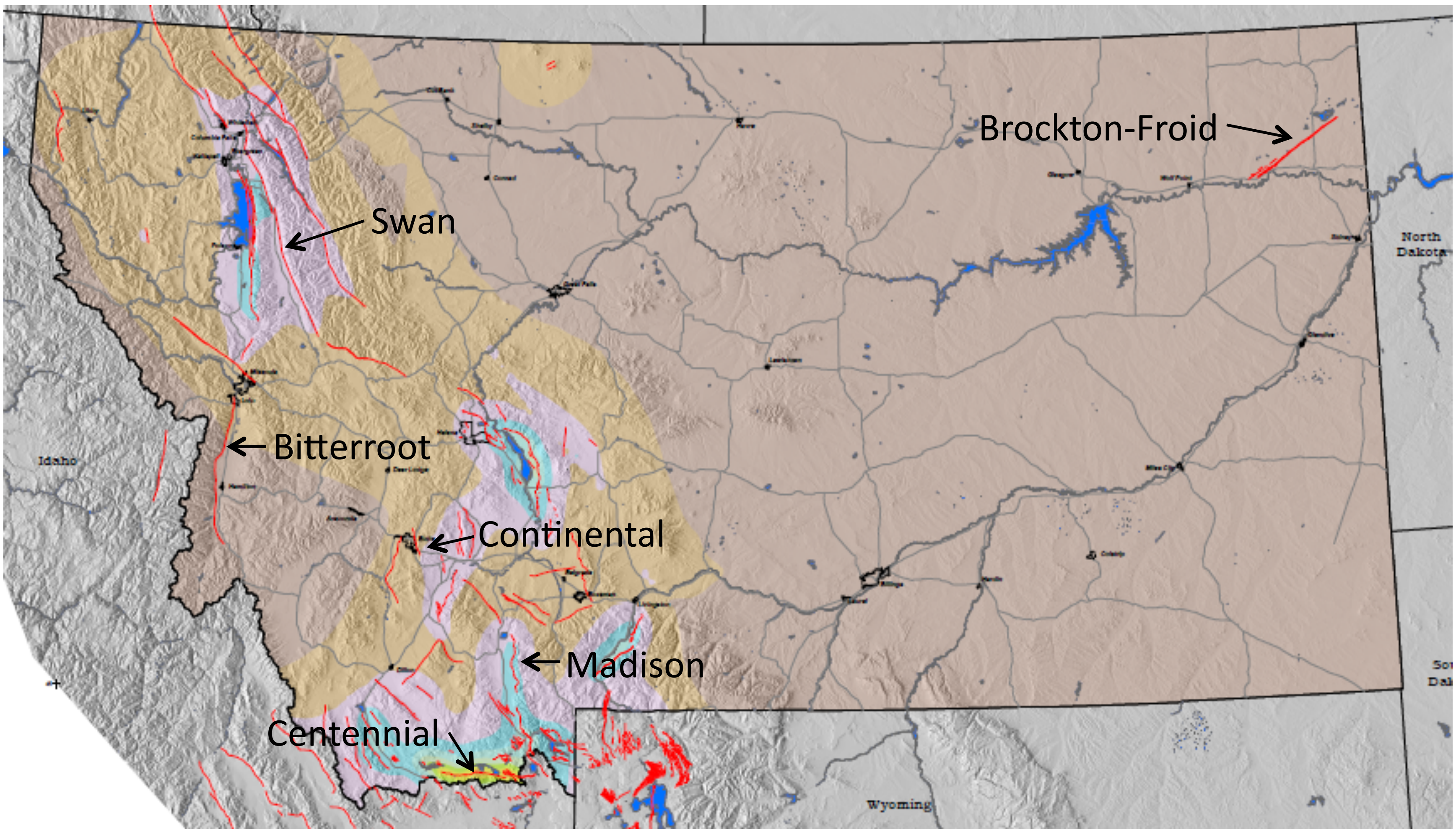
Glenn Thackray (ISU)

Kris Pankow (UUSS)

Mike Hylland (UGS)

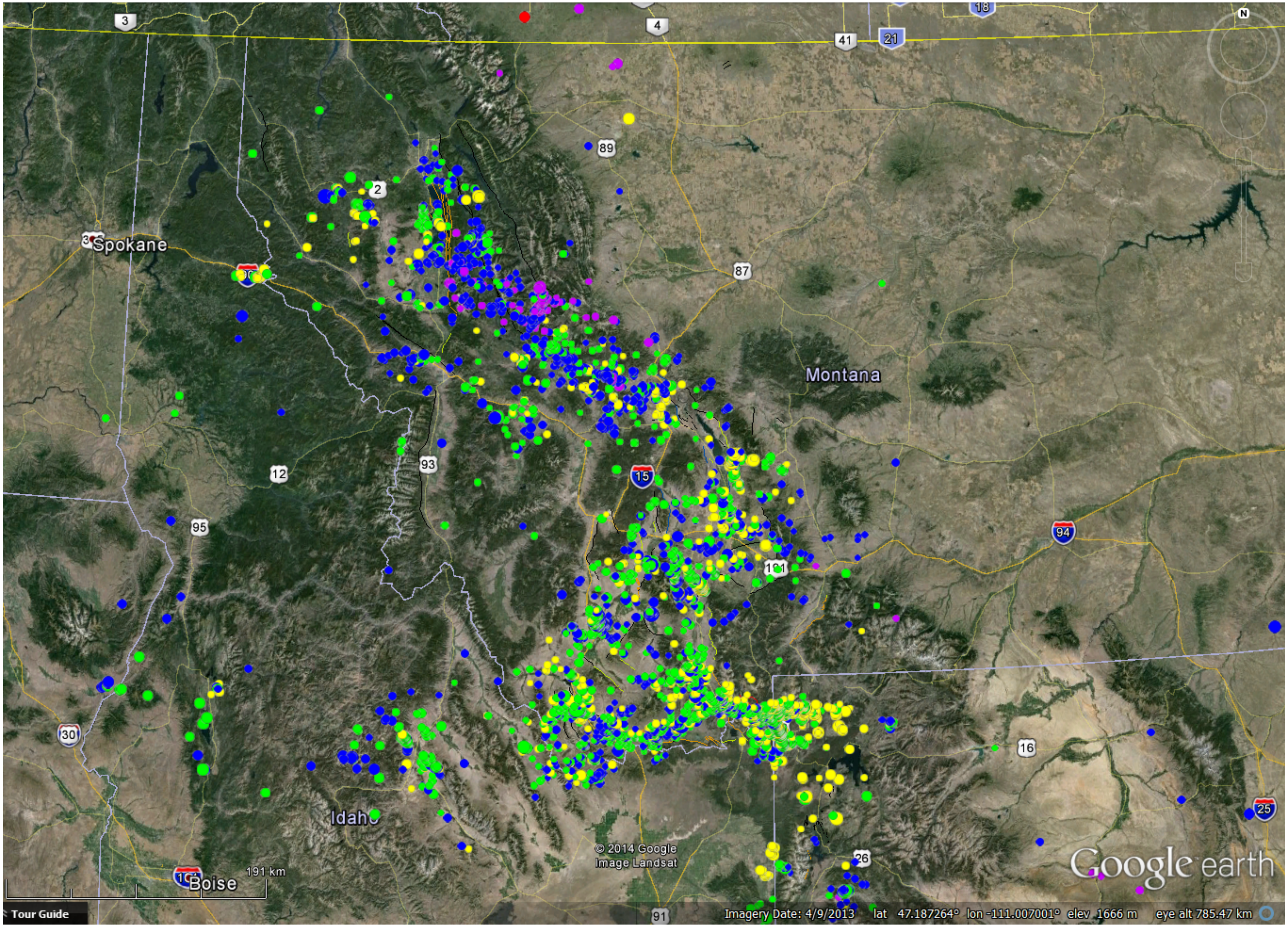

Montana Seismic Sources
Mike Stickney
Montana Bureau of Mines and Geology

PGA 2% in 50 years



Swan Fault

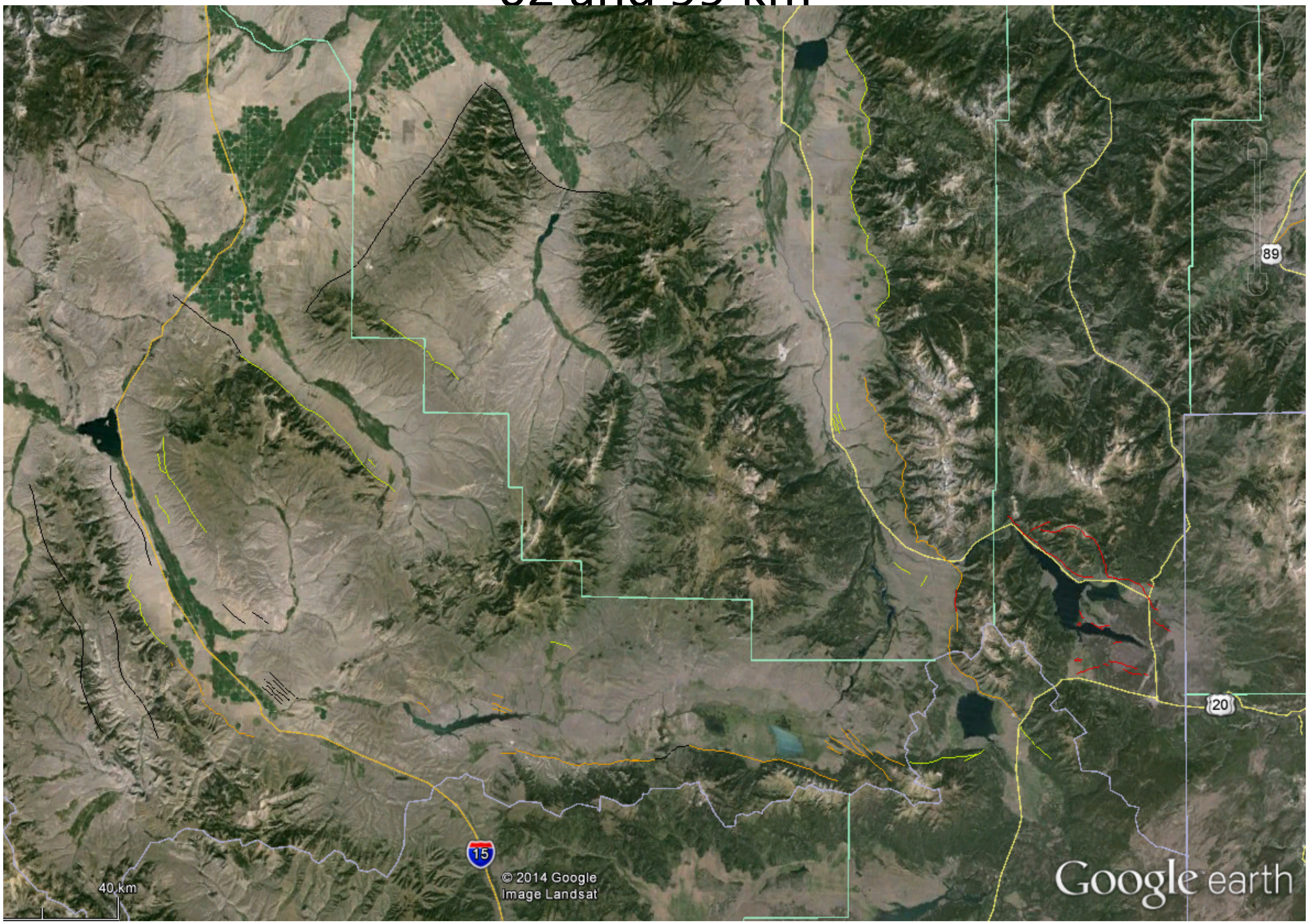
156 km long

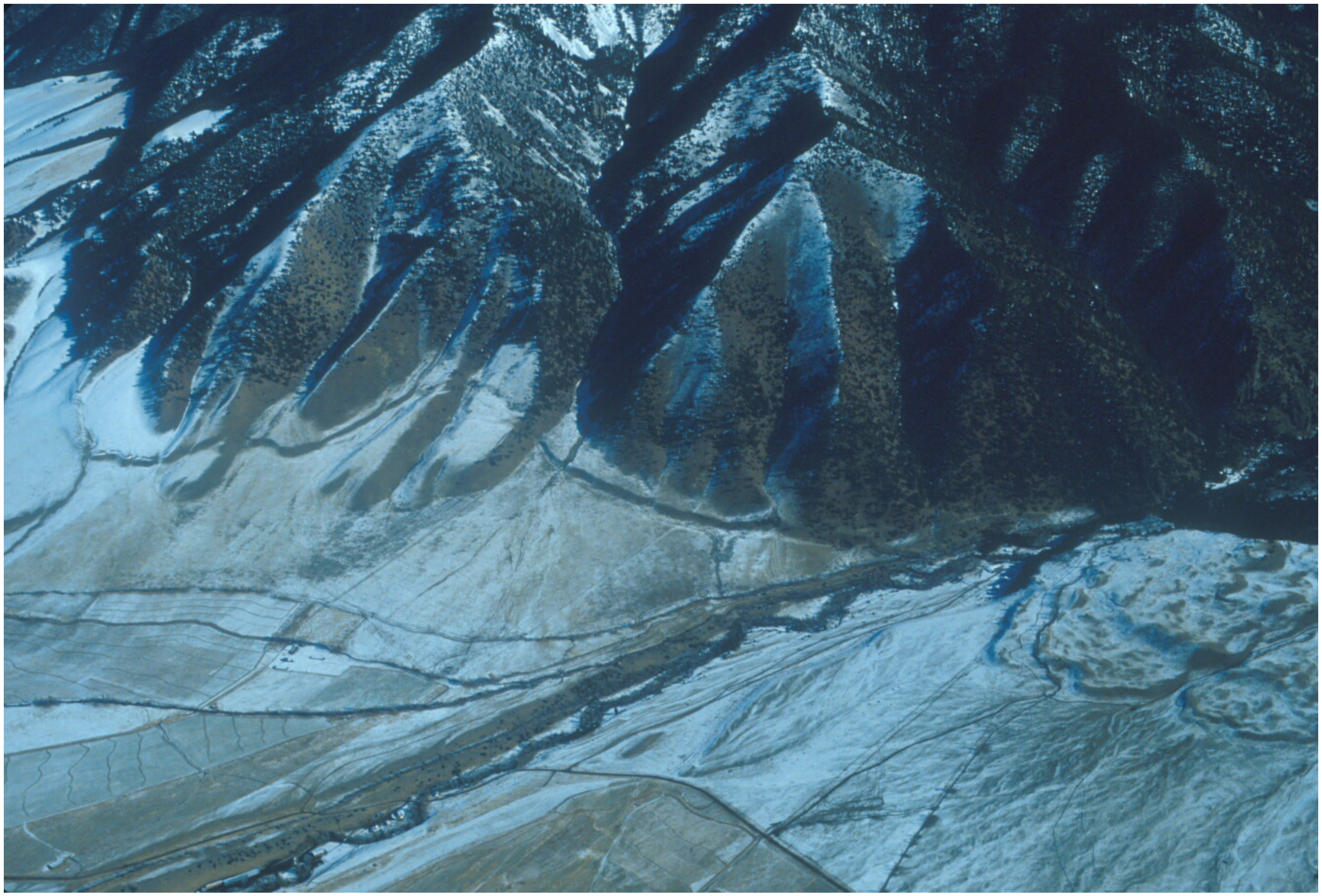


Spokane
Montana
Idaho
Boise
191 km
© 2014 Google
Image Landsat
Google earth
Tour Guide
Imagery Date: 4/9/2013 lat 47.187264° lon -111.007001° elev 1666 m eye alt 785.47 km

Centennial and Madison faults

62 and 99 km





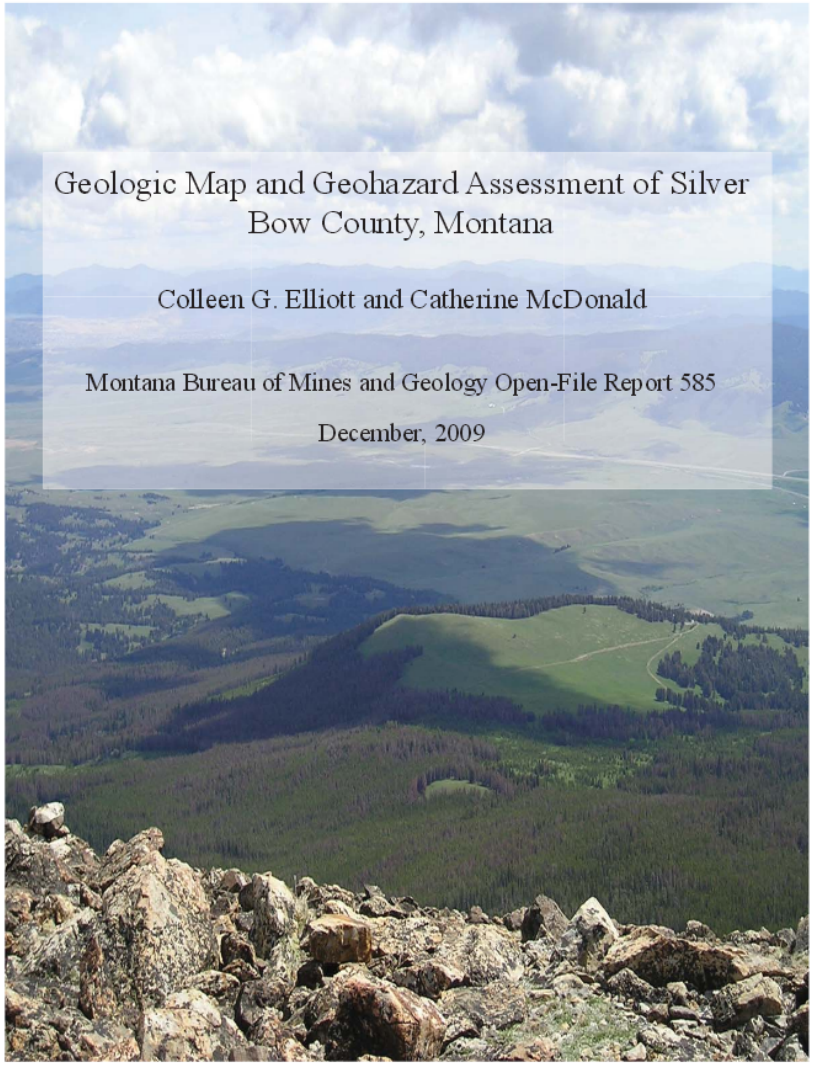
Continental Fault

18 km long

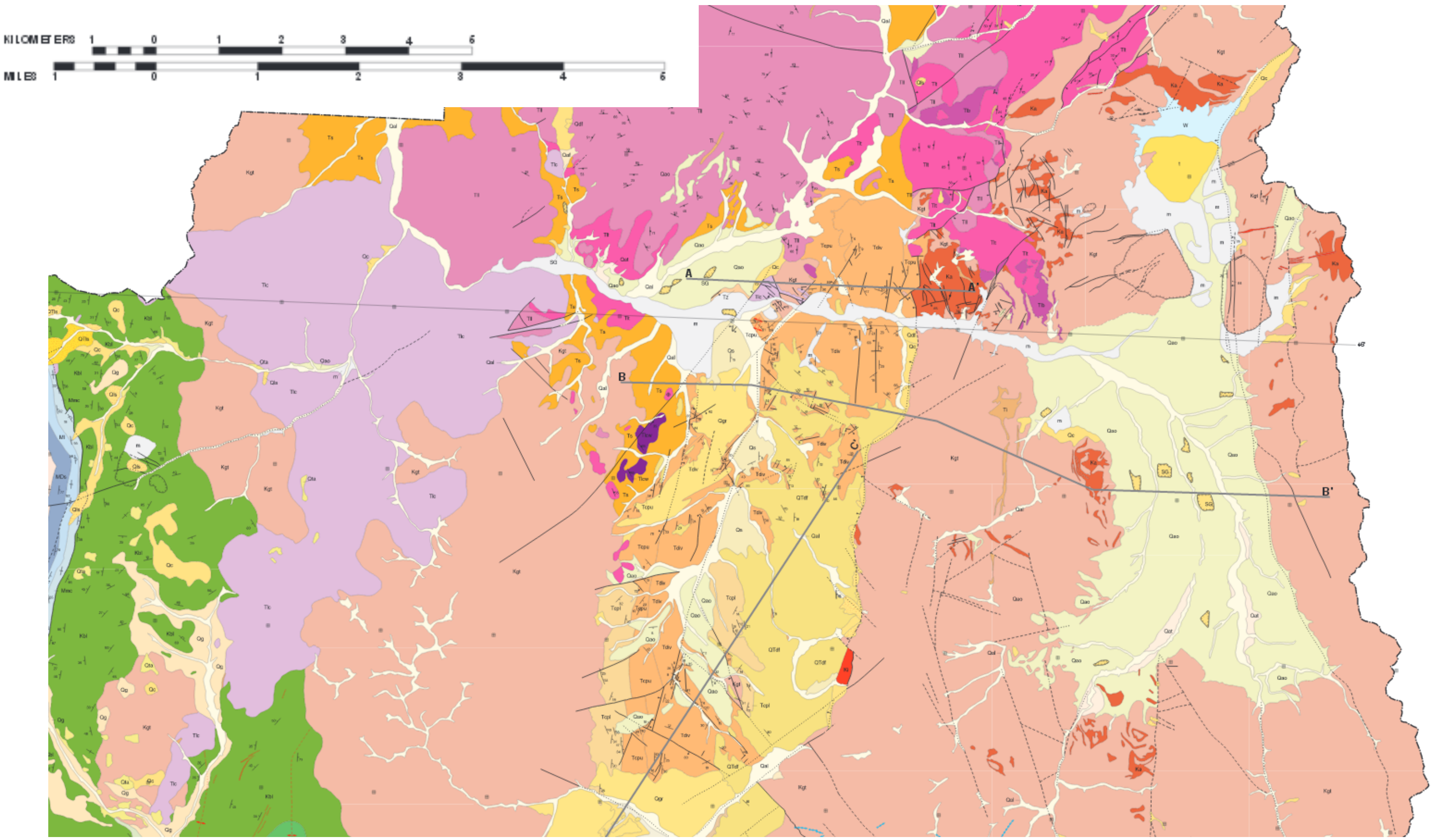
Continental Fault exposed in north wall of the Continental Pit

Continental Fault looking north

FEMA Sponsored Project

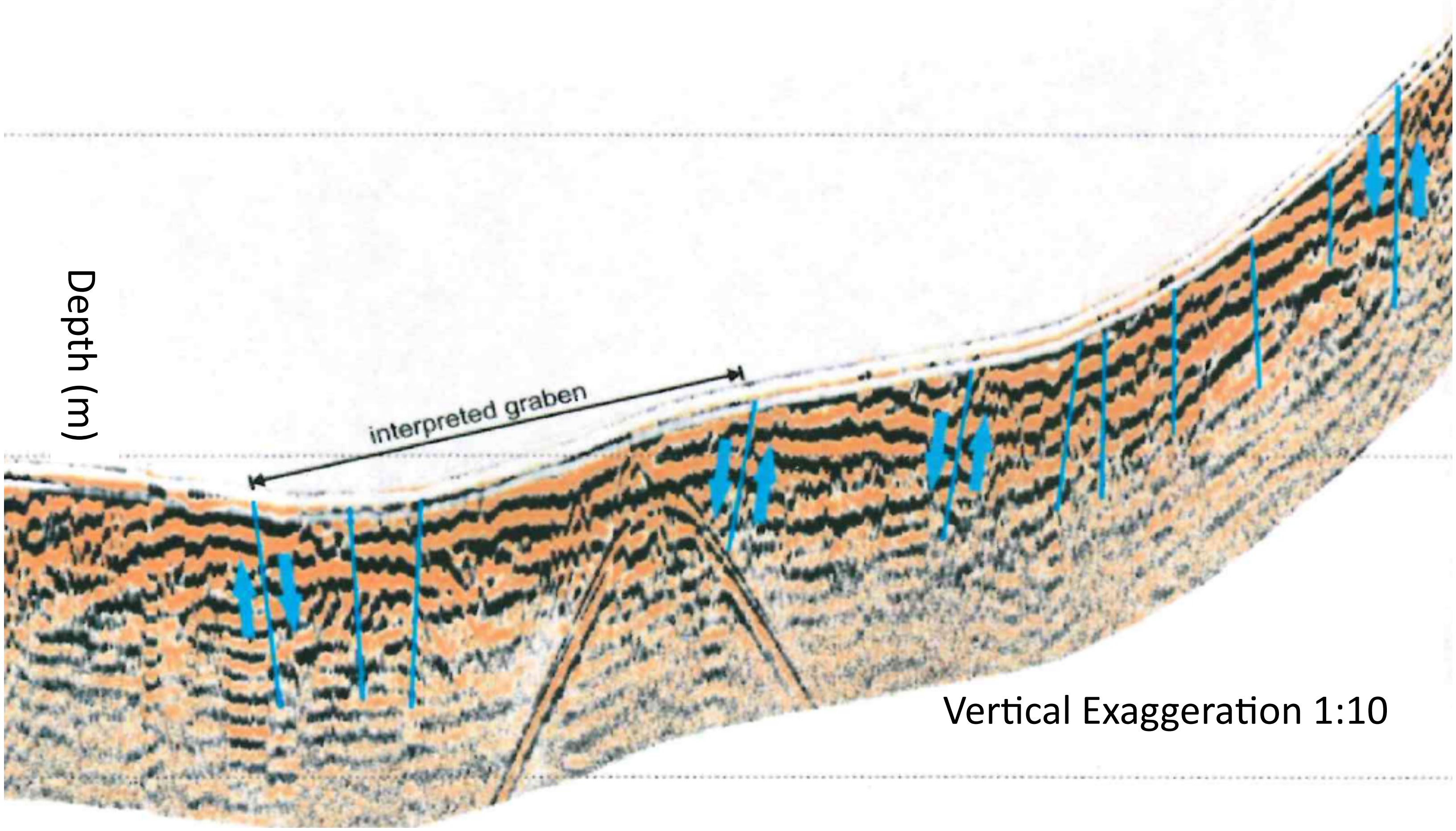


Geologic Map of Butte and Environs



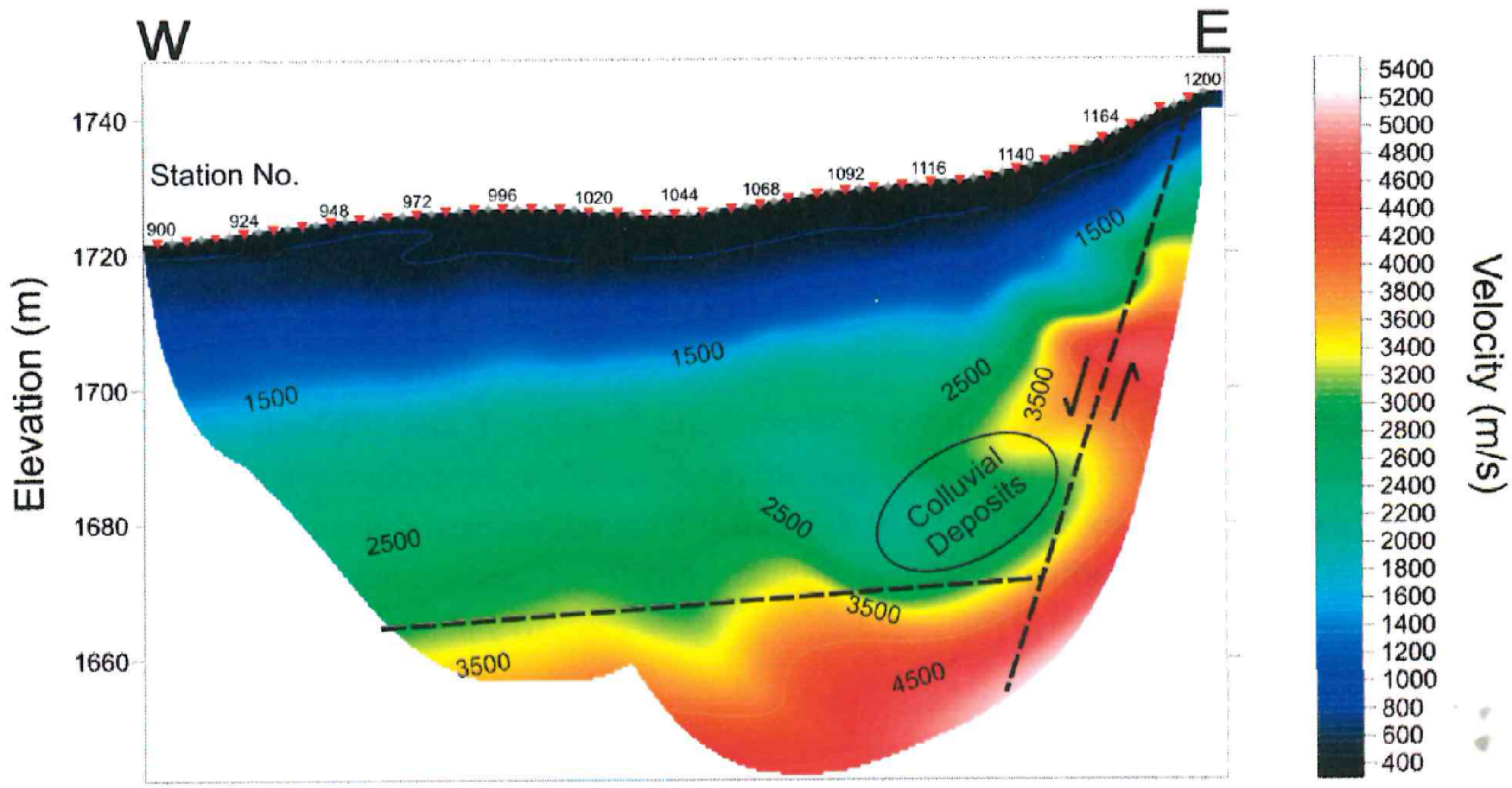
Ground Penetrating Radar Survey

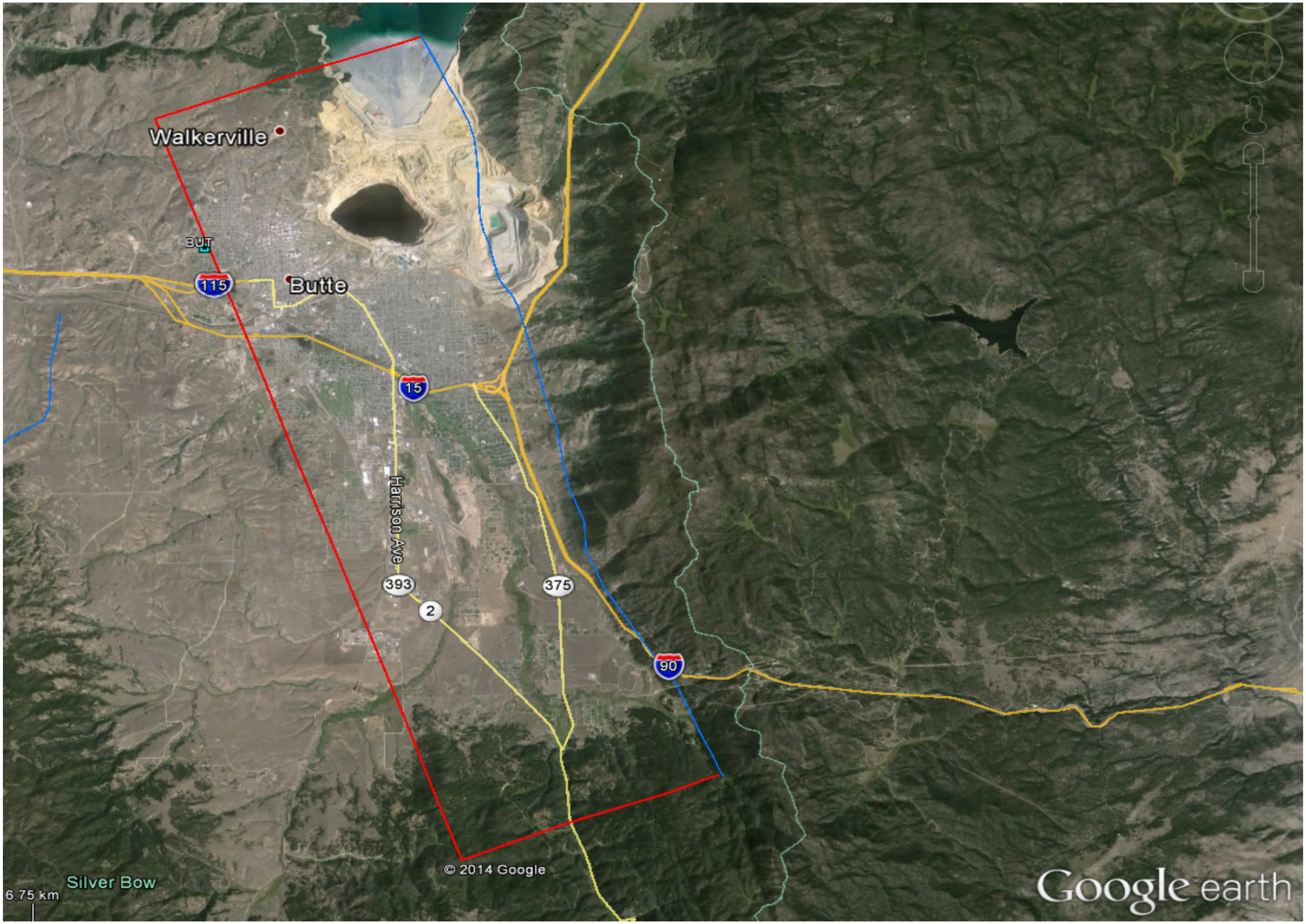
Ground Penetrating Radar Interpretation



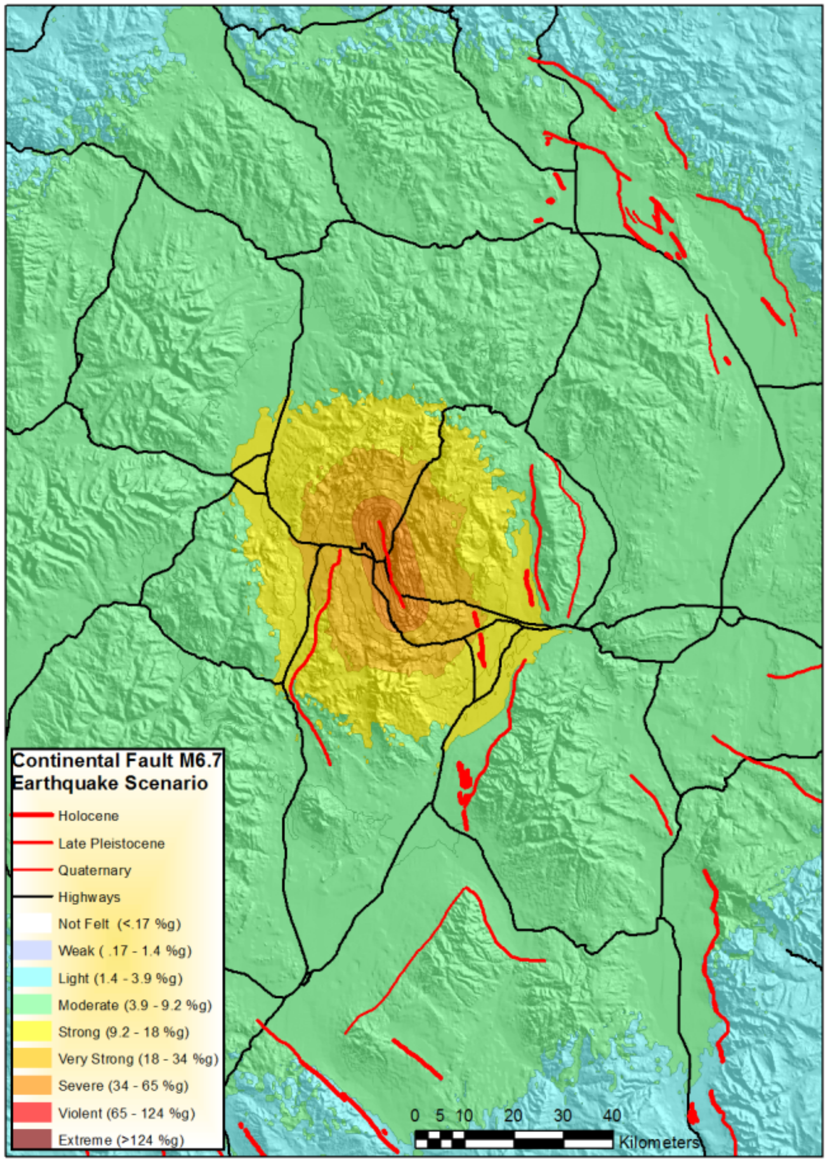
Seismic Refraction Tomography Survey

Seismic Refraction Tomography Results




Walkerville
BUT
Butte
115
15
Harrison Ave
393
2
375
90
Silver Bow
6.75 km
© 2014 Google
Google earth

M 6.7 Continental Fault Earthquake Scenario



Hazus-MH: Earthquake Event Report

Region Name: Continental Fault Scenario - M 6-7

Earthquake Scenario: M 6.7 Continental Fault ShakeMap Scenari

Print Date: October 07, 2014

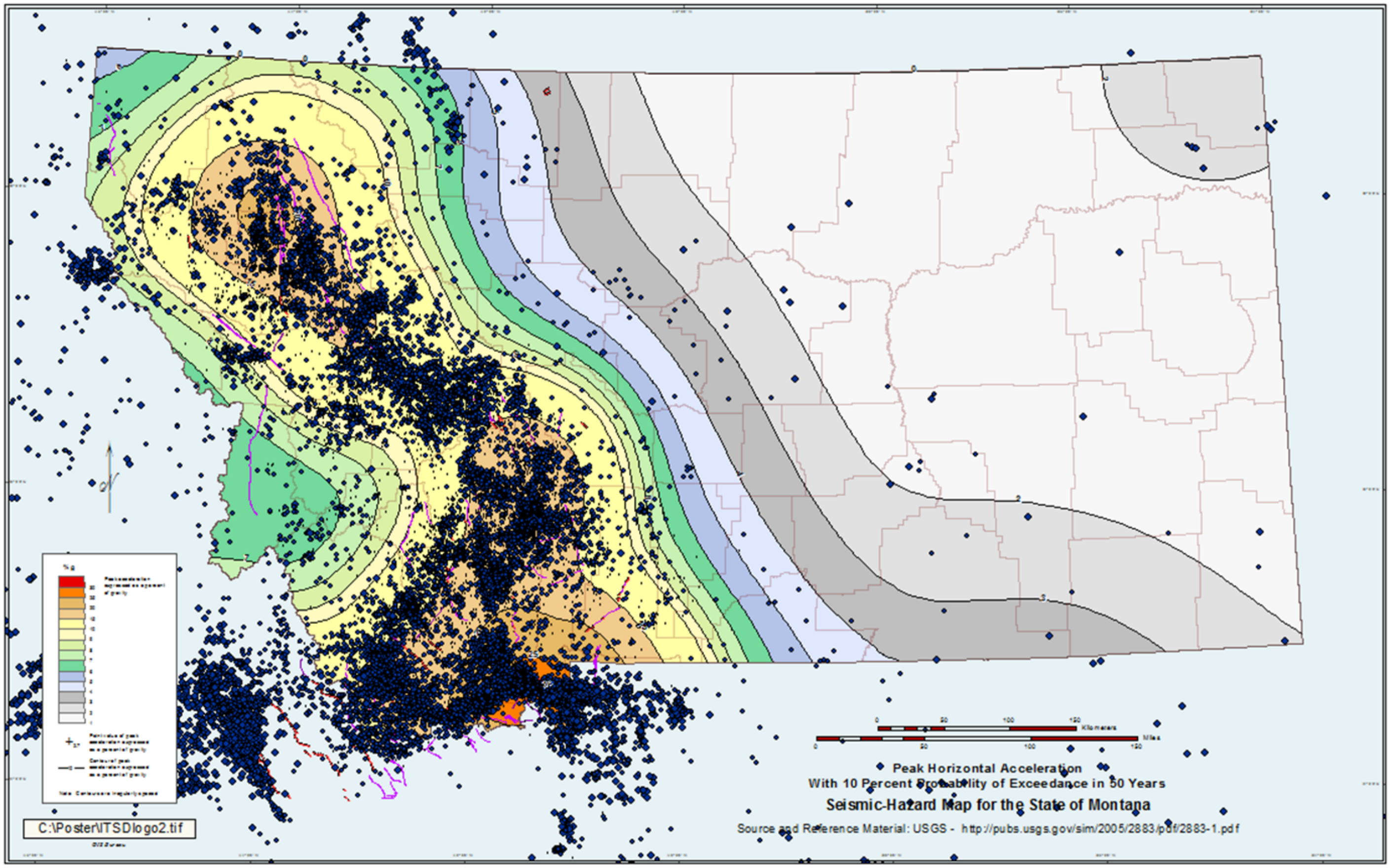
Debris generation	0.32 M tons = 12,640 truck loads
Casualties	8-46 (time of day dependent)
Building related economic losses	$833 M
Utility system economic losses	$415 M
Transportation System economic losses	$16 M
Total economic losses	$1.26 Billion

Totals only reflect data for those census tracts/blocks included in the user's study region.

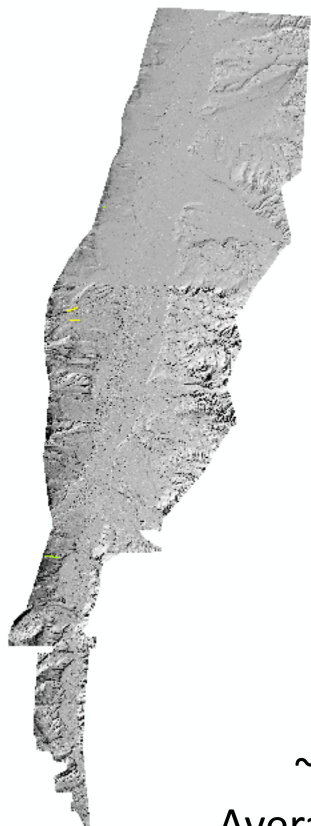
Disclaimer:
The estimates of social and economic impacts contained in this report were produced using Hazus loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific earthquake. These results can be improved by using enhanced inventory, geotechnical, and observed ground motion data.

Bitterroot Fault

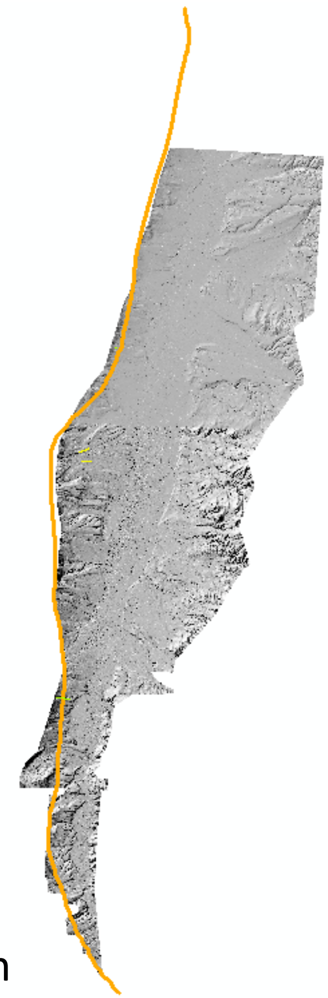
98 km long


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
% g
0 50 100 150 Kilometers
0 50 100 150 Miles
C:\Poster\ITSDlogo2.tif

Bitterroot Valley LiDAR coverage

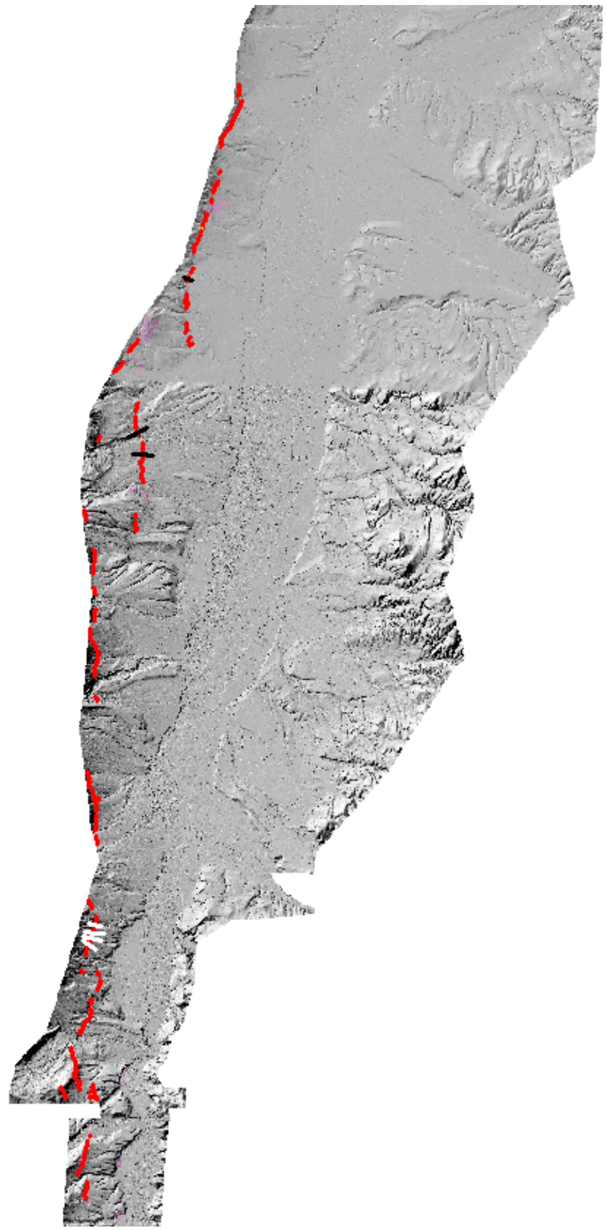


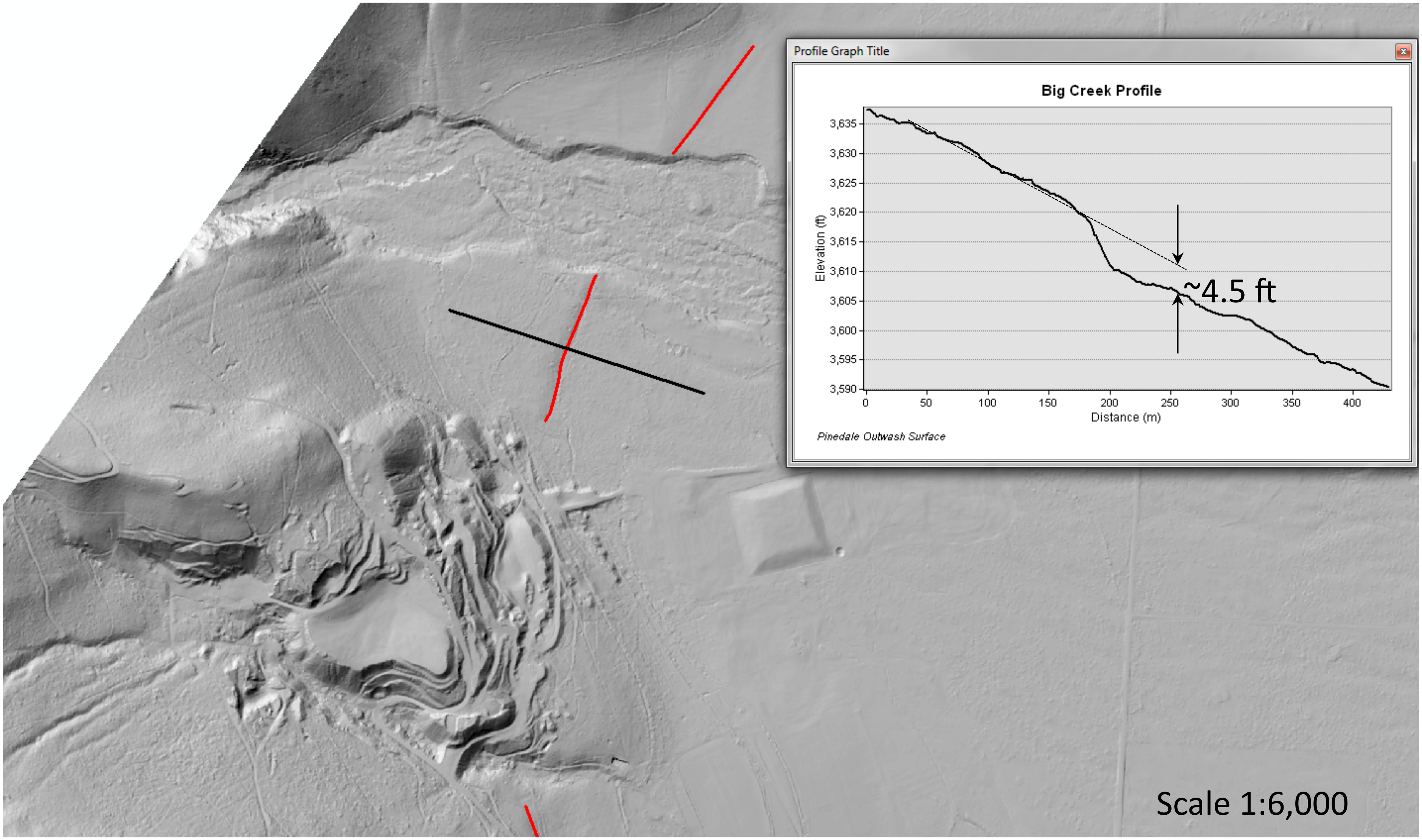
25 km

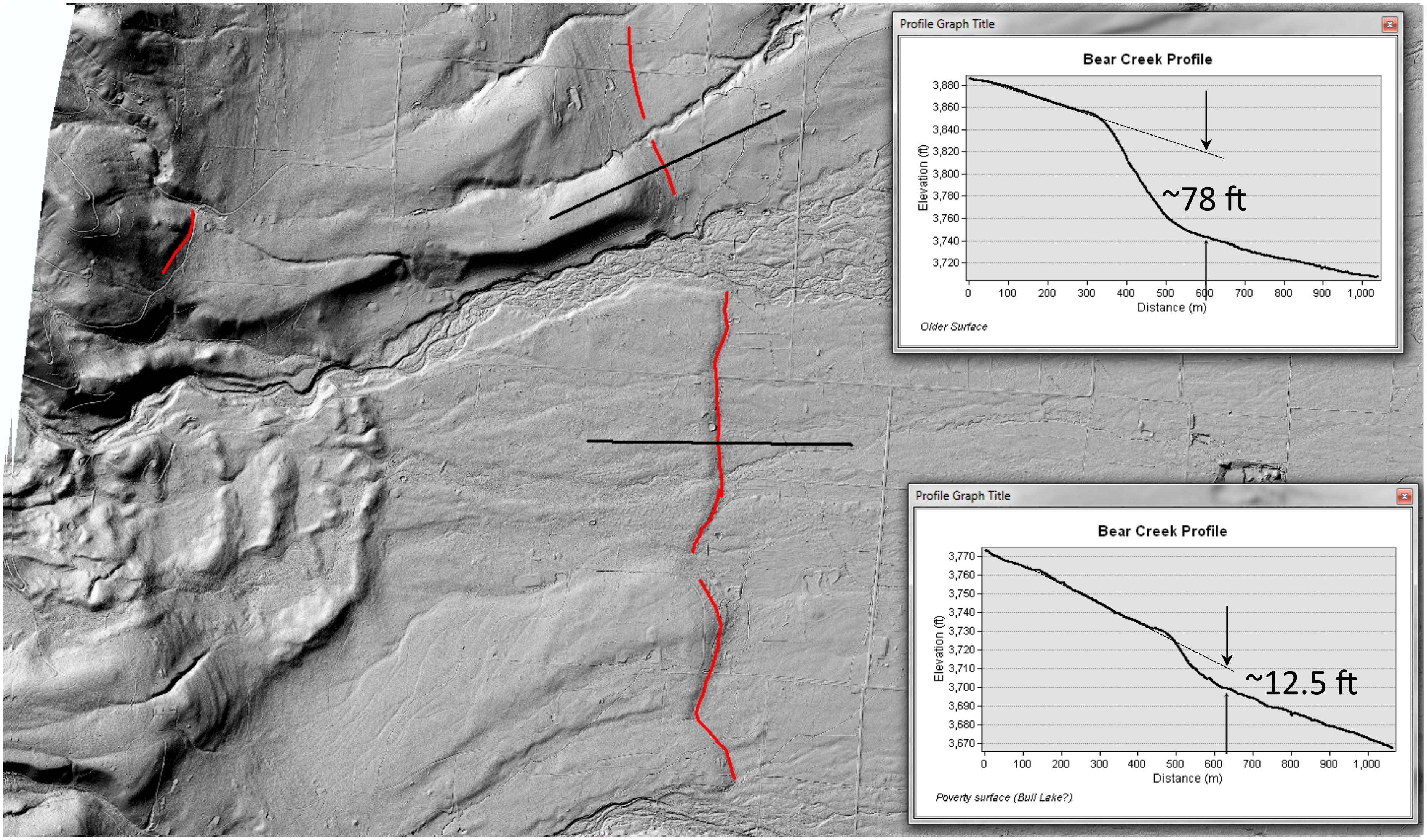


1,048 km^2
~4.5 x 10^9 LiDAR points
Average relative accuracy 6 cm

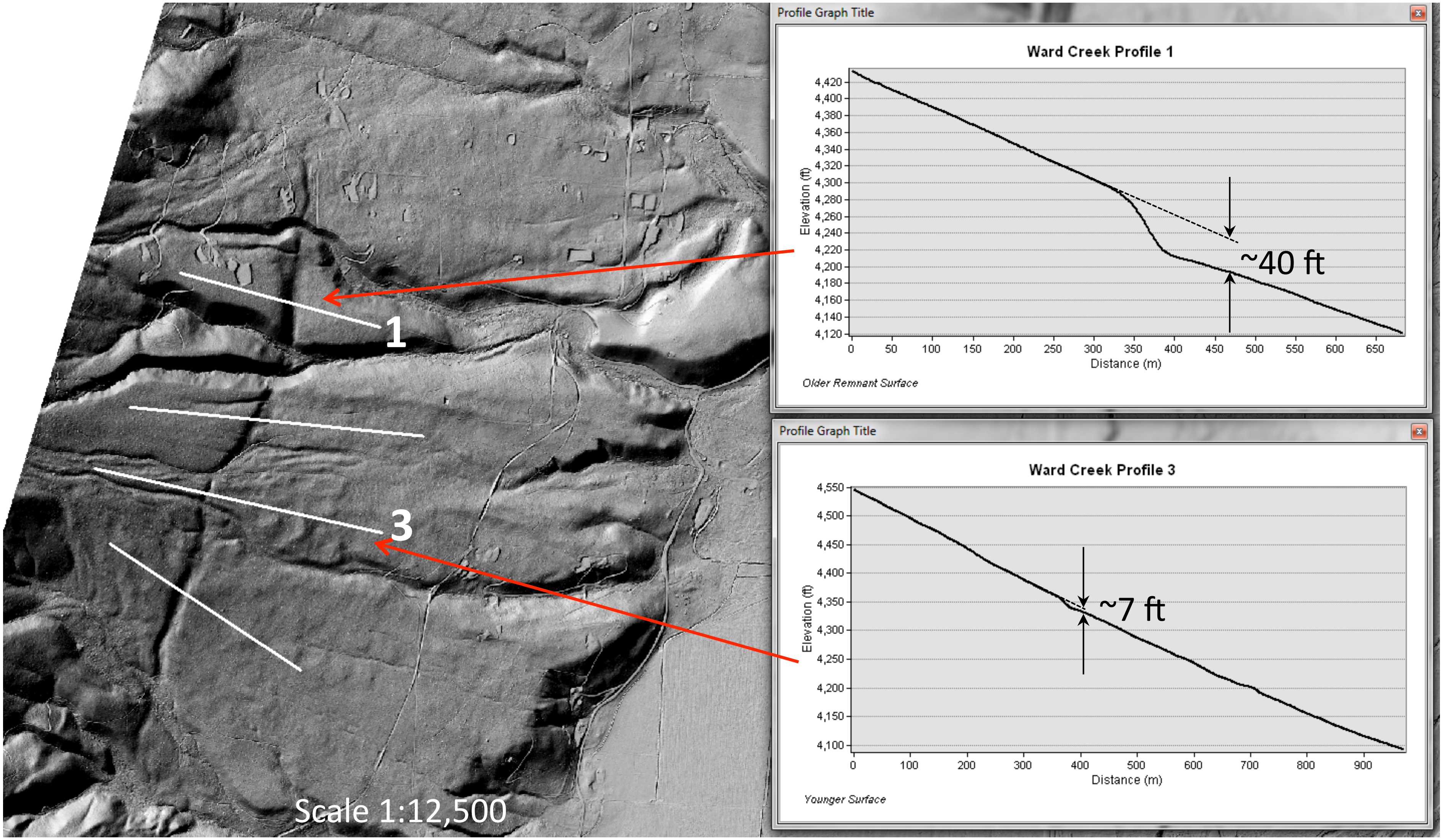
Late Quaternary fault scarps identified in LiDAR data



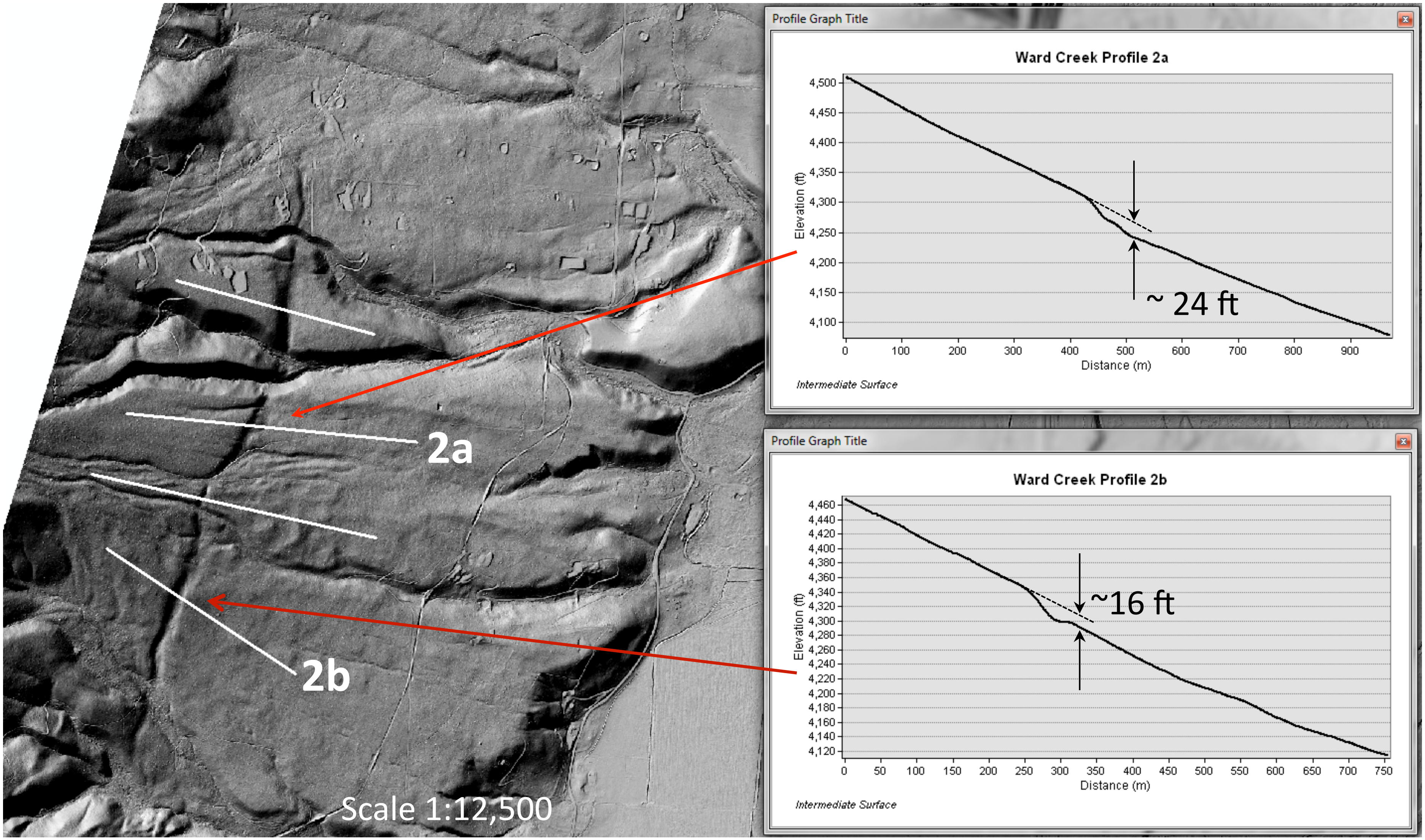

Profile Graph Title
Big Creek Profile
Elevation (ft)
3,635
3,630
3,625
3,620
3,615
3,610
3,605
3,600
3,595
3,590
0
50
100
150
200
250
300
350
400
Distance (m)
~4.5 ft
Pinedale Outwash Surface
Scale 1:6,000



Profile Graph Title
Bear Creek Profile
Elevation (ft)
3,880
3,860
3,840
3,820
3,800
3,780
3,760
3,740
3,720
~78 ft
0
100
200
300
400
500
600
700
800
900
1,000
Distance (m)
Older Surface
Profile Graph Title
Bear Creek Profile
Elevation (ft)
3,770
3,760
3,750
3,740
3,730
3,720
3,710
3,700
3,690
3,680
3,670
~12.5 ft
0
100
200
300
400
500
600
700
800
900
1,000
Distance (m)
Poverty surface (Bull Lake?)



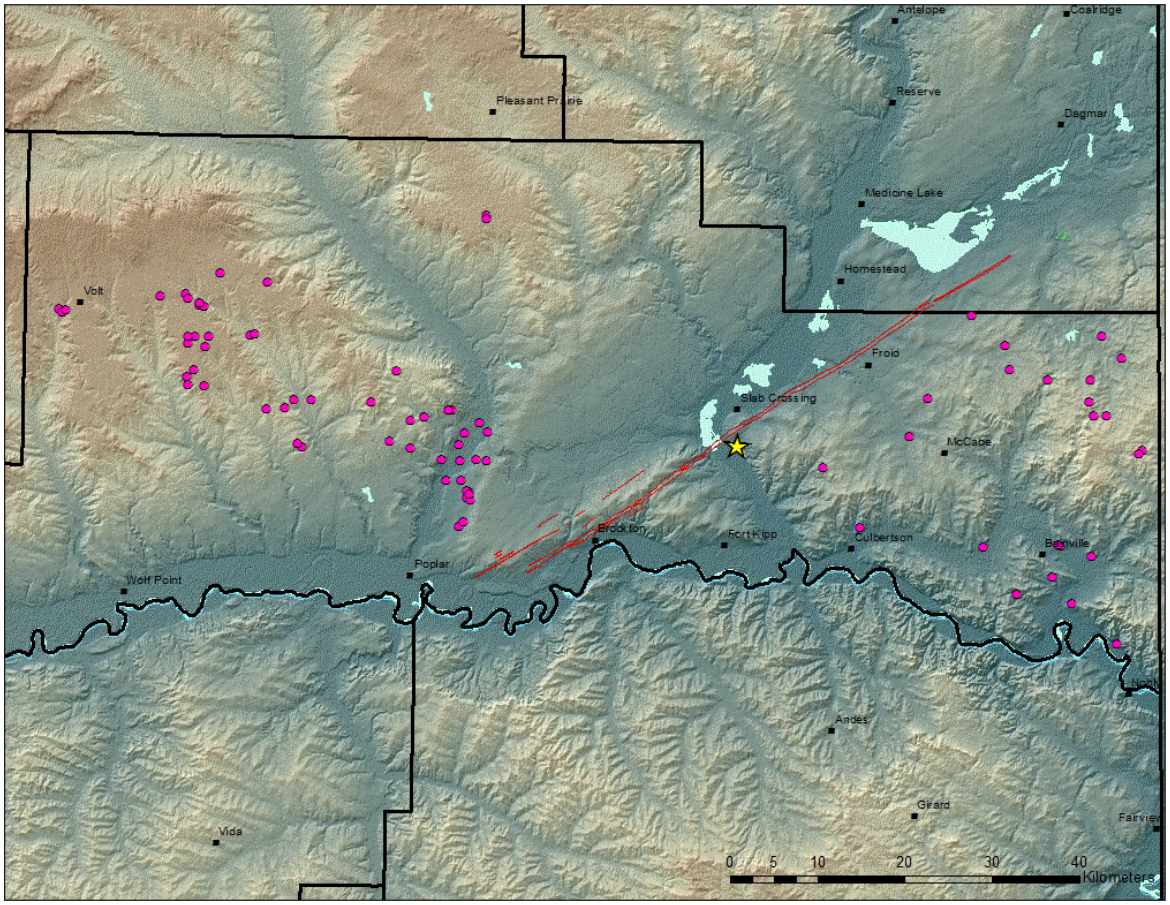
1
3
Scale 1:12,500
Profile Graph Title
Ward Creek Profile 1
Elevation (ft)
Distance (m)
~40 ft
Older Remnant Surface
Profile Graph Title
Ward Creek Profile 3
Elevation (ft)
Distance (m)
~7 ft
Younger Surface



2a
2b
Scale 1:12,500
Profile Graph Title
Ward Creek Profile 2a
Elevation (ft)
Distance (m)
Intermediate Surface
~ 24 ft
Profile Graph Title
Ward Creek Profile 2b
Elevation (ft)
Distance (m)
Intermediate Surface
~16 ft

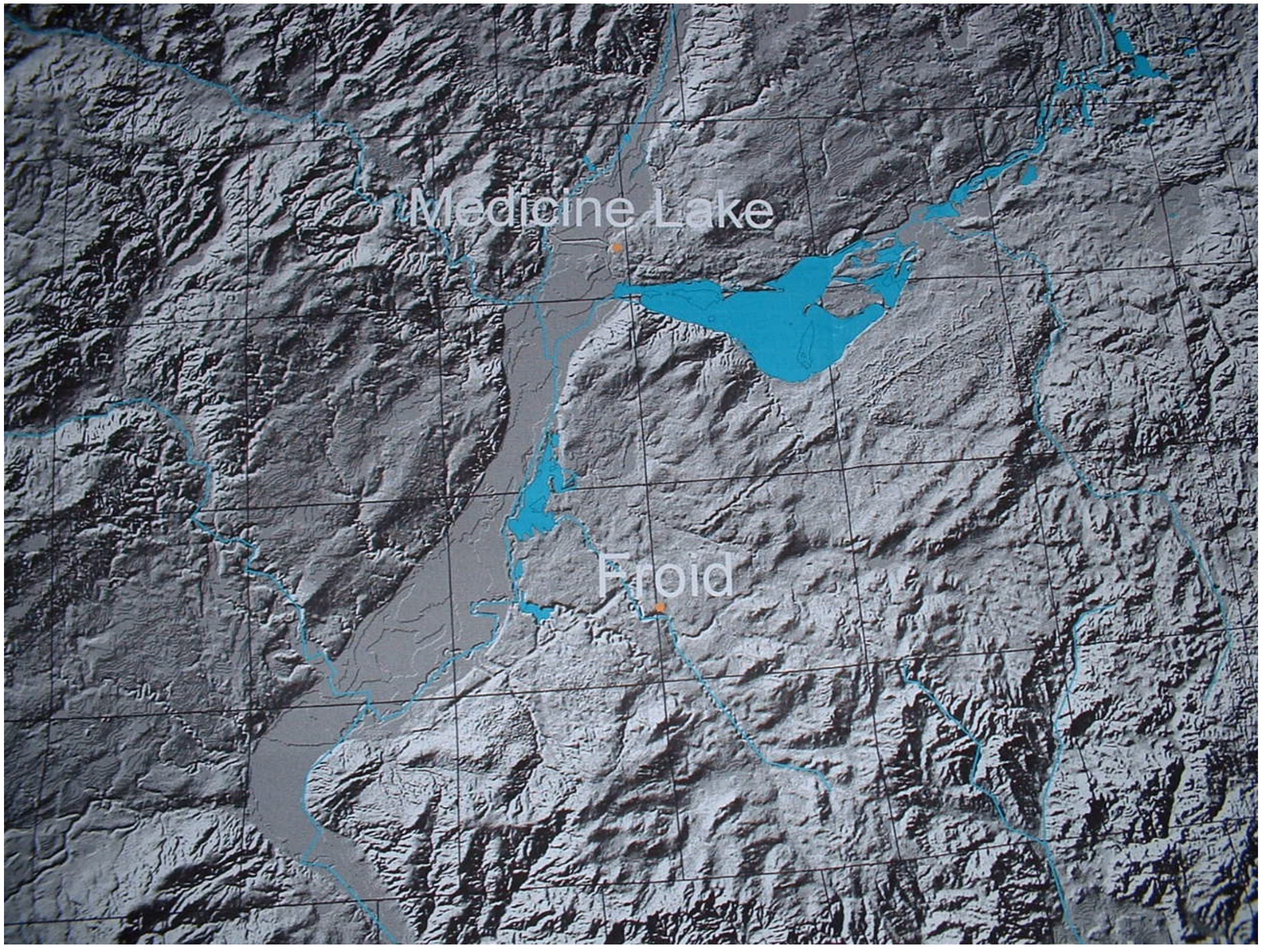

South of Ward Creek

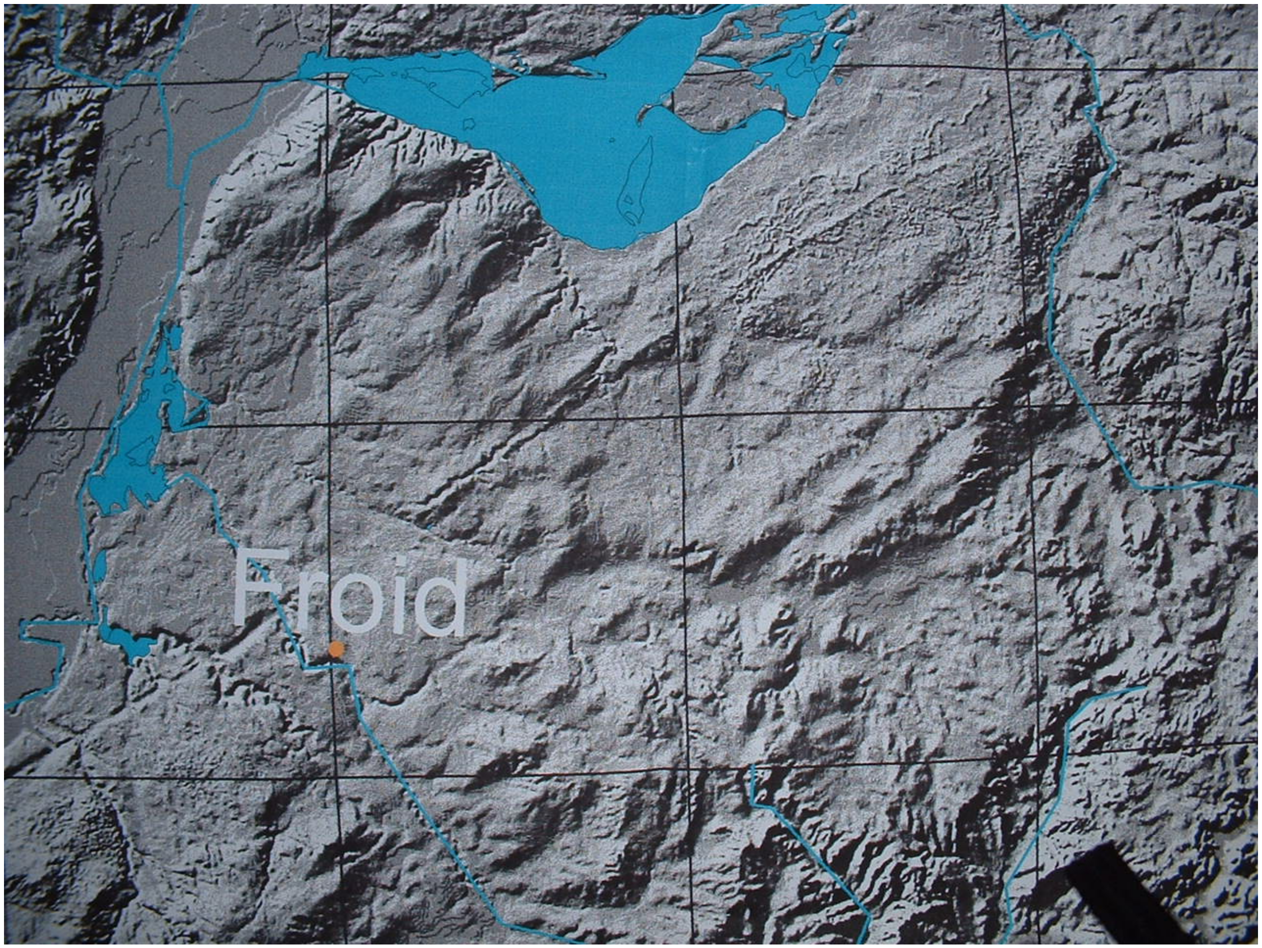
Feb 25, 2014 M 3.8 earthquake and active injection wells



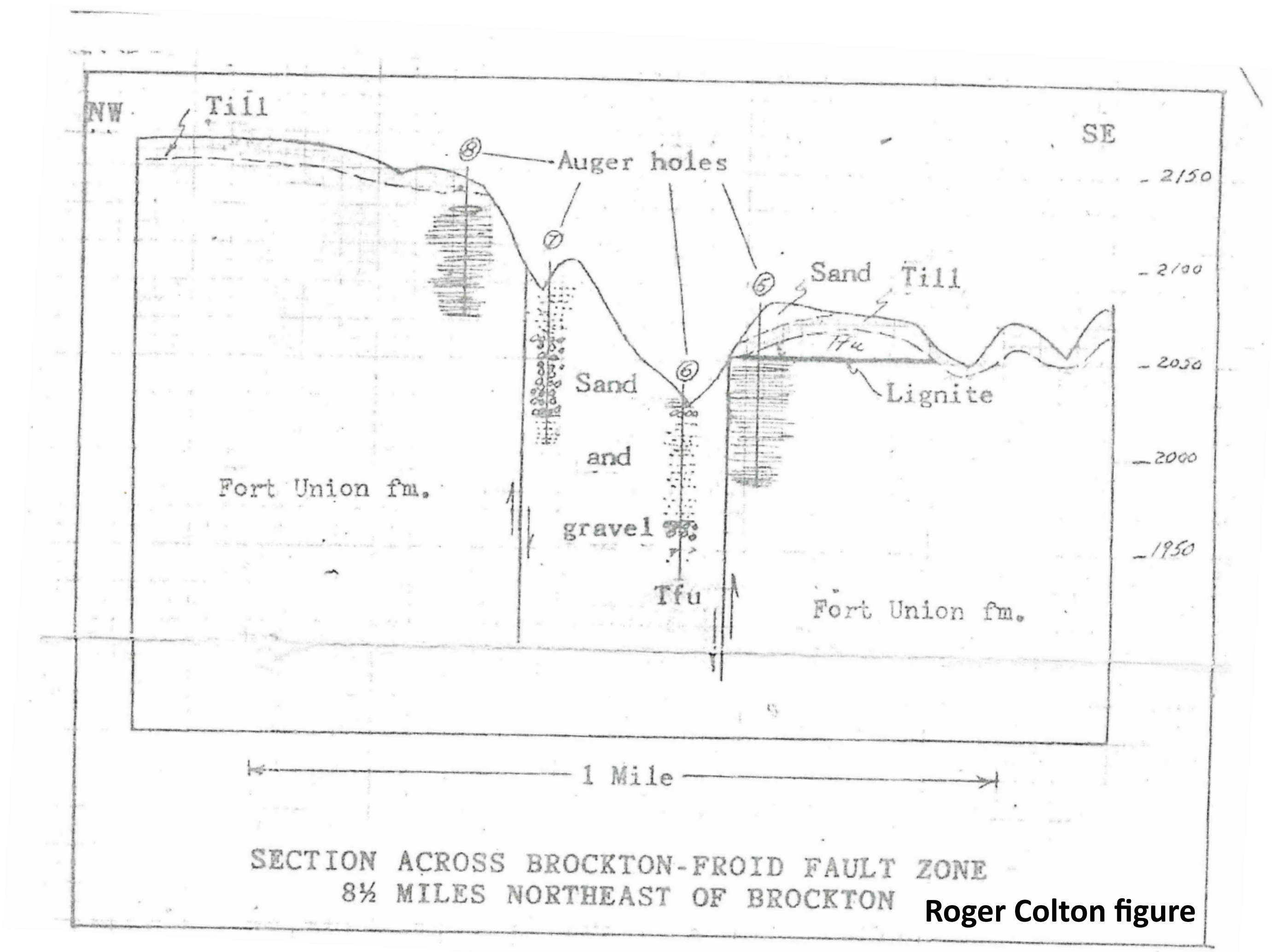
Brockton-Froid fault zone

81 km long




Froid

Auger hole transect across the Brockton-Froid fault zone



Roger Colton figure

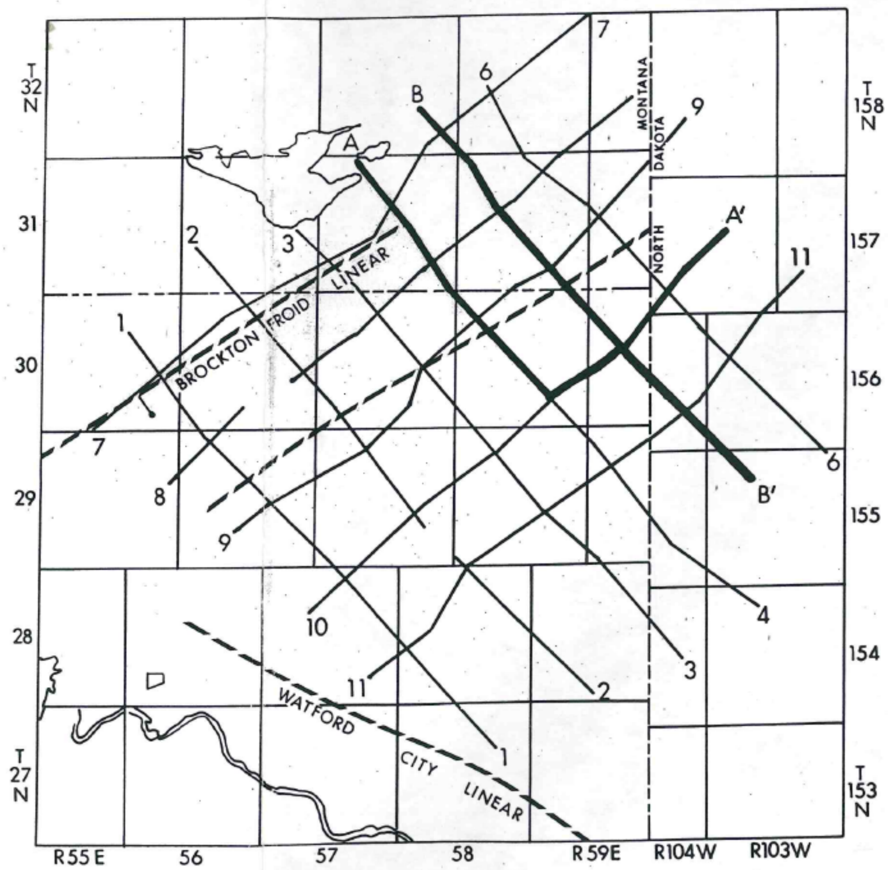


Fig.1

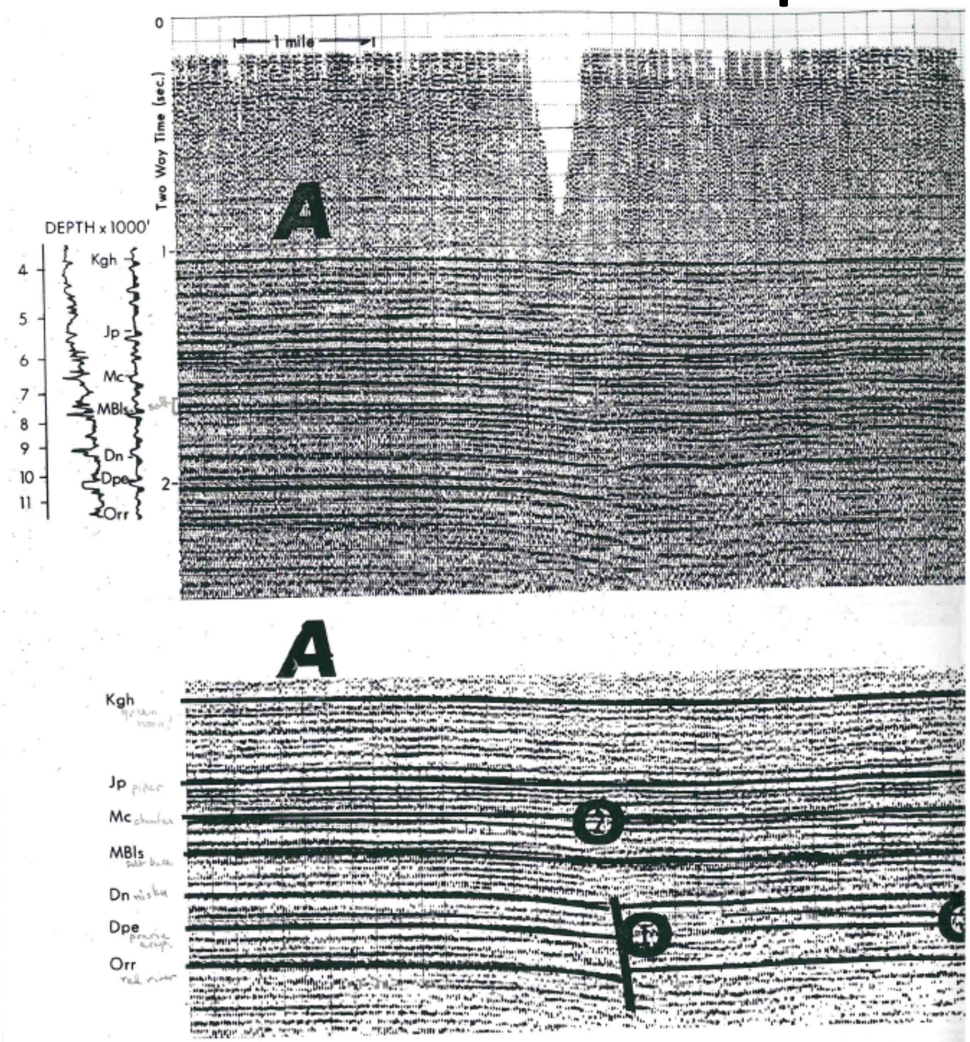
Seismic Lines Available For Solution Study

Seismic Lines Presented In A-A′, B-B′

LIMIT OF PRAIRIE SALT DEPOSITION IN WILLISTON BASIN, N.W. NORTH DAKOTA & N.E. MONTANA

Rogers and Mattox, 1985

Devonian and Ordovician formations faulted at depth



The Holocene 17,8 (2007) pp. 1155–1169

Episodic struvite deposits in a Northern Great Plains flyway lake: indicators of mid-Holocene drought?

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A HOLOCENE RESEARCH PAPER

Abstract: A series of 34 layers of struvite (hydrous Mg-ammonium-phosphate) were deposited in laminated sediments of Kettle Lake, North Dakota, in the Northern Great Plains, USA. Sedimentologic, mineralogic and nitrogen isotopic evidence suggest that struvite was deposited during nutrient-enriched eutrophication events within a Mg-rich lacustrine environment. The struvite layers are dispersed between 4650 and 8700 cal. yr BP, with particularly high frequency between 8068 and 8700 cal. yr BP. The youngest struvite layer dates to 2734 cal. yr BP. Key features of the struvite-forming events were (a) relatively low water stage and consequent elevated water salinity associated with the dry mid Holocene, (b) disappearance of most lakes and wetlands in the region, and (c) focused, but brief, visitations by large populations of migratory waterfowl. The lack of more frequent occurrence of struvite is ascribed to the rarity with which this combination of conditions was achieved, in combination with difficulty of preservation for this salt. ^{15}N isotopes in struvite (mean 7.51‰) are heavy relative to ^{15}N in sediment and also extremely uniform over time. The isotopes are interpreted to reflect a waterfowl waste source without extensive NH_4 volatilizaton. The timing of the struvite events does not closely correspond to century-scale mid-Holocene drought cycles inferred from oscillating aragonite concentrations, although there is a weak preferred occurrence in the humid phase of these cycles. Thus the struvite events are ephemeral prairie features of this generally arid period but tend not to occur at precisely the most arid intervals.

Key words: Struvite, Northern Great Plains, limnogeology, waterfowl, prairie pothole, palaeoclimate, drought indicators, Holocene.

Introduction

Palaeoecological studies of lake sediments have long focused on fossils, including those of diatoms, ostracodes, pollen and plants. With the exception of fish, vertebrate fossils are not commonly well represented in lake sediments. Although vertebrate fossils are abundant in certain terrestrial deposits – for example, caves – the Holocene fossil record for waterfowl, a common resident of lakes, is meager. Nonetheless, the nature of waterfowl populations in lakes has likely varied over time in response to climatic and limnologic change, and notions of this dynamic would add to the general picture of landscape response to climate. This paper describes an unusual geochemical proxy that we believe relates to waterfowl palaeoecology in Holocene sediments from Kettle Lake, North Dakota. We draw observations from lake sediments to infer ecological conditions in the arid mid Holocene (4650 to 8700 cal. yr BP) within the Northern Great Plains (NGP).

*Author for correspondence (e-mail: jdonovan@wvu.edu)

Study area and sediment sampling

Kettle Lake (48.6070°N, 103.6241°W, 605 m a.s.l.) is located approximately 50 km south of the USA–Canada border and just east of the North Dakota–Montana state border (Figure 1). The modern lake is small (2.2 ha) and lies within a roughly circular depression ~10 m below the surrounding landscape (Figure 1). As the name of the lake implies, the depression is a glacial kettle. It lies near an esker channel (Witkind, 1959) that trends NE–SW within a broad N–S-trending glaciofluvial outwash sequence deposited near the end of the Late Wisconsin glaciation. Maximum depth of the lake is ~10 m, and the lake has a simple 'coffee cup' morphometry. Based on depth of sediment, the lake would have been on the order of 30 m deep in the early Holocene, one of the deepest in the region. The only deeper lake within 100 km is Brush Lake, which lies in a 34 m deep depression ~50 km to the west. Bouldery fluvial deposits are exposed in a gravel quarry along the NW side of the lake. The lake is groundwater-dominated, in the sense of Shapley *et al.* (2005), in that it has no perennial or

10.1177/0959683607082556

Results

Kettle Lake sediments

The sediments of the bottom 16.5 m of sediment (excluding the slump) are laminated with alternating dark and light couplets. The dark layers are composed of organic matter and detrital clastics, whereas the light layers are almost exclusively aragonite, appearing nearly blond in thicker layers. The light layers are interpreted as endogenic sediments of summer months with active phytoplankton activity in the upper water column. The dark layers are autumn-through-spring layers created by settling of endogenic organic matter and allogenic clastic materials. Individual couplets as thin as 1 mm and up to >10 mm may be recognized at different depths in the core, although at some depths layering is less distinct. Bioturbation of bottom sediments is distinctly absent. While it is tempting to consider the couplets as 'varves', the continuity of layering is discontinuous because of multiple causes, including sediment slumping, thin or indistinct layering and other issues; thus there is no persistent usable varve chronology, even though couplets over short intervals may preserve an annual varve sequence. While not persistently annual, the laminations themselves do occur throughout the core, attesting to lack of bioturbation and persistent anoxia at the bottom of Kettle Lake throughout most or all of the Holocene.

There is a slump in lower Holocene Kettle Lake sediments at ~7500 cal. yr BP, with ~1.5 m of sediment clearly anachronous to the calibrated ^{14}C curve. Five ^{14}C dates within the slump are in stratigraphic order, and bracketed by abruptly younger dates above and below; thus the slump is ascribed to movement of a single near-intact block from shallower, steep littoral areas into the deepest part of the lake.

Struvite occurrence, mineralogy and stoichiometry

The platy euhedral mineral phase found at irregular intervals was identified by XRD as nearly pure struvite ($MgNH_4PO4 \cdot 6H_2O$). Multiple hand-picked samples from the core were closely matched to PDF-2 reference sample 01-077-2303, described as 'naturally occurring struvite' (Ferraris *et al.*, 1986). All peaks in the Kettle Lake unknown mineral match peaks in the reference mineral, with about 15 low-intensity peaks in the reference sample not observed in the field sample. Based on XRD evidence and the corroborating elemental chemistry, the mineral identification is positive.

A dominant proportion of the 34 identified crystalline separates are euhedral, pure or nearly pure struvite plates, up to 8 mm in thickness (Table 2). The only other detectable minerals associated with the salt are aragonite, an endogenic phase, and quartz, dolomite and calcite, all thought to be allogenic (detrital). Samples from core depths 1302–1322 and 1513–1600 cm are mixtures of marl with very thin struvite laminae.

All but two of the struvite samples lie between 1020 and 1656 cm core depths (4655–8698 cal. yr BP). In particular, the highest frequency of struvite samples occurs between 1500 and 1656 cm depth (8068–8698 cal. yr BP). The youngest struvite occurrence was at 2734 cal. yr BP.

Tables 2 and 3 show elemental chemistry for struvite samples, including N concentrations for selected samples, all normalized to sum to 100% as oxides. Excluded from the analysis are carbonates. Low elemental Al concentrations and lack of XRD detection suggest very low aluminosilicate content. The calculated Mg:P ratio ranges from 1.28 to 1.67, higher than the expected unit value of struvite (Mg:P:N = 1:1:1).

Also in Table 3 are the expected concentrations of $(NH_4)_2O$, MgO and P_2O_5 for (a) hydrous struvite and (b) anhydrous struvite. For comparison with oven-dried samples, the anhydrous stoichiometry is most appropriate. Kettle Lake struvite is enriched in MgO (30.7% to 54.9%, versus expected 29.3%) and depleted in $(NH_4)_2O$ (9.59 to 10.60, versus expected 19.0%) and P_2O_5 (25.2% to 44.4%, versus expected 51.7%). The quartz and aragonite/calcite contamination may represent either inclusions in (as in Figure 4, top) or surface contamination on the mineral grains. The struvite in these samples is consistently Mg-enriched and N/P depleted with respect to ideal stoichiometry. The extent to which this result depended on sample holding times prior to analysis was not assessed.

SEM observations

Struvite from Kettle Lake was uniformly tabular (platy), clear, vitreous, euhedral, with perfect cleavage along the [100] cleavage

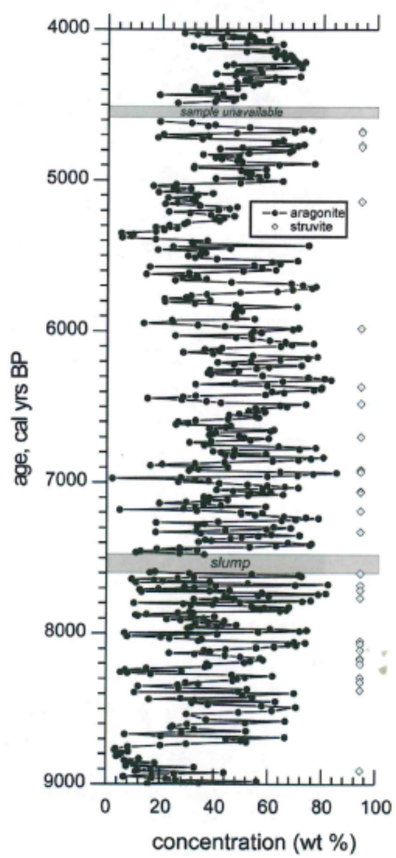


Figure 5 Fluctuations between 4000–8500 cal. yr BP in aragonite concentration (line) and depth of occurrence of struvite (diamond symbols). Aragonite concentrations expressed as weight percent of crystalline fraction

Conclusions

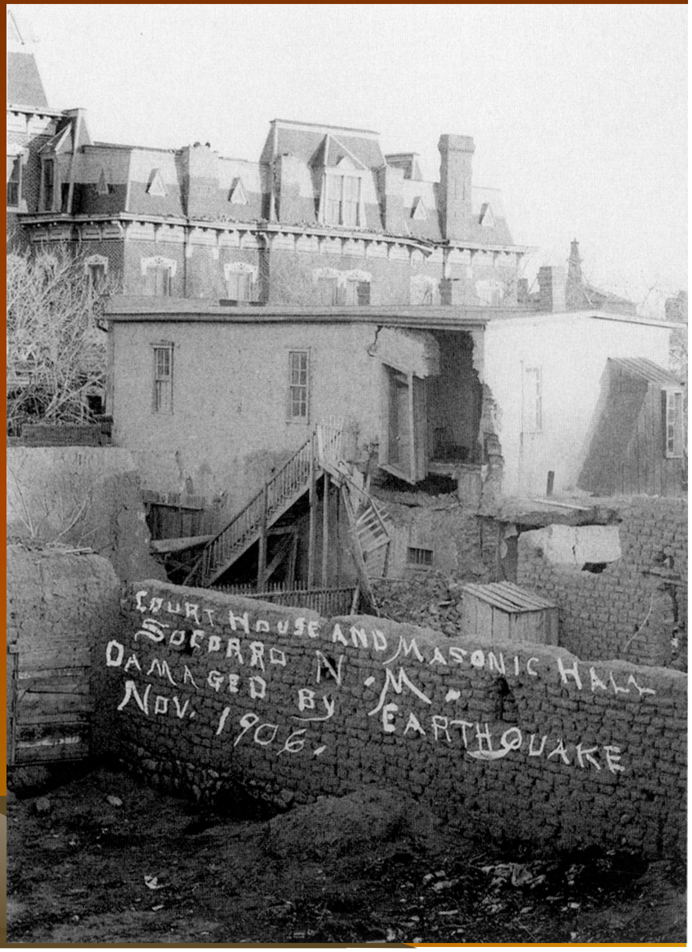
- High Resolution LiDAR coverage of these and other Quaternary faults (especially in forested regions) would be a major step forward in quantifying Montana's seismic hazards
- Some relatively low-hazard regions have potentially active faults
- Resources and personnel will be required to gain new knowledge about seismic hazards.

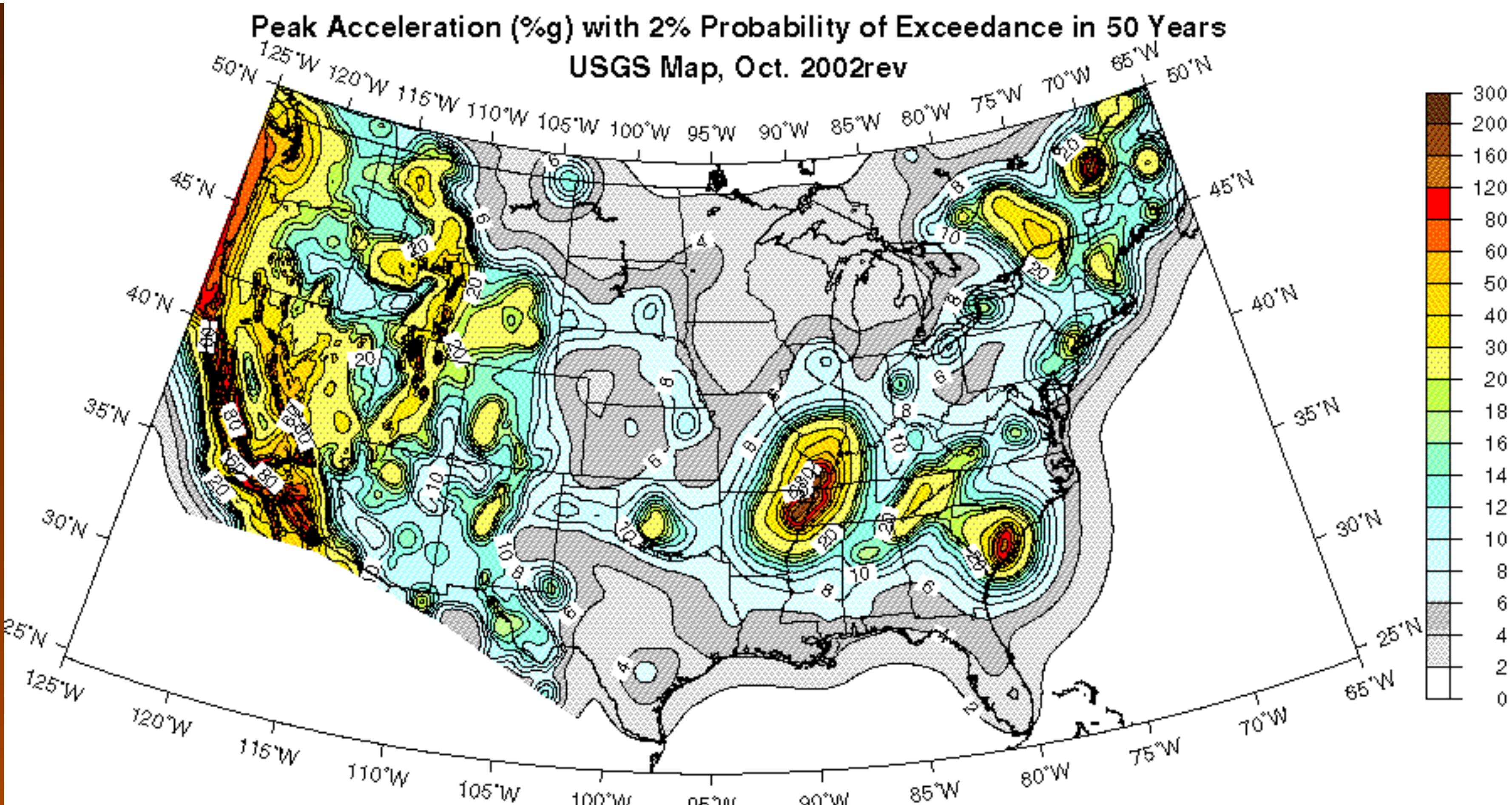
EARTHQUAKE PRIORITIES IN NEW MEXICO THROUGH 2017

New Mexico has moderate-probability hazards
The risks are substantial
We can take action to reduce the risks

David W. Love and Dan Koning
New Mexico Bureau of Geology & Mineral Resources
New Mexico Institute of Mining and Technology

With contributions from Al Sanford, Jon Price, Sean Connell, USGS, and many others

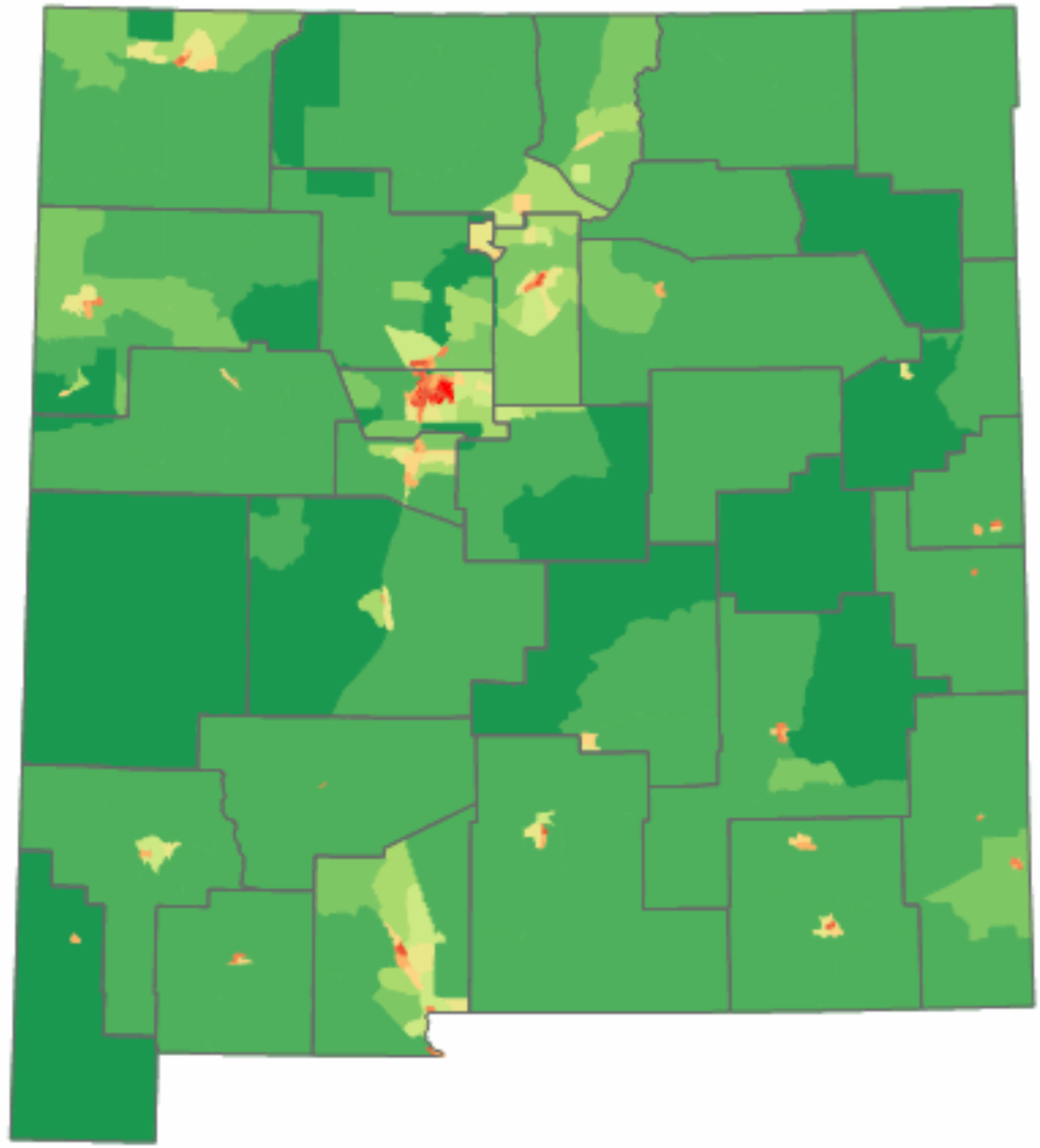




- New Mexico in 150 years: two magnitude 6 quakes
-
- California in 150 years: >150 magnitude 6 & 7quakes
- The 30 quakes of M 4.5 or greater in New Mexico in 150 years would occur in California in about 3 years

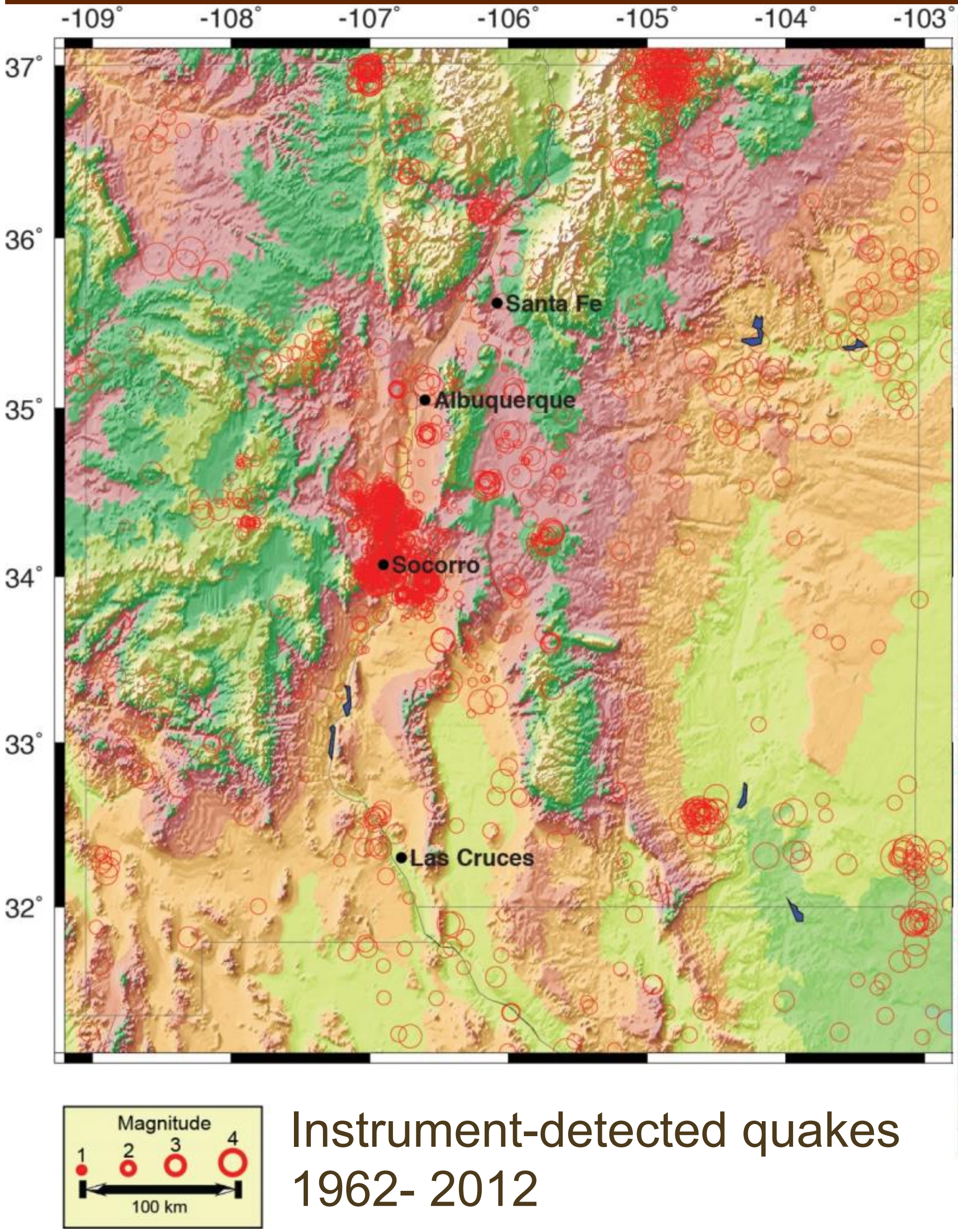
Points from 2008 meeting

- Many faults in NM remain unstudied
- Many critical unknowns
- Many more historic EQ in past (1900-1910)
- Poor correlation between quakes and fault scarps
- The Rio Grande rift has many faults and relay ramps, many buried
- Central rift has Socorro magma body
- Jemez caldera produced several Quaternary tephras, useful for dating
- Pleistocene terraces and lakes help establish chronology
- Alluvium and eolian deposits mask scarps
- Is extension and rift slowing down?
- Which faults should be considered active?

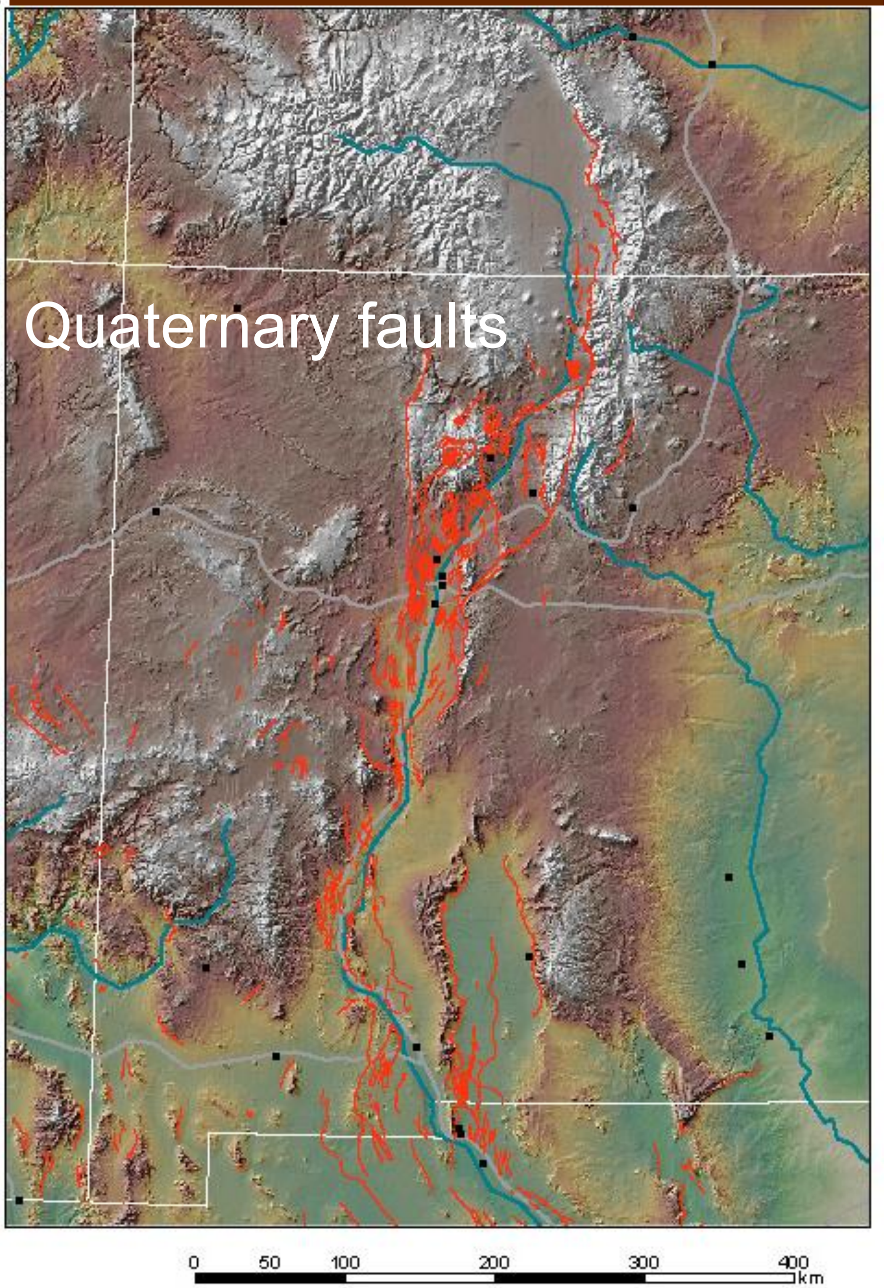


Source: U. S. Census Bureau
Census 2000 Summary File 1
population by census tract.

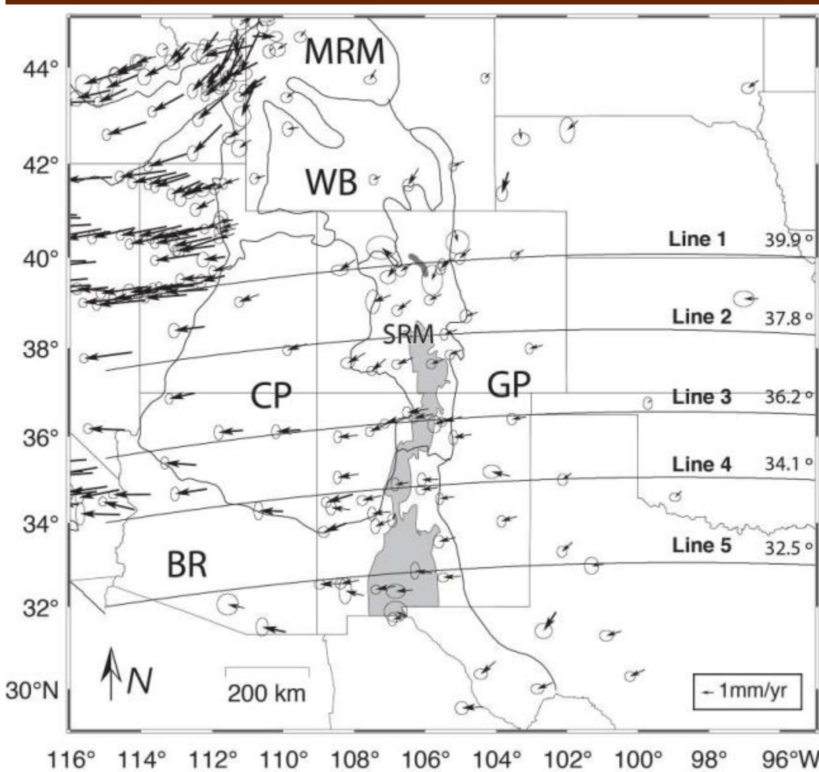
• New Mexico's overall hazard and risk



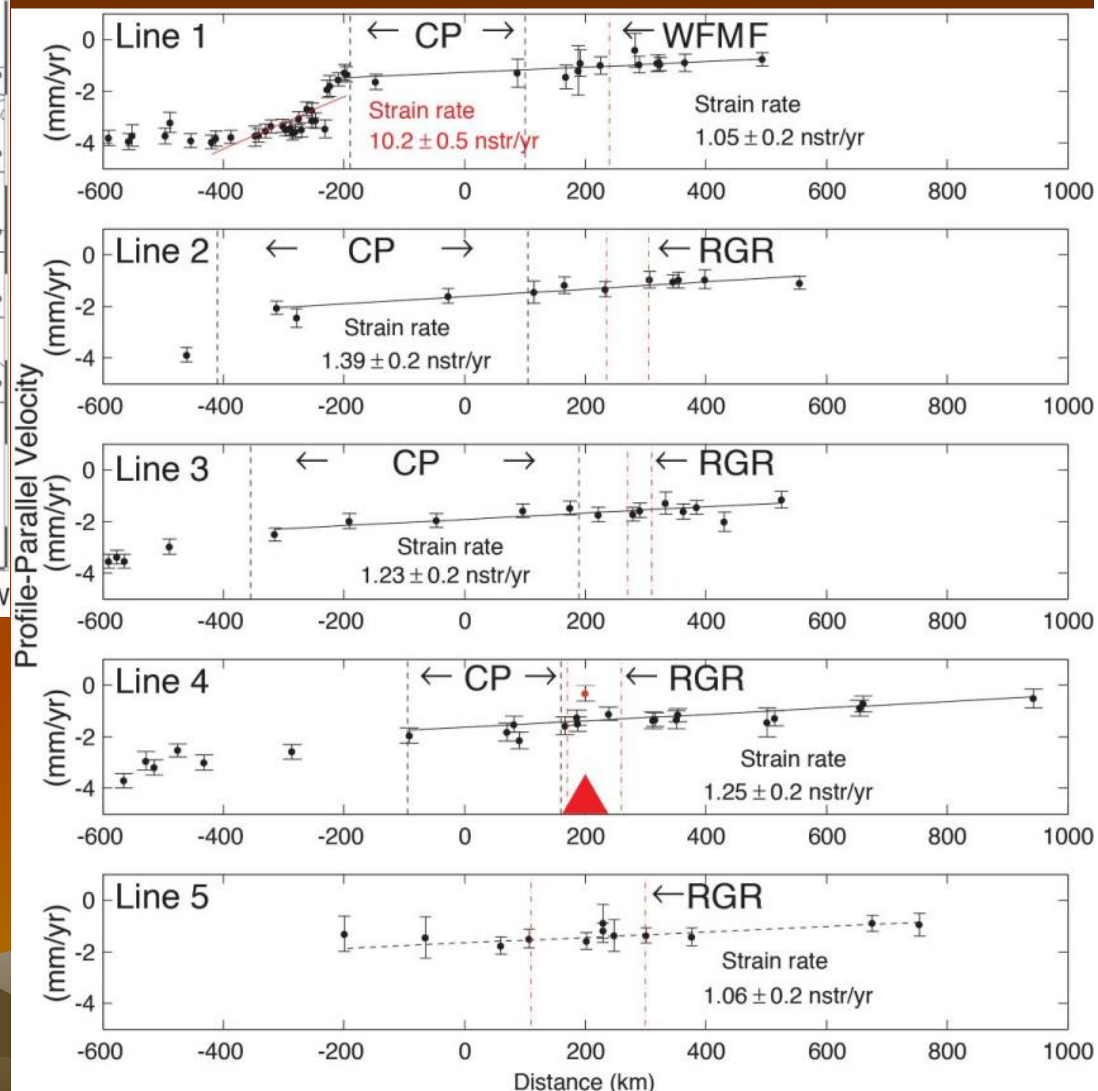
Instrument-detected quakes
1962- 2012



←Stretching of crust across New Mexico →

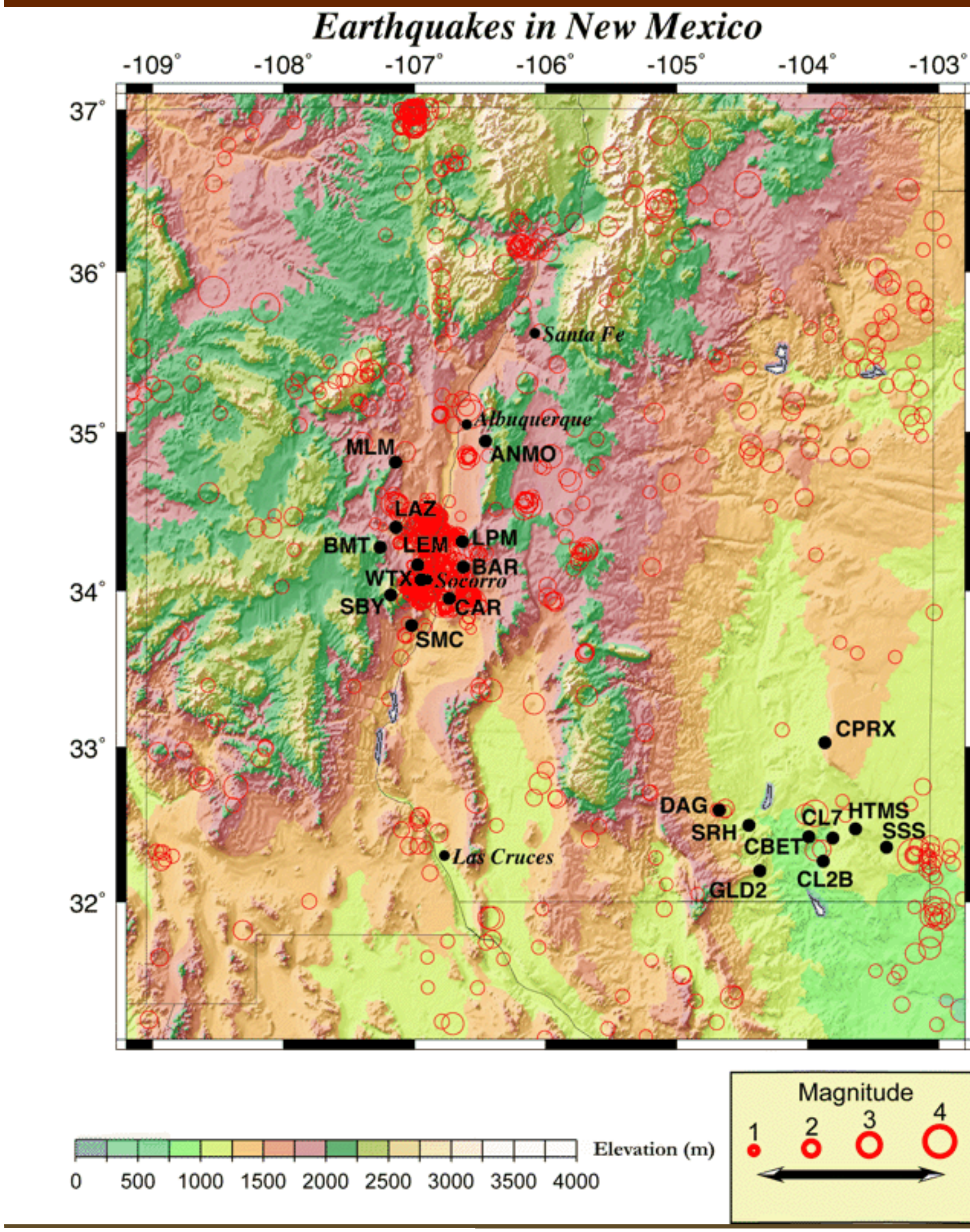


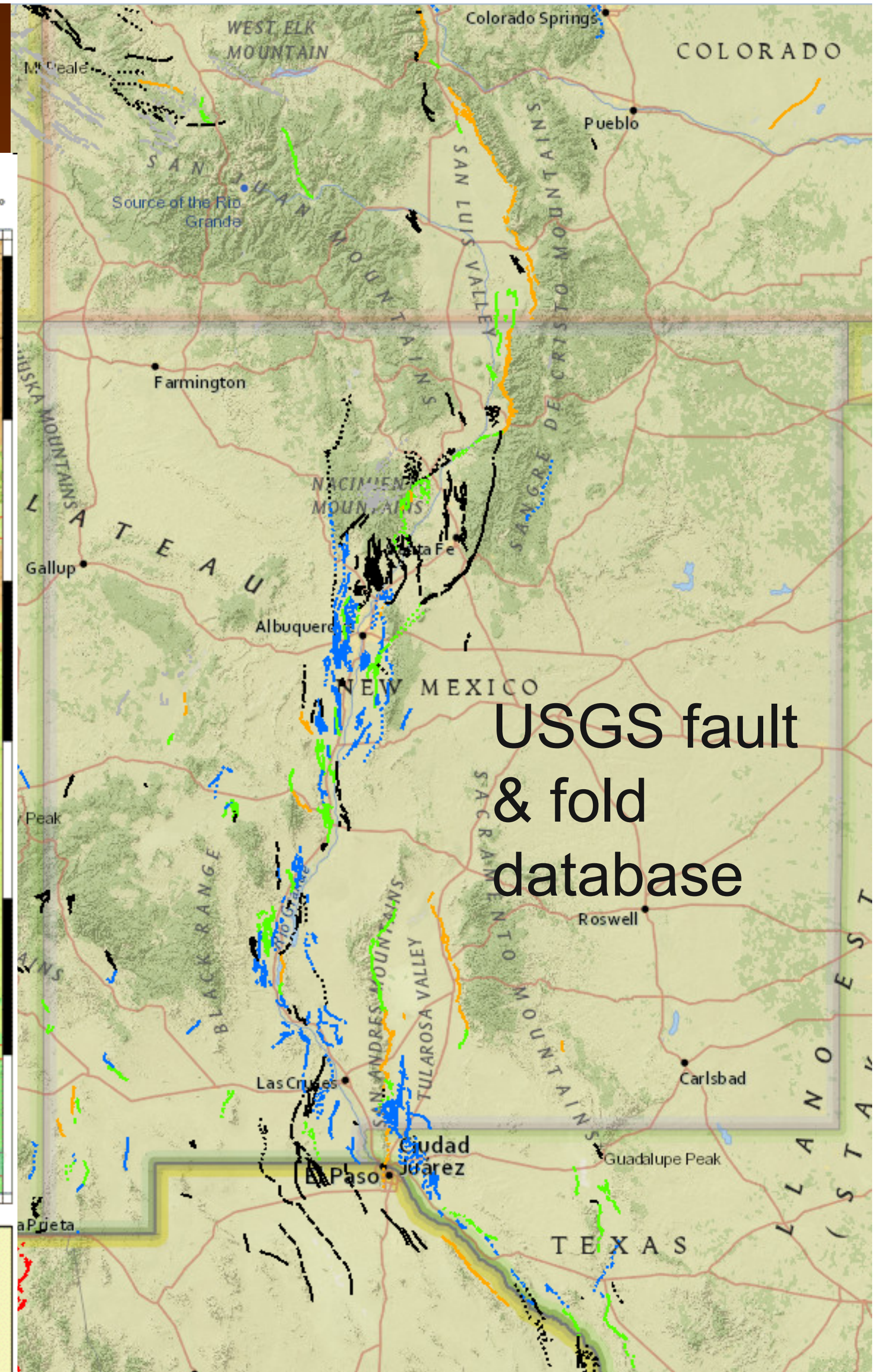
Berglund et al. (2012)



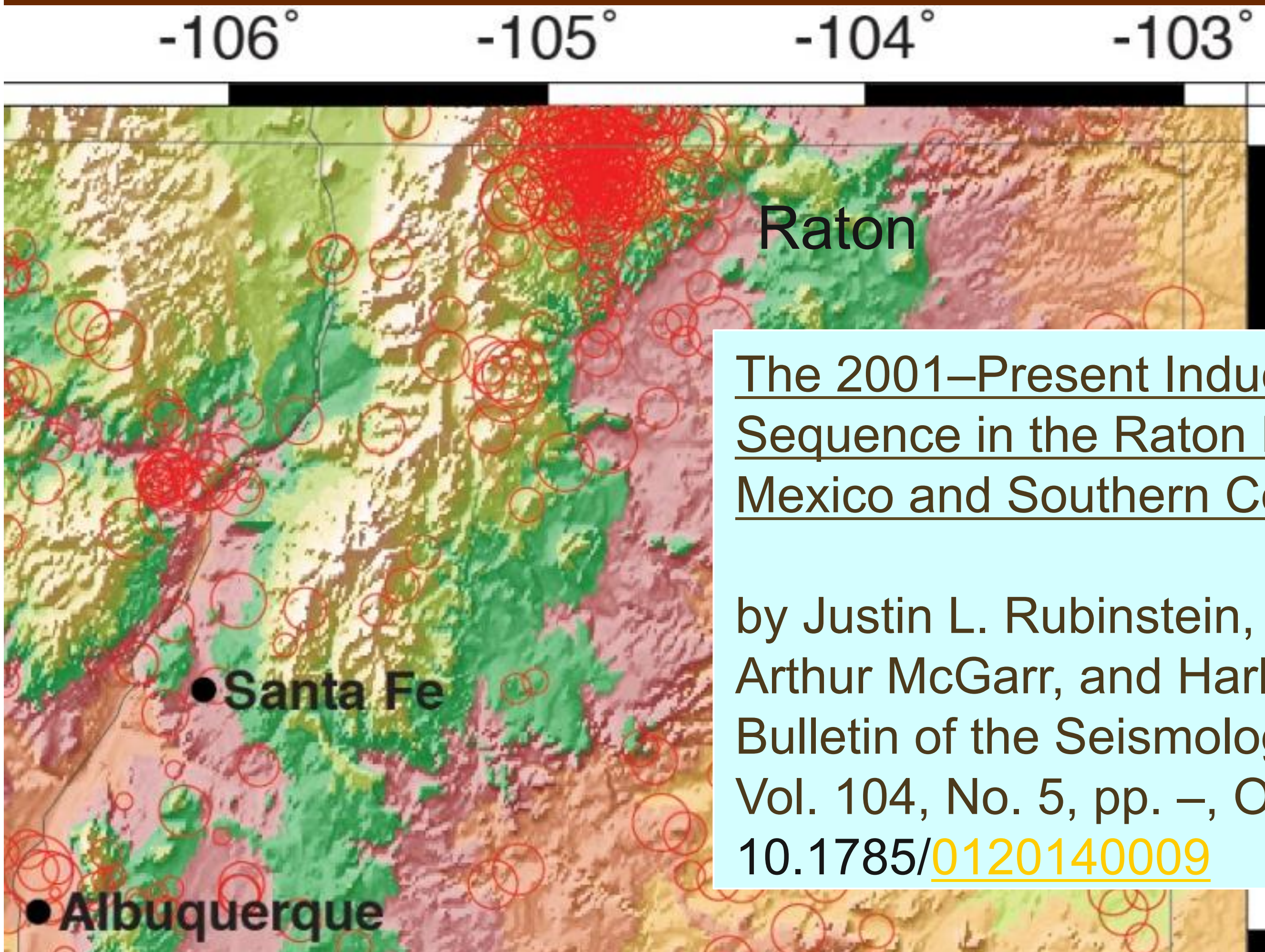
One nanostrain is the strain producing a deformation of one part per billion (10^{-9})

poor correlation between quakes & faults





Induced (and some natural) earthquakes in the Raton Basin



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

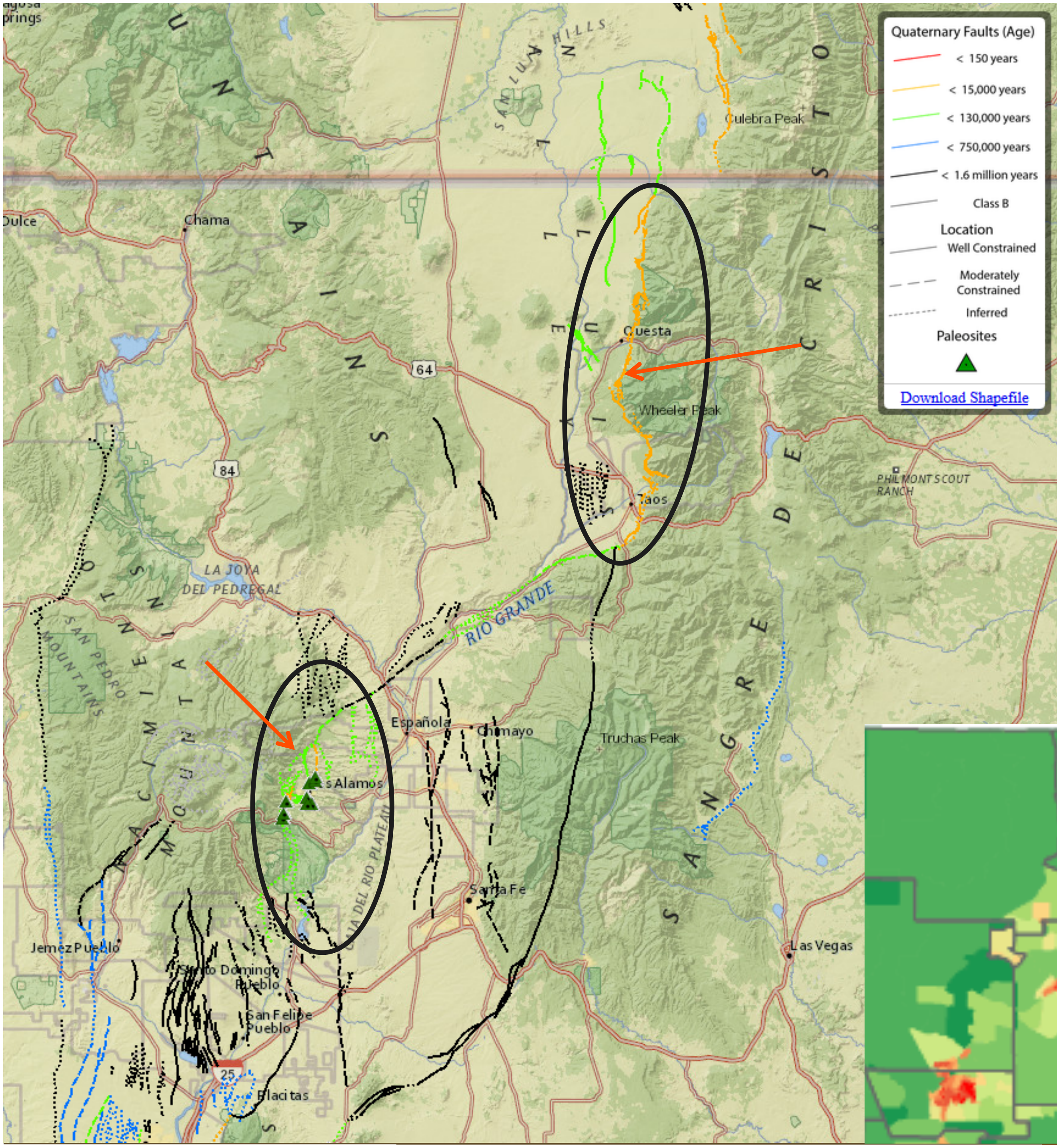
by Justin L. Rubinstein, William L. Ellsworth, Arthur McGarr, and Harley M. Benz
Bulletin of the Seismological Society of America, Vol. 104, No. 5, pp. –, October 2014, doi: 10.1785/0120140009

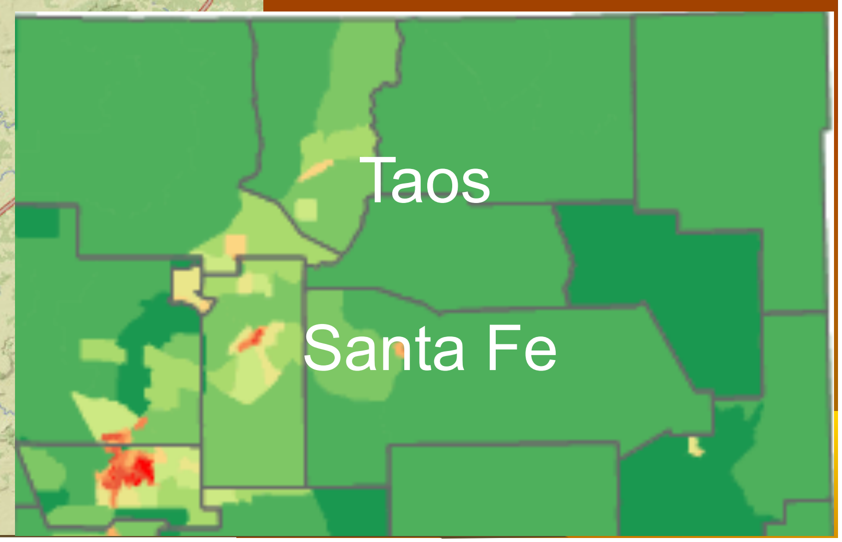
Induced earthquakes also occur NW of Carlsbad

Northern New Mexico

Sangre de Cristo fault zone

Pajarito fault system



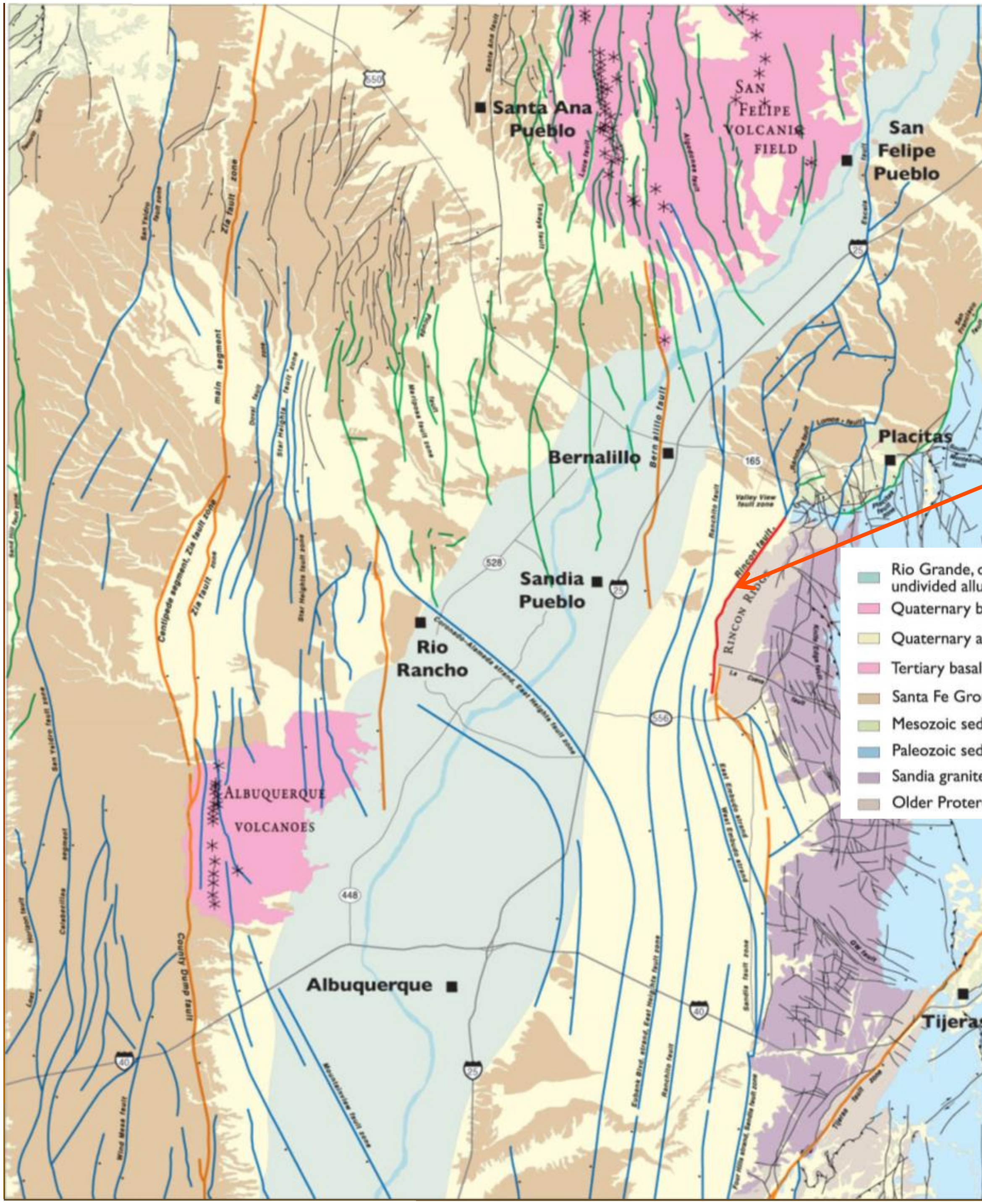


Fault	**Age of most recent surface rupture(s) (ka)** [µ]	**Recurrence interval/** ***slip rate***	**Avg vertical displacment per event**	**Reference**
Northern Sangre de Cristo	5-8 [8-13, 13-35]	3-40 ka *0.1-0.2 mm/yr*	1.5-2.5 m	McCalpin, 1982; 1986; 2006) Ruleman and Machette, 2007
Central Sangre de Cristo	9 +/- 2	~12 ka *0.17 mm/yr during late Pleistocene*	2.3 m	Crone and Machette, 2005
Southern Sangre de Cristo, north part		*0.18 mm/yr over past 3.9 Ma; 0.04 mm/yr since late middle Pleistocene*		Ruleman et al., 2013
Southern Sangre de Cristo, south part	10-30	10s of ka		Kelson et al., 2004
Pajarito	1.4*, 6.5-5.2, early Holocene	20-40 ka *0.1 mm/yr*[§]		McCalpin, 2005; Reneau et al., 2002
Rendija Canyon**	9 or 23	33-83 ka *0.03 ± 0.1 mm/yr*	2.0 ± 0.5 m	Wong et al., 1995 Kelson et al., 1996
Guaje Mountain**	6.5-4.0 [~39, 144-300]	10s of ka *0.01 mm/yr since 1.2 Ma*	0.5-2.0 m	Gardner et al., 2003 Wong et al., 1995

Courtesy Dan Koning

Central New Mexico

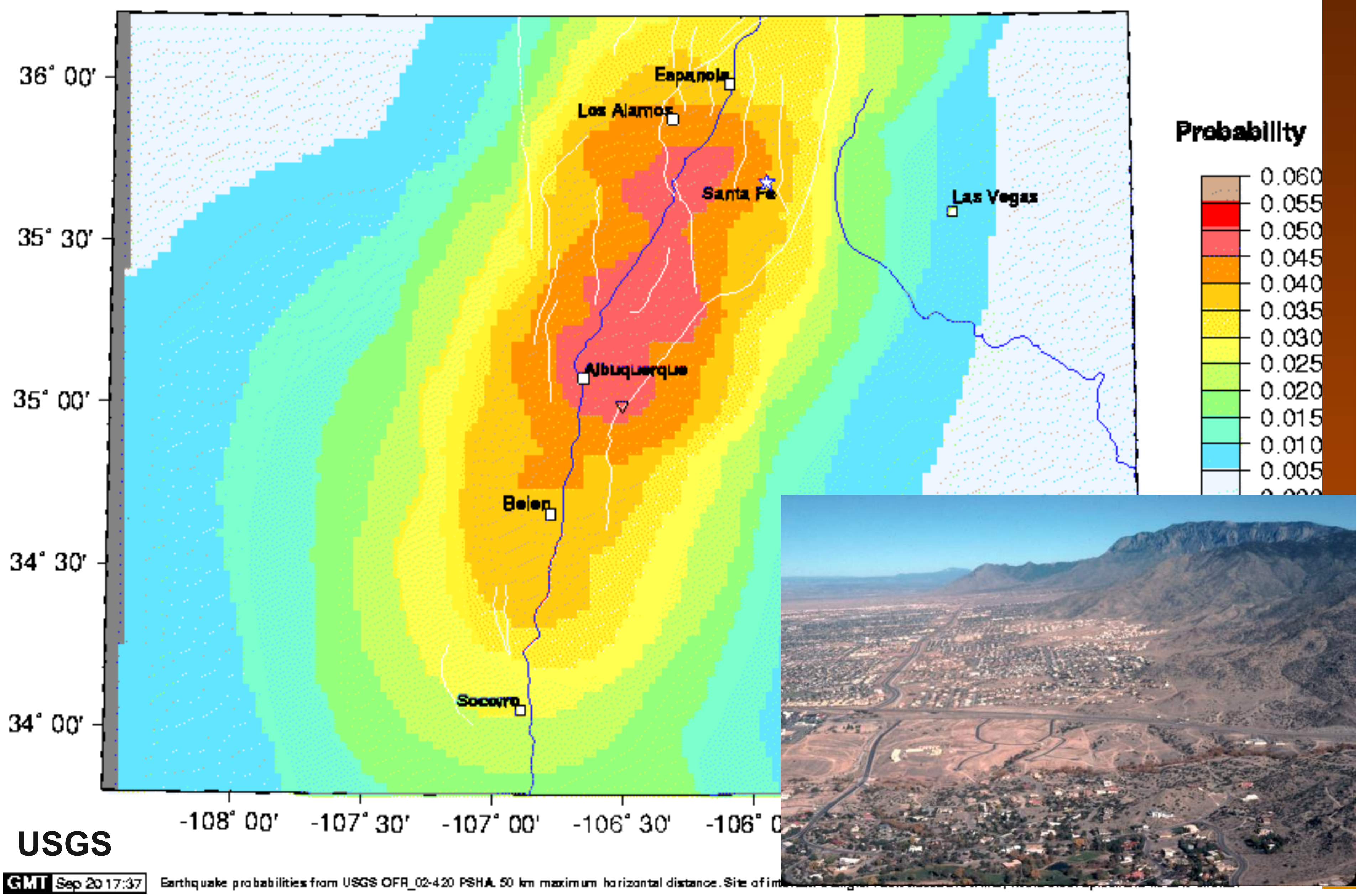
Greater Albuquerque area



Courtesy Sean Connell

Probability of earthquake with M $\geq$ 6.5 within 50 years & 50 km

Albuquerque, NM = 4 to 5%



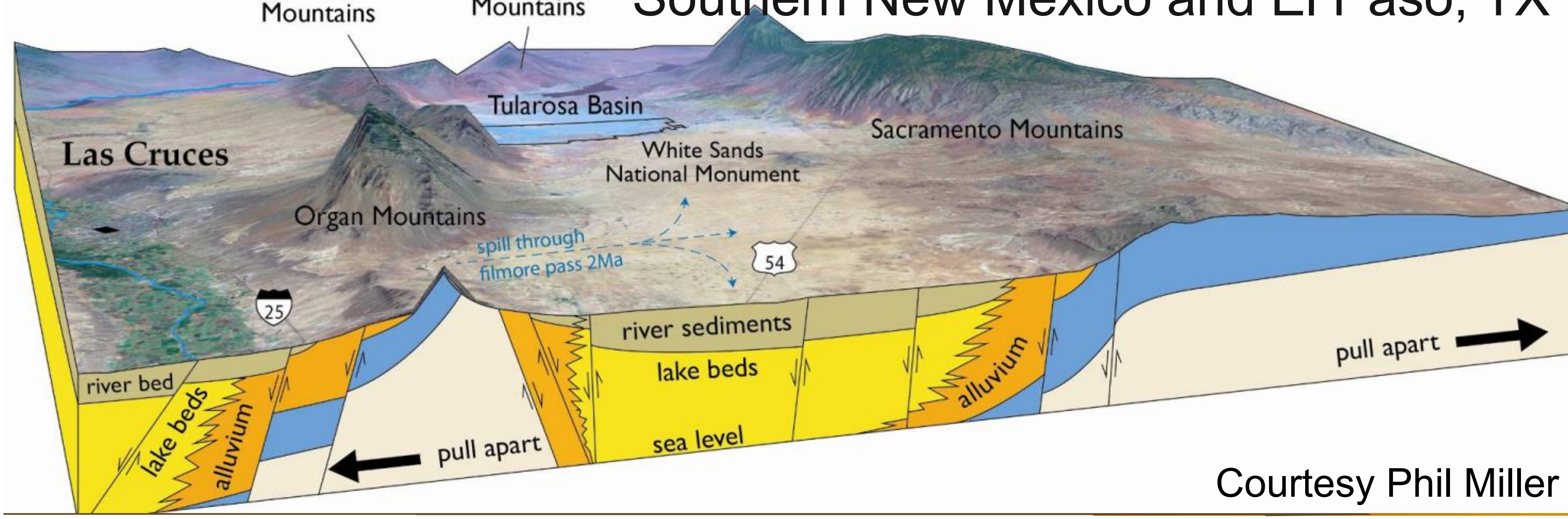
USGS

Central New Mexico

Fault	Age of most recent surface rupture(s) (ka)	Recurrence interval/ *slip rate*	Avg vertical displacment per event	Reference
County Dump	28 or 47-34 ka	10s of ka *0.02-0.05 mm/yr*	1.4 ± 0.7 m	McCalpin, 1997 Personius et al., 1999 McCalpin et al., 2006
East Paradise fault zone	10-80 ka	80-150 ka	0.5-1.3 m	Personius et al., 1999
Hubbell Spring	15-6 ka	14-27 ka *0.2-1.0 mm/yr*	0.4-3.7 m (vertical)	Olig et al., 2011 Personius et al., 2001 Personius and Mahan, 2003
Socorro Canyon	Late Holocene	~30-70 ka *0.04 mm/yr*	1.5-2.0 m	Phillips et al., 2003
La Jencia, north part	3, 28-40, 150 ka****	~100 ka	1.5-4.5	Machette, 1988
La Jencia, south part	5-6, 15		1-5	Machette, 1988

Courtesty Dan Koning

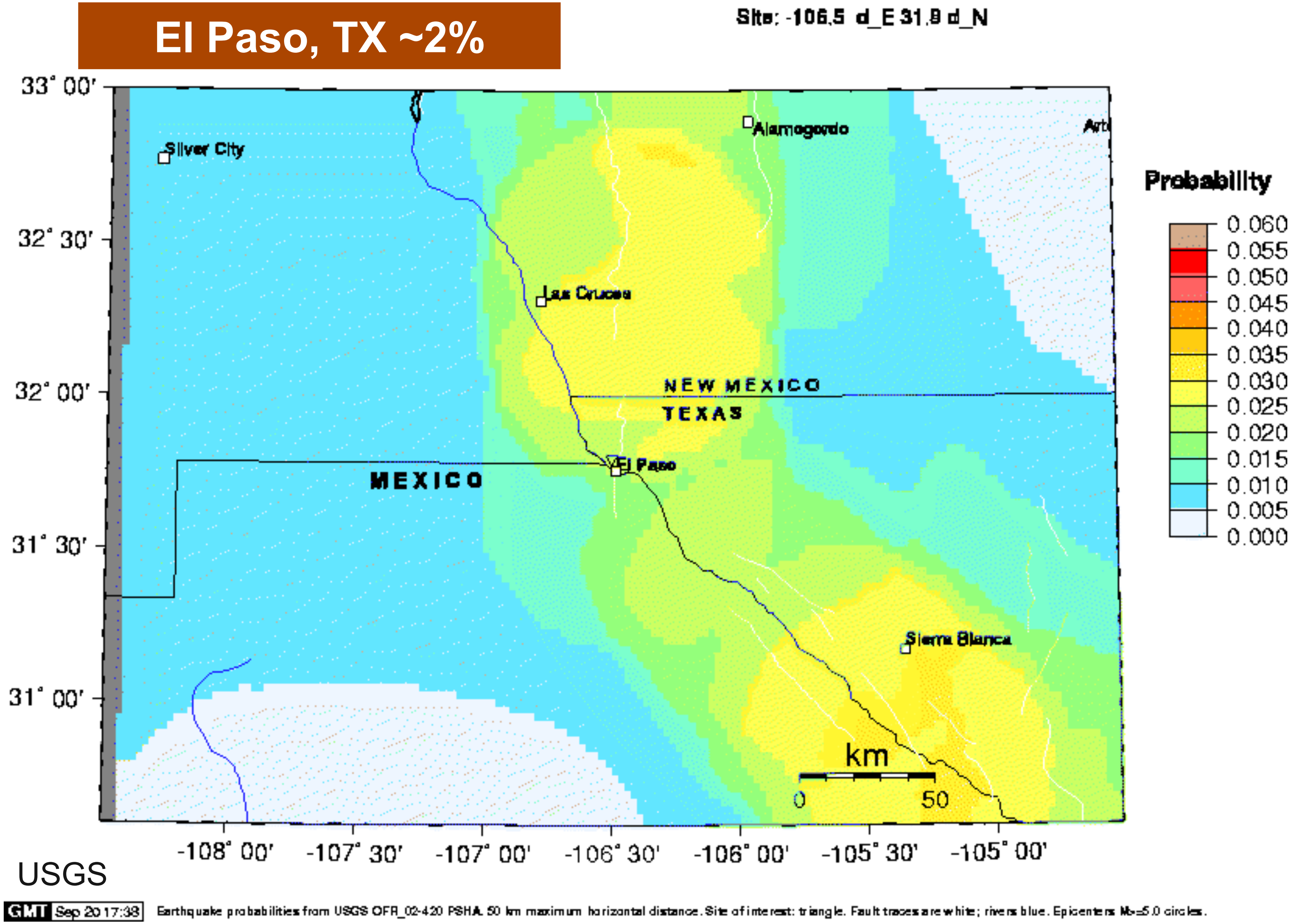
Southern New Mexico and El Paso, TX



Courtesy Phil Miller

Probability of earthquake with M $\geq$ 6.5 within 50 years & 50 km

El Paso, TX ~2%



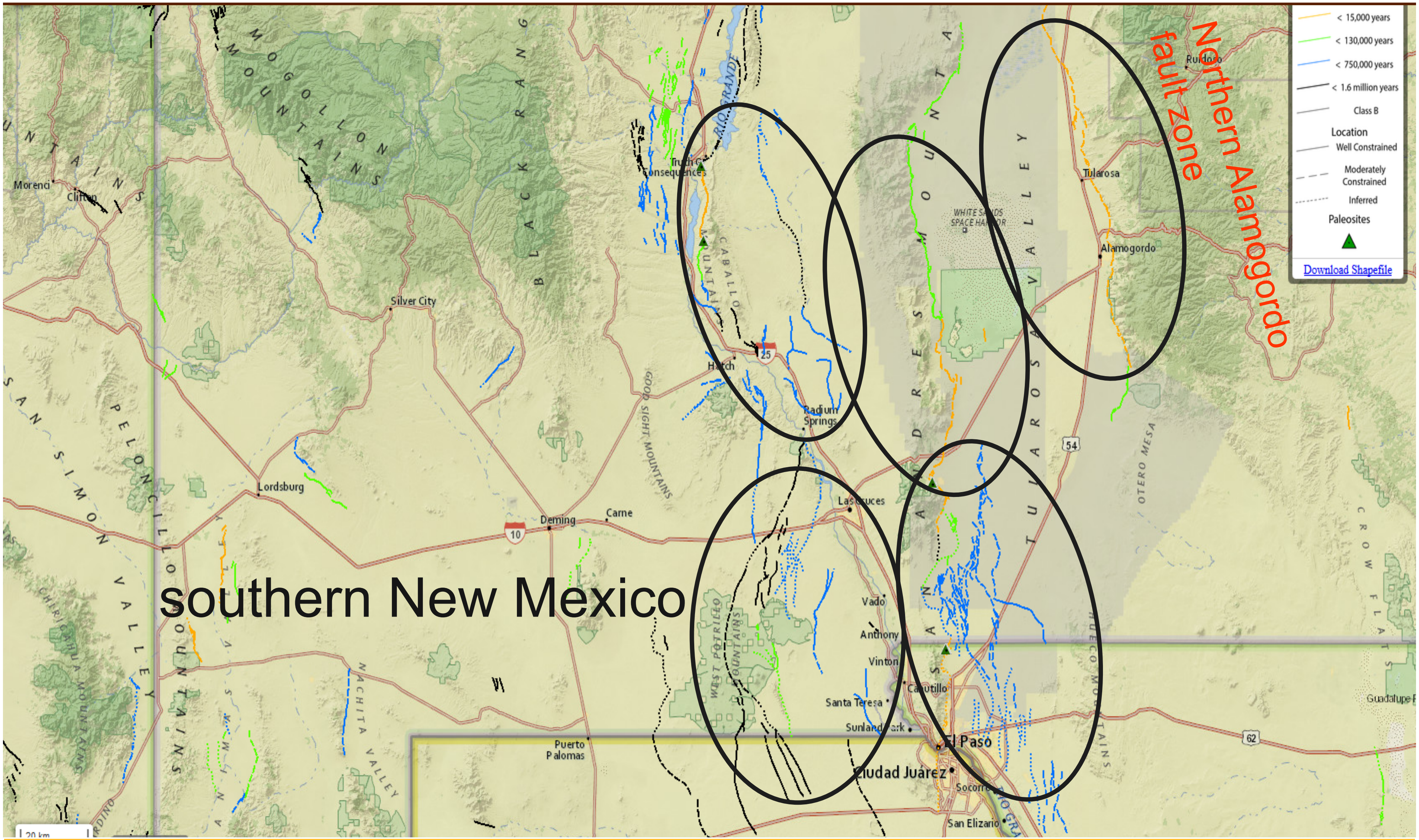
USGS

Southern New Mexico

Fault	Age of most recent surface rupture(s) (ka) µ	Recurrence interval/ *slip rate*	Avg vertical displacment per event	Reference
Caballo	1.6-5.0 ka	50-100 ka *0.02-0.03 mm/yr*	1.25-2.6	Foley et al., 1988 Machette et al., 1998
Alamogordo, south part	8-10; 10.5-11.2 ka*****	10s of ka***	1-6	Koning and Pazzaglia, 2002 Koning, 1999
Organ Mountains	1-5 ka	4-15 ka Poorly constrained	As much as 5 m	Gile, 1986, 1994; Machette et al., 1987
East Franklin Mountains	13-17 ka	14-19 ka *0.18 mm/yr for late Pleistocene; 0.145 mm/y post-500 ka*	~3-4.5 m	McCalpin, 2006

Probably should consider faults in Mesilla Basin, Hueco-Tularosa Basins, along San Andres Mountains, southern Jornada fault zone, and northern Alamogordo fault

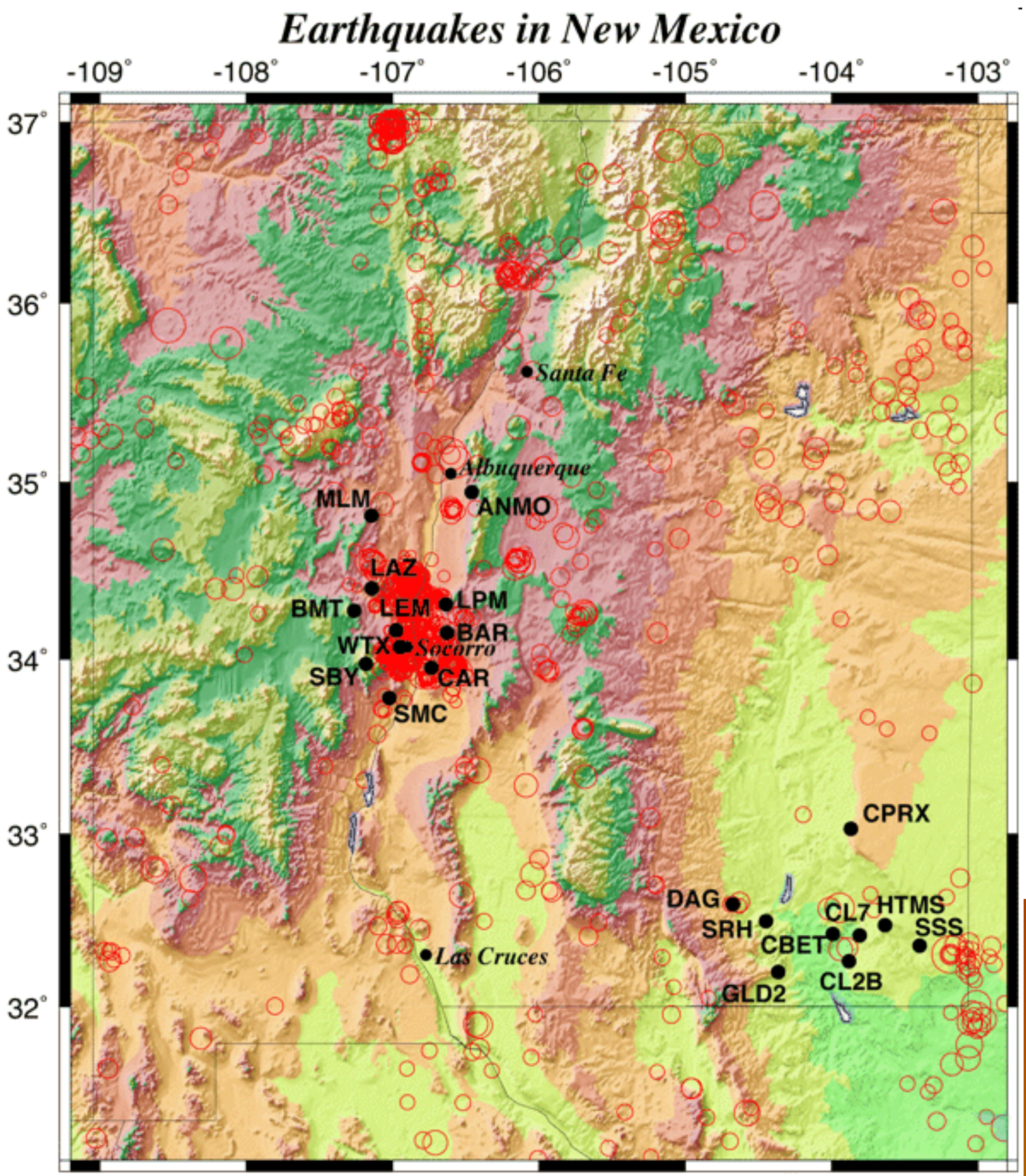
Courtesy Dan Koning



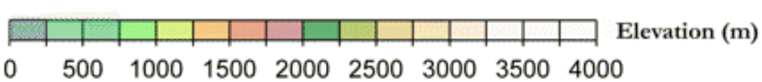
Faults with potential high hazard that deserve further study:
Mesilla Basin, Hueco-Tularosa Basins, along San Andres Mountains, southern Jornada fault zone, and northern Alamogordo fault

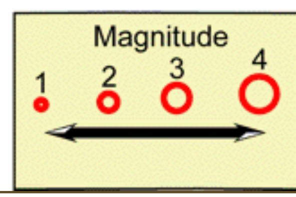
NM's Top five fault-study priorities through 2017

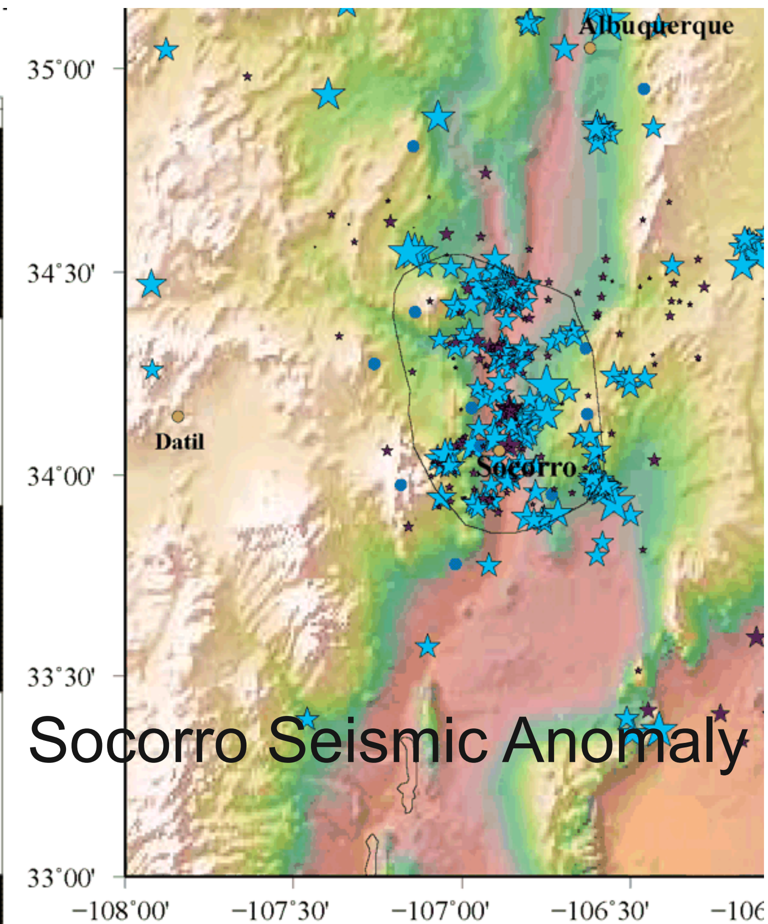
- 1. Rincon Ridge fault study if possible
- 2. northern Alamogordo fault
- 3. faults of Mesilla Basin
- 4. faults of Albuquerque Basin
- 5. southern San Andres Mountains



http://www.ees.nmt.edu/Geop/NM_Seismicity/



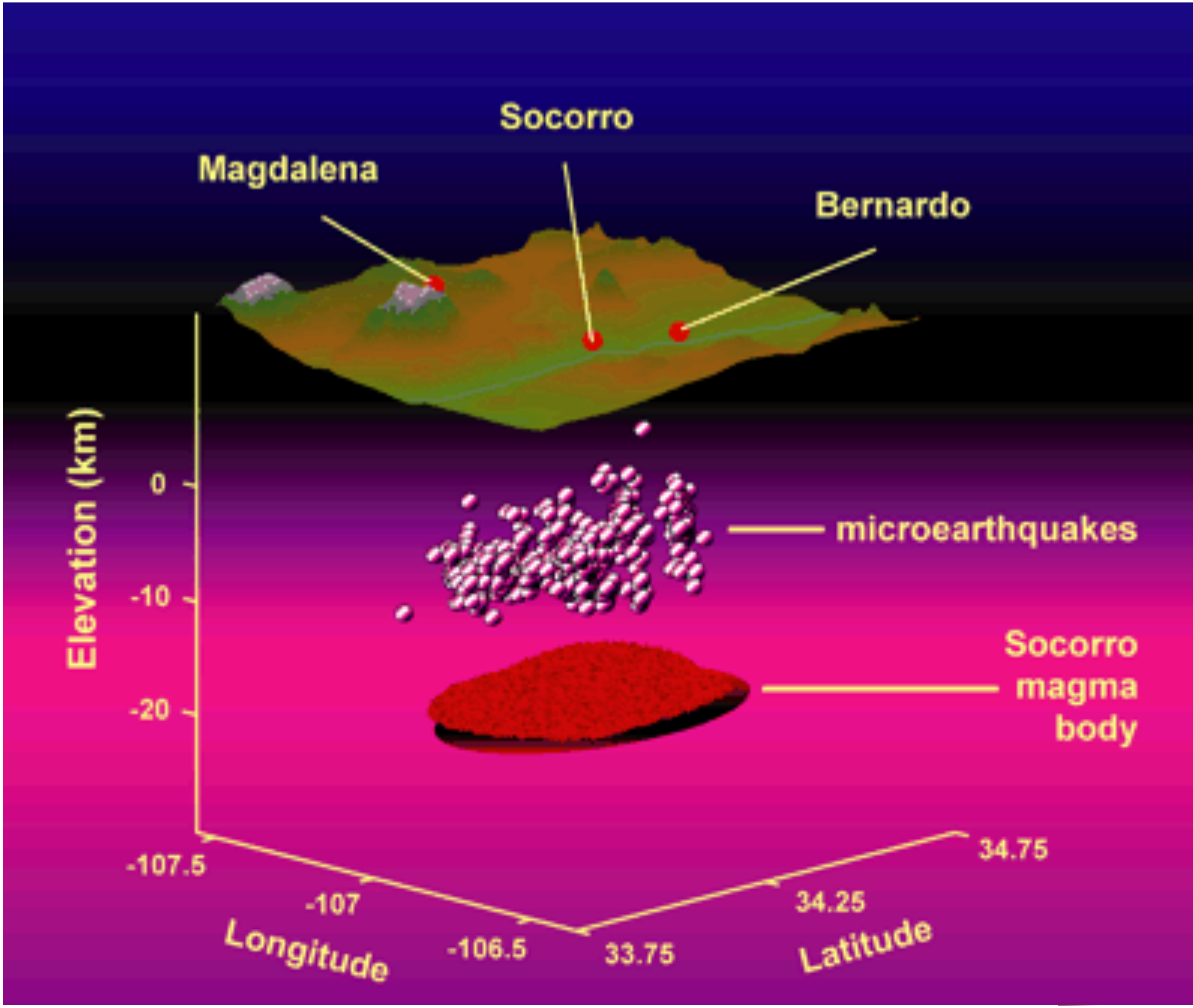




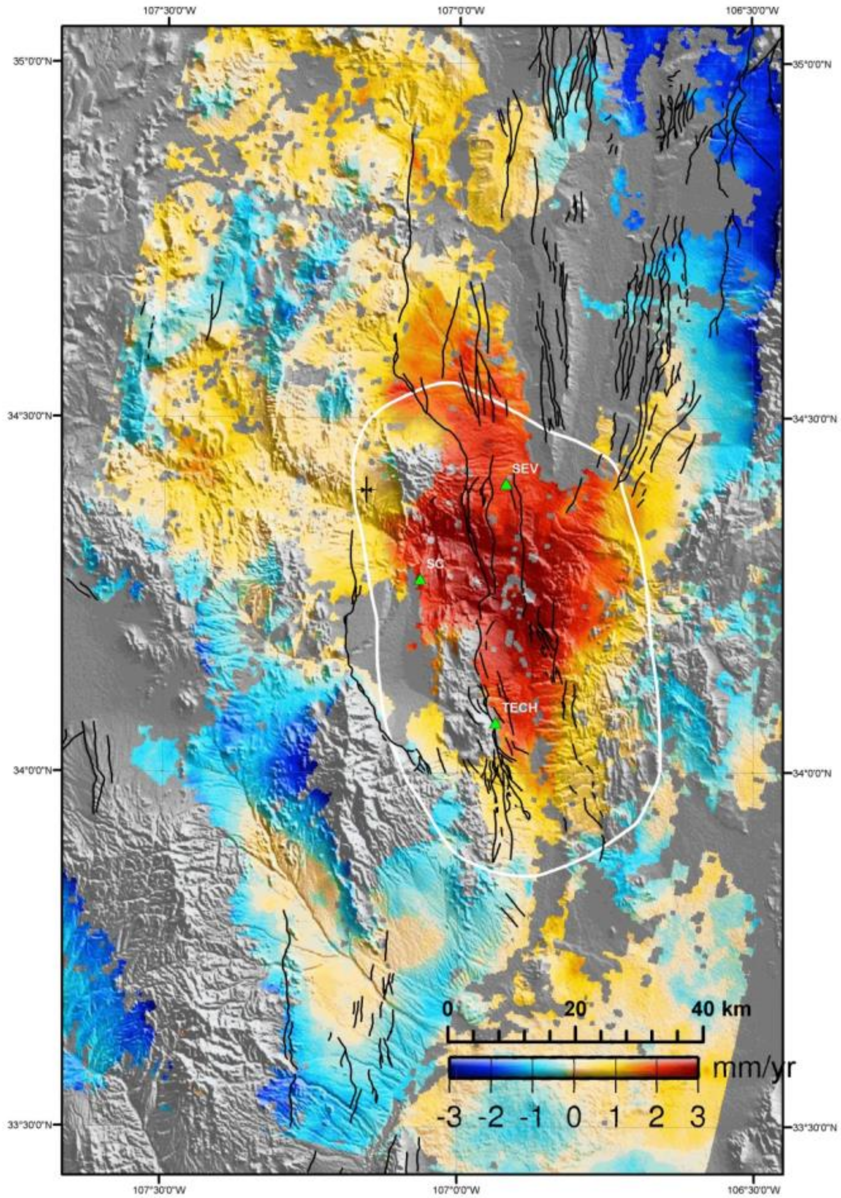
Socorro Seismic Anomaly

Socorro area has 37 % of earthquakes larger than magnitude 2, but only 1.6 percent of the area of New Mexico

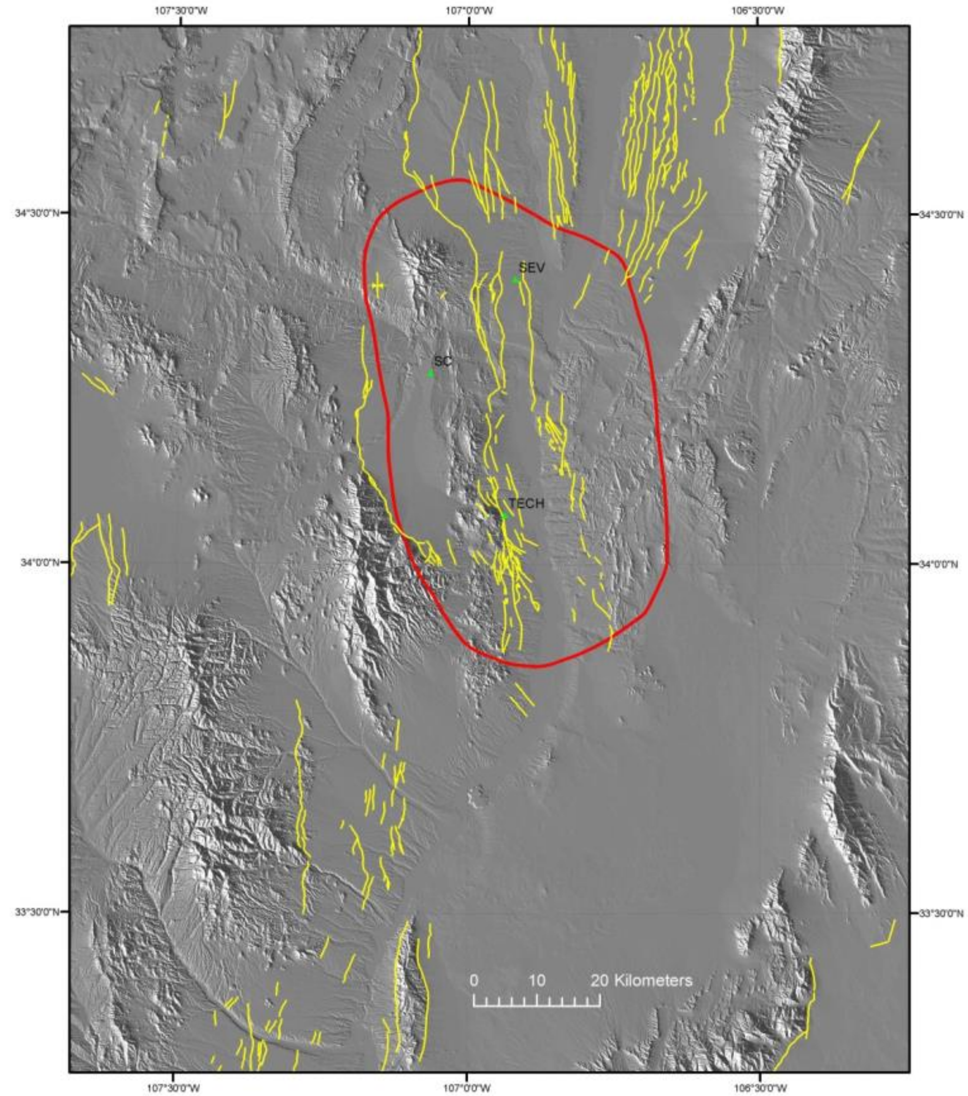
Earthquakes come in swarms



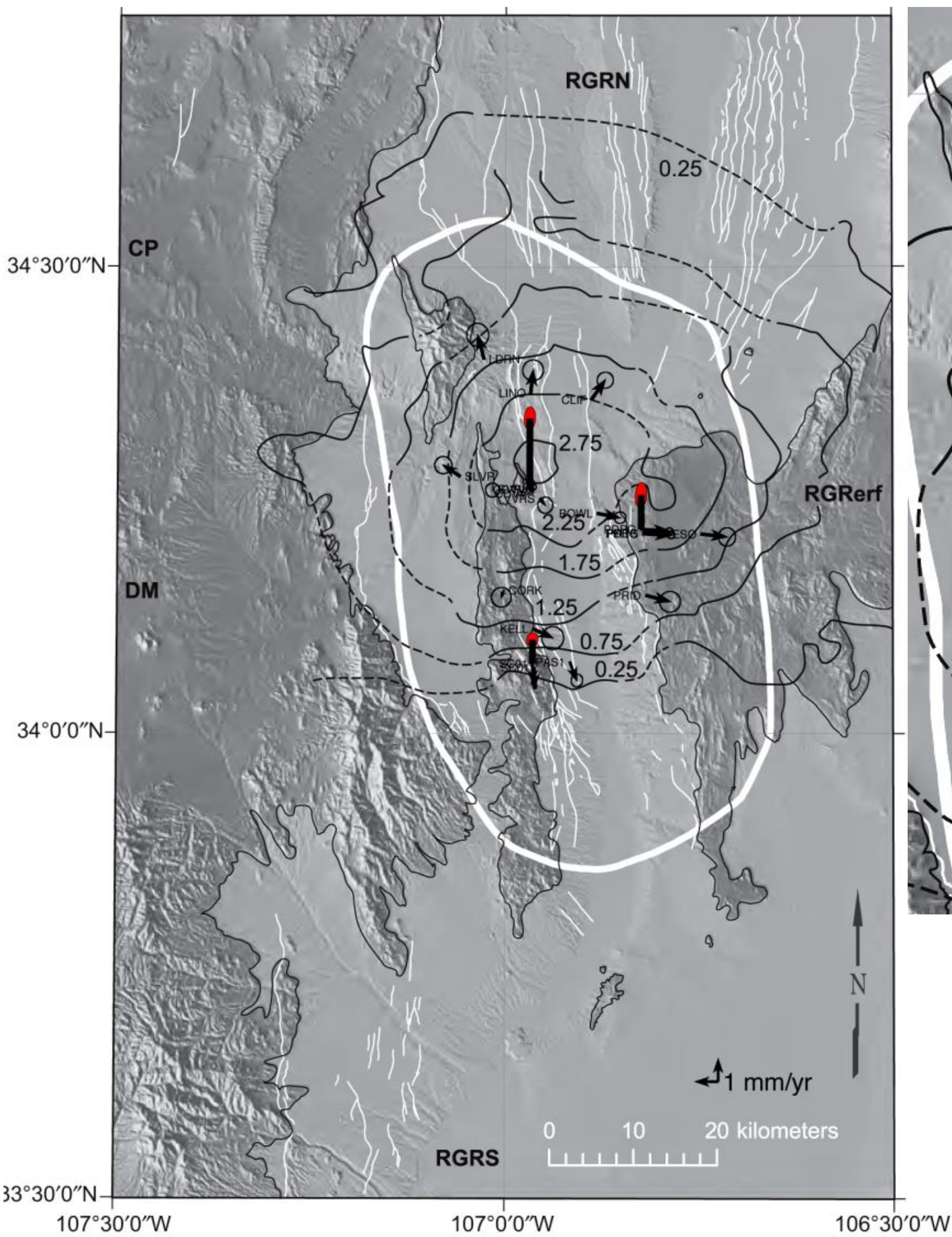
Socorro
Magdalena
Bernardo
Elevation (km)
0
-10
-20
microearthquakes
Socorro
magma
body
-107.5
-107
-106.5
Longitude
33.75
34.25
34.75
Latitude

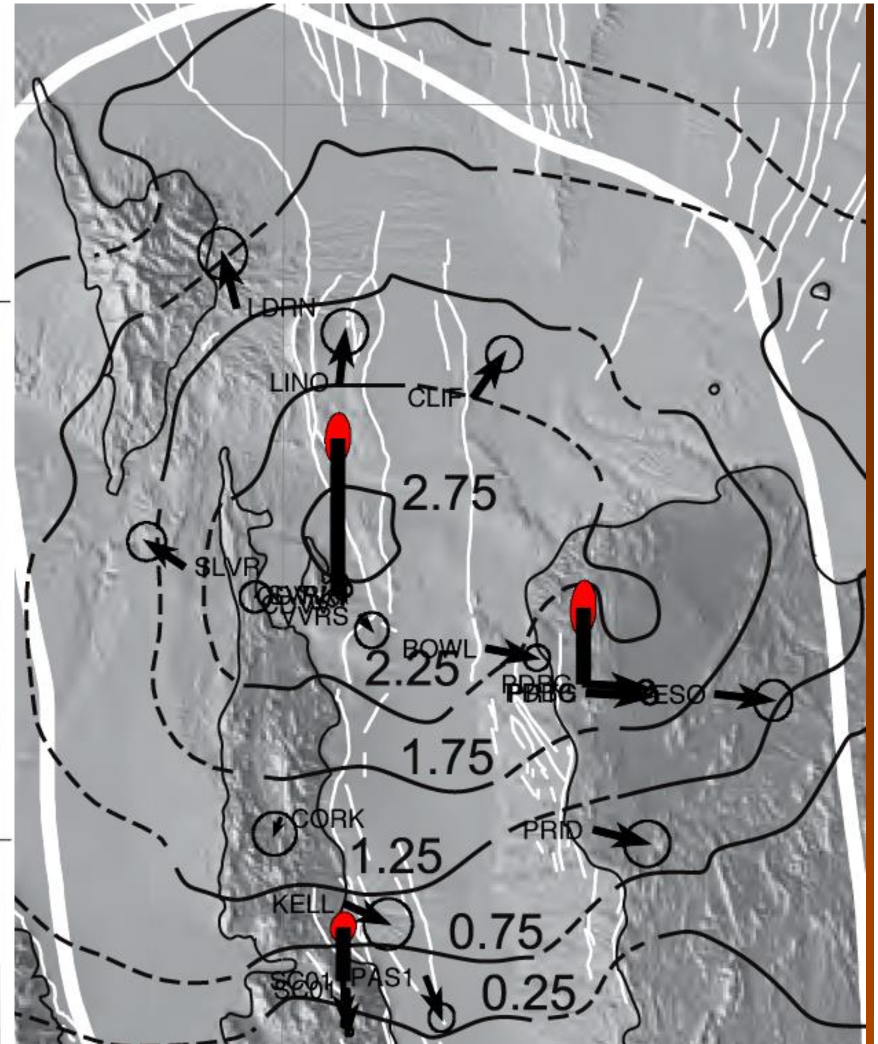


107°30'0"W
107°0'0"W
106°30'0"W
35°0'0"N
34°30'0"N
34°0'0"N
33°30'0"N
SEV
SC
TECH
0
20
40 km
mm/yr
-3 -2 -1 0 1 2 3

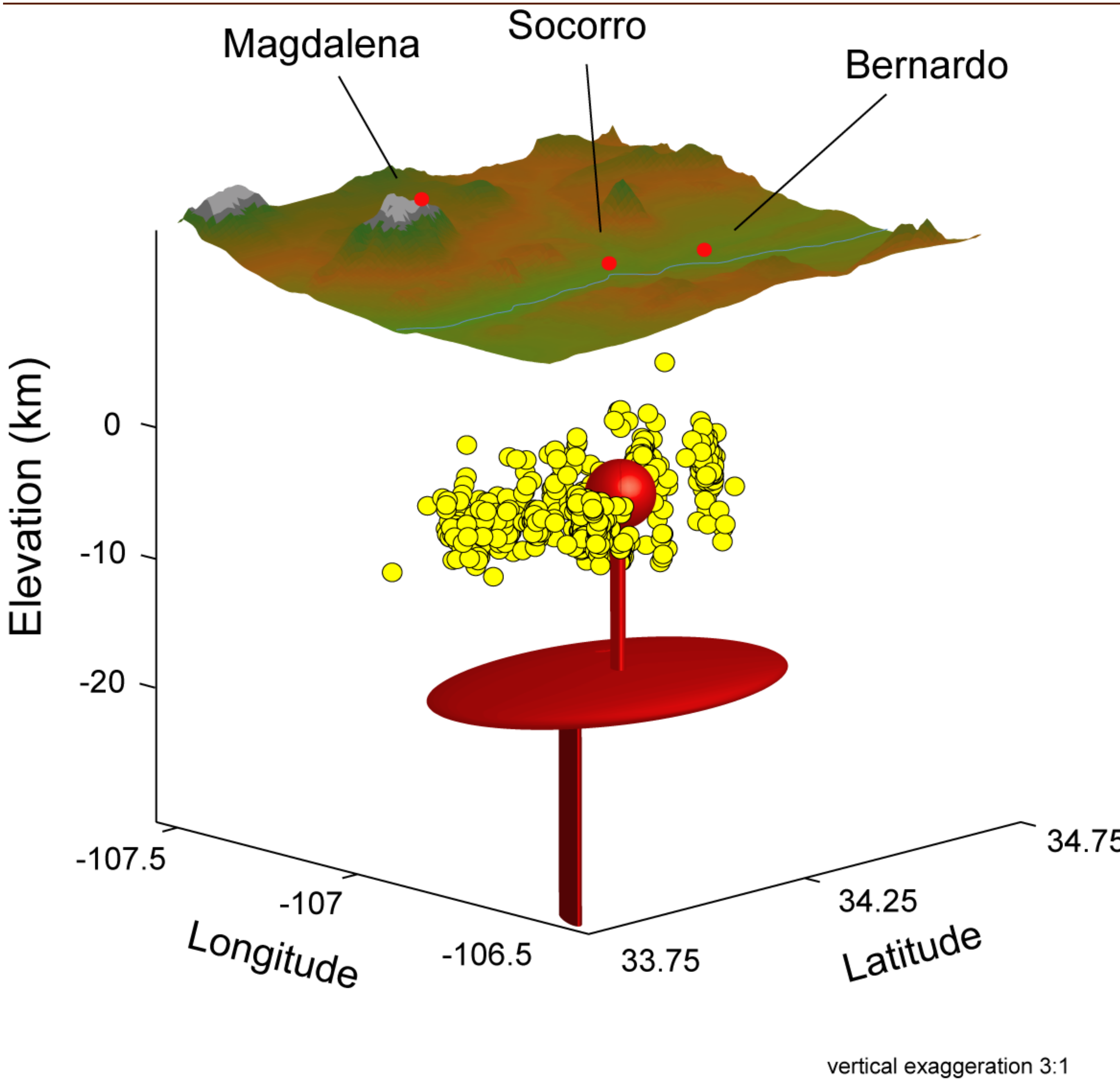


107°30'0"W
107°0'0"W
106°30'0"W
34°30'0"N
34°0'0"N
33°30'0"N
SEV
SC
TECH
0 10 20 Kilometers





"horizontal velocities of ~1-1.5 mm/ year and vertical velocities of ~2 mm/yr in a radial dilational pattern" (George et al. 2012)

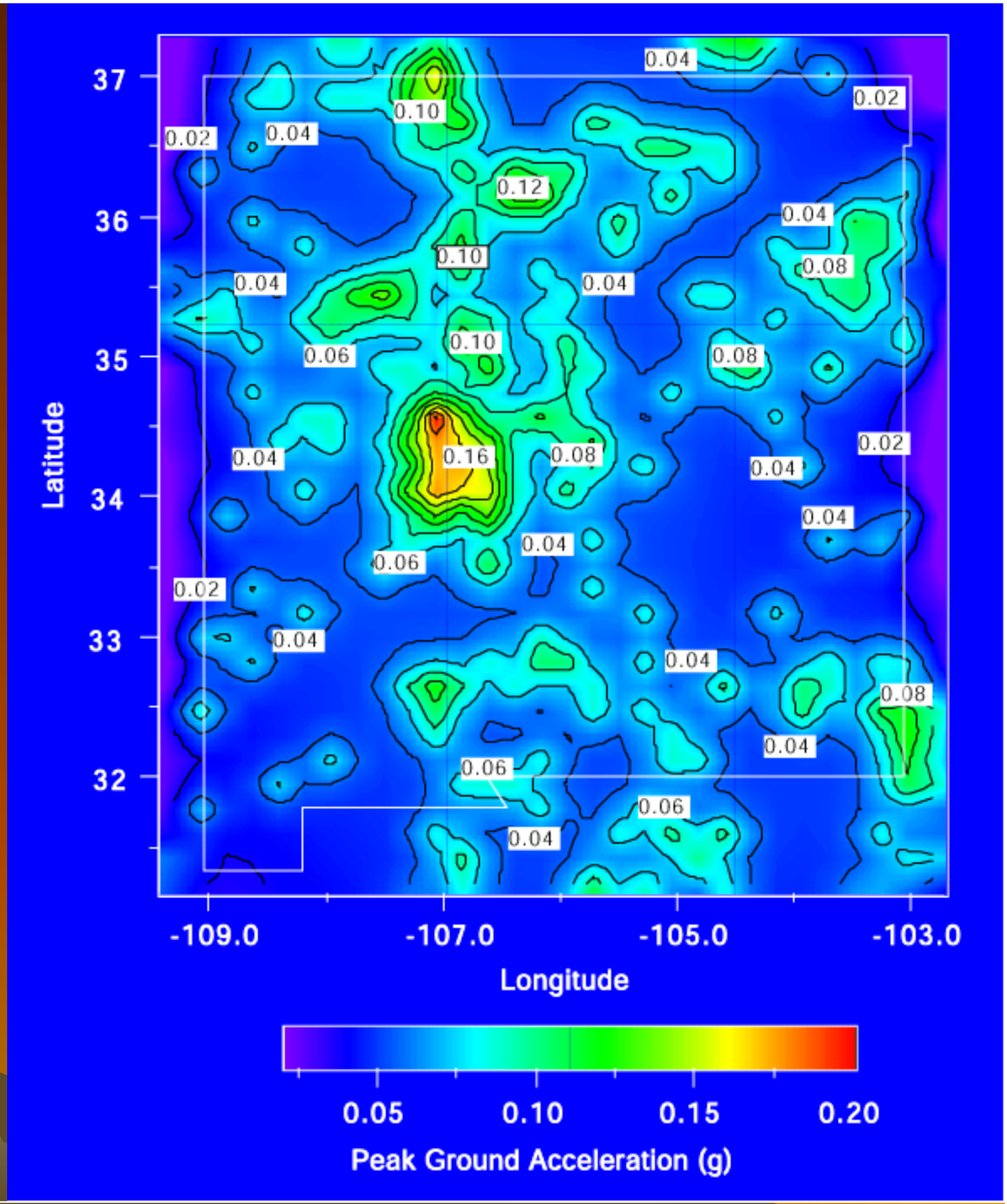


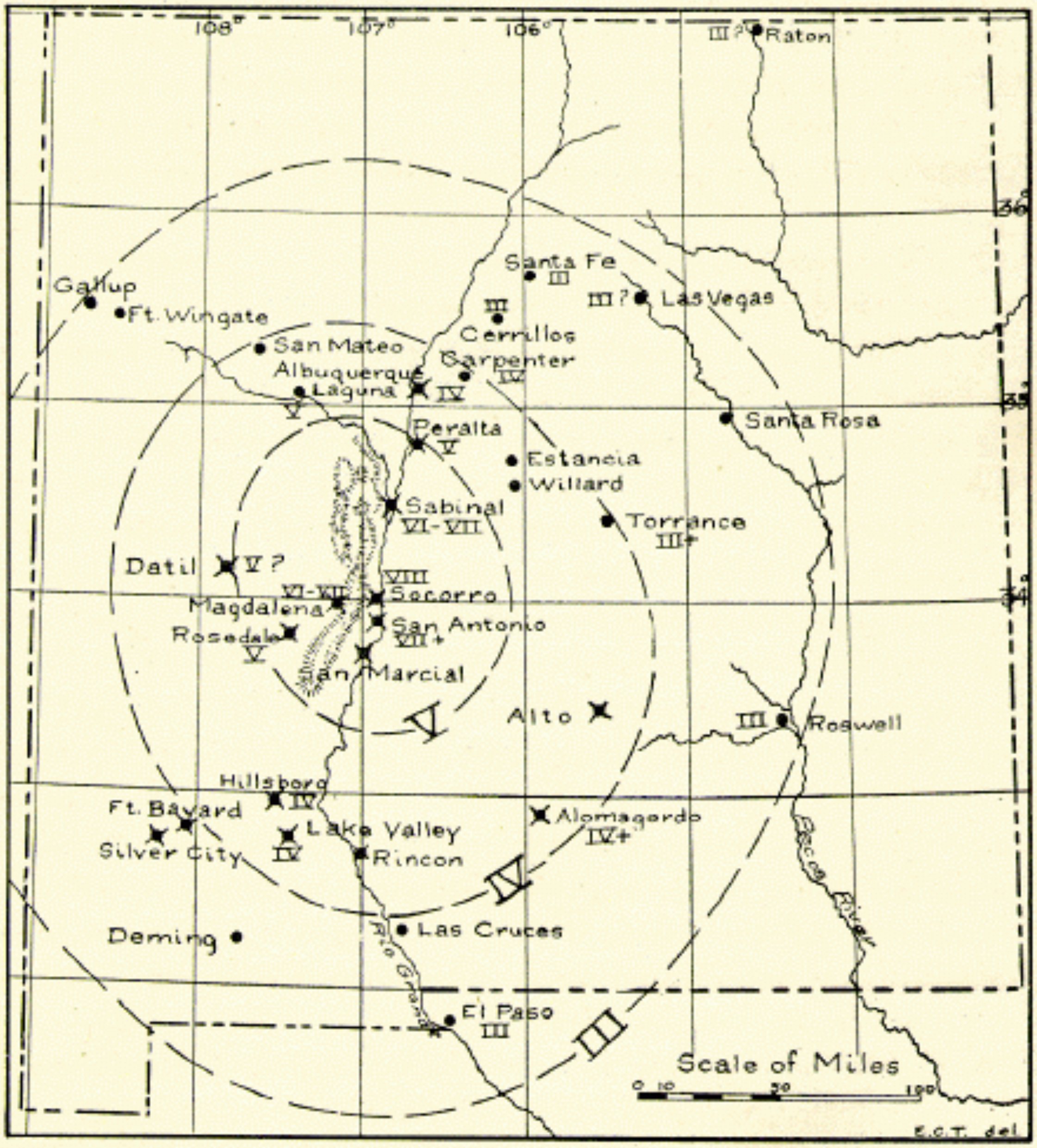
Hypothesis by Andy Newman to explain rapid uplift—still being tested

Peak Ground Acceleration at 10% probability of occurrence in a 50-year period

From Allan Sanford and Kuo-wan Lin

Probabilistic seismic hazard maps for New Mexico based on instrumental data show moderate to low seismic hazards



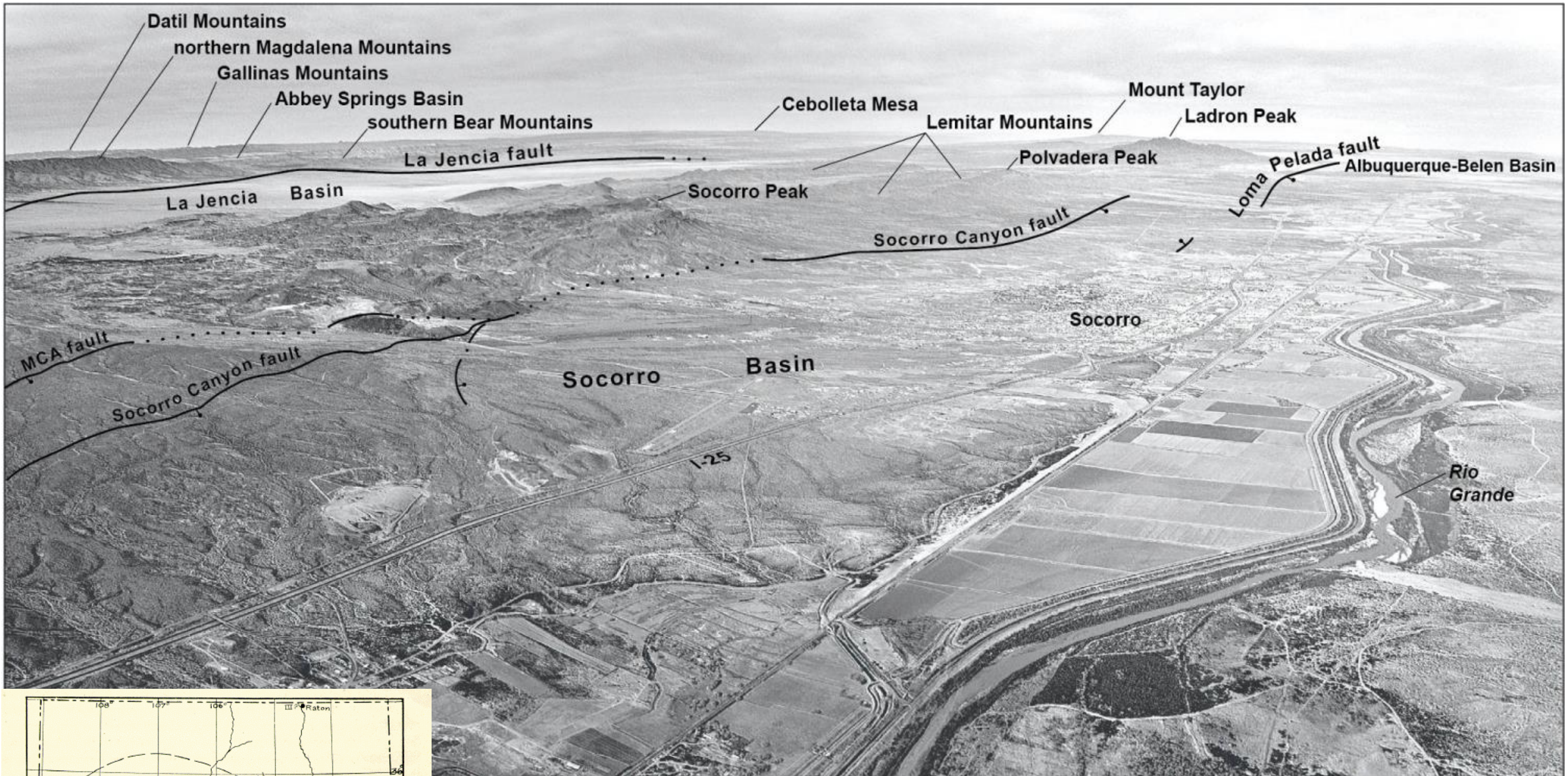


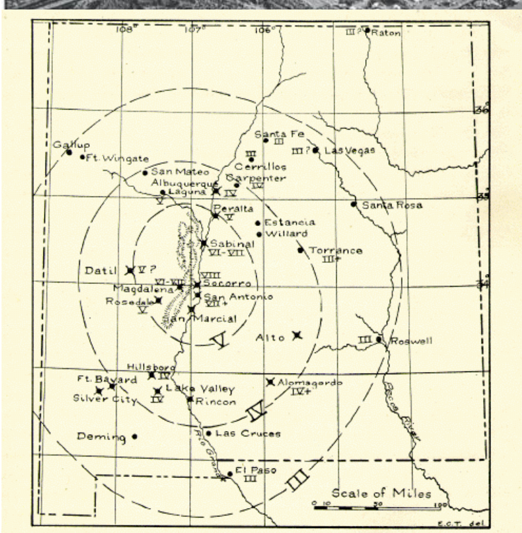
Map of New Mexico showing the isoseismals of the earthquake of November 15, 1906. Intensities (R.-F. scale) are indicated by Roman numerals. The towns marked with a cross reported the shock of July 2 or July 16.

Courtesy Smith family

Very similar in size to 1987 Whittier Narrows earthquake in California,

$522 million damage





Map of New Mexico showing the isoseismals of the earthquake of November 15, 1906. Intensities (R.-F. scale) are indicated by Roman numerals. The towns marked with a cross reported the shock of July 2 or July 16.

12 July 1906 M 5.57

16 July 1906 M 5.76

15 November 1906 M 6.18

Sanford (2008)

NM's Top five priorities through 2017

- 1. Need to upgrade seismic network
- 2. Rincon Ridge fault study if possible
- 3. northern Alamogordo fault
- 4. faults of Mesilla Basin
- 5. faults of Albuquerque Basin
- 6. southern San Andres Mountains

Oregon

Ian Madin, Oregon Department of Geology and Mineral Industries (DOGAMI)

(presented by Rich Briggs)

USGS

Oregon faults ranked in 2008

9. Metolius-Sisters faults, OR

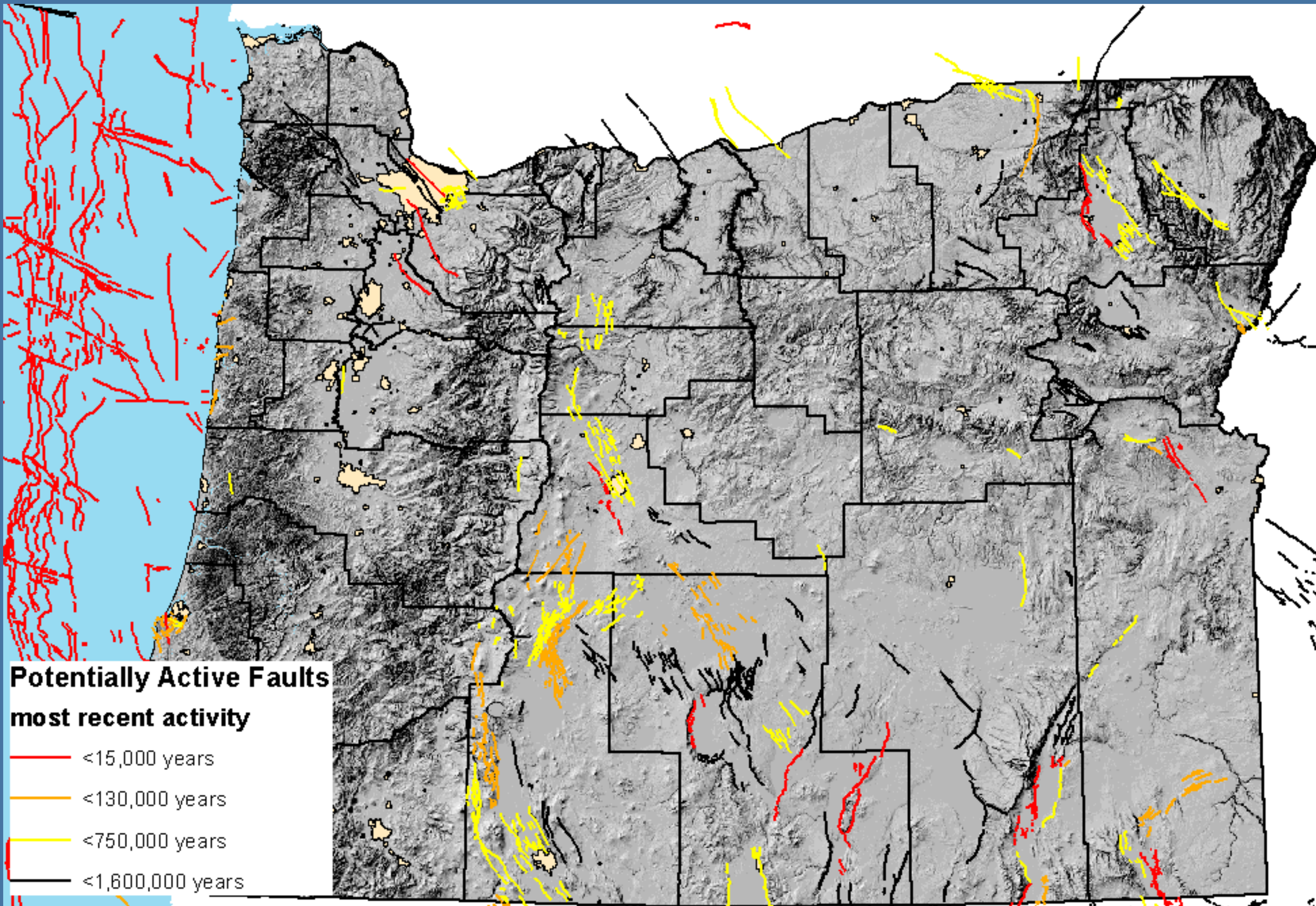
11. Klamath graben faults, OR

20. Wallula fault, OR

23. Powder River Peninsula fault, OR

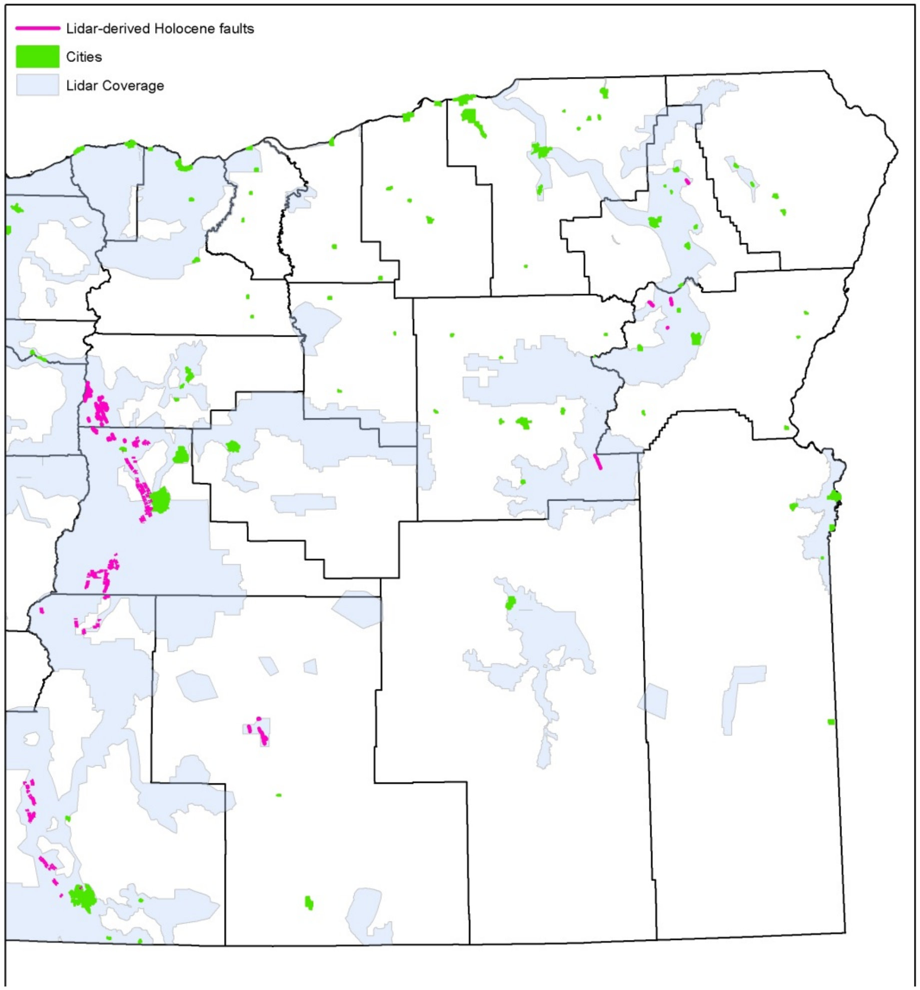
38. Grande Ronde Valley fault, OR

Basin And Range faults in Oregon

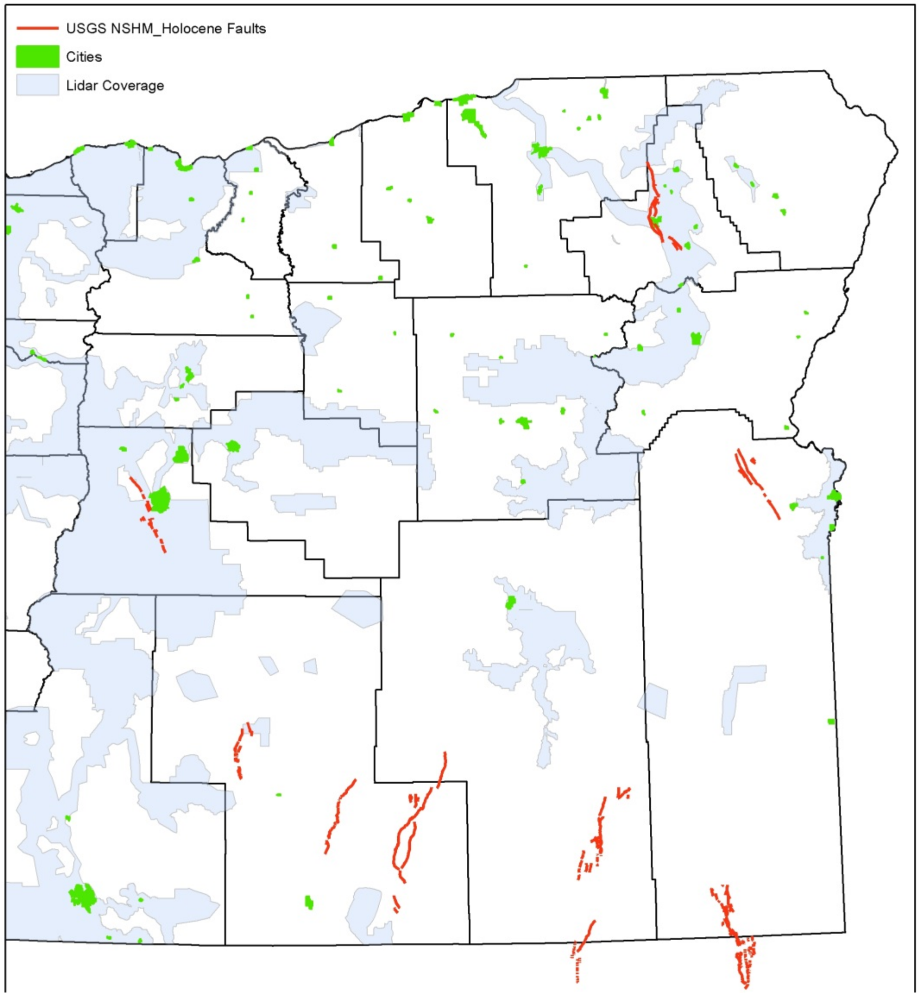


High Resolution Lidar data collected since 2007 has identified numerous Holocene faults in the Oregon Basin and Range even though none of the lidar was collected for the purpose of fault identification. Even in desert areas of Oregon, lidar is an essential tool for comprehensive identification and characterization of active faults. In addition to identifying several completely new faults, some previously mapped faults are not supported by the lidar topography.

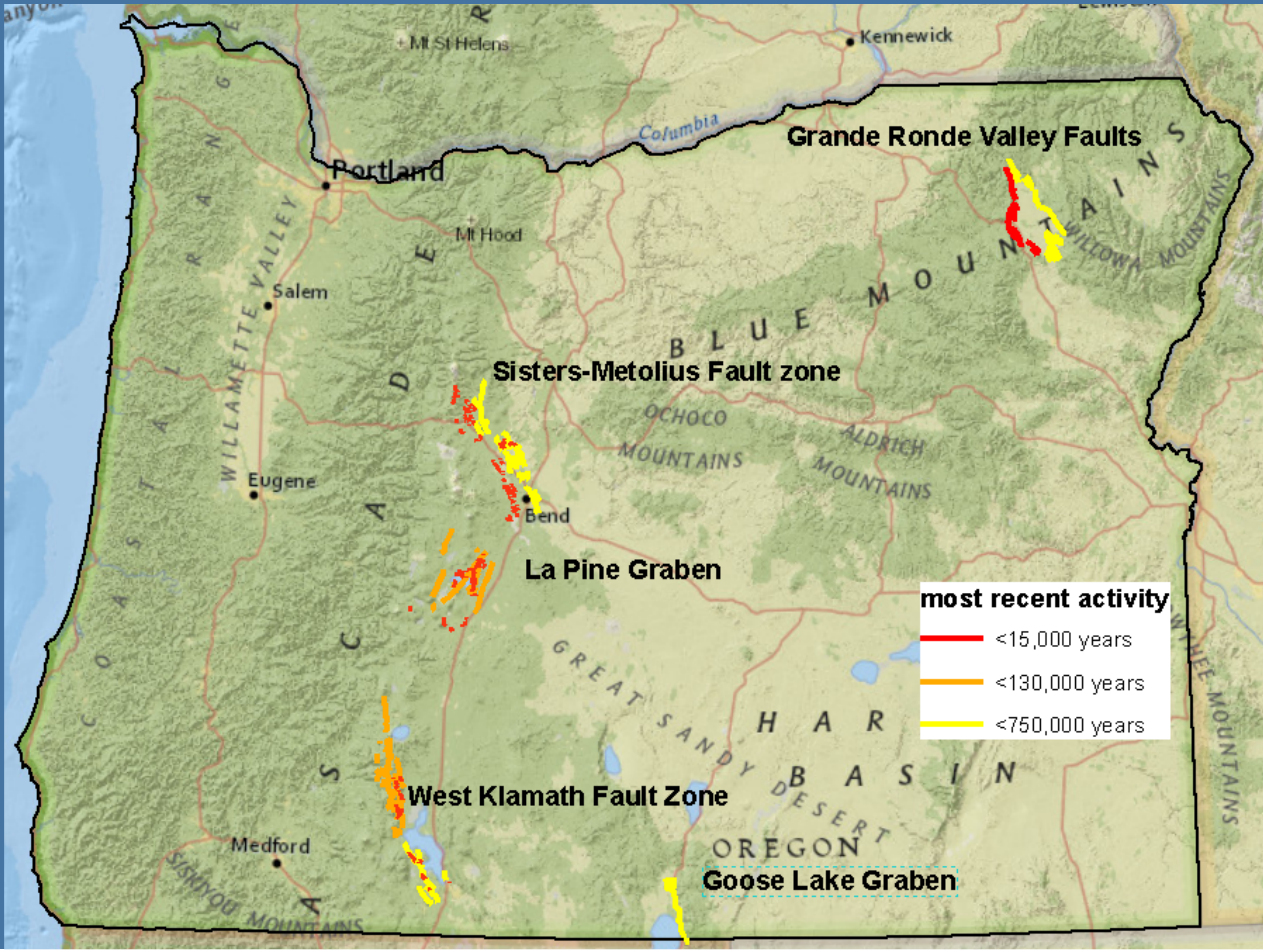
Holocene Basin and Range Faults identified with new lidar



Holocene Basin and Range Faults from 2003 USGS database (O-03-095)

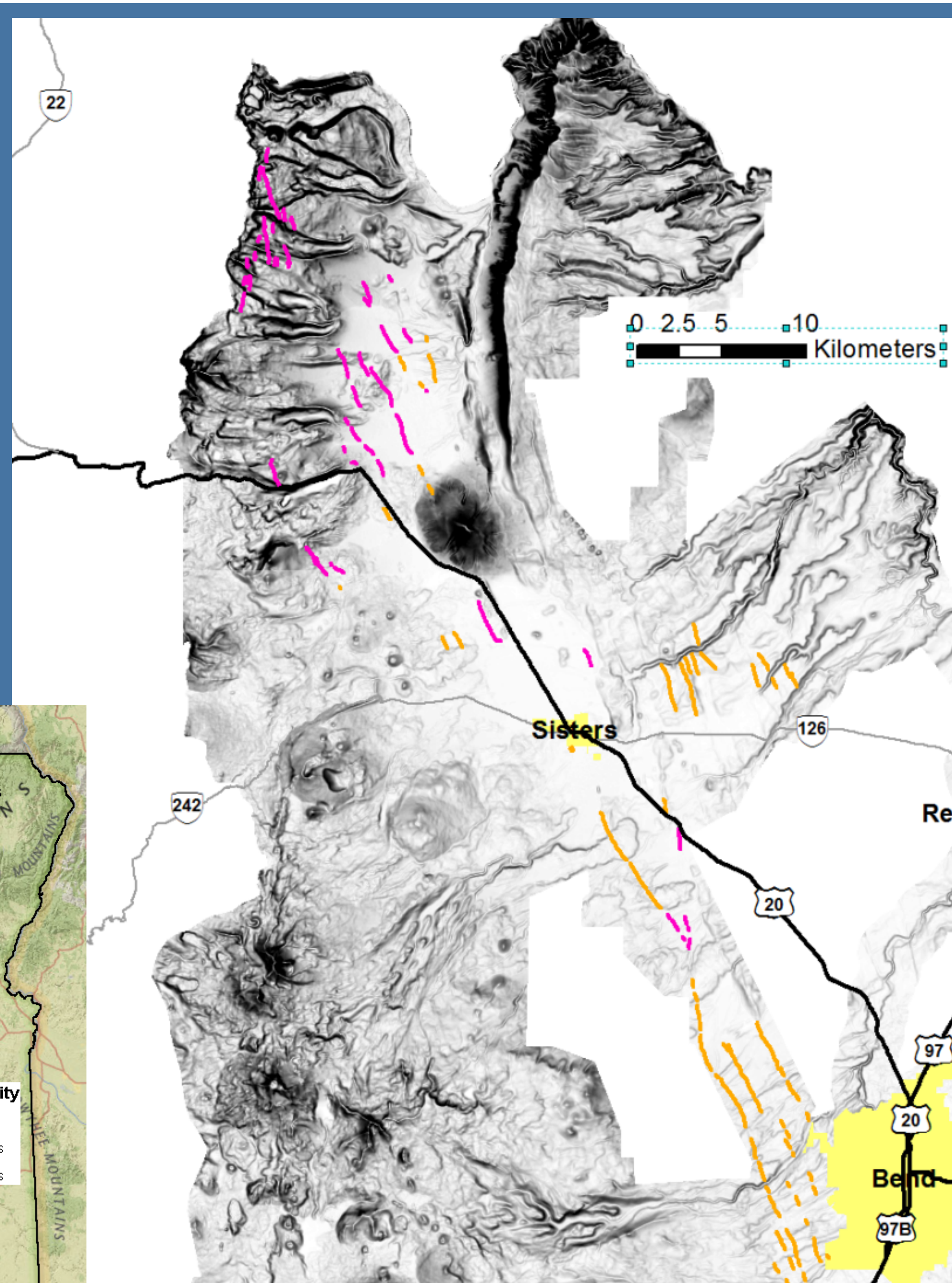


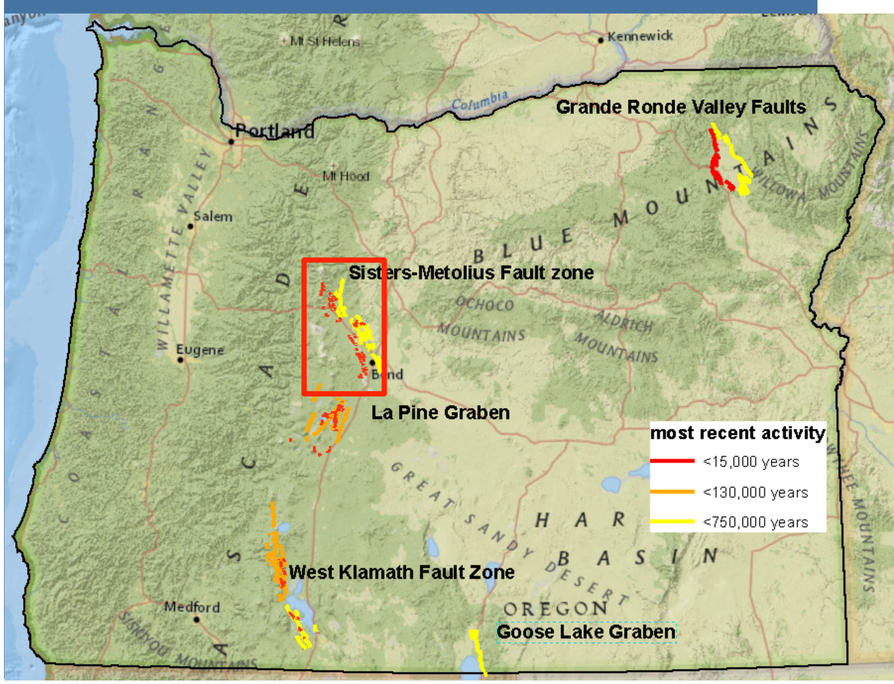
Oregon "Top Five" faults



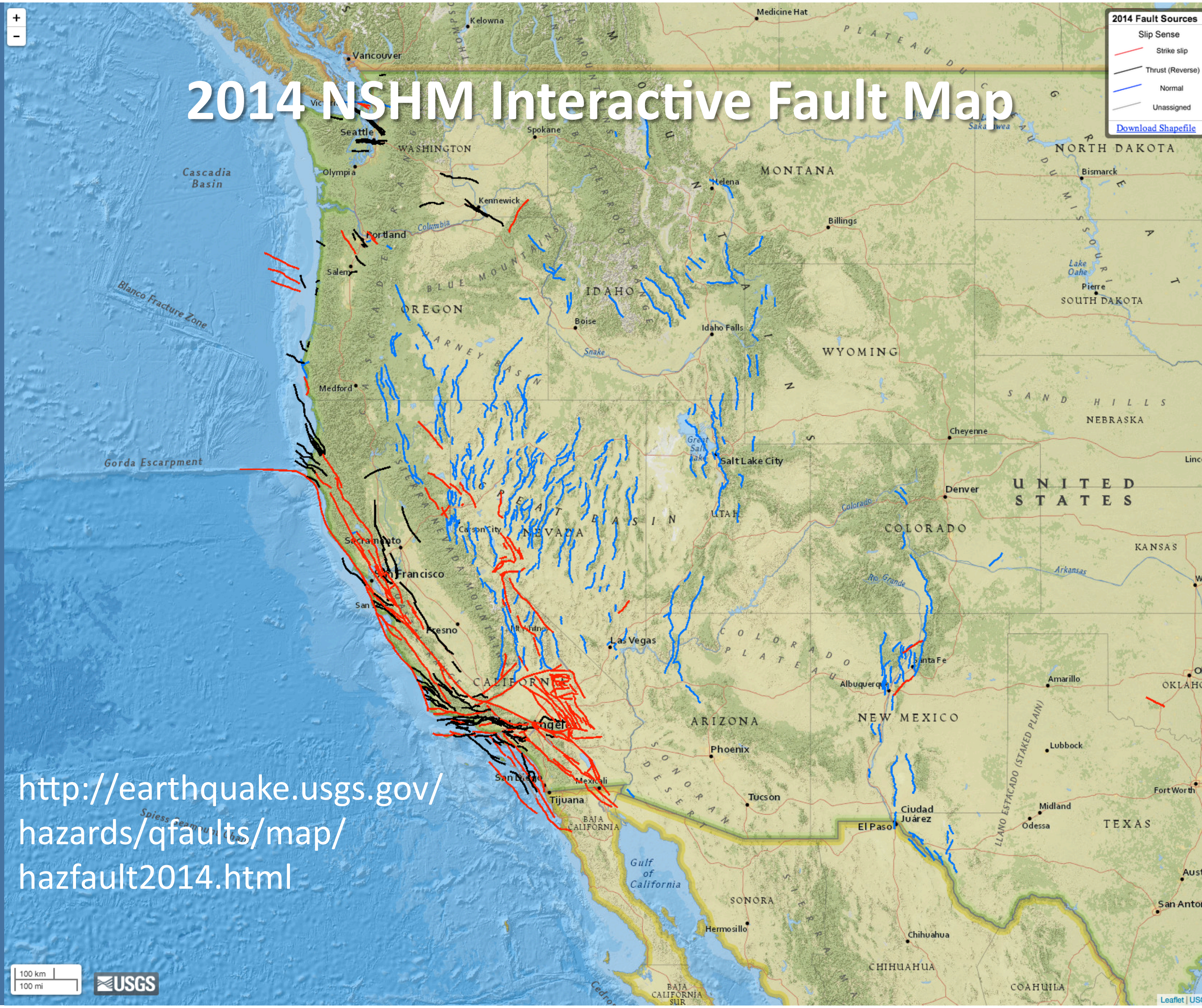
Sisters -Metolius Fault Zone

- Many cut last glacial deposits (pink) in steep, heavily glaciated and volcanically active terrain
- Extend 85 km from Bend to Mt. Jefferson (NW edge of lidar coverage)
- Estimated offset of ~20 ka surface of 7.6 m and 12. 2 m, slip rate ~0.38 and 0.61 mm/yr
- NSHM Metolius fault source crudely coincident in part, with slip rate of .038 mm/yr
- Population at risk ~ 200,000

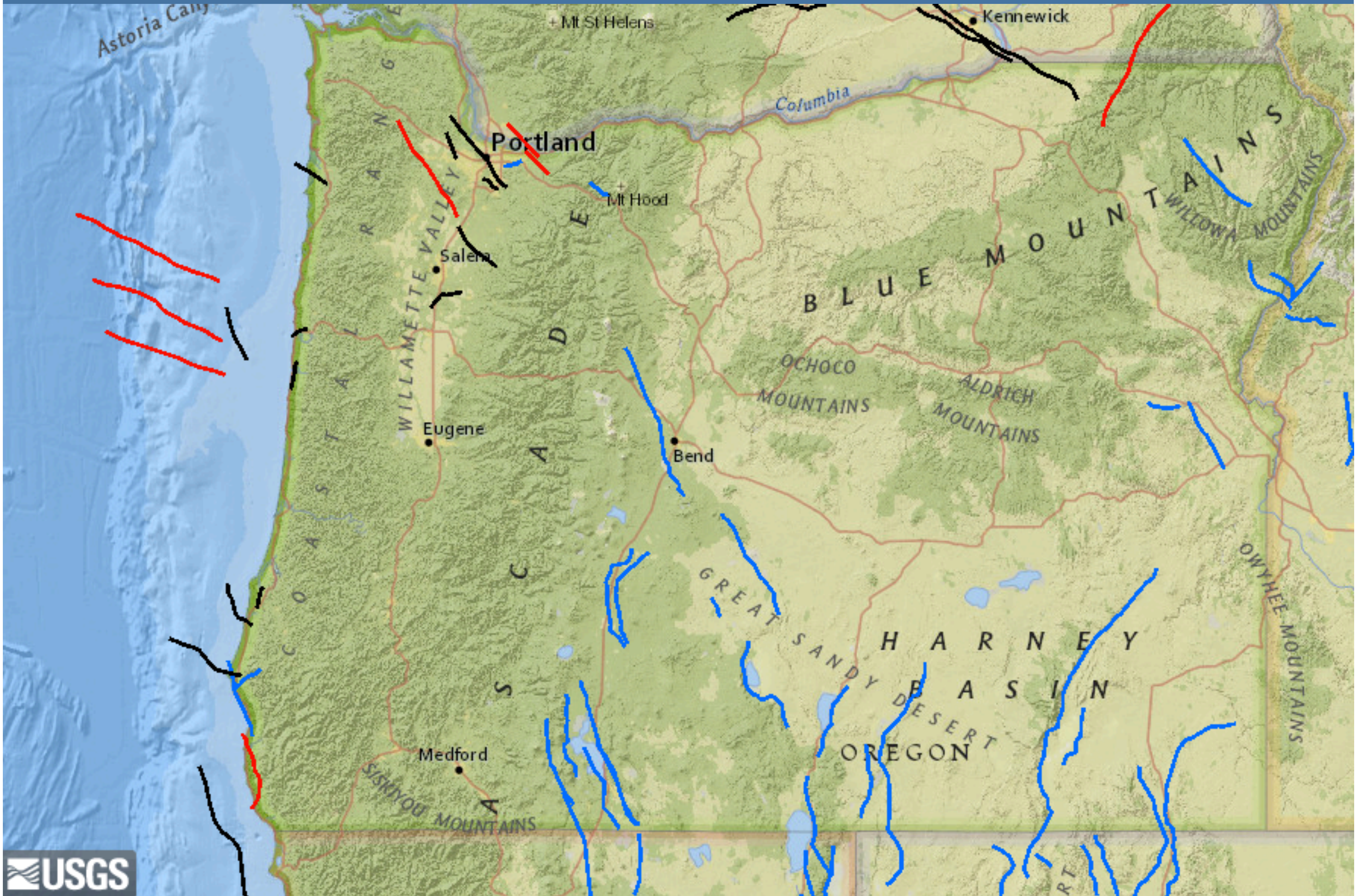




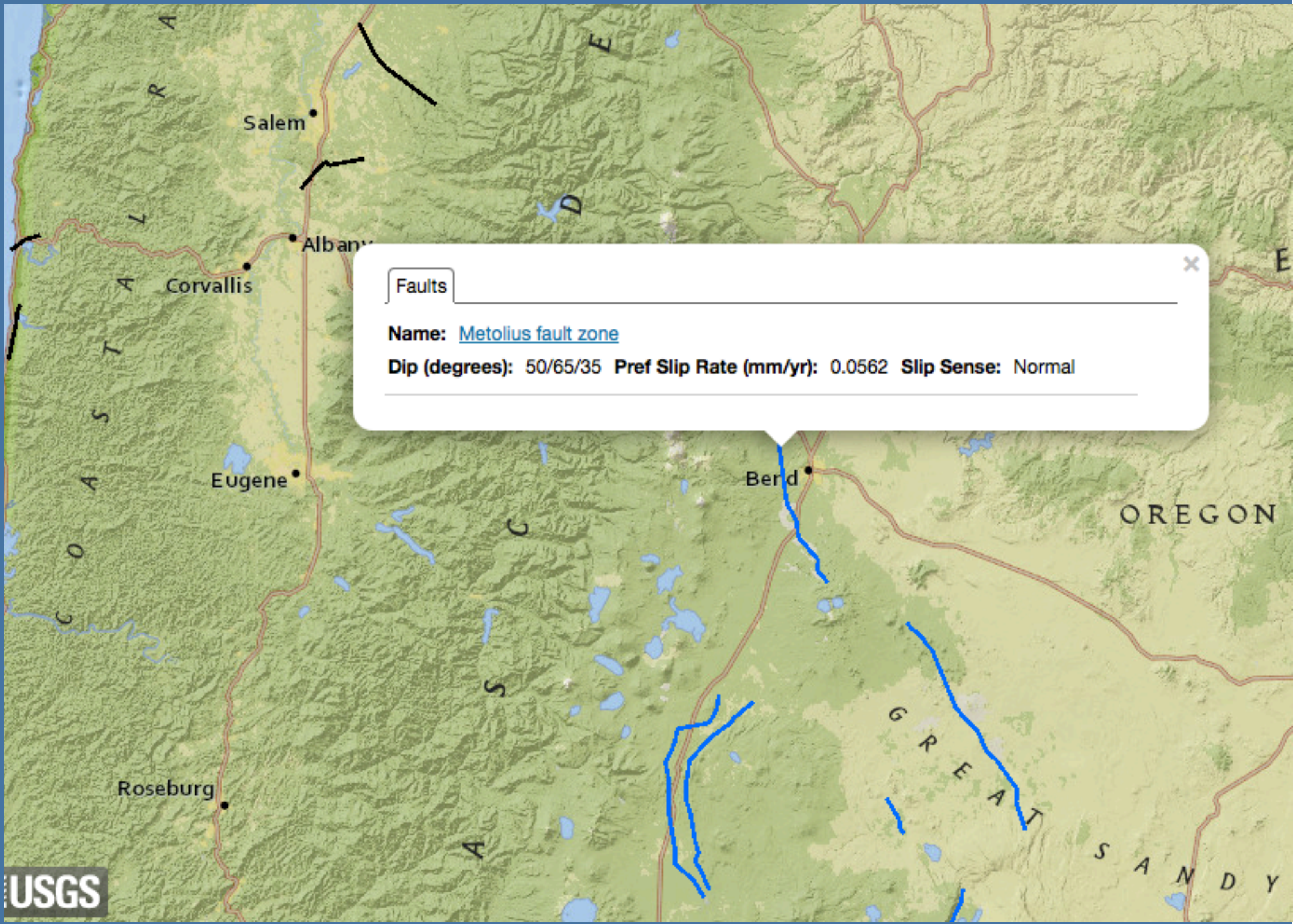
2014 NSHM Interactive Fault Map



http://earthquake.usgs.gov/hazards/qfaults/map/hazfault2014.html

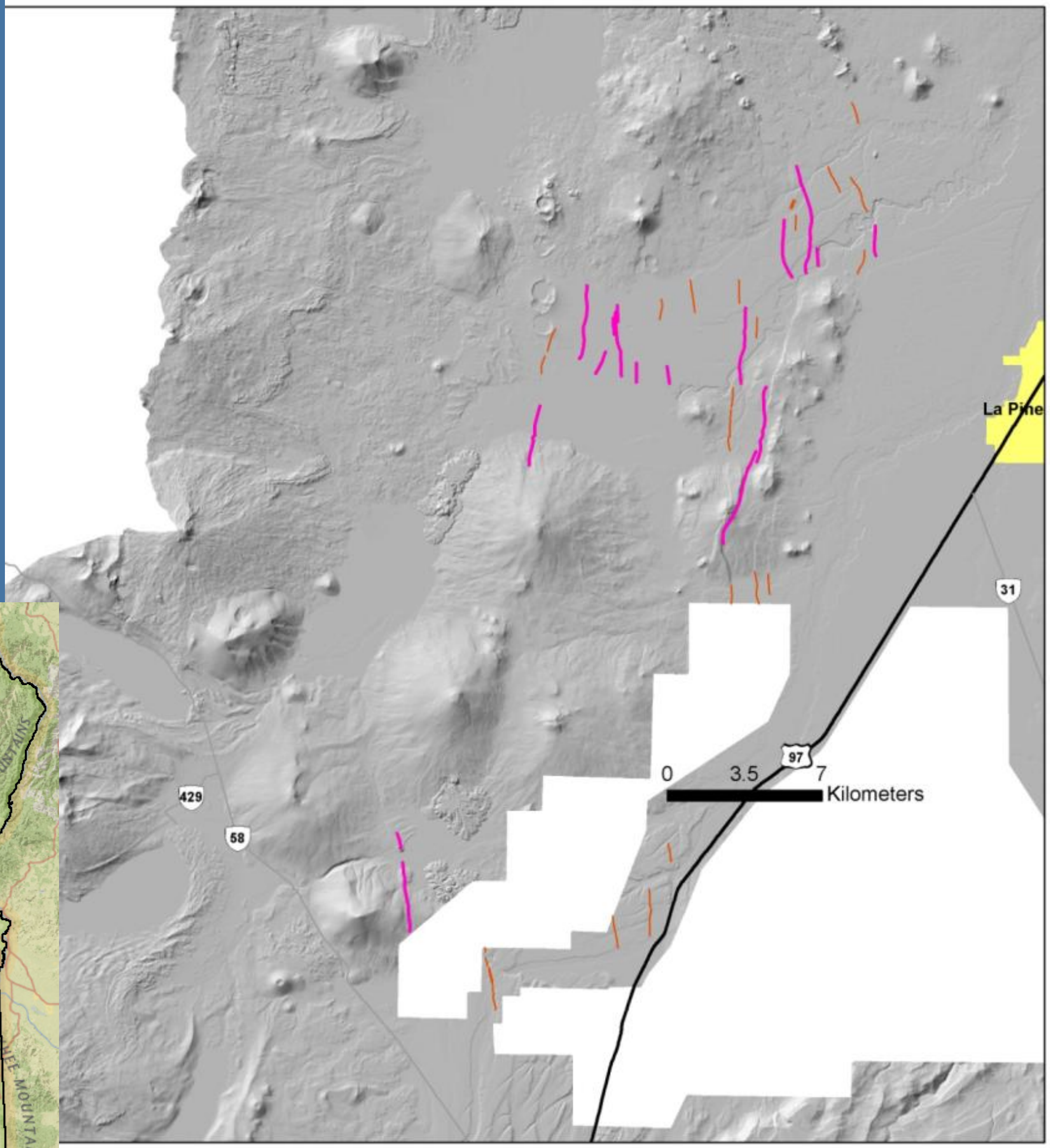


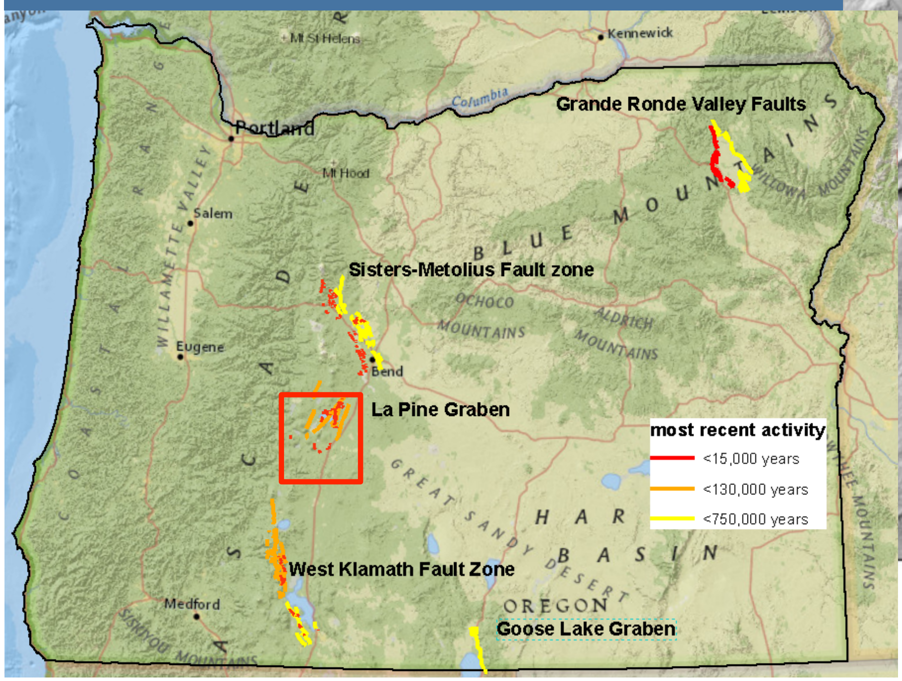
Astoria Canyon
Mt St Helens
Kennewick
Columbia
Portland
Mt Hood
Salem
Eugene
Bend
Medford
COAST RANGE
WILLAMETTE VALLEY
CASCADE
BLUE MOUNTAINS
WALLOWA MOUNTAINS
OCHOCO MOUNTAINS
ALDRICH MOUNTAINS
GREAT SANDY DESERT
HARNEY BASIN
OREGON
OWYHEE MOUNTAINS
SISKIYOU MOUNTAINS
USGS

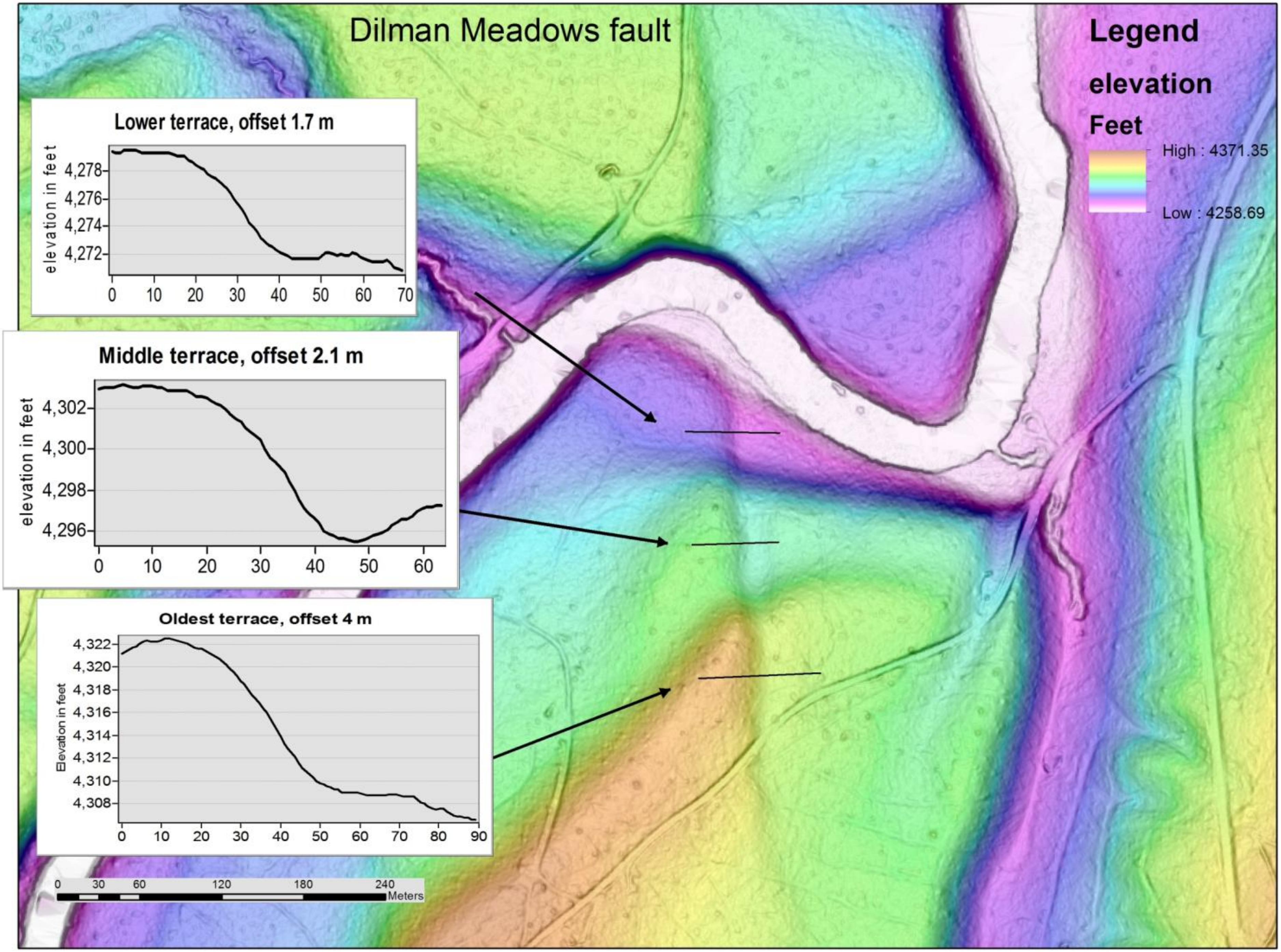

Salem
Albany
Corvallis
Eugene
Roseburg
Bend
OREGON
COAST RANGE
CASCADE
GREAT SANDY
Faults
Name: Metolius fault zone
Dip (degrees): 50/65/35 Pref Slip Rate (mm/yr): 0.0562 Slip Sense: Normal
USGS

La Pine Graben Faults

- Many faults identified from lidar, cut 20 ka last glacial deposits in volcanically active terrain(pink)
- Extend 20 km, longest continuous trace ~10 km
- 3 are in Quaternary fault database, not included as source in NSHM.
- Dilman Meadows scarp has three events post 20Ka, .5 to 2 m offset each, most recent post 7 ka.







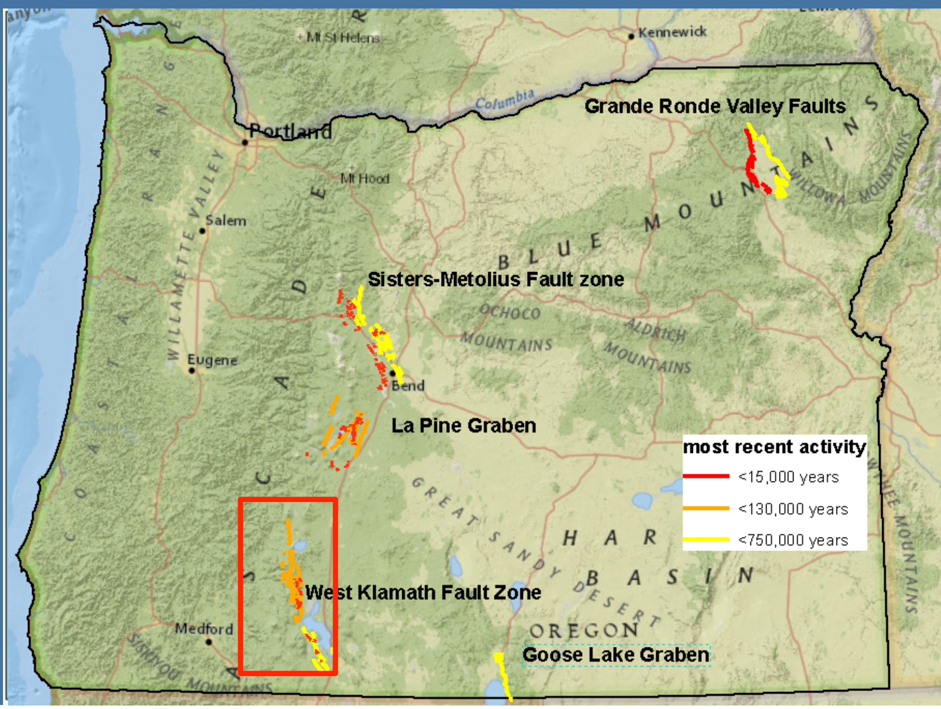
Dilman Meadows fault
Legend
elevation
Feet
High : 4371.35
Low : 4258.69
Lower terrace, offset 1.7 m
elevation in feet
4,278
4,276
4,274
4,272
0 10 20 30 40 50 60 70
Middle terrace, offset 2.1 m
elevation in feet
4,302
4,300
4,298
4,296
0 10 20 30 40 50 60
Oldest terrace, offset 4 m
Elevation in feet
4,322
4,320
4,318
4,316
4,314
4,312
4,310
4,308
0 10 20 30 40 50 60 70 80 90
0 30 60 120 180 240
Meters

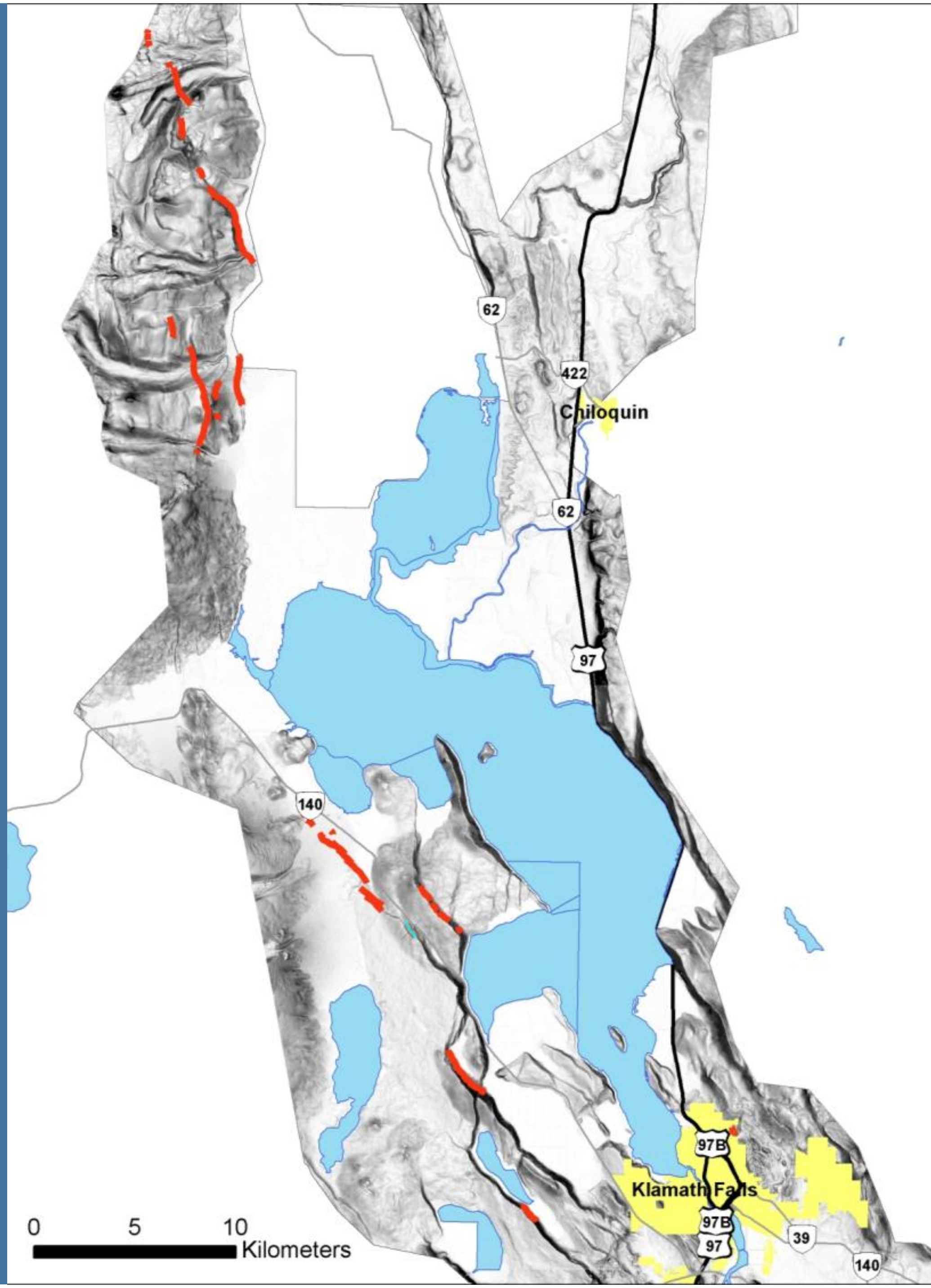
West Klamath Fault Zone

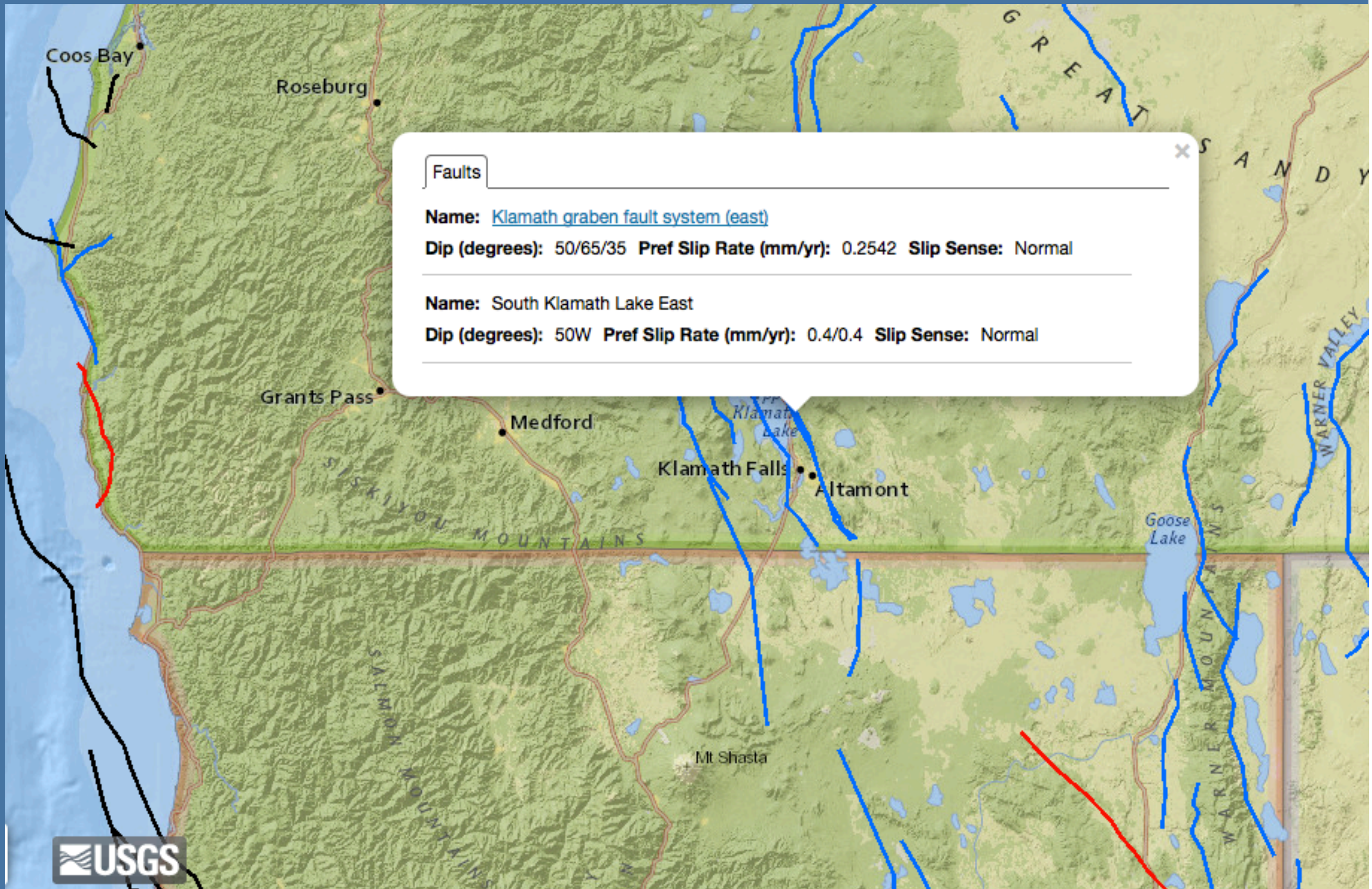
Scarps from lidar up to 13m high, more typically 1-2m high in 20 ka glacial deposits, or very young fans, extend 60 km along west side of Klamath Lake

West Klamath Fault zone is in Quaternary fault database and is source in NSHM, but all are given either 130 ka or 750 ka age class, whereas these scarps are Holocene.

Klamath Falls urban area experienced damaging earthquakes in 1993



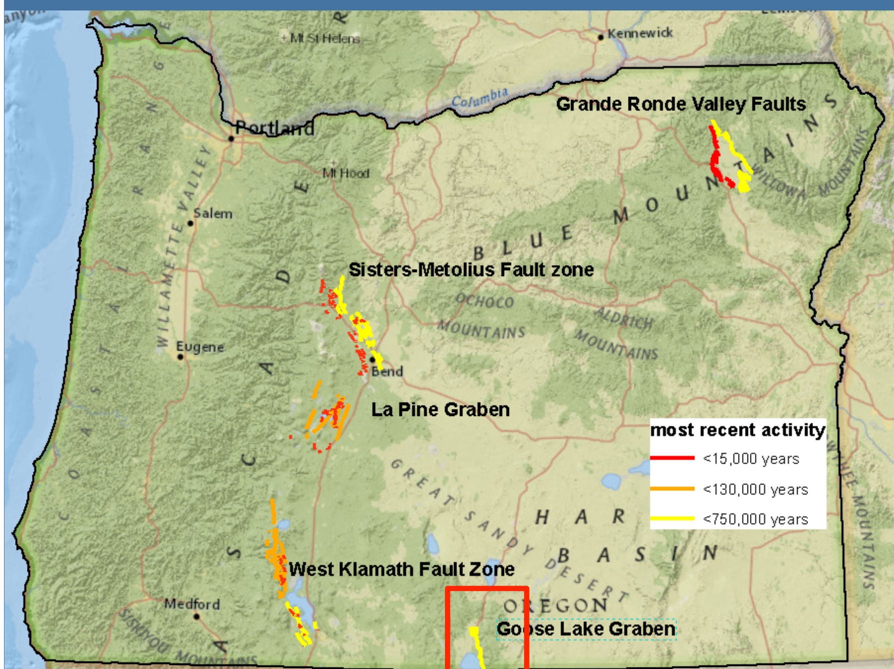


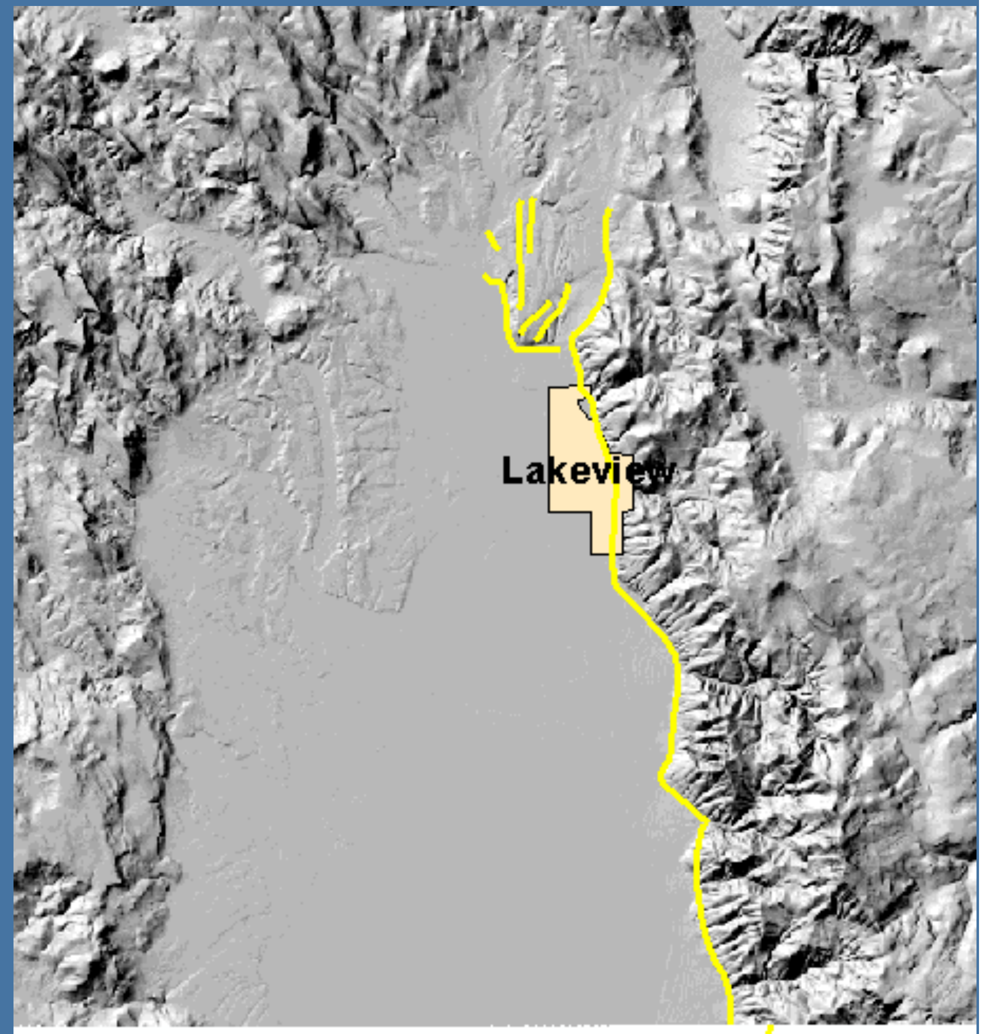


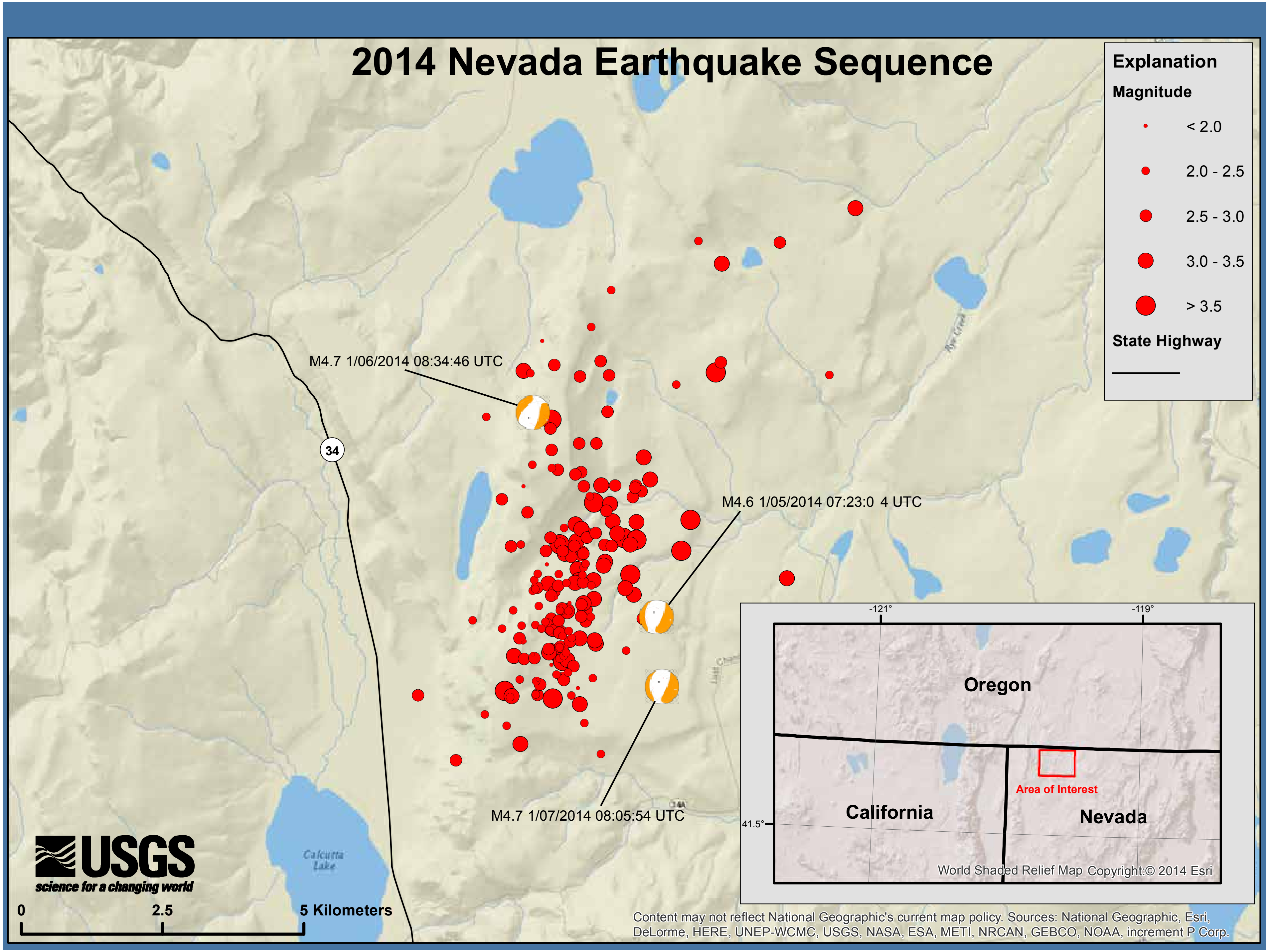
Faults
Name: Klamath graben fault system (east)
Dip (degrees): 50/65/35 Pref Slip Rate (mm/yr): 0.2542 Slip Sense: Normal
Name: South Klamath Lake East
Dip (degrees): 50W Pref Slip Rate (mm/yr): 0.4/0.4 Slip Sense: Normal
Coos Bay
Roseburg
Grants Pass
Medford
Klamath Falls
Altamont
Mt Shasta
Goose Lake

Goose Lake Graben Faults

- Fault passes through city of Lakeview
- In Quaternary fault database, not included as source in NSHM.
- Significant recent seismicity beneath Lakeview
- Lidar to be flown in 2015 (notfor seismic hazards, but for irrigation management)

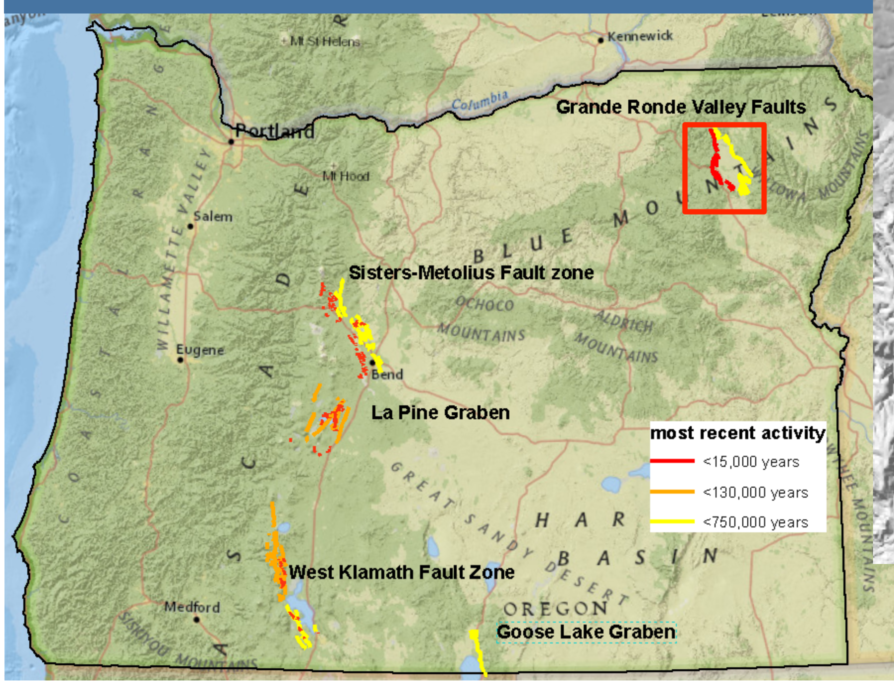


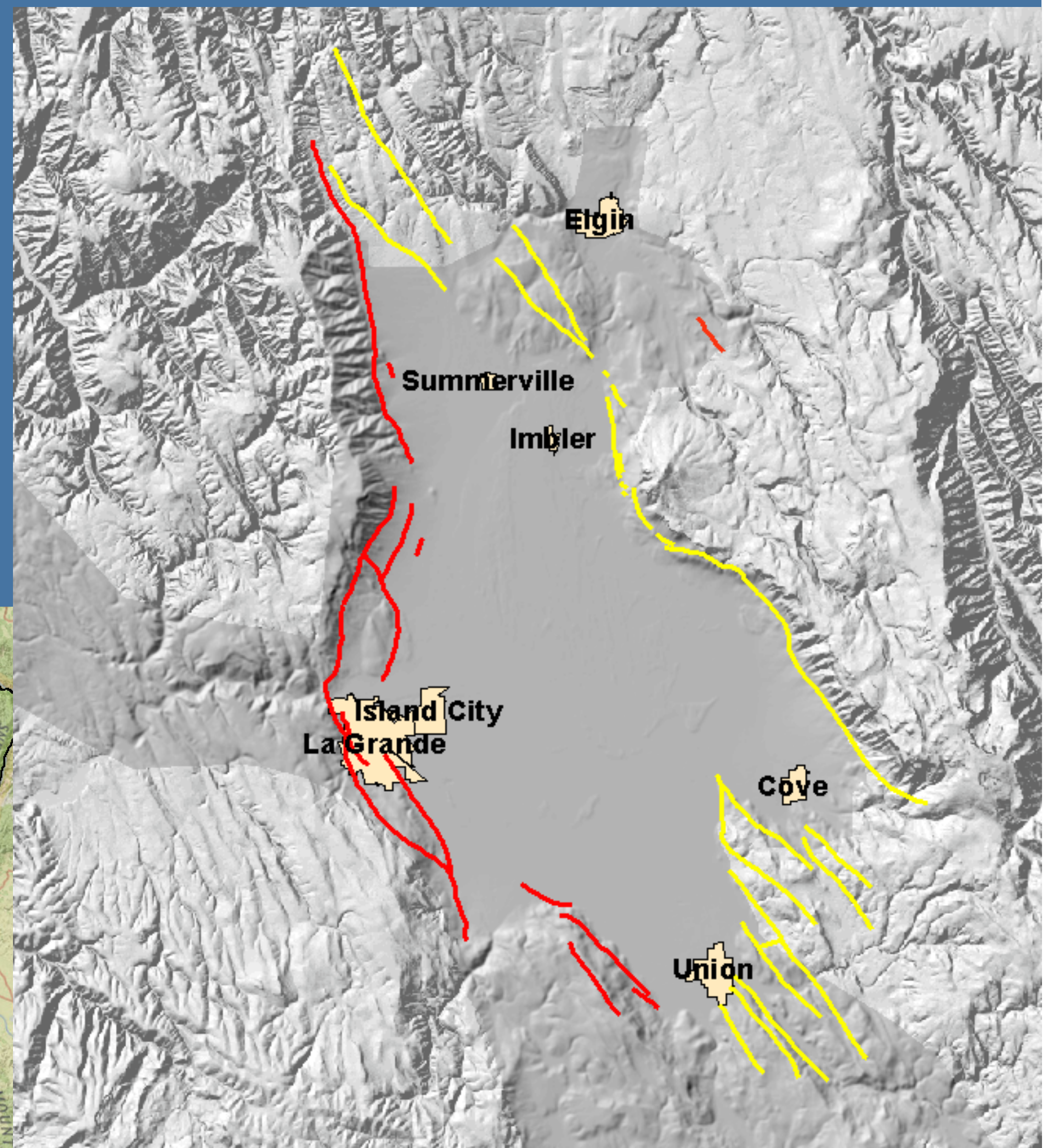


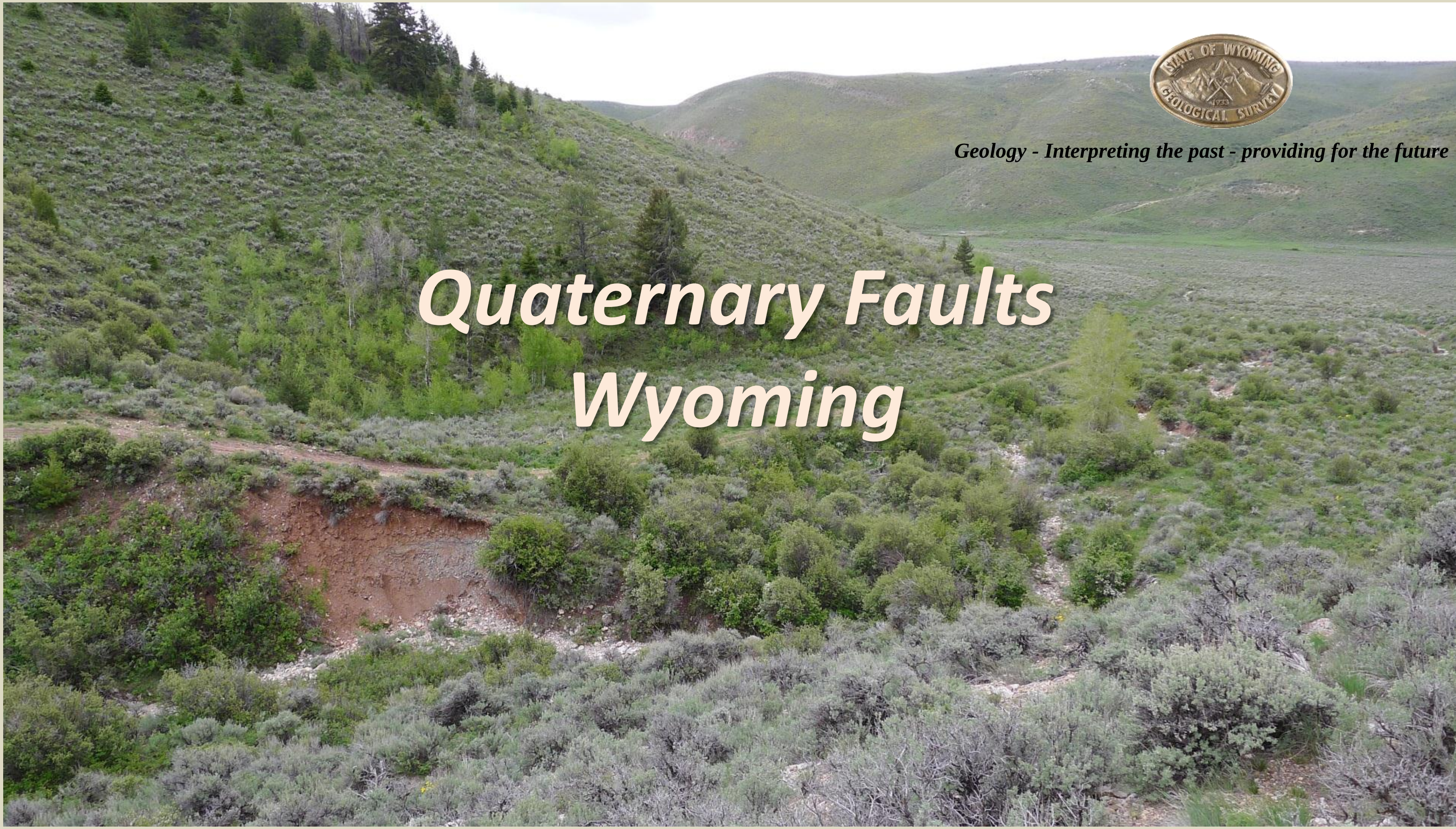

2014 Nevada Earthquake Sequence
Explanation
Magnitude
< 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
> 3.5
State Highway
M4.7 1/06/2014 08:34:46 UTC
M4.6 1/05/2014 07:23:0 4 UTC
M4.7 1/07/2014 08:05:54 UTC
34
Calcutta Lake
USGS
science for a changing world
0
2.5
5 Kilometers
-121°
-119°
41.5°
Oregon
California
Nevada
Area of Interest
World Shaded Relief Map Copyright:© 2014 Esri
Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Grande Ronde Valley Faults

- Many faults mapped, in Quaternary database, not a source in NSHM
- Lidar coverage shows most previously identified scarps are actually landslides along trace of fault
- Population of 25,000 at risk
- Faults are generally located on bedrock/colluvium slopes, do not cross many Quaternary deposits







Rock Creek Fault: Photo by Seth Wittke

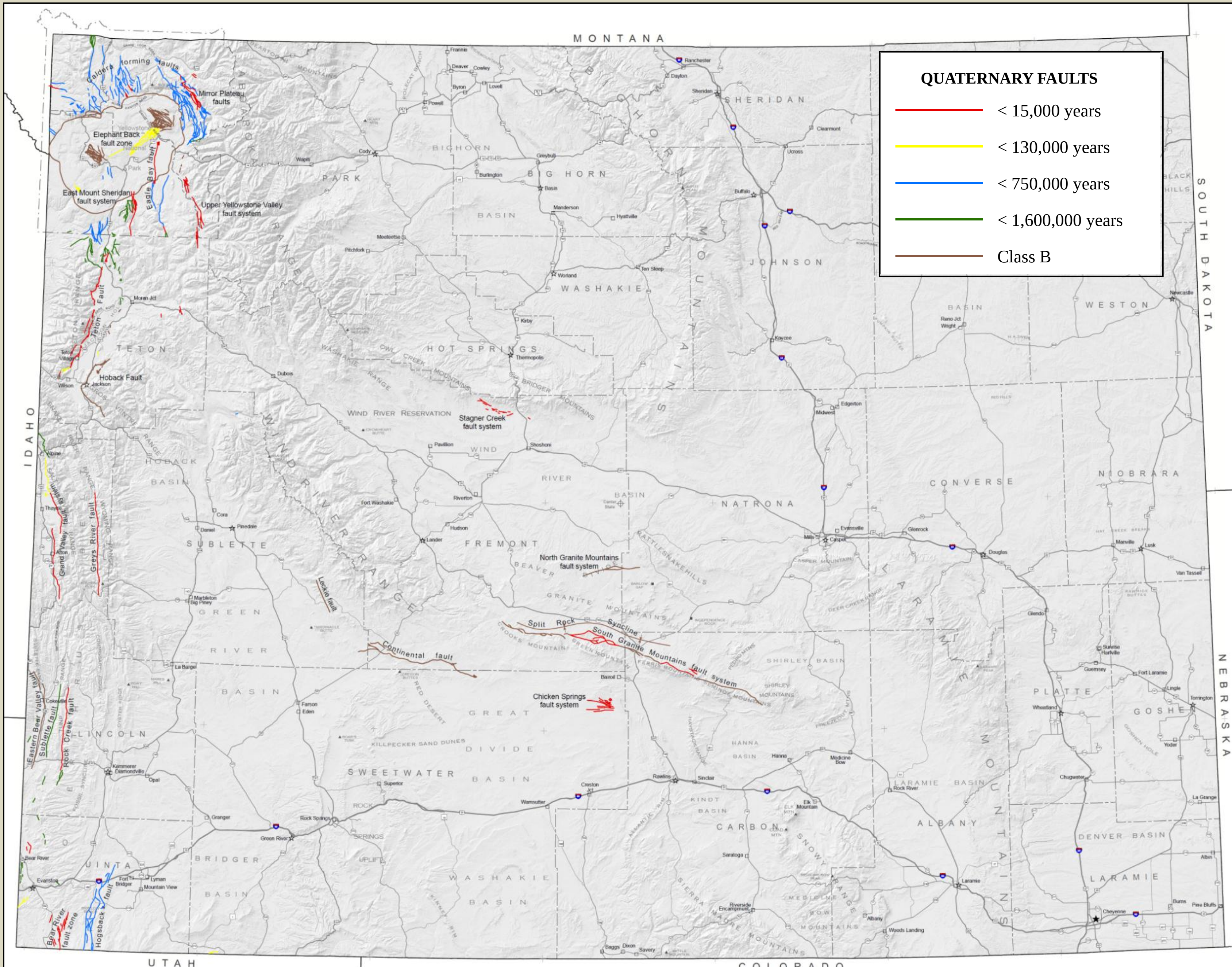
Wyoming State Geological Survey

Mort Larsen

BRPSHS III

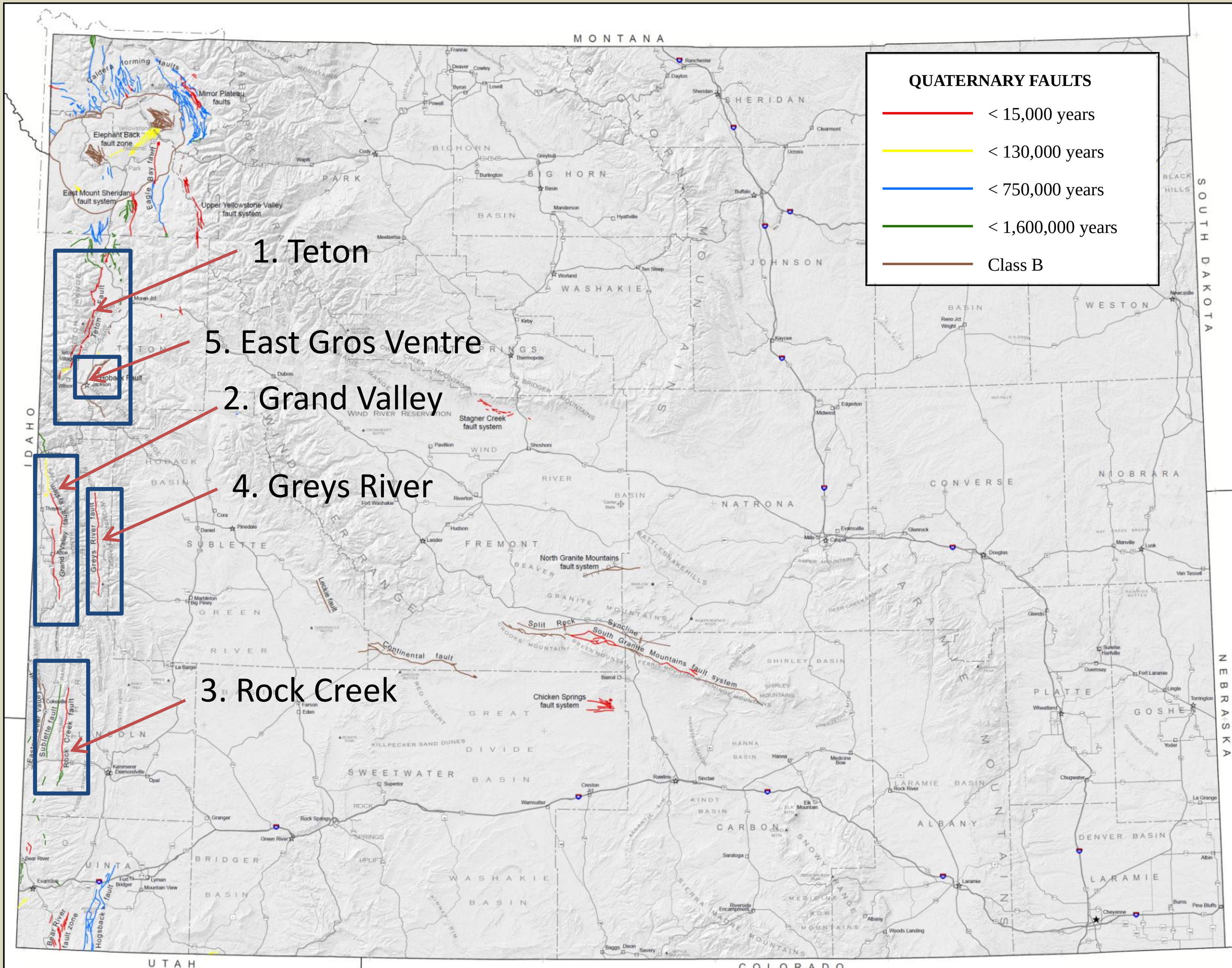
January 12,2015

martin.larsen@wyo.gov
307.766.2286 ext.233


QUATERNARY FAULTS
< 15,000 years
< 130,000 years
< 750,000 years
< 1,600,000 years
Class B
MONTANA
SOUTH DAKOTA
NEBRASKA
COLORADO
UTAH
IDAHO
Caldera forming faults
Mirror Plateau faults
Elephant Back fault zone
East Mount Sheridan fault system
Eagle Bay fault
Upper Yellowstone Valley fault system
Teton Fault
Hoback Fault
Stagner Creek fault system
North Granite Mountains fault system
Leckie fault
Continental fault
Split Rock Syncline
South Granite Mountains fault system
Chicken Springs fault system
Grand Valley fault
Greys River fault
Eastern Bear Valley fault
Sublette fault
Rock Creek fault
Bear River fault zone
Hogsback fault
SHERIDAN
BIG HORN
PARK
JOHNSON
WASHAKIE
HOT SPRINGS
TETON
WESTON
CAMPBELL
FREMONT
NATRONA
CONVERSE
NIOBRARA
SUBLETTE
LINCOLN
PLATTE
GOSHEN
SWEETWATER
CARBON
ALBANY
LARAMIE
UINTA
WIND RIVER RESERVATION
BIGHORN BASIN
WIND RIVER BASIN
GREEN RIVER BASIN
GREAT DIVIDE BASIN
WASHAKIE BASIN
BRIDGER BASIN
HANNA BASIN
SHIRLEY BASIN
LARAMIE BASIN
DENVER BASIN
Cody
Sheridan
Buffalo
Worland
Thermopolis
Jackson
Pinedale
Lander
Riverton
Casper
Douglas
Rawlins
Rock Springs
Green River
Evanston
Kemmerer
Laramie
Cheyenne
Wheatland
Torrington
Lusk
Newcastle

Top 5 Quaternary faults of concern in Wyoming (IMW)

1. Teton
2. Grand Valley
3. Rock Creek
4. Greys River
5. East Gros Ventre


QUATERNARY FAULTS
< 15,000 years
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< 750,000 years
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MONTANA
IDAHO
UTAH
COLORADO
SOUTH DAKOTA
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Mirror Plateau faults
Elephant Back fault zone
East Mount Sheridan fault system
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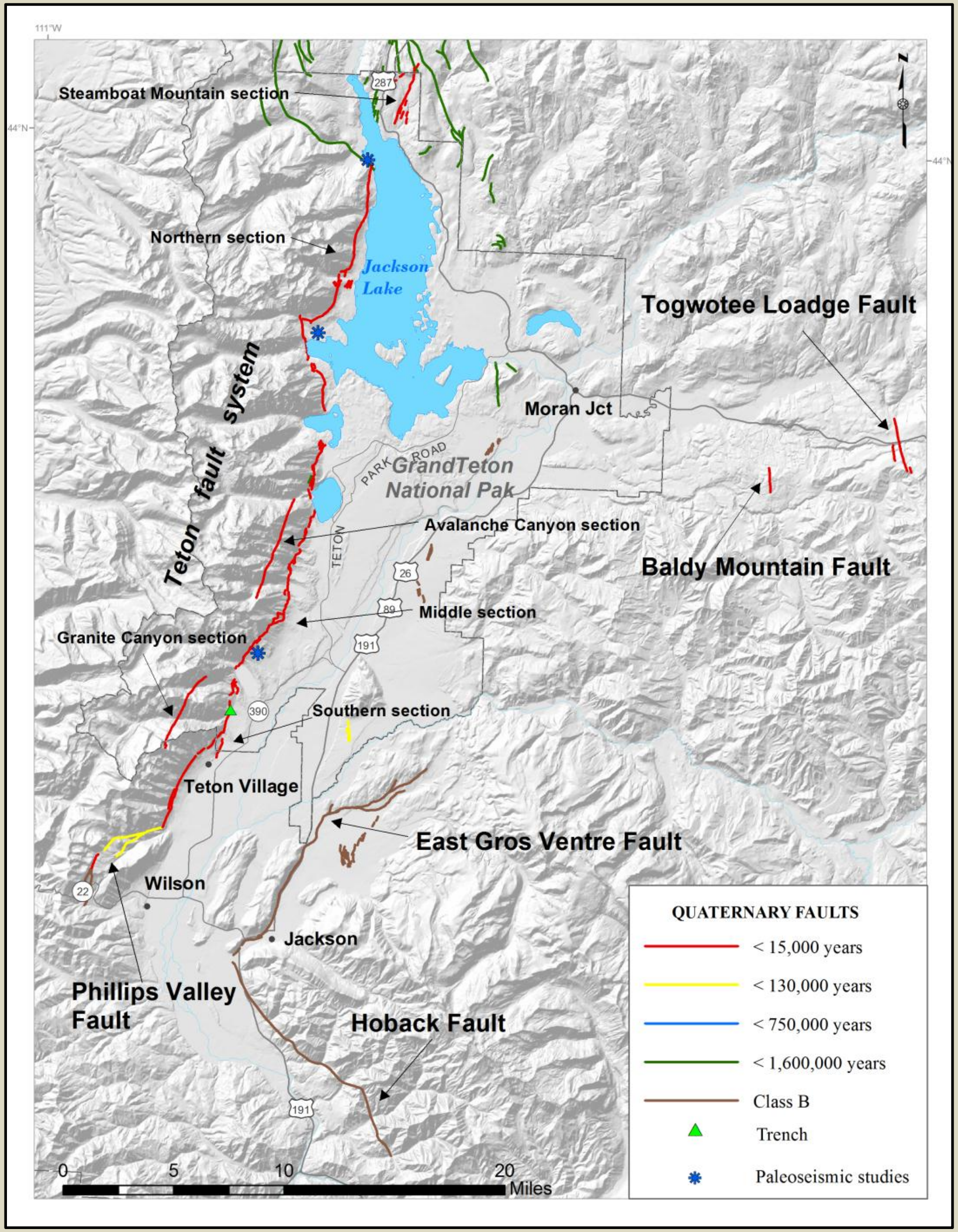
Eagle Bay fault
Teton fault
Hoback fault
Grand Valley fault
Greys River fault
Rock Creek fault
Sublette fault
Bear River fault zone
Stagner Creek fault system
North Granite Mountains fault system
Leckie fault
Continental fault
Split Rock Syncline
South Granite Mountains fault system
Chicken Springs fault system
BIGHORN BASIN
WIND RIVER BASIN
GREEN RIVER BASIN
GREAT DIVIDE BASIN
WASHAKIE BASIN
POWDER RIVER BASIN
DENVER BASIN
LARAMIE BASIN
SHIRLEY BASIN
HANNA BASIN
BRIDGER BASIN
PARK
BIG HORN
SHERIDAN
JOHNSON
WASHAKIE
WESTON
CONVERSE
NIOBRARA
NATRONA
FREMONT
SUBLETTE
LINCOLN
SWEETWATER
CARBON
ALBANY
PLATTE
GOSHEN
LARAMIE
UINTA
TETON
HOT SPRINGS

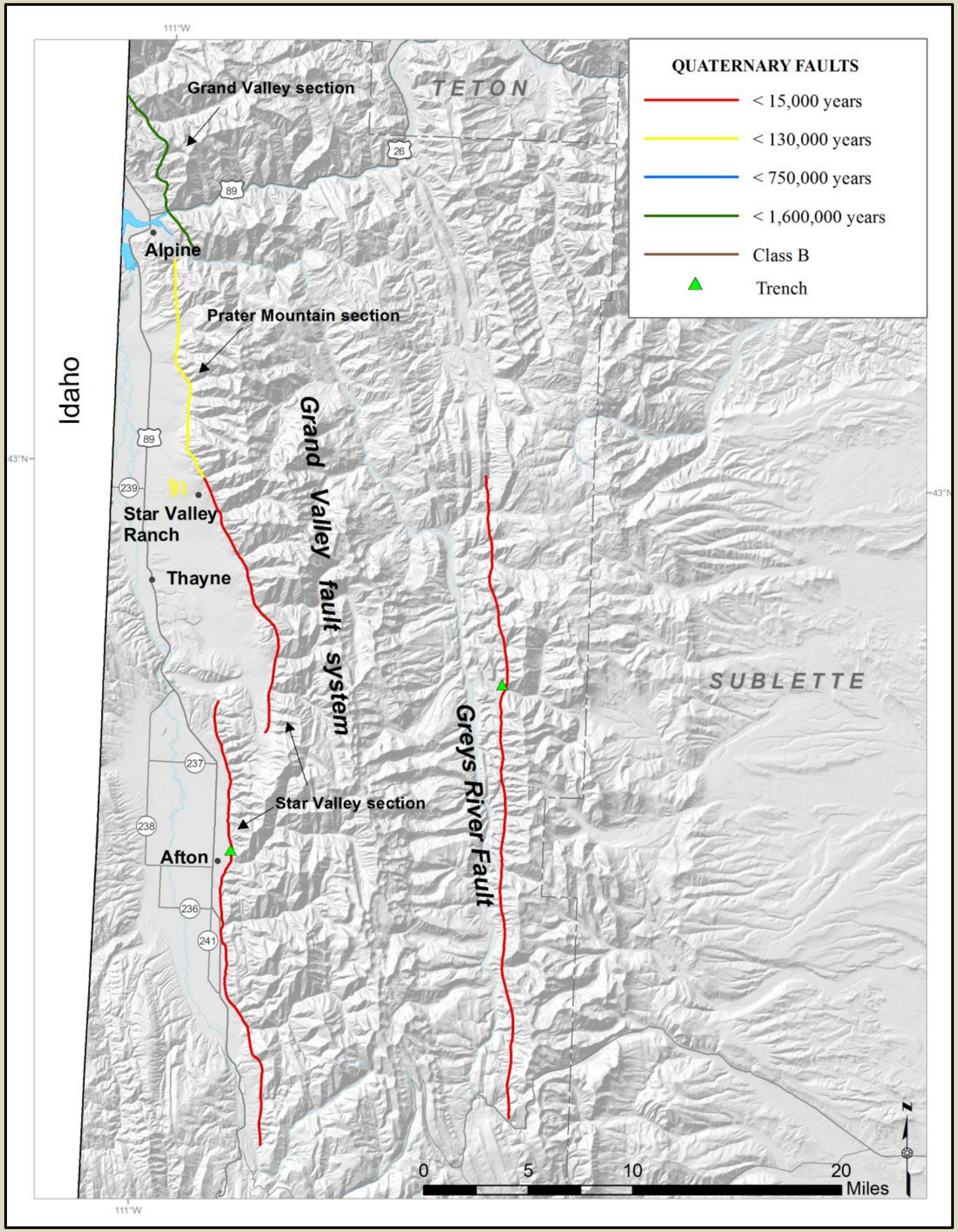
Teton Fault System

- Comprised of 6 sections
- Length of the fault system ~ 60 km
- Trench and paleoseismic studies completed on the Northern, Middle and Southern sections
- Latest event on the Southern Section ~ 7150 yr B.P.
- Potential Max M7.5
- Slip rate ~ 0.2-5.0 mm/yr
- Recurrence interval ~ 2,150-15,000 k.y.
- Populated area
  - High tourism numbers
- Impact to infrastructures
- Could be isolated from response



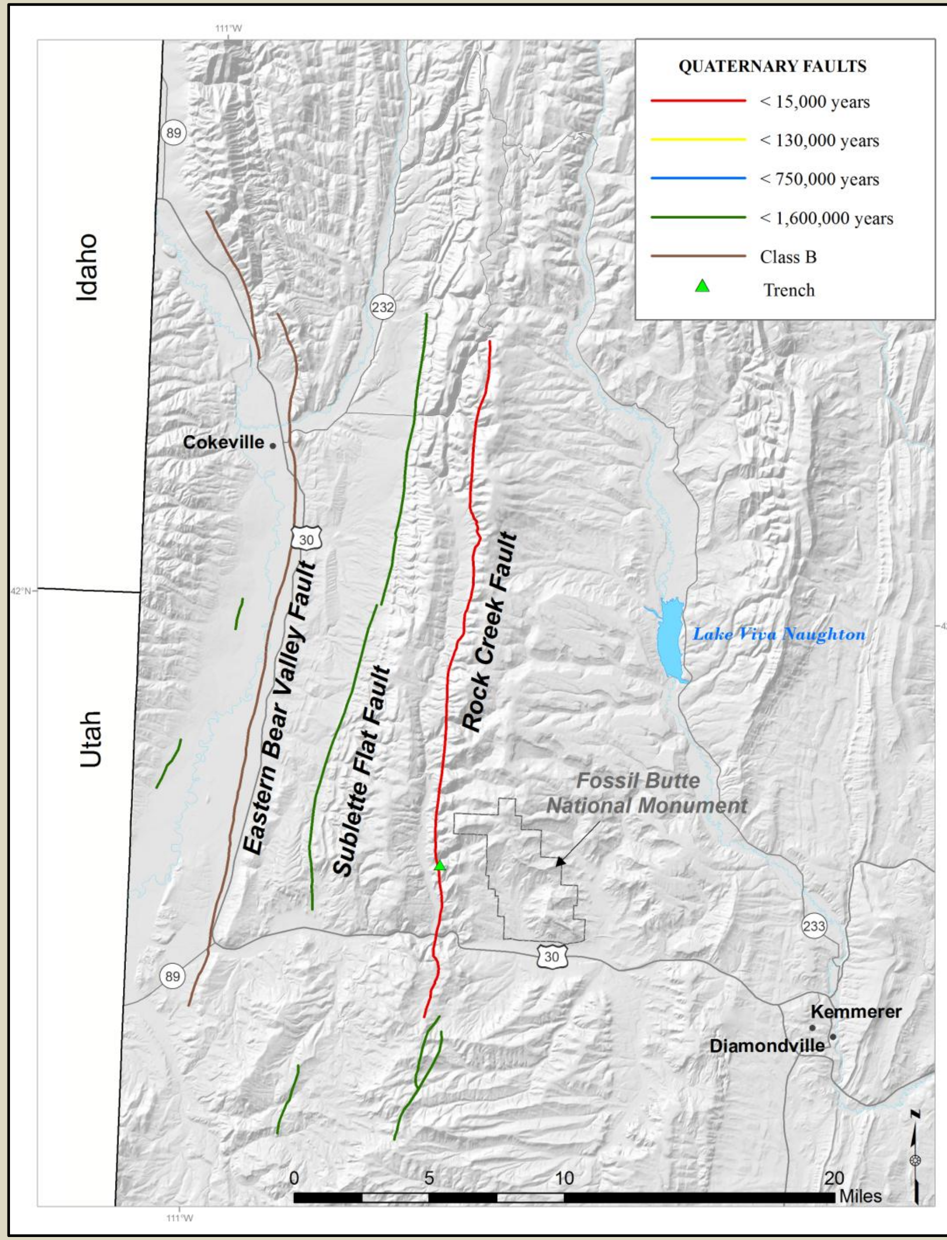
Grand Valley Fault System

- Comprised of 3 sections
  - Grand Valley
  - Prater Mountain
  - Star Valley
- Length of the fault ~ 95 km
- Star Valley (52 km)
  - Trench
  - Latest event occurred ~ 5540 yr B.P.
  - Potential Max M7.5
  - Slip rate 0.2 and 1 mm/yr
  - Recurrence interval > 4-7 k.y.
- Populated area
- Impact to infrastructures and agriculture



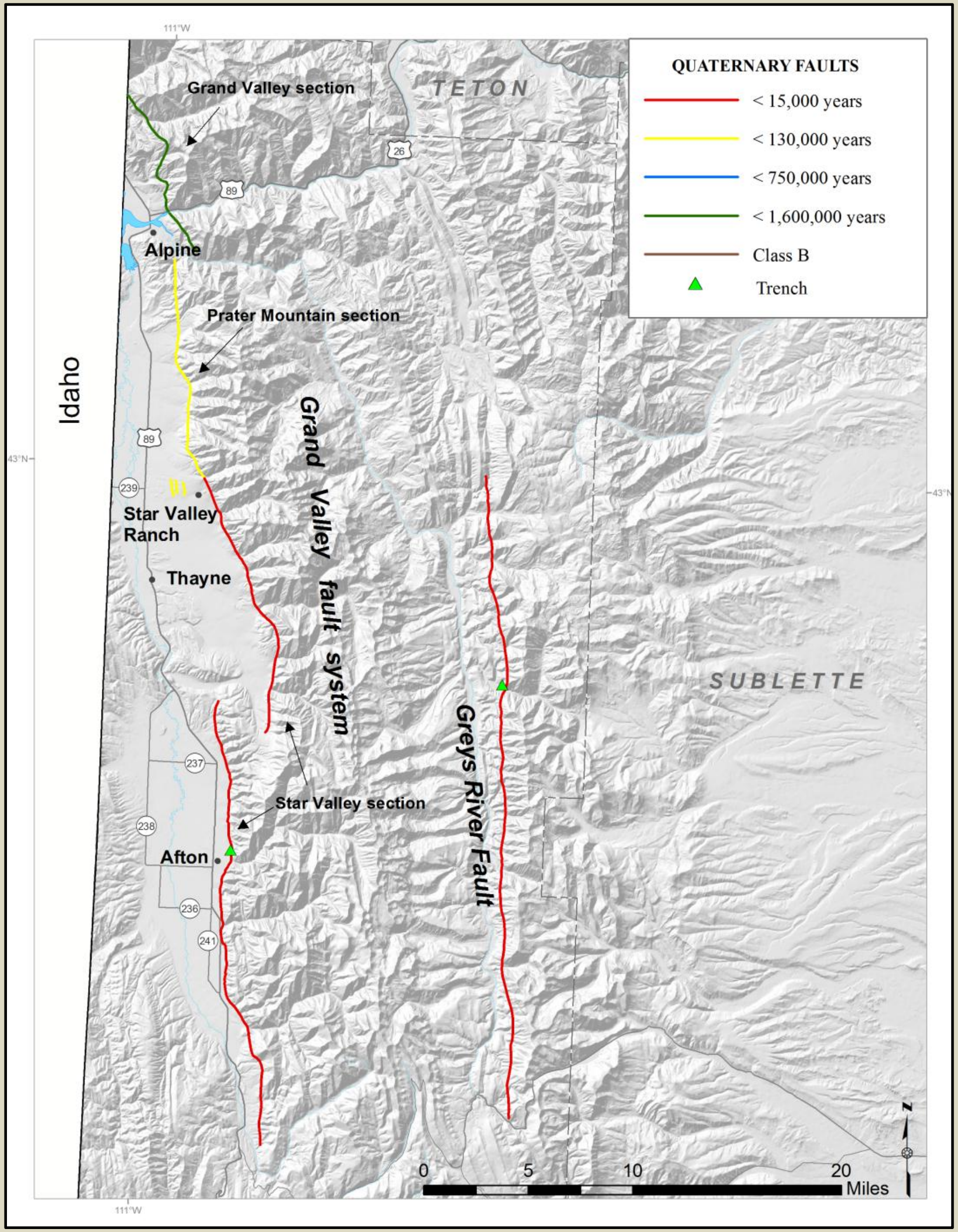
Rock Creek

- Length of the fault ~ 41 km
- Trench
- Latest event occurred ~3280 and 3880 yr B.P. and at least ~10 k.y. before the penultimate event
- Potential Max M7.2
- Slip rate ~ 0.2-1 mm/yr
- Recurrence interval 0.6-1.5, >3.3, and > 10 k.y.
- Size of the fault system
- Example of fault progression?
  - Sublette (750 ka- 1.6 Ma)
  - Eastern Bear Valley (1.6 Ma)



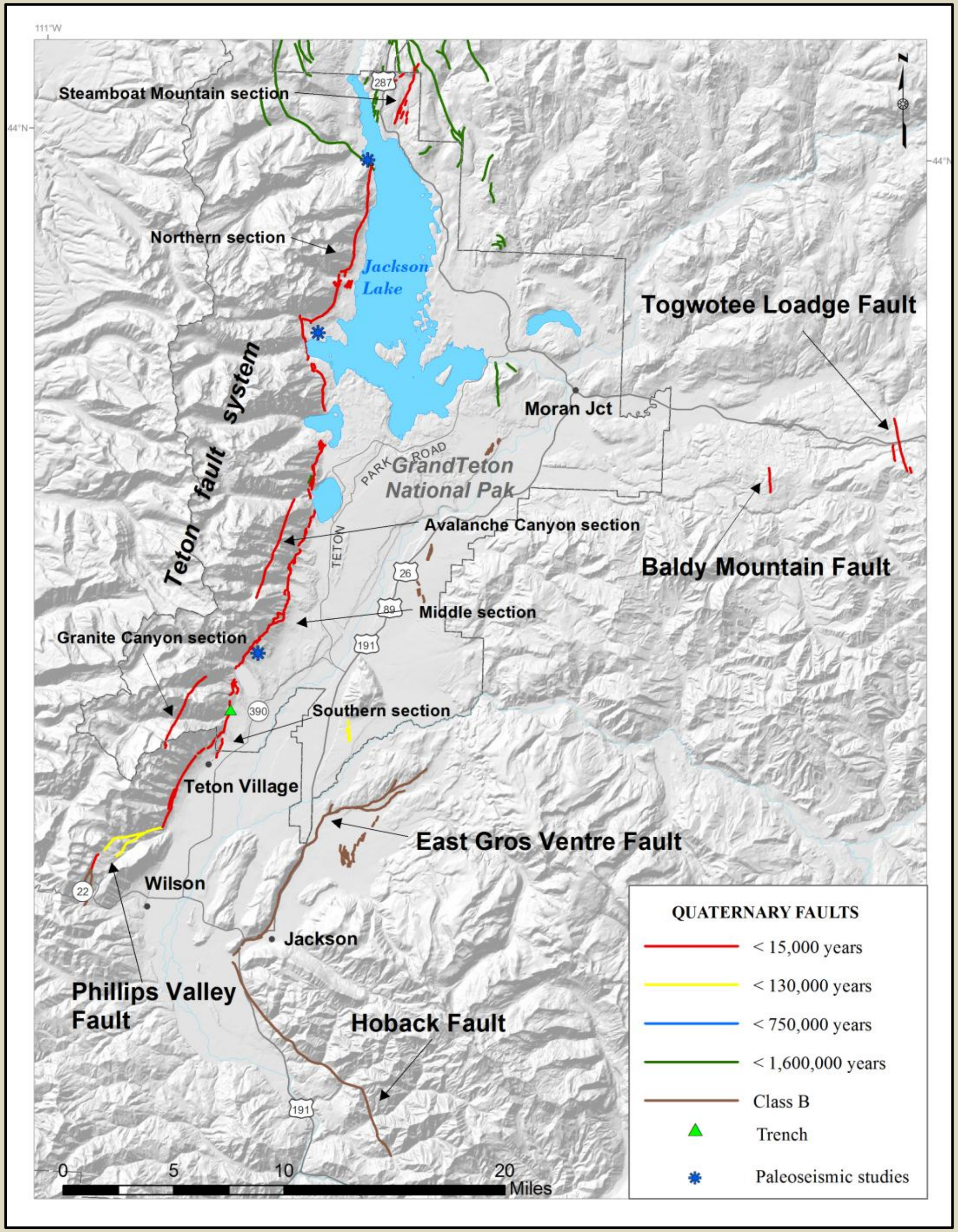
Greys River Fault

- Length of the fault ~ 50 km
- Trench
- Most recent faulting occurred ~1910 and 2110 yr B.P.
- Potential Max M7.1
- Slip rate 0.2 and 1 mm/yr
- Recurrence interval 2.0-5.2 k.y.
- Impact to infrastructures and agriculture



East Gros Ventre Class B fault

- Length of fault ~20 km
- Max M not determined
- Slip rate < 0.2 mm/yr
- Recurrence interval not determined
- Relationship to the Teton Fault?
- Populated area
  - High tourism numbers
- Impact to infrastructures
- Could be isolated from response



Texas
(presented by Rich Briggs)

USGS

Texas declined to send a representative on the basis of low perceived earthquake hazard.

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Live Chat: Bob Sturm answers Cowboys questions at 4:30 p.m.; ask yours now

Irving preps emergency plan as USGS confirms 11th quake since Tuesday

File 2013/Staff Photo

All of the quakes have been centered on the former Texas Stadium site in Irving, where State Highways 114 and 183 and Loop 12 converge.

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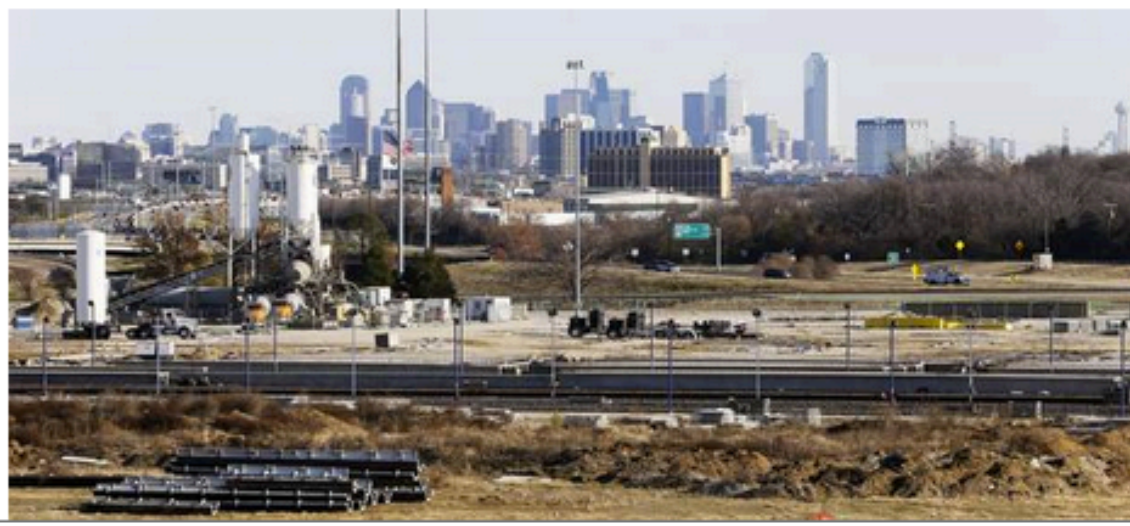

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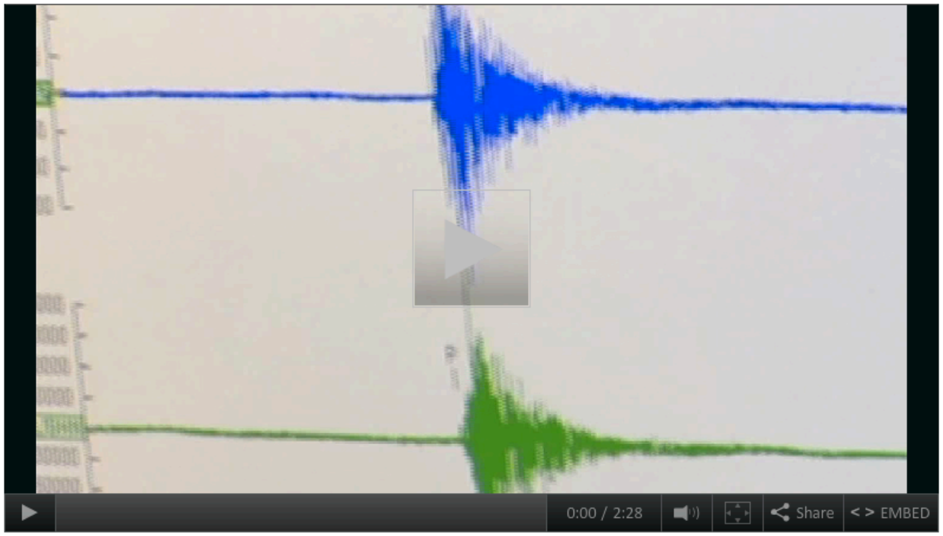
The Scoop Blog

SMU seismologist: Researchers are hoping to locate Irving quakes, not find what's causing them

Robert Wilonsky

Published: January 6, 2015 11:58 am



We received a handful of reports this morning from Northwest Dallas and Irving residents insisting they felt — and heard — another quake this morning. So far, though, the U.S. Geological Survey says it hasn't found one. But sometimes, seismologists say, the smaller ones in North Texas are hard to find. After all, there aren't a lot of sensors in this part of the

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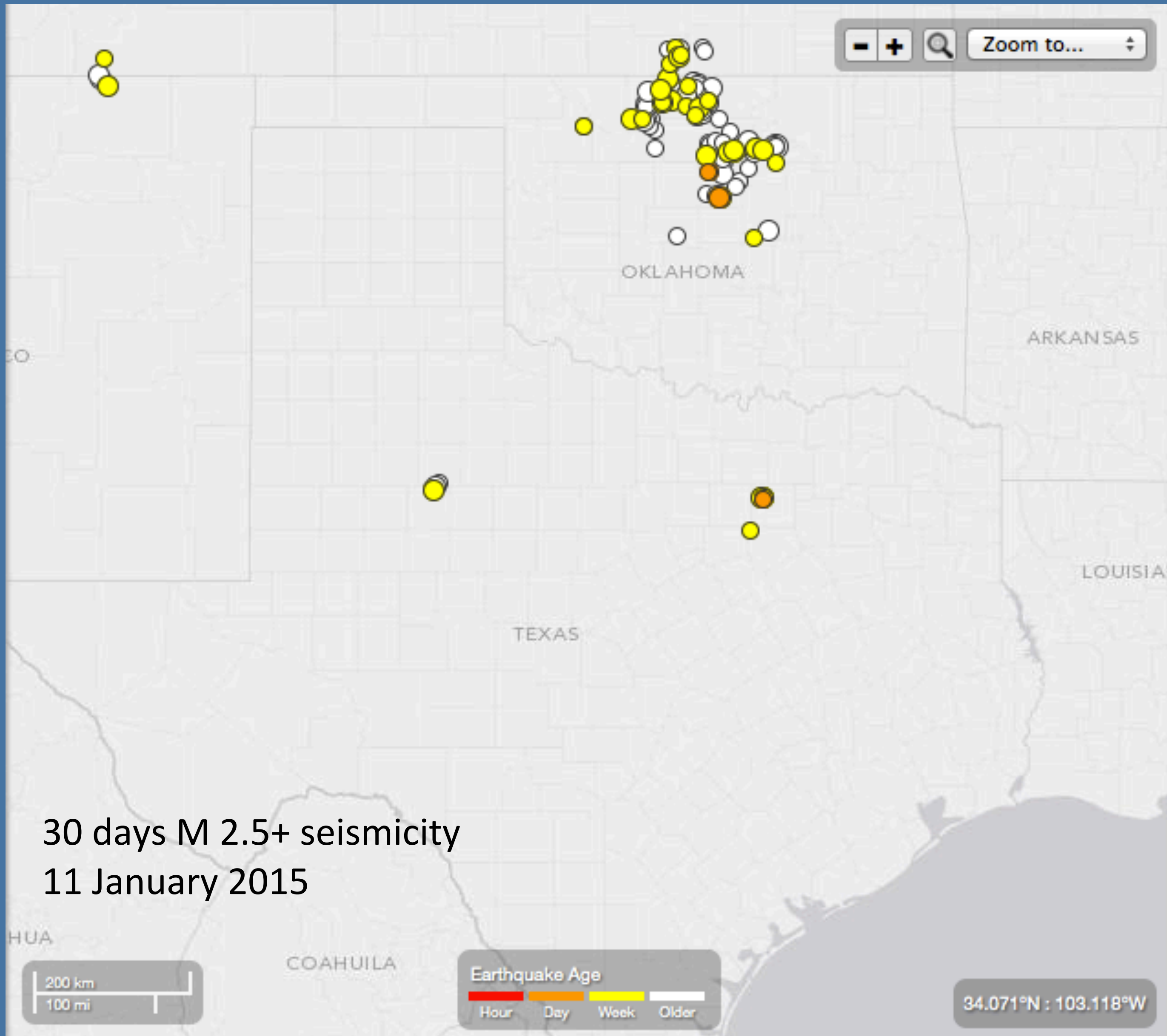
SMU seismologists to study 'increasing frequency' of earthquakes rattling Irving

Update: There were actually two 2.4-magnitude earthquakes in Irving on Friday

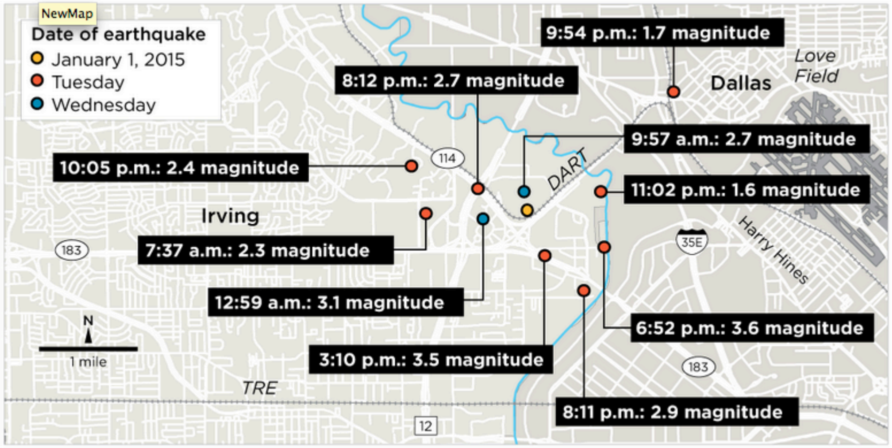


Zoom to...
OKLAHOMA
ARKANSAS
CO
LOUISIAN
TEXAS
HUA
COAHUILA
30 days M 2.5+ seismicity
11 January 2015
200 km
100 mi
Earthquake Age
Hour
Day
Week
Older
34.071°N : 103.118°W

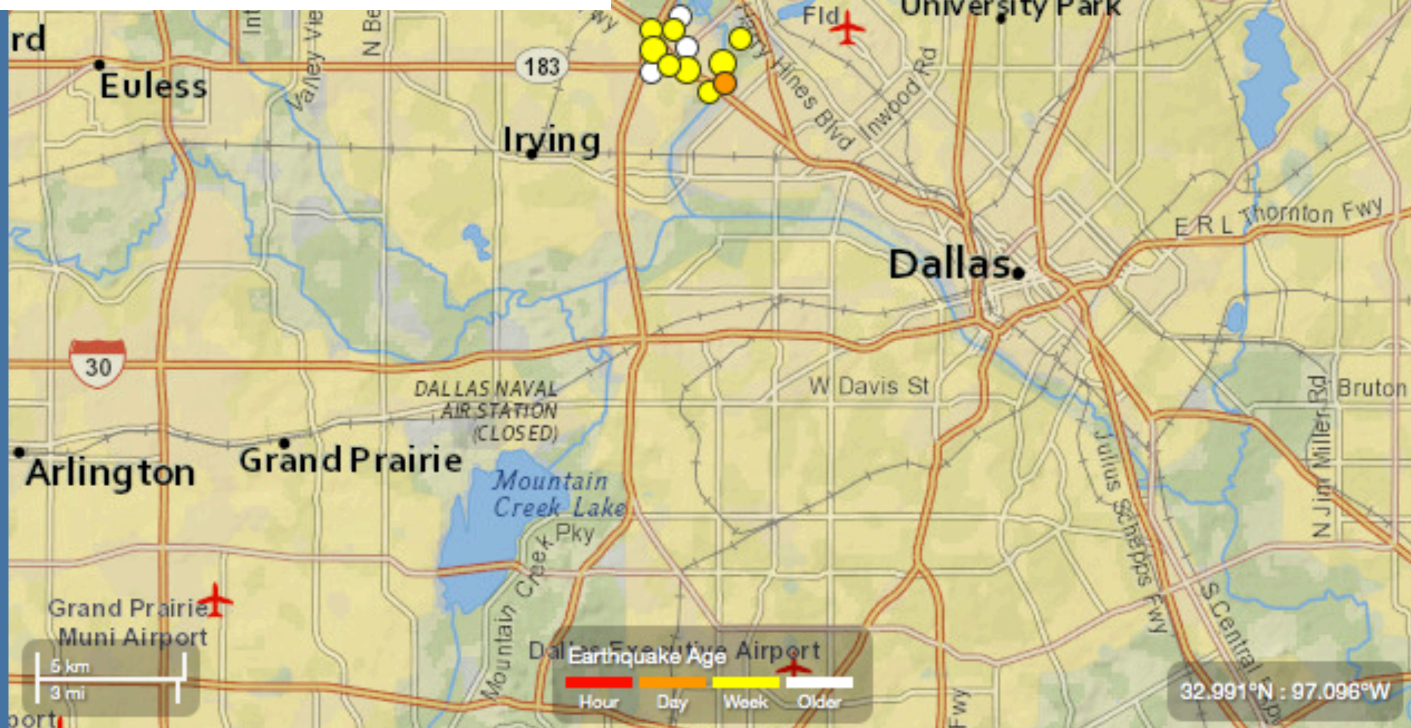
USGS

Irving-area earthquakes

Eleven earthquakes have been recorded near State Highways 114 and 183 in Irving since the beginning of 2015.



SOURCE: U.S. Geological Survey | Note: As of 11:00 a.m., Wednesday | Staff Graphic



USGS

West Texas faults ranked in 2008

1. E. Franklin Mtns. fault, NM and TX

30. Amargosa fault, northern Mexico

42. Lobo Valley fault, TX

USGS


2014 Fault Sources
Slip Sense
Strike slip
Thrust (Reverse)
Normal
Unassigned
Download Shapefile
ARIZONA
NEW MEXICO
OKLAHOMA
TEXAS
ARKANSAS
LOUISIANA
MISSISSIPPI
ALABAMA
SONORA
CHIHUAHUA
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Phoenix
Tucson
Albuquerque
Santa Fe
Amarillo
Lubbock
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Odessa
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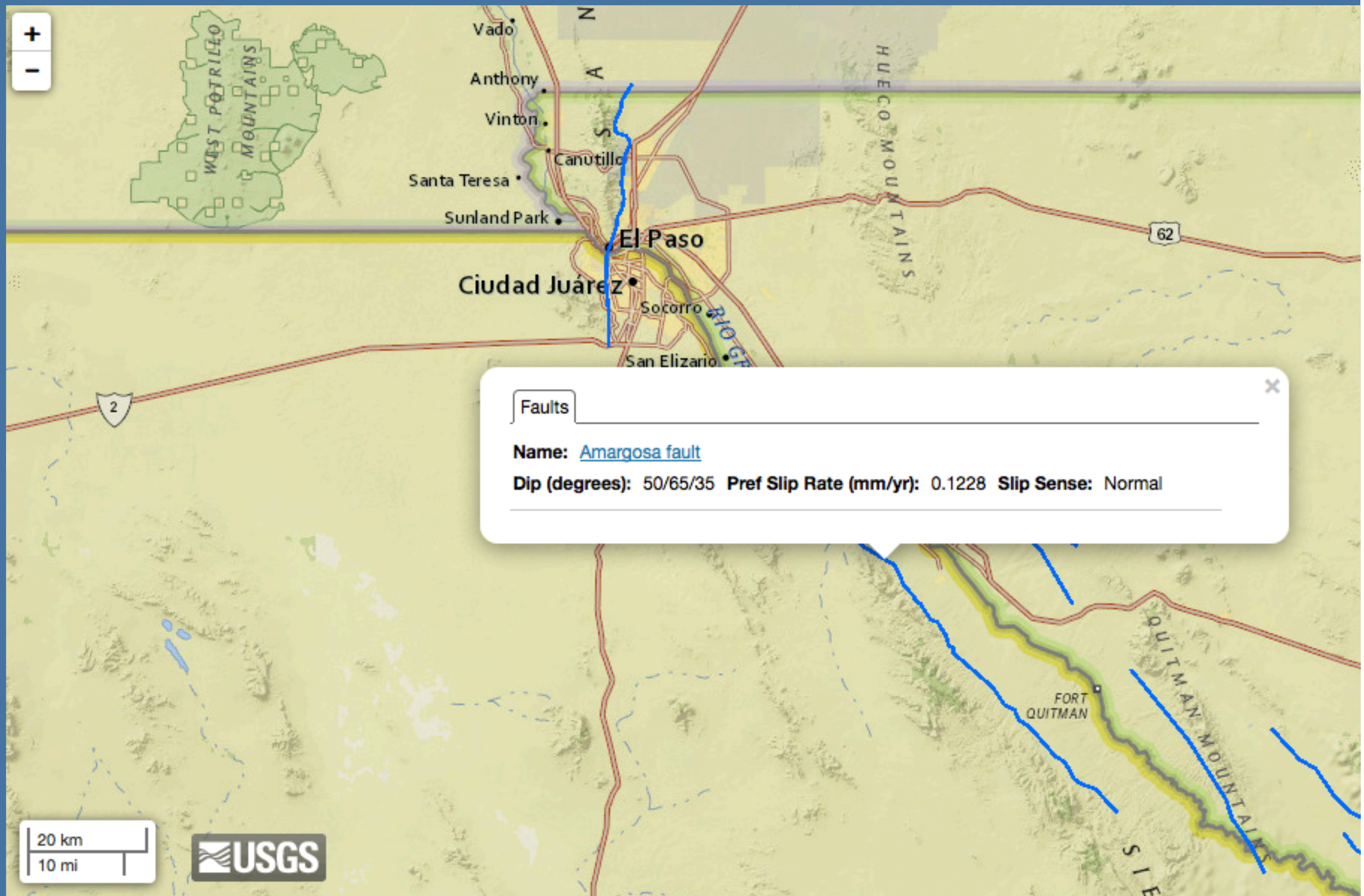
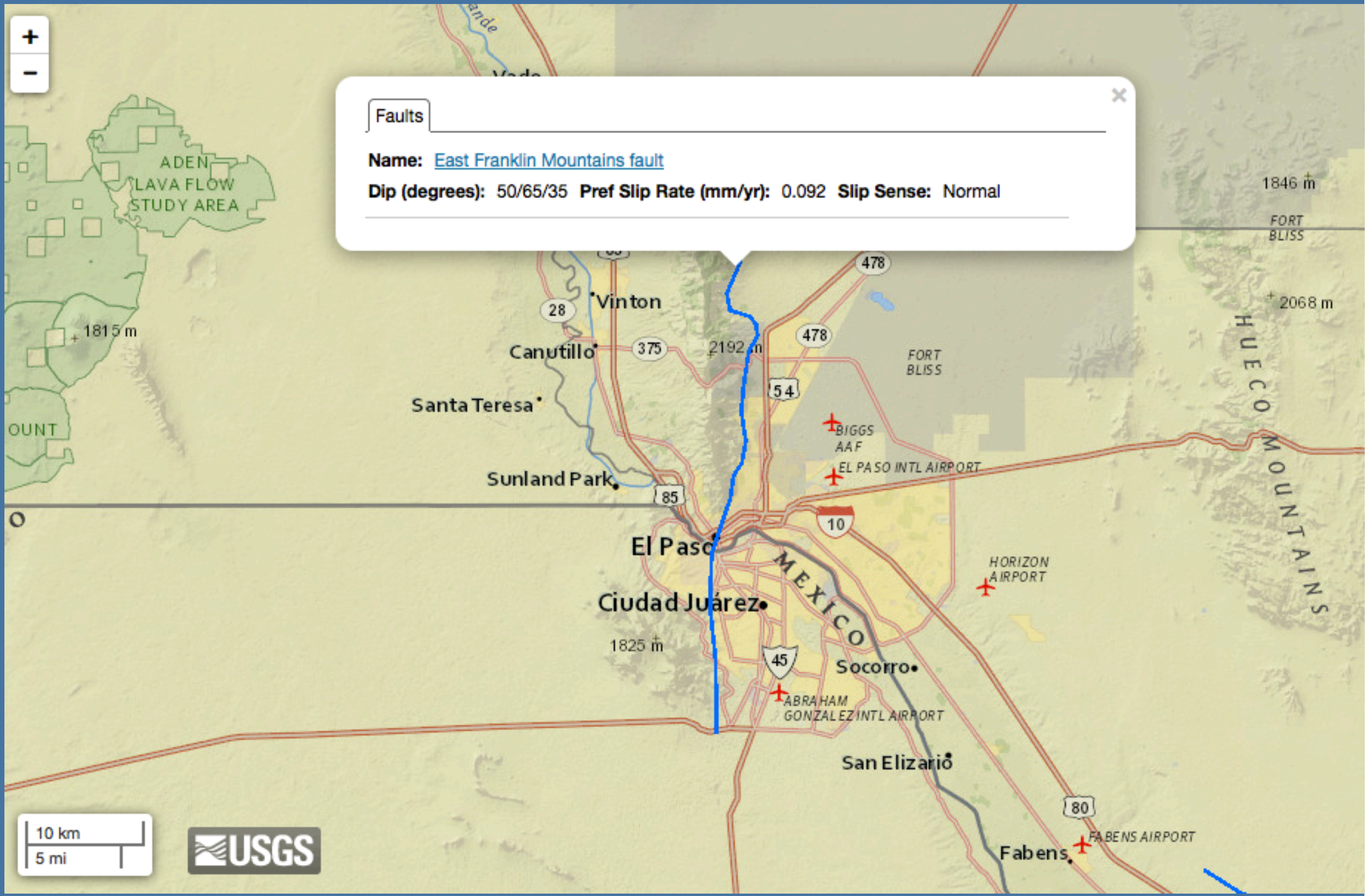
Oklahoma City
Little Rock
Dallas
Fort Worth
Austin
San Antonio
Houston
Baton Rouge
New Orleans
Jackson
Hermosillo
Chihuahua
Brownsville
Monterrey
200 km
100 mi
USGS
Leaflet | USGS

USGS

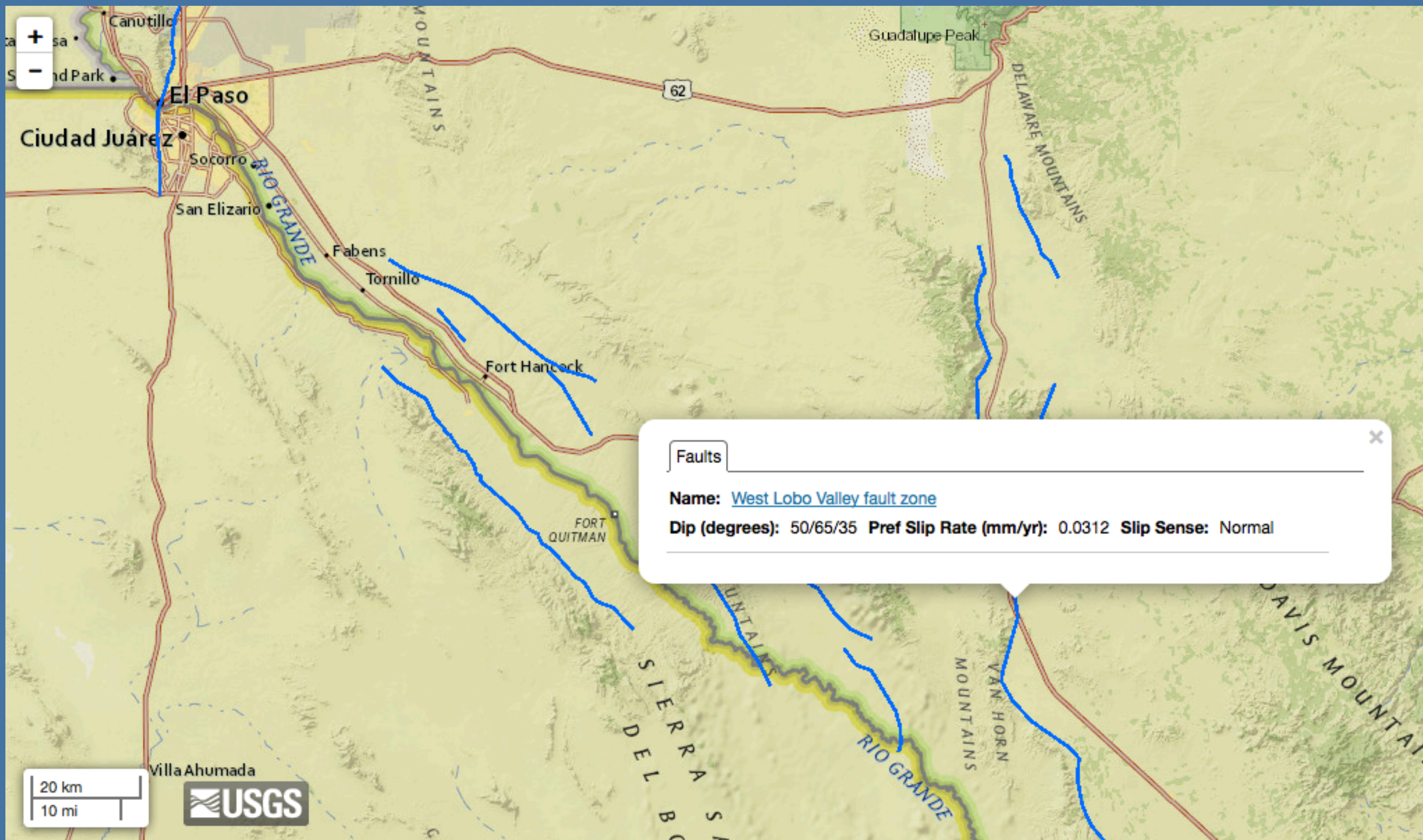

Vado
Anthony
Vinton
Canutillo
Santa Teresa
Sunland Park
El Paso
Ciudad Juárez
Socorro
San Elizario
WEST POTRILLO MOUNTAINS
HUECO MOUNTAINS
QUITMAN MOUNTAINS
FORT QUITMAN
62
2
Faults
Name: Amargosa fault
Dip (degrees): 50/65/35 Pref Slip Rate (mm/yr): 0.1228 Slip Sense: Normal
20 km
10 mi
USGS

USGS



Faults
Name: East Franklin Mountains fault
Dip (degrees): 50/65/35 Pref Slip Rate (mm/yr): 0.092 Slip Sense: Normal
ADEN LAVA FLOW STUDY AREA
1815 m
Vinton
Canutillo
2192 m
Santa Teresa
Sunland Park
El Paso
Ciudad Juárez
1825 m
MEXICO
Socorro
San Elizario
Fabens
FABENS AIRPORT
ABRAHAM GONZALEZ INTL AIRPORT
HORIZON AIRPORT
BIGGS AAF
EL PASO INTL AIRPORT
FORT BLISS
1846 m
2068 m
HUECO MOUNTAINS
10 km
5 mi
USGS

USGS


Canutillo
El Paso
Ciudad Juárez
Socorro
San Elizario
RIO GRANDE
Fabens
Tornillo
Fort Hancock
FORT QUITMAN
Guadalupe Peak
62
DELAWARE MOUNTAINS
VAN HORN MOUNTAINS
Villa Ahumada
20 km
10 mi
USGS
Faults
Name: West Lobo Valley fault zone
Dip (degrees): 50/65/35 Pref Slip Rate (mm/yr): 0.0312 Slip Sense: Normal