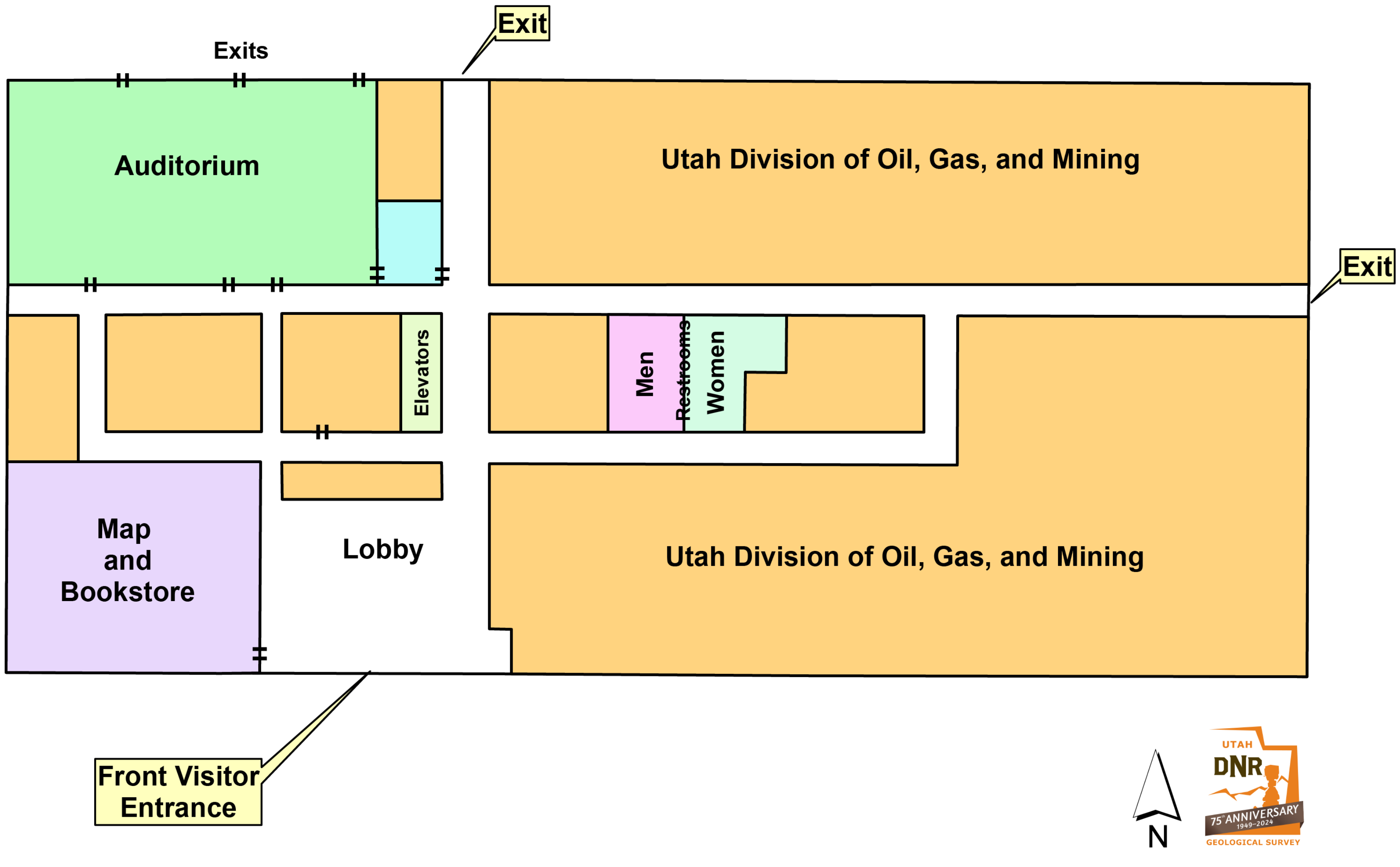
2024 Utah Earthquake Working Group Meetings

Utah Quaternary Fault Parameters Working Group

Monday, February 5, 2024

UTAH DNR
75th ANNIVERSARY 1949–2024
GEOLOGICAL SURVEY

2024 Utah Earthquake Working Groups
Utah DNR 1st Floor Map

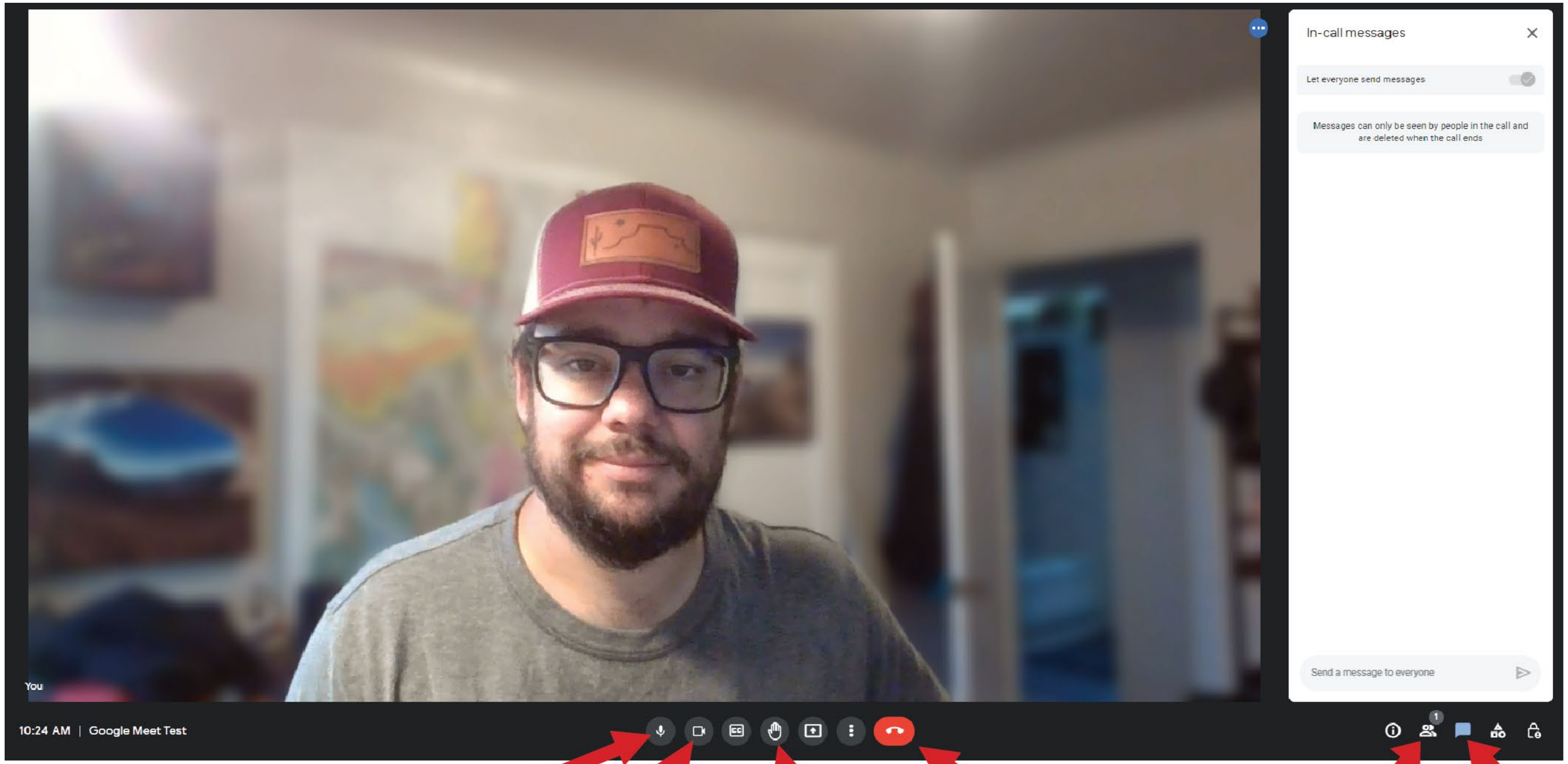


Presenters

- Speaker Timer in front of you to keep things on track!
- Meeting is being recorded
- Talk to me if you don't want the recording of your talk publicly available – we can remove it
- Make sure to stay in front of the podium so the mic's pick up your voice for virtual attendees to hear
- Q/A – Mics on each table are muted, if you'd like to ask a question, please use the mic and press the button to unmute before you talk
- Remote Q/A – Please put your questions into the meeting chat – we will read them in order when we get them.

Virtual Attendees – Google Meet Guide

- Please keep your microphone muted during talks
- Put Q/A in the meeting chat – we will read them in order after presentations



Mute/Un-mute Microphone

Video feed on/off

Raise Hand

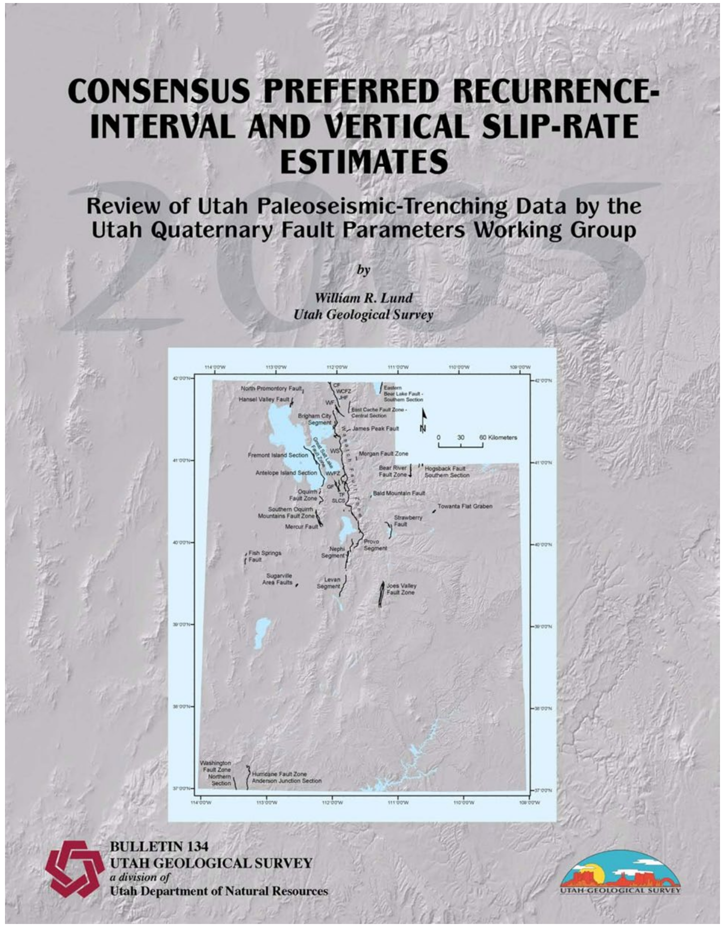
Leave Meeting

View Participants

Open Chat

UQFPWG History and Purpose

- Began in 2004 by developing consensus slip-rate and recurrence-interval data for all faults with paleoseismic data in Utah (UGS B-134, Lund, 2005).
- Group developed an initial priority list of Utah Quaternary faults requiring additional study, list updated annually and incorporated into the annual USGS Earthquake Hazards Program External Research Support funding announcements.
- Review ongoing paleoseismic, earthquake timing, and fault characterization studies ongoing in Utah with the goal of maintaining and updating consensus slip-rate recurrence intervals.
- Group is dependent on the active involvement of researchers (academic, government, etc), consultants, and the public.



2022 UQFPWG Review

- 10-minute "Lightning Talk" format
  - Emily Kleber – Utah Geological Survey - Welcome and Introduction
  - Chris DuRoss – U.S. Geological Survey - Earthquake Hazards Program – External Grants and 2023 Funding Announcement Updates
  - Alex Hatem – U.S. Geological Survey - 2023 National Seismic Hazard Maps (NSHM) Update
  - Nathan Toke – Utah Valley University - Timpanogos and Provo Peak Massifs – New Fault Mapping
  - Ivan Wong – Lettis Consultants International - Warm Springs Fault - East Bench Fault Stepover - New Research
  - Adam Hiscock – Utah Geological Survey - Utah Geological Survey Quaternary Fault Mapping Update

2023 UQFPWG Priorities

- Acquire new paleoseismic information for areas with ongoing or completed lidar fault mapping projects:
  - *West Valley fault zone – Granger and Taylorsville faults – UGS Funded in 2022*
  - Cache Valley faults – East Cache fault zone and West Cache fault zone
  - Five central segments of the Wasatch fault zone – Brigham City, Weber, Salt Lake City, Provo, and Nephi segments
  - Oquirrh fault zone
  - Sevier fault

- “Salvage paleoseismology” (i.e., earthquake timing investigations as rapid development is encroaching on un-modified paleoseismic trenching sites:
  - West Valley fault zone – Granger and Taylorsville faults
  - Cache Valley faults – East Cache fault zone and West Cache fault zone - exposure in North Logan sampled. USU led.

2023 UQFPWG Priorities

- Use recently acquired lidar data to more accurately map the traces of the:
  - Scipio Valley faults
  - Beaver Basin faults (partial coverage)
  - Hansel Valley faults
  - Paunsaugunt fault
  - Mineral Mountains west side faults - *some recon mapping done*
  - Stansbury fault zone - *Lidar mapping completed by UGS in 2021. Ongoing work by UVU.*
  - Faults in the West Desert (Escalante Desert, Sevier Desert, Pilot Valley, Tintic Valley, Skull Valley) – *Some recon level lidar mapping completed by UGS as part of the U.S. Department of Energy INGENIOUS project, needs to be fully peer reviewed and added to Utah Quaternary Fault Database.*

2023 UQFPWG Priorities

- Opportunistic trenching sites – Funding for dating samples left over from other projects that have been stored and would be useful.
  - Joes Valley – U.S. Bureau of Reclamation Work?
- *Post-Magna earthquake research – Use geophysical methods to collect more data about the subsurface of the Salt Lake Valley - Funded UGS/U of U 2023*
  - *3D Basin structural model of the Salt Lake Valley using new gravity, and existing well data, seismic data*
    - *Warm Springs fault*
  - *Community velocity model input improvements*
  - *Collect, compile, and analyze new geological and geophysical data to improve subsurface models of the Salt Lake Basin. Improved basin models will enable more accurate numerical ground motion modeling and may provide insight into subsurface fault geometries.*

- Utah Lake faults - New methods or techniques to improve on this work?

Utah Quaternary Fault Parameters Working Group

8:00 Refreshments and Coffee

8:30 Welcome, Overview of Meeting, and Review of Previous Years' Activities: Adam I. Hiscock, Utah Geological Survey

8:45 Update on the U.S. Geological Survey (USGS) External Grants Program and Topics Across the Intermountain West Region: Chris DuRoss, USGS Geologic Hazards Science Center

9:00 Technical Presentations of Work Completed or In Progress

- 9:00 Towards an Improved Salt Lake Valley Community Velocity Model Through Seismic and Gravity Joint Inversion, Part I— New Geological Constraints and Geophysical Data: Adam McKean, Christian Hardwick, and Kayla Smith, Utah Geological Survey
- 9:30 Towards an Improved Salt Lake Valley Community Velocity Model Through Seismic and Gravity Joint Inversion, Part 2—Seismic Data and Joint Inversion: Fan-Chi Lin, University of Utah

10:00 Break (15 minutes)

- 10:15 Intrabasin Faulting Beneath Salt Lake City—New Seismic Data Map the West Valley and Downtown Fault Systems: Lee Liberty, Boise State University
- 10:45 New Paleoseismic Data and Challenges from the Urban Taylorsville Fault, West Valley Fault Zone, Utah: Emily J. Kleber and Adam I. Hiscock, Utah Geological Survey
- 11:15 The Great Salt Lake as a recorder of Sublacustrine Surface Rupture and Strong Shaking in the Wasatch Front Region: Chris DuRoss, U.S. Geological Survey

11:45 Lunch (75 minutes)

1:00 Technical Presentations of Work Completed or In Progress (continued)

- 1:00 The Most Recent Rupture of the Thousand Lake Fault (Post-LGM)—Examining Rupture Length and Average Displacement using Southern Utah Lidar Data: Nathan Toke, Utah Valley University
- 1:30 Utah Quaternary Fault Mapping Updates, Including Cache Valley and Southern Utah: Adam I. Hiscock, Utah Geological Survey
- 2:00 Utah Paleoseismic Sites Database Update: Adam I. Hiscock, Utah Geological Survey

2:15 Break (15 minutes)

- 2:30 Updating the Working Group on Utah Earthquake Probabilities Forecast for the Wasatch Front: Ivan Wong, Lettis Consultants, LLC
- 3:00 Quaternary Faults of the Uncompahgre Plateau, Utah and Colorado—Are they Q and are they Faults?: Jim McCalpin, GeoHaz Consulting/Colorado Geological Survey

3:30 Break (15 minutes)

3:45 Group Discussion Time

4:15 Working Group 2025 Fault Investigation Priorities Discussion

5:00 Adjourn

UQFPWG – 2023 Priority Faults

- Acquire new paleoseismic information for areas with ongoing or completed lidar fault mapping projects:
    - West Valley fault zone – Granger and Taylorsville faults – *UGS Funded in 2022*
    - Cache Valley faults – East Cache fault zone and West Cache fault zone
    - Five central segments of the Wasatch fault zone – Brigham City, Weber, Salt Lake City, Provo, and Nephi segments
    - Oquirrh fault zone
    - Sevier fault
- "Salvage paleoseismology" (i.e., earthquake timing investigations as rapid development is encroaching on un-modified paleoseismic trenching sites:
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- Use recently acquired lidar data to more accurately map the traces of the:
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    - Paunsaugunt fault
    - Mineral Mountains west side faults - *some recon mapping done*
    - Stansbury fault zone - *Lidar mapping completed by UGS in 2021. Ongoing work by UVU.*
    - **Faults in the West Desert (Escalante Desert, Sevier Desert, Pilot Valley, Tintic Valley, Skull Valley) –** *Some recon level lidar mapping completed by UGS as part of the U.S. Department of Energy INGENIOUS project, needs to be fully peer reviewed and added to Utah Quaternary Fault Database.*
- Opportunistic trenching sites – Funding for dating samples left over from other projects that have been stored and would be useful.
    - **Joes Valley – U.S. Bureau of Reclamation Work?**
- **Post-Magna earthquake research – Use geophysical methods to collect more data about the subsurface of the Salt Lake Valley**
    - **3D Basin structural model of the Salt Lake Valley using new gravity, and existing well data, seismic data**
        - **Warm Springs fault**
    - **Community velocity model input improvements**
    - **Collect, compile, and analyze new geological and geophysical data to improve subsurface models of the Salt Lake Basin. Improved basin models will enable more accurate numerical ground motion modeling and may provide insight into subsurface fault geometries.**
- **Utah Lake faults - New methods or techniques to improve on this work?**

UQFPWG – Priority Faults Discussion

Potential faults to add:

- Salt-tectonic related faulting?
- Southern Utah/Rural Area faults:
  - Thousand Lake Mountain fault
  - Paunsaugunt (already on list)

Basin and Range Earthquake Working Group

8:00 Refreshments and Coffee

8:30 Welcome, Overview of Meeting, and Review of Previous Years' Activities: Adam I. Hiscock, Utah Geological Survey

8:45 Update on the U.S. Geological Survey (USGS) External Grants Program and Topics Across the Intermountain West Region: Chris DuRoss, USGS Geologic Hazards Science Center

9:00 Basin and Range States – Earthquake Geology Updates

- 9:00 Arizona – Jeri Young Ben-Horin
- 9:30 California
- 10:00 Colorado – Jim McCalpin and Enrique Chan

10:30 Break (15 minutes)

- 10:45 Idaho – Zach Lifton
- 11:15 Montana Update – Yann Gavillot
- 11:35 Montana Seismic Network – Mike Stickney

11:45 Lunch (75 minutes)

1:00 Basin and Range States – Earthquake Geology Updates (continued)

- 1:00 Nevada – Rich D. Koehler
- 1:30 New Mexico – Dan Koning
- 2:00 Oregon – Lalo Guerrero

2:30 Break (15 minutes)

- 2:45 Utah – Adam I. Hiscock
- 3:15 Wyoming – James P. Mauch

3:45 Break (15 minutes)

4:00 Group Discussion
Working Group Priorities and Future Direction for 2025 and Beyond

5:00 Adjourn

BRPEWG – Priorities and Future Direction

USGS Earthquake Hazards Program (EHP) External Grants Update

Christopher DuRoss

USGS Intermountain West Regional Coordinator

cduross@usgs.gov

USGS EHP External Grants Program

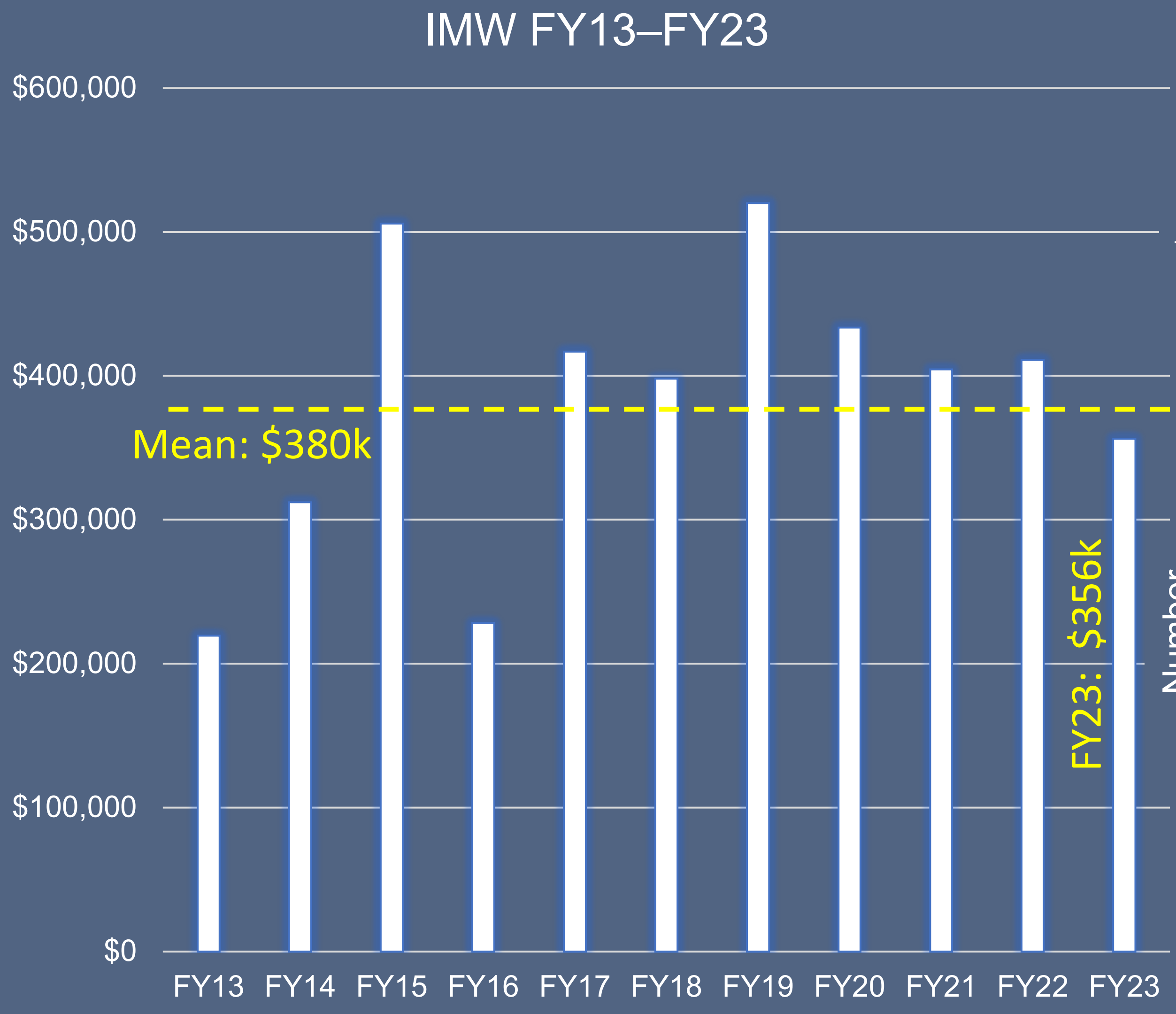
- **FY23 (last year)**
  - EHP funding: $3.8M distributed over 5 regional and 4 topical areas:
  - FY23 Intermountain West (IMW) funding: $356k (8 proposals)

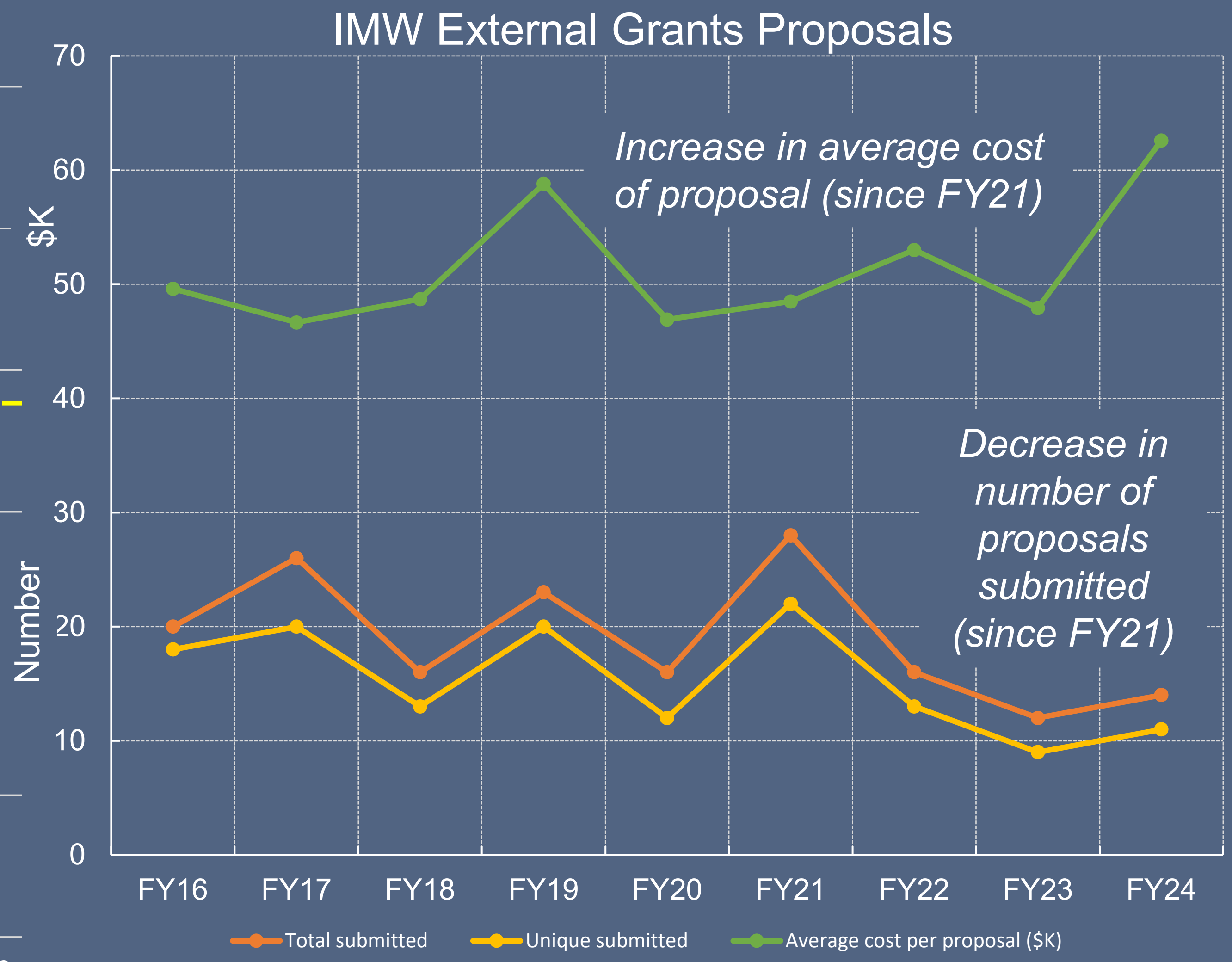
Regional/Topical Area	FY23 Funded Amount	%	FY23 # of new grants funded
CEUS	$348k	9%	6
ESI	$463k	12%	7
EP/IS	$522k	14%	6
IMW	$356k	9%	8
NAT	$342k	9%	6
NC	$335k	9%	4
PNA	$485k	13%	5
SC	$337k	9%	5
EEW	$608k	16%	7
Totals	**$3.8M**	**100%**	**54**

CEUS – Central and Eastern United States
IMW – Intermountain West
NC – Northern California
PNA – Pacific Northwest and Alaska
SC – Southern California

EP/IS – Earthquake Physics/Induced Seismicity
ESI – Engineering Seismology and Impacts
NAT – National
EEW – Earthquake Early Warning

USGS External Grants Program, IMW Region





Preliminary Information-Subject to Revision. Not for Citation or Distribution.

USGS science for a changing world

USGS EHP External Grants Program

- **FY24 (in progress) –** Included reorganization of regional and topical areas:

Regions

- Central and Eastern United States (CEUS)
- Intermountain West (IMW)
- Northern California (NC)
- Pacific Northwest and Alaska (PNA):
- Southern California (SC)

Topical areas

- Earthquake Early Warning (EEW)
- Earthquake Rupture Forecasting (ERF)
- Earthquake Source Processes (ESP)
- Hazard, Impacts, and Risk (HIR)
- Ground Motion (GM)

Previous organization:

CEUS – Central and Eastern United States
IMW – Intermountain West
NC – Northern California
PNA – Pacific Northwest and Alaska
SC – Southern California

EP/IS – Earthquake Physics/Induced Seismicity
ESI – Engineering Seismology and Impacts
NAT – National
EEW – Earthquake Early Warning

IMW External Grants FY2024 (in progress)

- **FY24 IMW proposals:**
  - 14 proposals (2 collaborative)
  - 3 two-year proposals
  - Average cost: $62.5k
  - Total request: $875k

- **Status** (late January 2024):
  - One proposal funded
  - Six proposals in Hold status
  - Federal budget: Continuing Resolution (CR) until early March 2024
  - Final award letters anticipated before March 31, 2024

FY25 Program Announcement

- March 2024; proposals due May 2024
- IMW Panel: ~August 2024. Contact me (cduross@usgs.gov) if you're interested in serving.
- Contact Jill Franks (jfranks@usgs.gov) for more information on the announcement.

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science for a changing world

IMW External Grants

➢ **Please provide feedback on the External Grants process and IMW research priorities to cduross@usgs.gov**

- ➢ How satisfied are you with the External Grants proposal process?
- ➢ What elements need to be improved?
- ➢ Do IMW research priorities reflect an adequate scope of research for the region?
  - Should a list of priority faults be included for the entire IMW?
  - What priority topics are missing?
- ➢ How can we better serve the needs of the IMW research community?

Towards an Improved Salt Lake Valley Community Velocity Model Through Seismic and Gravity Joint Inversion, Part I— New Geological Constraints and Geophysical Data

Adam McKean, Christian Hardwick, and Kayla Smith

Geologic Hazards and Energy and Minerals Programs

Utah Geological Survey

Co-Authors/Collaborators:

University of Utah: Fan-Chi Lin, HyeJeong Kim, Tonie Van Dam, and James Pechmann

Utah Geological Survey: Torri Duncan, Skadi Kobe

Outline of Presentation

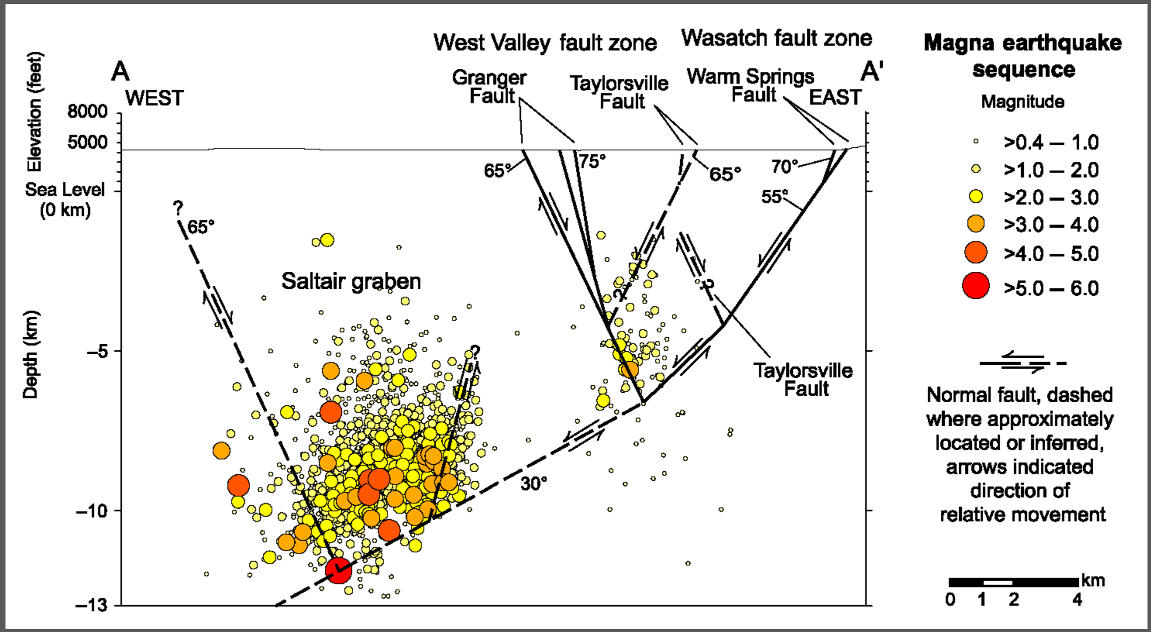
- M_w 5.7 Magna, Utah, Earthquake
- Current Project
- Previous Work: Wasatch Front Community Velocity Model (CVM)
- Existing and New Well Data
- Existing and New Gravity Data
- Conclusion/Future Work

Reasons for Research

Focus Section: Intermountain West Earthquakes

Geologic Setting, Ground Effects, and Proposed Structural Model for the 18 March 2020 M_w 5.7 Magna, Utah, Earthquake

Emily J. Kleber*[1], Adam P. McKean[1], Adam I. Hiscock[1], Michael D. Hylland[1], Christian L. Hardwick[1], Greg N. McDonald[1], Zachary W. Anderson[1], Steve D. Bowman[1], Grant C. Willis[1], and Ben A. Erickson[1]



12th National Conference on Earthquake Engineering
Salt Lake City, Utah
27 June - 1 July 2022
Hosted by the Earthquake Engineering Research Institute

The Implications of a Listric Wasatch Fault for Seismic Hazard, Design, and Risk Along Utah's Wasatch Front

Ivan G. Wong[1], Patricia A. Thomas[2], and James C. Pechmann[3]

Geophysical Research Letters

RESEARCH LETTER
10.1029/2020GL089798

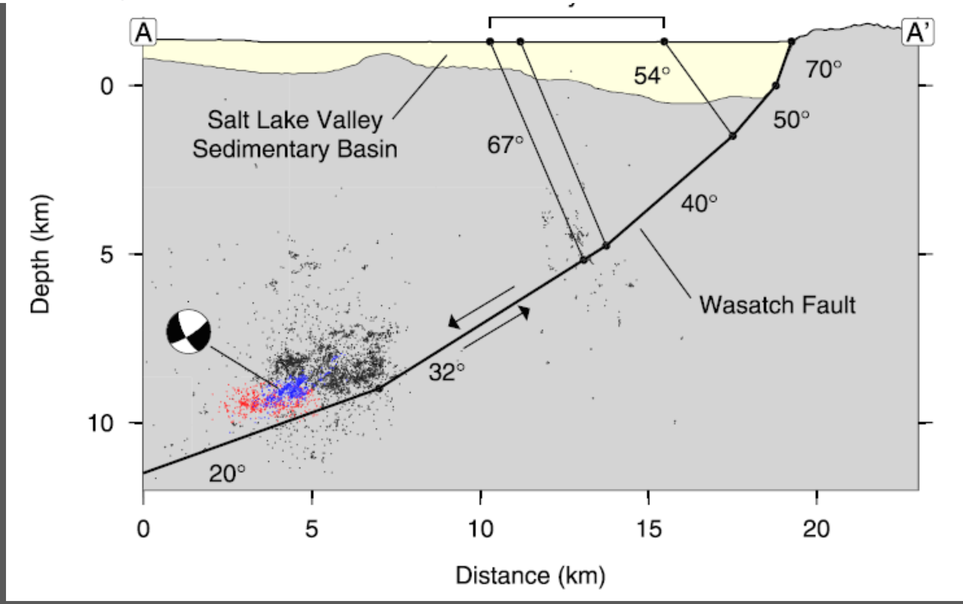
Seismic Analysis of the 2020 Magna, Utah, Earthquake Sequence: Evidence for a Listric Wasatch Fault

Guanning Pang[1], Keith D. Koper[1], Maria Mesimeri[1], Kristine L. Pankow[1], Ben Baker[1], Jamie Farrell[1], James Holt[1], J. Mark Hale[1], Paul Roberson[1], Relu Burlacu[1], James C. Pechmann[1], Katherine Whidden[1], Monique M. Holt[1], Amir Allam[1], and Christopher DuRoss[2]

[1]Department of Geology and Geophysics, University of Utah, Salt Lake City, UT, USA, [2]Geologic Hazards Science Center, U.S. Geological Survey, Golden, CO, USA

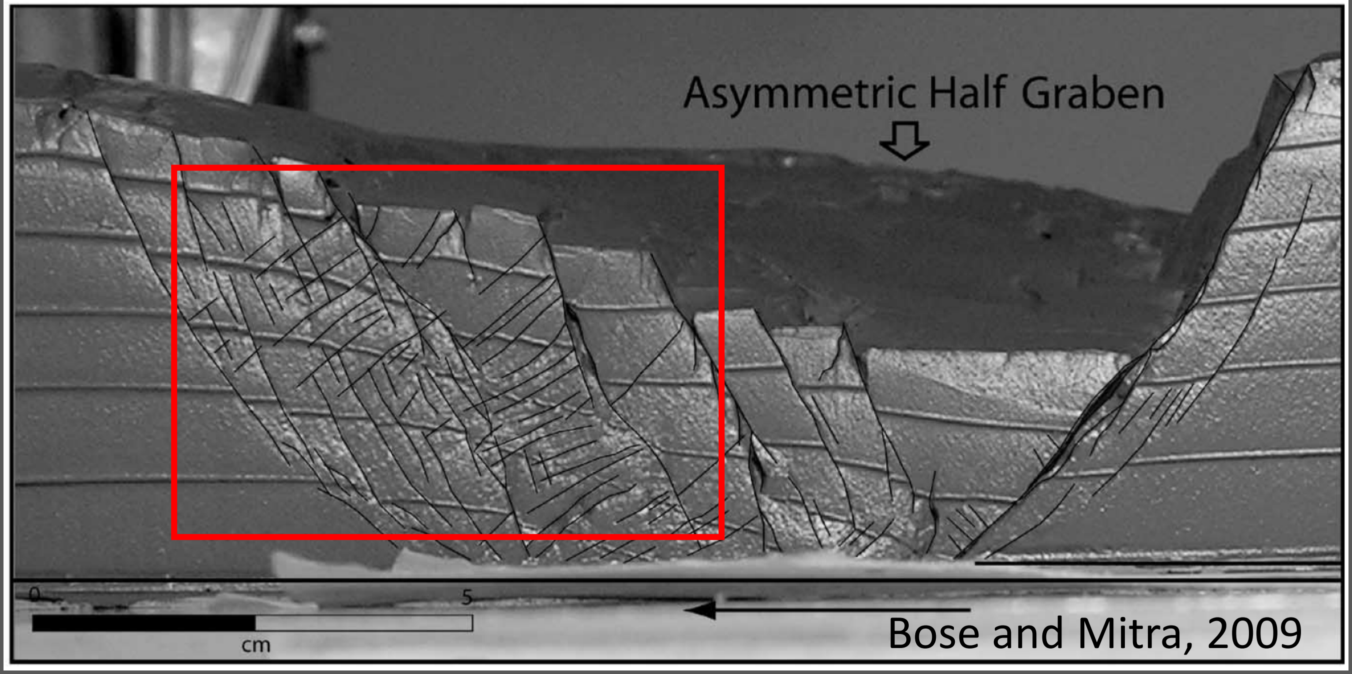
Key Points:

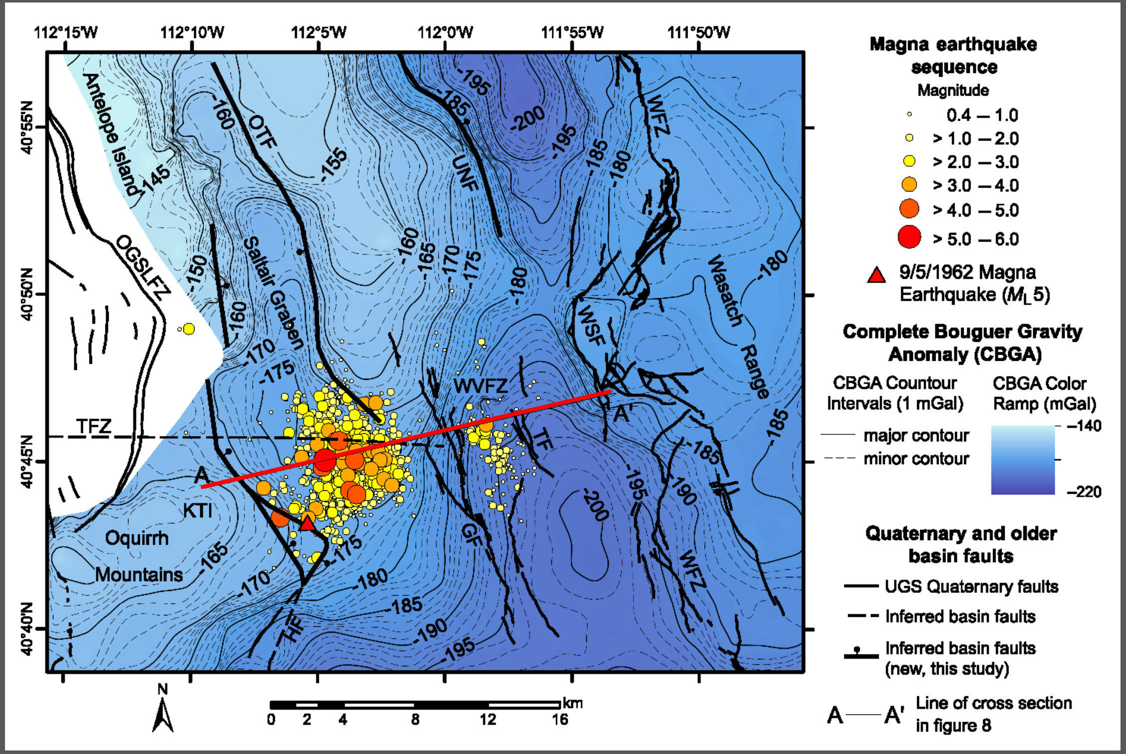
- High-precision relocation of the Magna, Utah, aftershocks supports a listric model for the Salt Lake City segment of the Wasatch fault
- The shallow dip of planar aftershock patterns—and many nodal planes—suggests that shallow-dipping normal faults can fail seismically

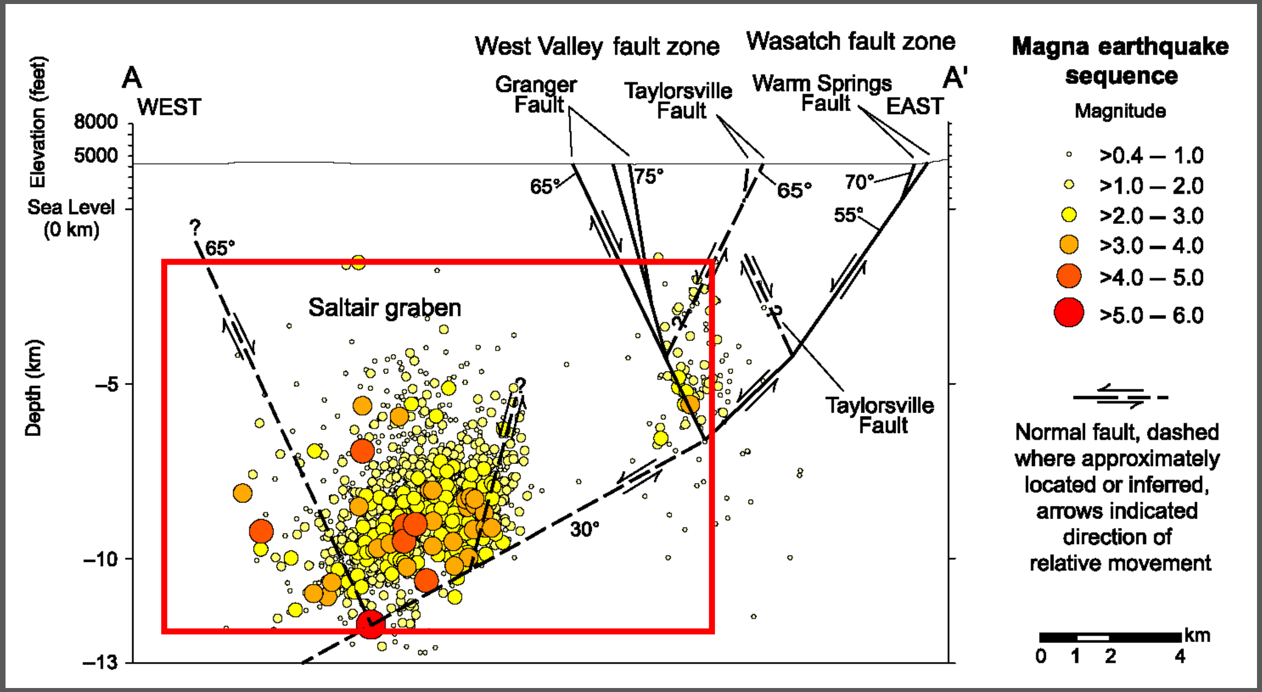


M_w 5.7 Magna, Utah, Earthquake

- Potential for listric Wasatch fault zone
- Potential for shallower earthquake focus than previously expected
- Well instrumented aftershocks
- Note clay model example of complex basin conjugate faults
- We created a draft Complete Bouguer Gravity Anomaly map (Kleber et al., 2021)







Current Project

Goals:

1. Perform a teleseismic receiver function analysis across the Salt Lake seismic array to look at structure [UU].
2. Compile existing geophysical and geologic data pertinent to the study area. [UGS]
3. Perform gravity surveys to validate legacy measurements and reduce uncertainty. [UU/UGS].
4. Model the gravity field with an updated Complete Bouguer Gravity Anomaly (CBGA) [UU/UGS].
5. Construct a new 3D velocity and density model of Salt Lake Valley by jointly inverting surface wave, receiver function, and gravity data [UU].
6. Compare seismic and gravity observation with the Wasatch Front Community Velocity Model (CVM; Magistralle et al., 2008) predictions [UU/UGS].
7. Investigate the potential of updating the CVM using the newly inverted 3D model as the reference model [UU/UGS].

Towards an Improved Salt Lake Valley Community Velocity Model Through Seismic and Gravity Joint Inversion

USGS EHP Grants G23AP00051 & G23AP00021

University of Utah:

Fan-Chi Lin

Tonie Van Dam

HyeJeong Kim

James Pechmann (retired)

Utah Geological Survey:

Christian Hardwick

Adam McKean

Kayla Smith

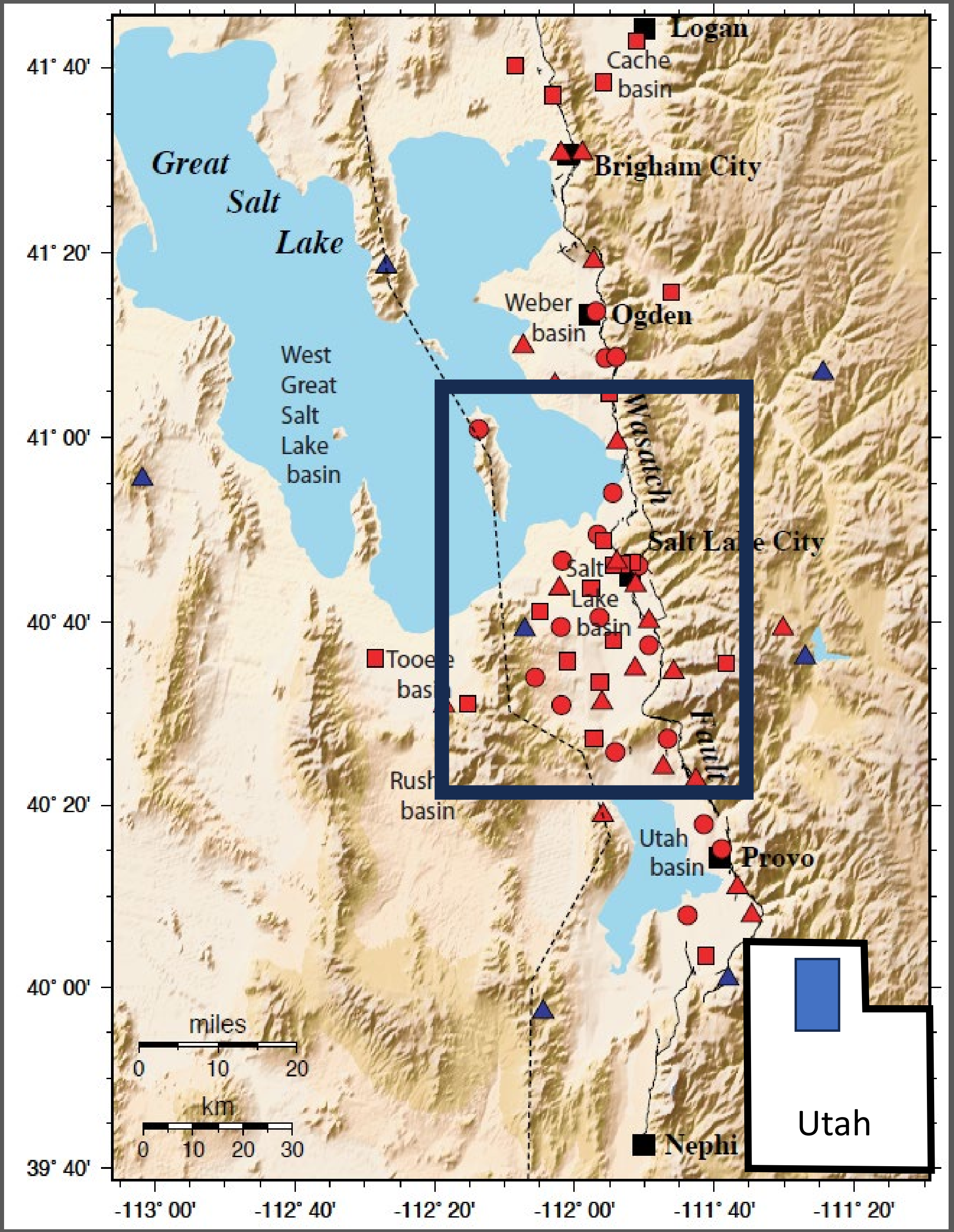
Torri Duncan

Skadi Kobe

Previous Work

Wasatch Front Community Velocity Model (CVM)

- A community velocity model (CVM) is a computer code where the seismic velocity at any location can be determined
- A CVM provides parameters for realistic earthquake ground motion simulations for various fault rupture scenarios
- The current CVM for the Wasatch Front was developed in 2008 (Magistrale *et al.*)
- Our study focuses on a smaller portion of the Wasatch Front CVM



■ ▲ ● U of U seismic network

Modified from Magistrale *et al.*, 2008

Previous Work

CVM inputs

Magistrale *et al.*, 2008

Gravity surveys: *depth to basement*

Radkins *et al.*, 1990; Mabey, 1992; McNeil and Smith, 1992

Well sonic logs: *velocity age-depth relation*

Geologic data: *defines surface contours for faults and different geologic materials*

Davis, 1983a,b, 1985; Witkind and Weiss, 1991

Seismic data: *basin geometry, crust-mantle boundary*

Loeb 1986; Loeb and Pechmann, 1987

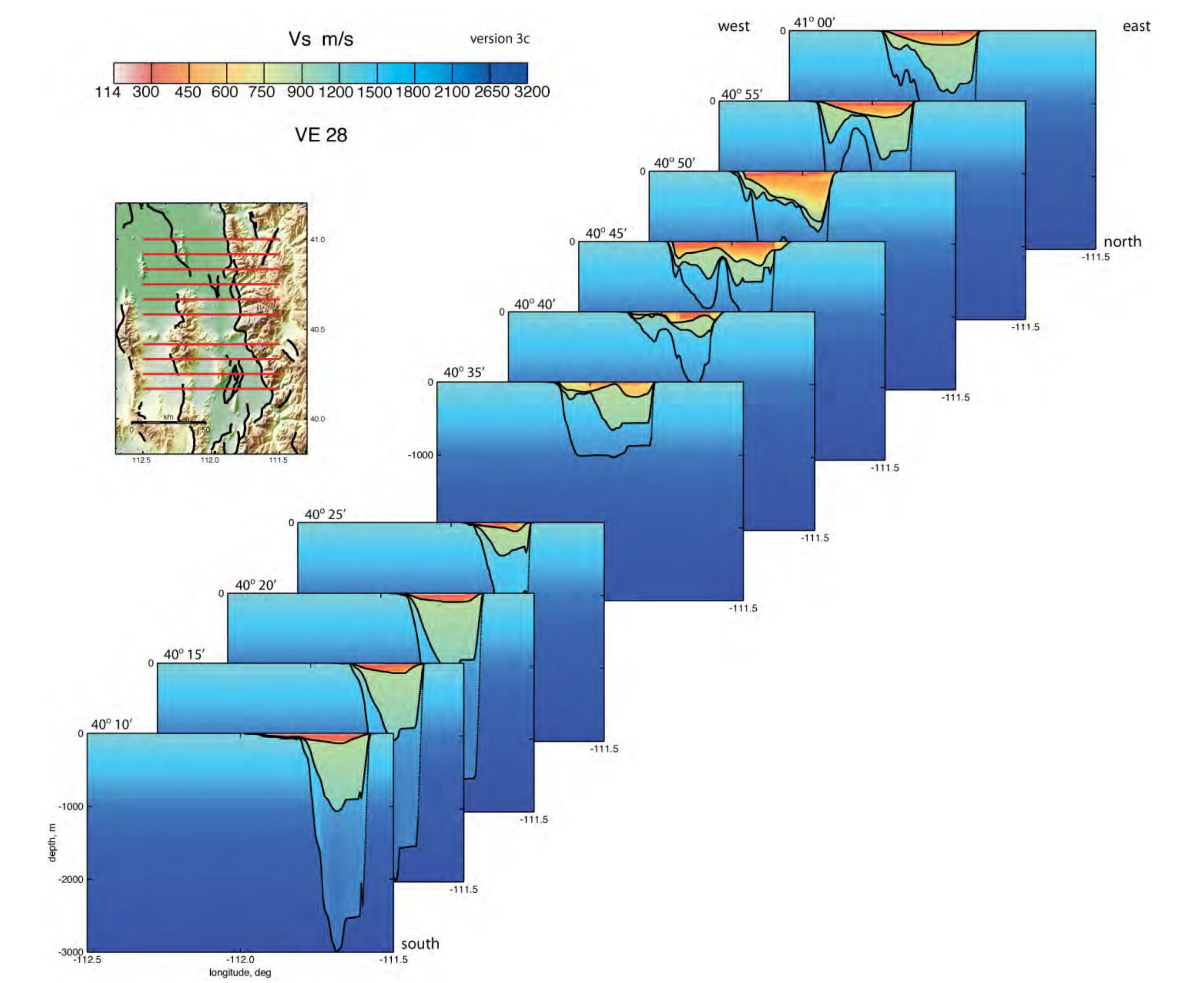
Well data: *model ground-truthing*

Tinsley *et al.*, 1991; Williams *et al.*, 1993; UGS, 2005

Output: seismic velocity at any given point

Previous Work

Wasatch Front Community Velocity Model (CVM)



Pechmann, et al., 2010 presentation

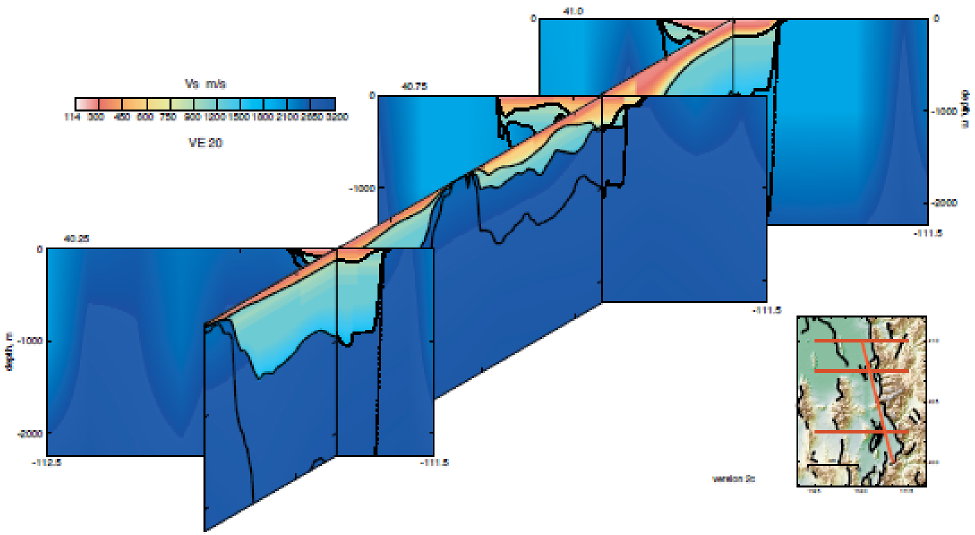


Figure 2. Fence diagram of Vs (see color scale) along the Wasatch Front from the current CVM. Red lines on index map show fence panel locations. Black lines indicate, from top to bottom, R1, R2, and R3 (see text, some of the R3 line goes of the bottom of the panels).

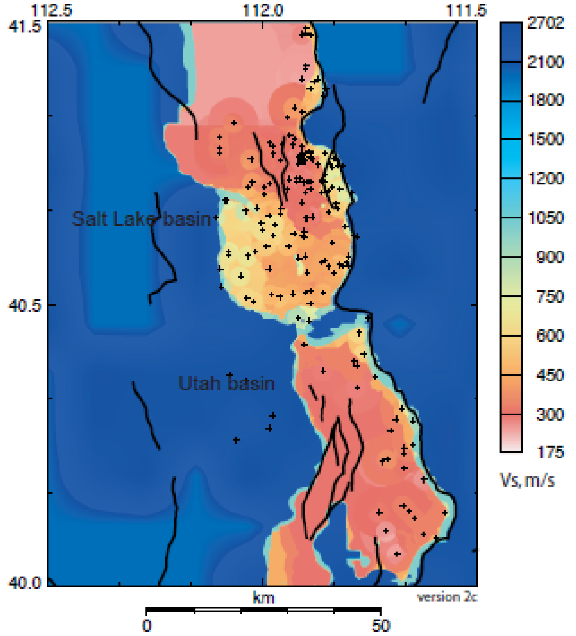


Figure 3. Map of Vs (see color scale) at 30 m depth. Crosses indicate borehole locations.

Magistrale et al., 2008

Previous Work

Wasatch Front Community Velocity Model (CVM)

SALT LAKE BASIN MODEL (Hill et al., 1990)
Unconsolidated Quaternary Sediments R1
Semiconsolidated Tertiary Sediments R2
Tertiary Sedimentary Rocks R3
Basement

Seismic reflectors R1, R2, and R3 are names that Hill (1988), Radkins et al. (1989), and Hill et al. (1990) assigned to prominent seismic reflectors from seismic profile R-11 recorded by Mountain Fuel Supply in the northern Salt Lake Valley.

Image from James C. Pechmann, et al. 2010 presentation (Sonic Log Analyses for the Wasatch Front Community Velocity Model)

CVM Model Layers

Wasatch Front Community Velocity Model (CVM)

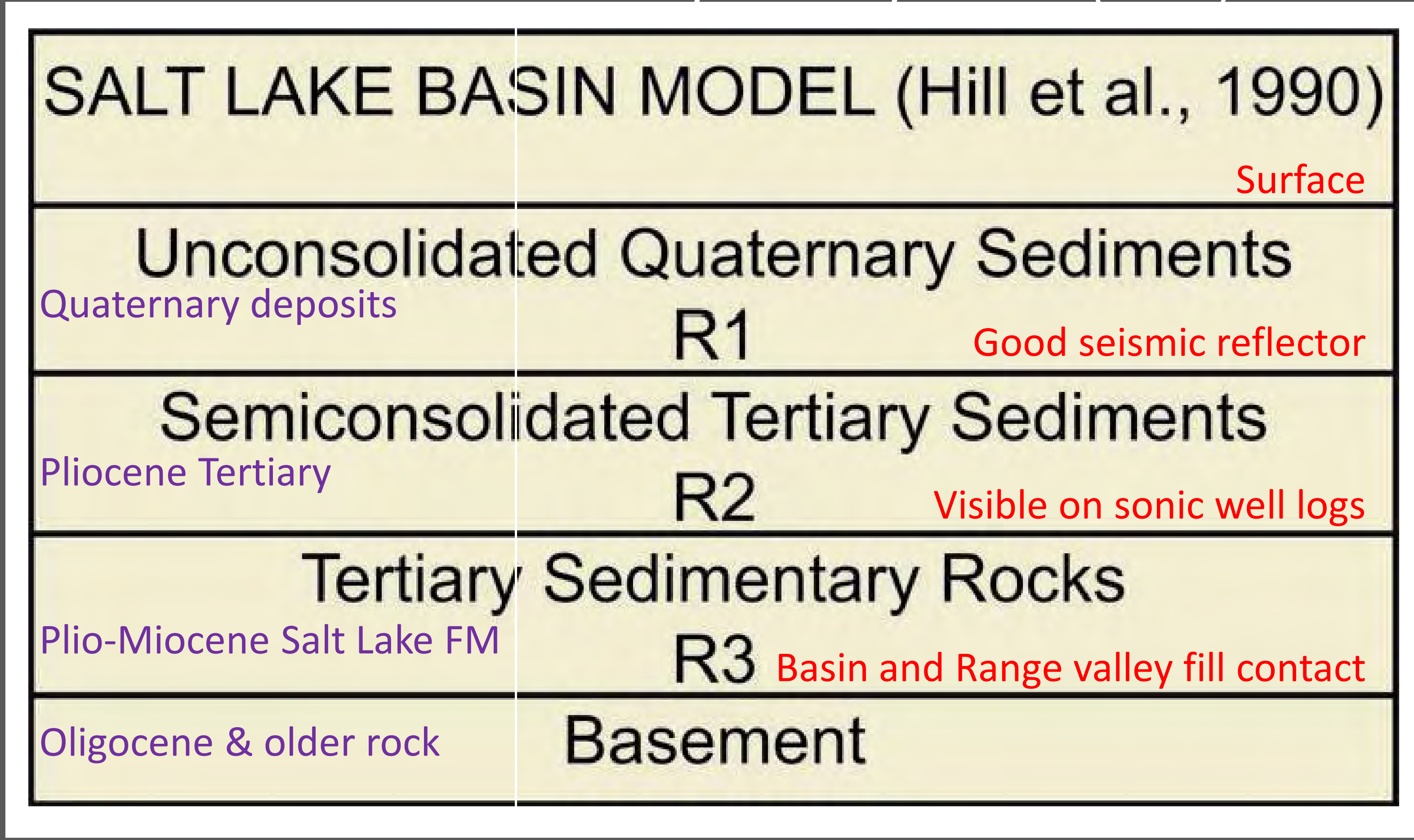
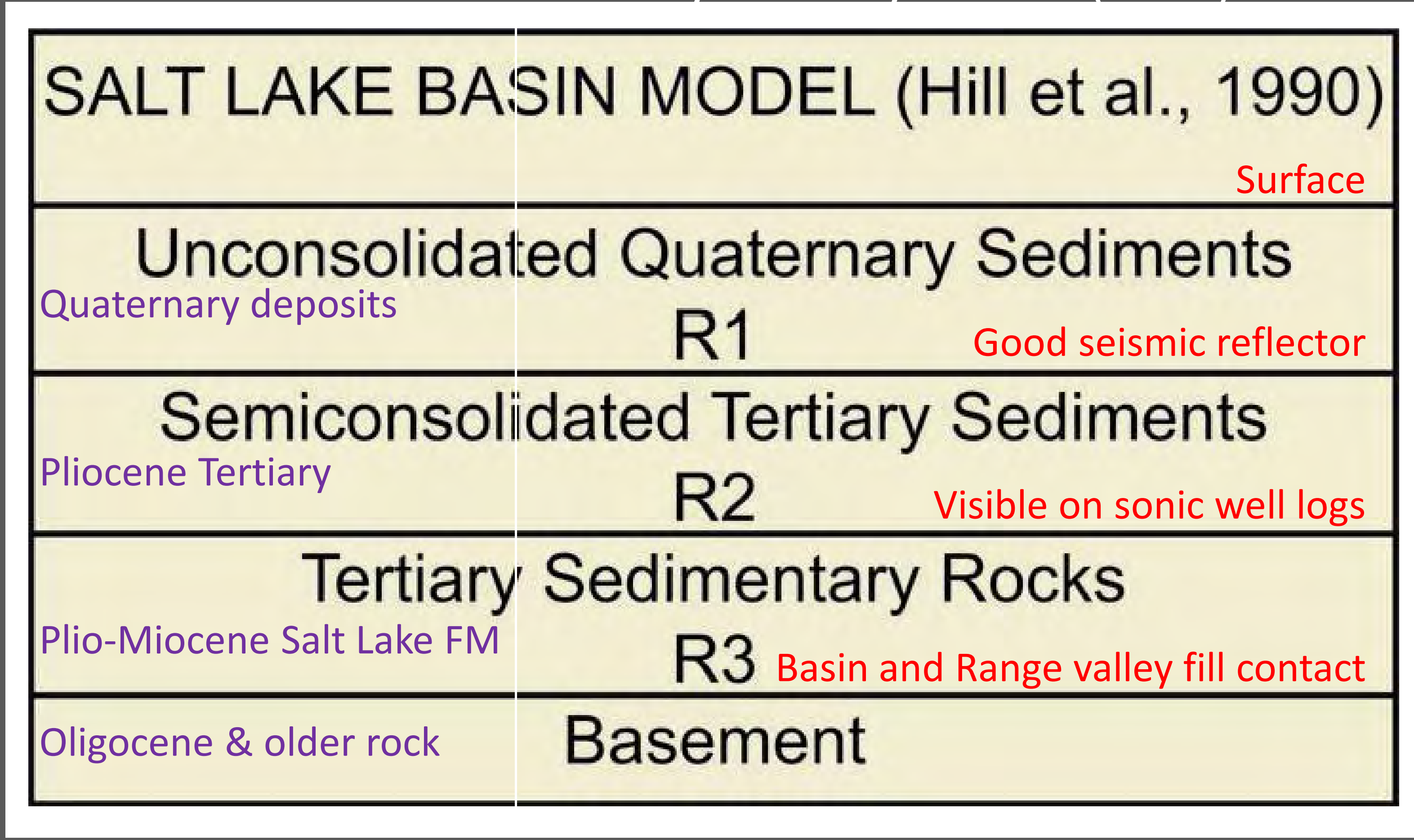


Image from James C. Pechmann, et al. 2010 presentation (Sonic Log Analyses for the Wasatch Front Community Velocity Model)

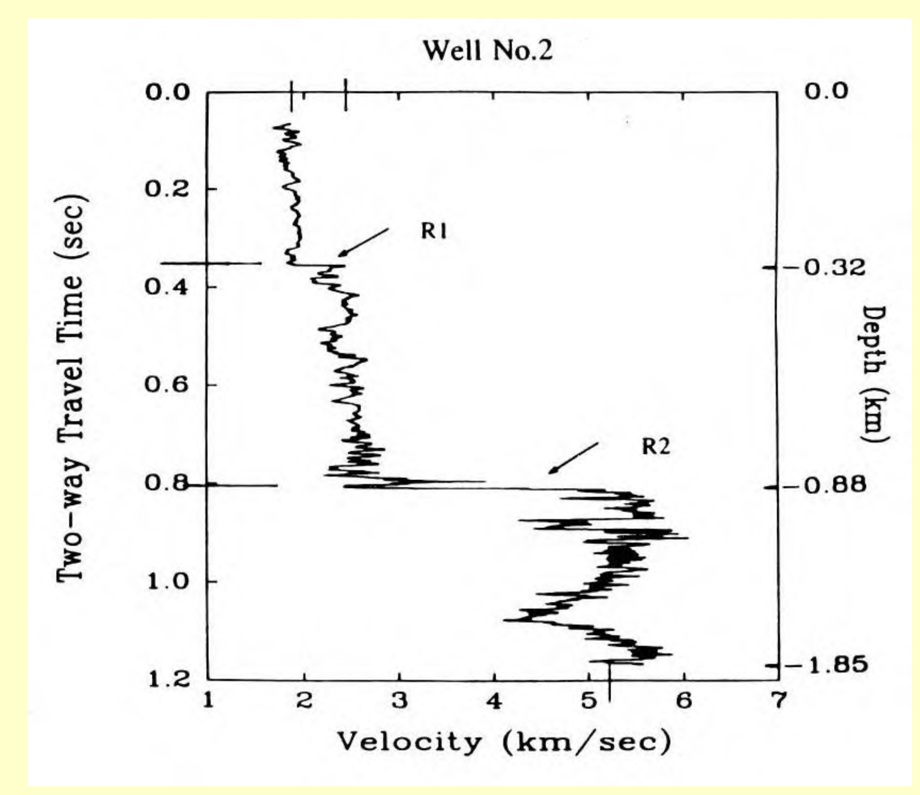
Hill and others (1990) describe the **reflectors** as follows: “Each represents a strong impedance contrast and are interpreted as the contacts between the unconsolidated Quaternary and semi-consolidated Tertiary sediments (R1), the semi-consolidated Tertiary and underlying consolidated deep basin sediments (R2), and the consolidated deep basin sediments and basement rocks (R3).”

CVM Model Layers

Wasatch Front Community Velocity Model (CVM)



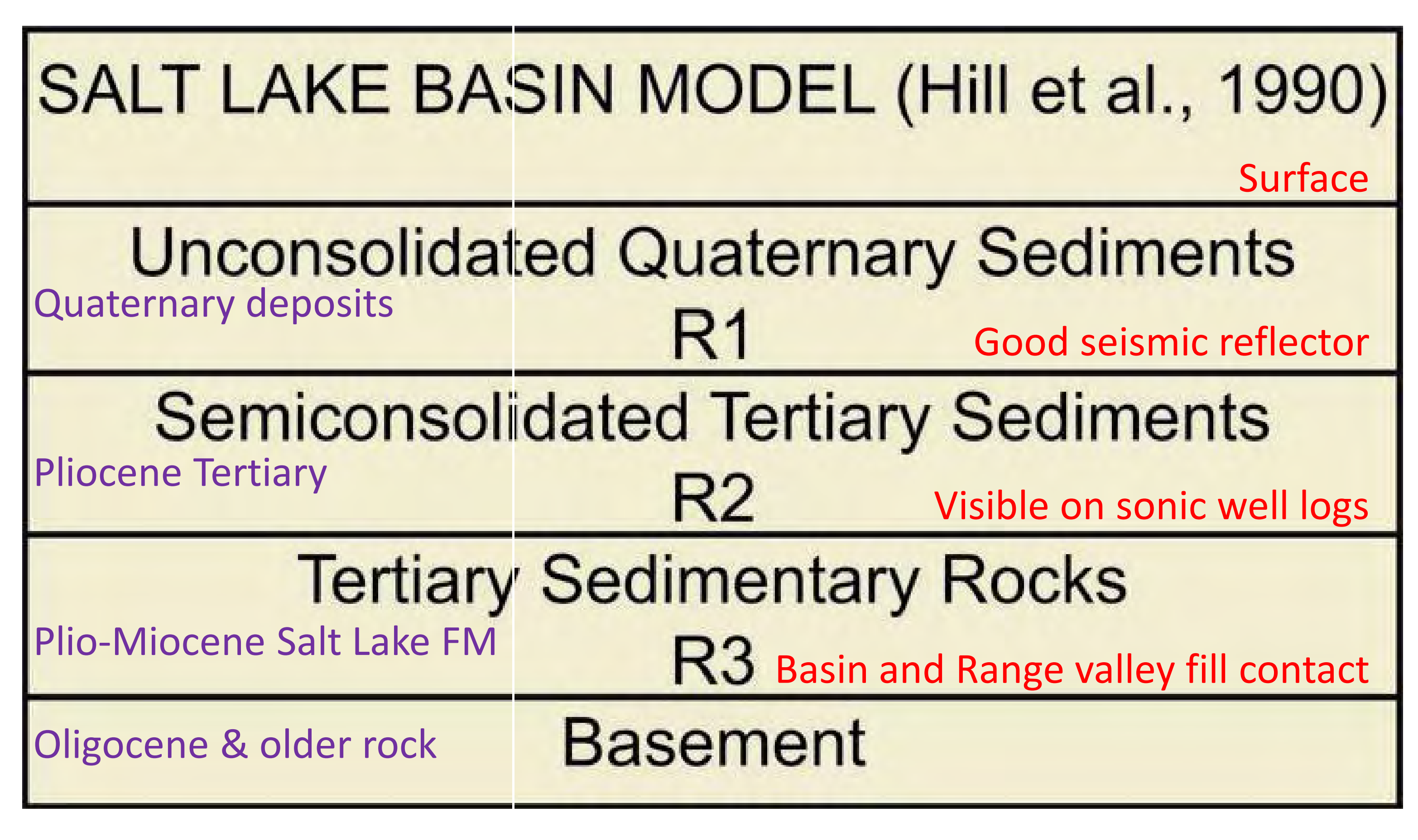
Gillmar Fee #1

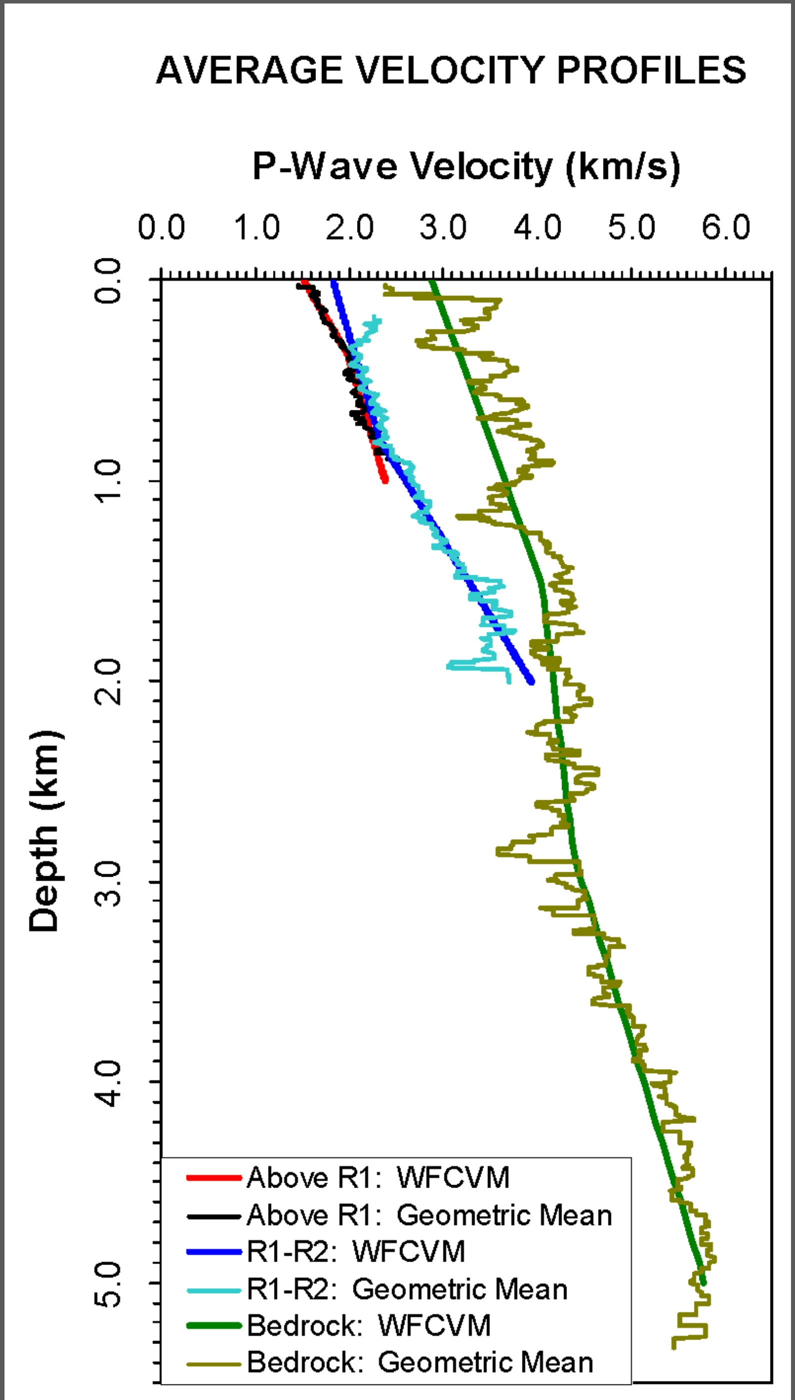


Images from James C. Pechmann, et al. 2010 presentation (Sonic Log Analyses for the Wasatch Front Community Velocity Model)

CVM Model Layers

Wasatch Front Community Velocity Model (CVM)

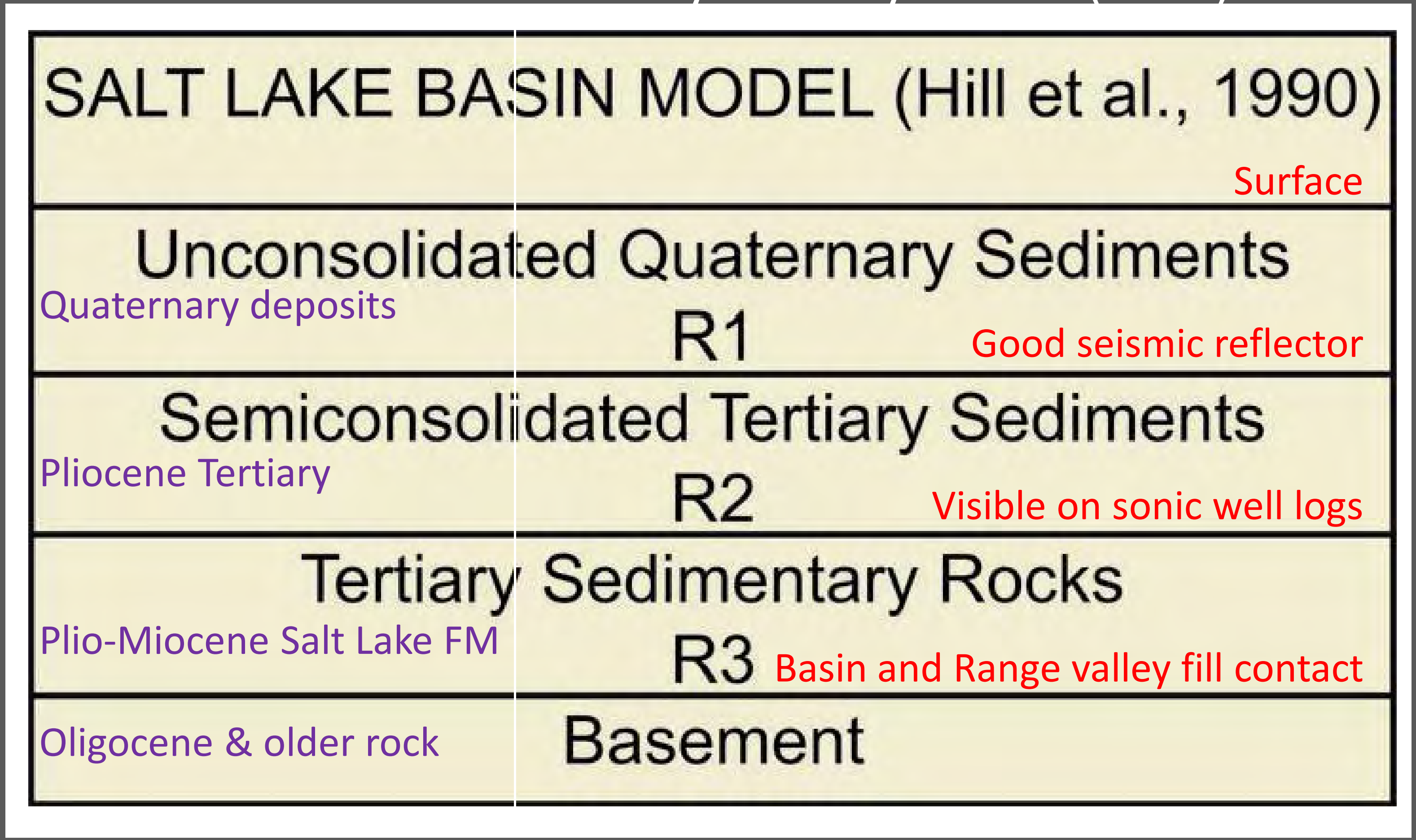




Images from James C. Pechmann, et al. 2010 presentation (Sonic Log Analyses for the Wasatch Front Community Velocity Model)

CVM Model Layers

Wasatch Front Community Velocity Model (CVM)



These three contacts subdivided the Basin and Range age (younger than ~17–20 million years along the Wasatch Fault Zone) sediments into three main deposits according to Hill and others (1990).

Image from James C. Pechmann, et al. 2010 presentation (Sonic Log Analyses for the Wasatch Front Community Velocity Model)

Current Work

CVM component updates

PACES, 2012

Gravity surveys: ***added over 1000 measurements from legacy and recent surveys***

Geologic data: ***updated structural models after the Magna earthquake***

Pang *et al.*, 2020; Kleber *et al.*, 2021

Seismic data: ***Magna aftershock receiver array- 168 nodes deployed***

Well data: ***compiled additional deep-basin wells***

Objective: Validate or invalidate the 2008 CVM

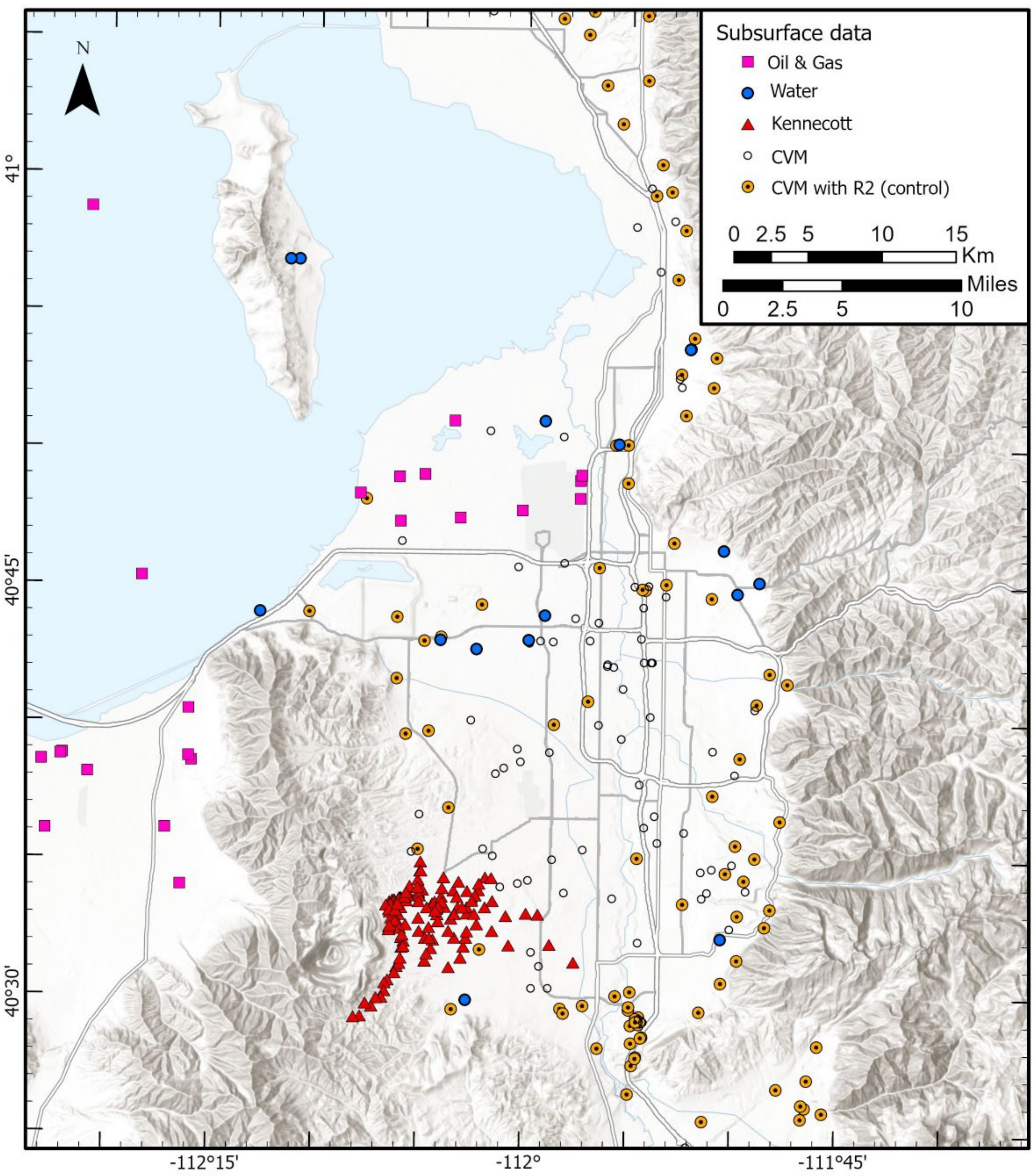
Existing and new wells

<u>Existing wells used for CVM</u>

- UGS deep basin drill hole database (272 wells)

<u>Wells add (180 this project)</u>

- 27 older oil and gas wells
- 19 new water wells
- 134 Kennecott wells



Gravity Surveys

Gravity Method Primer

- 9.8 m/s^2 (mean acceleration due to gravity at the Earth's surface)

Applied unit of measure:

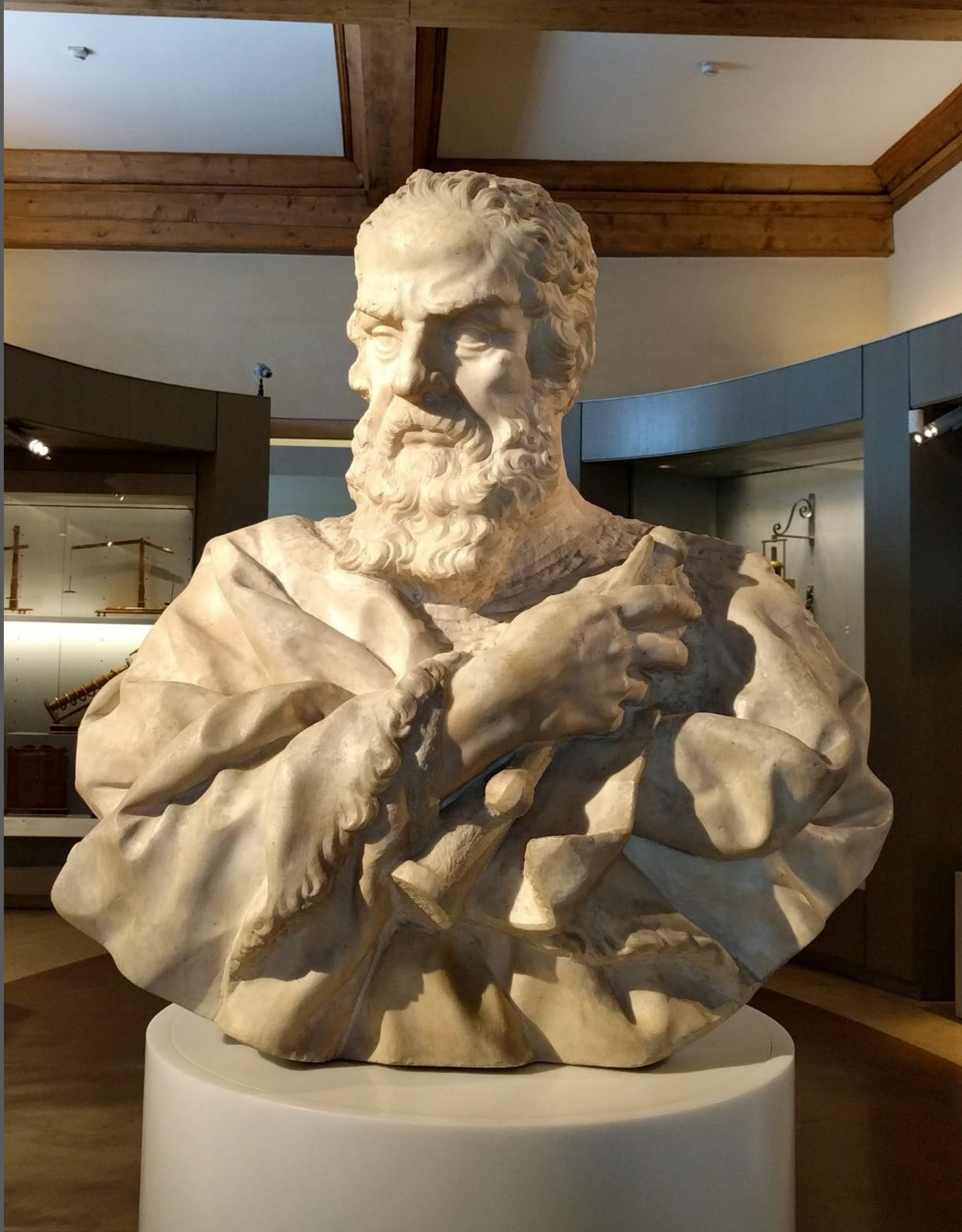
- Gal => Galileo Galilei => cm/s^2
- 9.8 m/s^2 = 980 Gal = 980,000 mGal = 980,000,000 μGal

Equipment:

- Scintrex CG-5 gravimeter with precision 1 μGal; accuracy 5 μGal
- Multiband GNSS with vertical precision .01 m; accuracy .03 m

Application:

- Free air (elevation) correction: 0.3086 mGal/m
- Latitudinal correction: 0.8 mGal/km (the maximum at 45° latitude)



- Scintrex CG-5 relative gravimeter
- Multiband GNSS (0.1 m vertical accuracy results in 0.03 mGal gravity accuracy)
- Gravity corrections for CBGA
  (Gettings *et al.,* 2008 & Hinze *et al.,* 2015)
  - Free air (elevation)
  - Local and regional terrain corrections
  - Latitudinal
  - Earth tides
  - Bouguer slab
  - CG-5 Sensor drift

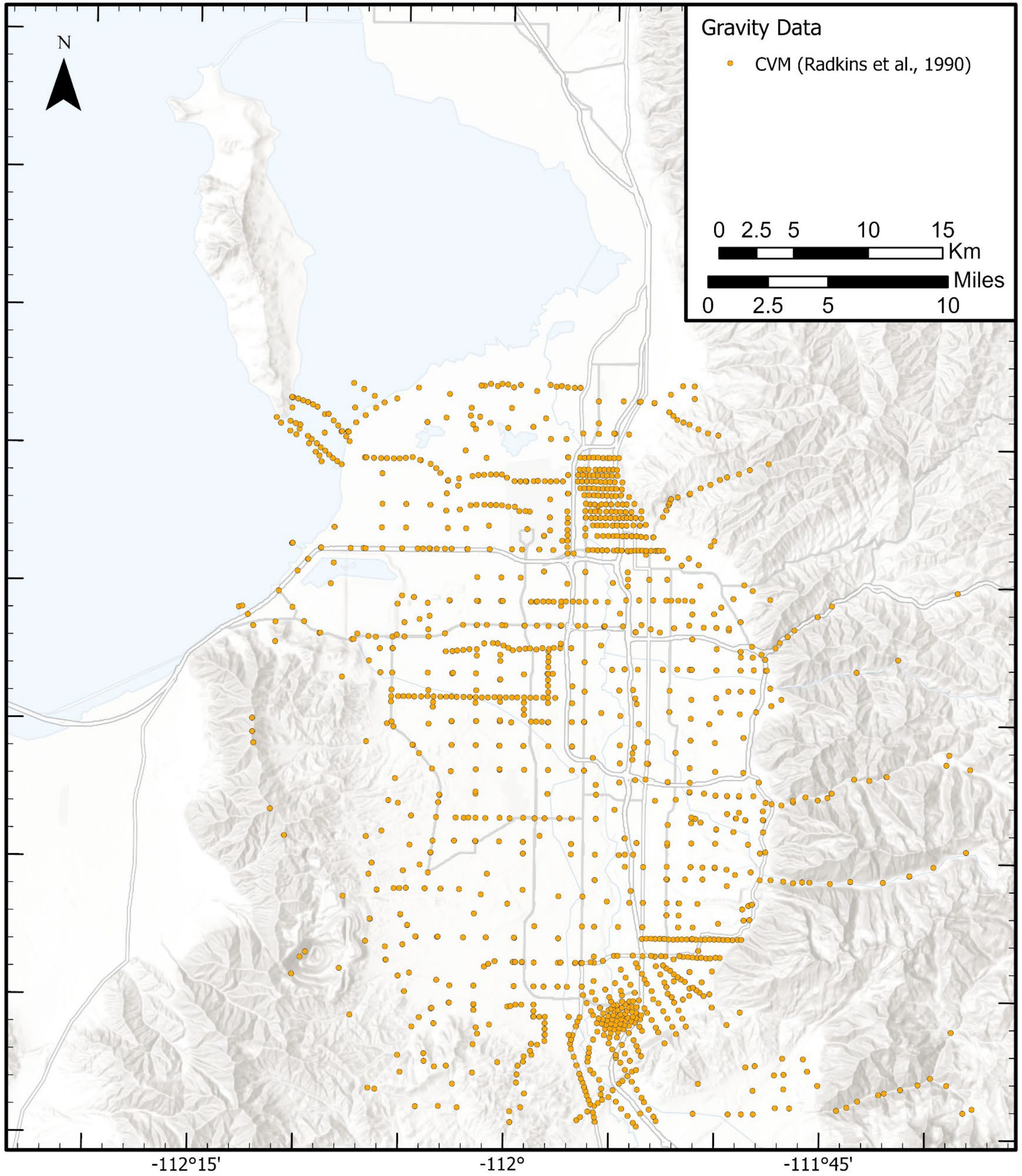
Existing and new gravity

Existing data used for CVM
- ~1,400 Radkins (et al. 1990)

Gravity data added

SL Valley:
- 975 legacy (PACES, 2012)
- 95 modern (2023)
- 127 modern (unpublished UGS)

Regional (excluding SL Valley):
- 650 modern (UGS)
- 4,972 legacy (PACES, 2012)



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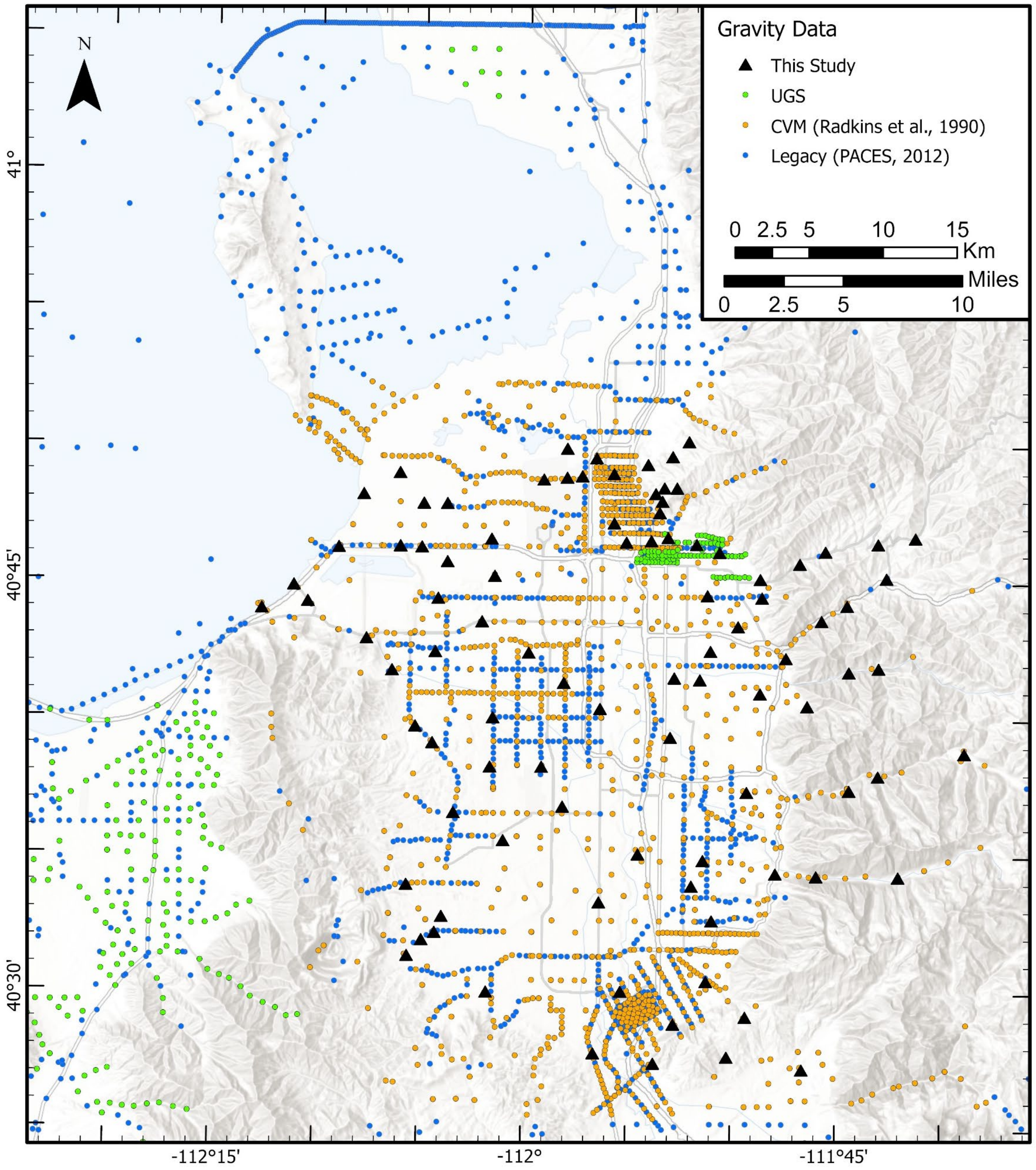

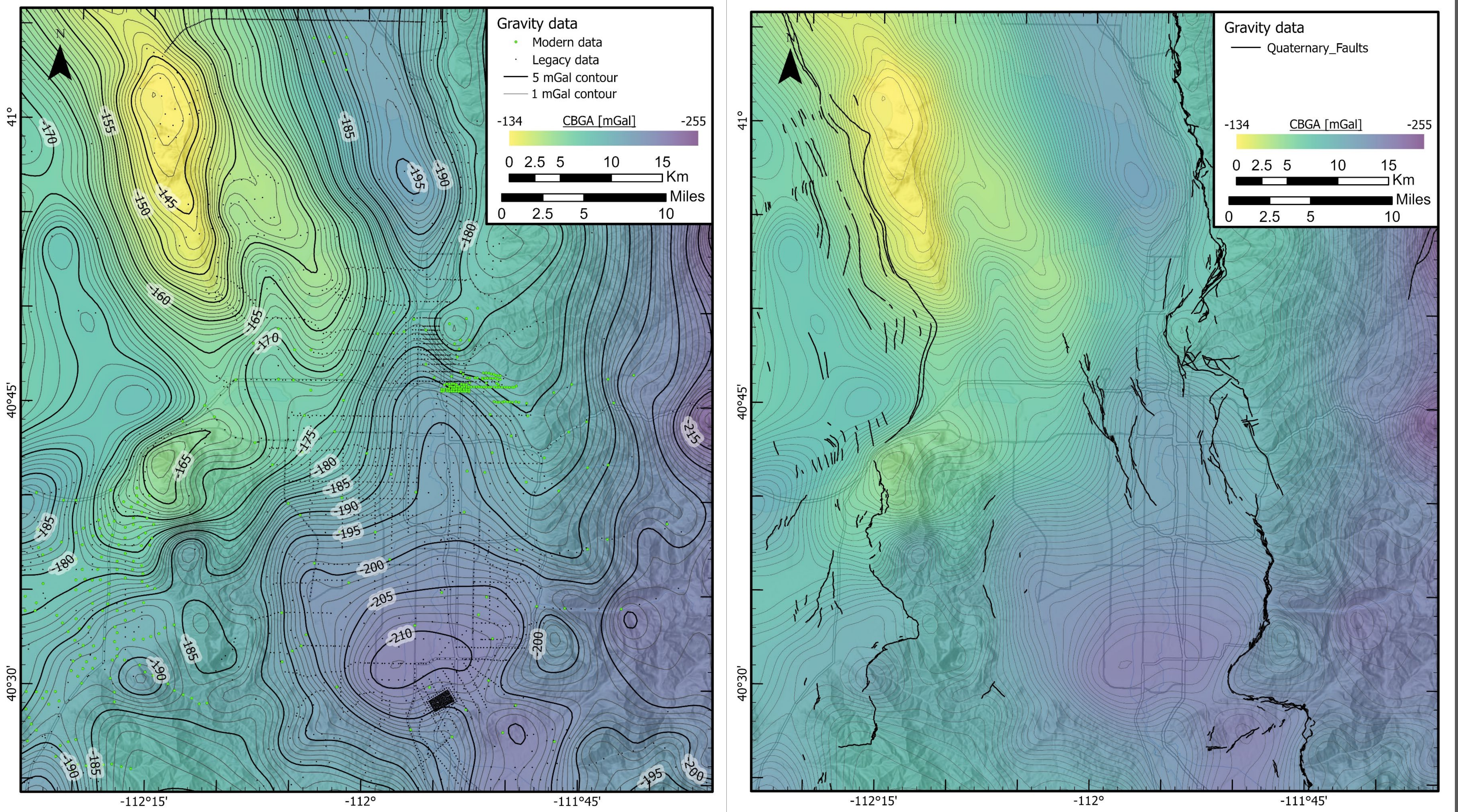
Gravity data
Modern data
Legacy data
5 mGal contour
1 mGal contour
-134
CBGA [mGal]
-255
0 2.5 5 10 15
Km
Miles
0 2.5 5 10
41°
40°45'
40°30'
-112°15'
-112°
-111°45'
Gravity data
Quaternary_Faults
-134
CBGA [mGal]
-255
0 2.5 5 10 15
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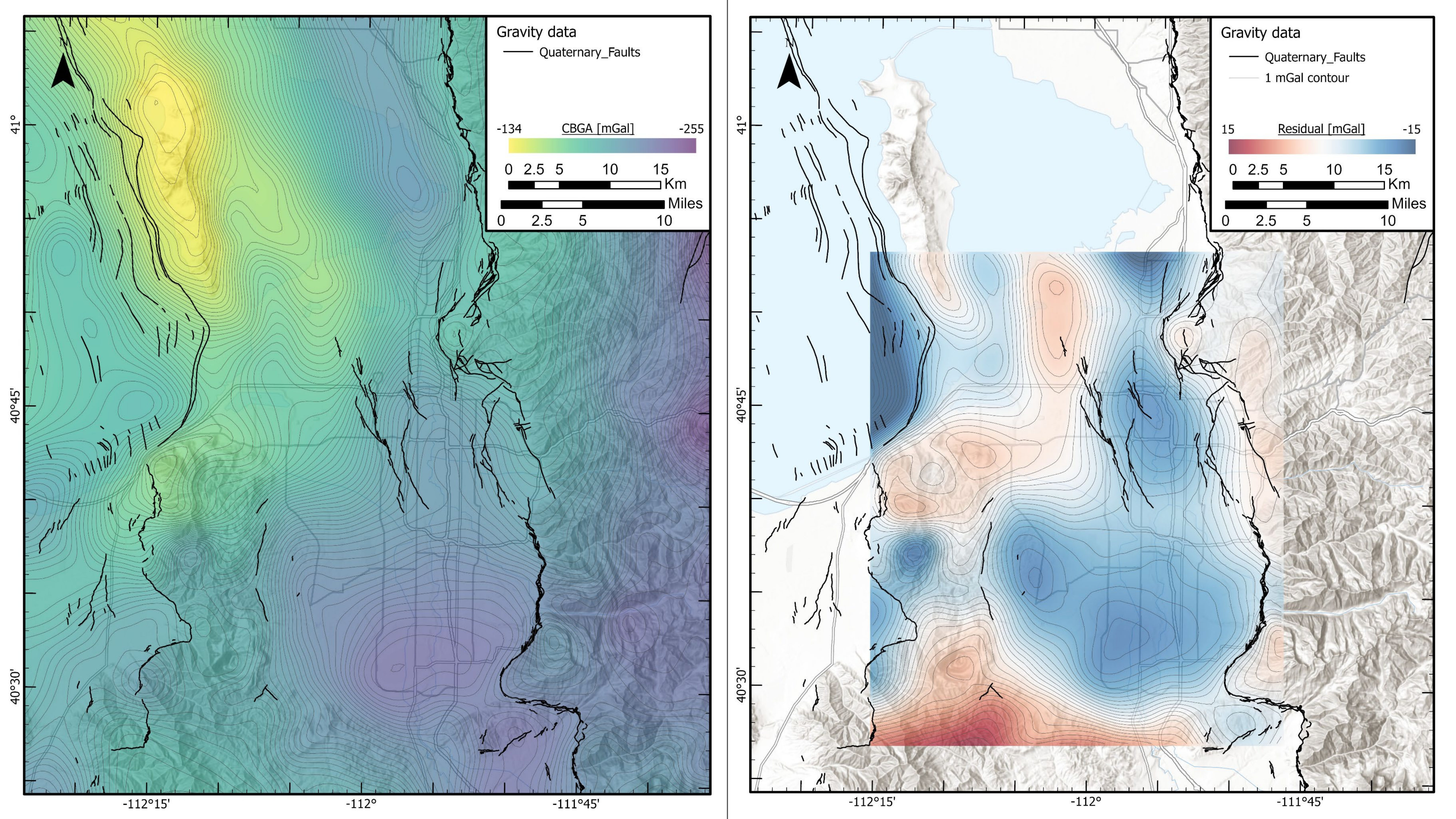

Gravity data
Quaternary_Faults
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41°
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Gravity data
Quaternary_Faults
1 mGal contour
15
Residual [mGal]
-15
0 2.5 5 10 15 Km
0 2.5 5 10 Miles
41°
40°45'
40°30'
-112°15'
-112°
-111°45'

Conclusion

- Project was not intended to redo the CVM but see if new methods and data could be used to evaluate it and potentially be used in a new version of the CVM
- 180 new wells added
- Added 222 modern and 975 legacy gravity stations in the SL Valley
- New Complete Bouguer Gravity Anomaly, preliminary residual map
- Next talk, Part 2—Seismic Data and Joint Inversion by Fan-Chi Lin

Next Steps:

- Finalize residual gravity anomaly of SL Valley incorporating well data as controls
- Perform a final joint seismic and gravity inversion to construct a new 3D model of the Salt Lake basin
- Use new model to evaluate 2008 CVM

Thank you

adammckean@utah.gov
christianhardwick@utah.gov

Acknowledgements:

Thank you to Jim Pechmann for his guidance on this projects and expertise from the 2008 CVM

USGS Award: FY2023 EHP Program
G23AS00249 – Proposal 2023-0078

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Towards an Improved Salt Lake Valley Community Velocity Model Through Seismic and Gravity Joint Inversion: Part II - seismic data and joint inversion

HyeJeong Kim*, Fan-Chi Lin , James Pechmann, Adam McKean, Emily Kleber, Kayla Smith, Christian Hardwick, Tonie van Dam

UTAH GEOLOGICAL SURVEY

USGS science for a changing world

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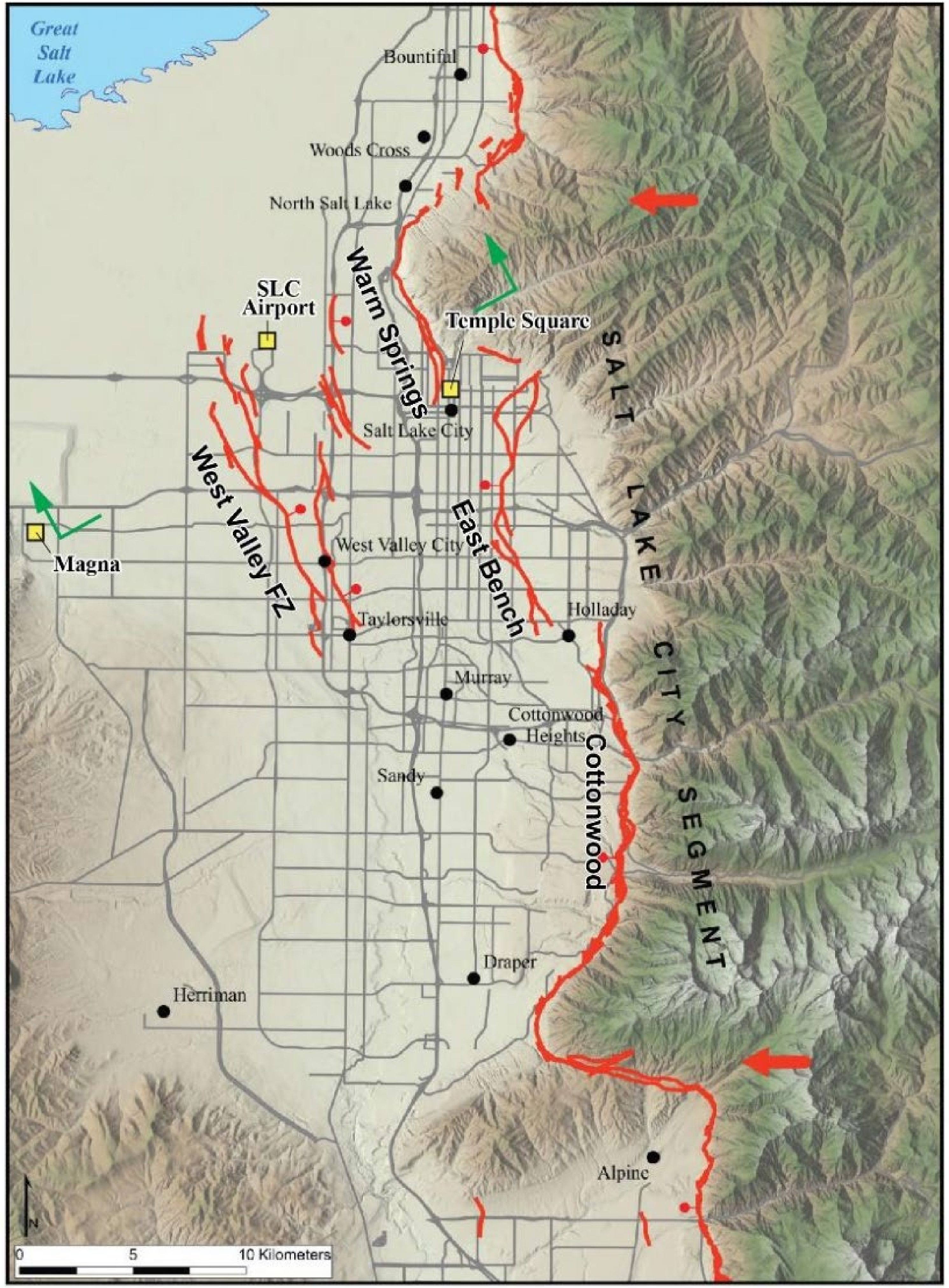
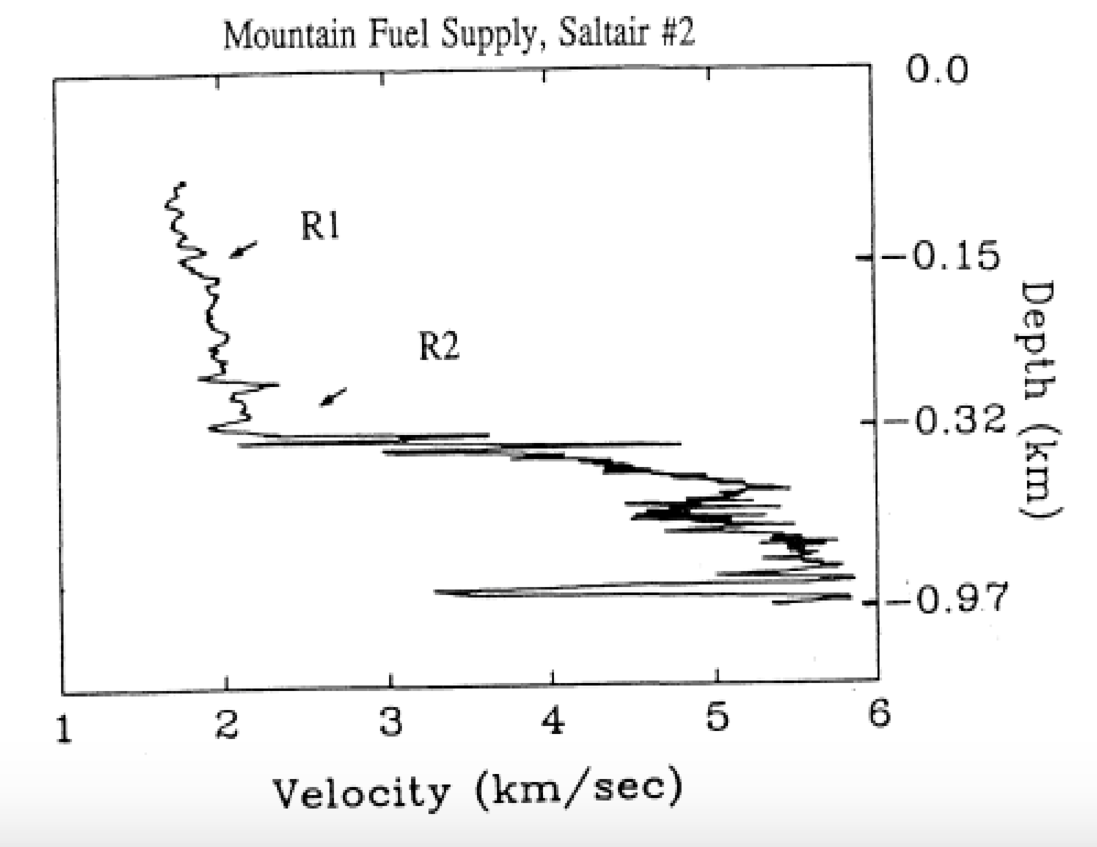
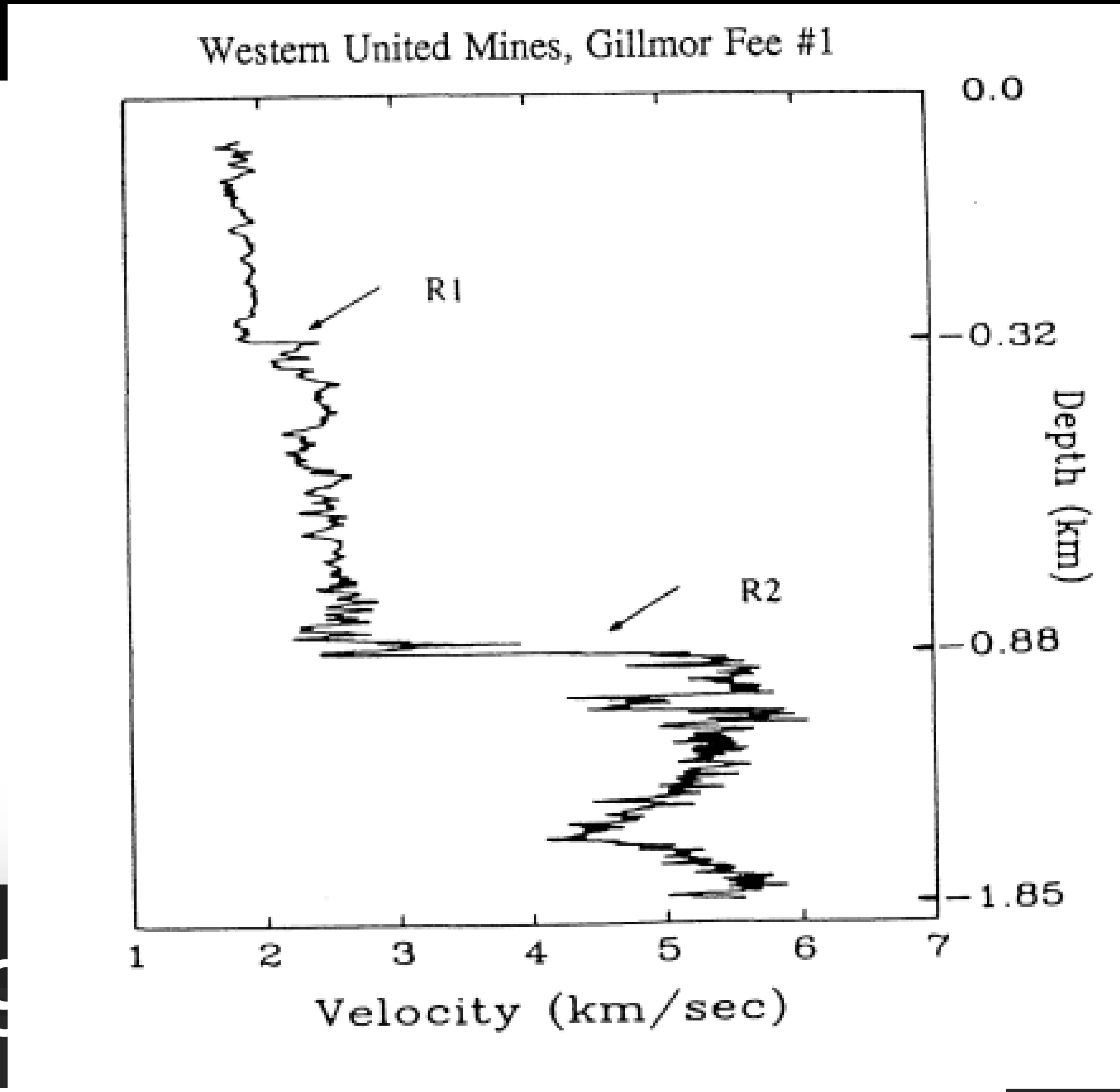
Salt Lake Valley CVM



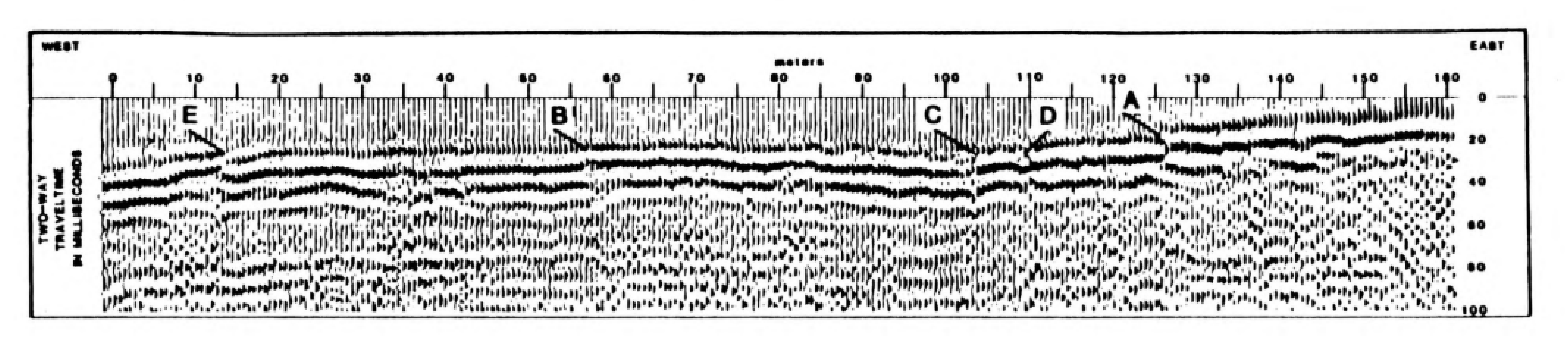
Roten et al. (2011)

Depth to bedrock (R2)

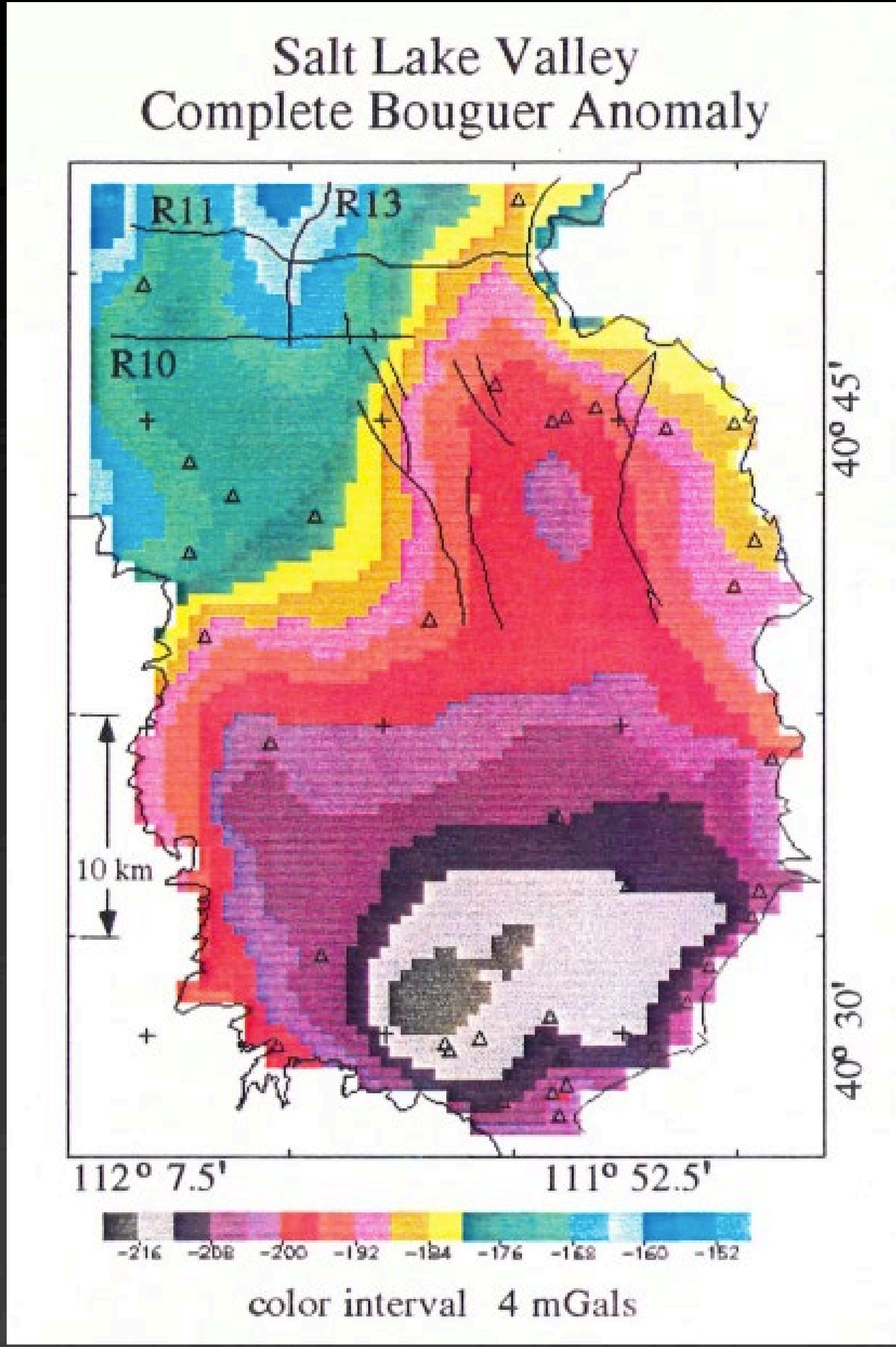


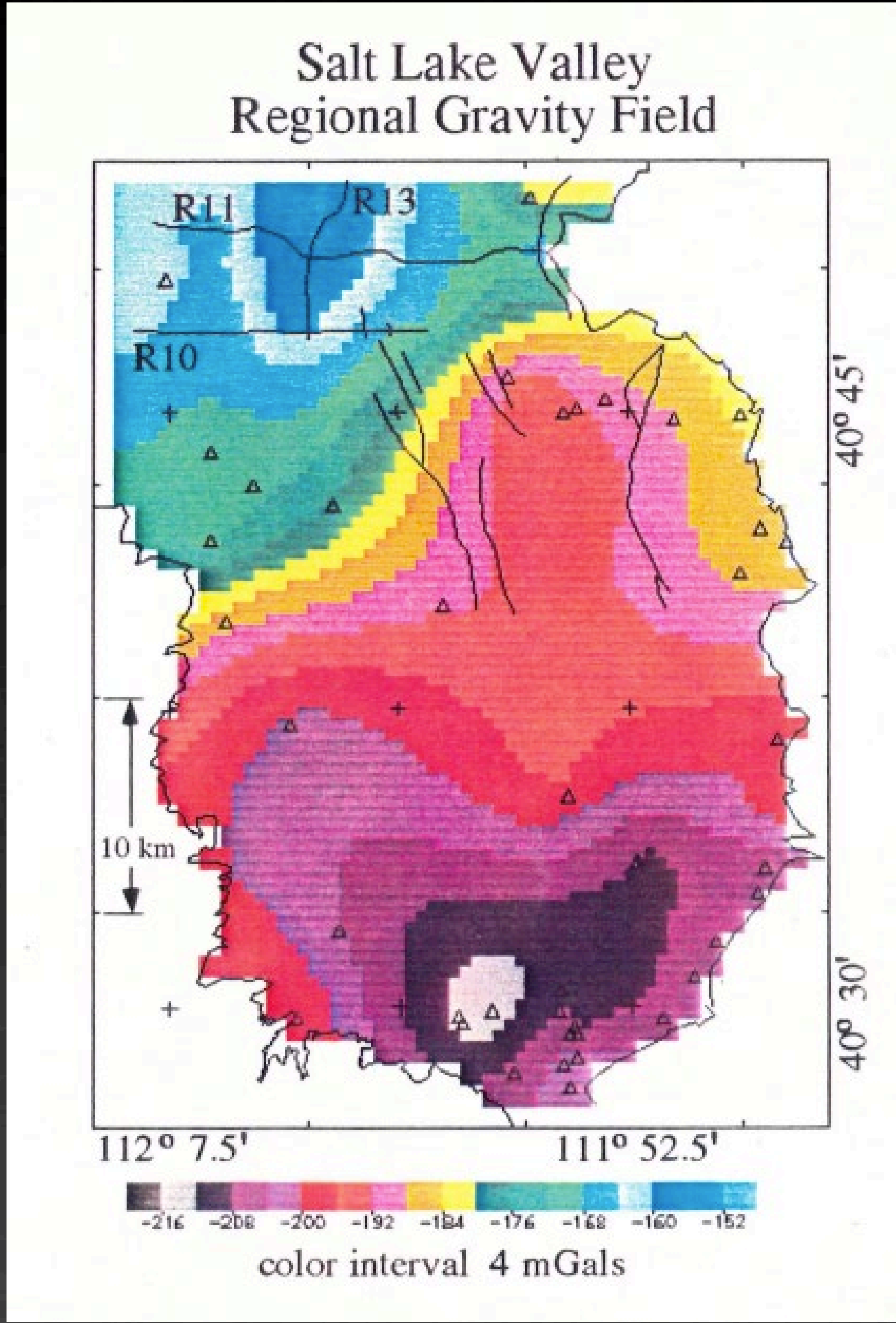


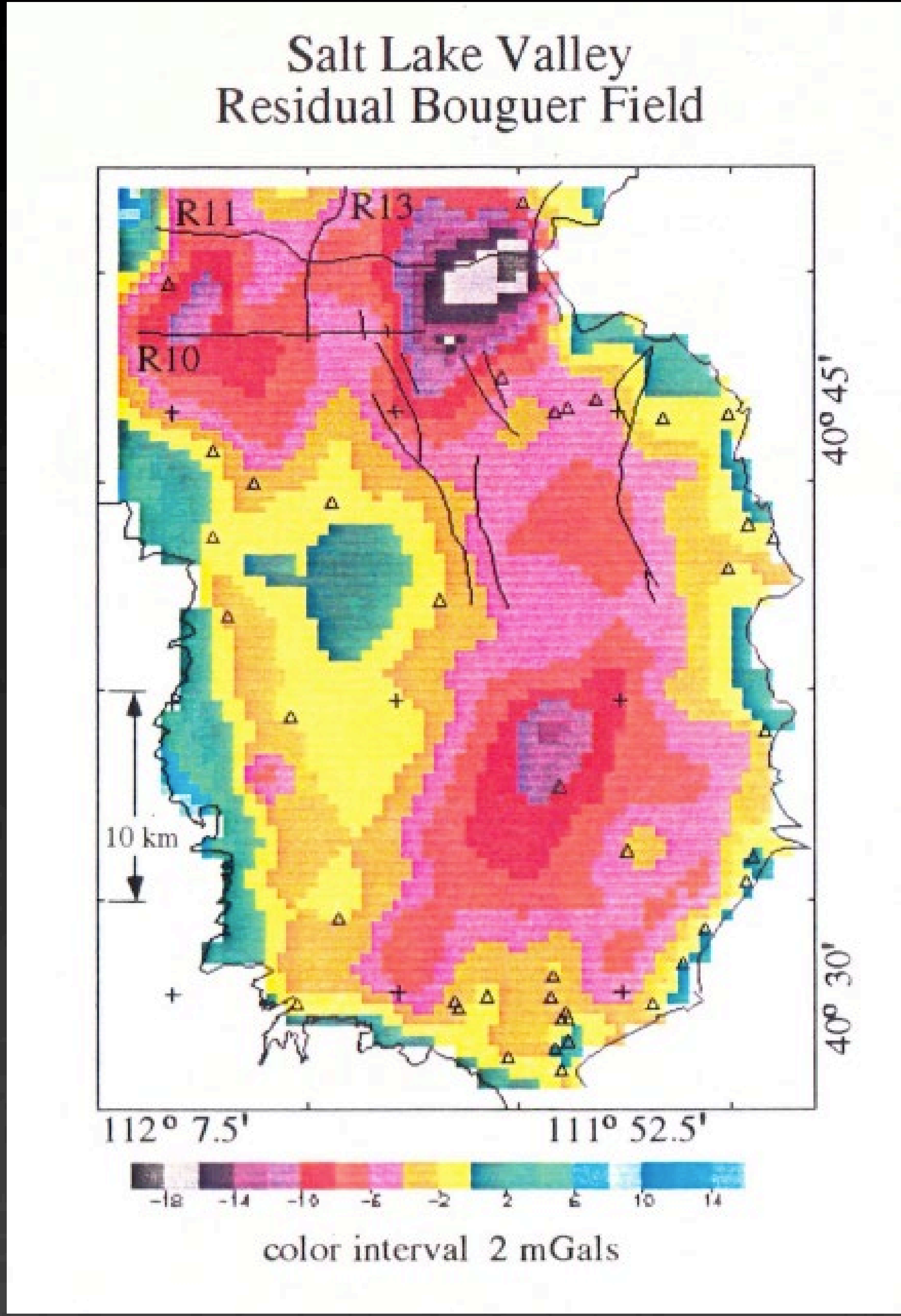
Radkins et al (1989)



Mapping R2 using gravity

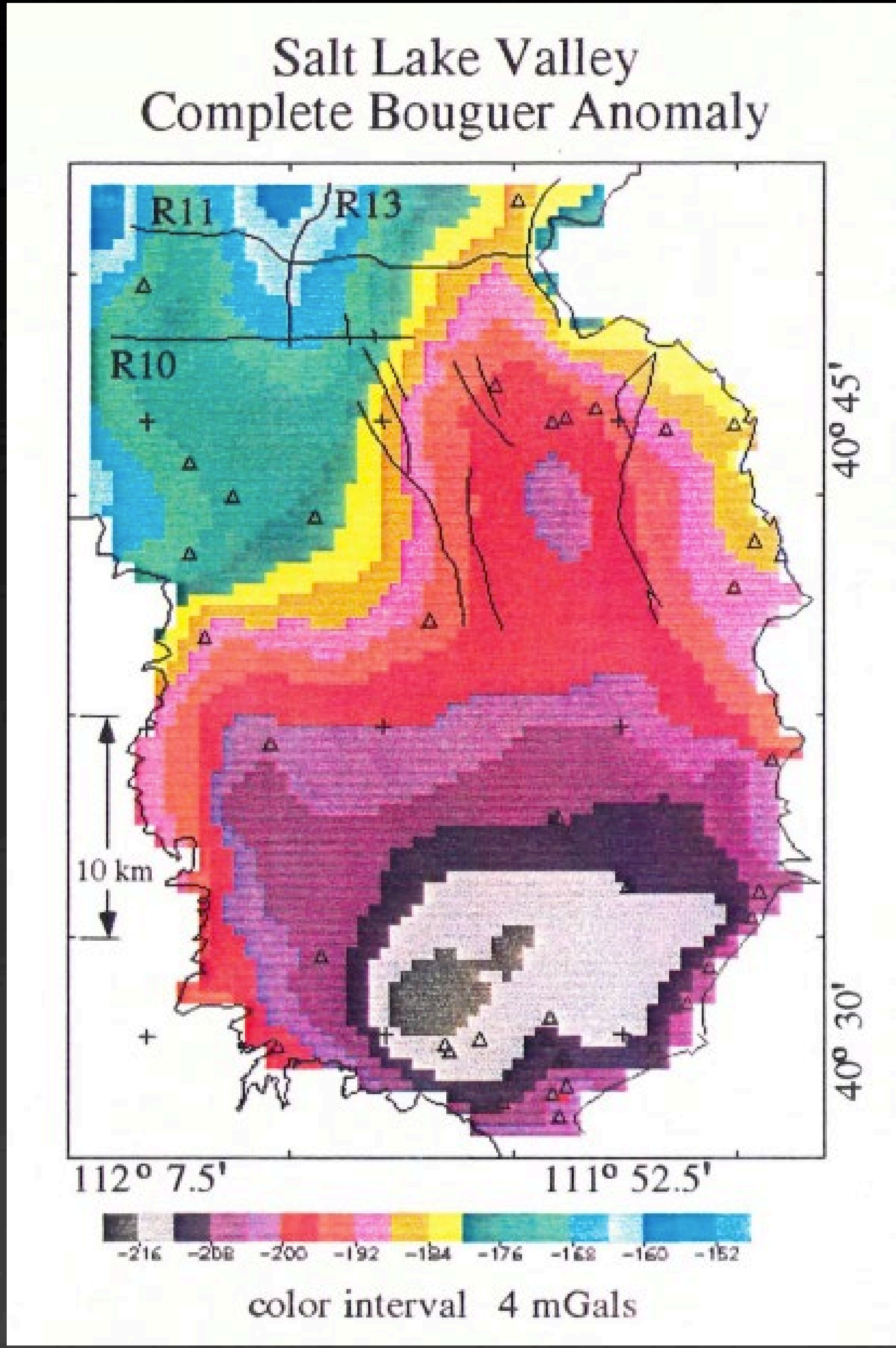


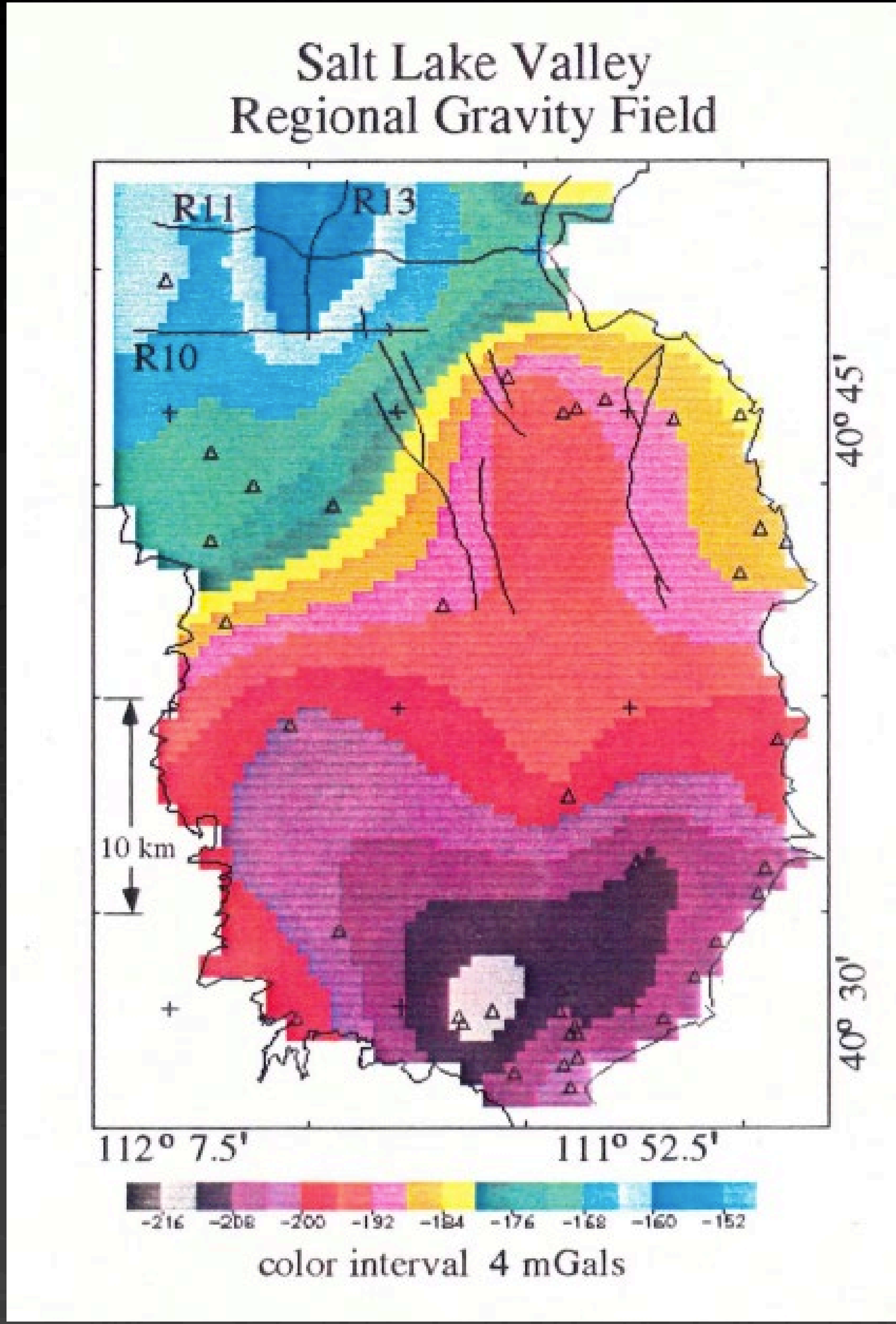


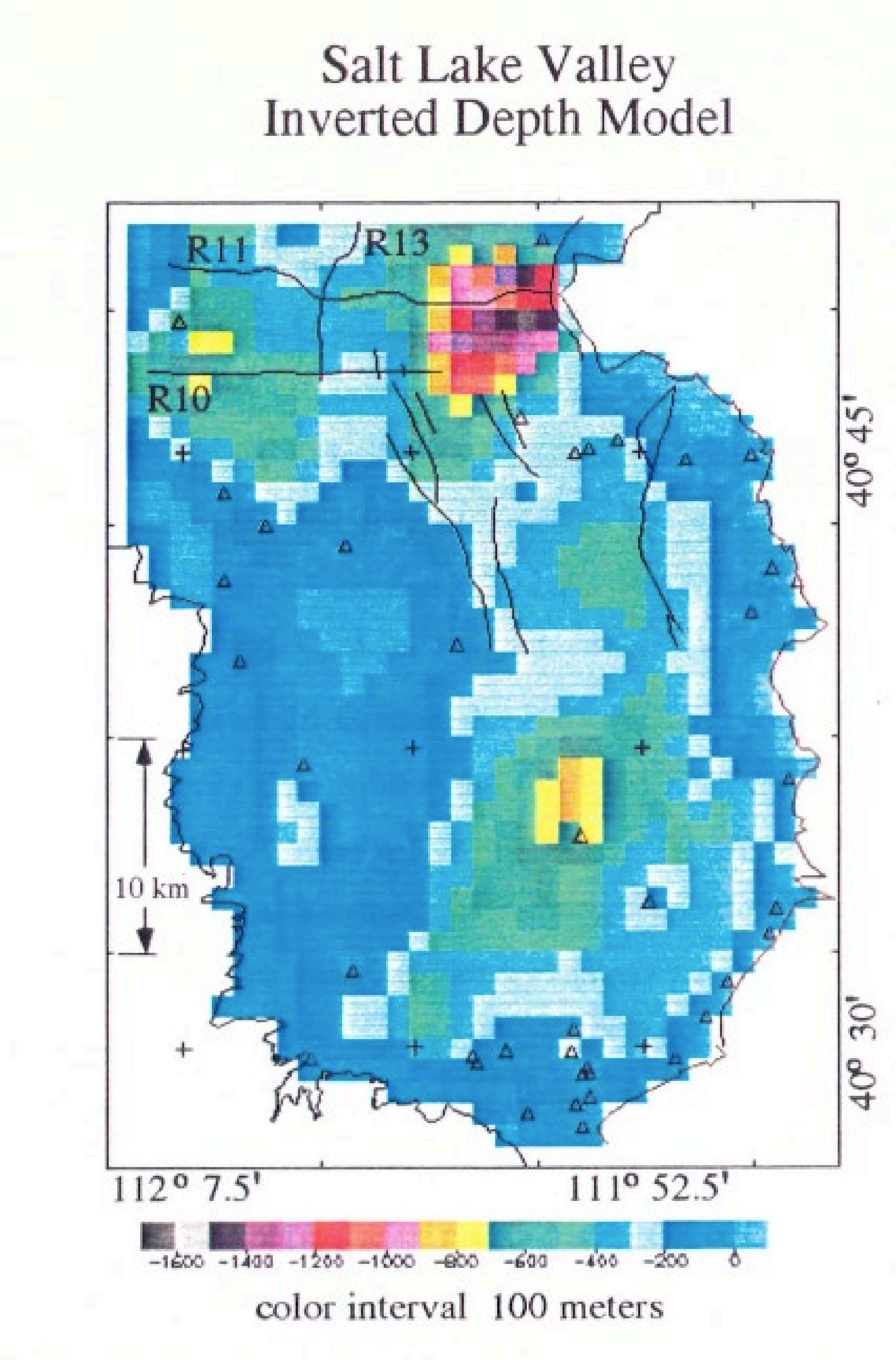


Radkins (1990)

Mapping R2 using gravity

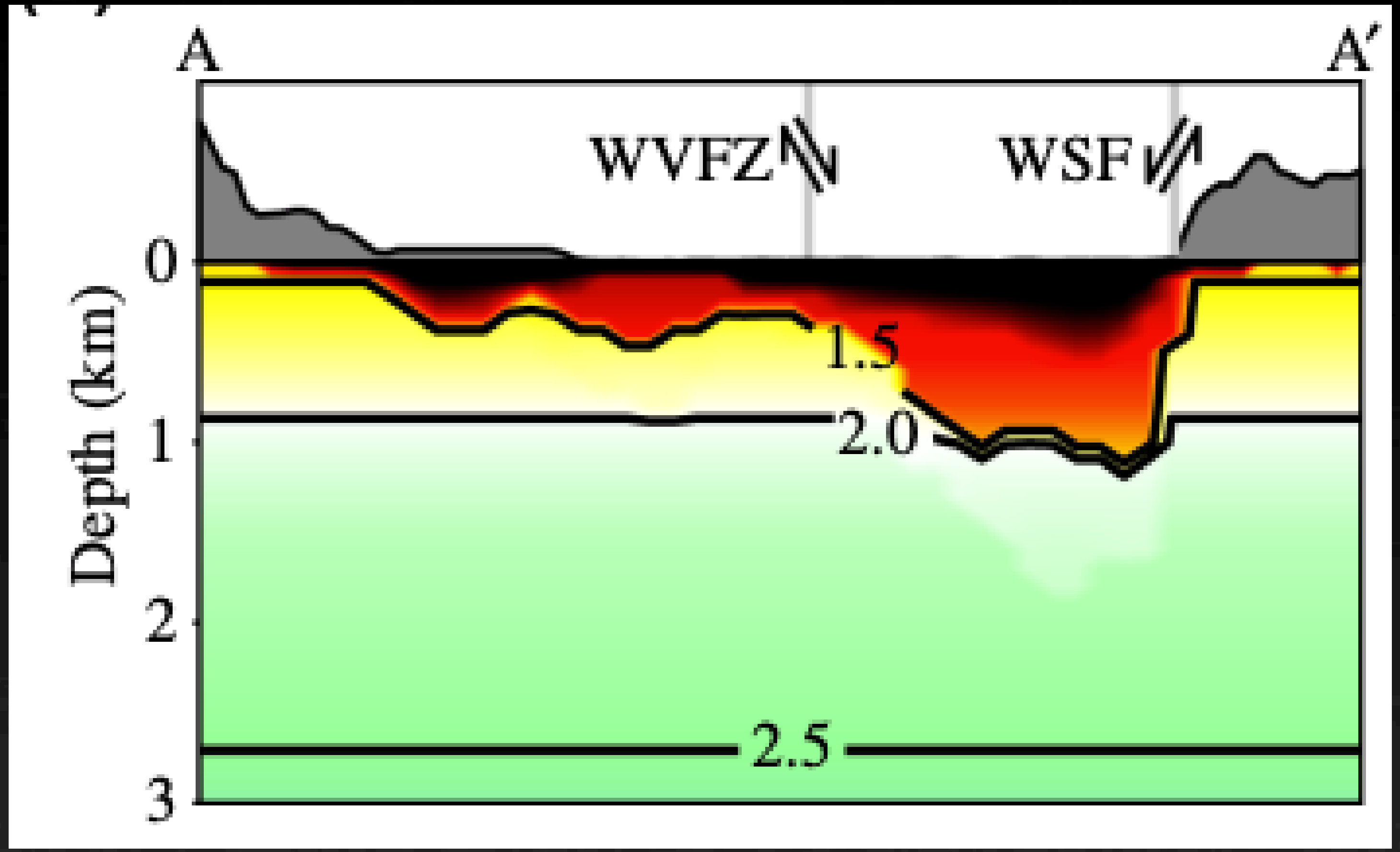


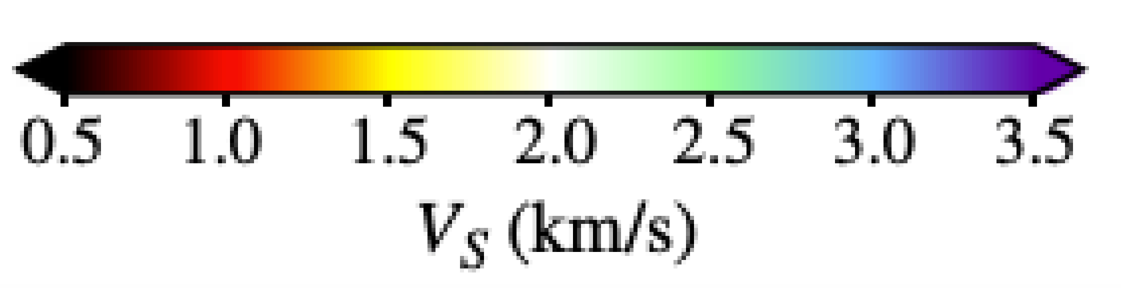


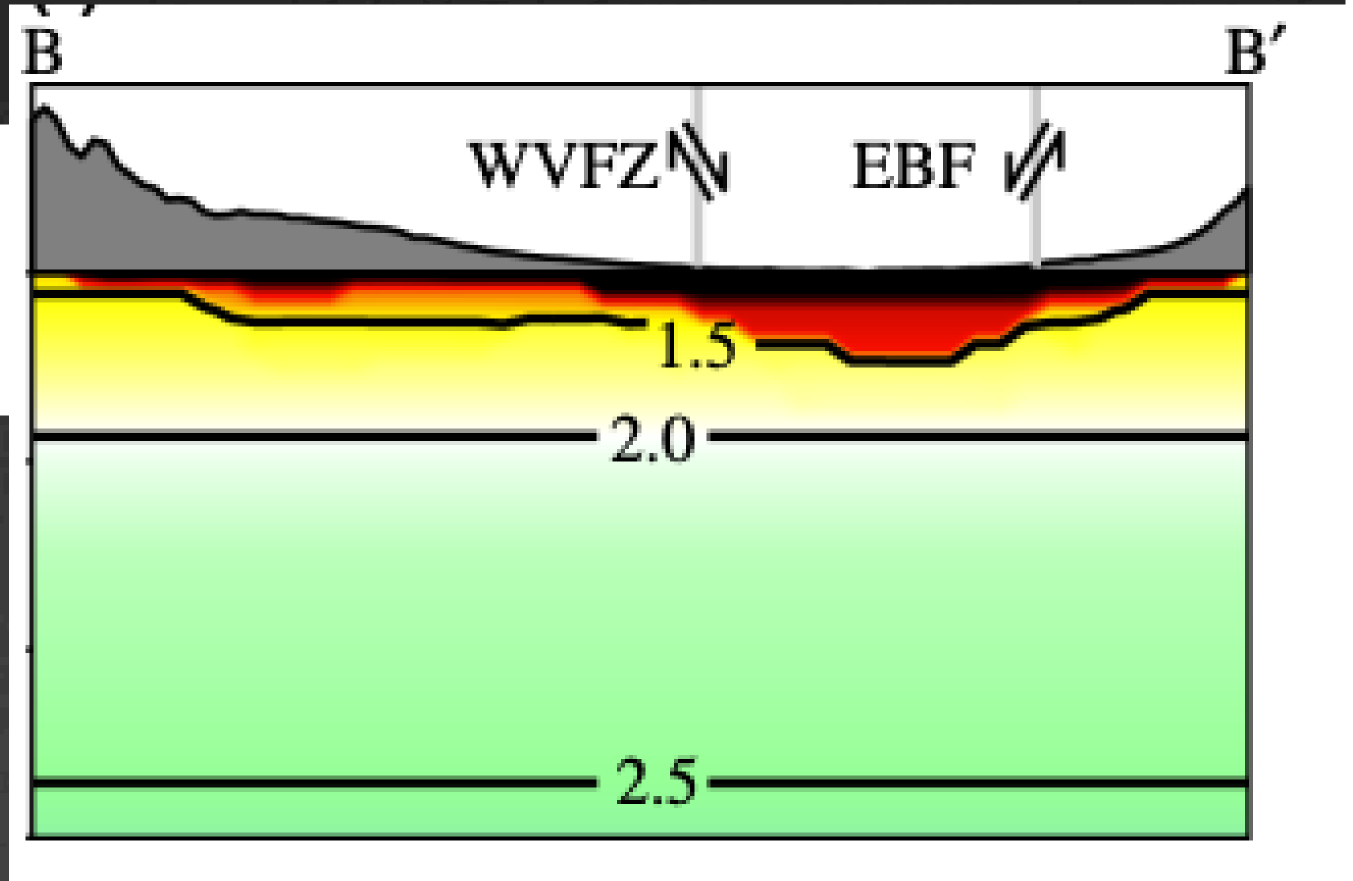


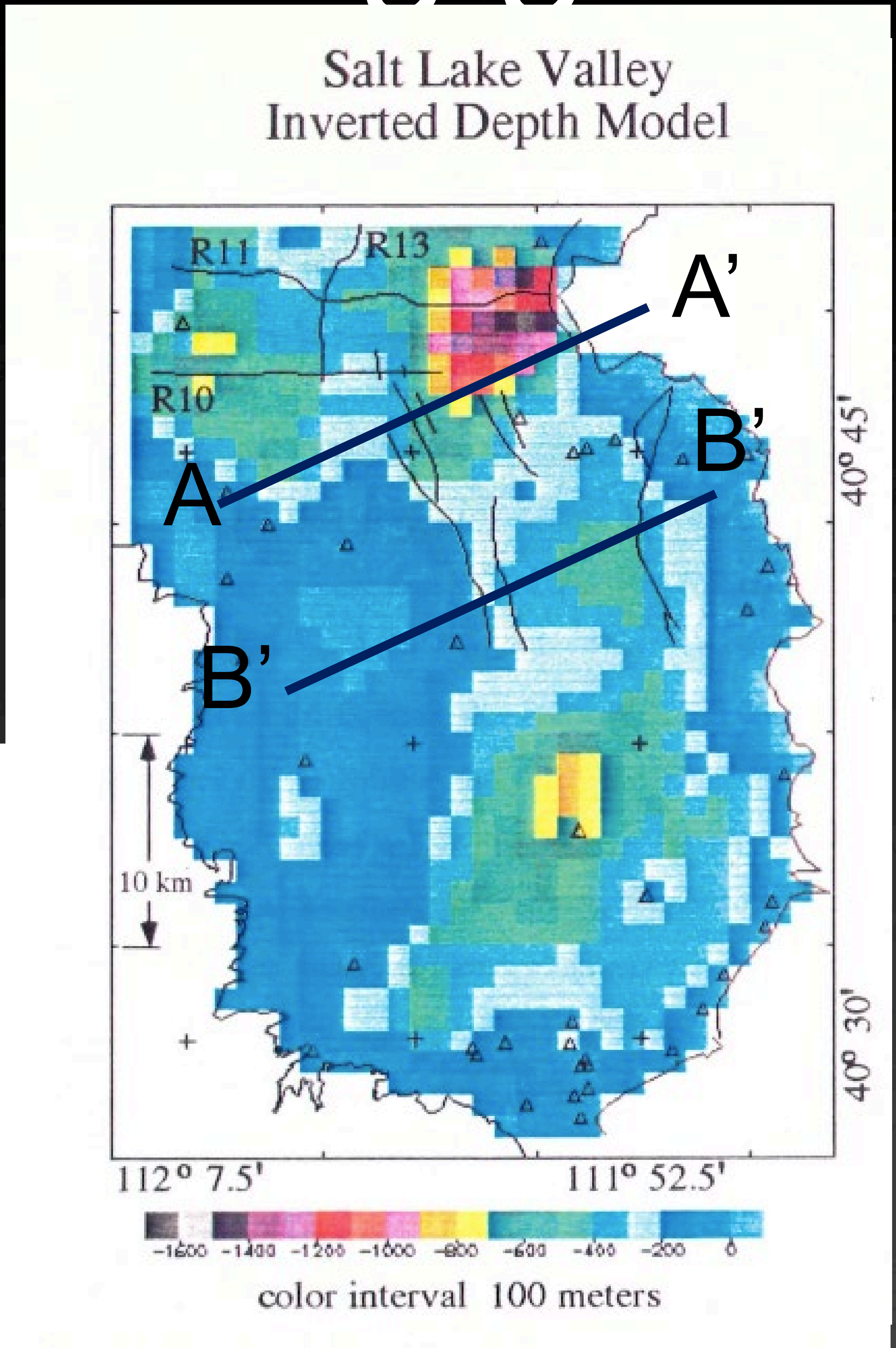
Radkins (1990)

Mapping R2 using gravity





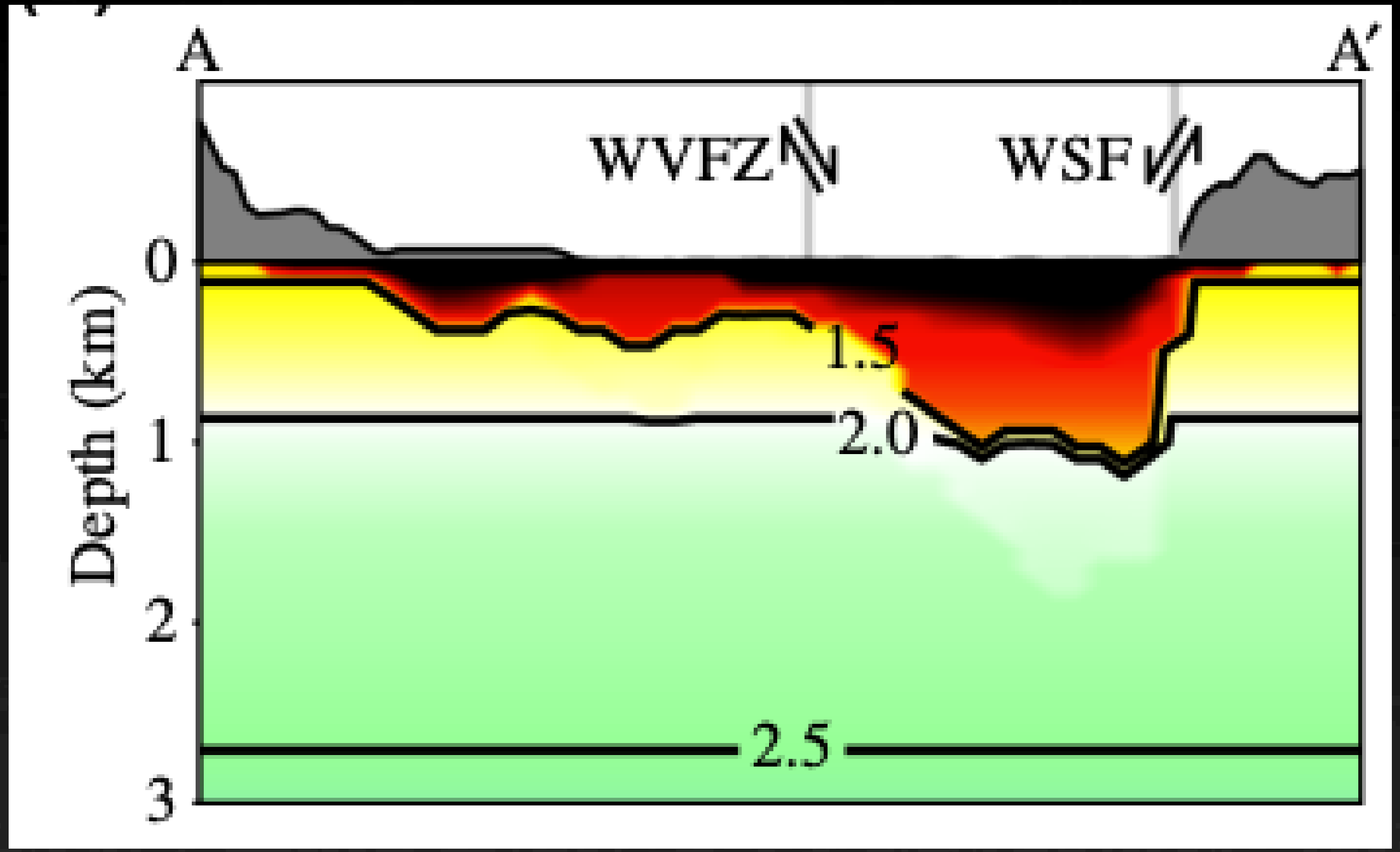


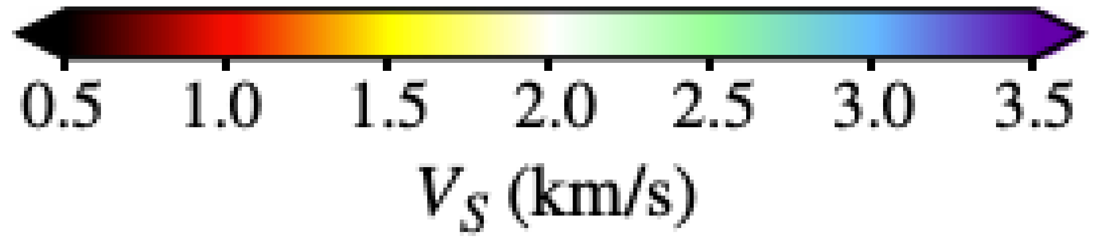


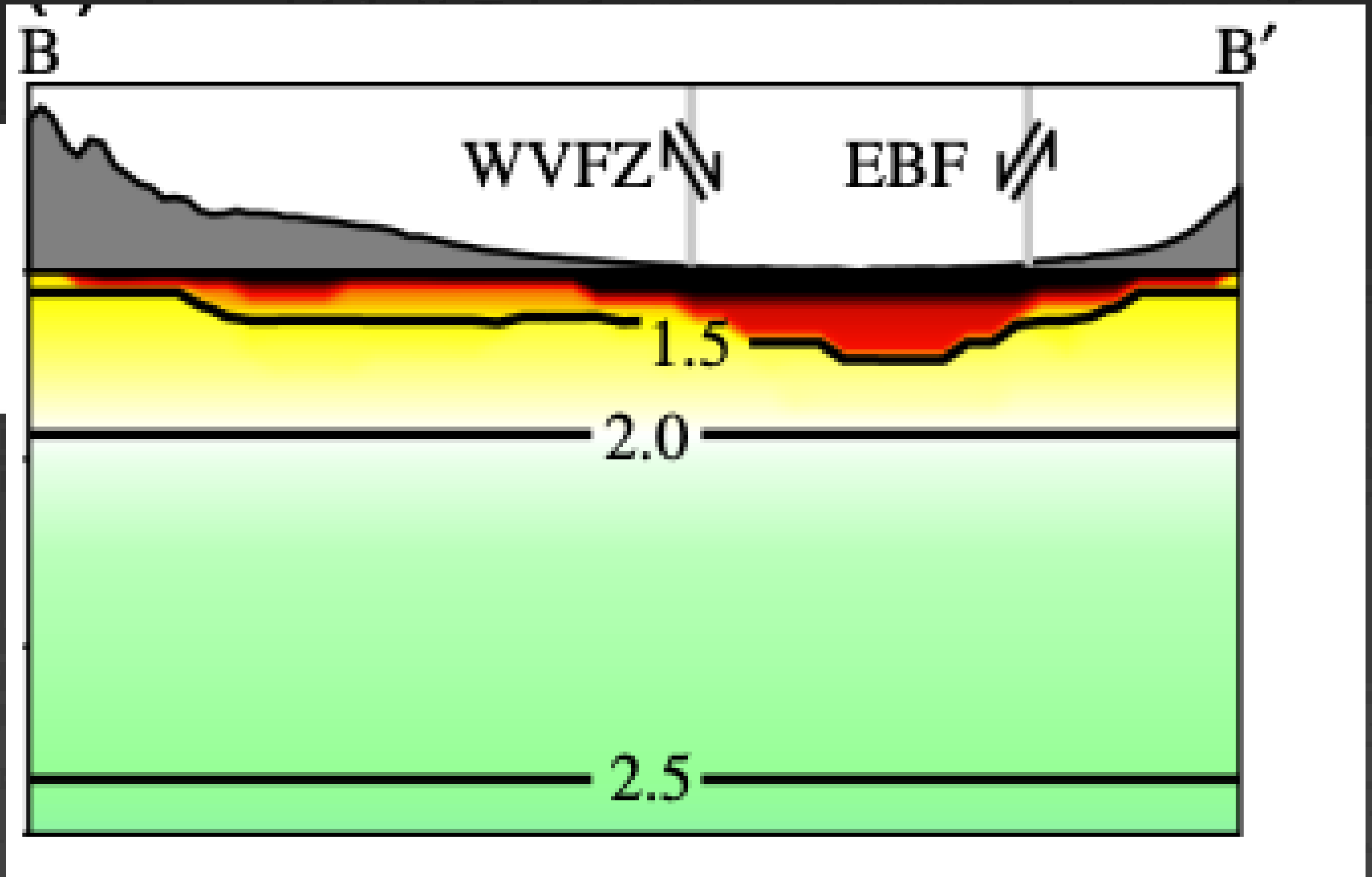
CVM
(Magistrale et

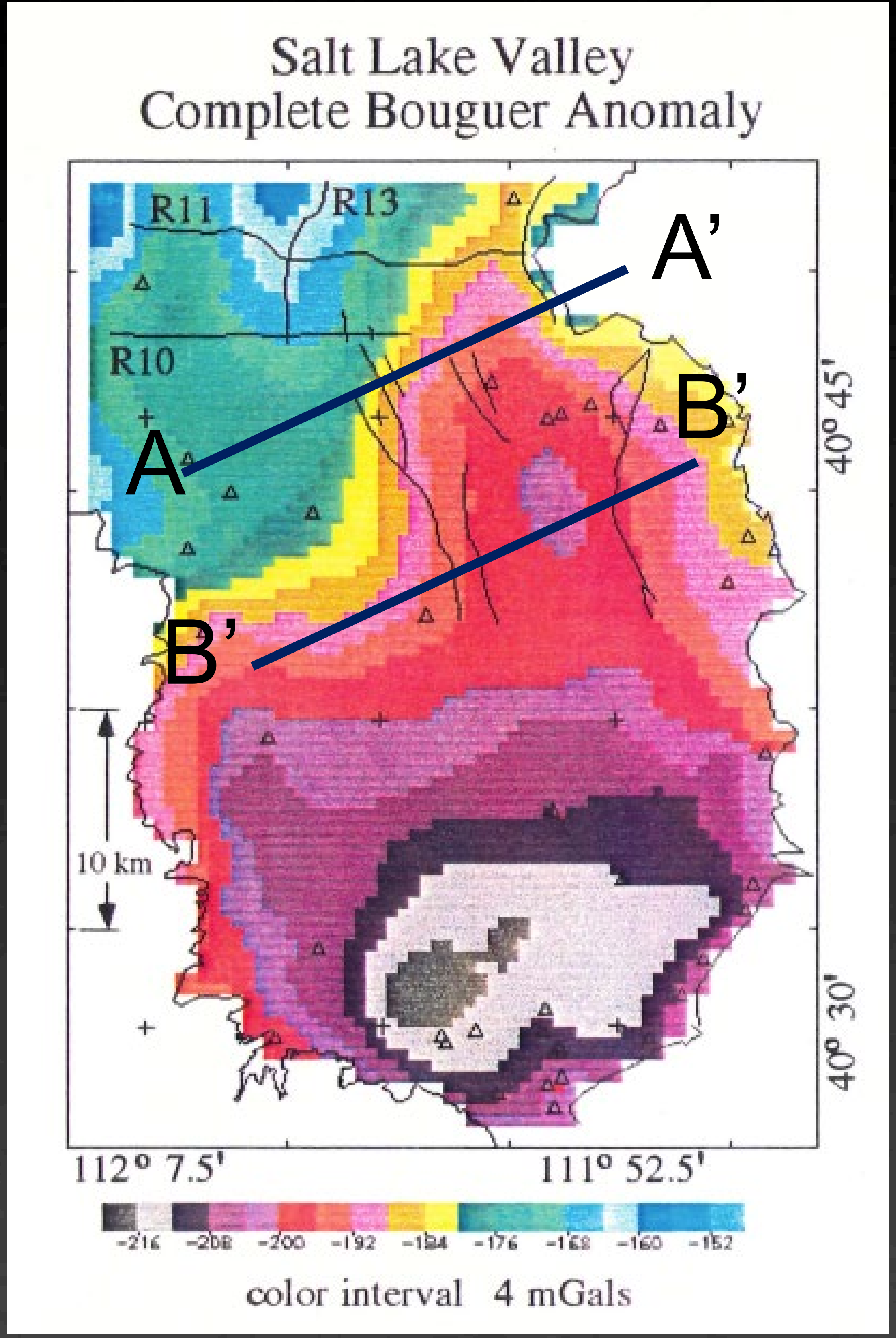
Radkins (1990)

Mapping R2 using gravity









CVM (Magistrale et

Radkins (1990)

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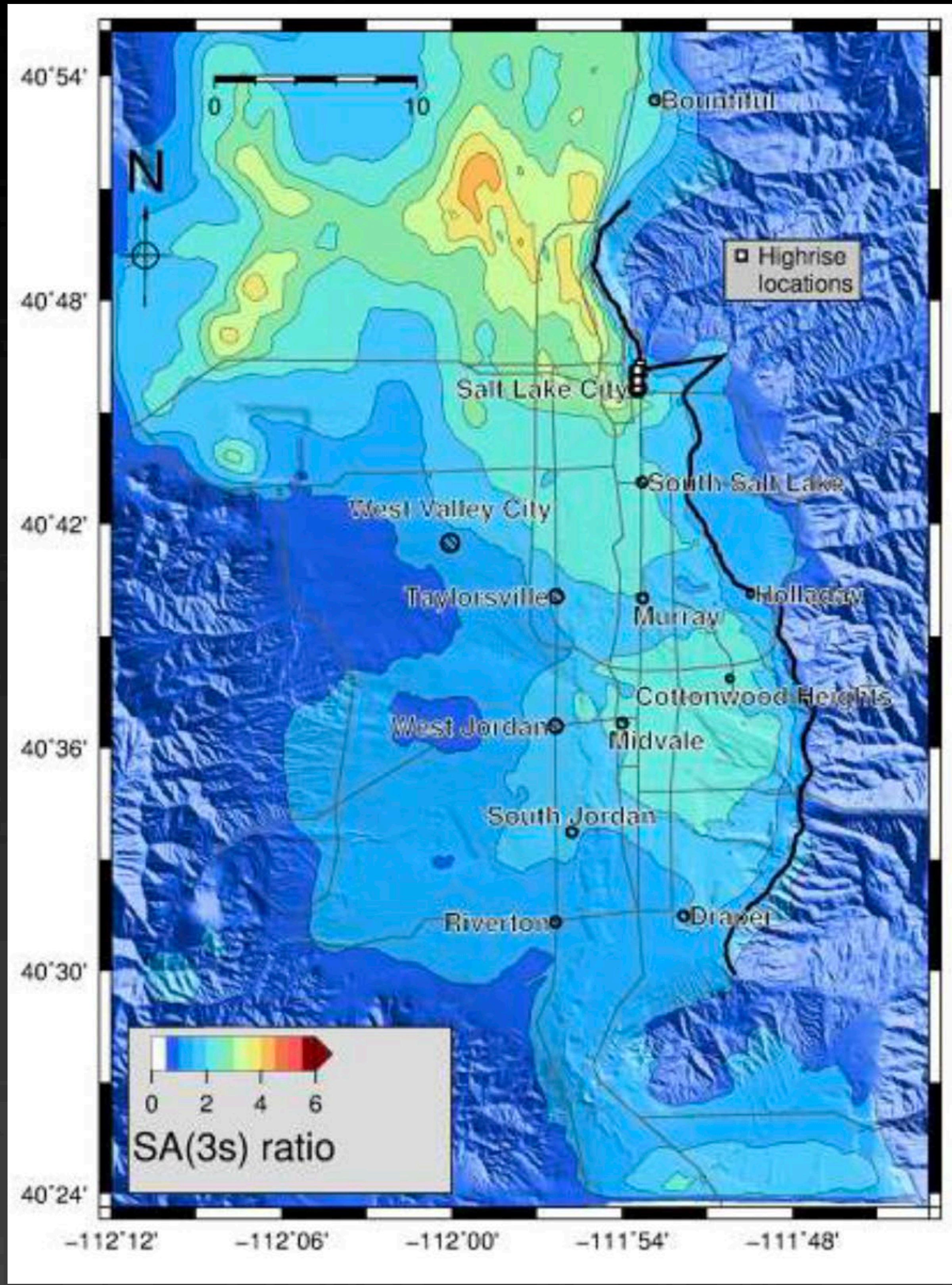
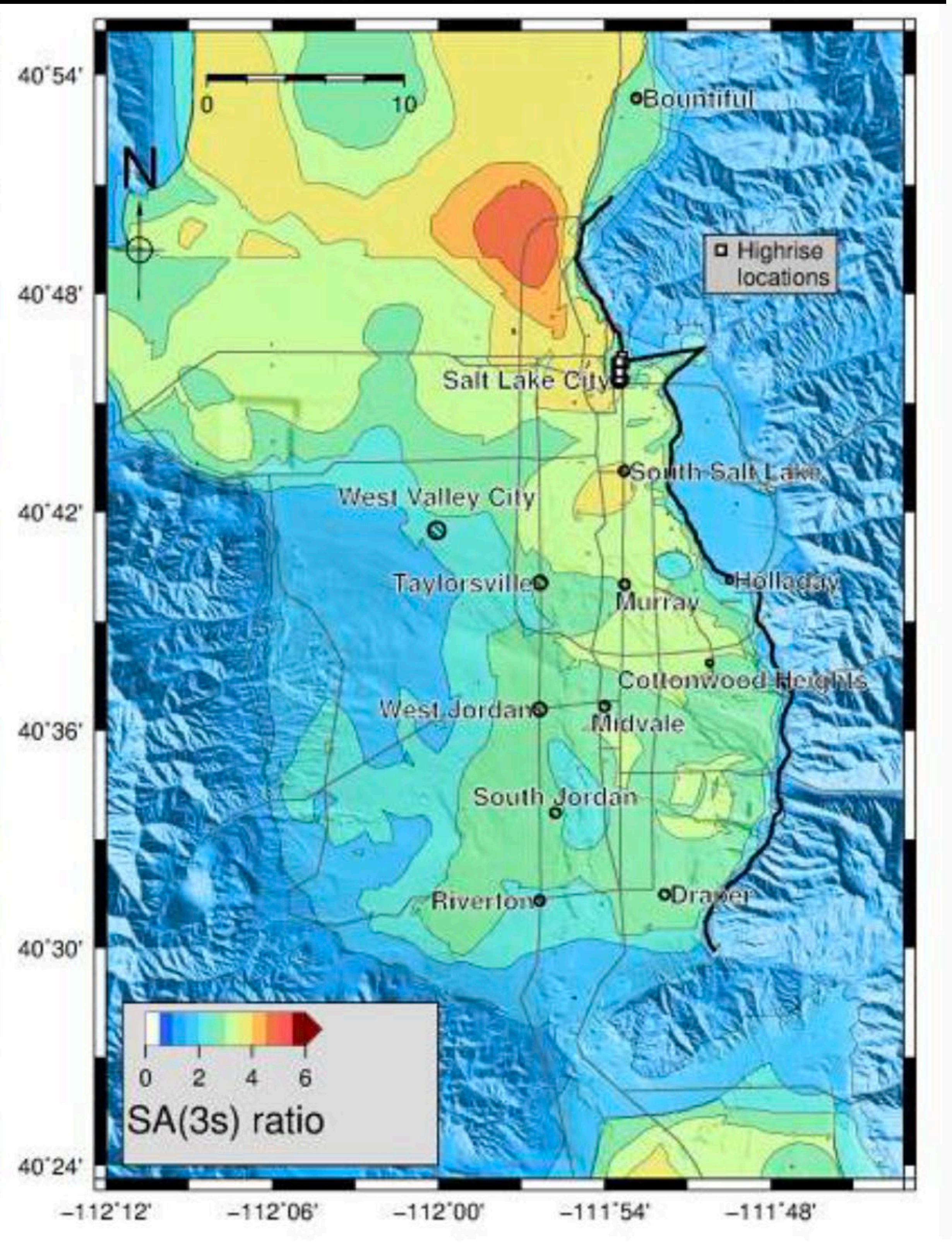
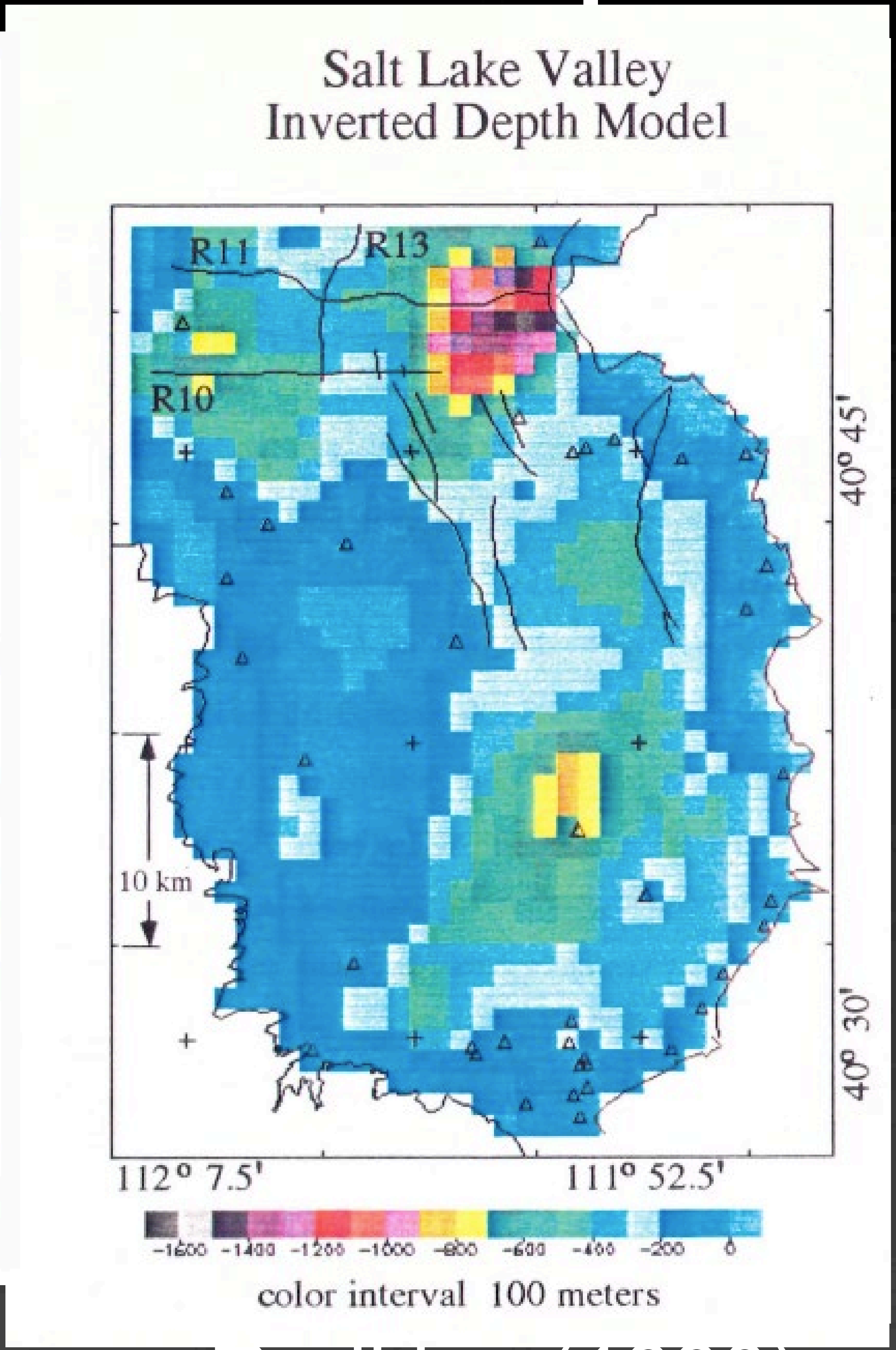
Amplification at 3 sec perio



Wang et al., (2016)



Boore et al. (2014)



Radkins (1990)

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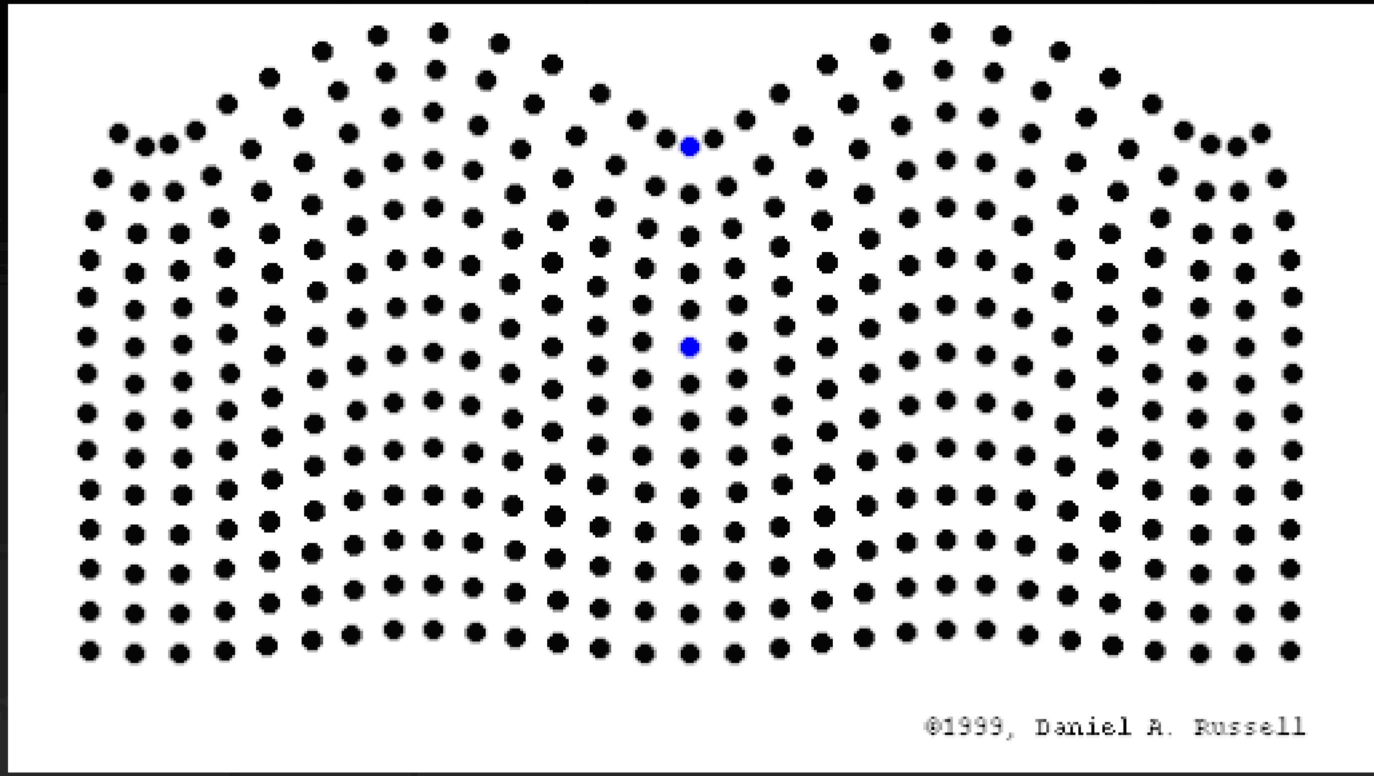
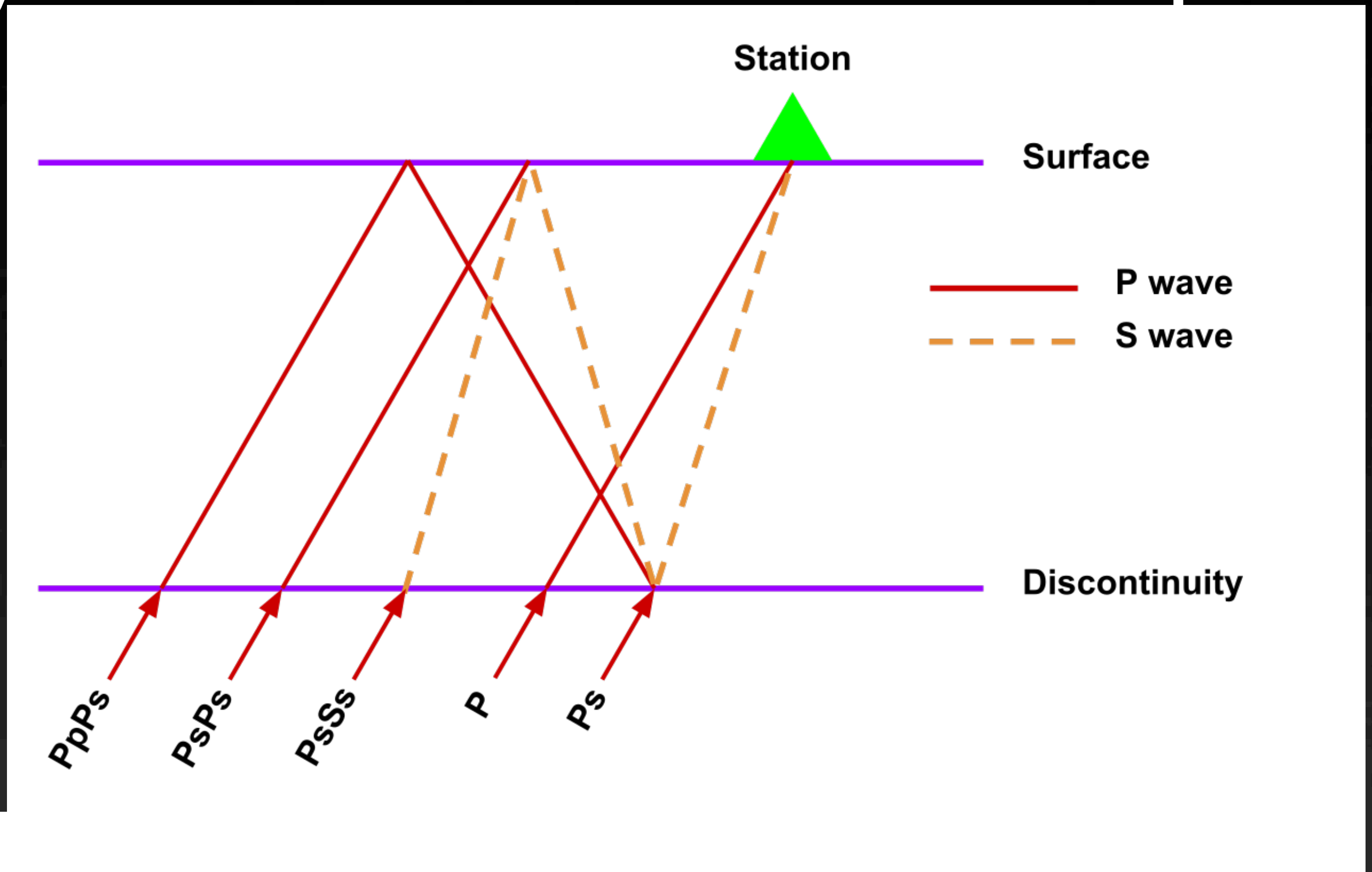
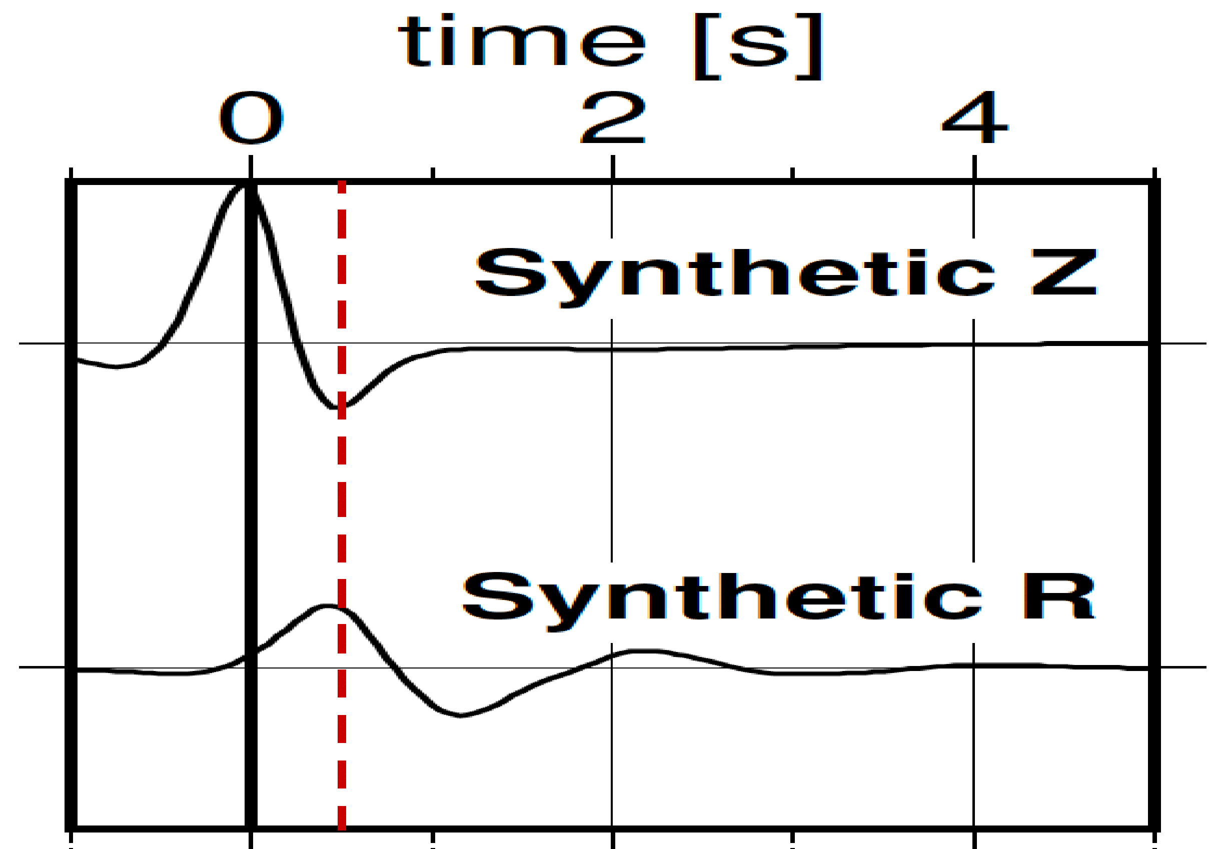
Novel shallow imaging techniqu

Rayleigh wave phase velocity and ellipticity

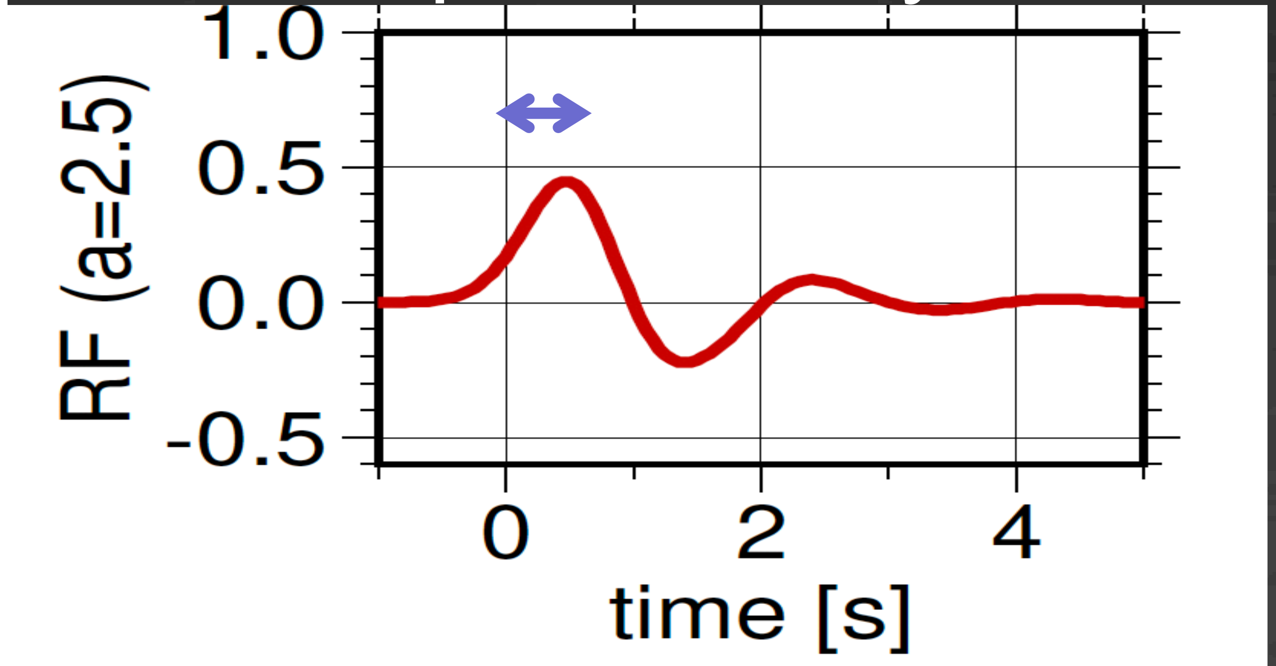


Receiver function initial phase





Initial phase delay time



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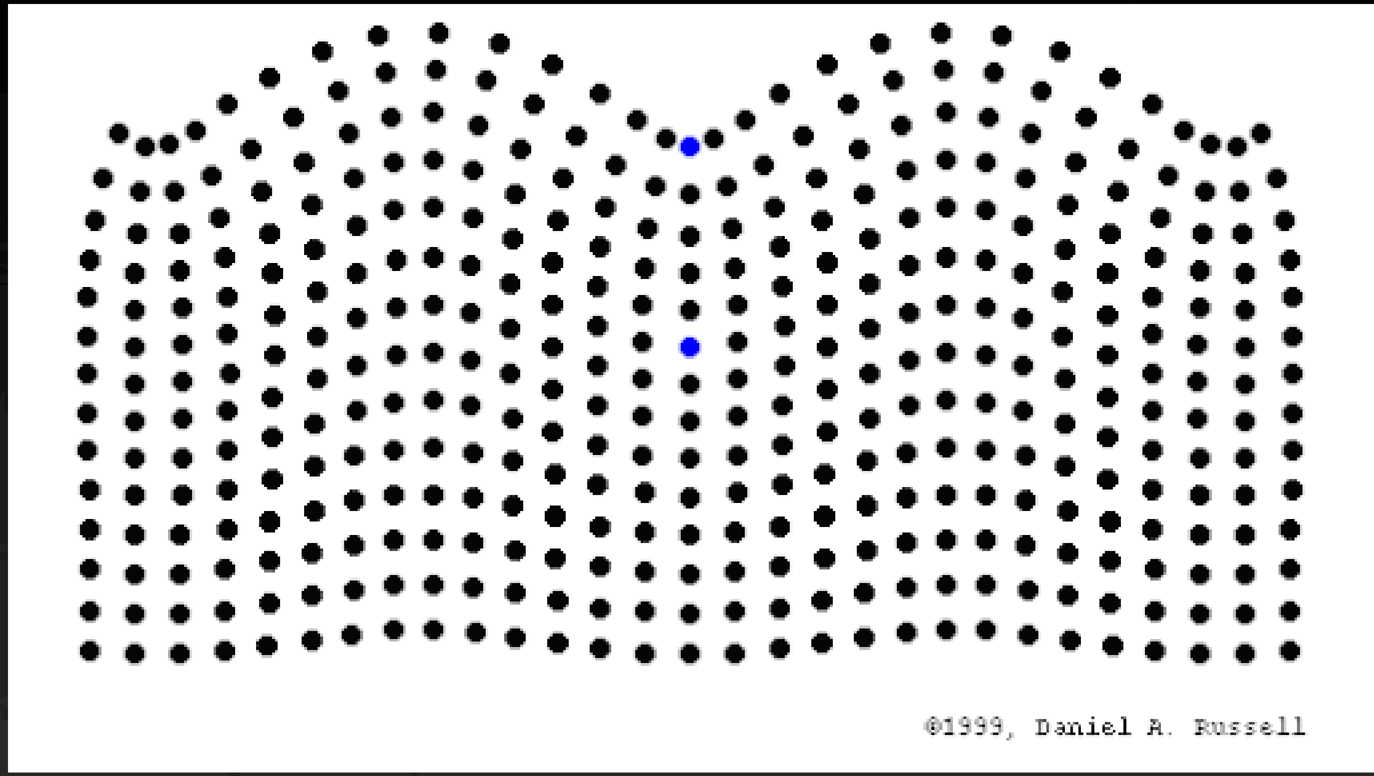
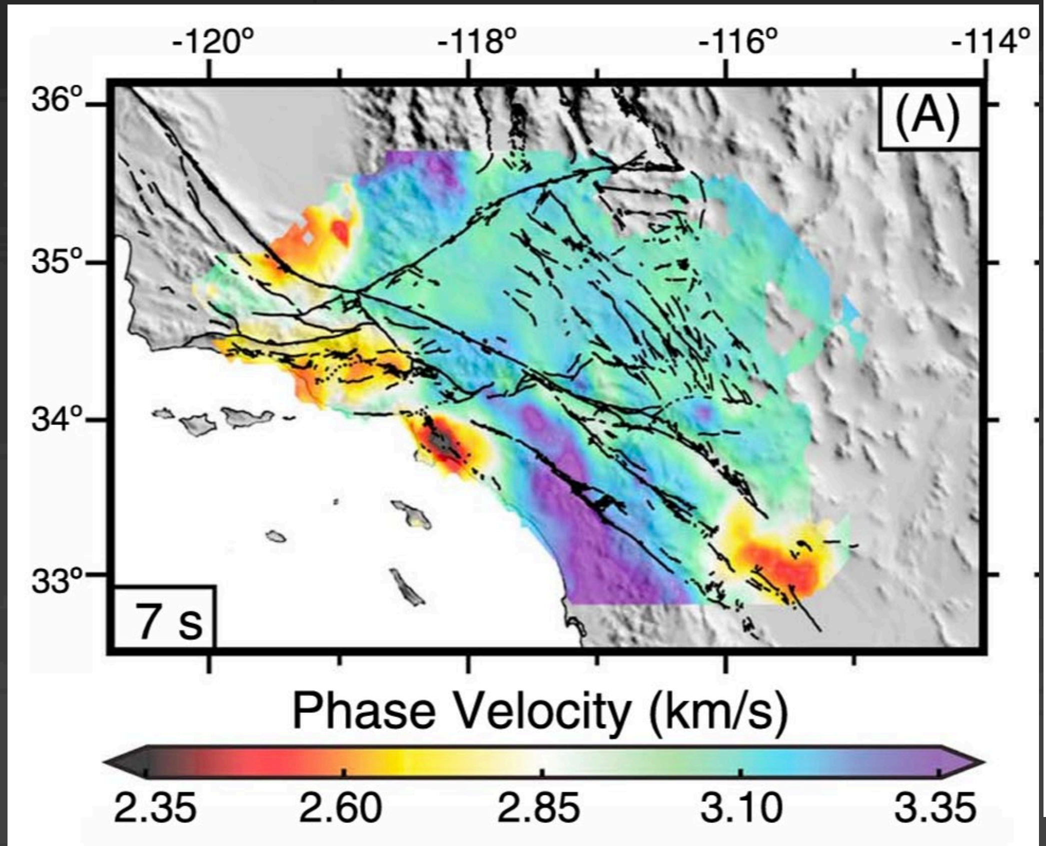
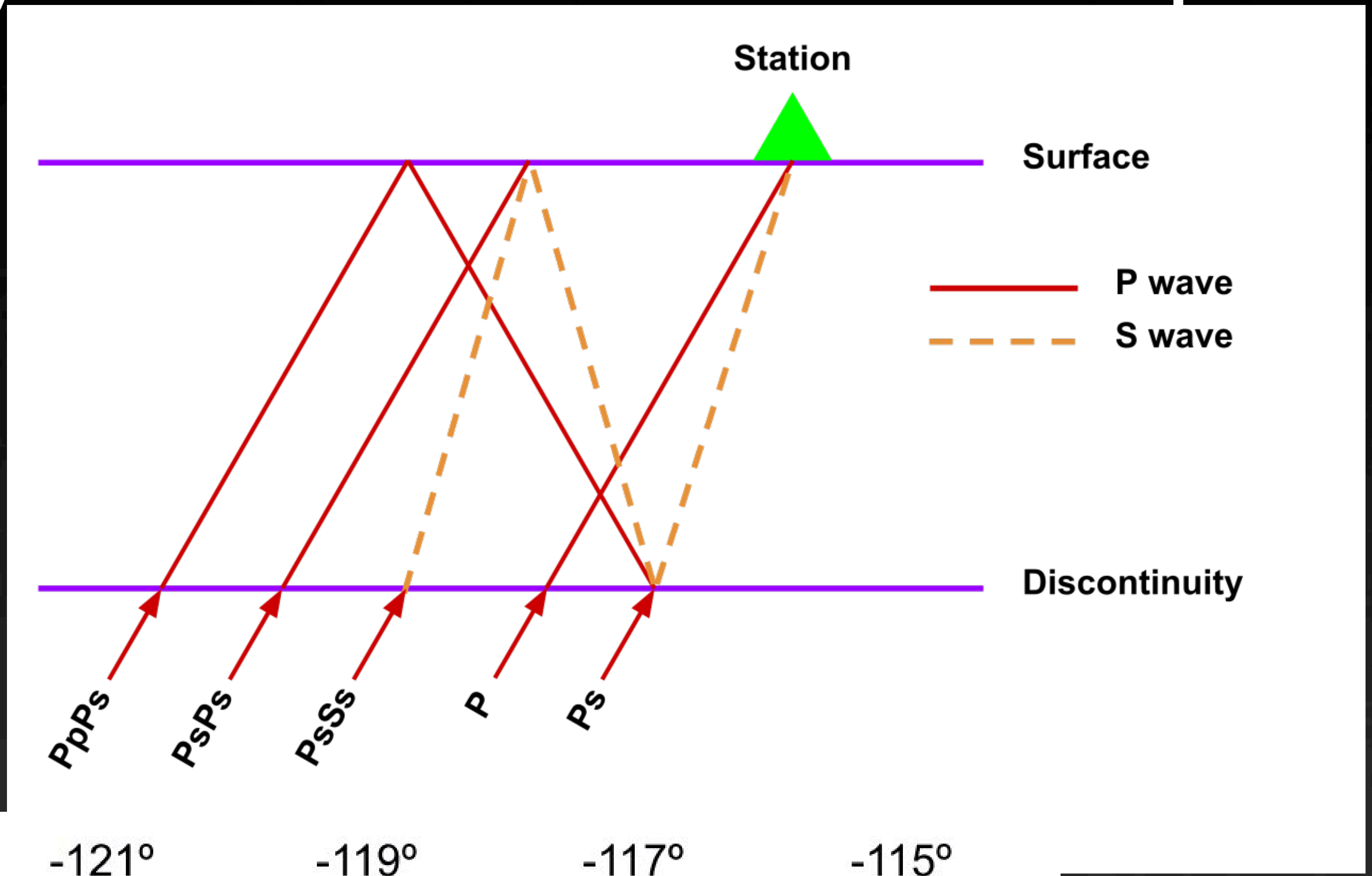
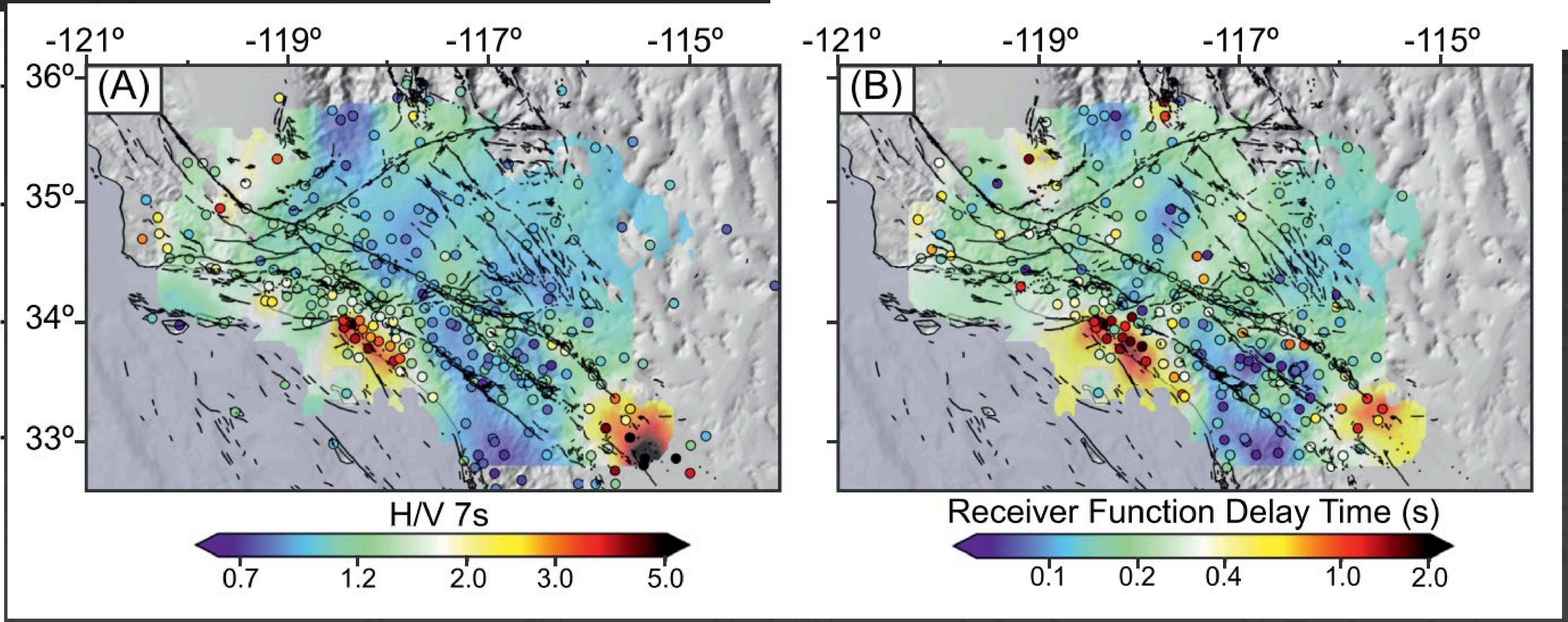




Receiver function initial phase





Berg et al. (2018 &

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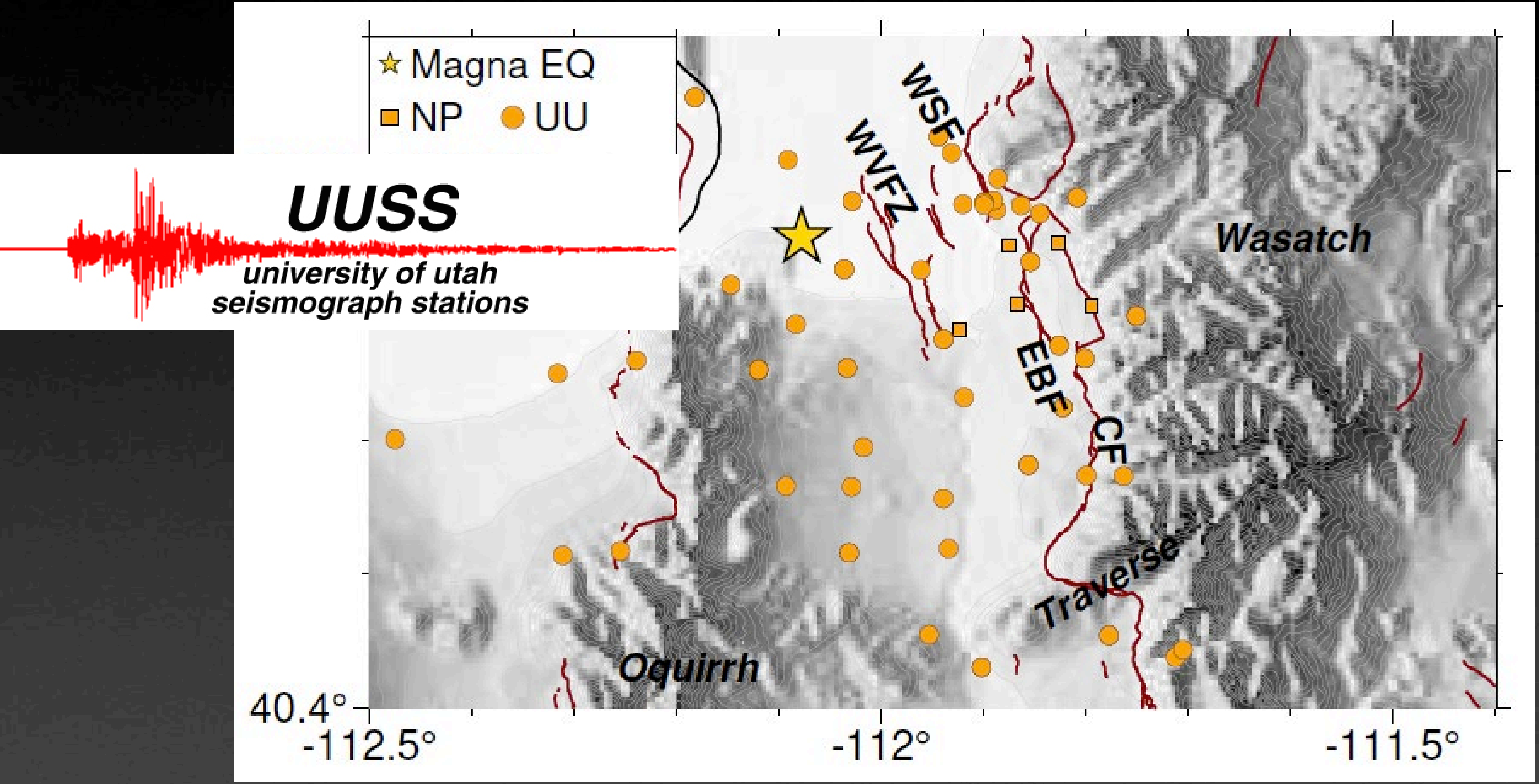
Seismic Station distribution



New seismic instrumentation

- Easy to deploy
- Low cost
- Continuous recording for ~30 days
- Great for temporally densifying a region of interest
- Good data quality up to 10 sec period

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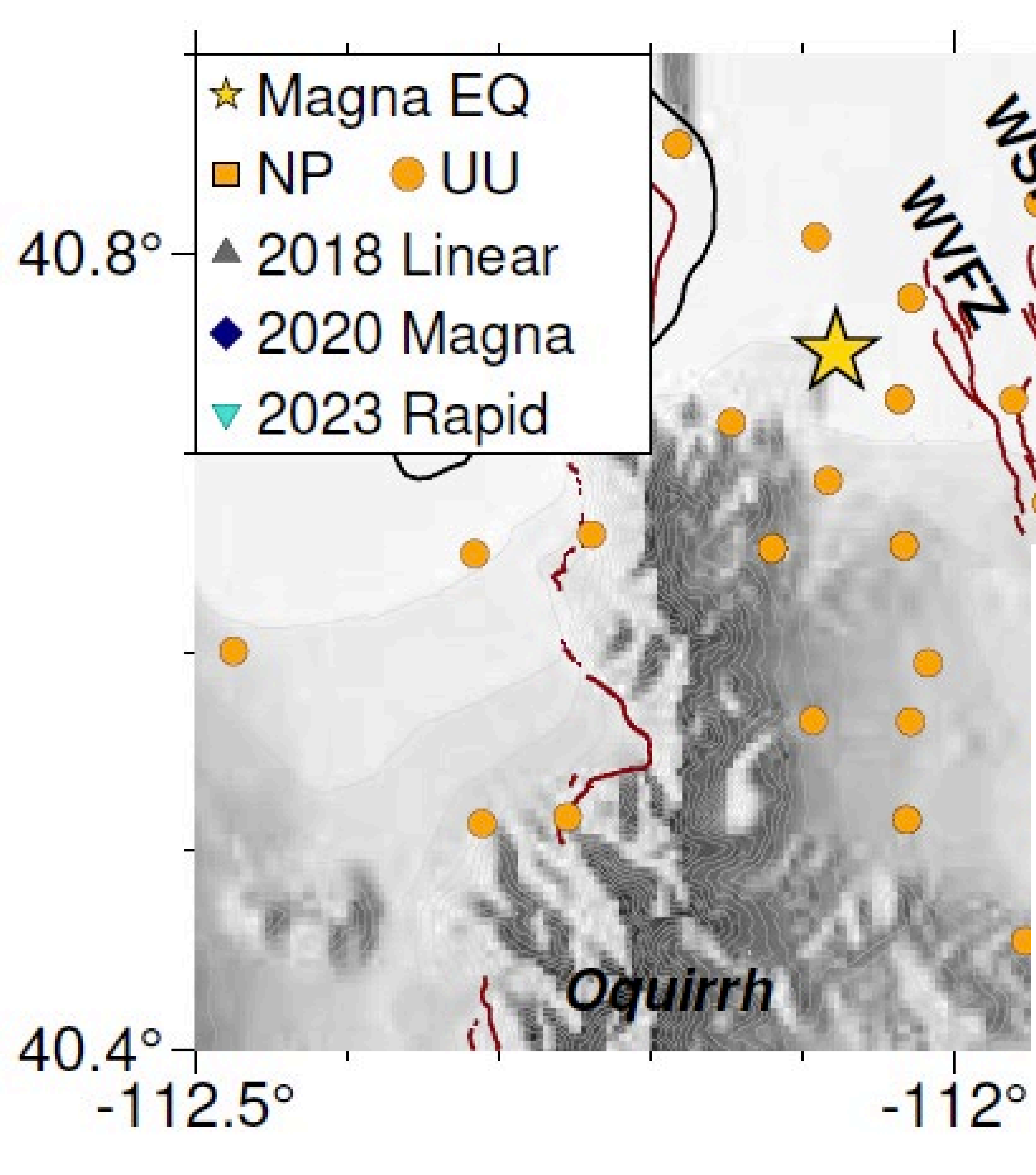
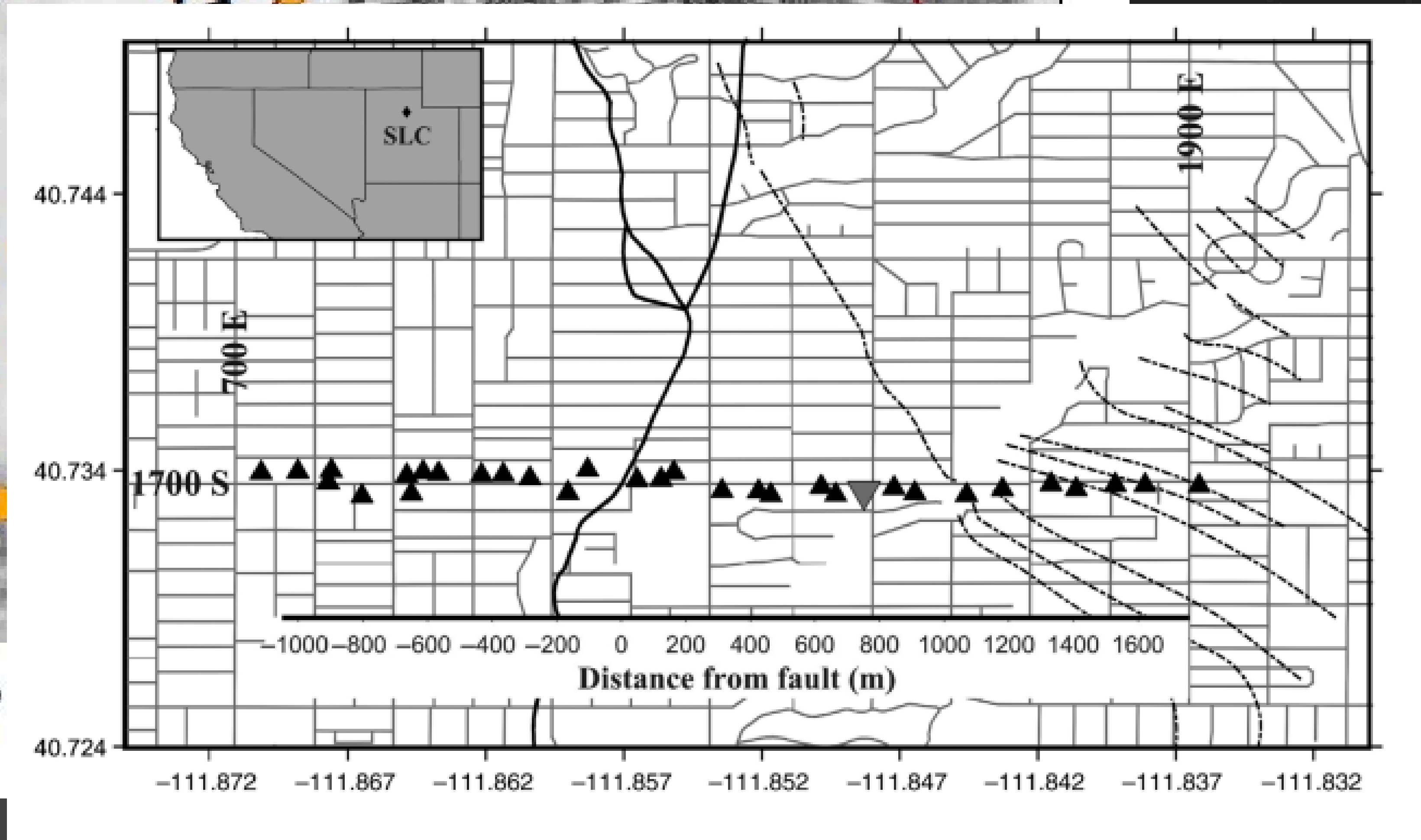
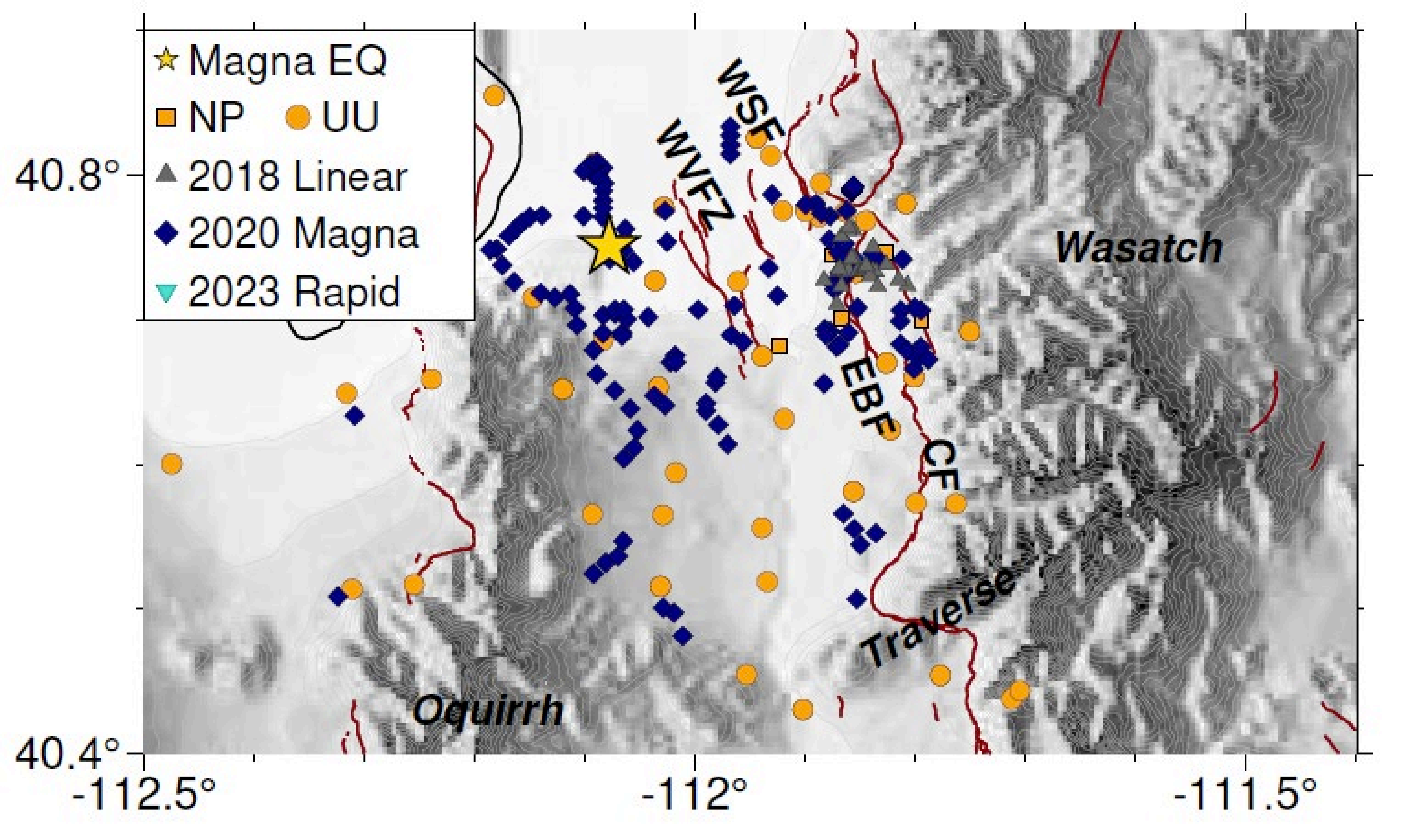
Seismic Station distribution (201

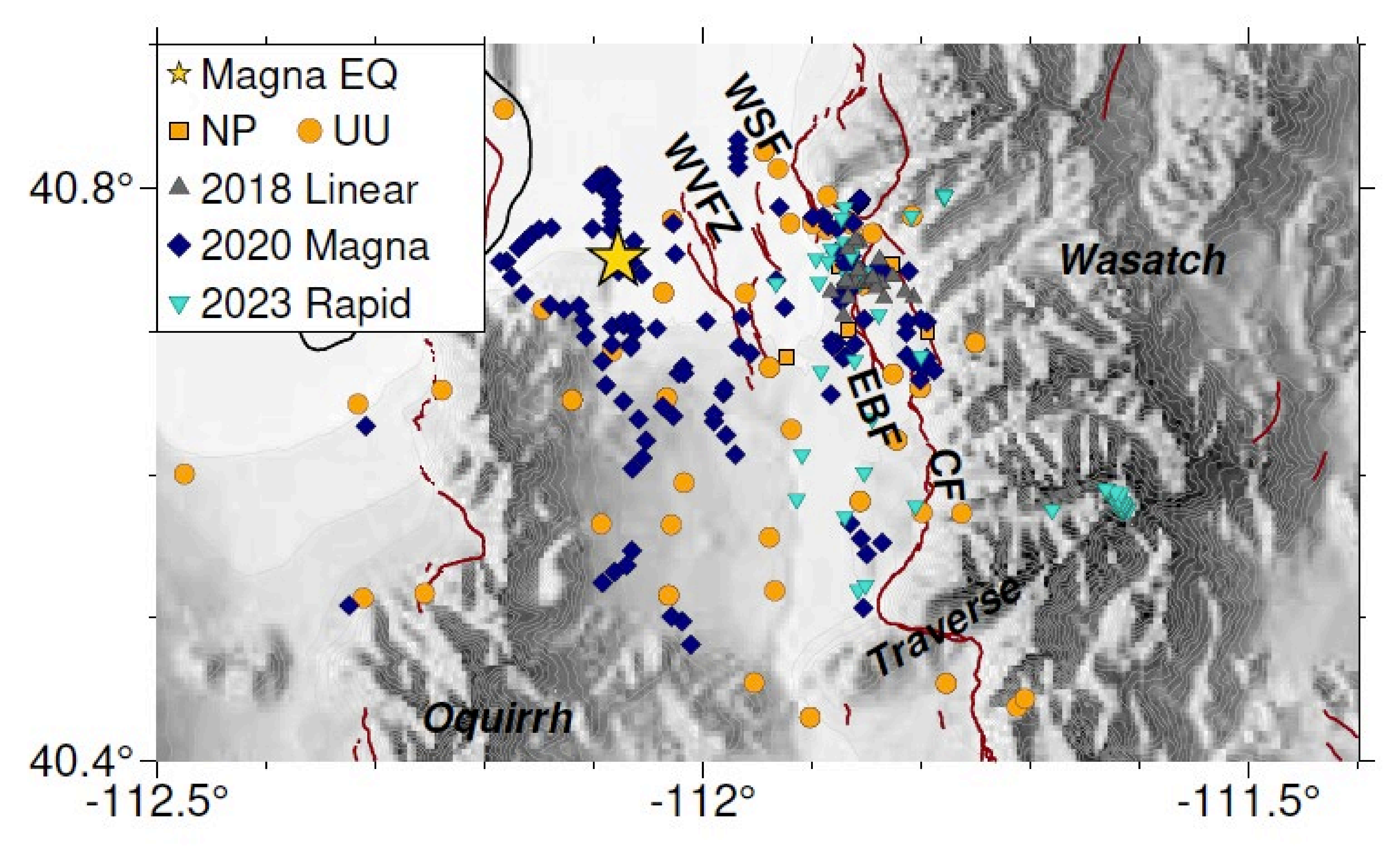




Seismic Station distribution (202



Seismic Station distribution (202



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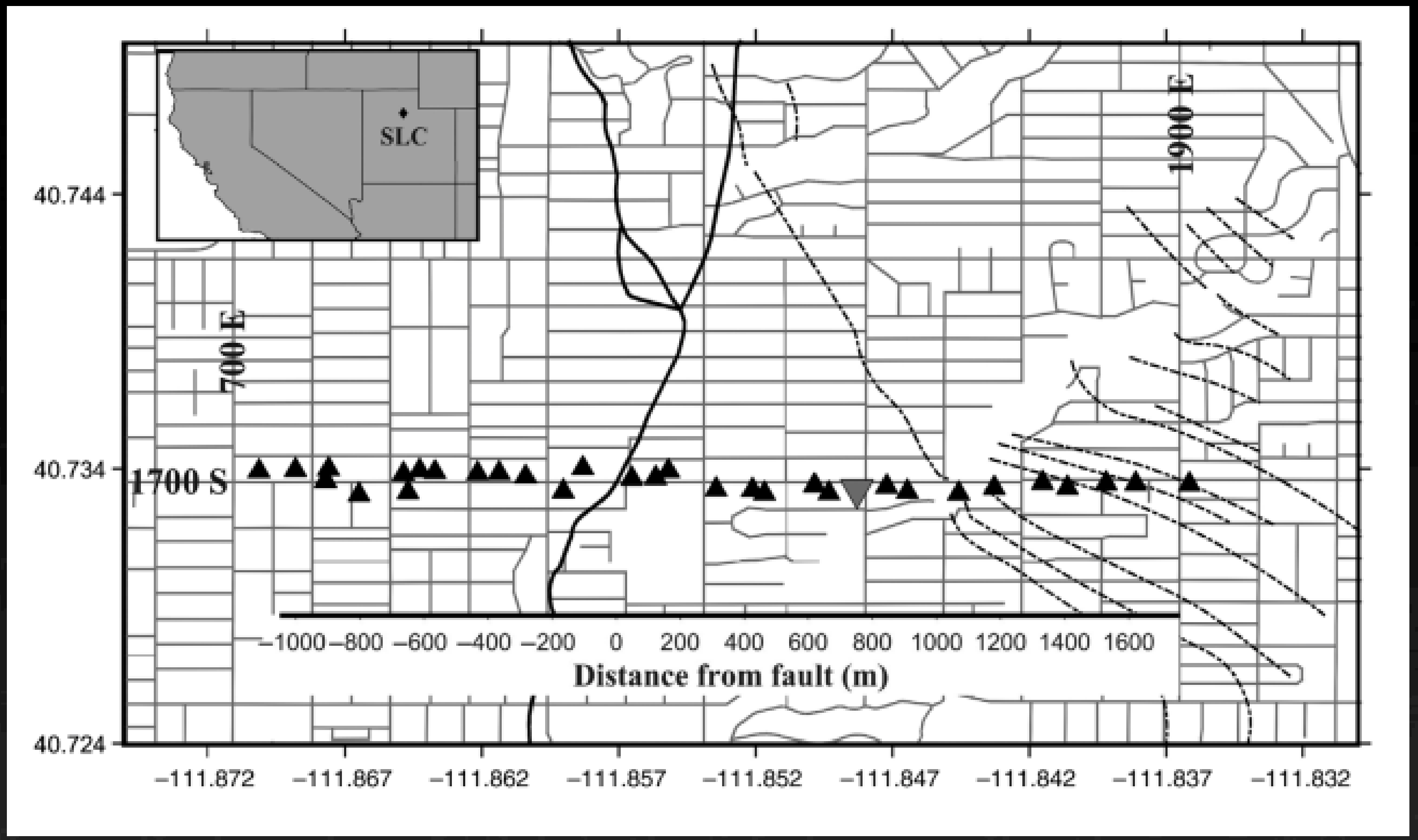
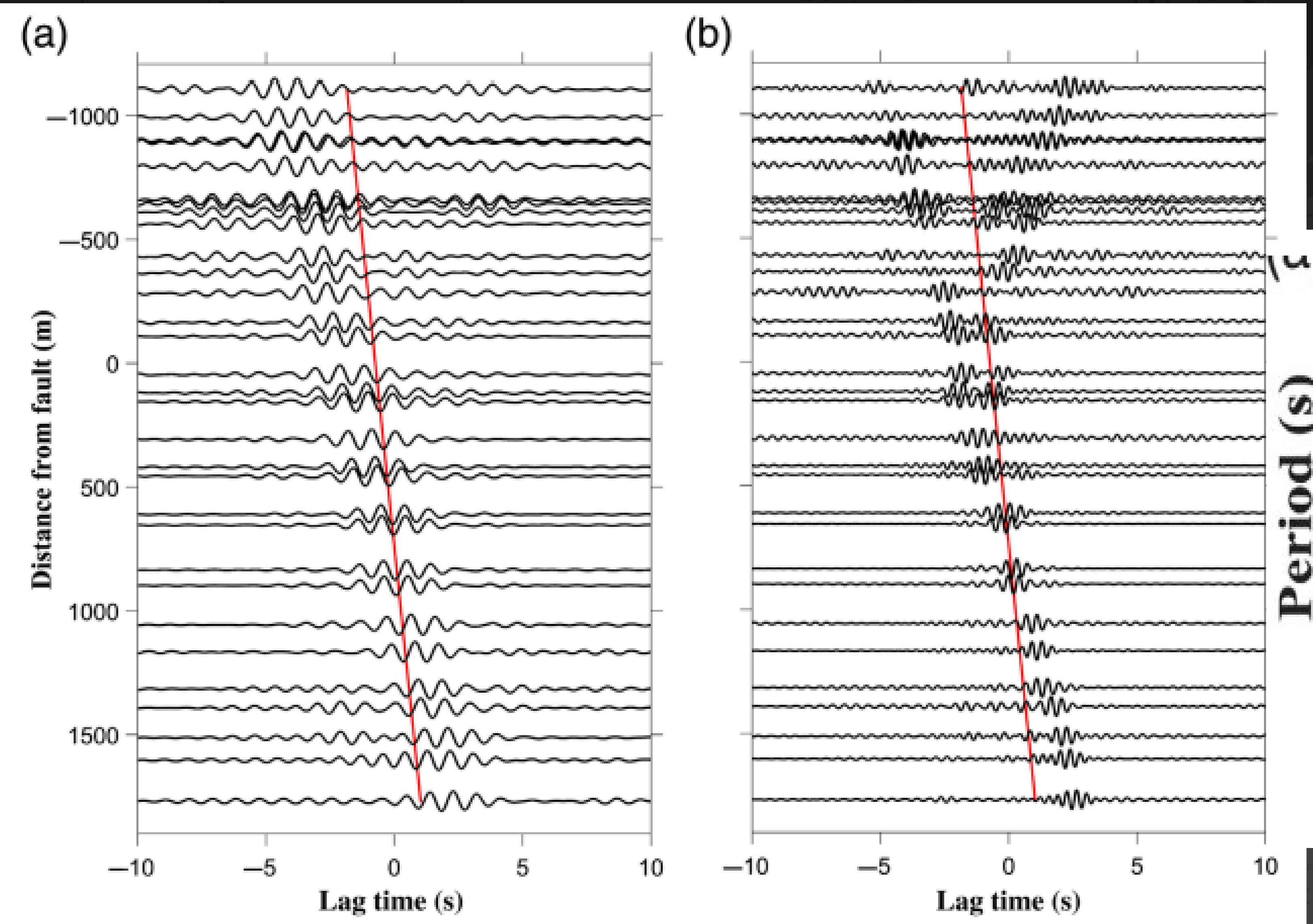
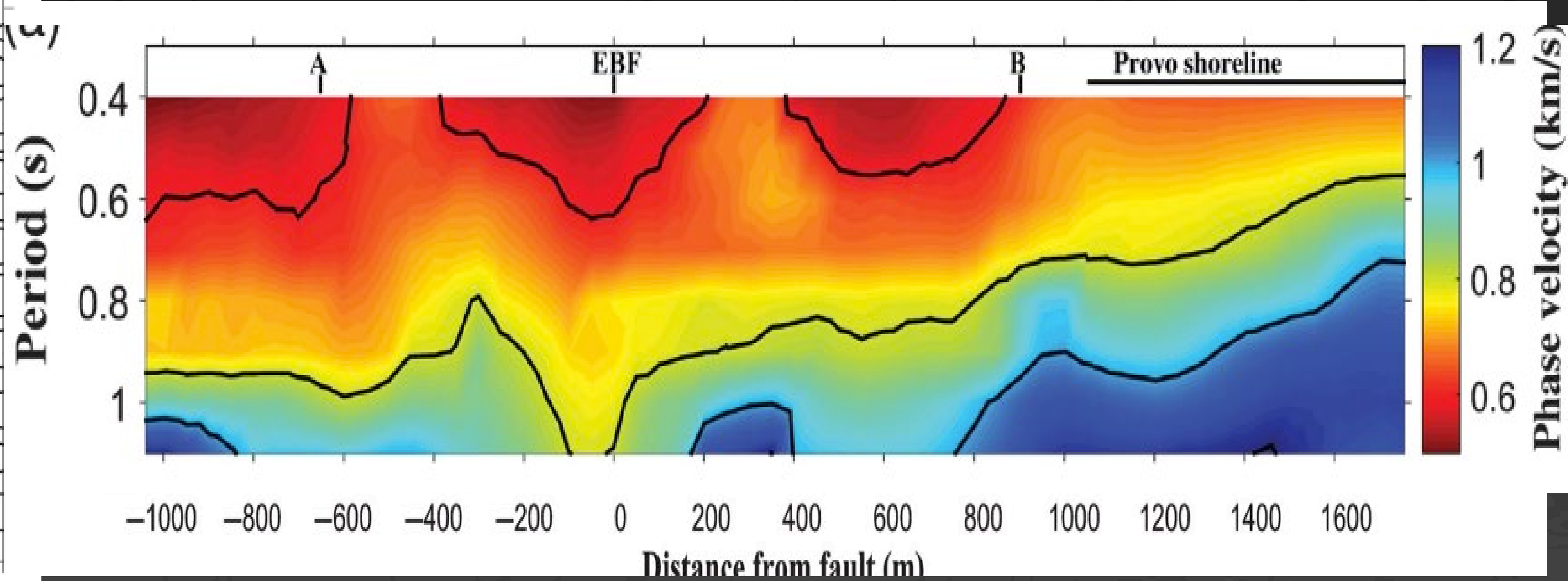
2018 Linear Array



0.9 s

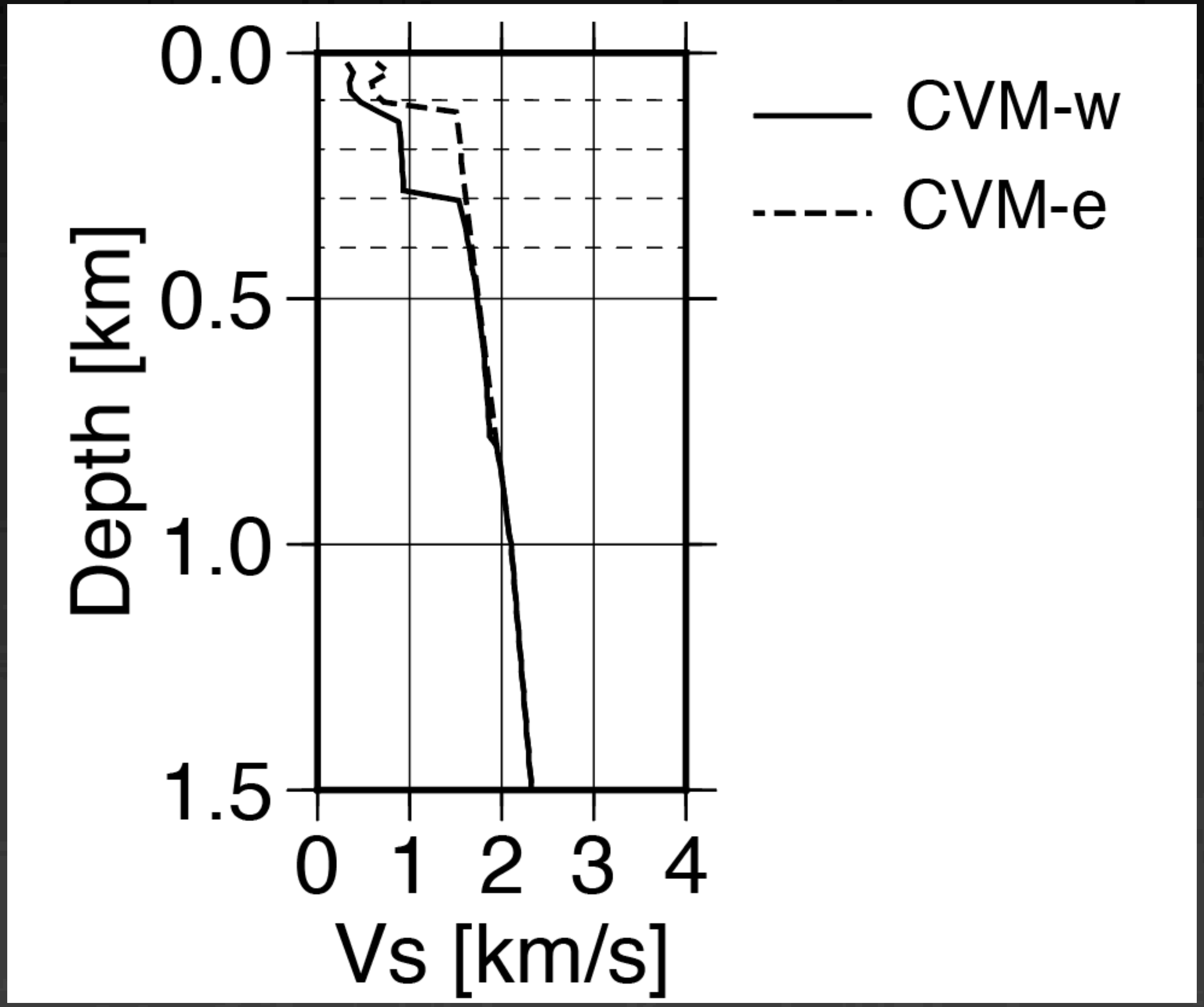
0.4 s

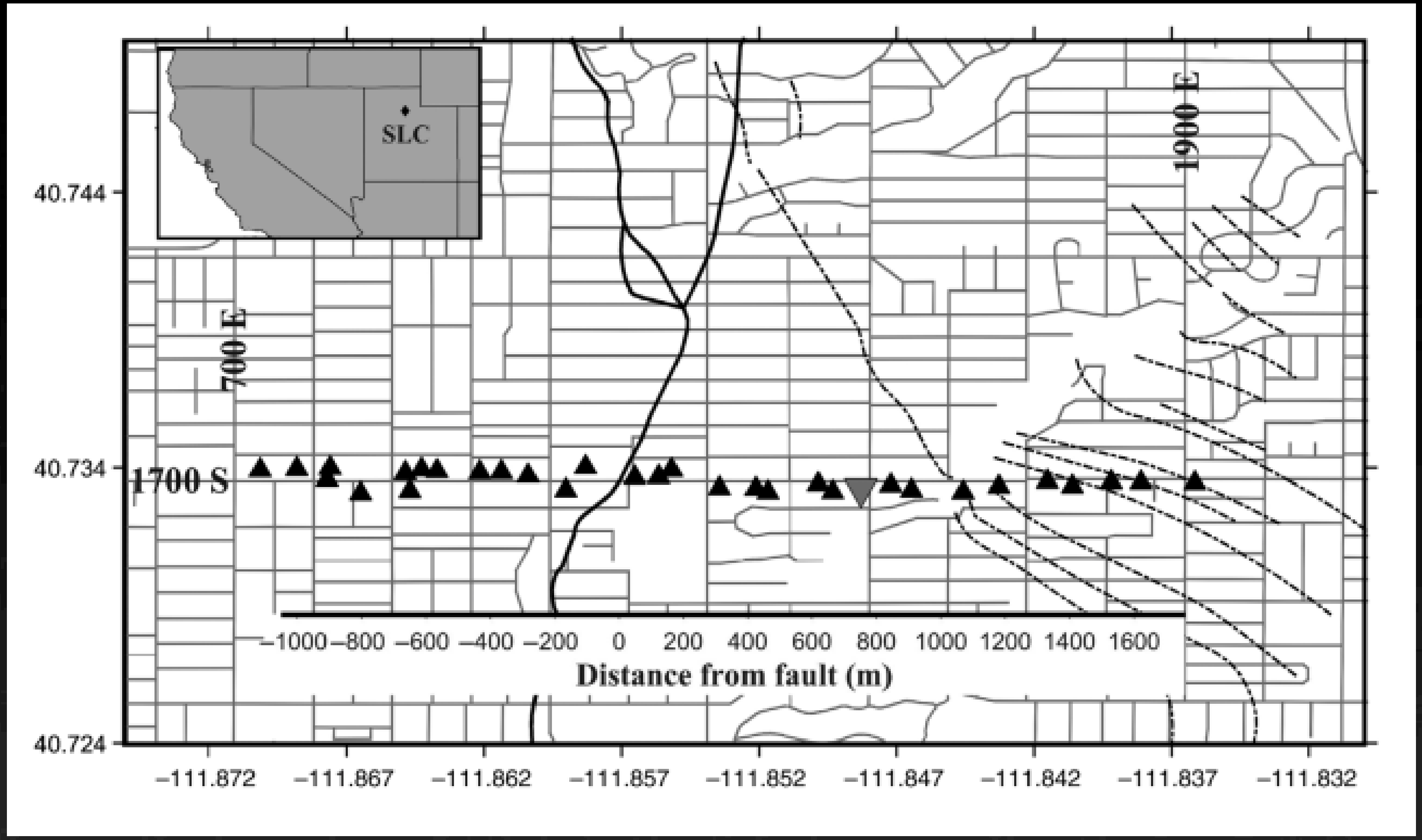


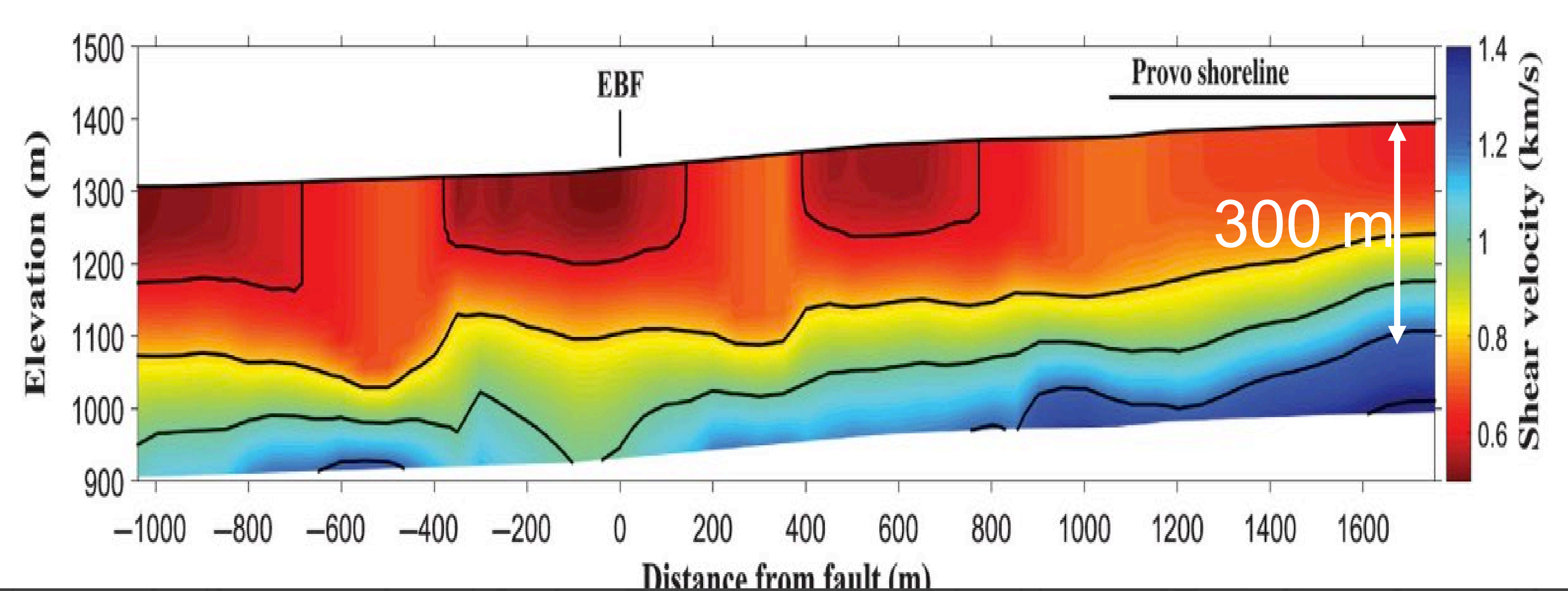


Gkogkas et al. (2021)

2018 Linear Array

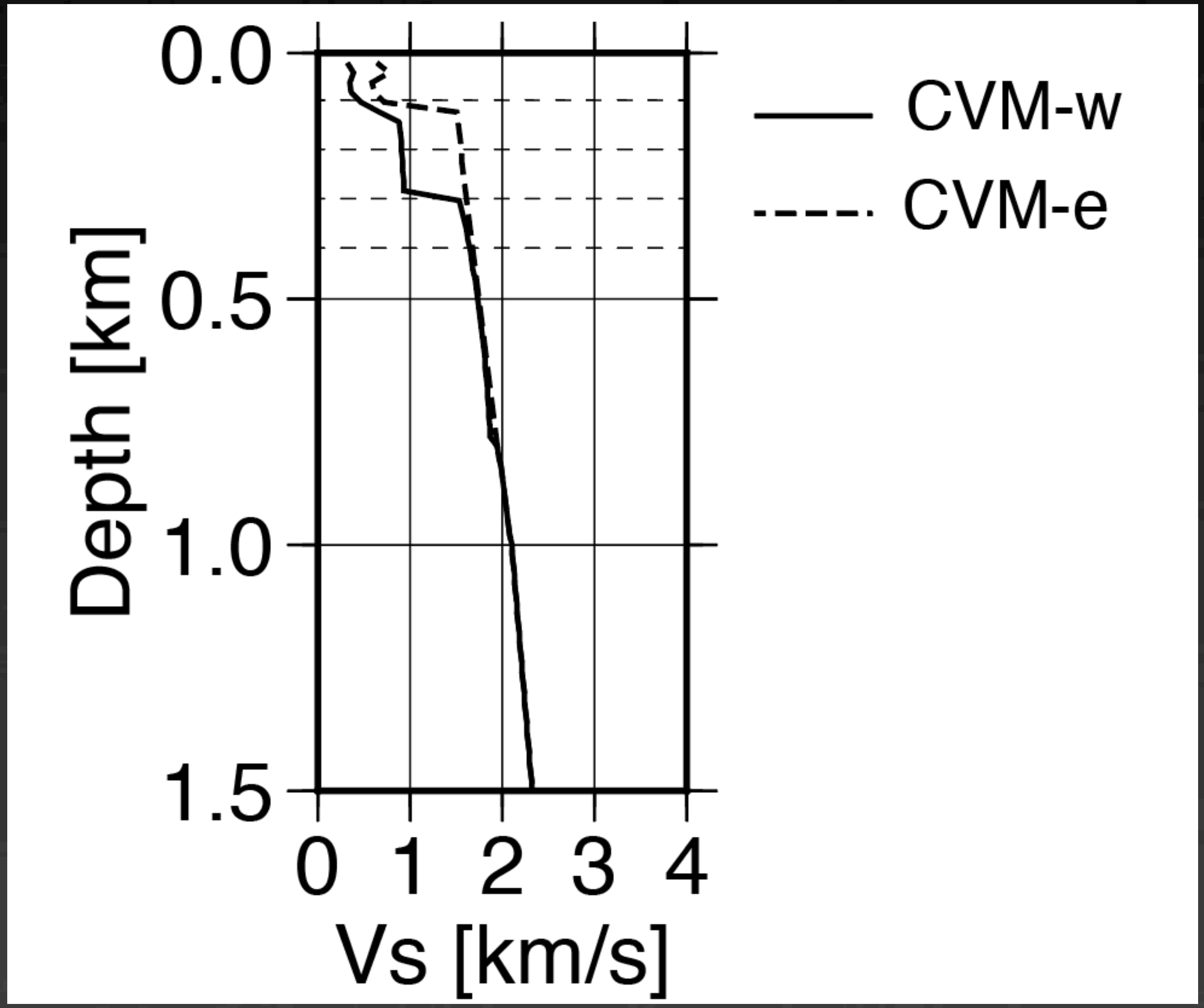


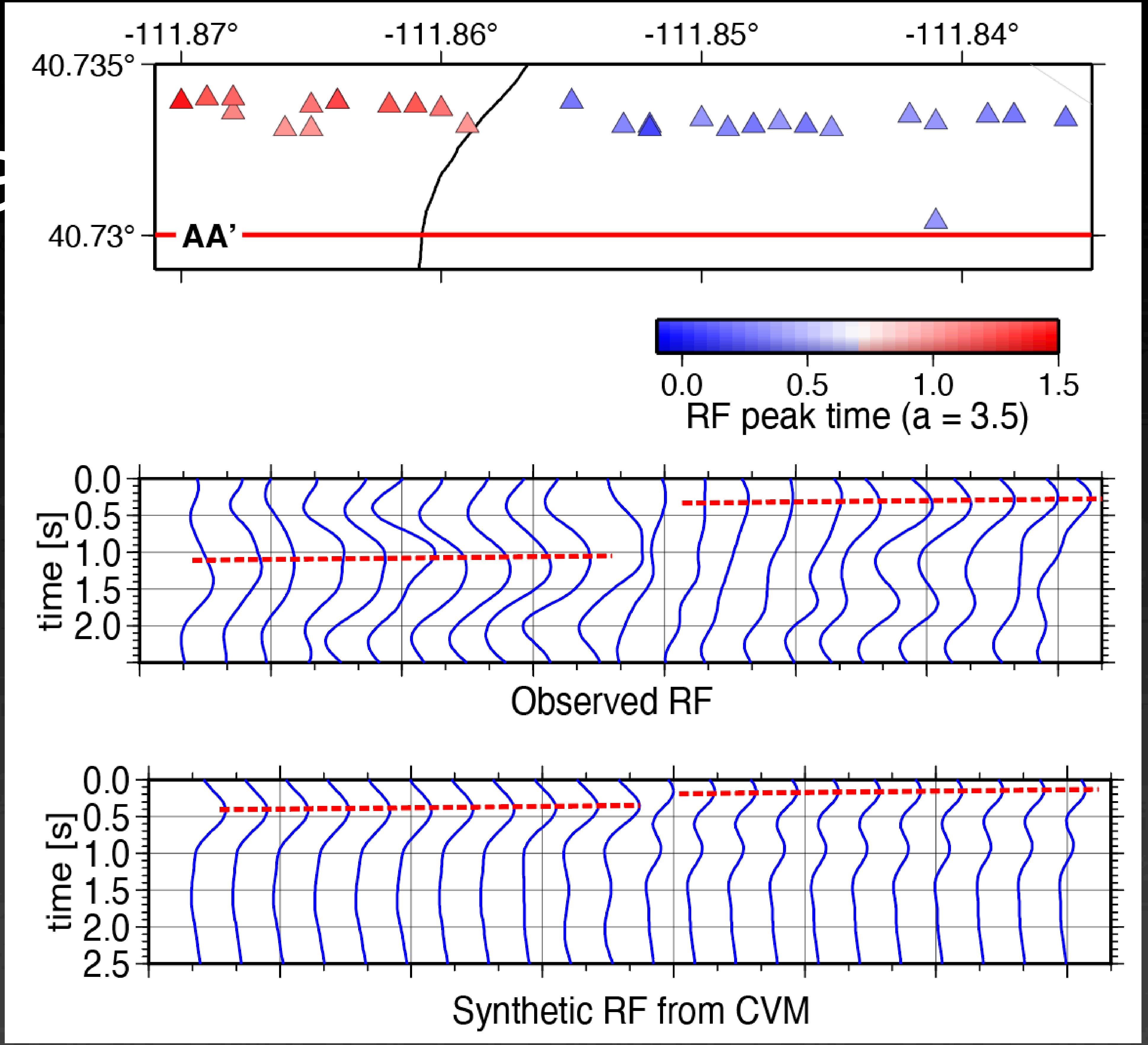




Gkogkas et al. (2021)

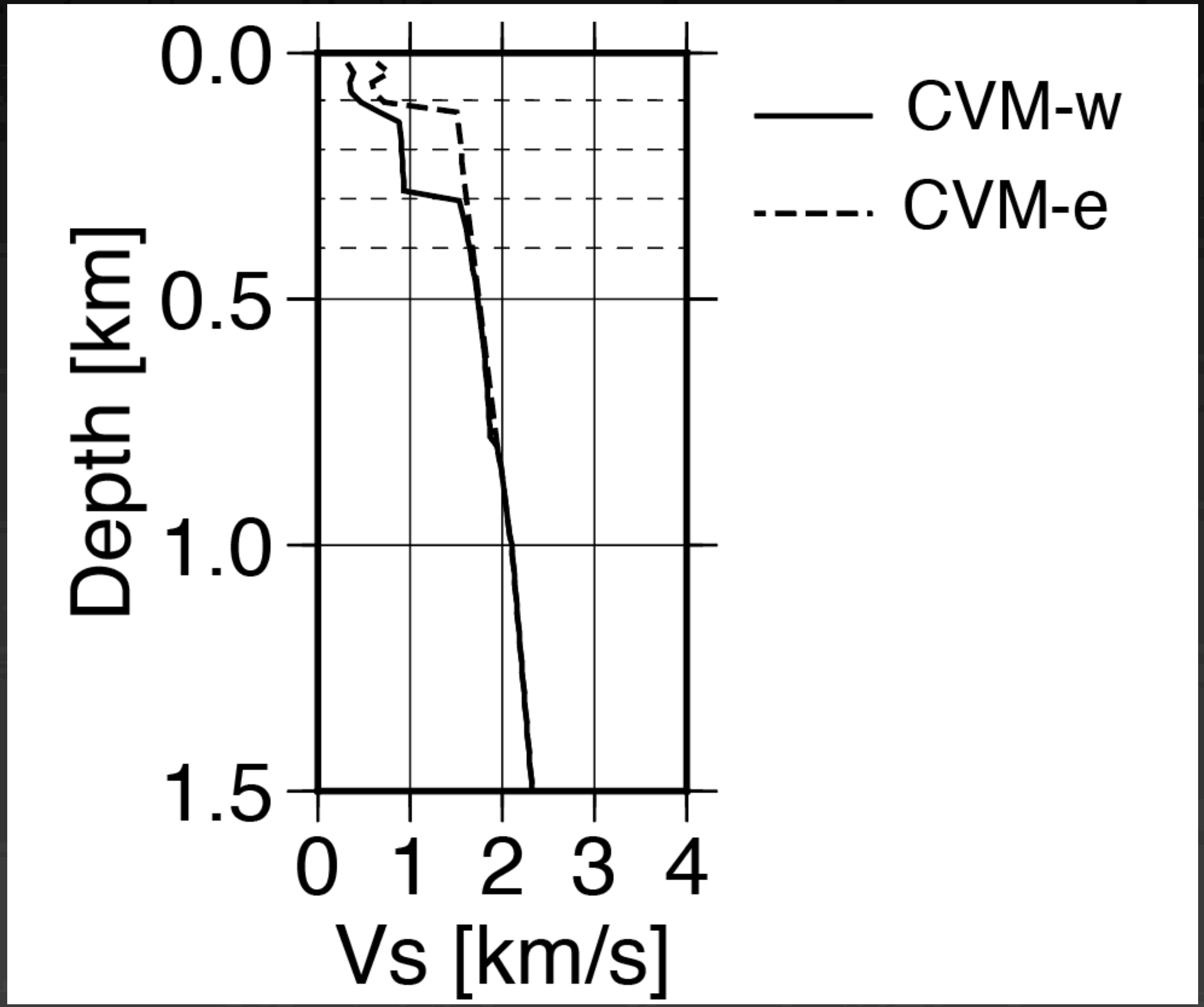
2018 Linear Arra

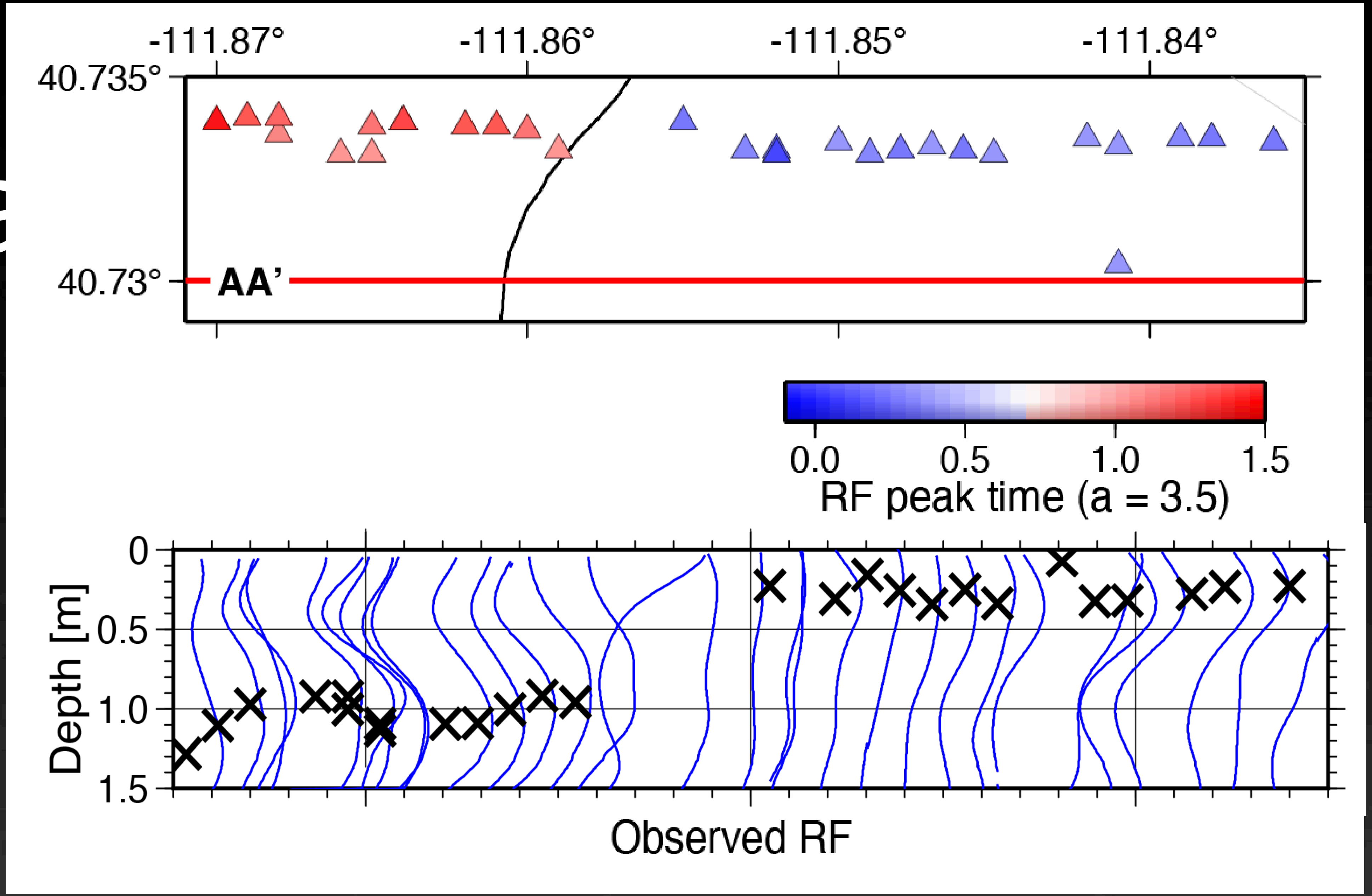




Kim et al. (in preparation

2018 Linear Arra



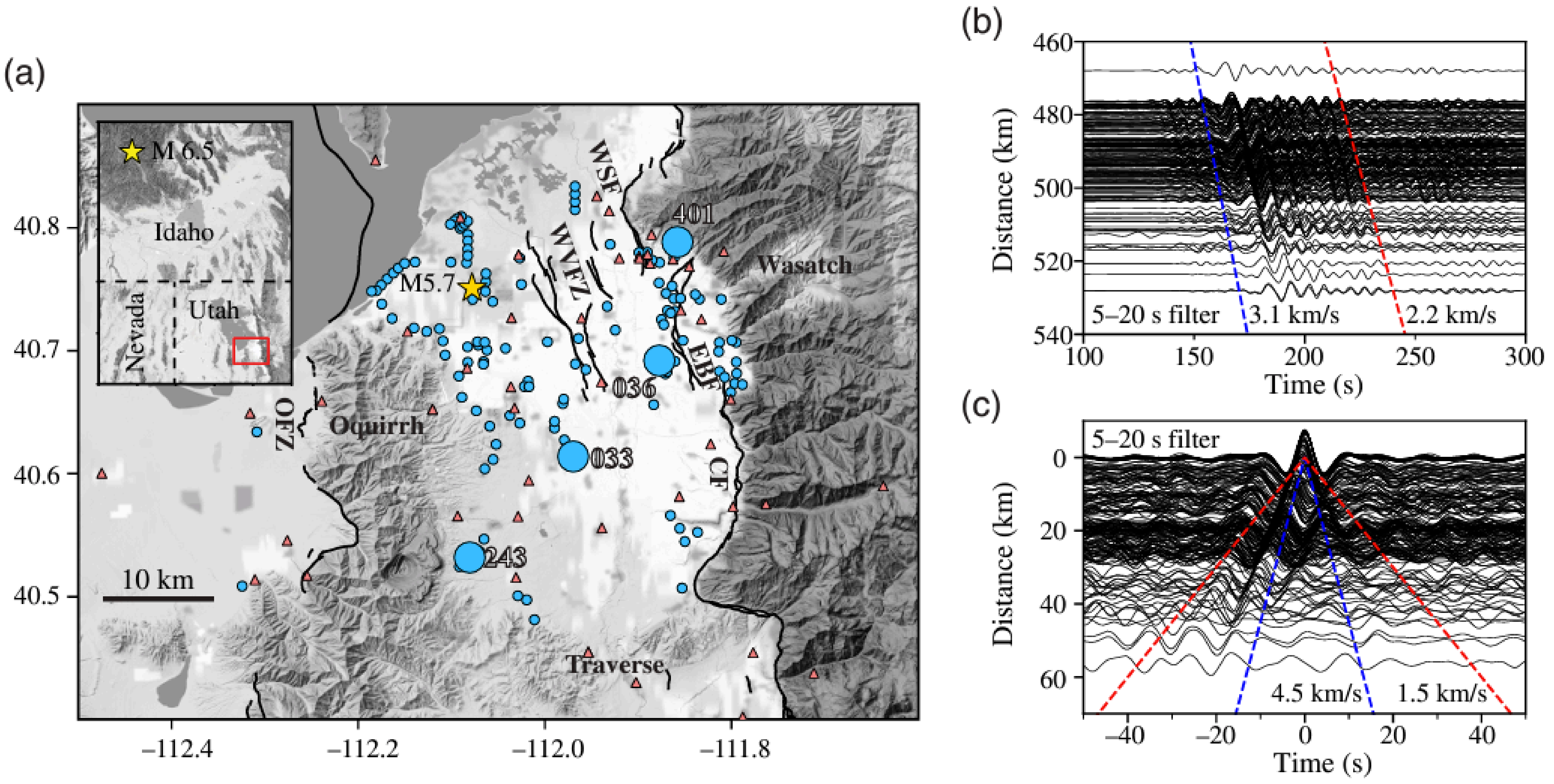


~700-800 meter R2 offset across the East Bench Fault

Active since ~0.45Ma assuming 1.7 mm/yr

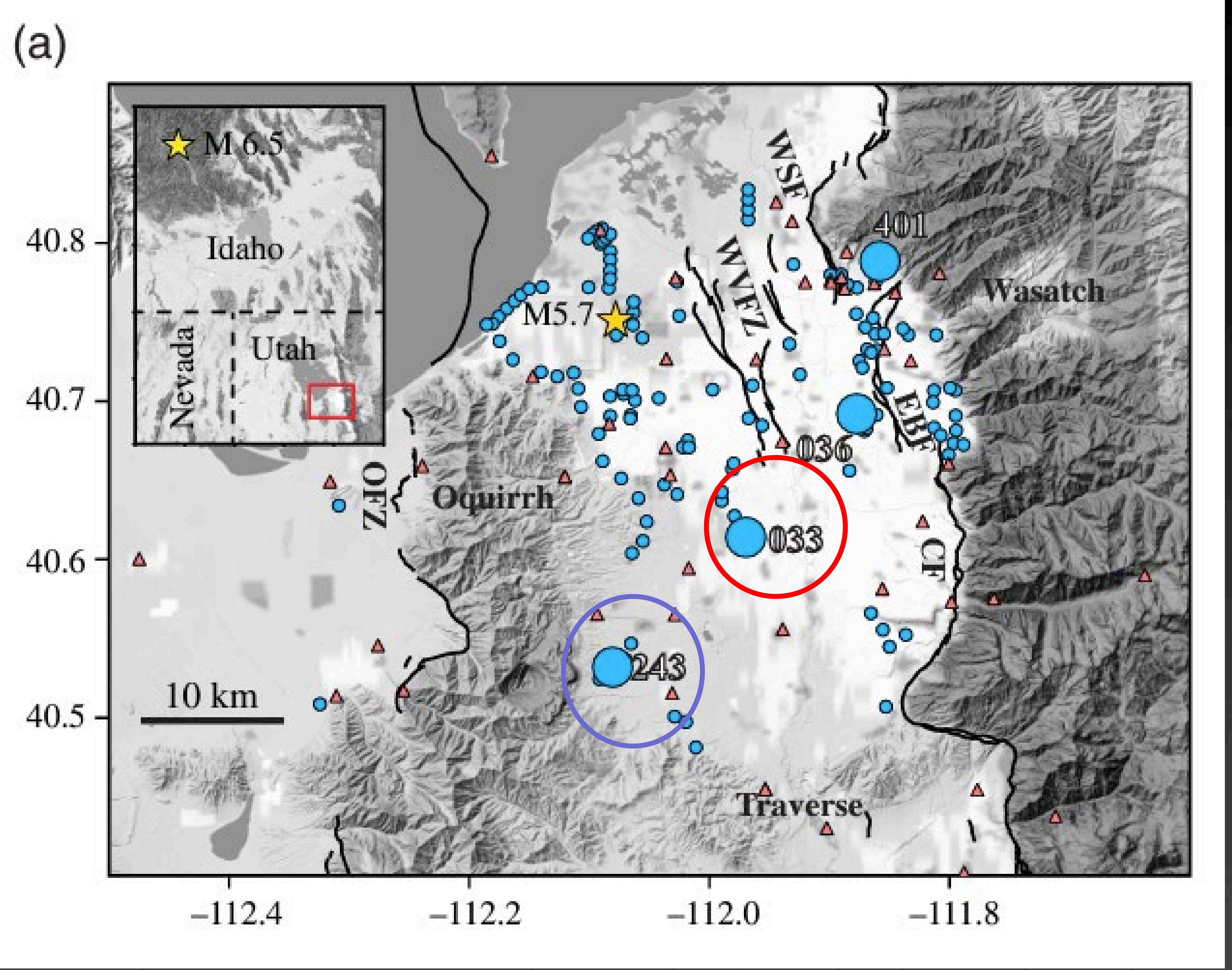
Kim et al. (in preparation

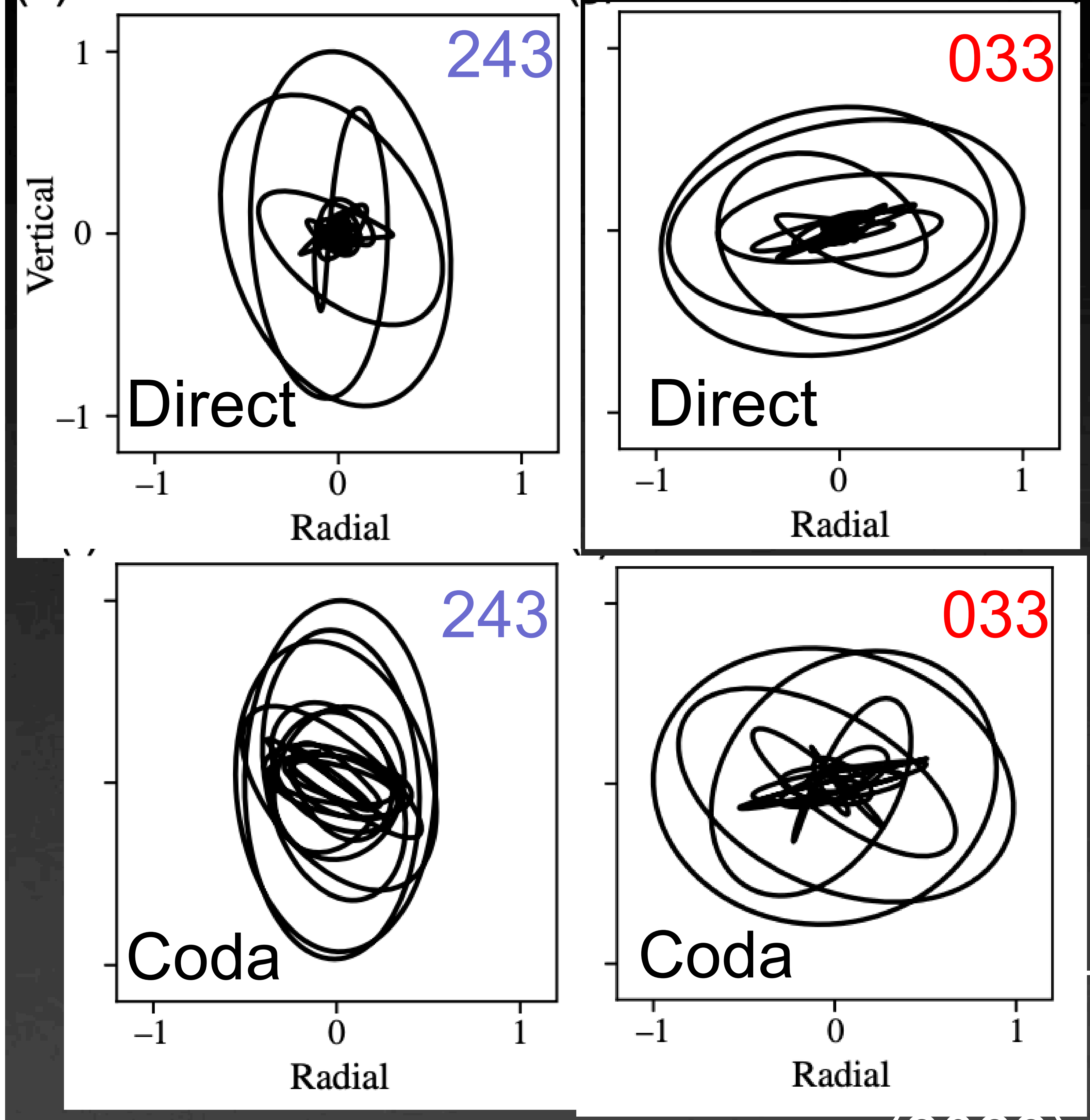
2020 Magna Aftershock Array



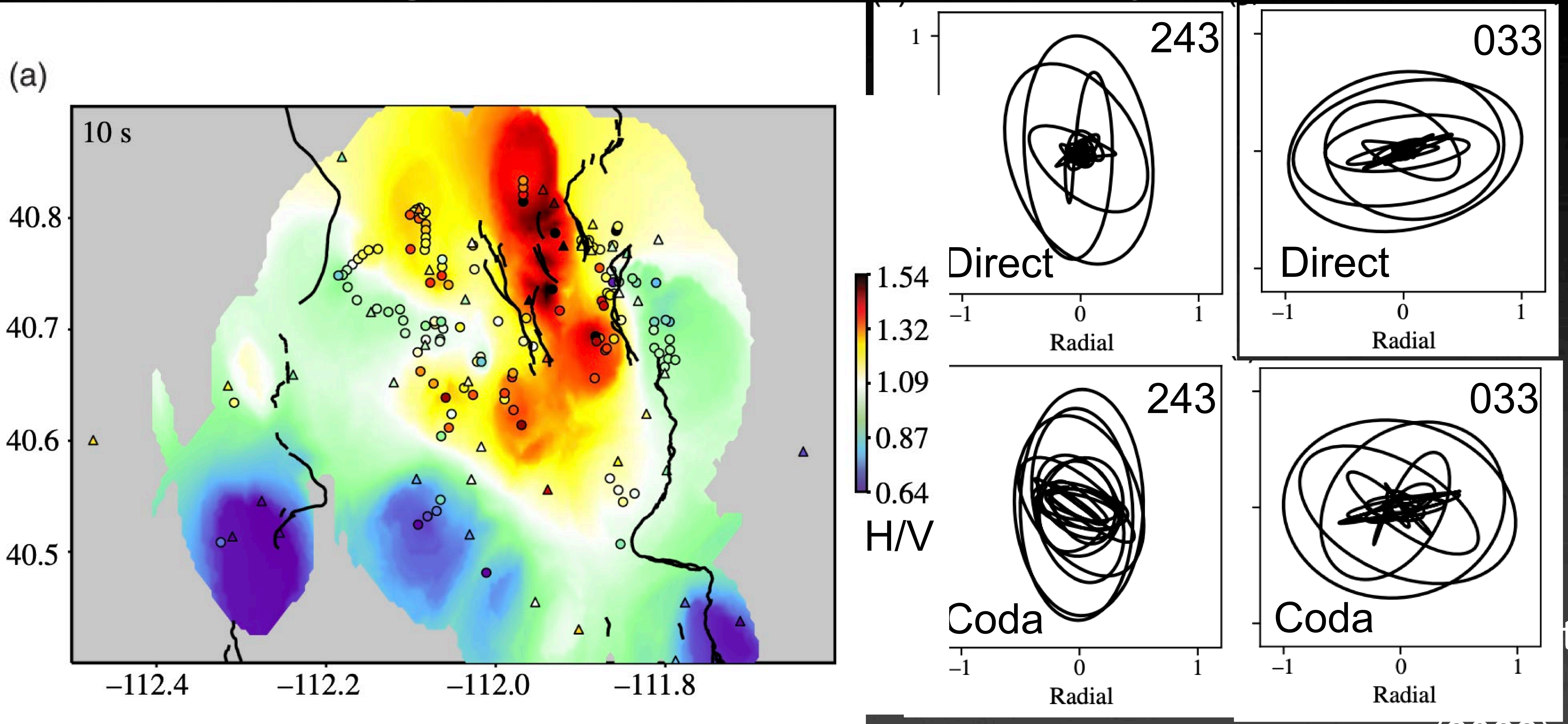
Zeng et al. (2022)

2020 Magna Aftershock Array

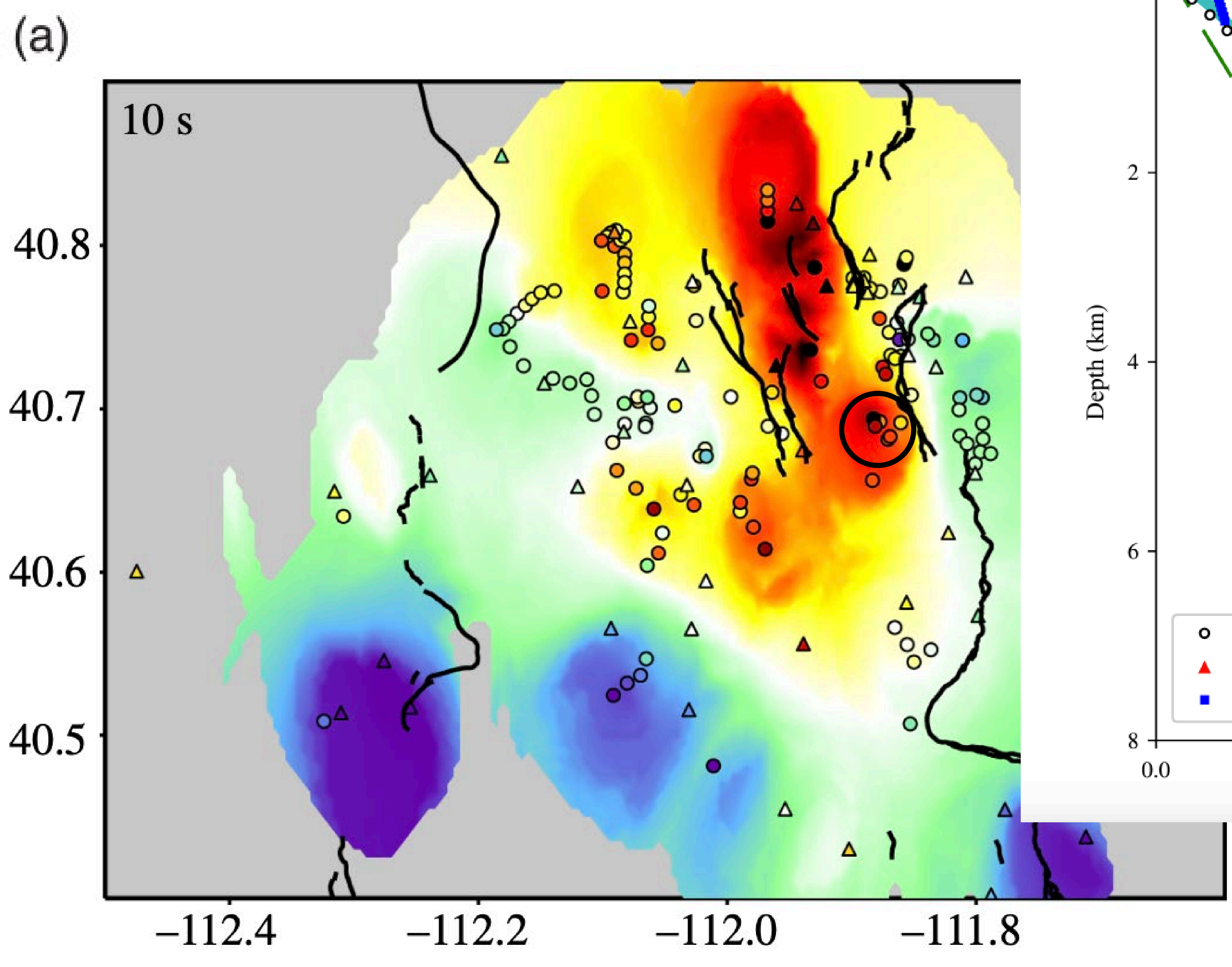


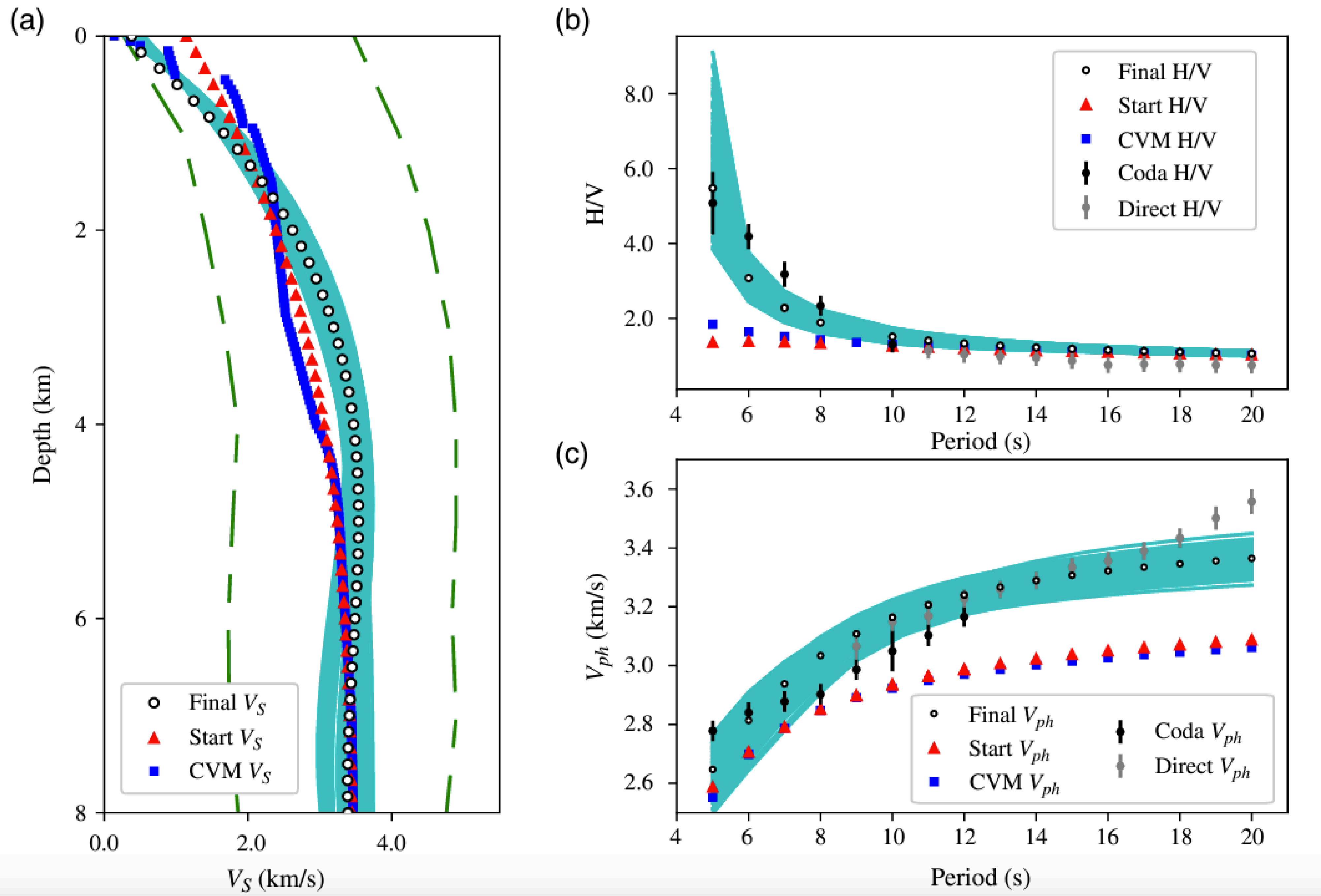


2020 Magna Aftershock Array



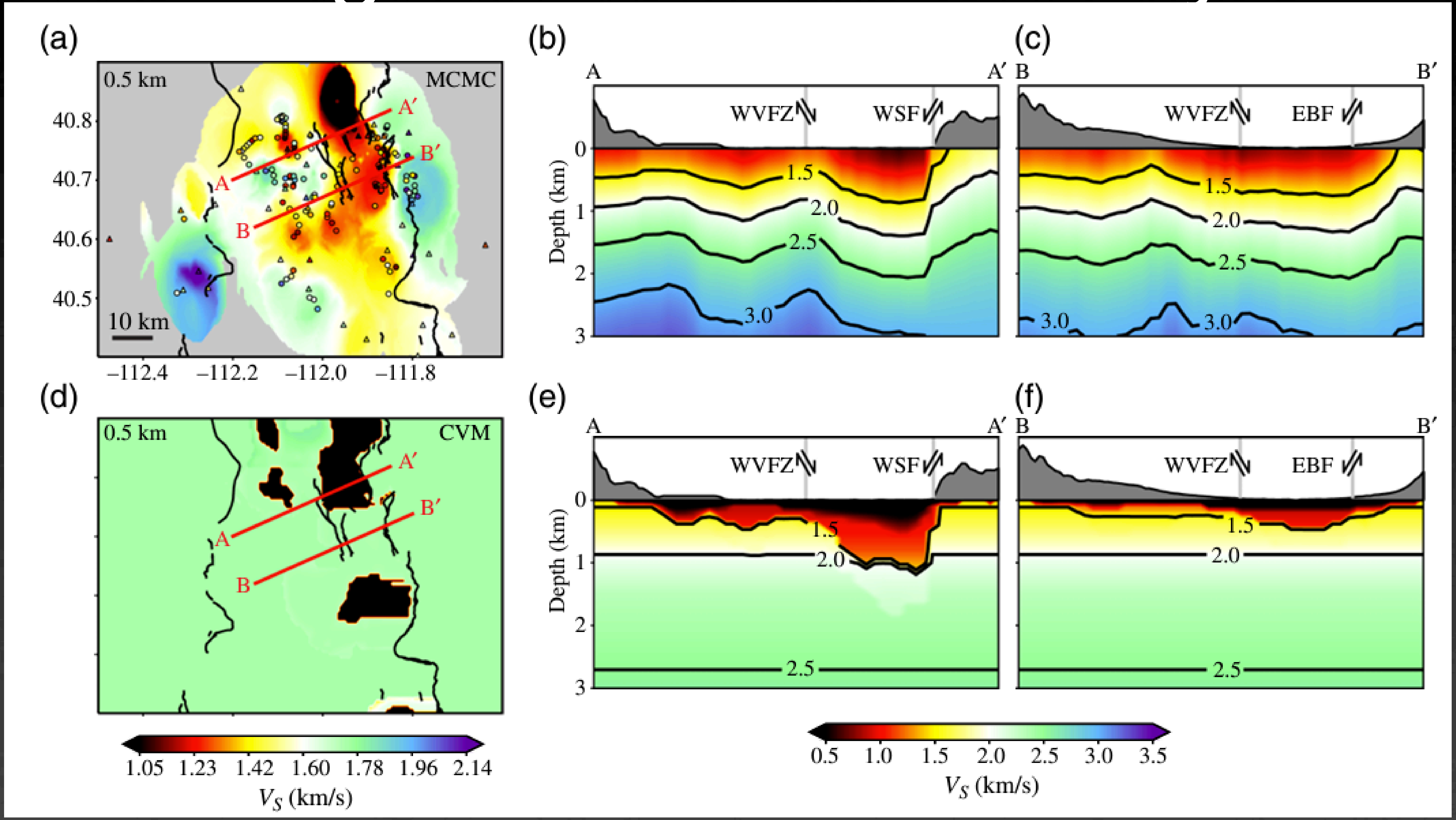
2020 Magna Aftershock Array





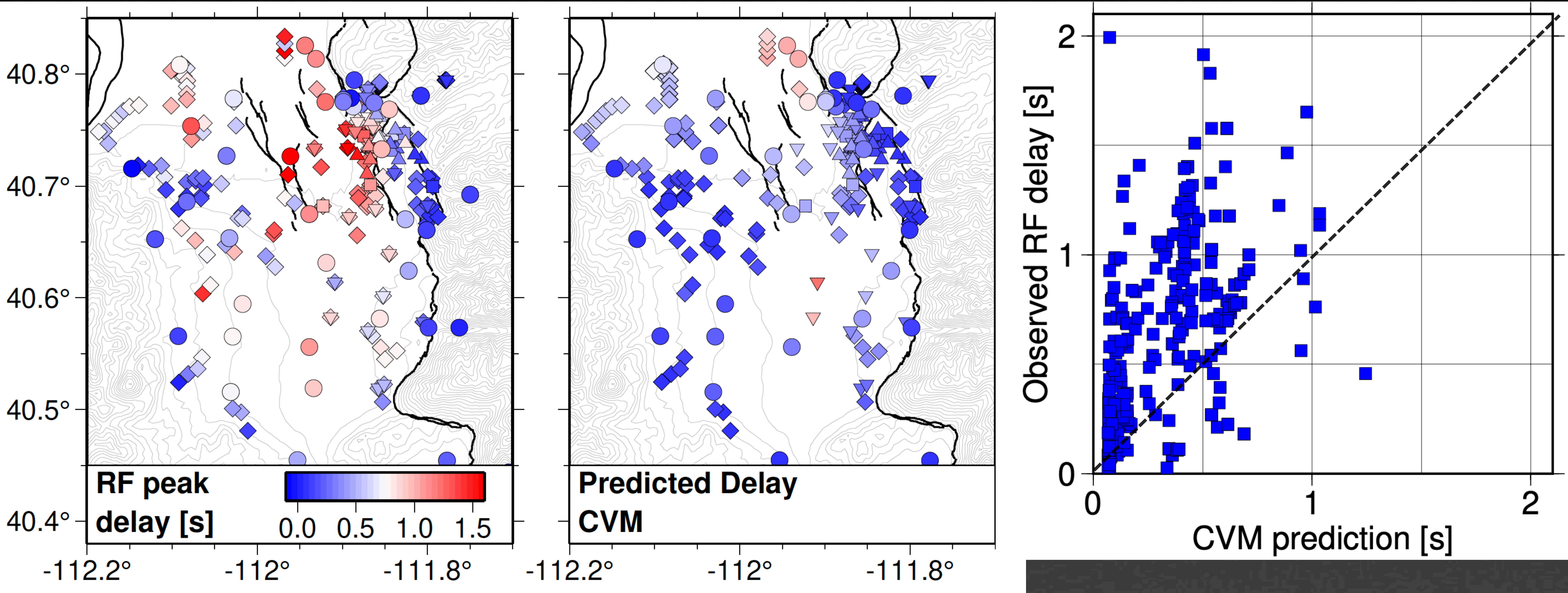
Zeng et al. (2022)

2020 Magna Aftershock Array



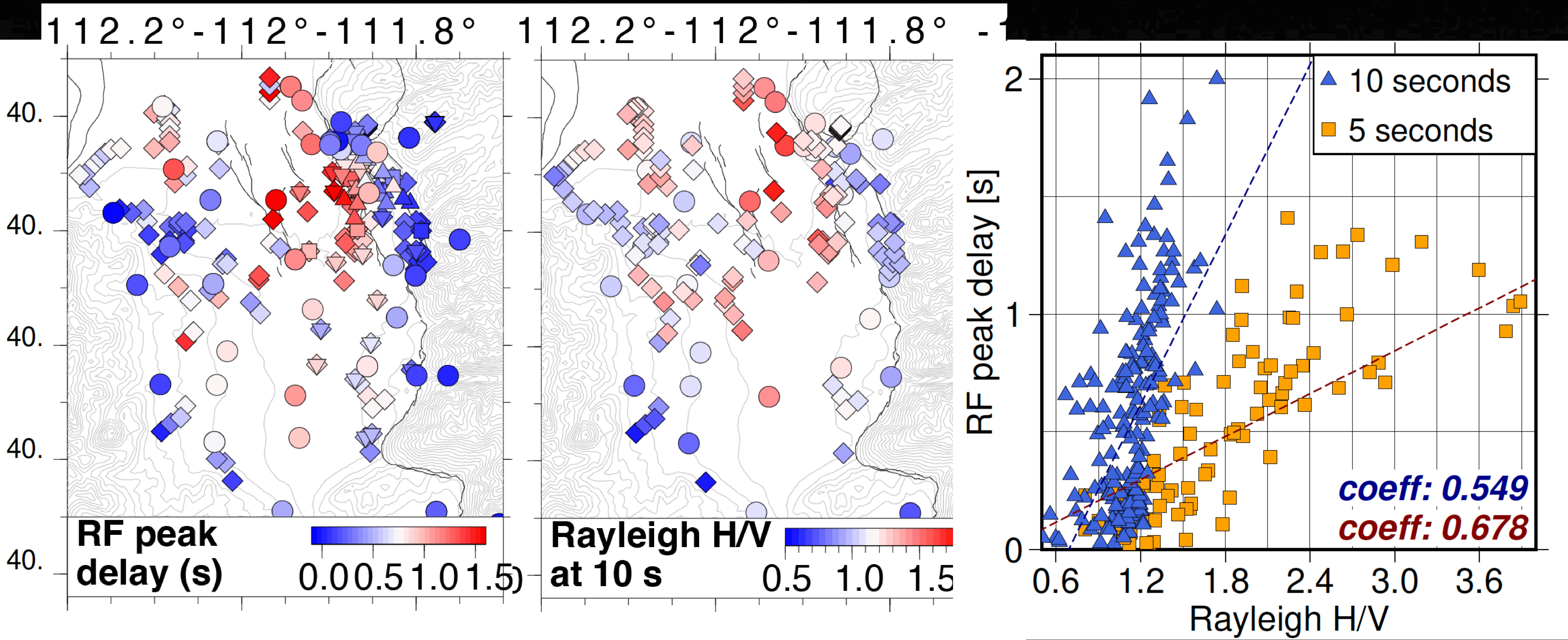
Zeng et al. (2022)

Receiver function



Kim et al. (in preparation

Receiver Function versus Rayleigh wave



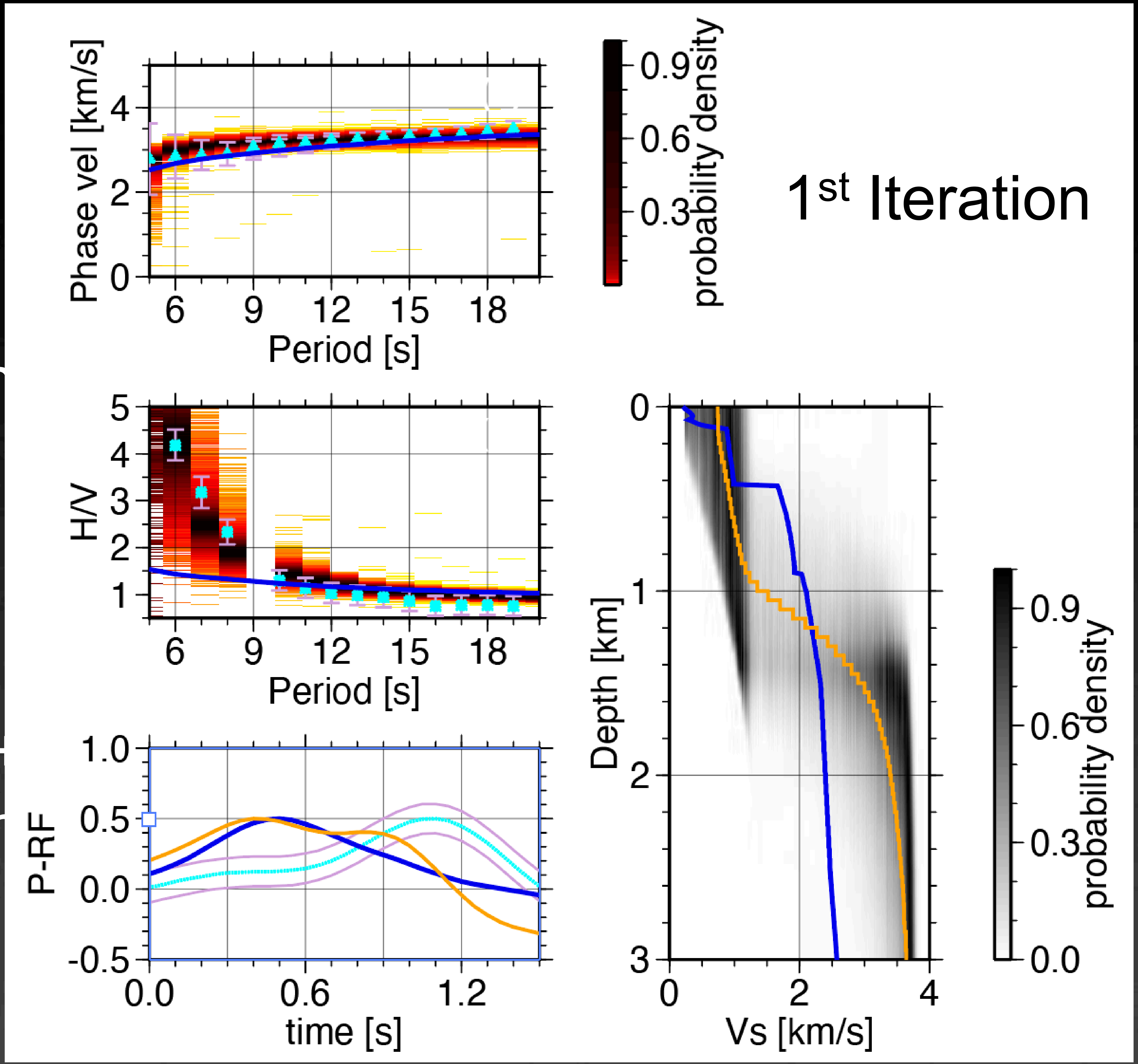
Kim et al. (in preparation

Joint Seismic Inversion

Iterative 1D MCMC inversion

1st Iteration: Rayleigh wave phase velocity + H/V ratios

2nd Iteration: phase velocity + H/V ratios + receiver function

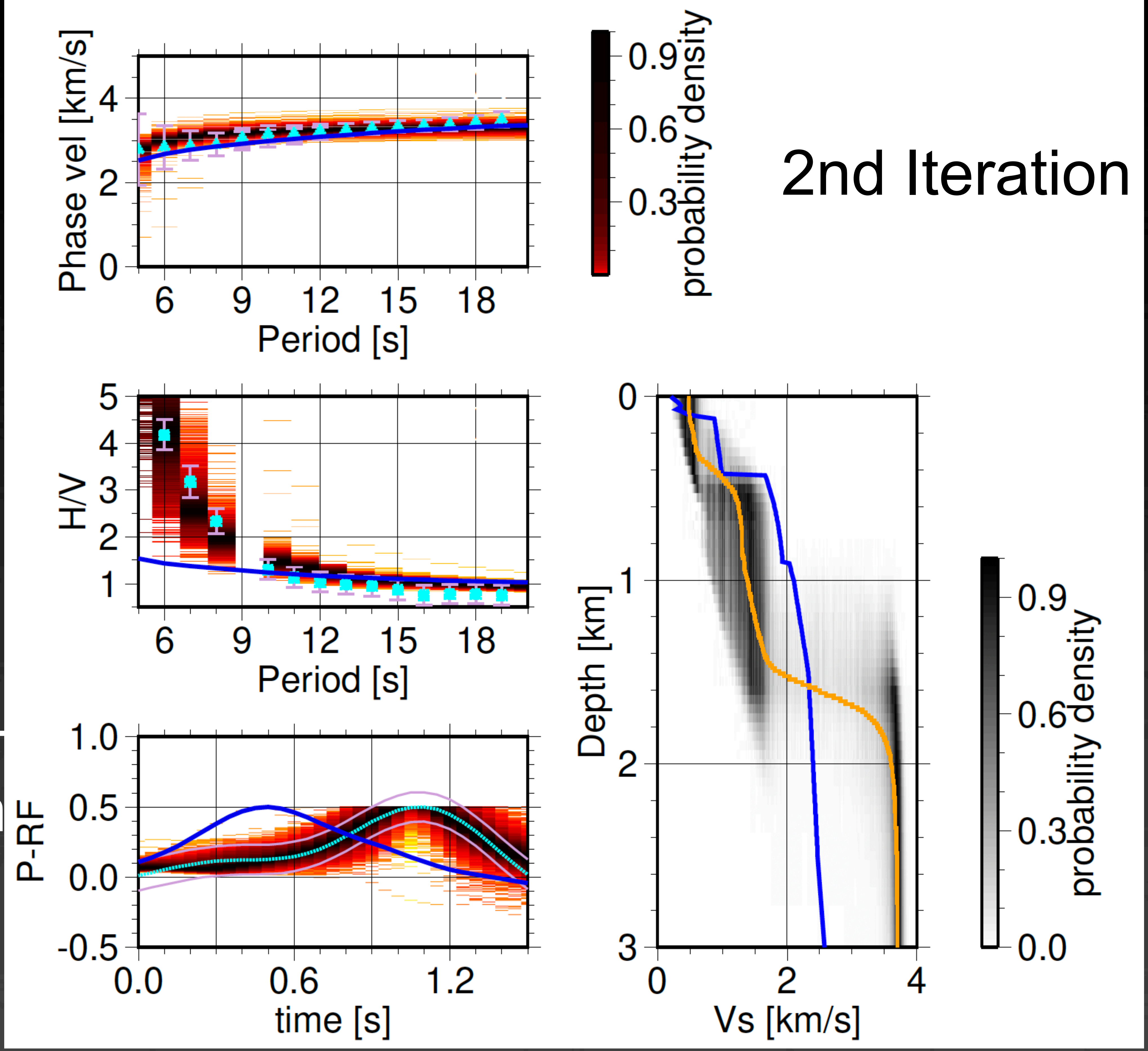


Joint Seismic Inversion

Iterative 1D MCMC inversion

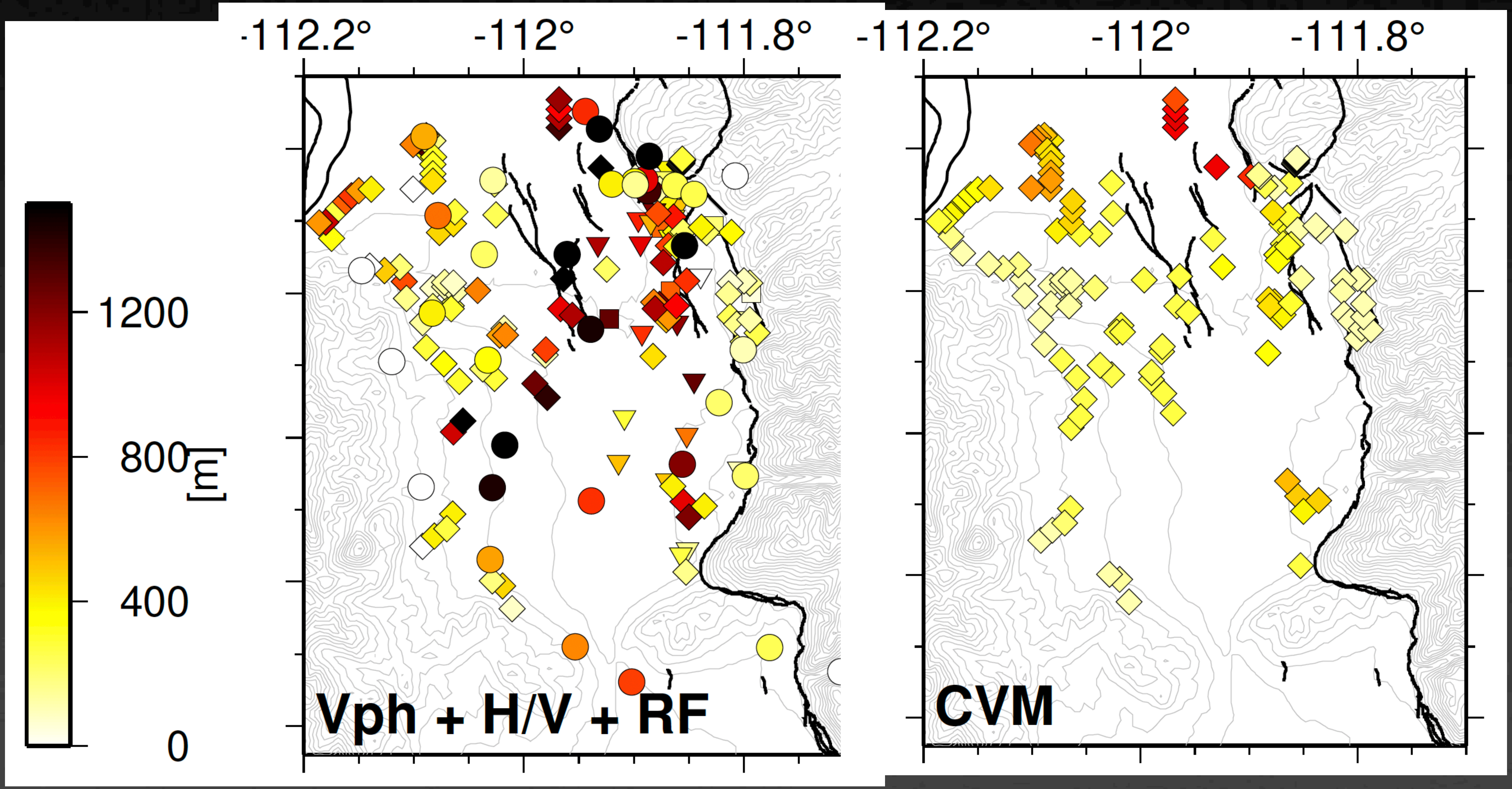
1st Iteration: Rayleigh wave phase velocity + H/V ratios

2nd Iteration: phase velocity + H/V ratios + receiver function



THE UNIVERSITY OF UTAH

Inversion result of R2 (depth = 1500 m/s)



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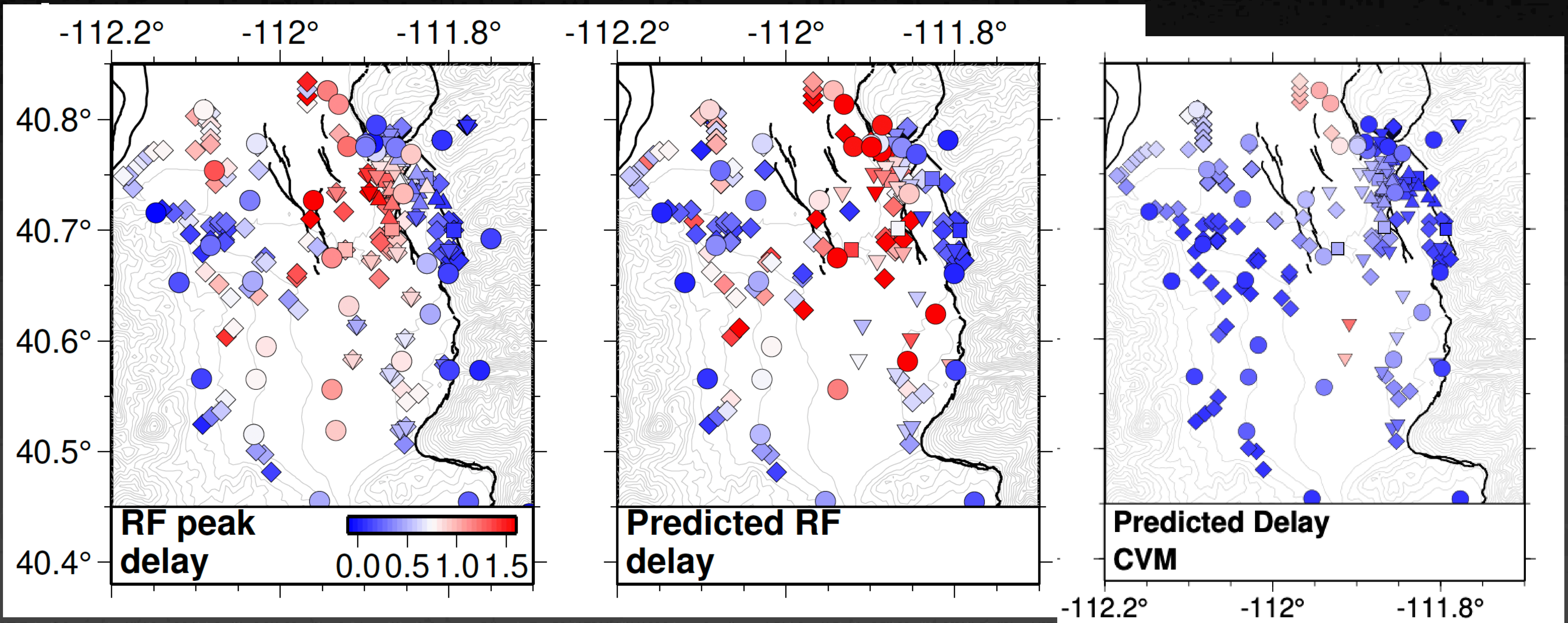
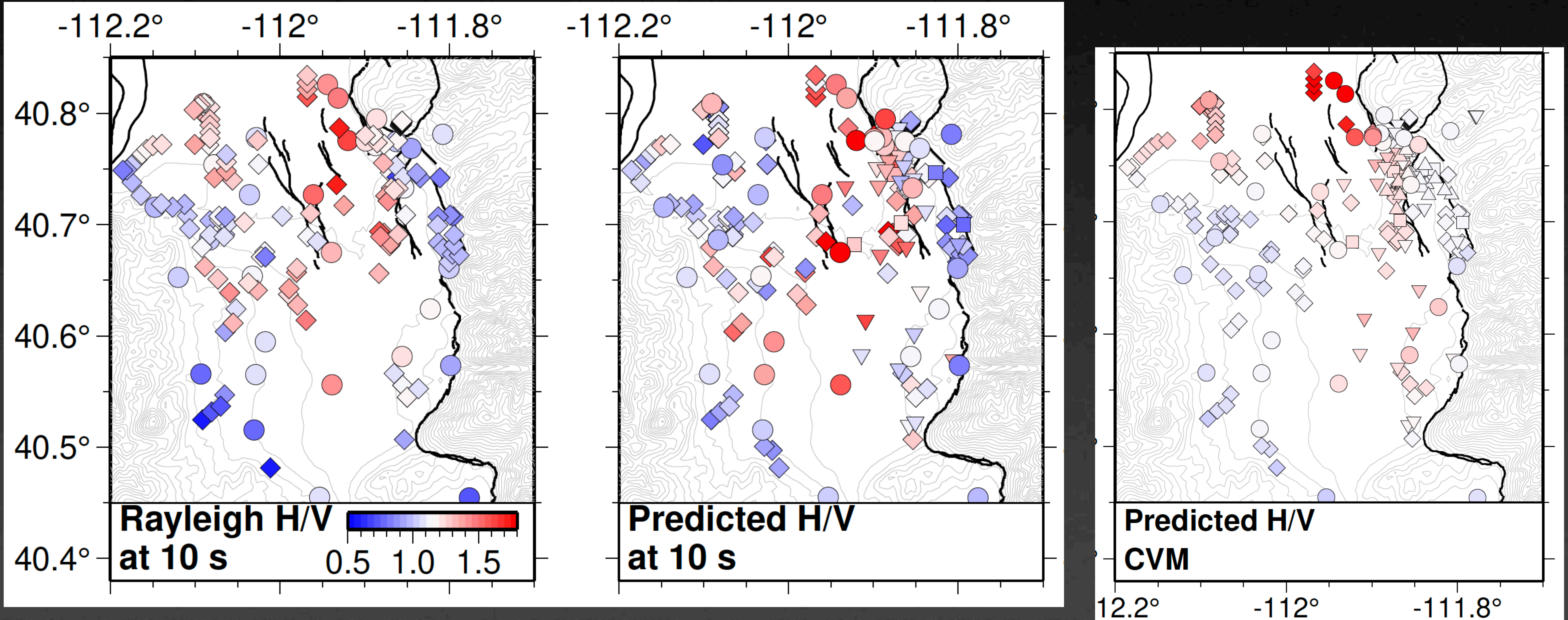
Observed and predicted receiver function delay



Predicted and observed Rayleigh wave H/V ratios



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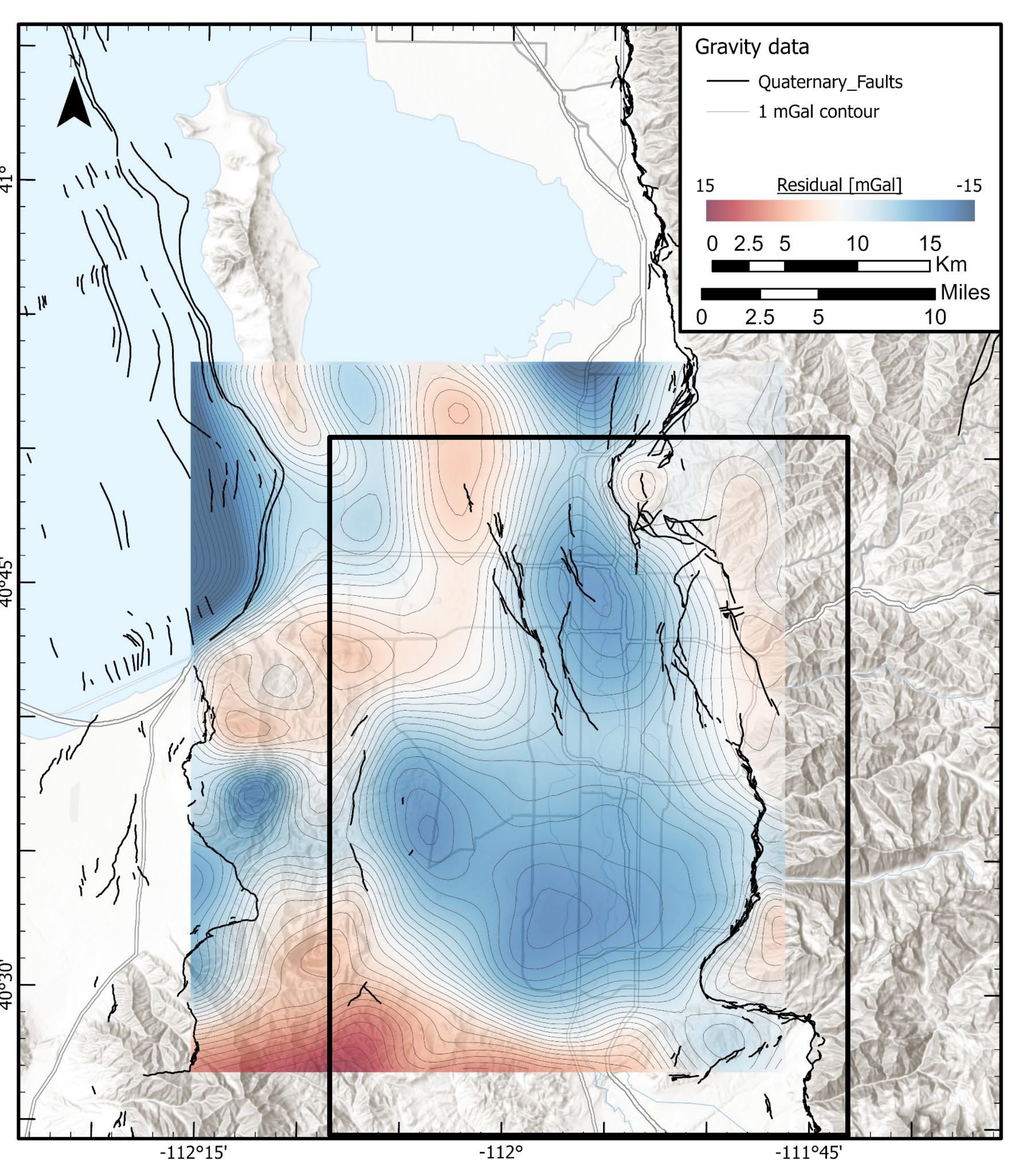
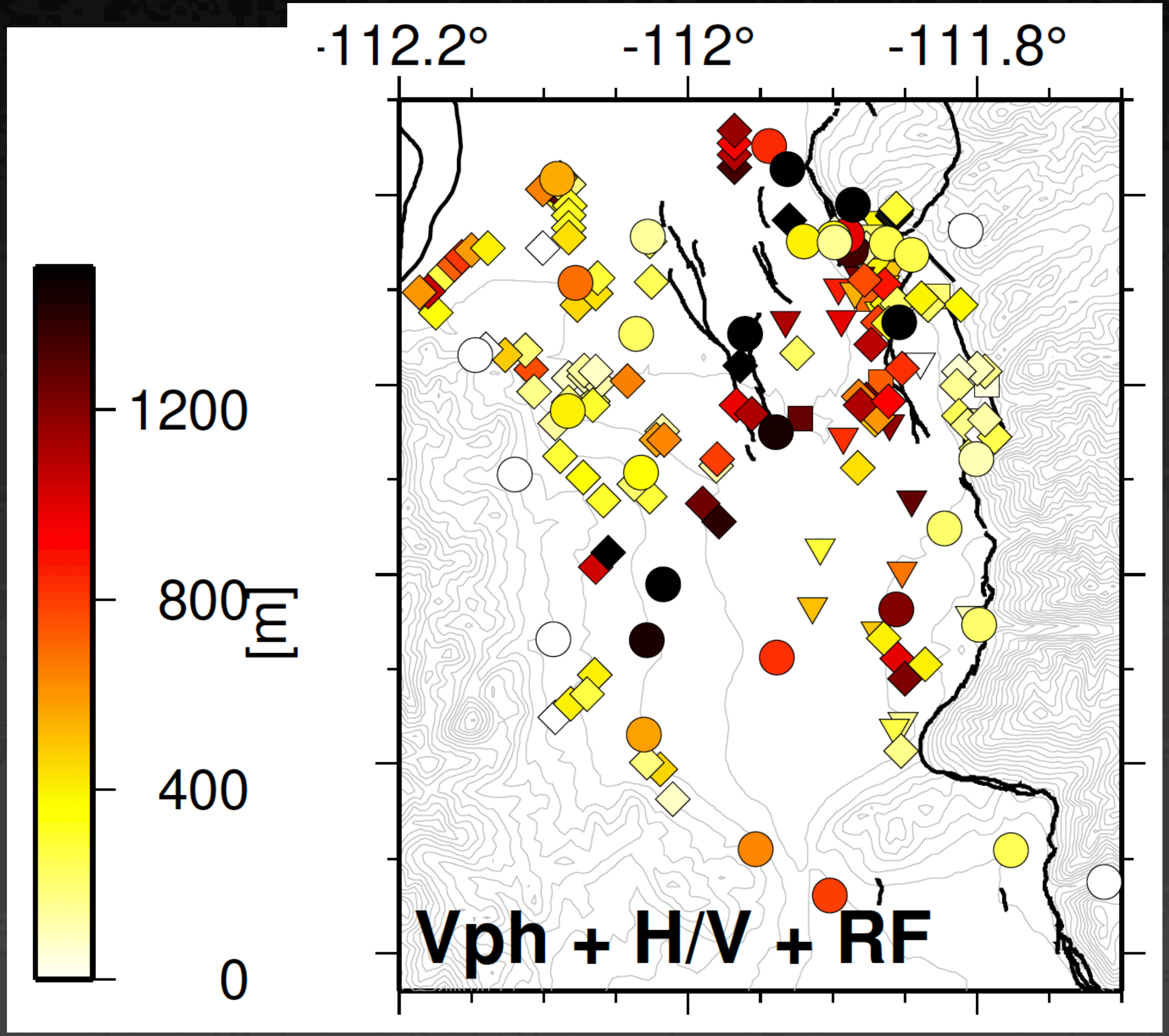
Residual gravity

Next Step: Determine the regional gravity correction based on the seismic model





R2 depth based on seismic inversion

Summary

- Recent nodal deployments have significantly improved seismic data coverage in Salt Lake Valley.
- Both surface wave and receiver function measurements show clear sensitivity to shallow basin structure.
- A deeper R2 discontinuity is observed between the East Bench Fault and the West Valley Fault.
- This suggests a stronger amplification effect and a lower resonance frequency near downtown Salt Lake compared to predictions from CVM.

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Acknowledgement

- Thanks to Amir Allam, Santiago Rabade, Kevin Mendoza, Qicheng Zeng, Kostas Gkogkas, Chloe Barry, Gabriela Zaldivar, and other students who help to deploy nodal geophones across Salt Lake


Questions?

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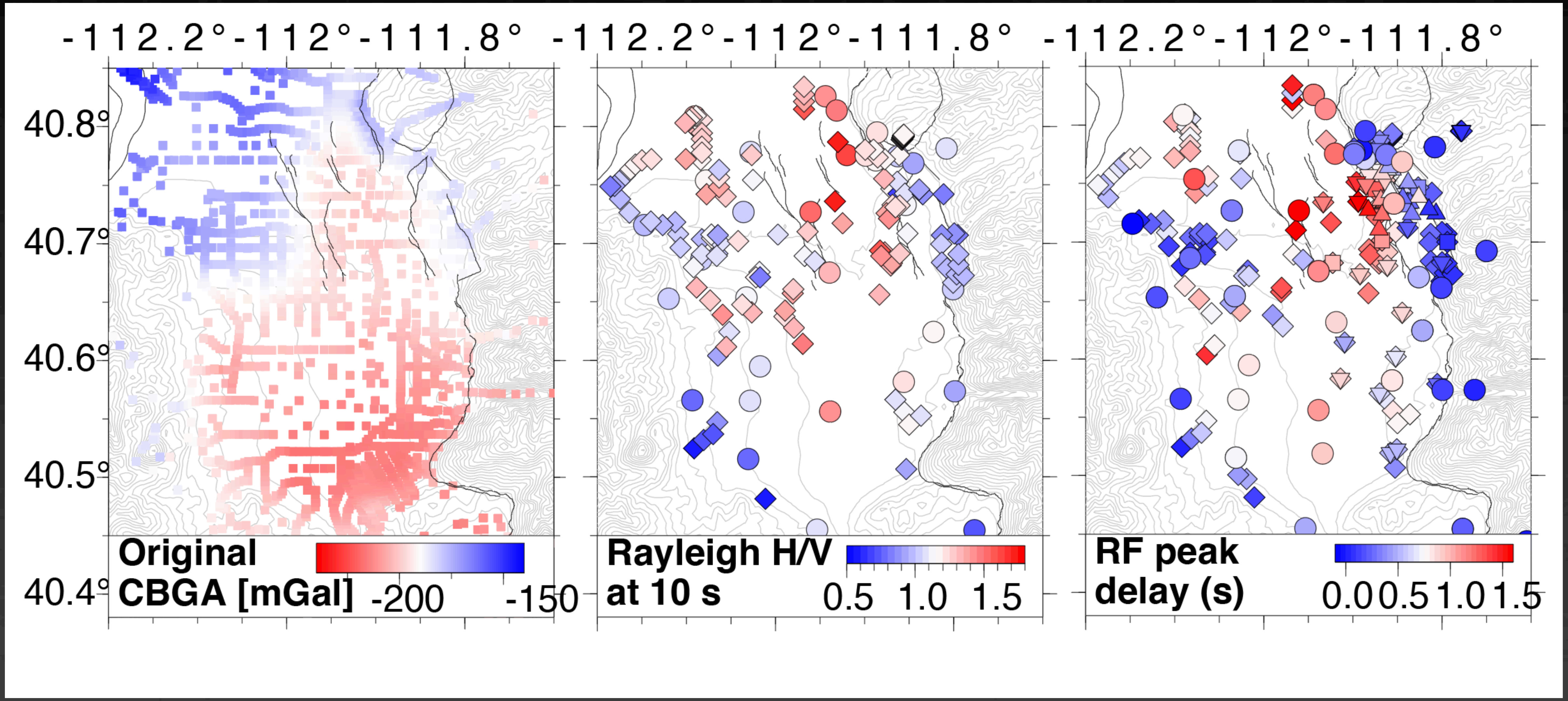

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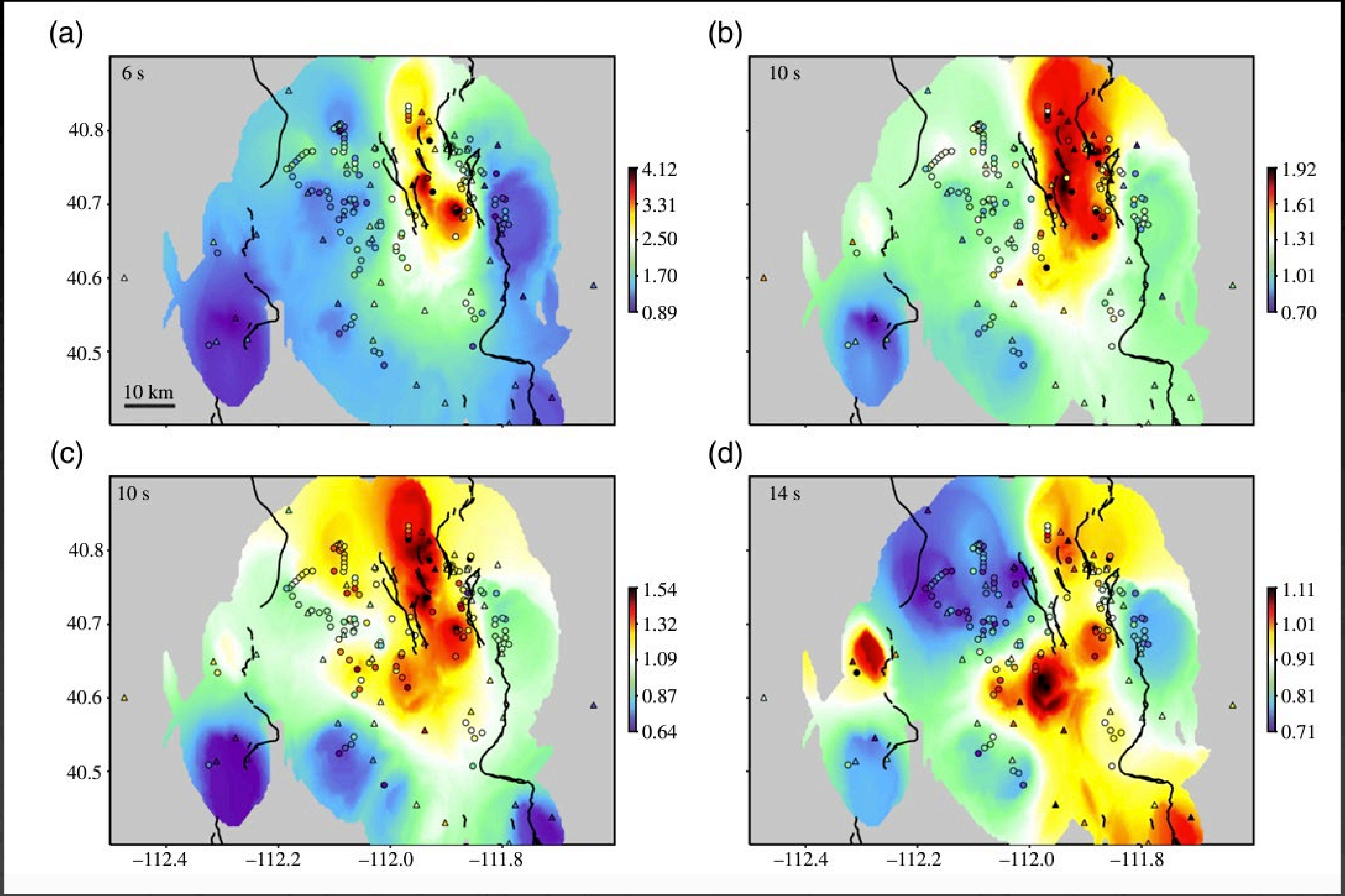

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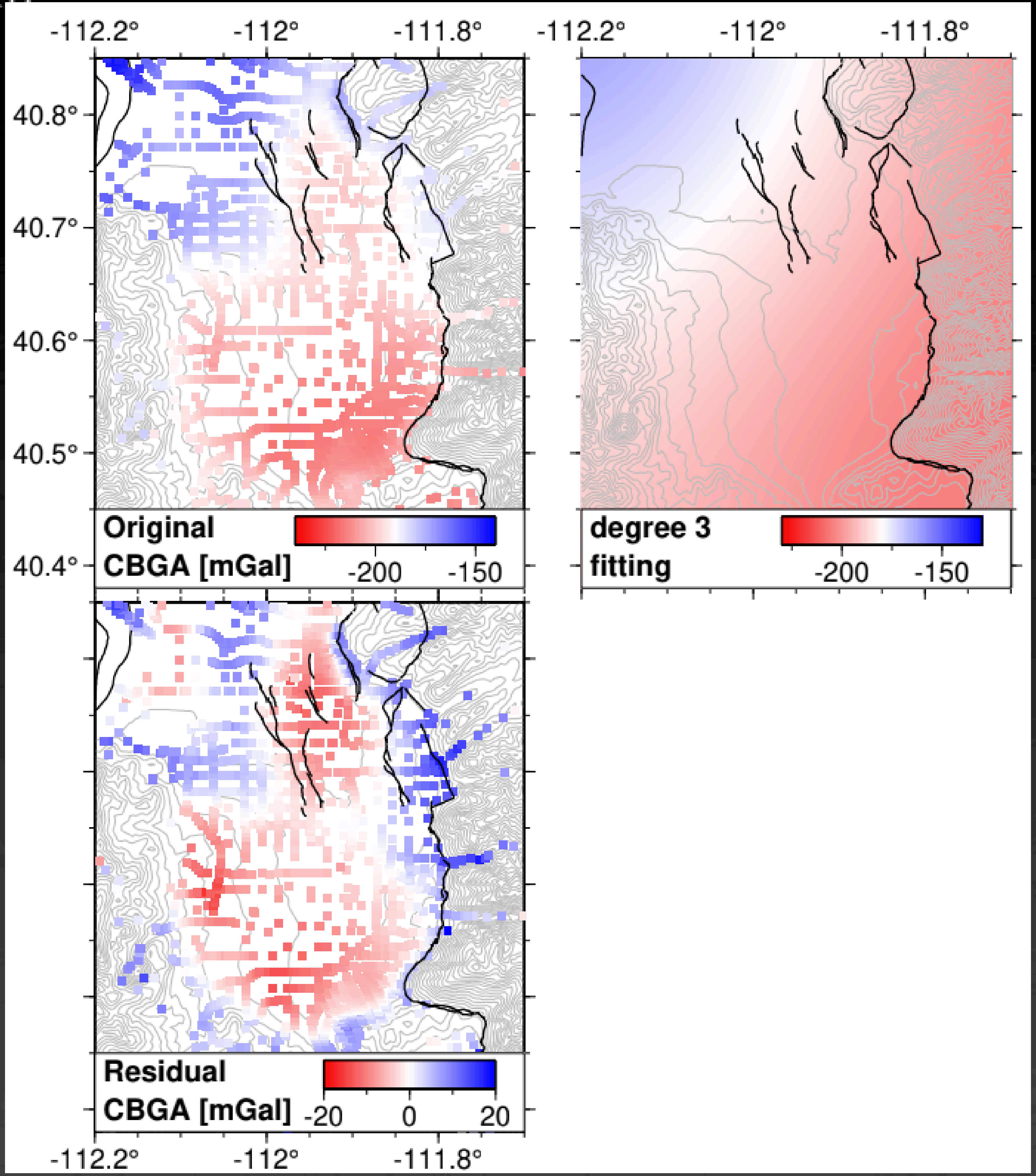
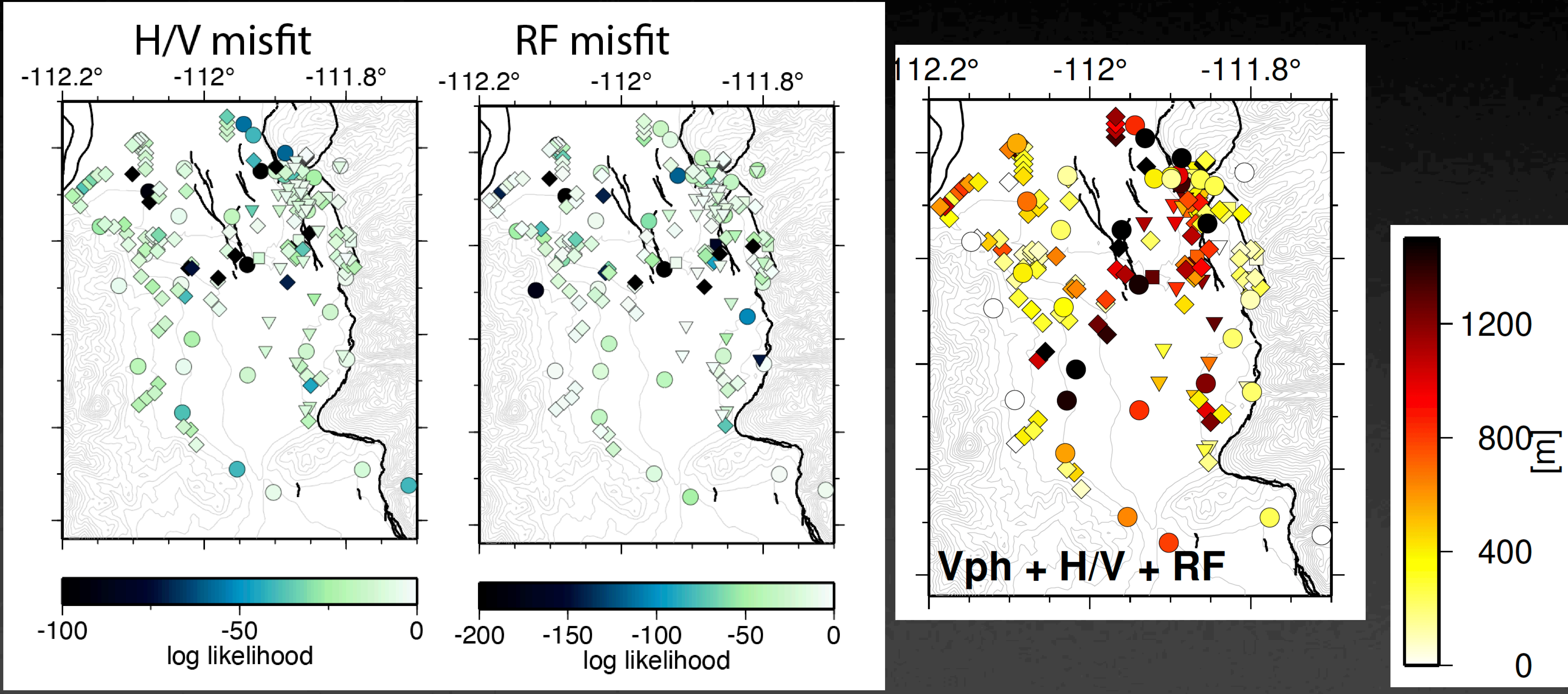
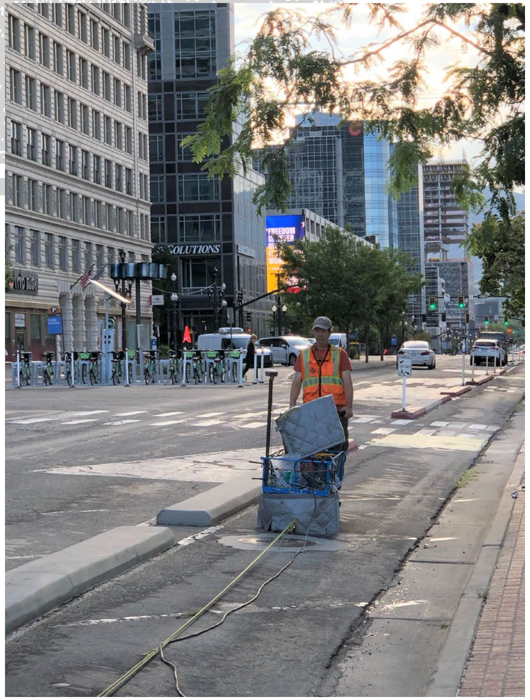


Joint Seismic Inversion



BOISE STATE UNIVERSITY

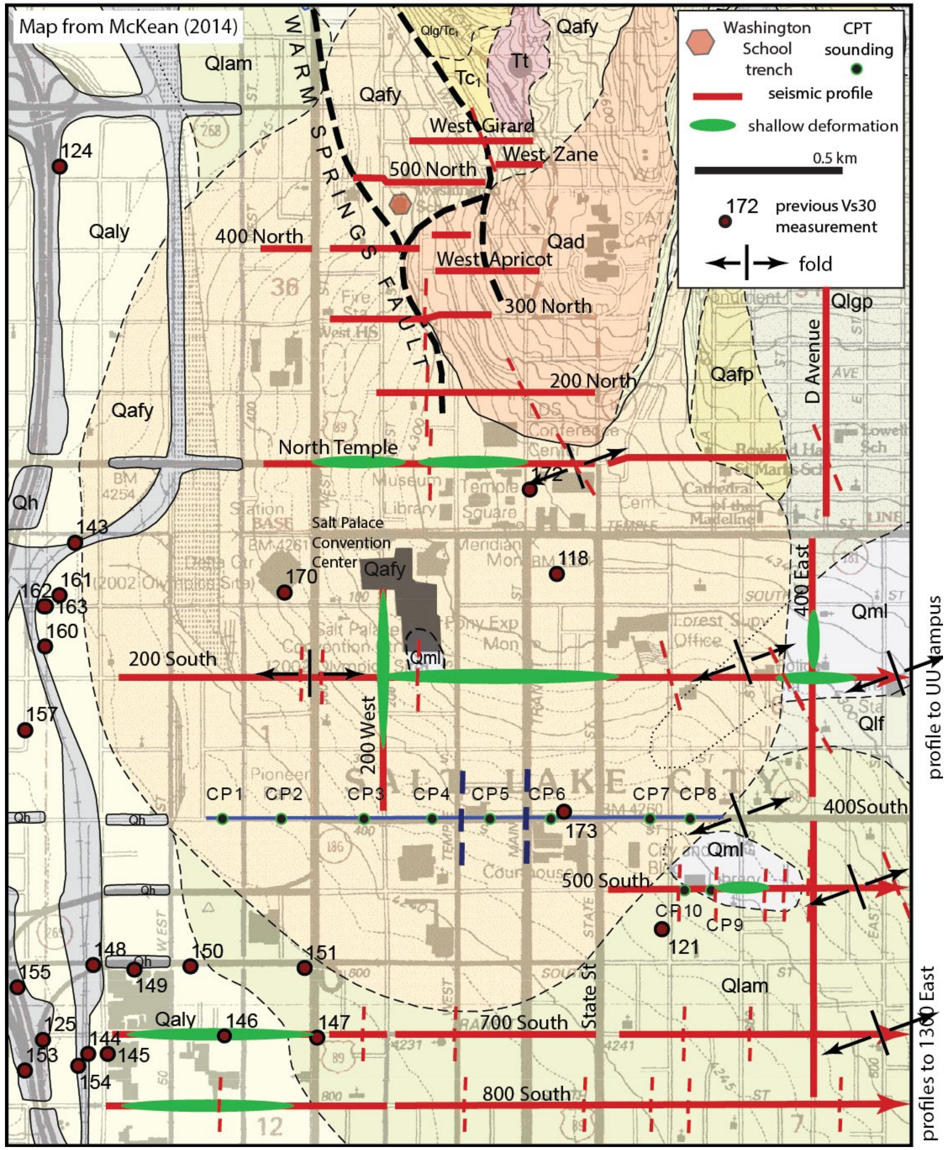
INTRABASIN FAULTING BENEATH SALT LAKE CITY: NEW SEISMIC DATA MAP THE WEST VALLEY AND DOWNTOWN FAULT SYSTEMS



Lee M. Liberty, Boise State University

February 5, 2024

2015/2018 LAND STREAMER



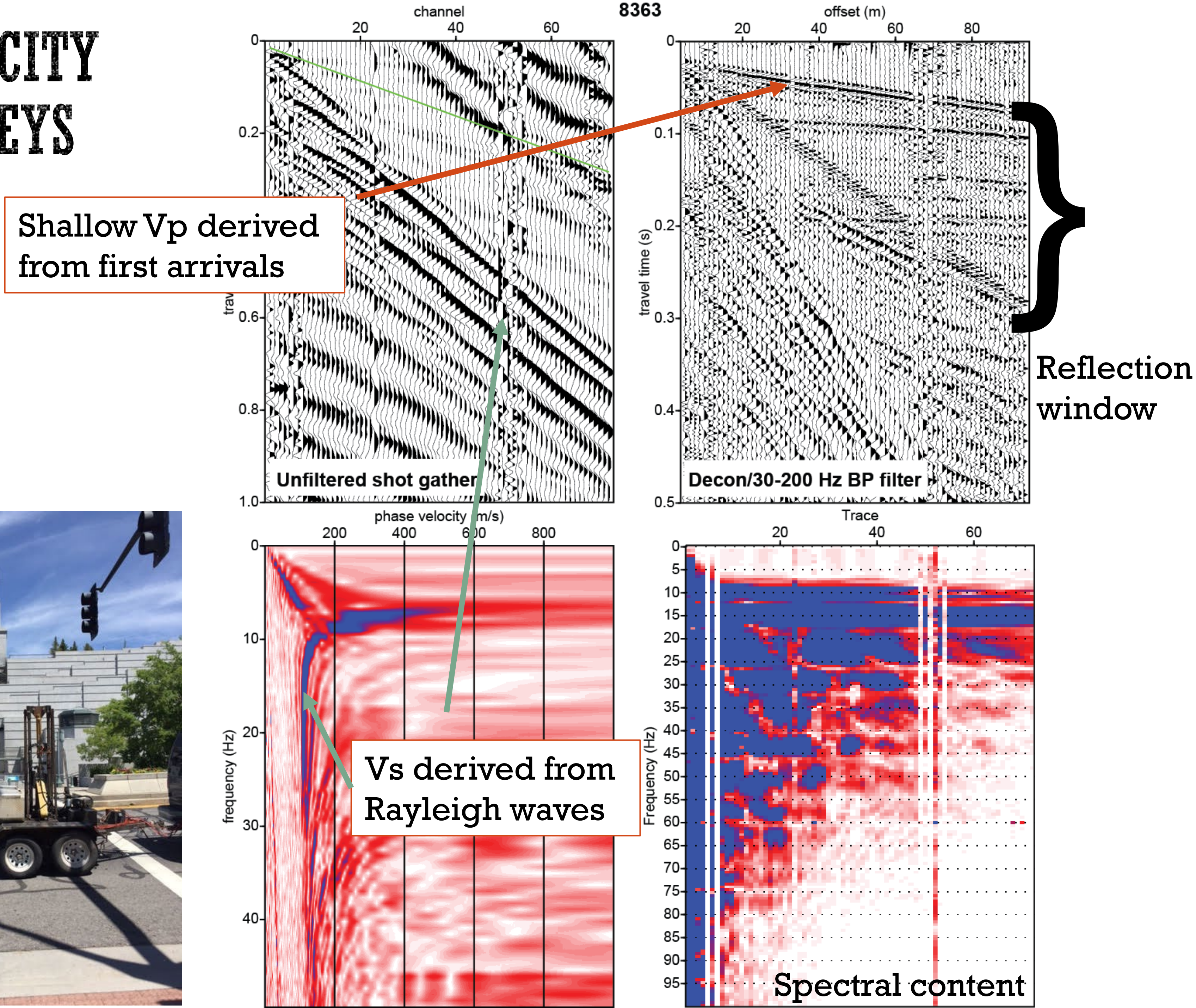
2015/2018 SALT LAKE CITY LAND STREAMER SURVEYS

15,000 shots
34 linear km of data
48 2-C 4 Hz geophones

First arrivals for Vp
(~30 meters)

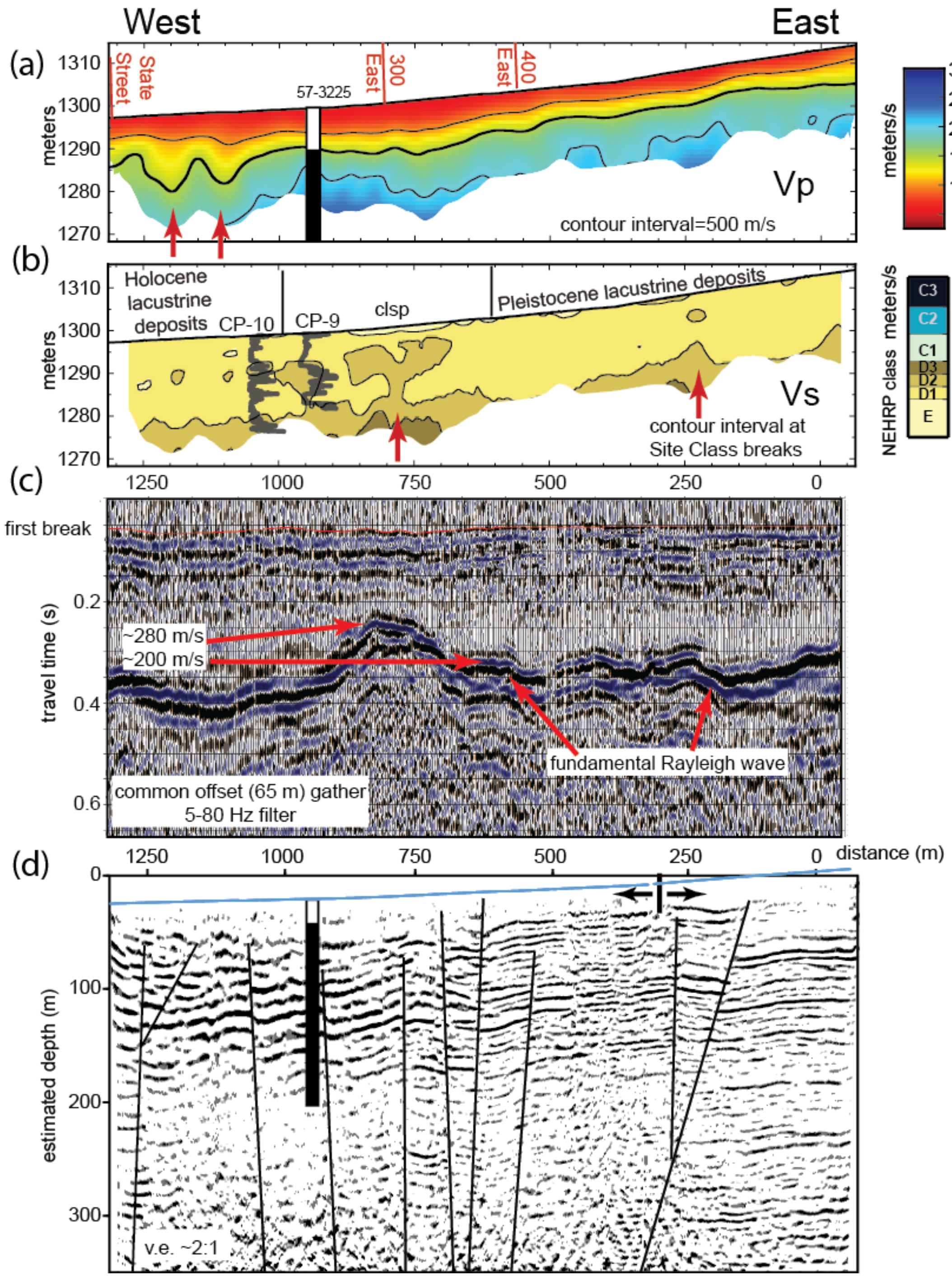
Surface waves for Vs
(~30 meters)

Reflections to obtain structure/stratigraphy
(100's of meters)



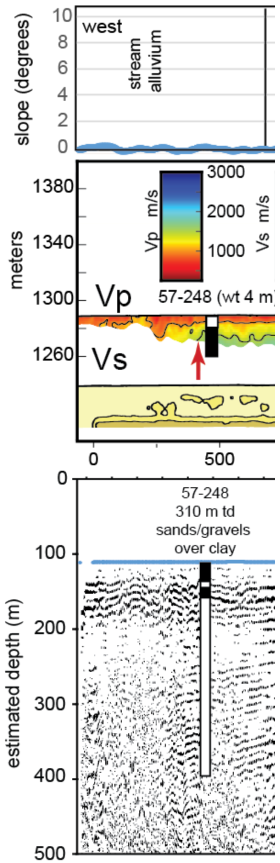
LAND STREAMER DATA – 500 SOUTH

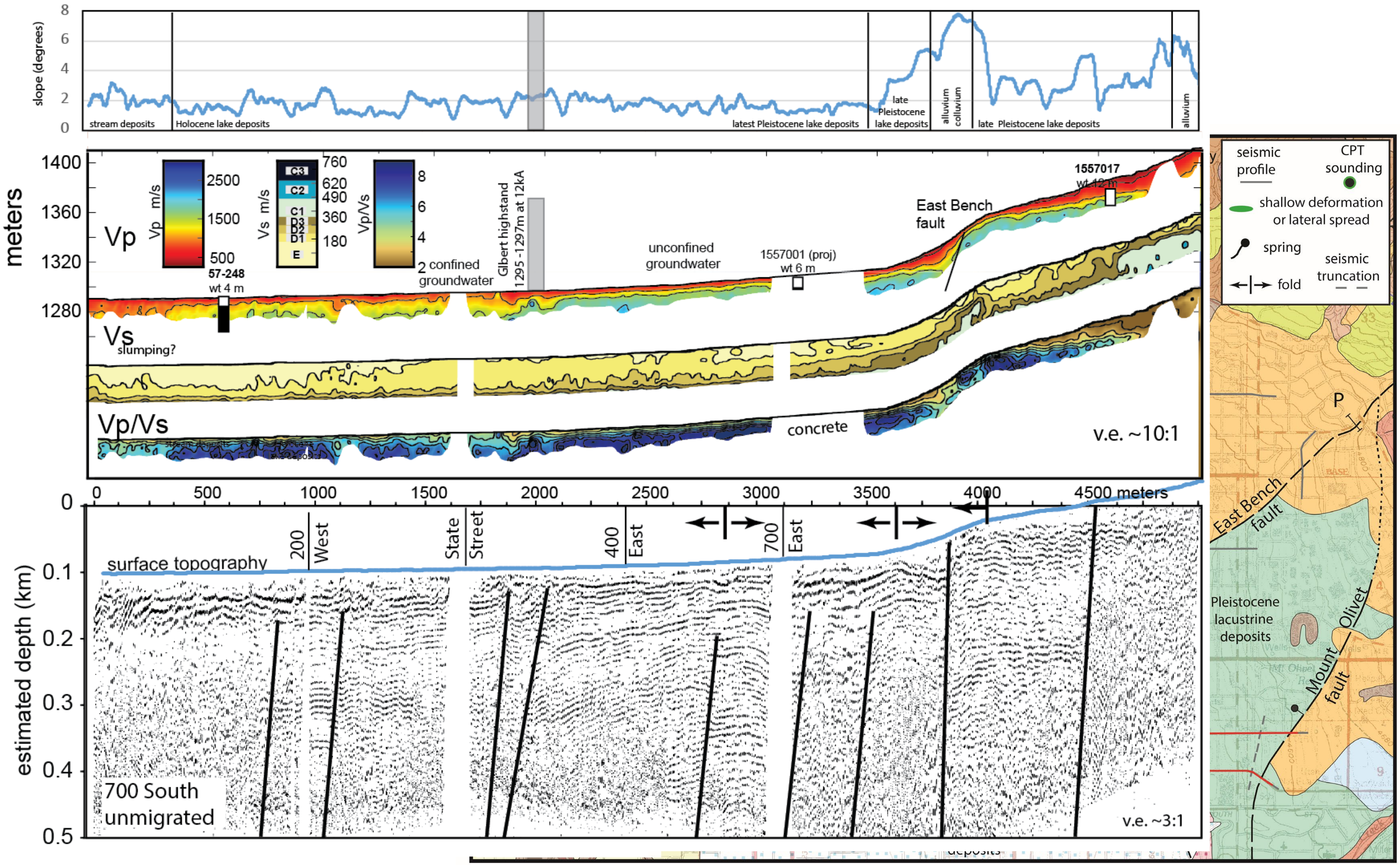
- Water table depths (using Vp=1,500 m/s) follows topography on the eastern portions of the profile.
- Vs30 suggests mostly Class D2 soils beneath downtown with locally stiffer soils (e.g., lateral spread deposits).
- The fast velocity zones are easily observed with common offset gathers and coincide with lateral spread deposits.
- Mostly west-dipping (latest Quaternary) reflectors showing lateral reflector truncations suggesting wide spread faulting.
- Reflection character changes beneath the western portions of the profile.



GEOL

- Higher appear table is



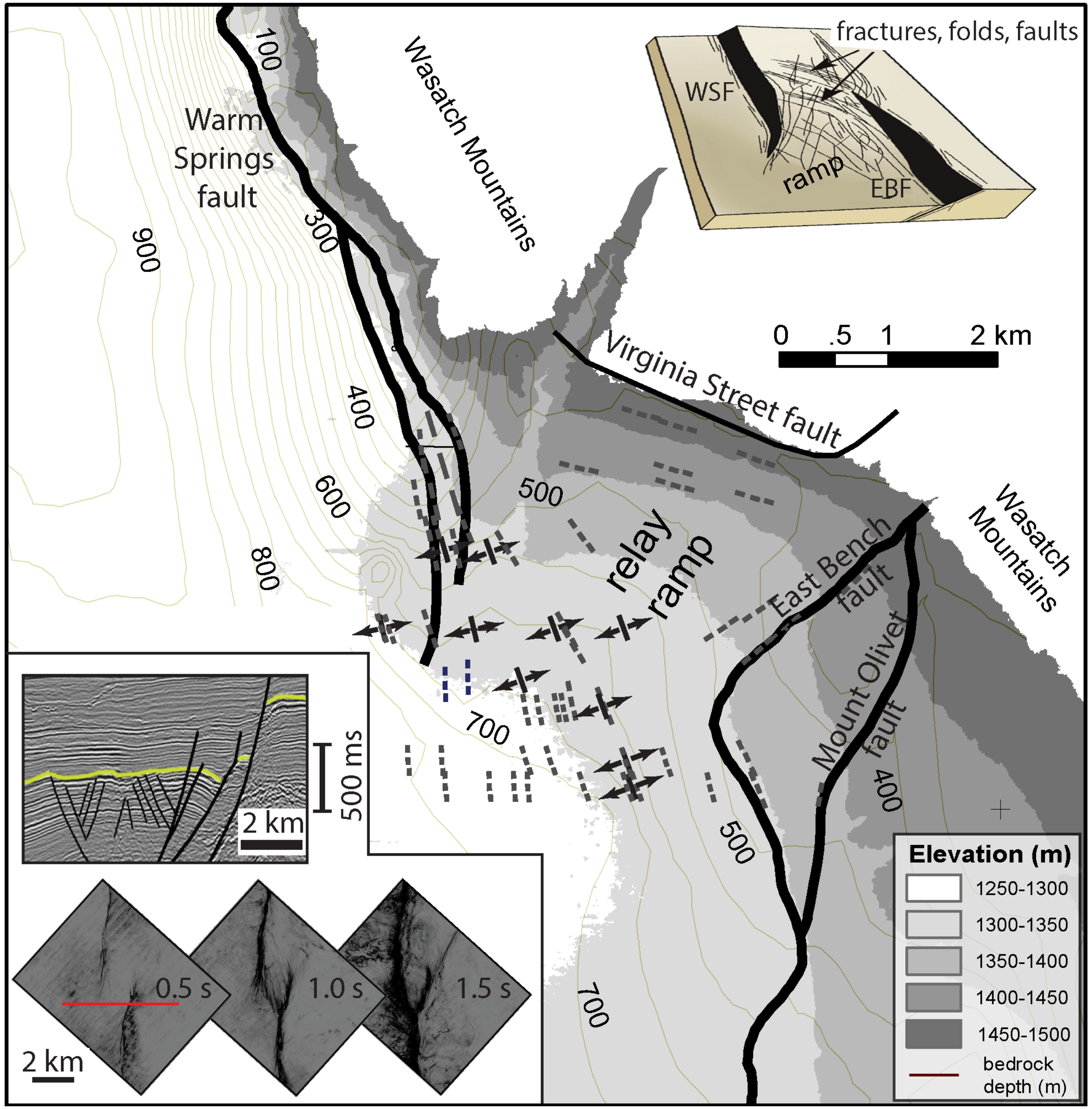


The Seismic Record
A journal of the Seismological Society of America

A Broad, Distributed Active Fault Zone Lies beneath Salt Lake City, Utah

Lee M. Liberty[*1], James St. Clair[2], and Adam P. McKean[3]

- Broad distributed zone of faults that offset the shallowest strata that we imaged
- Relay ramp structure connects the Warm Springs and East Bench fault segments



Liberty et al (2021)

The portable hand streamer — Rapid seismic imaging for shallow targets

Lee M. Liberty[1] and L. Thomas Otheim[1]

https://doi.org/10.1190/tle4302095.1

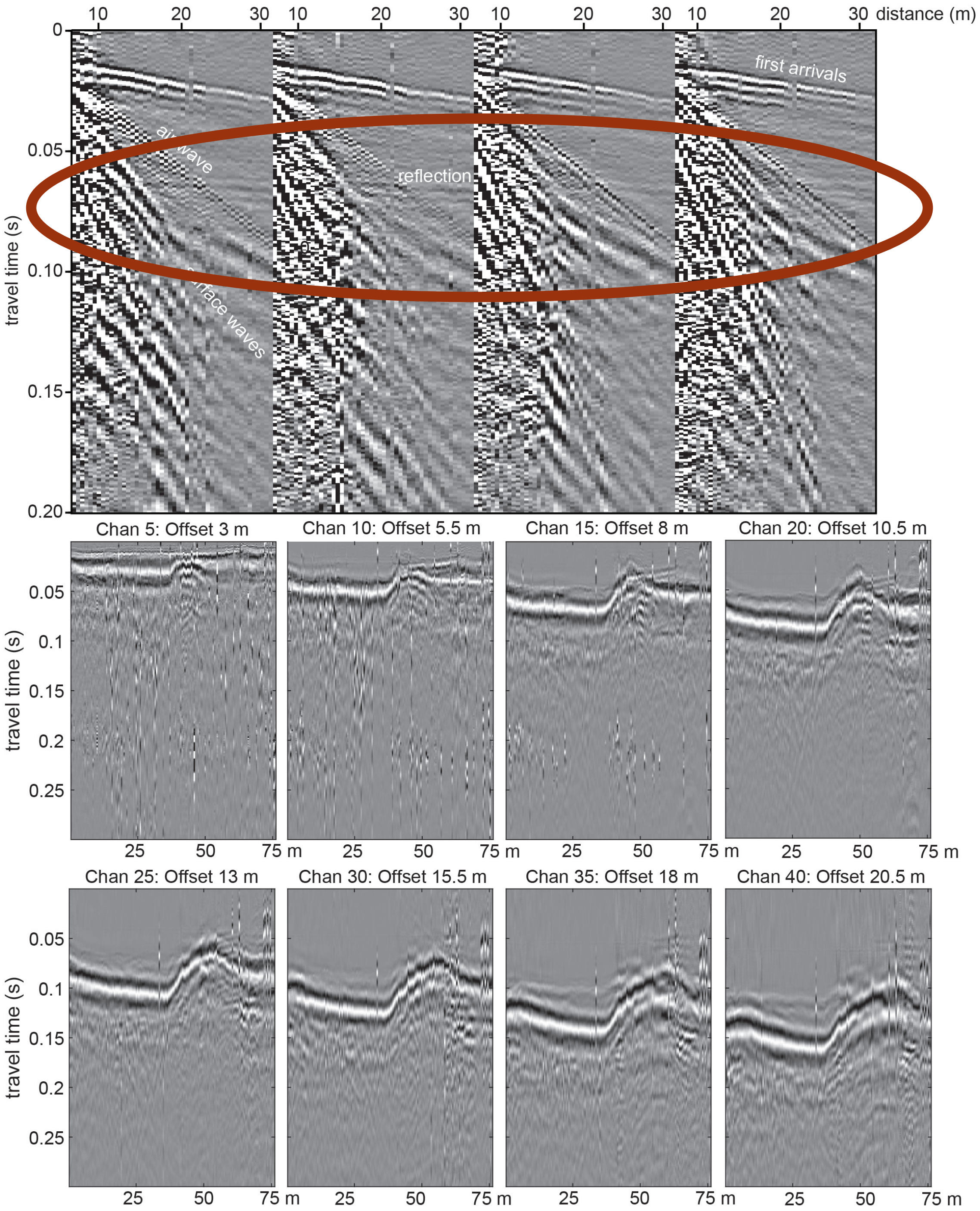
- Shallow imaging tool for the upper 10's of meters
- Single person portable seismic system
- 48 40-Hz vertical geophones spaced 0.5 m
- Electric hammer source
- Extract reflection, first arrival (Vp) and surface wave (Vs) signals
- Used to characterize "active" processes or engineered structure

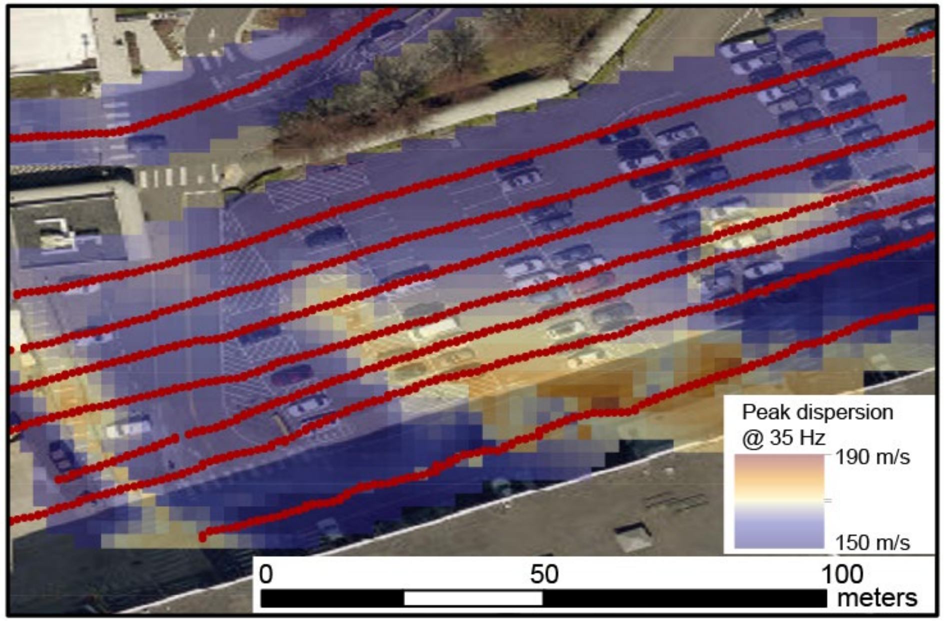
The Leading Edge, Feb 2024 "The Future of Applied Geophysics"

SHOT GATHERS

- First arrivals show shallow p-wave velocities (~upper 5 m)
- Surface waves show shallow s-wave velocities (~upper 5 m)
- Reflectivity to ~100 m depth

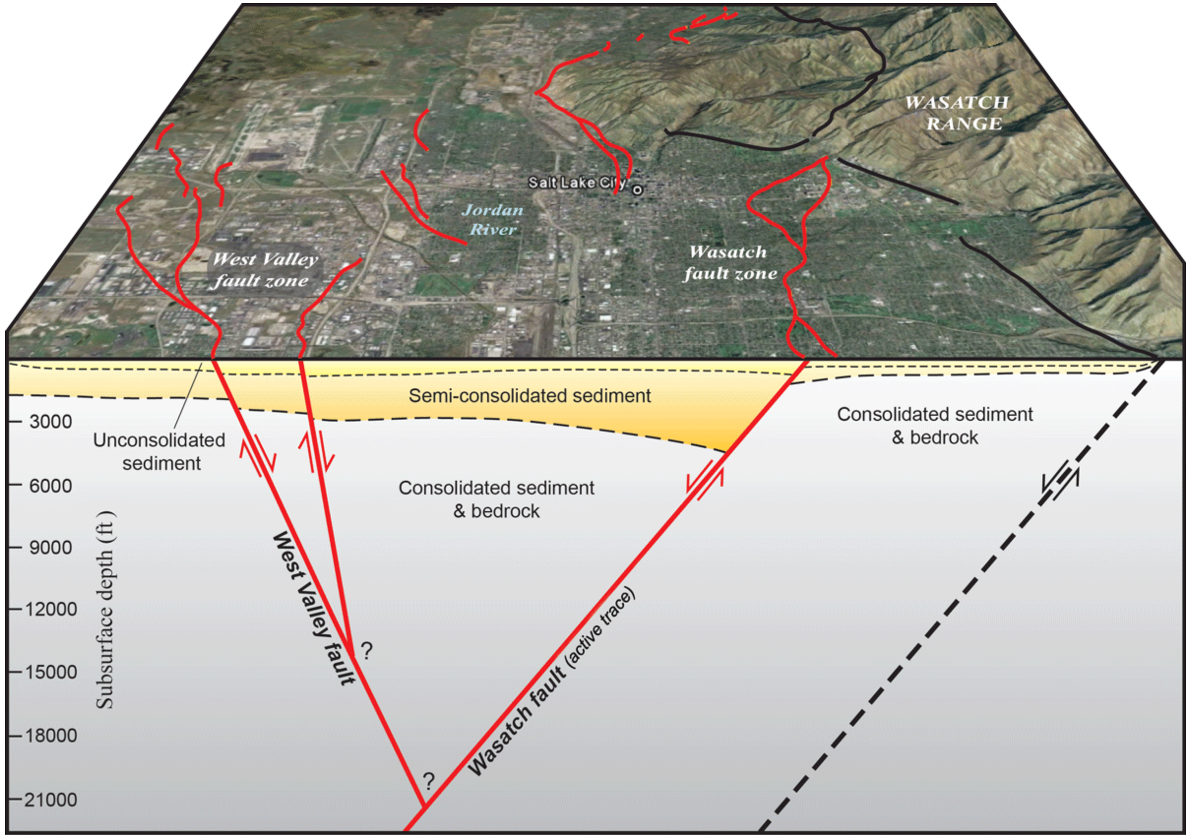
Reflection
@ 50 m depth

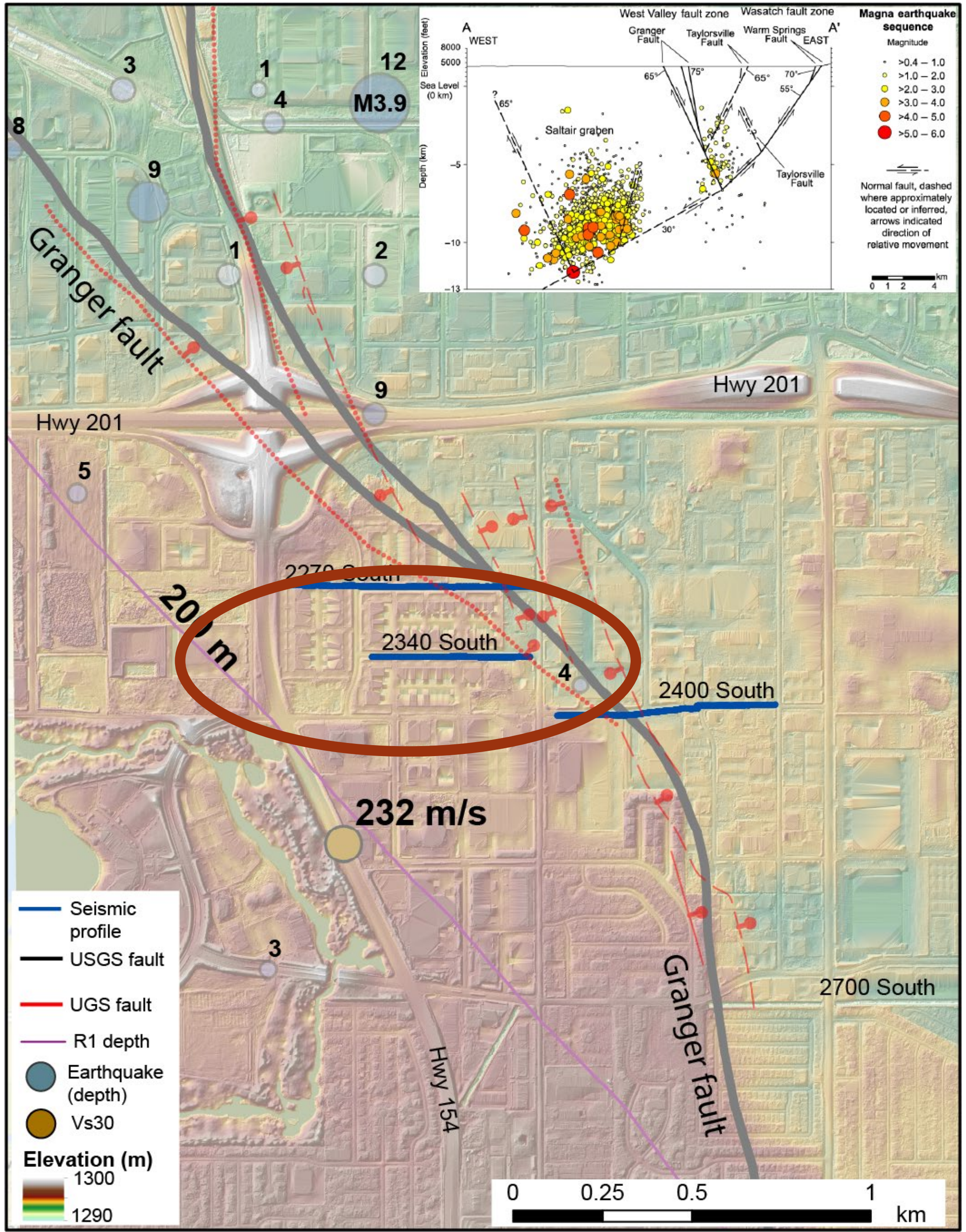




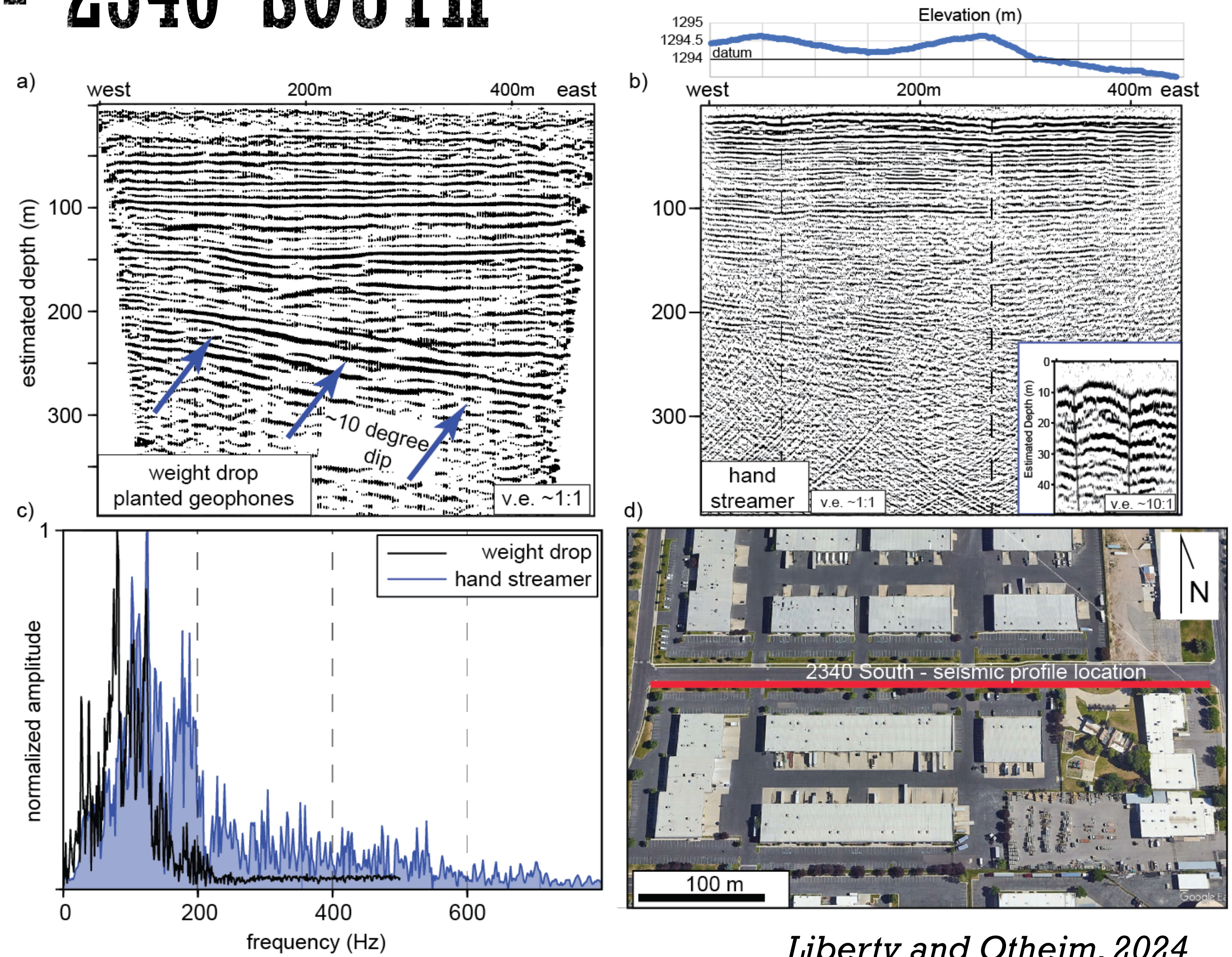
WEST VALLEY INTRABASIN FAULTS

- Granger fault
- Taylorsville fault





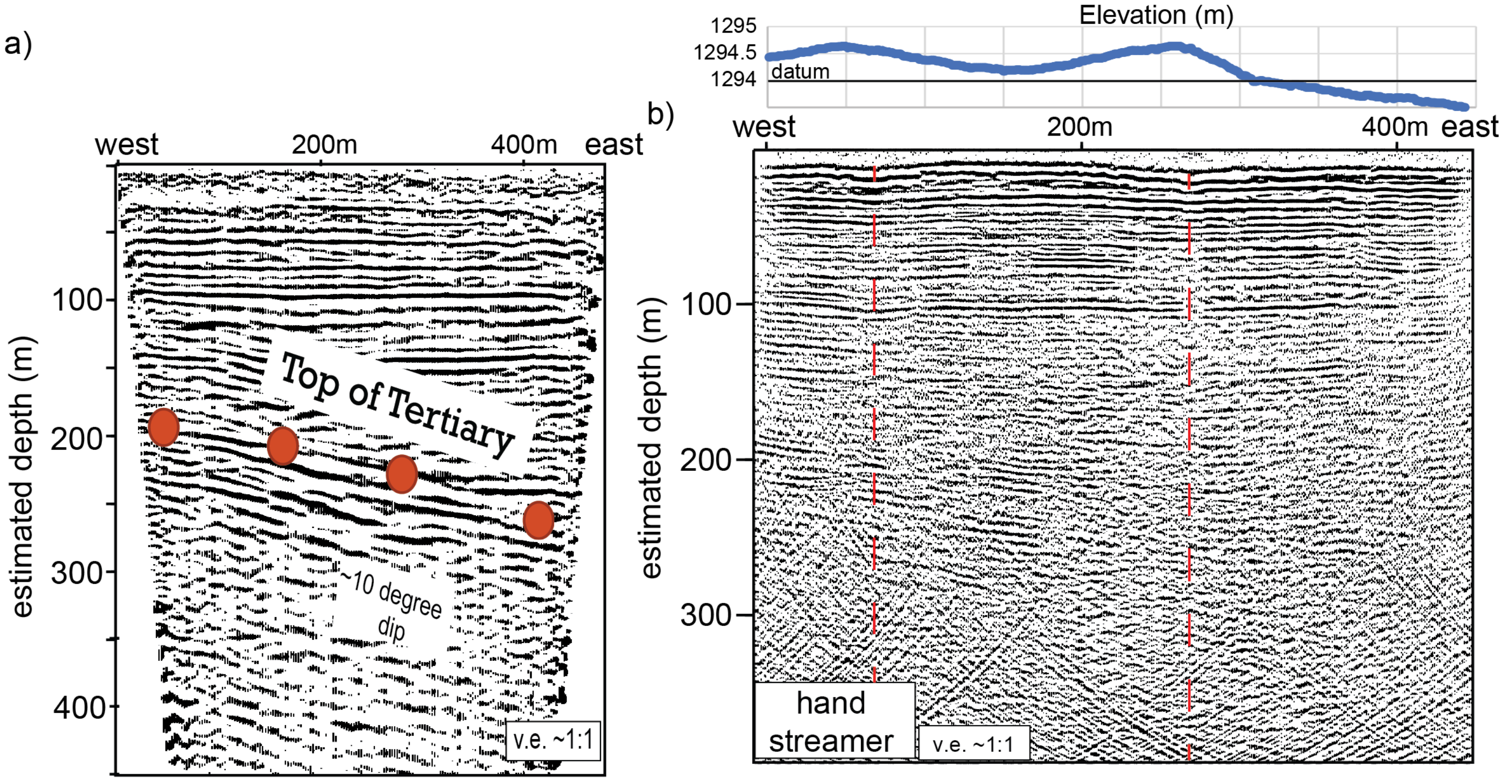
GRANGER FAULT - 2340 SOUTH

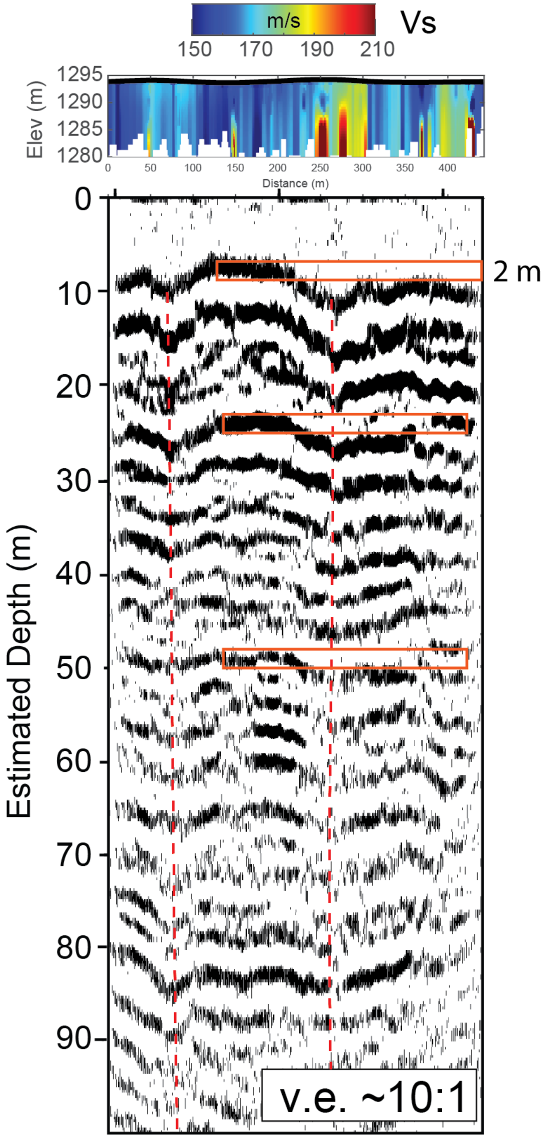


Liberty and Otheim, 2024

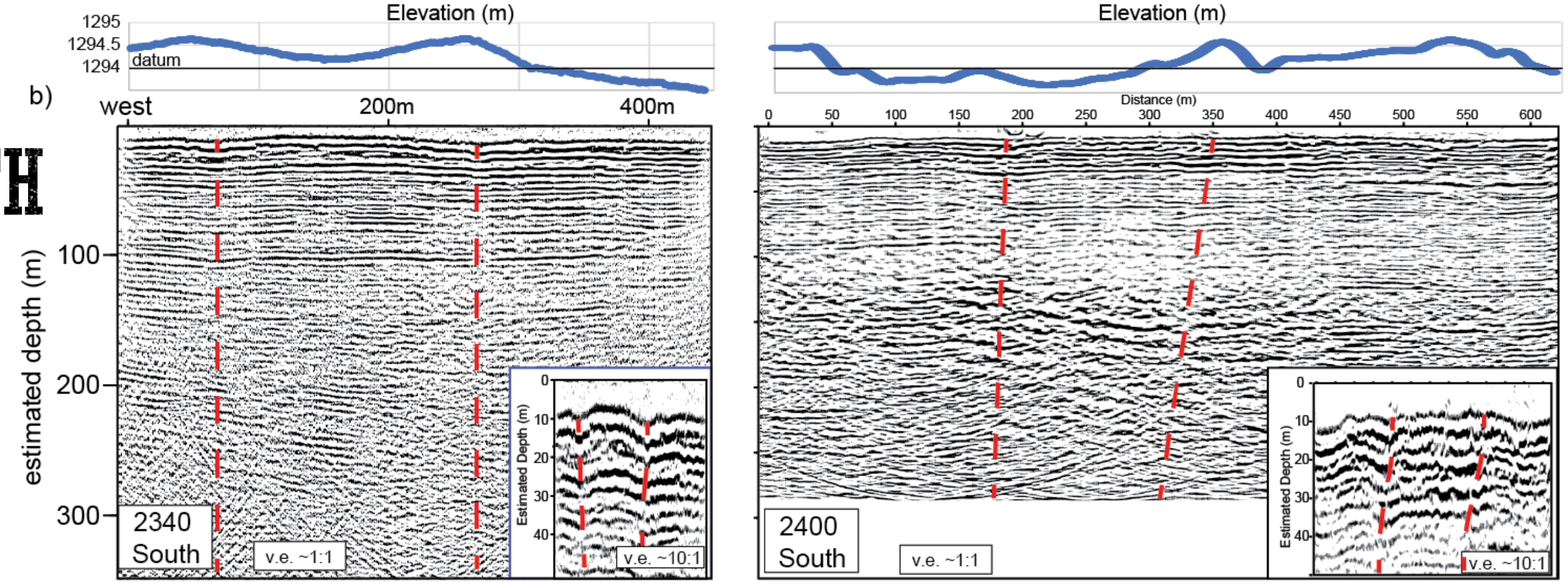
GRANGER FAULT - 2340 SOUTH

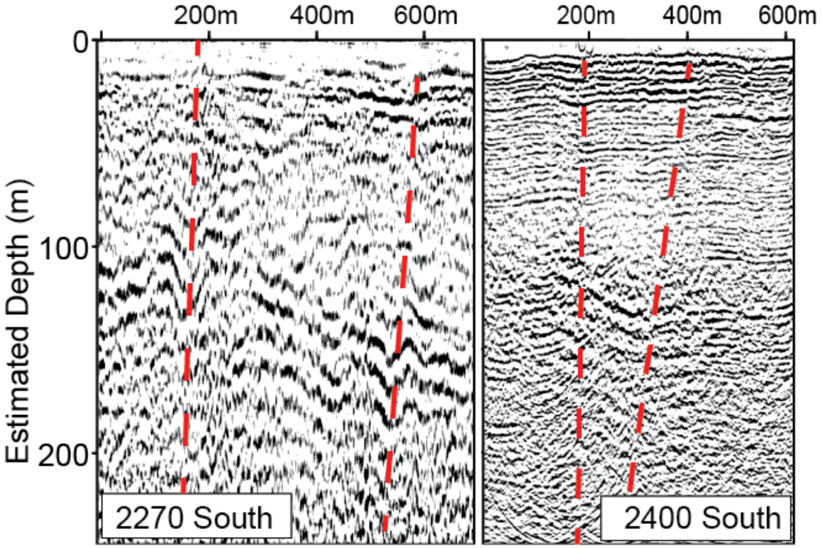
- ~10 degree east-dipping top of Tertiary
- Folded strata suggest shortening
- Little evidence for long-term displacements
- 2 m offset of 20 ka?? strata would suggest 0.1 mm/year slip rate

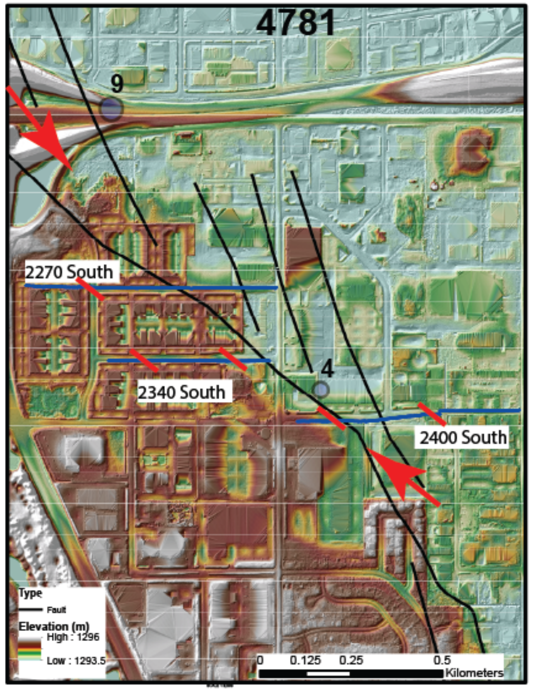




GRANGER FAULT – 2400 & 2270 SOUTH



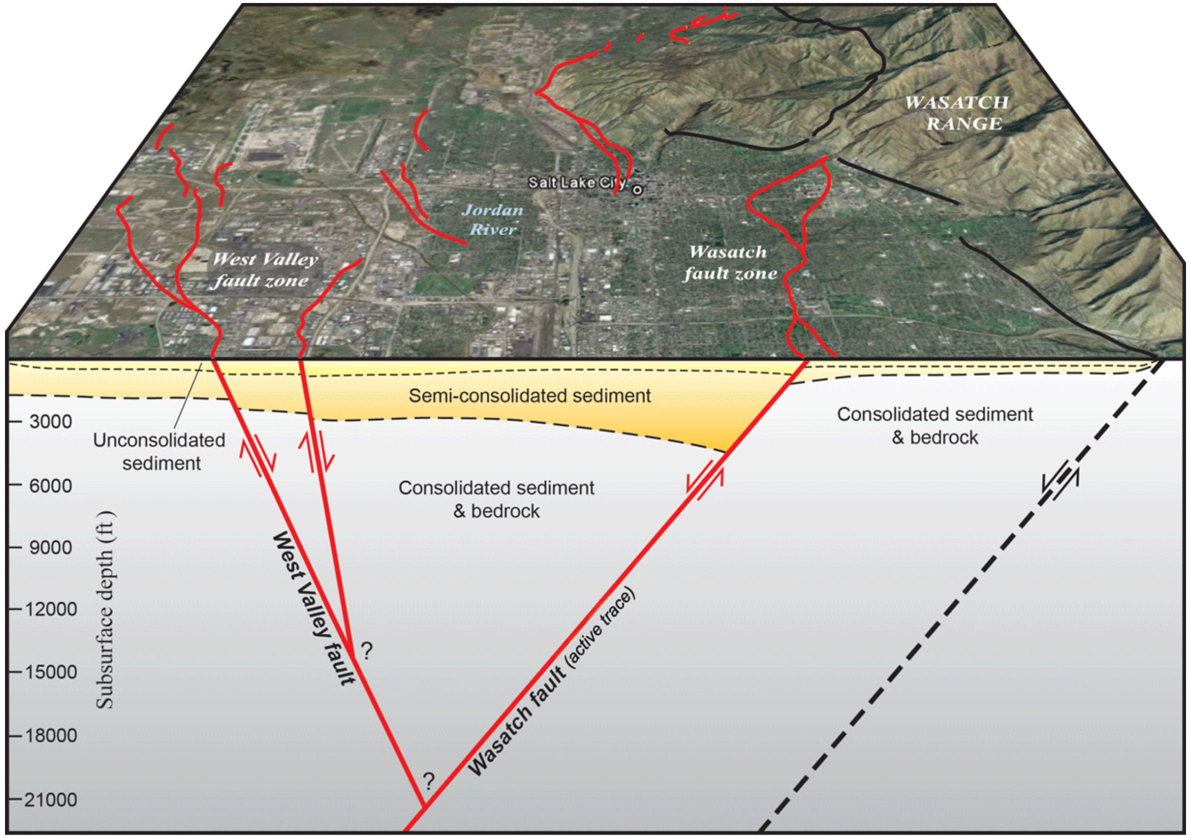


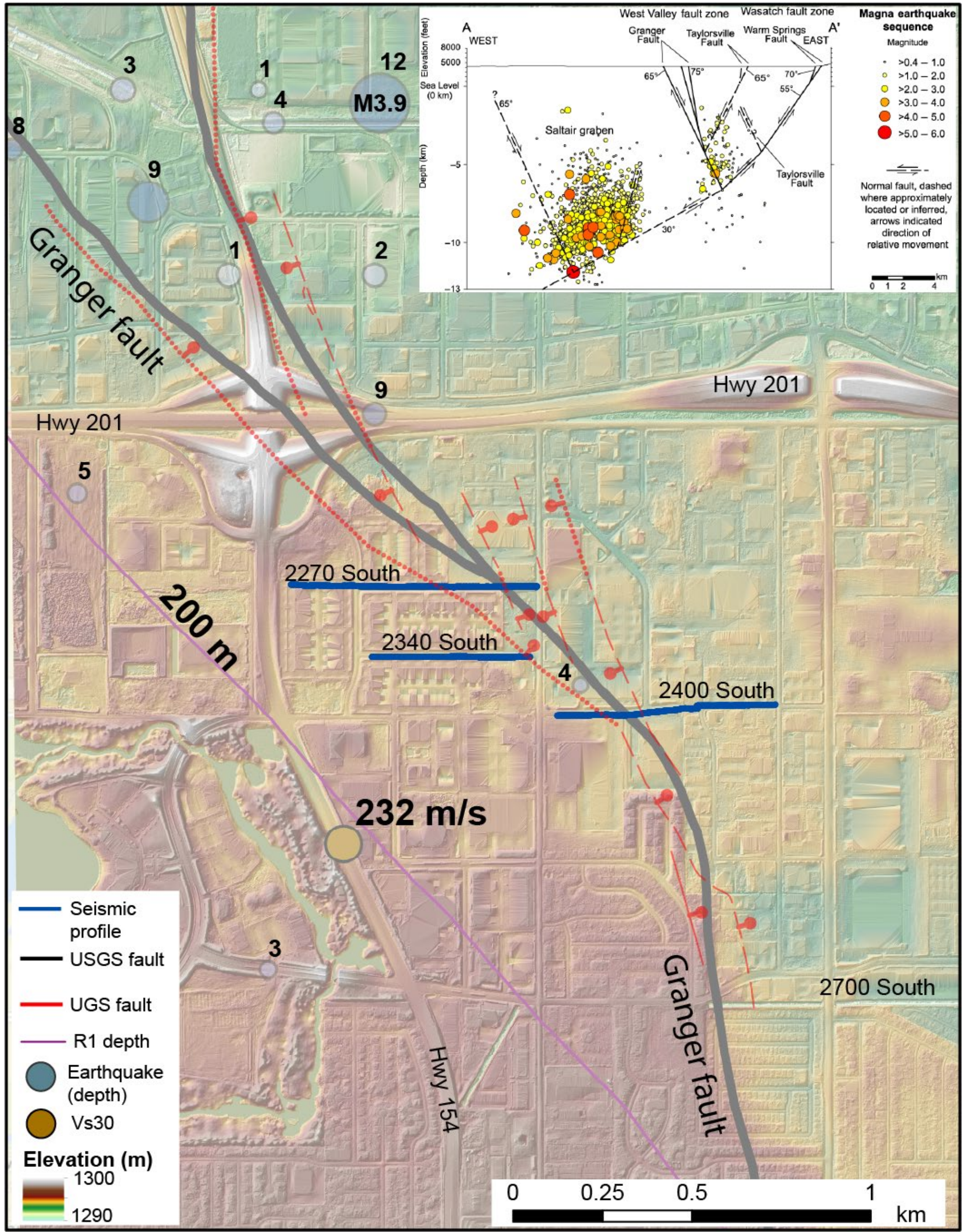


- Similar shallow deformation compared to 2340 South
- Top of Tertiary shows evidence for a ~100 m wide kink-band
- Granger fault shows evidence for compression

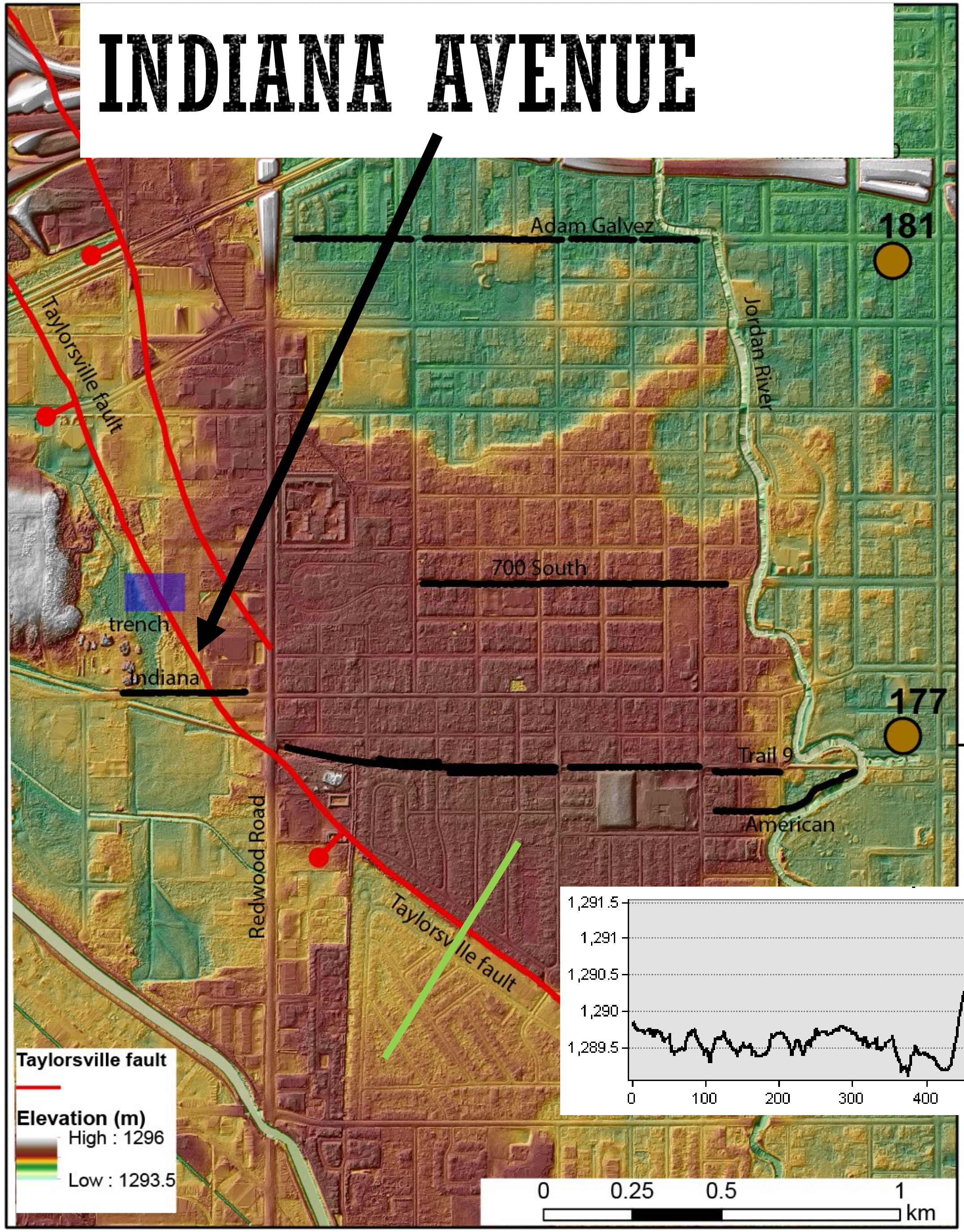
WEST VALLEY INTRABASIN FAULTS

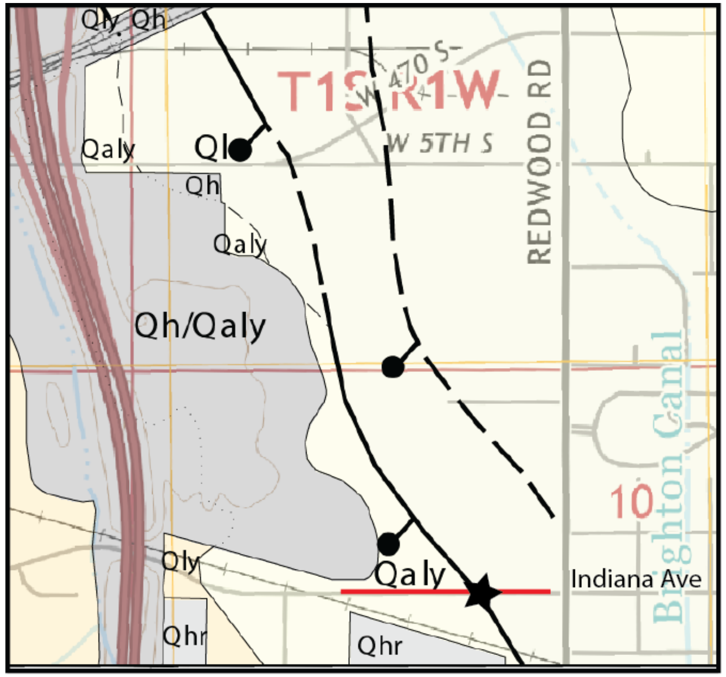
- Granger fault – distributed fault zone that (locally) accommodates shortening
- Taylorsville fault

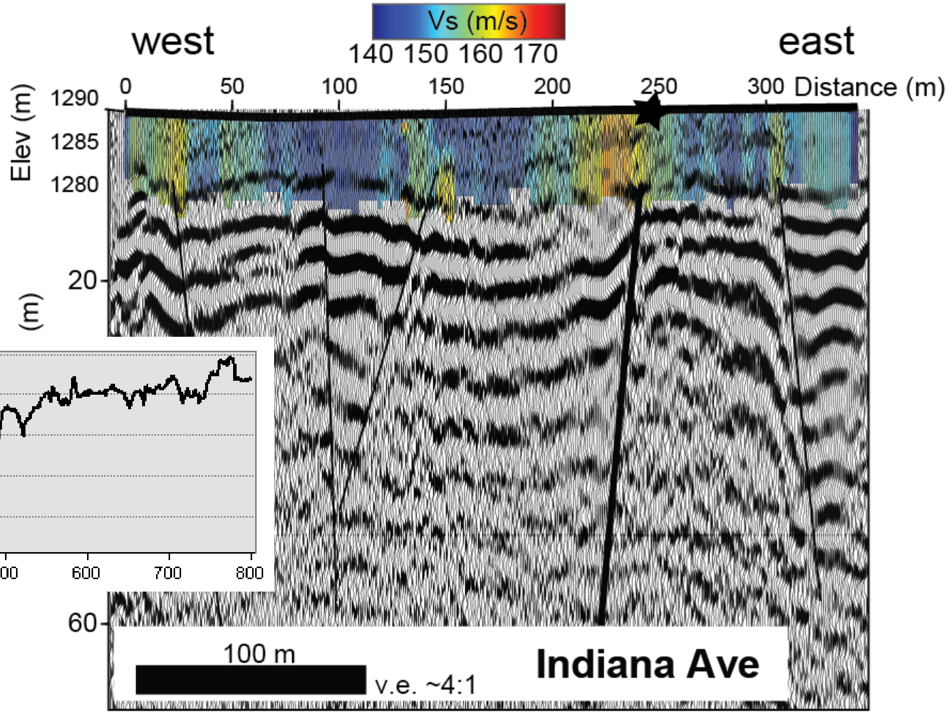


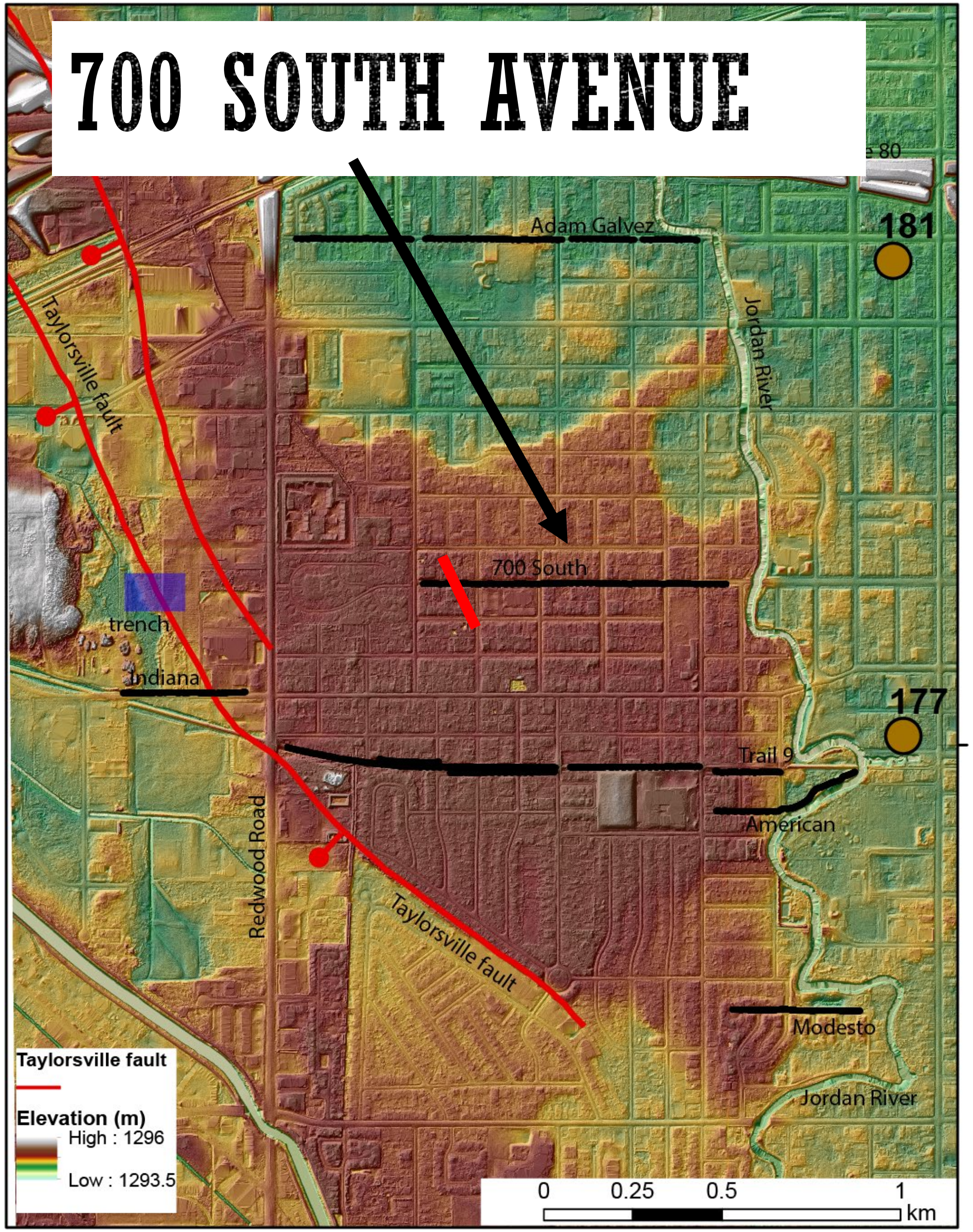


- Profile acquired 200 m south of trench
- Broad (hundreds of meters wide) deformation zone
- ~10 m down-to-the-west displacement at 10 m depth
- Taylorsville fault accommodates intra-basin shortening

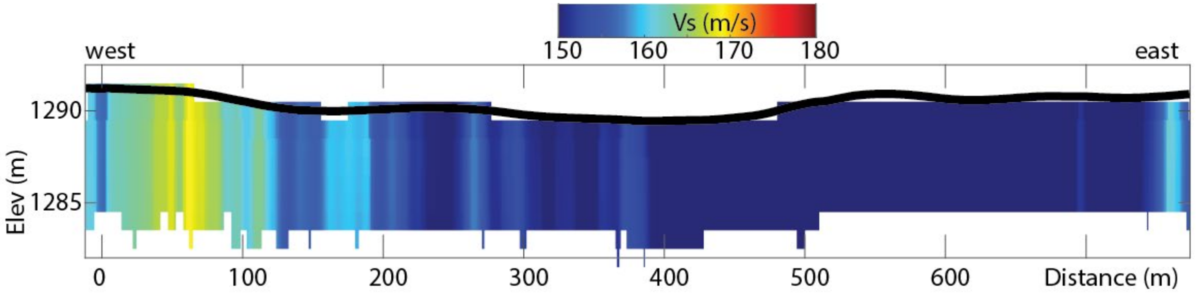


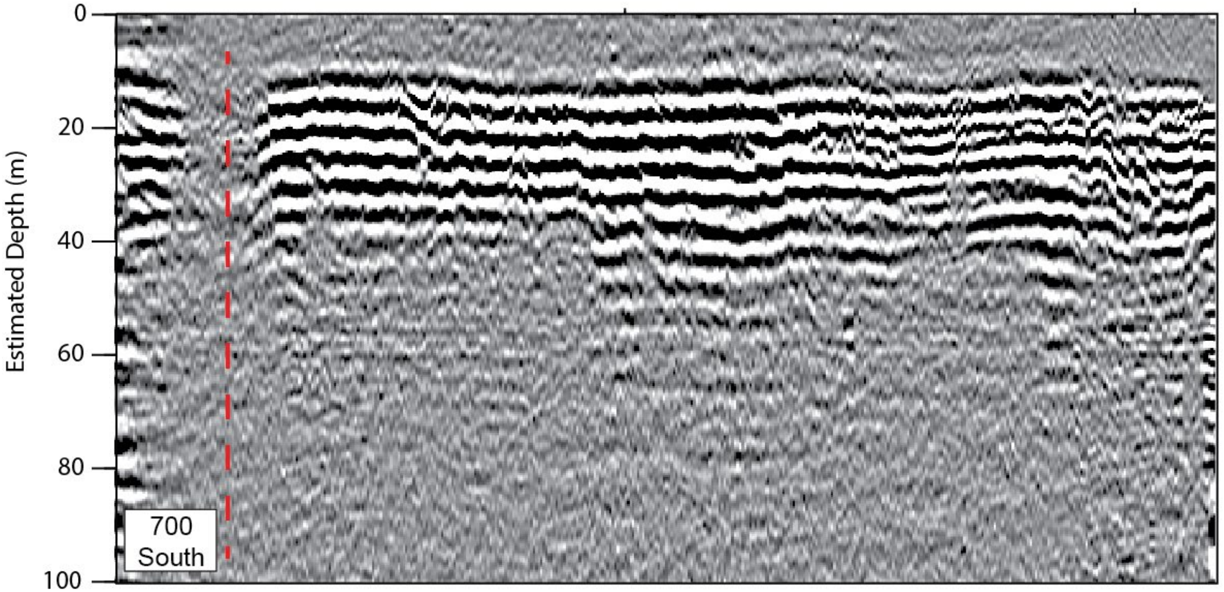


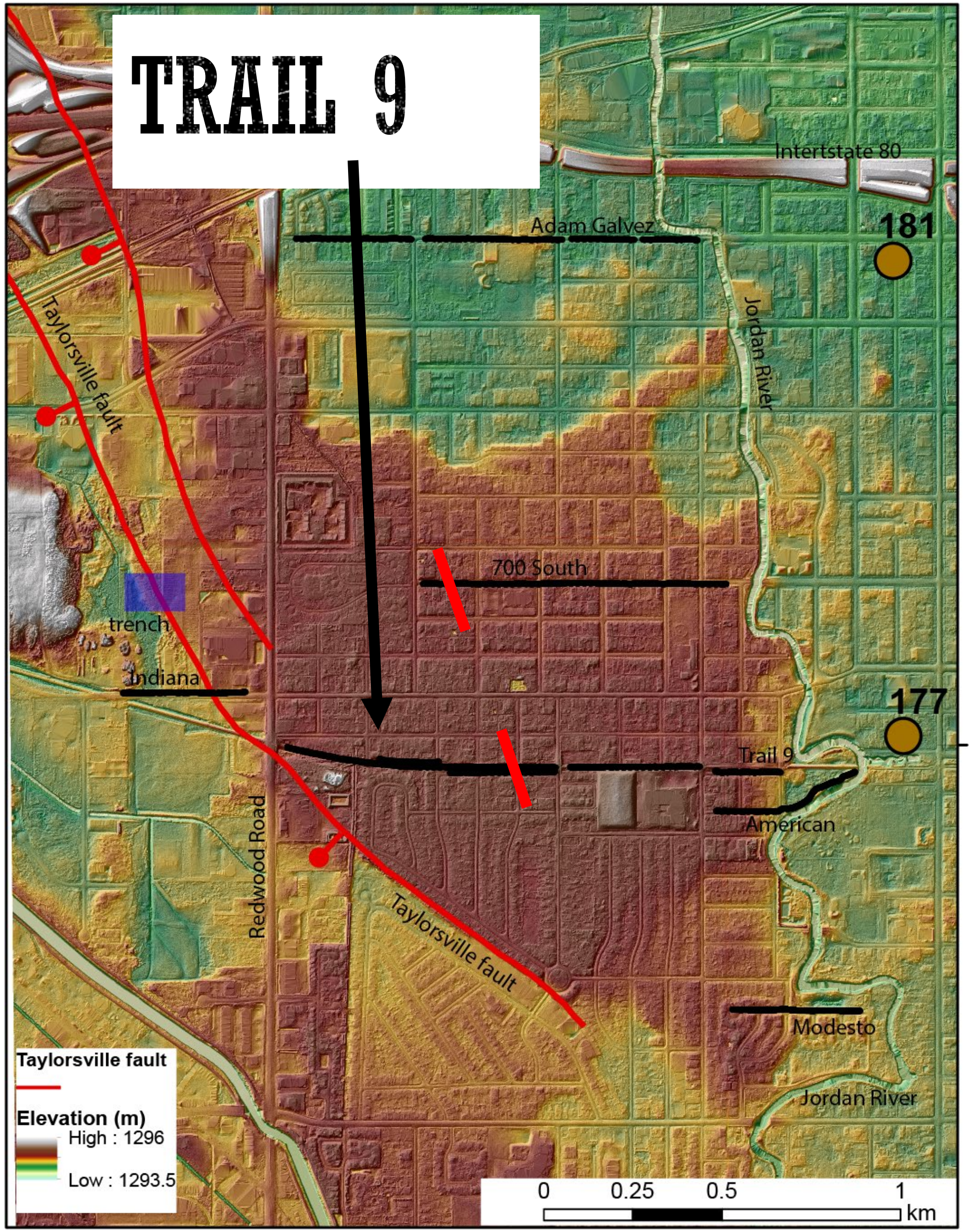




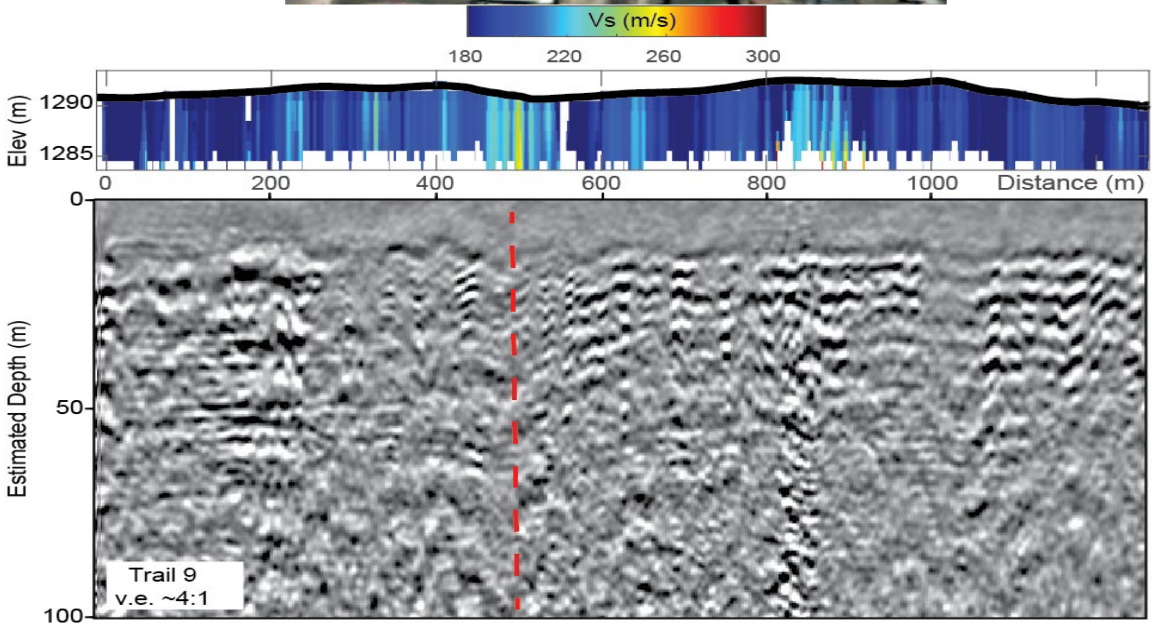
- Mostly flat-lying reflectors and uniform Vs
- Possible fault near west end of profile



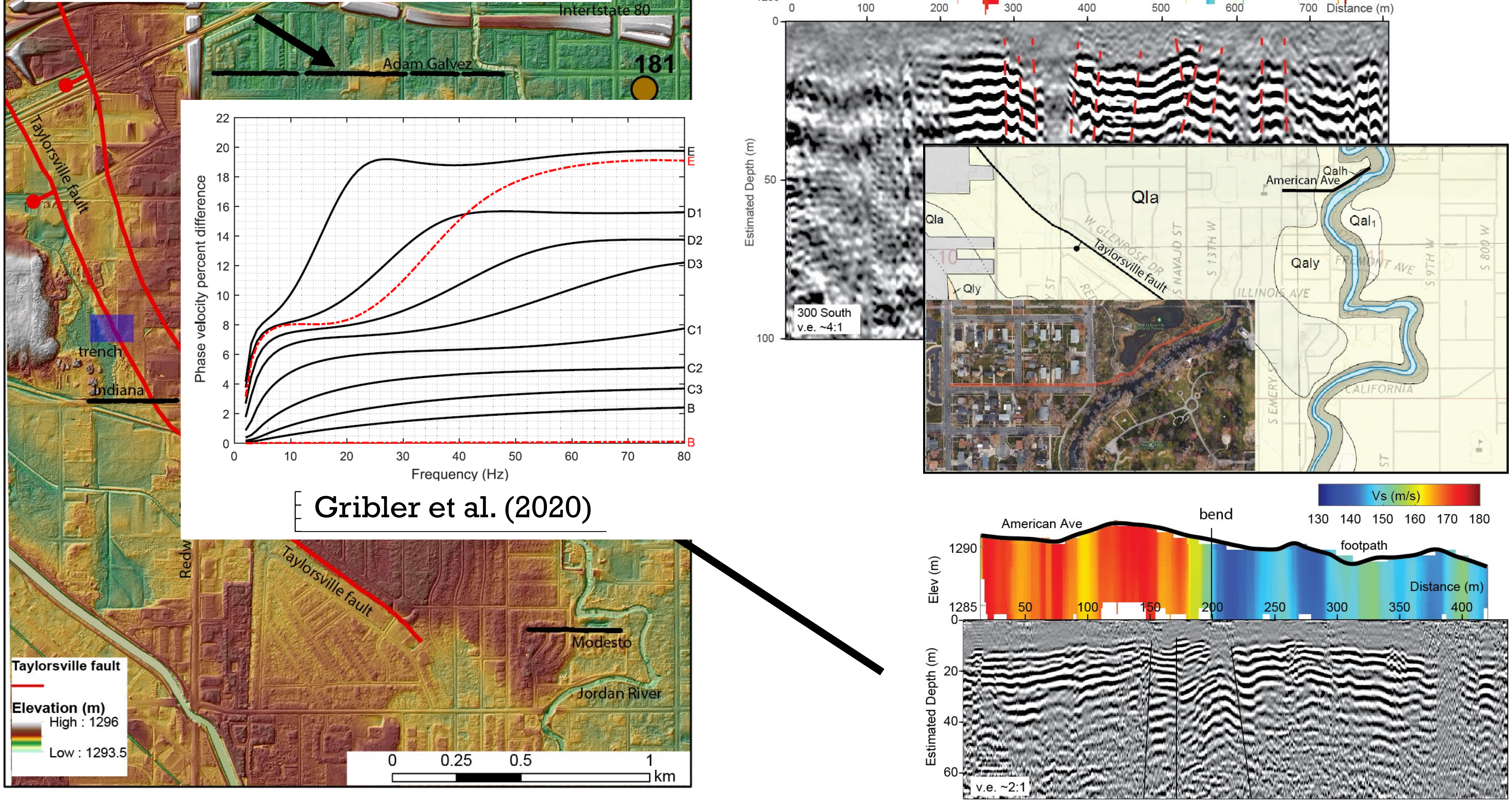




- Mostly flat-lying reflectors and uniform Vs
- Possible fault near center of profile

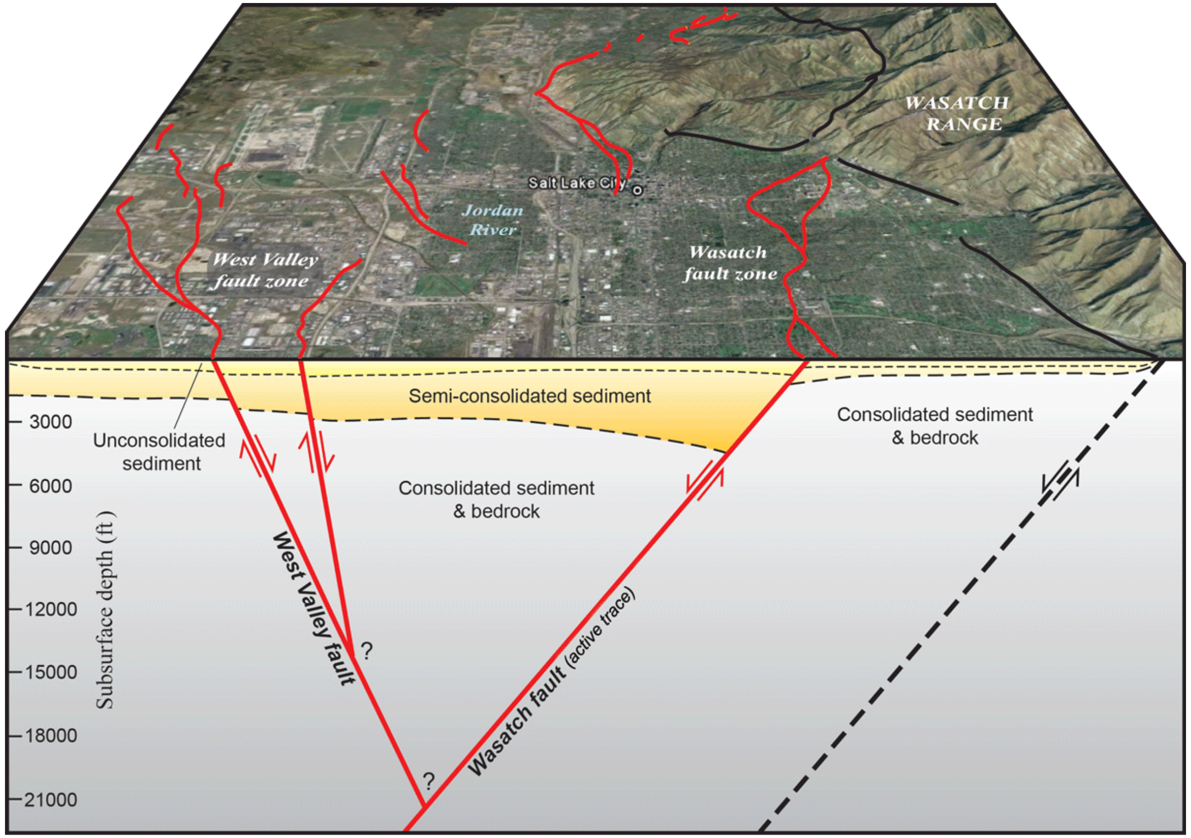


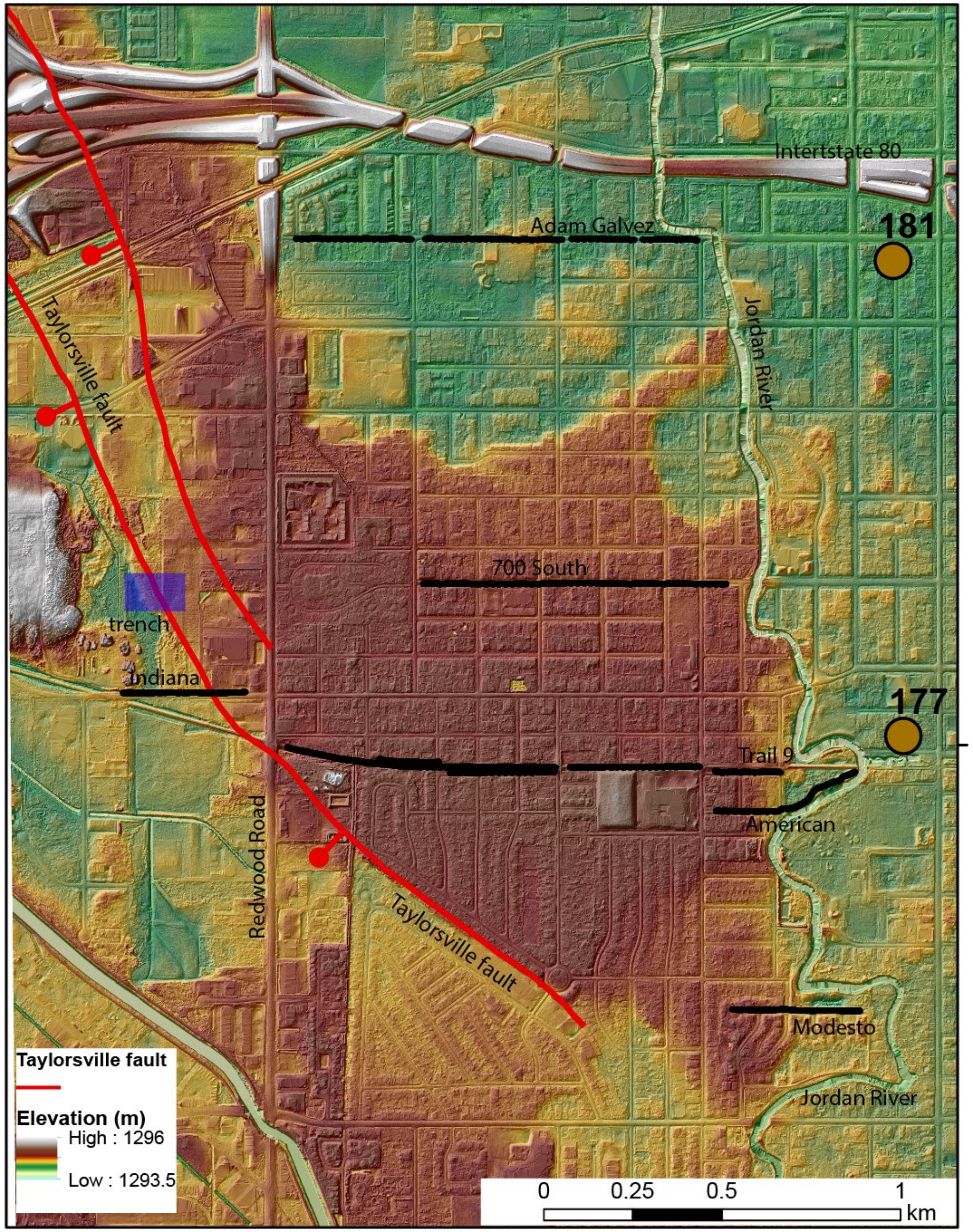
300 SOUTH (ADAM GALVEZ)



WEST VALLEY FAULTS

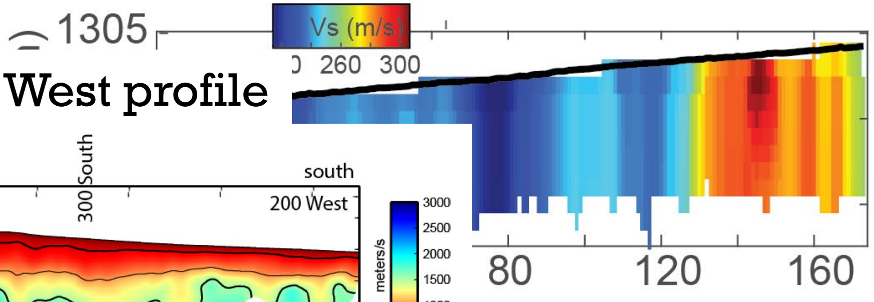
- Distributed fault zone similar to what was observed beneath downtown SLC area from previous seismic imaging

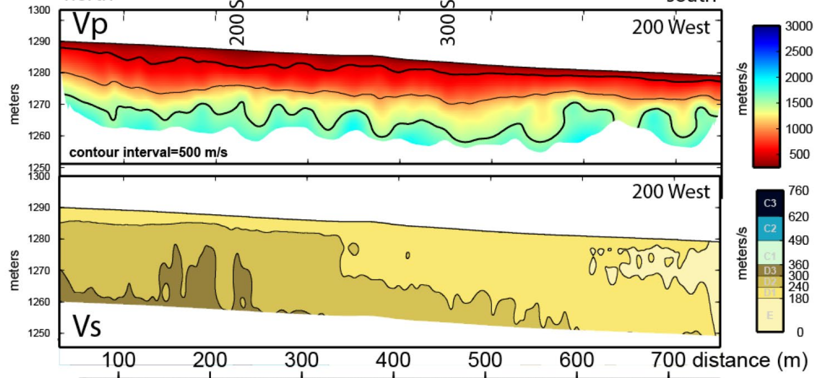


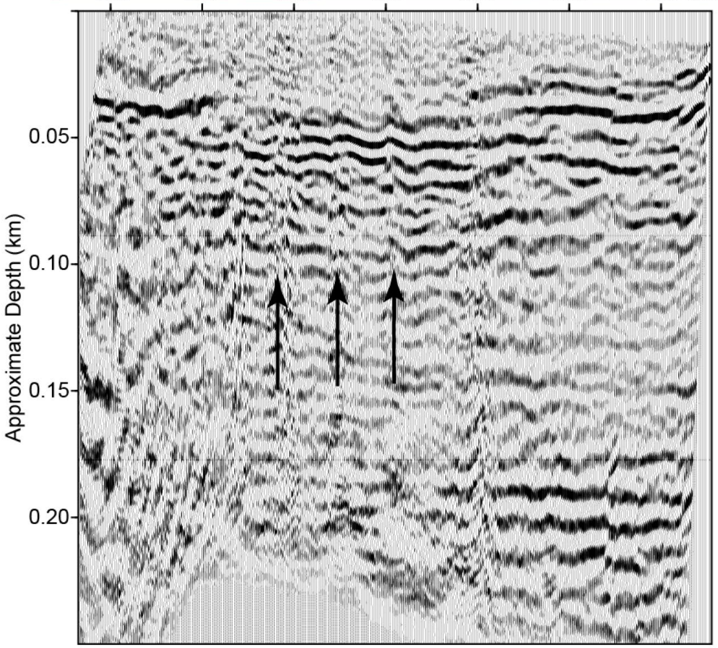


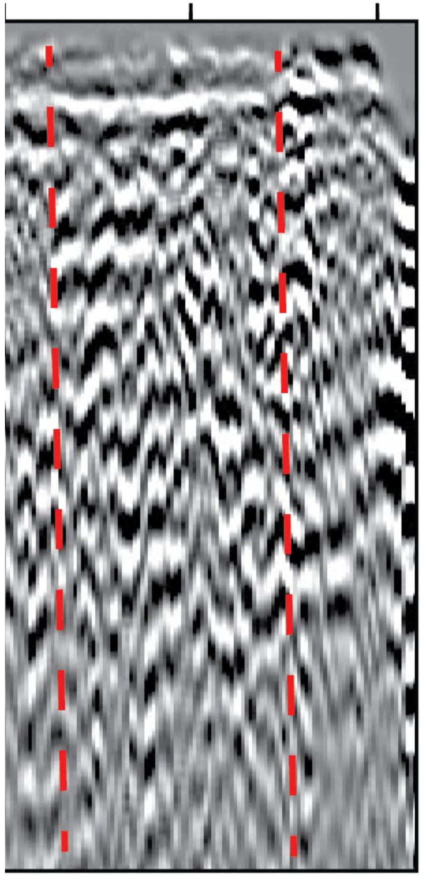
DOWNTOWN SEISMIC

200 West profile









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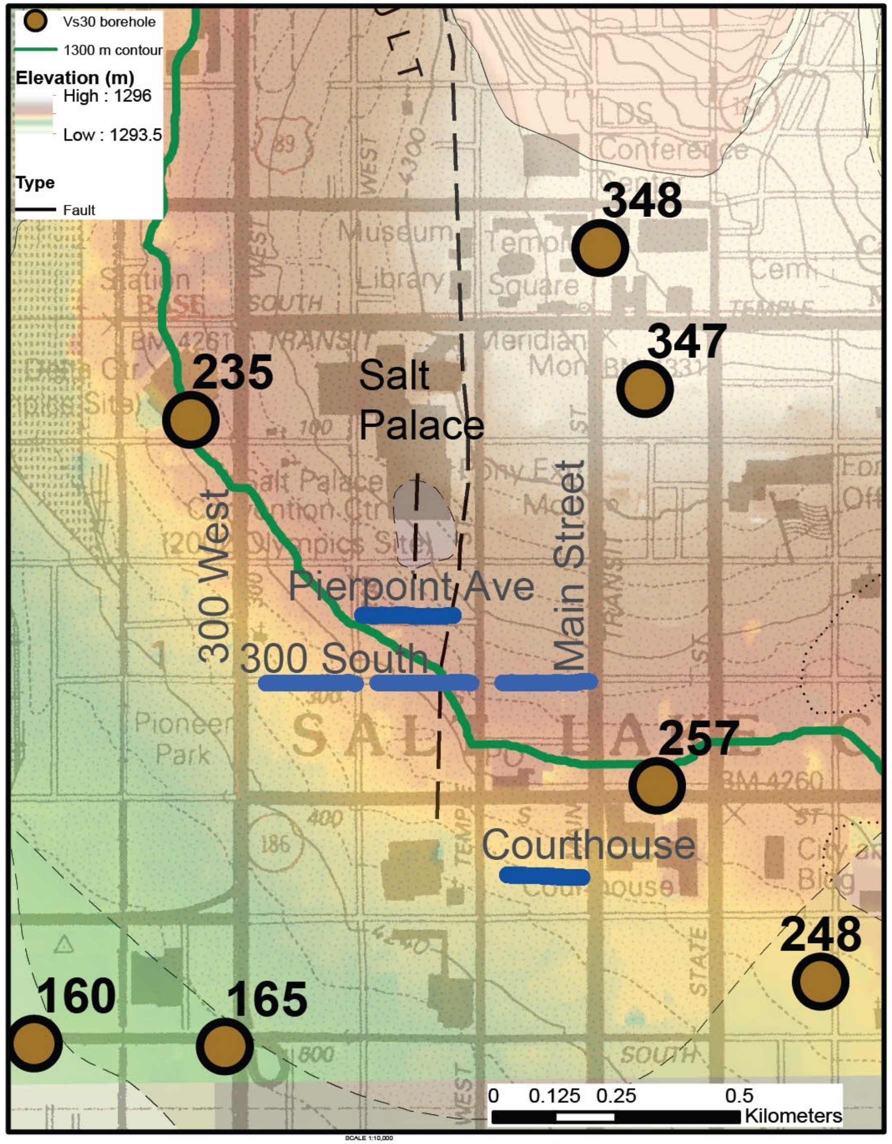
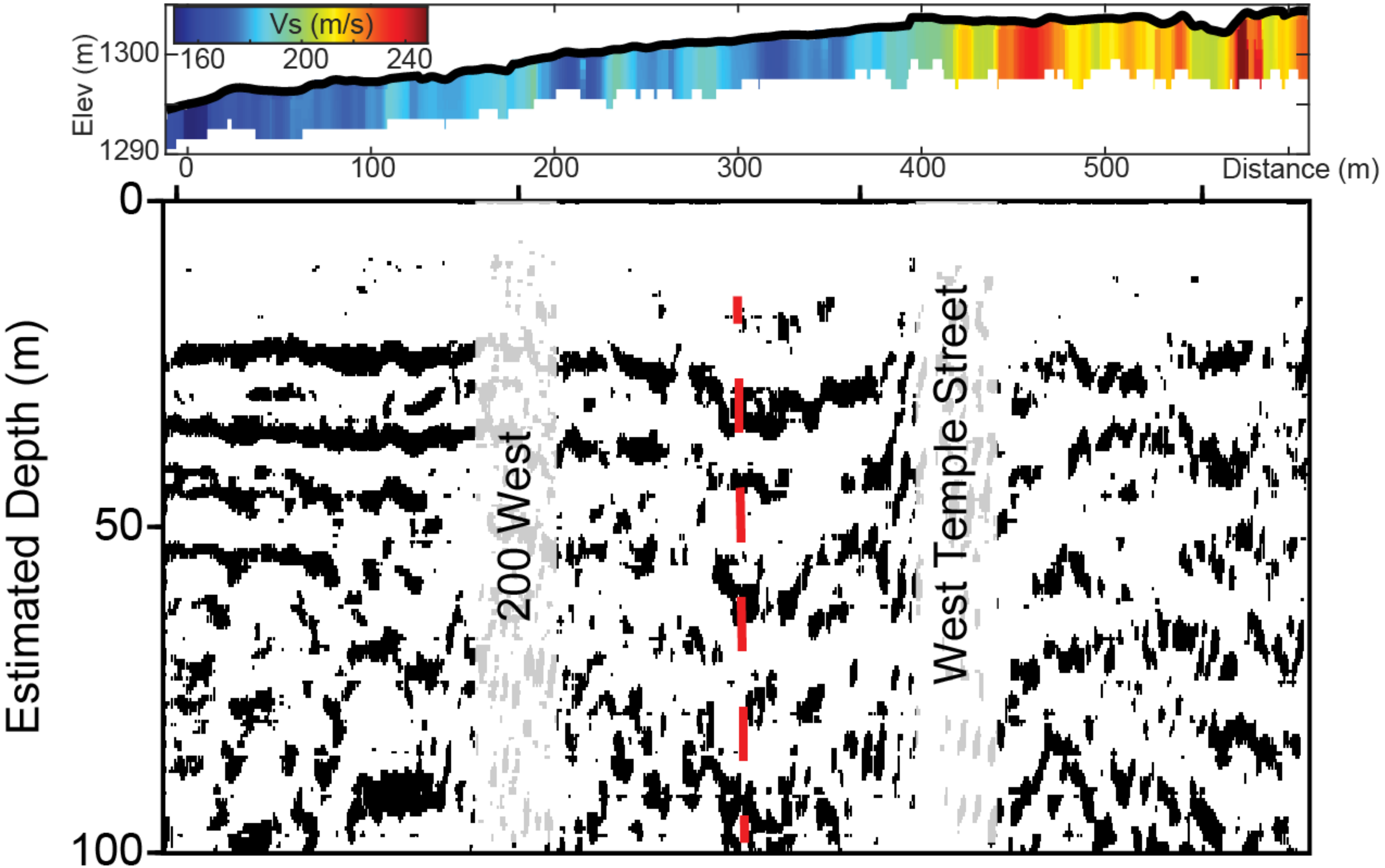
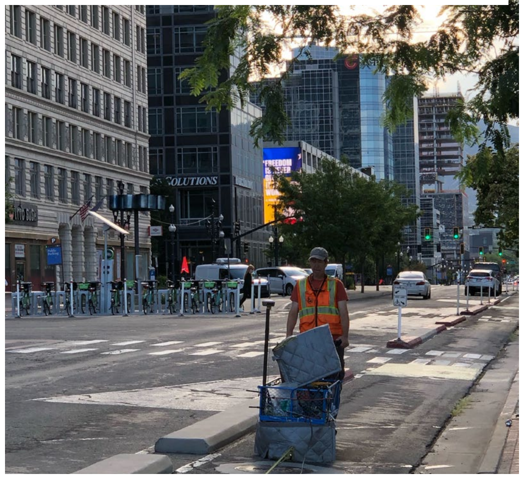
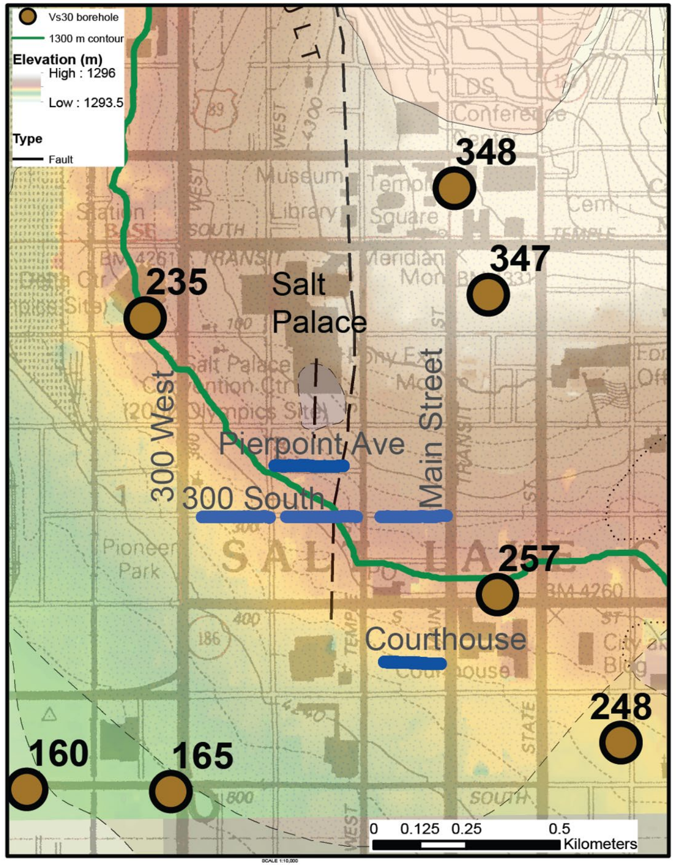


DOWNTOWN SEISMIC



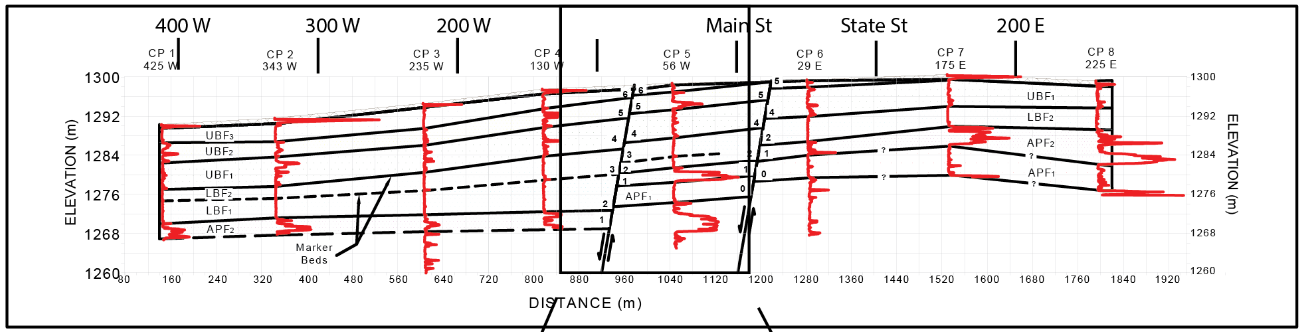
300 South (bike path)

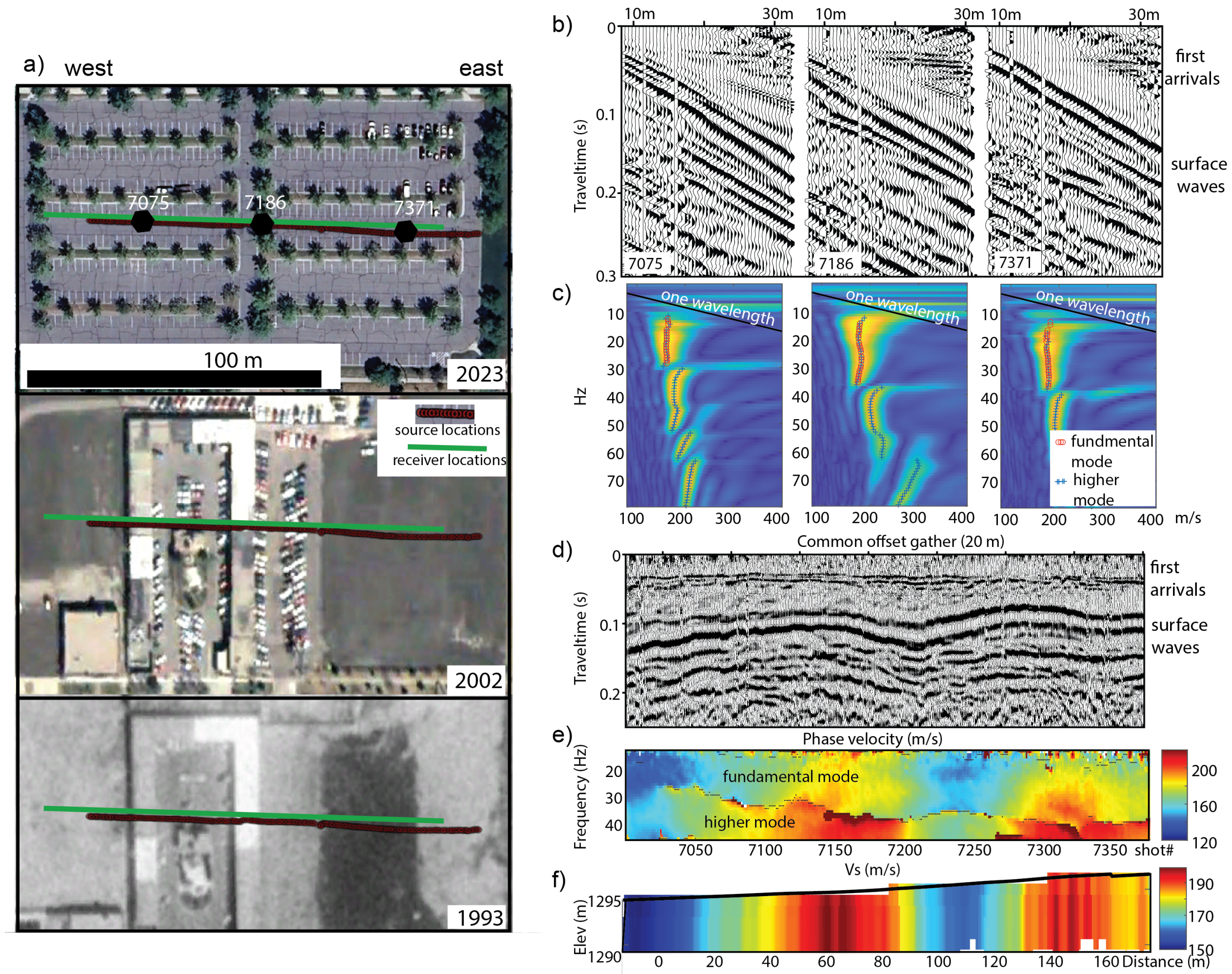


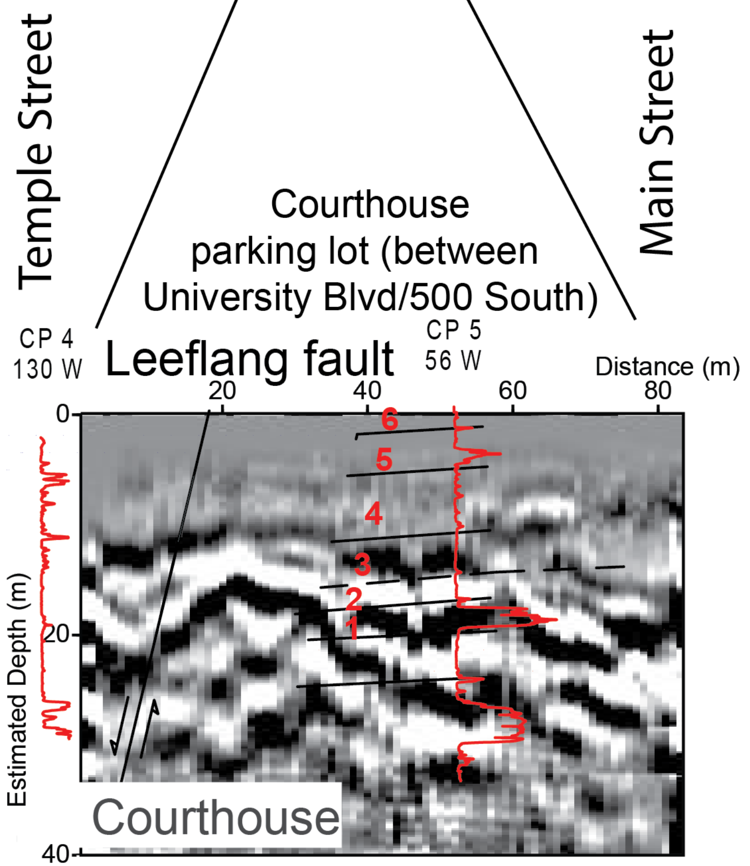


CPT/SEISMIC COMPARISON 400 SOUTH/500 SOUTH

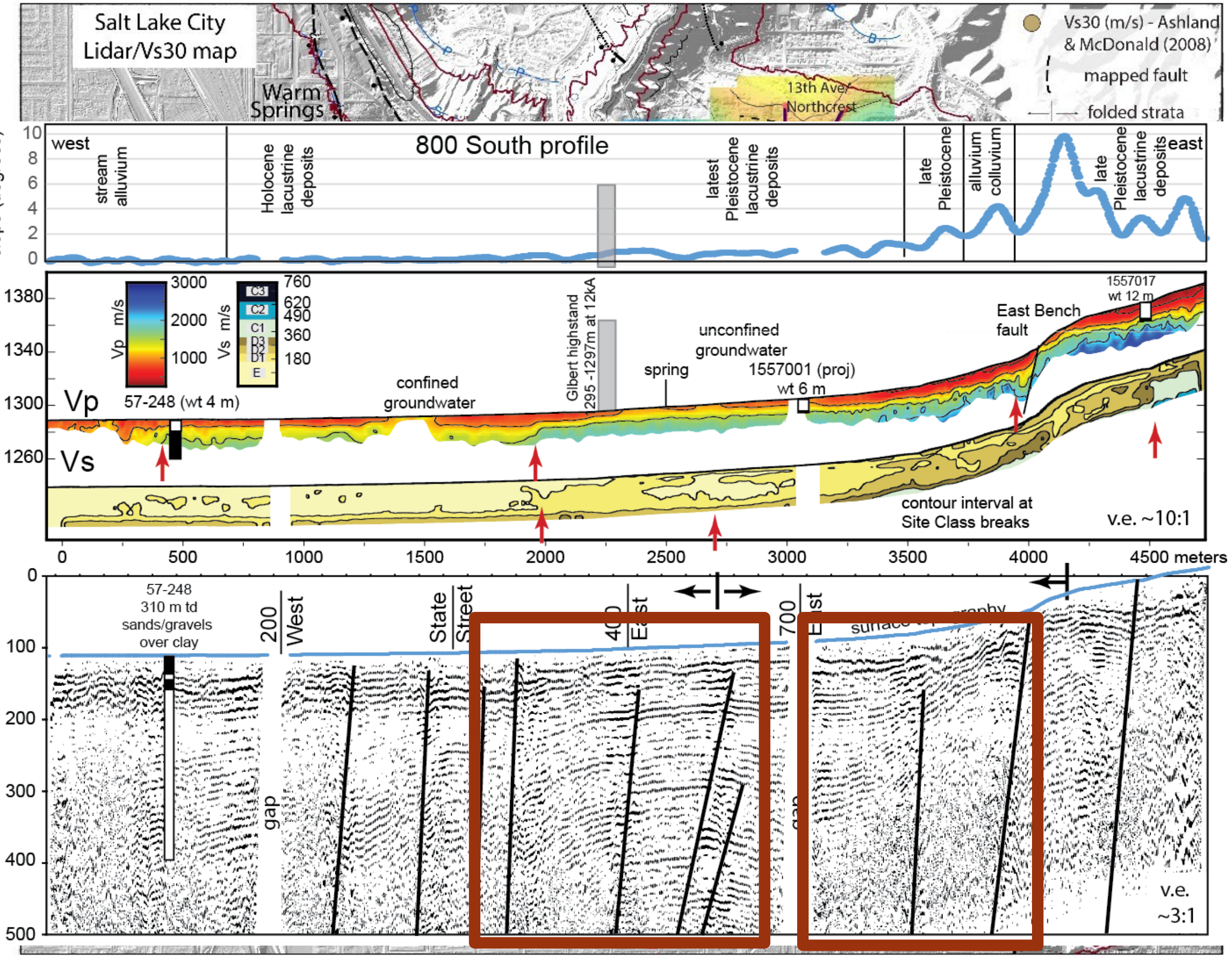
CPT profile along 400 South

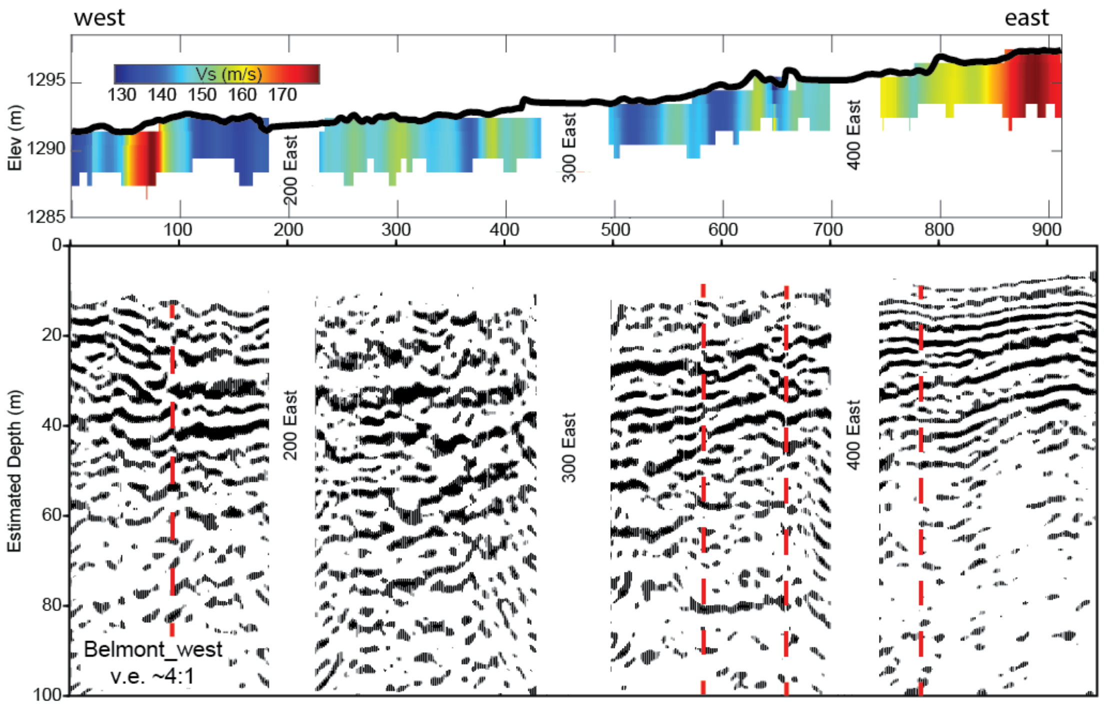


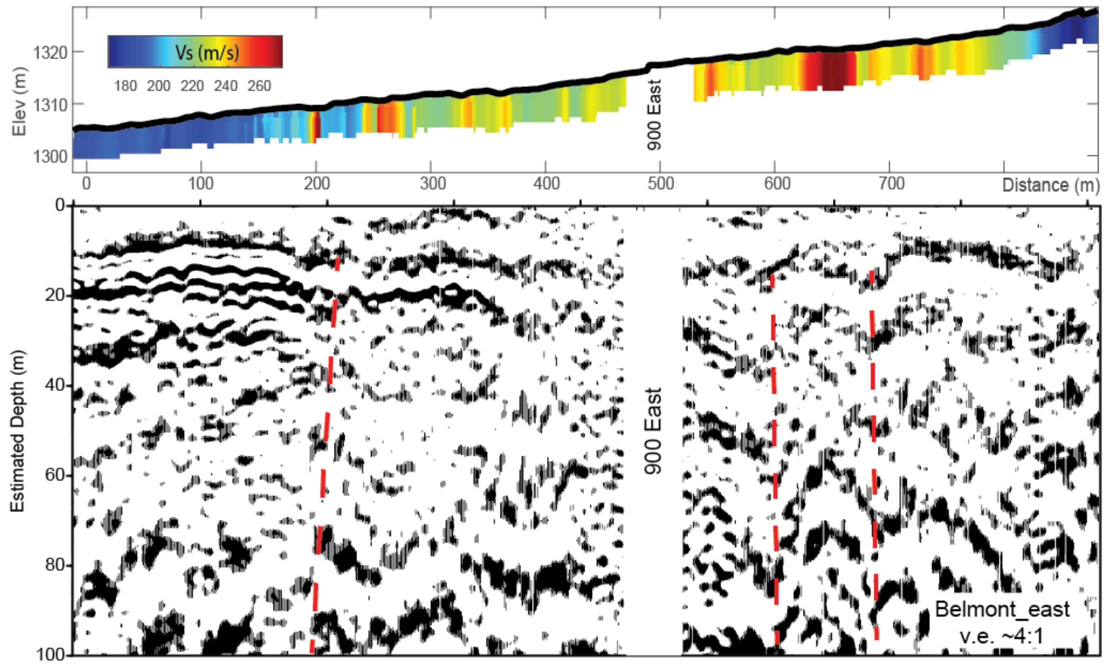




BELMONT AVENUE







VS_{30} MAP FOR DOWNTOWN SLC

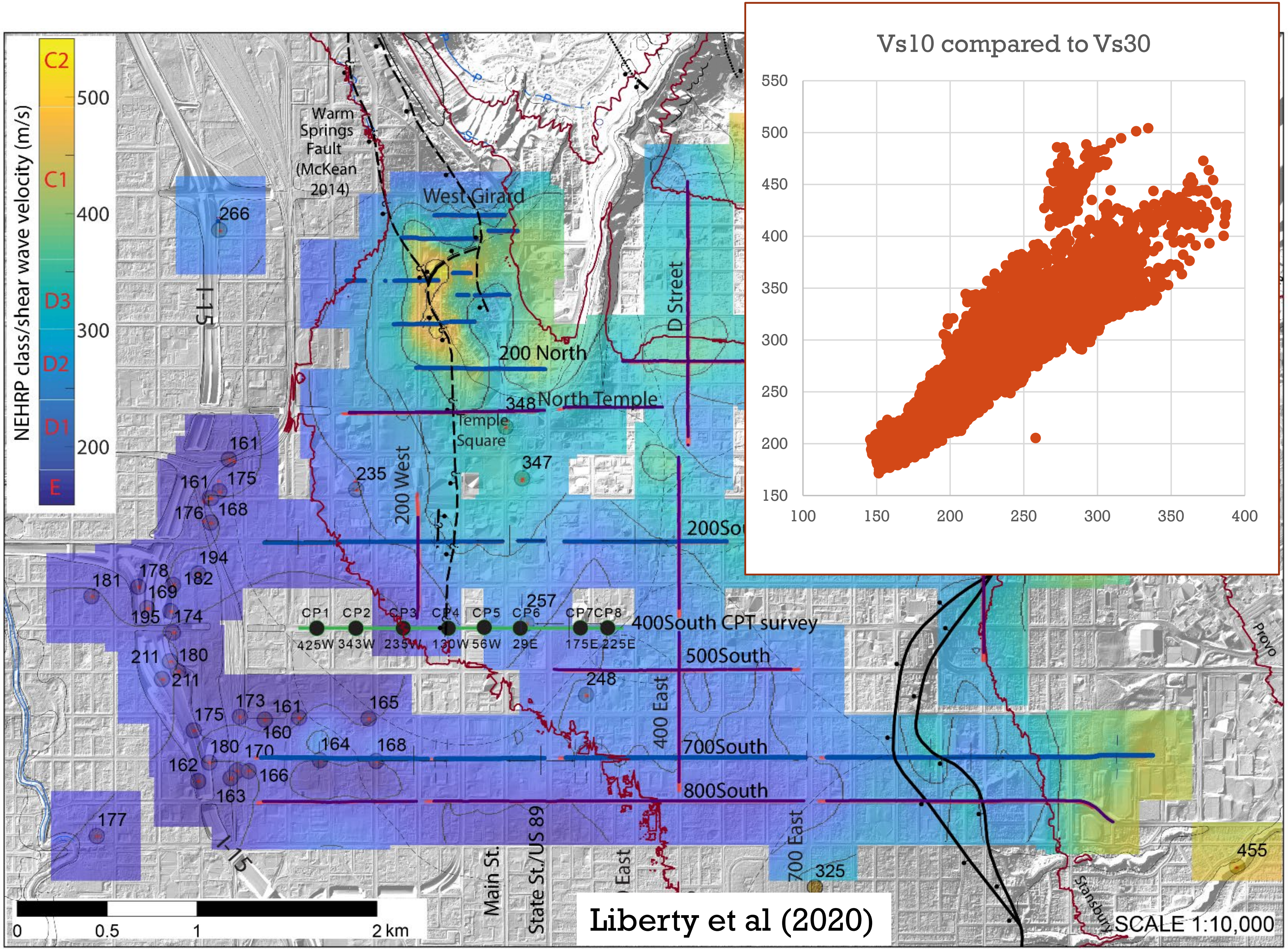
- 36 downhole Vs measurements

McDonald and Ashland (2008)

- *2015/2018 - 15,000 VS30 profiles*

via seismic land streamer

- *2023 - 20,000 additional shots to obtain Vs10*



SUMMARY

- We analyzed ~10 km of new seismic data using the hand streamer seismic system.
- Evidence for active slip along multiple strands of the West Valley faults suggest localized shortening.
- Evidence for ~10 degree east dip on top of Tertiary reflector beneath the Granger fault suggests R1 surface that may be more complex than currently mapped → influences on local site response.
- Downtown seismic data quality changes on a block-by-block scale. This changing reflection character suggests laterally discontinuous stratigraphy
- Evidence for faulting extends south to 900 South, broadening the downtown fault system

February 5, 2024

Utah Geological Survey

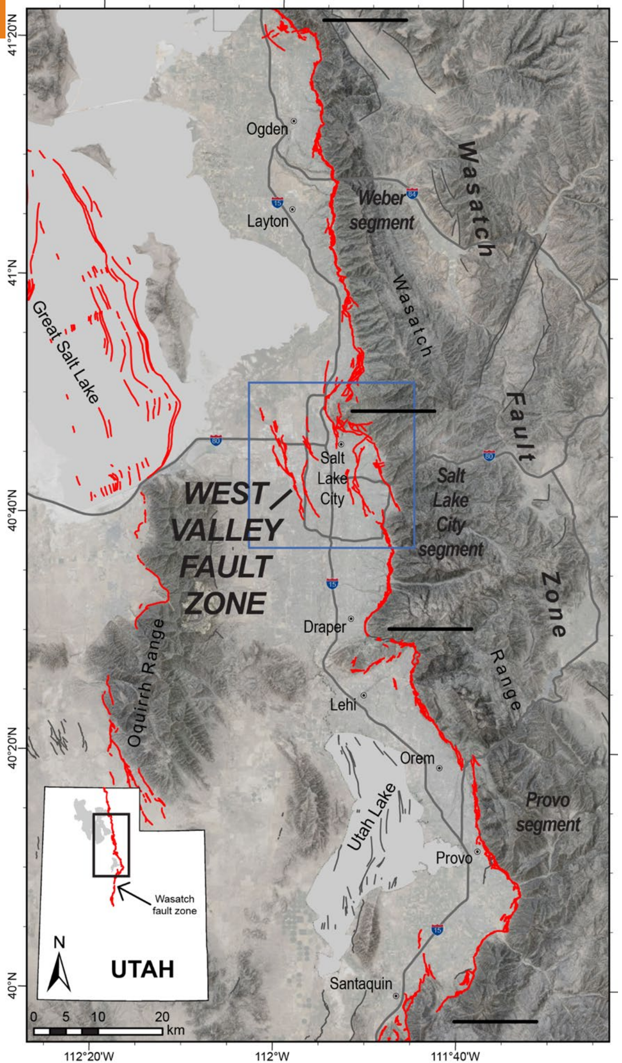
New Paleoseismic Data and Challenges from the Urban Taylorsville Fault, West Valley Fault Zone, Utah

UGS: Emily Kleber, Adam Hiscock, Greg McDonald, Michael Hylland, Kristi Rasmussen, Elizabeth Williams (now with Lincoln County, WY), Rich Giraud (now retired)

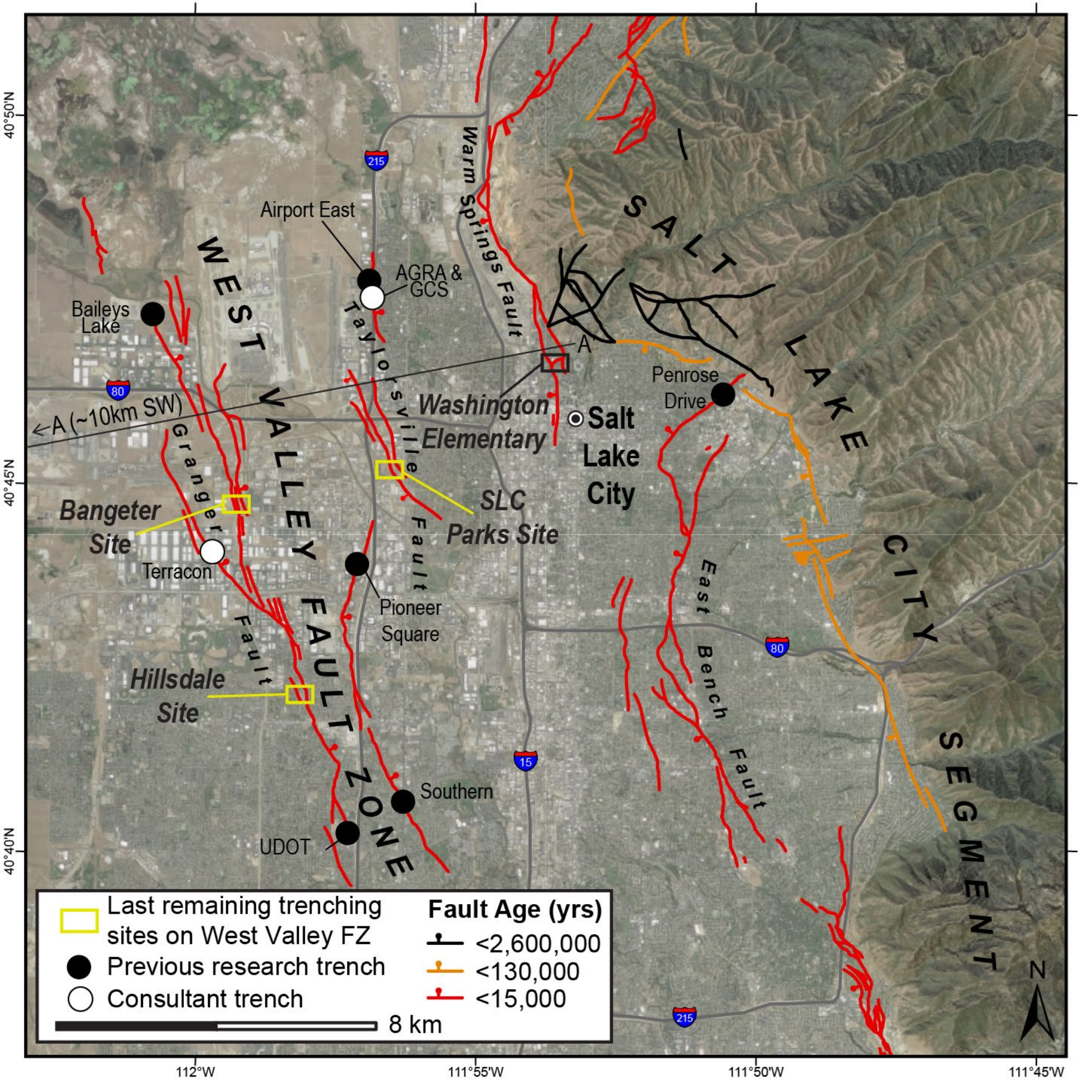
USGS: Shannon Mahan, Harrison Gray, and Christopher DuRoss

MSSST Students: Andrew Starace (Granger High School), and Joanna McLean (Mountain Ridge High School)

UTAH DNR 75th ANNIVERSARY 1949–2024 GEOLOGICAL SURVEY



Ogden
Layton
Weber segment
Wasatch
Wasatch
Fault
Zone
Range
Great Salt Lake
Salt Lake City
WEST VALLEY FAULT ZONE
Salt Lake City segment
Oquirrh Range
Draper
Lehi
Orem
Utah Lake
Provo
Provo segment
Santaquin
Wasatch fault zone
N
UTAH
0 5 10 20 km
41°20'N
41°N
40°40'N
40°20'N
40°N
112°20'W
112°W
111°40'W



West Valley fault zone

- Taylorsville fault
  - Airport East Trench: 3 surface rupturing and earthquake-related deformation
- Granger fault
  - Baileys Lake Trench: 4 surface rupturing earthquakes since Bonn. HS.
  - 5 total on Granger fault.
- Displacements of 0.5 m+/event.
- Evidence for liquefaction, and warping from earthquakes.

Figure by A. Hiscock

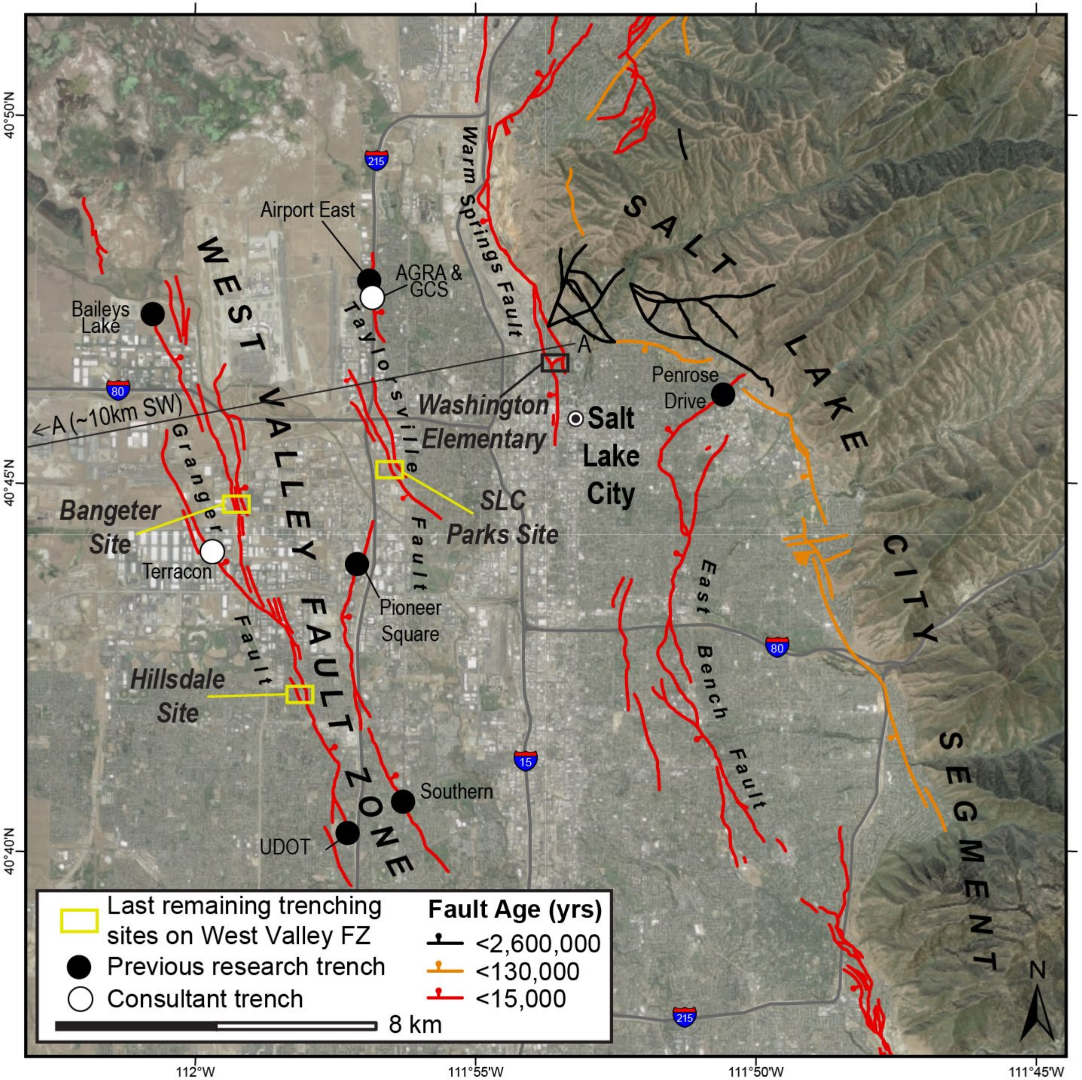
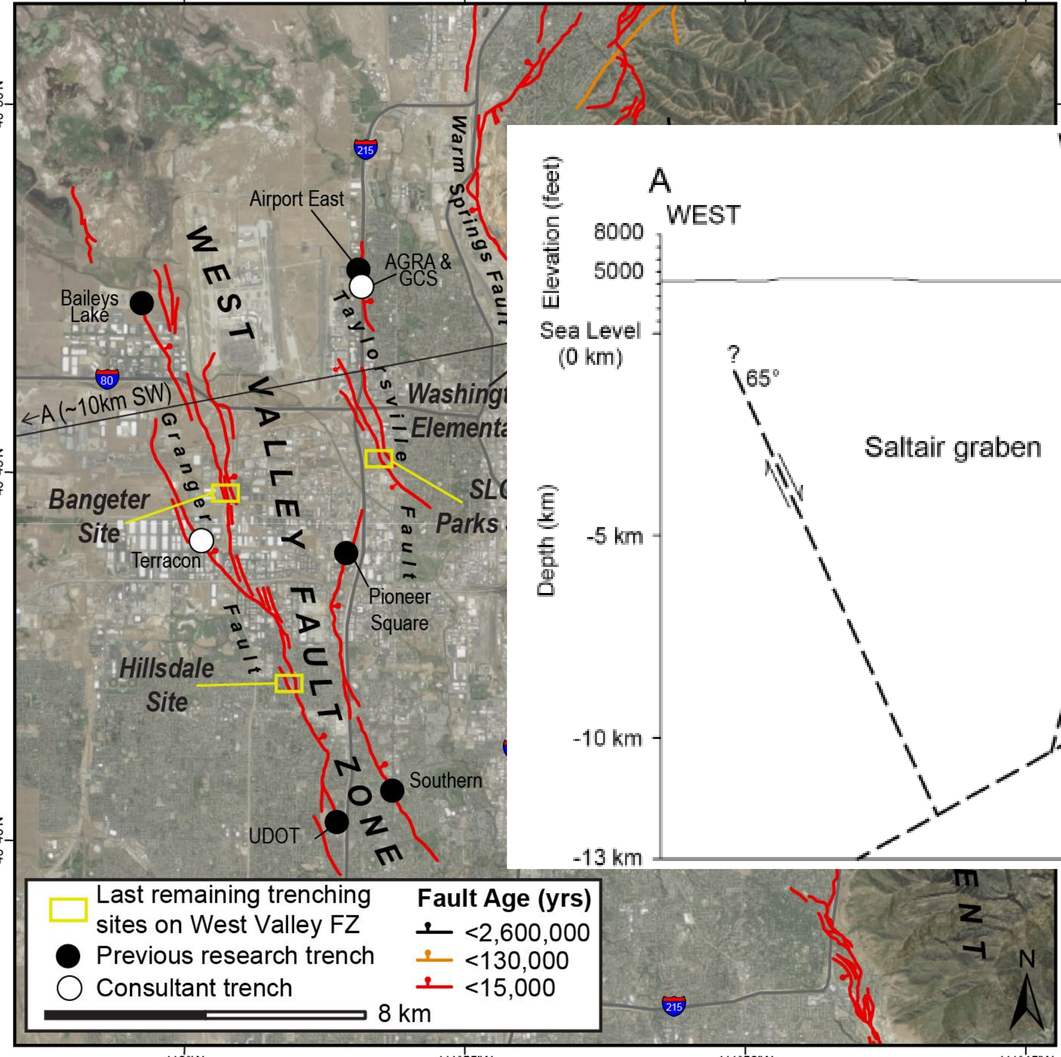


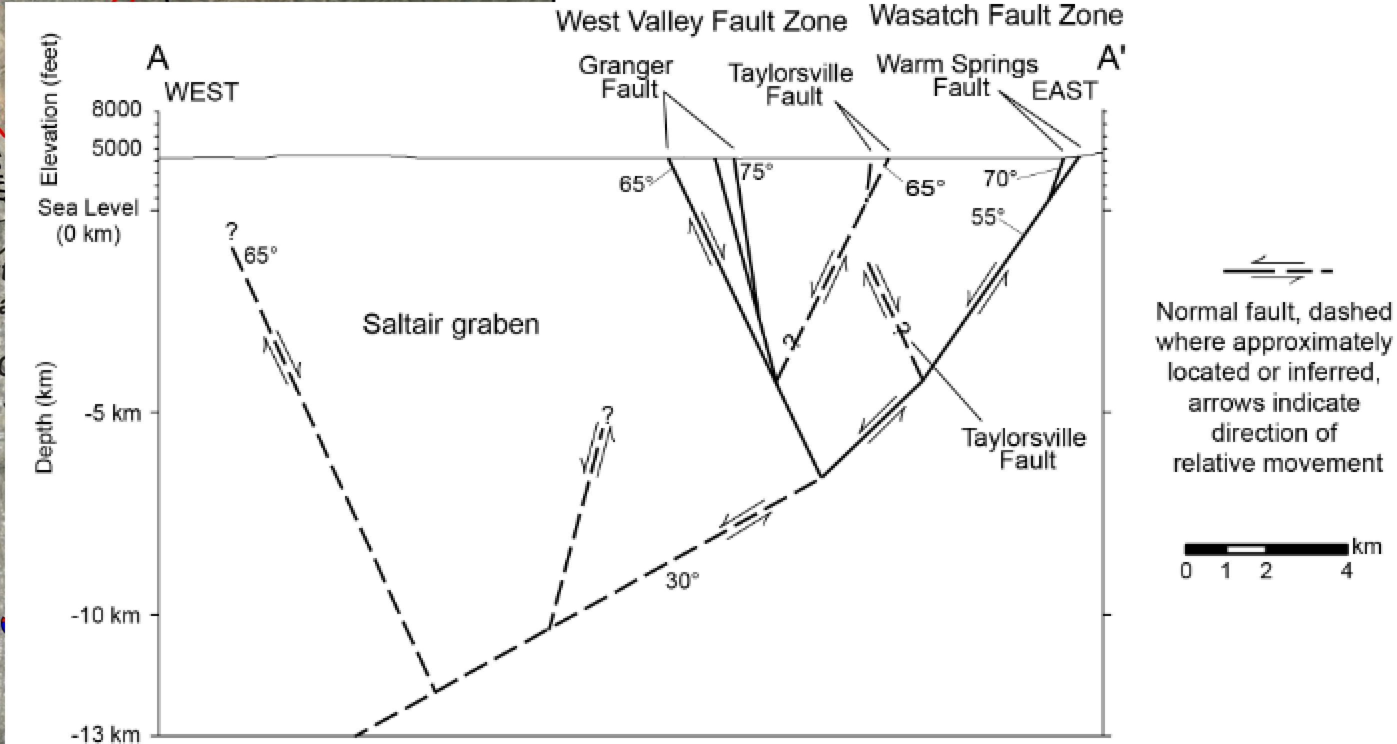
Figure by A. Hiscock

Motivations

- Disappearing paleo sites!
- More paleoseismic data.
- No evidence of coseismic events on Taylorsville and Granger faults.
- Better understanding of WVFZ movement in earthquakes.

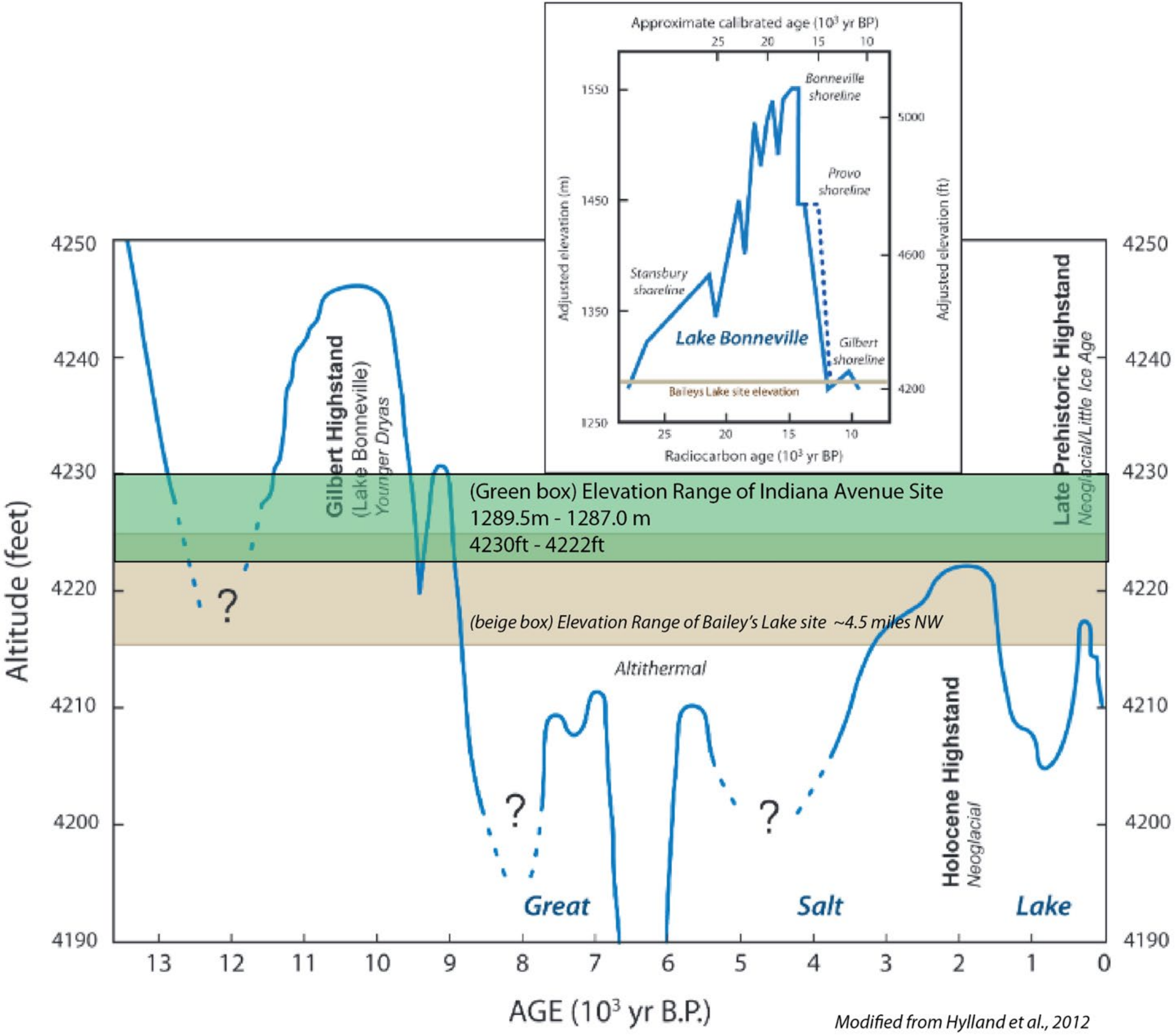
Image by A. Hiscock



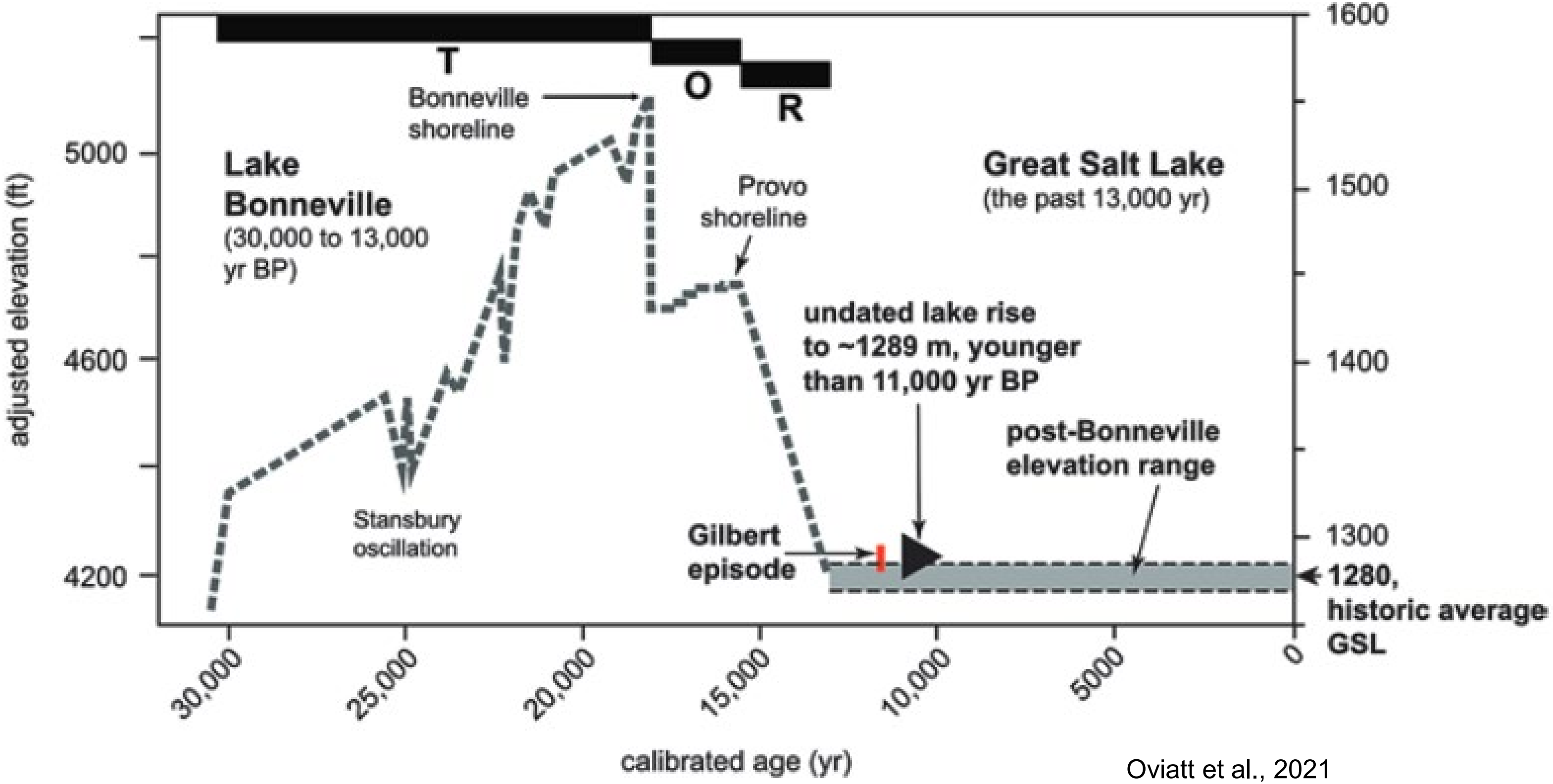


Hylland et al., 2022

Figure by A. Hiscock

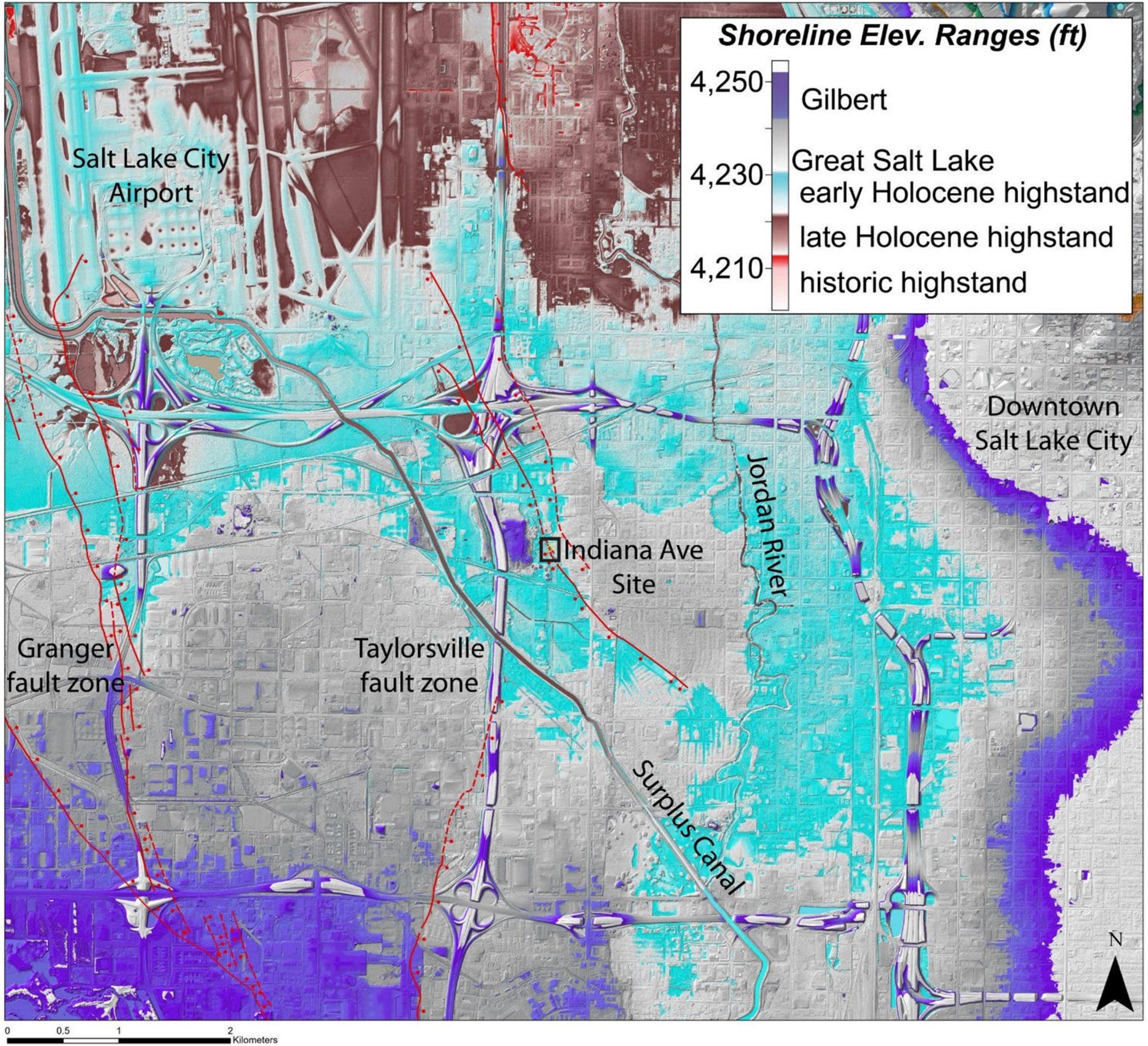


Approximate calibrated age (10³ yr BP)
Bonneville shoreline
Provo shoreline
Stansbury shoreline
Lake Bonneville
Gilbert shoreline
Baileys Lake site elevation
Adjusted elevation (m)
Adjusted elevation (ft)
Radiocarbon age (10³ yr BP)
Altitude (feet)
Gilbert Highstand
(Lake Bonneville)
Younger Dryas
Late Prehistoric Highstand
Neoglacial/Little Ice Age
(Green box) Elevation Range of Indiana Avenue Site
1289.5m - 1287.0 m
4230ft - 4222ft
(beige box) Elevation Range of Bailey's Lake site ~4.5 miles NW
Altithermal
Holocene Highstand
Neoglacial
Great
Salt
Lake
AGE (10³ yr B.P.)
Modified from Hylland et al., 2012



Oviatt et al., 2021

Image by A. Hiscock

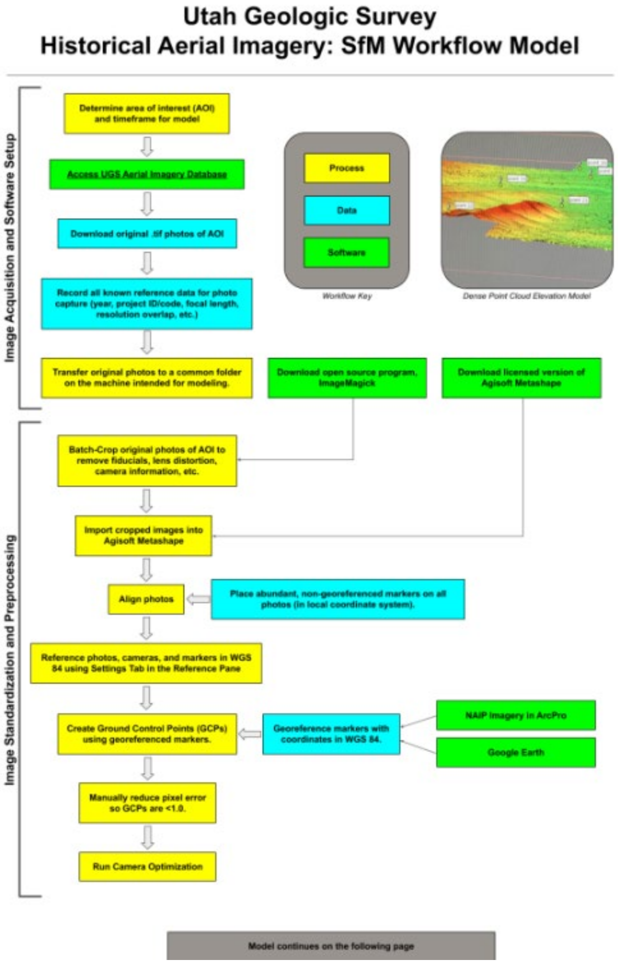


Lidar shader courtesy of A. McKean, UGS

Research Highlight- Andrew Starace

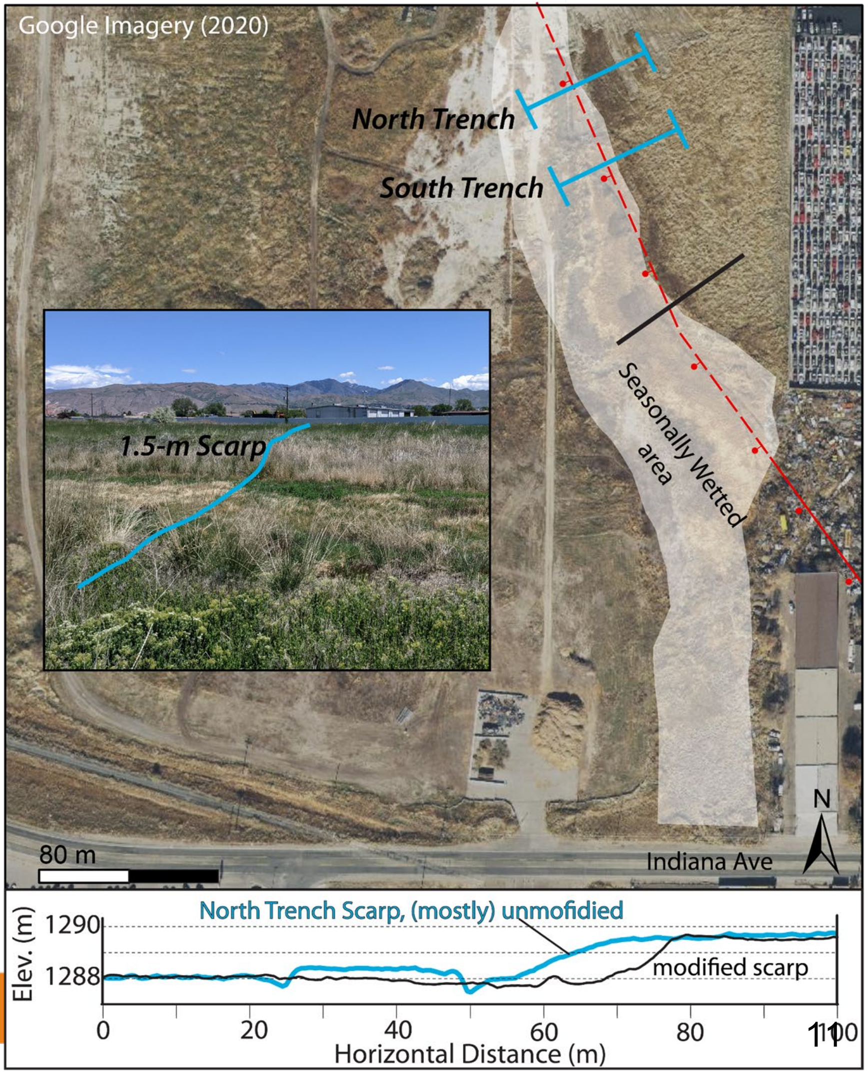
MS Thesis - “*Using Utah Geological Survey’s Aerial Imagery Database for Photogrammetric Modeling in Agisoft Metashape*”

- Assisted with trench excavation, cleaning, and logging summer 2022.
- Granger High School Earth Science Teacher.
- Developed workflow for processing stereo-paired historic images into digital elevation models (DEMs).

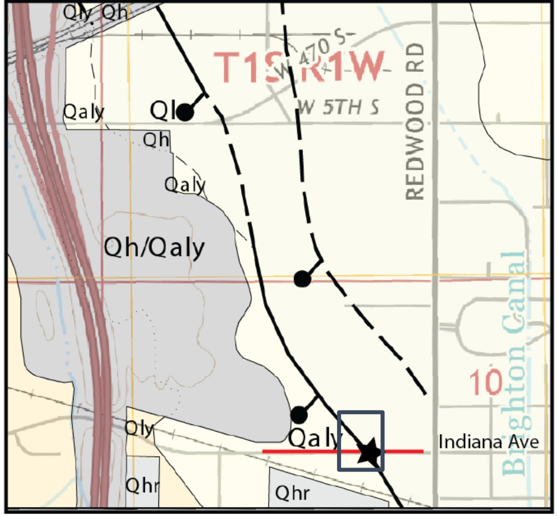


Indiana Avenue Trench Site

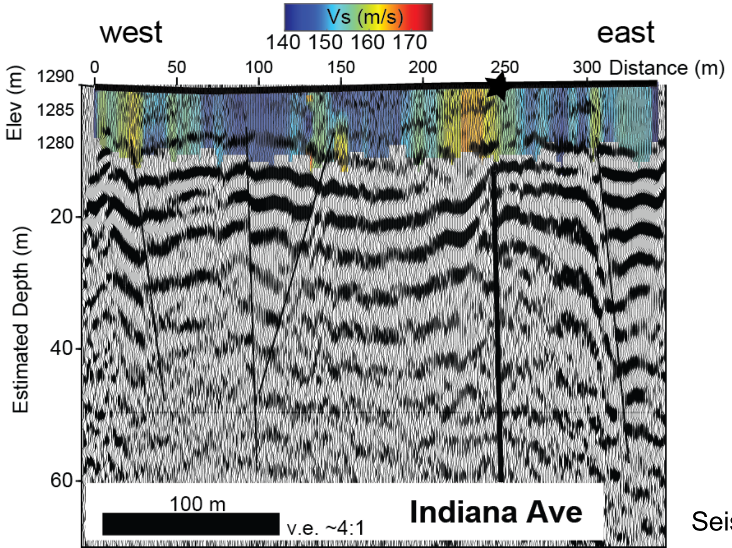
- Land owned by Salt Lake City Corporation, and used by Parks Department.
- 1.5 meter southwest dipping scarp identified in lidar.
- High groundwater table at site and seasonally wetted area along scarp.
- Excavated 2 trenches (north and south).



Utah Geological Survey



Geologic mapping from Adam McKean, UGS



Seismic data from Lee Liberty, BSU

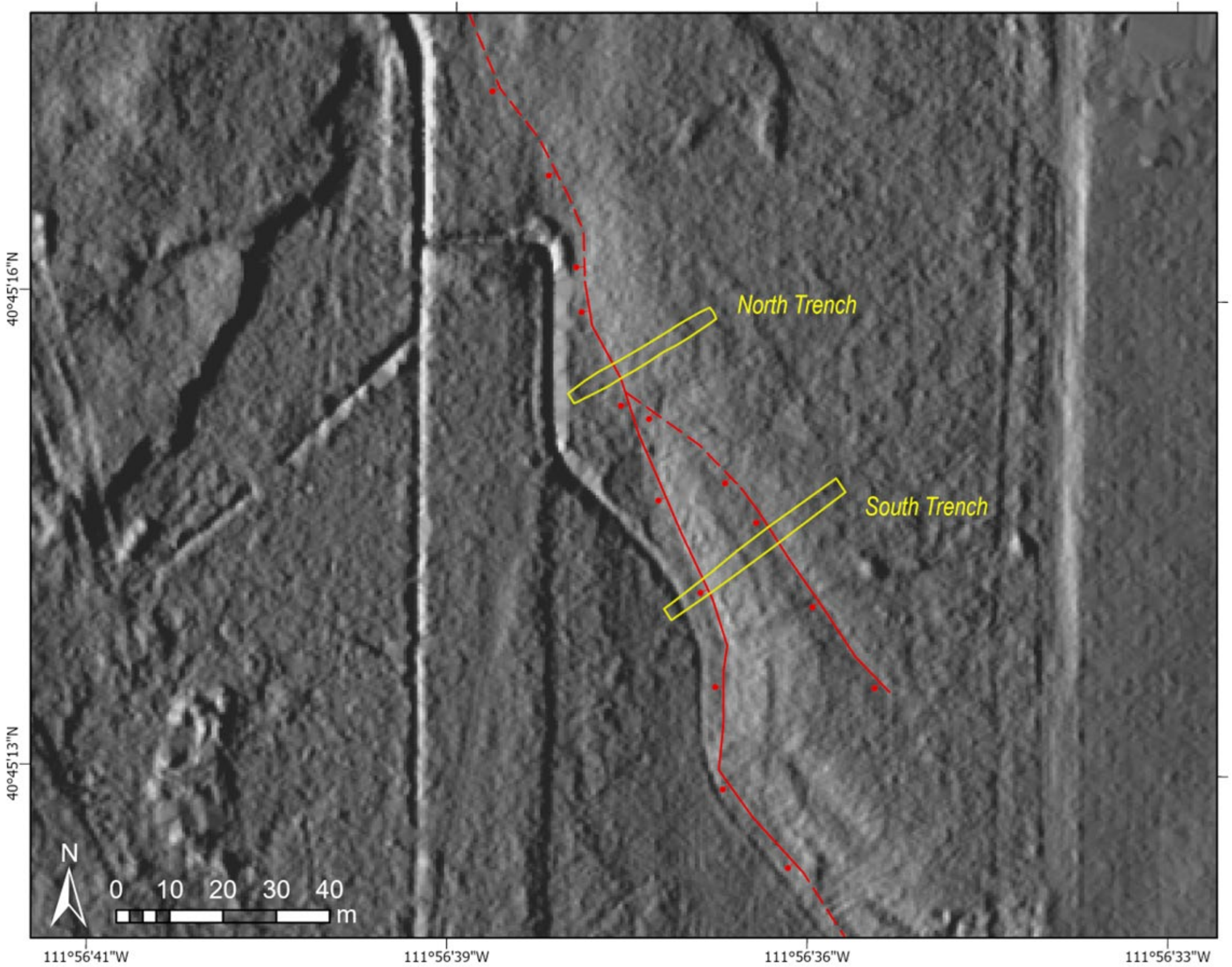
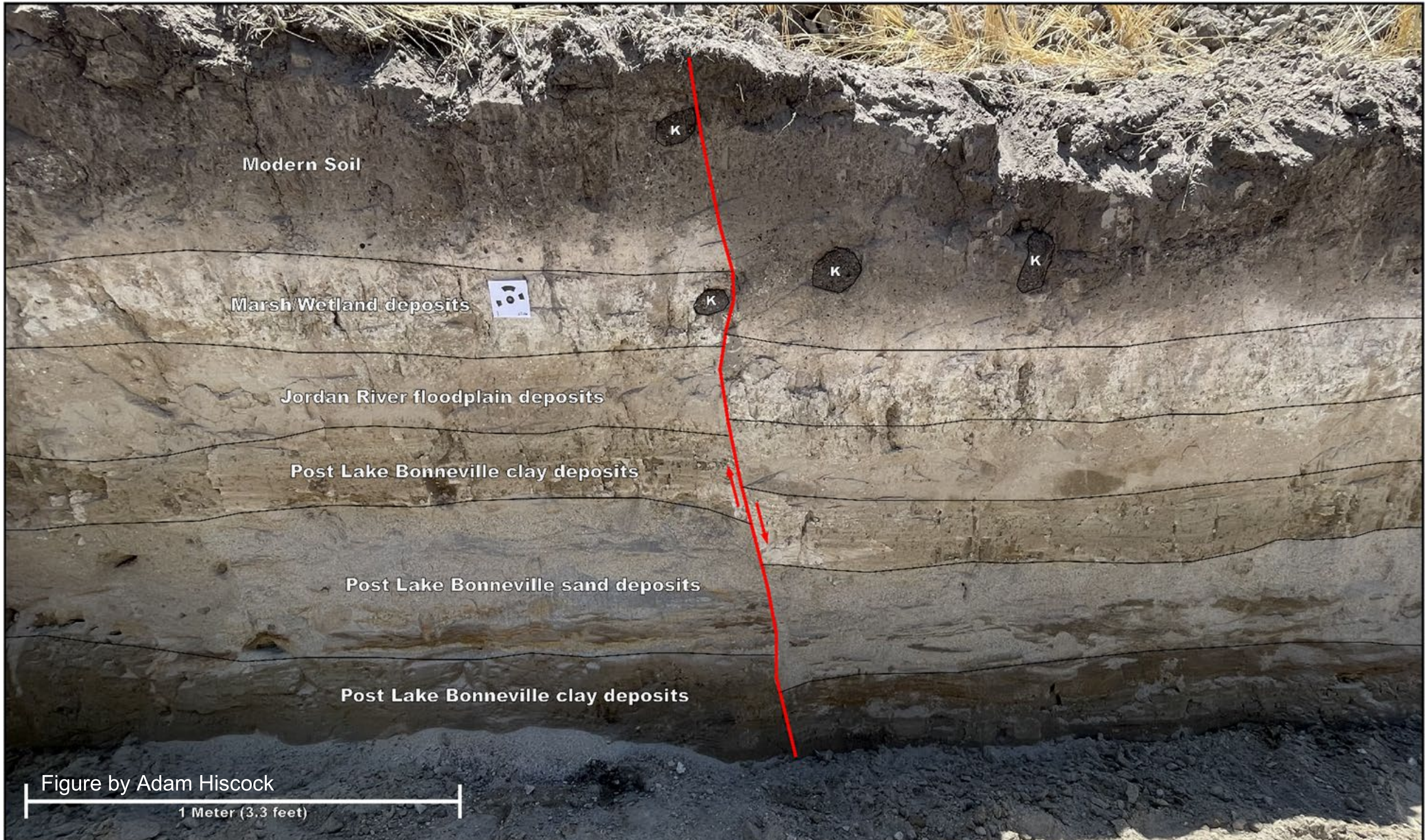


Figure by A. Hiscock

Research Highlight- Joanna McLean

MS Thesis - "*Contextualizing the Stratigraphy of the Indiana Avenue Trench, West Valley Fault Zone, Salt Lake City, Utah*"

- Mountain Ridge High School Biology teacher.
- Detailed description of trench stratigraphy.
- Helped with trench cleaning, logging, and geochronology sampling, Summer 2022.



Modern Soil
K
K
K
K
Marsh/Wetland deposits
Jordan River floodplain deposits
Post Lake Bonneville clay deposits
Post Lake Bonneville sand deposits
Post Lake Bonneville clay deposits
Figure by Adam Hiscock
1 Meter (3.3 feet)

Geochronology

Sampled southern trench only.

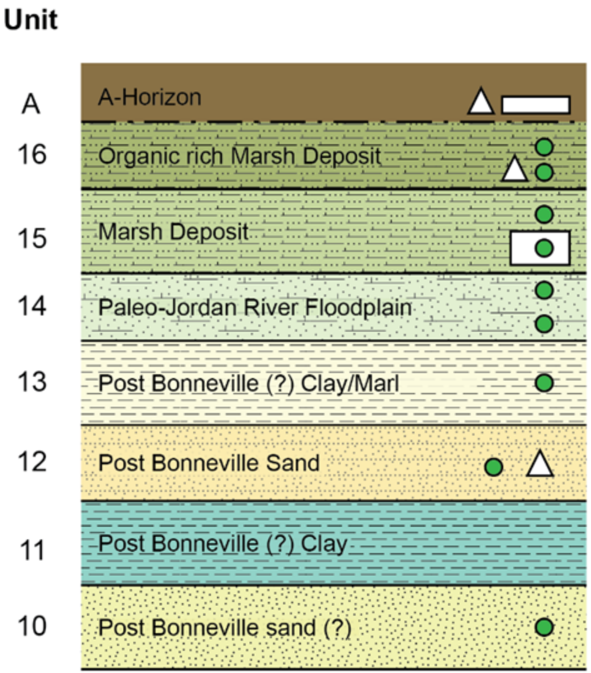
6 radiocarbon samples.

- Pre-processing by PaleoResearch and ages from NOSAMS.
- Macrocharcoal and bulk soil.
- 2 samples no C-14.

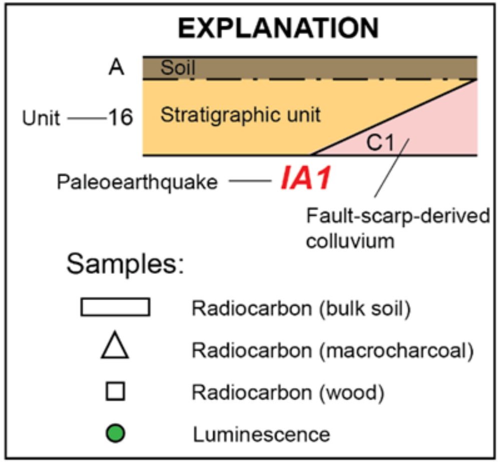
9 Luminessence samples.

- Samples run by USGS Luminessence Lab, Colorado.
- 9 OSL (quartz).
- 4 additional IRSL (feldspar).

Adam luminescence sampling.

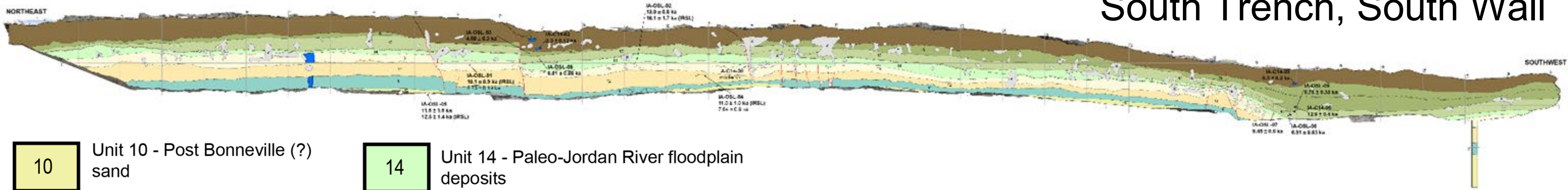


Unit	OSL Samples	C-14 Samples
A / 16	IA-OSL-03: ***4.08 ± 0.3 ka*** IA-OSL-09: ***6.78 ± 0.4 ka***	*IA-C14-01: NO C-14* IA-C14-02: ***2.3 ± 0.12 ka*** IA-C14-03: ***0.3 ± 0.2 ka*** IA-C14-05: ***12.9 ± 0.4 ka***
15	IA-OSL-06: ***6.81 ± 0.9 ka*** IA-OSL-08: ***6.92 ± 0.6 ka***	*IA-C14-04: NO C-14*
14	IA-OSL-02: ***13.0 ± 0.8 ka/IRSL: 16.1 ± 1.7 ka*** IA-OSL-07: ***9.48 ± 0.6 ka***	
13	IA-OSL-01: 5.73 ± 0.2 ka/***IRSL: 10.1 ± 0.9 ka***	
12	IA-OSL-04: 7.64 ± 0.6 ka ***IRSL: 11.0 ± 1.0 ka***	*IA-C14-06: Modern*
11		
10	IA-OSL-05: ***11.5 ± 1.5 ka*** ***IRSL: 12.8 ± 1.4 ka***	



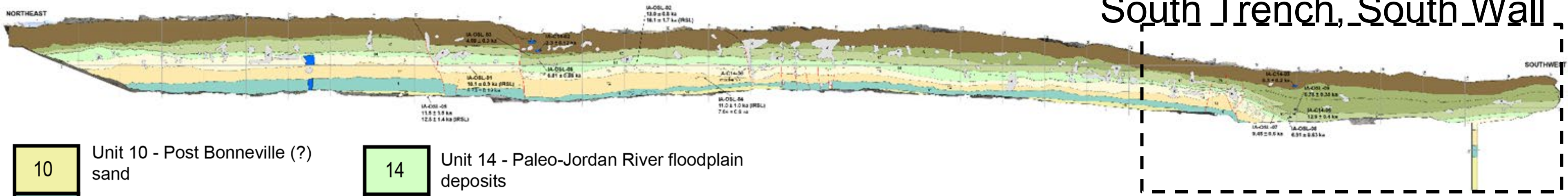
*OSL Ages reported using Central Age Model (CAM). Ages in **bold** are preferred ages.

South Trench, South Wall

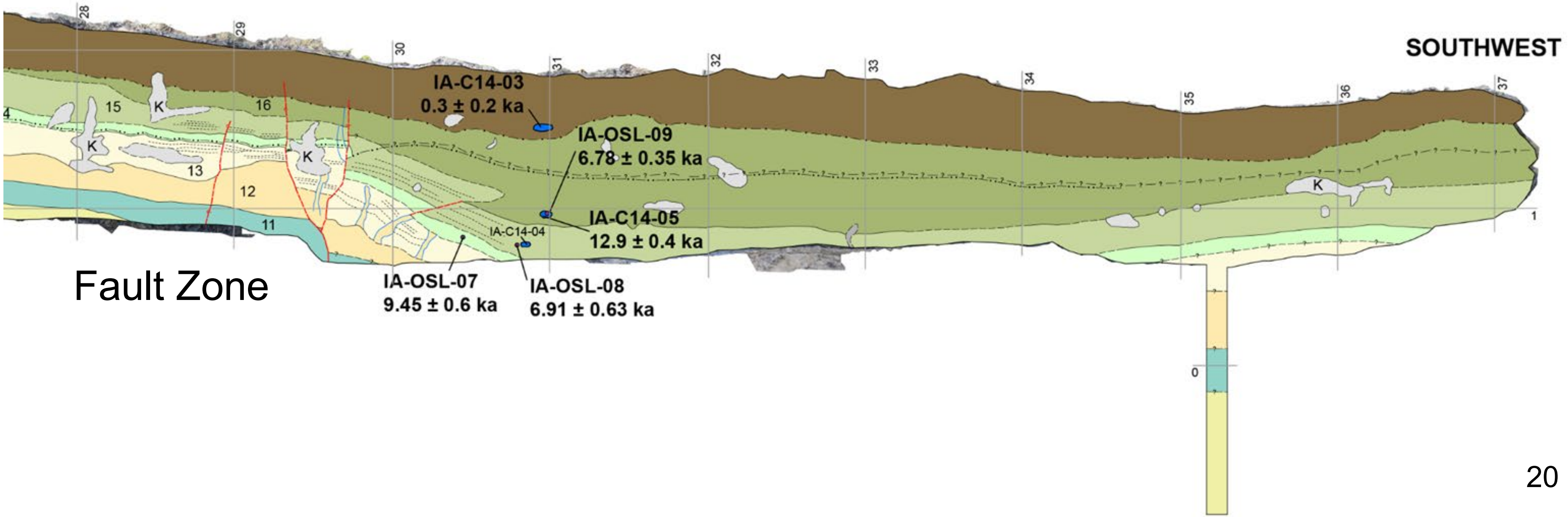


10	Unit 10 - Post Bonneville (?) sand
11	Unit 11 - Post Bonneville (?) clay
12	Unit 12 - Post Bonneville sand
13	Unit 13 - Post Bonnevile (?) Clay/Marl
14	Unit 14 - Paleo-Jordan River floodplain deposits
15	Unit 15 - Marsh/wetland deposits
16	Unit 16 - Organic-rich marsh/wetland deposits
A	Soil Horizons

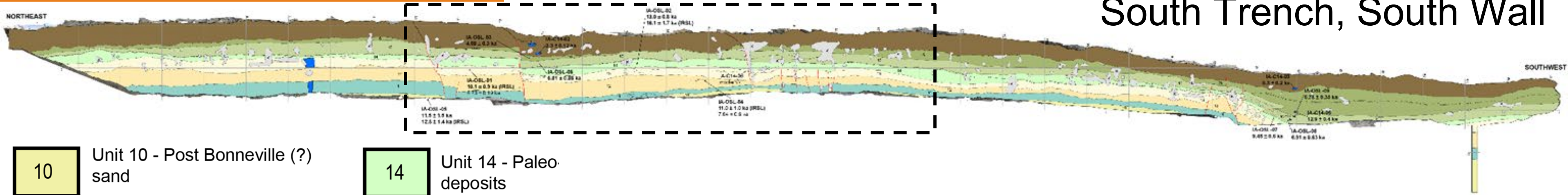
South Trench, South Wall



- **10** — Unit 10 - Post Bonneville (?) sand
- **11** — Unit 11 - Post Bonneville (?) clay
- **12** — Unit 12 - Post Bonneville sand
- **13** — Unit 13 - Post Bonnevile (?) Clay/Marl
- **14** — Unit 14 - Paleo-Jordan River floodplain deposits
- **15** — Unit 15 - Marsh/wetland deposits
- **16** — Unit 16 - Organic-rich marsh/wetland deposits
- **A** — Soil Horizons



South Trench, South Wall



10	Unit 10 - Post Bonneville (?) sand
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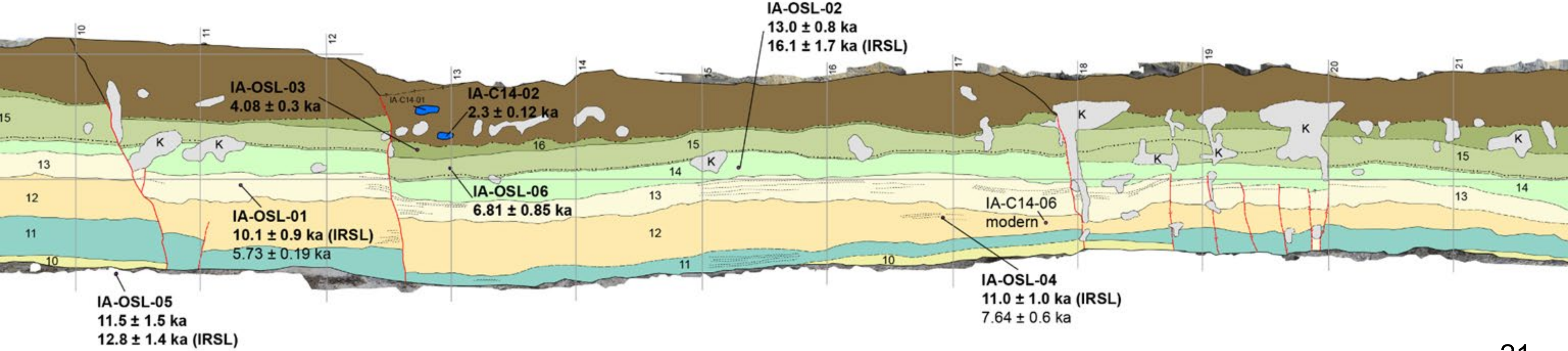
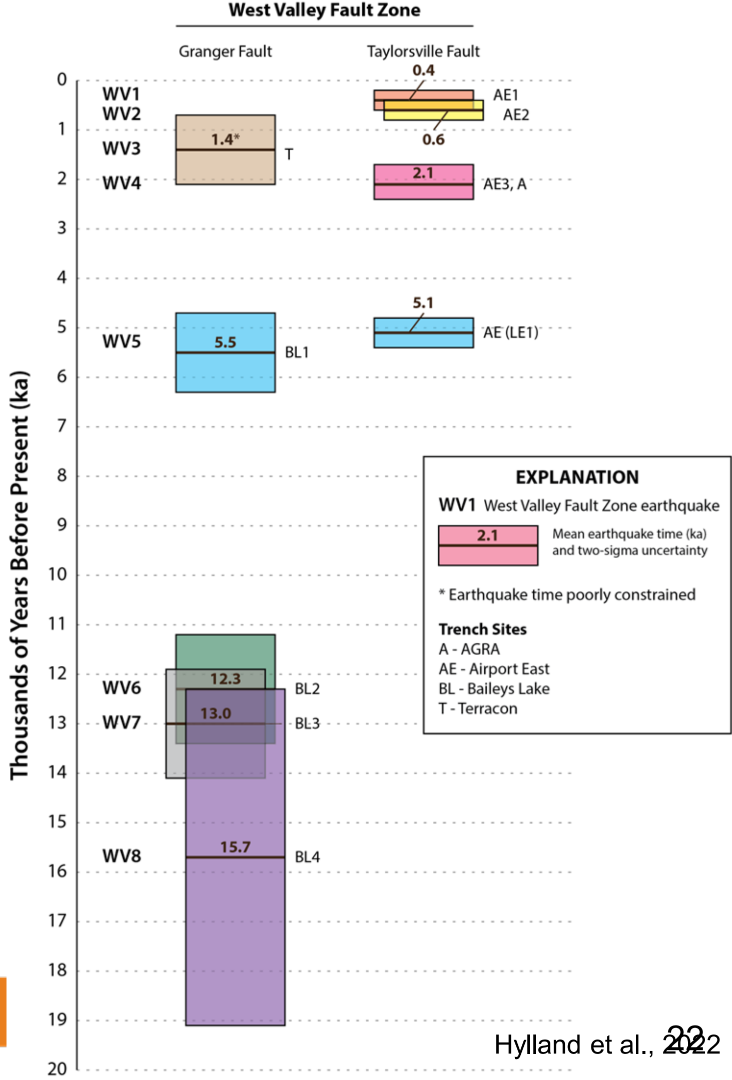
12	Unit 12 - Post Bonneville sand
13	Unit 13 - Post Bonnevile (?) Clay/Marl
14	Unit 14 - Paleo deposits
15	Unit 15 - Marsh/wetland deposits
16	Unit 16 - Organic-rich marsh/wetland deposits
A	Soil Horizons

Footwall Deformation



Next Steps

- Continue discussing the nuance in earthquake events preserved in deposits (warping, thinning, etc.) and overall fault geometry of Taylorsville fault.
- OxCal calibration and earthquake modeling.
- Correlating with WVFZ and WFZ paleoseismic records.
- Final technical report due to USGS September 2024.



Hylland et al., 2022

Thank you.

Utah Geologic Survey
geology.utah.gov

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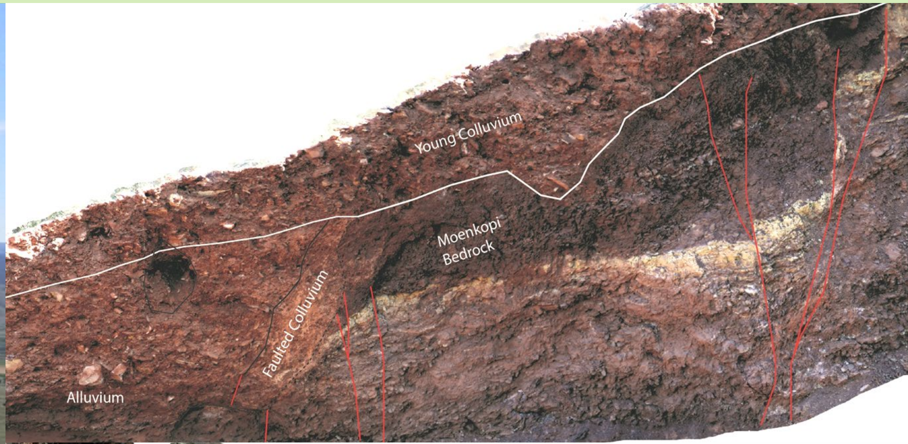
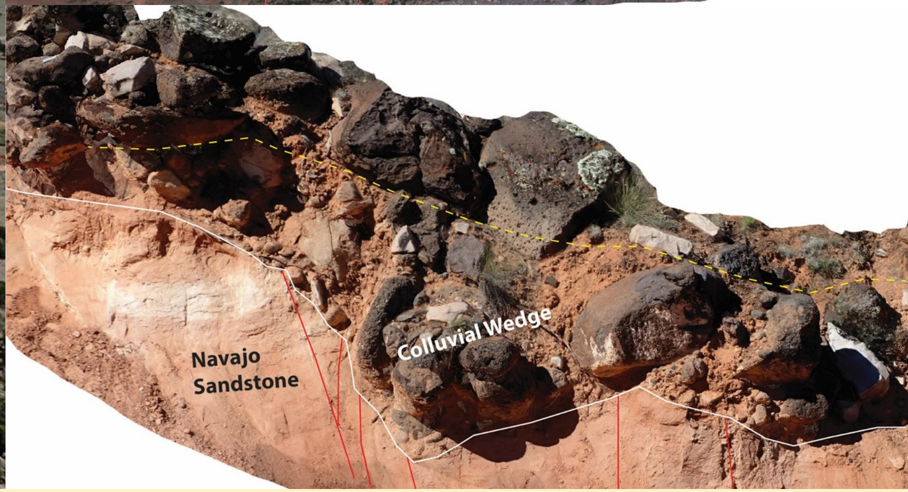
Suite 3110
Salt Lake City, UT 84116-6201
(801) 537-3300

The Most Recent Rupture of the Thousand Lake Fault (Post-LGM)—Examining Rupture Length and Average Displacement using Southern Utah Lidar Data:





TOKE, N.[1], D.J. JOHNSON[2], D. MARCHETTI[3], C. BAILEY[4], R. BIEK[5], H.C. BARTRAM[4], J. PHILLIPS[1], C. FORSTER[1], S. WARD[1], R. RICHARDS[1], C.J. IDEKER[6] and T. RITTENOUR[6]

1-Utah Valley, 2 – Idaho State University, 3-Western Colorado U., 4-William & Marry U., 5-Utah Geological Survey, and 6-Utah State University

UTAH VALLEY UVU UNIVERSITY Department of EARTH SCIENCE

2024 UQFPWG

The TLF lies along the boundary between the Basin and Range and Colorado Plateau Physiographic Provinces

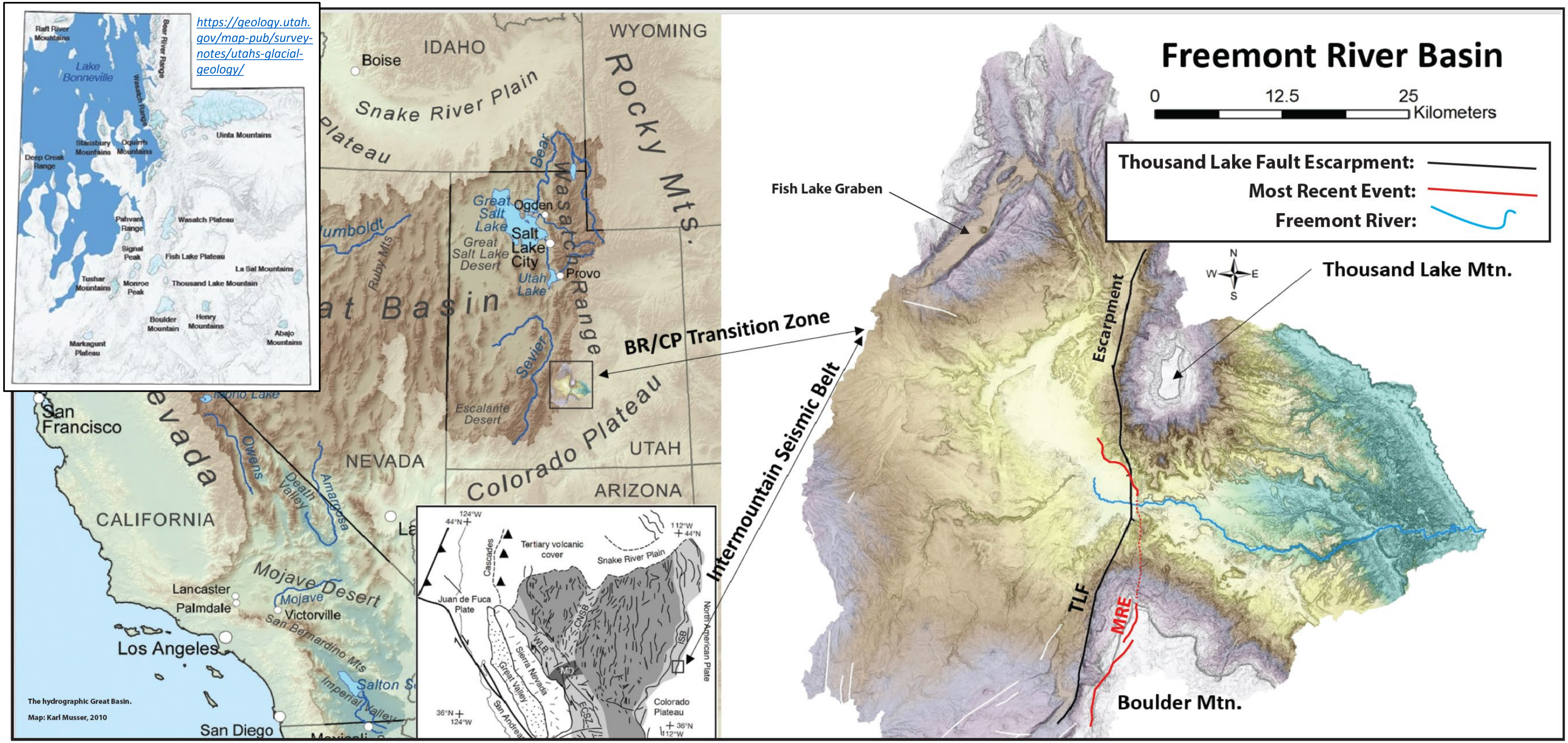
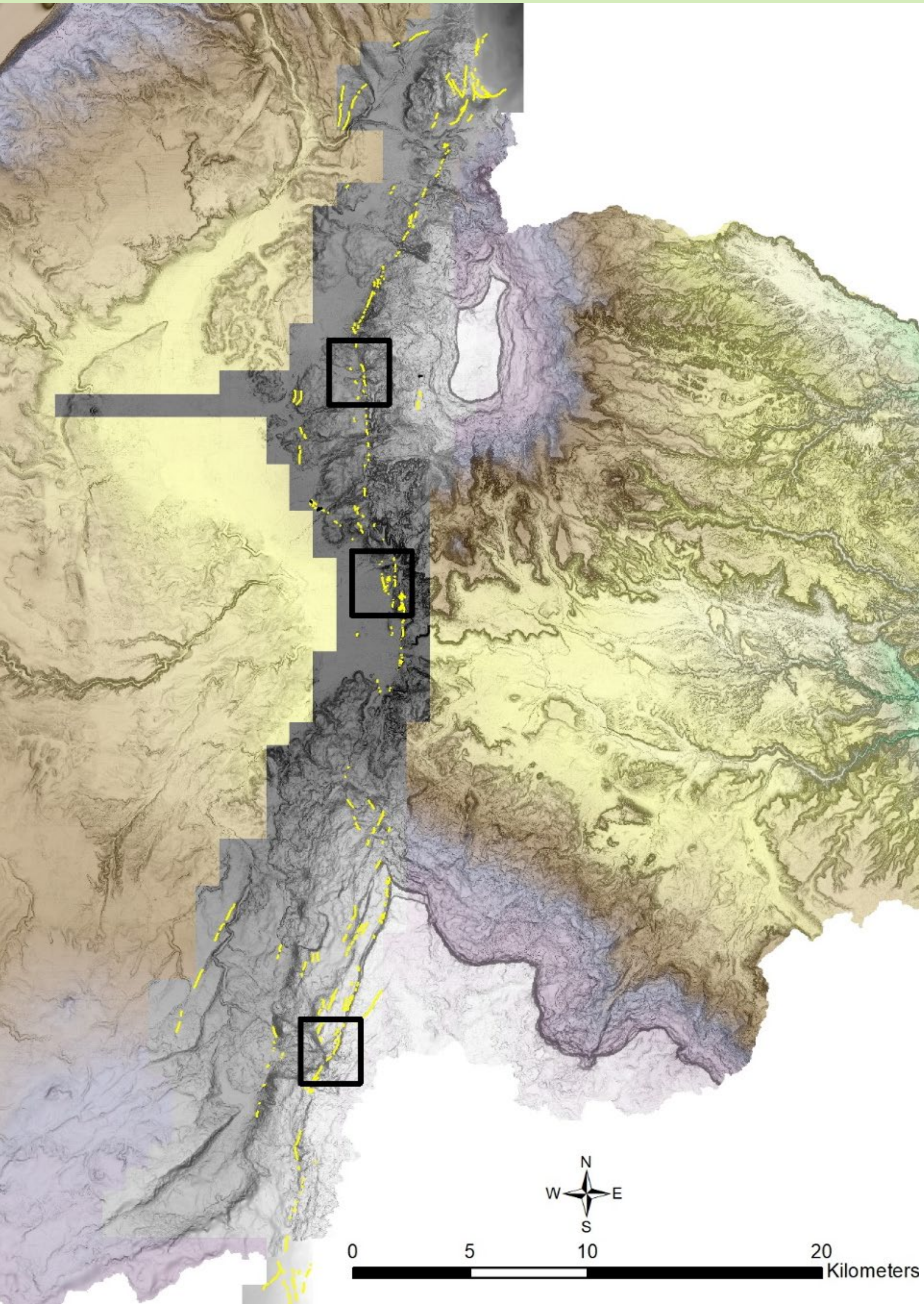


Figure 1. The TLF represents one of the easternmost Basin and Range faults within Utah. The TLF separates a province of units deformed by Sevier-Laramide orogenic activity and subsequent extension from the relatively undeformed laterally continuous units of the Colorado Plateau.

Prior Information about the Thousand Lake Fault



Quaternary Activity?

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

Earthquake Size?

- **Fault Length ~ 49 km**

Slip Rate?

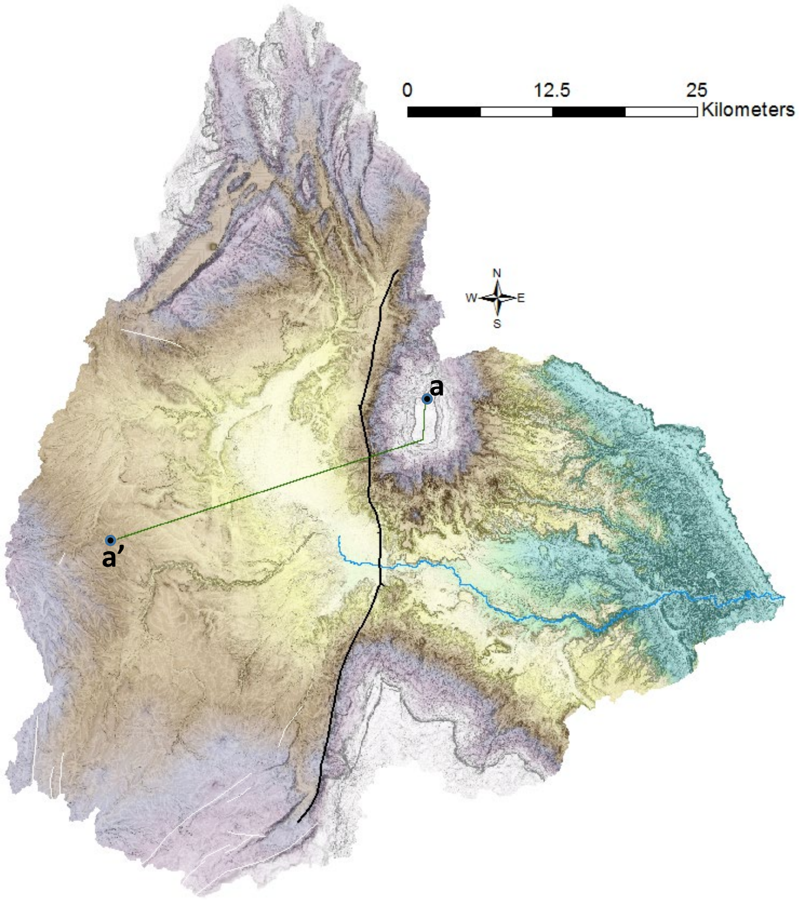
- **< 0.2 mm/yr** *(Utah Q Fault Database)*

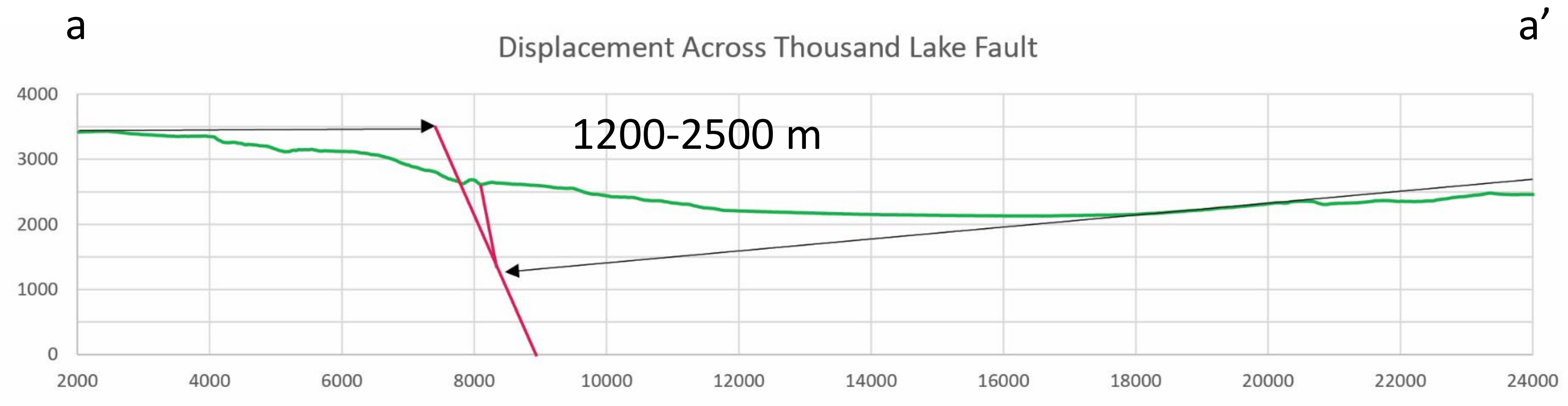
What more can we say?

- **Long-Term Displacement**
- **2018 Paleoseismic Trench and OSL dates**
- **2020 Lidar data**


Thousand Lake Mountain
24 Ma Volcanic Rocks

Total Displacement and Long-Term Slip Rate





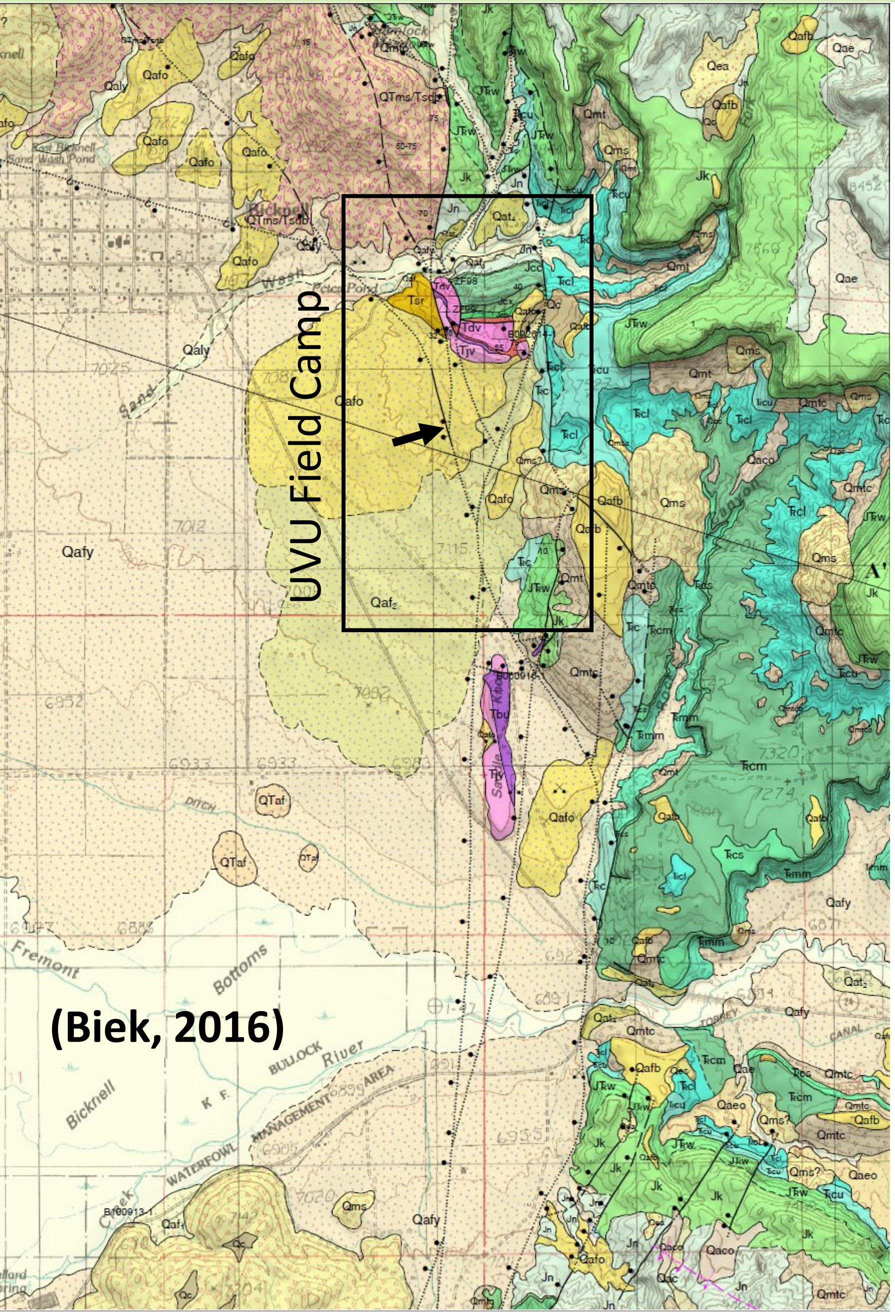
- Age of Displaced Volcanic Rocks ~24.5 Ma (e.g., Mattox, 2001)
- Tectonic Initiation 10-16 Ma (Various Basin and Range Papers)

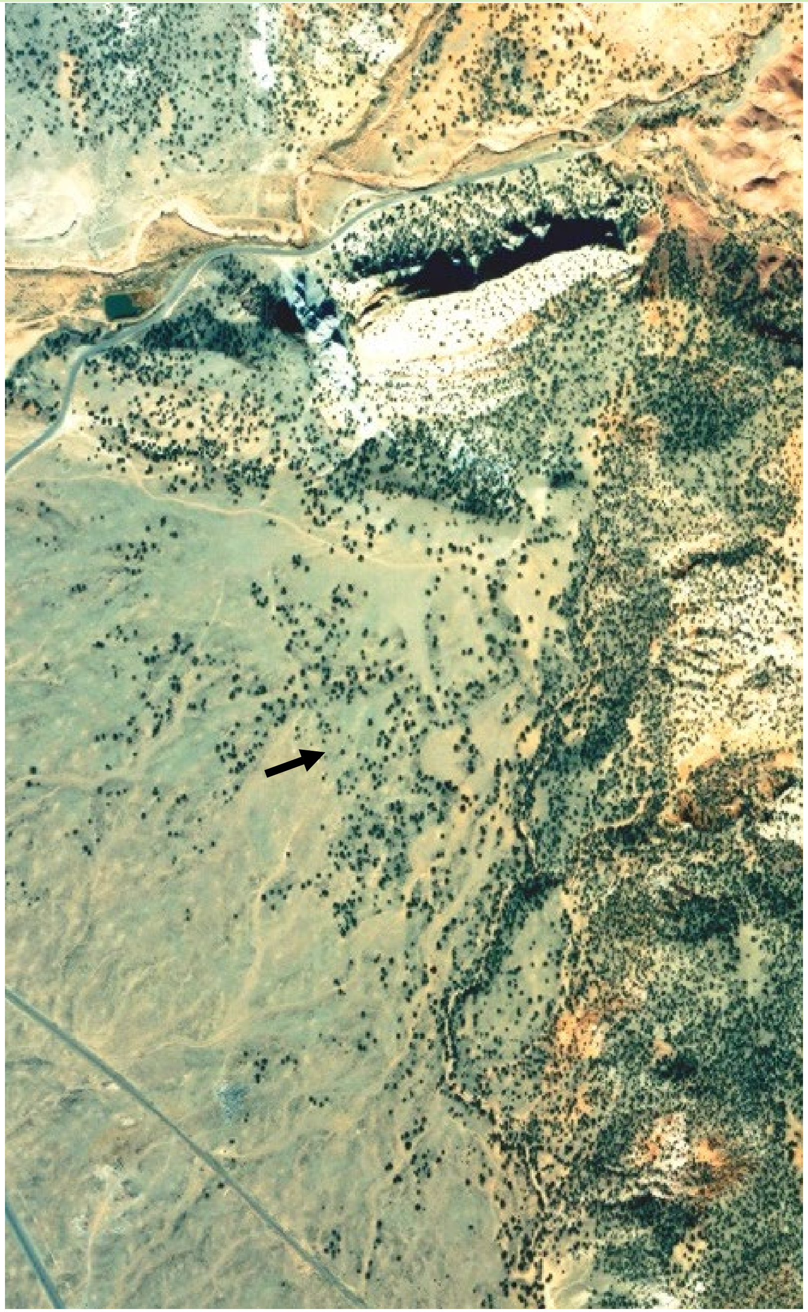
<u>Near Fault Center</u>

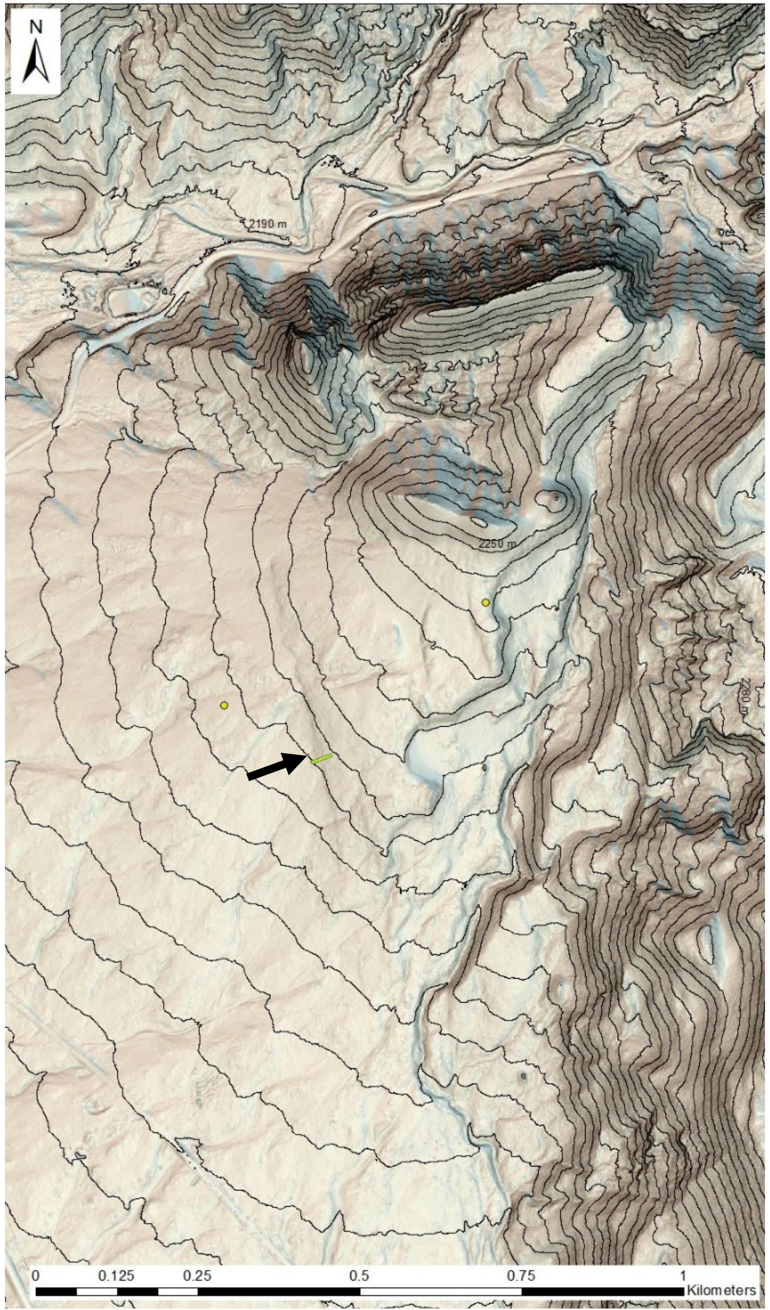
Minimum Long Term Slip Rate ~ 0.08 mm/a

Maximum Long Term Slip Rate ~ 0.25 mm/a

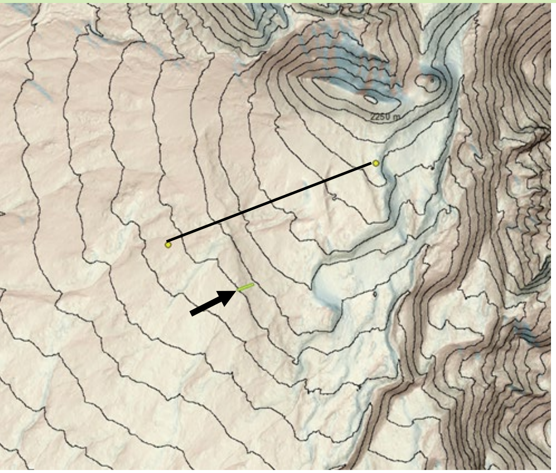
Paleoseismology on Central TLF (Bicknell Site)

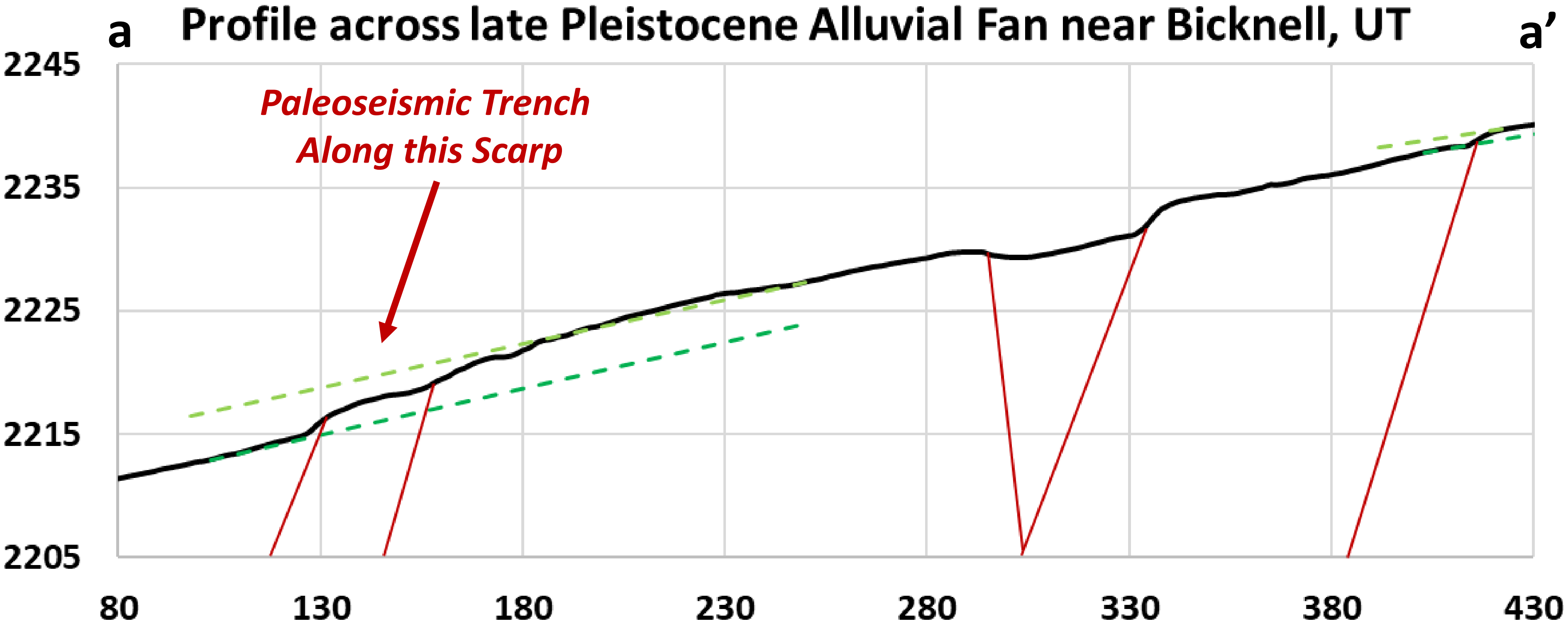


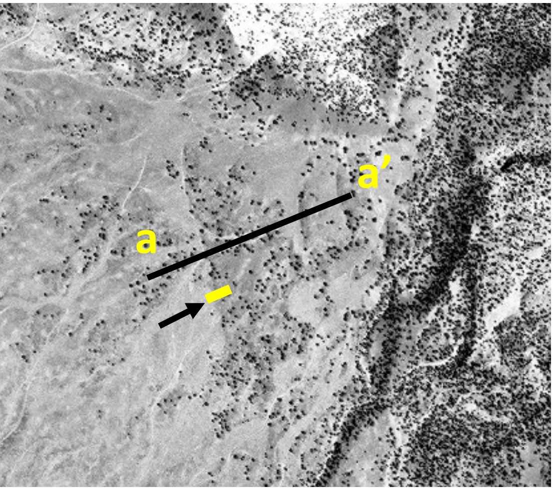




Fault Scarp Displacement Analysis







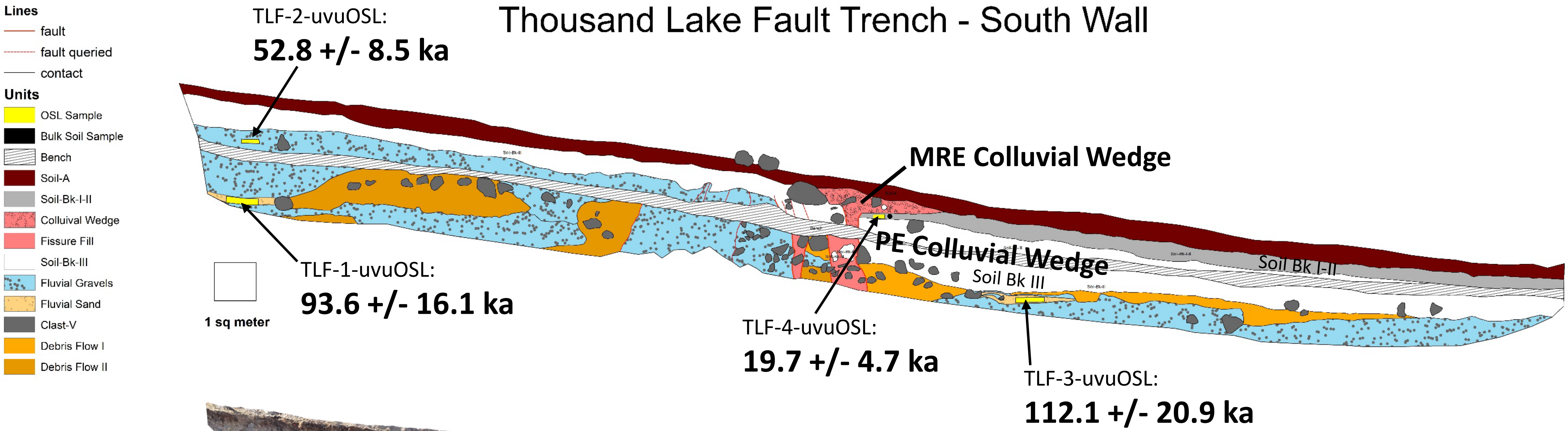
4.4 – 4.8 m of total surface displacement (since fan abandonment)

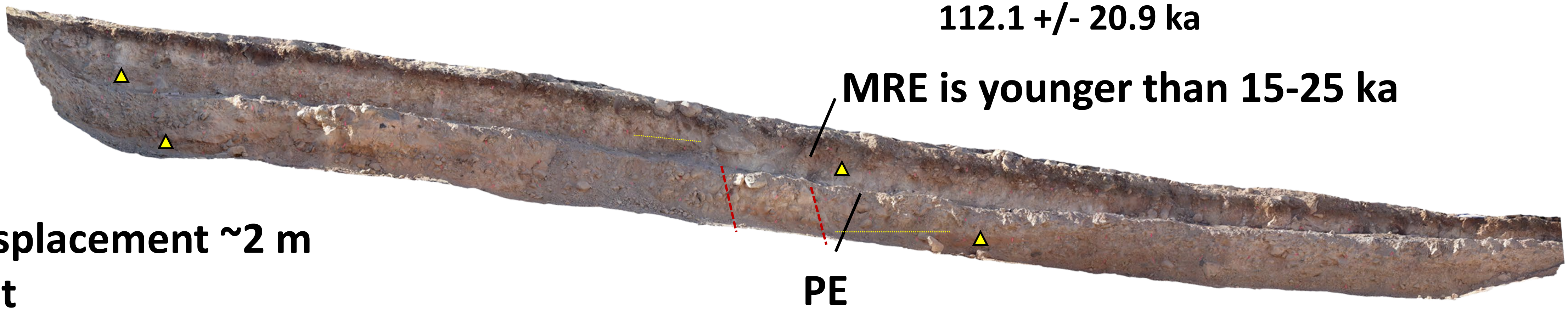
<u>**Uncertainties:**</u>

inflation/deflation of surfaces

width of fault zone

TLF Trench at the Bicknell Paleoseismic Site

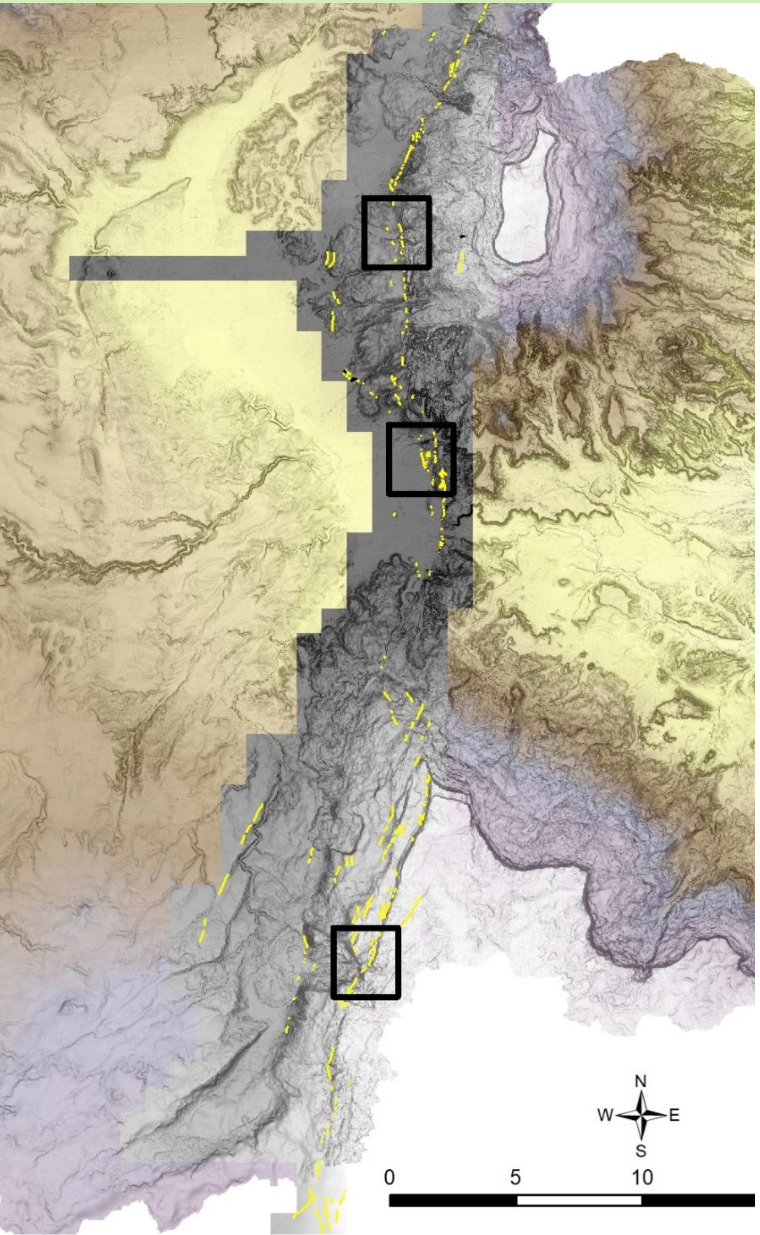




Vertical Displacement ~2 m
~1 m/event

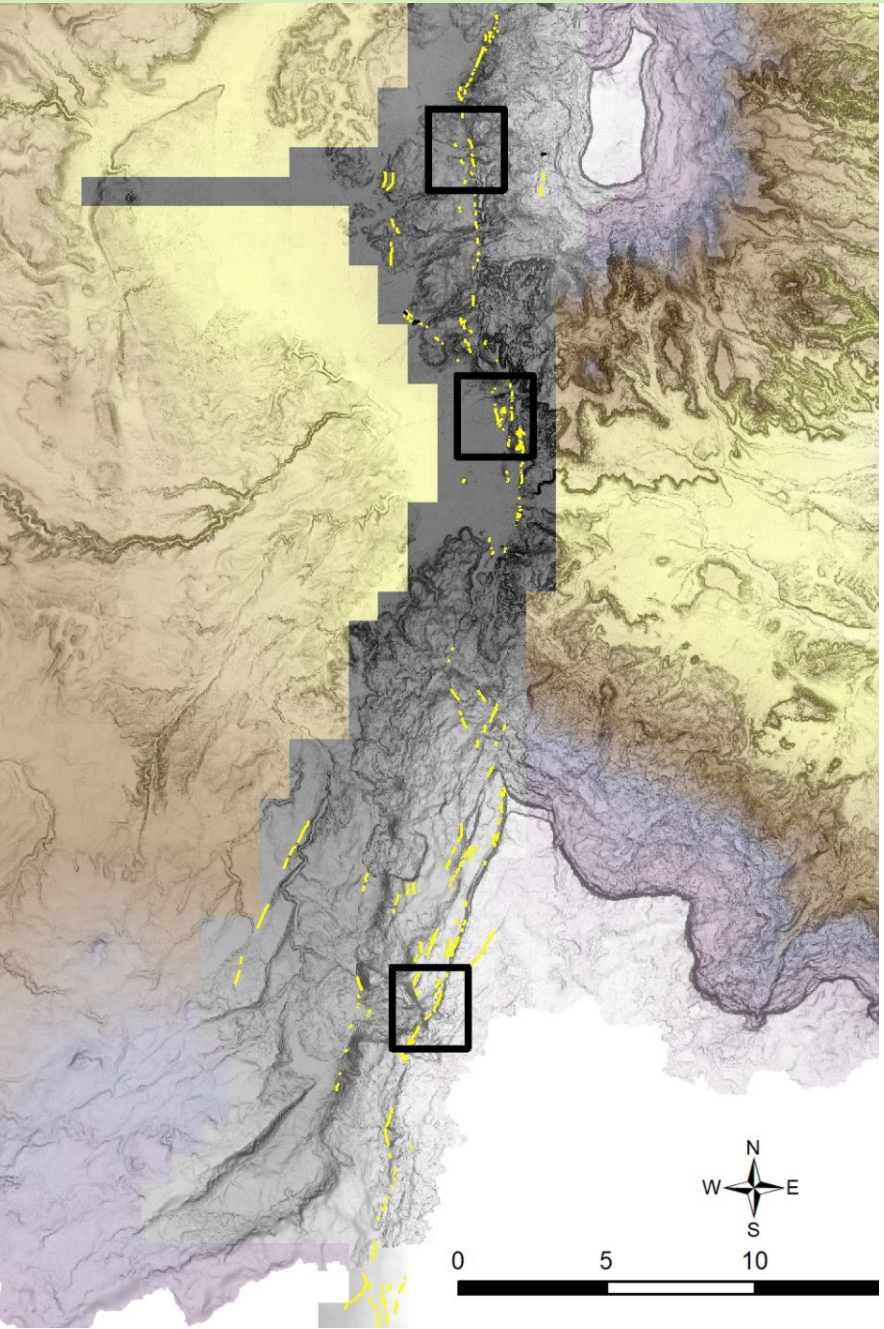
Likely occurred between 25 – 60 ka

Character of Faulting on the Southern TLF

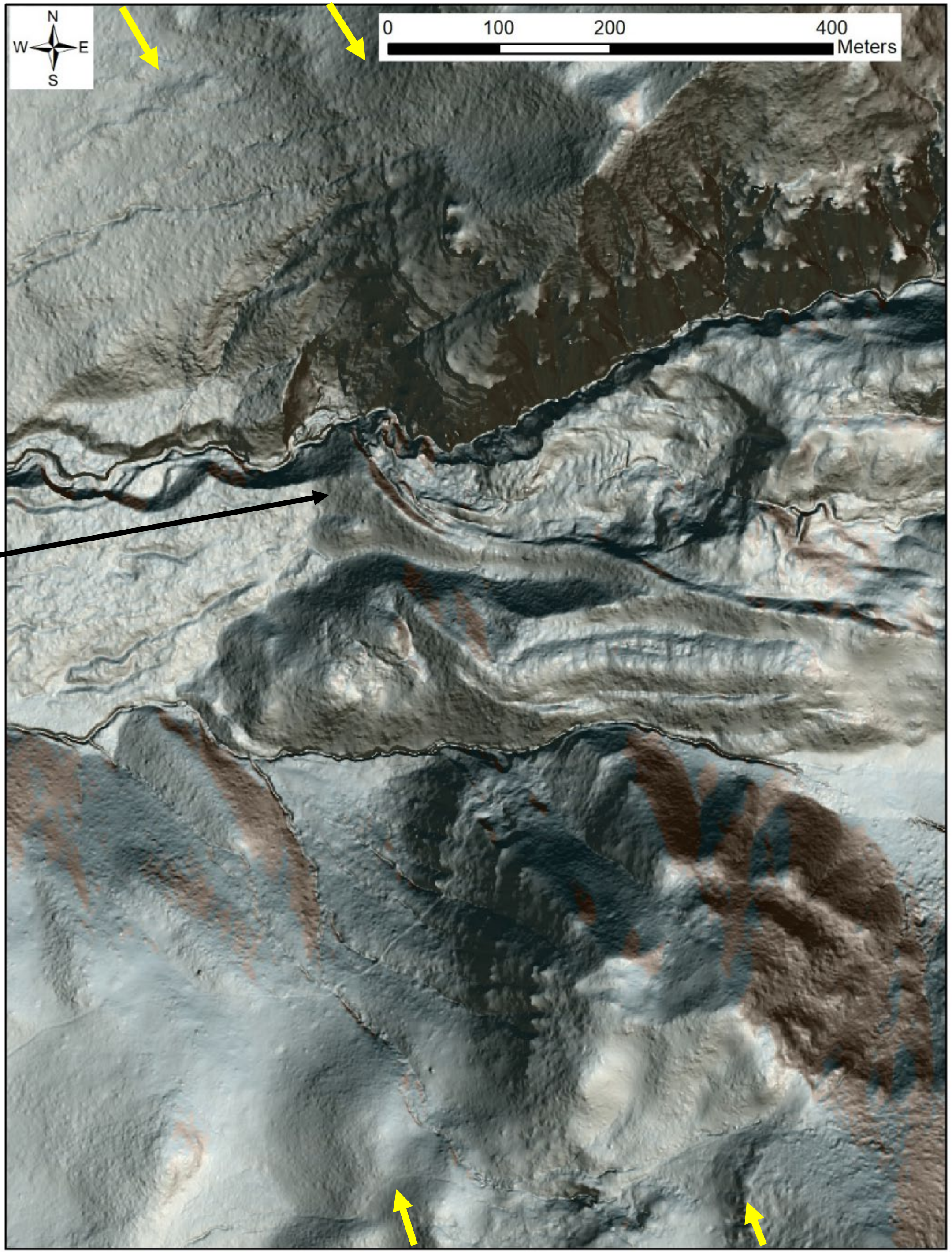


Clearly Scarps Cut:
Glacial Material
Post Glacial Debris Fan

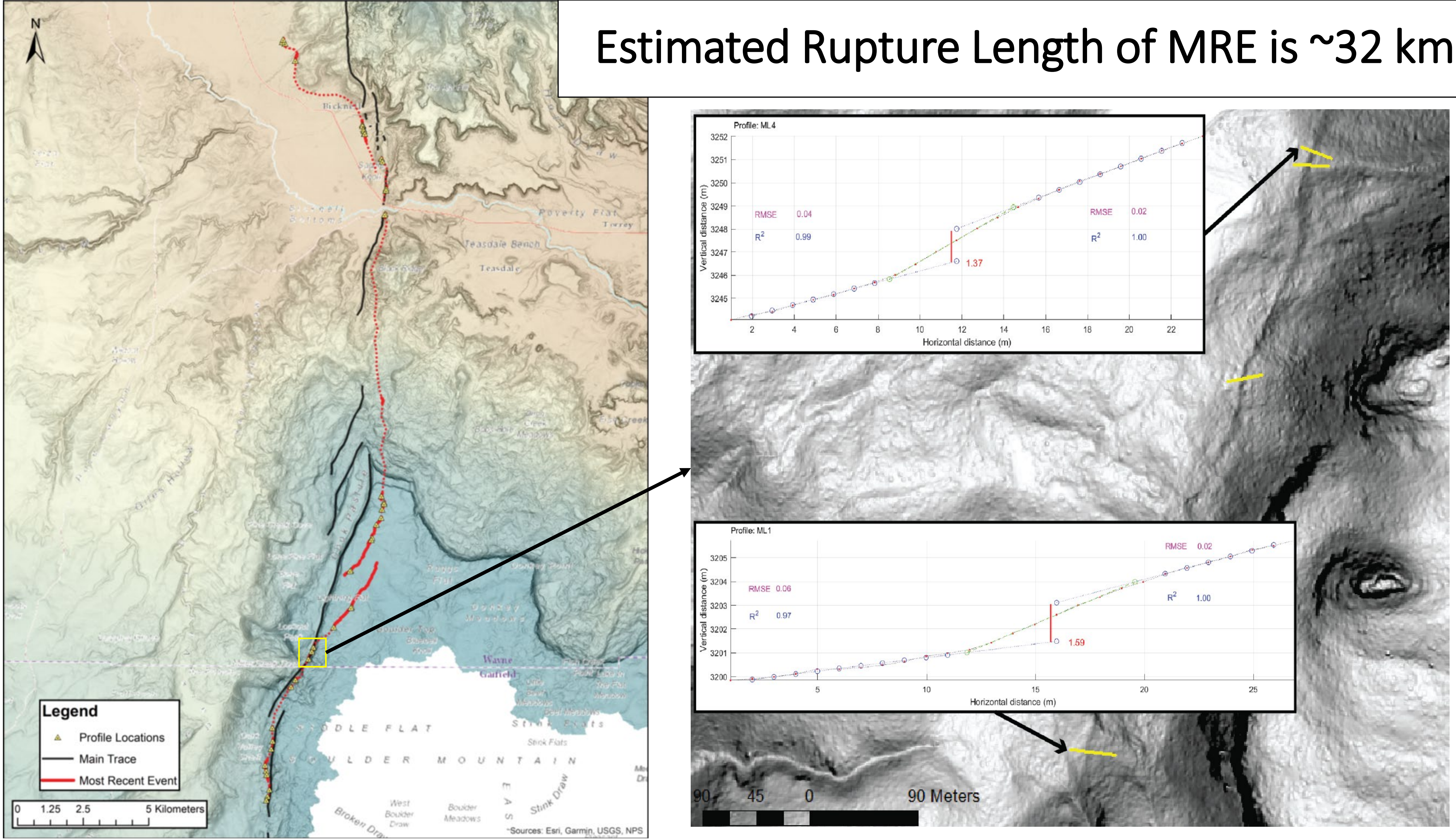
Character of Faulting in Northern TLF

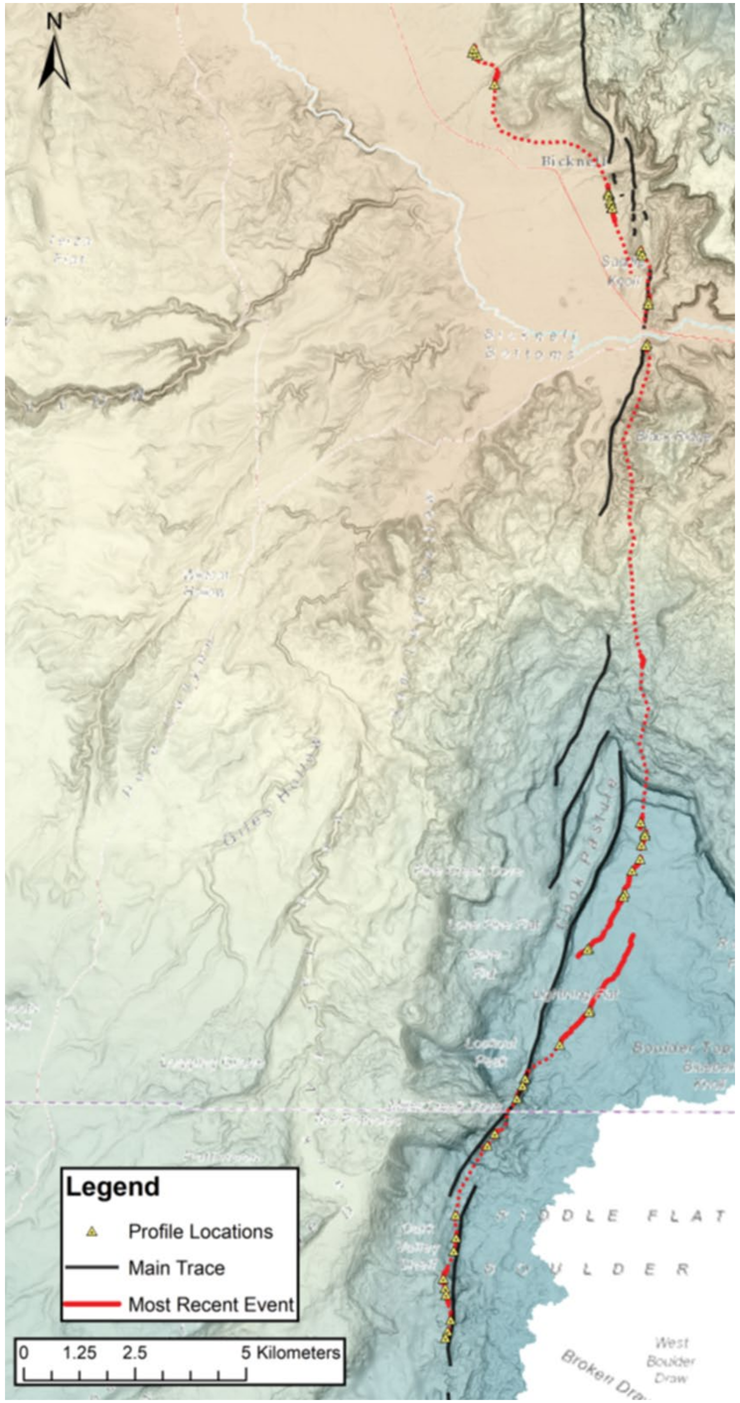


TLF Does not appear to cut LGM moraines



Estimated Rupture Length of MRE is ~32 km





Average displacements per 5km stretch of the MRE

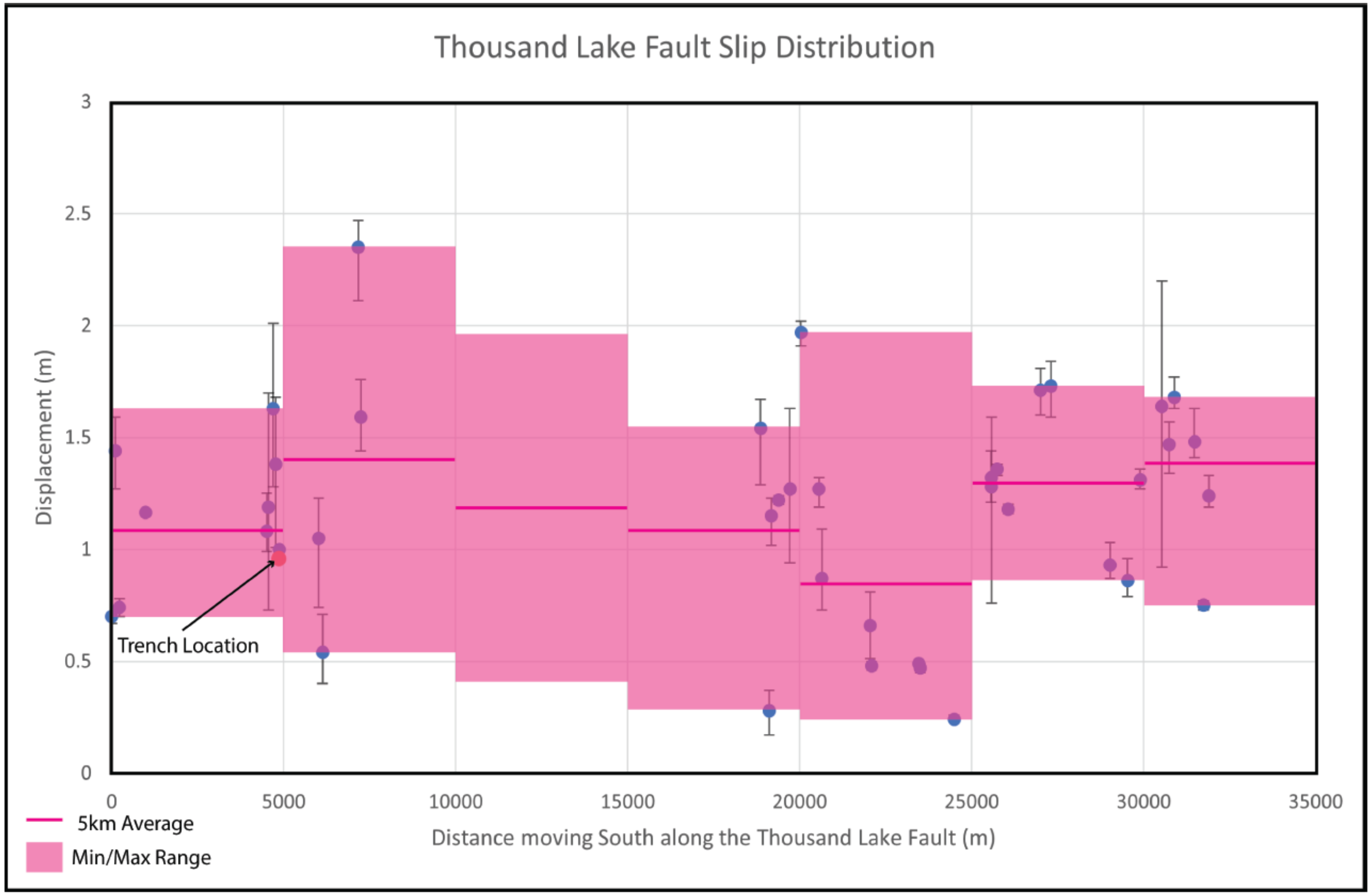
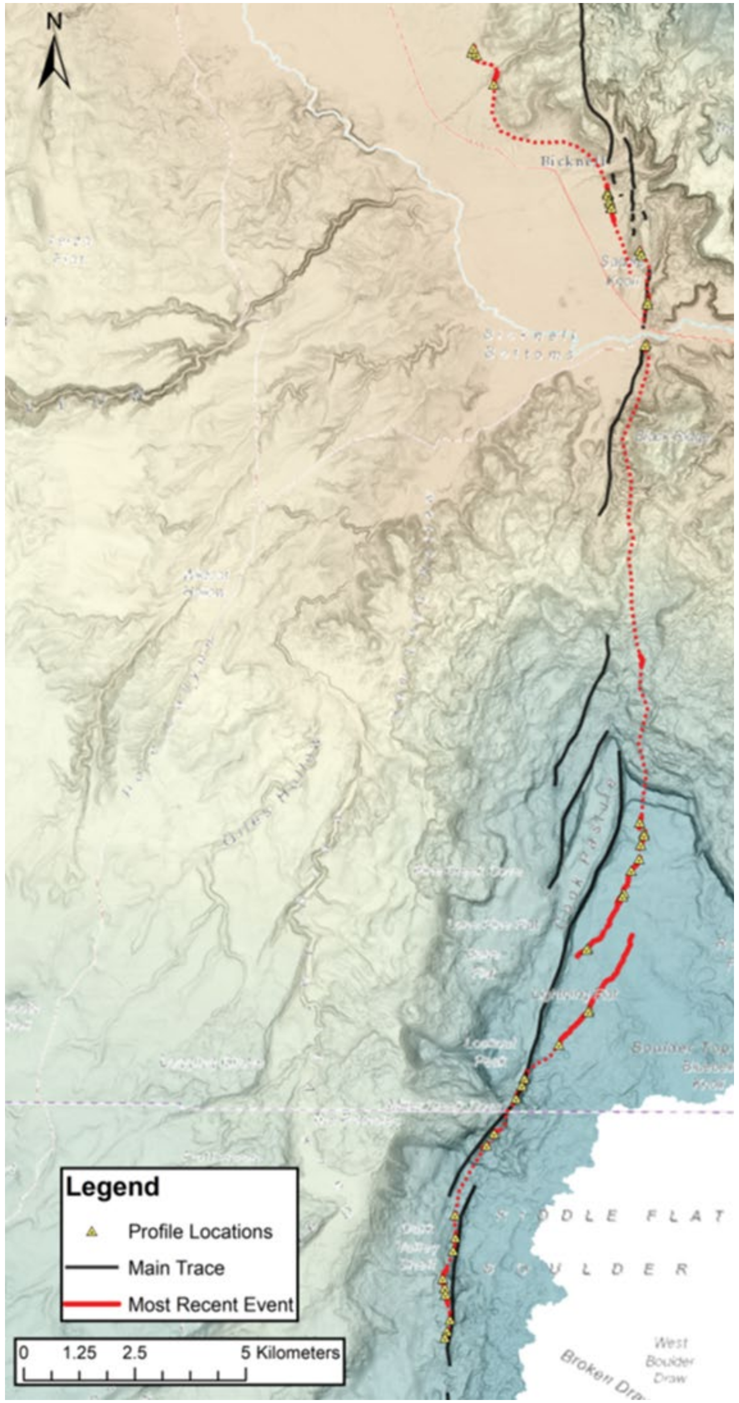


Figure 3. Mean, minimum, and maximum displacement values for each profile were obtained using the Scarp_VS program. Values were averaged within each 5km stretch of the TLF in order to calculate cumulative Moment for the MRE (**figure 4**).



The last event produced a M6.6-M6.9 earthquake

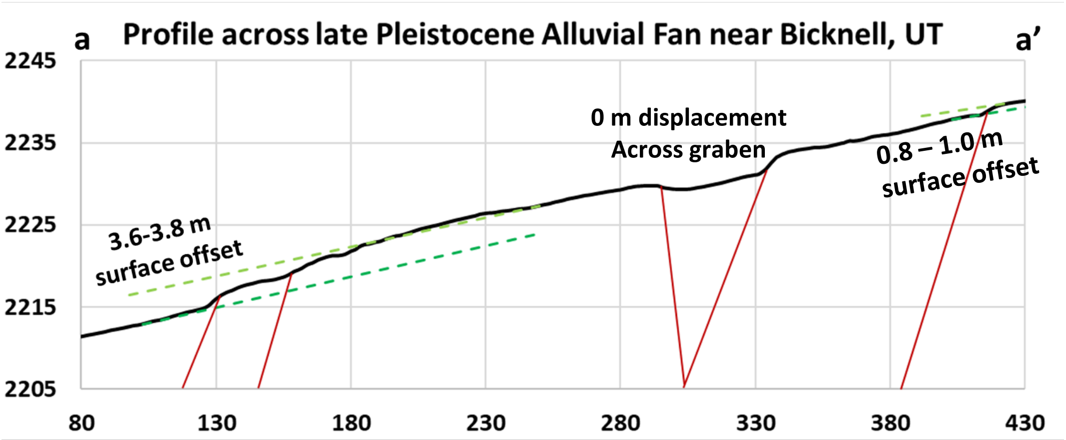
Moment Magnitude(M_W)									
	Displacement (m)			Fault Depth(km)			Seismic Moment(M_O)		
Stretch (km)	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
0-5	1.13	0.7	1.63	15	12	18	2.799E+25	1.389E+25	4.8521E+25
5-10	1.38	0.54	2.35	15	12	18	3.429E+25	1.072E+25	6.9954E+25
10-15	1.24	0.41	1.945	15	12	18	3.069E+25	8.136E+24	5.7898E+25
15-20	1.09	0.28	1.54	15	12	18	2.709E+25	5.557E+24	4.5842E+25
20-25	0.81	0.24	1.97	15	12	18	2E+25	4.763E+24	5.8642E+25
25-30	1.30	0.86	1.73	15	12	18	3.219E+25	1.707E+25	5.1498E+25
30-35	1.38	0.75	1.68	15	12	18	1.366E+25	5.954E+24	2.0004E+25
		Cumulative Moment					1.859E+26	6.608E+25	3.5236E+26
		Shear(μ)					3.31E+11		
		Moment Magnitude(M_W)					**6.813**	**6.513**	**6.998**

Standard (Hanks et al., 1979):
$M_W = (2/3)\log M_O - 10.7$
$\sigma = 0.243$ (in M_W)
$\mathbf{M_W = 6.76 \pm 0.24}$

Wesnousky (2008): $M_W = 6.12 + 0.47\log L$
L: surface rupture length (31.891km)
$\sigma = 0.27$ (in M_W)
$\mathbf{M_W = 6.83 \pm 0.27}$

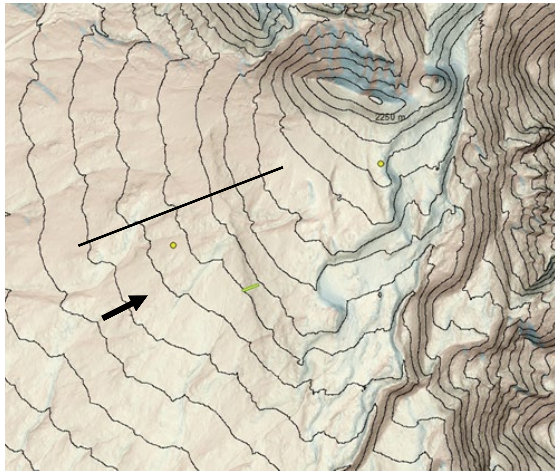
Figure 4. When using the standard equation for moment magnitude and the cumulative moment values for each 5km segment, a value for moment magnitude is obtained that is consistent with Wesnousky (2008).

Paleoseismic Summary: Thousand Lake Fault



At least 4.4 – 4.8 m surface displacement (since fan abandonment)

<u>Uncertainties:</u>
inflation/deflation of surfaces
width of fault zone



<u>Average Recurrence</u> (Trench Data)

- 2 Events since 61 ka = ~ 30 ka/event

<u>Average Recurrence</u> across alluvial Fan surface with ~ 5 m of displacement

- 4 events in ~60-120 ka = ~ 15-30 ka/event
- <u>Most likely Recurrence = 20-25 ka/event</u>

Expected recurrence from geologic slip rate and average slip-per-event = ~ 1+ m/event:

- 1*(m/event)*/0.25*(mm/yr)* = 4 ka/event
- 1.5(m/event)/0.08*(mm/yr)* = 19 ka/event

<u>Late Pleistocene Slip Rate</u>:
(4.4 to 4.8 m)/(60-120 ka) = 0.04-0.08 mm/a

Paleoseismic Summary: Thousand Lake Fault

- **Late Pleistocene Slip Rate**

0.04-0.08 mm/a

- **Active since LGM**

(< 20 ka)

- **Recurrence Rate**

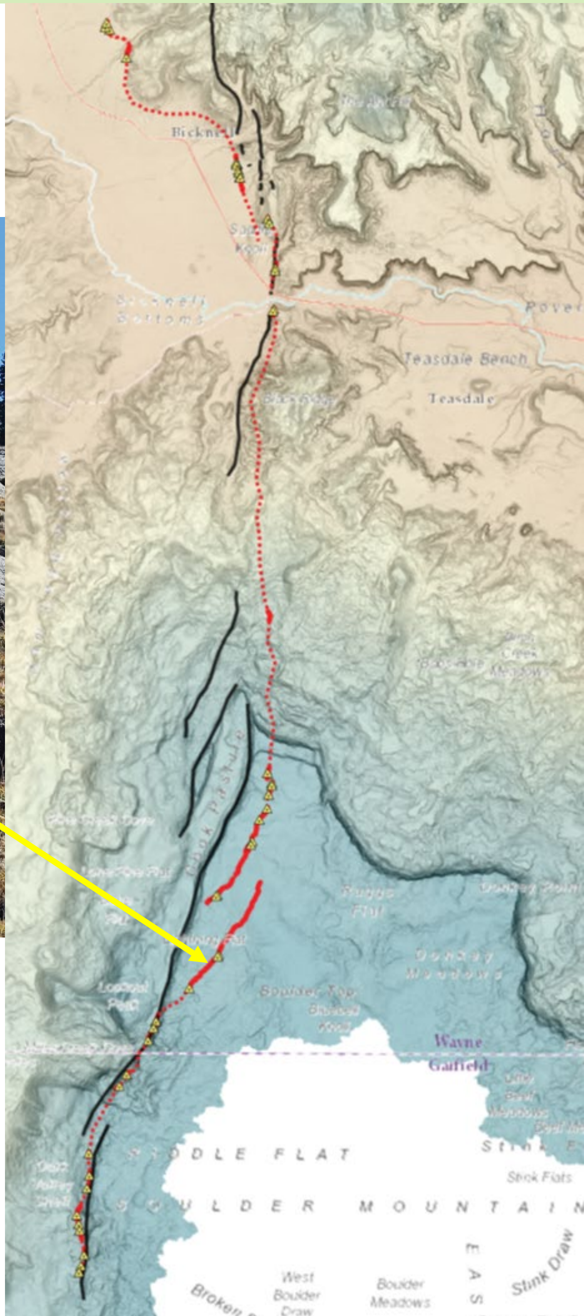
15-30 ka/event

- **Most Recent Event**

Rupture Length: ~ 30 km

Magnitude: 6.6-6.9

Some scarps may have soil creep enhancement!



References and Acknowledgments

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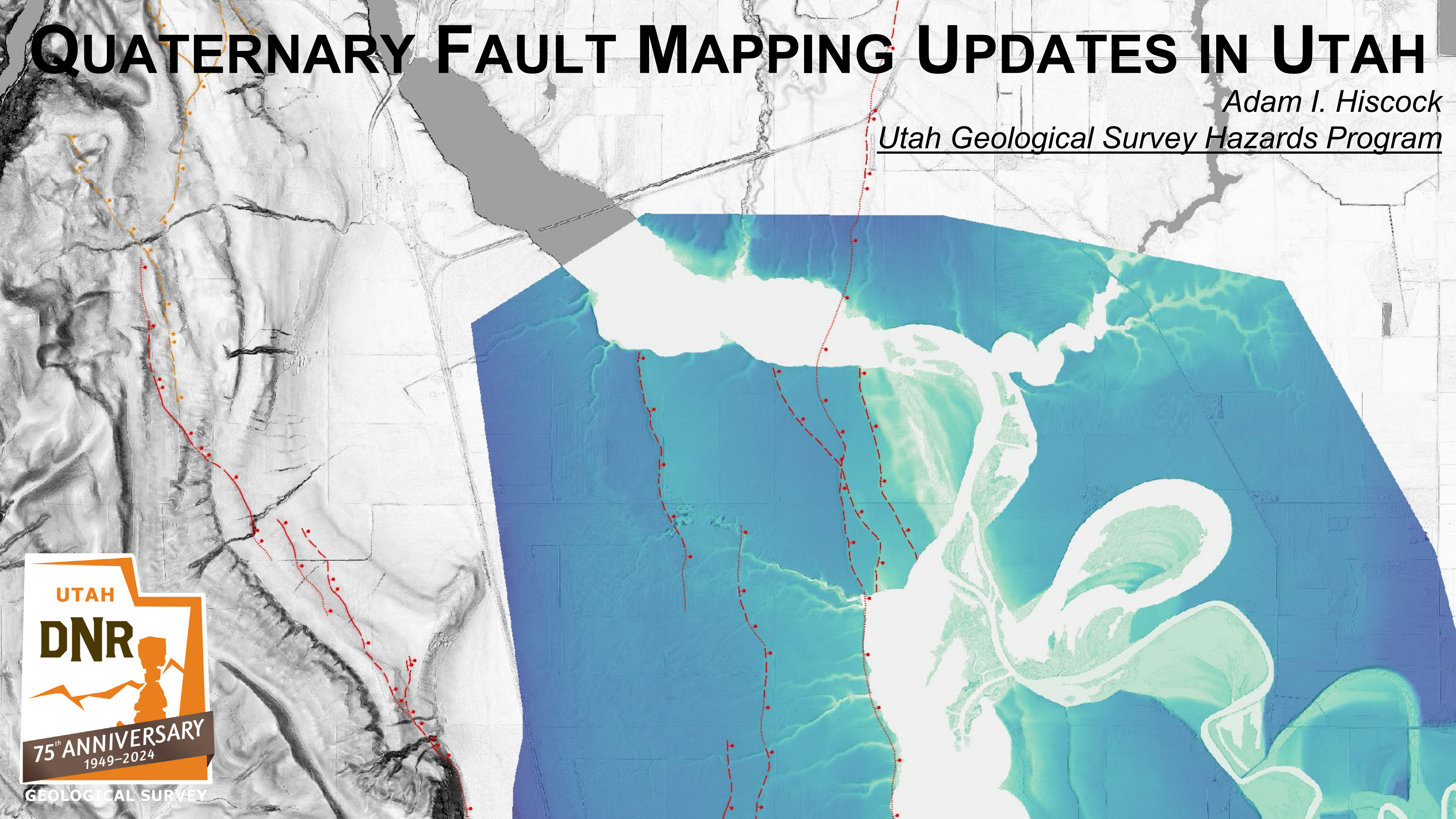
We would like to acknowledge collaboration since 2017 with David Marchetti, Chuck Bailey, and Tammy Rittenour who are not listed as co-authors on this poster but are coauthors and collaborators on the overall investigation. Additionally, Bob Biek's mapping and discussions helped inform some of our interpretations. Utah Geological Survey geologists (Adam Hiscock and Emily Kleber) provided review and advice with the 2018 trenching investigation. Previous aspects of this work have been aided by prior student collaborators including Rachel Richards, Sally Ward, Hanna Bartram, Chris Langevin, Joseph Phillips, and Clayton Forster. UVU's COS SAC program supported Rachel Richards and Sally Ward to prepare and process OSL samples at Utah State University under the guidance of Carlie Ideker and Tammy Rittenour. The department of Earth Science helped support Dr. Toke's time in the field while teaching GEO 4600.

QUATERNARY FAULT MAPPING UPDATES IN UTAH

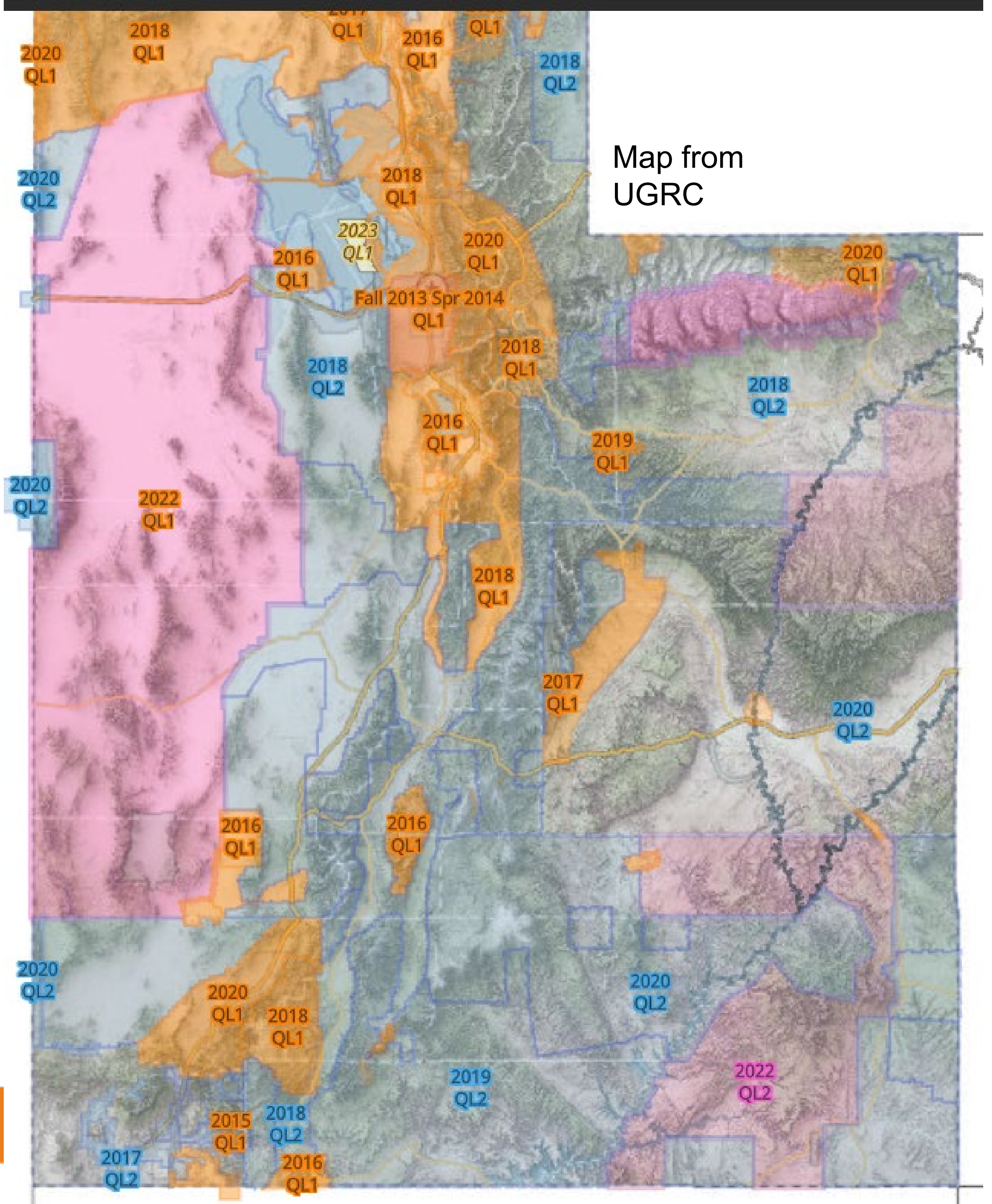
Adam I. Hiscock
Utah Geological Survey Hazards Program



UTAH DNR
75th ANNIVERSARY 1949–2024
GEOLOGICAL SURVEY

Objectives

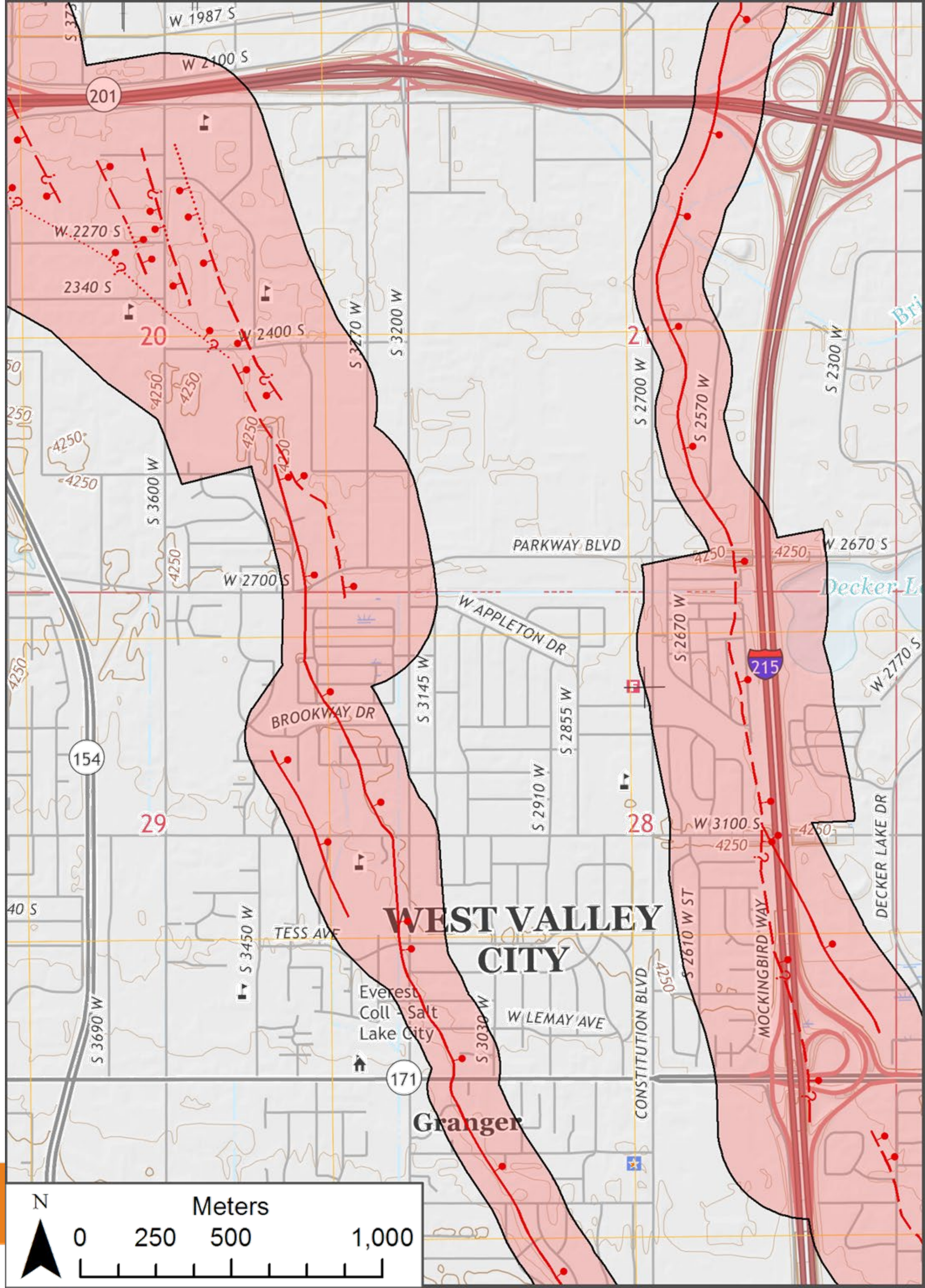
- Availability of high resolution lidar data has expanded greatly in the past decade - great tool for characterizing and identifying active faults
- The UGS has been involved in multiple USGS External Grants funded fault mapping projects since 2014
- New mapping available through the UGS's *Utah Geologic Hazards Portal,* and used for updates to the USGS National Seismic Hazard Maps.
- Necessary to help characterize and identify active faults in rapidly growing and urbanizing parts of Utah
- Identify potential paleoseismic trenching sites



Map from UGRC

Surface Fault Rupture Special-Study-Zones (SSZ)

- Special-study-zones are delineated around each mapped trace
- Assist local governments with urban planning and developing hazard ordinances
- Help facilitate understanding of the hazard by triggering additional surface faulting studies
- Based on UGS Circular 128 – *Guidelines for evaluating surface-fault-rupture hazards in Utah*. https://doi.org/10.34191/C-128.

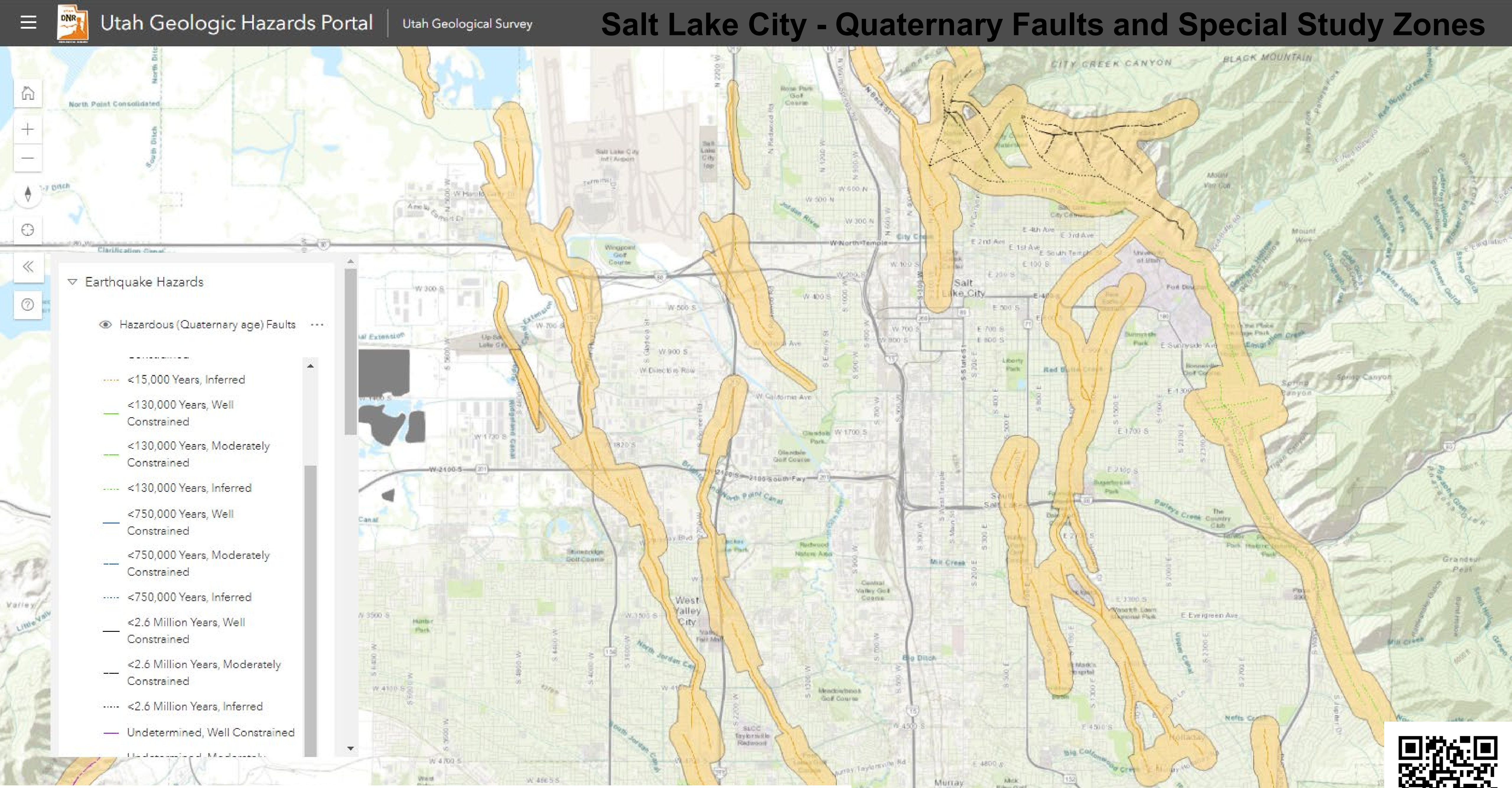


Utah Geologic Hazards Portal

- One-stop-shop for all UGS Geologic Hazards Mapping products (fault mapping, special-study-zones, landslide susceptibility, flooding, problem soils, etc.)
- Replaced the Utah Quaternary Fault and Fold Database (UQFFD) webmap – UQFFD now lives on the Hazards Portal.

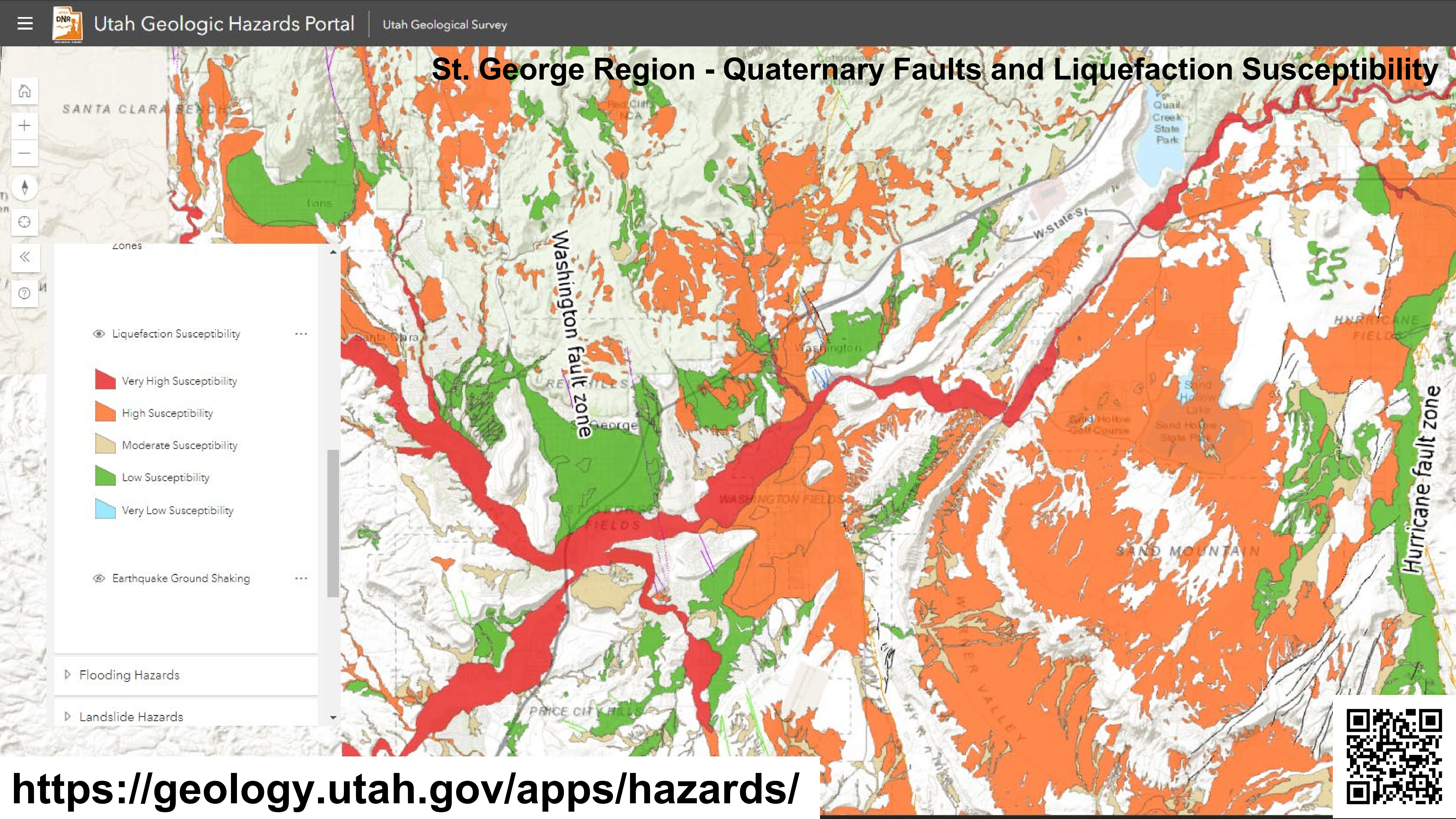
https://geology.utah.gov/apps/hazards/

Salt Lake City - Quaternary Faults and Special Study Zones



https://geology.utah.gov/apps/hazards/

St. George Region - Quaternary Faults and Liquefaction Susceptibility

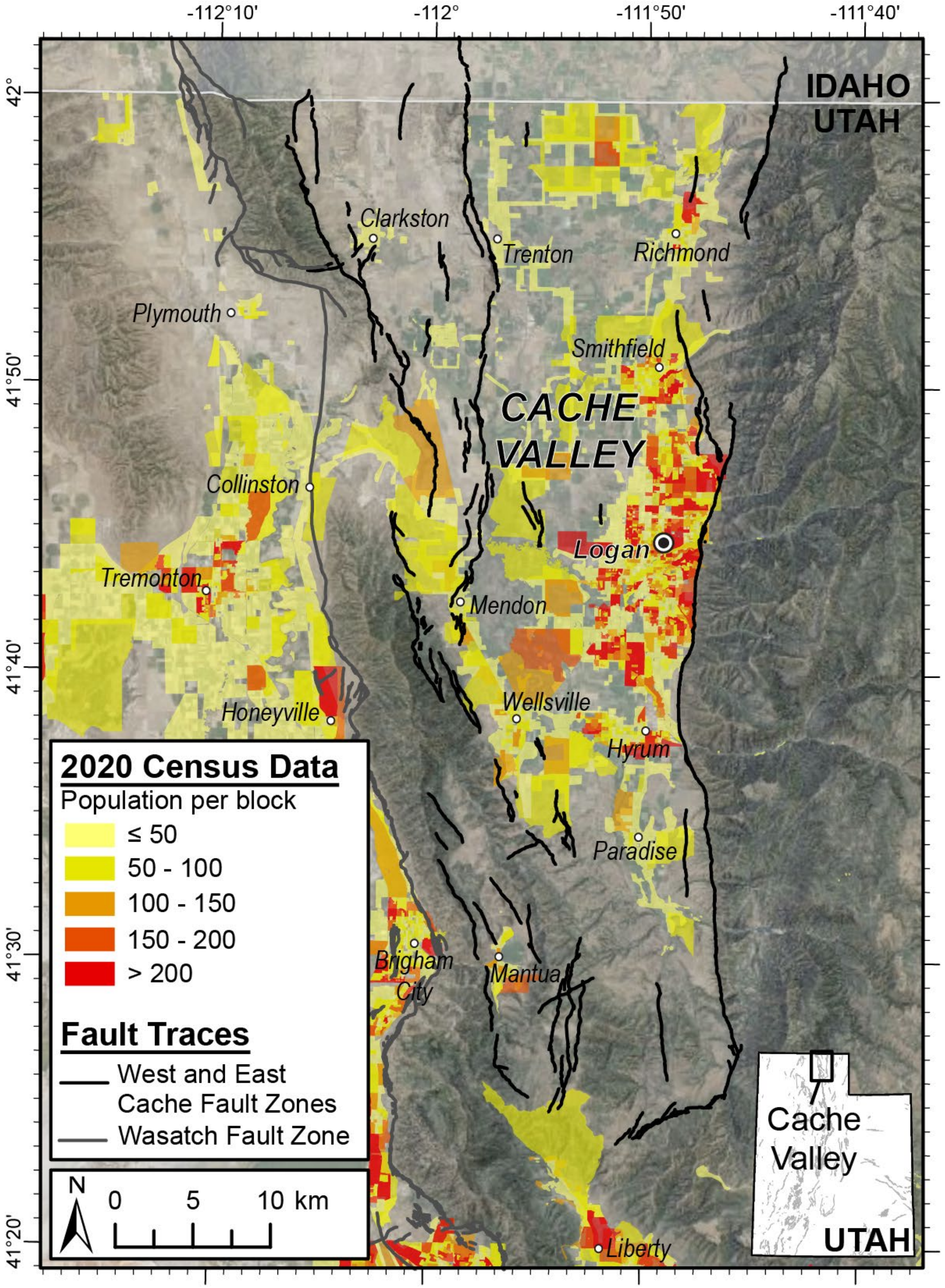


https://geology.utah.gov/apps/hazards/

Cache Valley Fault Mapping

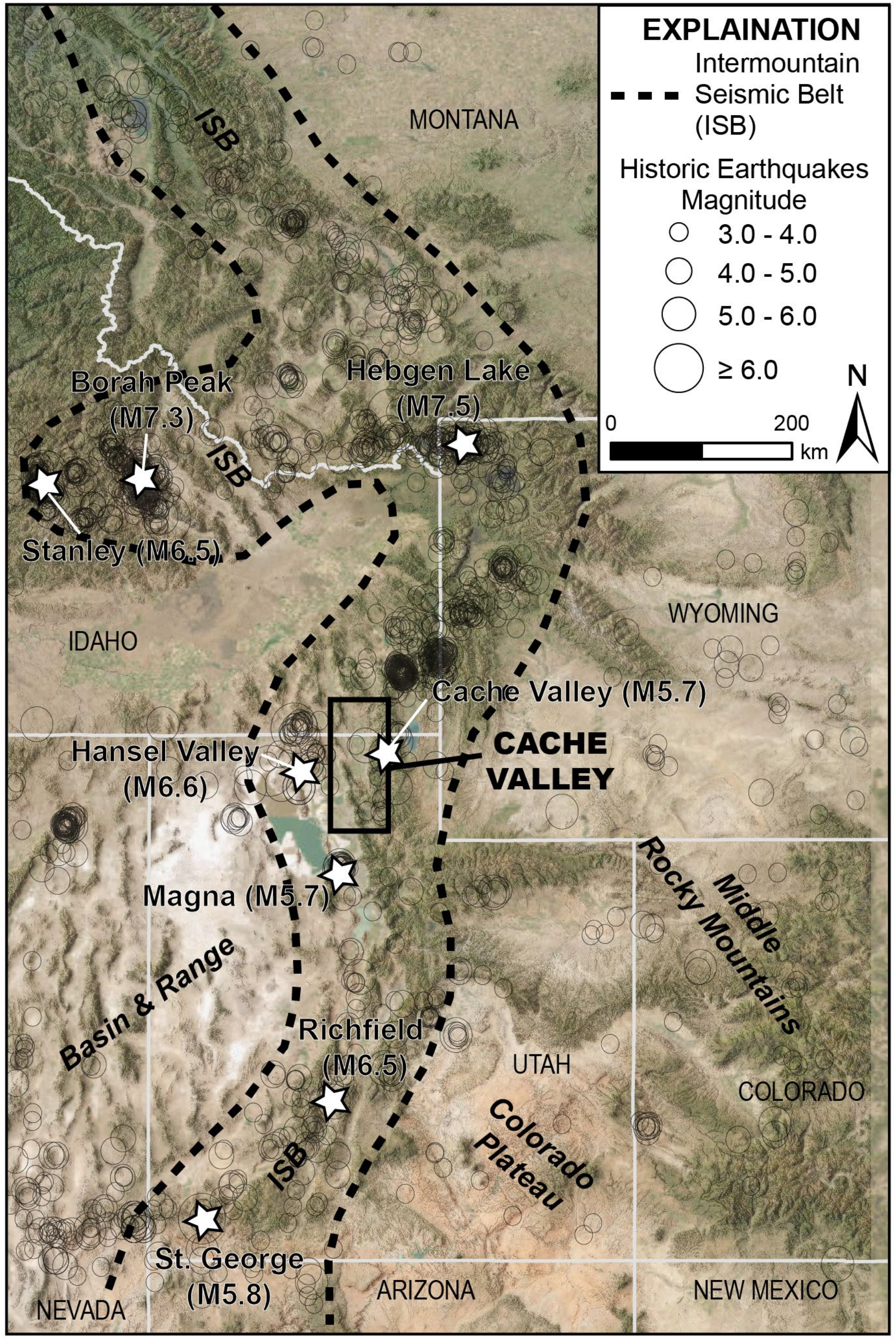
- Adam I. Hiscock, Emily J. Kleber, Greg N. McDonald (UGS); Susanne Jänecke, Bob Oaks, Tammy Rittenour (USU). Additional guidance, reviews from others at USU.
- Funded by USGS External Grants in 2017 - Final Technical Report submitted in 2020 (14 7.5-minute plates).
- Re-mapped at 1:10,000 scale (or better)

- **COMING SOON! Currently in review, hope to have published as a UGS Report of Investigation in the next couple months. Mapping will be in Hazards Portal & GIS Database w/report.**



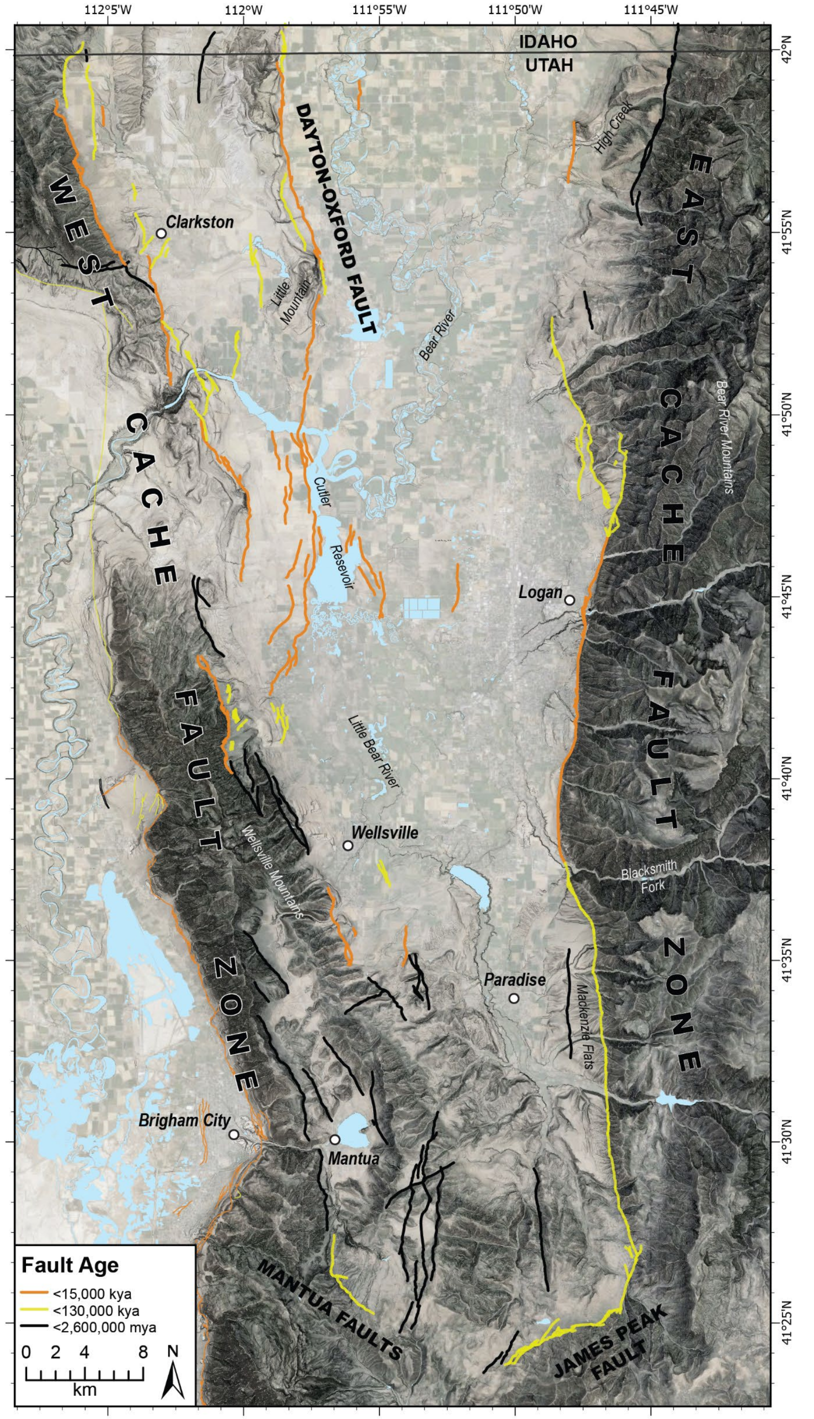
Cache Valley – Tectonic Setting

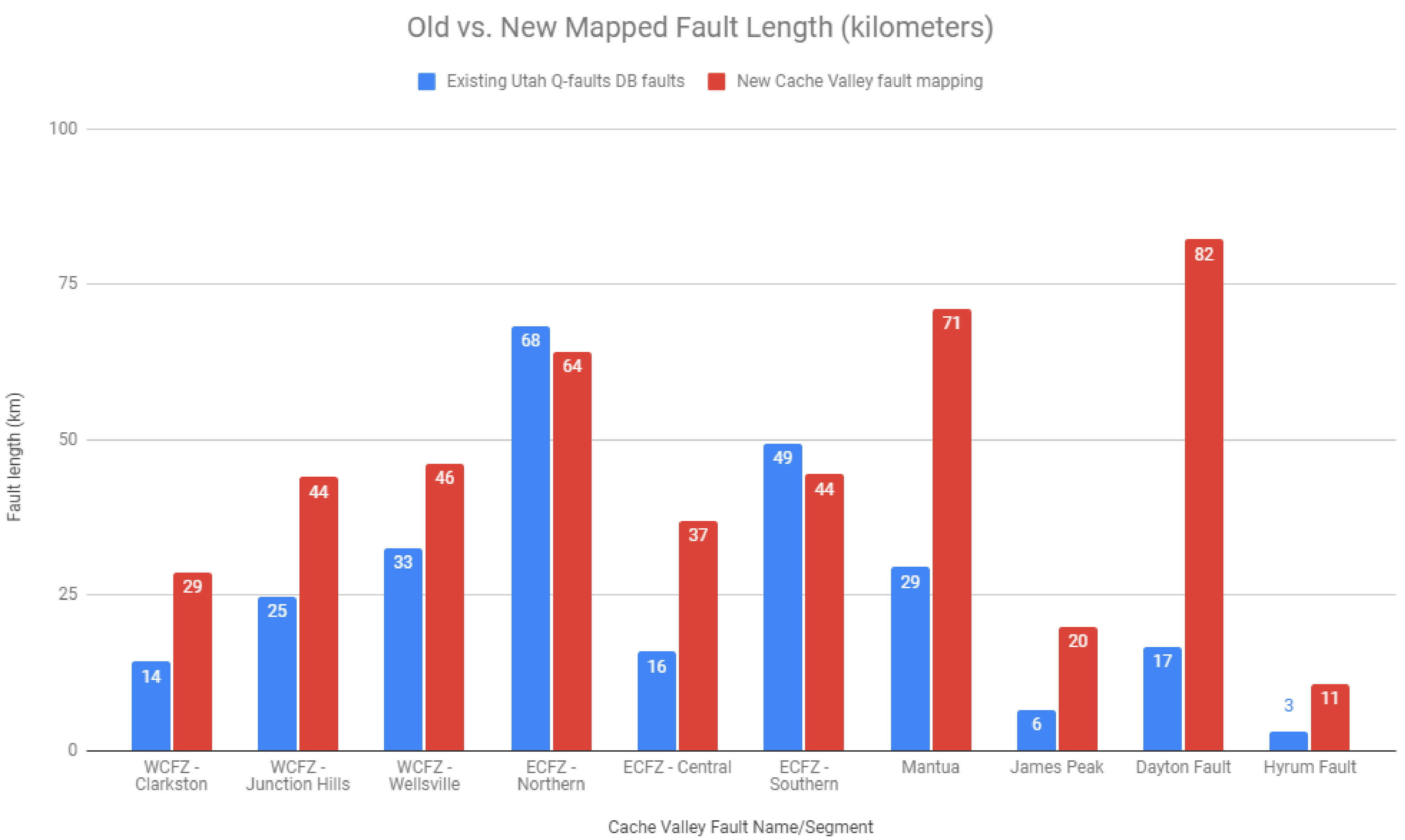
- In the structural transition zone between the extending Basin & Range to the west and the Rocky Mountains to the east.
- Structurally bounded by the ECFZ and WCFZ – seismic data suggests the WCFZ has less displacement than the ECFZ
- In the middle of the Intermountain Seismic Belt (ISB) zone of intraplate seismicity extending from Arizona to Montana.
- 1962 M5.7 Cache Valley quake: Property damage in Richmond including cracked/collapsed walls and roofs, broken masonry, etc.
- Very limited paleoseismic data available for the ECFZ and WCFZ – only a couple research-level trench studies conducted.



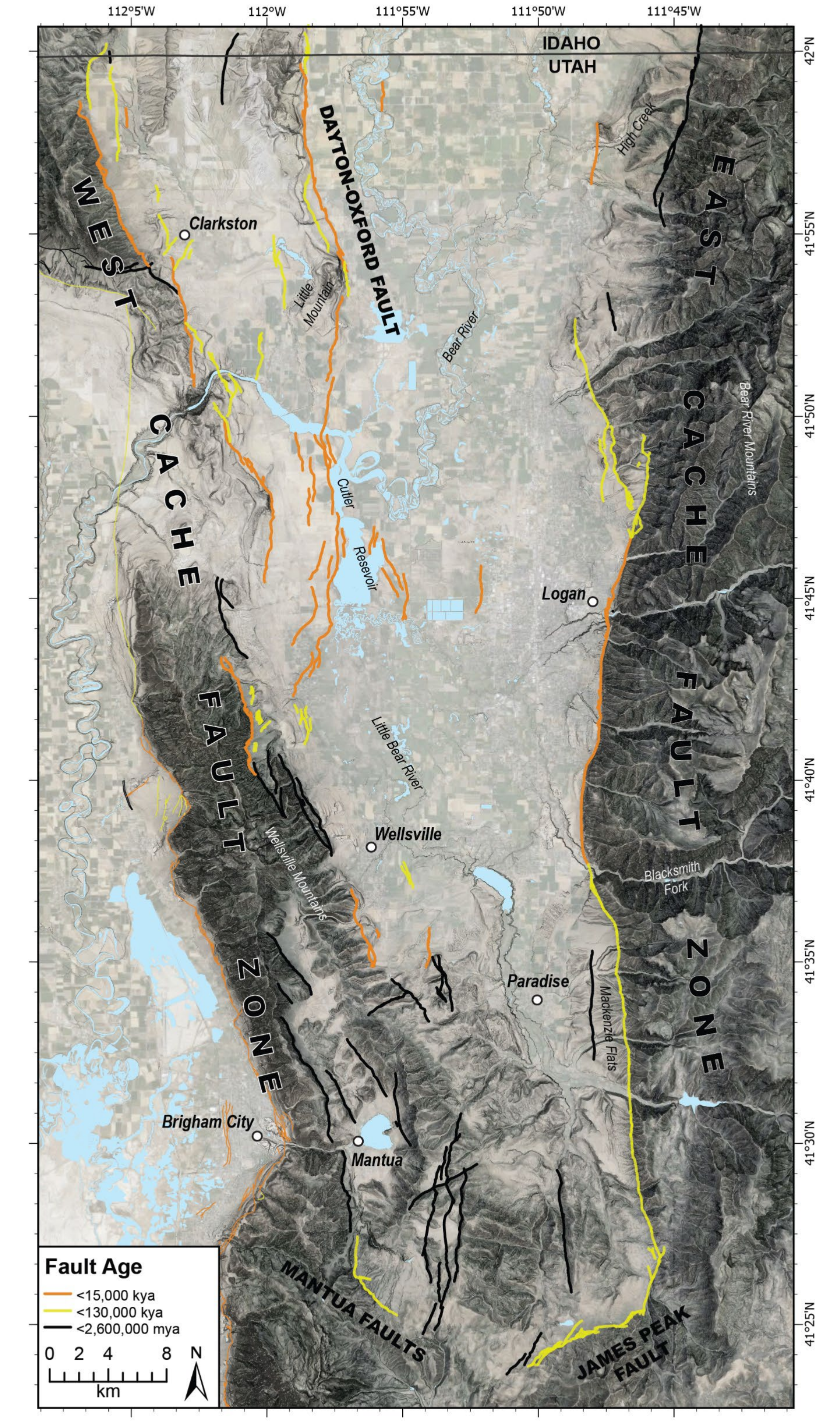
Cache Valley – New Mapping

- Re-Mapped the East and West Cache Fault Zones (ECFZ and WCFZ), and other regional faults, including: Dayton-Oxford Fault, Mantua Area Faults, Hyrum Fault, and James Peak Fault.
- Added substantial length and much better detail to all regional faults.
  - 188 km added length of faults compared to UQFFD.

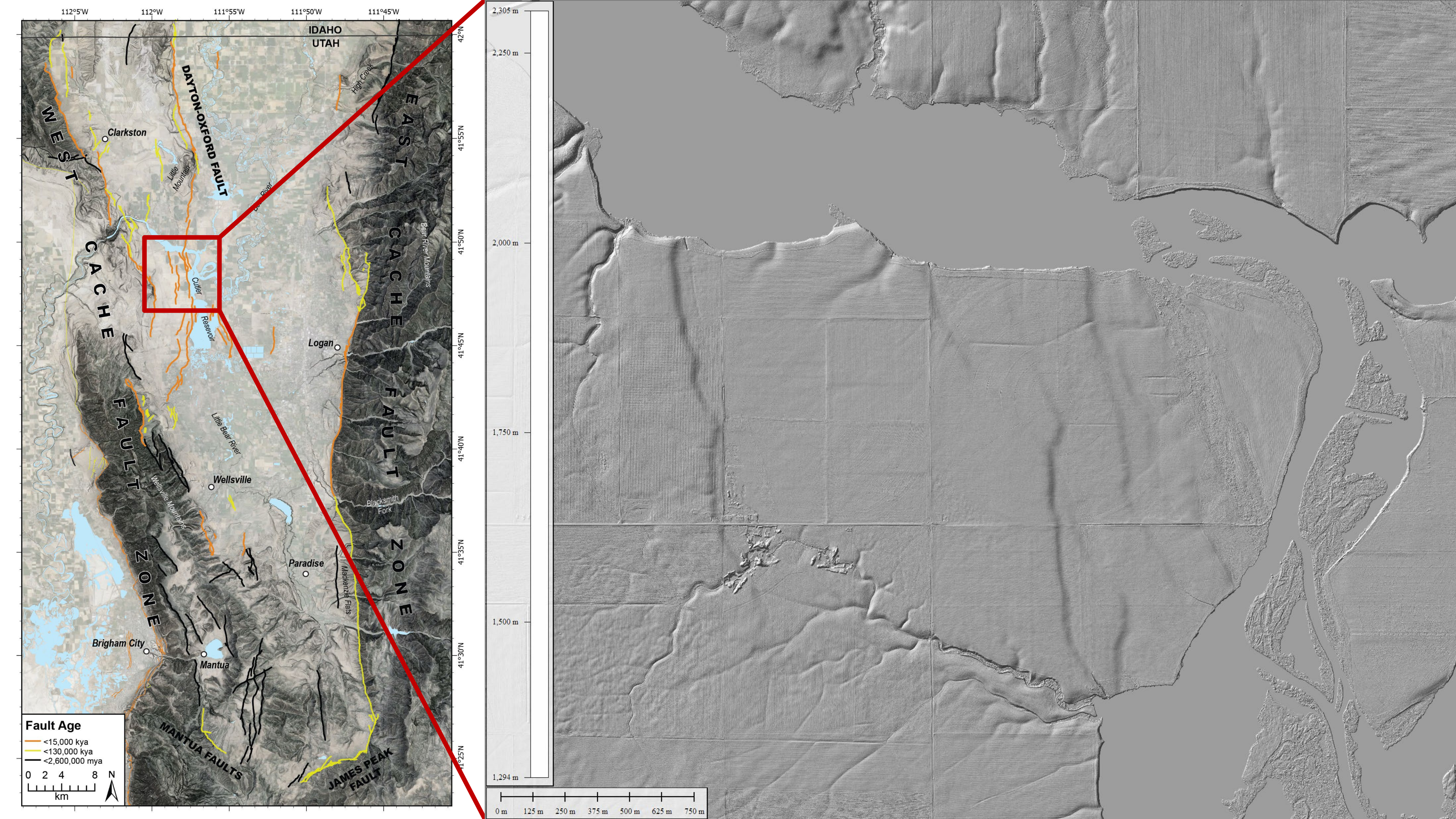




Old vs. New Mapped Fault Length (kilometers)
Existing Utah Q-faults DB faults
New Cache Valley fault mapping
Fault length (km)
100
75
50
25
0
14
29
25
44
33
46
68
64
16
37
49
44
29
71
6
20
17
82
3
11
WCFZ - Clarkston
WCFZ - Junction Hills
WCFZ - Wellsville
ECFZ - Northern
ECFZ - Central
ECFZ - Southern
Mantua
James Peak
Dayton Fault
Hyrum Fault
Cache Valley Fault Name/Segment



112°5'W
112°W
111°55'W
111°50'W
111°45'W
42°N
41°55'N
41°50'N
41°45'N
41°40'N
41°35'N
41°30'N
41°25'N
IDAHO
UTAH
DAYTON-OXFORD FAULT
High Creek
Clarkston
WEST CACHE FAULT ZONE
EAST CACHE FAULT ZONE
Little Mountain
Bear River
Bear River Mountains
Cutler Reservoir
Logan
Little Bear River
Wellsville
Wellsville Mountains
Blacksmith Fork
Paradise
Mackenzie Flats
Brigham City
Mantua
MANTUA FAULTS
JAMES PEAK FAULT
Fault Age
<15,000 kya
<130,000 kya
<2,600,000 mya
0 2 4 8
km
N


112°5'W
112°W
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42°N
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41°35'N
41°30'N
41°25'N
IDAHO
UTAH
DAYTON-OXFORD FAULT
WEST CACHE FAULT ZONE
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Clarkston
Little Mountain
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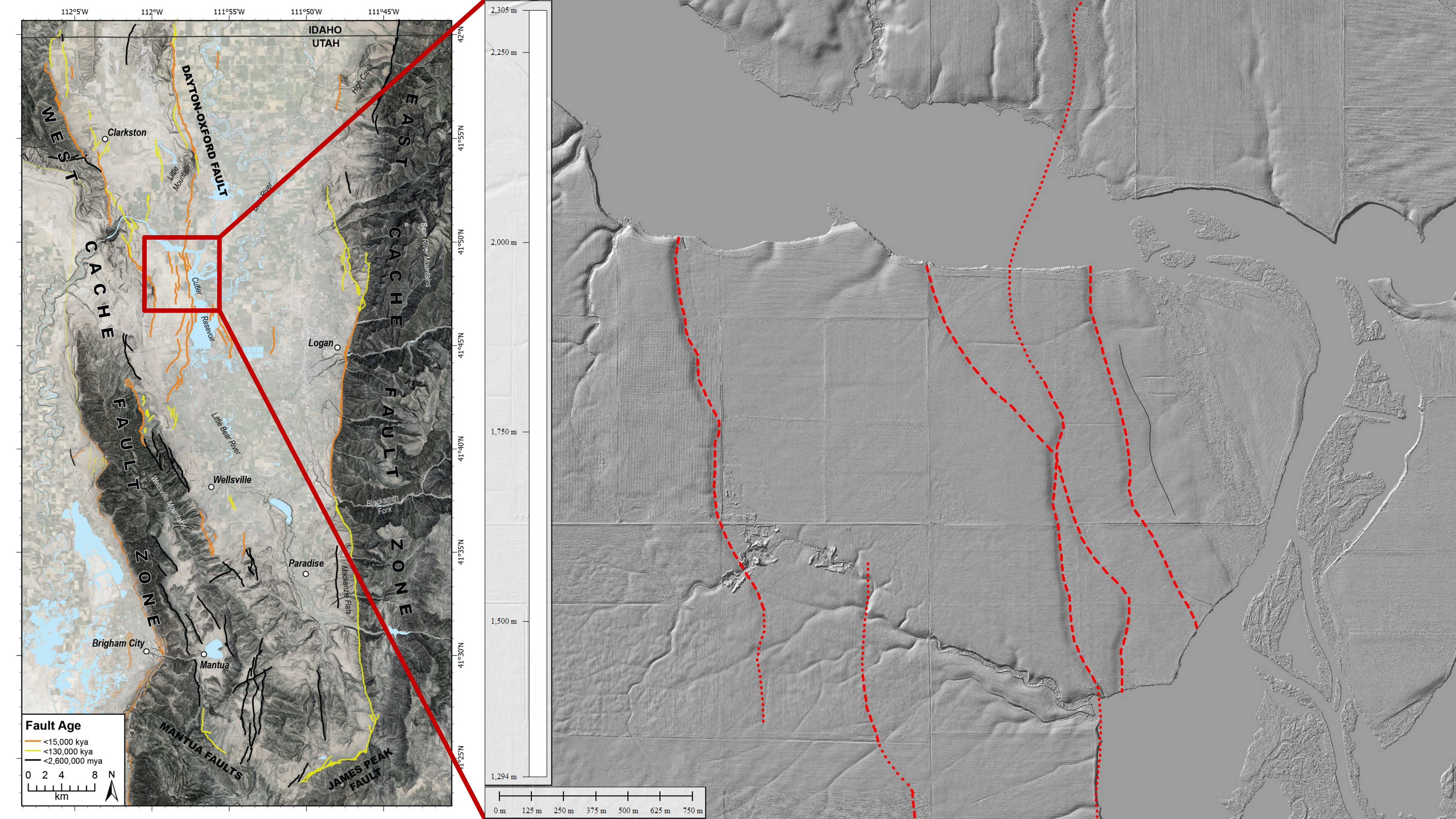
Paradise
Mackenzie Flats
Brigham City
Mantua
MANTUA FAULTS
JAMES PEAK FAULT
Fault Age
<15,000 kya
<130,000 kya
<2,600,000 mya
0 2 4 8
km
N
2,305 m
2,250 m
2,000 m
1,750 m
1,500 m
1,294 m
0 m
125 m
250 m
375 m
500 m
625 m
750 m



112°5'W
112°W
111°55'W
111°50'W
111°45'W
IDAHO
UTAH
42°N
41°55'N
41°50'N
41°45'N
41°40'N
41°35'N
41°30'N
41°25'N
WEST CACHE FAULT ZONE
DAYTON-OXFORD FAULT
EAST CACHE FAULT ZONE
Clarkston
Little Mountain
Bear River
High Creek
Bear River Mountains
Cutler Reservoir
Logan
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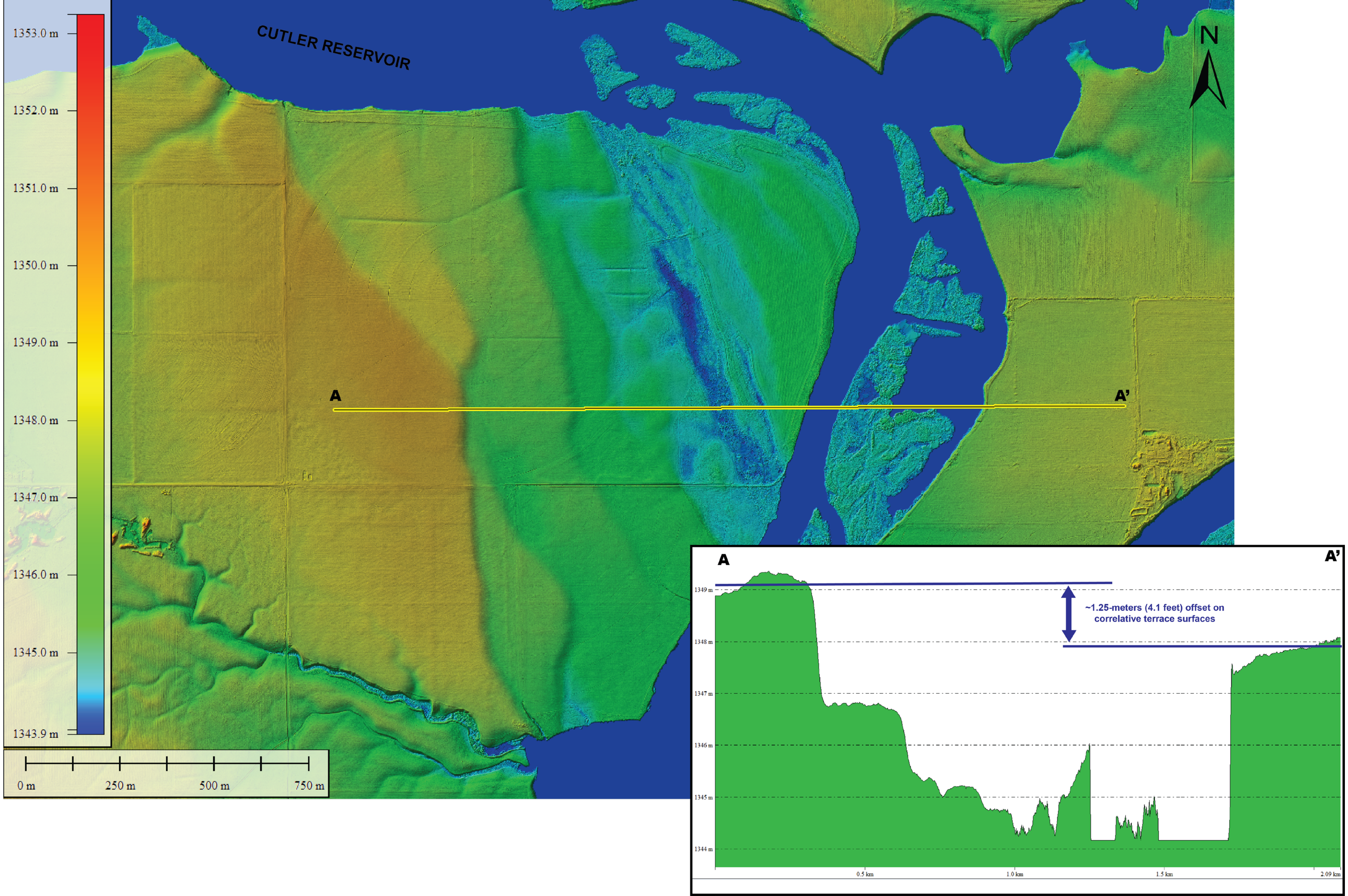
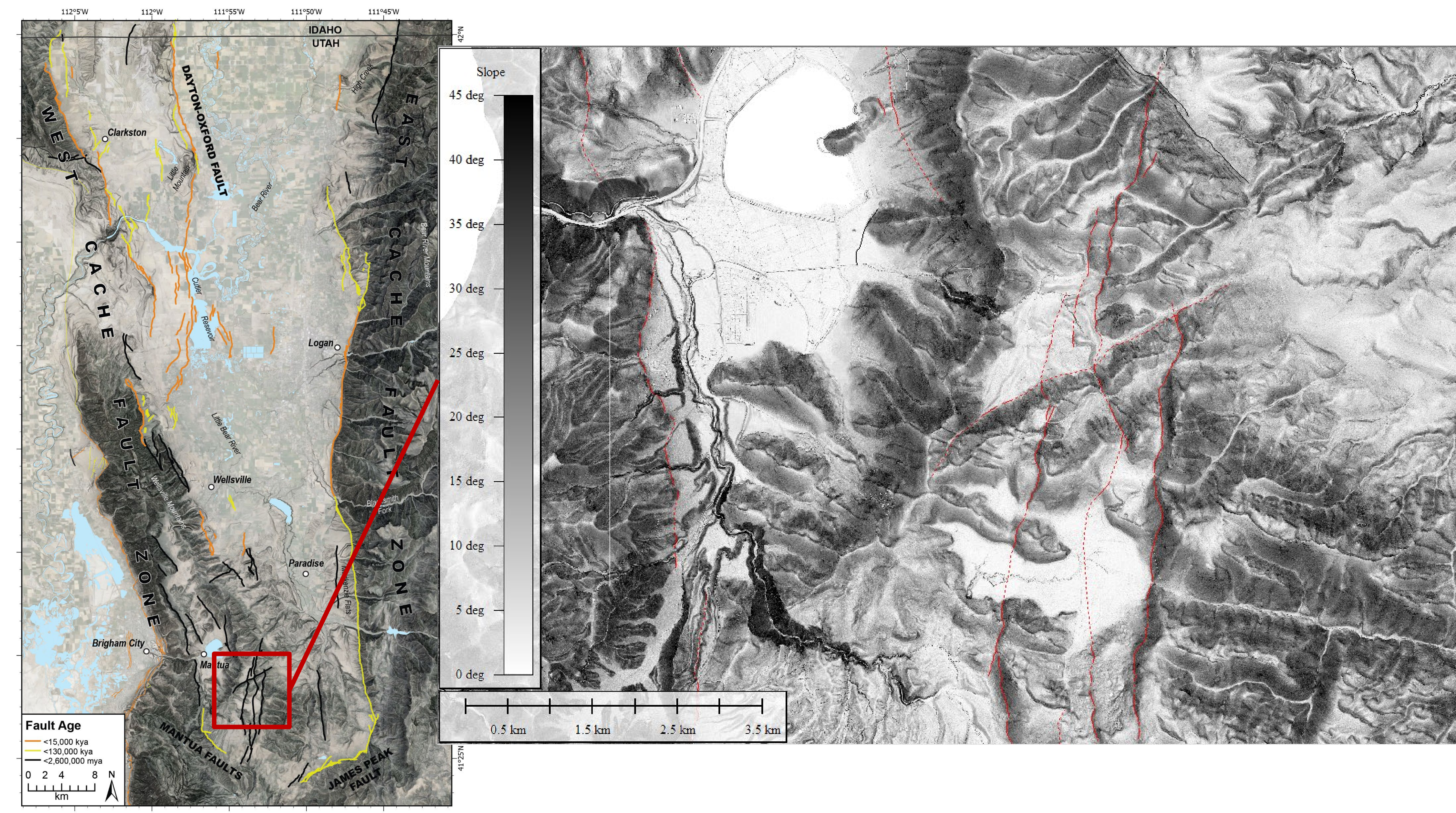
Mantua
MANTUA FAULTS
JAMES PEAK FAULT
Fault Age
<15,000 kya
<130,000 kya
<2,600,000 mya
0 2 4 8
km
N
2,305 m
2,250 m
2,000 m
1,750 m
1,500 m
1,294 m
0 m
125 m
250 m
375 m
500 m
625 m
750 m



CUTLER RESERVOIR
N
1353.0 m
1352.0 m
1351.0 m
1350.0 m
1349.0 m
1348.0 m
1347.0 m
1346.0 m
1345.0 m
1343.9 m
0 m
250 m
500 m
750 m
A
A'
~1.25-meters (4.1 feet) offset on correlative terrace surfaces
1349 m
1348 m
1347 m
1346 m
1345 m
1344 m
0.5 km
1.0 km
1.5 km
2.09 km



112°5'W
112°W
111°55'W
111°50'W
111°45'W
42°N
41°25'N
IDAHO
UTAH
High Creek
Clarkston
DAYTON-OXFORD FAULT
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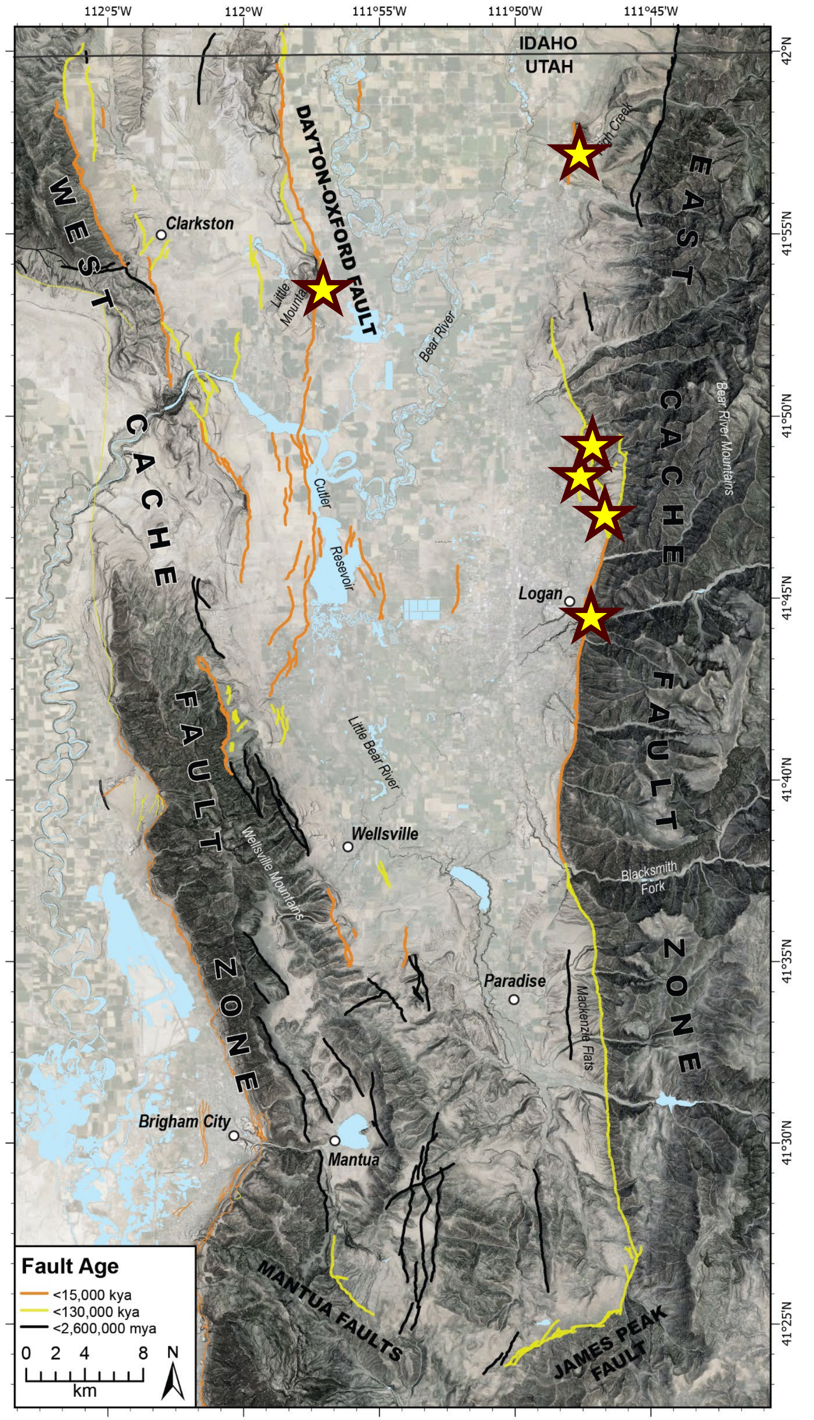
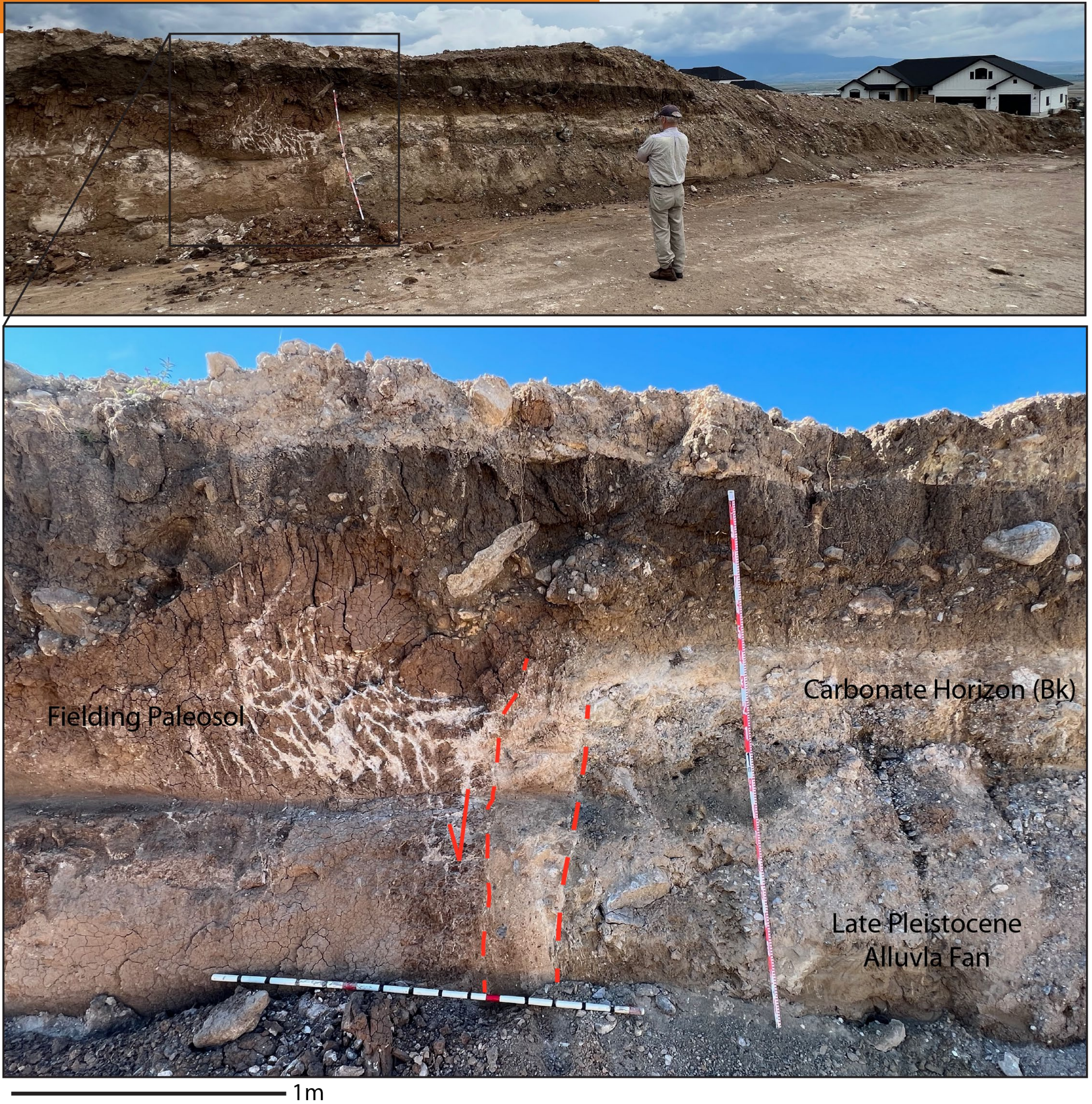
Wellsville Mountains
Blacksmith Fork
Paradise
Brigham City
Mantua
MANTUA FAULTS
JAMES PEAK FAULT
Fault Age
<15,000 kya
<130,000 kya
<2,600,000 mya
0 2 4 8
km
N
Slope
45 deg
40 deg
35 deg
30 deg
25 deg
20 deg
15 deg
10 deg
5 deg
0 deg
0.5 km
1.5 km
2.5 km
3.5 km

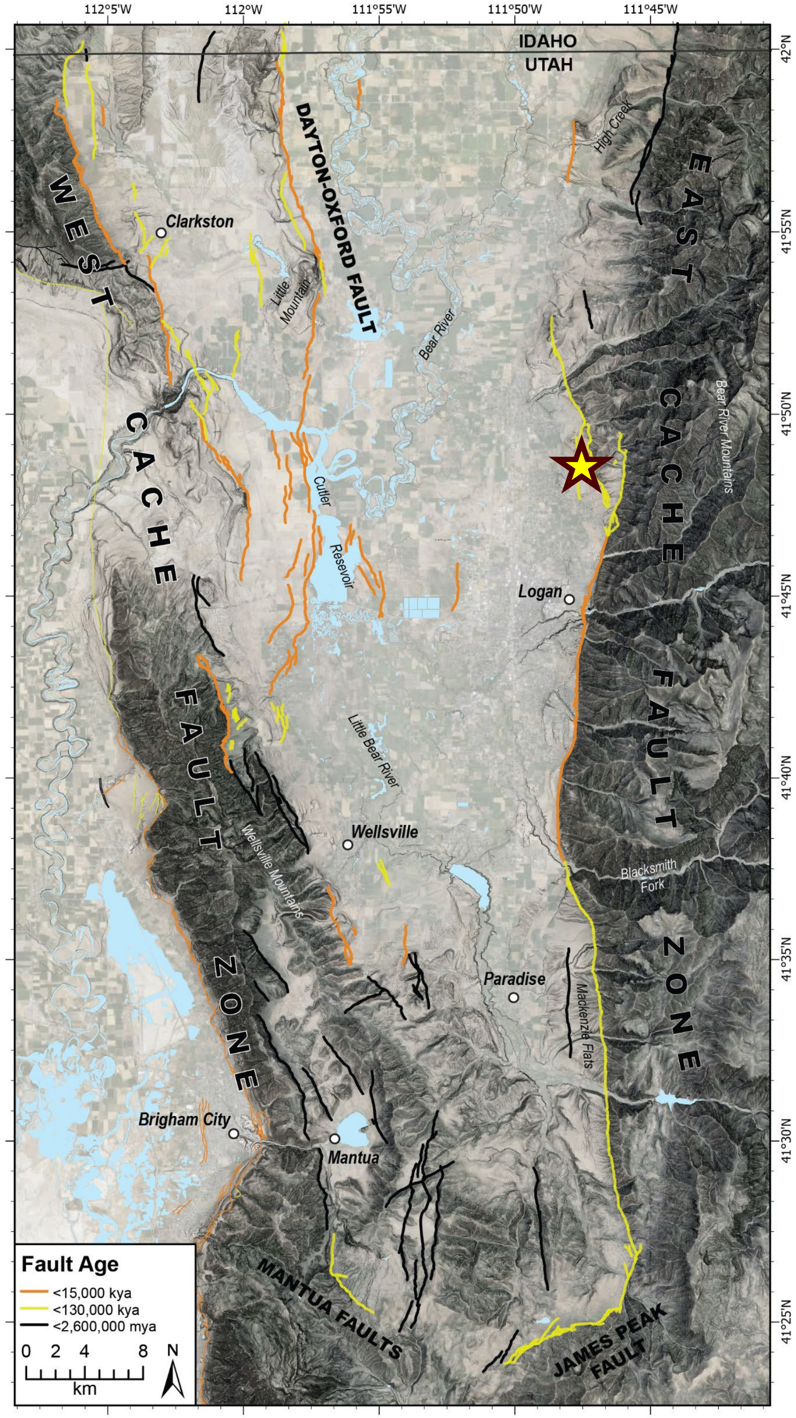
Opportunistic Fault Exposures (thanks USU!)

- Areas where development activities (building construction, road/trail cuts, gravel pits, etc.) have exposed the fault
- Especially useful along the ECFZ, where scarps are generally older, more degraded, and hidden by development.
- ECFZ - also more development leading to fault exposures



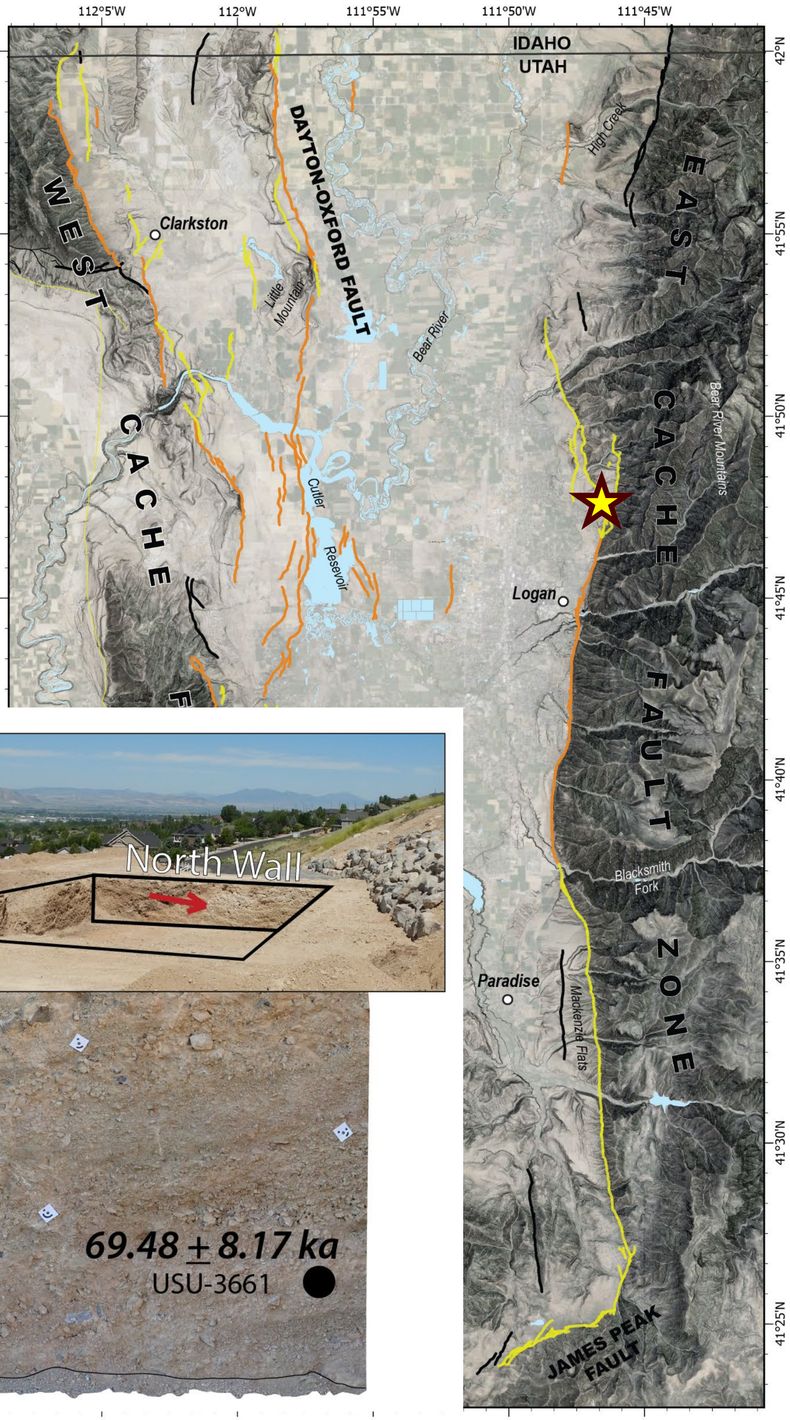


Photos and Interpretations from S. Jänecke & R. Oaks



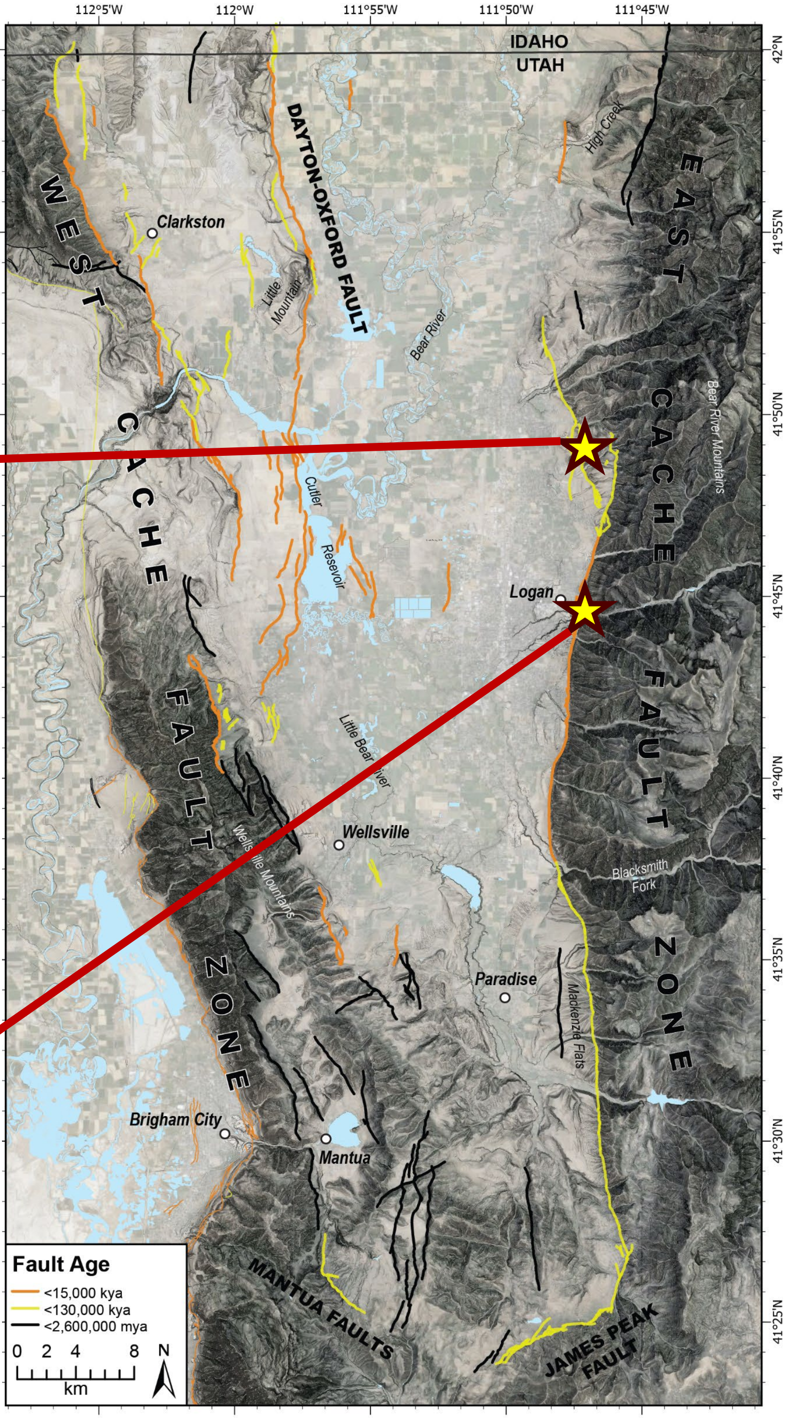
- Exposure in basement/foundation excavation near the mouth of Green Canyon in North Logan. UGS and USU allowed to document and study the exposure by the landowners.
- 3 OSL Samples collected and dated by Tammy Rittenour and students at USU Luminesce Lab.
- No clear colluvial wedges identified
- Ages interpreted as maximum constraints for earthquake timing.
- Allows us to change fault activity category from <2.6 mya to <130,000 ka for a large portion of the northern segment of ECFZ.

Figure from E. Kleber



- Additional exposures in areas of development, or sparse surficial scarps
- Both of these along trail cuts for recreational trails

Photos from E. Kleber



Paleoseismic Data

- Very limited paleoseismic data for both ECFZ and WCFZ.
  - WCFZ – Black and others (2000; UGS SS-98): Winter Canyon trench on Clarkston segment; Roundy Farm natural stream-cut exposure on Junction Hills segment, and Deep Canyon trench on Wellsville segment
  - ECFZ – McCalpin (1994; UGS SS-83): Bonneville and Provo trenches on Central segment, Evans and McCalpin (2012): Southern Segment

Table 2. *Comparison between ages of faulting and slip rates for the West Cache and East Cache fault zones.*

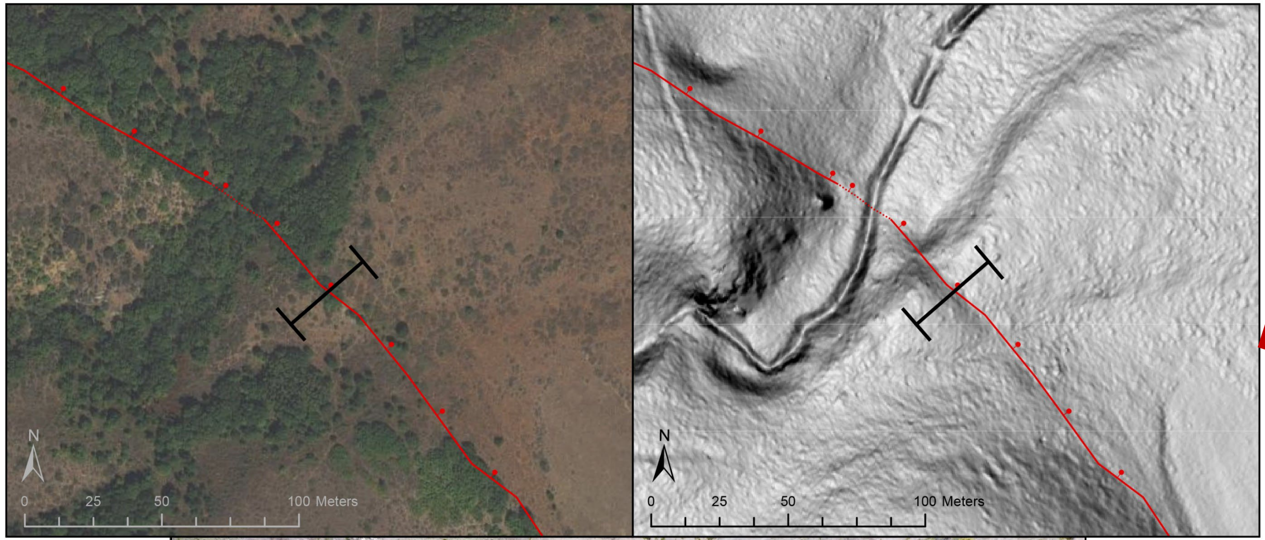
	Timing of most recent surface-faulting earthquake	**Timing of penultimate surface-faulting earthquake**	**Slip rate (time frame)**
WEST CACHE FAULT ZONE			
Clarkston fault	3,600-4,000 years ago	Post-Bonneville (<16,800 years ago)	<0.68 millimeters/year (late Pleistocene to middle Holocene)
Junction Hills fault	8,250-8,650 years ago	Pre-Bonneville (>16,800 years ago)	<0.21 millimeters/year (late Pleistocene to early Holocene)
Wellsville fault	4,400-4,800 years ago	15,000-25,000 years ago	0.11-0.22 millimeters/ year (late Pleistocene to middle Holocene)
EAST CACHE FAULT ZONE[1]			
Northern segment	Pre-Bonneville (>16,800 years ago)		0.25-0.5 millimeters/ year (early Pleistocene)
Central segment	4,300-4,800 years ago	15,000-18,000 years ago	0.28 millimeters/year (late Pleistocene to middle Holocene)
Southern segment	Pre-Bonneville (>16,800 years ago)		0.01-0.07 millimeters/ year (early Pleistocene)

[1] East Cache fault zone data are from McCalpin (1994). Ages reported in McCalpin (1994) are uncalibrated and are calibrated here for comparison only. We determined calibrated age of the most recent surface-faulting earthquake on the central segment using methods described in the Radiocarbon Dating section, based on a lab age of 4,240 ± 80 yr B.P., MRC of 200, and a CAS of 200. We estimated the age of the penultimate surface-faulting earthquake on the central segment by multiplying by 1.16, as per the method used to calibrate lake-cycle ages. Slip rates for the Clarkston and Junction Hills faults are maximums and the true slip rates are uncertain and likely lower. McCalpin (1994) indicates that the northern-segment slip rate may be overestimated.

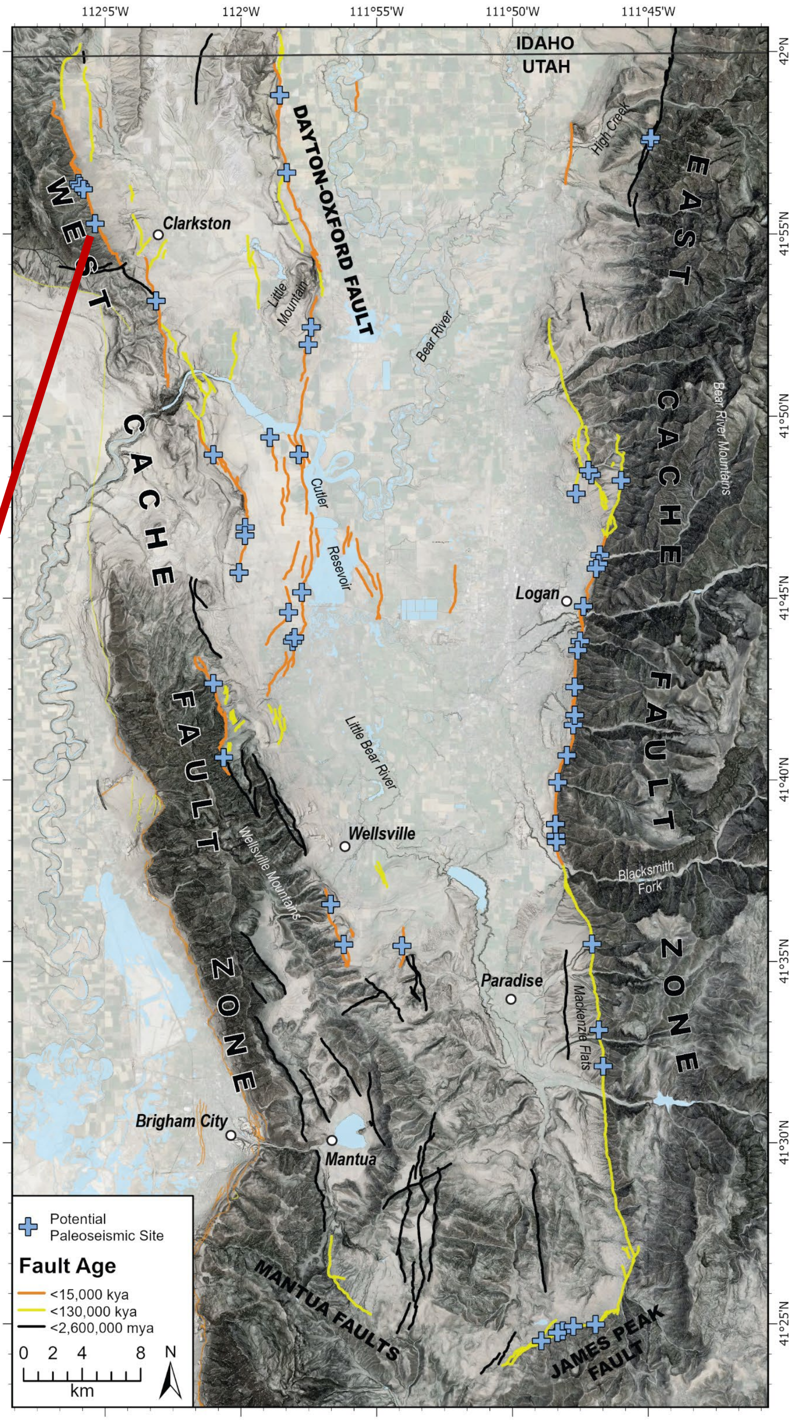
Table from UGS SS-98 (Black and others, 2000)

Paleoseismic Sites

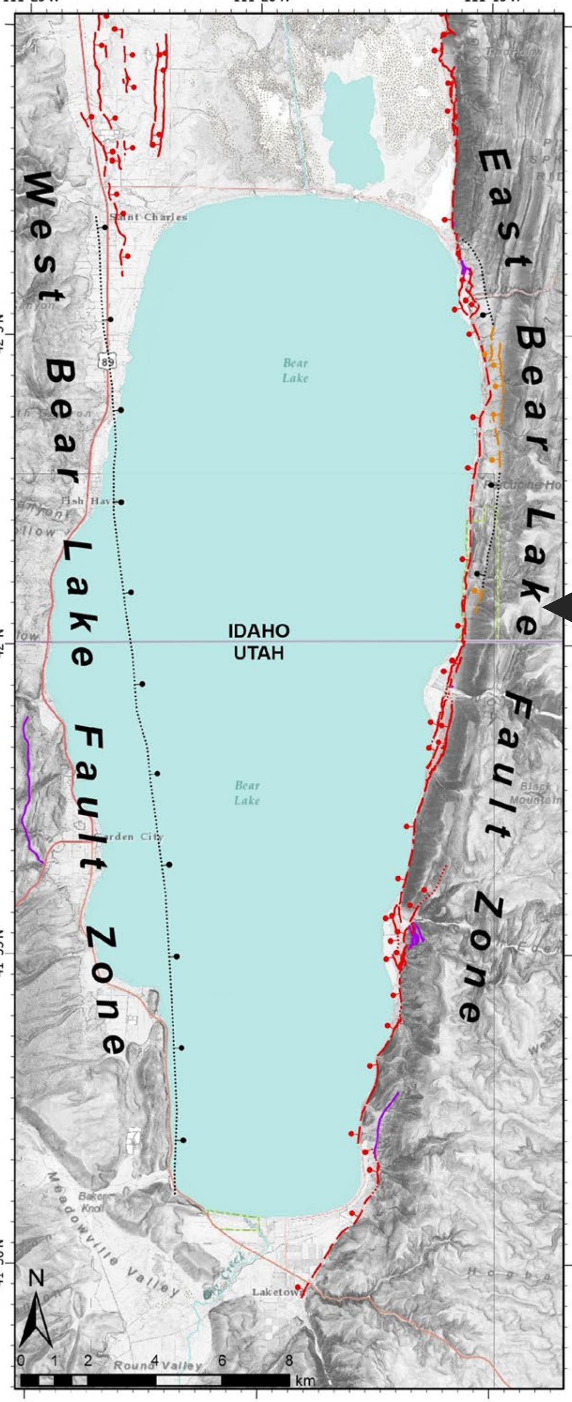
- Identified 52 potential sites for paleoseismic trenching



Raglanite Canyon trench site
Top: Lidar/Imagery comparison with fault trace shown in red/appx trench location in black
Bottom: UAV Photo of site

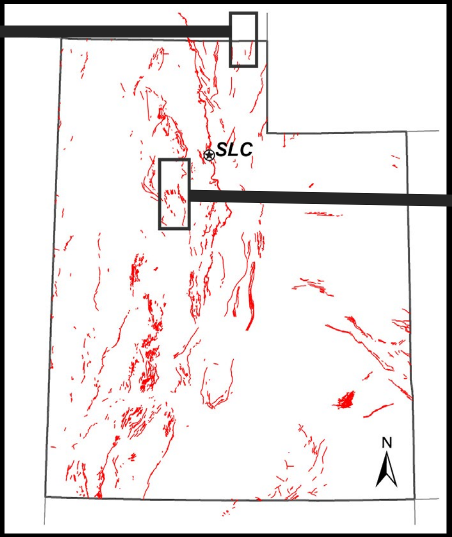


East and West Bear Lake Faults & Oquirrh-Topliff Hills Fault Zones

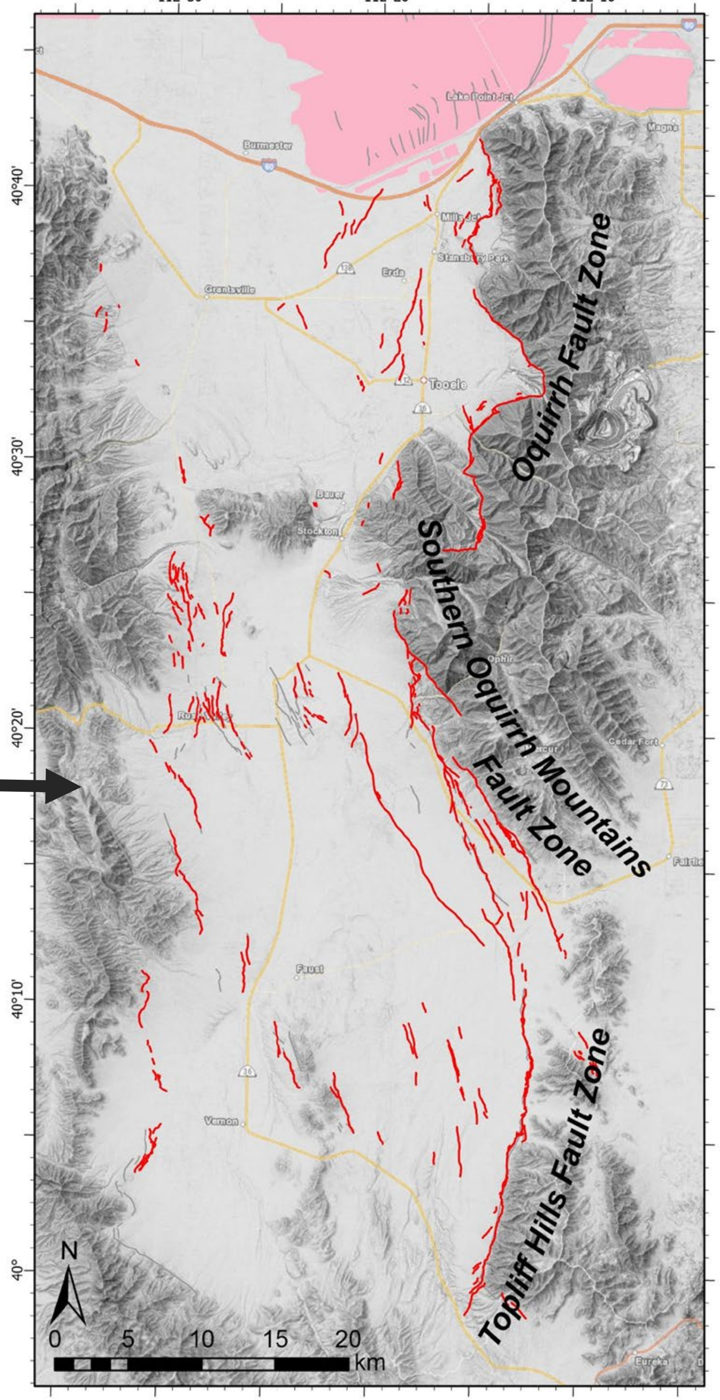


- Collaborative project with Idaho Geological Survey (Z. Lifton)
- Consistent cross-border fault geometry & attributes (BRPEWG Priority)

- FTR Submitted 2021
- Mappng available in *Utah Geologic Hazards Portal*

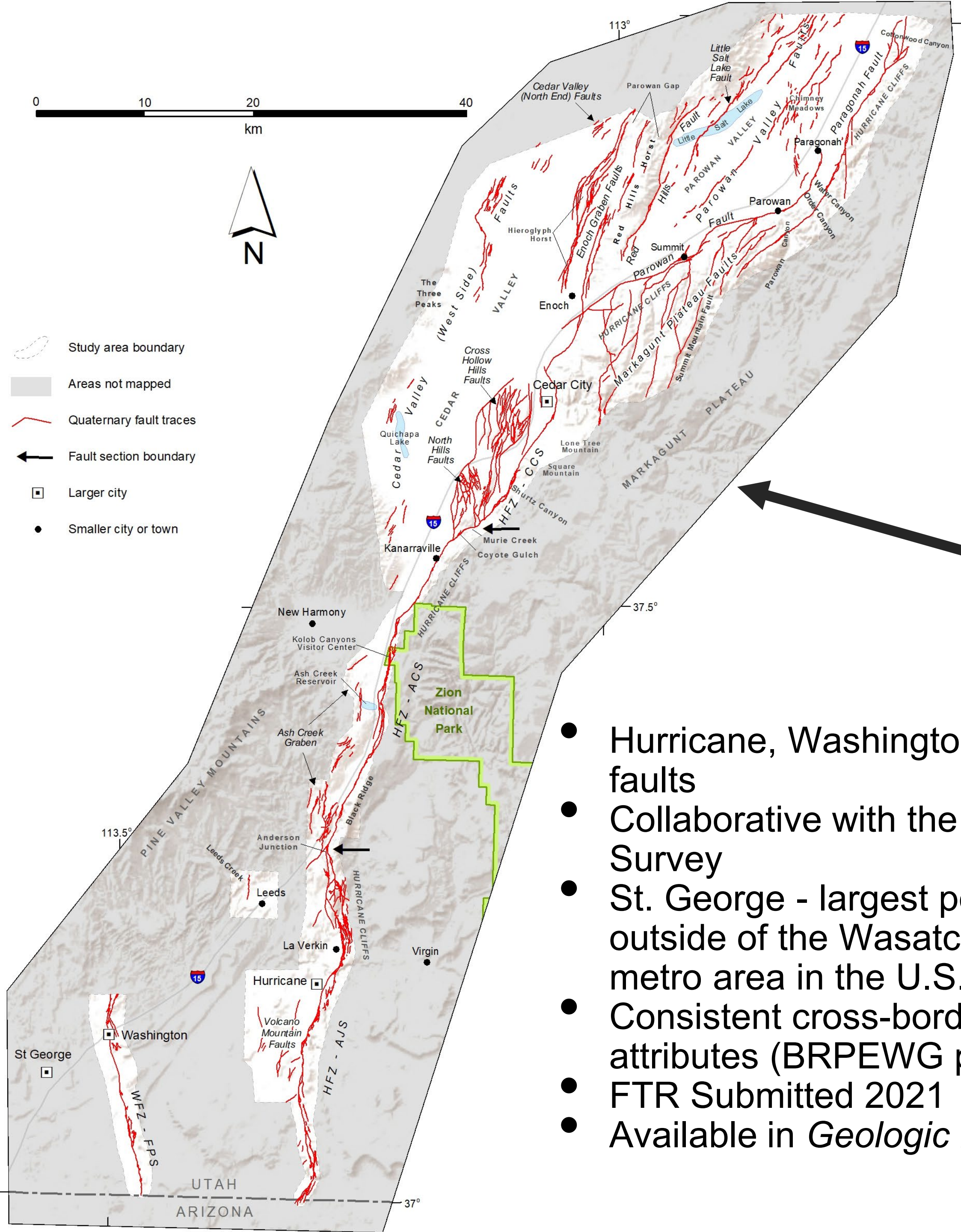


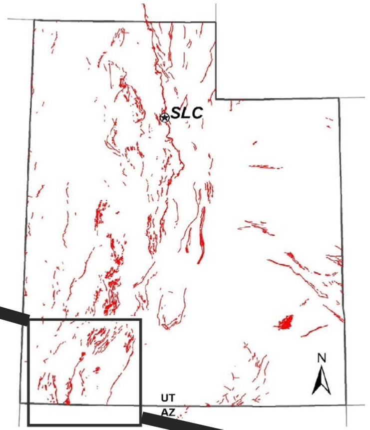
- Mappng available in *Utah Geologic Hazards Portal*

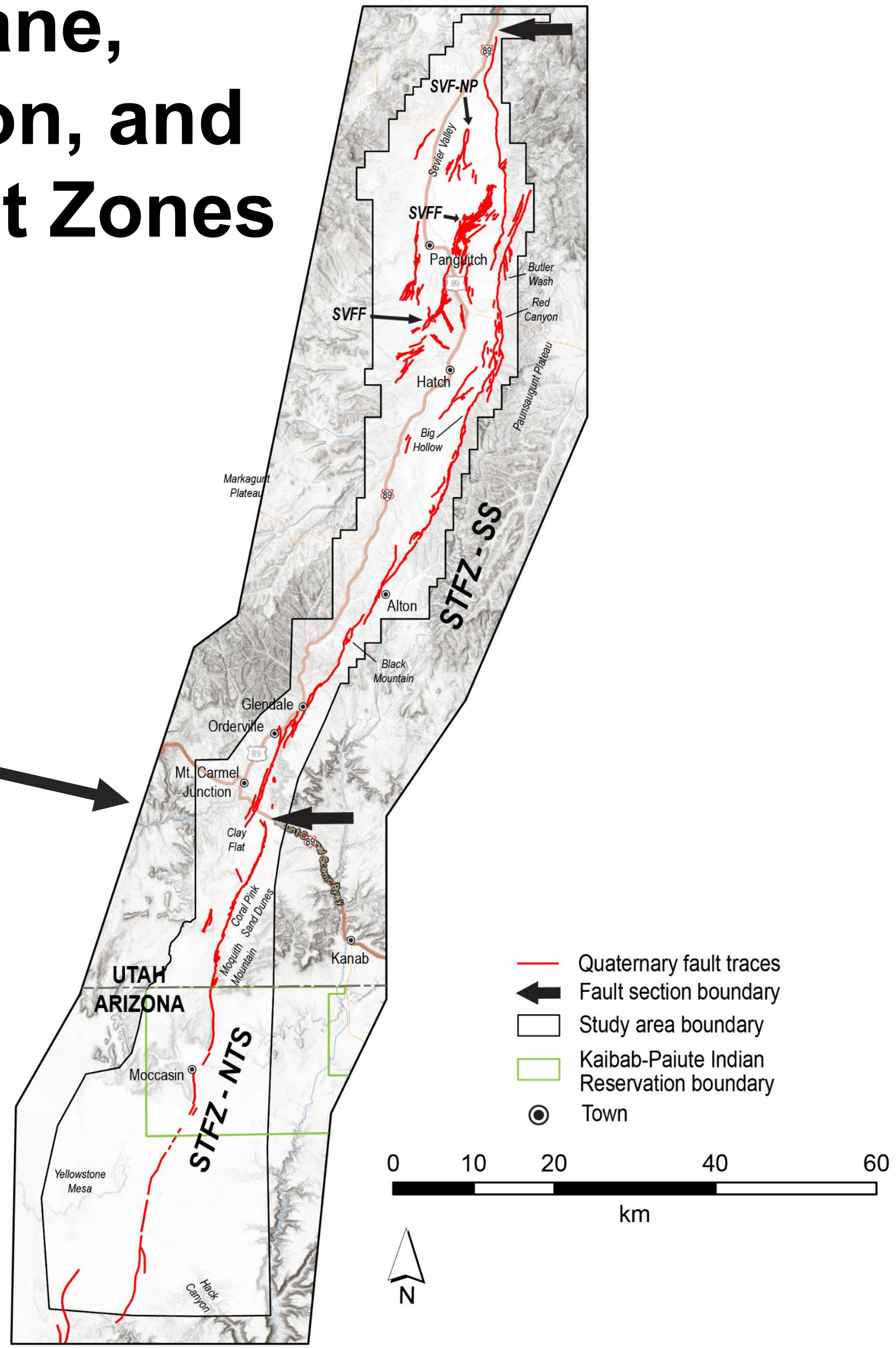


- Identified and extended many intra-basin faults in the Tooele and Rush Valleys

Hurricane, Washington, and Sevier Fault Zones



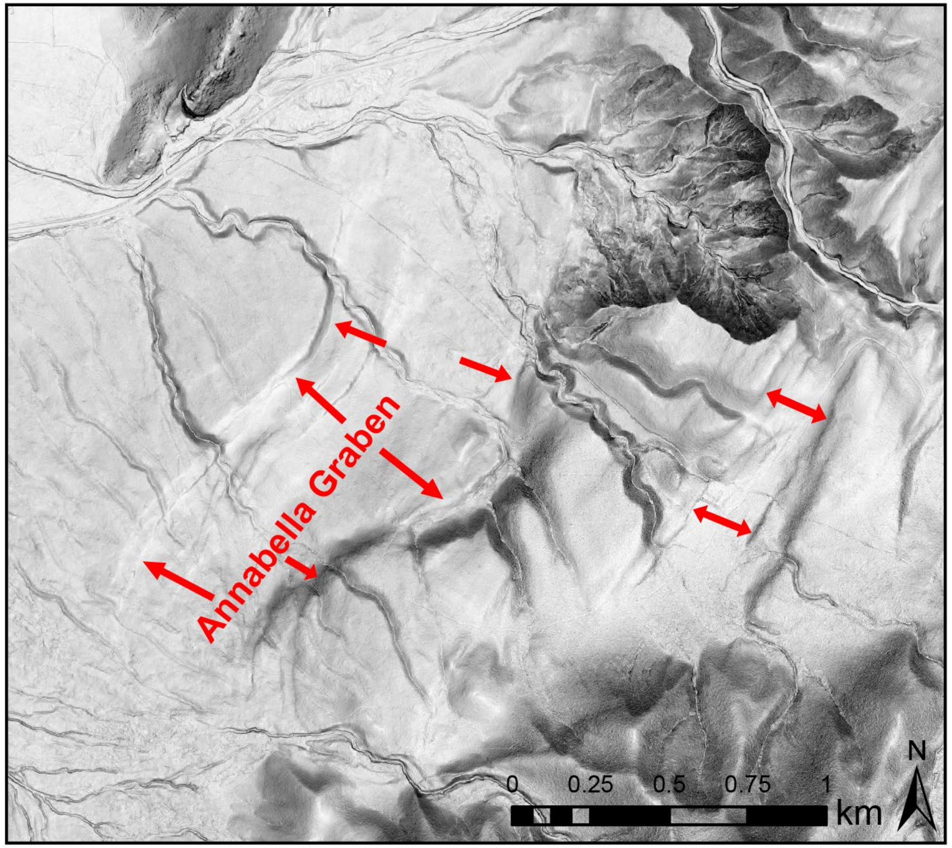


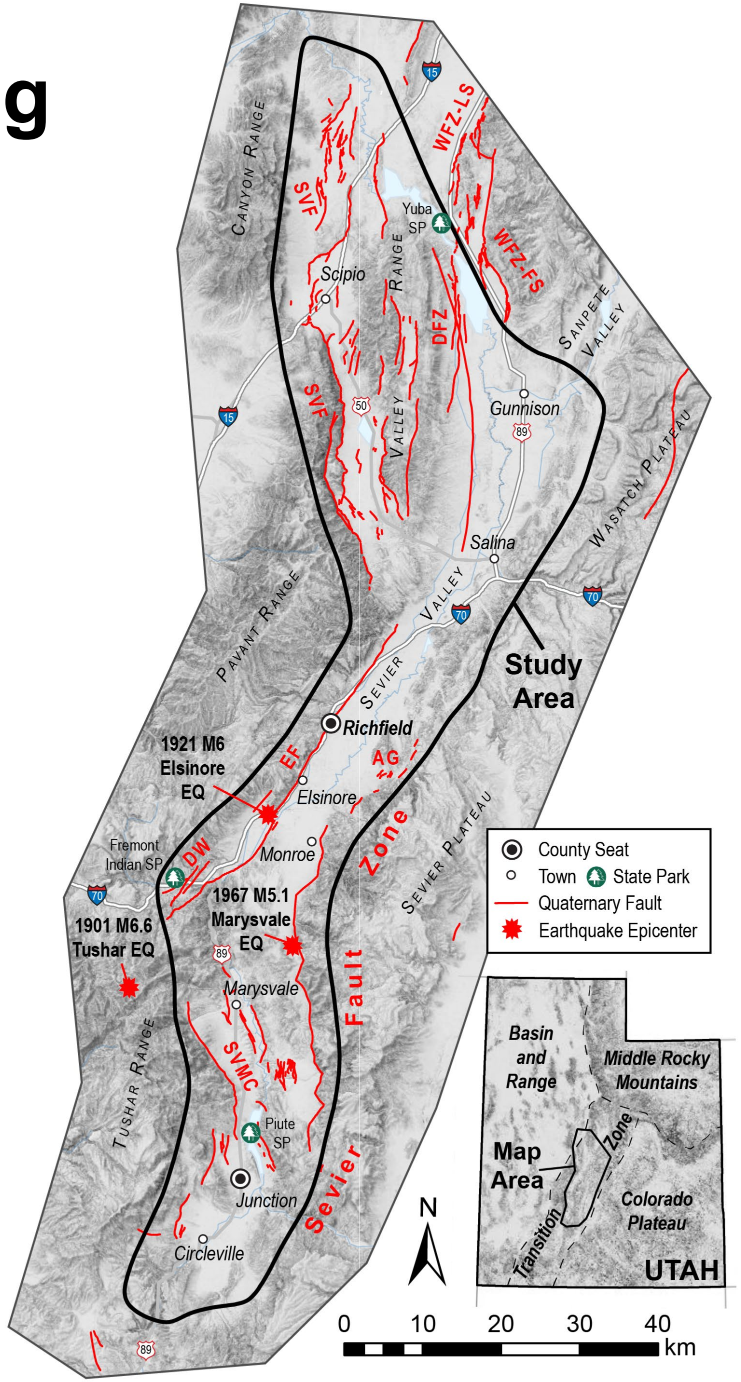


- Hurricane, Washington, and Sevier/Toroweap faults
- Collaborative with the Arizona Geological Survey
- St. George - largest population center in Utah outside of the Wasatch front, fastest growing metro area in the U.S. (2000-2006)
- Consistent cross-border fault geometry & attributes (BRPEWG priority)
- FTR Submitted 2021
- Available in *Geologic Hazards Portal*

Future Central/Southern Utah Fault Mapping

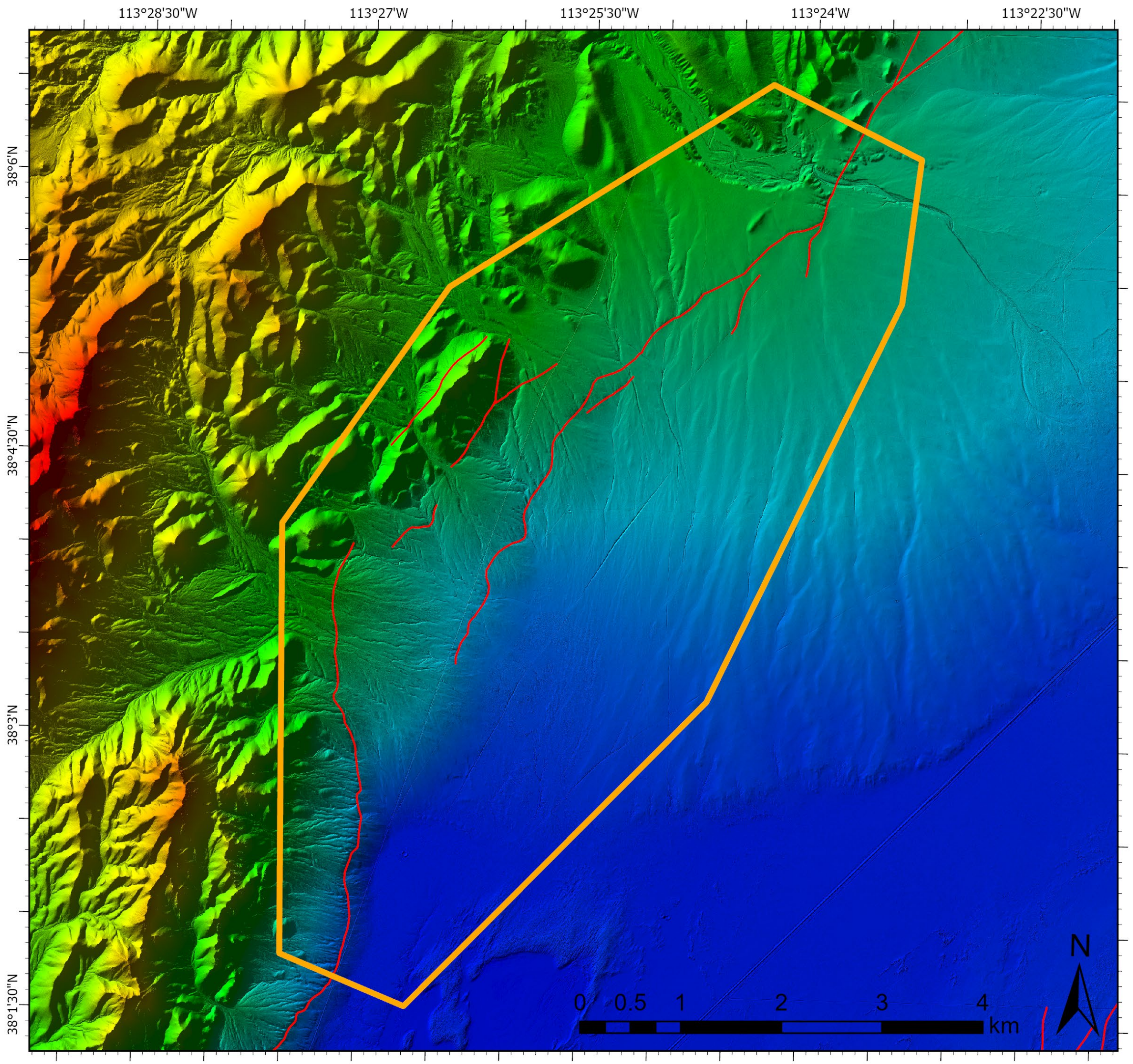
- USGS EHP Proposal submitted 2023
- Currently recommended for funding, but put in "hold" status pending final budgeting
- Continues mapping of the Sevier FZ up through Central Utah.
- Includes mapping of several other regional faults such as the Marysvale area faults, Dover fault zone, Scipio Valley faults, and the Annabella Graben.





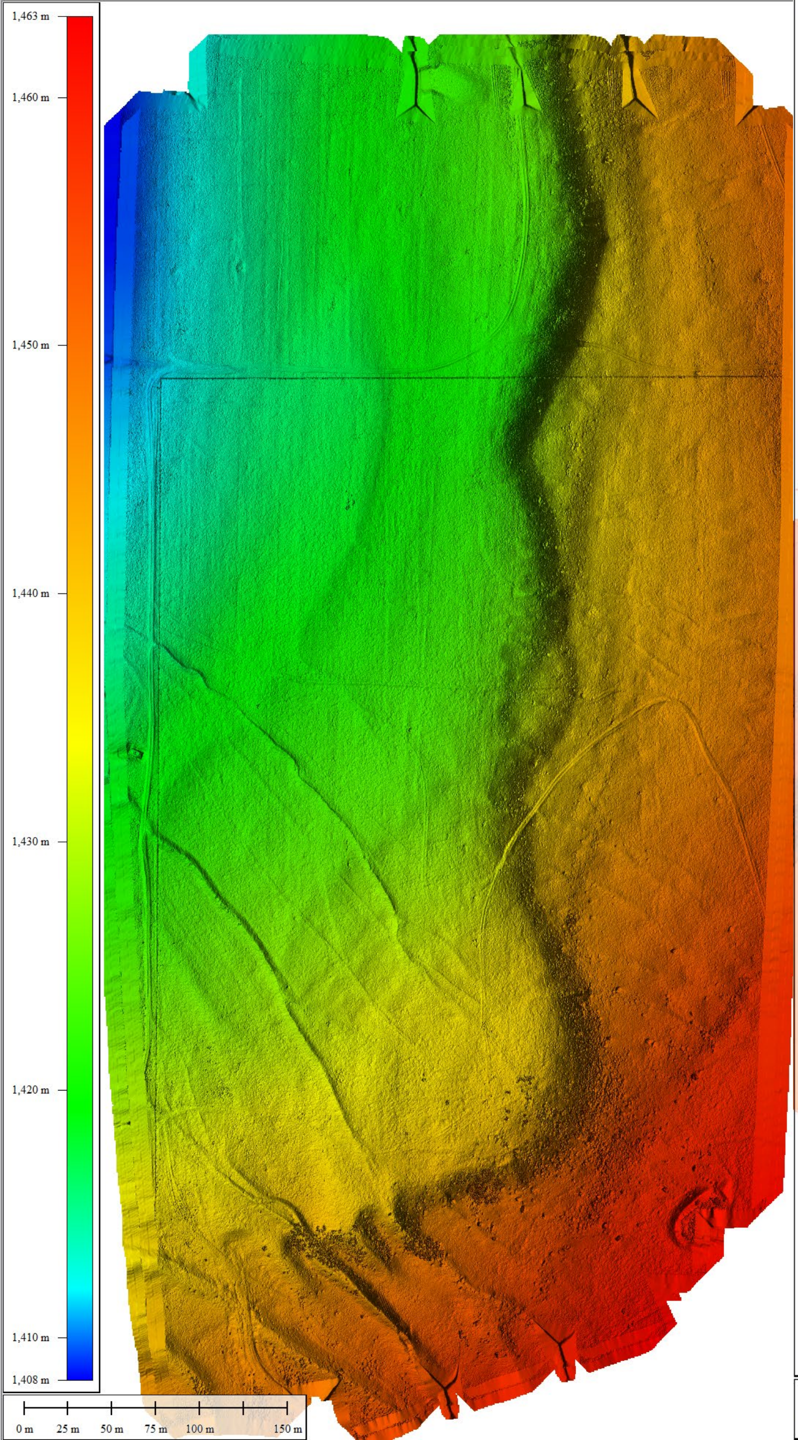
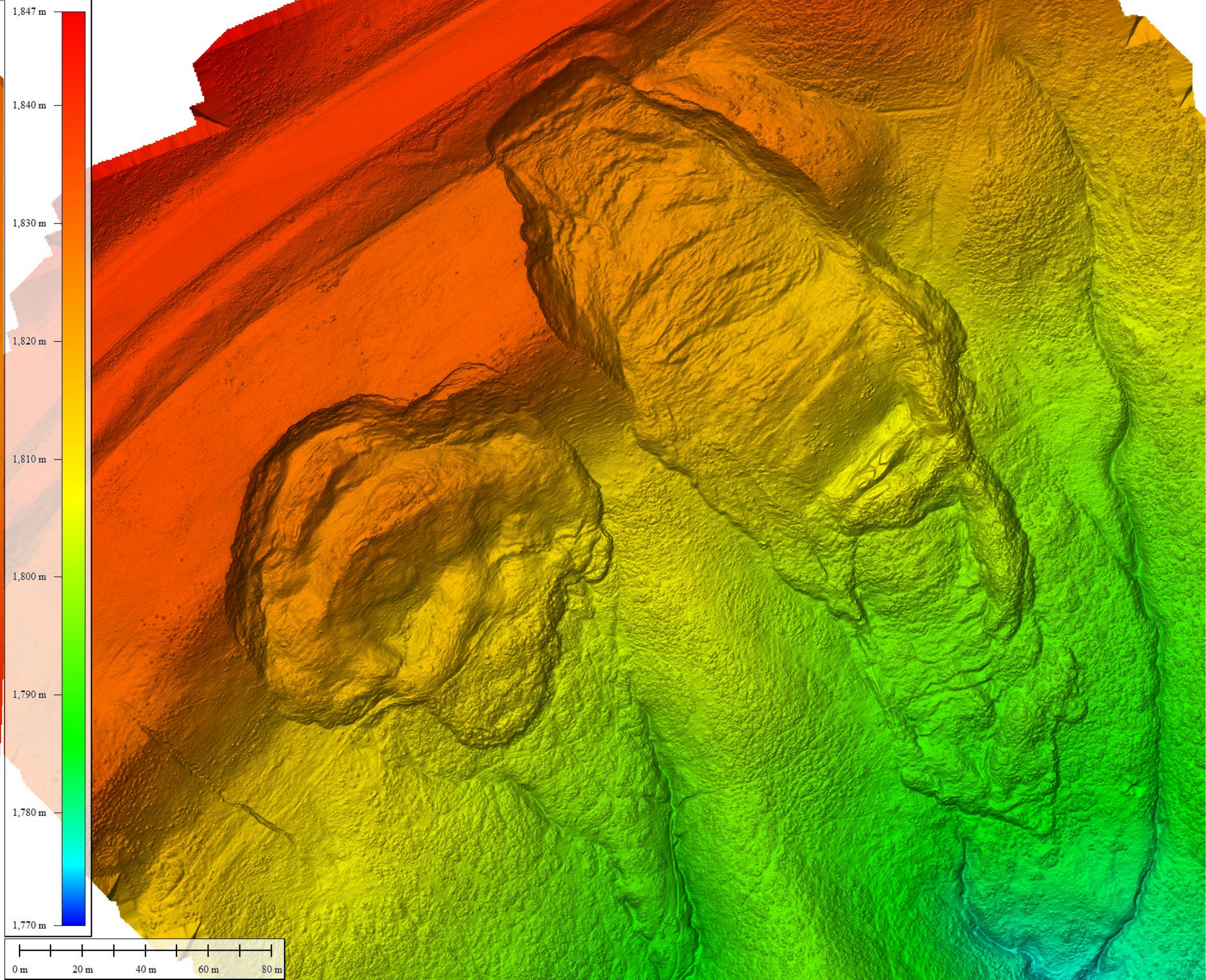
DOE INGENIOUS Project

- **IN**novative **G**eothermal **E**xploration through **N**ovel **I**nvestigations **O**f **U**ndiscovered **S**ystems (**INGENIOUS**)
- Project focused on geothermal play fairway analysis of areas to accelerate discoveries of new, commercially viable, hidden geothermal systems.
- From 2021-2023, performed reconnaissance mapping across the Utah portion of the Great Basin – only in areas with lidar data coverage.
- UGS Fault Mappers – Myself, Emily Kleber, Tyler Knudsen
- Mapped primarily using lidar data; minimal to no field checking or air photo mapping
- Future plans – revise/revisit this mapping and add it to the Utah QFDB and Geologic Hazards Portal.



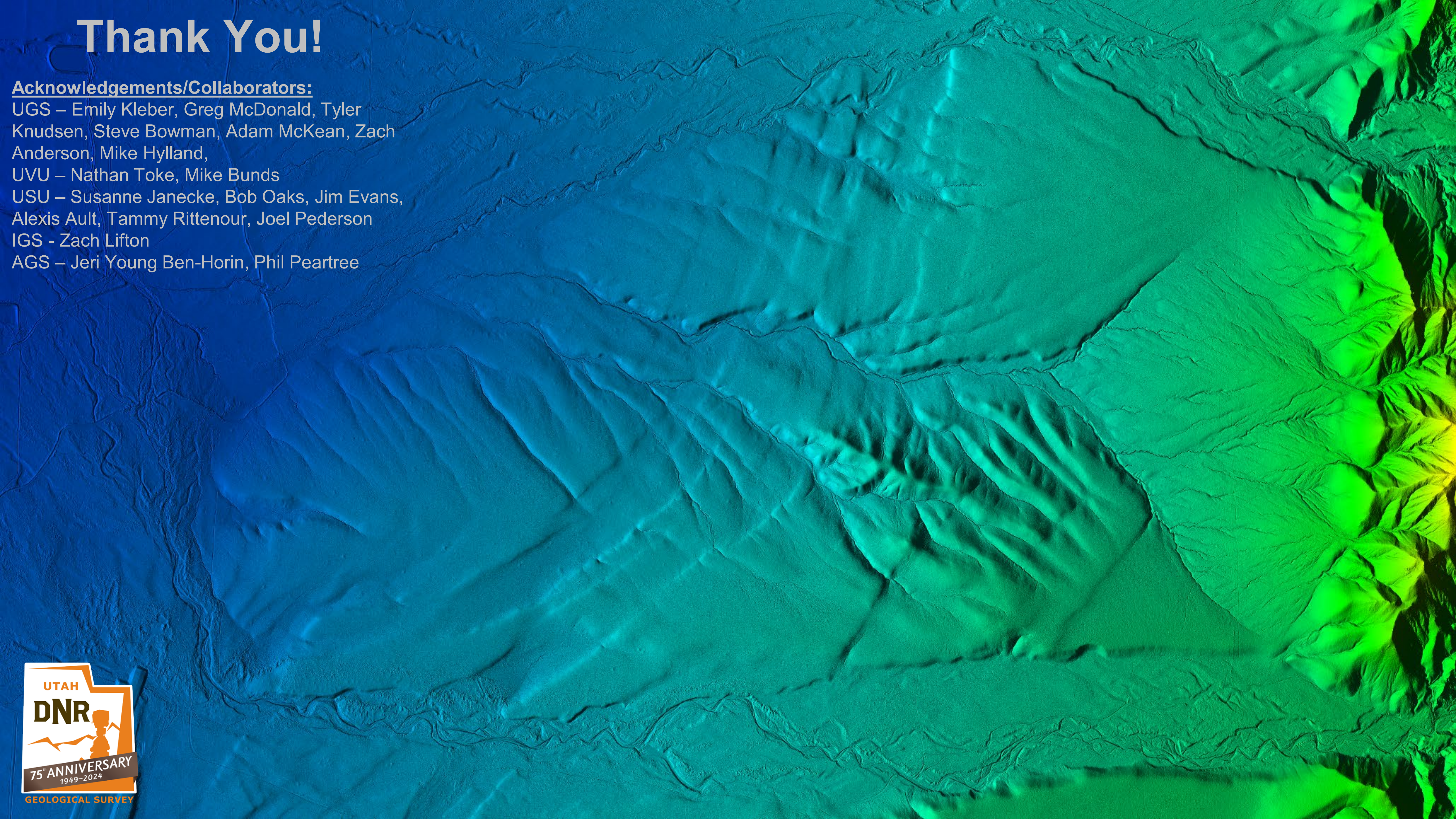
UGS Dronedar

- Purchased Summer 2023 - DJI Matrice m300 RTK UAV & DJI Zenmuse L1 Lidar Scanner
- Landslide monitoring, high-detailed fault scarp mapping, etc.
- Still working on the workflow for processing point cloud data and classifying points for vegetation removal


1,463 m
1,460 m
1,450 m
1,440 m
1,430 m
1,420 m
1,410 m
1,408 m
0 m
25 m
50 m
75 m
100 m
150 m

1,847 m
1,840 m
1,830 m
1,820 m
1,810 m
1,800 m
1,790 m
1,780 m
1,770 m
0 m
20 m
40 m
60 m
80 m

Thank You!

Acknowledgements/Collaborators:
UGS – Emily Kleber, Greg McDonald, Tyler Knudsen, Steve Bowman, Adam McKean, Zach Anderson, Mike Hylland,
UVU – Nathan Toke, Mike Bunds
USU – Susanne Janecke, Bob Oaks, Jim Evans, Alexis Ault, Tammy Rittenour, Joel Pederson
IGS - Zach Lifton
AGS – Jeri Young Ben-Horin, Phil Peartree



UTAH DNR
75th ANNIVERSARY 1949–2024
GEOLOGICAL SURVEY

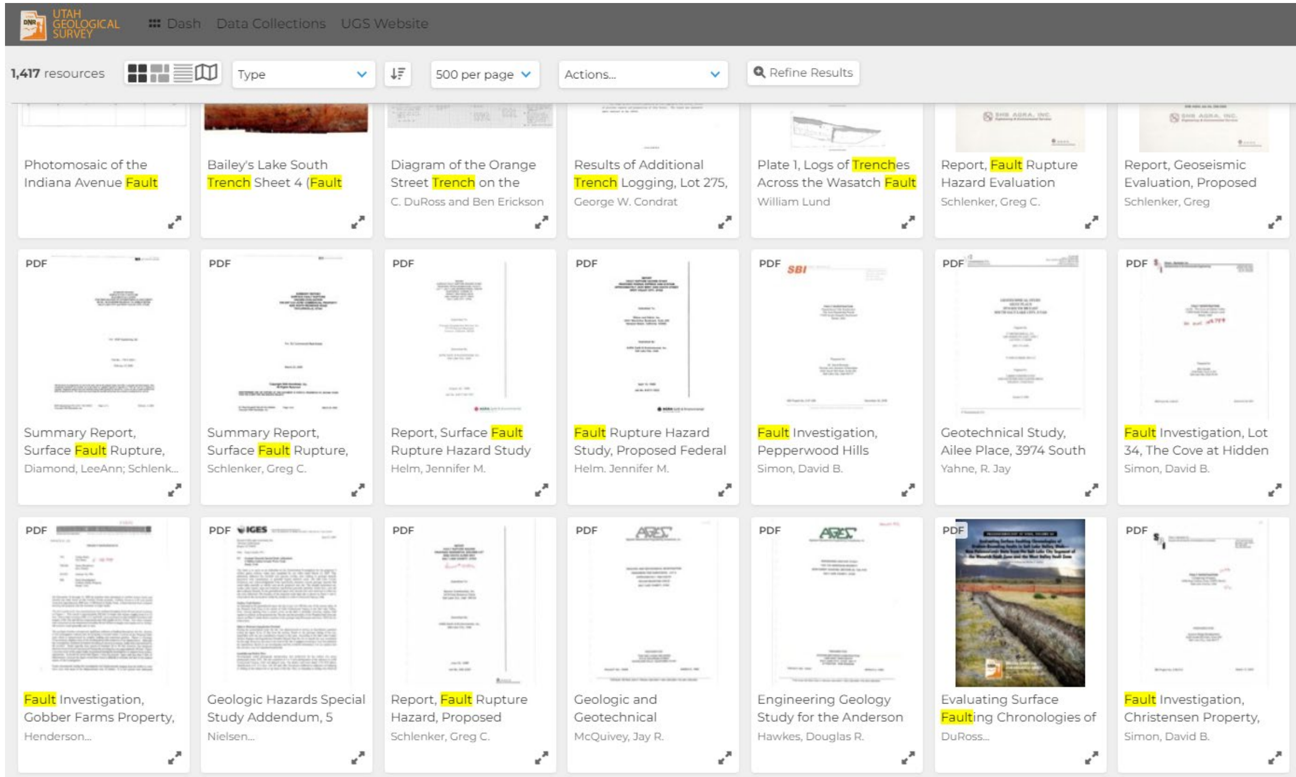
Utah Paleoseismic Sites Database

Adam I. Hiscock
Utah Geological Survey Hazards Program

UTAH DNR
75th ANNIVERSARY
1949–2024
GEOLOGICAL SURVEY

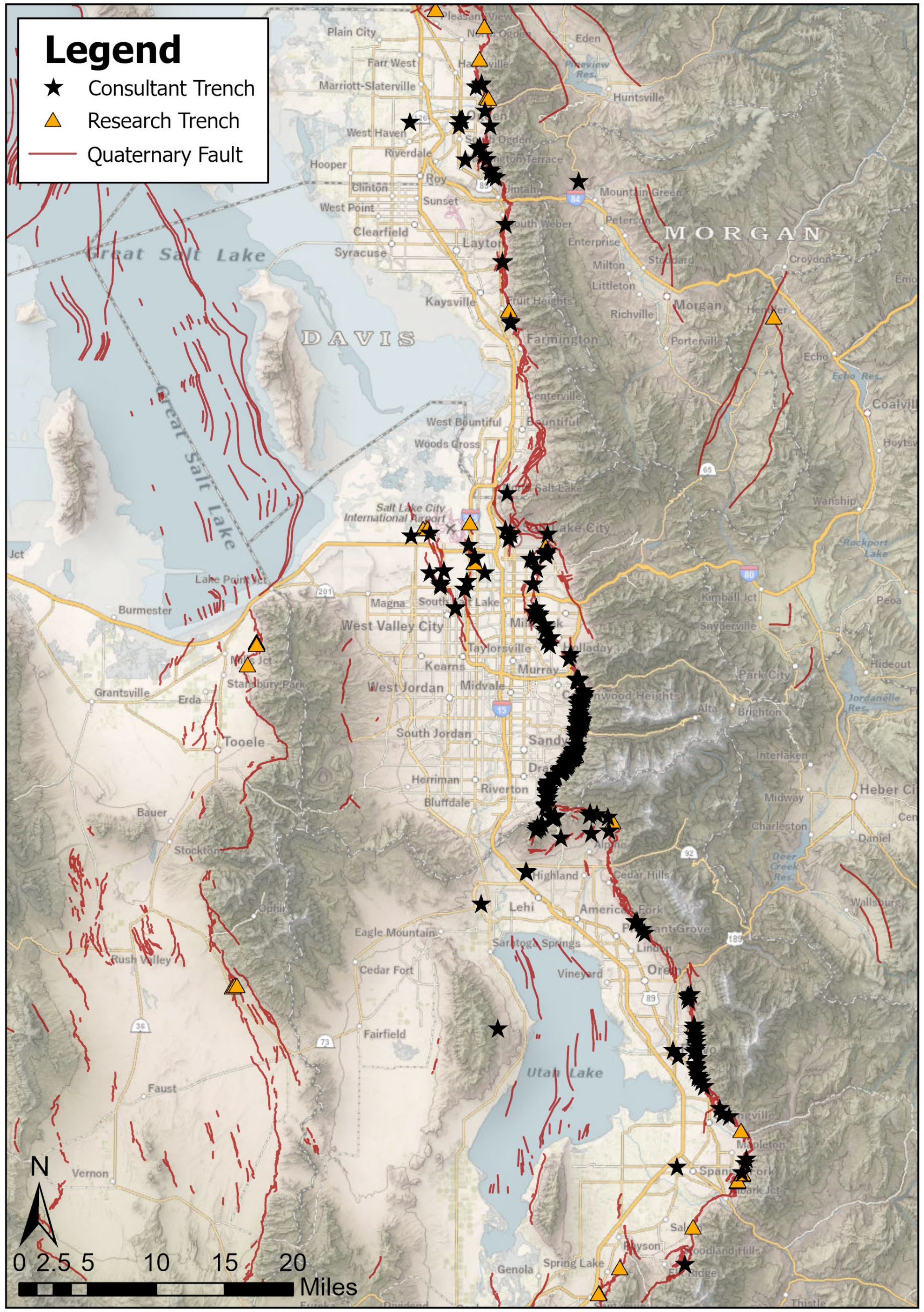
Objectives

- Over the years, 100's of fault trenches have been conducted by local geotechnical consulting firms.
- Many of these resulting reports have compiled by the UGS for geologic hazard mapping, and archived in the UGS's GeoData Archive System (https://geodata.geology.utah.gov/).
- Several UGS Student Interns over the past several years have worked compiling and extracting metadata from these reports
    - Christian Arner (Weber State)
    - Cal Thomson & Austin Tyler (University of Utah)



Objectives

- Compiled/added **678** consultant trenches to database (black stars)
  - 307 trenches encountered a fault
  - 371 trenches did not encounter a fault
- 141 Research-level trenches in database (orange triangles)
  - Mostly UGS, USGS, and University trenches



Objectives

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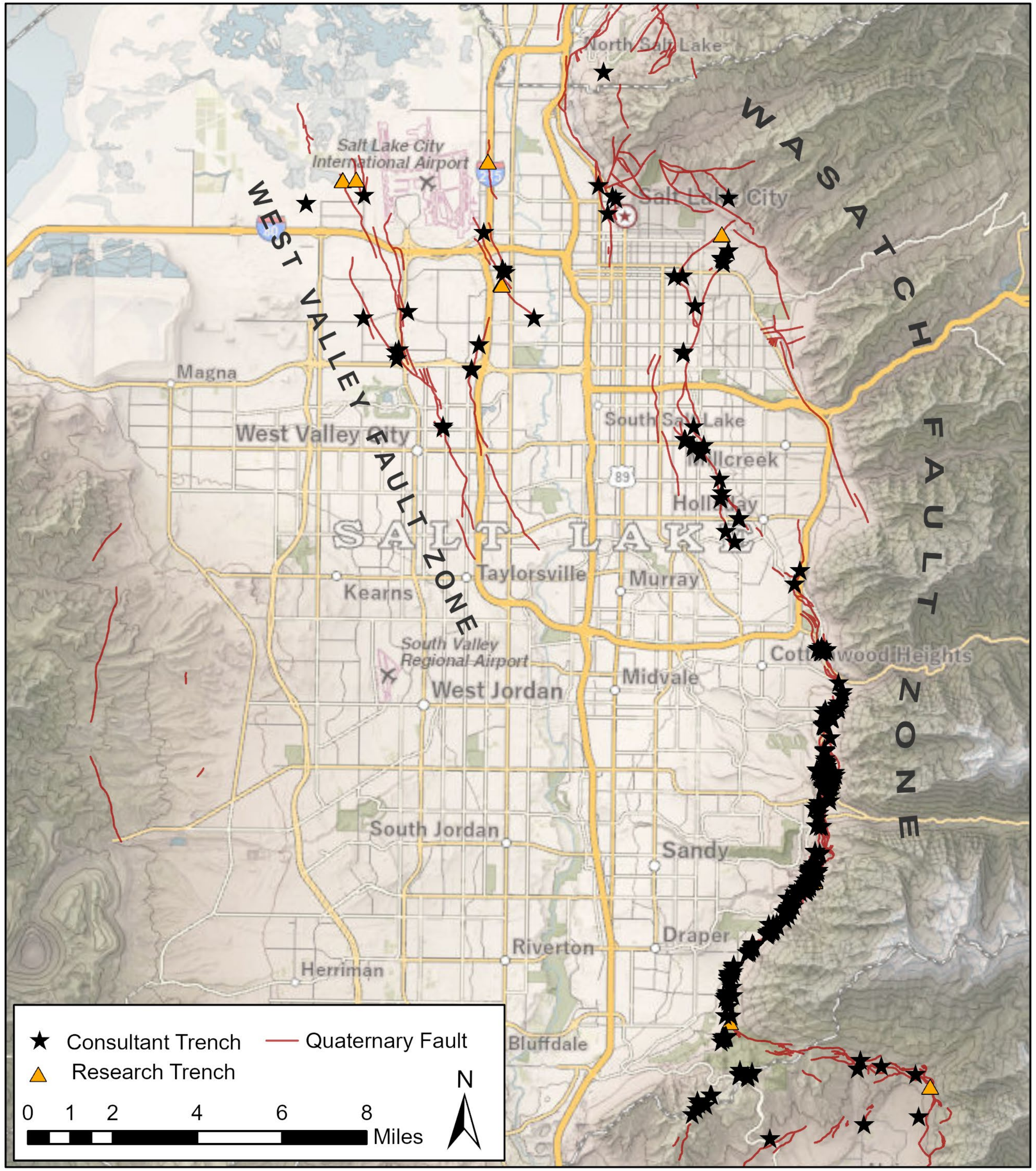
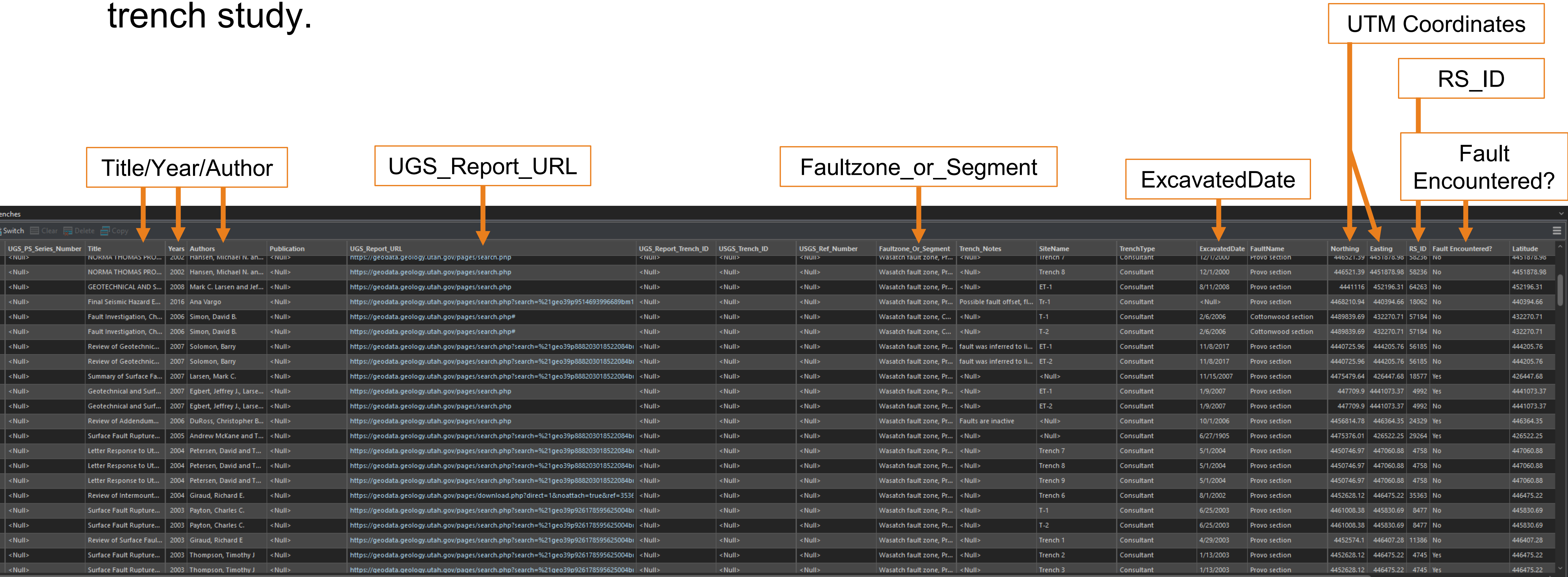


Metadata

- Metadata added to database from trench report in GeoData
- Numerous fields including study location (coordinates), report link, authors, fault zone/segment, etc.
- “Fault Encountered?” field to document if evidence of faulting was encountered in that trench study.



UGS_PS_Series_Number	Title	Years	Authors	Publication	UGS_Report_URL	UGS_Report_Trench_ID	USGS_Trench_ID	USGS_Ref_Number	Faultzone_Or_Segment	Trench_Notes	SiteName	TrenchType	ExcavatedDate	FaultName	Northing	Easting	RS_ID	Fault Encountered?	Latitude
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<Null>	NORMA THOMAS PRO...	2002	Hansen, Michael N. an...	<Null>	https://geodata.geology.utah.gov/pages/search.php	<Null>	<Null>	<Null>	Wasatch fault zone, Pr...	<Null>	Trench 8	Consultant	12/1/2000	Provo section	446521.39	4451878.98	58236	No	4451878.98
<Null>	GEOTECHNICAL AND S...	2008	Mark C. Larsen and Jef...	<Null>	https://geodata.geology.utah.gov/pages/search.php	<Null>	<Null>	<Null>	Wasatch fault zone, Pr...	<Null>	ET-1	Consultant	8/11/2008	Provo section	4441116	452196.31	64263	No	452196.31
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<Null>	Summary of Surface Fa...	2007	Larsen, Mark C.	<Null>	https://geodata.geology.utah.gov/pages/search.php?search=%21geo39p888203018522084bı	<Null>	<Null>	<Null>	Wasatch fault zone, Pr...	<Null>	<Null>	Consultant	11/15/2007	Provo section	4475479.64	426447.68	18577	Yes	426447.68
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<Null>	Letter Response to Ut...	2004	Petersen, David and T...	<Null>	https://geodata.geology.utah.gov/pages/search.php?search=%21geo39p888203018522084bı	<Null>	<Null>	<Null>	Wasatch fault zone, Pr...	<Null>	Trench 7	Consultant	5/1/2004	Provo section	4450746.97	447060.88	4758	No	447060.88
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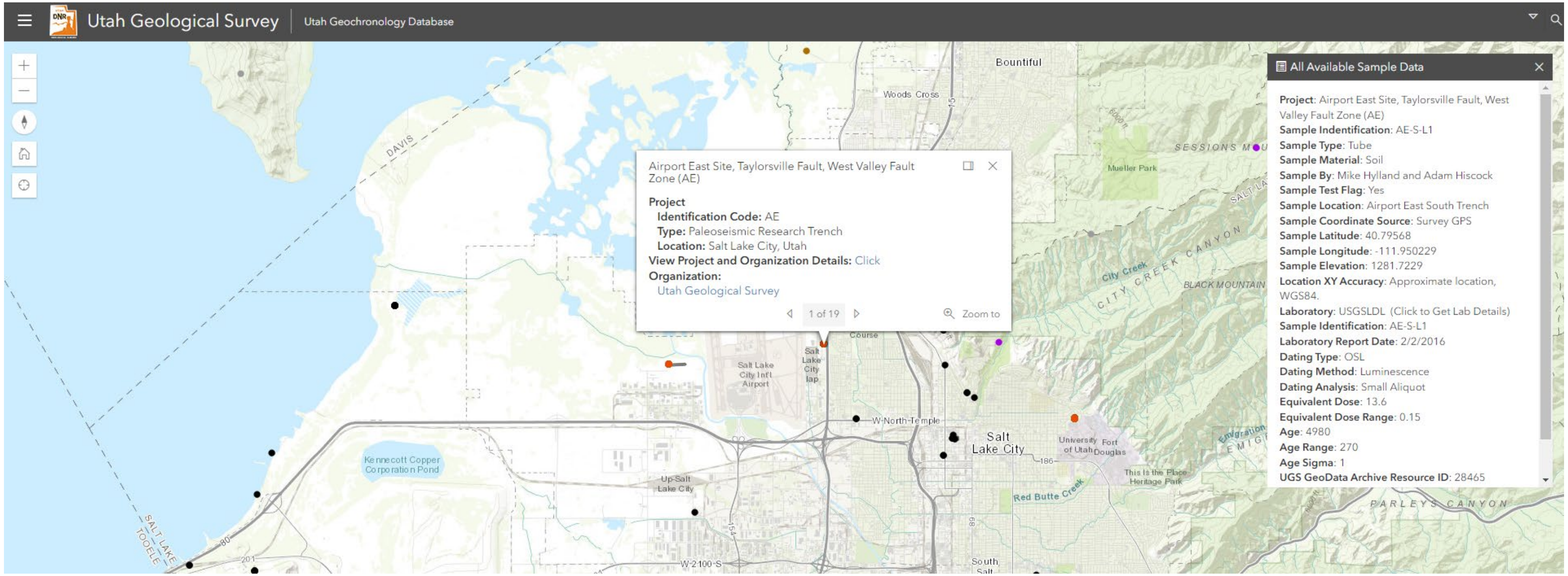
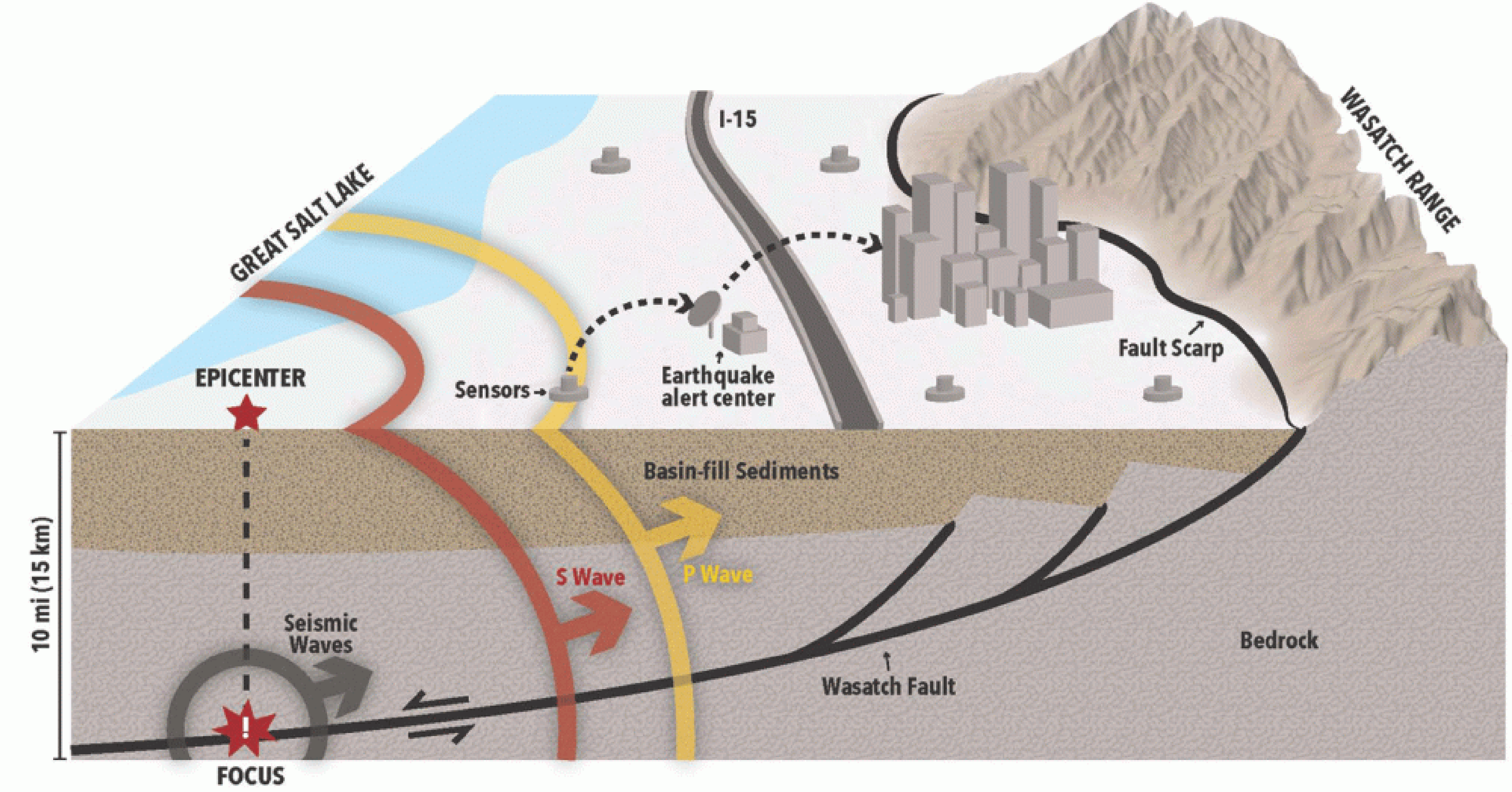
<Null>	Surface Fault Rupture...	2003	Thompson, Timothy J	<Null>	https://geodata.geology.utah.gov/pages/search.php?search=%21geo39p926178595625004bı	<Null>	<Null>	<Null>	Wasatch fault zone, Pr...	<Null>	Trench 3	Consultant	1/13/2003	Provo section	4452628.12	446475.22	4745	Yes	446475.22

Future Plans

- Add Paleoseismic Sites data to the UGS's Utah Geologic Hazards Portal
- Under "Earthquake Hazards" layer - Separate layers for research vs. consultant trenches
- Research trenches with geochronology data will have a hotlink to the UGS's Geochronology Database



Earthquake Early Warning in Utah



UGS: R. William Keach, II, Dr. Steve Bowman
UUSS: Relu Burlacu, Dr. Keith Koper, Dr. Emily Morton
Utah DEM: John Crofts, Debbie Worthen
UCSD/Scripps Institute of Oceanography: Dr. Debi Kilb

UTAH DNR GEOLOGICAL SURVEY
UNIVERSITY OF UTAH SEISMOGRAPH STATIONS

- Scenario for a hypothetical EEW system activation for an earthquake on the Brigham City Segment of the Wasatch Fault Zone

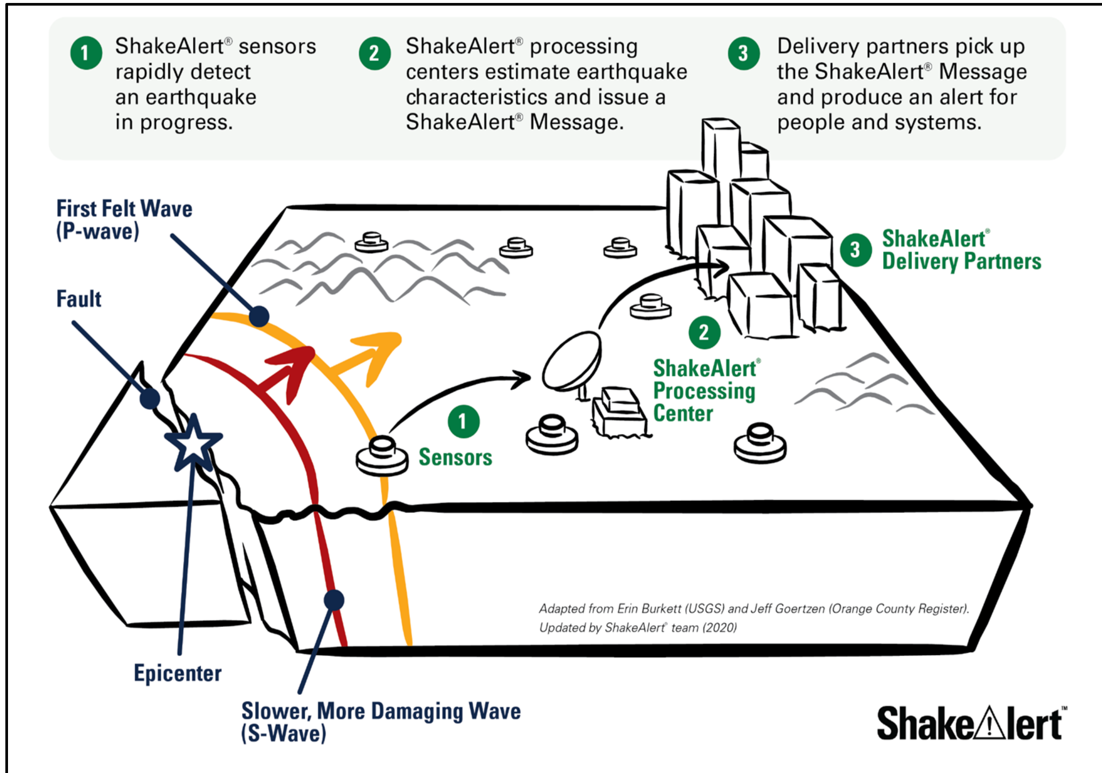
(1) When a fault ruptures and creates an earthquake, the fault sends out different types of seismic waves. The fast-moving, but less damaging, P-wave is the first to arrive. This wave is used to issue a warning before the slower but more damaging waves (S-wave and surface) arrive.

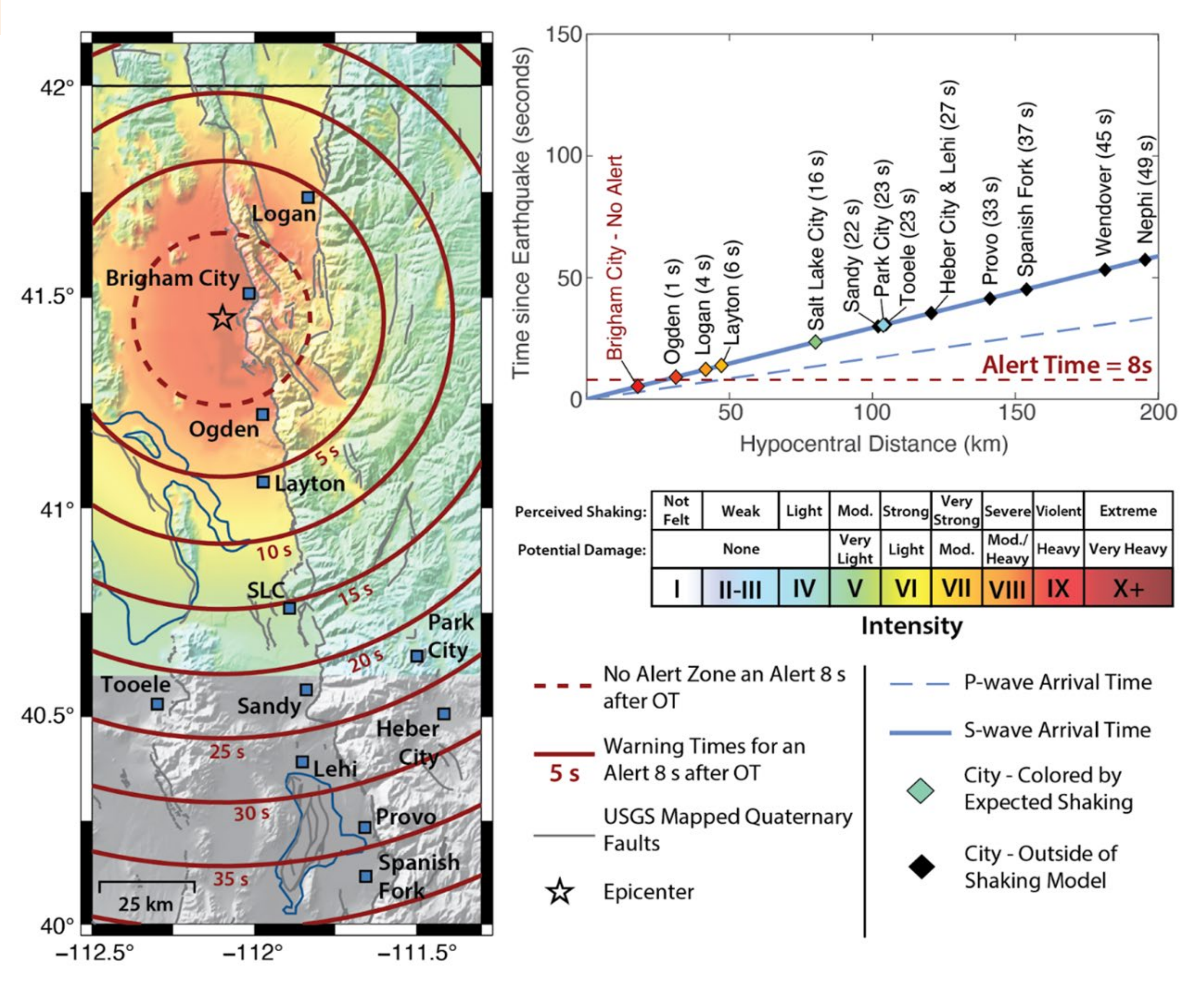
(2) Sensors detect P-waves and immediately transmit data to an earthquake alert center.

(3) The location, size, and estimated shaking of the earthquake are determined at the earthquake alert center.

(4) A message is sent to partners, such as transportation agencies, emergency facilities, and hospitals, to alert people to Drop, Cover, and Hold On as well as trigger automated actions, such as shutting down a train or halting industrial processes.

Possible scenario for implementing an earthquake early warning system in Utah. An earthquake on the Brigham City segment of the Wasatch fault may give populated areas to the south 10 or more seconds to prepare.



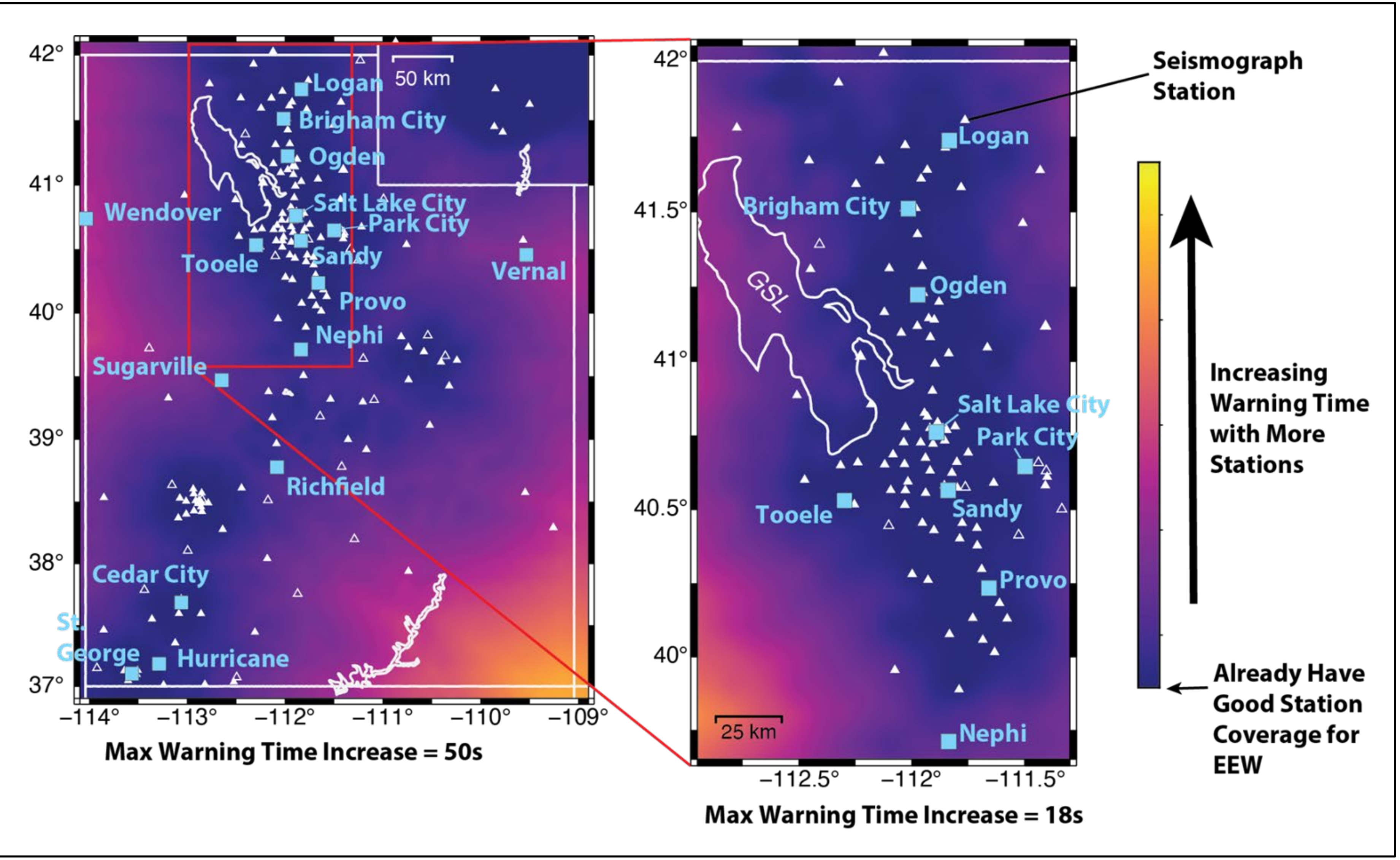


If an M7 earthquake occurred near Brigham City …

Ogden
1 second of warning time

Salt Lake City
16 seconds of warning time

Provo
33 seconds of warning time



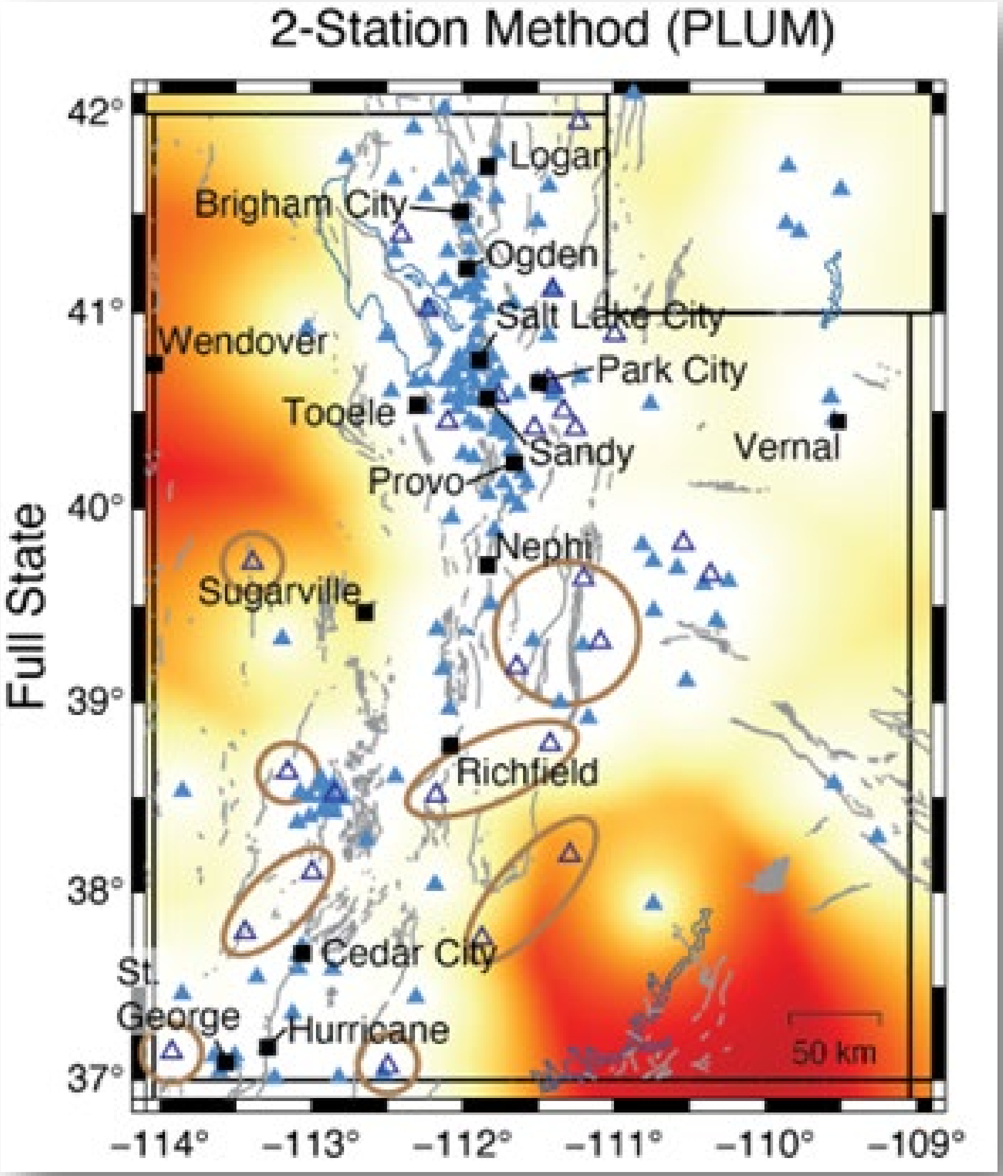
- The current UUSS seismic station coverage makes it feasible to establish an Earthquake Early Warning system within the most populated portions of Utah, with appropriate telemetry upgrades and some new stations.

A closer look

EEW Ready Stations

Need more/improved instruments/telemetry

Improvements will improve warning times in areas of dark red



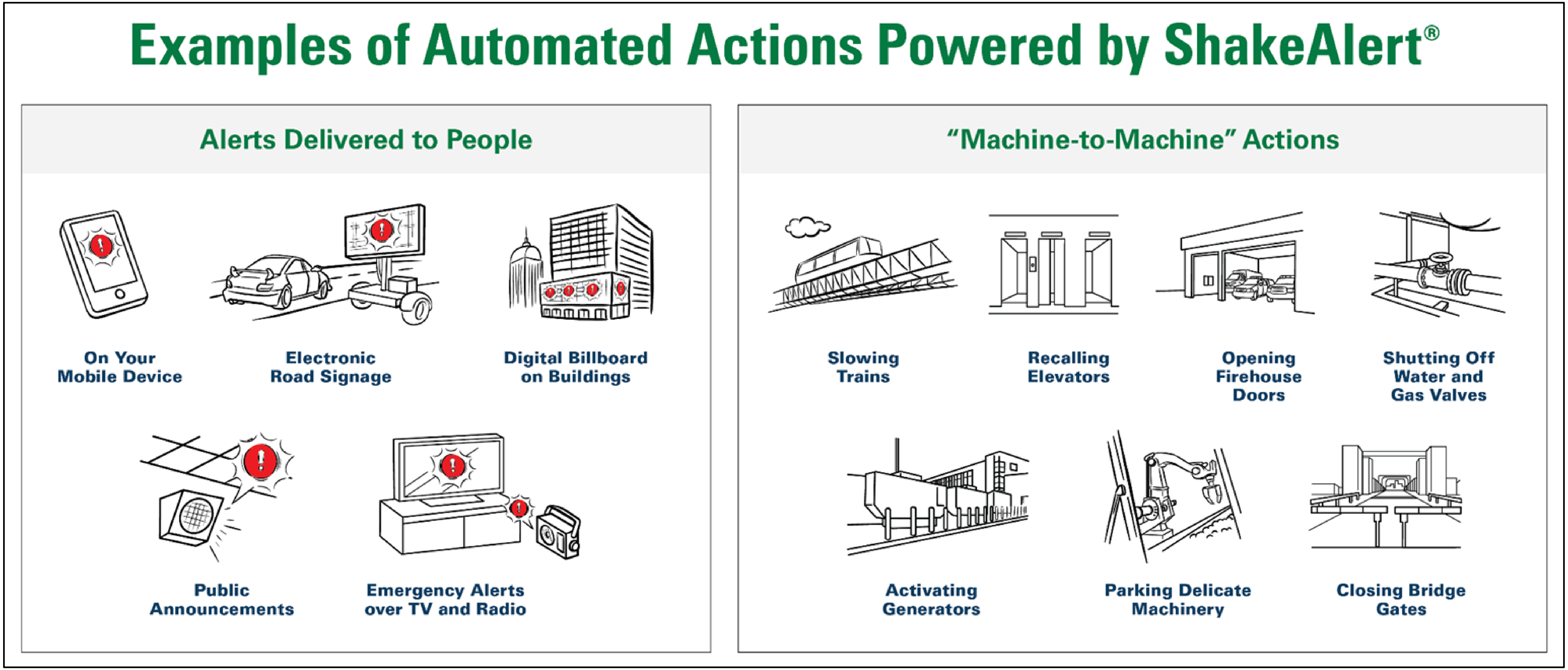


Figure from USGS - ShakeAlert

Utah Legislature – 2024 Session

RFA - FY25

~$5,040,000 one-time

To begin implementation

~$1,110,000 ongoing

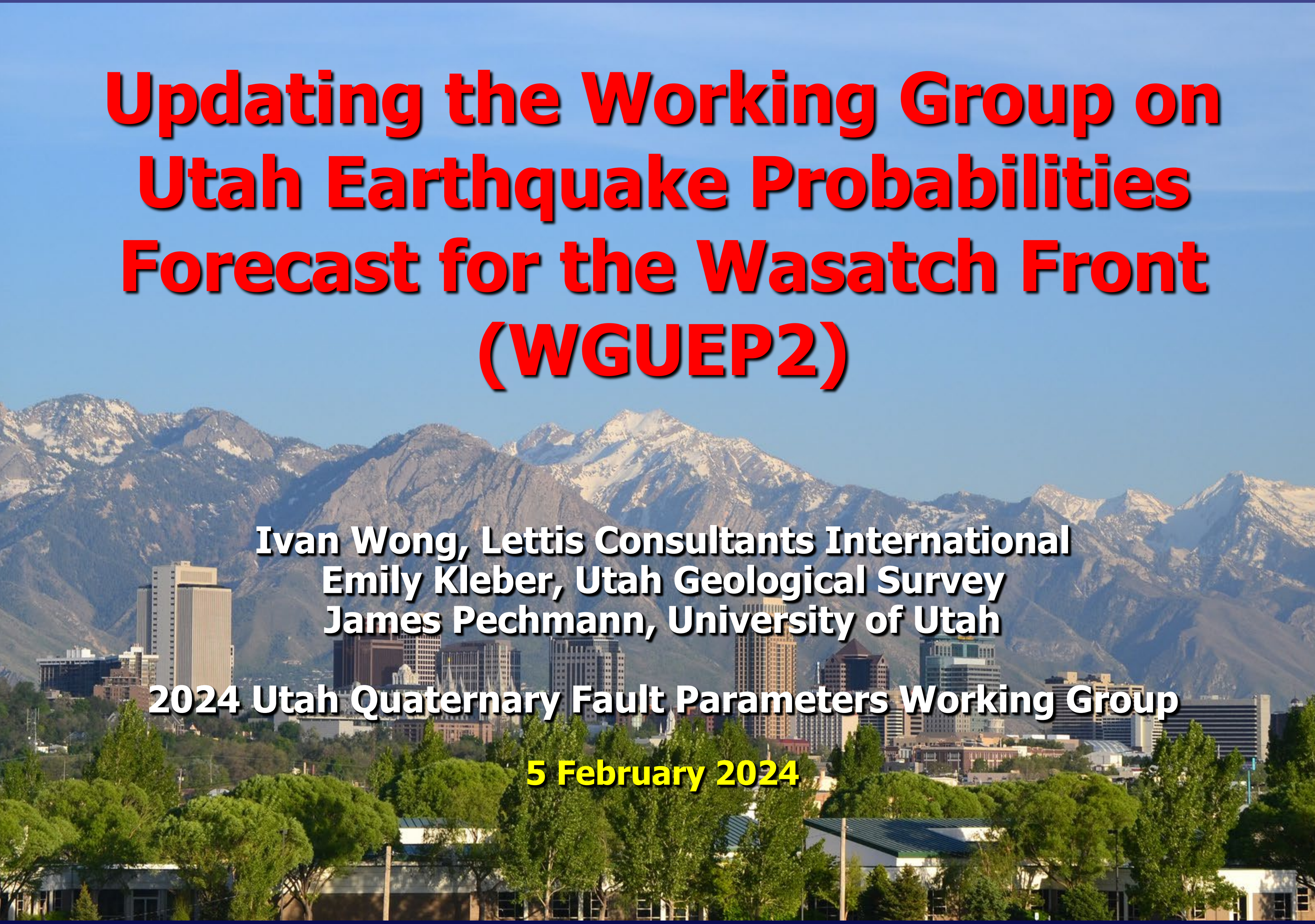
https://ussc.utah.gov/pages/view.php?ref=2138

On the Feasibility of Implementing an Earthquake Early Warning (EEW) System in Utah

Utah Geological Survey

UNIVERSITY OF UTAH SEISMOGRAPH STATIONS

Updating the Working Group on Utah Earthquake Probabilities Forecast for the Wasatch Front (WGUEP2)



Ivan Wong, Lettis Consultants International
Emily Kleber, Utah Geological Survey
James Pechmann, University of Utah

2024 Utah Quaternary Fault Parameters Working Group

5 February 2024

WGUEP

- The WGUEP was a three-year study (stretched to six years) funded by the USGS through NEHRP external grants to the UGS and URS Corporation from 2009 to 2012.
- The WGUEP forecast was released to the public and published in 2016.
- WGUEP2 will be funded for two years by NEHRP through grants to LCI and UGS.

WGUEP

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

WGUEP2

Ivan Wong, LCI (Chair)
Emily Kleber, UGS (Co-Chair)*
Chris DuRoss, USGS
Alex Hatem, USGS*
Bill Lund, UGS (emeritus)
Greg McDonald, UGS*
Jim Pechmann, UU (emeritus)
Mark Petersen, USGS
David Schwartz, USGS (emeritus)
Patricia Thomas, LCI

Objectives

- The WGUEP calculated the probability of moderate to large earthquakes (M $\geq$ 5.0) in the Wasatch Front region for a range of intervals varying from annually to 100 years.

- Time-dependent and time-independent earthquake probabilities that were estimated are:

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

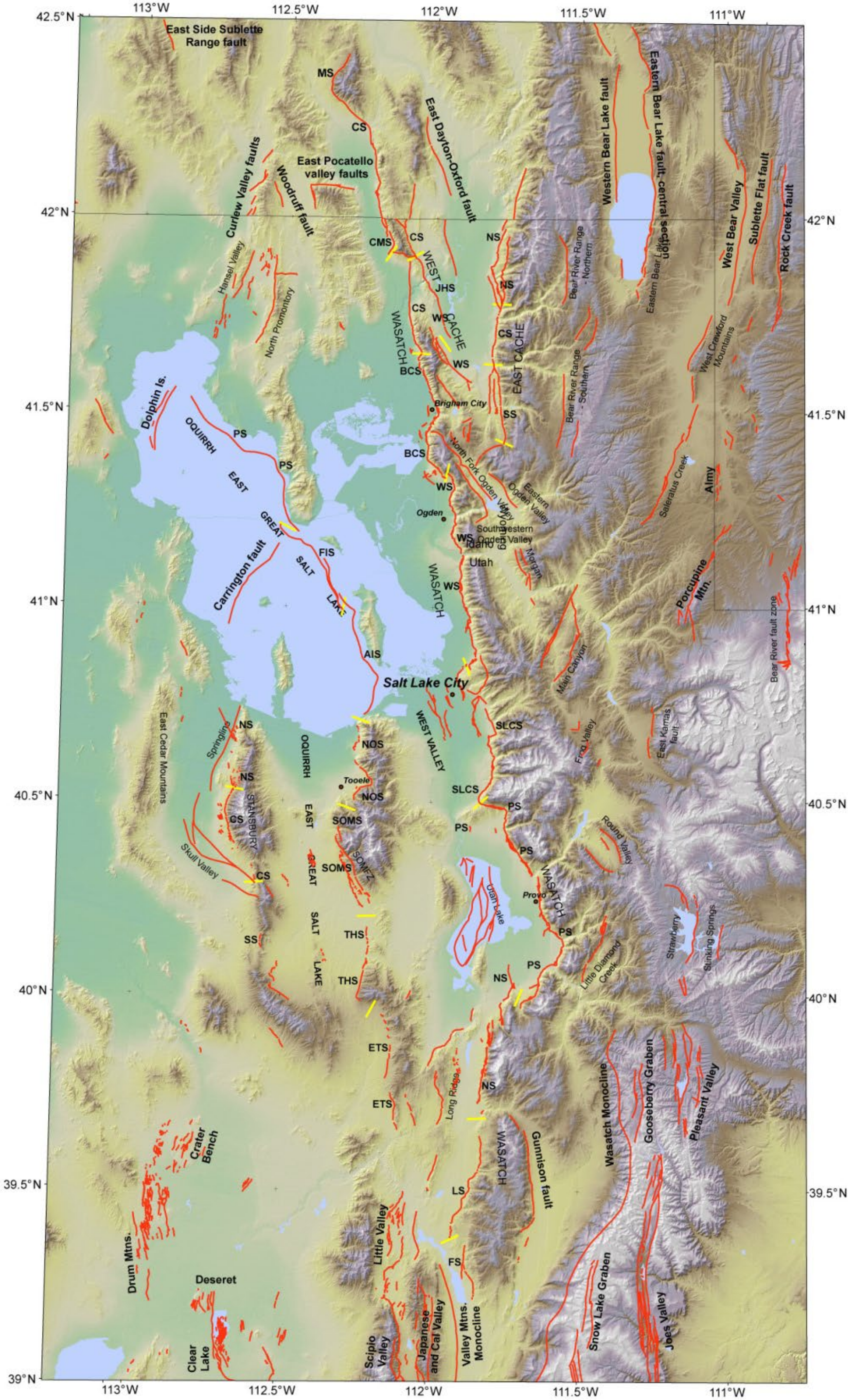
Scope of Work

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

Accomplishments

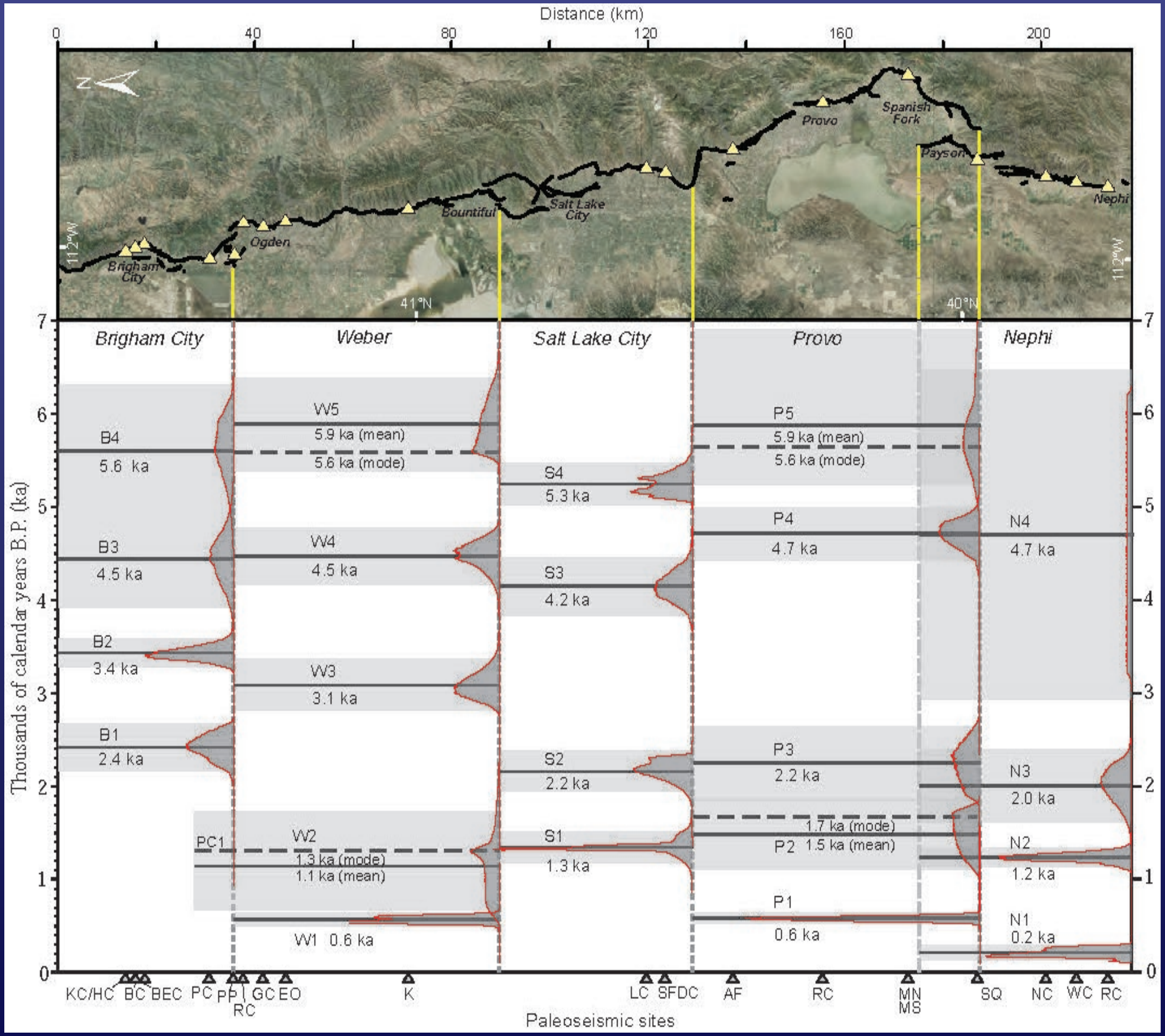
- Characterized all segments of Wasatch and Oquirrh-Great Salt Lake faults and other 45 significant faults and fault segments in the Wasatch Front.
- Developed model for coseismic rupture of antithetic faults
- Constructed a new moment magnitude catalog for the Utah region for 1850 through September 2012.
- Developed a methodology to estimate Mmax.
- Adopted a background earthquake Mmax of M 6.75 ± 0.25 and developed a new procedure to determine unbiased seismicity rates.
- The geodetic data was used as a check on regional moment rates but not to estimate slip rates.

Quaternary Faults Included in the Forecast



Segments of the Wasatch Fault Zone in Utah and Southernmost Idaho

Single-Segment Rupture Model for the Central WFZ (0.70)

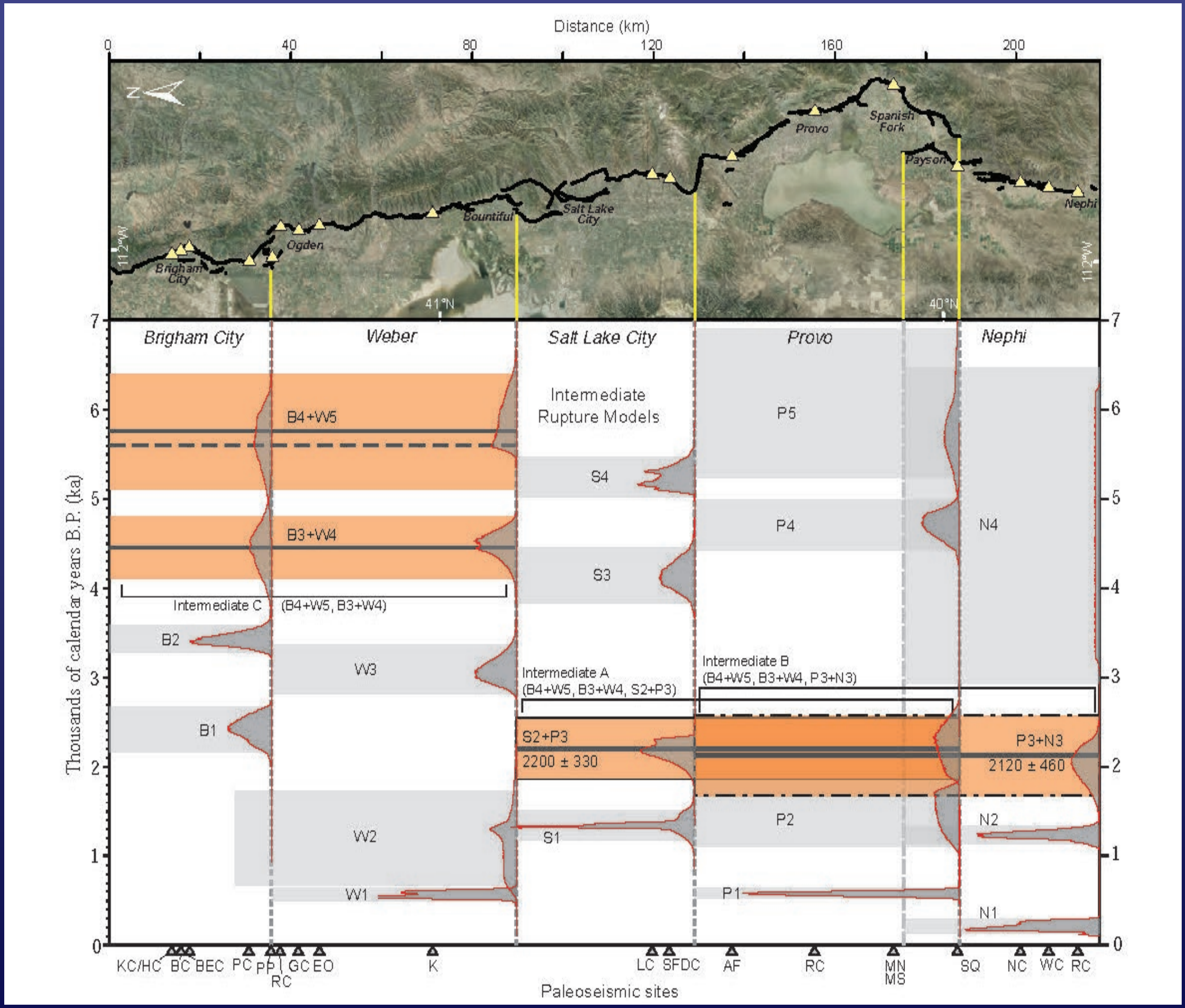


Intermediate Rupture Models for the Central WFZ

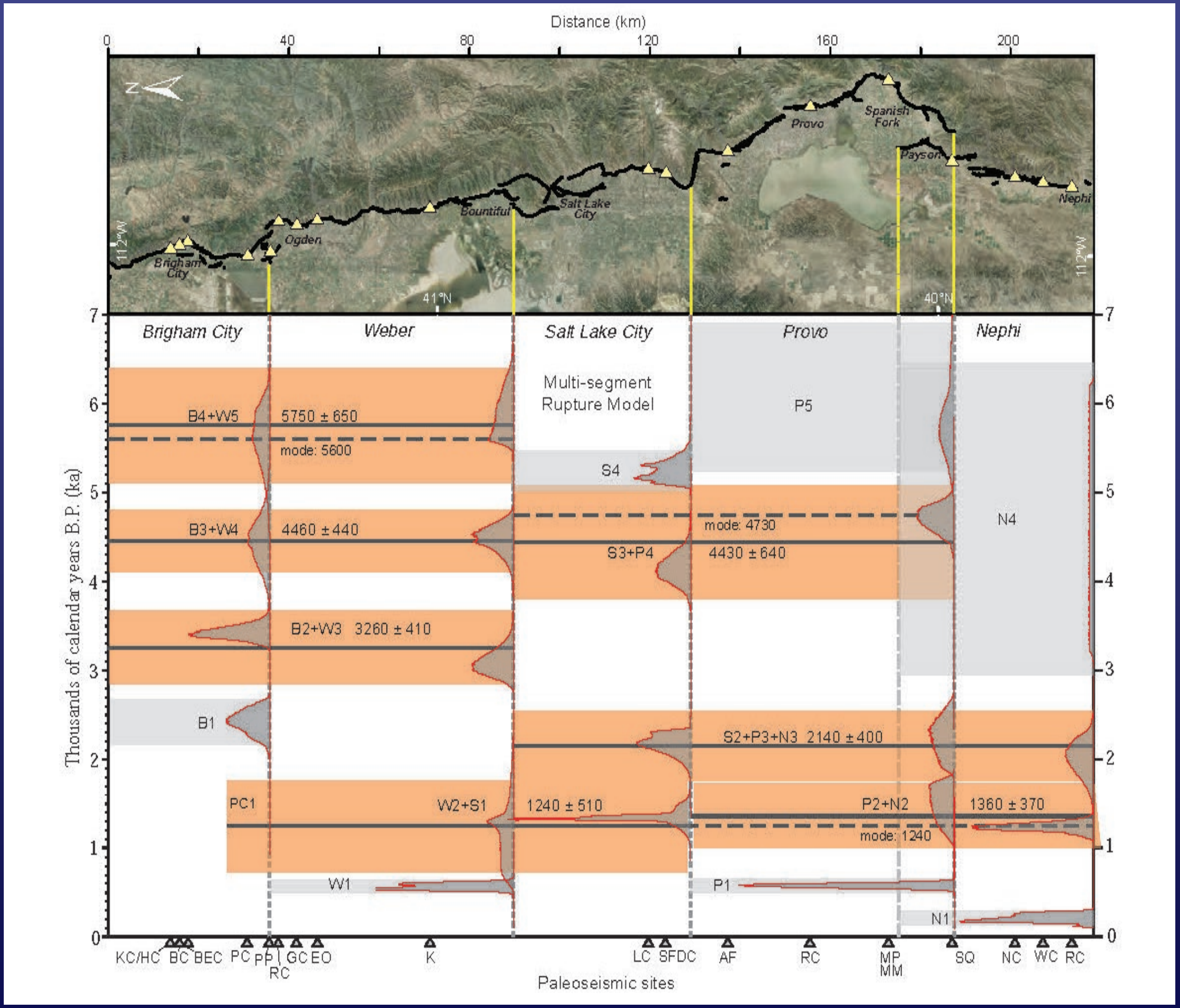
A – B4+W5, B3+W4 and S2+P3 (0.075)

B – P3+N3 in place of S2+P3 (0.05)

C – B4+W5 and B3+W4 (0.05)



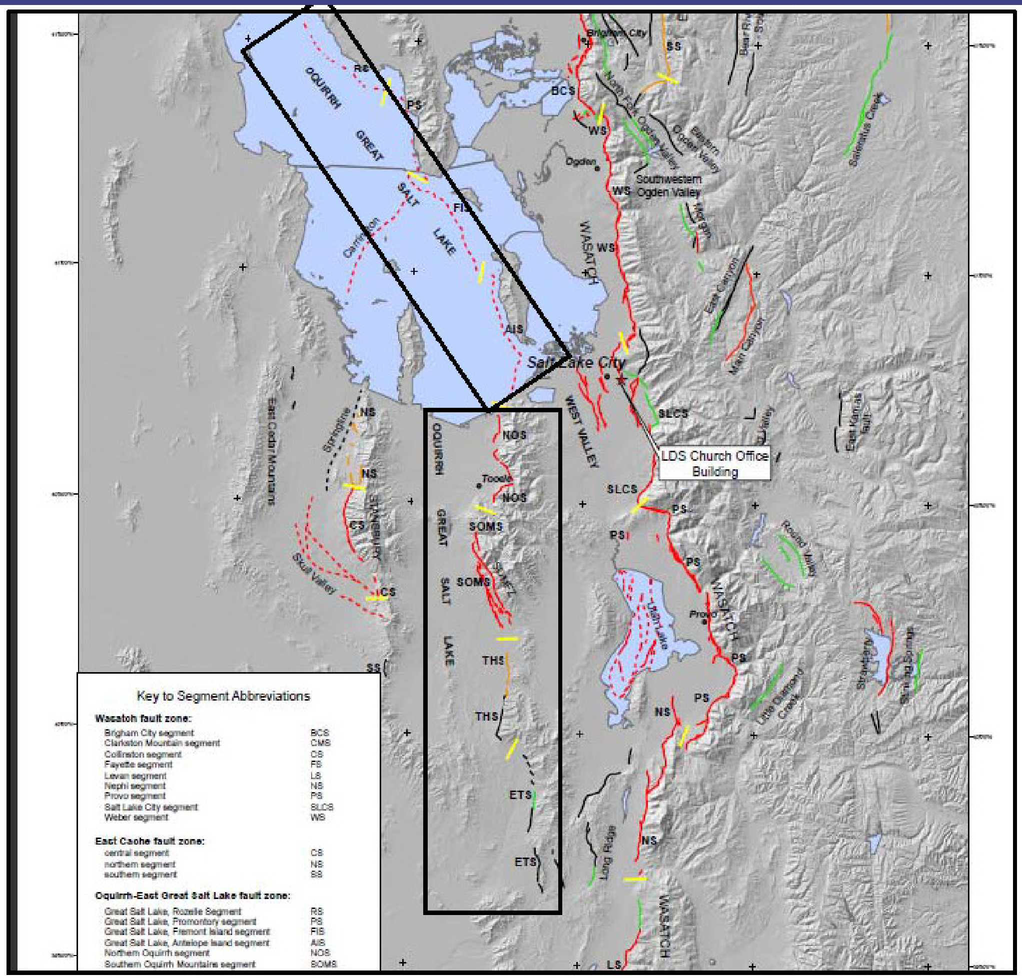
Multi-Segment Rupture Model for the Central WFZ (0.025)



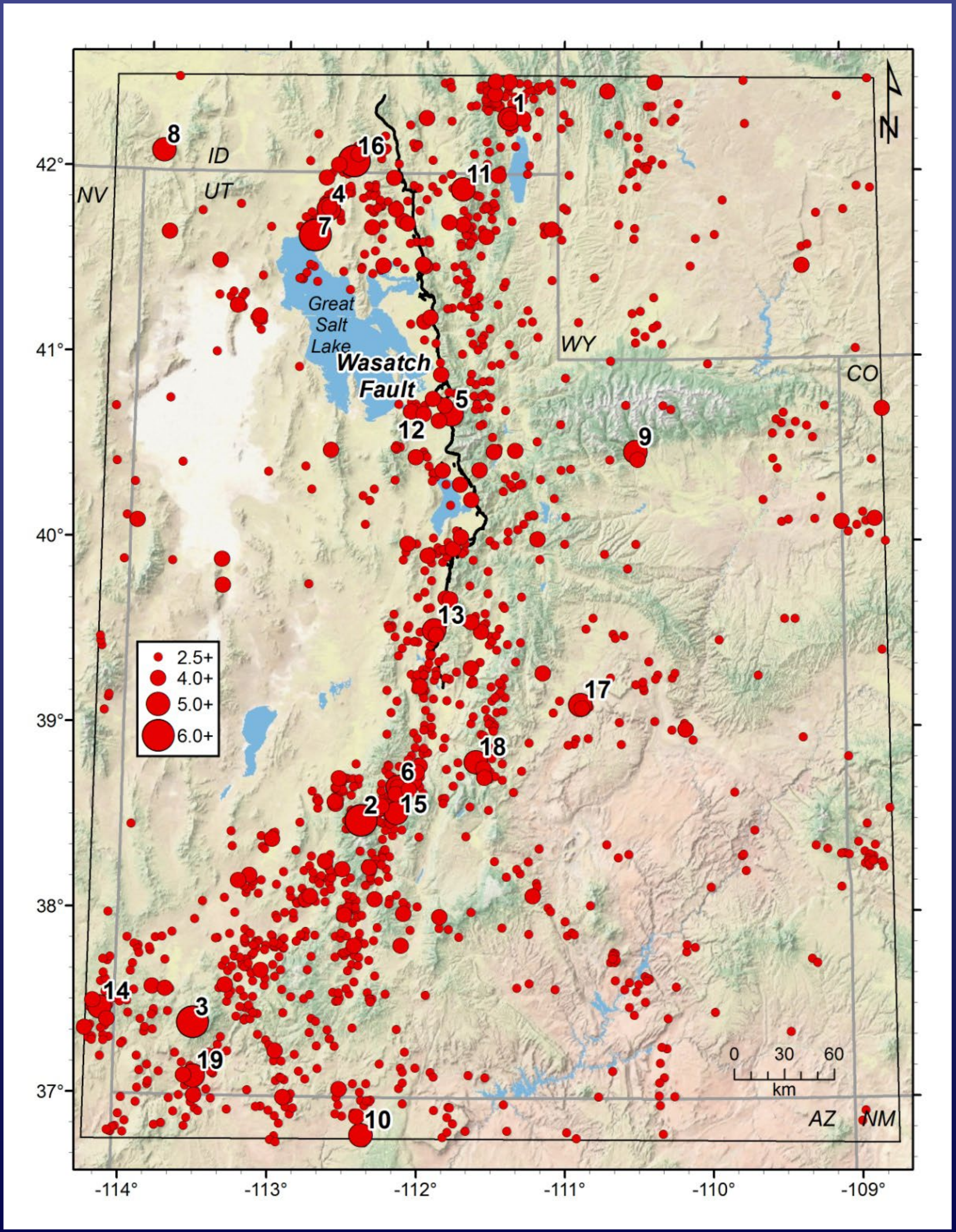
Segments of the Oquirrh-Great Salt Lake Fault Zone

O-GSLFZ SEGMENTS

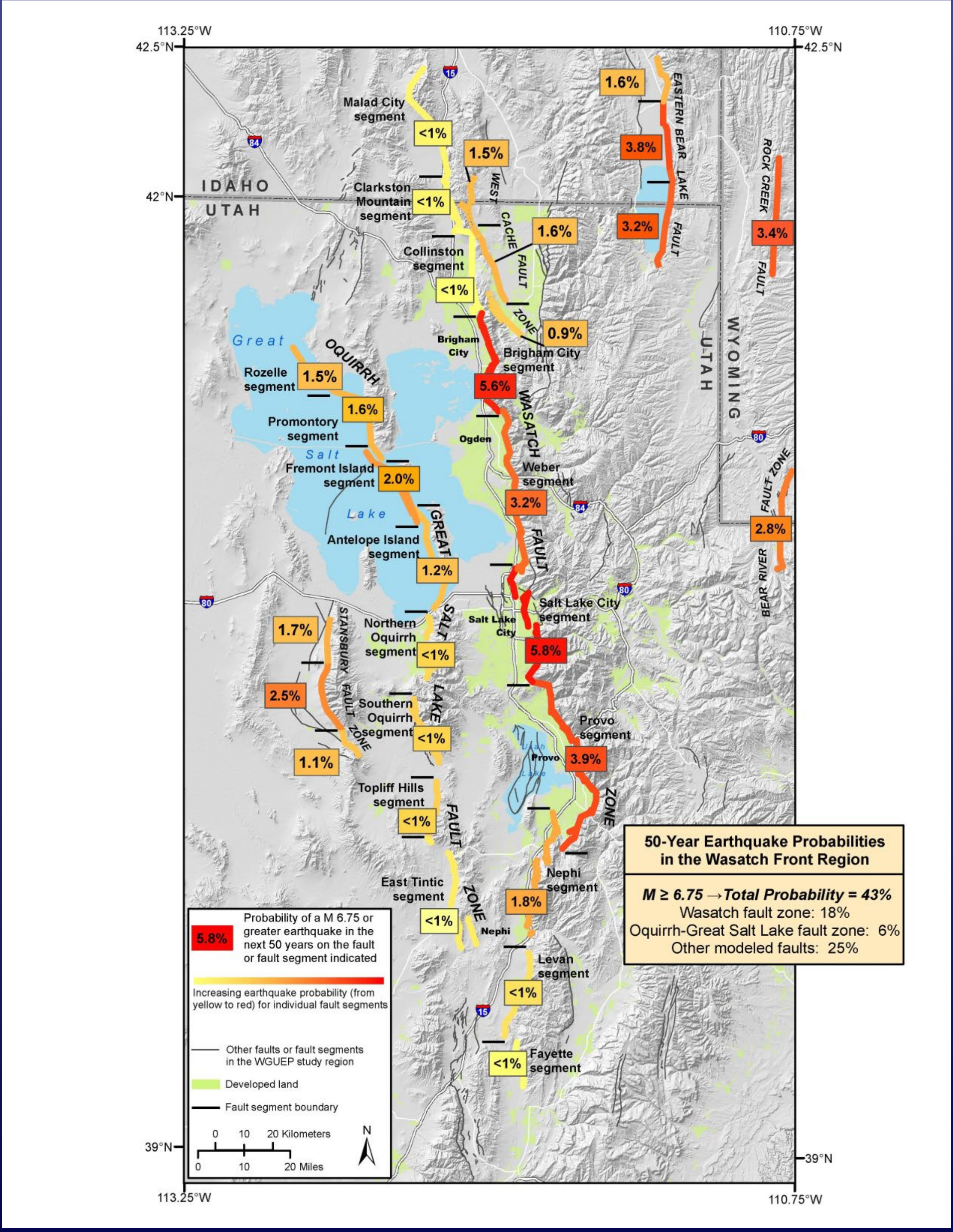
Rozelle (RZ) – 25 km
Promontory (PY) – 25 km
Fremont Is. (FI) – 25 km
Antelope Is. (AI) – 35 km
No. Oquirrh (NO) – 30 km
So. Oquirrh (SO) – 31 km
Topliff Hills (TH) – 26 km
East Tintic (ET) – 35 km



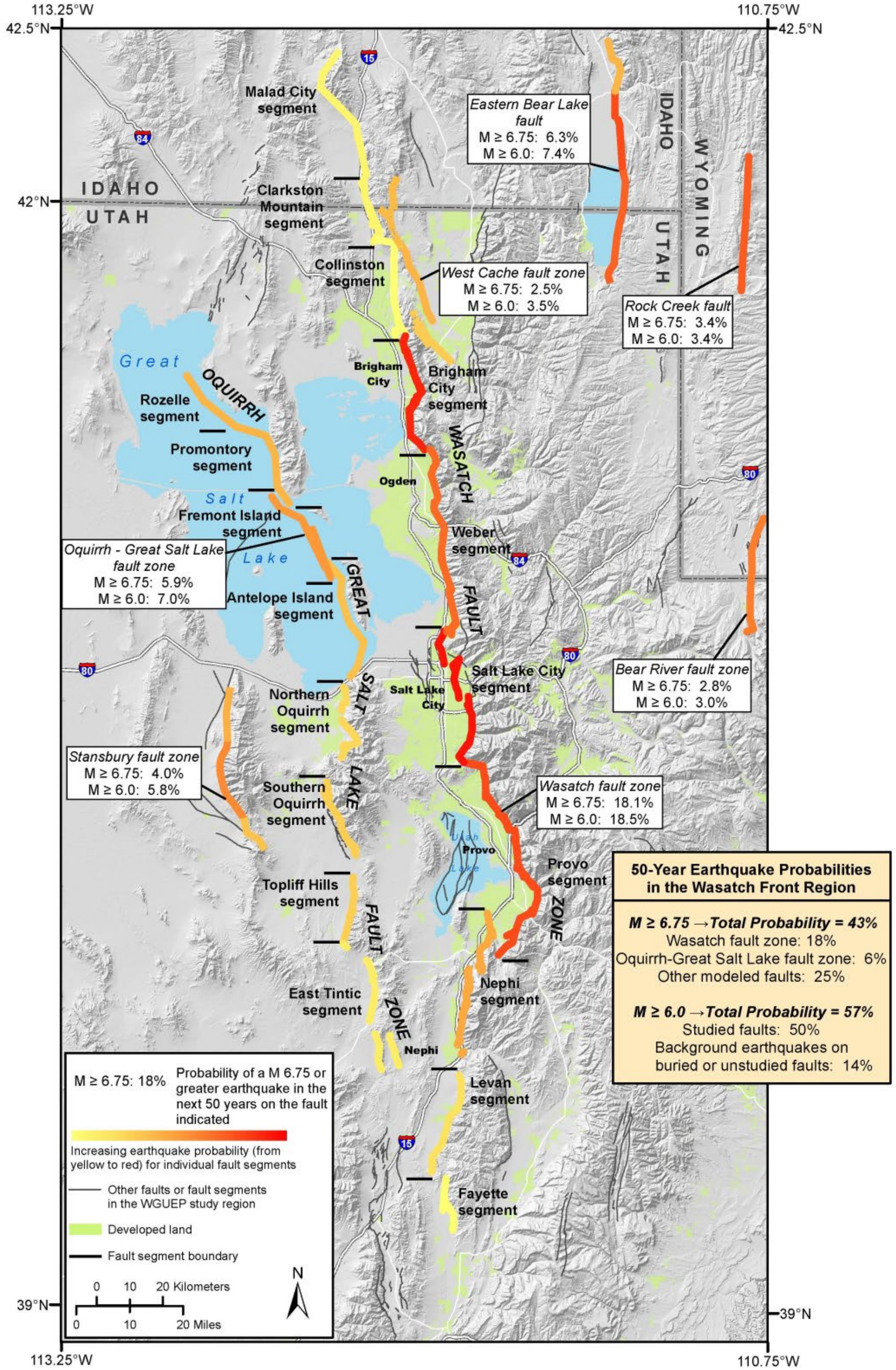
Independent Mainshocks 1850-September 2012



50-Year Probabilities for M≥6.75 2014-2063



50-Year Probabilities for M≥6.75 and 6.0 2014-2063



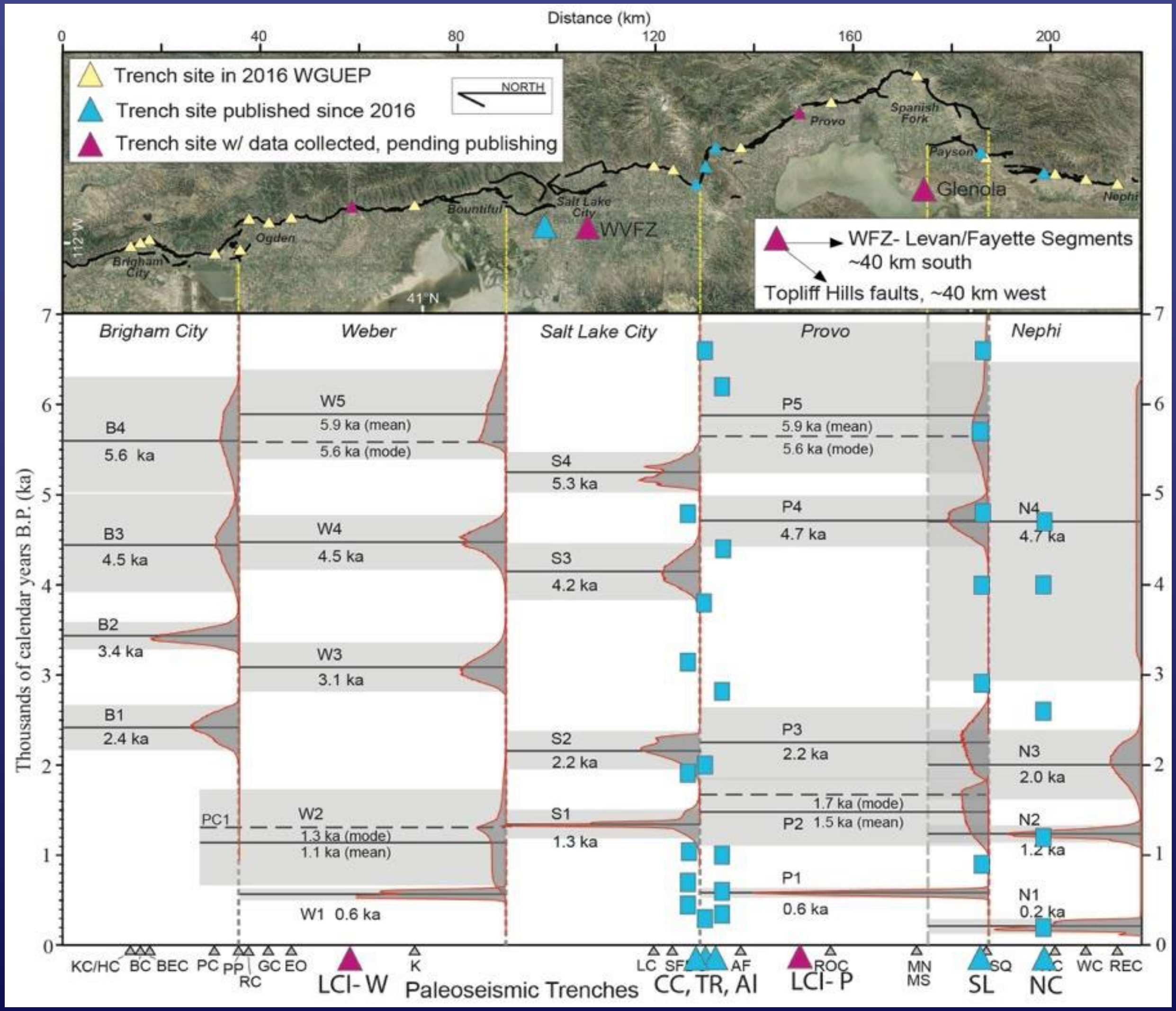
WGUEP2 Topics

- Recent paleoseismic data
- Geodetic deformation models
- Segmentation models
- 2020 Magna earthquake
- Update earthquake catalog and background seismicity rates
- Other faults in Wasatch Front region
- Effects of stress changes
- Other earthquake probability models

Recent Paleoseismic Data

- Studies on the boundaries between the SLCS and Provo segments (Bennett et al., 2018; DuRoss et al., 2018, and Toke et al., 2020) and Provo and Nephi segments (DuRoss et al., 2017).
- Additional timing information is available on the central Weber and Provo segments.
- More paleoseismic data on the West Valley fault zone (Hylland et al., 2022) and Levan and Fayette segments (DuRoss et al., 2016; Hiscock et al., 2017).
- Taylorsville fault – Indiana Avenue trench (Kleber)
- Great Salt Lake lacustrine studies (DuRoss)
- Weber segment trenching and dating (Givler and Bloszies)

Trench Studies Since 2016



Geodetic Deformation Models

- The 2023 NSHM considered five deformation models for the western U.S.: four geodetic inversion models with geologic constraints and one model which is basically a geologic model (Hatem et al., 2022).
- Need to evaluate these models to see if they should be considered in WGUEP2.

Segmentation Models

- Segmentation of Quaternary faults in the Wasatch Front, particularly for the WFZ and the Oquirrh-Great Lake fault zone, was a key issue evaluated in WGUEP.

- Valentini et al. (2020) evaluated the impact on time-independent hazard in the Wasatch Front of relaxing segmentation using the UCERF3 methodology.

- They defined three models with varying degrees of rupture penalization: 1) segmented ruptures confined to individual segments; 2) penalized (multi-segment ruptures allowed but penalized); and 3 unsegmented with all ruptures allowed.

- Their results showed that, on average, the hazard is highest for the segmented model with seismic moment being accommodated by relatively frequent moderate earthquakes (**M** 6.2 to 6.8) and lowest for the unsegmented model where the seismic moment release is partially accommodated by large infrequent ruptures (**M** 6.9 to 7.9).

2020 Magna Earthquake

- WGUEP assumed nearly all faults in the Wasatch Front area to be planar normal faults with dips of 50° ± 15°, based primarily on seismological studies of large continental normal-faulting earthquakes worldwide and in the Basin and Range Province.
- We used this assumed subsurface fault geometry to estimate the downdip widths of faults, calculate their characteristic magnitudes from these widths and the fault or segment lengths, and, for some faults, estimate earthquake recurrence rates from their slip rate.
- The assumed dip distribution of 50° ± 15° has been called into question, at least for the northern SLCS, by observations of the 2020 **M** 5.7 Magna, Utah earthquake.
- A subgroup of the WGUEP has developed a preliminary logic tree for the subsurface geometry of the SLCS (Pechmann et al., 2023).
- Should a listric fault geometry also be assumed for other sections of normal faults in the Wasatch Front region where antithetic faults are present?

Update Earthquake Catalog and Background Seismicity Rates

- Update the catalog.
- Update removal of induced earthquakes.
- Compile and evaluate moment magnitudes for newly-added earthquakes.
- Decluster using one or more approaches e.g., Gardner and Knopoff
- In the 2023 NSHM, the earthquake catalog was declustered to map out the spatial variability but the rates were scaled up using the full catalog to account for aftershock hazard. WGUEP2 will evaluate this approach and decide whether it should be implemented.

Other Faults in the Wasatch Front

- New data on the Topliff Hills fault (Ward et al., 2019)
- A new fault: the Glenola fault near Utah Lake (Smith et al.)
- New data???

Effects of Stress Change

- Bagge et al. (2018) simulated Holocene earthquakes on the WFZ, Oquirrh-Great Salt Lake, and WVFZ since 6400 BP using 3D viscoelastic finite-element forward modeling constrained by GPS data.
- Their goal was to calculate coseosmic and post-seismic Coulomb stress changes for the purpose of evaluating the slip and magnitude of hypothetical present-day and future **M** 6.5 and large earthquakes.
- Post-seismic viscoelastic effects can significantly modify coseismic stress changes and such changes are recognizable for more than 100 years after an event (Bagge et al., 2018).
- The results of their study indicate significant positive Coulomb stress changes for the Brigham City and Salt Lake City segments
- They also calculated stress changes for the Oquirrh-Great Salt Lake fault zone and computed a high stress change of 69 Mpa for the Fremont segment (higher than the Salt Lake City segment), indicating that it may have a probability of rupture (**M** 7.0) higher than that predicted by WGUEP.

Effects of Stress Change (continued)

- In a similar study, Verdecchia et al. (2019) calculated static and quasi-static Coulomb stress changes (deltaCFS) on the central WFZ and adjacent segments or faults.
- They calculated the cumulative (coseismic + post-seismic) Coulomb stress changes due to events younger than the most recent event on each segment and applied the resulting values to the time-dependent probability calculations.
- They concluded that the Brigham City and SLC segments have the highest probabilities of future rupture in the next 50 years, similar to the results of WGUEP.
- However, they estimate a probability of 43.3 $\pm$ 32.5% for the Brigham City segment in contrast to the 7.5% estimated by WGUEP.
- For the SLC, they estimated a 10.5 $\pm$ 3% probability compared to WGUEP’s 6.1%.
- Most of these differences can be attributed to their site-specific COVs, which tend to be lower than the broad global range used by WGUEP.
- In summary, the analyses of Bagge et al. (2018) and Verdecchia et al. (2019) need to be evaluated by WGUEP2 and the potential effects of Coulomb stress changes and segment specific COVs on earthquake probabilities should be considered in the next forecast.

Other Earthquake Probability Models

- Neely et al. (2022) have proposed a “more realistic earthquake probability model” using long-term fault memory (LTFM). They argue that current models including the Brownian Passage Time used in the WGUEP and WGCEP forecasts assume that large earthquakes release all their accumulated strain since the previous event.

- The advantage of LTFM, according to the authors, is that it can take better advantage of the long-term paleoseismic record where gaps or clusters may exist. An example of a large gap may be the elapsed time since the most recent earthquake on the Brigham City segment where the elapsed time has far exceeded the mean recurrence interval.

- Alternative earthquake probability models will be evaluated.

Schedule

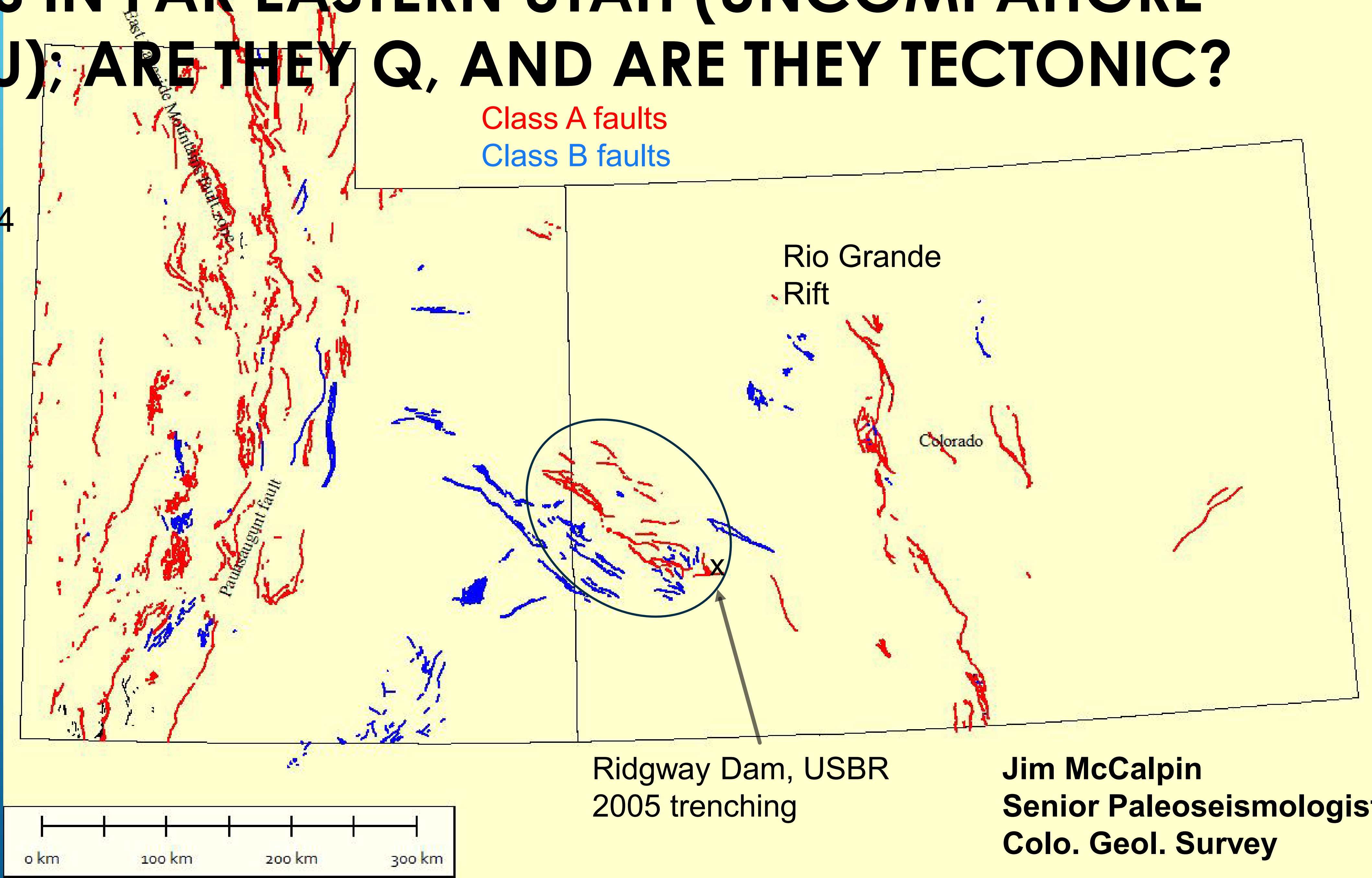
- Begin as soon as funding is released.

Schedule for the WGUEP2	
Workshop	Purpose
1	Kickoff: Review WGUEP2 scope of work (April 2024?).
2	Review paleoseismic data, reevaluate segmentation models for the WFZ, and other probability models.
3	Review seismicity data and Coulomb stress change studies.
4	Review geodetic deformation models used in the 2023 NSHM and characterization of other faults.
5	Review preliminary earthquake probability calculations.
6	Review and adopt final results.

- Assuming March 2024 startup, complete by June 2026 with press and TV coverage for the public release of the forecast at a meeting of the Utah Seismic Safety Commission and publication.

QFAULTS IN FAR EASTERN UTAH (UNCOMPAHGRE PLATEAU); ARE THEY Q, AND ARE THEY TECTONIC?

Qfaults from USGS online Database, 2024

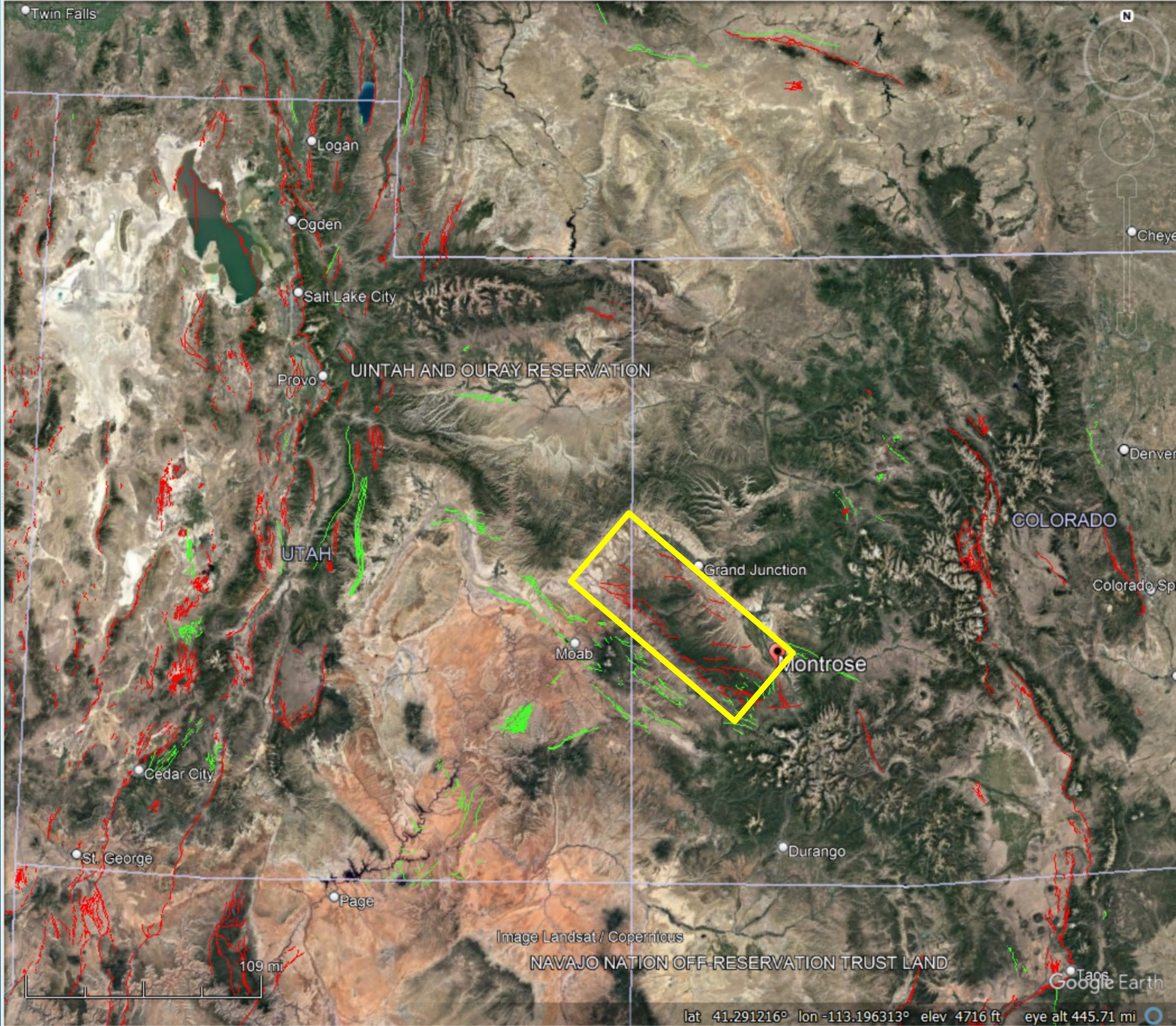


Jim McCalpin
Senior Paleoseismologist
Colo. Geol. Survey

Uncompahgre Plateau

Class A faults in USGS database

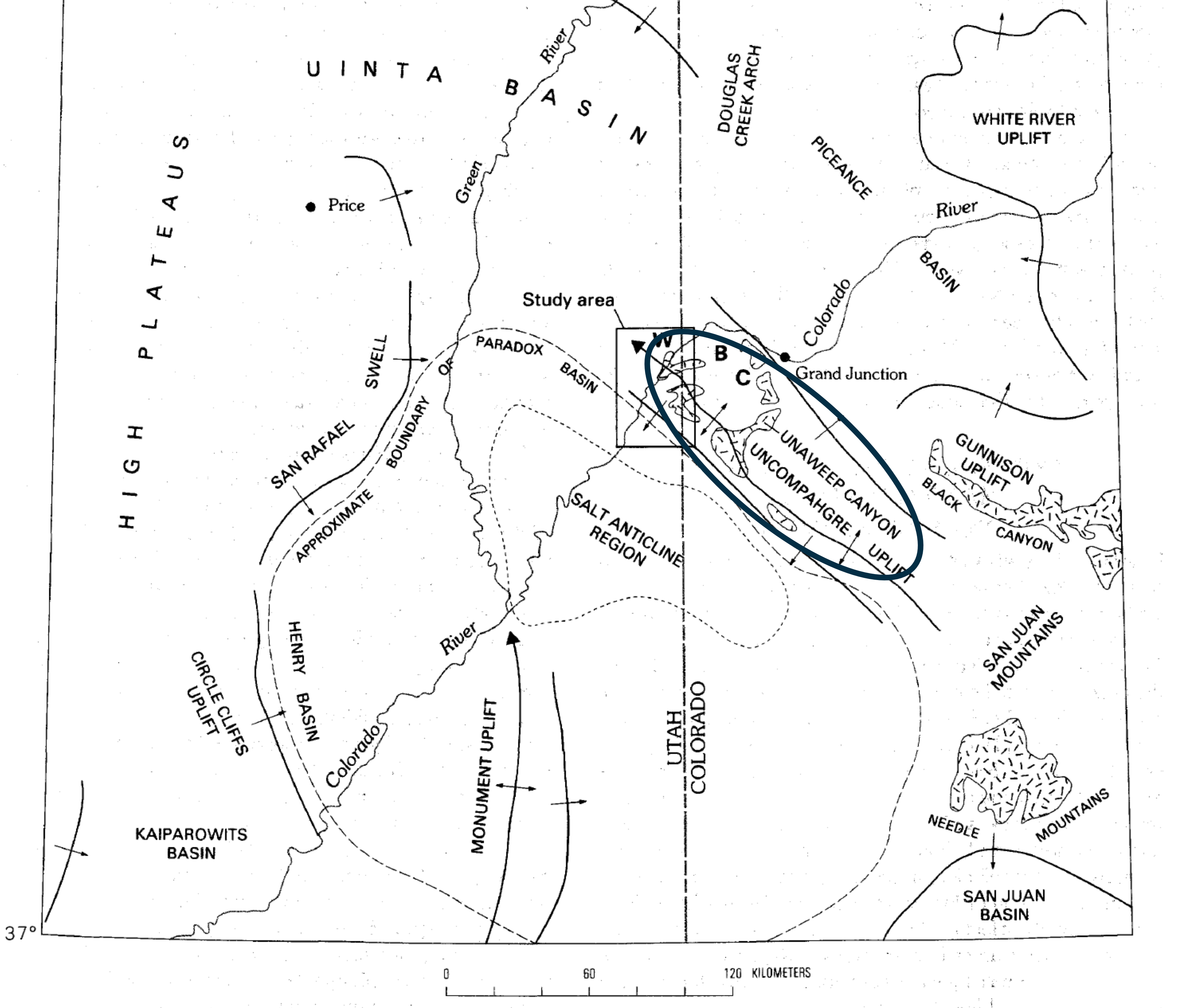
Class B faults in USGS database



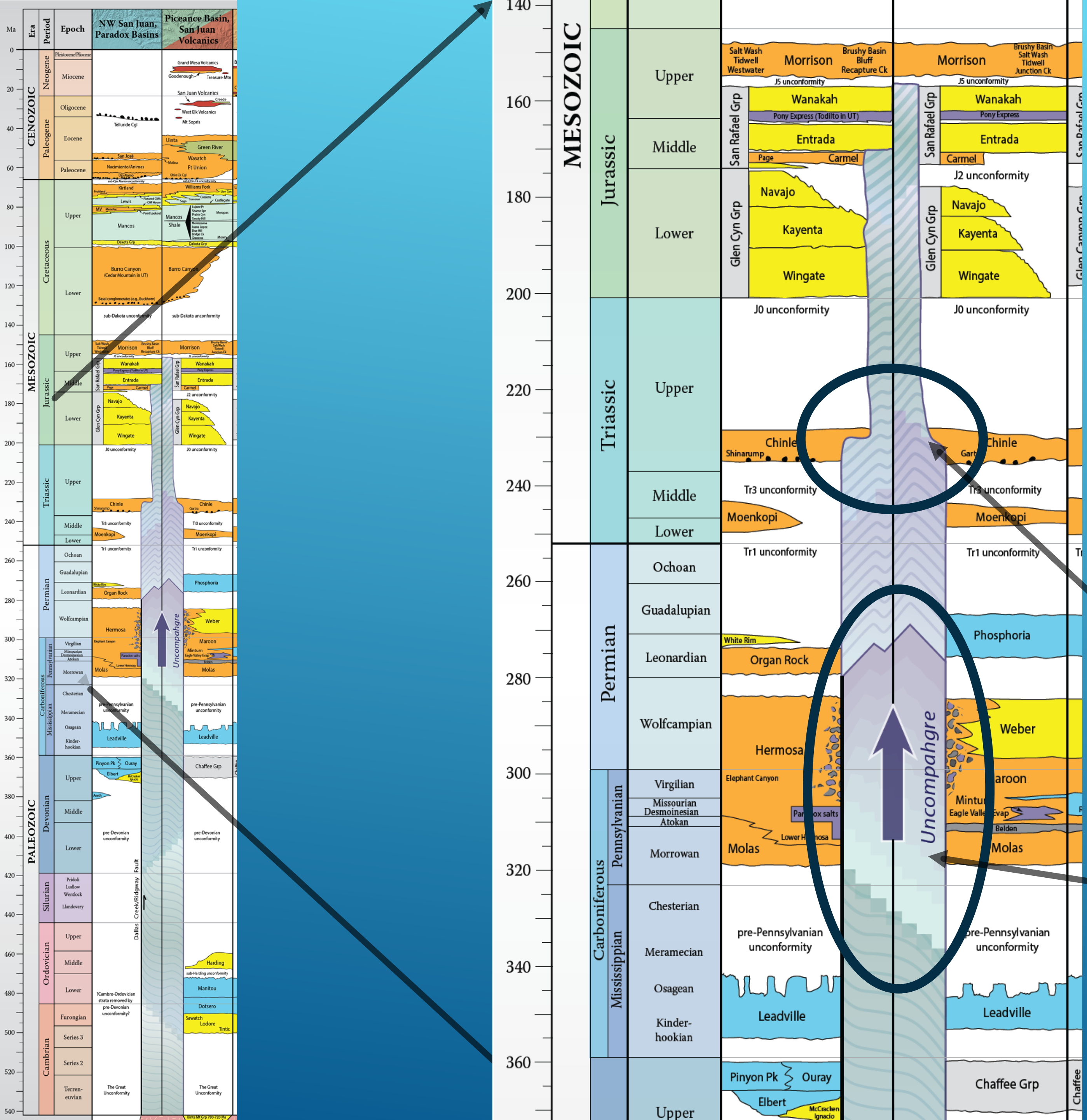
Qfaults from USGS online Database, 2024

Map of Laramide uplifts in the UT-CO region

Ellipse covers Uncompahgre faults



USGS map I-2088, booklet, 24k, Case, 1991



Due to two episodes of uplift and erosion, Pennsylvanian evaporites were eroded off the Uncompahgre Plateau;

Currently Chinle Fm. (Triassic) to Mancos Shale (Cretaceous) sit directly on Precambrian basement

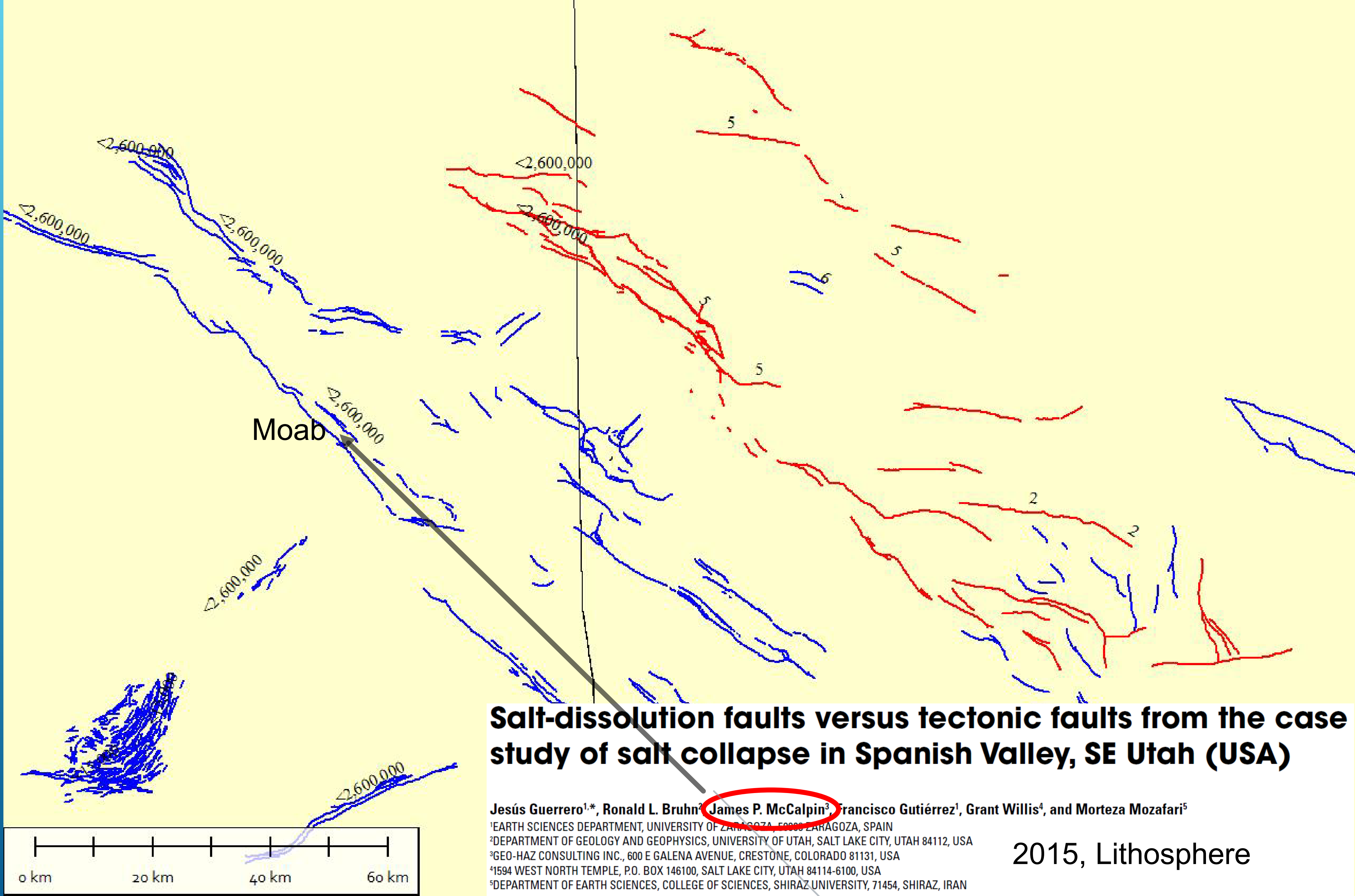
Laramide
Uplift and erosion

Ancestral Rockies
Uplift and erosion

Strat column from CGS map series 53, Raynolds & Hagedorn, 2016

Therefore, it is very unlikely that young-looking faults on the Uncompahgre Plateau can be attributed to salt dissolution.

That is, Class B faults.



Salt-dissolution faults versus tectonic faults from the case study of salt collapse in Spanish Valley, SE Utah (USA)

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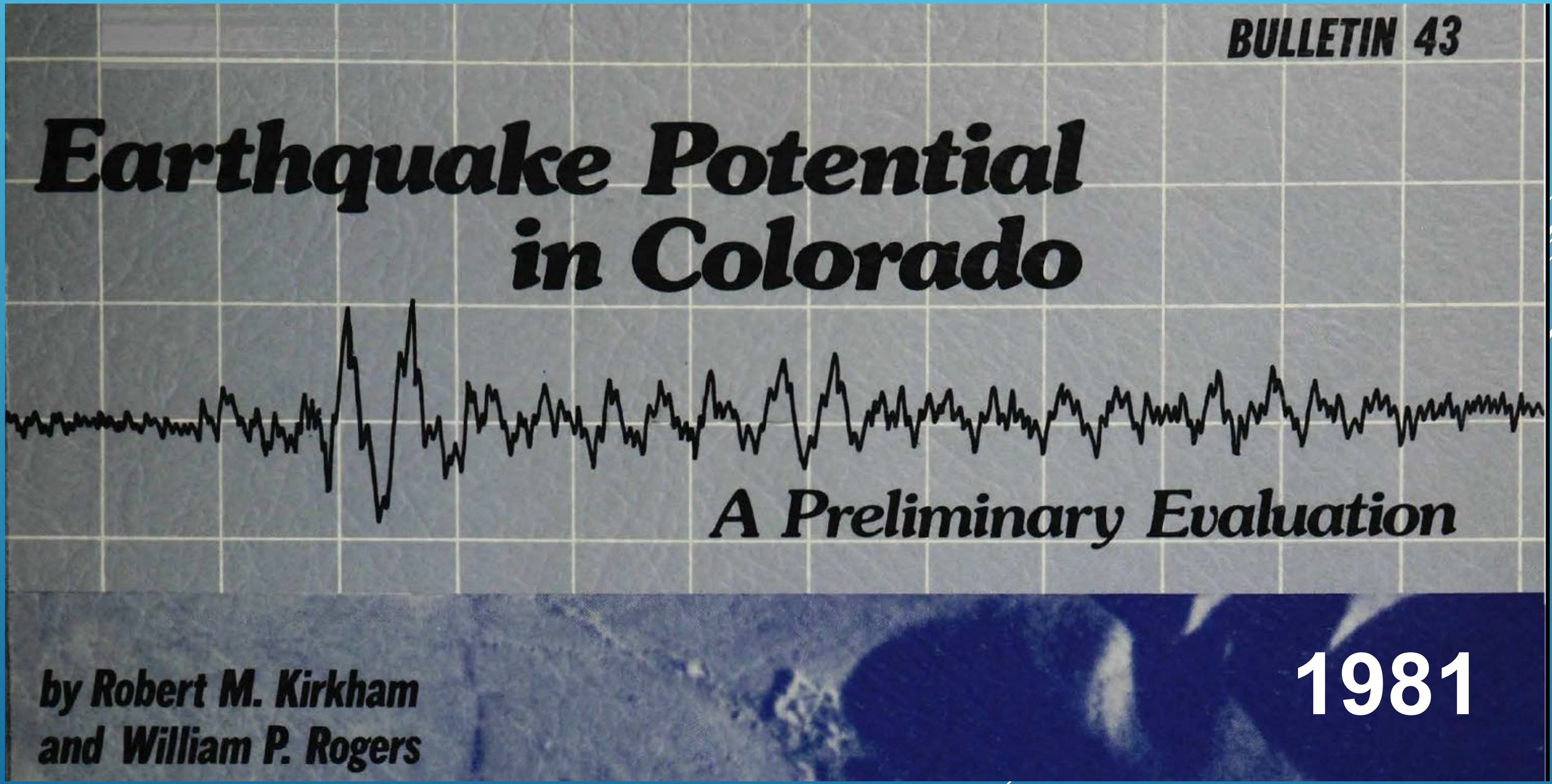
2015, Lithosphere

Historical Background on Qfaults in CO and far eastern UT.

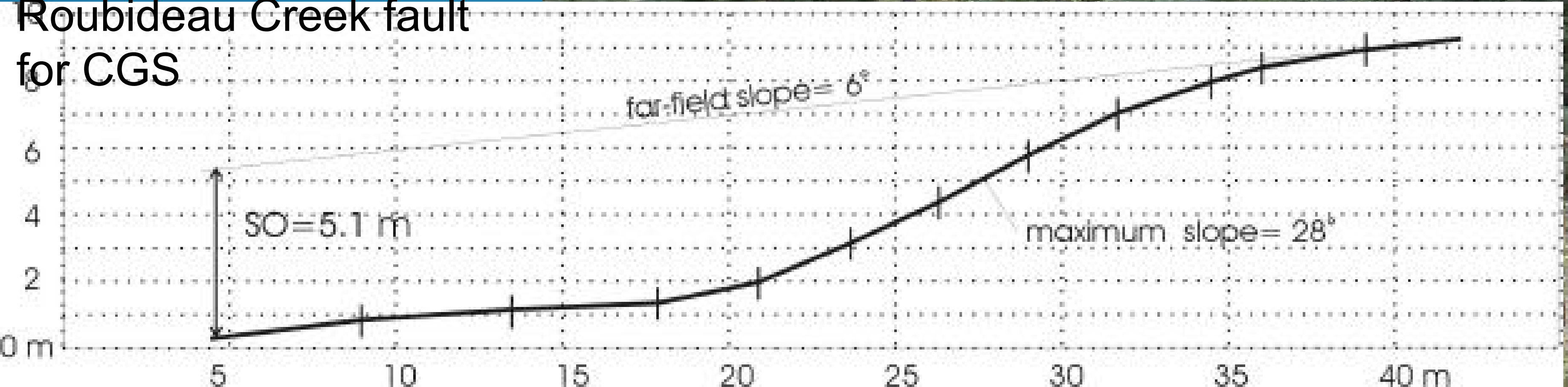
Prior to the late 1970s, all faults in CO were considered to be dead. Even those in the Rio Grande rift, because there was no associated historic seismicity. Rift faults were assumed to have ceased activity in the Pliocene.

That all changed in 1979 (Open-File) and 1981 (Bulletin); Bob Kirkham (Univ. of Nevada-Reno to CGS) published EQ Potential of Colo. He knew what Q Faults looked like, and identified the Roubideau Creek fault on the Uncompahgre Plateau as displacing Q deposits.



Bob, the most prolific mapper in CGS history, recently passed away at age 71.

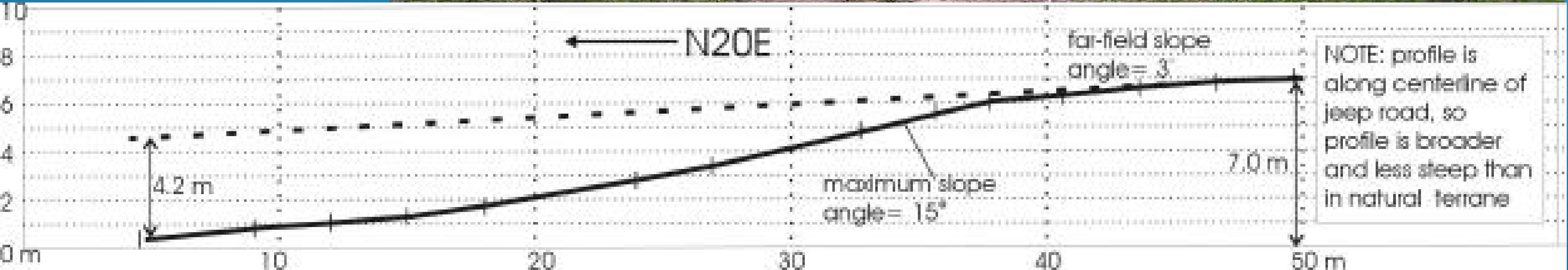
In the 1980s and 1990s many faults with similar appearance were identified on the Plateau. *And then became incorporated into the first versions of the Qfault Database of the US; some extended into UT.* In the early 2000s Mike West proposed that Kirkham's young fault scarp was a landslide scarp.
In 2003 I examined the Roubideau Creek fault for CGS

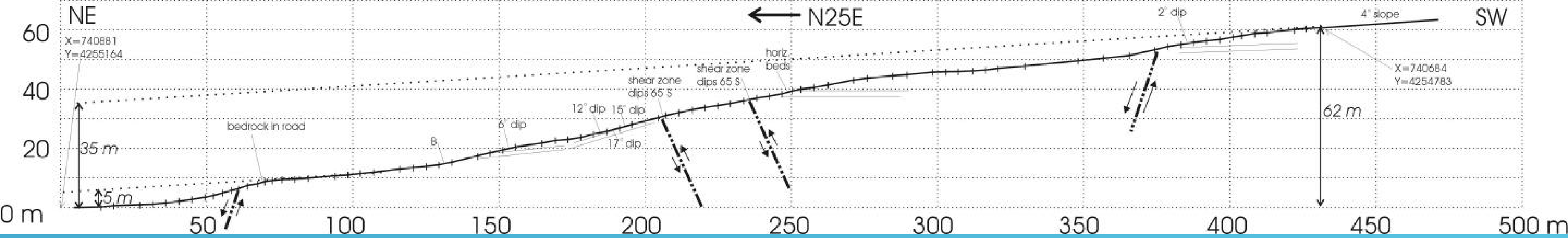


I agreed with West.

But then discovered many more young-looking scarps up on the dipslope. There were no landslides anywhere near these scarps.

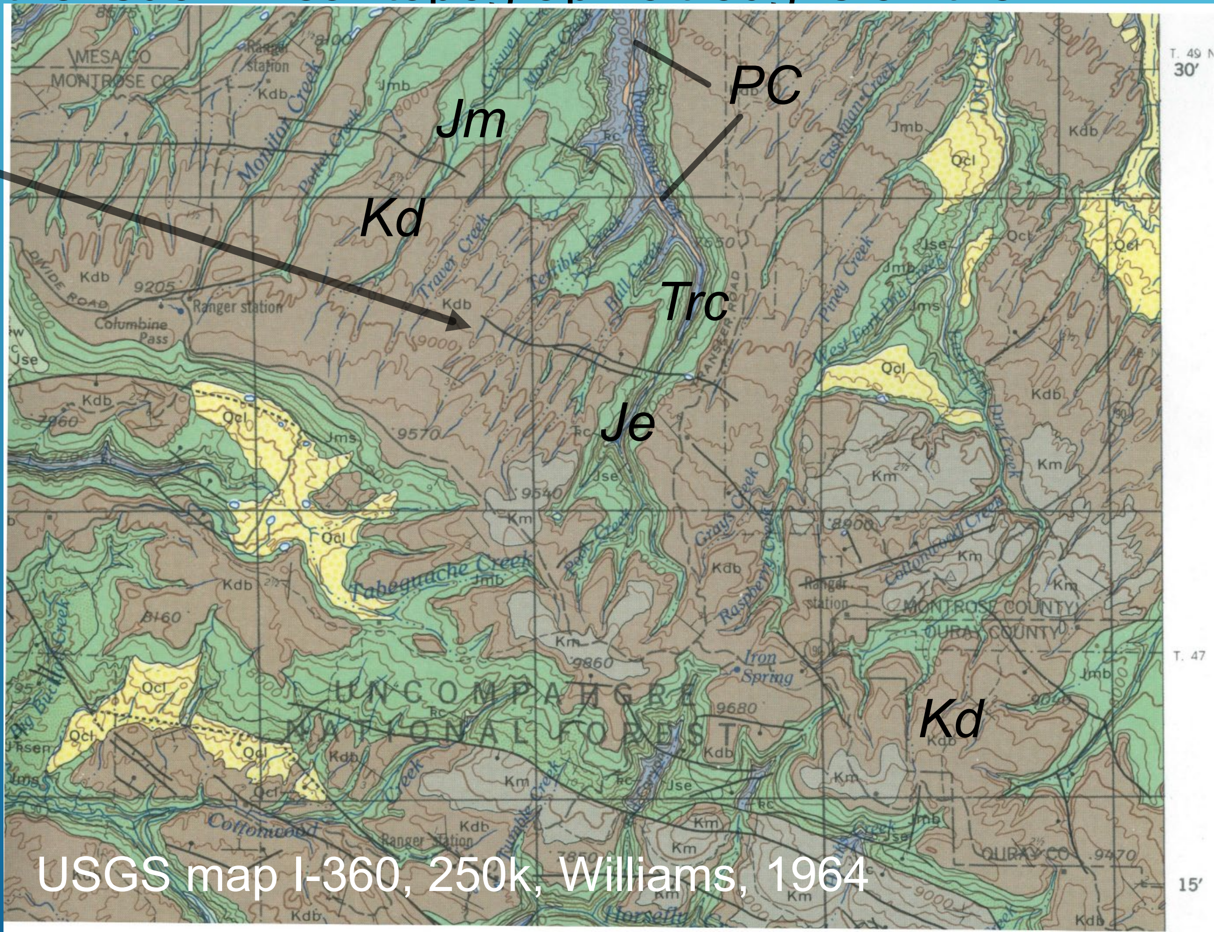
Most of the scarps were 4-12 m high and associated monoclines with vertical separations up to 35 m (next slide).





The steepest 4-12 m-high scarps lay at the toe of the monocline, and formed the western margin of a linear, NW-trending topographic trough. There were no other such linear topographic troughs on the Plateau.

Roubideau Creek fault



USGS map I-360, 250k, Williams, 1964

The Roubideau Creek fault & monocline are formed in Kd, Dakota Sandstone. Underlain by Jm (Morrison Fm, highly prone to landsliding); then Entrada Sandstone (Je); then Chinle Fm. (Trc).

In the deepest part of Roubideau Canyon Trc lies directly on PC, Precambrian basement. Clearly there are no Pennsylvanian evaporites underlying the fault.

In 2005 US Bur Reclamation performed 2 studies:

1-contracted me to map all the young-looking faults between the Busted Boiler and Roubideau, to support Seismic Source Characterization (rupture scenarios) for Ridgway Dam

2-they trenched the southernmost fault on the Plateau, the Busted Boiler fault.

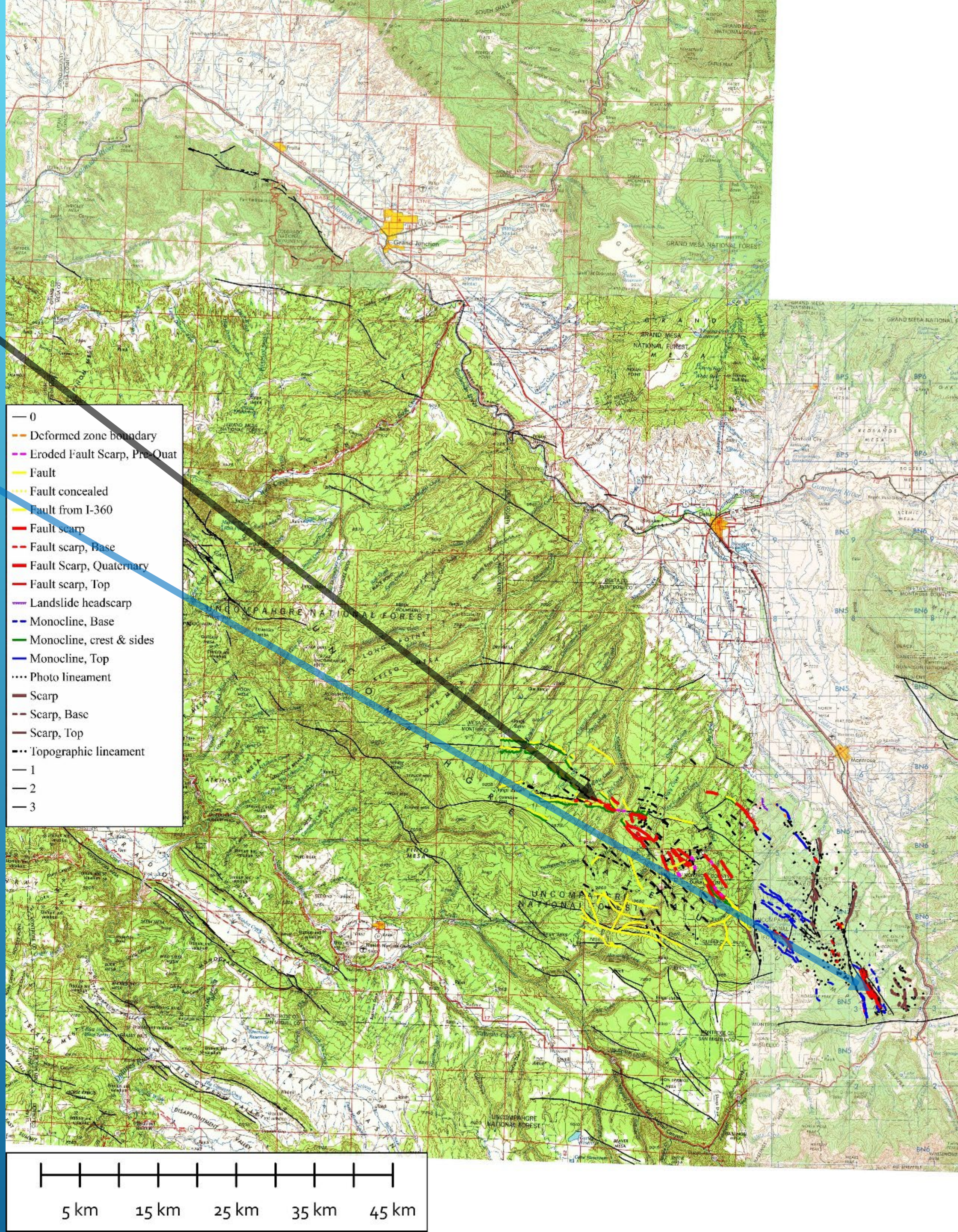
-The 4 trenched faults all faced upslope (SW), and 2 of the 4 had supporting evidence for Quaternary displacements on the decimeter scale.

So now we have a zone of faults 55 km long, with the ones at either end having alleged Q displacement.

But USBR stopped short of assuming that all other (untrenched) Plateau were late Q. Why??

A-Because geomorphic freshness does not 100% prove Q displacement, AND

B-none of the scarps clearly displaced a single Q landform



Roubideau Cr. fault

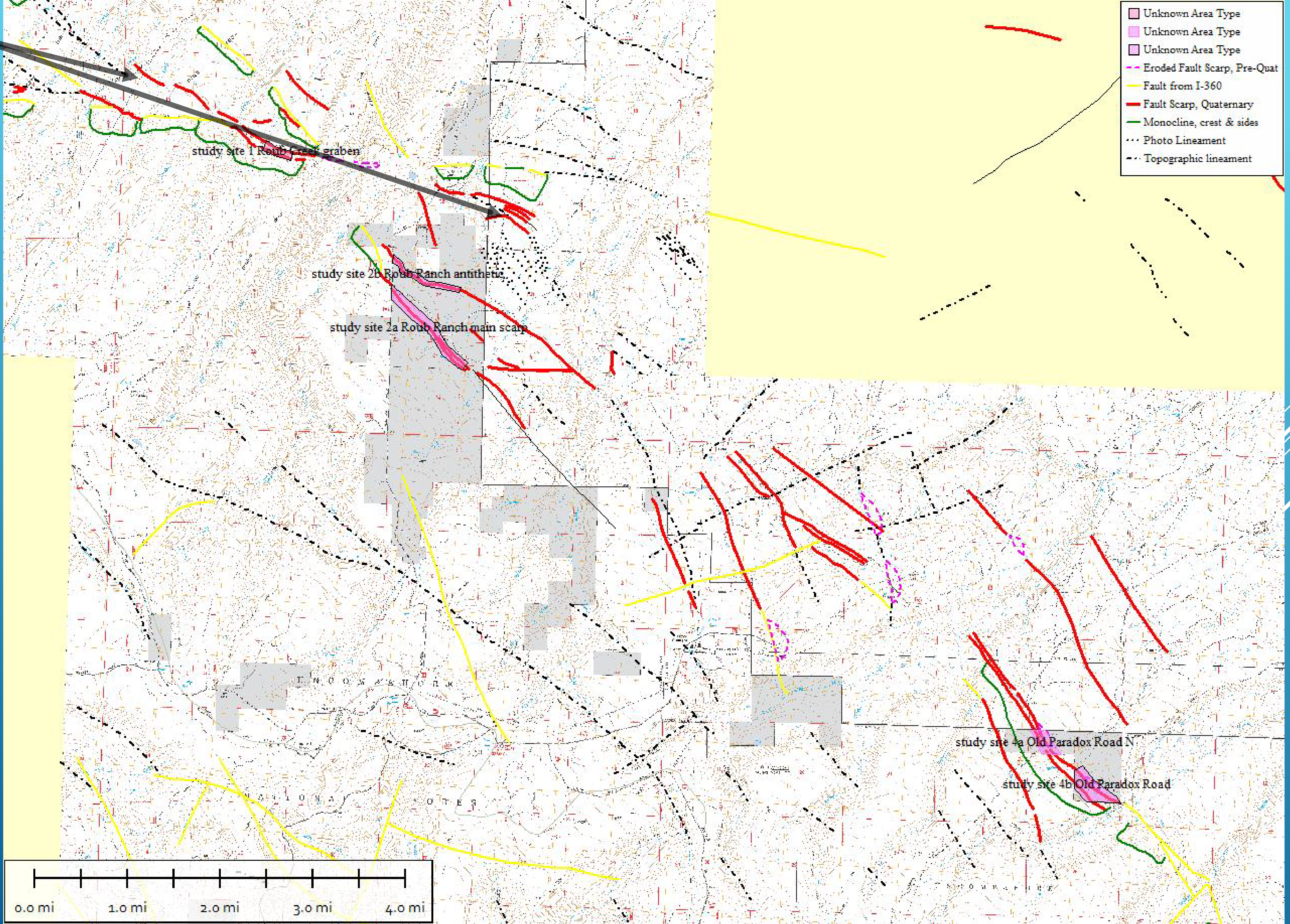
My 2005 report to USBR identified four clusters of young-looking scarps; from NW to SE:

-Roubideau Creek

-Roubideau Ranch

-Donley-Garrison

-Old Paradox Road



But this was all (2003-2005) based on stereo airphotos, in a generally forested region, PLUS
-ground observations on areas fairly near to public roads and public lands.

However, fault clusters Roubideau Ranch, Donley-Garrison, and Old Paradox Road are mostly private ranches.

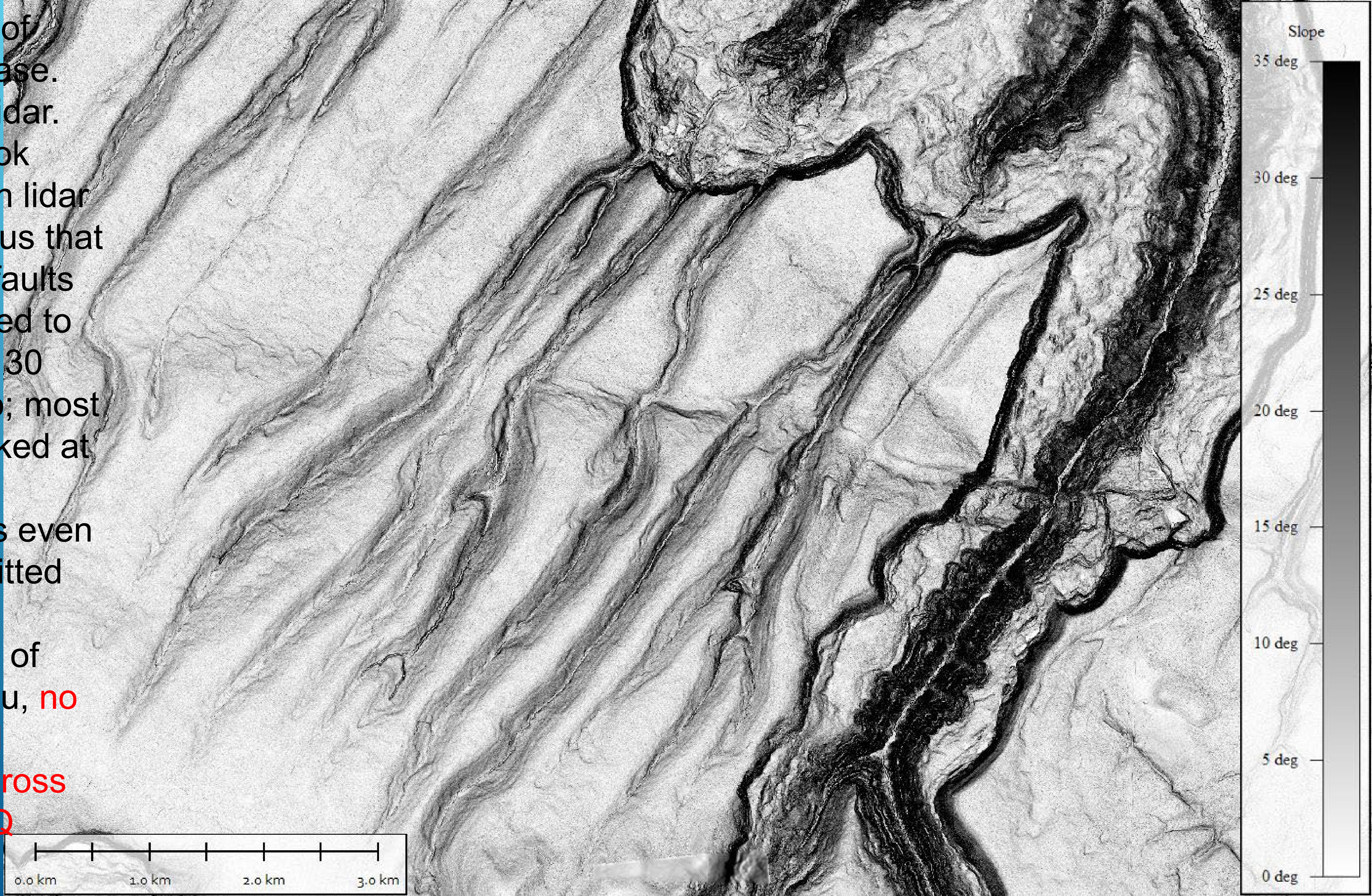
Fast forward 20 years to 2023…..

CGS Review of QFault database.

(1) There is lidar. Things look different in lidar

(2) Reminds us that all these faults were added to database 30 years ago; most never looked at again

(3) Compilers even then admitted that, with exception of Roubideau, no faults had scarps across mapped Q deposits



For Uncompahgre QFaults, USGS/CGS archive descriptions (mostly 1990s) admit there are no displaced Q deposits, but then all say "*Faults associated with the Uncompahgre Uplift, however, are often considered to have experienced Quaternary movement.*" This statement is supported by a single citation *(Cater F W , 1966, Age of the Uncompahgre Uplift and Unaweep Canyon, west central Colorado: U.S. Geological Survey, Professional Paper 550-C, p 86-92)*; every fault description contains this same sentence.

BUT…Between 1966 and 2023, multiple papers explain the "evidence" (episodes of Q incision affecting the Plateau), not from tectonic uplift, but by downstream stream piracy (Colorado and Gunnison Rivers) and resulting base-level fall (Andres Aslan et al.).

Recall, this is the area once covered by 2 km-thick Mancos Shale. The 10 Ma Grand Mesa basalts flowed down a paleovalley, which is now perched 1500 m above the Colorado River; this requires >1.5 km of vertical erosion since 10 Ma. Streams loaded with hard basement rocks, flowing across soft Cretaceous shale, act like a chainsaw. Commonly resulting in stream piracy. Which can be mistaken as evidence for tectonic uplift…..

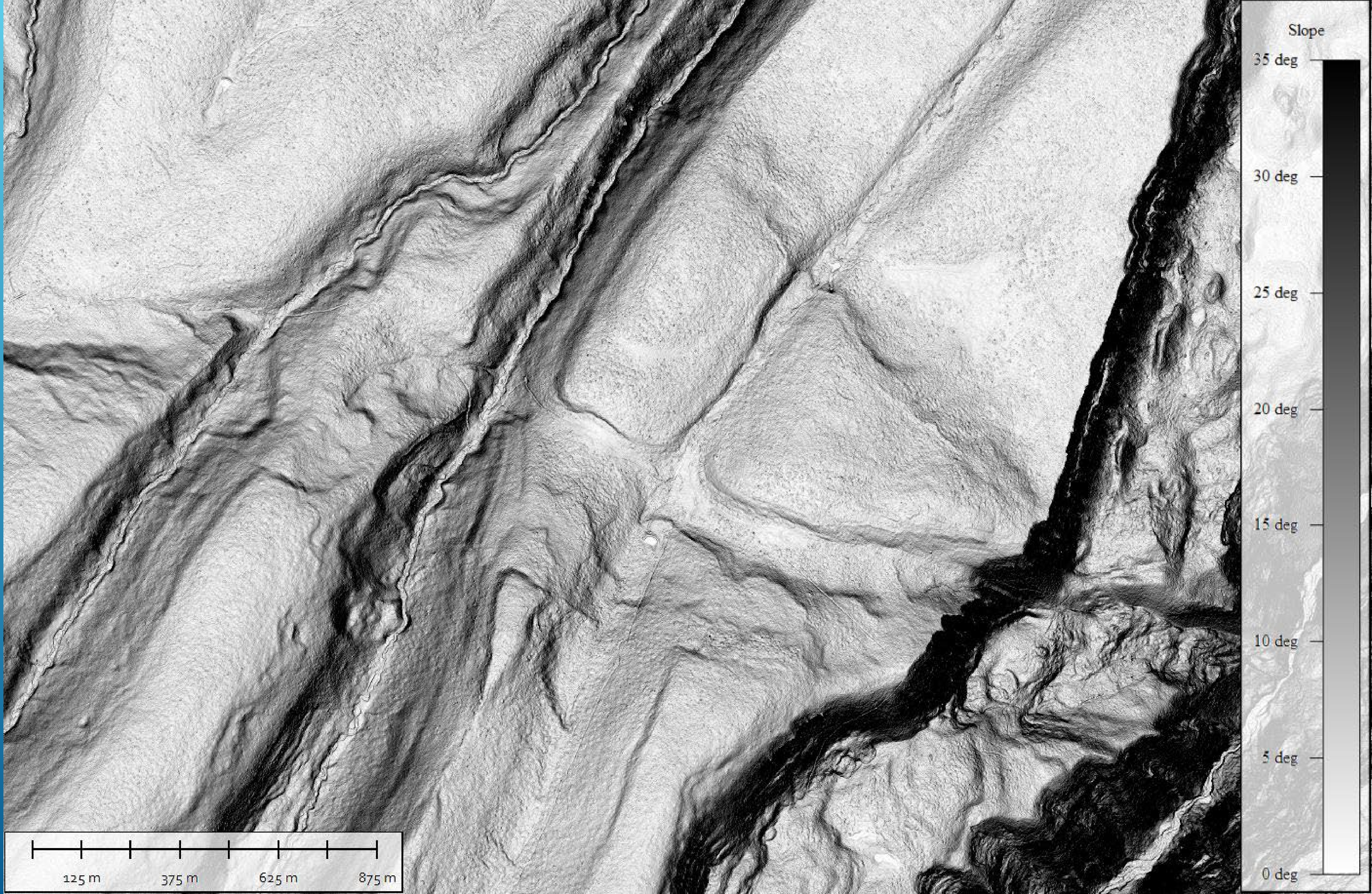
This leaves us, in 2024, having the Roubideau Creek fault as an active fault in the 2023 update of the NSHM; the only such fault outside the Rio Grande rift.
And with doubts that it is even a Class A fault, much less deserving a place on the NSHM

ALTERNATIVE EXPLANATION FOR FAULTS:
Livaccari et al. (2012, 2016 abstract) define the swarms of Uncompahgre faults trending WNW-ESE as Laramide left-lateral, oblique strike-slip faults that have a down-to-the-north vertical slip component, with the fault plane wobbling around a vertical dip. Thus in cross-strike exposures, faults appear to be steep normal faults in some places and steep reverse faults in other places. So-called “scissor faults.”

ALTERNATIVE EXPLANATION FOR YOUTHFUL LOOK:
Aslan et al suggest that the youthful look of these (perhaps Laramide) bedrock faults is a result of them being erosionally etched-out by Mio-Pliocene paleorivers, which scoured off the Mancos Shale to expose the much-harder Dakota Sandstone.

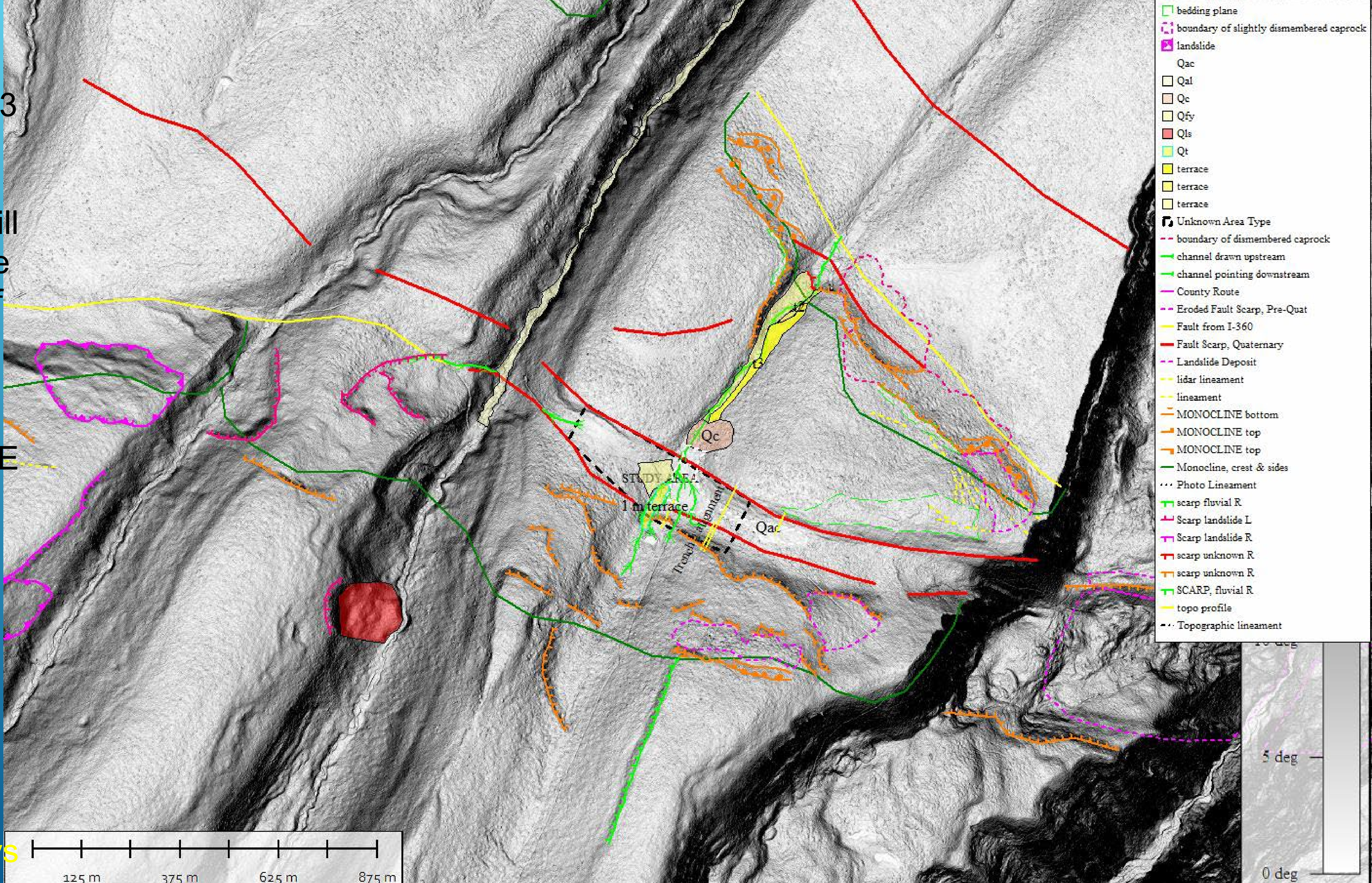
On lidar, the Roubideau Cr Fault (WNW-ESE) looks a lot like the perpendicular erosional valley sidewalls. Which in turn look like joint-controlled erosion in the hard Dakota caprock.

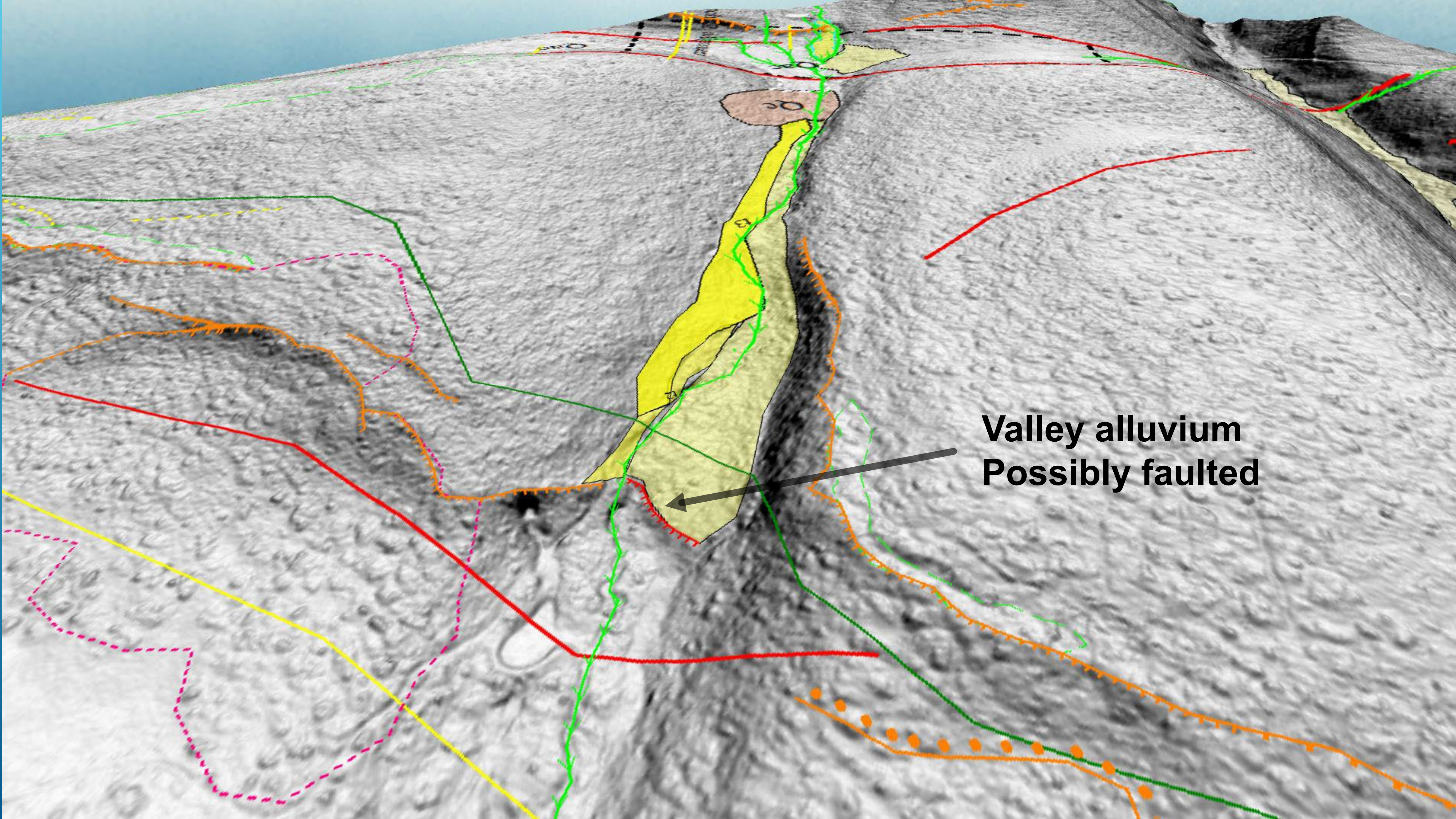
So maybe the fault's topography is also erosional



So CGS has applied to USFS to dig 3 trenches in summer 2024. Two will be across the SE margin of the “graben” (right center) and one across the NE margin,

If no Q deposits are faulted, and the lower deposits are paleoriver gravels, then it’s Class B for these guys




Valley alluvium
Possibly faulted

SO, WHAT DOES THIS HAVE TO DO WITH UTAH?

1-Away from the Wasatch Front, there may be “legacy Qfaults” from the 1990s, that would not make the cut in the 2020s.

2-Back in the 90s we were ‘loose’ on what faults to put into the Database. Just geomorphic evidence was enough. We figured that eventually all the faults would get trenched, and the imposters thrown out.

3-But this was naïve, assuming a trenching funding stream lasting 50 years or more.

4-USGS put the brakes on, when it said no more NEHRP funding for faults with slip rate of <0.2 mm/yr. Then later, no funding unless it could be proved to impact the NSHM. No more curiosity-driven trenches in the middle of nowhere…..

5-The Result: those faults in outlying, low-population areas never got trenched. And never will be. But they are still carried in the Database. Sometimes based on neotectonic concepts from the 1960s that are now discredited.