UTAH GEOLOGICAL SURVEY

UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP

Wasatch Fault Near Hobble Creek

Tuesday, February 5, 2013

www.geology.utah.gov

UQFPWG

- One of three standing committees created to help set and coordinate Utah's earthquake-hazard research agenda.
- Reviews ongoing paleoseismic research in Utah, and updates the Utah consensus slip-rate and recurrence-interval database as necessary.
- Provides advice/insight regarding technical issues related to fault behavior in Utah & the Basin and Range Province.
- Identifies and prioritizes Utah Quaternary faults for future study.

2012 MEETING REVIEW

Presentations on Paleoseismic Work Completed or in Progress

- Salt Lake City segment WFZ
- Granger fault WVFZ
- Utah Lake sediment study (seismic evidence)
- Hurricane fault (Lake Powell pipeline crossing)
- Blue Castle nuclear facility licensing project
- Paunsaugunt fault
- Nephi segment WFZ upcoming study
- Central Wasatch fault zone segments – parameter characterization
- Wasatch fault – GPS and earthquake moment rate comparisons
- Working Group on Utah Earthquake Probabilities – update
- Basin and Range Province Earthquake Working Group II - update

Technical Discussion Items

- Southern segment of the East Cache fault zone study – status
- Possible evidence for previously unrecognized Quaternary faulting in northern Utah

UQFPWG Fault Study Priorities

2012 FAULT PRIORITY LIST

2012 Highest Priority Faults/Fault Sections For Study		
Fault/Fault Section[1]	**Investigation Status**	**Investigating Institution[2]**
Acquire new paleoseismic information in data gaps along the five central segments of the WFZ – e.g., (a) Brigham City segment rupture extent (north and south ends); (b) long-tern earthquake record northern Provo segment; (c) long-term earthquake record southern Weber segment.	No activity	
Penultimate event Provo segment WFZ	No activity	
West Valley fault zone – Taylorsville fault	No activity	

Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution[2]**
Cedar City-Parowan monocline/Paragonah fault[3]	10	No activity	
Enoch graben	11	No activity	
Clarkston fault[3]	13	Black and others (2000)	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Rozelle section, Great Salt Lake fault[4]	2007	No activity	
Warm Springs fault/East Bench fault subsurface geometry and connection[4]	2010	No activity	
Hansel Valley fault[3]	2011	McCalpin, (1985), McCalpin and others (1992), Robinson (1986)	

Faults/Fault Sections Studies Complete or Ongoing			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution[2]**
Nephi segment WFZ	1	UGS Special Study 124 USGS Map 2966 New UGS study funded 2012	UGS/USGS
Long-term earthquake record Nephi segment WFZ	1a	Funded for 2012	UGS/USGS
West Valley fault zone (Granger fault)	2	Ongoing	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	On going	UUGG
Great Salt Lake fault zone	6	Ongoing	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
East Cache fault zone	12	Ongoing	USU
Wasatch Range back-valley fault (Main Canyon fault)	14	UGS Miscellaneous Pub. 10-5	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Ongoing	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north end	2009	On going	UGS/USGS

AGENDA
QUATERNARY FAULT PARAMETERS WORKING GROUP
Tuesday, February 5, 2013

8:00 Continental breakfast

- **8:20 Welcome, overview of meeting, and review of last year's activities** We are here
- **8:30 Utah Lake fault investigation; Ron Harris, BYU**
- **8:50 Automated fault scarp offset analysis of the Nephi segment of the Wasatch fault utilizing LiDAR derived, high resolution DEMs; Billie Smathers, BYU**
- **9:10 Nephi segment paleoseismic trenching; Chris DuRoss, UGS**
- **9:30 Penrose Drive/Baileys Lake paleoseismic studies final results; Chris DuRoss/Mike Hylland, UGS**
- **9:50 New information for the Taylorsville fault from Orange Street consultant's trench, Mike Hylland, UGS**

10:10 Break

- **10:30 Does fault segmentation limit earthquake magnitude on the Wasatch fault; Scott Bennett/Rich Briggs, USGS**
- **10:50 Bear River fault behavior–clues provided by LiDAR; Suzanne Hecker, USGS**
- **11:10 Update on U.S. Bureau of Reclamation Joes Valley fault study; Joanna Redwine, USBR**
- **11:30 GPS Monitoring of the Wasatch Fault: Earthquake Research and Hazard Assessment; R.B. Smith, W. Chang, J. Farrell, and C. Puskas, UUGG/UNAVCO**

12:00 Lunch

AGENDA
(Continued)

12:00 Lunch

- **1:00** Large liquefaction features and evidence for earthquakes induced by Lake Bonneville in Cache Valley; Susanne Janecke, USU
- **1:30** Washington fault mapping and fault section redefinition; Tyler Knudsen, UGS
- **1:50** Washington fault paleoseismic investigation; Bill Lund, UGS
- **2:10** Preliminary results of a high resolution seismic reflection profile at Hansel Valley, Utah; Pier Bruno, UUGG
- **2:30** Update Blue Castle nuclear facility licensing project; Dean Ostenaa, Fugro, Inc.
- **2:50** Paleoseismic-related NEHRP FTR reports for Utah; Steve Bowman, UGS

3:10 Break

- **3:30** WGUEP update; Ivan Wong, URS Corp.
- **3:50** Re-examination of trenches for early-mid Holocene climatic events and redefining "Active" faults; Darlene Batatian, Mountain Land Development Services

4:10 UQFPWG 2014 fault study priorities ← We need to get here

5:00 Adjourn

UQFPWG 2014 Fault Study Priorities

Fault/Fault Segment	Original UQFPWG Priority (2005)
Nephi segment WFZ	1
West Valley fault zone	2
Weber segment WFZ – most recent event	3
Weber segment WFZ – multiple events	4
Utah Lake faults and folds	5
Great Salt Lake fault zone	6
Collinston & Clarkston Mountain segments WFZ	7
Sevier/Toroweap fault	8
Washington fault	9
Cedar City-Parowan monocline/ Paragonah fault	10
Enoch graben	11
East Cache fault zone	12
Clarkston fault	13
Wasatch Range back-valley faults	14
Hurricane fault	15
Levan segment WFZ	16
Gunnison fault	17
Scipio Valley faults	18
Faults beneath Bear Lake	19
Eastern Bear Lake fault	20
Bear River fault zone	2007
Brigham City segment WFZ – most recent event	2007
Carrington fault (Great Salt Lake)	2007
Provo segment WFZ – penultimate event	2007
Rozelle section – East Great Salt Lake Fault	2007
Salt Lake City segment WFZ – northern part	2009
Warm Springs fault/East Bench fault subsurface geometry and connection	2010
Brigham City segment WFZ rupture extent (north and south ends)	2011
Long-term earthquake record northern Provo segment WFZ	2011
West Valley fault zone – Taylorsville fault	2011
Hansel Valley fault	2011
Acquire new paleoseismic information in data gaps along the five central segments of the WFZ	2012

2012 Highest Priority Faults/Fault Sections For Study			
Fault/Fault Section[1]	**Investigation Status**		**Investigating Institution[2]**
Acquire new paleoseismic information in data gaps along the five central segments of the WFZ – e.g., (a) Brigham City segment rupture extent (north and south ends); (b) long-tern earthquake record northern Provo segment; (c) long-term earthquake record southern Weber segment.	BYU LiDAR study BYU Utah Lake sediment study		BYU
Penultimate event Provo segment WFZ	No activity		
West Valley fault zone – Taylorsville fault	Consultant's trench of opportunity		UGS
Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution[2]**
Cedar City-Parowan monocline/Paragonah fault[3]	10	No activity	
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Nephi segment WFZ	1	UGS Special Study 124 USGS Map 2966 Ongoing	UGS/USGS
West Valley fault zone (Granger fault)	2	Ongoing	UGS/USGS
Long-term earthquake record Nephi segment WFZ	2012	Ongoing	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Ongoing	UUGG/BYU
Great Salt Lake fault zone	6	Ongoing	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
Washington fault zone	9	Contract deliverable FTR	UGS
East Cache fault zone	12	Contract deliverable FTR	USU
Wasatch Range back-valley fault (Main Canyon fault)	14	UGS Miscellaneous Publication 10-5	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Ongoing	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north part	2009	Ongoing	UGS/USGS
Hansel Valley fault[3]	2011	McCalpin, (1985), Robinson (1986), McCalpin and others (1992), UUGG ongoing	UUGG

Searching for Evidence of Seismic Events in Lacustrine Sediments of Utah Lake

Quincy Nickens, Ron Harris, Mitchell Power, Anthony Macharia, Steve Nelson, Terik Daly, Yujiro Ogawa

Methods

- Sediment Cores
- Establish a Chronology for lake sediments
  - Tephrachronology/magnetic susceptibility
  - Radiometric (14C) and Isotopic Ages (Pb210)
- Density Variations
  - North Anatolian Fault , Turkey (Boës et al., 2010)
  - Lake Suigetsu, central Japan (Kawakami et al., 1996)
  - Lake Lucerne, central Switzerland (Schnellmann et al., 2002)
- Soft sediment deformation
  - Seismites
  - Liquefaction

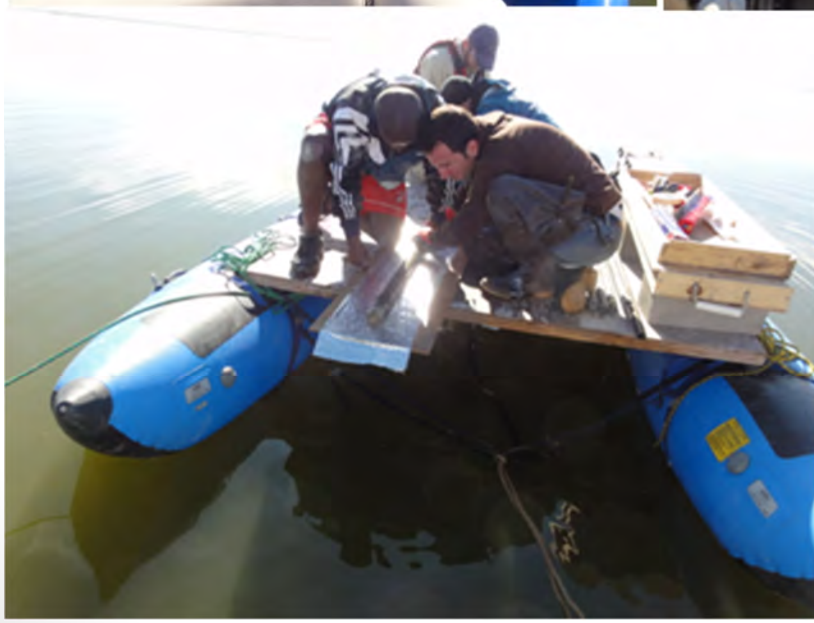
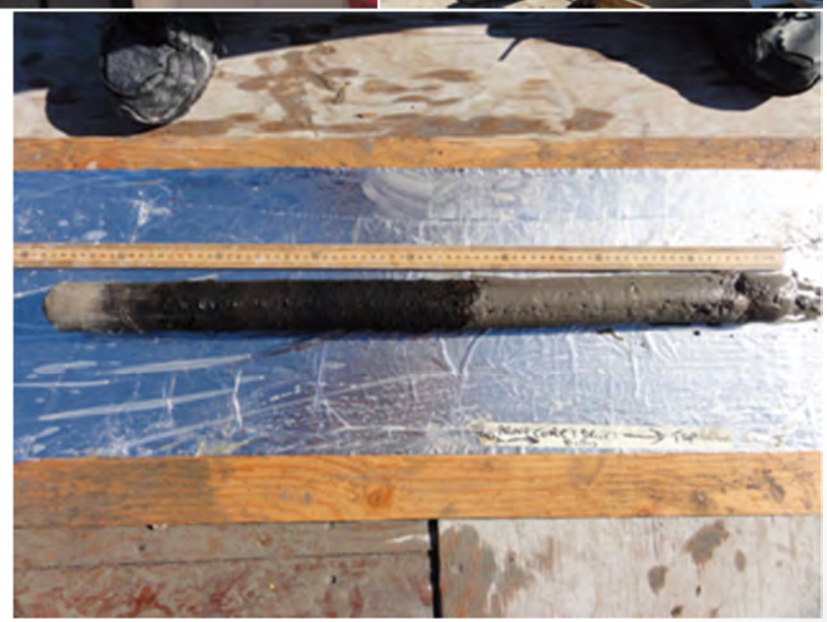
Advantages

- Advantages of using lacustrine sediments over sediments in trenches across active faults
  - Constant sedimentation record
  - Higher age resolution
  - Lake sediments extend the seismic record more than three times
  - Lacustrine sediments have the potential to record seismic events that do not rupture the surface

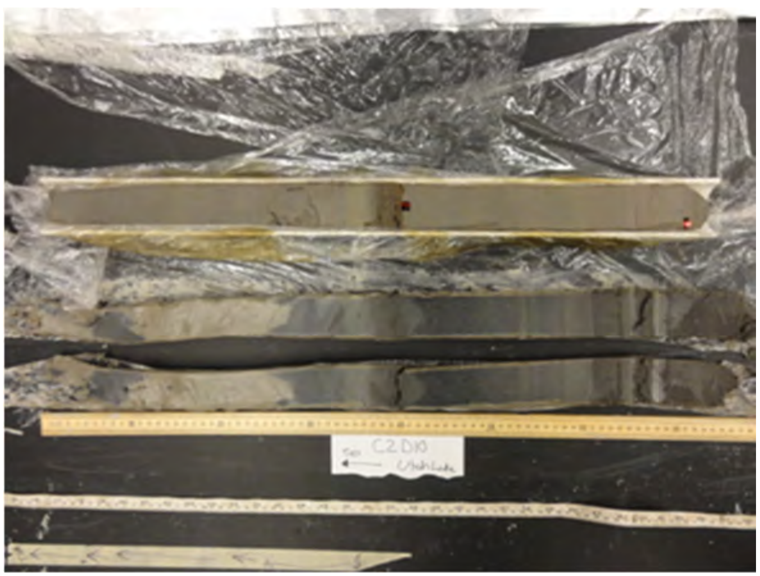
Sample Collection

Coring Methods



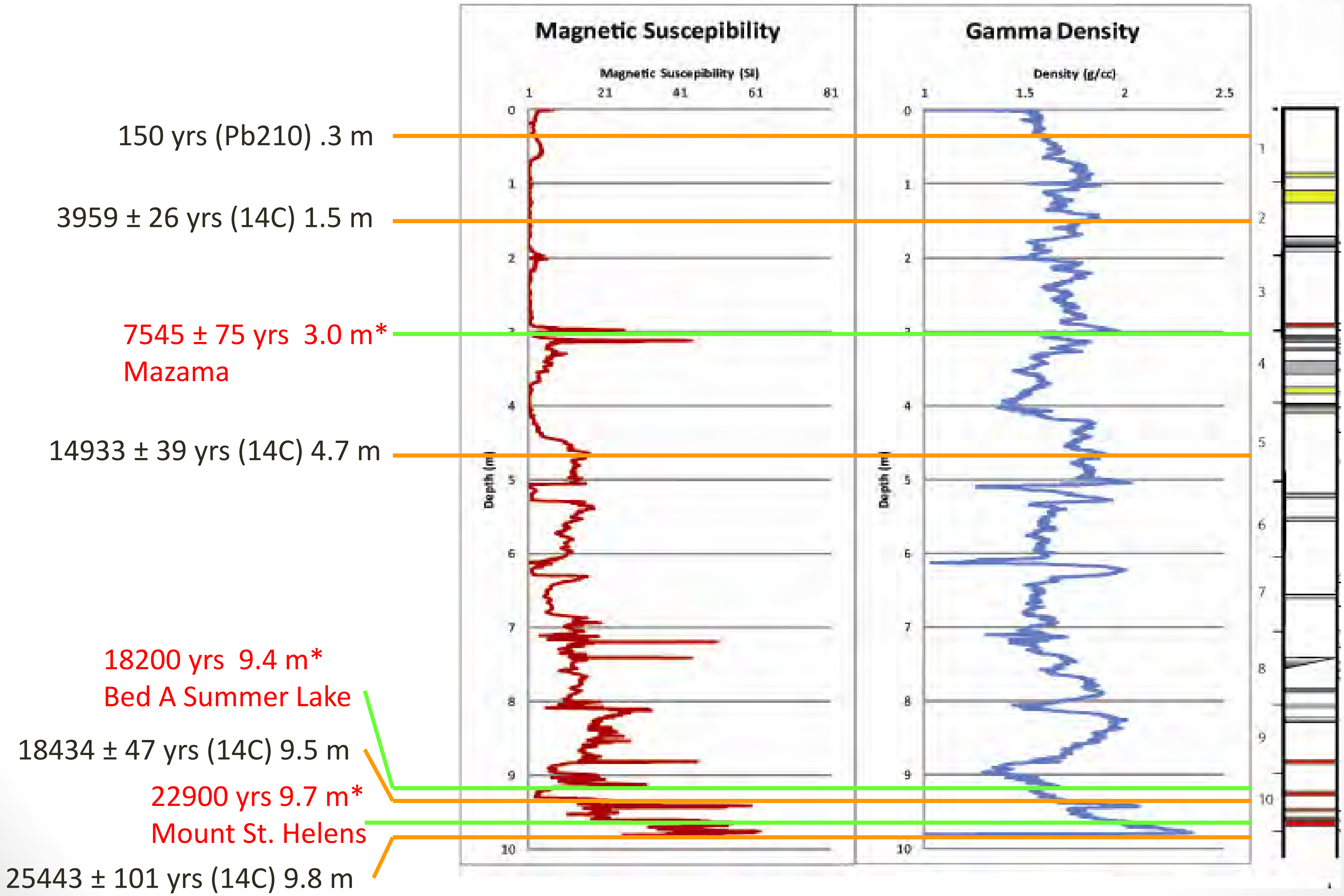
Logging cores



Labs Involved

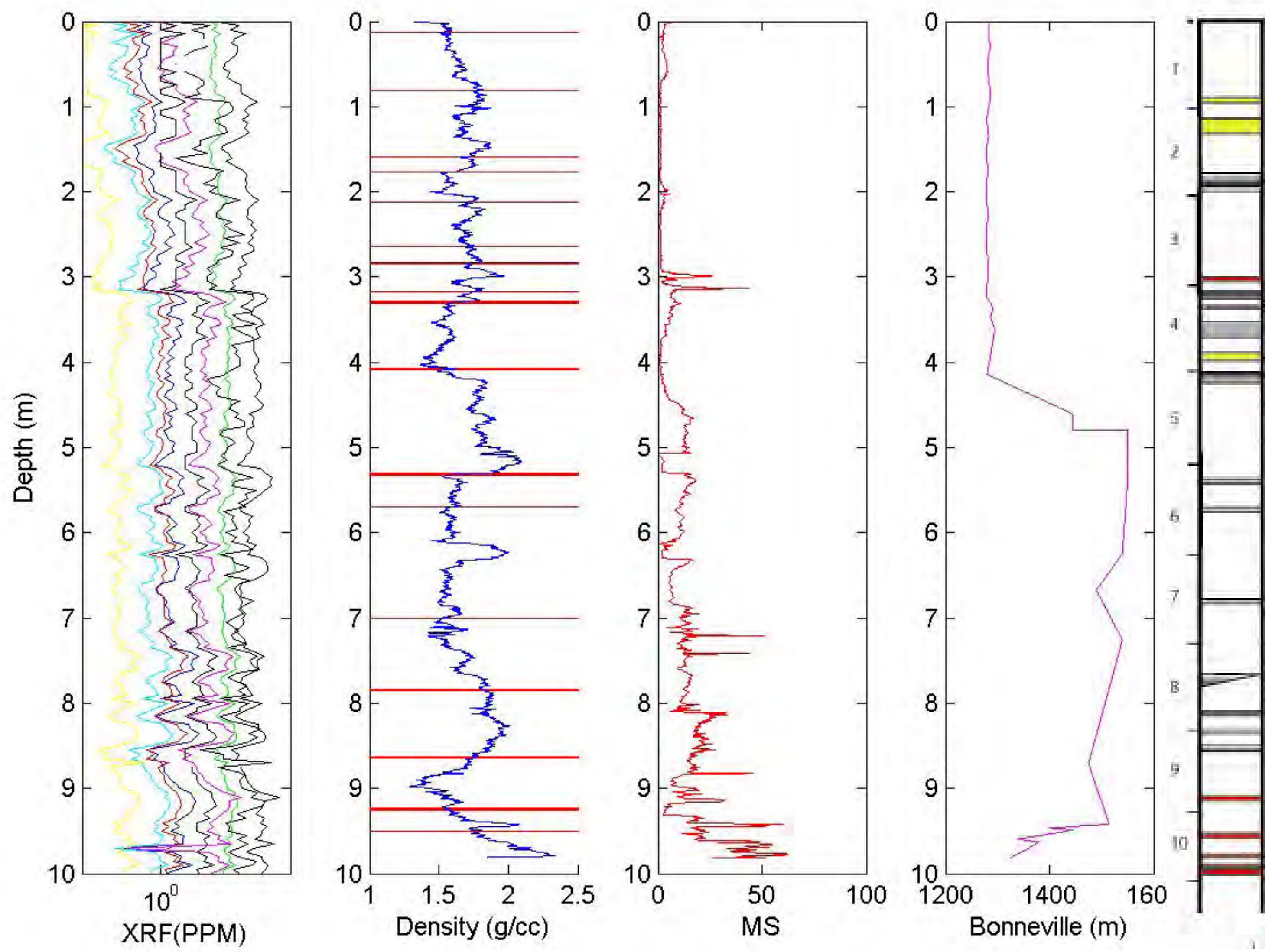
- Core Analysis
  - Utah Museum of Natural History, University of Utah
    - Mitchell Power, Anthony Macharia
  - The Shuman Laboratory, University of Wyoming
    - Bryan Shuman
- Radiometric Ages
  - Isotope Laboratory, BYU
    - Pb210/14C – Steve Nelson, Terik Daly
  - University of Georgia
    - C14, AMS

Mid-lake Core



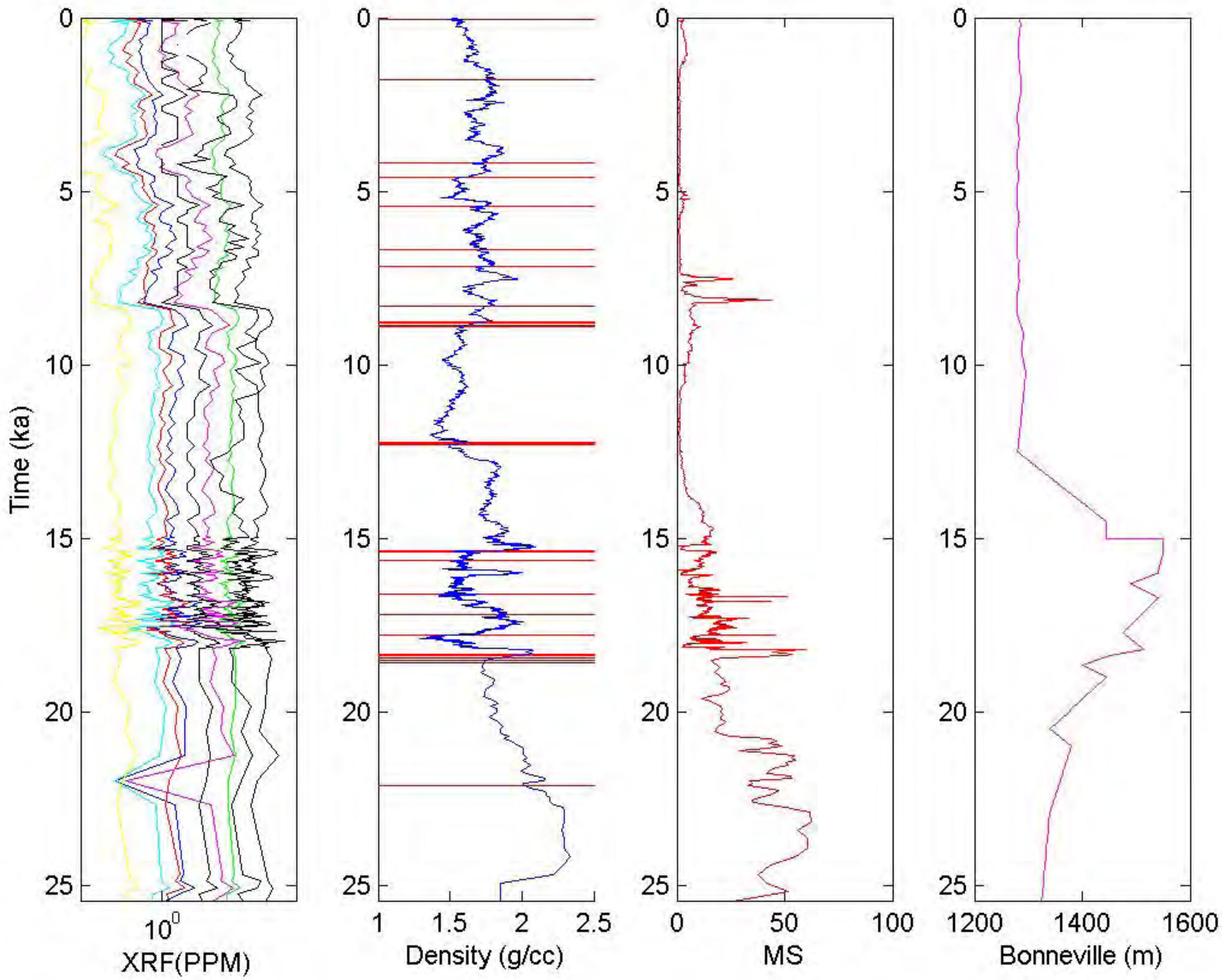
* Ash Ages from Kuehn and Begrini 2010

Mid-lake Core



*XRF – AL2O3, Fe2O3, Cu, K2O, SiO2, TiO2, V, Y, Zr

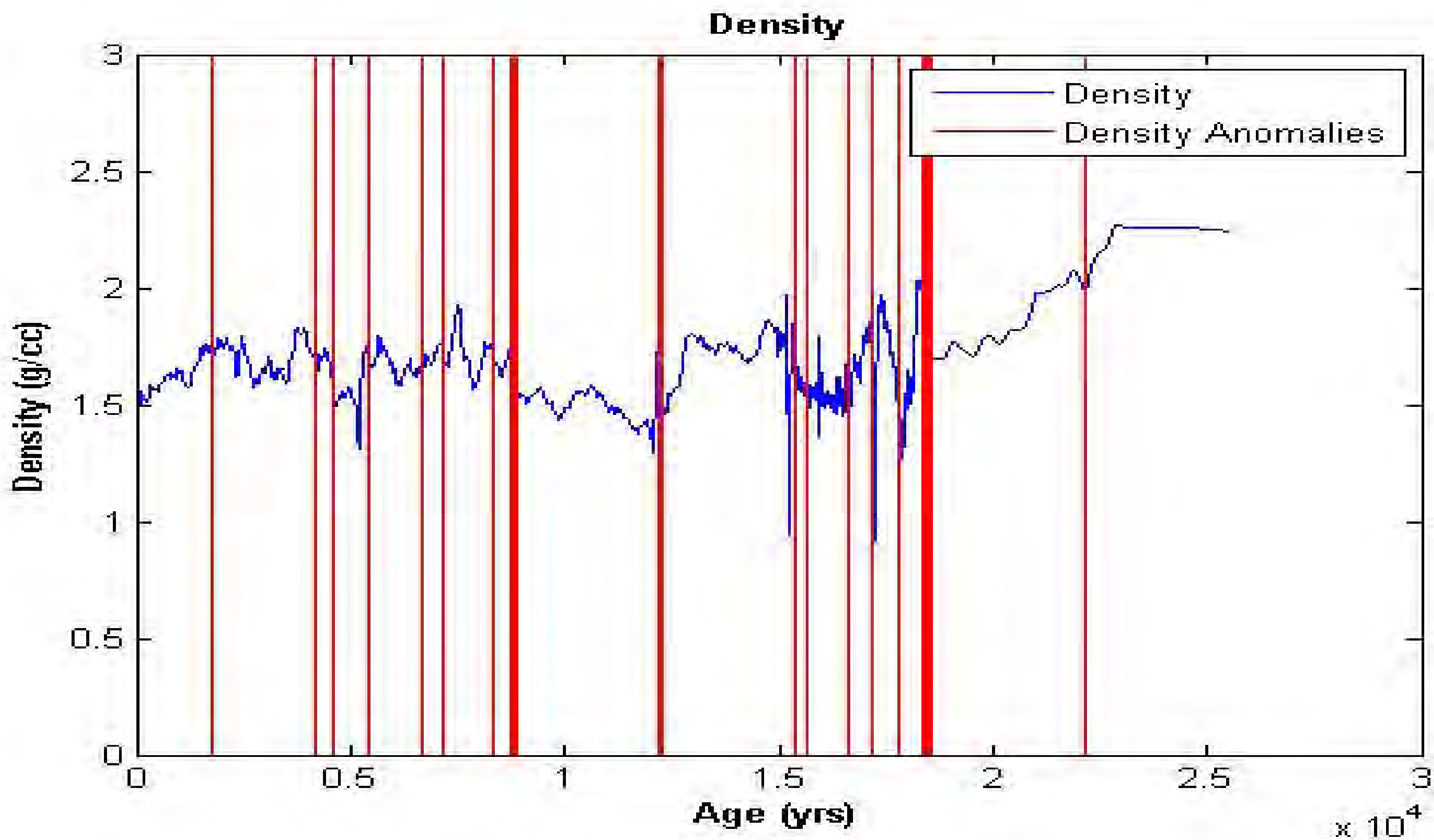
Mid-lake Core



*XRF – AL2O3, Fe2O3, Cu, K2O, SiO2, TiO2, V, Y, Zr

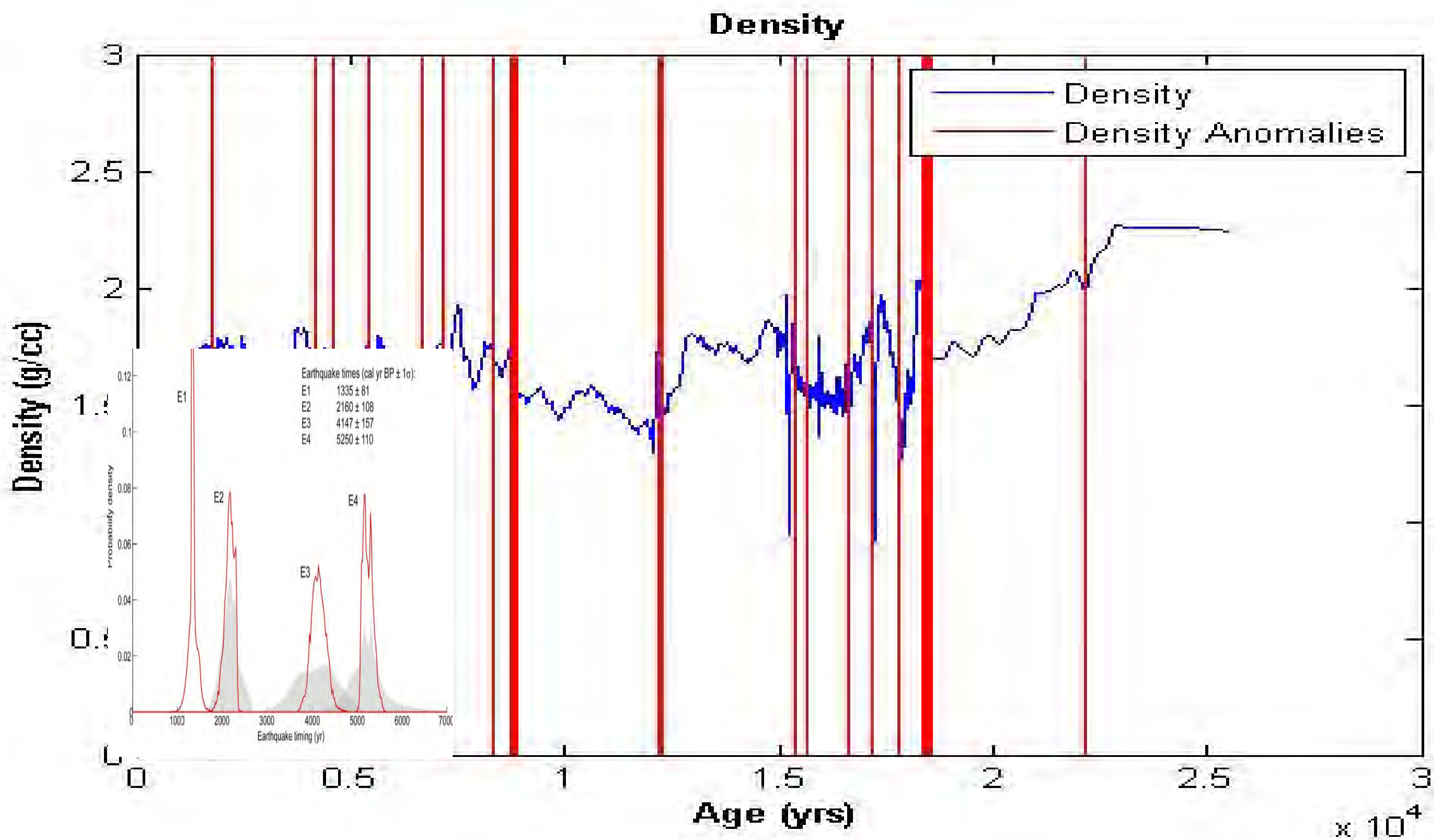
Density Anomalies

Density vs Time



Density Anomalies

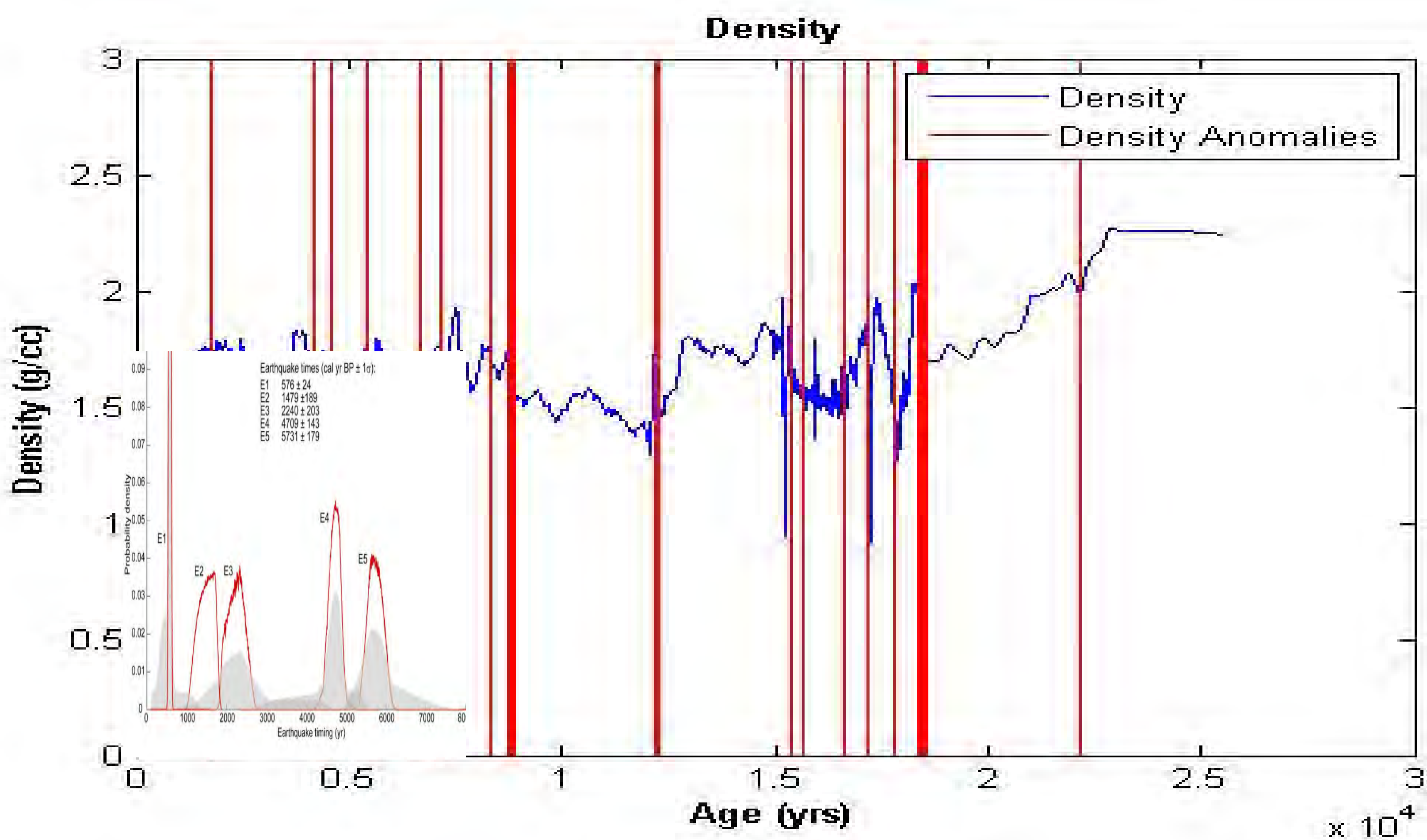
Salt Lake Segment



* Trench Data after Chris DuRoss

Density Anomalies

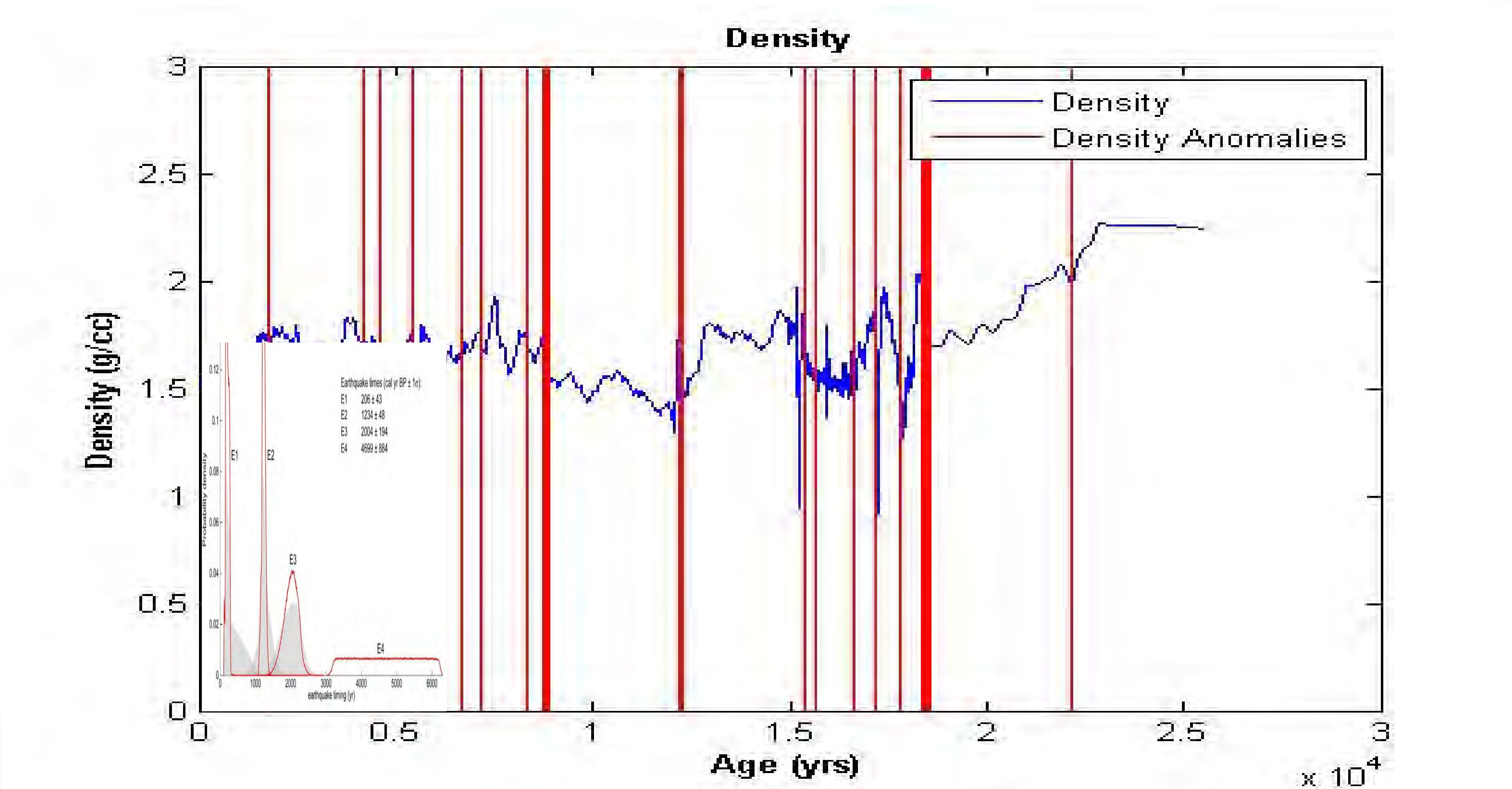
Provo Segment



* Trench Data after Chris DuRoss

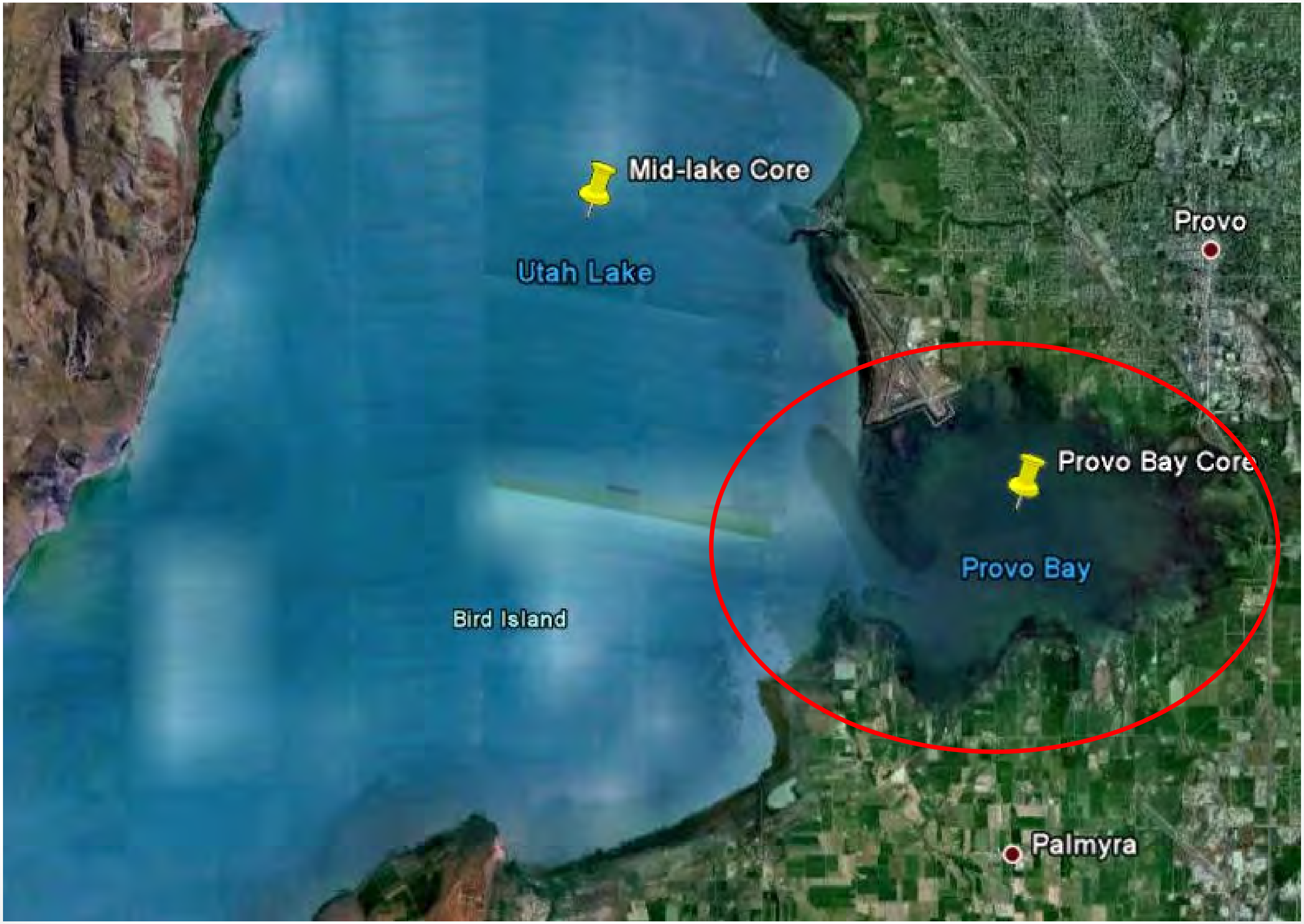
Density Anomalies

Nephi Segment

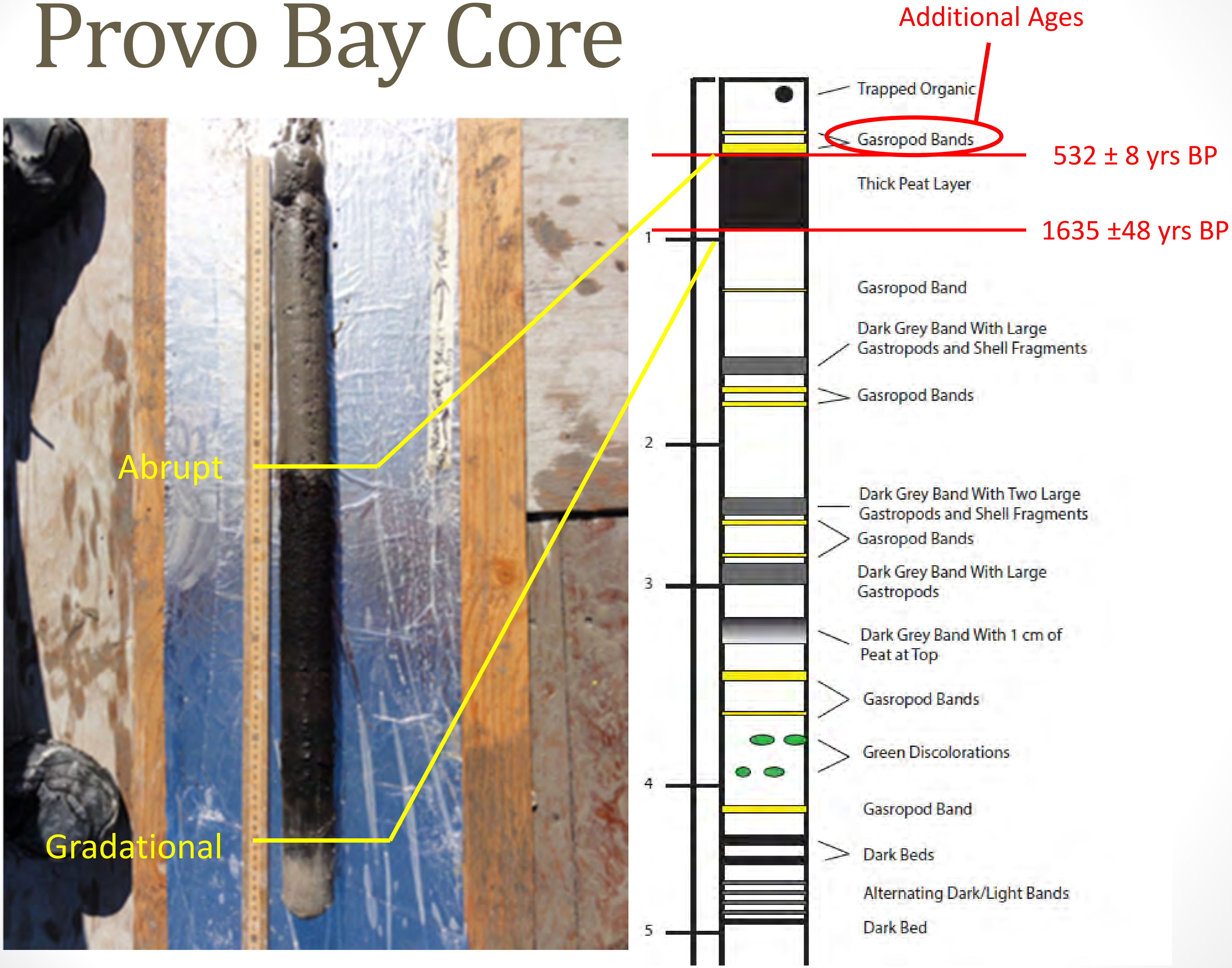


* Trench Data after Chris Duross

Provo Bay

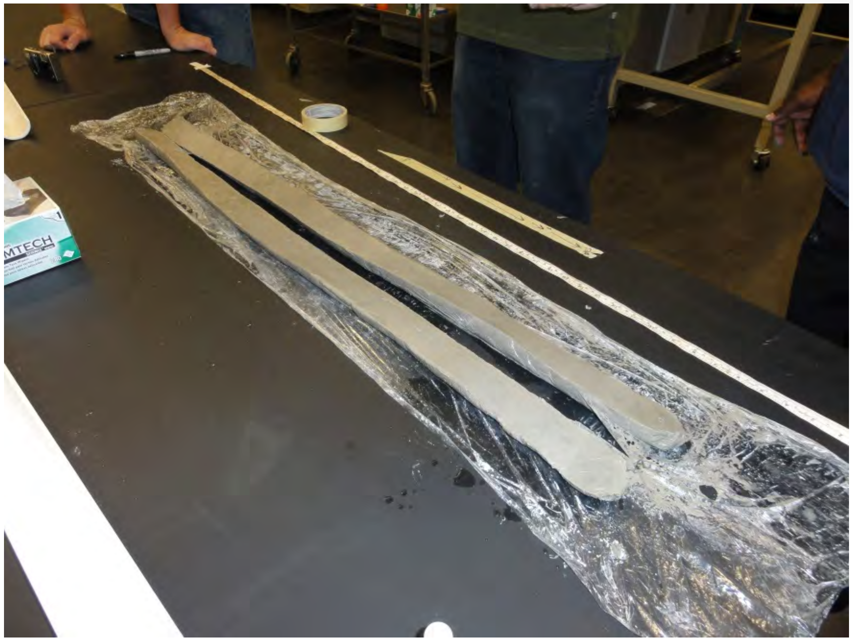

Mid-lake Core
Provo
Utah Lake
Provo Bay Core
Provo Bay
Bird Island
Palmyra

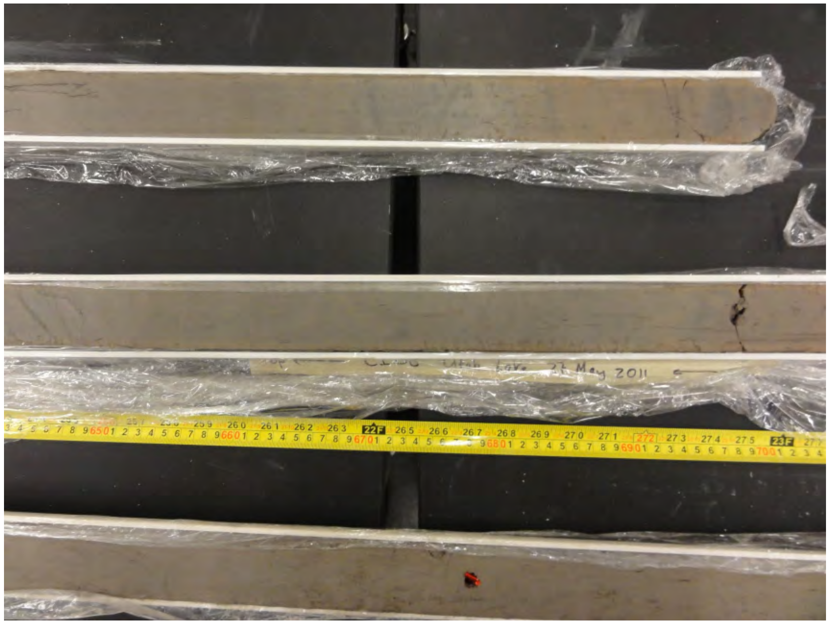
Provo Bay Core

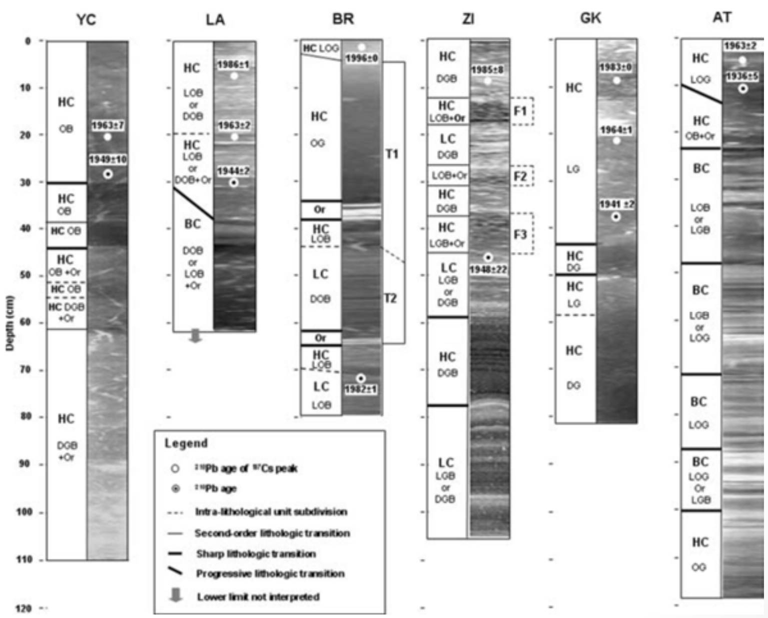


Future Work

- X-Rays
- Additional Ages
- LOI
- Deformation Model







(Boës et al., 2010)

REFERENCES

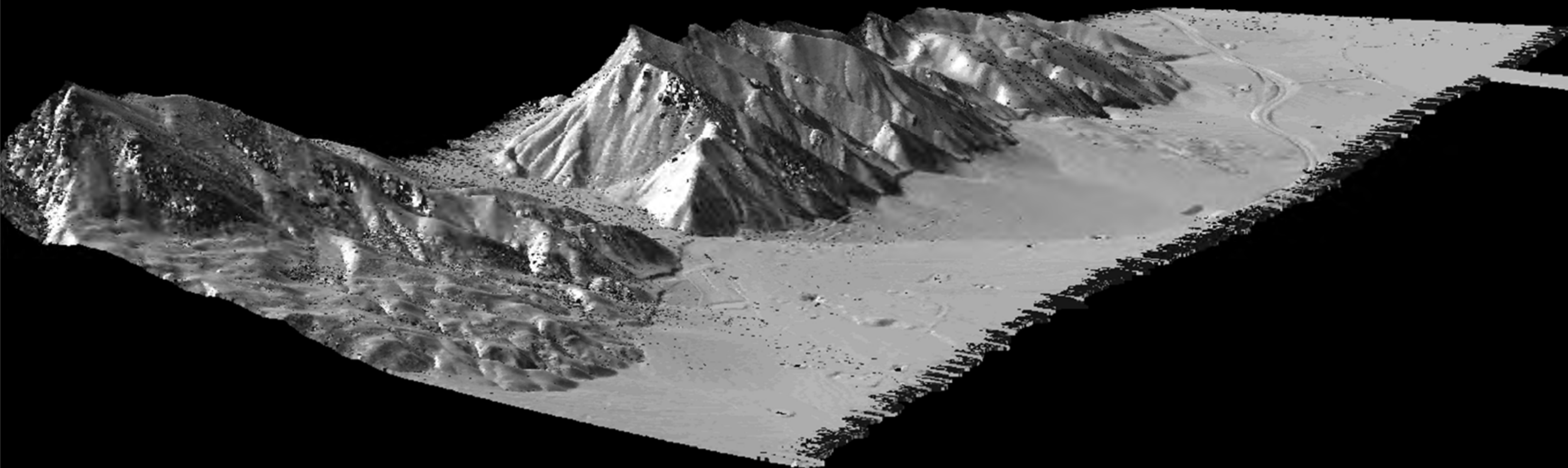
Boees, X., Moran, S. B., King, J., Caatay, M. N., & Hubert-Ferrari, A. (2010). Records of large earthquakes in lake sediments along the north anatolian fault, turkey. *Journal of Paleolimnology, 43*(4), 901-920. doi:10.1007/s10933-009-9376-x

Kawakami, S., Fukusawa, H., & Kanaori, Y. (1996). A new opportunity to detect paleo-earthquake events dating back to the past 10 millennia; a record from lacustrine sediment. *Engineering Geology, 43*(2-3), 177-188. Retrieved from http://search.proquest.com/docview/52772780?accountid=4488; http://www.sciencedirect.com/science/journal/00137952

Kuehn, S. C., & Negrini, R. M. (2010). A 250 k.y. record of cascade arc pyroclastic volcanism from late pleistocene lacustrine sediments near summer lake, oregon, USA. *Geosphere, 6*(4), 397-429. doi:10.1130/GES00515.1

Schnellmann, M., Anselmetti, F. S., Giardini, D., McKenzie, J. A., & Ward, S. N. (2002). Prehistoric earthquake history revealed by lacustrine slump deposits. *Geology (Boulder), 30*(12), 1131-1134. doi:10.1130/0091-7613(2002)030<1131:PEHRBL>2.0.CO;2

Automated fault scarp offset analysis of the Nephi segment of the Wasatch fault, Utah utilizing LiDAR derived, high resolution DEMs

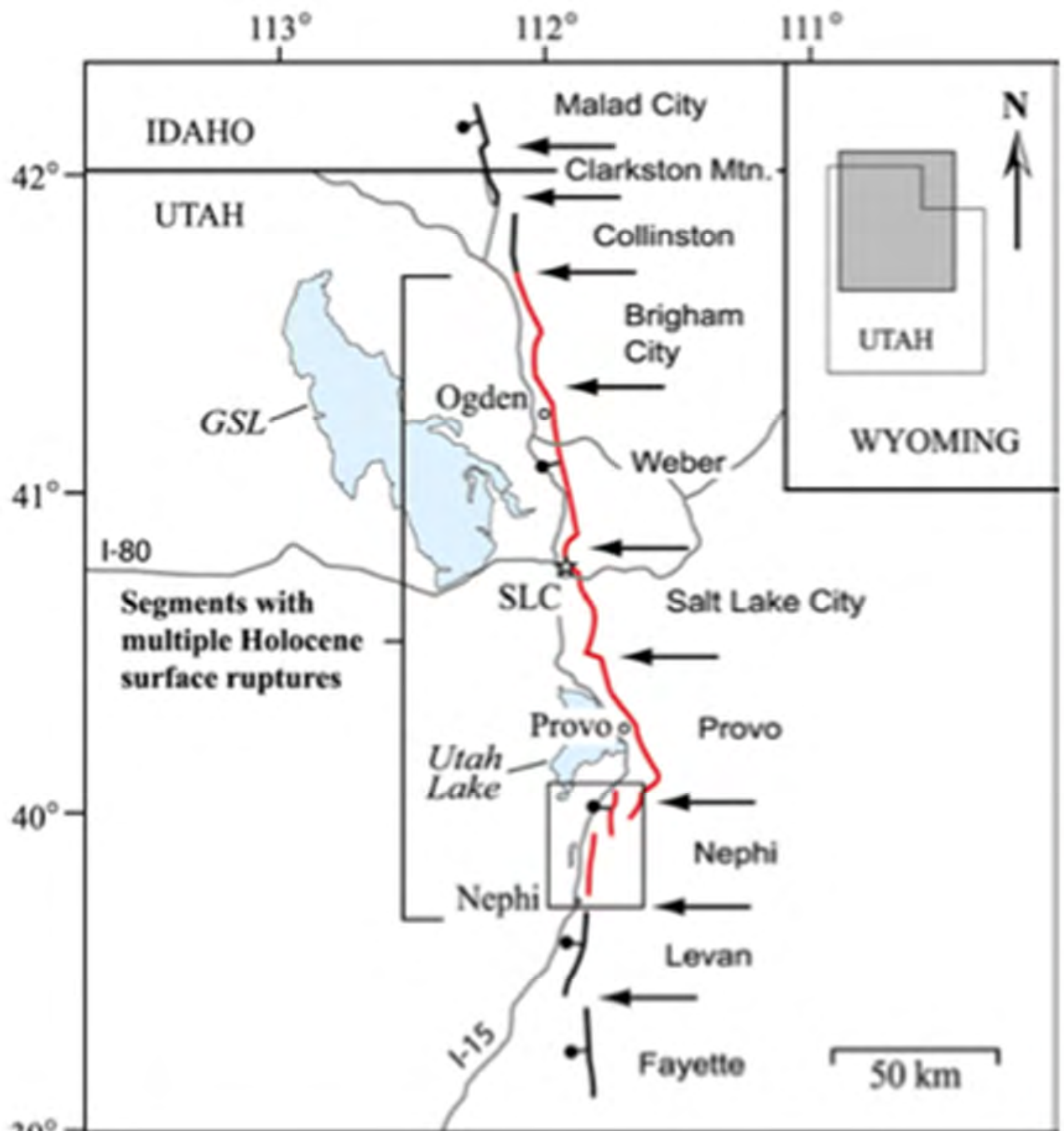


Billie Smathers, Ronald Bruhn

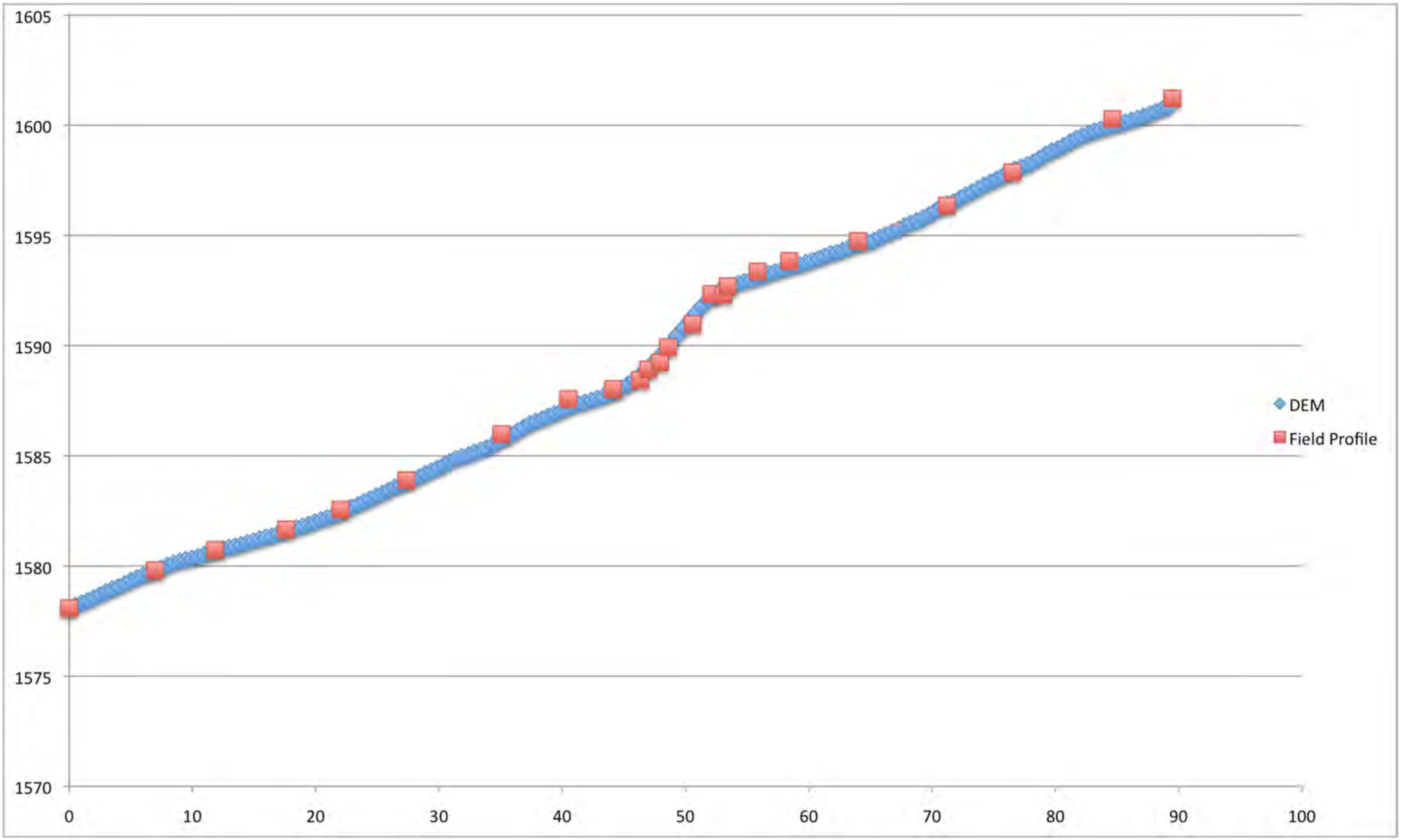
Department of Geology and Geophysics, University of Utah

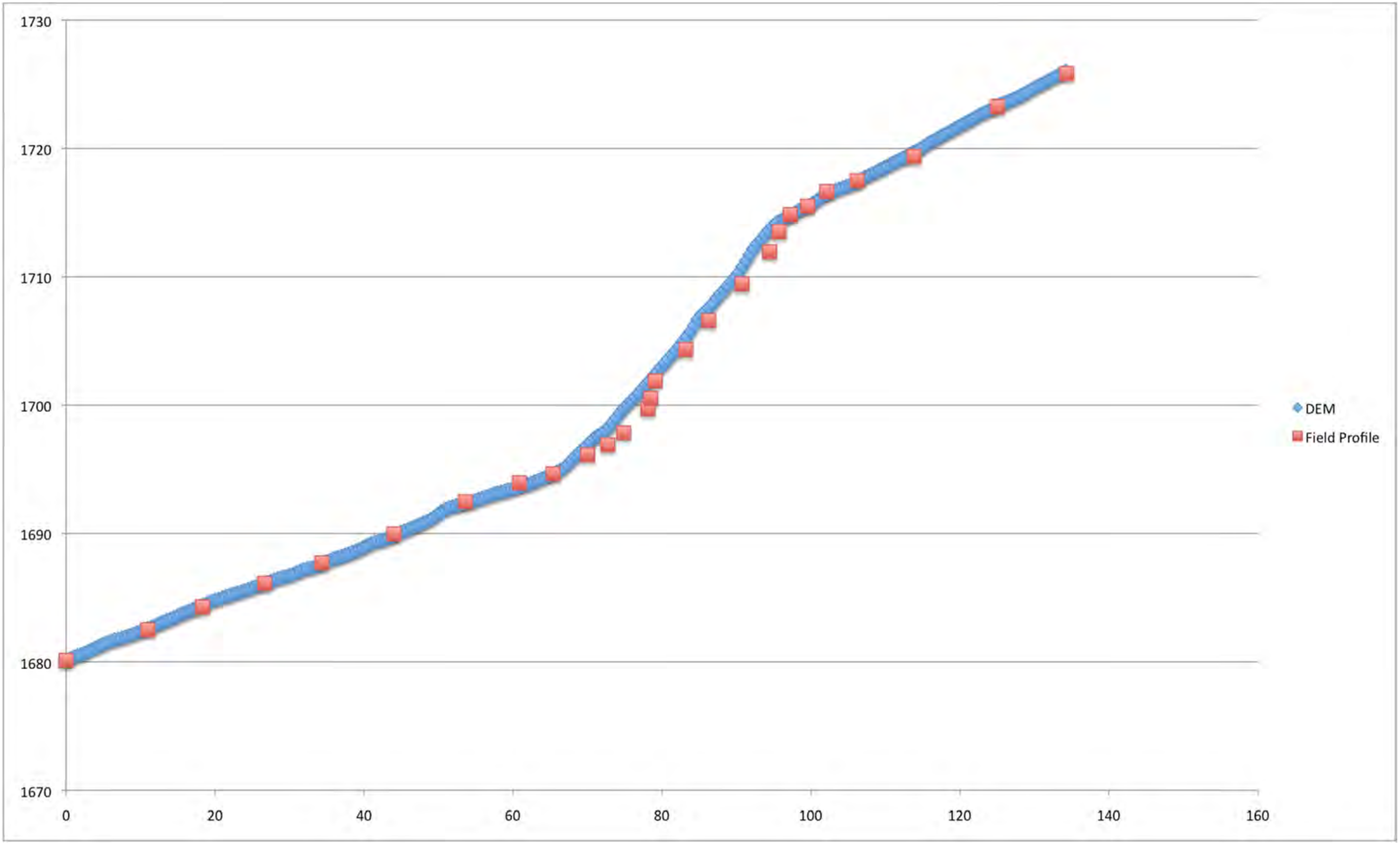
Objectives

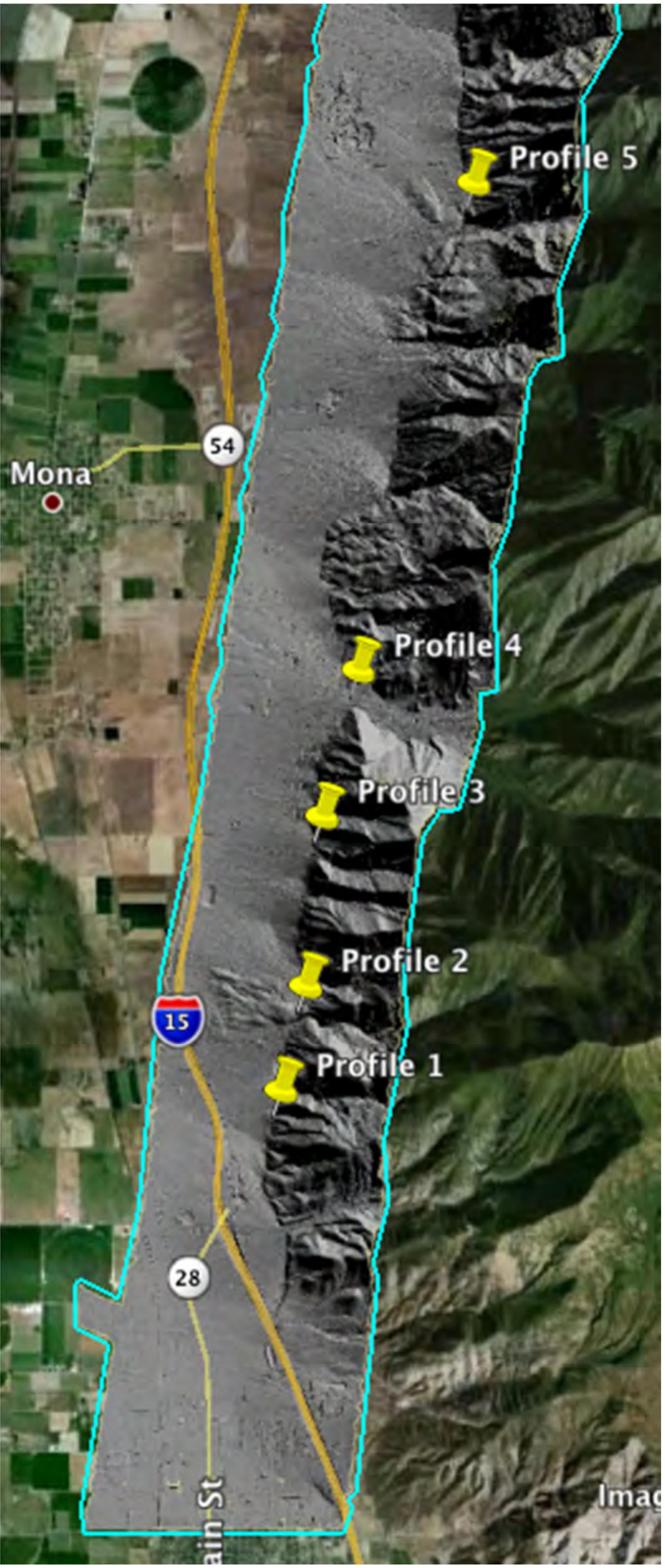
- A detailed study of scarp morphology over a large area utilizing high-resolution data
- Develop new software tools to extract important morphological parameters


113°
112°
111°
42°
41°
40°
39°
IDAHO
UTAH
WYOMING
N
Malad City
Clarkston Mtn.
Collinston
Brigham City
Ogden
GSL
Weber
I-80
Segments with multiple Holocene surface ruptures
SLC
Salt Lake City
Provo
Utah Lake
Nephi
Levan
I-15
Fayette
50 km


Payson
6
Santaquin
15
Nephi

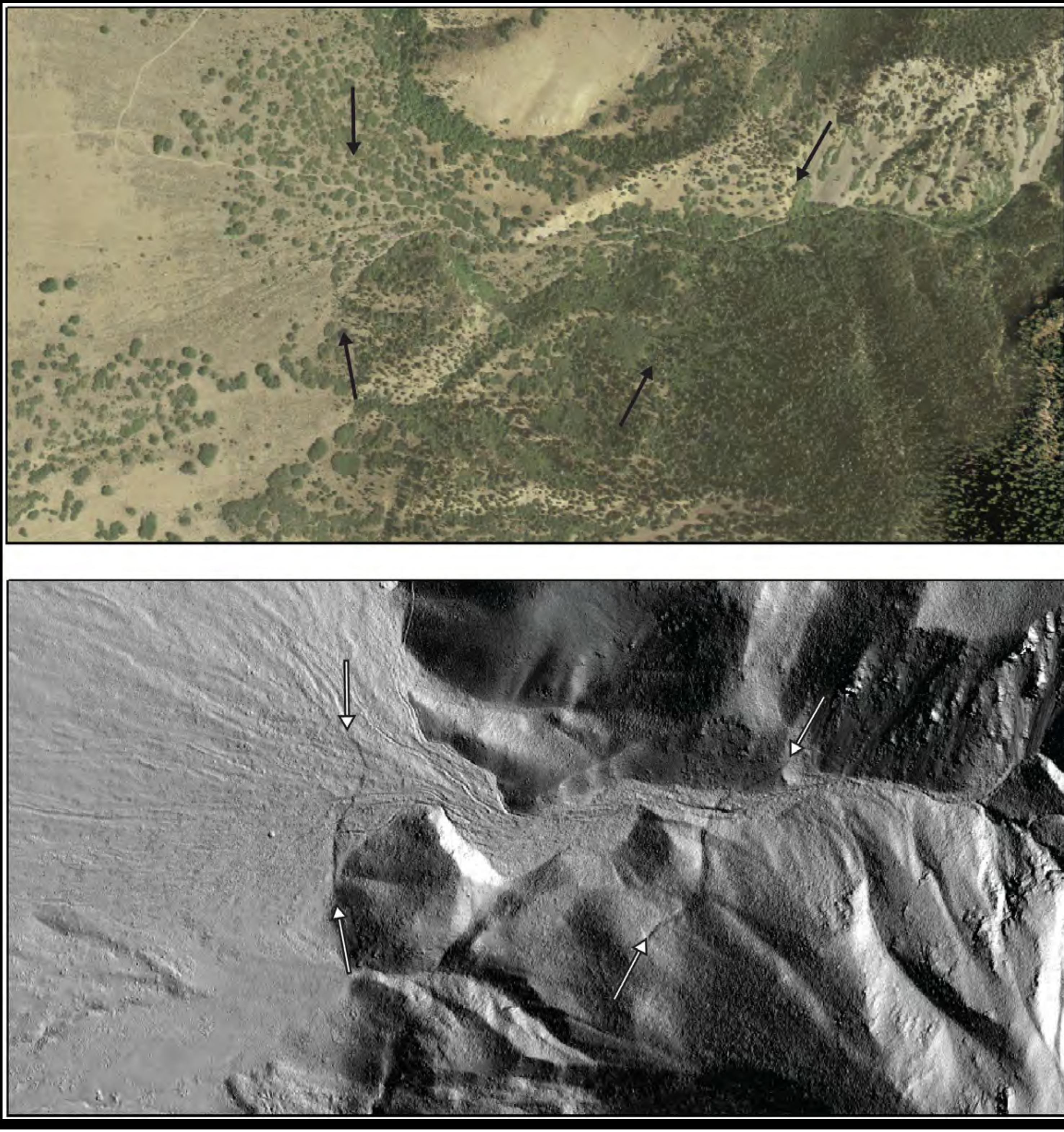

1605
1600
1595
1590
1585
1580
1575
1570
0
10
20
30
40
50
60
70
80
90
100
DEM
Field Profile


1730
1720
1710
1700
1690
1680
1670
0
20
40
60
80
100
120
140
160
DEM
Field Profile



Field Checks

Profile	Variance	Standard Deviation
1	0.05	0.22
2	0.20	0.45
3	0.73	0.85
4	0.20	0.44
5	0.24	0.49

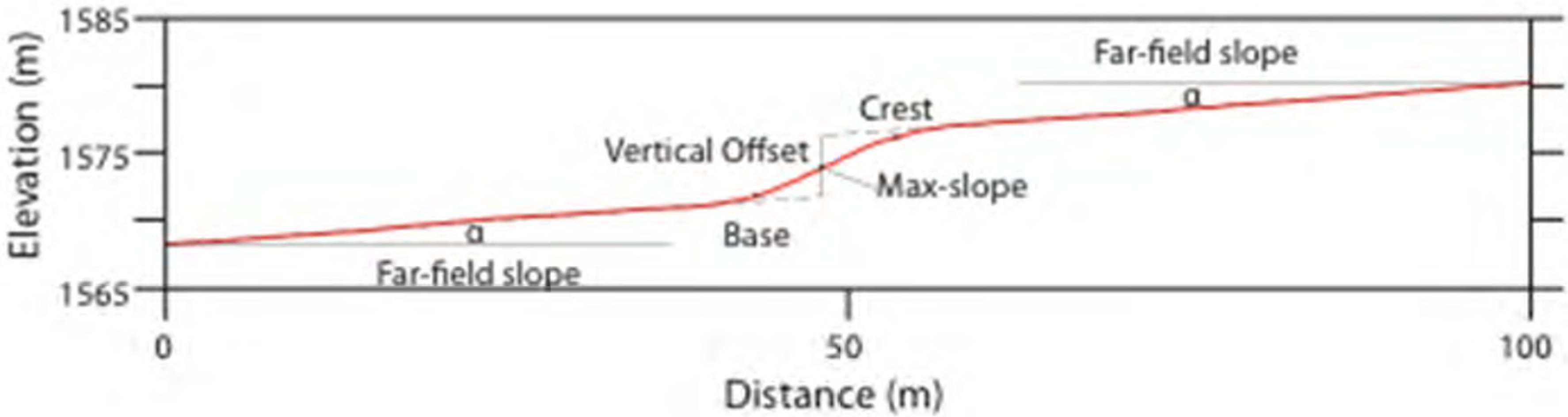


Software Applications

Esri ArcGIS: used to interact with DEMs, create hillshades, map fault, and visualize results

Python scripts: used to extract profiles, analyze profiles for morphological parameters

Python scripts interact with ArcGIS or can stand alone to be used with other GIS applications



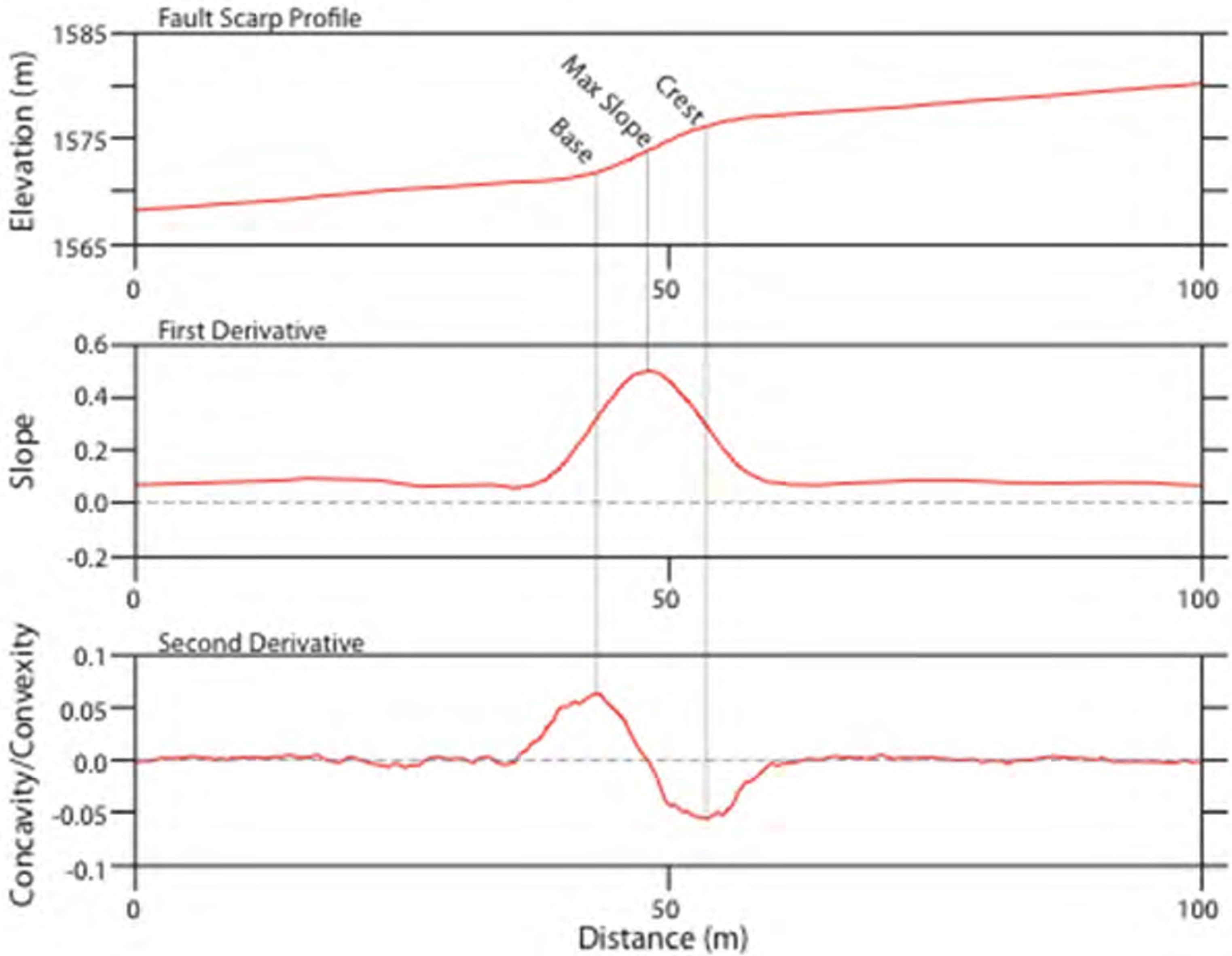
Base: Point of maximum slope curvature (concave-up) between the steepest part of the scarp face and the scarp toe

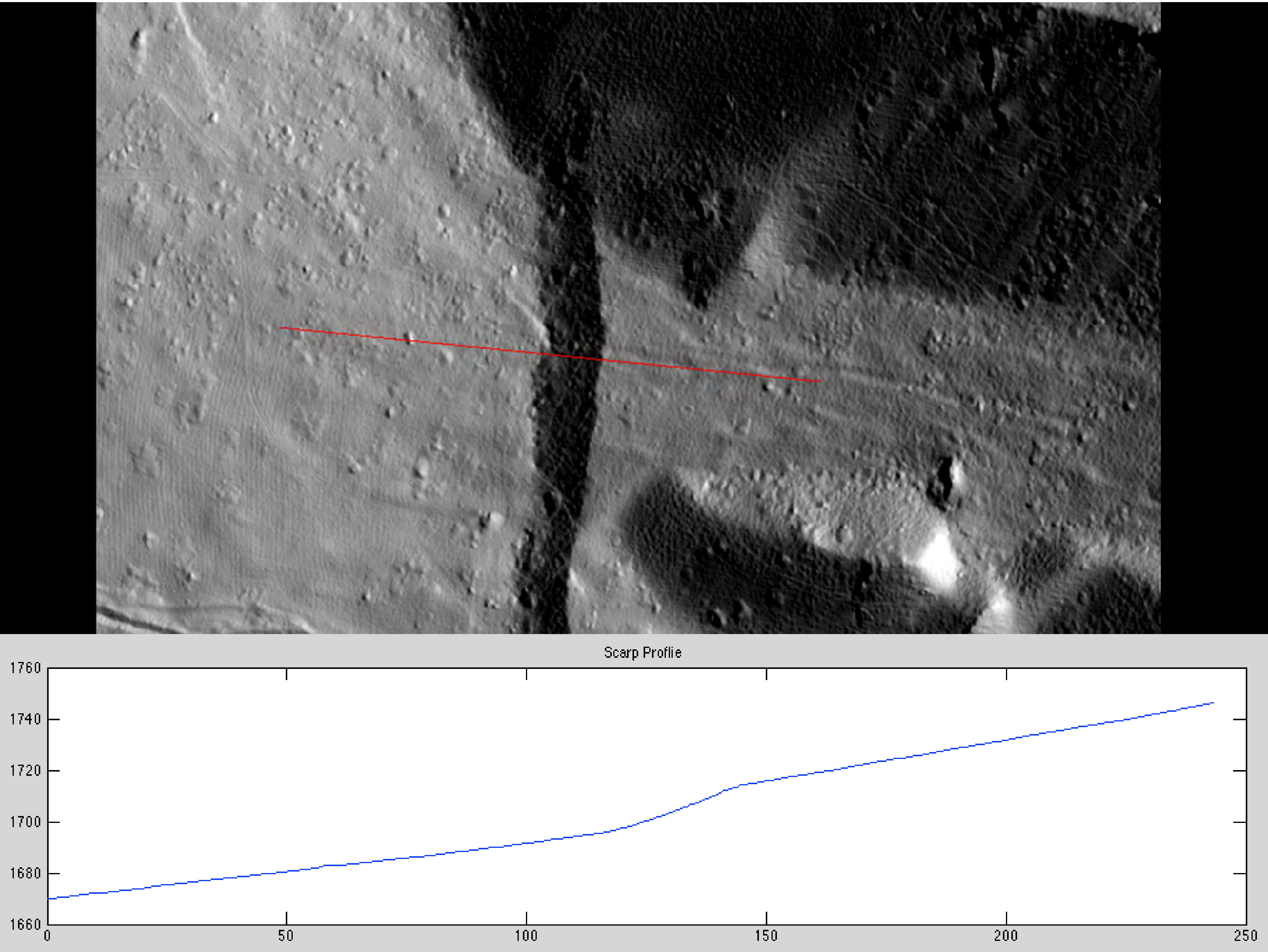
Max-slope: Gradient of the steepest part of the scarp face

Crest: Point of maximum slope curvature (convex-up) between the scarp head and the steepest part of the scarp face

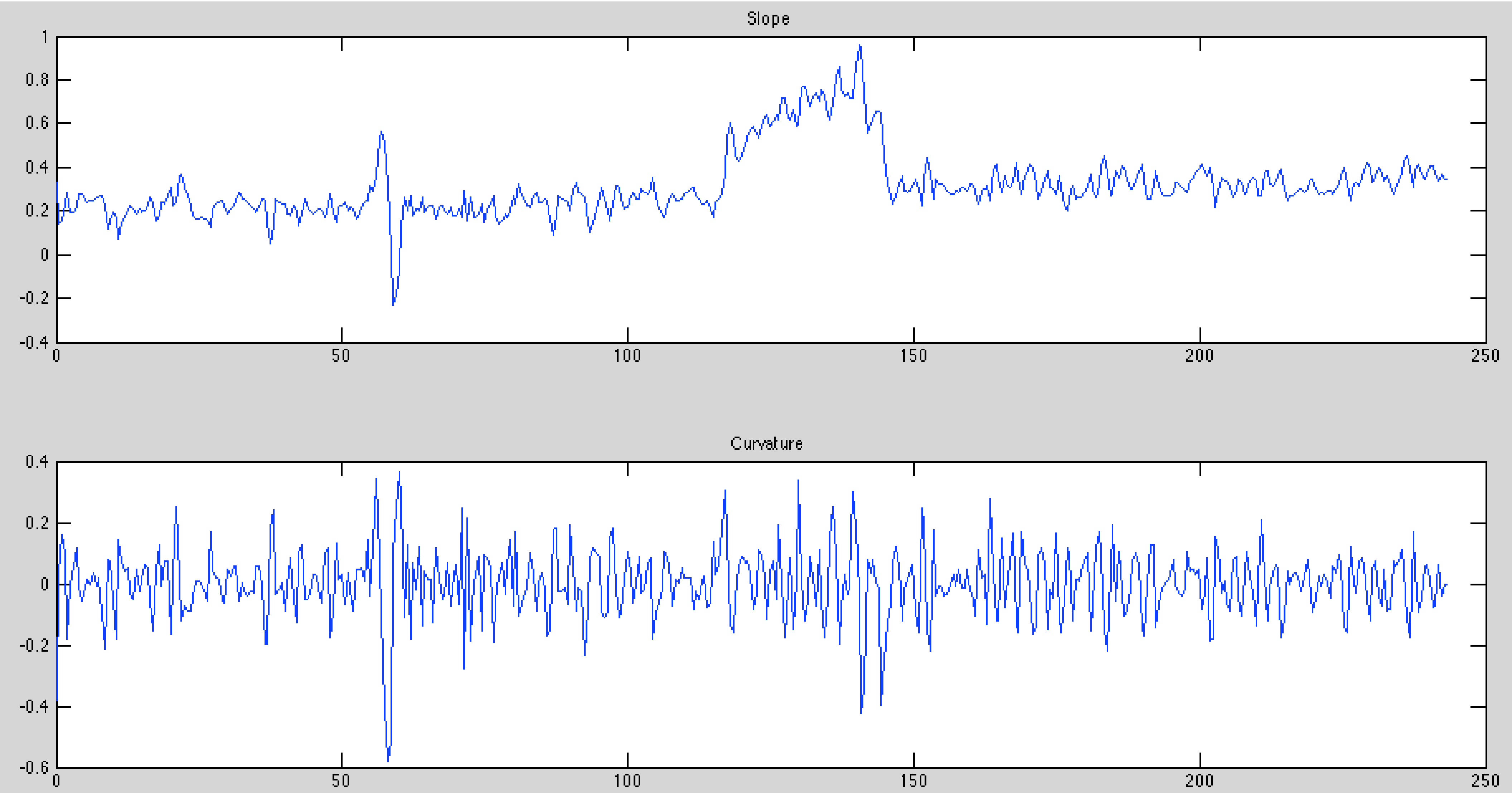
Far-field slope: Gradient of the faulted geomorphic surface

Vertical Offset: measurement of surface offset along vertical plane

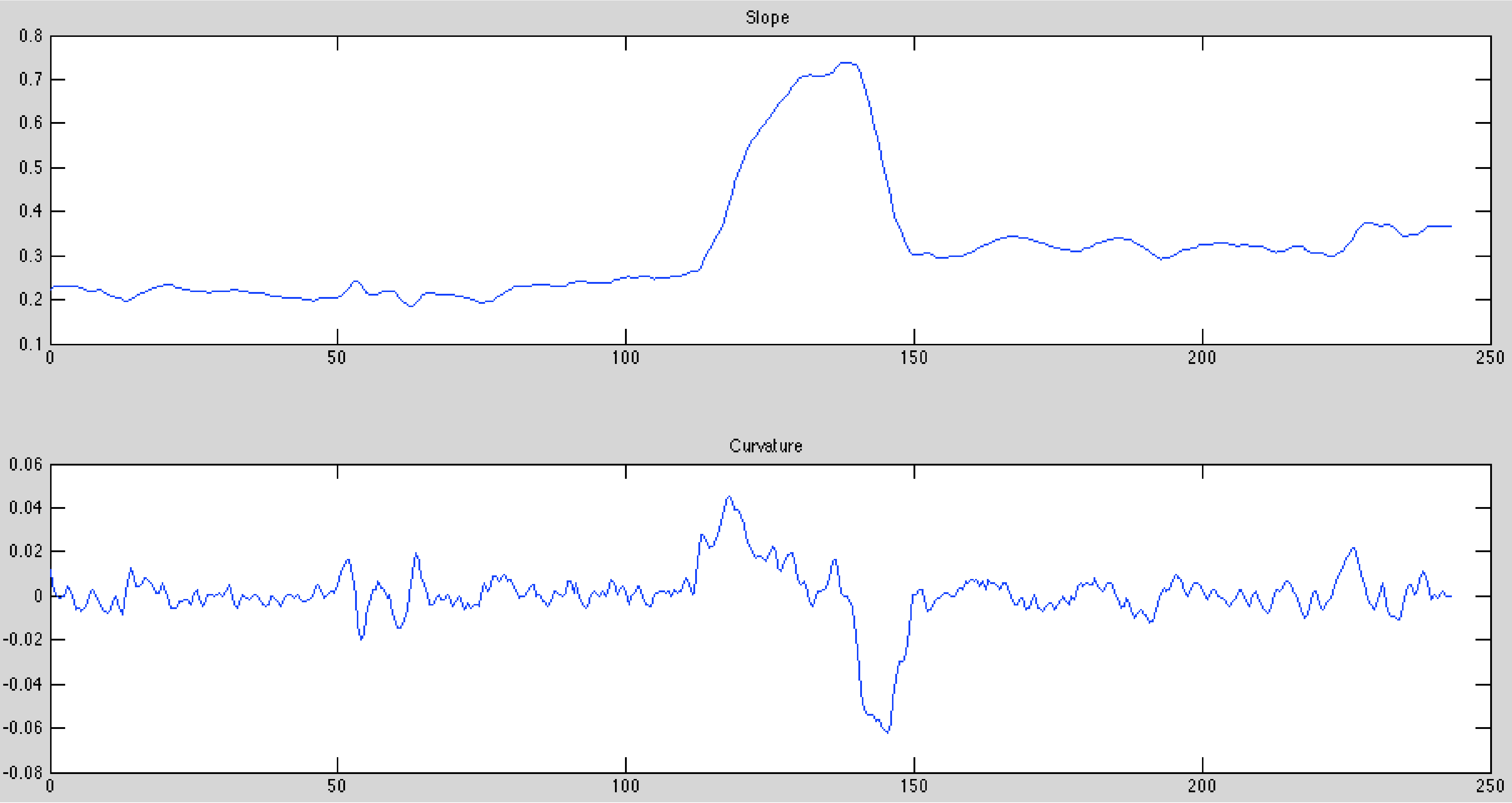

Fault Scarp Profile
Elevation (m)
1585
1575
1565
Base
Max Slope
Crest
0
50
100
First Derivative
Slope
0.6
0.4
0.2
0.0
-0.2
0
50
100
Second Derivative
Concavity/Convexity
0.1
0.05
0.0
-0.05
-0.1
0
50
100
Distance (m)

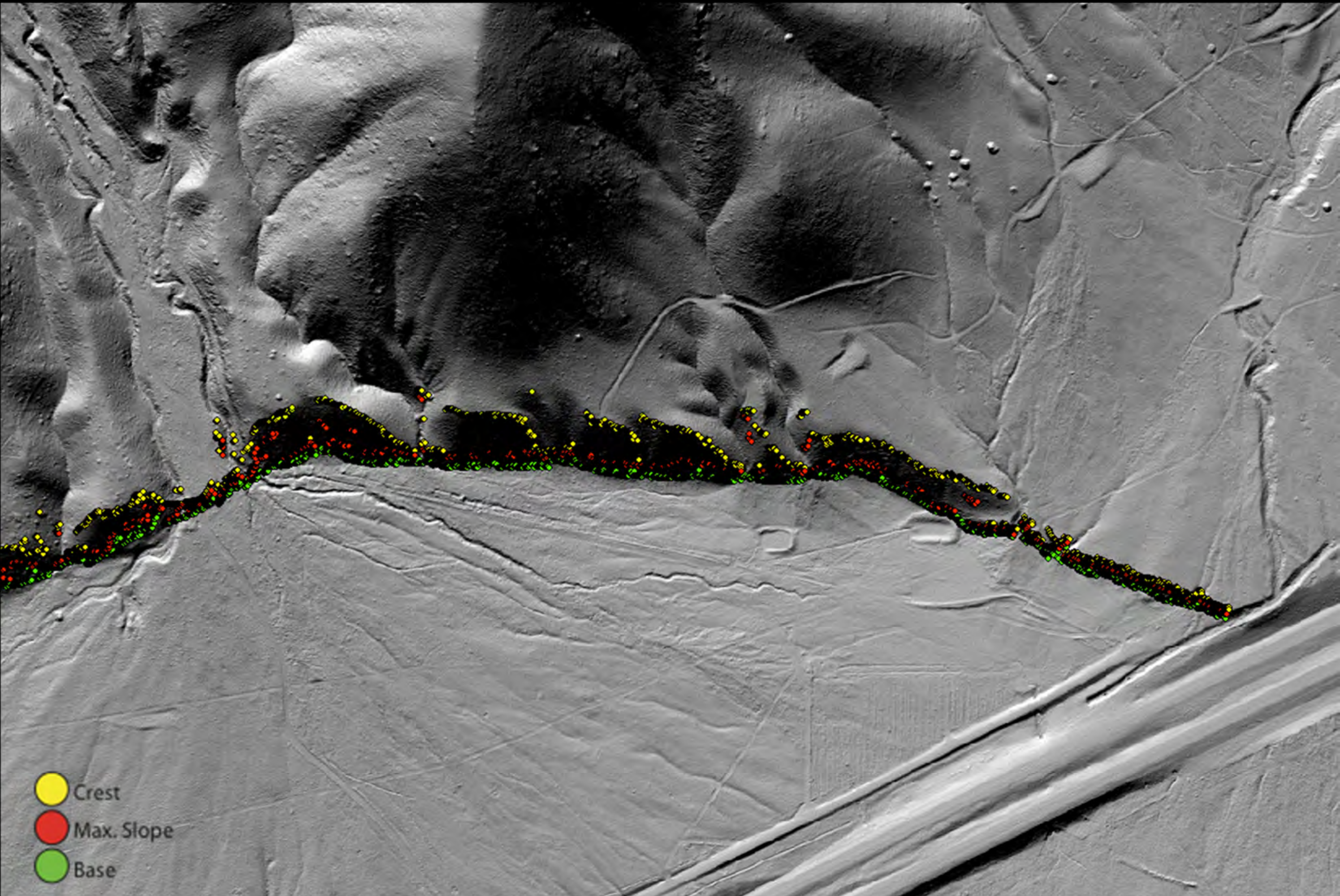

Scarp Profile
1760
1740
1720
1700
1680
1660
0
50
100
150
200
250

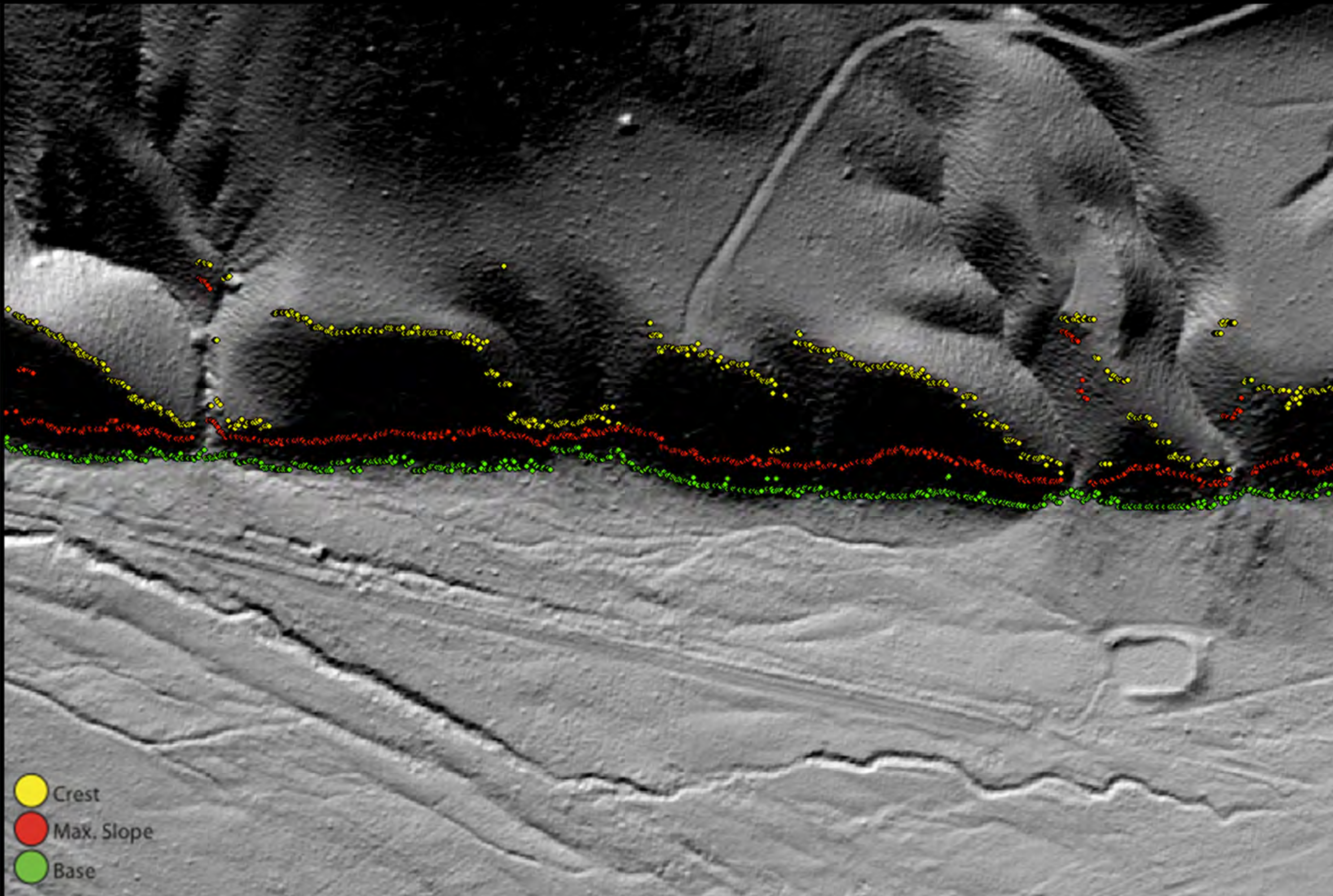
Full Resolution First and Second Derivative



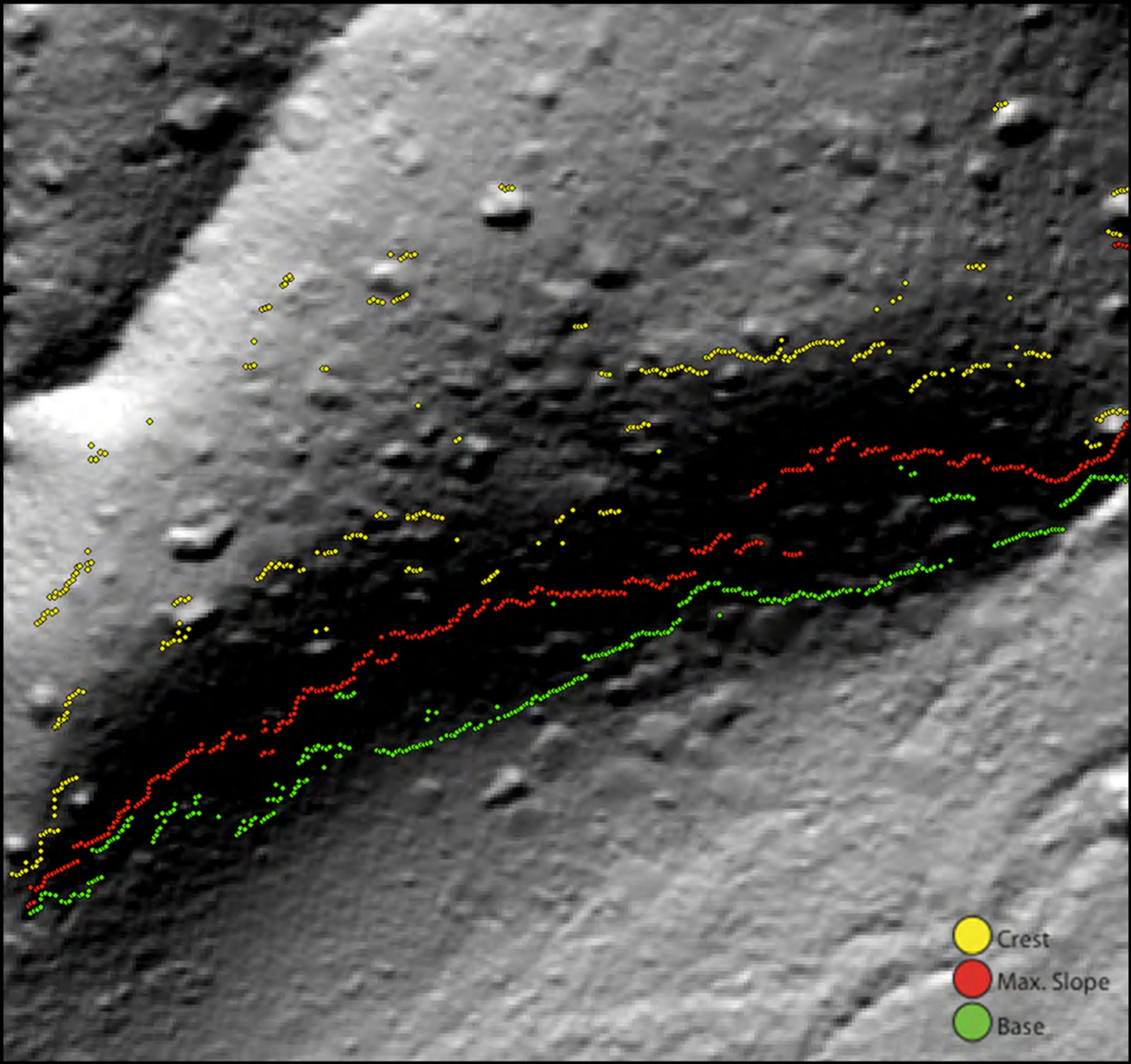
Downsampled First and Second Derivative

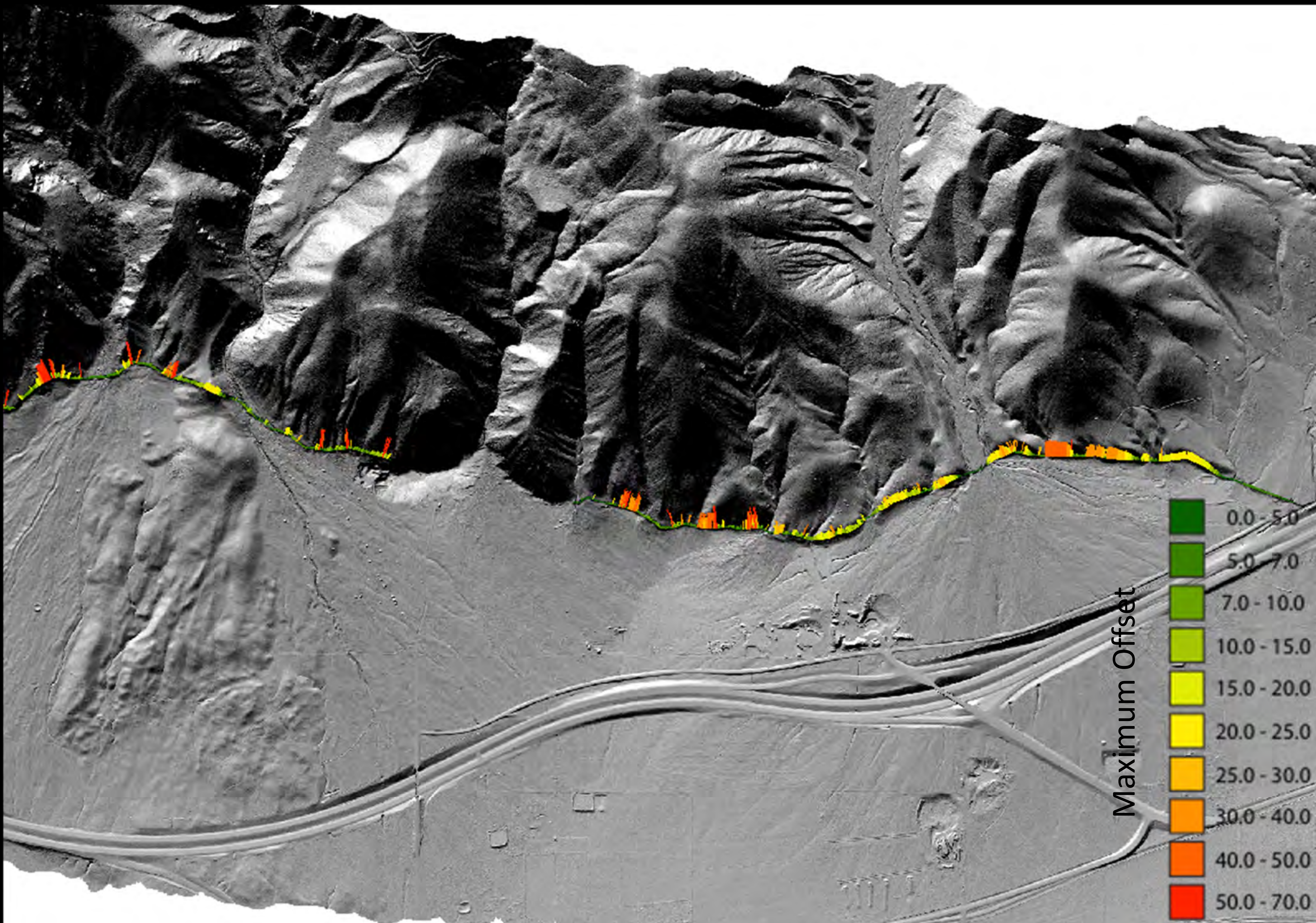


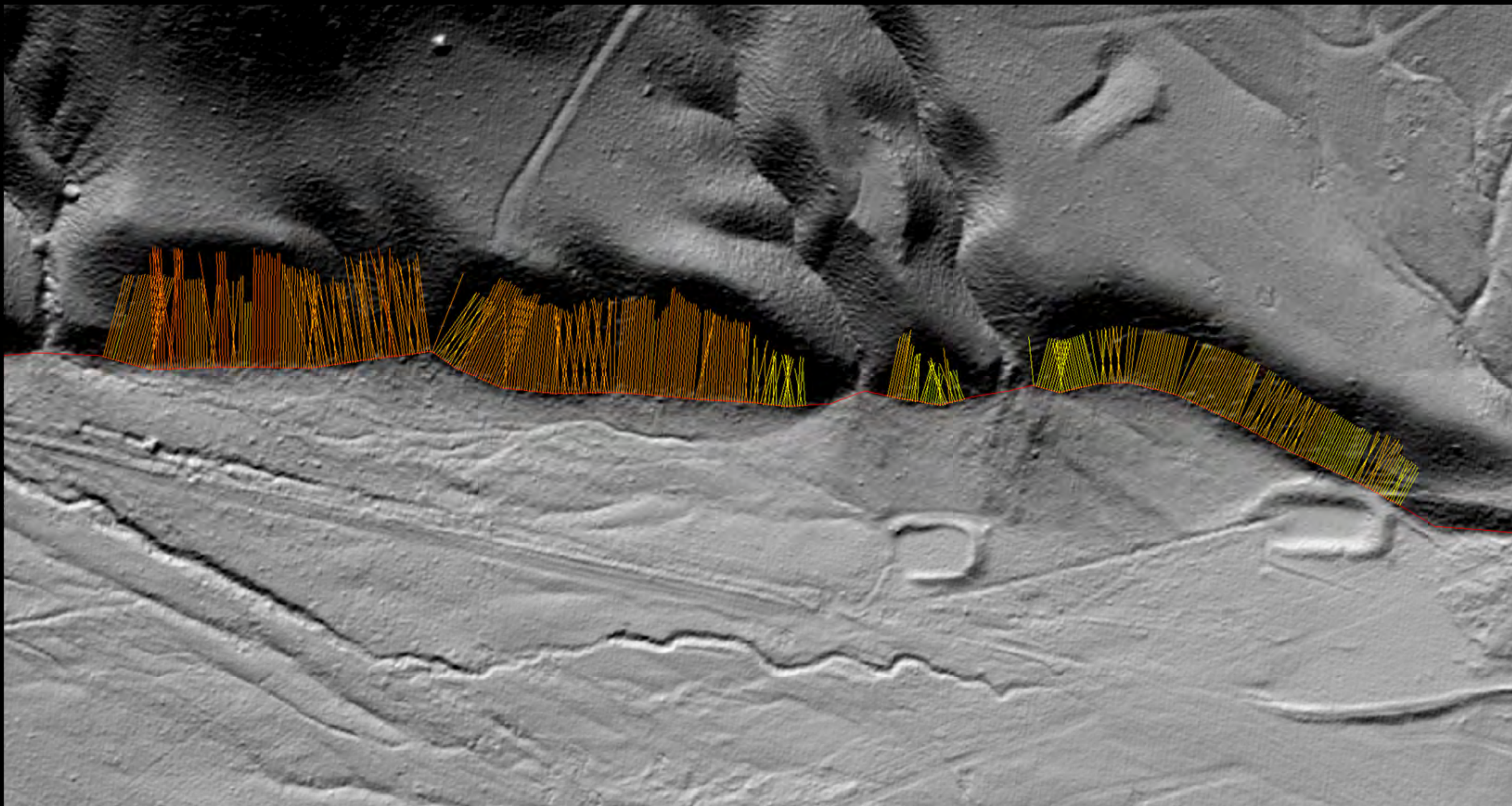

Crest
Max. Slope
Base

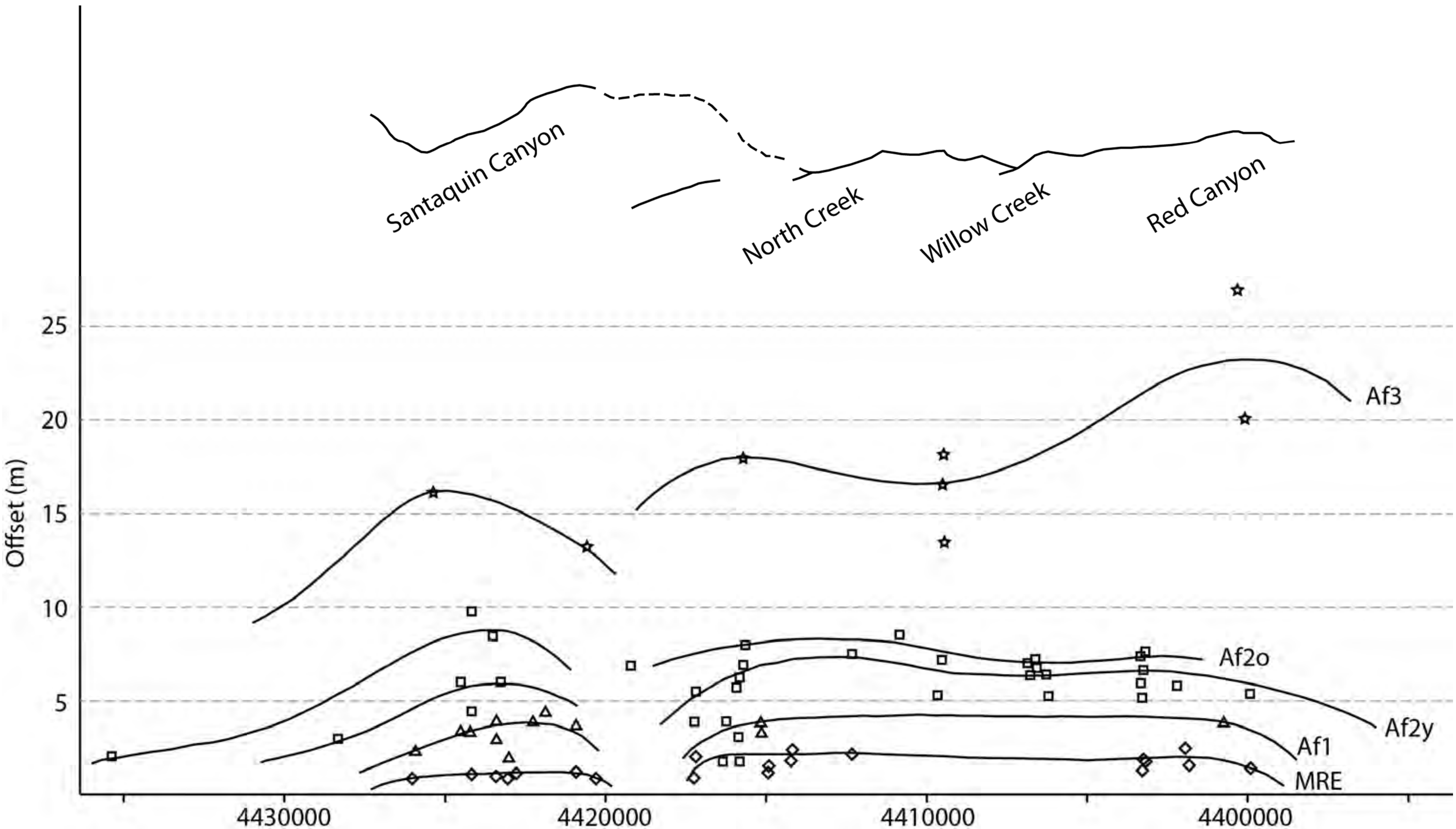


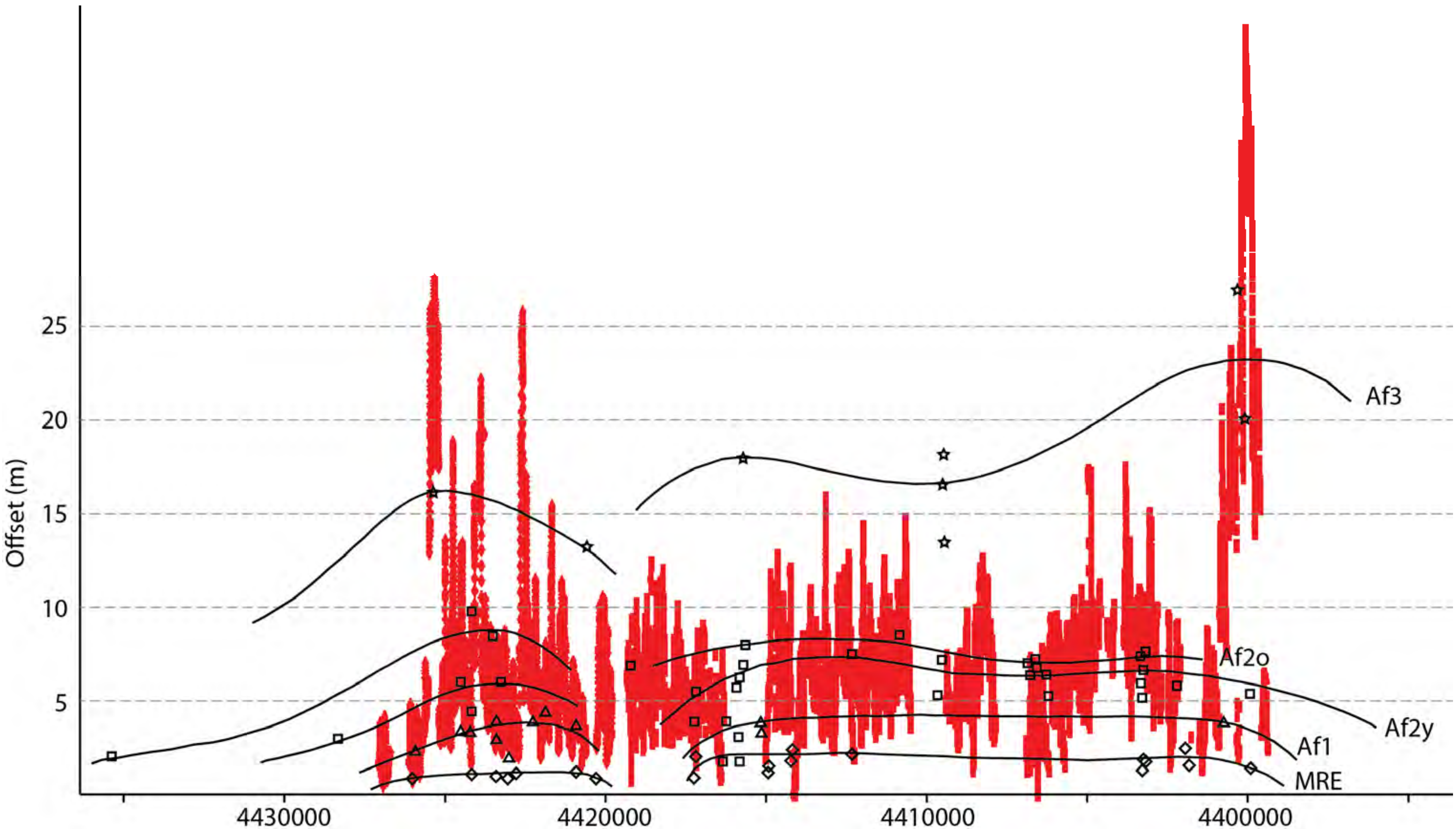
Crest
Max. Slope
Base


Crest
Max. Slope
Base


Maximum Offset
0.0 - 5.0
5.0 - 7.0
7.0 - 10.0
10.0 - 15.0
15.0 - 20.0
20.0 - 25.0
25.0 - 30.0
30.0 - 40.0
40.0 - 50.0
50.0 - 70.0

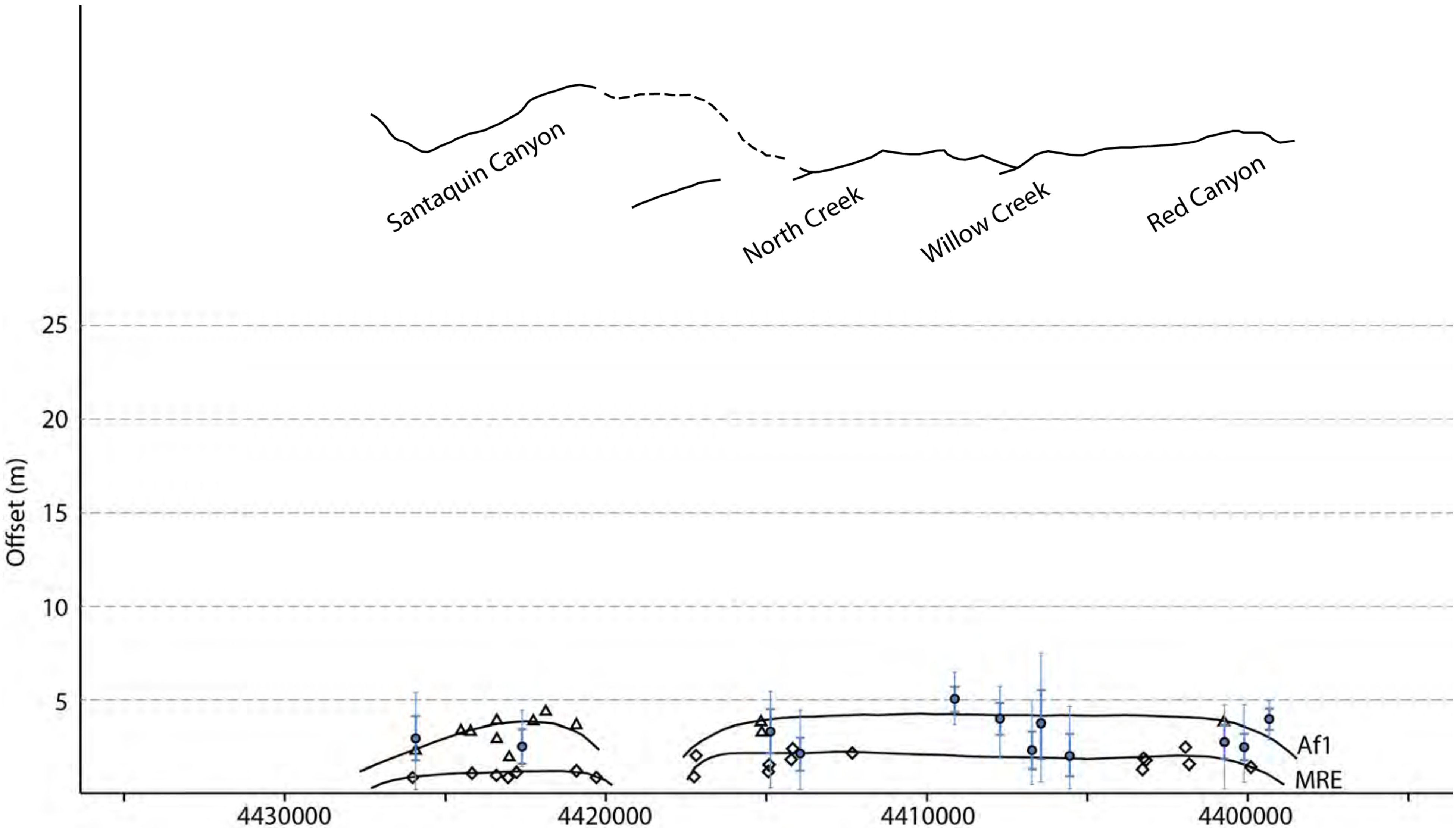



Santaquin Canyon
North Creek
Willow Creek
Red Canyon
Offset (m)
25
20
15
10
5
Af3
Af2o
Af2y
Af1
MRE
4430000
4420000
4410000
4400000



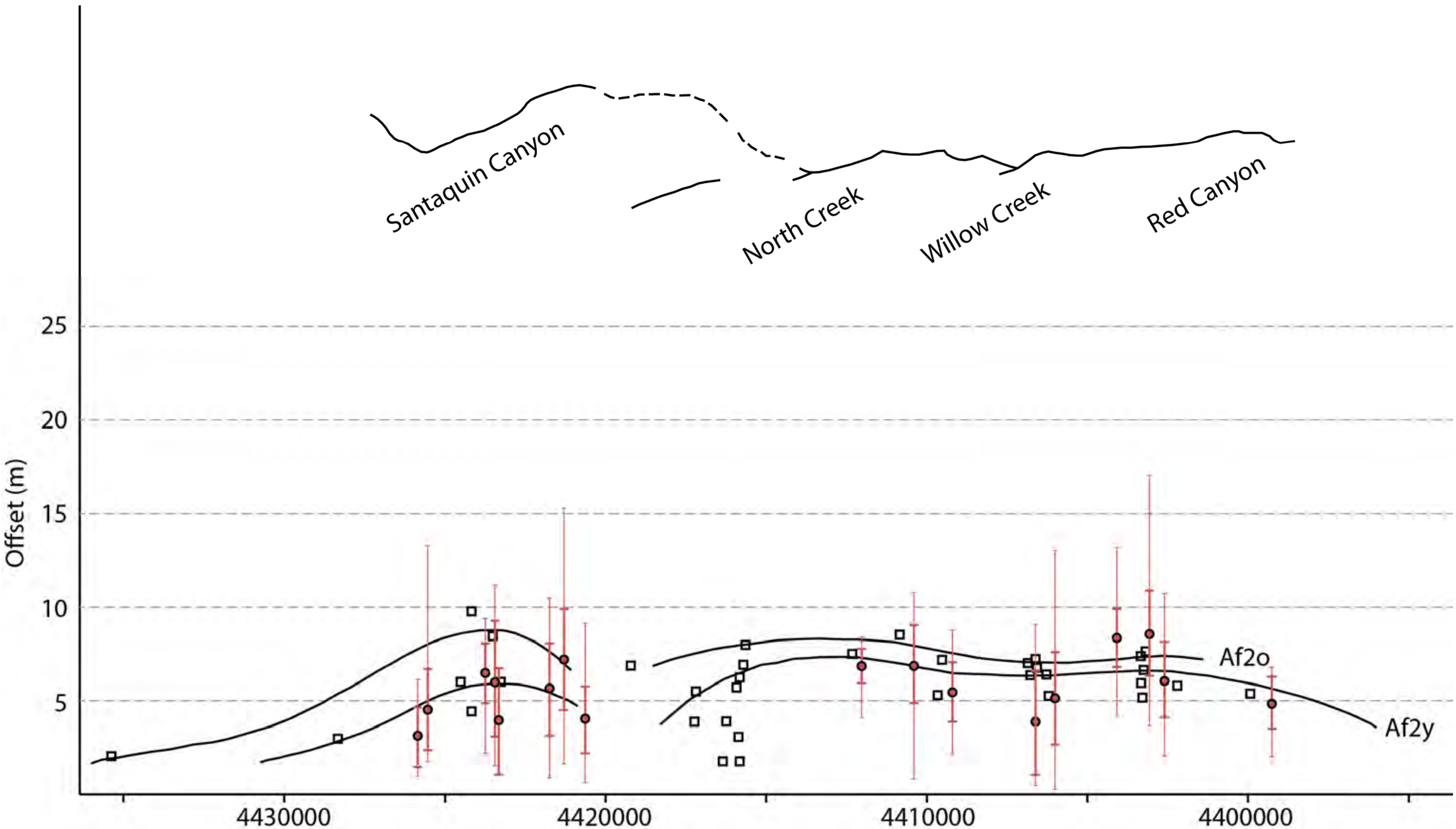
Offset (m)
25
20
15
10
5
4430000
4420000
4410000
4400000
Af3
Af2o
Af2y
Af1
MRE

Af1



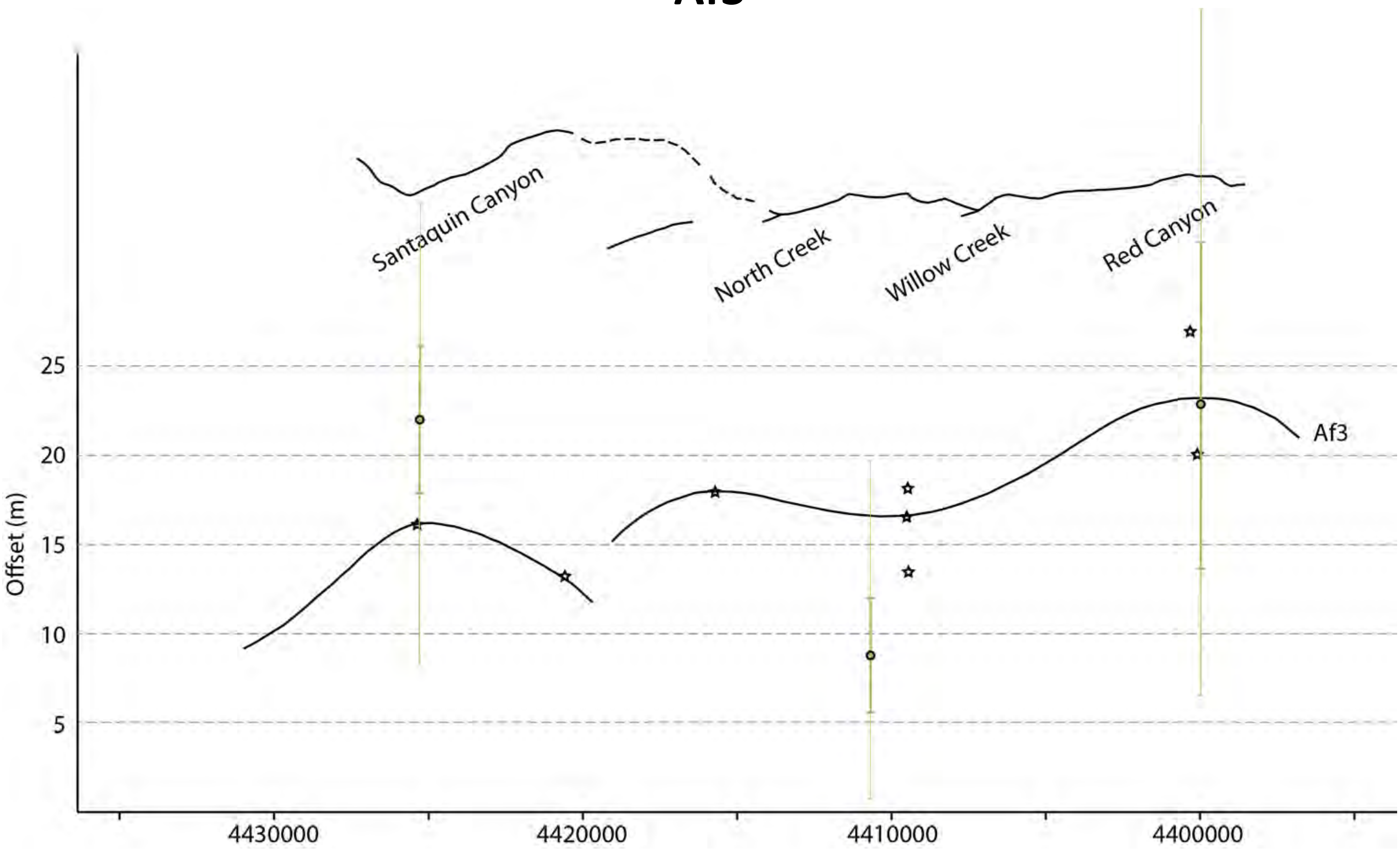
Santaquin Canyon
North Creek
Willow Creek
Red Canyon
25
20
15
10
5
Offset (m)
Af1
MRE
4430000
4420000
4410000
4400000

Af2



Santaquin Canyon
North Creek
Willow Creek
Red Canyon
Offset (m)
25
20
15
10
5
4430000
4420000
4410000
4400000
Af2o
Af2y

Af3



Santaquin Canyon
North Creek
Willow Creek
Red Canyon
Af3
25
20
15
10
5
Offset (m)
4430000
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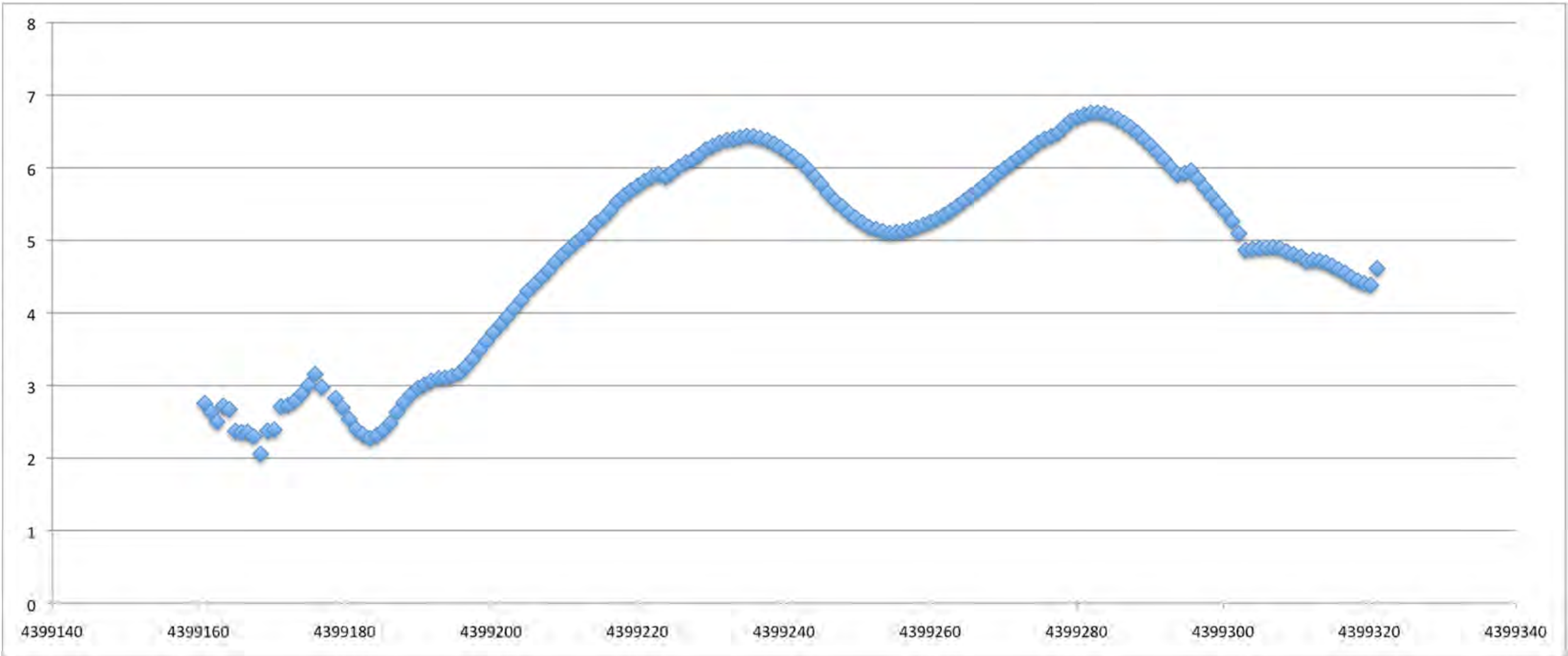


8
7
6
5
4
3
2
1
0
4399140
4399160
4399180
4399200
4399220
4399240
4399260
4399280
4399300
4399320
4399340

Questions?

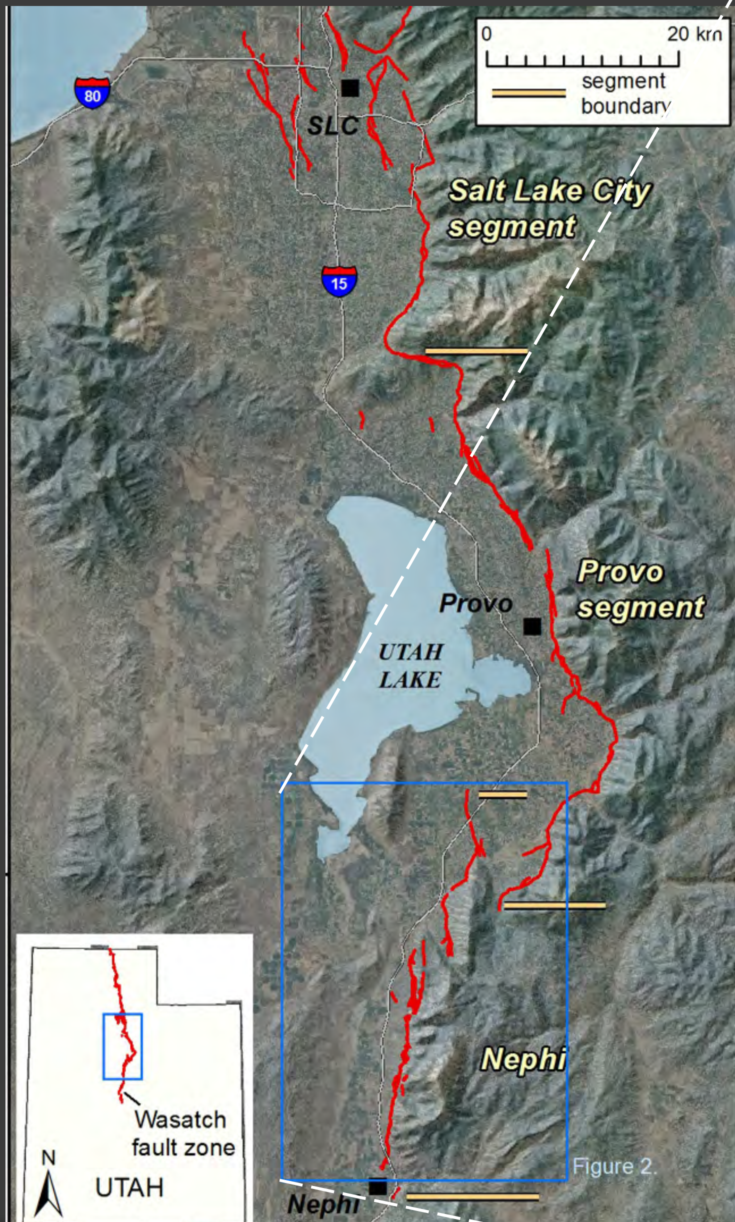
UPDATE: PALEOSEISMIC INVESTIGATION OF THE NORTHERN AND SOUTHERN STRANDS OF THE NEPHI SEGMENT

Chris DuRoss
Mike Hylland
Greg McDonald
Adam Hiscock
Gregg Beukelman
Ben Erickson

Steve Personius
Tony Crone
Rich Briggs
Ryan Gold
Steve Angster
Roslynn King

Utah Quaternary Fault Parameters Working Group – February 2013

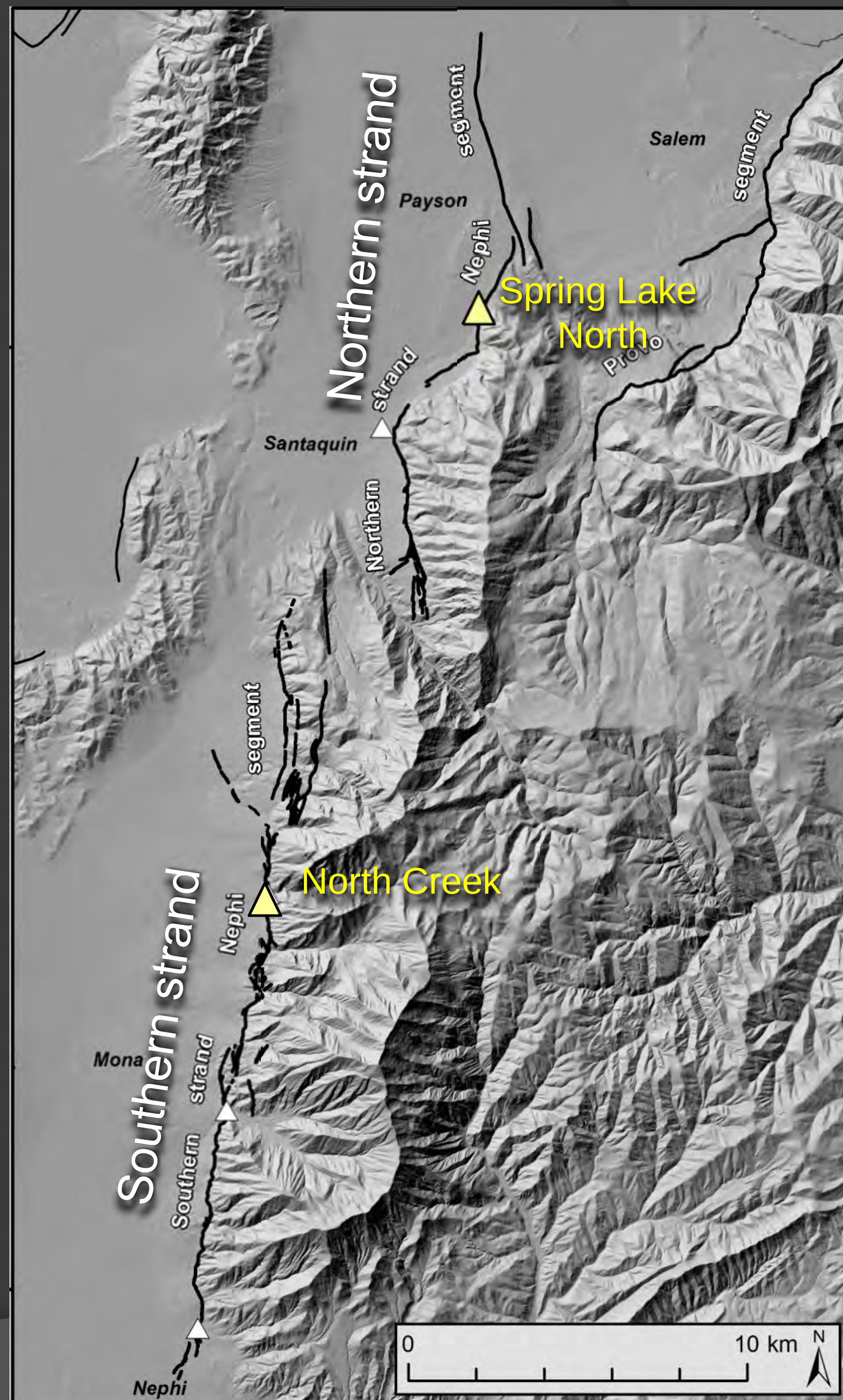
Nephi Segment



Nephi Segment

- Four previous trench studies, but, important questions regarding:
  1. Timing and recurrence of mid- Holocene surface-faulting earthquakes
  2. Rupture behavior of the northern and southern strands
  3. Relation between the northern strand and Provo segment

- Spring Lake North and North Creek site



Nephi Segment

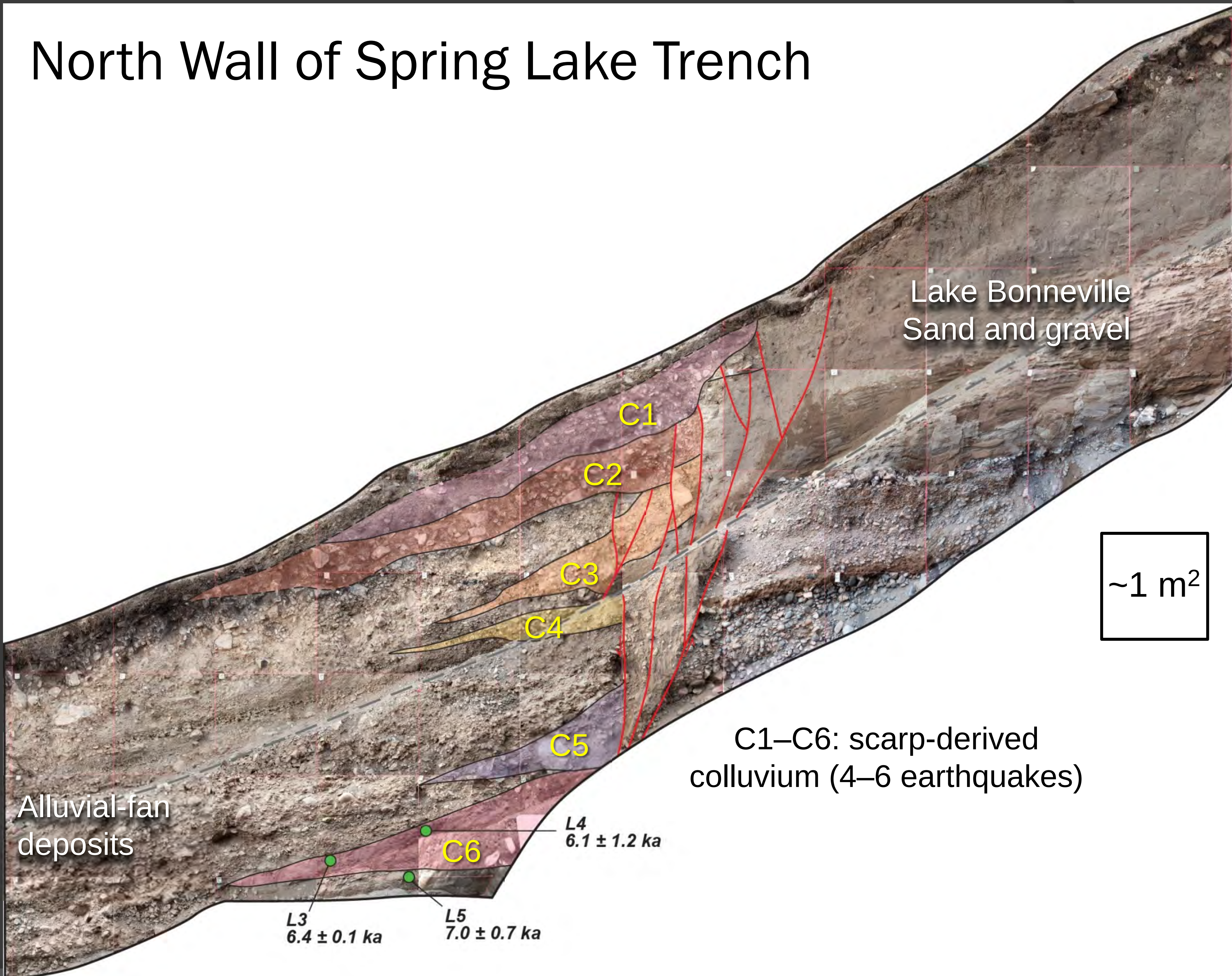
- Spring Lake site
  - 1 trench across prominent scarp on post-Bonneville-alluvial fan
  - Close to previous trenches excavated by UVU (Horns and others)

Northern Nephi segment – Spring Lake site

Northern Nephi segment – Spring Lake site

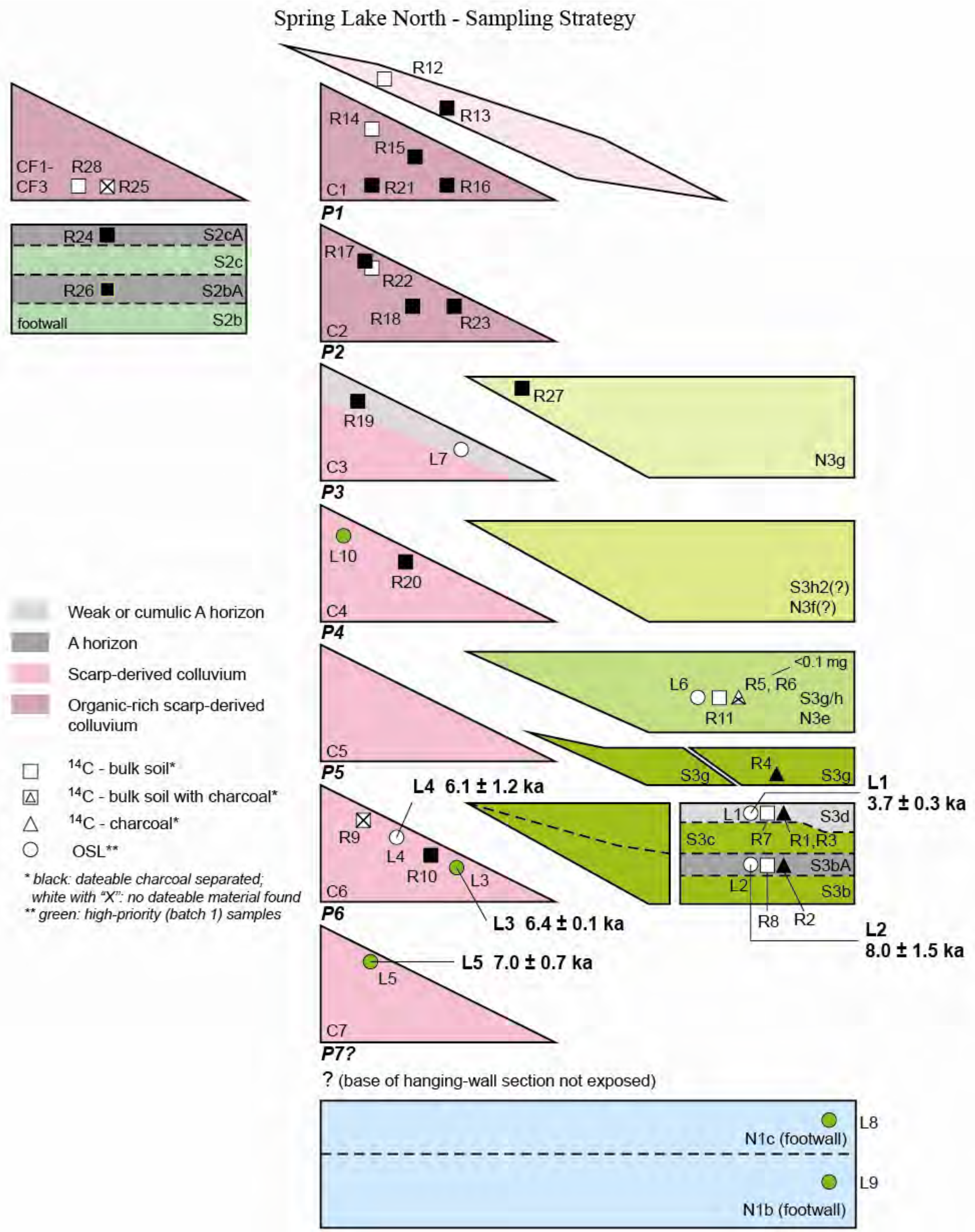
North Wall of Spring Lake Trench

North Wall of Spring Lake Trench



Prelim. Results

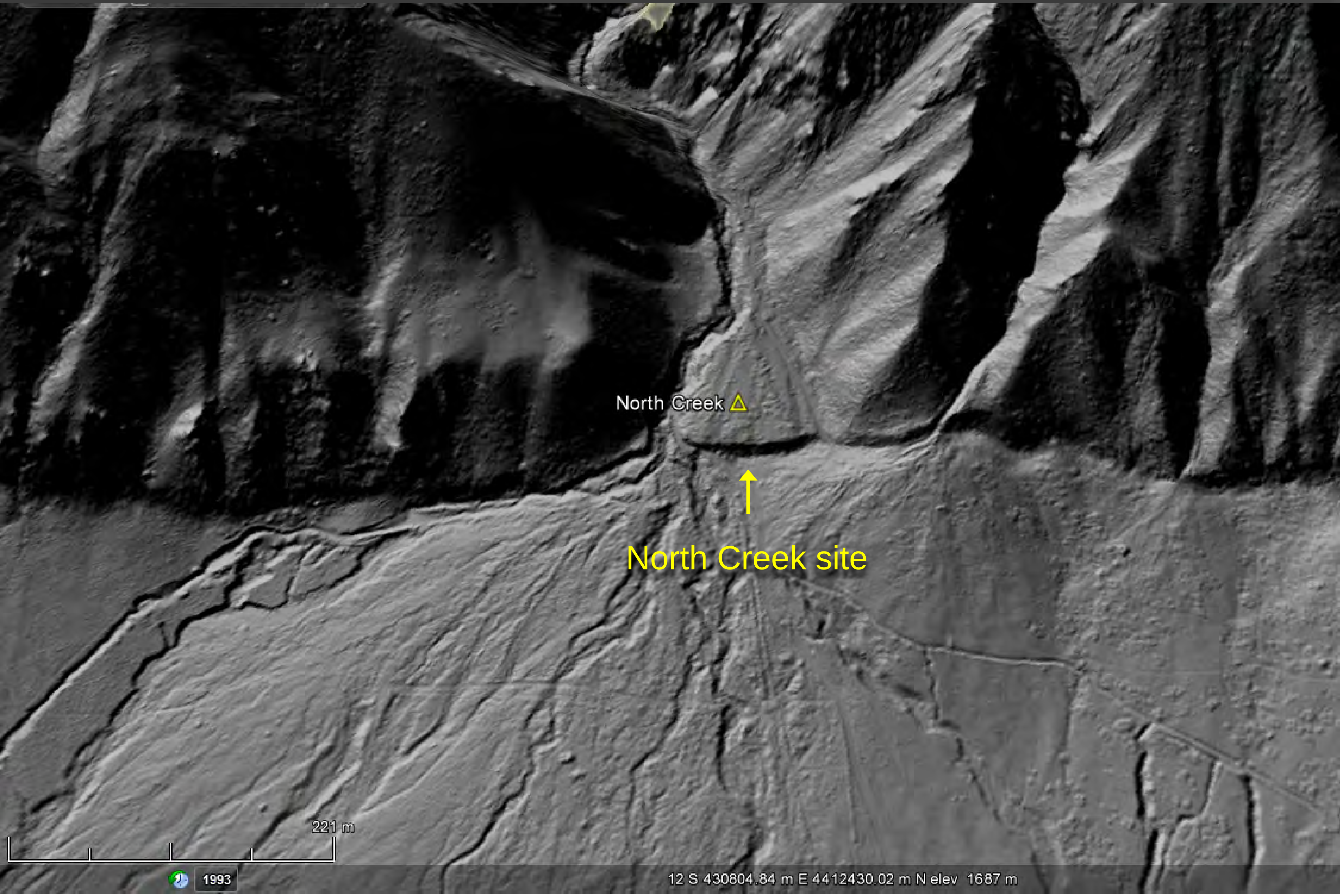
- Earthquakes
  - 4–6 after ~7 ka(?)
  - 5–7 earthquakes since Bonneville highstand
- Limiting ages:
  - 28 samples for ^{14}C dating (mostly bulk soil)
  - 10 OSL samples (preliminary results from 5)



Southern Strand

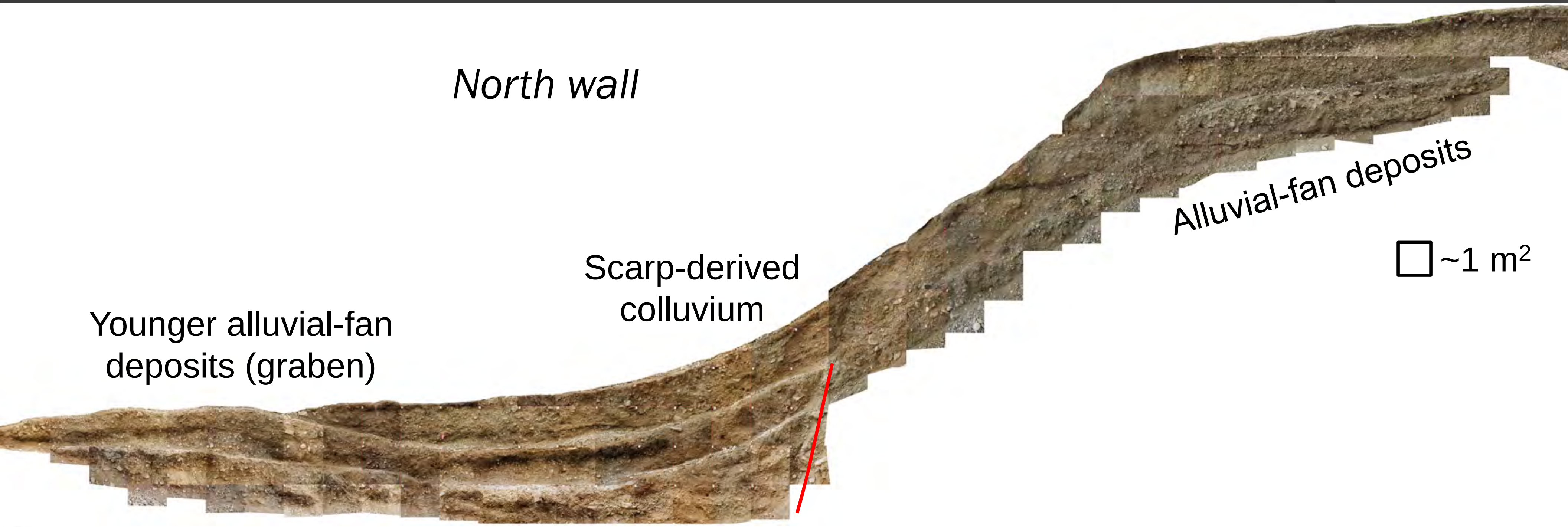
- North Creek site
  - 1 trench across large, steep scarp on ~mid-Holocene alluvial-fan deposits
  - Previously investigated by Hanson, Swan, and Schwartz in 1980

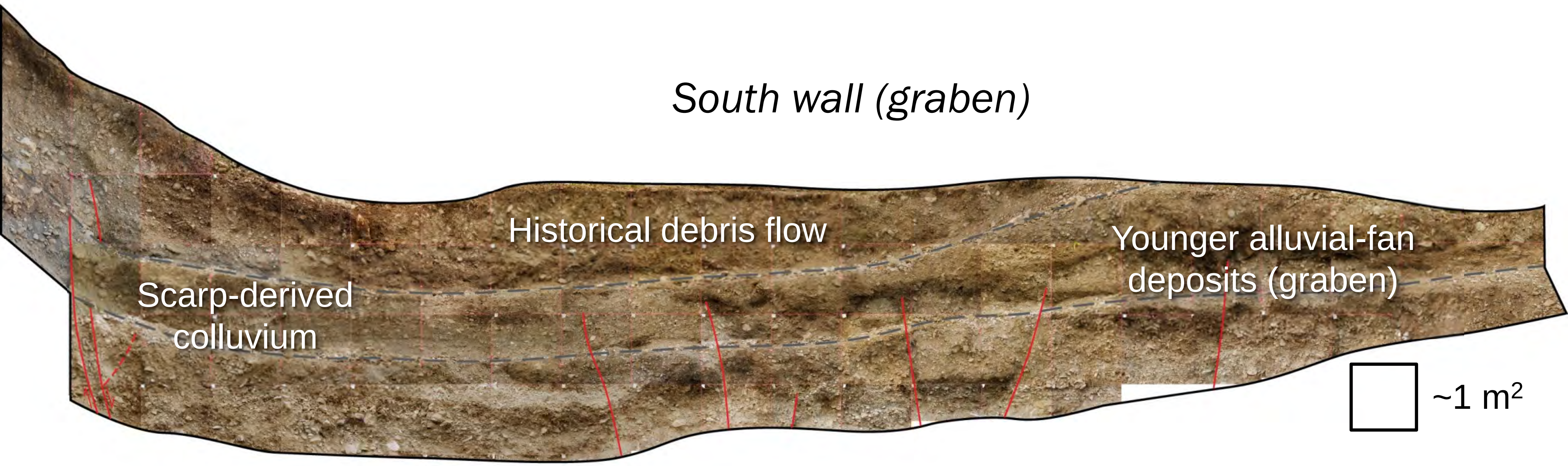
Southern Nephi segment – North Creek site



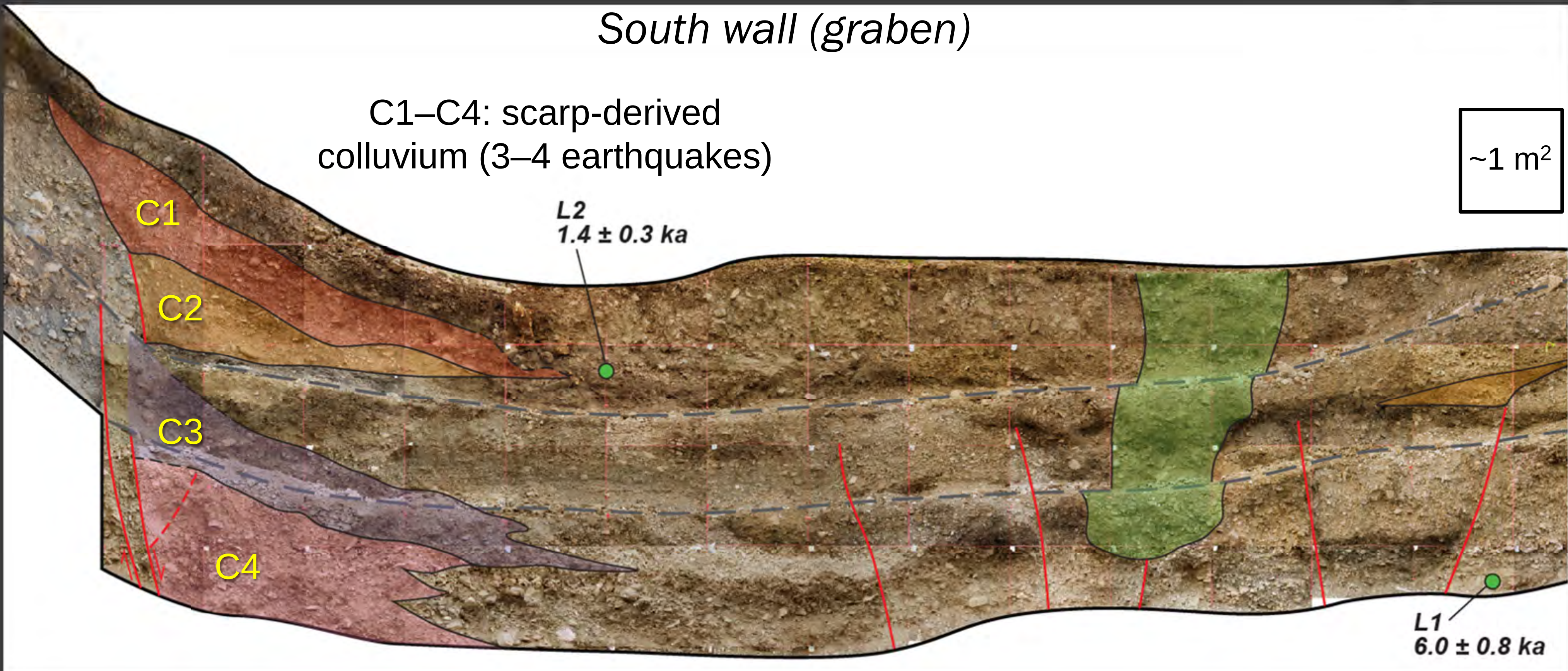

~7.5 m high

Southern Nephi segment – North Creek site



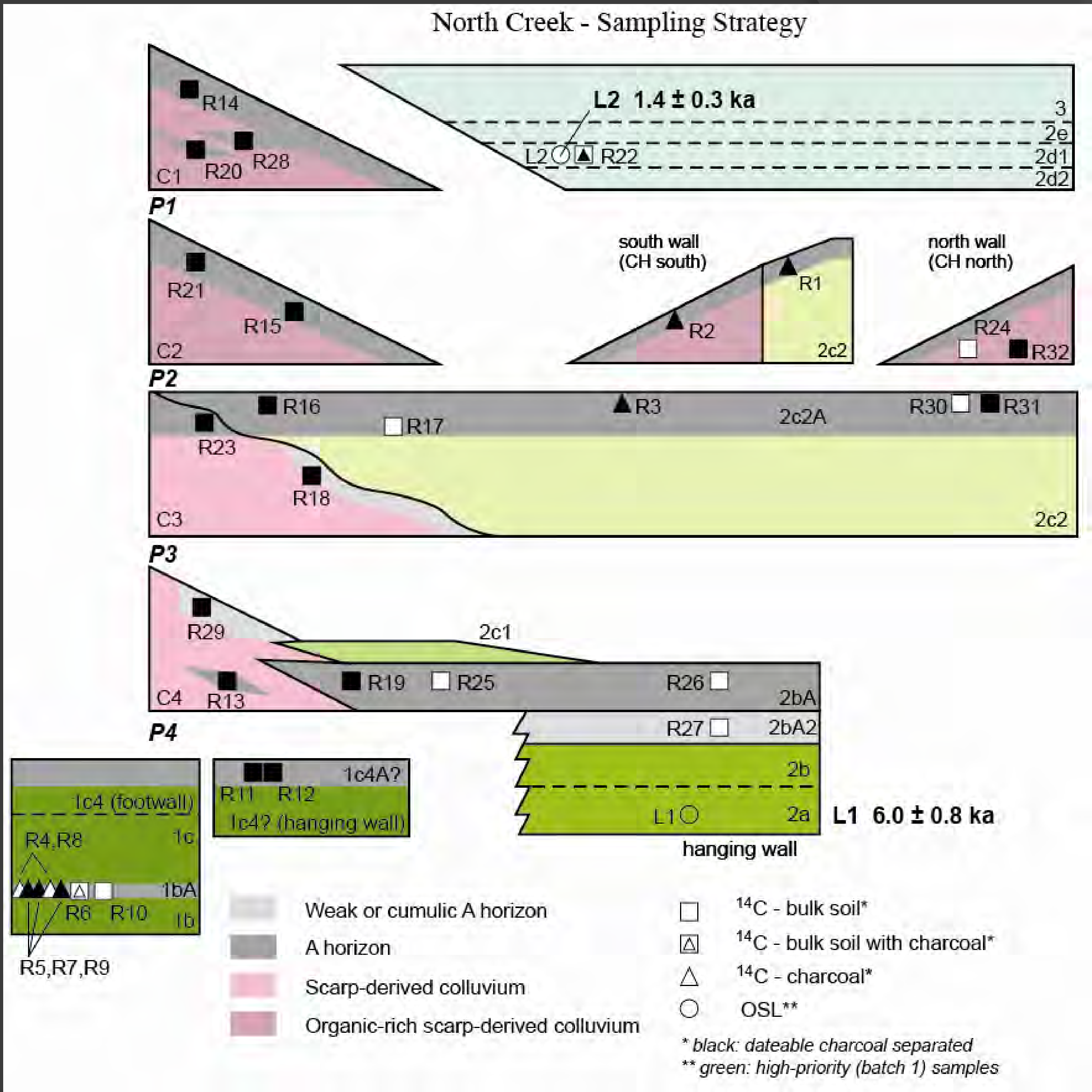


South Wall of North Creek Trench



Prelim. Results

- Earthquakes
  - 3–4 after ~6 ka(?)
- Limiting ages:
  - 32 samples for ^{14}C dating (mostly bulk soil)
  - 2 OSL samples



Summary & Conclusions

- Both sites yielded abundant evidence of surface faulting earthquakes:
  - Spring Lake north
    - 4–6 earthquakes since ~7 ka(?)
    - Moderate displacements (wedges <1 m thick)
  - North Creek
    - 3–4 earthquakes since ~6 ka
    - Large displacements (wedges ~1–2 m thick)

- With additional numerical ages, we hope to improve our understanding of the timing, recurrence, and displacement of earthquakes on the northern and southern Nephi strands

Results of Fault Trenching at the Baileys Lake Site, West Valley Fault Zone

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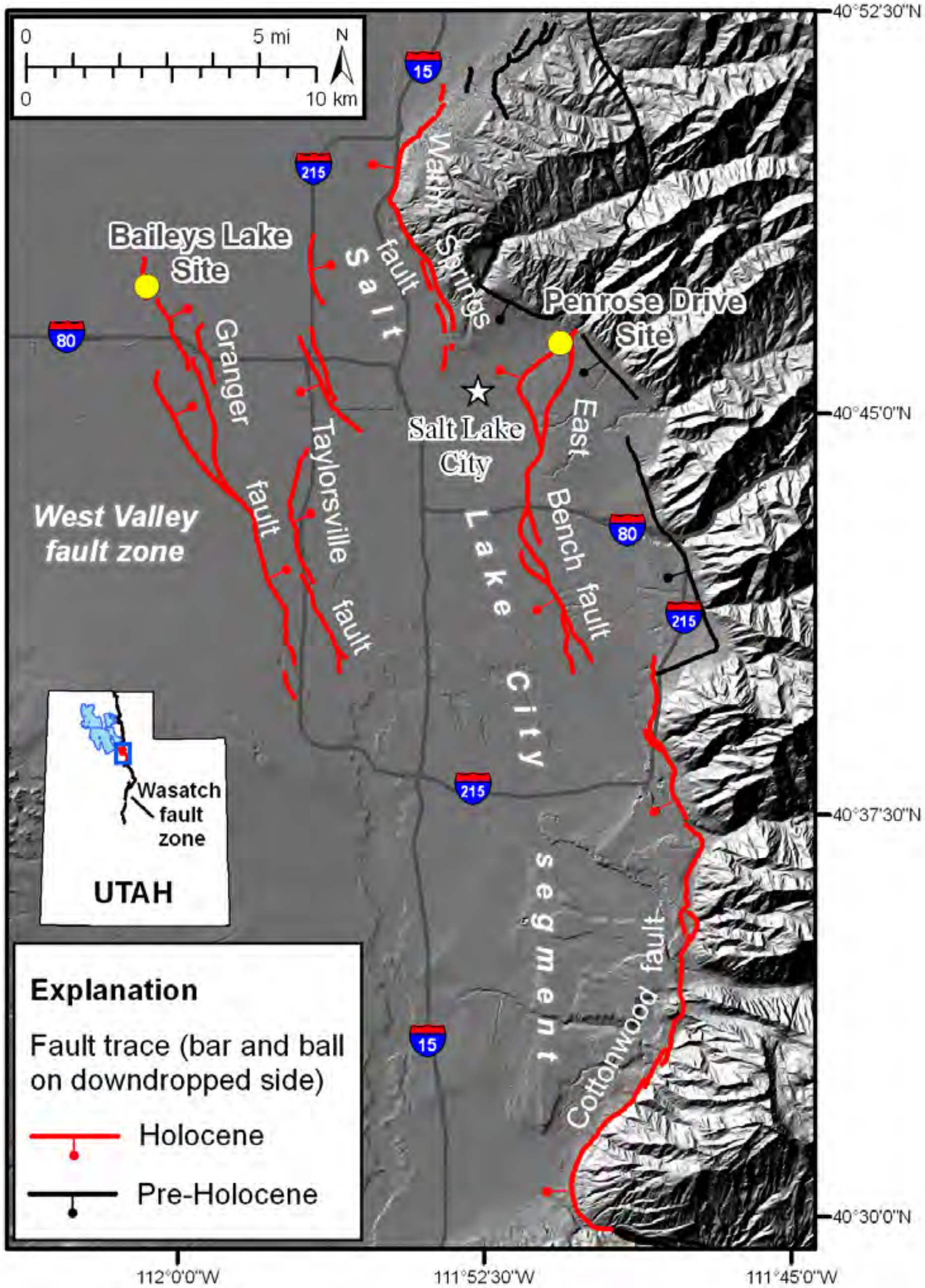
With Greg McDonald (UGS)
Susan Olig (URS)
Jack Oviatt (Kansas State University)
Tony Crone, Steve Personius, Shannon Mahan (USGS)

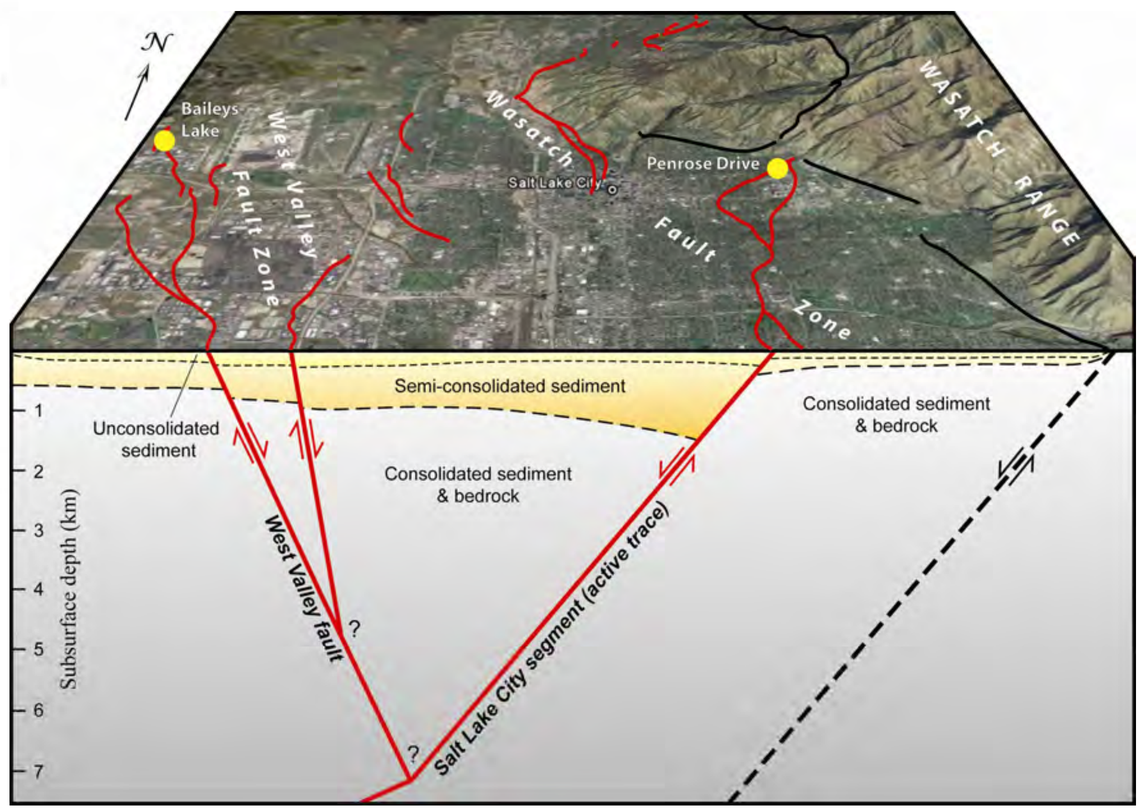
Utah Quaternary Fault Parameters Working Group
February 5, 2013

Research funded by the Utah Geological Survey and U.S. Geological Survey,
National Earthquake Hazards Reduction Program

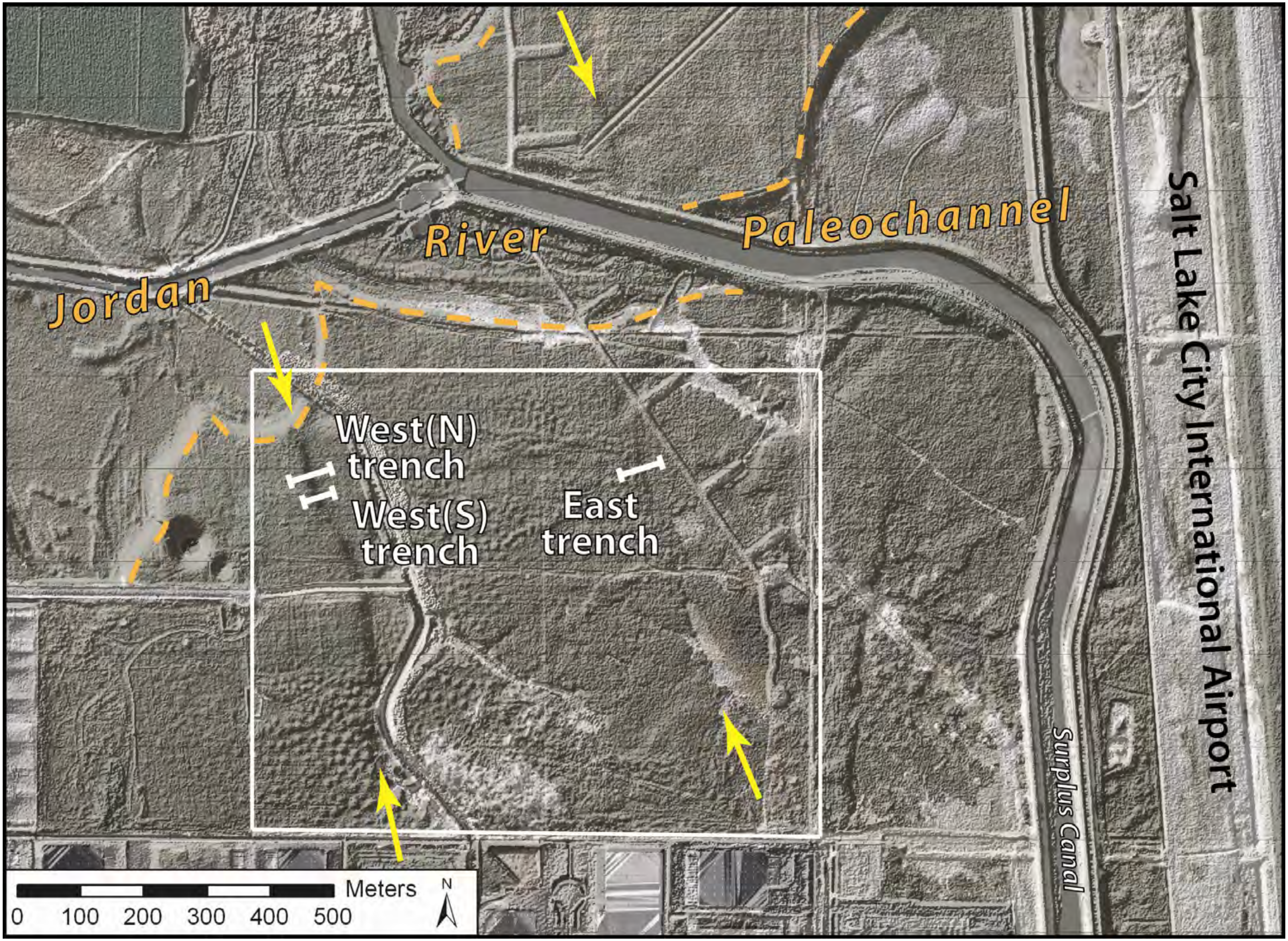


- WVFZ antithetic to SLCS
- Intrabasin graben
- Holocene active

Project goal: Compare timing of surface-faulting earthquakes on the WVFZ and SLCS



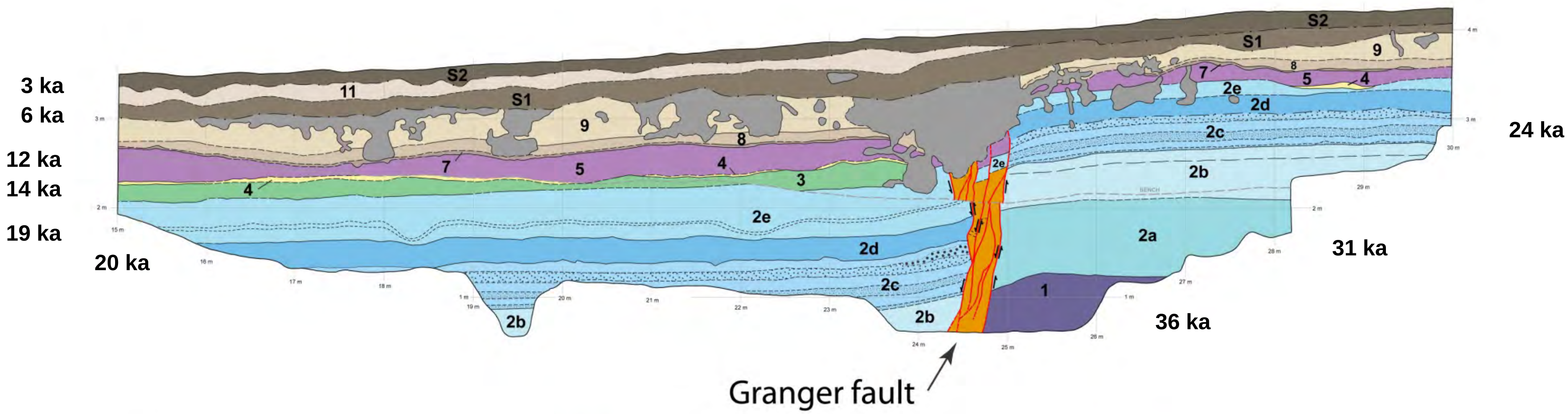
Baileys Lake Trench Site



LiDAR image from Utah Automated Geographic Reference Center (2006; 2 m, illumination from NW)

Baileys Lake West(S) Trench

South Wall

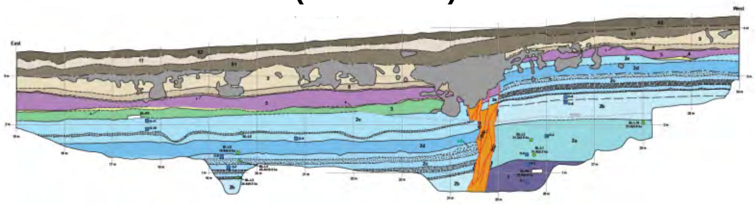


S2	Modern soil (A horizon)
S1	Buried soil (Bt horizon)
11	Loess (younger)
9	Loess (older)
8	Laminated marl (Gilbert phase)
7	Shoreline sand (Gilbert phase)
5	Laminated marl (Gilbert phase)
4	Shoreline tufa (Gilbert phase)
3	Bonneville laminated clay and silt (regressive)
2e	Bonneville clay (mid- to late transgressive)
2d	Turbidite marker bed
2c	Bonneville clay with turbidites (transgressive)
2b	Bonneville clay (transgressive)
2a	Bonneville sand, silt, clay (early transgressive)
1	Wetland/alluvial marsh (pre-Bonneville)
	Sheared sediment
	Burrowed sediment

Note: Units 6 and 10 are scarp-derived colluvial wedges associated with the two most recent surface-faulting earthquakes; not mapped on this log.

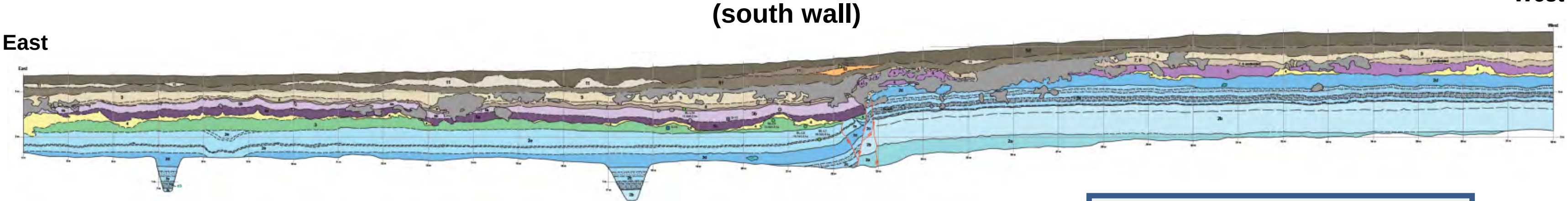
Geologic Evidence for ≥4* Surface-faulting Paleoearthquakes

Baileys Lake West(S) Trench
(south wall)



Baileys Lake West(N) Trench
(south wall)

East **West**



5 m

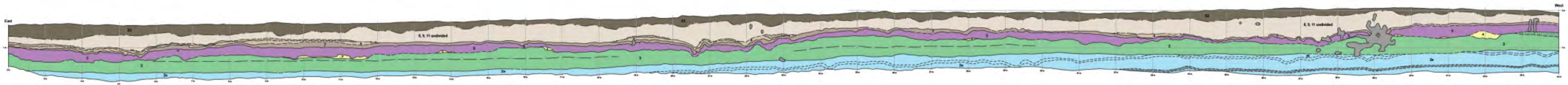
Scale
(no vertical exaggeration)

<u>Vertical Displacement</u>

Cumulative:
0.9 ± 0.2 m (post-13 ka)
1.9 ± 0.2 m (post-19 ka)

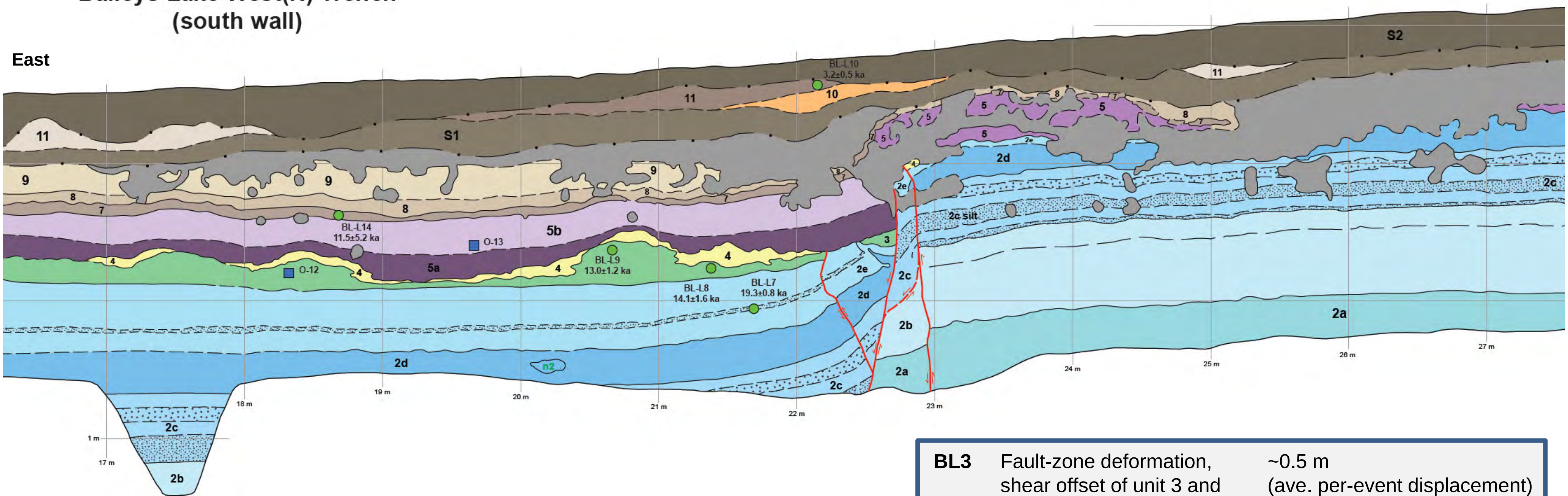
Per-event average:
0.5 ± 0.1 m

Baileys Lake East Trench
(south wall)



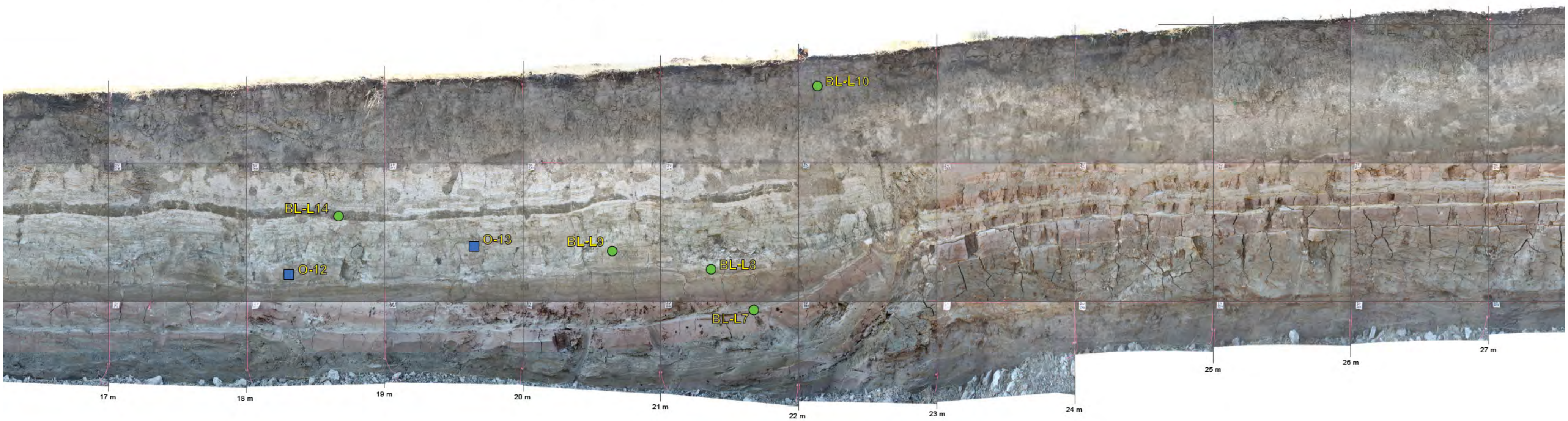
* Broad warping (0.5 ± 0.1 m vertical offset) in East trench indicates 1(?) undated (but post-Bonneville) earthquake.

Baileys Lake West(N) Trench
(south wall)

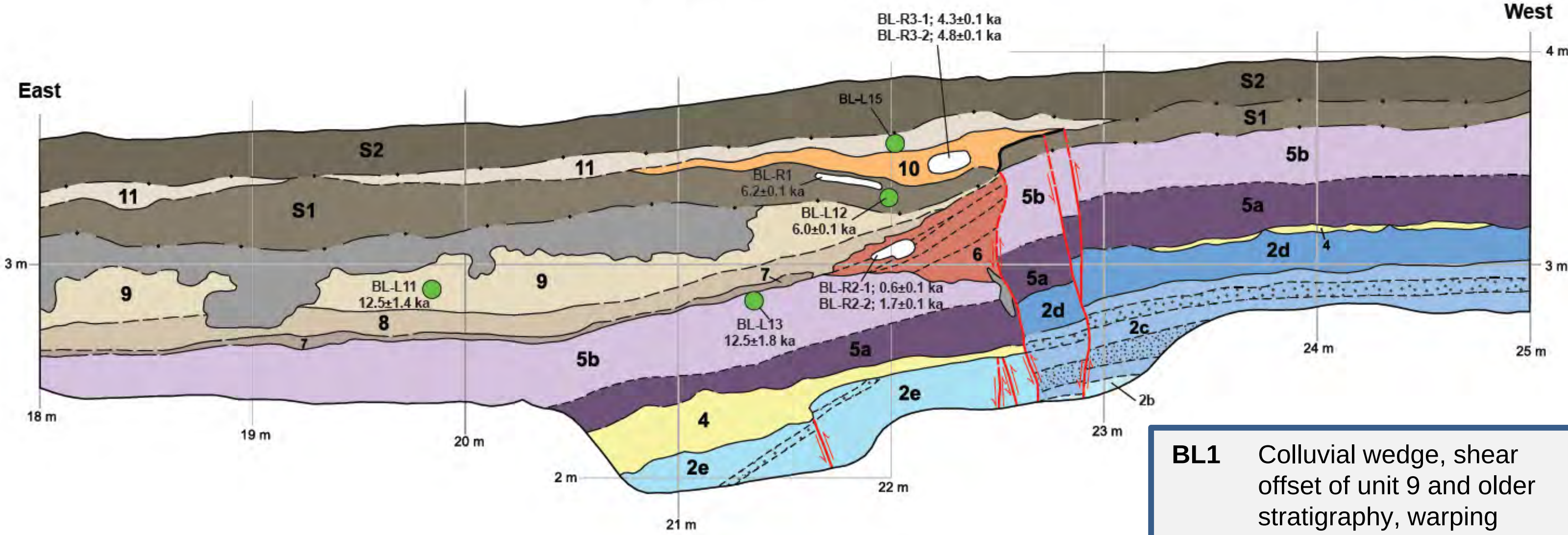


BL3	Fault-zone deformation, shear offset of unit 3 and older stratigraphy	~0.5 m (ave. per-event displacement)
BL4	Warping of pre-unit 3 stratigraphy, thinning of unit 2e	~0.5 m (ave. per-event displacement)

Photomosaic of Baileys Lake West(N) Trench
(south wall)

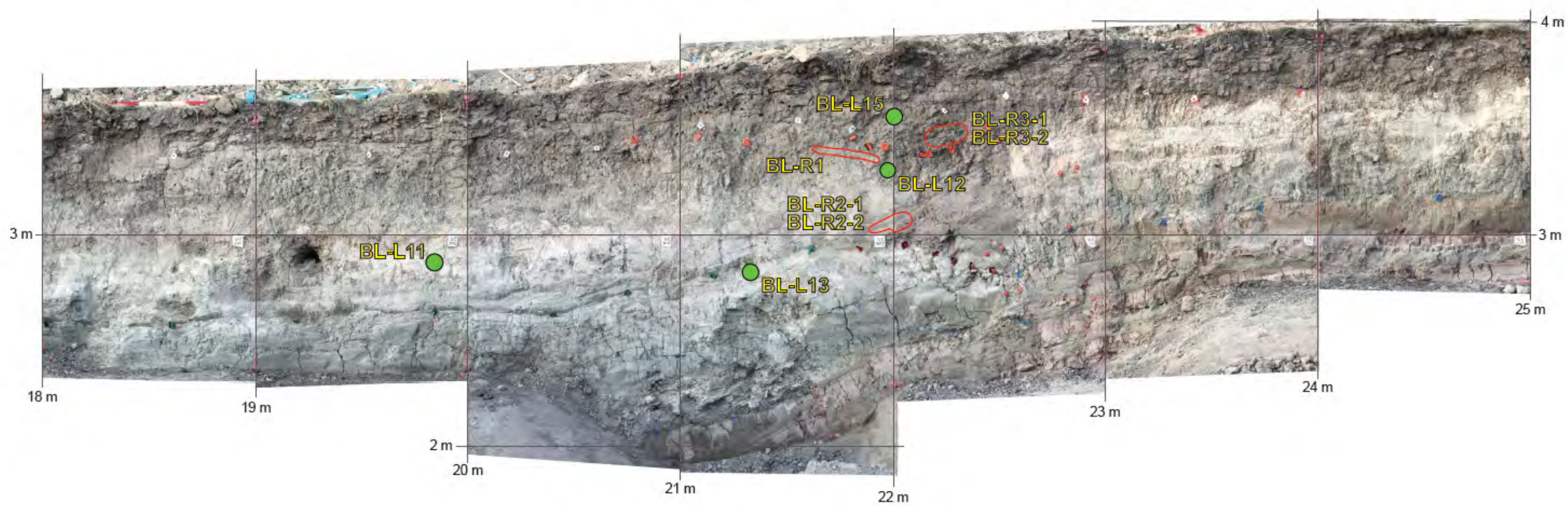


Baileys Lake West(N) Trench
(north wall, mirror image)



BL1	Colluvial wedge, shear offset of unit 9 and older stratigraphy, warping	0.17 (max. wedge thickness) + 0.3 (warping) 0.47 m
BL2	Colluvial wedge, shear offset of unit 5 and older stratigraphy	~0.5 m (max. wedge thickness)

Photomosaic of Baileys Lake West(N) Trench
(north wall, mirror image)

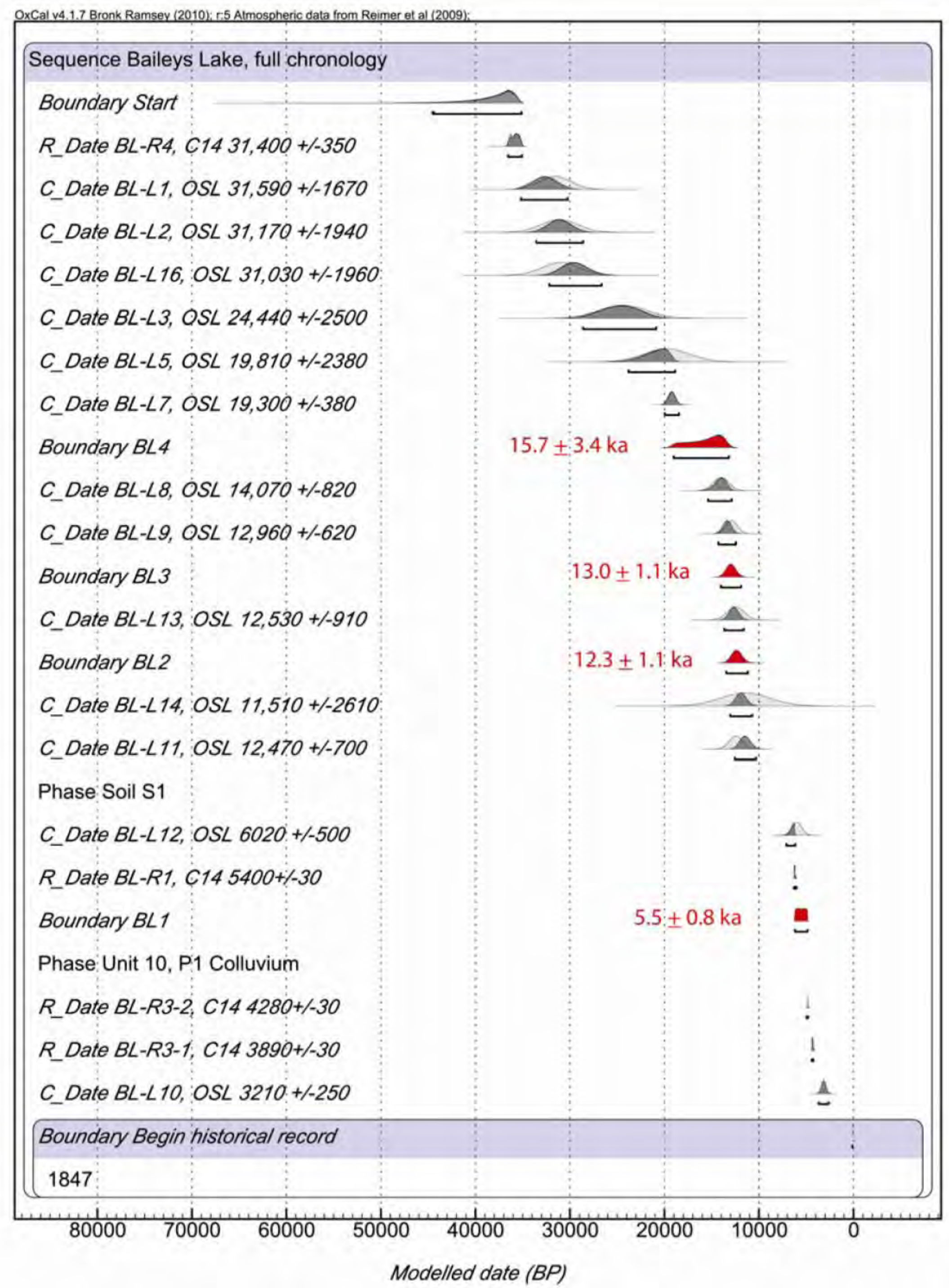


Baileys Lake Site – OxCal Model Results

13 OSL ages, 4 ^{14}C ages used in model

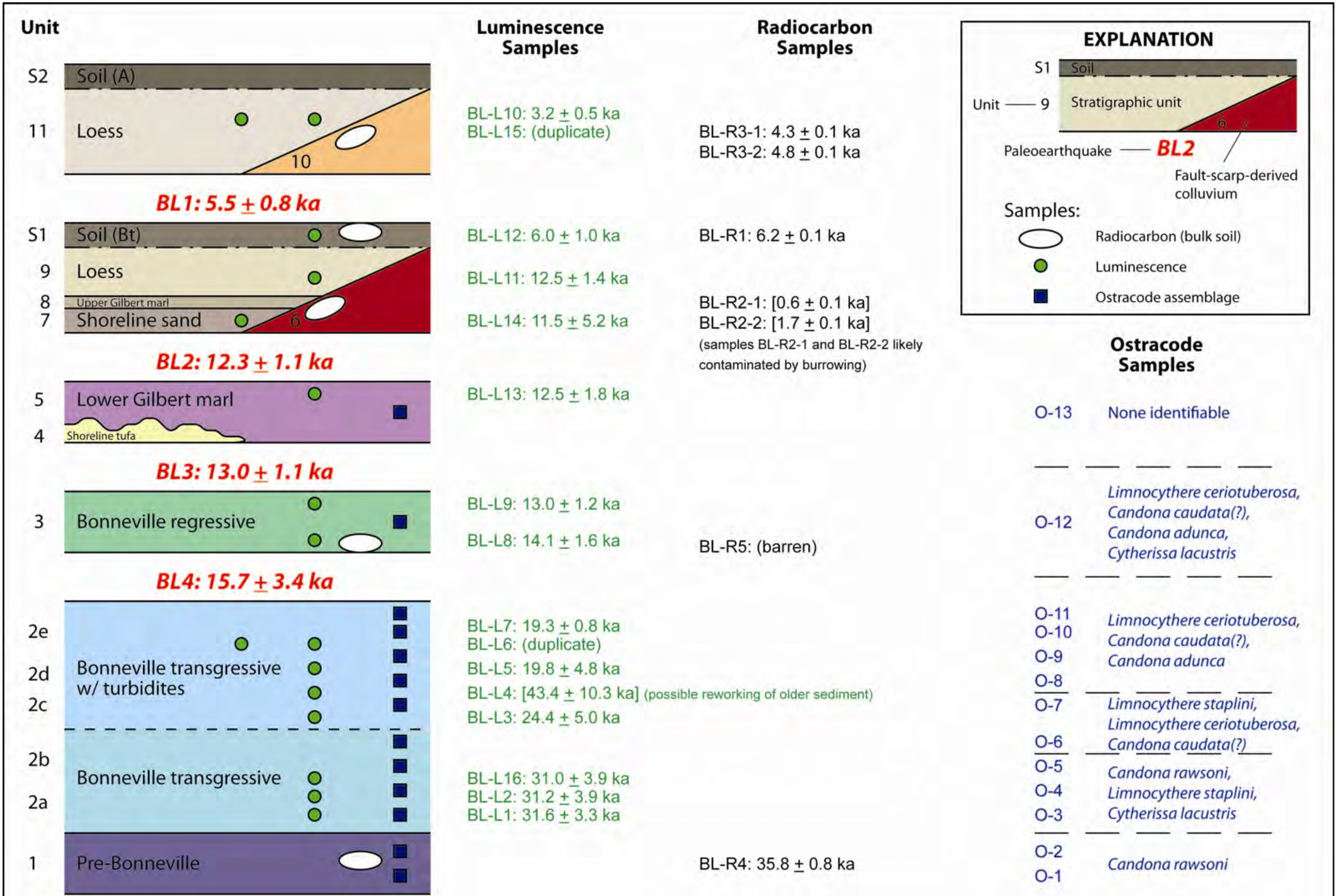
Model Output

Baileys Lake Full Chronology	Unmodelled (BP) mean	Unmodelled (BP) sigma	Modelled (BP) mean	Modelled (BP) sigma	Agreement
Boundary Start	38450	3010			
R_Date BL-R4, C14 31,400 ±350	35850	420	35780	410	99.7
C_Date BL-L1, OSL 31,590 ±1670	31530	1670	32660	1250	97.5
C_Date BL-L2, OSL 31,170 ±1940	31110	1940	31090	1240	119
C_Date BL-L16, OSL 31,030 ±1960	30970	1960	29470	1400	95.6
C_Date BL-L3, OSL 24,440 ±2500	24380	2500	24730	1990	109.3
C_Date BL-L5, OSL 19,810 ±2380	19750	2380	21050	1340	112.5
C_Date BL-L7, OSL 19,300 ±380	19240	380	19210	380	100.3
Boundary BL4			**15700**	**1690**	
C_Date BL-L8, OSL 14,070 ±820	14010	820	14080	630	112.5
C_Date BL-L9, OSL 12,960 ±620	12900	620	13360	460	95
Boundary BL3			**12960**	**530**	
C_Date BL-L13, OSL 12,530 ±910	12470	910	12640	520	121.2
Boundary BL2			**12340**	**570**	
C_Date BL-L14, OSL 11,510 ±2610	11450	2610	11890	580	136.2
C_Date BL-L11, OSL 12,470 ±700	12410	700	11450	560	62.6
Phase Soil S1					
C_Date BL-L12, OSL 6020 ±500	5960	500	6540	260	76.8
R_Date BL-R1, C14 5400±30	6220	50	6220	50	98
Boundary BL1			**5540**	**400**	
Phase Unit 10, P1 Colluvium					
R_Date BL-R3-2, C14 4280±30	4850	30	4850	30	98.9
R_Date BL-R3-1, C14 3890±30	4330	50	4330	50	99.9
C_Date BL-L10, OSL 3210 ±250	3150	250	3150	250	100
Boundary Begin historical record, 1847	100	0	100	0	100



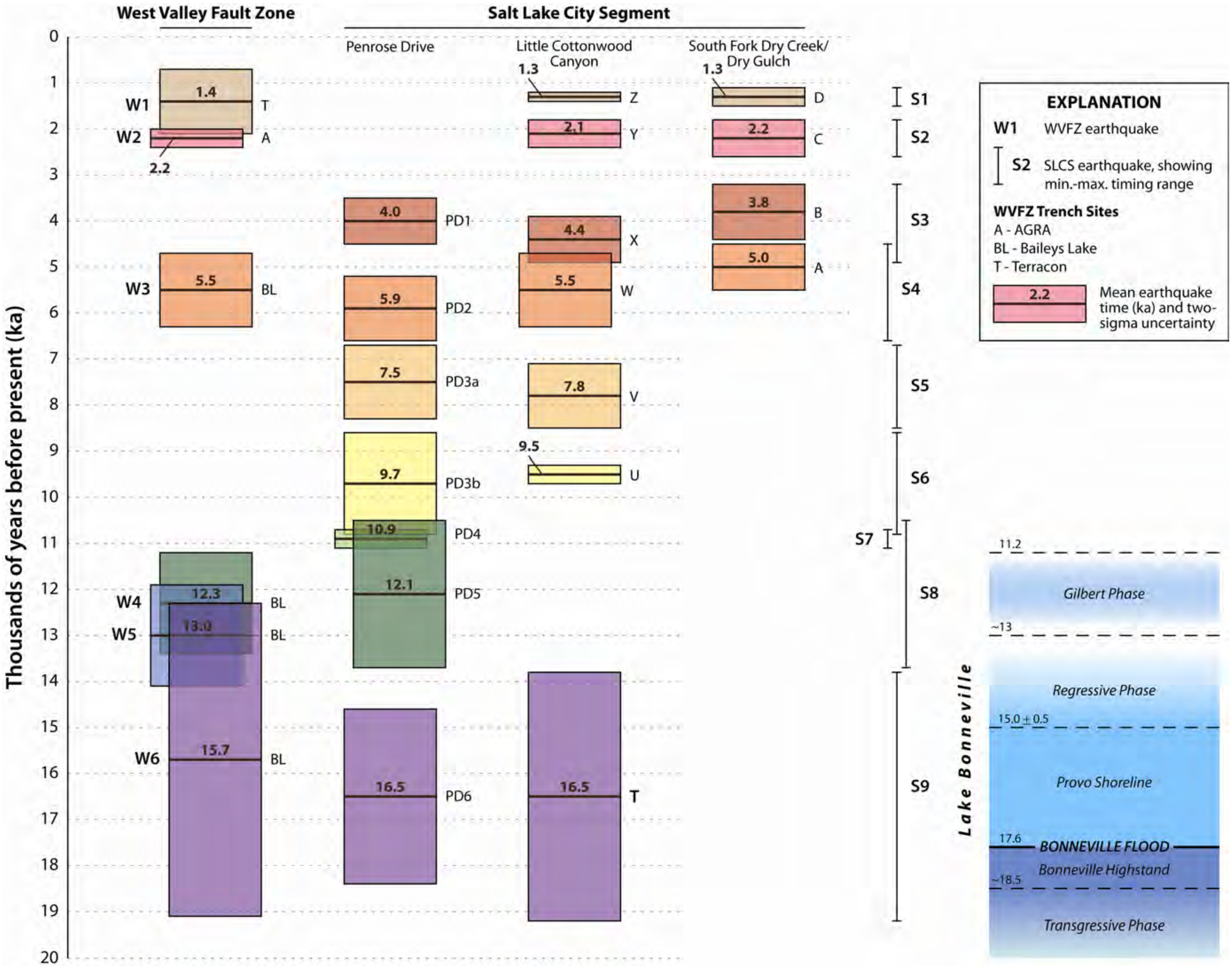
Red = mean earthquake time ± 2σ

Baileys Lake Site – Chronostratigraphic Summary



Modeled earthquake times (red) and all numerical ages are reported with two-sigma uncertainty.
Brackets indicate age out of stratigraphic order.

Comparison of WVFZ and SLCS Paleoearthquake Chronologies



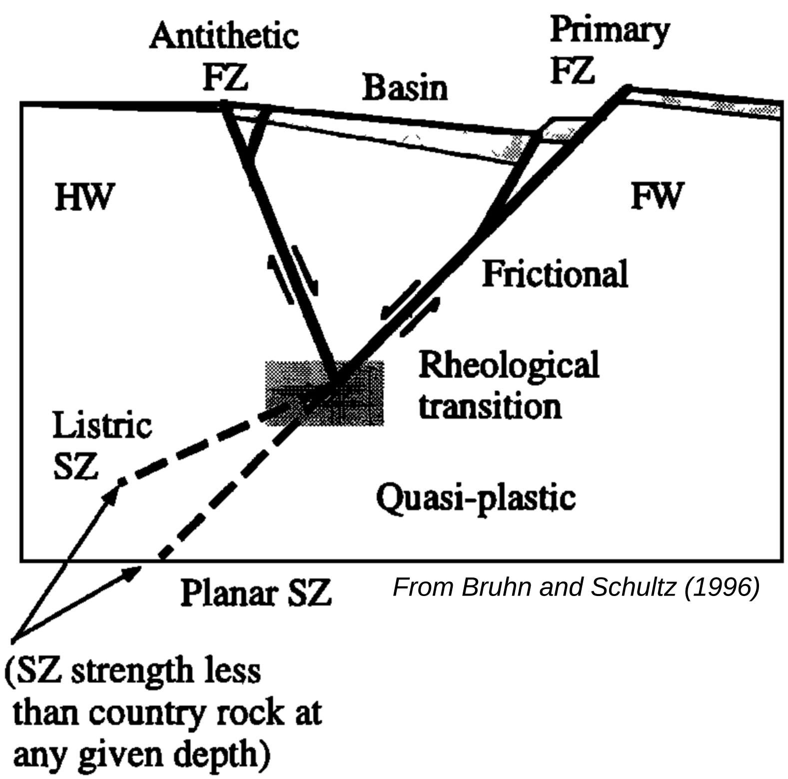
Comparison of WVFZ and SLCS Per-event Vertical Displacements

West Valley Fault Zone

0.5 0.1 m	Baileys Lake site
0.5 – 0.7 m	AGRA site (Solomon, 1998; UGS unpub. data)
1.2 – 1.5 m	(est. from geomorphic observations; Keaton and others, 1987)

Salt Lake City Segment

0.8 – 2.2 m (DuRoss and Hylland, 2012)



From Bruhn and Schultz (1996)

Two-dimensional boundary element modeling by Bruhn and Schultz (1996) showed that, on average, net slip and surface offset on antithetic faults was about 20–30% of the net slip on an underlying listric master fault.

(0.8–2.2 m) x (0.20–0.30) = 0.2–0.7 m

“This value is significantly less for an antithetic fault located above a planar fault zone, and the probability of surface rupturing is also less in this case because of greater difficulty in rupture propagation upward toward the surface from the point of initial failure.” (Bruhn and Schultz, 1996)

Baileys Lake Site – Paleoseismic Summary

Baileys Lake site shows evidence of at least 4 large earthquakes

Earthquake timing:
- **BL4** – Warping event during Provo phase of Bonneville lake cycle (**15.7 ± 3.4 ka**)
- **BL3** – Surface faulting during Bonneville lowstand just prior to the Gilbert transgression (**13.0 ± 1.1 ka**)
- **BL2** – Surface faulting during latter part of Gilbert lake cycle (**12.3 ± 1.1 ka**)
- **BL1** – Surface faulting during the mid-Holocene (**5.5 ± 0.8 ka**)
- Broad warping in East trench indicates 1(?) undated (but post-Bonneville) earthquake; may or may not correlate with BL1

Earthquake recurrence:
- 0.7–6.8 kyr (inter-event)
- 3.4 kyr (BL4–BL1 mean)

Vertical displacement:
- 0.9 ± 0.2 m (post-13 ka)
- 1.9 ± 0.2 m (post-19 ka)
- Average per-event vertical displacement 0.5 ± 0.1 m

Slip rate:
- 0.06–0.09 mm/yr (post-13 ka)
- 0.09–0.12 mm/yr (post-19 ka)

Baileys Lake Site – Paleoseismic Summary

Distributed nature of faulting (i.e., multiple strands) complicates slip rate and recurrence estimates, and comparisons with the SLCS

Modeled timing of five latest Pleistocene–Holocene earthquakes on the WVFZ is similar to timing of SLCS events; a sixth WVFZ earthquake (W5) occurred during a time when the SLCS record may be incomplete

- Large WVFZ earthquakes are likely dependent on SLCS fault movement (coseismic or triggered)

- Mechanical model of WVFZ–SLCS fault interaction suggests synchronous rupture is likely

- Likelihood of <u>independent</u> movement of the WVFZ appears to be very low

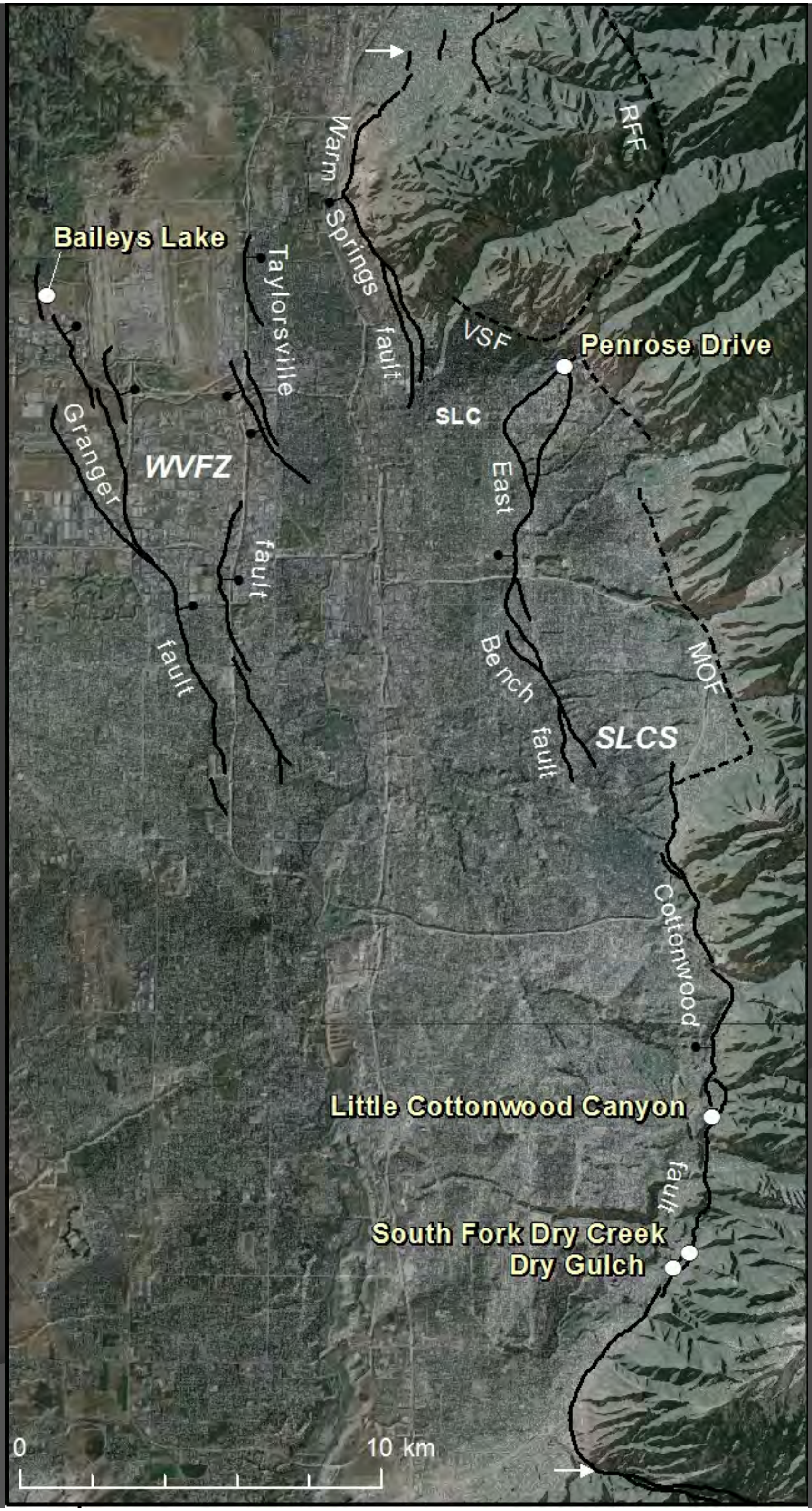
PALEOSEISMOLOGY OF THE SALT LAKE CITY SEGMENT AND ITS SEISMOGENIC RELATION TO THE WEST VALLEY FAULT ZONE

Chris DuRoss and Mike Hylland
Utah Geological Survey

Utah Quaternary Fault Parameters Working Group – February 2013

Salt Lake City Segment

- Outline:
  1. Review paleoseismic data for the SLCS, including final Penrose Drive results
  2. Integrate these data to determine the Holocene and latest Pleistocene earthquake chronology for the SLCS
  3. Compute mean recurrence times and vertical slip rates for the SLCS
  4. Compare SLCS earthquake-timing data with that for the West Valley fault zone (WVFZ) to assess their seismogenic relation



Previous Paleoseismic Data

Earthquake Timing per Site (ka)			
Little Cottonwood Canyon		**South Fork Dry Creek**	
Z	1.3 ± 0.04	D	1.3 ± 0.2
Y	2.1 ± 0.3	C	2.2 ± 0.4
X	4.4 ± 0.5	B	3.8 ± 0.6
W	5.5 ± 0.8	A	5.0 ± 0.5
V	7.8 ± 0.7		
U	9.5 ± 0.2		
No earthquakes between ~9.5 and 16.5 ka			
T	16.5 ± 2.7		

- Mean recurrence
  - Mid-Holocene: ~1.3 kyr
  - Holocene: ~1.6 kyr
  - Lt. Pleistocene (post-Bonn.): ~2.5 kyr
- Displacement
  - ~1.5–2.5 m per event
- Vertical slip rate
  - Bells Canyon glacial moraine ~0.7–1.7 mm/yr (<~16 ka)

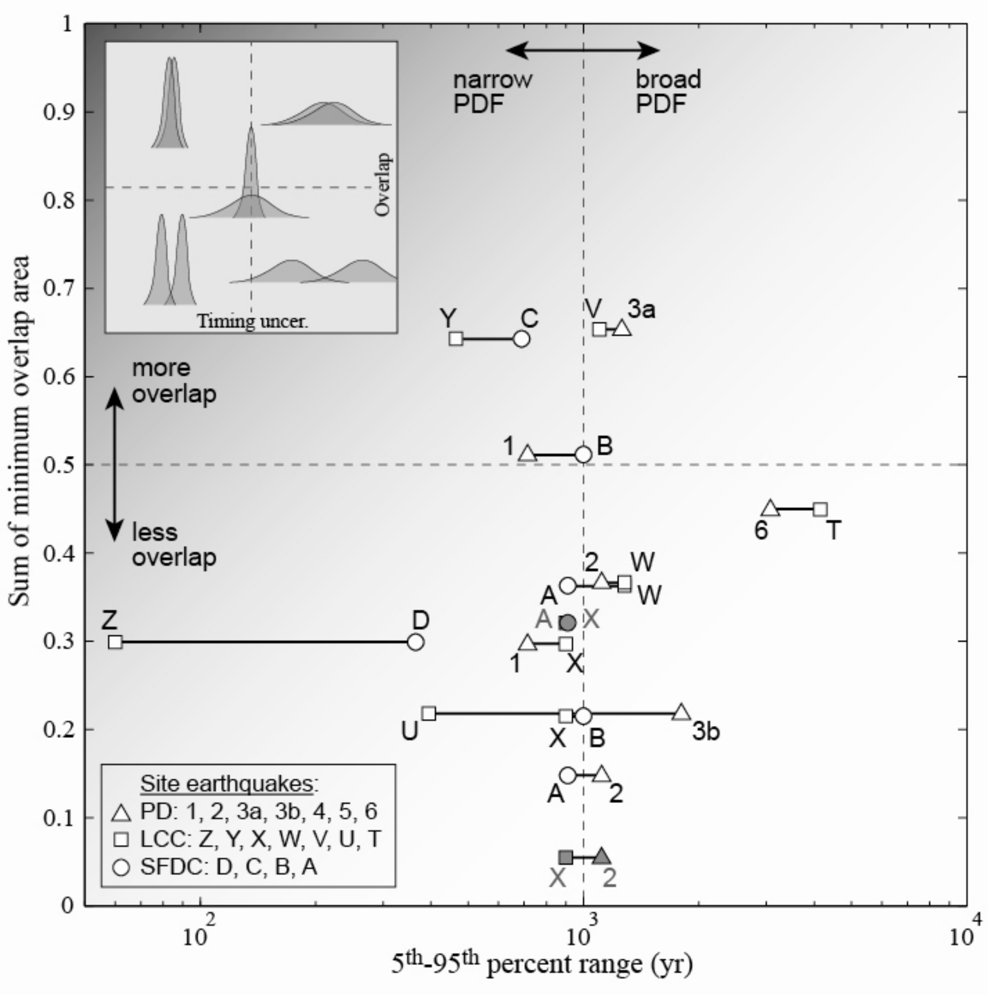
“Final” Penrose Drive Results

Earthquake Timing per Site (ka)					
Penrose Drive		Little Cottonwood Canyon		South Fork Dry Creek	
no evidence		Z	1.3 ± 0.04	D	1.3 ± 0.2
no evidence		Y	2.1 ± 0.3	C	2.2 ± 0.4
PD1	4.0 ± 0.5	X	4.4 ± 0.5	B	3.8 ± 0.6
PD2	5.9 ± 0.7	W	5.5 ± 0.8	A	5.0 ± 0.5
PD3a	7.5 ± 0.8	V	7.8 ± 0.7	*not exposed*	
PD3b	9.7 ± 1.1	U	9.5 ± 0.2	“	
PD4	10.9 ± 0.2	*no evidence*		“	
PD5	12.1 ± 1.6	*no evidence*		“	
PD6	16.5 ± 1.9	T	16.5 ± 2.7	“	

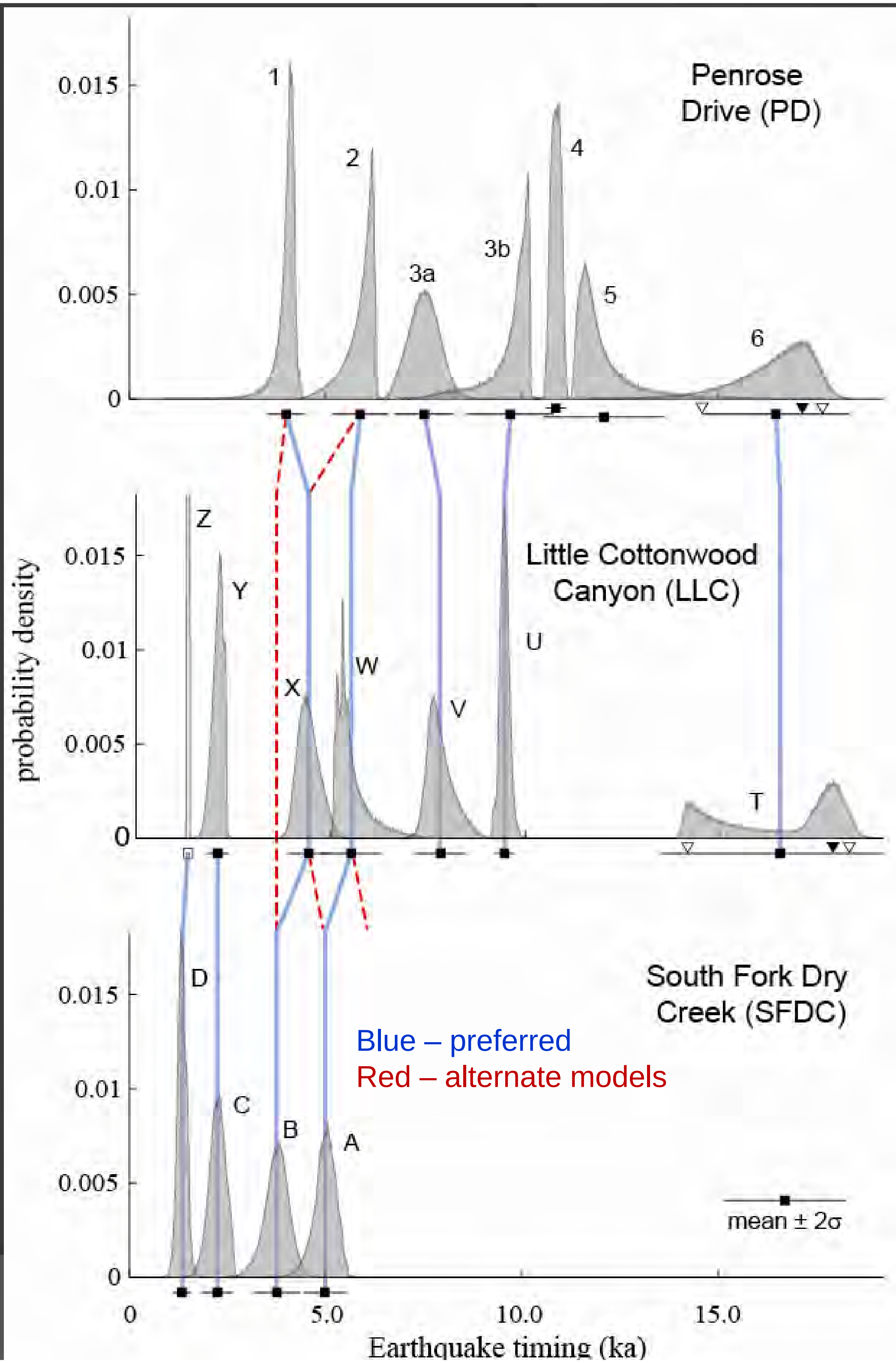
- Penrose mean recurrence
  - Holocene: ~1.7–1.9 kyr
  - Lt. Pleistocene (post-Provo): ~1.6 kyr
  - Lt. Pleistocene (post-Bonn.): ~2.1 kyr, but record likely incomplete prior to ~14 ka
- Displacement
  - ~1.0–1.4 m per event
- Vertical slip rate
  - Holocene/Lt. Pleistocene (post Provo): 0.5–0.9 mm/yr

Correlation of Site Earthquakes

- 9 surface-faulting earthquakes since Bonneville highstand

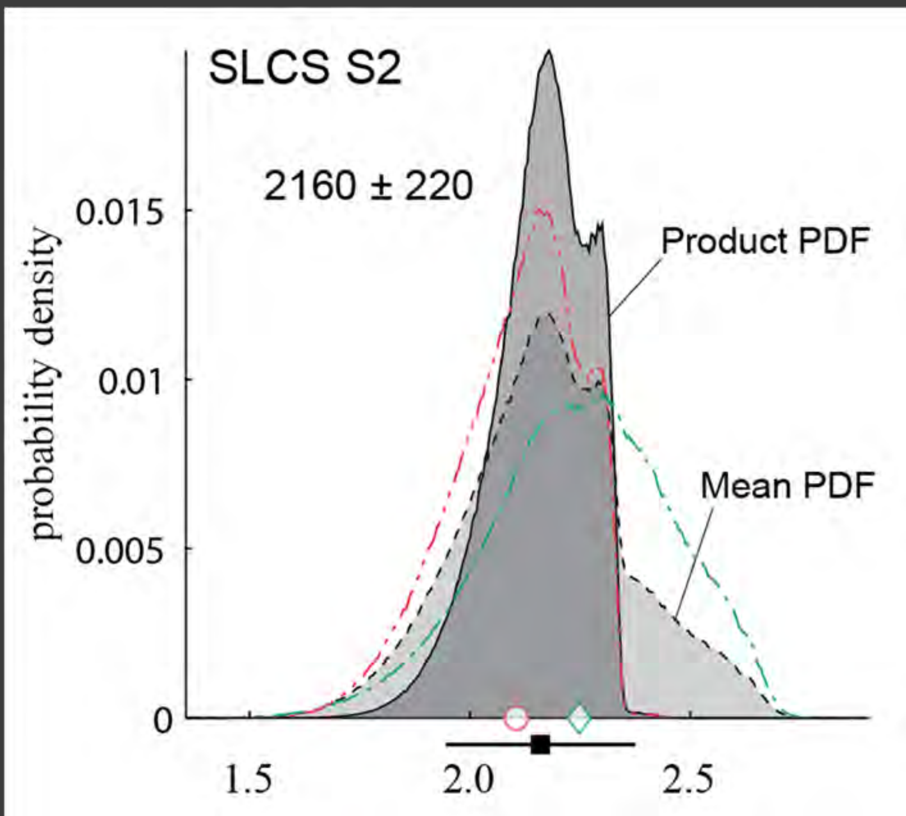


Quality of site-earthquake correlation

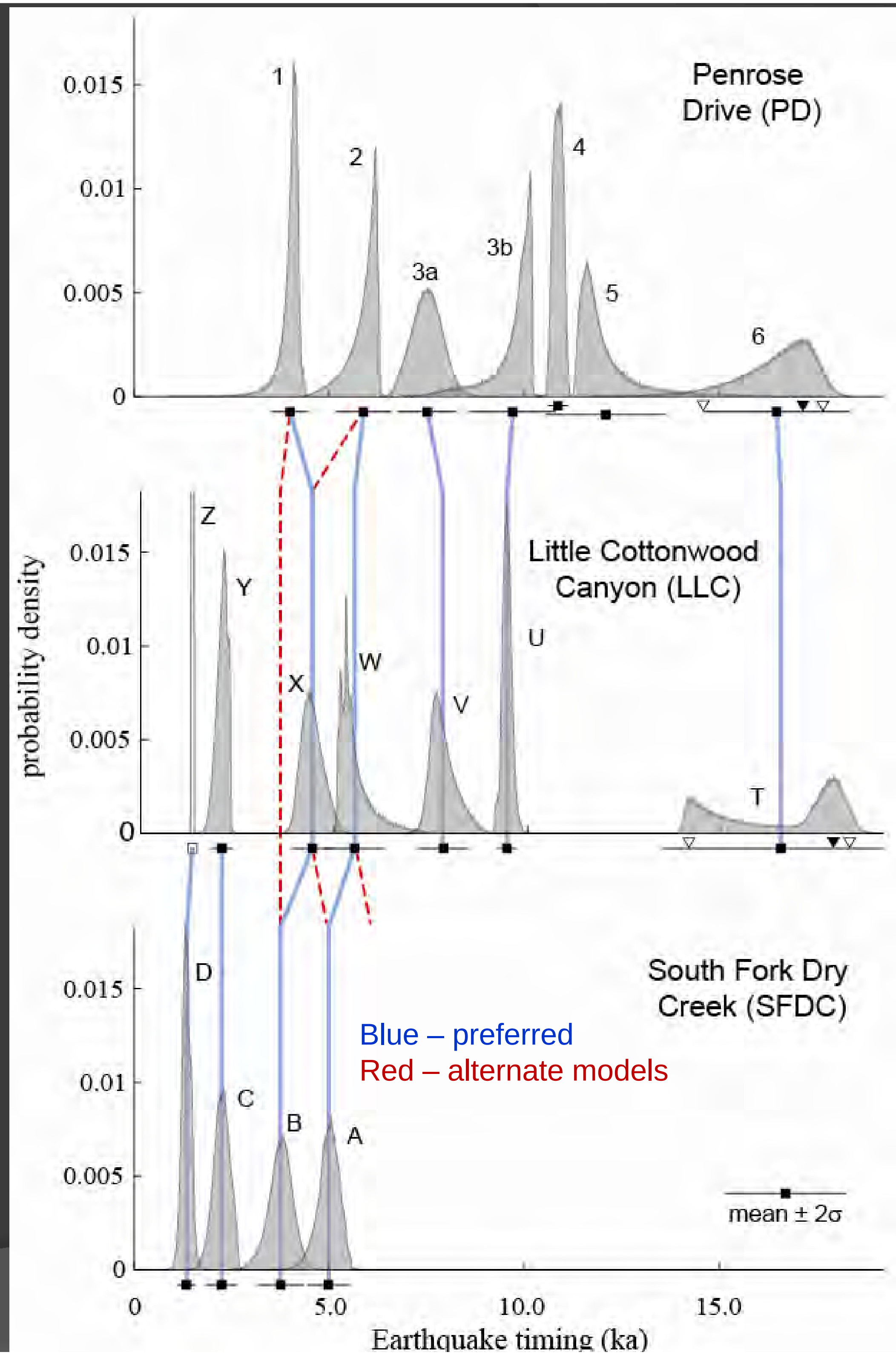


Correlation of Site Earthquakes

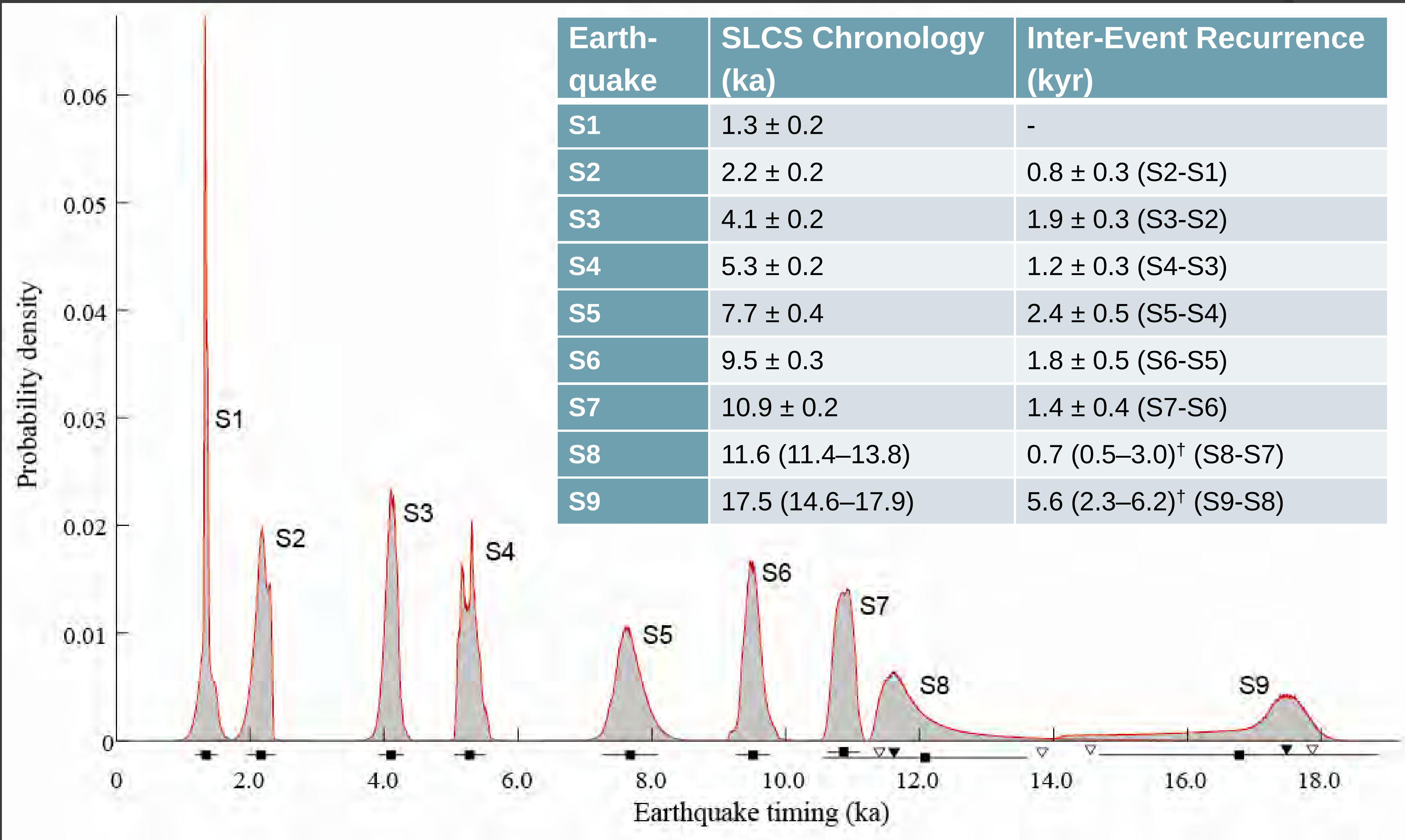
- 9 surface-faulting earthquakes since Bonneville highstand



Integration of site PDFs *(see DuRoss et al., 2011 and Personius et al., 2012)*



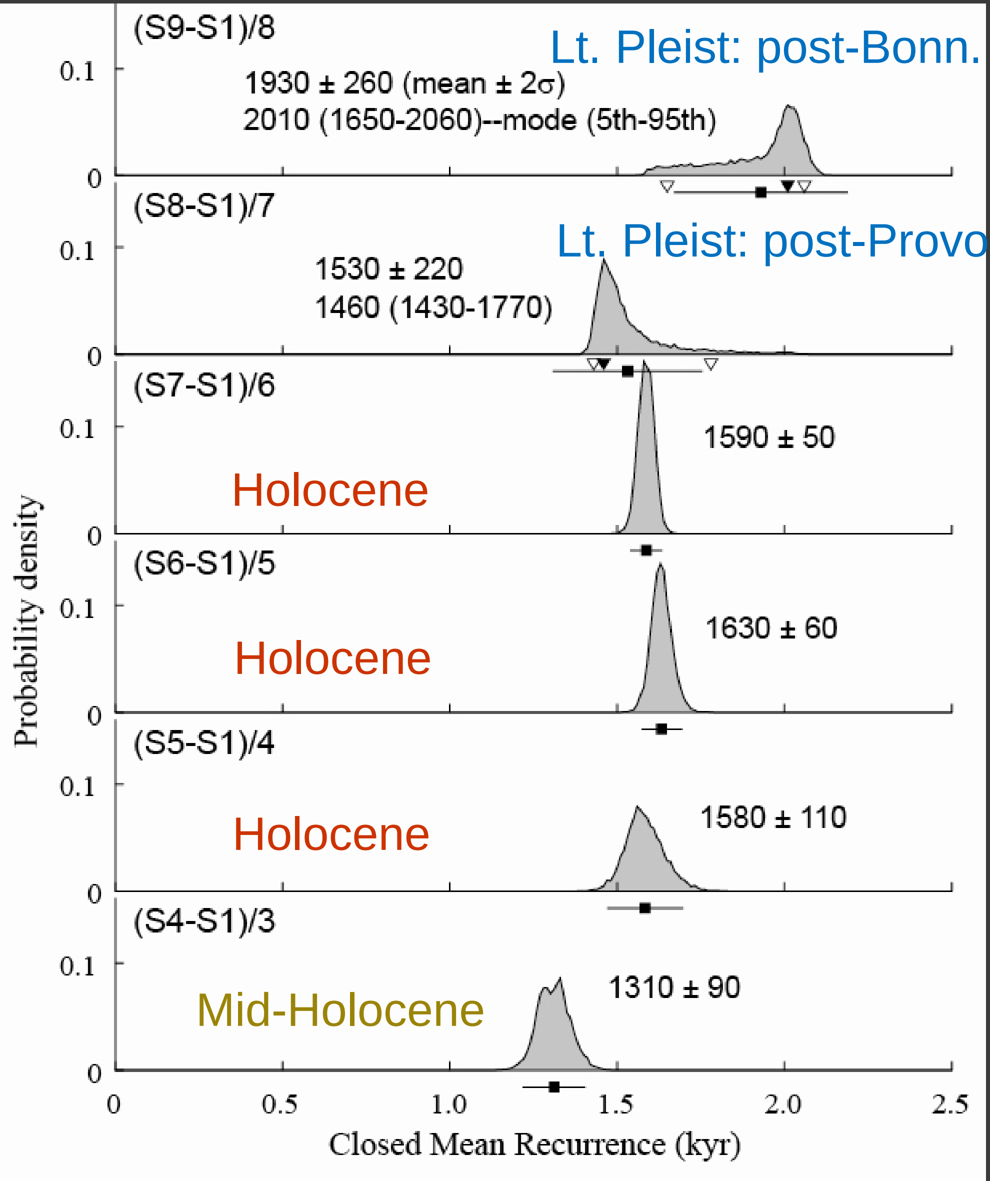
SLCS Earthquake Chronology



Earth-quake	SLCS Chronology (ka)	Inter-Event Recurrence (kyr)
S1	1.3 ± 0.2	-
S2	2.2 ± 0.2	0.8 ± 0.3 (S2-S1)
S3	4.1 ± 0.2	1.9 ± 0.3 (S3-S2)
S4	5.3 ± 0.2	1.2 ± 0.3 (S4-S3)
S5	7.7 ± 0.4	2.4 ± 0.5 (S5-S4)
S6	9.5 ± 0.3	1.8 ± 0.5 (S6-S5)
S7	10.9 ± 0.2	1.4 ± 0.4 (S7-S6)
S8	11.6 (11.4–13.8)	0.7 (0.5–3.0)† (S8-S7)
S9	17.5 (14.6–17.9)	5.6 (2.3–6.2)† (S9-S8)

SLCS earthquake-timing PDFs

Mean Recurrence and Slip Rate



Closed mean recurrence PDFs

Disp. interval	Time Interval	Mean SR (mm/yr)
S8-S1	S9-S1	0.7 (0.6-1.1)
S7-S1	S8-S1	1.0 (0.7-1.2)
S6-S1	S7-S1	0.9 (0.8-1.2)
S5-S1	S6-S1	0.9 (0.8-1.2)
S4-S1	S5-S1	1.0 (0.9-1.3)
S3-S1	S4-S1	1.4 (1.1-1.7)

Closed-interval vertical slip rate

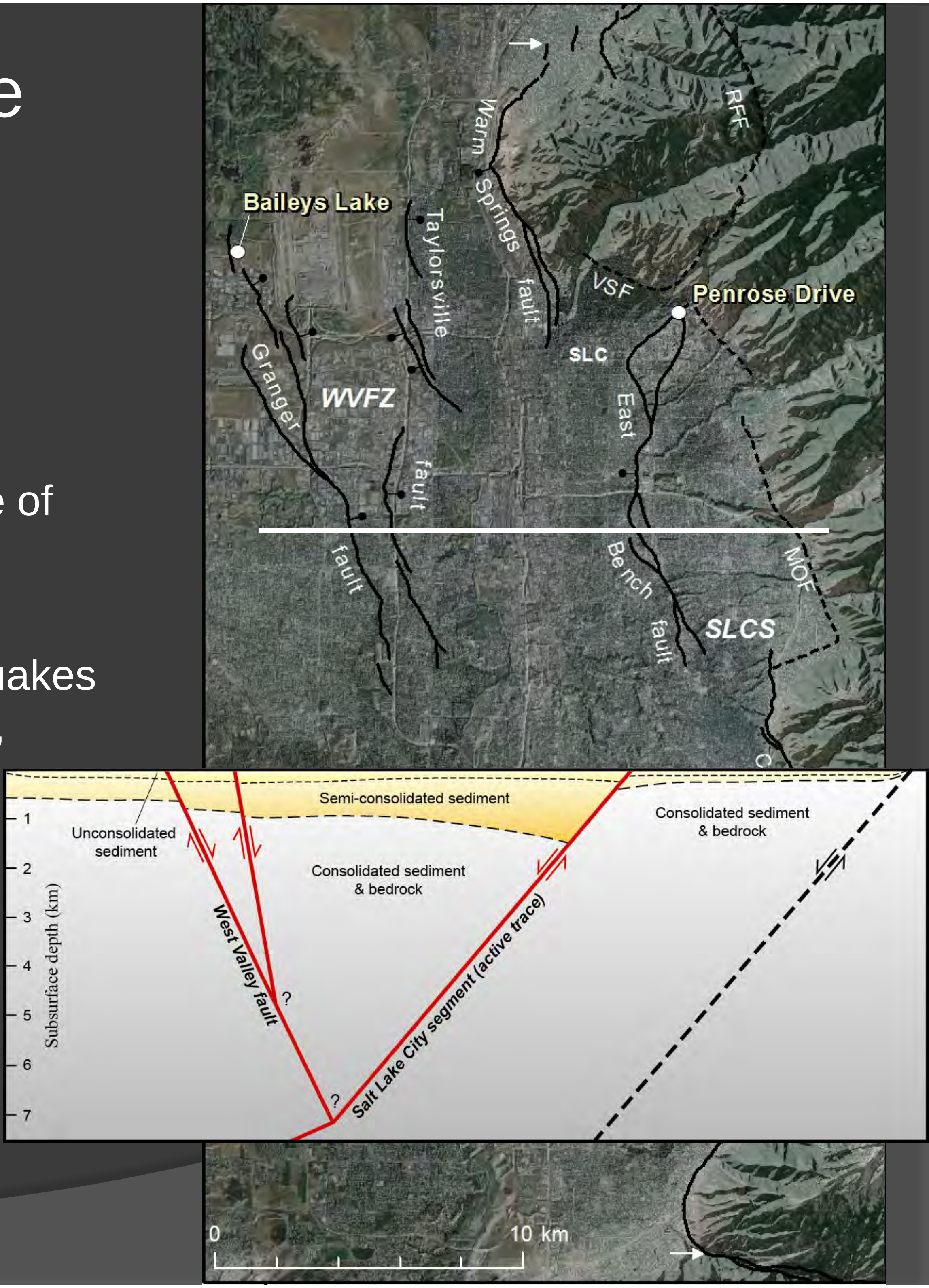
SLCS Conclusions

- SLCS is more active than previously thought:
  - Nine surface-faulting earthquakes (S1–S9) postdate the Bonneville highstand (previously 7)
  - S7 and S8 fill a previously interpreted ~8-kyr gap in the paleoseismic record
- The earthquake record is most complete since ~14 ka, yielding a post-Provo mean recurrence of ~1.5 kyr that corresponds well with Holocene (~1.6 kyr) and late Holocene (~1.3 kyr) estimates
- Important questions remain regarding rupture extent and the behavior of the Warm Springs, East Bench, and Cottonwood faults

SLCS & WVFZ Rupture

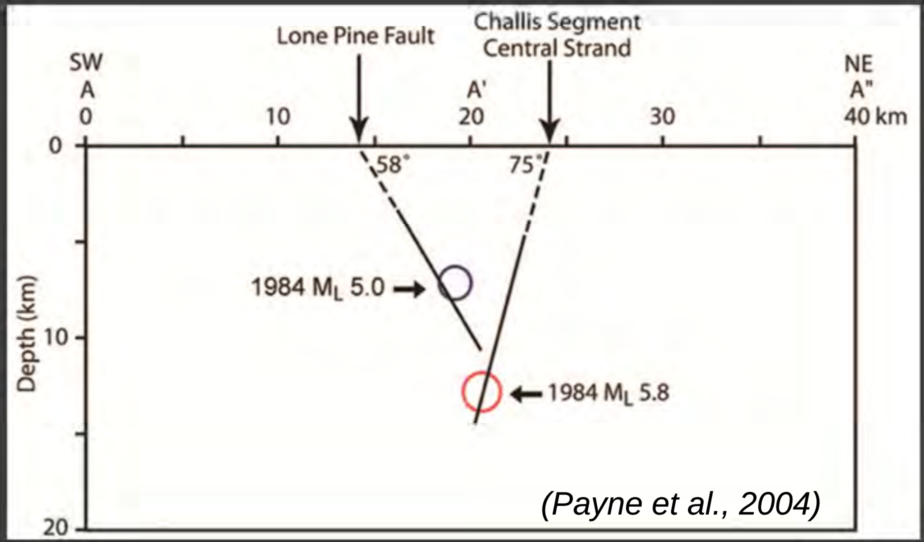
- WVFZ Rupture Options

  1. Independent.
     a) Completely independent. WVFZ is separate source of large earthquakes
     b) Triggered. WVFZ earthquakes related to SLCS ruptures, but occur after SLCS mainshock
  2. Synchronous (coseismic). WVFZ ruptures synchronously with SLCS

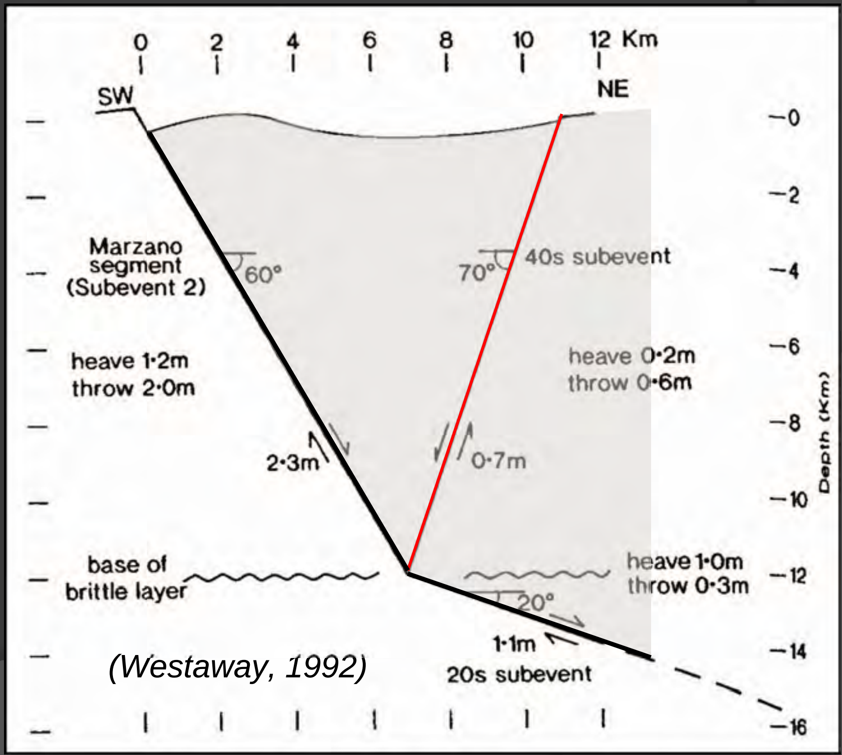


Antithetic-Fault Rupture Examples

- Independent
  - 1934 M 6.6 Hansel Valley earthquake?
- Independent – triggered
  - M 5.0 aftershock to 1984 M 5.8 Devil Canyon, Idaho earthquake
  - Triggered rupture of Lone Pine fault
- Coseismic
  - M 6.9 1980 Irpinia, Italy earthquake
  - Antithetic fault rupture (at 40s) contributed moment (~12%) to earthquake as a whole
  - Vert. slip: main–2.0 m, 0.6 m–antithetic



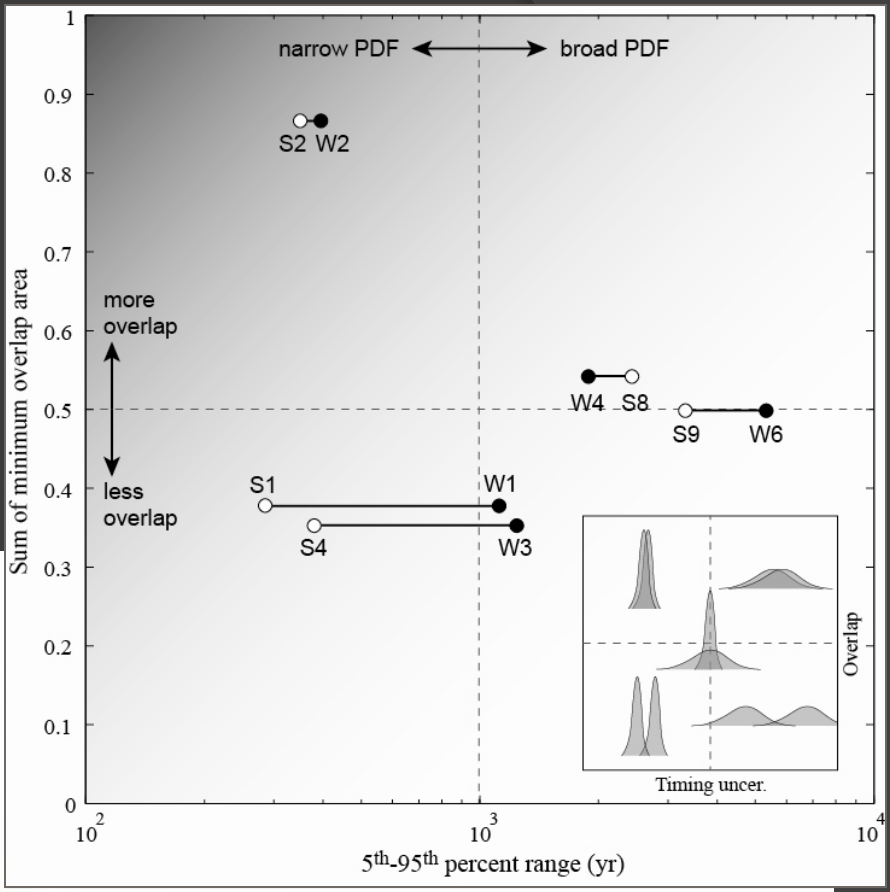
1984 Devil Canyon earthquake

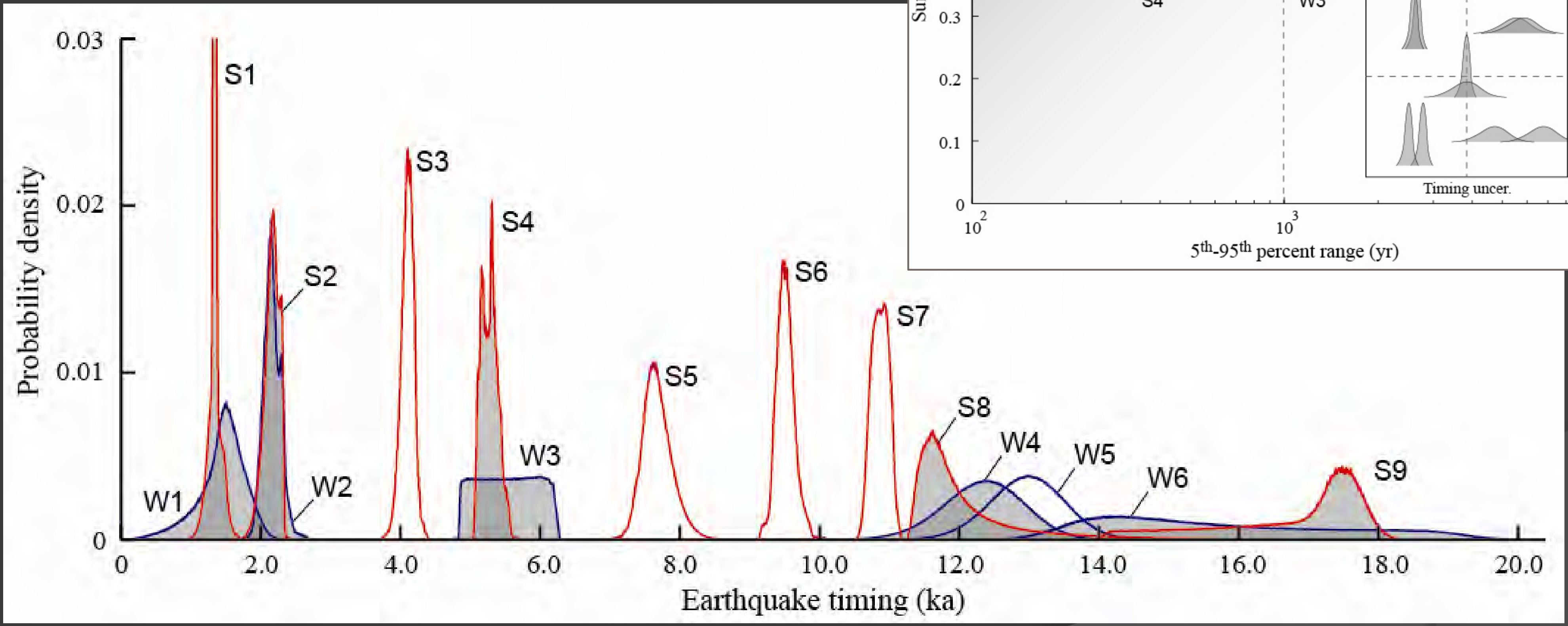


1980 Irpinia, Italy earthquake

SLCS & WVFZ Rupture

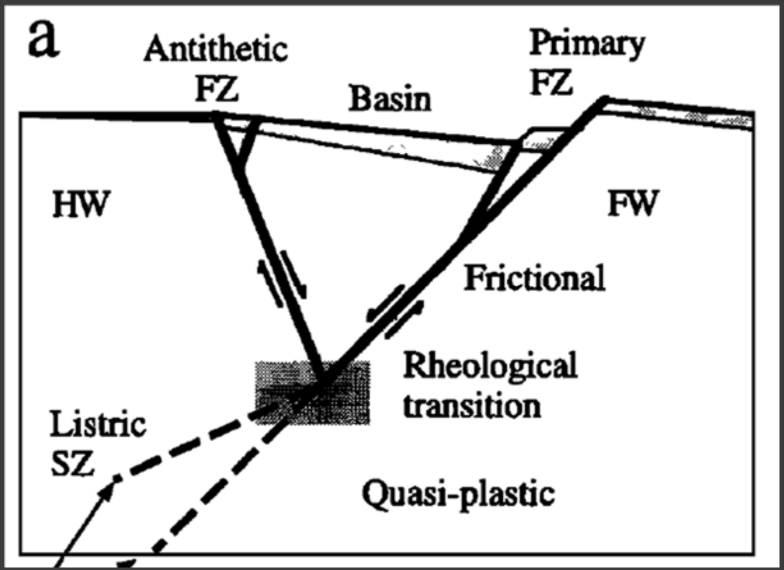
- Earthquake timing data suggest independent rupture is unlikely



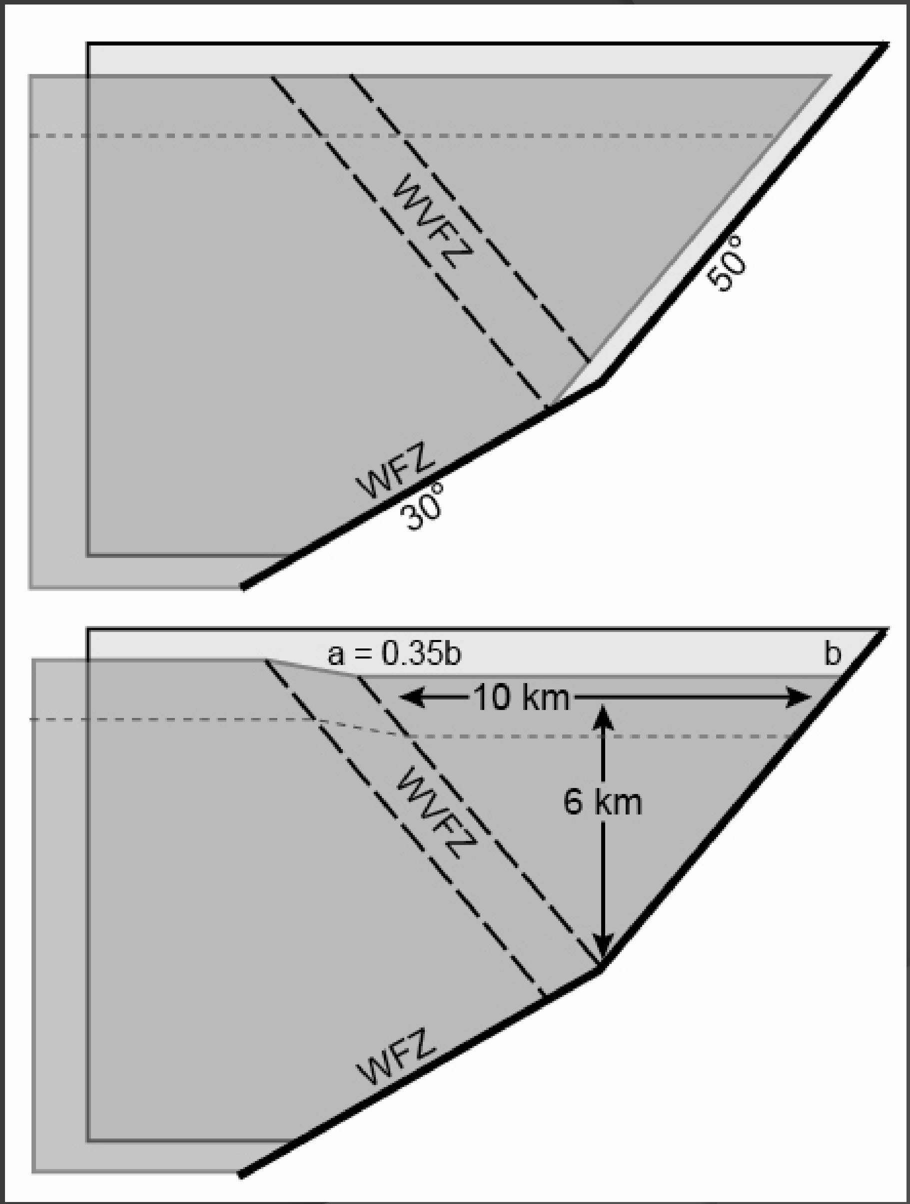


SLCS & WVFZ Rupture

- Mechanical models support coseismic rupture
  - Hanging wall deforms (instantaneously) to fill void created by change in master-fault dip



Bruhn & Schultz (1996)



Possible SLCS & WVFZ geometries; after Xiao and Suppe (1992)

Conclusions

- Improved paleoseismic data for the SLCS and WVFZ allow for the comparison of earthquake times on both the master and antithetic faults of a major graben-forming system

- We prefer a model of coseismic rupture on the SLCS and WVFZ based on:
  1. Historical analogs. Based on the fault geometries and displacements, coseismic rupture in the Irpinia earthquake is good analog for SLCS-WVFZ rupture
  2. Paleoseismic data. Holocene earthquakes on the SLCS and WVFZ have similar earthquake times and uncertainties—supporting coseismic or triggered behavior
  3. Mechanical models. Significant (surface-faulting) deformation of the SLCS hanging wall (WVFZ rupture) likely occurs instantaneously with earthquake rupture—supporting coseismic behavior

- However…
  - Triggered slip is still possible. The Devil Canyon, Idaho earthquake may be a good analog for non surface-rupturing earthquakes restricted to hanging wall

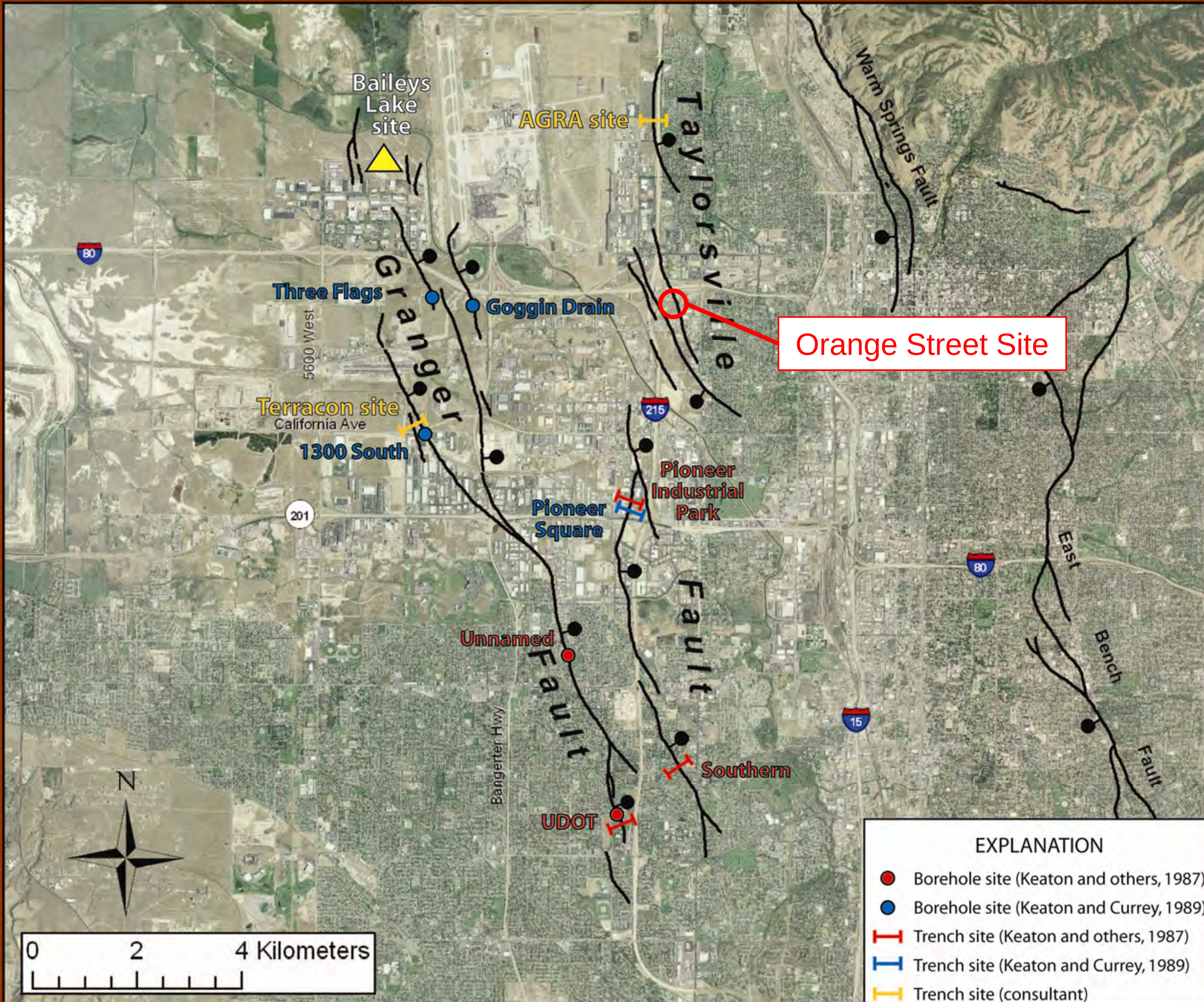
Summary of Recent Consultant's Trench, Orange Street Site, Taylorsville Fault, West Valley Fault Zone

Mike Hylland, Chris DuRoss, and Ben Erickson
Utah Geological Survey

Utah Quaternary Fault Parameters Working Group
February 5, 2013

UTAH DNR GEOLOGICAL SURVEY

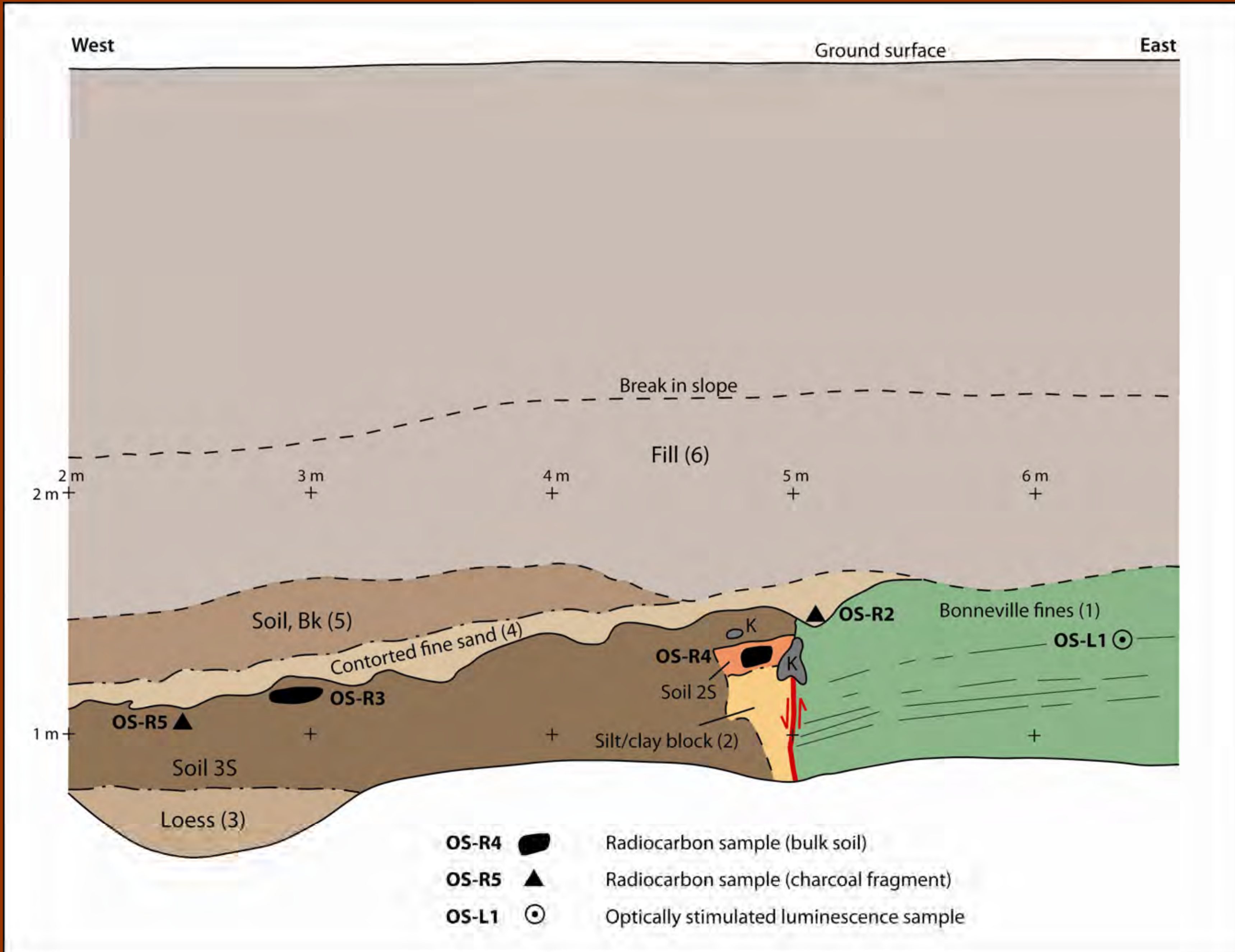
UTAH GEOLOGICAL SURVEY



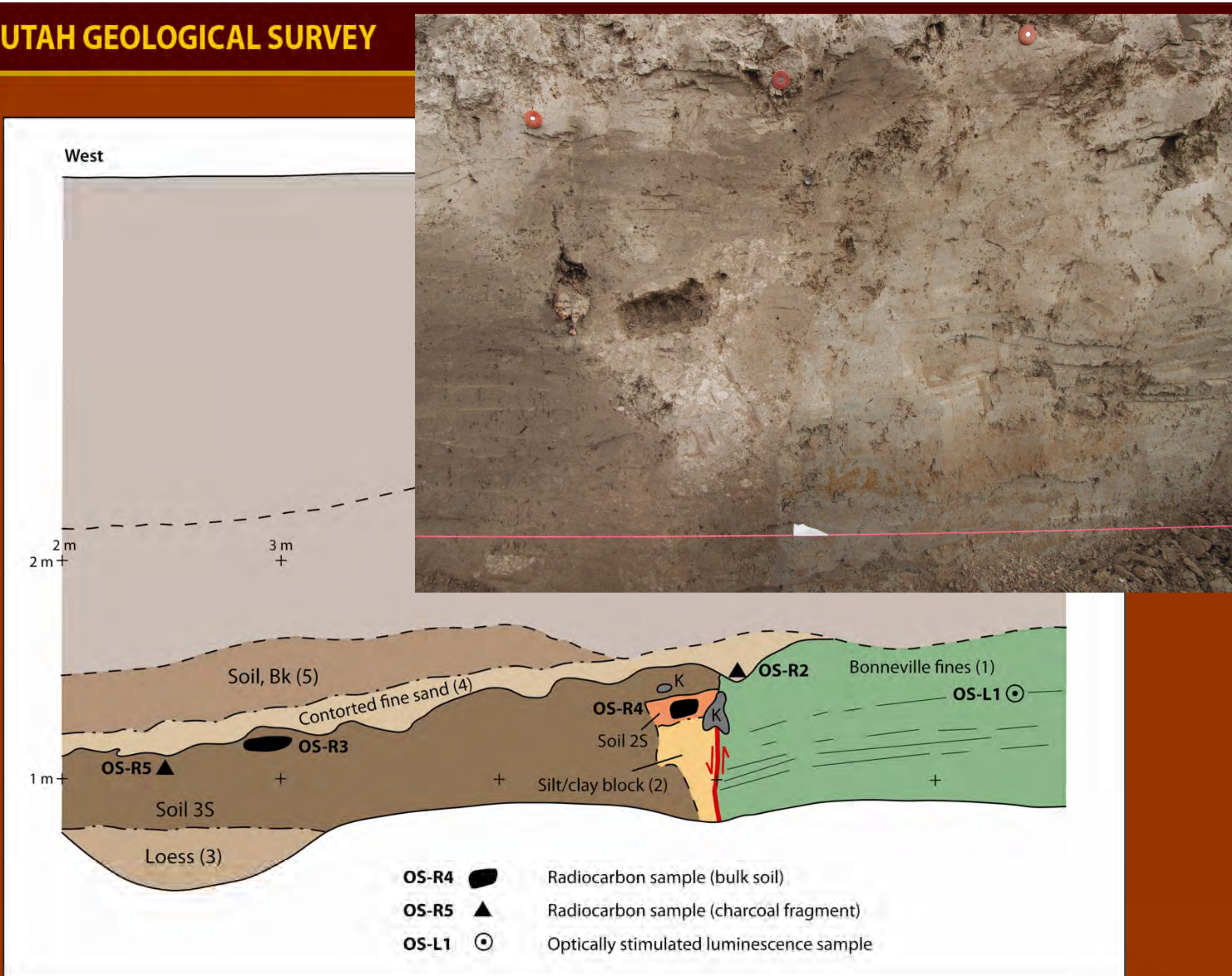
View looking west

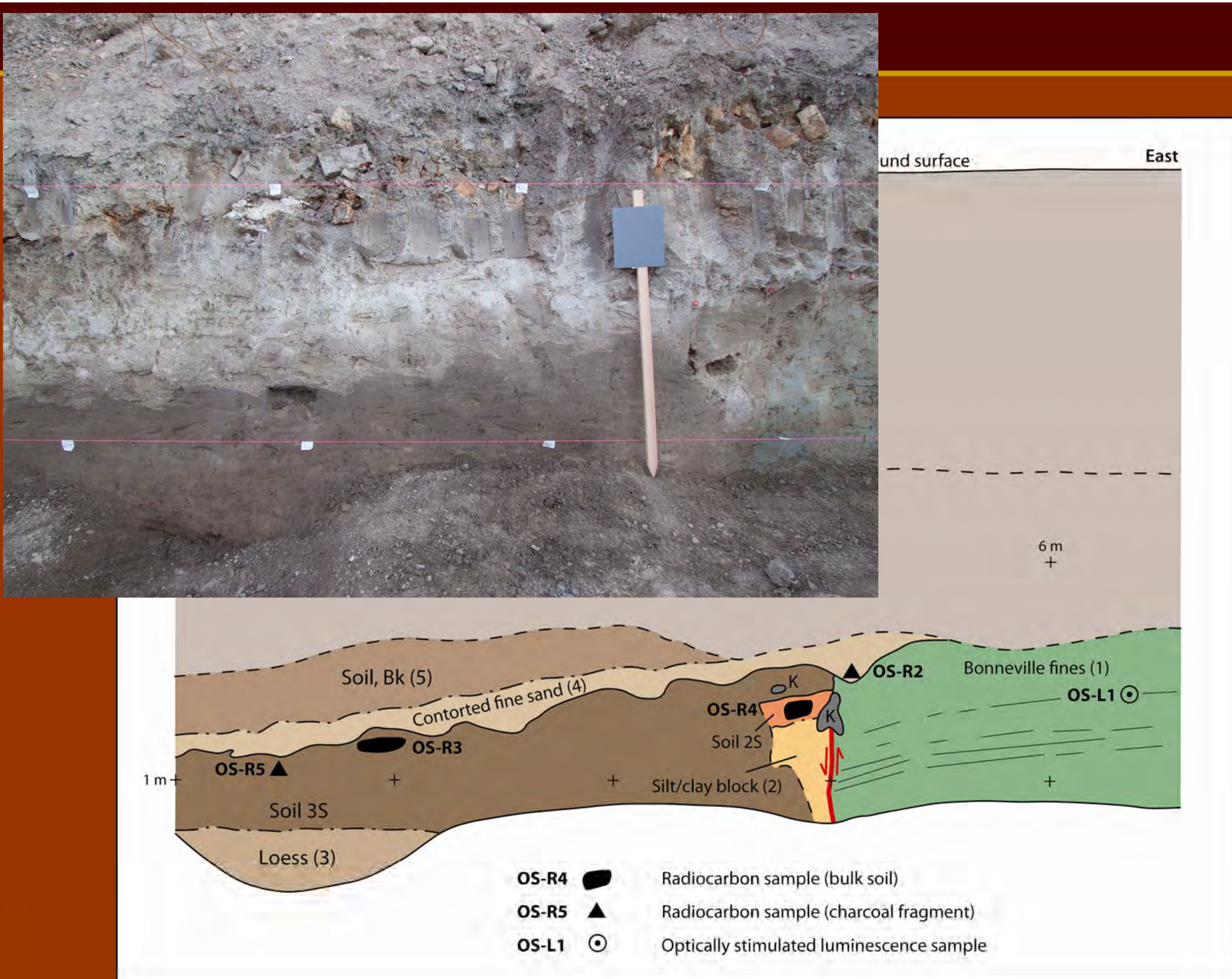
View looking east

View looking north



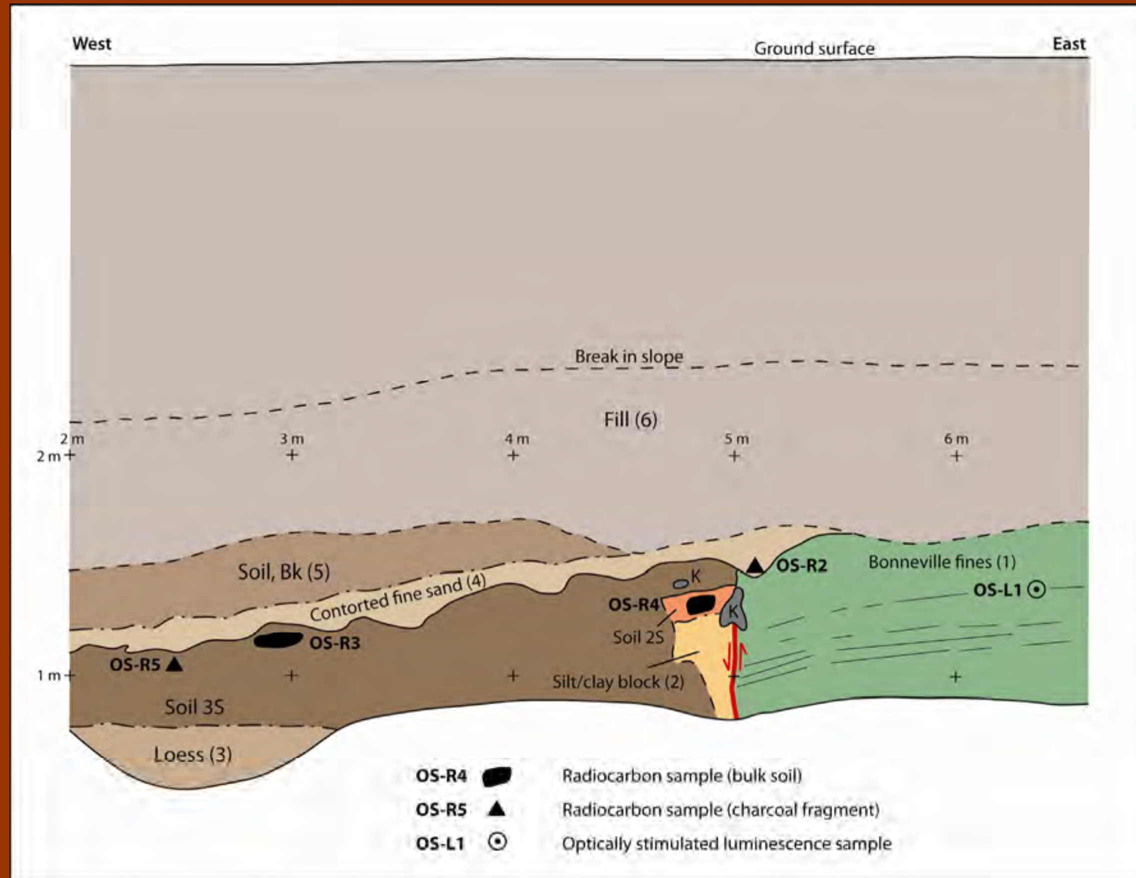
West
Ground surface
East
Break in slope
Fill (6)
2 m
3 m
4 m
5 m
6 m
2 m
1 m
Soil, Bk (5)
Contorted fine sand (4)
K
OS-R2
Bonneville fines (1)
OS-L1
OS-R4
K
Soil 2S
OS-R3
OS-R5
Silt/clay block (2)
Soil 3S
Loess (3)
OS-R4 Radiocarbon sample (bulk soil)
OS-R5 Radiocarbon sample (charcoal fragment)
OS-L1 Optically stimulated luminescence sample


West
2 m
3 m
2 m
1 m
Soil, Bk (5)
Contorted fine sand (4)
OS-R2
Bonneville fines (1)
OS-L1
K
OS-R4
K
Soil 2S
OS-R3
OS-R5
Silt/clay block (2)
Soil 3S
Loess (3)
OS-R4 Radiocarbon sample (bulk soil)
OS-R5 Radiocarbon sample (charcoal fragment)
OS-L1 Optically stimulated luminescence sample



und surface
East
6 m
1 m
Soil, Bk (5)
Contorted fine sand (4)
Bonneville fines (1)
OS-R2
OS-L1
K
OS-R4
Soil 2S
OS-R3
OS-R5
Silt/clay block (2)
Soil 3S
Loess (3)
OS-R4 Radiocarbon sample (bulk soil)
OS-R5 Radiocarbon sample (charcoal fragment)
OS-L1 Optically stimulated luminescence sample

- Regularly spaced “troughs” along base of contorted sand with organics
- Spacing ~40 cm
- Possibly related to liquefaction (i.e., ground oscillation)



Evidence for two events at this site:

1) Earlier surface faulting (E2), displacement of block in fault zone

2) Later liquefaction and warping (E1)

Potential timing constraints on earthquakes:

- OS-R4 – max. limit on E2
- OS-R3 – min. limit on E2, max. limit on E1
- OS-R5 – min. limit on E2, max. limit on E1
- OS-R2 – min. limit on E2, close max. limit on E1

Also, OS-L1 – control on age of Lake Bonneville deposits

Testing the Role of Fault Segmentation in Limiting Earthquake Magnitude: A Targeted Paleoseismic Investigation Along the Structurally Segmented Wasatch Fault Zone

Scott Bennett, incoming Mendenhall Postdoctoral Fellow, US Geological Survey

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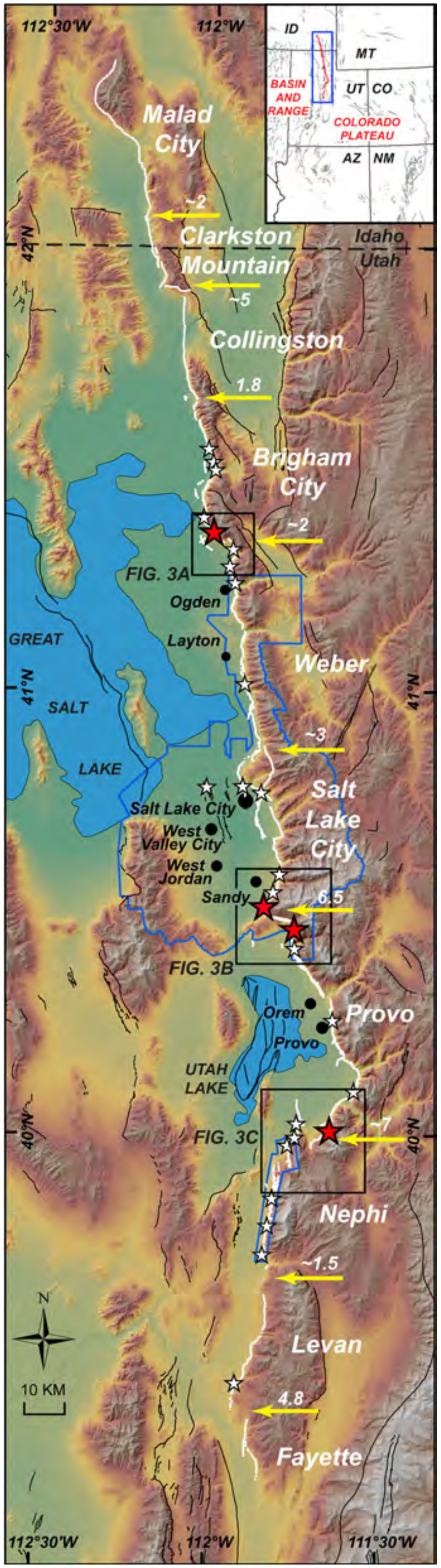
Advisors: Ryan Gold, Rich Briggs, Peter Powers, Ned Field, Gavin Hayes at the Geologic Hazards Science Center, Golden, CO

Collaborator: Chris DuRoss at the Utah Geological Survey



Project Outline

Data:

- Perform trench studies to obtain paleoseismic histories of event timing and displacement at structural segment boundaries that fill data gaps along the Wasatch fault zone.
- Excavations will be joint USGS/UGS effort.

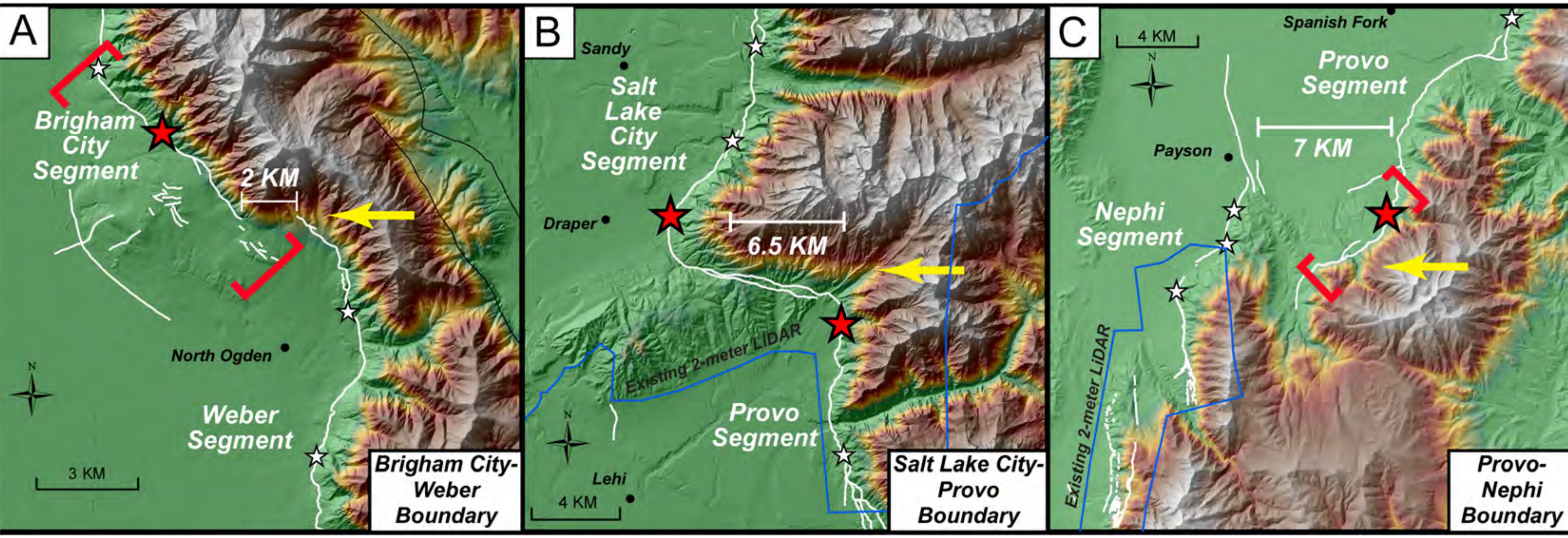
Practical application:

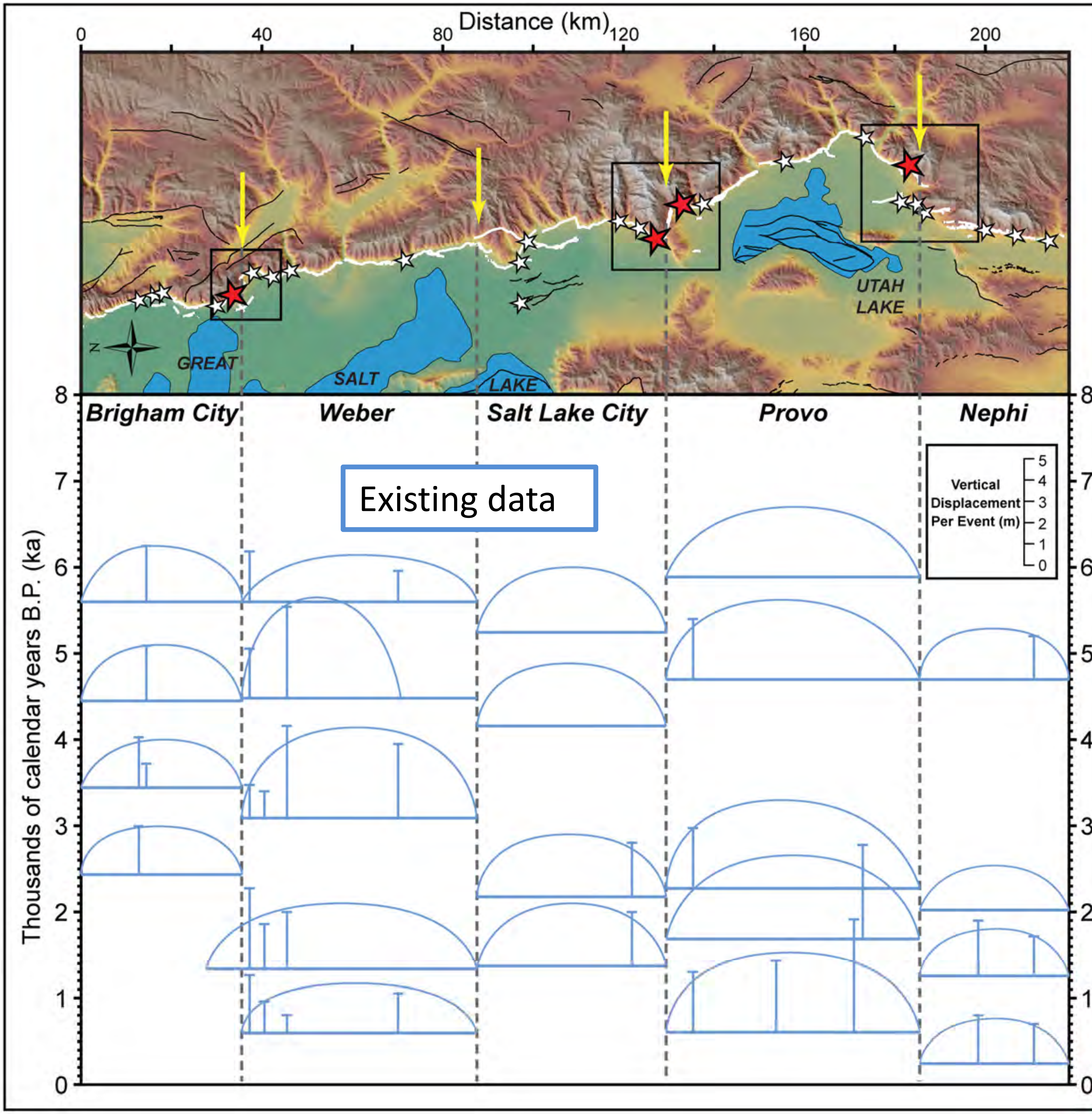
- Data will help weight various rupture models for the National Seismic Hazard Map.

Theoretical contribution:

- What happens if you “string pearls” (Biasi and Weldon, 2009) on the Wasatch? The 2011 update of the Uniform California Earthquake Rupture Forecast (UCERF 3) nearly completely relaxes the assumption of segmentation for California strike-slip faults (WGCEP, 2011), but it's not clear if this approach is warranted for large normal fault systems like the Wasatch.
- Wasatch data are now sufficient to allow statistical assessment of structural vs. seismic segmentation of an major normal fault system, and for the findings to be compared to thrust and strike-slip faults.

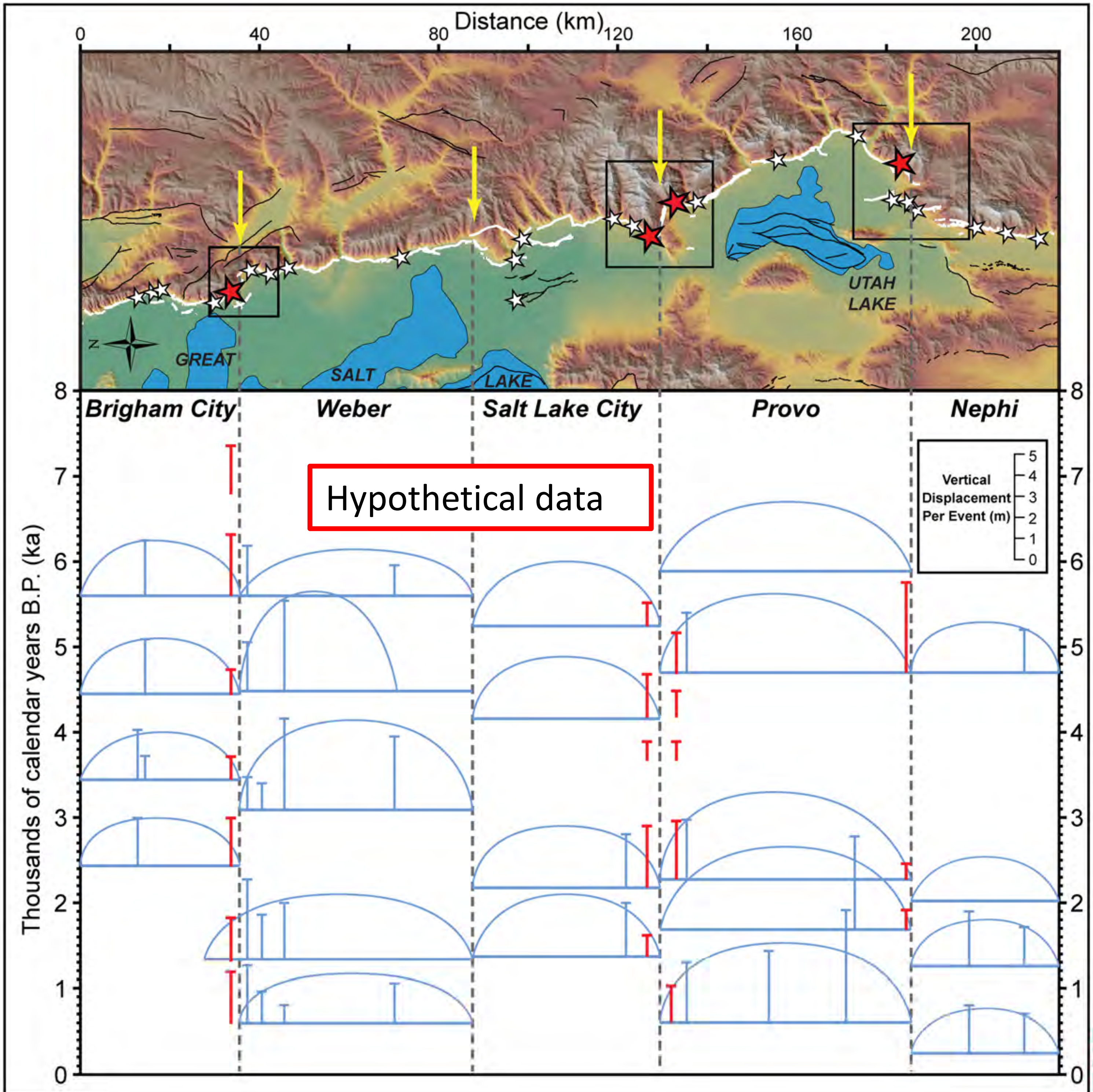
Trenching targets





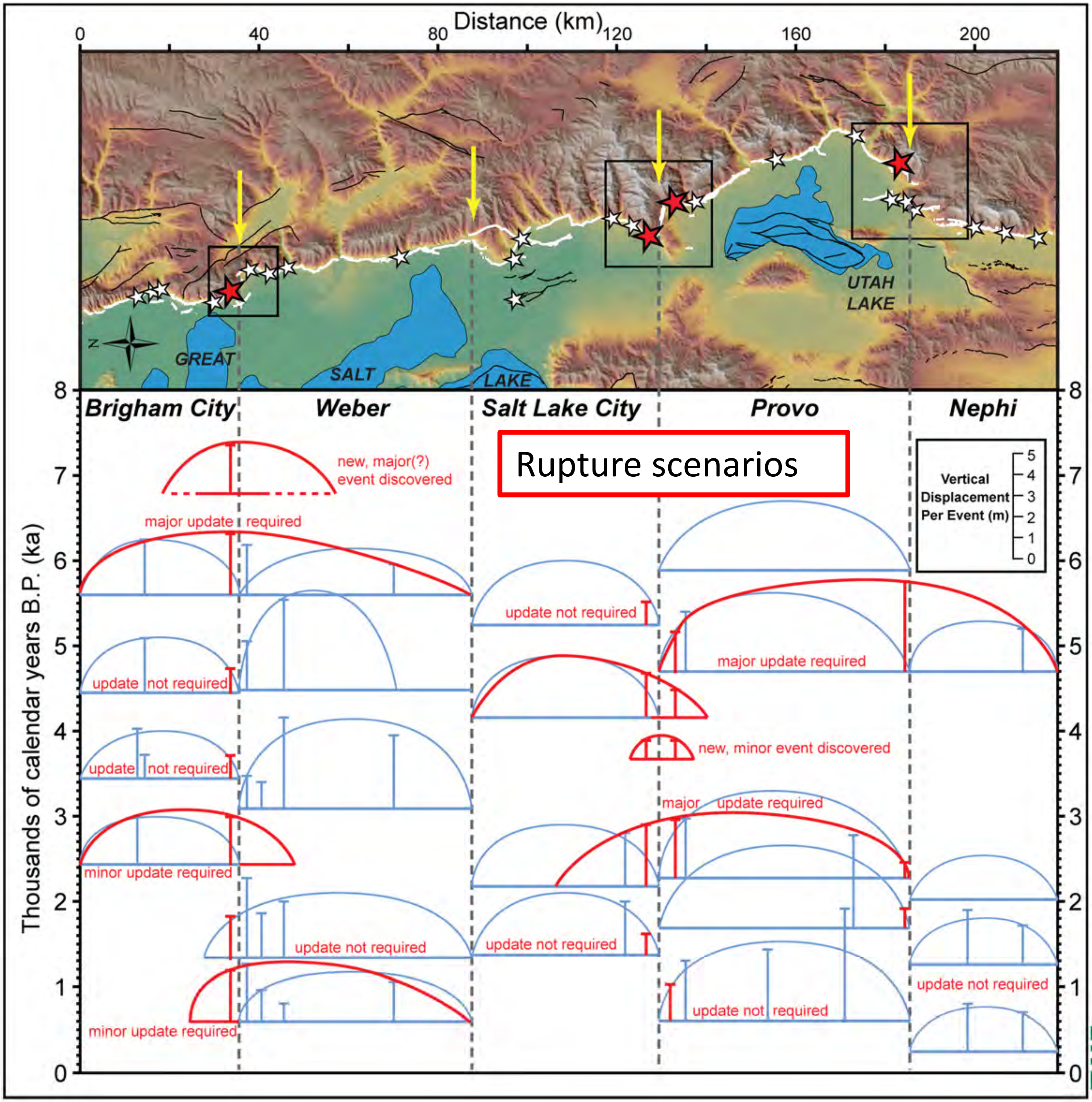
Displacement ellipses after Chang and Smith, 2002 and Biasi and Weldon, 2009

USGS
science for a changing world



Distance (km)
0
40
80
120
160
200
GREAT
SALT
LAKE
UTAH
LAKE
N
Brigham City
Weber
Salt Lake City
Provo
Nephi
Hypothetical data
Vertical Displacement Per Event (m)
Thousands of calendar years B.P. (ka)

Rupture scenarios



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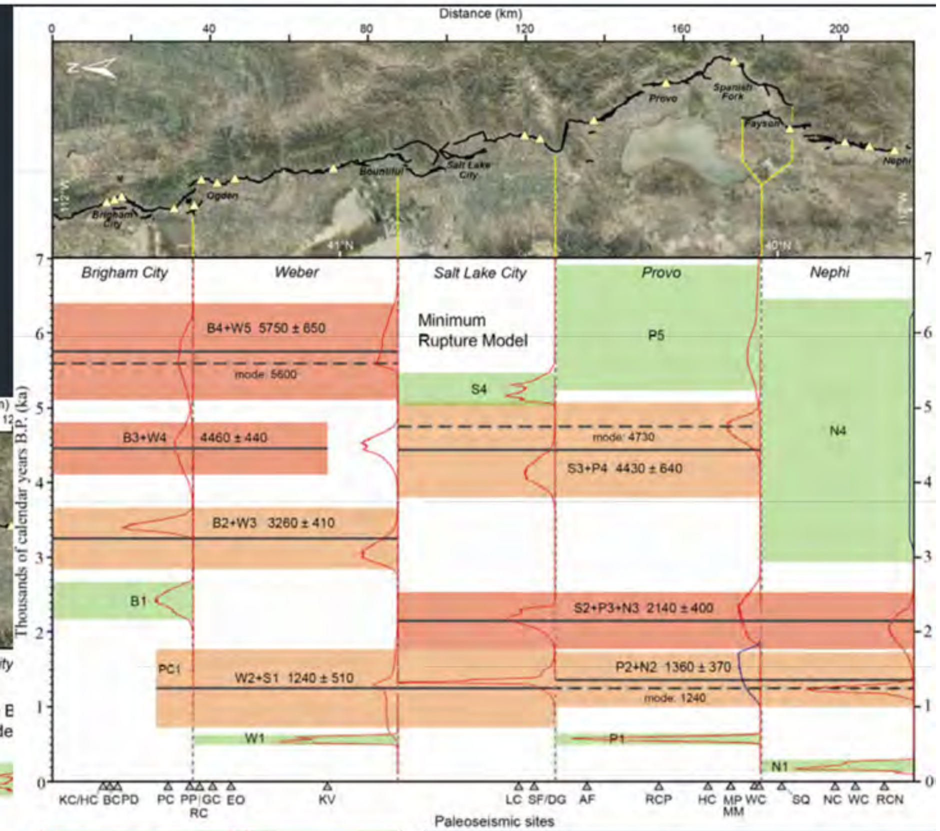
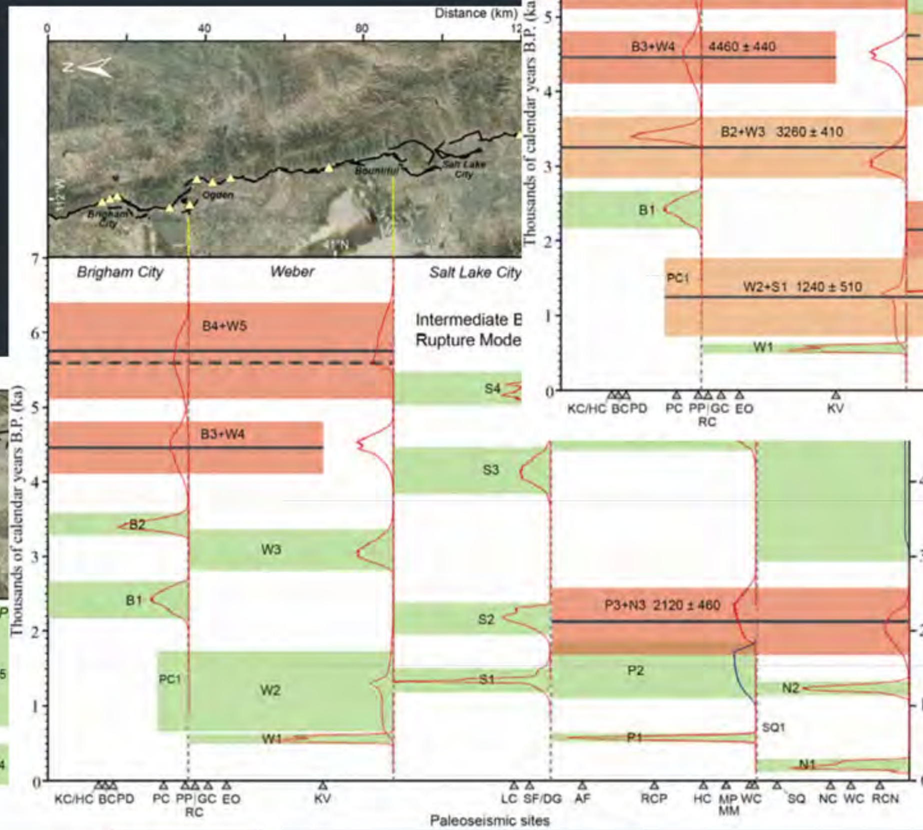
Rupture Models

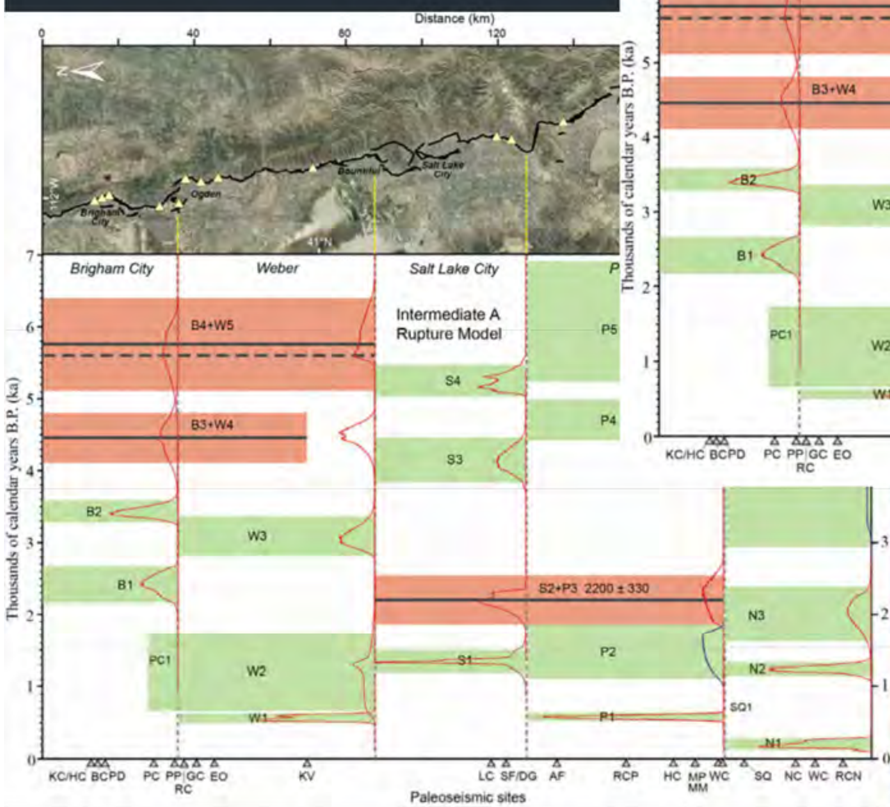
- Multi-segment rupture models
  - Recurrence for rupture that only occur once?



Multi-segment rupture model (fewest earthquakes)



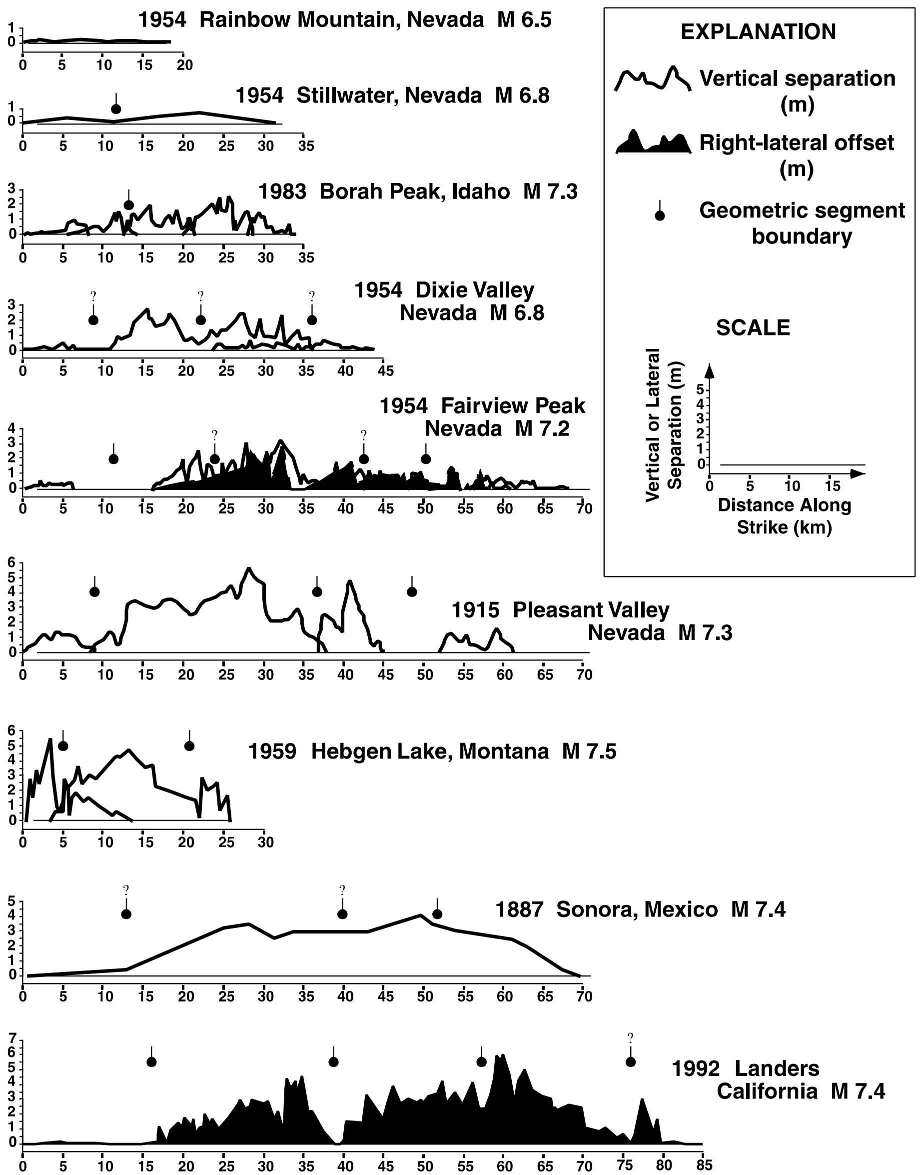
Intermediate B



Intermediate A

DuRoss, C.B., Olig, S.S., Crone, A.J., Personius, S.F., Lund, W.R., 2012, Characterizing the central Wasatch Fault Zone for the Working Group on Utah Earthquake Probabilities, February 2012

Preliminary data subject to revision



Pezzopane and Dawson, 1996 in Chang and Smith, 2002

What happens when the assumption

structural segmentation = rupture segmentation

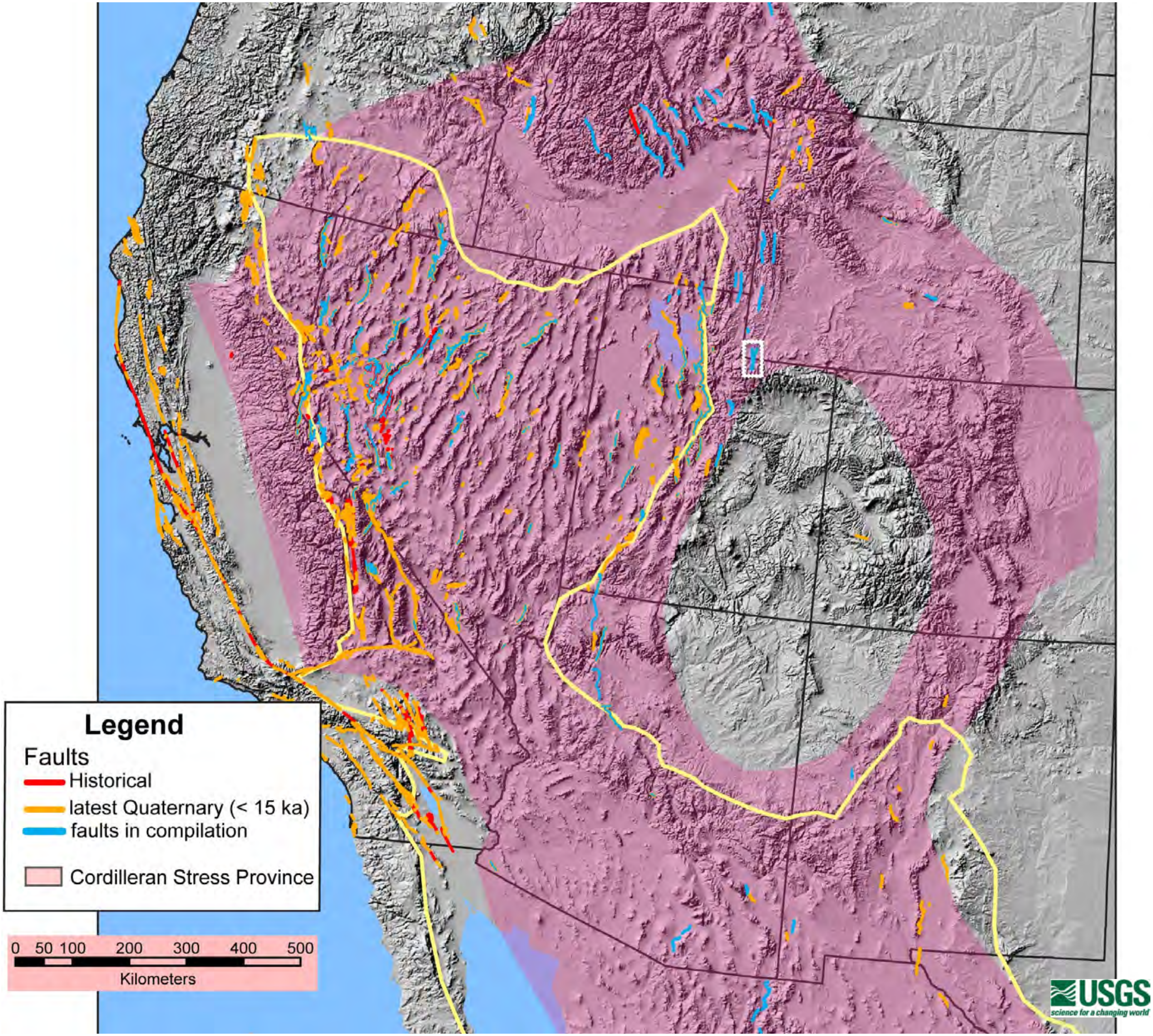
is completely relaxed on the Wasatch?

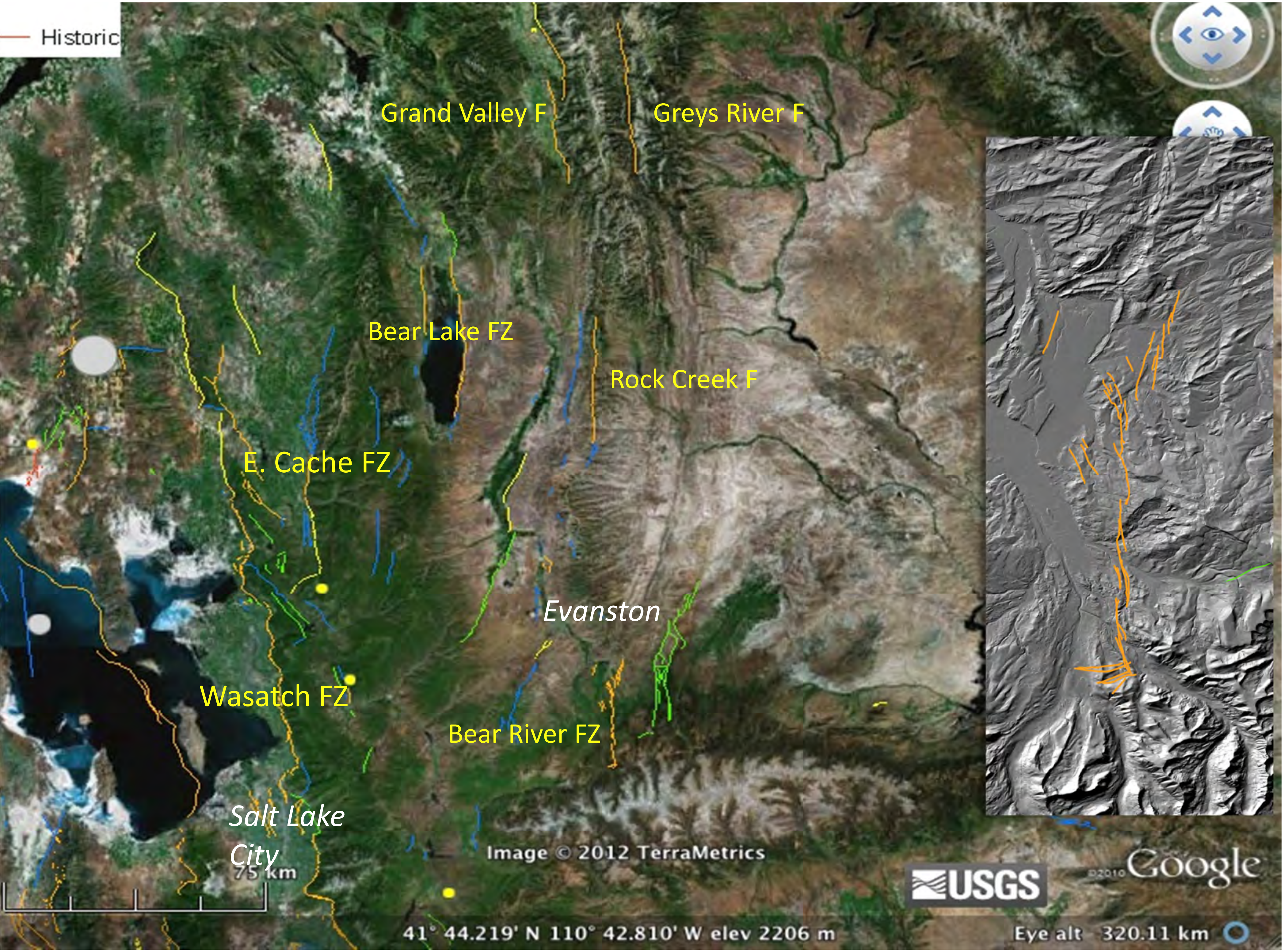
Bear River Fault behavior – Clues provided by Lidar

Suzanne Hecker[1], David Schwartz[1]

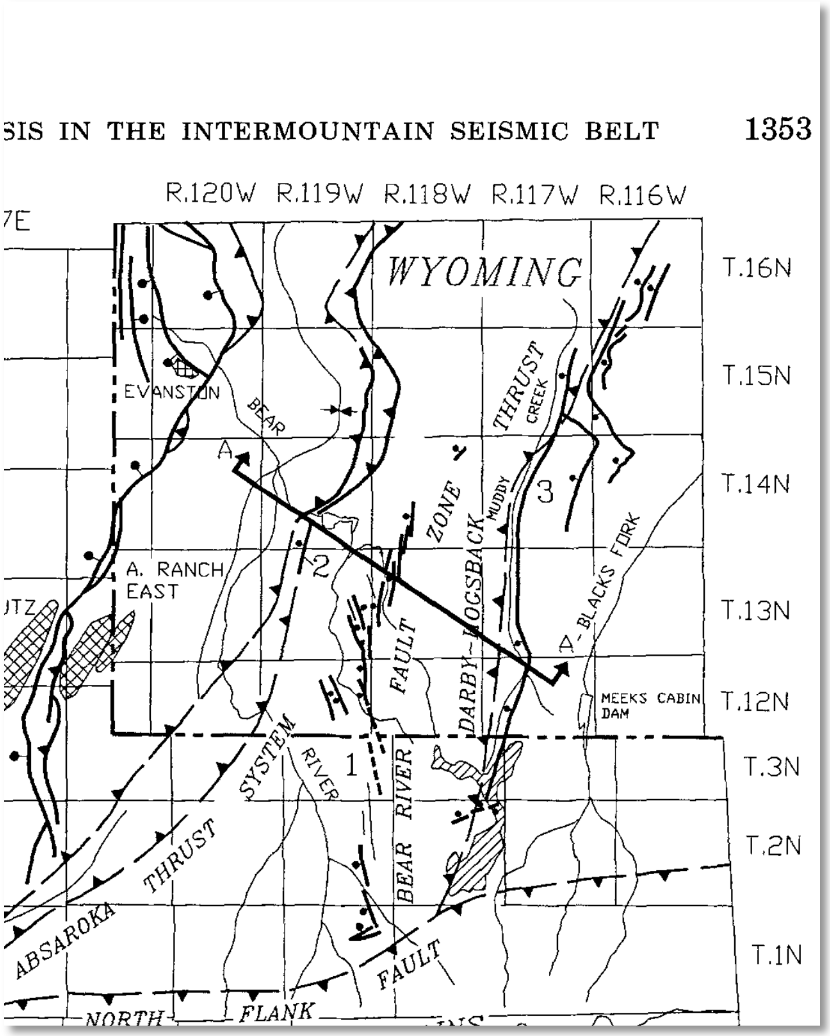
Chris DuRoss[2], Bill Lund[2], Gregg Beukelman[2], Ben Erickson[2], Francesca Cinti[3], Michael West[4]

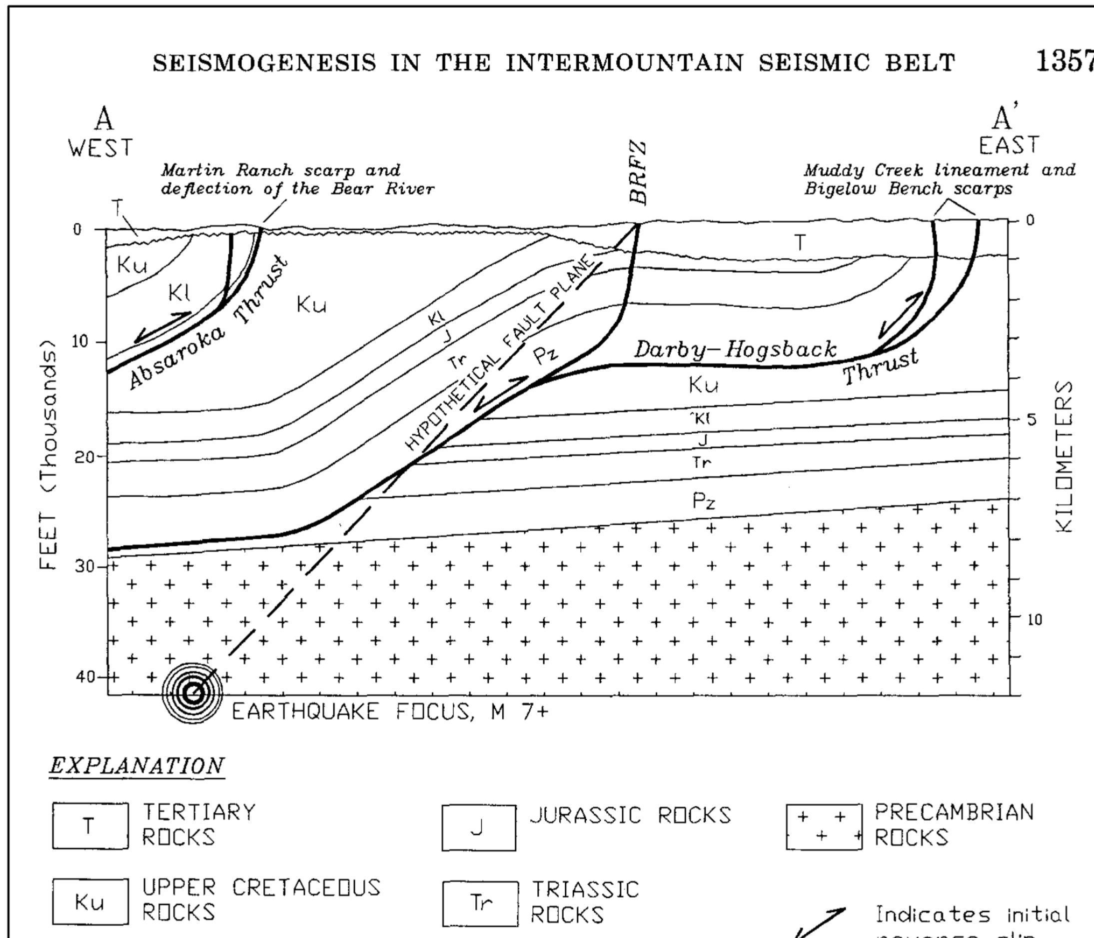
[1]U.S. Geological Survey
[2]Utah Geological Survey
[3]Istituto Nazionale di Geofisica e Vulcanologia
[4]Michael W. West & Associates, Inc.


Legend
Faults
Historical
latest Quaternary (< 15 ka)
faults in compilation
Cordilleran Stress Province
0 50 100 200 300 400 500
Kilometers
USGS
science for a changing world



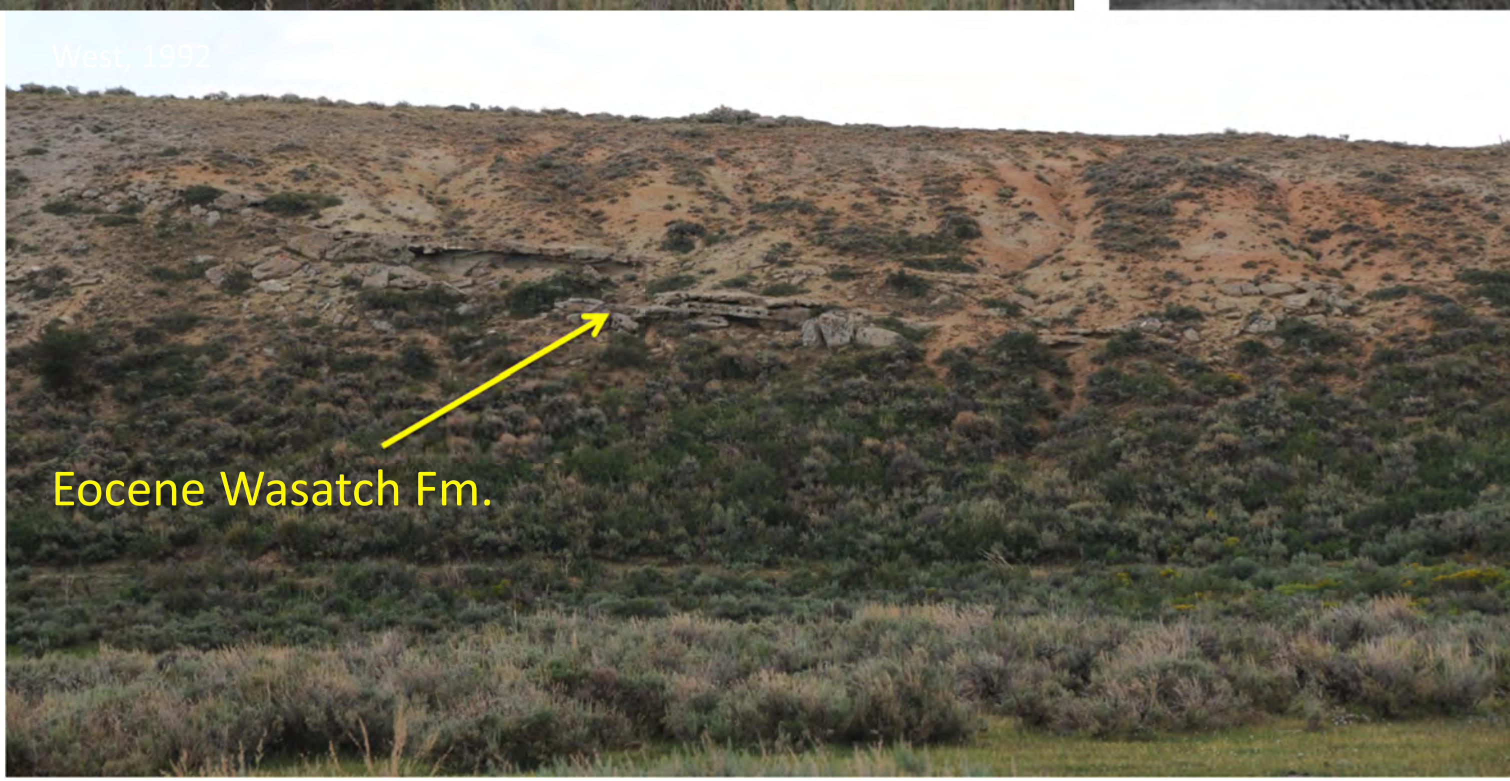
Historic
Grand Valley F
Greys River F
Bear Lake FZ
Rock Creek F
E. Cache FZ
Evanston
Wasatch FZ
Bear River FZ
Salt Lake City
75 km
Image © 2012 TerraMetrics
USGS
Google
41° 44.219' N 110° 42.810' W elev 2206 m
Eye alt 320.11 km


SIS IN THE INTERMOUNTAIN SEISMIC BELT
1353
R.120W R.119W R.118W R.117W R.116W
WYOMING
T.16N
T.15N
T.14N
T.13N
T.12N
T.3N
T.2N
T.1N
EVANSTON
BEAR
THRUST
CREEK
ZONE
MUDDY
DARBY-HOGSBACK
BLACKS FORK
A. RANCH EAST
FAULT
MEEKS CABIN DAM
SYSTEM
RIVER
BEAR RIVER
ABSAROKA
THRUST
FAULT
NORTH
FLANK
A
A'
1
2
3


SEISMOGENESIS IN THE INTERMOUNTAIN SEISMIC BELT
1357
A
WEST
A'
EAST
Martin Ranch scarp and deflection of the Bear River
BRFZ
Muddy Creek lineament and Bigelow Bench scarps
T
Ku
Kl
Absaroka Thrust
J
Tr
HYPOTHETICAL FAULT PLANE
Pz
Darby–Hogsback Thrust
FEET (Thousands)
KILOMETERS
EARTHQUAKE FOCUS, M 7+
EXPLANATION
TERTIARY ROCKS
UPPER CRETACEOUS ROCKS
JURASSIC ROCKS
TRIASSIC ROCKS
PRECAMBRIAN ROCKS
Indicates initial reverse slip

West, 1992

Bear River Fault Zone
Main Scarp



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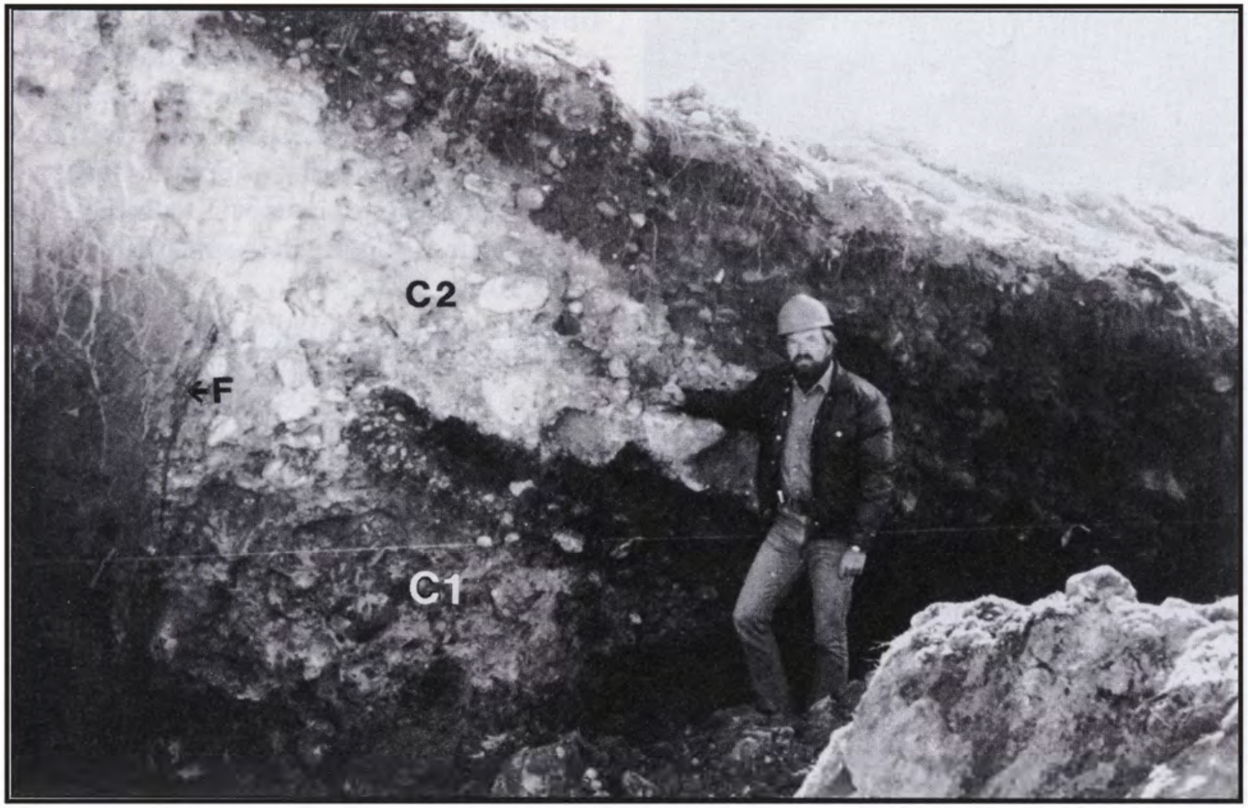
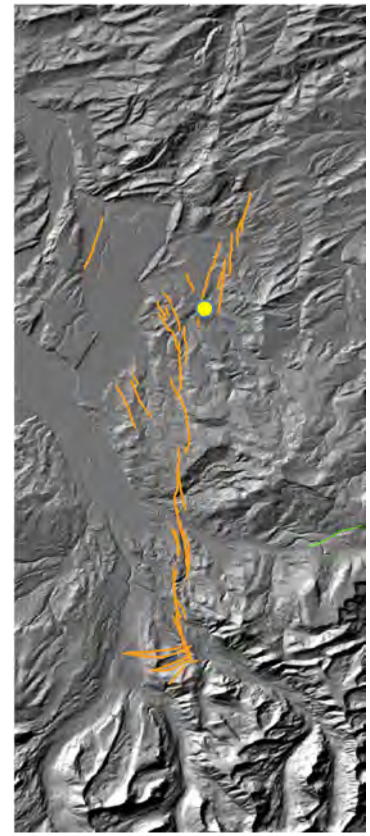


Lester Ranch trench, Bear River fault, Wyoming

(West, 1993)

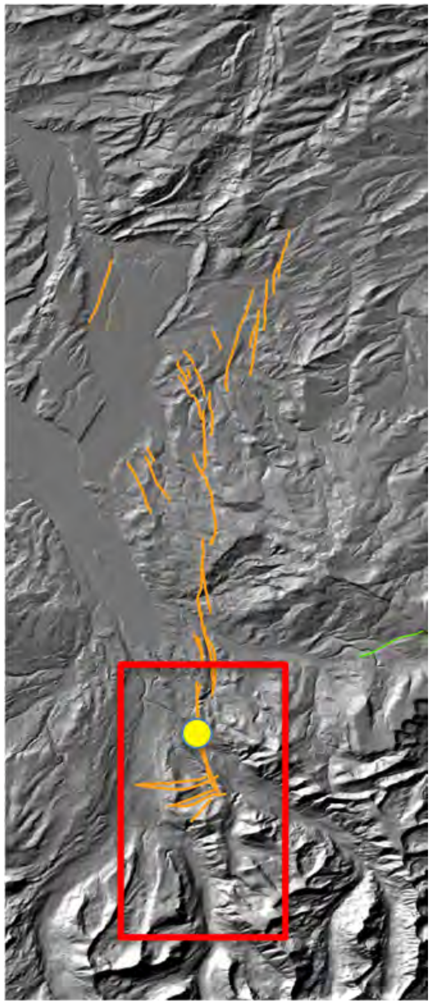


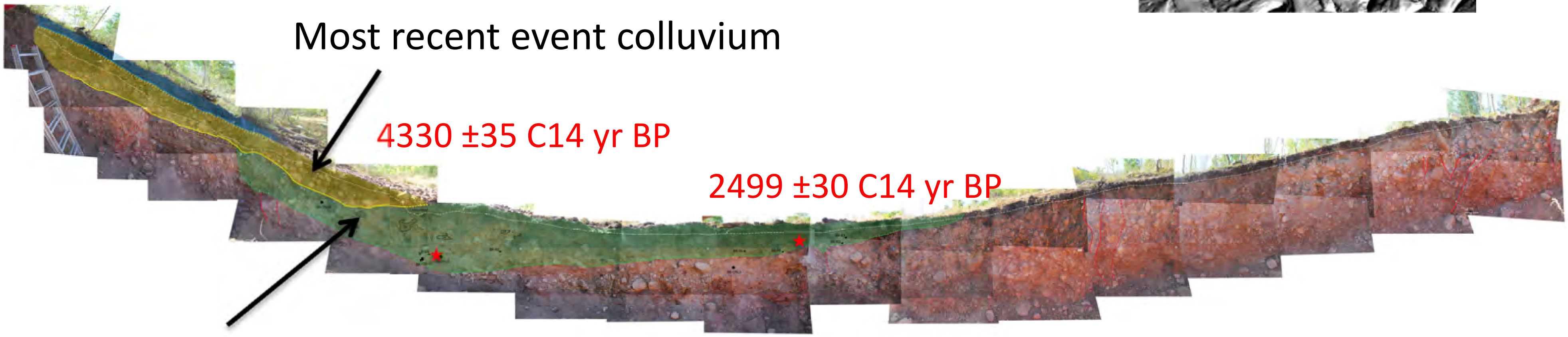
2 surface ruptures:

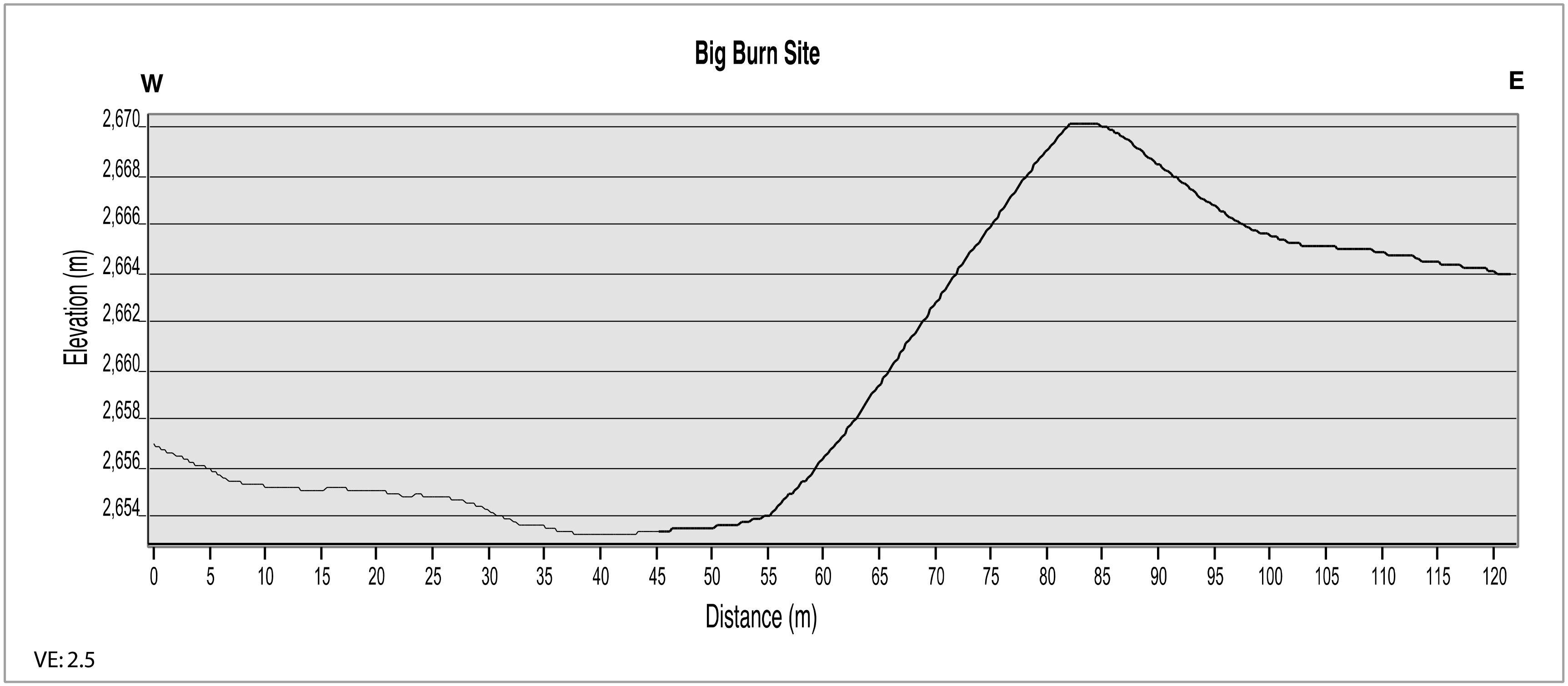
2.4 ± 1.1 ka
4.6 ± 0.7 ka

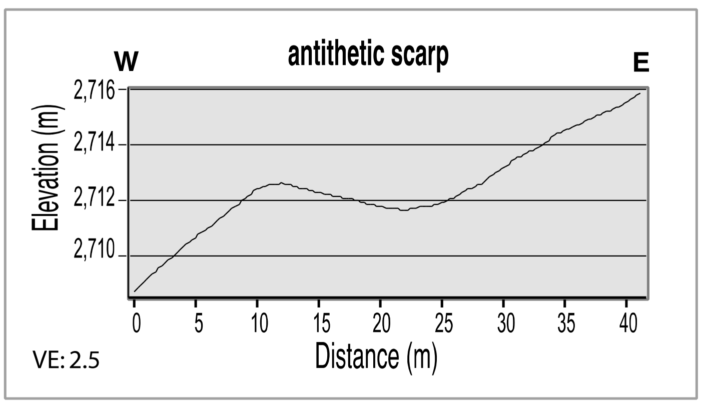
Bear River Fault Zone

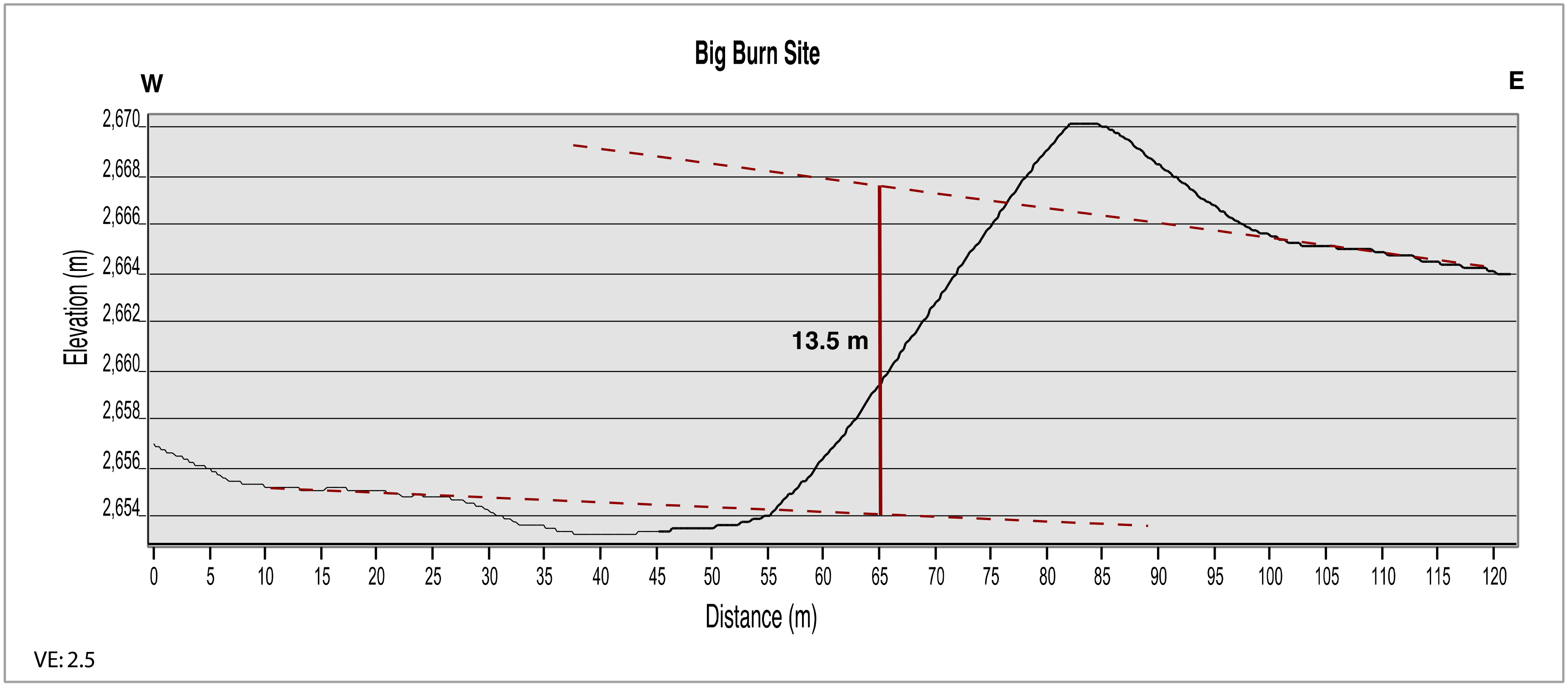
Big Burn Site

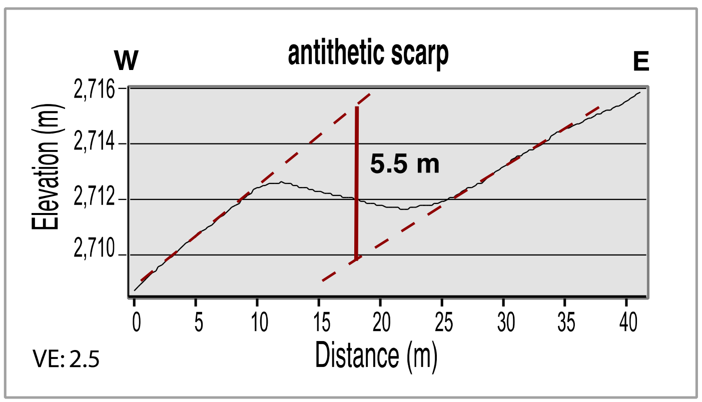




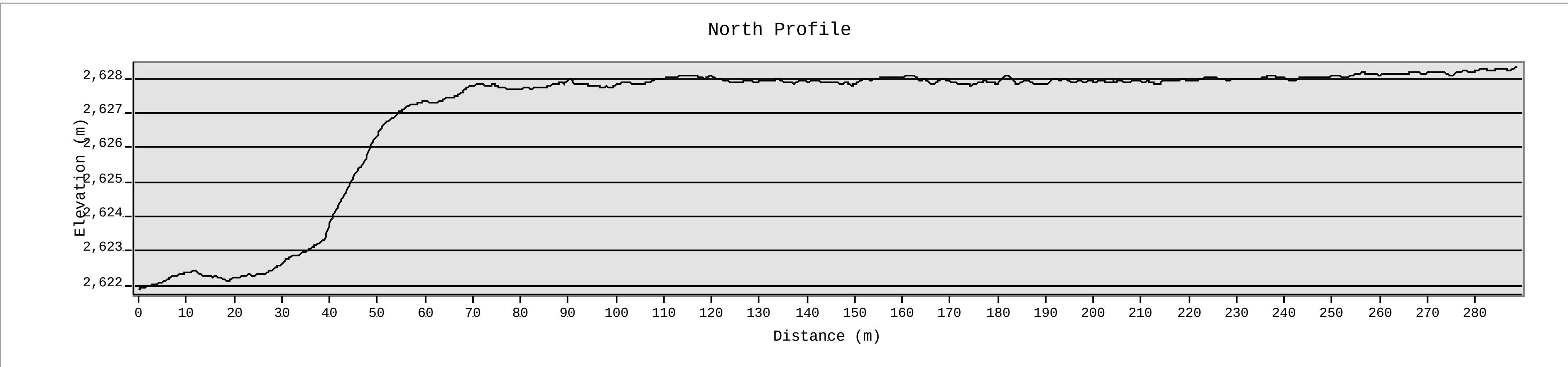

Big Burn Site
W
E
Elevation (m)
2,670
2,668
2,666
2,664
2,662
2,660
2,658
2,656
2,654
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
Distance (m)
VE: 2.5

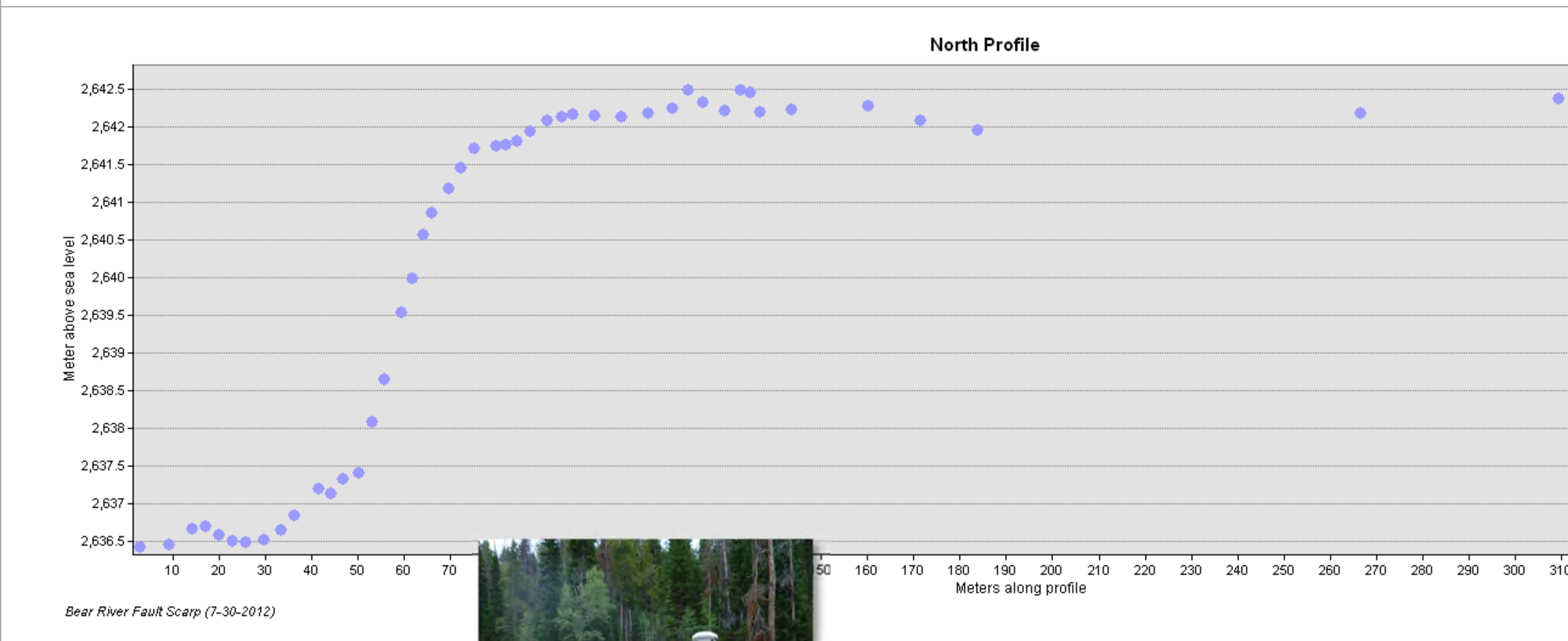

antithetic scarp
W
E
Elevation (m)
2,716
2,714
2,712
2,710
0
5
10
15
20
25
30
35
40
Distance (m)
VE: 2.5


Big Burn Site
W
E
2,670
2,668
2,666
2,664
2,662
2,660
2,658
2,656
2,654
Elevation (m)
13.5 m
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
Distance (m)
VE: 2.5


antithetic scarp
W
E
2,716
2,714
2,712
2,710
Elevation (m)
5.5 m
0 5 10 15 20 25 30 35 40
Distance (m)
VE: 2.5

NTVD ~ 8 m (max)


North Profile
Elevation (m)
2,628
2,627
2,626
2,625
2,624
2,623
2,622
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280
Distance (m)


North Profile
Meter above sea level
2,642.5
2,642
2,641.5
2,641
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2,638.5
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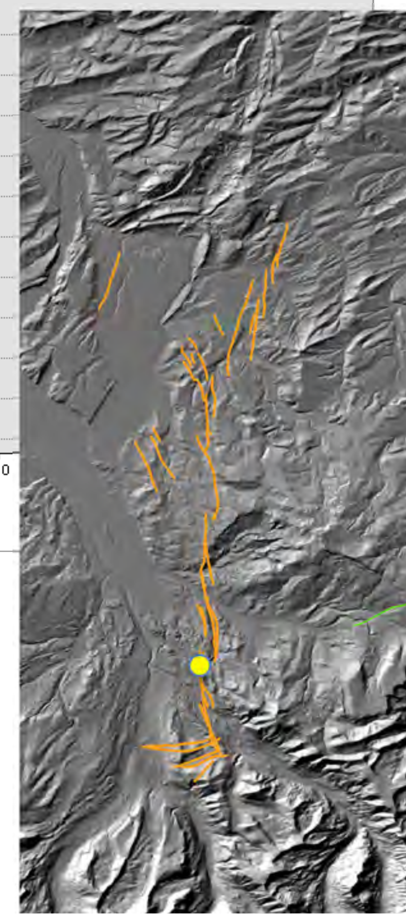
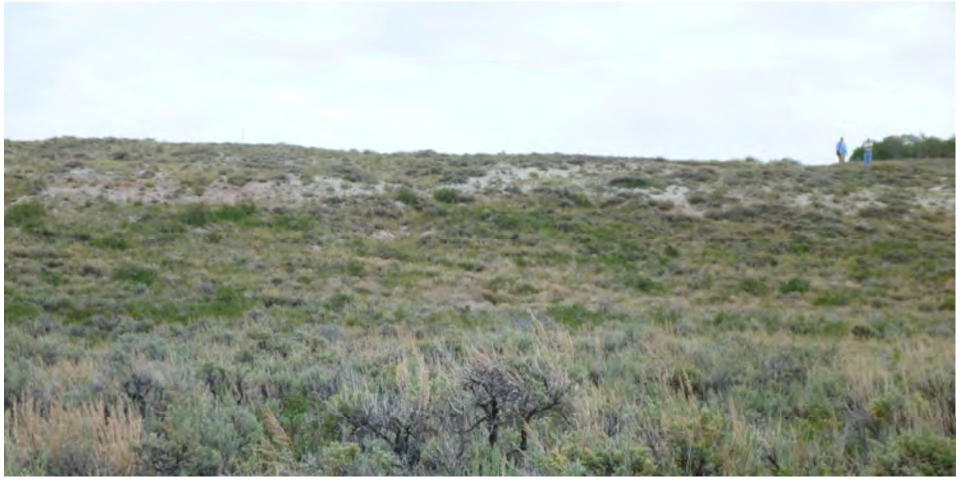
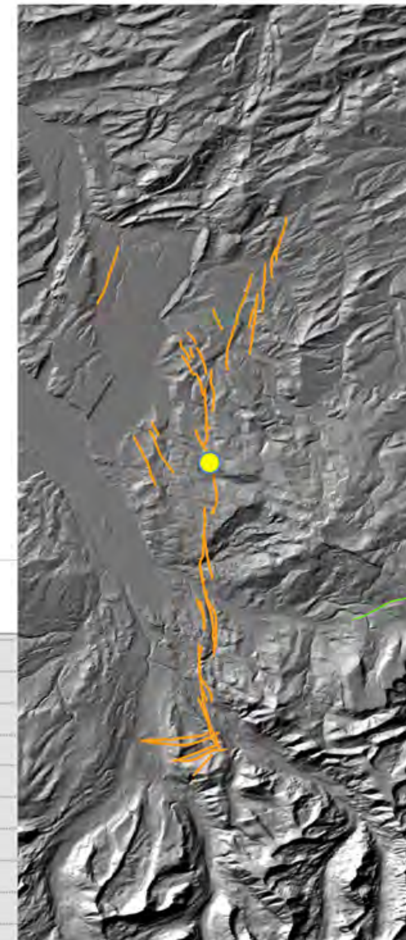
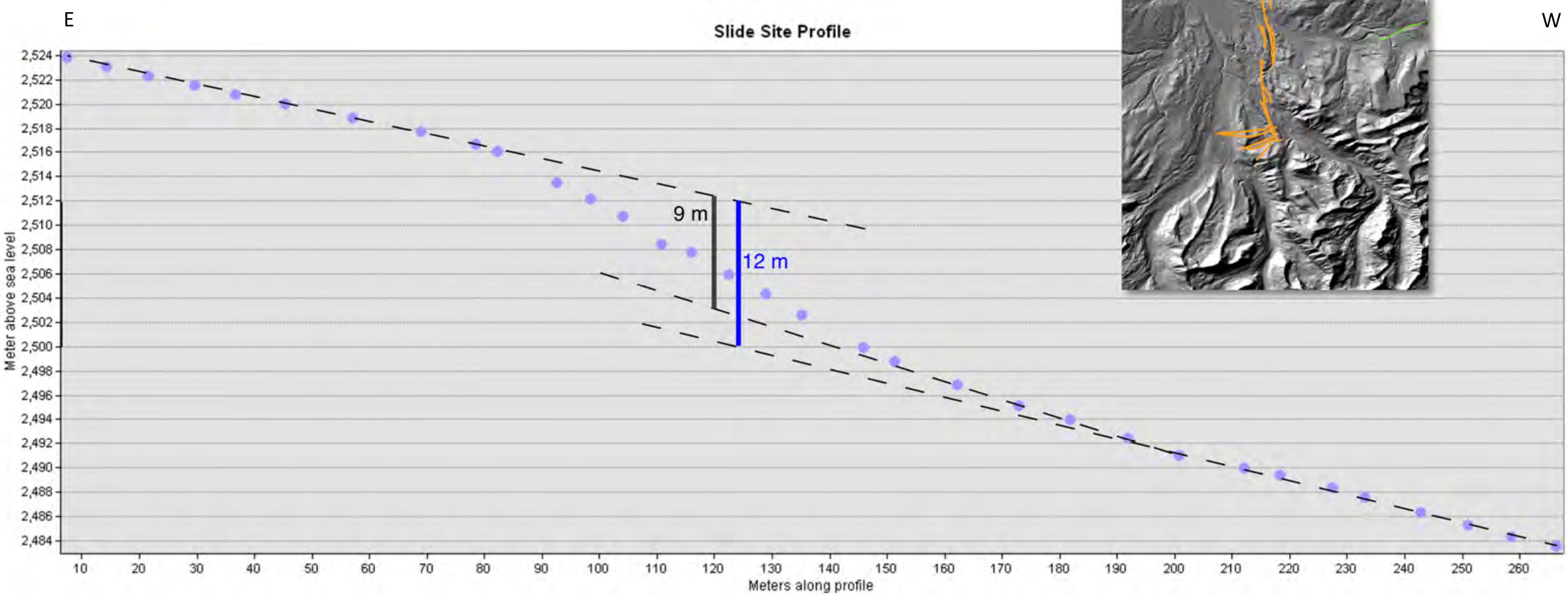
2,637.5
2,637
2,636.5
10 20 30 40 50 60 70
160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310
Meters along profile
Bear River Fault Scarp (7-30-2012)

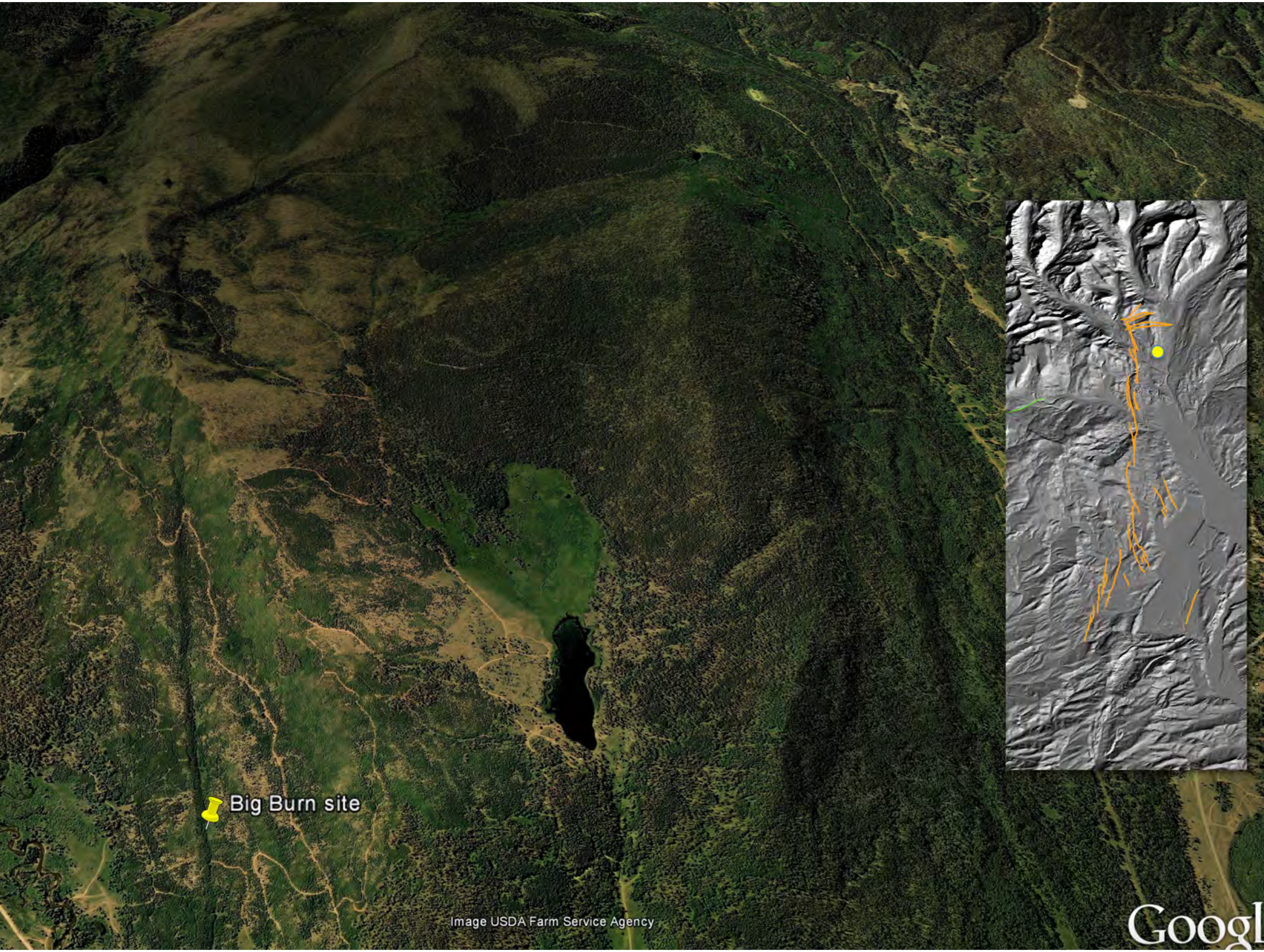


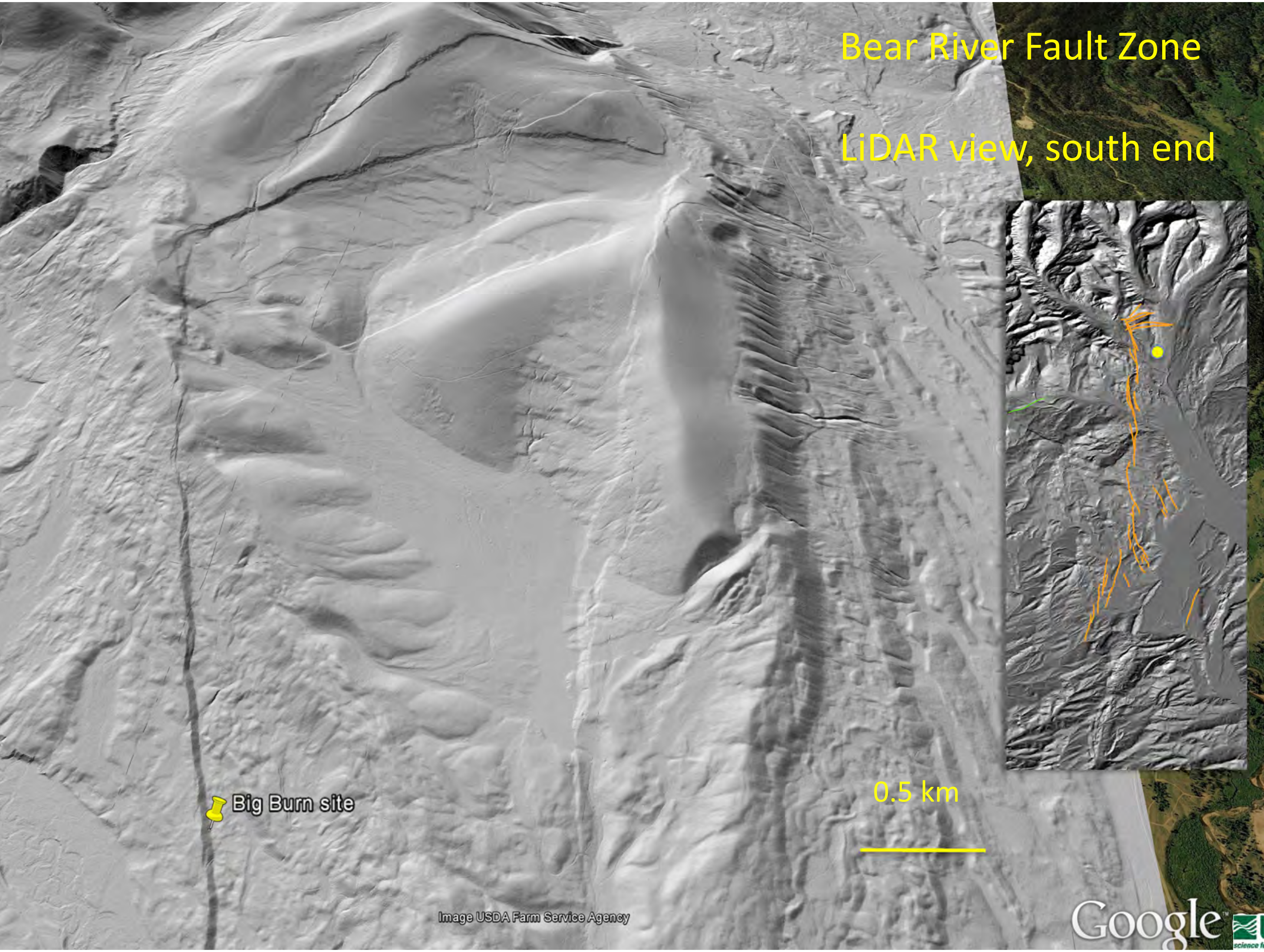


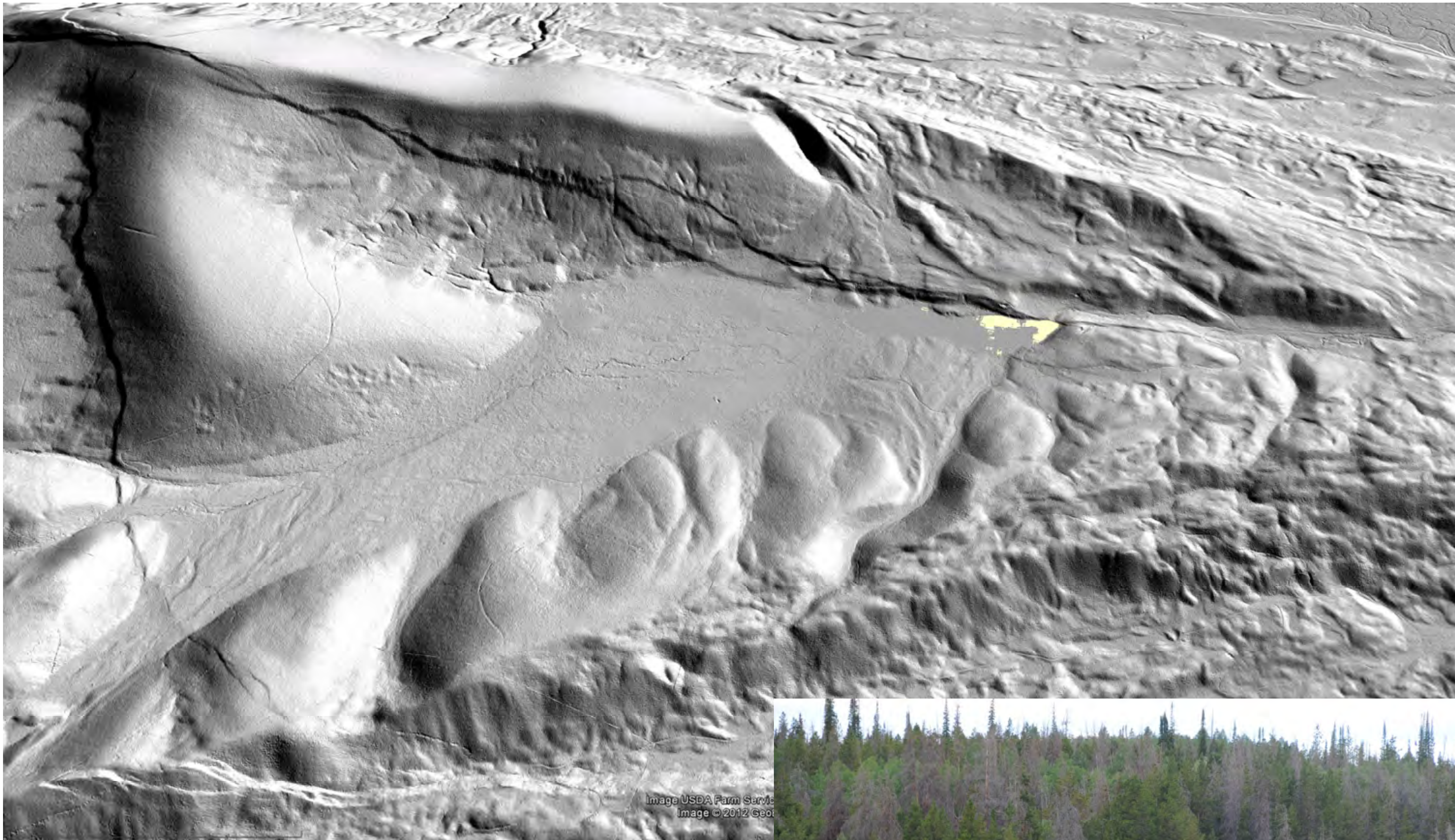




Bear River Fault Scarp (7-31-2012)


Big Burn site
Image USDA Farm Service Agency
Googl

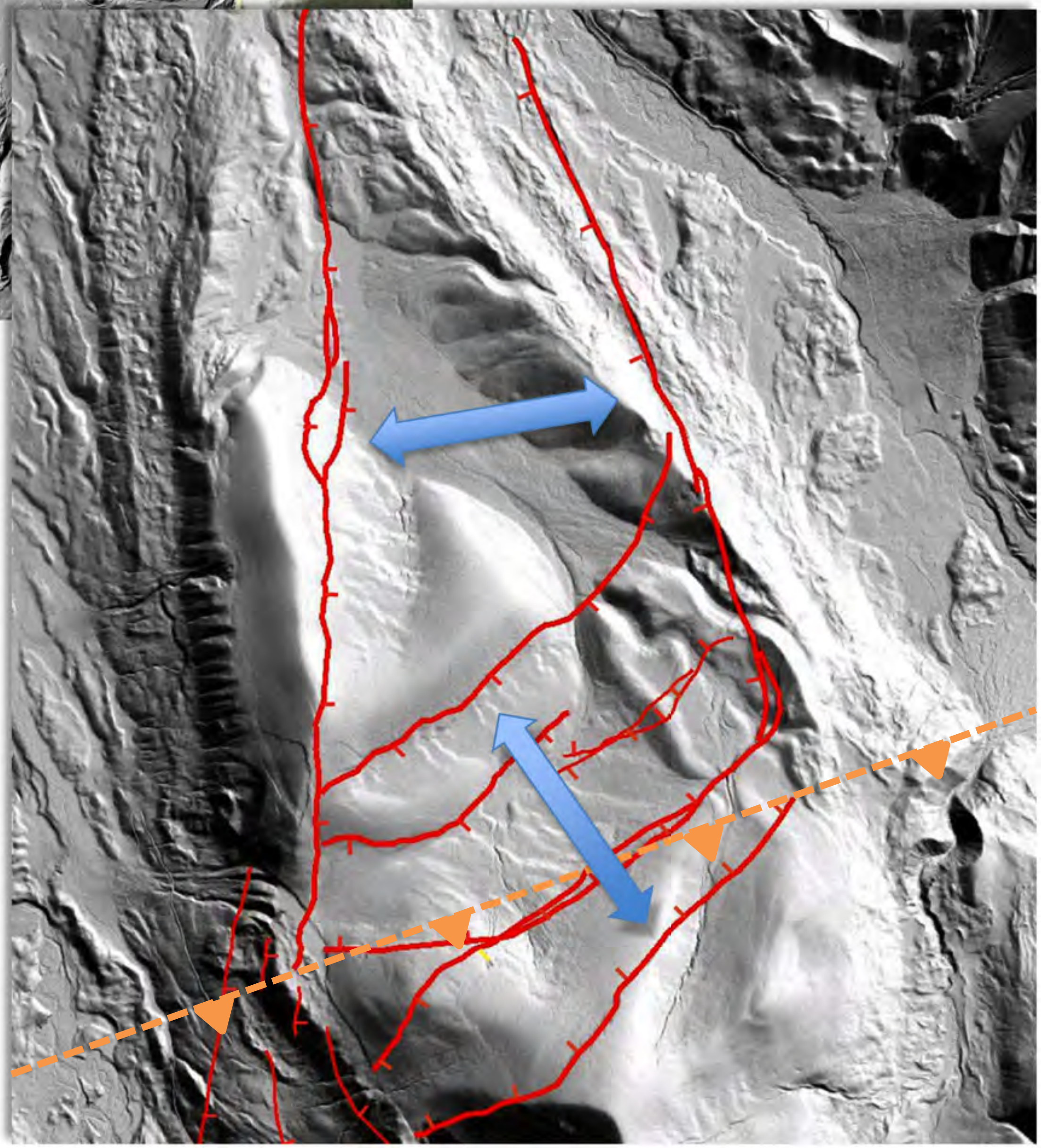

Bear River Fault Zone
LiDAR view, south end
0.5 km
Big Burn site
Image USDA Farm Service Agency
Google

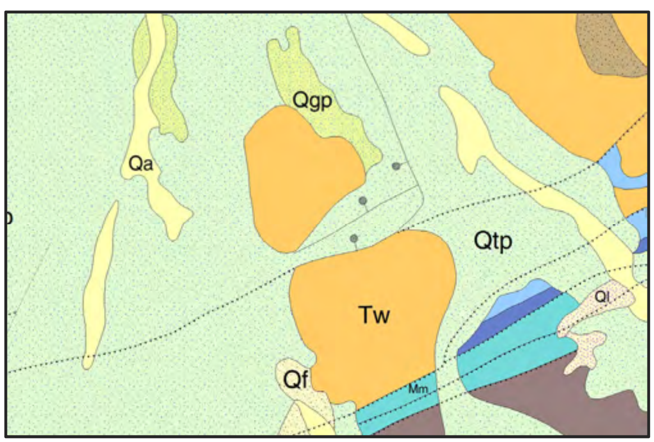


Bear River Fault Zone

LiDAR view, antithetic scarps

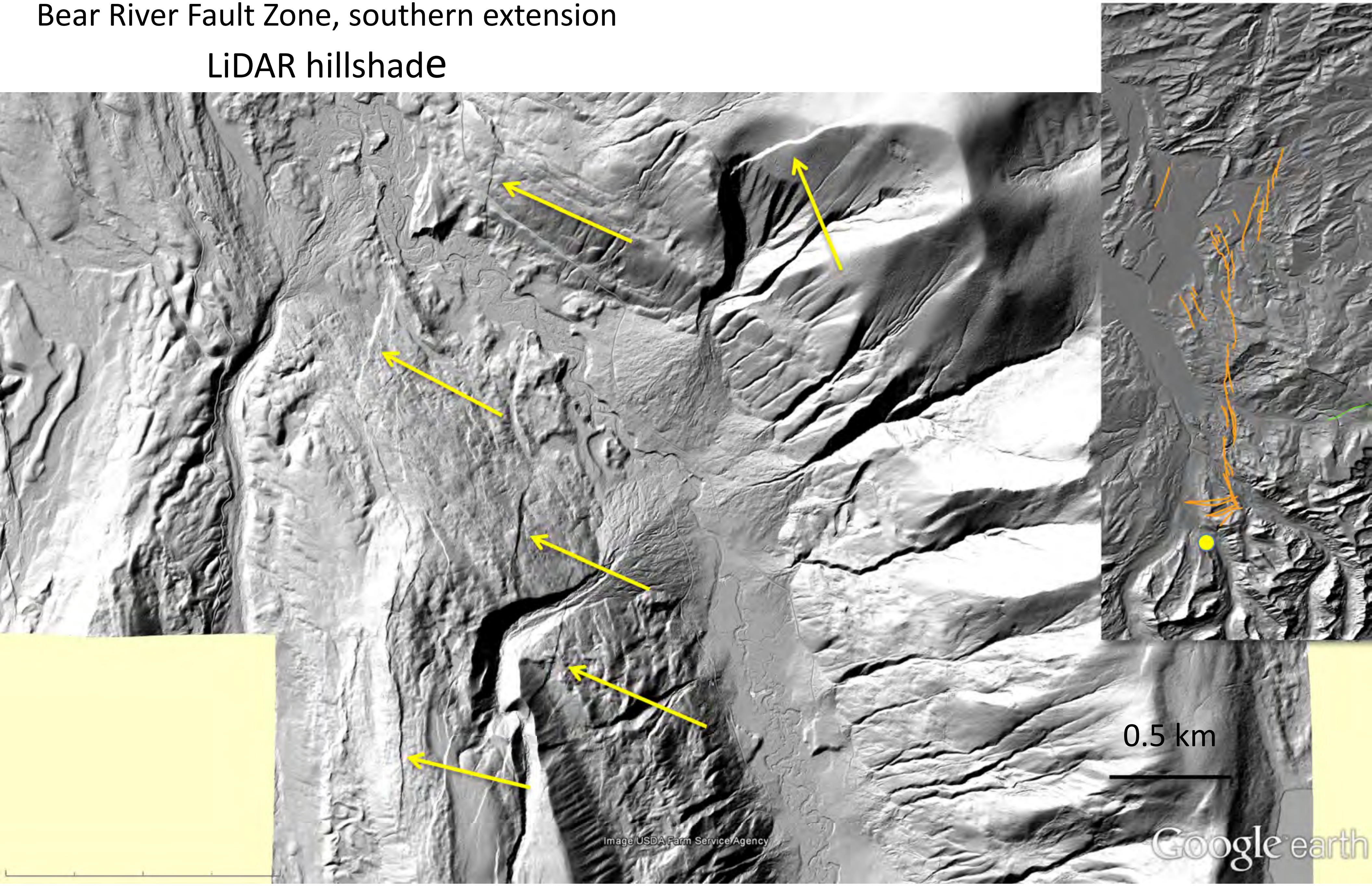

Big Burn site




Qgp
Qa
Qtp
Tw
Qf
Ql
Mm

Bear River Fault Zone, southern extension

LiDAR hillshade



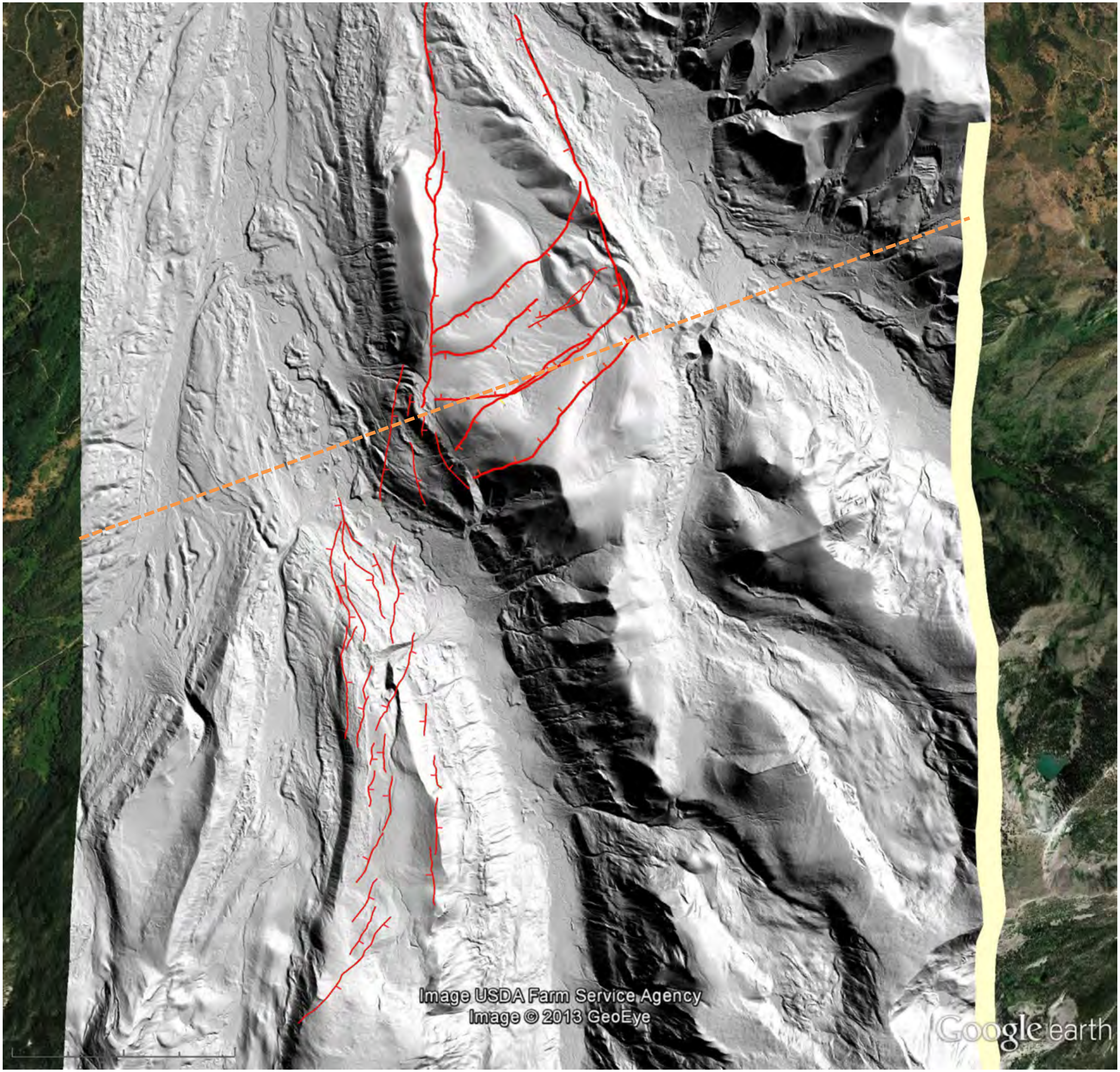


Image USDA Farm Service Agency
Image © 2013 GeoEye
Google earth

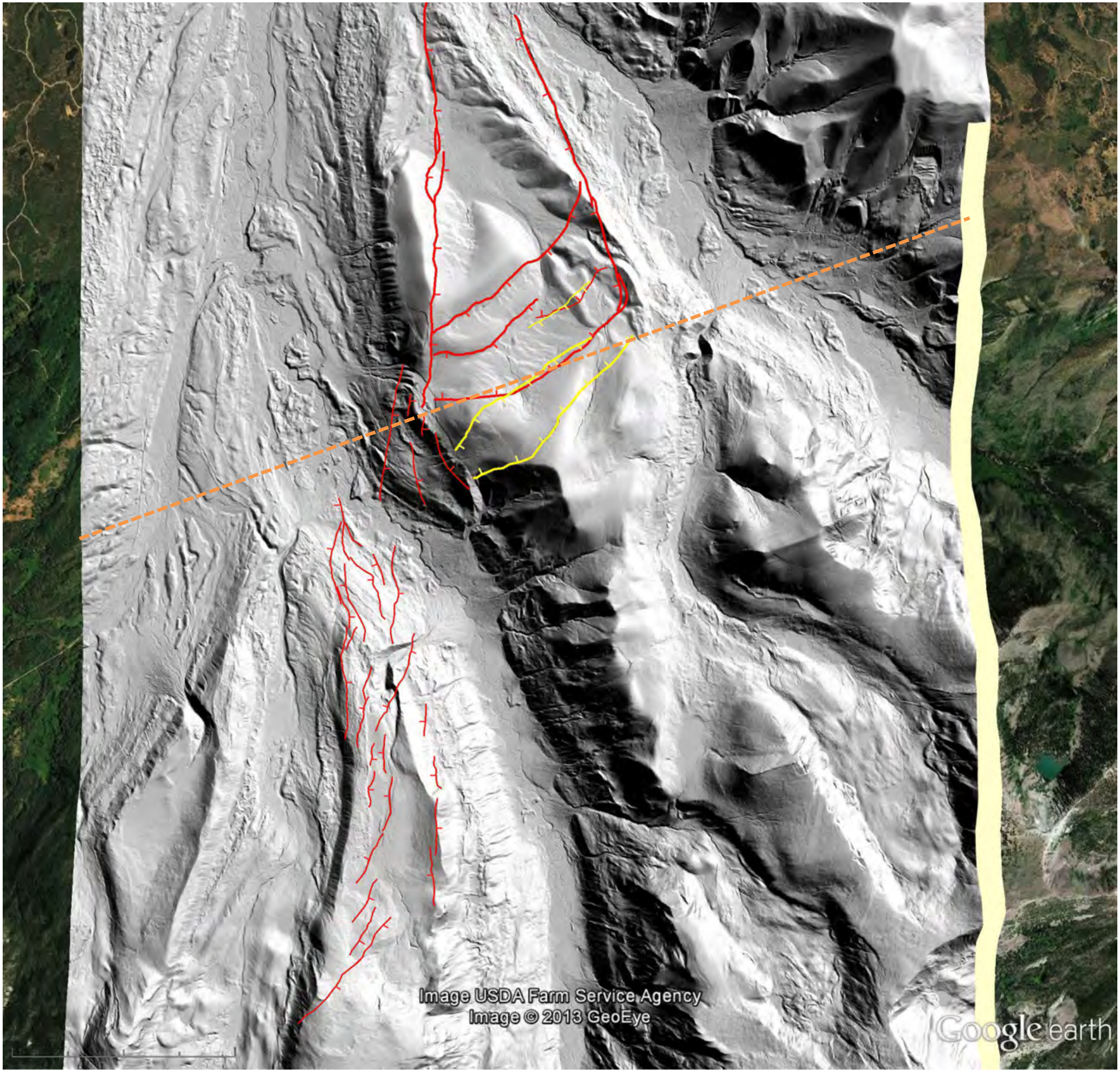


Image USDA Farm Service Agency
Image © 2013 GeoEye
Google earth

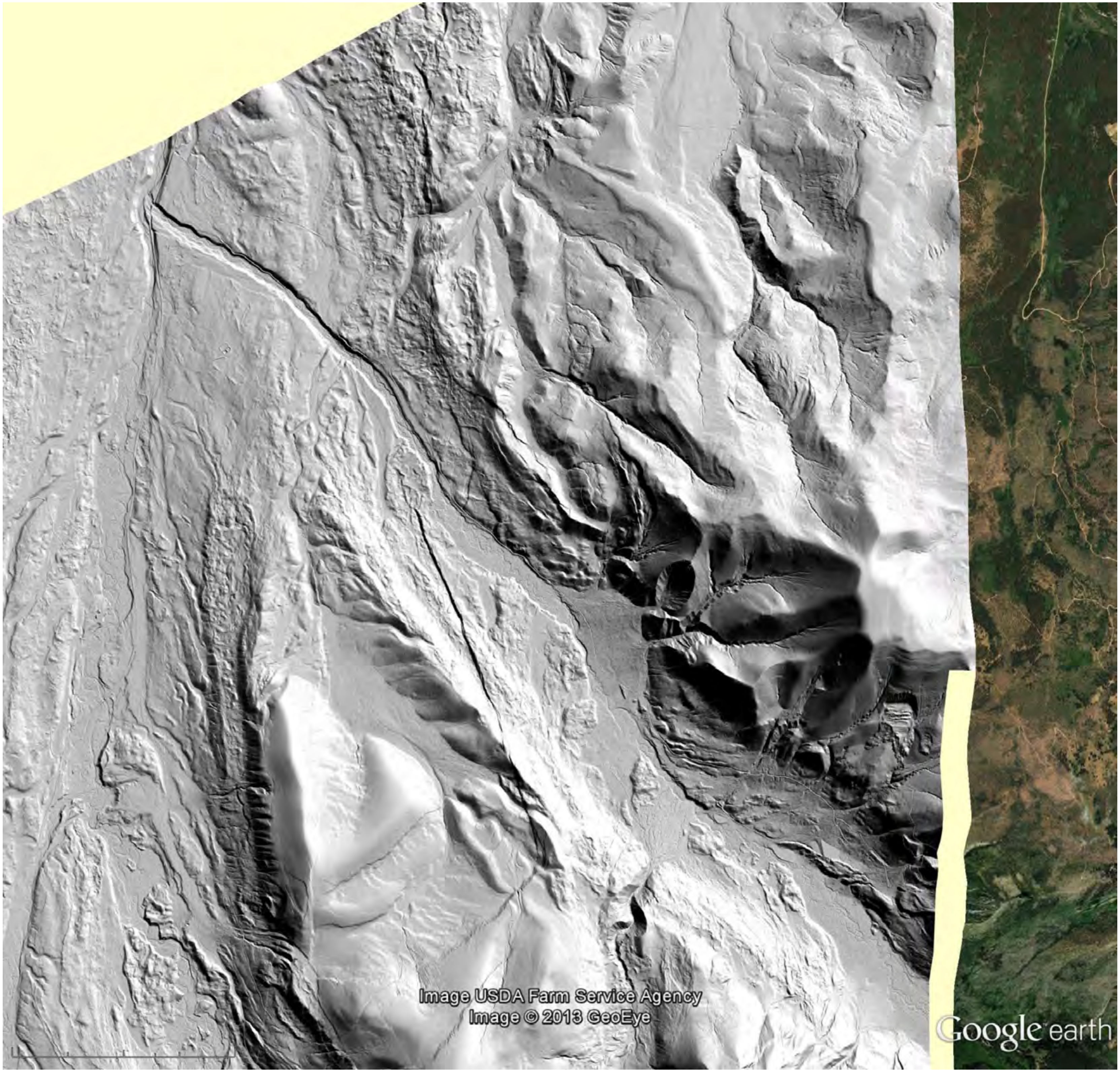


Image USDA Farm Service Agency
Image © 2013 GeoEye
Google earth

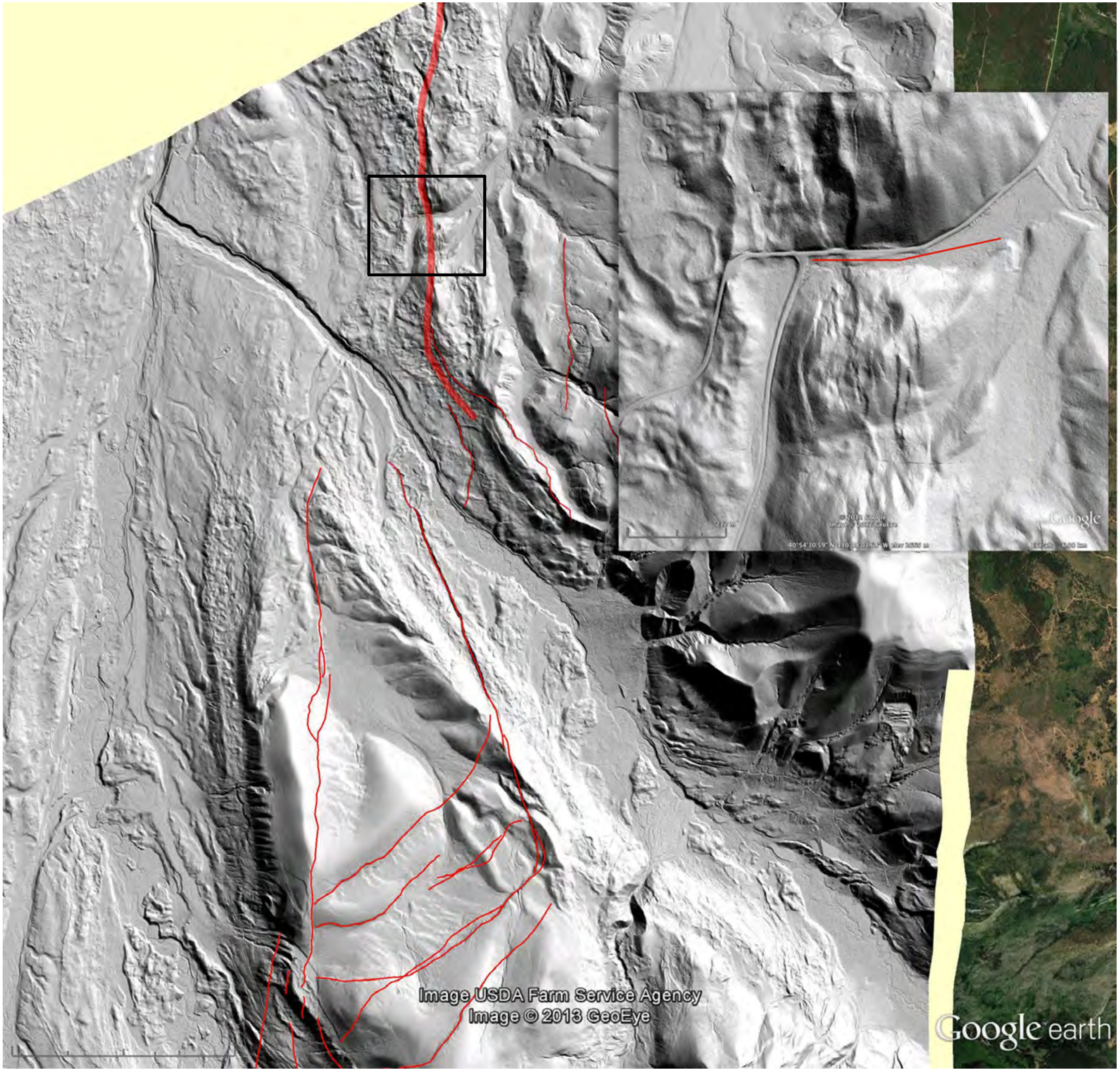


Image USDA Farm Service Agency
Image © 2013 GeoEye
Google earth
Google


New insights into BRFZ behavior-
gleaned from Lidar:
- Complex, evolving surface-rupture pattern
- First-order influence of pre-existing structure on fault evolution
- Near-fault distortion and large-scale graben development account for extraordinary size of scarps adjacent to Uinta Uplift.
- BRFZ is 6 km longer than previously mapped (~40 km total).
- Large net displacements (~2.5-5m/event) relative to length imply high stress drop earthquakes.

RECLAMATION
Managing Water in the West

Evaluation of the Quaternary History of the Joes Valley Fault Zone, Utah

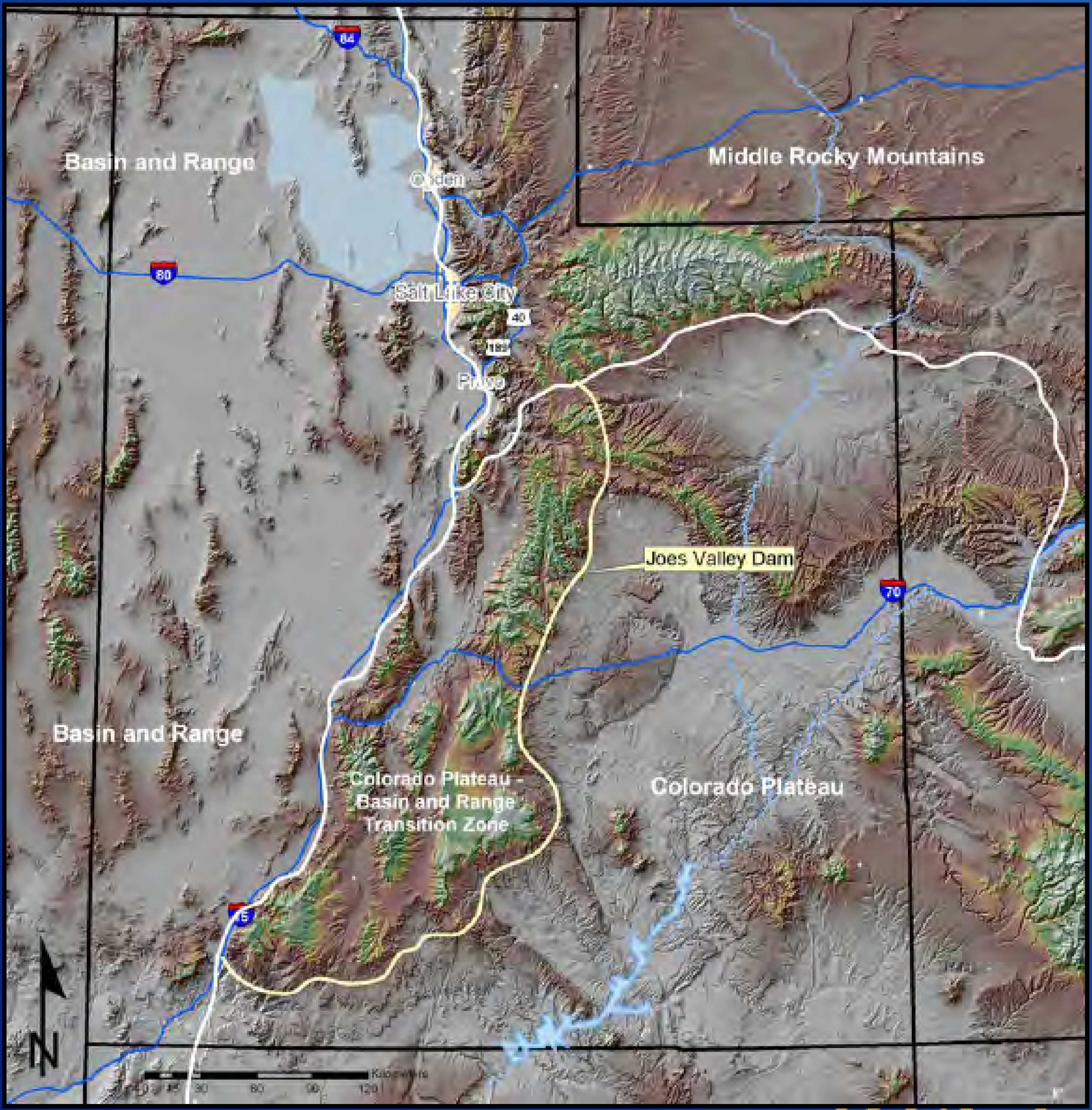
Background and Update

Joanna Redwine
Seismotectonics and Geophysics Group
Bureau of Reclamation
Denver, Colorado

U.S. Department of the Interior
Bureau of Reclamation

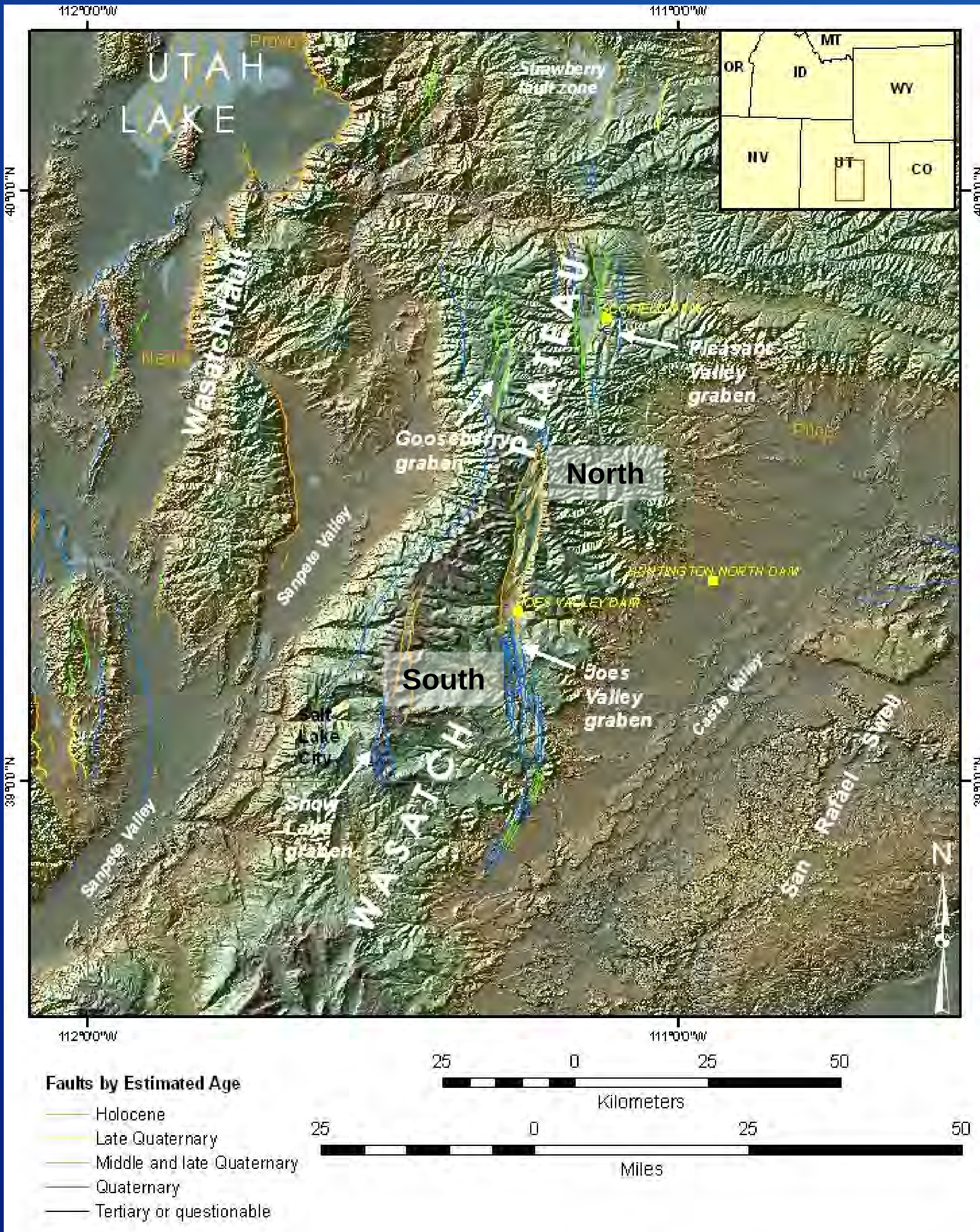
February 2013

Joes Valley Fault Zone



From O'Connell and others (2005)

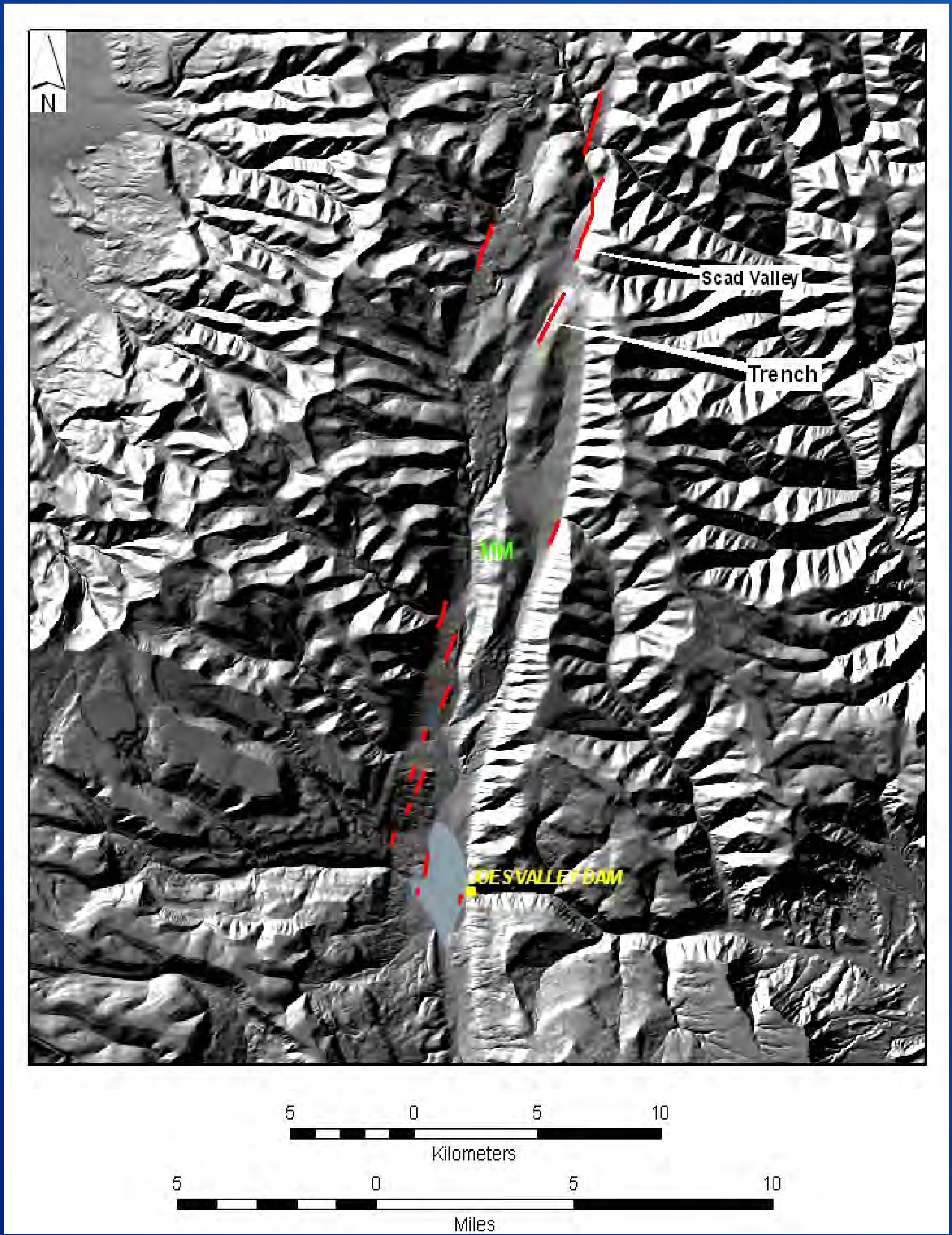
Is Joes Valley Fault Zone Seismogenic?



- This fault system appears very different than the Basin and Range to the west
- Valleys are narrow and scarps are relatively straight and discontinuous
- Similar valleys have formed related to collapse features formed from salt dissolution
- The Arapien shale is nearby and salt-rich.

RECLAMATION

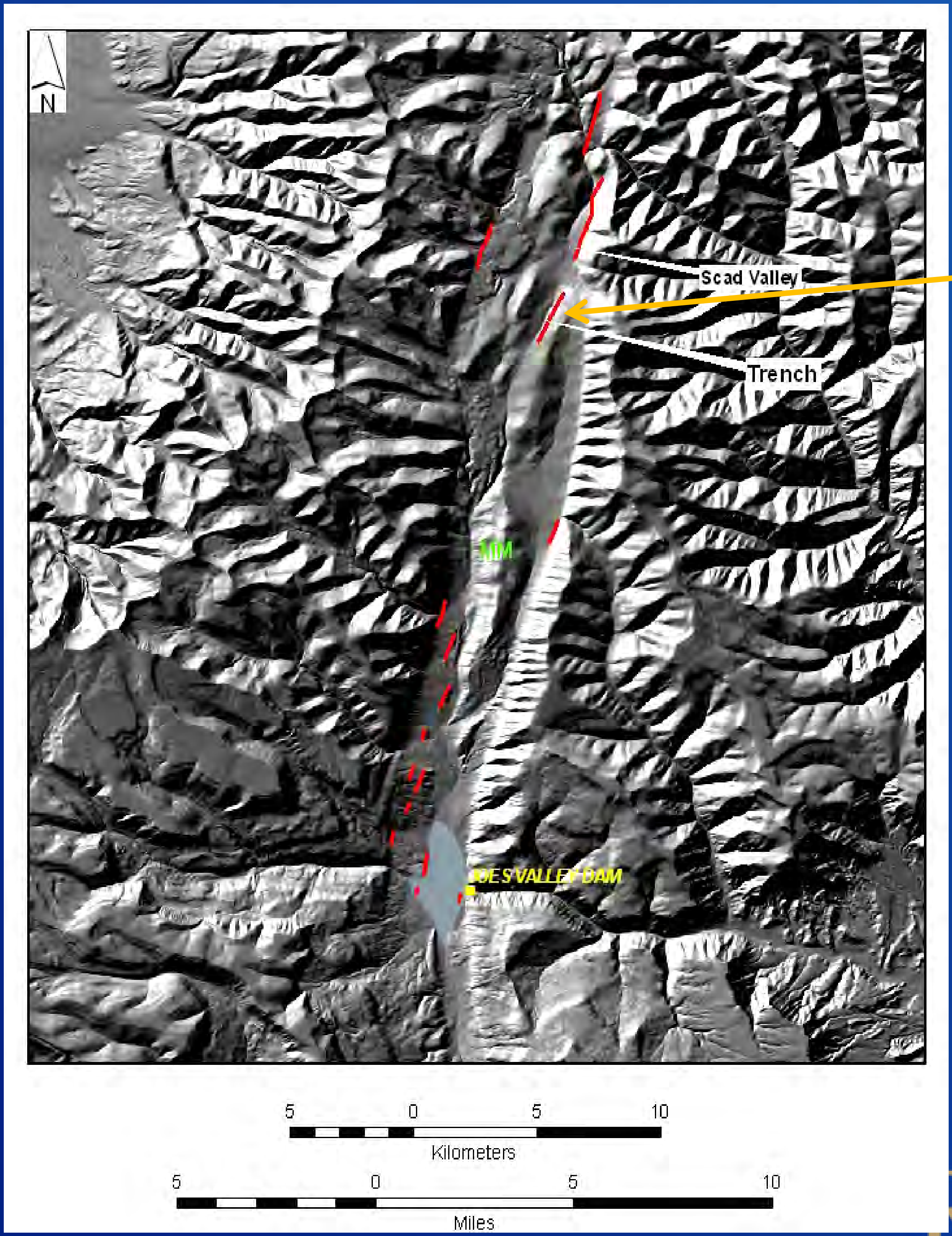
Geologic study (Foley and others, 1986)



- Mapping geology, lineaments, and scarps on aerial photographs and on the ground
- Identified graben-bounding and intragraben scarps in north Joes Valley
- Scarp profiles, 6 trenches, 20 soil pits, few charcoal dates

RECLAMATION

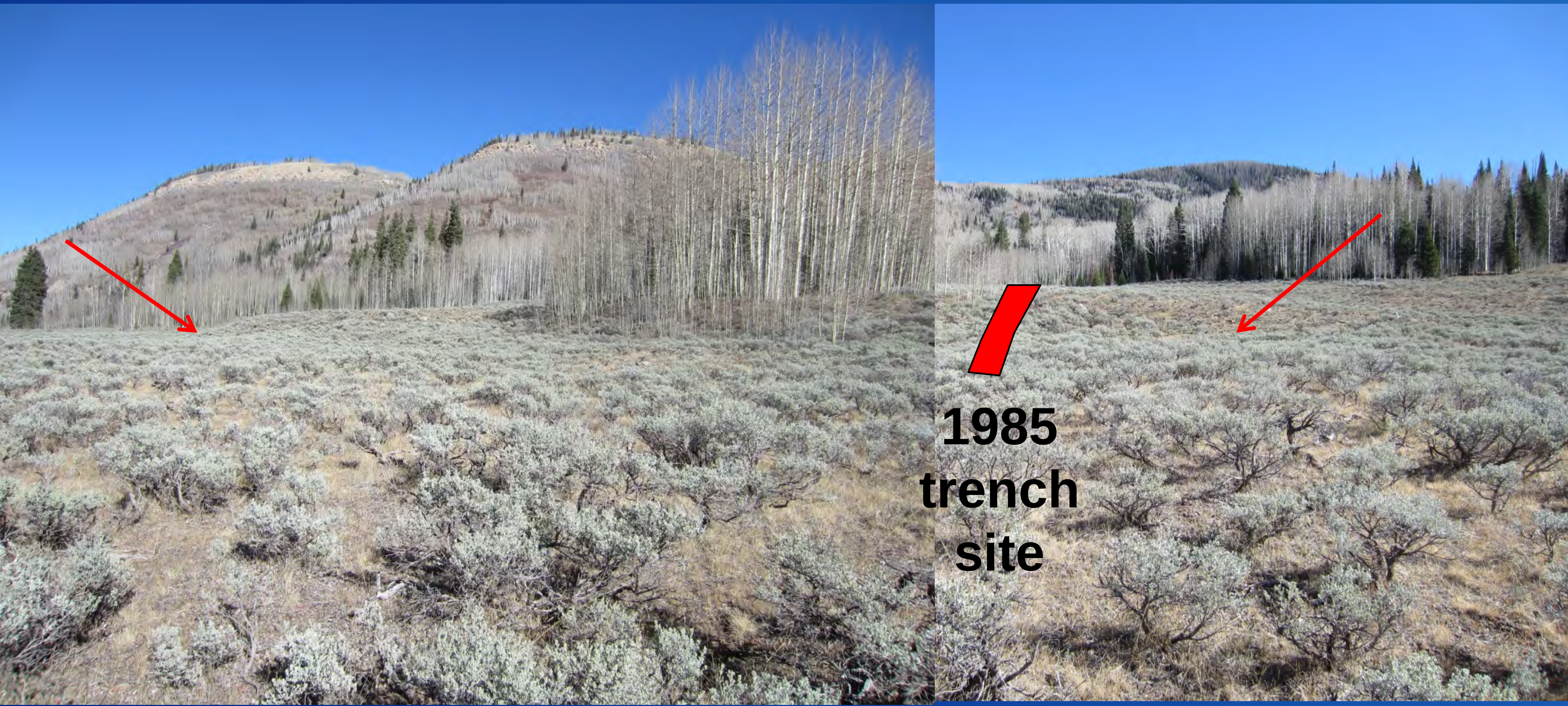
Scad Valley



Red lines—Fault scarps mapped by Foley and others (1986)

RECLAMATION

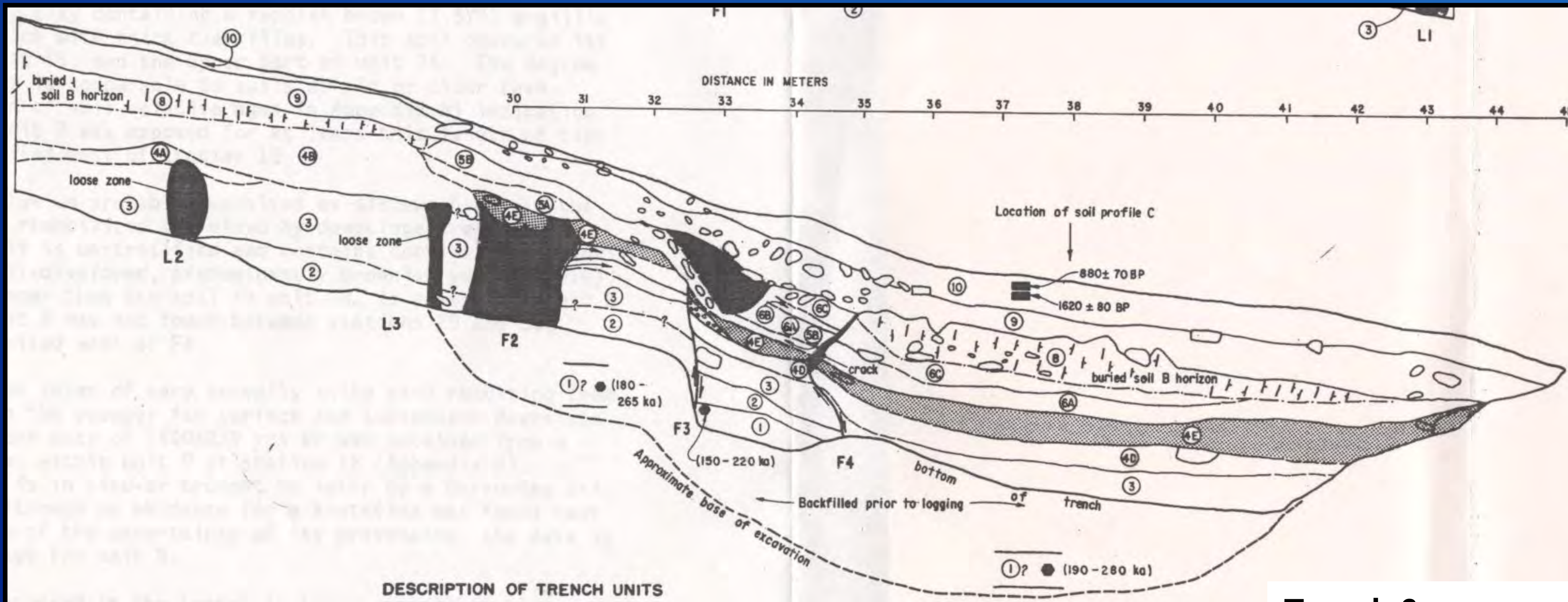
Scad Valley fault scarp



Scarp identified and trenched by Foley – this scarp was interpreted to have been formed by earthquakes

RECLAMATION

Scad Valley Fault Trench



Trench 6

Was assessed to be a 'typical' fault trench with evidence for :

≥ 4 faulting events <250 ka; 2 events <130 ka
Total vertical displacement about 3 m
Most recent event between 6.5 ka and 14-30 ka

RECLAMATION

Foley and others (1986) subsurface review

- Reviewed proprietary good quality seismic reflection profiles. Interpreted the Navajo Sandstone to be clearly disrupted and evidence for faults extending to 5-6 km, below which data was ‘incoherent’. Can not preclude the possibility the faults may extend to seismogenic depths.

- Micro-earthquakes suggest steep fault planes and at ~ 4.4 km, deeper than the Navajo Sandstone.

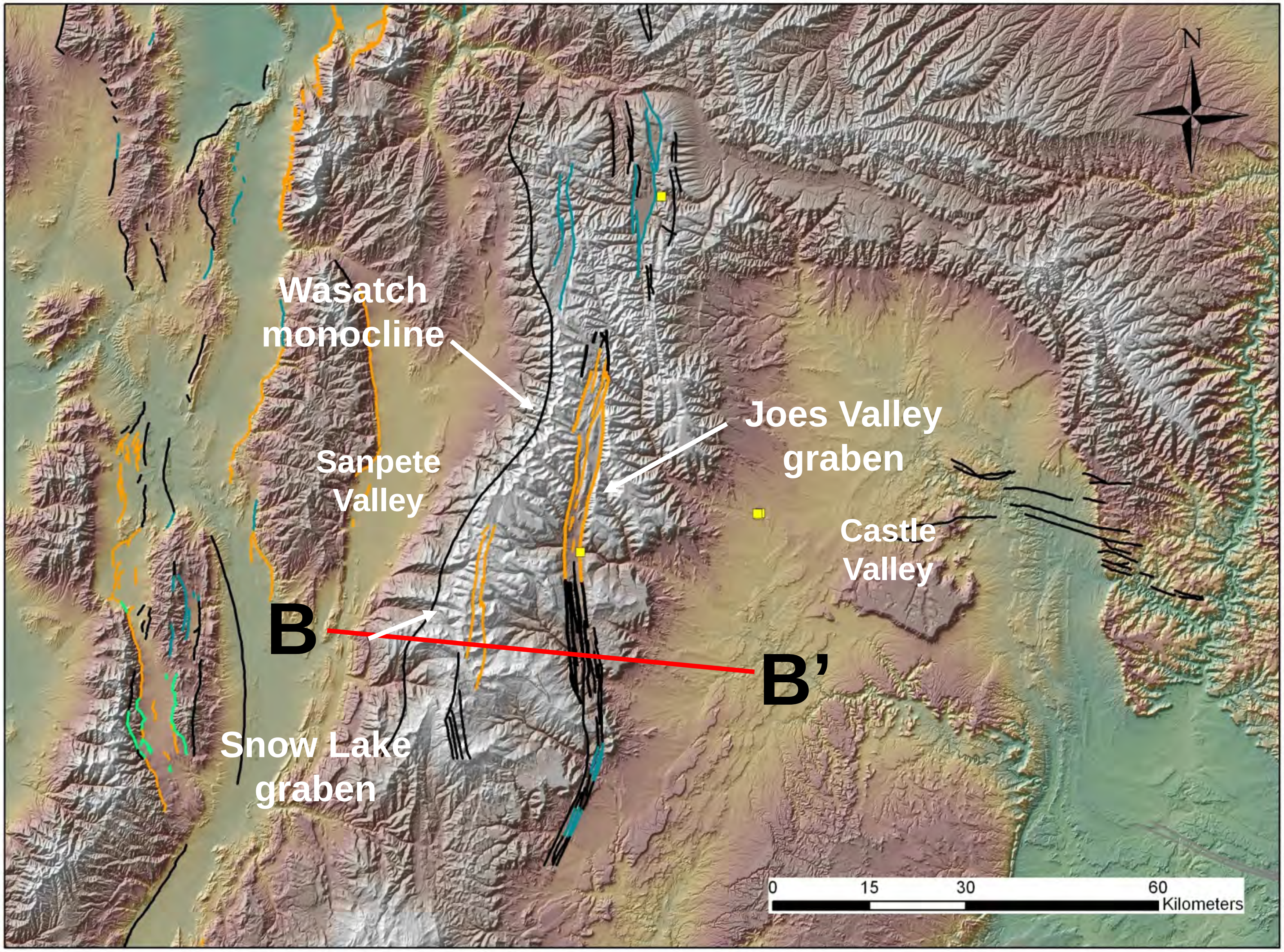
RECLAMATION

Results from Foley and others (1986) geologic study

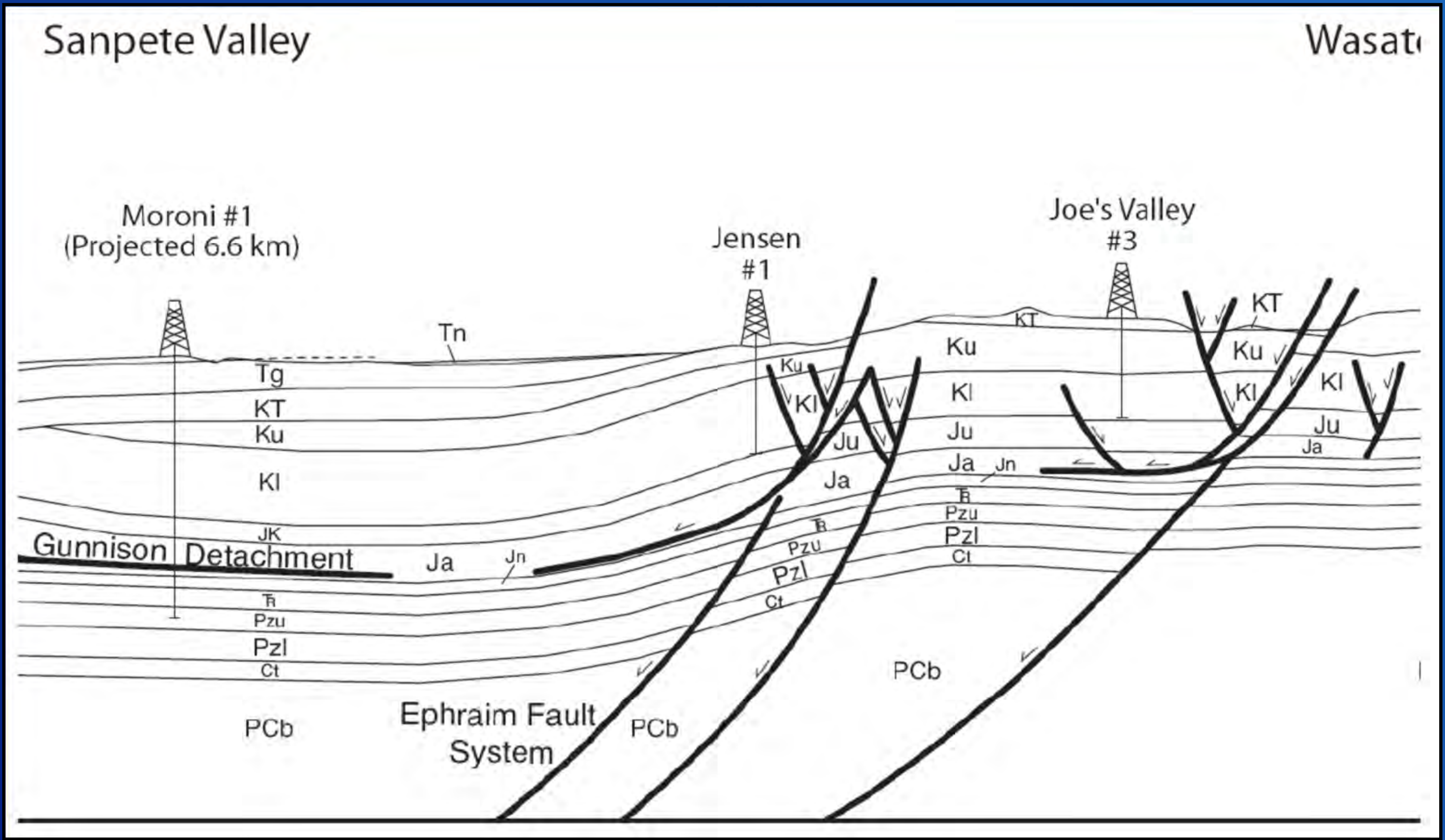
- Recurrent late Quaternary surface displacements in Northern Joes Valley graben (since 11 ka to 30 ka)
- Youngest event in early Holocene (11 ka to 6.5 ka); no scarps on younger Holocene surfaces
- Single-event vertical surface displacements of <1 to 5.5 meters
- Average recurrence about 10,000 to 20,000 years
- **Faults can generate large (7-7.5) earthquakes**

RECLAMATION

Schelling and others (2004)



Schelling and others (2004)
Part of balanced cross section B-B’



RECLAMATION

O’Connell and others (2005)

this study revisited Joe’s Valley fault studies because more subsurface data had become available.

Results: Identified **2 Possibilities** (inconclusive)

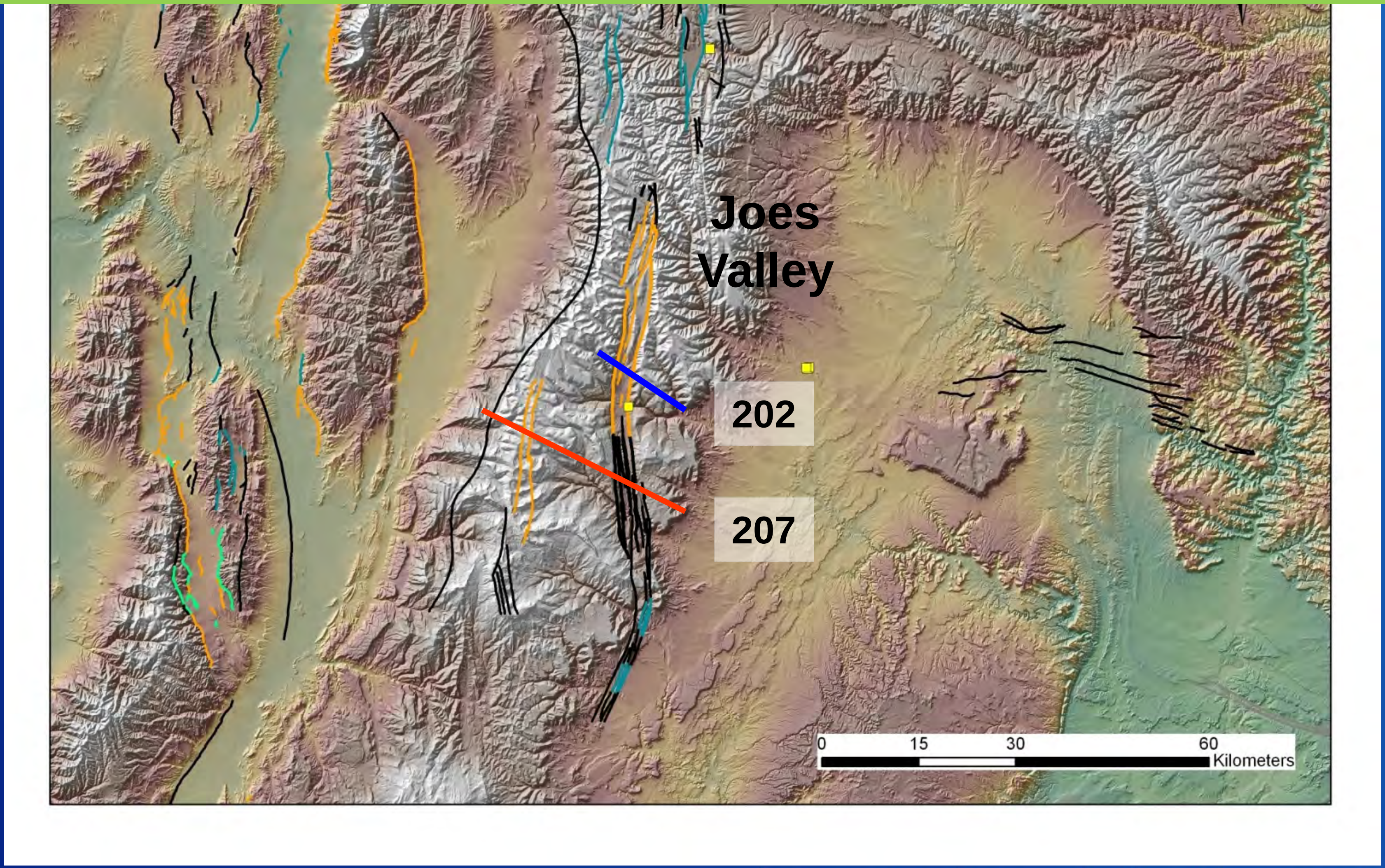
‘Case 1’ Joes Valley and other faults on Wasatch Plateau are fully seismogenic

‘Case 2’ Joes Valley and other faults on Wasatch Plateau are not seismogenic

RECLAMATION

• Subsurface Investigation Anderson (2008)

- New seismic reflection lines became available
- Jim Coogan (contract) interpreted seismic lines



Coogan in Anderson (2008)

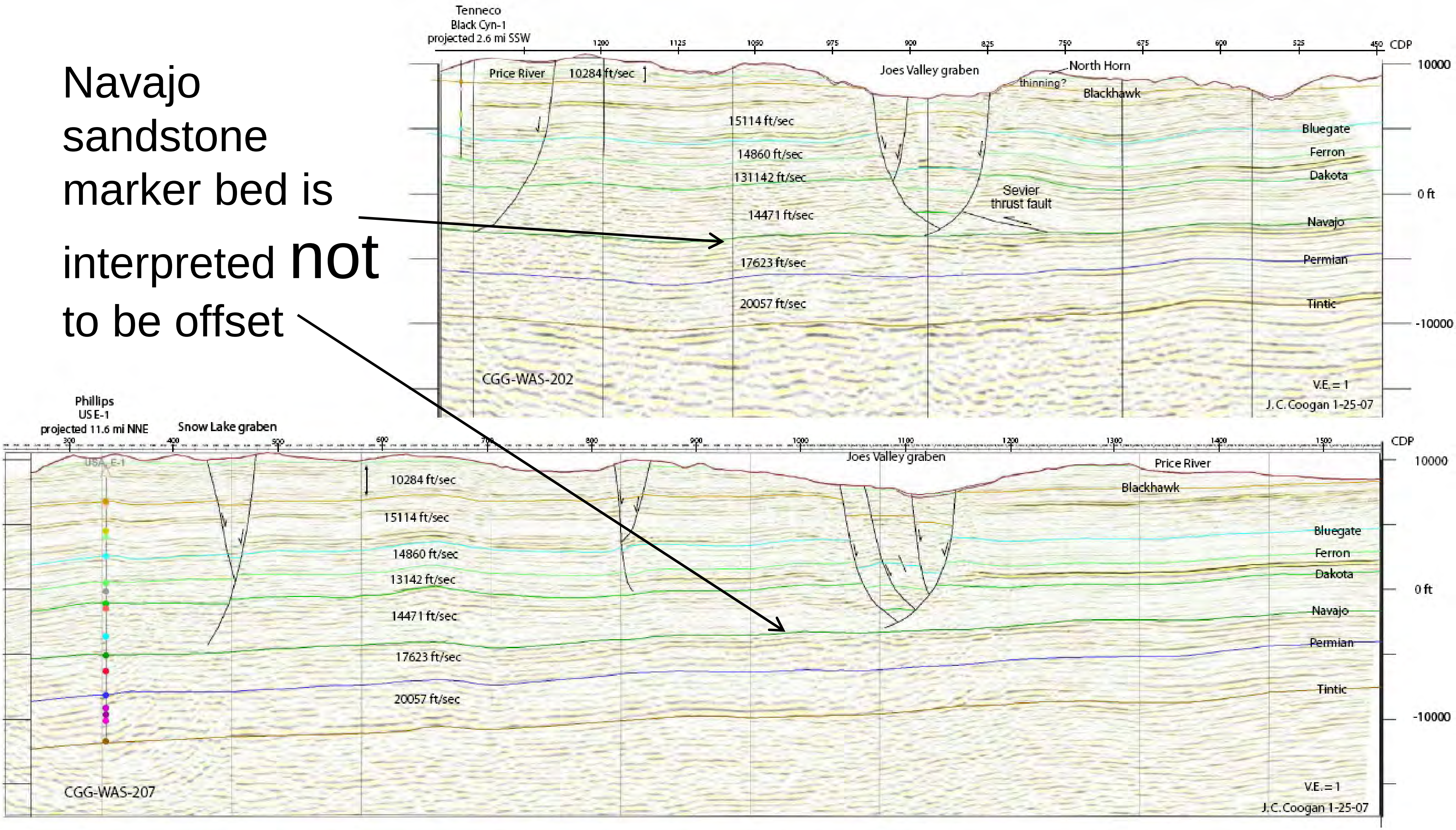
RECLAMATION

Subsurface Investigation 2008

NW

SE

Navajo sandstone marker bed is interpreted **not** to be offset



Coogan in Anderson (2008)

RECLAMATION

Other arguments suggesting Joes Valley faults are not typical of Basin and Range faulting and/or are not likely seismogenic

- Linearity of the faults
- Narrowness of graben
- Little or no net tectonic displacement across Joes Valley
- High vertical slip rates
- Steep fault dips
- Absence of older Quaternary basin fill

Anderson (2008)

RECLAMATION

CONCLUSIONS of Anderson (2008) –

Results

"Thus, **the result for Case 2 of O'Connell and others (2005**) is probably the preferred interpretation for representing the seismic hazard at Joes Valley Dam."
(Joes Valley and other faults on Wasatch Plateau are not seismogenic)

RECLAMATION

Ok Great! So problem solved, right?

Well…… not so much.

The need to explore this further was identified

Because the past studies were all BOR, we contracted Jim McCalpin to give this problem a fresh look

Evaluation of the Quaternary History of the Joes Valley Fault Zone, Huntington North Dam, Utah

Work by
Jim McCalpin
GEO-HAZ Consulting
For Bureau of Reclamation

Draft report dated 11/30/12

RECLAMATION

Jim’s work

- Evaluate the likely origin of scarps in Joes Valley graben
- Literature review of Joes Valley and Salt tectonic studies for comparison
- Week long reconnaissance mapping
- Review of subsurface data

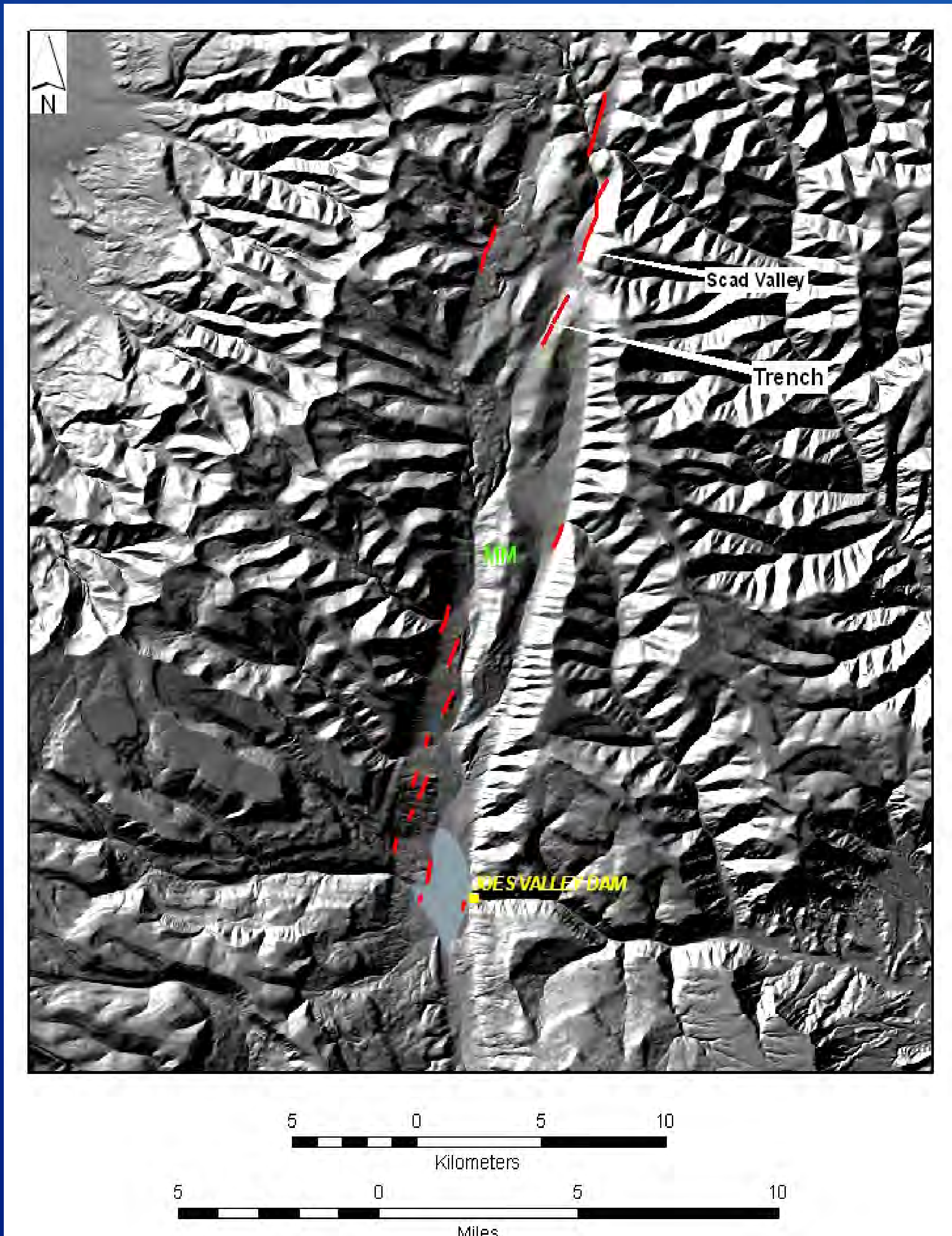
RECLAMATION

General thoughts on this problem

- Small scale features, such as scarps themselves, not clearly diagnostic of tectonic vs. non – tectonic setting.
- Of four reviews of subsurface data, only one interprets the faults as clearly shallow

Some new observations and ideas from McCalpin

RECLAMATION



Map pattern of intragraben faults suggestive of right-lateral component of displacement

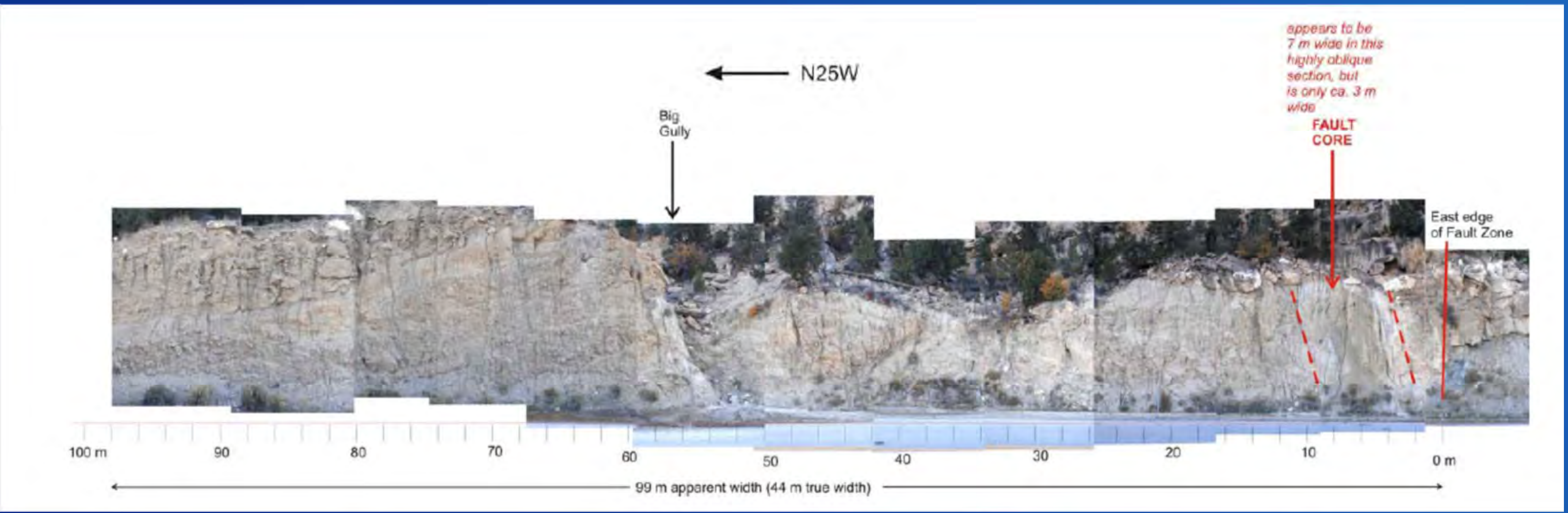
Left-stepping, en echelon pattern

Fault strike more to northeast than graben-Bounding faults

Red lines—Fault scarps mapped by Foley and others (1986)

Bedrock exposures in the fault zone near Joes Valley Dam

- Structural characteristics of fault zones in bedrock
- Macro-scale patterns of faulting

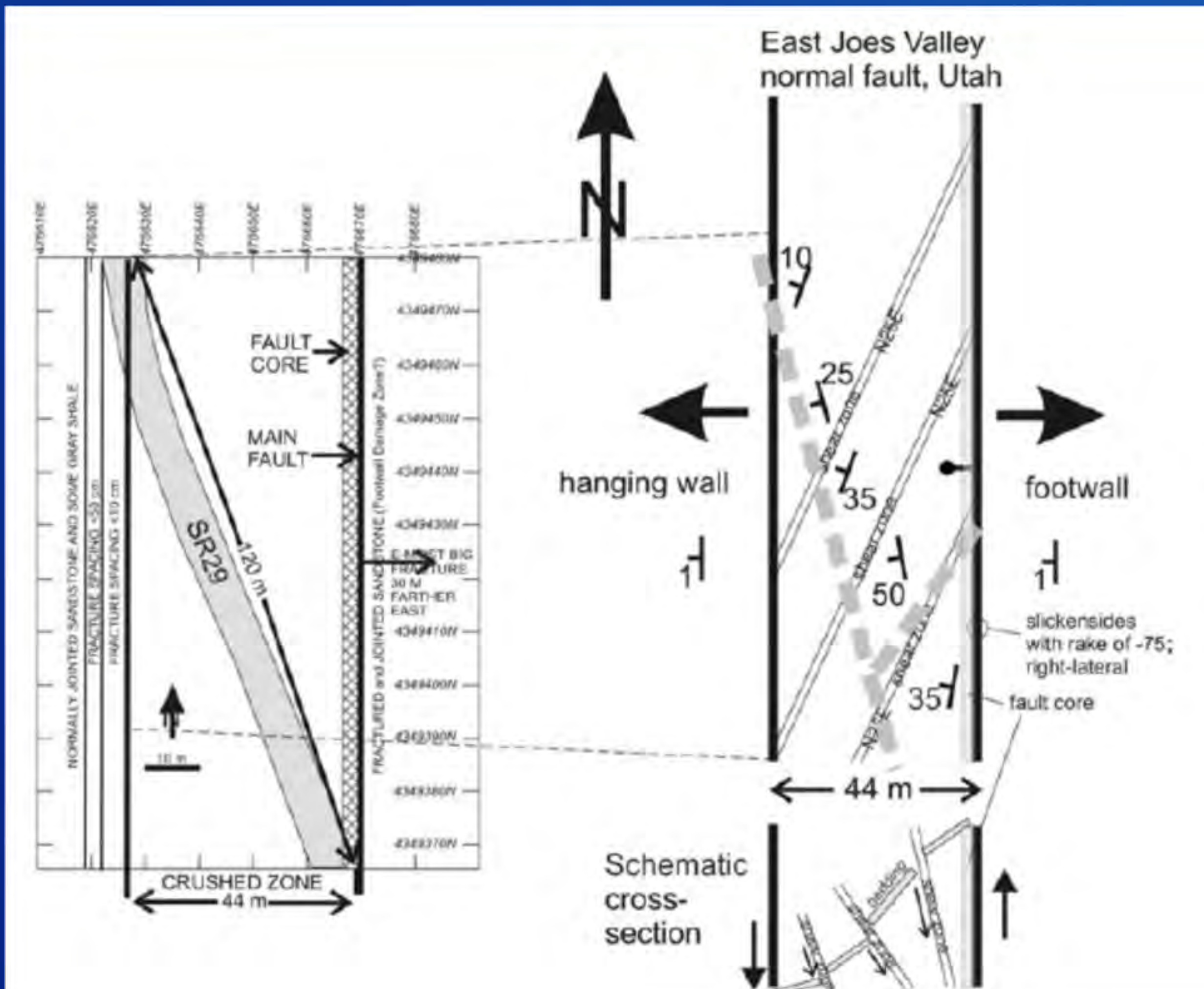


East Joes Valley fault
exposed in road cut on SR29 650 m north of Joes Valley Dam

McCalpin (in prep)

RECLAMATION

Rotation of bedding across shear zones and slickensides suggest a lateral component to faulting



Pattern, steep fault dip suggestive of **right-lateral component of ~25%. Orientation suggests Reidel Sheers**

McCalpin (in prep)

slickensides on footwall
in Castlegate Sandstone
fault plane N7W, 87°E
rake of slickensides ~15°

RECLAMATION

High slip rates

- Late Quaternary vertical slip rate (north Joes Valley) are 0.4 to 1.2 mm/yr (similar to vertical slip rates estimated for Wasatch fault)
- However – these rates were calculated on single faults within a complex graben and the dating was challenging at that time. So these rates may not be great estimates.
- Need to estimate net late Quaternary vertical slip rate across entire graben (need to sum across all active faults in the graben).

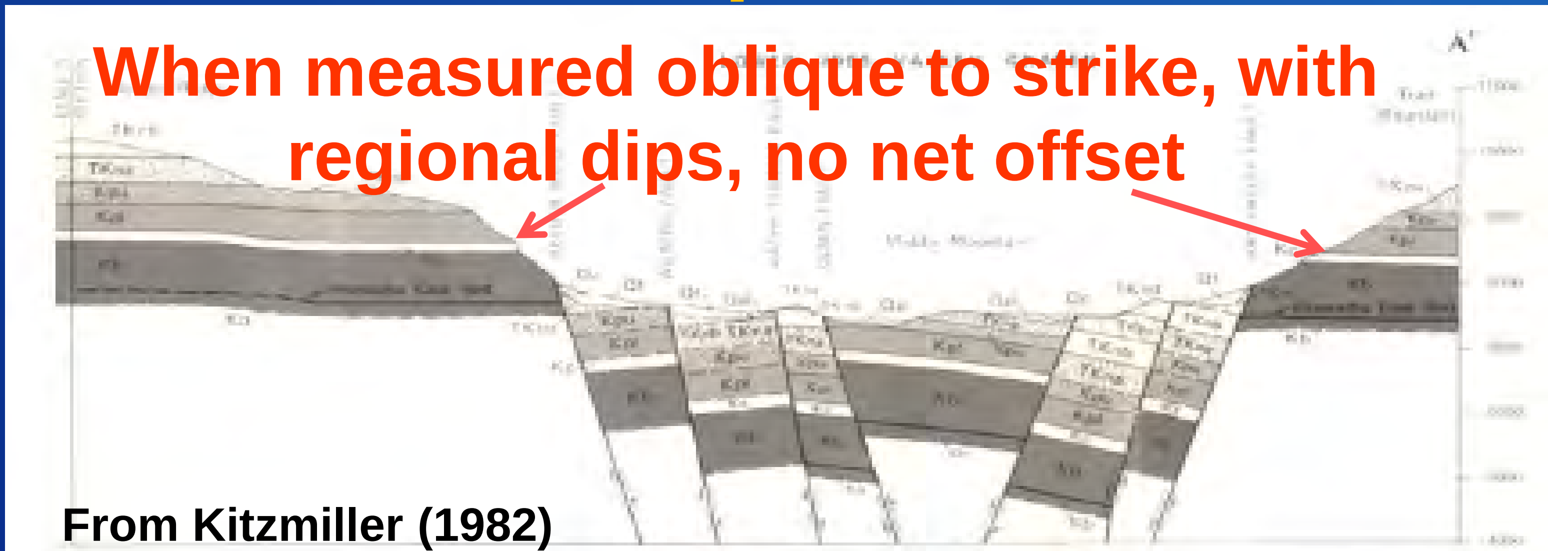
  1st order estimates using bedrock are ~ 0.02-0.05 mm/yr.

McCalpin (in prep)

RECLAMATION

Evaluation of “little or no net tectonic displacement”

When measured oblique to strike, with regional dips, no net offset



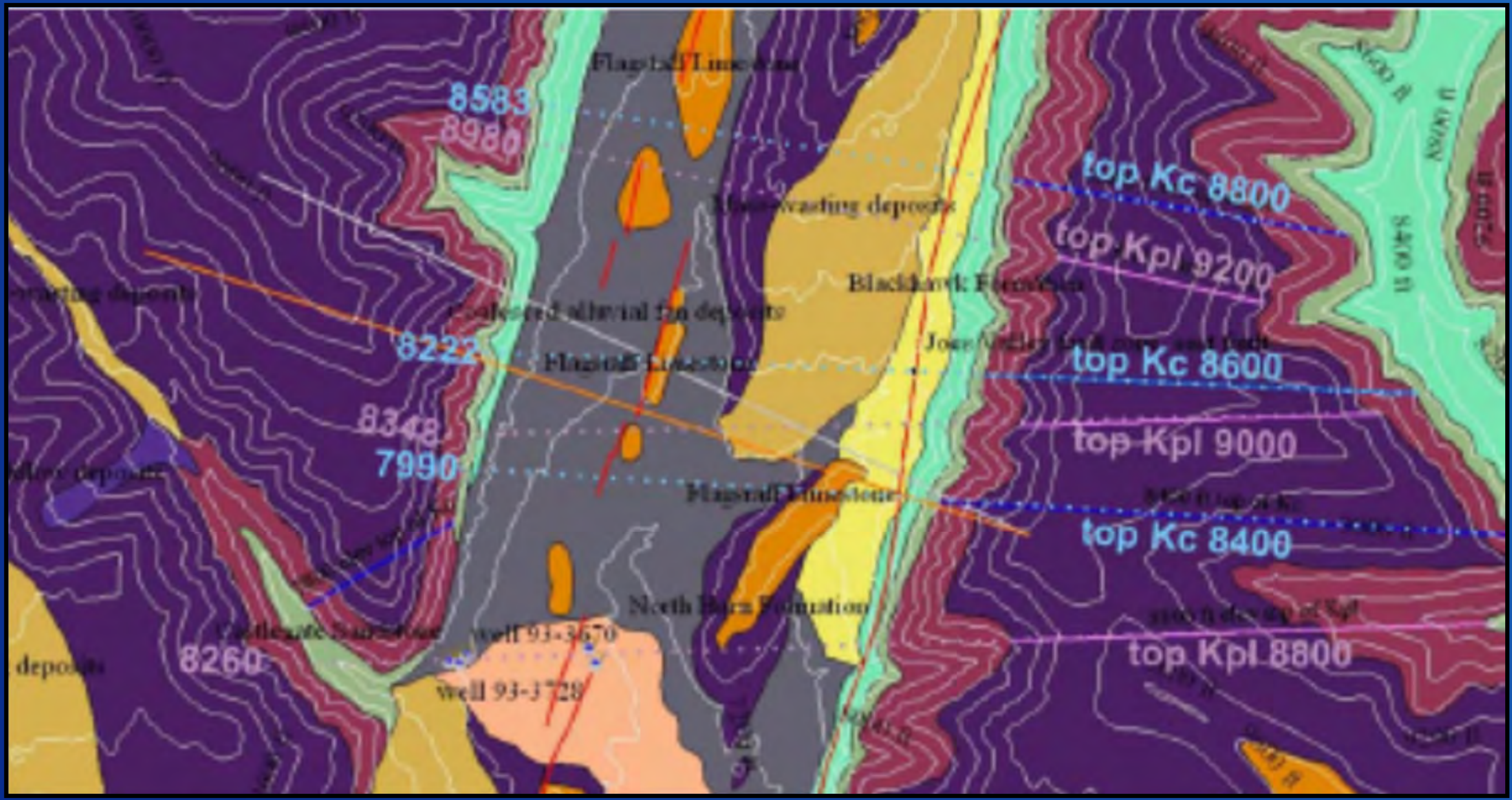
From Kitzmiller (1982)

When measured along strike with local dips, there is offset

Local bedrock dips are different in direction and magnitude than regional bedrock dips and early estimates were not made along strike. Locally it is clear that there is offset of bedrock units across Joes Valley

McCalpin (in prep)

Analysis of displacement across Joes Valley graben using bedrock mapping



Geologic formations on west side **215 to 540 feet lower** than on east side

- Interpret as down-to-the-west vertical offset across graben
- Indicates East Joes Valley fault is main fault and West Joes Valley is antithetic

McCalpin (in prep)

RECLAMATION

Reasons for absence of thick basin fill

- Joes Valley **graben is young** (early Quaternary?)
  - Apparently faults do not date from early Miocene Basin and Range extension
  - Seeley Creek and Ferron Canyon established before graben formed—flow across graben and not deflected through axial valley

McCalpin (in prep)

RECLAMATION

Arguments against a seismogenic interpretation

- Linearity of the faults
- Narrowness of graben
- Steep fault dips
- High vertical slip rates

- Little or no net tectonic displacement across Joes Valley
- Absence of older Quaternary basin fill

- Subsurface Data show faults do not extend deeper than ~ 3 km

RECLAMATION

Arguments against a seismogenic interpretation

- ~~Linearity of the faults~~
- ~~Narrowness of graben~~
- ~~Steep fault dips~~
- ~~High vertical slip rates~~

- ~~Little or no net tectonic displacement across Joes Valley~~
- ~~Absence of older Quaternary basin fill~~
- ~~Weak rocks possibly present at depths of about 3 km with resistant rock below????~~

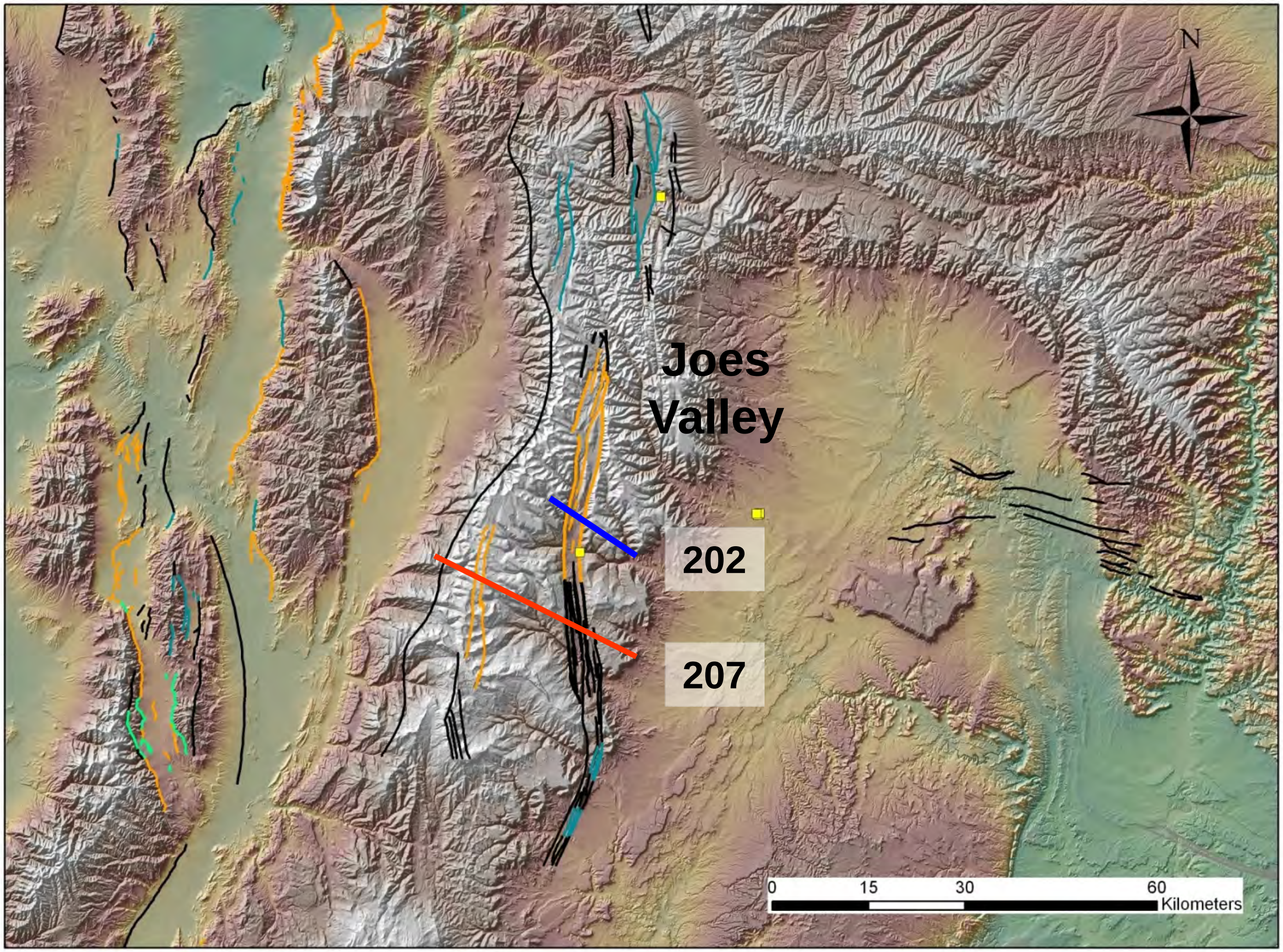
- **Subsurface Data show faults do not extend deeper than ~ 3 km**

RECLAMATION

OK, so there are explanations for geologic and geomorphic observations used to argue against a seismogenic structure, but what about the subsurface interpretations?

- Do the Joes Valley faults penetrate deeper than about 3 km depth and through the Navajo Sandstone (a strong reflector)?
- Can penetration to a depth below 3 km definitely be ruled out?

• Subsurface Investigation Anderson (2008)



Coogan in Anderson (2008)

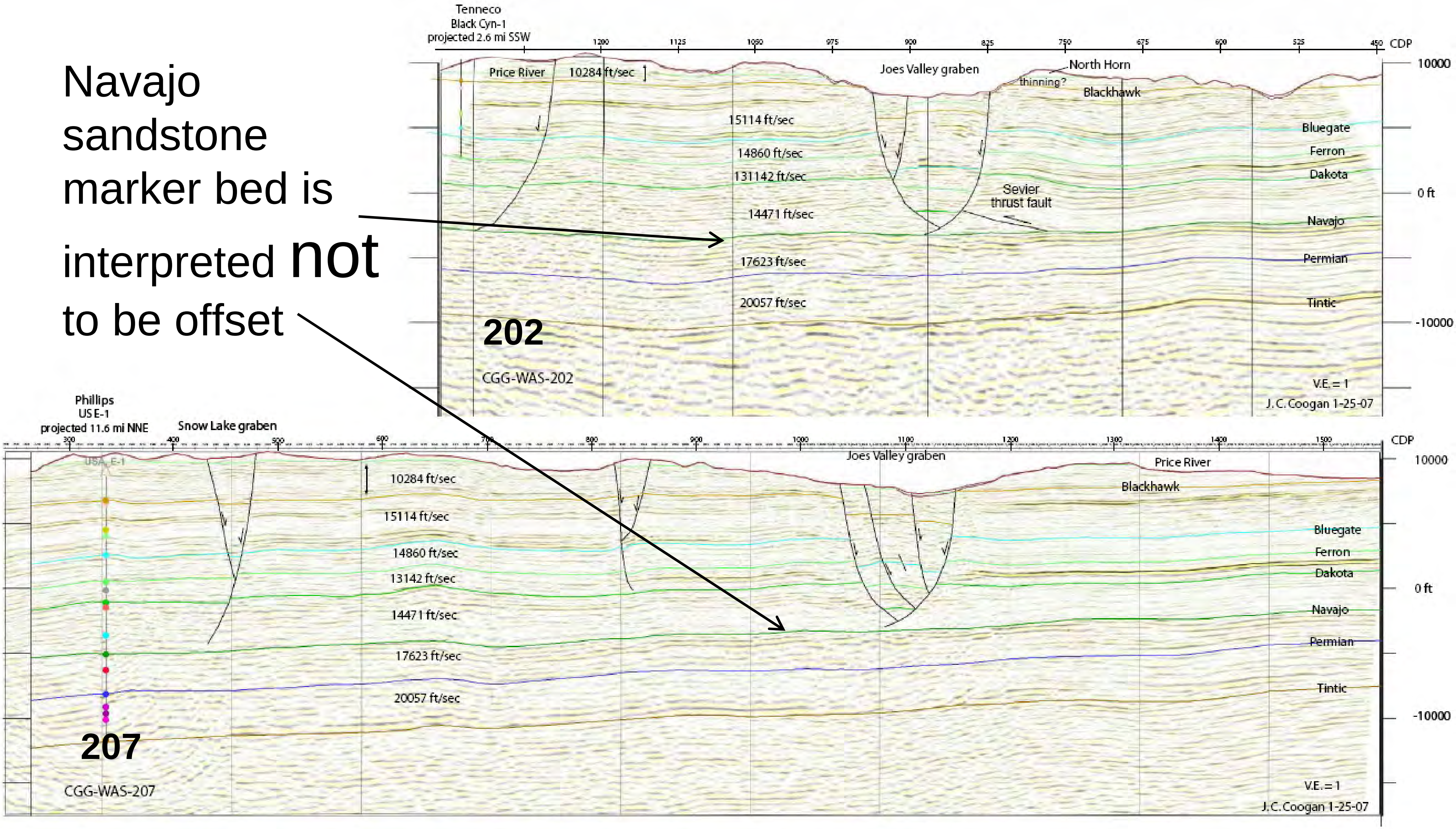
RECLAMATION

Subsurface Investigation 2008

NW

SE

Navajo sandstone marker bed is interpreted **not** to be offset



Coogan in Anderson (2008)

RECLAMATION

William Lettis & Assoc. (2008) interpreted the same data differently

NW

SE

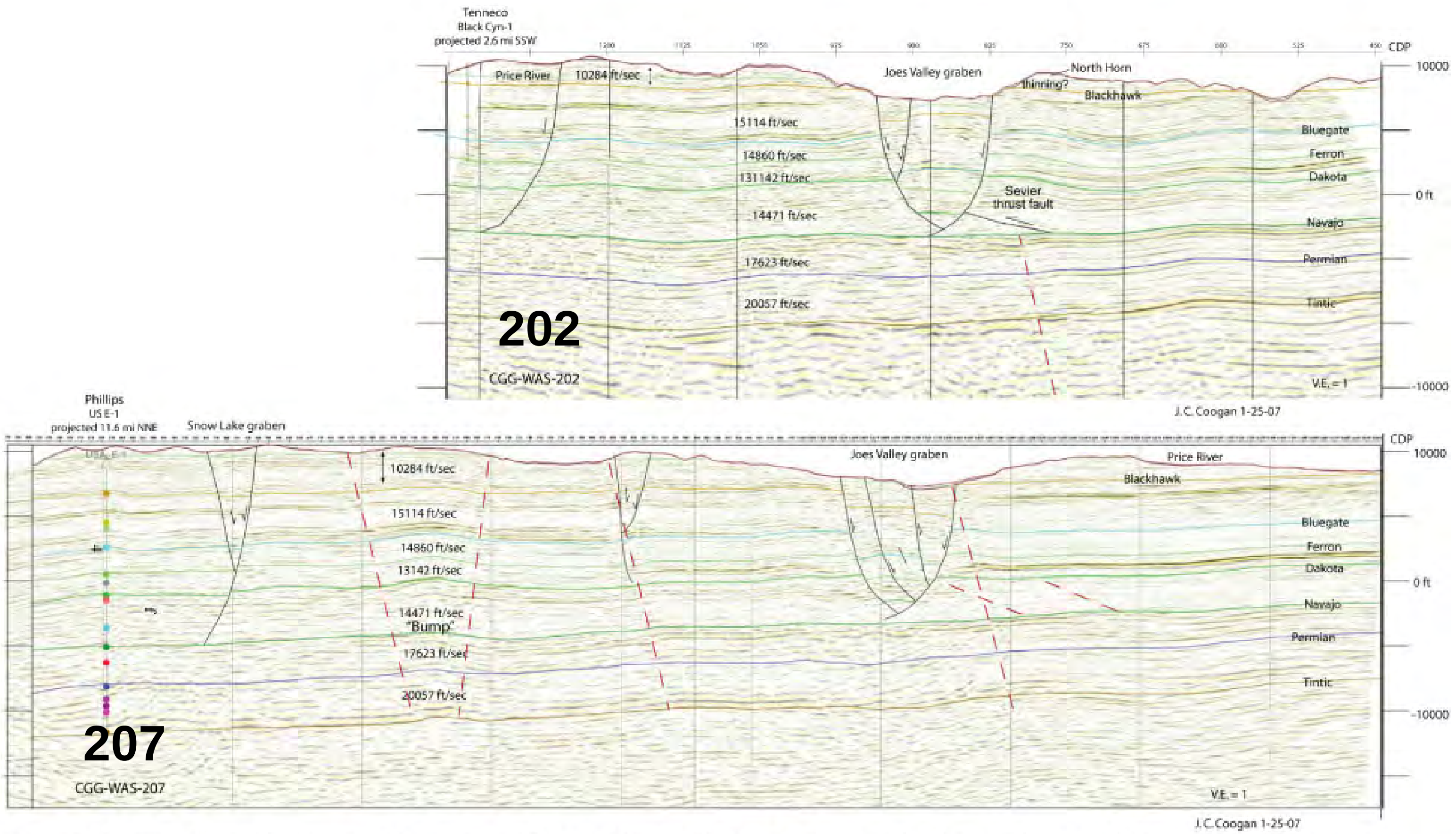
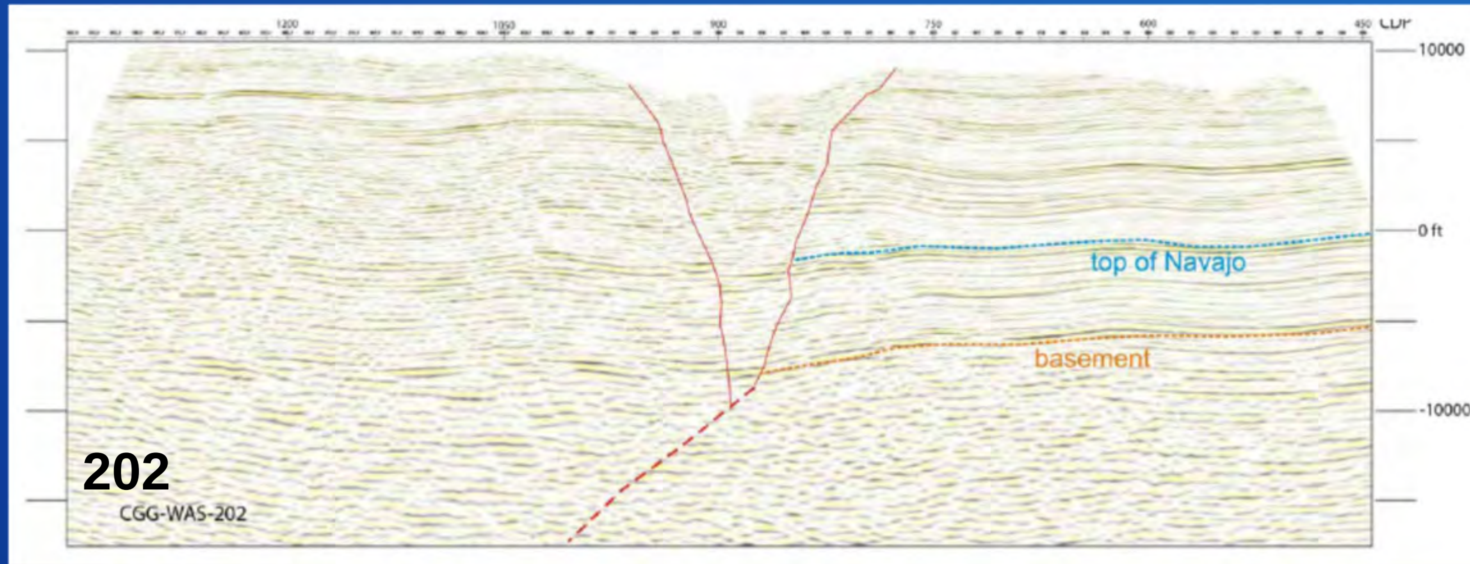
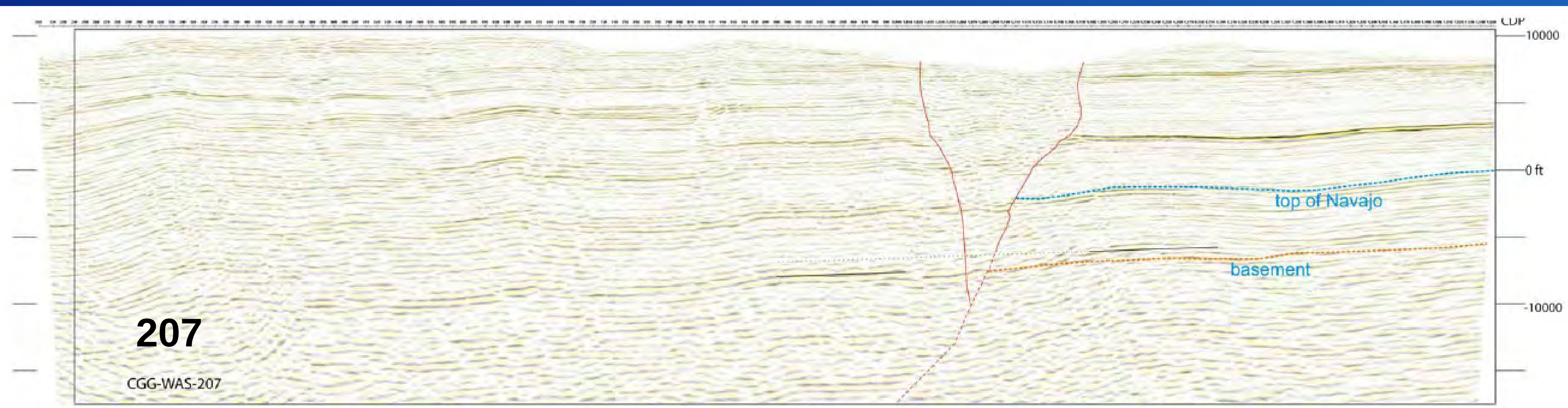


Figure R1. Figure 4 from the report with reverse fault/hinge lines indicated by the steeply-dipping dash red lines and thrust faults as the shallow-dipping dashed red lines. The "bump in CGG-WAS-207 indicates a region where the top of the Navajo is about 1000 ft higher to the west than the lowest portion of the synclinal folding of the top of the Navajo immediately east of the "bump"

McCalpin (in prep)

McCalpin (in prep) interpretation of same data





Top of Navajo Sandstone and basement interpretations from Coogan

McCalpin (in prep)

RECLAMATION

Current Interpretation of seismic lines

- faults that extend deeper than 3 km are possible
- regional geologic data suggests that shallow models not likely

Evidence for scarp origin is not perfectly clear

- Bedrock offset argues for tectonic.

- The footwall does not show changes in elevation, but the hanging wall does. This may suggest absolute motion is down in the graben and that argues for evaporite dissolution collapse structure.

- Willis (1986) - Arapien shale evaporite facies ends beneath Joes Valley and becomes limestone to the west. Also, it is not a thick unit near Joes Valley. Argues salt-related unlikely.

- Map pattern of en echelon faults imply strike-slip component - more commonly associated with tectonic features.

- Valley width : length ratios group Joes Valley clearly with salt related basins.

- Displacement : length ratios indicate tectonic is more likely than salt related

RECLAMATION

Conclusions and Recommendations from McCalpin (in prep)

- Interpretation that Joes Valley faults extend to seismogenic depths possible on seismic reflection profiles and seems likely when combined with regional geology

- Joes Valley faults should be included in PSHA

- East Joes Valley fault and intragraben faults are accommodating some right-lateral slip--Faults are normal oblique

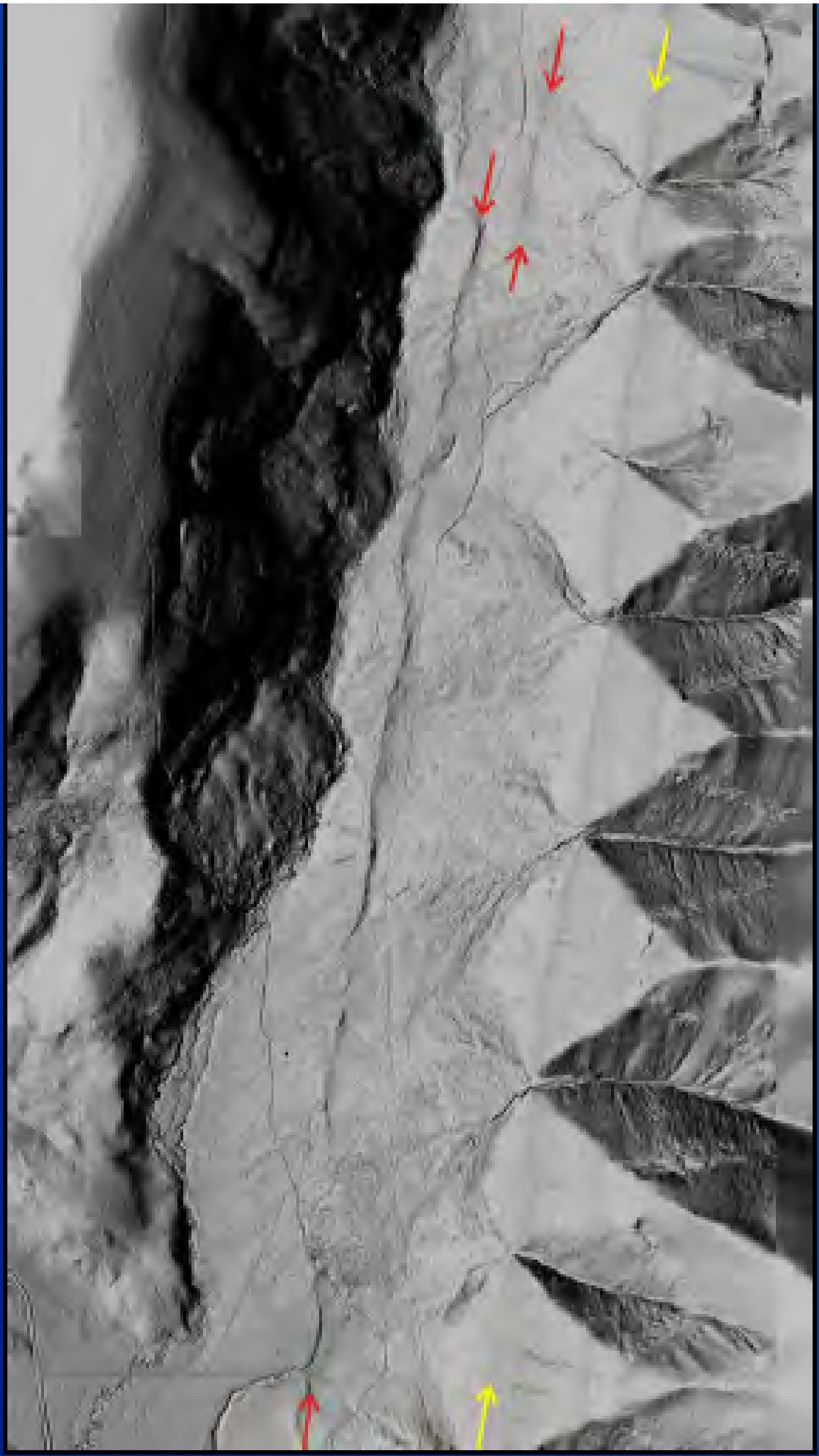
Recommends: characteristics of Joes Valley fault be refined

RECLAMATION

Is the surficial work completed in 1986 adequate to characterize Joes Valley Fault Zone?

- More complete mapping may help better characterize the style of faulting and seismogenic potential.

  - Scarps are not mapped completely
  - Event horizons are not well dated
  - Recurrence interval estimates need to be improved
  - Fault behavior (ie segmentation) should be evaluated
  - Trench data could be improved with modern techniques.



LiDAR hillshade from State of Utah
(only for this portion of Joes Valley)

An example of the need for more mapping:

LiDAR of Indian Creek Area

East Joes Valley fault (yellow arrows)

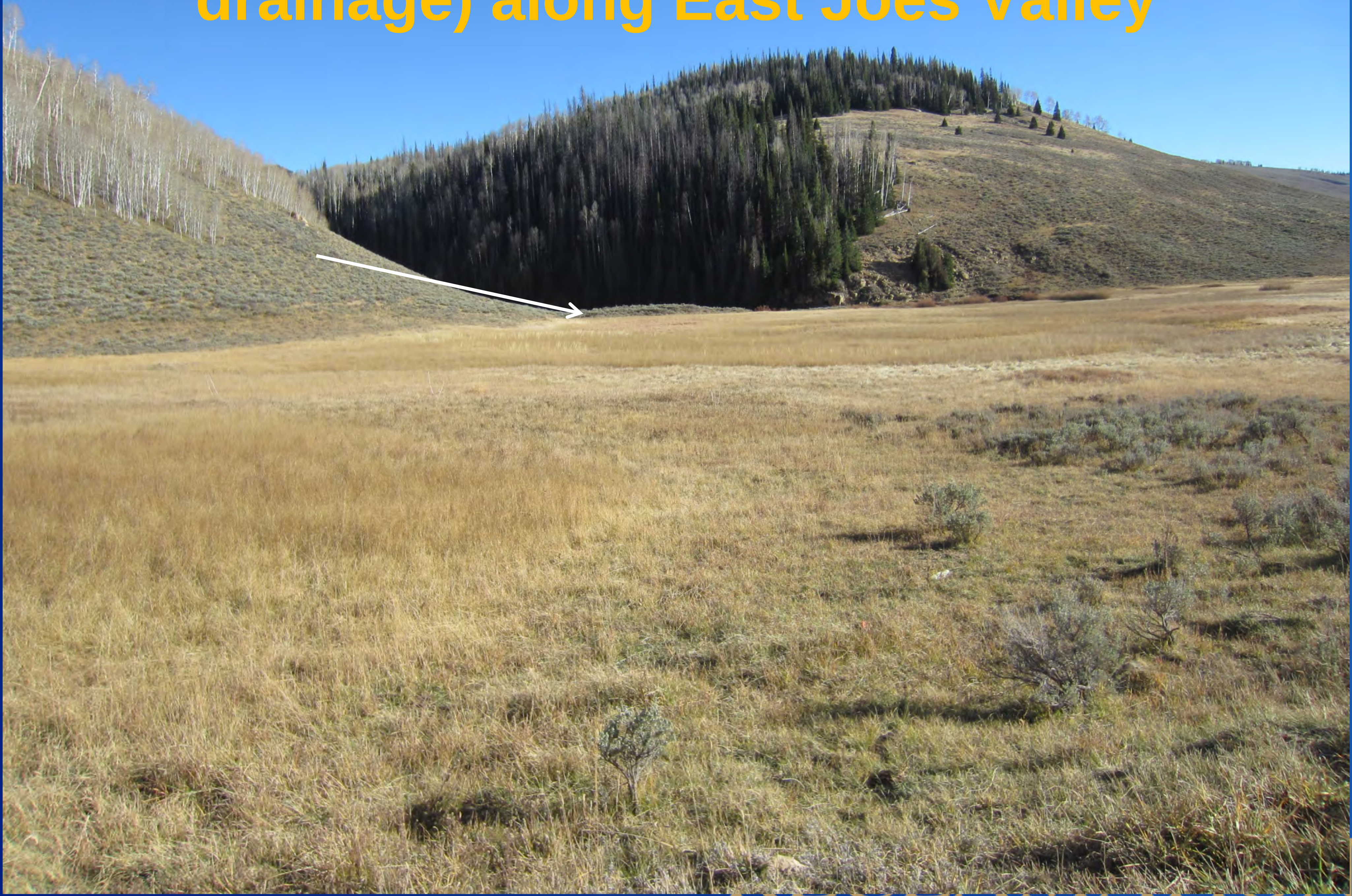
Red arrows show faults not previously identified

Antithetic fault across valley floor (red arrows)

- **Trends north**
- **7 km long**
- **Scarp faces east**
- **Scarp up to 1.8 m high**
- **Beheaded drainage suggests at least 2 late Quaternary surface rupture**

RECLAMATION

Previously unmapped scarp (beheaded drainage) along East Joes Valley



Future Work (?)

So,

Likely starting this Spring, the USBR will:

•Have LiDAR flown of the valley
•Proceed with more detailed geomorphic mapping of Joes Valley
•Trench more scarps within Joes Valley

And……..
Whatever other approaches we can come up with that may help solve this problem.

RECLAMATION

Questions and/or thoughts?

RECLAMATION

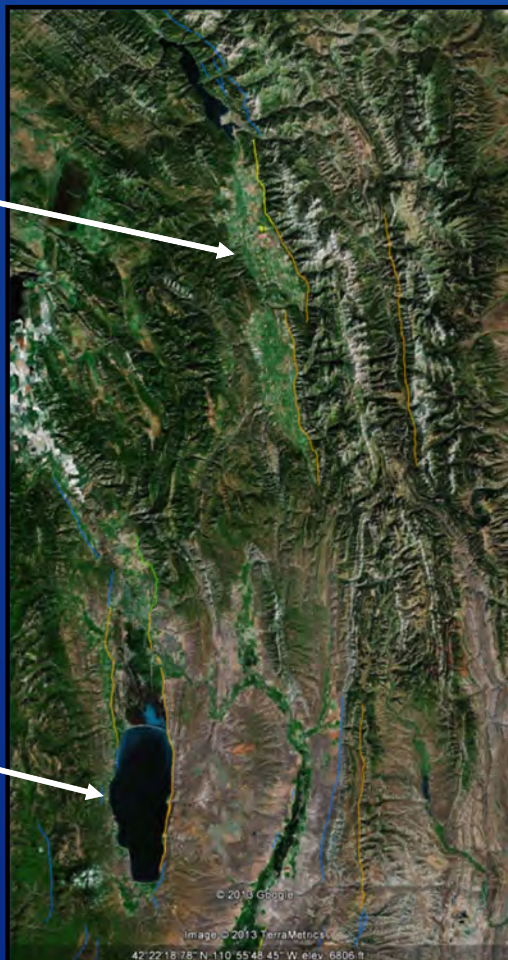
Ferron Canyon

RECLAMATION

Joes and Snow Lake Valleys are not like 'typical' Basin and Range Valleys

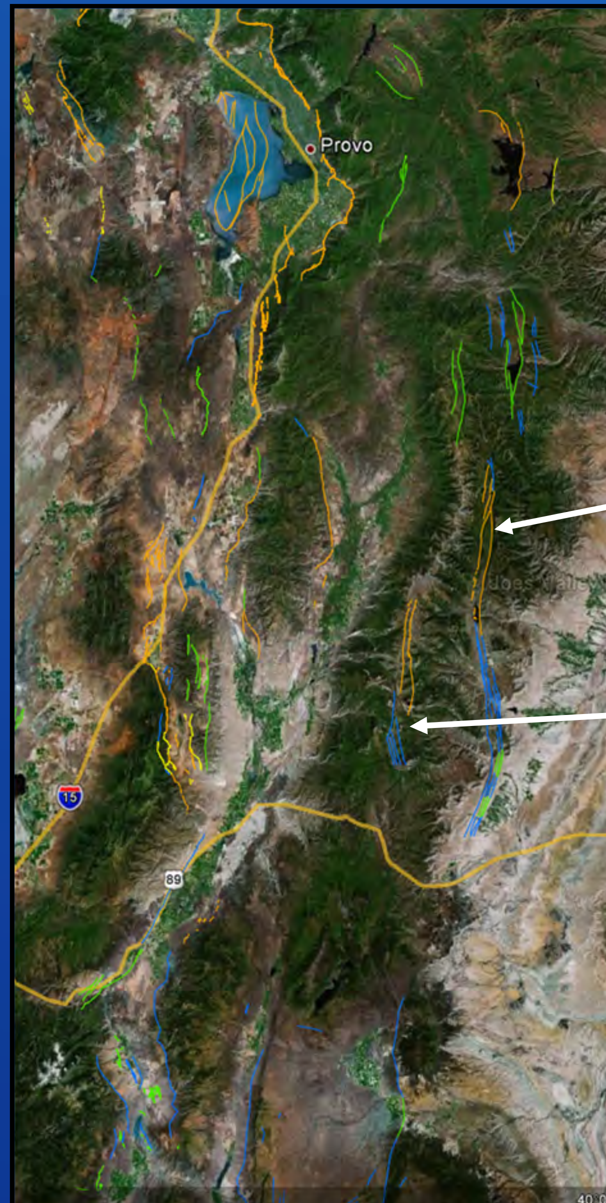
Basin and Range Valleys

Star Valley



Bear Lake Valley

Faults are more sinuous



More Narrow, linear Valleys

Joes Valley

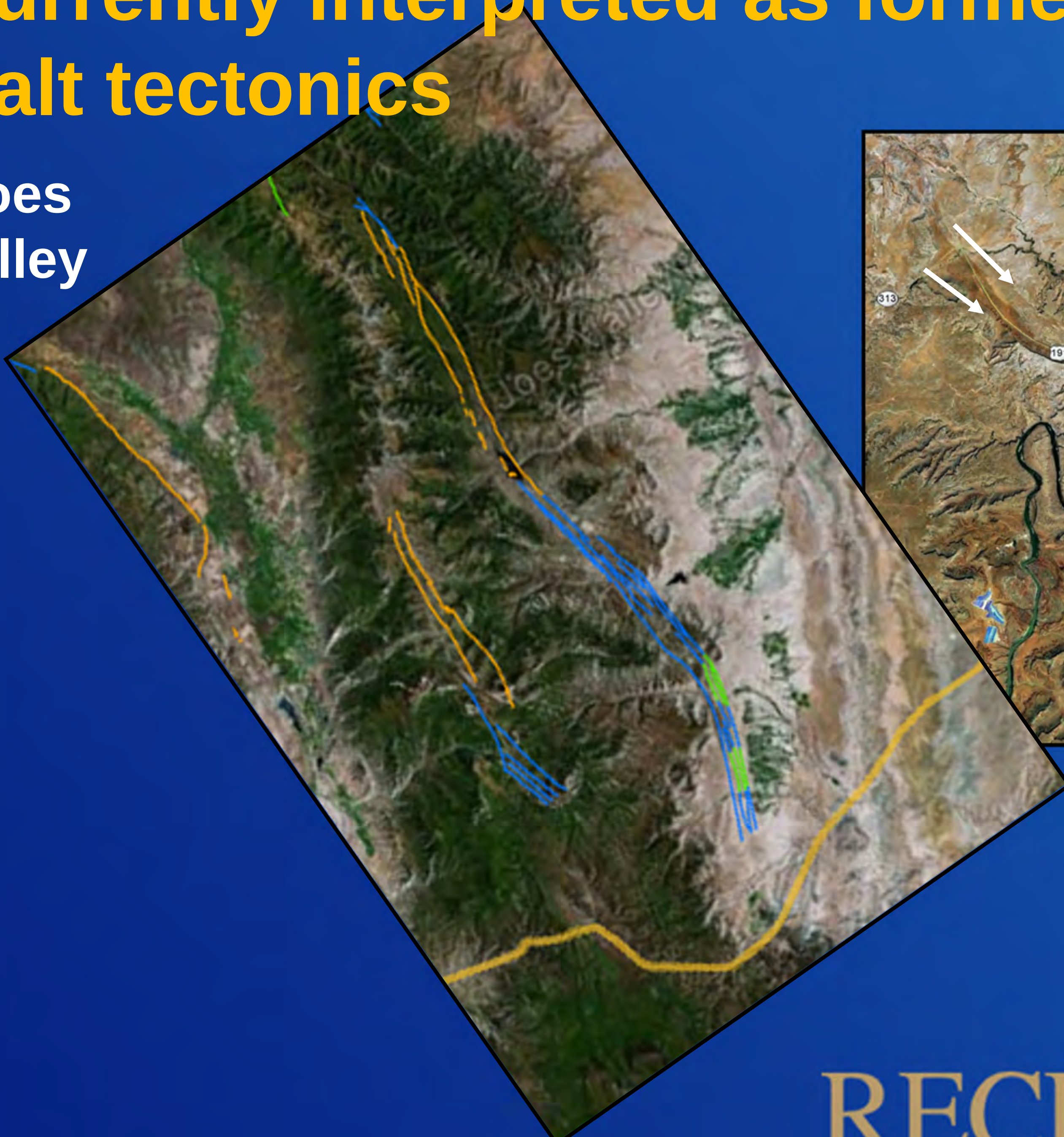
Snow Lake Valley

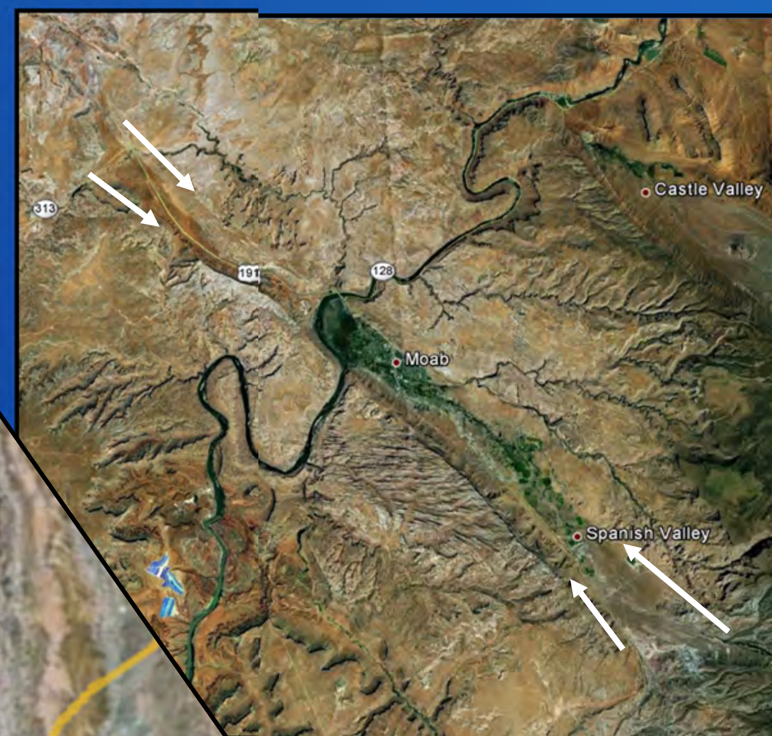
Faults are more linear

RECLAMATION

Joes Valley is similar to Spanish Valley, currently interpreted as formed as a result of salt tectonics

Joes Valley





Spanish Valley

RECLAMATION

Fault Scarps

Foley's fault scarps in North Joes Valley

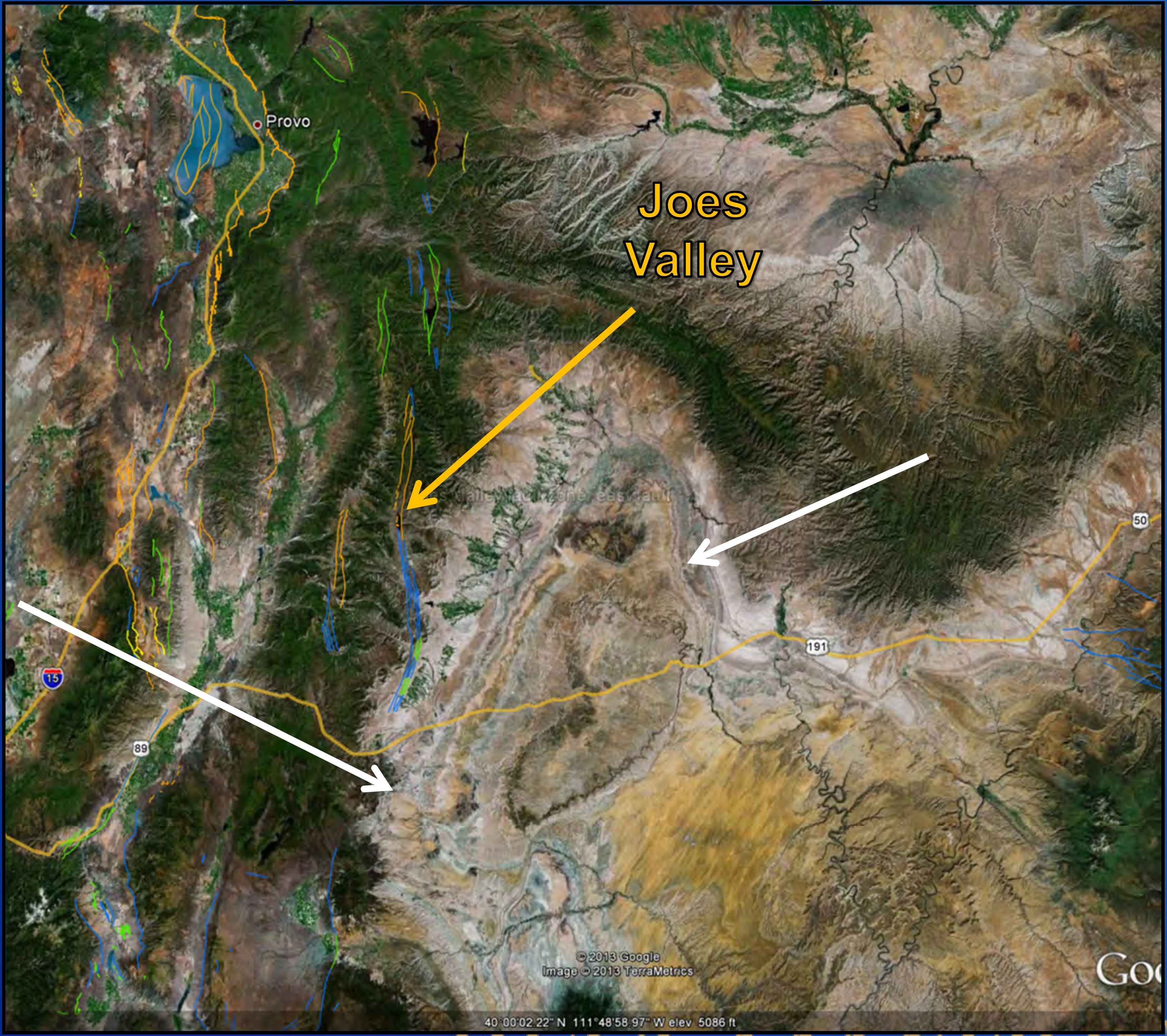
Foley's fault scarps near Joes Valley Dam

RECLAMATION

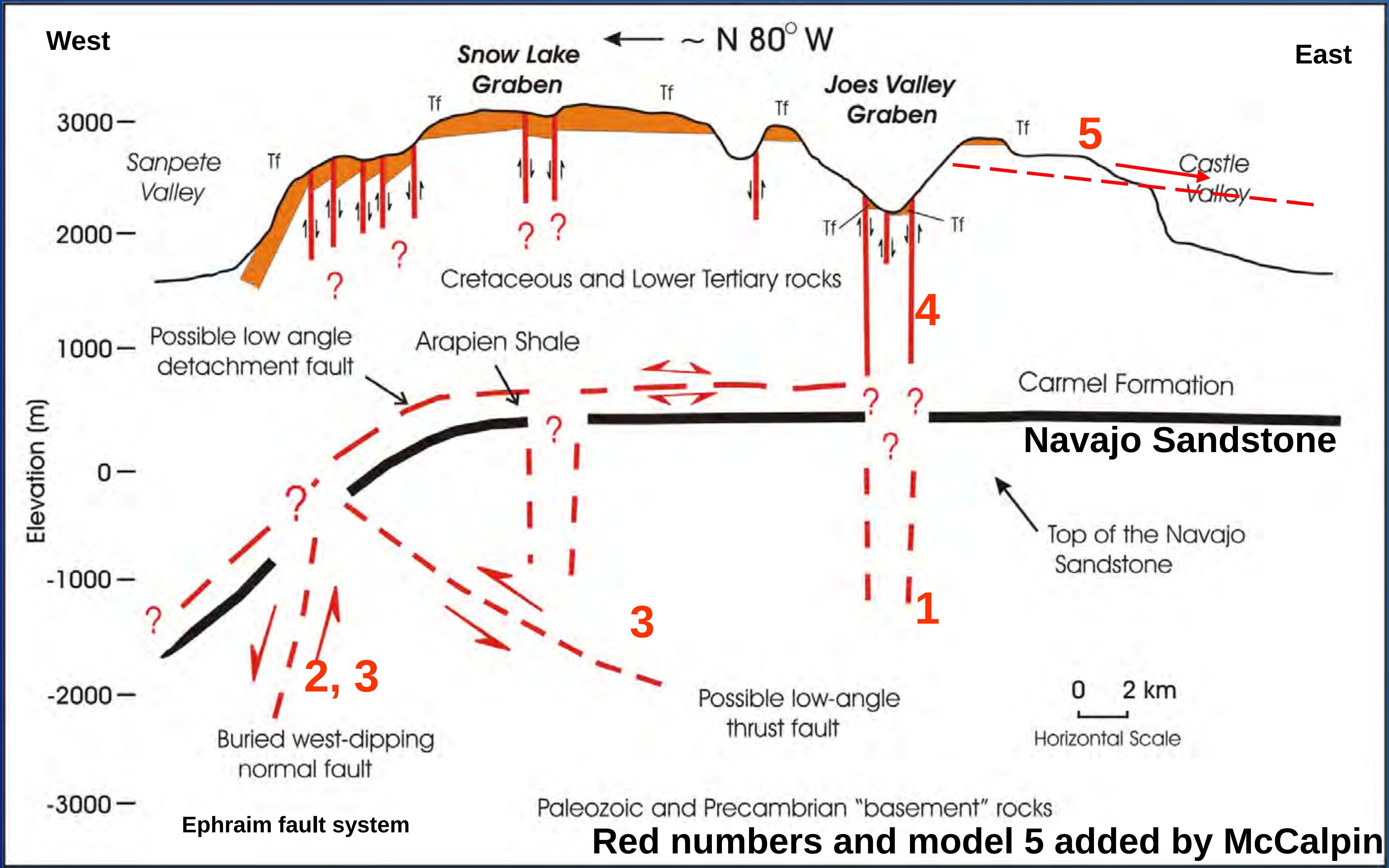
Close Proximity to salt-rich deposits

White arrows point to **ROUGHLY** the location of the salt-rich bedrock units

HOWEVER, these bedrock units remain ≥ 3 km deep in Joes Valley itself & the salt-rich facies may transition to limestone at Joes Valley



Diagrammatic cross section across Wasatch Plateau in area of Joes Valley



Orange is Eocene-Paleocene Flagstaff Limestone

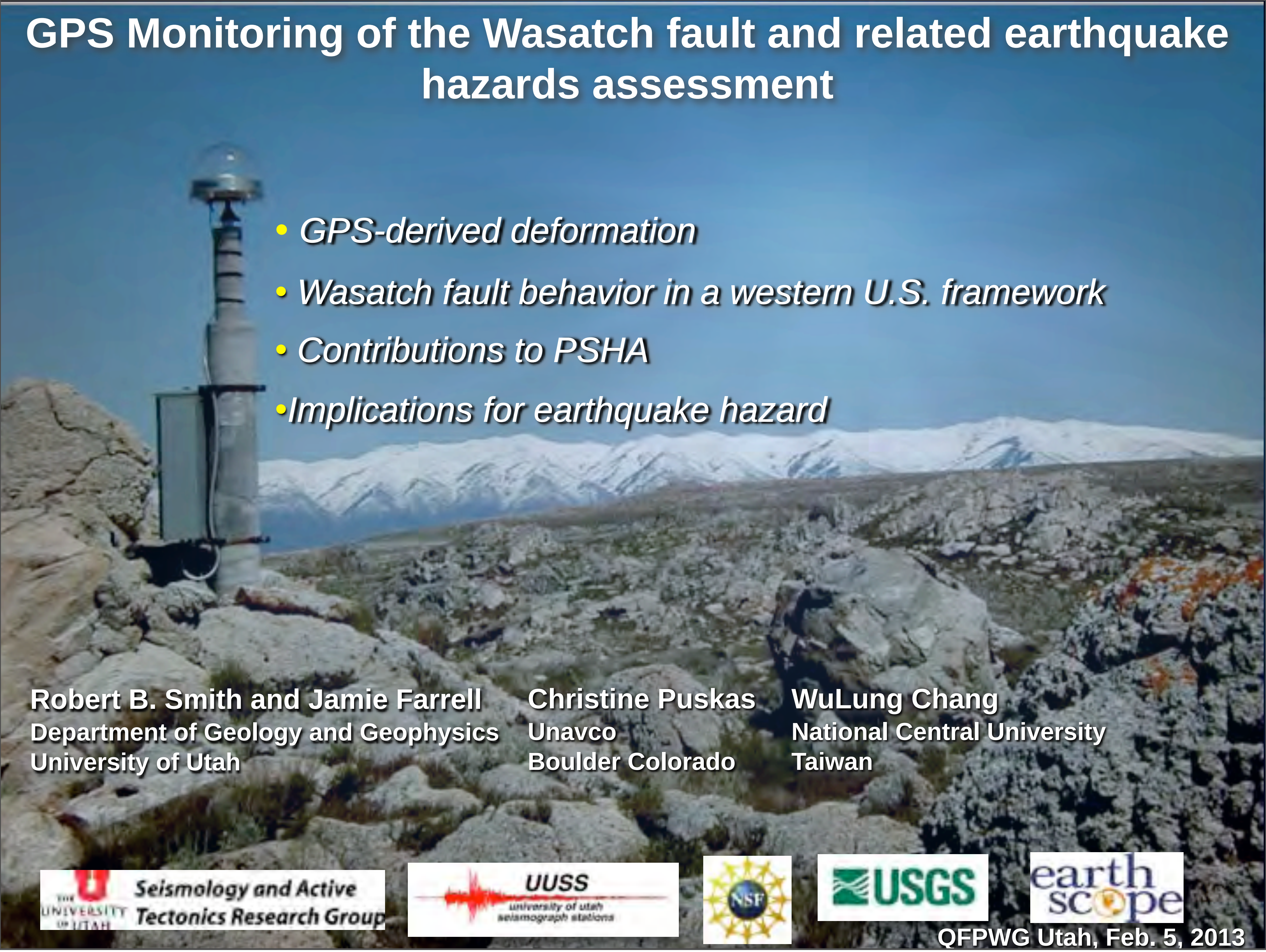
Vertical exaggeration is about 3 X

Anderson and Mahrer (2002)
O'Connell and others (2005)

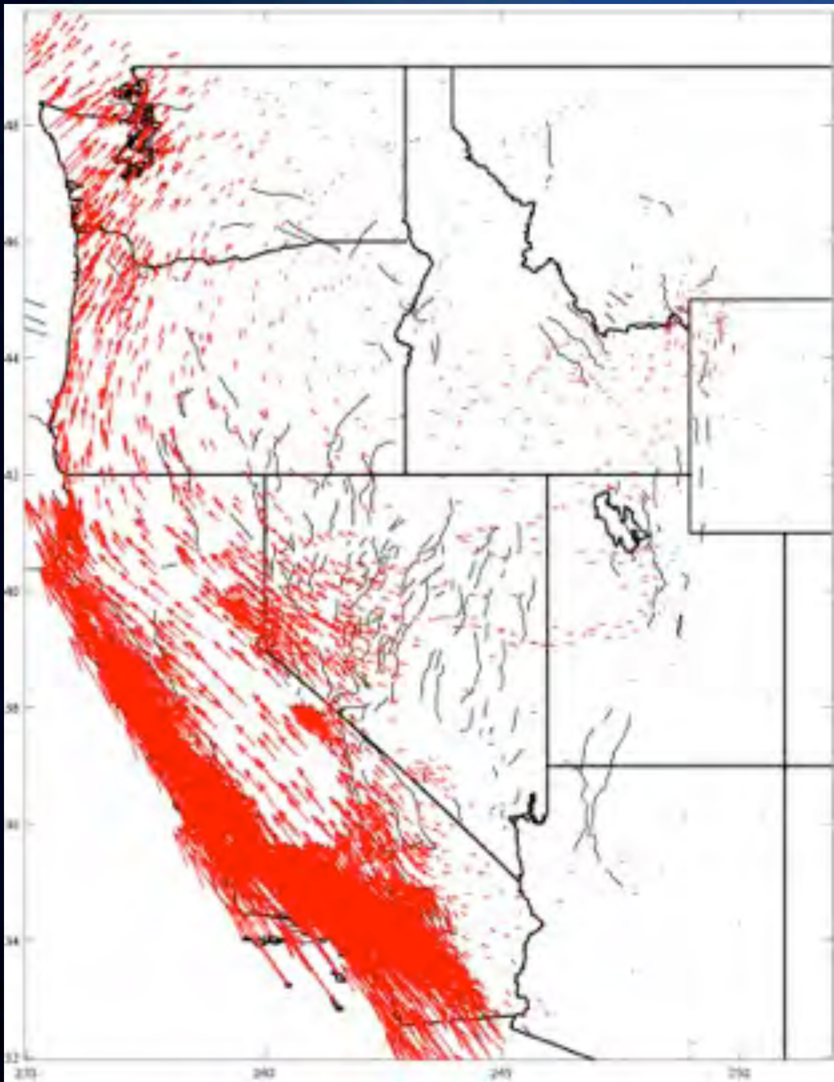
RECLAMATION

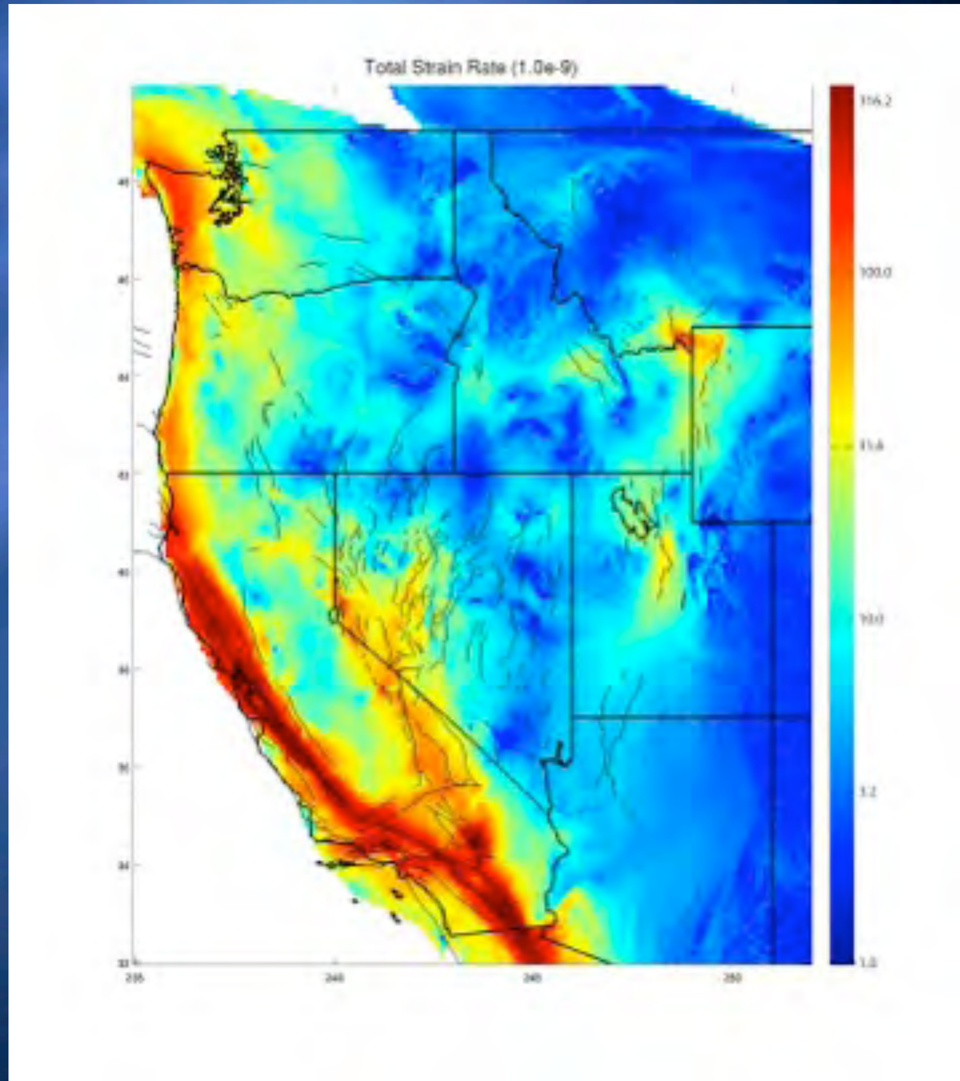
Proposed models of subsurface geology

- 4 models proposed for origin of geomorphic features in Joes Valley (Jim added another)
- One model assumes faults penetrate deep enough (10-15 km) to generate large earthquakes
- 3 models assume faults do not penetrate deeper than 3 km
- One model assumes faults result of evaporite dissolution and collapse


GPS Monitoring of the Wasatch fault and related earthquake hazards assessment
• GPS-derived deformation
• Wasatch fault behavior in a western U.S. framework
• Contributions to PSHA
•Implications for earthquake hazard
Robert B. Smith and Jamie Farrell
Department of Geology and Geophysics
University of Utah
Christine Puskas
Unavco
Boulder Colorado
WuLung Chang
National Central University
Taiwan
Seismology and Active Tectonics Research Group
UUSS
university of utah seismograph stations
NSF
USGS
earth scope
QFPWG Utah, Feb. 5, 2013

Western U.S. GPS-derived velocity and total strain deformation

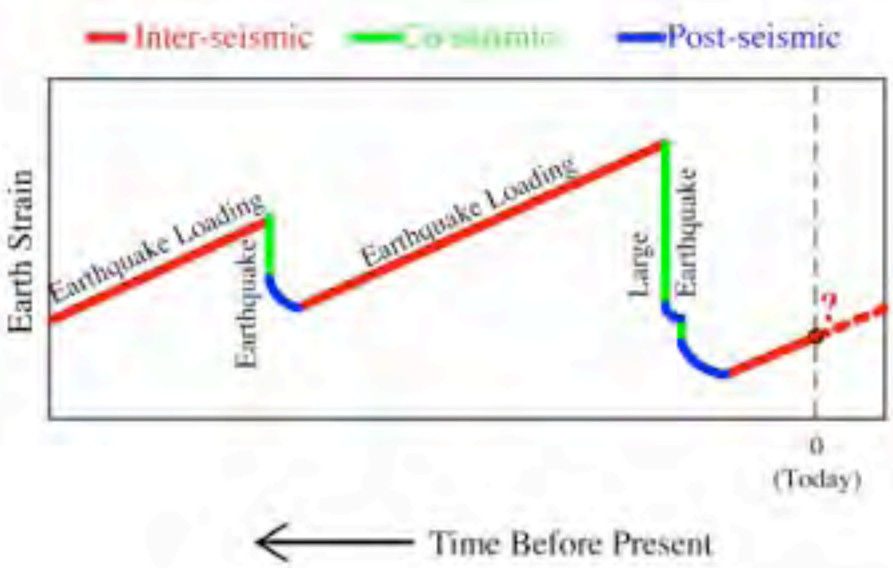




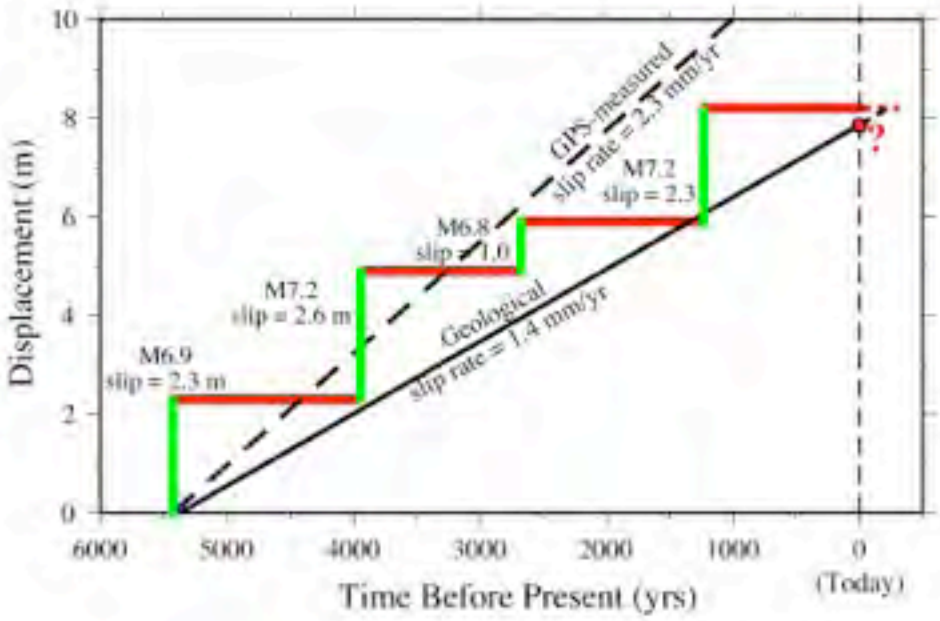
Zeng and Petersen, 2013

Earthquake Cycle

History of earthquakes
and earthquake loading



Wasatch fault earthquake history



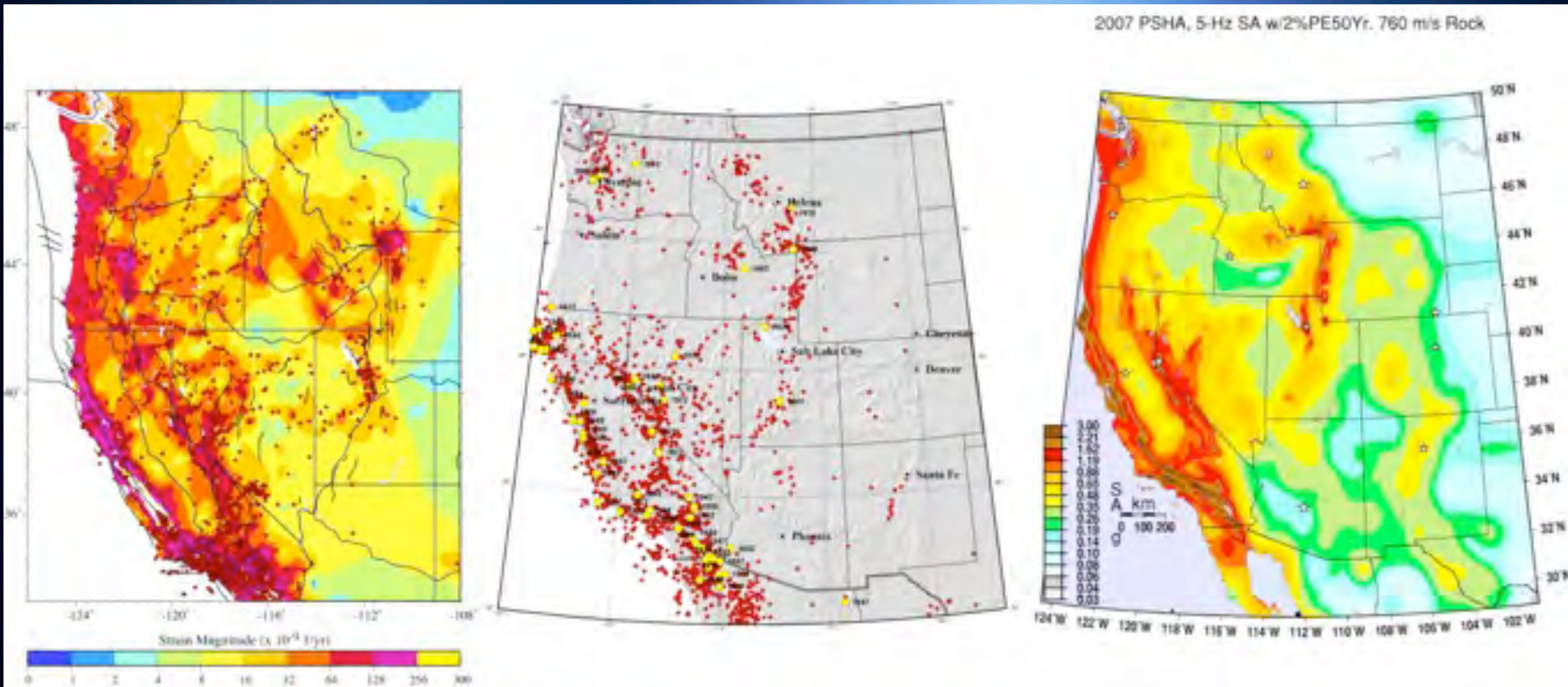
GPS measures interseismic loading rate that is taken as proxy for geologically determined fault slip rate.

GPS Deformation Closely Correlates With Earthquake Hazards

GPS derived strain rate

Earthquakes in the Western US

Spectral Acceleration 2% Probability of Exceedance in 50 Years



High deformation rates correlate with

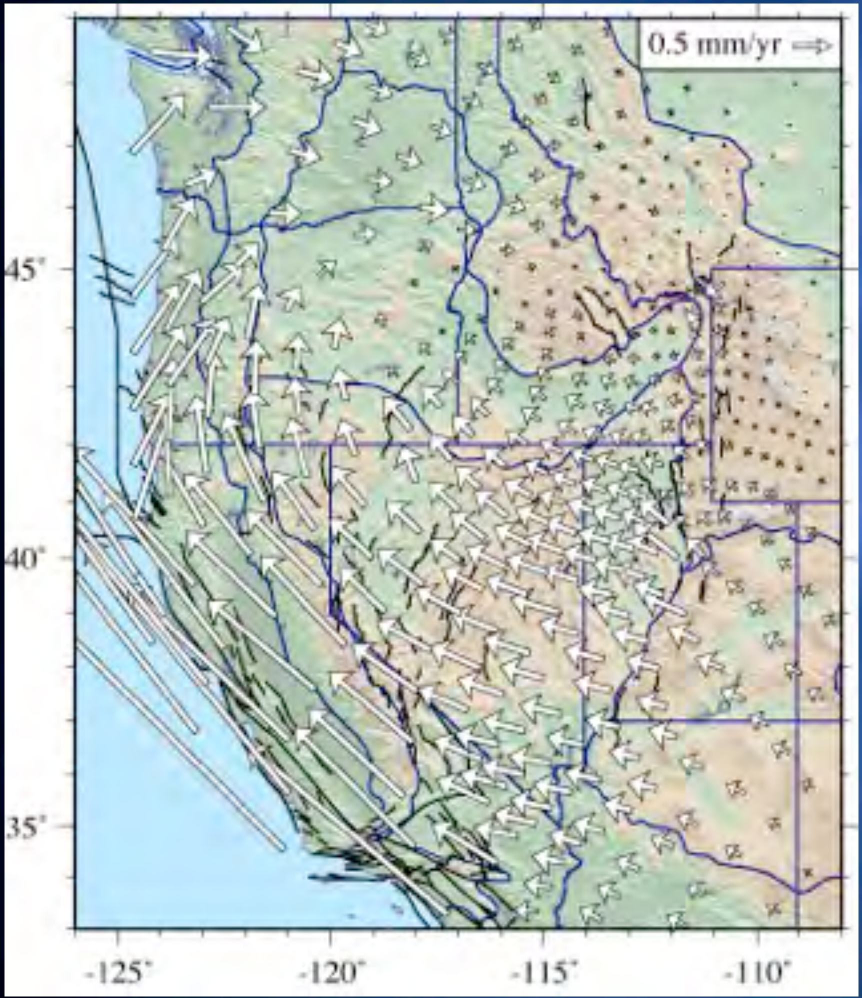
- Seismically active areas
- Regions of increased seismic hazard

Requires integration into hazard modeling

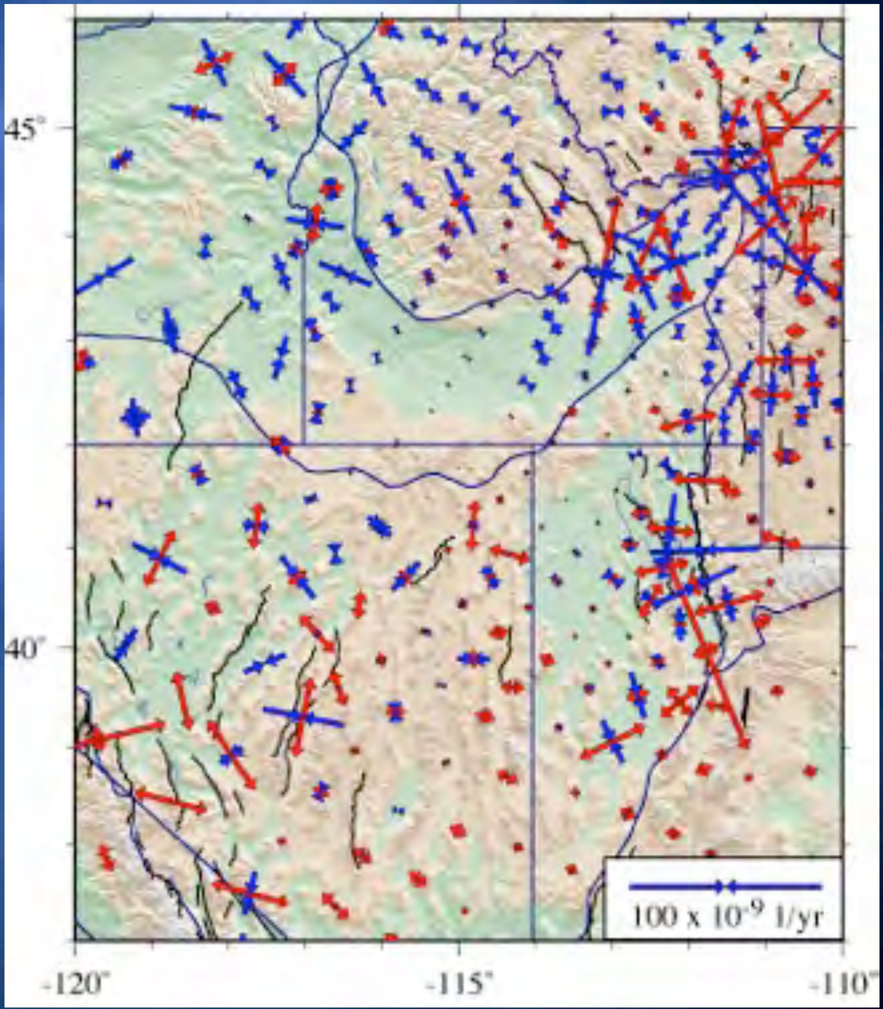
- Improving geodetic data set
- Deformation data available where paleoearthquake info. not well-known

Kinematics

Velocity Field



Strain Rate Field

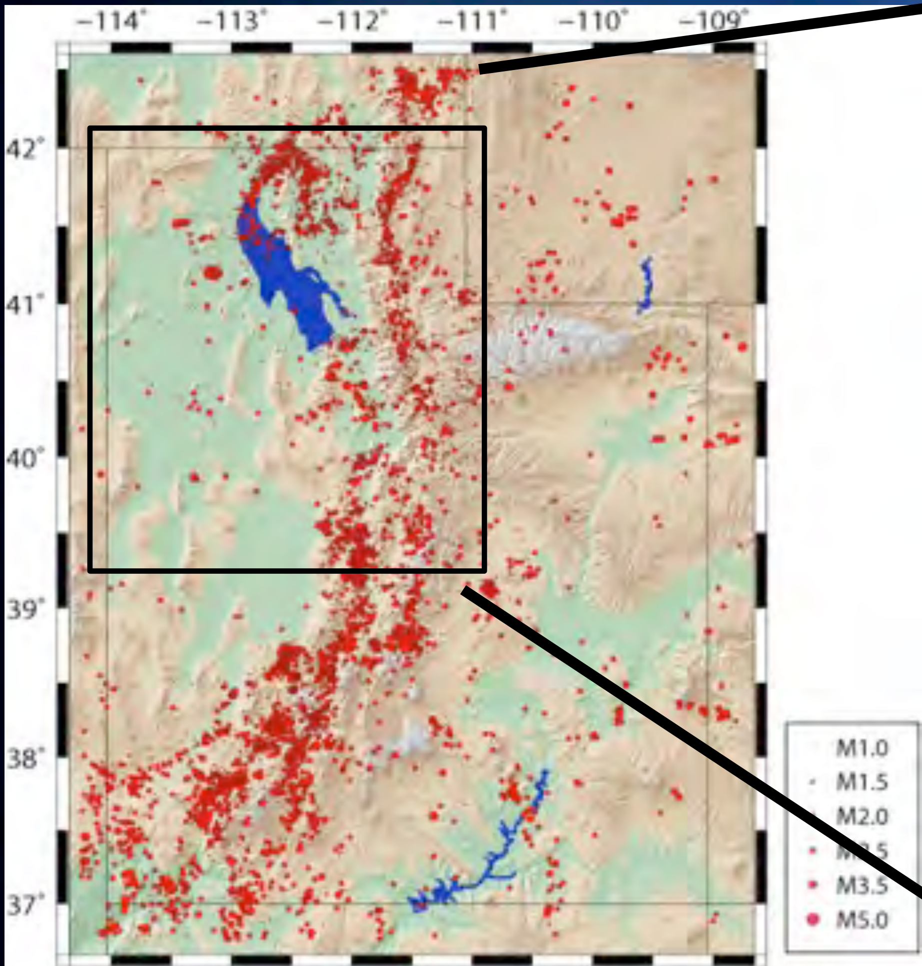


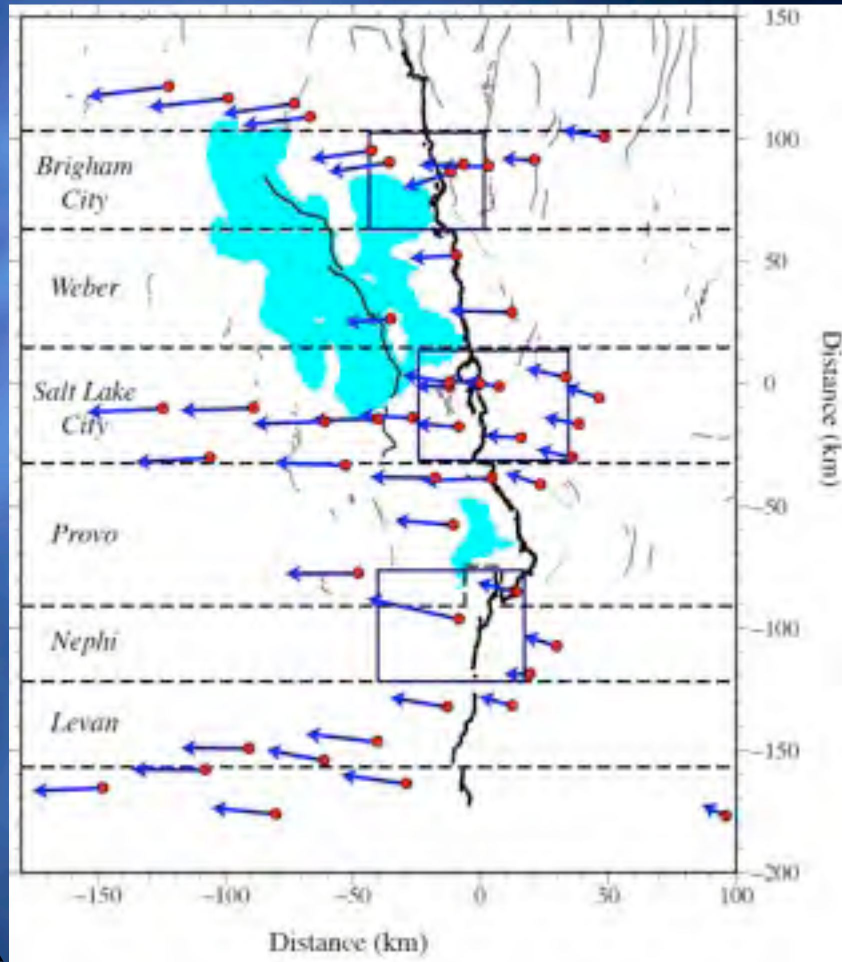
Continuum model solves for strain rates and velocities

- Obtain extension at Yellowstone Plateau and Basin-Range
- Contraction+shear in Eastern Snake River Plain
- Clockwise rotation of velocities

Utah seismicity and Wasatch GPS Network

Utah Seismicity

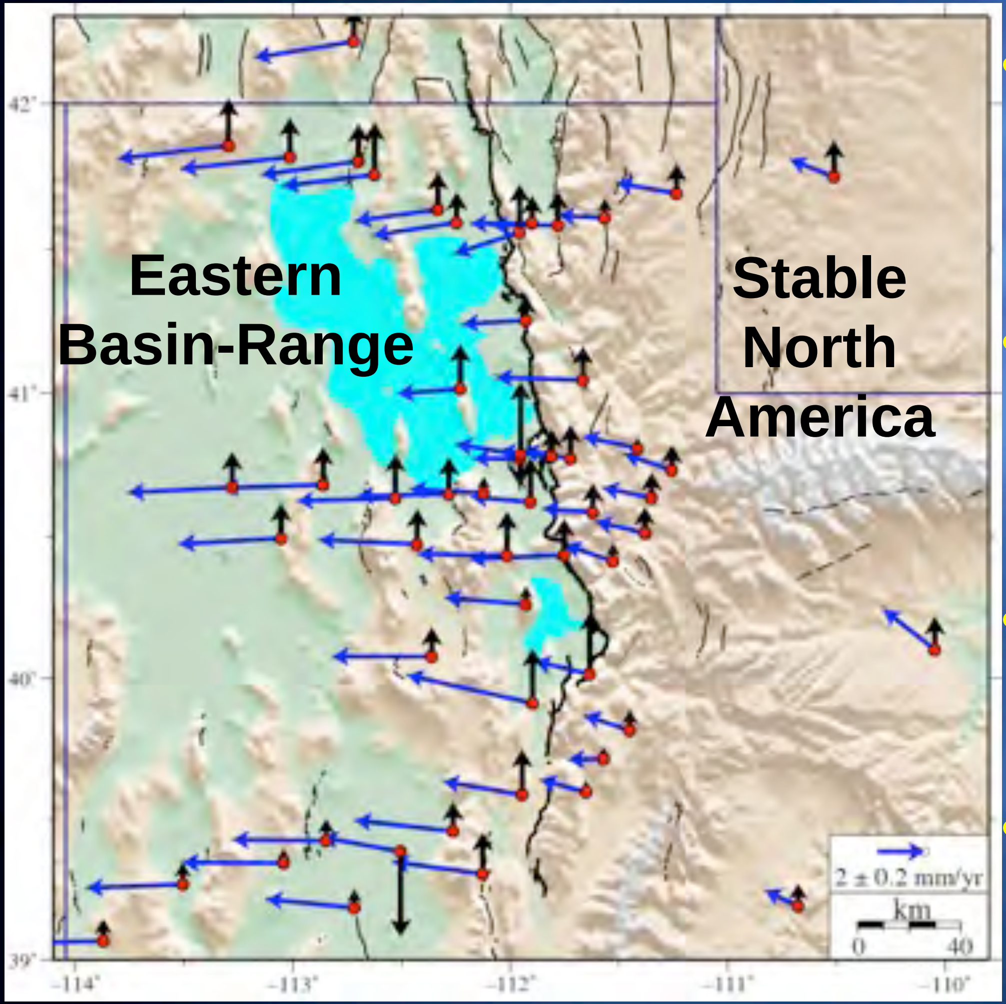




Data recorded and transmitted daily

- 55 permanent stations (Univ of Utah and PBO)
- Installed as part of the “tectonic extensional regime” EarthScope program
- 90 campaign, temporary stations
- Processed data real-time products

Horizontal and Vertical Velocities



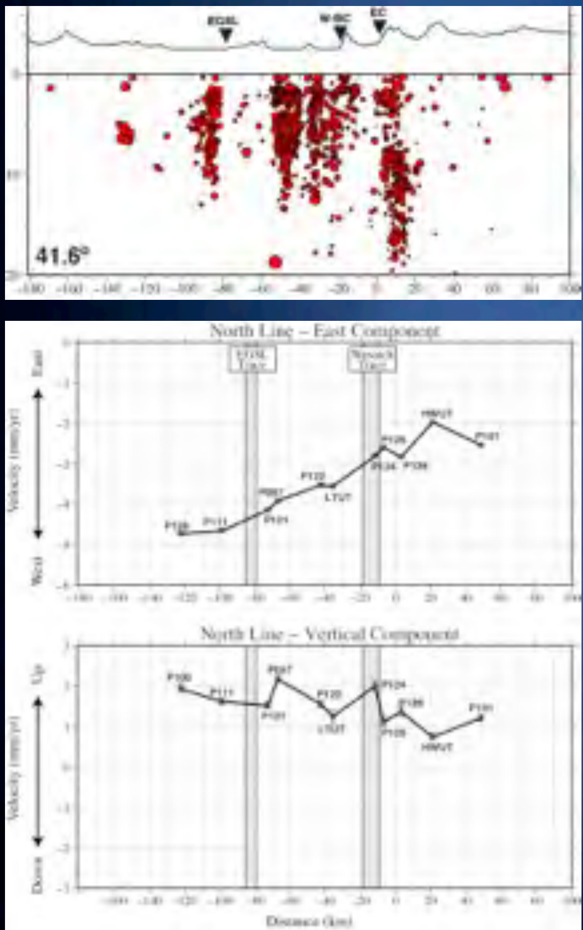
- Plate Boundary Observatory/ University of Utah operate GPS stations
- University of Utah processes data and monitors regional deformation
- 55 stations in network across Utah and Wasatch Front
- Updated processing software in 2011
  - Bernese 5 replaced version 4.2
  - Improved station positions
  - Data available at university web site: www.uusatrg.utah.edu

N. Wasatch Profile

3.18E23 dyne cm/yr geodetic loading (BC only)

110-km wide seismic zone

2.75 mm/yr net extension rate

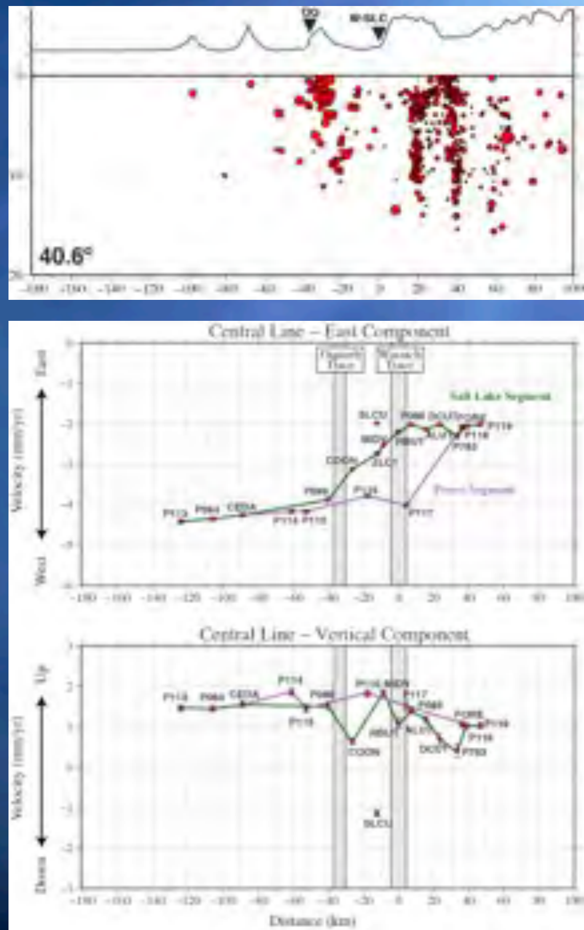


C. Wasatch Profile

6.13E23 dyne cm/yr geodetic loading (SLC only)

80-km wide seismic zone

2.35 mm/yr net extension rate

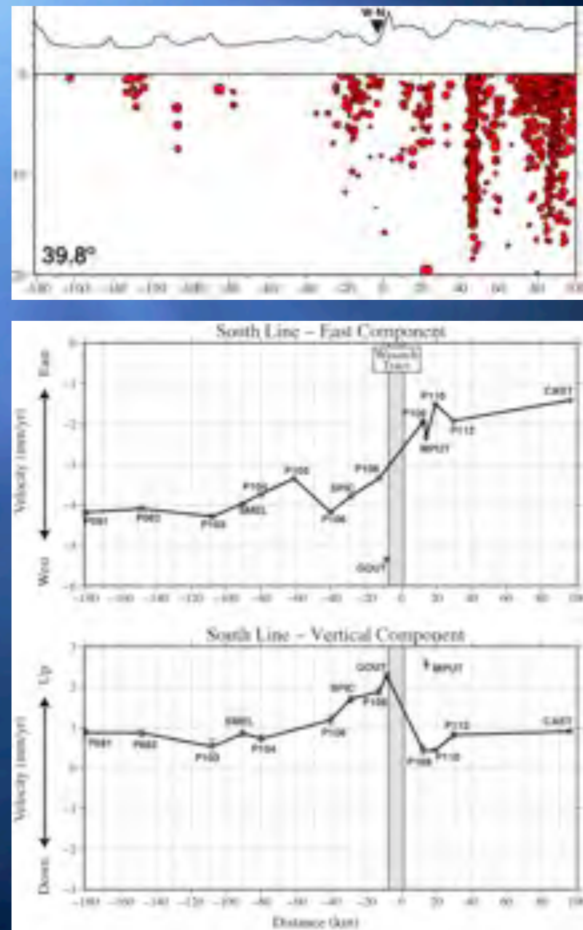


S. Wasatch Profile

6.71E23 dyne cm/yr geodetic loading (SLC only)

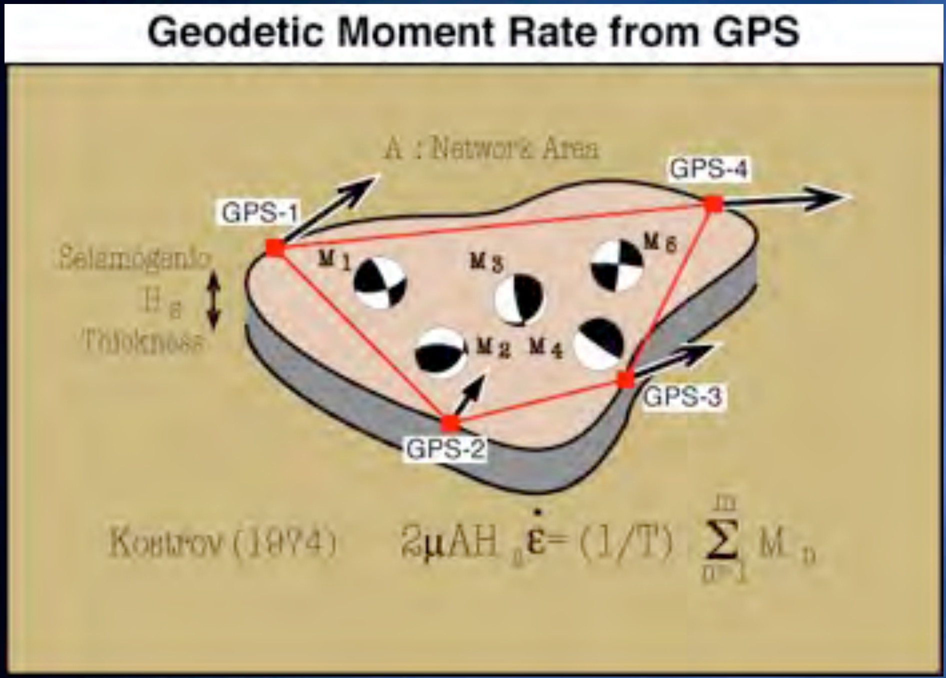
50-km wide seismic zone

2.17 mm/yr net extension rate

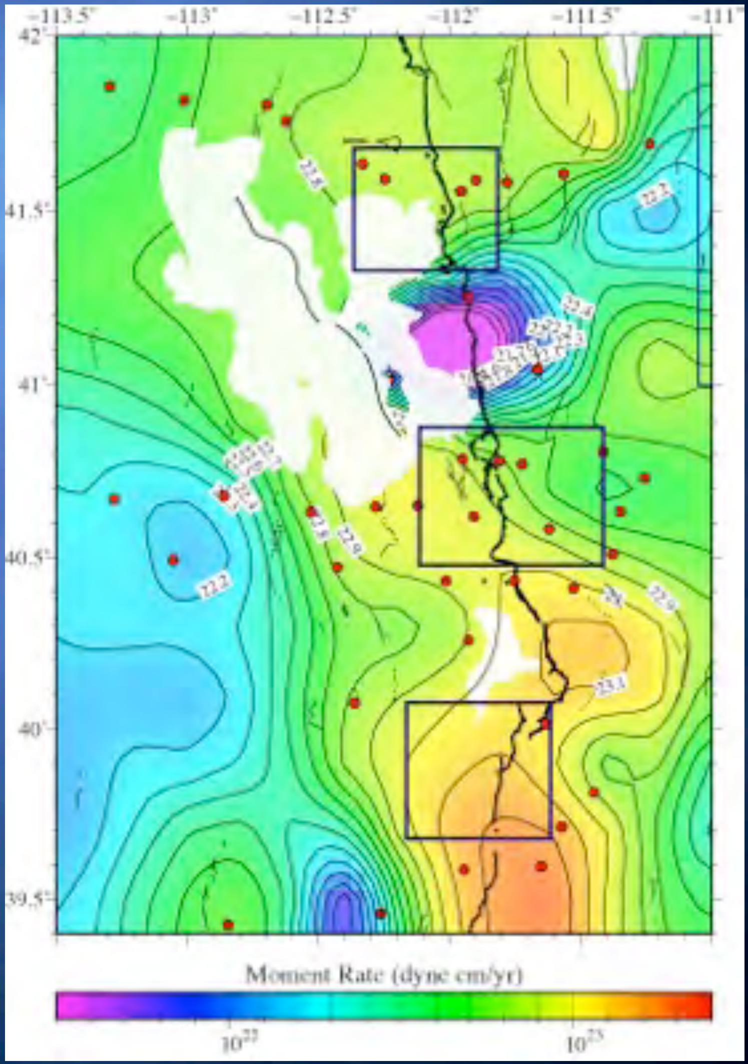


(Puskas and Smith, 2012)

Moment Tensor Strain Rate

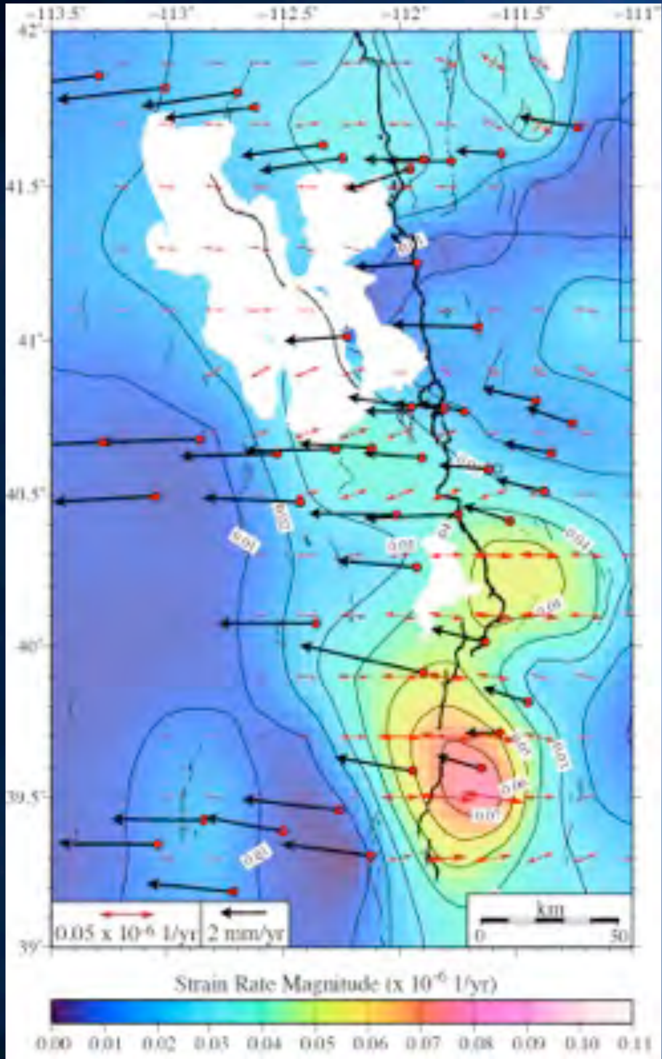


- Use Kostrov's formulation to convert deformation rate to geodetic moment rate
  - Moment is measure of energy required for deformation
- Moment from earthquakes depends on:
  - Seismogenic volume
  - Strain rate for network area

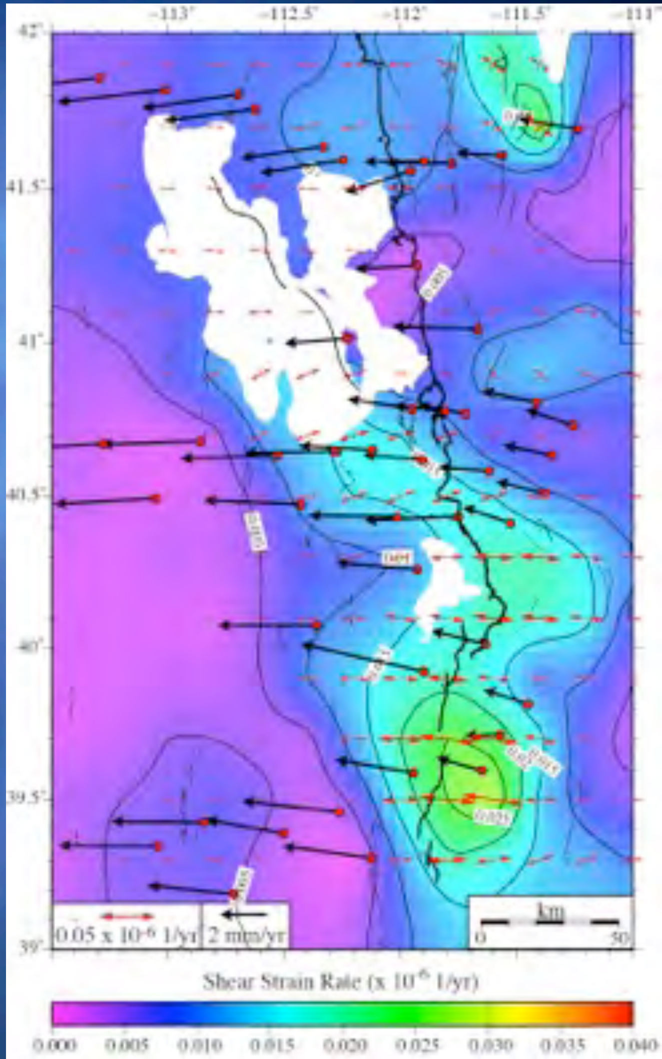


(Puskas and Smith, 2012)

Strain Rate Magnitude



Shear Strain Rate

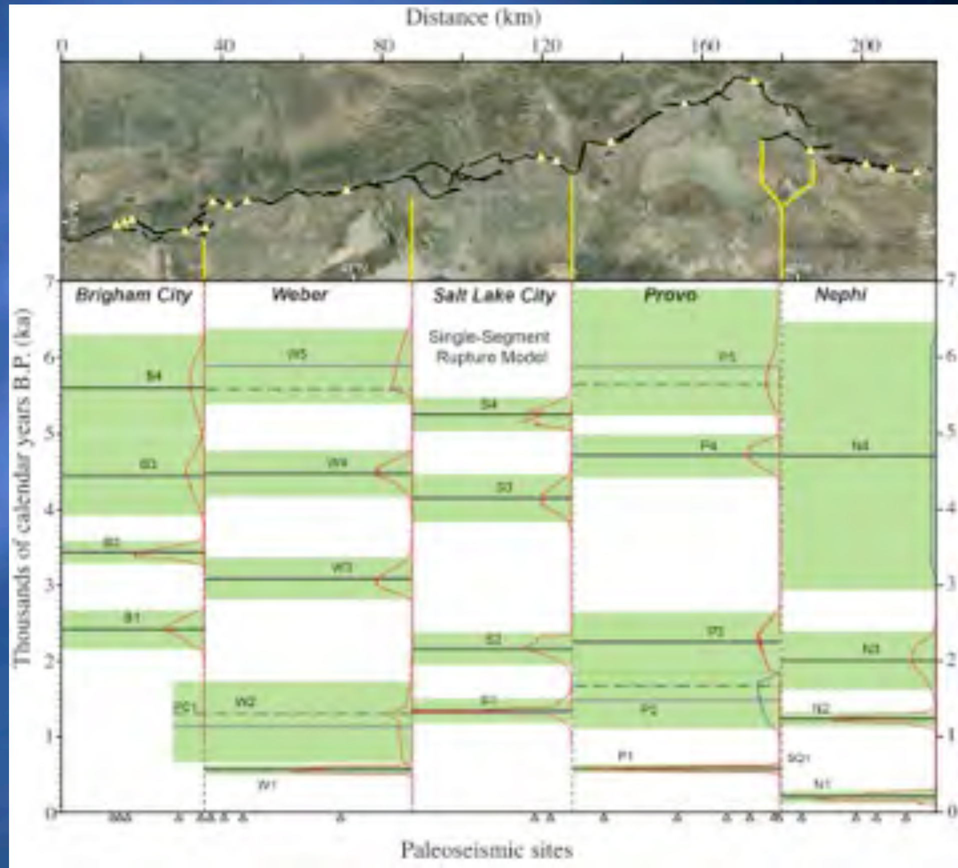


- Interpolate horizontal GPS velocities to strain rates
    - Eliminate outliers SLCU and GOUT
- Higher strain rates reflect larger changes of deformation over smaller areas

(Puskas and Smith, 2012)

Prehistoric Earthquakes Identified for Wasatch Fault

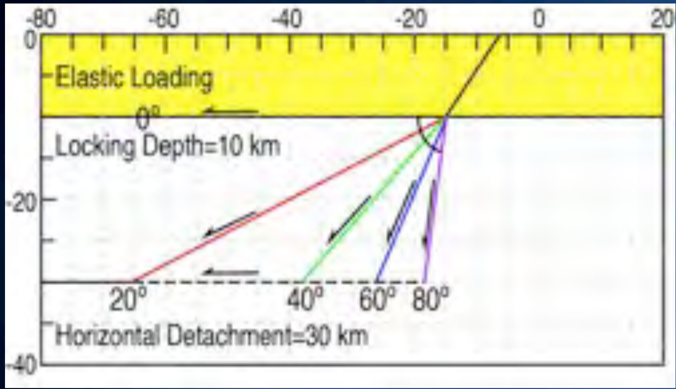
EQ Ref #	Segment Ref #	Age (yrs)	ΔAge (2-σ)	SRL (km)	ΔSRL (2-σ)
E1	N1	206	86	43	11.5
E2	P1	576	48	59	11.5
E3	W1	561	68	56	6.5
E4	W2	1137	641	65	8.5
E5	N2	1234	96	43	11.5
E6	S1	1343	162	40	6.5
E7	P2	1479	378	59	11.5
E8	N3	2004	388	43	11.5
E9	P3	2240	406	59	11.5
E10	S2	2160	215	40	6.5
E11	B1	2417	256	36	6
E12	W3	3087	275	56	6.5
E13	B2	3430	153	36	6
E14	B3	4452	543	36	6
E15	W4	4471	303	36	13
E16	S3	4147	315	40	6.5
E17	P4	4709	285	59	11.5
E18	N4	4699	1768	43	11.5
E19	S4	5250	221	40	6.5
E20	B4	5603	660	36	6
E21	P5	5888	1002	59	11.5
E22	W5	5891	502	56	6.5

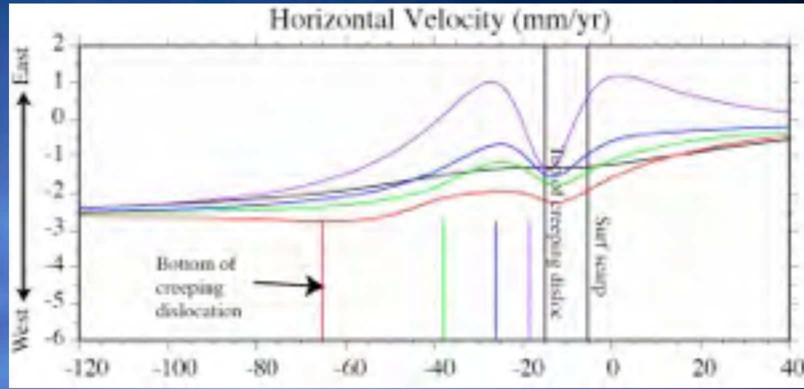


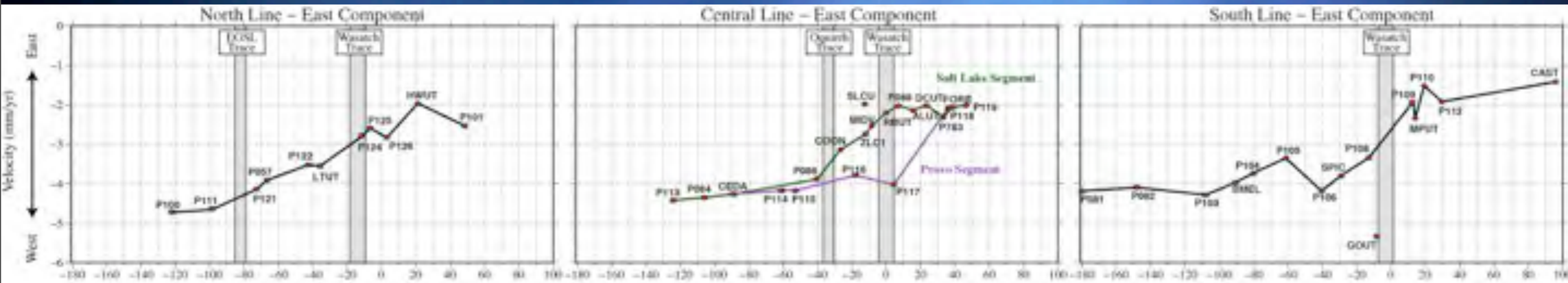
(DuRoss et al., 2011)

- 4-5 earthquake on each segment
- Events dated within last 6000 years

(Puskas and Smith, 2012)





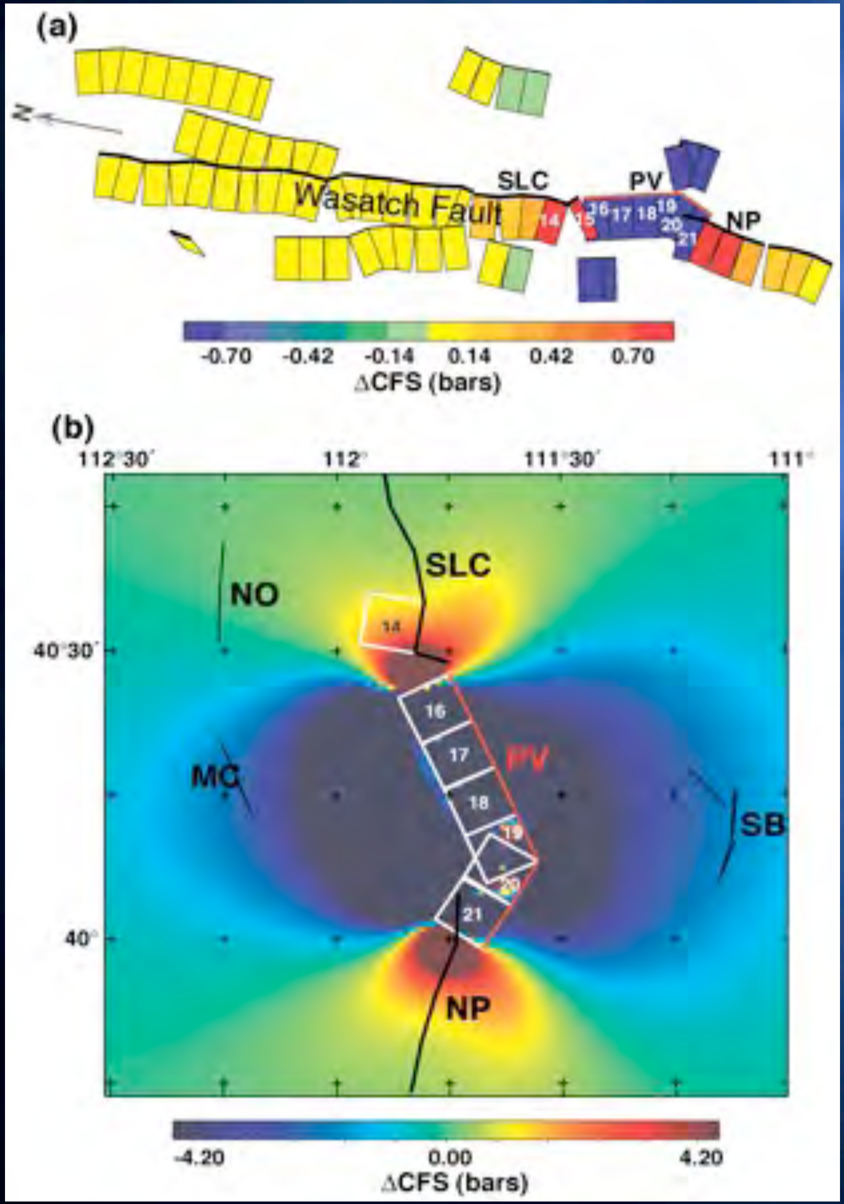


- 1-D horizontal dislocations for fault creeping at depth

- Model predicts smoothly varying surface velocities
    - Width of deformation zone: ~65 km
    - Deformation amplitude depend on dip, slip rate

- Observed GPS velocity profiles
    - 2-D station distribution with more complex deformation
    - Have at least 100-km wide deformation zone

Wasatch fault stress-loading (elastic) scenario earthquake



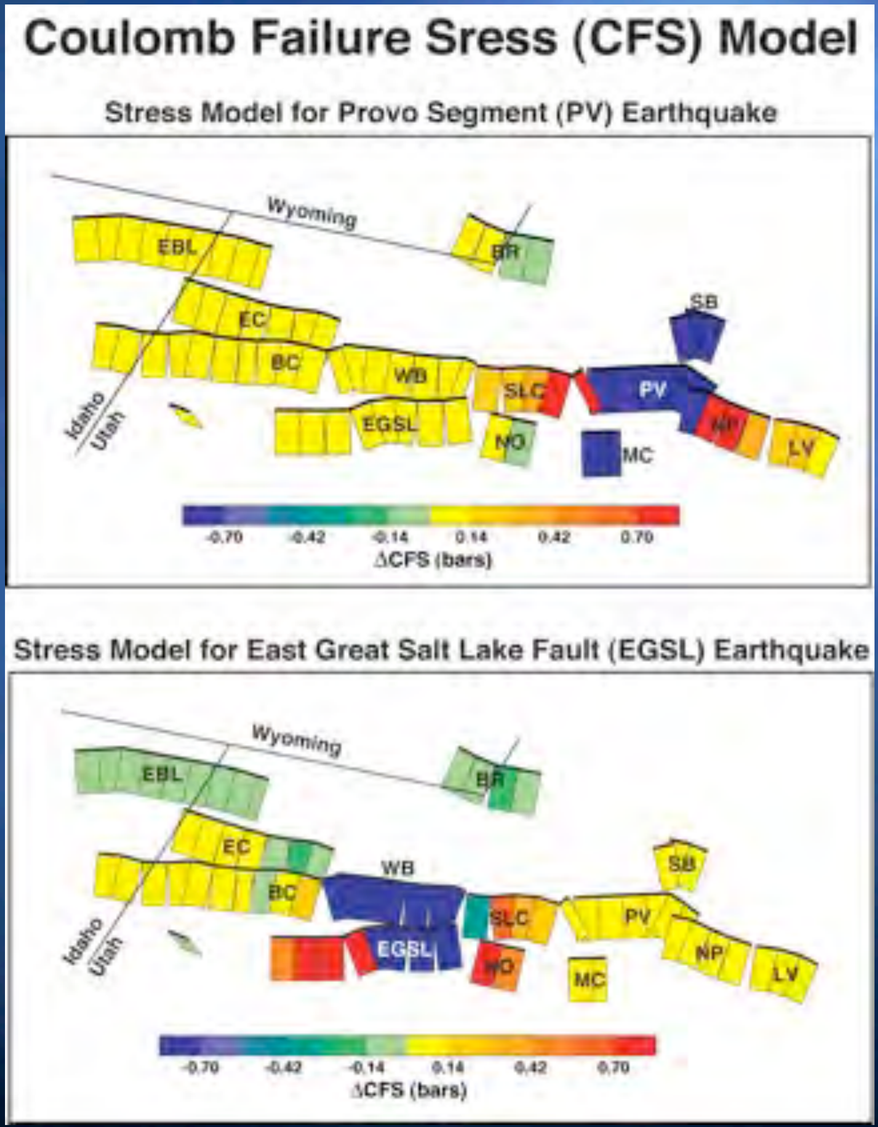
DCFS (Coulomb stress change) induced by a scenario earthquake on the Provo segment (PV

60 km ruptute 2 m of slip (Ms 7.1 and Mw 7.1).

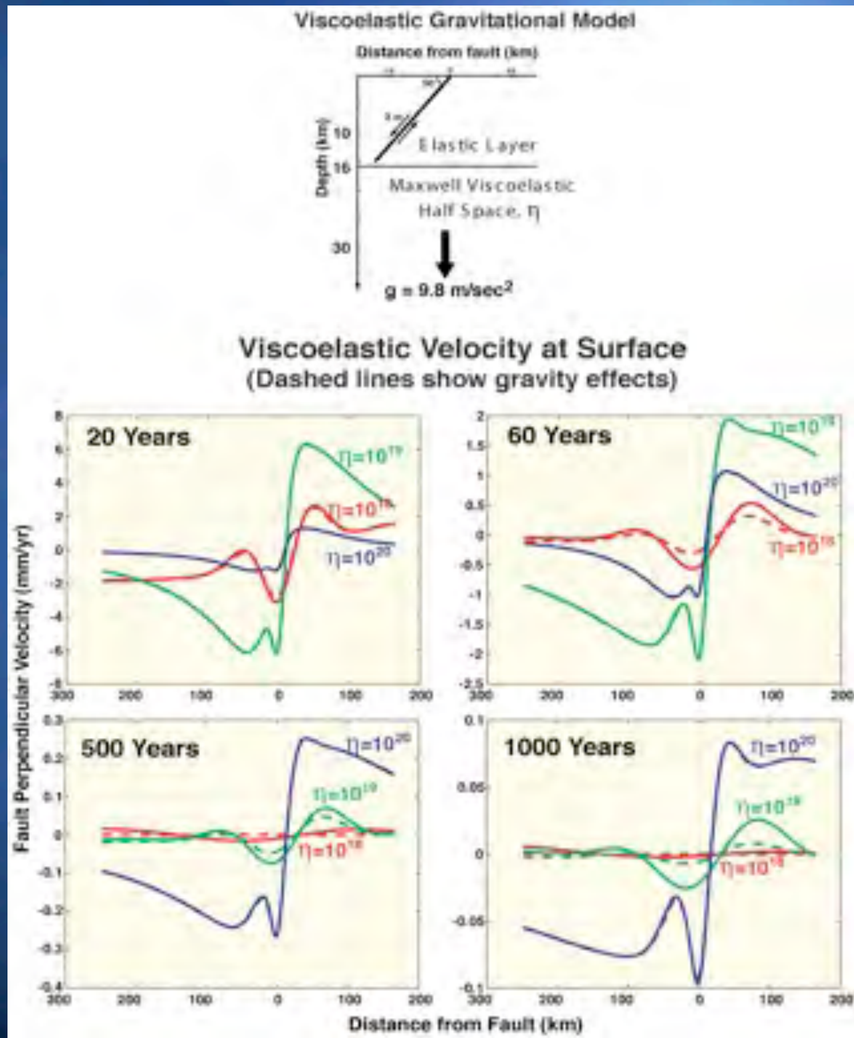
DCFS is shown (a) at the center of each fault patch, and (b) as a map-view of 10-km depth.

Large earthquakes on the Provo segment can increase the failure stress of the Salt Lake City segment

Time dependent stress contagion on Wasatch fault



Faults never stop loading?
because of viscoelastic flow of the lower crust

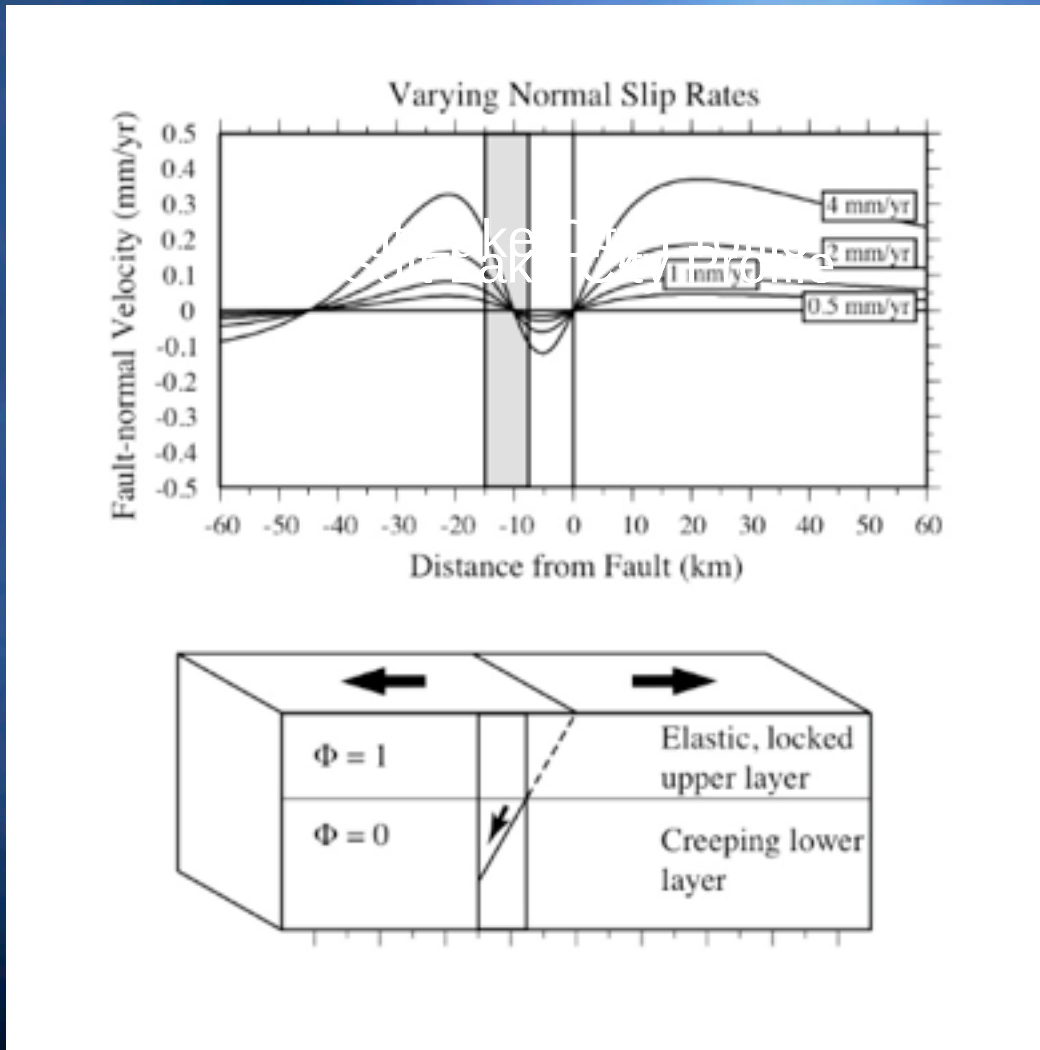


Wasatch fault measured motion

Best solution is for $\eta = 10^{19}$ Pa-sec.

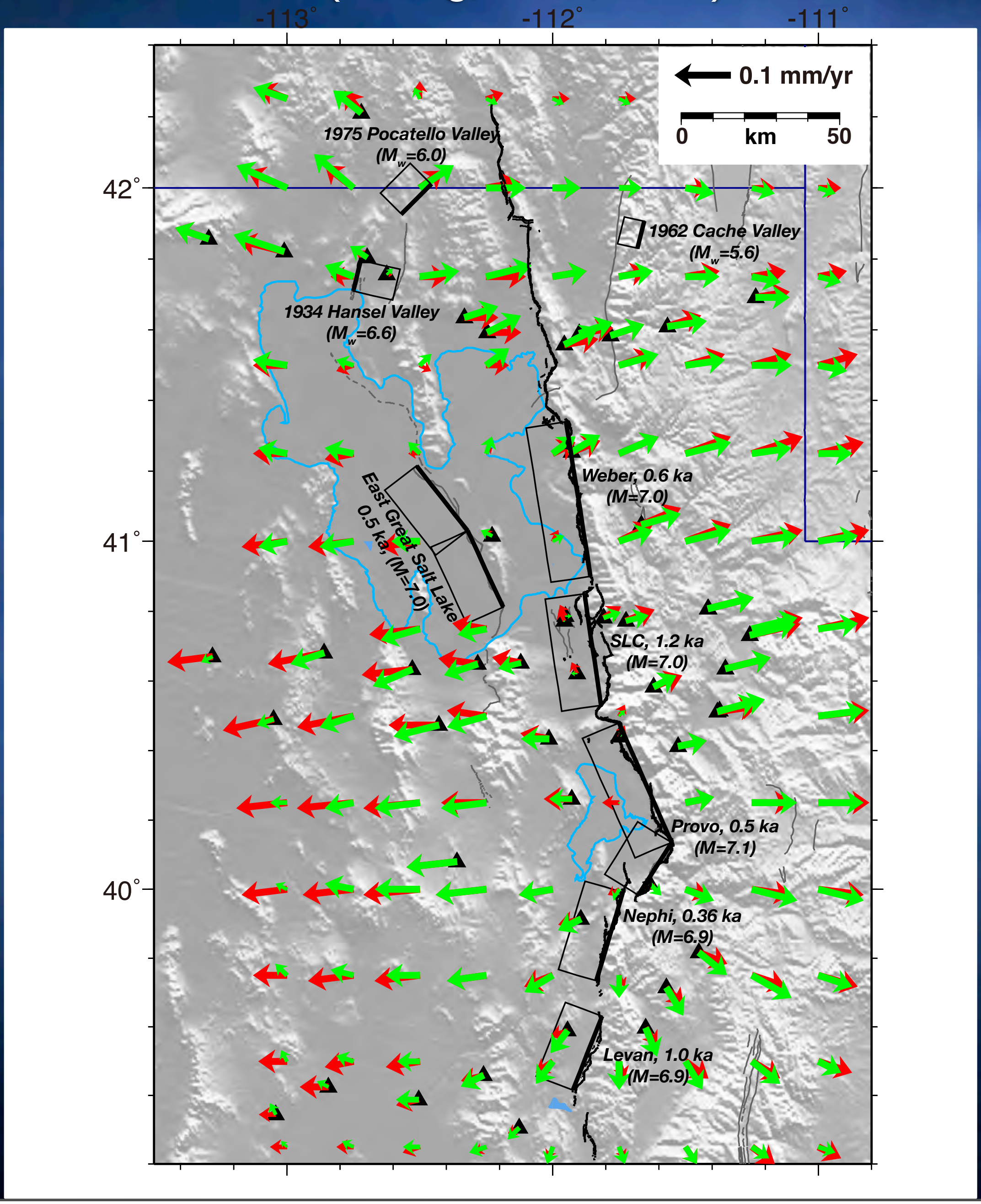
Time-dependent motion following a normal-faulting earthquake: interseismic loading

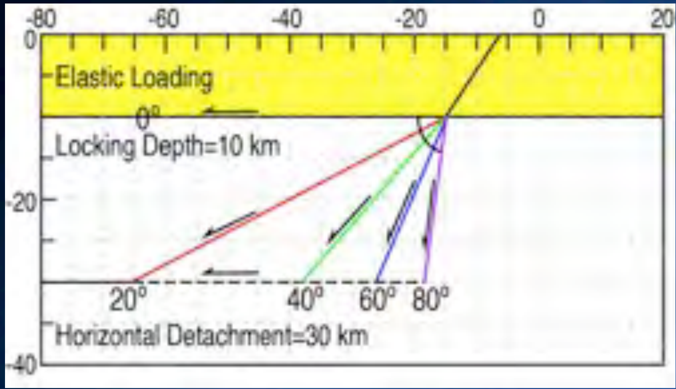
Interseismic Deformation: Post-seismic relaxation
requiring knowledge of rheology and ground motion rates

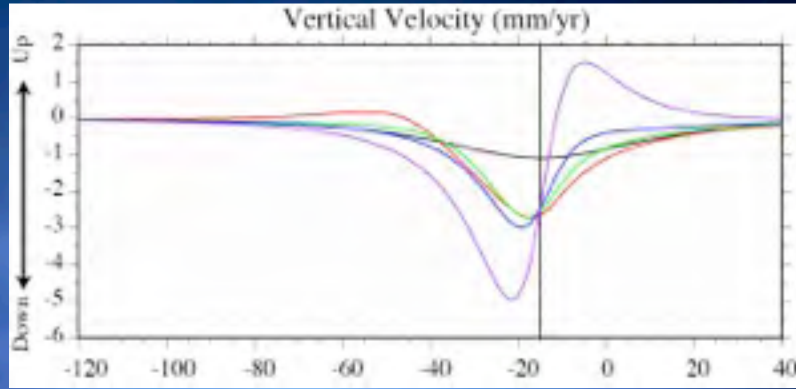


(Puskas and Smith, 2007)

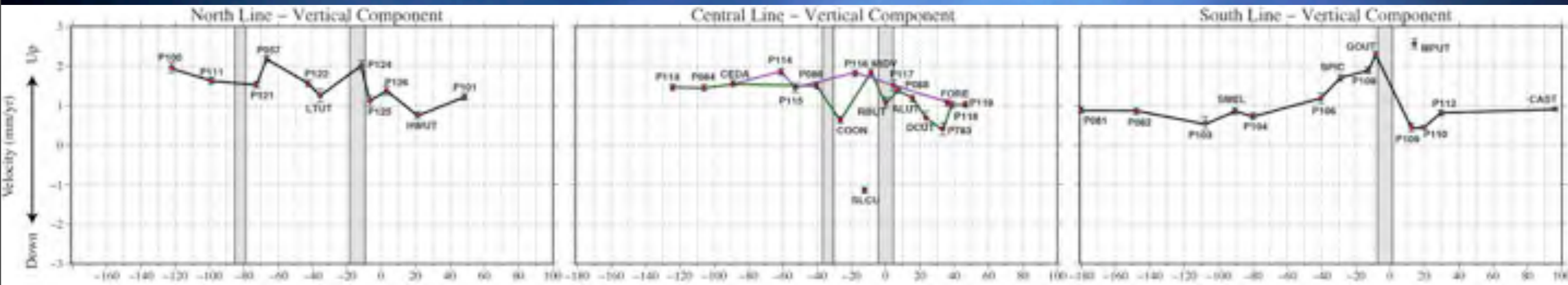
Wasatch Front Prehistoric earthquake, post-seismic deformation
(Chang, et al., 2013)







Brigham City Profile Salt Lake City Profile Nephi Profile



- 1-D vertical dislocations for fault creeping at depth
- Model predicts smoothly varying surface velocities
- Observed GPS velocity profiles
  - Do not resemble model profiles
  - More complex, noisy deformation pattern
- Possible multiple dislocations

Fault Segment Moment Rates (dyne cm/yr)

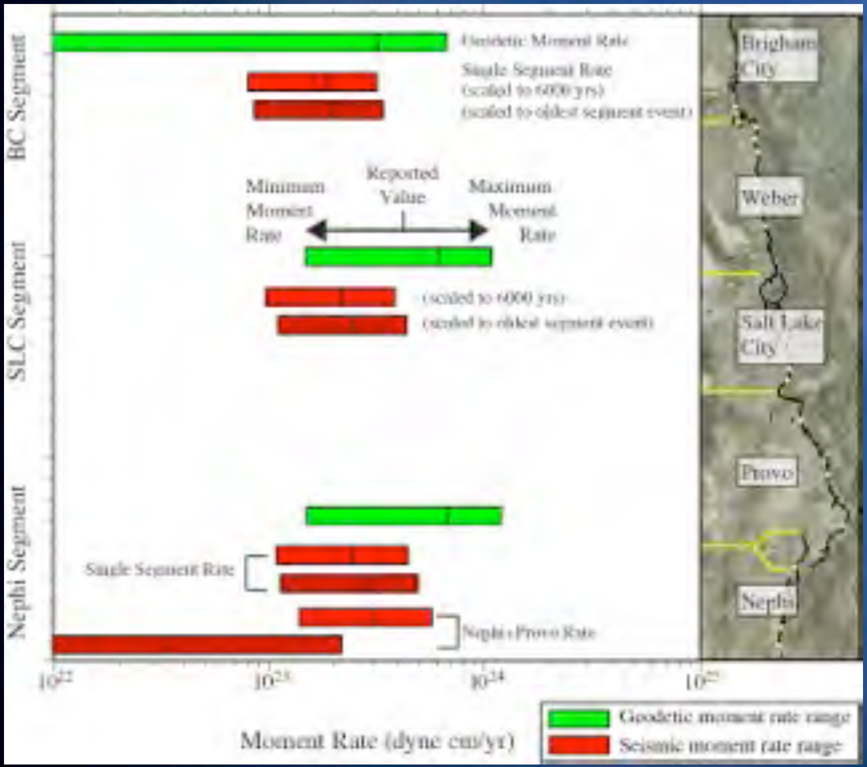
GPS-Derived Moment Rates	BC	SLC	Nephi
Interpolated Strain Rates	3.18E23	6.13E23	6.71E23
Direct Calc from GPS Vels	5.61E23	4.46E23	1.10E23

Paleoseismic Moment Rates (scale to 6000 yrs)			
Single Segment Ruptures	1.86E23	2.19E23	2.46E23
Nephi + Provo			2.83E23
Wasatch + Other Known EQs	1.96E23	2.34E23	

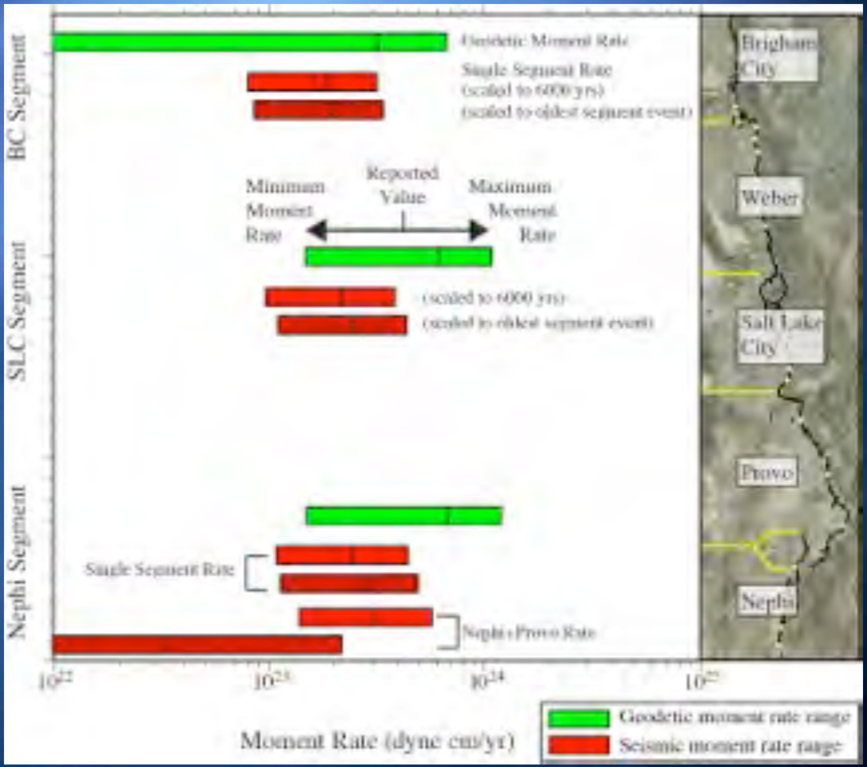
Paleoseismic Moment Rates (scale to oldest event on segment)			
Single Segment Ruptures	1.99E23	2.50E23	3.14E23
Nephi + Provo			2.18E23
Wasatch + Other Known EQs	2.10E23	2.68E23	

Seismic and Geodetic Moment Comparisons
Time Series vs. Network Solution

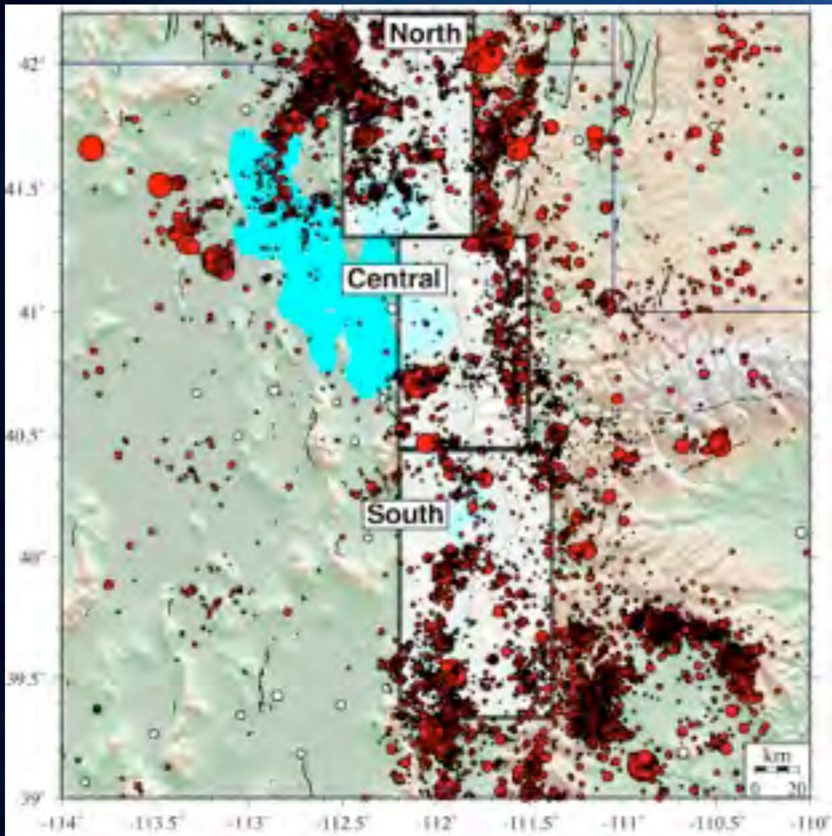
Geodetic Moment Rates (dyne cm/yr)

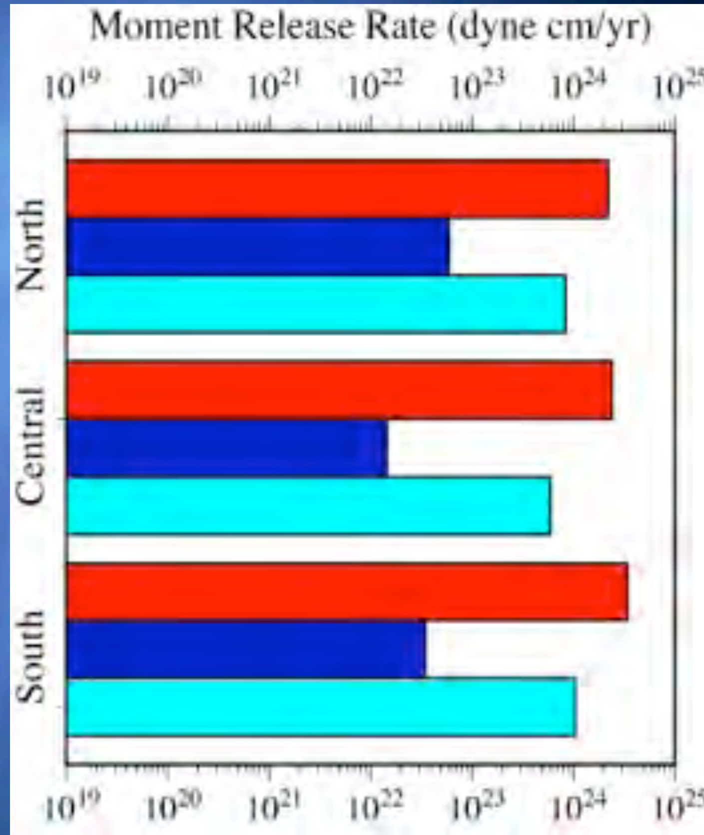


Fault Loading Moment Rates (dyne cm/yr)



Comparative moment release rates





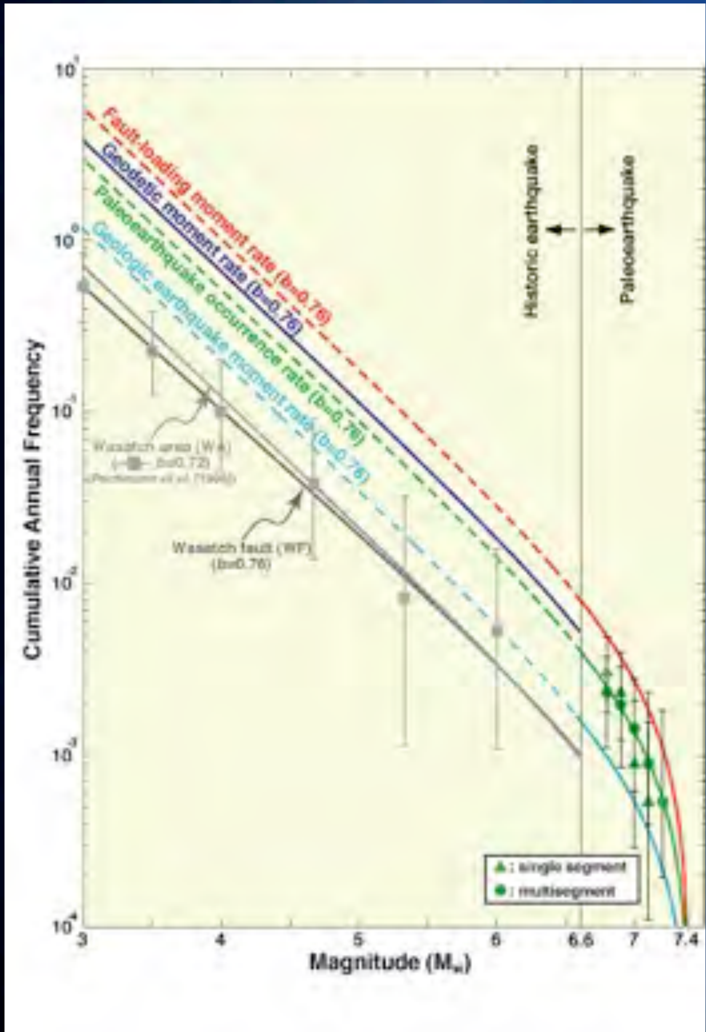
Seismic moment budget

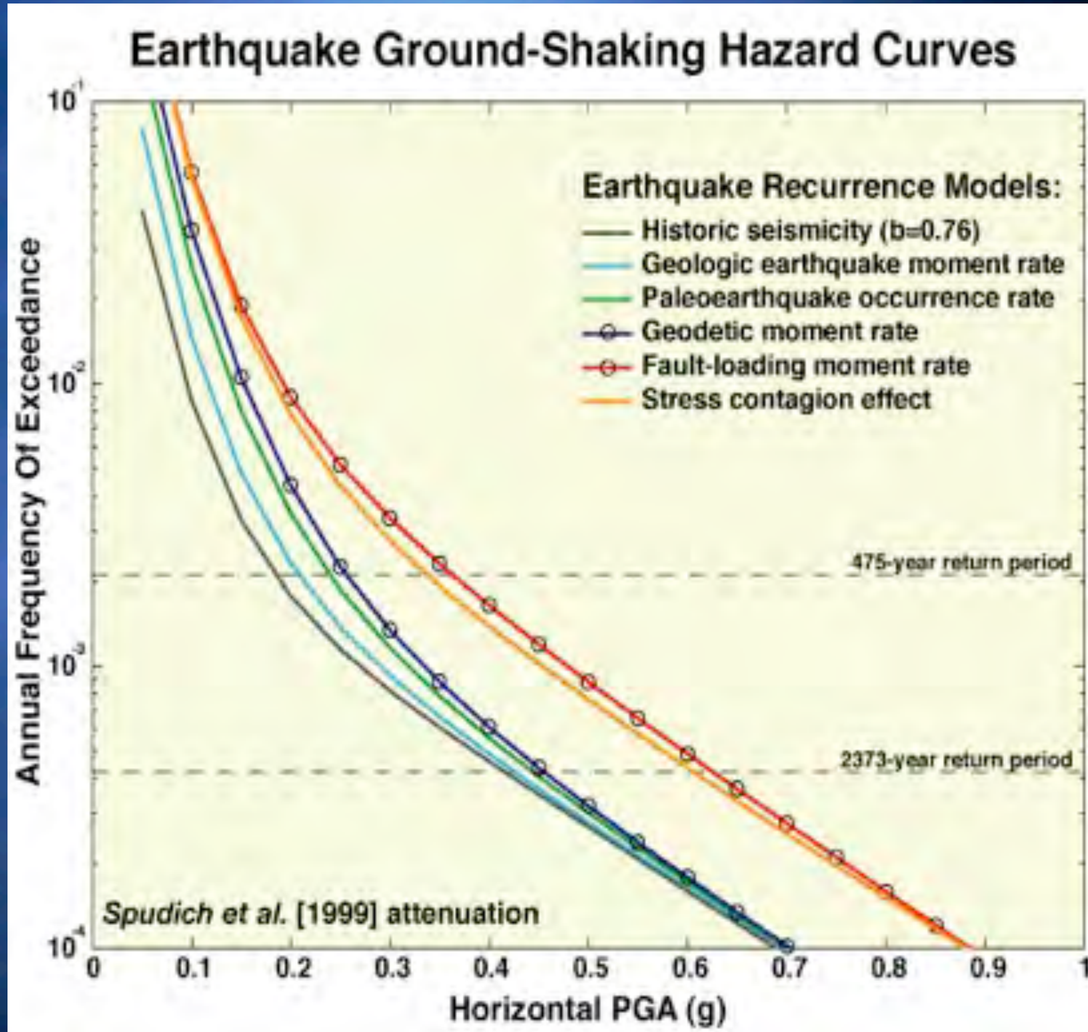
- GPS: total moment release
- Historic earthquakes: earthquake recurrence rate
- Fault slip rates: fault slip rate from trenching

Section	Total (dyne cm/yr)	Seismic (dyne cm/yr)	Fault Slip (dyne cm/yr)
North	2.18×10^{24}	5.94×10^{22}	8.26×10^{23}
Central	2.39×10^{24}	1.44×10^{22}	5.91×10^{23}
South	3.42×10^{24}	3.45×10^{22}	1.04×10^{24}

A Notable Deficit!

Integrated earthquake probabilistic seismic hazard assessment for the middle of Salt Lake Valley



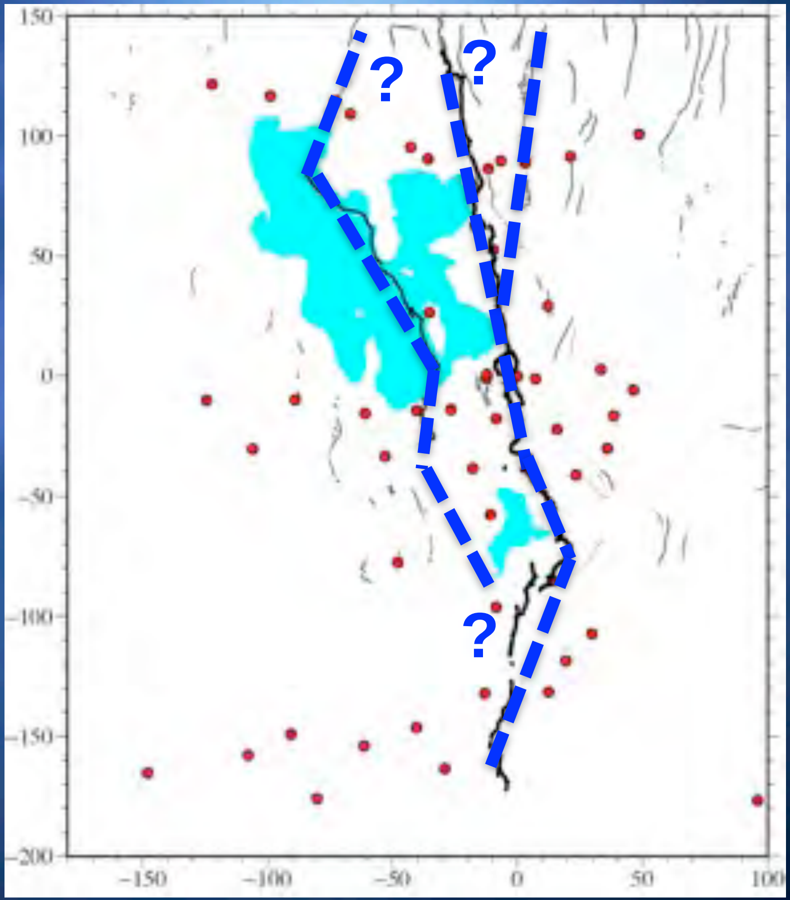


(Chang and Smith, 2007)

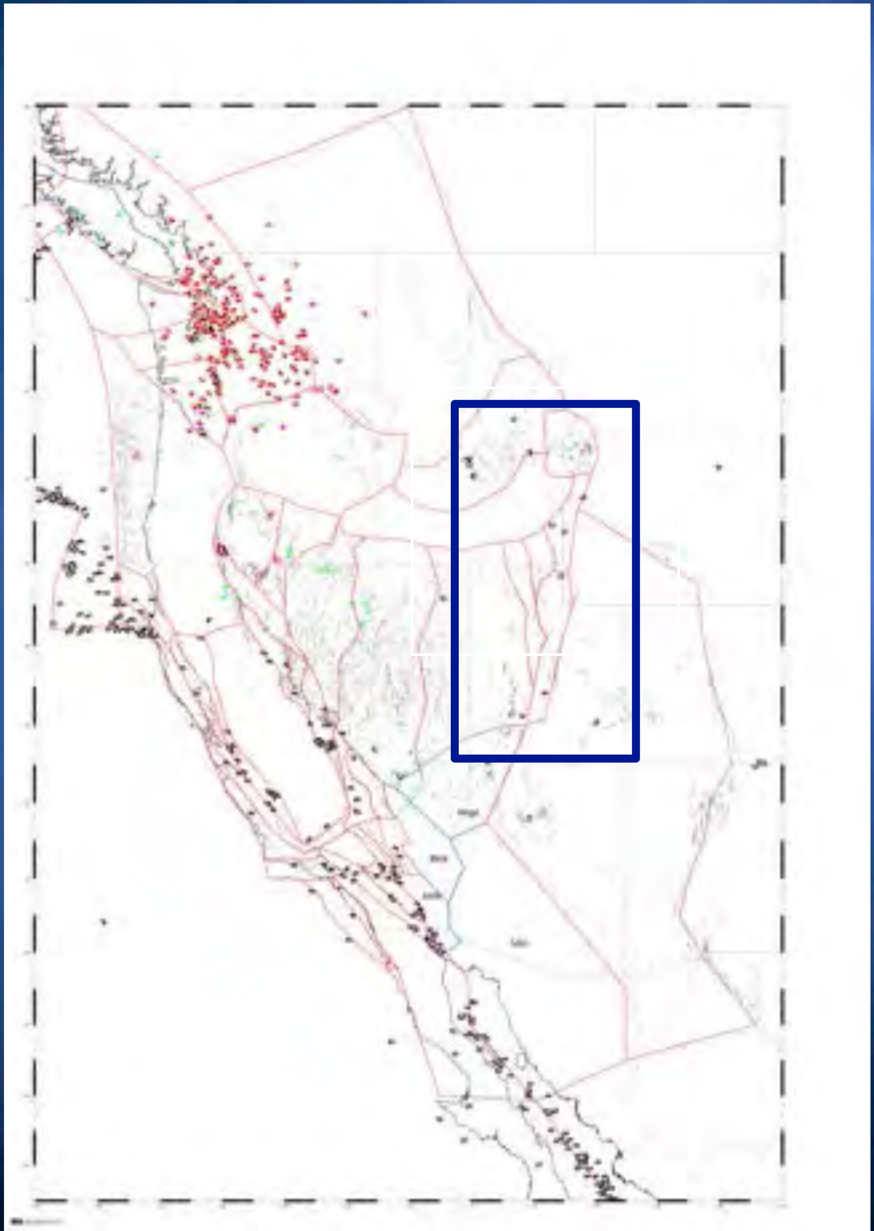
Wasatch Front block model deformation models: Original and used in new US earthquake hazard map

Older Deformation Models

Proposed New Block Model



Western U.S. block model for the 2013 US Hazard Map



Zeng and Petersen, 2012

Conclusions

- GPS data provide key areal coverage not covered by trenching adding a wider area to earthquake hazard assessment.

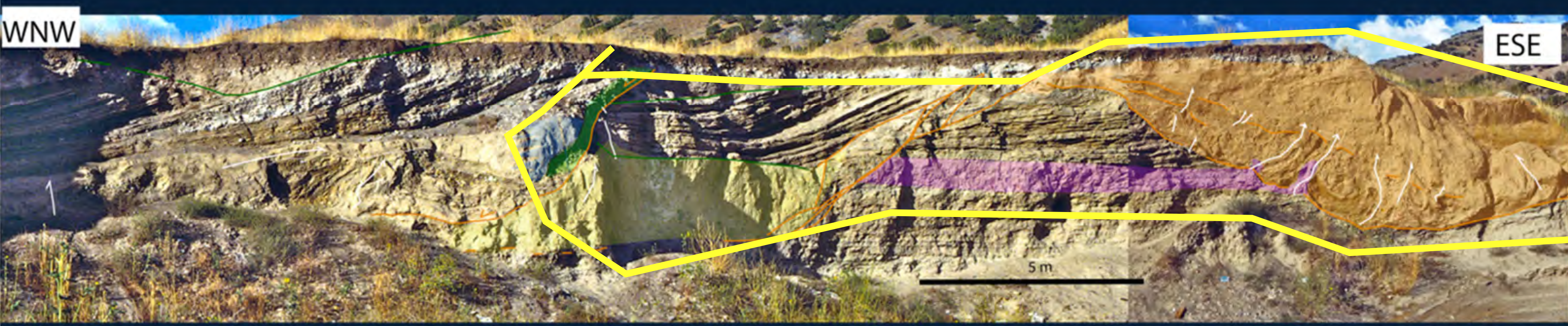
- GPS data provide time-dependent deformation and key information on the inter-seismic earthquake cycle

- Wasatch geodetic moment rate exceeds L. Quat fault moment rate by up to 2X

- Stress contagion by the M7 earthquakes are an important aspect of earthquake hazard evaluation of the Wasatch fault, i.e., implies need to assess multisegment hazard models.

- **GPS rates are estimated to reflect ~1000 year time history, i.e., a time window considered directly applicable to seismic hazard assessment.**

Large liquefaction features and evidence for earthquakes induced by Lake Bonneville in Cache Valley: A progress report

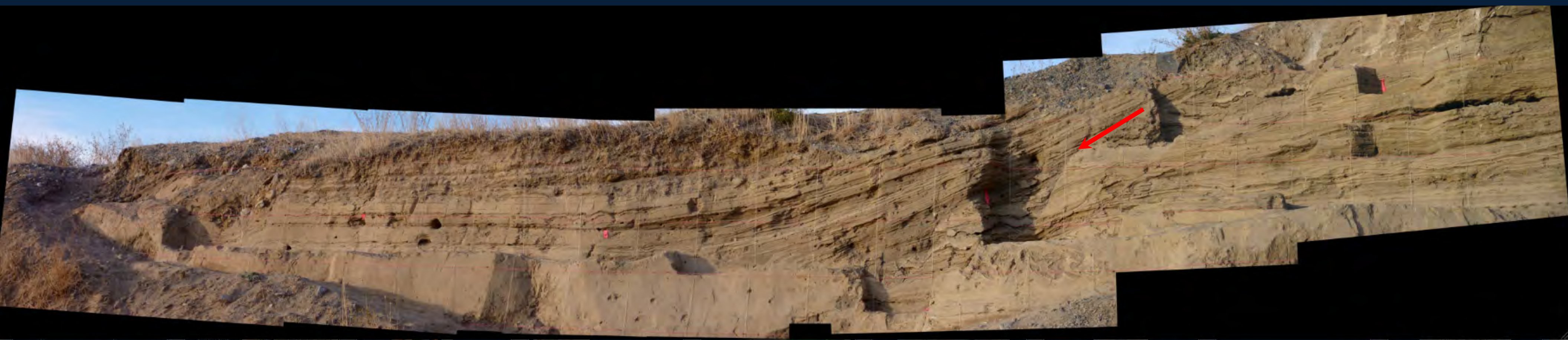


Susanne Janecke
Robert Q. Oaks, Jr.
A.J. Knight
Dallas Nutt
Tammy Rittenour
Utah State University

Please come and visit (and bring a shovel)

Janecke et al., 2013 UQFPWG

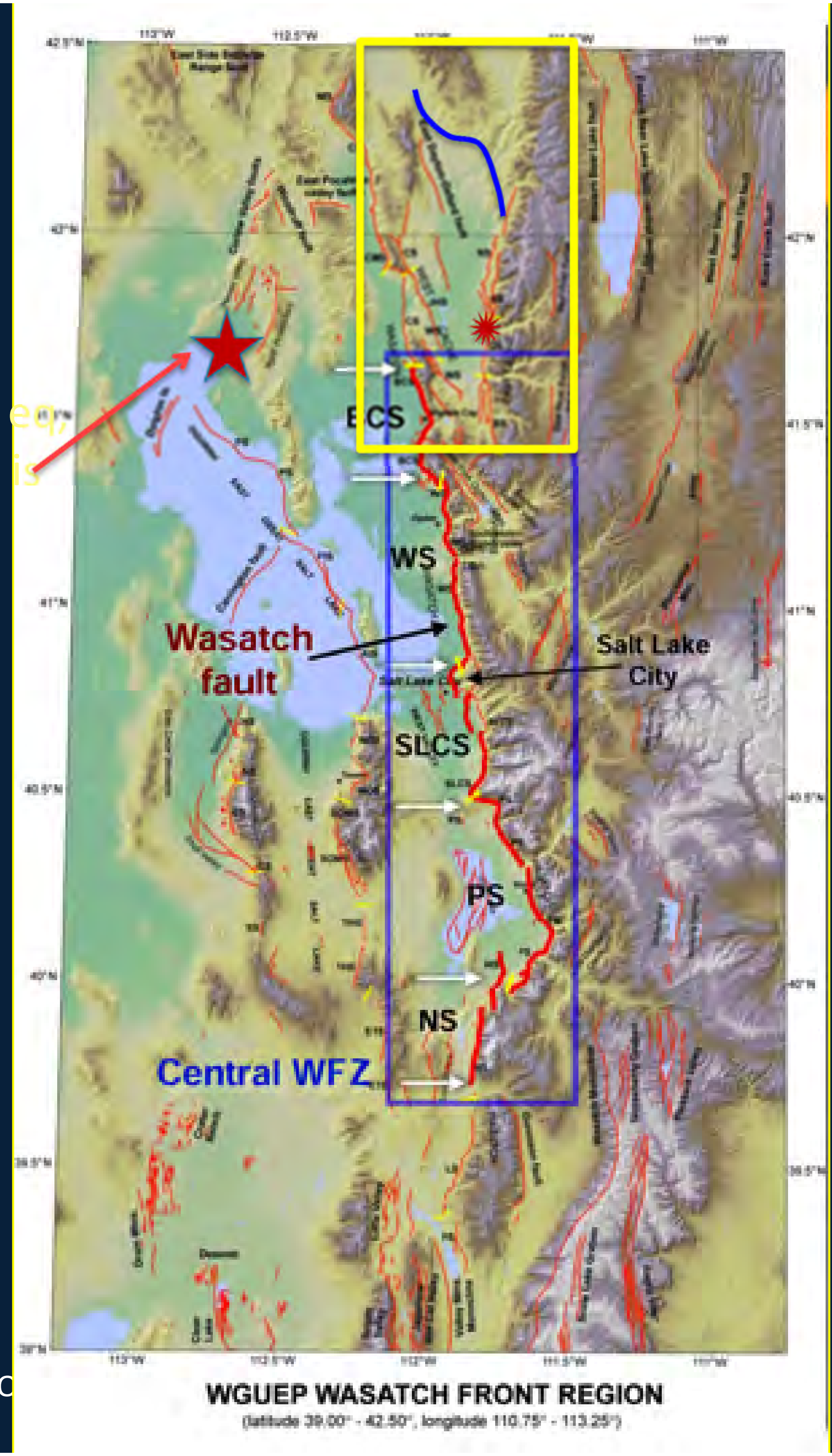
Please come and visit (and bring a shovel)



Why here?

- An earthquake may have triggered the Bonneville flood in late Pleistocene (Janecke and Oaks, 2011)
- That realization prompted our on-going examination of an outcrop near Logan UT

Hansel Valley eq, 1934, M6.6, is analogue



Central WFZ segments:
BCS – Brigham City segment
WS – Weber segment
SLCS – Salt Lake City segment
PS – Provo segment
NS – Nephi segment

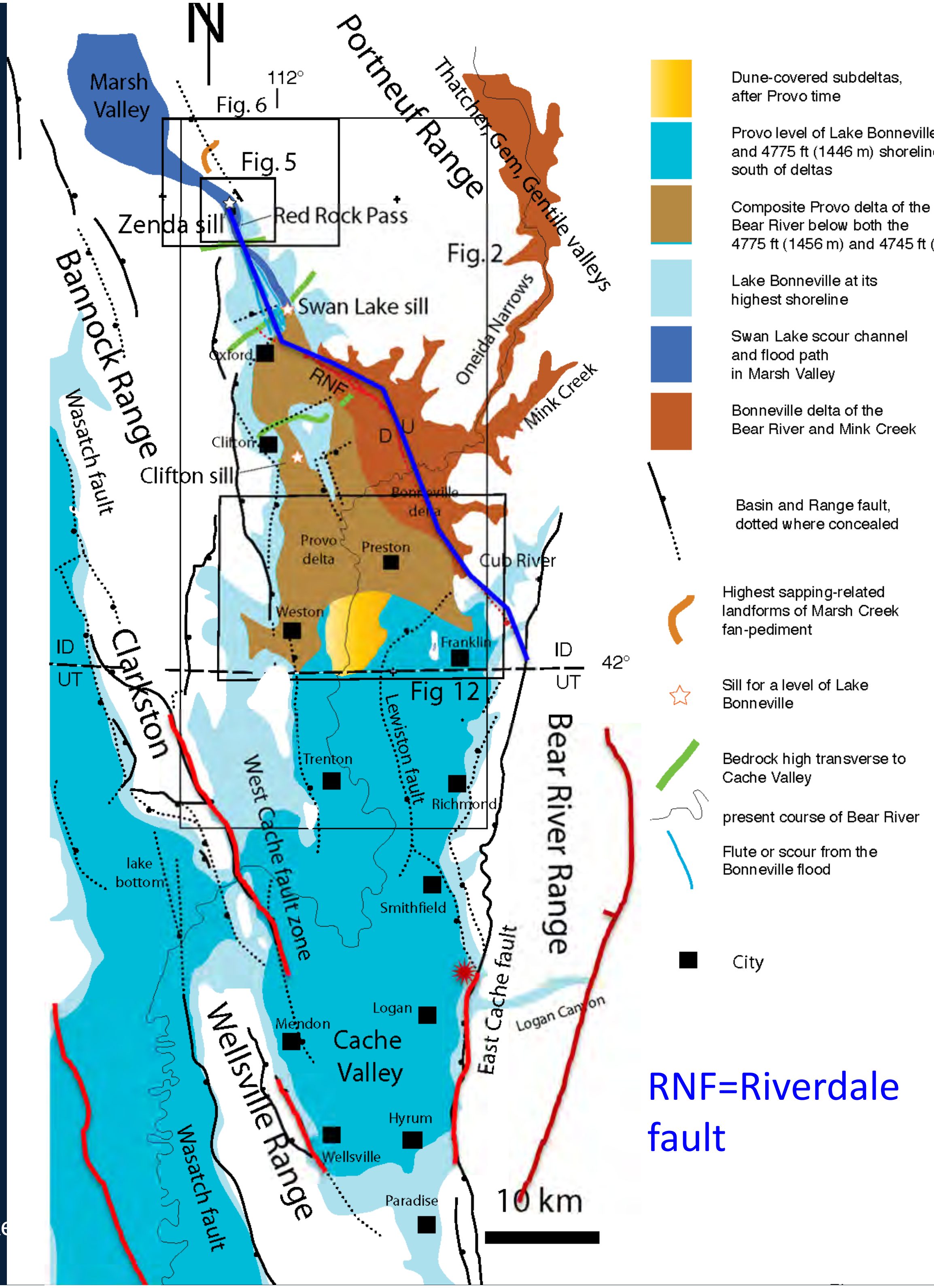
DuRoss 2005

Janecke et al., 2013 UC

A. Normal faults in Cache Valley have low slip rates and long recurrence intervals in the Holocene.

- Riverdale fault produced a significant earthquake around the time of the Bonneville flood. .
- Janecke and Oaks, 2011
- We wondered whether the liquefaction in an outcrop near Logan might be a record that event.

Janecke and Oaks, 2011



That exposure of liquefied sand existed since ~1980s and has been a field trip stop for many geology students. This is the exposure ~35 years ago (Oaks' slides)

WNW ESE

Site is ~40 m below Bonneville shoreline

225 m west of Bonneville shoreline

All outcrop shots are looking NNE

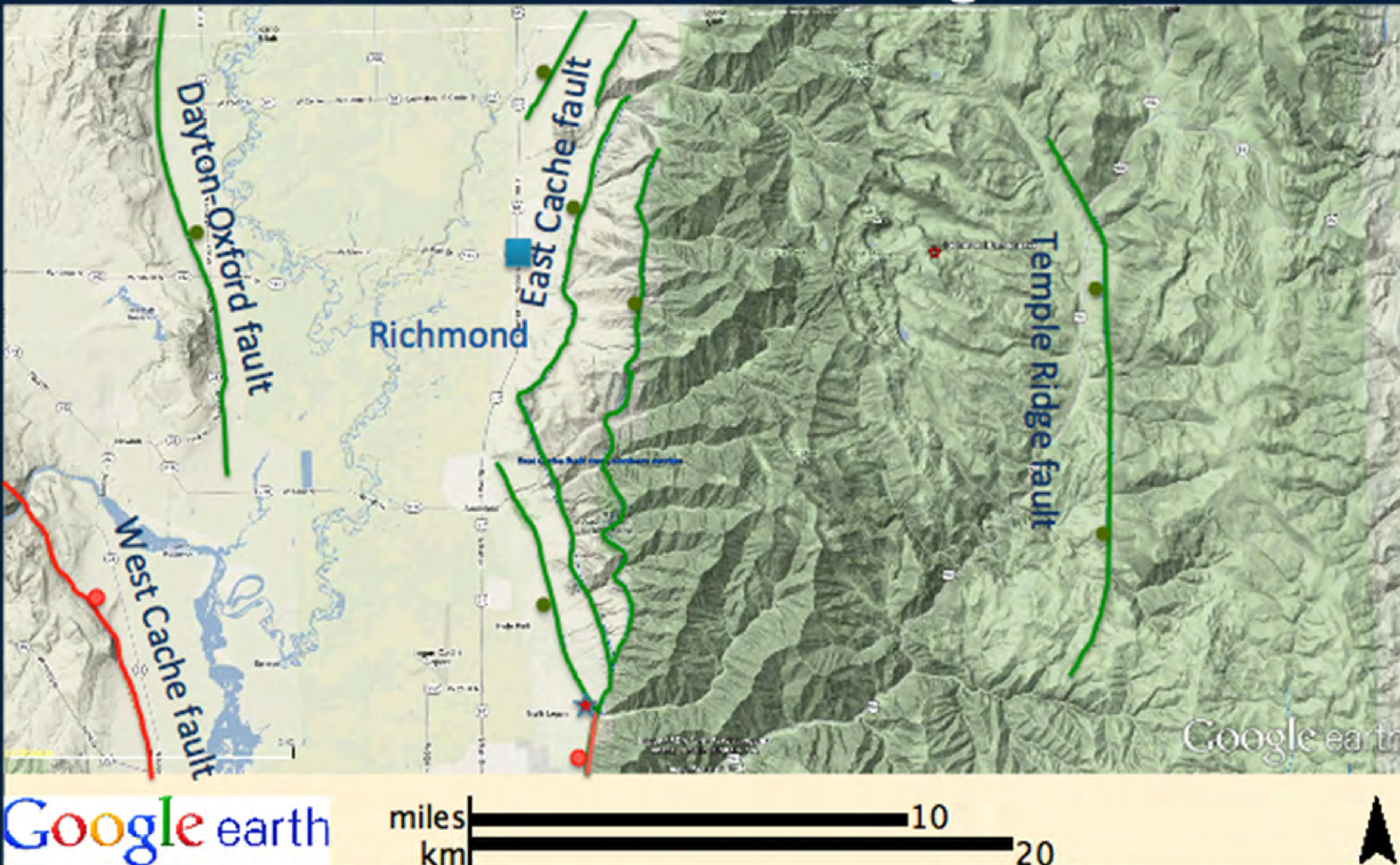
Janecke et al., 2013 UQFPWG

2011 Remnant

The outcrop had shrunk to this

Bag

Site is within a segment boundary: Central and northern segment



Inactive fault
Active fault

Janecke, Geology Dept. USU Aug. 2012

Fault traces from the Quaternary fault and fold database of USGS

Janecke et al., 2013 UQFPWG

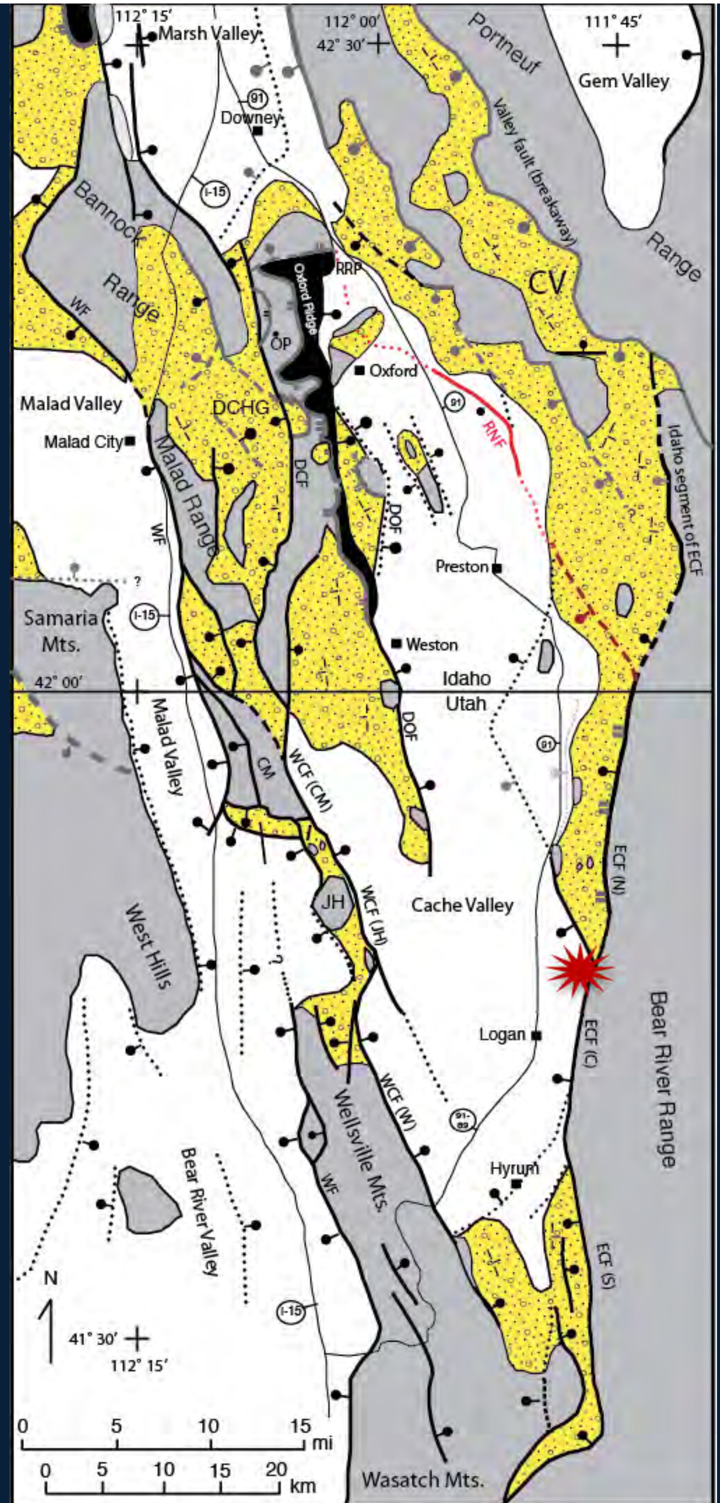
Central segment of ECF:

MRE 4 ka on central segment

Penultimate event is 13-15.5 ka during Provo time

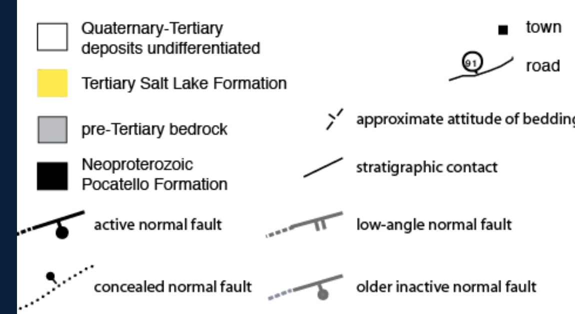
Northern segment:

No evidence of latest Quaternary slip except for a lateral spread (McCalpin 1987, 1994)



This map is modified from Janecke et al. (2003)

Figure 1. Simplified geologic map showing the distribution of the Salt Lake Formation around Cache Valley and the active Basin-and-Range normal faults. Some older normal faults are also shown (grayed). The Clifton horst is the up-thrown block between the Deep Creek and Dayton-Oxford faults. Abbreviations are: CV = Cottowood Valley, DCF = Deep Creek Fault, DCHG = Deep Creek half graben, DOF = Dayton-Oxford Fault, ECF = East Cache Fault (N = northern, C = central, S = southern segment), OP = Oxford Peak, Q = Quaternary sediment, RRP = Red Rock Pass, Tsl = Salt Lake Formation, WCF = West Cache fault zone (CM = Clarkston Mountain, JH = Junction Hills, RNF=Riverdale normal fault, W = Wellsville segment), WF = Wasatch Fault. Some buried faults (dotted) from Zoback (1983). This map is modified from Janecke et al. (2003), with updates from unpublished gravity data of Oaks et al., in Fig. 15, and Eversaul (2004).



Basic units:

WNW ESE

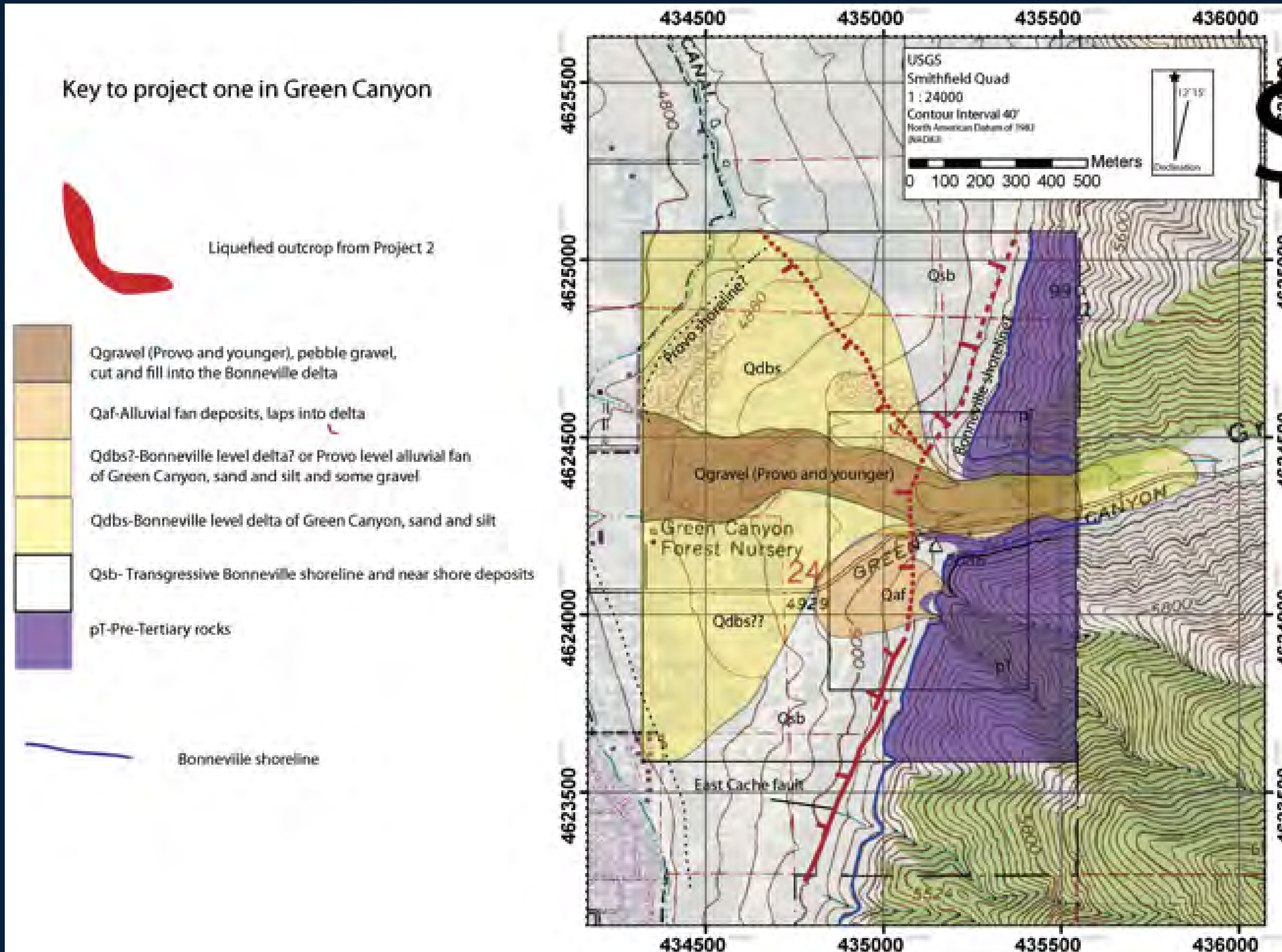
- Soil
- Provo? aged alluvial gravel,
- over Bonneville deltaic sand and silt (ss)
- over Bonneville prodelta muds (m)
- Bonneville deltaic? gravel in foresets at west end (g)

Janecke et al., 2013 UQFPWG

Study site is near East Cache fault

McCalpin inferred a buried strand of East Cache fault within 10-15 m of the site

on NE side



Janecke et al., 2013 UQFPWG

Evolution of the project

- Phase one

  Field Methods class, Fall 2011, studied the outcrop and exposed a little more of the original

  Main result was discovery of slip surfaces at west end of exposure and unfaulted overlap

All deformation is older than Bonneville flood

Slide 14

Janecke et al., 2013 UQFPWG

Evolution of the project

- Phase two
  - Senior thesis research: AJ Knight, Dallas Nutt, Susanne Janecke, Robert Q Oaks Jr., Tammy Rittenour

– Main question: what is significance of west dipping fault in the outcrop?

– Where there earthquakes involved in deformation?

– How? How many? When? Why?

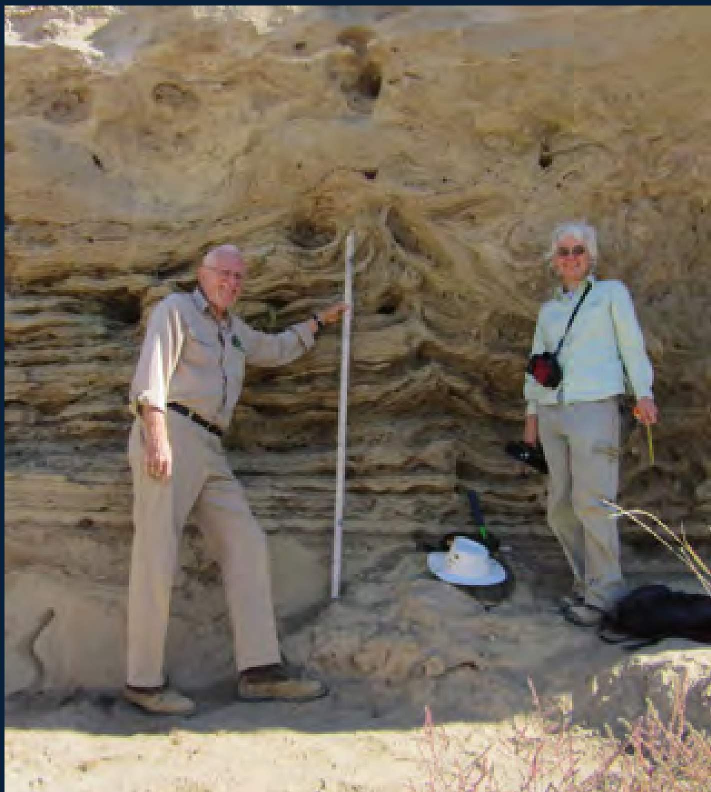
1 m

Logging string is spaced 50 cm apart
My jake staff is 160 cm long

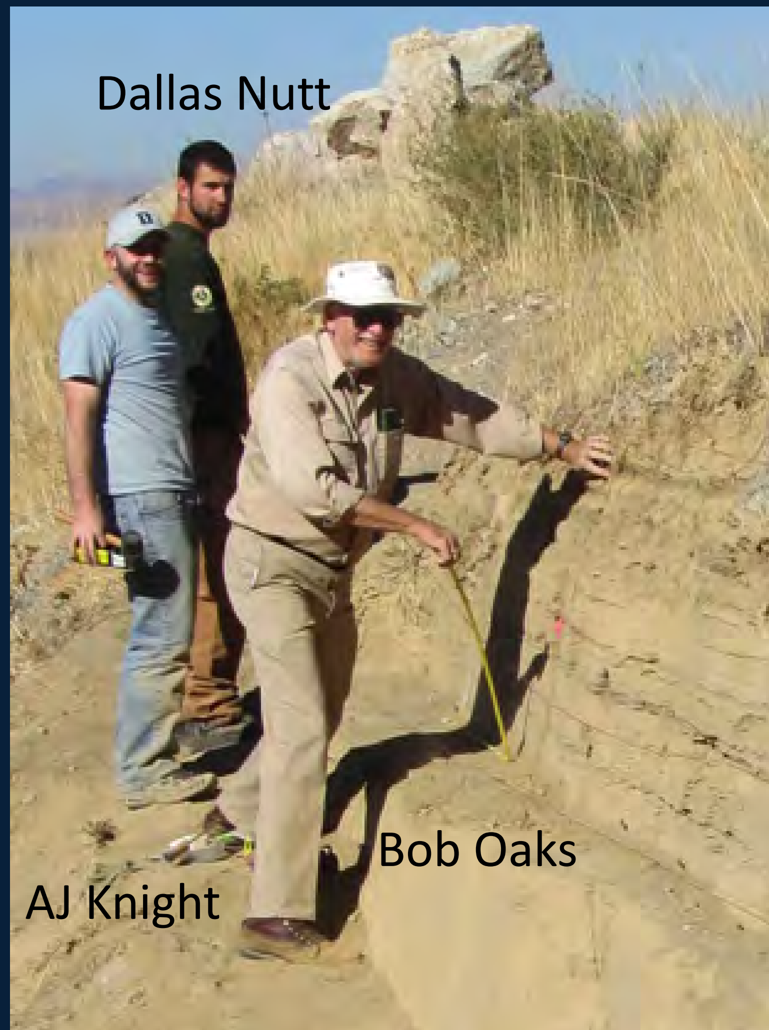
Hand digging: exposed another 15 m

Janecke et al., 2013 UQFPWG

Current research team



Bob and Susanne



Tammy Rittenour

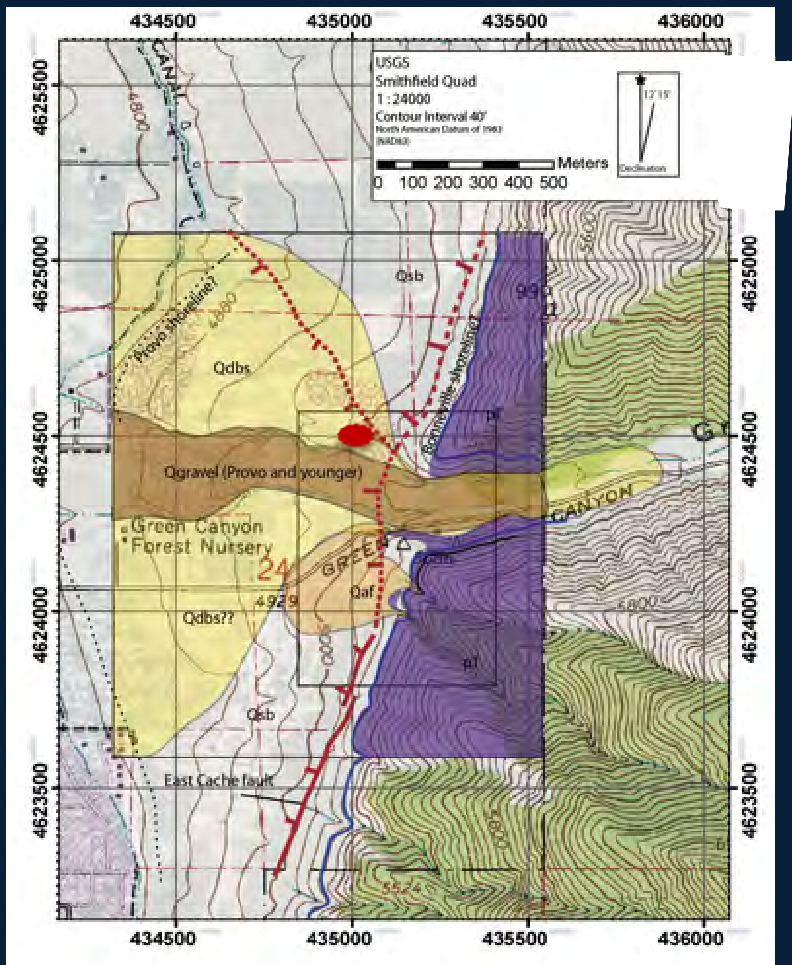
Today's talk will be about
phase 1 and 2:

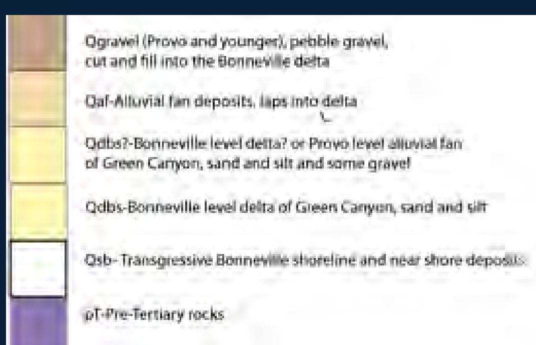
- Results from original and hand-dug exposures
- A few new results from backhoe work
- Educational concepts

Slide 14

Janecke et al., 2013 UQFPWG

Methods





- Geologic mapping, analysis of other outcrops in the gravel pit
- Digging, cleaning and logging of the "liquefied outcrop"
- Radiocarbon and OSL dating of beds below and above deformed layers
- Stereo analysis of 1980's photos of outcrop
- Use of backhoe to restore the outcrop

Janecke et al., 2013 UQFPWG

Research questions evolved as we uncovered more and more of the outcrop

1. Does the deformed outcrop at Green Canyon record an earthquake at the time of the Bonneville flood?
2. Is the fault in the outcrop a strand of the East Cache fault or a slip surface in a lateral spread?
3. Was the lateral spread activated by an earthquake?
4. How many large liquefaction events are preserved in the outcrop?
5. Did earthquakes produce any or all of the large liquefaction features?

Janecke et al., 2013 UQFPWG

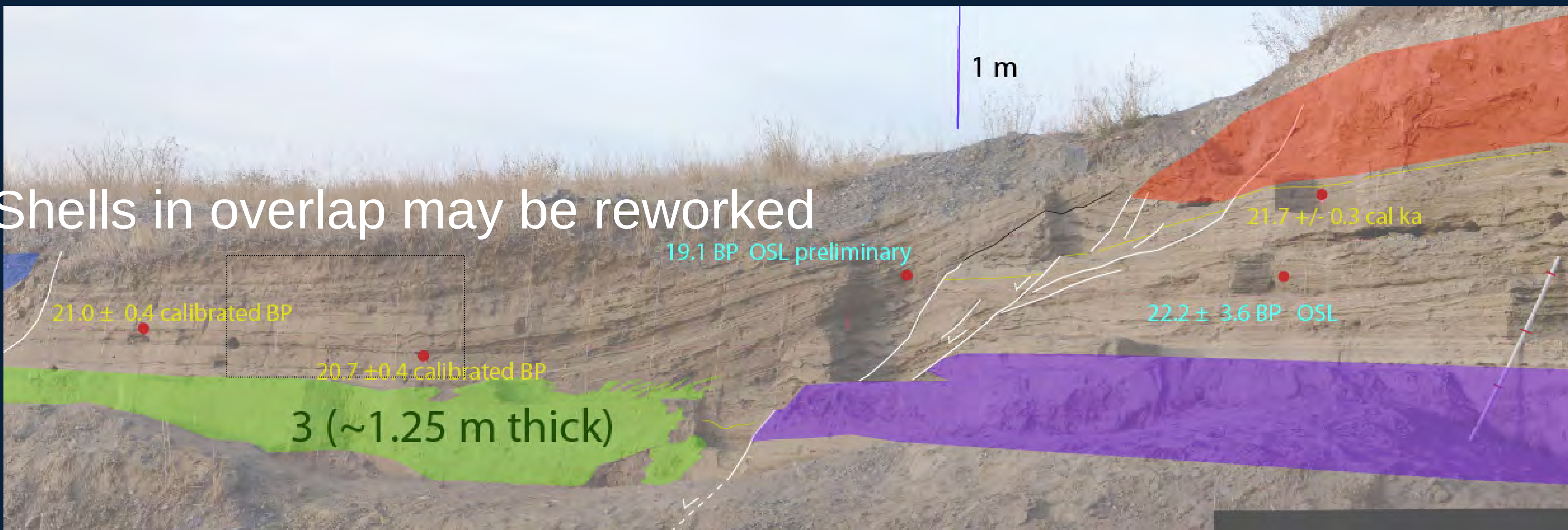
Except for capping gravel and soil, all sediment was deposited in Lake Bonneville

Evidence: Gastropod shell, ripples, cross beds, sedimentary facies, radiocarbon and OSL ages

Gastropod shells are common in sandy deltaic beds

Janecke et al., 2013 UQFPWG

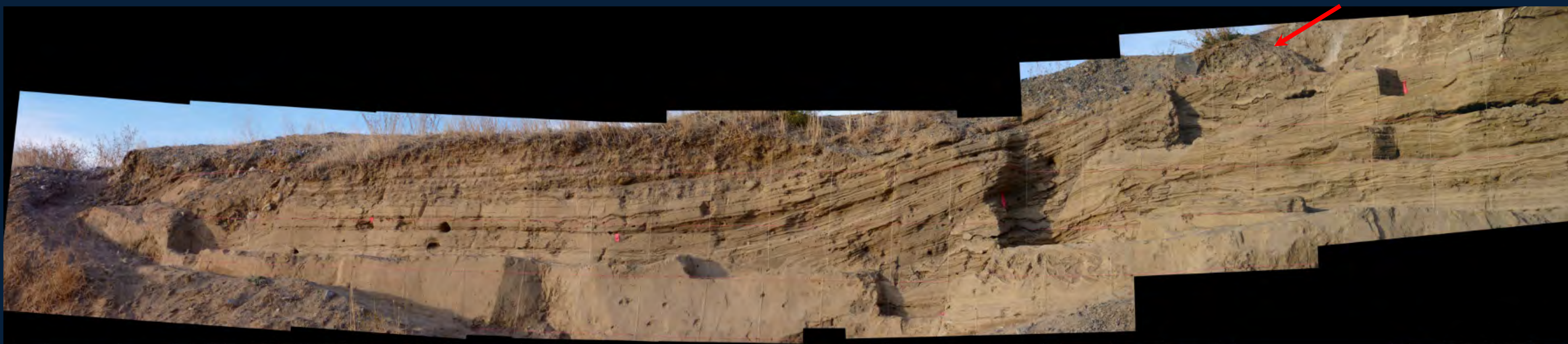
3 radiocarbon and 2 OSL dates All Bonneville age ~17-23 ka



Logging string is spaced 50 cm apart

Janecke et al., 2013 UQFPWG

Results of phase 2

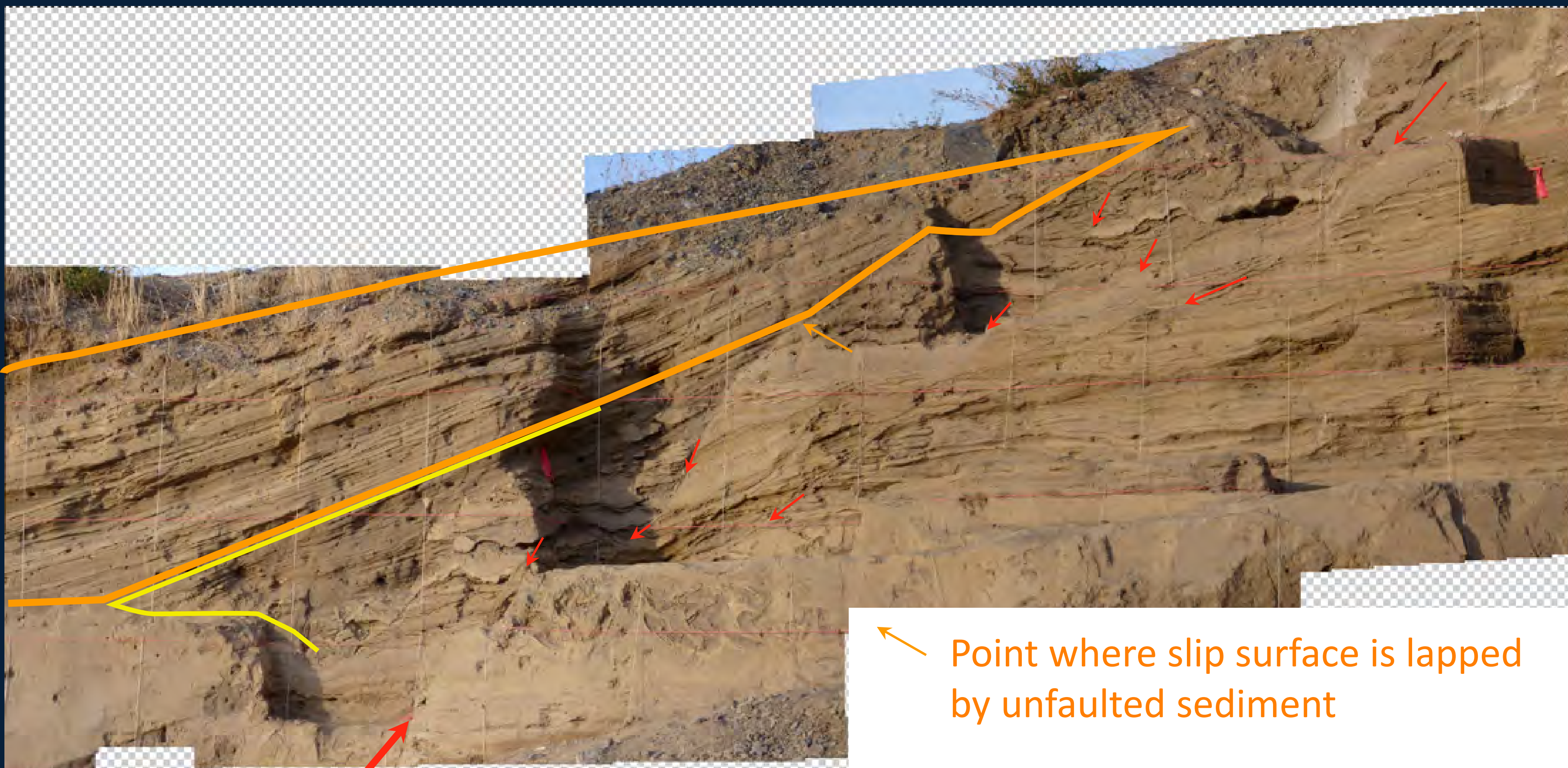


Summary result:

- Deltaic Bonneville transgressive sand
- Cut by faults or slip surfaces of a lateral spread,
- liquefied,
- Repeatedly

Janecke et al., 2013 UQFPWG

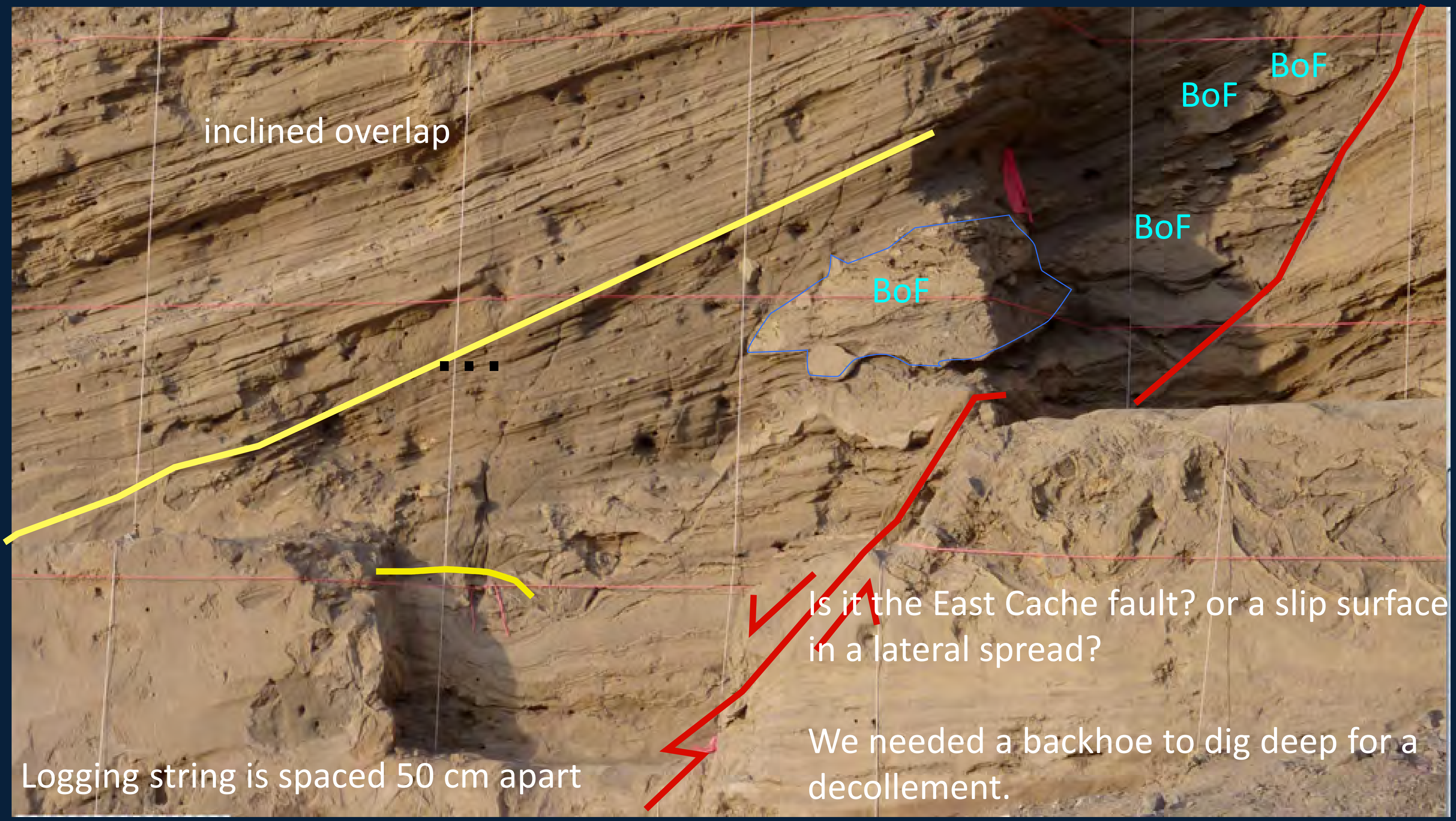
Central fault or slip surface has a fault wedge, slipped >once, and is overlapped by unfaulted sediment



Logging string is spaced 50 cm apart

Janecke et al., 2013 UQFPWG

Lacustrine fault wedge contains blocks of footwall



Janecke et al., 2013 UQFPWG

subsidiary structures

The liquefied beds are full of round features called pseudonodules, flames, fluid escape structures and load casts First we'll examine them in original outcrop

22 G. OWEN

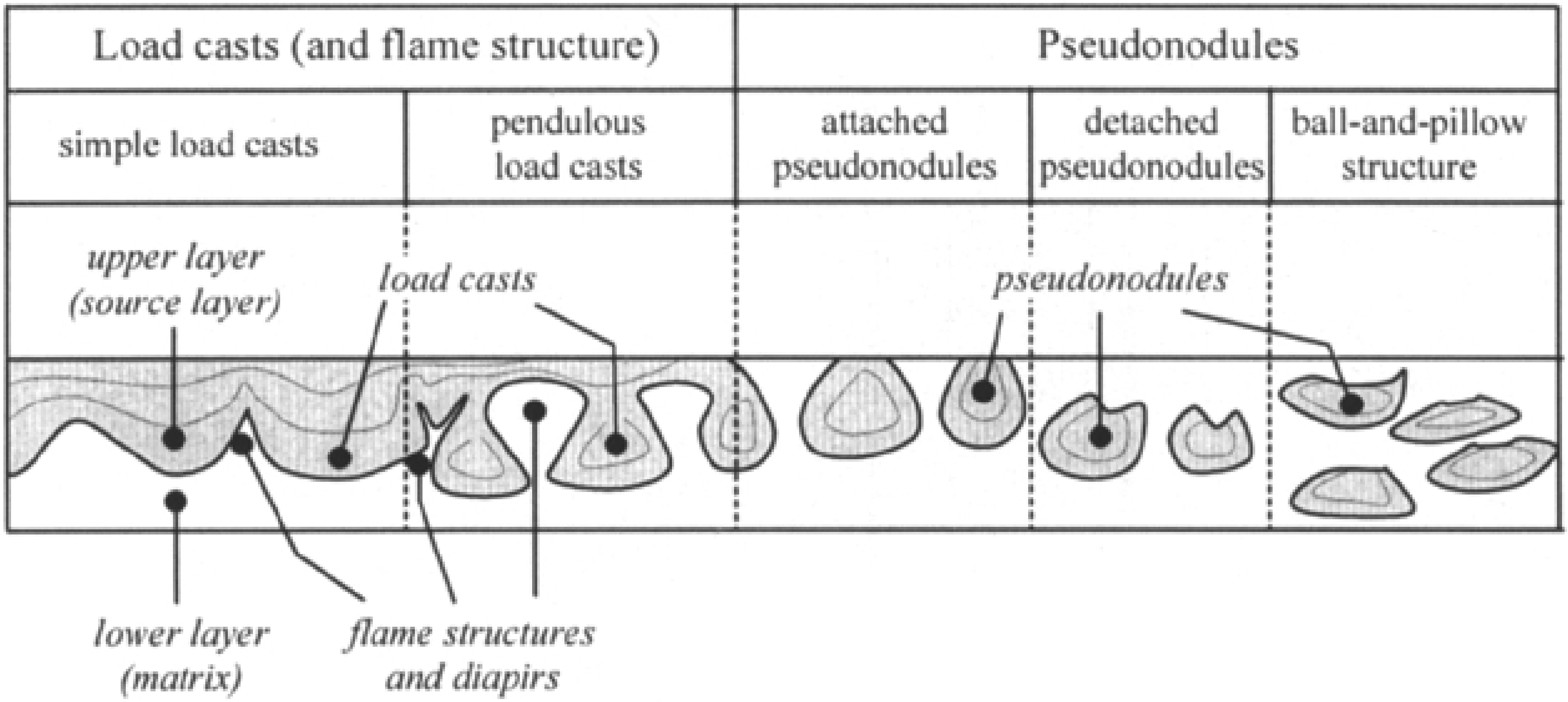


Fig. 1. Definition diagram for load structures.

Janecke et al., 2013 UQFPWG

Fluid escape strcts, sand dikes and slip surfaces/faults

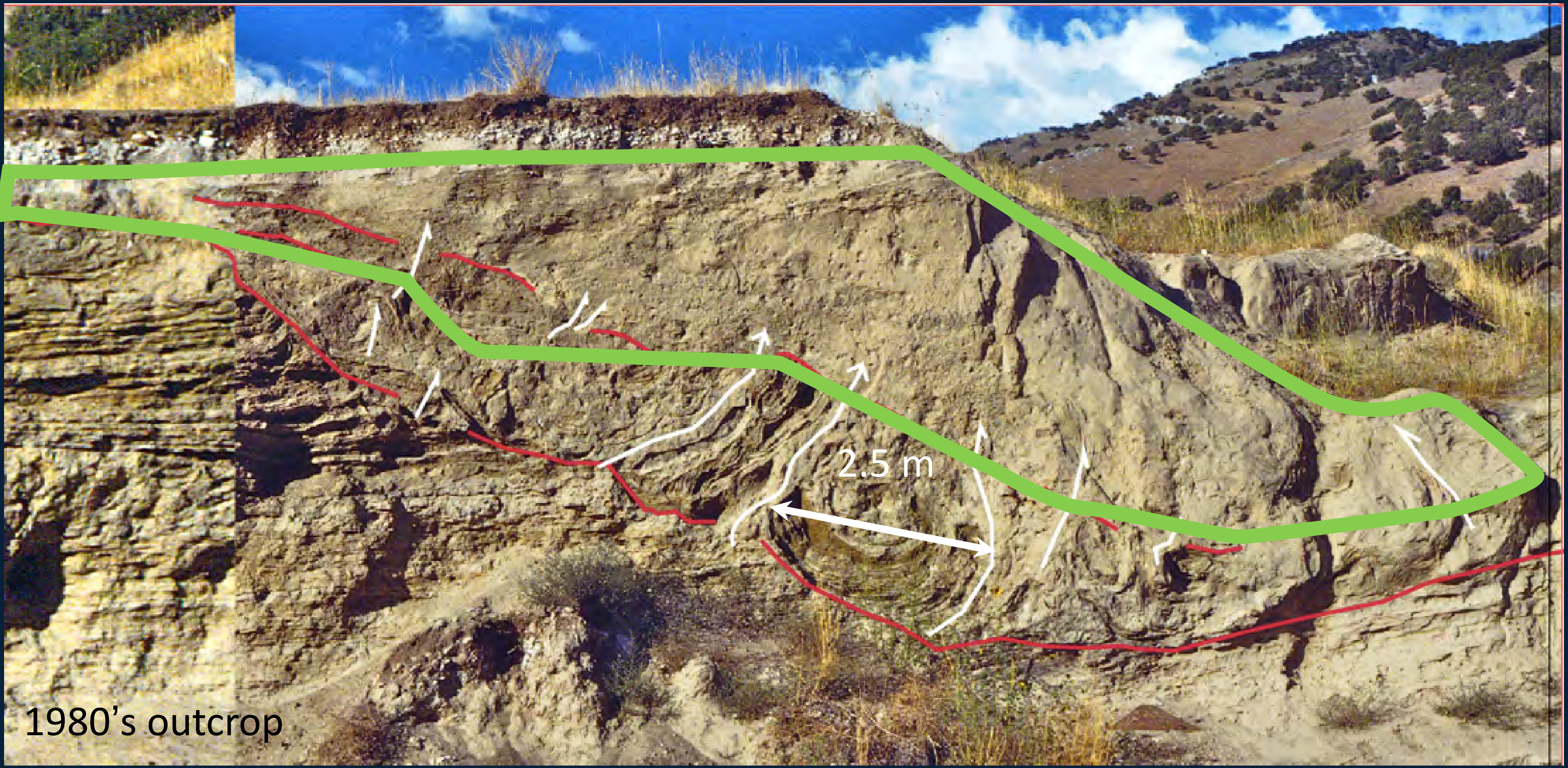
1980's outcrop

fluid escape paths are white

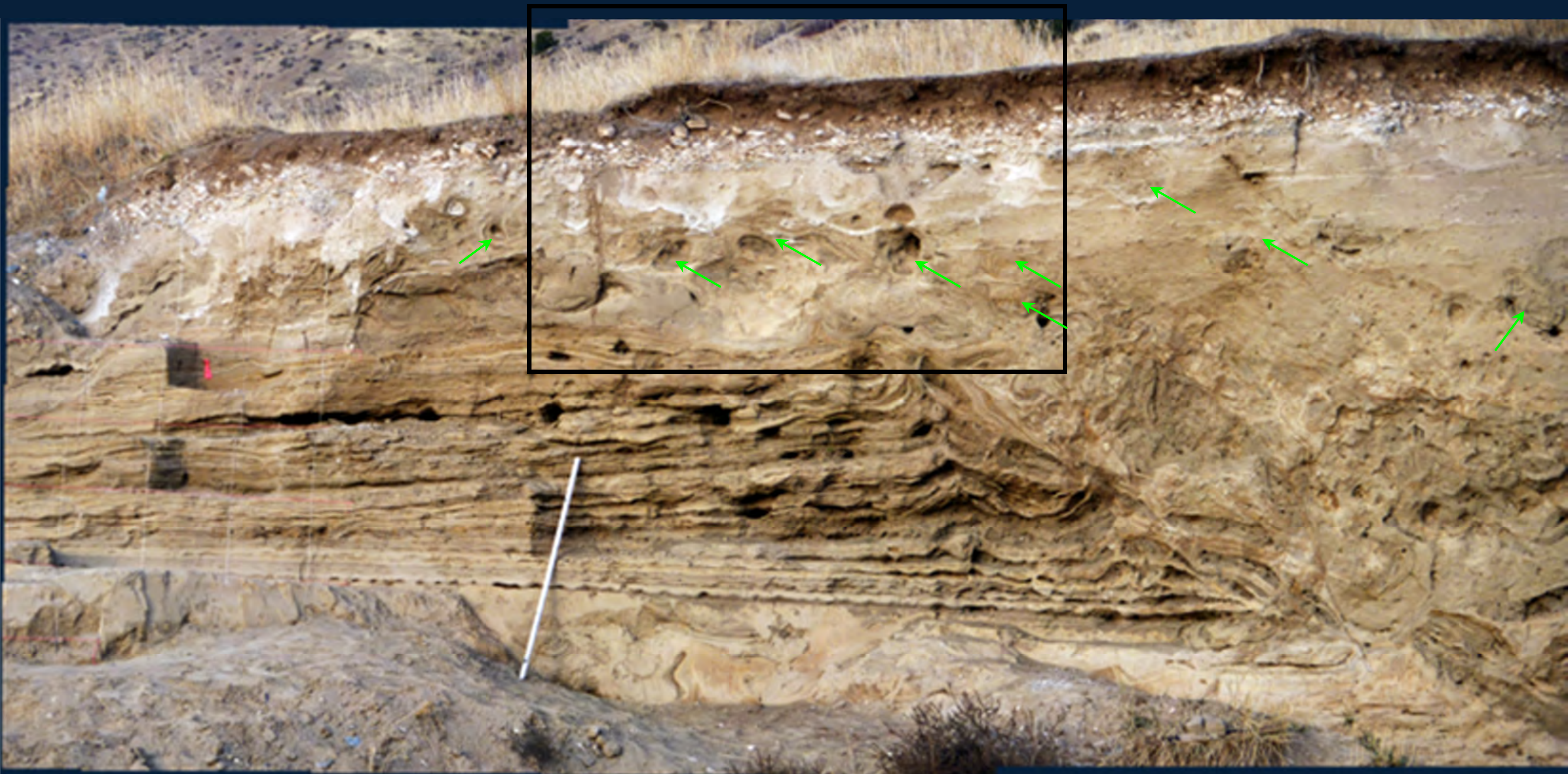
Janecke et al., 2013 UQFPWG

Pseudonodules are unusually large

They are overlain by 2.5-3 m of nearly structureless sand with dispersed pseudonodules



Today;s outcrop: Structure-less sand has both attached and detached pseudo-nodules in it



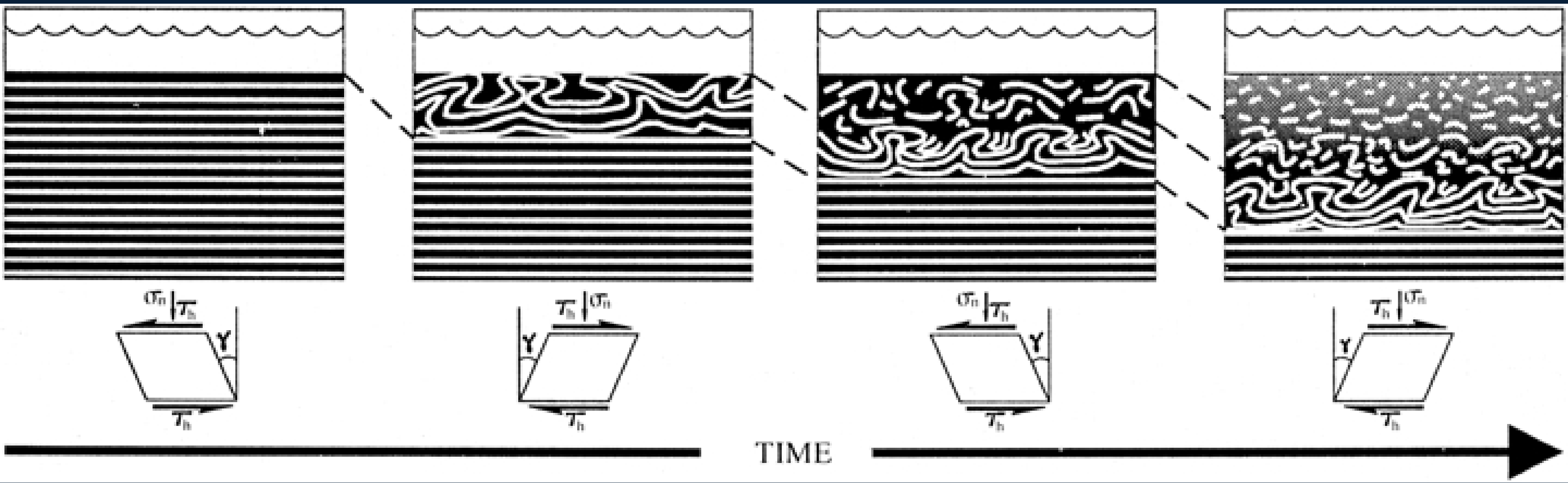
Jake staff is 160 cm long

Logging string is spaced 50 cm apart

Janecke et al., 2013 UQFPWG

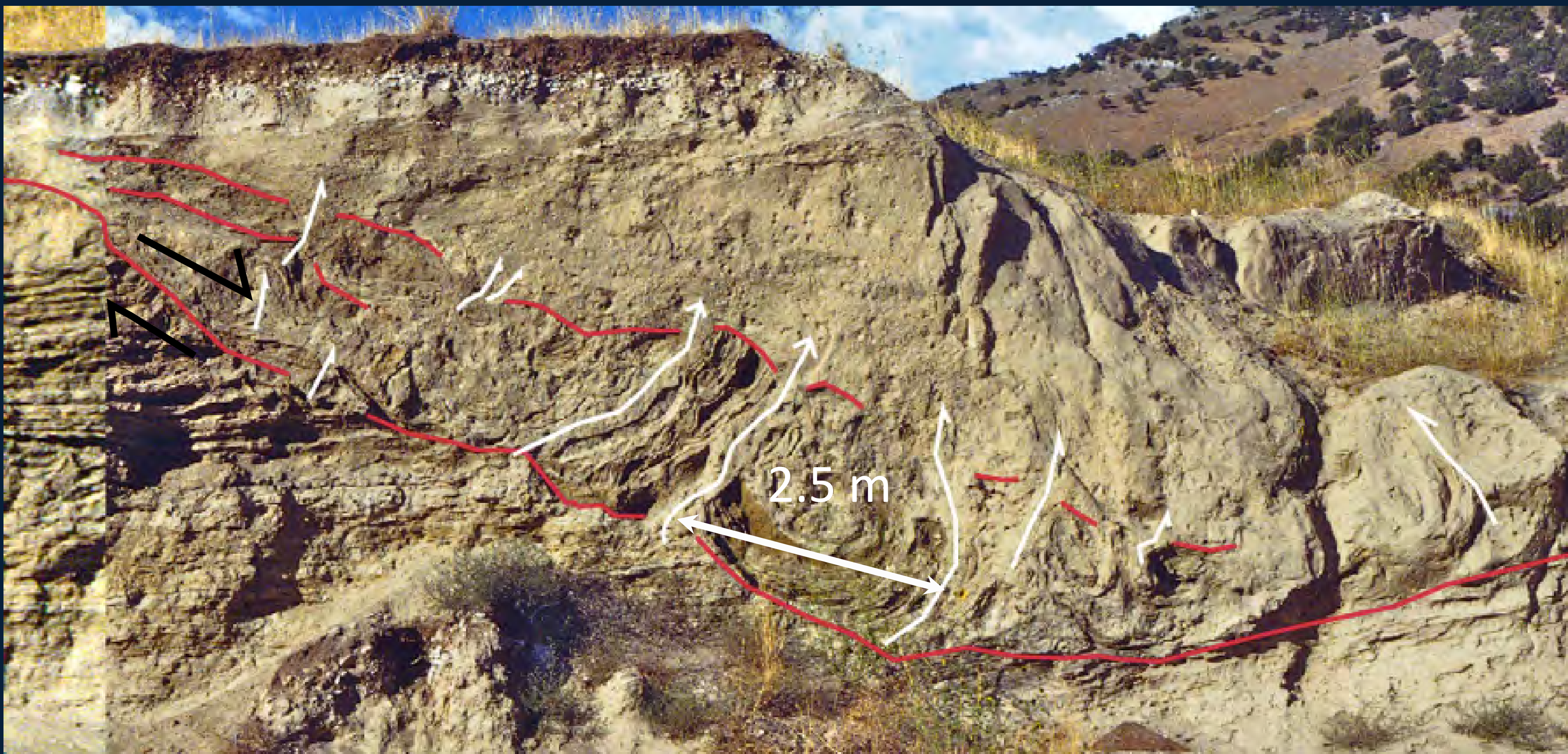
Janecke et al., 2013 UQFPWG

Fault graded bedding is diagnostic of seismic shaking of a lake bed



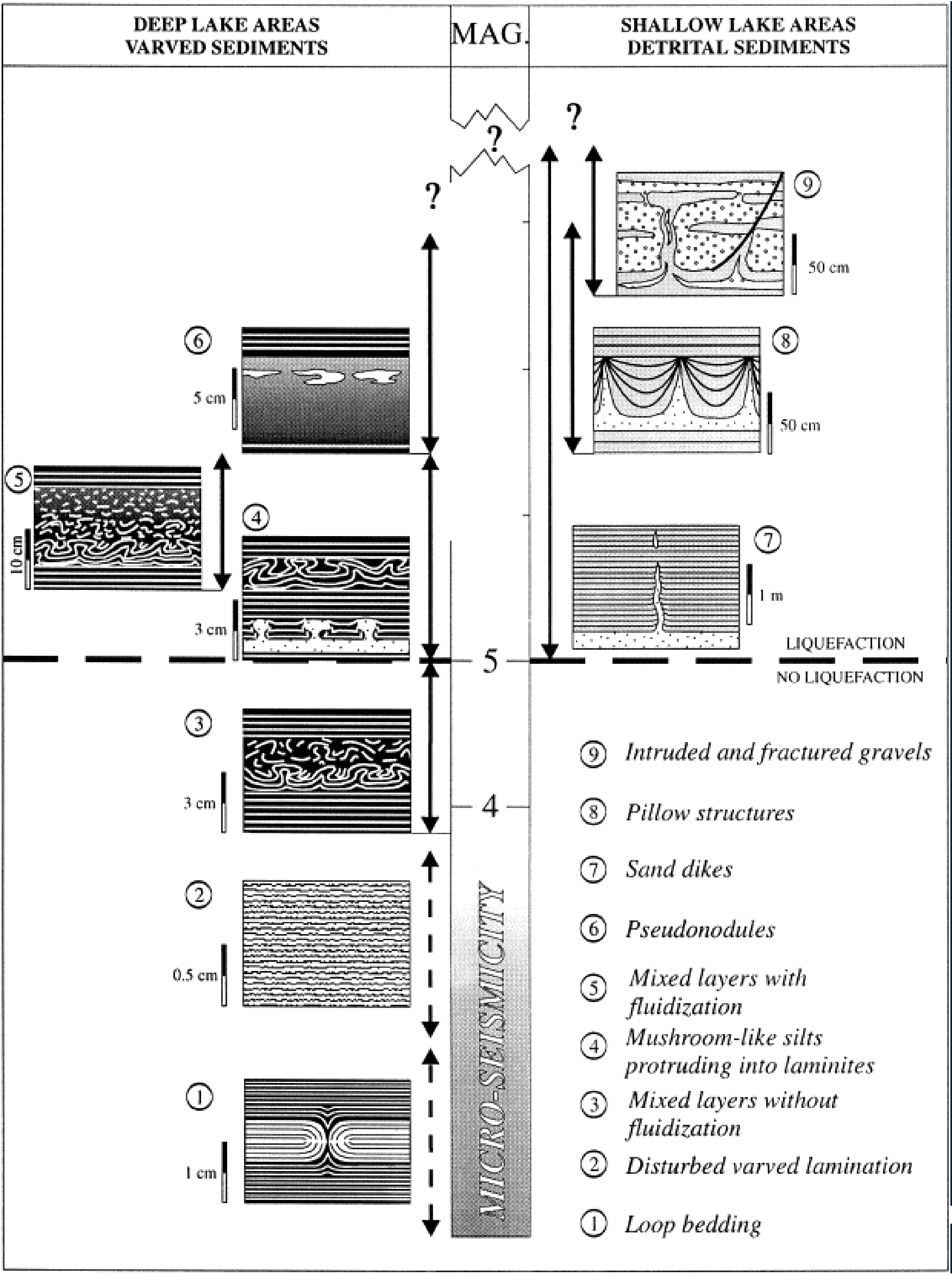
Rodriguez et al., 2000

Fault-graded beds ?



~6 m high exposure, 1980s

Janecke et al., 2013 UQFPWG



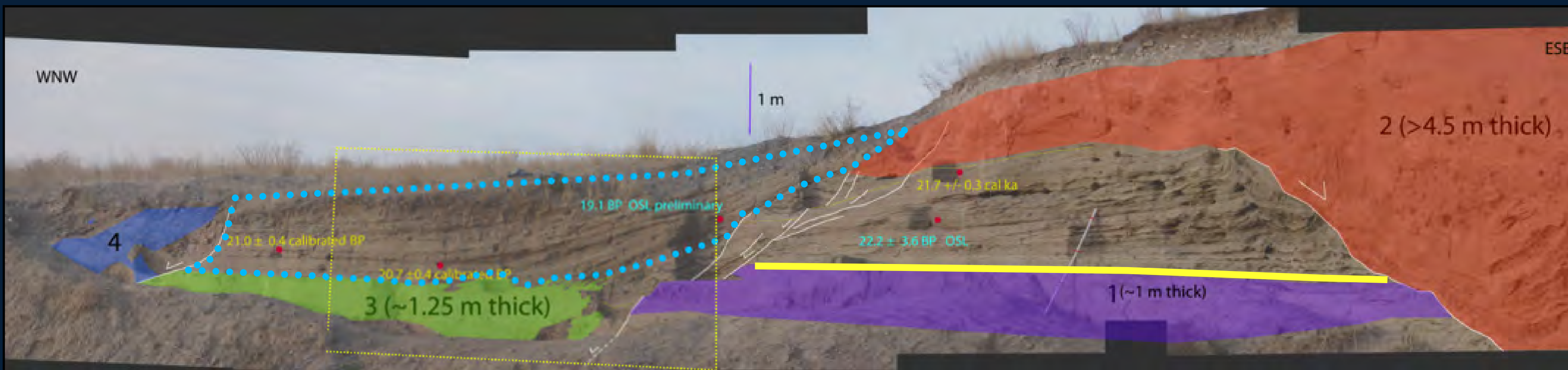
Intensity of fault graded bedding has been related to earthquake magnitude

Outcrop has every one of these features

Notice the bar scale- none of these features exceed tens of centimeter

Modified from Rodriguez et al., 2000

RESULT: There are 4 THICK liquefied intervals numbered and colored from oldest to youngest



Cross-cutting relationships between these beds and show that each is a different age, from 1 to 4

Unconformities,
slip surfaces and
overlapping beds

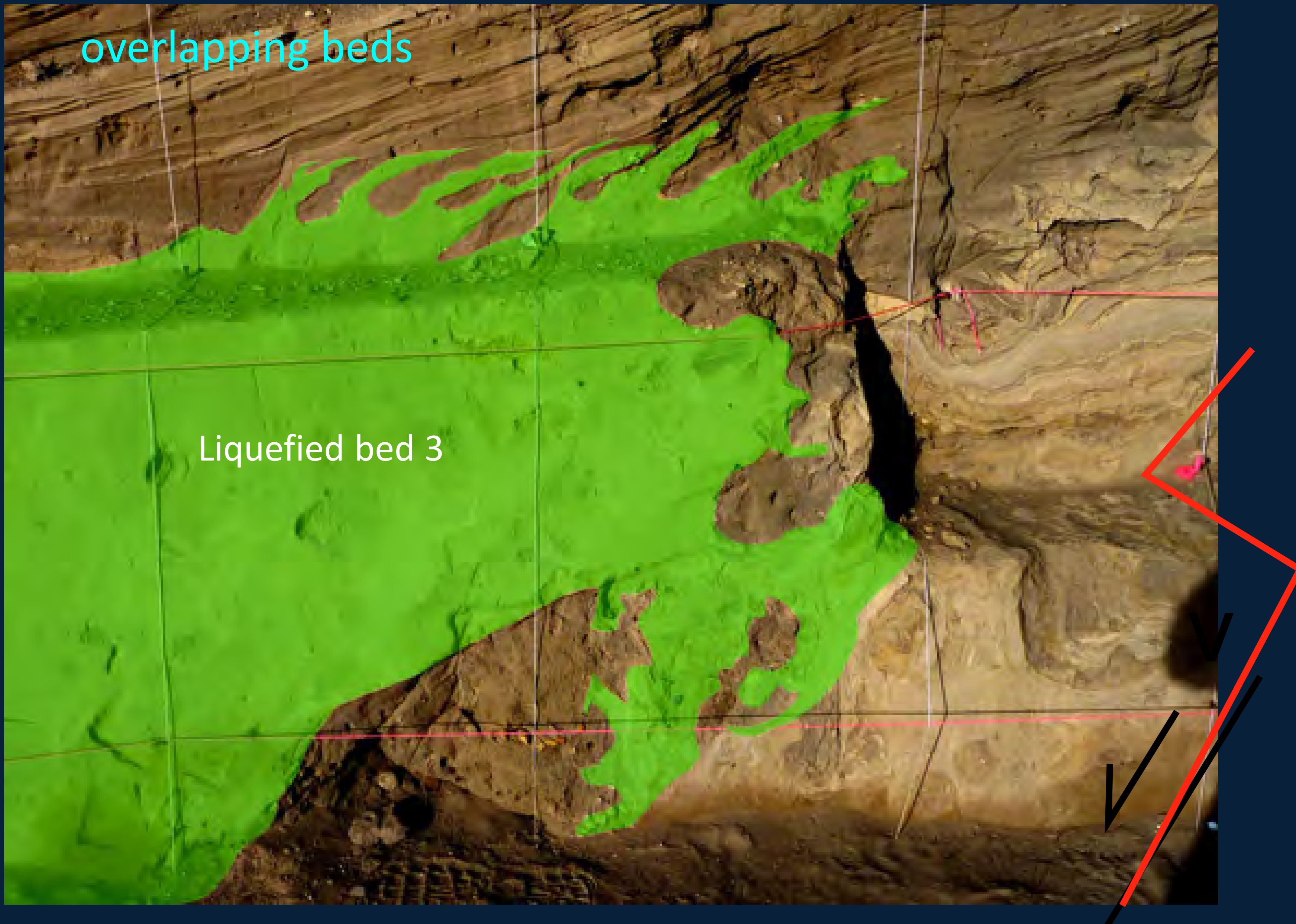
Janecke et al., 2013 UQFPWG

Bed 3 intruded into overlap beds at its east end

Logging string is spaced 50 cm apart

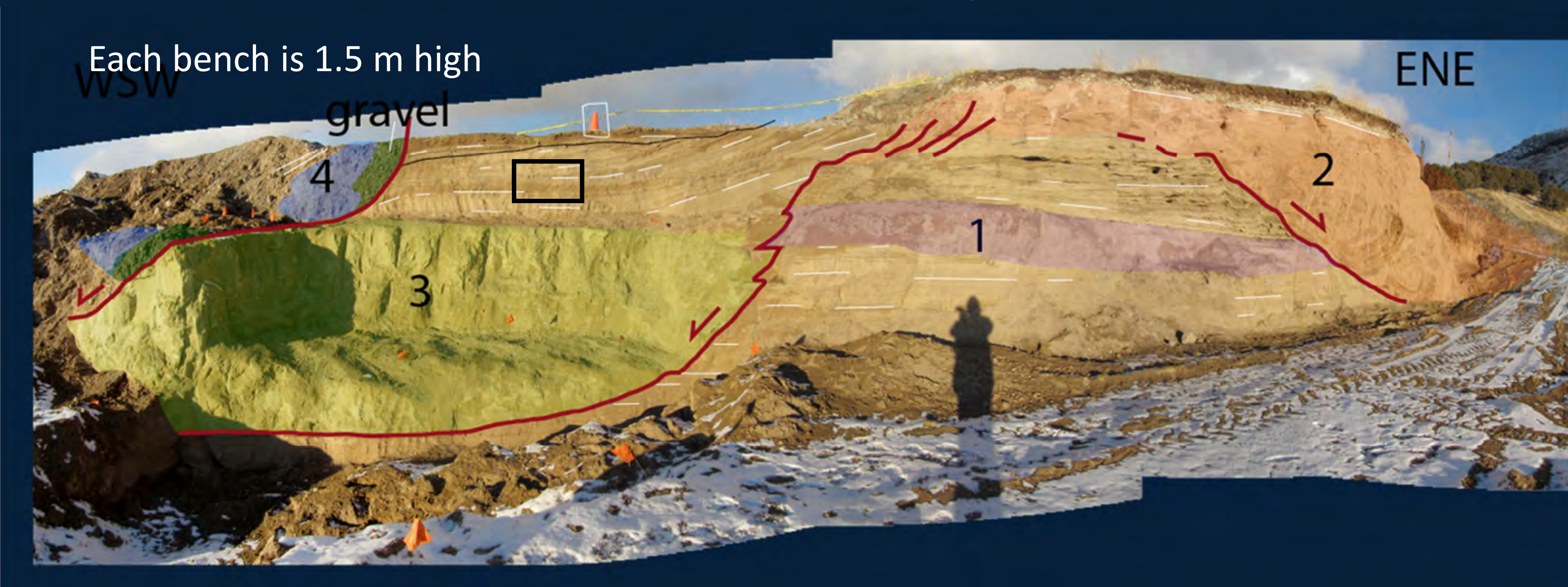
Janecke et al., 2013 UQFPWG

Some flames from Bed 3 intrude into overlap unit



Janecke et al., 2013 UQFPWG Logging string is spaced 50 cm apart

New exposure reveals that bed 3 is very thick

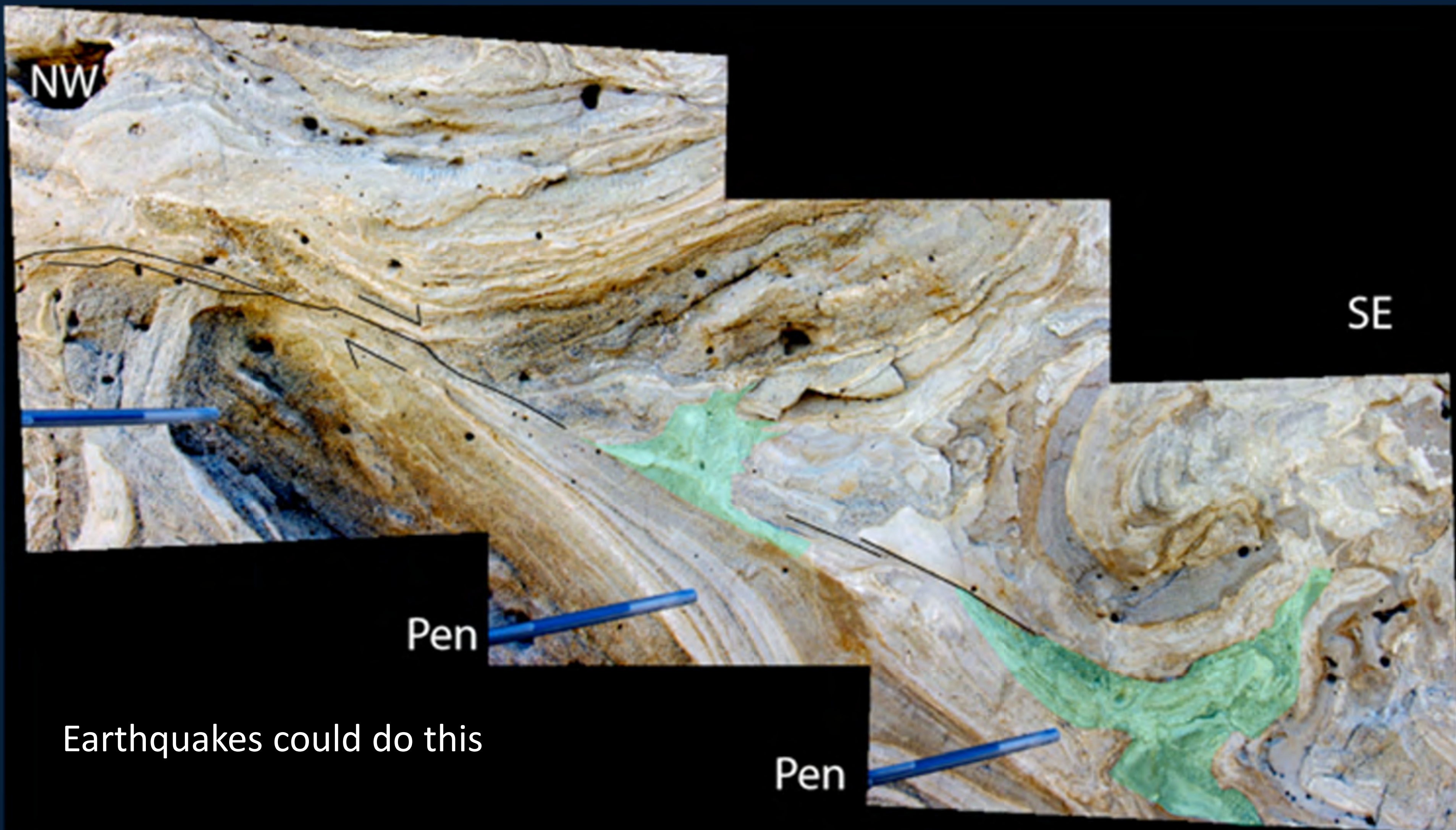


Bed 3 is mostly structureless sand + a few pseudonodules

Brittle faults and escaping fluids require high strain rates

Janecke et al., 2013 UQFPWG

Fluid escape across brittle faults requires varying conditions



Earthquakes could do this

Janecke et al., 2013 UQFPWG

Soft sediment deformation or seismite?

Or some of each?

- Features consistent with loading processes

  -Delta fronts are known to fail in lateral spreads and slumps

  -Possible association of deformational events and regressions in Paola et al's lab experiments

- Features consistent with seismite interpretation
  - Location near E Cache Flt.
  - Great thickness of structureless, liquefied beds
  - Injections, sand dikes and sills
  - The delta seems too small and gentle for such massive and repeated collapses
  - Structures are "fault graded bedding"
  - Brittle faults indicate high strain rates, > loading
  - Fluid escape across brittle faults from varying conditions
  - Hansel Valley earthquake produced similar liquefaction and lateral spreads (Robison, McCalpin)

Features in the liquefied outcrop seem too big, too intense and too frequent to be loading structures

Sedimentary Geology 235 (2011) 188–199

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Sedimentary Geology

journal homepage: www.elsevier.com/locate/sedgeo

Holocene soft-sediment deformation of the Santa Fe–Sopetrán Basin, northern Colombian Andes: Evidence for pre-Hispanic seismic activity?

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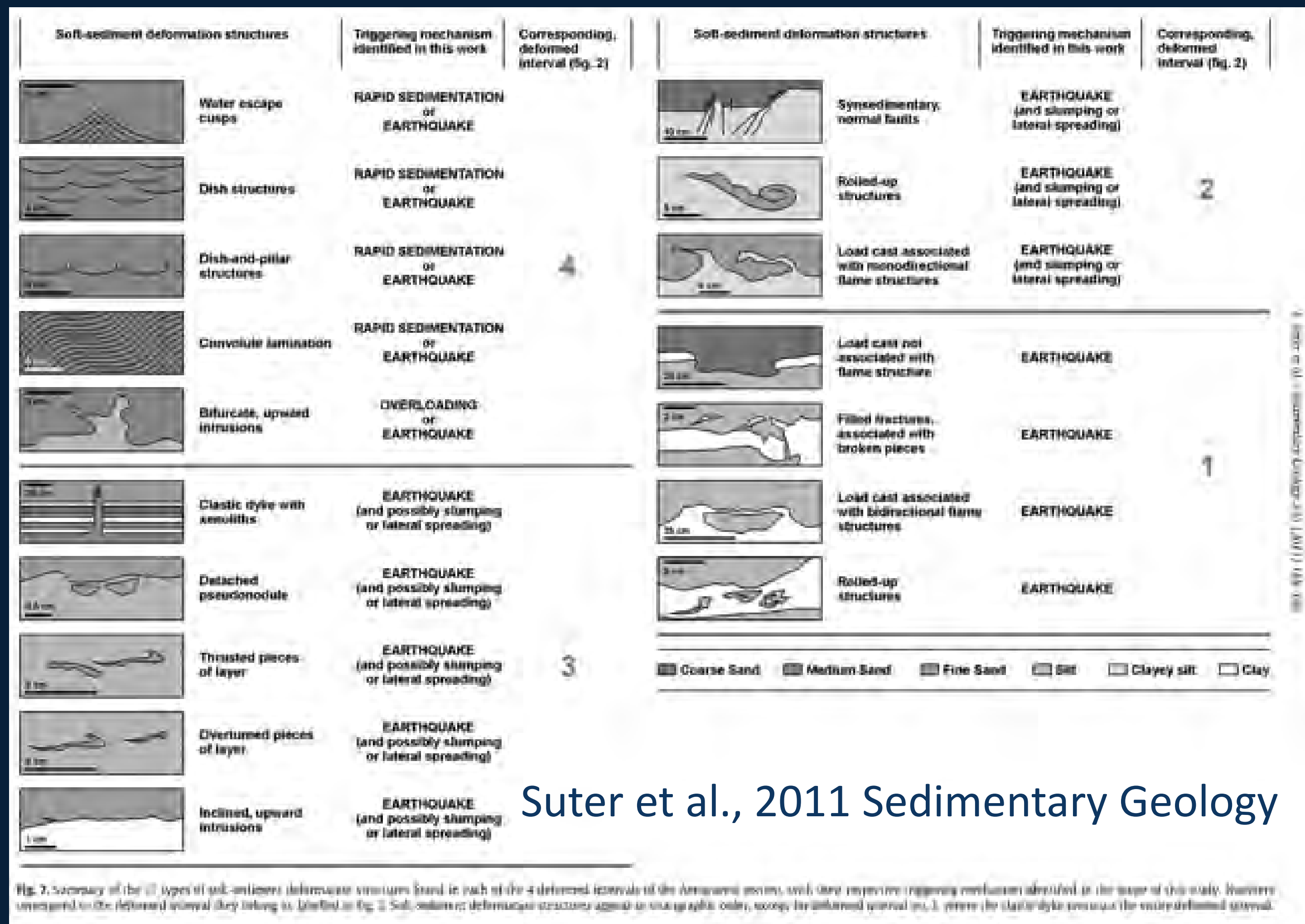
ABSTRACT

The detailed study of four deformed intervals from the Holocene fluvio-lacustrine deposits of the Santa Fe-Sopetrán Basin in northern Colombia shows 17 types of soft-sediment deformation (SSD) structures. Evidence indicates that seismic activity was responsible for the SSD structures, a conclusion reached after considering the environmental conditions at the time of sediment deposition and shortly after, and the detailed analysis of the driving force systems. Other triggers (i.e. overloading and rapid sedimentation), however, are not discarded. Intervals showing SSD structures occurred at centennial frequencies and apparently resulted from Mw 6–7 earthquakes. The Holocene age of these major shaking events should be seriously considered when evaluating the seismic hazard and risk for the middle Cauca Valley and the nearby city of Medellín with 3 million inhabitants.



Suter et al., 2011 Sedimentary Geology

Janecke et al., 2013 UQFPWG

Permission to dig came late in 2012

Janecke et al., 2013 UQFPWG

Backhoe exposed ~50% more and we dug as deep as possible to expose fault/or lateral spread

Janecke et al., 2013 UQFPWG

Excavation had an eye toward creating a public exposure with wide benches

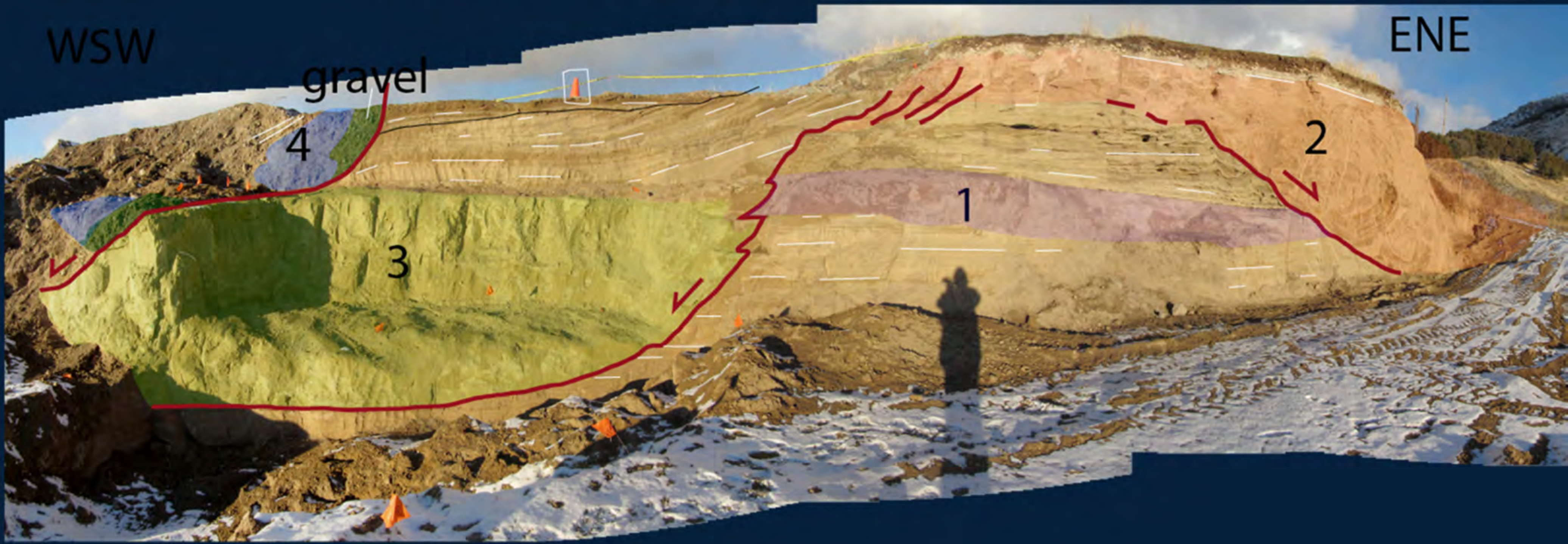
Janecke et al., 2013 UQFPWG

It snowed

Backhoe work restored ~ half of original outcrop

Janecke et al., 2013 UQFPWG

New results (so far)



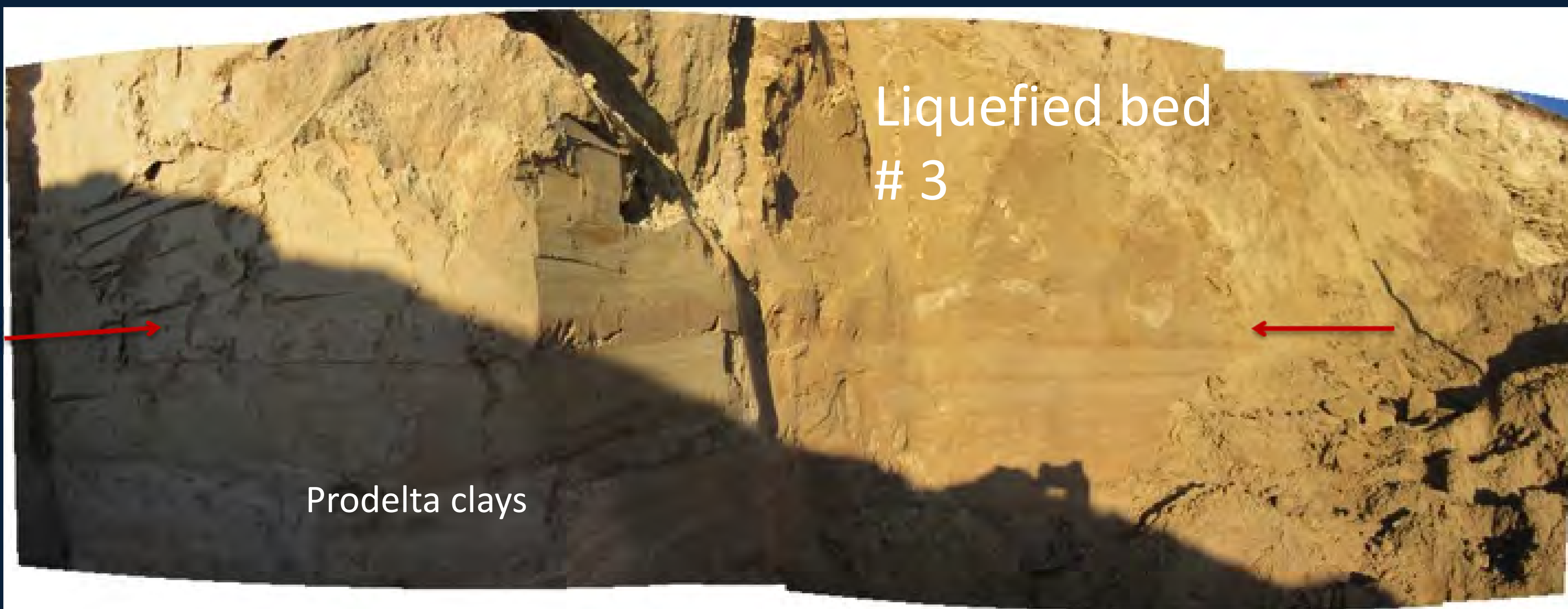
Central fault is not ECF,
but a slip surface in a lateral spread

Janecke et al., 2013 UQFPWG

Janecke et al., 2013 UQFPWG

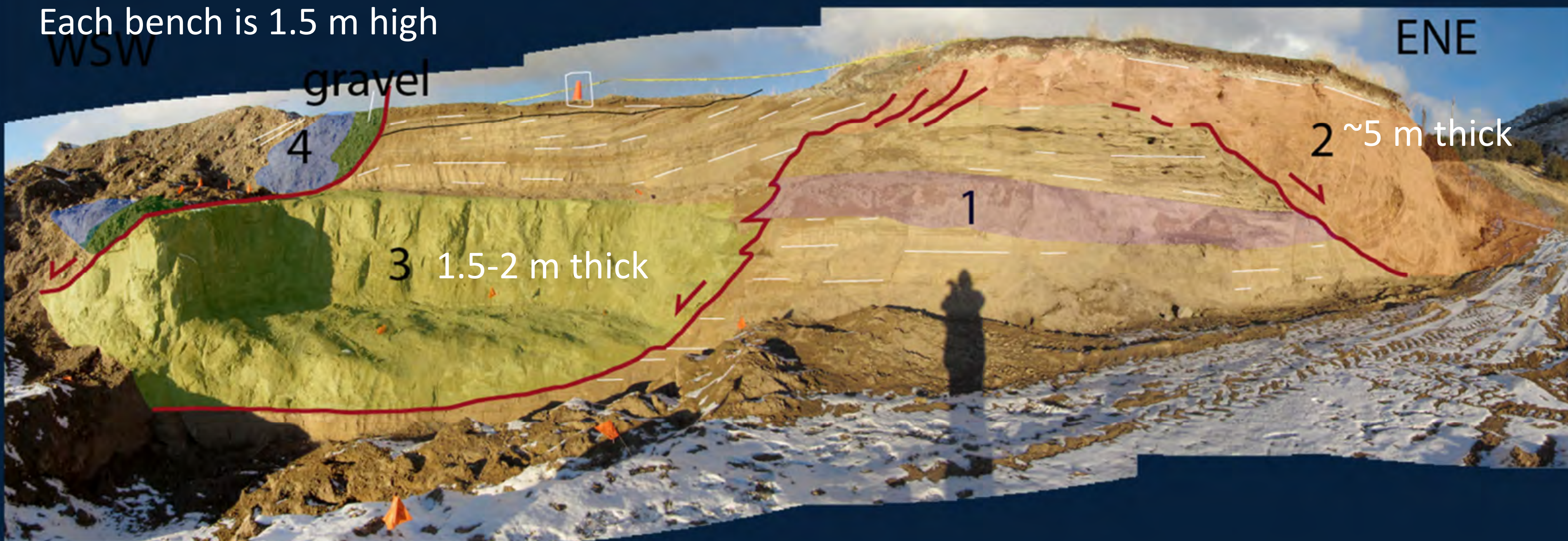
Listric geometry of slip surface proves a lateral spread

- Prodelta mud is below the decollement horizon



Janecke et al., 2013 UQFPWG footprints for scale

Four major liquefied “beds”

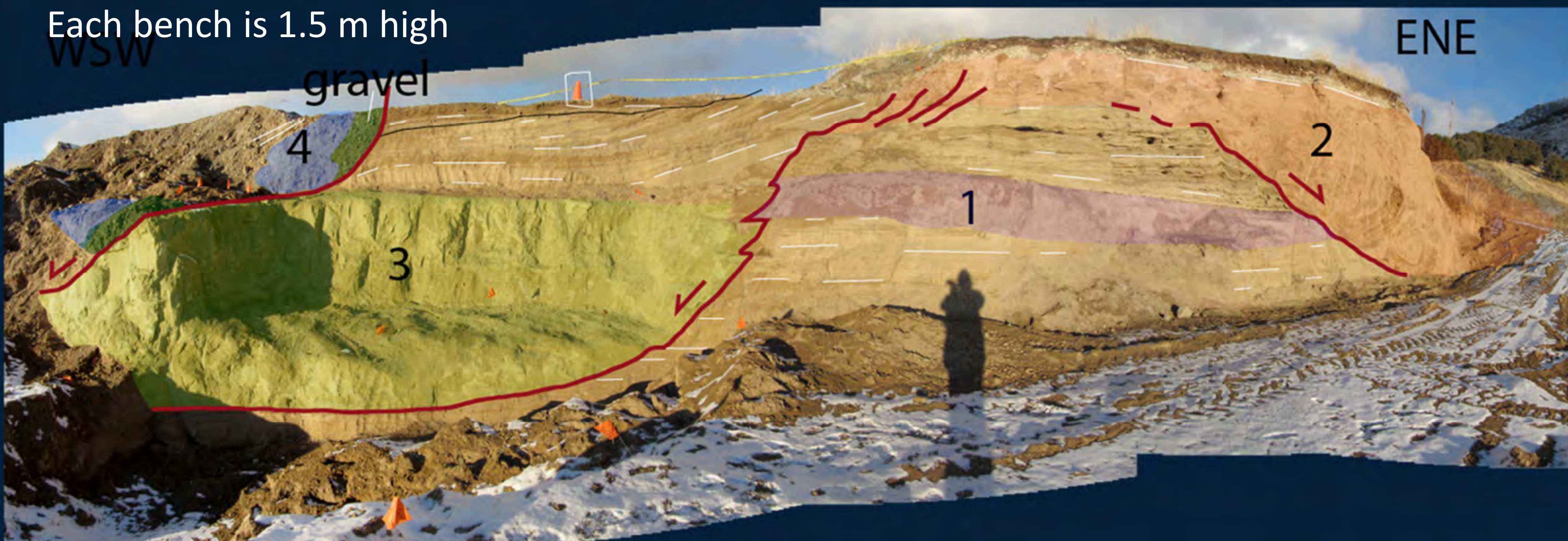


Cross-cutting relationships reveal sequence of events

- 1 to 4
- All deformation was in a 5-6 ky interval when Lake Bonneville was at this level or higher

Janecke et al., 2013 UQFPWG

Possible chronology

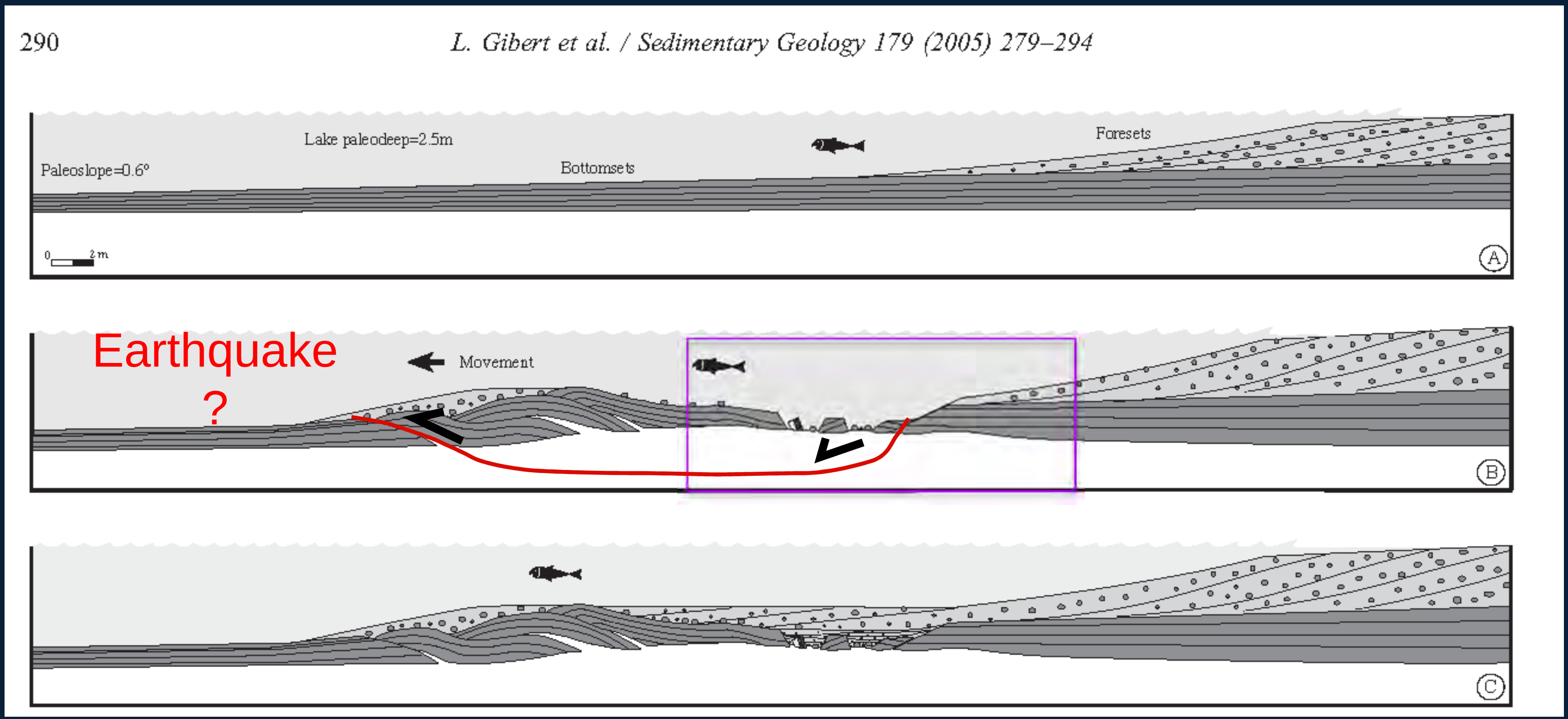


- Event bed number 1
- erosion
- deposition
- Event bed 2 ± lateral spreading
- Overlap beds are deposited across lateral spread

- Event bed 3 invades overlap succession
- Lateral spread slips again, cuts overlap and event 3 bed
- event 4 is a thick sand dike along western slip surface
- More deltaic gravel deposition

Possible gravel dike?

Interpretation



Repeat several times

Purple box shows what is preserved in the outcrop

Janecke et al., 2013 UQFPWG

Delta prograded across the site~4 times

Lateral spread was triggered at least twice and slid on prodelta mud

L. Gibert et al. / Sedimentary Geology 179 (2005) 279–294

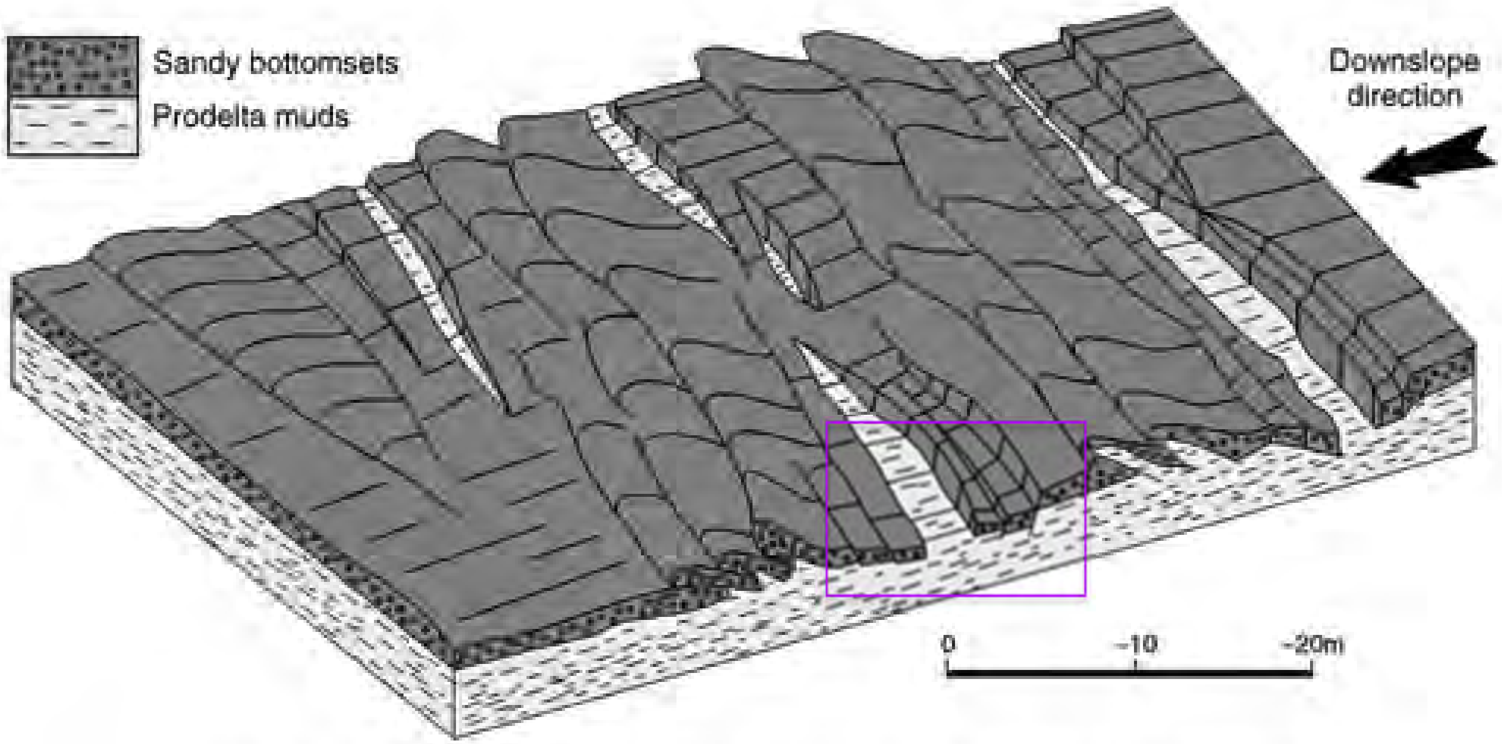


Fig. 9. Reconstruction of the landslide immediately after the initial movement.

Results

- Transgressive deltaic sand of Lake Bonneville preserves:
  - several large liquefied packages of sand
    - Each probably represents a major earthquake
  - a lateral spread with multiple slip events

- If this interpretation holds up we are probably documenting clustered slip events and loading induced seismicity during transgression of Lake Bonneville.

Future opportunities to use this outcrop

- Chance to refine the hydrograph of Lake Bonneville's transgression
- And refine events with more dating and analysis
- OSL and radiocarbon dating confirm the short time period of deposition- 22.7 to 17.4 ka.

modified from *Janecke and Oaks, 2011*

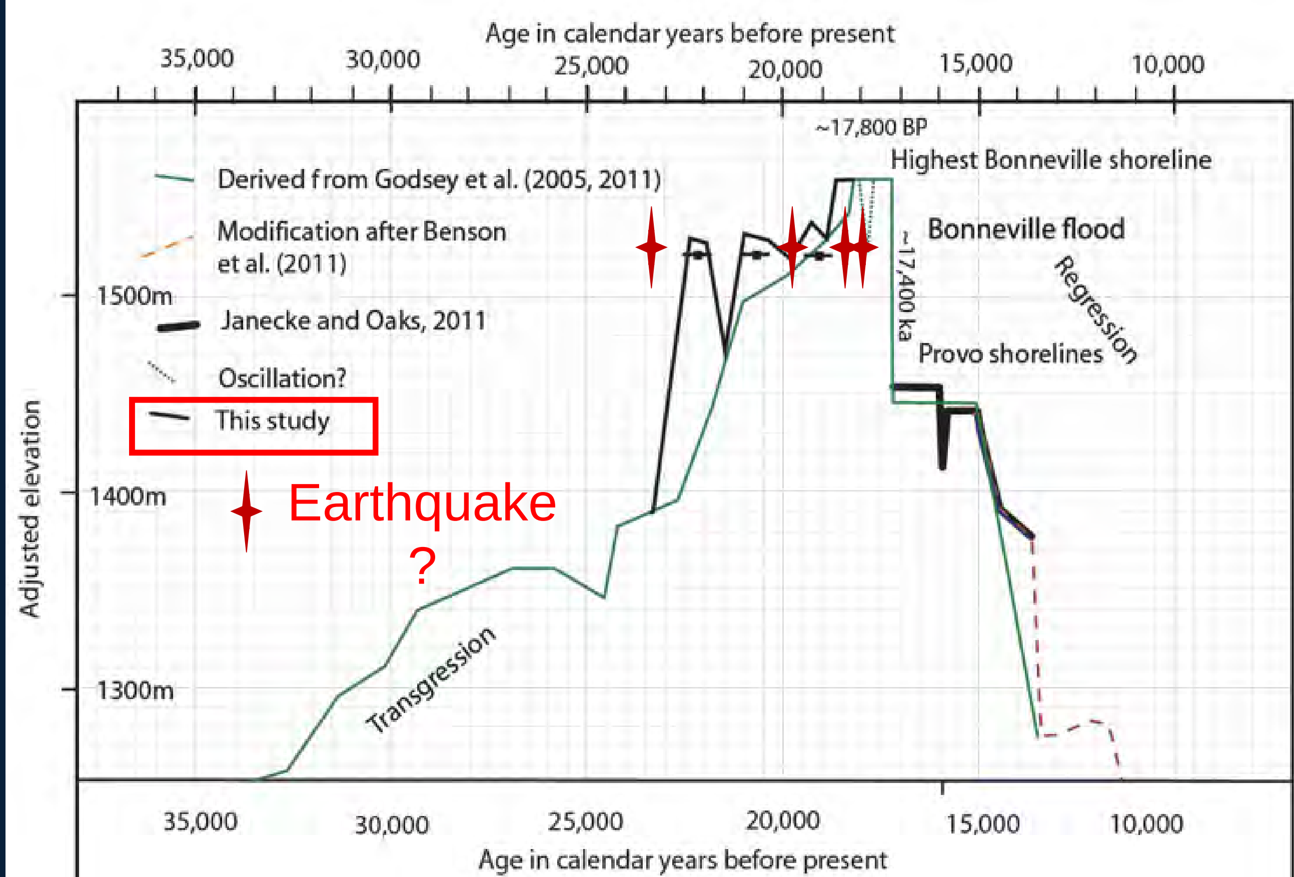


Figure 3. Hydrograph of Lake Bonneville modified to incorporate results from this study. Original data from Oviatt et al. (1992) and Godsey et al. (2005) were converted to calendar years using Marrero (2009) and Guido et al. (2007). Slightly different ages reported in Benson et al. (2011) suggest a shorter Provo occupation, a slightly younger Bonneville flood, but no change in the relative ages of the event. An oscillation of the lake below the Provo level at ~15.9 ka (Godsey et al., 2005; Benson et al., 2011) might have separated the main higher 4775 ft (1455 m) Provo shoreline from the lower 4745 ft (1446 m) Provo shoreline, as shown, but this is uncertain. Colors represent the possible times and durations of the upper and lower Provo shorelines in the Benson et al. (2011) chronology. Isotopic data from caves in Arizona (lower curves) (Wagner et al., 2010) provide evidence for glacial conditions during the Bonneville highstand and most of the Provo stillstand, followed by abrupt warming late in the Provo occupation.

Janecke et al., 2013 UQFPWG

Research questions: Some answers

1. Does the deformed outcrop at Green Canyon record an earthquake at the time of the Bonneville flood?
2. Is the fault in the outcrop a strand of the East Cache fault or a slip surface in a lateral spread?

1. No-all deformation was lacustrine and dates from the Bonneville transgression (Field Methods class showed this).
2. Backhoe exposed a basal decollement surface. Central fault is a slip surface in a lateral spread

Janecke et al., 2013 UQFPWG

More work is needed to fully resolve these questions

- 3. Was the lateral spread activated by an earthquake?

3. Probably, but more work is needed

- 4. How many large liquefaction events are preserved in the outcrop?

4. At least 4 major events, they are unlikely to be coeval

- 5. Did earthquakes produce any or all of the large liquefaction features?

5. All large liquefaction features appear to be result of earthquakes. More work is needed.

Janecke et al., 2013 UQFPWG

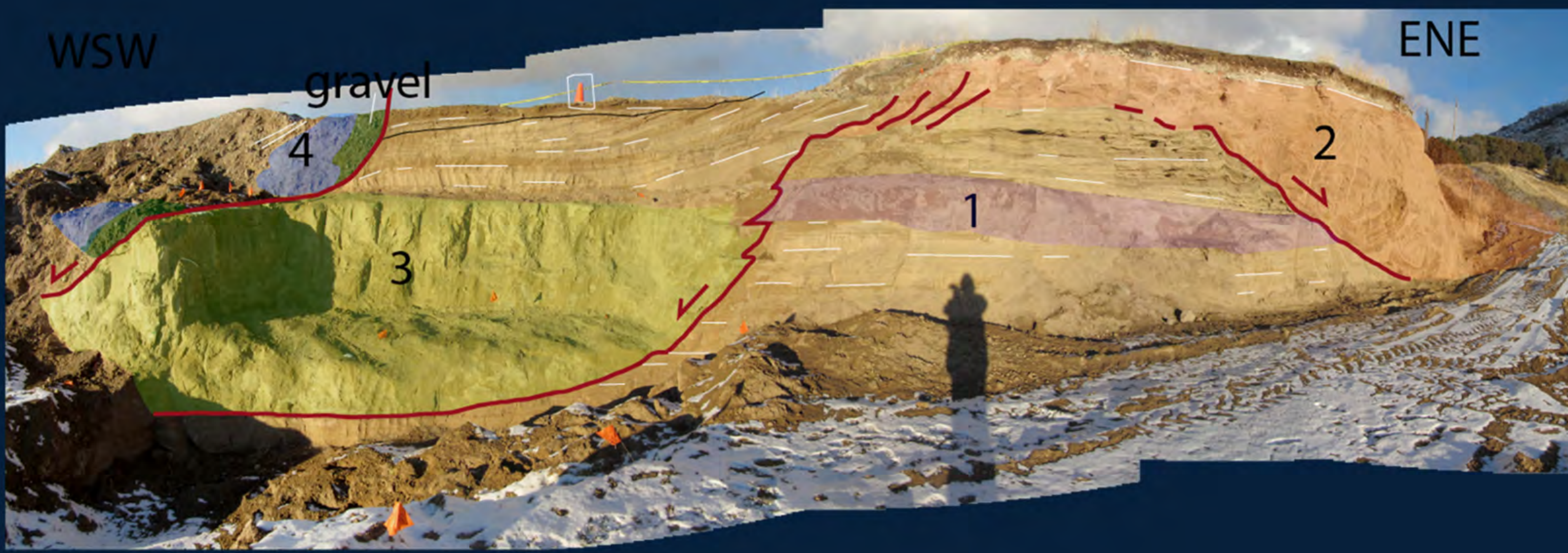
Educational Goals

1. To continue using the site for field trips in Geology courses
   - Introductory Geology
   - Sedimentology and Stratigraphy
   - Field Methods
   - Historical
   - Structural Geology
   - Geomorphology-all levels

Example of fault arrays in the upper 2 m of the central slip zone

Advantages of the site

- Close to urban centers
- Easy access
- Visually compelling
- Collapse hazard is minimized by cementation in liquefied sand and hillslope



Janecke et al, USU, UQFPWG Feb. 2013

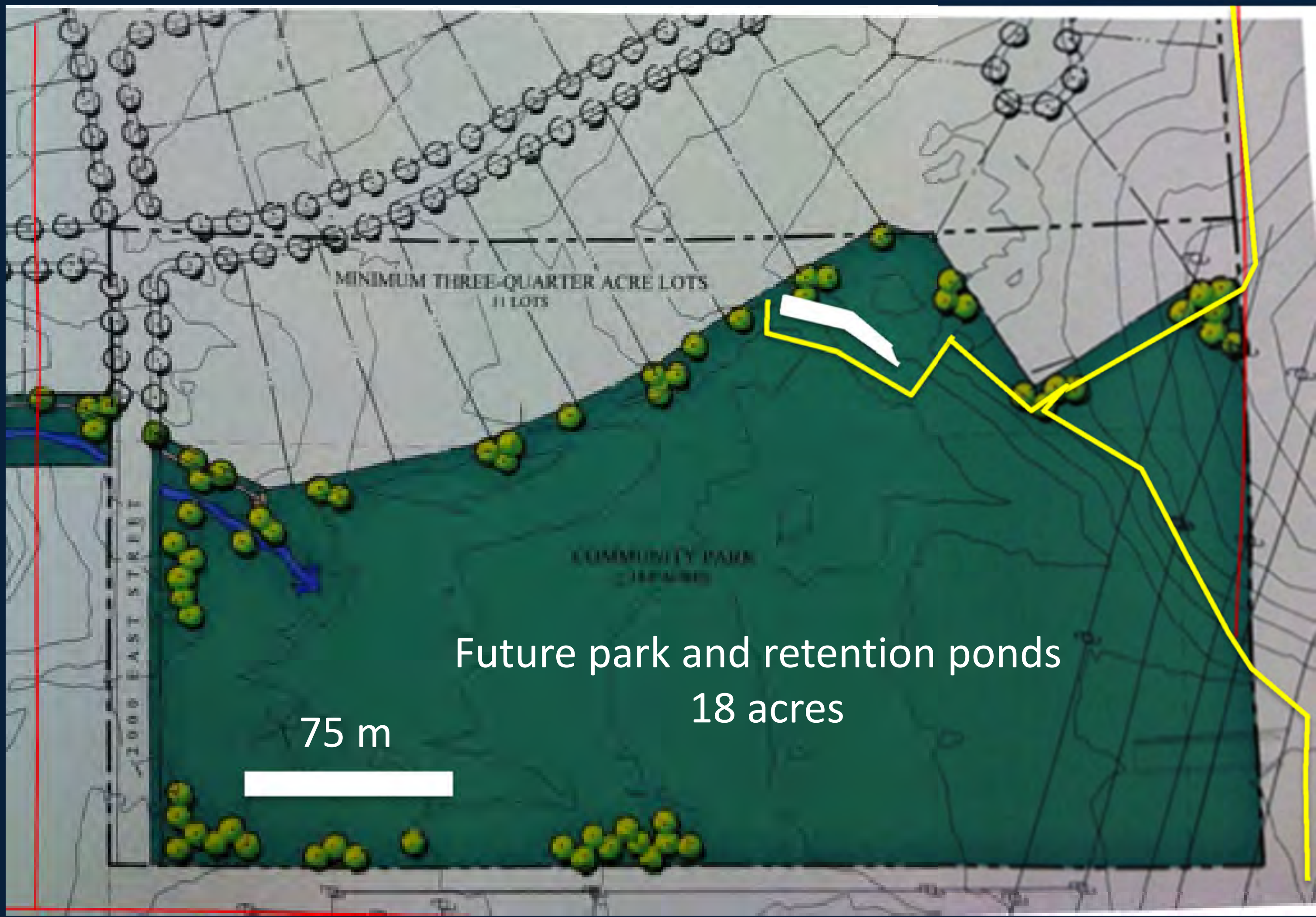
Biggest advantage of the site

- Location will be within a large park for water retention of Green Canyon

Your ideas for catchy names?

Possible name:

Bonneville Quicksand trail?



Janecke et al, USU, UQFPWG Feb. 2013

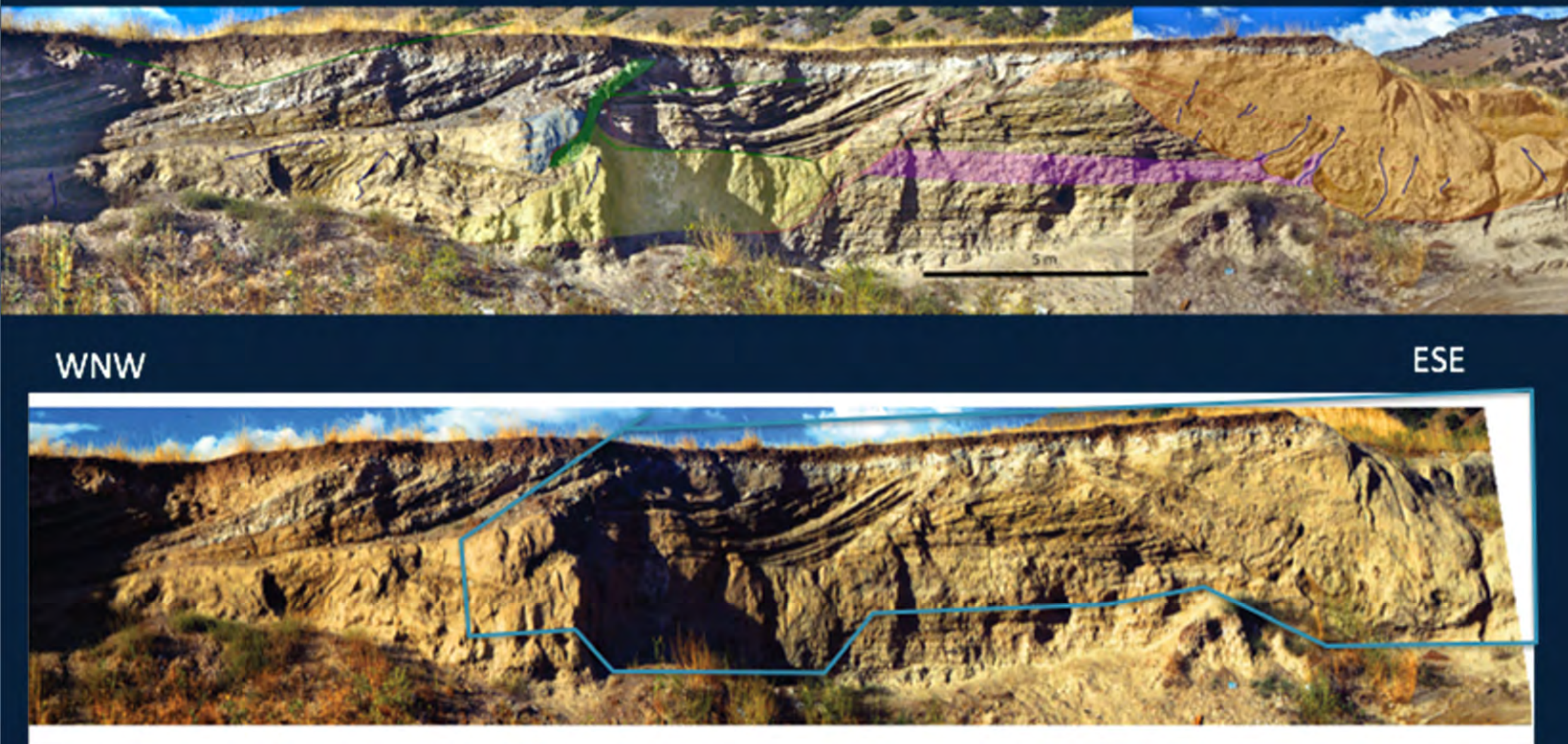
Educational Goals

- 2. To educate the public about geologic hazards
    a) Geologic nature trail could be a side spur from the Bonneville trail
    b) Focus on paleo-liquefaction in the outcrop
    c) And its potential in Cache Valley now
    d) Illustrate and explain the lateral spread
    e) Relationships to the East Cache fault and Lake Bonneville
    f) Age relationships, clustering of paleo-earthquakes?

The Ed Clark Museum of Missouri Geology is located at the Division of Geology and Land Survey, 111 Fairgrounds Road, Rolla.

http://dnr.mo.gov/newsrel/images/AEKioskRolla.jpg

Thanks for your attention and suggestions



Janecke et al., 2013 UQFPWG

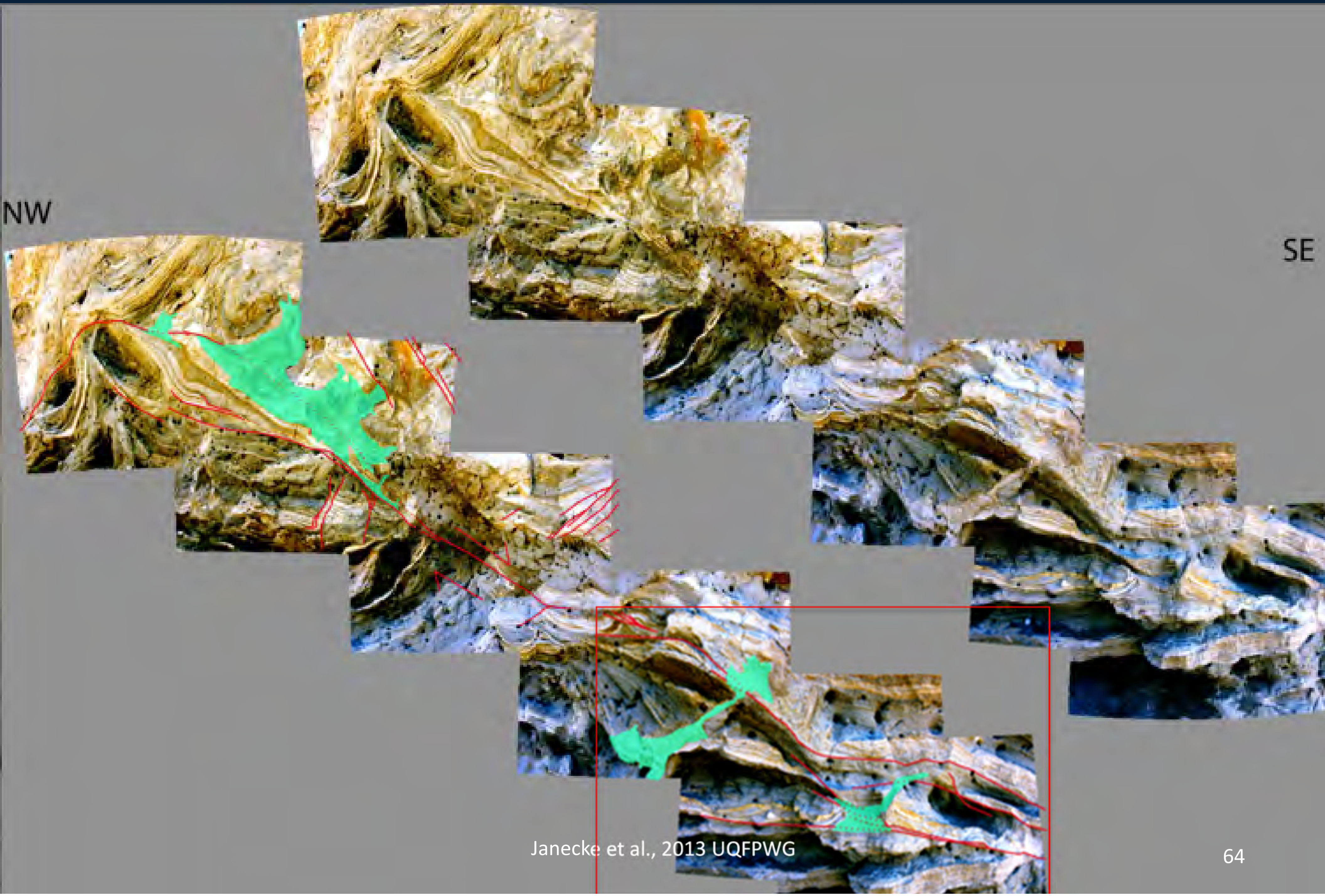
Is this a sand volcano?

Janecke et al., 2013 UQFPWG

Another fault wedge in a younger pseudo nodule??

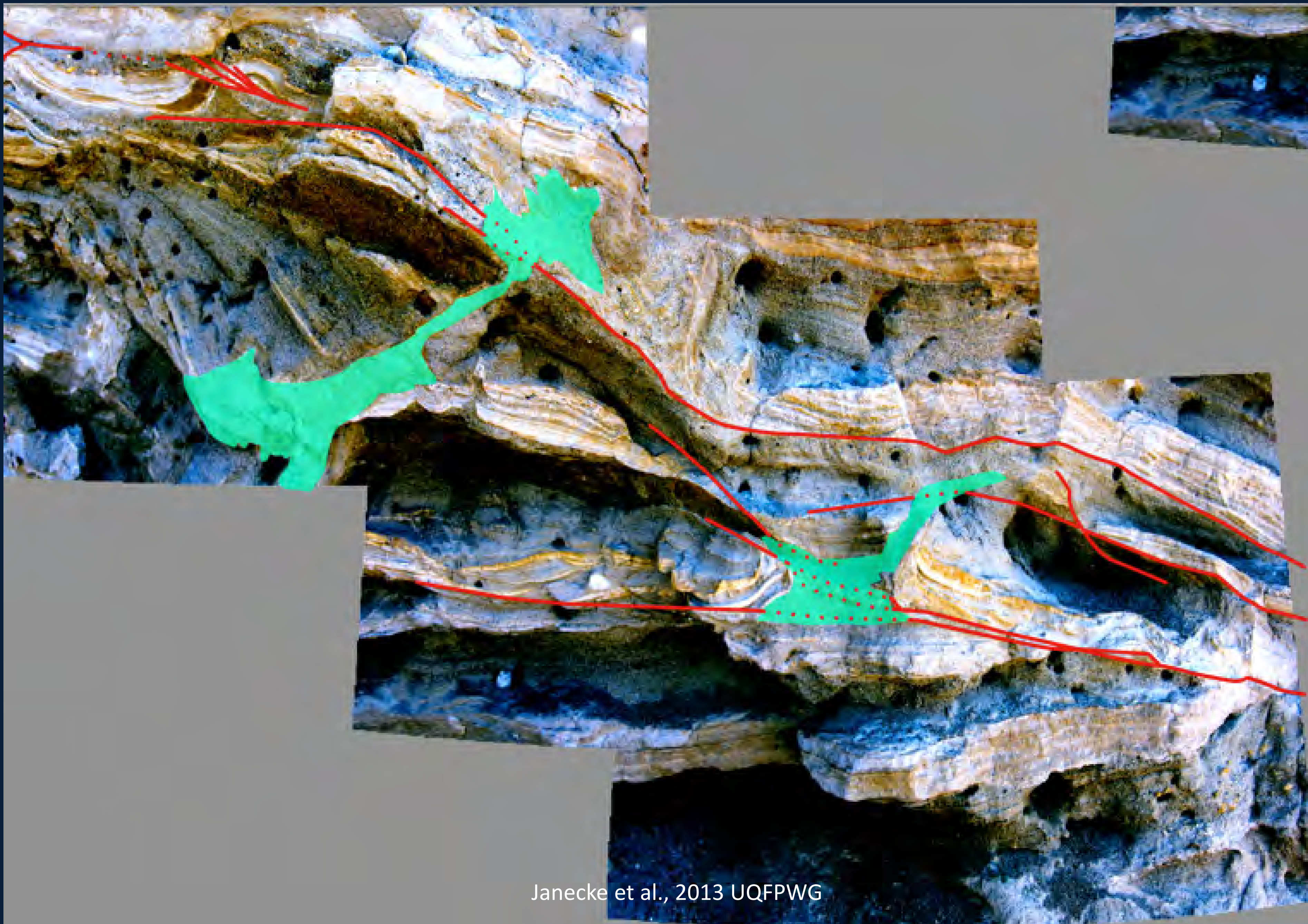
Janecke et al., 2013 UQFPWG

Fluid escape across brittle faults



Janecke et al., 2013 UQFPWG

Fluid escape across slip surfaces



Hansel Valley has ~7 liquefaction events in West Gully

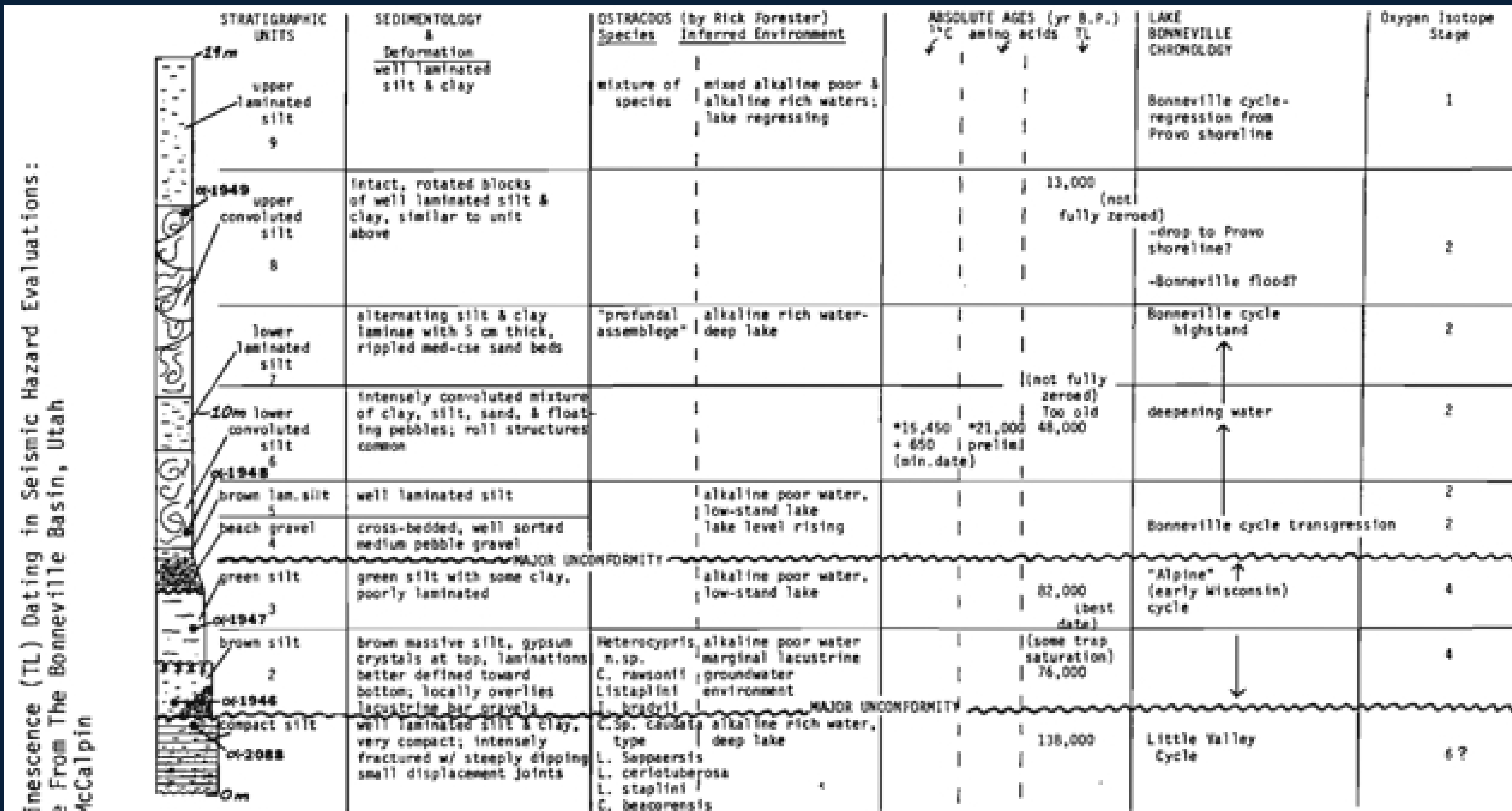


Fig. 5

Composite stratigraphic section from the West Gully. Evidence from sedimentology and ostracod assemblages (interpreted by R. Forester, USGS) is compatible with TL, ^{14}C, and amino-acid dates.

Is this a dike/sill?

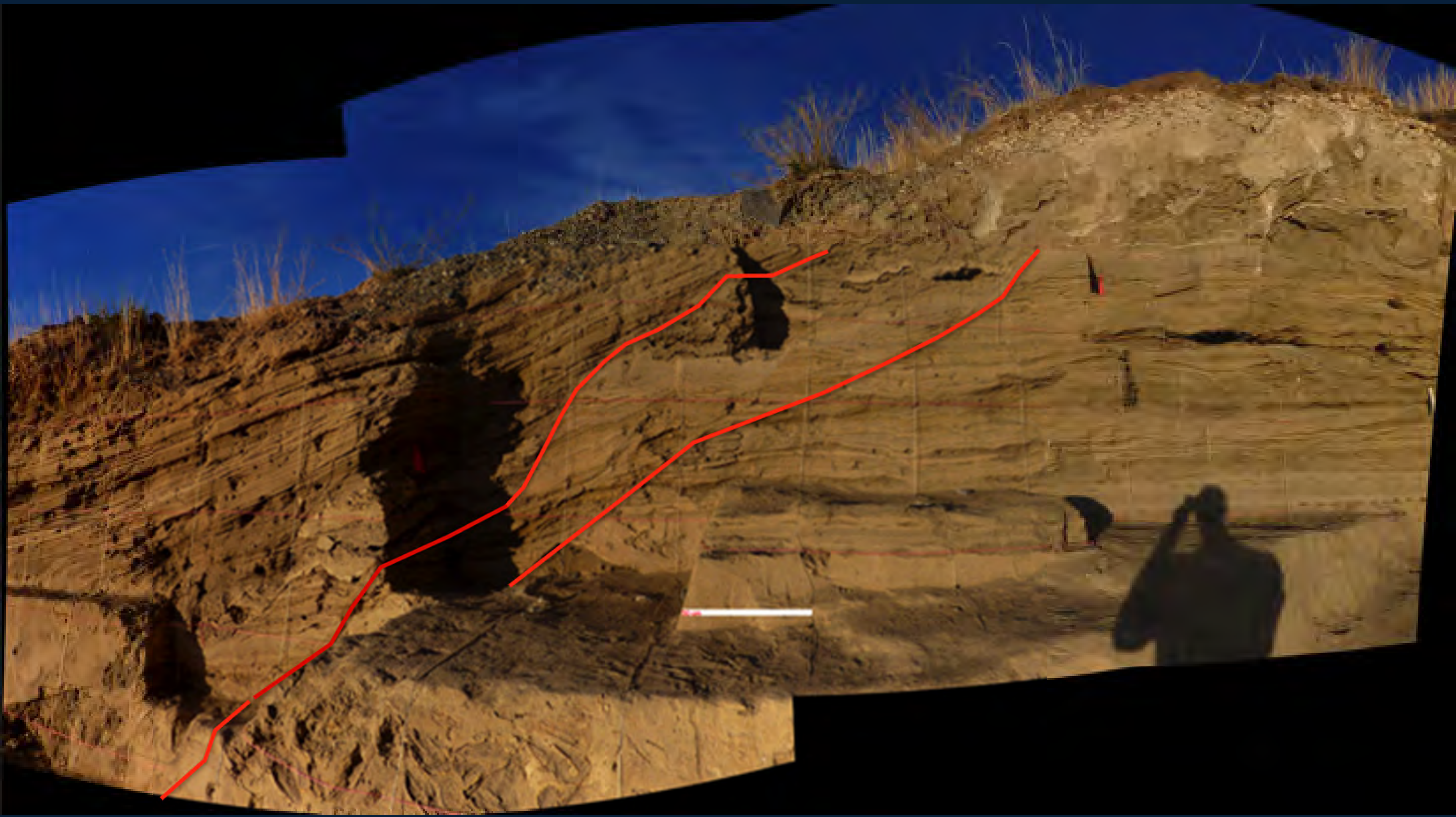
Comments?

Janecke et al., 2013 UQFPWG

How can we best deal with the vertical wall of sediment?

Janecke et al., 2013 UQFPWG

Central fault or slip surface



Logging string is spaced 50 cm apart

Janecke et al., 2013 UQFPWG

Brittle slip during escape of fluids suggests high strain rate

Janecke et al., 2013 UQFPWG

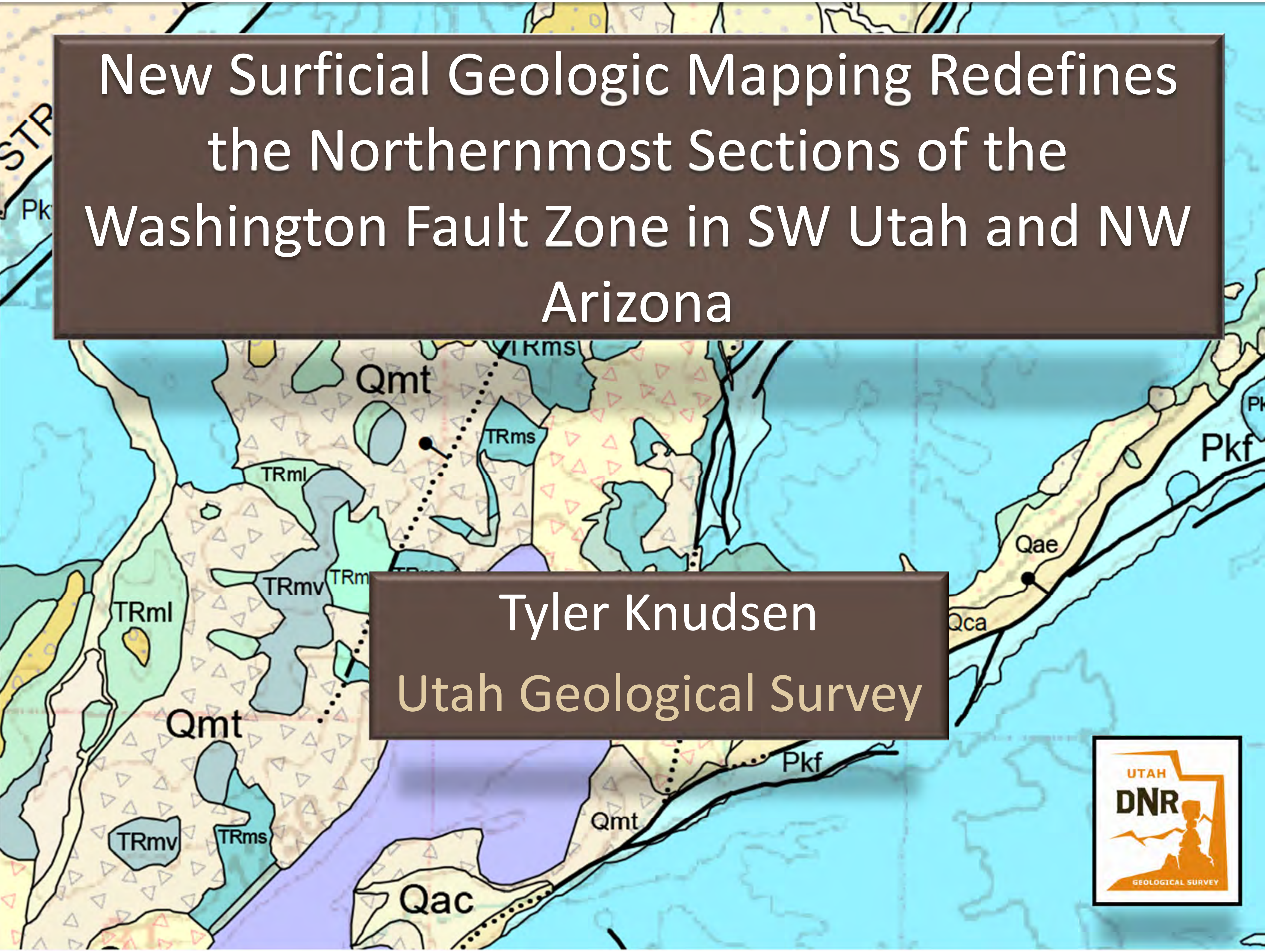
sand dike/sill

Janecke et al., 2013 UQFPWG

New Surficial Geologic Mapping Redefines the Northernmost Sections of the Washington Fault Zone in SW Utah and NW Arizona

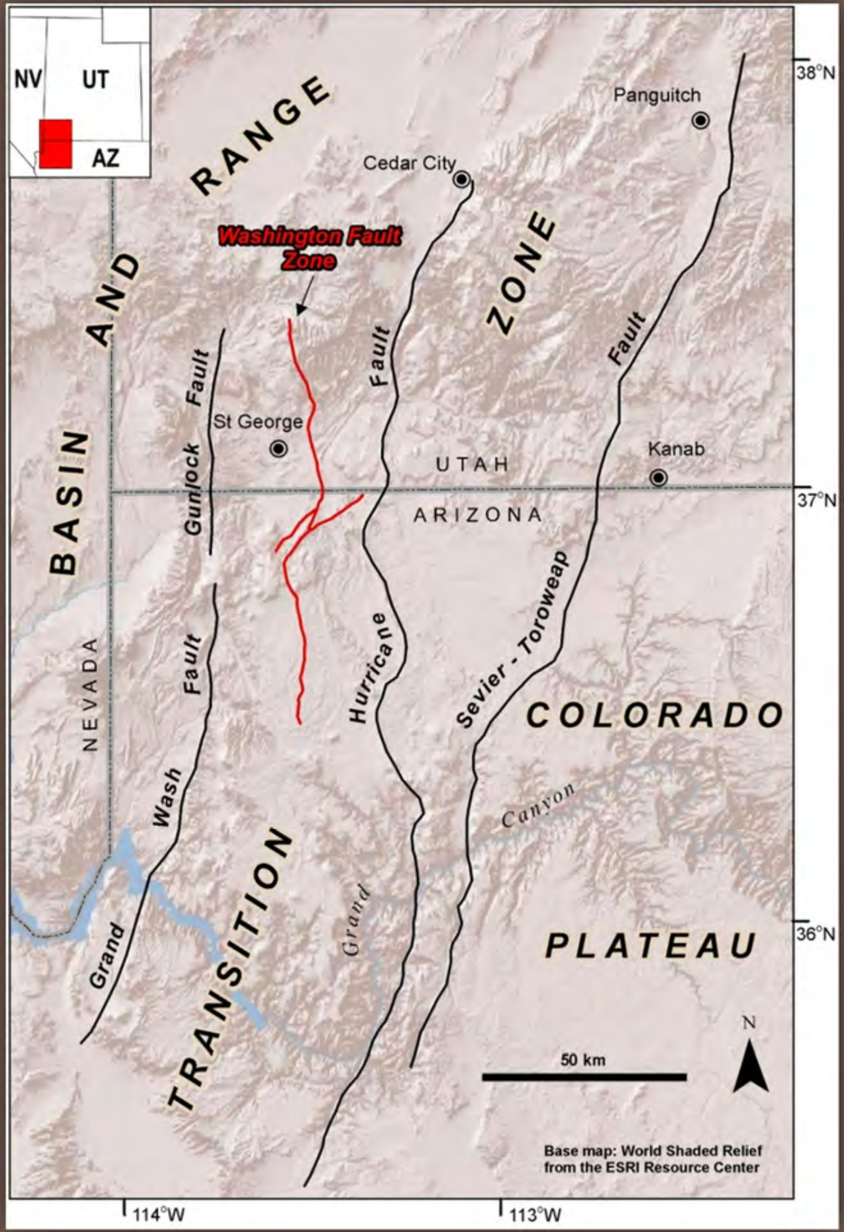
Tyler Knudsen

Utah Geological Survey



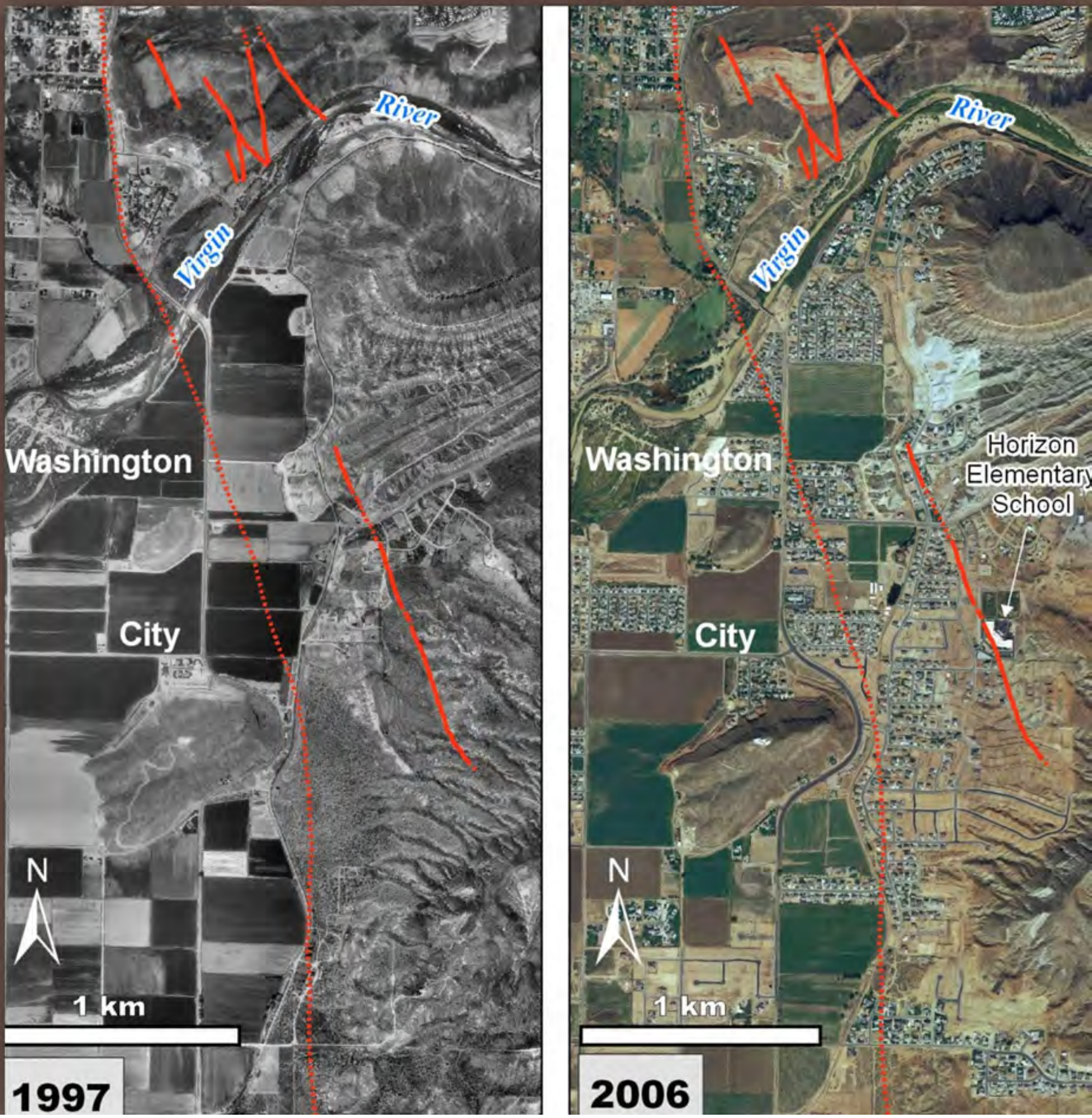
Washington Fault Zone

- Within transition zone
- Extends into Utah & Arizona
- ~~75~~ 97 km long
- Maximum displacement of ~700 m just south of UT-AZ border



Background

- Traverses heavily populated St. George Basin
- Only cursory study in 80s & 90s
- #9 on 2005 UQFPWG priority list
- Moved to near top of priority list in 2008
- NEHRP funding to complete & publish:
  - Detailed geologic mapping
  - Trenching
  - Basalt sampling

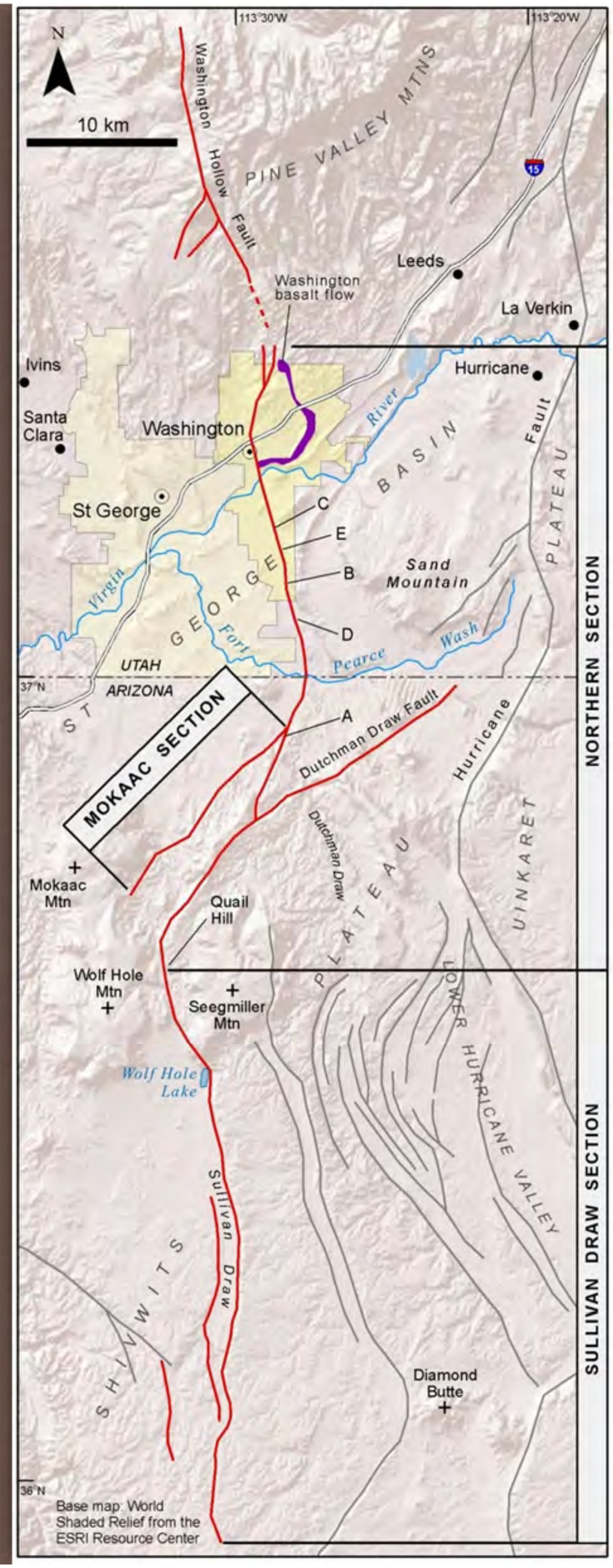


Washington Fault

- Divided into three sections by Pearthree (1998)
  1. Sullivan Draw (36 km)
  2. Northern (39 km)
  3. Mokaac (16 km)

- New mapping focused on parts of fault in UT

- Additional structures mapped:
  – Dutchman Draw & Washington Hollow faults

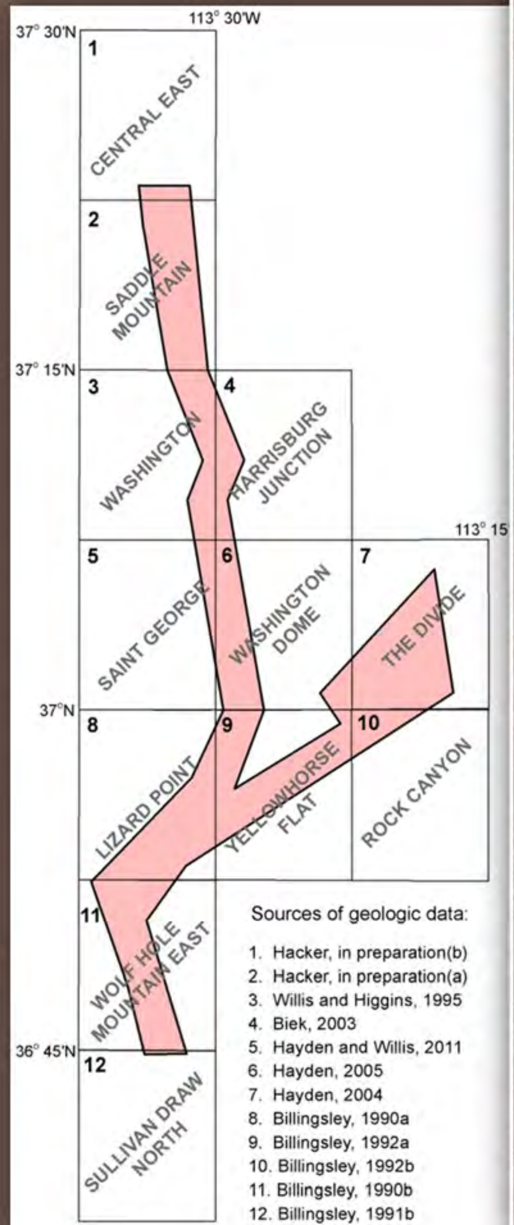


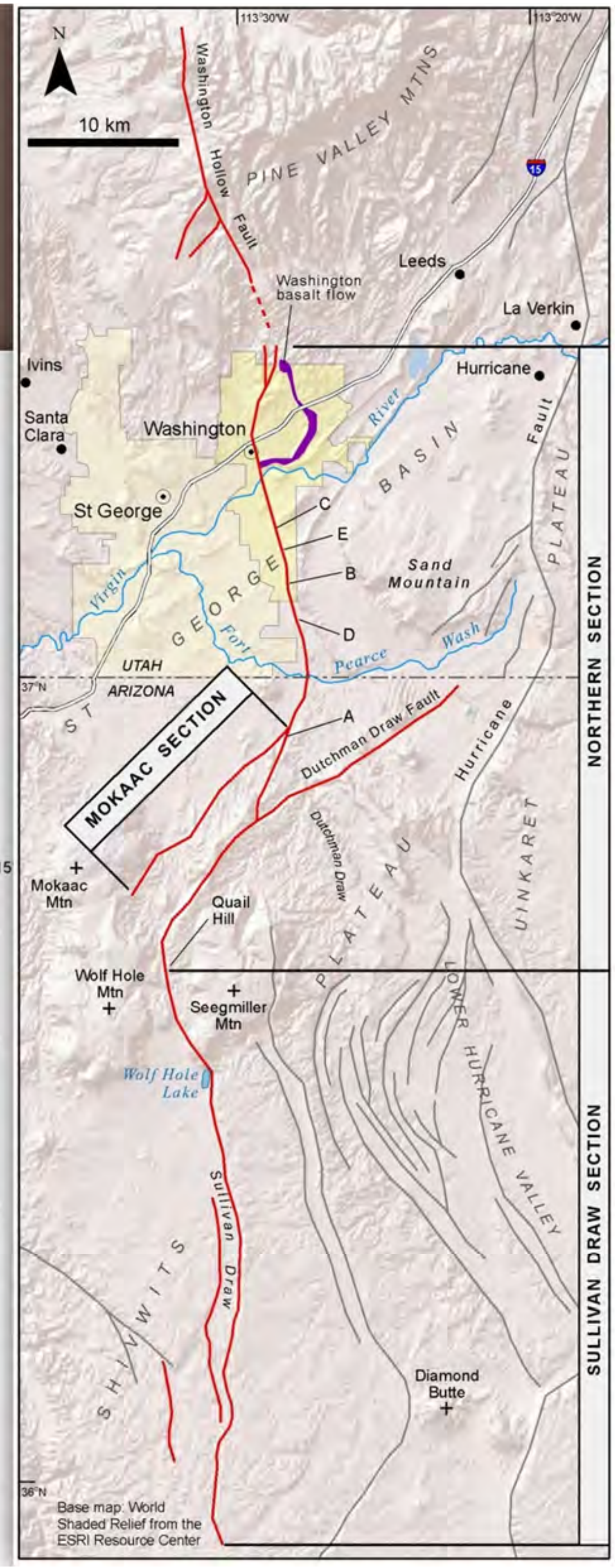
Mapping Goals

- Identify suitable trench site(s)
- Refine fault-section model

Methods

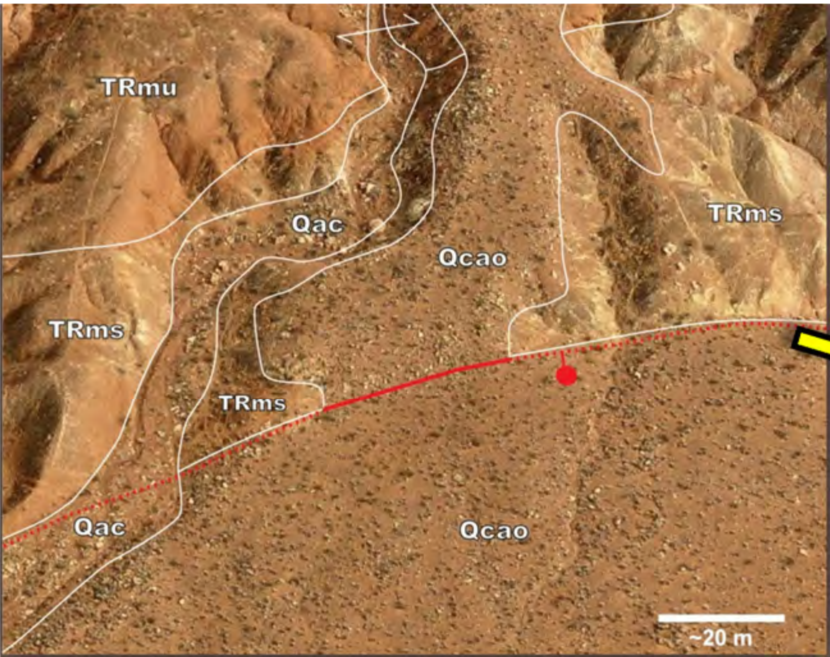
- Air-Photo and field Mapping at 1:24k
- Largely a compilation of parts of 12 7.5' quads (Hayden, Biek, Willis in UT and Billingsley in AZ)





Washington Fault Characteristics

- Erosion dominates: region is deeply dissected by Virgin River & tributaries
- Escarpment formation due mostly to differential erosion (up to 250 m high)
- Commonly bedrock on bedrock fault with thin, discontinuous cover of Quaternary-deposits
- Only three scarps developed on unconsolidated deposits identified



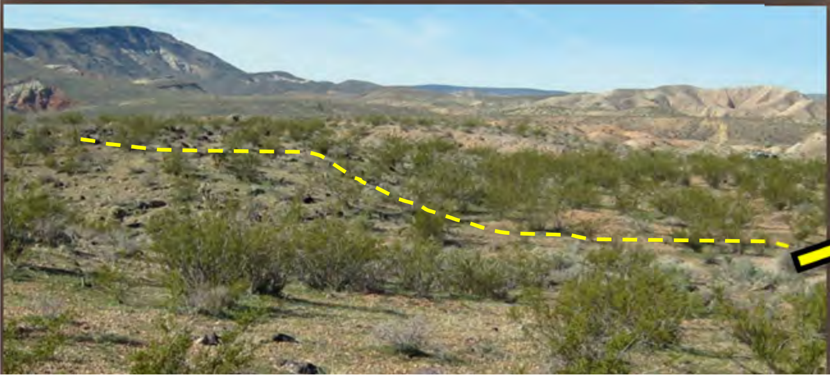
Scarps on late Pleistocene-Holocene fans

Warner Ridge

Anderson & Christenson, 1989 (bedrock-cored)

Dutchman Draw

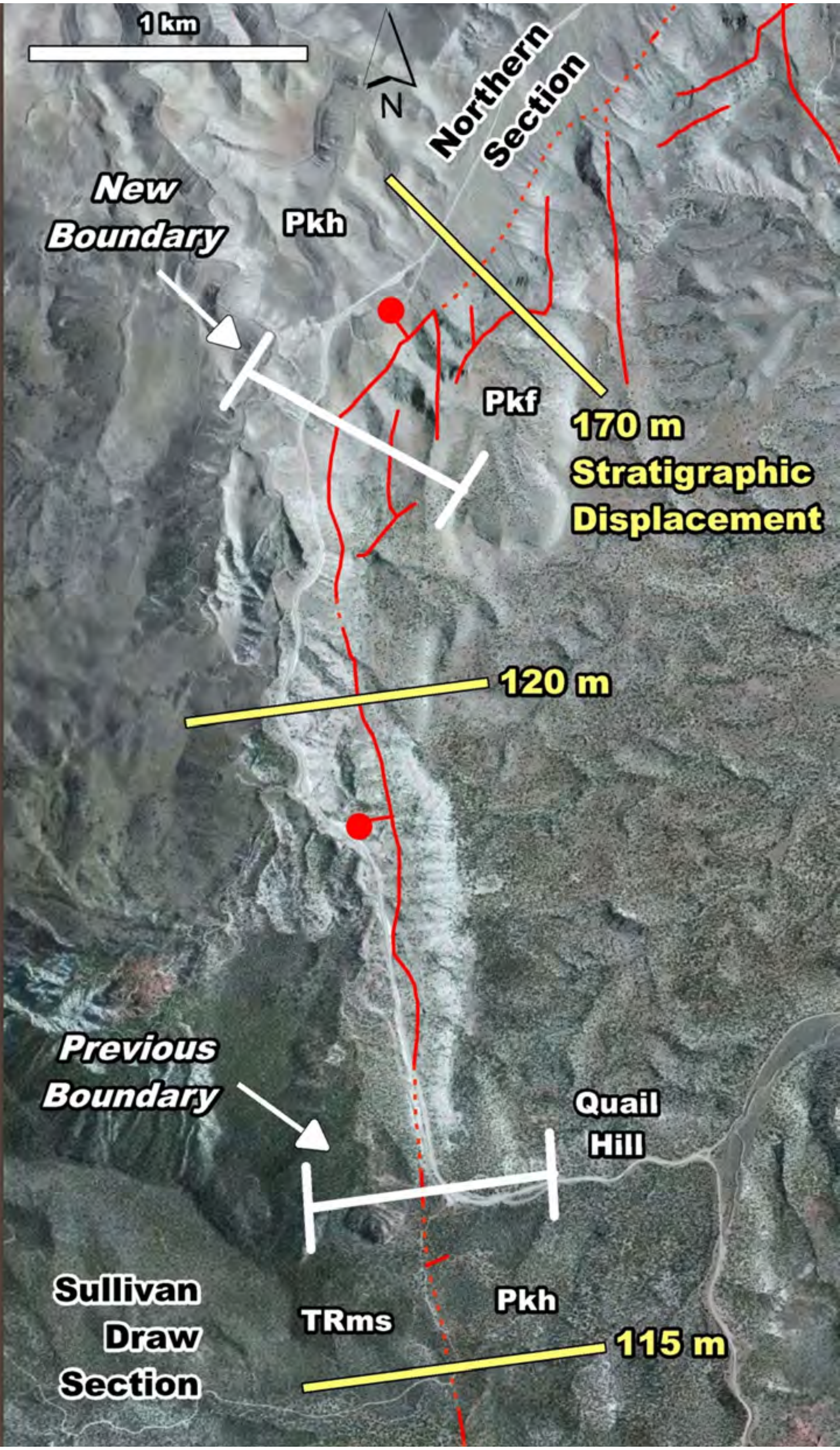
Trenched by UGS



Splay of Mokaac fault

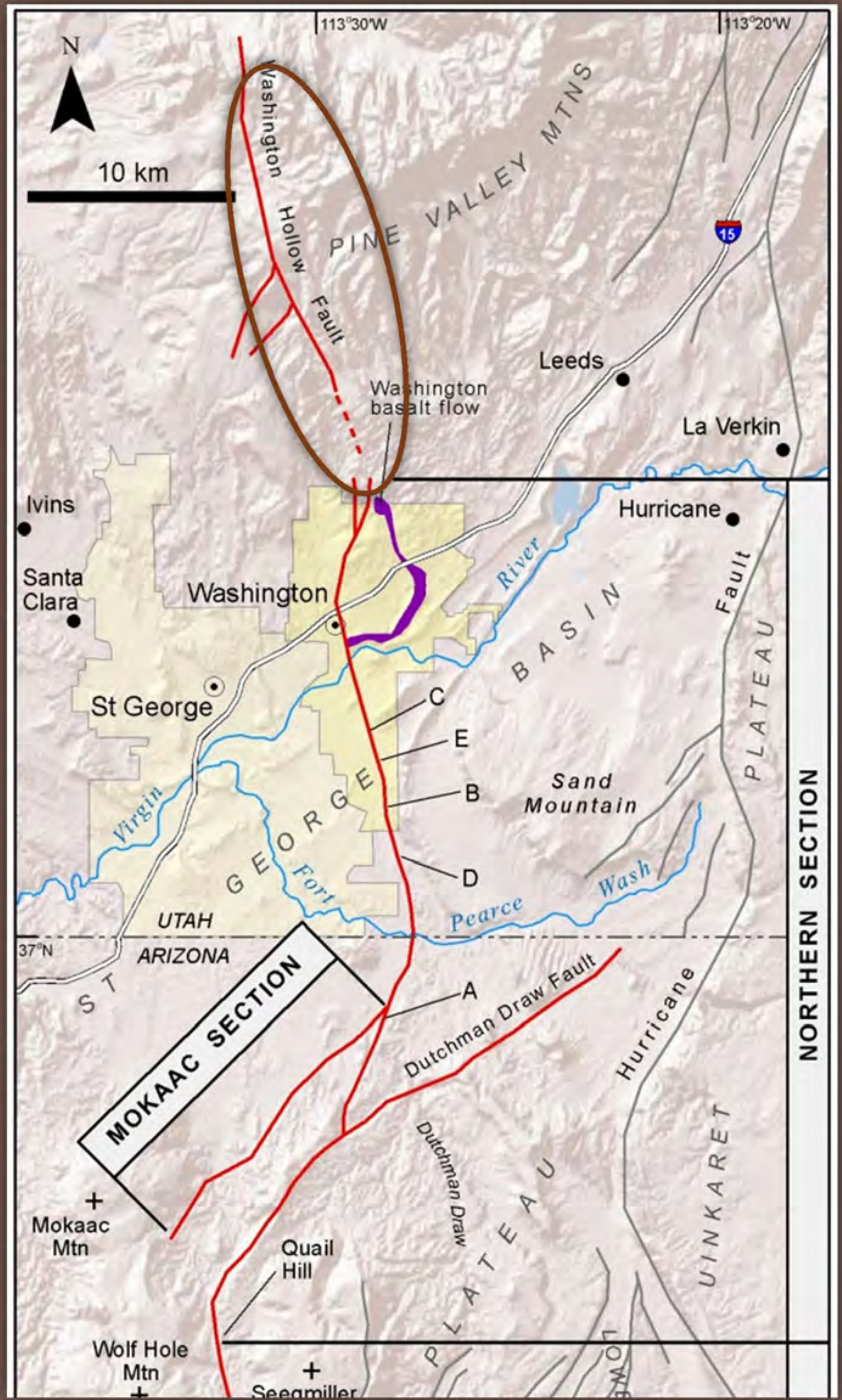
Sullivan Draw-Northern Section Boundary

- Pearthree (1998) placed boundary at change in scarp morphology near Quail Hill
- Change in scarp height due to differential erosion
- 50^{o} change in strike & large displacement gradient a better choice



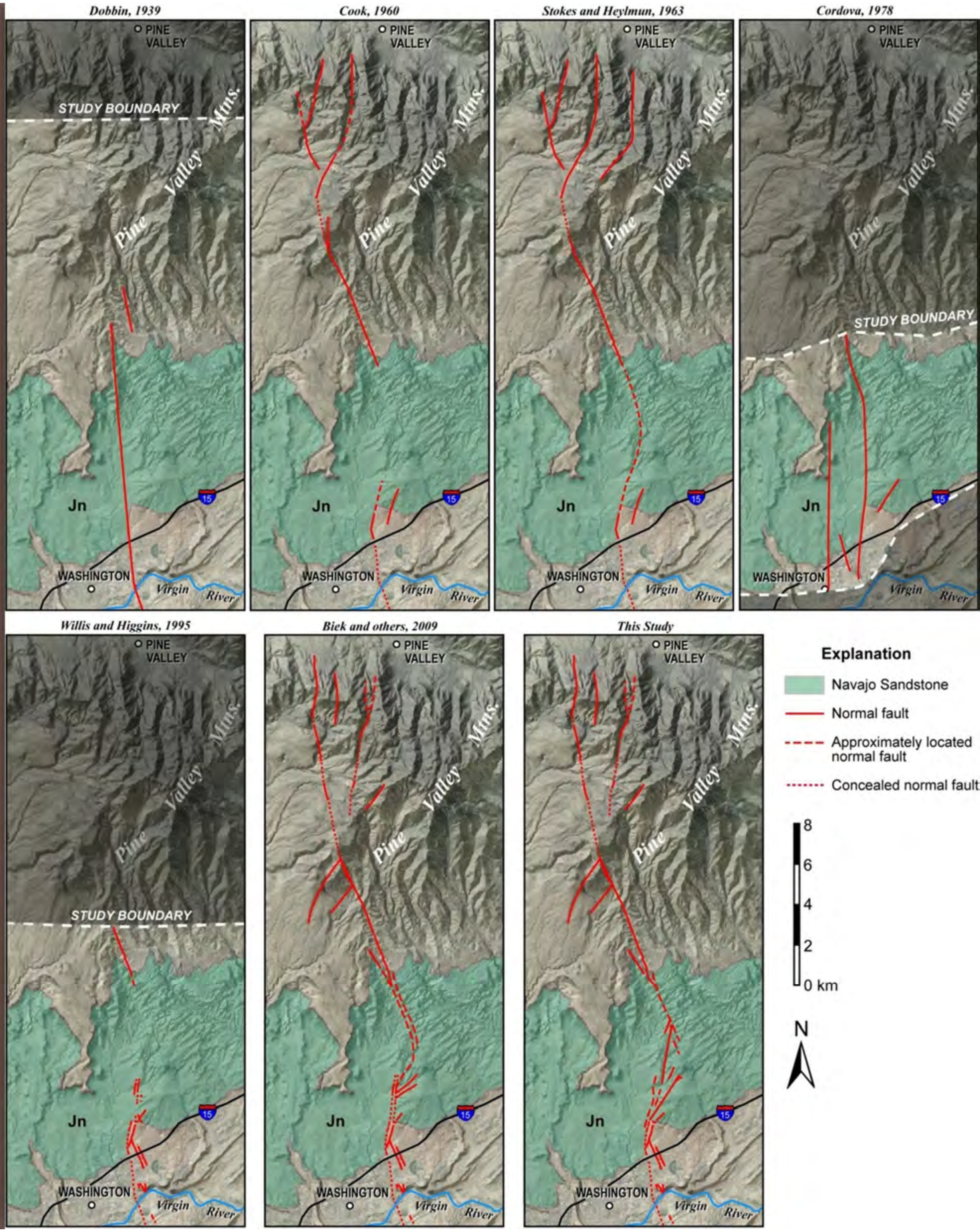
Washington Hollow Fault—a Northern Extension of the Washington Fault?

- Aligned with Washington fault
- Similar geometry
  - Both are west-dipping
  - Both are NNW-striking



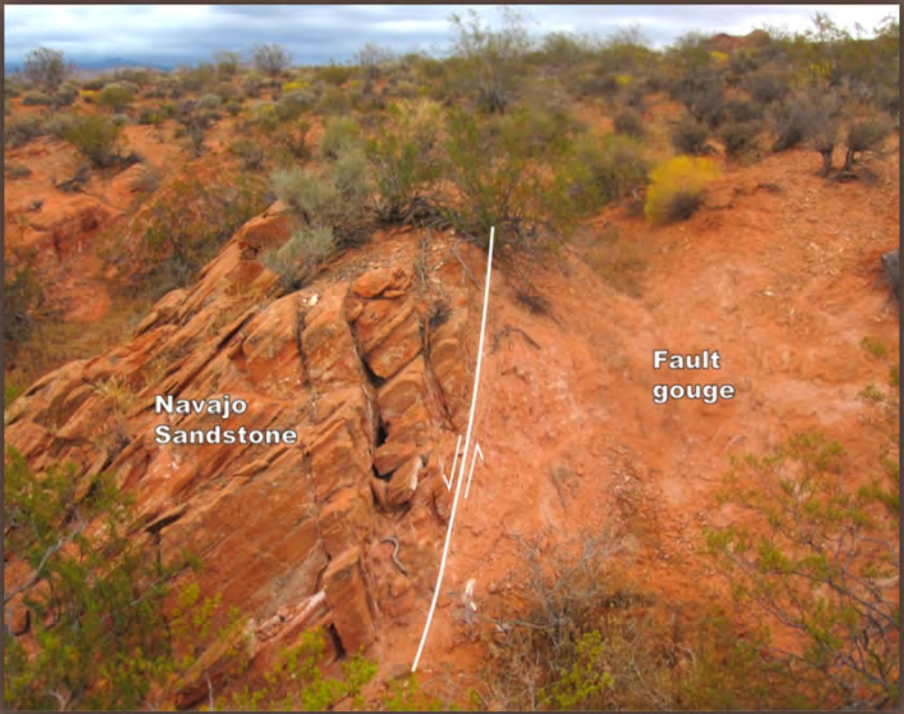
Washington Hollow Fault

- Has been mapped as either a separate fault or an extension of the Washington fault



WHF Most Likely is Part of the Washington Fault

- Evidence for a through-going fault
  - Brecciation zones
  - 2-3-m-wide crushed zones
  - Minor-displacement faulting



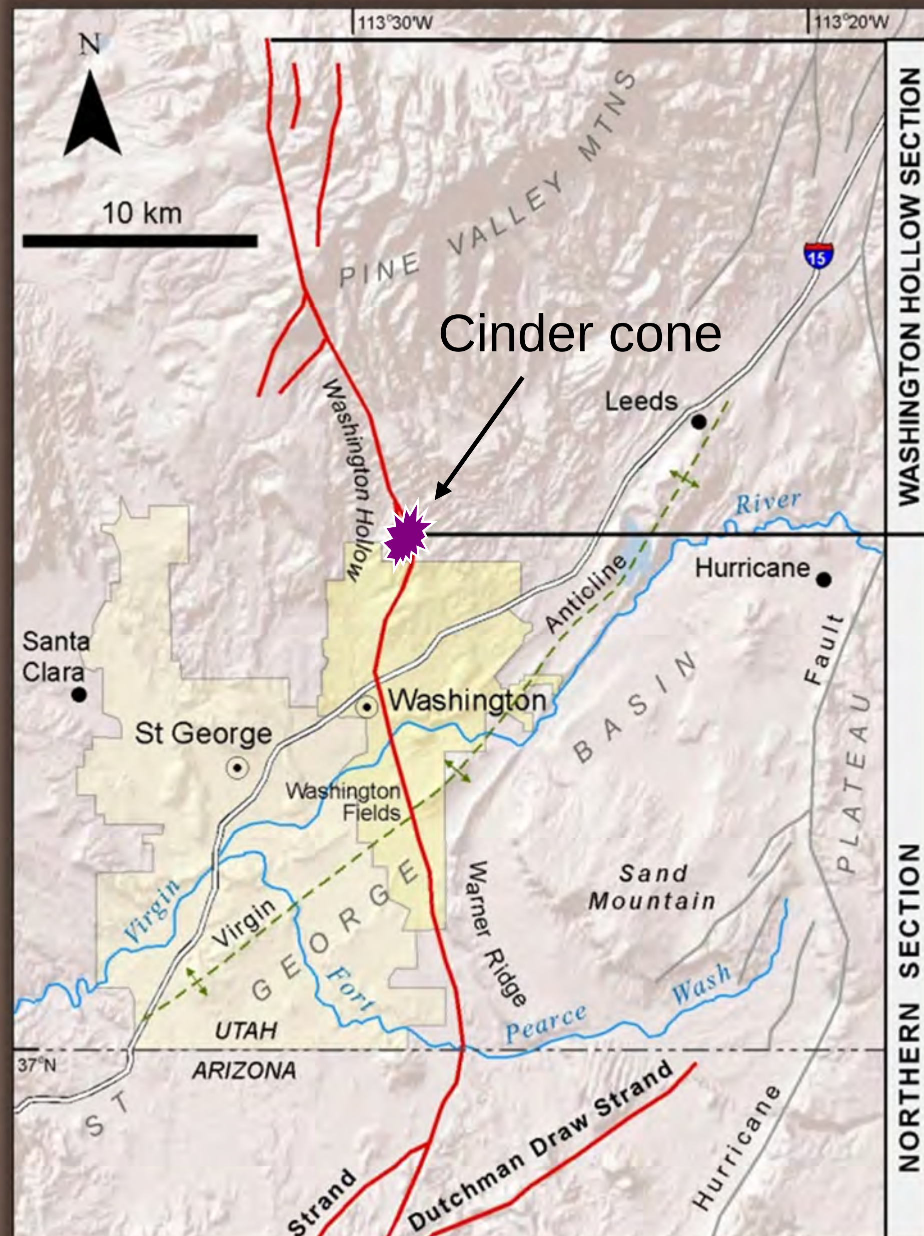
Washington Hollow Section

- Thoroughgoing structure appears to be relatively minor
- Does not displace Cretaceous-age joint set (dashed blue lines)
- Limited net vertical displacement

Washington Hollow Section

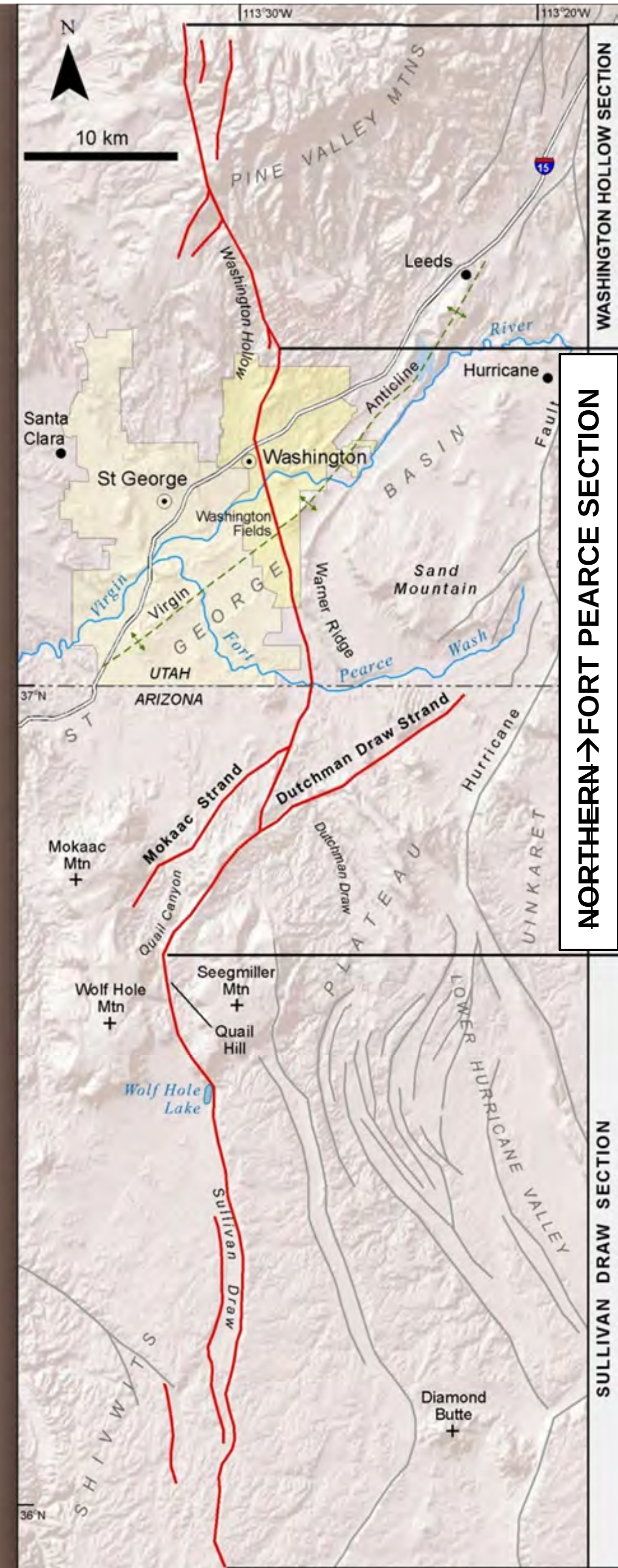
- Boundary placed near Washington flow cinder cone
  - 45⁰ change in strike
  - Increased structural complexity
  - Decreased net displacement

- Newly defined Washington Hollow section is 22 km long



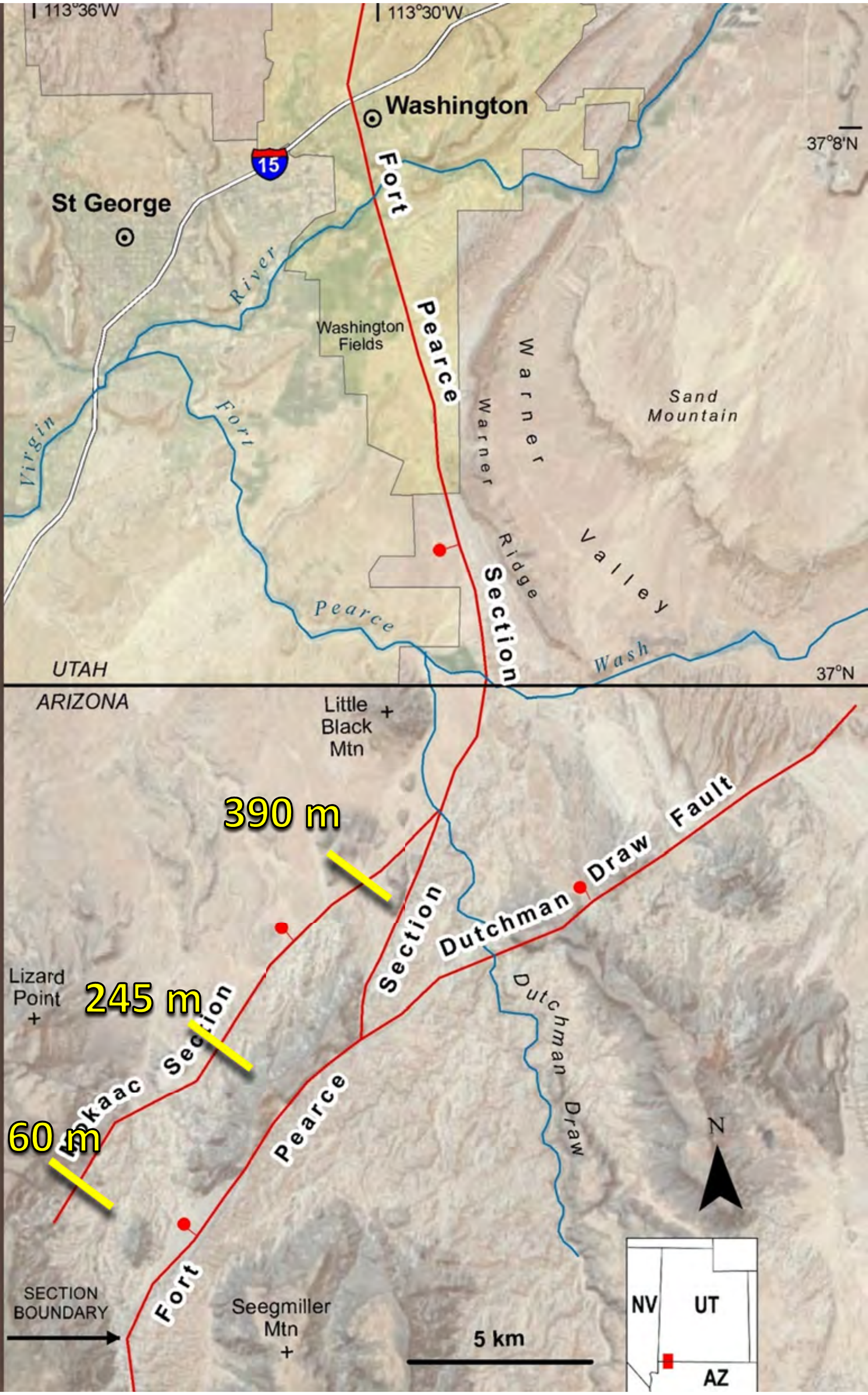
Fort Pearce Section

- Northern section as described by Pearthree (1998) is no longer the northernmost section
- Renamed the Fort Pearce section – 37 km long



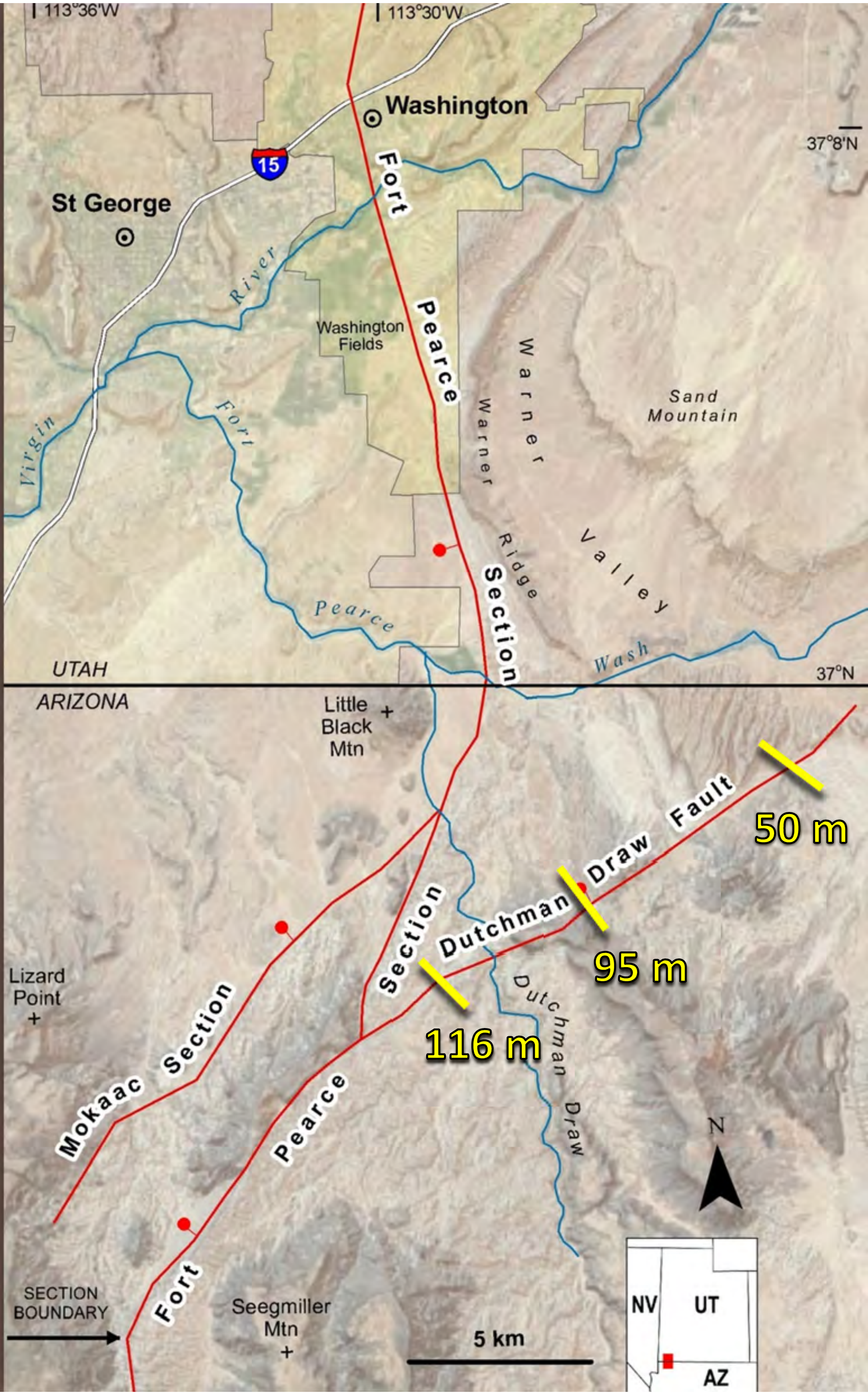
Mokaac Section(?)

- 16 km long
- Vertical displacement greatest at junction with Fort Pearce section
- No obvious rupture barrier with Fort Pearce section
- More likely to rupture sympathetically with Fort Pearce section
- Best described as a strand of the Fort Pearce section



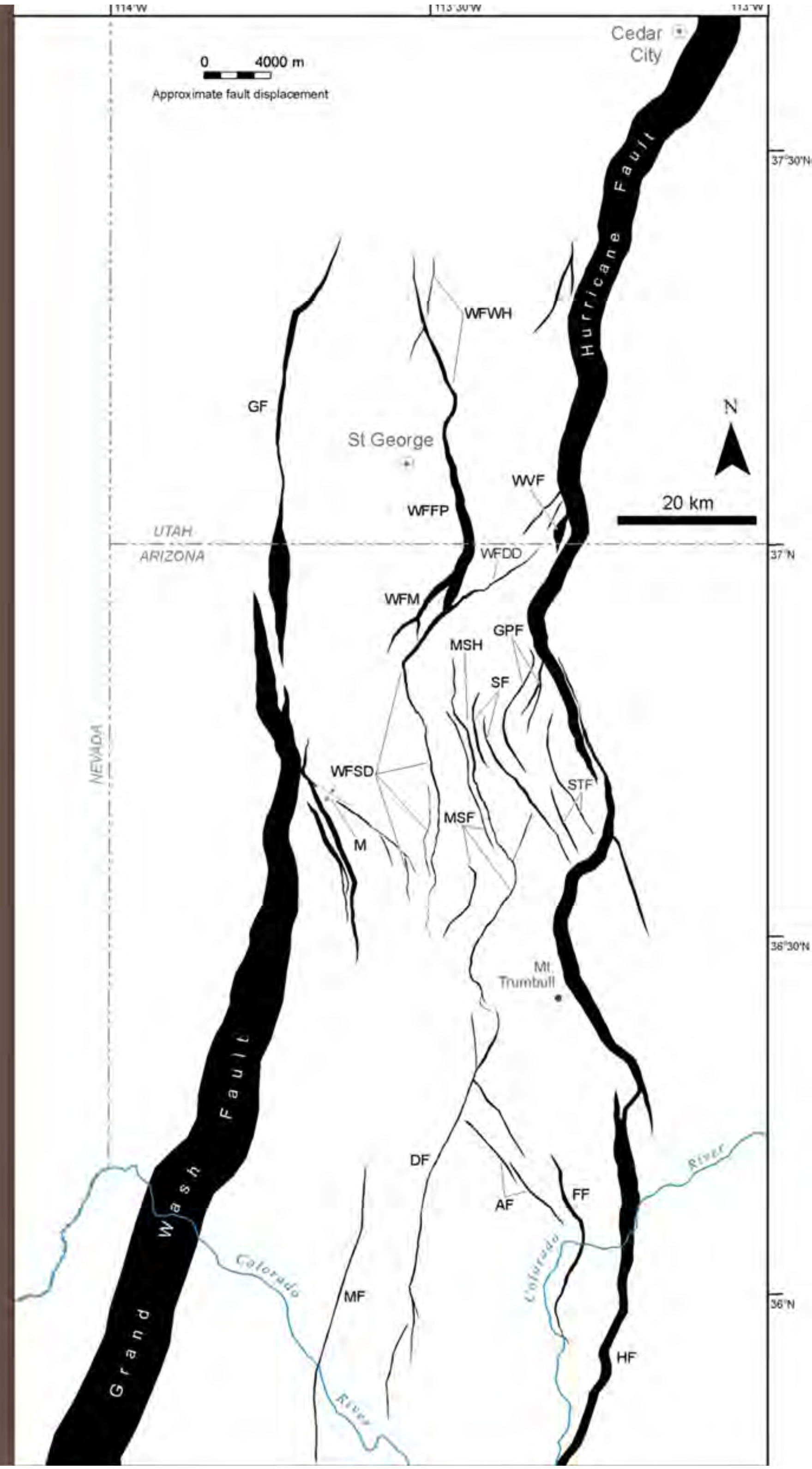
Dutchman Draw Fault

- 16 km long
- Vertical displacement greatest at junction with Fort Pearce section
- No obvious rupture barrier with Fort Pearce section
- More likely to rupture sympathetically with Fort Pearce section
- Best described as a strand of the Fort Pearce section



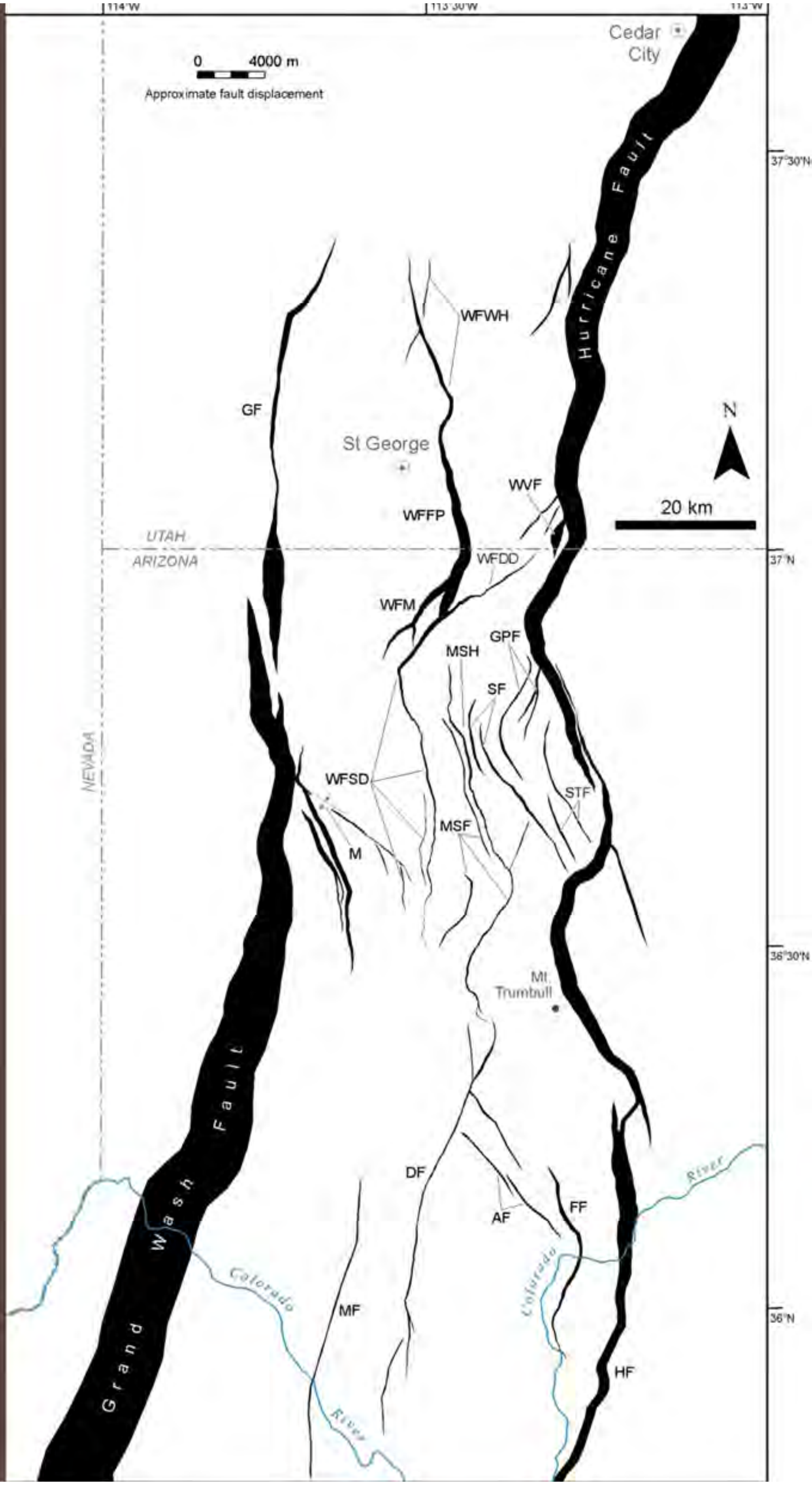
Regional Relations in Transition Zone

- Map patterns:
  - Intersecting
  - Branching
  - En echelon
  - Rhombic
  - Salients & reentrants at similar latitudes
- Similar activity rates
  - All faults displace Quaternary alluvium
- Structurally linked?



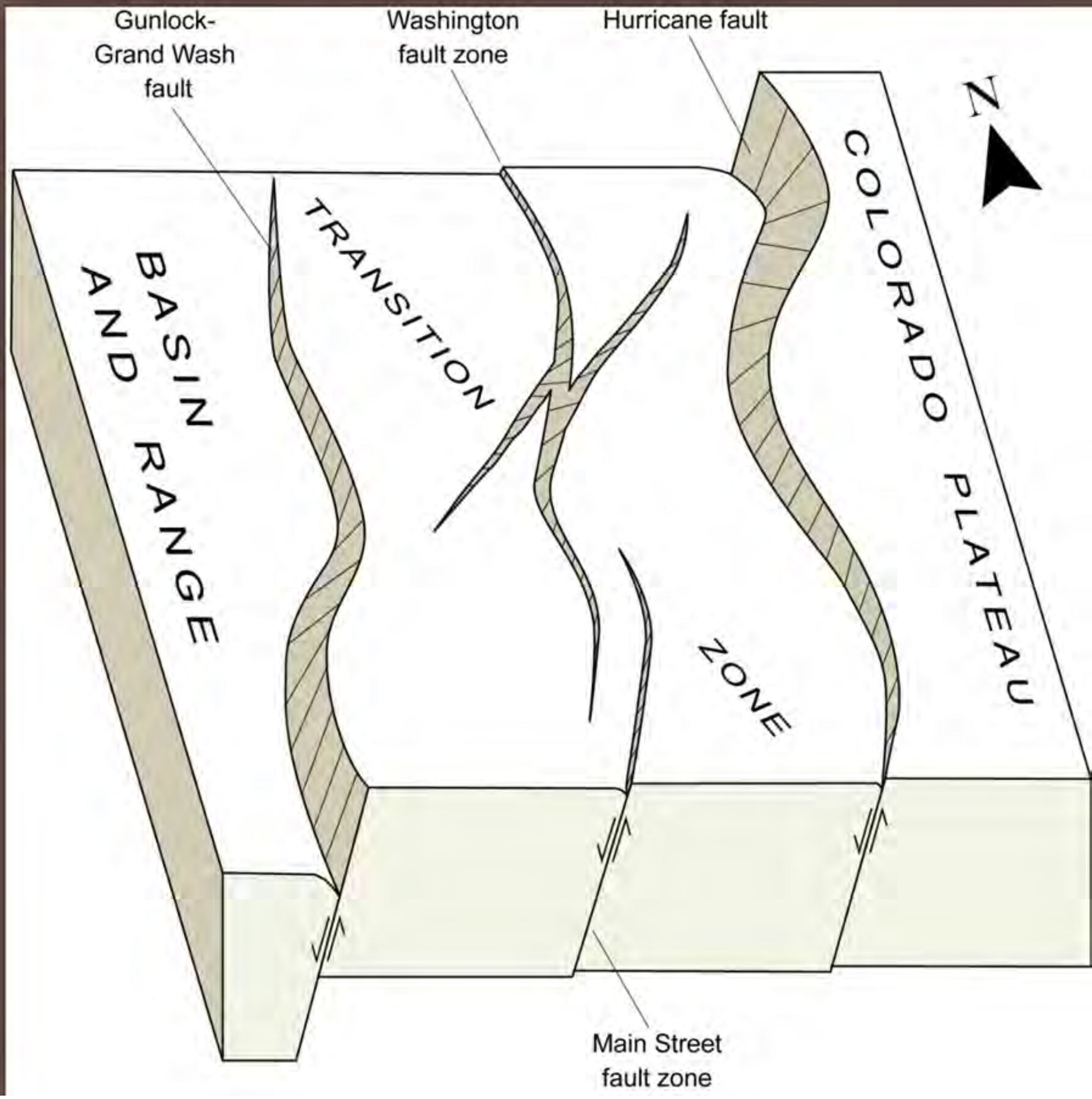
Displacement Transfer Zone or Regional Relay Ramp (?)
(Schramm, 1994)

- Similar geometries
- Slip on Grand Wash and Hurricane faults increases in opposite directions
- All faults displace Quaternary units
- Limited Earthquake record indicates WF, GWF, HF are all seismically active



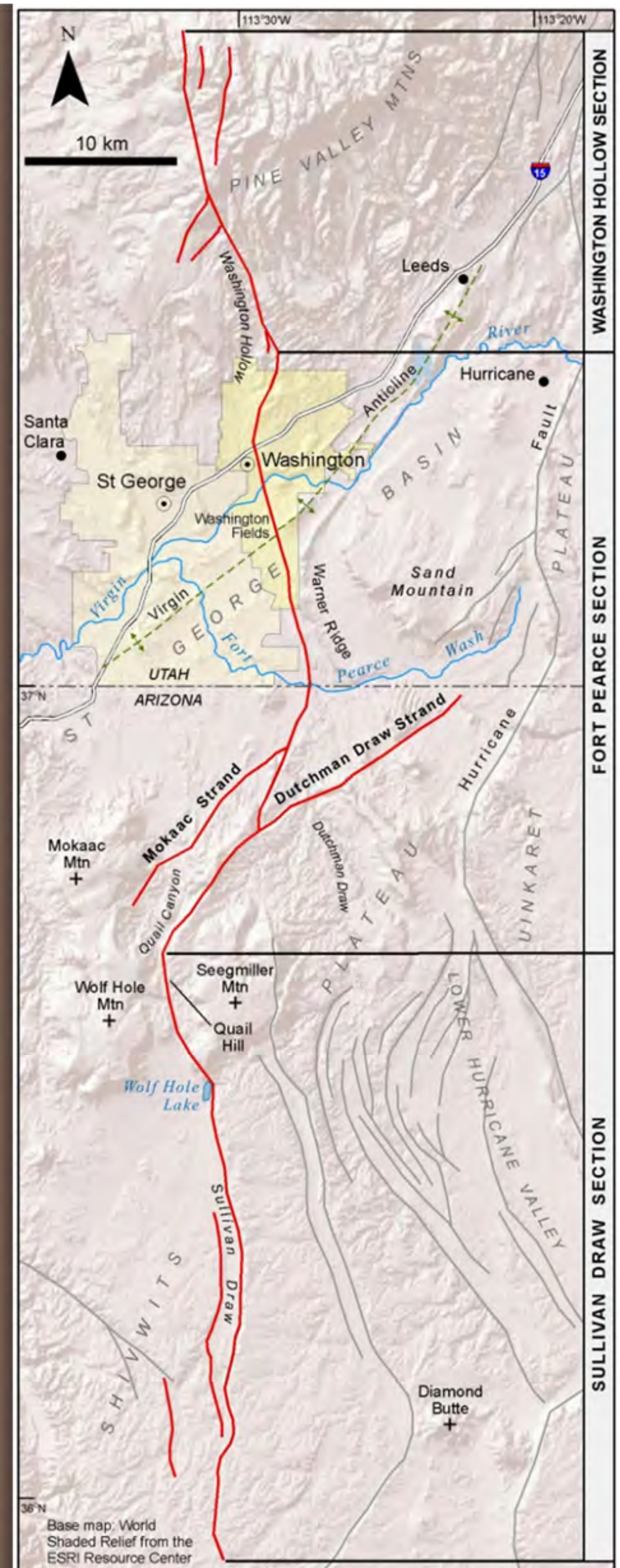
Regional Transfer Zone (Relay Ramp)

- Grand Wash fault initiates in Miocene
- Locus of extension shifts east, Hurricane fault initiates in Pliocene
- Strain in intervening block creates Washington fault zone
- More data/analyses necessary to evaluate existence of a master detachment



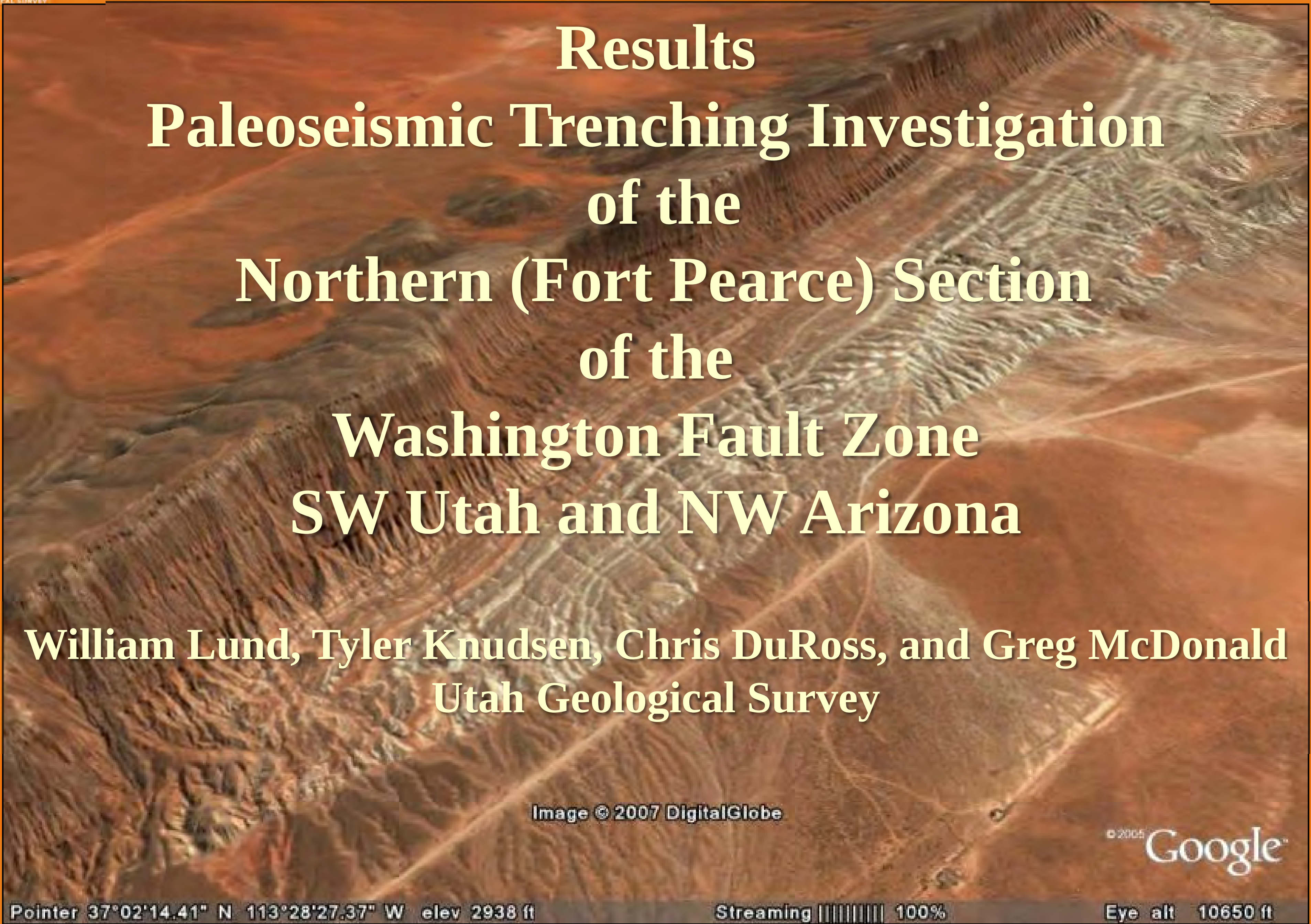
Summary

- High erosion rates
  - Fault-line scarps
  - Few scarps on unconsolidated units
- Washington Hollow fault is part of the Washington fault zone→ Washington Hollow section (22 km long)
- Northern section renamed the Fort Pearce section (37 km long)
- Mokaac section and Dutchman Draw fault are redefined as major strands of the Fort Pearce section
- Faults in the transition zone may be structurally linked as a regional transfer system



Results
Paleoseismic Trenching Investigation of the Northern (Fort Pearce) Section of the Washington Fault Zone SW Utah and NW Arizona

William Lund, Tyler Knudsen, Chris DuRoss, and Greg McDonald
Utah Geological Survey



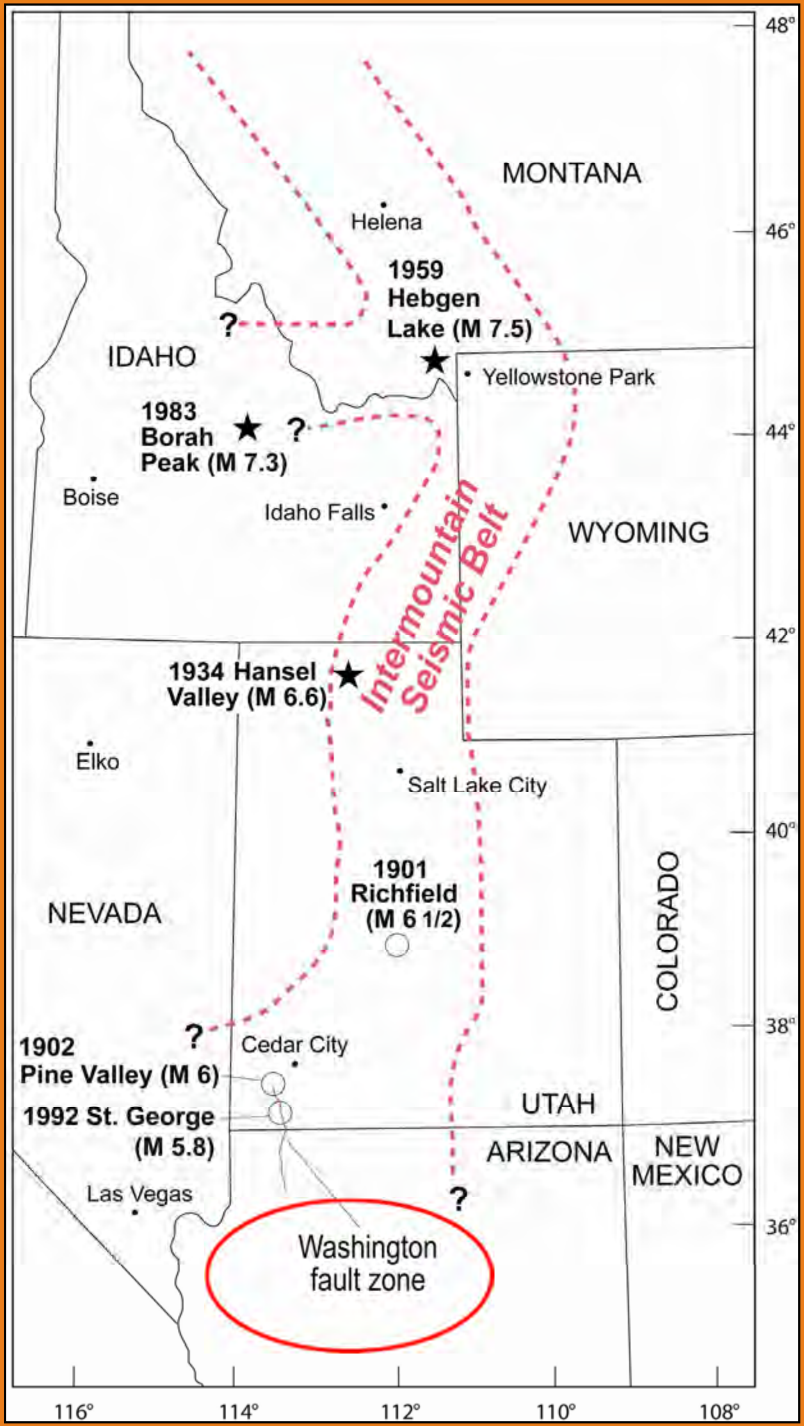
The Utah Geological Survey has conducted an integrated investigation of the Washington fault zone (WAFZ) in southwestern Utah that included:

- Making a 1:24,000-scale geologic strip map along the fault in Utah and northernmost Arizona.
- Trenching a fault scarp formed on a Holocene/latest Pleistocene alluvial fan in Arizona to obtain paleoseismic information for the fault.
- Dating ($^{40}Ar/^{39}Ar$) and geochemically correlating mafic volcanic flows displaced across the fault, and using that information together with the displacement information to calculate long-term (middle Quaternary) vertical slip rates for the fault.
- Cooperating with a Utah Department of Transportation surface-fault-rupture - hazard investigation for proposed interchange structures to obtain additional paleoseismic information on the WAFZ in Utah.

The study was chiefly funded by the Utah Geological Survey, with additional funding provided by the U.S. Geological Survey through the National Earthquake Hazard Reduction Program.

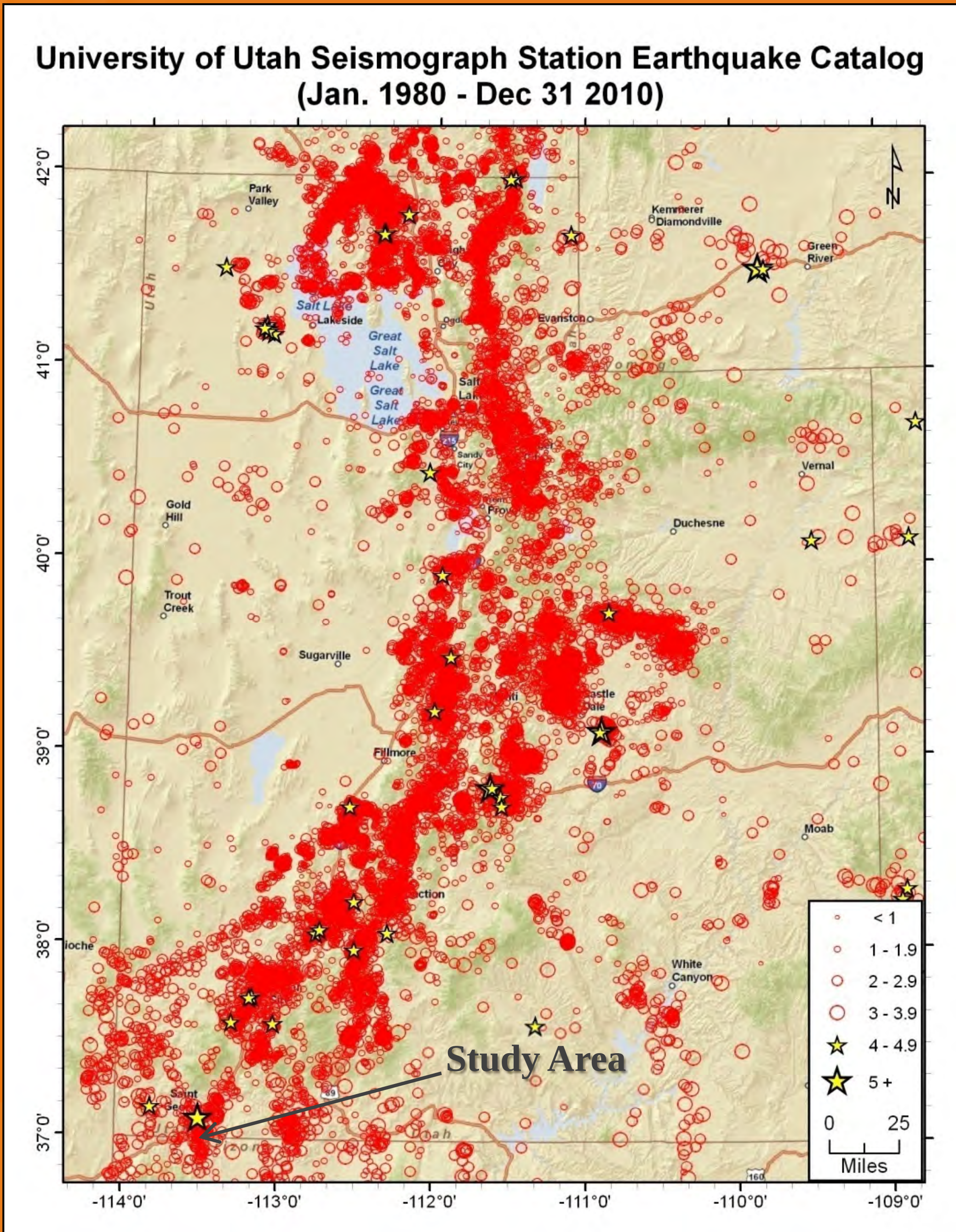
Why the Washington Fault Zone?

- The WAFZ lies within the Intermountain seismic belt, an interplate zone of increased earthquake activity and Quaternary faulting that extends from northern Montana to southern Nevada.
- The WAFZ has formed scarps on Holocene and latest Pleistocene unconsolidated geologic deposits, indicating that the fault has produced large surface-faulting earthquakes in recent geologic time.
- The WAFZ trends directly into the St. George metropolitan area (Washington County – pop. ~ 138,000), and more specifically directly through the rapidly urbanizing community of Washington, Utah.
- The WAFZ was identified in 2008 by the UQFPWG as a high priority fault requiring additional paleoseismic investigation.



The Intermountain seismic belt (ISB) has been the locus of all Intermountain West historical surface-faulting earthquakes, including Utah's only historical surface-faulting event, the 1934 Hansel Valley **M** 6.6 earthquake.

The ISB also produced southwestern Utah's two largest historical events, the 1902 Pine Valley ~ M 6 earthquake, and the 1992 St. George M_L 5.8 earthquake.



Intermountain Seismic Belt defined by Utah Earthquake Epicenters

The WAFZ study area is near the southern end of the ISB in an area of contemporary earthquake activity.

2006

Washington City, Utah

The photo that launched a 1000 backhoes
well, one anyway

Horizon Elementary School

It was this photo shown at the 2008 UQFPWG meeting that caused the Working Group to elevate the WAFZ to its list of highest priority faults for study.

2011 – Washington City, Utah

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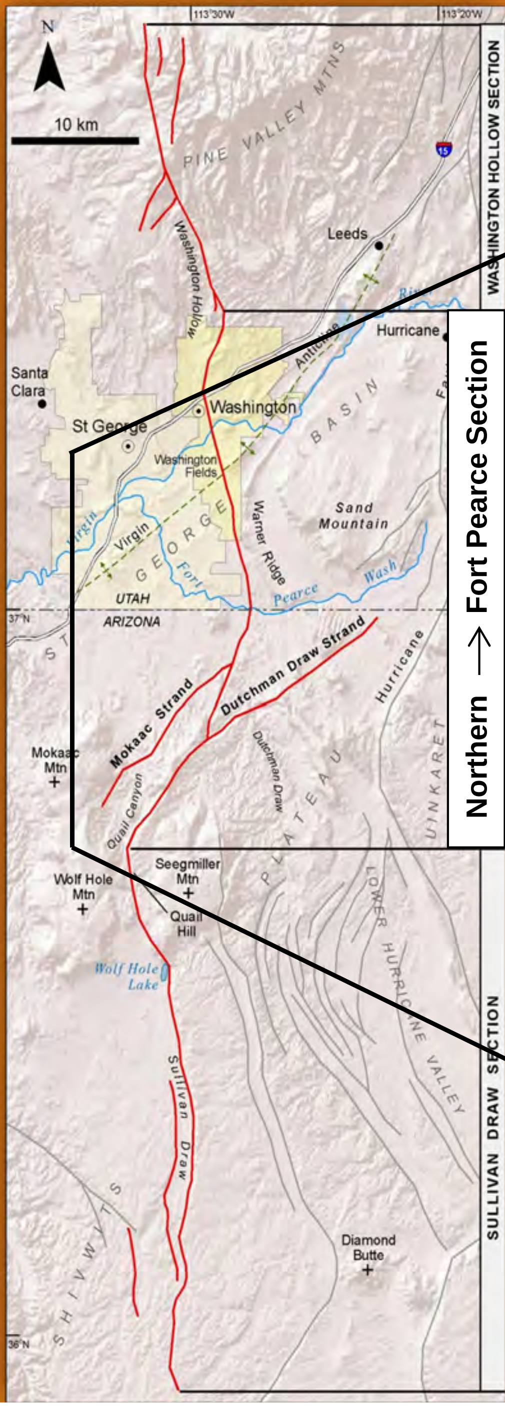
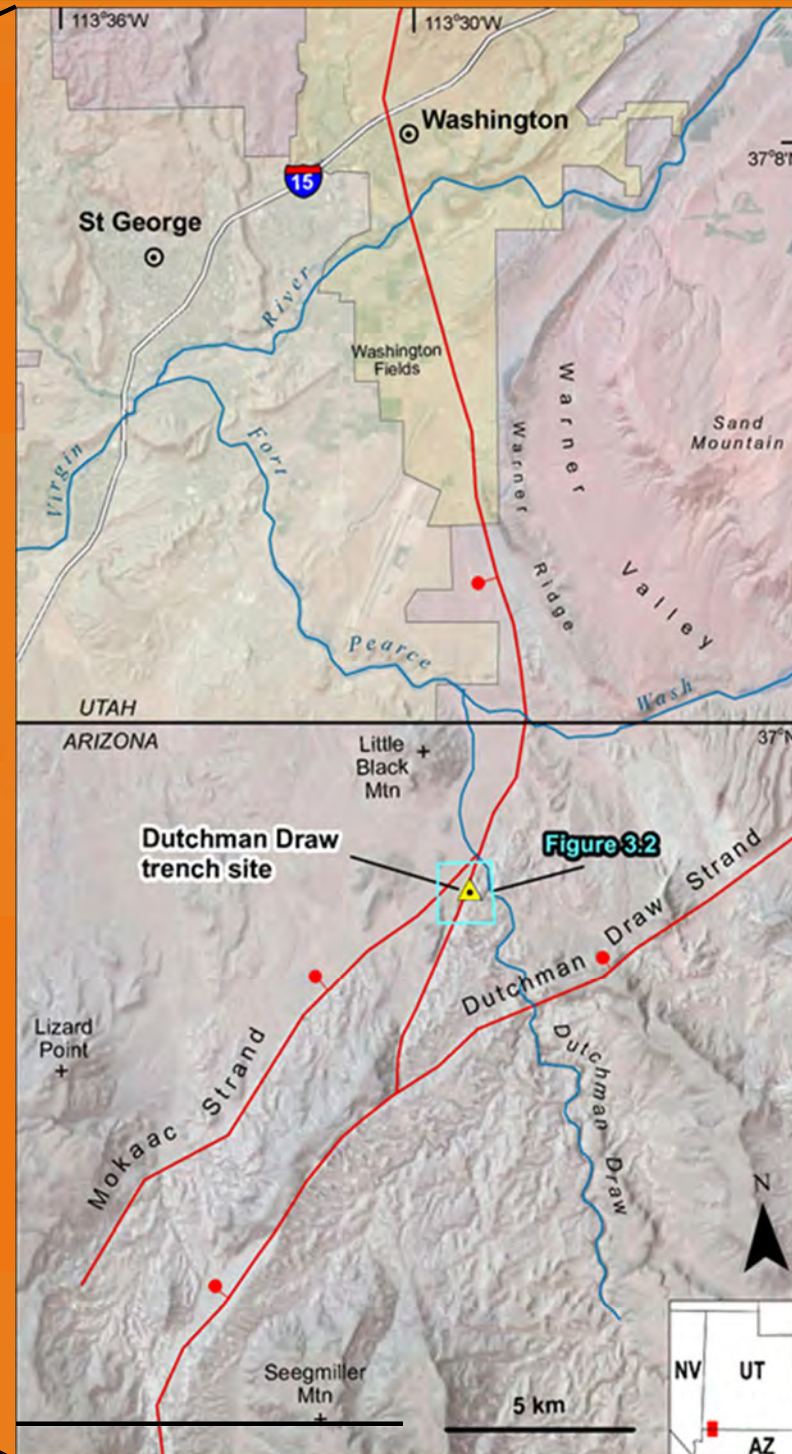


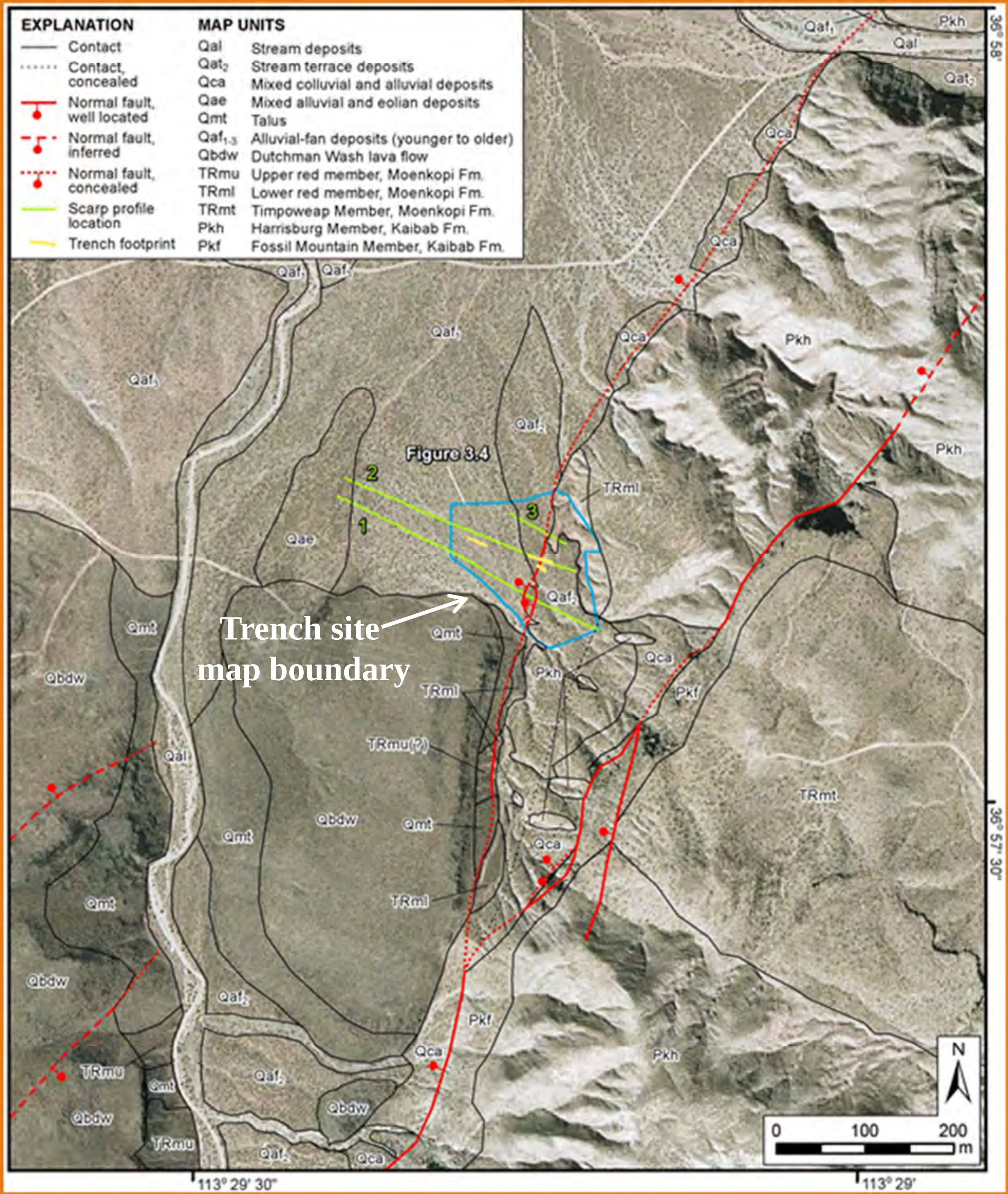
Fault Sections And Trench Location

(complications)

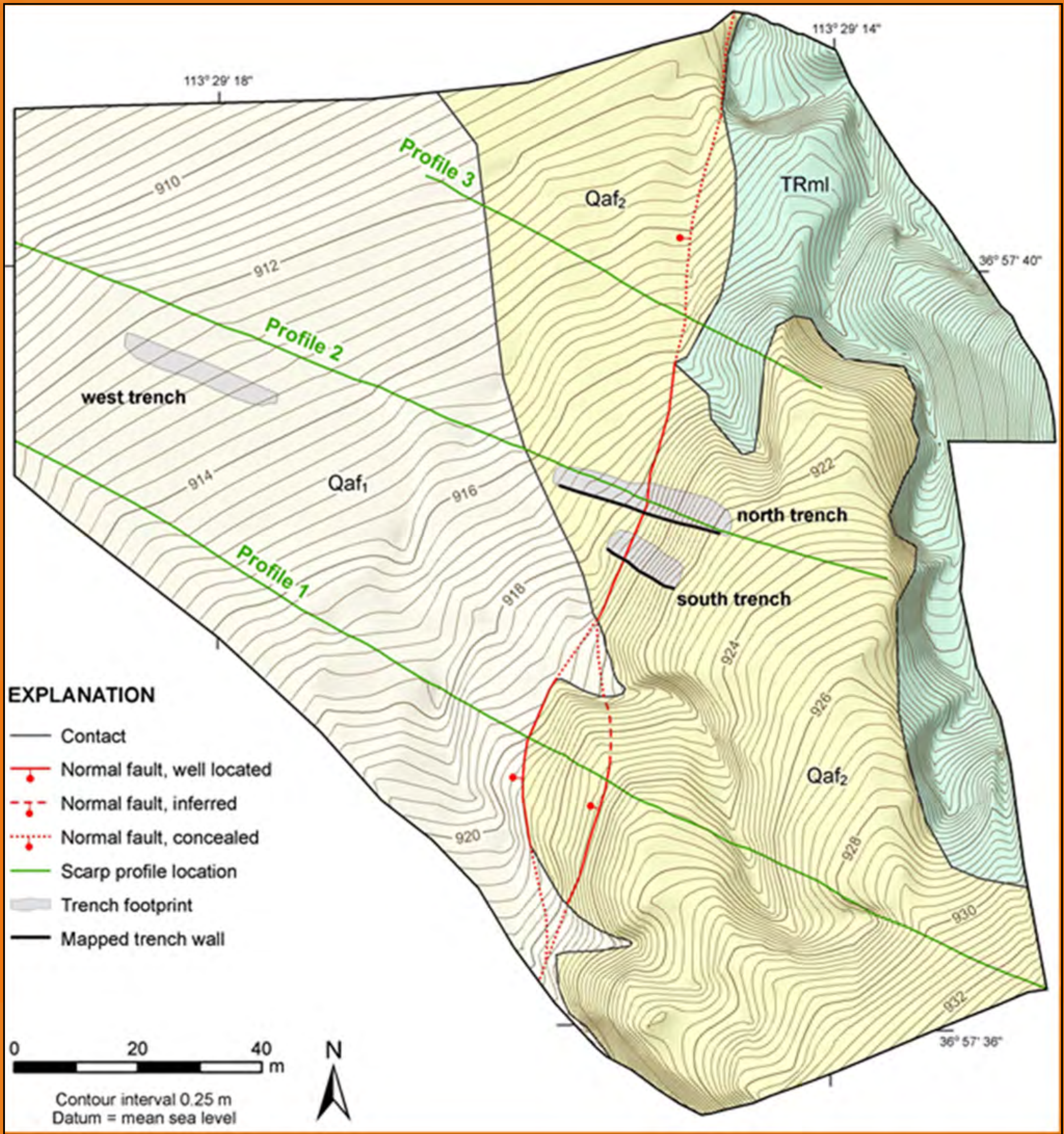


Dutchman Draw Fault Scarp – Mohave County, Arizona

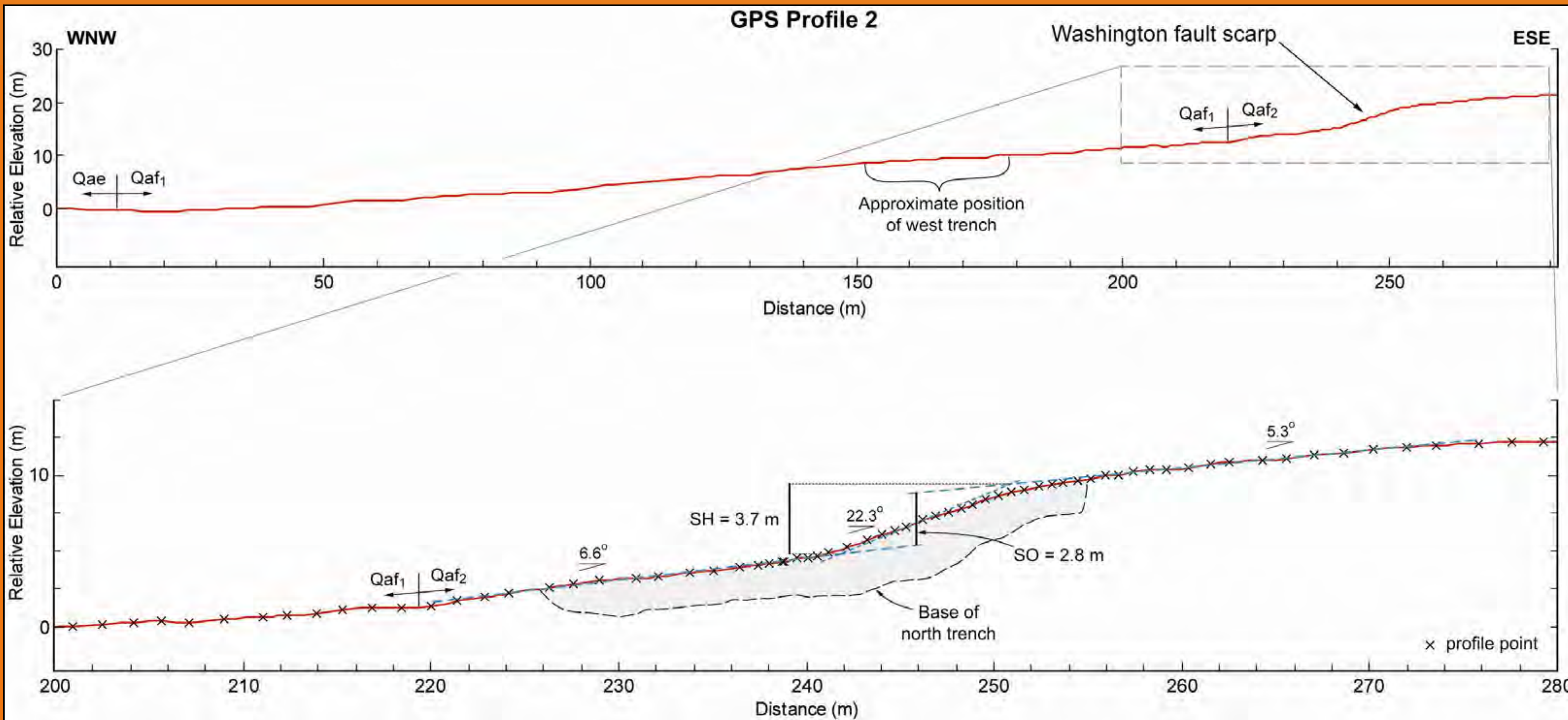
Dutchman Draw Area Geologic Map



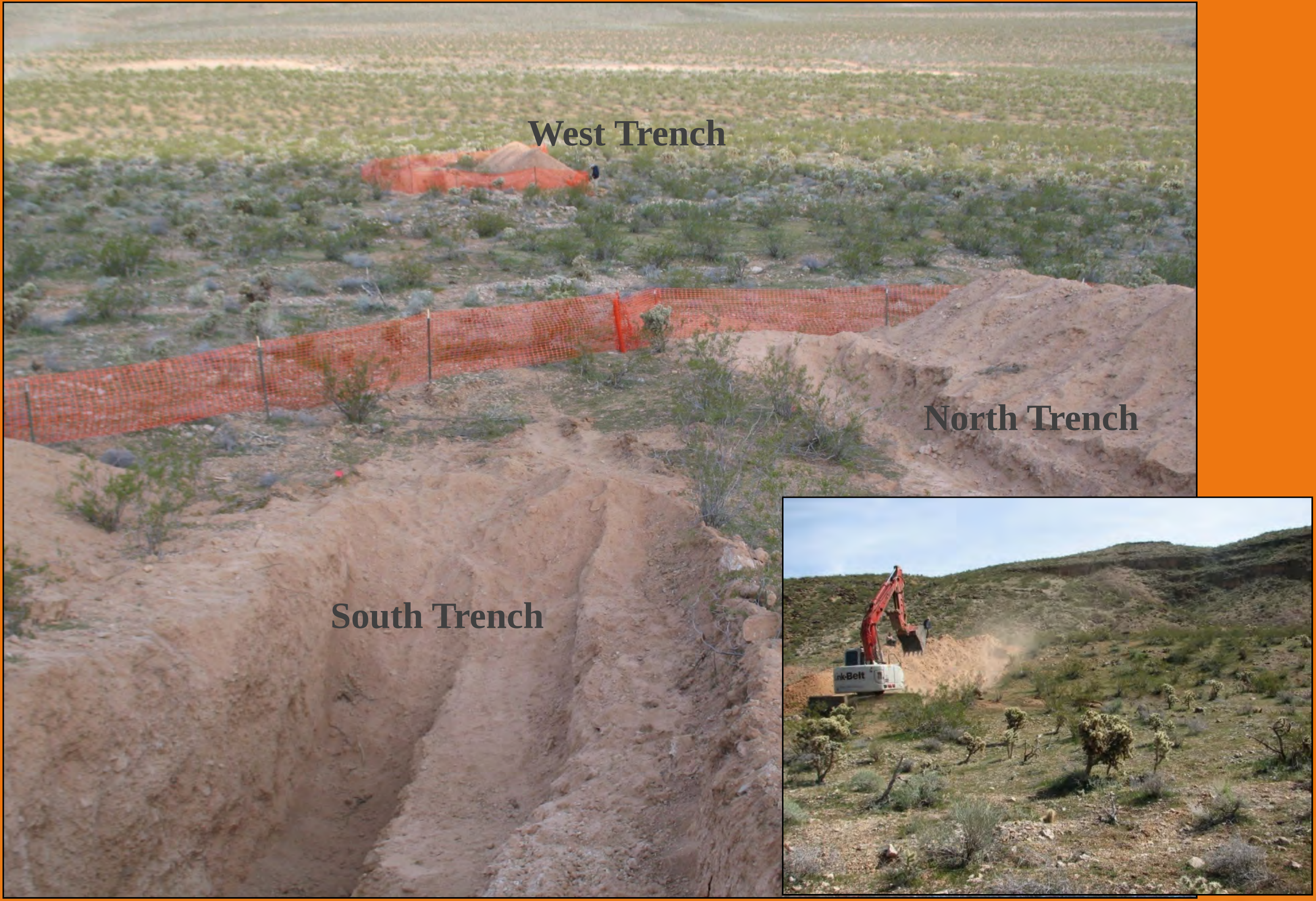
Dutchman Draw Trench Site Geologic and Topographic Map



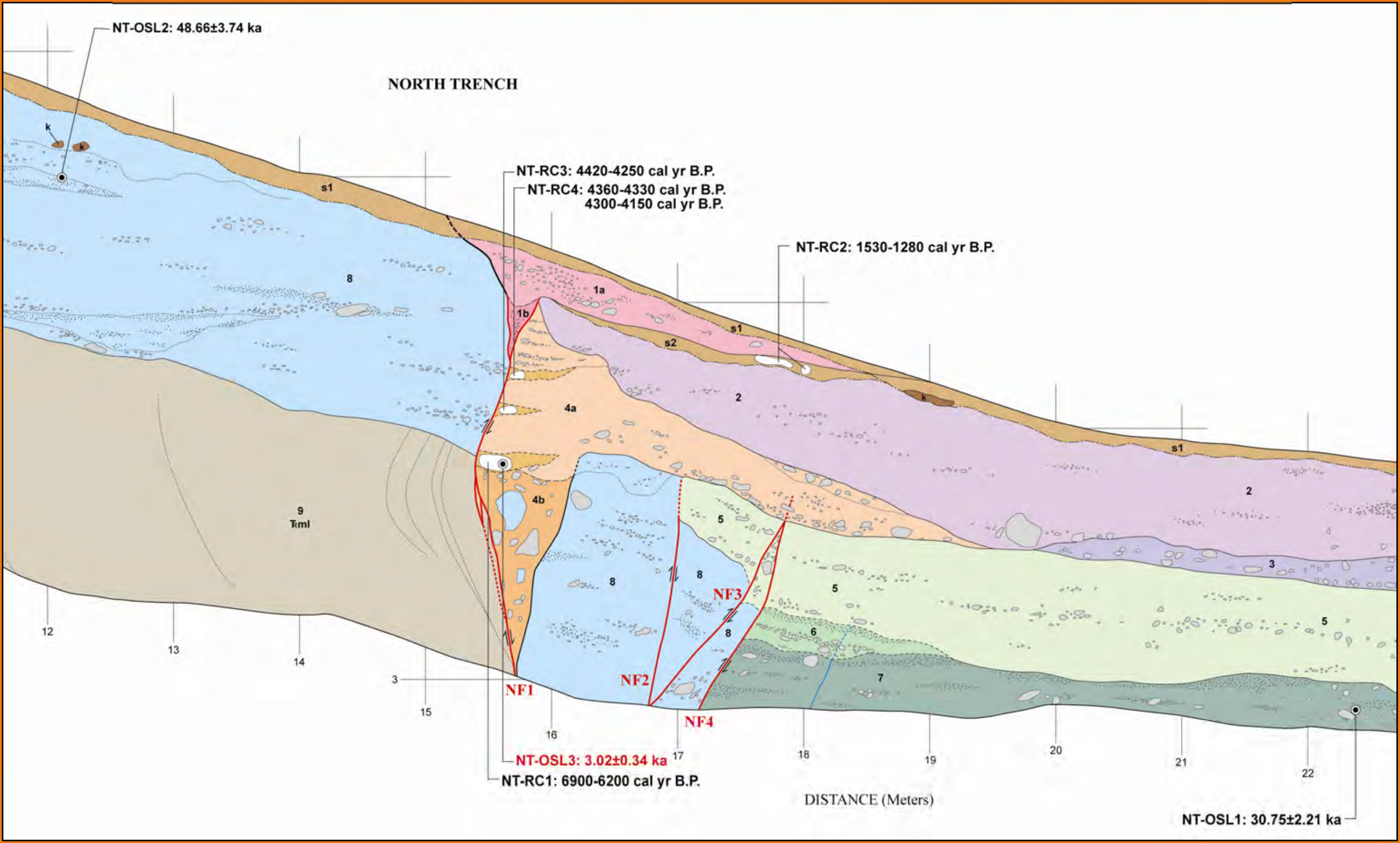
Scarp Profiles



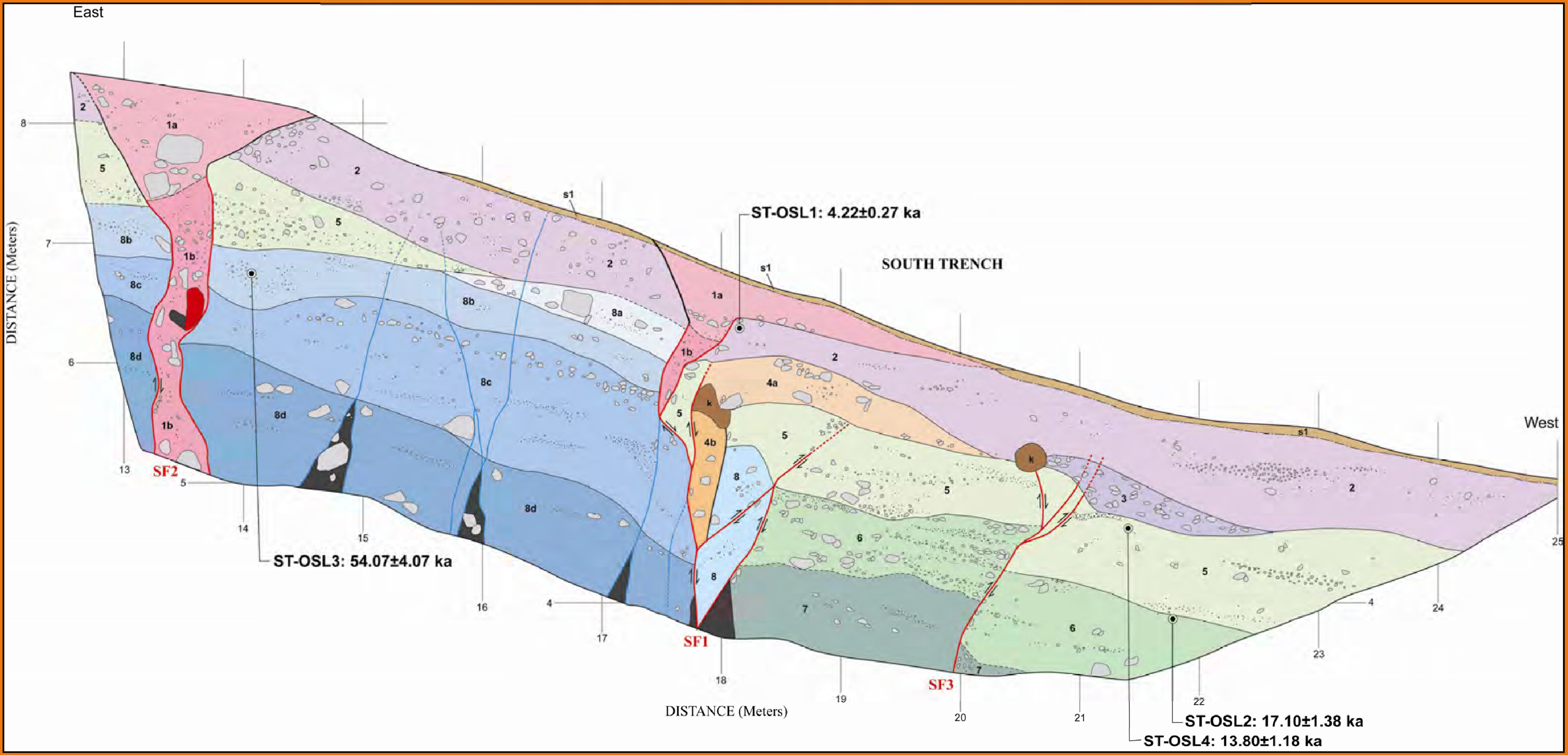
TRENCHING RESULTS



NORTH TRENCH FAULT ZONE (south wall)



SOUTH TRENCH (south wall)



SUMMARY OF TRENCHING RESULTS

- Two Holocene paleoearthquakes

P1 – 1.0 ± 0.6 ka

P2 – 7.7 ± 2.4 ka

(OxCal analysis of ^{14}C and OSL ages, rounded to nearest 100 yrs, 2σ uncertainty)

•Single closed-seismic-cycle recurrence interval (P2 – P1) = 6.6 ± 2.4 kyr.

•Indirect stratigraphic evidence in the trenches permissive of at least one latest Pleistocene earthquake between 13.8 ± 1.2 and 17.1 ± 1.4 ka.

•Net vertical displacement estimates range from ~1.0 m (P1) to 2.4 m (P2).

(Combination of scarp profiles, trench stratigraphy, and scarp free-face heights extrapolated from colluvial-wedge thicknesses. Caveats associated with all three methods, consider these displacement values poorly constrained "best estimates".)

•The vertical slip rate for the P2–P1 recurrence interval (6.6 ± 2.4 kyr) and a P1 net vertical displacement (1.0–1.2 m) is 0.11–0.29 mm/yr.

Paleomagnitude Estimates

Reflect current WGUEP regression relations

(SRL scenarios – 25 and 37 km, fault dip – 50 ± 15°, seismogenic crust – 15 ± 3 km)

- Hanks and Kanamori (1979) – Seismic moment

  $M_{w(25)}$ 6.9-7.2 & $M_{w(37)}$ 7.0-7.3

- Stirling and others (2002) – Censored instrumental SRL relation

  $M_{w(25)}$ 7.0 & $M_{w(37)}$ 7.1

- Wesnousky (2008) – SRL all fault types

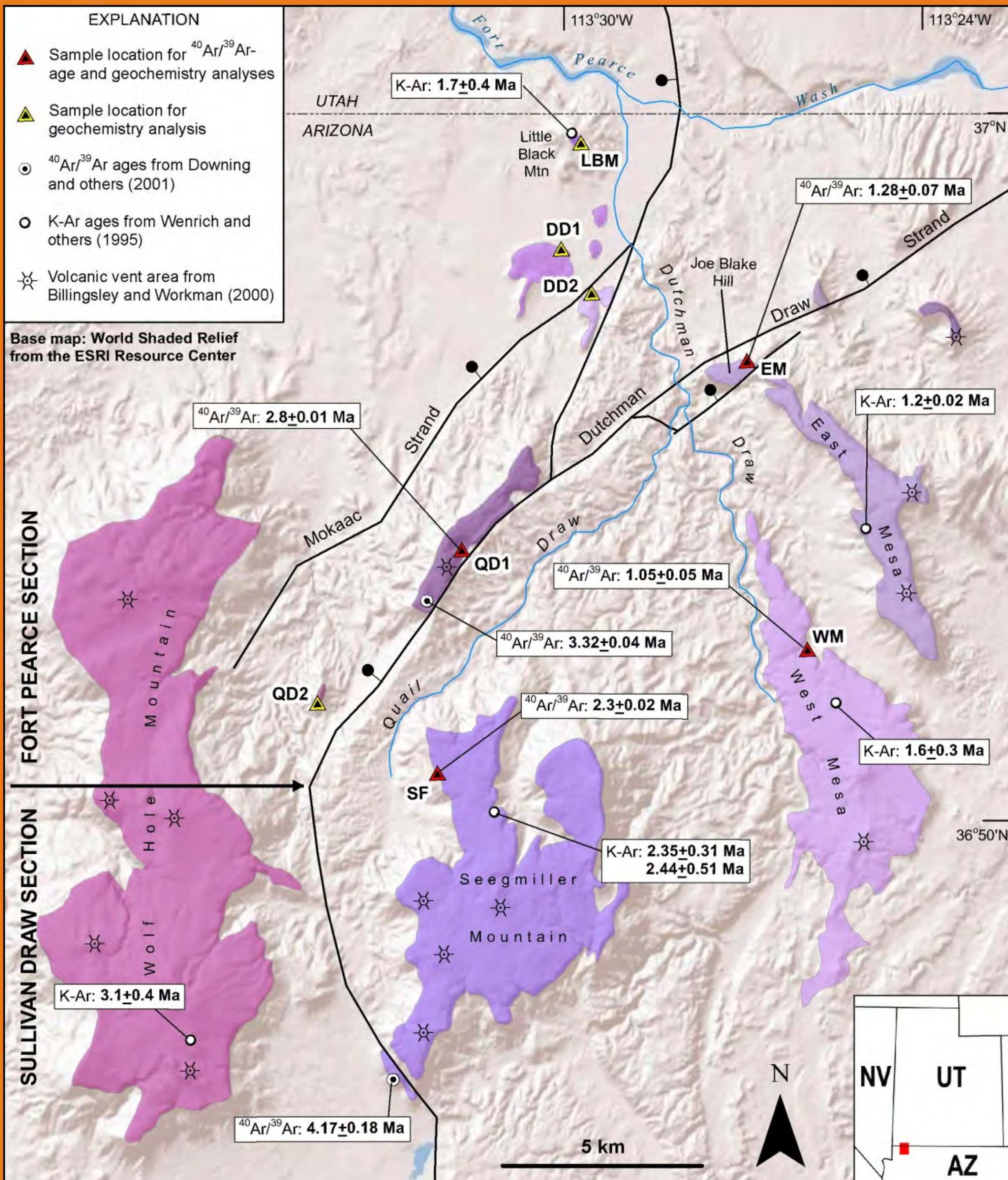
  $M_{w(25)}$ 6.7 & $M_{w(37)}$ 6.9

- Wells and Coppersmith (1994) – SRL all fault types

  $M_{w(25)}$ 6.7 & $M_{w(37)}$ 6.9

- Anderson and others (1996) – SRL for all fault types and SR

  $M_{w(25)}$ 6.9 & $M_{w(37)}$ 7.1



Long-Term Vertical Slip Rate Estimates Southern Fort Pearce and Northern Sullivan Draw Sections Washington Fault Zone

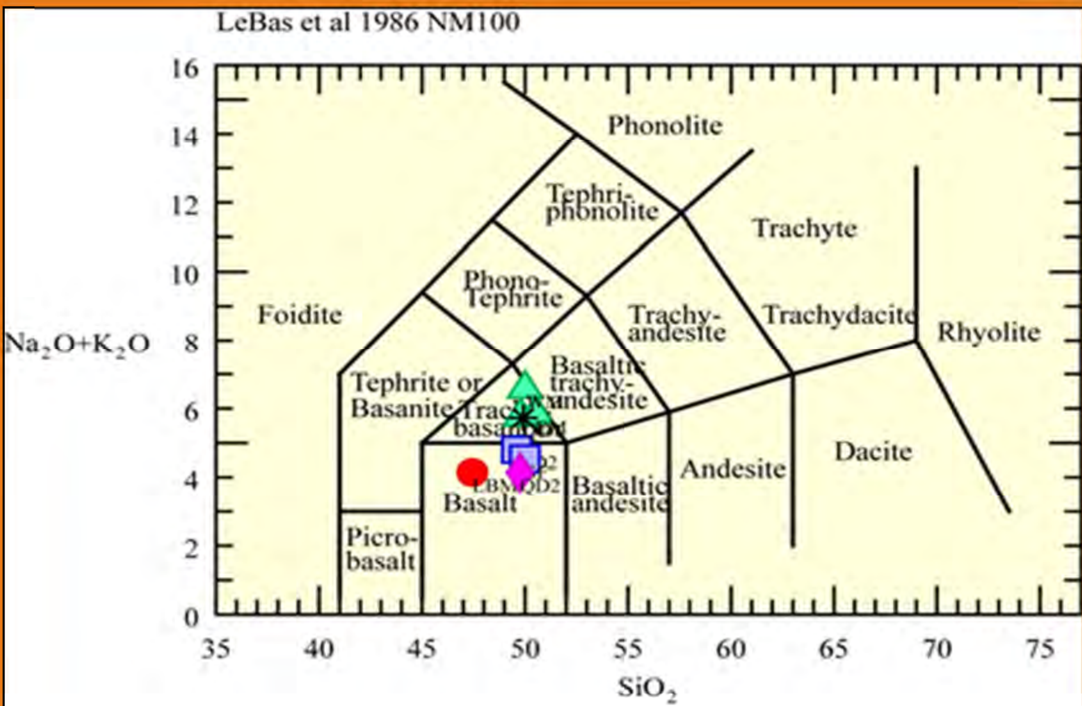
Available radiometric ages – Fort Pearce and Sullivan Draw sections WAFZ

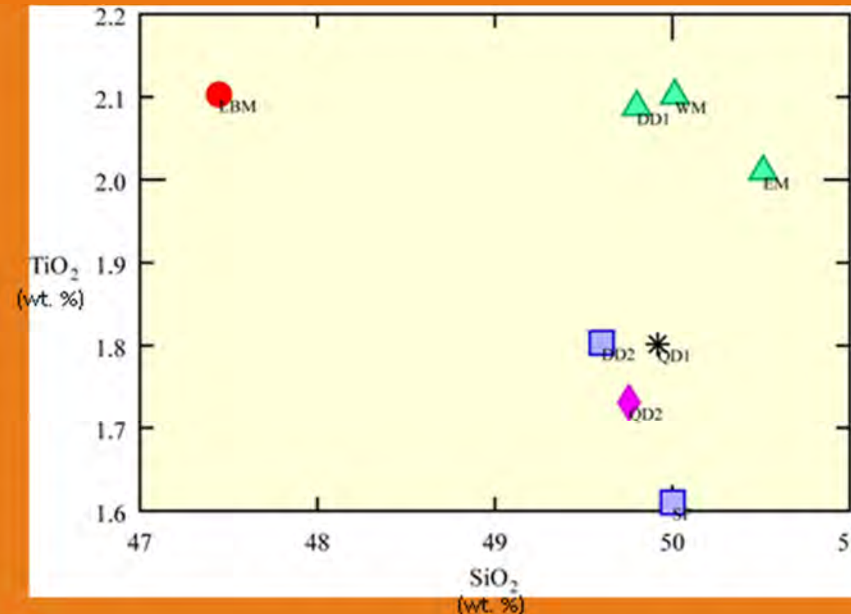
Location	Radiometric age (Ma)	Reference
East Mesa flow	1.4 ± 0.25 (K-Ar)	Wenrich and others (1995)
West Mesa flow	1.6 ± 0.3 (K-Ar)	Wenrich and others (1995)
Little Black Mountain flow	1.7 ± 0.4 (K-Ar)	Wenrich and others (1995)
Seegmiller Mountain flow	2.35 ± 0.31 and 2.44 ± 0.51 (K-Ar)	Wenrich and others (1995)
Wolf Hollow Mountain flow	3.1 ± 0.4 (K-Ar)	Wenrich and others (1995)
Quail Draw-1 flow	3.32 ± 0.04 ($^{40}Ar/^{39}Ar$)	Downing and others (2001)
Seegmiller Mountain flow	4.17 ± 0.18 ($^{40}Ar/^{39}Ar$)	Downing and others (2001)

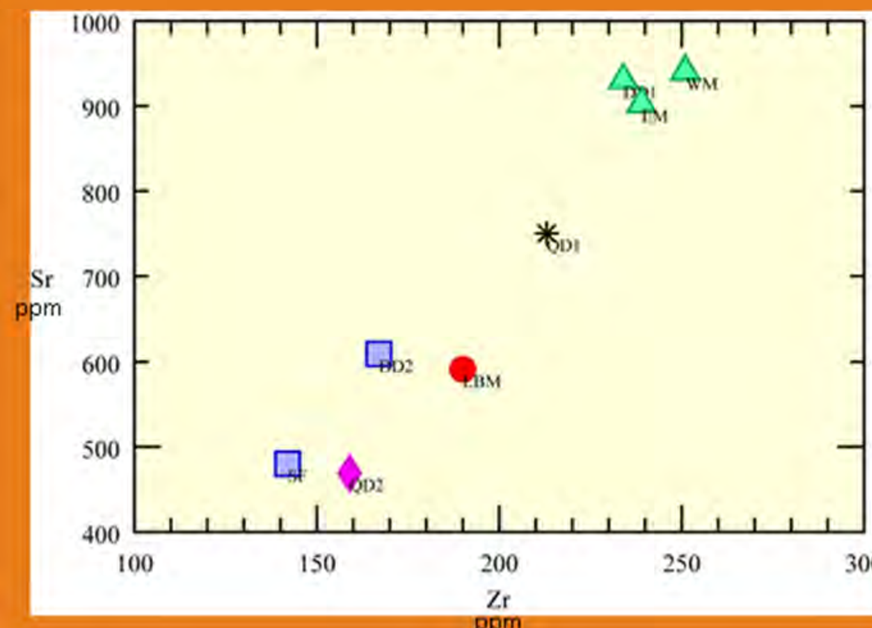
Newly acquired radiometric ages – Fort Pearce and Sullivan Draw sections WAFZ

Sample	Location	$^{40}Ar/^{39}Ar$ Age[2] (Ma)
EM	East Mesa flow	1.211 ± 0.015
WM	West Mesa flow	1.05 ± 0.05
SF	Seegmiller Mountain flow	2.32 ± 0.02
QD1	Quail Draw-1 flow	2.779 ± 0.017

Geochemical Classification and Correlation







Geochemical analysis performed by the GeoAnalytical Lab at Washington State University

Long-term vertical slip-rate estimates for the southern Fort Pearce and northern Sullivan Draw sections of the WAFZ .

Correlated Flows	Elev. A[1] (m)	Elev. B[1] (m)	Elevation Difference (m)	Horizontal Distance[2] (km)	Radiometric Age[3] (Ma)	Vertical Slip Rate (mm/yr)	Vertical Slip Across
Seegmiller Mountain Flow – Dutchman Draw-2 Flow Remnant	1650	1020	630	9.2	2.32 0.02	0.27[4]	Fort Pearce section main strand
West Mesa Flow– Dutchman Draw-1 Flow Remnant	1270	940	330	7.9	1.05 0.05	0.31[4]	Fort Pearce section composite
East Mesa Flow – Dutchman Draw-1 Flow Remnant	1220	940	280	6.3	1.211 0.015	0.23[4]	Fort Pearce section composite
East Mesa Flow – East Mesa Flow	1220	1170	50	Adjacent	1.211 0.015	0.04	Dutchman Draw strand single splay
Seegmiller Mountain Flow - Seegmiller Mountain Flow	1800	1710	90	Adjacent	2.32 0.02	0.04	Sullivan Draw section

[1]Elevation obtained in feet from Google Earth imagery dated 10/2/2011. We converted elevations in feet to meters by dividing the elevations by 3.2808 feet and rounded the result to the nearest 10 m. [2]Straight line distance measured on Google Earth imagery dated 10/2/2011. [3]New $^{40}Ar/^{39}Ar$ radiometric ages obtained for this study (see appendix C). See table 1 for older radiometric ages available for some flows. [4]Horizontal distances between these correlated points are measured in multiple kilometers. Based on geologic mapping, the flows are thought to have originated in the east and then to have flowed downslope to the west prior to faulting. The reported slip rates do not take into account the effect of pre-faulting topography (i.e., original elevation difference between the two points due to the pre-faulting topography), so we consider the slip rates reported here to be maximum values. It is also assumed, but cannot be confirmed, that the flows did not cascade over a pre-existing fault escarpment.

UTAH GEOLOGICAL SURVEY

Preliminary results from a high resolution seismic reflection profile at Hansel Valley, Utah;

Pier Paolo G. Bruno

G&G Dept. – The University of Utah, U.S.A

THE UNIVERSITY OF UTAH

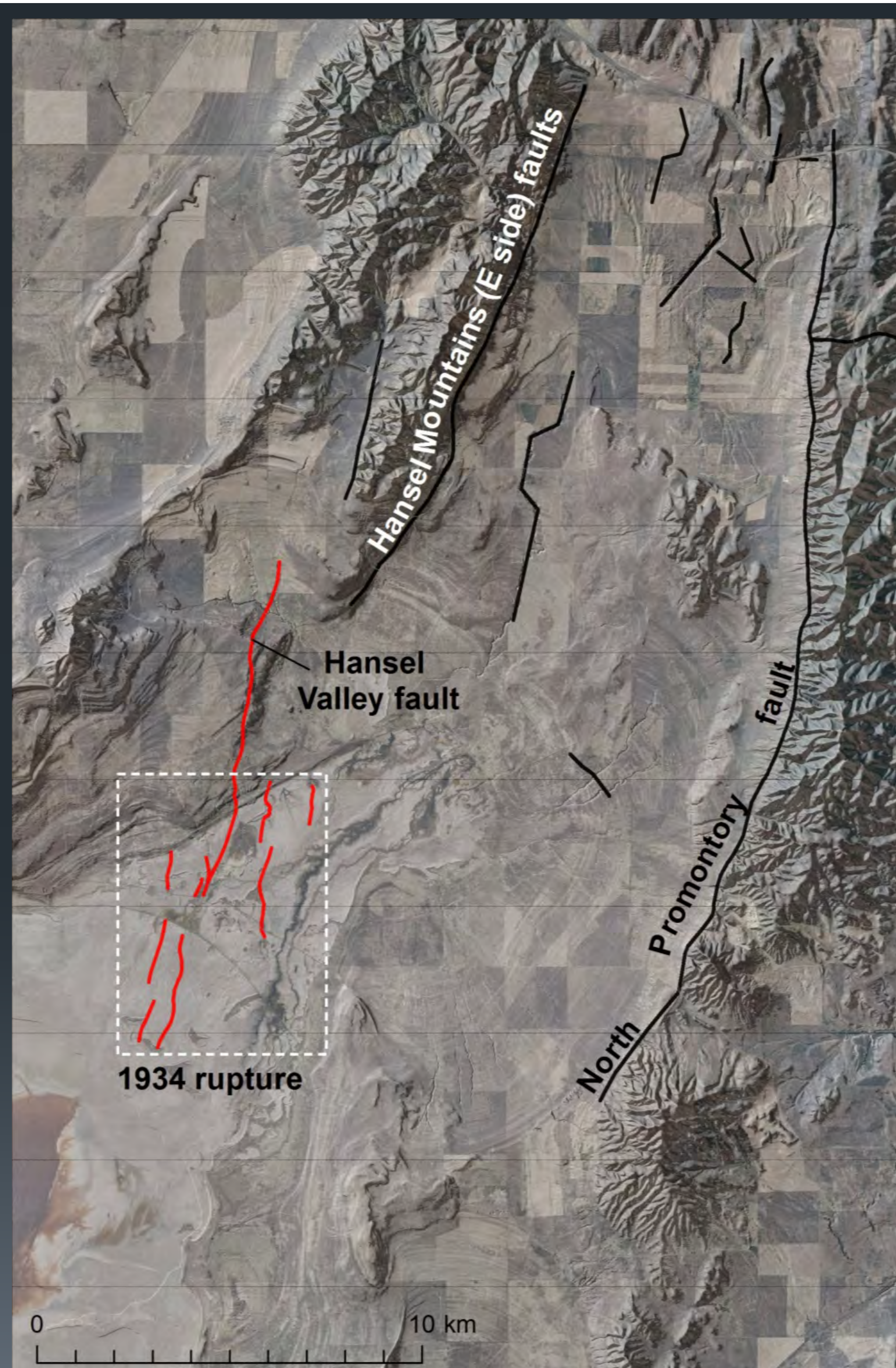
NGV – Istituto Nazionale di Geofisica e Vulcanologia, ***Italy***

INGV

1934 M 6.6 Hansel Valley Earthquake: Analog for Antithetic Fault Rupture?

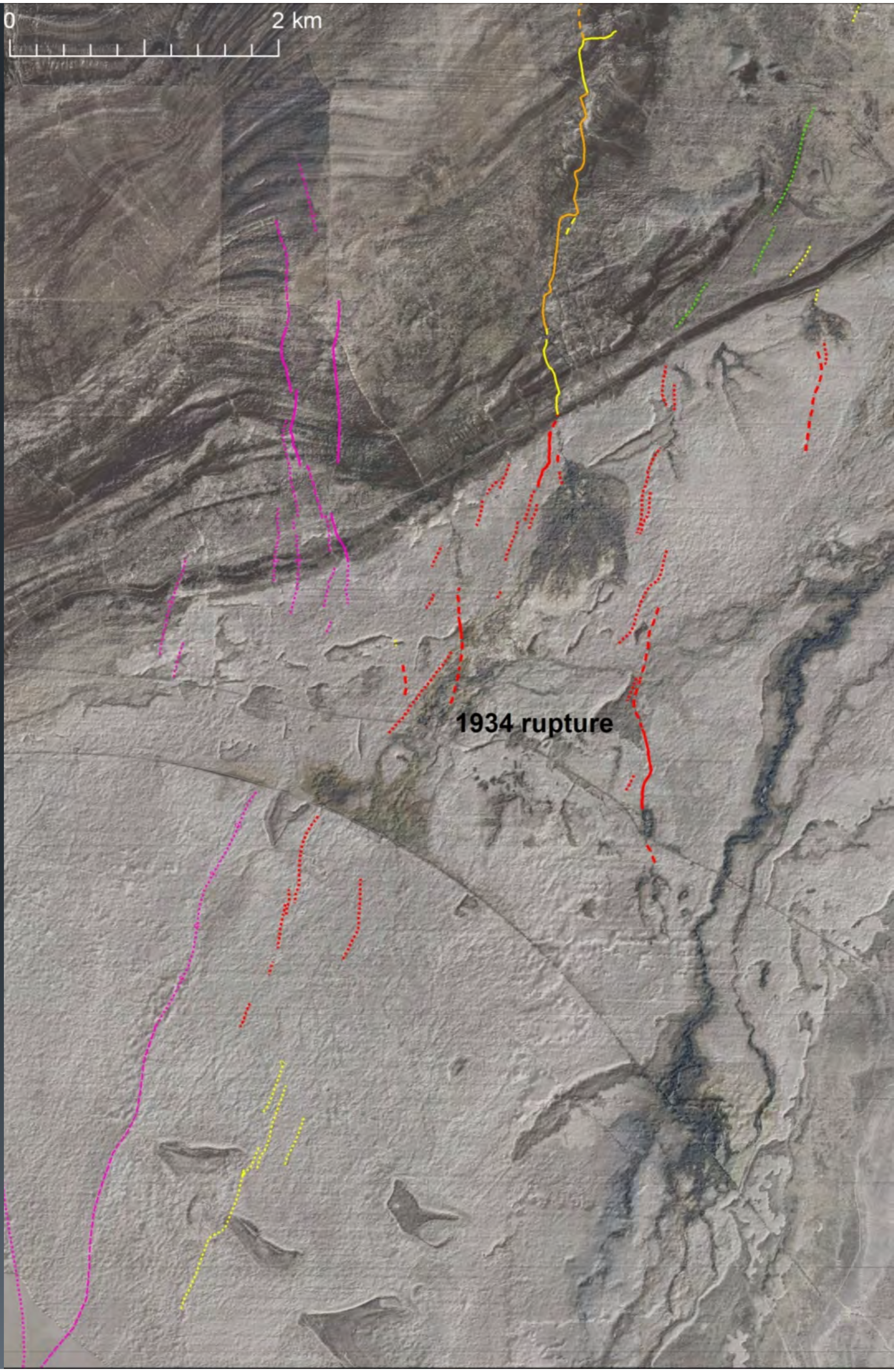
Chris DuRoss
Mike Hylland

Working Group on Utah Earthquake Probabilities
June, 2011



Geologic Observations

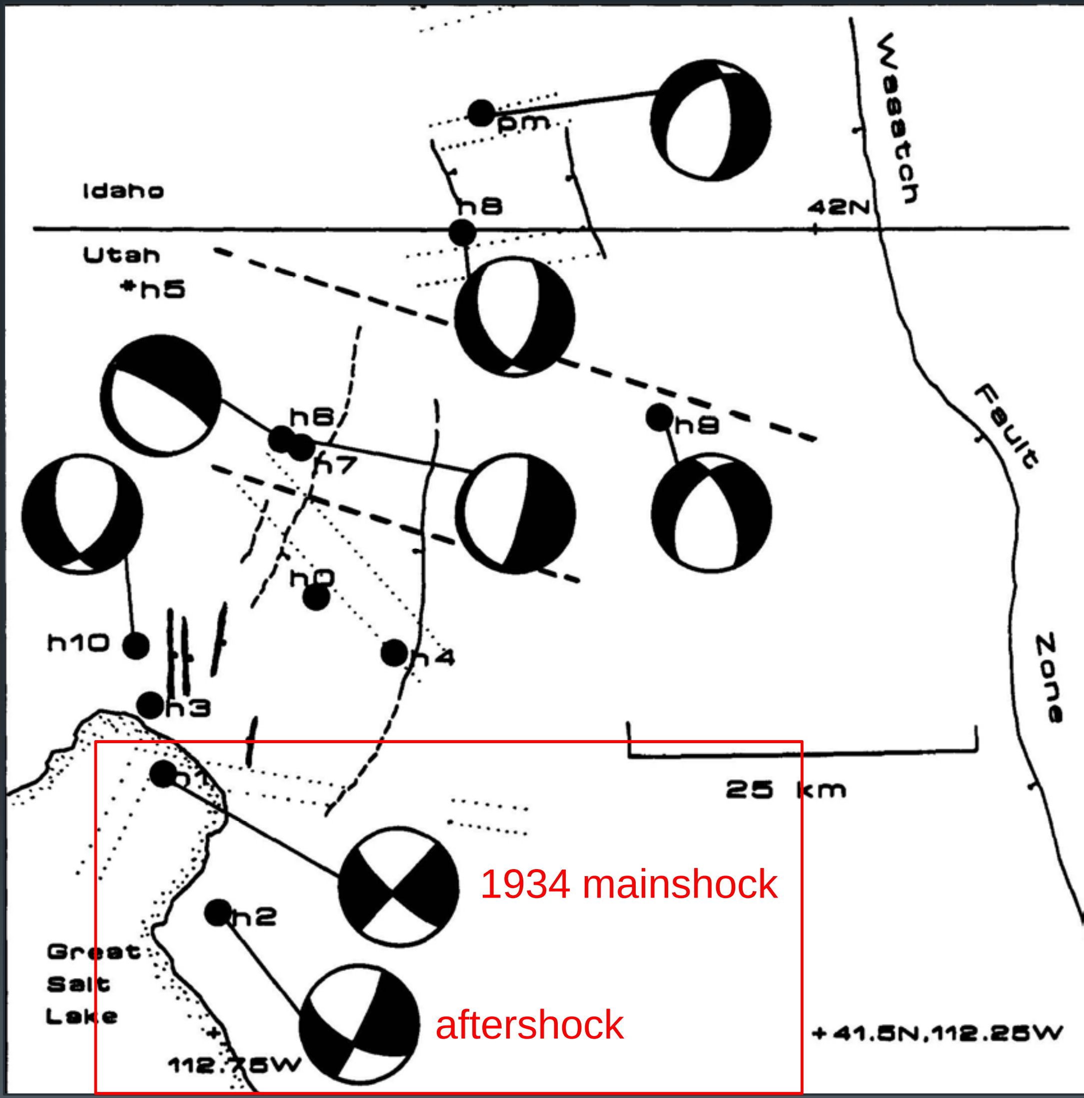
- 5–8-km-long, NE-oriented zone of ground cracks and minor surface faulting
- Down-to-the-east scarps related to 1934 earthquake
  - Maximum vertical displacement: ~50 cm, mostly down to the east
  - Maximum strike-slip displacement: ~25 cm (poorly documented)
- No reports of rupture along prehistoric rupture to the north, which has evidence of larger displacements (1+ m)




0
2 km
1934 rupture

Seismologic Observations

- Left-lateral strike-slip on near-vertical, NE oriented fault
- Rupture length: ~11 km using rupture time and velocity; NE propagation?
- Average horizontal slip: 2.3 m using seismic moment (M_0 = rigidity*area*slip)
- Average vertical slip: 20–25 cm using focal mechanism



Doser (1989)

Other puzzle pieces

- 1909 M ~6 Hansel Valley earthquake
  - No report of surface rupture, but newspaper report of waves passing over 3.5-m high railroad trestle
  - A: Bathymetry & shoreline data (1850–1934) could include displacement from this event
  - B: Linear shoreline south of 1934 rupture (and epicenter) suggests down-to-the-west faulting.
  - C: Lineaments and down-to-the-west scarps east of 1934 rupture related to 1909 earthquake?

Remaining Questions

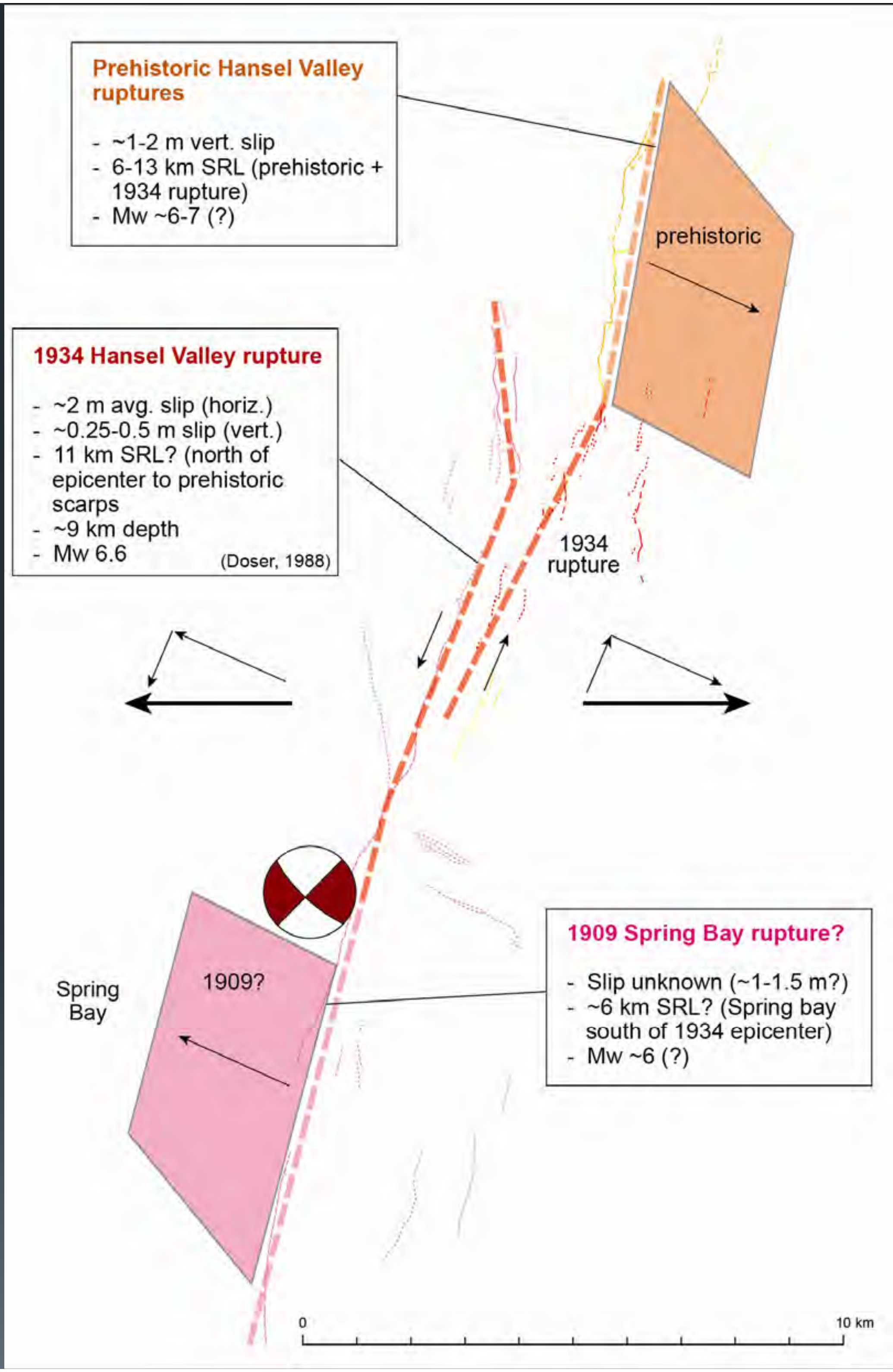
- Was the1934 M 6.6 earthquake a normal or strike slip event?
  - Normal surface rupture (~5–8-km L, 0.5 m vertical D)
  - Strike-slip focal mechanism (~11-km L, ~2 m horizontal D)

- Did the 1934 event occur as a strike slip event, only initiating normal faulting (or non-tectonic slip?) near the northern end of the rupture?

- How does the 1909 M~6 earthquake fit in? Did this event rupture faults in Spring Bay?

Speculation…

- Possible kinematic model: the 1934 earthquake was a dominantly strike-slip event that released strain accumulated between two normal faults.



Hansel Valley profile location

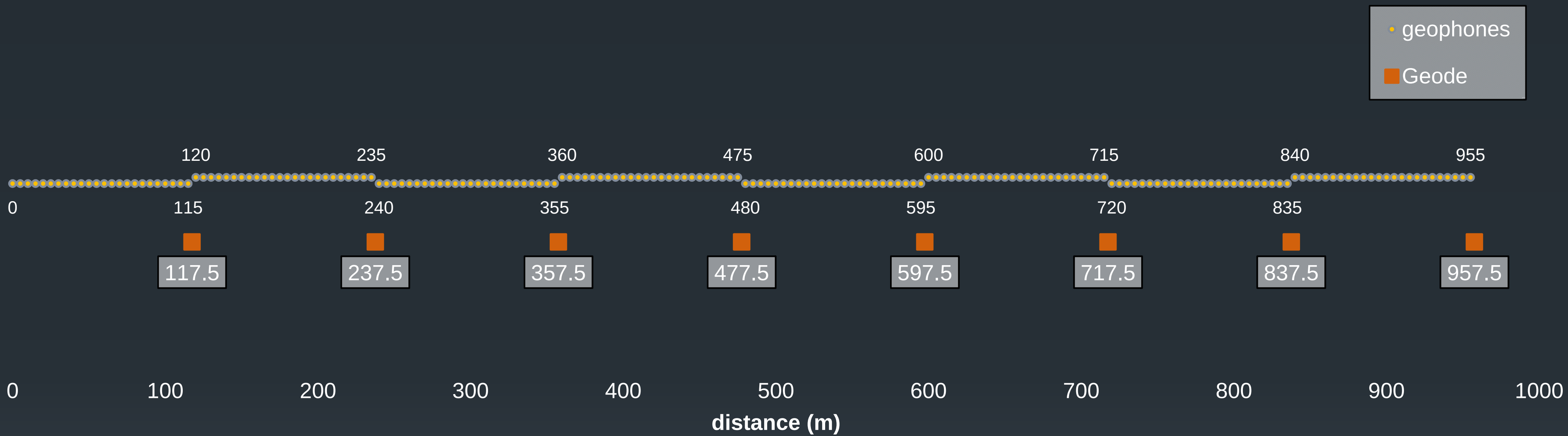
- **profile total length**: 6595 m (1320 geophone locations spaced each 5 m)

- **number of source positions:** 1207 vibration points (spaced each 5 m)

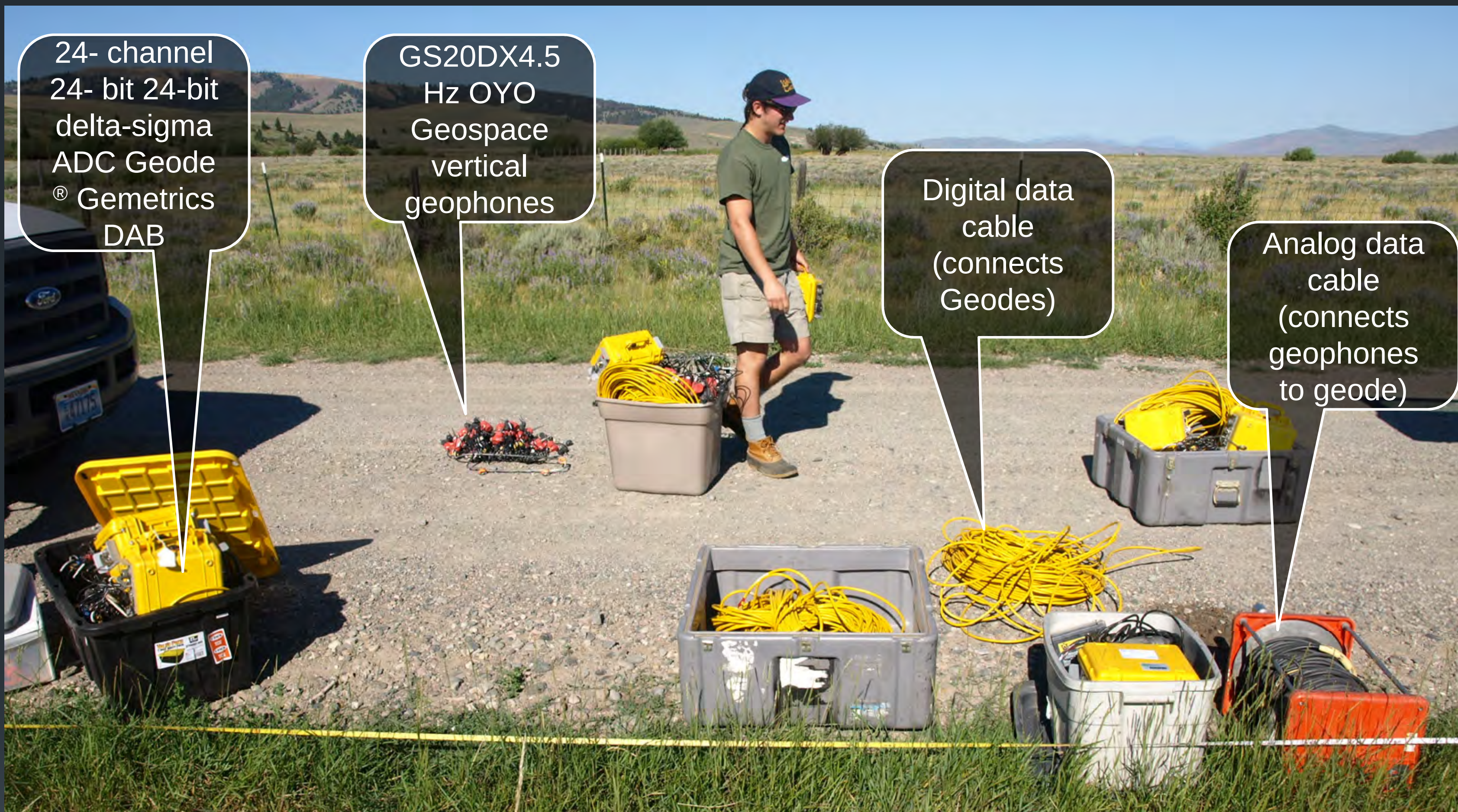
  2 linear sweeps from 5 to200 Hz, with 15 s. duration

  listening time: 16.5 s

dense wide aperture seismic array



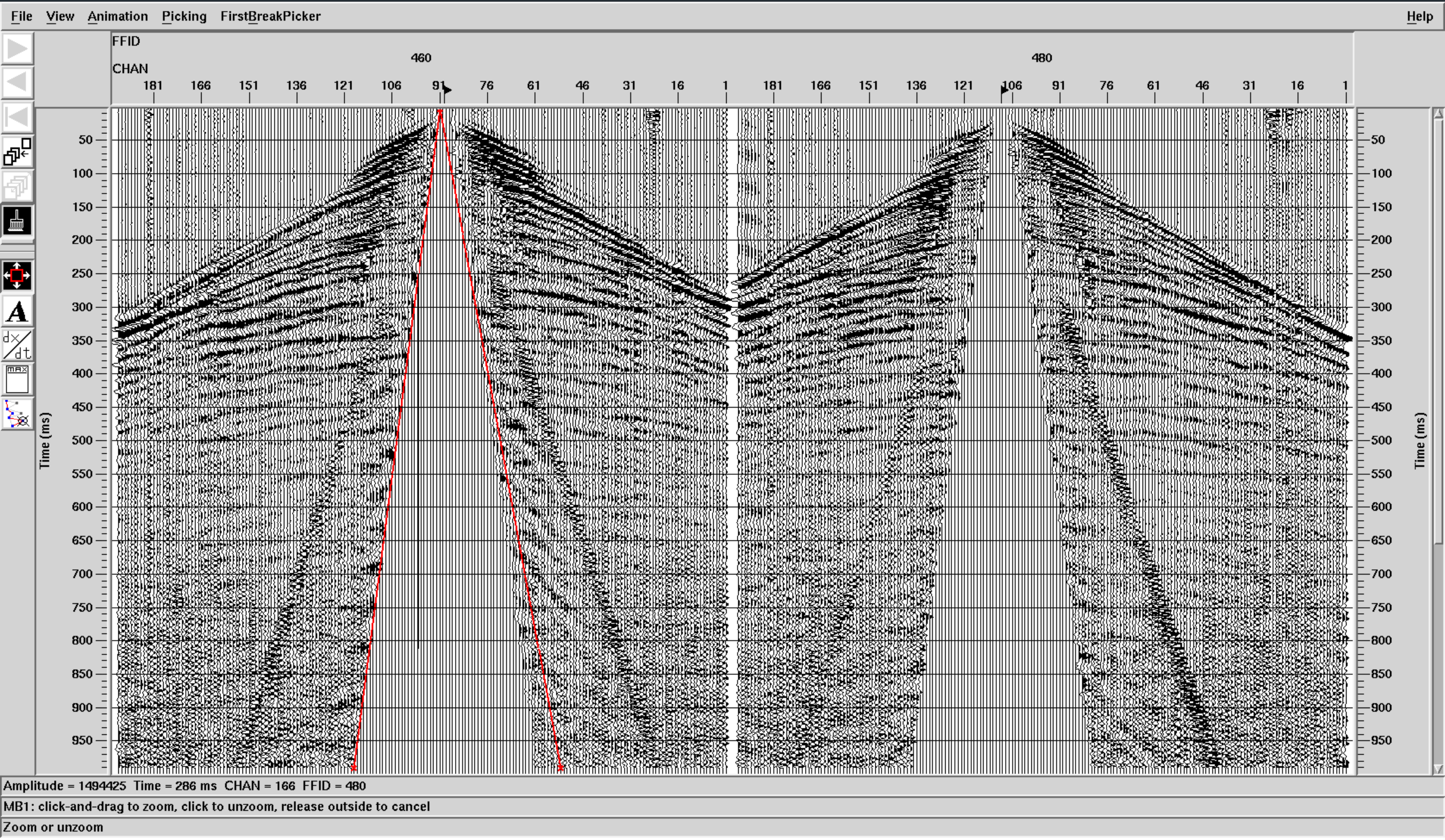
Setting up the seismic array



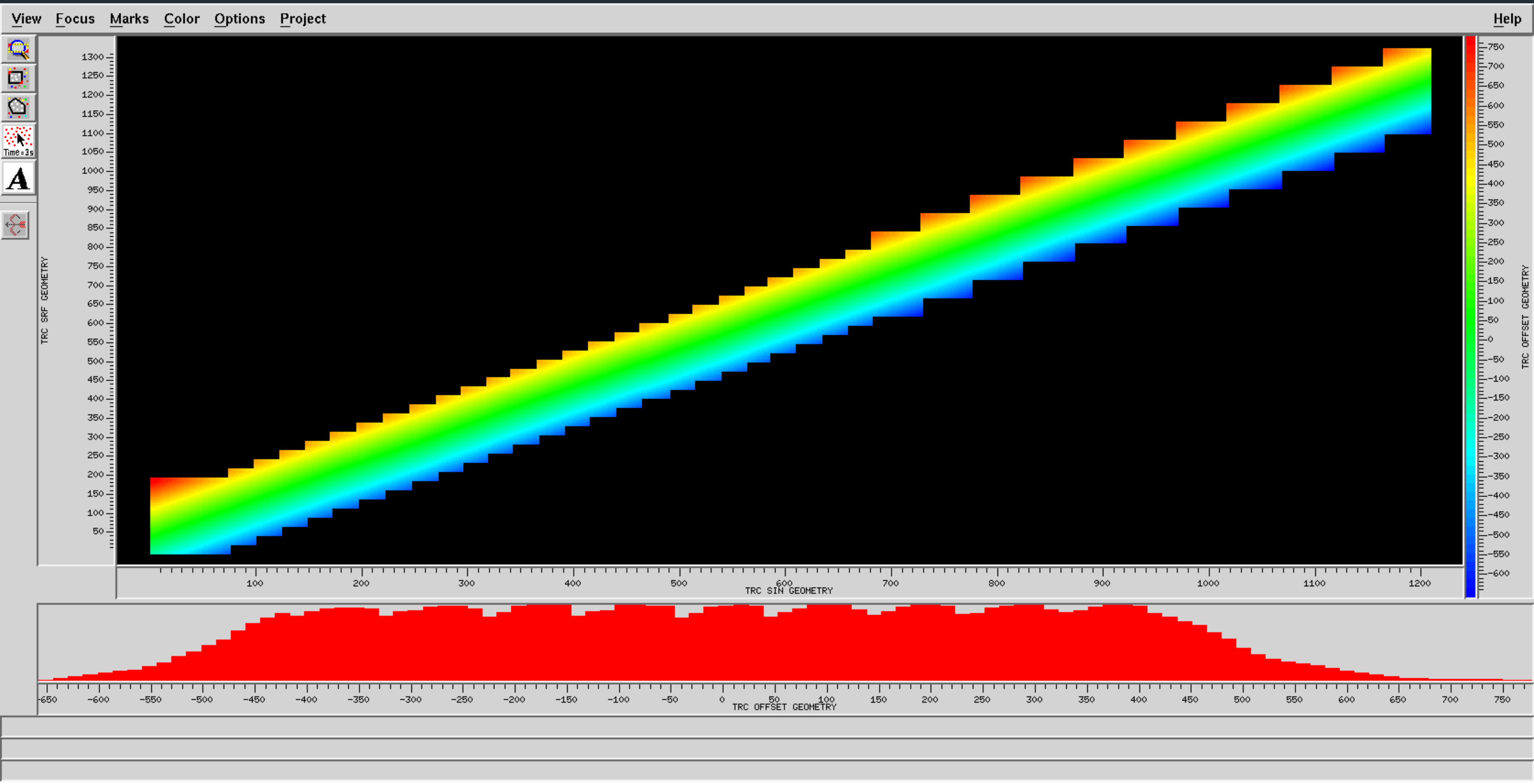
We used 168 vertical geophones spaced of 5 m, for a total active array length of 835m

ULNV T7000 minivib

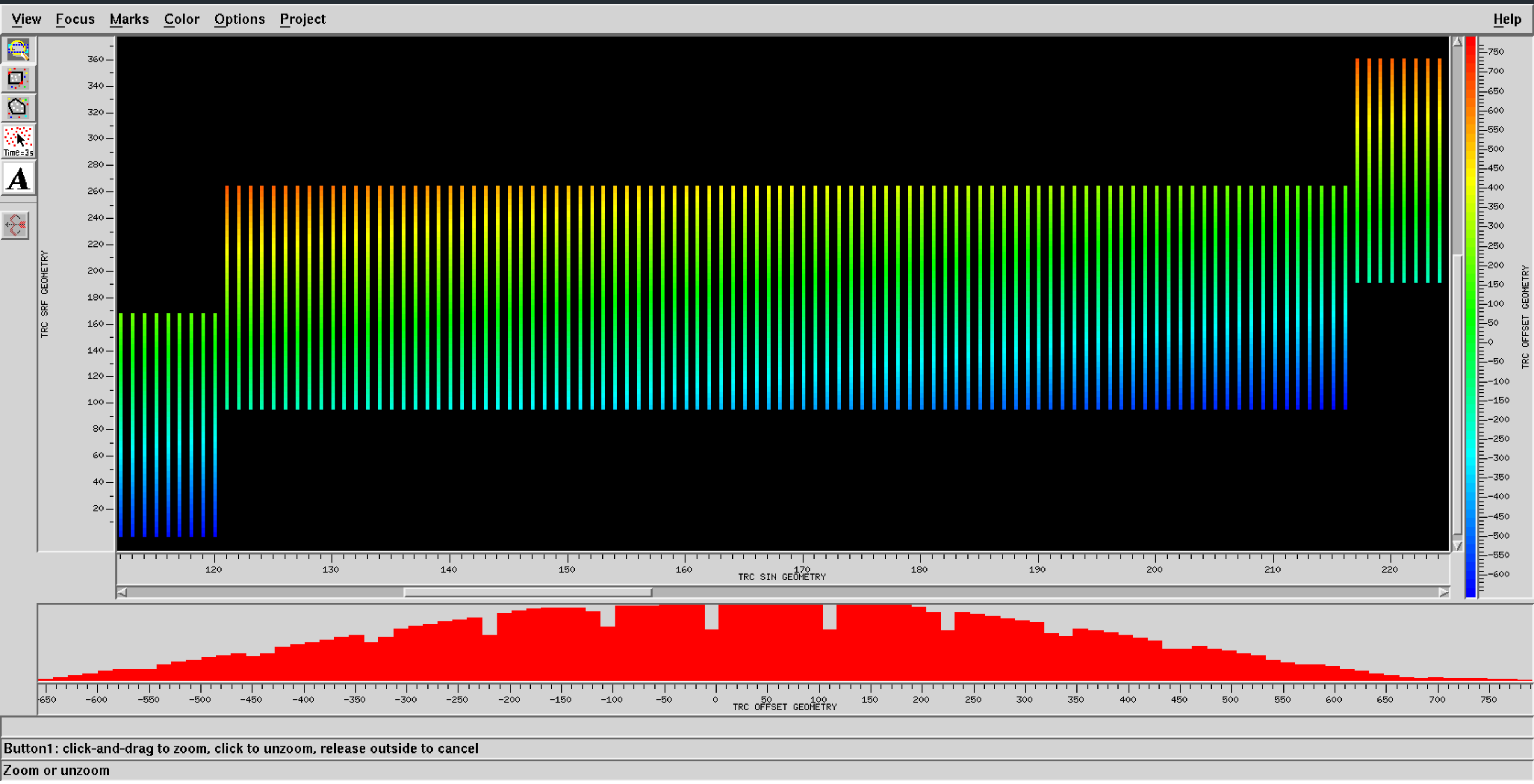
example of shot records (Hansel Valley)



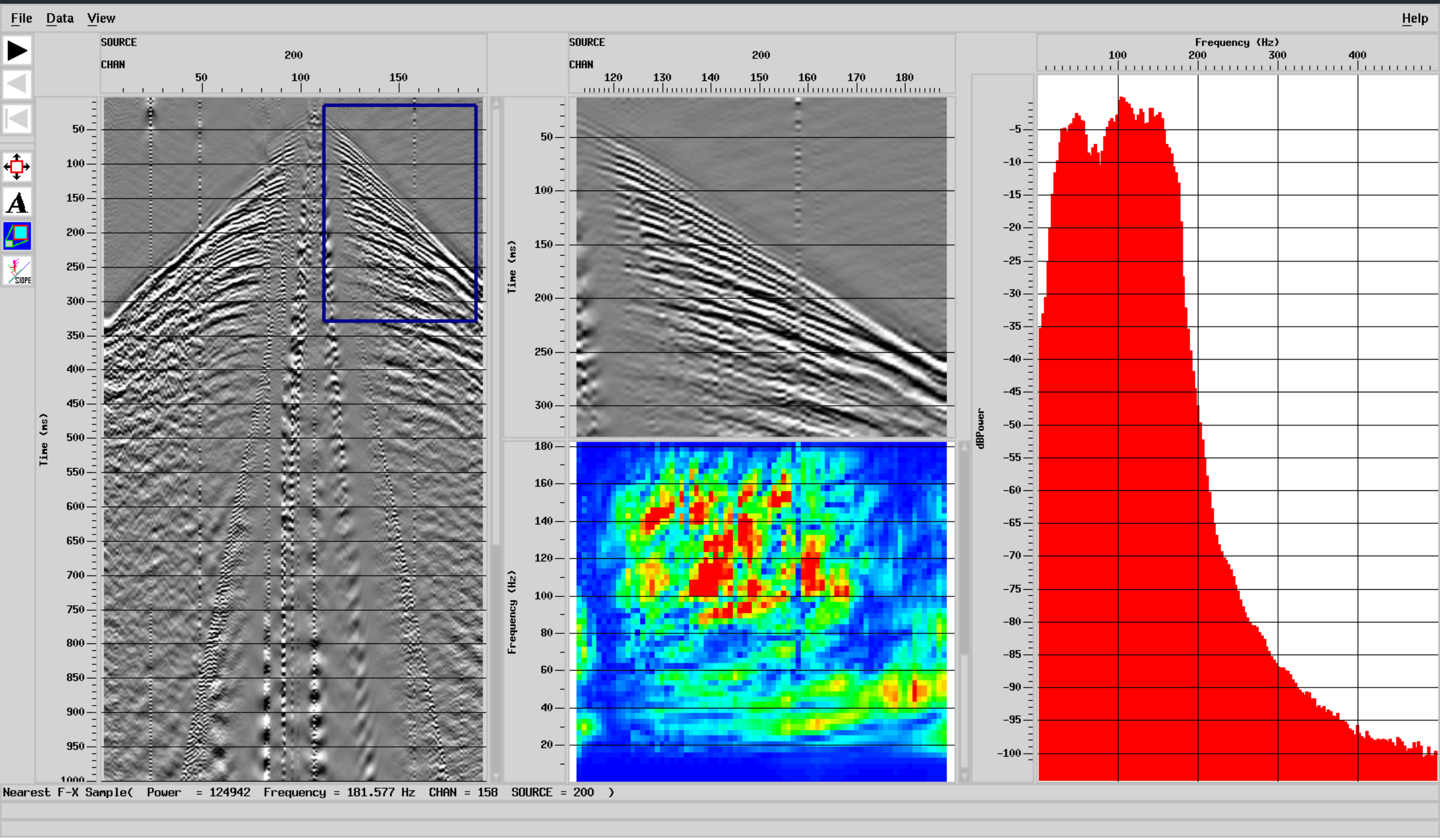
Source-Receiver-Offset Chart (Hansel Valley)



Source-Receiver-Offset Chart (Centennial)



Frequency content (Hansel Valley)



Participants

University of Utah

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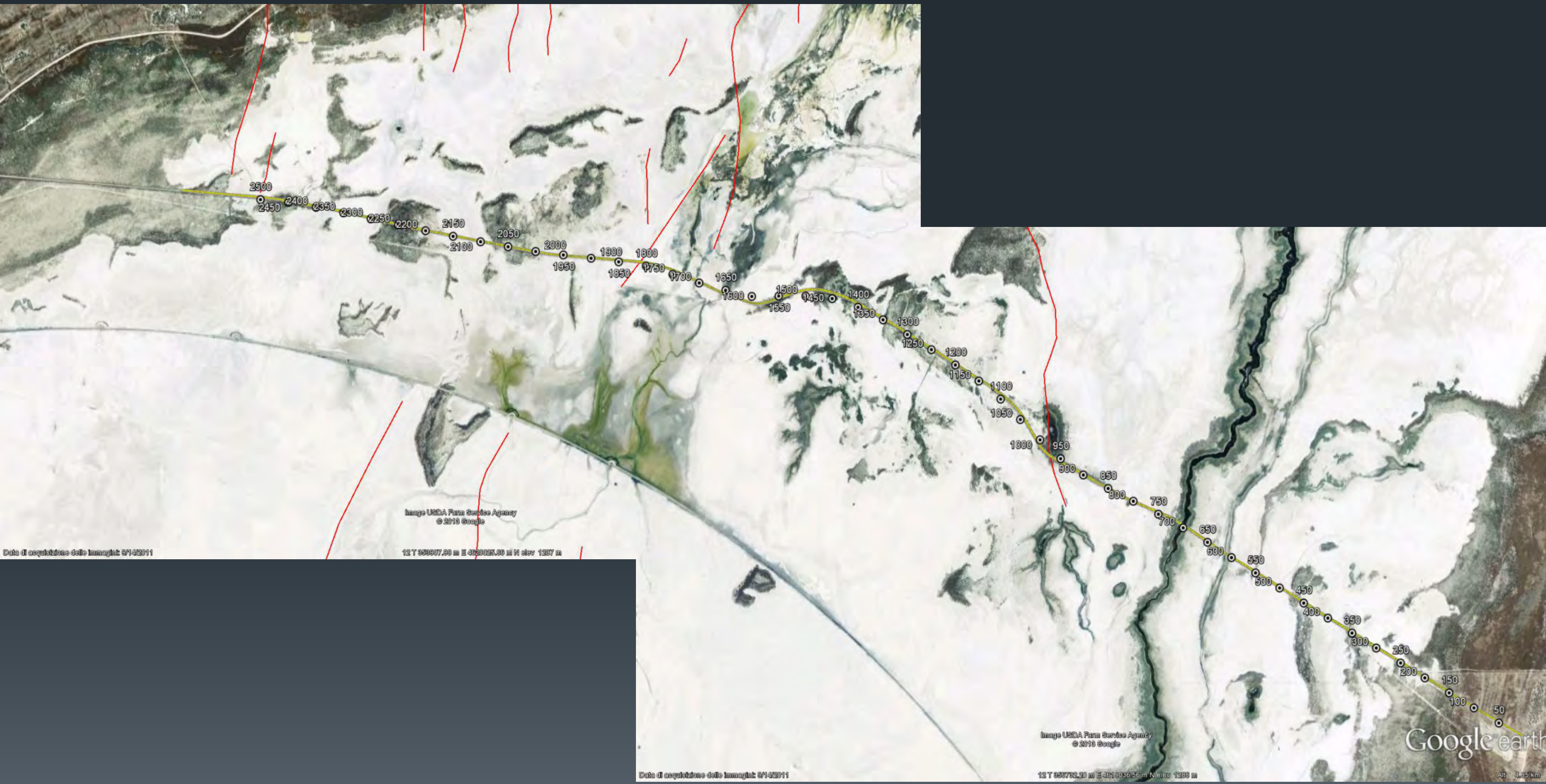
University of Nevada Las Vegas

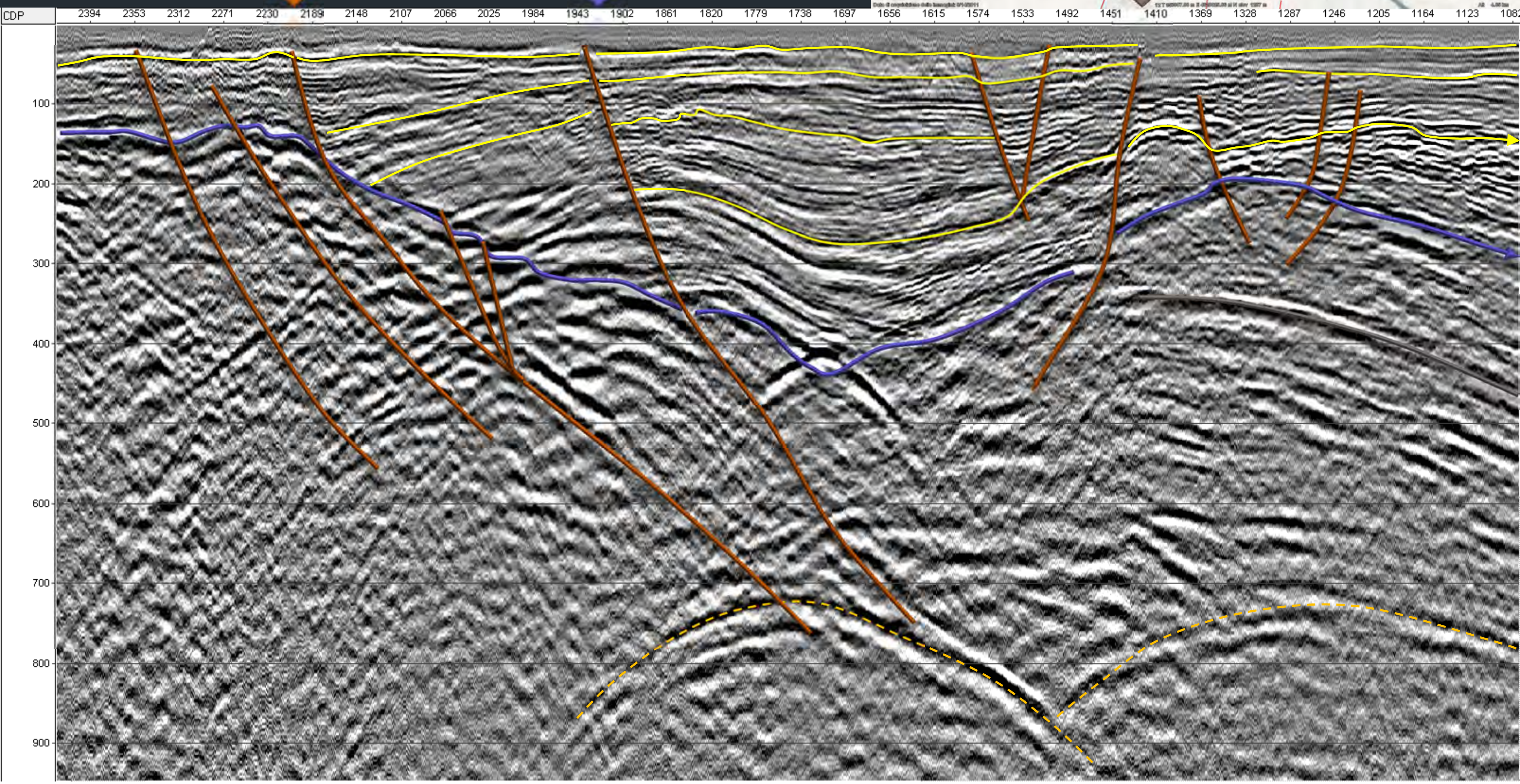
Chris Cothrun
Pinthep Kittipongdaja

Hansel Valley profile location

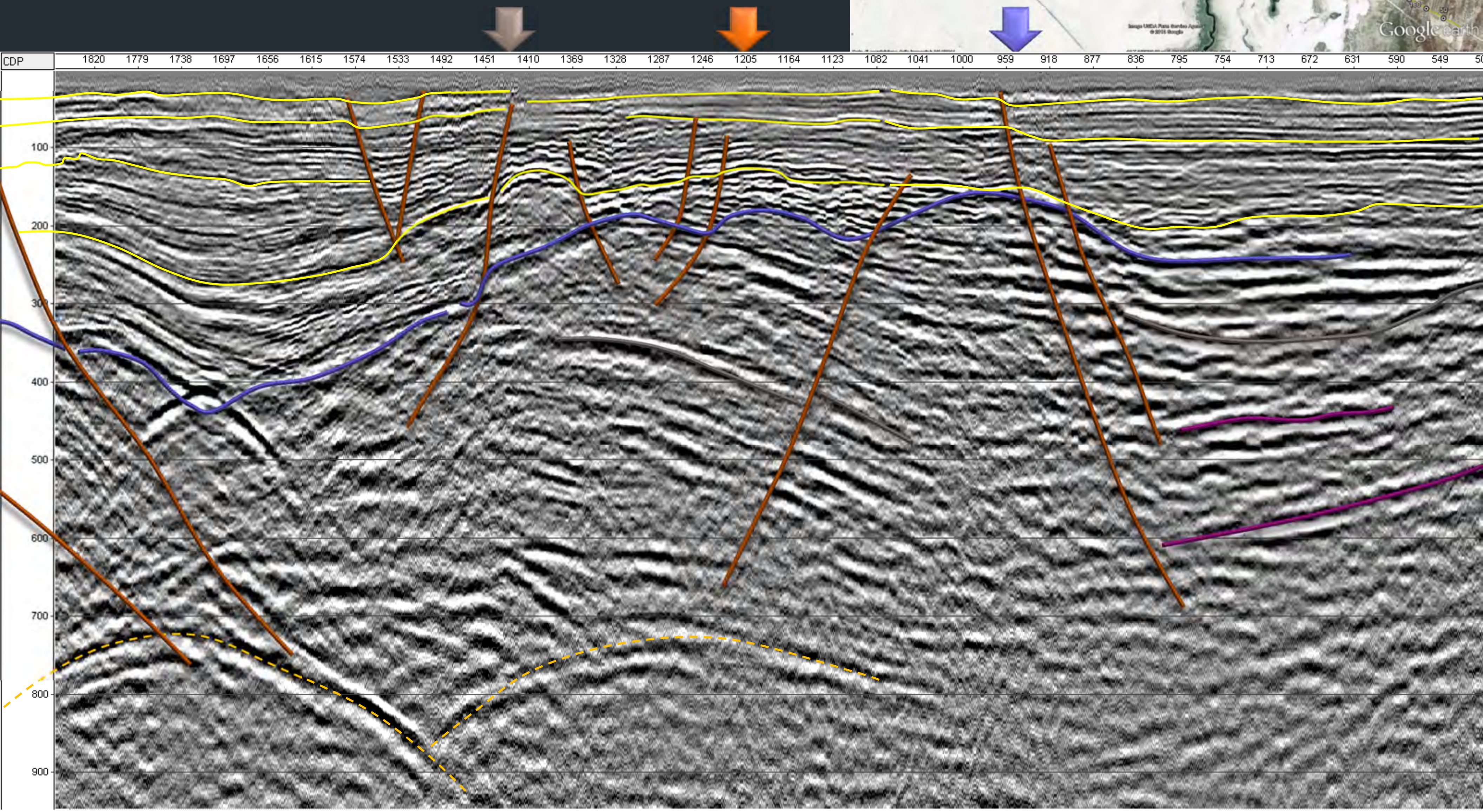
Hansel Valley profile location



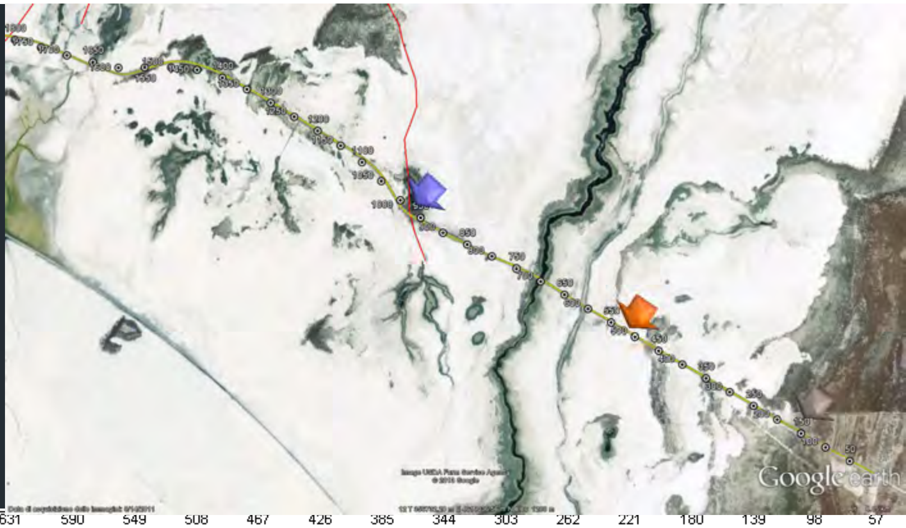
Hansel Valley profile
Zoom to the west

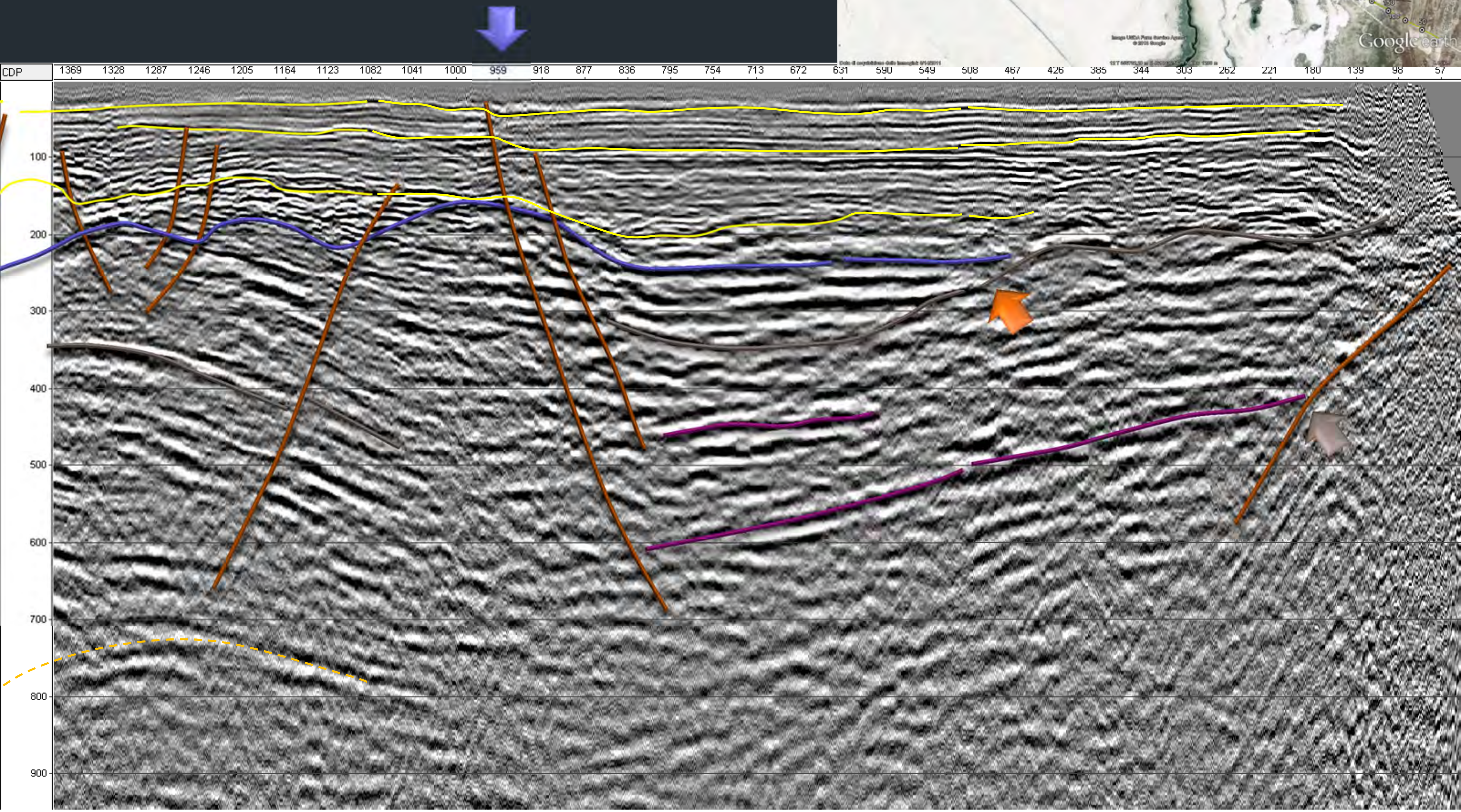


Hansel Valley profile centre

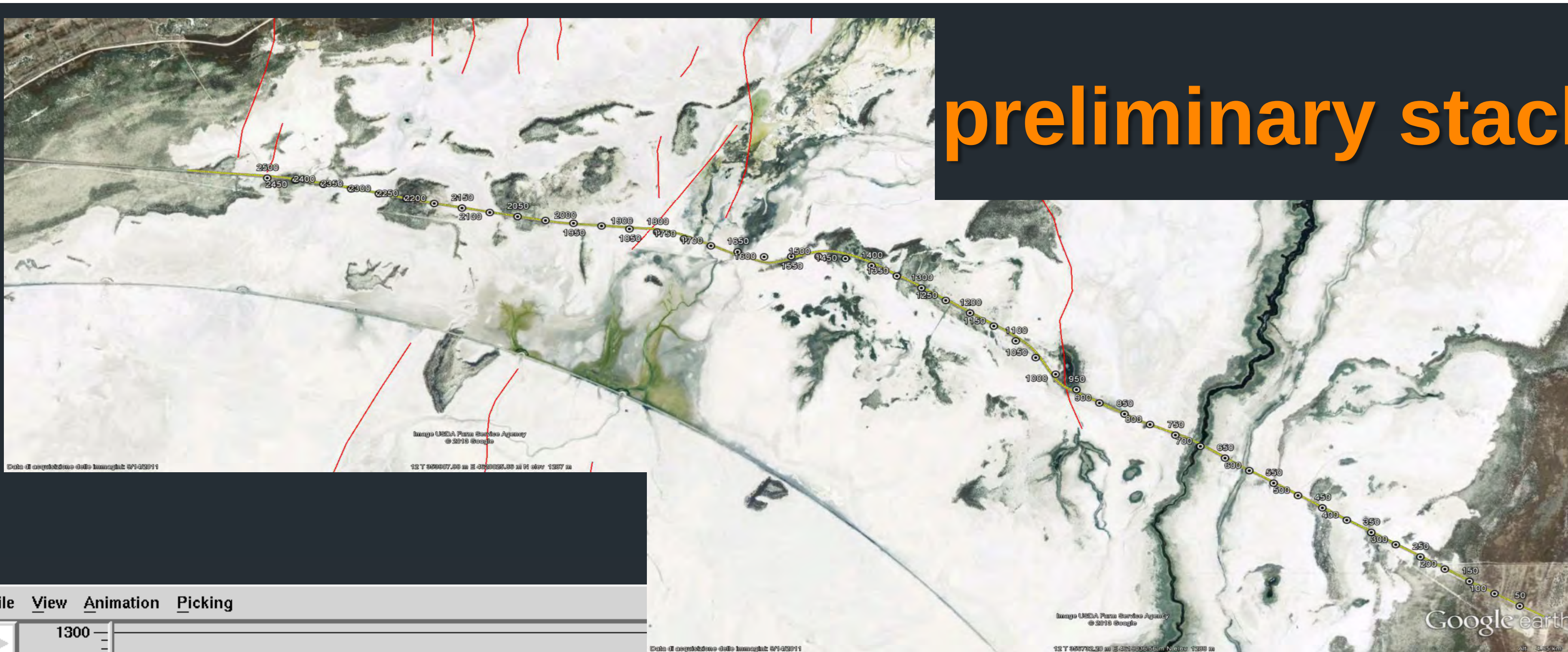


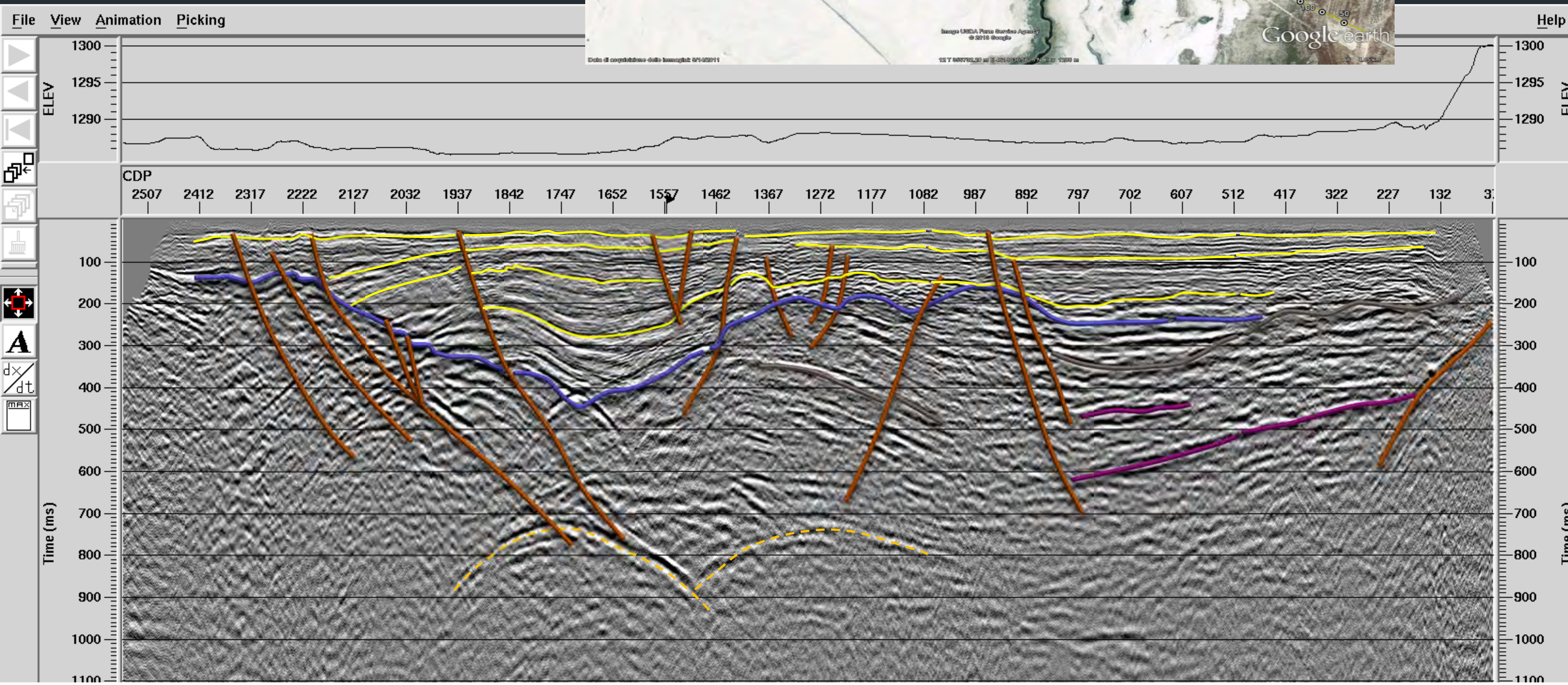
Hansel Valley profile eastern side





preliminary stack



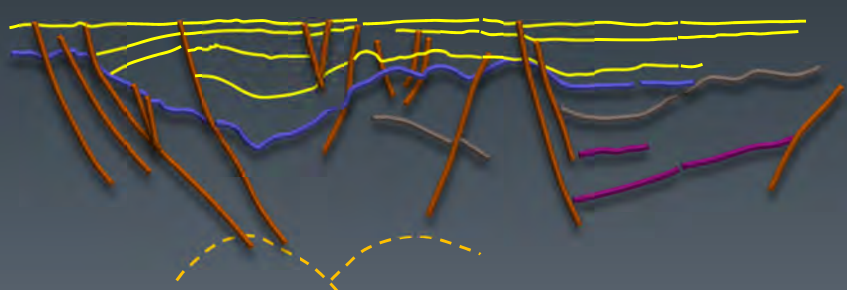


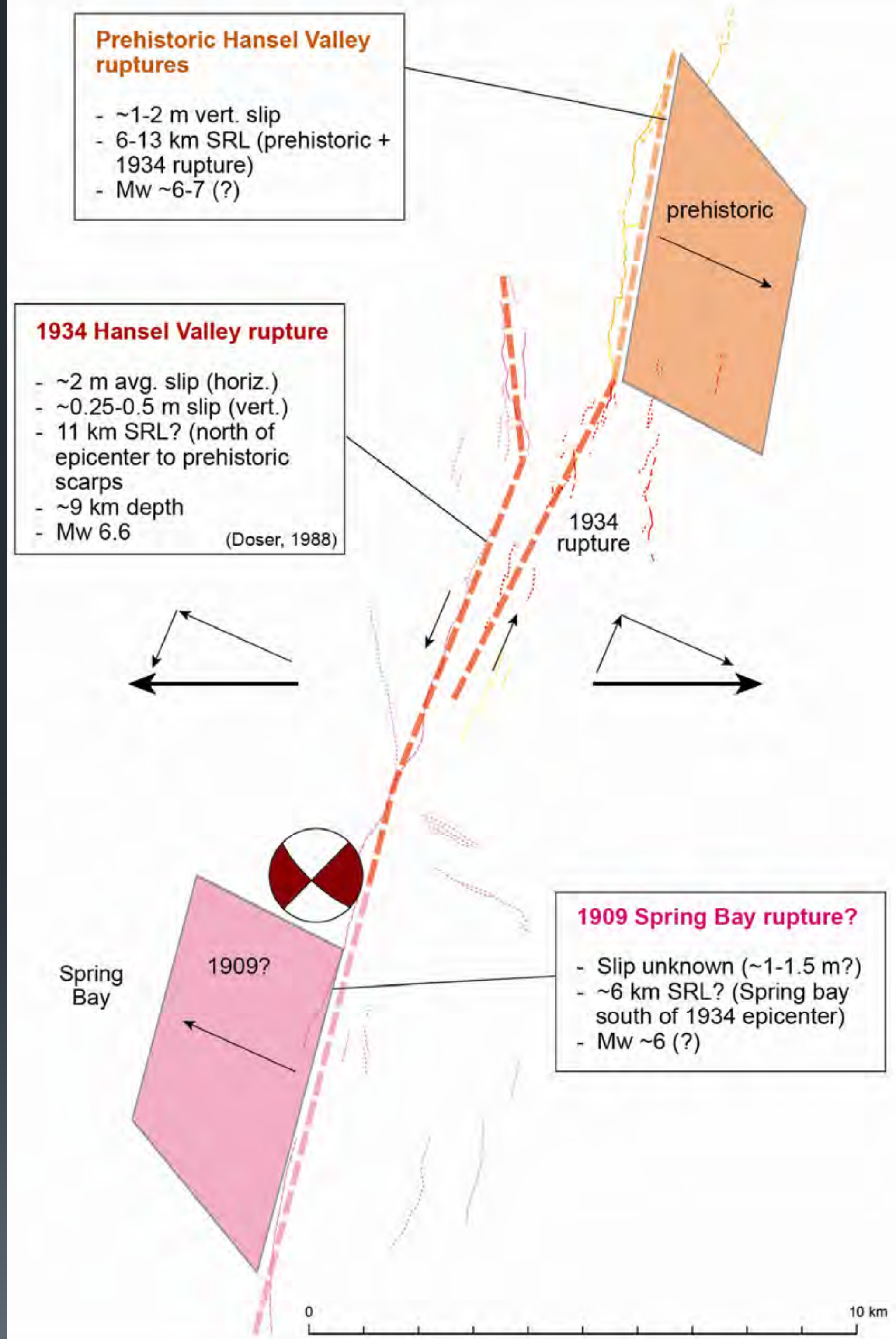
conclusions

- the clear evidence of faulting in the basin should put to rest a hypothesis that surface faulting in the 1934 earthquake was actually related to liquefaction-induced settlement rather than tectonic faulting.

- the preliminary stack shows evidence of variation of fault throw with depth (e.g. evidence multiple earthquakes)

- Possible kinematic model: the 1934 earthquake was a dominantly strike-slip event that released strain accumulated between two normal faults.



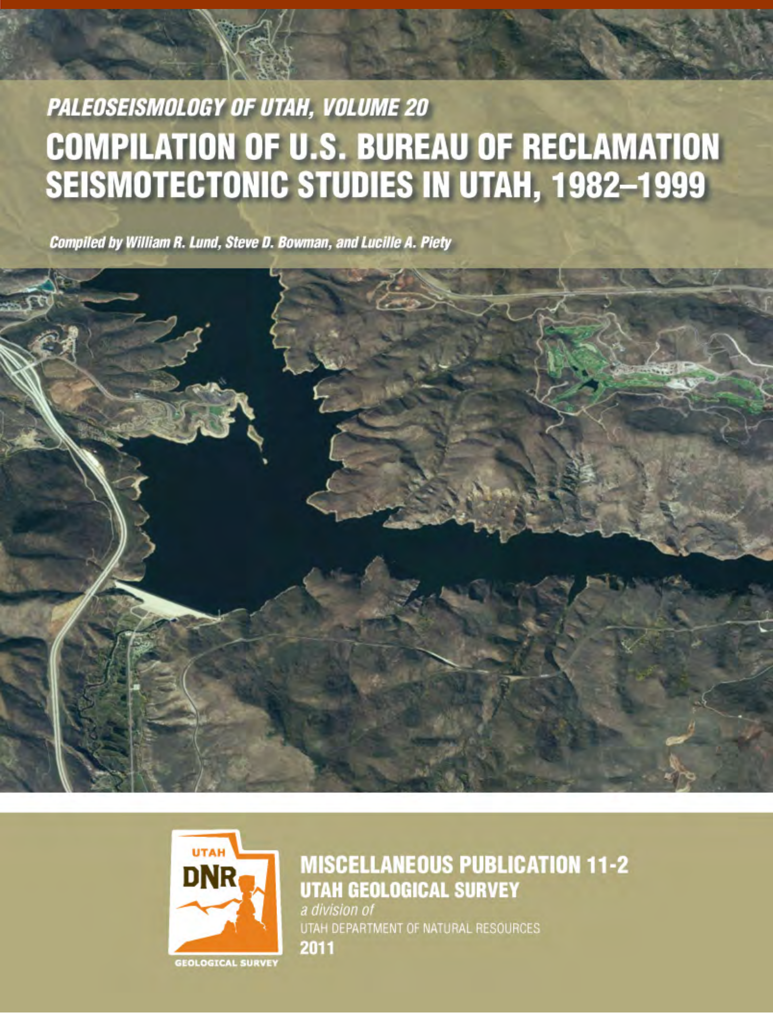


Utah Paleoseismic-Related USGS NEHRP FTR Report Compilation and Some New Data Resources

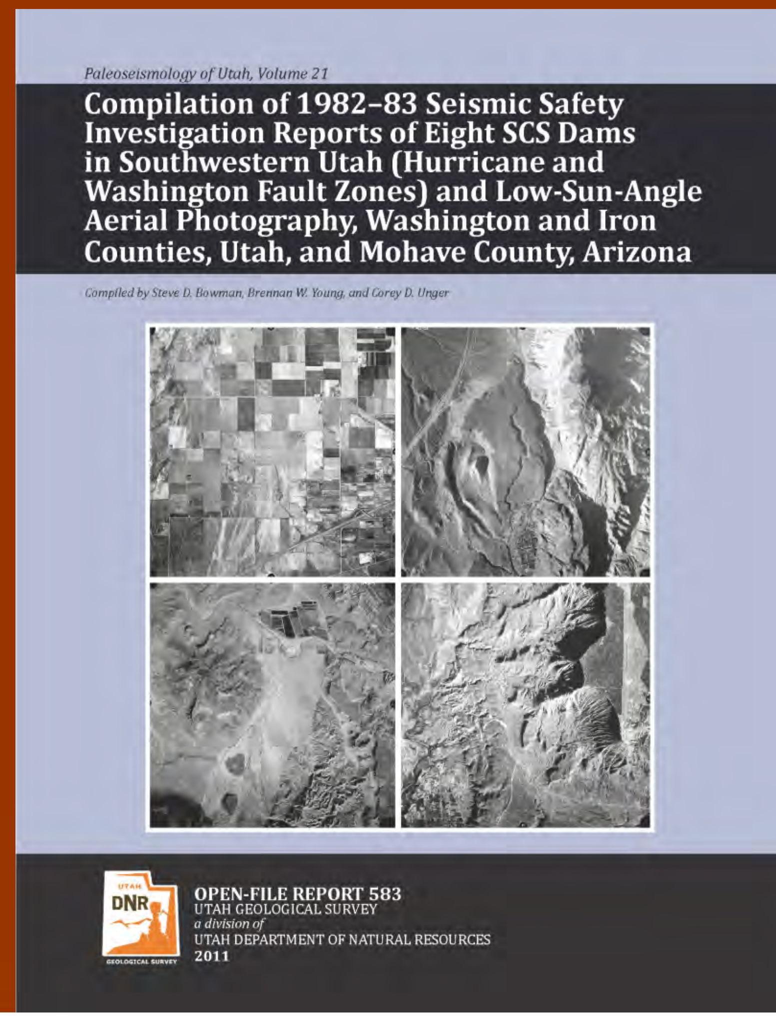
Steve D. Bowman
Utah Geological Survey
Geologic Hazards Program Manager

UGS Paleoseismology of Utah Series

- The UGS has published 22 paleoseismic-related reports.
  - Two are compilations of historical reports.



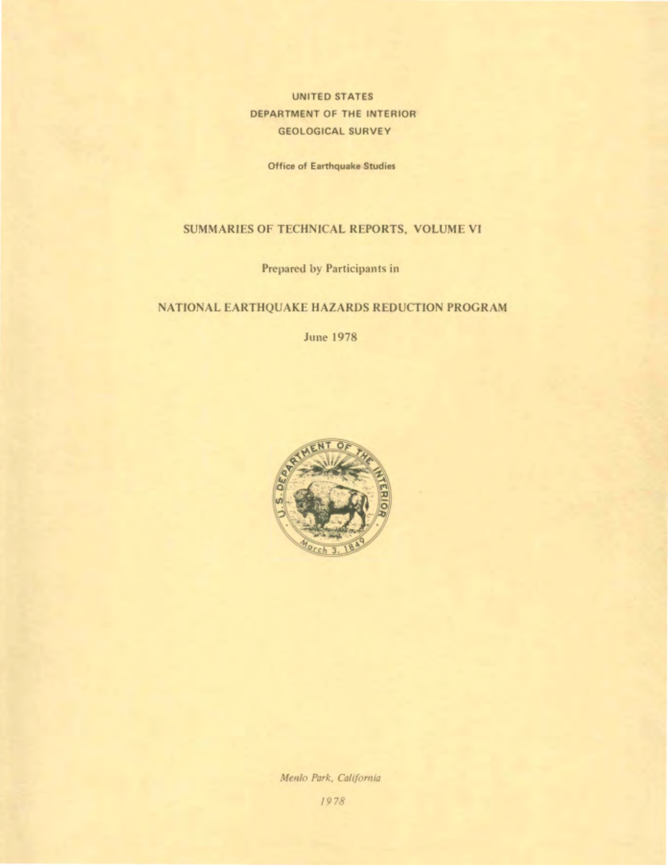
Volume 20



Volume 21

UGS Paleoseismology of Utah Series

- Many NEHRP Final Technical Reports (FTR) are not easily accessible.
  - 2000-current: Available on USGS website
  - Prior to 2000: Very limited availability
- NEHRP Summaries of FTR Volumes
  - Published between 1976 and 1995 by the USGS
  - Available as OFRs starting at Volume 9, online starting at Vol. 19



UTAH DNR GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY

WCC, 1975

STUDY OF
EARTHQUAKE RECURRENCE INTERVALS
on the
WASATCH FAULT, UTAH

Sponsored by the
U.S. Geological Survey
Contract No. 14-08-001-14567

WESTERN REGION
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS & ENVIRONMENTAL SCIENTISTS

Swan and others, 1979

Woodward-Clyde Consultants

STUDY OF
EARTHQUAKE RECURRENCE INTERVALS ON
THE WASATCH FAULT, UTAH

THIRD SEMI-ANNUAL TECHNICAL REPORT
October, 1979

By
Swan, III, David P. Schwartz, Lloyd S. Cluff,
athryn L. Hanson, and Peter L. Knuepfer

Sponsored By The
U.S. Geological Survey
Contract No. 14-08-0001-16827

d discussions in this document are those of
and should not be interpreted as necessarily
the official policies, either expressed or
the U.S. Government.

McCalpin, 1985

QUATERNARY FAULT HISTORY AND EARTHQUAKE POTENTIAL OF THE
HANSEL VALLEY AREA, NORTH-CENTRAL UTAH: FINAL TECHNICAL REPORT

BY JAMES McCALPIN

Olig, 1999

MAPPING AND QUATERNARY FAULT SCARP ANALYSIS
OF THE MERCUR AND WEST EAGLE HILL FAULTS,
WASATCH FRONT, UTAH

Revised from original application title:

LEOSEISMIC INVESTIGATION OF THE MERCUR FAULT AND ITS
LICATIONS TO SEISMIC HAZARD ALONG THE WASATCH FRONT
URBAN COORIDOR

Submitted to:

U.S. Geological Survey

National Earthquake Hazards Reduction Program
Award No. 1434-HQ-97-GR-03154

Program Elements I and II

Submitted by:

URS GREINER WOODWARD CLYDE

Principal Investigator: Susan S. Olig
Assisted By: Andrew E. Gorton and Lori Chadwell

June 16, 1999

h supported by the U.S. Geological Survey (USGS) Department of the Interior, under
ward number 1434-HQ-97-GR-03154. The views and conclusions contained in this
nt are those of the authors and should not be interpreted as necessarily representing
ial policies, either expressed or implied, of the U.S. Government.

Paleoseismic USGS NEHRP Reports

- We have acquired and scanned 16 NEHRP FTR reports (1975 – 2012) for projects not previously published by the UGS.
- Summaries of FTR Volumes 1 to 18 (1976 – 1984) scanned.
- Missing Report
  - Hanson, K.L., Swan, F.H., and Schwartz, D.P., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah: Fifth semi-annual technical report prepared for the U.S. Geological Survey under Contract No. 14-08-001-19115 by Woodward-Clyde Consultants, San Francisco, California, 21 p.

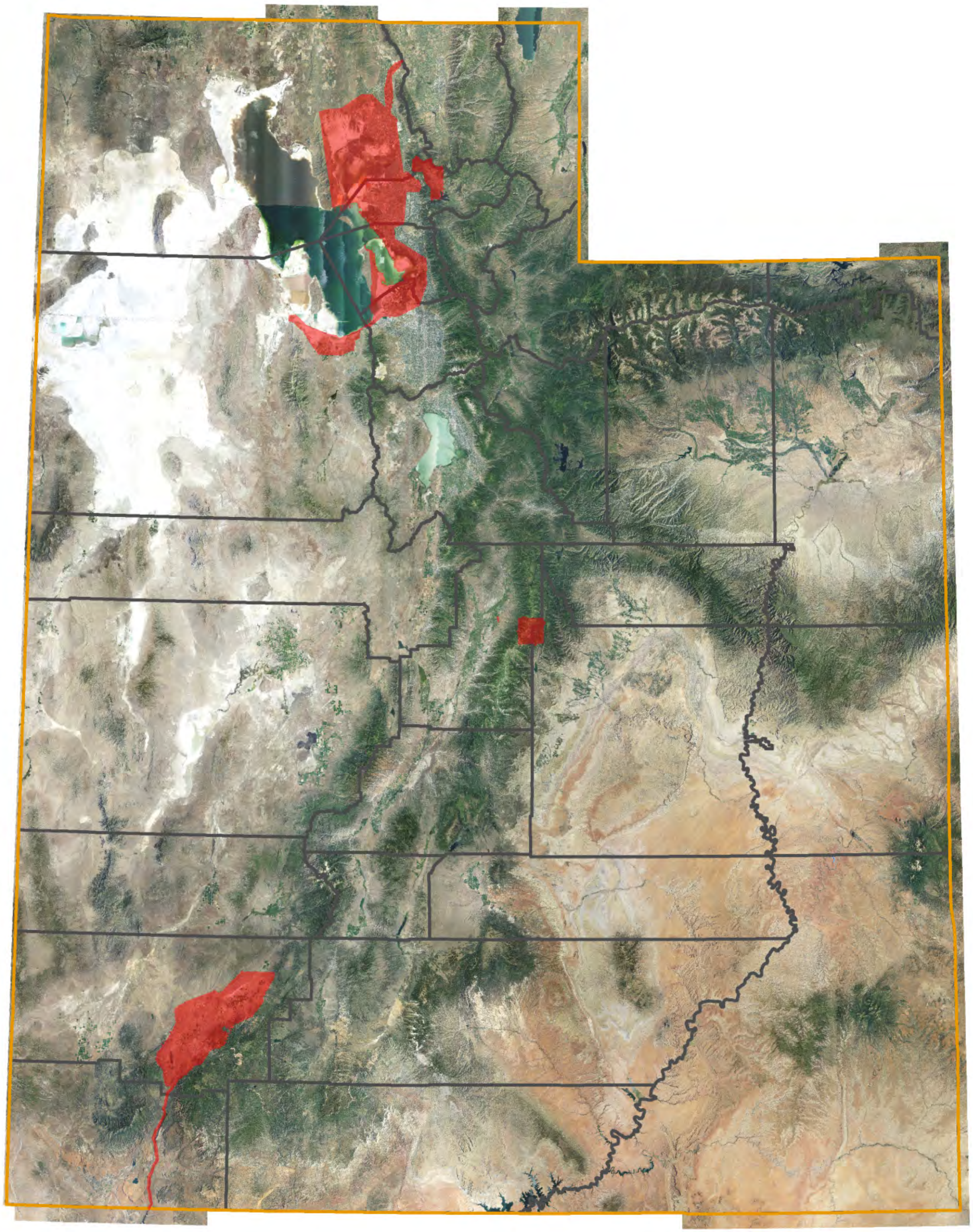
UTAH GEOLOGICAL SURVEY

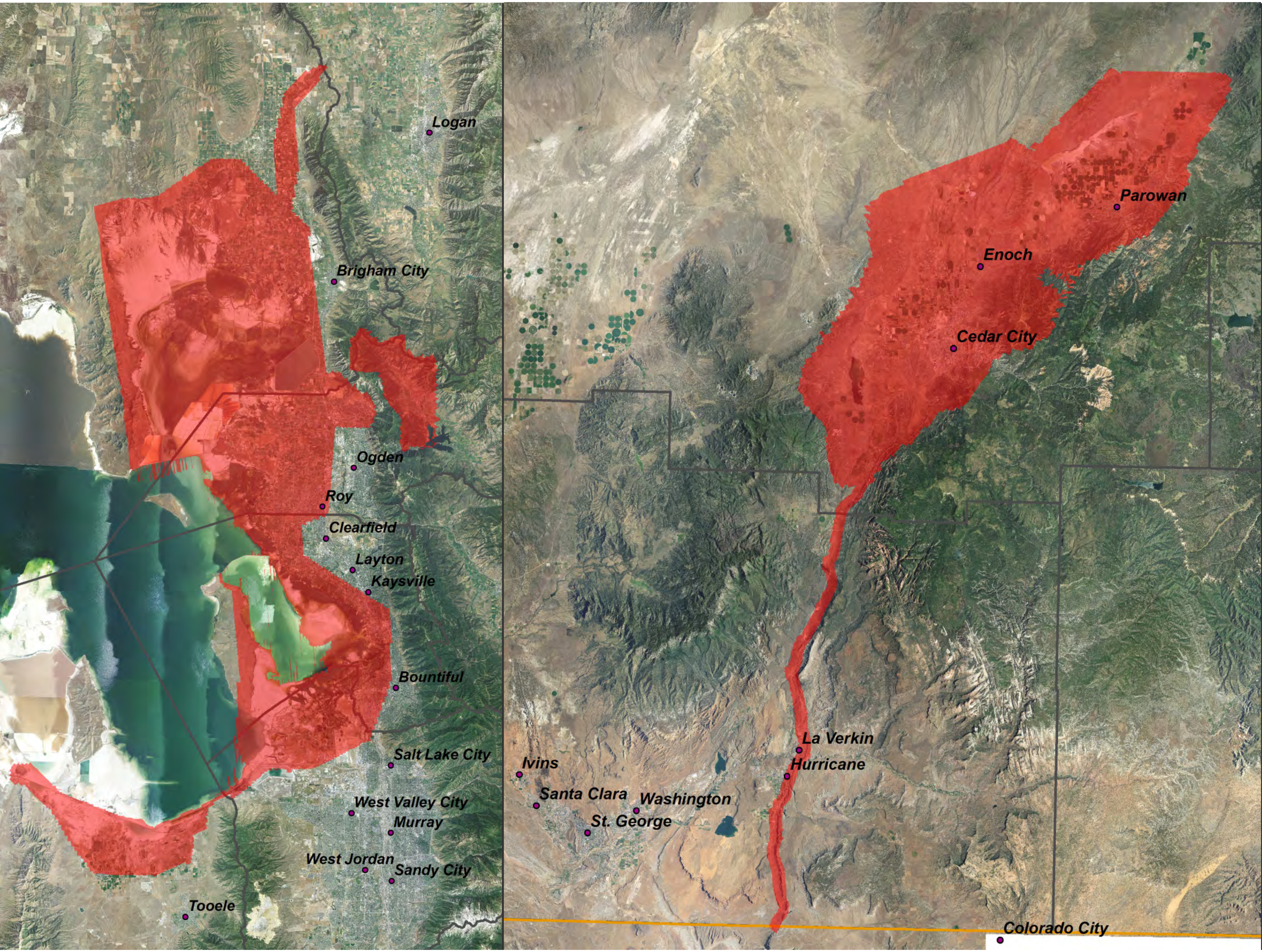
2011 UGS 1 m LiDAR Acquisition

- Hurricane Fault
- East Great Salt Lake
- West half of Ogden Valley
- Southern Great Salt Lake
- Cedar & Parowan Valleys
- North Odgen (FEMA/UDEM)
- Wasatch Plateau (Lowry Water area)

1867 square miles (4913 km^2)

Raw, DEM, and DSM data available shortly.




Logan
Brigham City
Ogden
Roy
Clearfield
Layton
Kaysville
Bountiful
Salt Lake City
West Valley City
Murray
West Jordan
Sandy City
Tooele
Parowan
Enoch
Cedar City
La Verkin
Hurricane
Ivins
Santa Clara
Washington
St. George
Colorado City

2011 LiDAR Data

- DEM data available from AGRC in March-April, 2013.
- All data, including raw data, to be available from OpenTopography (http://opentopography.org) this spring.

UTAH GEOLOGICAL SURVEY

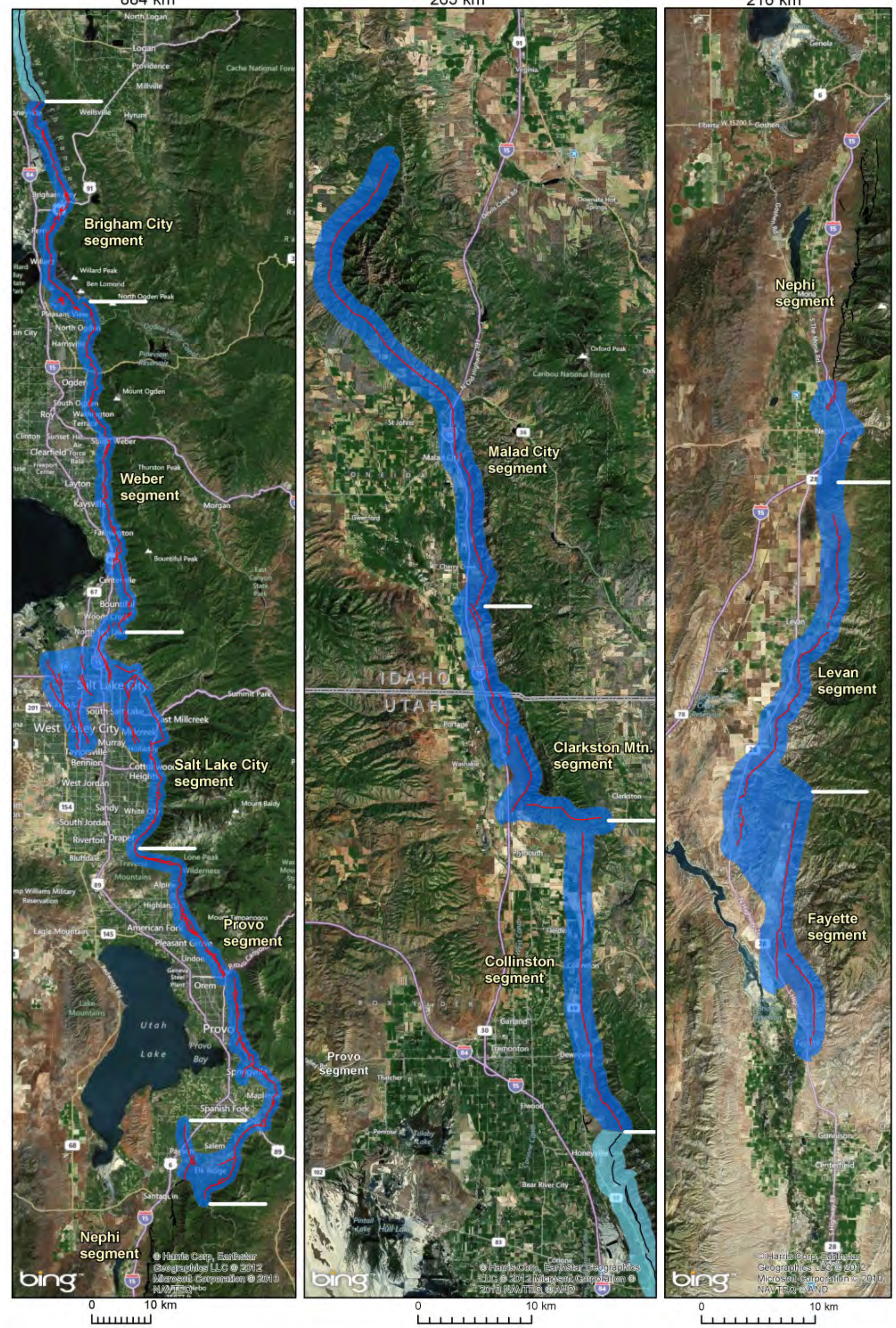
Proposed UGS Wasatch Fault LiDAR Acquisition Plan

- 1365 km² for the entire fault
- 1 meter data
  - At ~$330/mi² = $174k
- 1 km footwall buffer
- 1.5 km hanging wall buffer

- LiDAR data will be used to:
  - Improve fault mapping for
    - Utah/USGS fault database
    - Geologic and hazard maps
    - Special study zones
  - Provide pre-rupture topography
  - Identify potential paleoseismic trench sites

High-Resolution LiDAR Wasatch Fault Zone Phases

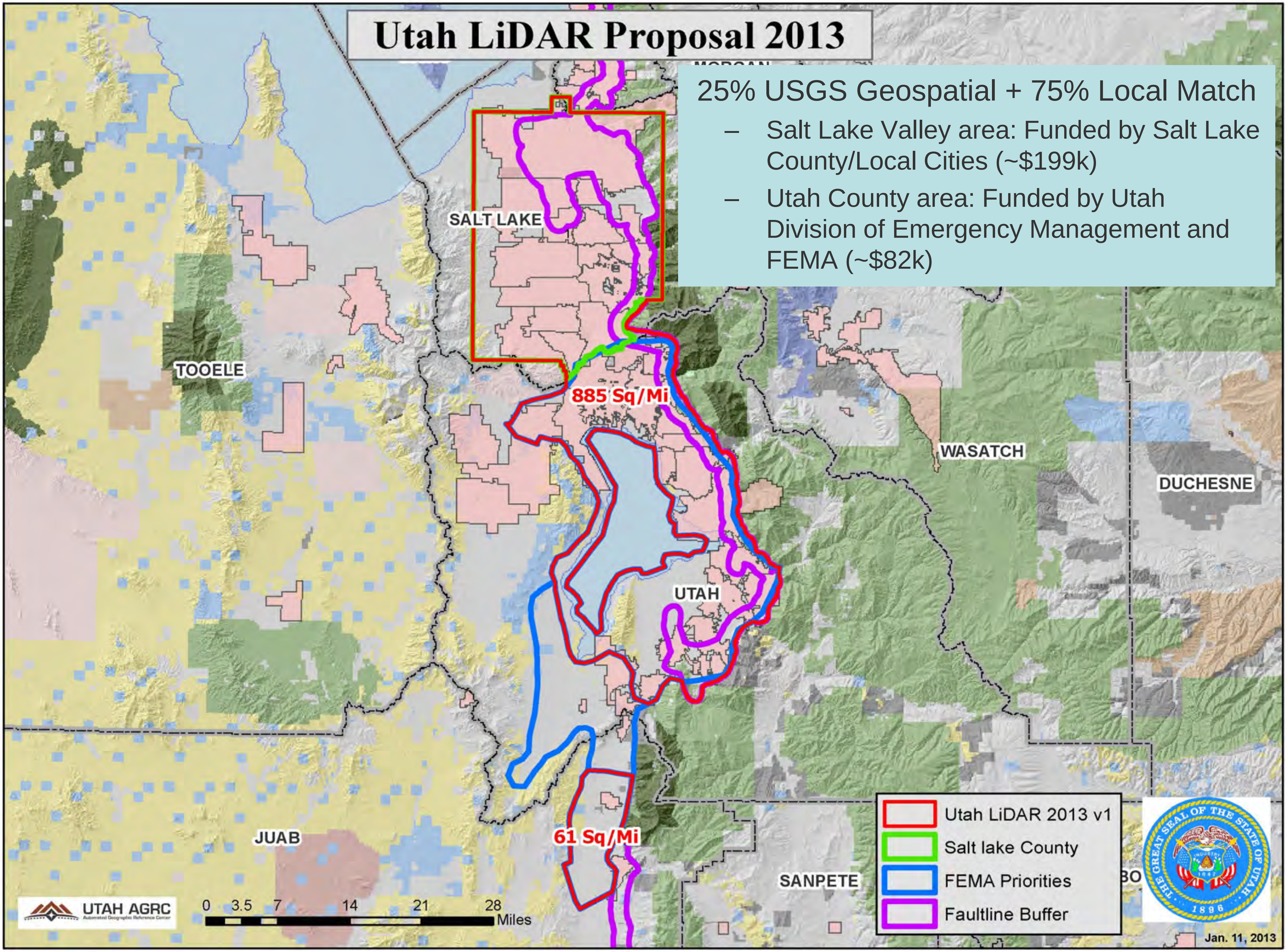
Phase 1: Central Segments 884 km²
Phase 2: Northern Segments 265 km²
Phase 3: Southern Segments 216 km²



 1365 km^2

Proposed 2013 Wasatch Front LiDAR Acquisition Partnership

- Utah Geological Survey
- Salt Lake County Surveyor's Office
- Salt Lake Valley Cities
- Utah Division of Emergency Management and FEMA
- U.S. Geological Survey
- Utah Geographic Reference Center


Utah LiDAR Proposal 2013
25% USGS Geospatial + 75% Local Match
– Salt Lake Valley area: Funded by Salt Lake County/Local Cities (~$199k)
– Utah County area: Funded by Utah Division of Emergency Management and FEMA (~$82k)
SALT LAKE
TOOELE
885 Sq/Mi
WASATCH
DUCHESNE
UTAH
JUAB
61 Sq/Mi
SANPETE
Utah LiDAR 2013 v1
Salt lake County
FEMA Priorities
Faultline Buffer
UTAH AGRC
0 3.5 7 14 21 28 Miles
THE GREAT SEAL OF THE STATE OF UTAH
1896
Jan. 11, 2013

UTAH GEOLOGICAL SURVEY

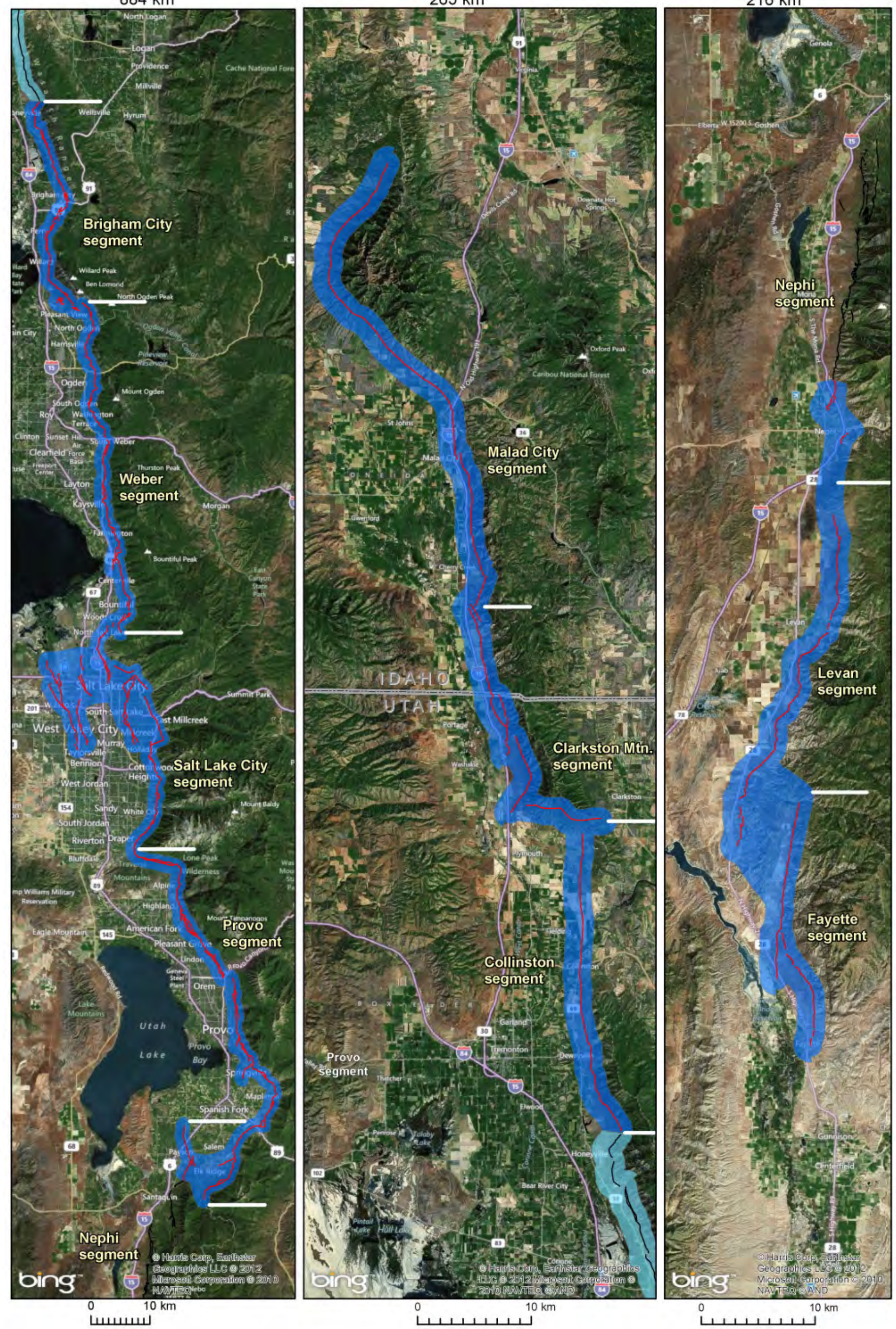
Proposed Wasatch Fault LiDAR Acquisition

- Segments Potentially Funded
  - Salt Lake City
  - Provo
  - Weber
  - Brigham City

- Segments not Funded
  - Southern segments (~$21k)
    - Levan and Fayette
  - Northern segments (~$25k)
    - Collinston, Clarkston Mountain, and Malad City

Bottom Line = $46k needed

High-Resolution LiDAR Wasatch Fault Zone Phases



Aerial Imagery Collection

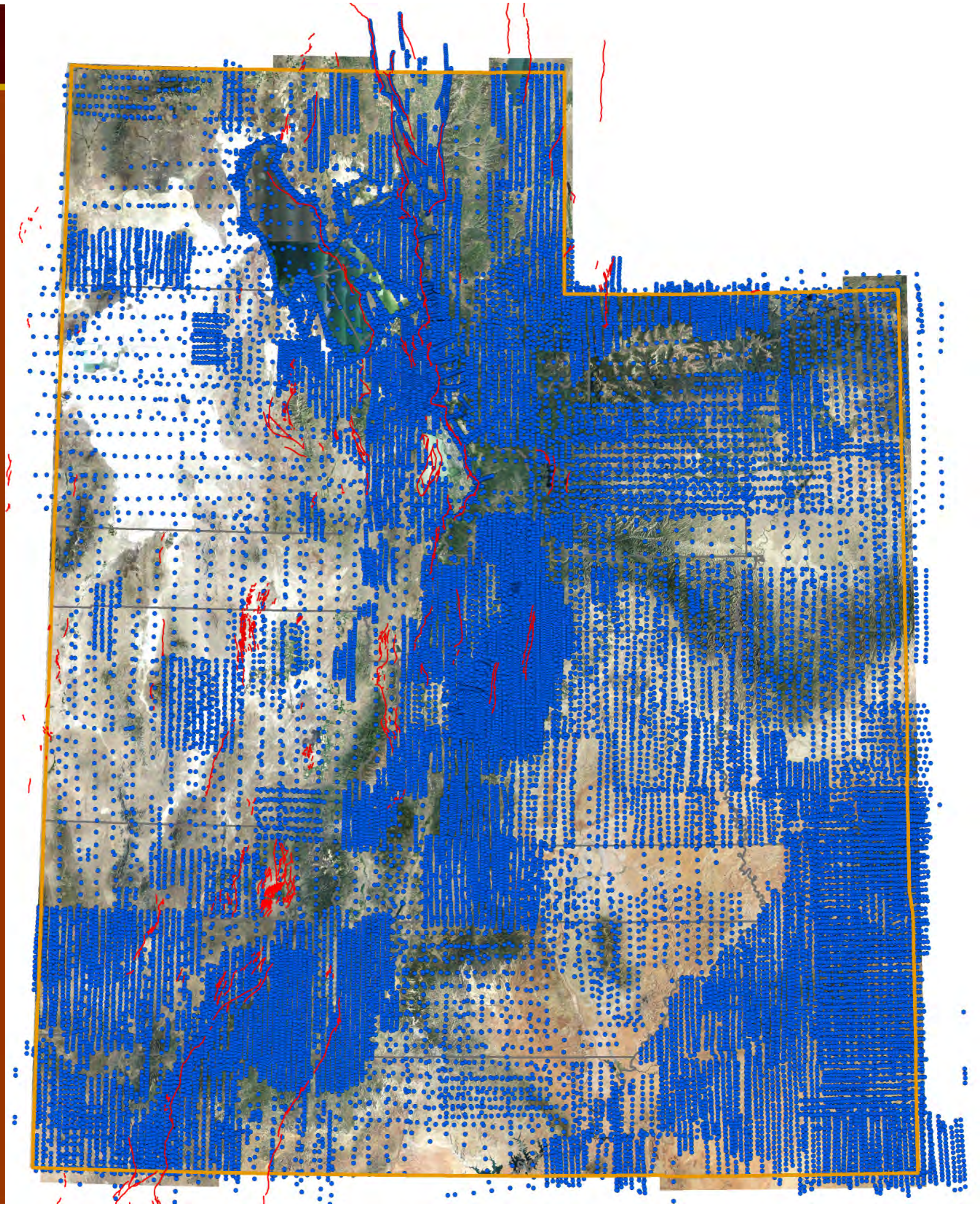
- UGS collection of about 120,000 frames from 1935 to 2002.
  - 71,800 in database (as of February 1)
  - 260 individual aerial projects

- Digitally scanned
  - Paper prints scanned at 600 or 800 (starting 2010) dpi
  - Film scanned at 1200 dpi
  - TIFF (archive) format with lossless ZIP compression

- Available online at http://geology.utah.gov/databases/imagery/.

UTAH GEOLOGICAL SURVEY

71,800 frames currently entered into the UGS Aerial Imagery database.



Aerial Imagery Collection

- Database includes a variety of metadata describing each aerial project and associated frames (photos).
  - Flight line, roll number, and frame number
  - Acquisition date and time (if available)
  - Scale
  - Type (B&W, color, color infrared)
  - Spatial location (latitude, longitude)
  - Scanner details (scanner ID, resolution, color depth, etc.)
  - Scanned material condition
  - Acquiring agency, aerial contractor
  - Other information, as available

UTAH GEOLOGICAL SURVEY

1970s Woodward-Lundgren Low-Sun-Angle Aerial Photographs
Corner Canyon Area, Draper, Utah

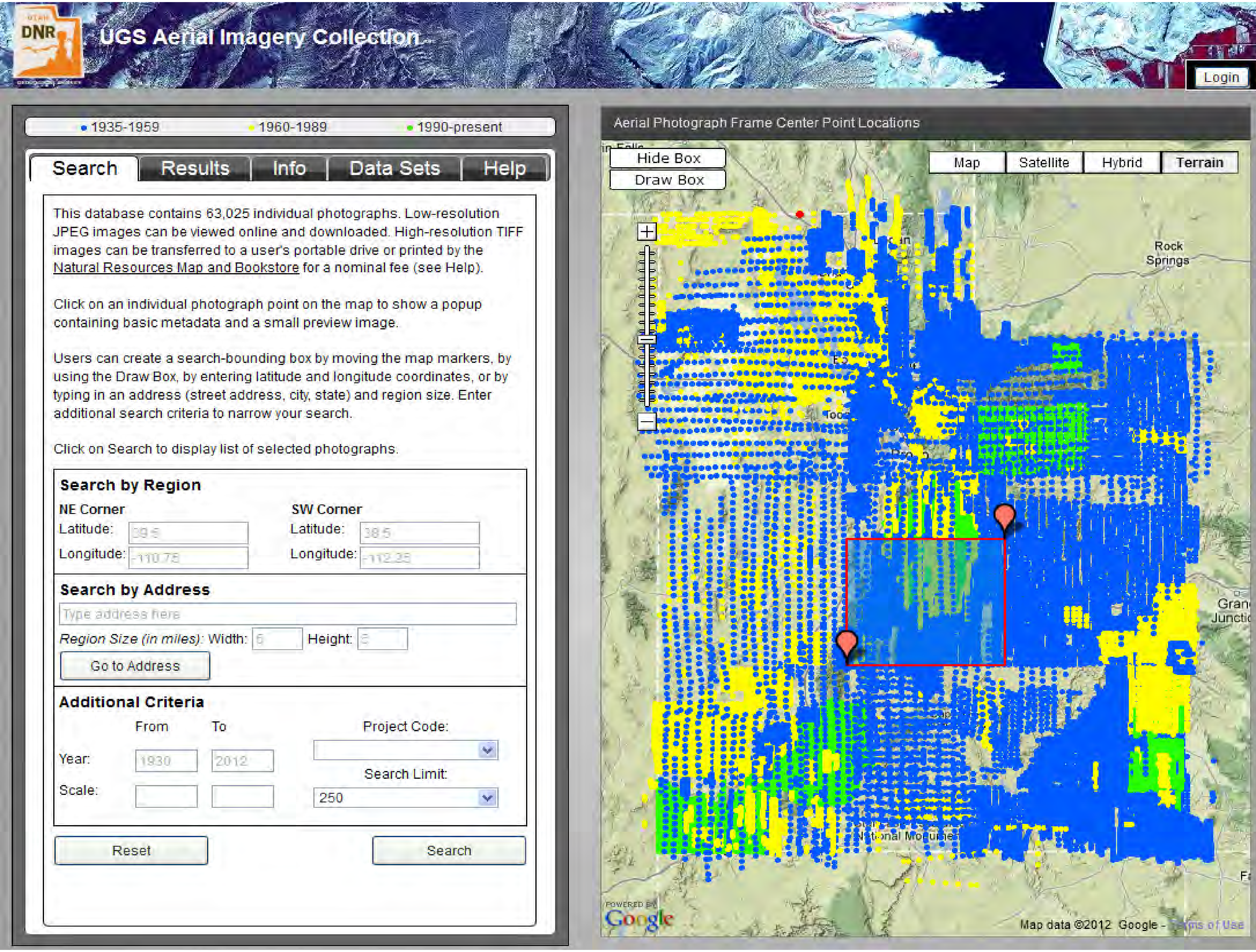
Scan From Print (600 dpi) UGS Open-File Report 548	Scan From Original Film (1200 dpi) Future UGS Publication

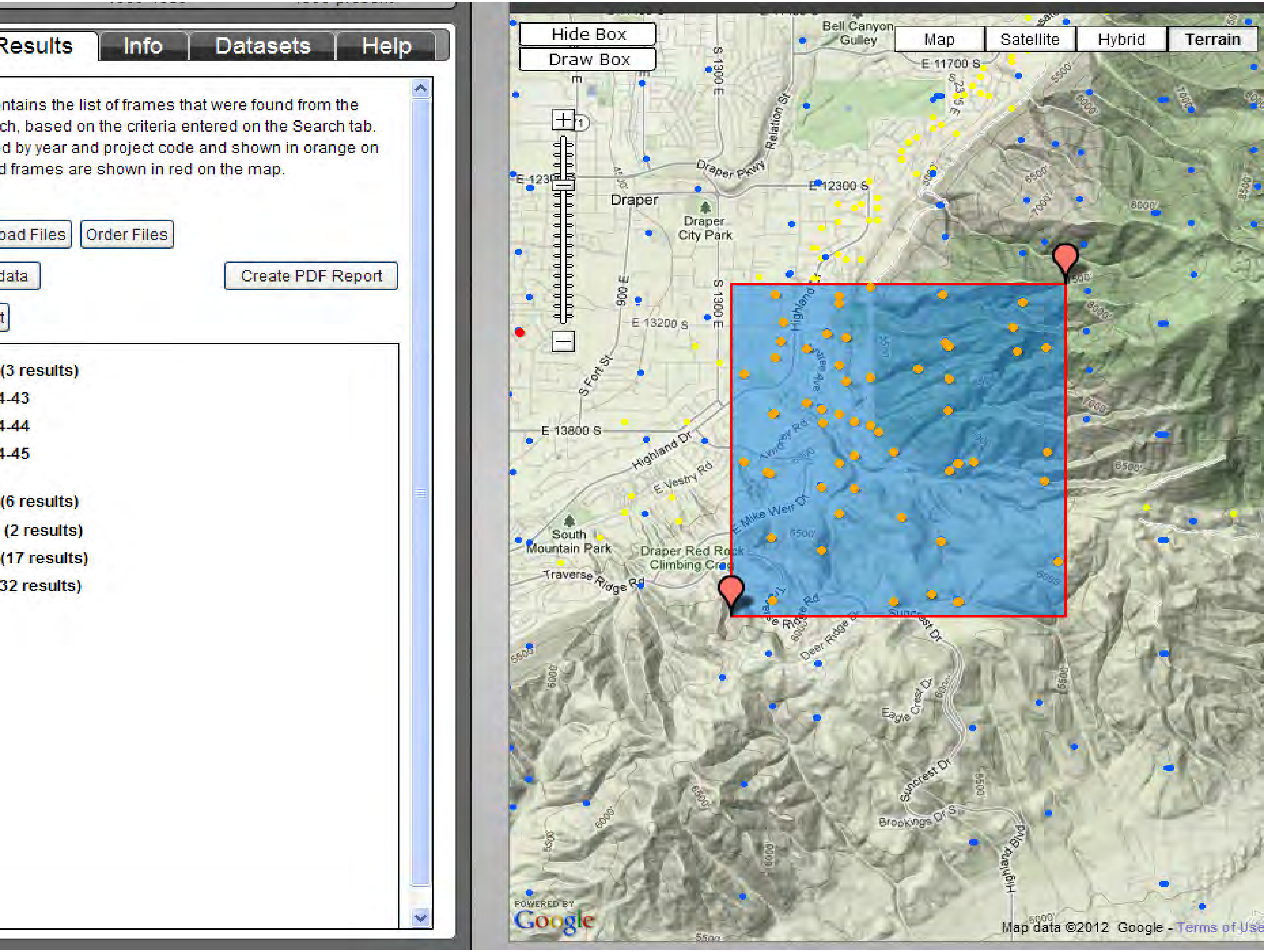
UTAH GEOLOGICAL SURVEY

1970s Woodward-Lundgren Low-Sun-Angle Aerial Photographs
Corner Canyon Area, Draper, Utah

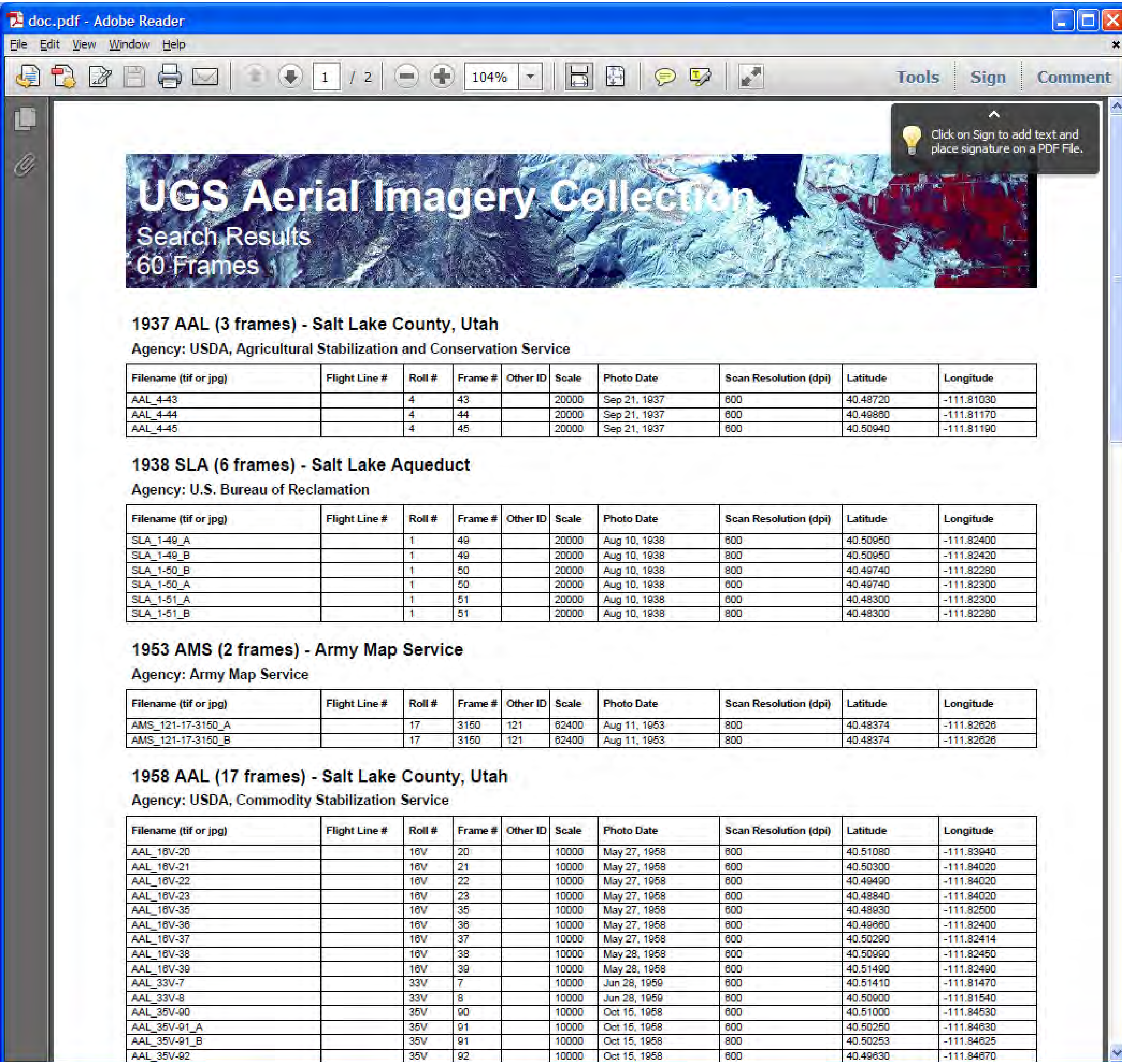
Scan From Print (600 dpi)
UGS Open-File Report 548

Scan From Original Film (1200 dpi)
Future UGS Publication


UGS Aerial Imagery Collection
Login
1935-1959
1960-1989
1990-present
Search
Results
Info
Data Sets
Help
This database contains 63,025 individual photographs. Low-resolution JPEG images can be viewed online and downloaded. High-resolution TIFF images can be transferred to a user's portable drive or printed by the Natural Resources Map and Bookstore for a nominal fee (see Help).
Click on an individual photograph point on the map to show a popup containing basic metadata and a small preview image.
Users can create a search-bounding box by moving the map markers, by using the Draw Box, by entering latitude and longitude coordinates, or by typing in an address (street address, city, state) and region size. Enter additional search criteria to narrow your search.
Click on Search to display list of selected photographs.
Search by Region
NE Corner
Latitude: 39.5
Longitude: -110.75
SW Corner
Latitude: 38.5
Longitude: -112.25
Search by Address
Type address here
Region Size (in miles): Width: 5 Height: 5
Go to Address
Additional Criteria
From
To
Project Code:
Year: 1930 2012
Search Limit:
Scale:
250
Reset
Search
Aerial Photograph Frame Center Point Locations
Hide Box
Draw Box
Map
Satellite
Hybrid
Terrain
Rock Springs
National Monument
POWERED BY Google
Map data ©2012 Google - Terms of Use



Results
Info
Datasets
Help
ntains the list of frames that were found from the
ch, based on the criteria entered on the Search tab.
d by year and project code and shown in orange on
d frames are shown in red on the map.
oad Files
Order Files
data
Create PDF Report
(3 results)
4-43
4-44
4-45
(6 results)
(2 results)
(17 results)
32 results)
Hide Box
Draw Box
Map
Satellite
Hybrid
Terrain
Bell Canyon Gulley
E 11700 S
Draper Pkwy
E 12300 S
Draper
Draper City Park
E 13200 S
S 1300 E
900 E
S Fort St
E 13800 S
Highland Dr
E Vestry Rd
E Mike Weir Dr
South Mountain Park
Draper Red Rock Climbing Crag
Traverse Ridge Rd
Deer Ridge Dr
Suncrest Dr
Eagle Crest Dr
Brookings Dr S
Highland Blvd
POWERED BY Google
Map data ©2012 Google - Terms of Use



UGS Aerial Imagery Collection

Search Results
60 Frames

1937 AAL (3 frames) - Salt Lake County, Utah

Agency: USDA, Agricultural Stabilization and Conservation Service

Filename (tif or jpg)	Flight Line #	Roll #	Frame #	Other ID	Scale	Photo Date	Scan Resolution (dpi)	Latitude	Longitude
AAL_4-43		4	43		20000	Sep 21, 1937	600	40.48720	-111.81030
AAL_4-44		4	44		20000	Sep 21, 1937	600	40.49860	-111.81170
AAL_4-45		4	45		20000	Sep 21, 1937	600	40.50940	-111.81190

1938 SLA (6 frames) - Salt Lake Aqueduct

Agency: U.S. Bureau of Reclamation

Filename (tif or jpg)	Flight Line #	Roll #	Frame #	Other ID	Scale	Photo Date	Scan Resolution (dpi)	Latitude	Longitude
SLA_1-49_A		1	49		20000	Aug 10, 1938	600	40.50950	-111.82400
SLA_1-49_B		1	49		20000	Aug 10, 1938	800	40.50950	-111.82420
SLA_1-50_B		1	50		20000	Aug 10, 1938	800	40.49740	-111.82280
SLA_1-50_A		1	50		20000	Aug 10, 1938	600	40.49740	-111.82300
SLA_1-51_A		1	51		20000	Aug 10, 1938	600	40.48300	-111.82300
SLA_1-51_B		1	51		20000	Aug 10, 1938	800	40.48300	-111.82280

1953 AMS (2 frames) - Army Map Service

Agency: Army Map Service

Filename (tif or jpg)	Flight Line #	Roll #	Frame #	Other ID	Scale	Photo Date	Scan Resolution (dpi)	Latitude	Longitude
AMS_121-17-3150_A		17	3150	121	62400	Aug 11, 1953	800	40.48374	-111.82626
AMS_121-17-3150_B		17	3150	121	62400	Aug 11, 1953	800	40.48374	-111.82626

1958 AAL (17 frames) - Salt Lake County, Utah

Agency: USDA, Commodity Stabilization Service

Filename (tif or jpg)	Flight Line #	Roll #	Frame #	Other ID	Scale	Photo Date	Scan Resolution (dpi)	Latitude	Longitude
AAL_16V-20		16V	20		10000	May 27, 1958	600	40.51080	-111.83940
AAL_16V-21		16V	21		10000	May 27, 1958	600	40.50300	-111.84020
AAL_16V-22		16V	22		10000	May 27, 1958	600	40.49490	-111.84020
AAL_16V-23		16V	23		10000	May 27, 1958	600	40.48840	-111.84020
AAL_16V-35		16V	35		10000	May 27, 1958	600	40.48930	-111.82500
AAL_16V-36		16V	36		10000	May 27, 1958	600	40.49660	-111.82400
AAL_16V-37		16V	37		10000	May 27, 1958	600	40.50290	-111.82414
AAL_16V-38		16V	38		10000	May 28, 1958	600	40.50990	-111.82450
AAL_16V-39		16V	39		10000	May 28, 1958	600	40.51490	-111.82490
AAL_33V-7		33V	7		10000	Jun 28, 1959	600	40.51410	-111.81470
AAL_33V-8		33V	8		10000	Jun 28, 1959	600	40.50900	-111.81540
AAL_35V-90		35V	90		10000	Oct 15, 1958	600	40.51000	-111.84530
AAL_35V-91_A		35V	91		10000	Oct 15, 1958	600	40.50250	-111.84630
AAL_35V-91_B		35V	91		10000	Oct 15, 1958	800	40.50253	-111.84625
AAL_35V-92		35V	92		10000	Oct 15, 1958	600	40.49630	-111.84670

PDF report of search results with basic metadata

GeoData Archive System

- Contains a collection of geologic hazard and geotechnical data on Utah.
  - Consultant Reports
    - Geotechnical reports
    - Geologic-hazard reports
    - Fault evaluation reports
  - UGS Technical Reports
  - Unpublished Geologic-Hazard Information
    - Field Investigations
    - Documents
    - Maps
    - Photographs

GeoData Archive System

- New system based on open-source software (web-based).
  - ResourceSpace Digital Asset Management System
  - mySQL Database
- Compatible with several hundred document, graphic, audio, and video formats.
  - PDF, JPEG, TIFF, MP3, MPEG, MOV, etc.
- All files available for download locally (per permissions).
- System is highly expandable in terms of storage.
  - Current collection of 4752 items uses 51 GB of disk space.

Themes

Groups of similar collections containing geologic information resources.

Select...

> View All

Utah Geological Survey GeoData Archive System

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

Authorized users may log in for more functionality and resource viewing. Not all resources may be available to all users due to copyright and/or distribution restrictions.

Upon searching for specific resources, they may be viewed directly, or downloaded to your local device. Documents are predominately in text-searchable PDF format. Adobe Reader 9 or greater, is needed to view the PDF files. Firefox 9 or greater is recommended for best web browser performance.

Simple Search

Search using descriptions, keywords and resource numbers

- [x] All
- [x] Photo
- [x] Document
- [x] Video
- [x] Audio

Title

Author

County

Keywords

By Date

Any year | Any month

Clear | Search

> Geographic Search

> Go to Advanced Search

> View New Material

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Password

Log in

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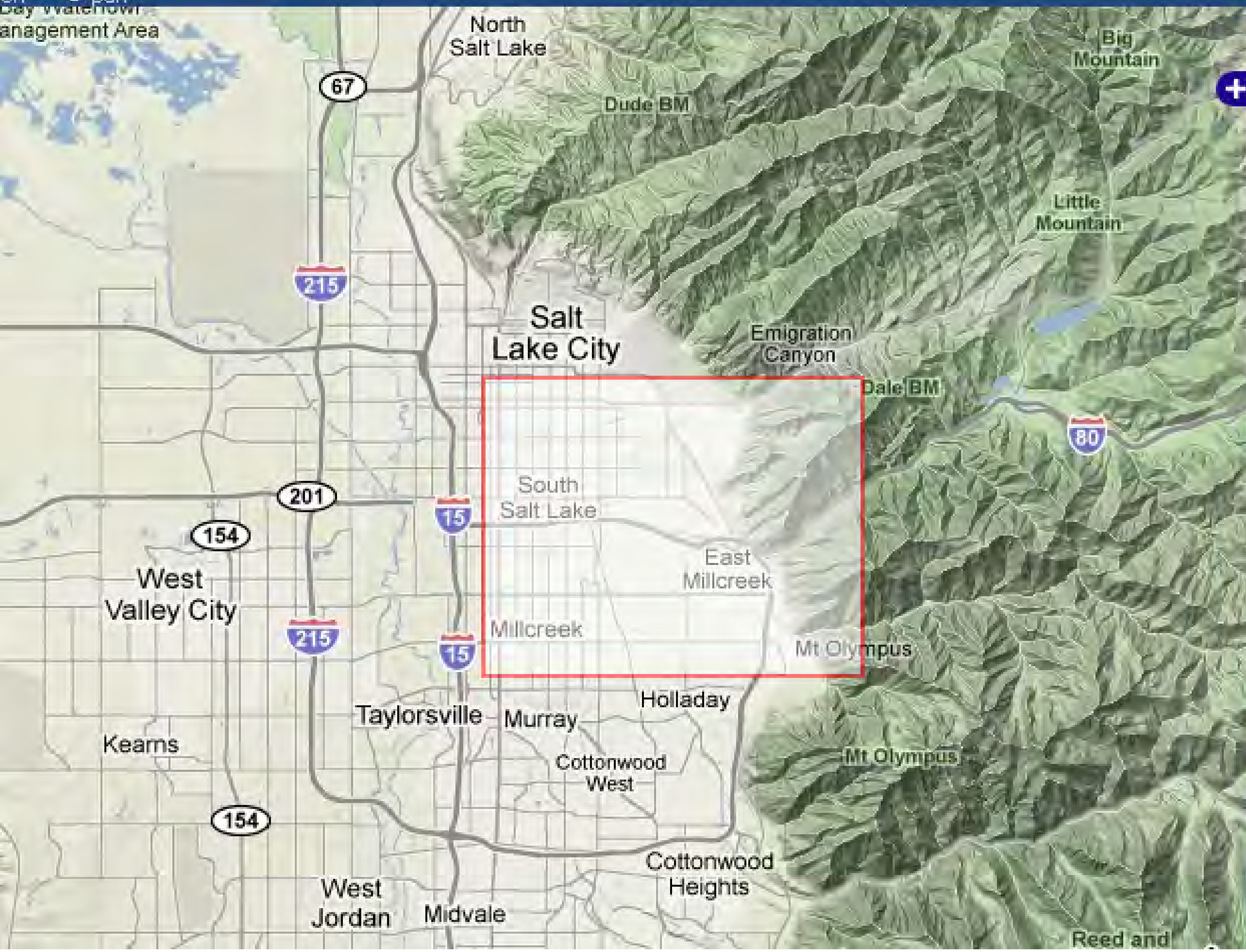

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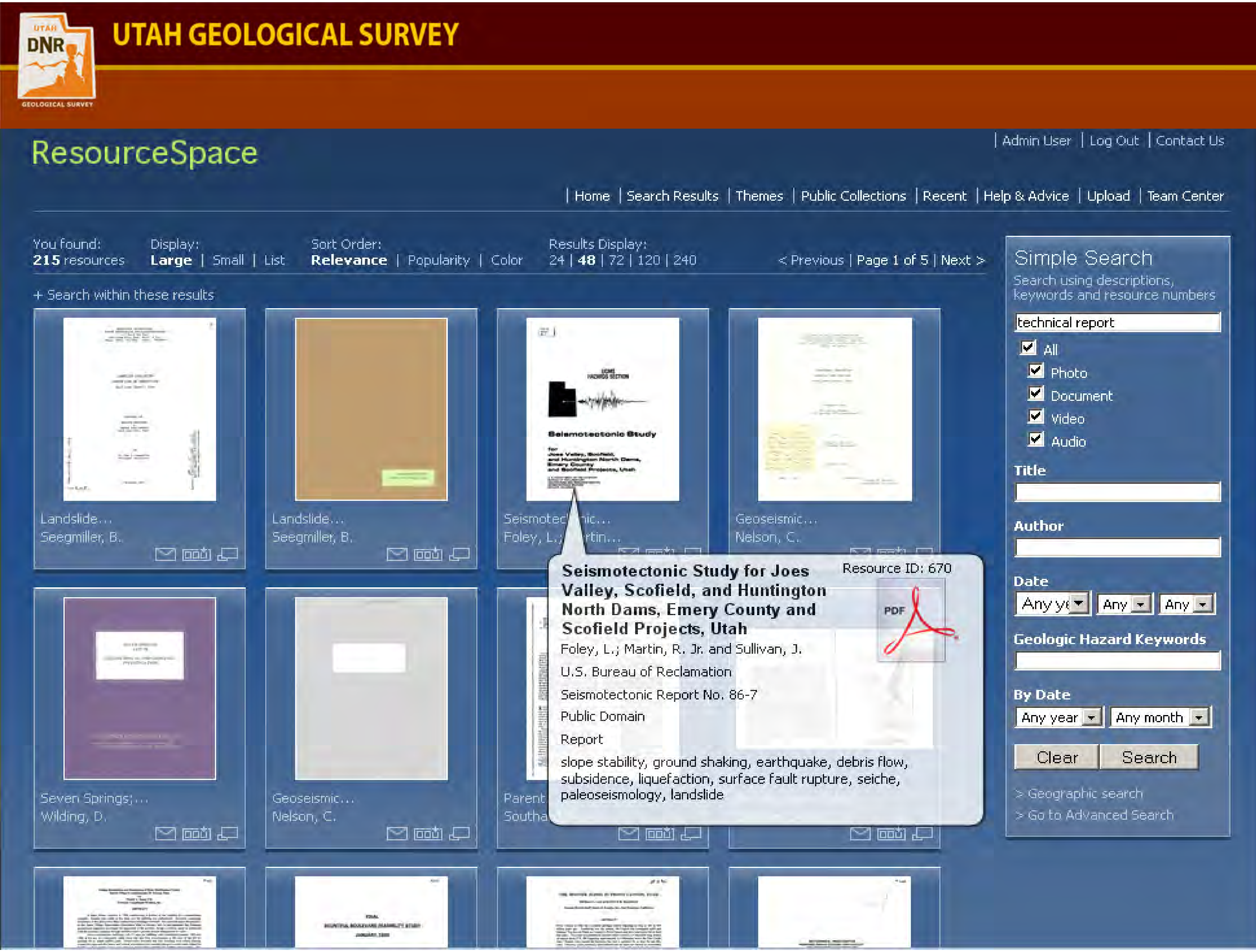
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Seismotectonic Study for Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah
Resource ID: 670
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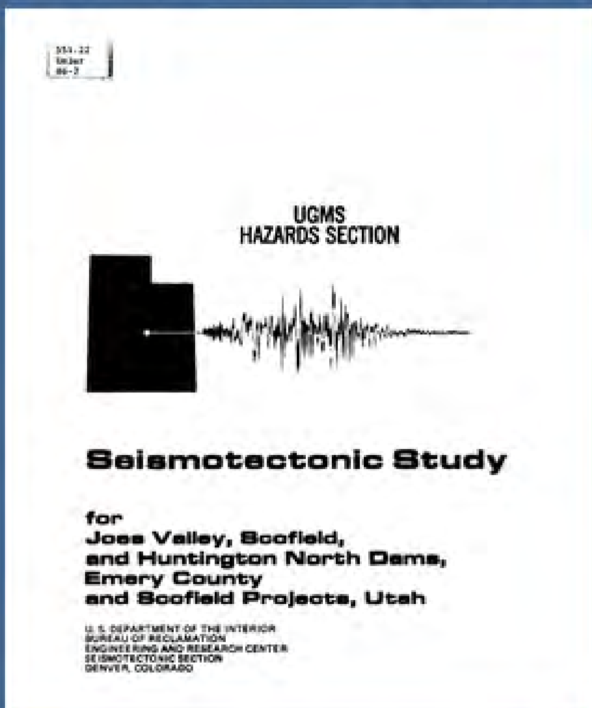
Seismotectonic Study for Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah



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Author
Foley, L.; Martin, R. Jr. and Sullivan, J.

Publisher
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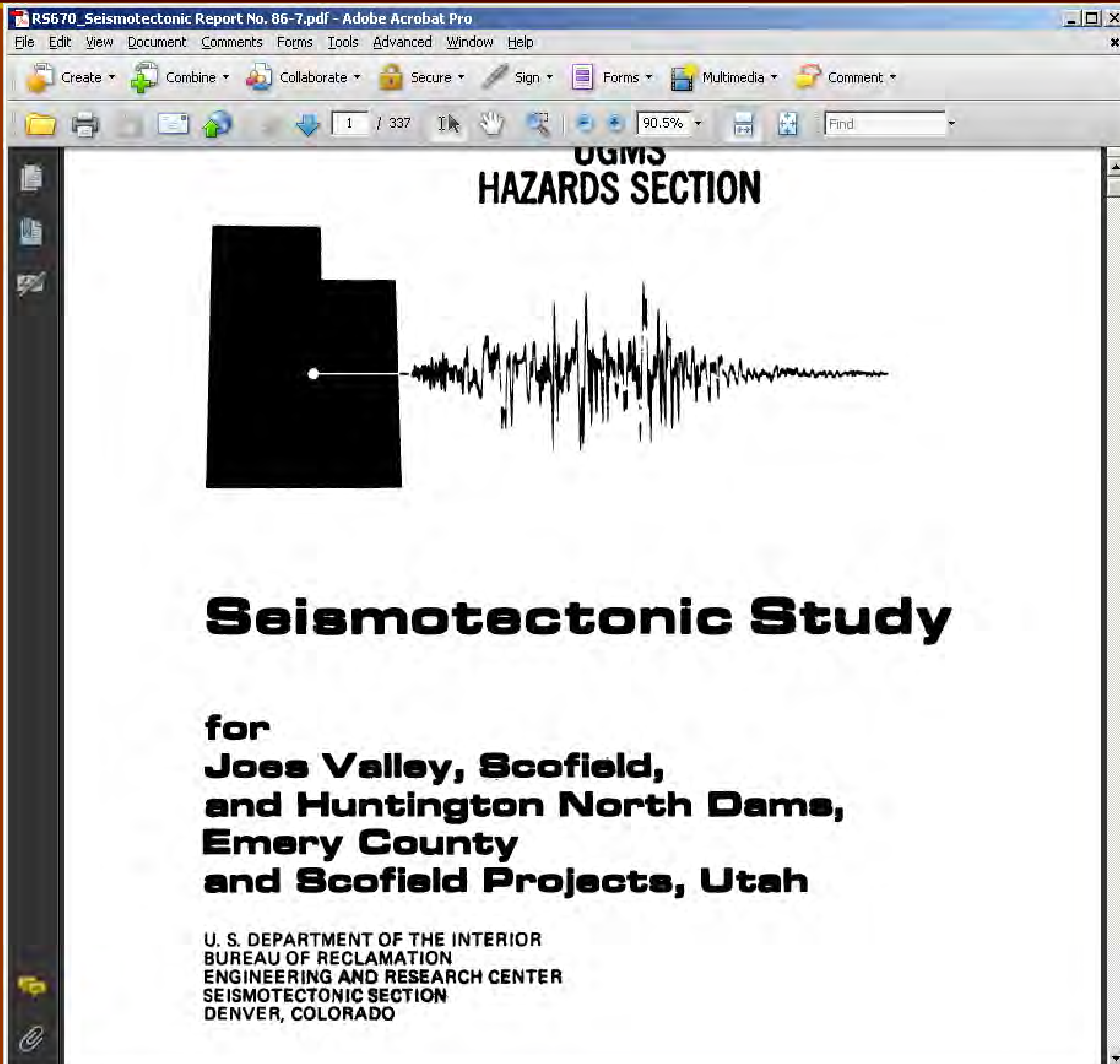

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Seismotectonic Study

for
Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah

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BUREAU OF RECLAMATION
ENGINEERING AND RESEARCH CENTER
SEISMOTECTONIC SECTION
DENVER, COLORADO

Forecasting Large Earthquakes Along the Wasatch Front

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Patricia Thomas and Susan Olig
Seismic Hazards Group, URS Corporation, Oakland, CA

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Tony Crone, Nico Luco, Steve Personius, and Mark Petersen
U.S. Geological Survey, Denver, CO

David Schwartz
U.S. Geological Survey, Menlo Park, CA

Utah Quaternary Fault Parameters Working Group
Salt Lake City, UT

5 February 2013

Introduction

- A consensus-based estimate of earthquake probabilities for the Wasatch Front can be used to raise public awareness and incorporated into public policy that will drive greater and more sustained earthquake mitigation efforts in Utah.

- Previous estimates of Wasatch Front earthquake probabilities have been made by individual authors using the limited data available at the time. The results of these investigations had little impact on public policy.

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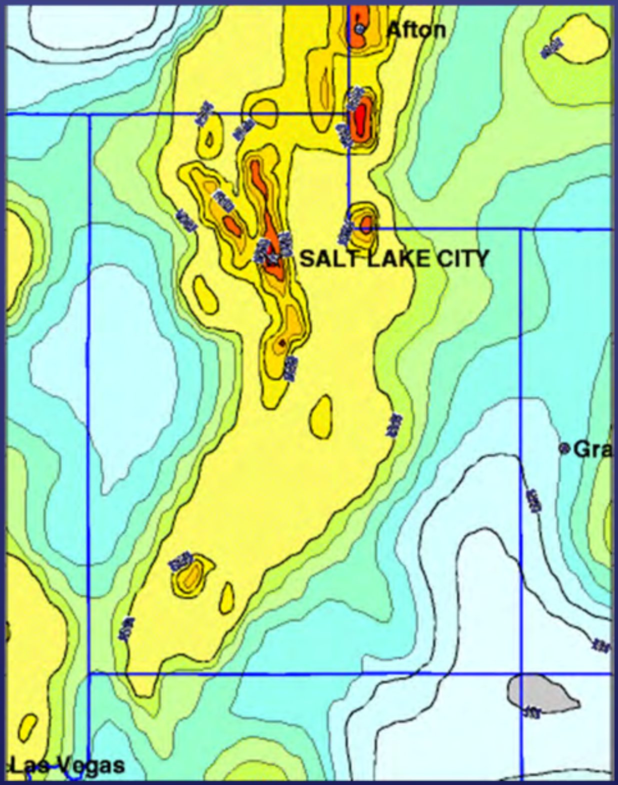
Introduction (cont.)

- Data developed by the WGUEP can be incorporated into the USGS National Hazard Maps.
- Wasatch Front urban hazard maps are planned by the USGS, and time-dependent probabilities can also be incorporated into those maps.



Introduction (cont.)

- The final forecast will undergo a formal internal USGS review, and will be sent to the National Earthquake Prediction Council for review and comment as well.
- There will be a media release of the WGUEP results. Project results will also be presented at meetings for the general public and at professional and scientific society meetings.

URS

WGUEP

- The Working Group on Utah Earthquake Probabilities was formed in late 2009.
- Funded by the USGS through the NEHRP external grants program for 3 years and the Utah Geological Survey.
- The final report and results will be released by end of 2013.

WGUEP Members

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

Assistance from Steve Bowman, UGS

Scope of Work

- Calculate time-dependent probabilities of large earthquakes on the major faults where the data is available on the expected mean frequency of earthquakes and the elapsed time since the most recent large earthquake.
- Even for these faults, some weight will be given to the time-independent model.
- Where such information is lacking on less well-studied faults, time-independent probabilities are estimated.
- Epistemic uncertainties in all input parameters will be explicitly addressed by the WGUEP using logic trees.

Products

- The WGUEP will calculate 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 will be 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 Great Salt Lake Fault.
  4. Time-independent fault-specific for all other faults (46) in the Wasatch Front.
  5. Time-independent for background earthquakes (M 5.0 to 6.75).
  6. Total for the Wasatch Front region.

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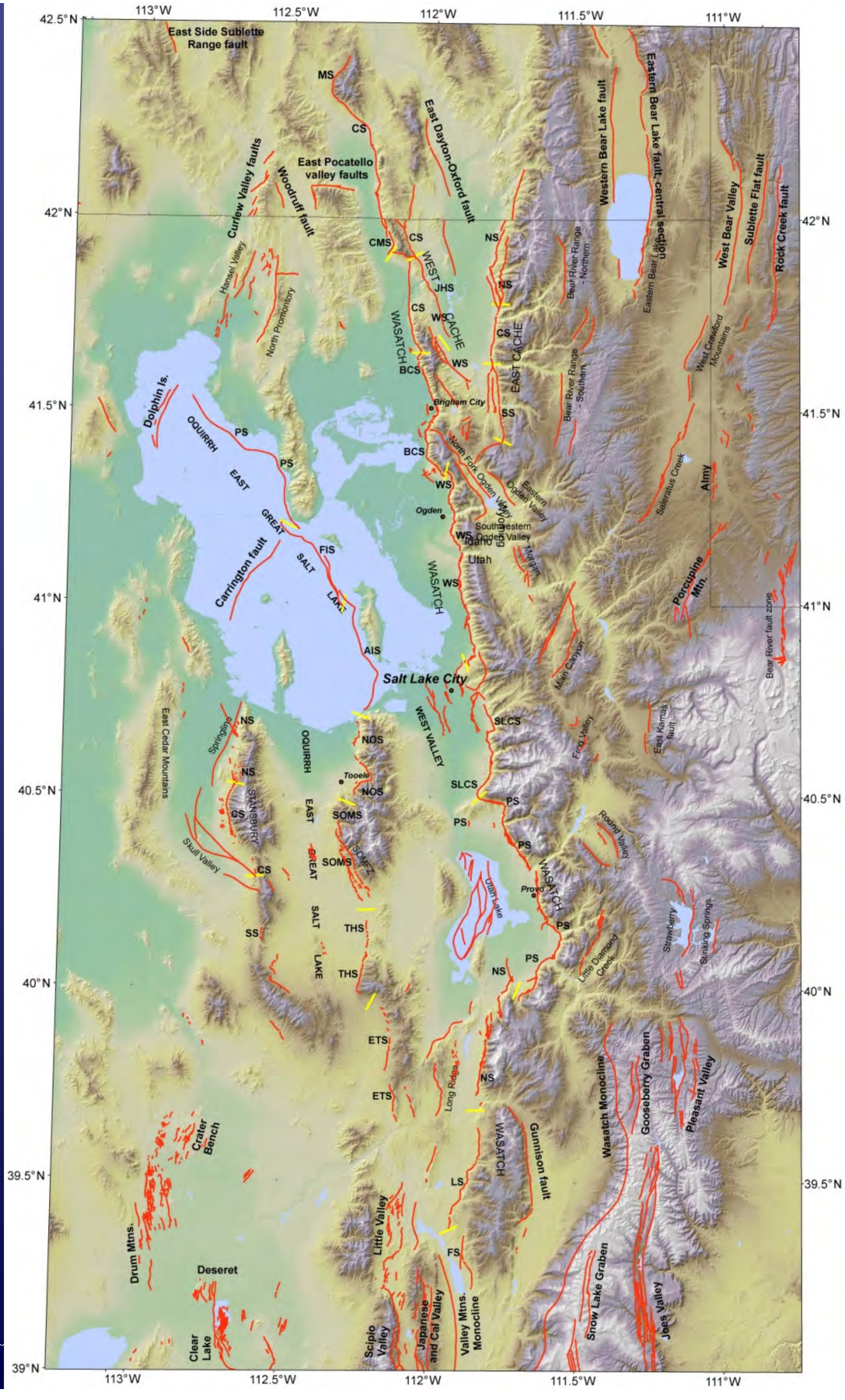
WGUEP Wasatch Front



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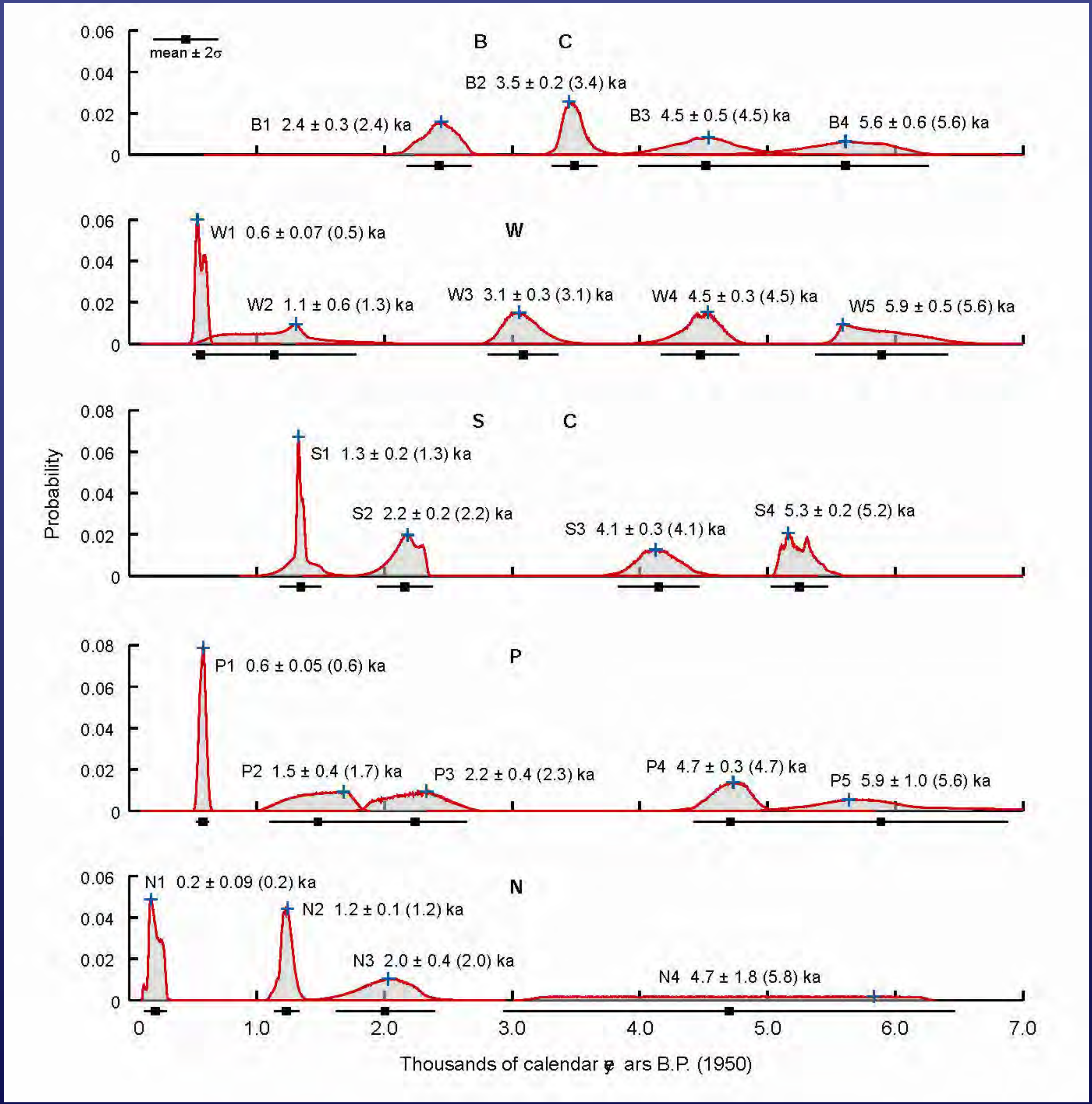
Segments of the Wasatch Fault Zone (WFZ) in Southern Idaho and Northern Utah

Accomplishments

- Developed earthquake chronology for central segments of the Wasatch fault. Selected single and multiple-segment rupture scenarios for Wasatch fault central segments.
  - Examined the original paleoseismic site investigation reports and associated trench logs/maps to evaluate geologic and chronologic evidence for interpreted events.
  - Considered common limitations in dating paleoearthquake event horizons.
  - Constructed time-stratigraphic OxCal models for each site.
  - Qualitatively correlated events between sites to develop segment-wide earthquake histories.
  - Computed composite PDF for each earthquake.
  - Used the composite earthquake PDFs to construct segment-wide PDF data to calculate mean recurrence and evaluate associated uncertainties.

Paleoseismic Trench Sites Along the Central Segments of the WFZ

Surface-Faulting Earthquake Histories for the Central Segments of the WFZ



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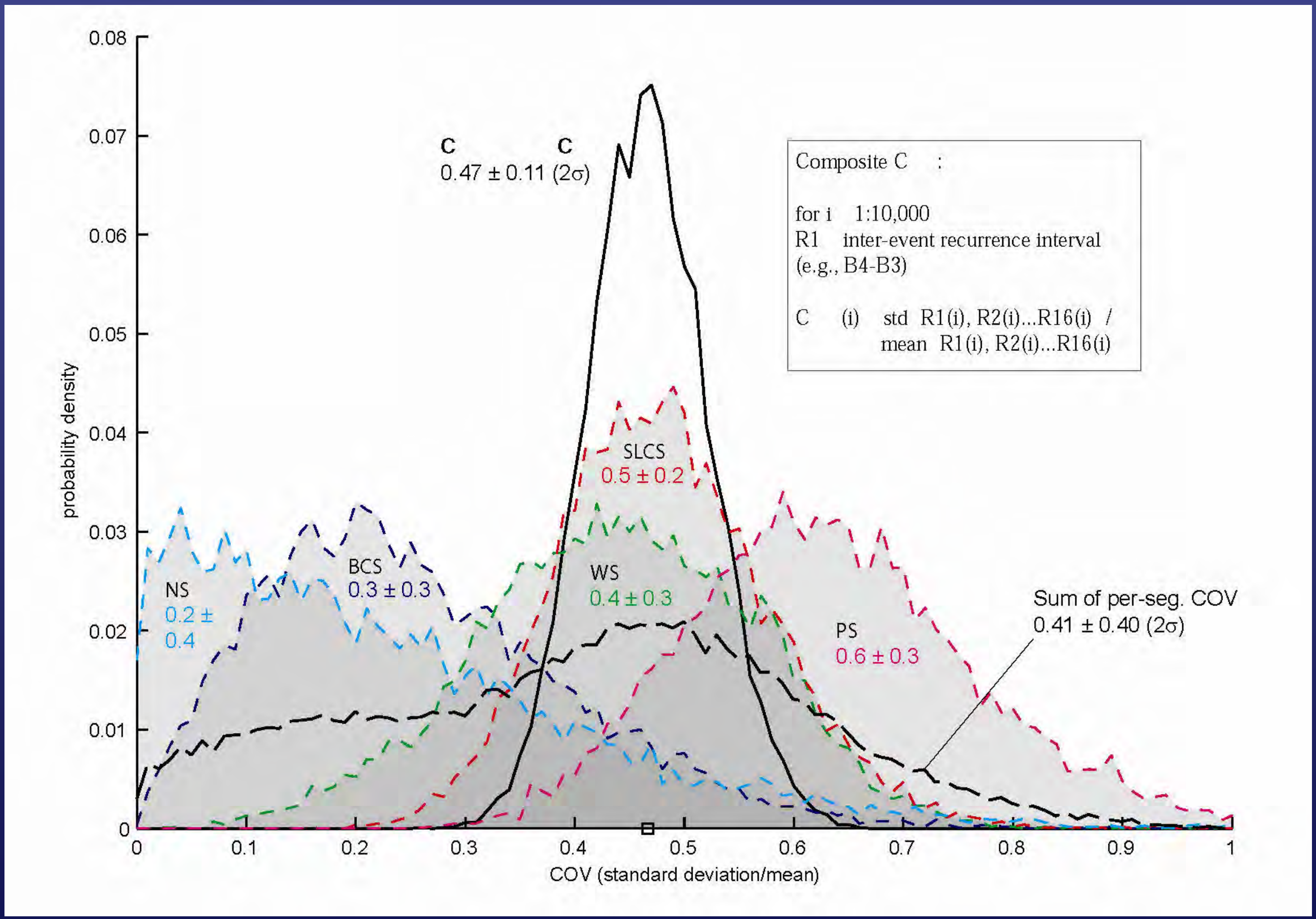
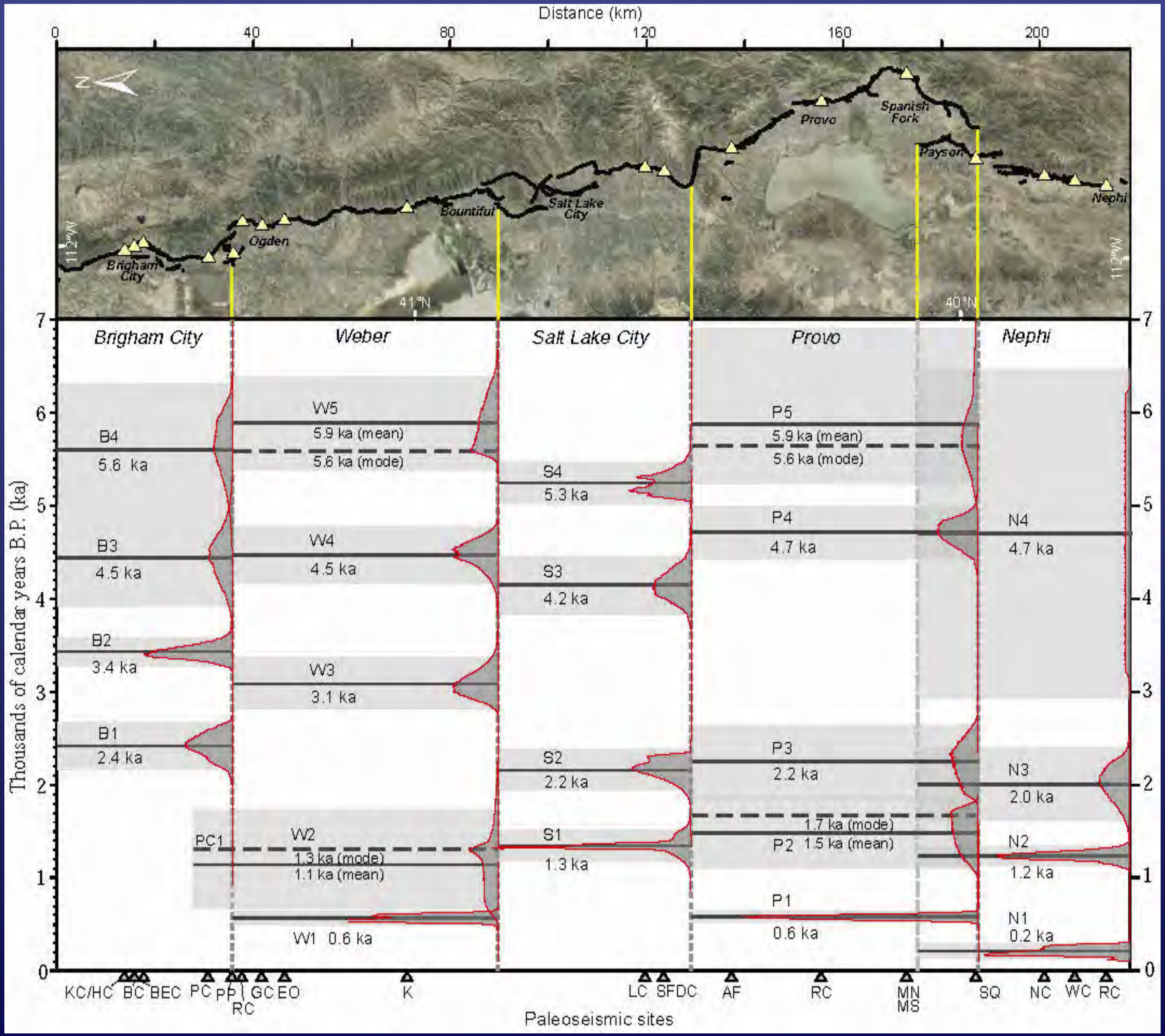
Composite Coefficient of Variation on Recurrence for the Central WFZ



Single-Segment Rupture Model for the Central WFZ



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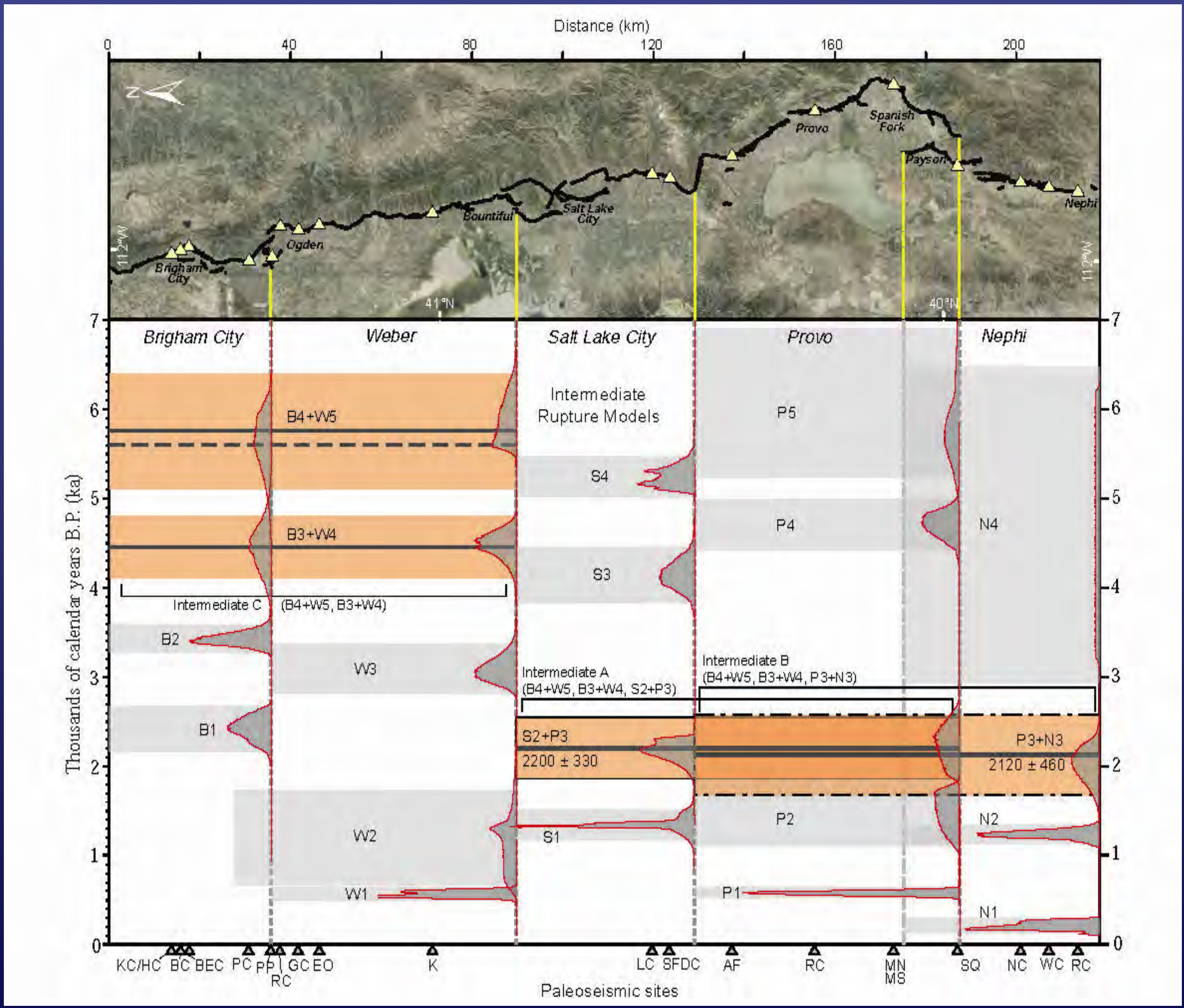
Intermediate Rupture Models for the Central WFZ

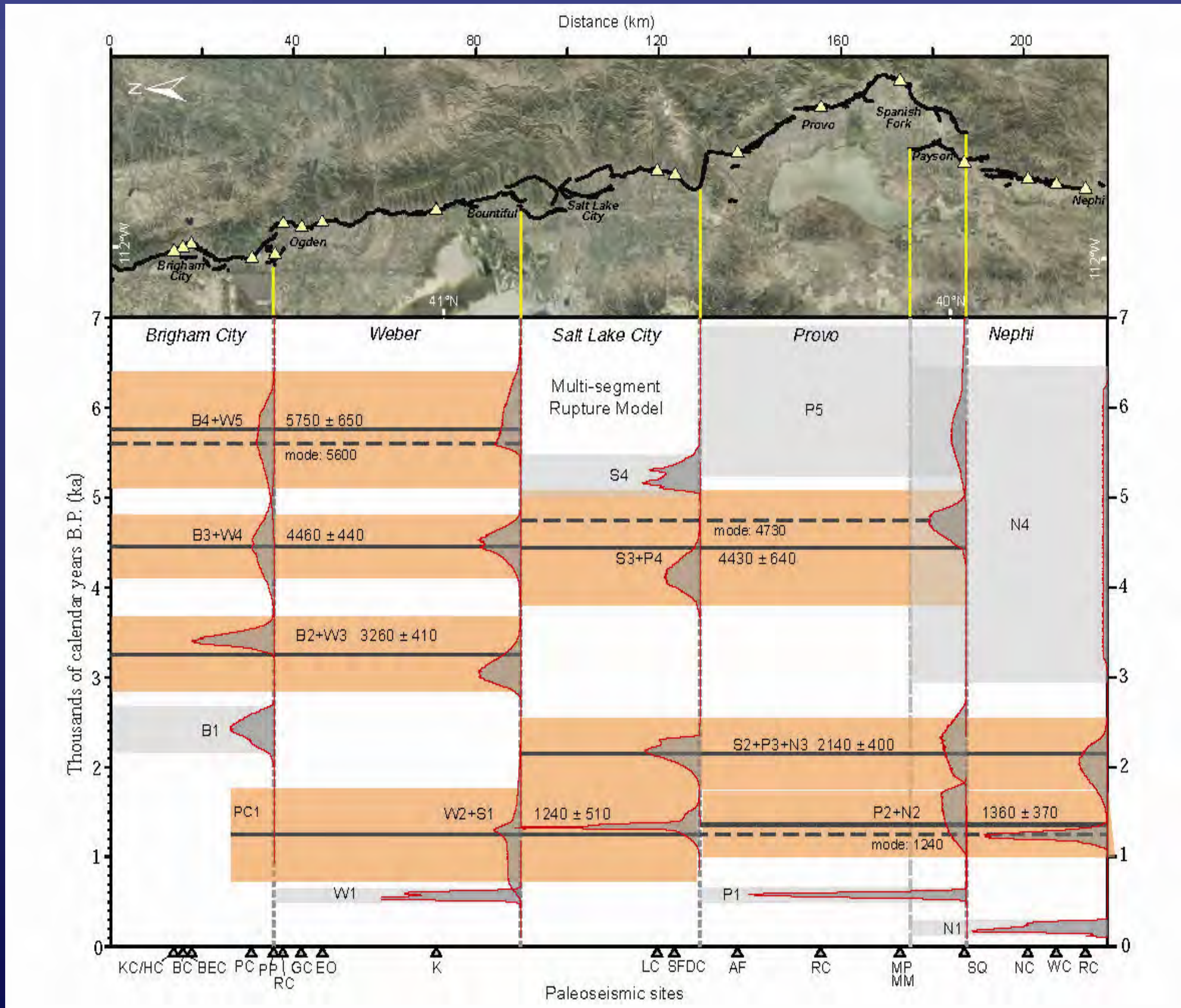
A – B4+W5, B3+W4 and S2+P3

B – P3+N3 in place of S2+P3

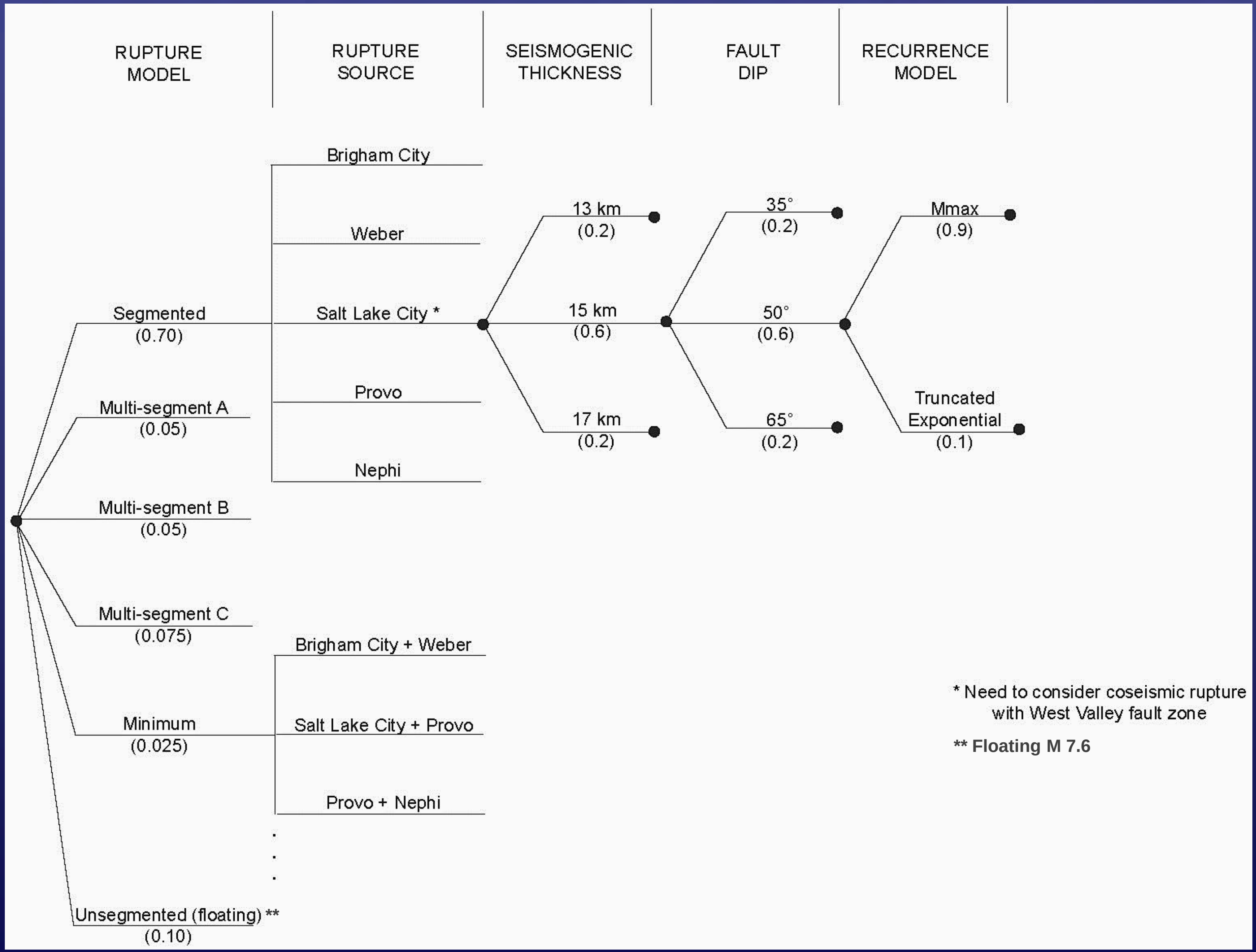
C – B4+W5 and B3+W4



Multi-Segment Rupture Models for the Central WFZ



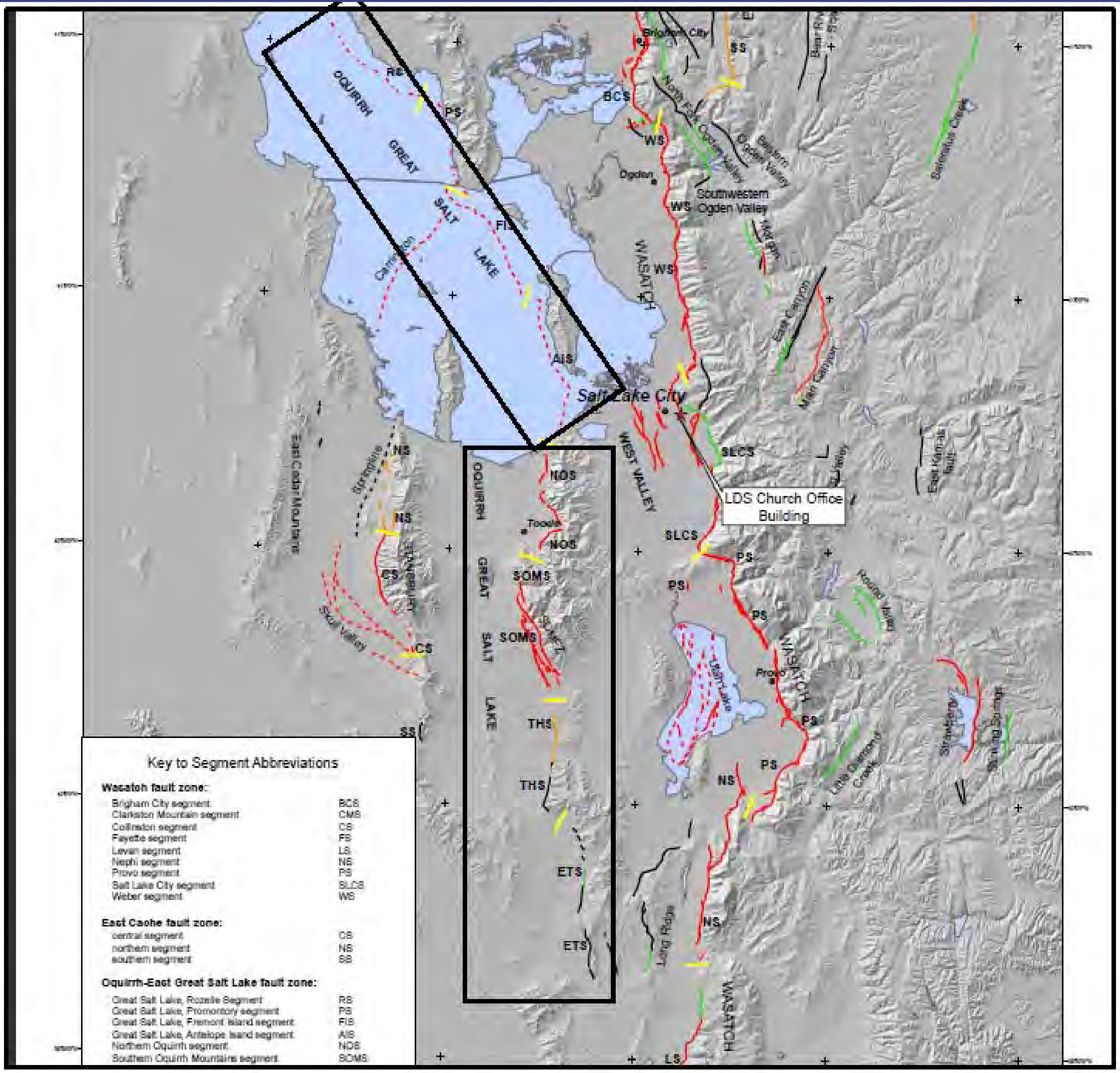
Generalized Logic Tree for Calculating the Recurrence of the Central Segments of WFZ



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



Proposed Rupture Models and Weights for the Oquirrh-Great Salt Lake Fault Zone

	Rupture Scenarios	Weights
1	RZ, PY, FI, AI, NO+S0, TH, ET	0.15
2	RZ, PY, FI, AI NO, SO, TH, ET	0.4
3	RZ, PY, FI+AI, NO, SO, TH, ET	0.15
4	RZ, PY, FI, AI, NO, SO+TH, ET	0.1
5	Unsegmented (floating)	0.2

"Other" Faults/Fault Segments in the Wasatch Front Region Retained in the WGUEP Probabilistic Earthquake Forecast

Bear River fault zone
Broadmouth Canyon faults[1]
Carrington fault
Crater Bench fault[2]
Crawford Mountains (west side) fault
Curlew Valley faults
Drum Mountains fault zone[2]
East Cache fault zone
- Northern segment
- Central segment
- Southern segment[1]

East Dayton – Oxford faults
Eastern Bear Lake fault
- Northern segment
- Central segment
- Southern segment

Gunnison fault
Hansel Valley fault[3]
Hansel Valley (east side) faults[3]
Hansel Valley (valley floor) faults[3]
James Peak fault[1]
Joes Valley faults
Little Valley faults
Main Canyon fault
Maple Grove faults[4]
Morgan fault
- Northern section[5]
- Central section[5]
- Southern section[5]

North Promontory fault
Porcupine fault
Pavant Range fault[4]
Reactivated section Absaroka thrust fault
Red Canyon faults[4]
Rock Creek fault
Scipio fault zone[4]
Scipio Valley faults[4]
Skull Valley (mid valley) faults
Snow Lake graben
Stansbury fault
Stinking Springs fault
Strawberry fault
Utah Lake faults
West Cache fault zone
- Clarkston fault
- Junction Hills fault
- Wellsville fault

West Valley fault zone
- Granger fault
- Taylorsville fault

Western Bear Lake fault

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Accomplishments (cont.)

- Characterized end segments of Wasatch fault and other faults in Wasatch Front.
- Characterized all other “significant” faults in the Wasatch Front.
- Developed model for coseismic rupture of antithetic faults
  - SLC Segment/West Valley (0.75/0.25)
  - Provo Segment/Utah Lake (0.5/0.5)
  - Hansel Valley/North Promontory (0.4/0.6)
  - Western/Eastern Bear Lake (0.5)/0.5)
- Compiled new consensus historical catalog through 2010 for the Wasatch Front.

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Accomplishments (cont.)

- Developed a methodology to estimate Mmax.

  A faults (segmented with 2+ paleoseismic sites):
  45% Mo (Hanks and Kanamori)
  45% SRL-c (Stirling)
  5% SRL (W&C-all)
  5% W-SRL (Wesnousky)

  B faults (segmented, but limited D data):
  60% SRL-c (Stirling)
  40% SRL (W&C-all)

  C faults (not segmented, limited D data):
  50% SRL-c (Stirling)
  50% SRL (W&C-all)

- We have adopted a background earthquake Mmax of M 6.75 ± 0.25. USGS recurrence approach (e.g., recurrence models) is being used.

- Fault dip uncertainty adopted is 50 ± 15 degrees.

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Accomplishments (cont.)

- Seismogenic crustal depths (km):
  - East of WFZ 12 (0.1), 15 (0.7), 18 (0.2)
  - West of WFZ 12 (0.2), 15 (0.7), 18 (0.1)
- Considerable effort has been expended comparing moment rates derived from available geodetic, historical seismicity, and paleoseismic data. A discrepancy remains between geodetic rates and the paleoseismic and historical seismicity-based rates that is difficult to reconcile; the geodetic rates are at least 50% higher. The WGUEP will use the geodetic data as a constraint on regional moment rates. (Smith, Puskas, Petersen)

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Results

- Stay Tuned.

REDEFINING 'ACTIVE' FAULTS:

PROPOSAL TO EVALUATE PALEO-SEISMOLOGY STUDIES FOR EVIDENCE OF HOLOCENE CLIMATIC VARIATION & BASIN-WARD MIGRATION OF FAULTING

Darlene Batatian

Mountain Land Development Services LLC

and

David Simon, SBI Simon-Bymaster Inc.

STATUS OF FAULT HAZARD GUIDELINES

- 2003 UGS Guidelines (Christenson et al) defined “active” Holocene fault:
  - Minimum 4” displacement
  - Evidence of deformation within past 10,000 years
- Poor post-Bonneville stratigraphy… Faults that displace post-Bonneville sediments are (by default) usually defined as “ACTIVE”
- Improvements in last 10 years:
  - Better resolution of Wasatch fault rupture timing, recurrence intervals (Past 6 EQ)
  - More detailed Holocene climate chronology (Madsen, et al)
  - Basin-Range normal-fault kinematics- Lateral migration of active fault splays
- **IF** we can refine the Holocene stratigraphic record and fault timing…
- Can we narrow the definition of ‘active’ faulting to exclude ‘inactive’ fault traces?
- *What is a ‘hazardous’ fault?* (Bray, 2013)

WHY DOES IT MATTER?

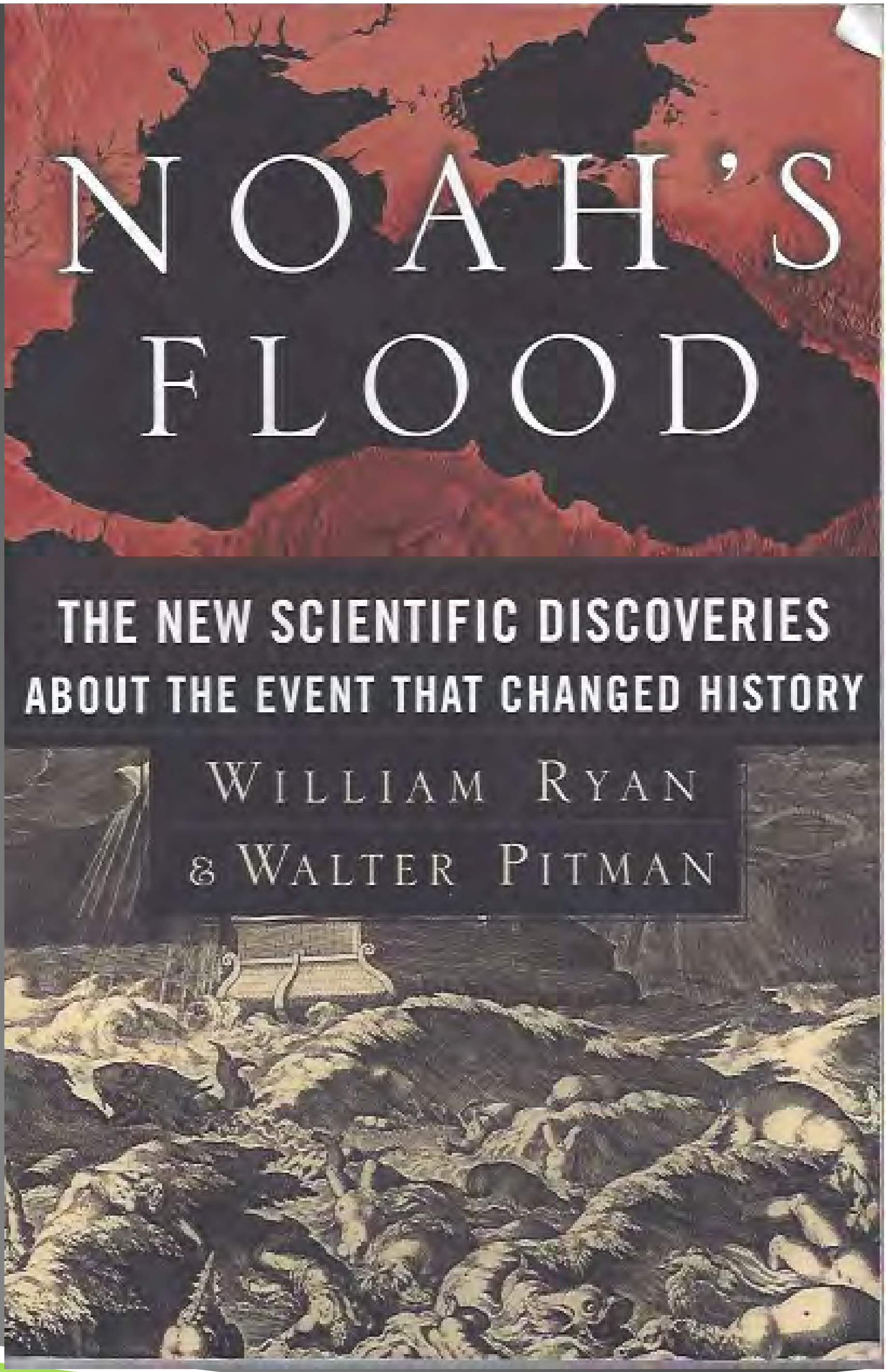
- Approached by developer (Sandy City) to re-consider large areas within fault setback at Pepperwood Hills (SBI, 2009)
  - 1,000-wide fault zone- Several discrete fault splays
  - Buried faults <u>do not</u> offset thick debris flow sequences
  - Loess deposits (radiometric age dates ~5,950 cal YBP)
- Mapleton Presidio Fault Investigation (IGES, 2006)
  - Buried fault traces- Displaced sediments overlain by undeformed loess deposits w/ ages ~5,700 & 9,400 YBP (<10,000 yrs)
  - Still defined as 'active' faults even though no displacement during most recent (# events?) along the Provo fault??

NORMAL FAULT KINEMATICS: BASIN-WARD MIGRATION OF ACTIVE NORMAL FAULTING

- Basin-ward migration of surface traces of normal faults is reported from rift zones; Working assumption in the Basin & Range
- Kinematic/Geometric spatial problems with extensional slip along a curvi-planar surface
- As fault trace matures, less and less extension can be accomplished along the plane of displacement
- New active fault splays form in hanging wall
- Locus of faulting shifts towards hanging wall (basinward)
- *Should* leave behind de-activated fault traces…. (?)
- ? Is this observed along Wasatch fault?

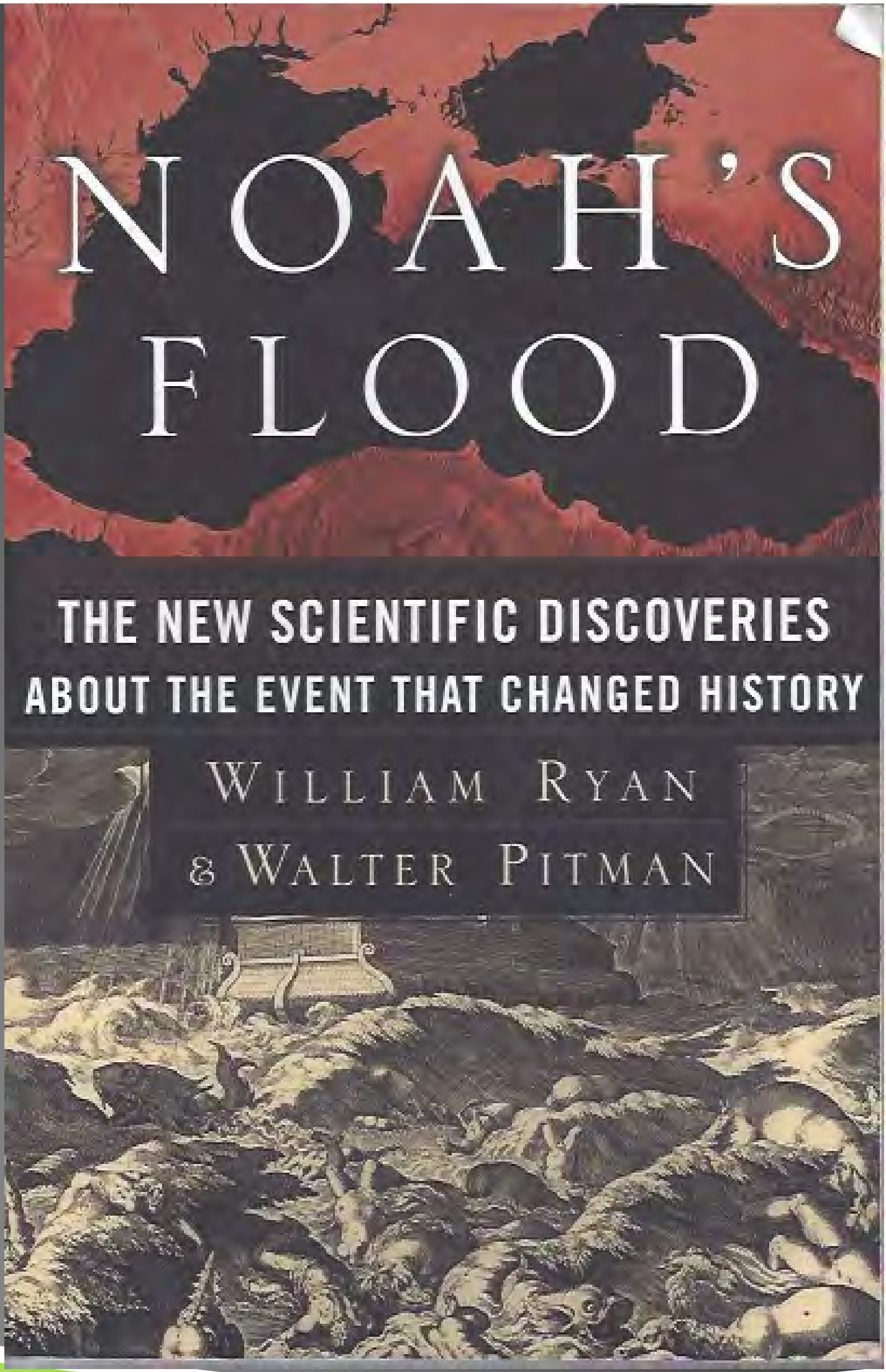
RYAN & PITMAN, 1998

- Cross-disciplinary synthesis of geology, anthropology, Biblical & Sumerian texts, pottery, art, language, genetics, etc.
- Geological analysis of freshwater/lacustrine and marine deposits, changes in sea & lake levels, climate & glacial history
- Identify significant post-glacial intervals:
  - Pulses of rapid melting
  - Hiatus' of glacial melting
- Cold, dry, arid climate intervals= Loess
- Resulted in widespread loess deposits



LOCAL CLIMATIC EVIDENCE?

- Similar setting around shoreline of former Lake Bonneville: De-glaciation, exposed lakeshore, abundant parent material (unconsolidated glacial sediments), wind, mountains act as topographic barriers to loess dispersal
- Is there evidence for Holocene "cold snaps" along the Wasatch Front?
- Loess observed in trenches, overlies faults
- Are loess deposits of comparable age?
- Can loess marker beds be used to constrain 'active' vs.' inactive' fault traces?



SEASONAL WIND CIRCULATION PATTERNS DURING GLACIATION

(LAABS ET AL, 2006 AFTER MUNROE, 2001)

HOLOCENE TEMPERATURE VARIATIONS- GREAT SALT LAKE BASIN

FROM POLLEN SAMPLES, SNOWBIRD BOG
(AFTER MADSEN & CURRY, 1979)

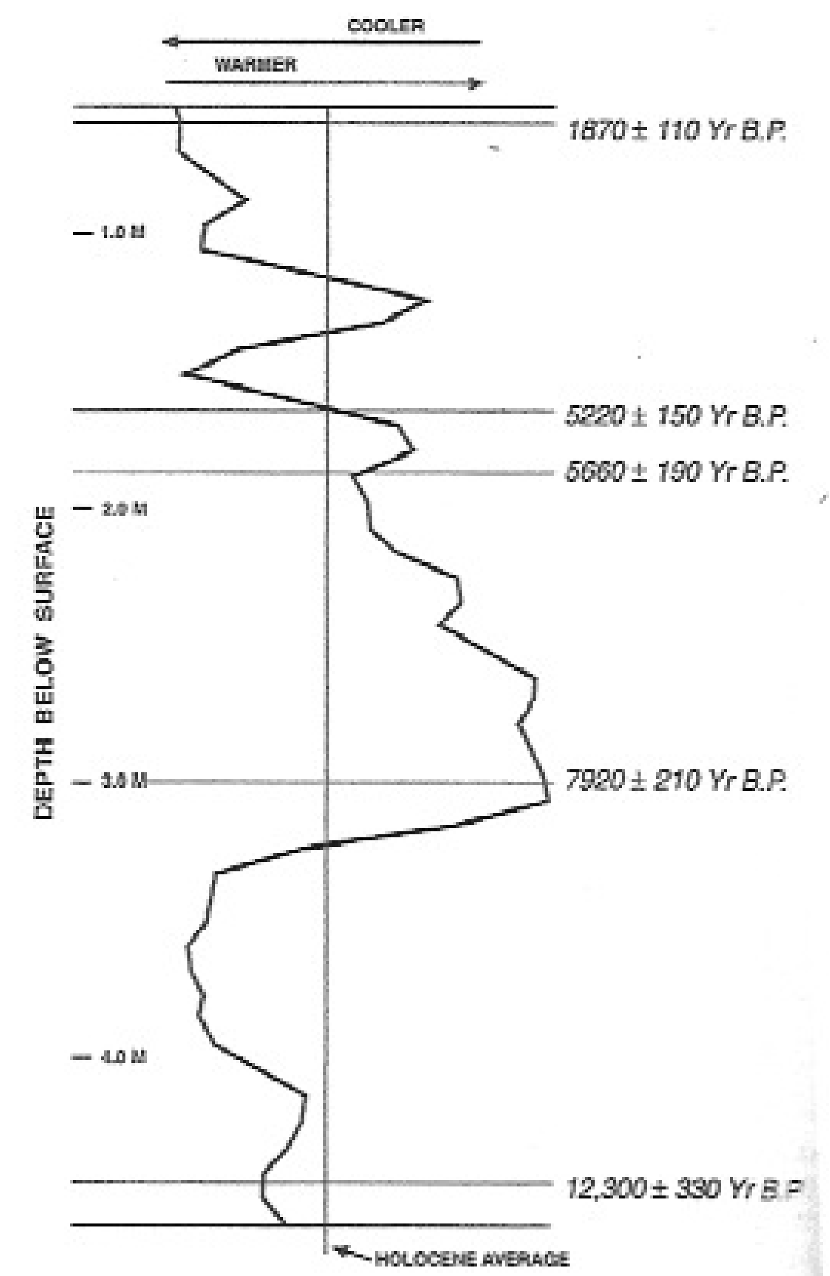


Figure 5. Estimate of Holocene temperature change in the Great Sa Lake basin based on changes in the relative proportion of co pollen to all other pollen at Snowbird Bog, Little Cottonwood Ca Wasatch Range, Utah. The curve is smoothed by a weighted three- moving average. Modified from Madsen and Currey (1979).

PITMAN & RYAN, 1998 HIATUS IN GLACIAL MELTING (COLD, ARID CLIMATE INTERVAL)

5,900 YBP

9,700 YBP

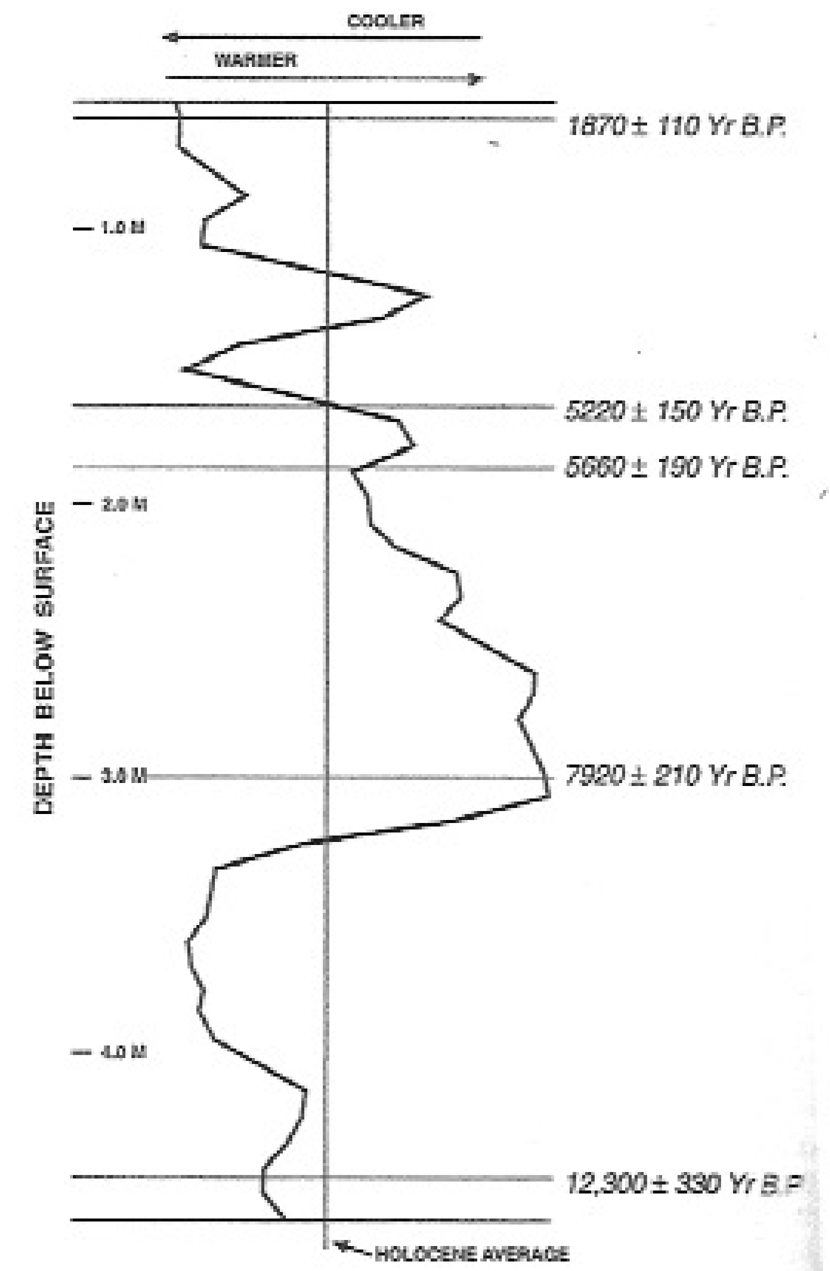


Figure 5. Estimate of Holocene temperature change in the Great Salt Lake basin based on changes in the relative proportion of conifer pollen to all other pollen at Snowbird Bog, Little Cottonwood Canyon, Wasatch Range, Utah. The curve is smoothed by a weighted three-level moving average. Modified from Madsen and Currey (1979).

LOESS RADIOMETRIC DATES (QUICK OVERVIEW)

- Mapleton Trenches (IGES, 2006)- Provo segment, Wasatch fault
  - 5,740-5,940+/- 40 YBP (Two samples, closely correlated)
  - 6,480 +/- 50 YBP
  - 9,370 +/- 50 YBP
- Pepperwood Hills (SBI, 2009)- Salt Lake segment
  - 5,990-5,930 cal YBP
- McCalpin Mega-Trench- Salt Lake segment
  - 9,535 – 9,880 cal YBP

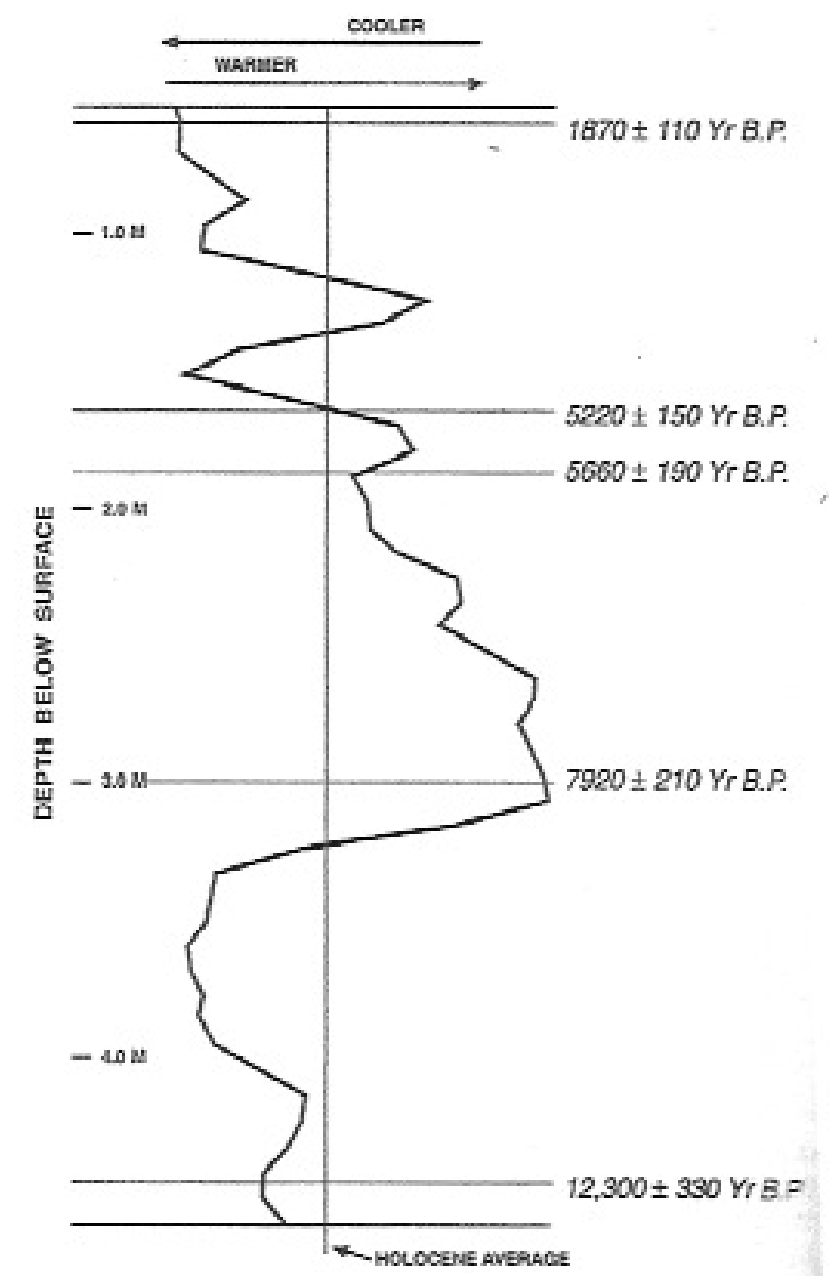
LOCAL LOESS AGE RESULTS

PEPPERWOOD HILLS (SBI, 2009)
5,990-5,930 CAL YBP

MAPLETON (IGES, 2006)
5,740 & 5,940+/- 40 YBP
6,480 +/- 50 YBP

9,370 +/- 50 YBP

MCCALPIN
9,535 – 9,880 CAL YBP



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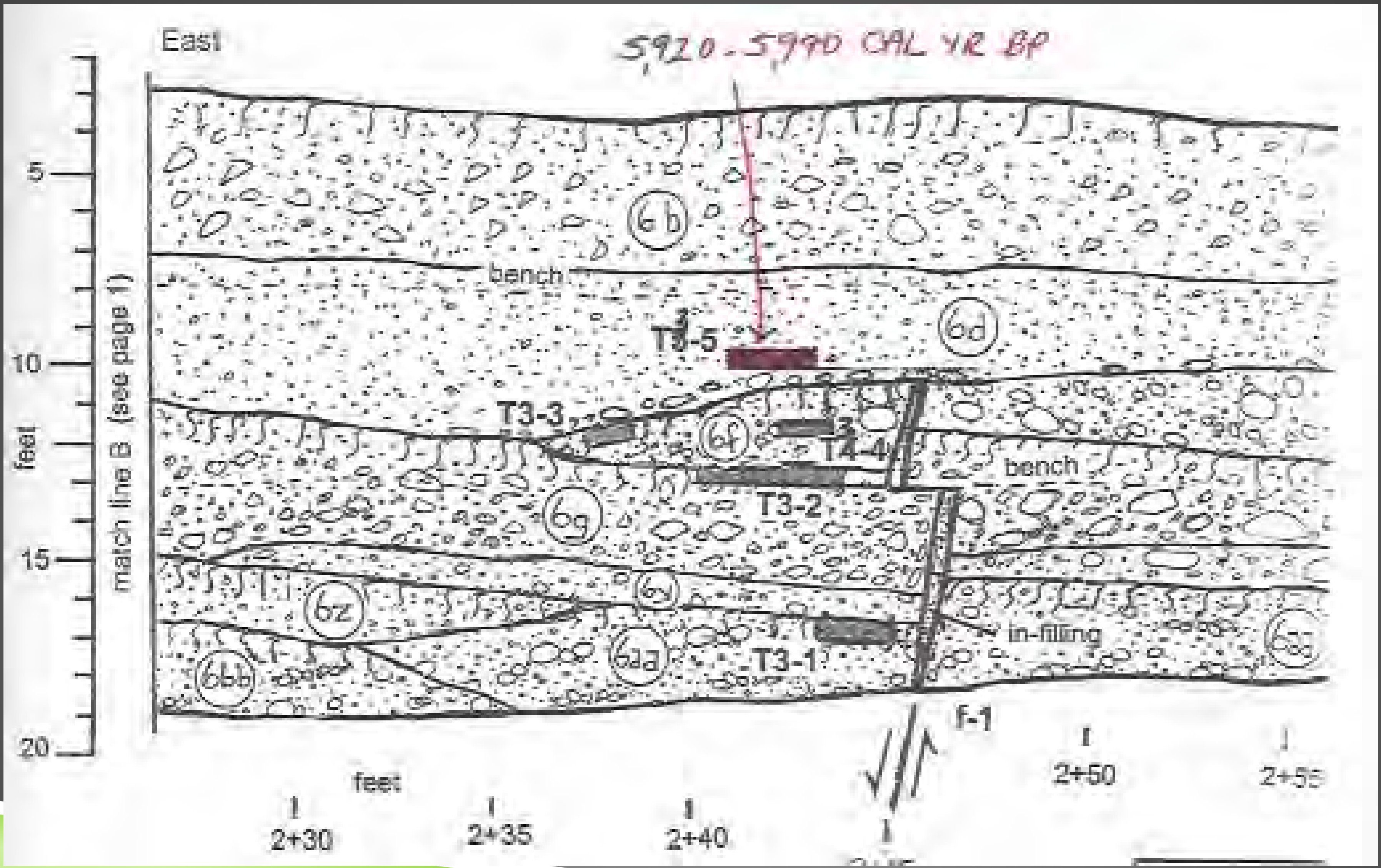
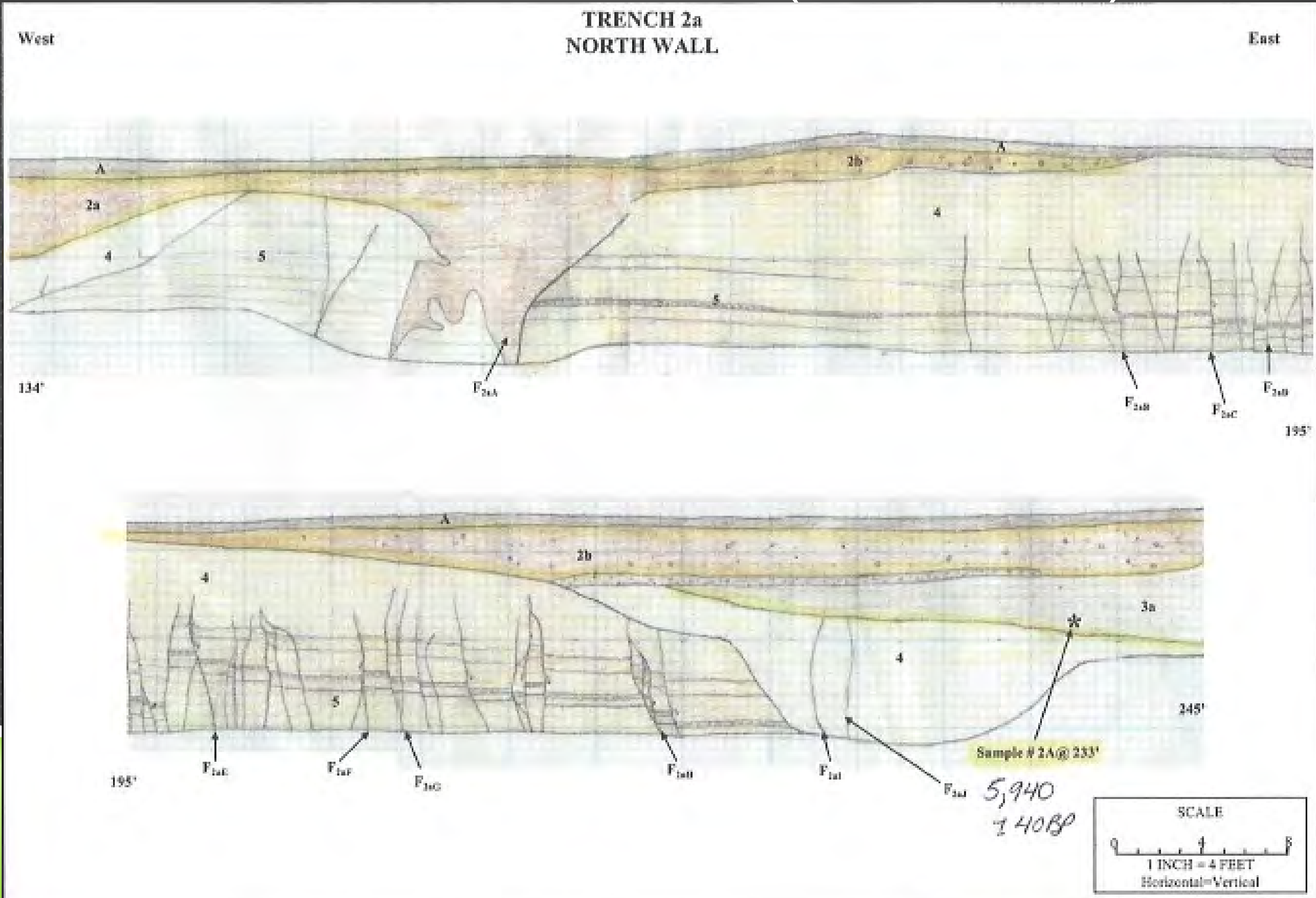
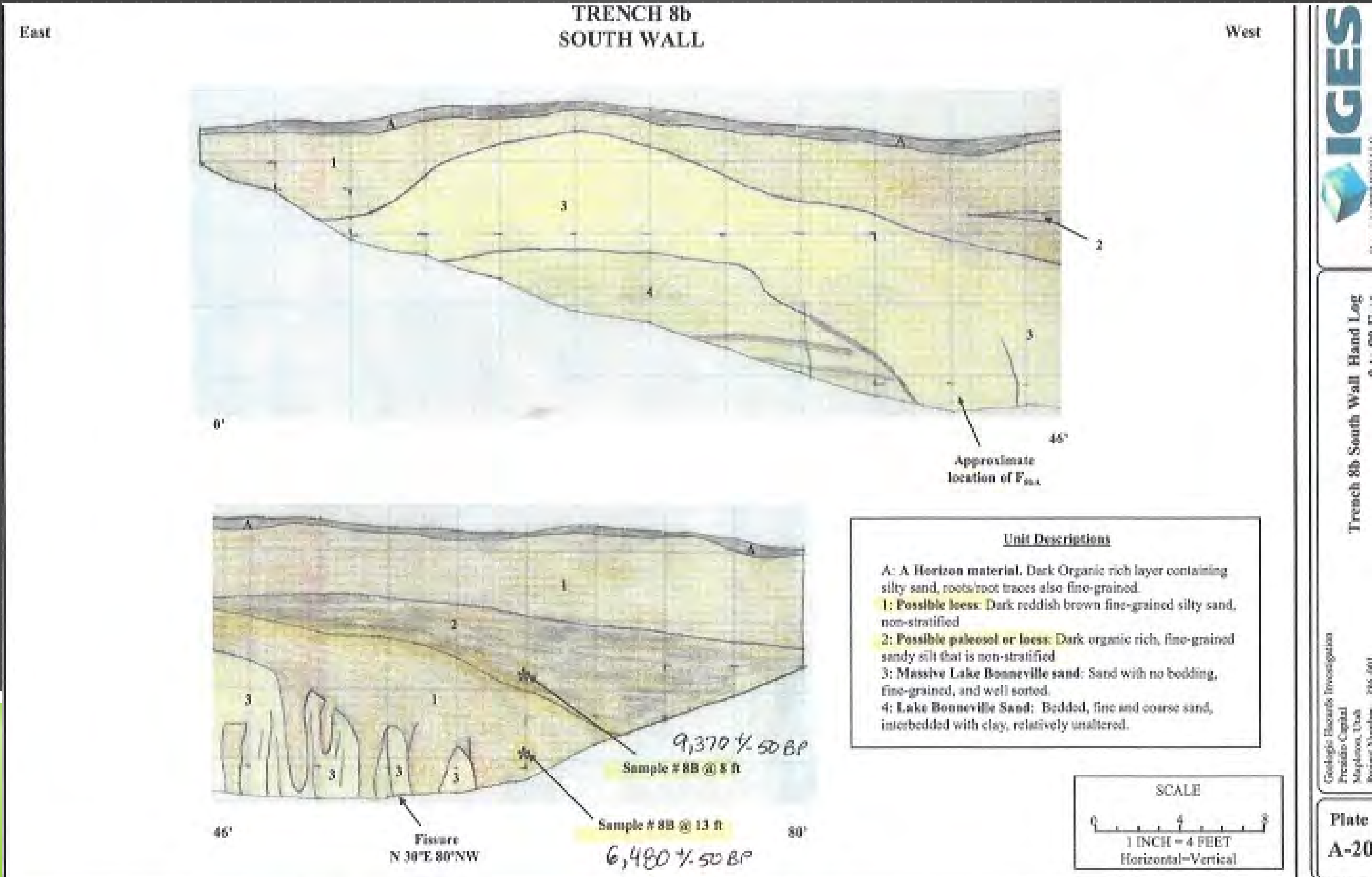
PEPPERWOOD HILLS (SBI, 2006)



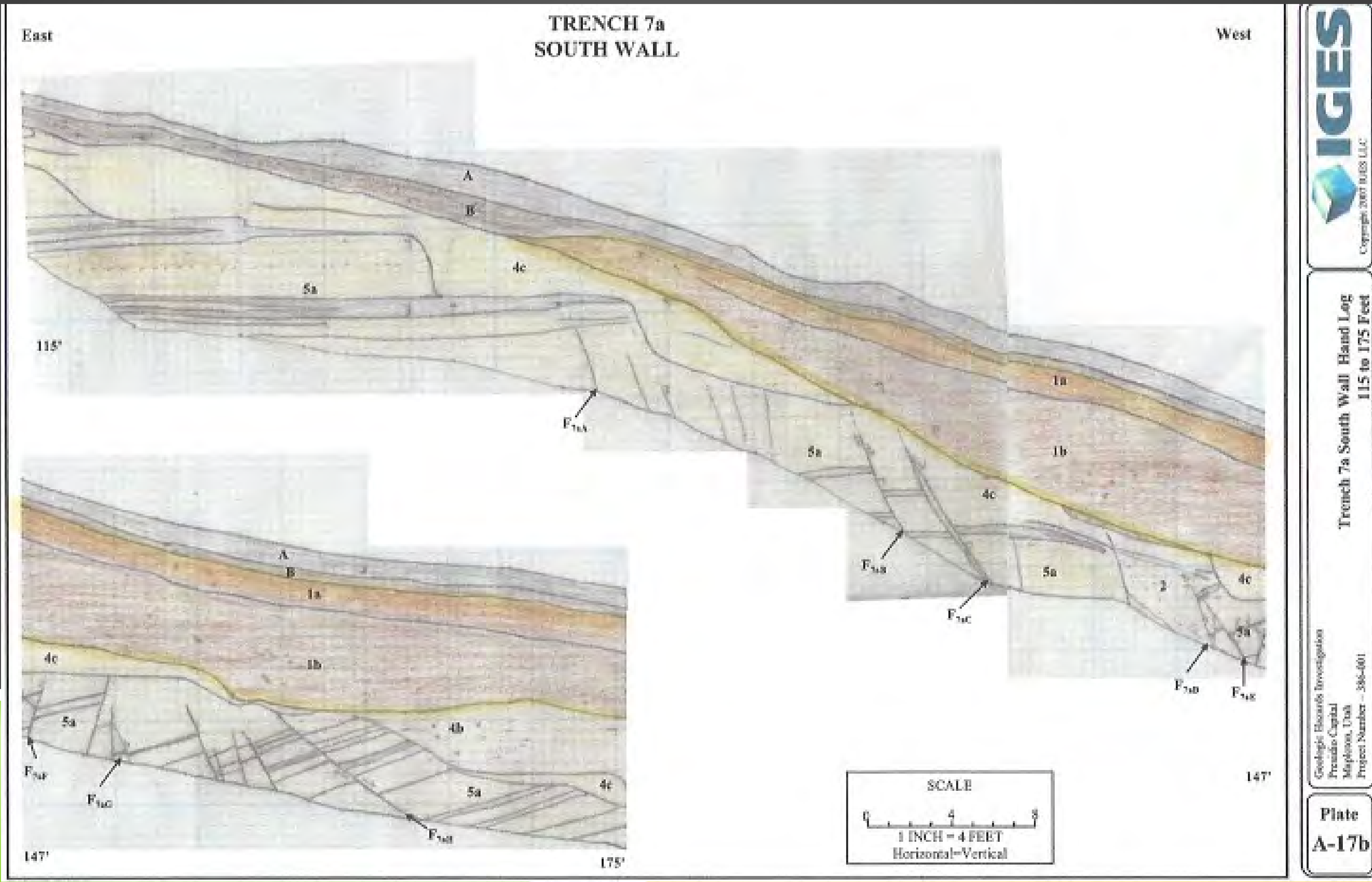
MAPLETON- PRESIDIO (IGES, 2006)



MAPLETON- PRESIDIO (IGES, 2006)



MAPLETON- PRESIDIO (IGES, 2006)



MAPLETON- PRESIDIO (IGES, 2006)

OTHER TYPES OF HOLOCENE DEPOSITS W/ POTENTIAL CLIMATE VARIABILITY:

HYPER-VOLUMINOUS, HYPER-MASSIVE DEBRIS FLOWS (DATES?)
(LOST CREEK ESTATES, PEPPERWOOD)

PROGRESSIVE FILLING AND/OR INCISION ALONG AXIAL GRABEN CHANNELS
(CANYON RACQUET CLUB, WASATCH OFFICE BLGS, MCCALPIN, MAPLETON)

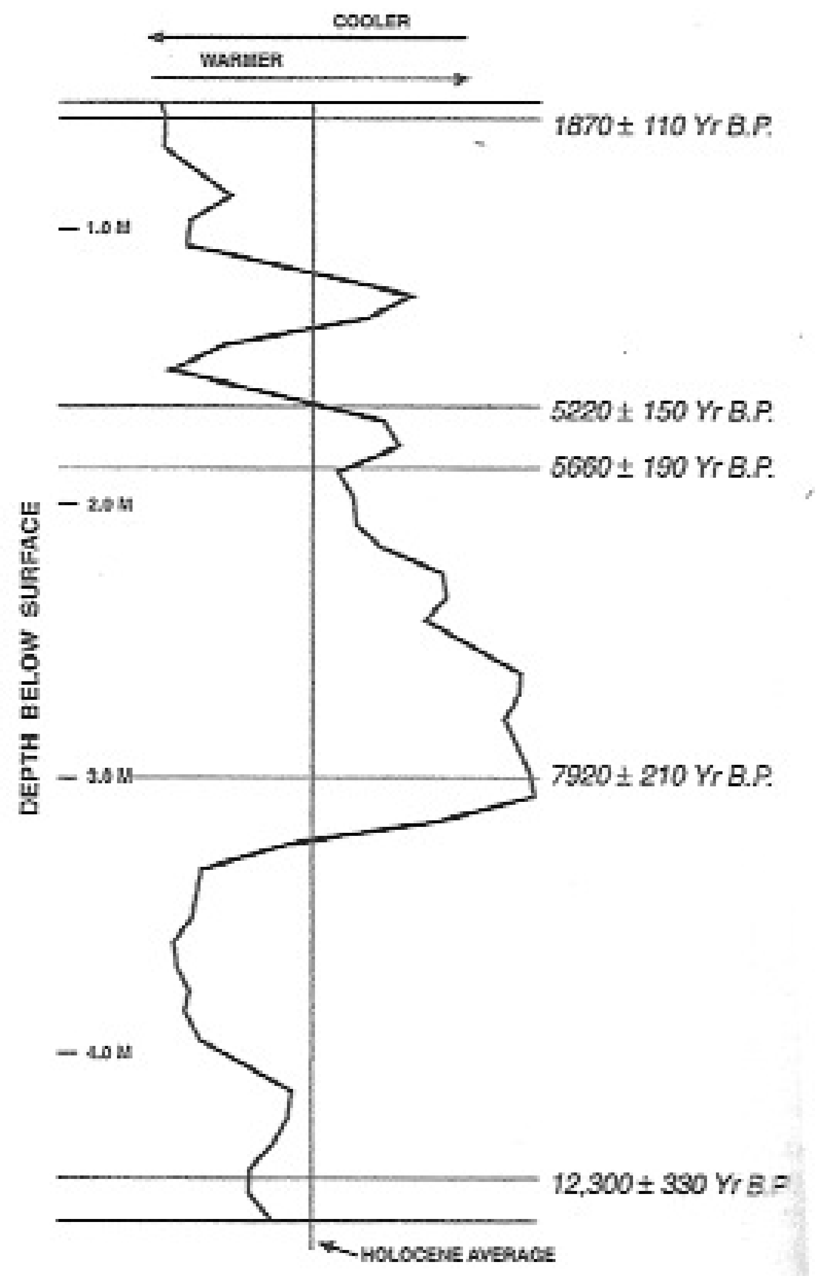


Figure 5. Estimate of Holocene temperature change in the Great Salt Lake basin based on changes in the relative proportion of conifer pollen to all other pollen at Snowbird Bog, Little Cottonwood Canyon, Wasatch Range, Utah. The curve is smoothed by a weighted three-level moving average. Modified from Madsen and Currey (1979).

PROPOSED STUDY

- Research Holocene climate variation & chronology (Madsen, Curry, Oviatt, et al)
- Compile available paleoseismology investigations:
- Document loess, etc. deposits that are/can be reliably dated:
  - Pepperwood Hills (SBI), Mapleton (IGES), Megatrench (McCalpin)
  - Others??
- Determine if loess etc horizons correlate reliably- Are the ages consistent? Do they correlate with significant climatic event(s)?
- What is the nature of loess vs. faulting history at each site?
- Is basin-ward migration of active fault splays observed?
- If certain fault traces are inactive during last 5-7 EQ events-

Are these 'active' traces?

POSSIBLE MODIFICATIONS TO ACTIVE FAULT CLASSIFICATION

- Depends on results of assessment, and
- Based on discussions w/ Working Group, etc professionals

OPTIONS:

- Performance-based: "Hazardous" vs. "Active"
- Following Bray (2013): "Hazardous" fault based on observed displacements (Δhoriz, Δvert), potential for damage to structure, design/engineering limitations
- If specific fault traces are demonstrated to be inactive during past (5-7?) EQ events AND if faulting is demonstrated to have shifted,

Are these 'inactive' fault traces?

PROPOSED TIMELINE

- Spring: Research & Interviews
  - Research Holocene climate variation & chronology
  - Review available paleoseismology investigations
- Summer: Field Work: Re-occupy trenches (if needed)
  - Pepperwood Hills (SBI), Mapleton (IGES), Megatrench (McCalpin)
  - Others??
- Fall: Reconvene to discuss findings
  - Gauge appetite & basis for reconsidering 'active' fault definition
- Shlemon Conference: Dialogue about "active" fault definition vs using a completely new criteria (hazardous vs. non-hazardous)
- *Please contact myself or Dave Simon with any information*

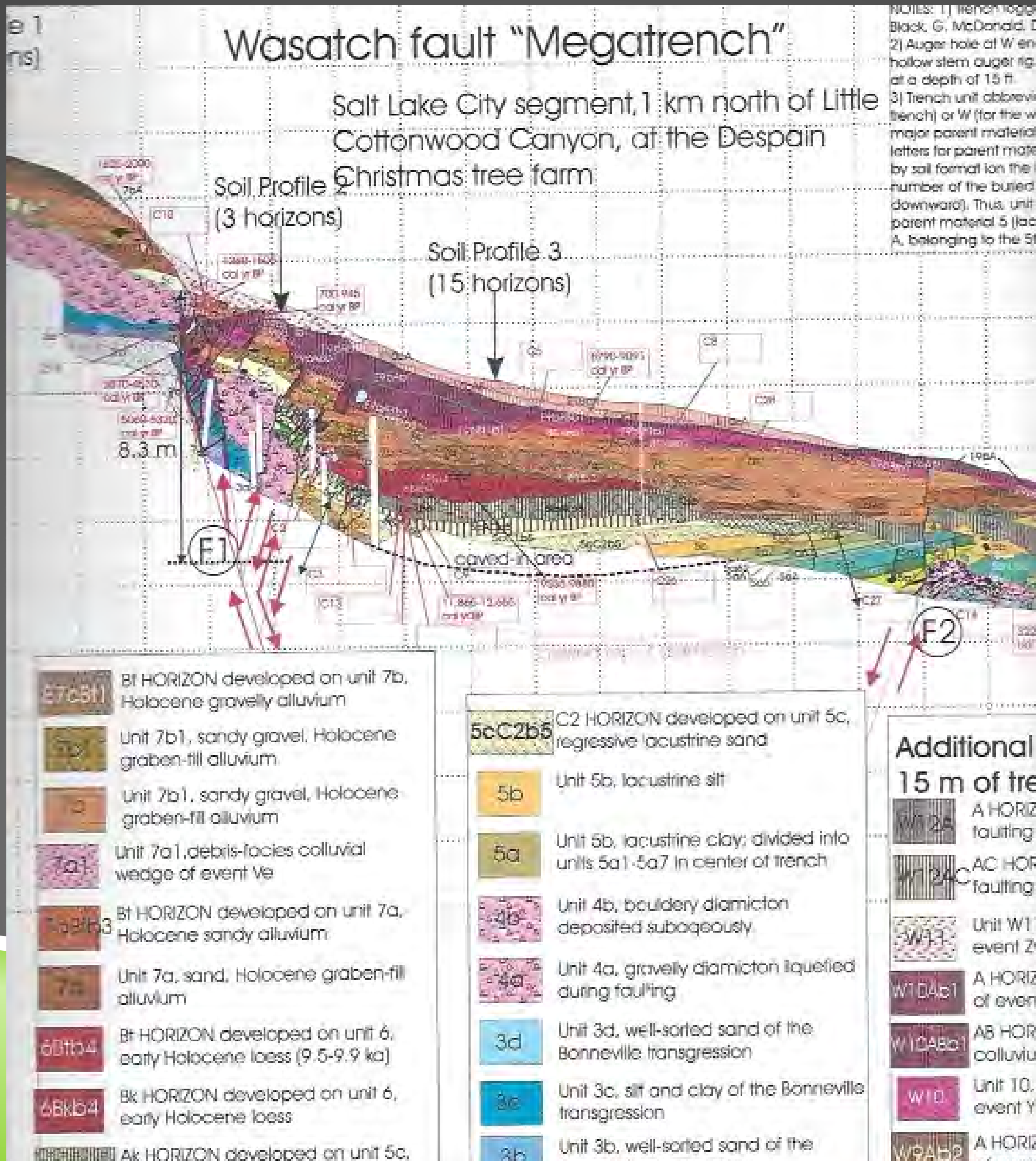
HAZARDOUS VS NON-HAZARDOUS FAULT? ONE POSSIBLE APPROACH?

- No longer use "Active" in regards to fault mitigation
- Possible Approach to fault mitigation based on engineering technology and fault characteristics – not age of fault
- Replace "active fault" with "hazardous fault" and "non-hazardous fault"
- Hazardous Fault: Cannot be mitigated by contemporary engineering technology
- Non-Hazardous Fault: Regardless of antiquity, surface displacement associated with the fault can be mitigated by contemporary engineering technology

HAZARDOUS VS NON-HAZARDOUS FAULT?

- What about schools, hospitals, critical facilities?
- How to address the low-probability high-consequence events?
- Does recurrence interval factor in?

MCCALPIN, 2000 LOESS UNIT 6



PITMAN & RYAN, 1998 "NOAH'S FLOOD"

PITMAN & RYAN, 1998 "NOAH'S FLOOD"

Fault/Fault Segment	Original UQFPWG Priority (2005)
Nephi segment WFZ	1
West Valley fault zone	2
Weber segment WFZ – most recent event	3
Weber segment WFZ – multiple events	4
Utah Lake faults and folds	5
Great Salt Lake fault zone	6
Collinston & Clarkston Mountain segments WFZ	7
Sevier/Toroweap fault	8
Washington fault	9
Cedar City-Parowan monocline/ Paragonah fault	10
Enoch graben	11
East Cache fault zone	12
Clarkston fault	13
Wasatch Range back-valley faults	14
Hurricane fault	15
Levan segment WFZ	16
Gunnison fault	17
Scipio Valley faults	18
Faults beneath Bear Lake	19
Eastern Bear Lake fault	20
Bear River fault zone	2007
Brigham City segment WFZ – most recent event	2007
Carrington fault (Great Salt Lake)	2007
Provo segment WFZ – penultimate event	2007
Rozelle section – East Great Salt Lake Fault	2007
Salt Lake City segment WFZ – northern part	2009
Warm Springs fault/East Bench fault subsurface geometry and connection	2010
Brigham City segment WFZ rupture extent (north and south ends)	2011
Long-term earthquake record northern Provo segment WFZ	2011
West Valley fault zone – Taylorsville fault	2011
Hansel Valley fault	2011
Acquire new paleoseismic information in data gaps along the five central segments of the WFZ	2012

2012 Highest Priority Faults/Fault Sections For Study			
Fault/Fault Section[1]	**Investigation Status**		**Investigating Institution[2]**
Acquire new paleoseismic information in data gaps along the five central segments of the WFZ – e.g., (a) Brigham City segment rupture extent (north and south ends); (b) long-tern earthquake record northern Provo segment; (c) long-term earthquake record southern Weber segment.	BYU LiDAR study BYU Utah Lake sediment study		BYU
Penultimate event Provo segment WFZ	No activity		
West Valley fault zone – Taylorsville fault	Consultant’s trench of opportunity		UGS
Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution[2]**
Cedar City-Parowan monocline/Paragonah fault[3]	10	No activity	
Enoch graben	11	No activity	
Clarkston fault[3]	13	Black and others (2000)	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Rozelle section, Great Salt Lake fault[4]	2007	No activity	
Warm Springs fault/East Bench fault subsurface geometry and connection[4]	2010	No activity	
Faults/Fault Sections Studies Complete or Ongoing			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution[2]**
Nephi segment WFZ	1	UGS Special Study 124 USGS Map 2966 Ongoing	UGS/USGS
West Valley fault zone (Granger fault)	2	Ongoing	UGS/USGS
Long-term earthquake record Nephi segment WFZ	2012	Ongoing	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Ongoing	UUGG/BYU
Great Salt Lake fault zone	6	Ongoing	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
Washington fault zone	9	Contract deliverable FTR	UGS
East Cache fault zone	12	Contract deliverable FTR	USU
Wasatch Range back-valley fault (Main Canyon fault)	14	UGS Miscellaneous Publication 10-5	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Ongoing	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north part	2009	Ongoing	UGS/USGS
Hansel Valley fault[3]	2011	McCalpin, (1985), Robinson (1986), McCalpin and others (1992), UUGG ongoing	UUGG