UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP

Tuesday, February 10, 2009

WELCOME

UQFPWG

- **One of three standing committees created to help set and coordinate the earthquake-hazard research agenda for the State of Utah.**

- **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.**

2008 MEETING REVIEW

Presentations on work completed/in progress

- Nephi segment, Spring Lake trenching update – UVSC
- Weber segment, Rice Creek trenching results – UGS
- East Cache fault zone trenching update – USU
- East Canyon and Main Canyon fault trenching results – USBR
- Washington fault reconnaissance – UGS
- Upcoming Brigham City segment trenching – UGS
- Vertical displacement on the central segments of the Wasatch fault zone – UGS
- Update on EarthScope/Lidar studies in Utah, new GPS data for the Wasatch Front, and ideas on fault segment scale – UUGG

2008 MEETING REVIEW

(Continued)

Technical discussion items

- New Levan segment vertical-slip-rate estimate – UGS
- New Nephi segment vertical-slip-rate and recurrence-interval estimates – UGS /USGS
- UQFPWG fault priorities for 2009
- Wasatch Front community fault model
- Time dependent earthquake models – is the Wasatch fault a candidate?

2009 FAULT PRIORITY LIST

2009 Highest Priority Faults/Fault Sections For Study			
Fault/Fault Section	**Priority[1]**	**Investigation Status**	**Investigating Institution**
Provo segment – penultimate event	1	No activity	
West Valley fault zone	1	No activity	
Washington fault	3	Reconnaissance study	UGS
Carrington fault (Great Salt Lake)	4	No activity	
Rozelle section, Great Salt Lake fault	5	No activity	
Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**
Cedar City-Parowan monocline/ Paragonah fault	10	No activity	
Enoch graben	11	No activity	
Clarkston fault	13	No activity	
Wasatch Range back-valley faults	14	No activity	
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	
Bear River fault zone	2007	No activity	
Faults/Fault Sections Studies Complete or Ongoing			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**
Nephi segment WFZ	1	UGS Special Study 124/USGS Map 2966/UVSC study ongoing	UGS/USGS/UVSC
Weber segment WFZ - most recent event	3	Ongoing	UGS/USGS
Weber segment WFZ – multiple events	4	Ongoing	UGS/USGS
Utah Lake faults and folds	5	Study begins summer 2008	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
Hurricane fault	15	UGS Special Study 119	UGS
Levan	16	UGS Map 229	UGS
Brigham City section - most recent event	2007	Study begins summer 2008	UGS/USGS

AGENDA

QUATERNARY FAULT PARAMETERS WORKING GROUP

Tuesday, February 10, 2009
Utah Department of Natural Resources Building, Room 1010
1594 West North Temple, Salt Lake City

7:30	Continental breakfast
8:00	Introduction, overview of meeting, review of last year's activities
8:20	Technical presentations of work completed or in progress 8:20 – Nephi segment, Spring Lake trenching update; Danny Horns, UVSC 8:40 – Weber segment, Rice Creek trenching update; Chris DuRoss, UGS 9:00 – Brigham City segment, trenching update; Tony Crone, USGS 9:20 – East Cache fault zone trenching update; Stephanie Davi, USU 9:40 – Geologic evidence of high-stress-drop earthquakes in the Rocky Mountains; Suzanne Hecker, USGS
10:00	Break
10:20	Technical presentations of work completed or in progress (continued) 10:20 –Evaluating the seismic potential of the Joes Valley fault zone; Lucy Piety, USBR 10:40 – New Lidar data for the southern Wasatch fault; Ron Bruhn, U of U 11:00 – Update on contemporary deformation and stress field of the Wasatch Front; Christine Puskas, U of U
11:20	Technical discussion items 11:20 – Issues regarding the NSHM generalization of the Salt Lake City segment (Wasatch fault) surface trace; Jim Pechmann, U of U 11:40 – Discussion
12:00	Lunch

12:30 **Technical discussion items - West Valley Fault Zone, Part 1**

- **12:30 – The "WVFZ problem" and why it is a NSHM issue; Bill Lund, UGS**
- **12:50 – Geologic and paleoseismic review of the WVFZ, geometry and paleoseismic history of the two fault strands, data quality, and evidence for coseismic rupture with the Wasatch fault; Mike Hylland, UGS**
- **1:10 – WVFZ rupture models (simultaneous, clustered, independent, others?); issues encountered in modeling the WVFZ/WFZ interaction, details of the model selected for this version of the NSHMs; Steve Harmsen, USGS**
- **1:30 – How URS treats the WVFZ in their PSHAs; Ivan Wong, URS Corp**
- **1:50 – Final WVFZ model, implications for hazard calculations, recommendations for future research to improve the model; Mark Petersen, USGS**
- **2:10 – Discussion regarding new data required to improve the WVFZ model**

2:30 **Break**

2:50 **Technical discussion items - West Valley Fault Zone, Part 2**

- **2:50 – Other active, graben-producing fault pairs in Utah/Basin and Range Province and issues they raise regarding the NSHMs; Kathy Haller, USGS**
- **3:10 – The East and West Cache Valley fault pair as an example, what do we know about the geometry and earthquake history of these two faults, do they potentially intersect above seismogenic depths, is coseismic rupture a possibility, how are they the same/different from the WVFZ; Chris Du Ross, UGS**
- **3:30 – Discussion of how to handle active fault pairs on the NSHMs in Utah**

3:50 **Break**

4:00 **UQFPWG 2010 fault priorities**

5:00 **Adjourn**

New constraints on the history of large earthquakes along the Nephi segment of the Wasatch fault, Utah.

Daniel Horns, Kevin A. Rey, Donald Bagshaw, Mallory Palmer, R. Dawn McShinsky, Rachelle M. Vanderplas, Connie S. Barnes,
Department of Earth Science, Utah Valley University, Orem, Utah.

UTAH VALLEY UVU UNIVERSITY

With plenty o’ help from Chris DuRoss and Greg McDonald
Utah Geological Survey

New constraints on the history of large earthquakes along the Nephi segment of the Wasatch fault, Utah.

1. Introduction to the Nephi segment of the Wasatch Fault

2. How UVU became involved

3. Results

The three southern segments of the Wasatch Fault

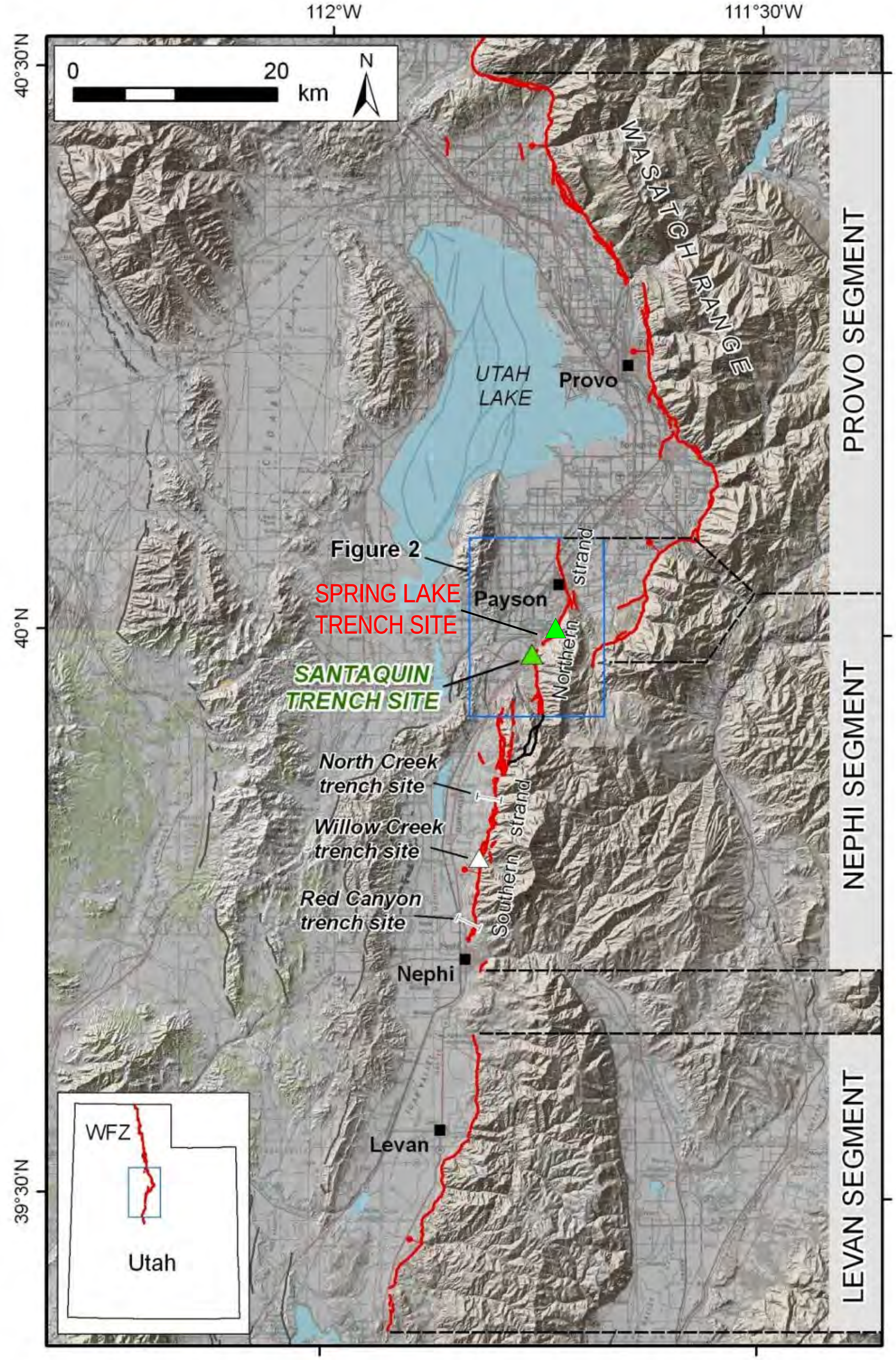


Figure from DuRoss and others, 2008.

UTAH GEOLOGICAL SURVEY

SURVEY NOTES

Volume 39, Number 1 January 2007

Previous investigations on the Nephi segment

North Creek (Hanson and others, 1981)
P1: 300-500? P2: ≥3700-4100

Red Canyon (Jackson, 1991)
P1: ≤1,400   P2: 3,000 - 3500

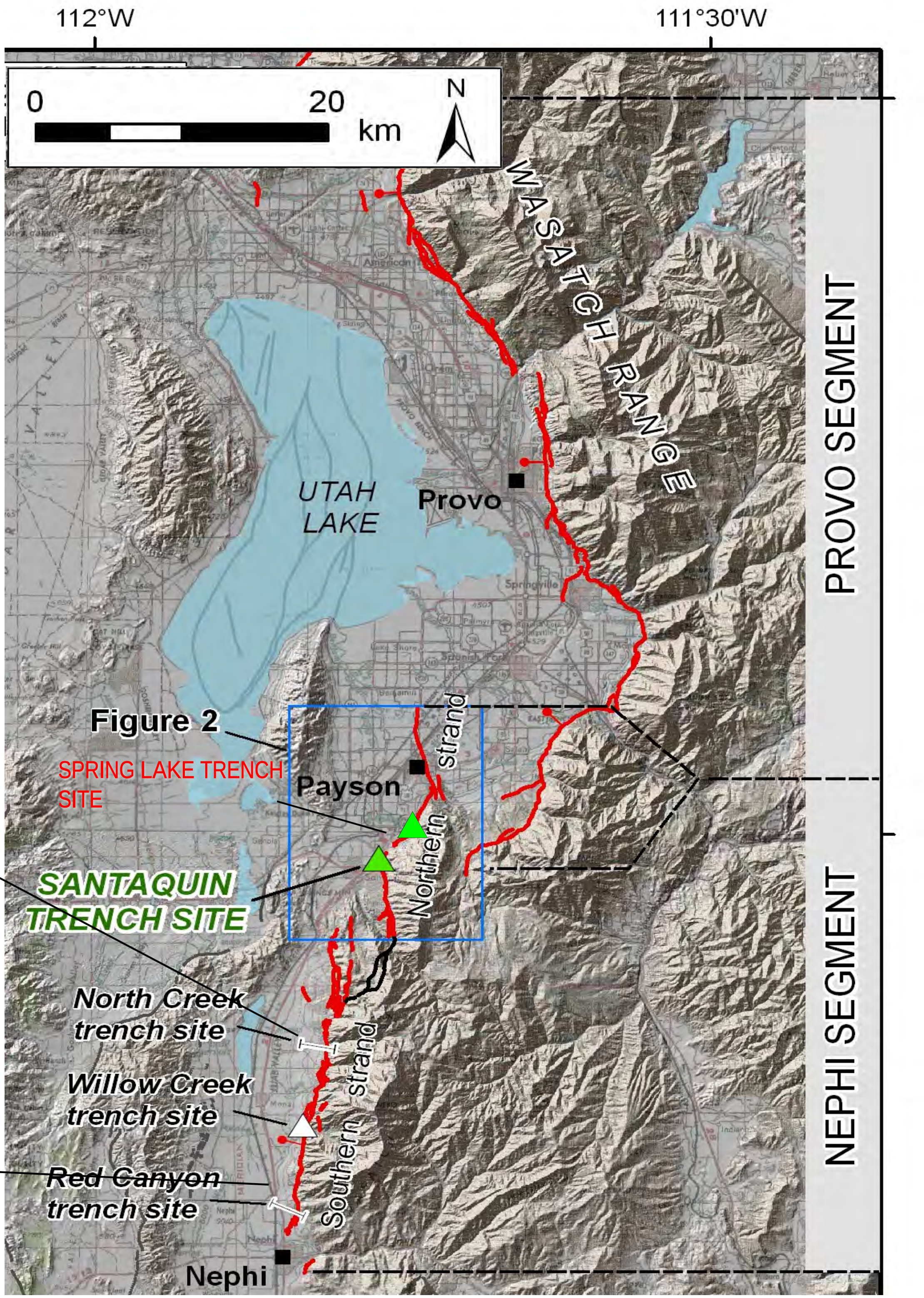


Fig. from DuRoss and others, 2008.

Santaquin (DuRoss and others, 2008)
P1: 500 +100/-150 yr BP

Machette and others, 2007
P1:   300 yr BP
P2:   1230 yr BP
P3: ≤ 2320 yr BP

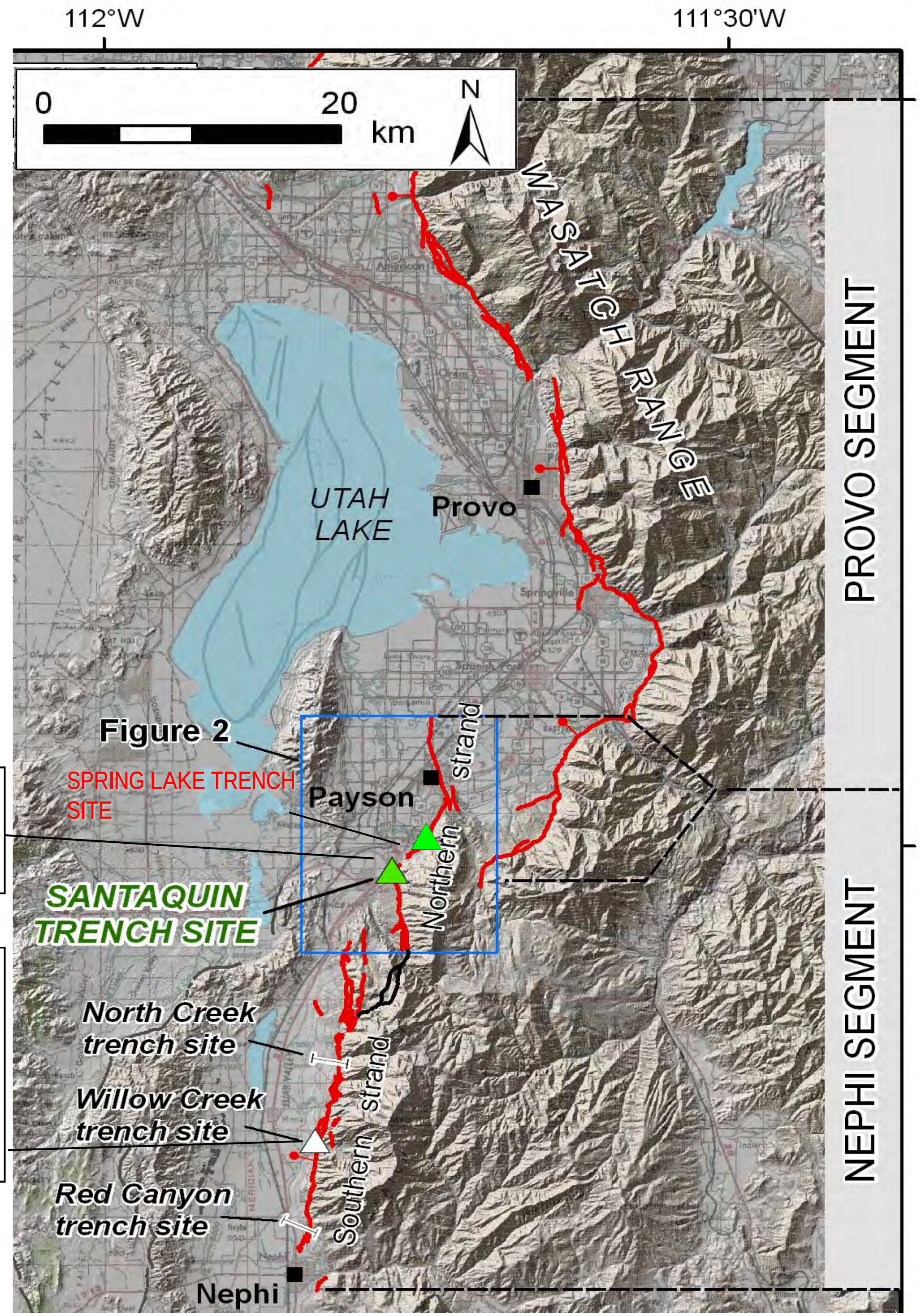


Fig. from DuRoss and others, 2008.

The best estimates as of 2008 (Crone and others, 2008)
P1: 150-400 yr BP
P2: 1100 – 1400 yr BP
P3: 1600-2550 yr BP

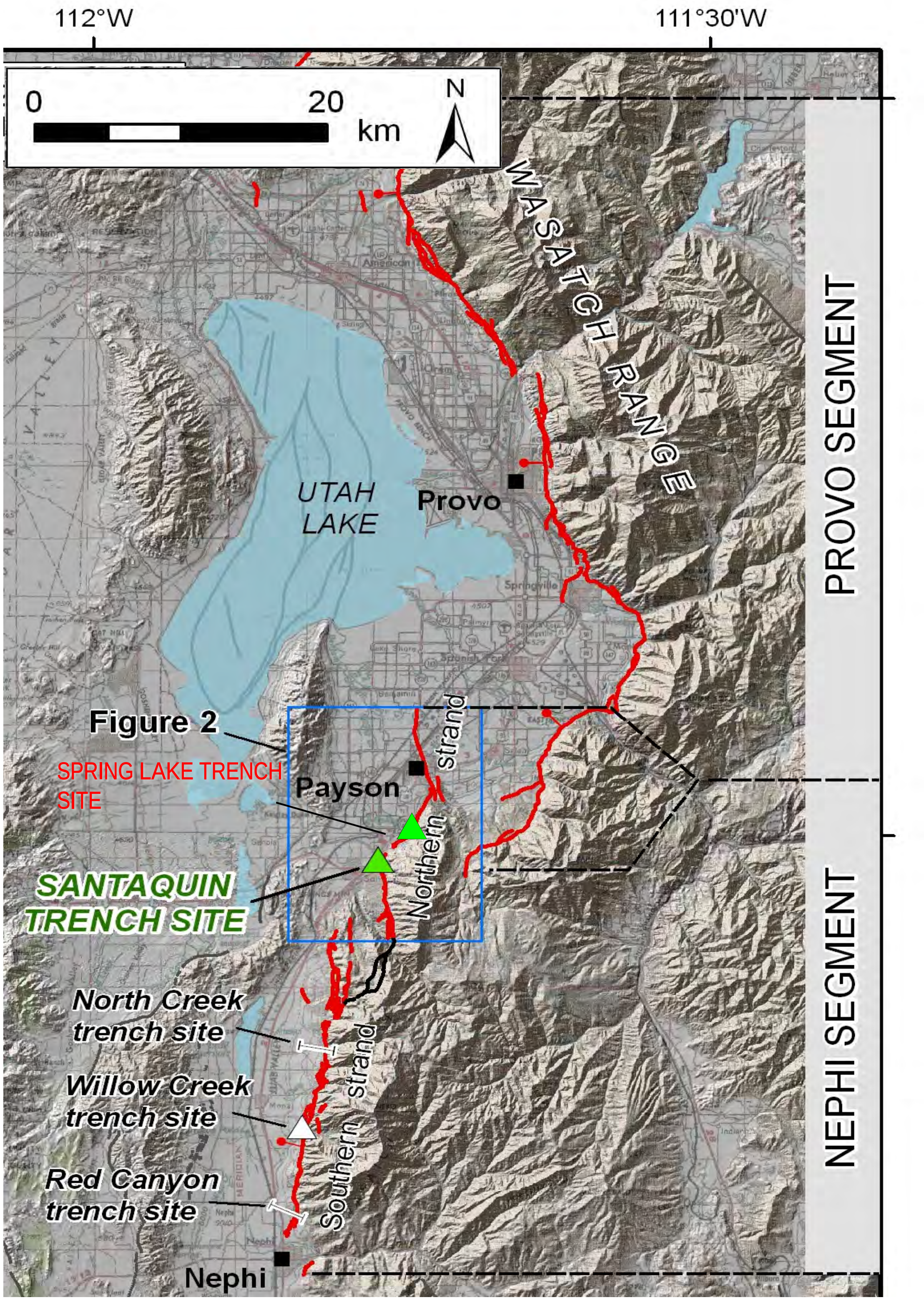


Fig. from DuRoss and others, 2008.

Paleoseismic Investigation of the Wasatch Fault Near Spring Lake, Utah

1. Introduction to the Nephi segment

2. How UVU became involved

3. Results

Summer field project for 2006...

UGS: “Take another look at the northern strand of the Nephi segment.”

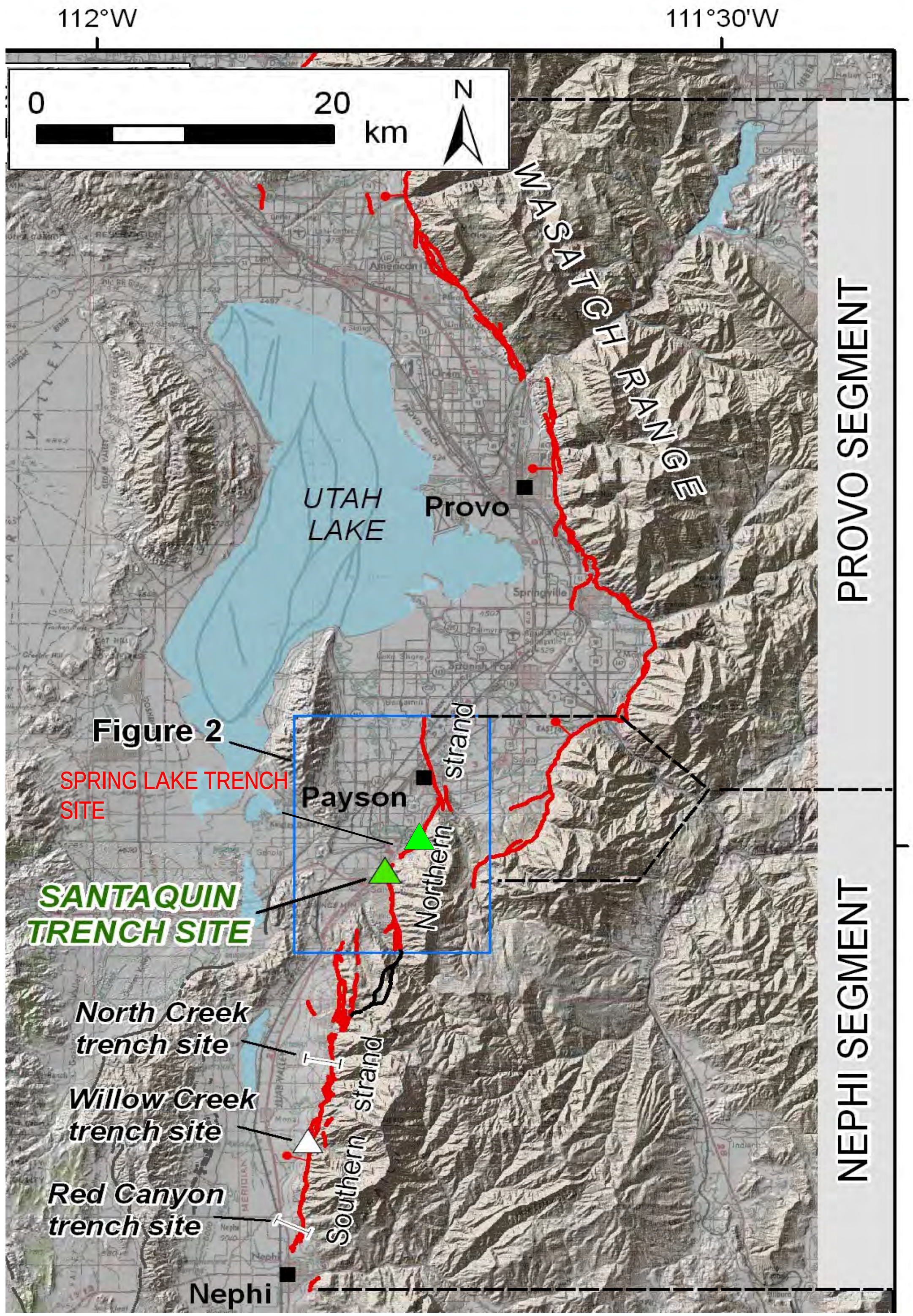


Fig. from DuRoss and others, 2008.

Closeup of the northern strand of the Nephi segment

•Separated from the Southern Strand by a step-over

•Near the step-over to the Provo Segment

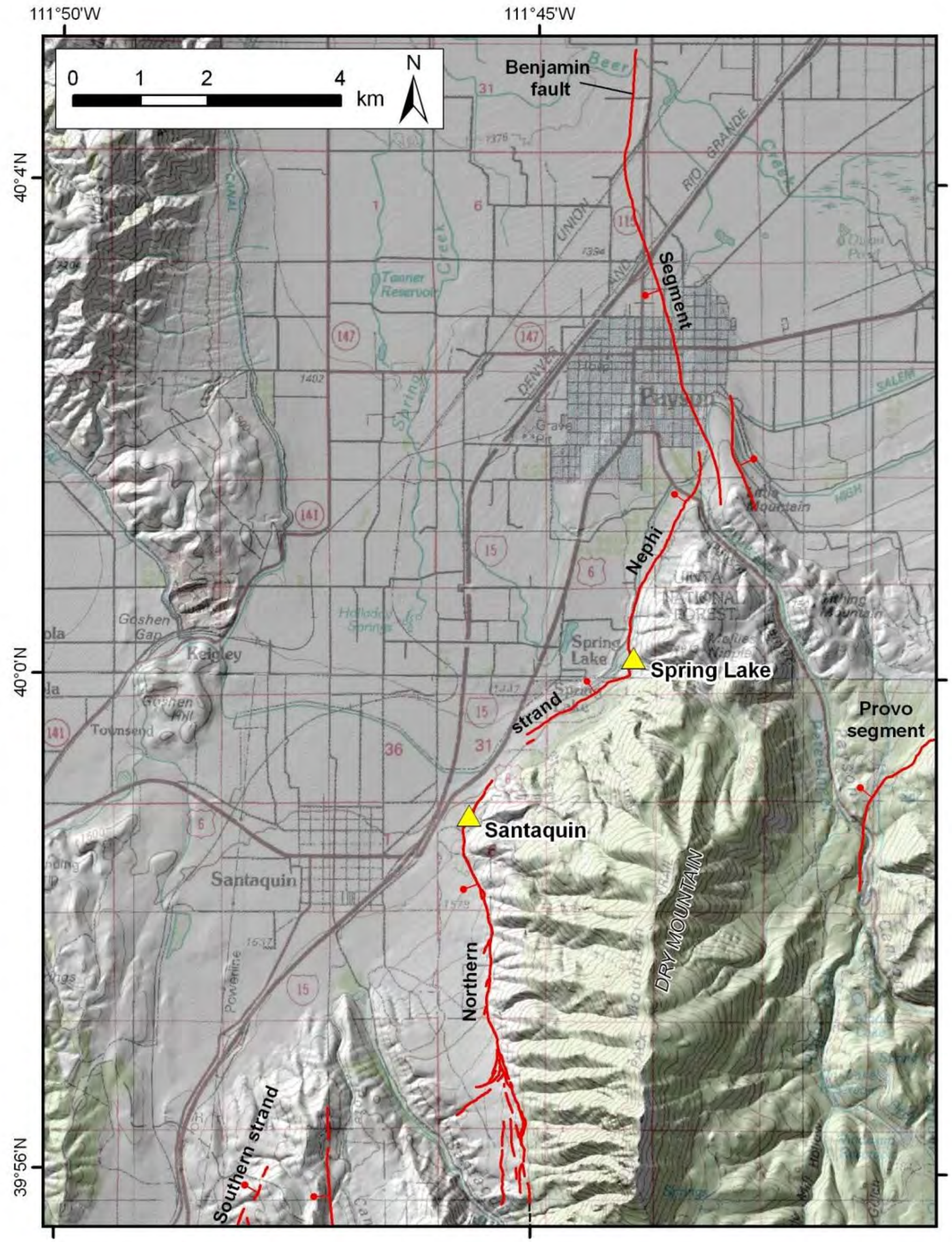


Fig. from DuRoss and others, 2008.

Summer field project for 2006:

Focus on Spring Lake area

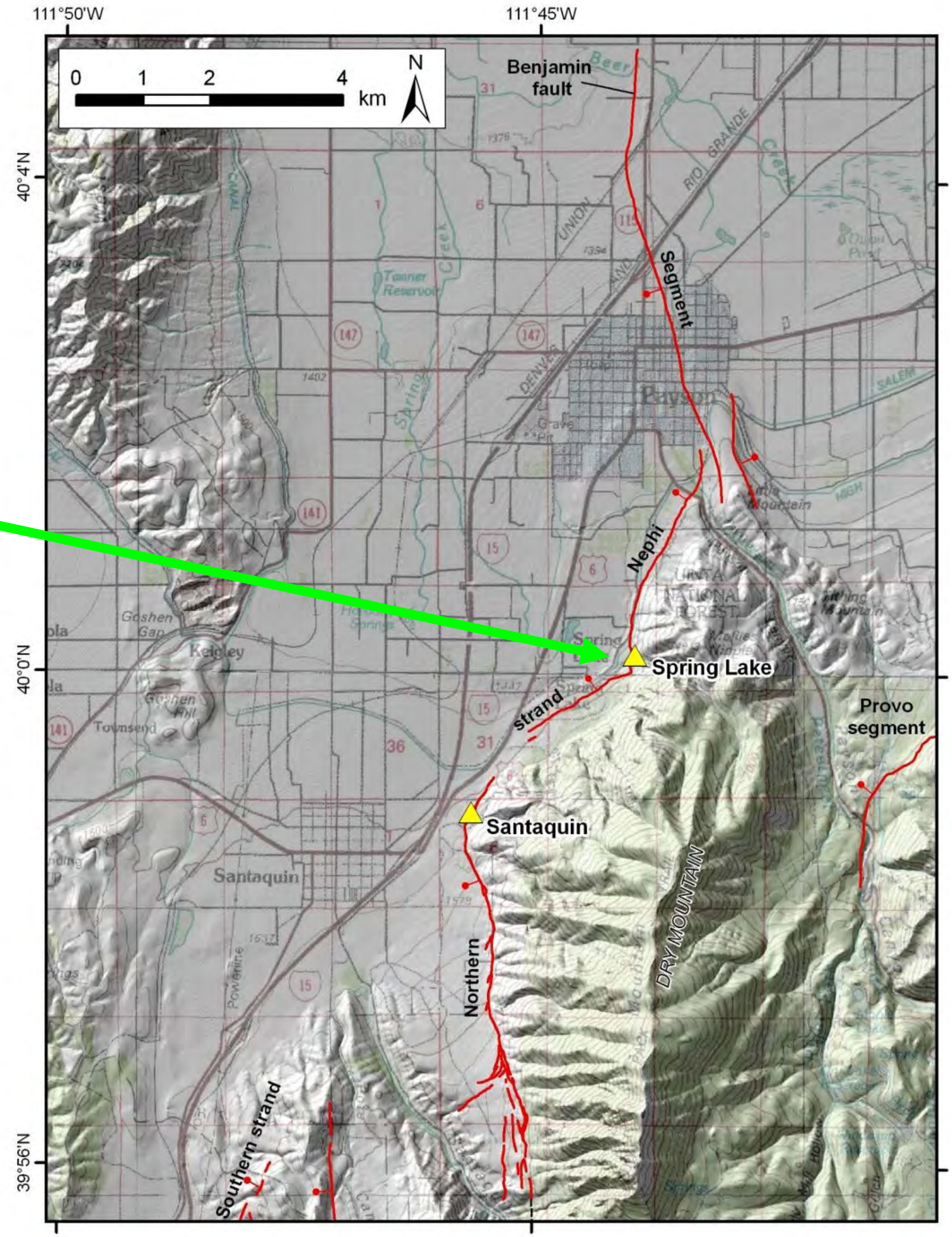


Fig. from DuRoss and others, 2008.

Summer field project for 2006?

Focus on Spring Lake area

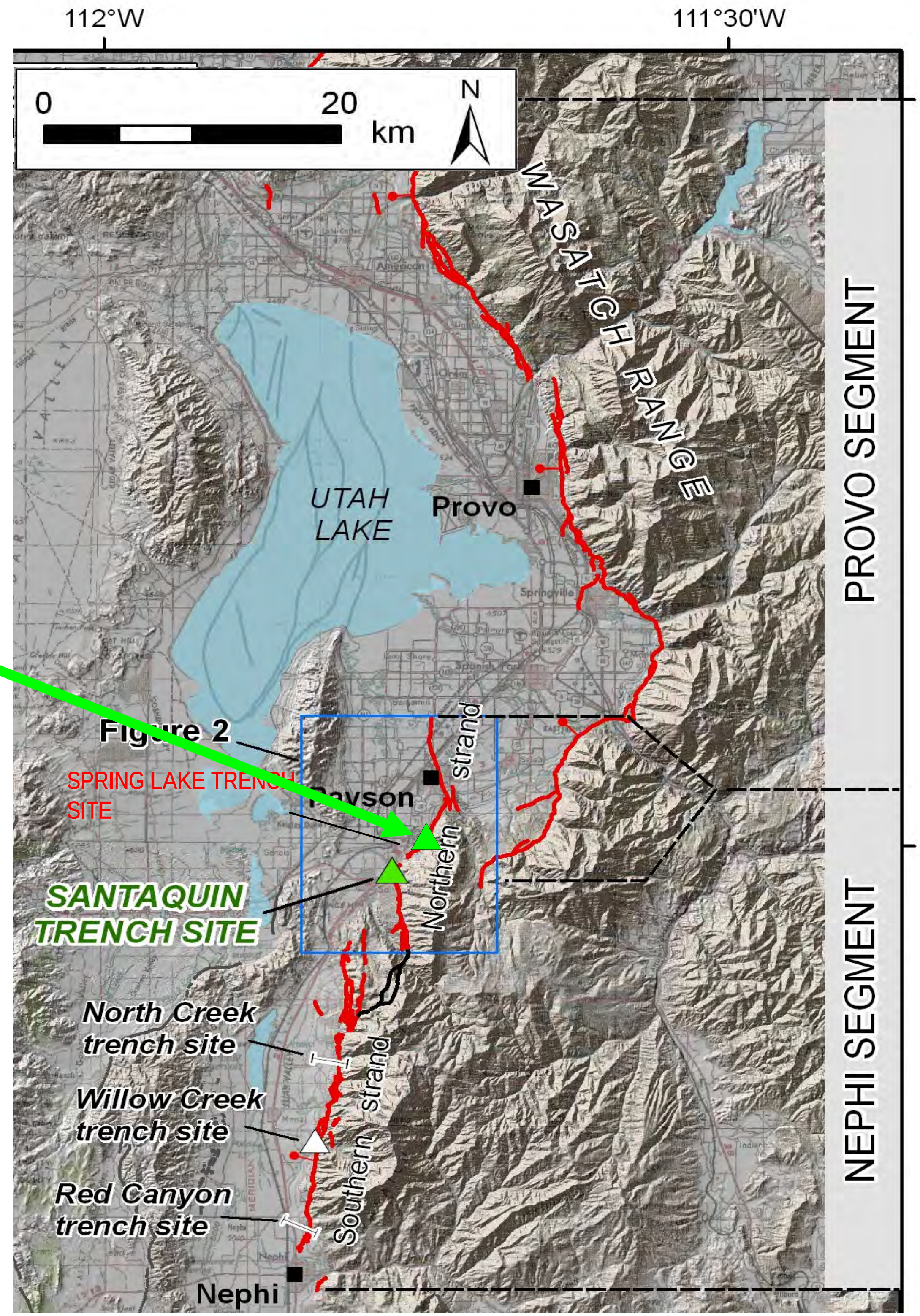
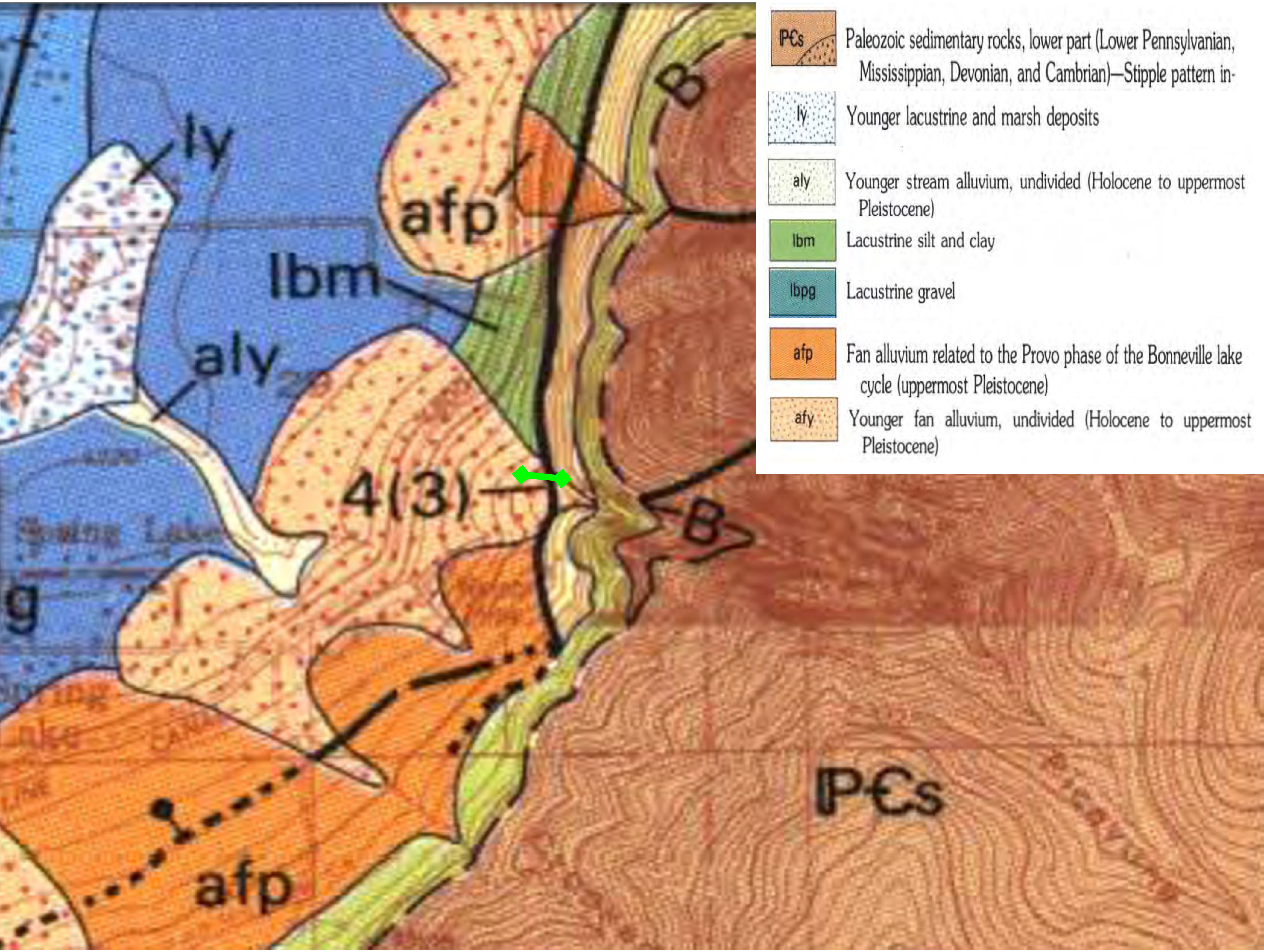


Fig. from DuRoss and others, 2008.

Spring Lake area on an old Woodward Clyde photo



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afp
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aly
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B
B
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afp
PЄs
PЄs
Paleozoic sedimentary rocks, lower part (Lower Pennsylvanian, Mississippian, Devonian, and Cambrian)—Stipple pattern in-
ly
Younger lacustrine and marsh deposits
aly
Younger stream alluvium, undivided (Holocene to uppermost Pleistocene)
lbm
Lacustrine silt and clay
lbpg
Lacustrine gravel
afp
Fan alluvium related to the Provo phase of the Bonneville lake cycle (uppermost Pleistocene)
afy
Younger fan alluvium, undivided (Holocene to uppermost Pleistocene)

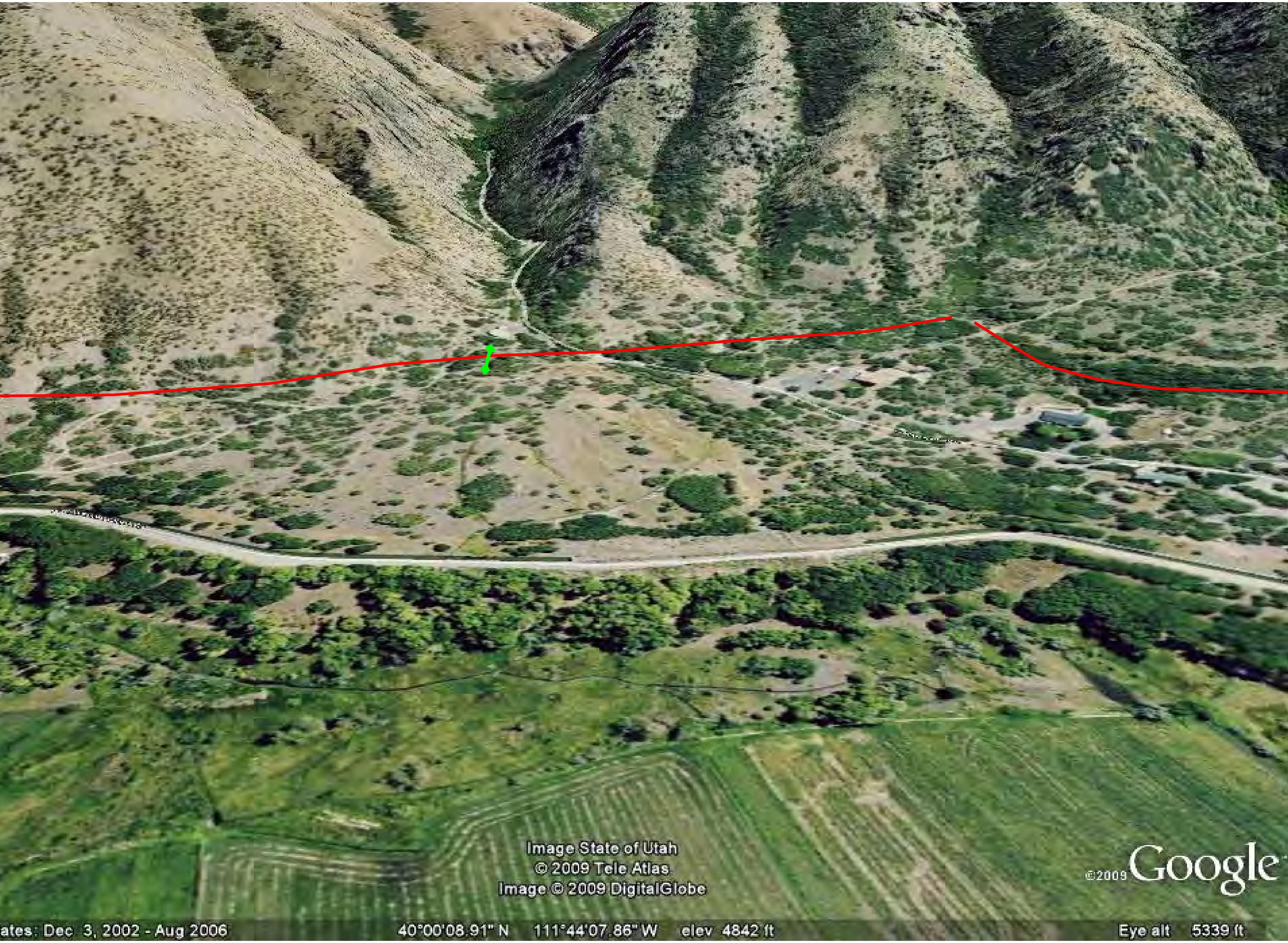
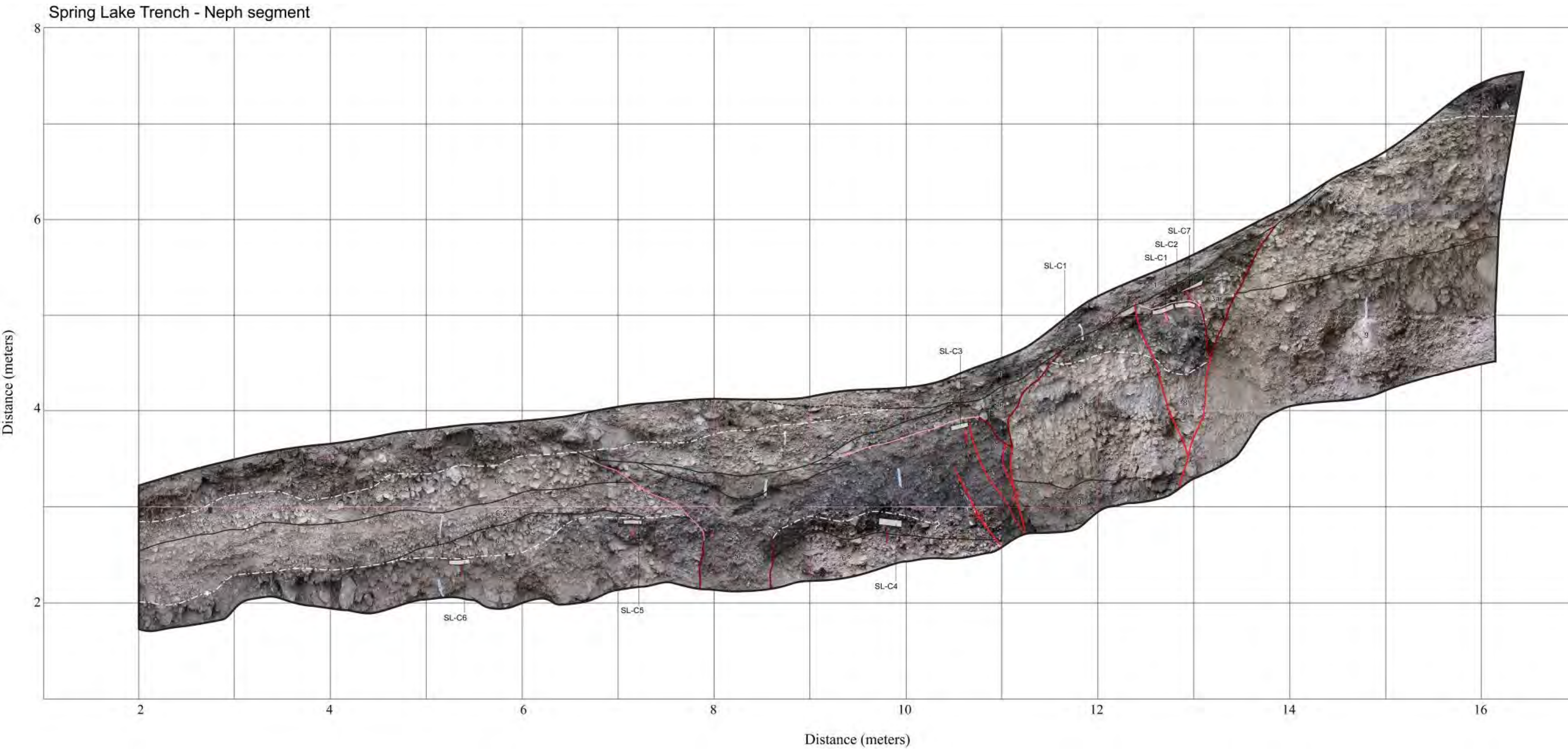


Image State of Utah
© 2009 Tele Atlas
Image © 2009 DigitalGlobe
©2009 Google
ates: Dec 3, 2002 - Aug 2006
40°00'08.91" N
111°44'07.86" W
elev 4842 ft
Eye alt 5339 ft

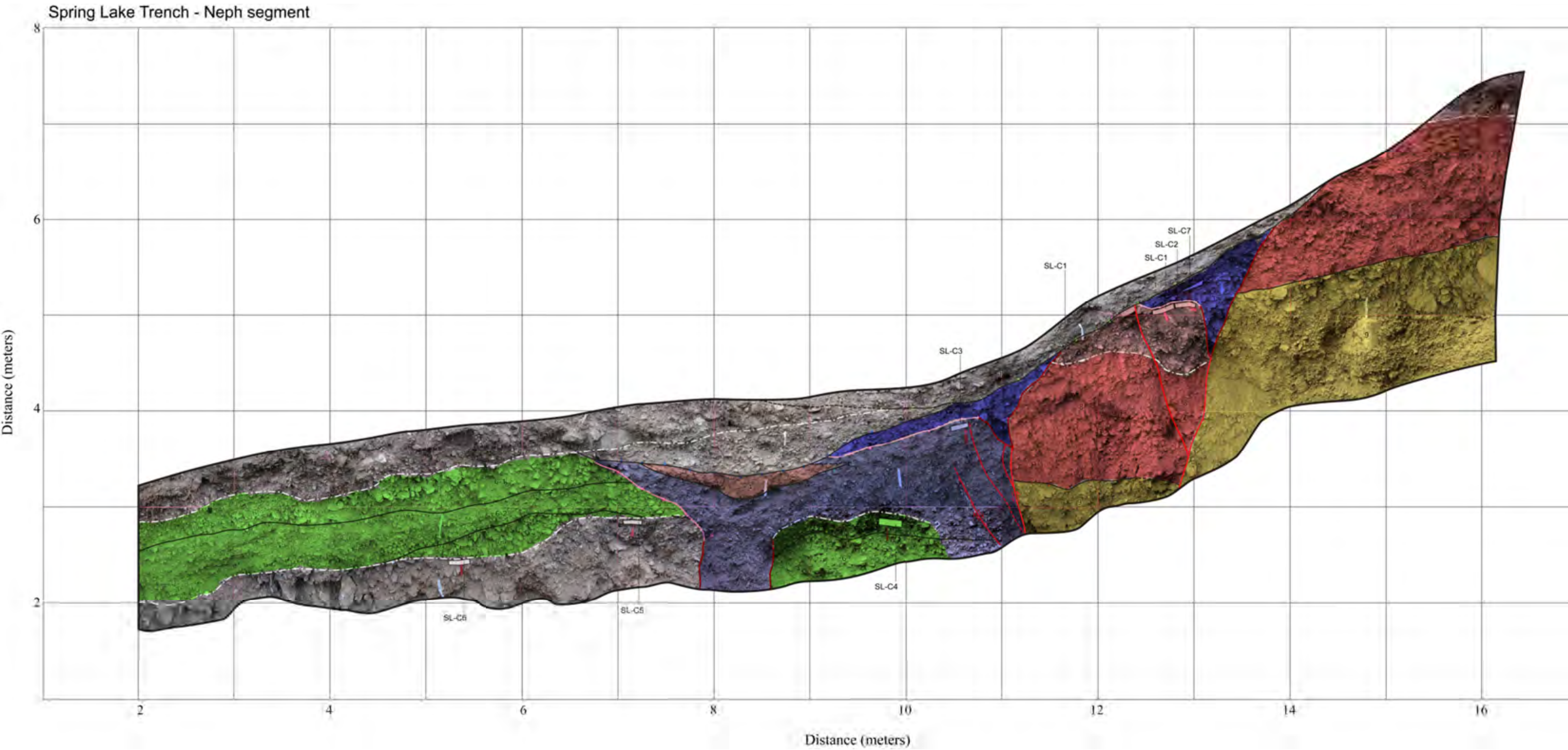
It quickly became apparent that we had fairly well-defined debris flow deposits and very well-defined colluvial wedges.

Paleoseismic Investigation of the Wasatch Fault Near Spring Lake, Utah

1. Introduction to the Nephi segment
2. How UVSC students became involved
3. Results



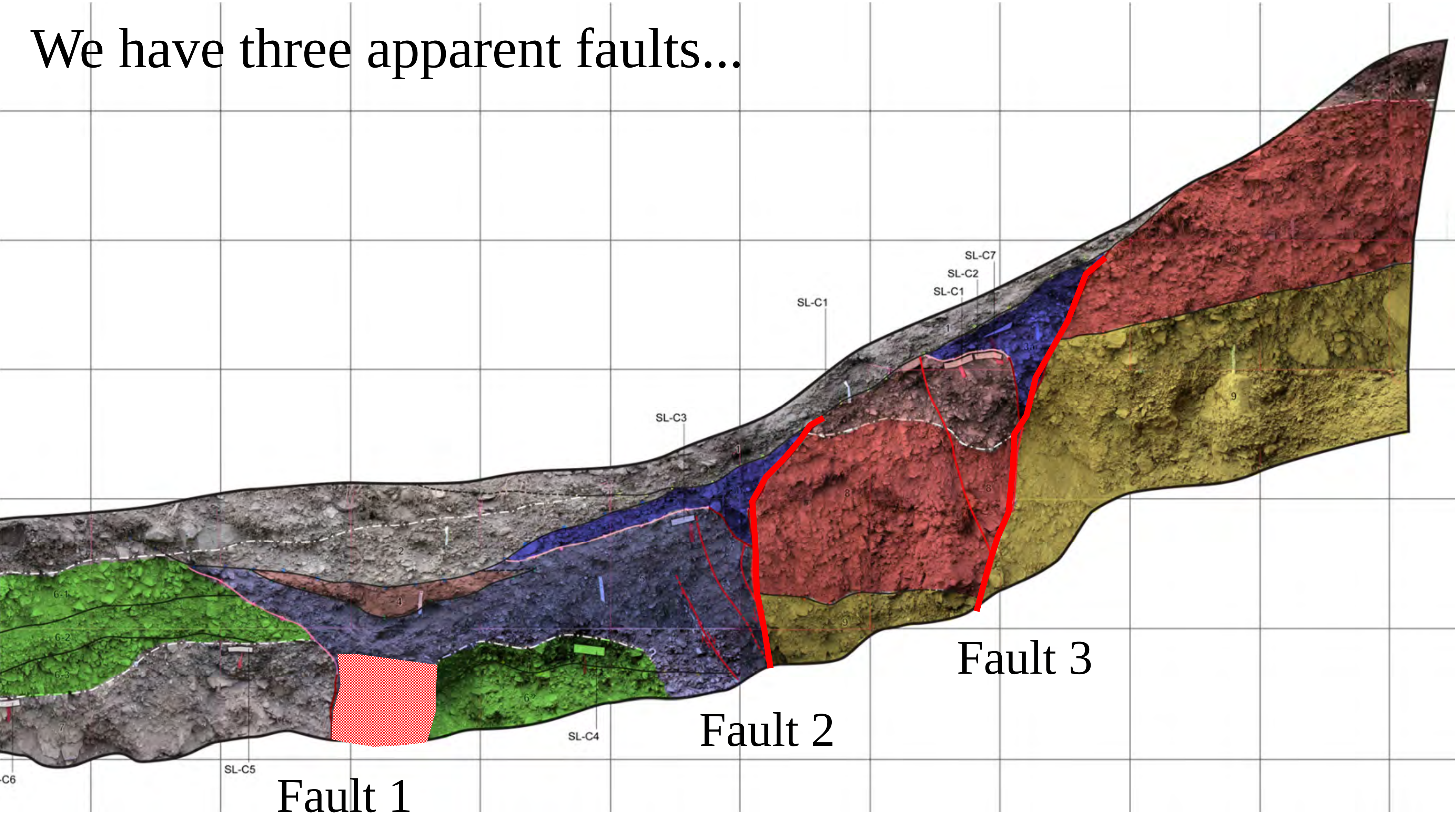
Photomosaic of the north wall (by Chris DuRoss) with interpretations of faults and sedimentary units.



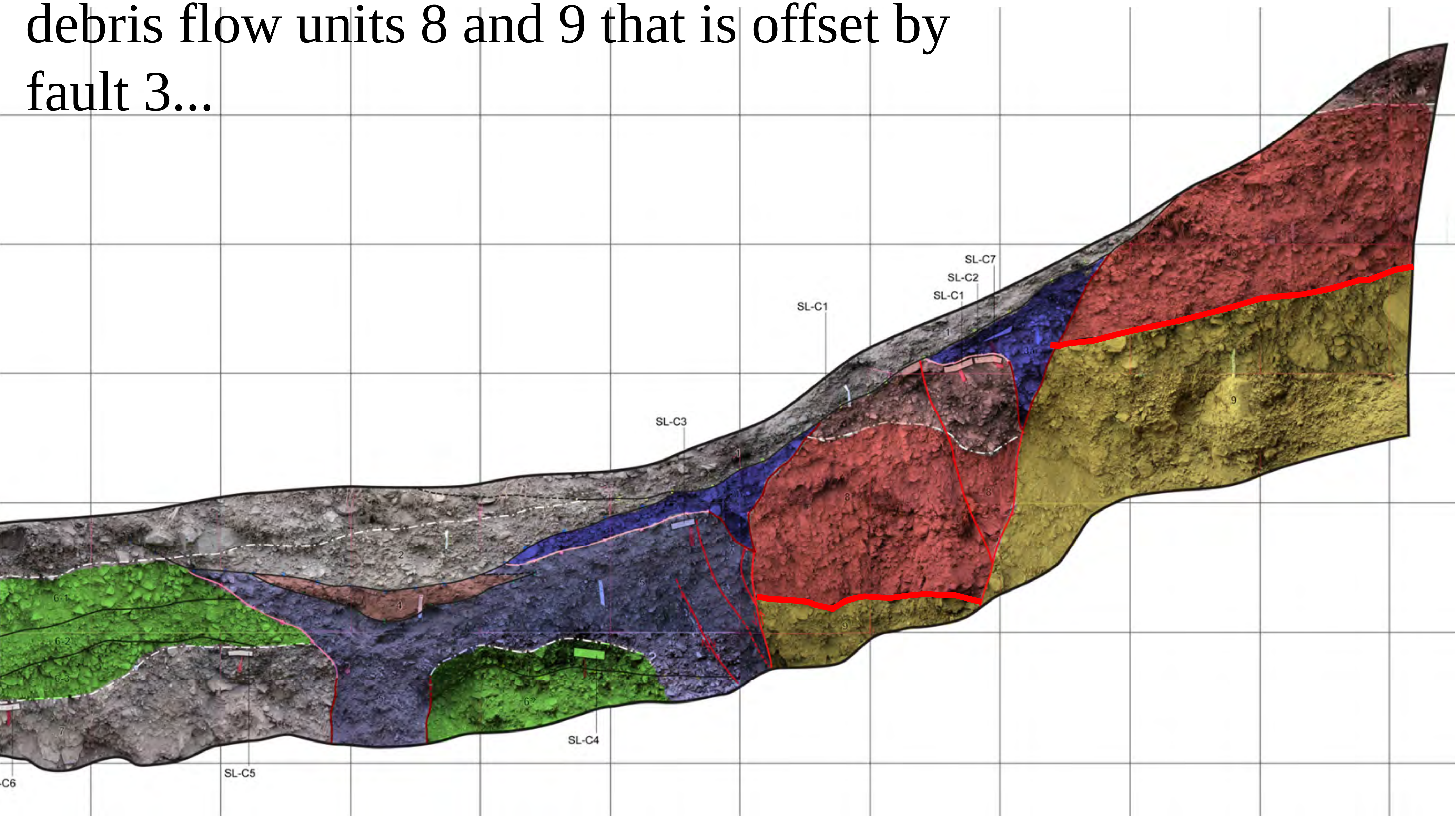
With map units colored-in.

Let's look at some key features:

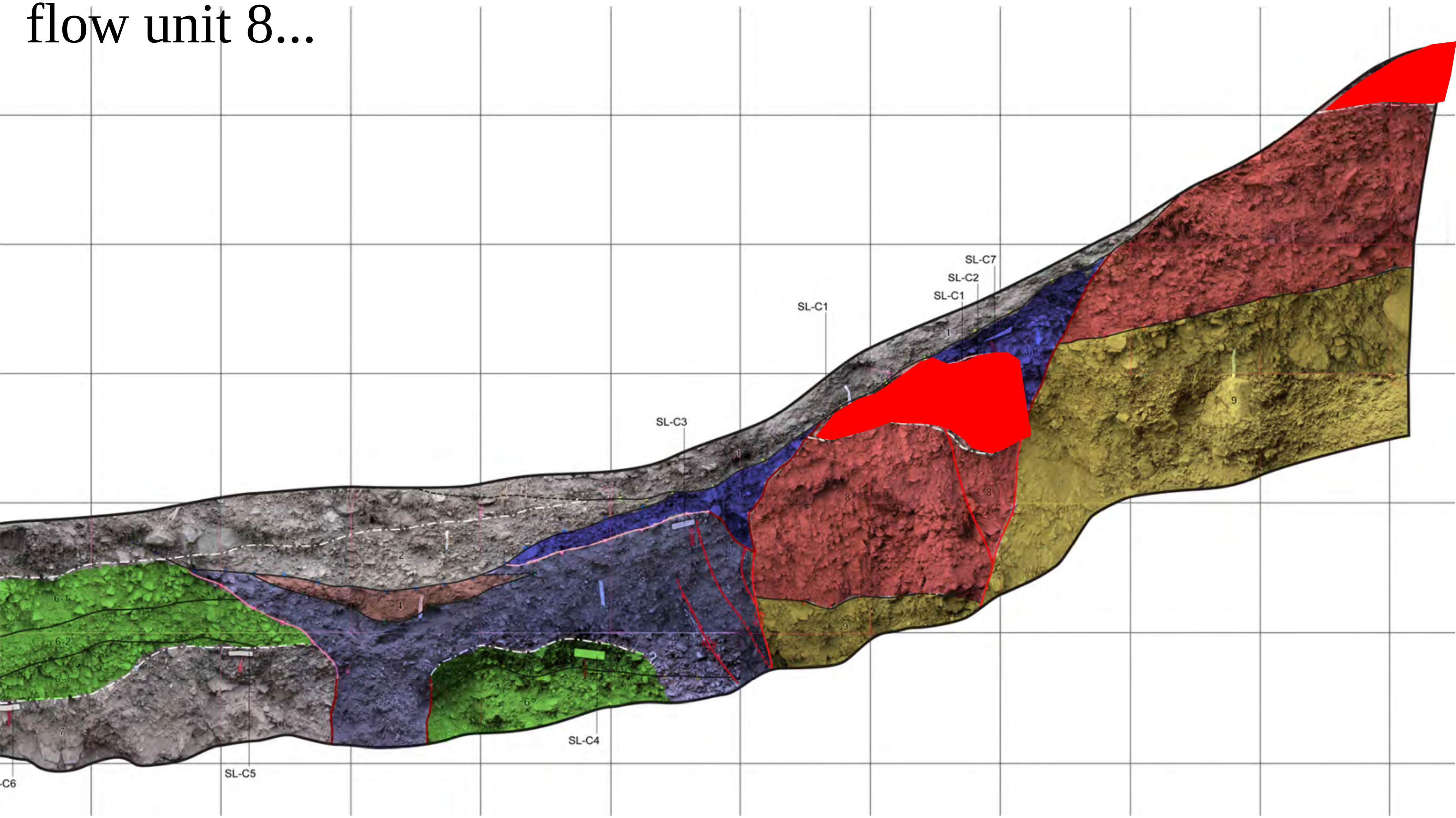
We have three apparent faults...



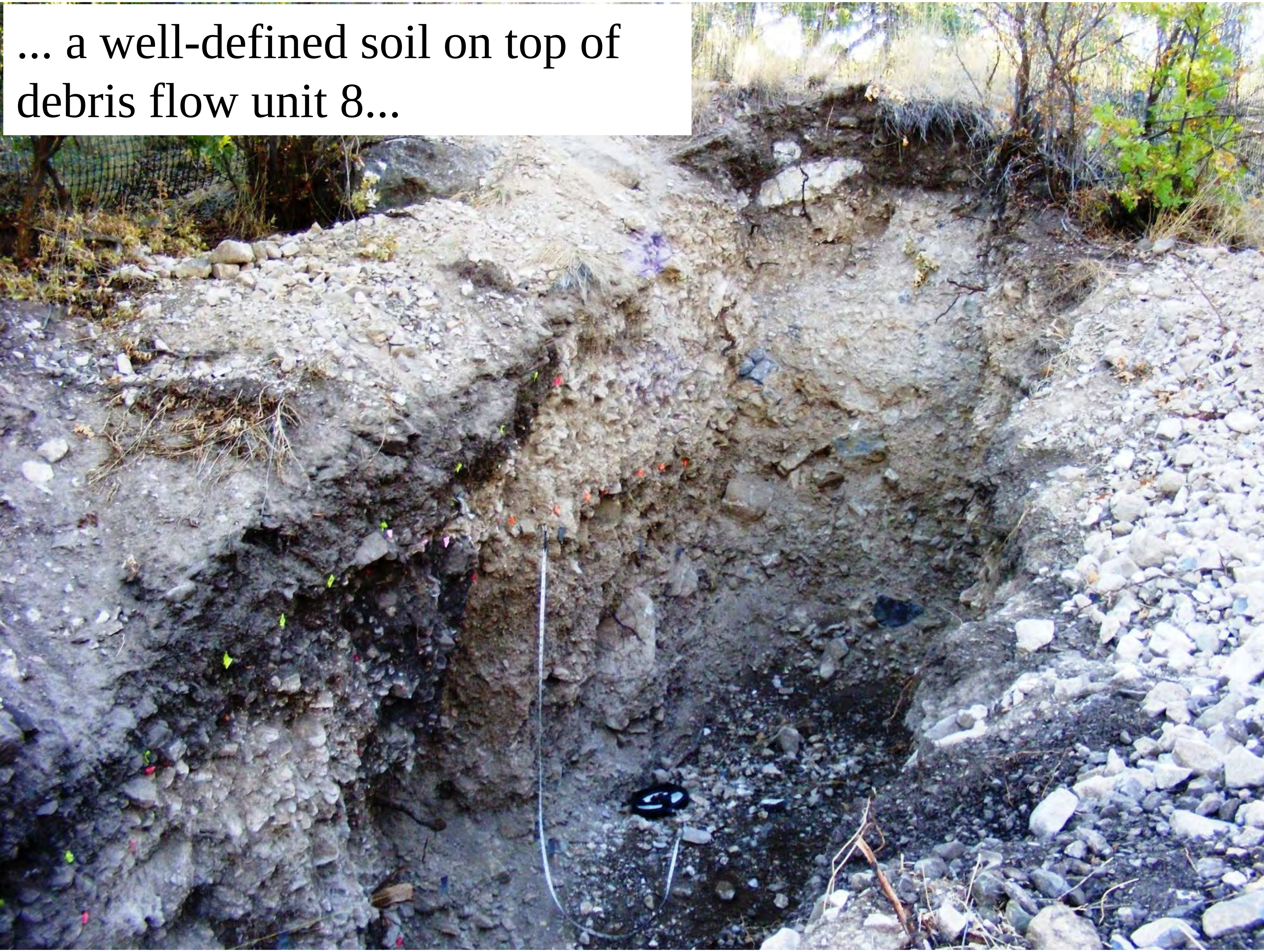
...a very well-defined contact between debris flow units 8 and 9 that is offset by fault 3...



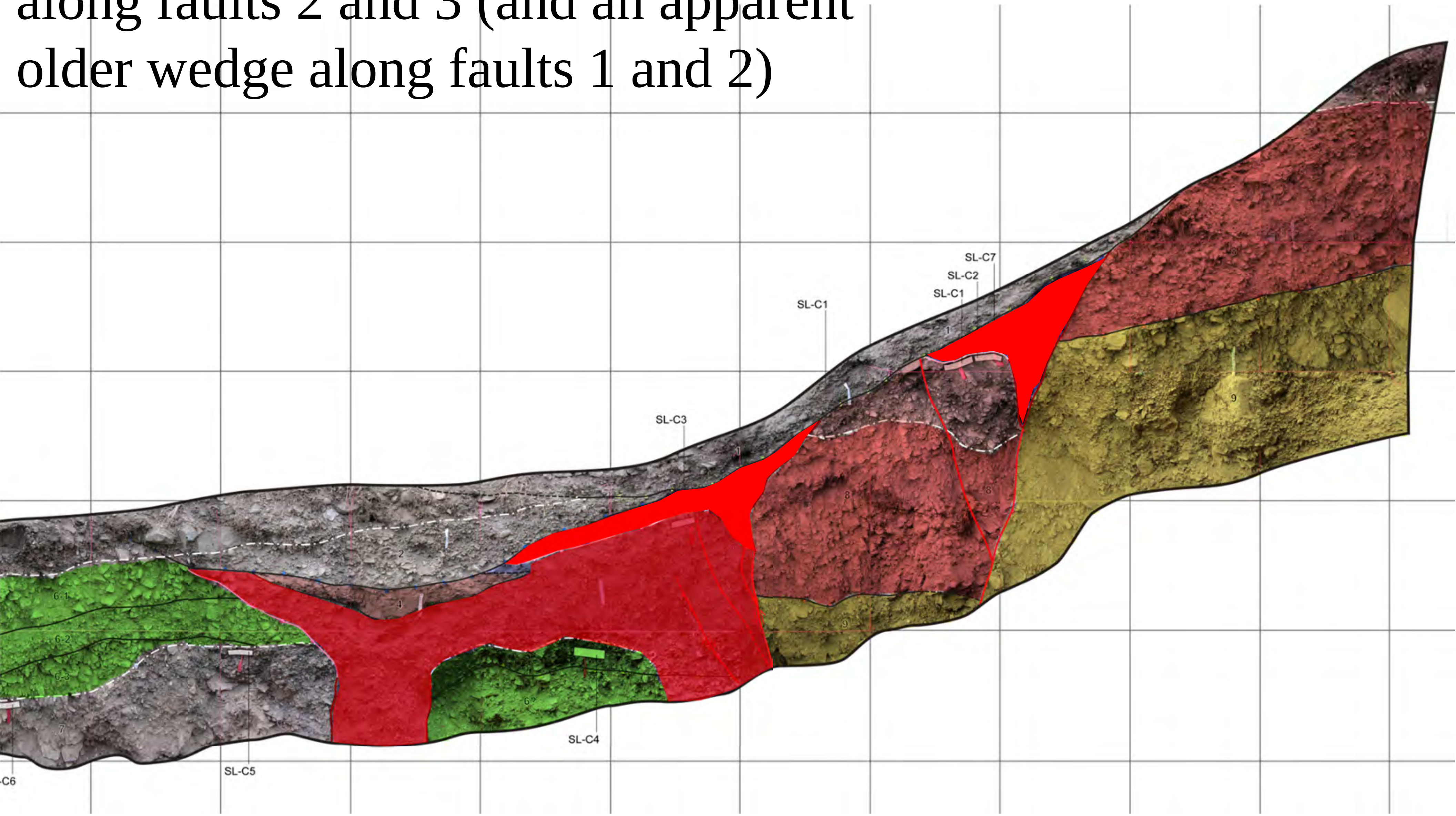
... a well-defined soil on top of debris flow unit 8...



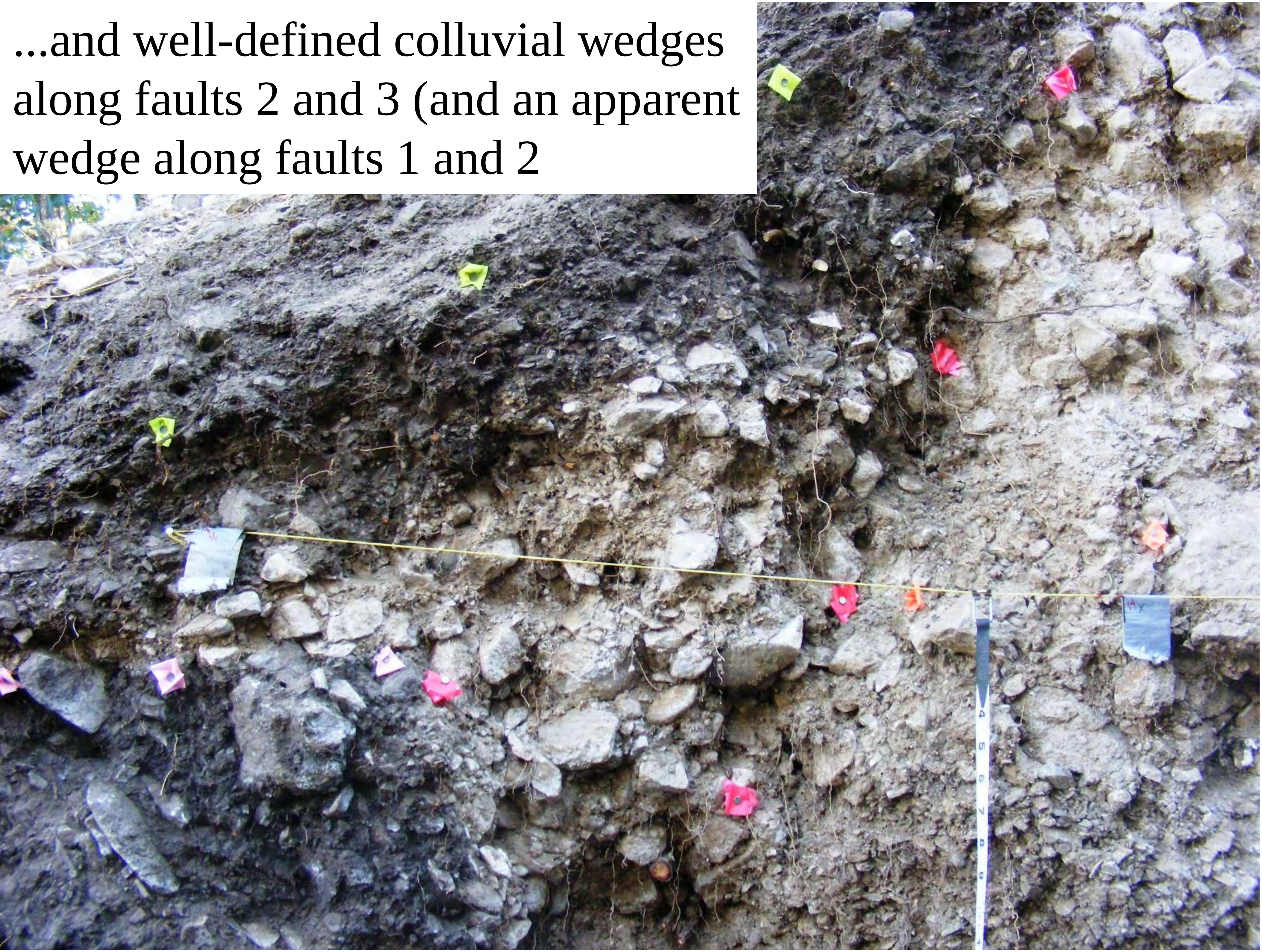
... a well-defined soil on top of debris flow unit 8...



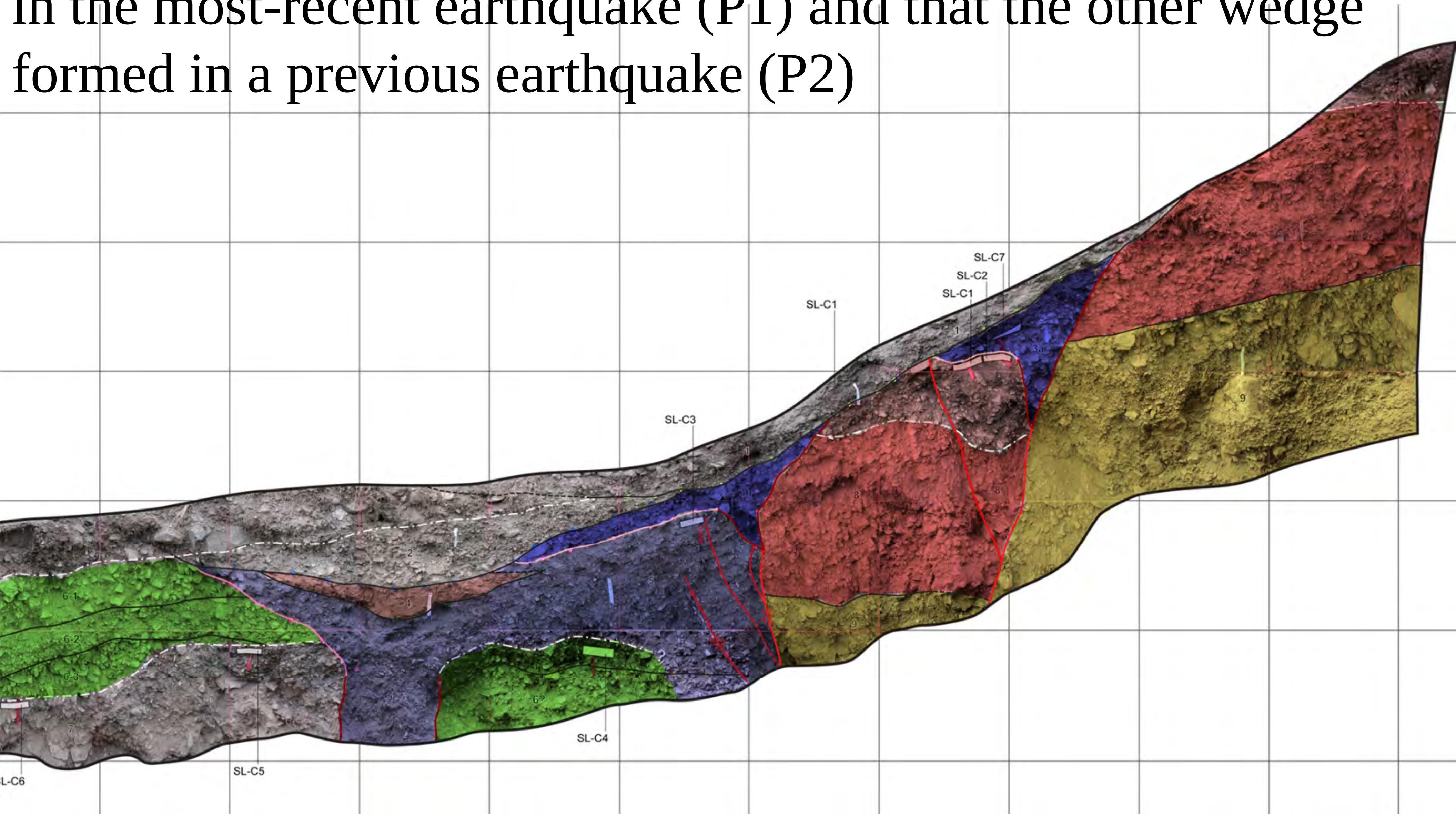
...and well-defined colluvial wedges along faults 2 and 3 (and an apparent older wedge along faults 1 and 2)



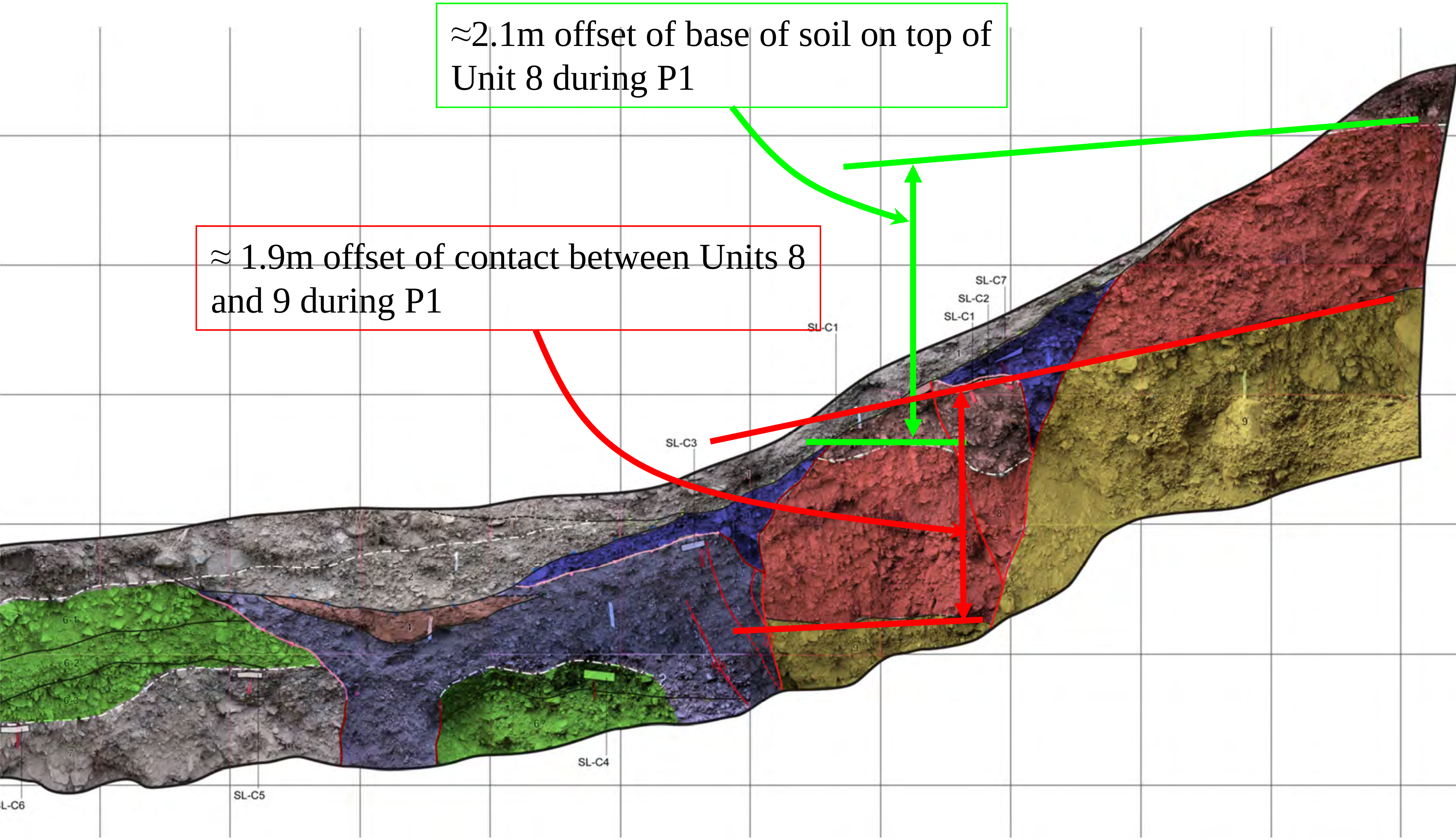
...and well-defined colluvial wedges along faults 2 and 3 (and an apparent wedge along faults 1 and 2

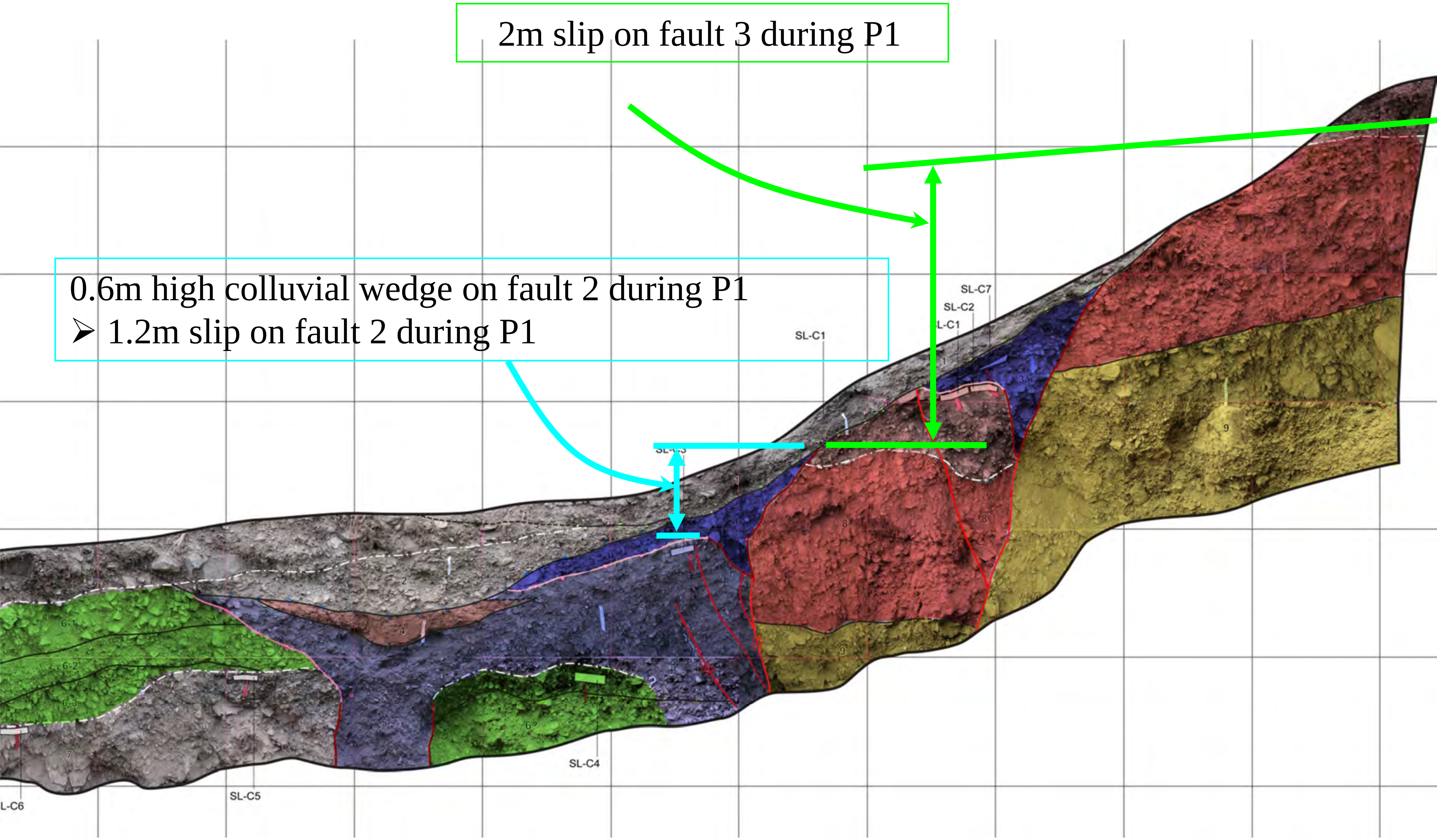


We think that the two well-defined colluvial wedges formed in the most-recent earthquake (P1) and that the other wedge formed in a previous earthquake (P2)



Estimating the amount of slip during P1: fault 3

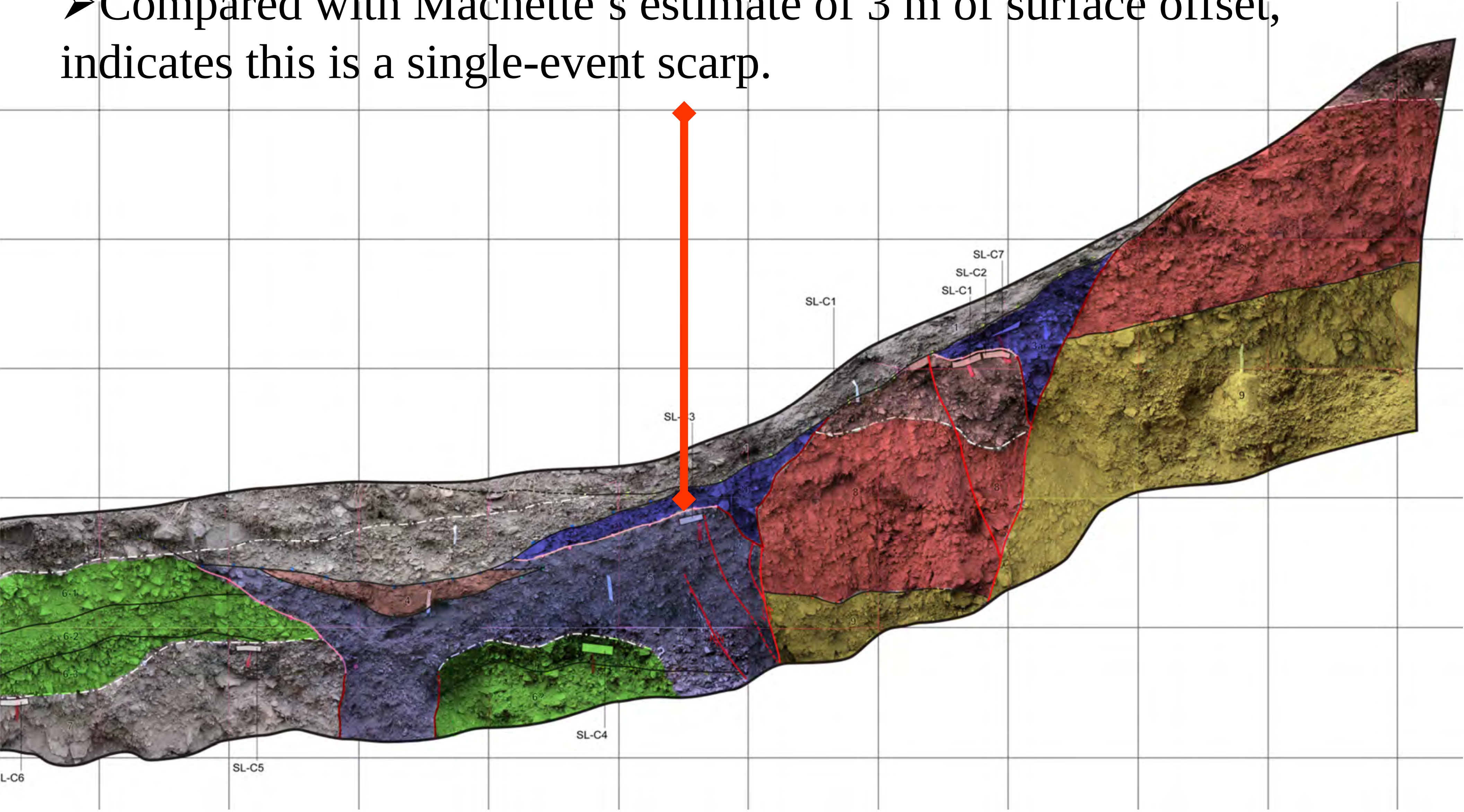




2m slip on fault 3 during P1
0.6m high colluvial wedge on fault 2 during P1
➢ 1.2m slip on fault 2 during P1
SL-C7
SL-C2
L-C1
SL-C1
SL-C4
SL-C5
L-C6
6-1
6-2
4
9

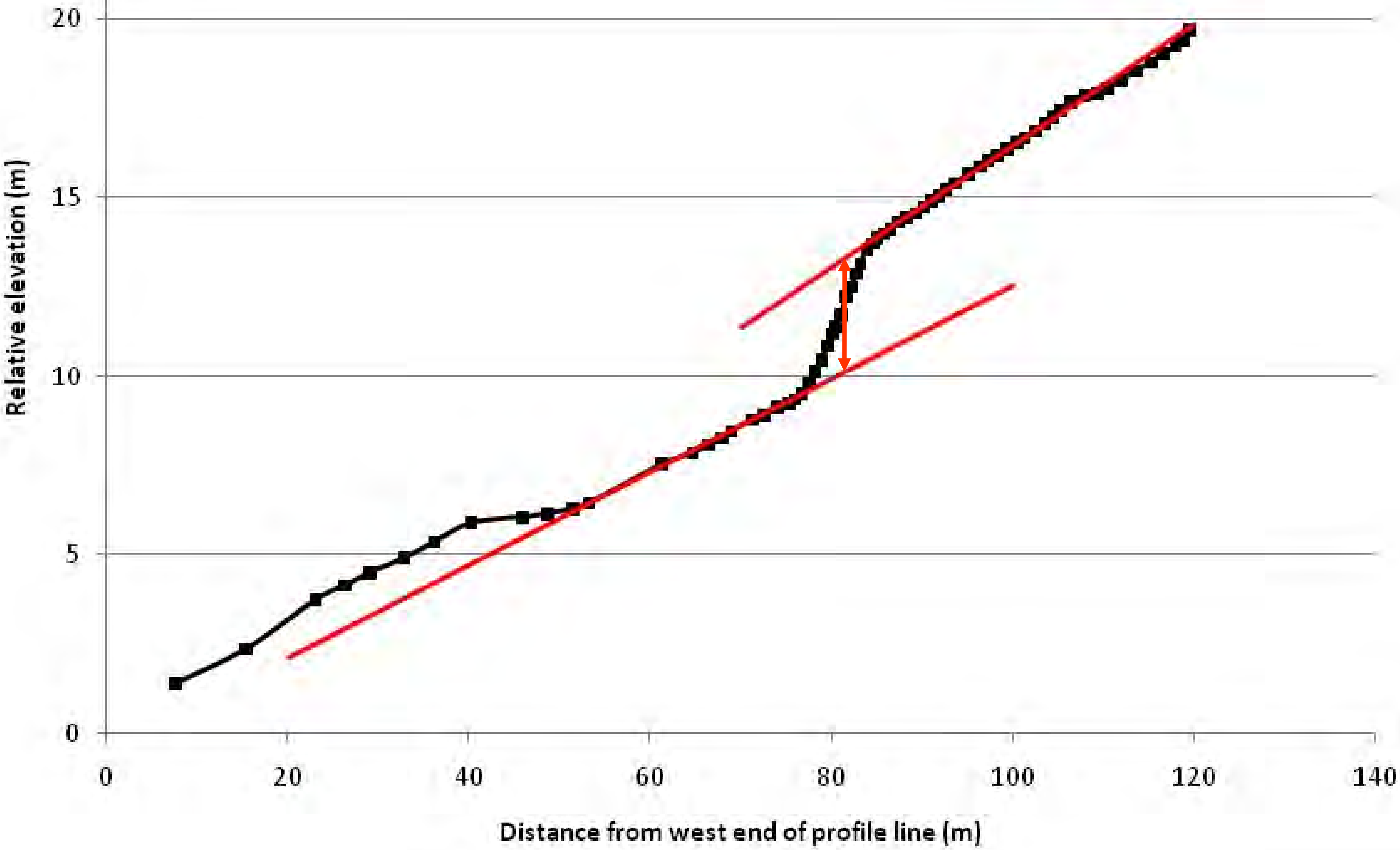
3.2 m of slip during P1

➢Compared with Machette's estimate of 3 m of surface offset, indicates this is a single-event scarp.



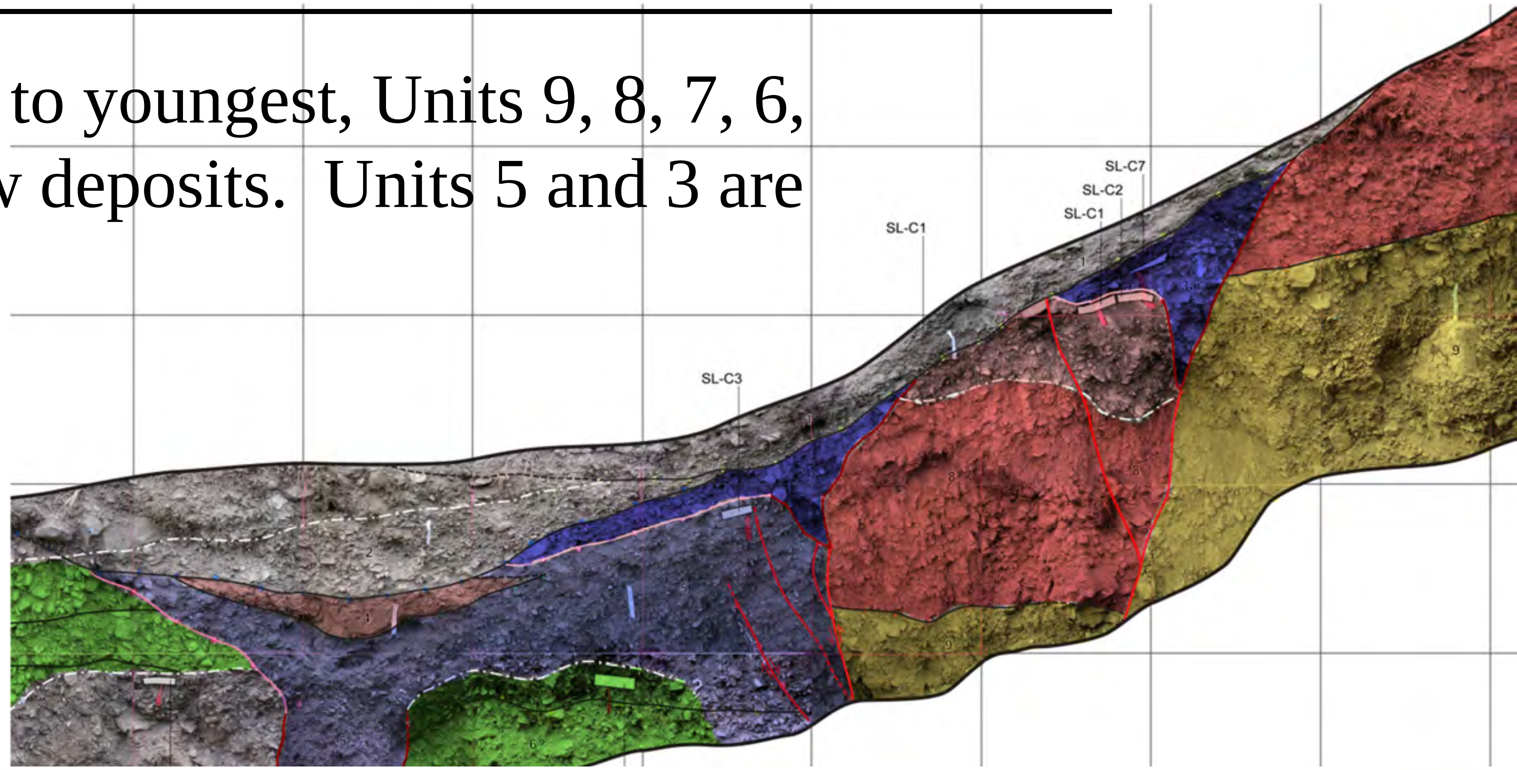
3.2 m of slip during P1

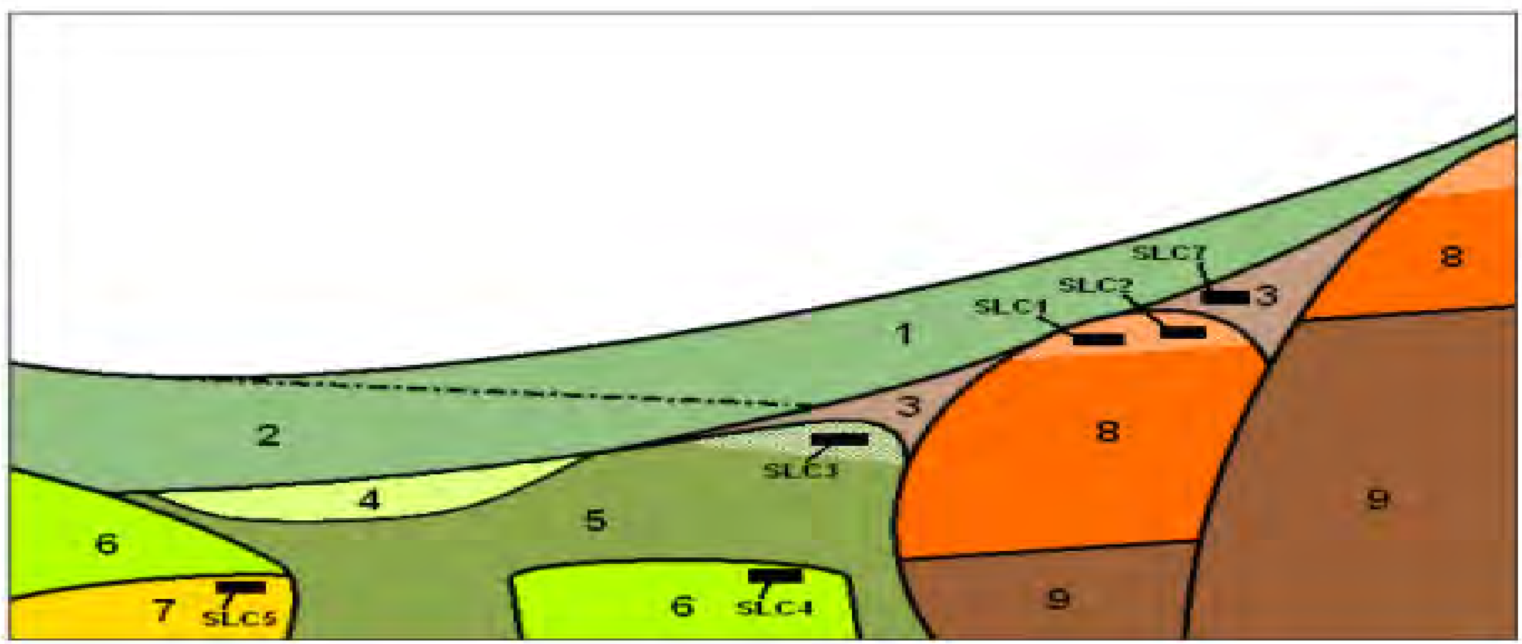
➢Compared with 3.3 m scarp height based on our profiling, fairly consistent with a single-event scarp.



Interpreted reconstruction of series of events

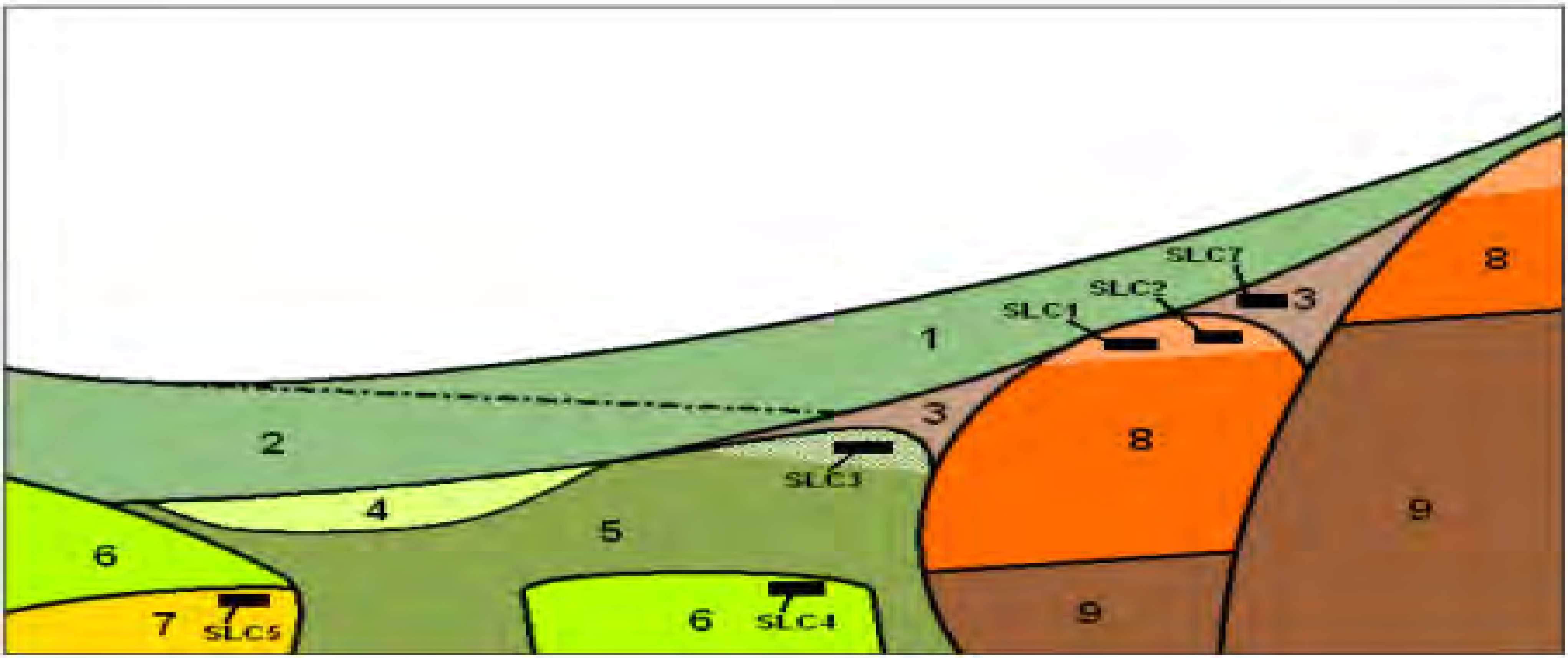
In order from oldest to youngest, Units 9, 8, 7, 6, and 2 are debris flow deposits. Units 5 and 3 are colluvial wedges.





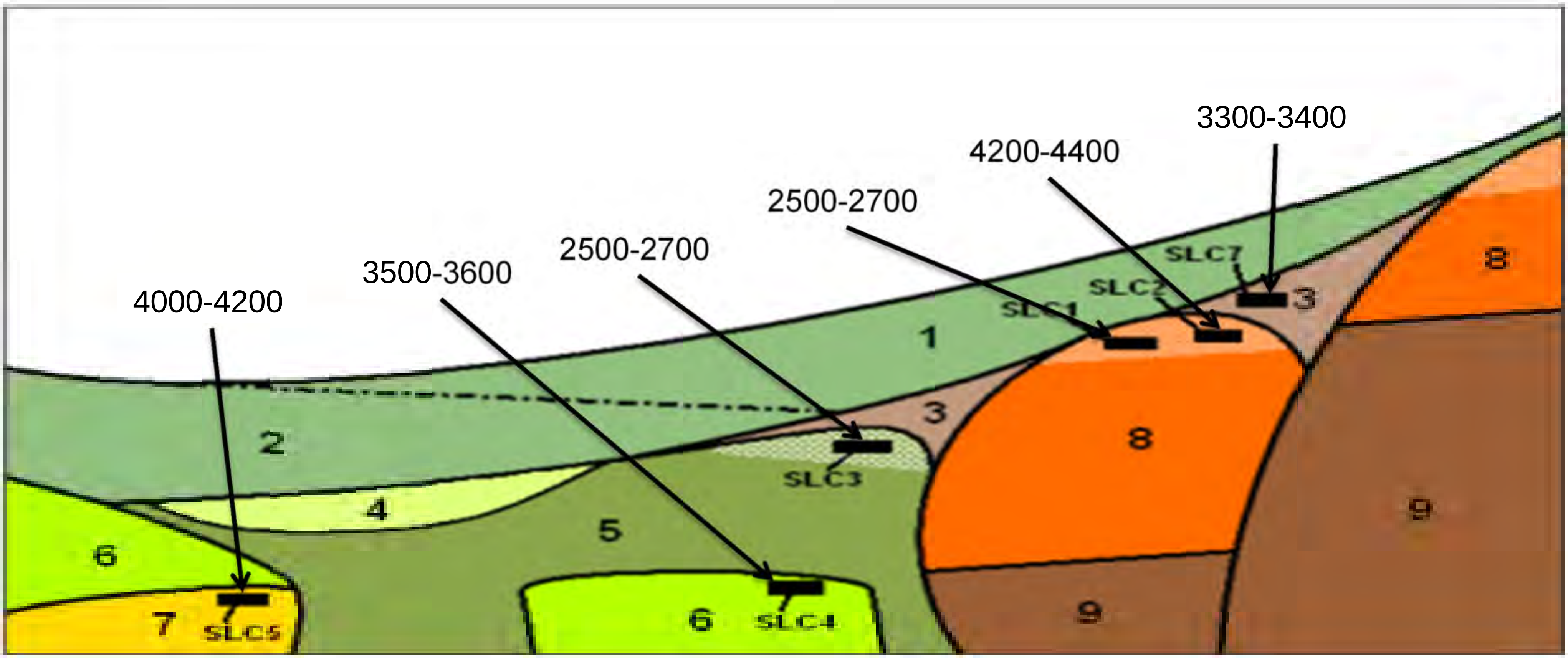
Relative Ages

- In order from oldest to youngest, Units 9, 8, 7, 6, and 2 are debris flow deposits.
- Unit 3 is two colluvial wedges that we think both formed after P1
- Unit 5 is a colluvial wedge that we think formed after P2.



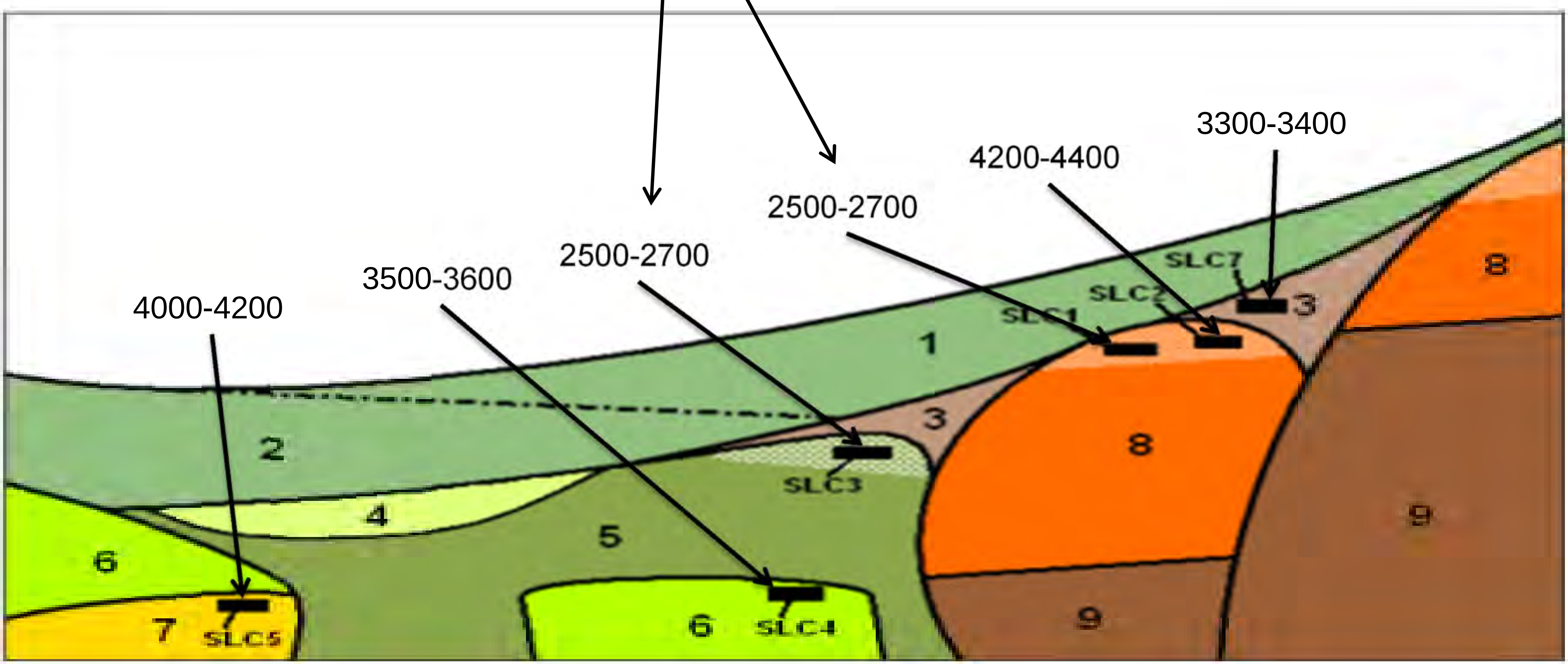
Ages

Calibrated AMS ages from milligram-size samples of charcoal by Paleo Research Institute.



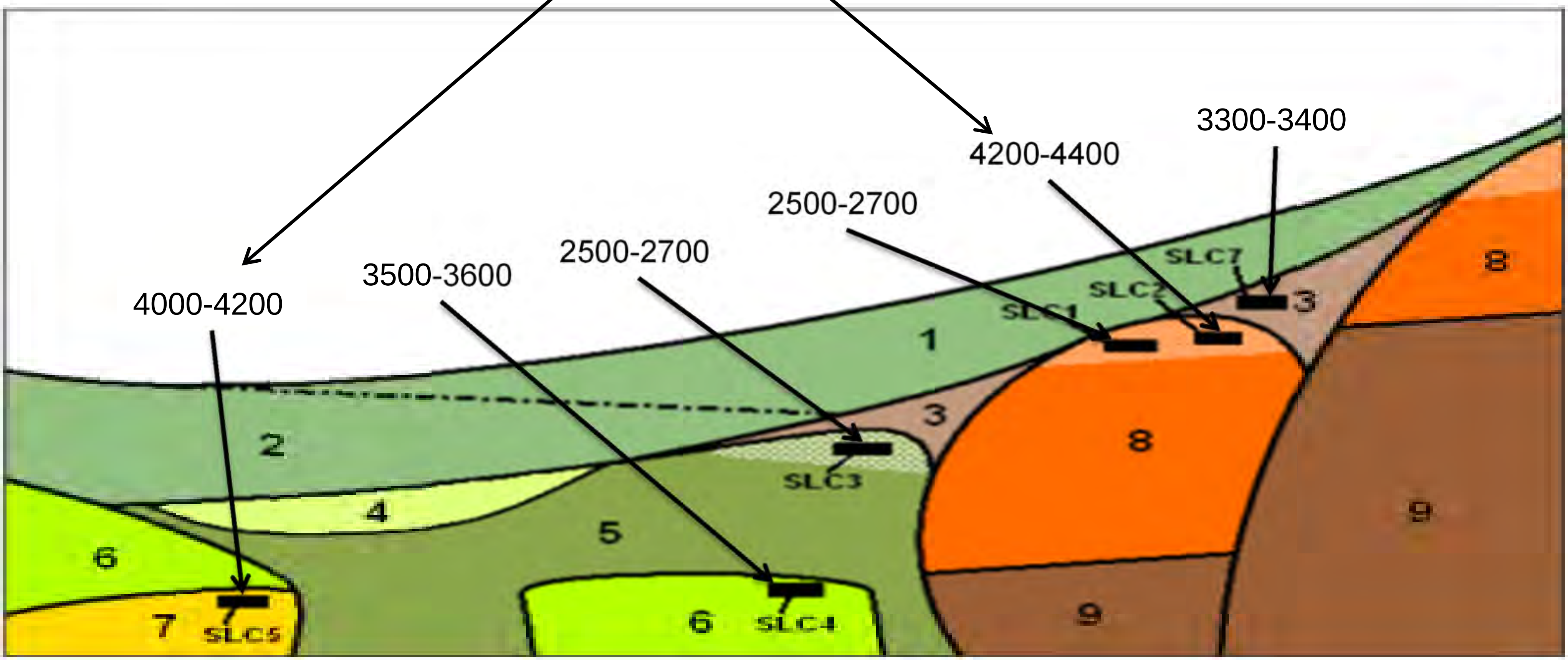
Ages

Two identical ages (2500-2700 years) for soil buried by P1 colluvial wedges



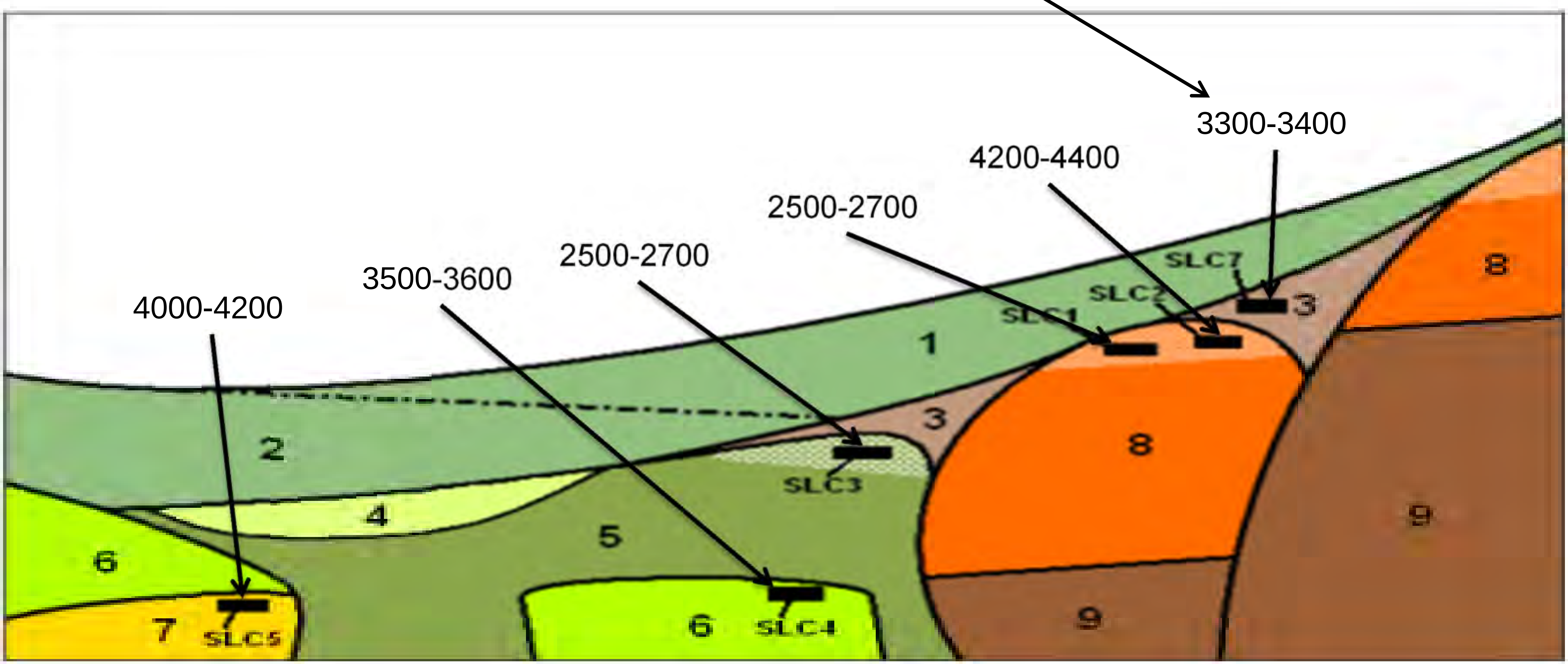
Ages

Out-of-sequence age (4200-4400 years) for one sample from buried soil is consistent with the age of the parent material (>4000-42000 year age for unit 7)



Ages

Out-of-sequence age (3300-3400 years) for upper colluvial wedge is consistent with the wedge being derived from older materials up-slope

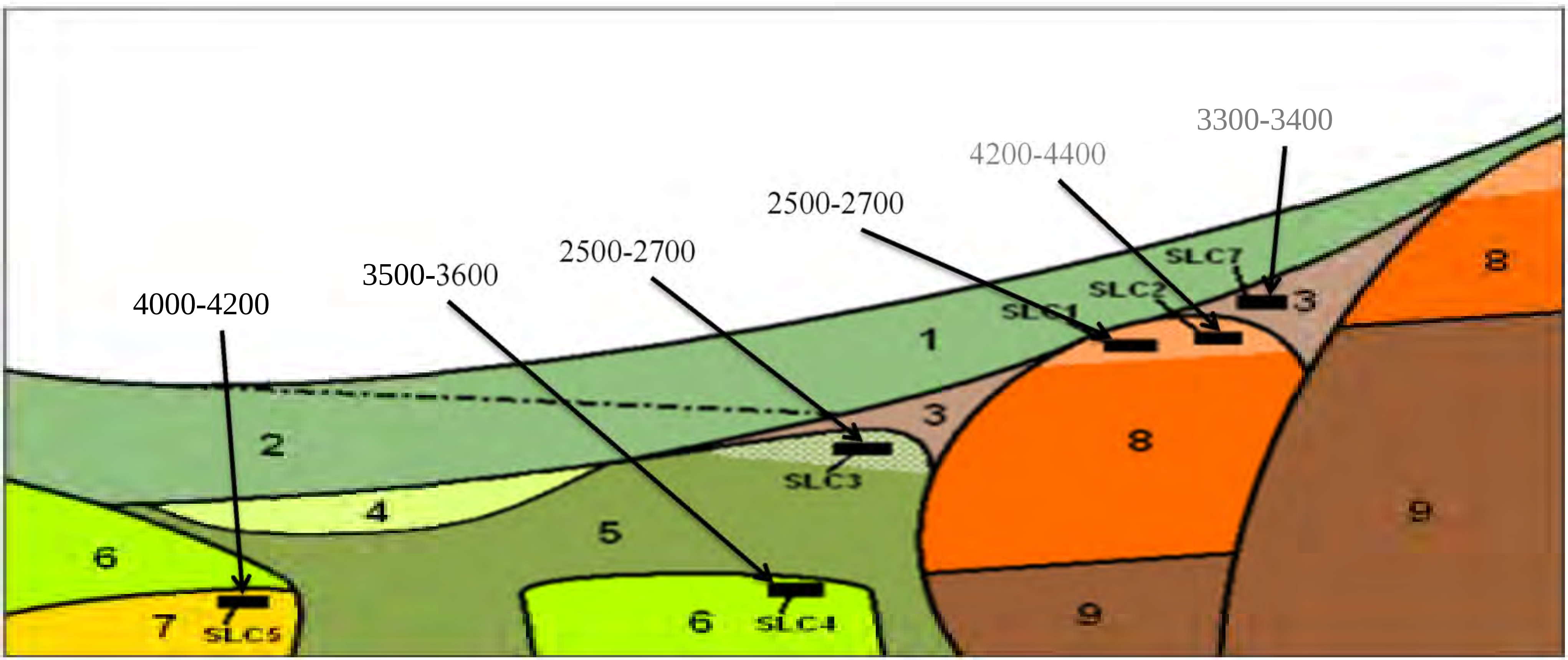


Age constraints

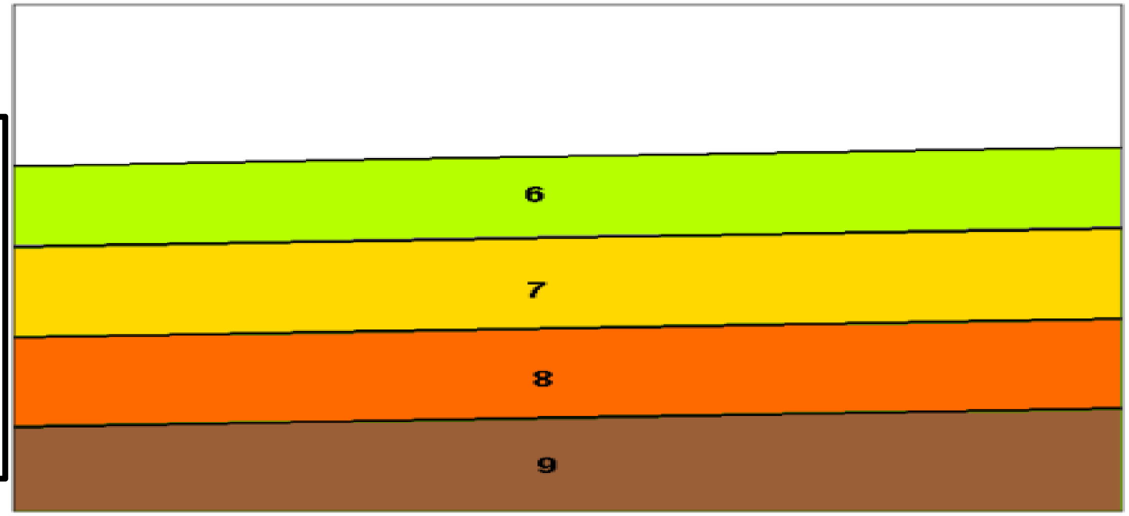
Ignoring the two out-of-sequence ages:

•Samples SL-C1 and SL-C3 provide maximum limiting age of about 2500 years for P1.

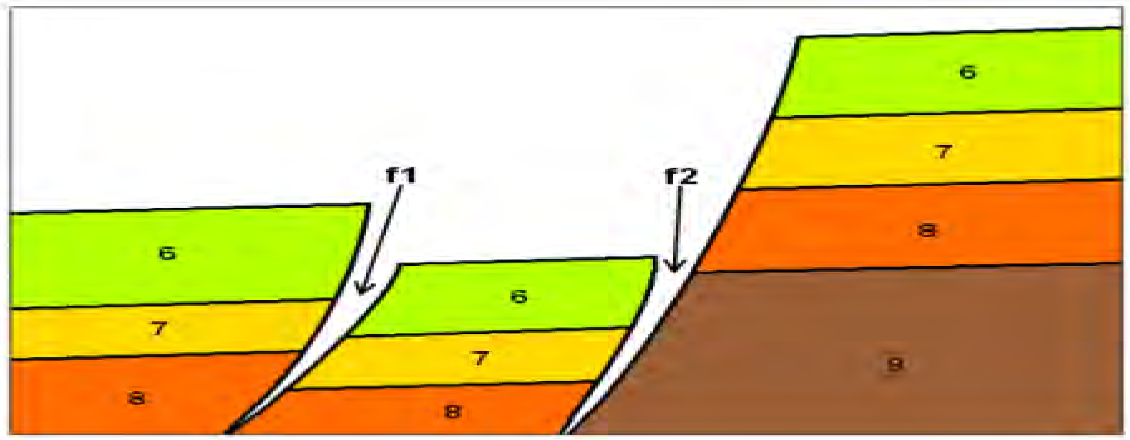
•Sample SL–C4 provides a maximum limiting age of 3500-3600 years for P2.



>3500 ybp– Deposition of multiple debris flows (6, 7, 8, 9). No faulting has occurred.



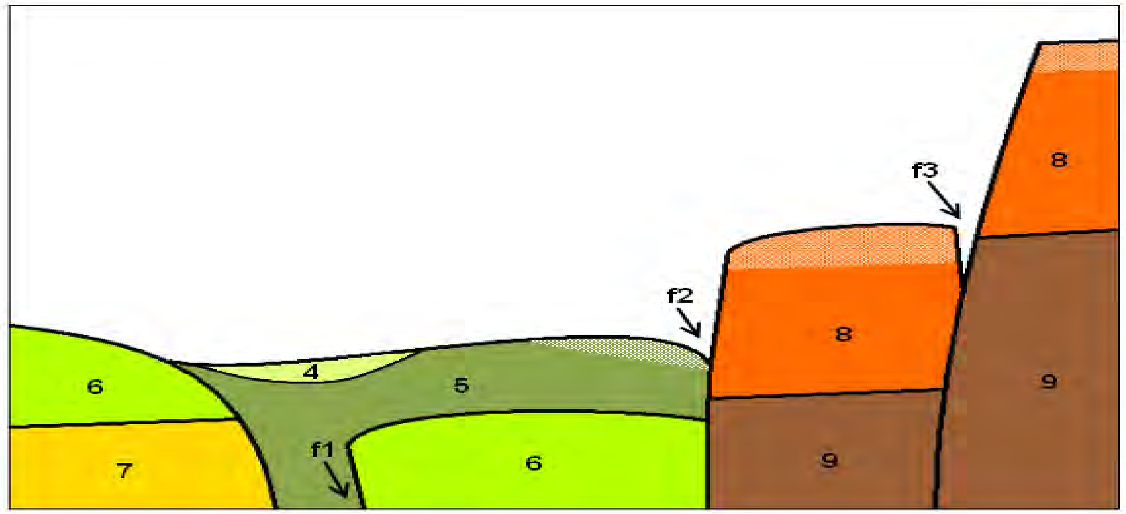
<3500 ybp– First faulting event (P2). Slip on faults f1 & f2; formation of graben.



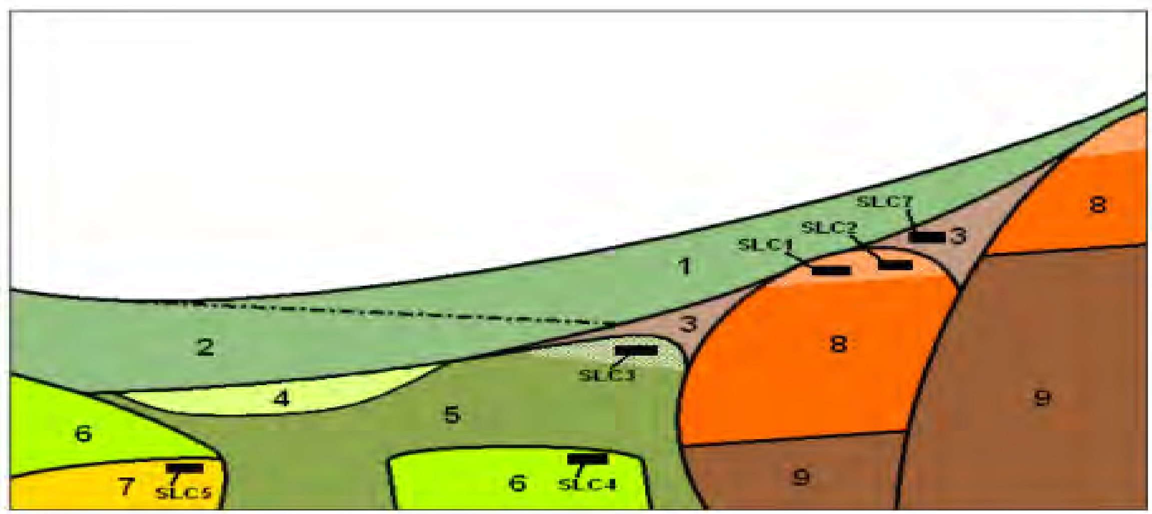
3500 – 2500 ybp – Unit 5 (colluvial wedge) deposited in graben. Soils form on units 5 & 8.

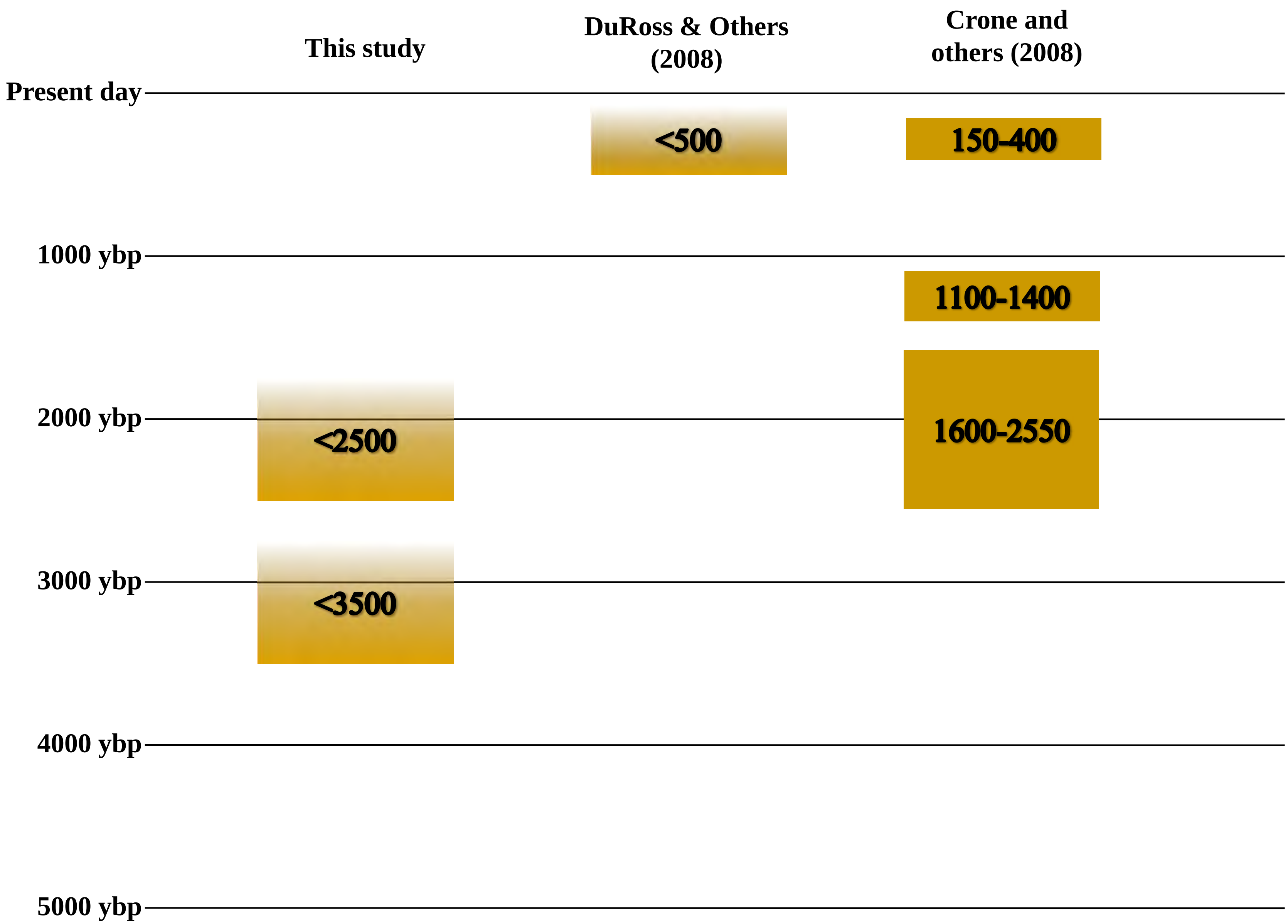
3500 – 2500 ybp– Unit 5 (colluvial wedge) deposited in graben. Soils form on units 5 & 8.

<2500 ybp– Second faulting event (P1). Reactivation of fault f2 and larger slip on fault f3.



Today—Unit 3 (colluvial wedge) deposited along P1 scarps. Unit 2 (debris flow) and unit 1 (slope wash) laid down.




This study
DuRoss & Others (2008)
Crone and others (2008)
Present day
1000 ybp
2000 ybp
3000 ybp
4000 ybp
5000 ybp
<500
150-400
1100-1400
<2500
1600-2550
<3500

Previous investigations on the Nephi segment

Spring Lake
P1: <2500, P2: <3500

Santaquin
P1: <500, P2: >5000

North Creek
P1: 300-500? P2: ≥3700-4100

Red Canyon P1: ≤1,400, P2: 3,000 - 3500

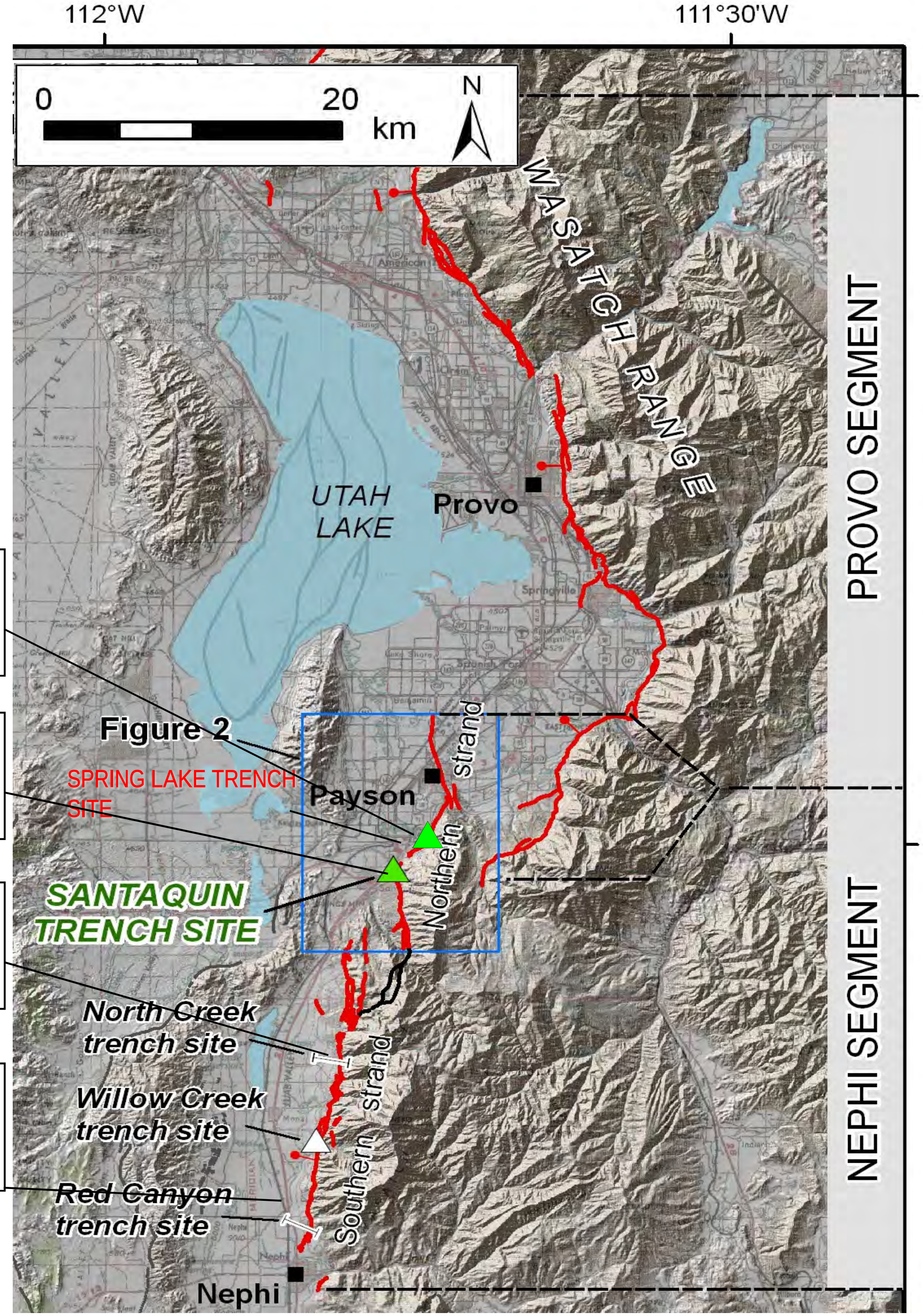


Fig. from DuRoss and others, in prep.

Closeup of the northern strand of the Nephi segment

- Separated from the Southern Strand by a step-over
- Near the step-over to the Provo Segment

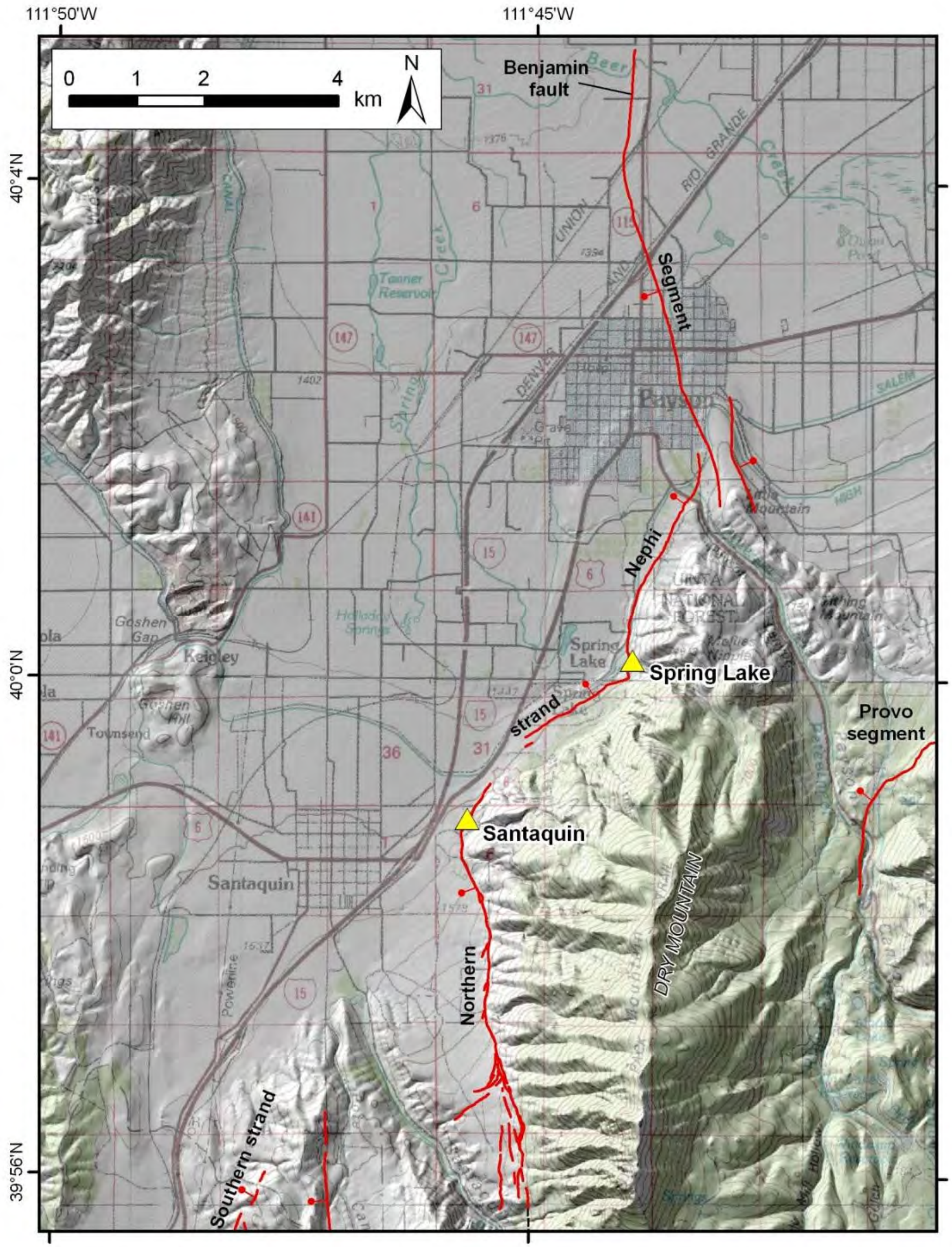
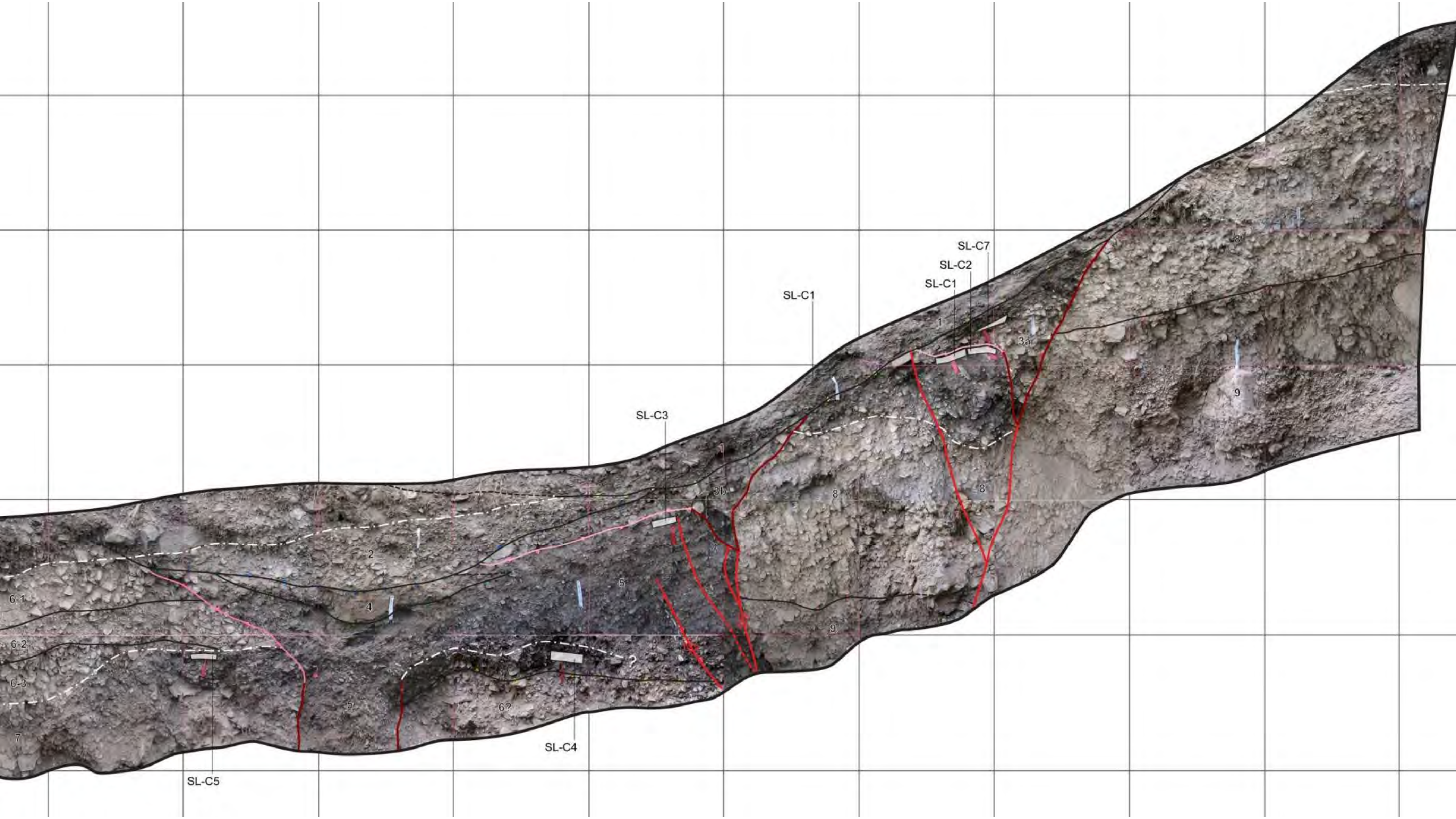
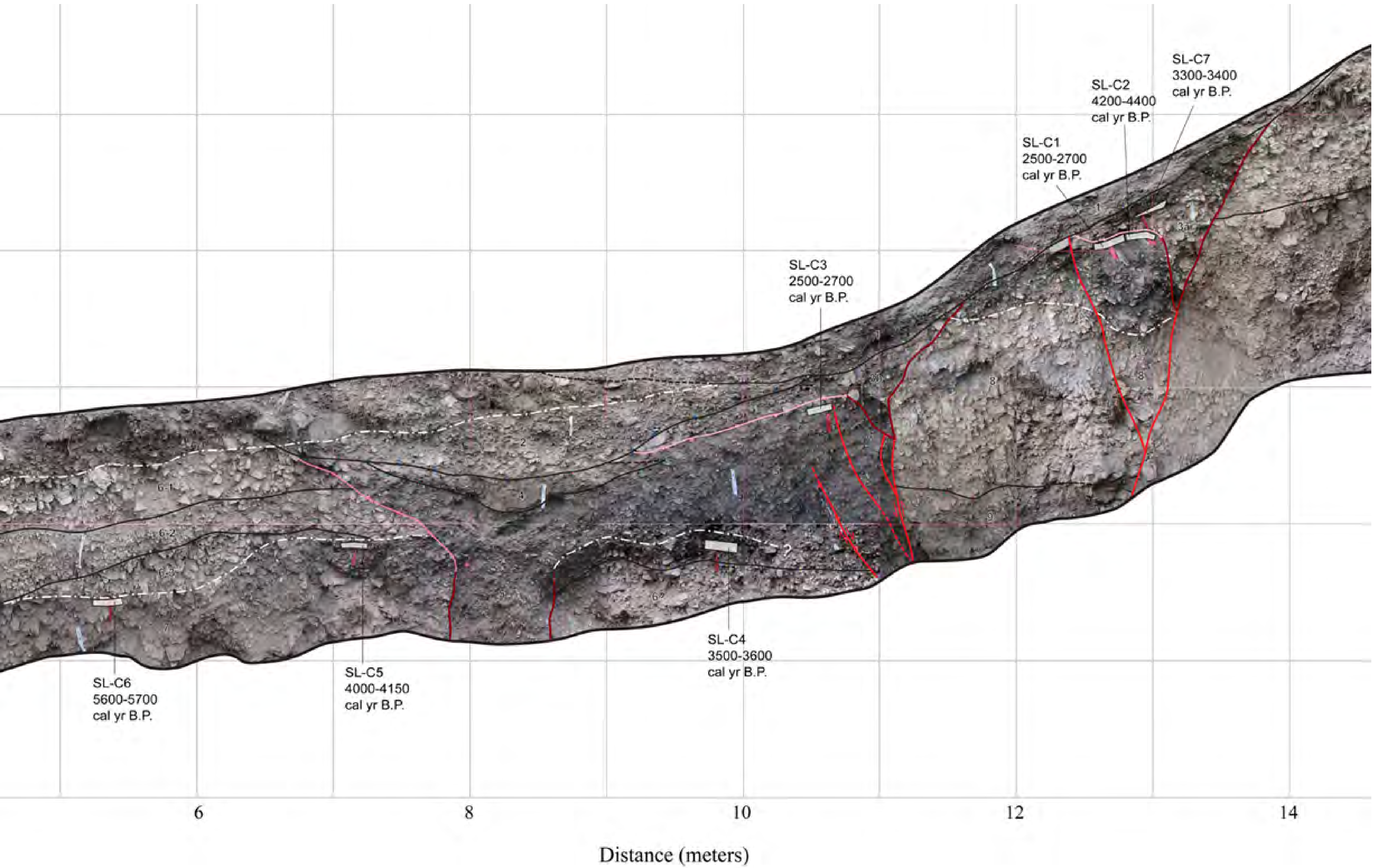


Fig. from DuRoss and others, in prep.



SL-C7
SL-C2
SL-C1
SL-C1
SL-C3
SL-C4
SL-C5
1
3a
3b
8
9
2
4
5
6-1
6-2
6-3
6?
7



SL-C7
3300-3400
cal yr B.P.
SL-C2
4200-4400
cal yr B.P.
SL-C1
2500-2700
cal yr B.P.
SL-C3
2500-2700
cal yr B.P.
SL-C4
3500-3600
cal yr B.P.
SL-C5
4000-4150
cal yr B.P.
SL-C6
5600-5700
cal yr B.P.
6
8
10
12
14
Distance (meters)

Possibility that Provo and Nephi segments rupture concurrently

Utah Quaternary Fault Parameters Working Group (2005)

<u>Provo Segment</u>
P1: 600 ± 350

Utah Quaternary Fault Parameters Working Group (2005)

<u>Nephi Segment</u>
P1: ≤1,000 ± 400

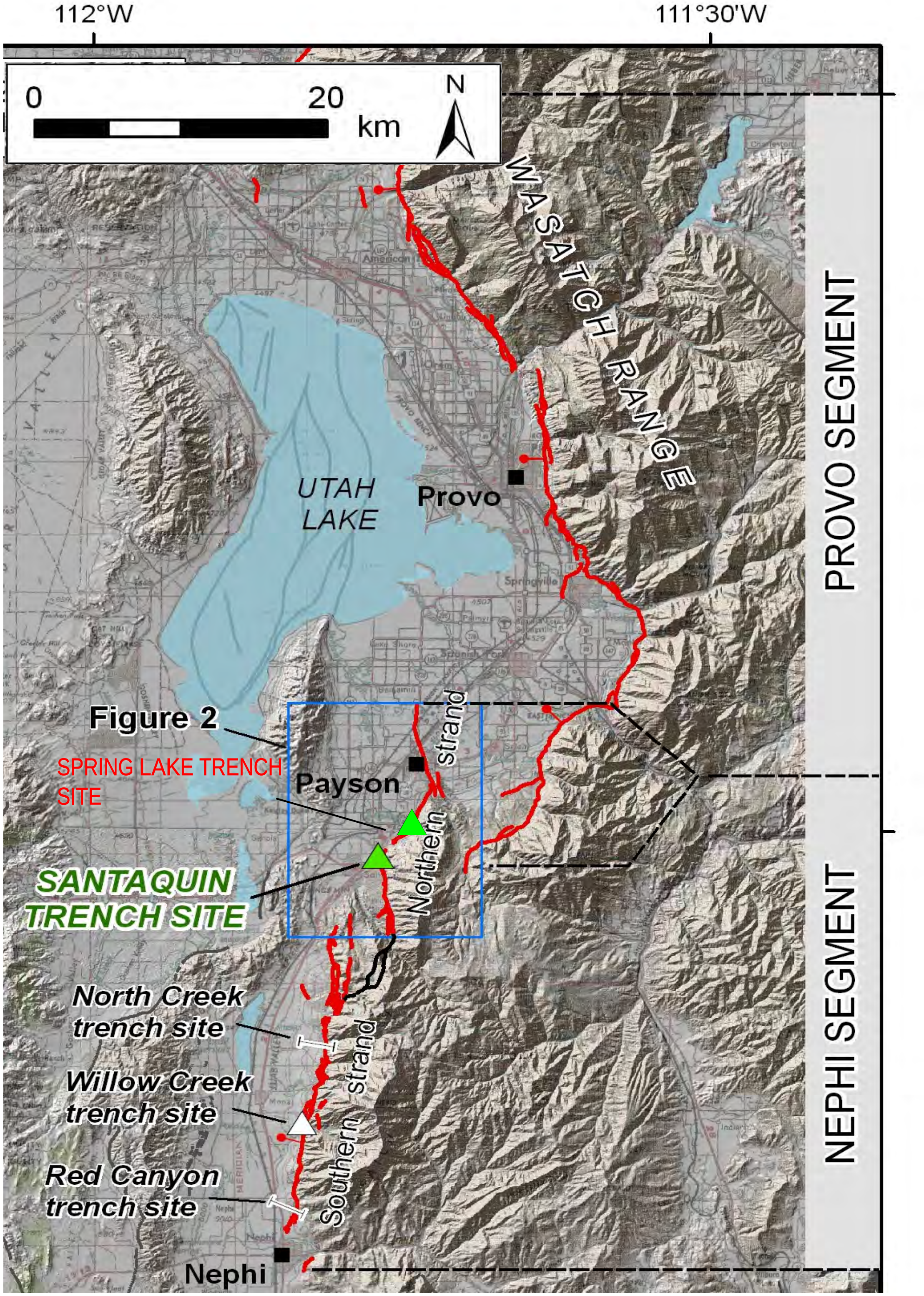
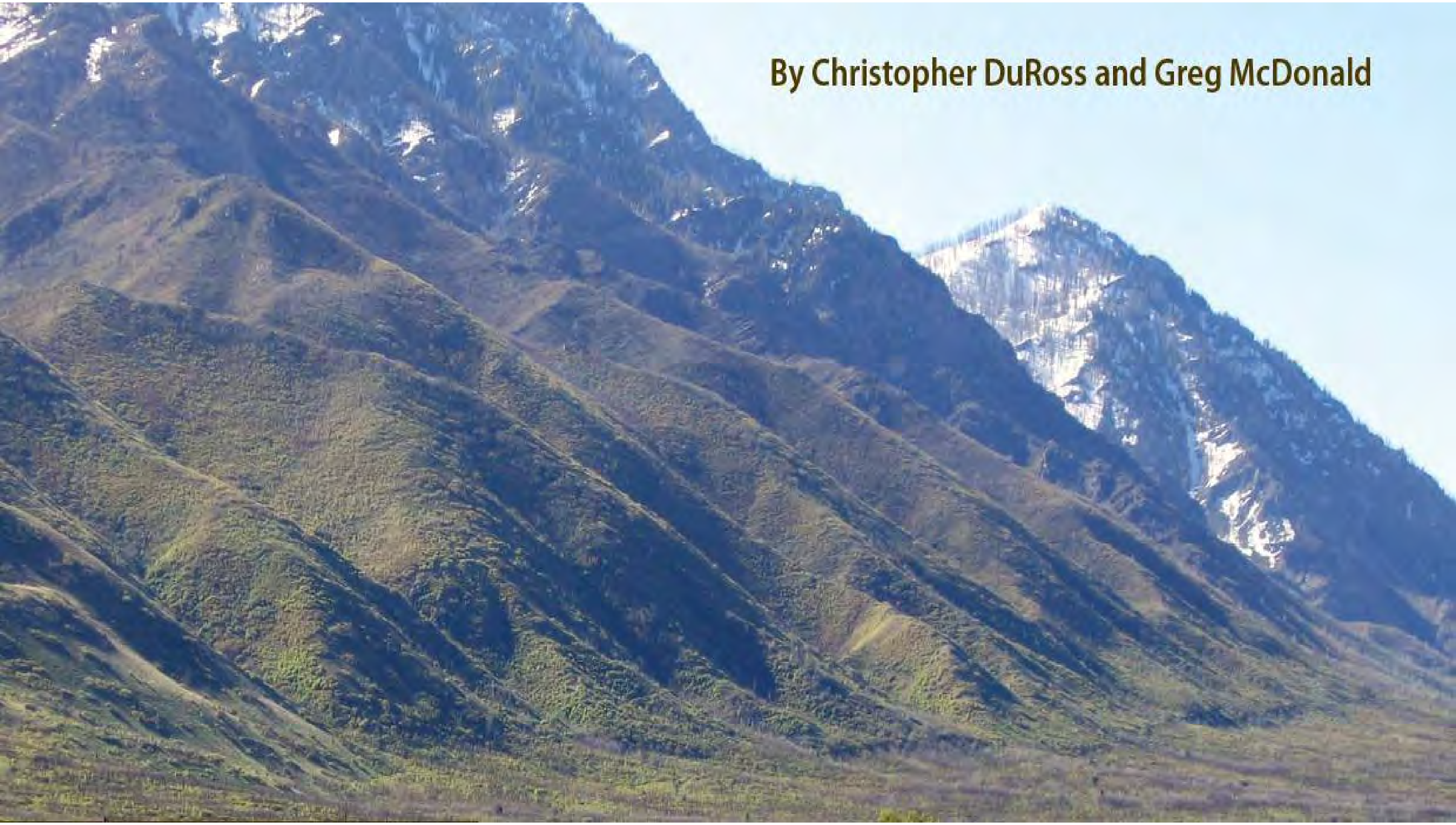
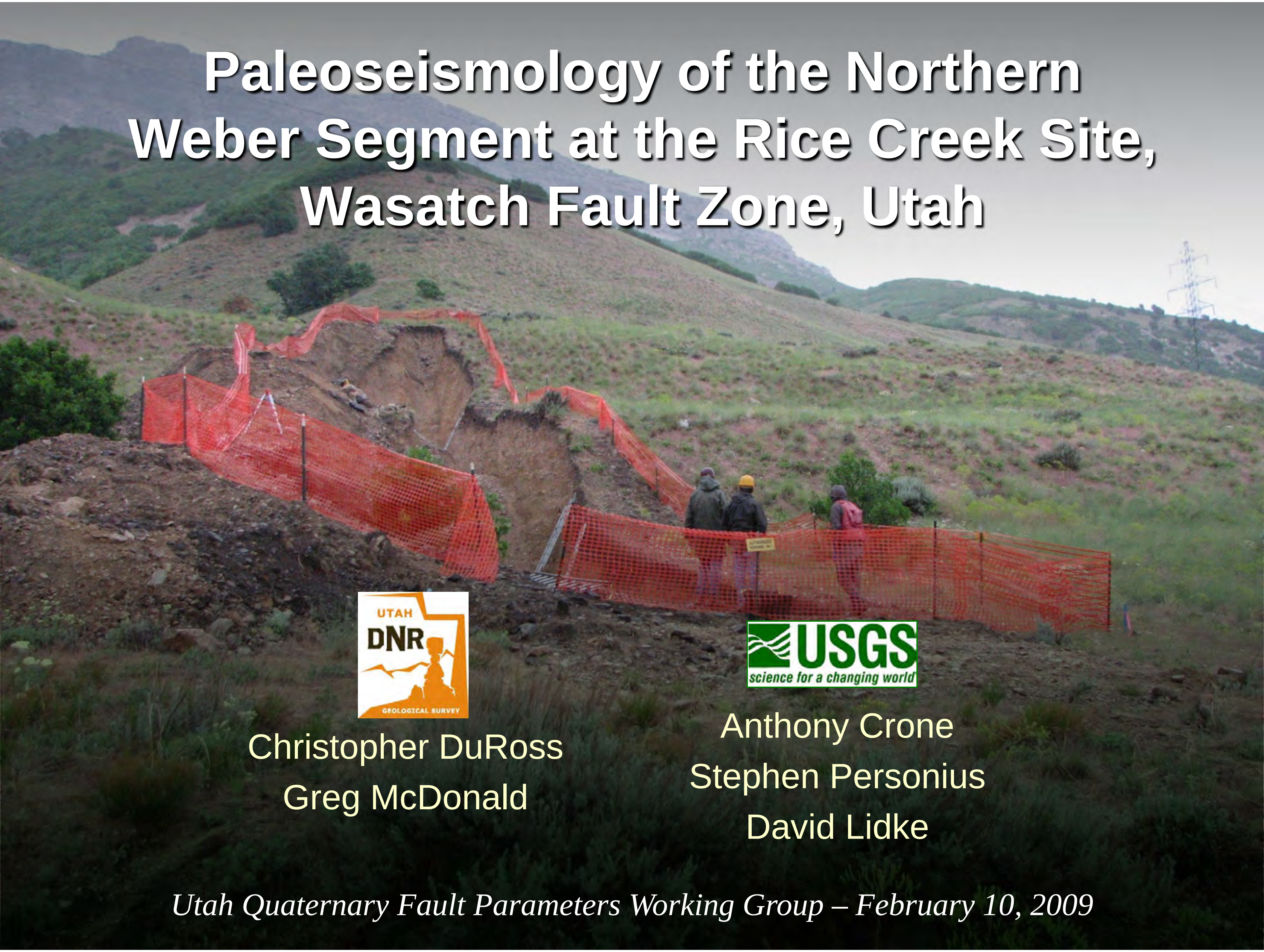


Fig. from DuRoss and others, in prep.


By Christopher DuRoss and Greg McDonald

Summer field 2007:
Trenching

Agreement with forest service and budget constraints limit us to a single "5-foot" slot.



Paleoseismology of the Northern Weber Segment at the Rice Creek Site, Wasatch Fault Zone, Utah

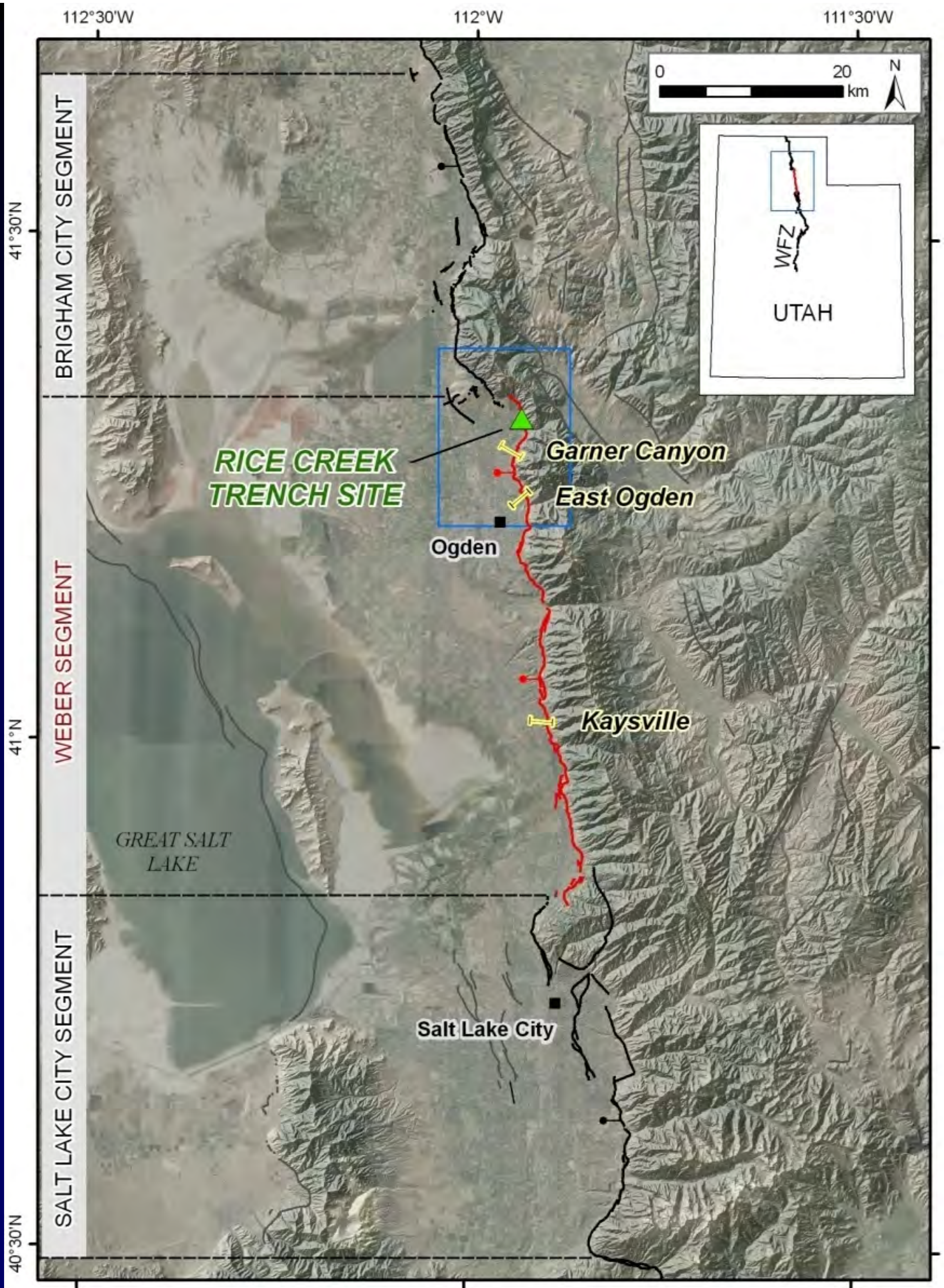
Christopher DuRoss
Greg McDonald

Anthony Crone
Stephen Personius
David Lidke

Utah Quaternary Fault Parameters Working Group – February 10, 2009

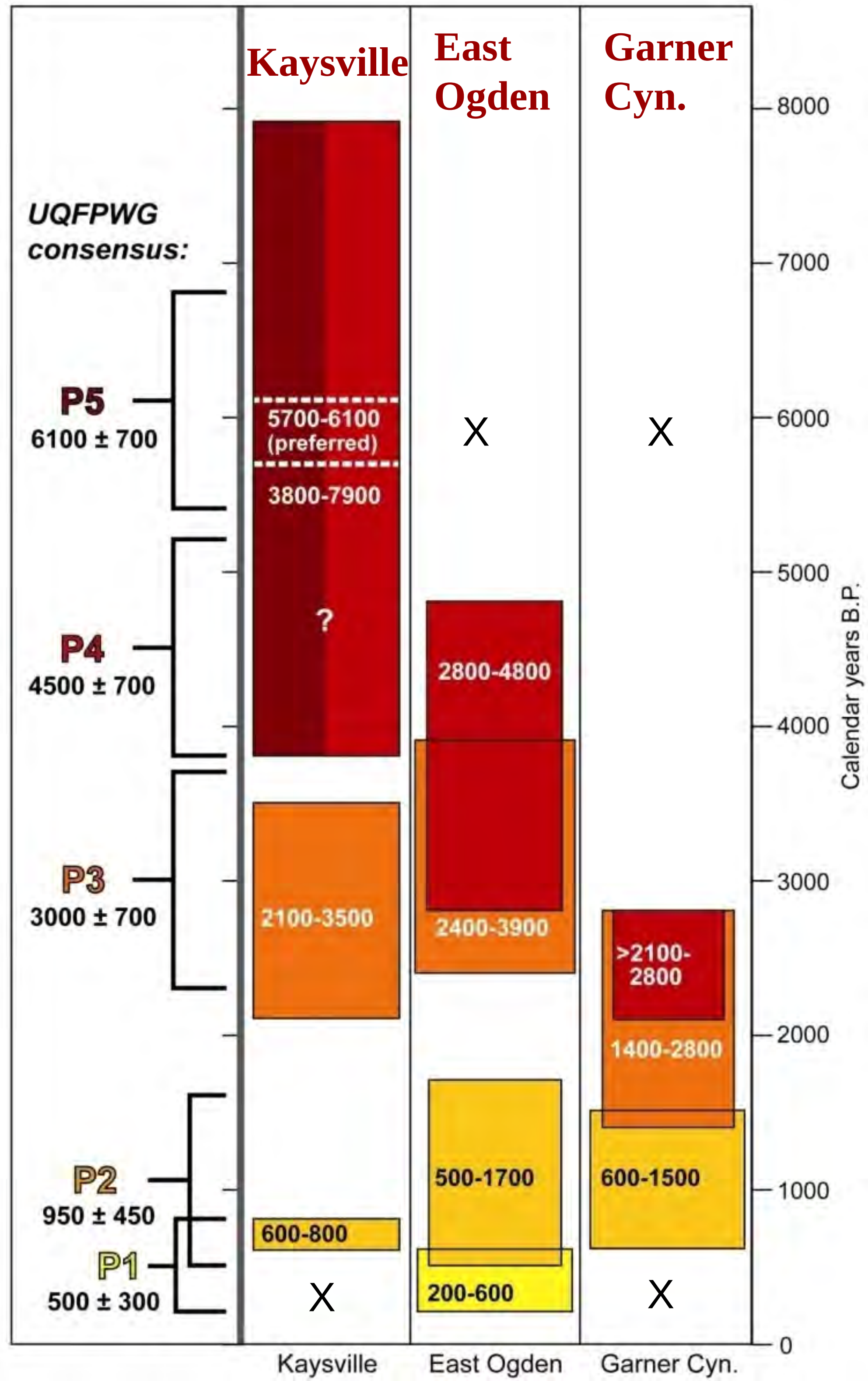
Introduction

- Weber segment:
  - 56-km long
  - Previous paleoseismic studies:
    - Kaysville (Swan et al., 1980; McCalpin et al., 1994)
    - East Ogden (Nelson et al., 2006)
    - Garner Canyon (Nelson et al., 2006)



Purpose

- To address poorly constrained paleoevent parameters:
  - Timing and correlation
    - Partial segment rupture (P1)?
    - Older events (P4, P5)
  - Recurrence, slip rate – uncertain, depend on event correlation

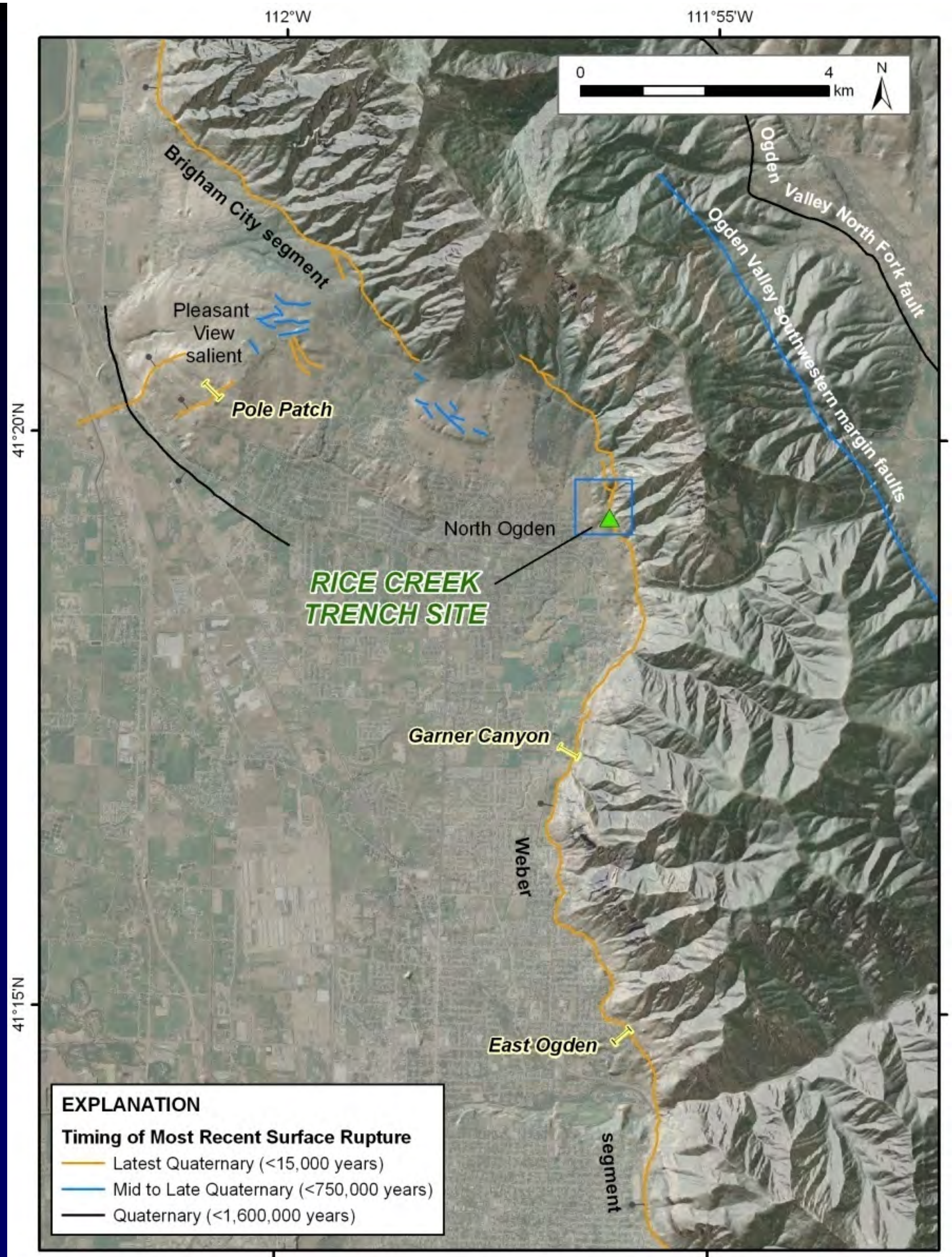


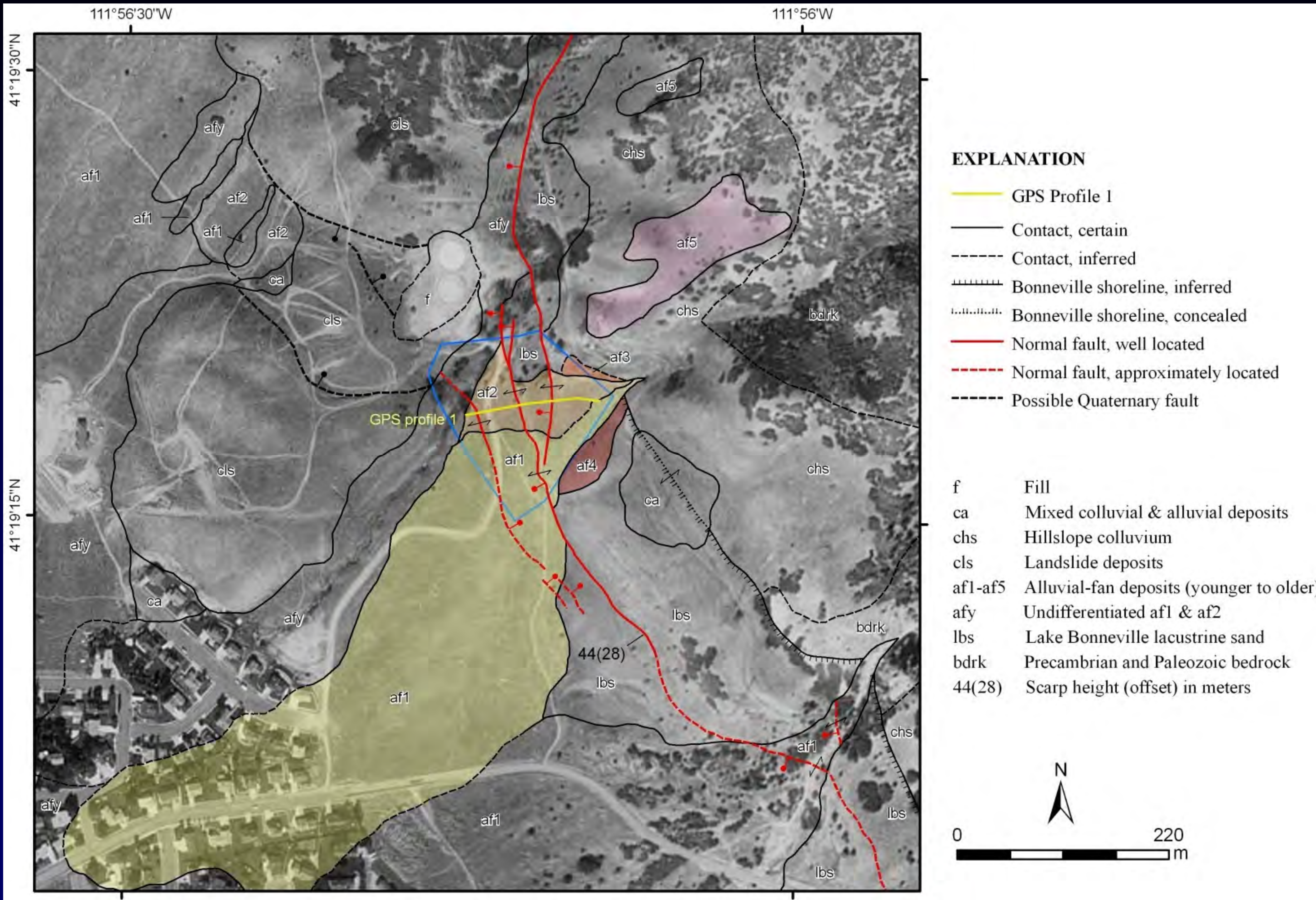
Summary of existing data

(X – evidence for an event of this age not exposed)

Rice Creek Trench Site

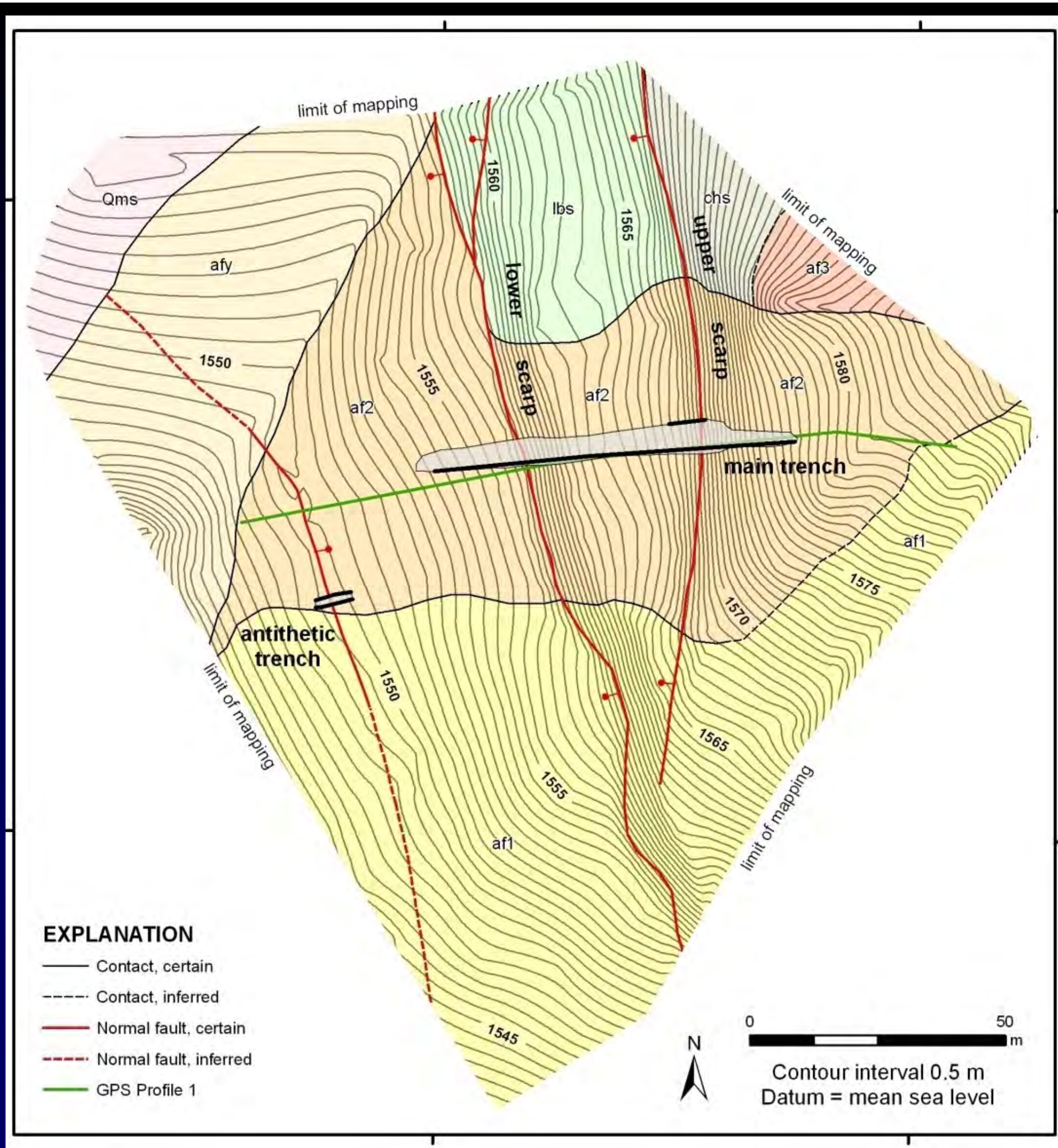
- Located close to northern segment boundary
- Large, unmodified scarps on Holocene alluvial fan



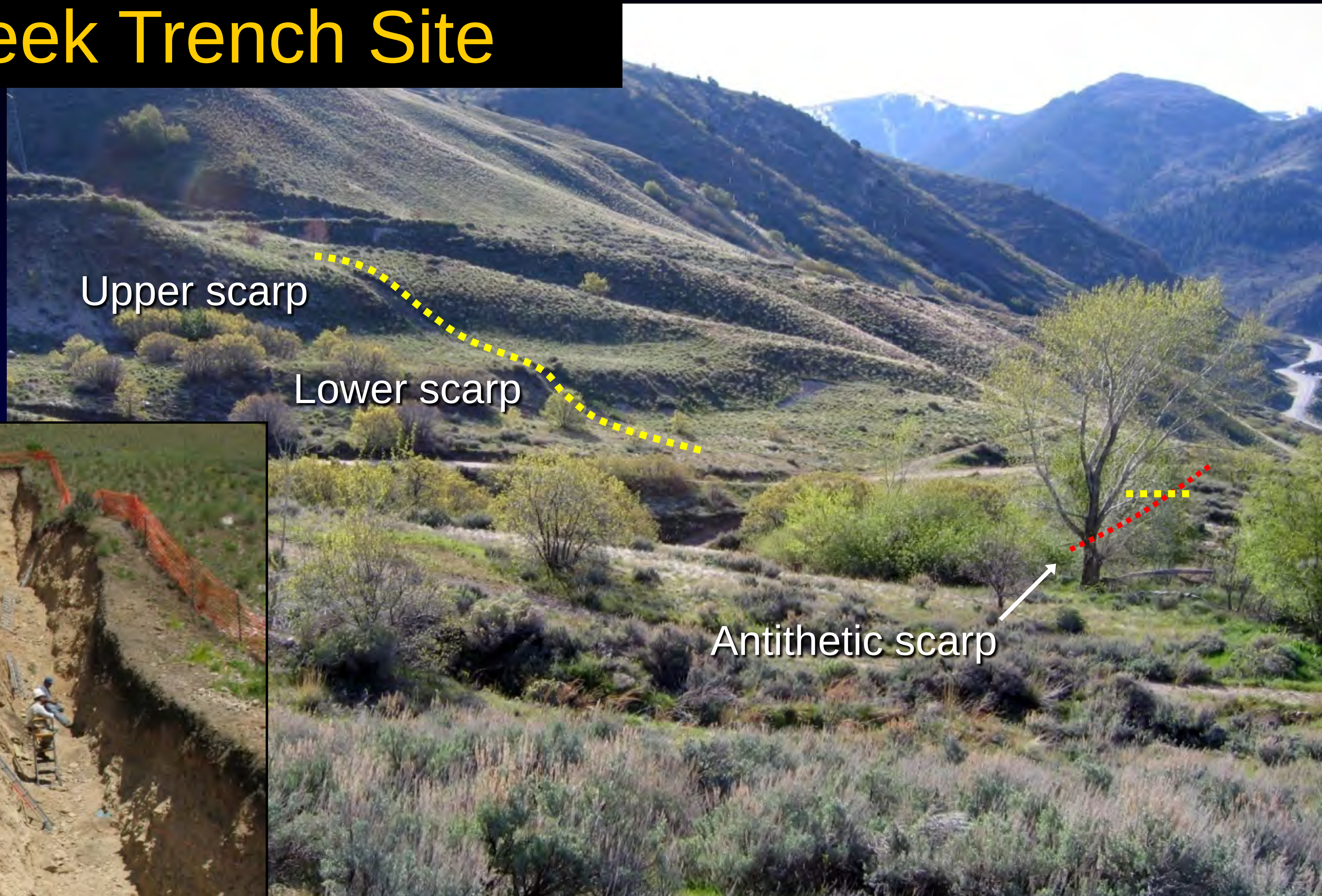

111°56'30"W
111°56'W
41°19'30"N
41°19'15"N
afy
cls
af5
af1
af2
af1
af1
af2
chs
lbs
afy
af5
ca
f
cls
chs
bdrk
lbs
af3
af2
GPS profile 1
af1
af4
cls
ca
chs
afy
ca
afy
lbs
bdrk
44(28)
lbs
af1
chs
af1
afy
af1
lbs
lbs
EXPLANATION
GPS Profile 1
Contact, certain
Contact, inferred
Bonneville shoreline, inferred
Bonneville shoreline, concealed
Normal fault, well located
Normal fault, approximately located
Possible Quaternary fault
f Fill
ca Mixed colluvial & alluvial deposits
chs Hillslope colluvium
cls Landslide deposits
af1-af5 Alluvial-fan deposits (younger to older)
afy Undifferentiated af1 & af2
lbs Lake Bonneville lacustrine sand
bdrk Precambrian and Paleozoic bedrock
44(28) Scarp height (offset) in meters
N
0
220
m

Rice Creek Trench Site

- Two scarps (upper and lower)
- Two trenches:
  - 75-m long main trench
  - 7-m long antithetic trench



Rice Creek Trench Site



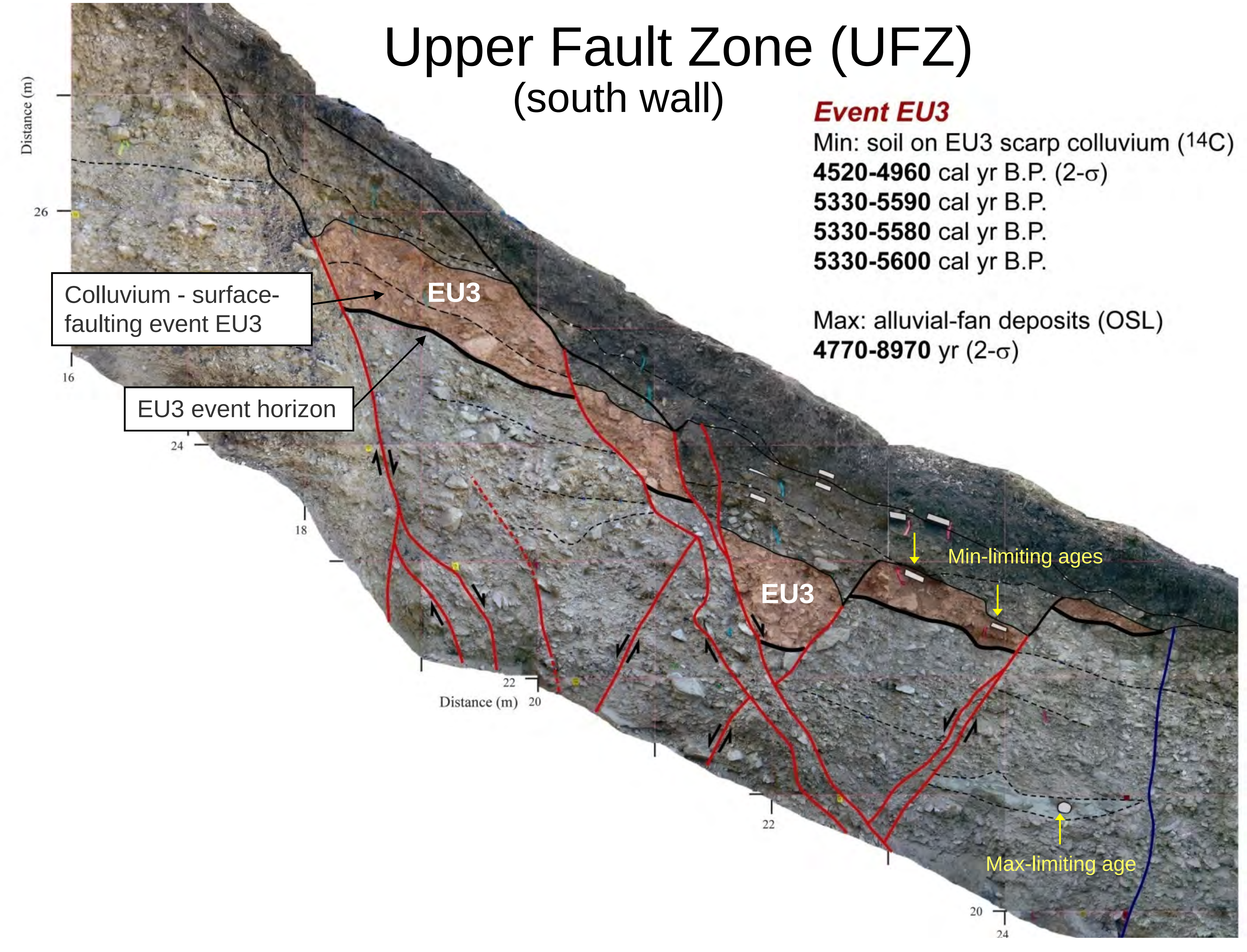
- Main trench: Upper and lower fault zones (UFZ, LFZ)
- Scarp-profile surface offset: **9.3-11.5 m** (site)

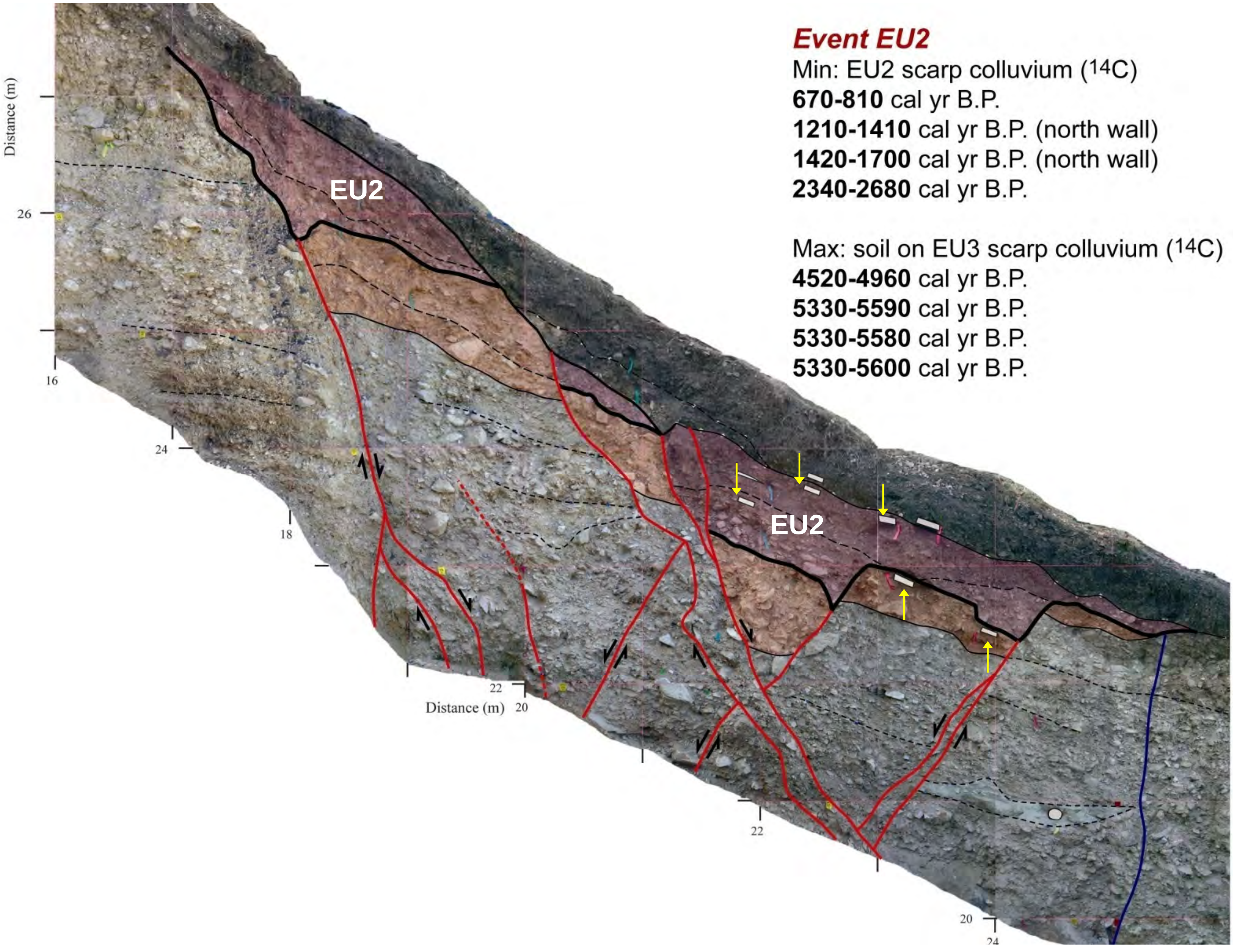
Upper Fault Zone (UFZ)
(south wall)

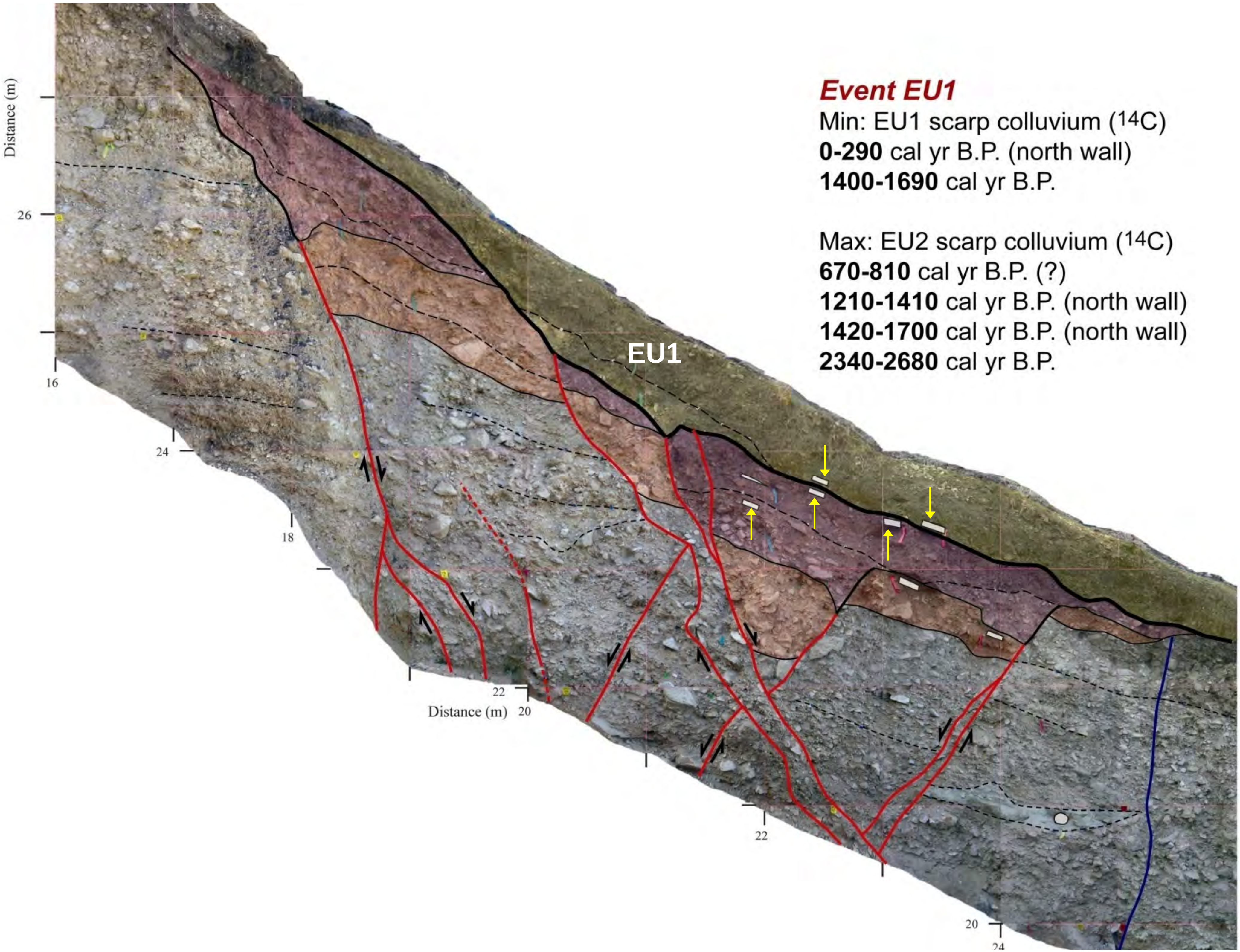
Event EU3

Min: soil on EU3 scarp colluvium (^{14}C)
4520-4960 cal yr B.P. (2-σ)
5330-5590 cal yr B.P.
5330-5580 cal yr B.P.
5330-5600 cal yr B.P.

Max: alluvial-fan deposits (OSL)
4770-8970 yr (2-σ)

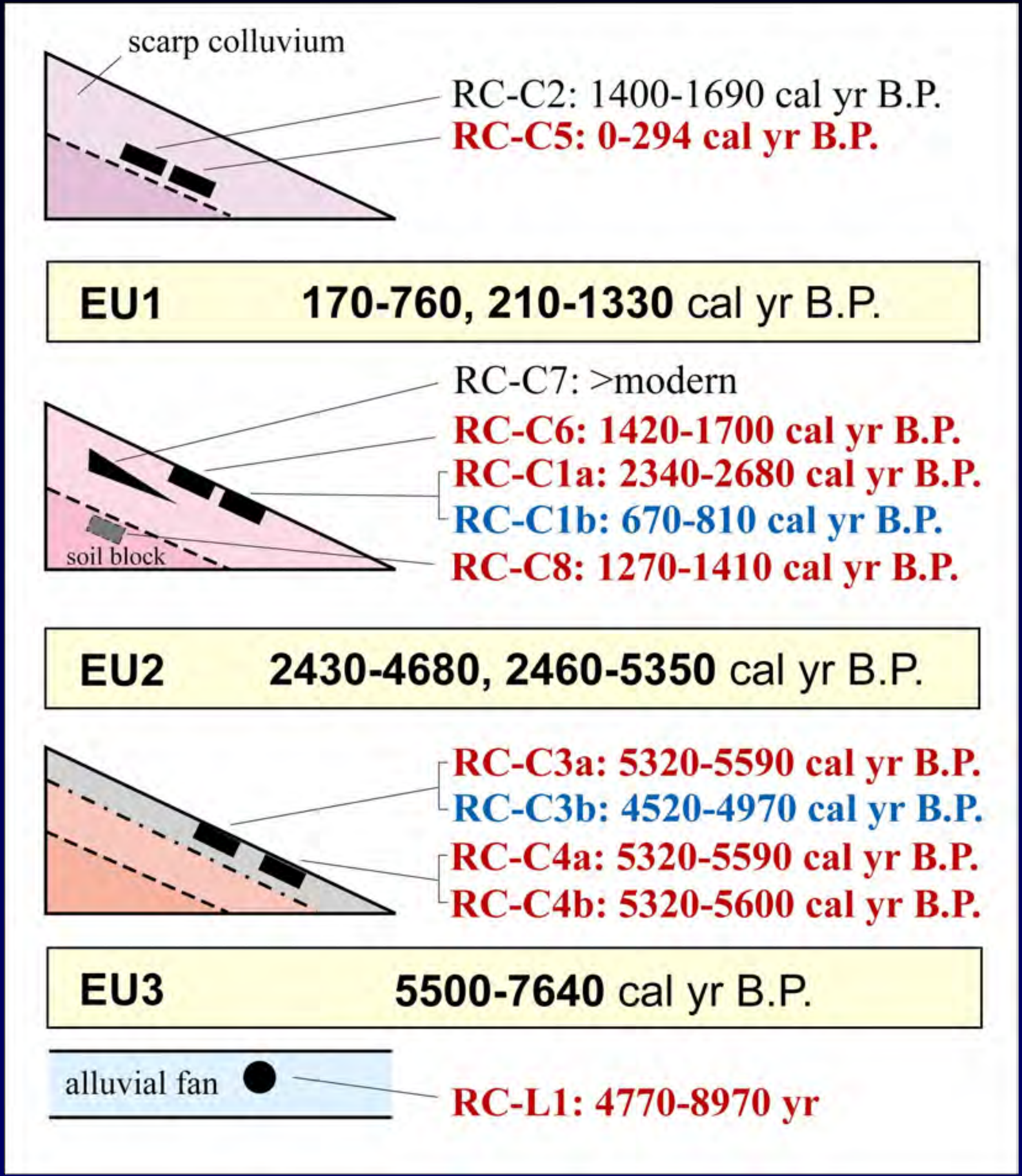



Event EU2
Min: EU2 scarp colluvium (^{14}C)
670-810 cal yr B.P.
1210-1410 cal yr B.P. (north wall)
1420-1700 cal yr B.P. (north wall)
2340-2680 cal yr B.P.
Max: soil on EU3 scarp colluvium (^{14}C)
4520-4960 cal yr B.P.
5330-5590 cal yr B.P.
5330-5580 cal yr B.P.
5330-5600 cal yr B.P.
EU2
EU2
Distance (m)
26
16
24
18
22
20
Distance (m)
22
20
24

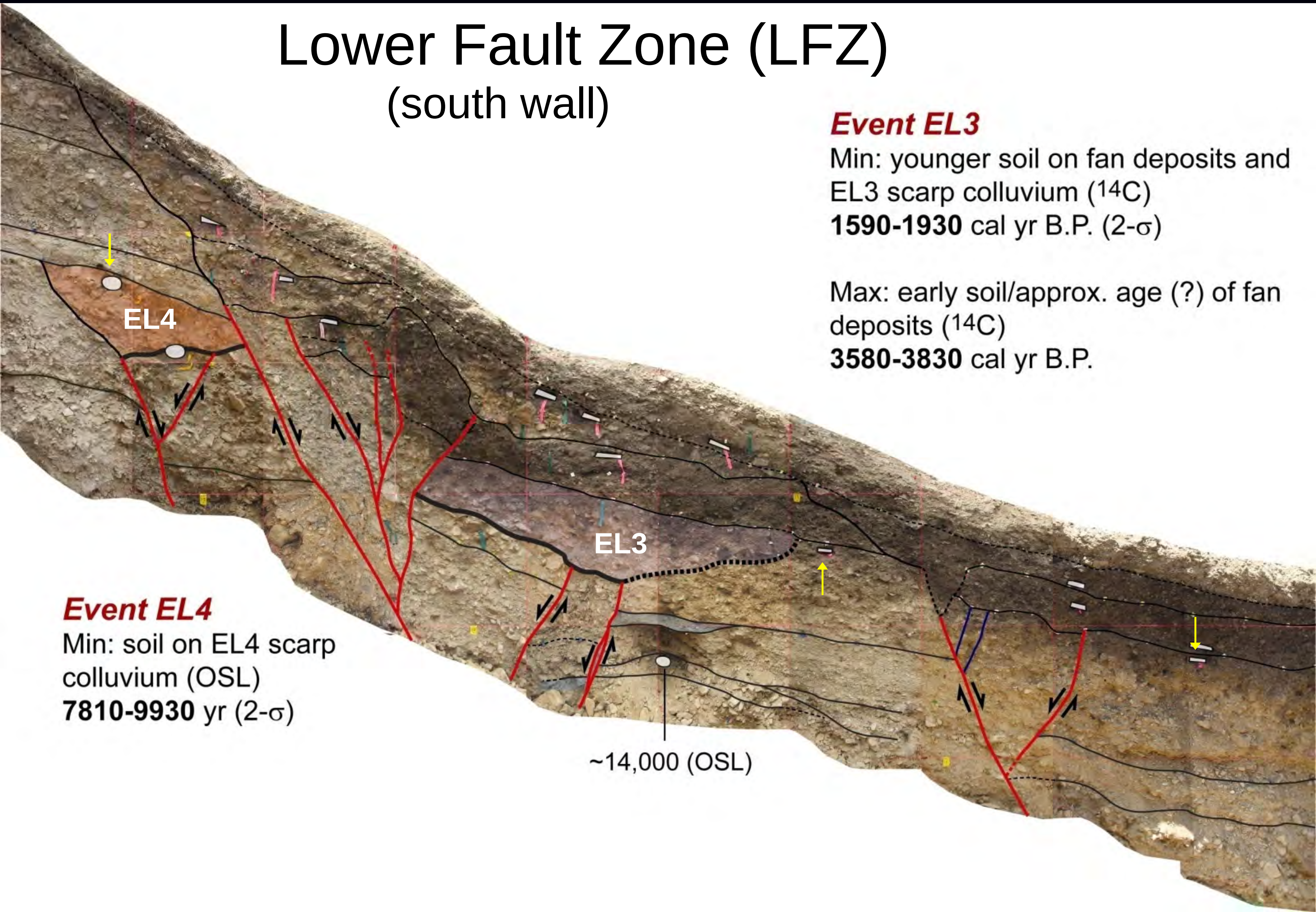

Event EU1
Min: EU1 scarp colluvium (14C)
0-290 cal yr B.P. (north wall)
1400-1690 cal yr B.P.
Max: EU2 scarp colluvium (14C)
670-810 cal yr B.P. (?)
1210-1410 cal yr B.P. (north wall)
1420-1700 cal yr B.P. (north wall)
2340-2680 cal yr B.P.
EU1
Distance (m)
26
16
24
18
22
Distance (m)
20
22
20
24

Summary of UFZ event timing

- 3 events in UFZ modeled using OxCal
- Poor minimum constraints for EU1 & EU2
- Age variability complicates event time determinations



Lower Fault Zone (LFZ)
(south wall)



Event EL3

Min: younger soil on fan deposits and EL3 scarp colluvium (^{14}C)
1590-1930 cal yr B.P. (2-σ)

Max: early soil/approx. age (?) of fan deposits (^{14}C)
3580-3830 cal yr B.P.

Event EL4

Min: soil on EL4 scarp colluvium (OSL)
7810-9930 yr (2-σ)

Event EL2

Min: EL2 scarp colluvium (^{14}C)

20-290 cal yr B.P.

510-560 cal yr B.P.

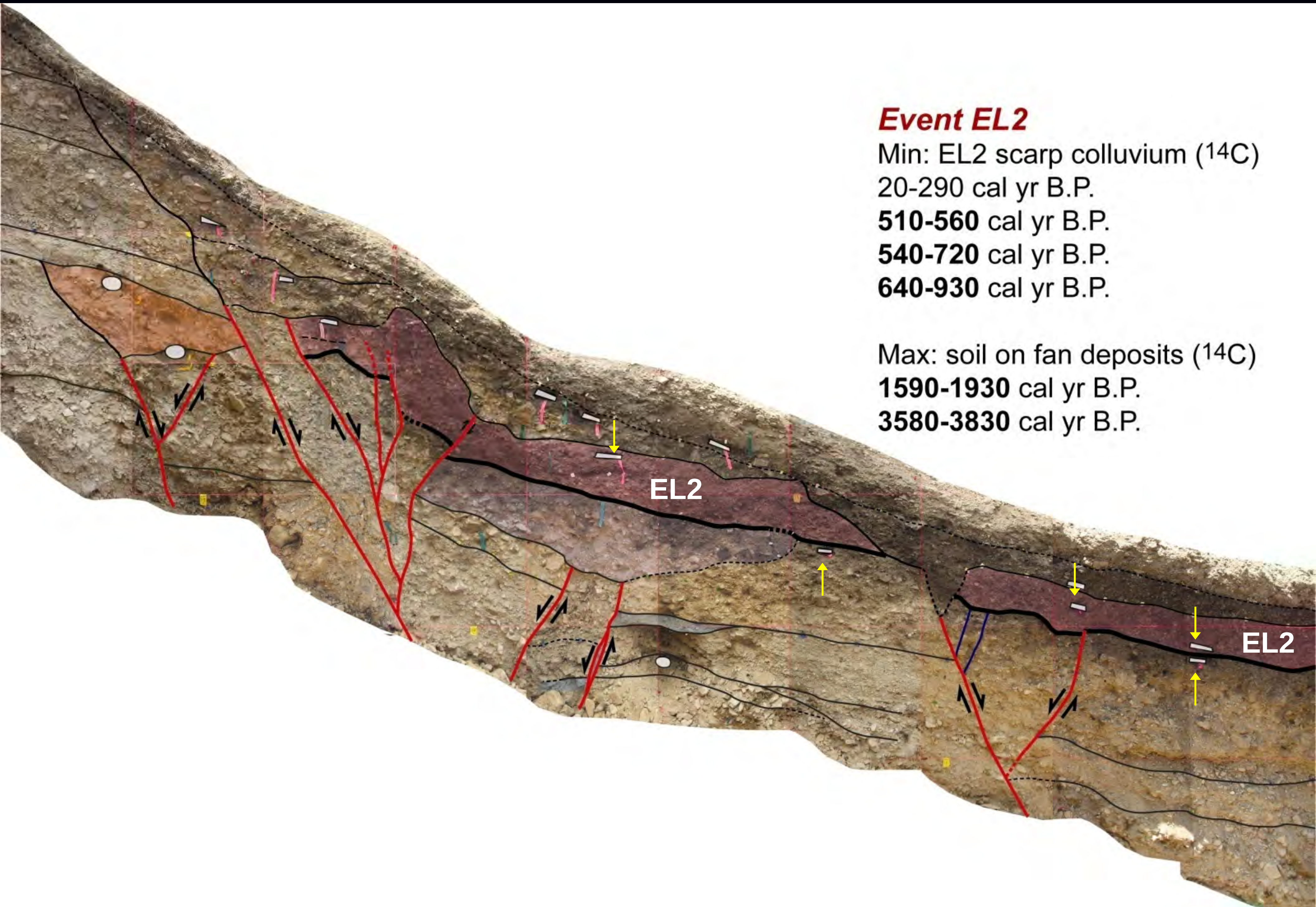
540-720 cal yr B.P.

640-930 cal yr B.P.

Max: soil on fan deposits (^{14}C)

1590-1930 cal yr B.P.

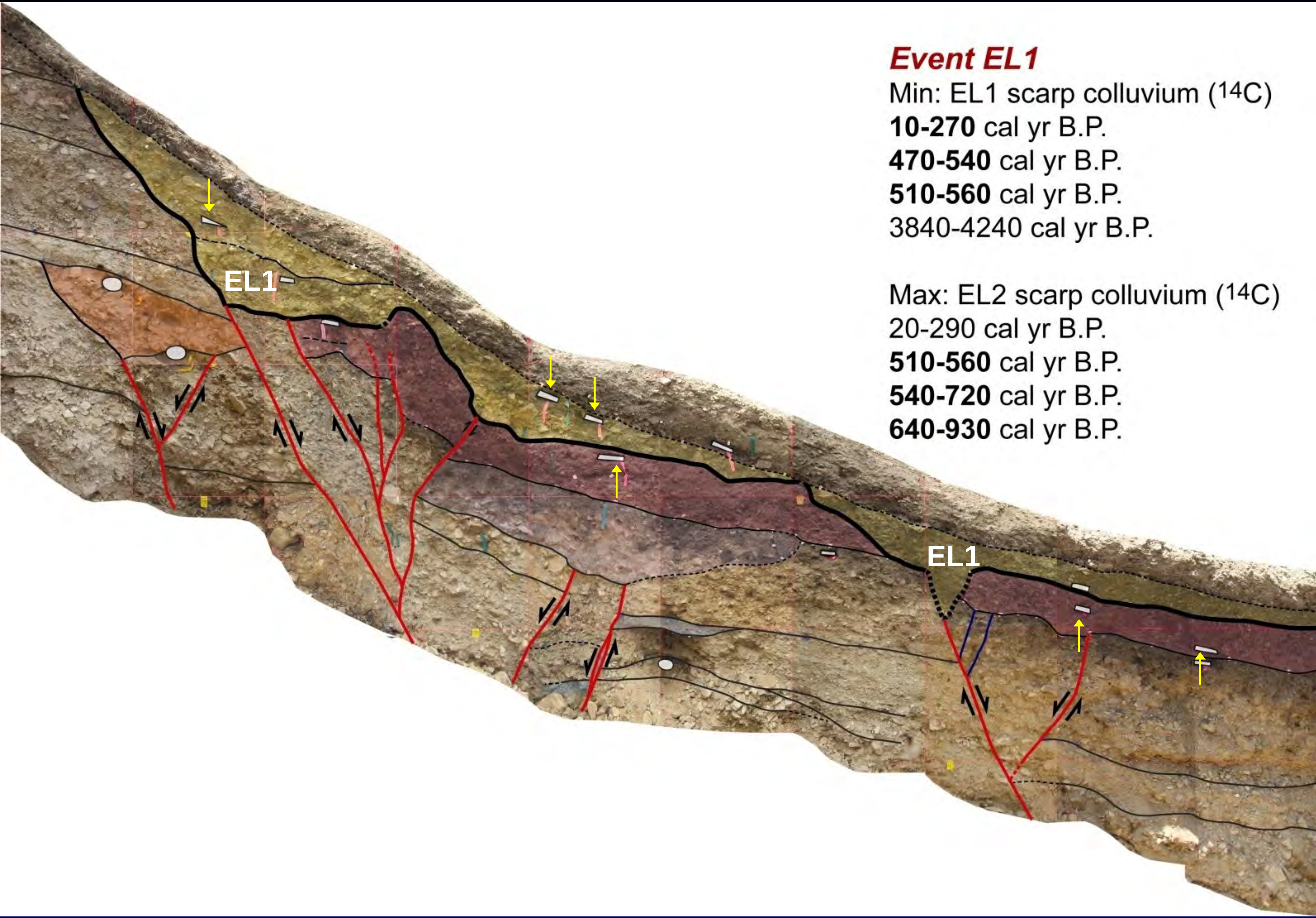
3580-3830 cal yr B.P.



Event EL1

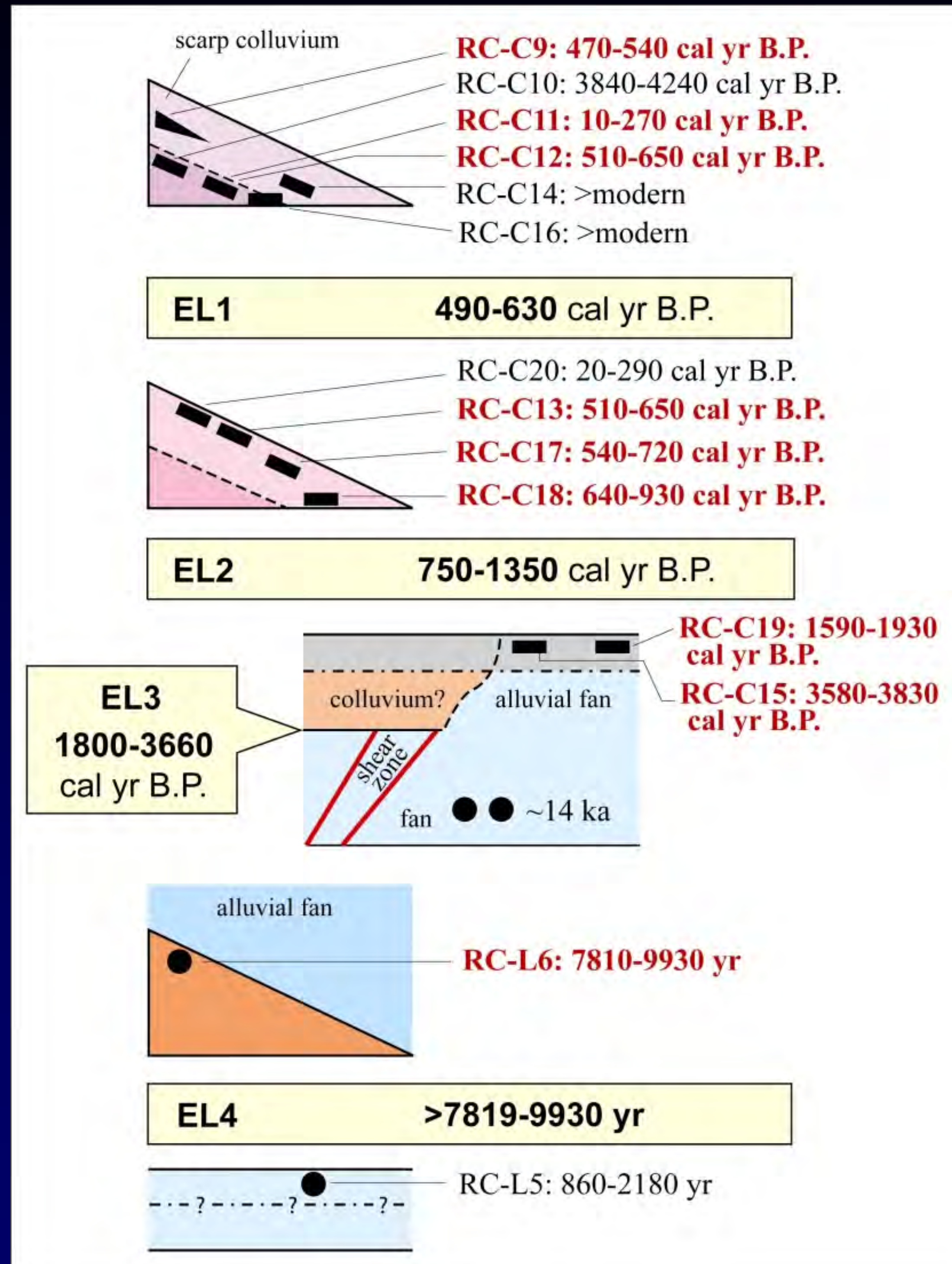
Min: EL1 scarp colluvium (^{14}C)
10-270 cal yr B.P.
470-540 cal yr B.P.
510-560 cal yr B.P.
3840-4240 cal yr B.P.

Max: EL2 scarp colluvium (^{14}C)
20-290 cal yr B.P.
510-560 cal yr B.P.
540-720 cal yr B.P.
640-930 cal yr B.P.

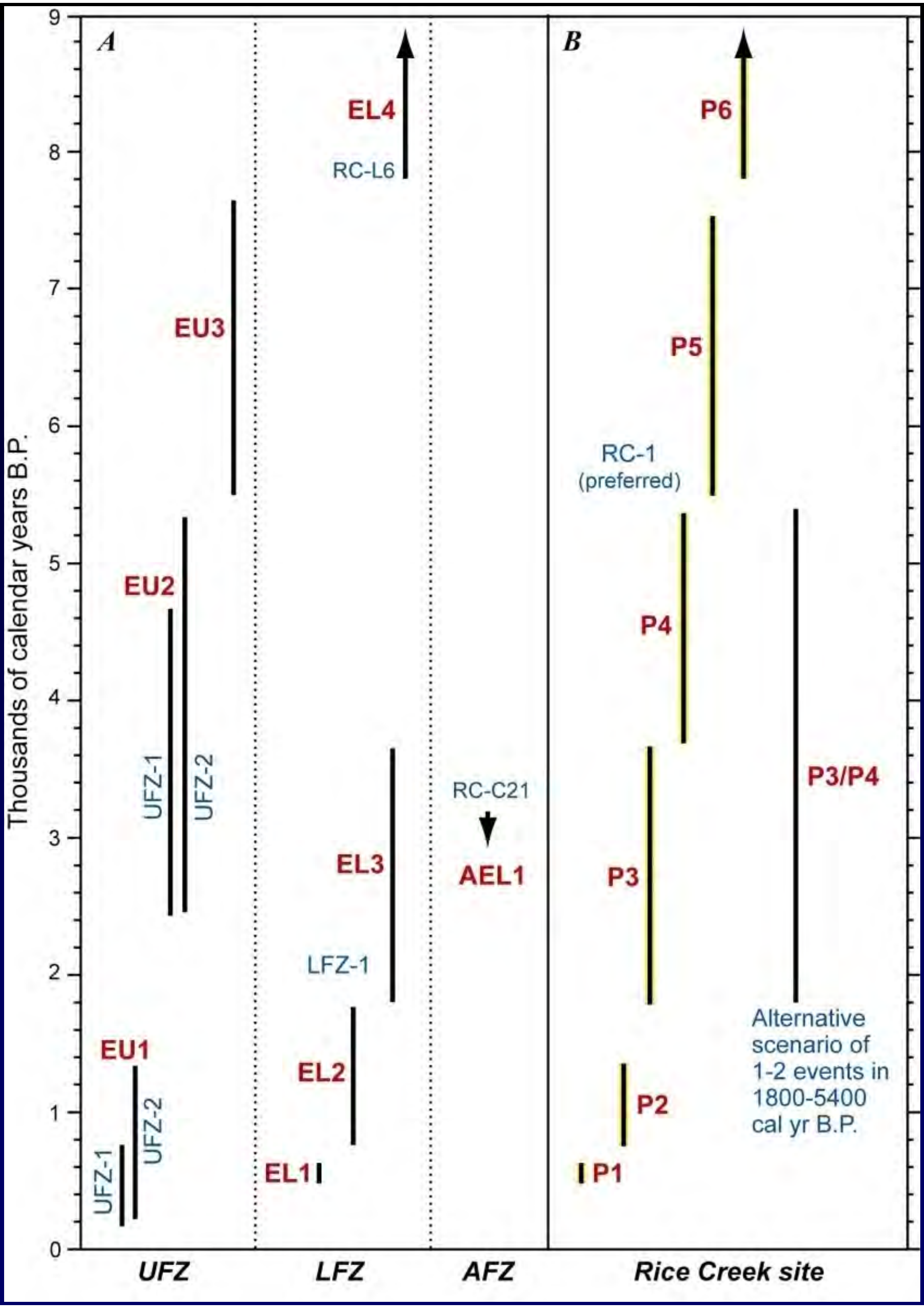


Summary of LFZ event timing

- 3 events in LFZ modeled in OxCal;
  4th: only minimum time constraint
- Good minimum & maximum constraints for EL1 & EL2
- EL3 interpretation is tenuous

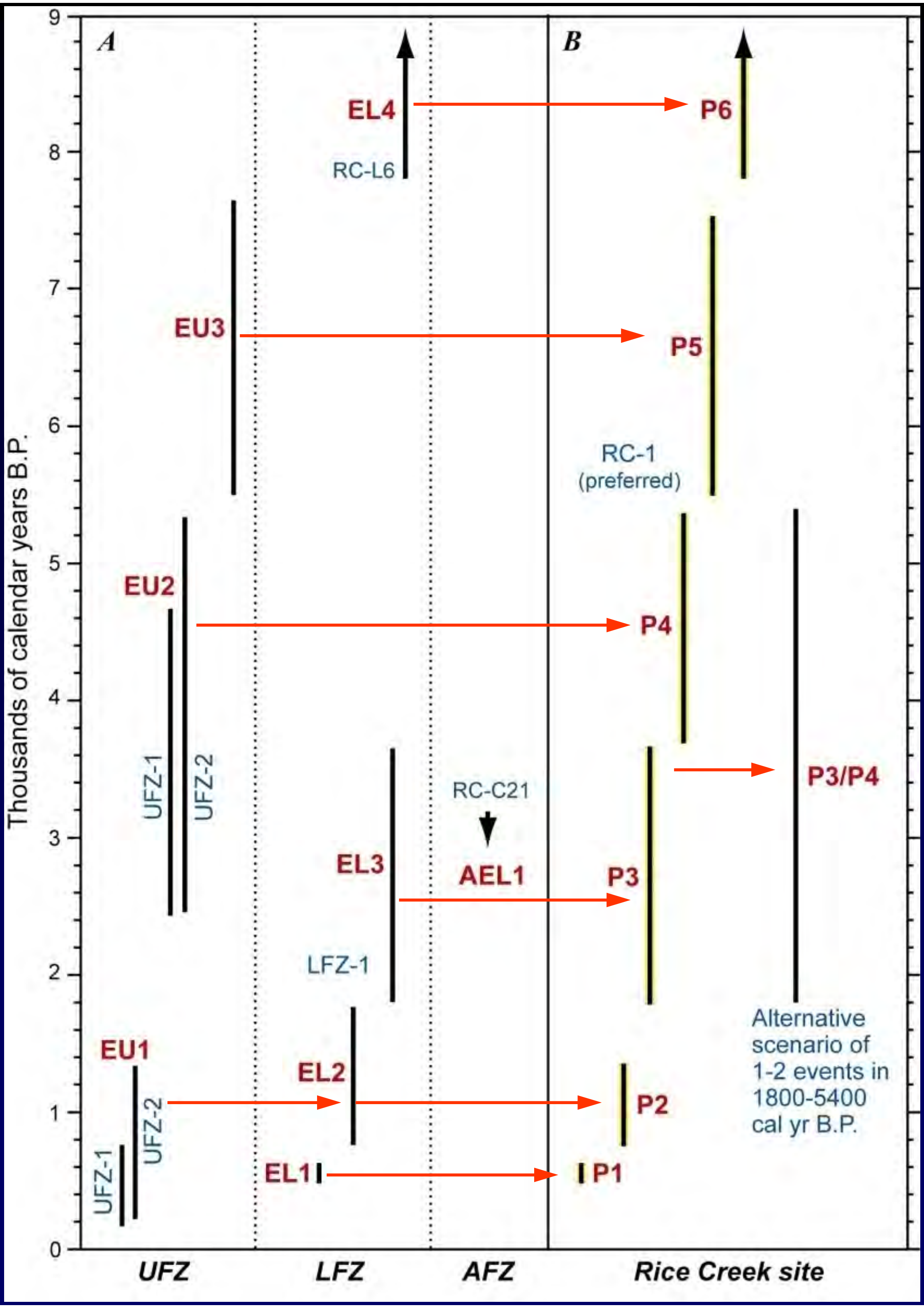


Correlation of OxCal models



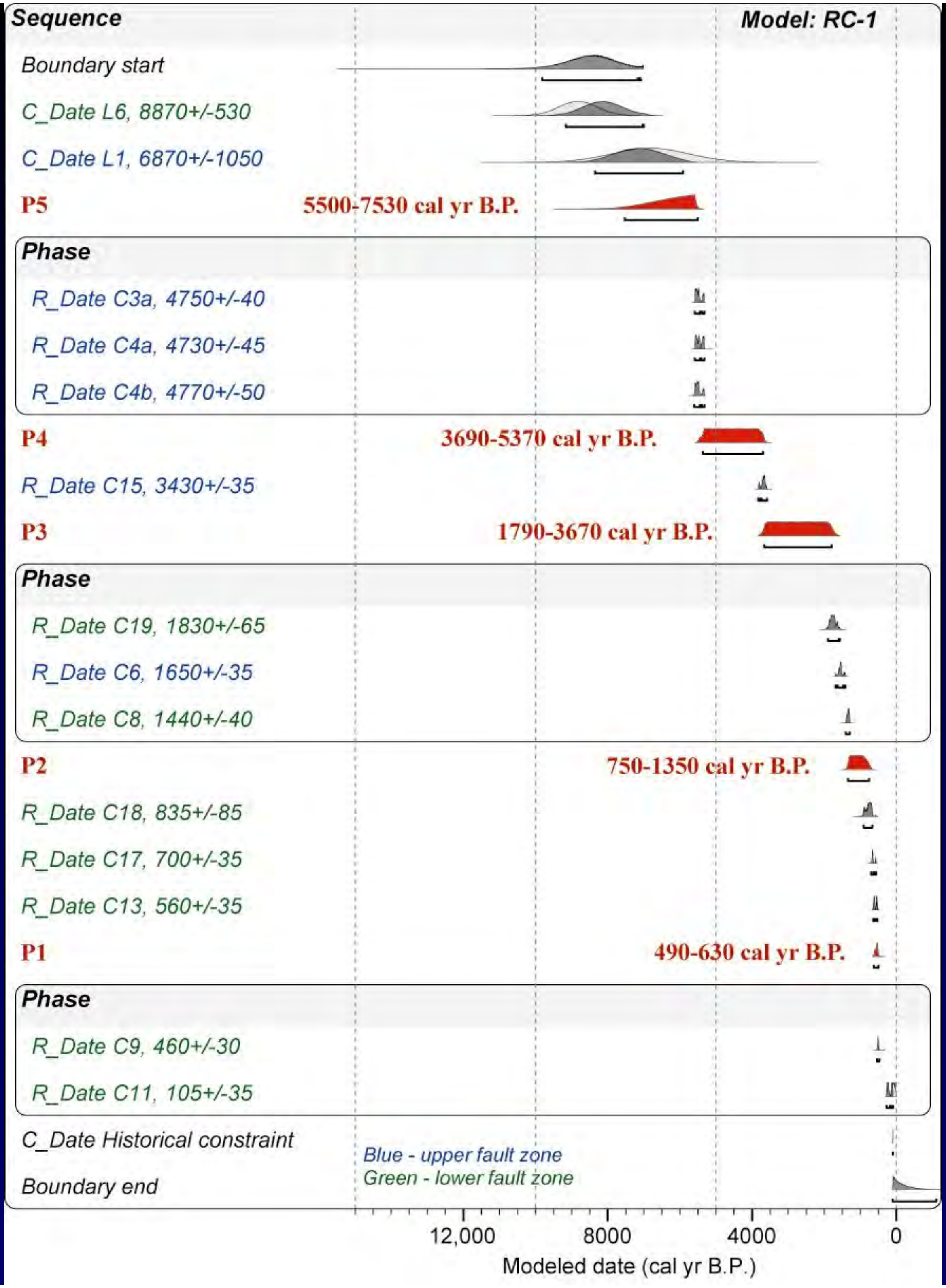
Correlation of OxCal models

- 5 or 6 paleoearthquakes:
  - **P1** (EL1)
  - **P2** (EU1 & EL2)
  - **P3**? (EU2)
  - **P4**? (EL3)
  - **P5** (EU3)
  - **P6** (EL4)

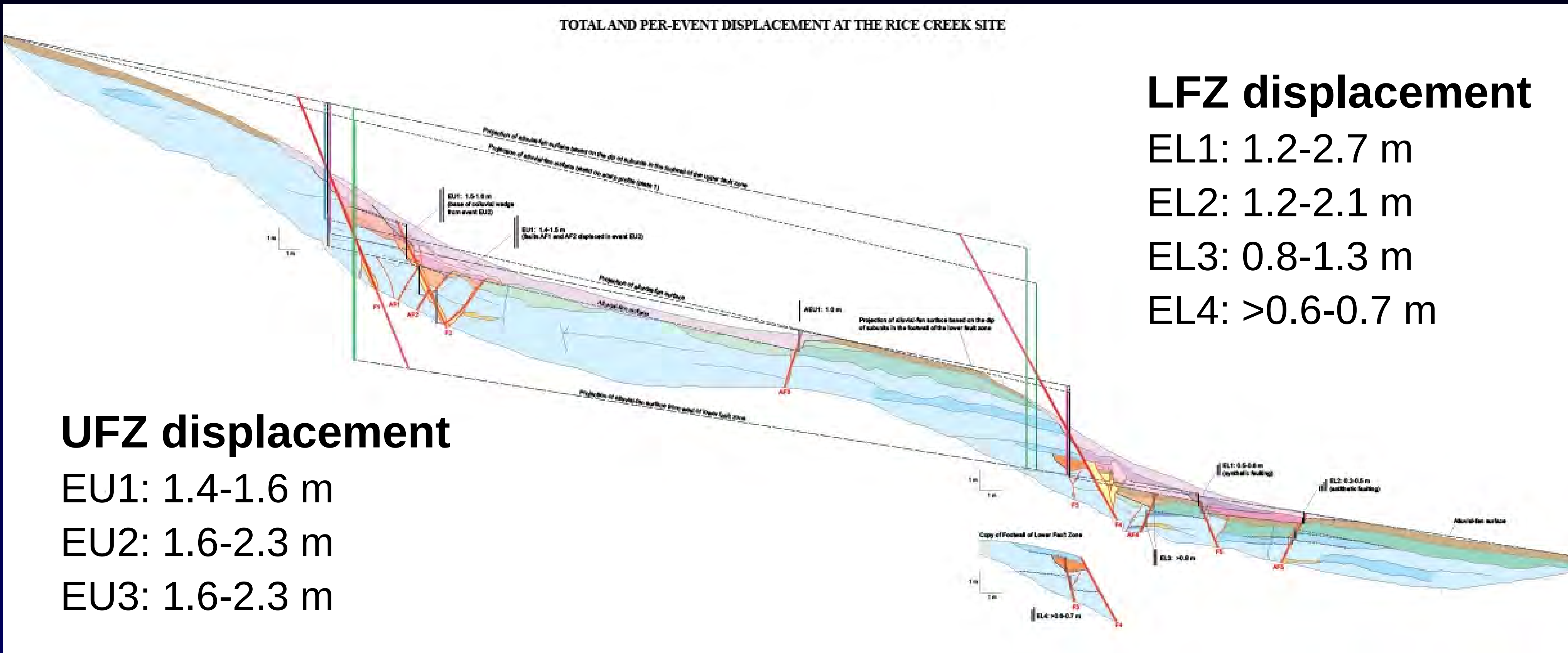


Rice Creek paleoearthquake chronology

- OxCal model for UFZ and LFZ combined
- P1,P2: well constrained
- P3, P4, P5: more poorly constrained
- P6: >7700-9900 yr B.P.



Per-event and site displacements



LFZ displacement

EL1: 1.2-2.7 m

EL2: 1.2-2.1 m

EL3: 0.8-1.3 m

EL4: >0.6-0.7 m

UFZ displacement

EU1: 1.4-1.6 m

EU2: 1.6-2.3 m

EU3: 1.6-2.3 m

- Site displacement: 8.5-11.4 m
- Sum of per-event displacements: 7.6-12.3 m
- Trench reconstruction: 9.5-9.9 m
- Surface offset: 9.3-11.5 m

Fault and Paleoearthquake Parameters

Earthquake timing (2-σ)	UQFPWG (~2-σ)
P1: **490-630** cal yr B.P.	200-800 cal yr B.P.
P2: **750-1350** cal yr B.P.	500-1400 cal yr B.P.
P3: **1790-3670** cal yr B.P.	2300-3700 cal yr B.P.
P4: **3690-5370** cal yr B.P.	3800-5200 cal yr B.P.
P5: **5500-7530** cal yr B.P.	5400-6800 cal yr B.P.
P6: **>8-10** ka	

- Displacement
  - Average per-event displacement: **1.6-2.5** m (P1 to P5)
  - Net (site) displacement: **7.3-12.3** m

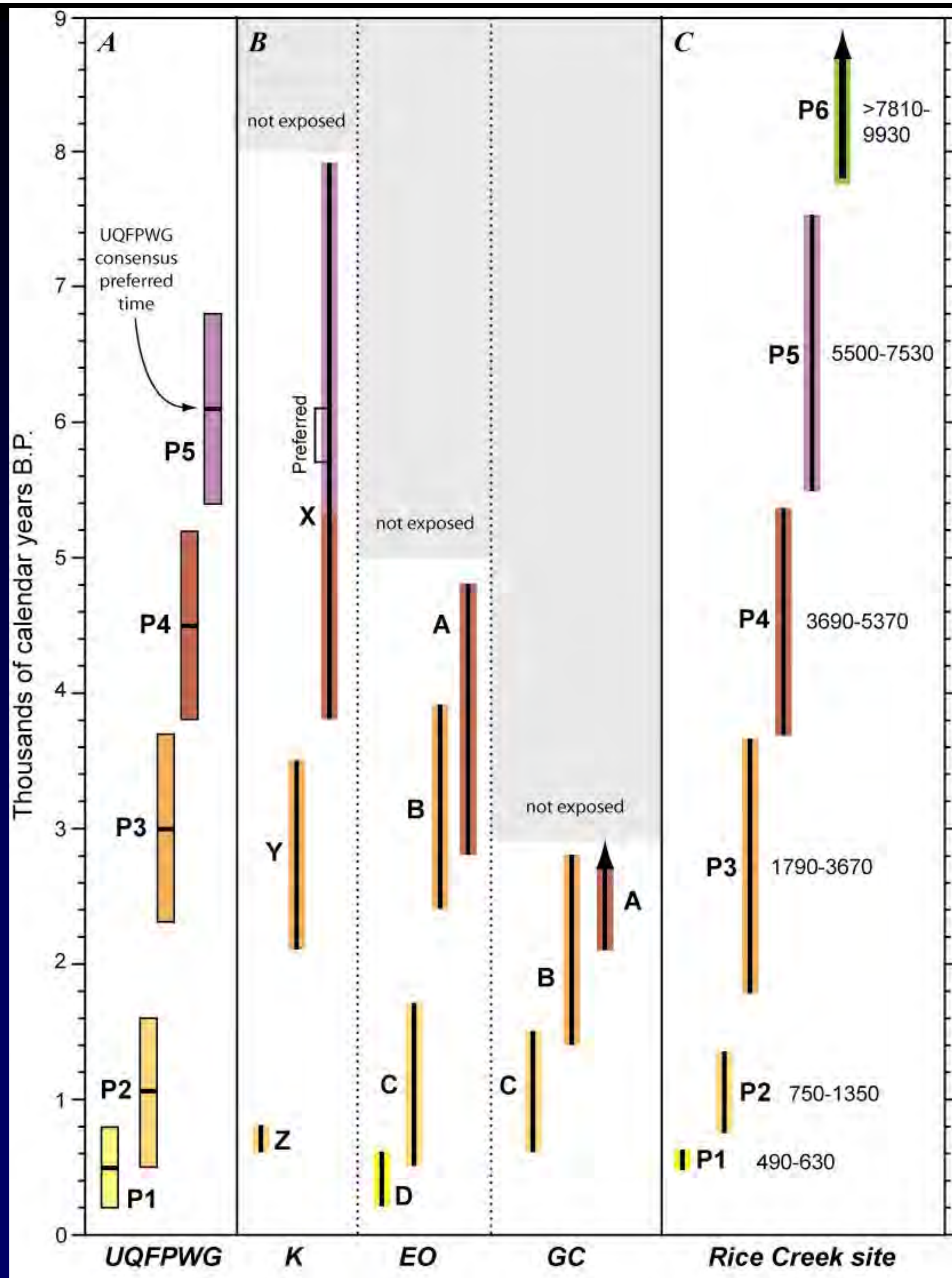
Fault and Paleoearthquake Parameters

- 2-σ Recurrence intervals*
  - P1-P2: 200-800 yr
  - P2-P3: 600-2700 yr
  - P3-P4: 400-3200 yr
  - P4-P5: 300-3300 yr
  - P5-P6: >300-4400 yr
  - P1-P5 mean: **1200-1800** yr
  - P2-P5 mean: **1400-2300** yr
  - UQFPWG: 500-**1400**-2400 yr (four intervals between 0.5 and 6.1 ka)
- Slip rate:
  - Broadly constrained seismic interval rates (0.2-14.7 mm/yr)
  - Average based on net (site) displacement: **1.0-2.2** mm/yr
  - Long-term (post-Bonneville) rate: 1.6-1.7 mm/yr
  - UQFPWG: 0.6-**1.2**-4.3 mm/yr

***based on Oxcal modeling**

Comparison with previous data

- P1, P2: well constrained and correlate well with previous data
- P3 to P5: correlate moderately well with previous data (and UQFPWG times), but more broadly constrained
- P6: previously unexposed



Conclusions

- Event Chronology & Correlation:
  - 5, probably 6, paleoearthquakes after 8-10 ka
  - Additional evidence for ~500-yr earthquake on northern Weber segment (partial-segment rupture?)
  - Weber segment earthquake chronology extended into early Holocene

- Paleoearthquake Parameters:
  - Holocene recurrence interval: 500-1650-3100 yr
  - Displacement per event: 1.6-2.5 m
  - Holocene slip rate: 1.0-2.2 mm/yr

Update of Brigham City Segment Trenching

Investigations at Hansen, Kotter, and Pearsons Canyons

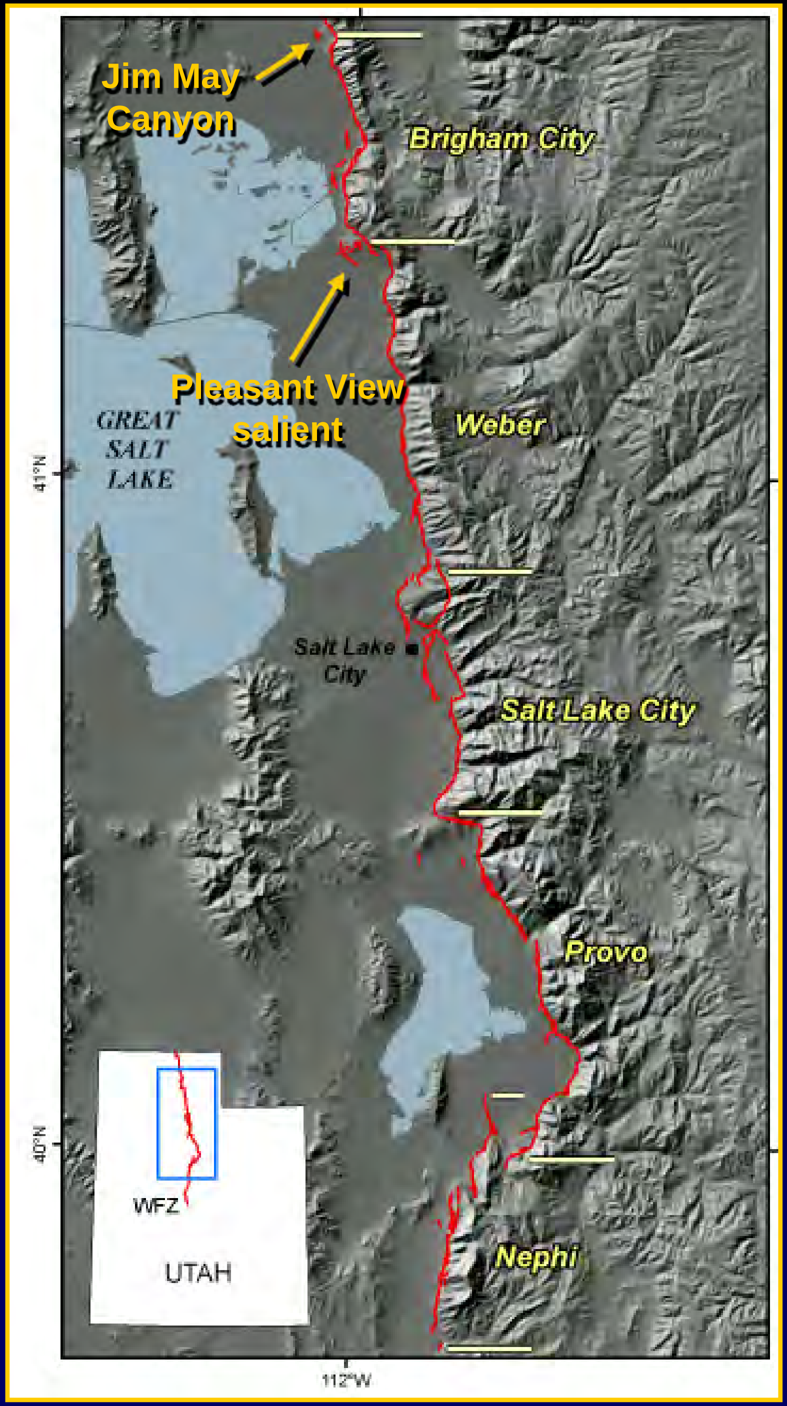
Utah Quaternary Fault Parameters Working Group

Chris DuRoss
Anthony Crone
Greg McDonald
Stephen Personius
Richard Briggs

Kotter Canyon trench

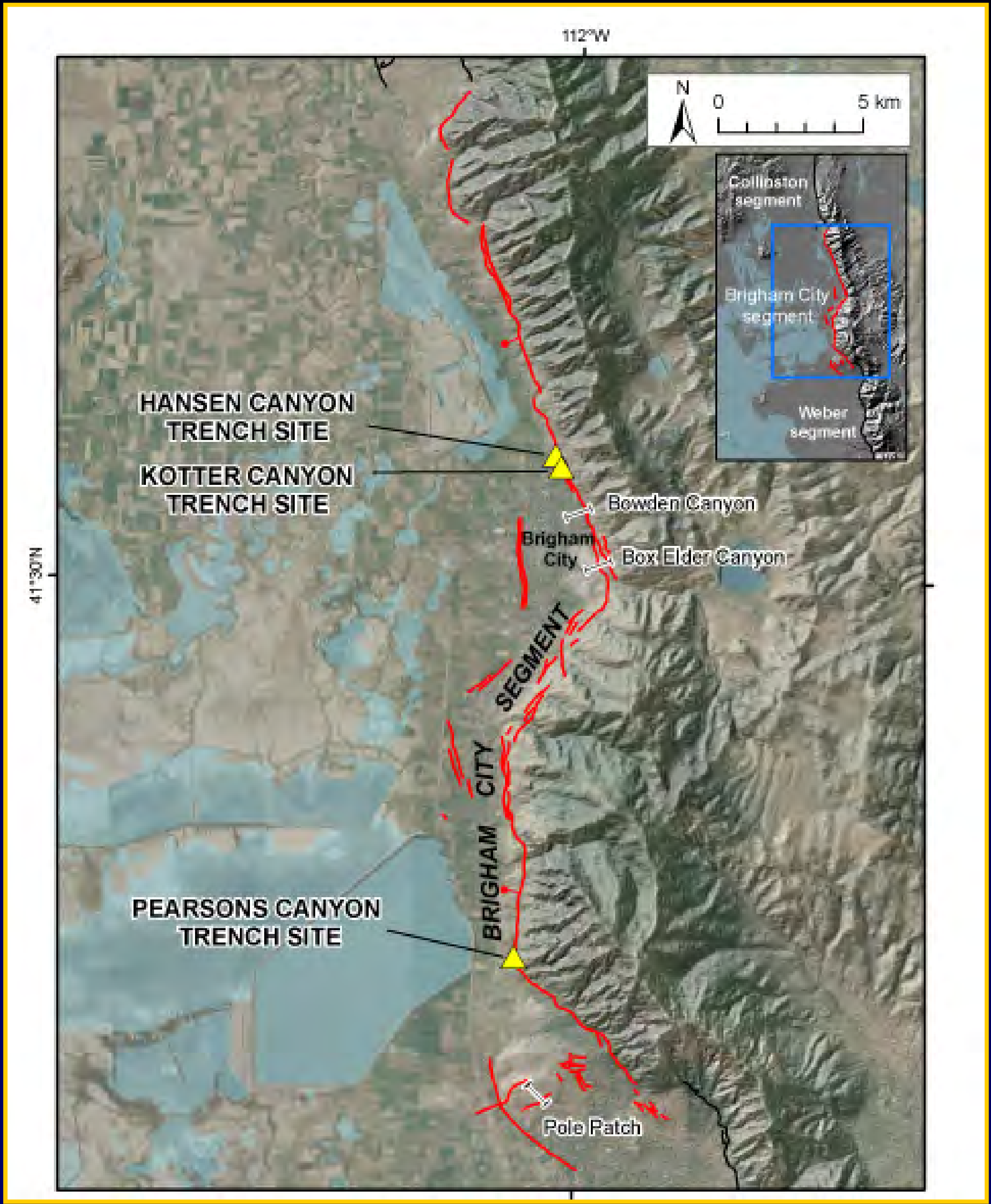
Brigham City Segment

- **~37 km long**
  - From Pleasant View salient on south to near Honeyville (Jim May Canyon) on north
- **UQFPWG Parameters for BCS**
  - MRE: 2100±800 cal yr B.P.
  - Slip Rate: 0.6–**1.4**–4.5 mm/yr (max. range)
  - Recurrence Interval: 1300±400 yr (based on last five events) 500–**1300**–2800 (max. range)



Brigham City Segment

- **Previous paleoseismic studies**
  - Bowden Canyon (center)
  - Box Elder Canyon (center)
  - Pole Patch (south end at segment boundary)



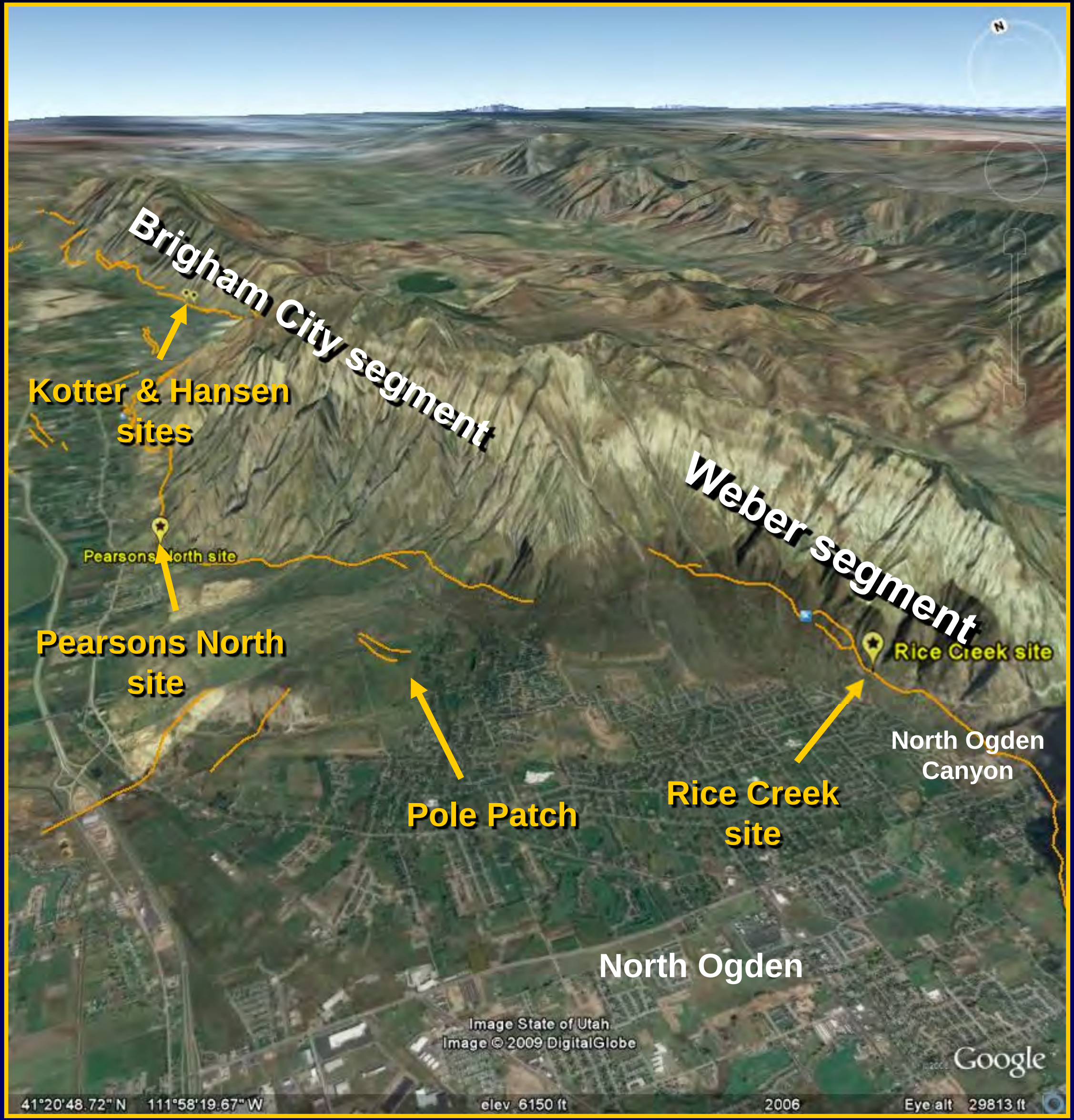
Why study the Brigham City segment?

1. **Elapsed time since the MRE:**
   - Mean Holocene recurrence: ~1300 yr
   - Elapsed time since MRE: ~2100 yr
   - Does BCS have highest likelihood of next surface-rupturing earthquake?

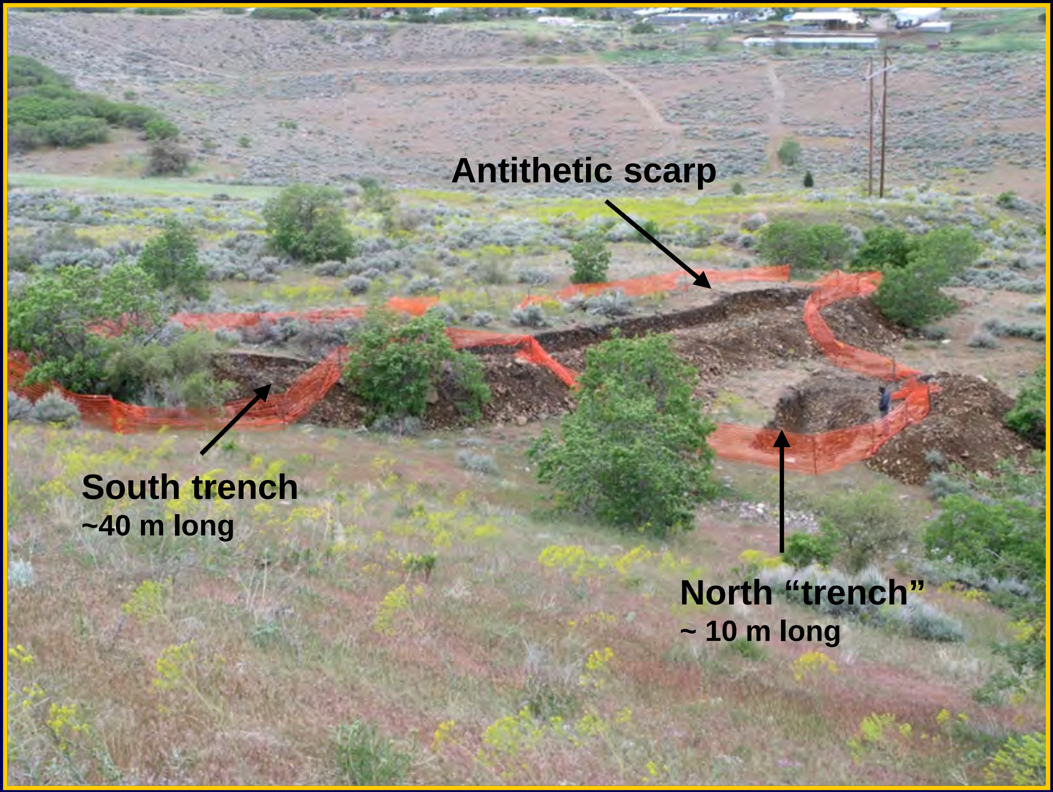
2. **Segmentation:**
   - New results from northern Weber segment indicate a 500-yr-old partial-segment rupture
   - Did rupture extend into southern BCS?
   - Surficial mapping (Personius, 1991) indicates very young scarp at Pearsons Canyon

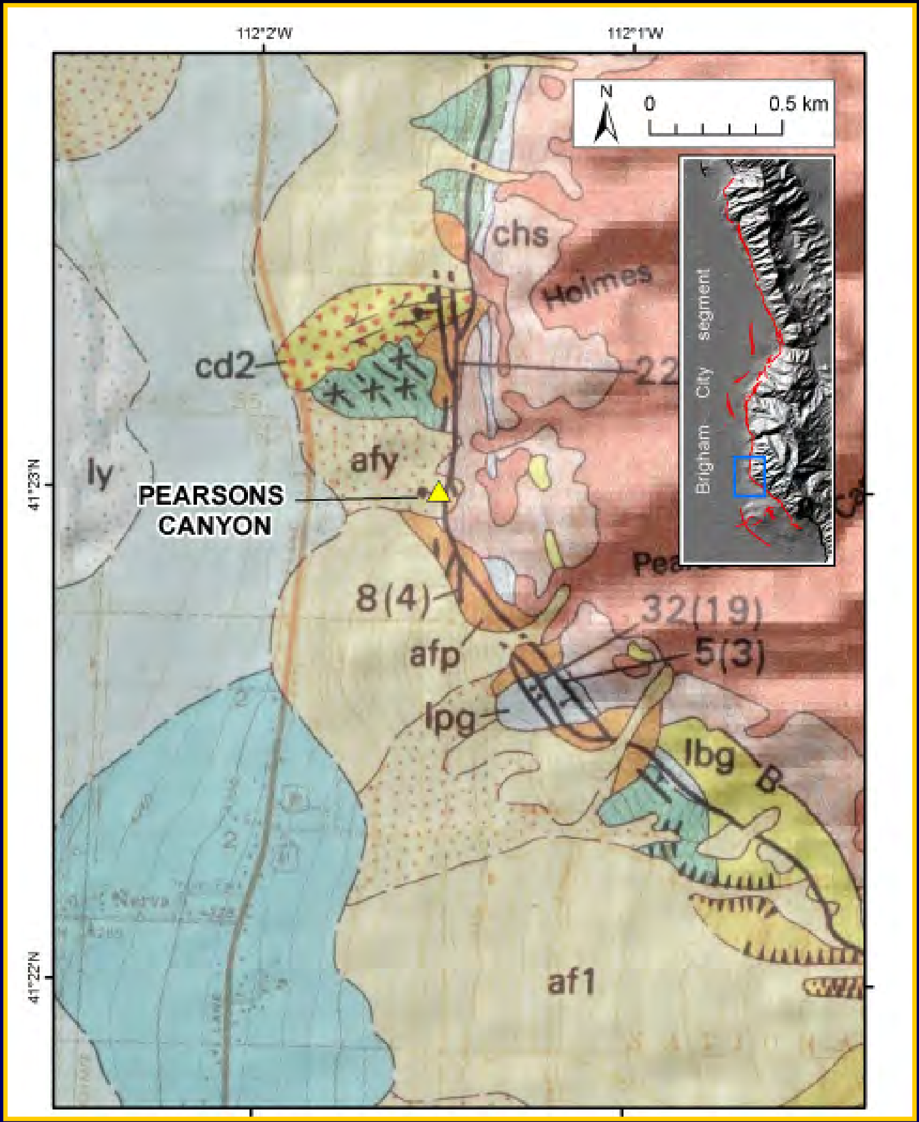
Why the Pearsons North site?

- Evidence of young scarps along southern part of BCS
- No previous study sites on southern part of BCS (subsidiary strand in Pole Patch)
- One of few available sites where scarps are of workable size and accessible
- Evidence of partial segment rupture on northern WS at Rice Creek



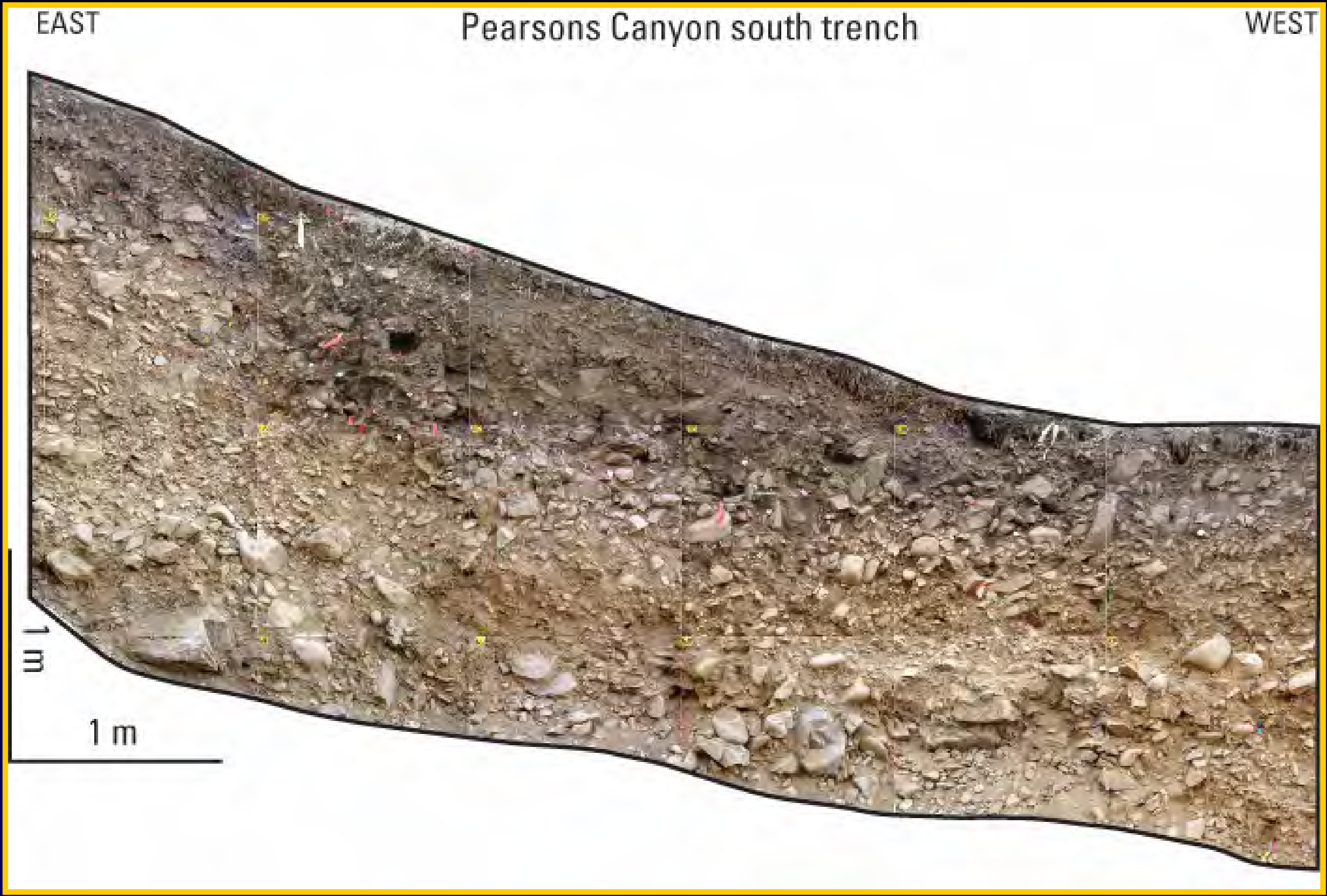
Pearsons North Trench Site





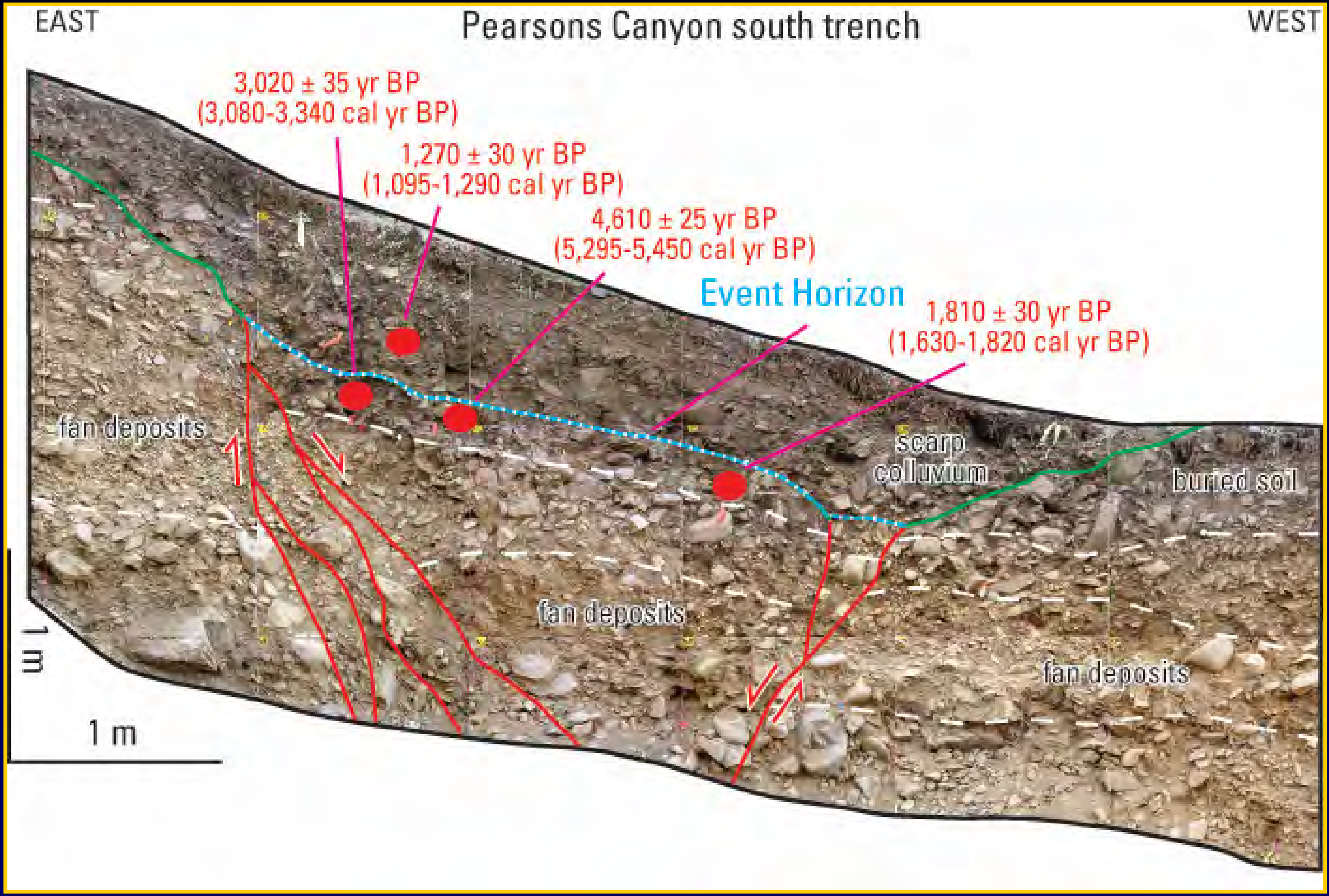
- Approximately 1- to 3-m-high scarp
- Small antithetic scarp <1 m high
- Formed on Holocene alluvial fan below Bonneville shoreline

Pearsons North Trench Site:
South trench



- **Single colluvial wedge buries soil formed on alluvial-fan deposits**
- **Coarse nature of fan gravel and rapid facies changes makes correlations of units from hanging wall to foot wall uncertain**

Pearsons North Trench Site:
South trench



- Single colluvial wedge buries soil formed on alluvial-fan deposits
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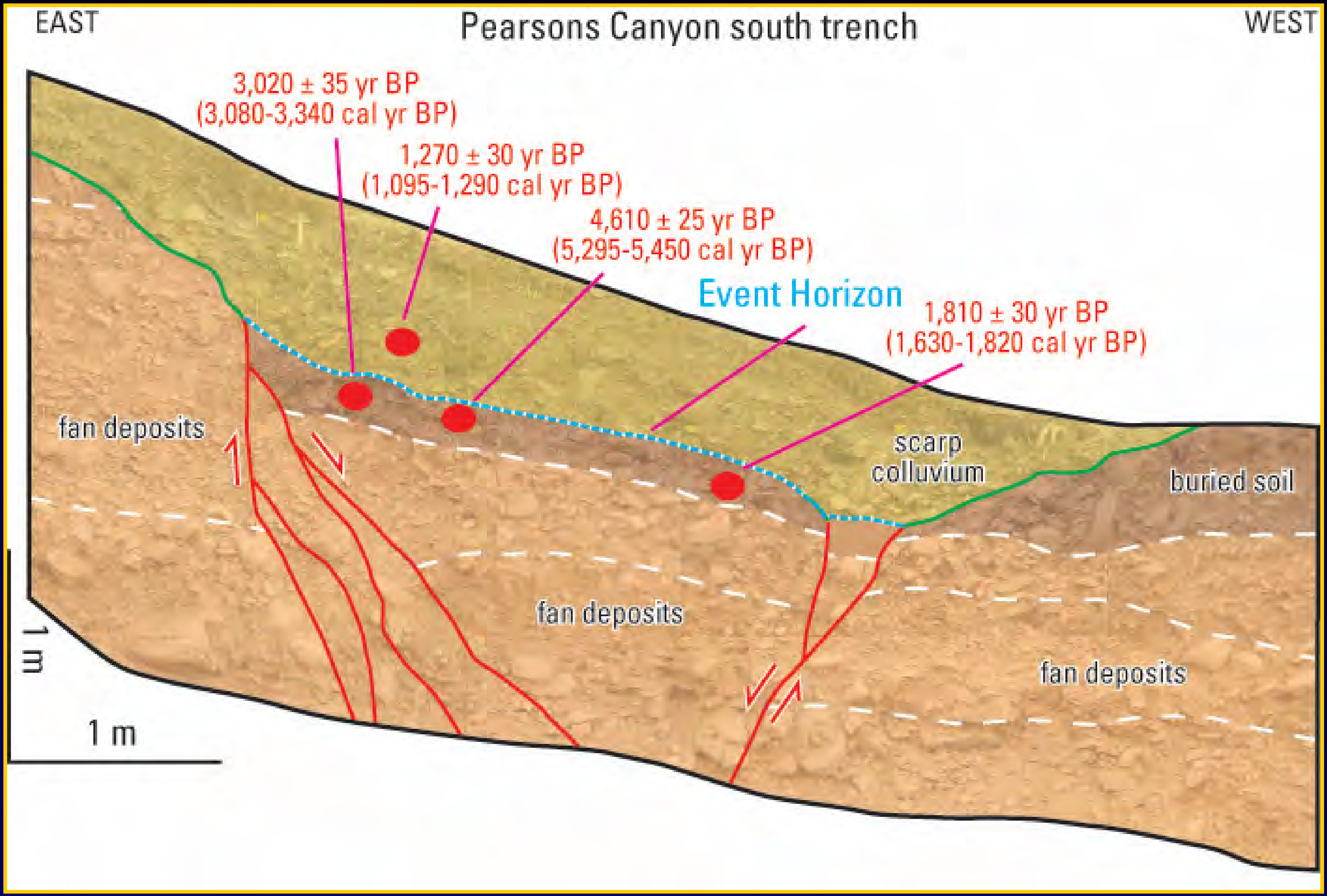
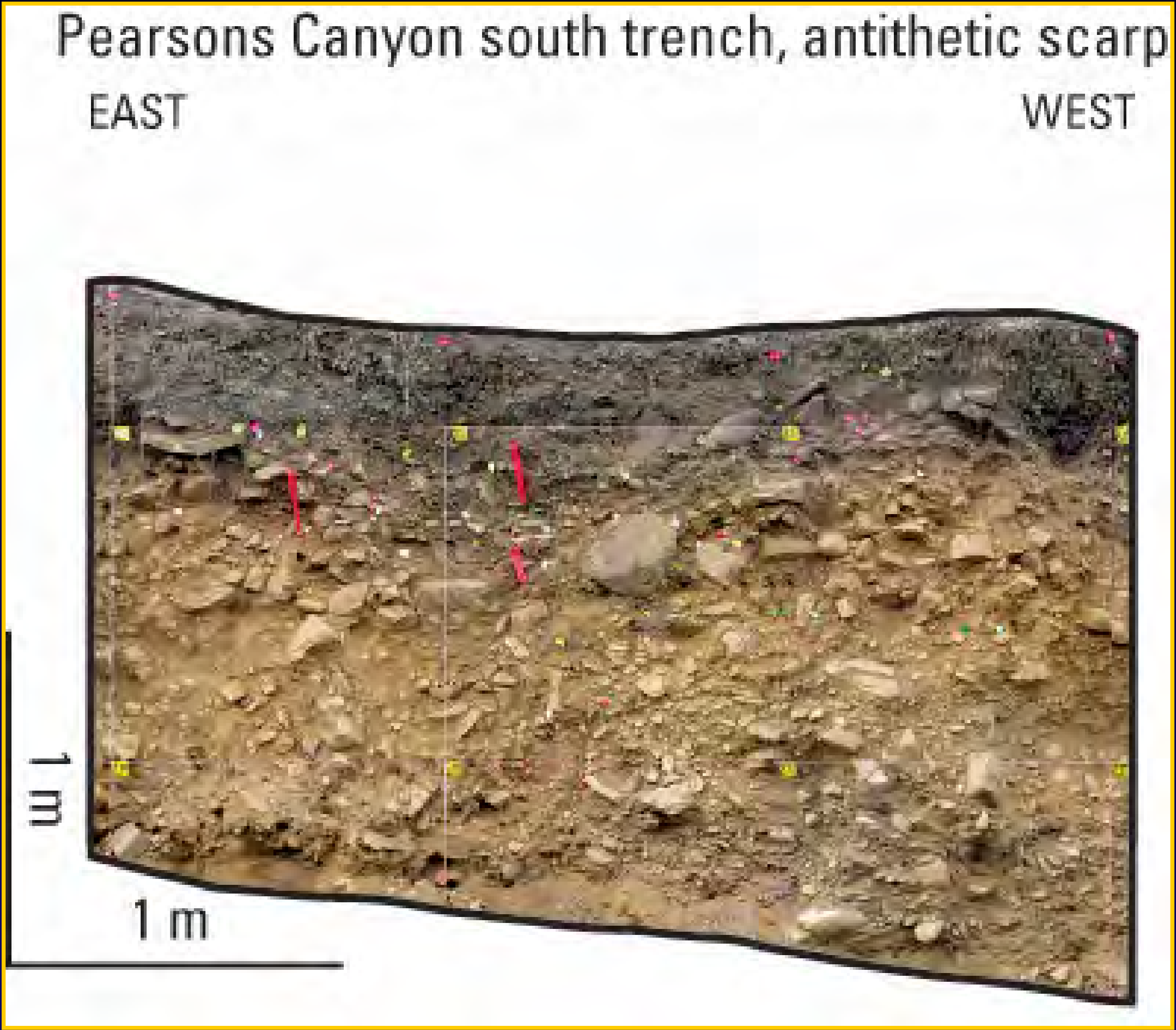
Pearsons North Trench Site:
South trench



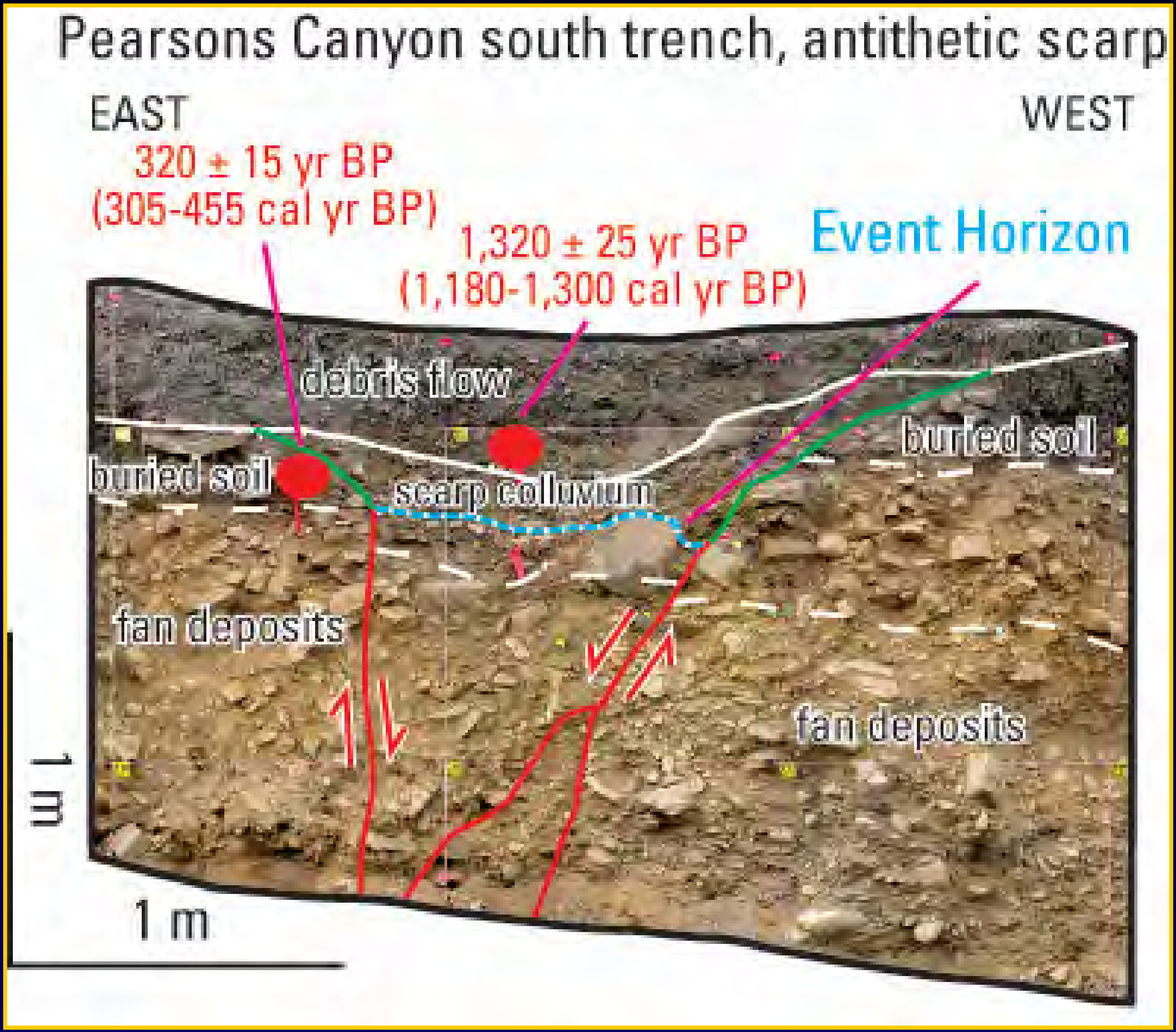
- **Single colluvial wedge buries soil formed on alluvial-fan deposits**
- **Coarse nature of fan gravel and rapid facies changes makes correlations of units from hanging wall to foot wall uncertain**

Pearsons North Trench Site:
Antithetic scarp



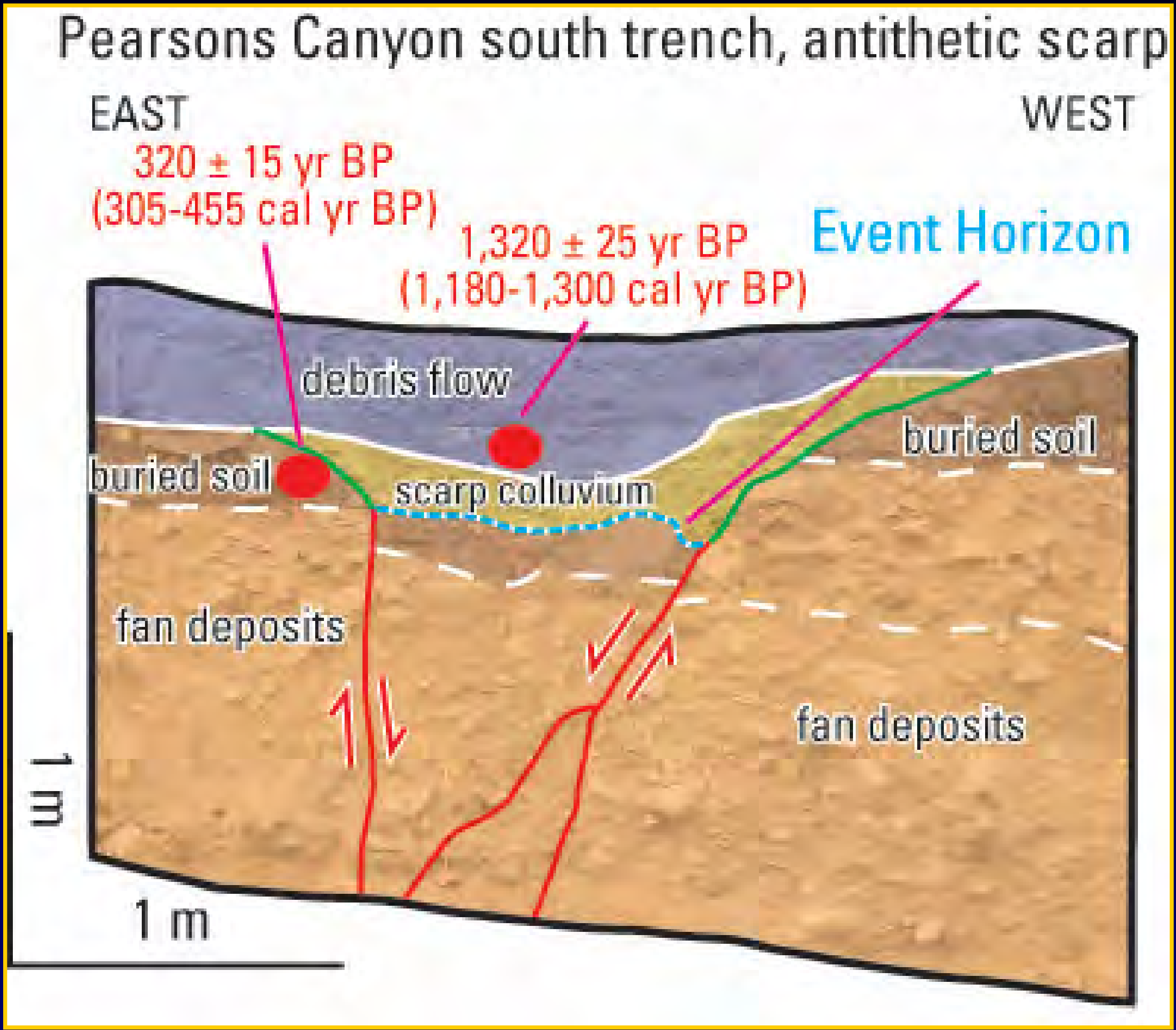
- Single event
- About 1 m of stratigraphic throw on scarp
- Debris flow ponded against scarp; did not completely bury it

Pearsons North Trench Site:
Antithetic scarp



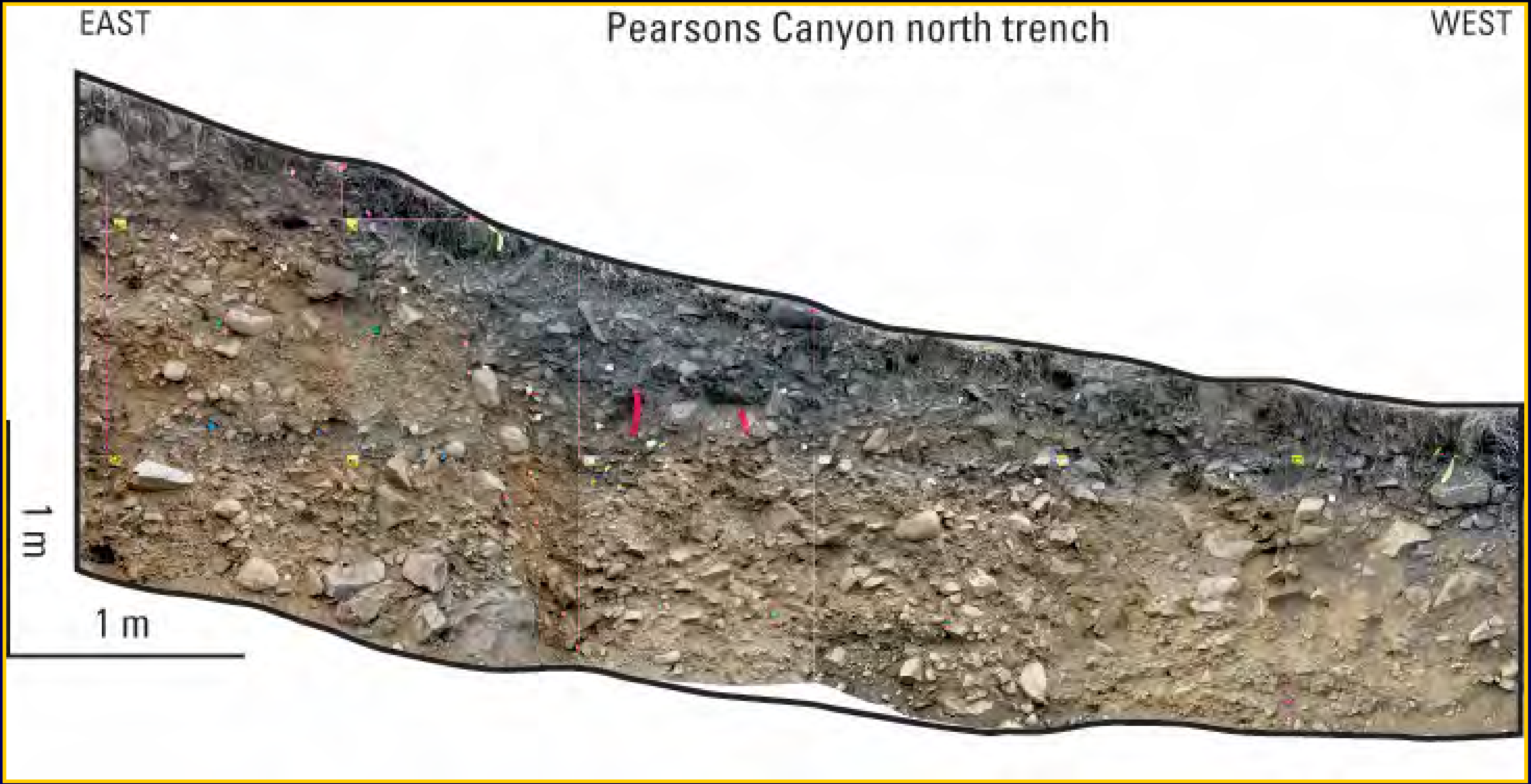
- **Single event**
- **About 1 m of stratigraphic throw on scarp**
- **Debris flow ponded against scarp; did not completely bury it**

Pearsons North Trench Site:
Antithetic scarp



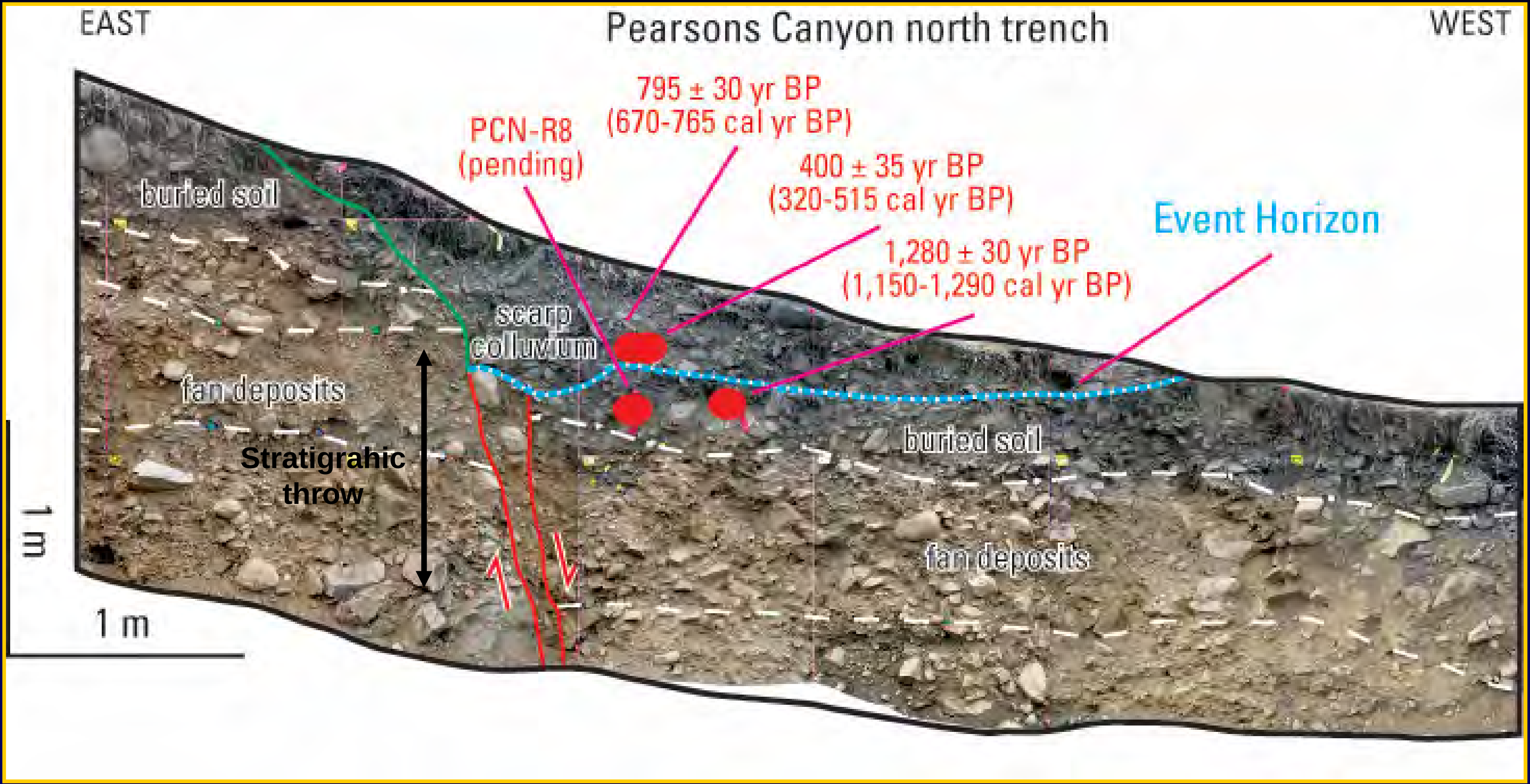
- **Single event**
- **About 1 m of stratigraphic throw on scarp**
- **Debris flow ponded against scarp; did not completely bury it**

Pearsons North Trench Site:
North trench



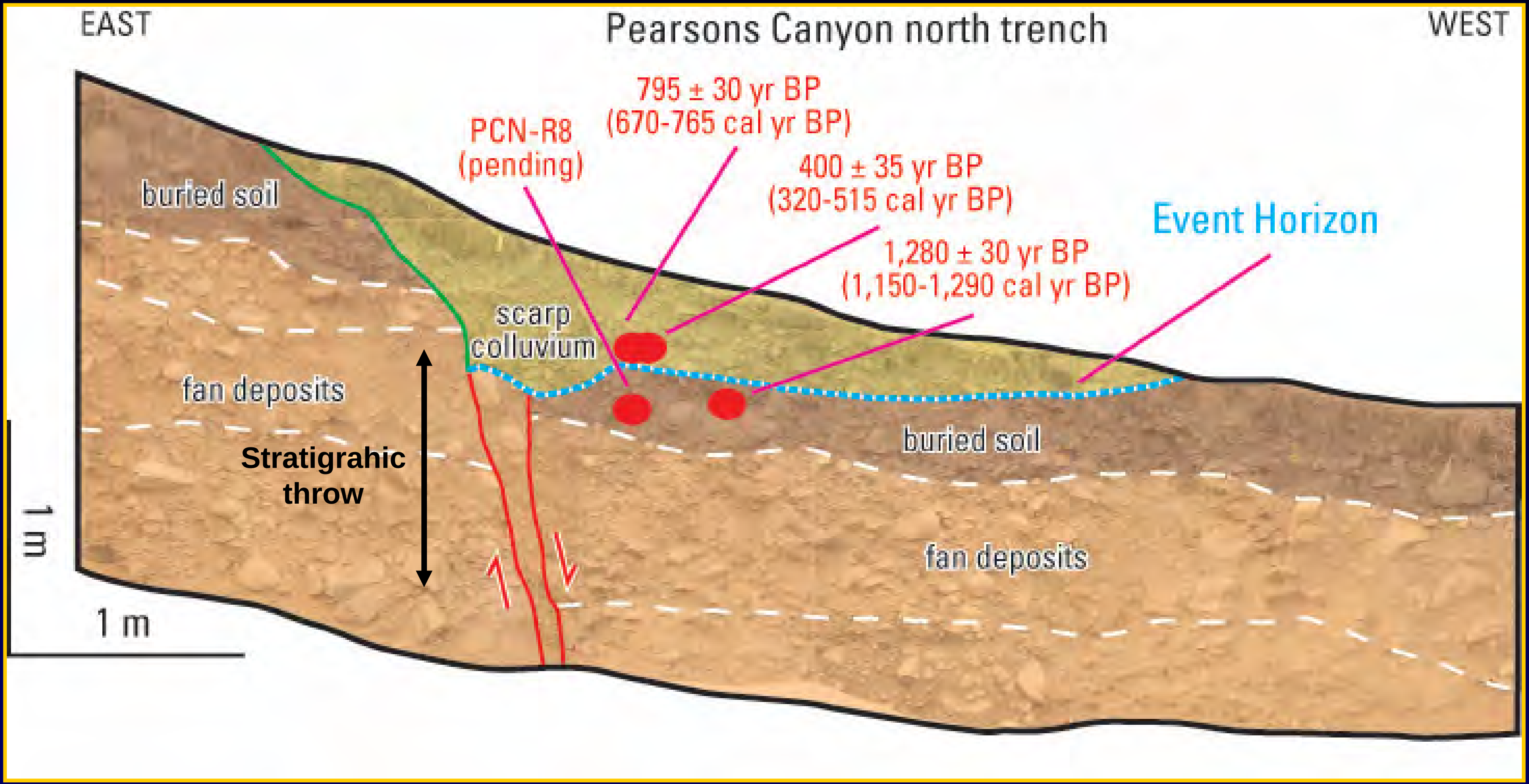
- Single colluvial wedge buries soil formed on alluvial-fan deposits
- Stratigraphic throw of ~1 m in fan gravel

Pearsons North Trench Site:
North trench



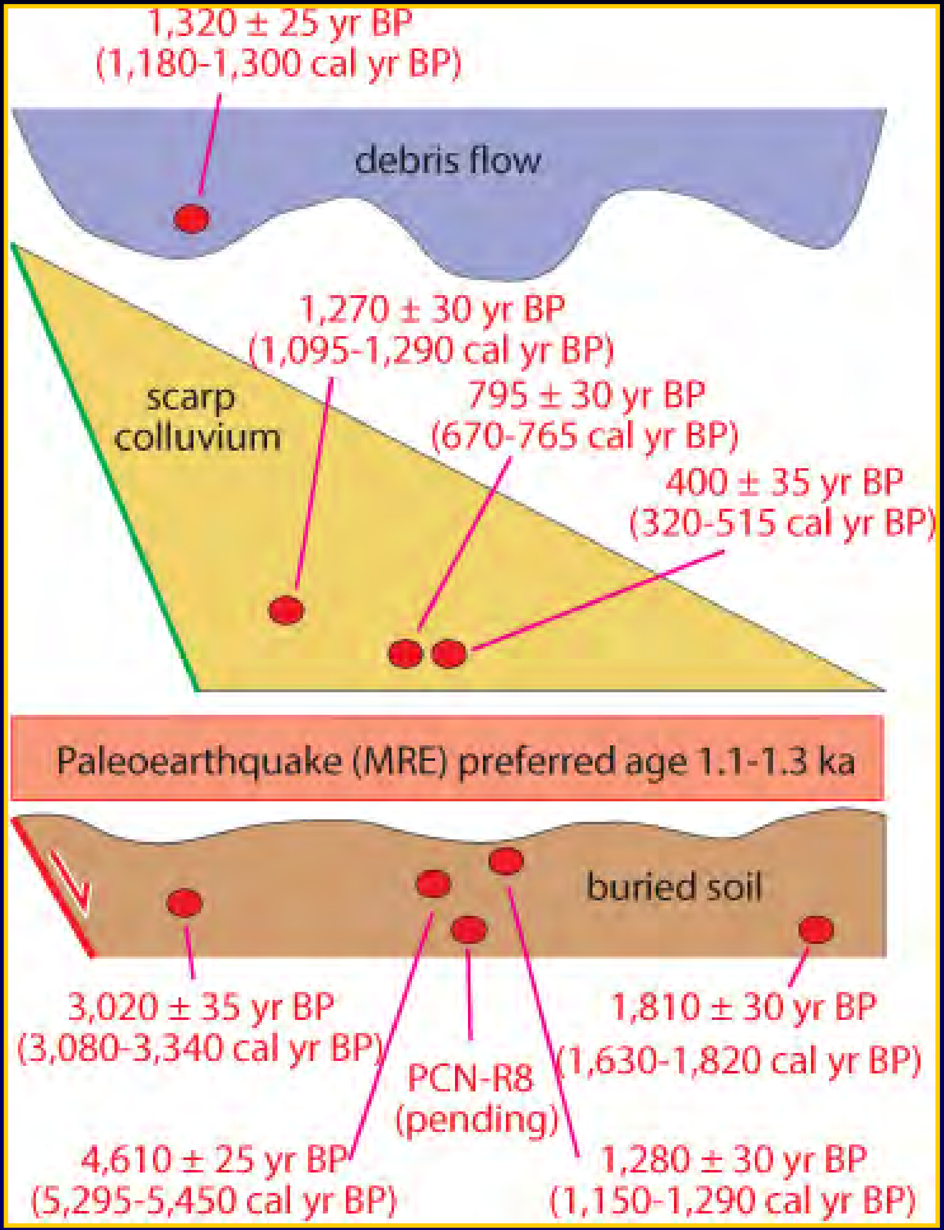
- Single colluvial wedge buries soil formed on alluvial-fan deposits
- Stratigraphic throw of ~1 m in fan gravel

Pearsons North Trench Site:
North trench



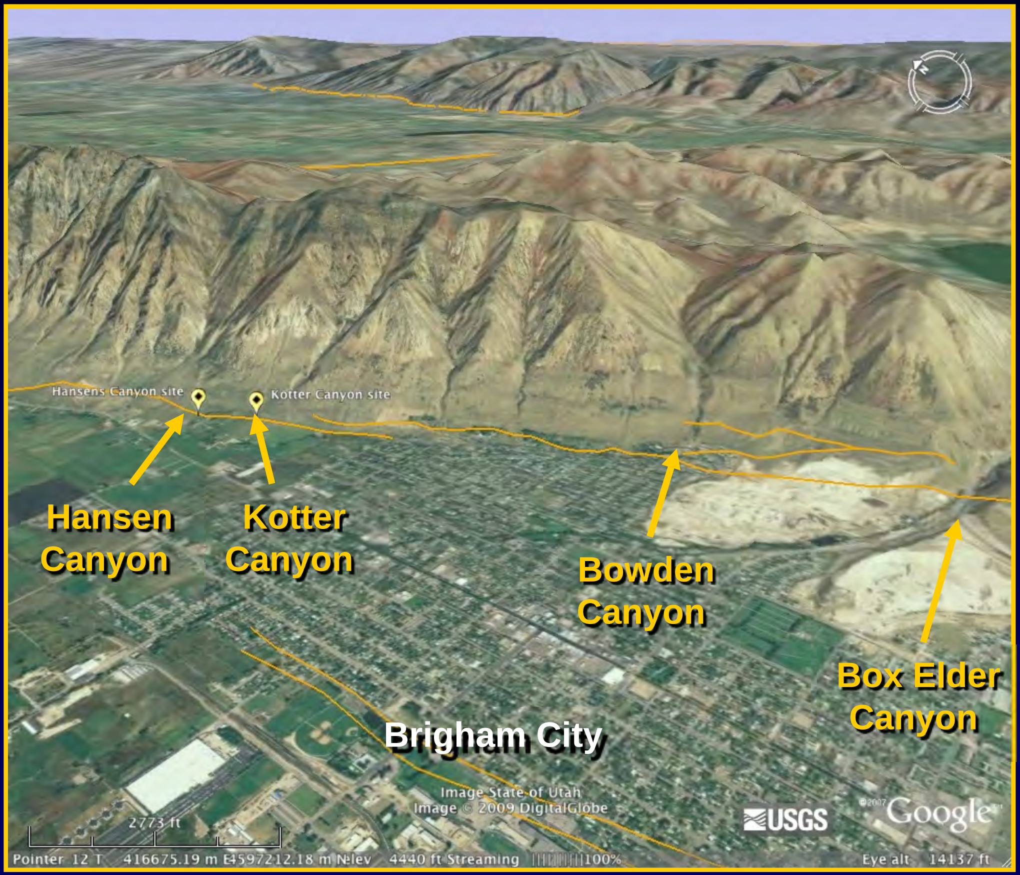
- Single colluvial wedge buries soil formed on alluvial-fan deposits
- Stratigraphic throw of ~1 m in fan gravel

Pearsons North Trench Site



- **Diverse ranges of radiocarbon ages indicate abundant reworking of charcoal in deposits**
- **Bounding ages from scarp colluvium and buried soil on top of fan suggest MRE was about 1.1-1.3 ka**

Hansen and Kotter Canyons Trench Sites

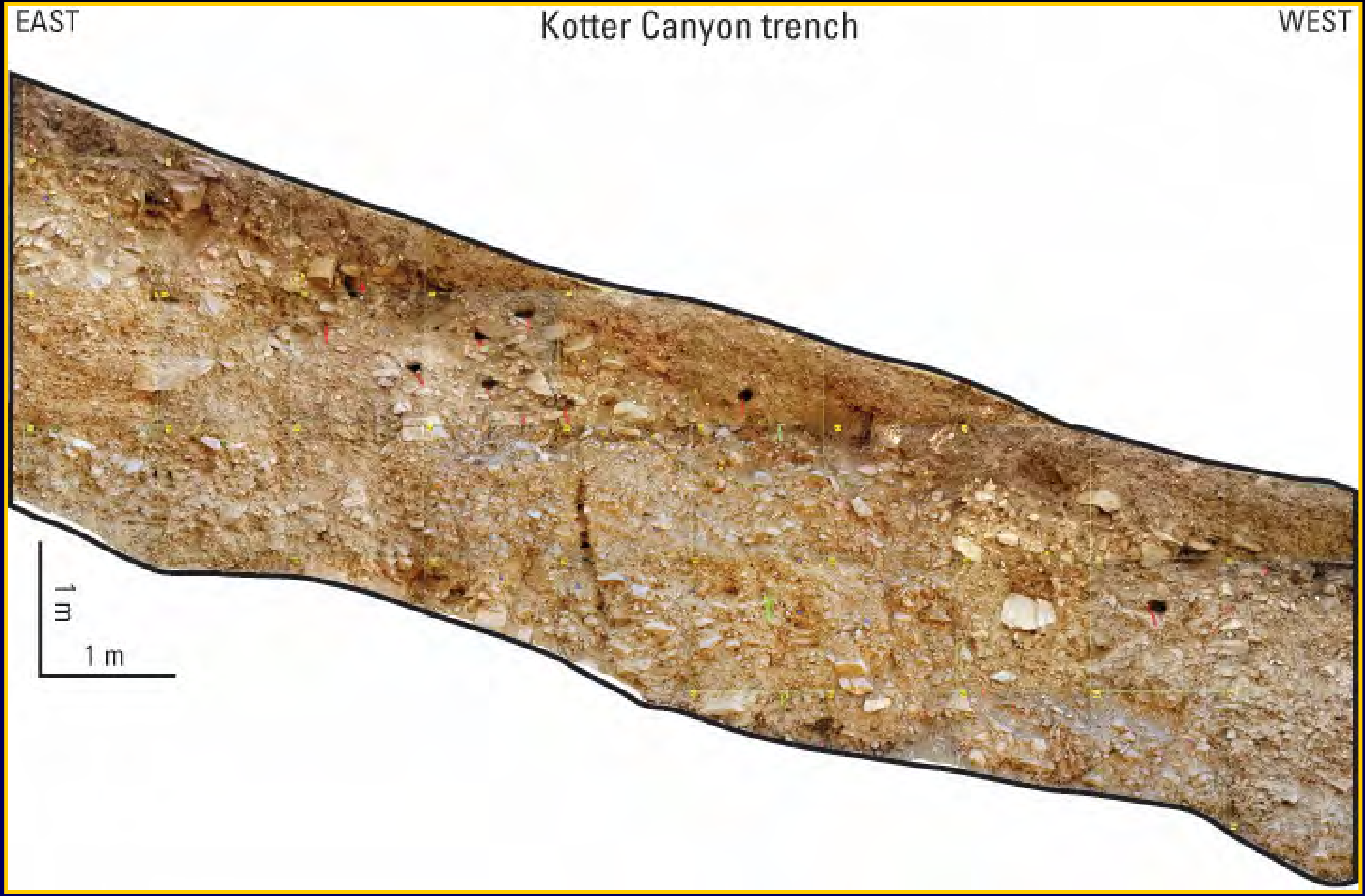


Sites are on northern part of BCS

Kotter Canyon Trench Site

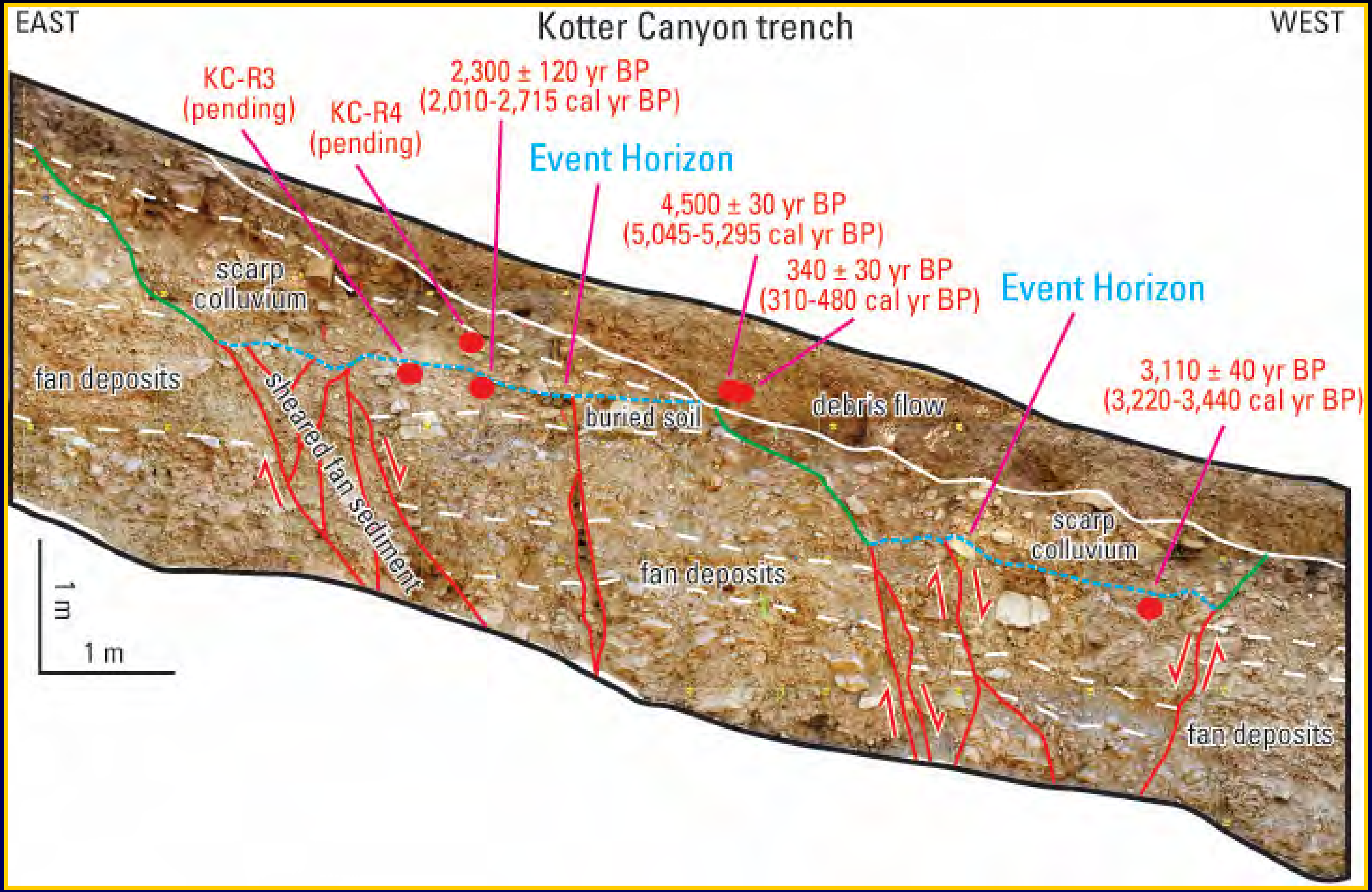
- ~37-m-long trench on Holocene alluvial fan below Bonneville shoreline
- At base of steep range front; fan deposits are boulder gravel
- 6- to 8-m-high scarp but young fan likely buries older scarp

Kotter Canyon Trench Site



- Weak soil horizon present on top of fan deposit beneath colluvial wedge; youngest deposit is pebbly debris flow that contains reworked organic material
- Difficult to measure net stratigraphic throw because of sets of antithetic faults and facies changes
- Single event with colluvium deposited against large free face at main fault zone

Kotter Canyon Trench Site



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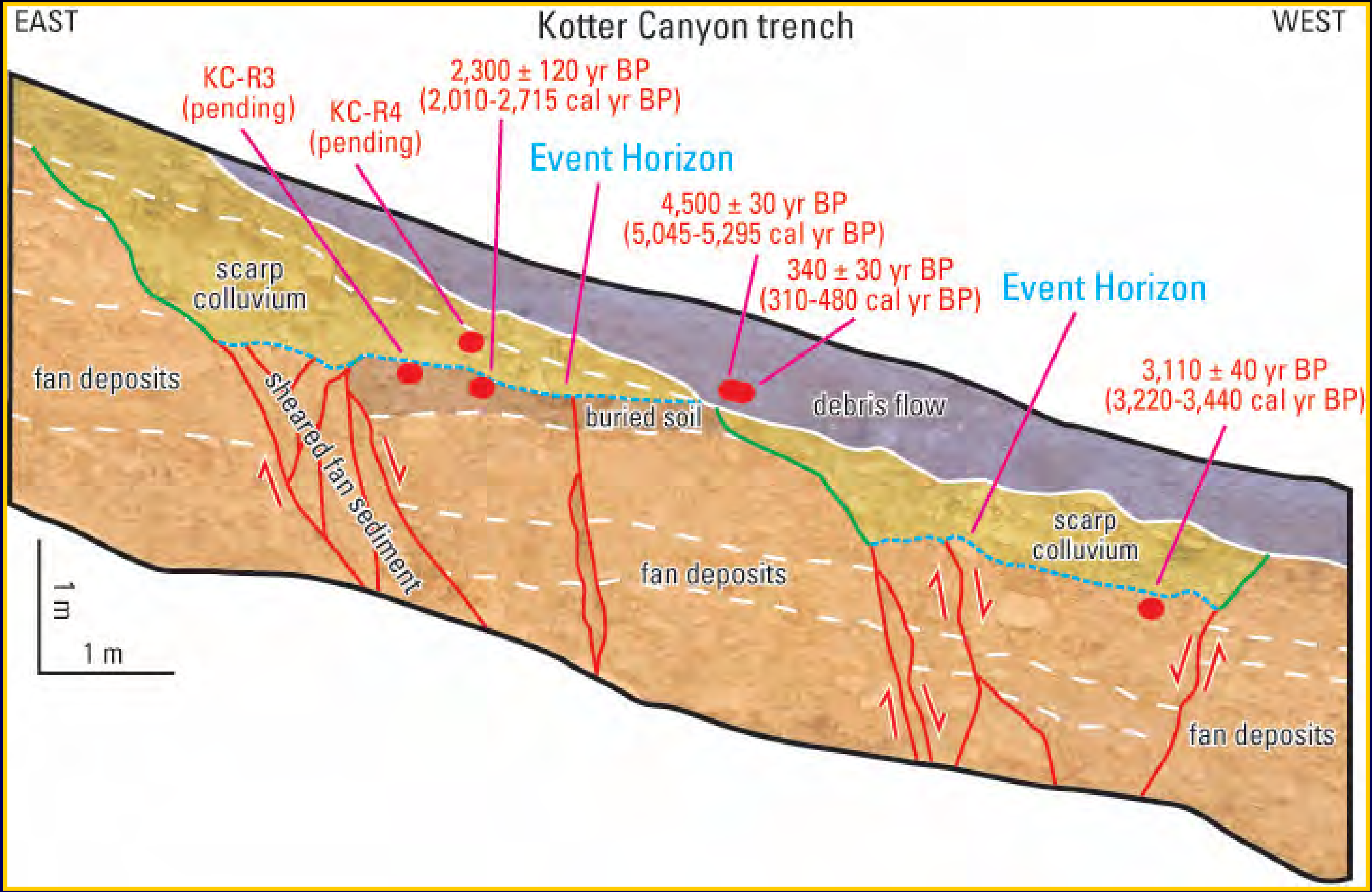

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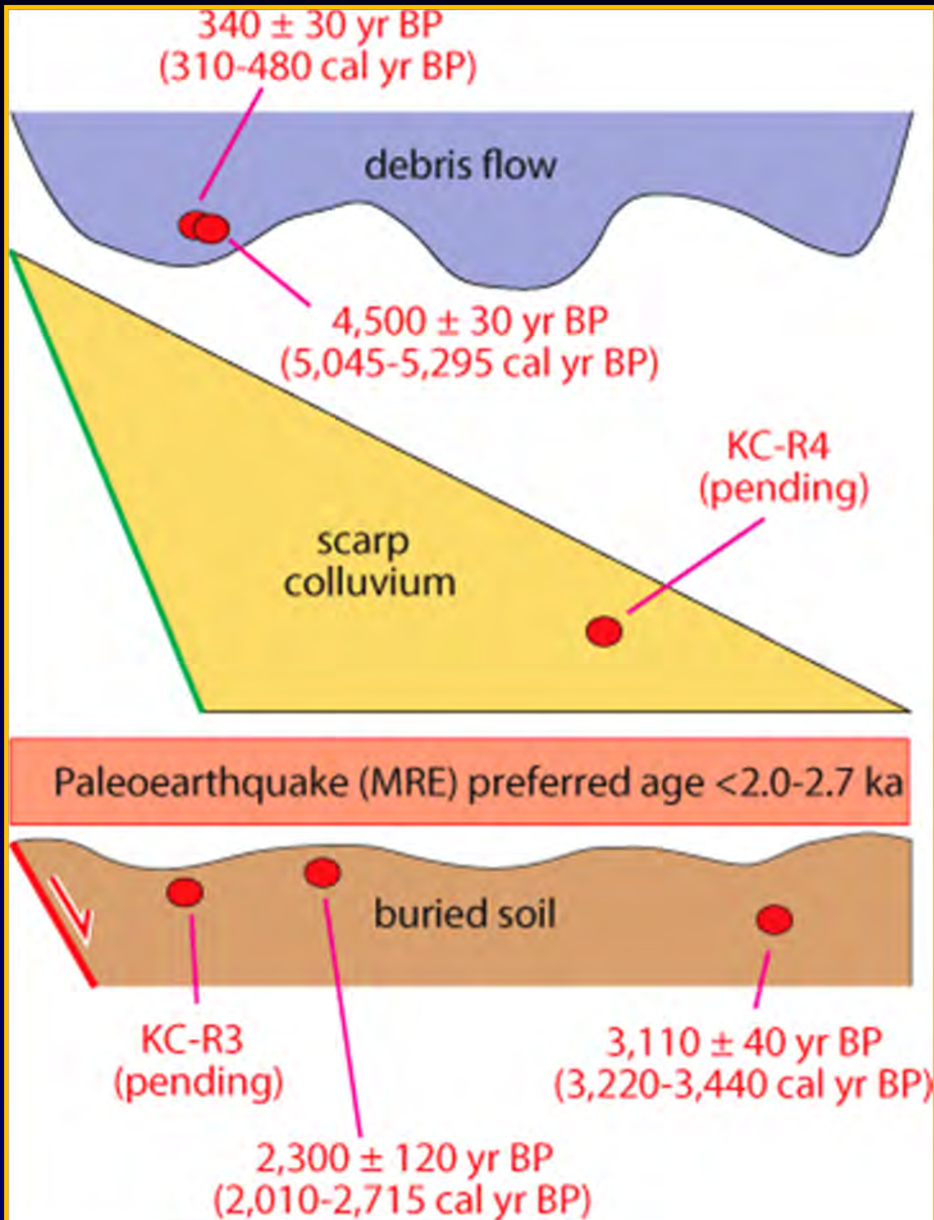
Kotter Canyon Trench Site



- **Extensive bioturbation complicates dating**
- **Stratigraphic evidence: only one event with preferred age of <2.0-2.7 ka.**
- **Pending radiocarbon ages may refine time of event**

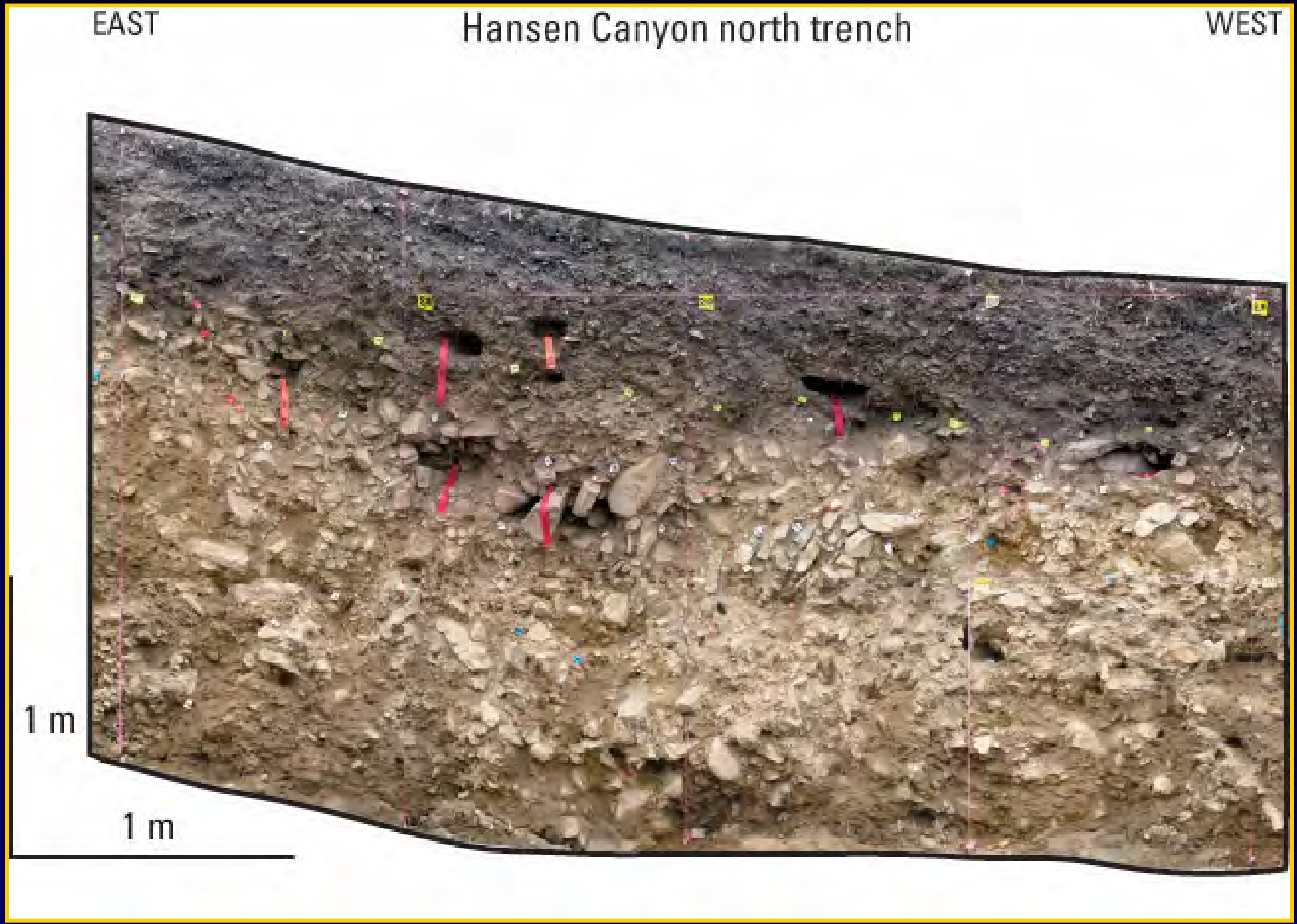
Hansen Canyon Trench Site

- Small scarp; only about 1 m of surface offset
- Scarp is likely product of MRE

Hansen Canyon Trench Site

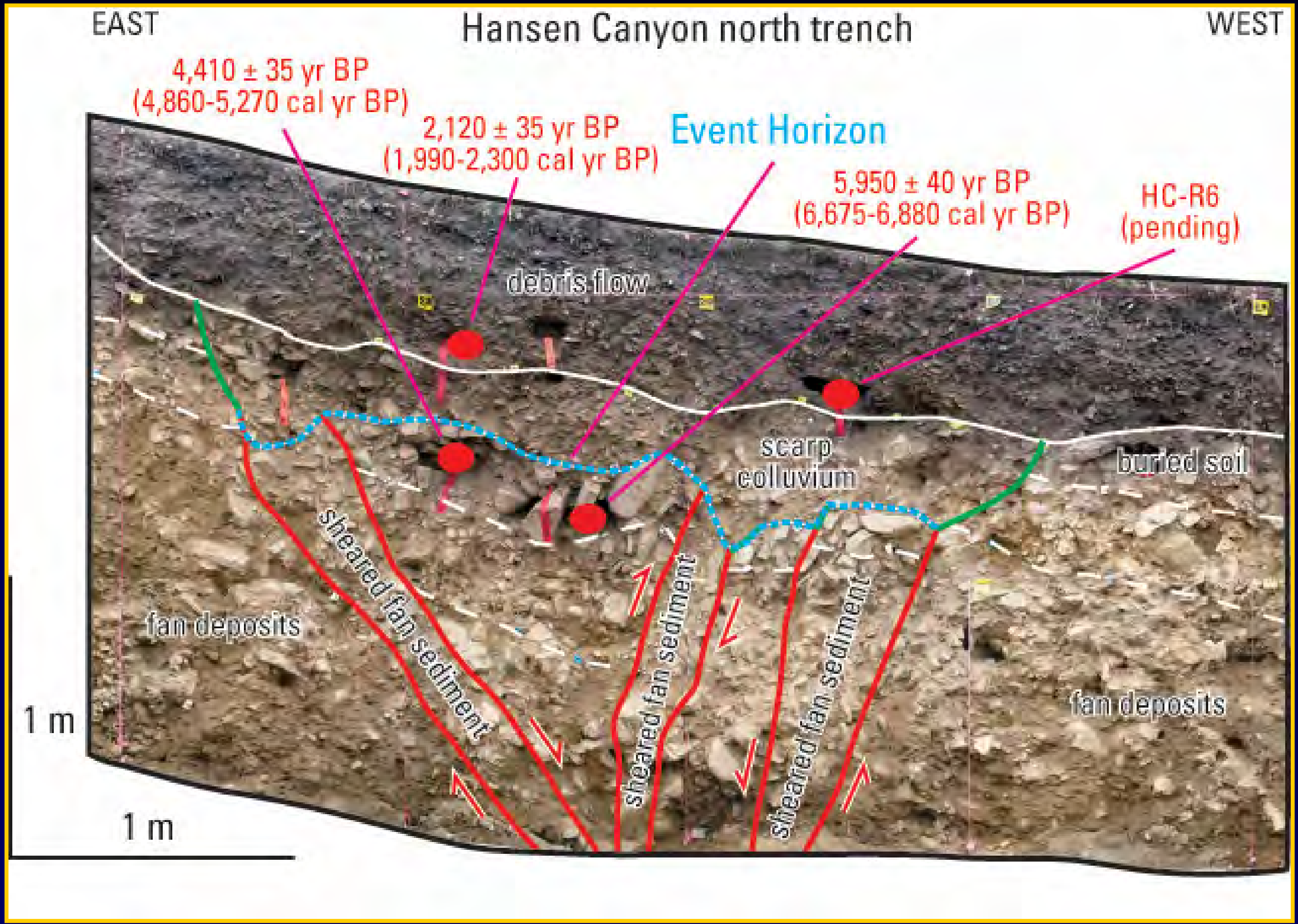
- North trench: ~27 m long
- South trench: ~6 m long
- Youngest deposit at site is pebbly debris flow

Hansen Canyon Trench Site
North trench



- Faulting concentrated in one zone
- One colluvial wedge on fan deposits
- Colluvium buries soil developed on fan gravel

Hansen Canyon Trench Site
North trench



- Faulting concentrated in one zone
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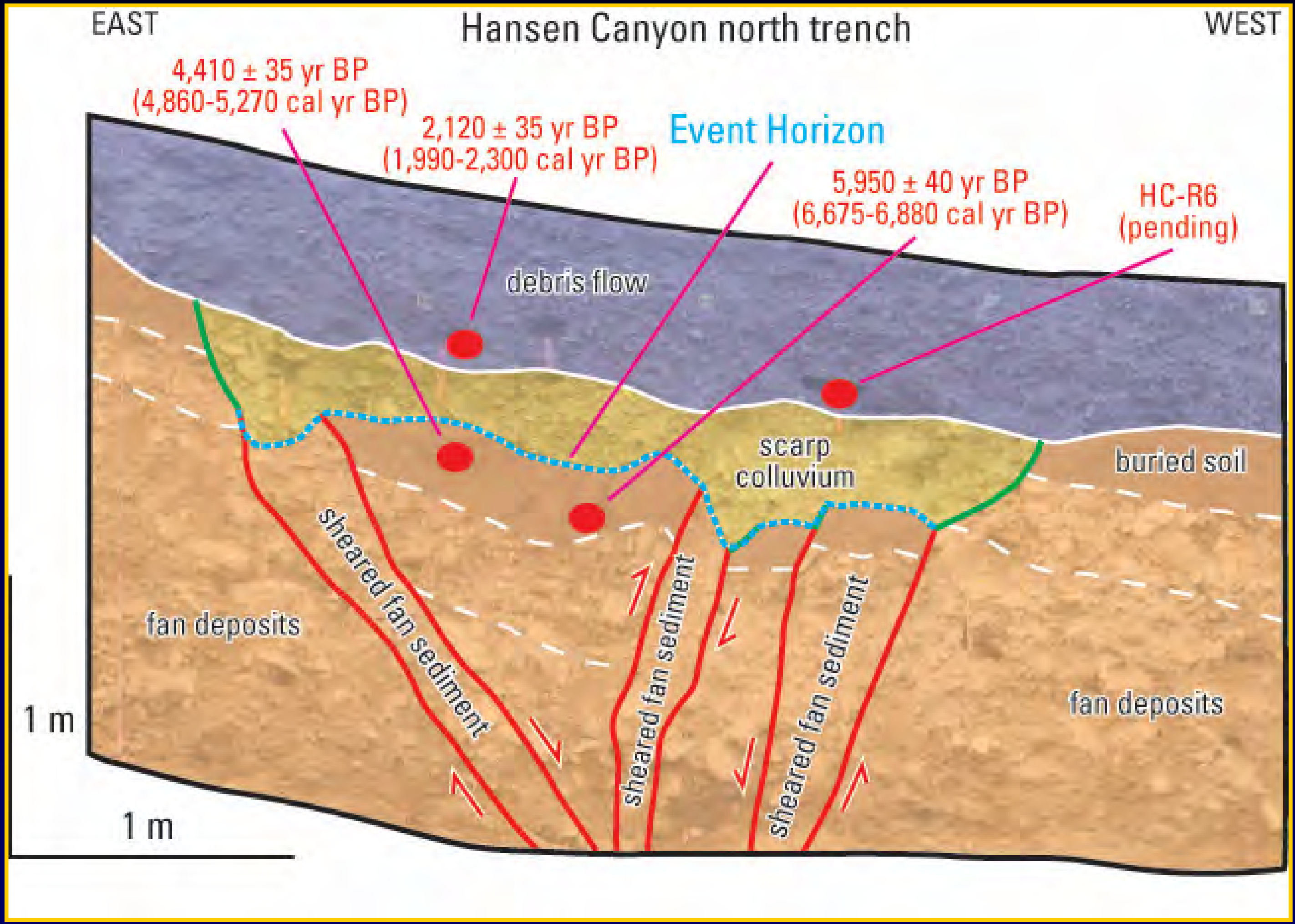
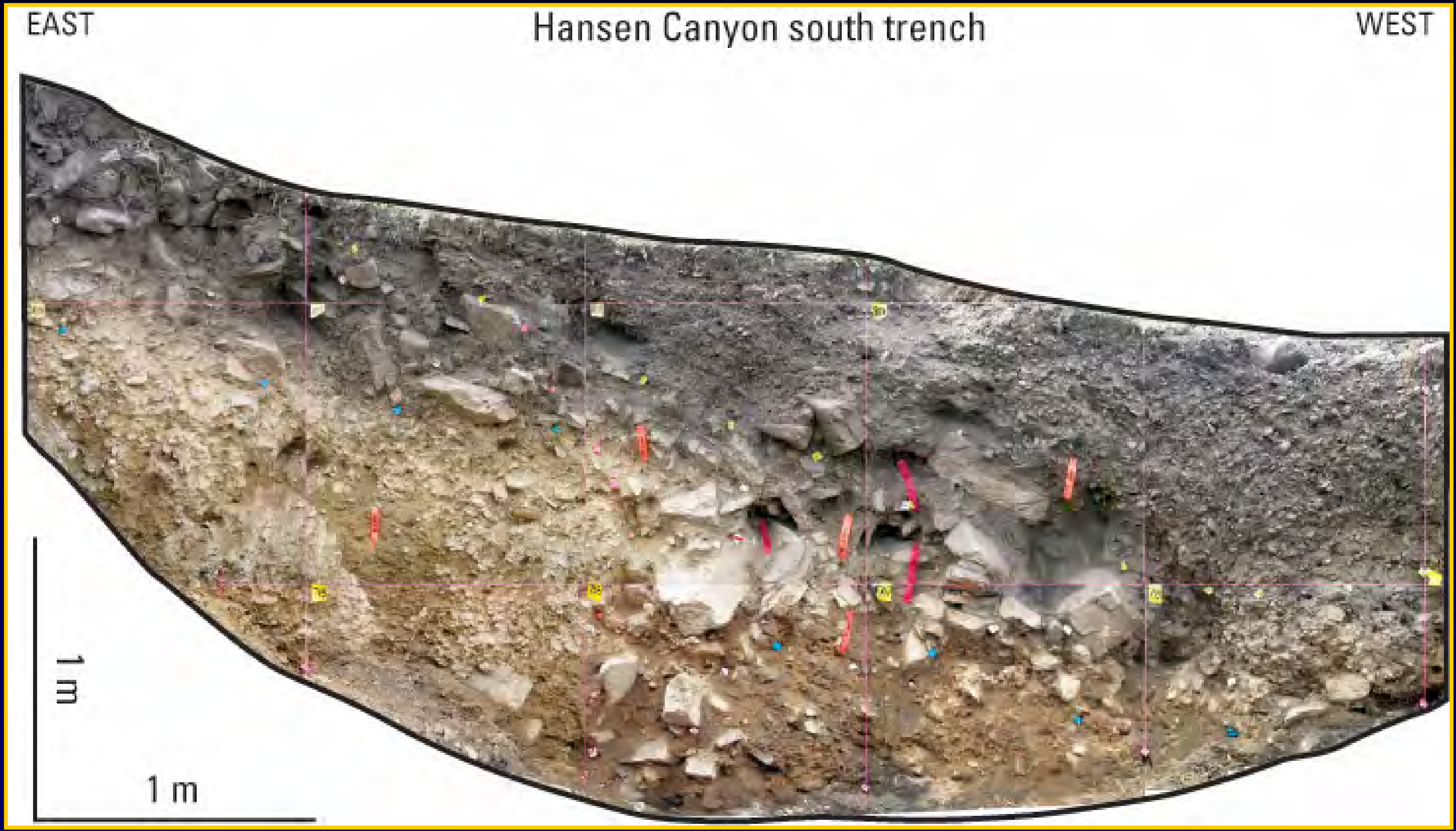
Hansen Canyon Trench Site
North trench



- **Faulting concentrated in one zone**
- **One colluvial wedge on fan deposits**
- **Colluvium buries soil developed on fan gravel**

Hansen Canyon Trench Site

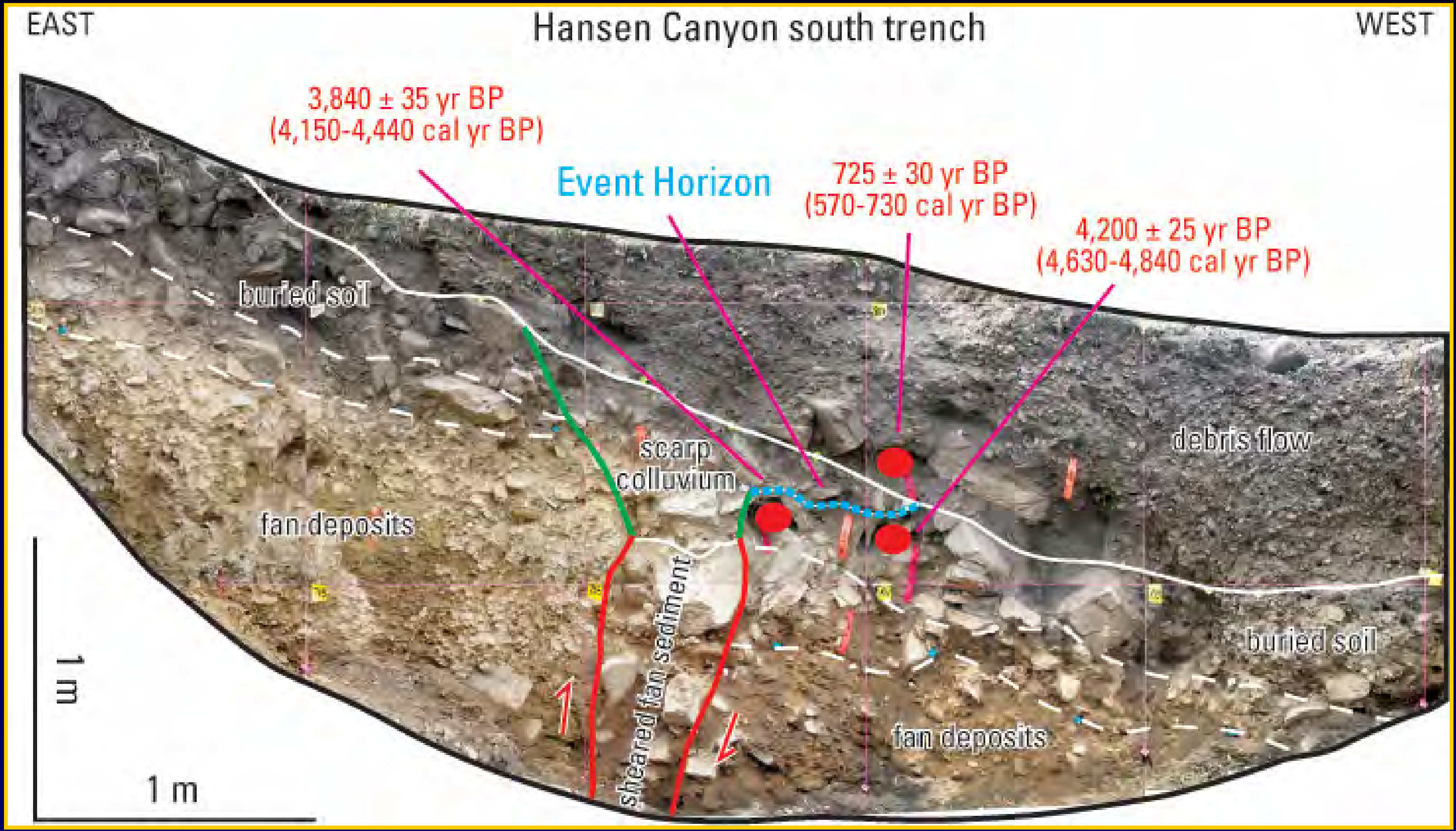
South trench



- **Stratigraphic relations similar to North trench**
- **Stratgraphic throw of about 0.75 m**

Hansen Canyon Trench Site

South trench



- Stratigraphic relations similar to North trench
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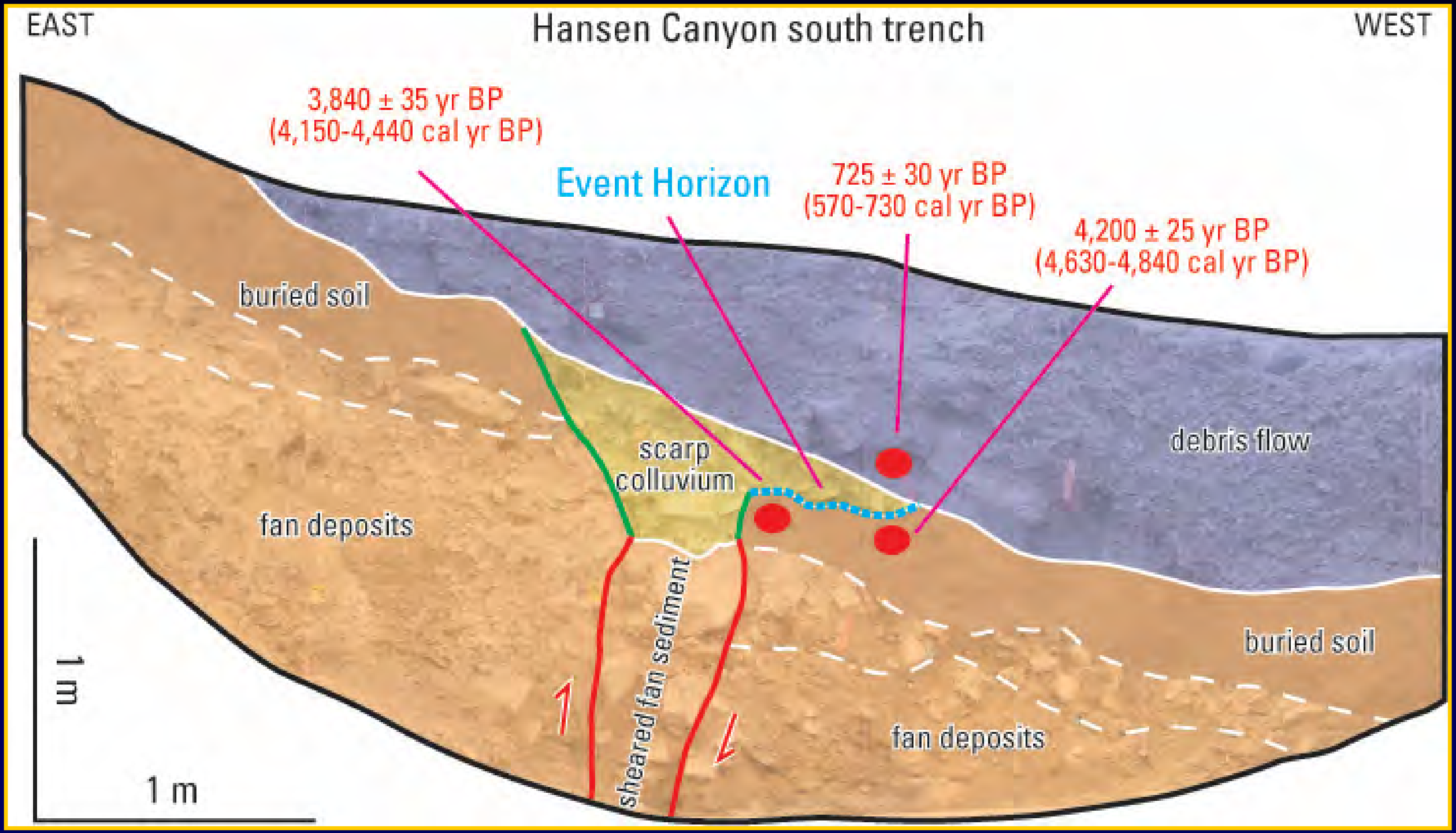
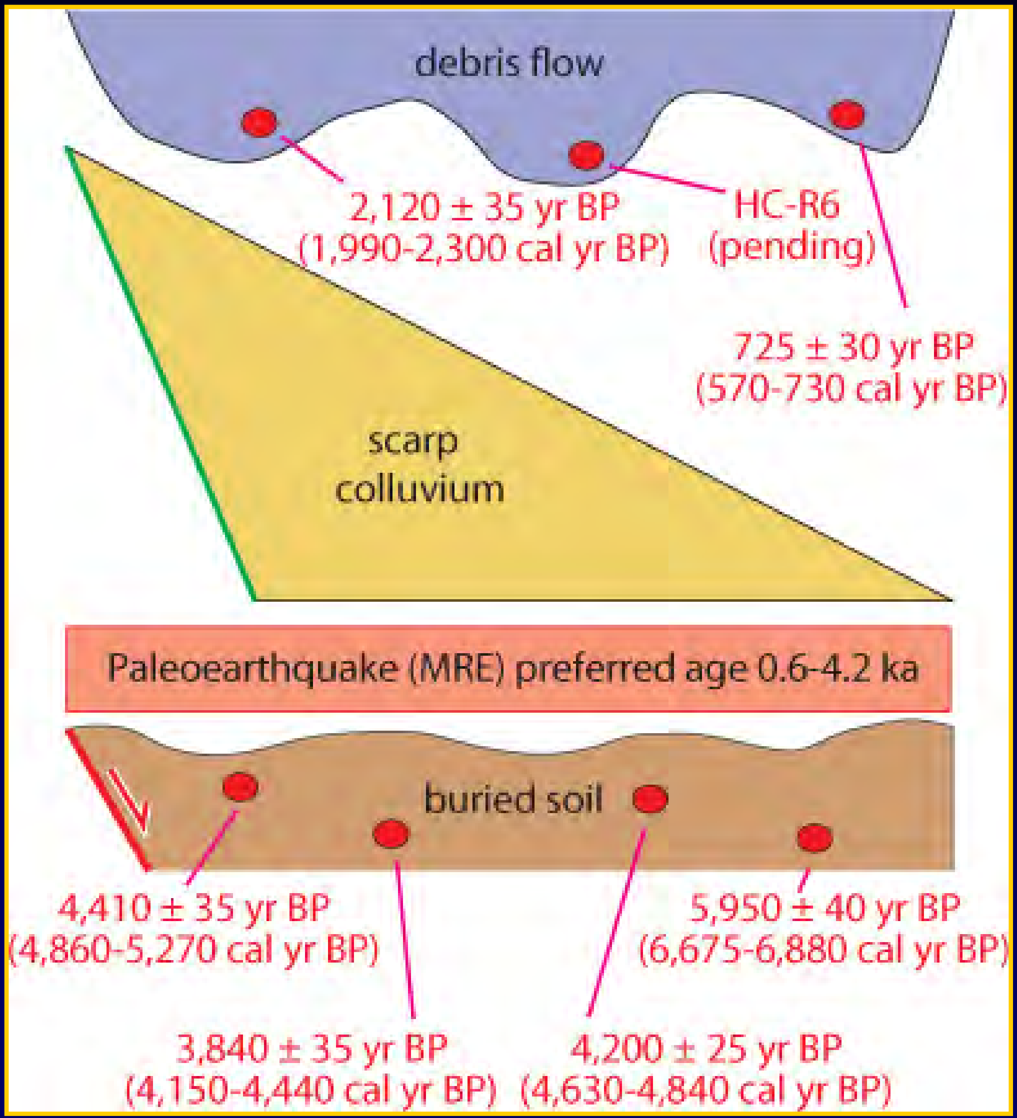
Hansen Canyon Trench Site
South trench



- Stratigraphic relations similar to North trench
- Stratgraphic throw of about 0.75 m

Hansen Canyon Trench Site



- **Diverse ranges of radiocarbon ages indicate abundant reworking of charcoal in deposits**
- **One colluvial wedge on fan deposits**
- **Age of debris flow could be as old as ~2 ka or as young as ~0.6 ka**
- **Constraints on age of event are broad**

Preliminary Results

		Brigham City segment			Weber segment
Event	*UQFPWG*	*Hansen Cyn.*	*Kotter Cyn.*	*Pearsons N Cyn.*	*Rice Creek*
P1	2.1 ± 0.8 ka	0.6-4.2 ka	<2.7 ka	1.1-1.3 ka ?	0.5-0.6 ka
P2	3.5 ± 0.3 ka	–	–	–	0.7-1.4 ka
P3	4.7 ± 0.5 ka				1.8-3.7 ka
P4	6.0 ± 0.3 ka				3.7-5.4 ka
P5	7.5 ±1.0 ka				5.5-7.5 ka
P6	8.5 ±1.5 ka				>7.8-9.9 ka

Brigham City Segment Preliminary Conclusions

- Trenches at three site all contain evidence of one surface-faulting event
- Age constraints on events are broad; may be refined with further dating
- MRE at southern end of BCS could correlate with event P2 on northern end of Weber segment at Rice Creek
- Debris flows are prevalent process by which modern fans are aggrading

Next Steps

- Complete radiocarbon dating and refine time of MRE using OxCal analysis
- Compare age of MRE from Kotter and Hansen sites with age of Event Z (McCalpin and Forman, 2002) at Box Elder Canyon
- Compare age of MRE at Pearsons North site with ages of events at Rice Creek and other WS sites
- Perhaps attempt to refine extent of southern MRE rupture on BCS (not promising based on previous detailed mapping)

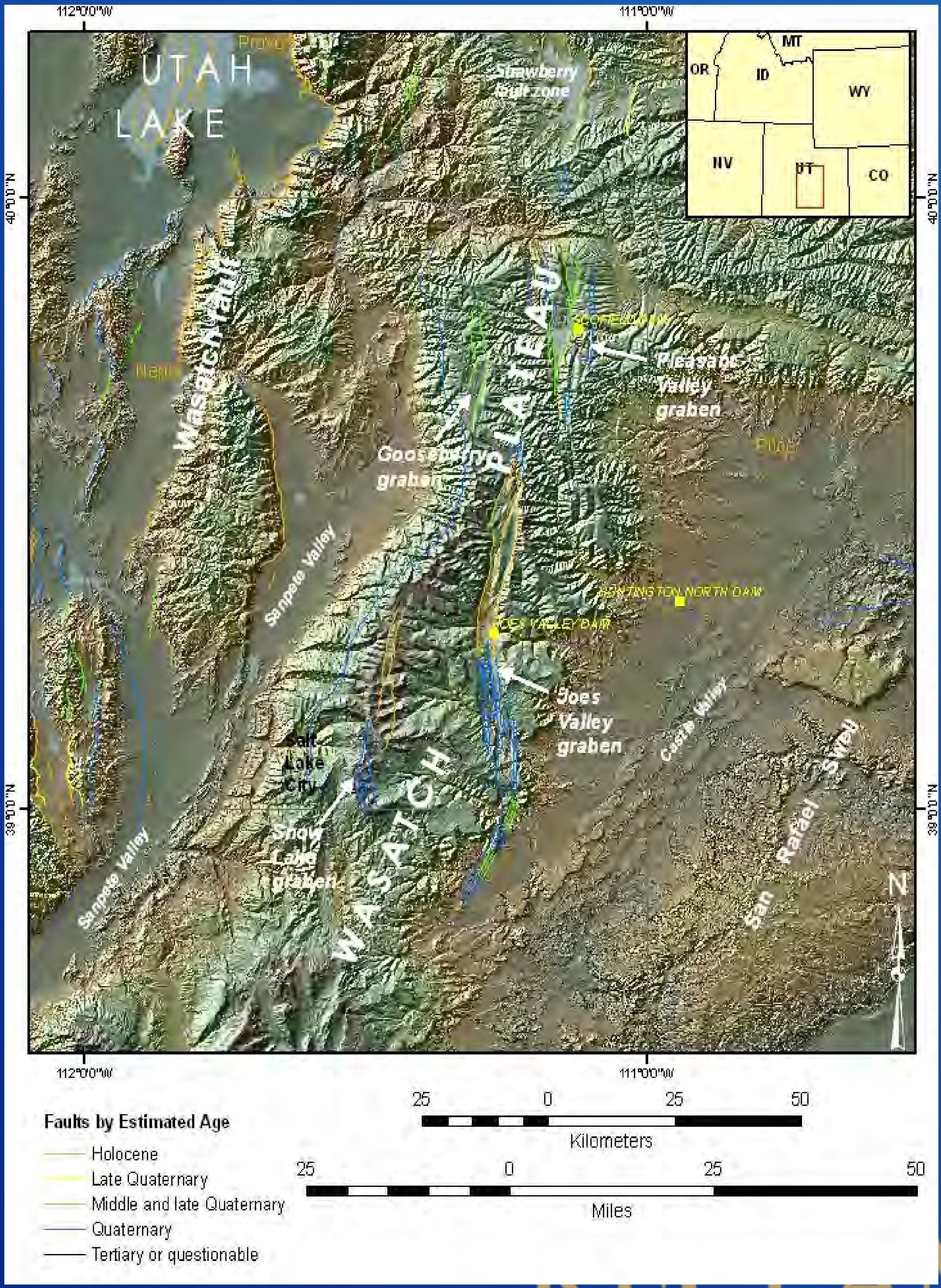
RECLAMATION
Managing Water in the West

JOES VALLEY FAULT ZONE

- ***Foley and others (1986) Seismotectonic study Joes Valley, Scofield, and Huntington North dams***
- ***Coogan, James C. (2008) Stratigraphic, structural, and velocity interpretation of seismic reflection profiles***

February 10, 2009

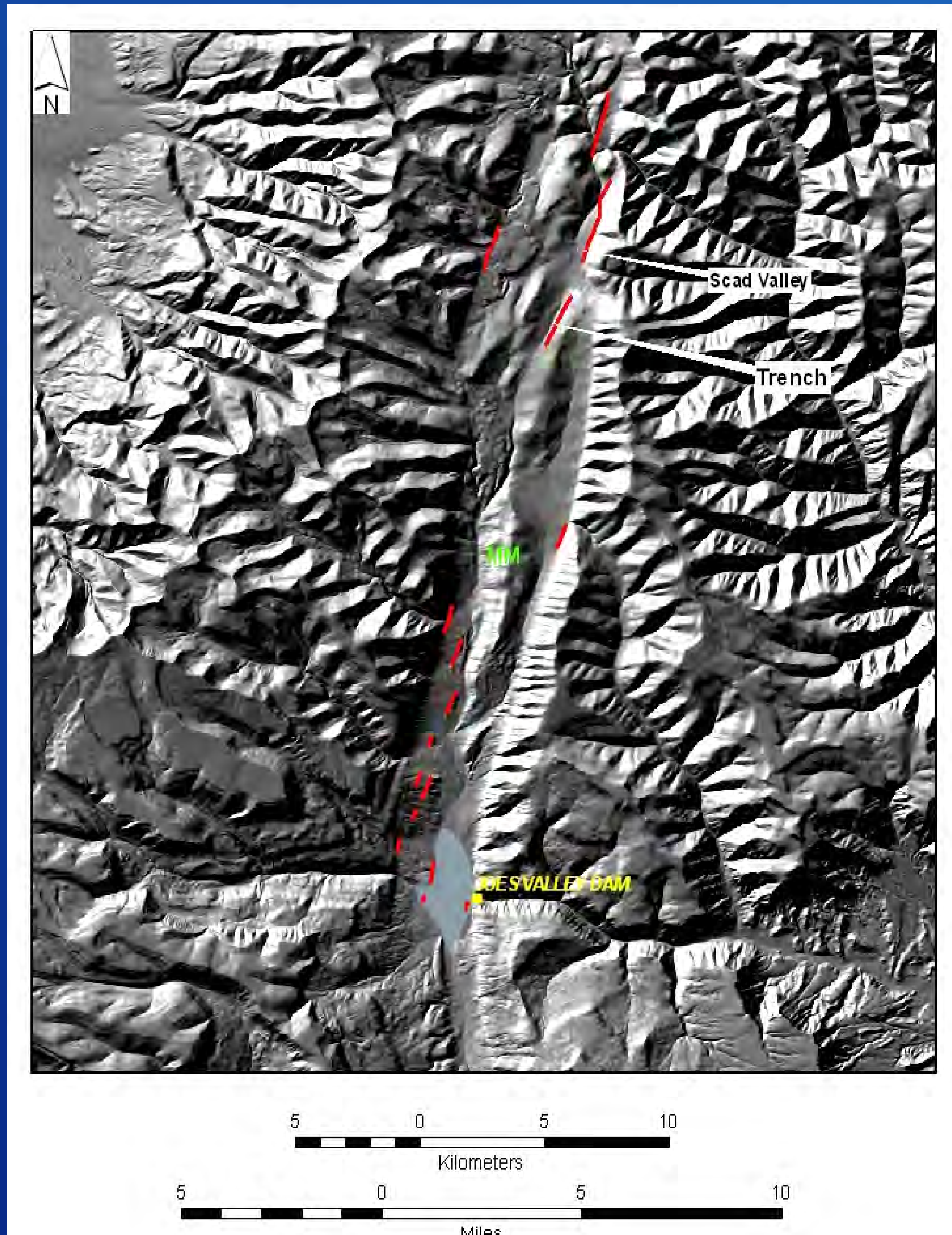
U.S. Department of the Interior
Bureau of Reclamation



RECLAMATION

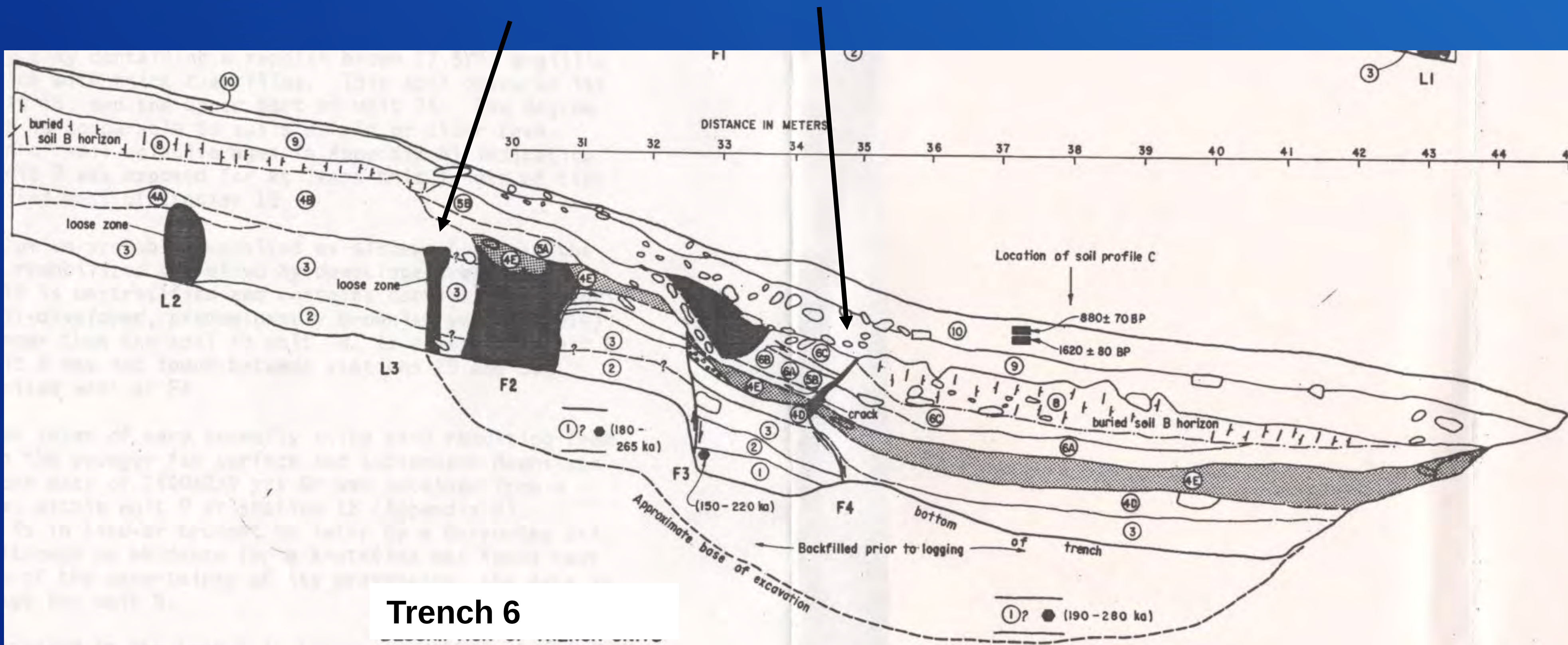
Seismotectonic study (Foley and others, 1986)

- Mapping geology, lineaments, and fault scarps on aerial photographs and on the ground
- Scarp profiles
- Excavation 6 trenches and 20 soil pits
- Relative and numeric dating



N
Scad Valley
Trench
MM
JOES VALLEY DAM
5 0 5 10
Kilometers
5 0 5 10
Miles

Fault zone



At least 4 faulting events <250 ka; 2 events <130 ka
Total vertical displacement about 3 m
Most recent event between 1.5 ka and 14-30 ka

Seismotectonic study (Foley and others, 1986)

- Recurrent late Quaternary surface displacements (Northern Joes Valley graben)
- Trench displacements; higher scarps in older terraces
- 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
- Listric fault model and salt collapse considered but could not evaluate

RECLAMATION

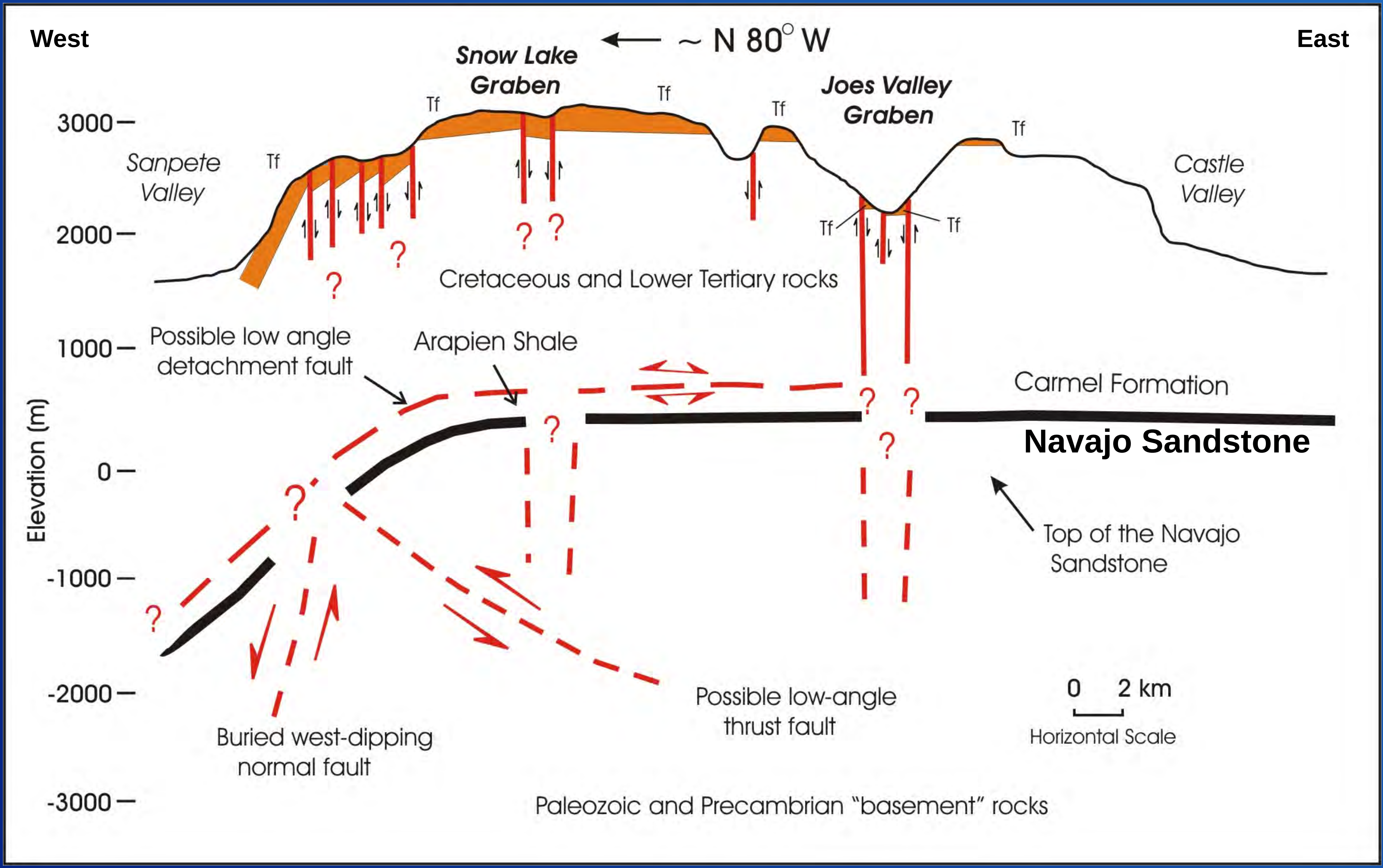
Proposed models

- Steeply dipping normal faults that extend to seismogenic depths (10-15 km)
- Collapse caused by flow of Arapien Shale or Carmel Formation
- Steeply dipping normal faults are detached in lower Carmel Formation
- Reactivation of back thrusts off a low-angle, east-dipping fault

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

RECLAMATION

Diagrammatic cross section across Wasatch Plateau in area of Joes Valley



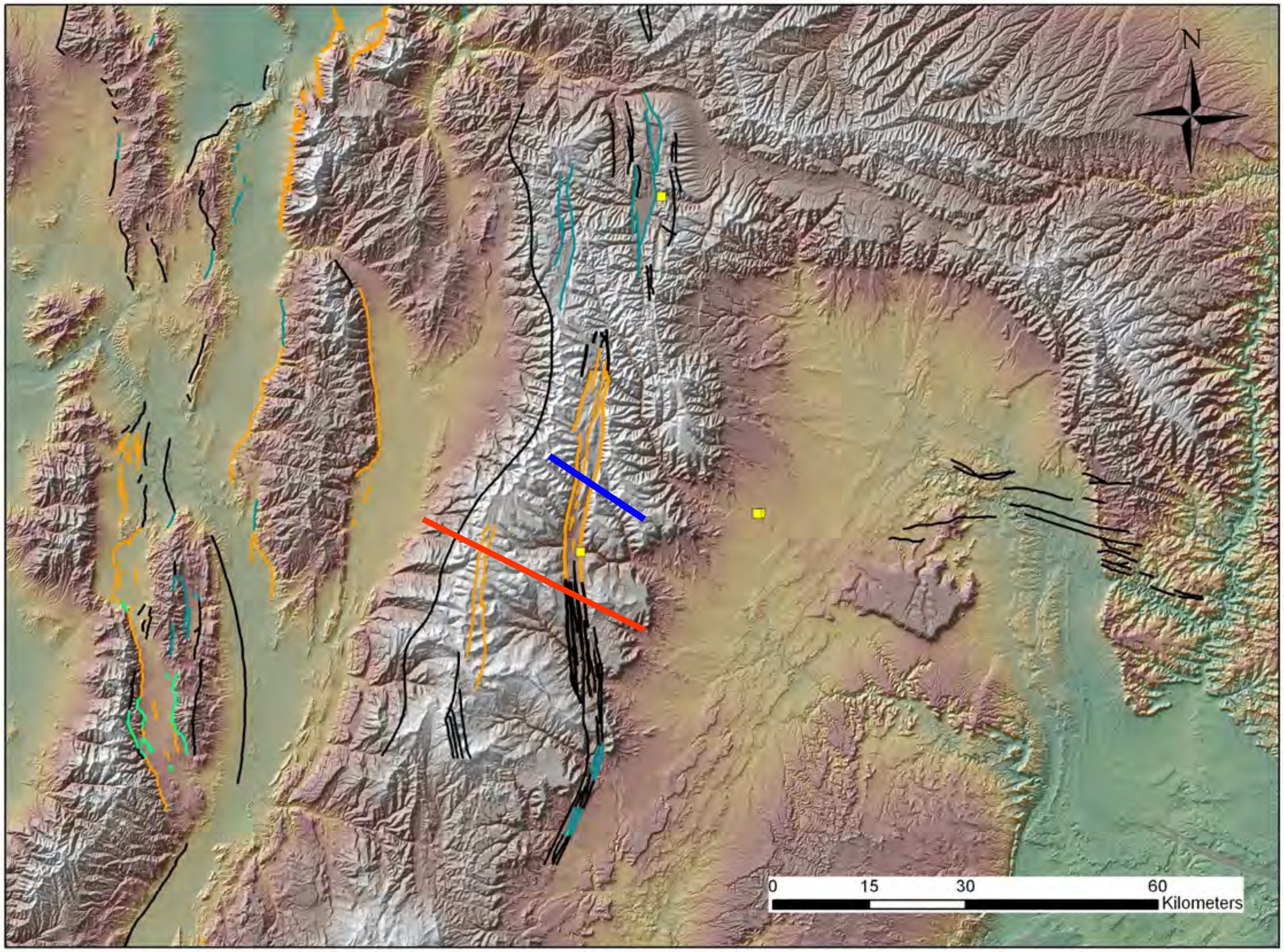
Orange is Eocene-Paleocene Flagstaff Limestone

Vertical exaggeration is about 3 X

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

RECLAMATION

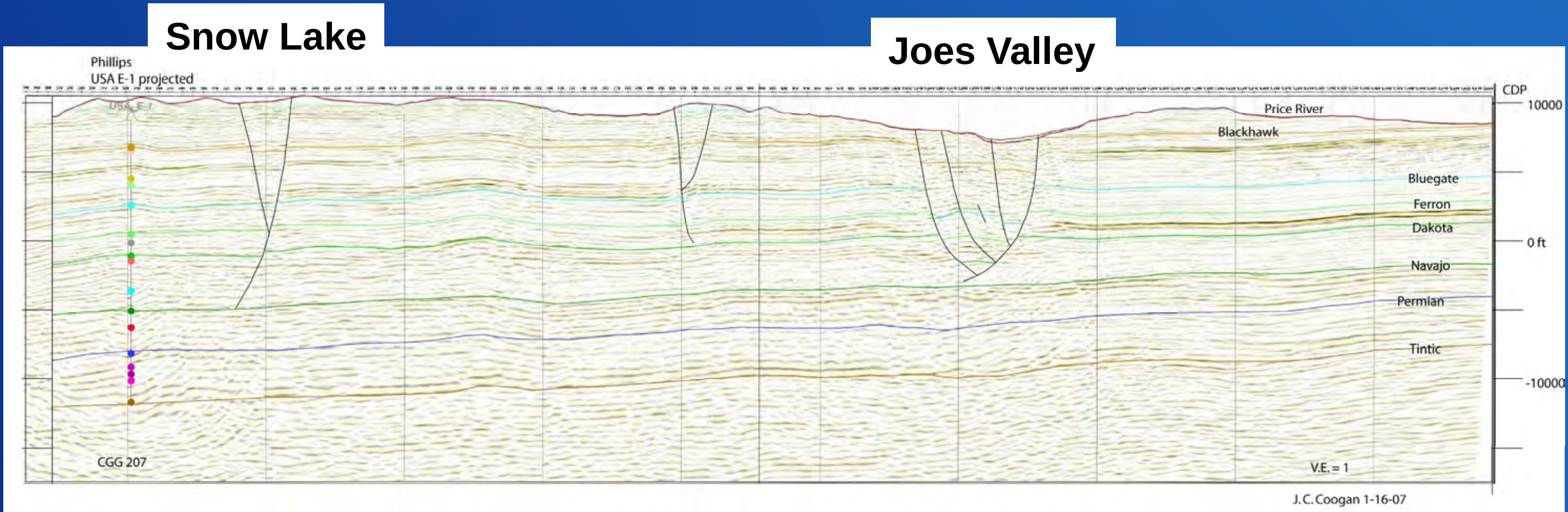
JOES VALLEY

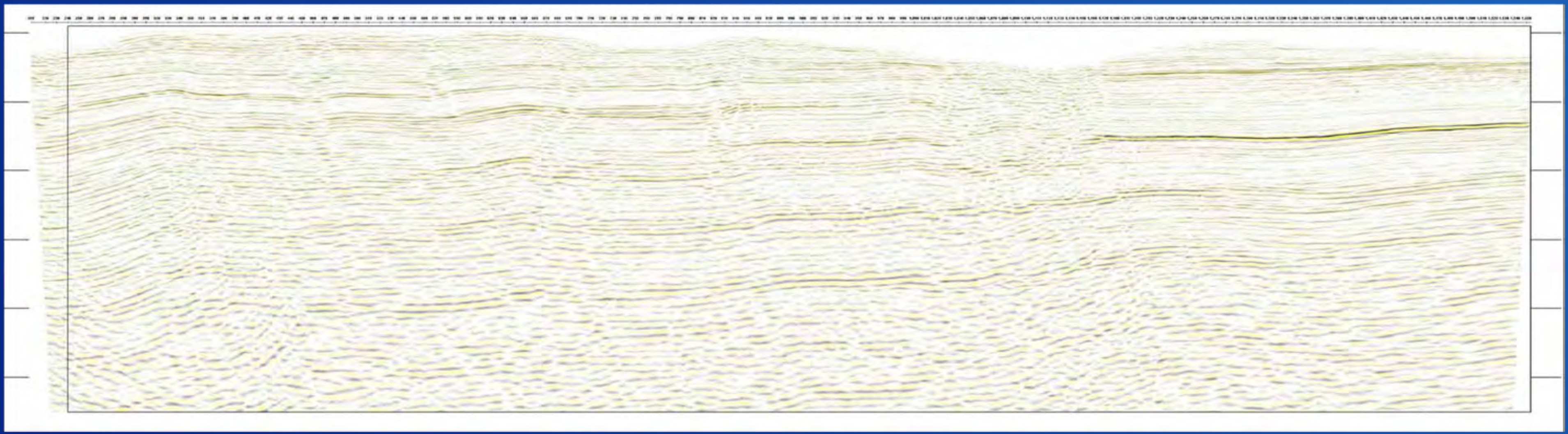


Coogan (2008)

RECLAMATION

Interpreted depth cross section





Uninterpreted

Coogan (2008)

Pre-stack depth migration images

RECLAMATION

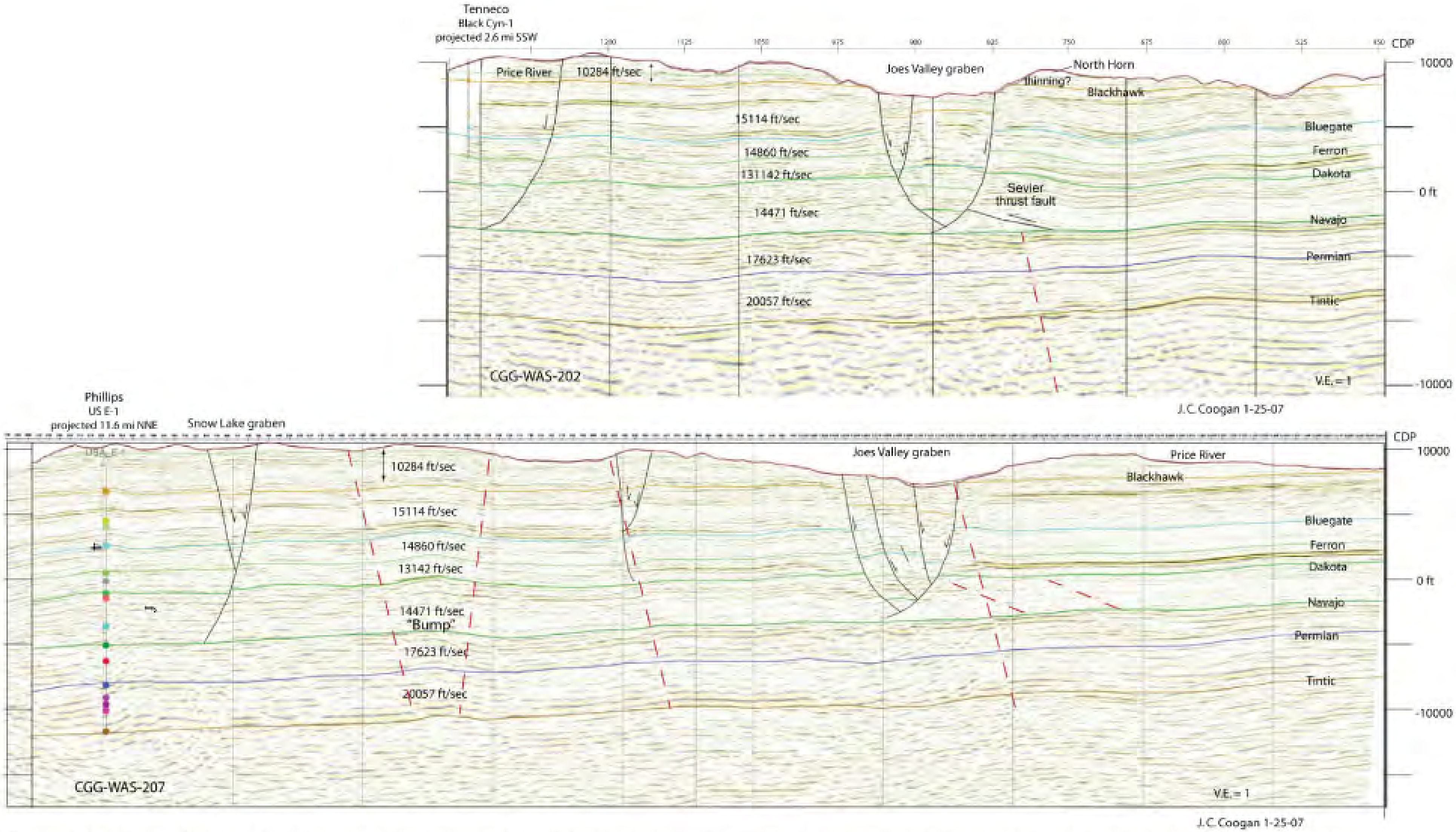
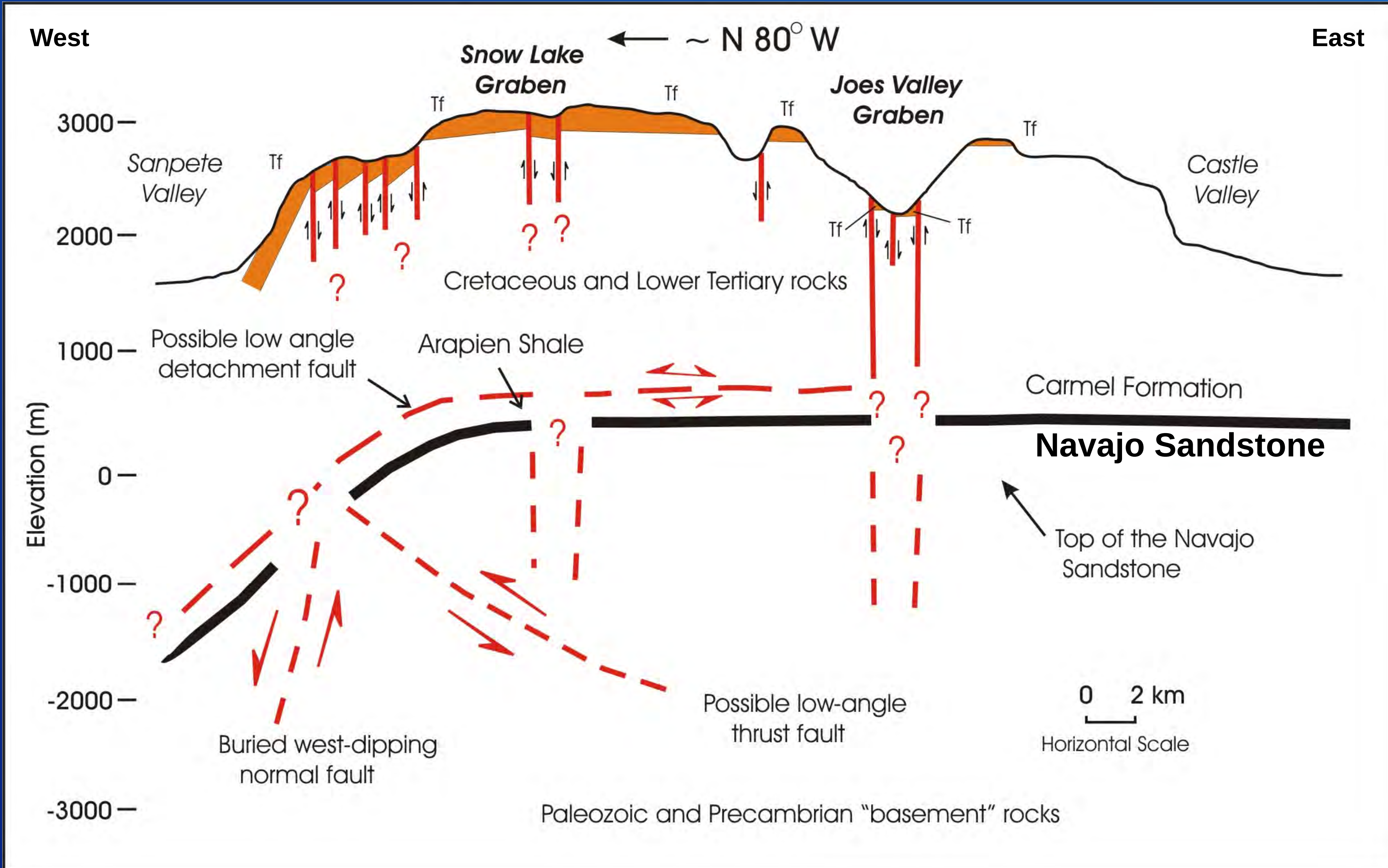


Figure R1. Figure 4 from the report with reverse fault/hinge lines indicated by the steeply-dipping dash red lines and thrust faults as the shallow-dipping dashed red lines. The "bump in CGG-WAS-207 indicates a region where the top of the Navajo is about 1000 ft higher to the west than the lowest portion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

O'Connell (2008)

RECLAMATION

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

Continuing Questions

- If faults do not extend to seismogenic depths, then how are fault scarps generated?
- What are the implications for seismic hazard?

RECLAMATION

GeoEarthScope LIDAR Data Acquisition

Report of Progress by Ron Bruhn, U of Utah

Nephi Fault Segment, Utah

Specifications:

1) Appropriate for 50 cm posting
2) Available spring 09
3) Point cloud, filtered and unfiltered data set will be available to public via OpenTopography web site.

GeoEarthScope

LiDAR Working Group Report

September, 2006

earth
scope

Report of Working Group Task to
Define and Prioritize LiDAR (ASLM)
Targets for GeoEarthScope

Prepared for:
ırthscope Program
al Science Foundation

Report Prepared by:

Kevin P Furlong (Penn State University),
Chair of Working Group

Ron Bruhn, (University of Utah)
Doug Burbank, (UC Santa Barbara)
James Dolan, (Univ. Southern Cal.)
John Oldow, (Univ. of Idaho)
Charlie Rubin, (Central Washington)
Carol Prentice, (USGS-Menlo Park)
Brian Wernicke, (Cal Inst Tech)
Steve Wesnousky, (Univ. Nevada, Reno)

2. The Regional Targets are:

a. Northern California – including the San Andreas Fault north of Parkfield, and other major strands of the San Andreas Fault system (e.g. southern Hayward, Rodgers Creek, Ma'acama, etc. Faults)
Proposed Priority 1 Data Acquisition: ~ 1370 km²

b. Southern California – including the Garlock Fault, Eastern California Shear zone south of the Garlock, the Elsinore Fault, and regions of the transpressional faulting in the Transverse Range region. Large segments of the San Andreas and San Jacinto faults have previously acquired LiDAR as part of the B4 project.
Proposed Priority 1 Data Acquisition: ~ 1953 km²

c. Eastern California, Walker Lane, and Basin and Range fault systems – including faults of the Eastern California Shear Zone north of the Garlock Fault.
Proposed Priority 1 Data Acquisition: ~ 2010 km²

d. Intermountain Seismic Belt – including the Wasatch Fault, Teton Fault, Yellowstone Park area, and northern extensions of the system through Idaho and Montana.
Proposed Priority 1 Data Acquisition: ~ 1513 km²

e. Alaska – including the Castle Mountain and Denali Faults, and the Nenana River terraces.
Proposed Priority 1 Data Acquisition: ~ 540 km²

f. Cascadia – including the Mad River and Little Salmon fault zones in southern Cascadia, the Calawah Fault in the Washington forearc, and imagery in the Yakima Fold belt termination.
Proposed Priority 1 Data Acquisition: ~ 550 km²

TOTAL Proposed Priority 1 Data Acquisition: ~ 7936 km²

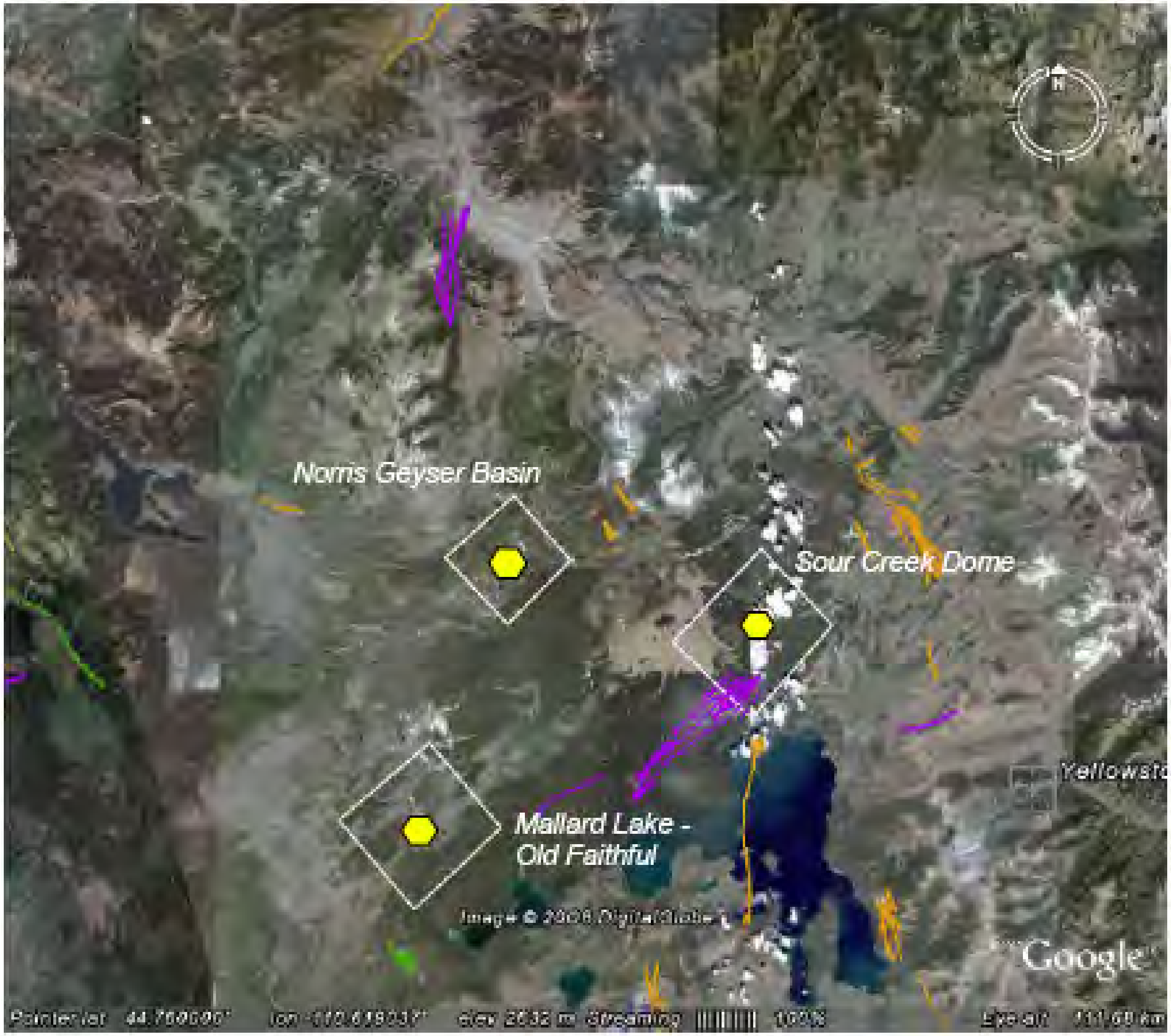


Figure 3: Yellowstone Survey Areas (B4 Required) -
1) Sour Creek Dome – Mirror Plateau Fault System (Center Point at 44.645636 N, -110.396387 W. Rectangular 15 km on edge, centered on Center Point.)

2) Mallard Lake – Old Faithful (Center Point at 44.463032 N, -110.952503 W. Rectangular survey area 15 km on edge, centered on Center Point).

3) Norris Geyser Basin (Center Point at 44.715482 N, -110.725227 W. Rectangular survey area 15 km on edge, centered on Center Point.).

Center Points – Yellow hexagons, white lines provide rough outline of area.

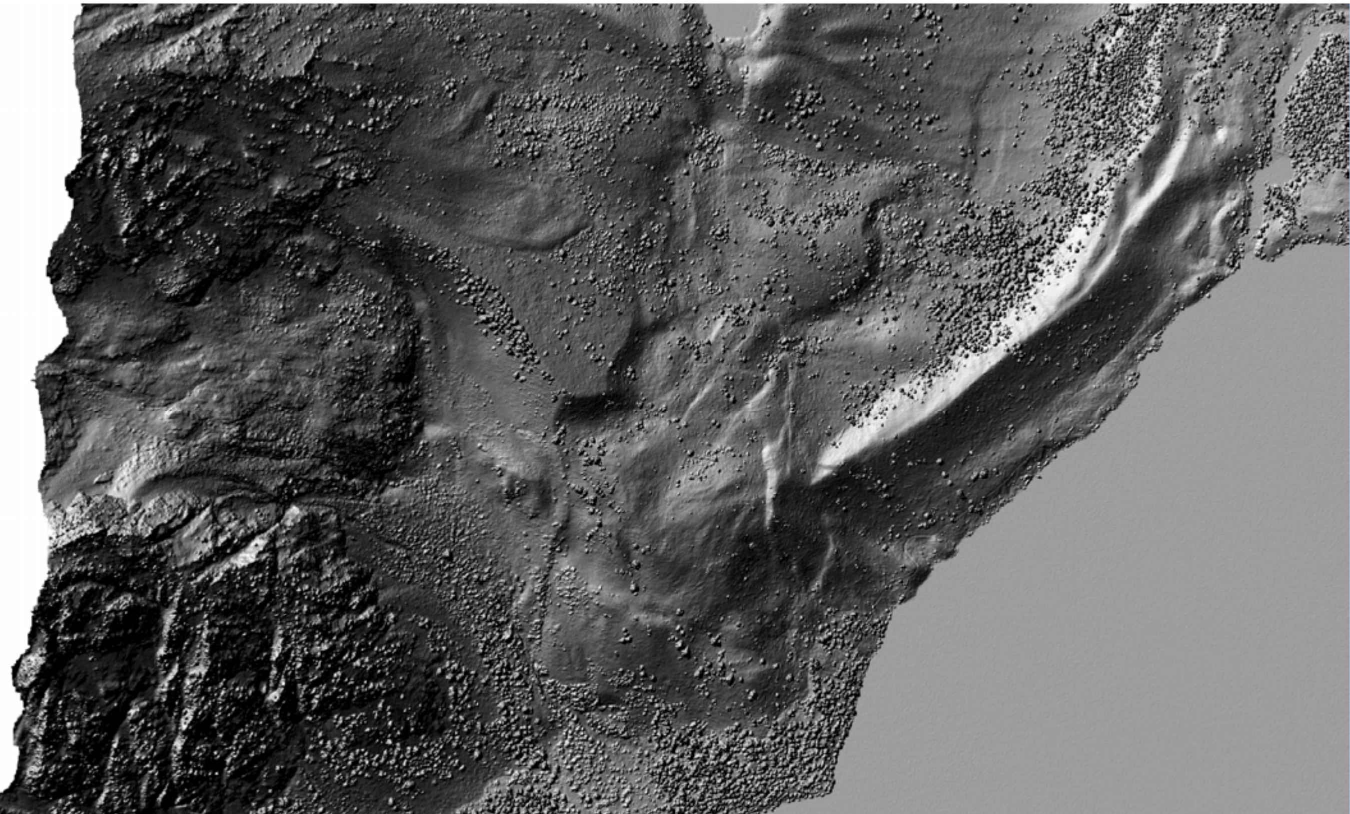
Image: Bob Smith & Jamie Farrel, U of Utah

Figure 2: Teton Fault – Central Segment. Priority 1 – Polygon A: 43.880264 N, -110.760496 W, B: 43.645488 N, -110.802797 W.

Priority 2: Mountain Segment – Polygon C: 43.766775 N, -110. 758544 W, D: 43.693887 N, -110.791676 W.

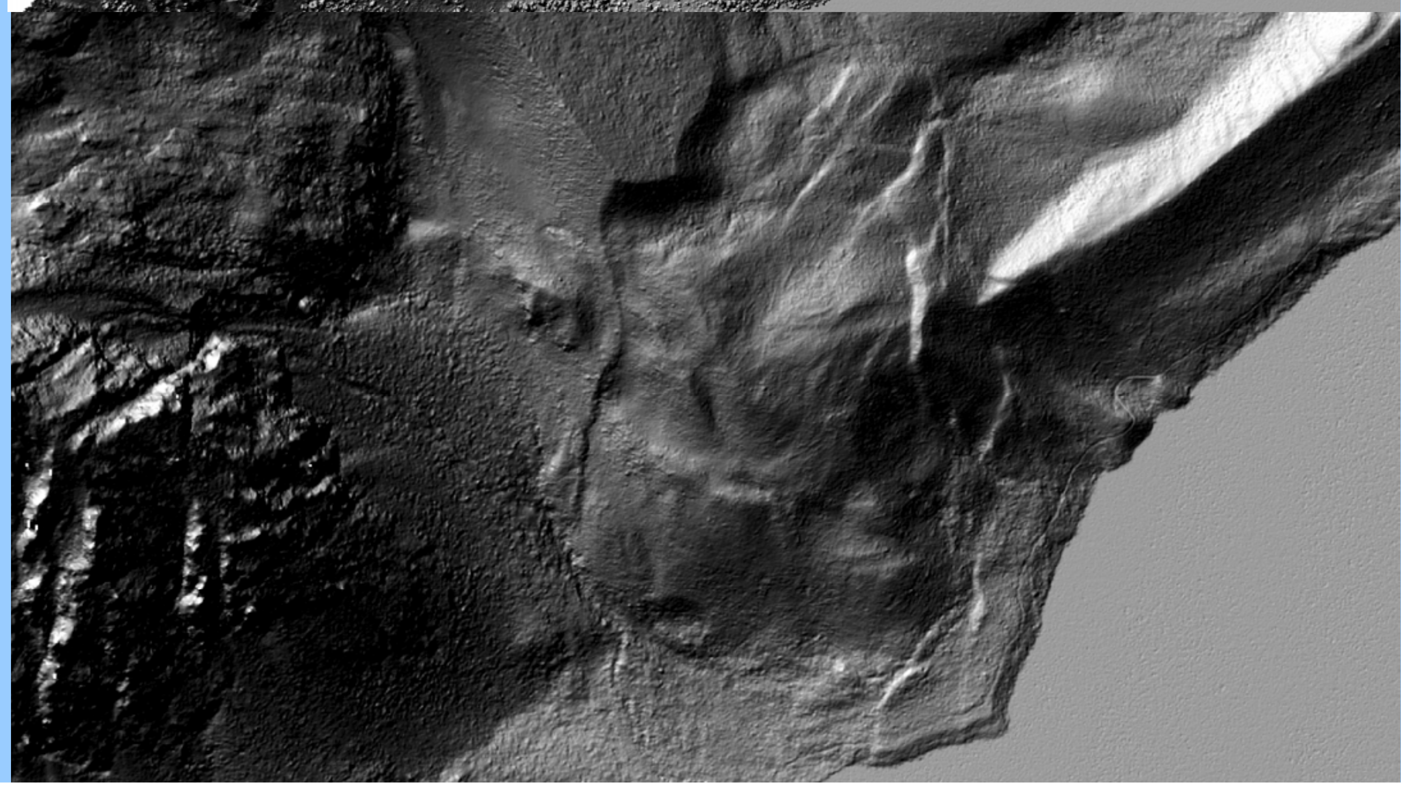
Image: Bob Smith and Jamie Farell, U of Utah

Vegetatio
n



NCALM data, Teton
Fault, Preliminary

Bare Earth

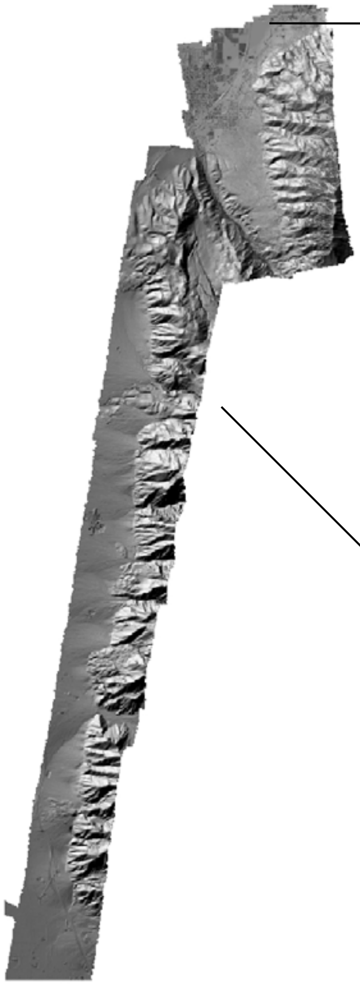


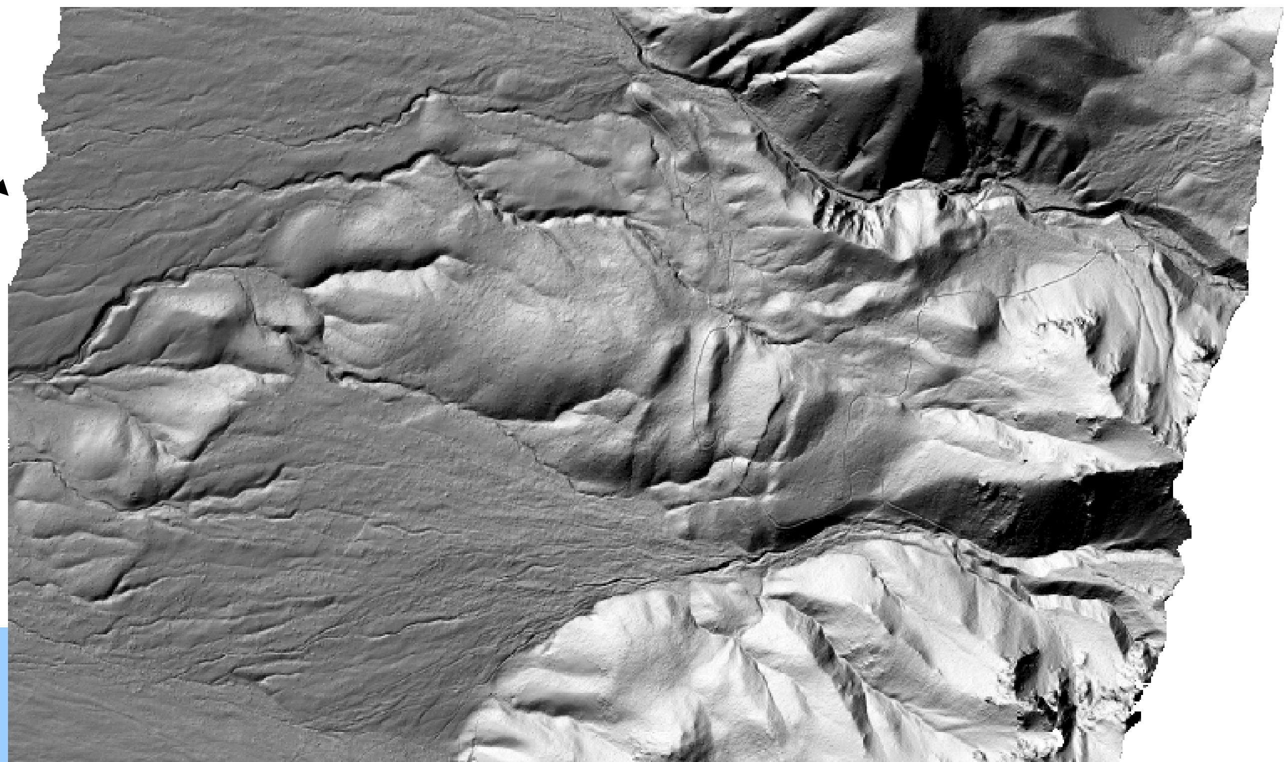
Ron Bruhn,
U of Utah

Figure 1: Wasatch Fault – Nephi Segment. Priority 1 areas in white, priority 2 in red. Points A through F are centered at ends of each polygon. **Priority 1 polygons -** *A: 39.986894 N, -111.763573 W, B: 39.927881N, -111.752817 W, C: 39.938798 N, -111.791328 W, D: 39.724309 N, -111.831522 W.*

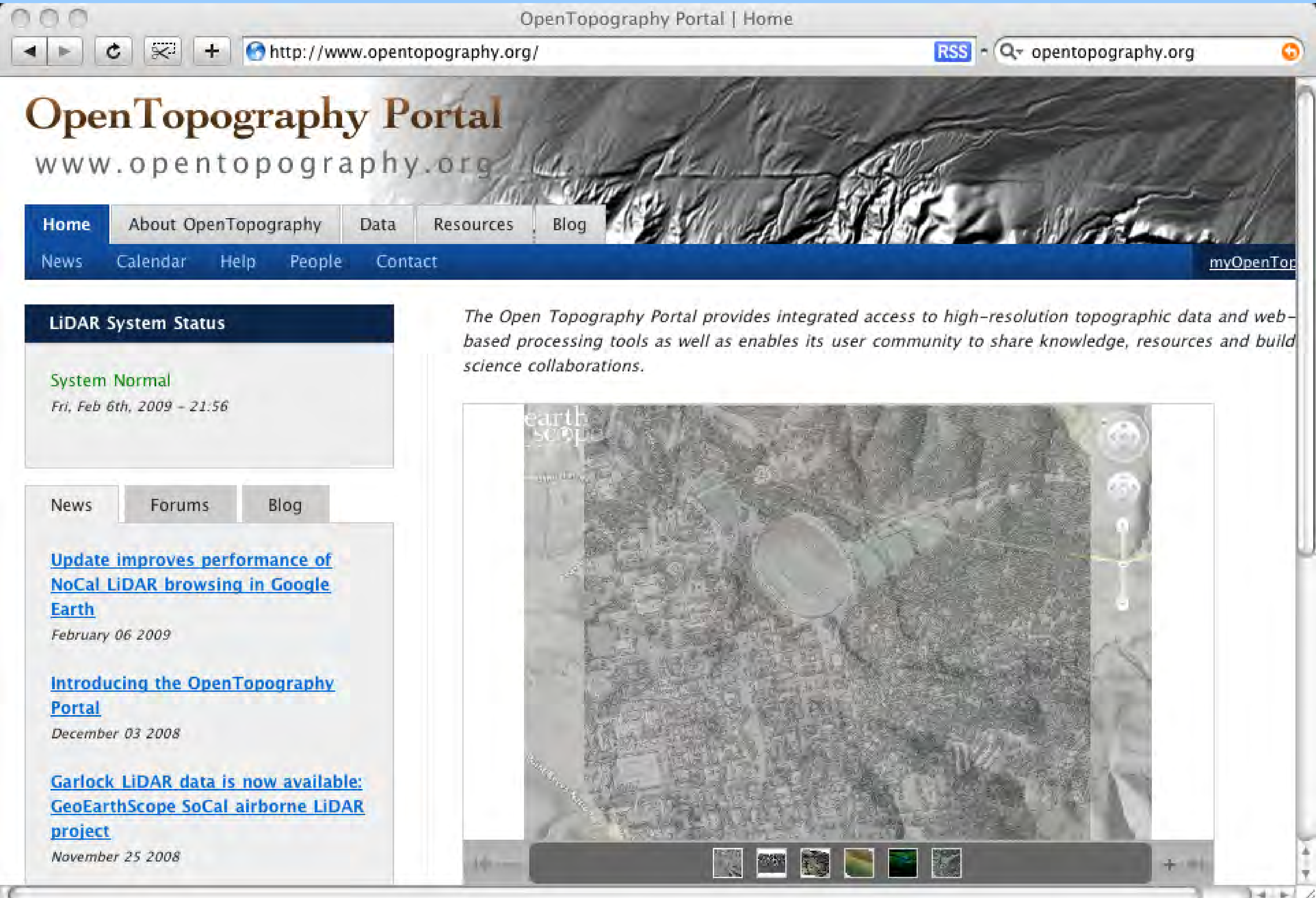
Priority 2 - E: 40.036998 N, -111.715932 W, F: 39.990391 N, -111.753481 W.

NEPHI Segment
NCALM Prelim.





Mendenhall
Cr. - Wash Cyn
area



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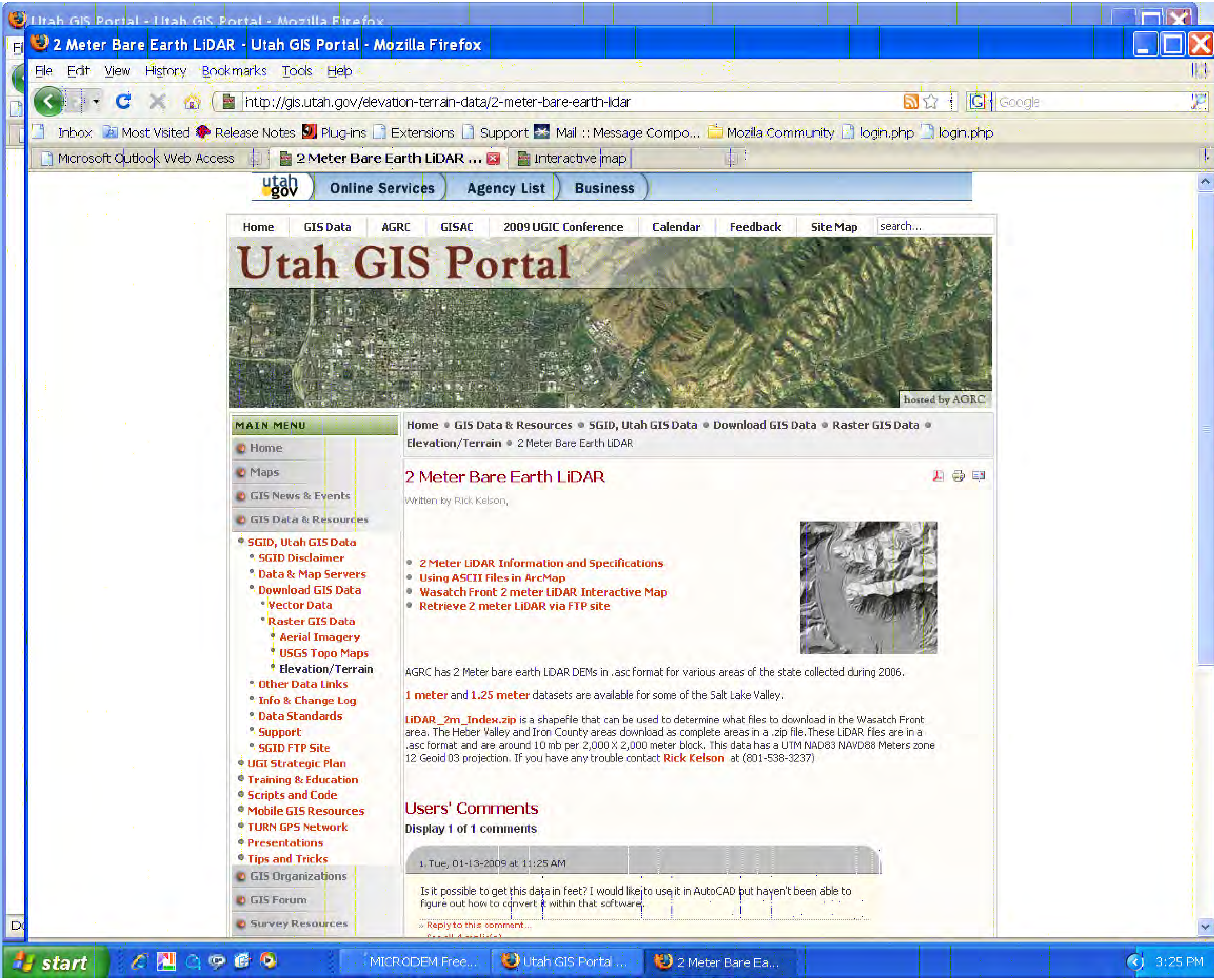
Introducing the OpenTopography Portal
December 03 2008
Garlock LiDAR data is now available: GeoEarthScope SoCal airborne LiDAR project
November 25 2008
The Open Topography Portal provides integrated access to high-resolution topographic data and web-based processing tools as well as enables its user community to share knowledge, resources and build science collaborations.
earthscope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2 Meter Bare Earth LiDAR
Written by Rick Kelson,
2 Meter LiDAR Information and Specifications
Using ASCII Files in ArcMap
Wasatch Front 2 meter LiDAR Interactive Map
Retrieve 2 meter LiDAR via FTP site
AGRC has 2 Meter bare earth LiDAR DEMs in .asc format for various areas of the state collected during 2006.
1 meter and 1.25 meter datasets are available for some of the Salt Lake Valley.
LiDAR_2m_Index.zip is a shapefile that can be used to determine what files to download in the Wasatch Front area. The Heber Valley and Iron County areas download as complete areas in a .zip file. These LiDAR files are in a .asc format and are around 10 mb per 2,000 X 2,000 meter block. This data has a UTM NAD83 NAVD88 Meters zone 12 Geoid 03 projection. If you have any trouble contact Rick Kelson at (801-538-3237)
Users' Comments
Display 1 of 1 comments
1. Tue, 01-13-2009 at 11:25 AM
Is it possible to get this data in feet? I would like to use it in AutoCAD but haven't been able to figure out how to convert it within that software.
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start
MICRODEM Free...
Utah GIS Portal ...
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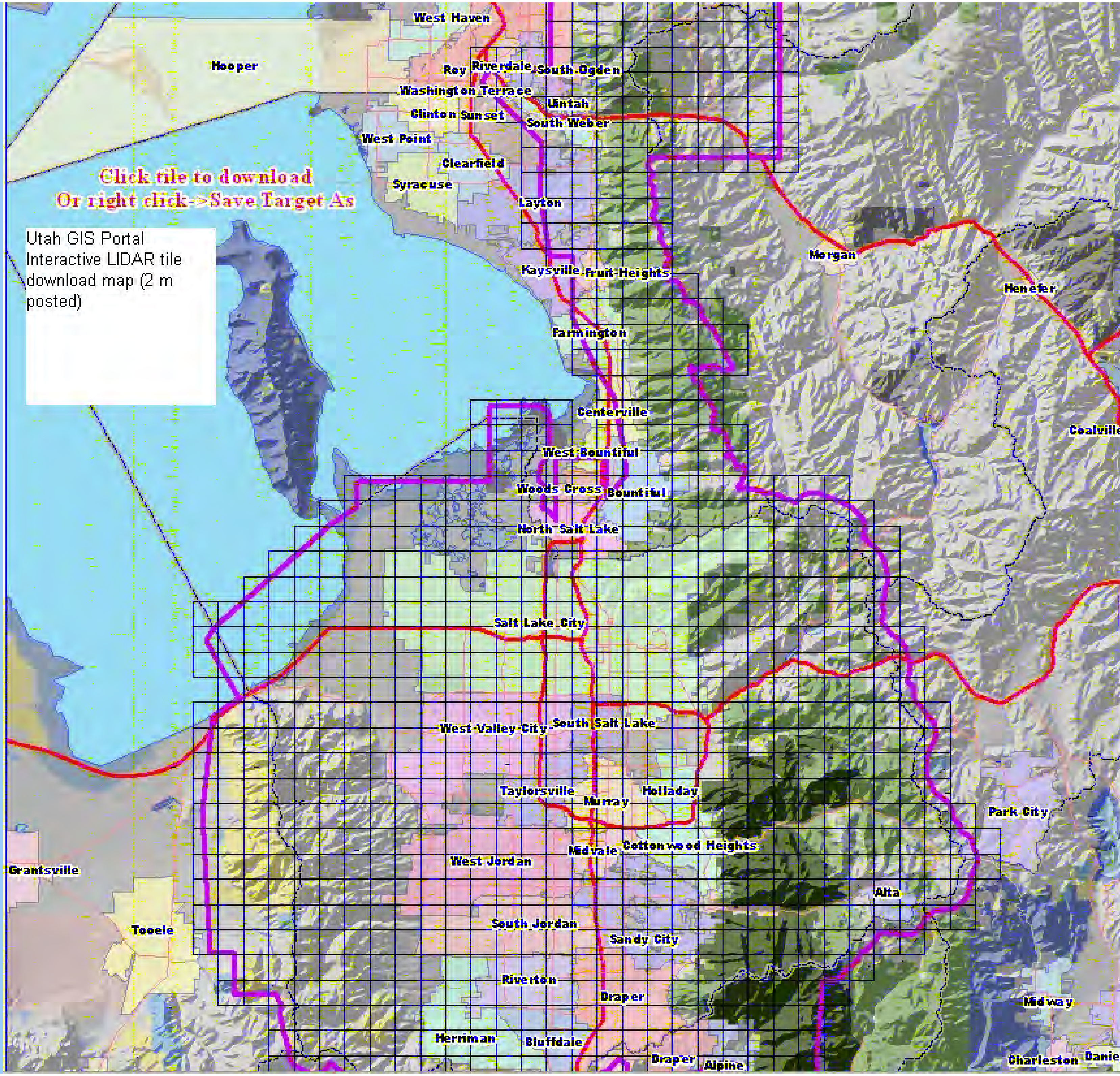
3:25 PM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Salt Lake City
West Valley City
South Salt Lake
Taylorsville
Holladay
Murray
Park City
Midvale
Cottonwood Heights
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Sandy City
Riverton
Draper
Midway
Herriman
Bluffdale
Draper
Alpine
Charleston
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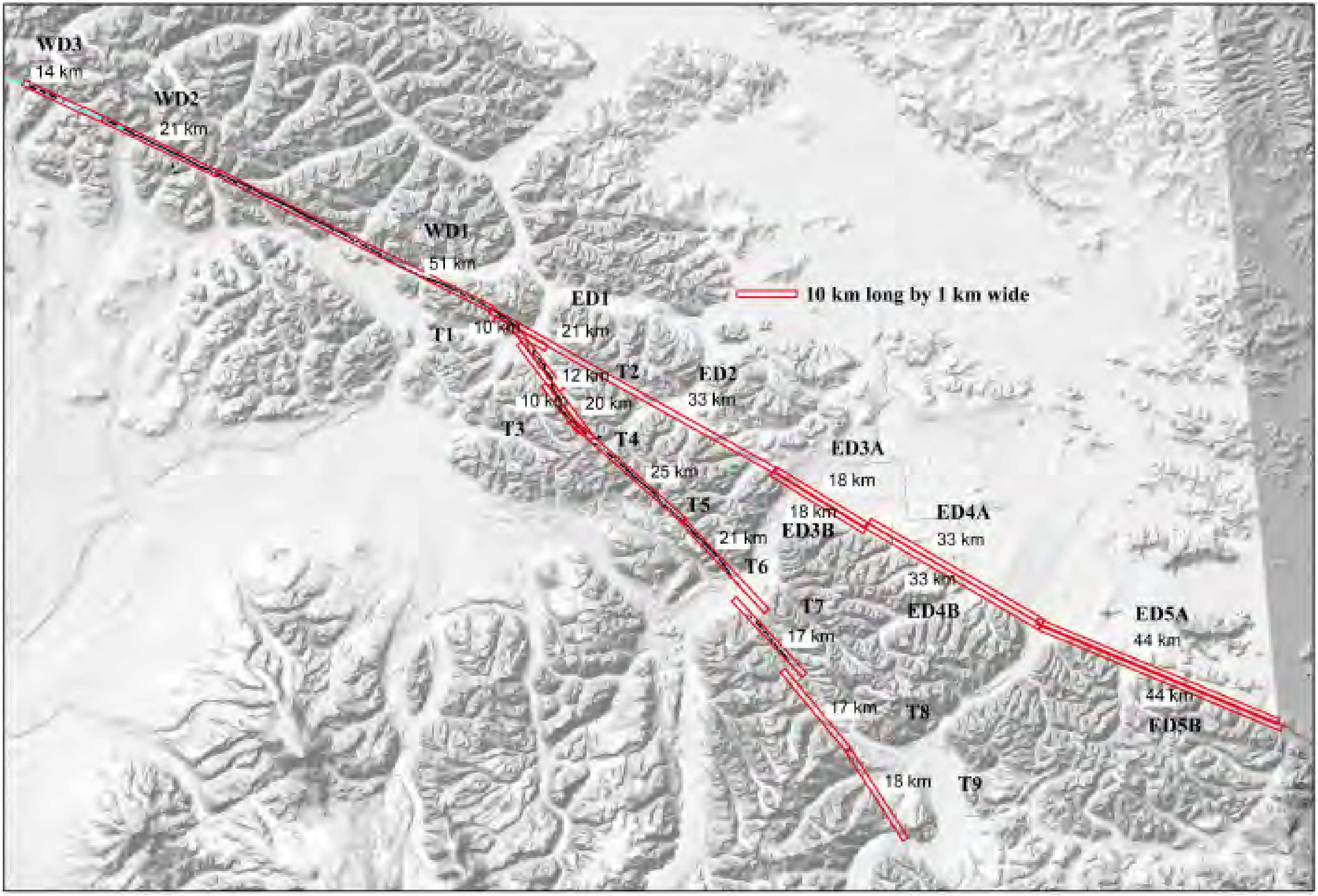
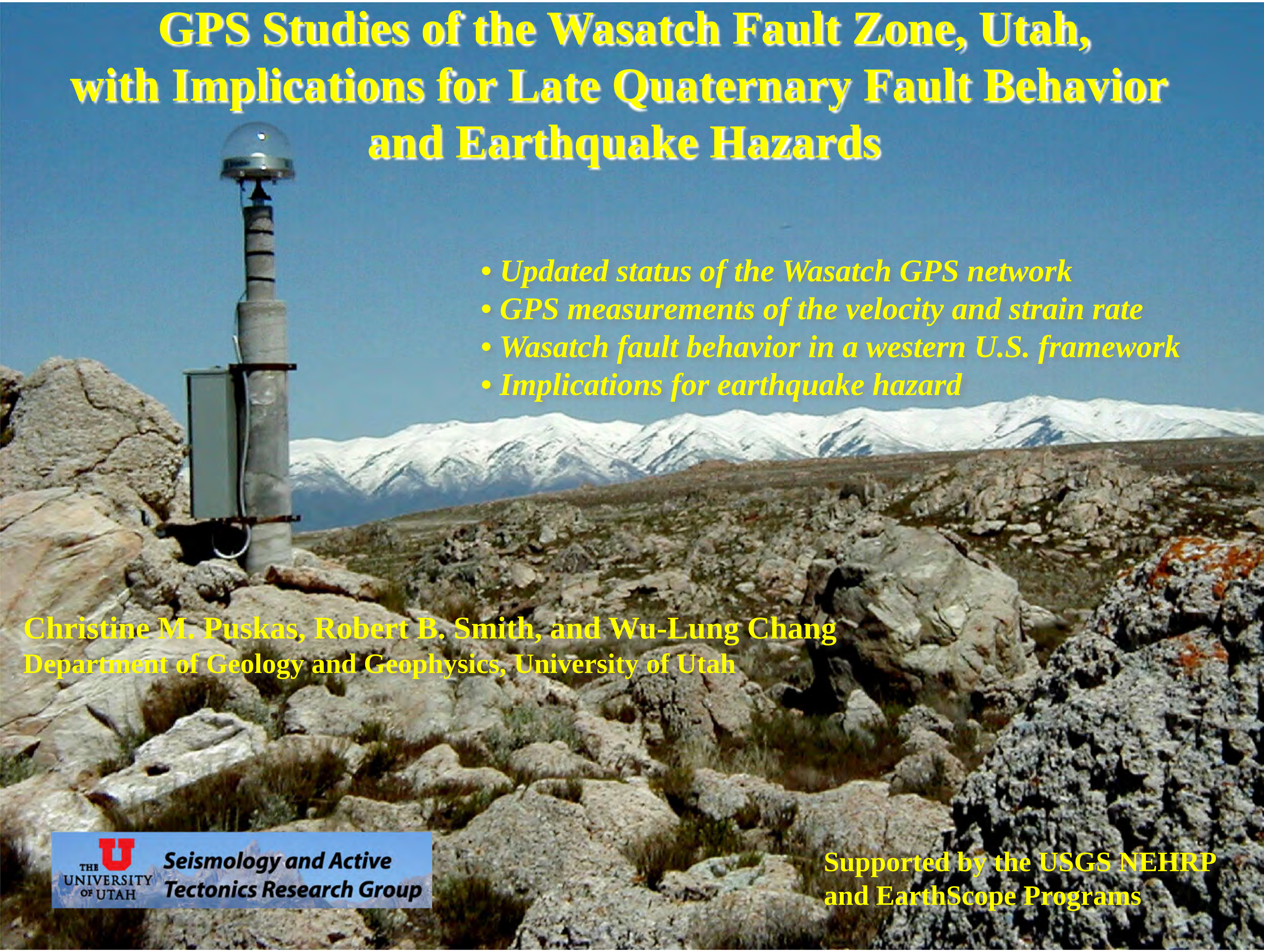


Figure 1. Priority 1, 2 and 3 targets as listed in table. WD = Western Denali fault. ED = Eastern Denali fault. T = Totschunda fault. Highest priority areas are near intersection.

GPS Studies of the Wasatch Fault Zone, Utah, with Implications for Late Quaternary Fault Behavior and Earthquake Hazards



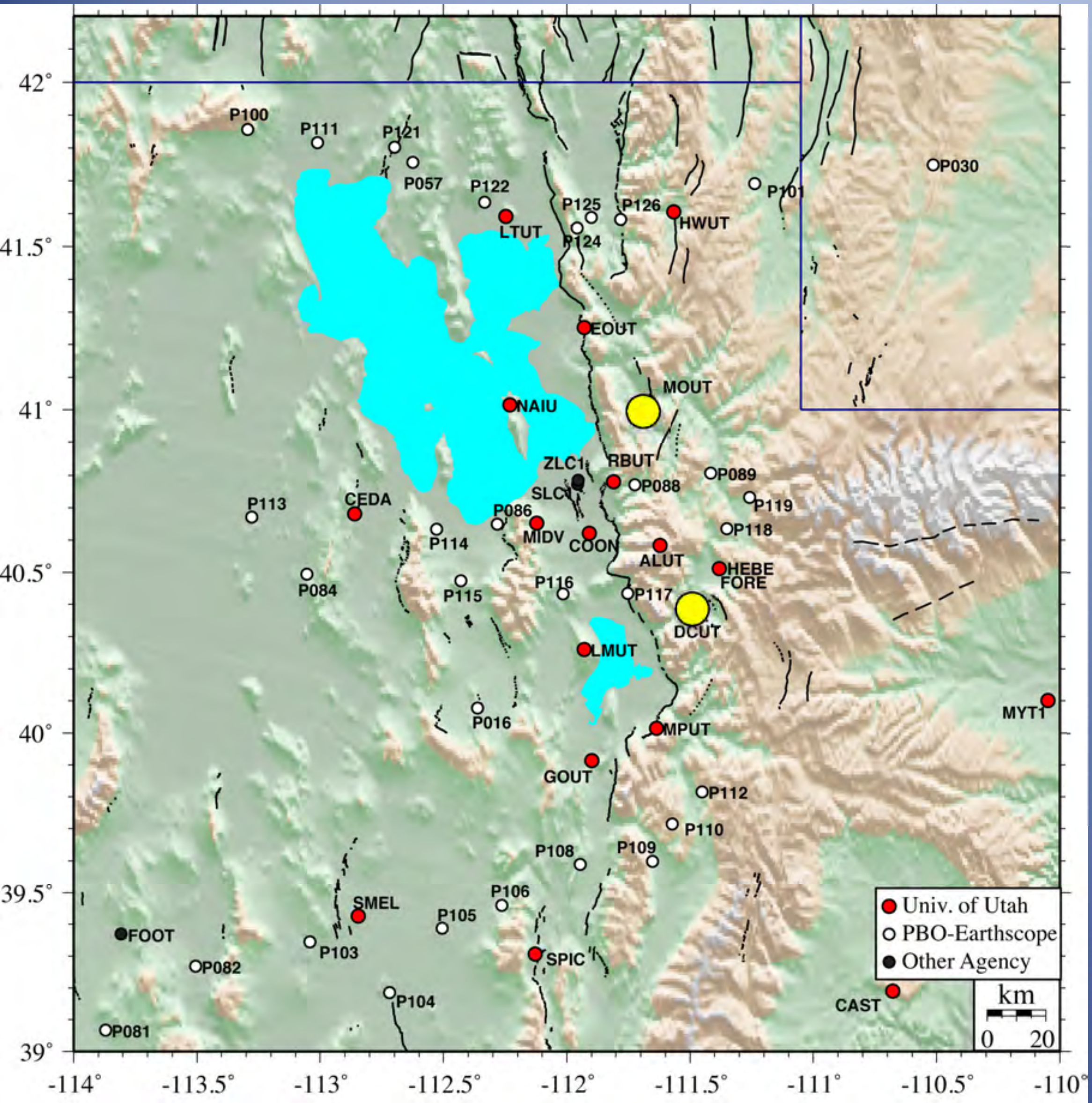
- *Updated status of the Wasatch GPS network*
- *GPS measurements of the velocity and strain rate*
- *Wasatch fault behavior in a western U.S. framework*
- *Implications for earthquake hazard*

Christine M. Puskas, Robert B. Smith, and Wu-Lung Chang
Department of Geology and Geophysics, University of Utah

THE UNIVERSITY OF UTAH
Seismology and Active Tectonics Research Group

Supported by the USGS NEHRP and EarthScope Programs

GPS Monitoring of Wasatch Front



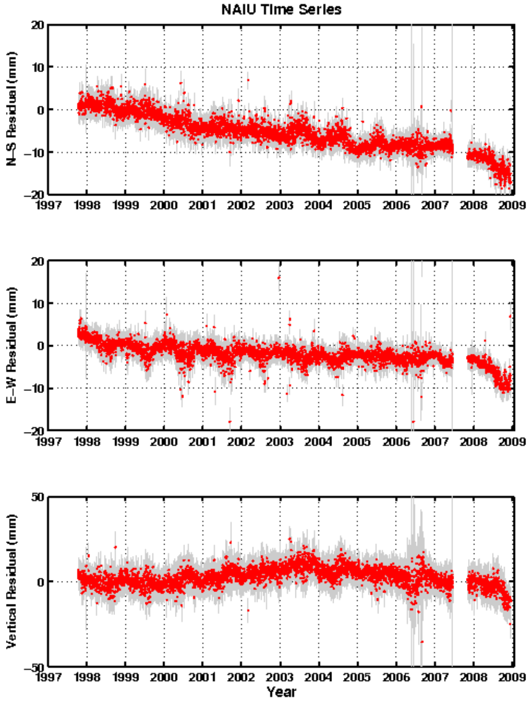
Data recorded and transmitted daily

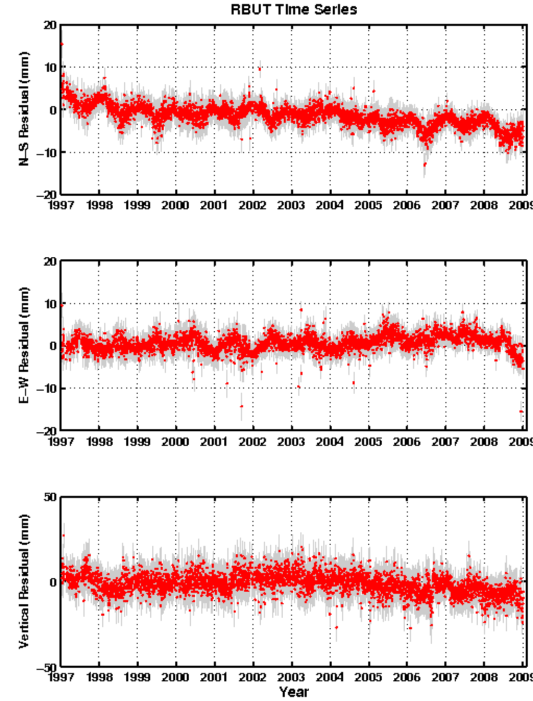
- 30-second recording rate
- ~60 stations in Wasatch Front
- University of Utah
  (http://www.utah.edu/~ggcmpsem/UUSATRG)
- Plate Boundary Observatory
  (http://www.earthscope.org/)

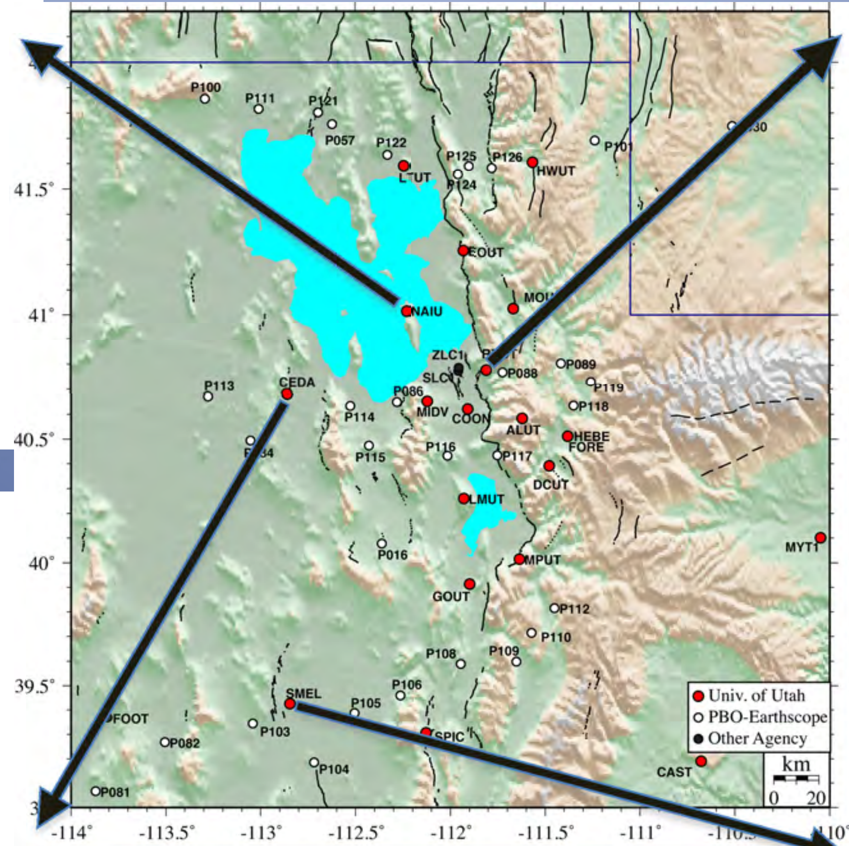
Processed data products

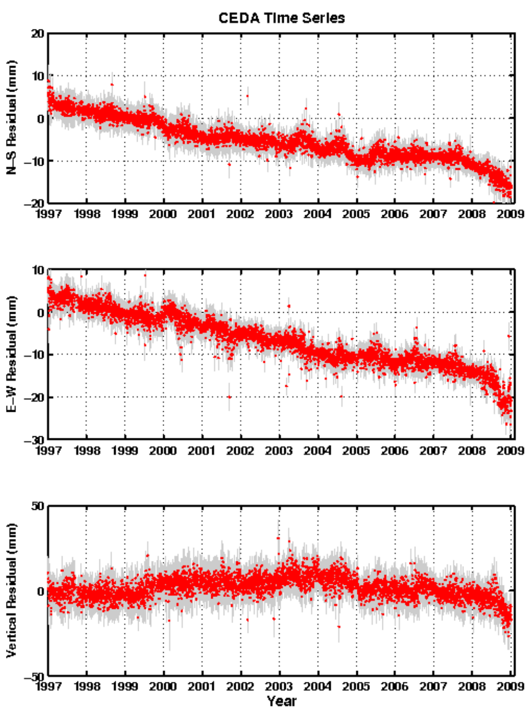
- Daily position solutions
- Site velocities

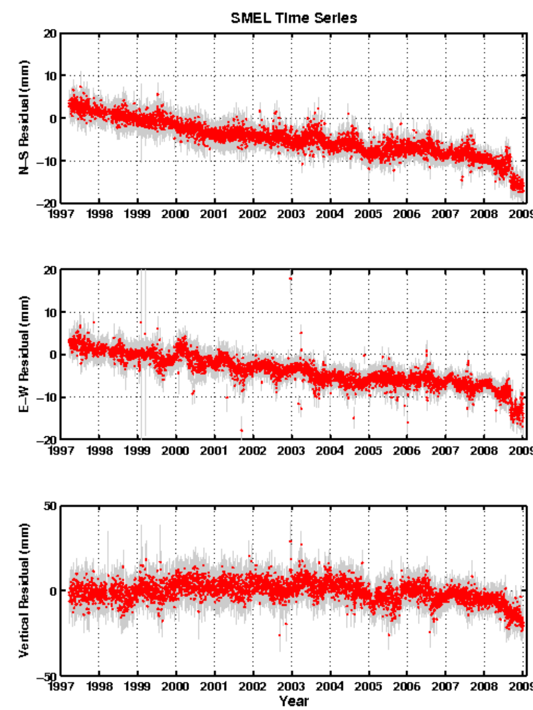
Continuous GPS Time Series







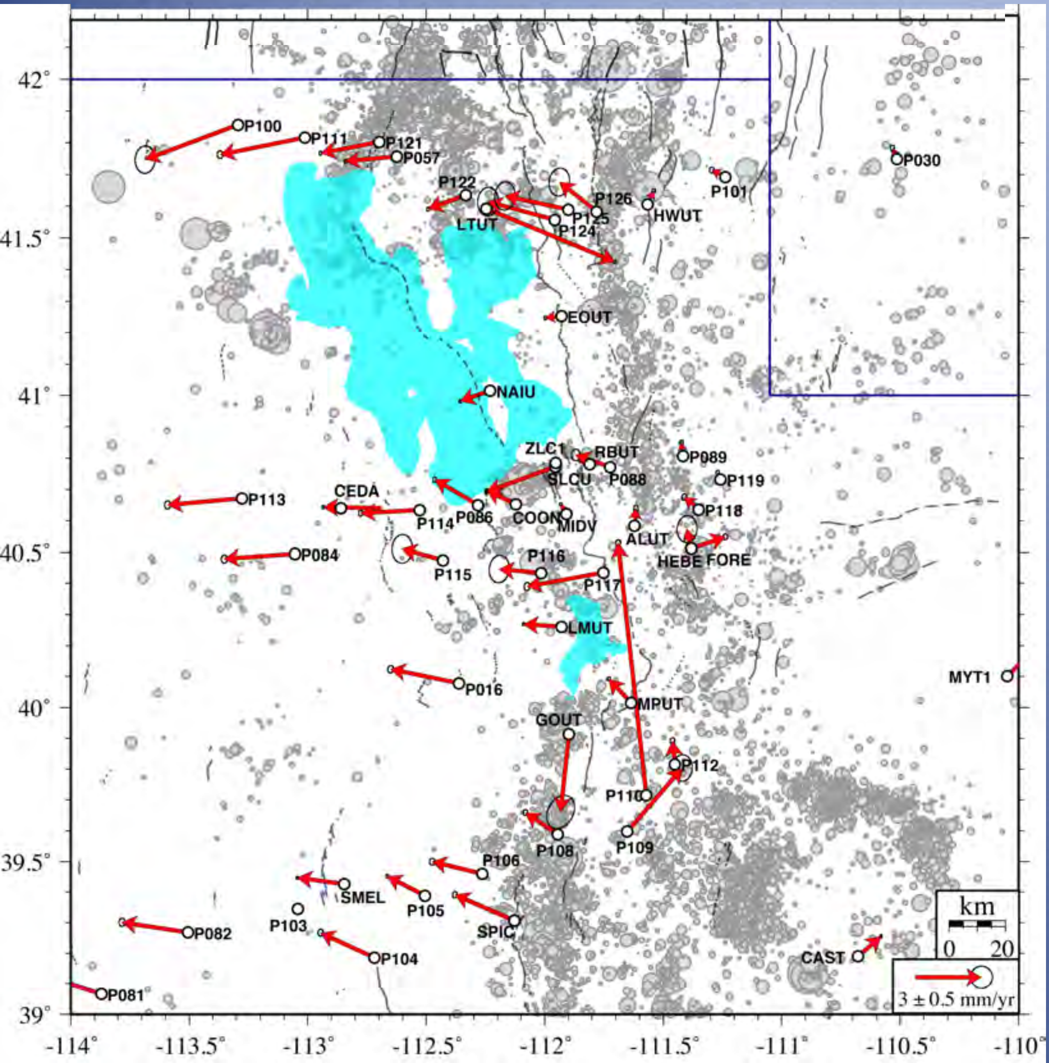




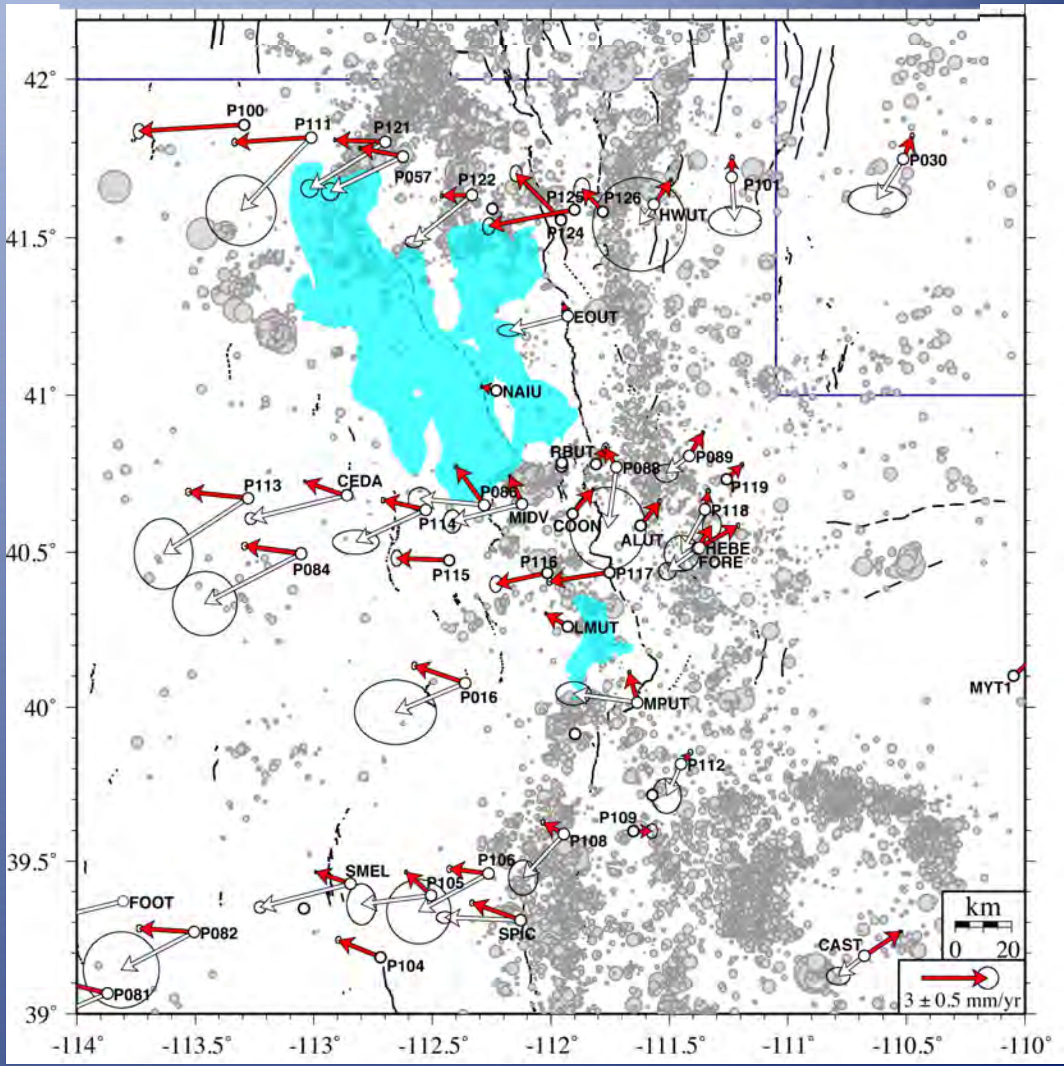
Measures precise change in position for north, east, vertical components

Deformation Rates across the Wasatch Front

Originally Processed Data with Outliers

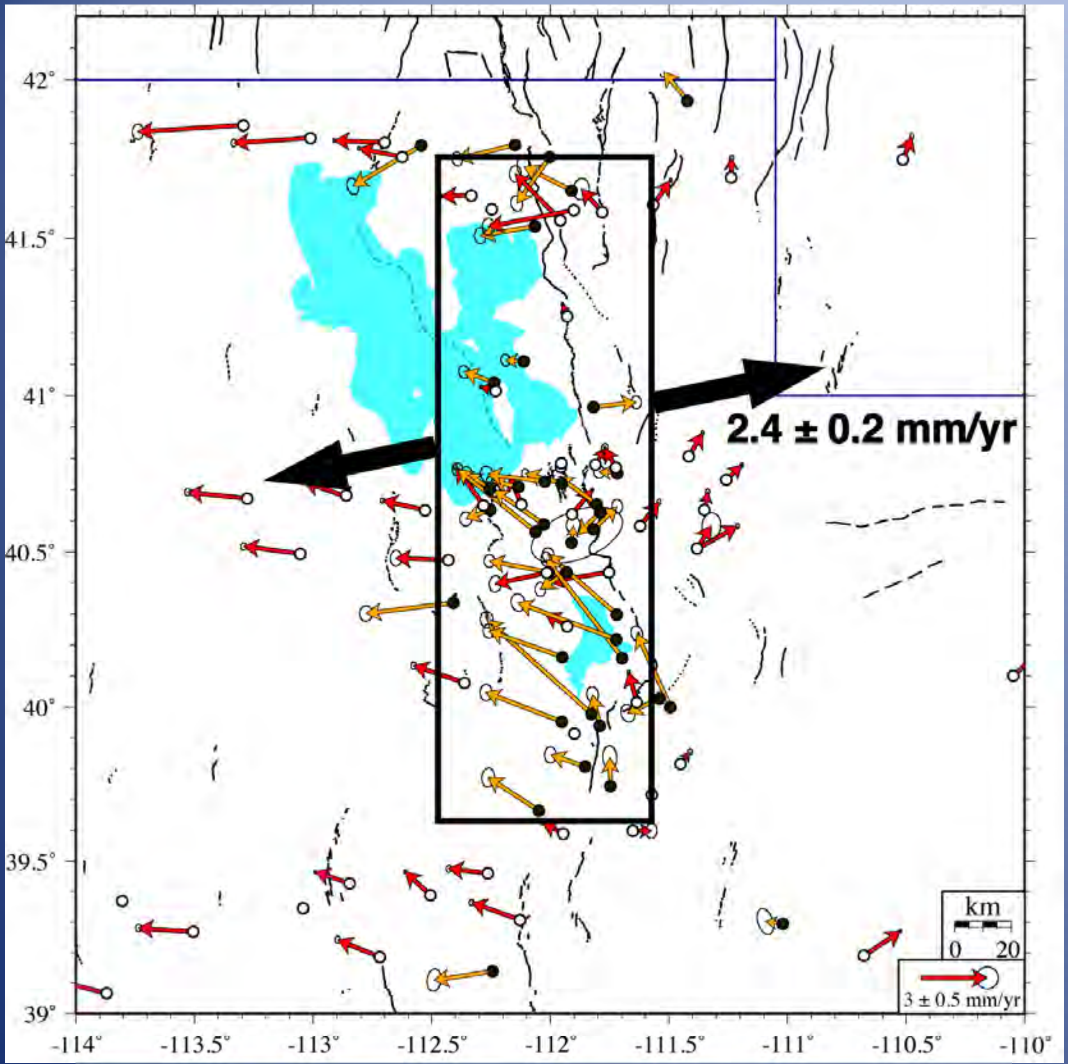


Processed Data with Outliers Removed



Red = University of Utah GPS Velocities
White = PBO GPS Velocities
Gray = Historic seismicity, 1975-2009

Late Quaternary Fault Slip and Deformation Rates



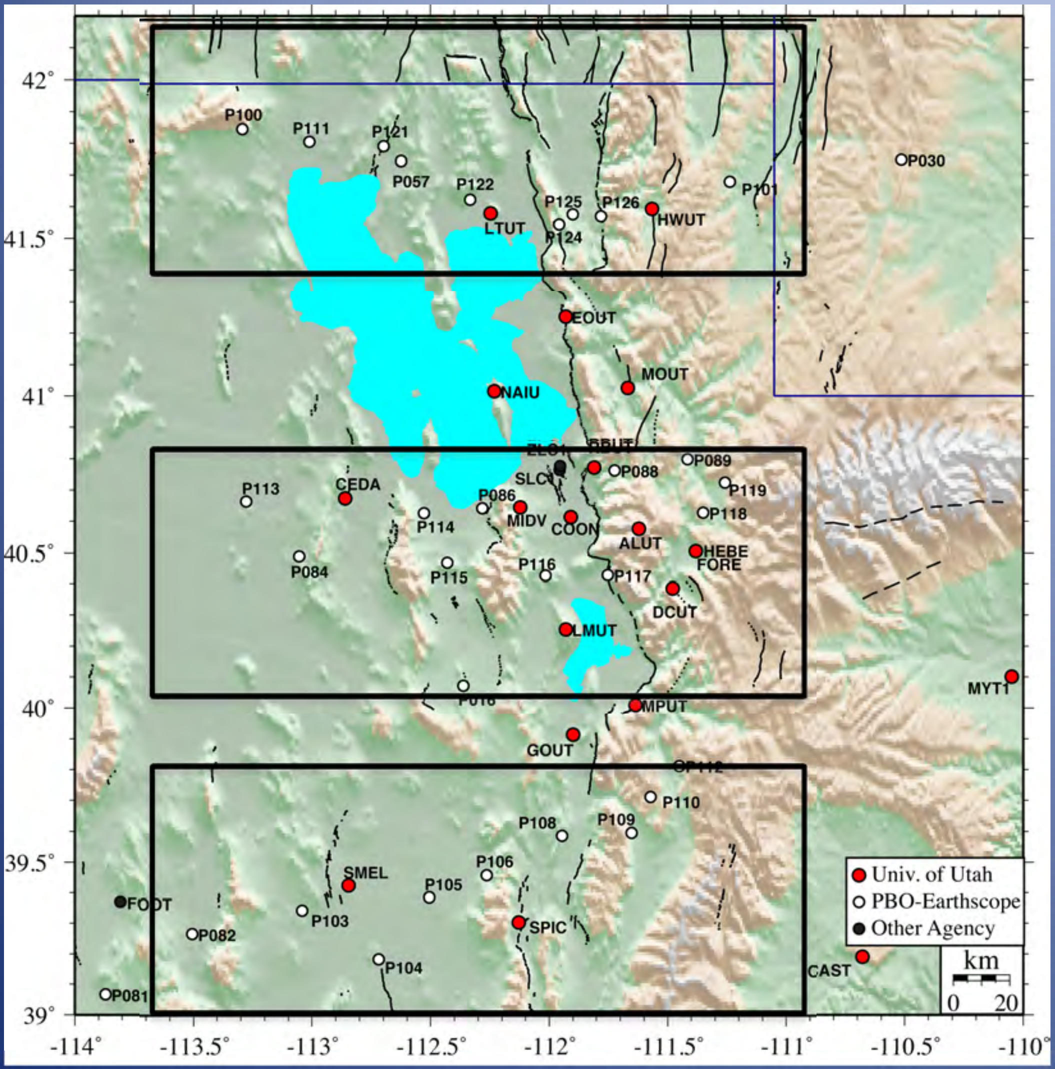
Red = University of Utah Permanent GPS Velocities
Orange = Campaign GPS Velocities 1992-2008

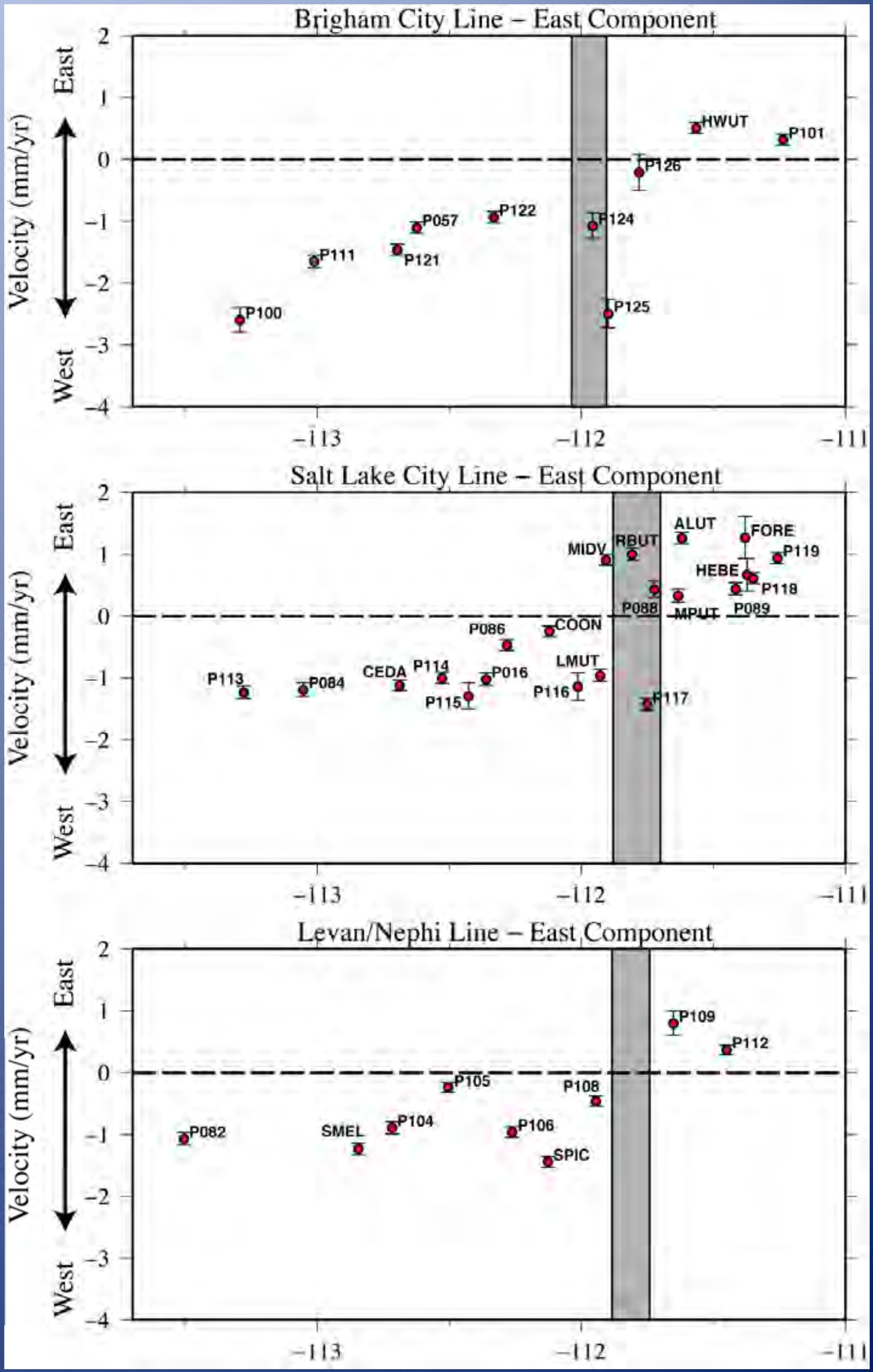
Fault	Slip rate mm/yr
Wasatch-Brigham City	0.9
Wasatch-Weber	1.6
Wasatch-Salt Lake City	1.2
Wasatch-Provo	1.2
Wasatch-Nephi	1.7
E Great Salt Lake	0.6
E Cache	0.2
E Bear Lake	0.6
Bear River	2.0
Rock Creek	1.7
Stansbury	0.4
Wasatch Front GPS	**2.4 ± 0.2 mm/yr**

Monitoring of Wasatch fault
- Campaign GPS: 1992-2003
- Permanent GPS: 1996-2009

Average GPS rate for Wasatch Front from models of velocity field.

Contemporary Extension across the Wasatch Fault

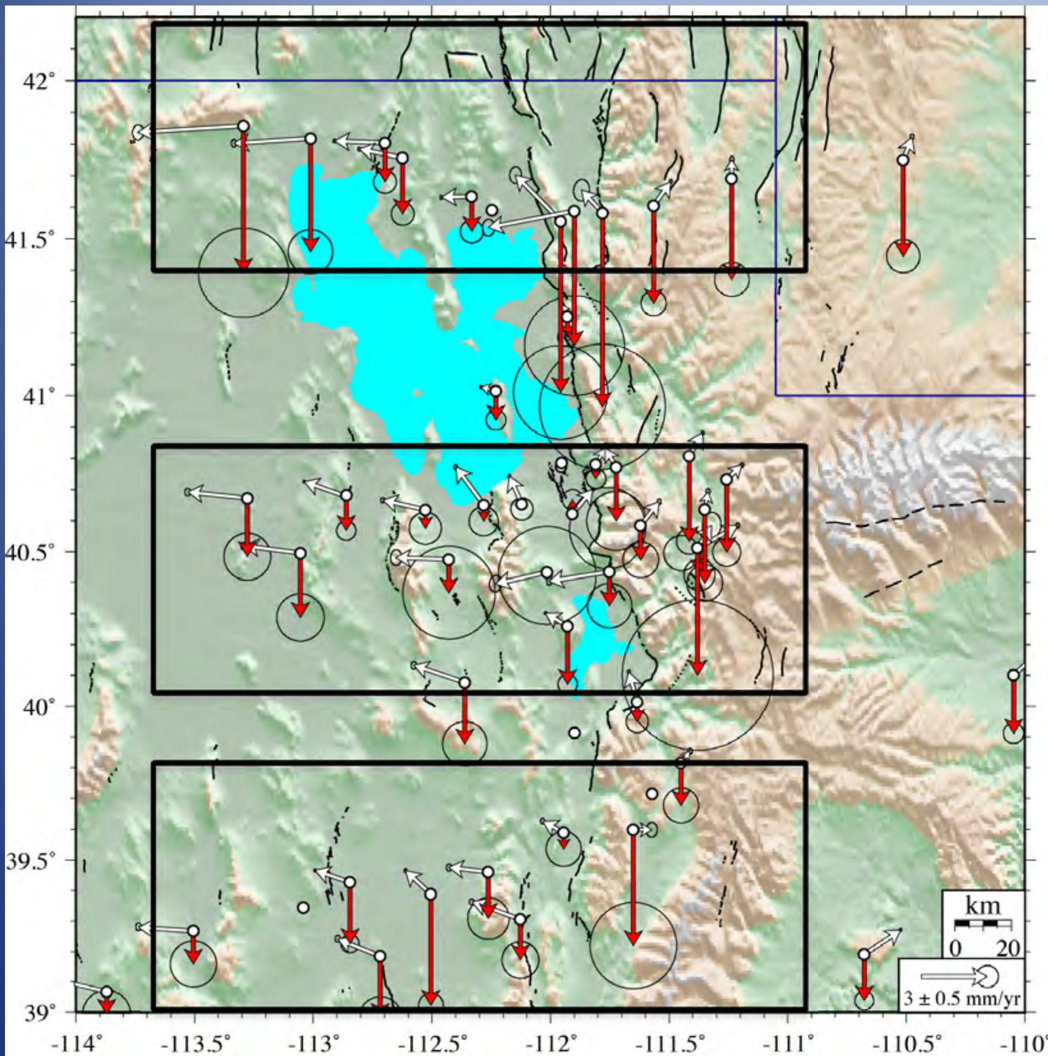


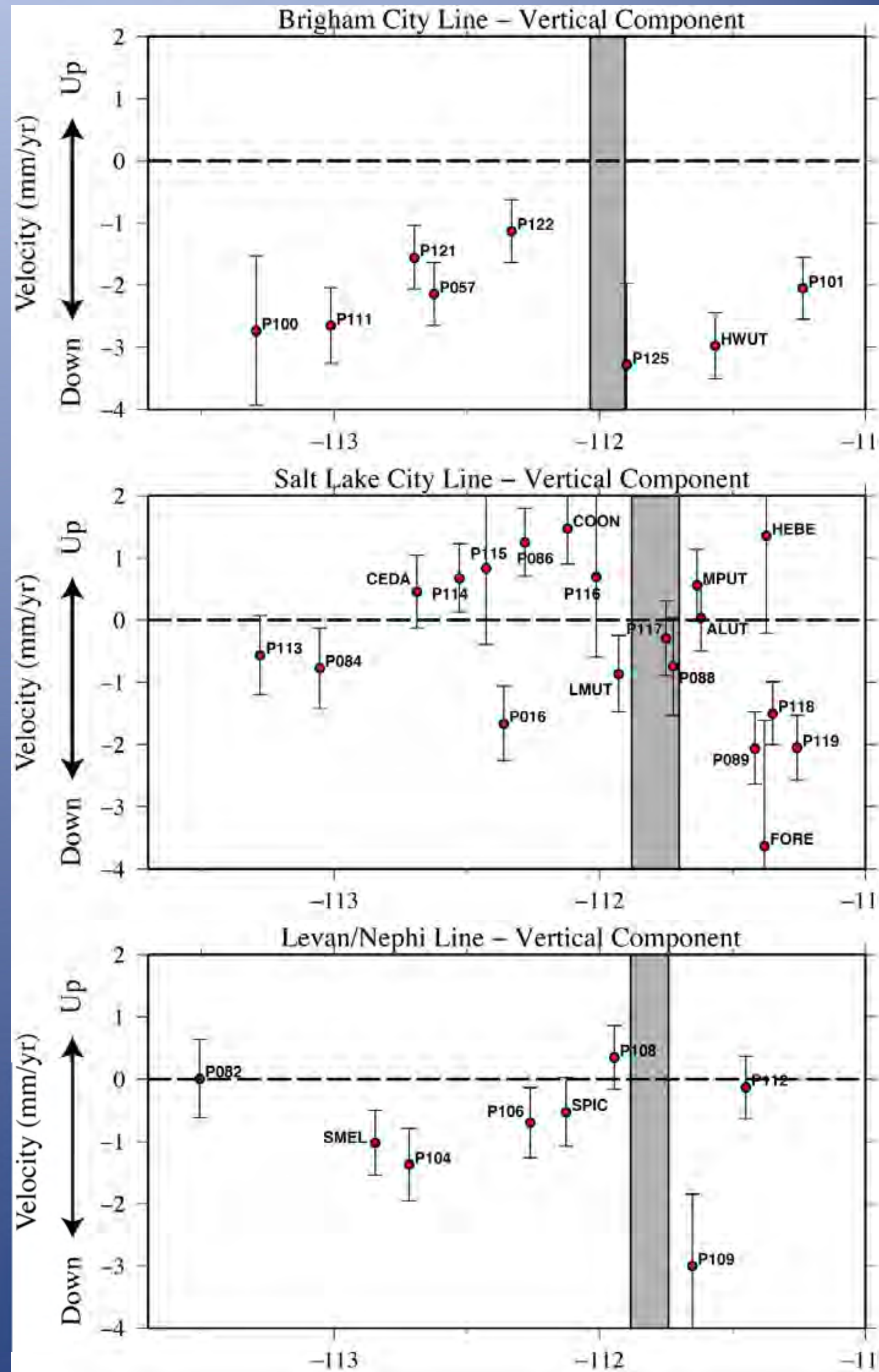


Increased westward velocity in hanging wall

- Total increase ~3 mm/yr
- Maximum change in north, central profiles

Vertical Deformation across the Wasatch fault

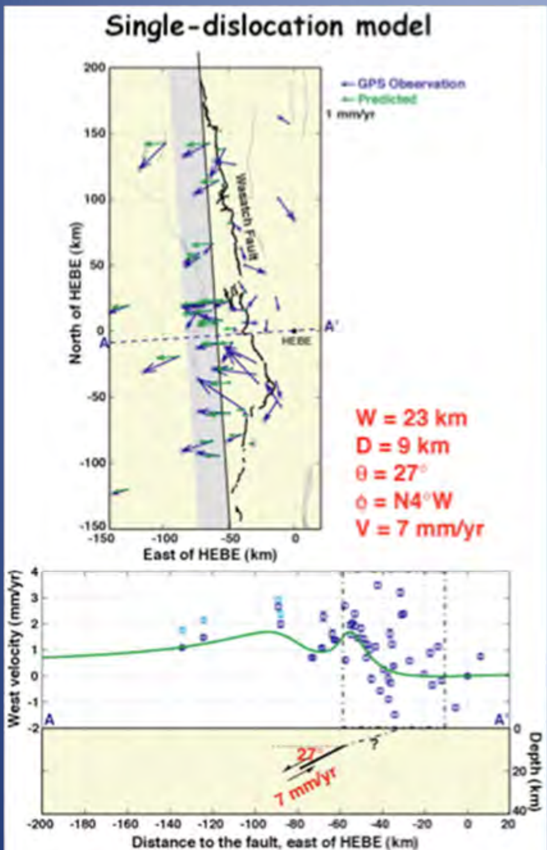


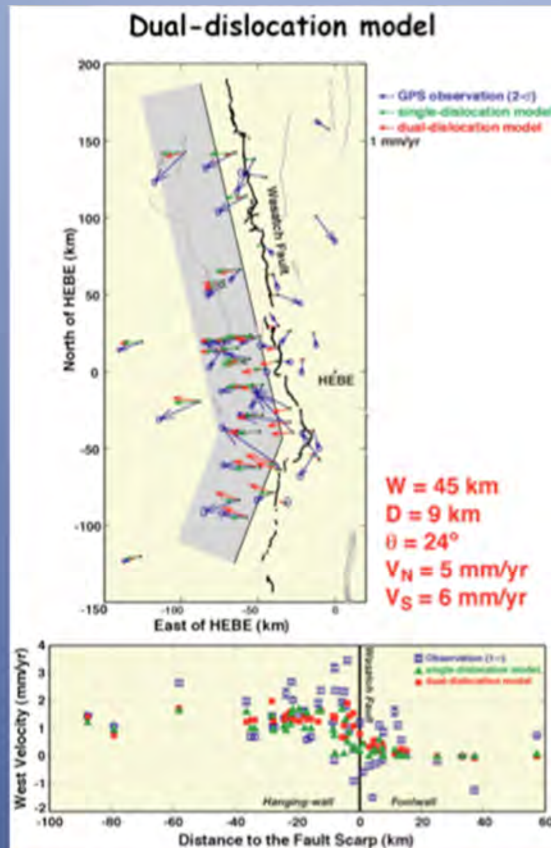


Vertical shifts resolved by GPS

- 2-3 mm/yr uplift at fault trace
- Hanging wall subsidence

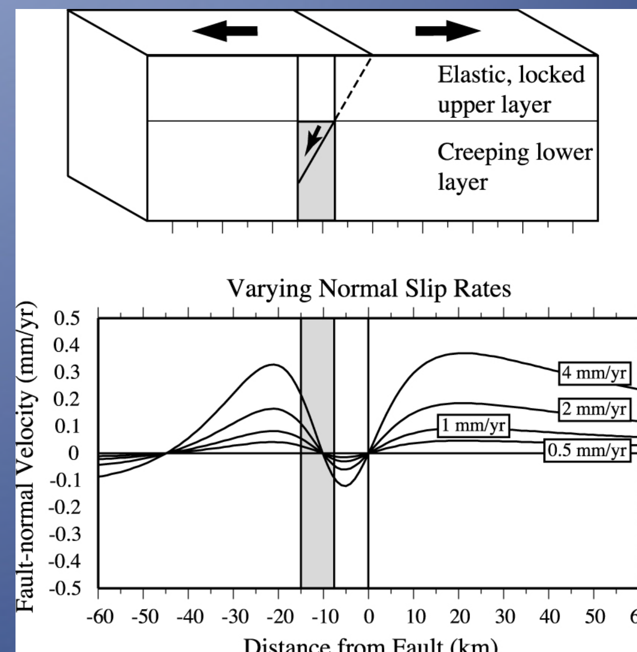
Dislocation Models of Wasatch fault deformation

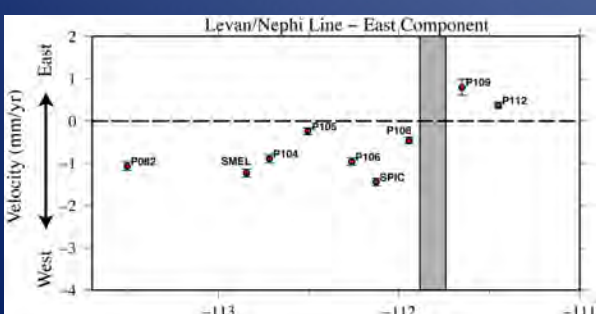


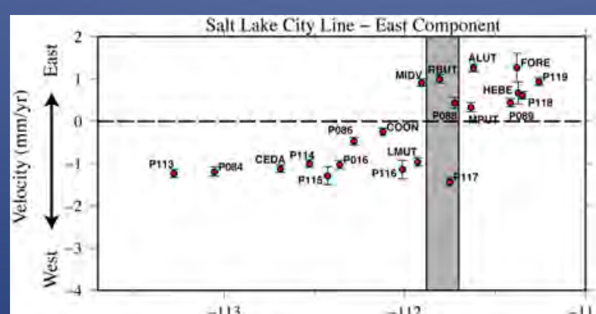


New data constrain better loading models

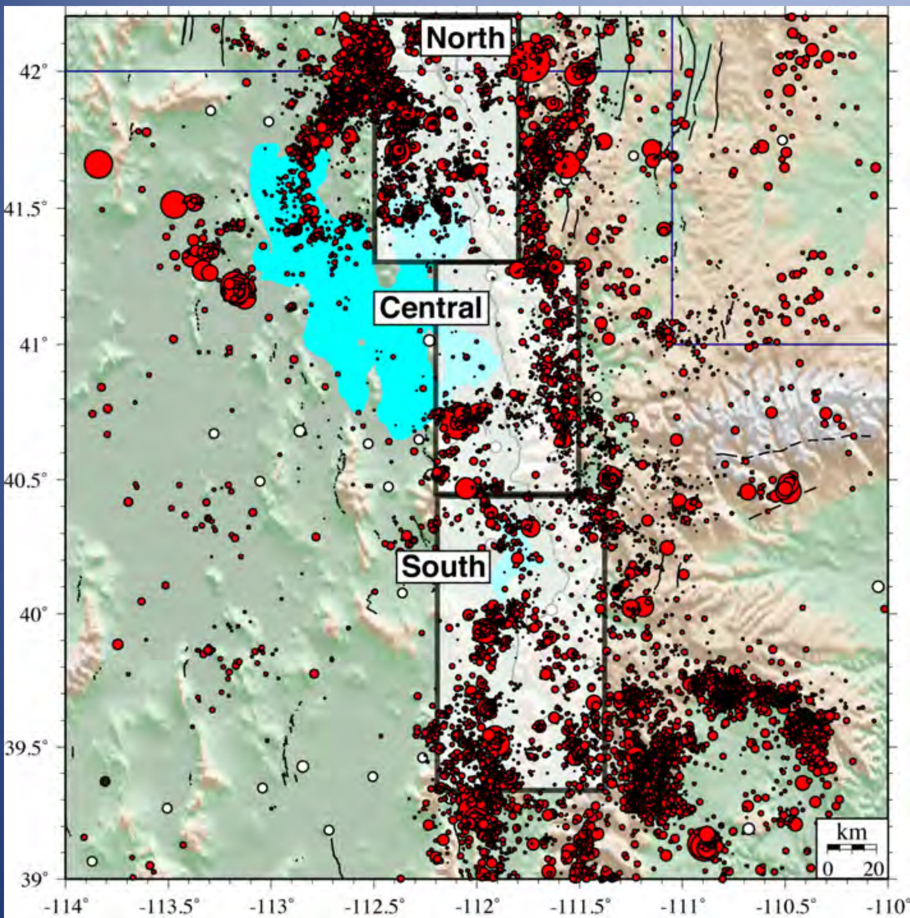
- Include vertical constraints
- Multiple faults, complex geometry

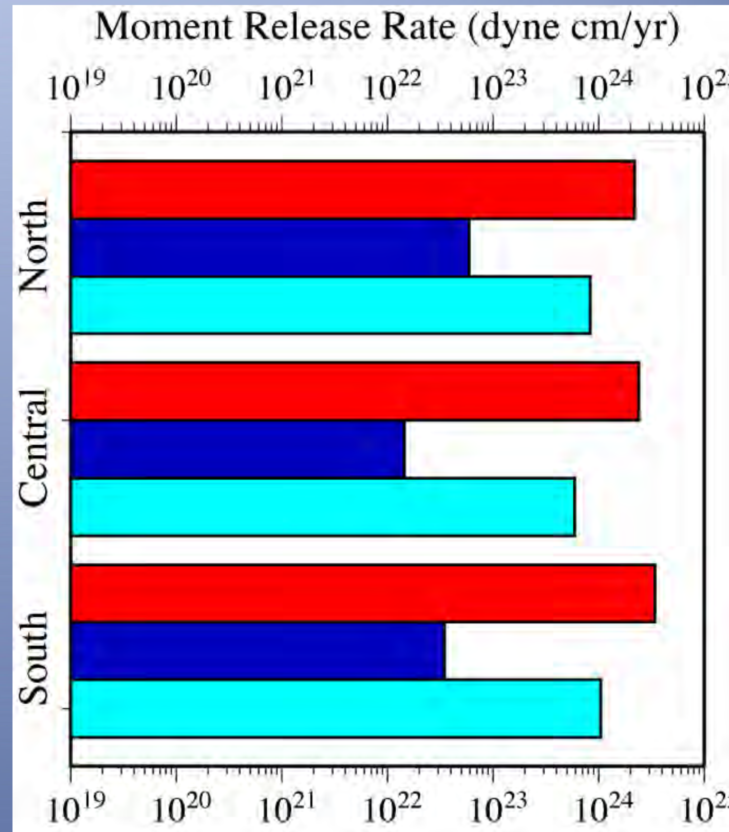






Moment Release Rates





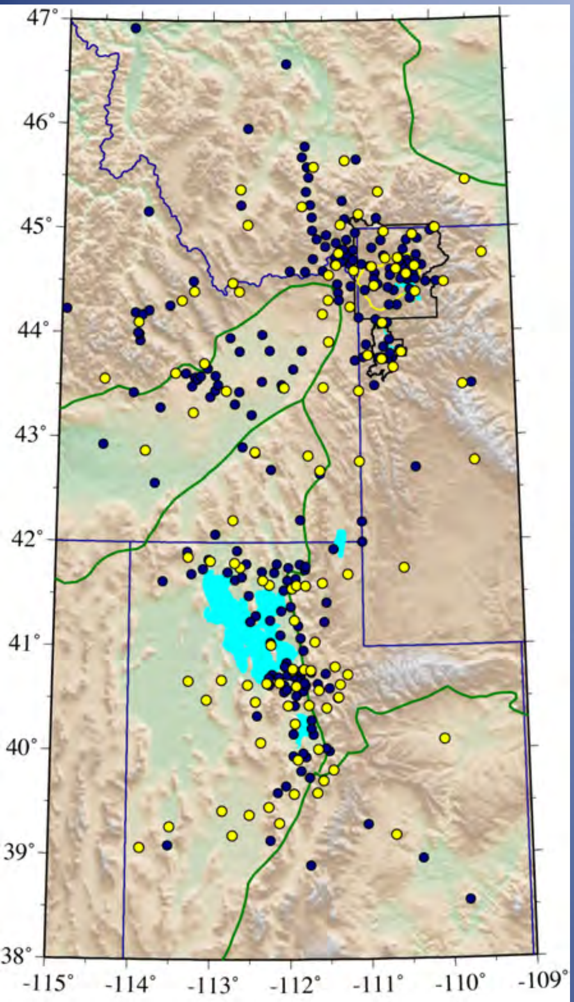
Section	Total (dyne cm/yr)	Seismic (dyne cm/yr)	Fault Slip (dyne cm/yr)
North	2.18×10^{24}	5.94×10^{22}	8.26×10^{23}
Central	2.39×10^{24}	1.44×10^{22}	5.91×10^{23}
South	3.42×10^{24}	3.45×10^{22}	1.04×10^{24}

Measure energy of deformation

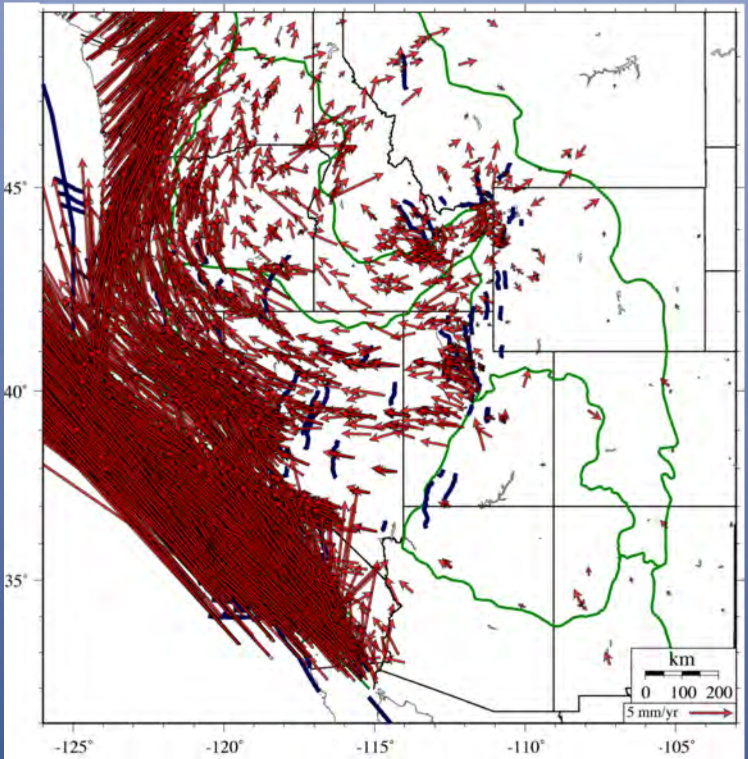
- GPS: total moment release
- Historic earthquakes: seismic slip on faults
- Fault slip rates: expected moment for fault loading

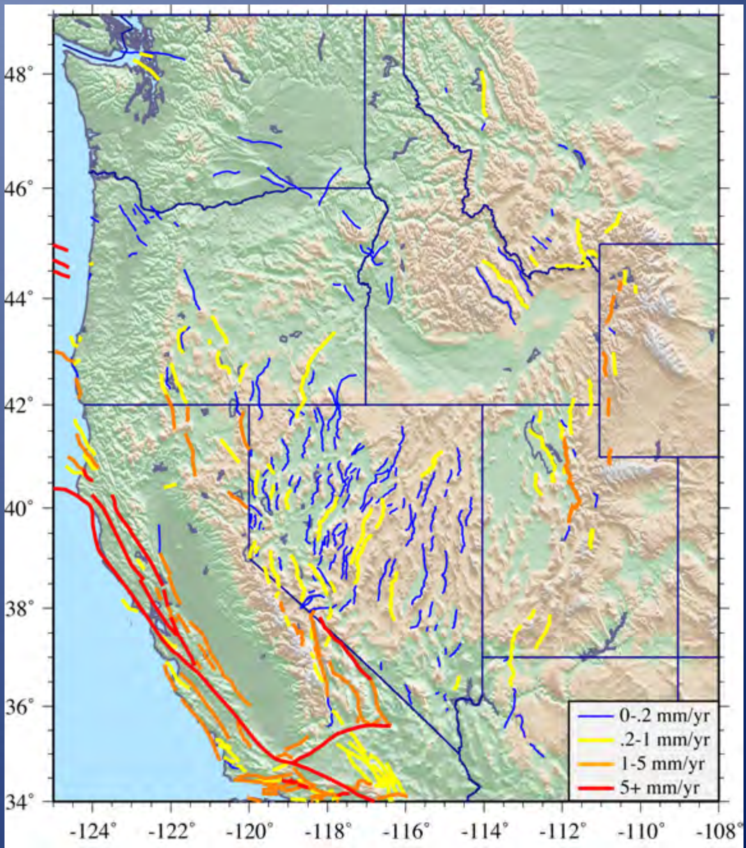
Big seismic deficit!

GPS and Late Quaternary Fault Slip Data



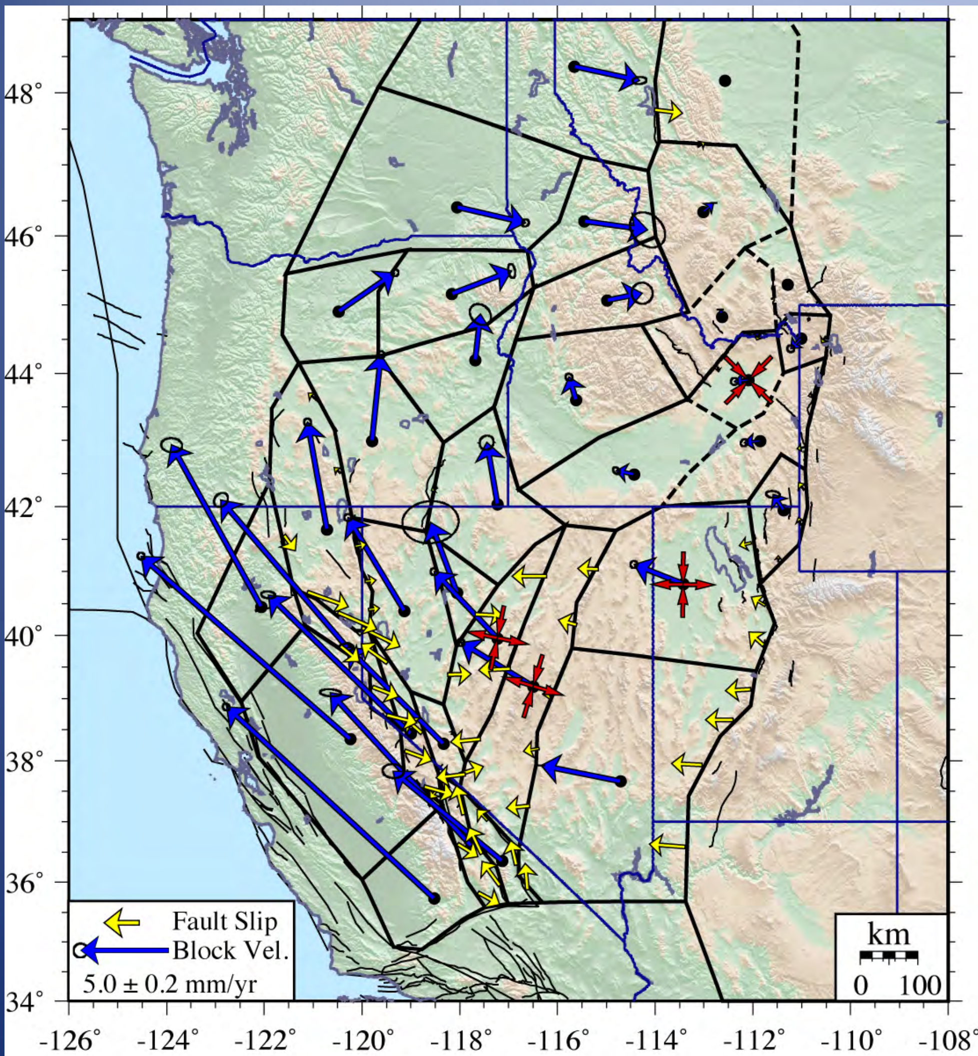
Construct models of Western U.S. deformation
• Microplate tectonic blocks
• Continuum finite element model

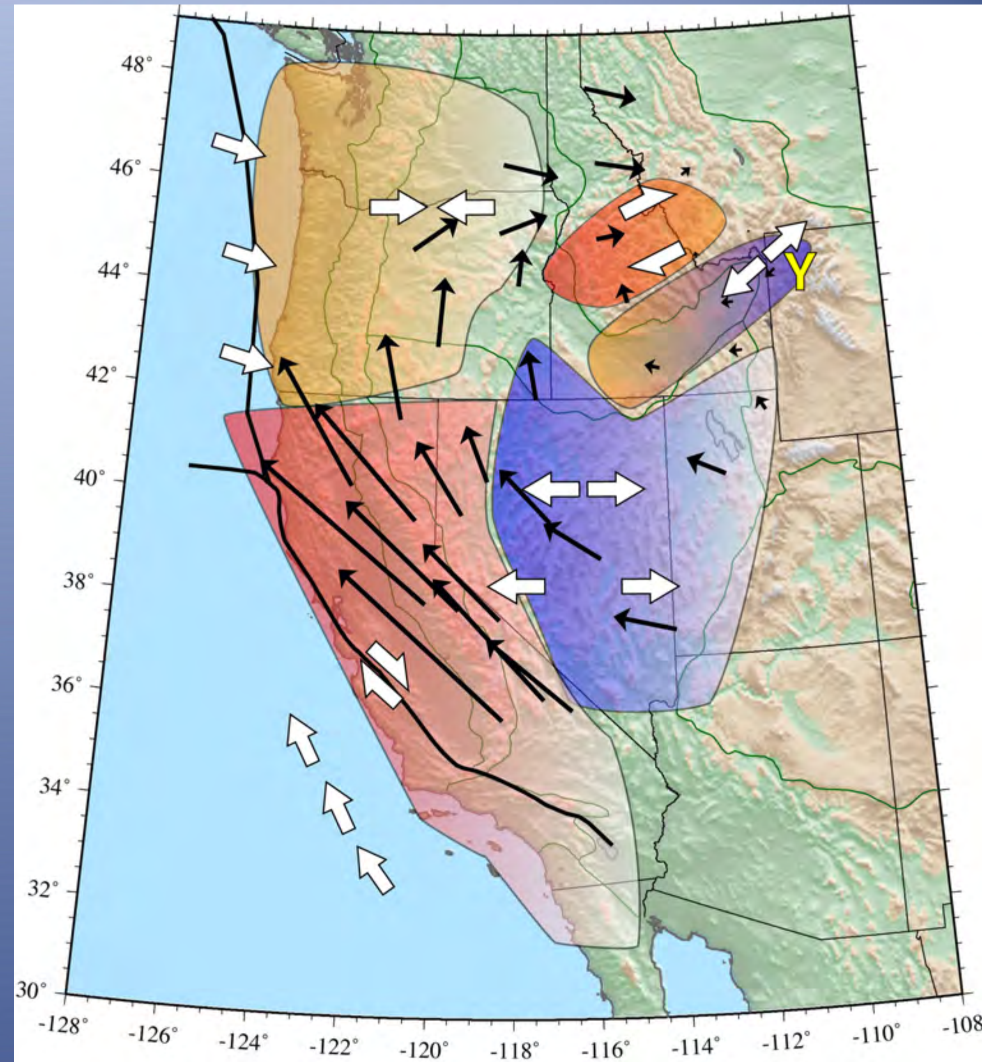




Compile deformation data
• University of Utah GPS data
• Published horizontal GPS vectors
• Fault slip rates

Microplate Tectonics

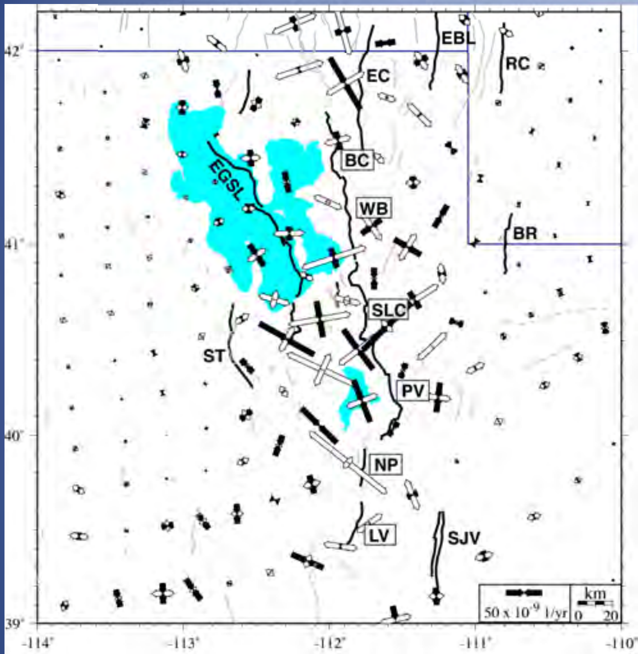


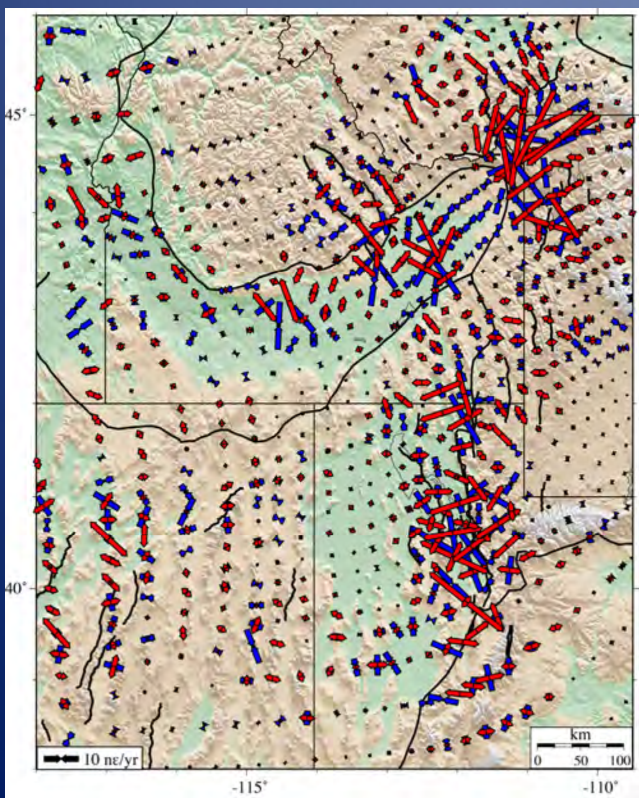


Parameterize western U.S. into microplates

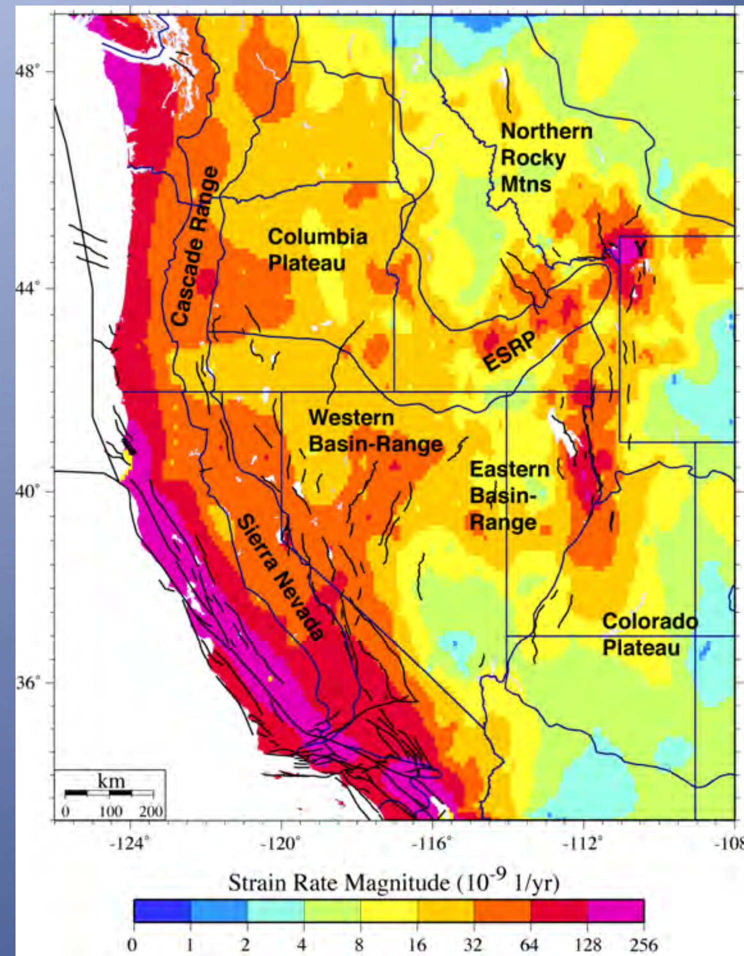
- Resolve clockwise regional rotation
- Westward extension of eastern Basin-Range
- Smaller, complex blocks in western Basin-Range and transition to shear

Distribution of Deformation





Region	Max Magnitude (x 10^{-9} 1/yr)
Yellowstone Plateau	240
Wasatch Front	210
Eastern Basin-Range	14
Northern Rockies	17

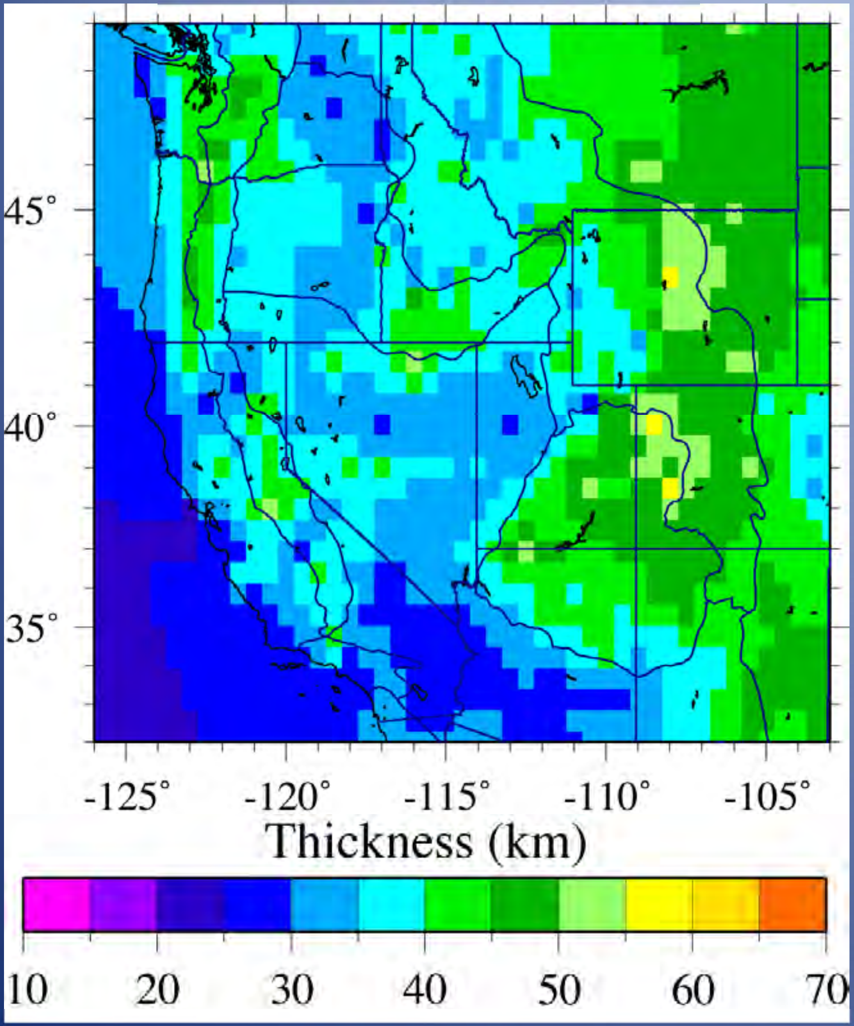


Continuum finite element deformation modeling

- Interpolate strain rate tensors and magnitudes
- Magnitudes reflect seismic belts, tectonic blocks
- Wasatch comparable to Yellowstone Plateau

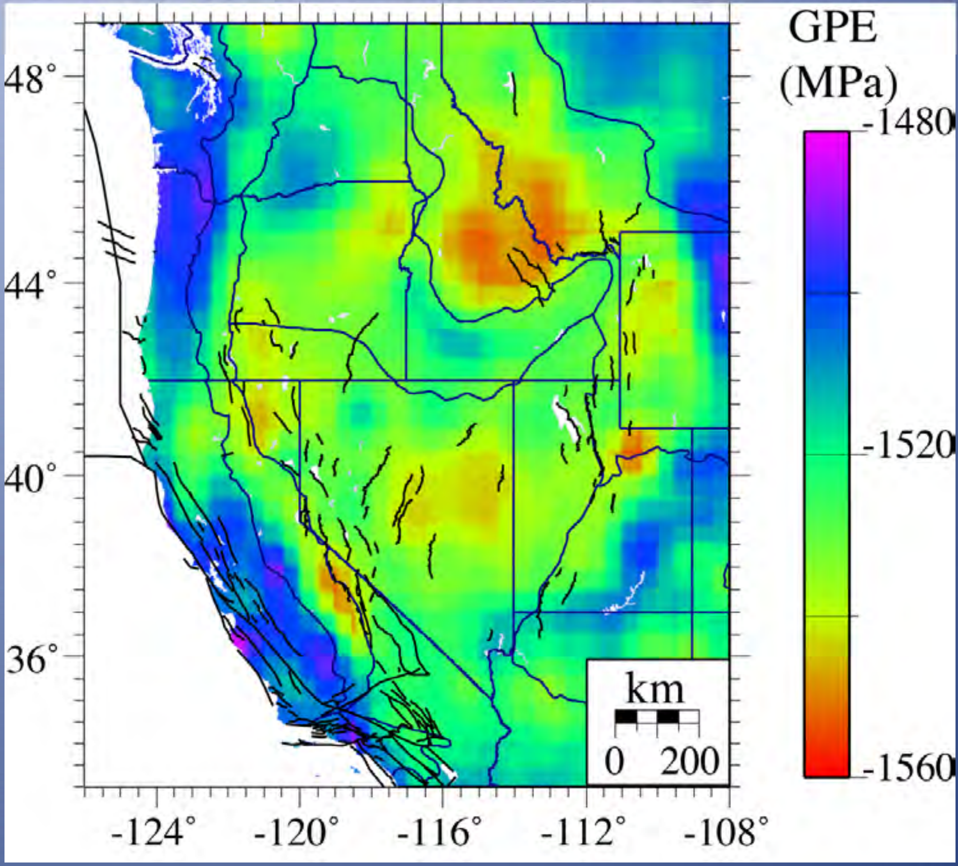
Intraplate Tectonic Stresses

Crustal Thickness



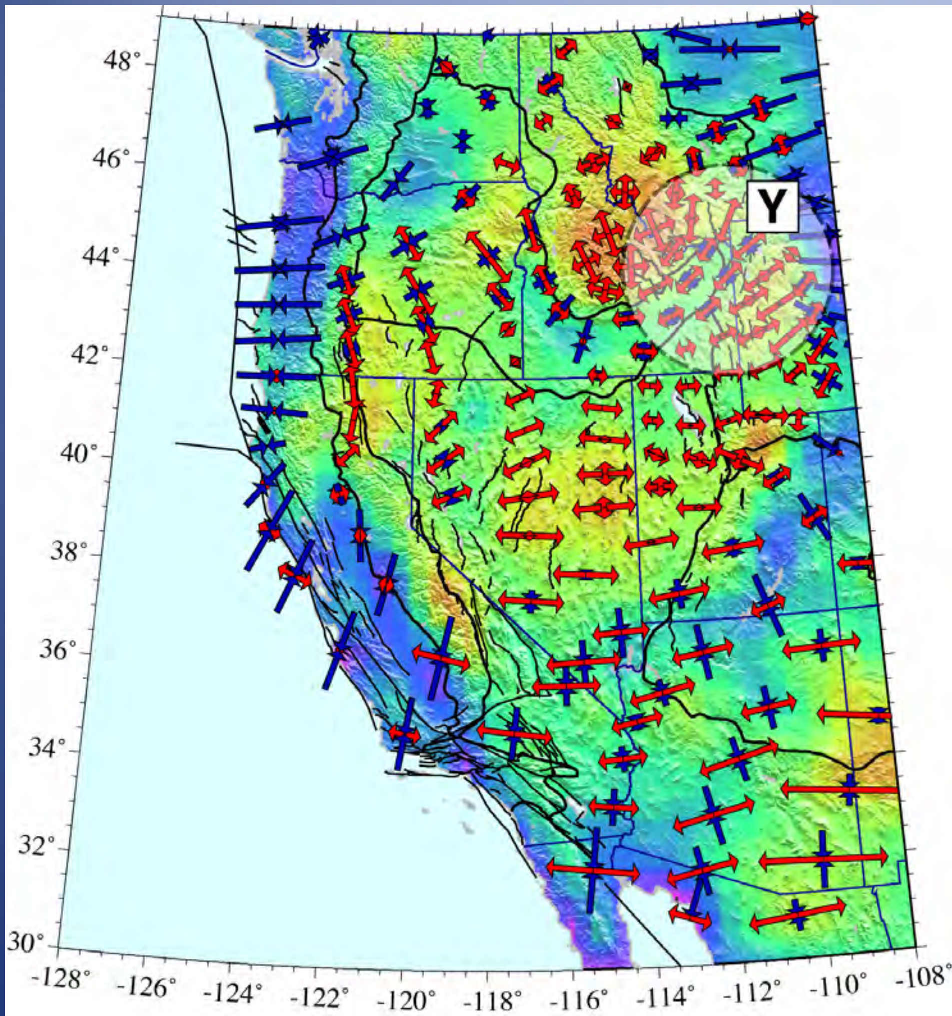
Lithospheric density structure model
- Based on seismic, gravity data
- 0.5° resolution

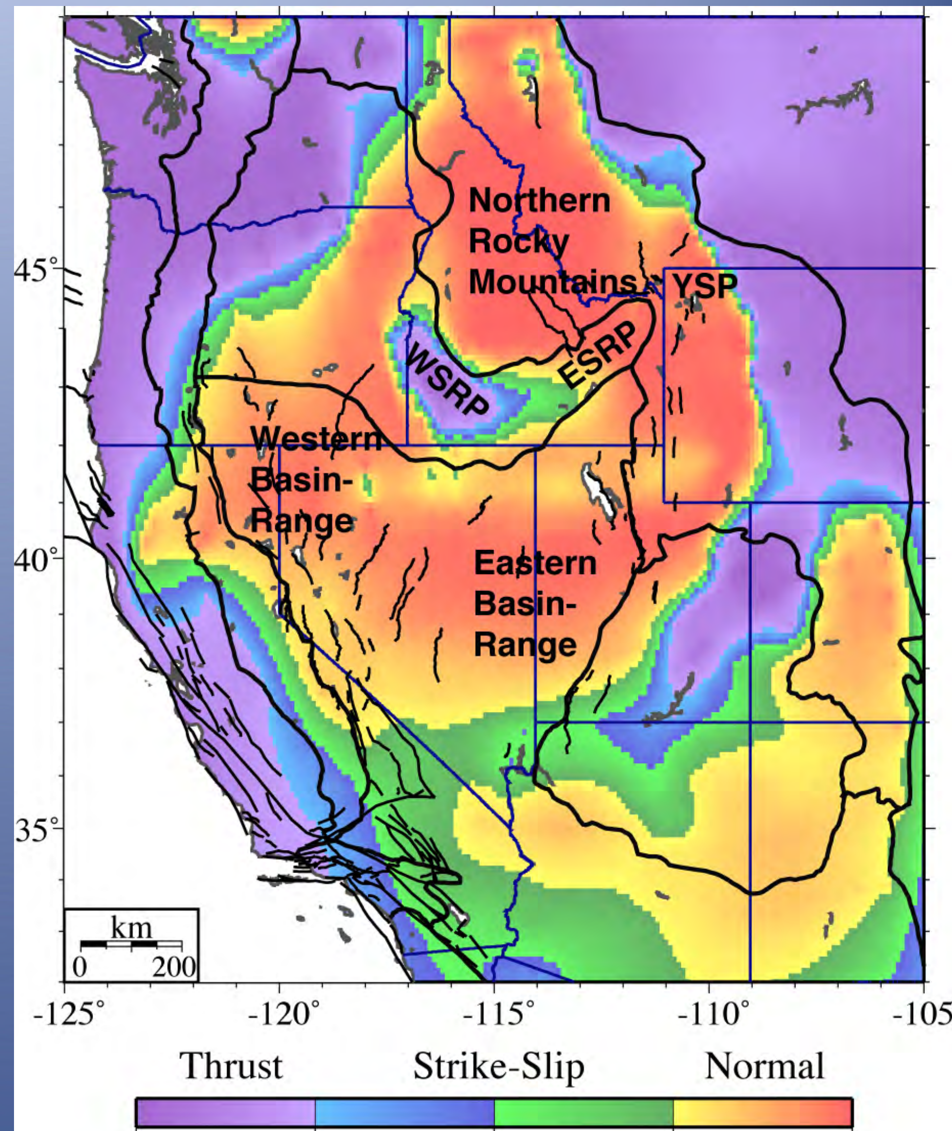
Gravitational Potential Energy (GPE)



GPE obtained from density and topo model
- Depends on elevation, mass
- Directly related to deviatoric stresses
- High GPE for Basin-Range

Predicted Stress and Tectonic Style

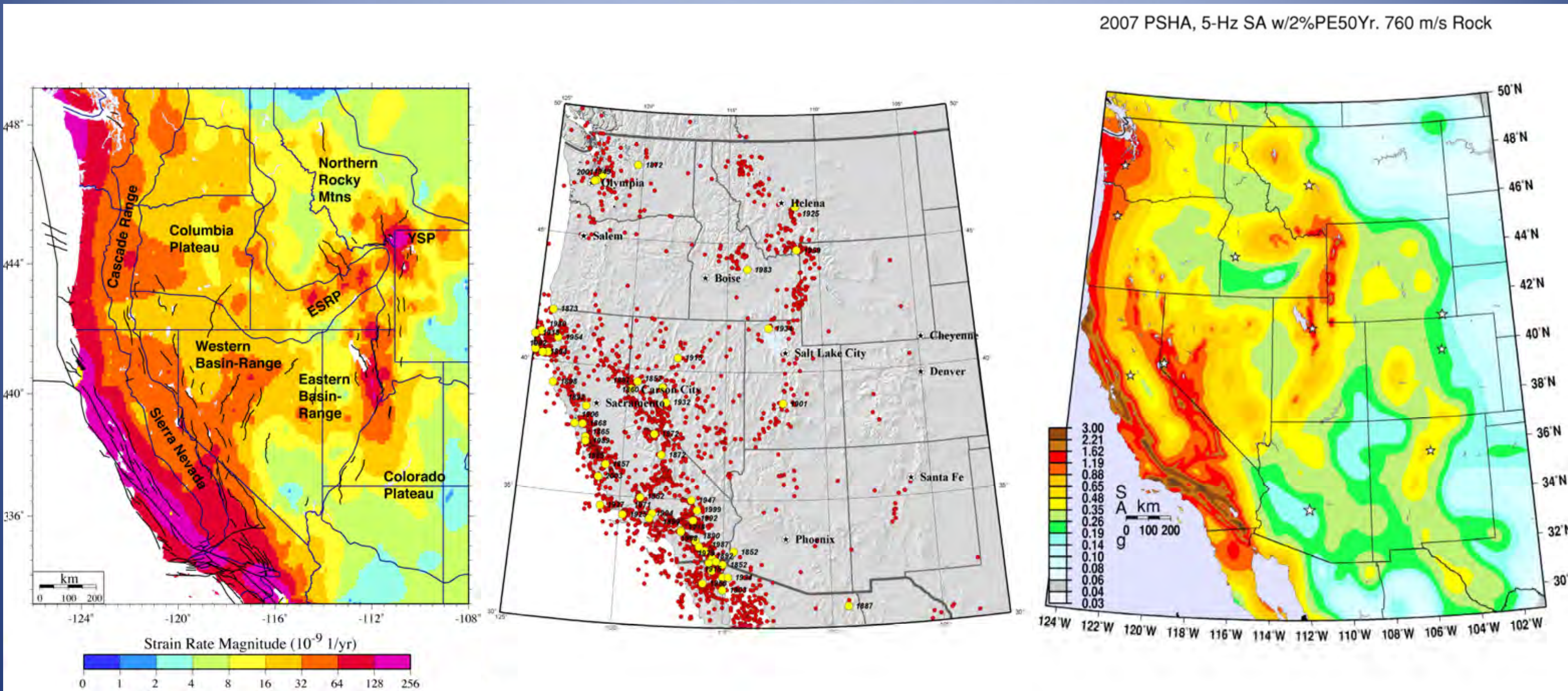




Horizontal principal deviatoric stresses

- Constrained at boundaries by deformation model
- Tensional stresses correlate with high GPE
- Compression and shear at North America plate boundary
- Rotation of maximum stress direction associated with YSRP

Contemporary Deformation and Earthquake Hazards



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 history not well-known

Conclusions

Sources of stresses driving contemporary deformation

- Gravitational collapse: Basin-Range extension
- North America-Pacific-JDF interplate motions: CA shear and Pacific NW compression
- Yellowstone hotspot buoyancy: YSRP, northern Wasatch Front extension

Regional kinematics

- Clockwise rotation of direction of motion
- Accommodated at microplate boundaries defined by active faults, seismicity

Implications for Wasatch fault zone

- High extension rate of 2.4 to 3 mm/yr
  - *20% of total Basin-Range extension rate*
- Total moment rate:
  - 100 time seismic moment rate
  - 2.5-4 times Late Quaternary fault slip rate
- Total loading on Wasatch fault leaves slip deficit of ~2.5 -3 mm/yr
- How is loading integrated into seismic hazard?

Wasatch Fault, Little Cottonwood Canyon

Introduction to Discussion: Issues Regarding the NSHM Generalization of the Salt Lake City Segment (Wasatch Fault) Surface Trace

by

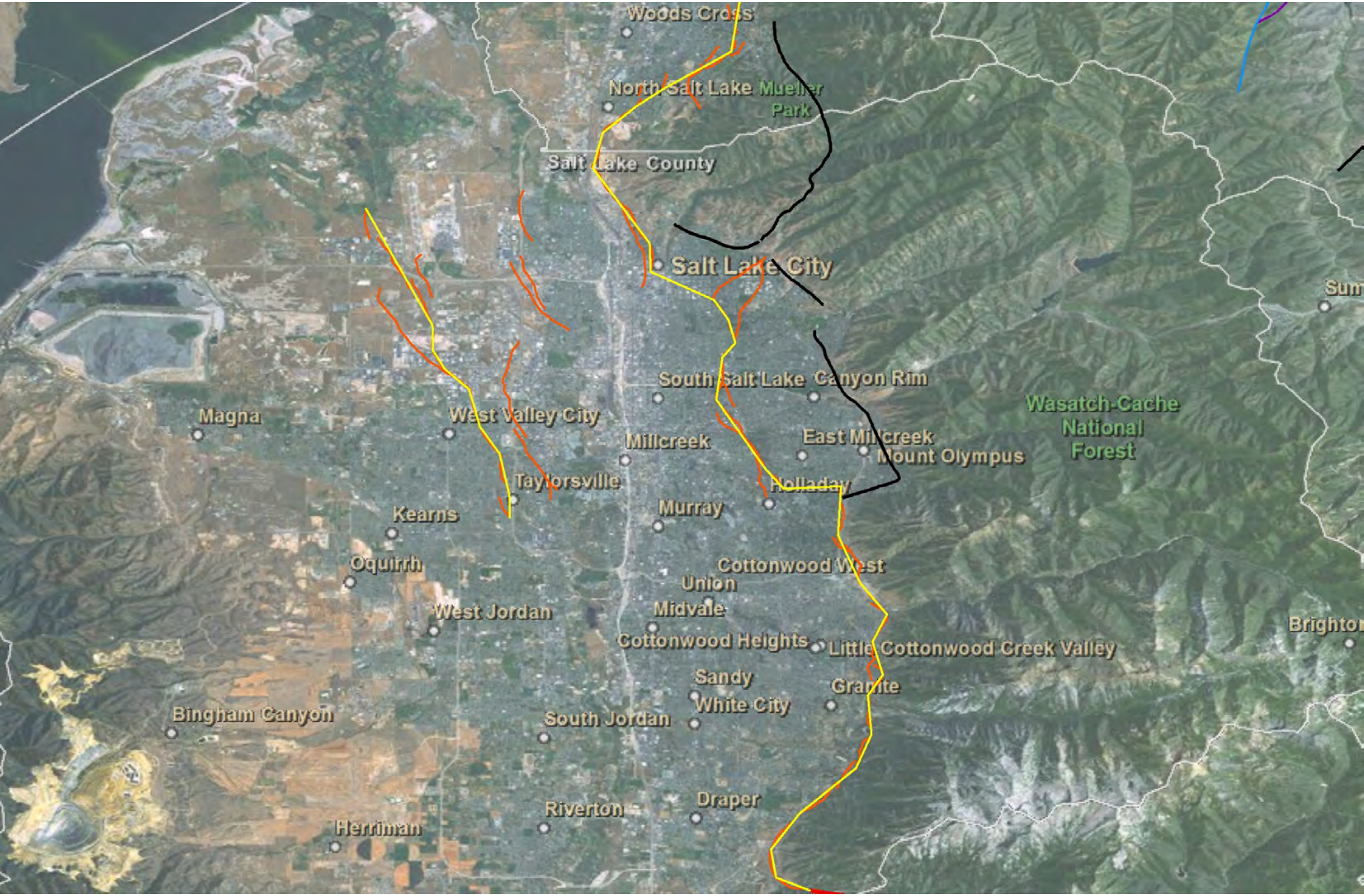
James C. Pechmann
University of Utah Seismograph Stations

Acknowledgments

Ron Bruhn
Dave Dinter
Mike Perkins
University of Utah

Steve Personius
U.S. Geological Survey

Kim Olsen
Harold Magistrale
Daniel Roten
San Diego State University



Mapped fault traces: Orange (post glacial) and Black (Quaternary)
NSHM Generalized faults: Yellow (from Kathy Haller, 2008)

Main Question

1. Should the NSHM generalization of the SLC segment (Wasatch fault) be revised? If so, how?

Related Questions

2. Is it necessary and/or desirable for the fault traces used in the NSHM PSHA calculations to be continuous?

3. Are there subsurface connections across stepovers in normal faults?

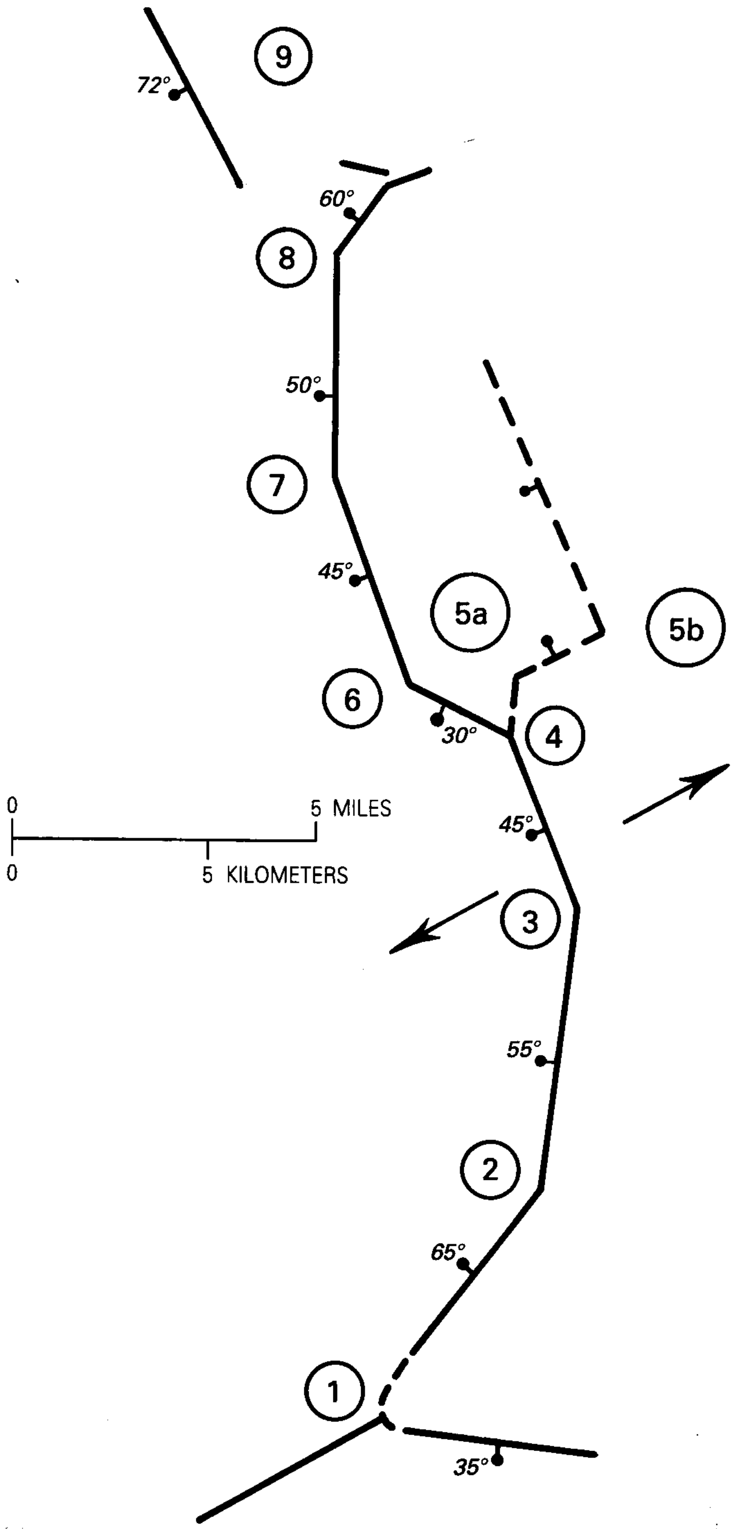
4. What about the NSHM generalizations of the rest of the Wasatch fault—and other normal faults?

Alternative Generalization for SLC Segment (Roten et al., 2008)

- **Why? 3-D model of the SLC segment needed for 3-D numerical ground motion modeling of an M ~7.0 earthquake on this segment.**
- **Basic model is from Bruhn et al. (1992) near surface, transitioning to 50° dip at depth.**
- **We decided to connect the stepovers based on:**

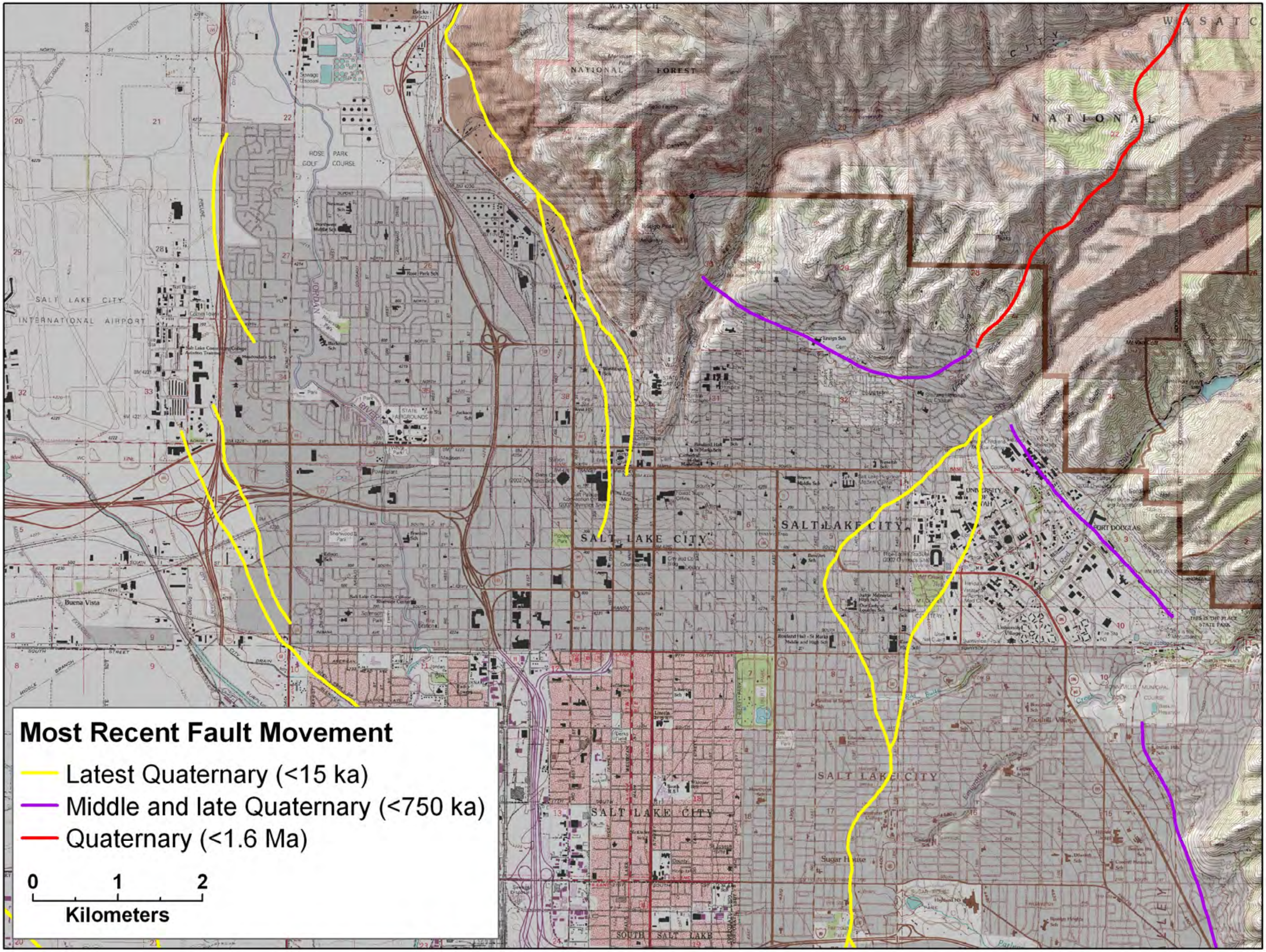
  (1) Mechanical considerations (structural geologists)

  (2) Dynamic rupture considerations (seismologists): Dynamic rupture models do not support rupture jumps across 3- to 5-km fault discontinuities.
- **Counter argument (Quaternary geologists): No evidence for a connection across the northern SLC segment stepover.**

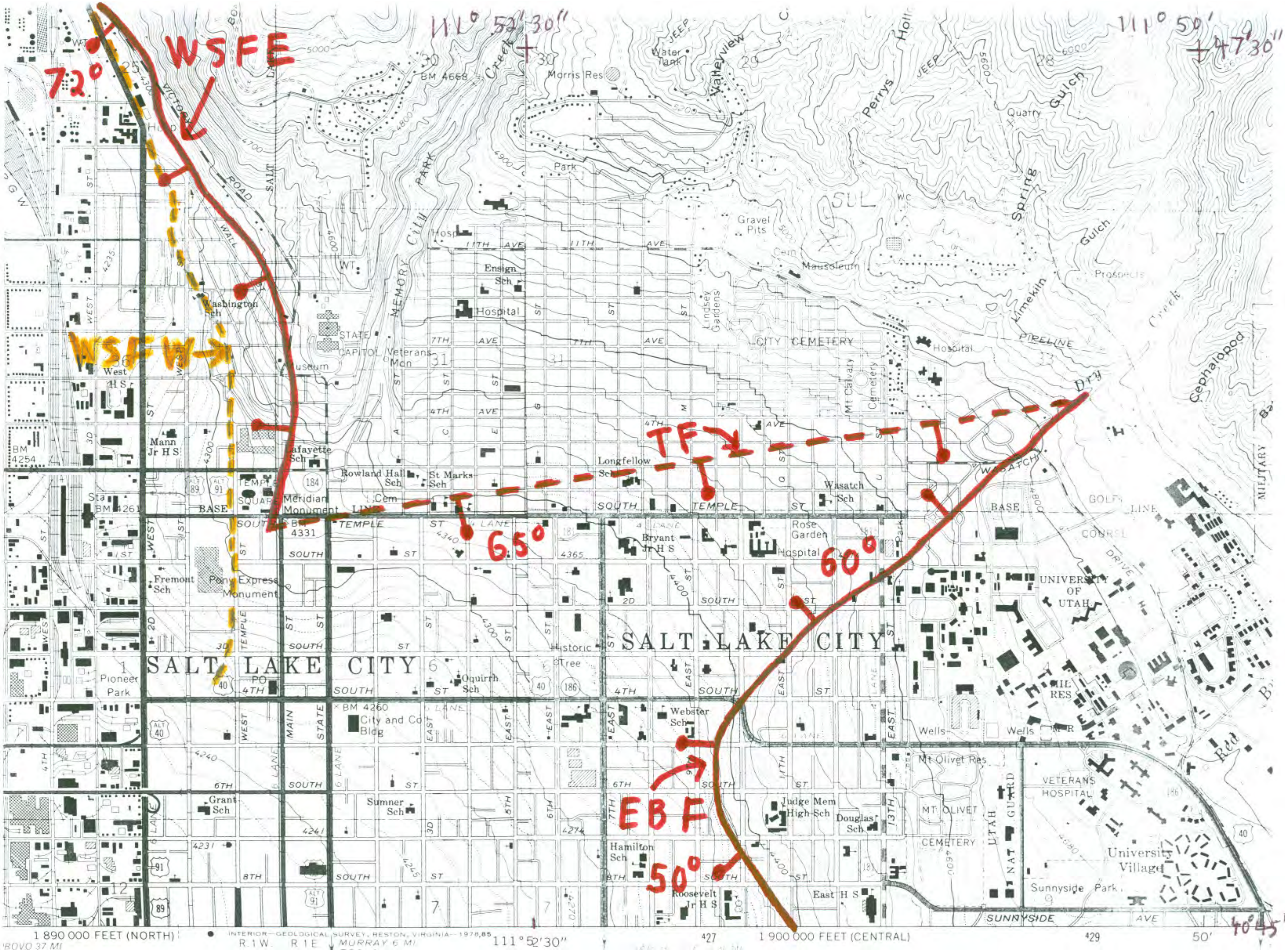


Bruhn et al. (1992) Model

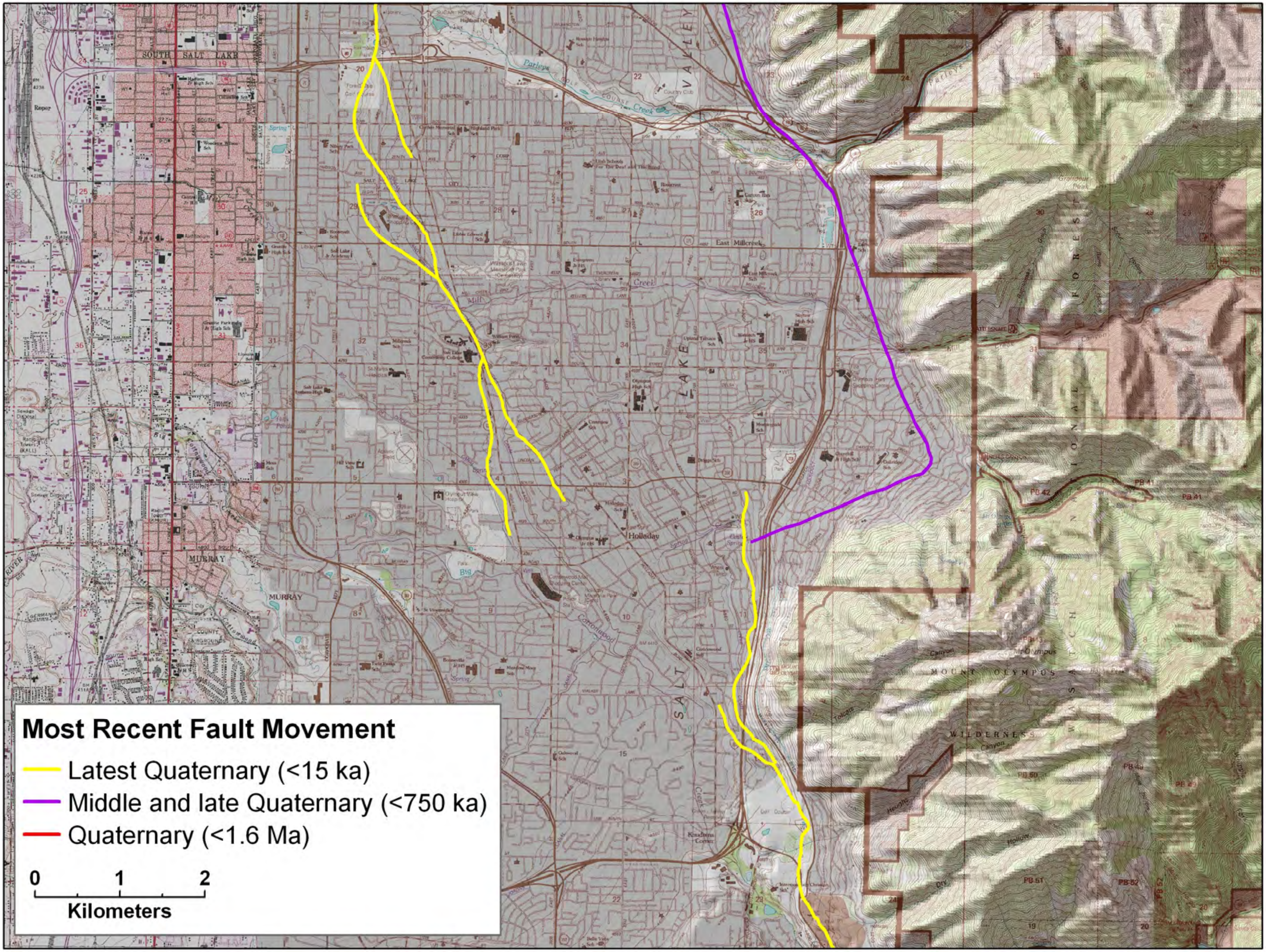
- Based on slickenside and fault surface orientations at N and S ends of the segment
- Slip azimuth = 240°
- Assumes conservative barriers between fault sections with different strikes
- Dips of 35° to 72°; mean ~50°

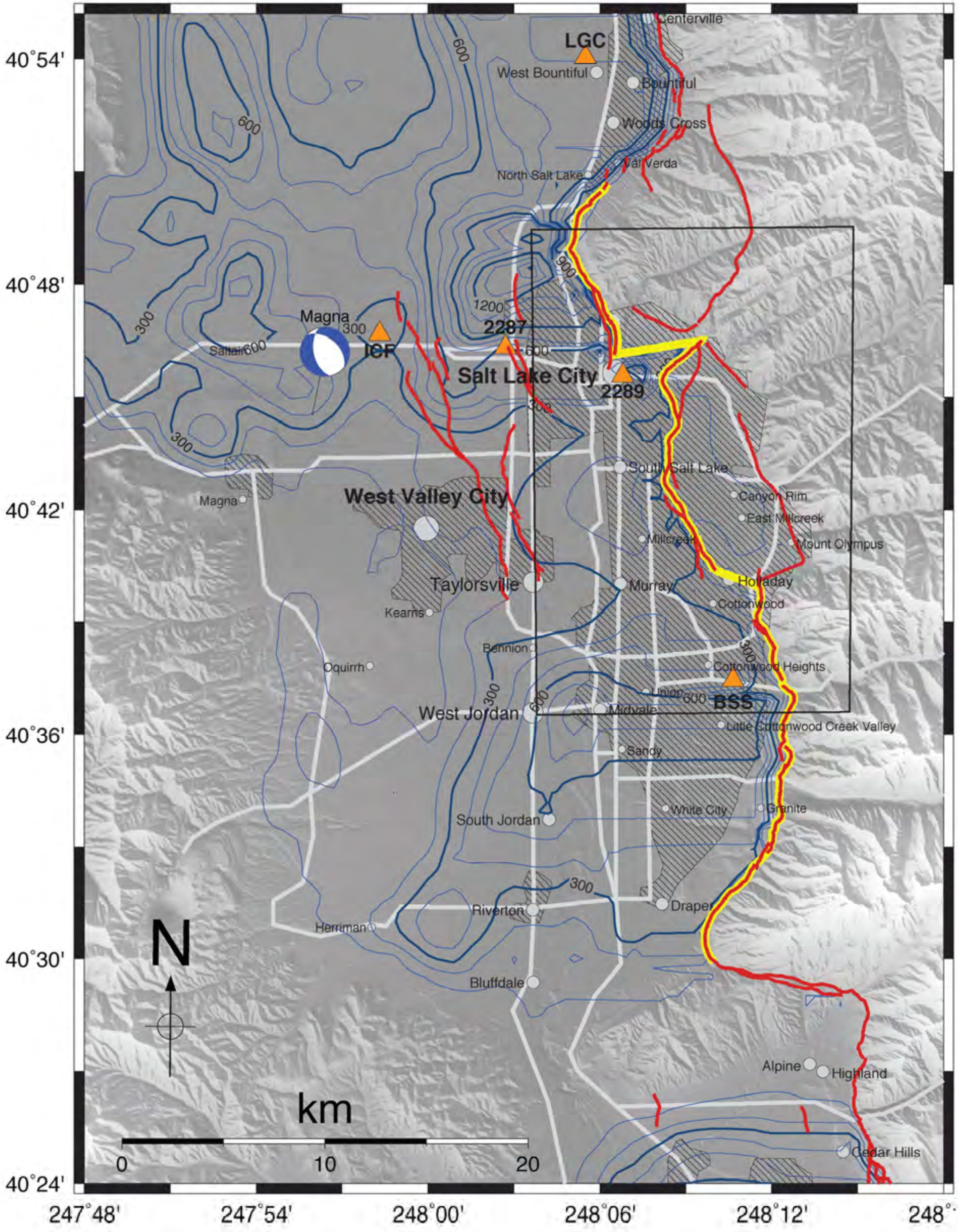


Most Recent Fault Movement
Latest Quaternary (<15 ka)
Middle and late Quaternary (<750 ka)
Quaternary (<1.6 Ma)
0 1 2
Kilometers
SALT LAKE CITY
SALT LAKE CITY INTERNATIONAL AIRPORT
NATIONAL FOREST



111° 52' 30"
111° 50'
47' 30"
WSFE
72°
WSFW
TF
65°
60°
EBF
50°
40° 45'
SALT LAKE CITY
Washington Sch
STATE CAPITOL
Museum
West H S
Mann Jr H S
Lafayette Sch
TEMPLE SQUARE
Meridian Monument
Rowland Hall Sch
St Marks Sch
Longfellow Sch
Bryant Jr H S
Rose Garden
Hospital
Wasatch Sch
UNIVERSITY OF UTAH
GOLF COURSE
CITY CEMETERY
Mausoleum
Gravel Pits
Morris Res
Water Tank
Quarry
Prospects
Perrys Hollow
Spring Gulch
Limekiln Gulch
Cephalopod
Dry Creek
MEMORY PARK
City Creek
Ensign Sch
Hospital
Veterans Mon
Fremont Sch
Pony Express Monument
Pioneer Park
Oquirrh Sch
Historic Tree
City and Co Bldg
Webster Sch
Grant Sch
Sumner Sch
Hamilton Sch
Roosevelt Jr H S
Judge Mem High Sch
Douglas Sch
East H S
Mt Olivet Res
MT OLIVET CEMETERY
VETERANS HOSPITAL
UTAH NAT GUARD
University Village
Sunnyside Park
MIL RES
Wells
SUNNYSIDE AVE
BASE LINE
SOUTH TEMPLE ST
1 890 000 FEET (NORTH)
1 900 000 FEET (CENTRAL)
INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1978,85
R 1 W. R 1 E
MURRAY 6 MI
PROVO 37 MI
111° 52'30"
427
429
50'


Most Recent Fault Movement
Latest Quaternary (<15 ka)
Middle and late Quaternary (<750 ka)
Quaternary (<1.6 Ma)
0 1 2
Kilometers



Roten et al. (2008) Model

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4. **What about the NSHM generalizations of the rest of the Wasatch fault—and other normal faults?**

WEST VALLEY FAULT ZONE
PART 1

The
“WVFZ Problem”
and
Why It Is An Issue
For The
National Seismic Hazard Maps

(or)

Everything Should Be As Simple As Possible But Not Simpler

Albert Einstein
(Calaprice, 2000)

THE PROBLEM BRIEFLY STATED

(paraphrasing Mark Petersen – September 2008)

How to treat the WVFZ on the NSHMs?

Our [USGS] calculations show that the WVFZ contributes almost equally with the WFZ to the ground shaking hazard at sites on the hanging wall of the WVFZ, resulting in a spike in the short-period hazard in downtown Salt Lake City.

This level of hazard is controversial to many regional geologists and hydrologists, and **we need to have a discussion** on whether or not to make a change in the map before engineers vote on the final maps for the building code in two weeks time.

The discussion produced one long conference call, and approximately 30 emails (several long and involved with attached maps, figures, graphs, and equations) from the various discussion participants.

And then at the end Mark said:

"Bill, I think you should write down the ideas expressed over the past two weeks and discuss them at the Quaternary Fault Parameter Working Group Meeting in February."

To which Bill replied

Right Mark, you betcha

So
In Approximate Chronological Order
Here Are The Questions/Issues Surfaced
During The WVFZ Discussion

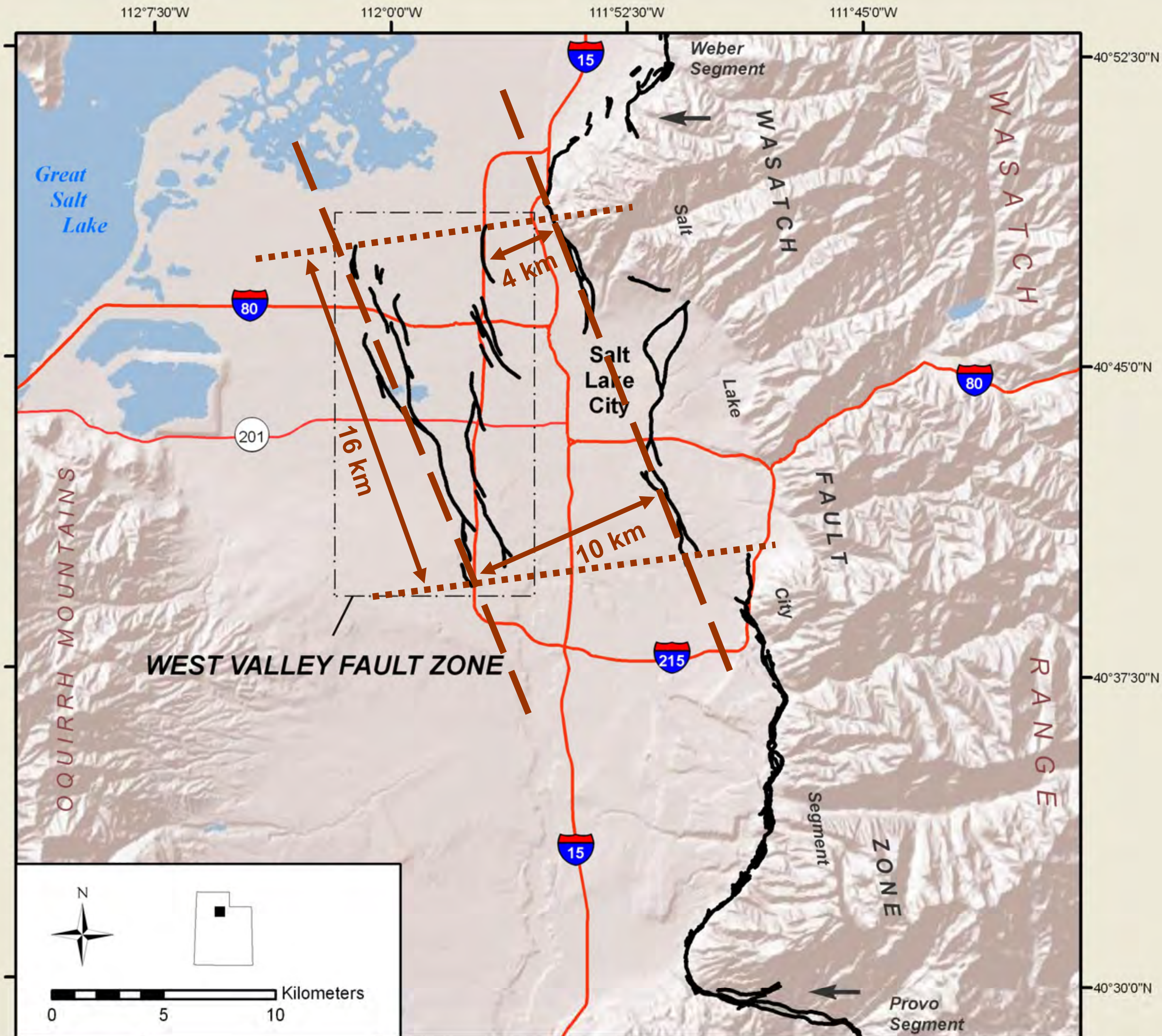
- What kind of fault model (independent, simultaneous, clustered) best describes the relation between the WVFZ and the WFZ, and what are the parameters for that model?
- If the WVFZ does rupture simultaneously with the WFZ, how much, if any, moment does it contribute to ground shaking; are there good models /examples of coseismic rupture of a master and associated antithetic fault?
- Is the Granger fault or the Taylorsville fault the “master” WV fault, and what is the relation between them at depth?
- How far away is the surface trace of the Granger fault from the surface trace of the Salt Lake City segment of the WFZ really?

- Are the surface traces of the Granger, Taylorsville, and the Salt Lake City segment of the WFZ as currently shown on the NSHMs too generalized?
- What are the dip angles of the WVFZ and WFZ, and at what depth do the two faults intersect, if at all?
- How well constrained are the WVFZ recurrence-interval data?
- How well constrained are the WVFZ slip-rate data?
- How well constrained is the WVFZ slip per event data?
- What is the magnitude of a characteristic WVFZ earthquake, and what is the average displacement during a characteristic event?

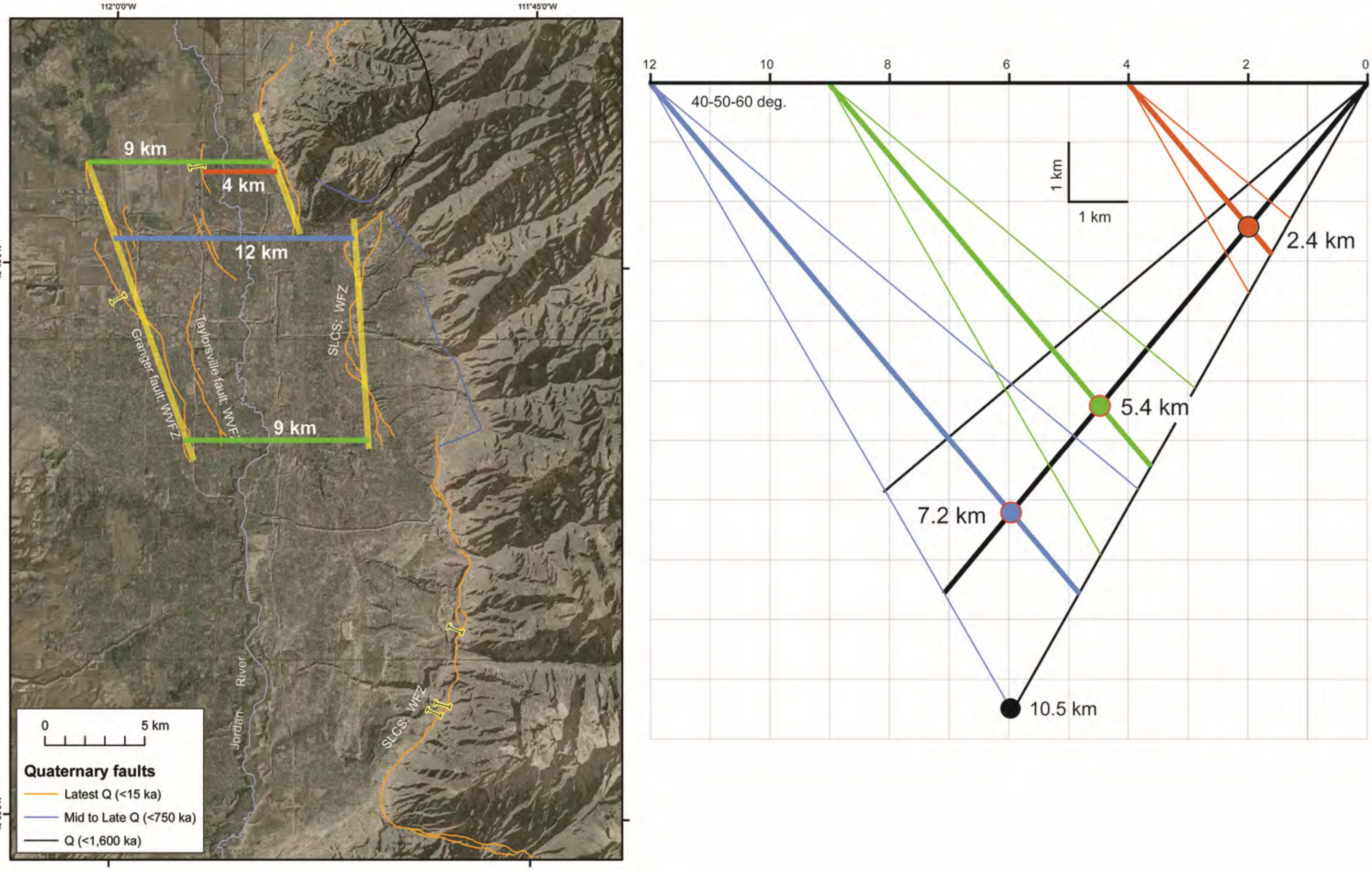
- Is there a significant component of aseismic slip on the WVFZ?
- Is the WVFZ just an aseismic manifestation of half graben formation on a listric WFZ?
- What new data are needed to improve the WVFZ model?
- What about the other potentially active master/antithetic fault pairs in Utah/Basin and Range – how should they be handled on the NSHMs?

West Valley Fault Zone

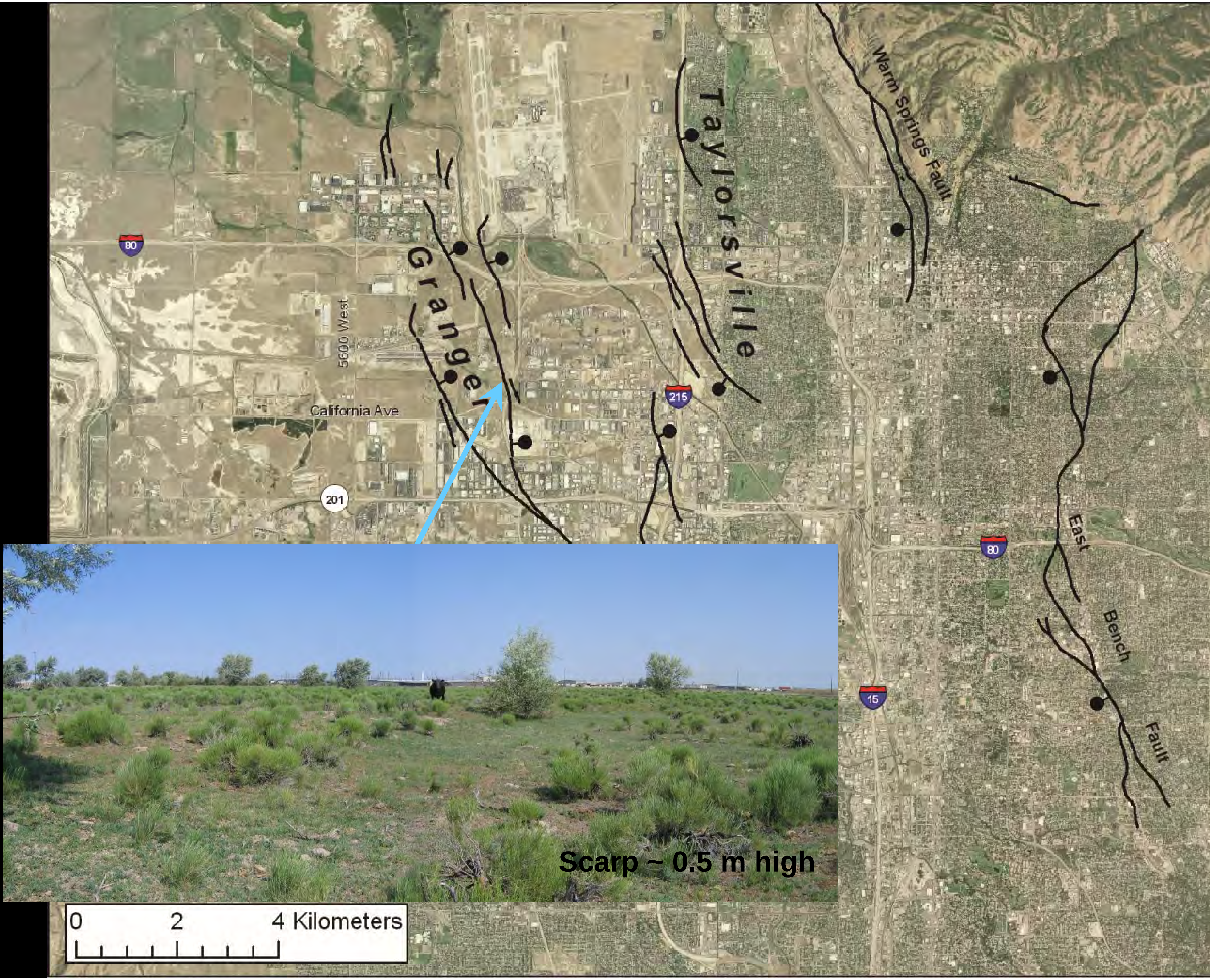
Geologic Overview and
Summary of Paleoseismic Studies



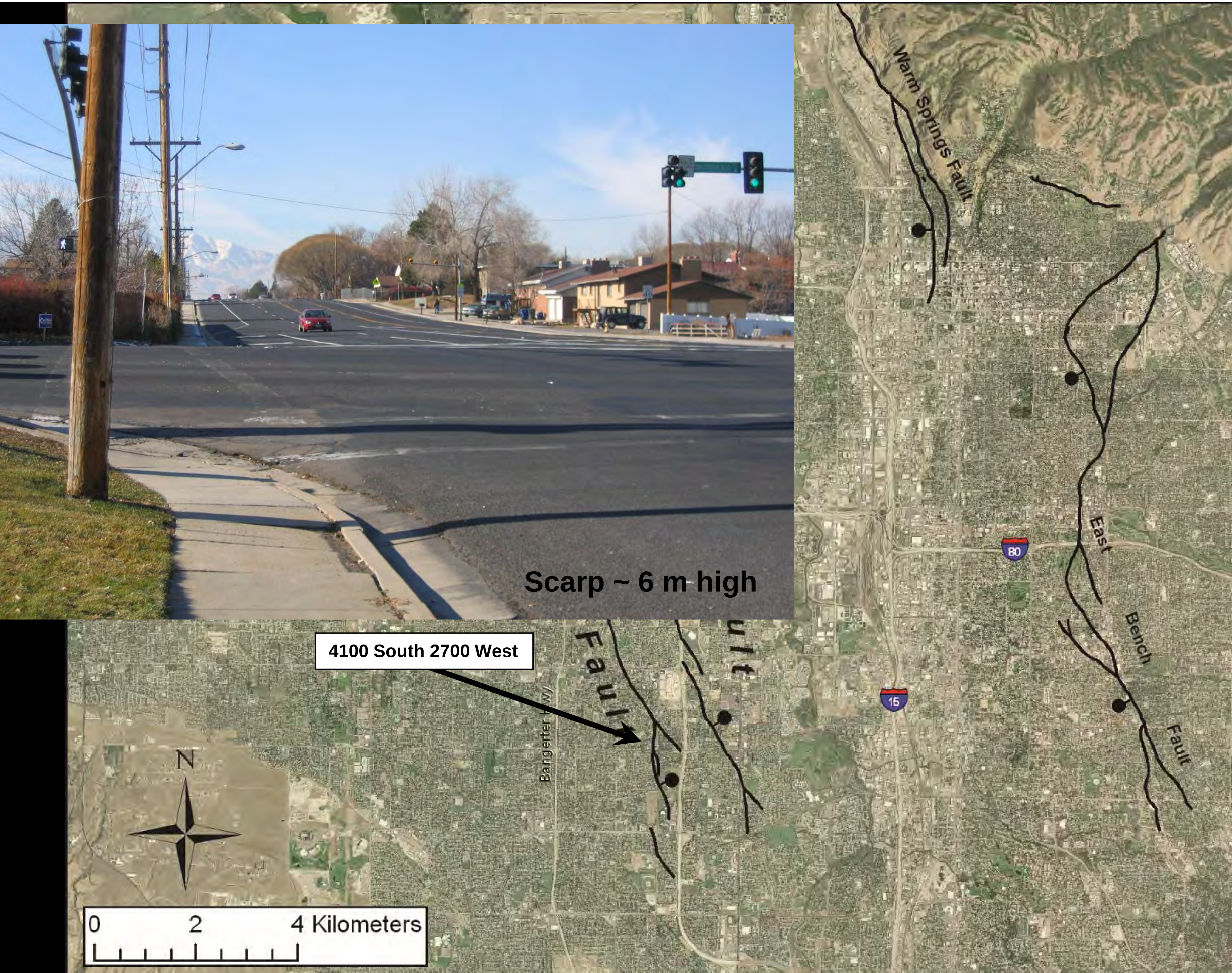
112°7'30"W
112°0'0"W
111°52'30"W
111°45'0"W
40°52'30"N
40°45'0"N
40°37'30"N
40°30'0"N
Great Salt Lake
Weber Segment
WASATCH
WASATCH
Salt
Lake
City
Salt Lake City
4 km
16 km
10 km
80
80
15
15
201
215
OQUIRRH MOUNTAINS
WEST VALLEY FAULT ZONE
FAULT
ZONE
Segment
RANGE
Provo Segment
N
Kilometers
0
5
10

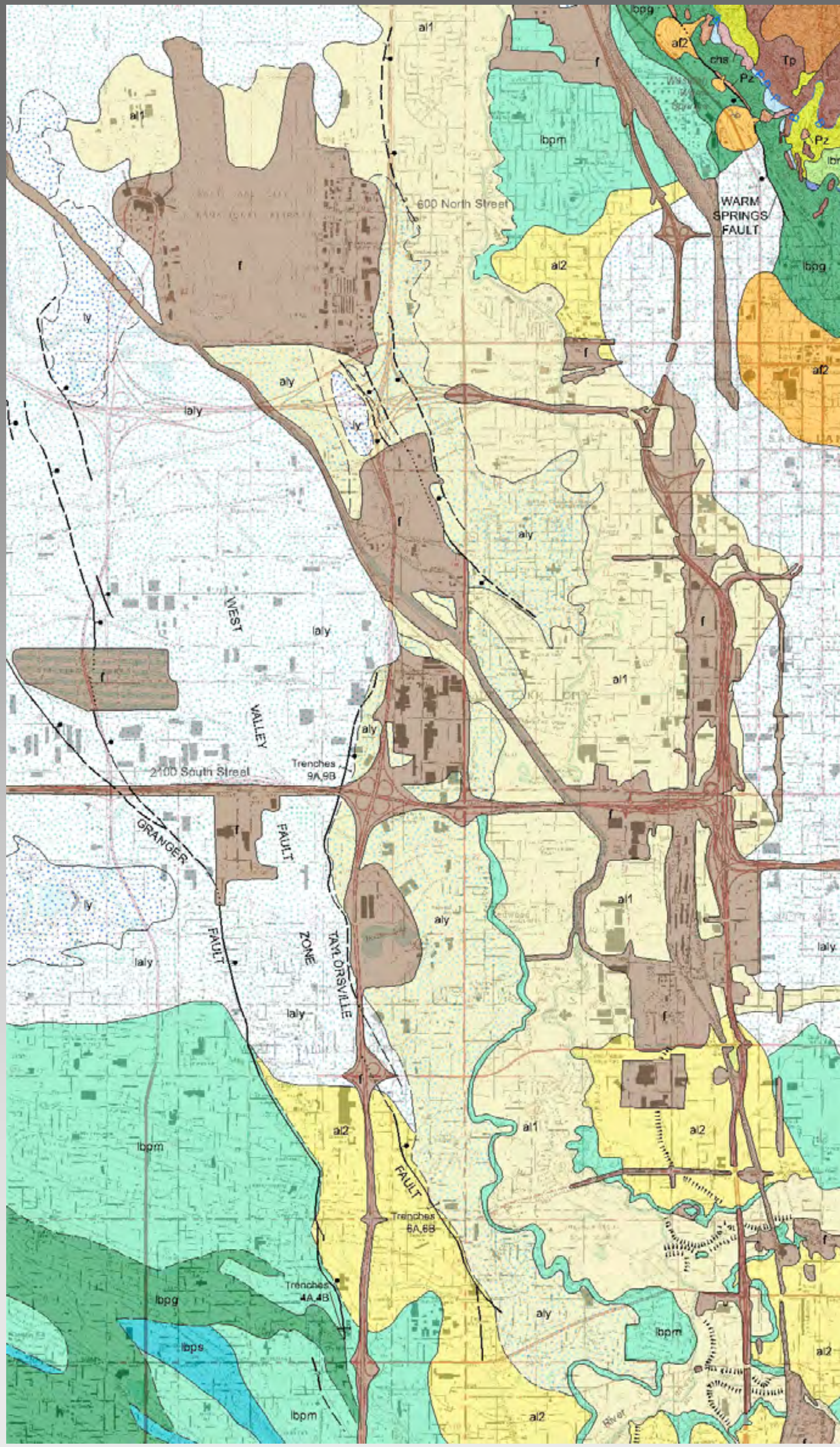


112°0'0"W
111°45'0"W
40°45'0"N
40°30'0"N
9 km
4 km
12 km
9 km
Granger fault: WVFZ
Taylorsville fault: WVFZ
SLCS: WFZ
Jordan River
SLCS: WFZ
0
5 km
Quaternary faults
Latest Q (<15 ka)
Mid to Late Q (<750 ka)
Q (<1,600 ka)
12
10
8
6
4
2
0
40-50-60 deg.
1 km
1 km
2.4 km
5.4 km
7.2 km
10.5 km



Warm Springs Fault
Taylorsville
Granger
5600 West
California Ave
80
215
201
East
Bench
Fault
80
15
Scarp ~ 0.5 m high
0
2
4 Kilometers


Warm Springs Fault
East
Bench
Fault
80
15
Scarp ~ 6 m high
4100 South 2700 West
N
0
2
4 Kilometers



MAP UNITS

f Manmade fill (historical)

Alluvial Deposits

al1 Stream alluvium 1 (upper Holocene)

al2 Stream alluvium 2 (middle Holocene to uppermost Pleistocene)

aly Younger stream alluvium, undivided (Holocene to uppermost Pleistocene)

Lacustrine Deposits

ly Marsh and lacustrine deposits (Holocene to uppermost Pleistocene)

laly Lacustrine, marsh, and alluvial deposits (Holocene to uppermost Pleistocene)

lbpg Lacustrine sand and gravel, undivided (upper Pleistocene)

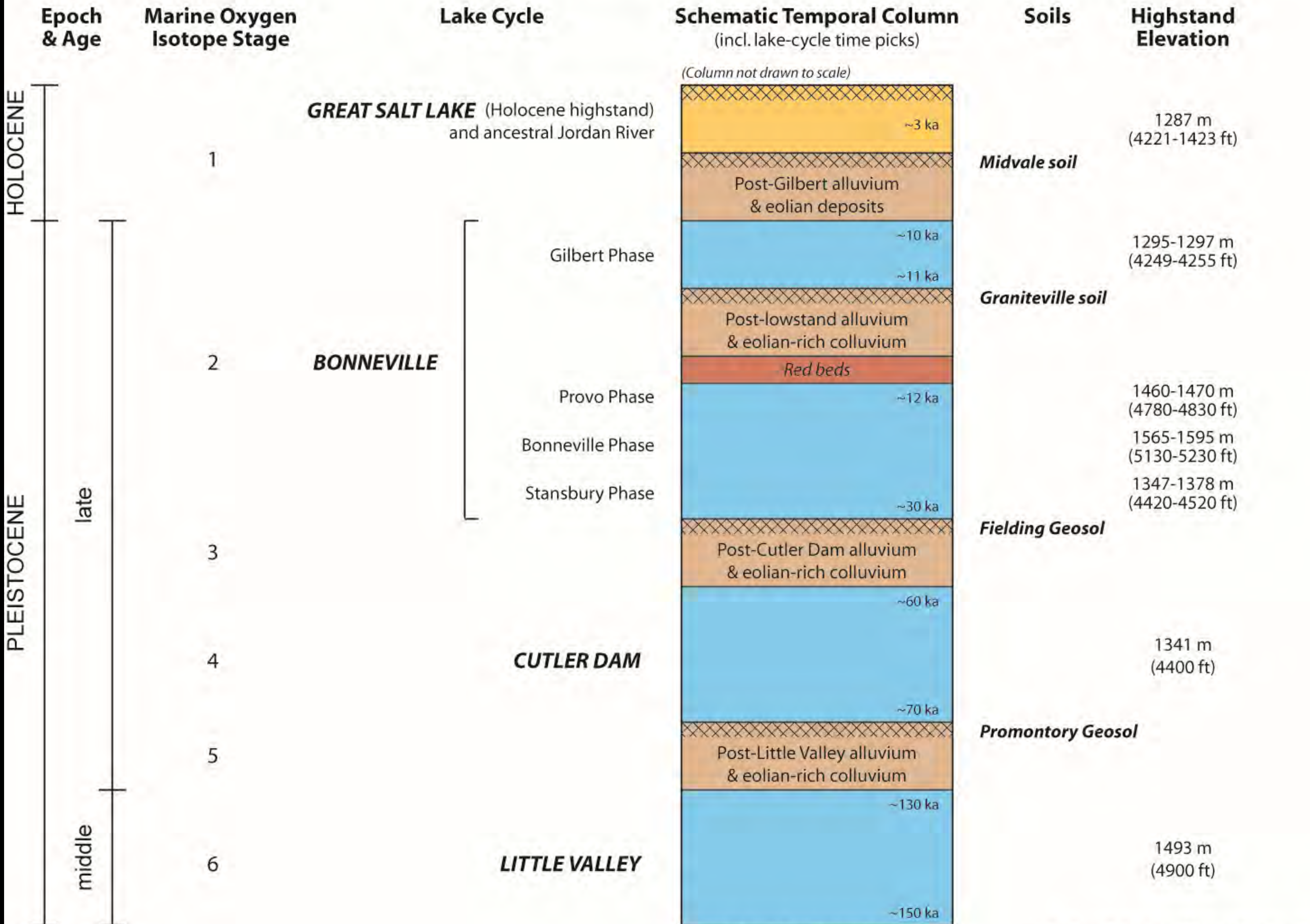
lbps Lacustrine sand, undivided (upper Pleistocene)

lbpm Lacustrine clay and silt, undivided (upper Pleistocene)

From Personius and Scott (1992)

Generalized Late Quaternary Stratigraphy of Northern Salt Lake Valley

(modified from Keaton and Currey, 1989)



Time picks from TL ages (Little Valley and Cutler Dam) and uncalibrated ^{14}C yr B.P. (Bonneville and Great Salt Lake)

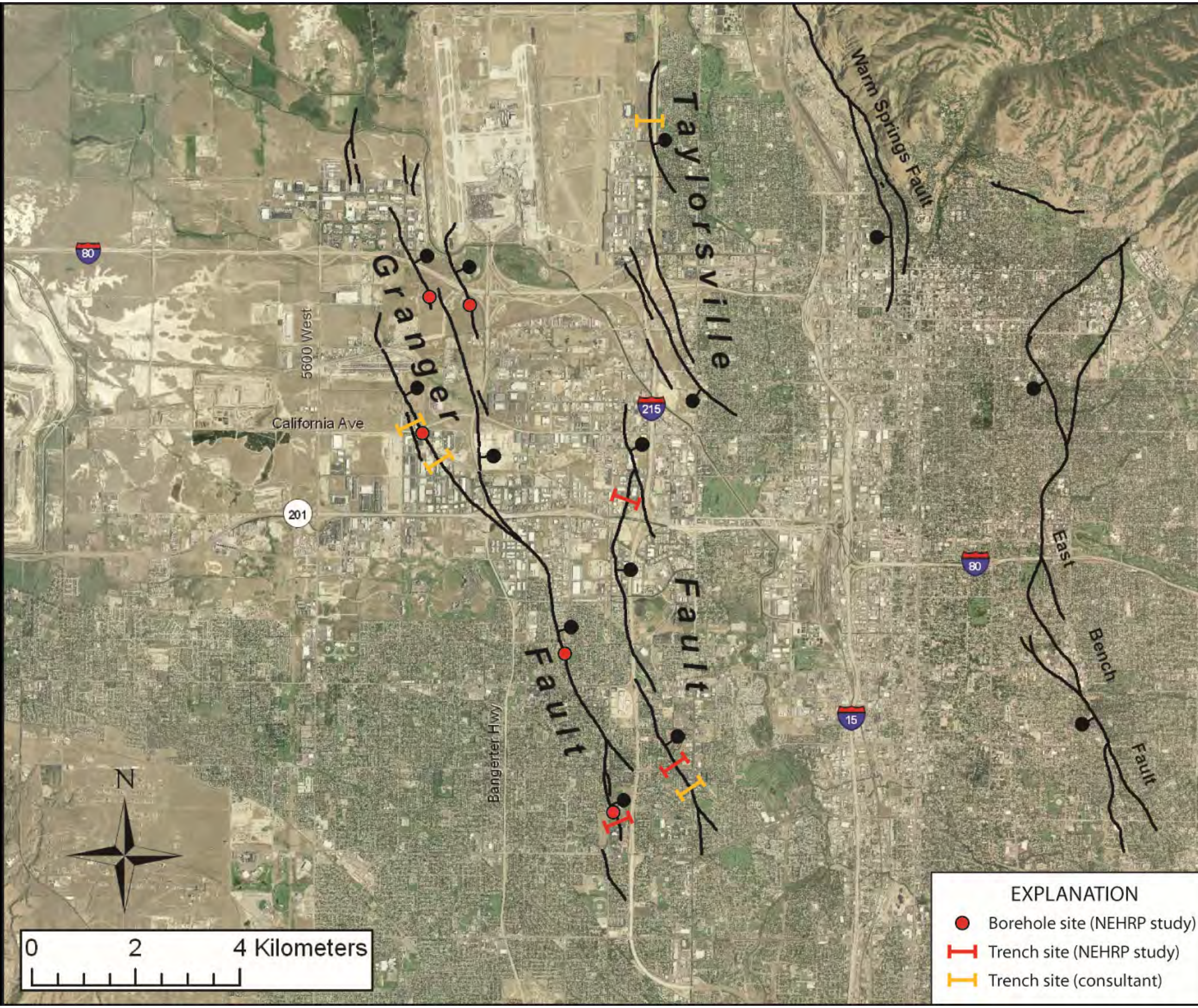
For Great Salt Lake and Bonneville lake cycles, elevations are for shoreline features in vicinity of Salt Lake Valley

Previous NEHRP Studies

1. Keaton, Currey, and Olig (1987)
2. Keaton and Currey (1989)

Methods of Investigation

- Trenches
  - 6 excavated (4 on Taylorsville fault, 2 on Granger fault)
  - max. depth 2 – 4 m (typ. 2 – 3 m; limited by shallow ground water)
  - disturbed near-surface soils and fill common
- Boreholes
  - 34 drilled, all on Granger fault
  - depth range 3 – 18 m
  - continuous sampling (tube, split-spoon)
  - marker-bed offset determined from horizontal projection (10 – 100 m) and trend surface analysis
- Scarp mapping and geomorphic analysis
  - historical aerial photos and topographic maps

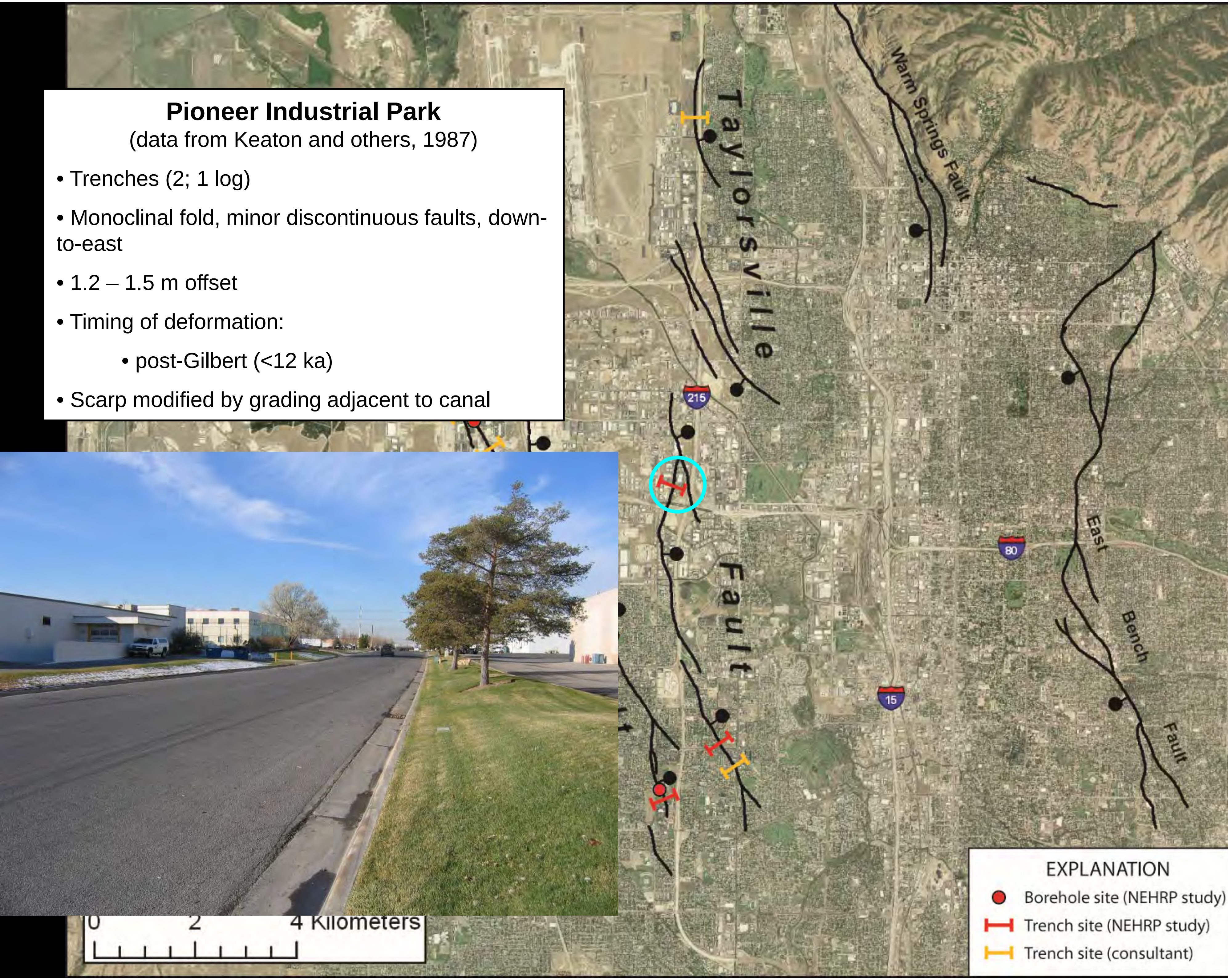


Taylorsville Fault
Granger Fault
Warm Springs Fault
East Bench Fault
80
215
15
201
5600 West
California Ave
Bangerter Hwy
N
0 2 4 Kilometers
EXPLANATION
Borehole site (NEHRP study)
Trench site (NEHRP study)
Trench site (consultant)

Pioneer Industrial Park

(data from Keaton and others, 1987)

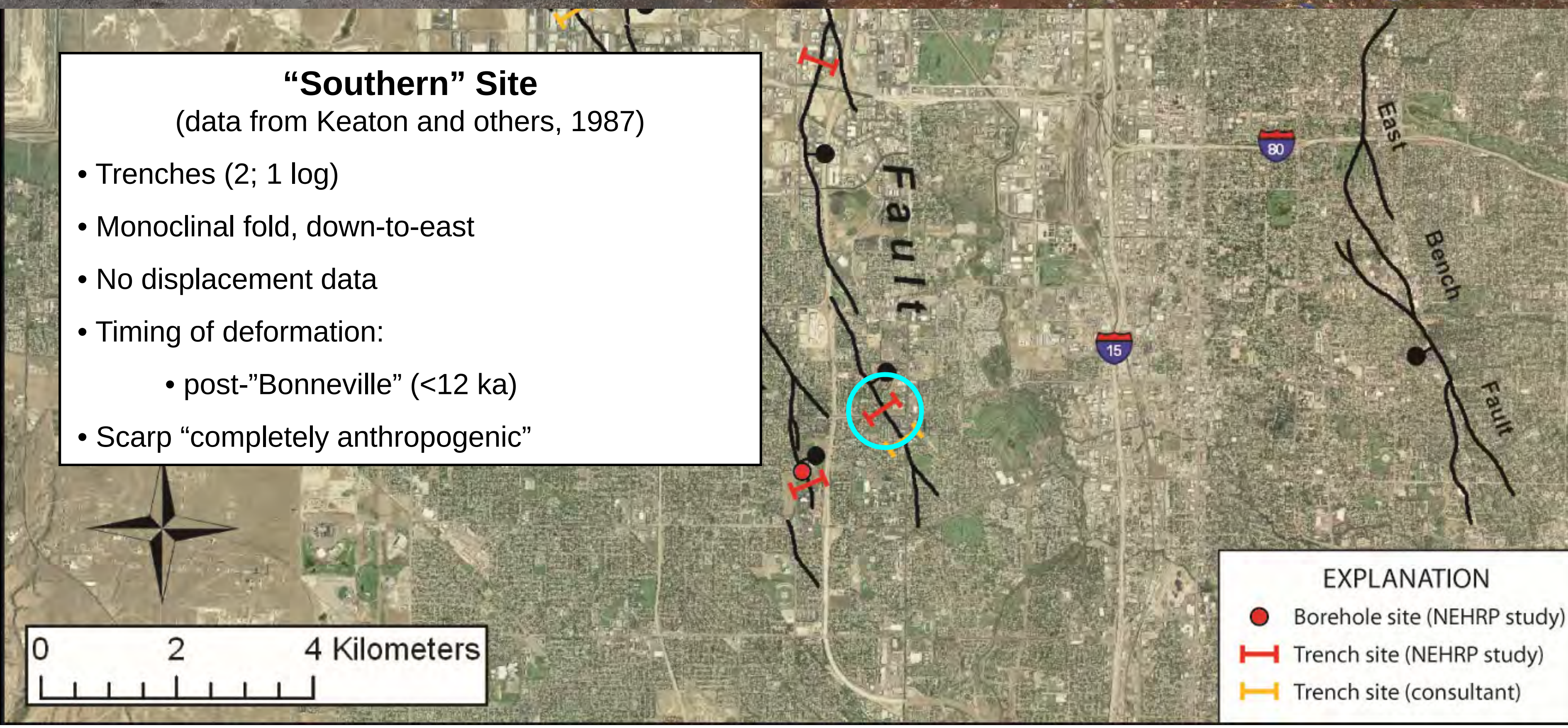
- Trenches (2; 1 log)
- Monoclinal fold, minor discontinuous faults, down-to-east
- 1.2 – 1.5 m offset
- Timing of deformation:
  - post-Gilbert (<12 ka)
- Scarp modified by grading adjacent to canal



“Southern” Site

(data from Keaton and others, 1987)

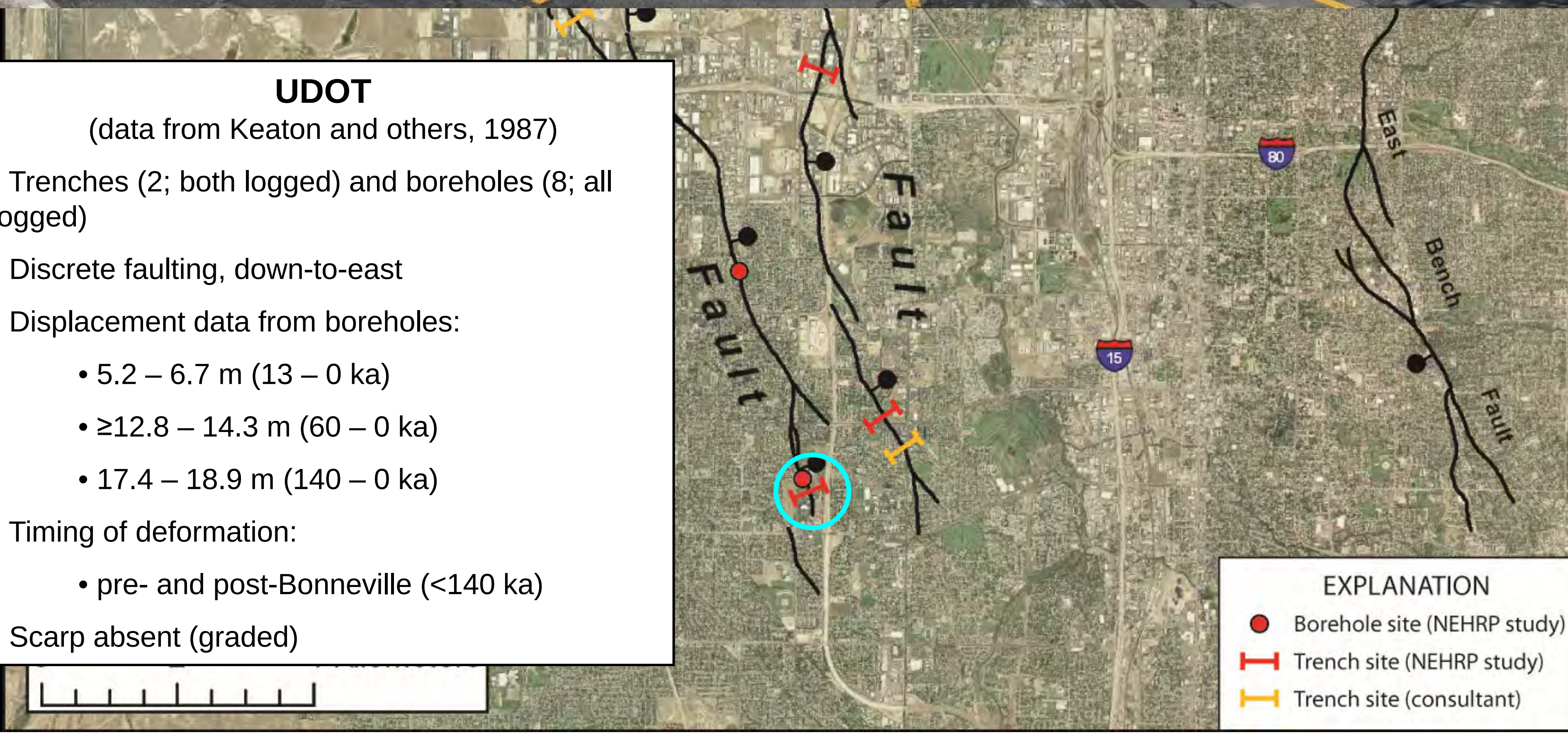
- Trenches (2; 1 log)
- Monoclinal fold, down-to-east
- No displacement data
- Timing of deformation:
  - post-”Bonneville” (<12 ka)
- Scarp “completely anthropogenic”



UDOT

(data from Keaton and others, 1987)

- Trenches (2; both logged) and boreholes (8; all logged)
- Discrete faulting, down-to-east
- Displacement data from boreholes:
    - 5.2 – 6.7 m (13 – 0 ka)
    - ≥12.8 – 14.3 m (60 – 0 ka)
    - 17.4 – 18.9 m (140 – 0 ka)
- Timing of deformation:
    - pre- and post-Bonneville (<140 ka)
- Scarp absent (graded)



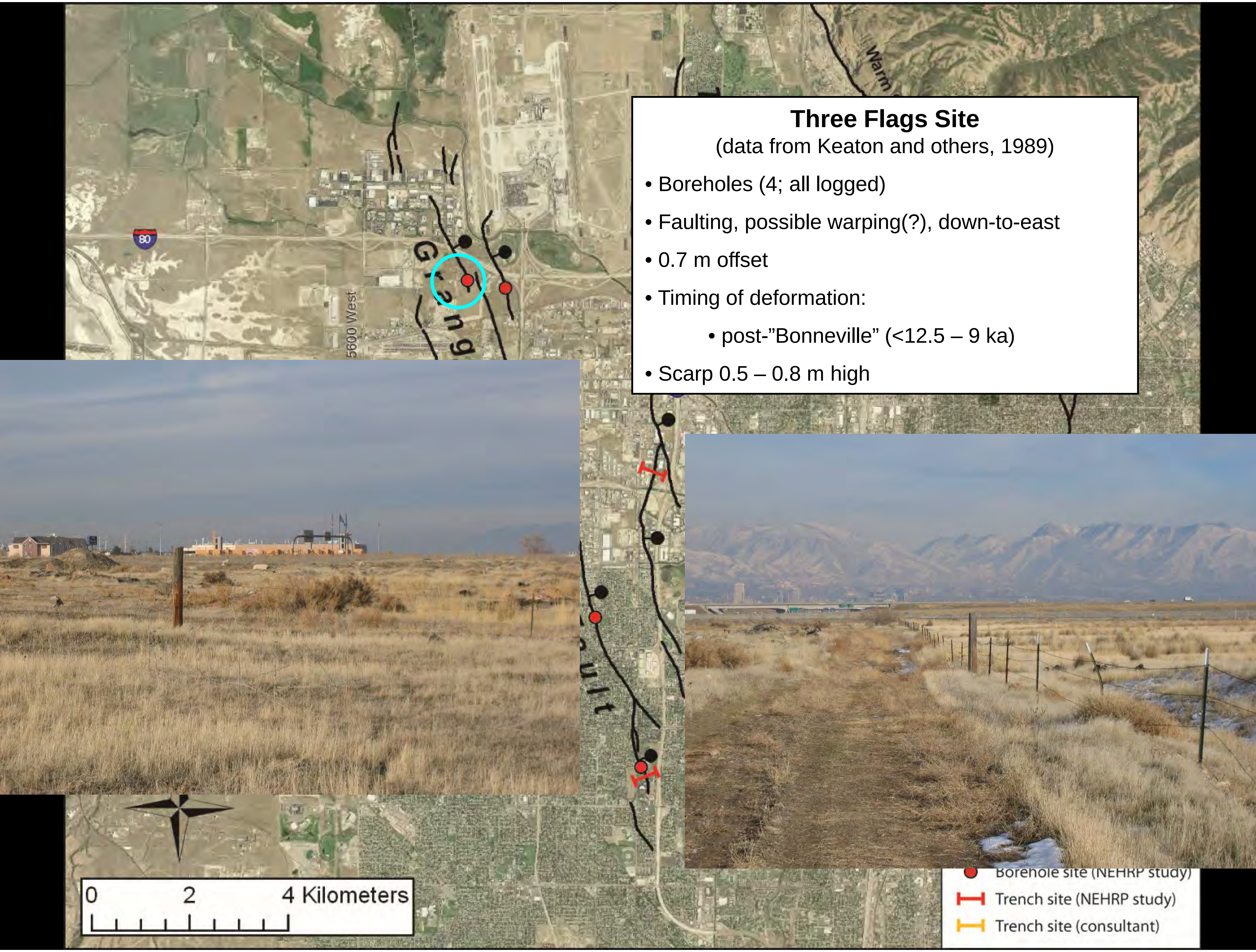
3166 South 3200 West

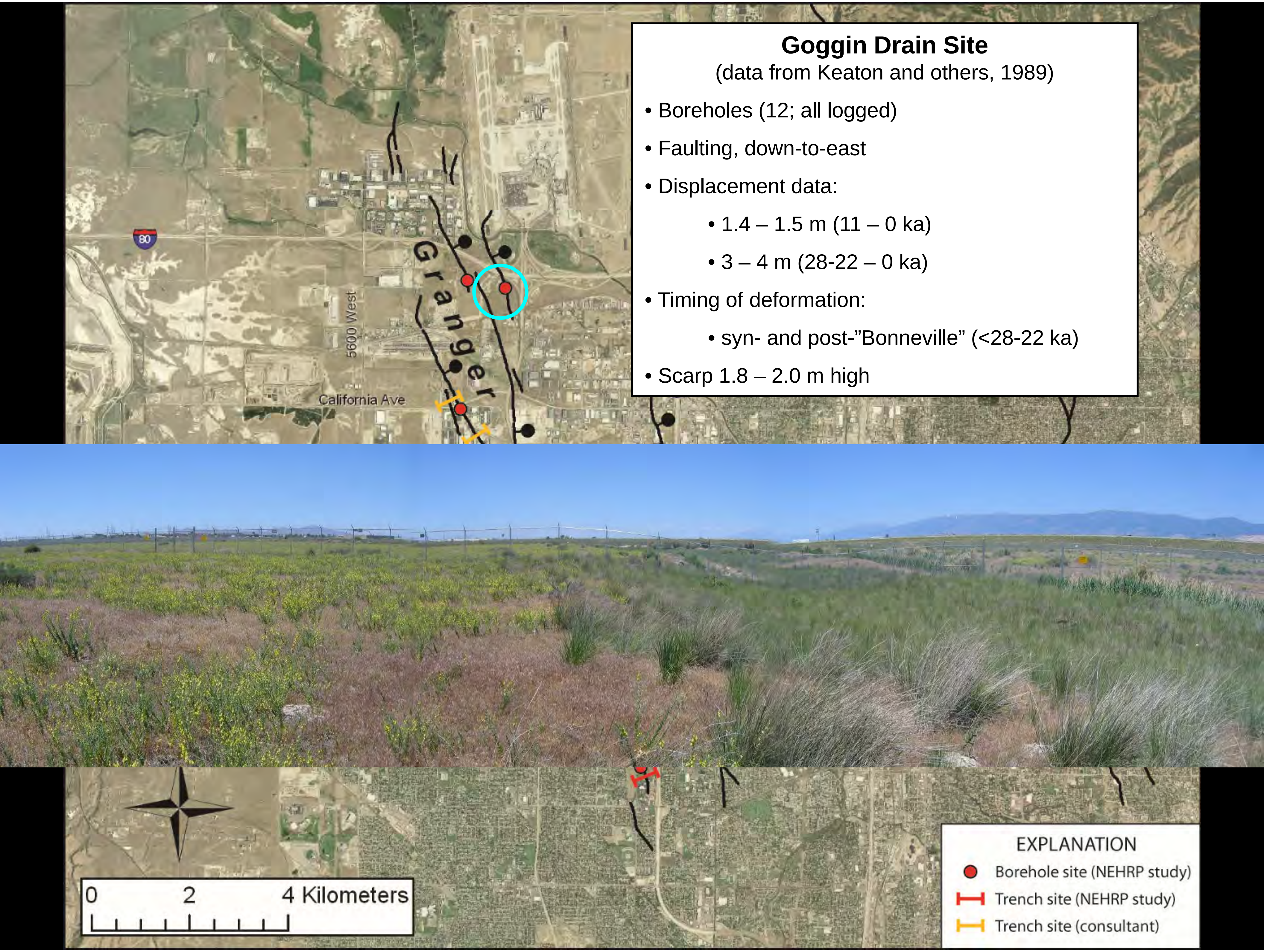
(data from Keaton and others, 1987)

- Boreholes (2; both logged)
- Down-to-east offset
- No displacement data reported
- No timing data reported
- “Pronounced” scarp

Three Flags Site
(data from Keaton and others, 1989)

- Boreholes (4; all logged)
- Faulting, possible warping(?), down-to-east
- 0.7 m offset
- Timing of deformation:
    - post-"Bonneville" (<12.5 – 9 ka)
- Scarp 0.5 – 0.8 m high

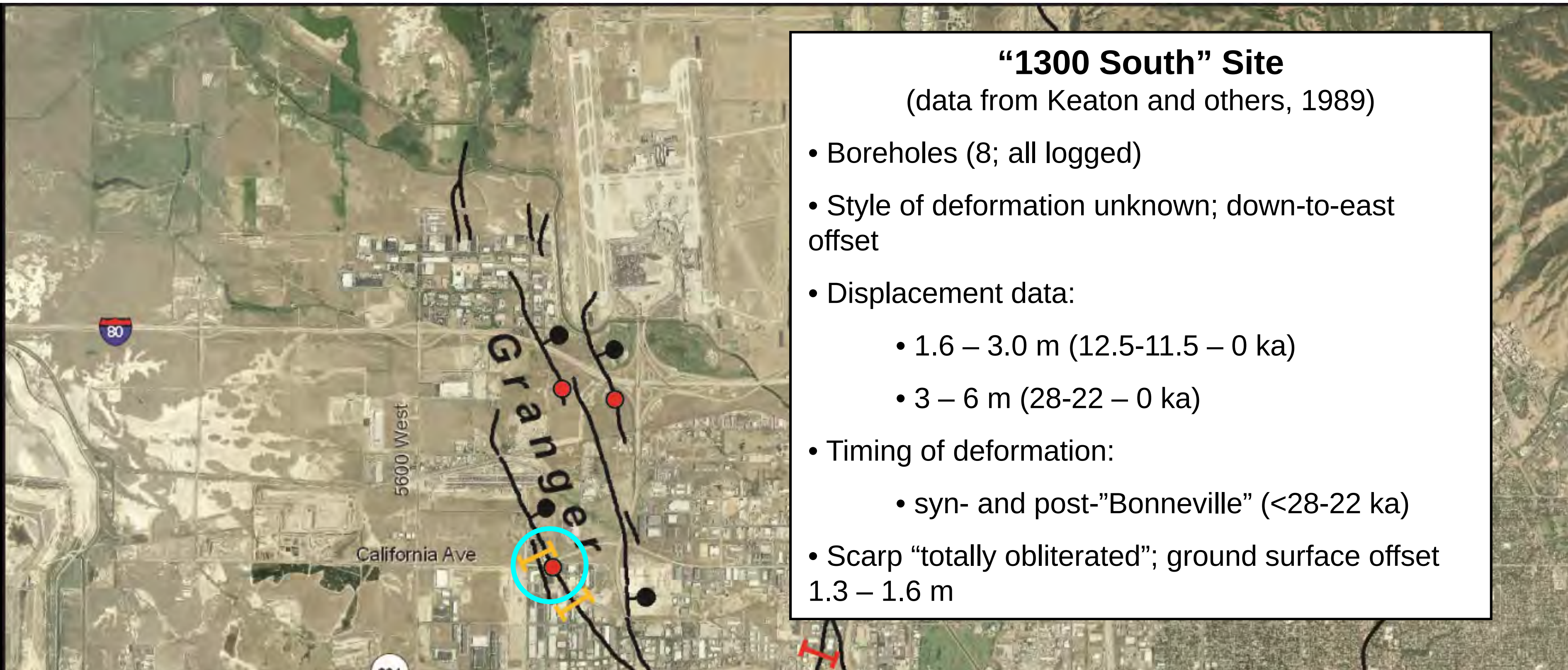


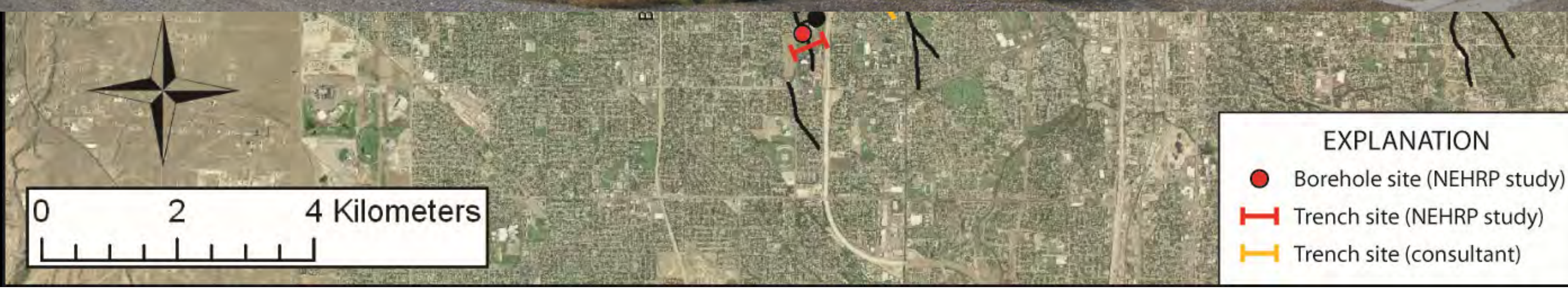

Goggin Drain Site
(data from Keaton and others, 1989)
• Boreholes (12; all logged)
• Faulting, down-to-east
• Displacement data:
• 1.4 – 1.5 m (11 – 0 ka)
• 3 – 4 m (28-22 – 0 ka)
• Timing of deformation:
• syn- and post-"Bonneville" (<28-22 ka)
• Scarp 1.8 – 2.0 m high
80
Granger
5600 West
California Ave
0 2 4 Kilometers
EXPLANATION
Borehole site (NEHRP study)
Trench site (NEHRP study)
Trench site (consultant)

“1300 South” Site

(data from Keaton and others, 1989)

- Boreholes (8; all logged)
- Style of deformation unknown; down-to-east offset
- Displacement data:
  - 1.6 – 3.0 m (12.5-11.5 – 0 ka)
  - 3 – 6 m (28-22 – 0 ka)
- Timing of deformation:
  - syn- and post-”Bonneville” (<28-22 ka)
- Scarp “totally obliterated”; ground surface offset 1.3 – 1.6 m





Consultant Studies

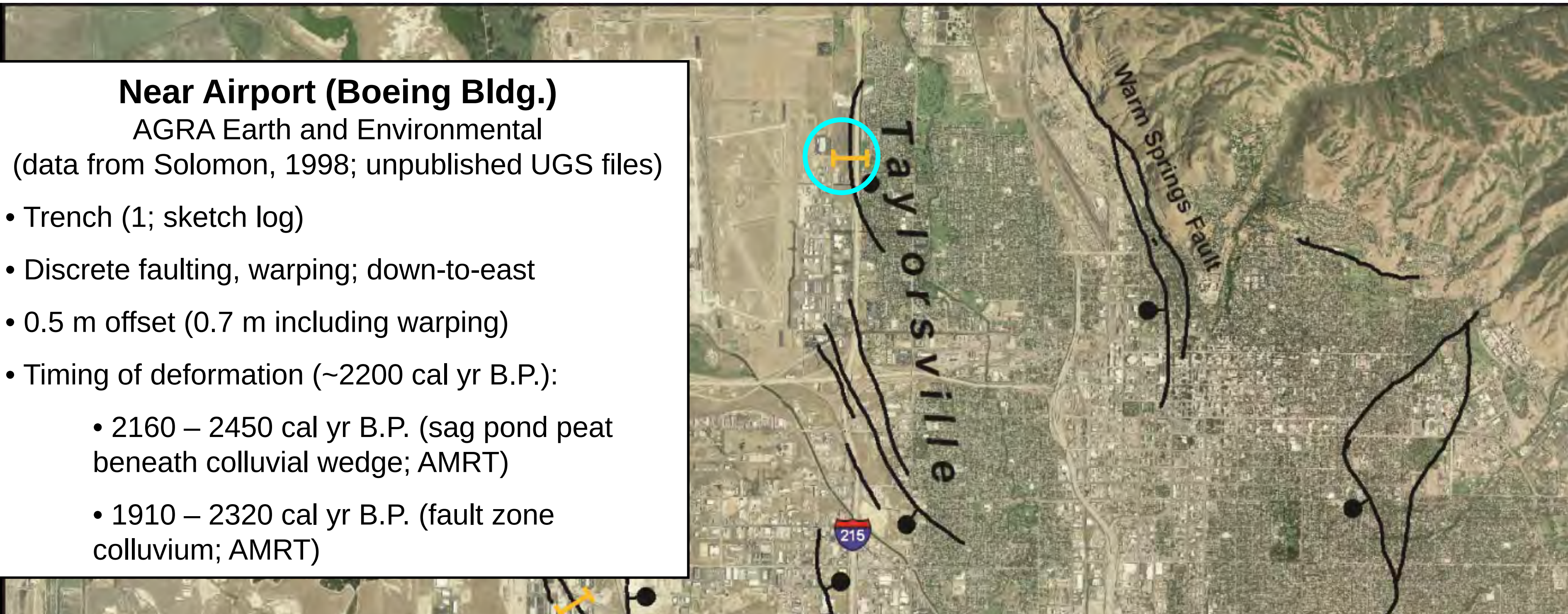
(resulting in displacement or timing data)

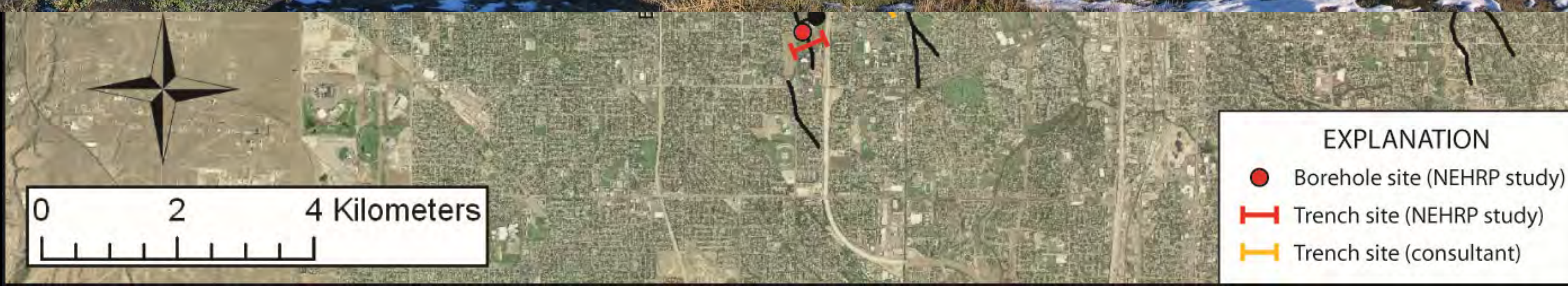
Near Airport (Boeing Bldg.)

AGRA Earth and Environmental

(data from Solomon, 1998; unpublished UGS files)

- Trench (1; sketch log)
- Discrete faulting, warping; down-to-east
- 0.5 m offset (0.7 m including warping)
- Timing of deformation (~2200 cal yr B.P.):
    - 2160 – 2450 cal yr B.P. (sag pond peat beneath colluvial wedge; AMRT)
    - 1910 – 2320 cal yr B.P. (fault zone colluvium; AMRT)





AGRA Trench Site, West Valley fault zone, 9-16-97

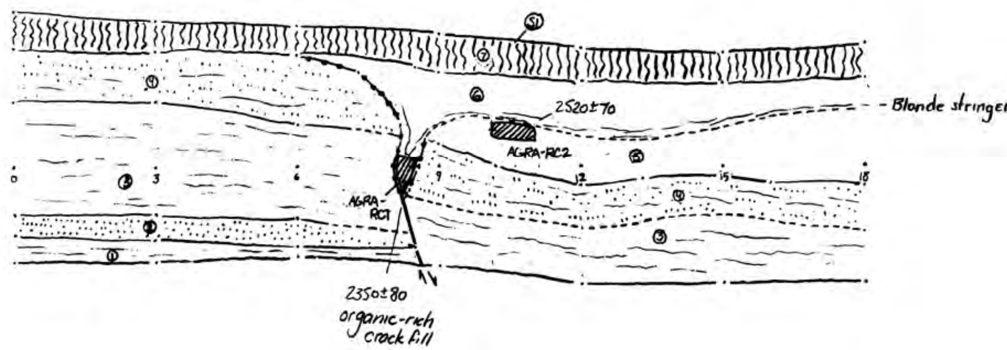
Near Boeing Plant and I-215, South-facing exposure

B. Black, R. Giraud, B. Solomon

Iceelon
Olig
Curry

scale 1'

7-3



① Lake Bonneville clay
② Lake Bonneville fine-grained sand, micaceous
③ Lake Bonneville clay, organic stained on downthrown side?
④ Lake Bonneville sandy silt, carbonate-cemented nodules, high dry strength, shell fragments
⑤ Organic-rich sag pond deposit, upper contact with unit 6 indistinct, possibly at base of blonde silt stringer. Missing on upthrown side.
⑥ Peat deposit with blonde silt stringer, possible wedge.
⑦ Great Salt Lake silty sand with clay.
⑤① Modern soil developed on unit 7.

4200 South Redwood Road

Chen-Northern
(data from Olig, 1989)

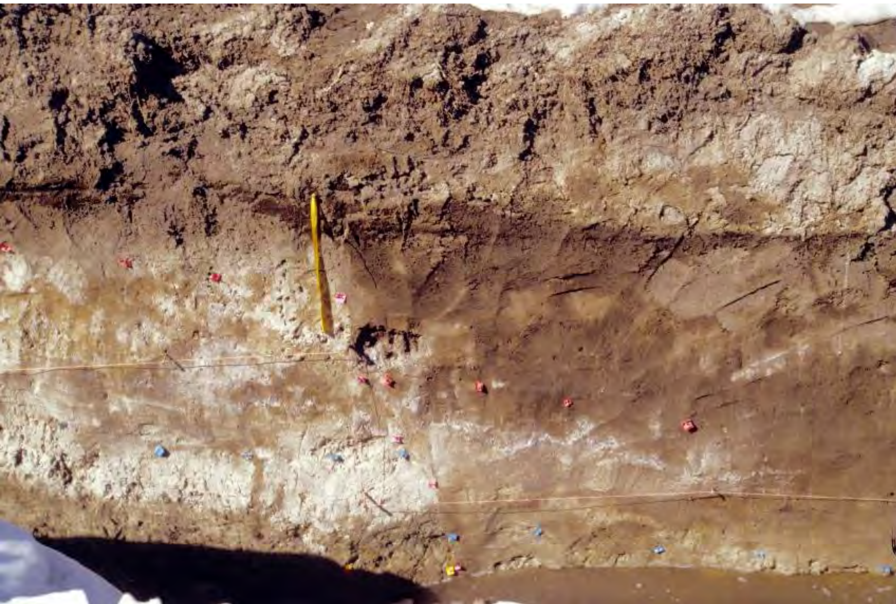
- Trenches (2; no log)
- Discrete faulting, warping; down-to-east
- 1.5 m min. offset
- Timing of deformation:
  - post-Bonneville
- Scarp destroyed by grading (but scarp profiled by Olig in 1986; ~1.5 m high)

1700 South 4450 West

Terracon

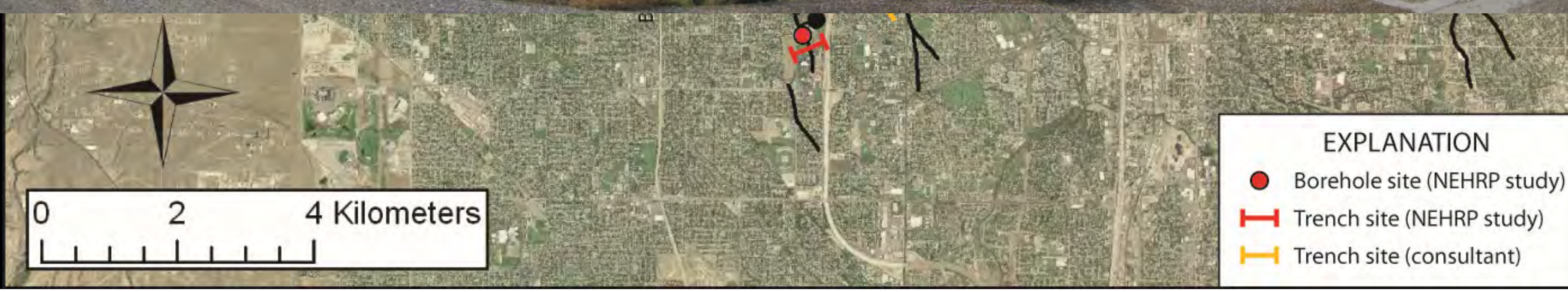
(data from unpublished UGS files)

- Trench (1; no log)
- No displacement data
- Timing of deformation:
  - 1305 – 1690 cal yr B.P. (fault zone colluvium; AMRT)

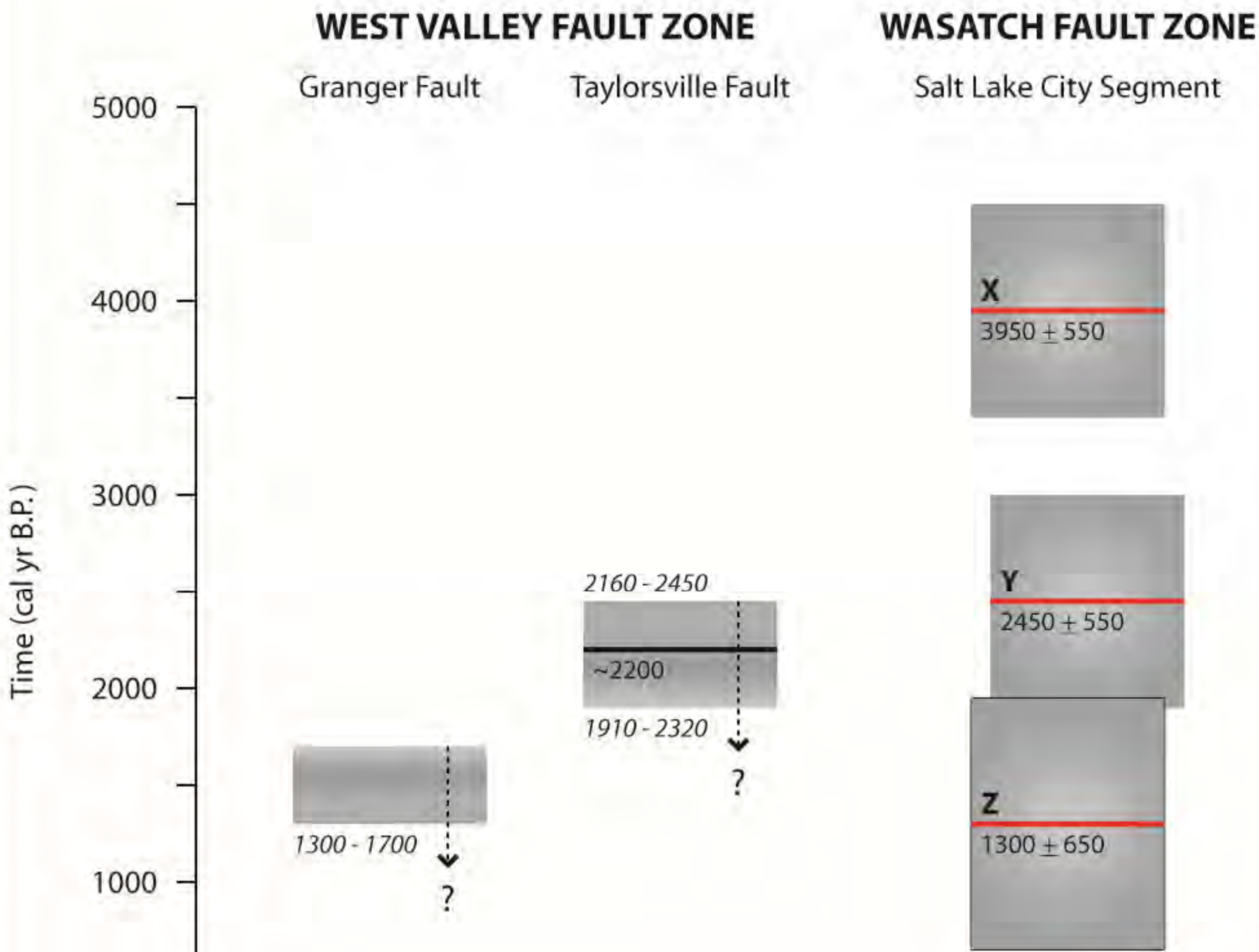


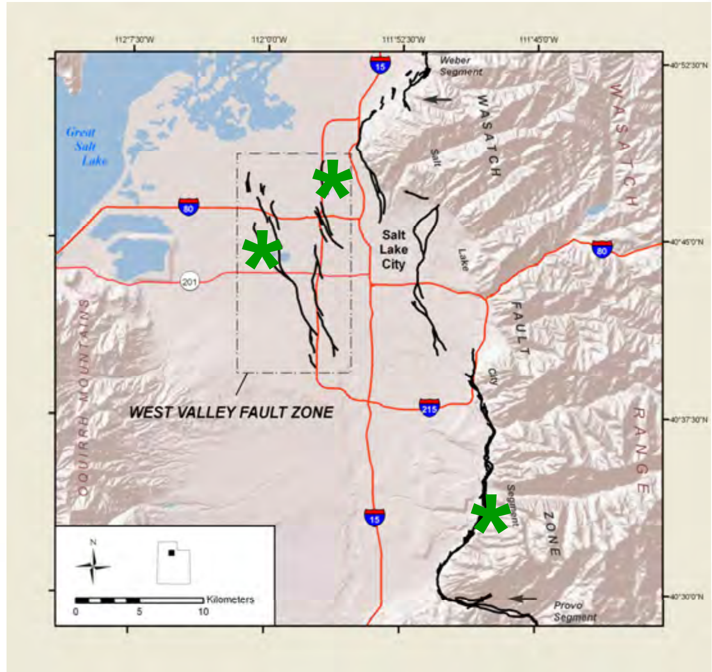
1300 South 4800 West
Terracon
(data from unpublished UGS files)

- Trench (1; no log)
- No displacement data
- Timing of deformation:
  - 1330 – 1630 cal yr B.P. (colluvial wedge material; AMRT)



Evidence for Coseismic Rupture of the West Valley Fault and Wasatch Fault





UQFPWG consensus preferred earthquake timing and uncertainty (Lund, 2005)

Average of maximum-limiting ages (Solomon, 1998)

Minimum limit on timing unknown ?

Granger fault data from *westernmost* strand.
Taylorsville fault data from *northernmost* strand.
Salt Lake City segment data from *south end* of Cottonwood sub-section.

General Considerations and Limitations of Existing Data

- WVFZ is spatially complex; numerous strands, distributed slip
- Apparent geometric relationships between map traces of WVFZ and SLC segment of WFZ
- WVFZ fault plane(s) likely truncated at seismogenic depths by the WFZ
- With few exceptions, WVFZ scarps are small, modified by development-related ground disturbance, or no longer exist
- Data from focused paleoseismic research now 20+ years old
- Majority of displacement data come from borehole investigations
  - long-term (post-140 ka) cumulative displacement relatively well established
  - per-event displacement not well known (MRE in only a couple trenches)
- Earthquake timing is not well known
  - only 2 events dated (one each in different trenches)
  - timing based on AMRT ^{14}C ages
  - dating provides only maximum limits on earthquake timing

General Considerations and Limitations of Existing Data

- Slip-rate estimates are poorly constrained
  - lack of data for Holocene events
  - for long-term slip rates (≤140 kyr), age of offset surfaces is not well known
  - UQFPWG consensus slip rate & uncertainty: 0.1 – **0.4** – 0.6 mm/yr
- Recurrence intervals have been calculated for WVFZ, but:
  - number of events is estimated using "average" per-event displacement of 1.2 – 1.5 m; also crosscutting geomorphic relationships
  - "average" per-event displacement based on one event observed in a single trench
  - no UQFPWG consensus recurrence interval; data insufficient
- Existing data indicate possible temporal coincidence between at least some WVFZ and WFZ paleoearthquakes

Normal-fault Modeling in USGS PSHA: Wasatch and West Valley Faults

Problems Encountered Implementing Intersecting Faults

Stephen Harmsen, USGS

Feb 10 2009

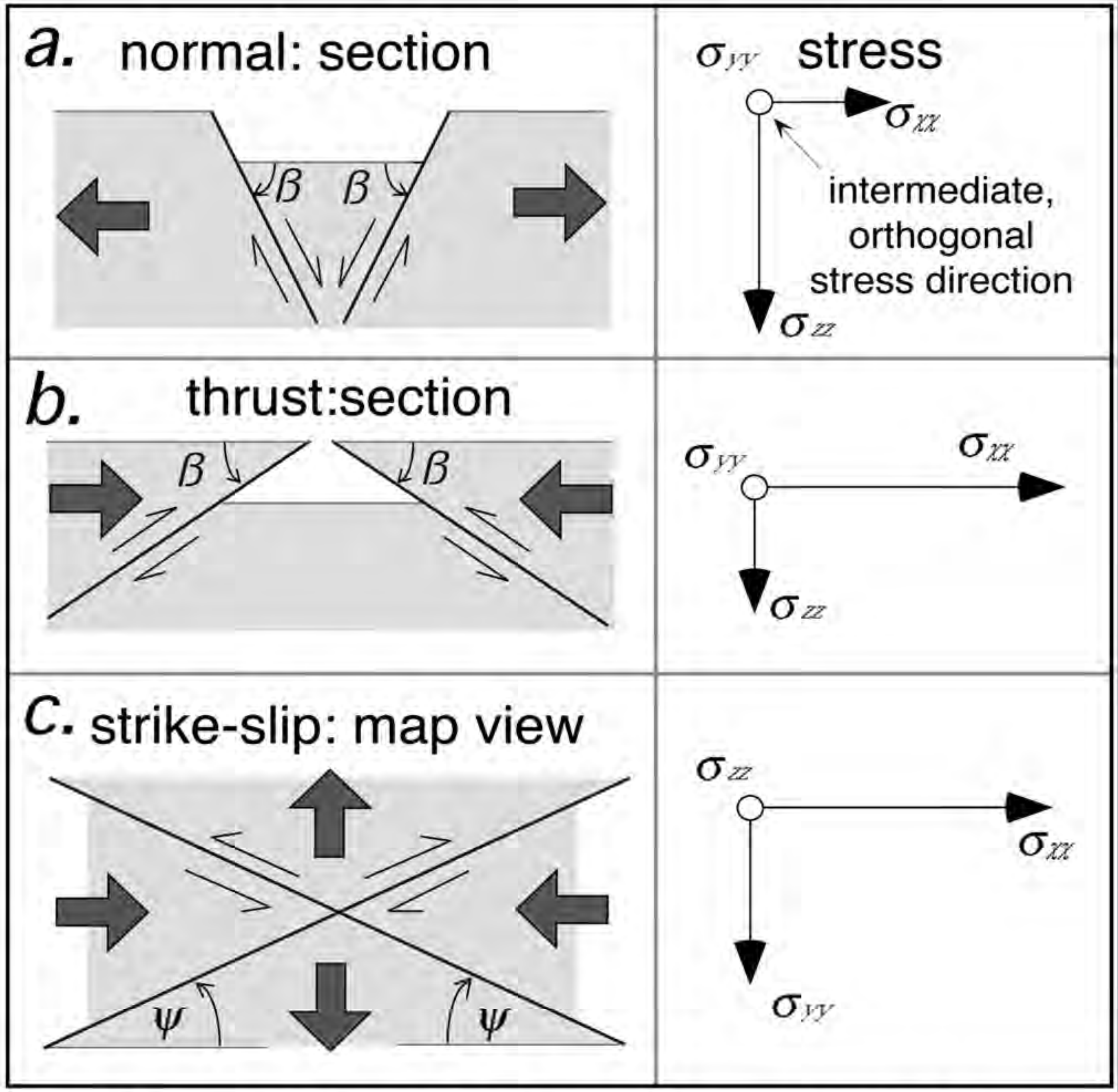
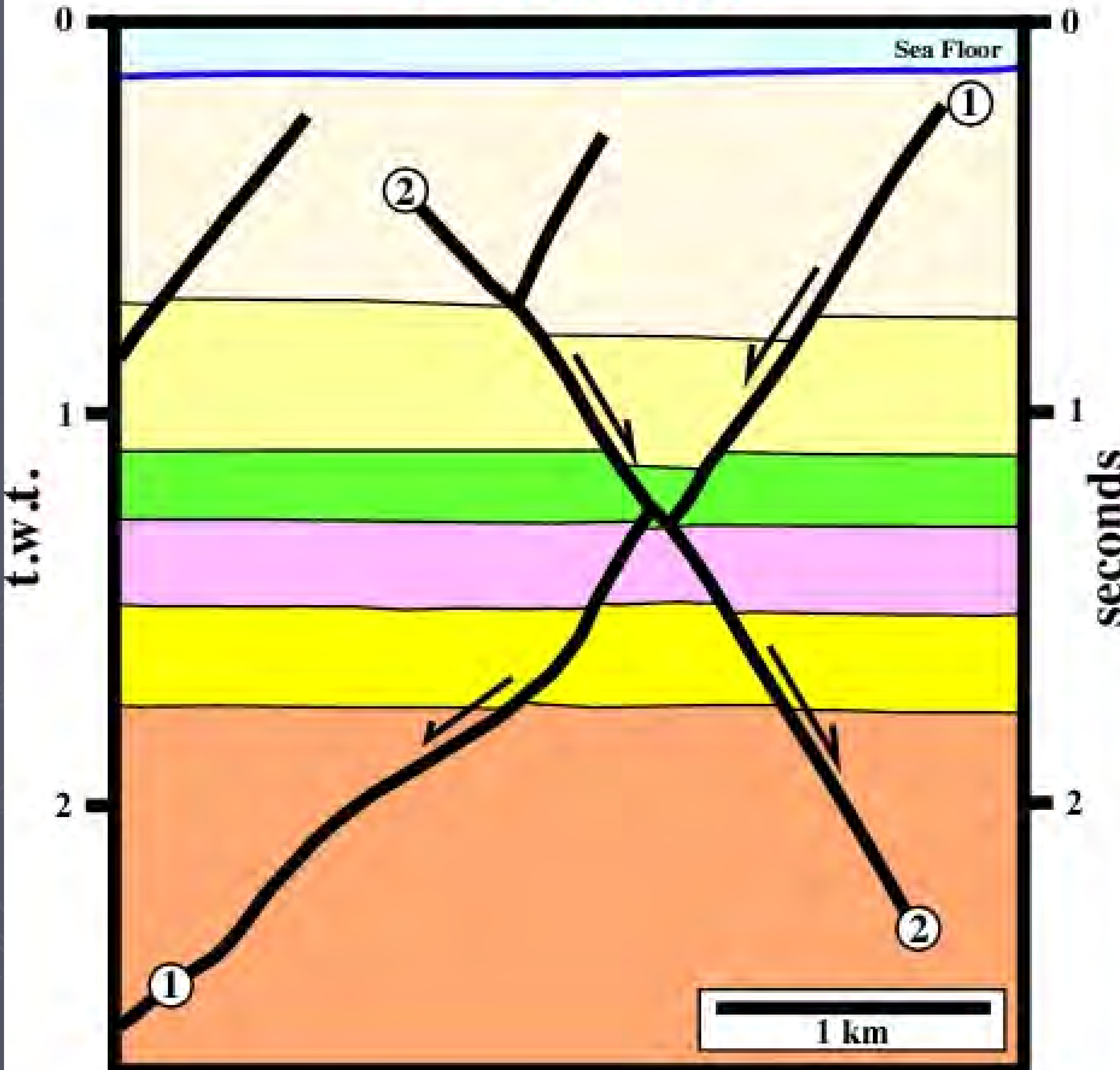


Figure 4.1: Schematic figure of fault orientations with respect to principal stress orientations.

Classic Anderson Theory

- A basis for past PSHA models of normal faults (60 d dip, planes of weakness exhibit symmetry about principal compressive stress axis $\sigma 1$; assumed direction of $\sigma 1$ is vertical)
- Intersecting (X-) faults are just as likely as other fault configurations as far as Coulomb-Mohr optimally oriented planes of weakness are concerned.

X-Faults



Classical Theory meets NGA

- Several NGA models predict large incremental motion at sites on hanging wall of normal fault ruptures (as well as reverse).
- In PSHA, sites over normal X-faults with assumed independent rupture may experience significantly higher probabilistic motion than sites over just one such fault.
- For pre-NGA GMPEs, the hanging-wall effect was absent or less prominent for normal faults, and that’s why we are concerned with X-faults now, rather than earlier.

Crux of the Matter

- Does the WVF continue downdip after intersecting the Wasatch with only a minimal offset in the Wasatch fault zone?
- No free lunch. Depth of bottom of this fault, as any other fault, might be better constrained by further study, analysis of microseismicity, and so on.

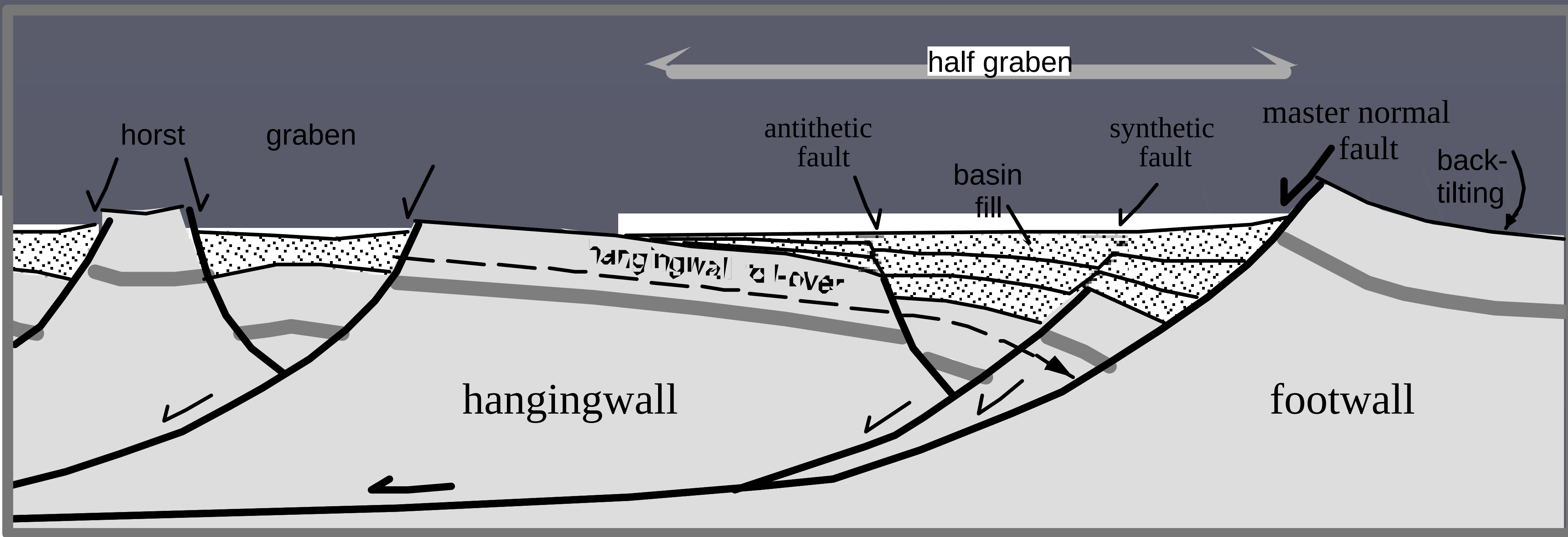


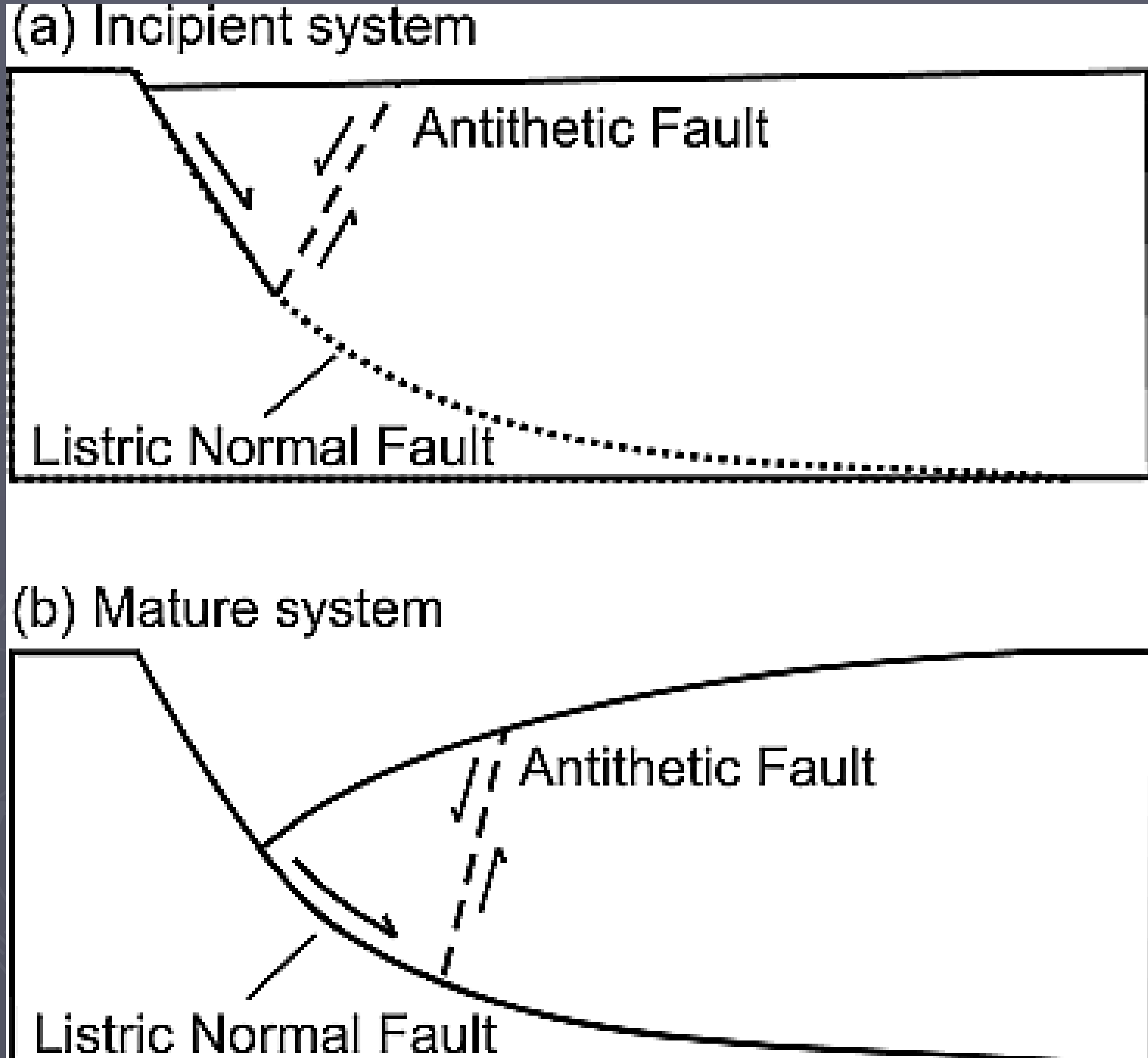
Figure 4.20: Schematic of cross section of normal faults in an extensional regime.

Listric Fault Models By the Book:

No X faults

Antithetic fault steepens as system matures

This argument was offered for considering 70 degree dip of West Valley fault. USGS PSHA models have not yet included this possibility.


(a) Incipient system
Antithetic Fault
Listric Normal Fault
(b) Mature system
Antithetic Fault
Listric Normal Fault

Listric Wasatch?

- Topic was debated in 1980s in other places in B&R. Proponents: Wernicke, Axen, Hamilton. Re-emerging?
- If Wasatch is listric, a steeply dipping (i.e., mature) WVF may intersect master fault at a shallow depth.
- Wax models (Brune and Ellis, 1999) and others demonstrate that listric normal faults develop naturally in extensional stress tests. Are there lessons from these analogue models?
- UGS has several web sites which document listric faults in different parts of state including SLC region.
- Listric and planar fault geometry: aleatory branches?
- Listric geometry is potentially important when modeling seismic wave field in SLV, broad focusing potential.

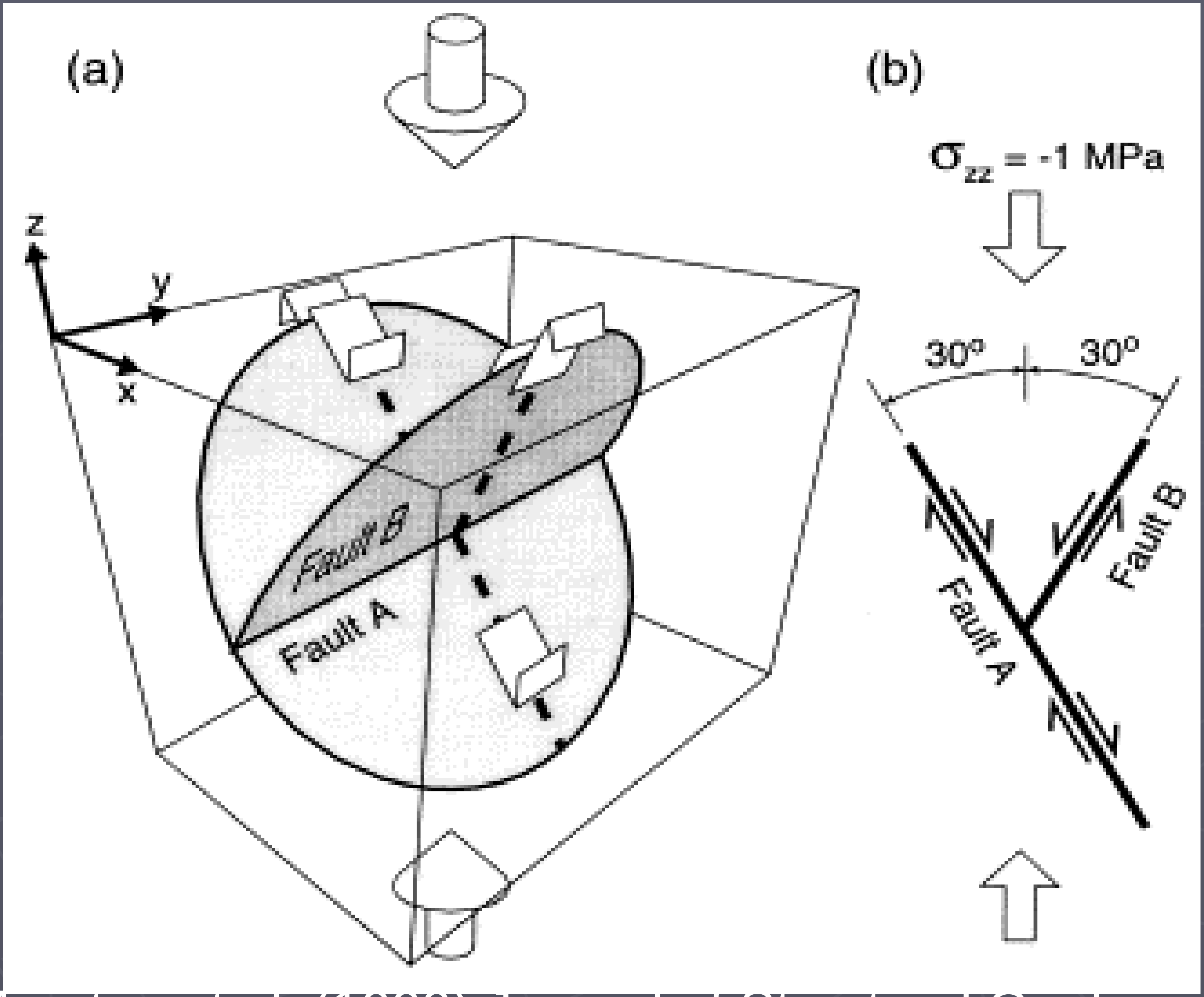
Conversely, how USGS currently models B&R faults

- Planar in downdip direction.
- A primary reference for Utah, Arabasz and Julander (1986)
- Sergio Barrientos & Ross Stein,"Geodetic data do not permit listric faulting for Borah Peak rupture" (1987)

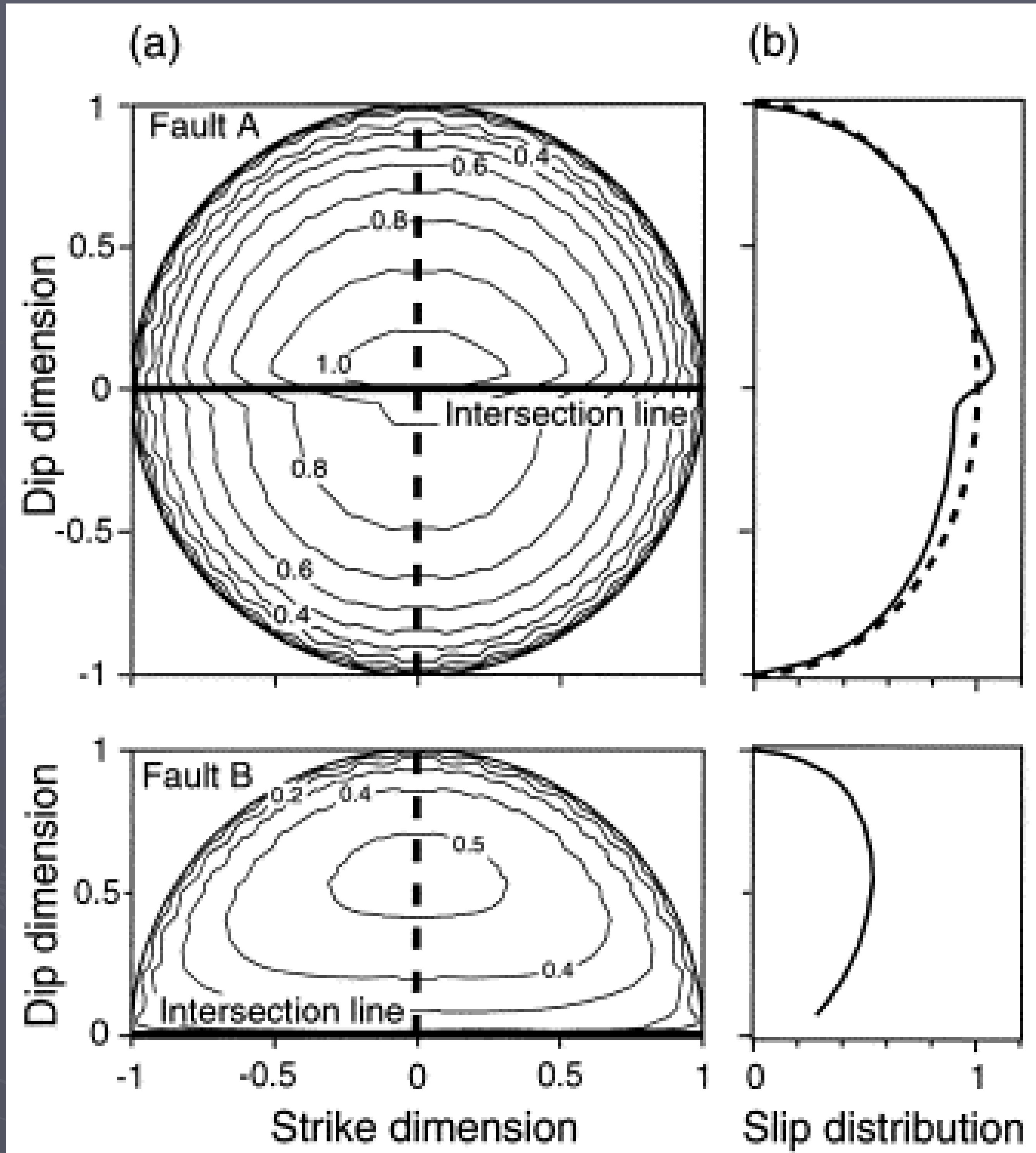
NSHMP hazard models (1996, 2002, 2008) have no listric faults, in Utah, Nevada, or anywhere.

Modeling slip on intersecting faults

- Theoretical and lab work, uniaxial σ_z applied to master and antithetic circular faults
- Result: They slip. Slip on antithetic fault goes to zero at intersection with master fault. Maximum slip of master occurs about halfway downdip (i.e., near intersection).



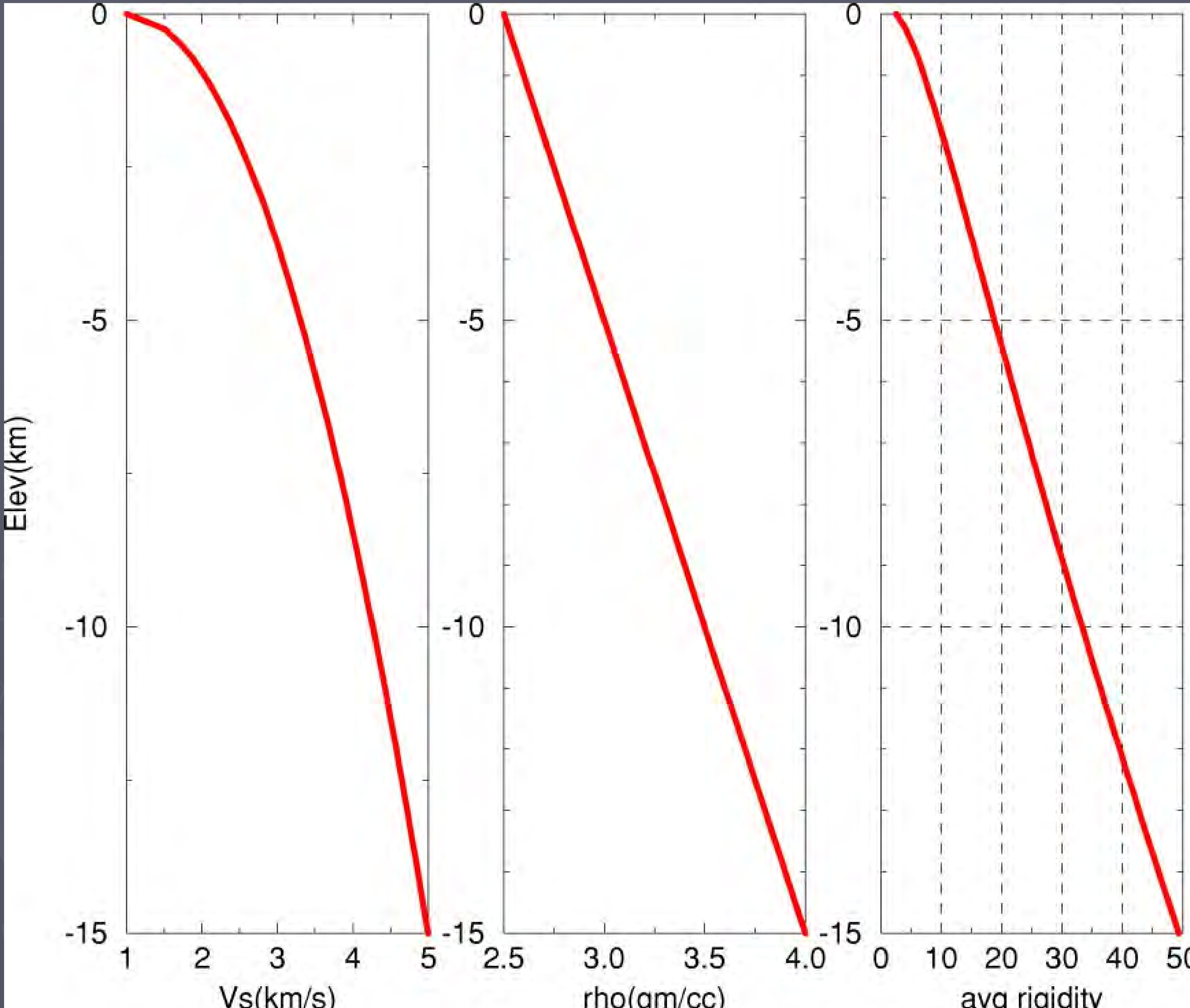
Maerten et al. (1999) Journal of Structural Geology



(a)
(b)
Fault A
0.4
0.6
0.8
1.0
Intersection line
0.8
0.6
0.4
Fault B
0.2
0.4
0.5
0.4
Intersection line
Dip dimension
Dip dimension
Strike dimension
Slip distribution
1
0.5
0
-0.5
-1
1
0.5
0
-1
-0.5
0
0.5
1
0
1

Lessons from the lab?

- Lab model suggests that M should be restricted for the West Valley fault rupture because the deeper part – where strength (shear modulus) is greatest – has very limited slip.
- Field conditions are different from lab: (a), free-surface slip; (b), Wasatch may continue slipping (plastic mode) in lower crust, (c) heterogeneous country rock, (d) triaxial stress.



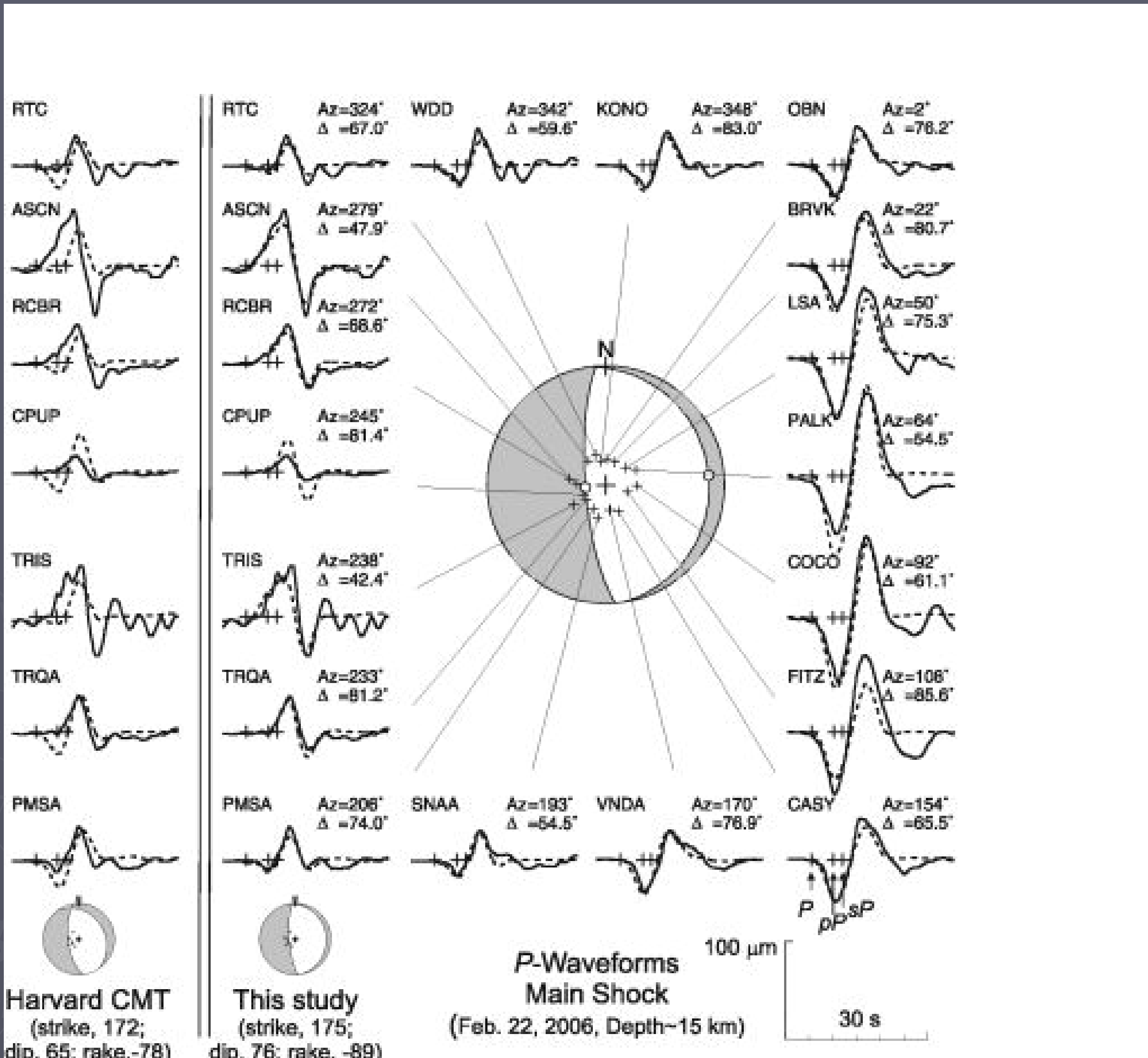
0
-5
-10
-15
Elev(km)
1
2
3
4
5
Vs(km/s)
2.5
3.0
3.5
4.0
rho(gm/cc)
0
10
20
30
40
50
avg rigidity

Consequences of lower rigidity μ

- Lower moment rate for a specified slip rate
- Lower expected magnitude compared to M(SRL)
- These might balance to yield same event rate λ. Suppose shallow μ is 40% of seismogenic-crust μ
- λ= 0.4 moment rate / 0.4 moment per event.
- M6.5 could be reduced to M6.23 (not done but a plausible mod. for the future) for WVF char. src.
- WVF M reduction was suggested by Pechmann last October based on independent M(A) argument.

What about a steeply dipping Wasatch fault?

- 2008 PSHA model defines all Wasatch fault sections with 50+- 10 degree dip
- We moved away from steep-dip normal faults in 2008. Prior to 2008, we assumed 60 d dip w/o uncertainty for all but 1 Basin and Range normal faults.
- A steeply-dipping Wasatch permits a relatively large-area WVF, i.e., plausible source of M6.5 earthquake. Wasatch δ 76 d, WVF δ 63 d, intersect at 10 km depth.
- Are there global analogues? Not many.
- M7 Africa eq, focal mech has a 76 degree NP dip.


RTC
ASCN
RCBR
CPUP
TRIS
TRQA
PMSA
Harvard CMT
(strike, 172; dip, 65; rake,-78)
RTC Az=324° Δ =67.0°
ASCN Az=279° Δ =47.9°
RCBR Az=272° Δ =66.6°
CPUP Az=245° Δ =61.4°
TRIS Az=238° Δ =42.4°
TRQA Az=233° Δ =61.2°
PMSA Az=206° Δ =74.0°
This study
(strike, 175; dip, 76; rake, -89)
WDD Az=342° Δ =59.6°
KONO Az=348° Δ =83.0°
OBN Az=2° Δ =76.2°
BRVK Az=22° Δ =80.7°
LSA Az=50° Δ =75.3°
PALK Az=64° Δ =54.5°
COCO Az=92° Δ =61.1°
FITZ Az=106° Δ =85.6°
CASY Az=154° Δ =65.5°
SNAA Az=193° Δ =54.5°
VNDA Az=170° Δ =76.9°
N
P pP sP
100 µm
30 s
P-Waveforms
Main Shock
(Feb. 22, 2006, Depth~15 km)

NP1:

76 d δ

Focal-Mechanism Dip Uncert

- USGS and Harvard CMT solutions both report a more typical dip for this Mozambique M7 earthquake (USGS fast moment-tensor NP1 dip is 60 degrees; Harvard 65 degrees. Surface-waveform fitting algorithms)
- There are many expert opinions, and without a reasonably deep understanding of all of the technical assumptions and hidden details, how to assign quality rankings to these competing solutions?

Suppose P-wave solution is correct. How to explain? Anderson theory

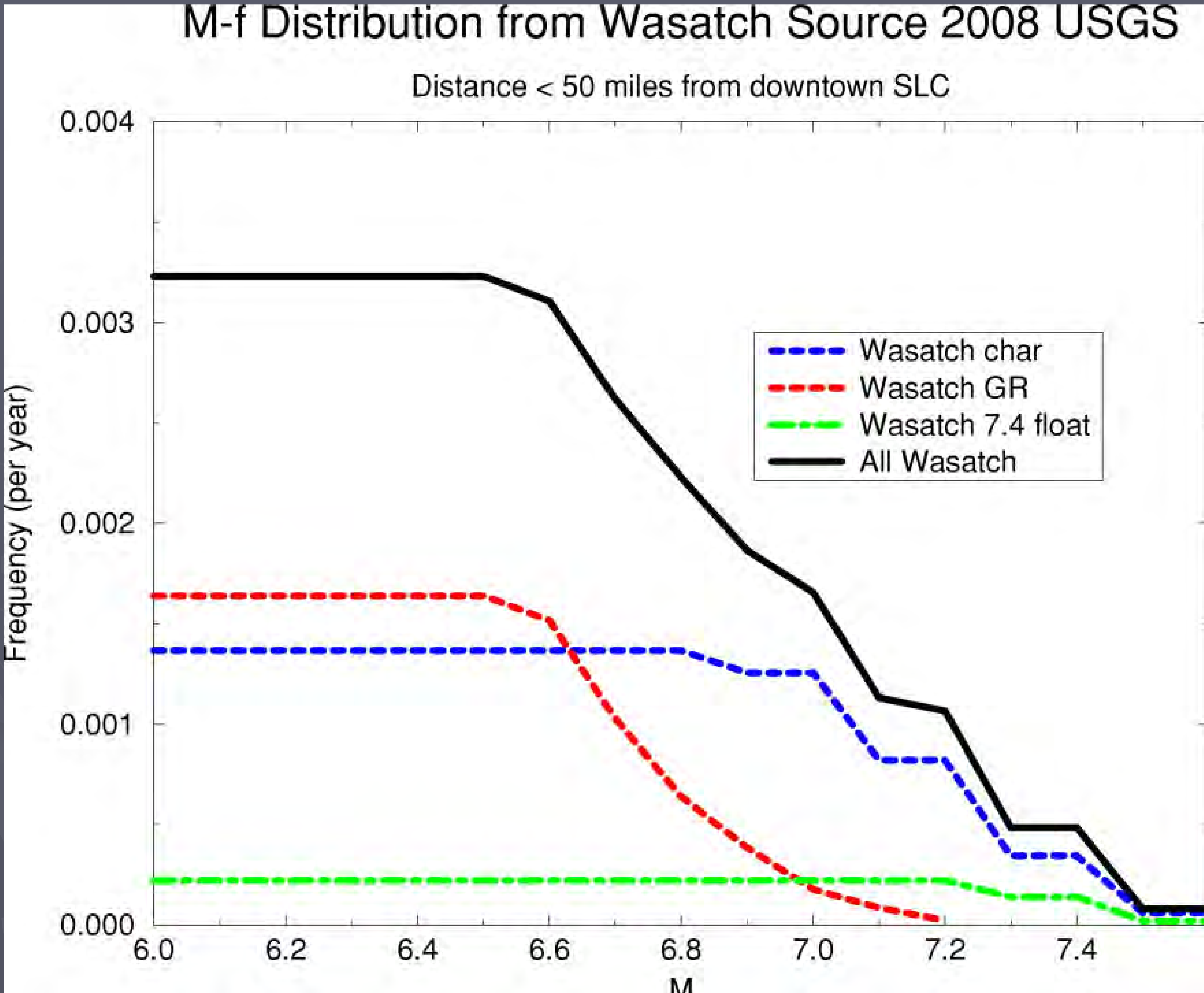
- $\sigma 1$ at depth is rotated from expected vertical direction.
- Event whose mechanism was pictured is in a plate-boundary area (Nubian, Somalian plates).
- Is there an analogy with Wasatch fault?
- Any lessons from Mozambique M7 earthquake?
- Any lessons from body-wave solution varying significantly from surface-wave solutions?

End of Topics for Potential Future Growth of UT SH Logic Tree

- Next, I move on to models that were considered or at least talked about for 2008 PSHA.

Clustering: A Considered Model

- Wasatch (SLC) and West Valley may rupture with characteristic or other eqs. over a short time interval. Short = within minutes (like Dixie Valley-Fairview Peak, 1954), a few hours (Landers-Big Bear, 1992), many hours (conj. faulting at Superstition Hills, CA), or months (like New Madrid sequence of 1811-1812).
- But, OT difference is assumed to be more than a few seconds when using cluster models. Otherwise, surface waves traveling E&W over basin could sum coherently at select locations and many waves sum incoherently.


M-f Distribution from Wasatch Source 2008 USGS
Distance < 50 miles from downtown SLC
Frequency (per year)
0.004
0.003
0.002
0.001
0.000
6.0
6.2
6.4
6.6
6.8
7.0
7.2
7.4
M
Wasatch char
Wasatch GR
Wasatch 7.4 float
All Wasatch

How We Applied Cluster Model to WVF/Wasatch

- Assume same recurrence interval, RI for all events in the cluster.
- Shorter mean RI of Wasatch was handled as $\lambda=\lambda c+\lambda i$ for the characteristic rupture only, $\lambda=1/RI$. No cluster model was considered for associating WVF with the Gutenberg-Richter branches of Wasatch rupture or the *uber*-event.
- What we could do for Wasatch/WVF cluster models was limited to what we did with NMSZ in the 2007-2008 PSHA. NMSZ cluster model has characteristic-rupture only and no rate uncert.

Simultaneous rupture

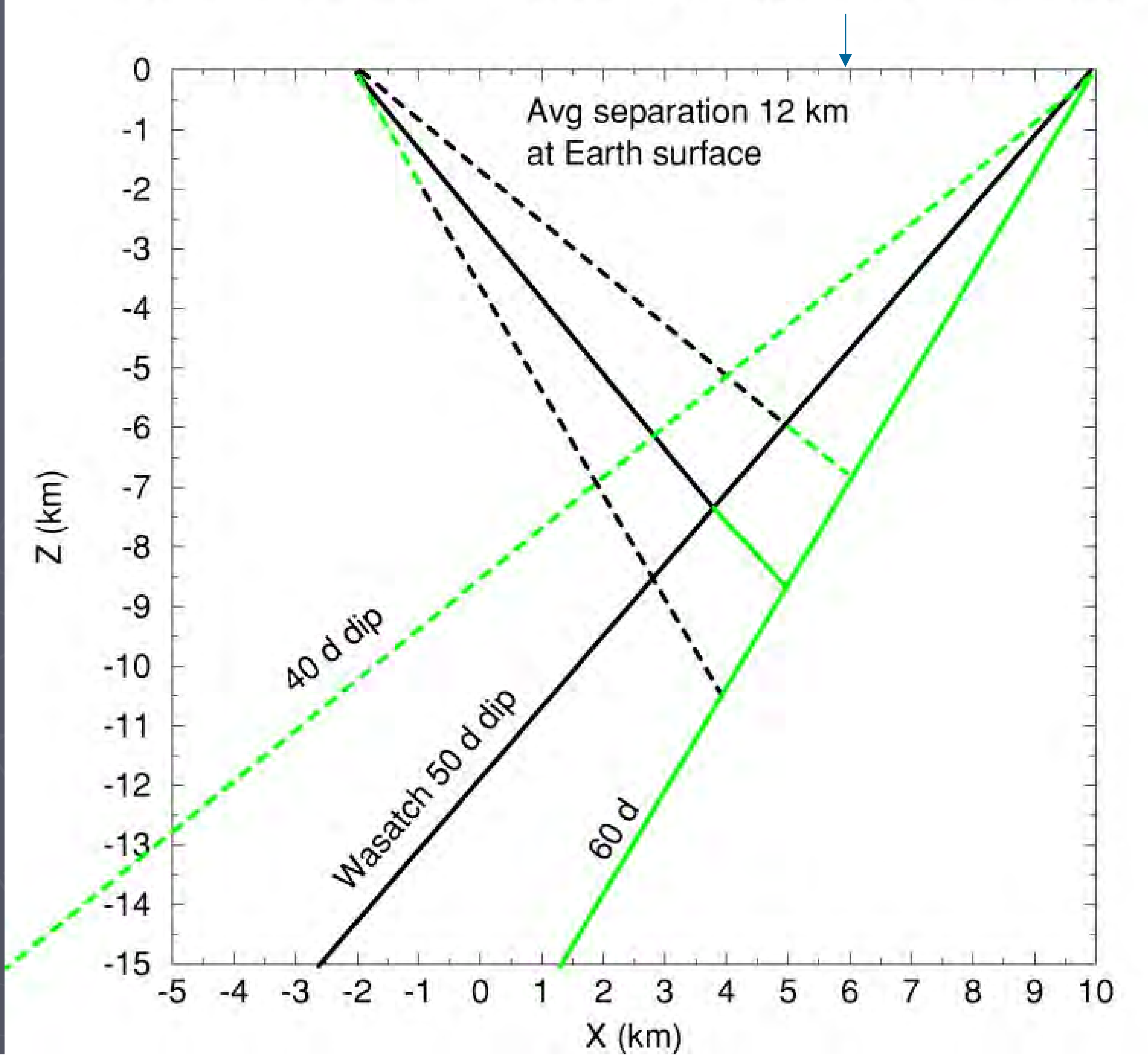
- Talked about, but not calculated for 2008 model
- We still have not done a sensitivity study using Norm Abrahamson’s program (don’t have program yet 2/04/2009).
- Should we use an incoherent-summation rule to modify GMPE expected motion?
- We don’t know of cases. Denali followed Sutsina Glacier, many other examples of sequential rather than simultaneous ruptures.

Final WVF characterization in 2008 model

- Granger segment used. Assumed separation 12 km at surface. 12 km corresponds to a rangefront Wasatch trace
- Intersects and is truncated by Wasatch, SLC section
- Dip uncert.: 3 WVF dip branches for each Wasatch dip
- Dip uncertainty model is 50+-10 degrees for these and almost all other B&R normal faults.
- Recurrence model for all WVF branches is determined by fixed slip rate, M(SRL), standard rigidity, and rupture area to W(int), which is a function of dips of these two faults.
- For alternate M (6.5+-0.2), moment-rate balancing yields alternate recurrence intervals, */2 preferred RI.

Rupture times are random and independent of Wasatch rupture times.

Wasatch-WVF Intersection Model 2008 PSHA

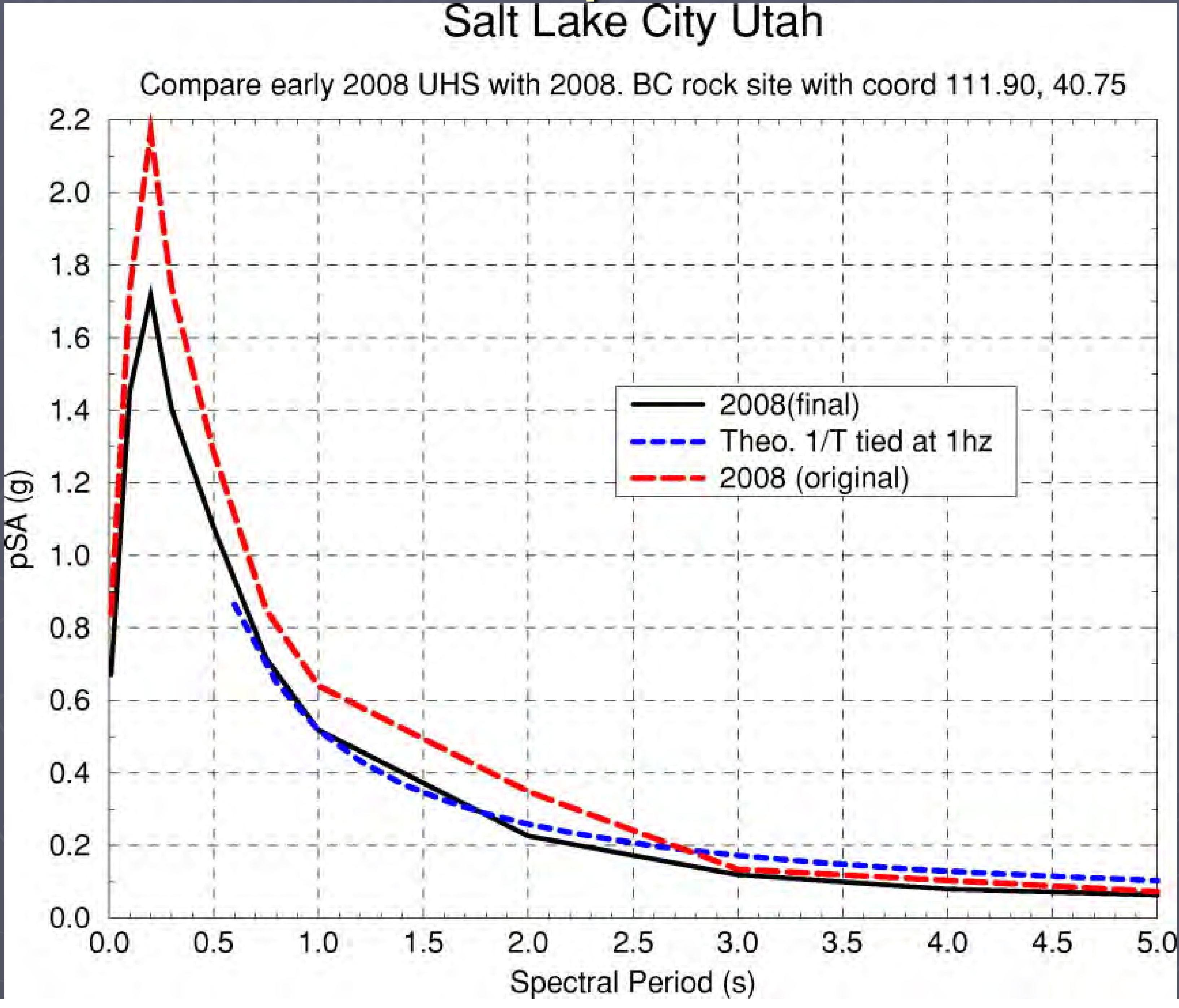


δ Wasatch, δ WVF	Rate M6.5 10**-4	Weight % *0.6	Width (km)	Z where they intersect
50, 50	3.9	36	9.3	7.2
50, 40	4.5	12	9.2	5.9
50, 60	3.6	12	9.8	8.5
60, 50	4.6	12	11.1	9.6
60, 40	5.2	4	10.5	6.7
60, 60	4.4	4	12	10.4
40, 50	3.2	12	7.7	5.9
40, 40	3.9	4	7.8	5.0
40, 60	2.9	4	7.8	6.8

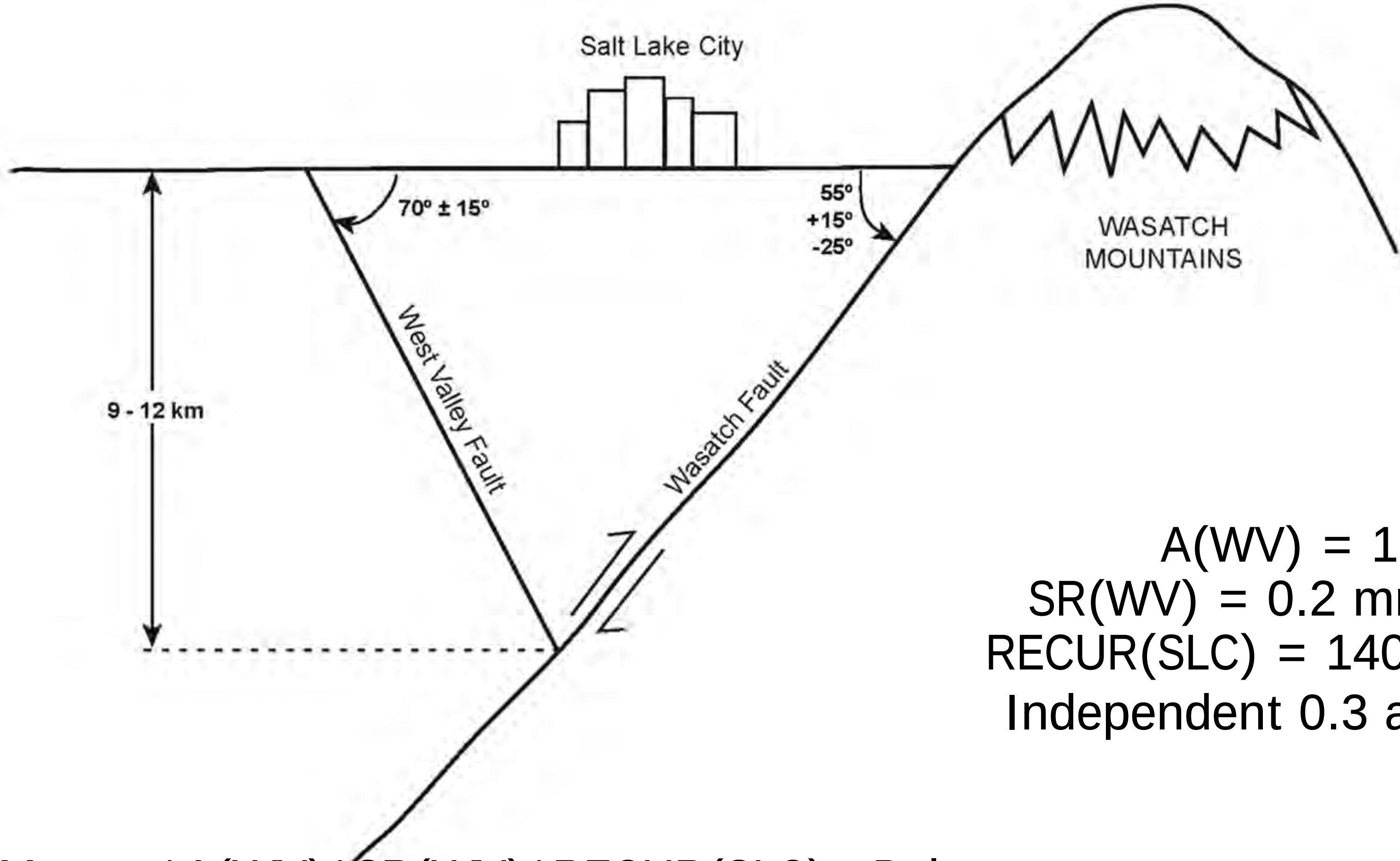
Bottom Line

- Modifications to West Valley fault geometry and mean rate of earthquakes substantially reduced the probabilistic ground motion in downtown SLC at most spectral periods (less than 3 s) of engineering interest. Quantified in the uniform hazard spectrum. Uniform means same probability of exceedance everywhere in the USA
- Future maps might consider modifications that produce more reductions (lower M for WVF; asymmetric M-uncertainty for WVF, currently we use M6.5 +-0.2. Or lower weight on upper M branches)

Uniform Hazard Spectrum or UHS



Coseismic rupture of the West Valley fault and Salt Lake City (SLC) segment occurs when the SLC characteristic earthquake (**M** 7.0 ± 0.3) occurs



A(WV) = 183 sq. km
SR(WV) = 0.2 mm/yr (0.03, 0.7)
RECUR(SLC) = 1400 yrs (610, 4090)
Independent 0.3 and coseismic 0.7

$M_O = \mu * A(WV) * SR(WV) * RECUR(SLC)$ Balances moment

$M\ (WV) = (\log M_O - 16.05)/1.5$

M 5.0 to 6.5

GM = SRSS [GM(WV),GM(SLC)]

RECOMMENDATIONS TO THE UTAH FAULT WORKING GROUP ON RESEARCH PRIORITIES

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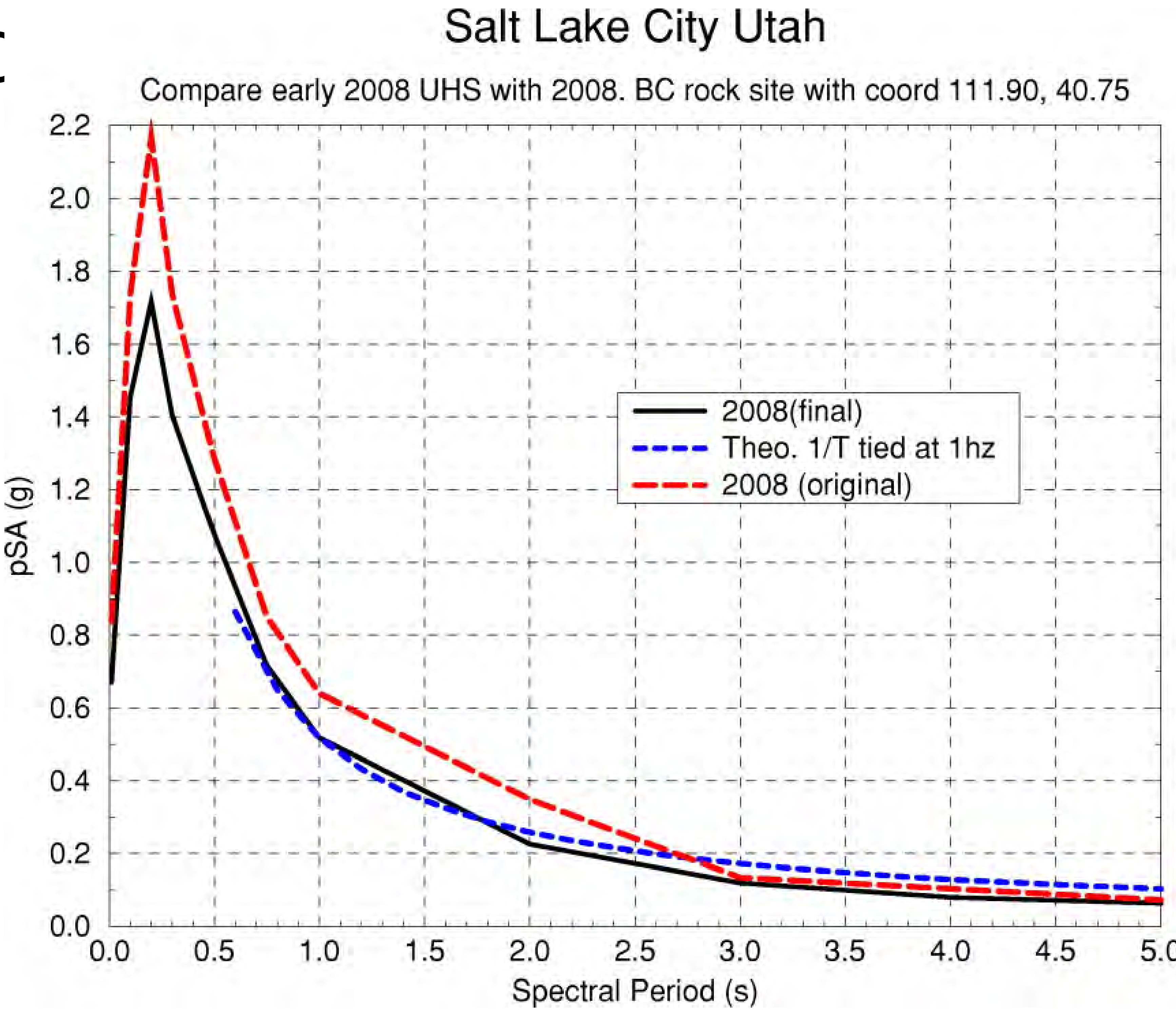
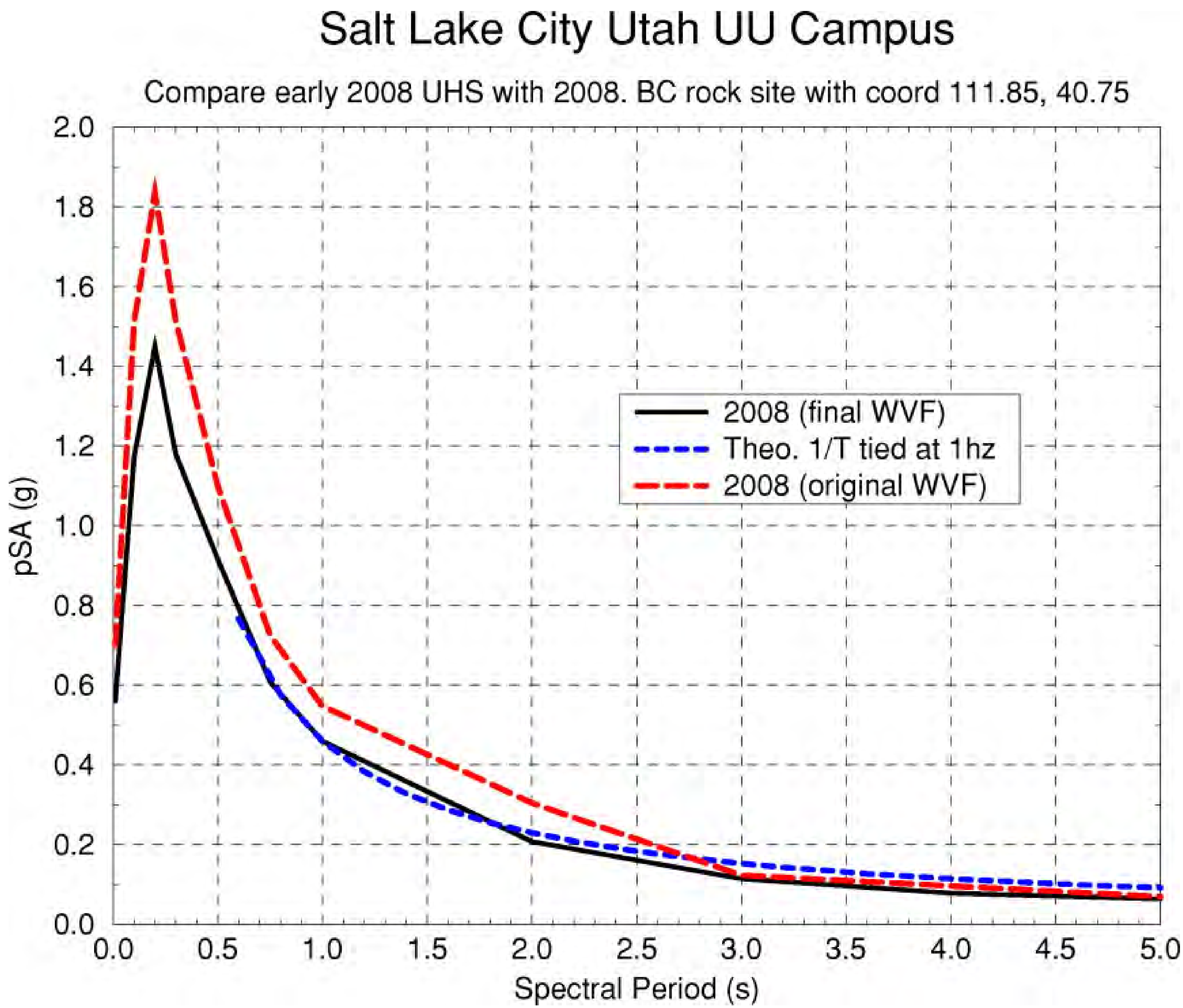


Salt Lake City Utah
Compare early 2008 UHS with 2008. BC rock site with coord 111.90, 40.75
pSA (g)
Spectral Period (s)
2008(final)
Theo. 1/T tied at 1hz
2008 (original)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0


Salt Lake City Utah UU Campus
Compare early 2008 UHS with 2008. BC rock site with coord 111.85, 40.75
2008 (final WVF)
Theo. 1/T tied at 1hz
2008 (original WVF)
pSA (g)
Spectral Period (s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.5
1.5
2.5
3.0
3.5
4.0
4.5
5.0

Fault Geometry

- Ground motion working group needs to define a rupture for their models
  - Dynamic rupture (Simple plane defined by 2 points, downdip width, dip, and moment (Mw 7.0)
  - Kinematic rupture complex feature (Is the current NSHM model adequate?

Fault Geometry

- Locations of fault along strike and downdip (alternatives, e.g., listric)
- Master fault secondary fault relationships
- Methods for study
  - Vibroseis
  - Surface mapping
  - GPS studies
  - Other?

Analogs and models for simultaneous rupture, clustered ruptures, triggered ruptures, independent ruptures

- Superstition Hills-Superstition Mountain
- Dixie Valley – Fairview Peak
- Landers – Big Bear
- Denali Susitna Glacier
- Wasatch – West Valley – Great Salt Lake
- Hansel Valley

Fault interactions

- Wasatch fault – West Valley – Great Salt Lake interactions
  - Paleoseimology
  - Microseismicity
  - GPS
  - Mechanical models for interaction

Rupture interaction

- Segmentation – how persistent are segment boundaries
  - Paleoseismic – Interaction of Nephi and Provo segments (floating ruptures)
  - Mechanical (Physics based) models

Other considerations

- Magnitude distribution of earthquakes on each fault (e.g., floating rupture M 7.4)
- GPS vs Geologic discrepancies in strain rate (aseismic slip)
- Matching the model and historical rate of seismicity

WEST VALLEY FAULT ZONE
PART 2

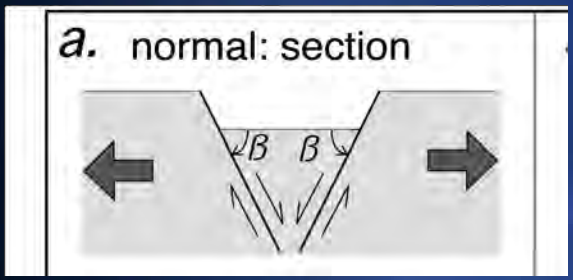
What About All Those Other Active, Graben-Producing Fault Pairs in Utah/Basin and Range Province?

Considerations for modeling graben-bounding faults in the NSHM

Conclusion

- Maybe we don’t understand the coseismic behavior of this type of fault as well as we think we do.

What is the magnitude of the issue



- WSSPC recommendation to change default dip of normal faults to 50° and consider 40° and 60° alternatives

@ 60° dip, faults must be more than 17 km apart not to intersect

@50° dip, >25 km

@40° dip, >36 km

The distance between most faults in the Basin and Range is <40 km.

Northern Utah Analog

- Blue faults dip east
  - Hansel Valley bounds minor range front
  - historical surface rupture
- Red faults dip west
  - North Promontory fault
  - bounds predominant range front
  - possible recurrent late Pleistocene surface rupture

@13 km spacing-the faults intersect at all dips

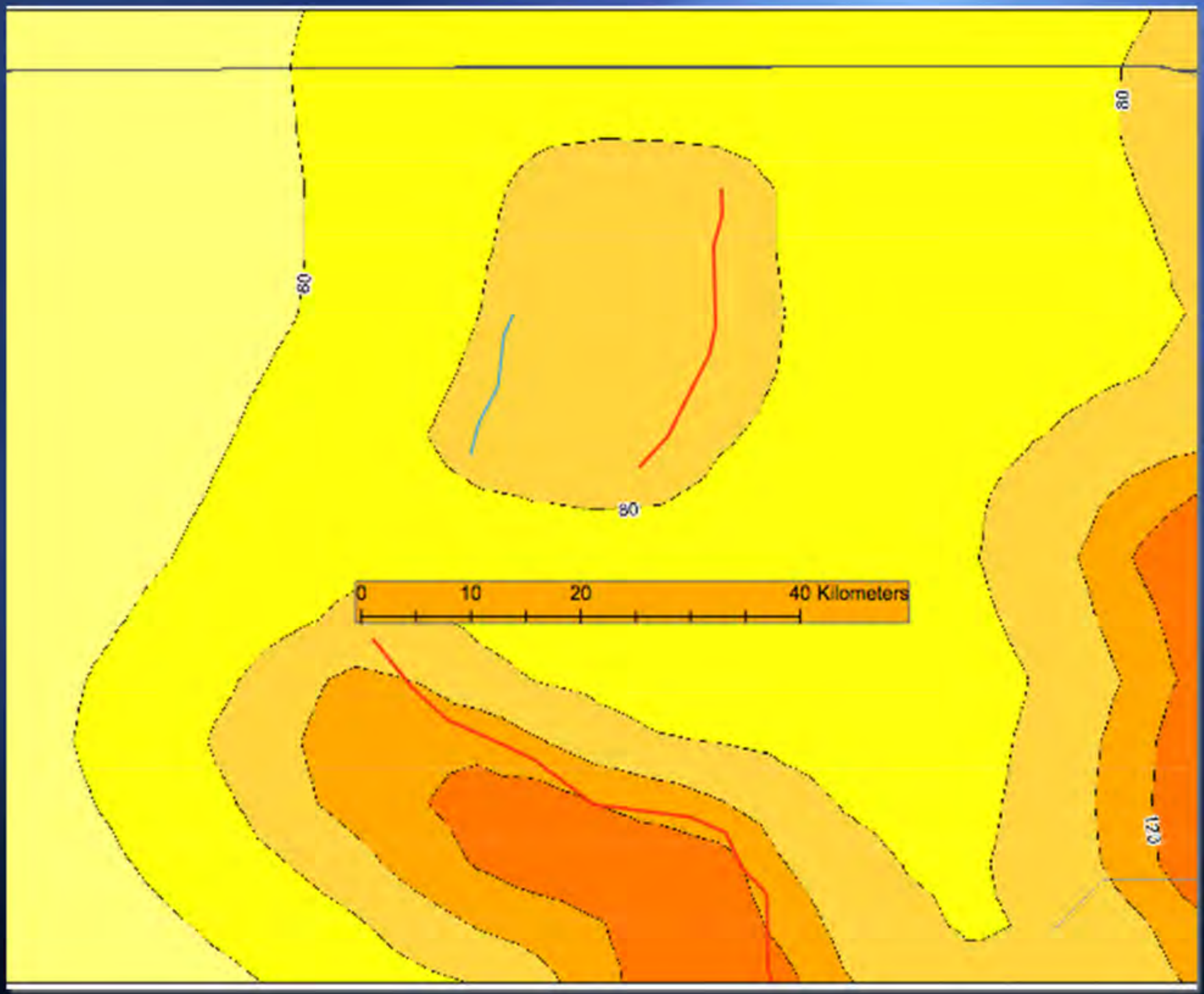
Hansel Valley

- 1934 M6.6 (red) produced maximum 0.5 m vertical displacement.
- The most-recent prehistoric event produced 2.2-2.6 m displacements.

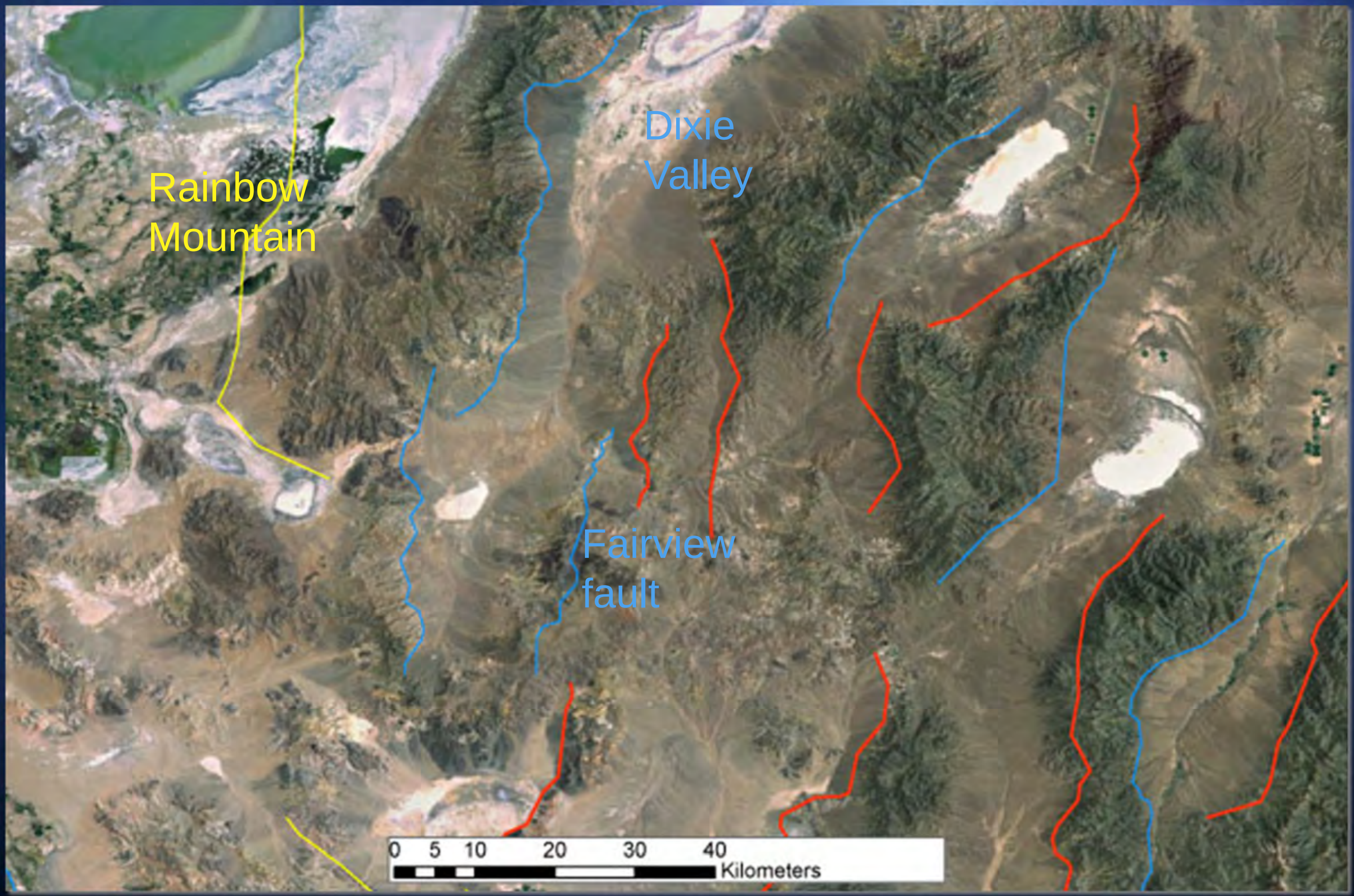
North Promontory fault

- Meets all the criteria of being the master fault.
- Prominent range front
- Possible recurrent late Pleistocene and Holocene surface rupture
- Relatively simple surface trace

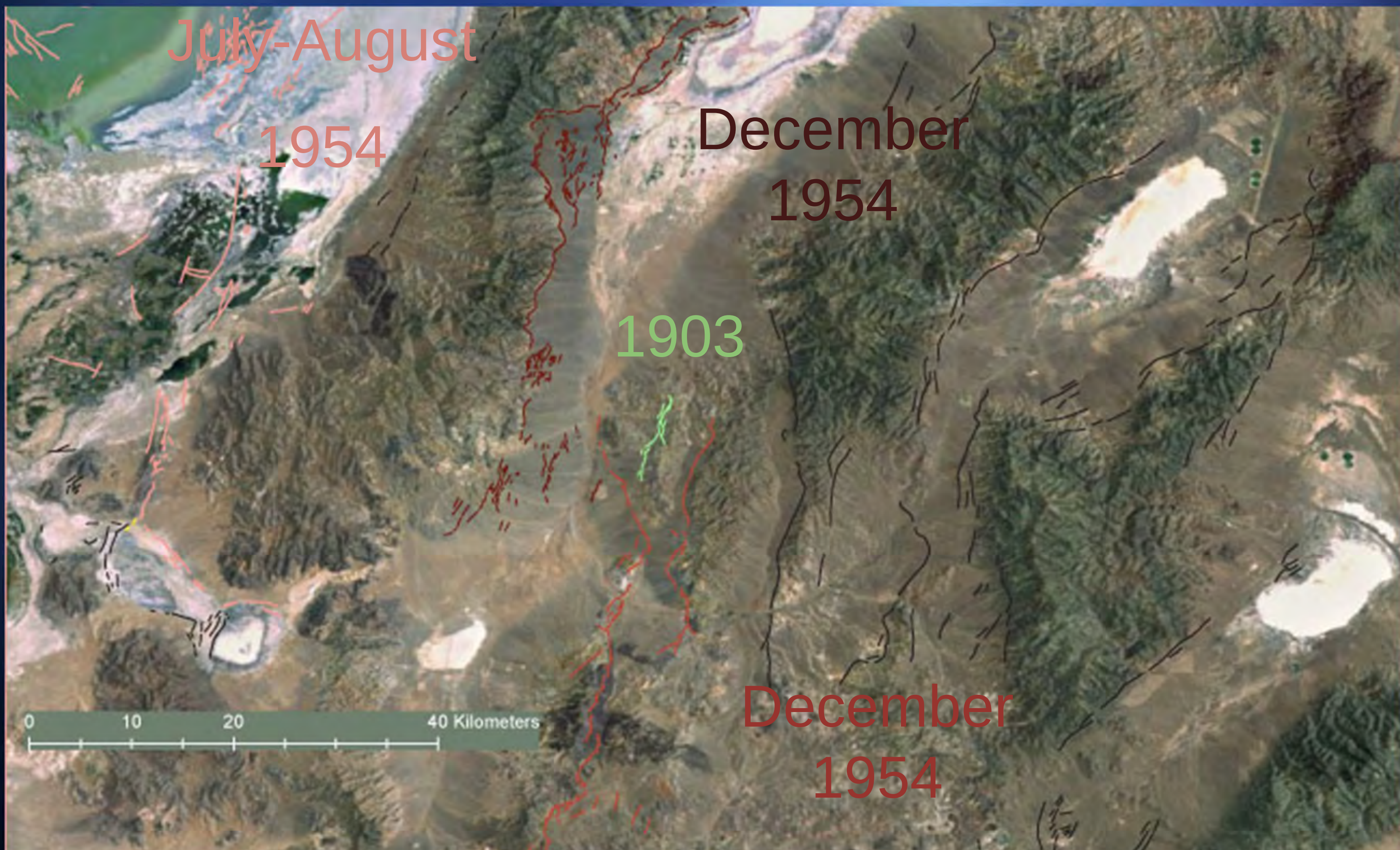
0.2-sec horizontal acceleration with 2% in 50 yr



Central Nevada Seismic Zone

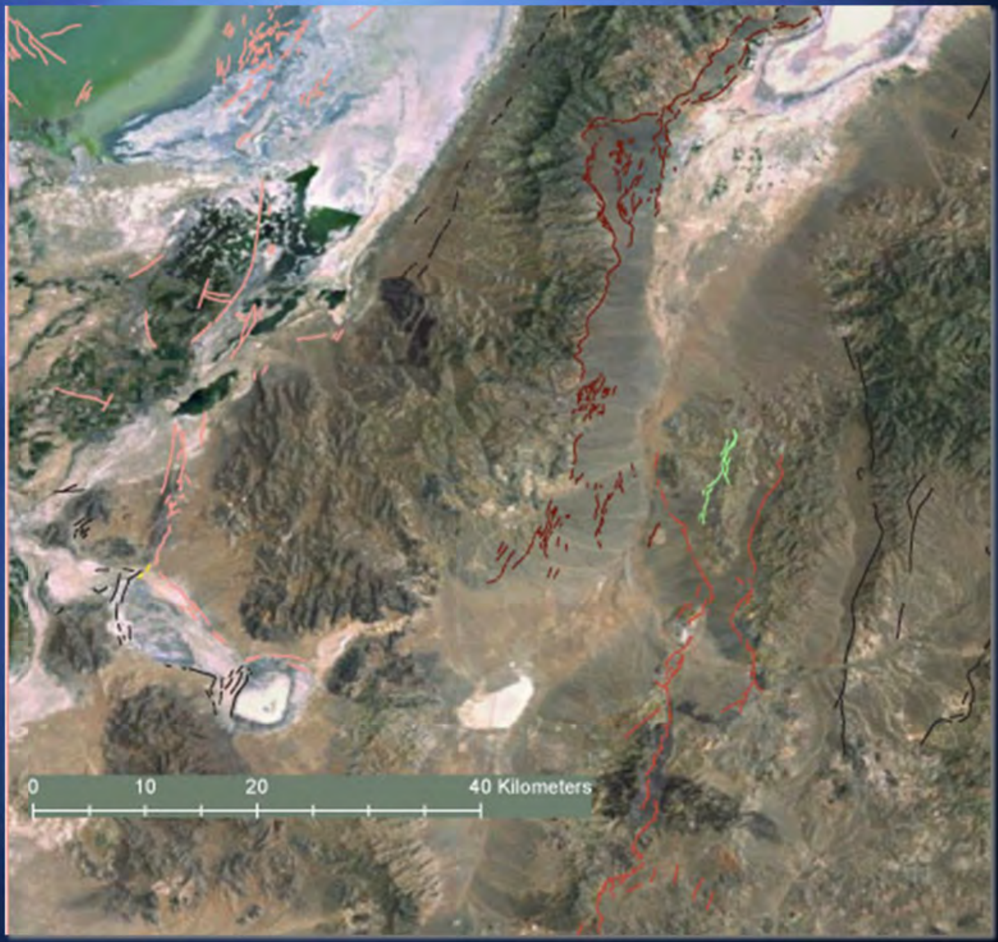


Historic surface ruptures

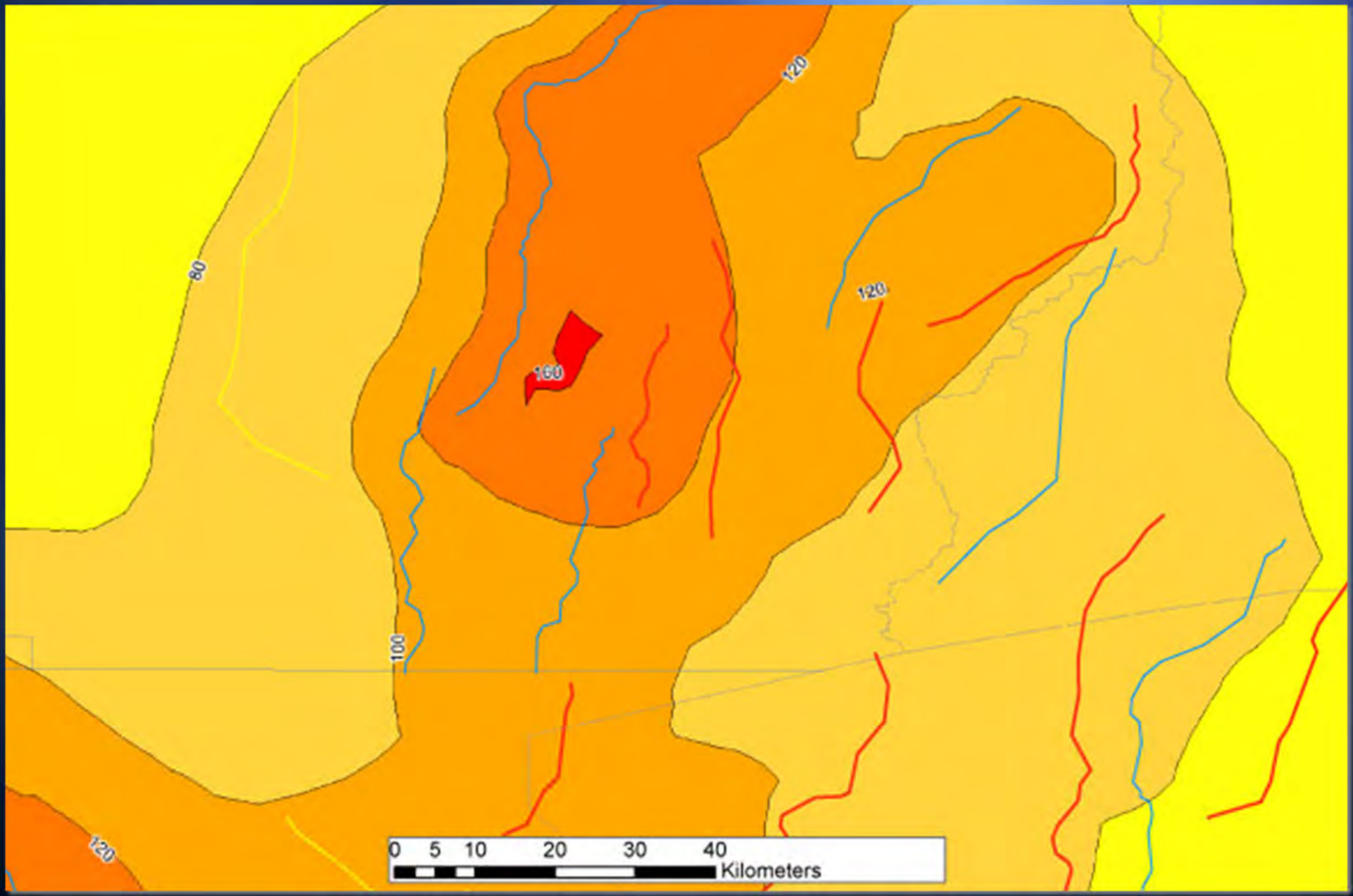


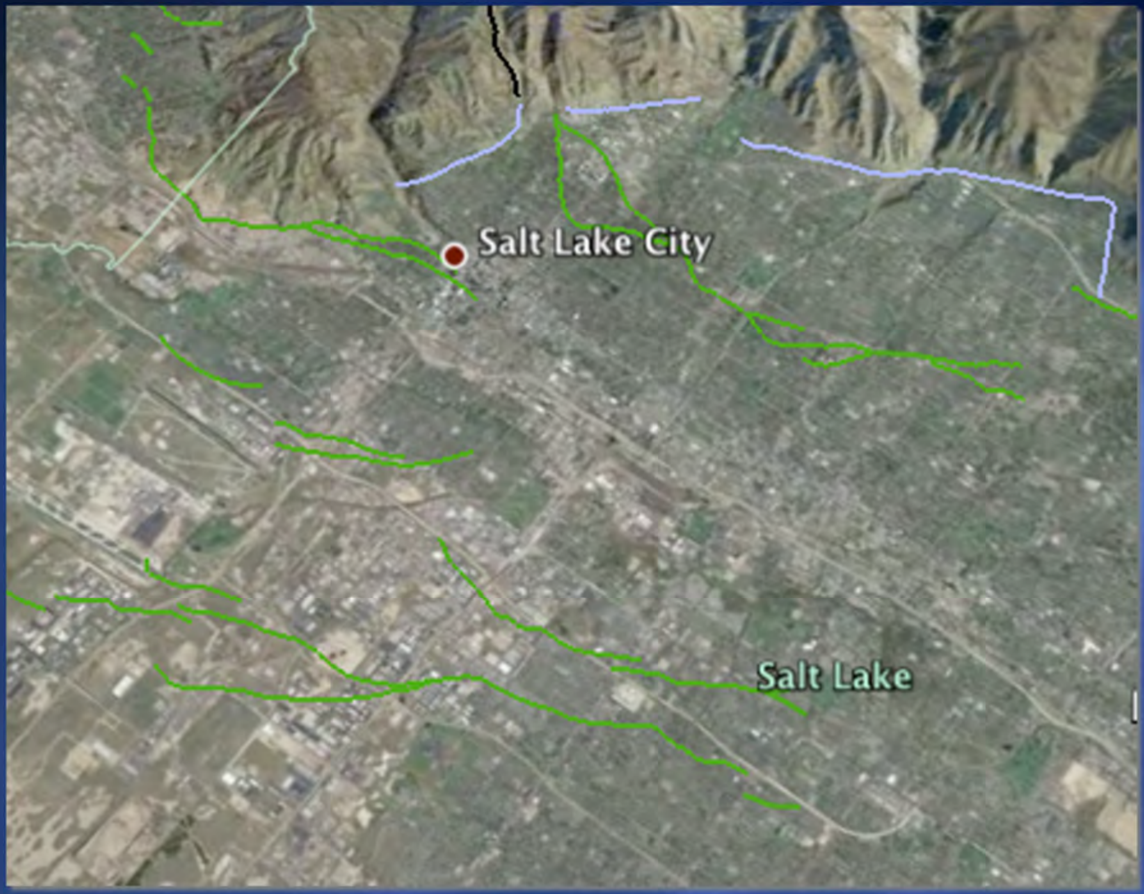
Independent and dependent ruptures

- Gold King fault dips to the west ruptured in 1903 and December 1954
- Surface rupture from Dixie Valley and Fairview Peak earthquakes occurred on multiple east and west dipping faults.
- Nearly all of these faults have clear geomorphic evidence that suggests that they are likely independent sources.



0.2-sec horizontal acceleration 2% in 50 yr





- Historic record suggests that we should not make broad assumptions
- Hansel Valley may provide one analog for the seismic potential of the West Valley fault
- We will never resolve the timing of events on the Wasatch and West Valley to rule out a Central Nevada Seismic Belt analog

Discussion of the West and East Cache faults

What do we know about their geometries and earthquake histories?

Do they potentially intersect above seismogenic depths (is coseismic rupture possible)?

How are they the same/different from the West Valley and Wasatch faults?

Chris DuRoss – Utah Geological Survey

Utah Quaternary Fault Parameters Working Group – February 10, 2009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Logan
Ogden
Salt Lake City


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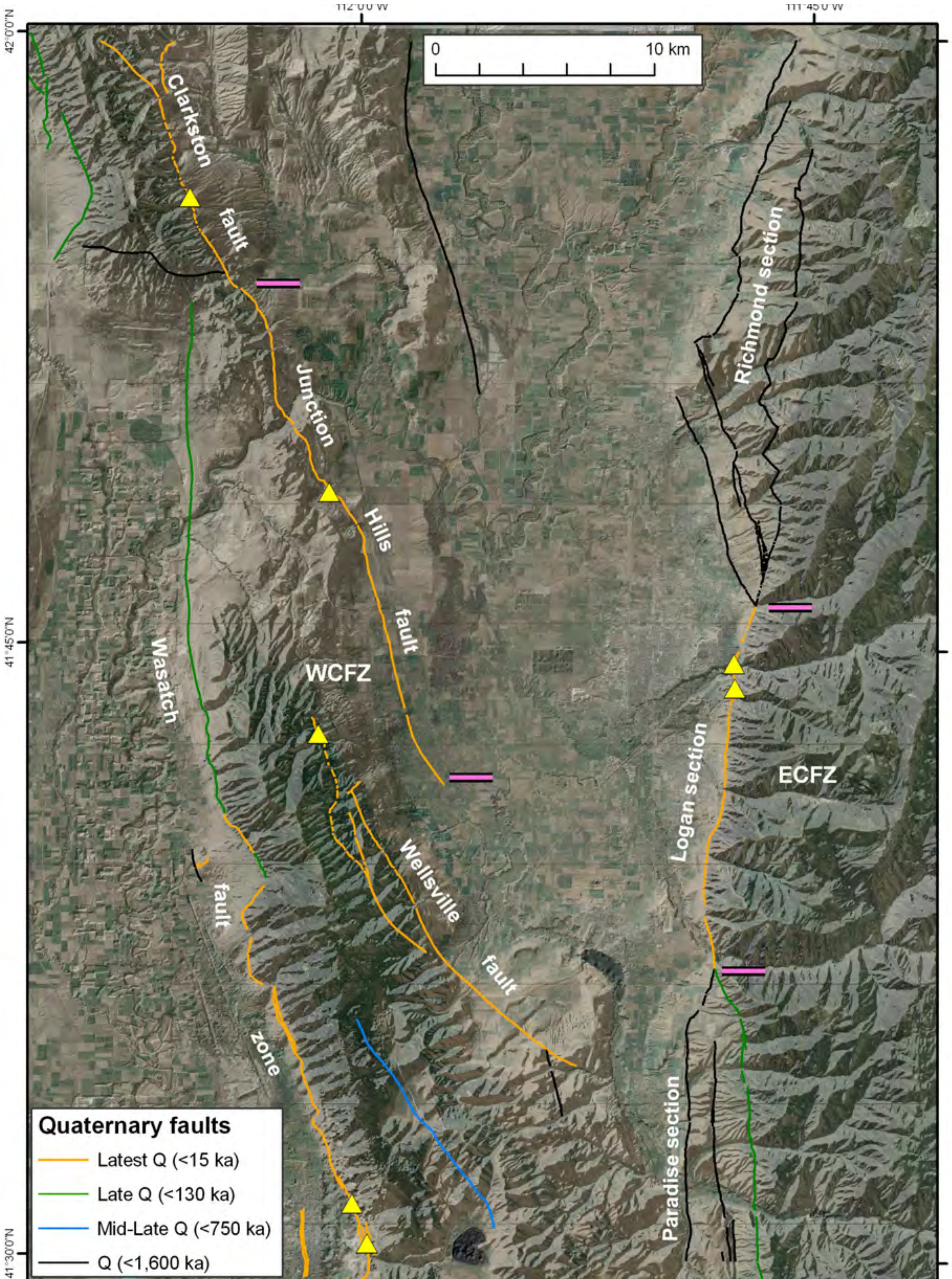
Logan
Ogden
Salt Lake City

West Cache fault zone (WCFZ)

- 59 km
- 3 sections:
  - –22 km Clarkson fault
  - –24 km Junction Hills fault
  - –20 km Wellsville fault
- 3 paleoseismic sites



East Cache fault zone (ECFZ)

- 86 km
- 4 sections:
  - –41 km Richmond
  - –16 km Logan
  - –22 km Paradise
  - –10 km James Peak
- 2 paleoseismic sites

Summary of WCFZ Paleoseismic Data

- **Clarkston fault**
  - Trench at Winter Canyon site – one event
  - **P1**: 3.6-4.0 ka (2 ^{14}C ages)
  - **P2**: unknown, but likely post-Bonneville
- **Junction Hills fault**
  - Natural exposure at Roundy Farm site – two events
  - **P1**: ~8.3-8.7 ka (1 ^{14}C age)
  - **P2**: pre-Bonneville
- **Wellsville fault**
  - Trench at Deep Canyon site – two events
  - **P1**: 4.4-4.8 ka (3 ^{14}C ages)
  - **P2**: pre-Bonneville, <25 ka (1 ^{14}C age)

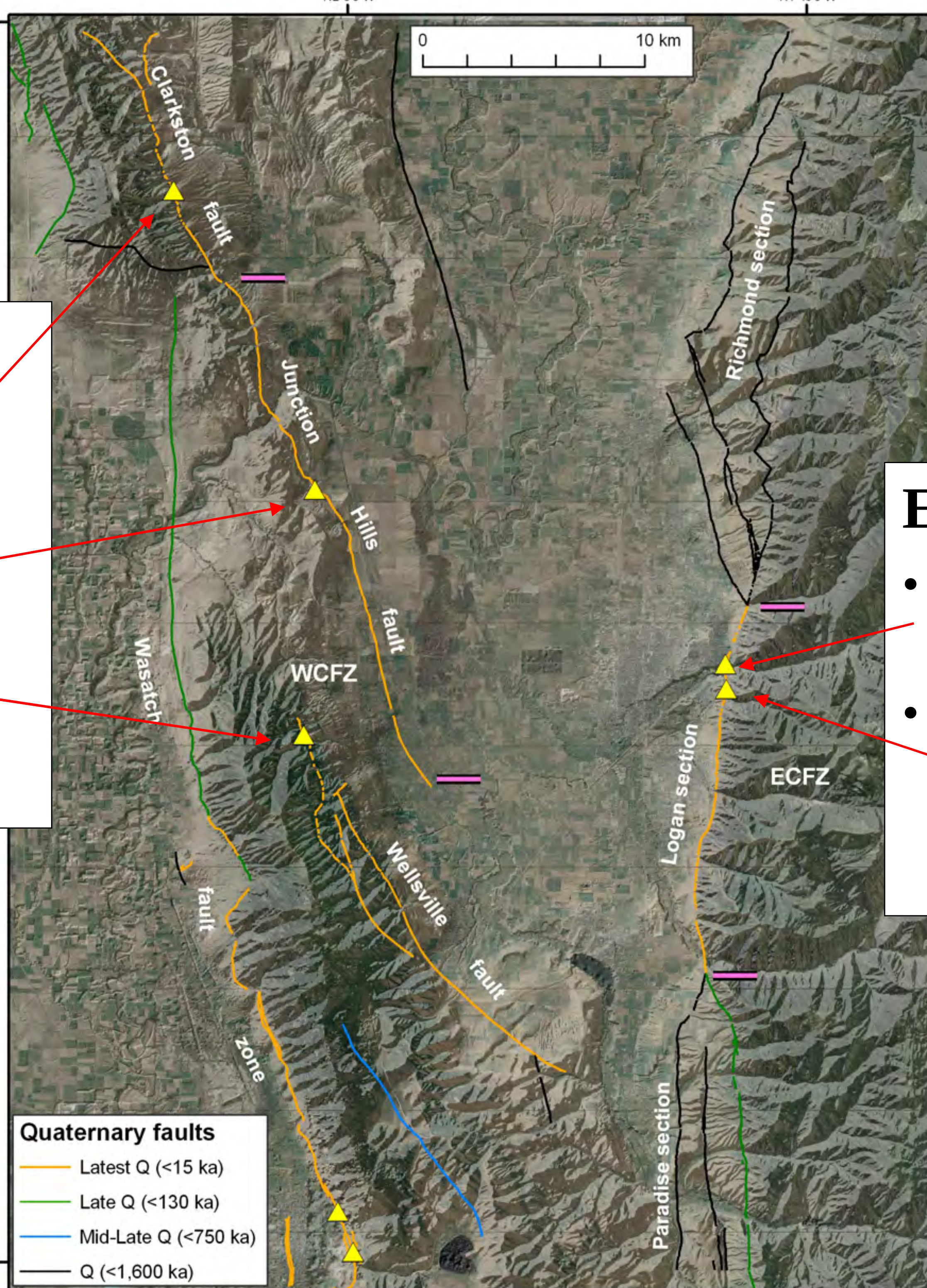
(Paleoseismic data from Black and others, 2000)

Summary of ECFZ Paleoseismic Data

- **Richmond (Northern) section**
  - No paleoseismic data
- **Logan (Central) section:**
  - McCalpin (1994) – two trenches
  - Provo trench: **P1**: 4.3-4.6 ka (3 ^{14}C ages)
  - Bonneville trench: **P2**: >7.7-9.7 ka (TL age), possibly >12 ka, <18.6 ka (1 ^{14}C age)
- **Paradise (Southern) section**
  - Work in progress
- **James Peak section**
  - Nelson and Sullivan (1992)
  - Late Pleistocene most recent earthquake

WCFZ

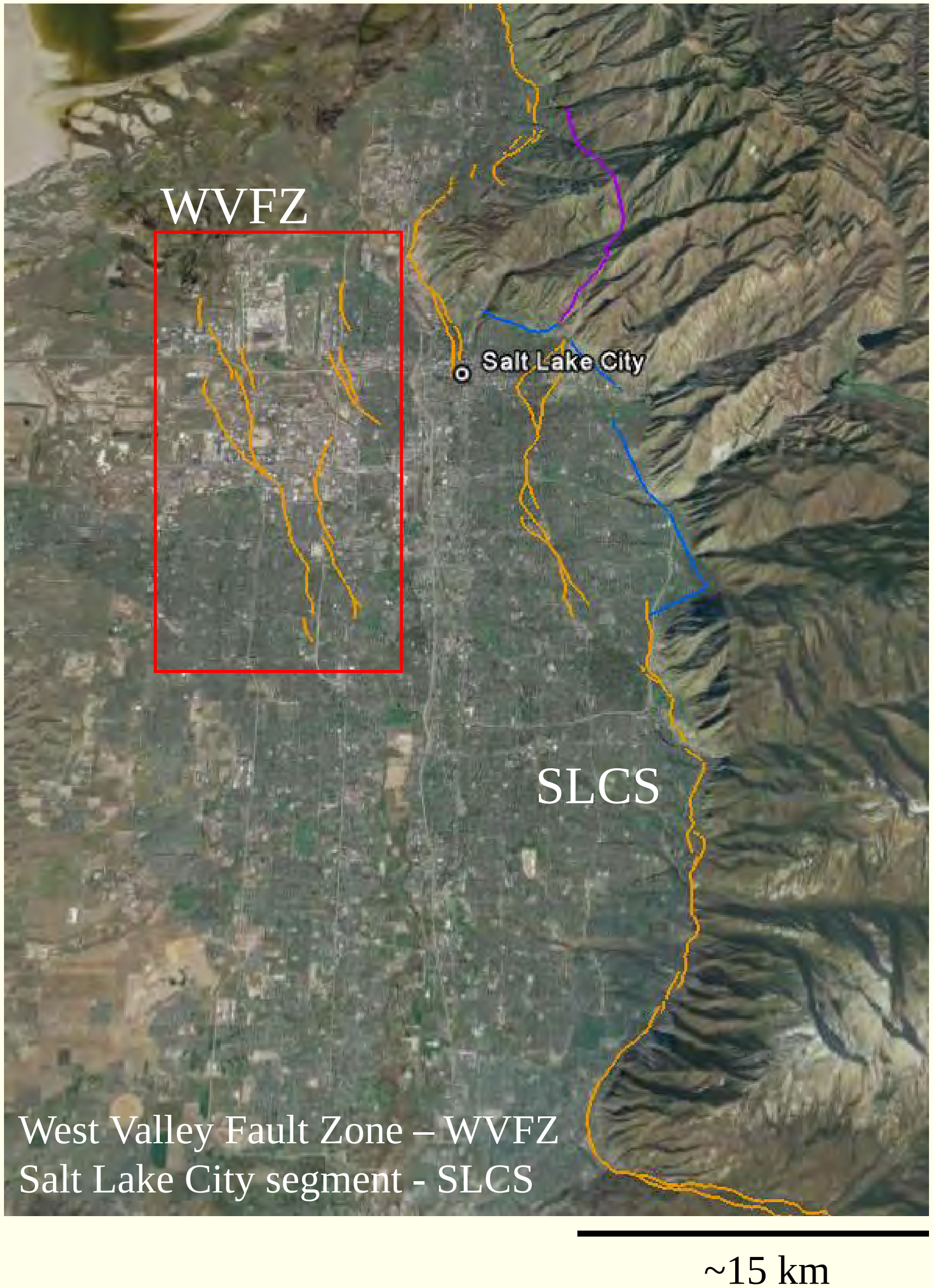
- Winter Canyon
  P1: **3.6-4.0** ka
- Roundy Farm
  P1: ~**8.3-8.7** ka
- Deep Canyon
  P1: **4.4-4.8** ka

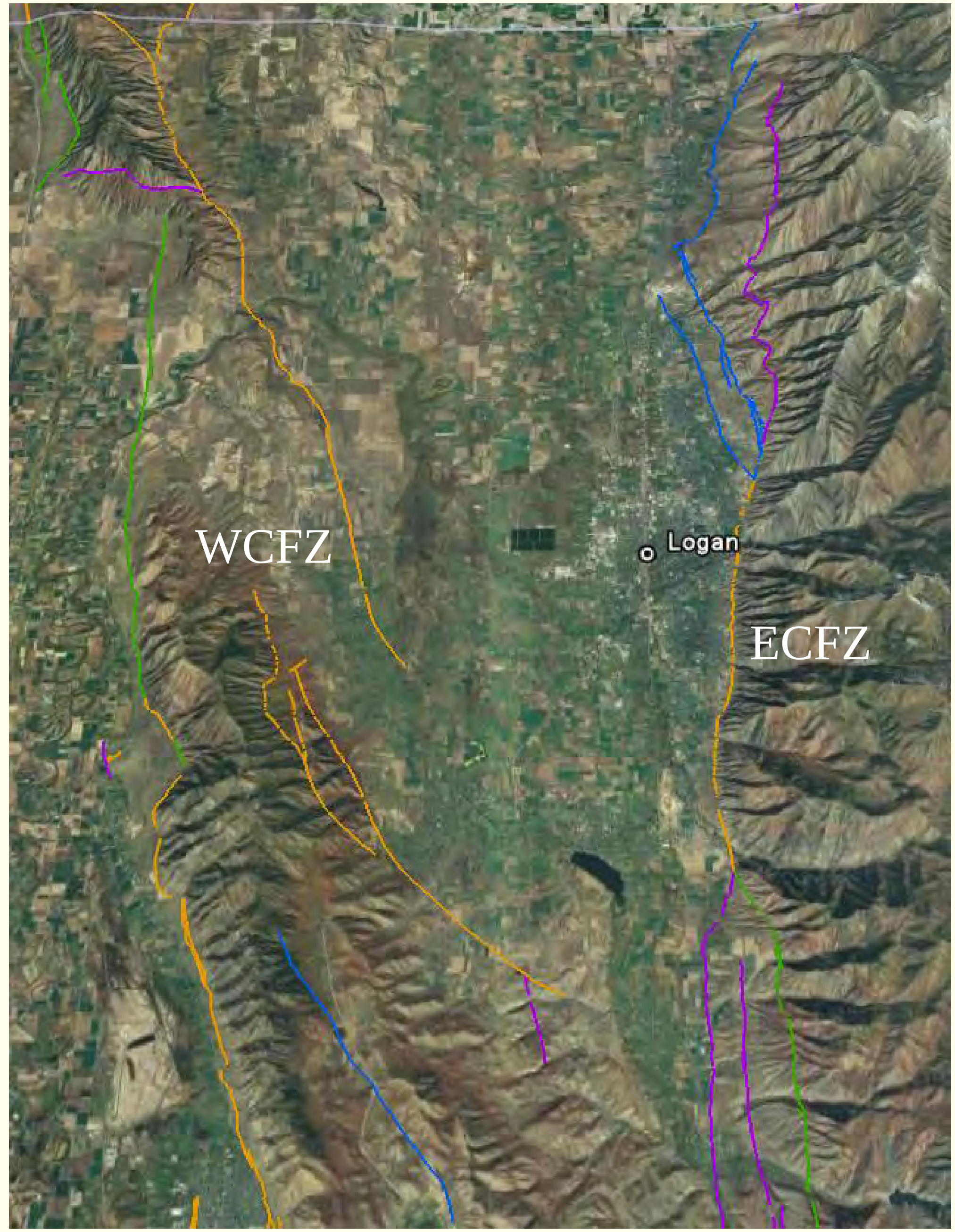


ECFZ

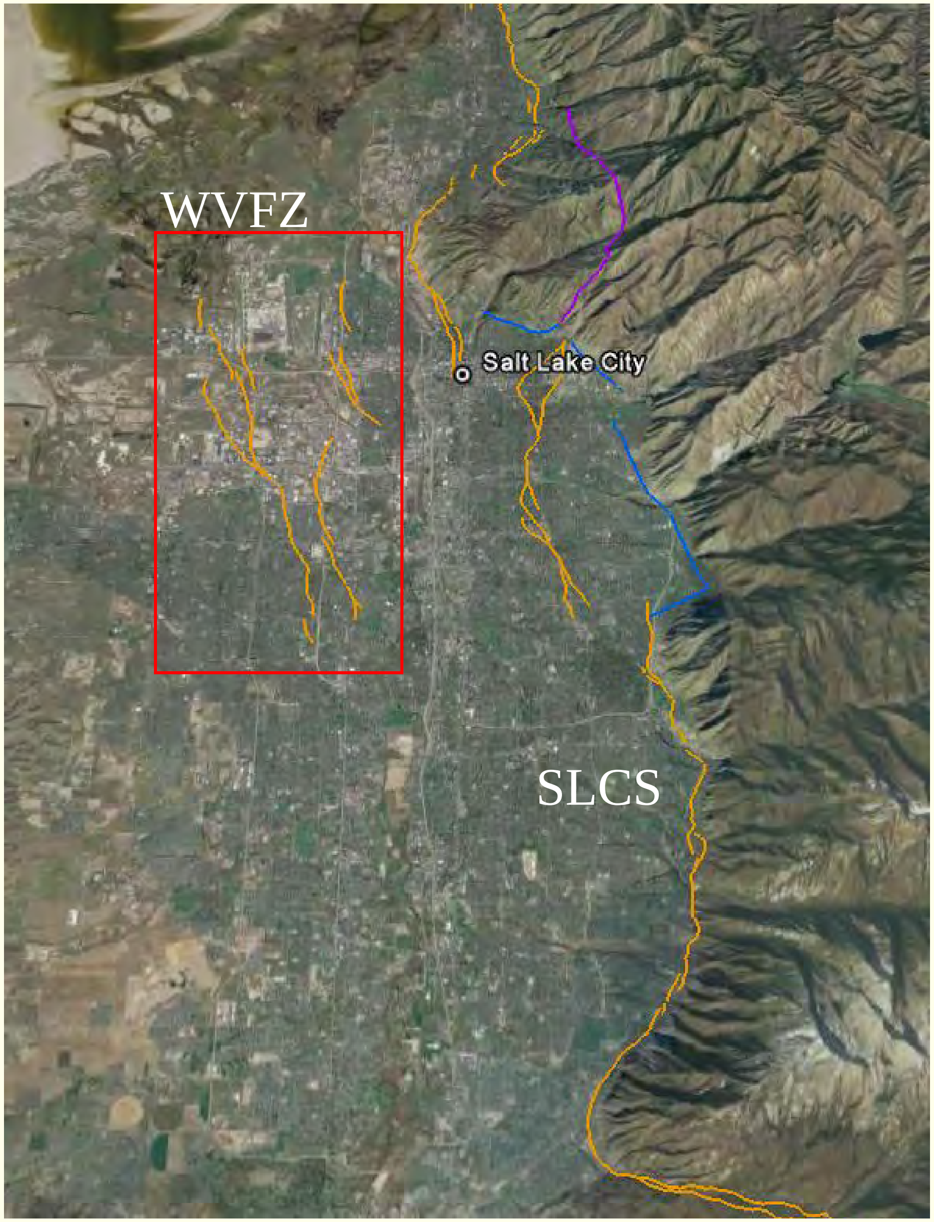
- Provo trench
  P1: **4.3-4.6** ka
- Bonneville trench
  P2: **8-19** ka

WCFZ-ECFZ versus WCFZ-SLCS





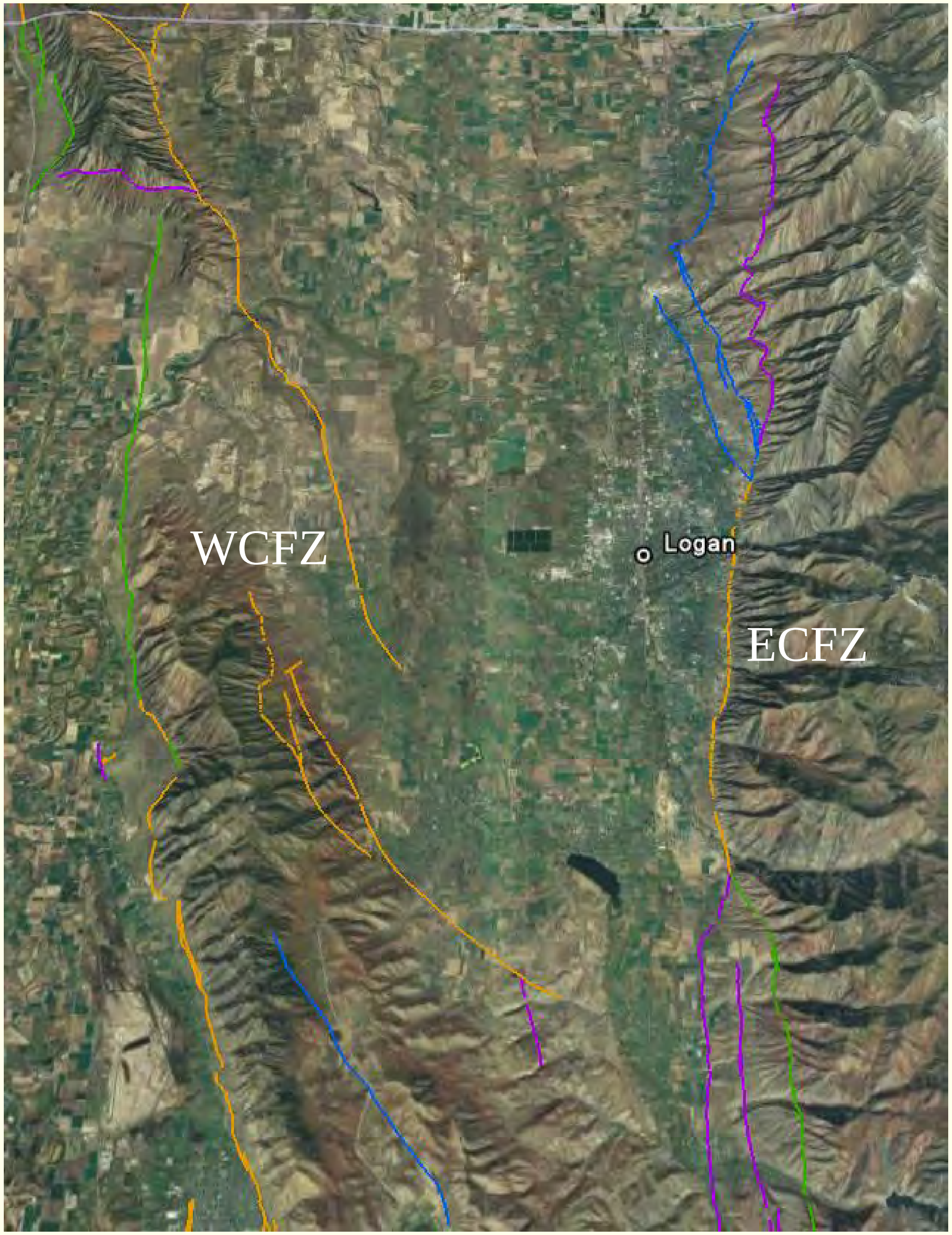
WCFZ-ECFZ versus WCFZ-SLCS



- WVFZ: short (16 km), complex, multiple dip directions
- Geometry of WVFZ mimics SLCS
- WVFZ not range bounding
- WVFZ timing similar to SLCS
- Horizontal separation ~3-12 km (average ~9 km)
- Intersection depth ~5-7 km (dip: 50 ± 10°)

WCFZ-ECFZ versus WCFZ-SLCS

- Both traces long, segmented, range-bounding
- Geometry not symmetrical: “V,” opening to the north
- Segments: different levels of Quaternary activity
- Horizontal separation ~5-30 km, 12-17 km for Holocene traces
- Intersection depth (Holocene traces) ~7-10 km (dip: 50 ± 10°)



ECFZ-WCFZ Discussion Items

- **Fault geometry**
  - Holocene-active Logan section of ECFZ overlaps with WCFZ Junction Hills and Wellsville faults sections
  - WCFZ-ECFZ are both long, segmented, range bounding faults (significantly different from West Valley FZ example)

- **Paleoseismic data**
  - **ECFZ P1** (4.3-4.6 ka) similar to **WCFZ Wellsville fault P1** (4.4-4.8 ka), though both based on a single paleoseismic site
  - Older events on both WCFZ and ECFZ broadly constrained

- **Potentially intersect above seismogenic depths?**
  - Possibly. Holocene traces are 12-17 km apart (intersection depth of 7-10 km). Entire fault traces: 5-30 km apart

- **WCFZ-ECFZ Conclusion**
  - Most recent earthquakes ~4-5 ka weakly suggest coseismic behavior; fault-trace and subsurface geometries and different levels of Quaternary activity do not.

2010 UTAH QUATERNARY FAULT RESEARCH PRIORITIES

Photo courtesy of
The Salt Lake Tribune newspaper

Hansel Valley earthquake, 1934

2009 FAULT PRIORITY LIST

2009 Highest Priority Faults/Fault Sections For Study			
Fault/Fault Section	**Priority**	**Investigation Status**	**Investigating Institution**
Provo segment – penultimate event	1	No activity	
West Valley fault zone	1	No activity	
Washington fault	3	Reconnaissance study	UGS
Carrington fault (Great Salt Lake)	4	No activity	
Rozelle section, Great Salt Lake fault	5	No activity	
Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**
Cedar City-Parowan monocline/ Paragonah fault	10	No activity	
Enoch graben	11	No activity	
Clarkston fault	13	No activity	
Wasatch Range back-valley faults	14	No activity	
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	
Bear River fault zone	2007	No activity	
Faults/Fault Sections Studies Complete or Ongoing			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**
Nephi segment WFZ	1	UGS Special Study 124/USGS Map 2966/UVSC study ongoing	UGS/USGS/UVSC
Weber segment WFZ - most recent event	3	Ongoing	UGS/USGS
Weber segment WFZ – multiple events	4	Ongoing	UGS/USGS
Utah Lake faults and folds	5	Study begins summer 2008	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
Hurricane fault	15	UGS Special Study 119	UGS
Levan	16	UGS Map 229	UGS
Brigham City section - most recent event	2007	Study begins summer 2008	UGS/USGS

Fault/Fault Section	UQFPWG Priority	Investigation Status	Investigator
Nephi segment WFZ[1,2]	1	UGS Special Study 124	UGS/USGS/UVSC
West Valley fault zone	2	No activity	
Weber segment WFZ[1]	3	On going	UGS/USGS
Weber segment WFZ – multiple event[1]	4	On going	UGS/USGS
Utah Lake faults and folds[1]	5	?	U of U
Great Salt Lake fault zone[1]	6	On going	U of U
Collinston & Clarkston Mountain segments WFZ[1]	7	UGS Special Study 121	UGS
Sevier/Toroweap fault[1]	8	UGS Special Study 122	UGS
Washington fault[3]	9	On going/reconnaissance	UGS
Cedar City-Parowan monocline/ Paragonah fault	10	No activity	
Enoch graben	11	No activity	
East Cache fault zone[1]	12	On going	USU
Clarkston fault	13	No activity	
Wasatch Range back-valley faults	14	No activity	
Hurricane fault[1]	15	UGS Special Study 119	UGS
Levan segment WFZ[1]	16	UGS Map 231	UGS
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	
Bear River fault zone	Added 2007	Reconnaissance	USGS
Brigham City segment WFZ, most recent event[1]	Added 2007	On going	UGS/USGS
Carrington fault (Great Salt Lake)	Added 2007	No activity	
Provo segment WFZ – penultimate event	Added 2007	No activity	
Rozelle section, Great Salt Lake fault	Added 2007	No activity	

[1]NEHRP funded, [2]UVSC study ongoing, [3]Proposal not funded