UTAH GEOLOGICAL SURVEY

UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP

15 April 2010 M_W 4.5 (M_L 4.9) Randolph, Utah, Earthquake
Photo courtesy of Chris DuRoss

Tuesday, February 15, 2011

www.geology.utah.gov

UQFPWG

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

2010 MEETING REVIEW

Presentations on Paleoseismic Work Completed or in Progress

- Brigham City segment, trenching update; USGS
- Washington fault northern segment, trenching update; UGS
- Washington fault Southern Beltway trenching investigation; SBI
- U.S. Bureau of Reclamation Utah fault studies update; USBR
- Bear River fault zone, trenching update; USGS
- Salt Lake City segment/West Valley fault zone investigation, progress report: UGS
- Working Group on Utah Earthquake Probabilities; UGS/URS Corp.

2010 MEETING REVIEW

(Continued)

Technical Discussion Item

An Updated Chronology of Surface-Faulting Earthquakes on the Weber Segment, Wasatch Fault Zone; Chris DuRoss, UGS/Steve Personius, USGS

2011 FAULT PRIORITY LIST

2011 Highest Priority Faults/Fault Sections For Study			
Fault/Fault Section	**Priority**	**Investigation Status**	**Investigating Institution**
Warm Springs fault/East Bench fault subsurface geometry and connection	1	No activity	
Penultimate event Provo segment WFZ	2	Trench site reconnaissance	UGS
Long-term earthquake record Nephi segment WFZ	3	No activity	
Washington fault	4	Two trenching investigations	UGS/Simon-Bymaster
Mid- to late-Holocene earthquake chronology southern part Weber segment WFZ	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	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (submerged beneath Great Salt Lake)	2007	No activity	
Rozelle section, fault (submerged beneath Great Salt Lake)	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 UVU study ongoing	UGS/USGS/UVU
West Valley fault zone	2	Study funded for 2010	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Study funded 2009	UUGG
East Great Salt Lake fault zone	6	Ongoing	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
East Cache fault zone	12	Ongoing	USU
Wasatch Range back-valley faults	14	Ongoing	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Ongoing	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north end	2009	Study funded for 2010	UGS/USGS

AGENDA

QUATERNARY FAULT PARAMETERS WORKING GROUP

Tuesday, February 15, 2011

Utah Department of Natural Resources Building, Room 2000 (2nd floor)

1594 West North Temple, Salt Lake City

7:30 Continental breakfast

8:00 Introduction, overview of meeting, review of last year's activities

8:15 Technical presentations of work completed or in progress

- 8:15 – Salt Lake City segment trenching update; Chris DuRoss, UGS
- 8:45 – West Valley fault zone trenching update; Mike Hylland, UGS
- 9:15 – Nephi segment trenching update; Danny Horns, UVU.
- 9:45 – Joes Valley fault zone update; Lucy Piety, USBR

10:15 Break

10:30 Technical presentations of work completed or in progress

- 10:30 – East Canyon & East of East Canyon (Main Canyon) fault updates; Lucy Piety, USBR
- 11:00 – Interactive Utah Quaternary fault map; Cory Unger/Mike Hylland, UGS
- 11:30 – East Cache fault zone trenching update; Jim Evans, USU

12:00 Lunch

AGENDA
(Continued)

1:00 Technical presentations of work completed or in progress

1:00 – Utah Lake faults study update; Dave Dinter, UU

1:20 – Working Group on Utah Earthquake Probabilities update; Ivan Wong, URS/Bill Lund, UGS

1:50 – Revised Wasatch fault zone earthquake timing and recurrence; Chris DuRoss, UGS

2:40 – Implementation: The third dimension of Seismic Hazard Mitigation; Ron Harris, BYU

3:00 Break

3:15 Technical discussion item

Recommendations (?) to the USGS for the National Quaternary Fault and Fold Map regarding the Joes Valley fault zone and the East Canyon & East of East Canyon (Main Canyon) faults – discussion

3:45 UQFPWG 2012 fault study priorities

4:45 Adjourn

Preliminary results from the Penrose Drive trench on the Salt Lake City segment

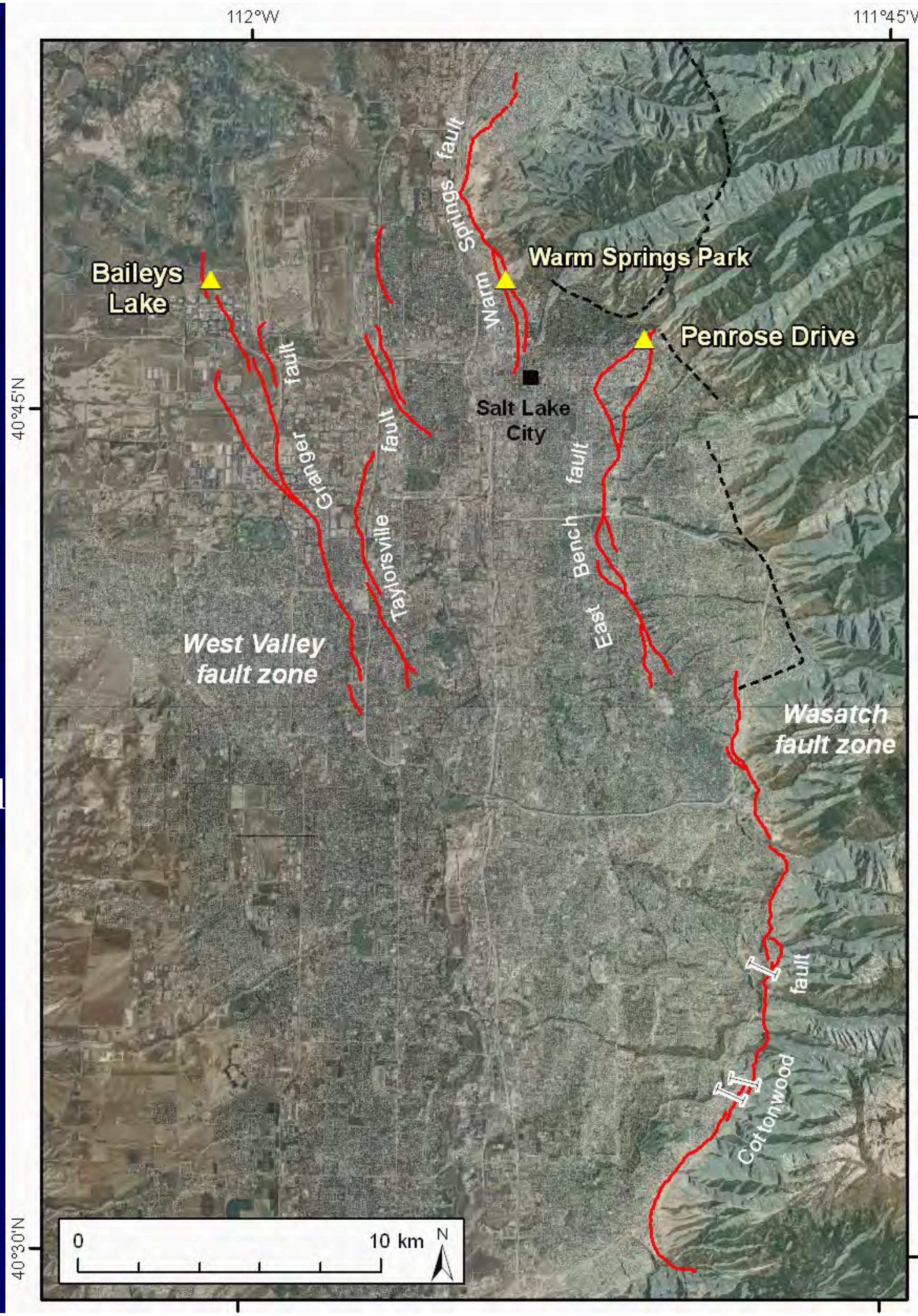
Chris DuRoss, Mike Hylland, Greg McDonald (UGS),
Tony Crone, Steve Personius, Ryan Gold, and Brad King (USGS)

Utah Quaternary Fault Parameters Working Group, Feb. 2011

Wasatch and West Valley Fault Zones

- **Ongoing studies:**
  - Penrose Drive (SLCS)
  - Baileys Lake (WVFZ)

- **Primary goals:**
  - Resolve the timing and displacement of individual surface-faulting earthquakes on the northern part of the SLCS and the WVFZ
  - Clarify the seismogenic relation (dependent or independent) between these two faults.



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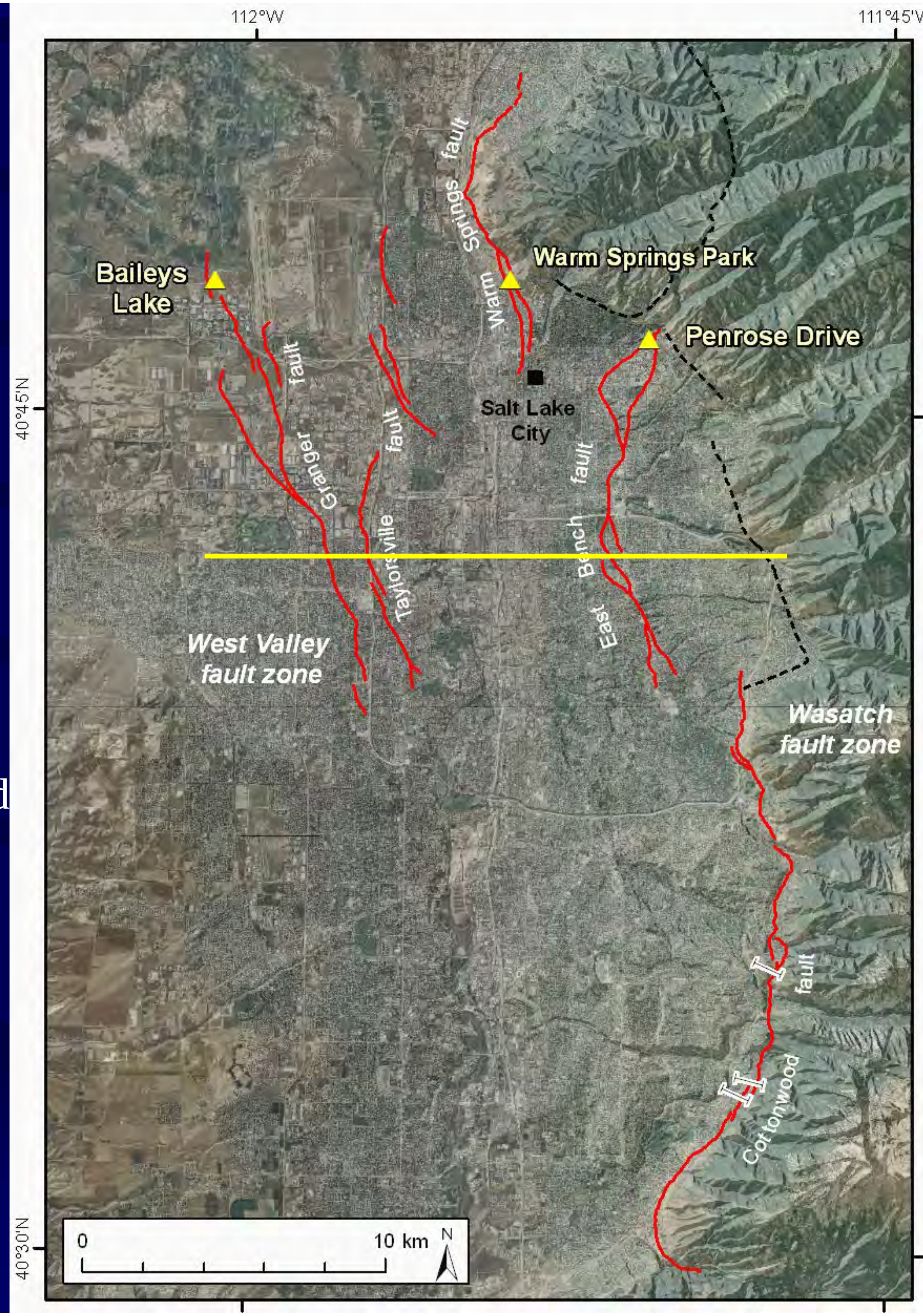
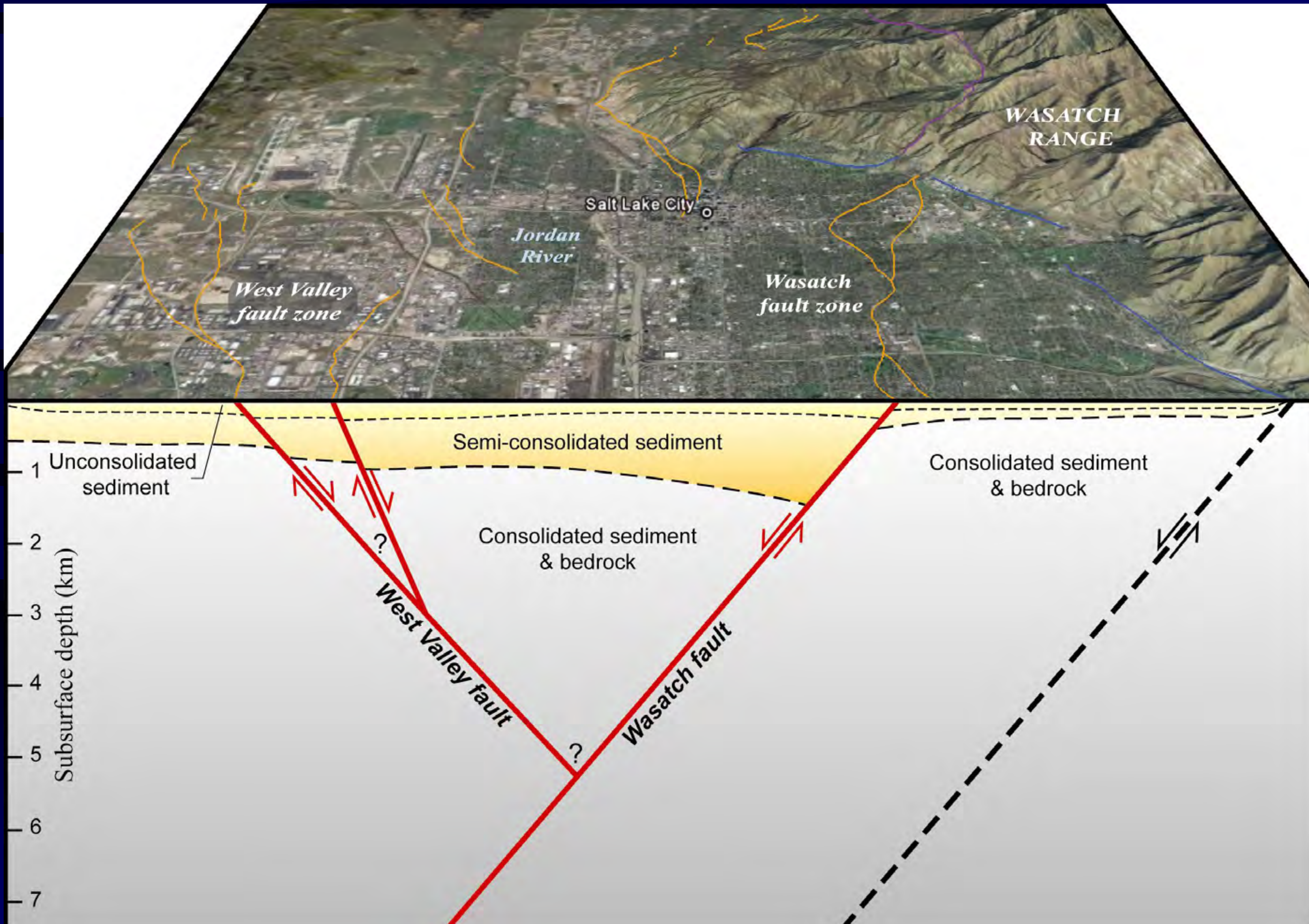
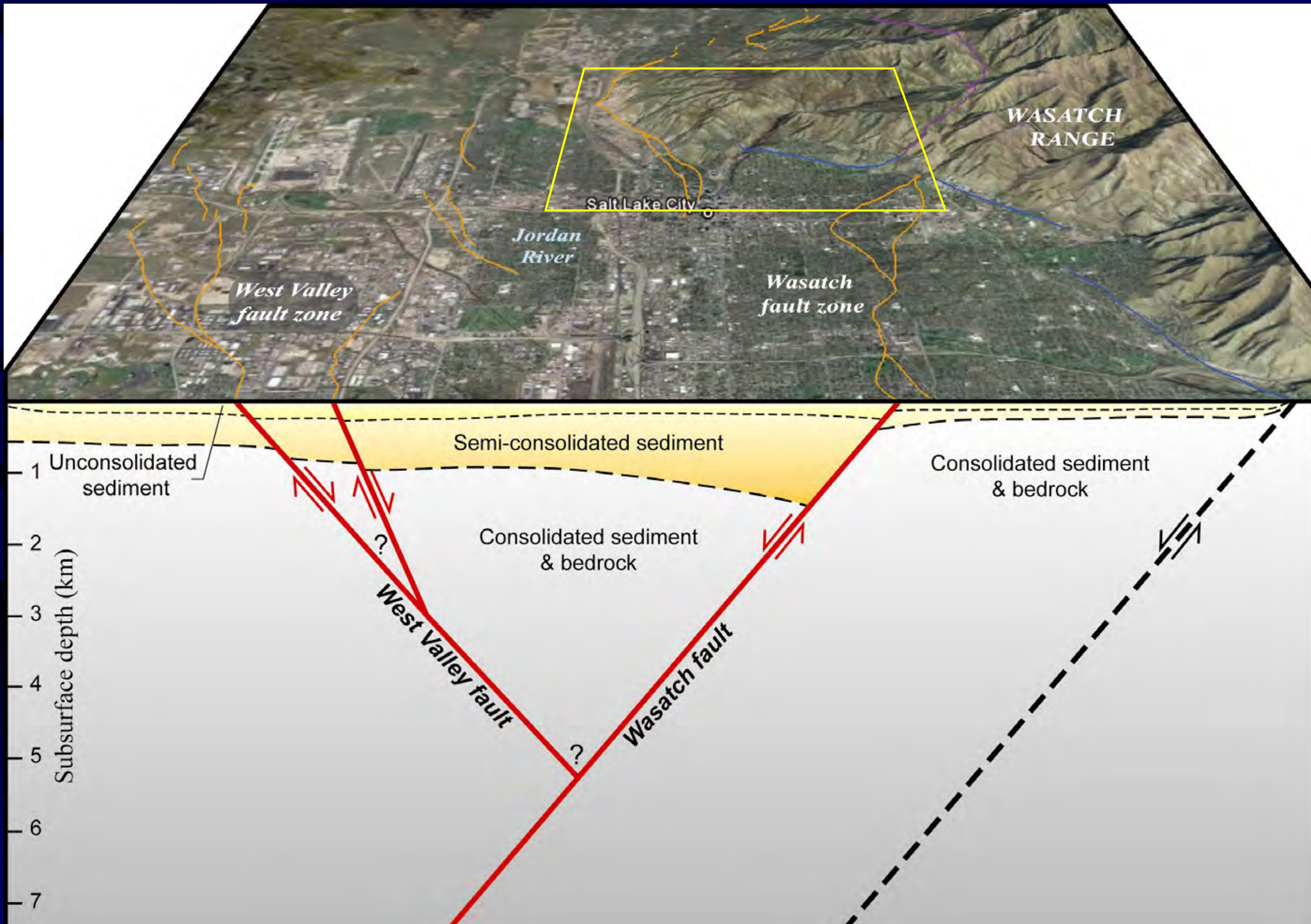
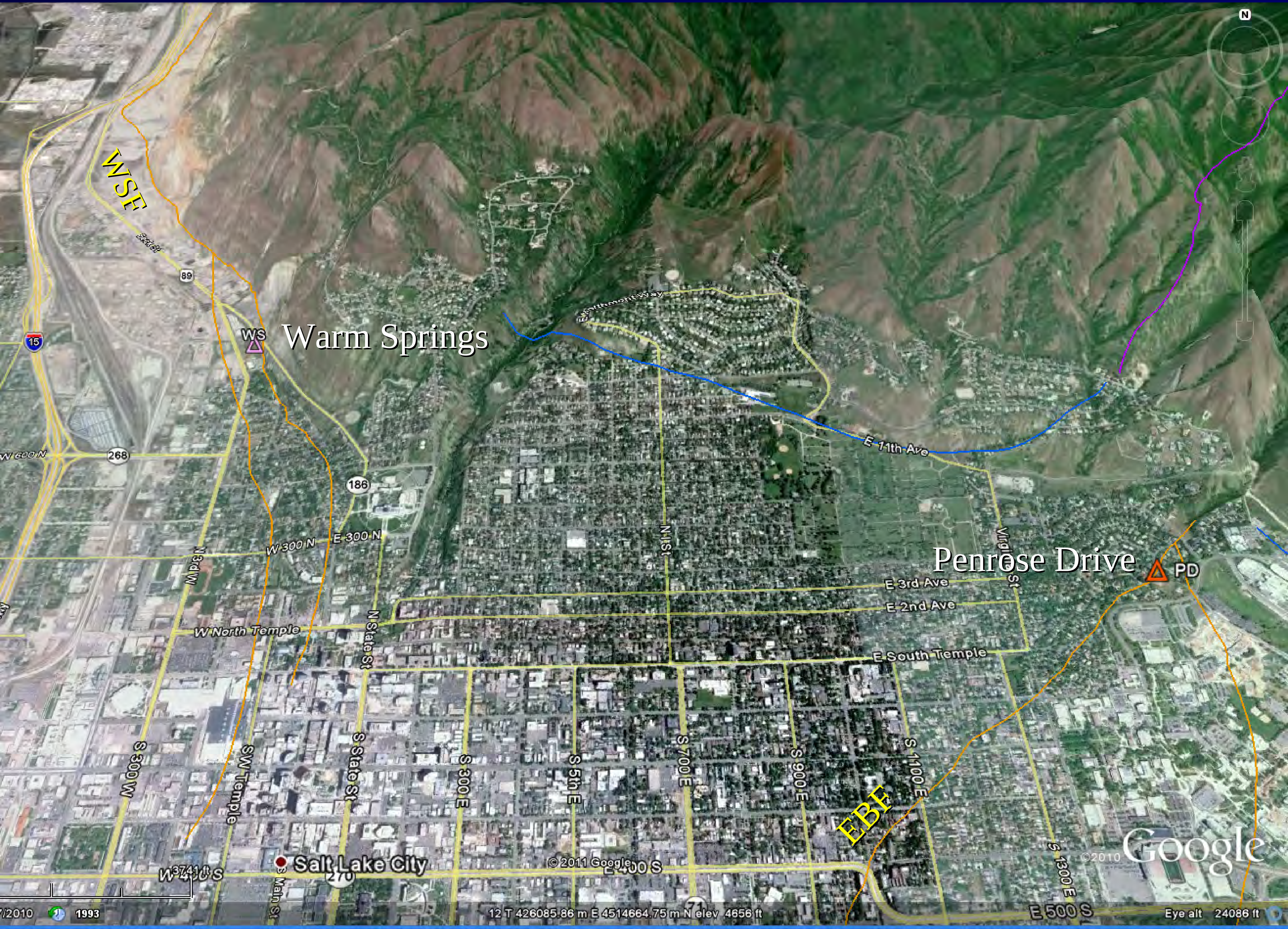


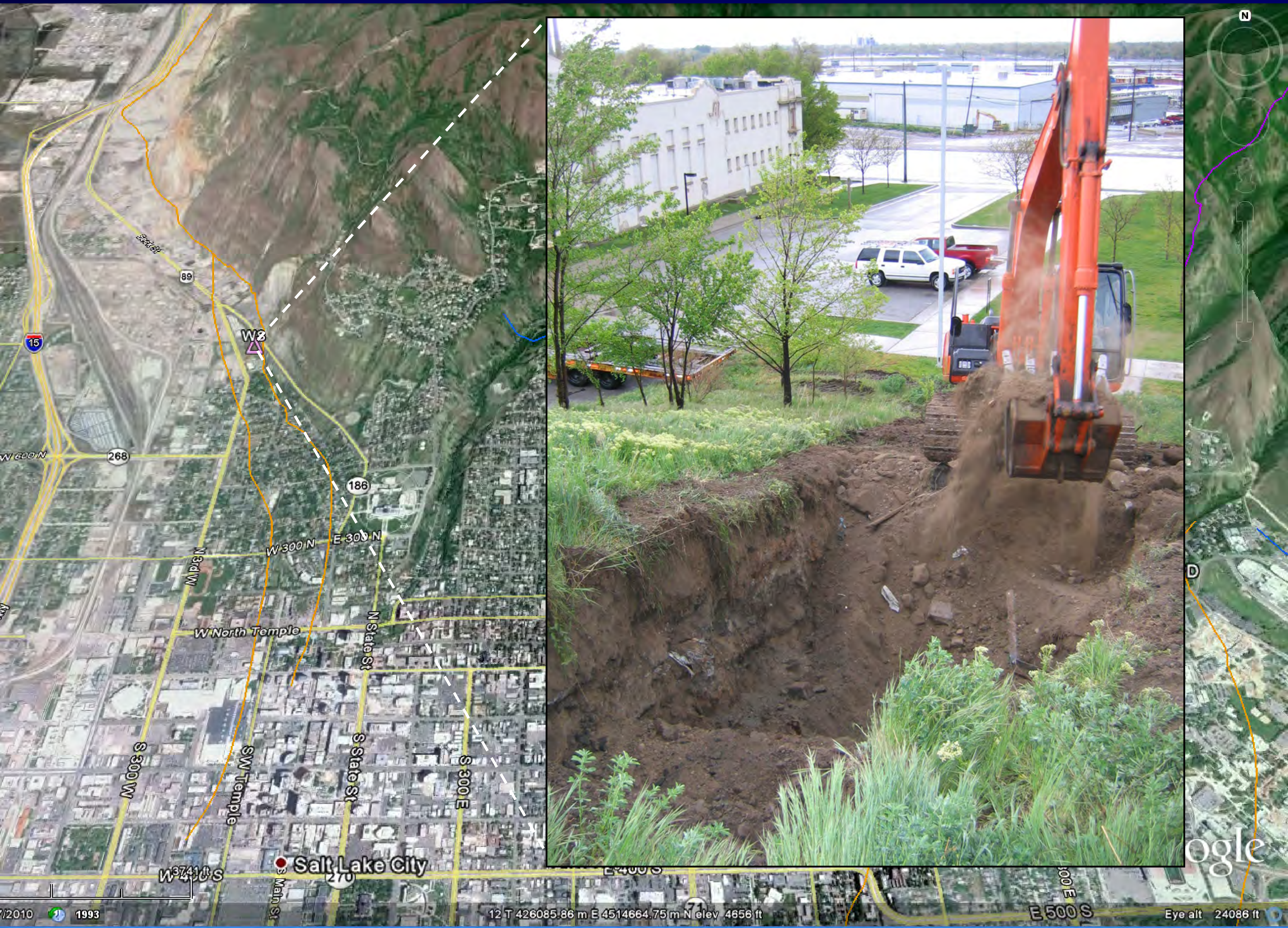
Salt Lake Valley



Salt Lake Valley




WSF
Warm Springs
WS
Penrose Drive
PD
EBF
Salt Lake City
E 11th Ave
E 3rd Ave
E 2nd Ave
E South Temple
W North Temple
W 300 N
E 300 N
N State St
S State St
N 1st St
S 300 E
S 500 E
S 700 E
S 900 E
S 1100 E
S 1300 E
S 300 W
N 3rd W
S W Temple
S Main St
W 400 S
E 400 S
E 500 S
Virginia St
W 600 N
12 T 426085.86 m E 4514664.75 m N elev 4656 ft
Eye alt 24086 ft
© 2011 Google
Google



W8
15
89
268
186
W 600 N
W 300 N
E 300 N
N State St
W North Temple
S 300 W
S W Temple
S State St
S 300 E
Salt Lake City
W 400 S
E 400 S
E 500 S
270
1993
12 T 426085.86 m E 4514664.75 m N elev 4656 ft
Eye alt 24086 ft

Penrose Drive Site

- **East Bench fault**
  - Fault trace and Holocene activity well known from mapping and consultant's trenches
  - Timing of individual events unknown
- **Last remaining unmodified scarp on the East Bench fault!**

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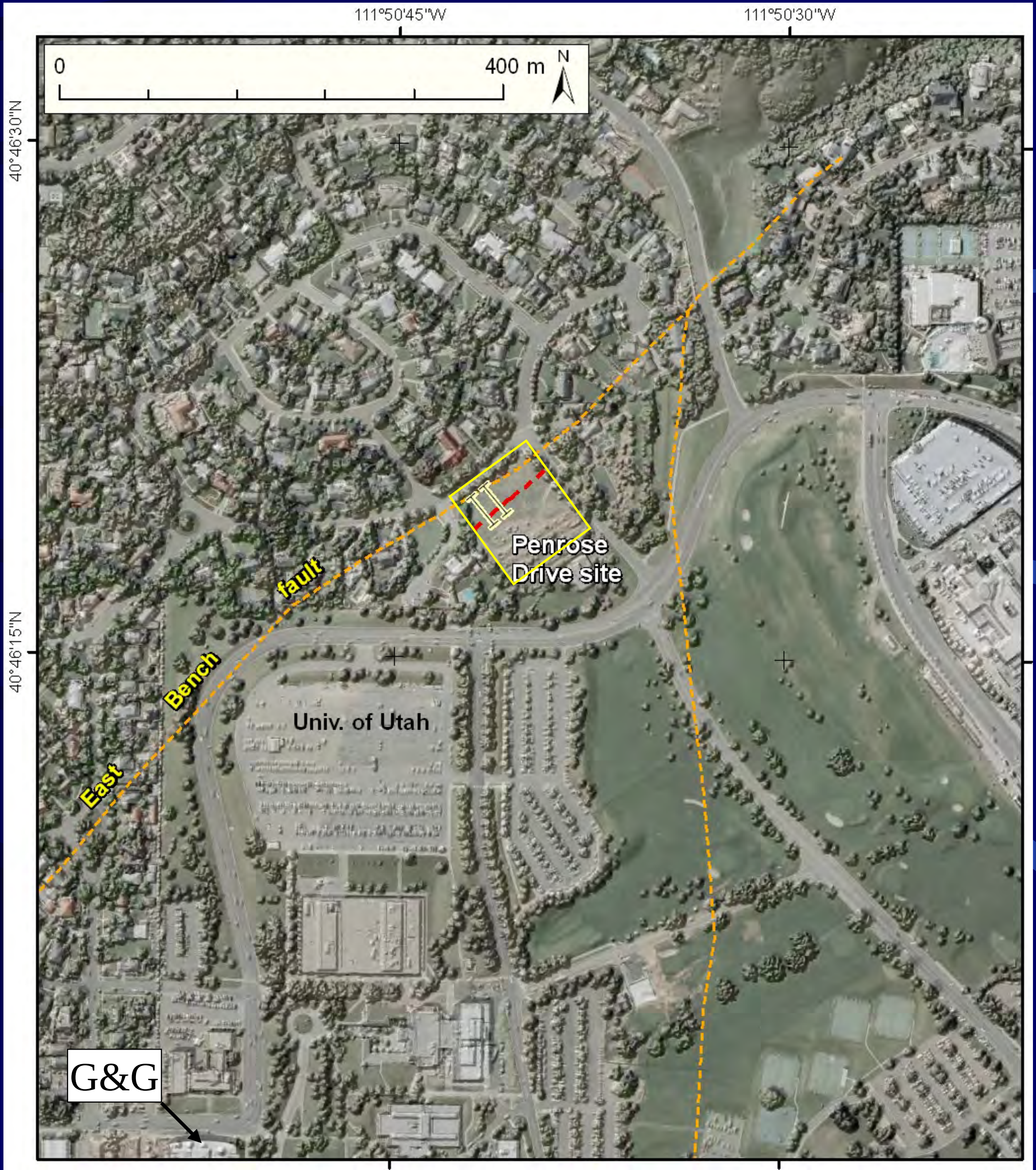
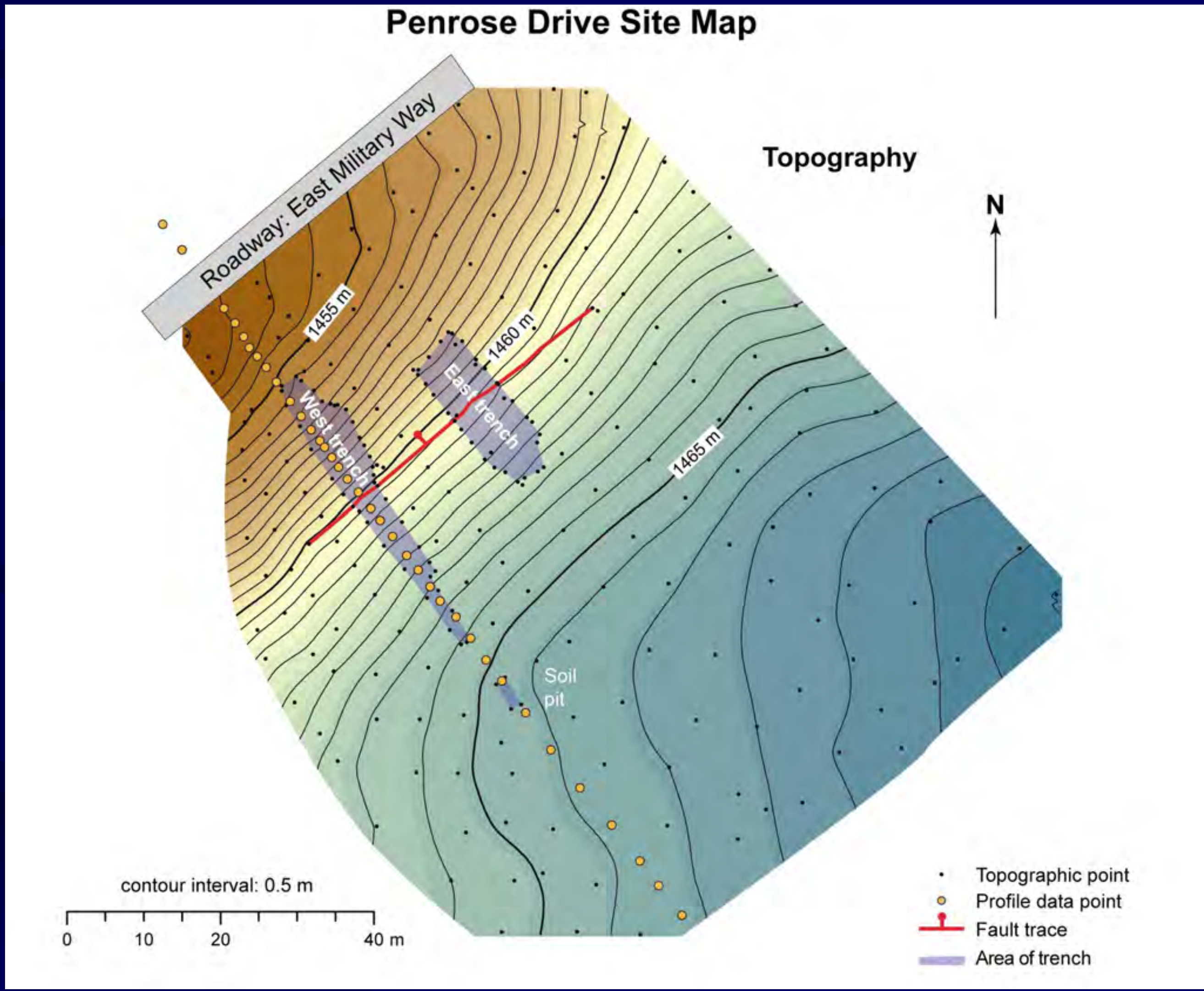


Penrose Drive Site

- **Northwest facing scarp**
  - Apparently unmodified
  - Upper surface near elevation of Provo shoreline of Lake Bonneville (~4800 ft)

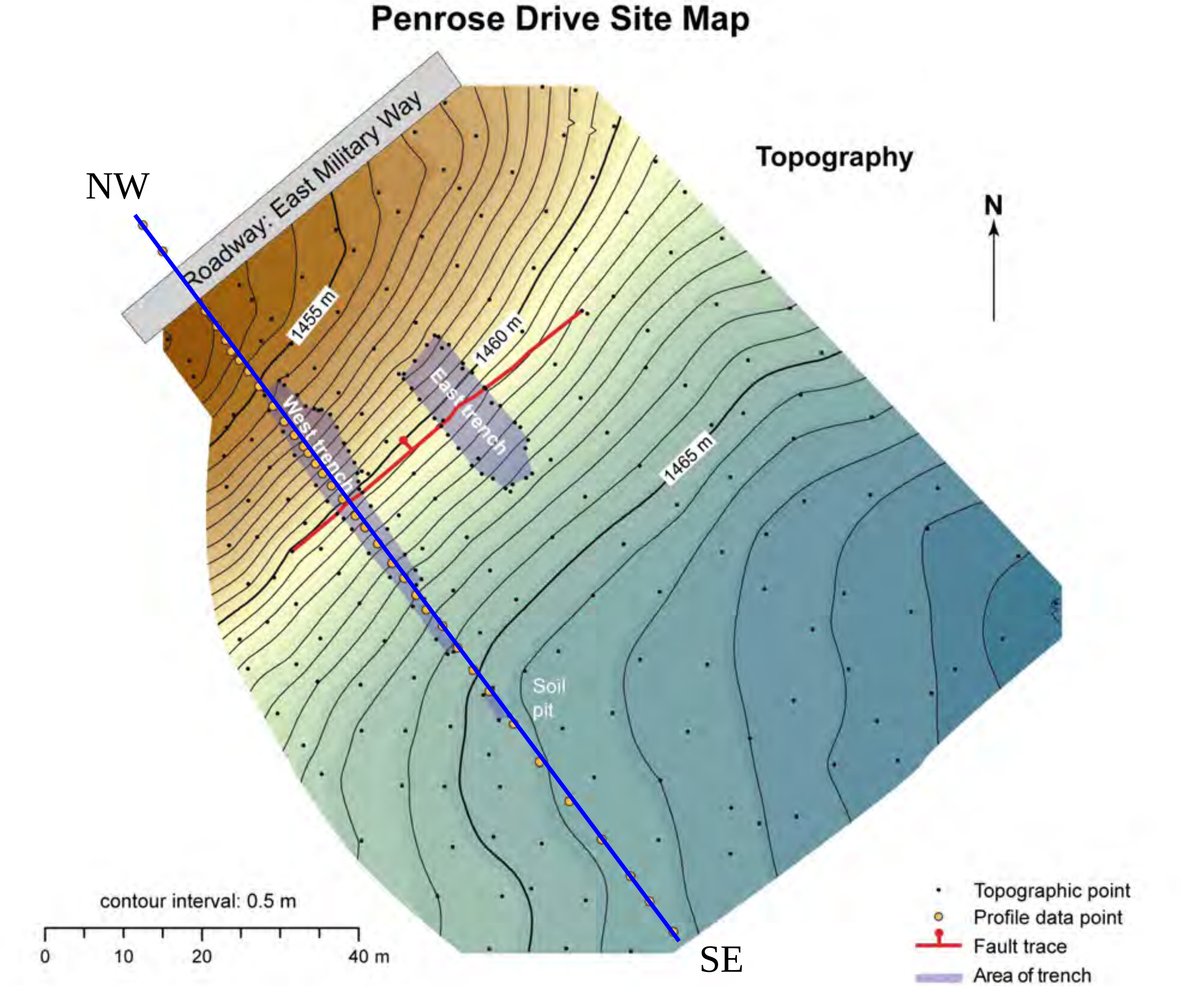
- **Two trenches:**
  - West trench (36 m)
  - East trench (11 m)

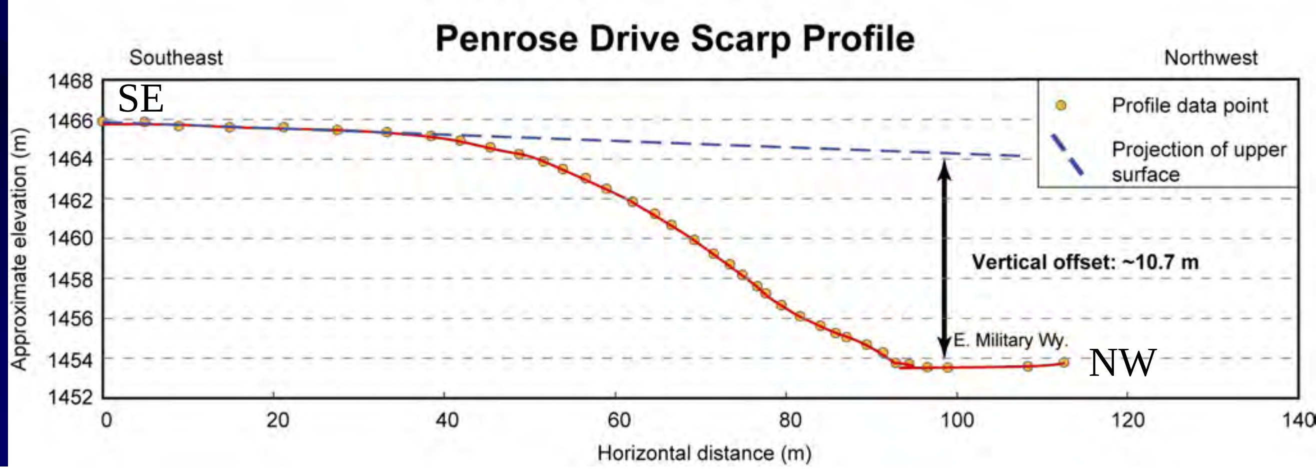


Penrose Drive Site

- **Scarp vertical offset ~11 m**

- **Questions:**
  - Correlative surfaces?
  - Lower surface modified?



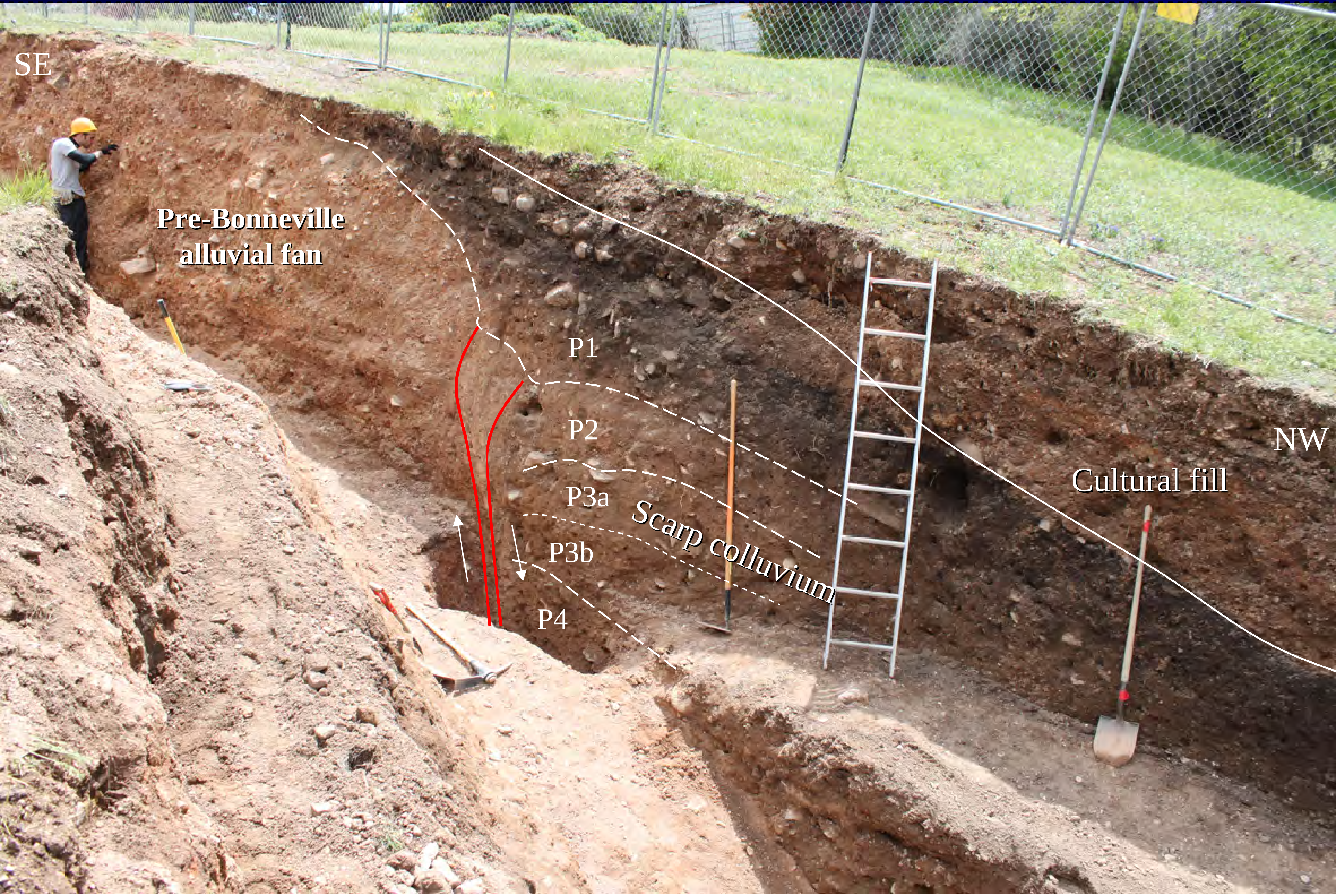


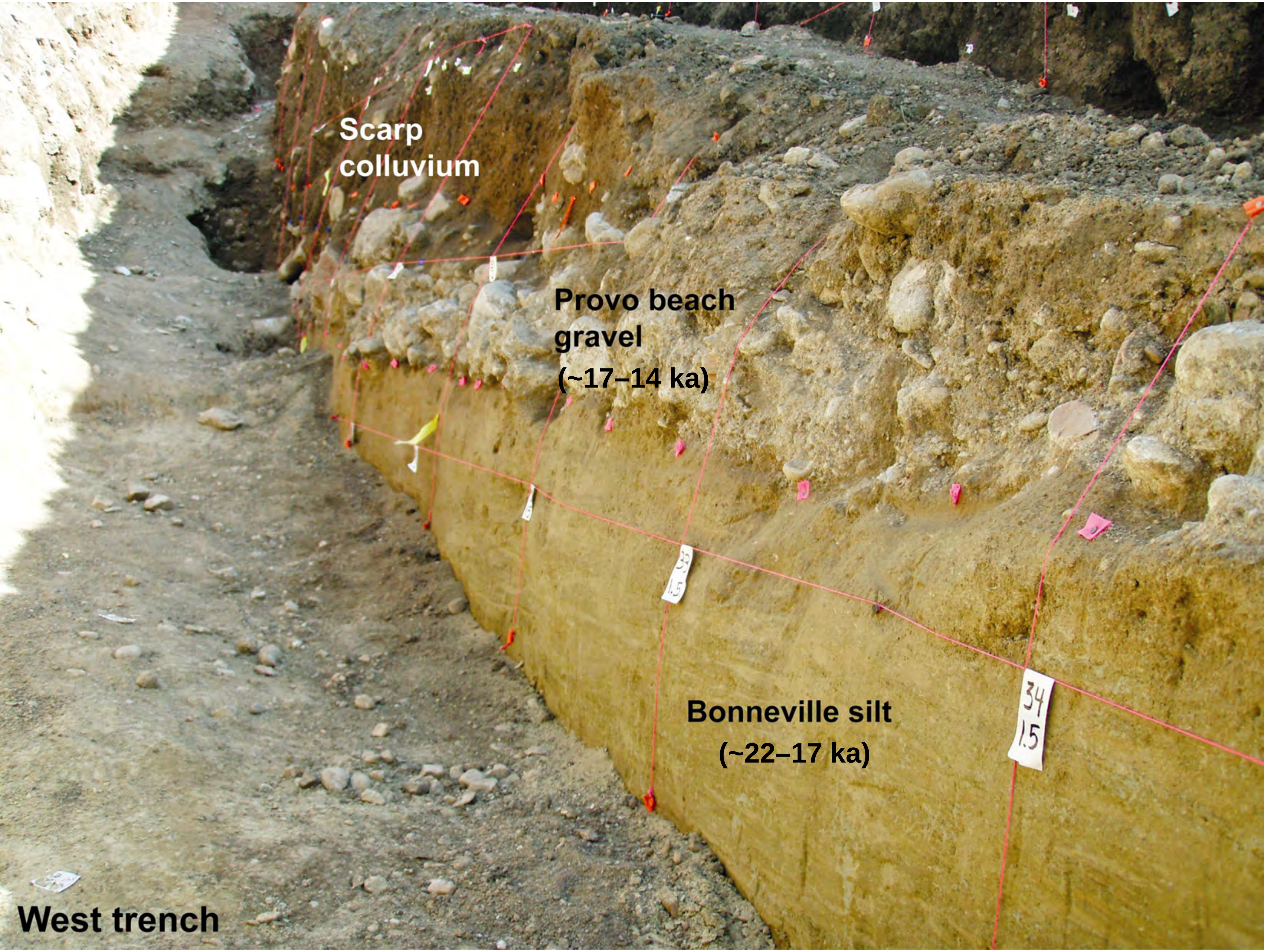
Penrose Drive Site

View to the southwest

West Trench

West Trench


SE
Pre-Bonneville alluvial fan
P1
P2
P3a
P3b
P4
Scarp colluvium
Cultural fill
NW

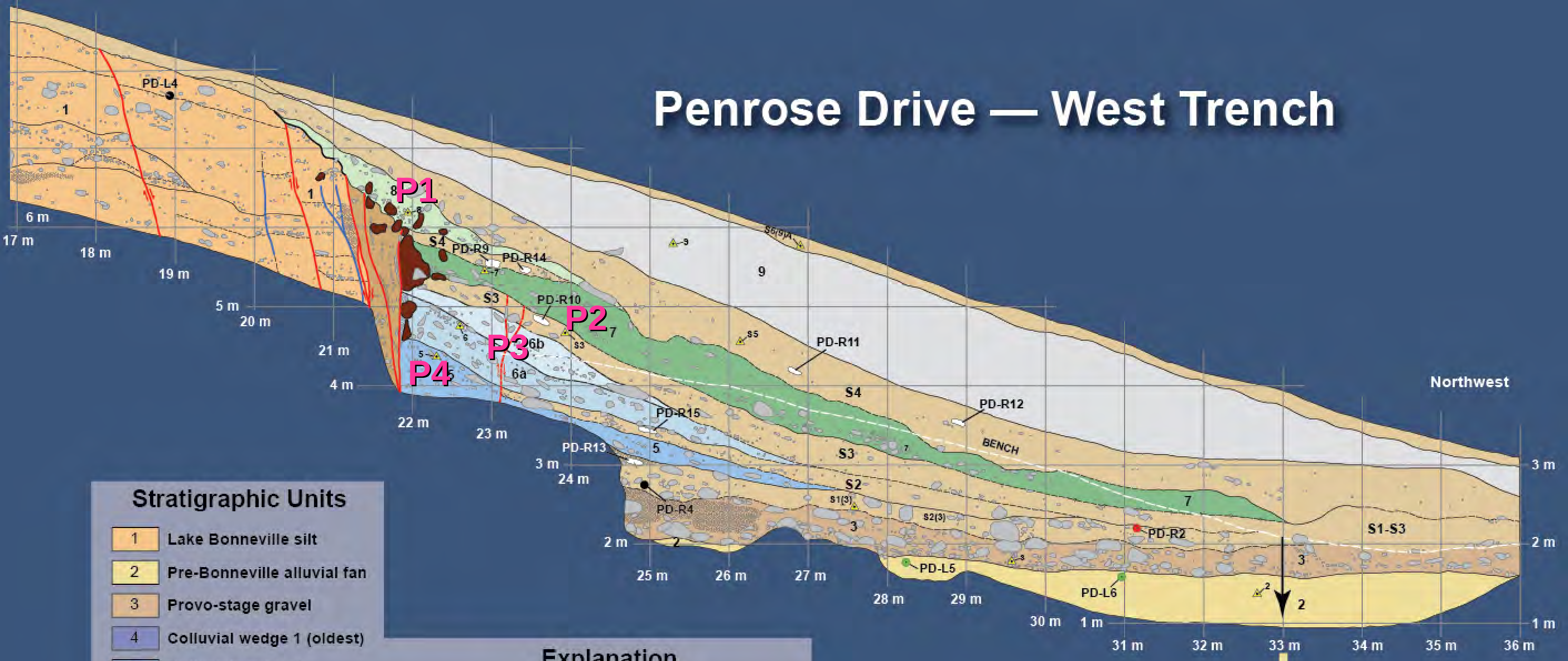

Scarp colluvium
Provo beach gravel
(~17–14 ka)
Bonneville silt
(~22–17 ka)
West trench
33
1.5
34
1.5

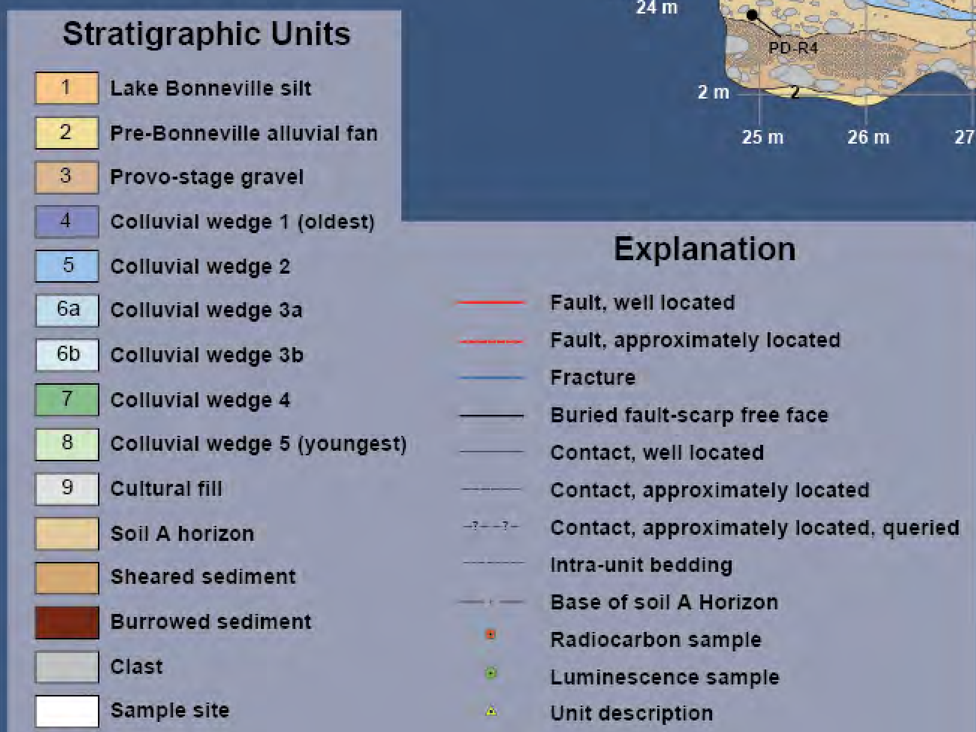
West Trench

- **Where are the pre-Bonneville fan gravels in the fault hanging wall?**

- **5.9-m deep auger hole**
  - At refusal: no fan gravels; only Bonneville silt/sand

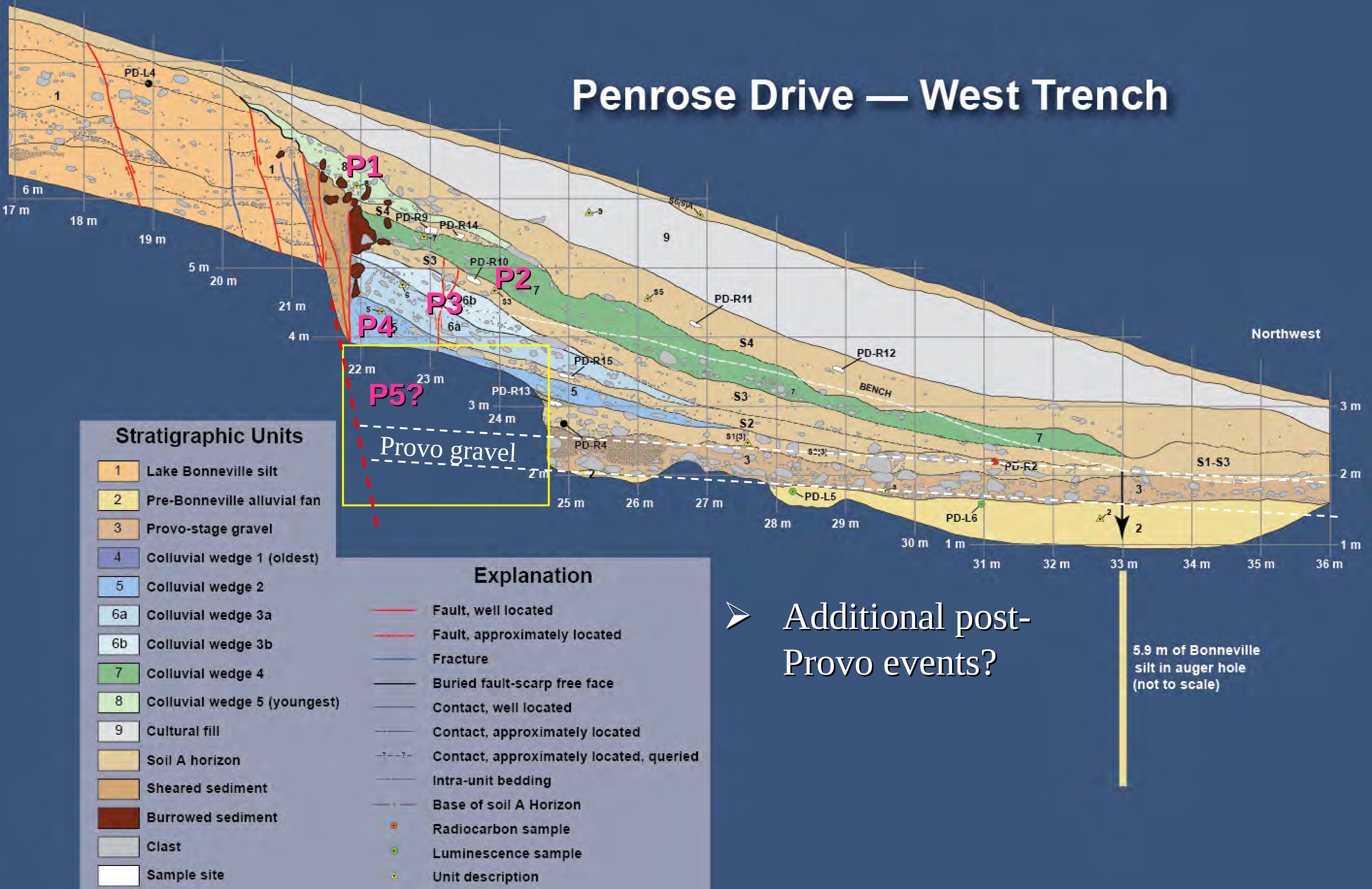
Penrose Drive — West Trench





- four and possibly five colluvial wedges (P1–P4)

Penrose Drive — West Trench

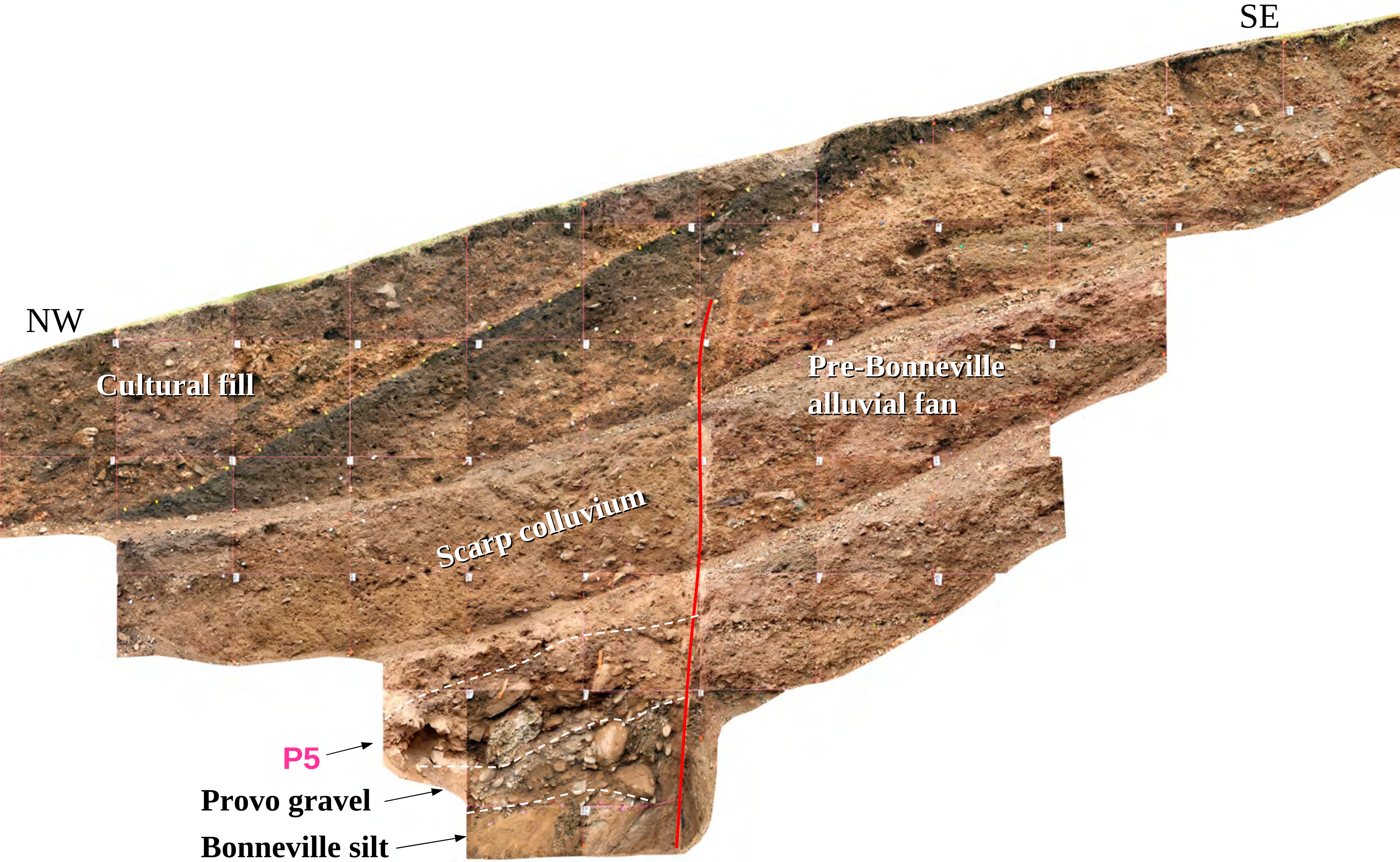


➤ Additional post-Provo events?

East Trench

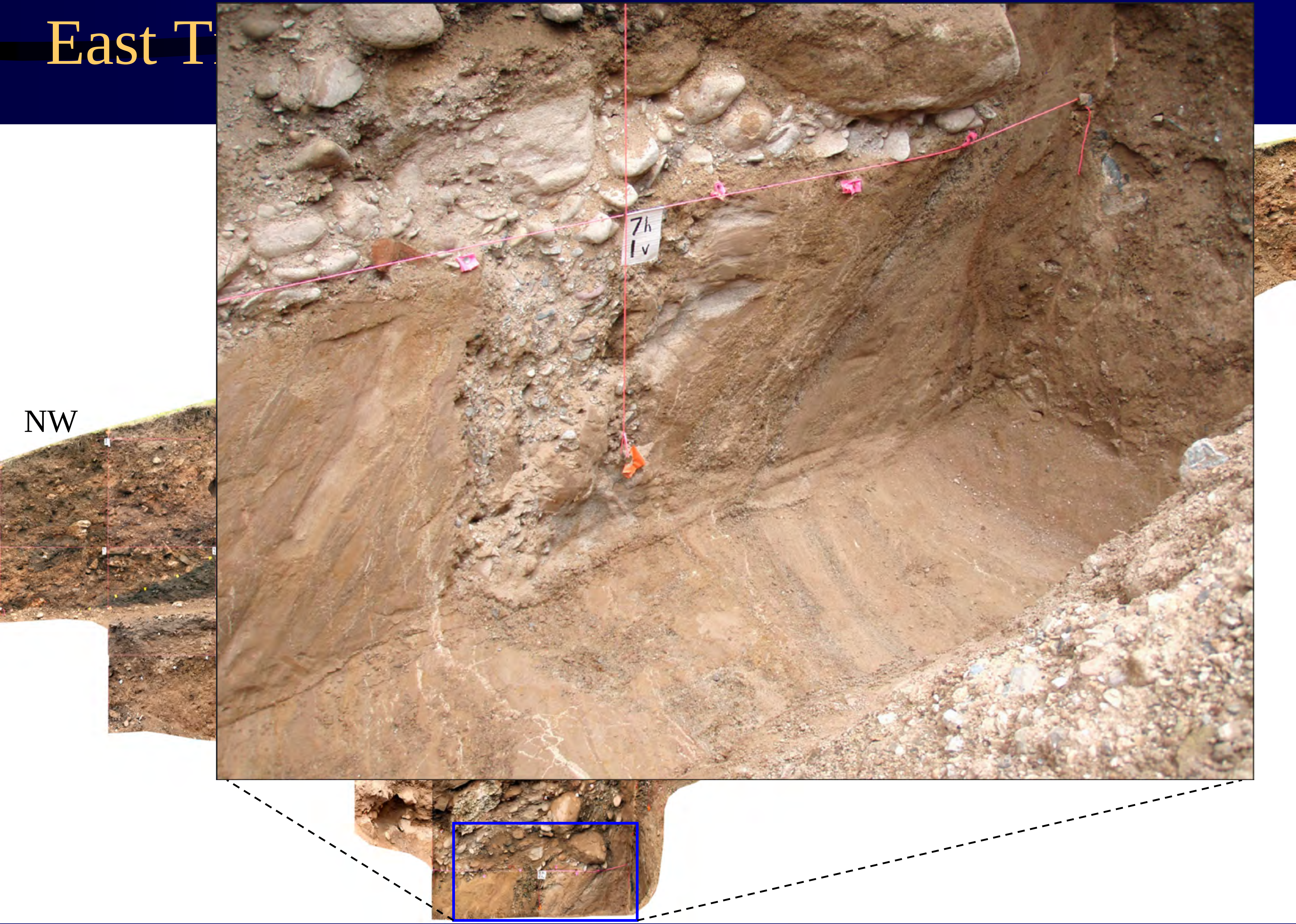
East Trench

East Trench



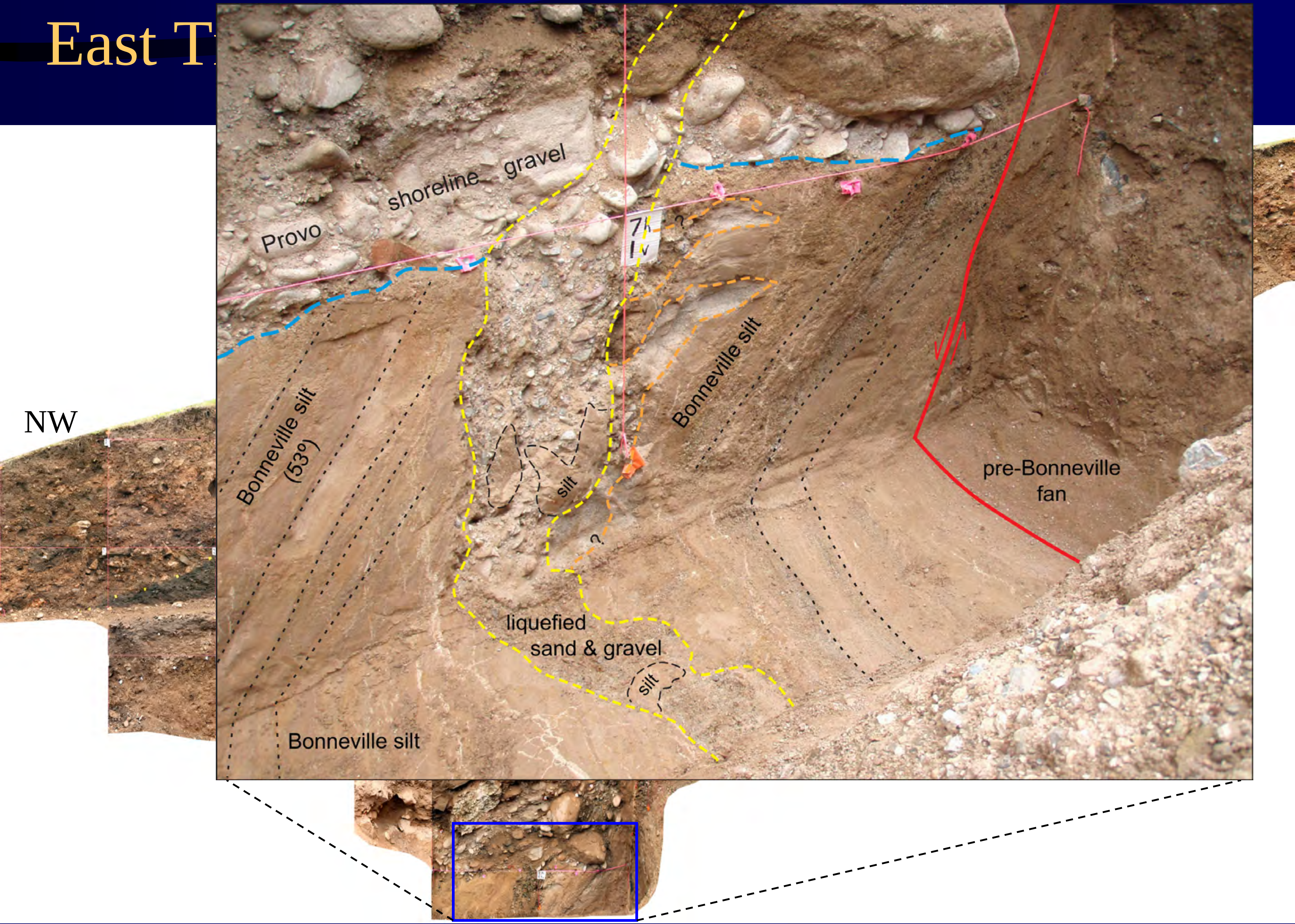
SE
NW
Cultural fill
Pre-Bonneville
alluvial fan
Scarp colluvium
P5
Provo gravel
Bonneville silt

East T



East T

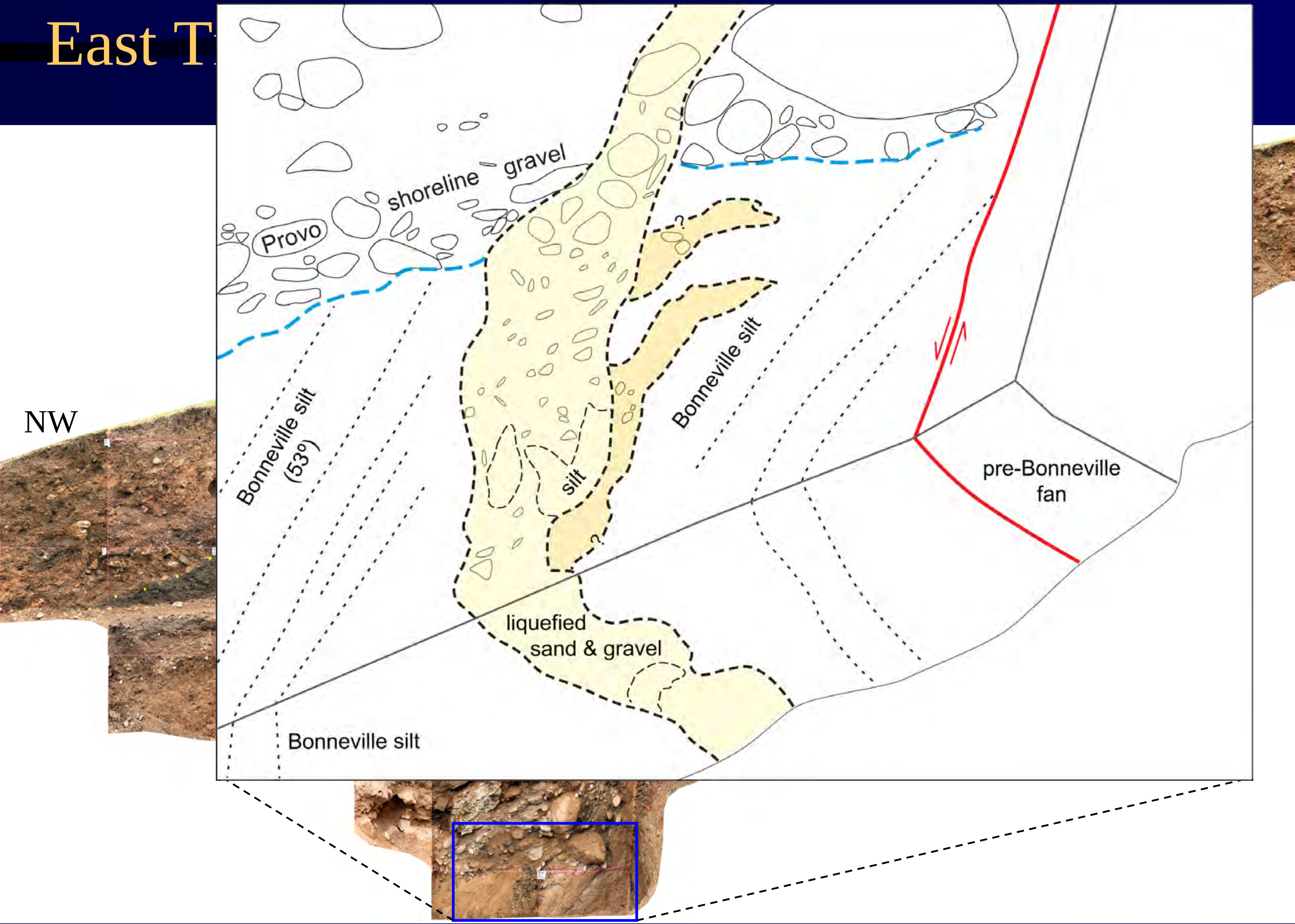
NW



Provo
shoreline
gravel
7h
1v
?
Bonneville silt
(53°)
Bonneville silt
silt
?
liquefied
sand & gravel
silt
Bonneville silt
pre-Bonneville
fan

East T

NW



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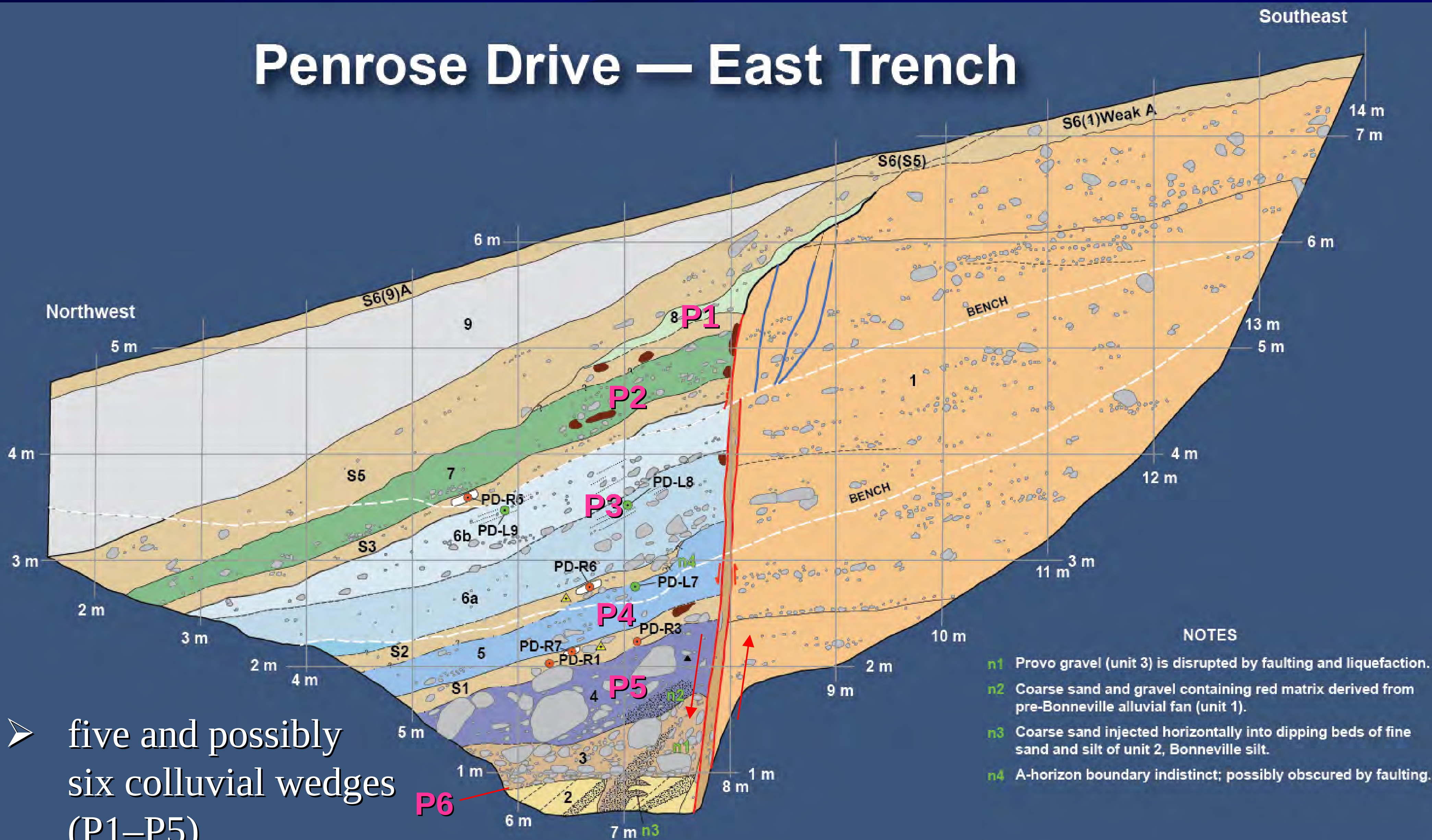
Penrose Drive — East Trench

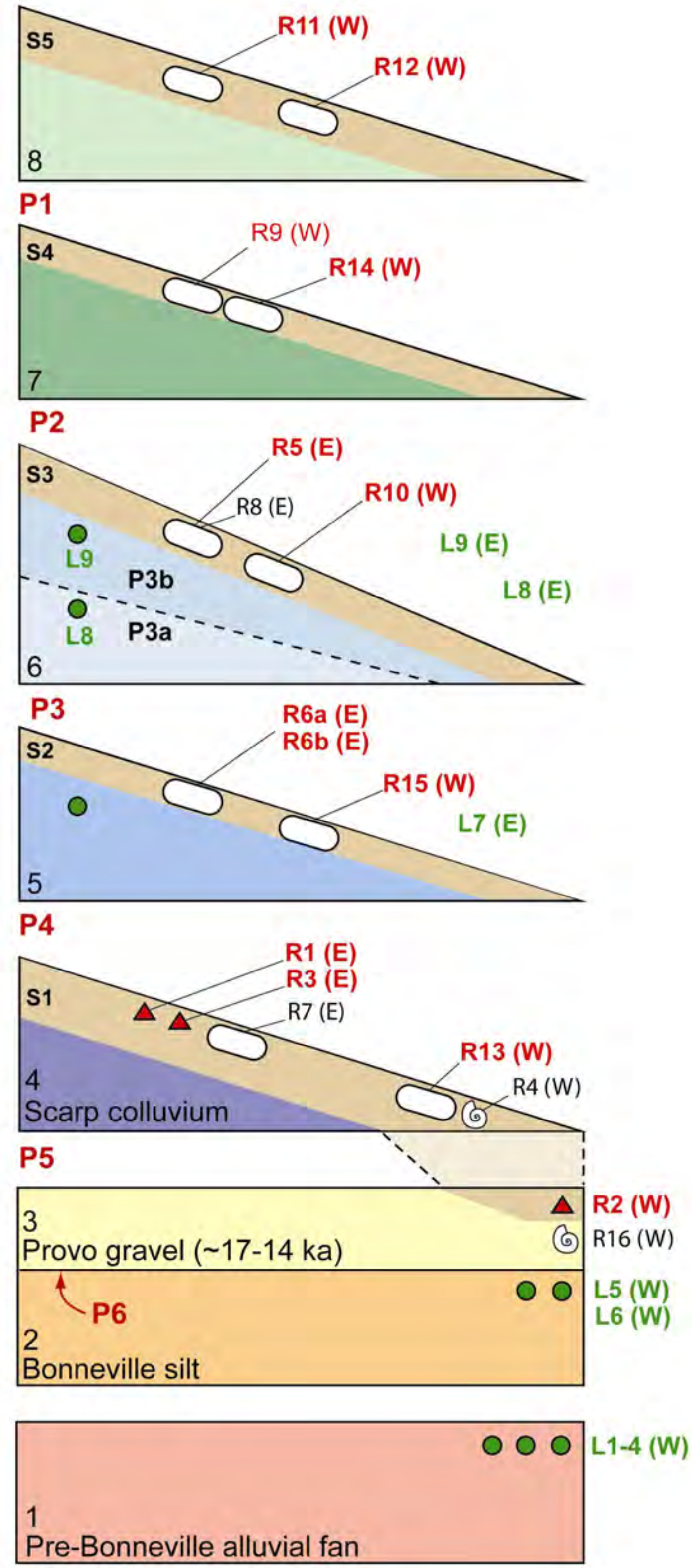


- five and possibly six colluvial wedges (P1–P5)
- P6: angular unconformity between 53°-dipping Bonneville silt beds and near-horizontal Provo-stage beach gravels adjacent to the fault.

Sampling Strategy and Preliminary Ages

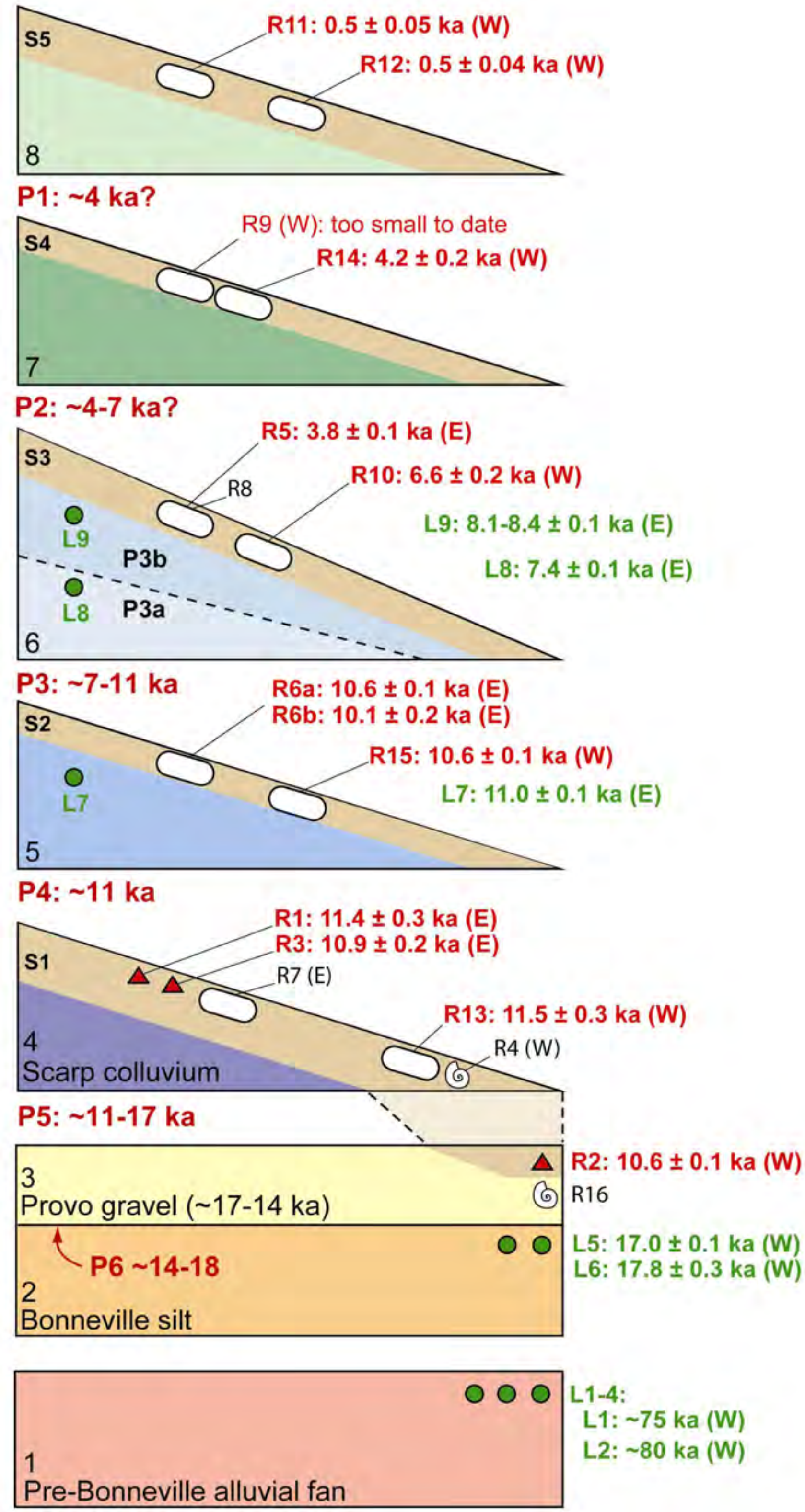
- **16 samples for radiocarbon dating**
  - 3 macro charcoal
  - 11 bulk soil sediment, which yielded numerous charcoal fragments
  - 2 samples of gastropod shells

- **9 samples for luminescence dating**
  - 4 near top of pre-Bonneville fan
  - 2 top of Bonneville silt
  - 3 P3-P4 colluvium



Sampling Strategy and Preliminary Ages

- **Preliminary chronology:**
  - P1 ~4 ka?
  - P2 ~4–7 ka?
  - P3 ~7–11 ka
  - P4 ~11 ka
  - P5 ~11–17 ka
  - P6 ~14–18 ka



Comparison with Previous Data

East Bench fault

- **This Study**
  - E1 ~4 ka?
  - E2 ~4–7 ka?
  - E3 ~7–11 ka
  - E4 ~11 ka
  - E5 ~11–17 ka
  - E6 ~14–18 ka

Cottonwood fault

	LCC	SFDC	UQFPWG
S1	1.3 ± 0.04 (1.3)	1.3 ± 0.2	1.3 ± 0.65
S2	2.1 ± 0.3 (2.3)	2.2 ± 0.4	2.45 ± 0.55
S3	4.4 ± 0.5 (3.5)	3.8 ± 0.6	3.95 ± 0.55
S4	5.5 ± 0.8 (5.3)	5.0 ± 0.5	5.3 ± 0.75
S5	7.8 ± 0.7 (7.5)		~7.5 (5–9)
S6	9.5 ± 0.2 (9)		~9 (<9.5–9.9)
S7	18.1 ± 0.8 (17)		
S8	19.1 ± 1.2 (17-20)		

LCC: Little Cottonwood Canyon megatrench (McCalpin, 2002)
SFDC: South Fork Dry Creek/Dry Gulch (Black and others, 1996)

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- **This Study**

E1	~4 ka?
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S5	7.8 ± 0.7 (7.5)		~7.5 (5–9)
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? ? ?

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Significant Observations

1) Pre-Bonneville alluvial-fan gravels (~75–80 ka) are exposed in the footwall but not the hanging wall of the fault. The oldest hanging-wall unit is Lake Bonneville silt (~17–18 ka), which is not present in the footwall block of the fault.

2) An auger hole in the bottom (hanging wall) of the West trench penetrated 5.9 m of Bonneville silt, and at refusal, did not encounter the pre-Bonneville fan gravels.

3) We correlated units between the exposures and interpreted 5 and possibly 6 colluvial-wedge deposits, with weak to very weak soils developed on them.

4) A possible older event is based on the angular unconformity between tilted Bonneville silt and Provo shoreline gravel.

5) Each colluvial wedge is on the order of 60–80 cm thick with the exception of unit 6, which is about 1.1 m thick near the fault.

6) The fault zone is narrow, planar, and steeply dipping. Only minor faulting is present in the footwall.

Preliminary Conclusions

1) We interpret 5 (and possibly 6) surface-faulting earthquakes on the East Bench fault. Preliminary ages suggest these events occurred between ~4 and 17 ka.

2) An older event (P6) may have occurred at about ~14–18 ka based on the unconformity between the Bonneville silt and Provo gravel.

3) Pending radiocarbon ages will (hopefully) further constrain the timing of P1 and P2.

4) Each colluvial wedge is on the order of 60–80 cm thick, suggesting that the vertical displacement per event is probably 0.6–1.6 m (0.8 m x 2).

5) The northern EBF may have a significant component of lateral slip based on the narrow, planar, near-vertical character of the fault zone. Also, strike of fault at site is northeast compared to the generally east-west regional extension direction.

Update on Fault Trenching at the Baileys Lake Site, West Valley Fault Zone

Mike Hylland, Chris DuRoss, Greg McDonald (UGS)
Susan Olig (URS)

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

Many thanks to:

• Tony Crone, Steve Personius, Rich Briggs, Ryan Gold (USGS – Denver)
• David Madsen (Texas Archeological Research Laboratory, U. Texas – Austin)
• David Miller (USGS – Menlo Park)
• Elliott Lips (Great Basin Earth Science)
• Charles (Jack) Oviatt (Kansas State U.)
• GHP staff
• Salt Lake City Department of Airports

West Valley and Wasatch fault zones

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  - Baileys Lake (WVFZ)
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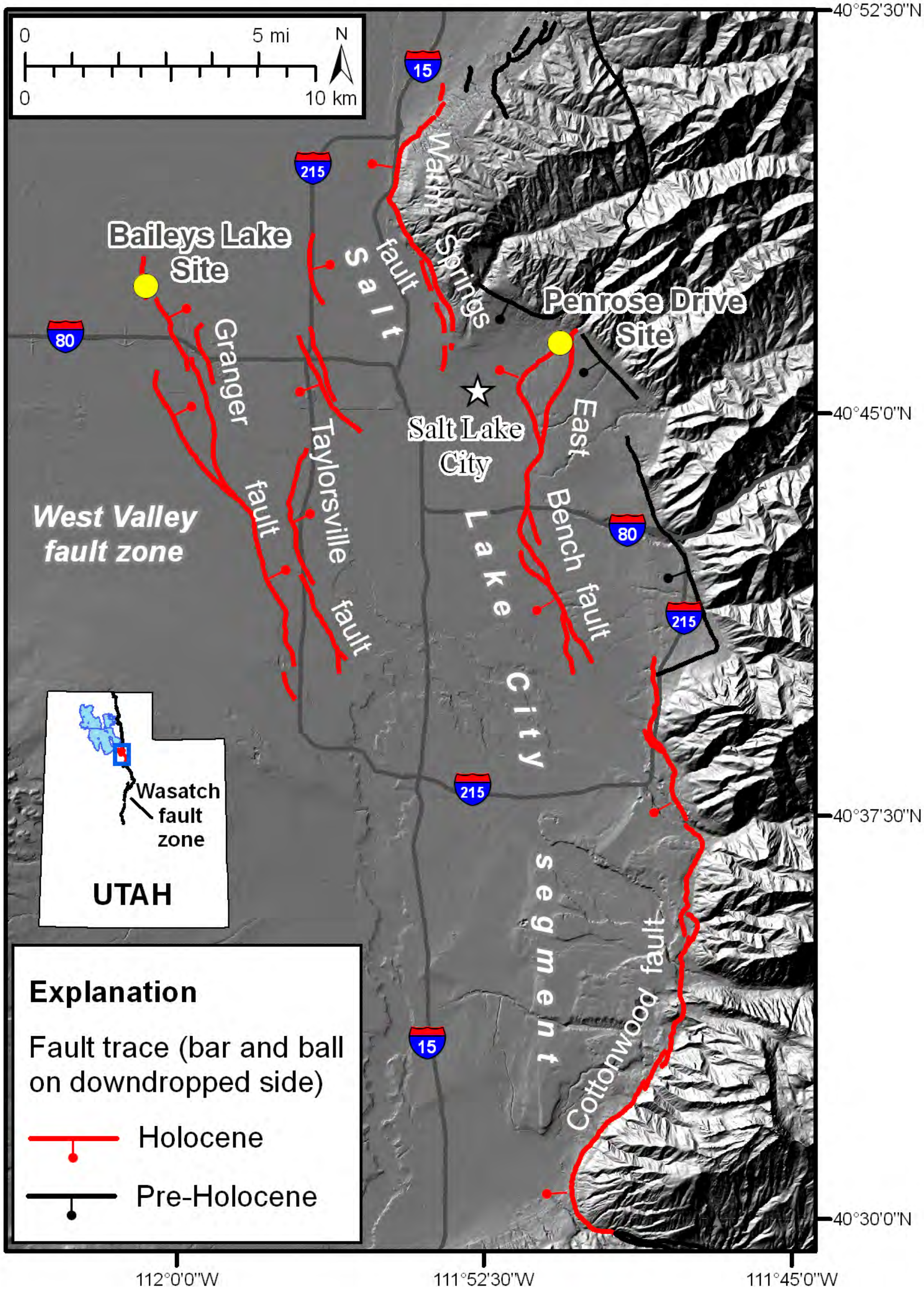
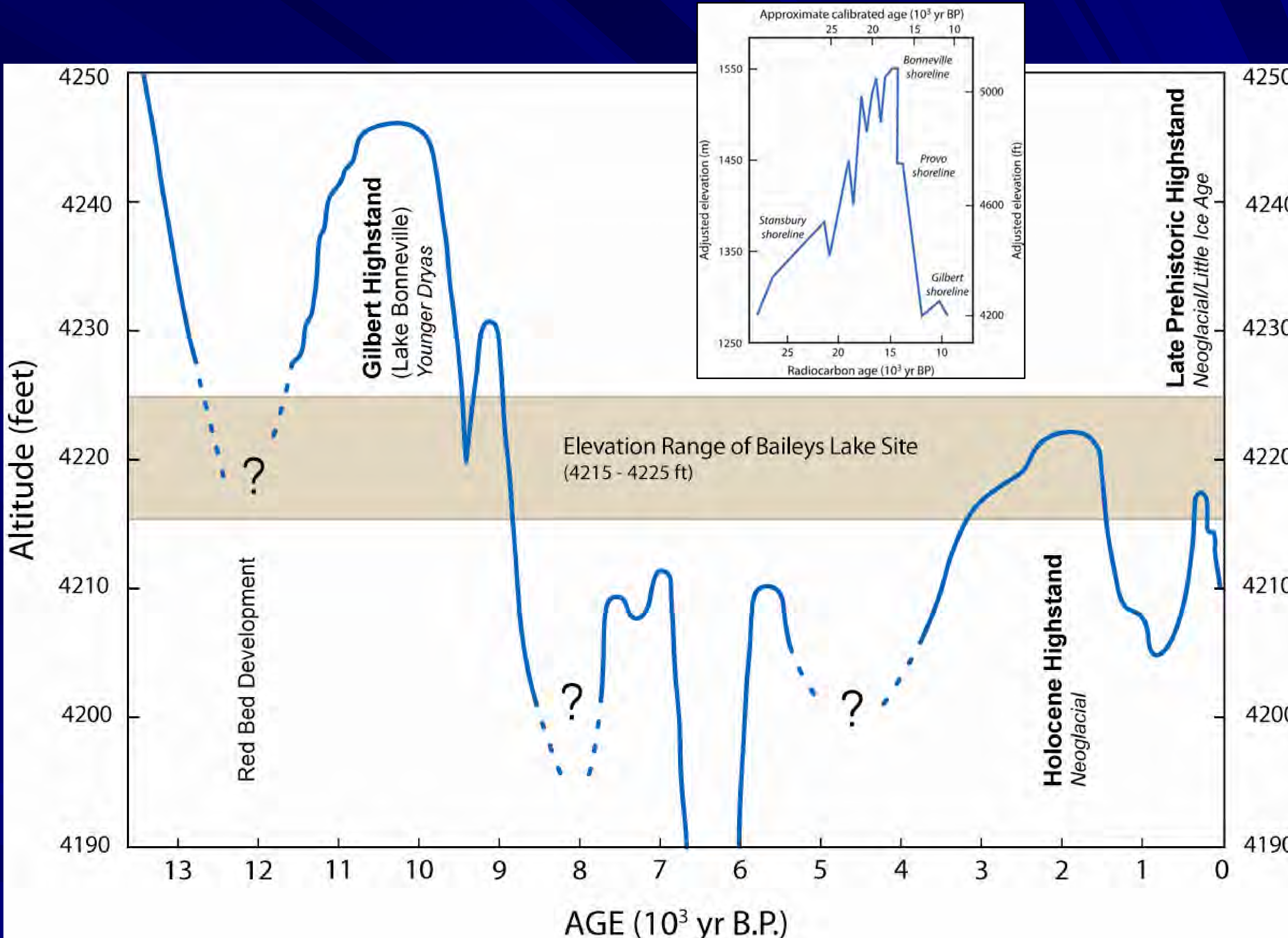
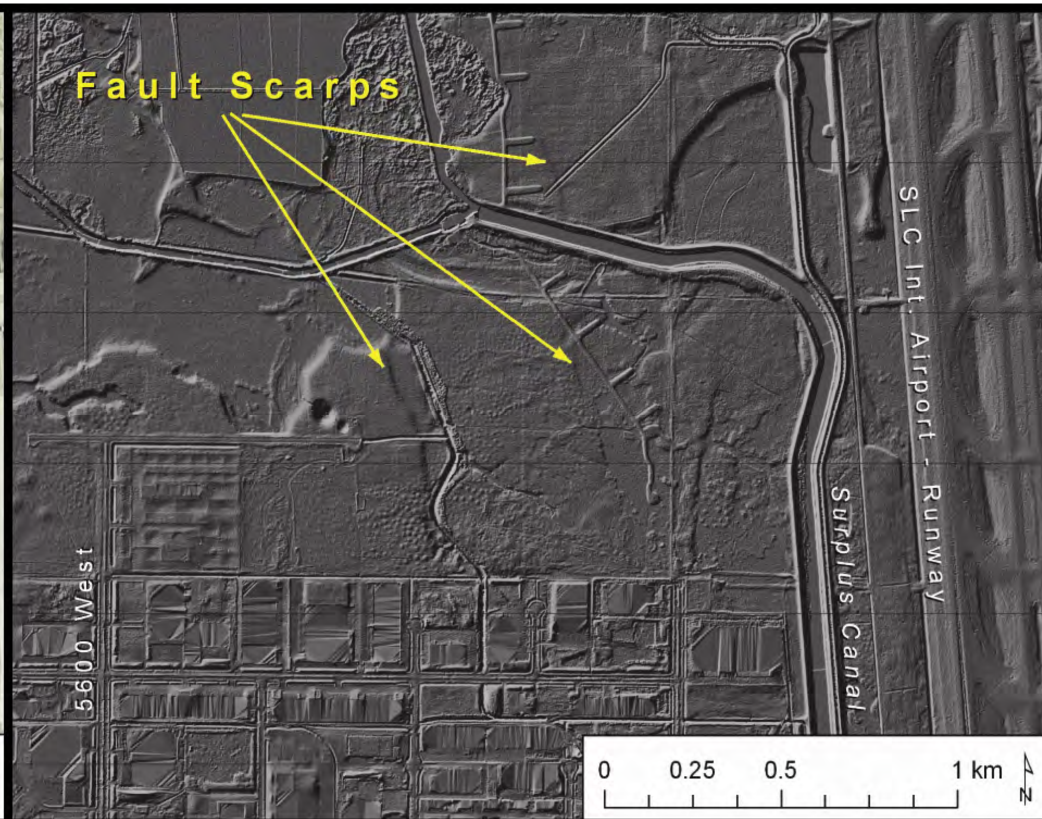




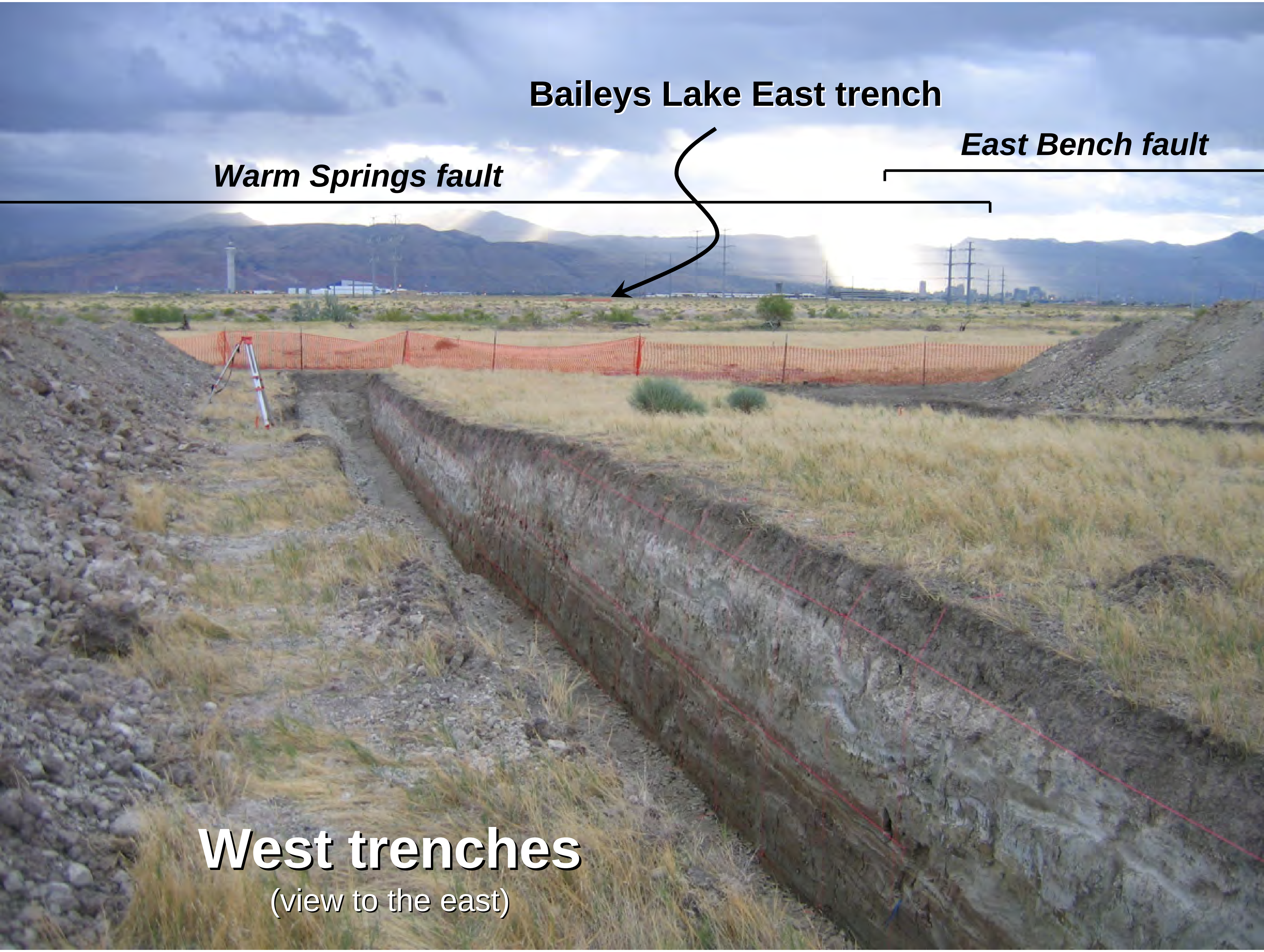
Great Salt Lake hydrograph from Murchison (1989)
Bonneville hydrograph after Oviatt (1997)



Baileys Lake Trench Site

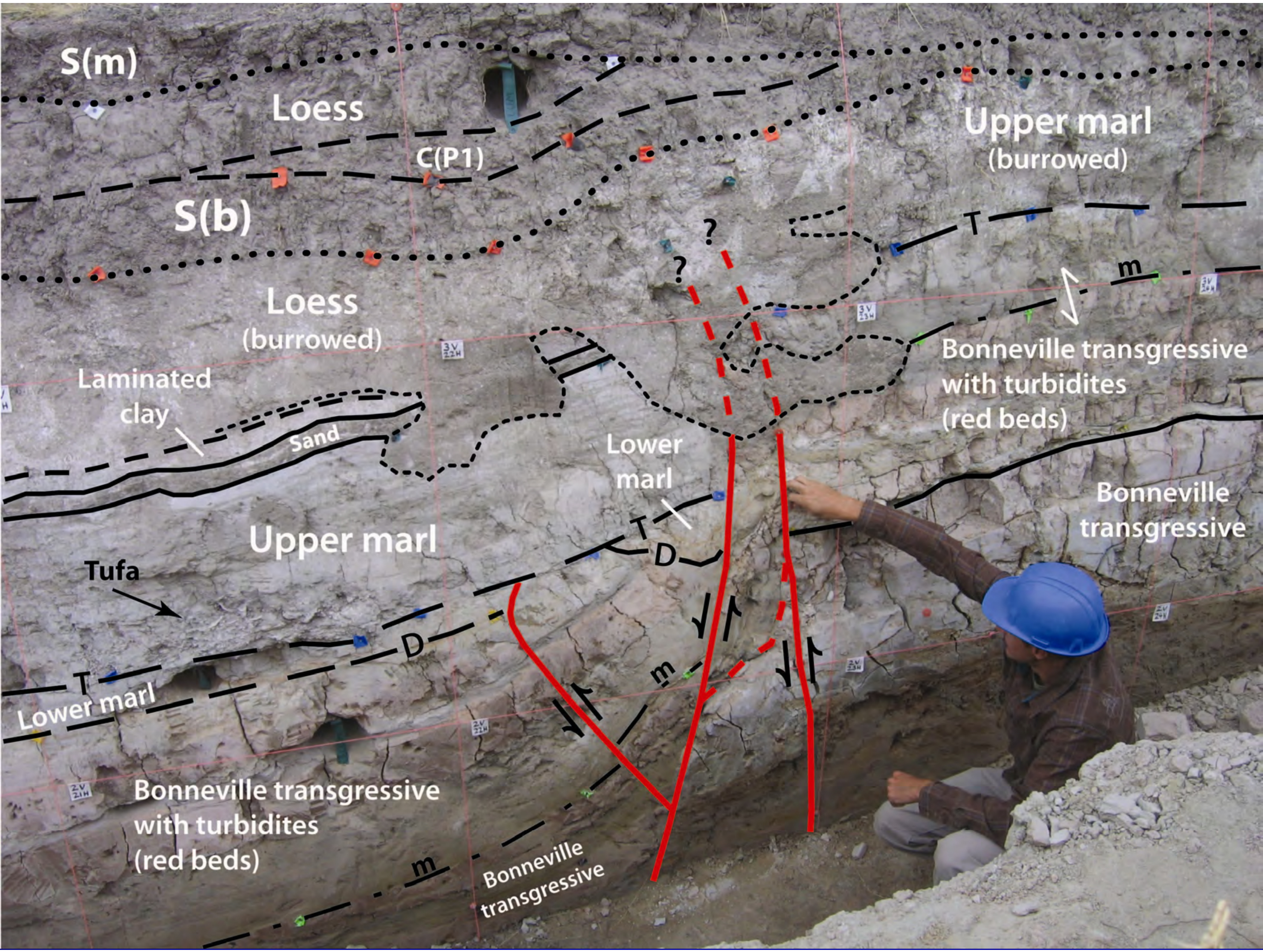
Three trenches:

- Two across western scarp
  - scarp ~1 m high
  - trenches 44 and 21 m long, max. 3.3 m deep
- One across eastern scarp
  - scarp ~0.25 m high
  - trench 52 m long, max. 1.5 m deep

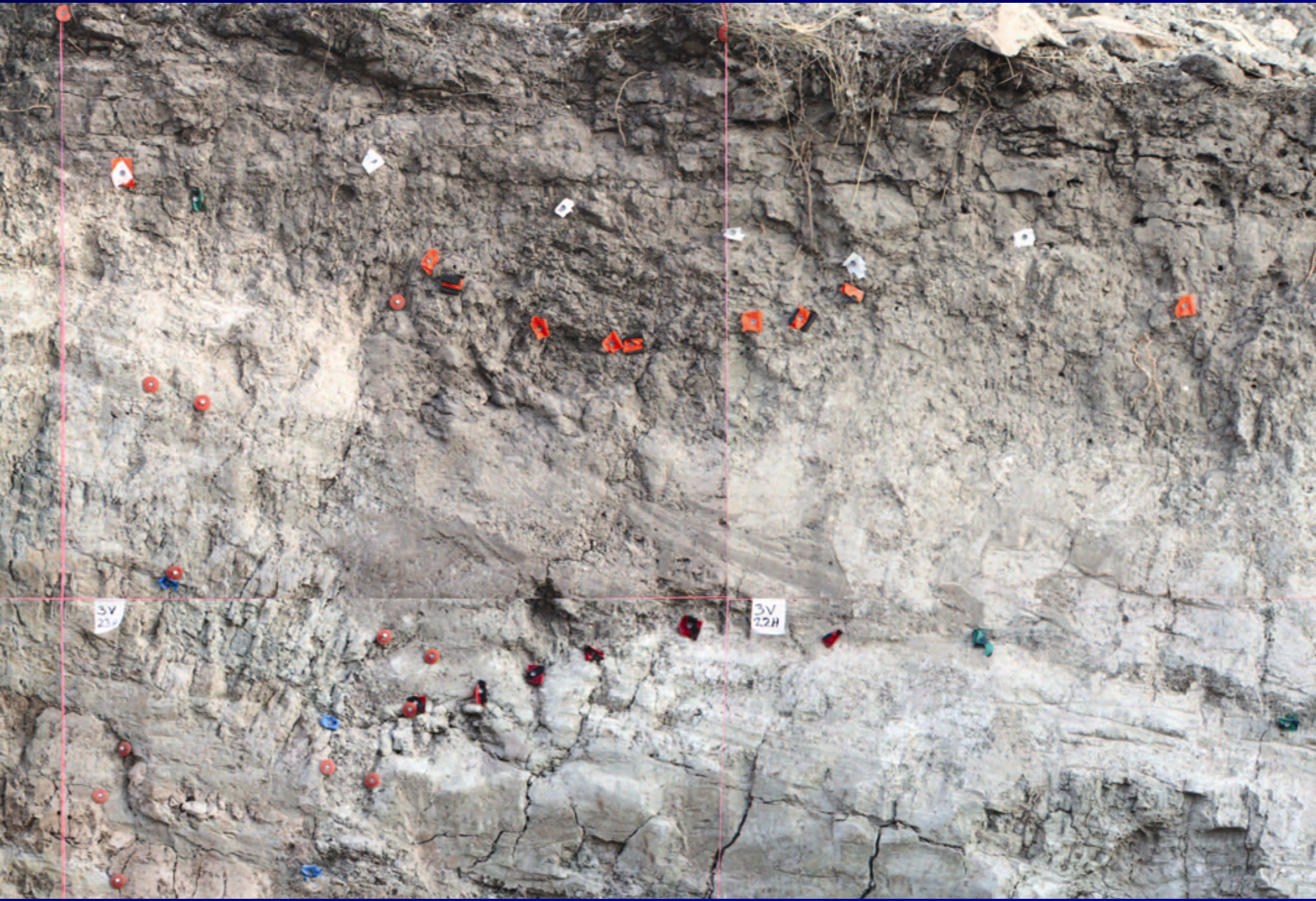

Baileys Lake East trench
East Bench fault
Warm Springs fault
West trenches
(view to the east)

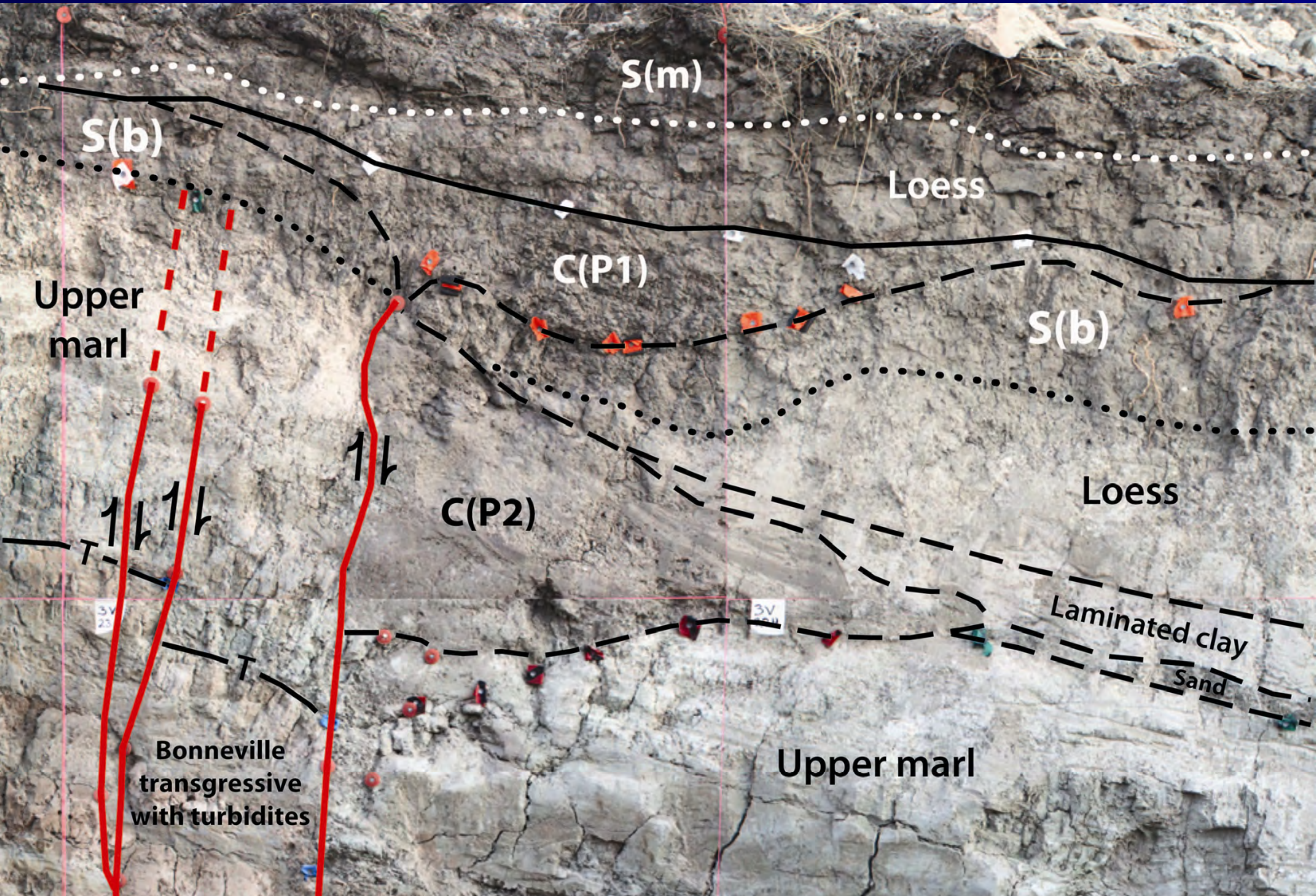
West(S) trench

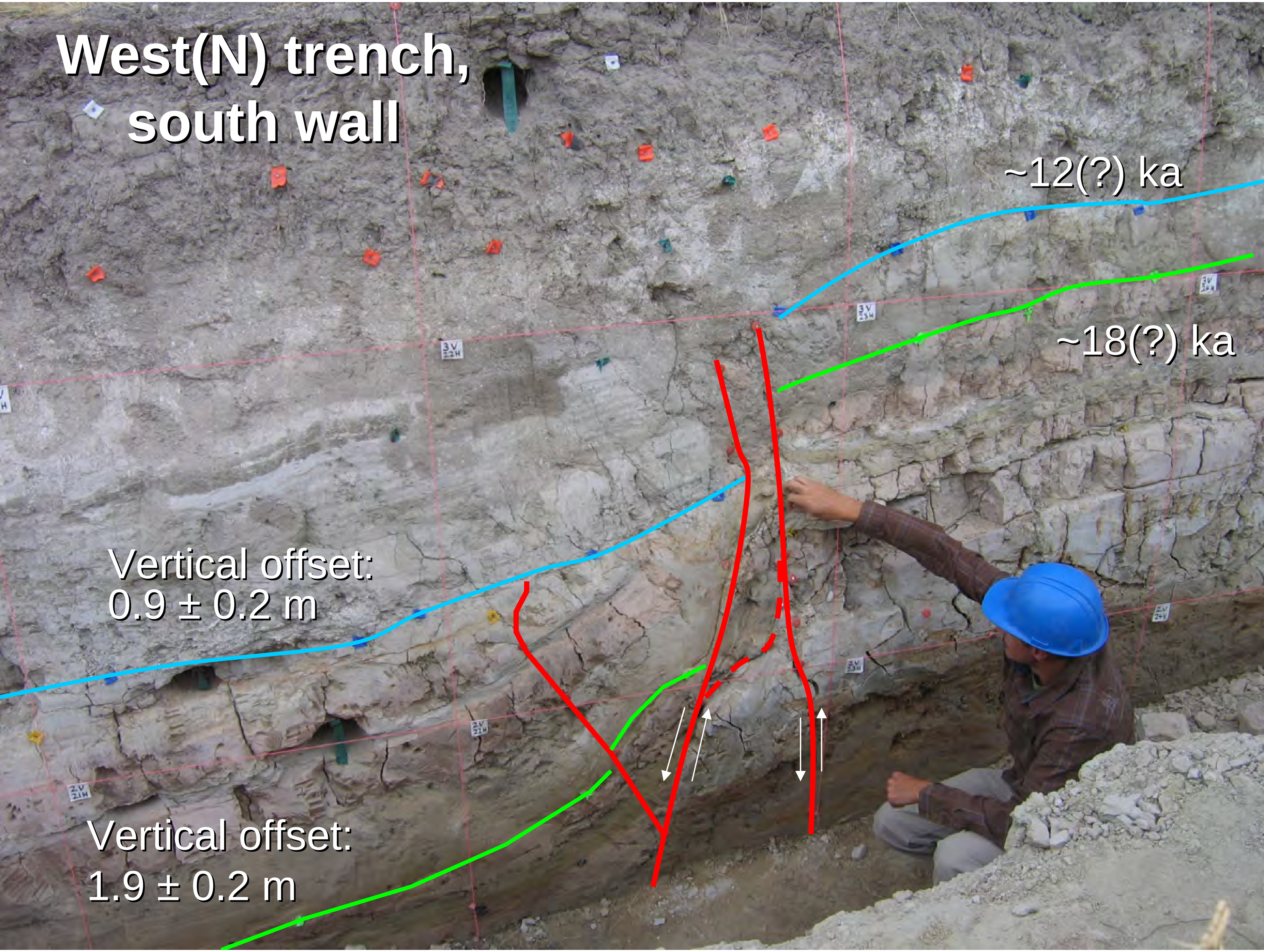

West(N) trench,
south wall



S(m)
Loess
C(P1)
S(b)
Upper marl
(burrowed)
T
m
Loess
(burrowed)
Bonneville transgressive
with turbidites
(red beds)
Laminated
clay
Sand
Lower
marl
Bonneville
transgressive
Upper marl
T
D
Tufa
D
T
Lower marl
m
Bonneville transgressive
with turbidites
(red beds)
m
Bonneville
transgressive


3V
22H


S(m)
S(b)
Loess
C(P1)
Upper marl
S(b)
C(P2)
Loess
T
T
Laminated clay
Sand
Bonneville transgressive with turbidites
Upper marl

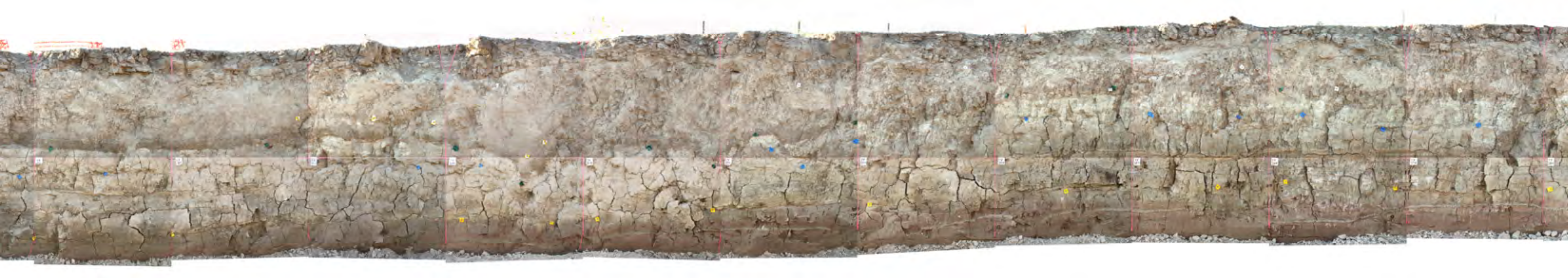


West(N) trench,
south wall
~12(?) ka
~18(?) ka
Vertical offset:
0.9 ± 0.2 m
Vertical offset:
1.9 ± 0.2 m

~25-cm-high, east-facing scarp (zone of warping)

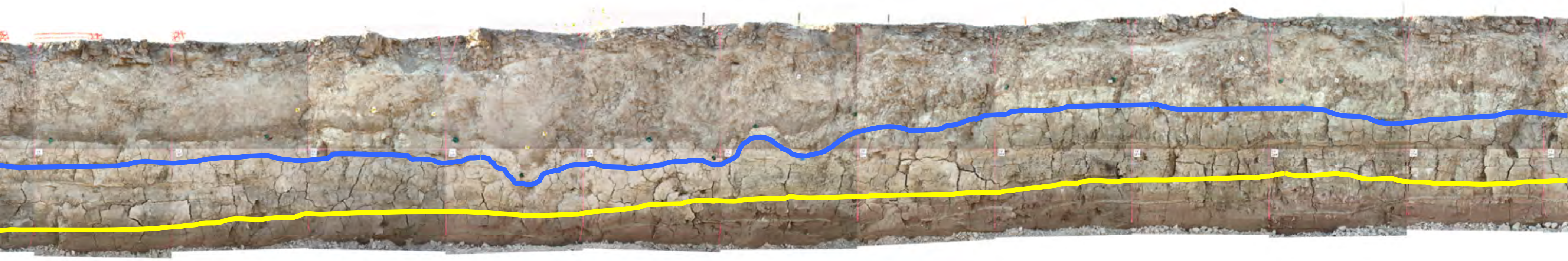
East trench

(view to the east)



East trench, south wall

Vertical offset: 0.5 ± 0.1 m



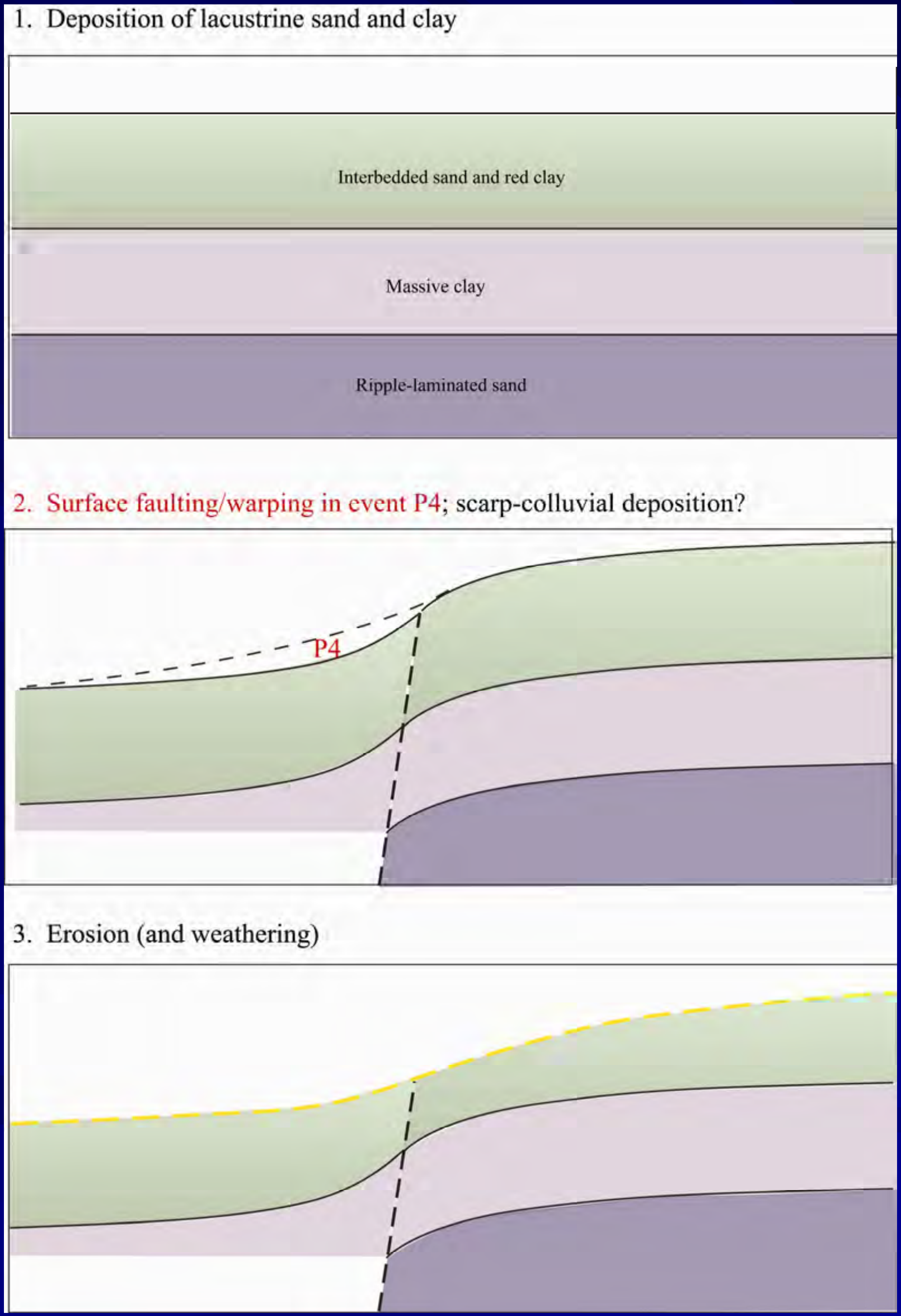
East trench, south wall

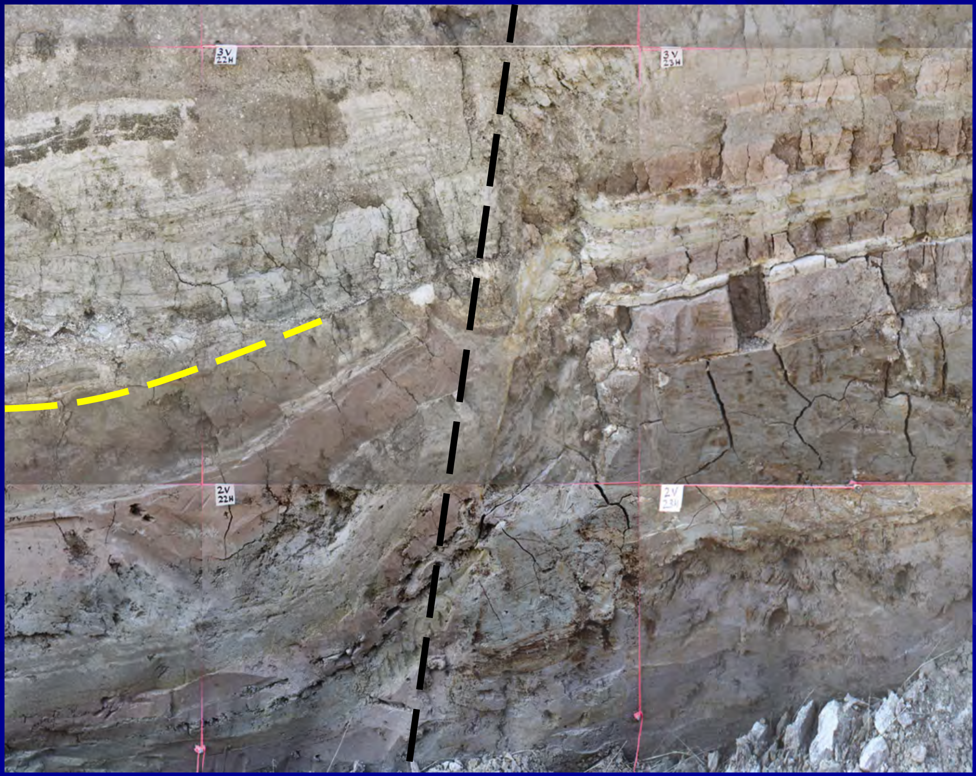
Evidence for 4 (5?) paleoearthquakes:

Post-Gilbert lake cycle	P1 (most recent paleoearthquake) P2
Post-Bonneville highstand	P3 P4 (earliest paleoearthquake)

*Single(?) warping event recorded at eastern scarp may or may not correlate with one of the four events recorded at the western scarp.

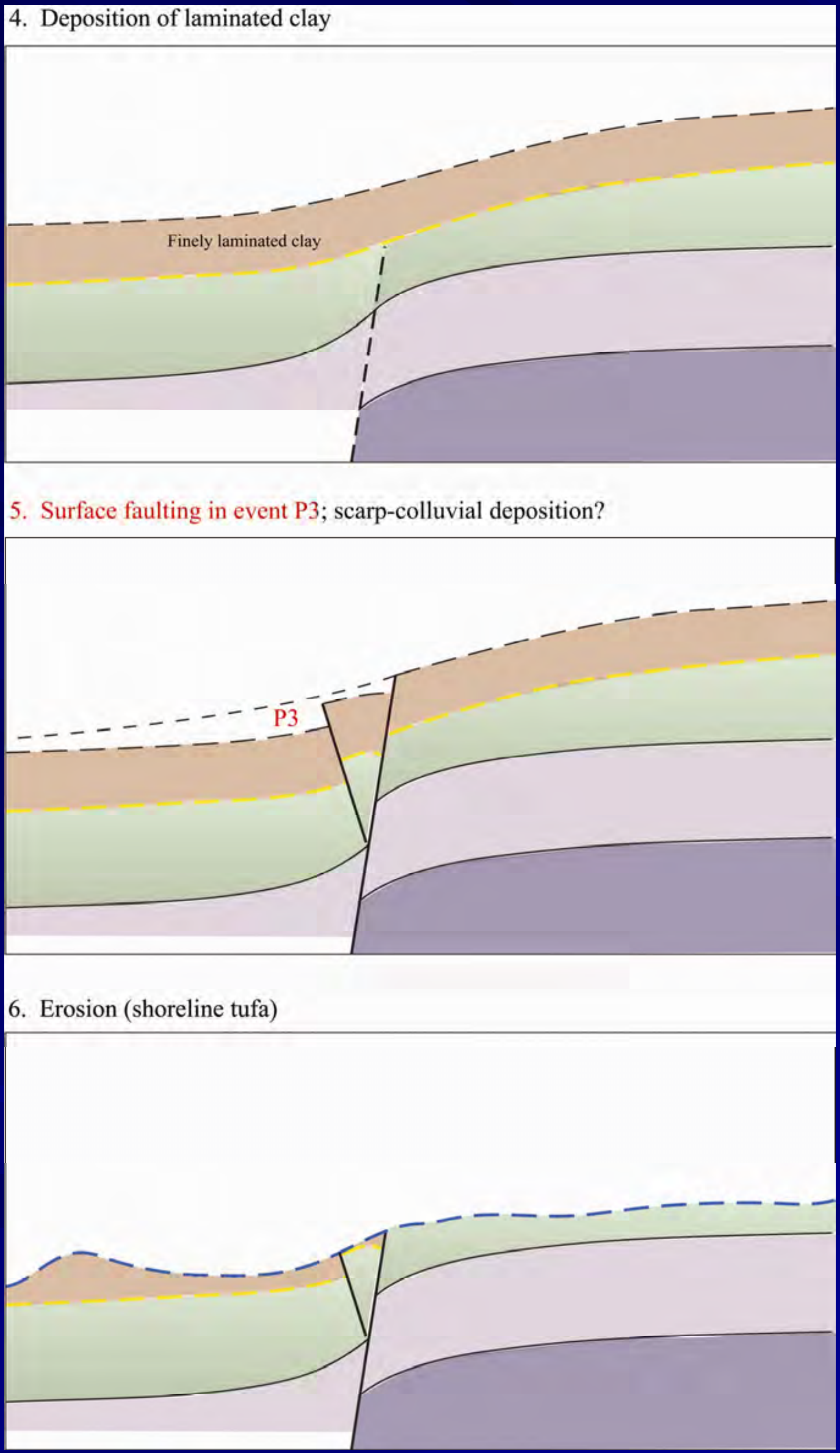
P4 – Warping of Bonneville strata (sub-lacustrine event)



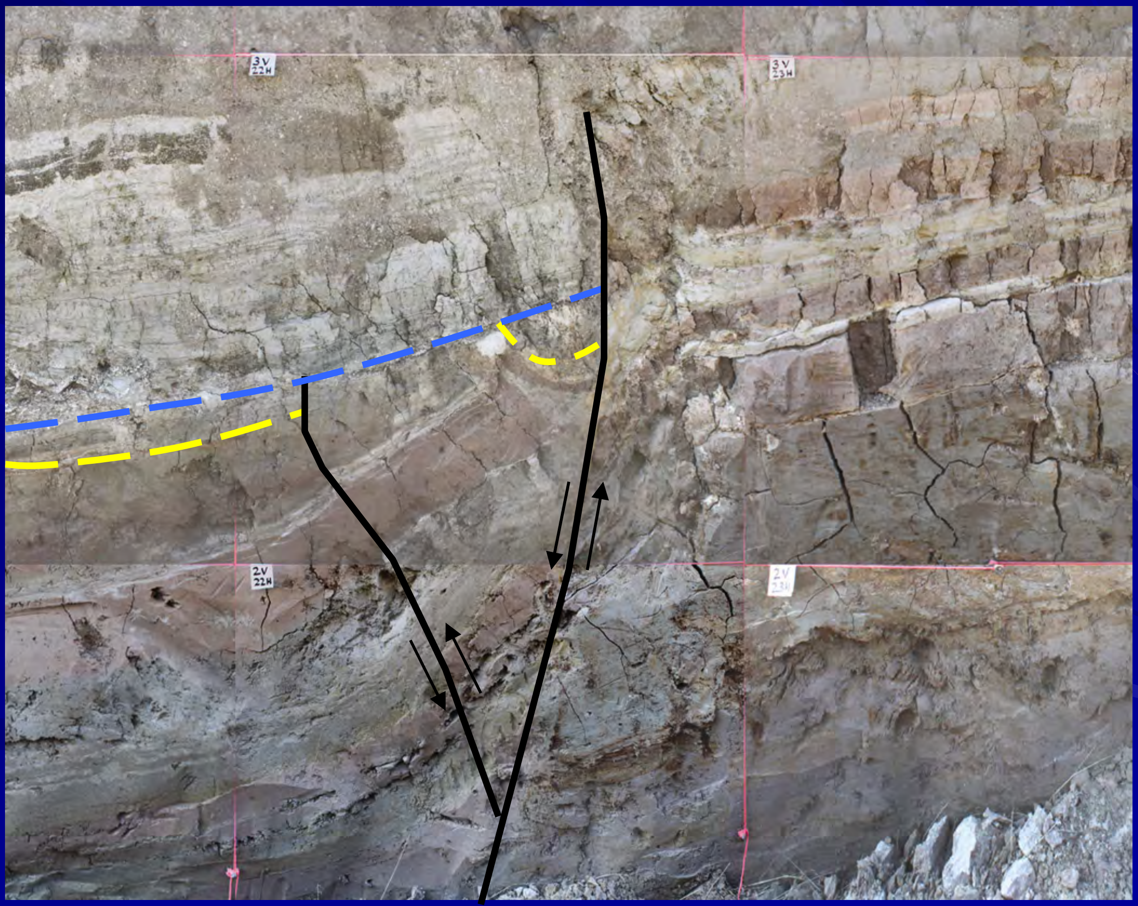


West(N) trench, south wall


2V
17H

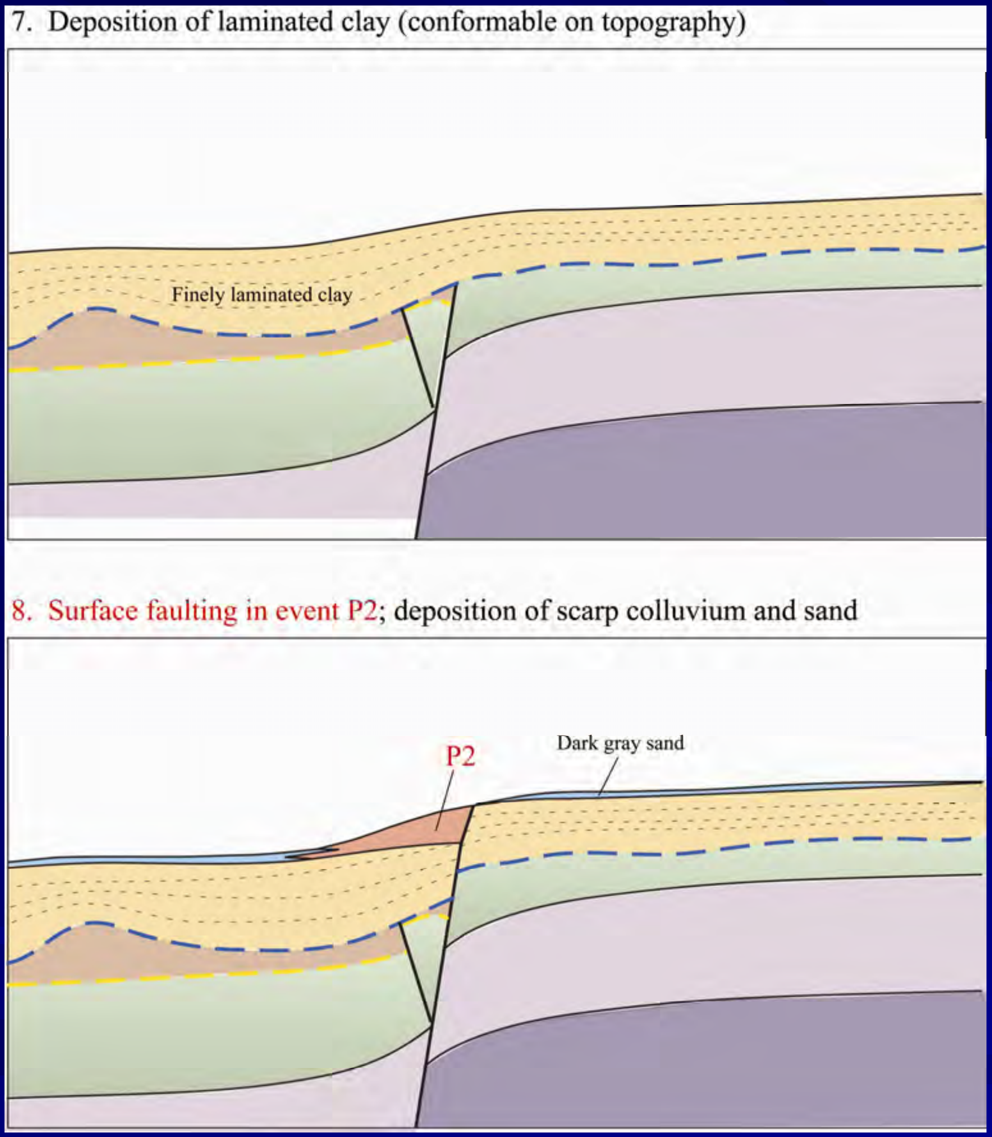


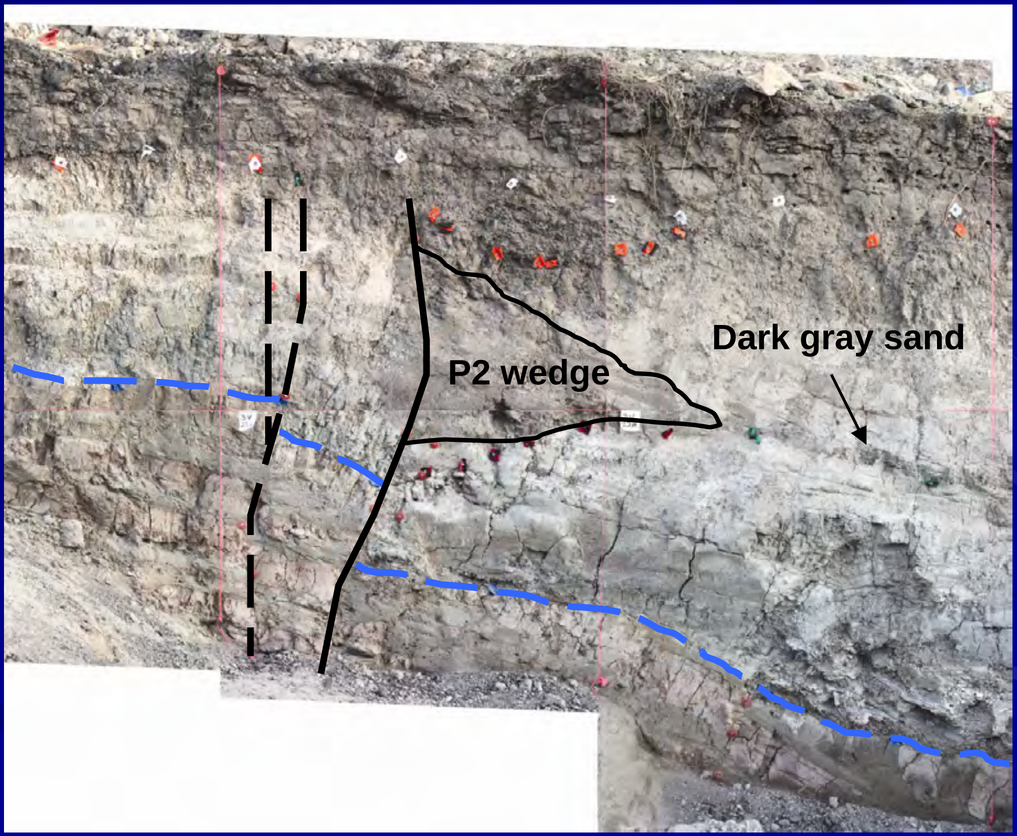
P3 – Fault-zone deformation (shear and folding) of warped beds and unconformity



West(N) trench, south wall

P2 – Shear of laminated clay, deposition of stratified "colluvial" wedge

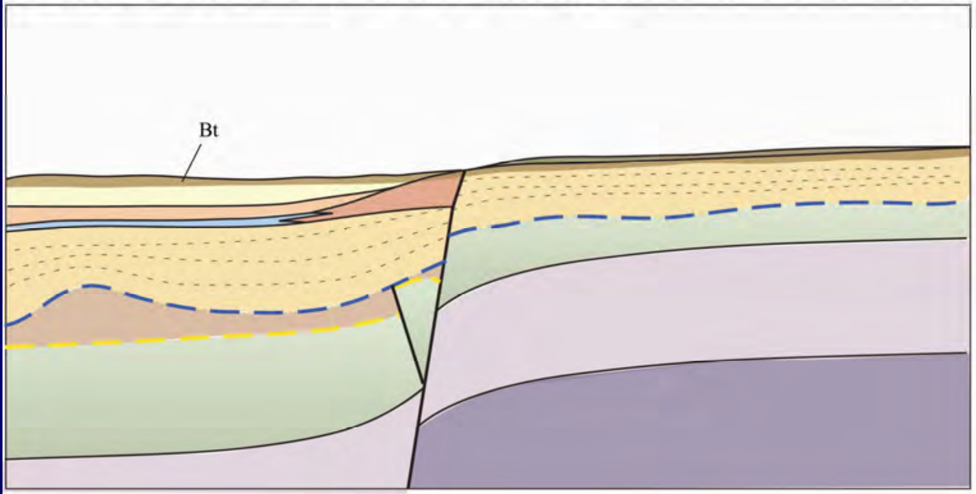




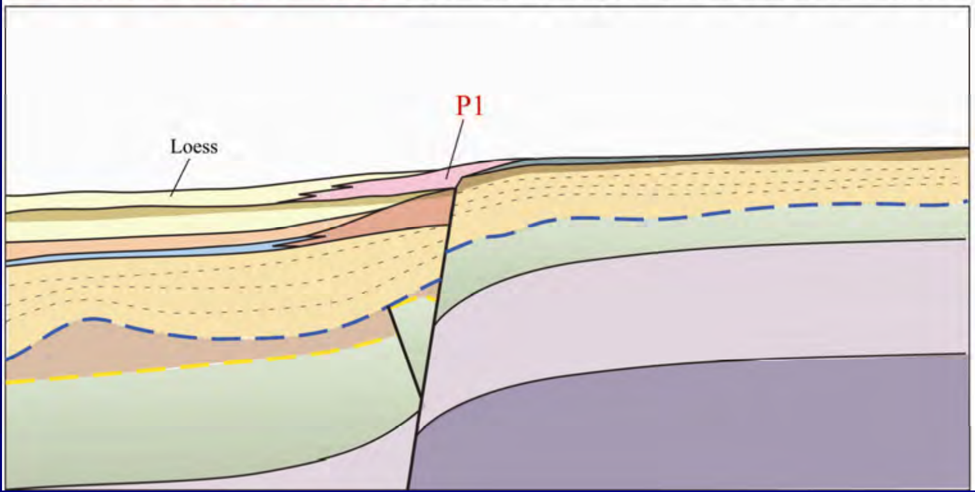
West(N) trench, north wall

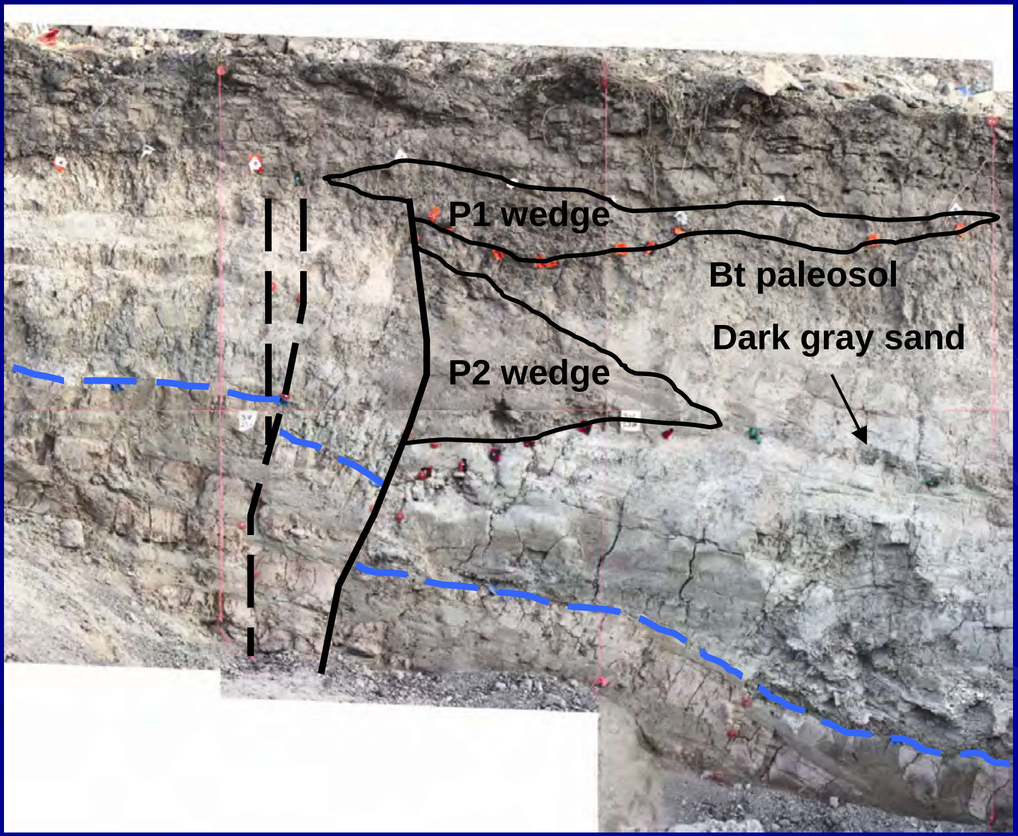
P1 – Shear of P2 wedge, deposition of organic-rich scarp colluvium

9. Deposition of wind-blown silt; Bt soil development



10. Surface faulting in event P1; depostion of scarp colluvium and wind-blown silt





West(N) trench, north wall

Numerical Constraints on Earthquake Timing

- Luminescence (16 samples)
- Radiocarbon (5 bulk samples, analyzed for charcoal)

+ Ostracode biostratigraphy (13 samples)

Preliminary Findings

Evidence for 4 (5?) large earthquakes that post-date the Bonneville highstand (~18 ka)
- P4 – sub-lacustrine, Bonneville cycle
- P3 – subaerial(?), between Bonneville highstand and Gilbert cycle (~12 ka)
- P2 – post-Gilbert; subaerial, but under wet climatic conditions(?)
- P1 – typical subaerial scarp-colluvial deposition

Average per-event vertical displacement ~0.5 m (western scarp)

Vertical displacement (~0.5 m) at eastern scarp produced only broad warping

A Brief Summary of Recent Work on the Northern Nephi segment of the Wasatch fault, Utah.

Daniel Horns, Patti Garcia, Tracy Kemp, Ashley Peay, Scott Robertson, Preston College, Department of Earth Science, Utah Valley University, Orem, Utah.
(Chris DuRoss, Mike Hylland, and Greg McDonald, Utah Geological Survey
David Simon, Simon Bymaster)

The three southern segments of the Wasatch Fault

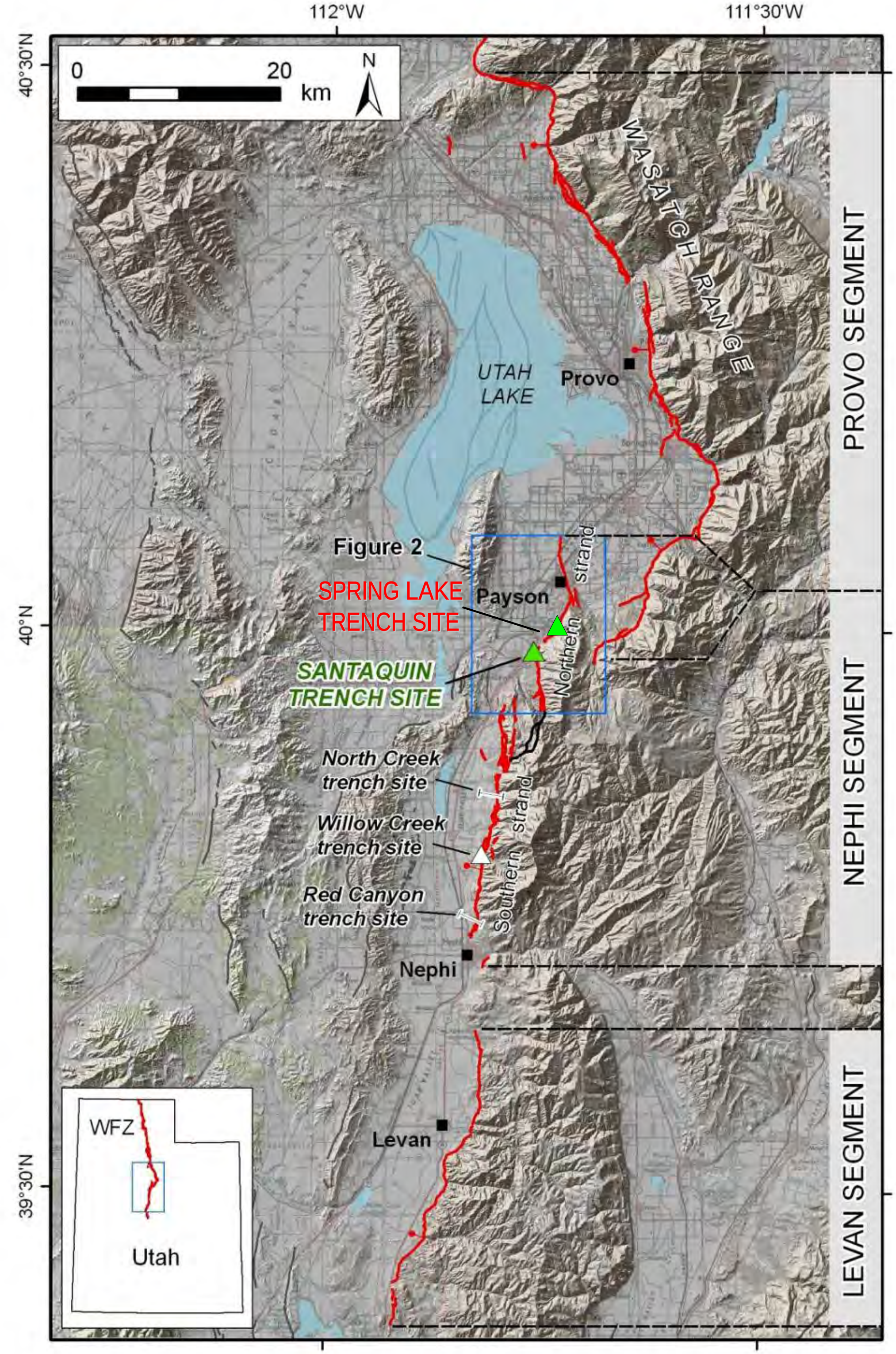


Figure from DuRoss and others, 2008.

This study

Spring Lake (Horns and others, 2008)
P1: <2500, P2: <3500

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

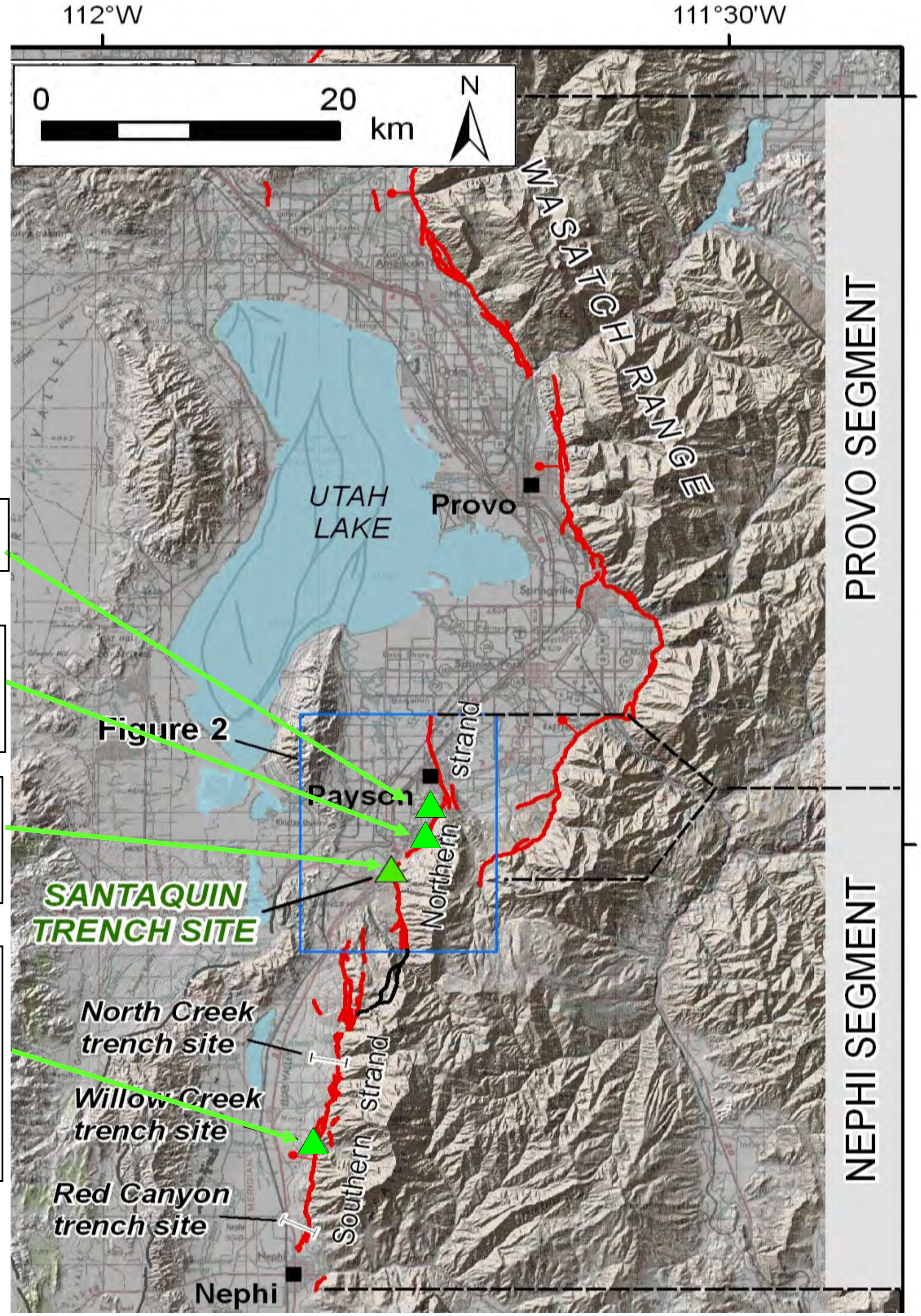


Fig. from DuRoss and others, 2008.

Close up 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

This study

Spring Lake (Horns and others, 2008)
P1: <2500, P2: <3500

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

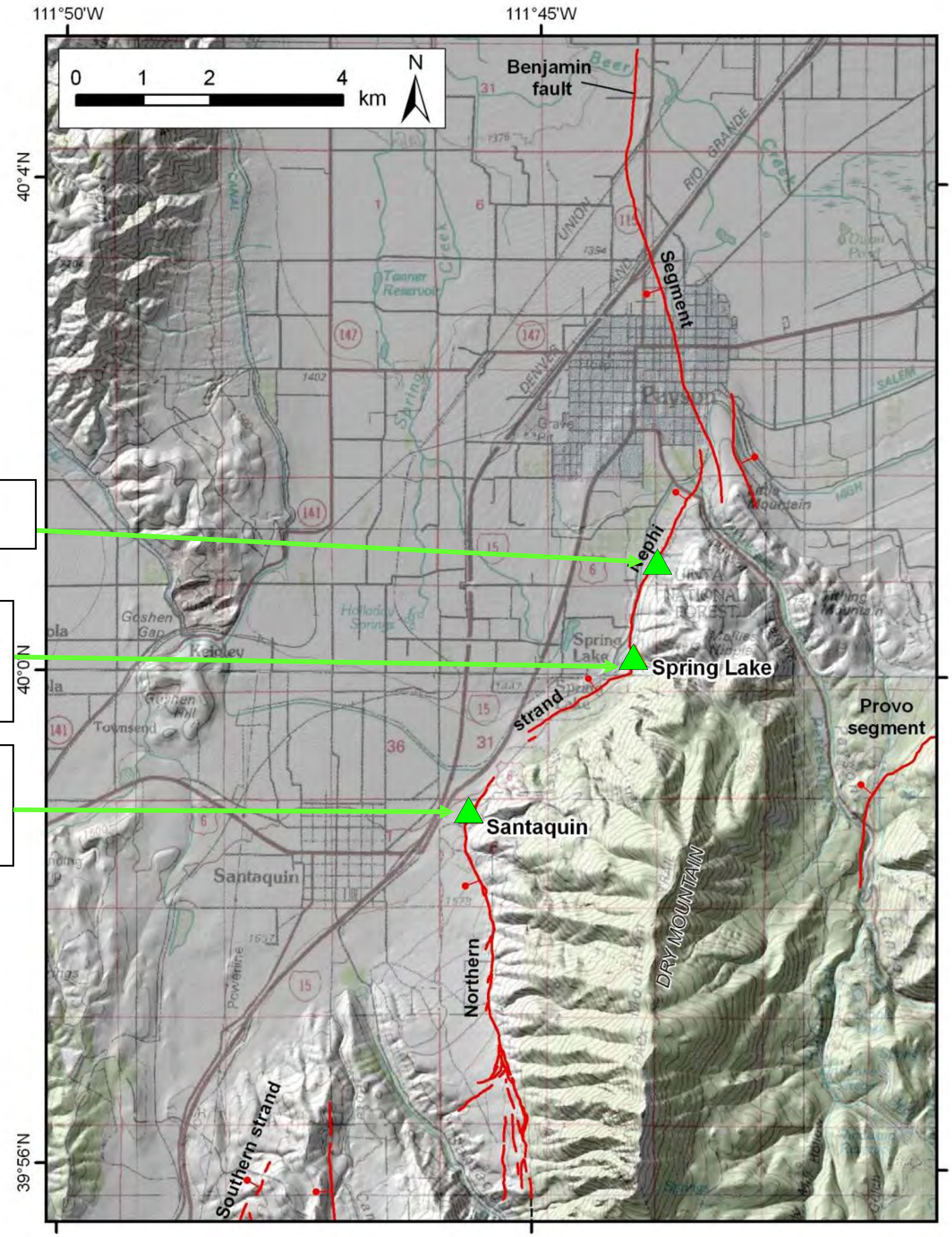
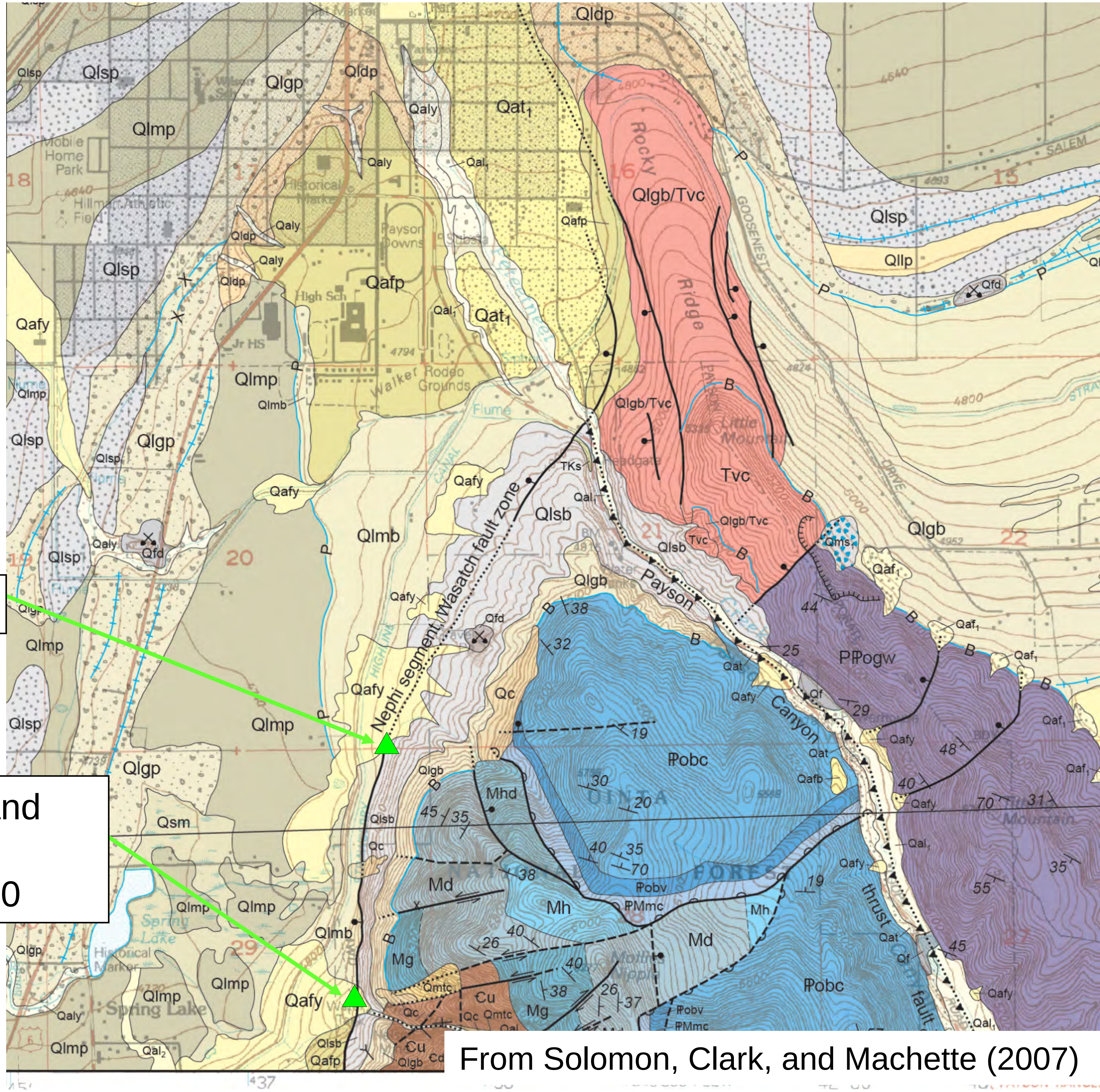


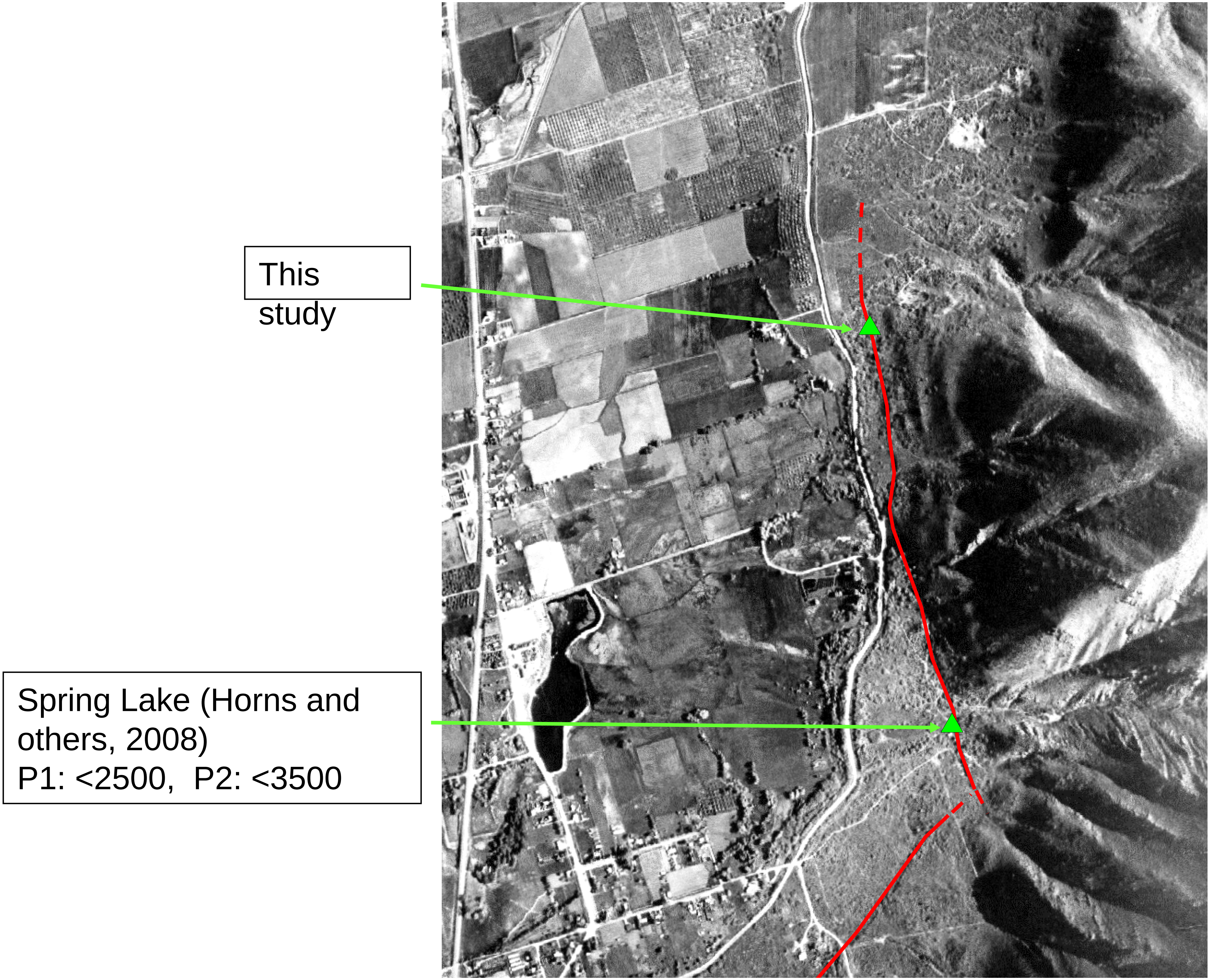
Fig. from DuRoss and others, 2008.

This study

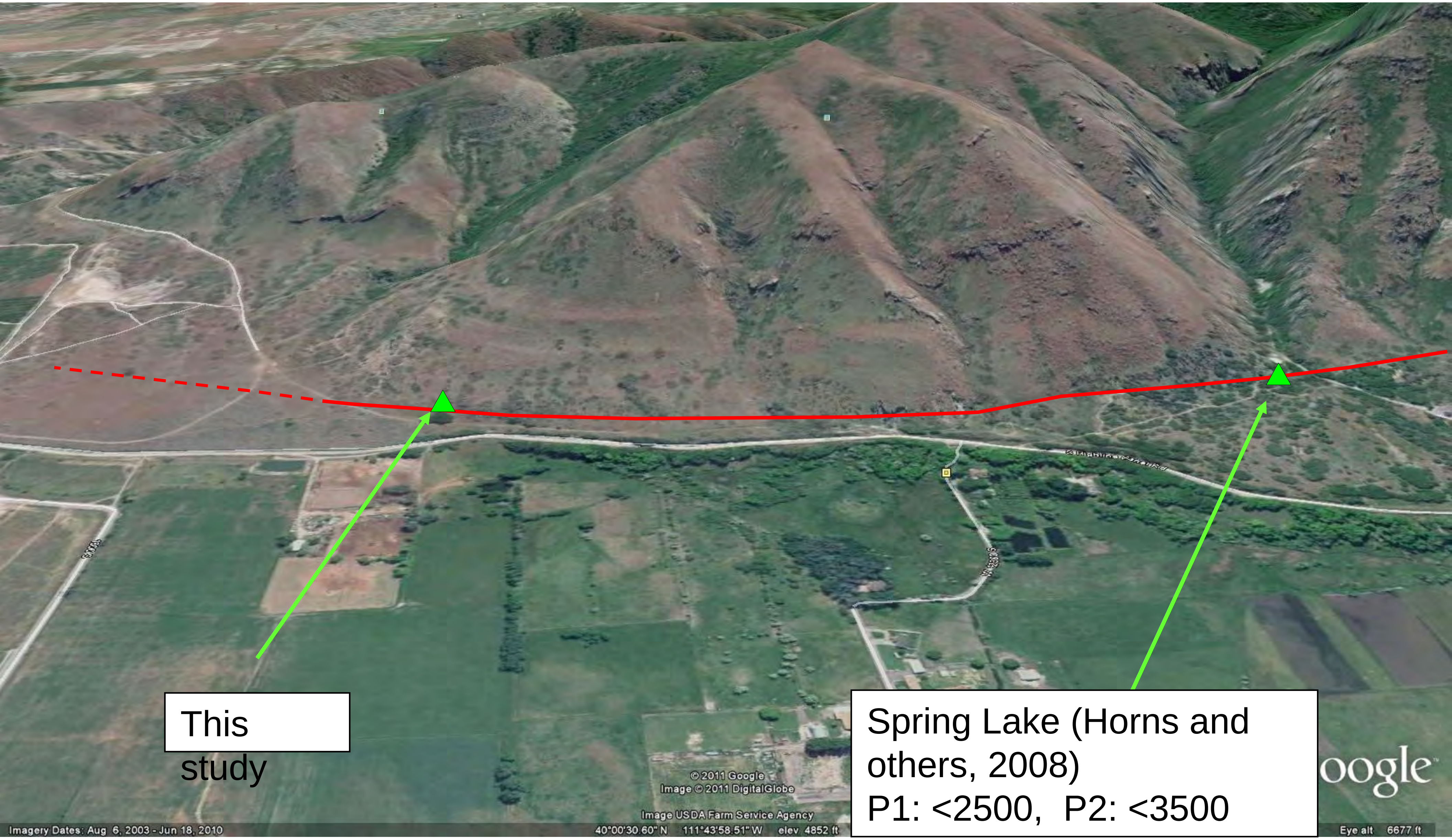
Spring Lake (Horns and others, 2008)
P1: <2500, P2: <3500



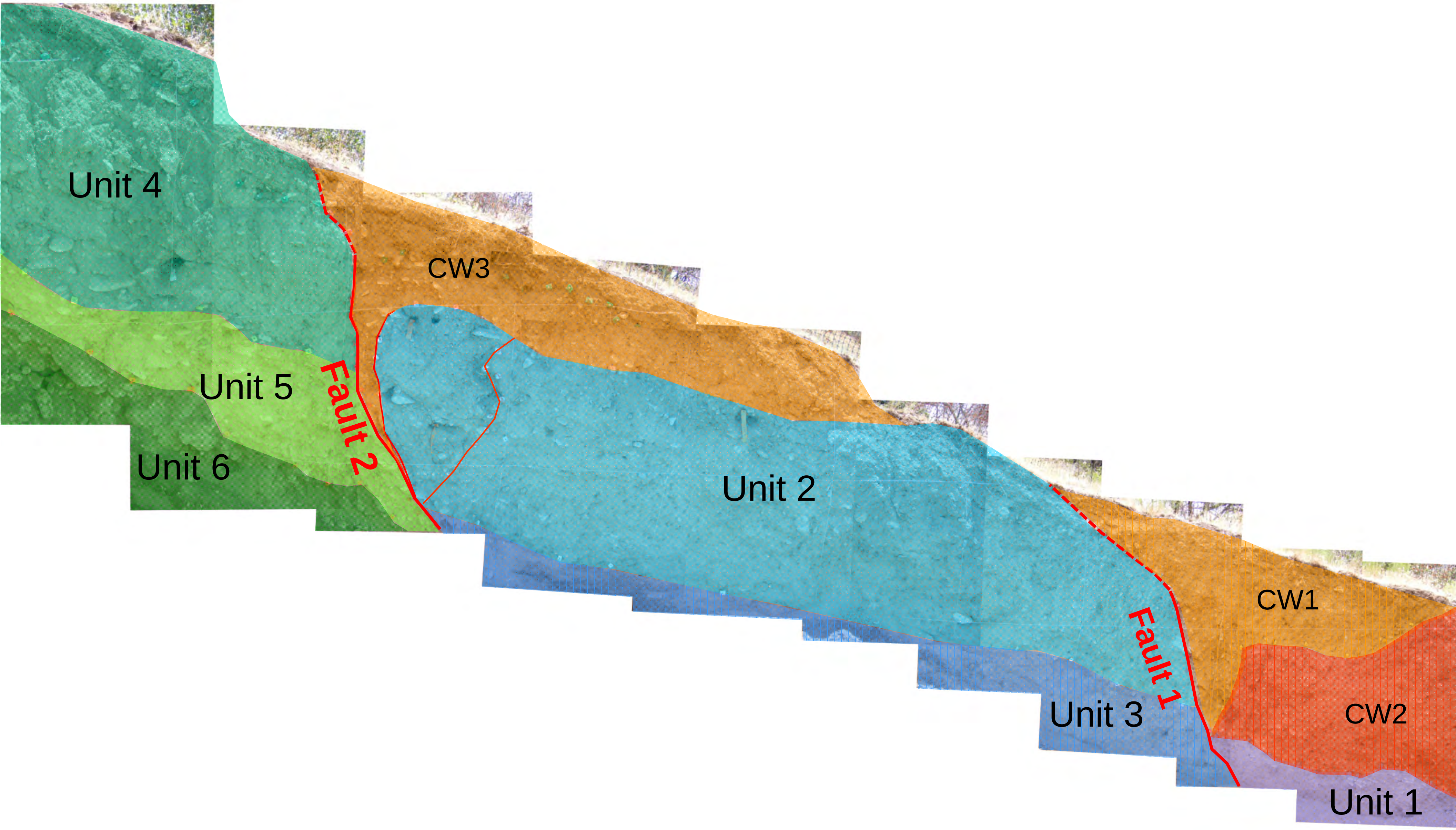
From Solomon, Clark, and Machette (2007)


This study
Spring Lake (Horns and others, 2008)
P1: <2500, P2: <3500

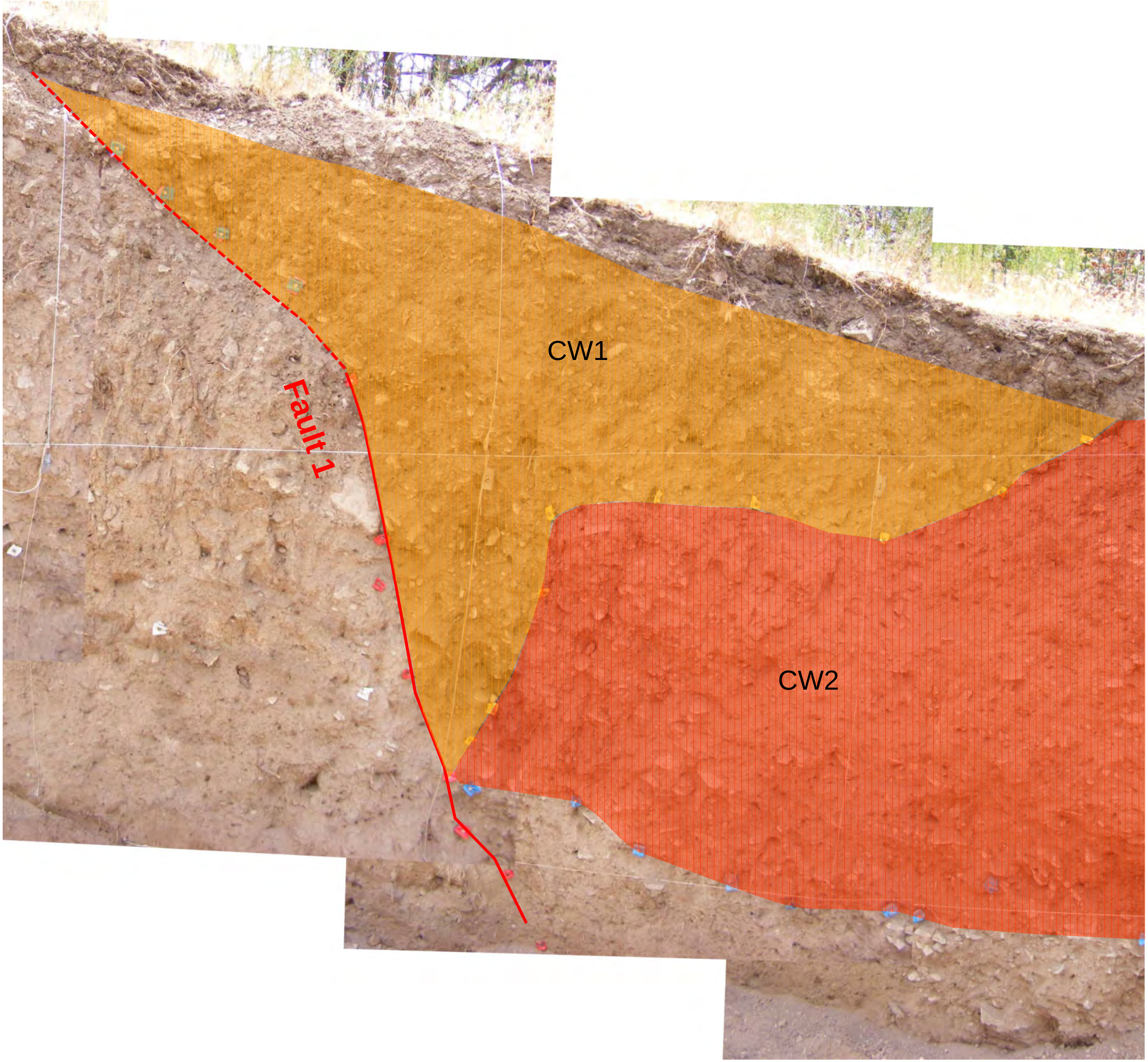
This study
Spring Lake (Horns and others, 2008)
P1: <2500, P2: <3500
Spring Lake
© 2011 Google
©2010 Google
Imagery Date: Jun 18, 2010
40°00'34.97" N 111°43'43.08" W elev 5393 ft
Eye alt 16065 ft

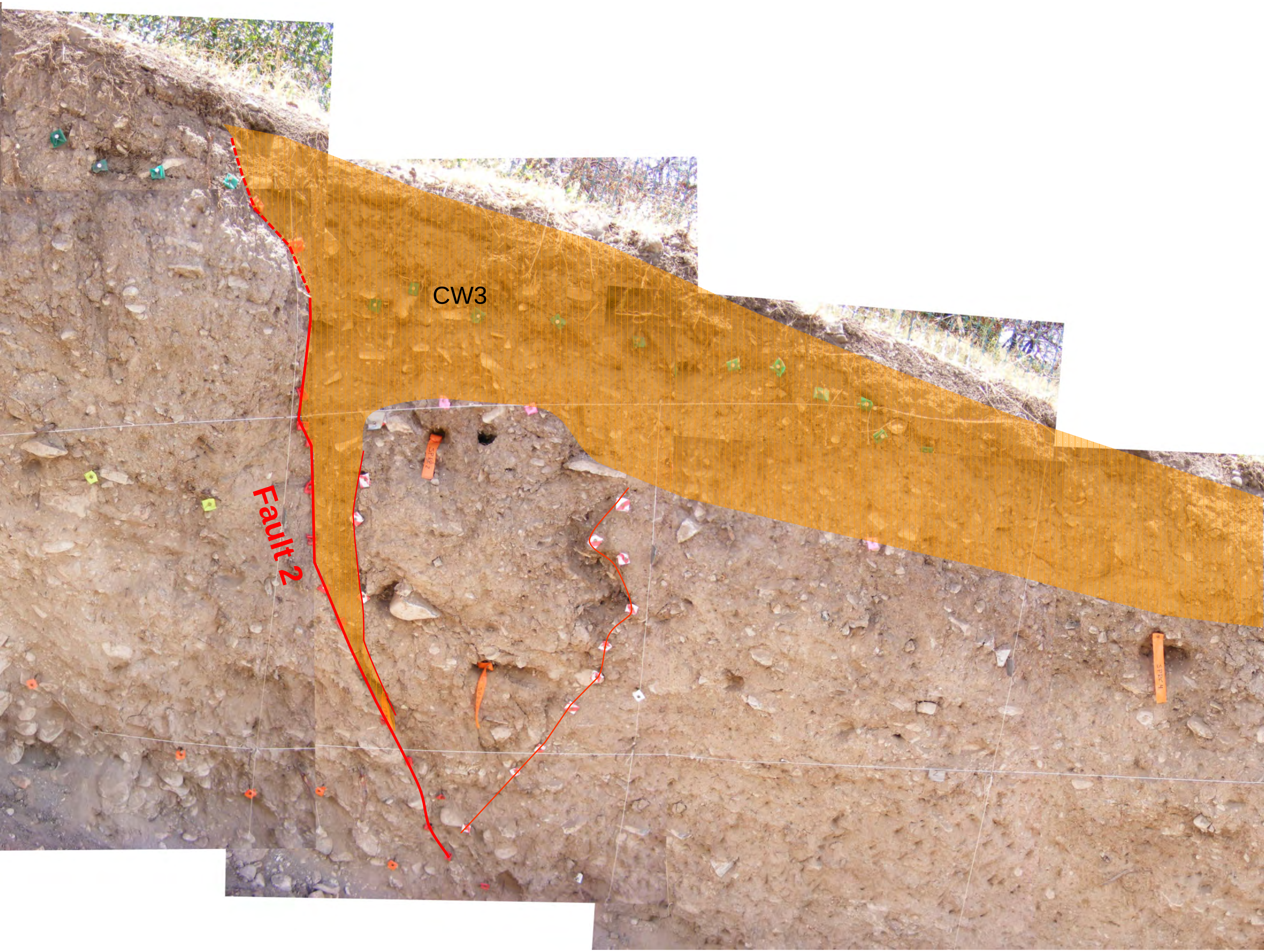

This study
Spring Lake (Horns and others, 2008)
P1: <2500, P2: <3500
© 2011 Google
Image © 2011 DigitalGlobe
Image USDA Farm Service Agency
Imagery Dates: Aug 6, 2003 - Jun 18, 2010
40°00'30.60" N   111°43'58.51" W   elev 4852 ft
Eye alt   6677 ft

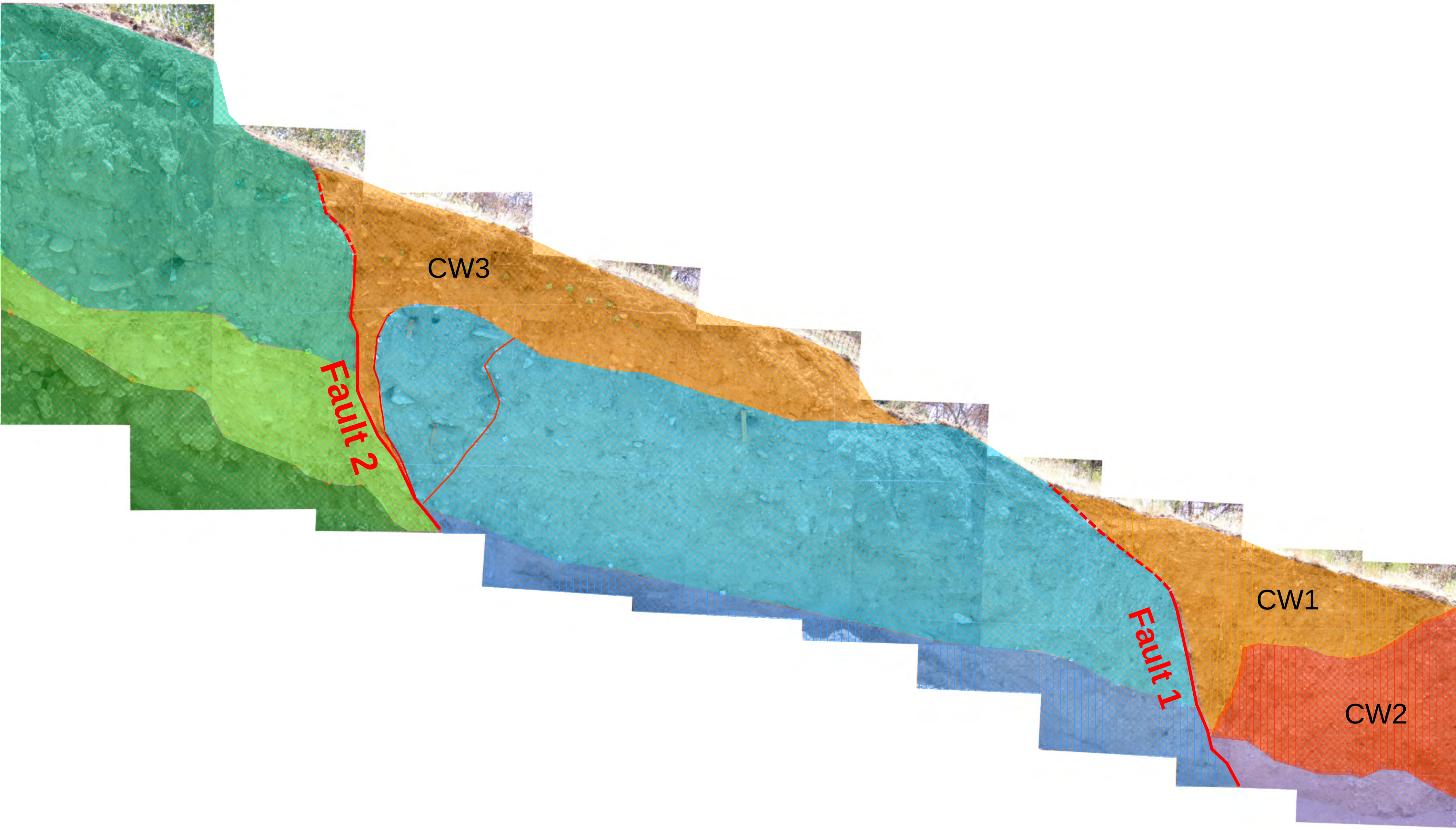
© 2011 Google
Image © 2011 DigitalGlobe
Image USDA Farm Service Agency
©2010 Google
Imagery Dates: Aug 11, 2002 - Jun 18, 2010
40°00'40.45" N 111°43'56.41" W elev 4831 ft
Eye alt 5220 ft



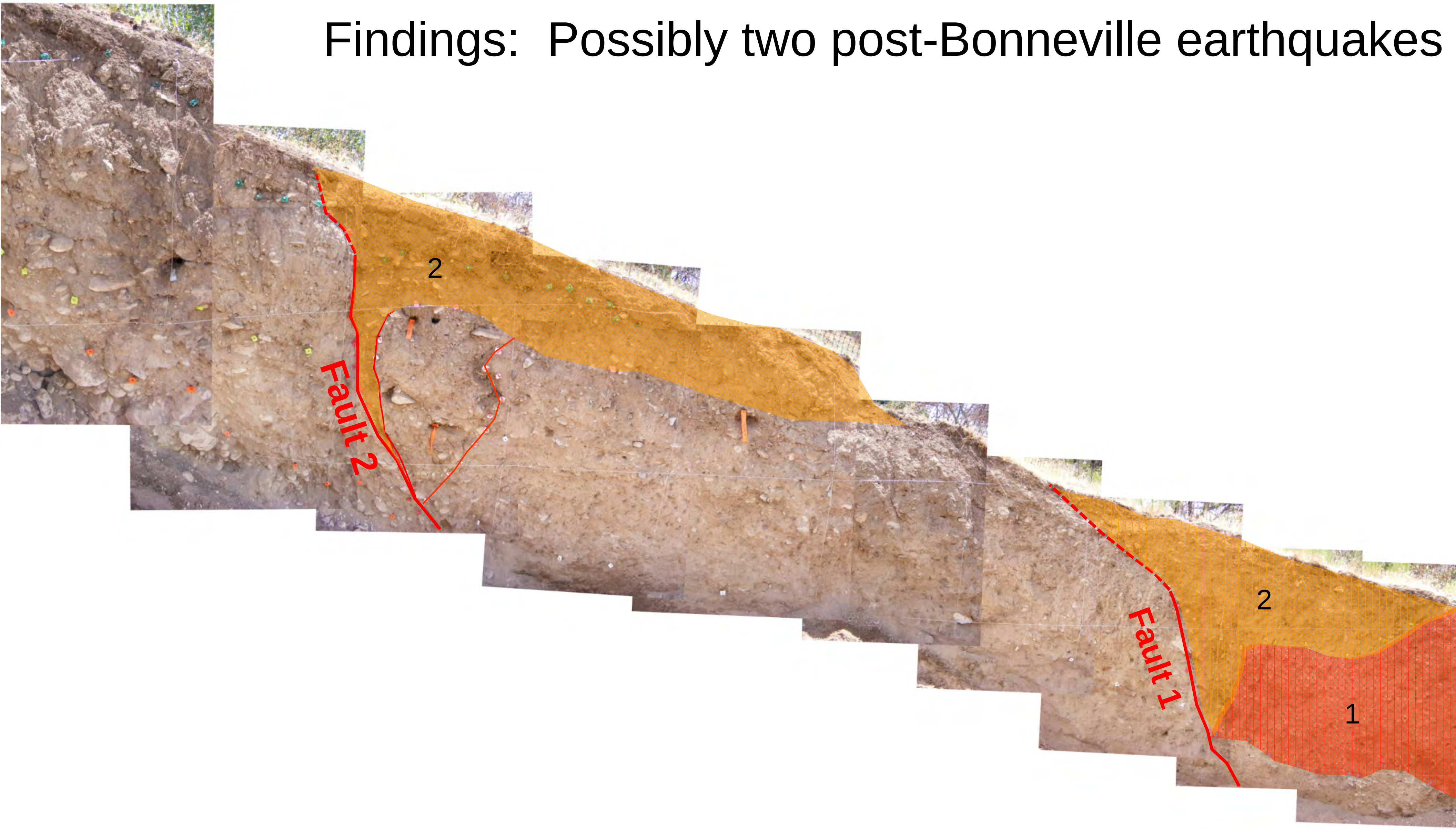
Unit 4
CW3
Unit 5
Fault 2
Unit 6
Unit 2
CW1
Fault 1
Unit 3
CW2
Unit 1


CW1
Fault 1
CW2

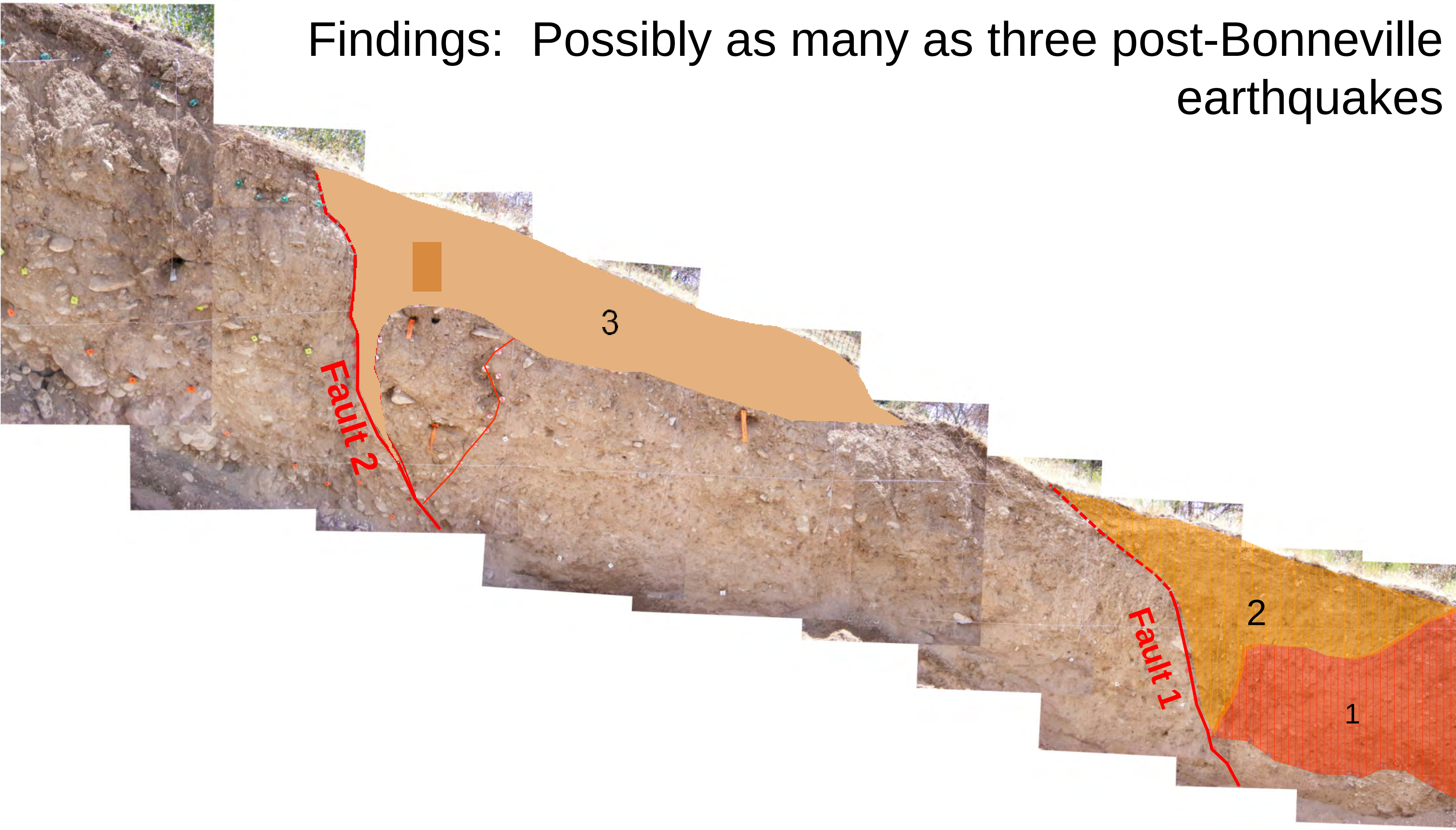

CW3
Fault 2

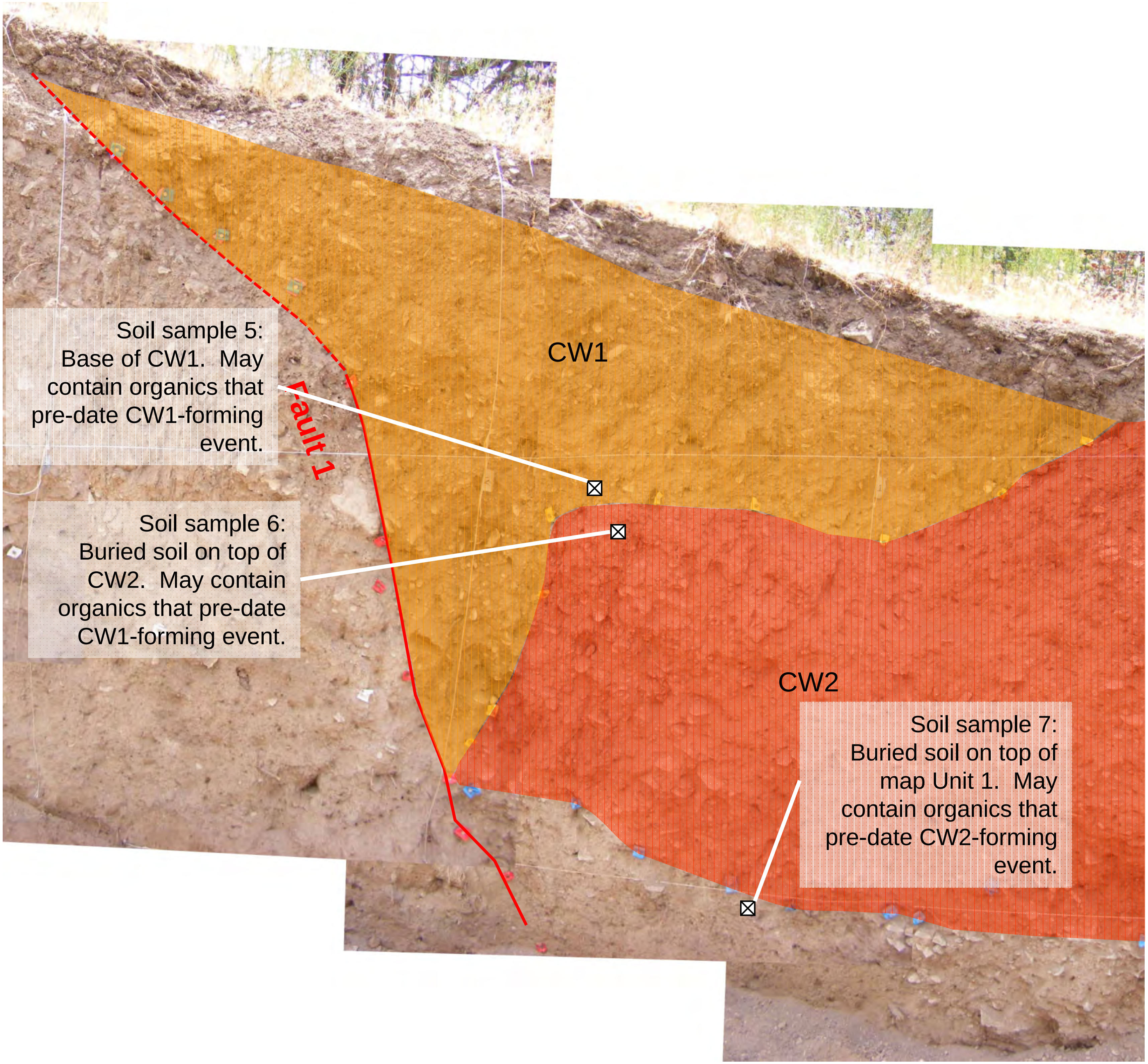

CW3
Fault 2
CW1
Fault 1
CW2

Findings: Possibly two post-Bonneville earthquakes

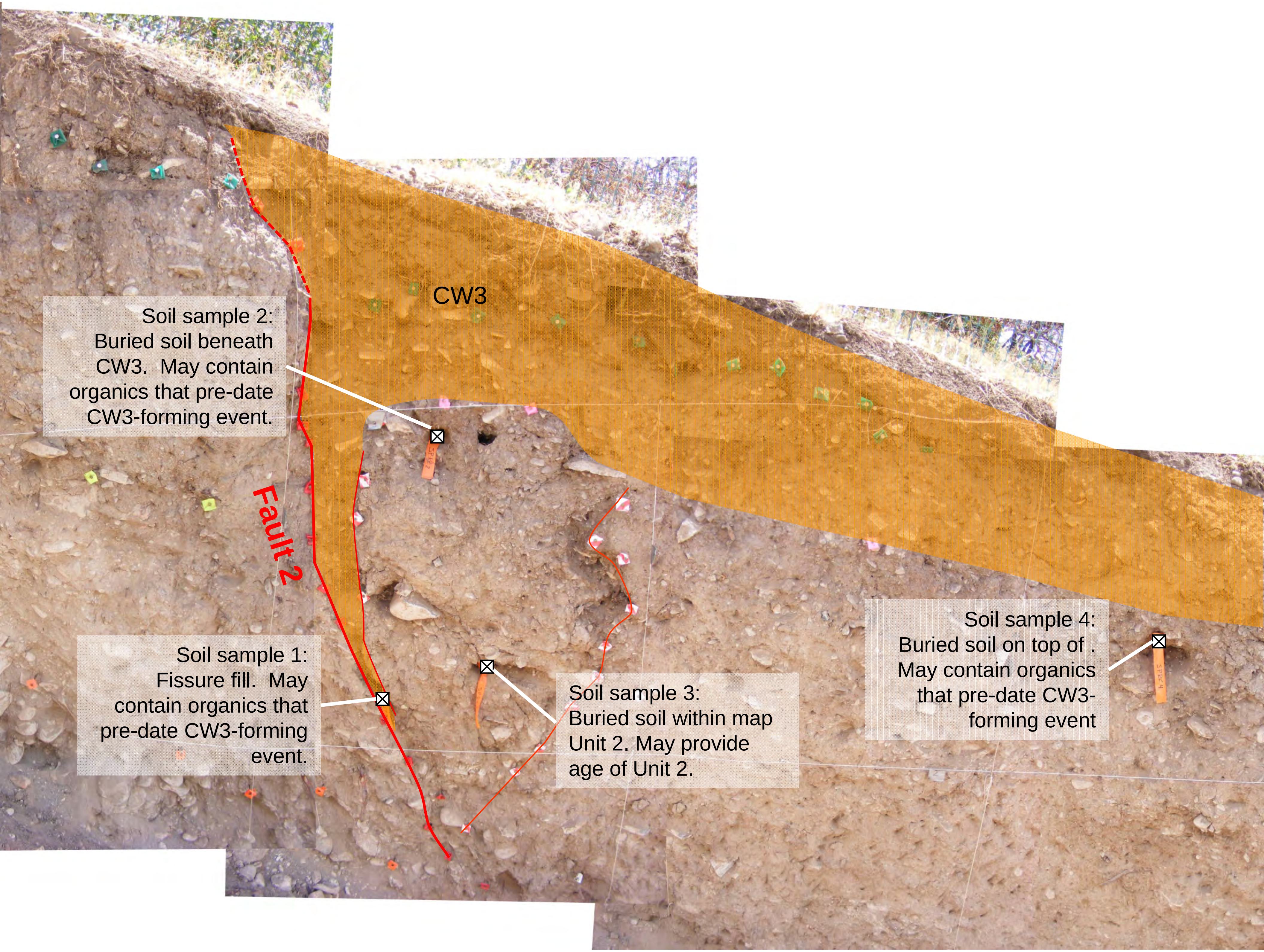


Findings: Possibly as many as three post-Bonneville earthquakes



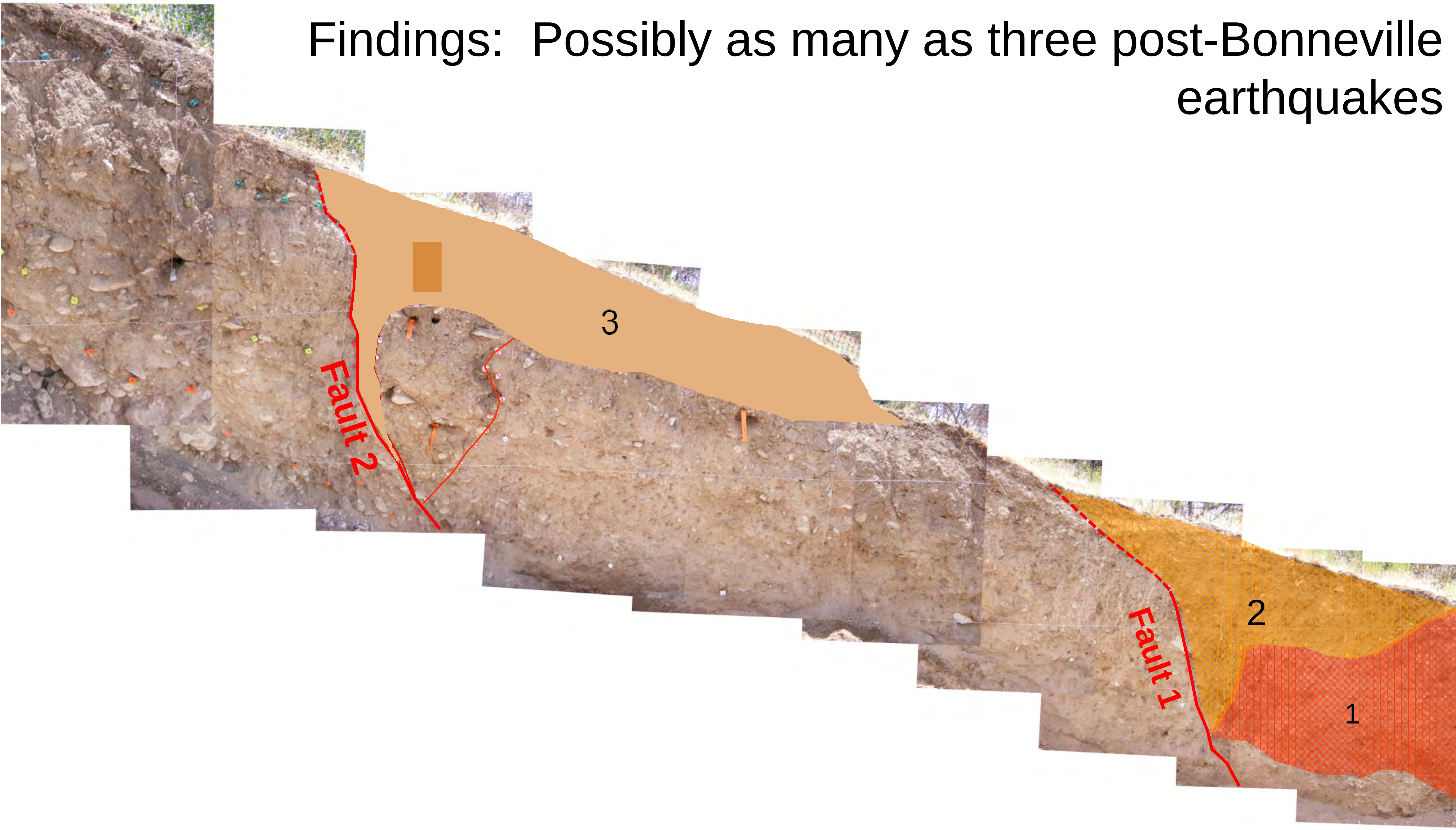


Soil sample 5:
Base of CW1. May contain organics that pre-date CW1-forming event.
Fault 1
CW1
Soil sample 6:
Buried soil on top of CW2. May contain organics that pre-date CW1-forming event.
CW2
Soil sample 7:
Buried soil on top of map Unit 1. May contain organics that pre-date CW2-forming event.


CW3
Fault 2
Soil sample 2: Buried soil beneath CW3. May contain organics that pre-date CW3-forming event.
Soil sample 1: Fissure fill. May contain organics that pre-date CW3-forming event.
Soil sample 3: Buried soil within map Unit 2. May provide age of Unit 2.
Soil sample 4: Buried soil on top of . May contain organics that pre-date CW3-forming event


SP RC4
SP RC3
ALL NATURAL MEAL
italian style
FROM OUR FAMILY TO YOURS
PREMIUM

Findings: Possibly as many as three post-Bonneville earthquakes

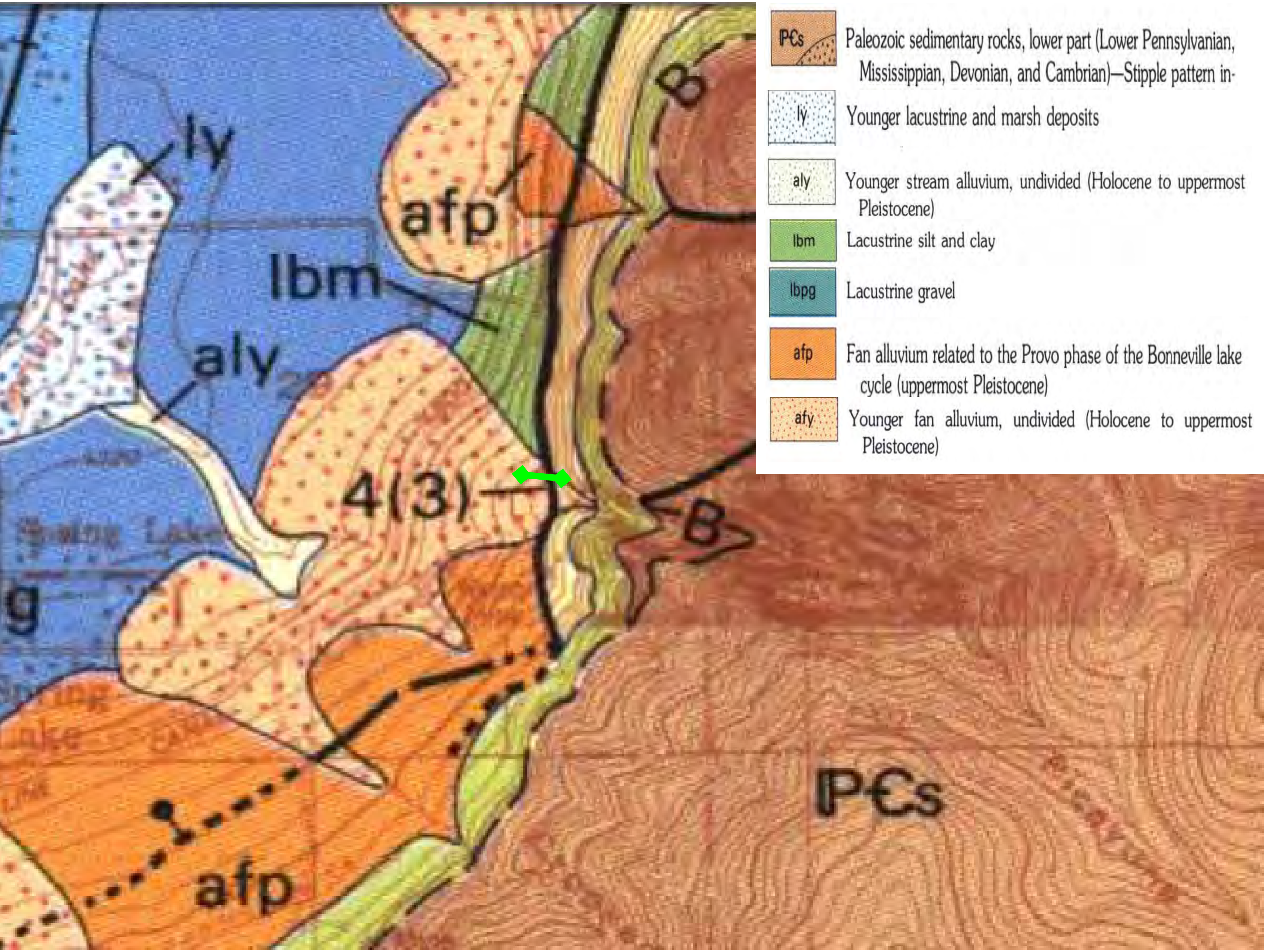


U T A H   G E O L O G I C A L   S U R V E Y

SURVEY NOTES

Volume 39, Number 1

January 2007



ly
afp
lbm
aly
4(3)
g
afp
B
B
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)

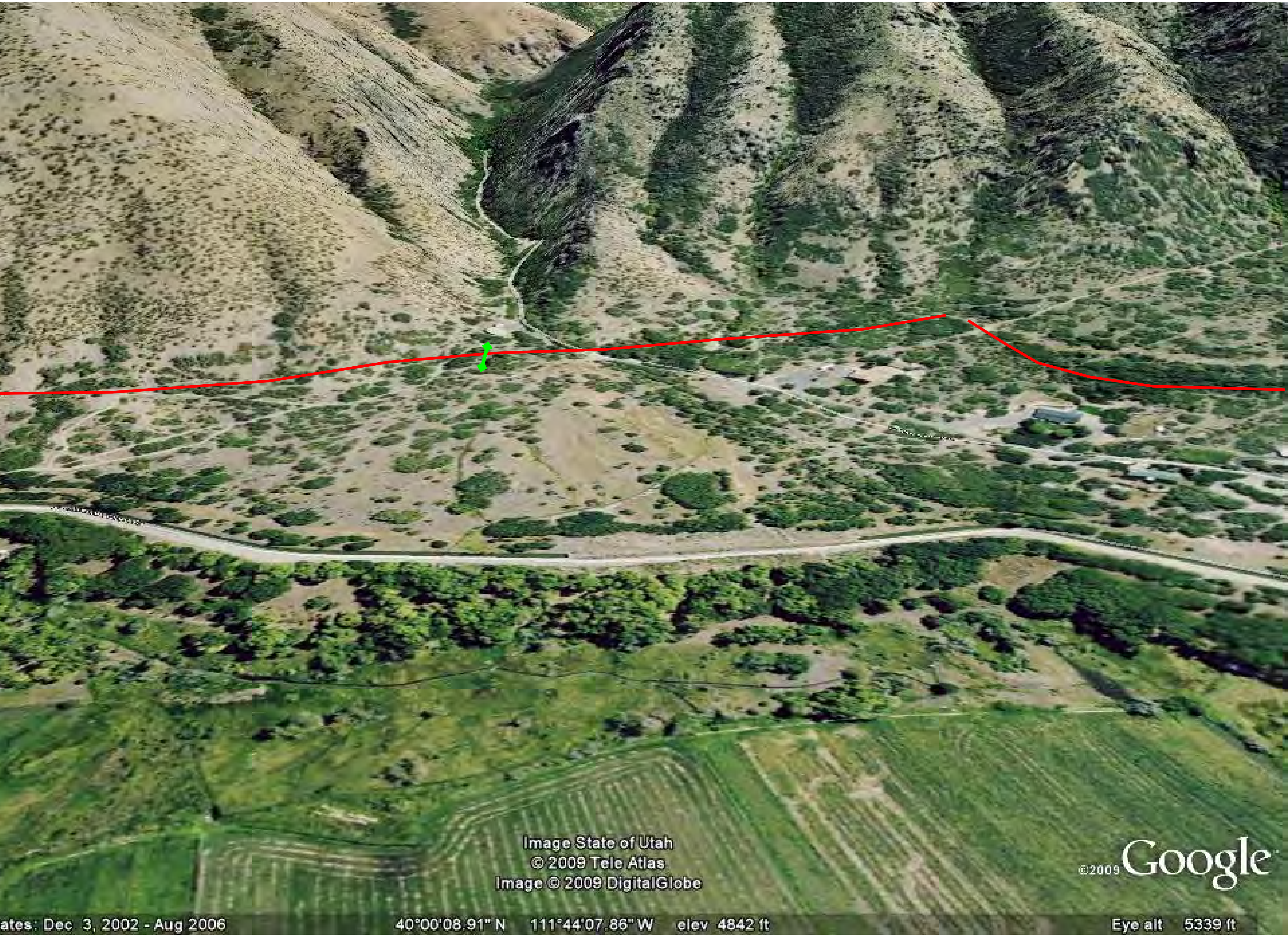


Image State of Utah
© 2009 Tele Atlas
Image © 2009 DigitalGlobe
©2009 Google
ates: Dec 3, 2002 - Aug 2006
40°00'08.91" N
111°44'07.86" W
elev 4842 ft
Eye alt 5339 ft

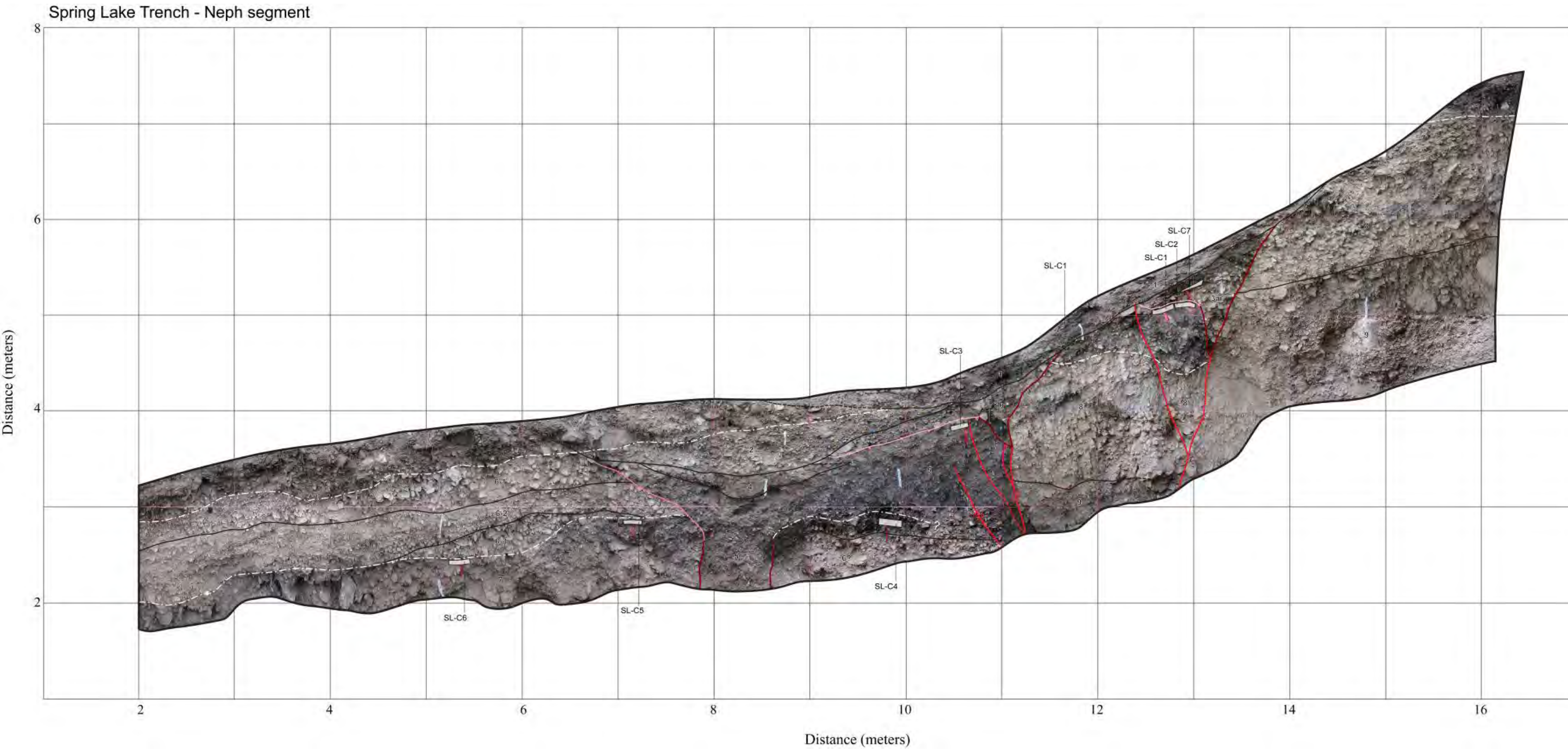
It quickly became apparent that we had fairly well-defined debris flow deposits and very well-defined colluvial wedges.

Paleoseismic Investigation of the Wasatch Fault Near Spring Lake, Utah

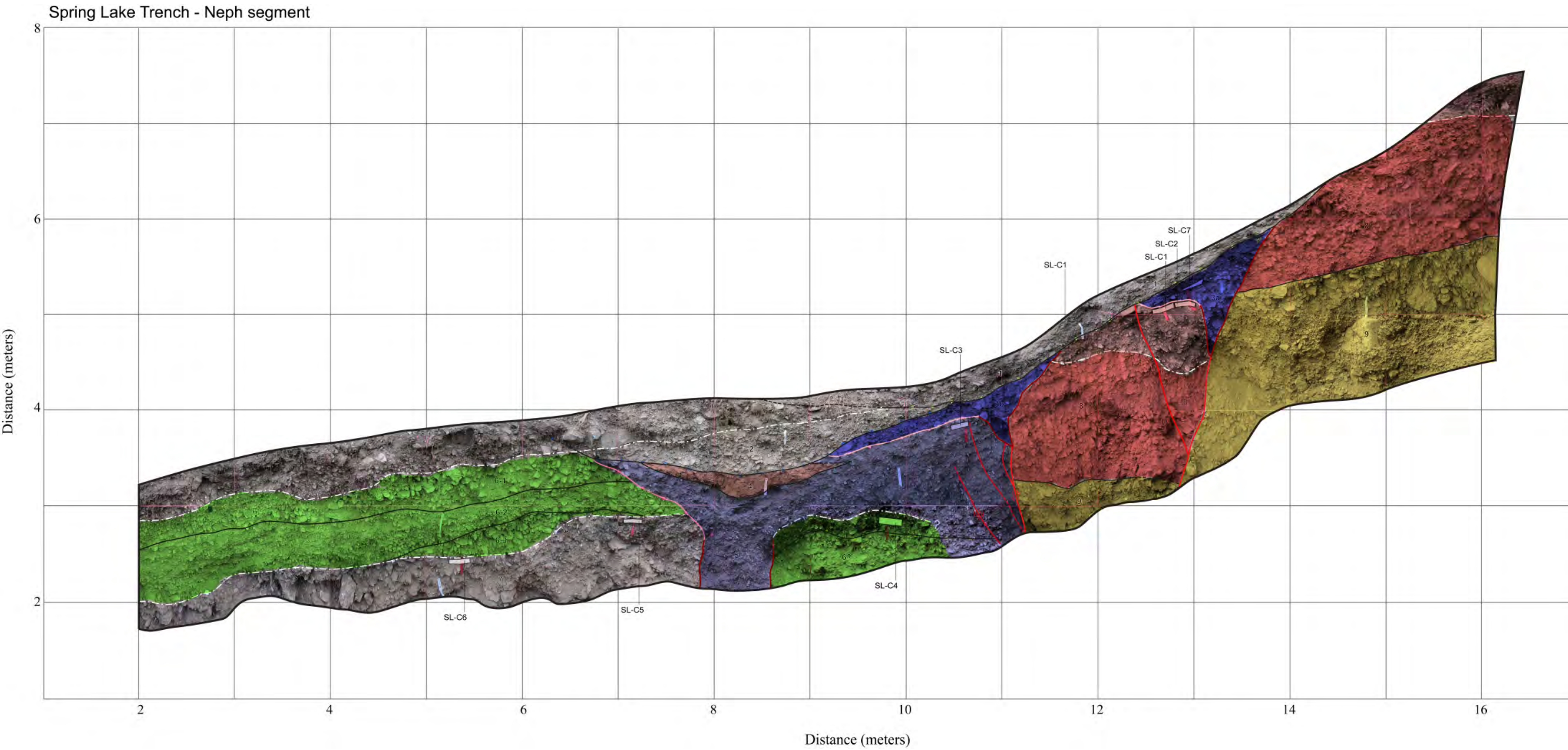
1. Introduction to the Nephi segment

2. How UVSC students became involved

3. Results



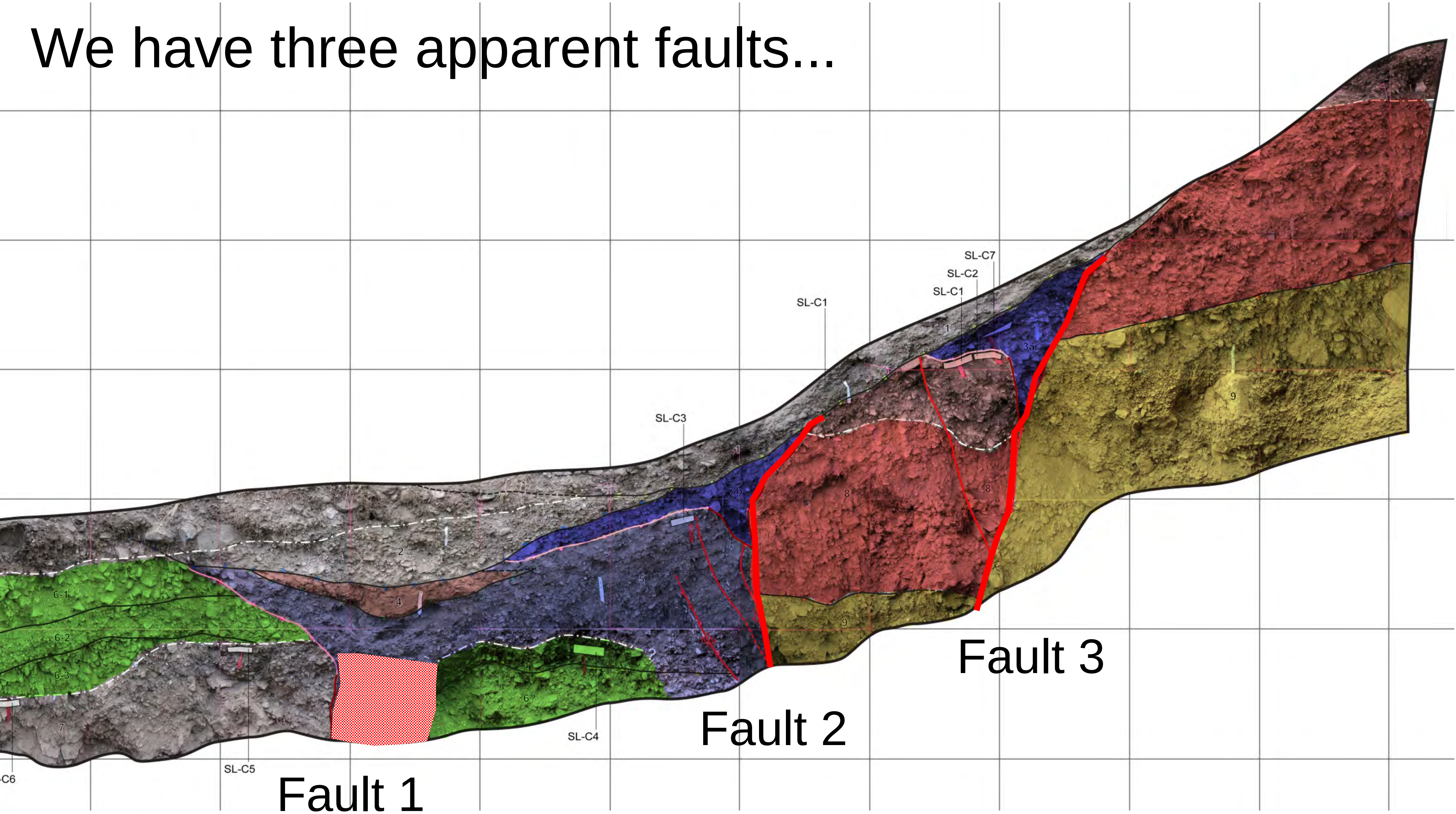
Photomosaic of the north wall (by Chris DuRoss) with interpretations of faults and sedimentary units.



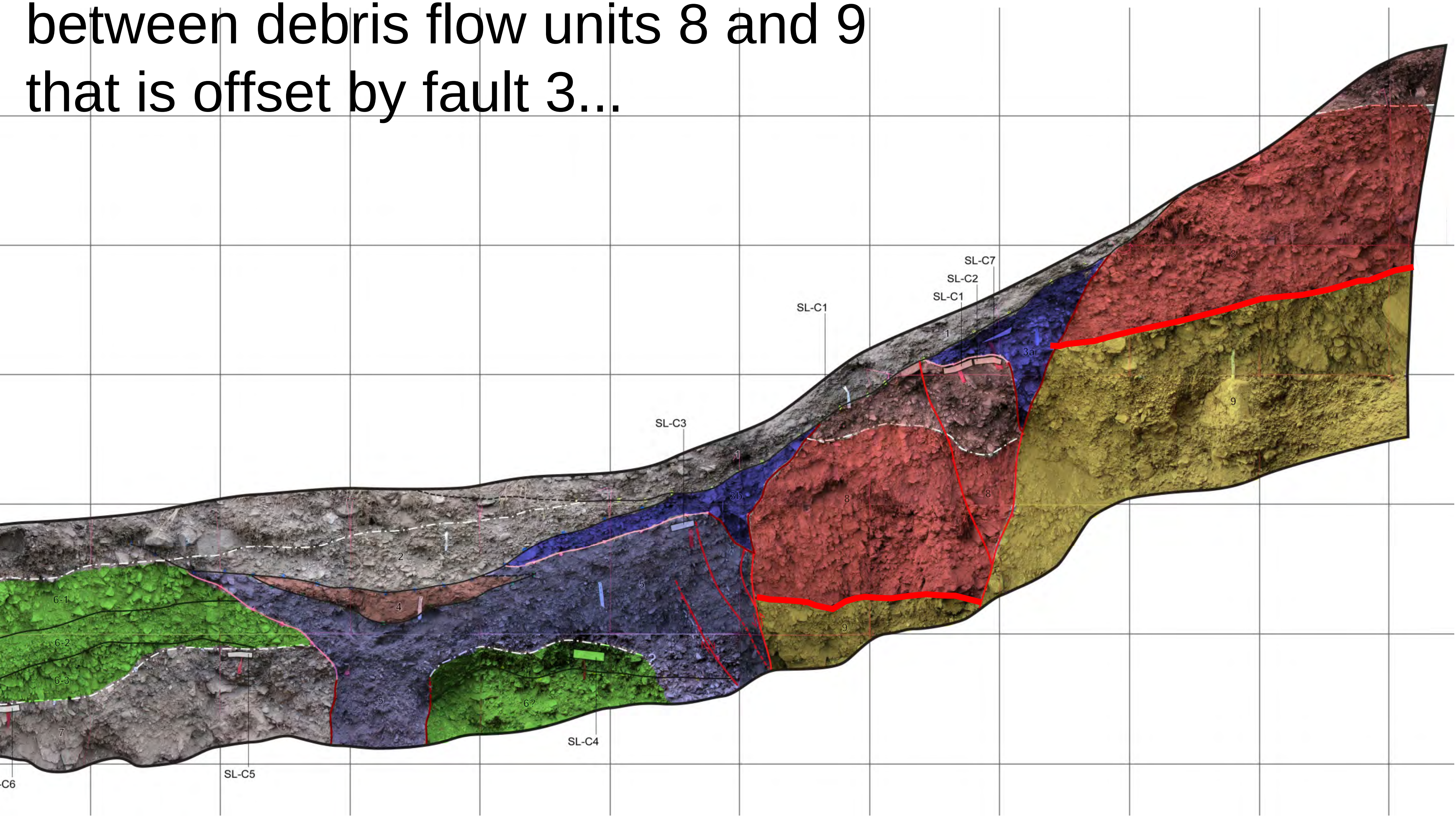
With map units colored-in.

Let’s look at some key features:

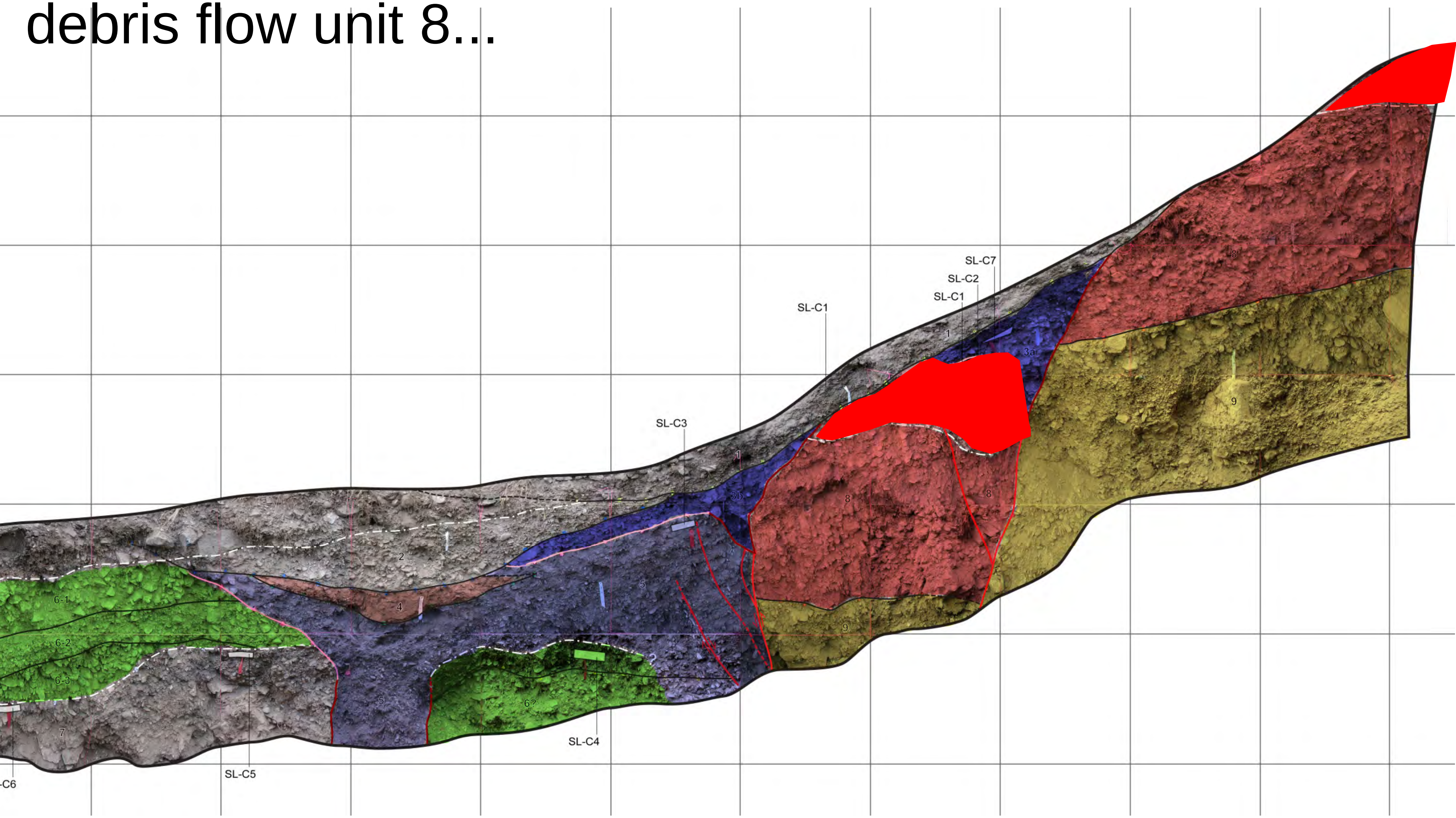
We have three apparent faults...



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

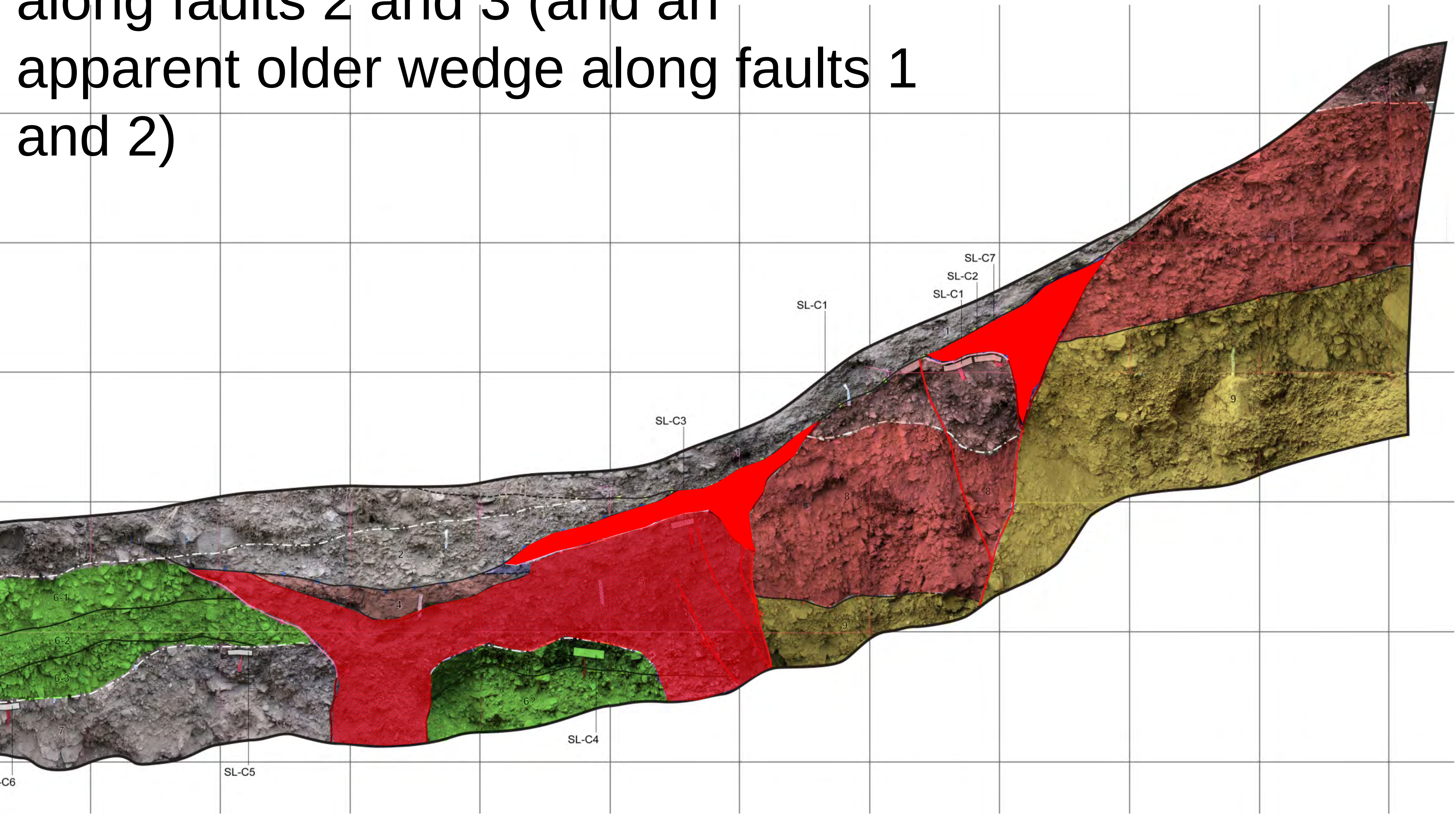


... a well-defined soil on top of debris flow unit 8...

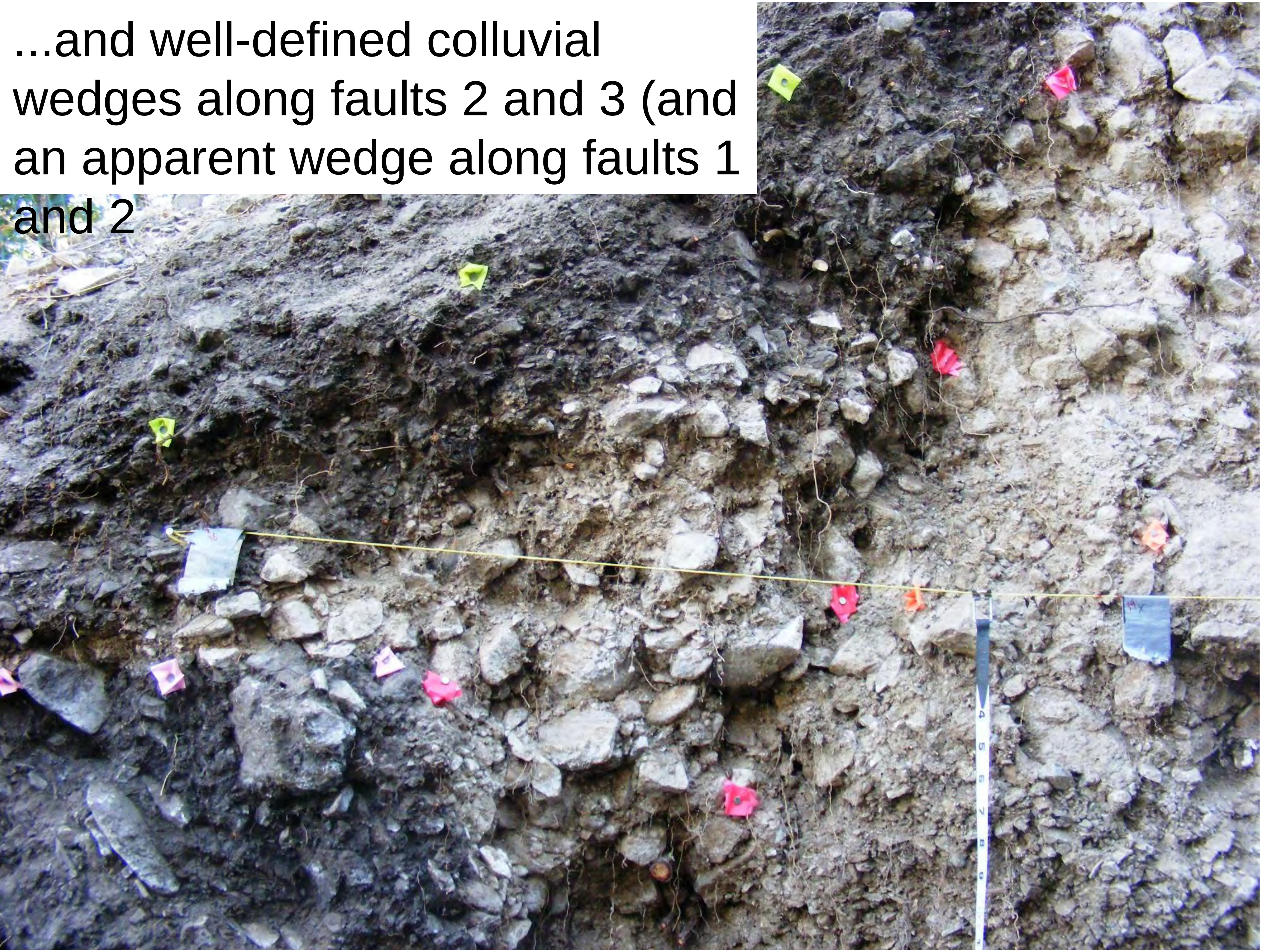



... a well-defined soil on top of debris flow unit 8...

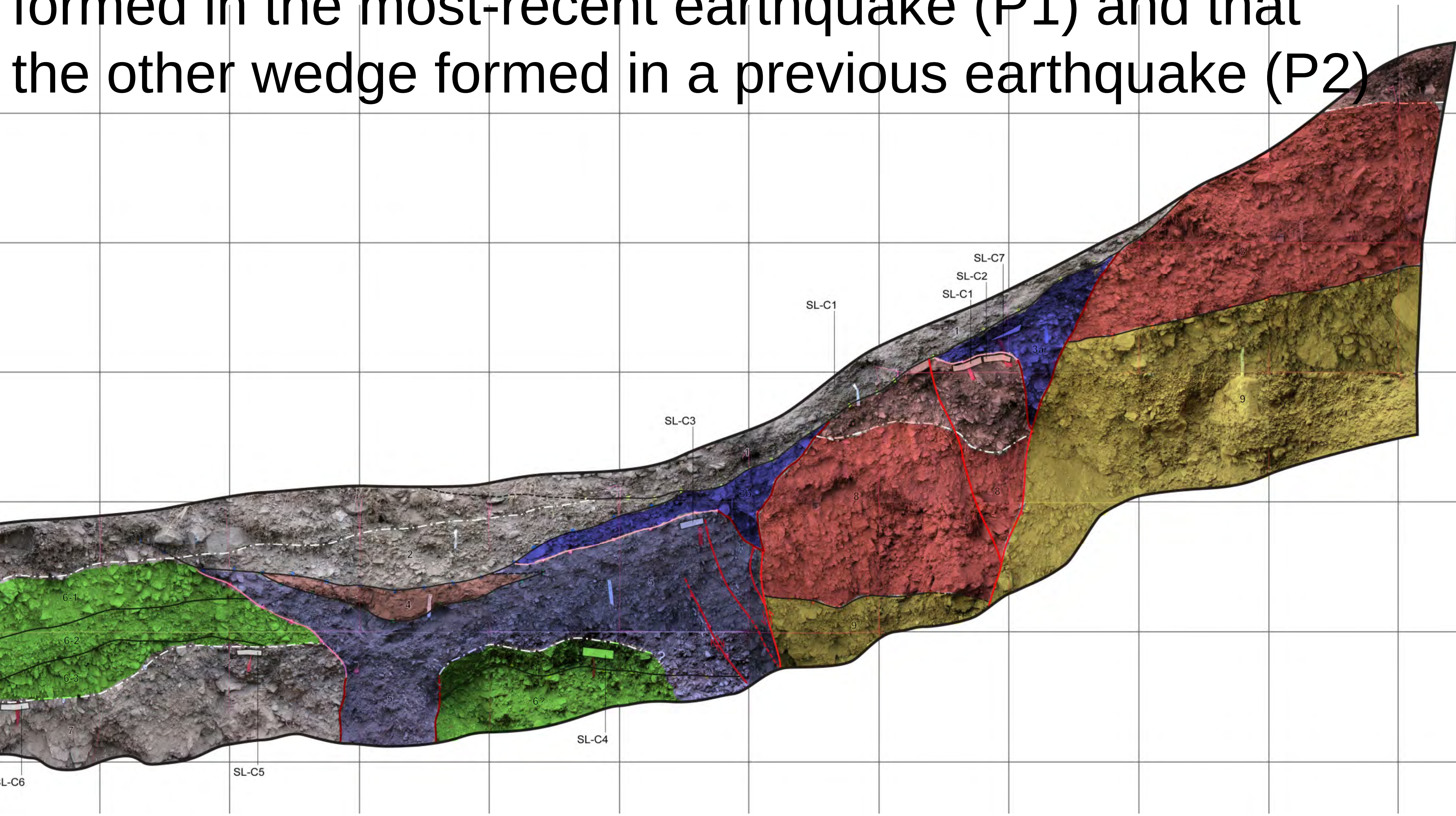
...and well-defined colluvial wedges along faults 2 and 3 (and an apparent older wedge along faults 1 and 2)



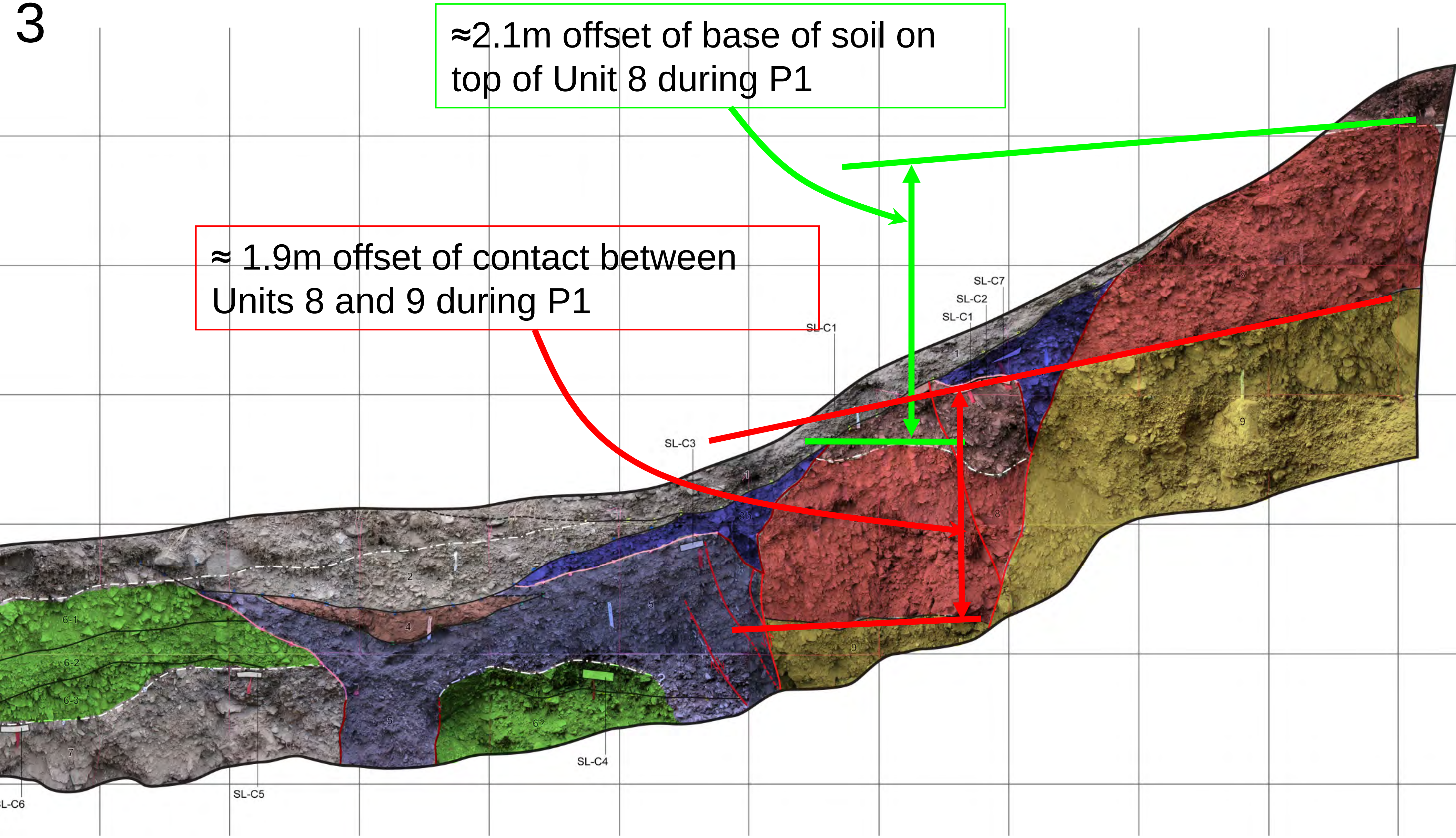
...and well-defined colluvial wedges along faults 2 and 3 (and an apparent wedge along faults 1 and 2

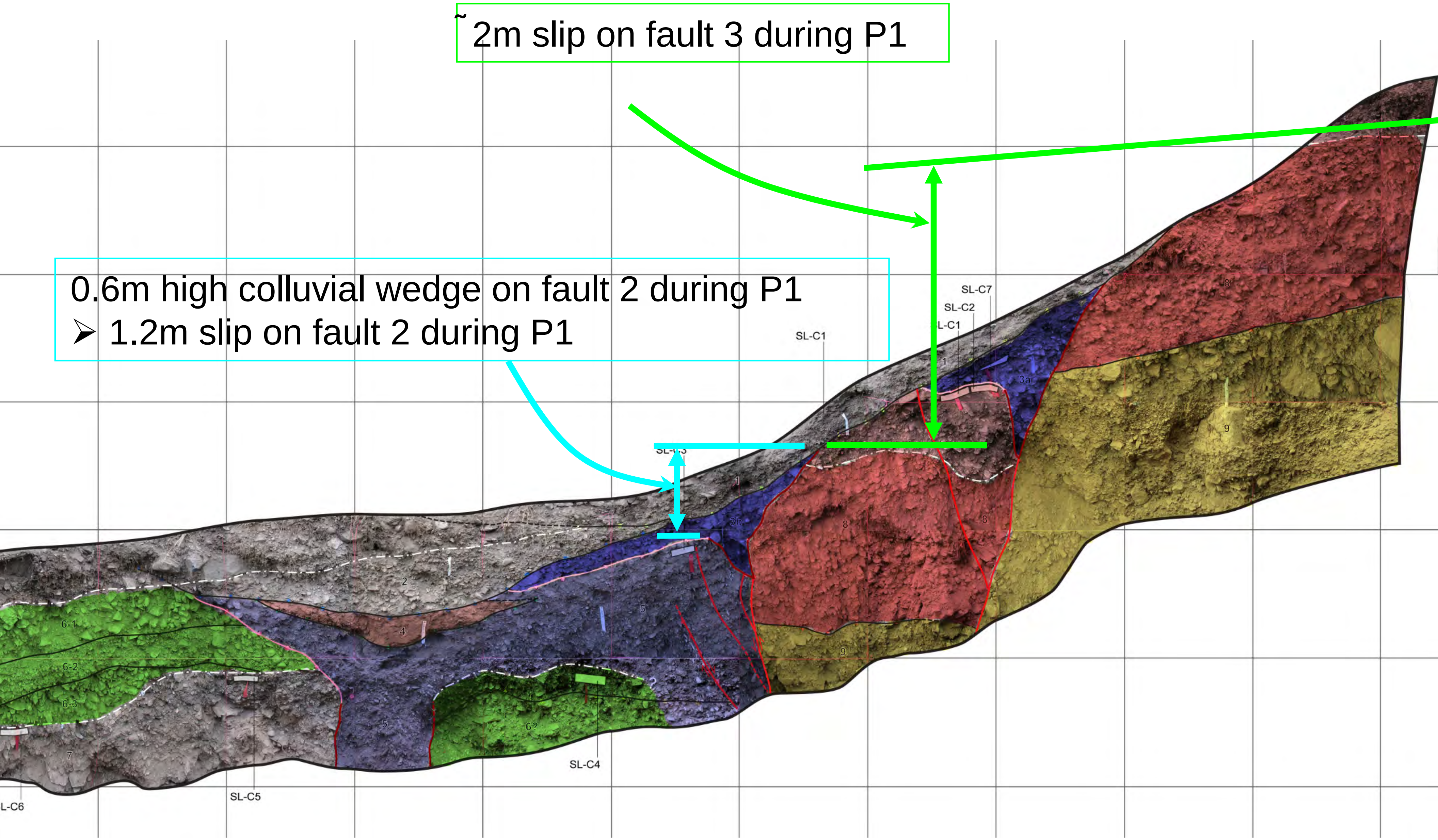


We think that the two well-defined colluvial wedges formed in the most-recent earthquake (P1) and that the other wedge formed in a previous earthquake (P2)



Estimating the amount of slip during P1: fault 3

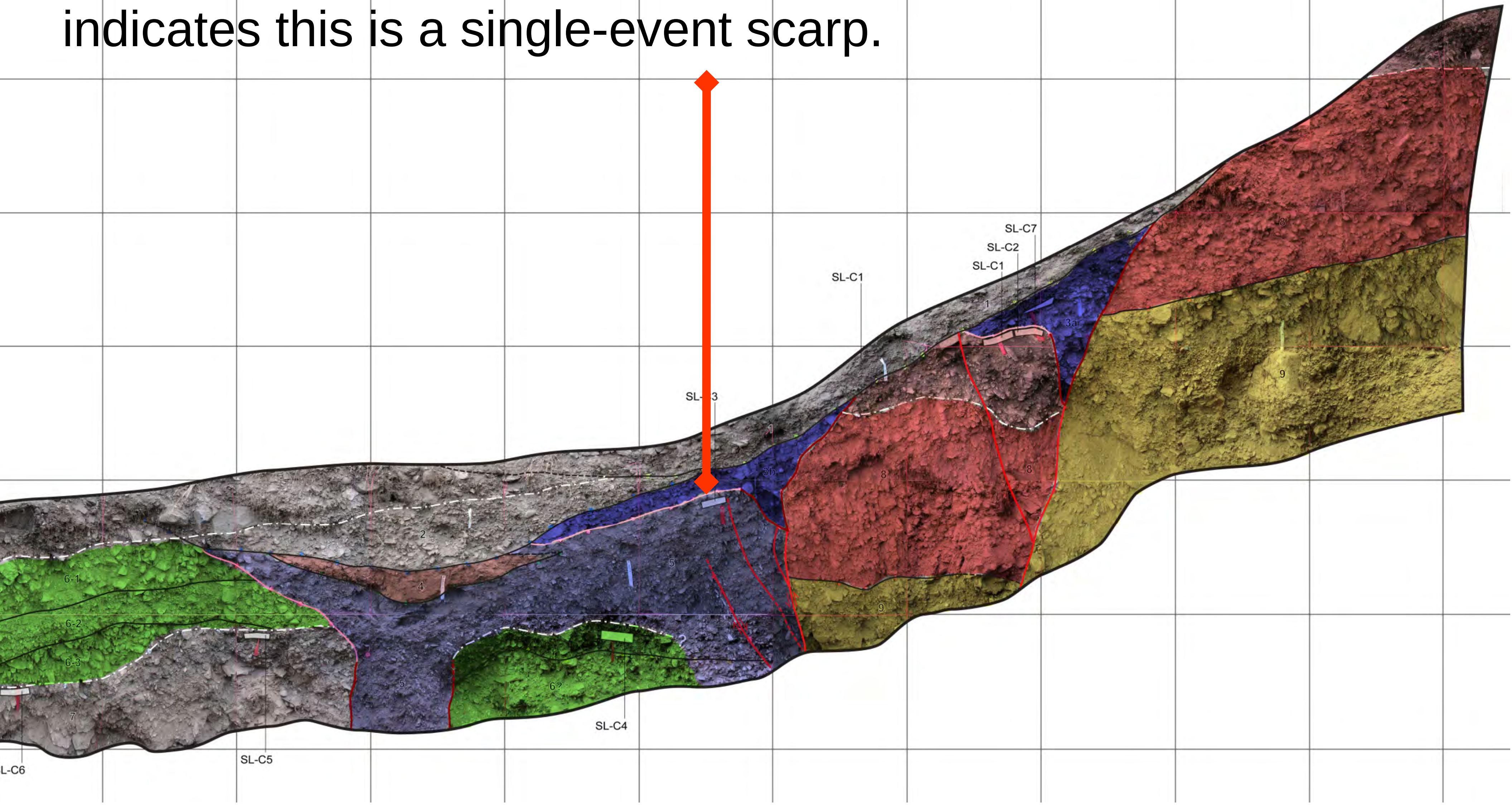




˜2m slip on fault 3 during P1
0.6m high colluvial wedge on fault 2 during P1
➢ 1.2m slip on fault 2 during P1
SL-C7
SL-C2
SL-C1
SL-C1
SL-C4
SL-C5

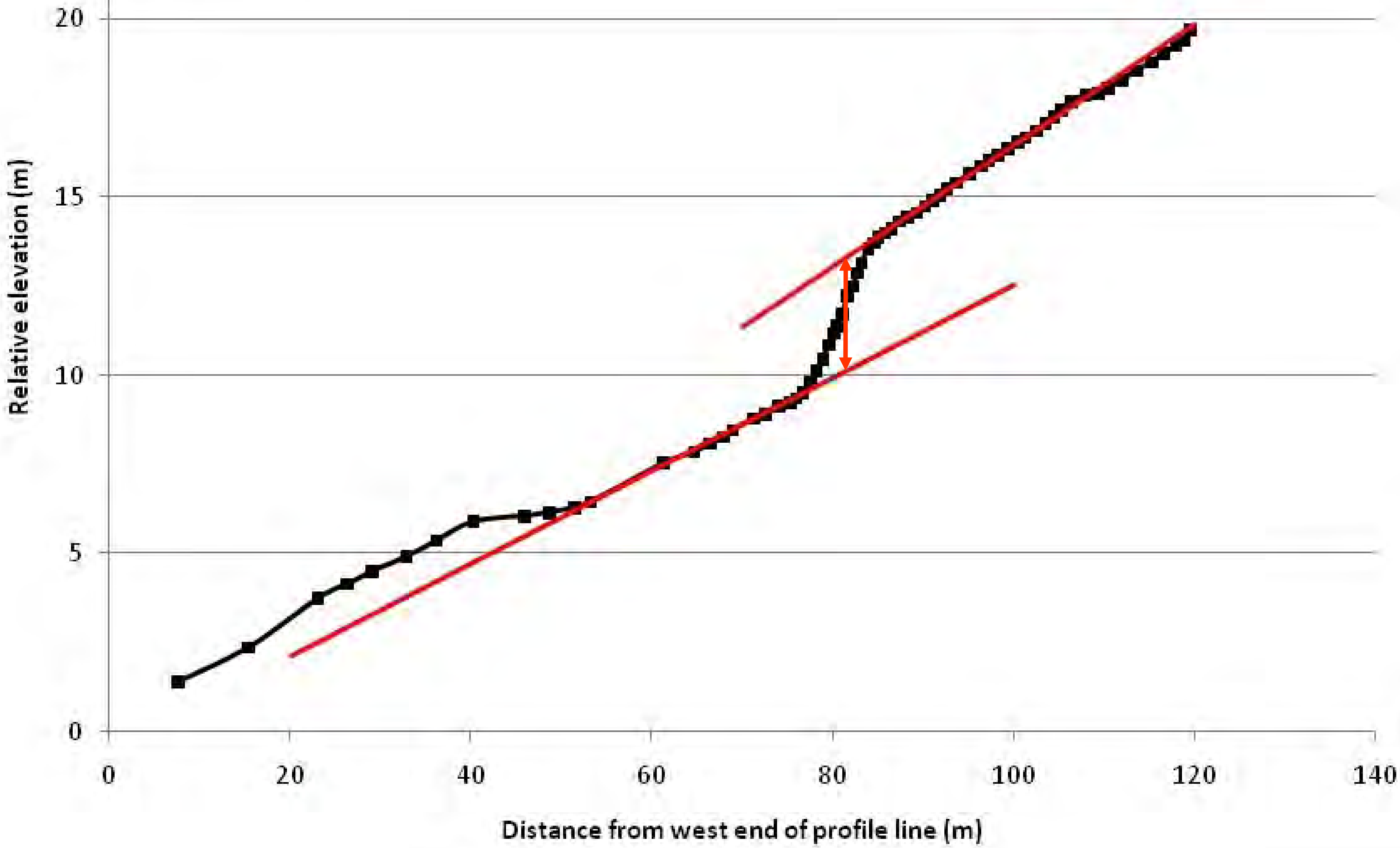
3.2 m of slip during P1

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



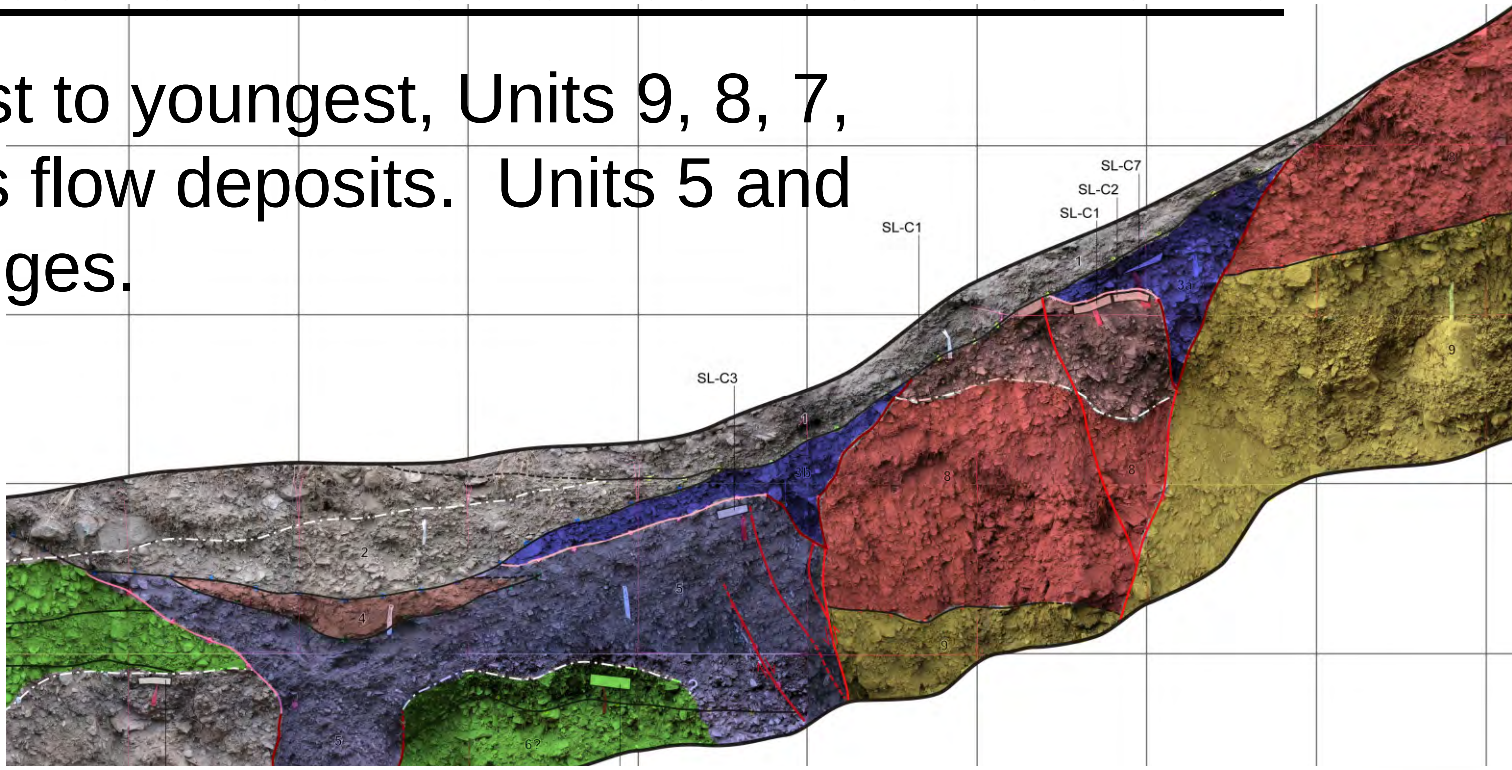
3.2 m of slip during P1

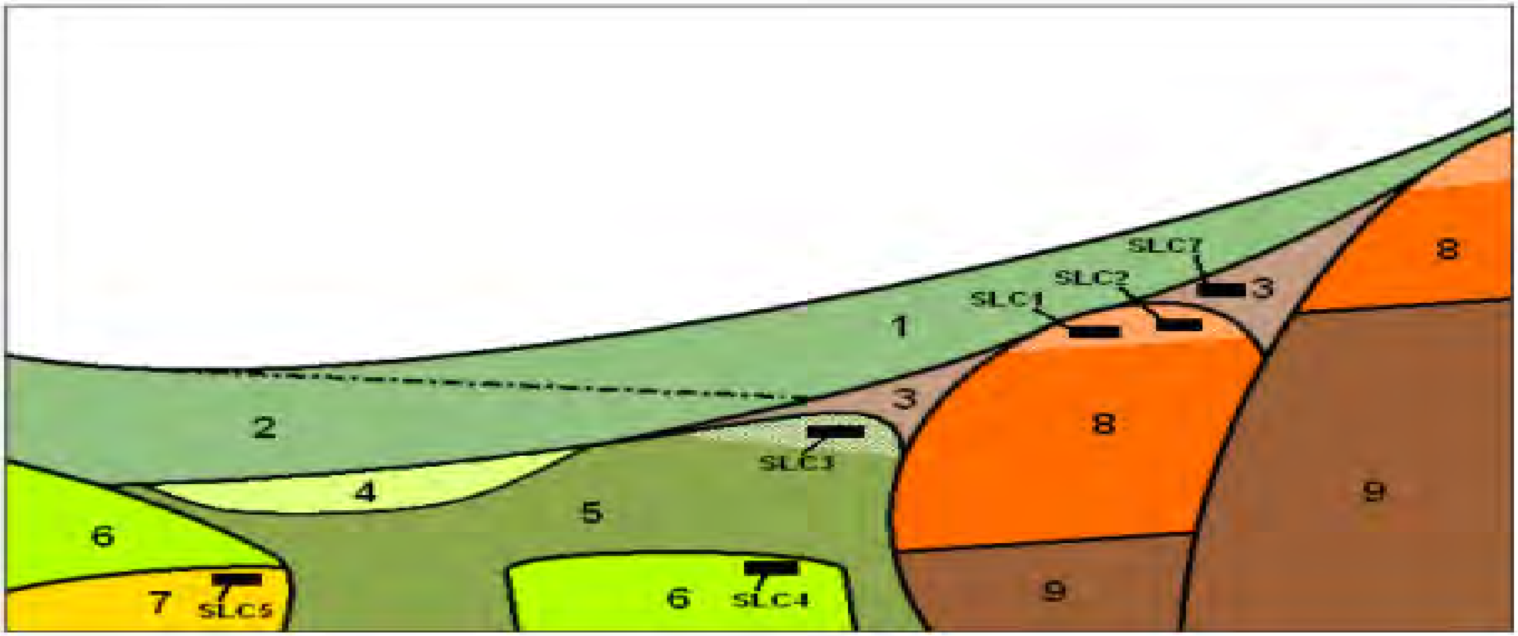
➢Compared with 3.3 m scarp height based on our profiling, fairly consistent with a single-event scarp.



Interpreted reconstruction of series of events

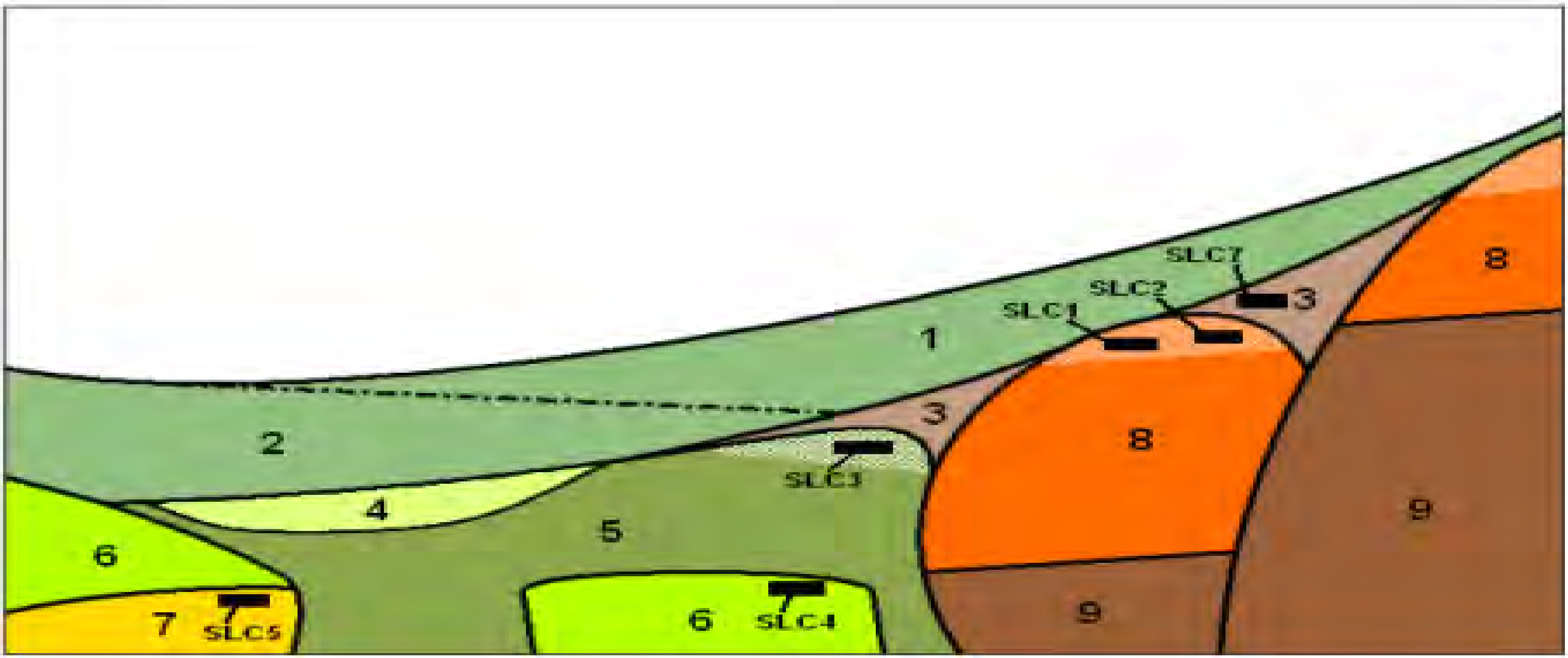
In order from oldest to youngest, Units 9, 8, 7, 6, and 2 are debris flow deposits. Units 5 and 3 are colluvial wedges.





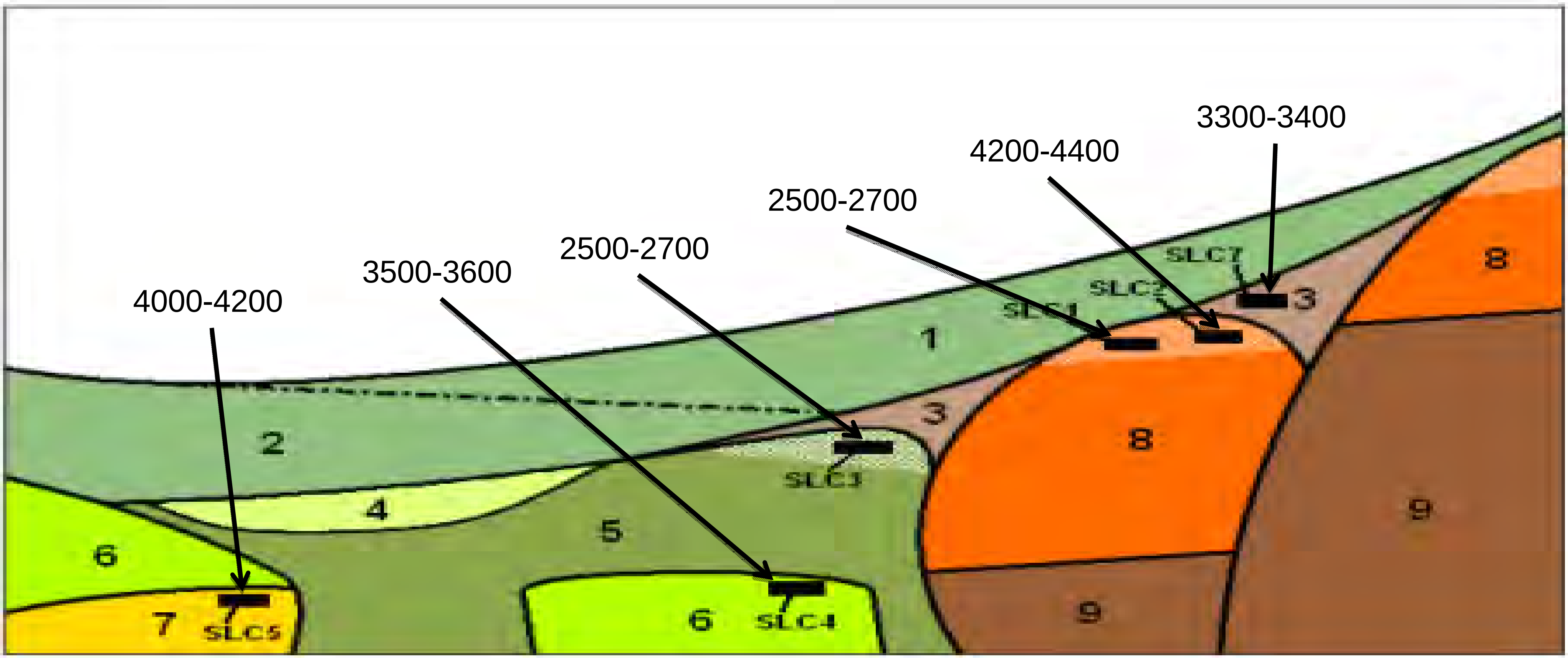
Relative Ages

- 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.



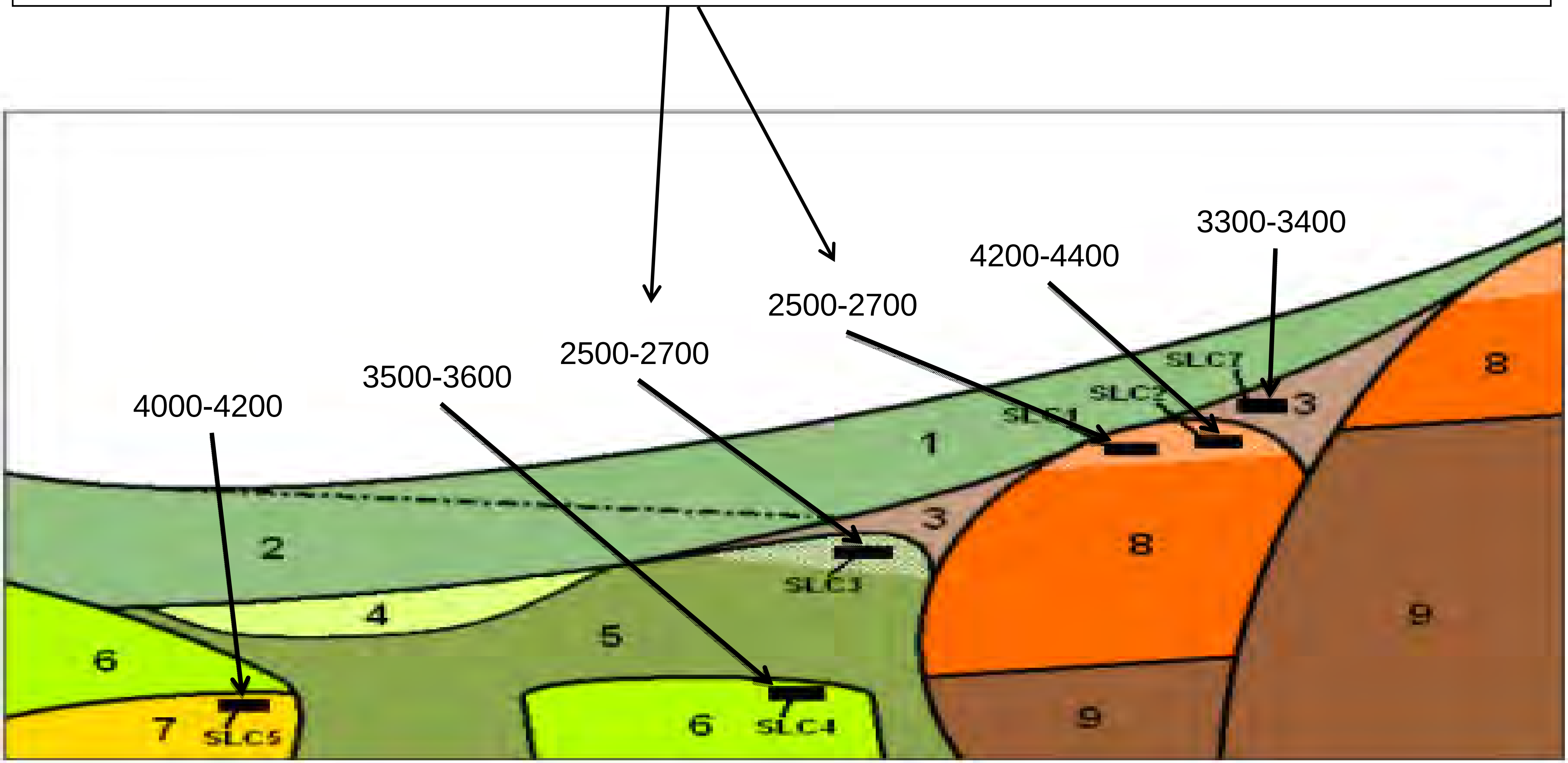
Ages

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



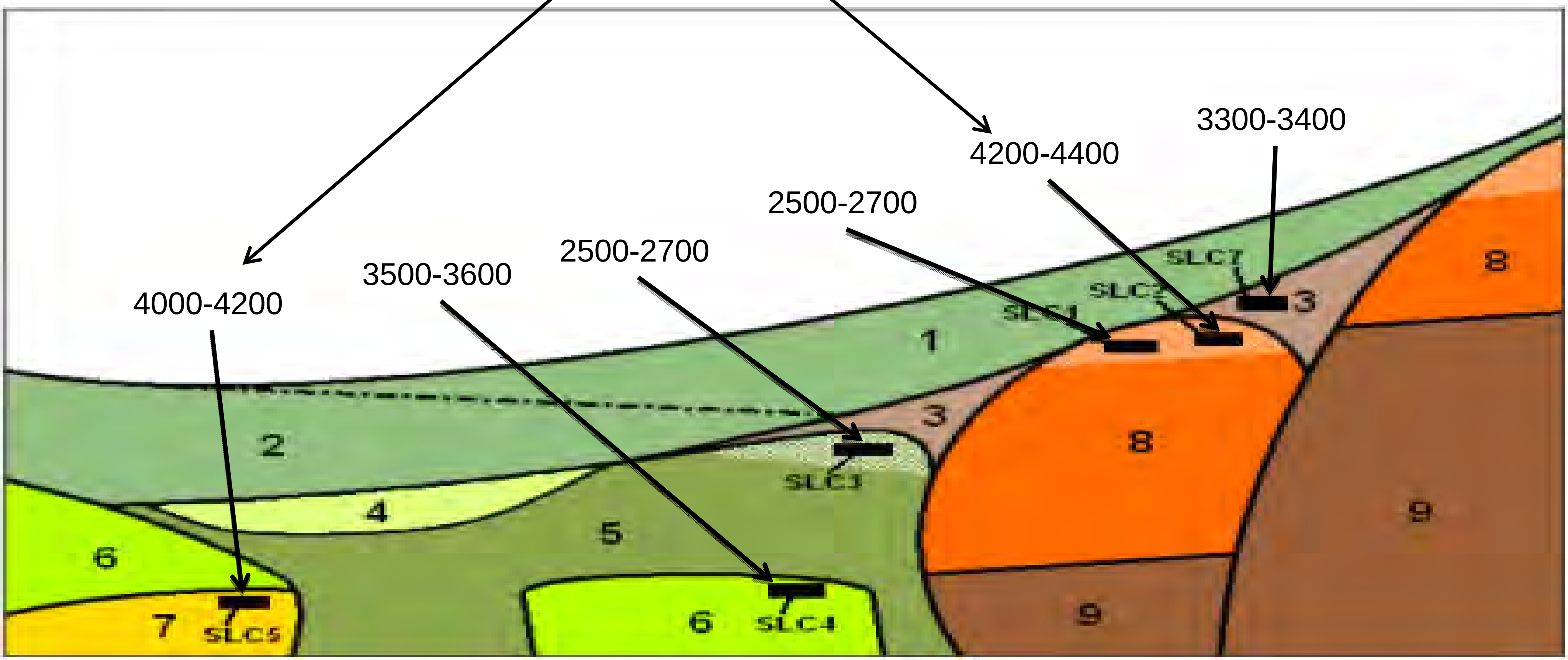
Ages

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



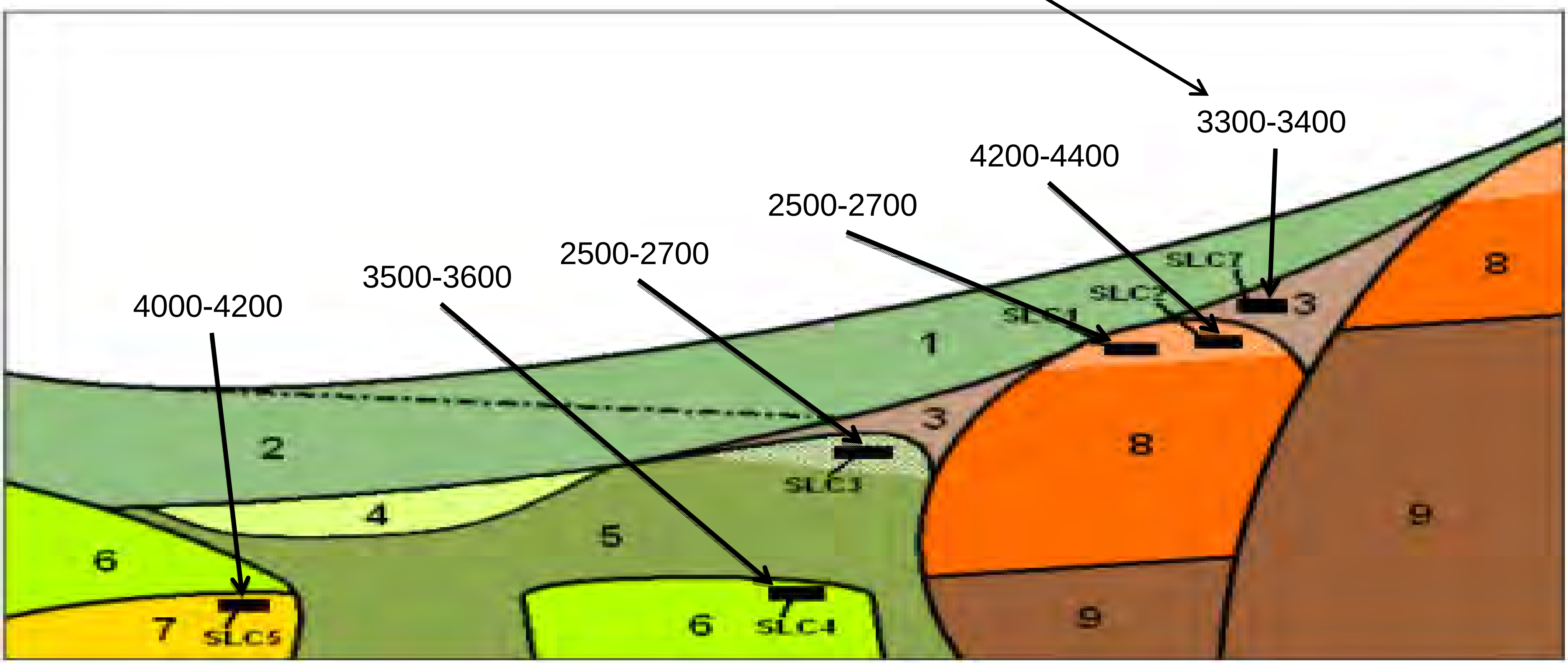
Ages

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

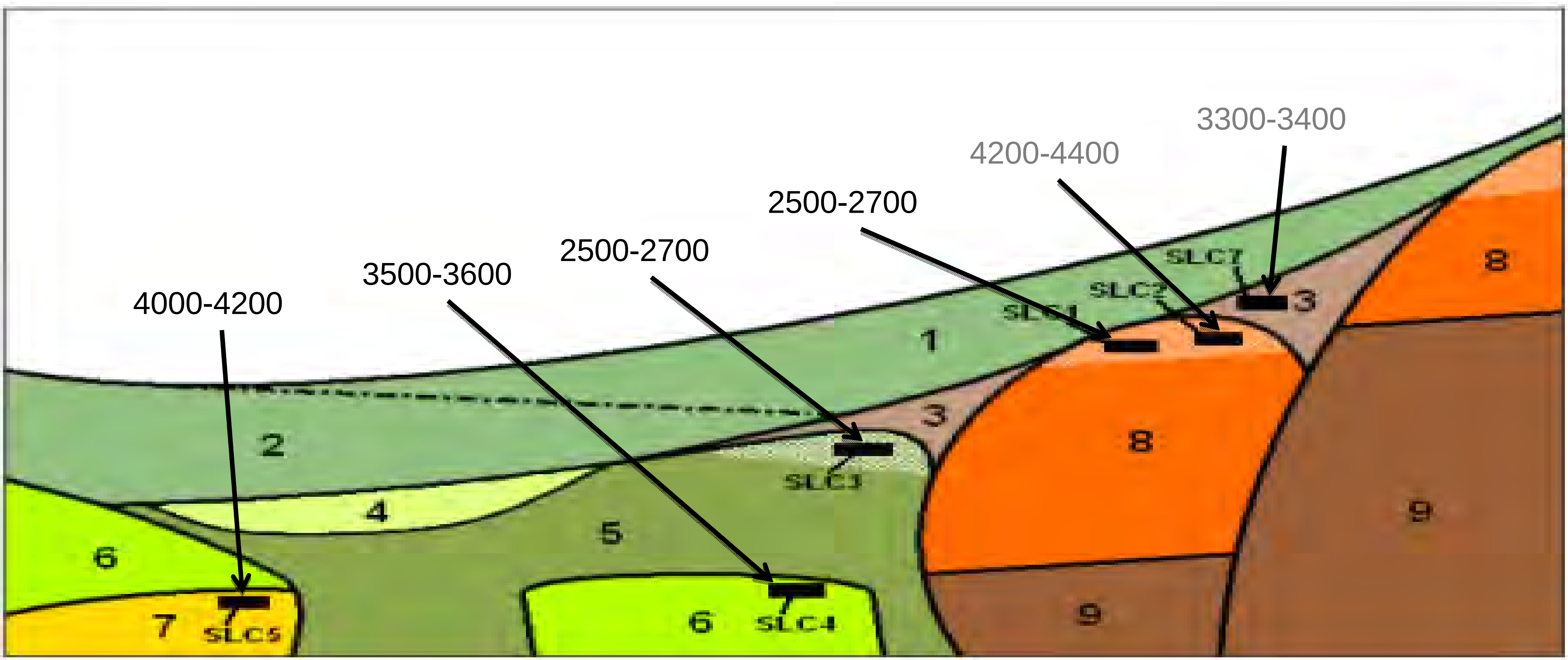


Age constraints

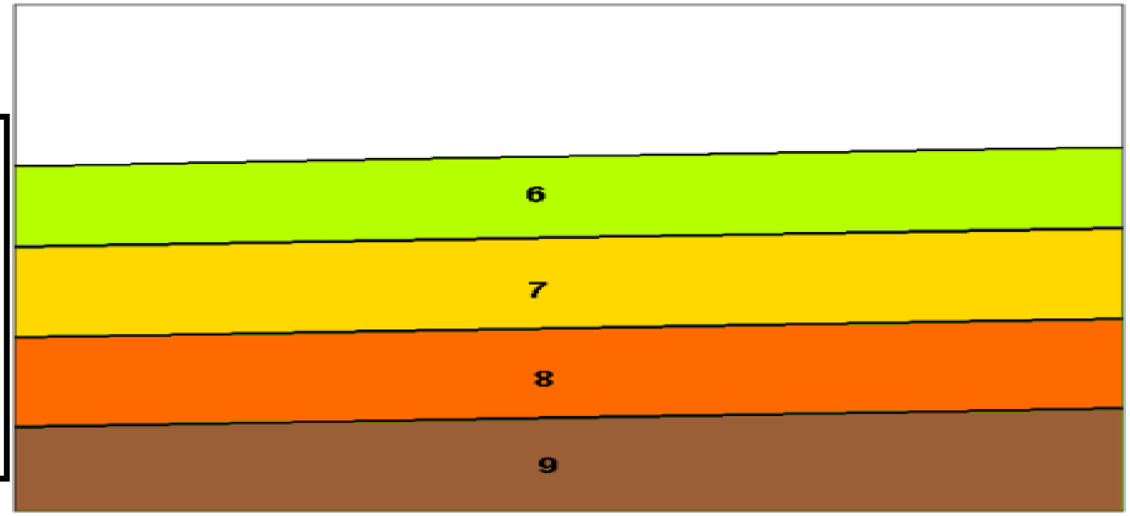
Ignoring the two out-of-sequence ages:

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

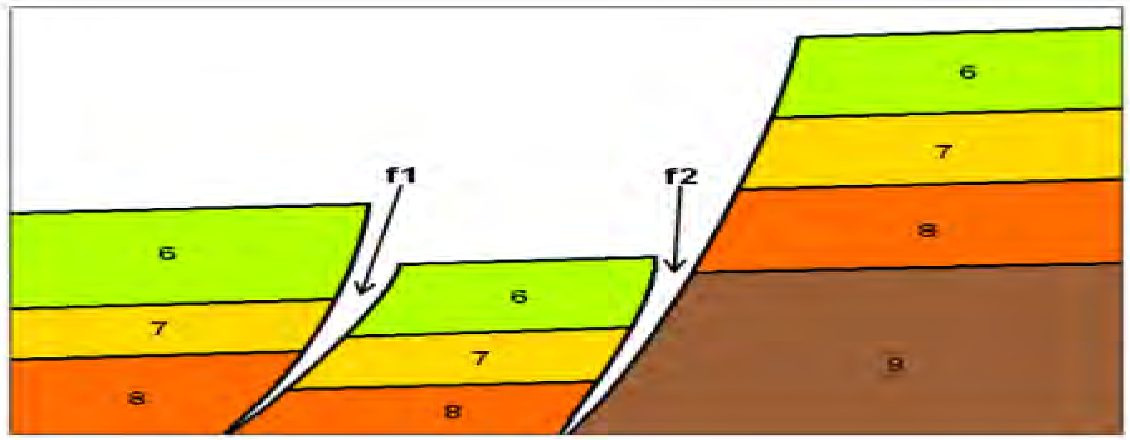
•Sample SL–C4 provides a maximum limiting age of 3500-3600 years for P2.



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



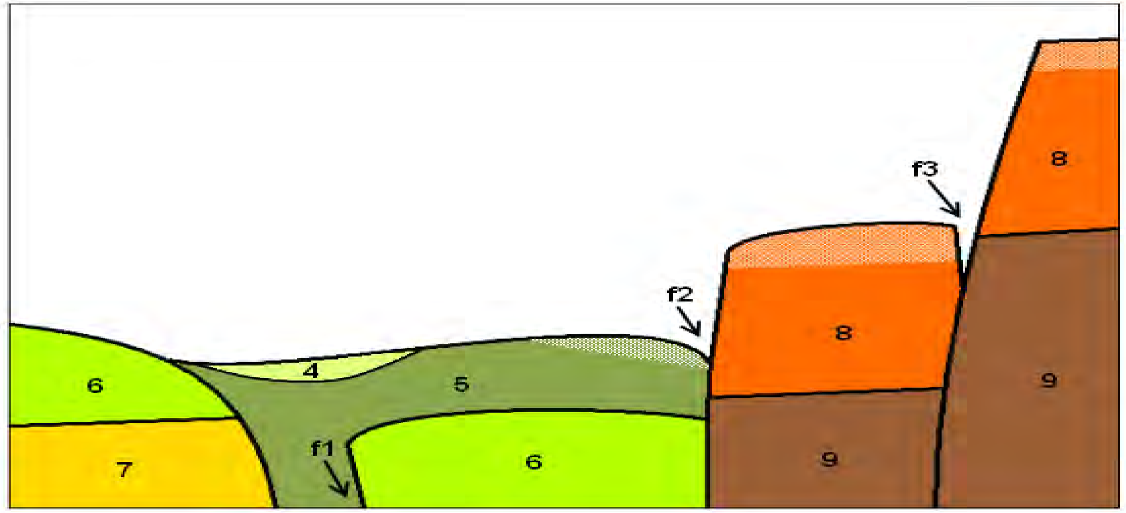
<3500 ybp– First faulting event (P2). Slip on faults f1 & f2; formation of graben.



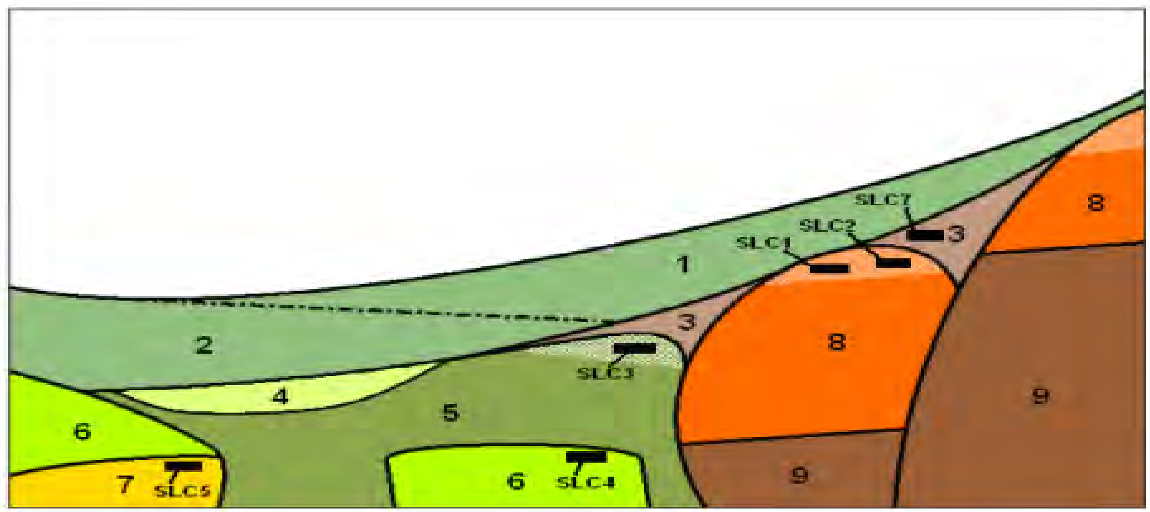
3500 – 2500 ybp – Unit 5 (colluvial wedge) deposited in graben. Soils form on units 5 & 8.

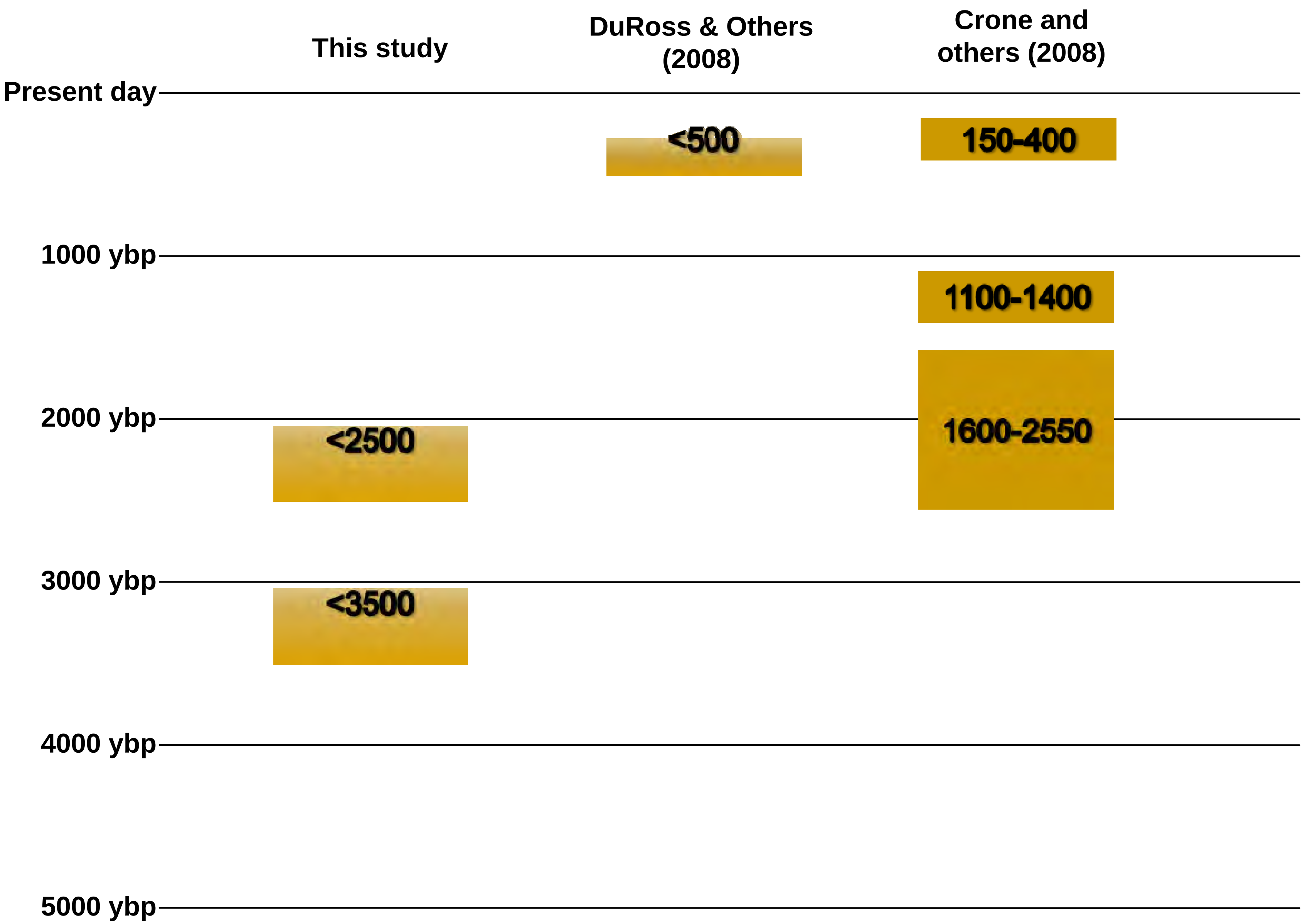
3500 – 2500 ybp– Unit 5 (colluvial wedge) deposited in graben. Soils form on units 5 & 8.

<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.



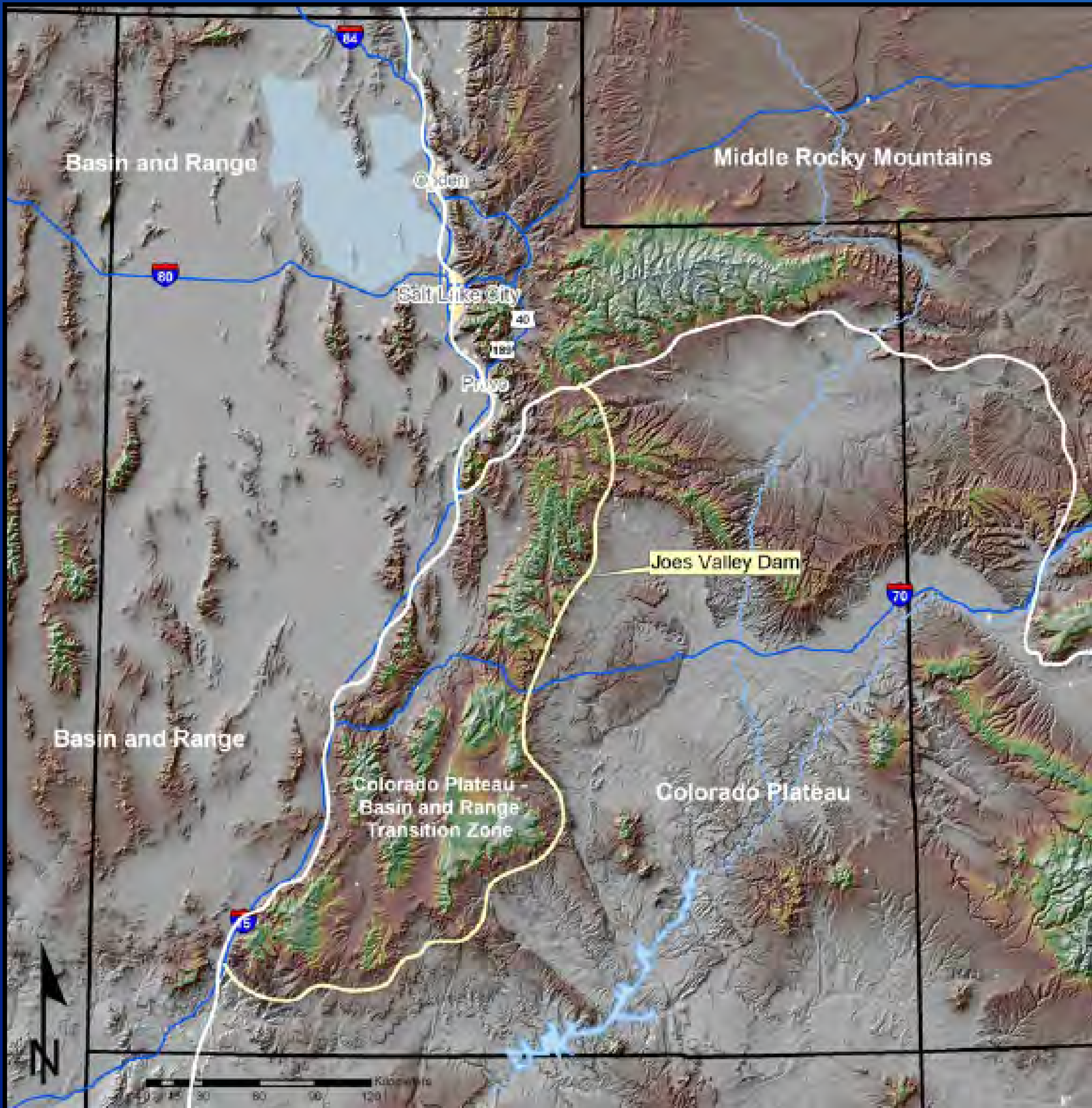

This study
DuRoss & Others (2008)
Crone and others (2008)
Present day
1000 ybp
2000 ybp
3000 ybp
4000 ybp
5000 ybp
<500
150-400
1100-1400
1600-2550
<2500
<3500

RECLAMATION

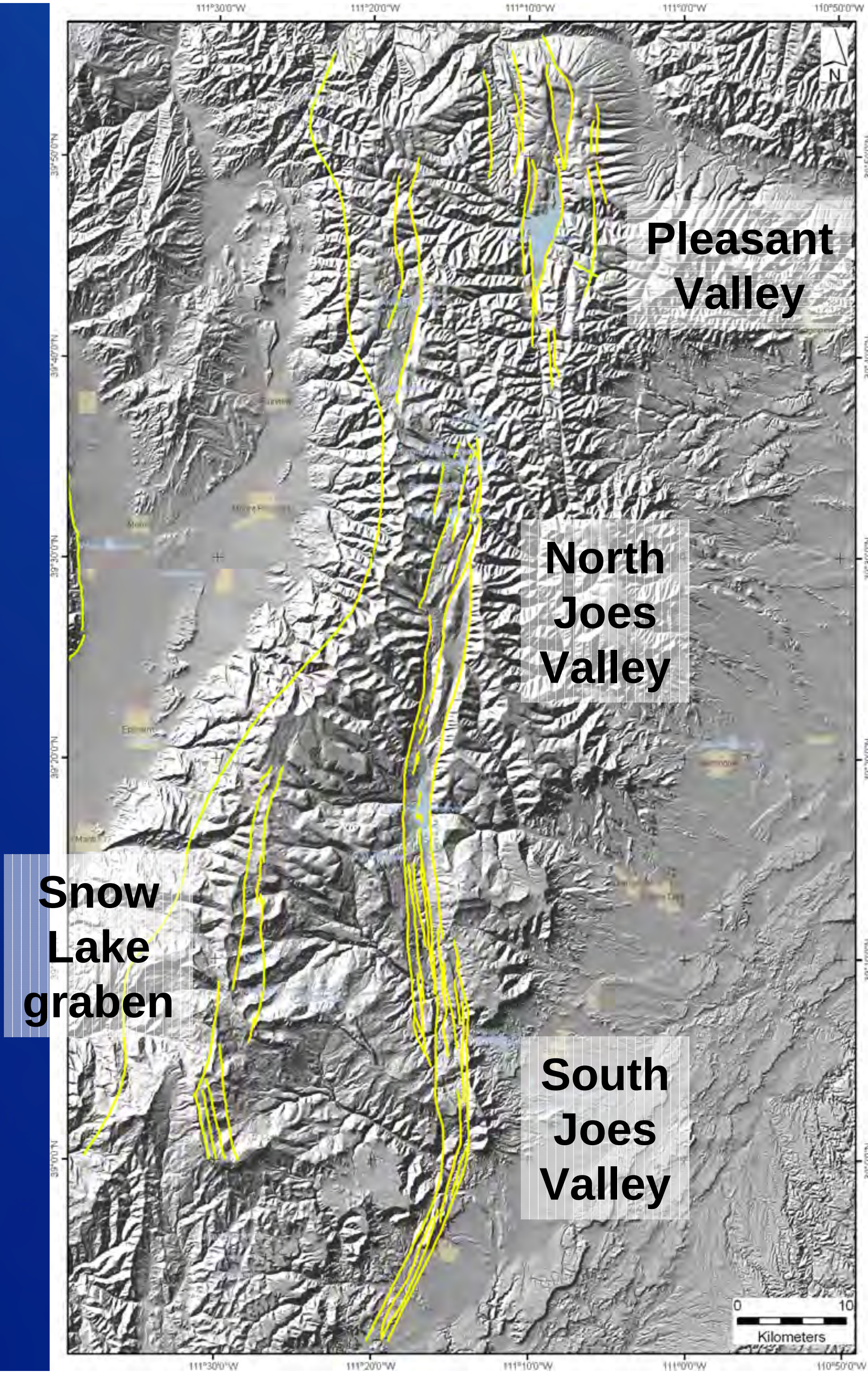
Managing Water in the West

JOES VALLEY FAULT ZONE

- ***Foley and others (1986) Seismotectonic study Joes Valley, Scofield, and Huntington North dams***
- ***O'Connell and others (2005) Probabilistic seismic hazard, ground motion, and seiche wave analyses for Joes Valley Dam***
- ***Coogan, James C. (2008) Stratigraphic, structural, and velocity interpretation of seismic reflection profiles***



From O'Connell and others (2005)



East and West Joes Valley fault Intergraben faults

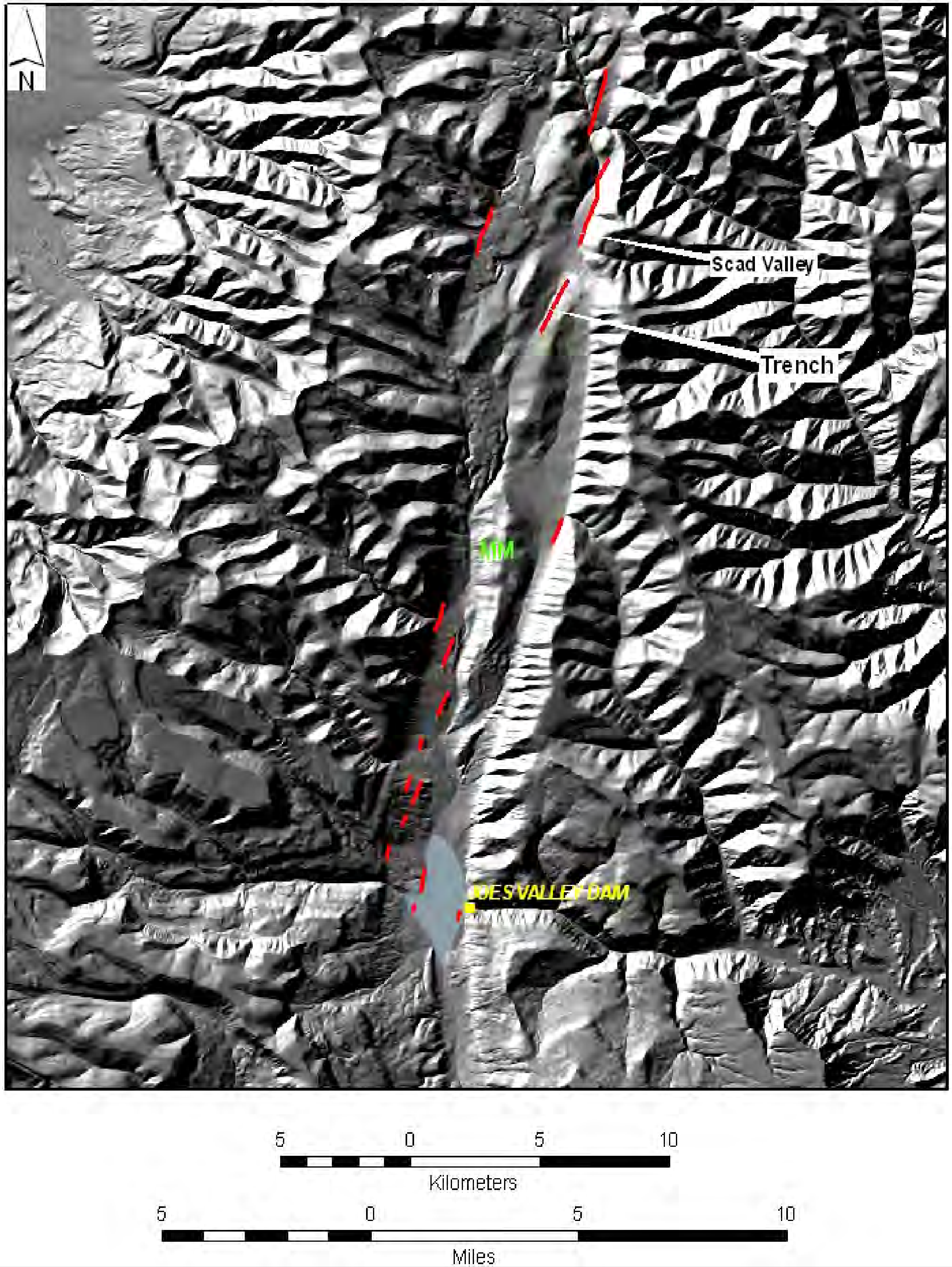
Fault traces in yellow from USGS database

RECLAMATION

Seismotectonic study (Foley and others, 1986)

- Mapping geology, lineaments, and fault scarps on aerial photographs and on the ground
- Identified scarps in north Joes Valley on bounding and intergraben faults
- Scarp profiles
- Excavation 6 trenches and 20 soil pits
- Relative (soils) and numeric dating

RECLAMATION



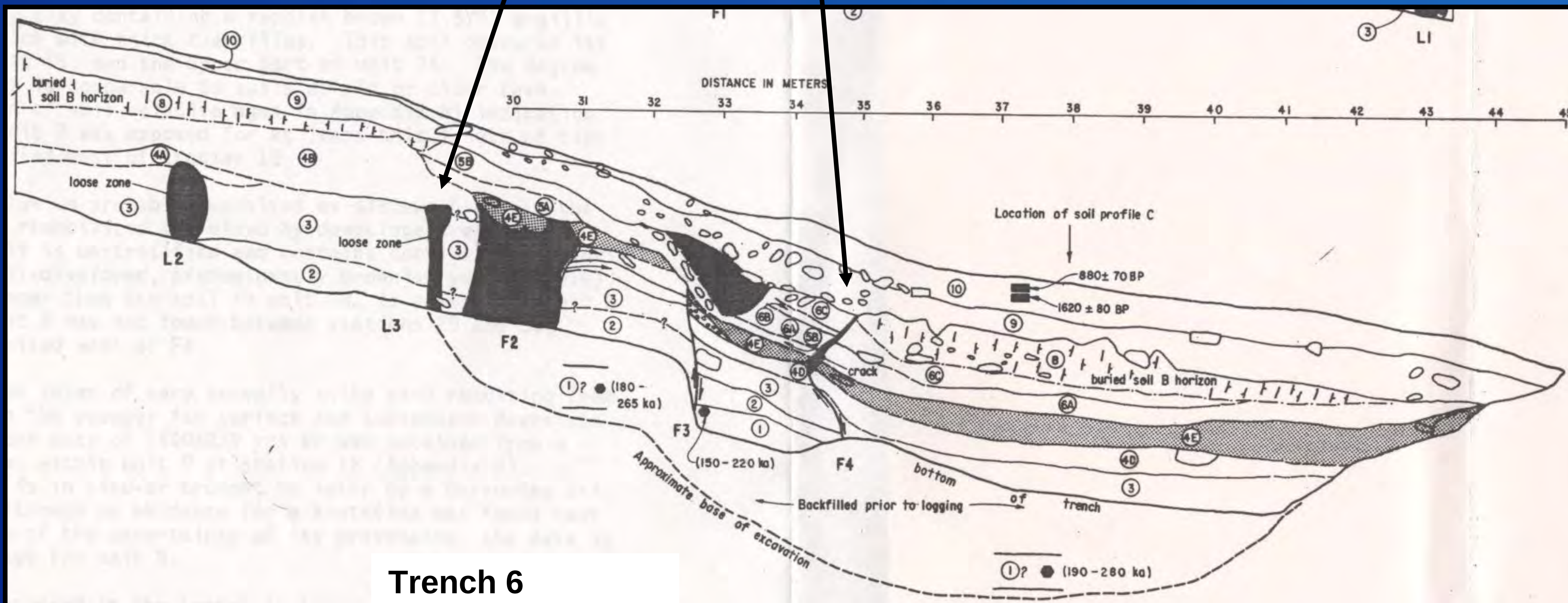
North Joes Valley

- •2-4 km wide
- •40-50 km long
- •graben-bounding and intergraben faults
- •upper Cret./lower Tert. rocks displaced 600-900 m

Red lines – mapped scarps
MM – Middle Mountain

CLAMATION

Fault zone



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

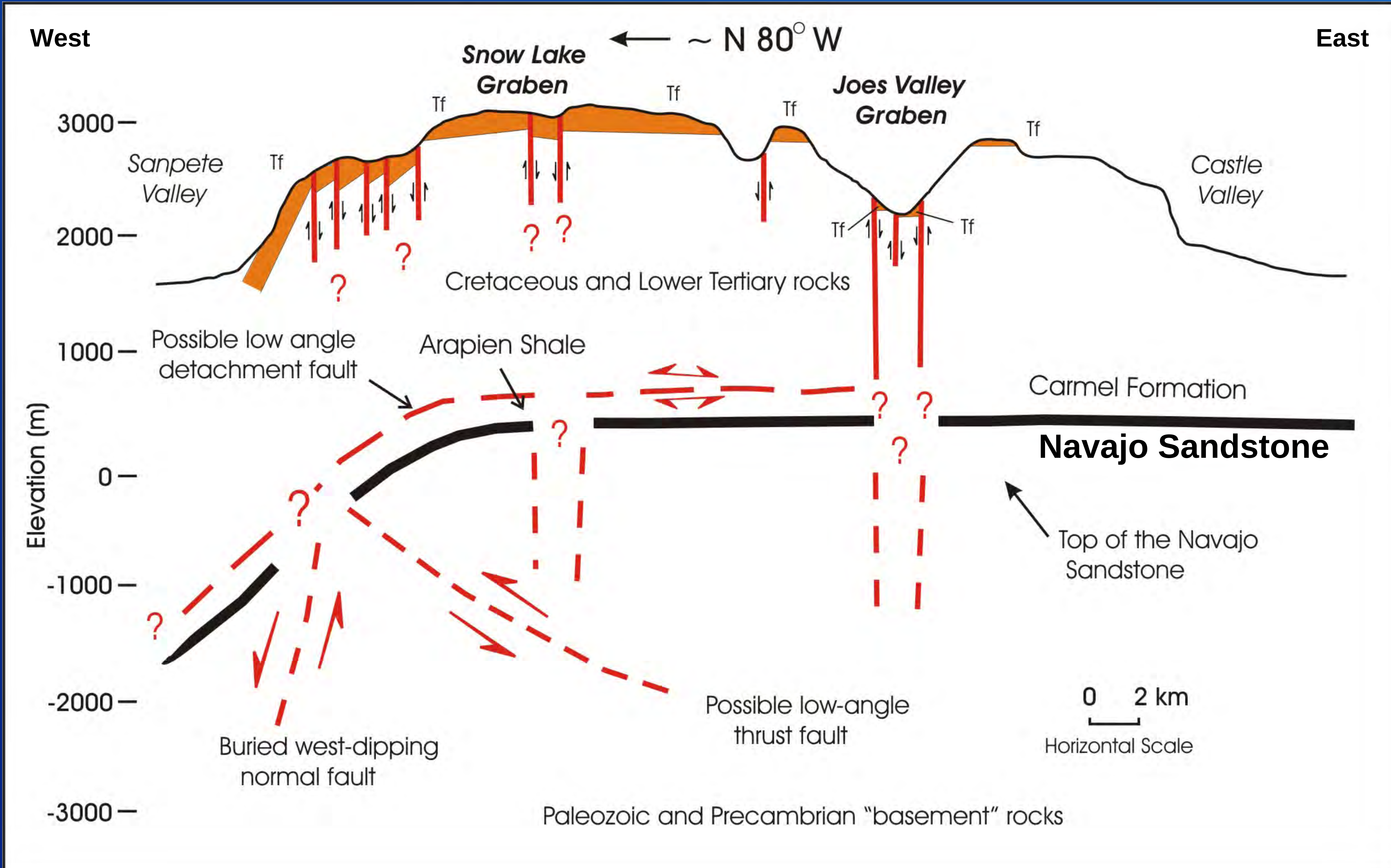
RECLAMATION

Seismotectonic study (Foley and others, 1986)

- Recurrent late Quaternary (since 11 ka to 30 ka) surface displacements (Northern Joes Valley graben)
- Interpretation trench exposures; higher scarps on older terraces
- Youngest event in early Holocene (11 ka to 6.5 ka); no scarps on younger Holocene surfaces
- Single-event vertical surface displacements of <1 to 5.5 meters
- Average recurrence about 10,000 to 20,000 years
- Faults can generate large (7-7.5) earthquakes
- Listric fault model and salt collapse considered but could not evaluate

RECLAMATION

Diagrammatic cross section across Wasatch Plateau in area of Joes Valley

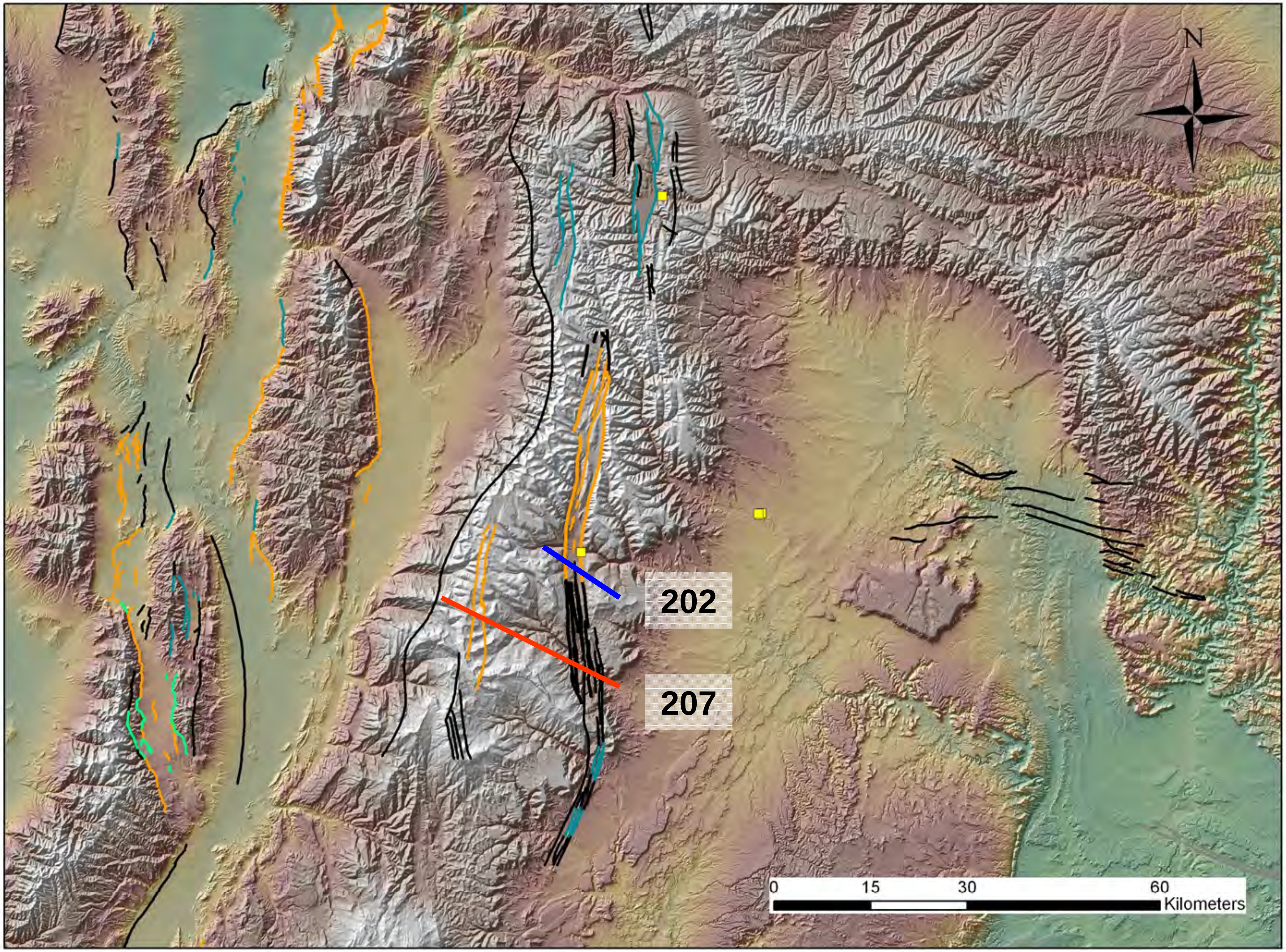


Orange is Eocene-Paleocene Flagstaff Limestone

Vertical exaggeration is about 3 X

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

RECLAMATION

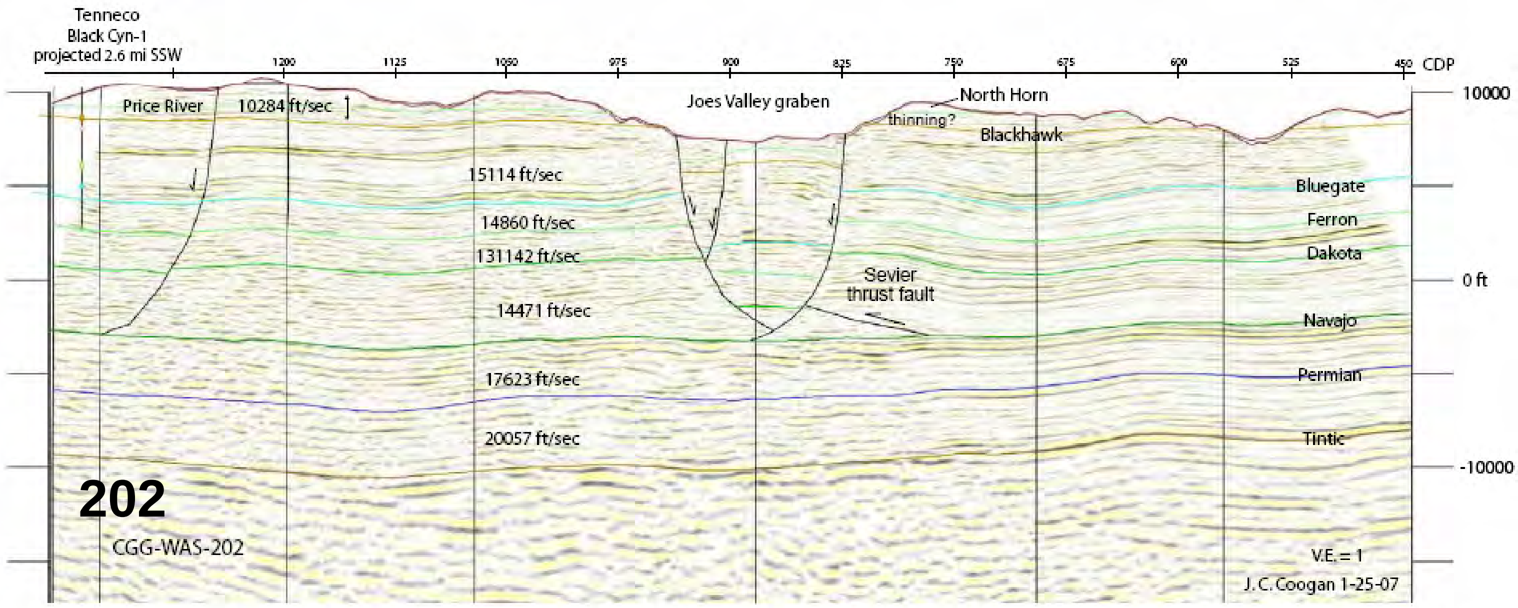


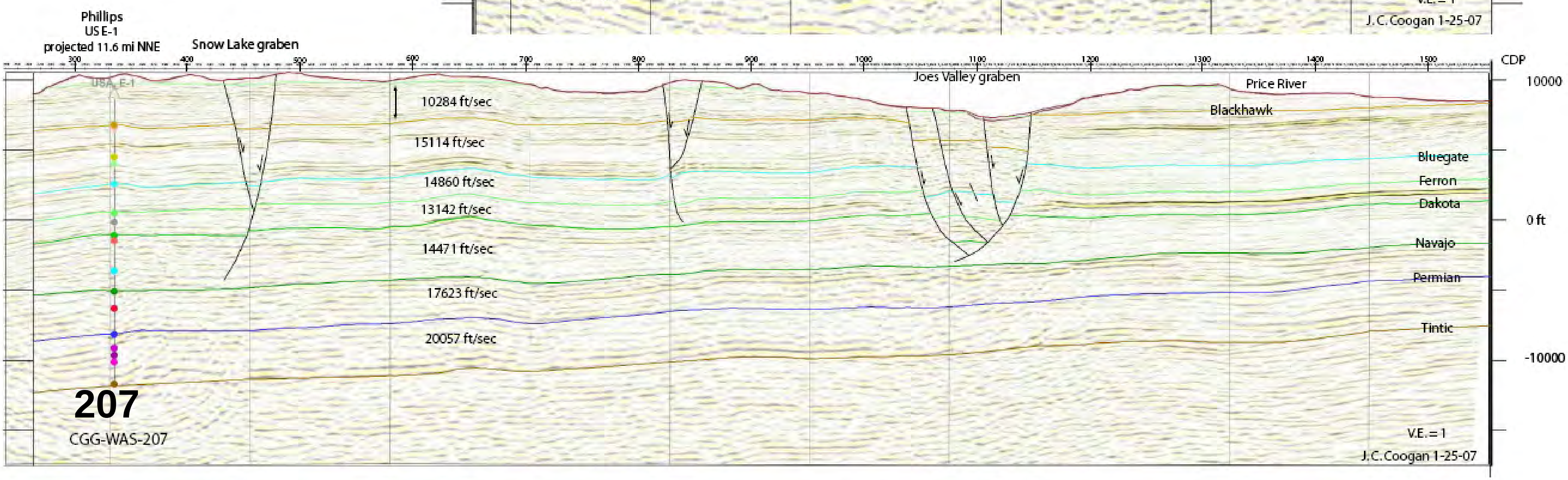
Coogan (2008)

Seismic reflection profiles--Interpreted depth cross section

NW

SE

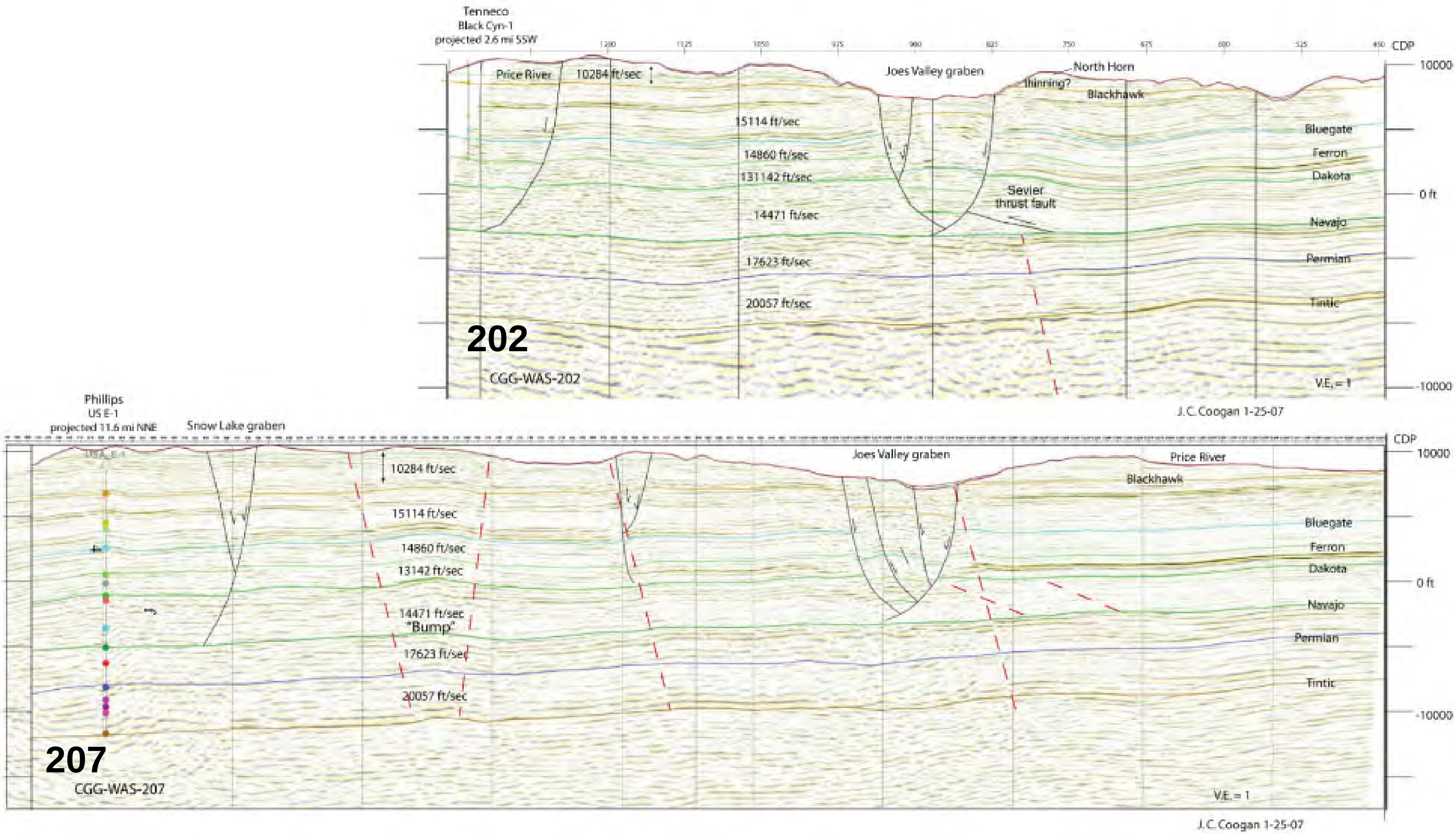




Coogan (2008)

RECLAMATION

NW SE



William Lettis & Assoc. (2008)

Red lines indicate other possible faults

Fault Interpretations

Interpretation	Evidence	Possible Problems	Seismic Hazard Implications
Basin & Range type extension on high-angle normal faults that extend to seismogenic depths (10-15 km)	Regional faults in Basin & Range Larger historical earthquakes on normal faults in western US Scarps and trench interpretations	Multiple, closely spaced faults with opposing dips along and within graben Narrow basin No basin fill	Fault rupture generates large earthquakes. Infer activity rate from surficial geology and exposures
Salt tectonics	Stratigraphy Anhydrite and other salts present	Mechanism for scarp formation Deformation not reported Depth to salt	Fault rupture presumably would be aseismic (creep)
High-angle normal faults near surface that sole into low-angle detachments at ~5 km depth (listric faulting)	Regional structural models inferred from seismic reflection data suggest little or no offset of Navajo sandstone	Historic normal faulting earthquakes have seemingly occurred on high-angle planar structures extending to ~15 km depths. Different interpretations of reflection data are possible.	Few (no?) historic analogs. If fault rupture is seismic, a smaller rupture area (and smaller characteristic magnitude) would be inferred

RECLAMATION

Continuing Questions

- Are the Joes Valley faults seismogenic?
- If seismogenic, then how large could earthquakes be?
- What is the origin of scarps and features exposed in trenches?
- If faults do not extend to seismogenic depths, then how are fault scarps generated?
- What is the structural relationships among faults?
- What are the implications for seismic hazards?

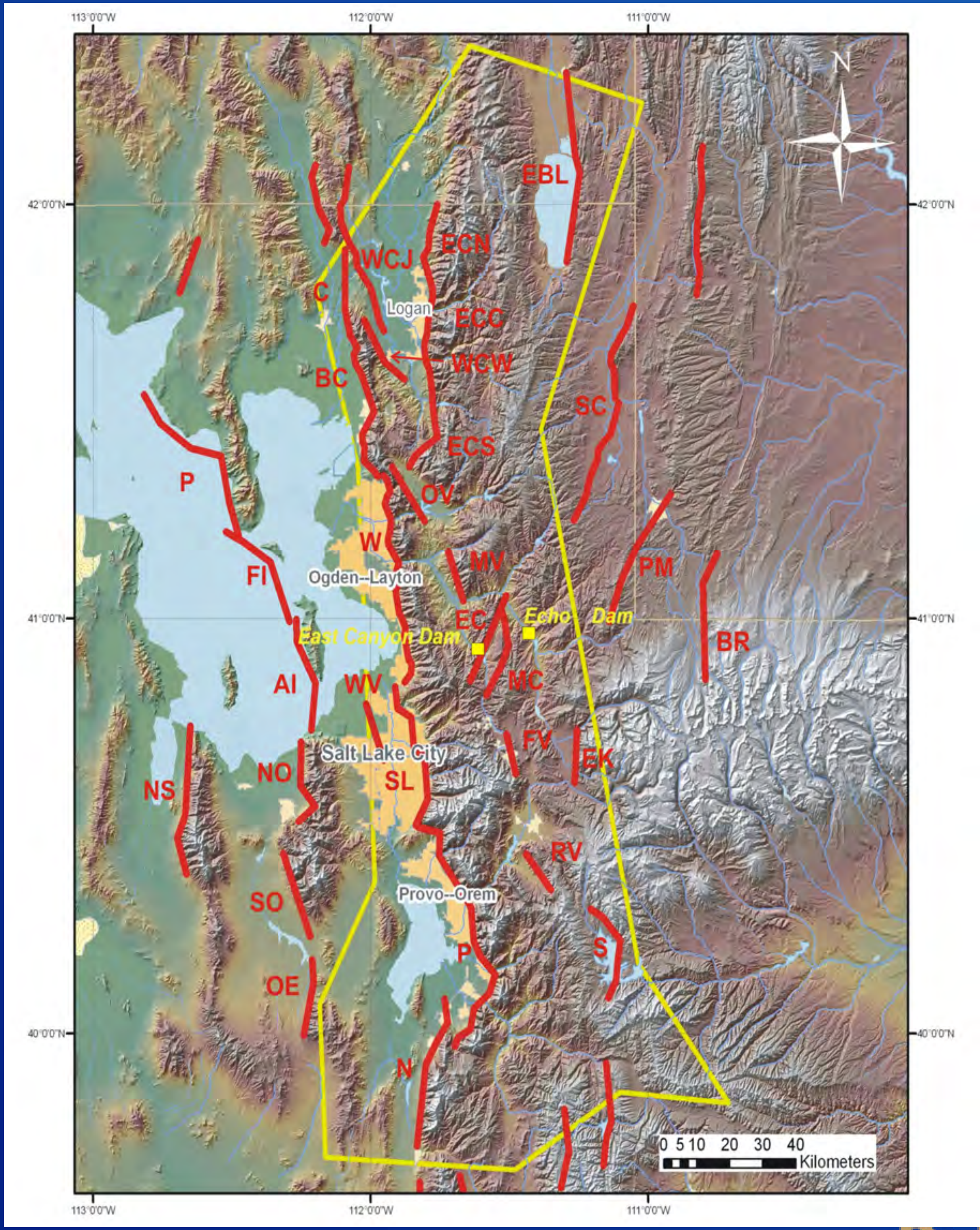
Proposed work

- Evaluate surficial expression and origin of scarps
- Improve age control
- Improved geodetic models constrained by GPS measurements?
- Other studies?

RECLAMATION
Managing Water in the West

Main Canyon and East Canyon faults

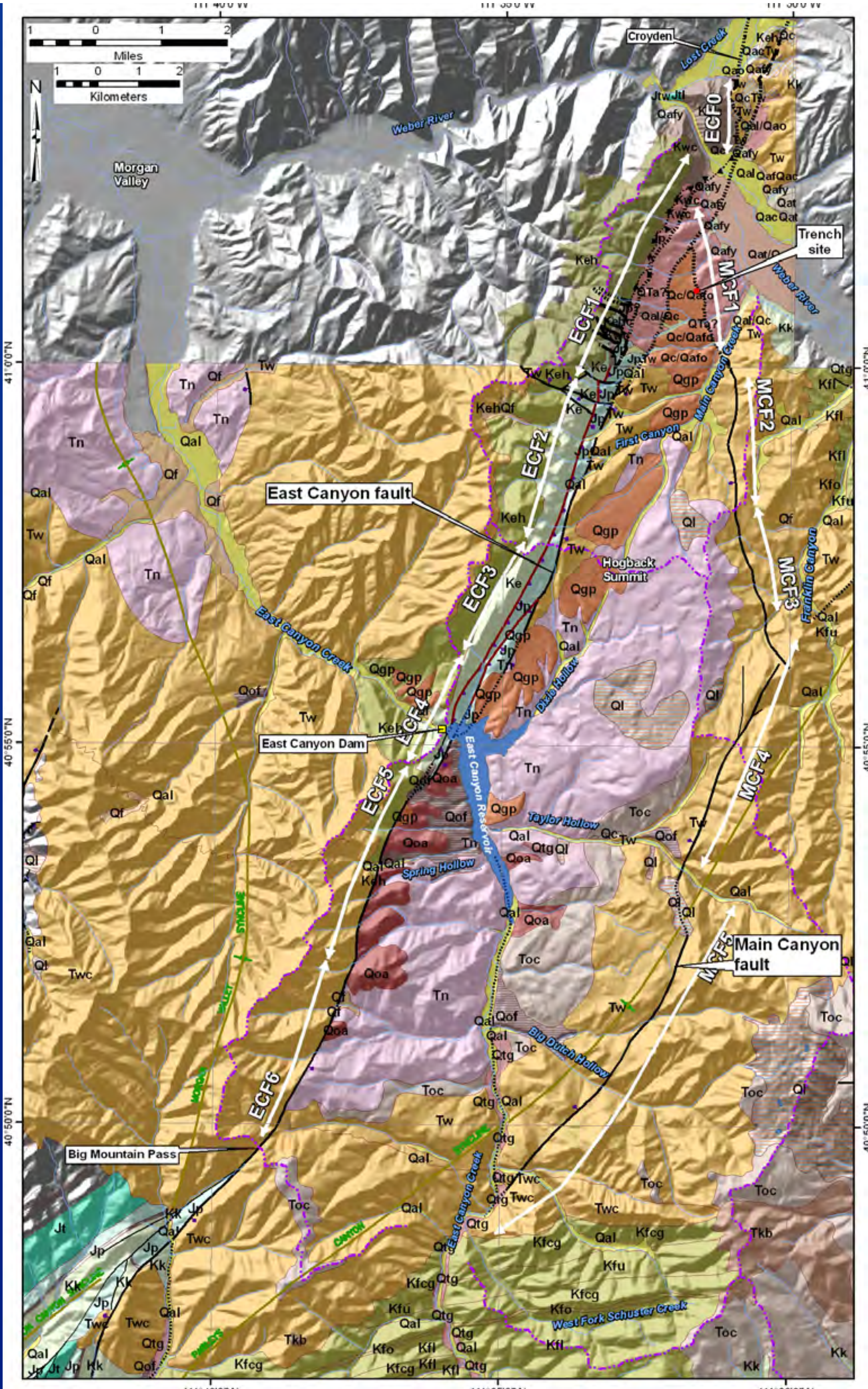
- ***Sullivan and others (1988) Central Utah regional seismotectonic study***
- ***Coogan, James C. (2007) Summary of stratigraphic, structural, and velocity interpretation of seismic profiles across East Canyon and "East of East Canyon" faults***
- ***Piety and others (2010) Late Quaternary faulting in East Canyon Valley***
- ***Wong and others (2010) Updated probabilistic seismic hazards analyses, Echo Dam and East Canyon Dam***



Primary faults:
EC, East Canyon
MC, Main Canyon
ECS, East Cache Valley, South
ECC, East Cache Valley, Central
ECN, East Cache Valley, North
MV, Morgan Valley
W, Wasatch, Weber
WCW, West Cache, Wellsville
WCJ, West Cache, Junction

Faults:
BR, Bear River
CM, Crawford Mine
AI, E. Great Salt Lake, Antelope Island
FI, E. Great Salt Lake, Fremont Island
P, E. Great Salt Lake, Promontory
EK, East Kamas
FV, Frog Valley, Parleys Park
NO, N. Oguirrh Mtn
NS, N. Stansbury
OV, Ogden Valley
OE, Oquirrh, East Tintic
PM, Porcupine Mtn.
RV, Round Valley
SC, Saleratus Creek
SO, S. Oquirrh Mtn.
S, Strawberry
BC, Wasatch, Brigham City
C, Wasatch, Collinston
N, Wasatch, Nelphi
P, Wasatch, Provo
SL, Wasatch, Salt Lake City
WV, West Valley

Red lines—simplified fault traces
Yellow polygon—northern Utah-ISB seismic source zone



Yellow – Quaternary alluvium

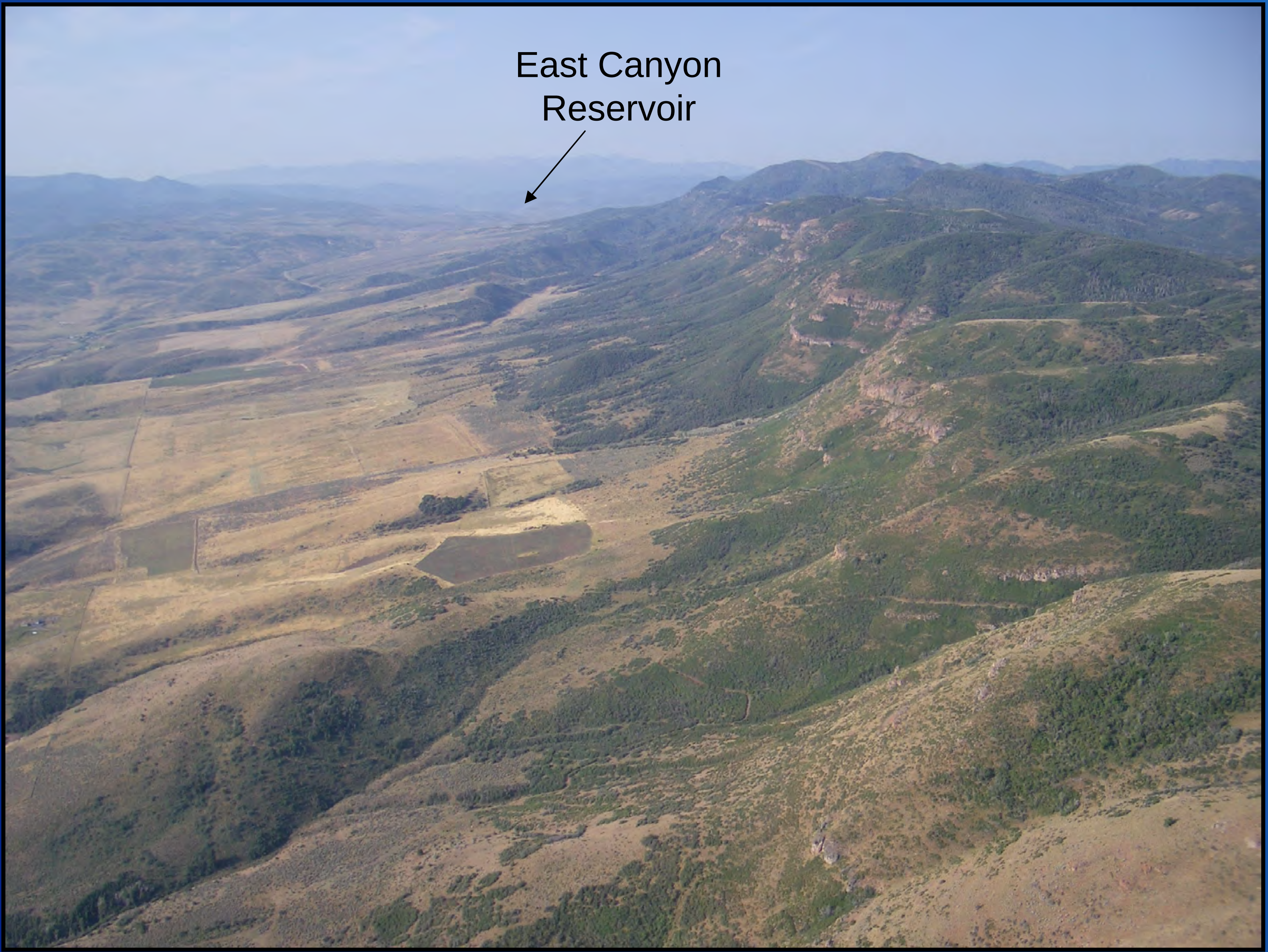
Basin-fill sediments:

Dark red and orange - older Quaternary surfaces/deposits
Pink - Tertiary Norwood Tuff (Tn)
Light brown – Tertiary conglomerate

Orange - Tertiary Wasatch Formation
Green shades - Cretaceous and Jurassic rocks

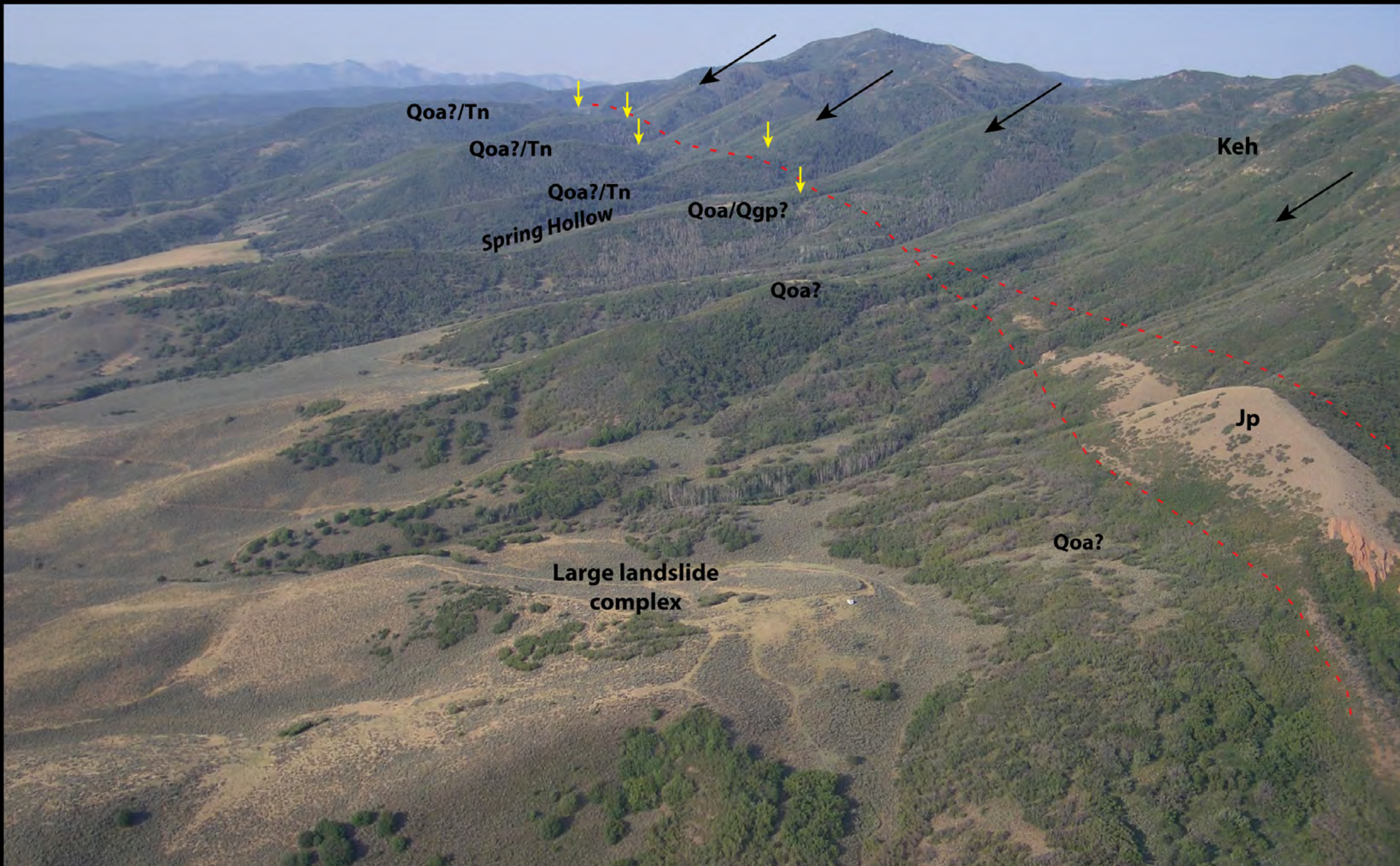
Bryant, B., 1990, Geologic map of Salt Lake City 30' by 60' quad
Coogan, J.C., and King, J.K., 2001, Progress report—Geologic map of Ogden 30' by 60' quad
Coogan, J.C., 2002,, Progress report—Geologic map of Devils Slide quad

RECLAMATION



East Canyon fault
(looking south)

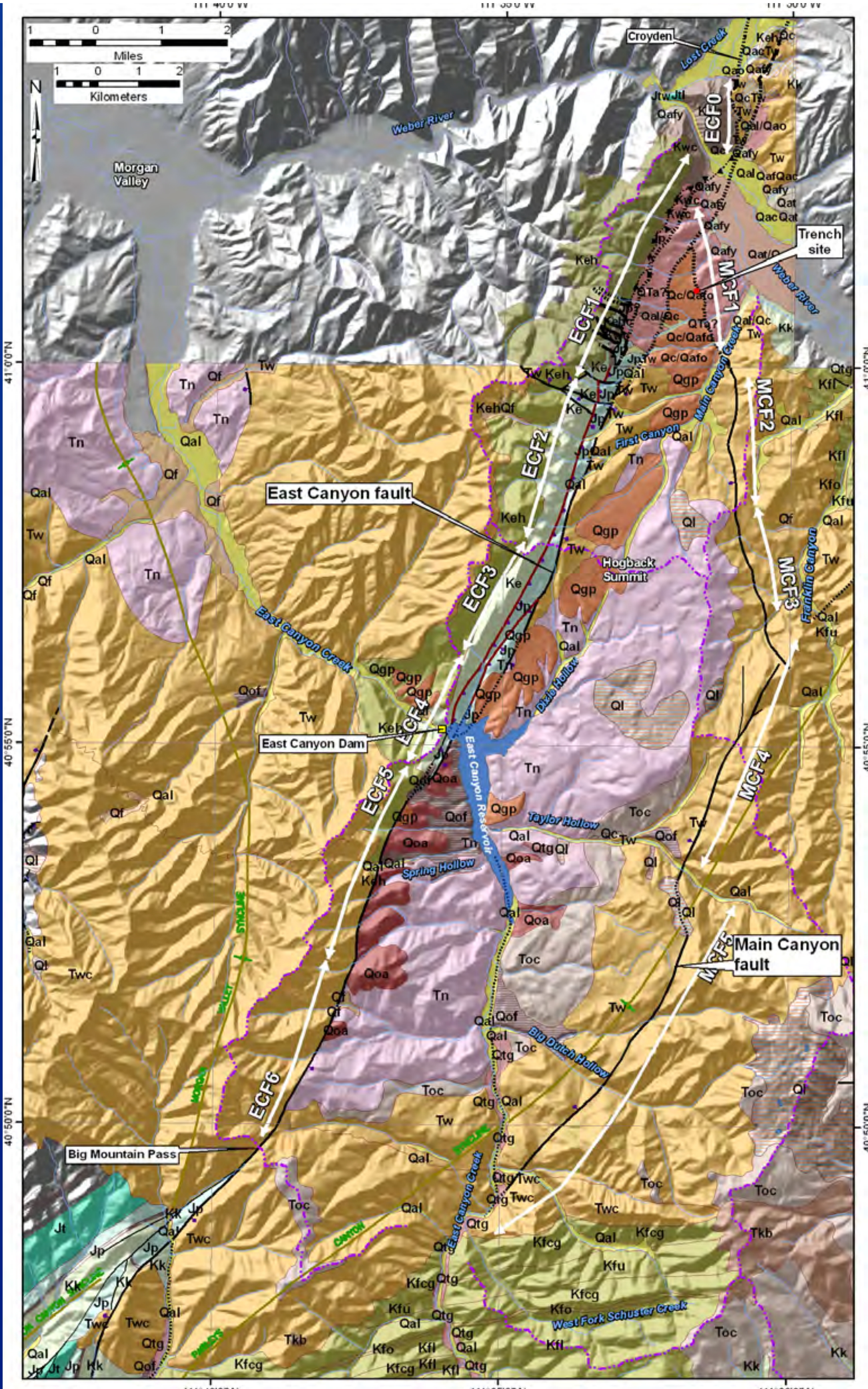
Photograph taken by L. Anderson in 2005



East Canyon fault (looking south from near East Canyon Reservoir)

Photograph taken by L. Anderson in 2005

RECLAMATION



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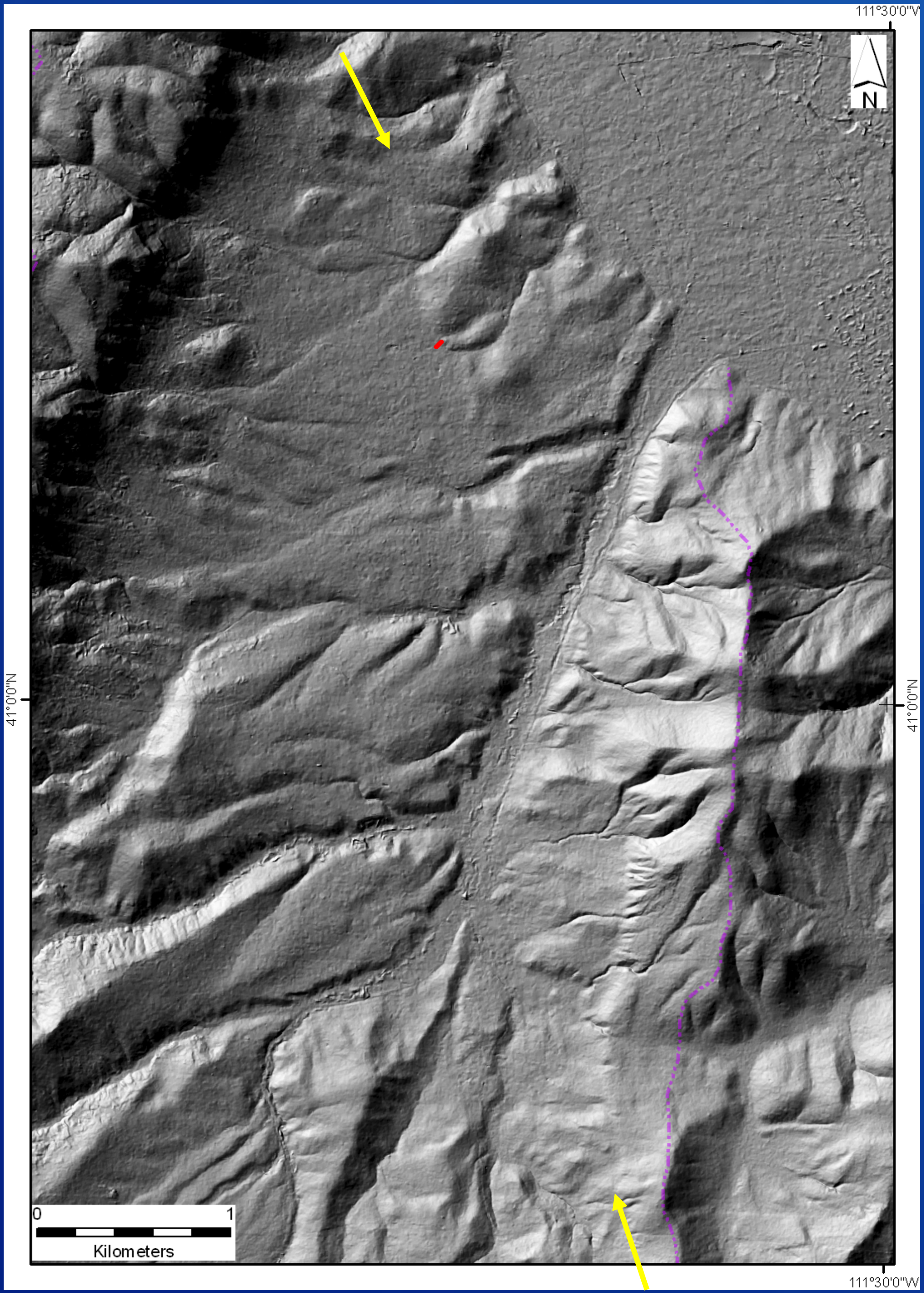

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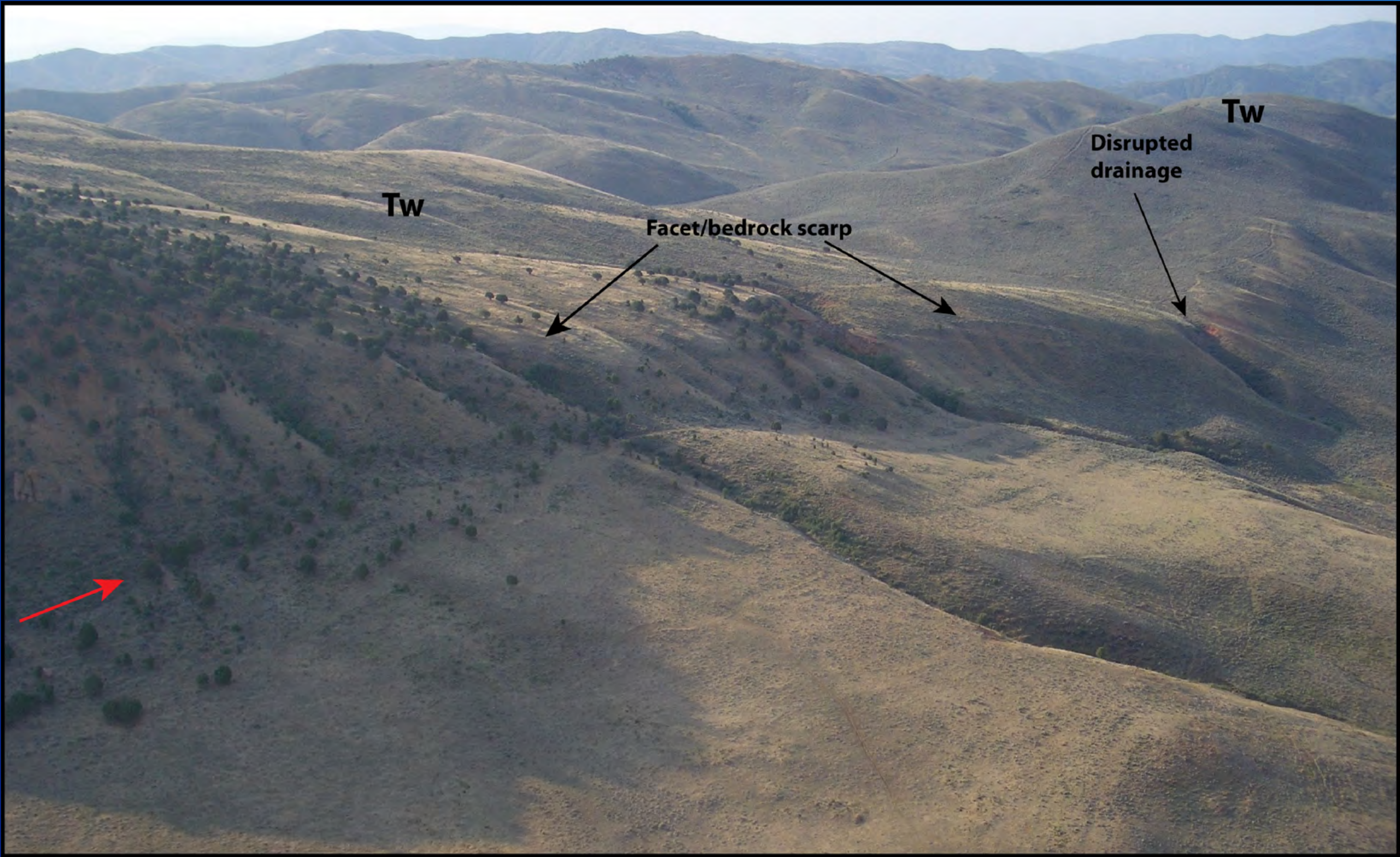
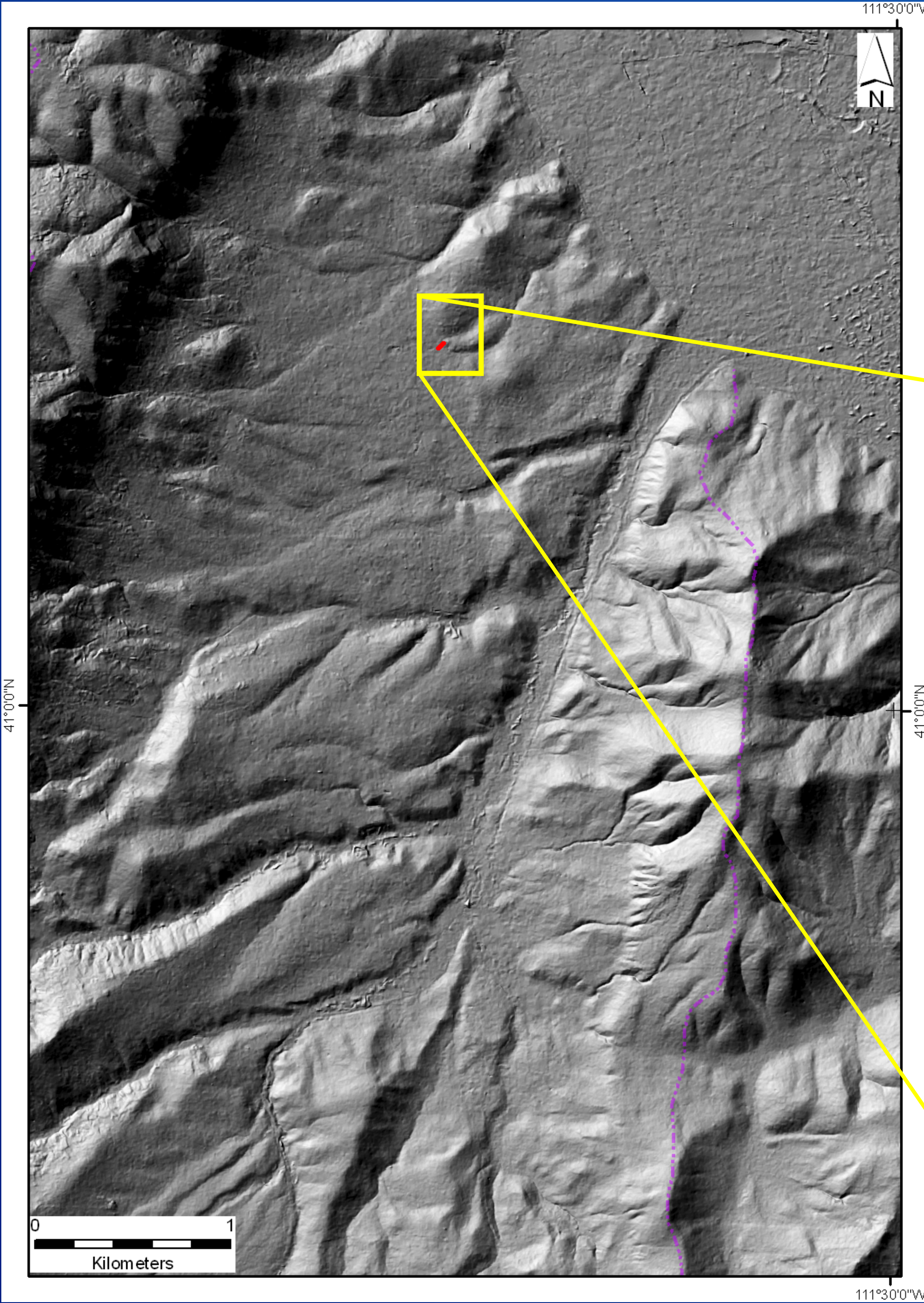


Photograph taken by L. Anderson in 2005

Main Canyon fault

RECLAMATION



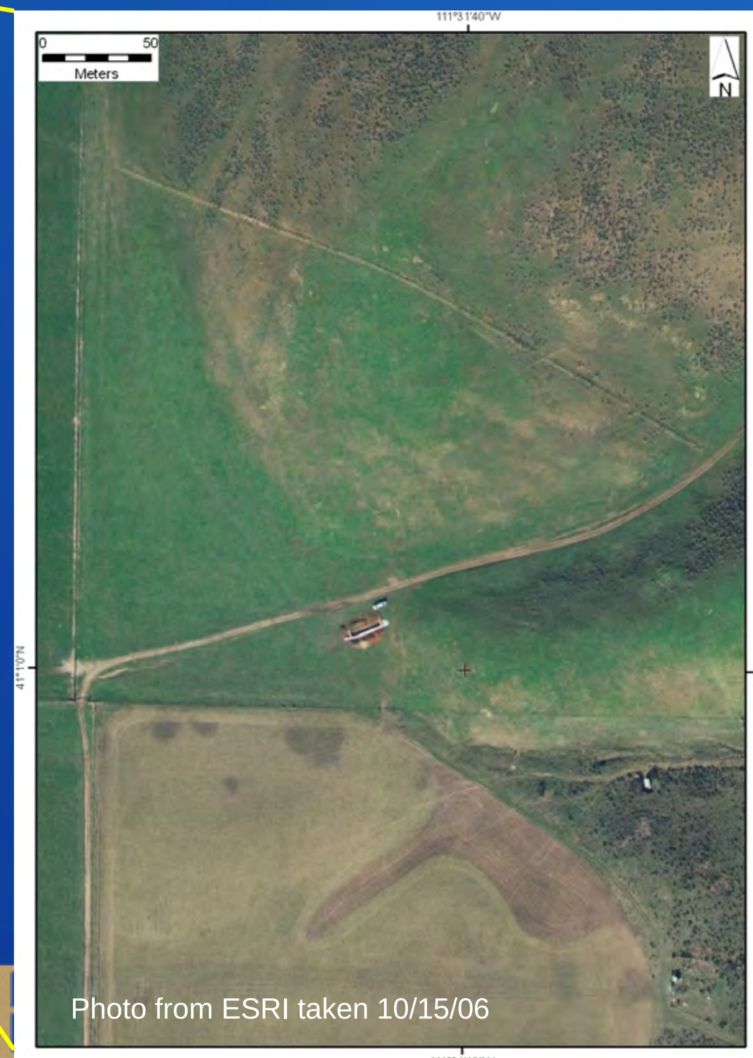
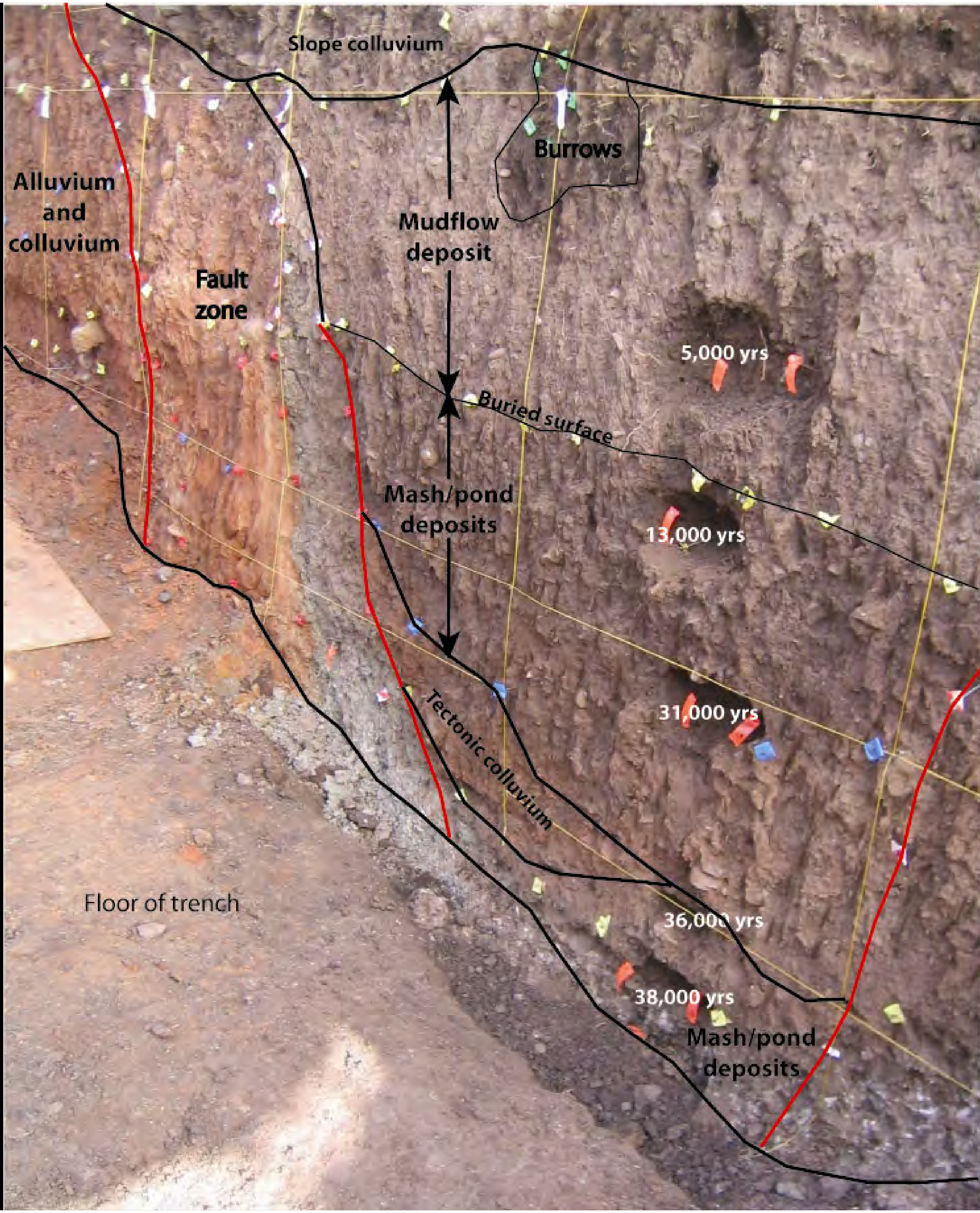


Photo from ESRI taken 10/15/06

East

West



Trench across 0.4-m-high scarp along Main Canyon fault

Looking south

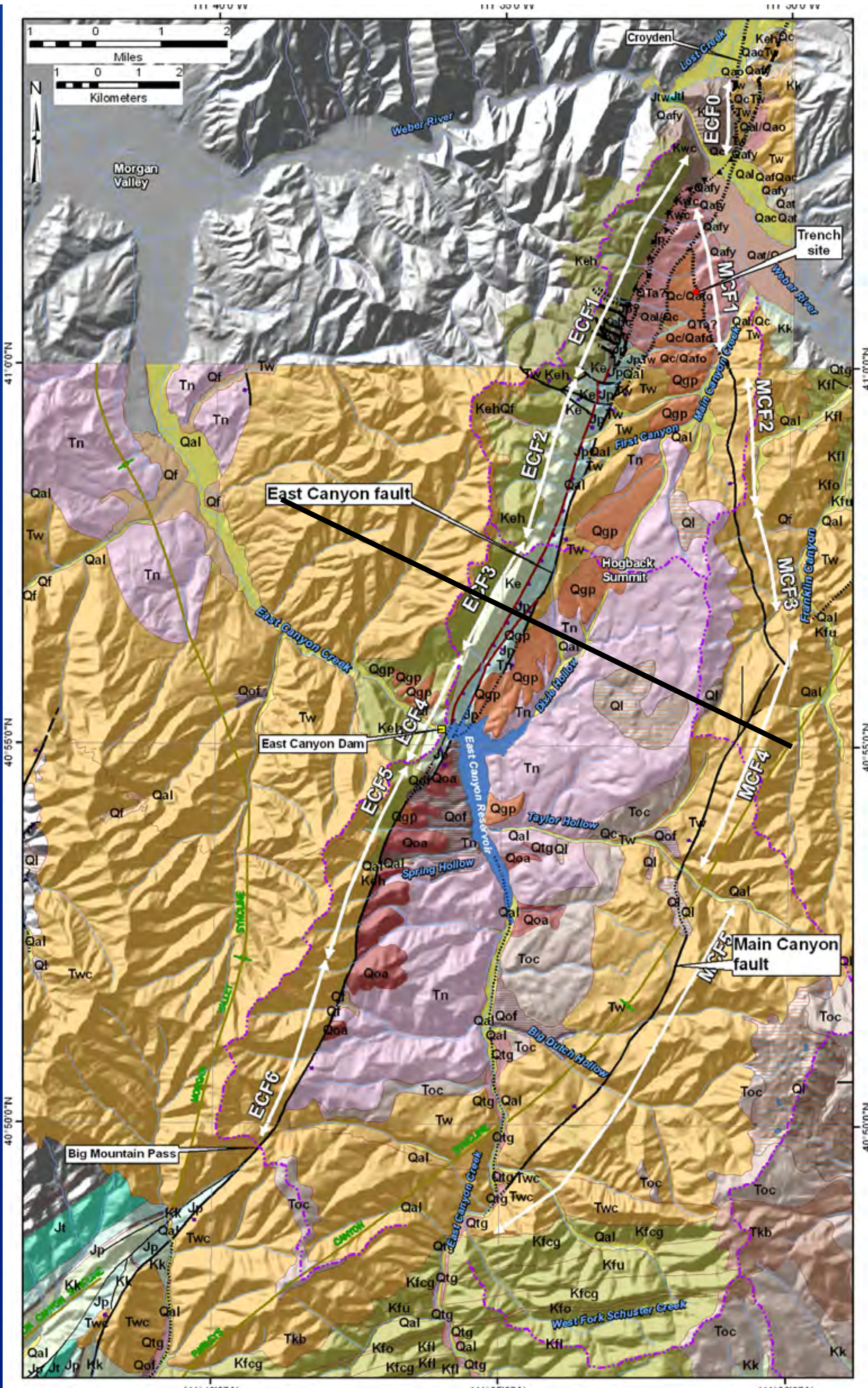
LAMATION

Characteristics of Main Canyon and East Canyon faults

Fault	Dip	Estimated normal-slip displace-ment	Late Quaternary surface rupture	Geomorphic expression	Timing of displacements
Main Canyon	55°, W	≤200 m	2 faulting events since 30,000-35,000 years ago Youngest event before 5,000 to 6,000 years ago; could be as old as 12,000 to 15,000 years ago (from trench)	Fault scarps, facets, saddles, lineaments nearly continuous for 26 km; features cut across topography, but are readily visible	Few million years(?) to present
East Canyon	55°, E	1900-2900 m	No evidence observed (no scarps on unconsolidated deposits)	Eroded fault-line escarpment in resistant rocks for north 20 km; facets/bedrock scarps for south 5-6 km	Few tens of millions of years to ?

Faults intersect or merge at depth 3-4 km

RECLAMATION



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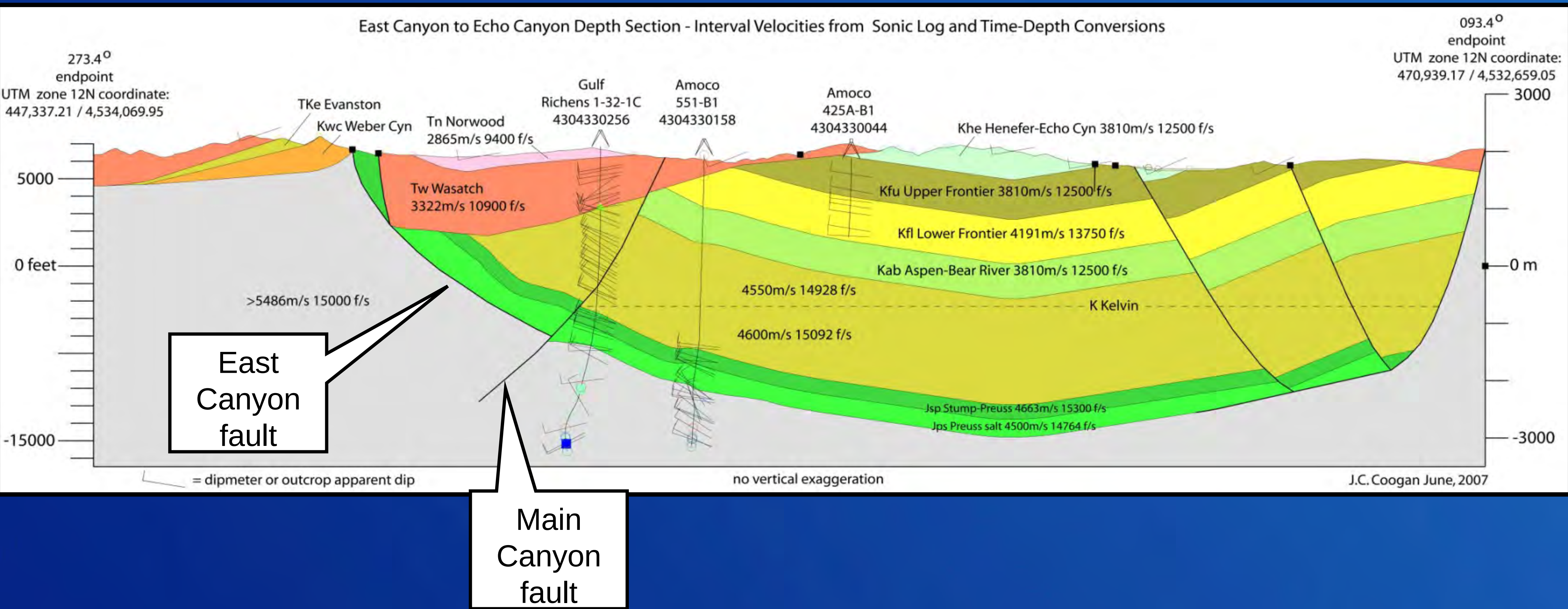
Coogan, J.C., 2002,, Progress report—Geologic map of Devils Slide quad

RECLAMATION

Interpreted seismic reflection line (Coogan, 2007)



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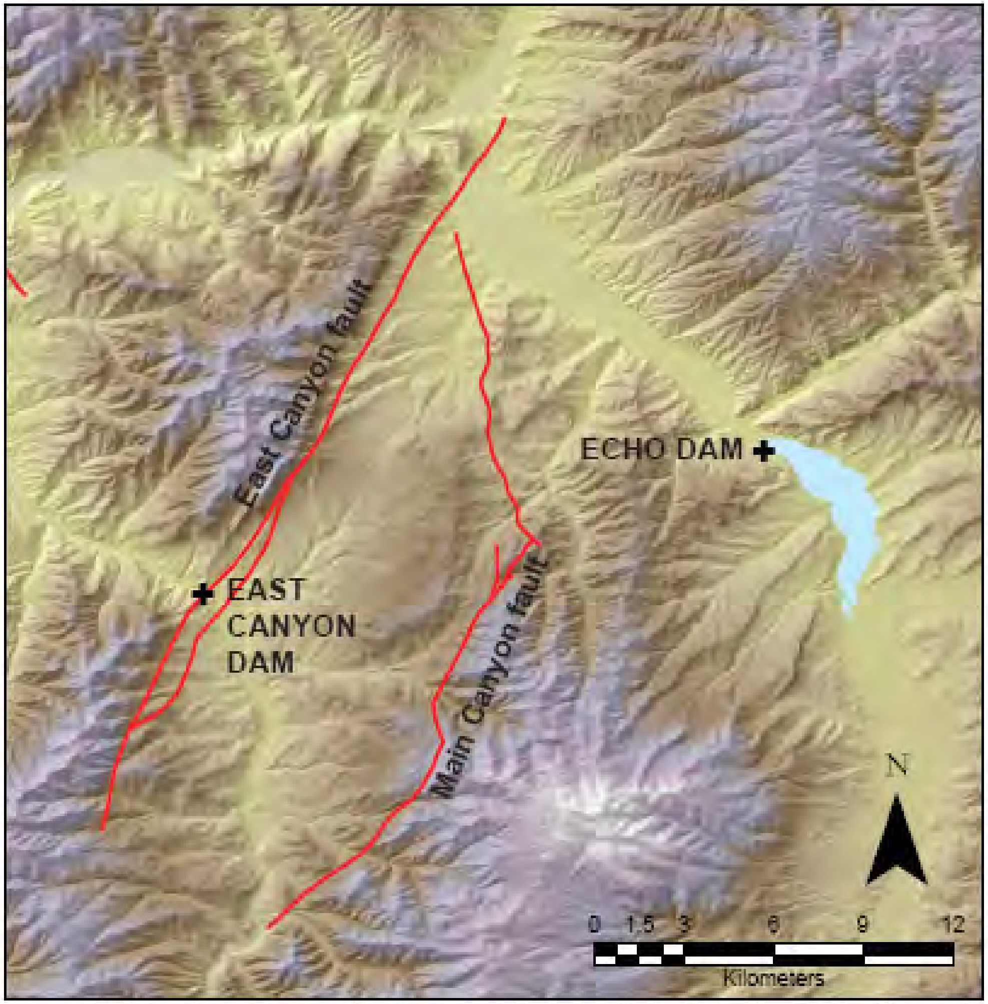

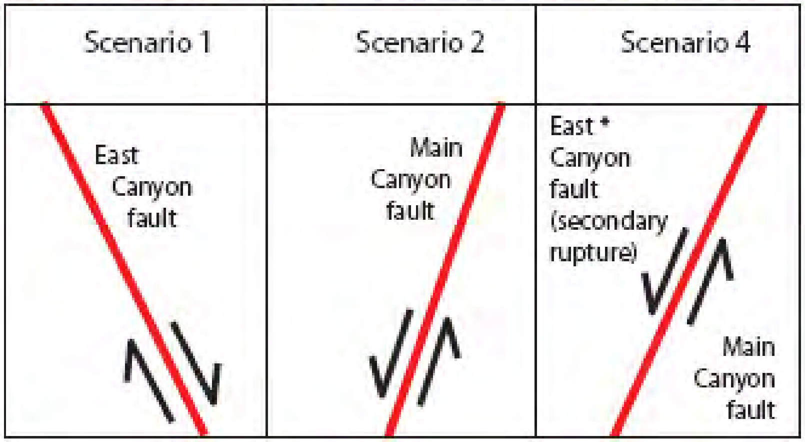

Wong and others (2010)

Scenario 1: East Canyon fault dominant

Scenario 2: Main Canyon fault dominant

Scenario 4: East Canyon & Main Canyon Faults rupture synchronously;
rupture on East Canyon fault triggered in larger events n Main Canyon fault

RECLAMATION

Calculating Time-Dependent Probabilities of Large Earthquakes for the Wasatch Front

Working Group on Utah Earthquake Probabilities

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Oakland, CA 94612

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Utah Geological Survey
88 Fiddler Canyon Rd, Suite C
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Salt Lake City, UT 15 February 2011

WGUEP Members

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Bill Lund, UGS (Coordinator)
Susan Olig, URS
Jim Pechmann, UUSS
Steve Personius, USGS
Mark Petersen, USGS
David Schwartz, USGS
Bob Smith, UUGG
Ivan Wong, URS (Chair)
With assistance from Patricia Thomas (URS) and
Steve Bowman and Mike Hylland (UGS)

Approach

- Four models will be implemented in the forecast process:
  1. Fault model
  2. Deformation model
  3. Earthquake rate model
  4. Probability model
- Epistemic uncertainties in all model input parameters will be explicitly addressed by the WGUEP.

Products

- The WGUEP will calculate the probability of a range of moderate to large earthquakes ($M \geq 5.5$) in the Wasatch Front Region for a range of intervals varying from annually to 100 years.
- The earthquake probabilities that will be estimated are:
  1. Segment-specific for the Wasatch fault
  2. Total for the Wasatch fault
  3. Fault-specific for other major faults in the area
  4. Total for the Wasatch Front region.

Products (cont.)

- The final forecast will undergo a formal internal USGS review, and will be sent to the National Earthquake Prediction Council for review and comment as well.

Accomplishments

- Paleoseismology Subgroup:
  - Comprehensive review of all paleoseismic data for central segments of Wasatch fault zone (WFZ)
  - Development of OxCal earthquake timing models for each paleoseismic site
  - Final earthquake chronologies and recurrence intervals for segments based on integration of OxCal analyses among sites
  - Development of six rupture scenarios for the central WFZ
  - Methodology paper in review

Accomplishments

- Strawman time-independent recurrence intervals/slip rates for end segments of Wasatch fault.
- Strawman time-independent recurrence intervals for Great Salt Lake fault (time-dependent recurrence intervals will be calculated).
- List of other faults and strawman slip rates that will be included in time-independent calculations.

Remaining Issues

1. GPS moment rate versus geologic and seismicity data

2. Moment balancing the Wasatch fault

Next Steps

1. Historical seismicity catalog update and calculation of background earthquake rates.
2. Update West Valley rupture scenarios (including coseismic rupture with Salt Lake City segment).
3. Calculate time-dependent and/or time-dependent rates for all faults.
4. Develop forecast.

Next Steps (cont.)

5. Produce draft report for review.
6. Review and finalize report.
7. Public release and outreach.

Integration of paleoseismic data from multiple sites to develop an objective earthquake chronology:

Application to the Weber segment of the Wasatch fault zone, Utah

Chris DuRoss (UGS)

Steve Personius (USGS)

Tony Crone (USGS)

Susan Olig (URS)

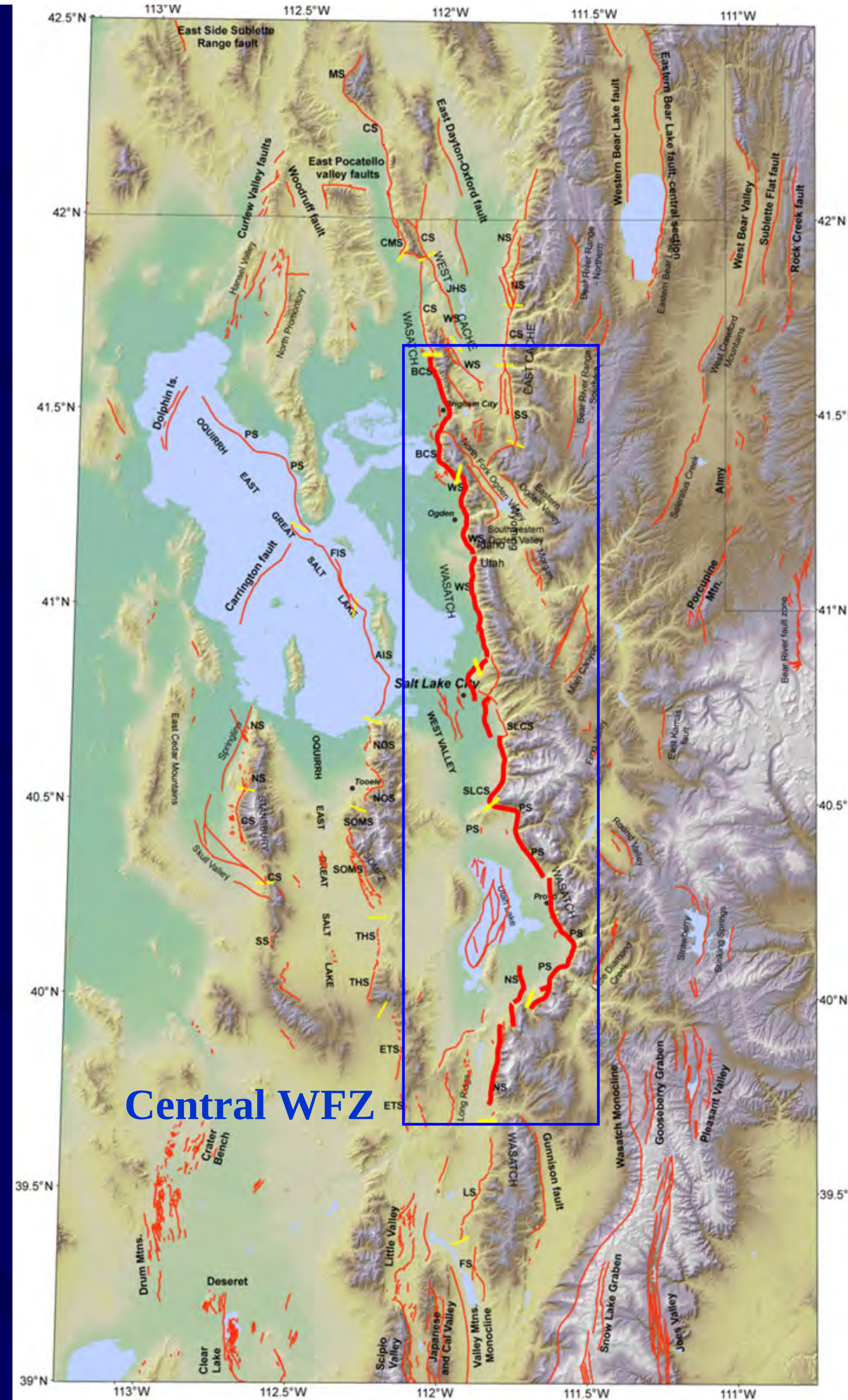
Bill Lund (UGS)

Utah Quaternary Fault Parameters Working Group 2011

Introduction

- **Motivation:** <u>Time-dependent earthquake forecast</u> (M $\geq$ 6.5) for the central Wasatch fault planned by the Working Group on Utah Earthquake Probabilities (WGUEP)

WGUEP
study region

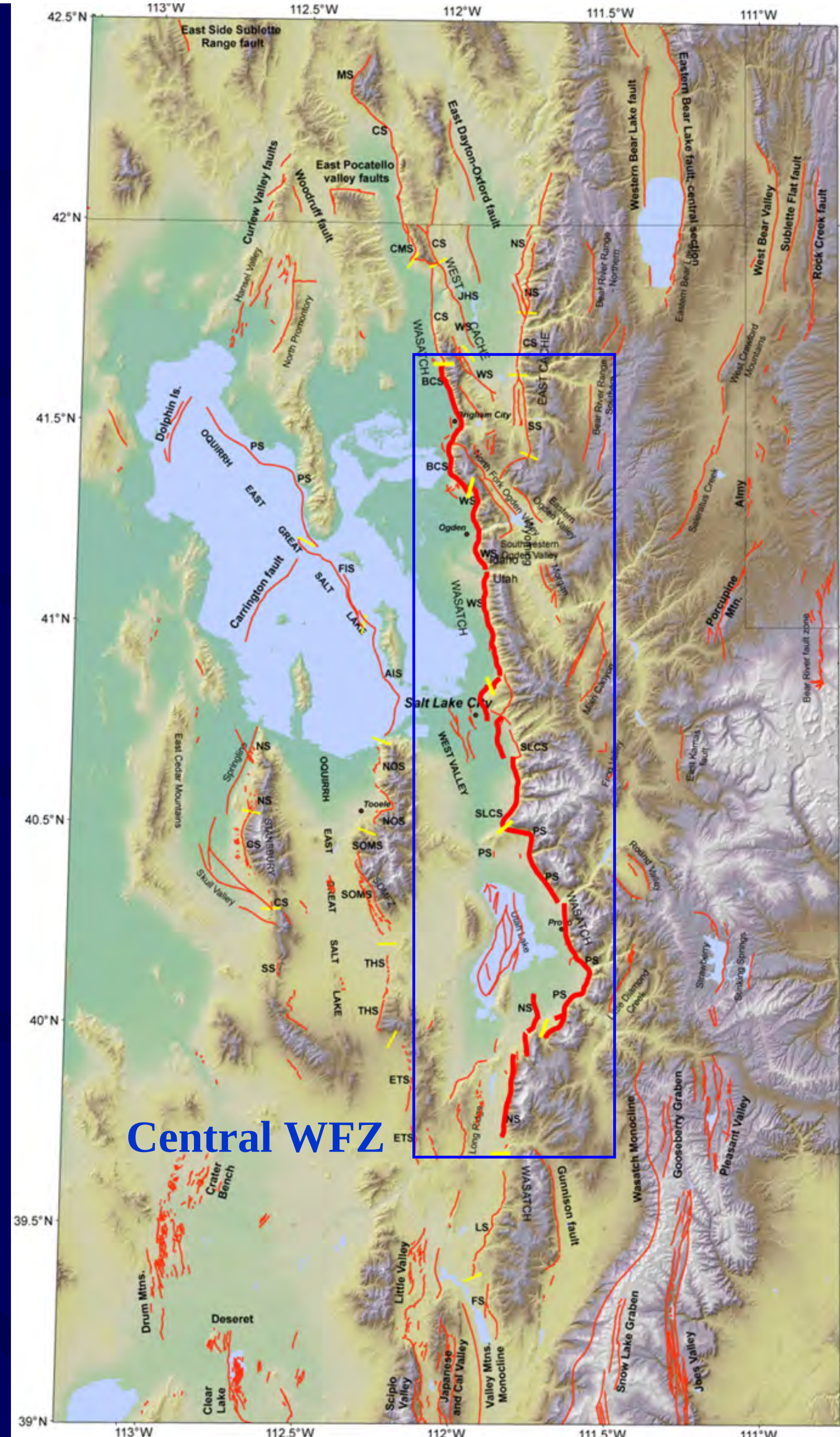


WGUEP WASATCH FRONT REGION
(latitude 39.00° - 42.50°, longitude 110.75° - 113.25°)

Introduction

- **Need up-to-date paleoseismic data:**
  - Earthquake timing information (elapsed time since MRE)
  - Recurrence intervals for segments and entire fault
  - Uncertainties in these values
  - Segmentation models (earthquake rupture lengths, displacements, and moment release)

WGUEP
study region



WGUEP WASATCH FRONT REGION
(latitude 39.00° - 42.50°, longitude 110.75° - 113.25°)

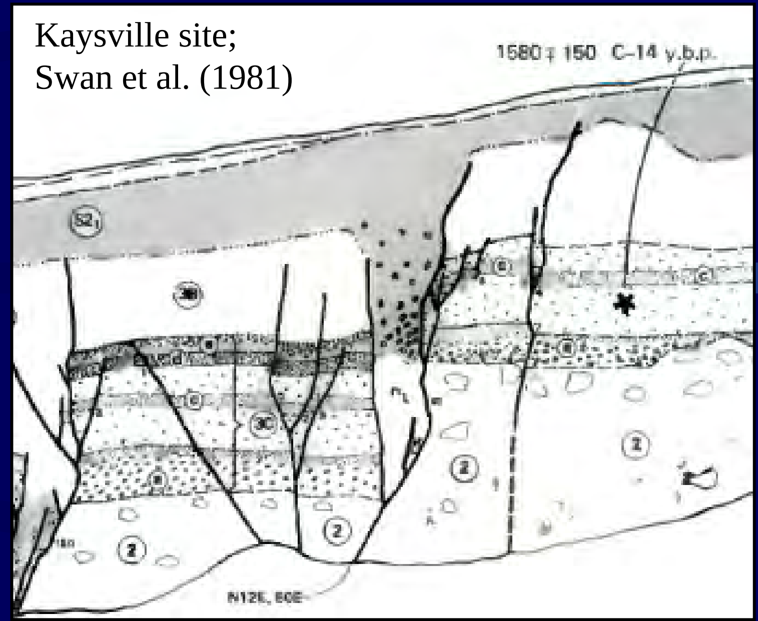
The Problem

- Although we have abundant data for the WFZ, there are still significant challenges:

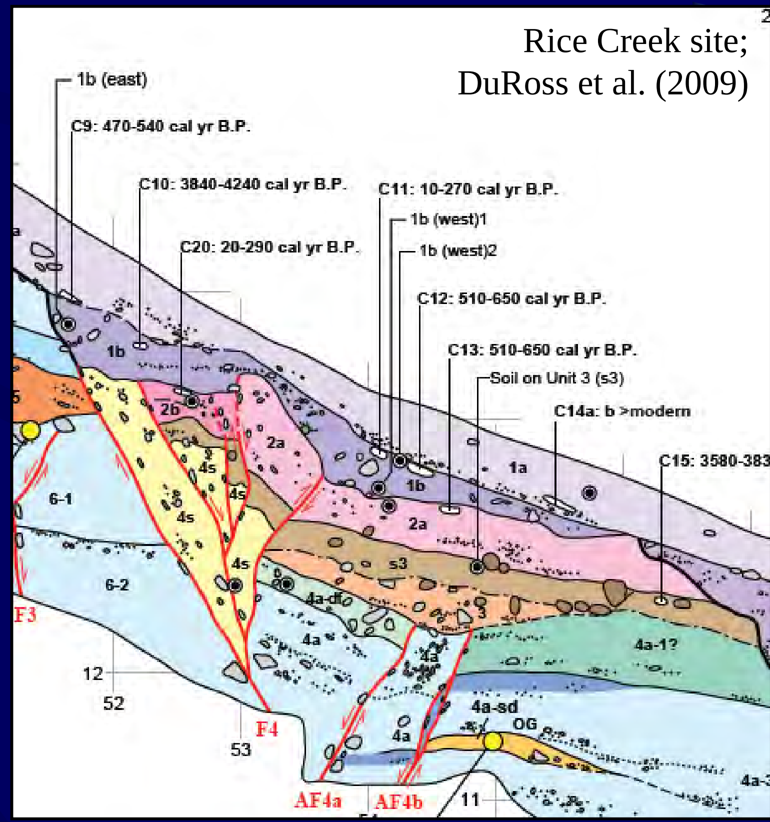
  1. Trenching and dating methods have evolved over the past 30 years:
     - Early trench studies: limited or shallow trenches with few bulk-soil ^{14}C ages
     - More recent studies: trenching campaigns with numerous luminescence and AMS ^{14}C ages on charcoal

  2. Correlating earthquakes between trench sites is not always obvious

Kaysville site; Swan et al. (1981)



Rice Creek site; DuRoss et al. (2009)



The Problem

- **Although we have abundant data for the WFZ, there are still significant challenges:**

  3. More recent paleoseismic data not included in the consensus earthquake times reported by 2003–2004 Utah Quaternary Fault Parameters Working Group
     - Working group did not consider details of individual trench sites
     - 7 trench studies completed/ published after 2004

7 sites completed after 2004 (yellow)

The Problem

- **Thus, how do we distill variable-quality paleoseismic data from multiple sites into an objective earthquake record that applies to the entire segment?**
  - Use only the most recent paleoseismic data?
  - Throw out troublesome numerical ages or conflicting data?
  - Average all data?
  - Use expert opinion?
  - How evaluate these data in a <u>reproducible</u> manner?

Our Approach – OxCal and Matlab Modeling

- **We present a method to systematically evaluate and integrate paleoseismic site data to develop an objective measure of earthquake timing and recurrence**

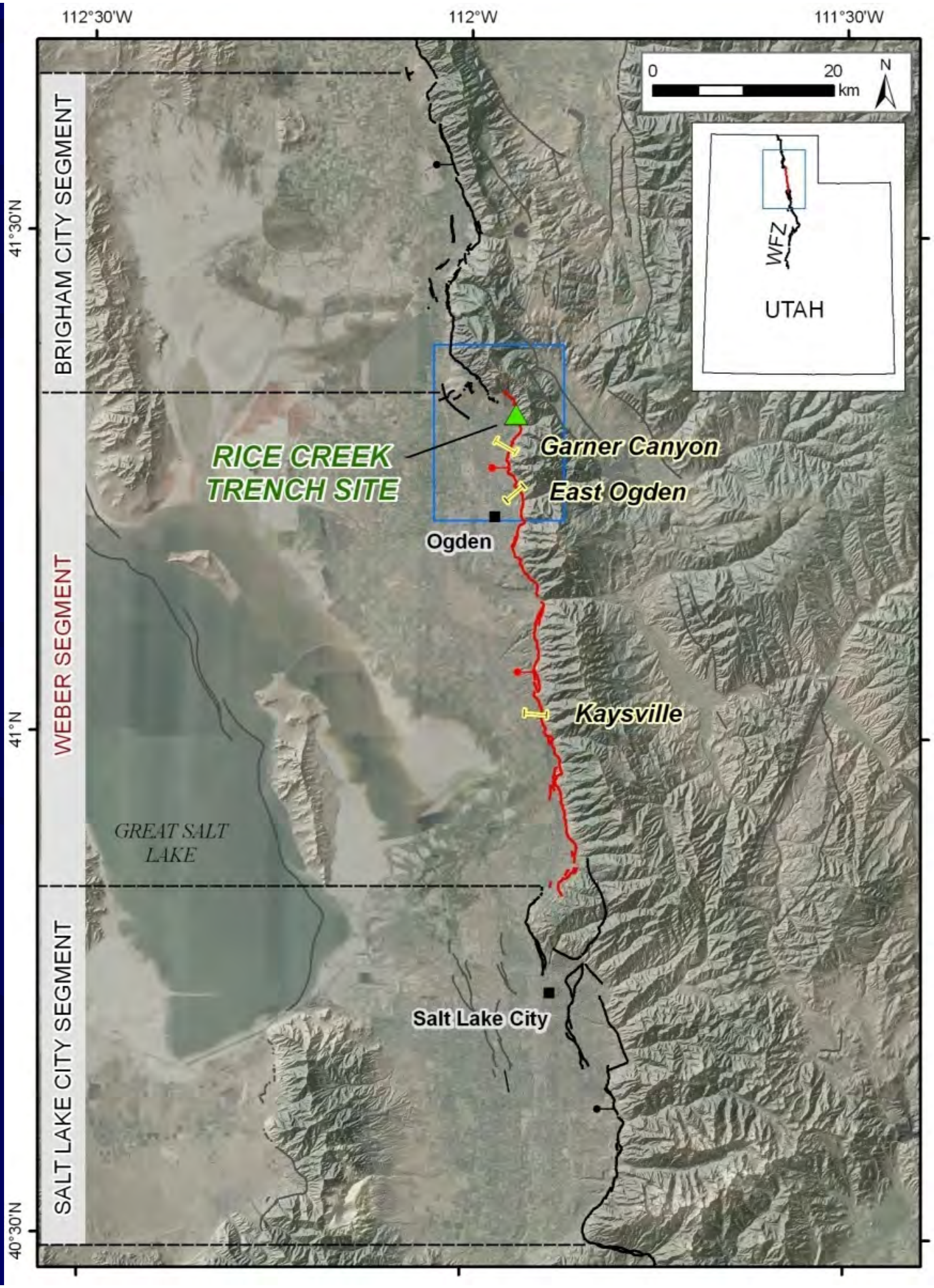
- **The product PDF method:**
    1. Carefully review all paleoseismic data, especially evidence for earthquakes and dating methods and results
    2. Construct time-stratigraphic OxCal models for each trench site
    3. Correlate events between sites to develop a segment-wide history
    4. Compute probability density functions (PDFs) for the time of each segment-wide earthquake (using Matlab)
    5. Use segment-wide earthquake data to determine earthquake recurrence

- **We apply this method to the Weber segment of the WFZ**

Weber Segment

- **Paleoseismic studies:**
  - Kaysville (K)
    (Swan et al., 1981; McCalpin et al., 1994)
  - East Ogden (EO)
    (Nelson et al., 2006)
  - Garner Canyon (GC)
    (Nelson et al., 2006)
  - Rice Creek (RC)
    (DuRoss et al., 2009)

- **Purpose – to integrate new Rice Creek data with previous paleoseismic data**



Summary of Previous Paleoseismic Data

Garner Cyn (GC)	*East Ogden (EO)*	*Kaysville (K)*
GC1: ~0.4–1.4 ka	EO1: 0.2–0.6 ka	K1: before 0.6–0.8 ka
GC2: 1.2–2.8 ka	EO2: 0.5–1.7 ka	K2: 2.8 ± 0.7 ka
GC3: 2.3–4.0 ka	EO3: 2.4–3.9 ka	K3: ~5–7 (3.8–7.9?) ka
GC4: ~4–5?	EO4: 2.8–4.8 ka	

- **At least 3 surface-faulting events at each site**

Summary of Previous Paleoseismic Data

Garner Cyn (GC)	*East Ogden (EO)*	*Kaysville (K)*
GC1: ~0.4–1.4 ka	EO1: 0.2–0.6 ka	K1: before 0.6–0.8 ka
GC2: 1.2–2.8 ka	EO2: 0.5–1.7 ka	K2: 2.8 ± 0.7 ka
GC3: 2.3–4.0 ka	EO3: 2.4–3.9 ka	K3: ~5–7 (3.8–7.9?) ka
GC4: ~4–5?	EO4: 2.8–4.8 ka	

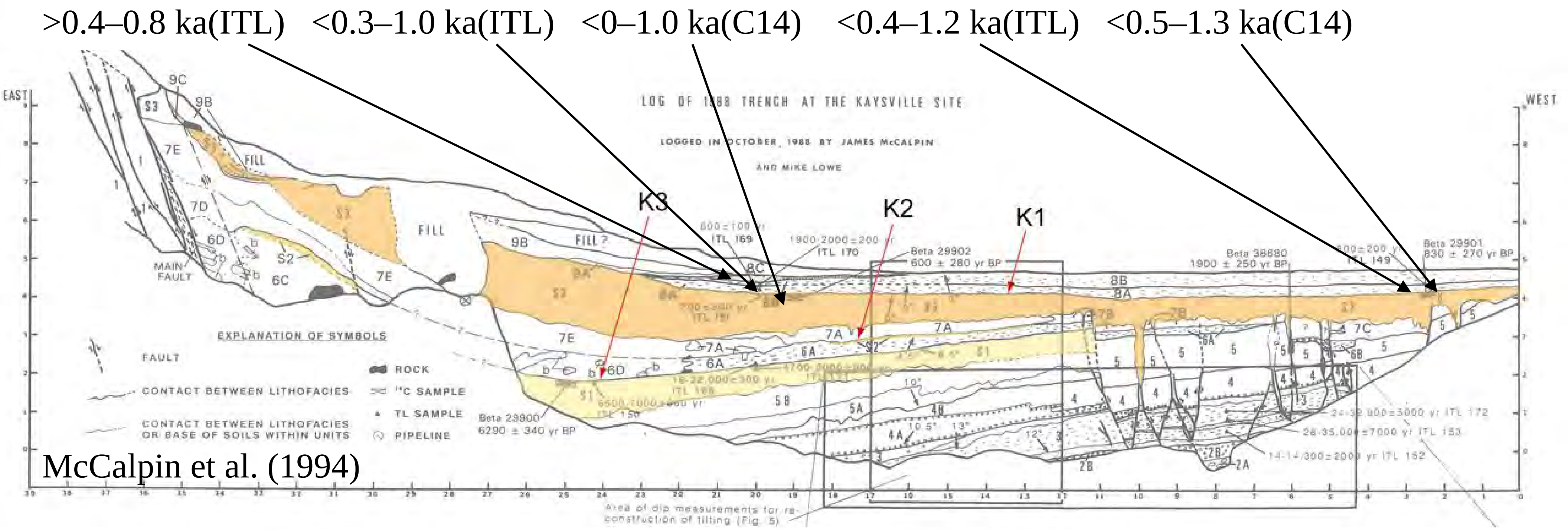
- **However, questions remain:**
  - Partial rupture of northern Weber segment at ~500 years (EO1)?
  - K3 correlate with EO4 or older event not exposed at East Ogden?
  - Why only three events identified at Kaysville?
  - How determine earthquake timing and recurrence for the segment?

1. Paleoseismic Site Data Review

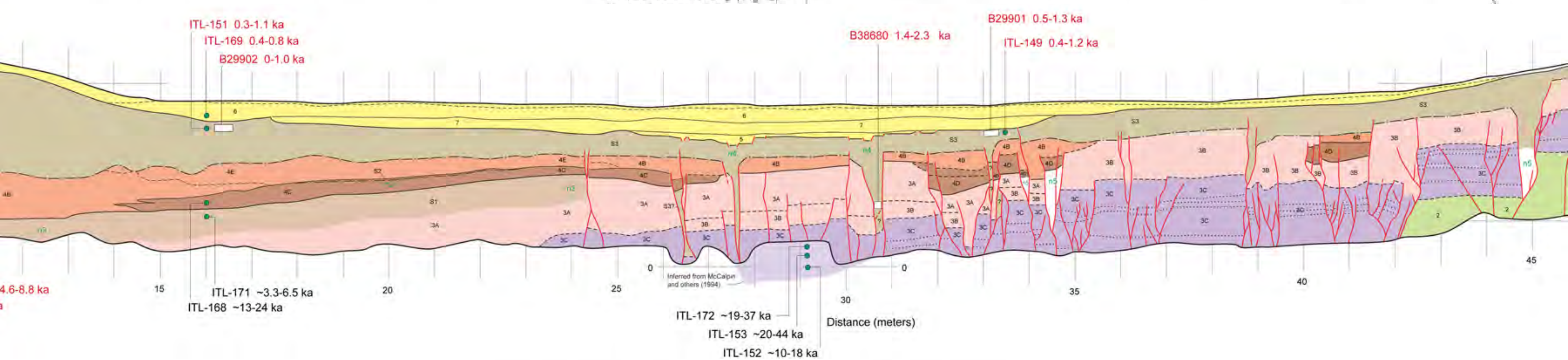
- **Evidence for earthquakes**
  - Stratigraphic framework for events
  - Completeness of record
    - All scarps trenched?
    - Orphan (undated) colluvial wedges?
    - Events missing, but expected?

- **Limiting ages and uncertainties**
  - Sample locations and contextual uncertainties
  - Mean-residence-time (MRT) correction(s) for bulk-soil ^{14}C ages

Example – Kaysville Site, Weber Segment



McCalpin et al. (1994)



Swan et al. (1981)

Log of Trench A; Kaysville Site

Swan, F.H., Schwartz, D.P., Hanson, K.L, Knuepfer, P.L., and Cluff, L.S.

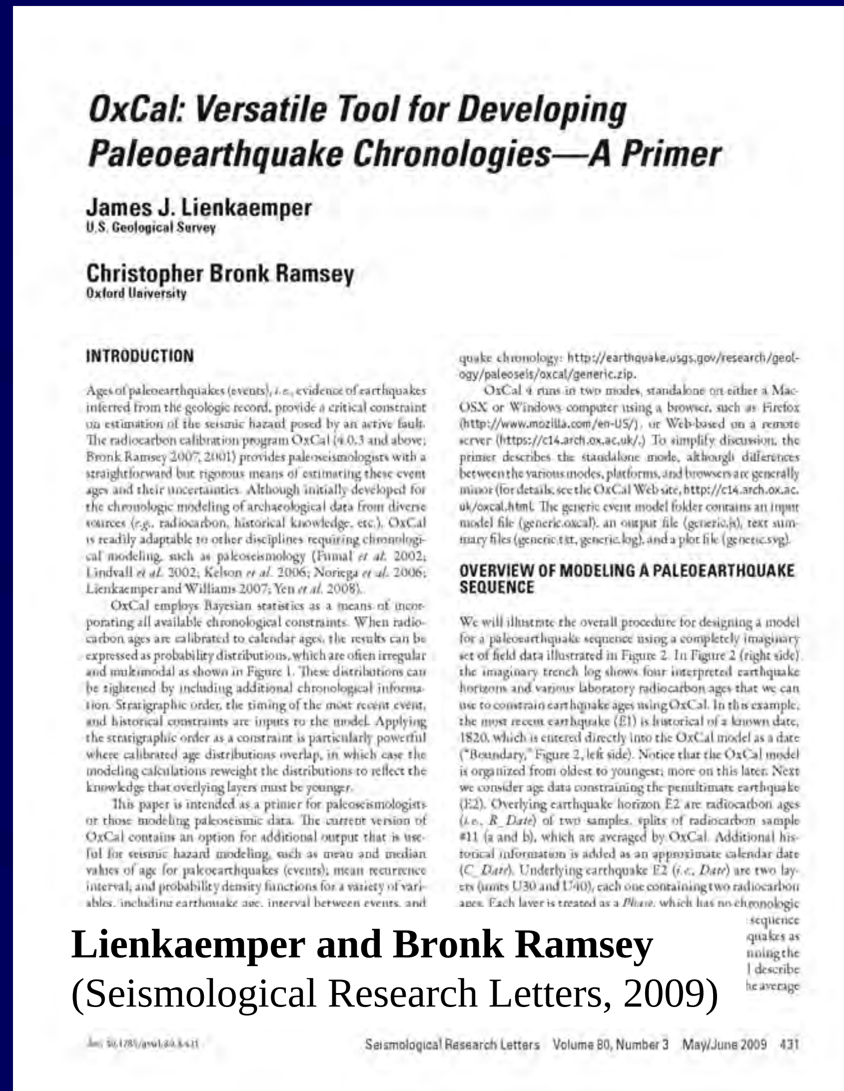
1981

2. OxCal Models

- **OxCal**
  - Models the time distributions (PDFs) of undated events in a model that includes stratigraphic and chronological constraints
  - Allows for the objective evaluation of paleoseismic data

- **Constructing OxCal models**
  - Include depositional units and limiting ages based on author's interpretation, discussion, and trench logs
  - For bulk-soil ages: apply MRT correction, with uncertainty if not specified by original authors

- **Export PDFs for each site earthquake (*site PDFs*)**



OxCal: Versatile Tool for Developing Paleoearthquake Chronologies—A Primer

James J. Lienkaemper
U.S. Geological Survey

Christopher Bronk Ramsey
Oxford University

INTRODUCTION

Ages of paleoearthquakes (events), *i.e.*, evidence of earthquakes inferred from the geologic record, provide a critical constraint on estimation of the seismic hazard posed by an active fault. The radiocarbon calibration program OxCal (4.0.3 and above; Bronk Ramsey 2007, 2001) provides paleoseismologists with a straightforward but rigorous means of estimating these event ages and their uncertainties. Although initially developed for the chronologic modeling of archaeological data from diverse sources (*e.g.*, radiocarbon, historical knowledge, etc.), OxCal is readily adaptable to other disciplines requiring chronological modeling, such as paleoseismology (Fumal *et al.* 2002; Lindvall *et al.* 2002; Kelson *et al.* 2006; Noriega *et al.* 2006; Lienkaemper and Williams 2007; Yen *et al.* 2008).

OxCal employs Bayesian statistics as a means of incorporating all available chronological constraints. When radiocarbon ages are calibrated to calendar ages, the results can be expressed as probability distributions, which are often irregular and multimodal as shown in Figure 1. These distributions can be tightened by including additional chronological information. Stratigraphic order, the timing of the most recent event, and historical constraints are inputs to the model. Applying the stratigraphic order as a constraint is particularly powerful where calibrated age distributions overlap, in which case the modeling calculations reweight the distributions to reflect the knowledge that overlying layers must be younger.

This paper is intended as a primer for paleoseismologists or those modeling paleoseismic data. The current version of OxCal contains an option for additional output that is useful for seismic hazard modeling, such as mean and median values of age for paleoearthquakes (events); mean recurrence interval; and probability density functions for a variety of variables, including earthquake age, interval between events, and

quake chronology: http://earthquake.usgs.gov/research/geology/paleoseis/oxcal/generic.zip.

OxCal 4 runs in two modes, standalone on either a Mac-OSX or Windows computer using a browser, such as Firefox (http://www.mozilla.com/en-US/), or Web-based on a remote server (https://c14.arch.ox.ac.uk/.) To simplify discussion, the primer describes the standalone mode, although differences between the various modes, platforms, and browsers are generally minor (for details, see the OxCal Web site, http://c14.arch.ox.ac.uk/oxcal.html. The generic event model folder contains an input model file (generic.oxcal), an output file (generic.js), text summary files (generic.txt, generic.log), and a plot file (generic.svg).

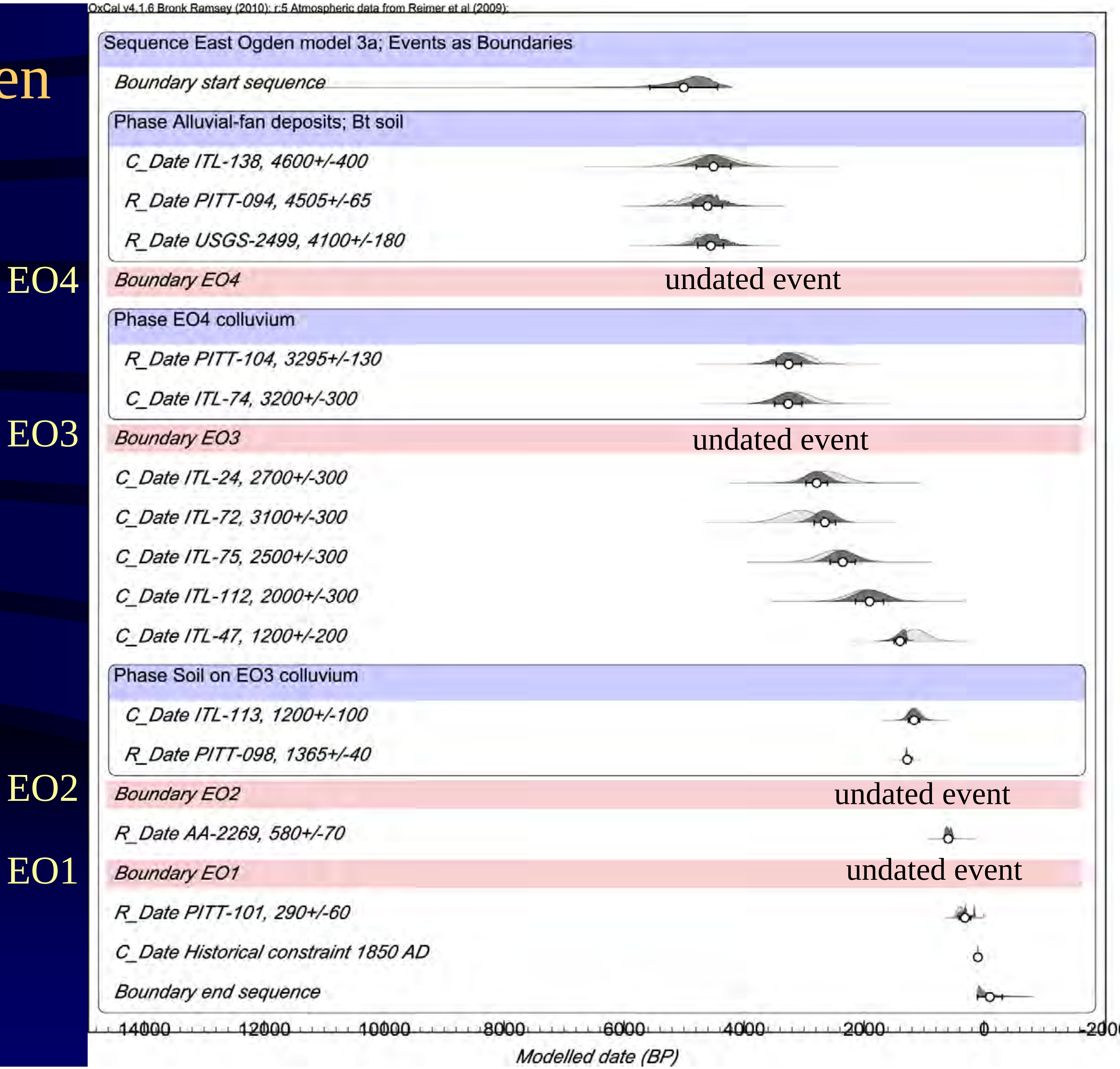
OVERVIEW OF MODELING A PALEOEARTHQUAKE SEQUENCE

We will illustrate the overall procedure for designing a model for a paleoearthquake sequence using a completely imaginary set of field data illustrated in Figure 2. In Figure 2 (right side) the imaginary trench log shows four interpreted earthquake horizons and various laboratory radiocarbon ages that we can use to constrain earthquake ages using OxCal. In this example, the most recent earthquake (E1) is historical of a known date, 1820, which is entered directly into the OxCal model as a date ("Boundary," Figure 2, left side). Notice that the OxCal model is organized from oldest to youngest; more on this later. Next we consider age data constraining the penultimate earthquake (E2). Overlying earthquake horizon E2 are radiocarbon ages (*i.e.*, *R_Date*) of two samples, splits of radiocarbon sample #11 (a and b), which are averaged by OxCal. Additional historical information is added as an approximate calendar date (*C_Date*). Underlying earthquake E2 (*i.e.*, *Date*) are two layers (units U30 and U40), each one containing two radiocarbon ages. Each layer is treated as a *Phase*, which has no chronologic

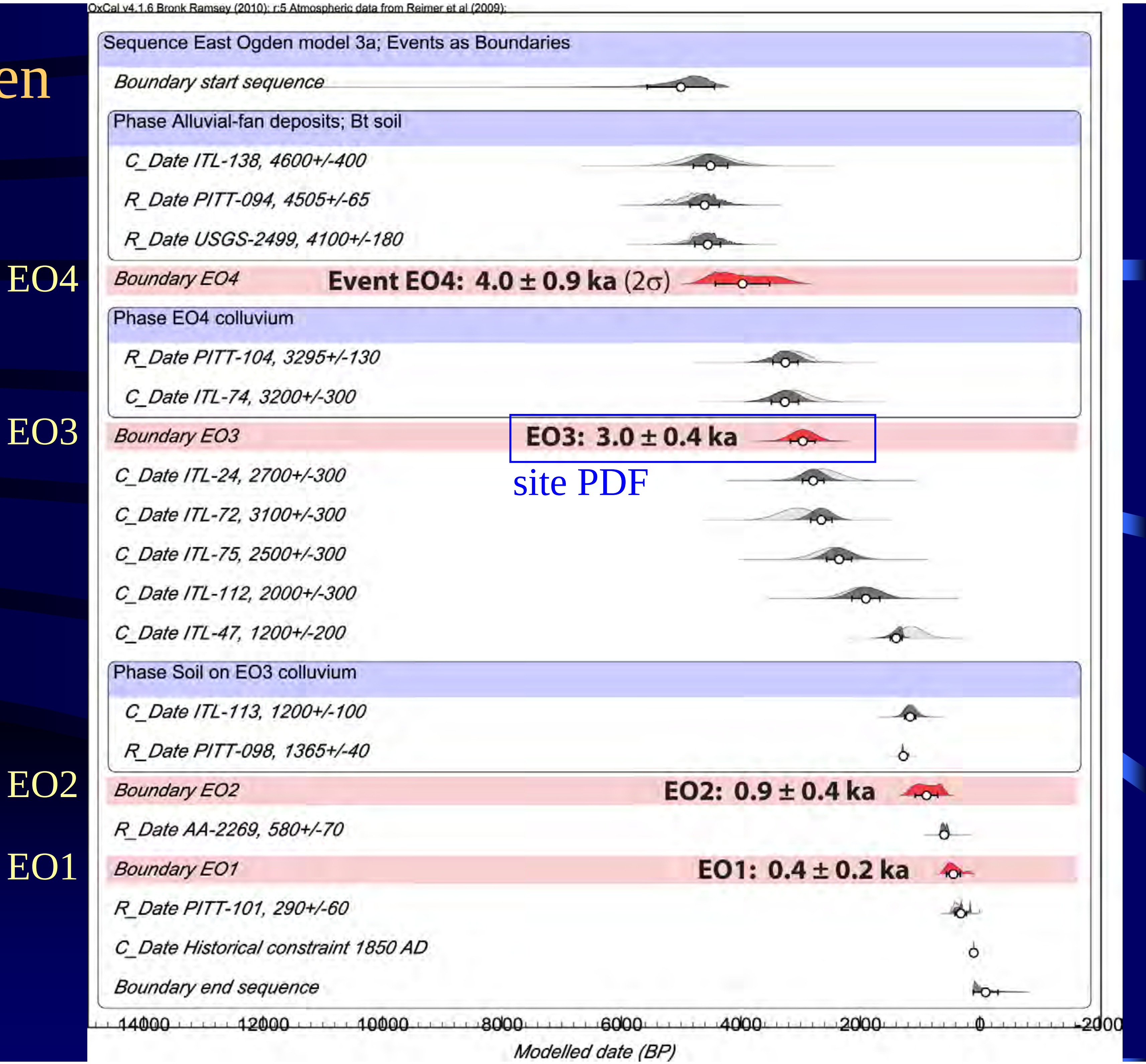
Lienkaemper and Bronk Ramsey
(Seismological Research Letters, 2009)

OxCal: c14.arch.ox.ac.uk

East Ogden OxCal Model



East Ogden OxCal Model



2. OxCal Models

Rice Creek	*Garner Cyn.*	*East Ogden*	*Kaysville*
0.6 ± 0.1 (2σ)	0.6 ± 0.4	0.4 ± 0.2	0.6 ± 0.2
1.2 ± 0.2	1.5 ± 0.5	0.9 ± 0.4	0.9 ± 0.5
3.4 ± 0.7	3.2 ± 0.6	3.0 ± 0.4	2.8 ± 1.7
4.6 ± 0.5	4.4 ± 0.6	4.0 ± 0.9	-
6.0 ± 1.0	-	-	5.8 ± 1.3

(Earthquake times are mean ± 2 sigma)

- **Revised data**
  - Evidence for 5 events since mid Holocene at Rice Creek
  - Revised timing of most recent earthquake at Kaysville (~600 yr)
  - Strong stratigraphic and structural evidence for additional event at ~1-ka event at Kaysville (K2)

3. Earthquake Correlation

	Rice Creek		*Garner Cyn.*		*East Ogden*		*Kaysville*
E1:	0.6 ± 0.1 (2σ)	⟷	0.6 ± 0.4	⟷	0.4 ± 0.2	⟷	0.6 ± 0.2
E2:	1.2 ± 0.2	⟷	1.5 ± 0.5	⟷	0.9 ± 0.4	⟷ ?	0.9 ± 0.5
E3:	3.4 ± 0.7	⟷	3.2 ± 0.6	⟷	3.0 ± 0.4	⟷	2.8 ± 1.7
E4:	4.6 ± 0.5	⟷	4.4 ± 0.6	⟷	4.0 ± 0.9	?	-
E5:	6.0 ± 1.0	⟷					5.8 ± 1.3

(Earthquake times are mean ± 2 sigma)

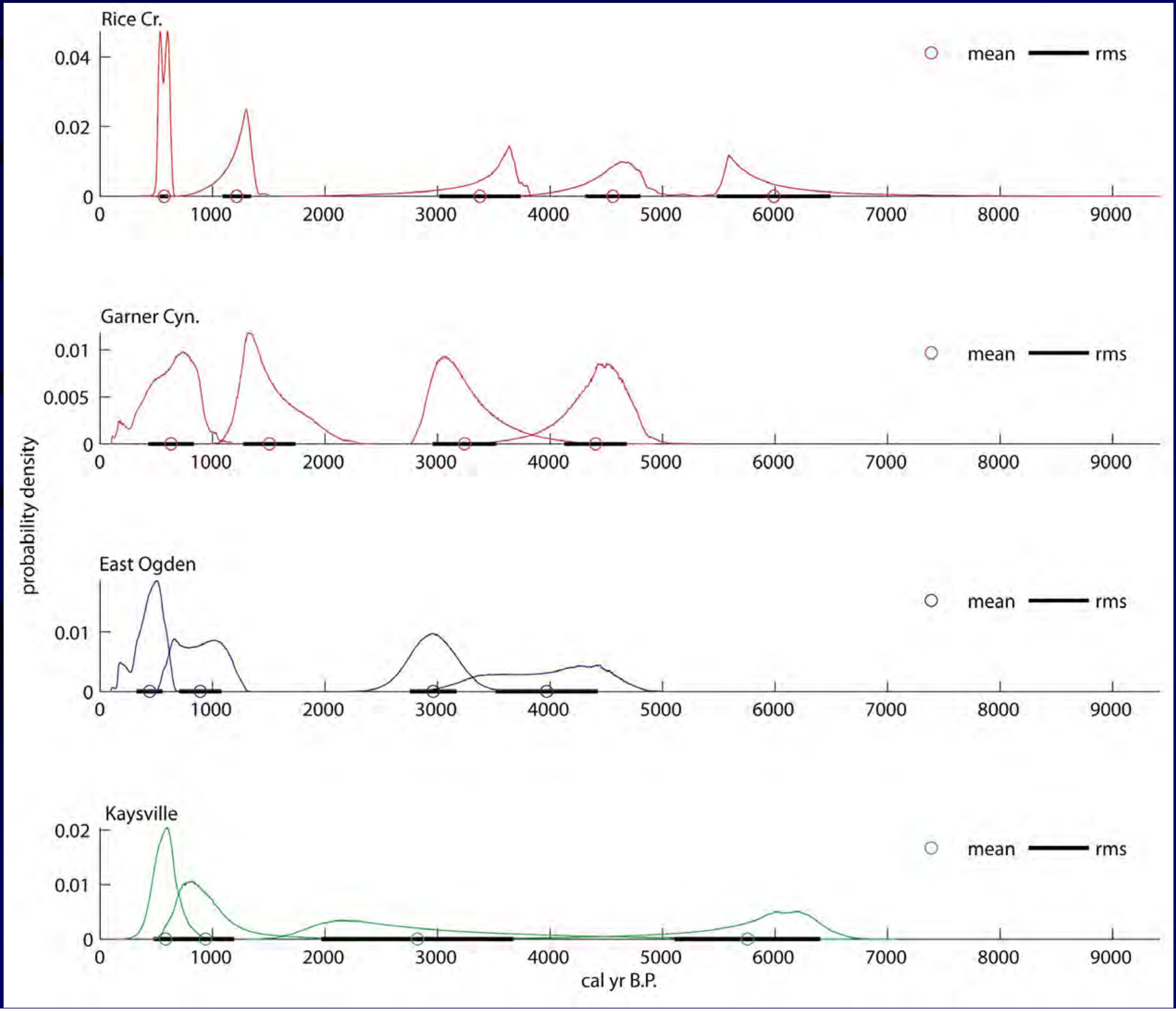
- **Correlate site PDFs to develop a segment-wide history**
  - MRE (**E1**) at 400–600 yr
  - Kaysville K2 likely evidence of earthquake **E2**
  - **E4** not identified at Kaysville (is complete record?)
  - Oldest Kaysville event (5.8 ka) likely corresponds with oldest Rice Creek event (~6 ka) to form **E5**

3. Earthquake Correlation

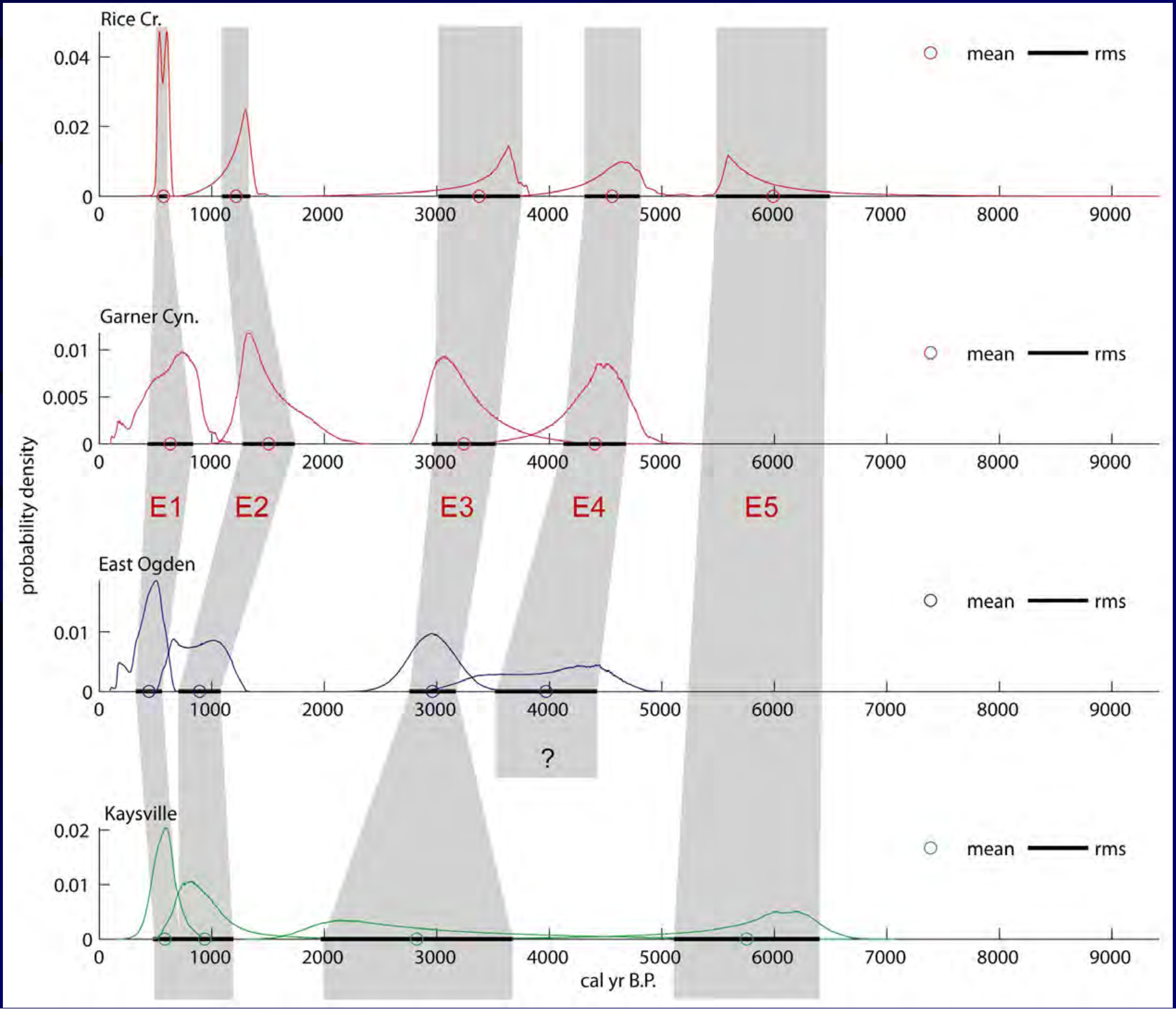
- **Caveats:**
  - Our earthquake correlation inherently assumes characteristic behavior (full segment ruptures)
  - We interpret the similar earthquake histories at the four paleoseismic sites as evidence of 5 segment-wide earthquakes ruptures.
  - We do not consider multi-segment rupture or more importantly, partial-segment rupture if earthquakes at adjacent sites don’t have identical times.

  - This is supported by the overlap in the site PDFs, large per-event displacements (~2-m avg; 4-m max), and prominent segment boundaries

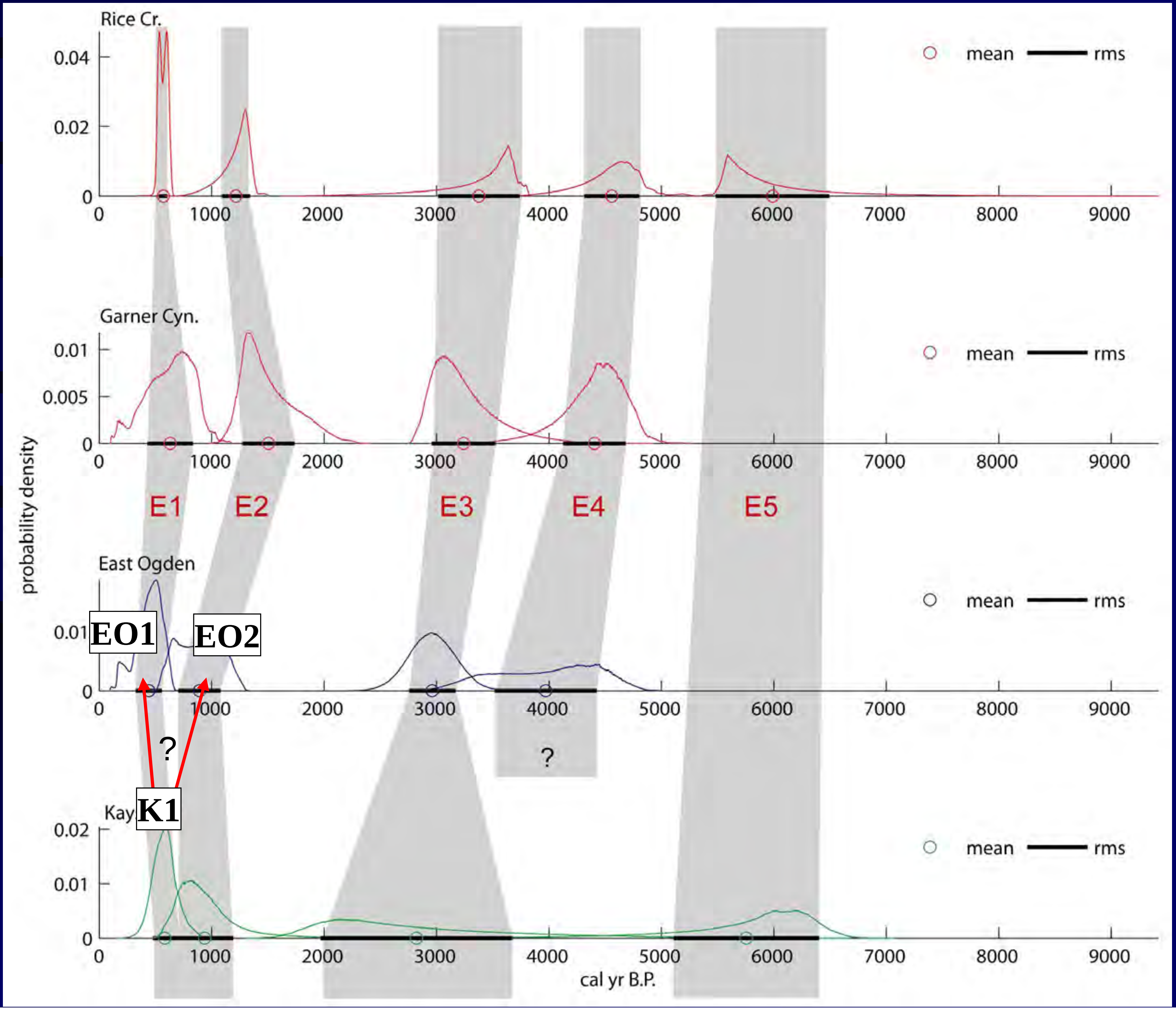
3. Earthquake Correlation – Site PDFs



3. Earthquake Correlation – Site PDFs

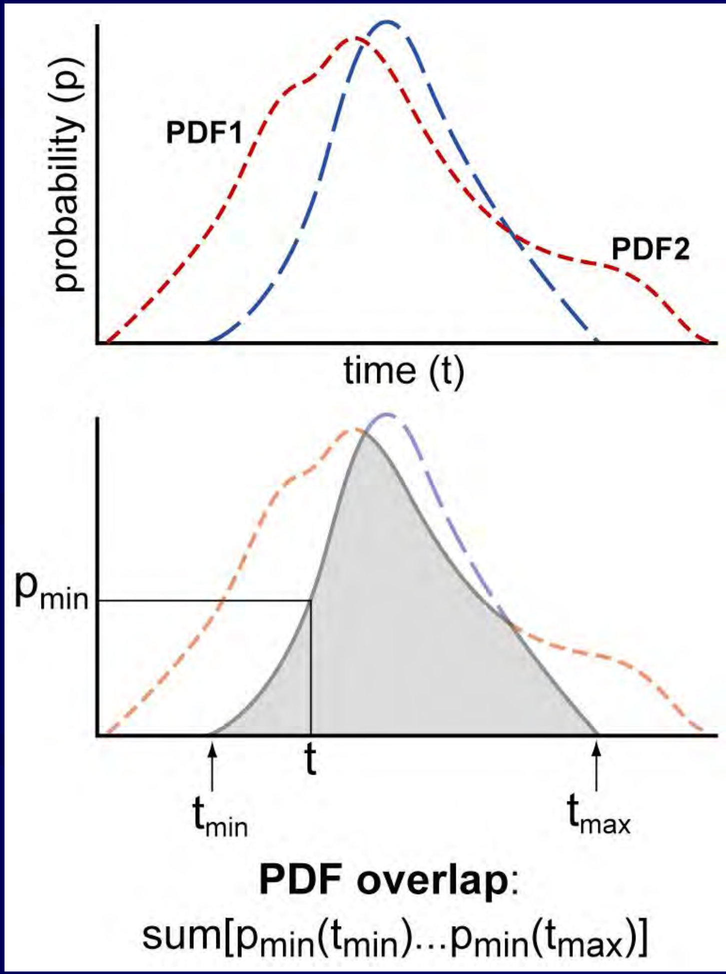


3. Earthquake Correlation – Site PDFs



PDF Overlap

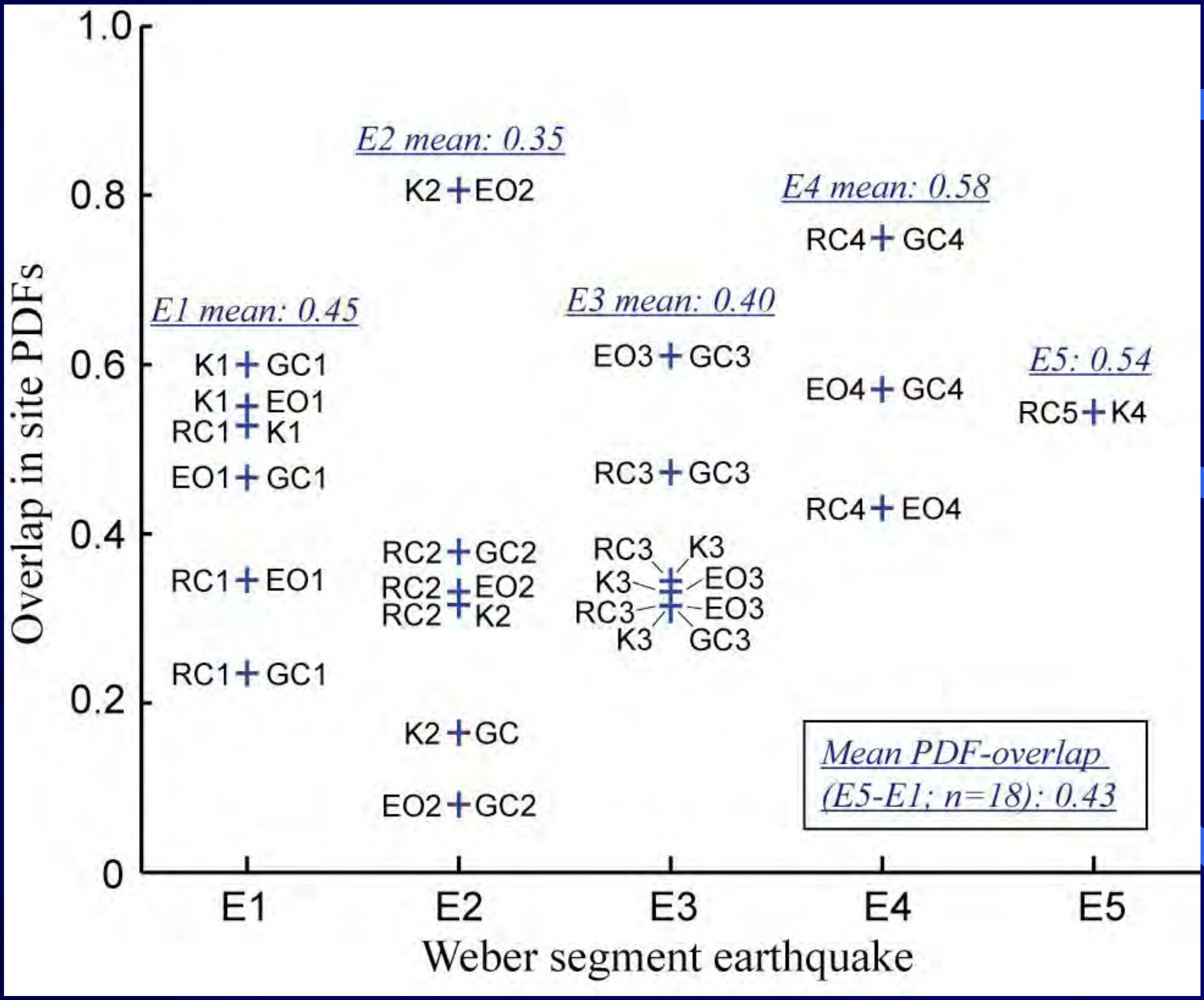
- **PDF overlap***
  - For two overlapping PDFs, sum of the minimum probabilities for each time bin in area of overlap (t_{min} to t_{max} in figure)
  - 0–1: zero to full overlap
  - K1 correlate with EO1 or EO2?
    - K1-EO1 overlap: 0.55
    - K1-EO2 overlap: 0.33



* from Biasi and Weldon (2009); BSSA v. 99, no. 2A, p. 471–498

PDF Overlap

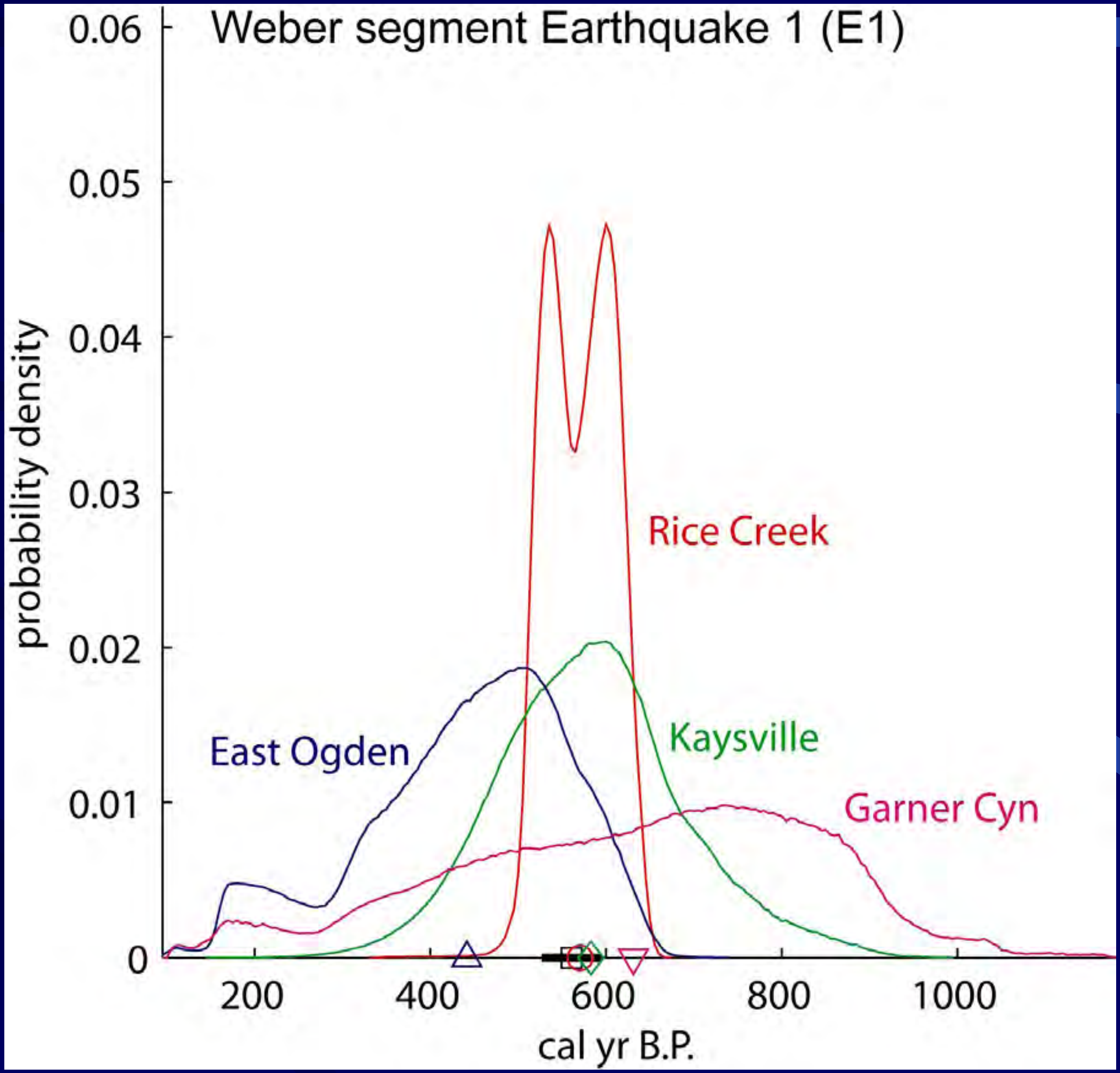
- **PDF overlap***
  - Moderate overlap in site PDFs per earthquake
  - Mean PDF overlap:
    - E1: 0.45
    - E2: 0.35 (some <0.2)
    - E3: 0.40
    - E4: 0.58
    - E5: 0.54 (2 site PDFs)



* from Biasi and Weldon (2009); BSSA v. 99, no. 2A, p. 471–498

4. PDFs for Segment-Wide Earthquakes

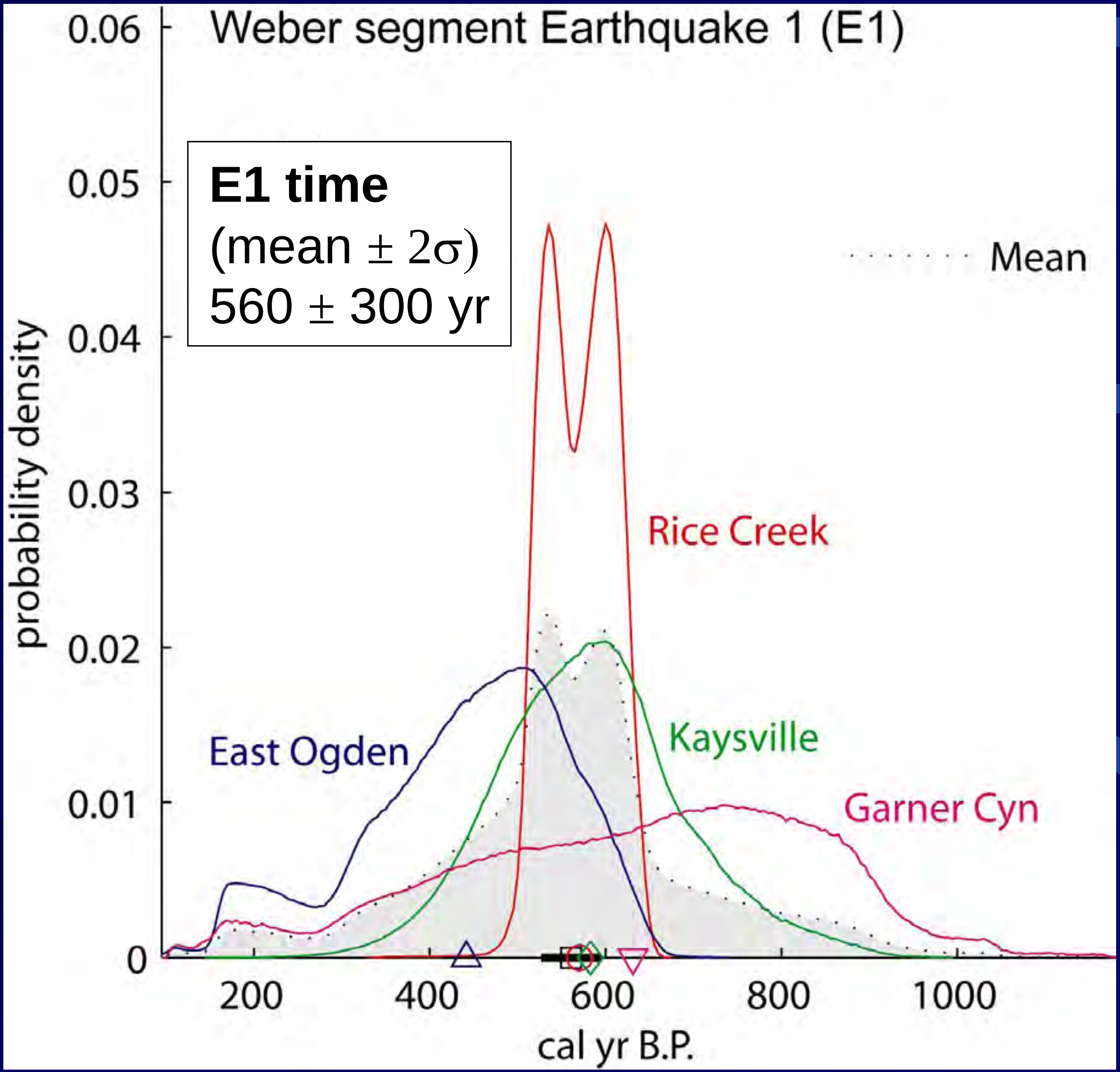
- **Combine OxCal models into segment chronology** (Matlab)
  - Using correlation of events, combine correlative site PDFs to form single "**segment PDF**"



- **Two approaches:**
  - Mean of site PDF probabilities (or weighted mean, using PDF shape)
  - Product of site PDF probabilities

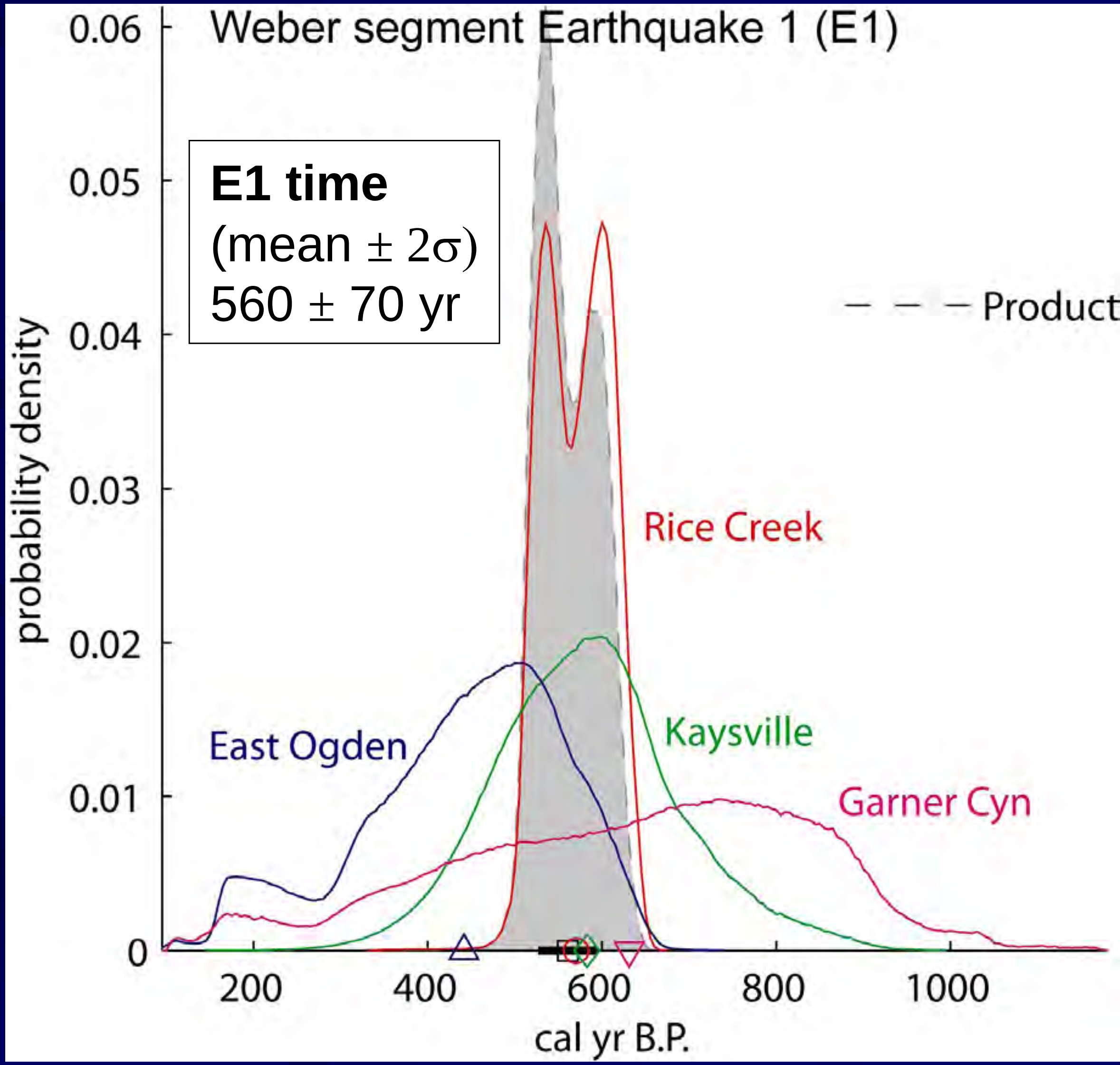
Example – Weber Segment (E1)

- **Mean of site PDFs** (light gray)
  - All site PDFs given equal weight
  - Mean earthquake time influenced by least well constrained data (broadest PDFs)
  - E1 PDF has long tails because of poorly constrained Garner Canyon data

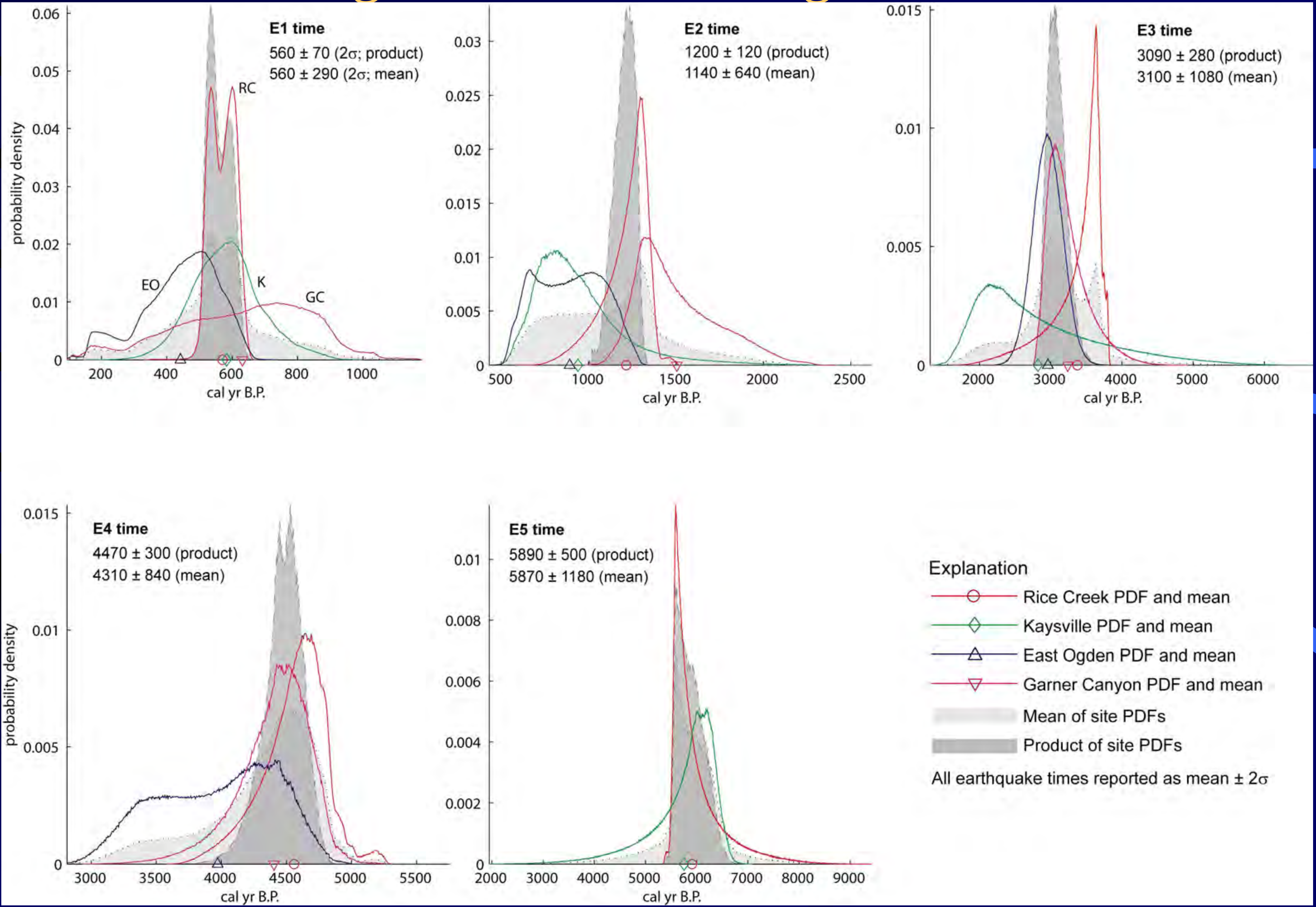


Example – Weber Segment (E1) – Refined

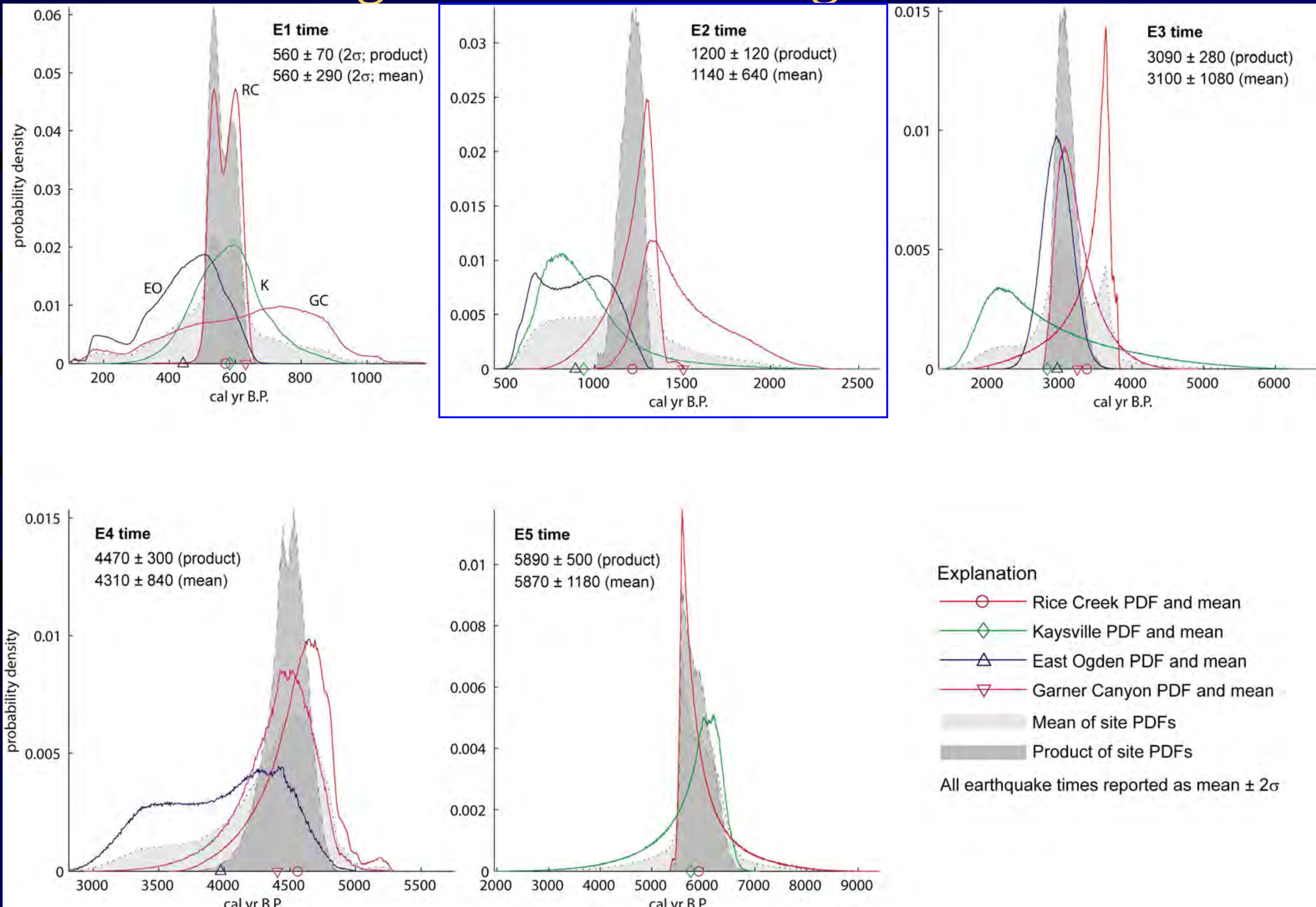
- **Product of site PDFs** (dark gray)
  - For independent events A & B, probability of both events occurring at time t: $P(A \text{ and } B)_t = P(A)_t * P(B)_t$
  - E1 PDF based on overlap in site PDFs: best-constrained, narrowest PDFs receive most weight
  - Basis: some paleoseismic sites better suited to constraining an earthquake time than others



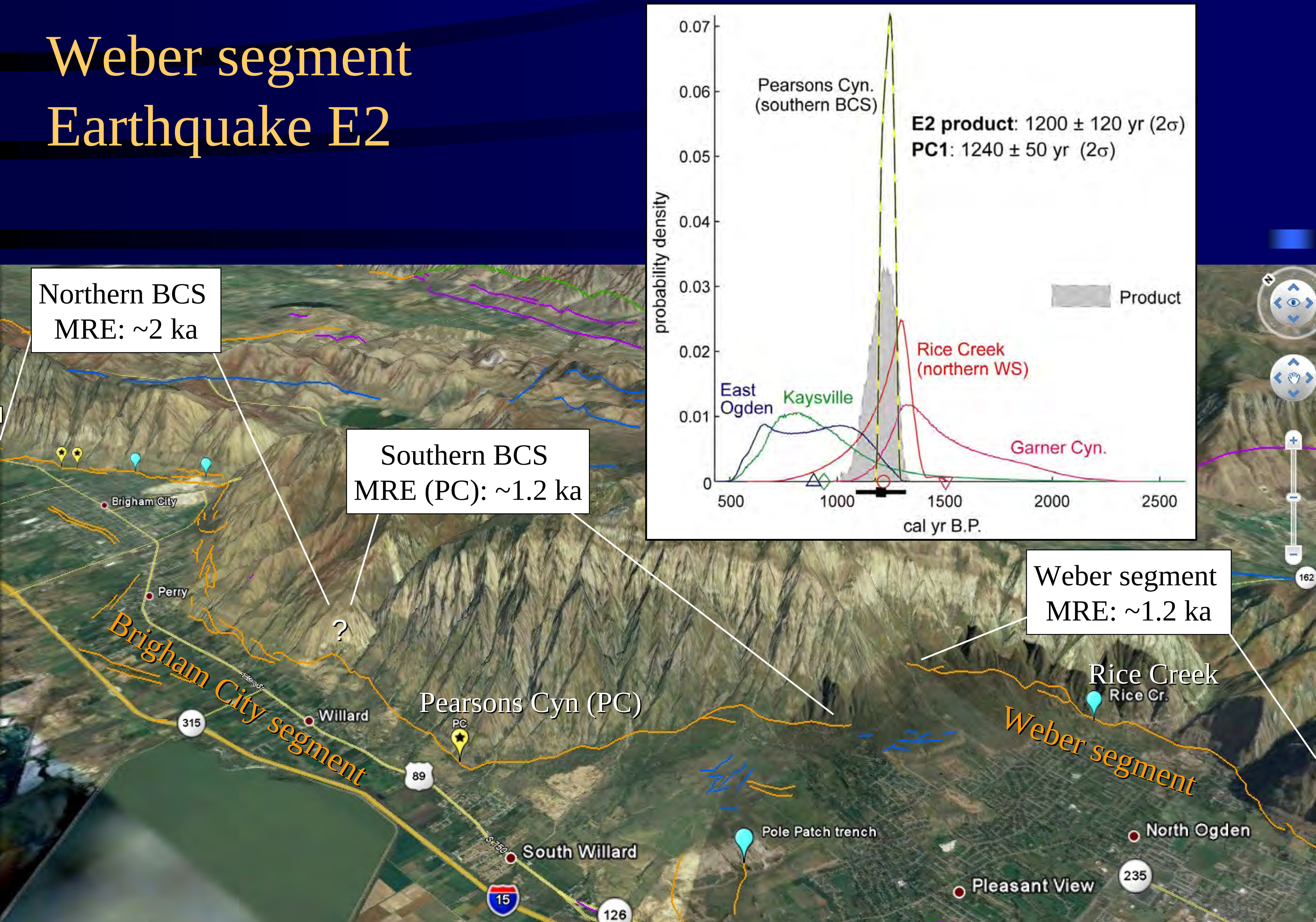
Matlab Timing Refinement – Segment PDFs



Matlab Timing Refinement – Segment PDFs

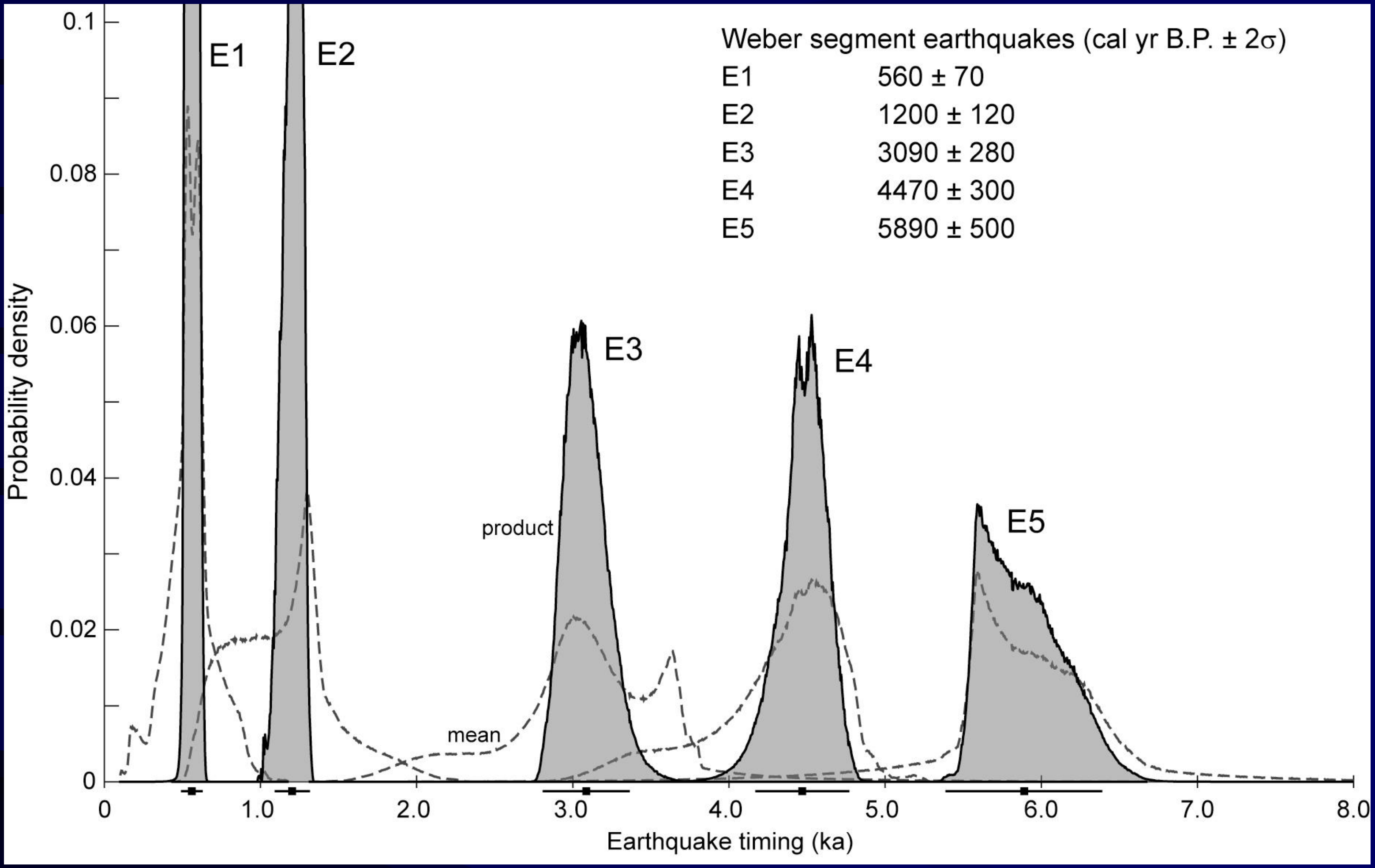


Weber segment Earthquake E2



Step over between Brigham City (BCS) and Weber segments

Final Weber segment chronology

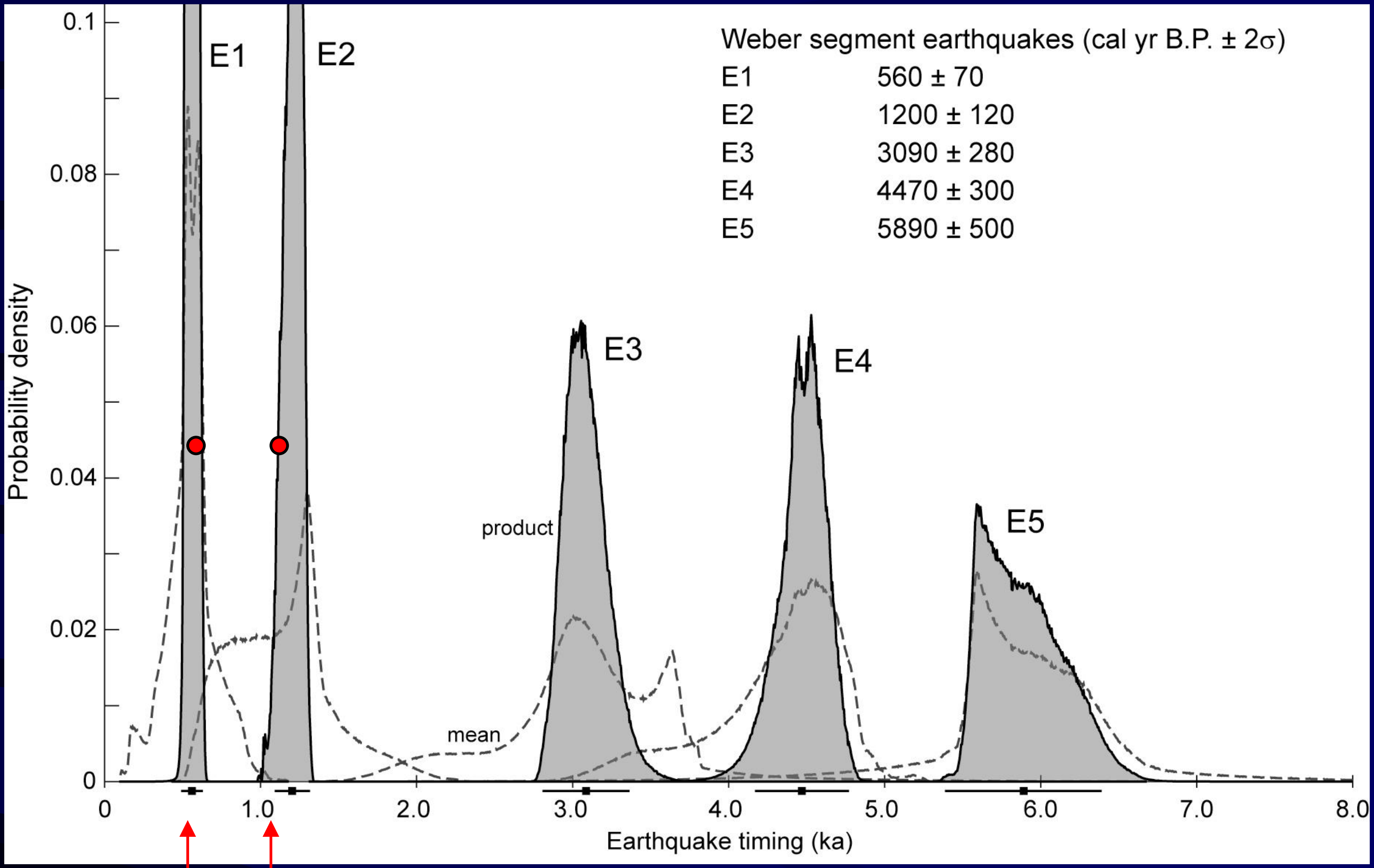


- **Product method helps refine earthquake timing**
  - Similar mean times, but product uncertainties are ~20–40% of mean uncertainties
  - Important for estimates of elapsed time since MRE, Coefficient of Variation (COV) or periodicity, and mean recurrence

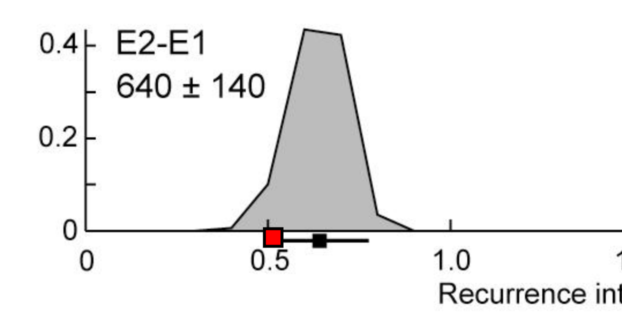
5. Earthquake Recurrence

- **Recurrence intervals**
  - Determined using earthquake PDFs (product PDFs)
  - Closed recurrence (between two or more earthquakes)
  - Open recurrence (including elapsed time since most recent earthquake, which is an open interval
- **Monte Carlo model**
  - In each scenario:
    1. Randomly sample earthquake PDFs
    2. Compute inter-event (e.g., E5–E4) and mean (e.g., E5–E1/4) recurrence
    3. Compile values and plot as PDFs

Inter-Event Recurrence

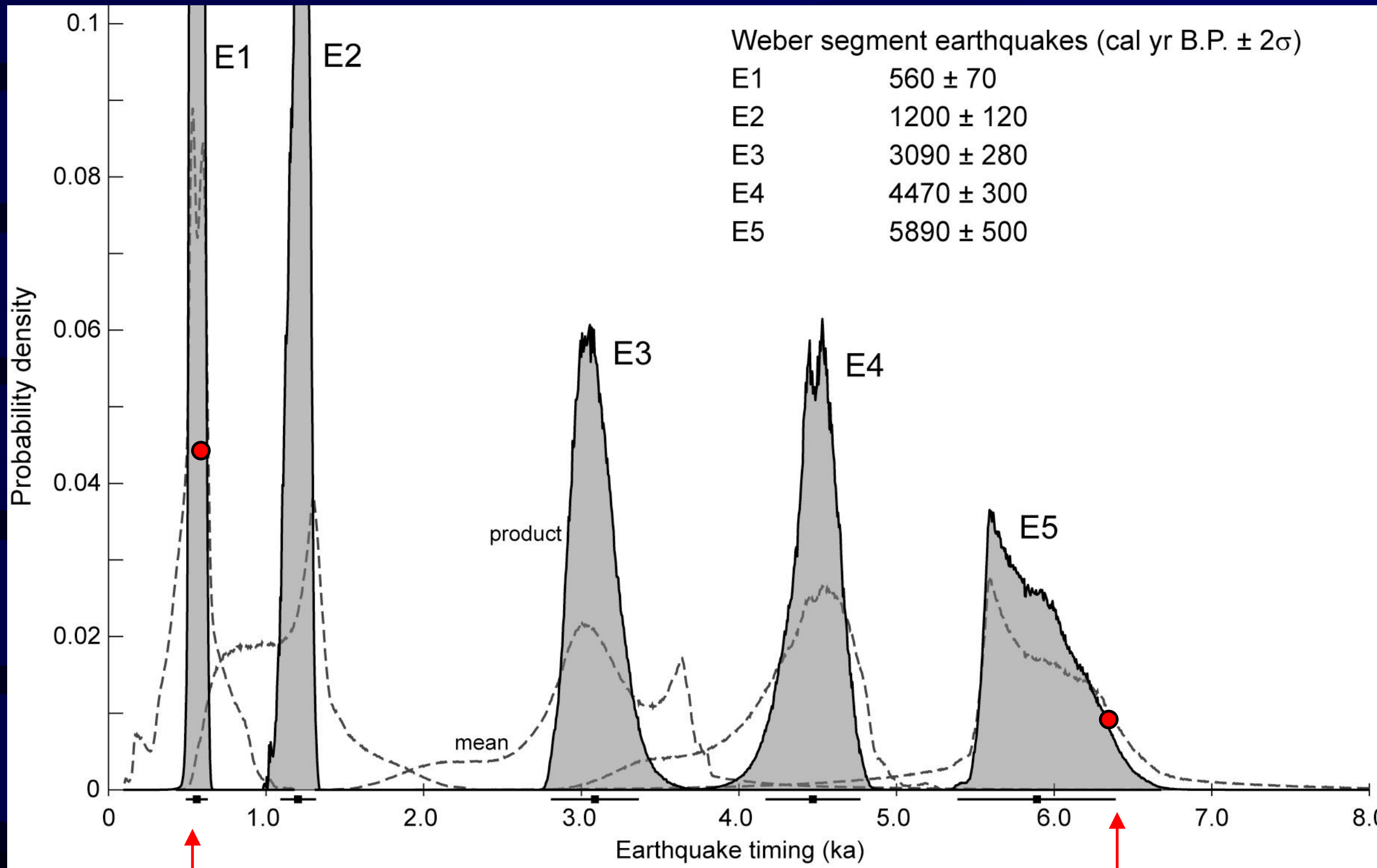


Simulation 1
E2: 1.1 ka
E1: 0.6 ka

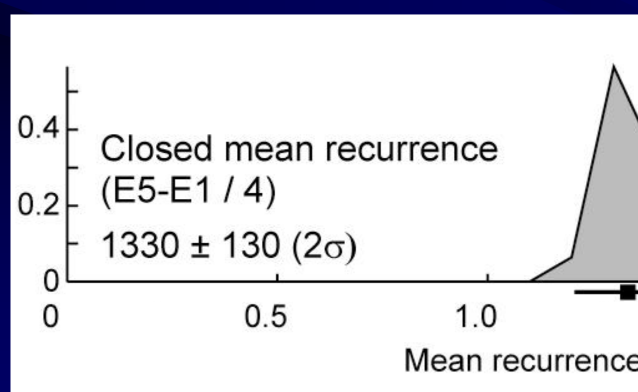


E2–E1 recurrence =
= 0.5 ky

Closed Mean Recurrence



Simulation 1
E5: 6.4 ka
E1: 0.6 ka



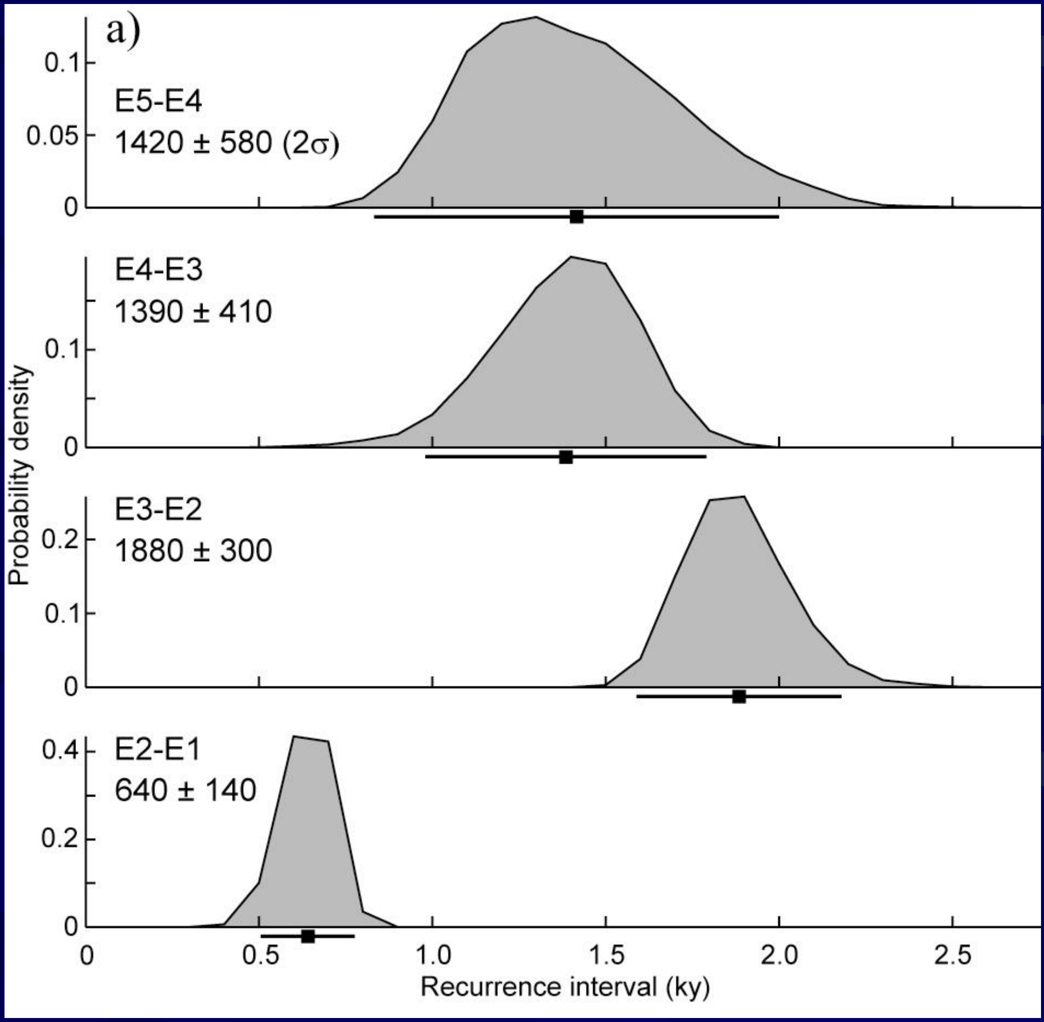
E5–E1 mean recurrence =
5.8 ky / 4 = 1.5 ky

Inter-Event Recurrence PDFs

- **Inter-event recurrence**
  - Recurrence distributions from 10,000 simulations
  - PDFs show aperiodicity of segment chronology:

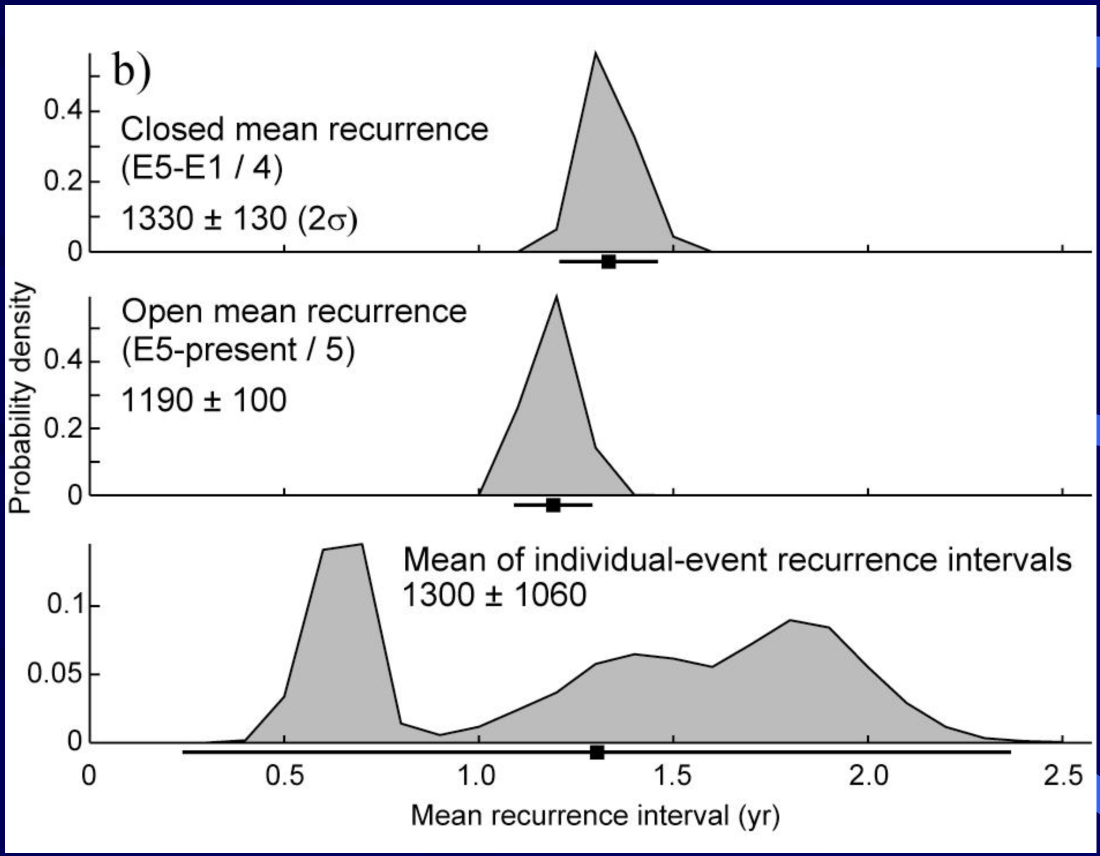
    E3–E2: ~1.9 ky

    E2–E1: ~0.6 ky



Mean Recurrence PDFs

- **Mean recurrence**
  - Using both closed and open intervals
  - Mean recurrence (using only closed intervals): ~1.3 ky
  - Uncertainty is based on population of means (one per simulation)



Weber Segment Summary

- **Five segment-wide earthquakes occurred on the Weber segment**
  - Method has helped refine earthquake timing and resolve questions regarding the extent of the youngest (E1) and oldest (E5) earthquakes
  - Recurrence estimates apply to the entire segment (for post-mid-Holocene)

	Revised Chronology	**UQFPWG (Lund, 2005)**
E1	0.6 ± 0.1 ka (2σ)	0.5 ± 0.3 ka (~2σ) (partial rupture?)
E2	1.2 ± 0.1 ka	0.95 ± 0.45 ka
E3	3.1 ± 0.3 ka	3.0 ± 0.7 ka
E4	4.5 ± 0.3 ka	4.5 ± 0.7 ka
E5	5.9 ± 0.5 ka	6.1 ± 0.7 ka
E5-E1	1.3 (0.6–1.9) ky	1.4 (0.5–2.4) ky

- Final earthquake chronology similar to that published by the UQFPWG (modified from McCalpin and Nishenko, 1996), but is based on our more objective approach and includes new Rice Creek data

Conclusions

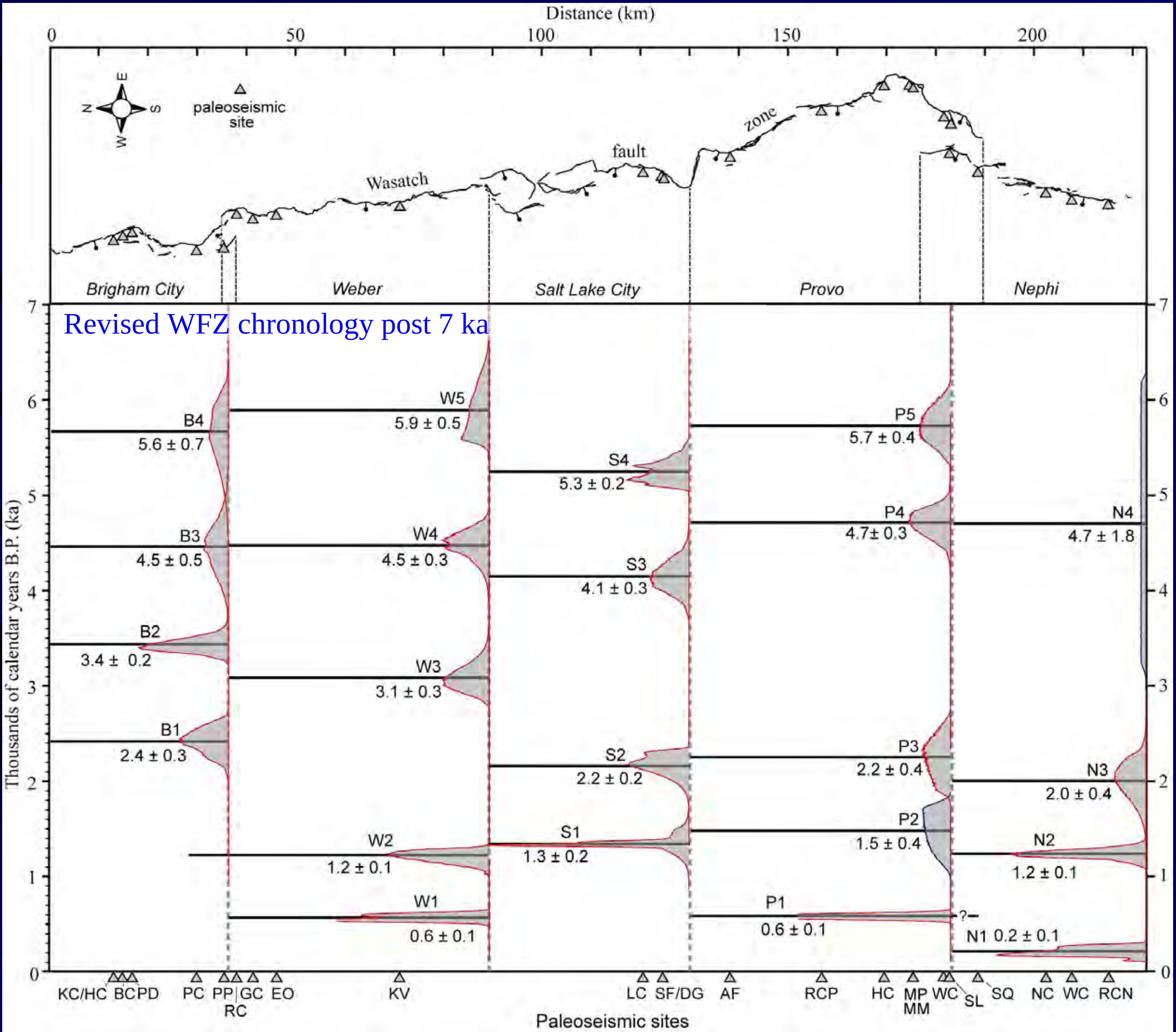
- **The product PDF method (product of site PDFs) helps refine earthquake timing**
  - OxCal is powerful tool for evaluating paleoseismic site data
  - Product PDF method integrates OxCal site data and objectively determines earthquake timing and recurrence (with uncertainties propagated through model)
  - Includes all site PDF data, rather than excluding or subjectively weighting the least well constrained data
  - Focuses on the overlap in the site PDF data – giving more weight to narrowest, best-constrained PDFs
  - Well suited to paleoseismic datasets in which earthquakes defined by broad, overlapping site PDFs
  - Product method yields similar mean earthquake times compared to mean method, but smaller timing uncertainties, which is important for time-dependent modeling

Conclusions

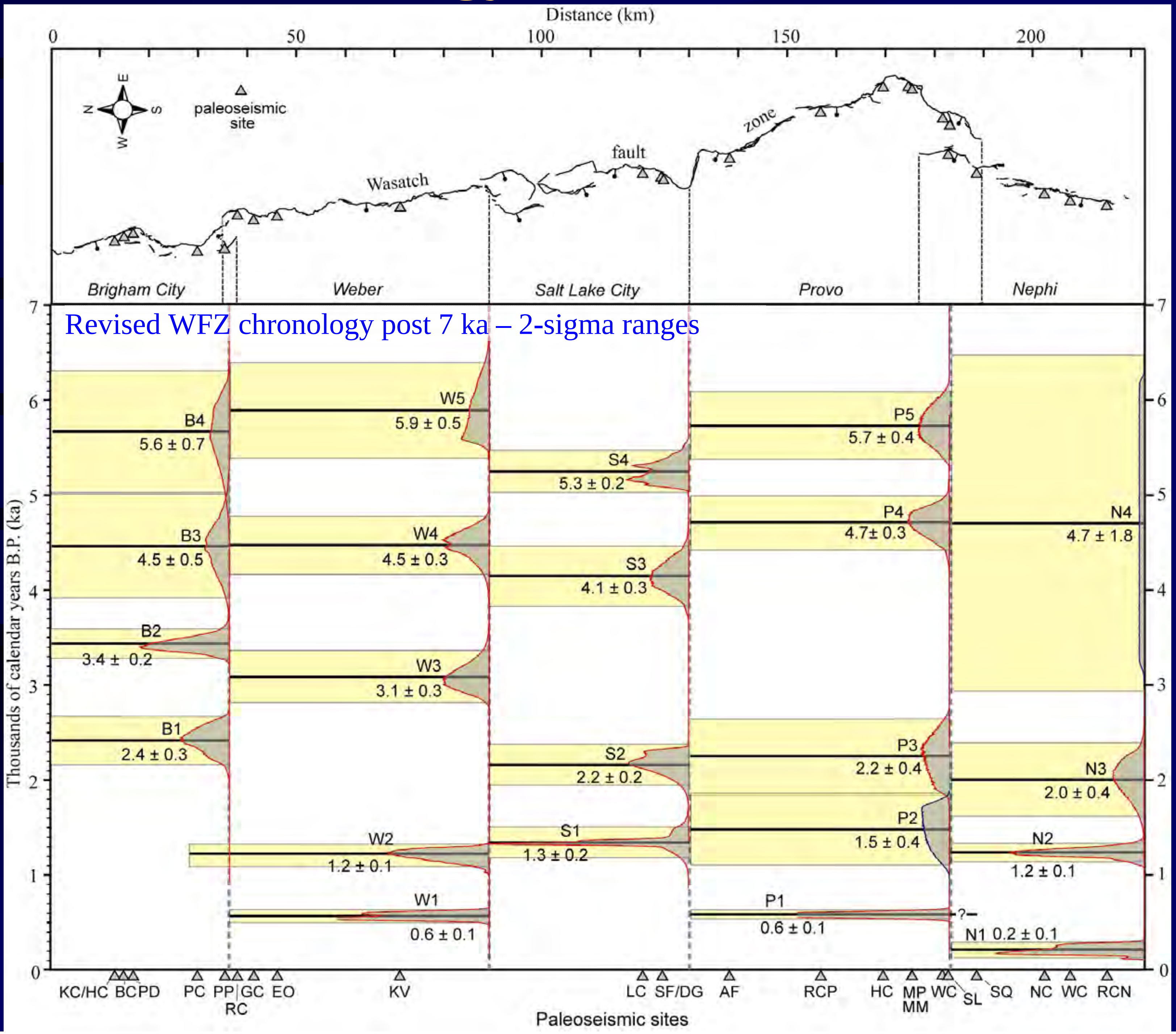
- **Correlation of events introduces a subjective component to our analysis**
  - Correlation of site PDFs along segment supported by PDF overlap values (0.40–0.60 per earthquake), large per-event displacements, and prominent segment boundaries
  - More objective approach would include non-characteristic behavior (e.g., partial ruptures)

- **From here…**
  - Publish method and results (Bull. Seis. Soc. Am.)
  - Apply to other central WFZ segments (mostly completed)
  - Consider ways to objectively correlate site PDFs (multi-segment rupture scenarios)

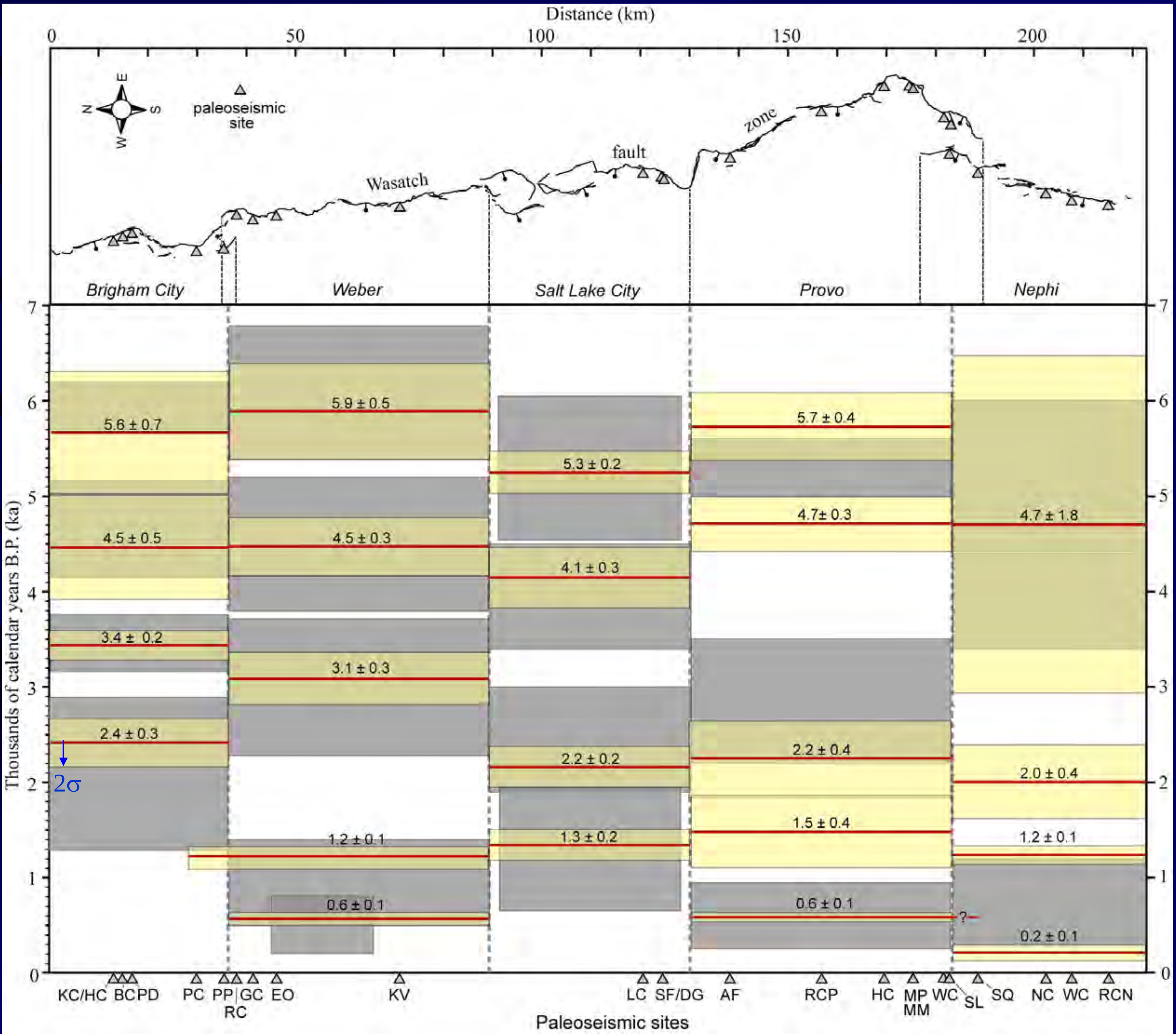
Final WFZ Chronology



Final WFZ Chronology



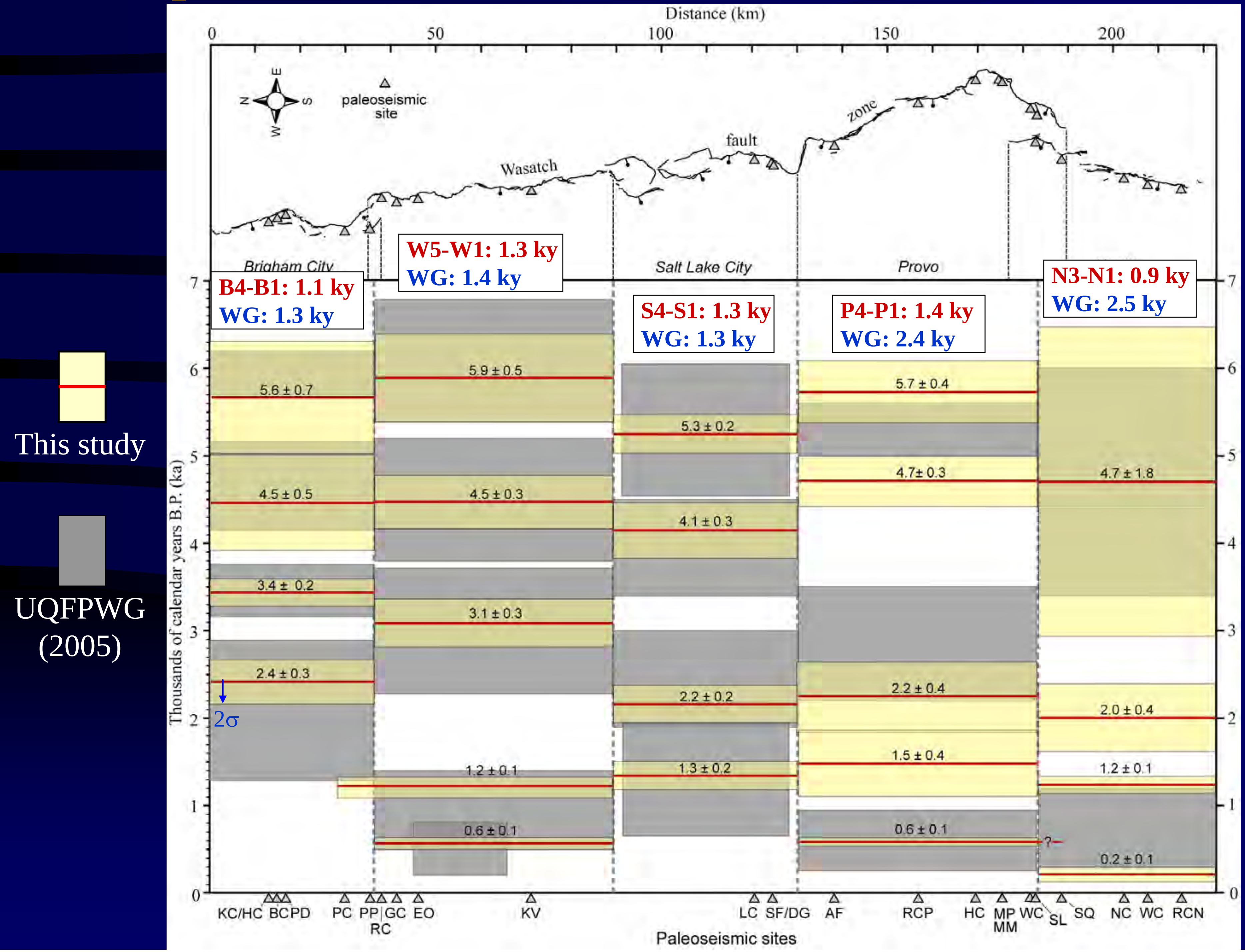
Comparison with UQFPWG



This study

UQFPWG (2005)

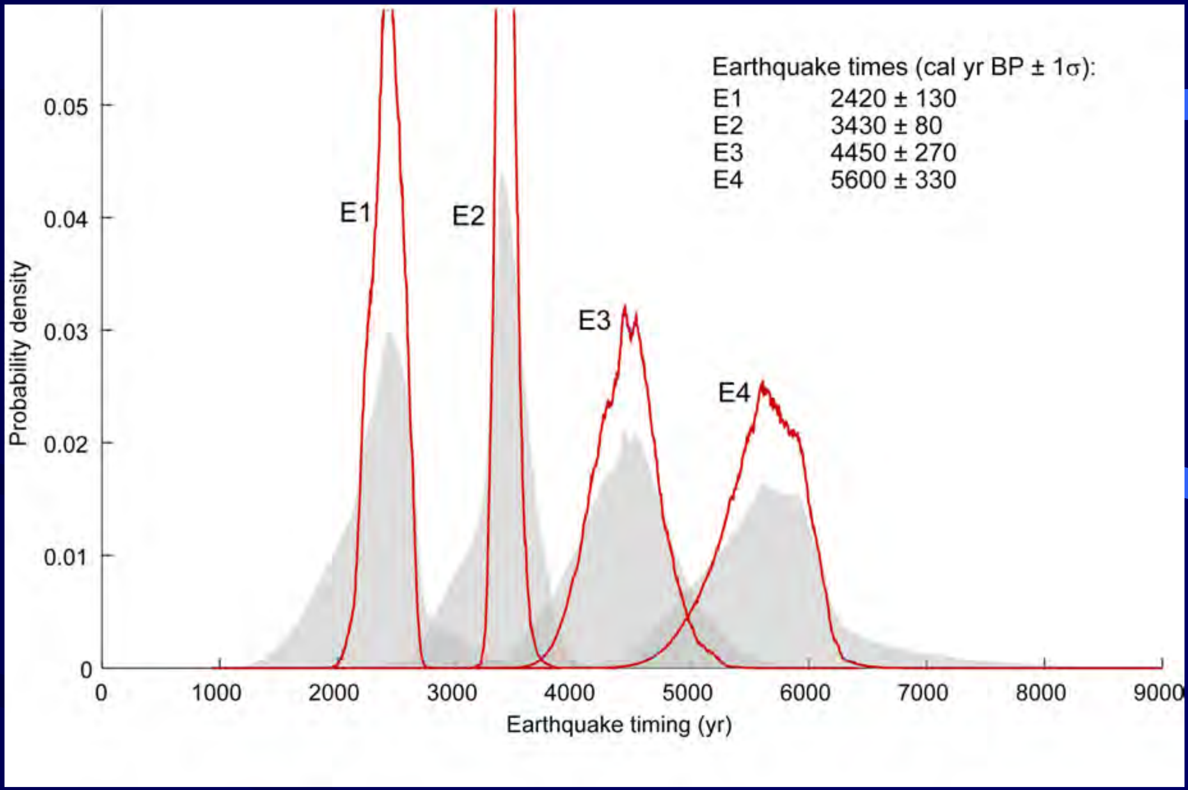
Comparison with UQFPWG



Earthquake timing and recurrence for the central segments of the Wasatch fault zone

Brigham City Segment Summary

- **EQ Chronology**
  - E1 2.4 ± 0.3 ka (2σ)
  - E2 3.4 ± 0.2 ka
  - E3 4.5 ± 0.5 ka
  - E4 5.6 ± 0.7 ka



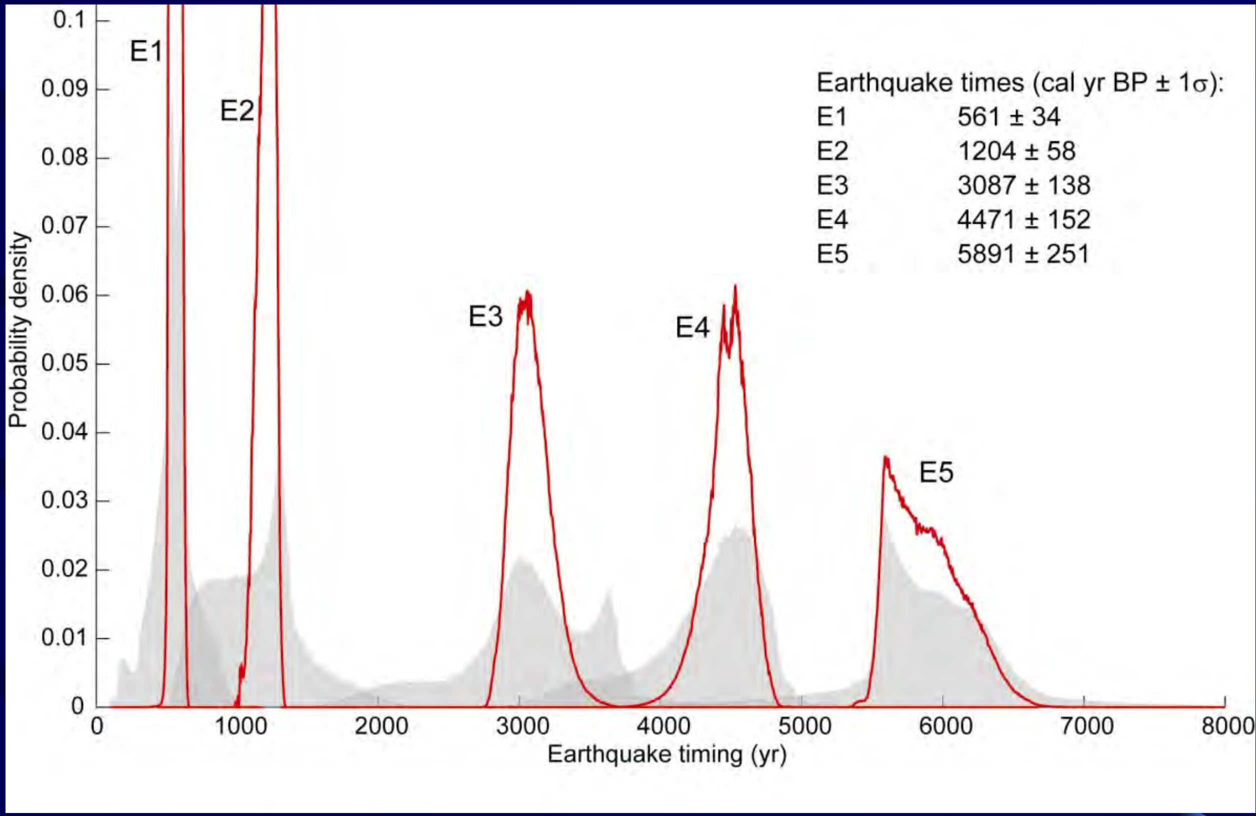
- **Recurrence**
  - Closed mean recurrence (E4–E1): 1.1 ± 0.2 ky (1.4 ky – open)
  - Elapsed time since MRE: 2480 ± 260 yr

- **Miscellaneous**
  - Earthquake at Pearsons Canyon (PC1) on southern BCS occurred at 1.1–1.3 ka as partial rupture of southern BCS in 1.2 ka Weber segment earthquake

UQFPWG
- 2.1 ± 0.8 ka
- 3.45 ± 0.3 ka
- 4.65 ± 0.5 ka
- 5.95 ± 0.25 ka

Weber Segment Summary

- **EQ Chronology**
  - E1 0.6 ± 0.1 ka (2σ)
  - E2 1.2 ± 0.1 ka
  - E3 3.1 ± 0.3 ka
  - E4 4.5 ± 0.3 ka
  - E5 5.9 ± 0.5 ka



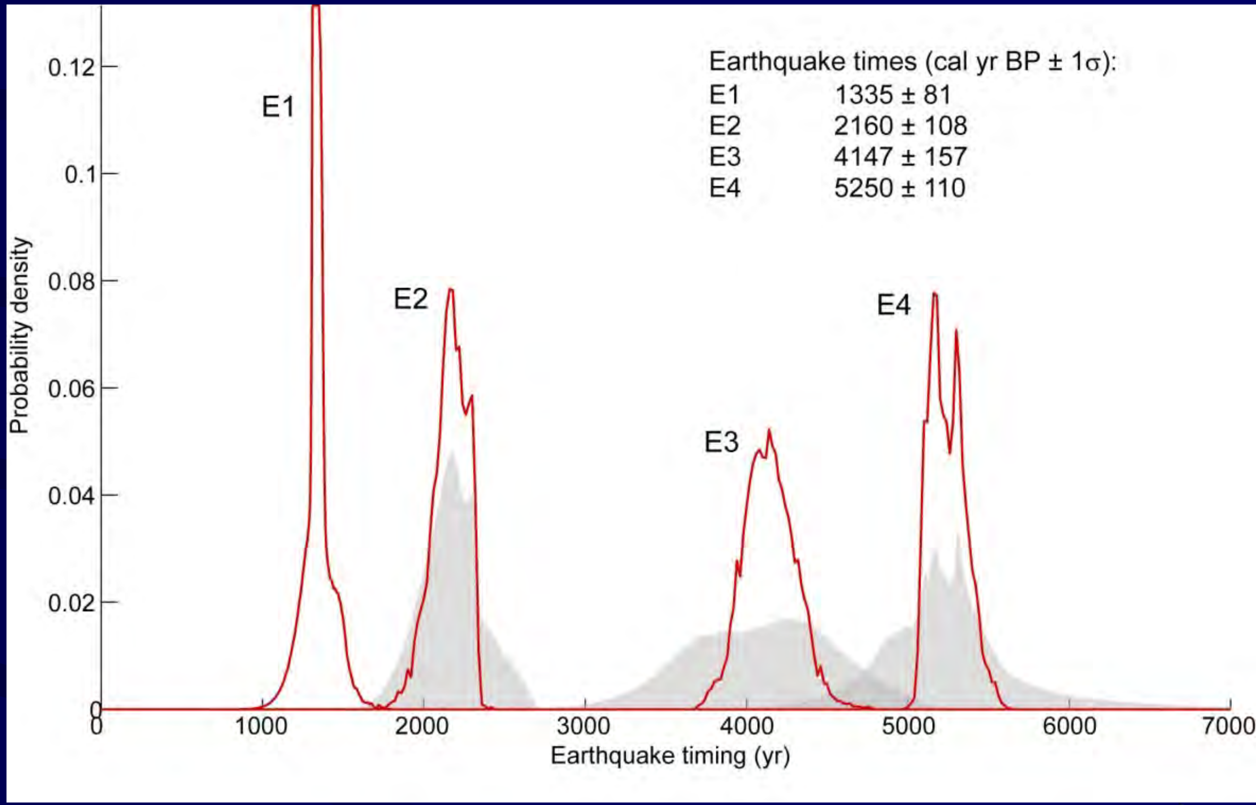
- **Recurrence**
  - Closed mean recurrence (E5–E1): 1.3 ± 0.1 ky (1.2 ky – open)
  - Elapsed time since MRE: 620 ± 70 yr

- **Miscellaneous**
  - Southern extent of E2 rupture (at Kaysville site) uncertain (but this doesn't affect E2 mean time)

UQFPWG
- 0.5 ± 0.3 ka
- 0.95 ± 0.45 ka
- 3.0 ± 0.7 ka
- 4.5 ± 0.7 ka
- 6.1 ± 0.7 ka

Salt Lake City Segment Summary

- **EQ Chronology**
  - E1 1.3 ± 0.2 ka (2σ)
  - E2 2.2 ± 0.2 ka
  - E3 4.1 ± 0.3 ka
  - E4 5.3 ± 0.2 ka



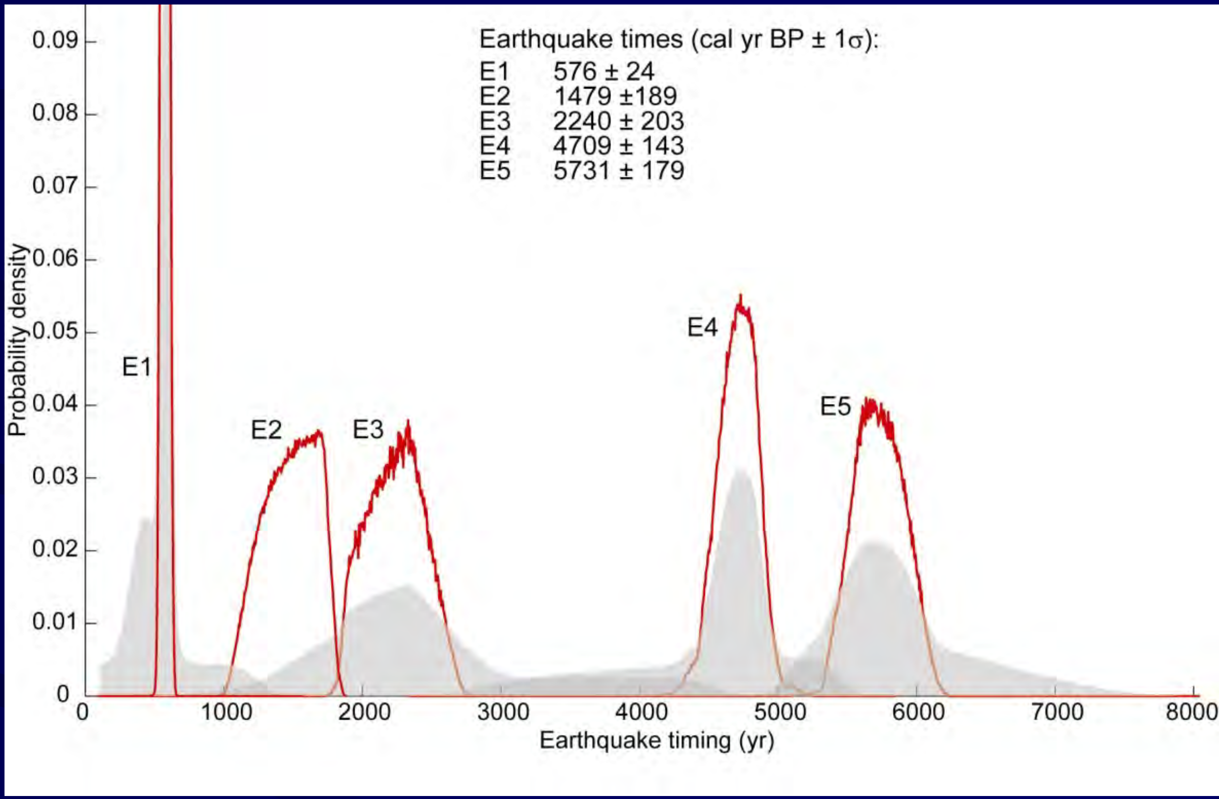
- **Recurrence**
  - Closed mean recurrence (E4–E1): 1.3 ± 0.1 ky (1.3 ky – open)
  - Elapsed time since MRE: 1400 ± 160 yr

- **Miscellaneous**
  - Using average, rather than product, of site PDFs for E1
  - Preliminary data for northern SLCS (Penrose site) not included

UQFPWG
- 1.3 ± 0.65 ka
- 2.45 ± 0.55 ka
- 3.95 ± 0.55 ka
- 5.3 ± 0.75 ka

Provo Segment Summary

- **EQ Chronology**
  - E1 0.6 ± 0.05 ka (2σ)
  - E2 1.5 ± 0.4 ka
  - E3 2.2 ± 0.4 ka
  - E4 4.7 ± 0.3 ka
  - E5(?) 5.7 ± 0.4 ka



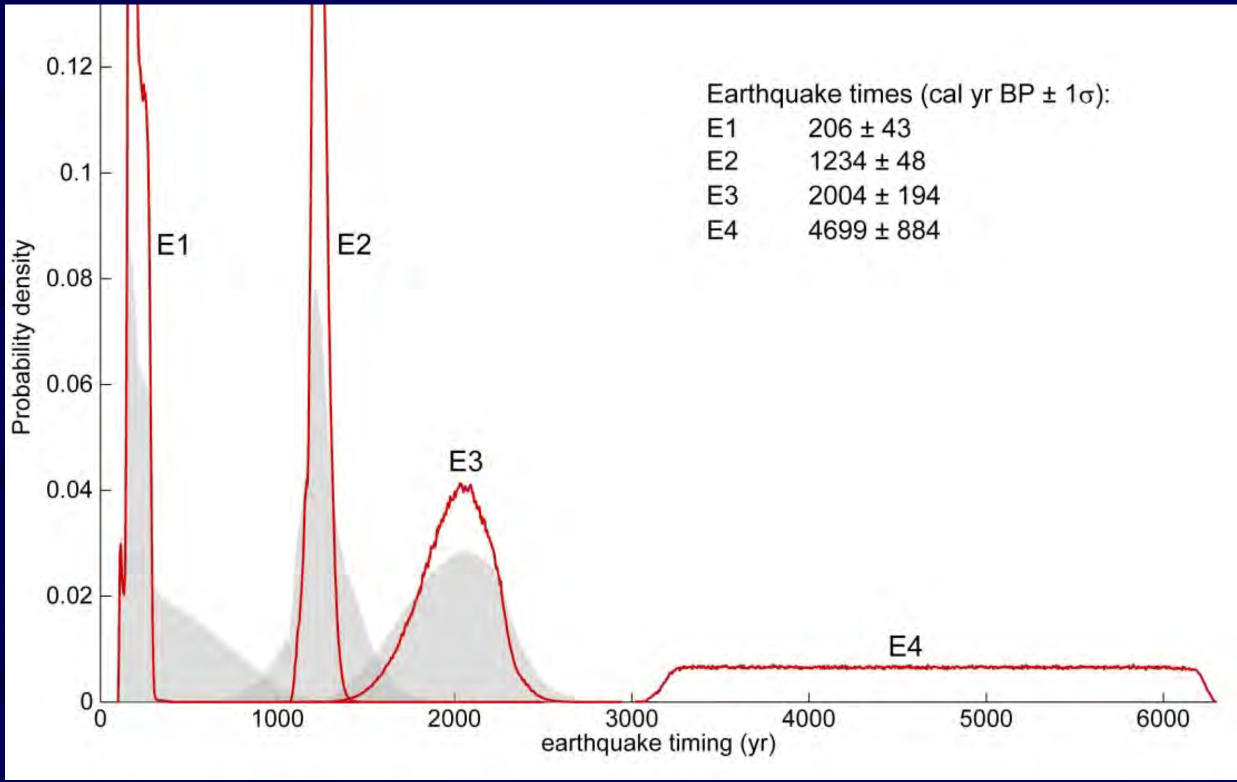
- **Recurrence**
  - Closed mean recurrence (E4–E1): 1.4 ± 0.1 ky (1.2 ky – open)
  - Elapsed time since MRE: 640 ± 40 yr

UQFPWG
- 0.6 ± 0.35 ka
- 2.85 ± 0.65 ka
- 5.3 ± 0.3 ka

- **Miscellaneous**
  - Chronology based on preferred correlation of site PDFs; other correlation schemes are possible, but these do not affect timing of E1 and E4, or the average recurrence

Nephi Segment Summary

- **EQ Chronology**
  - E1 0.2 ± 0.1 ka (2σ)
  - E2 1.2 ± 0.1 ka
  - E3 2.0 ± 0.4 ka
  - E4(?) 4.7 ± 1.8 ka



- **Recurrence**
  - Close mean recurrence (E3–E1): 0.9 ± 0.2 ky (0.7 ky – open)
  - Elapsed time since MRE: 270 ± 80 yr

- **Miscellaneous**
  - Does Santaquin SQ1 correlate with Nephi (N1) or Provo (P1) segment?

UQFPWG
- < 1.0 ± 0.4 ka
- ~3.9 ± 0.5 ka
- >3.9 ± 0.5, <5.3 ± 0.7 ka

Implementation: The Third Dimension of Seismic Hazard Mitigation

Ron Harris

Brigham Young University

AGU - What is Our Responsibility?

- Fundamental research and monitoring of natural hazards
- Dissemination of relevant results to the public, especially vulnerable communities
- Implementation of multidisciplinary efforts needed to apply effective mitigation strategies worldwide.

(EOS 11 Jan. 2005)

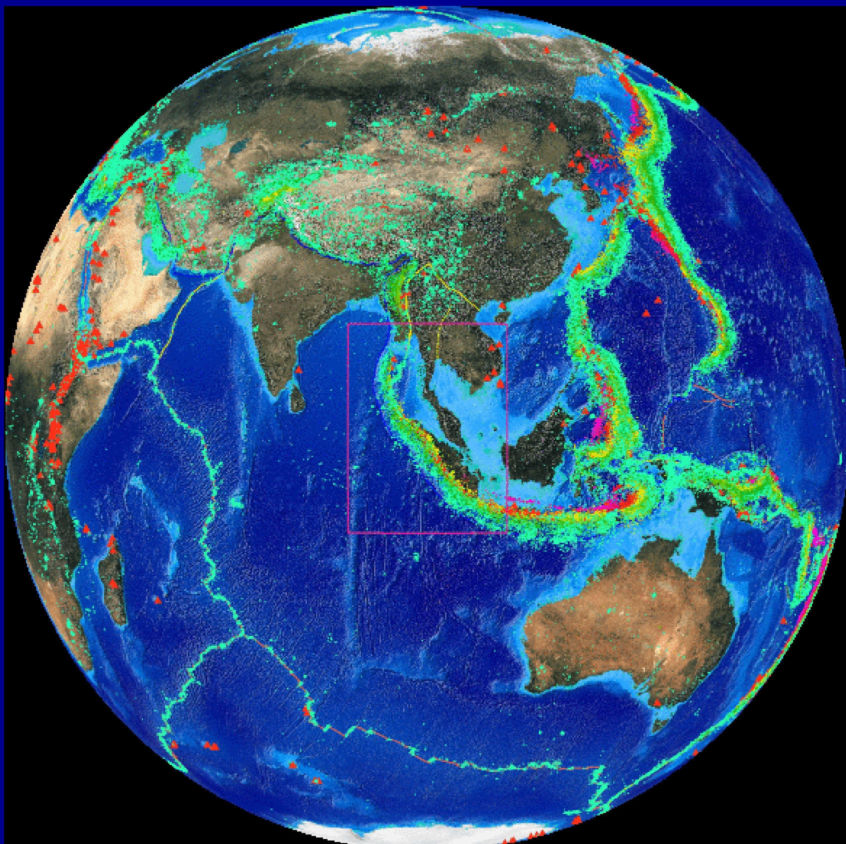
Issues

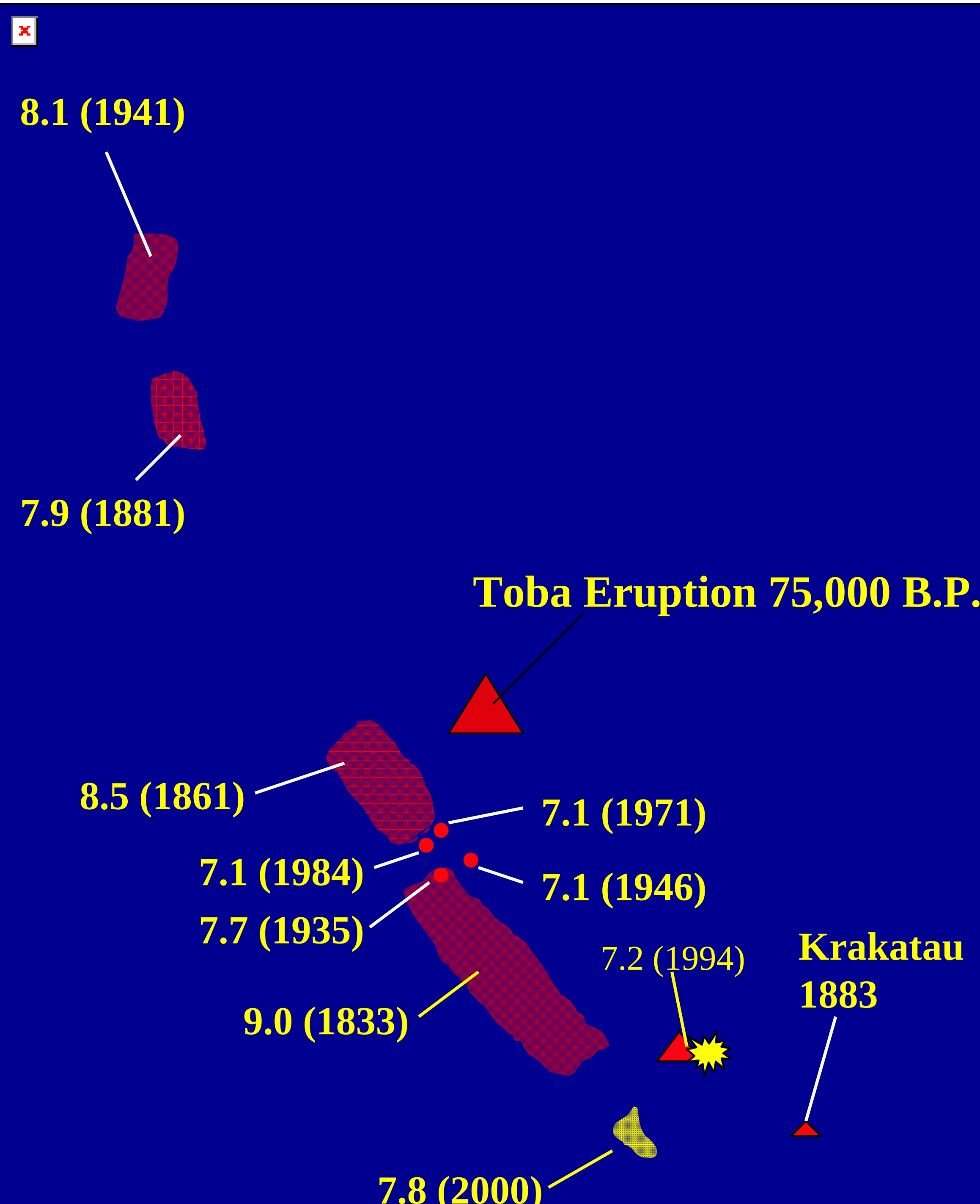
- Finishing - Making a difference with level of preparedness
- Problems and recommendations for:
  - Assessment
  - Communication
  - implementation

My Perspective

- Natural hazards research in SE Asia
- Sumatra event
- Merapi event

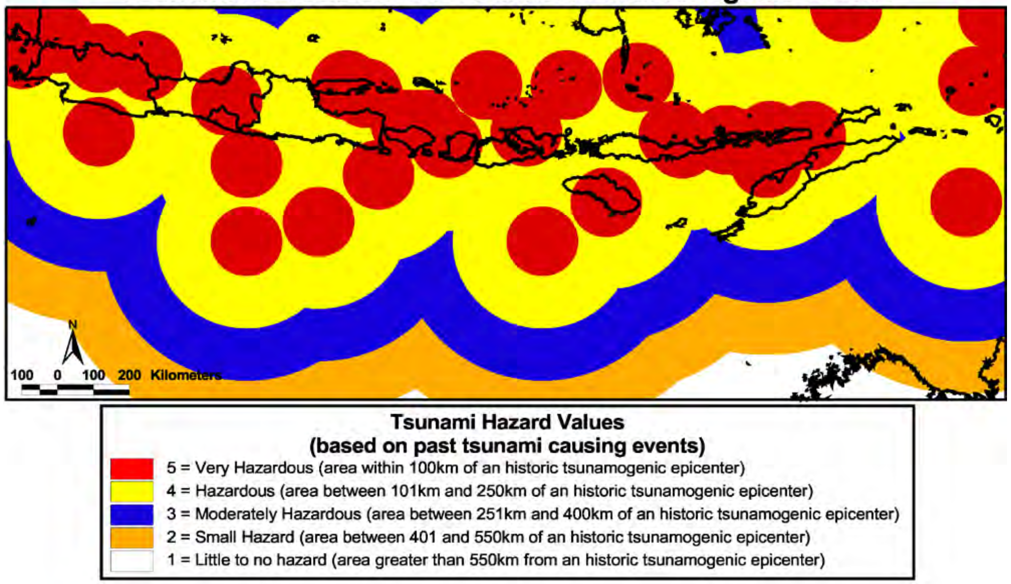
Sumatra Event



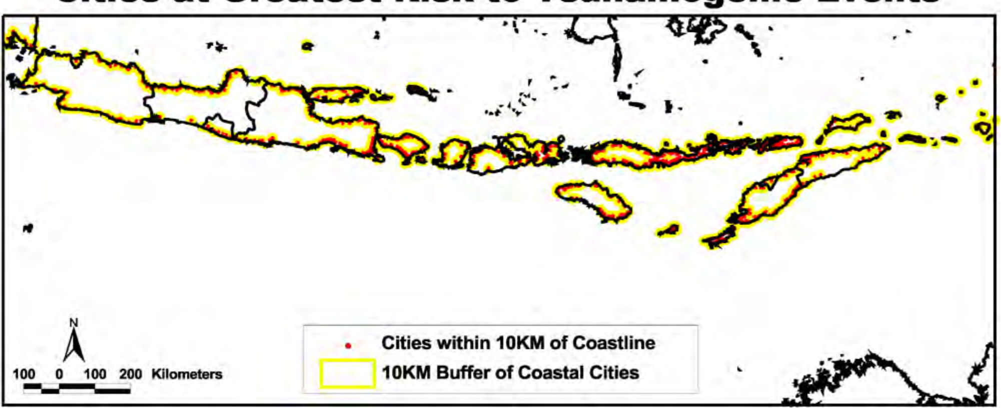


TSUNAMI HAZARDS

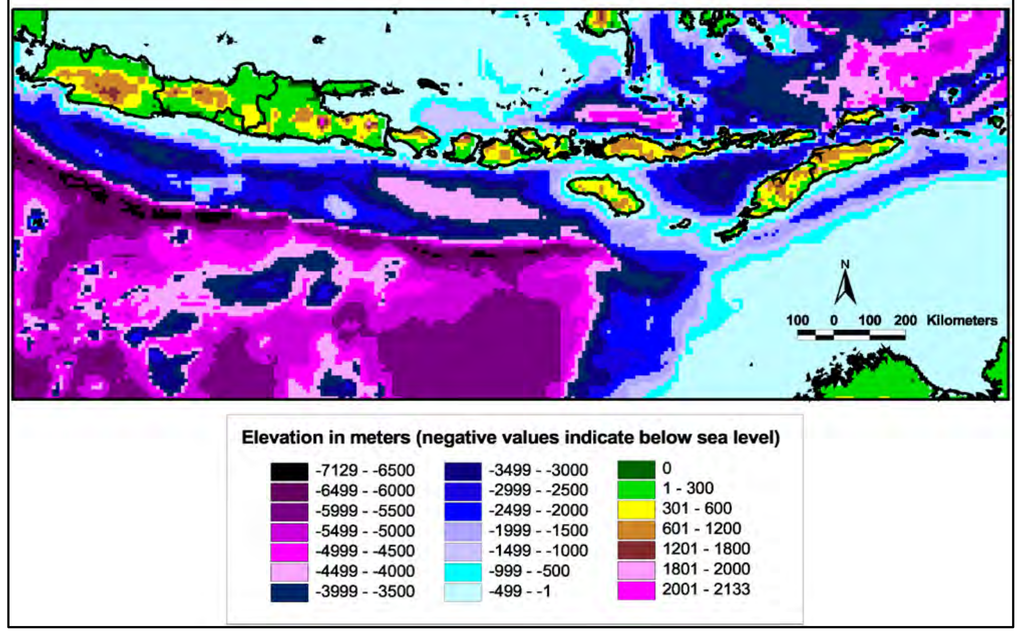
Tsunami Hazards based on Historic Tsunamogenic Events



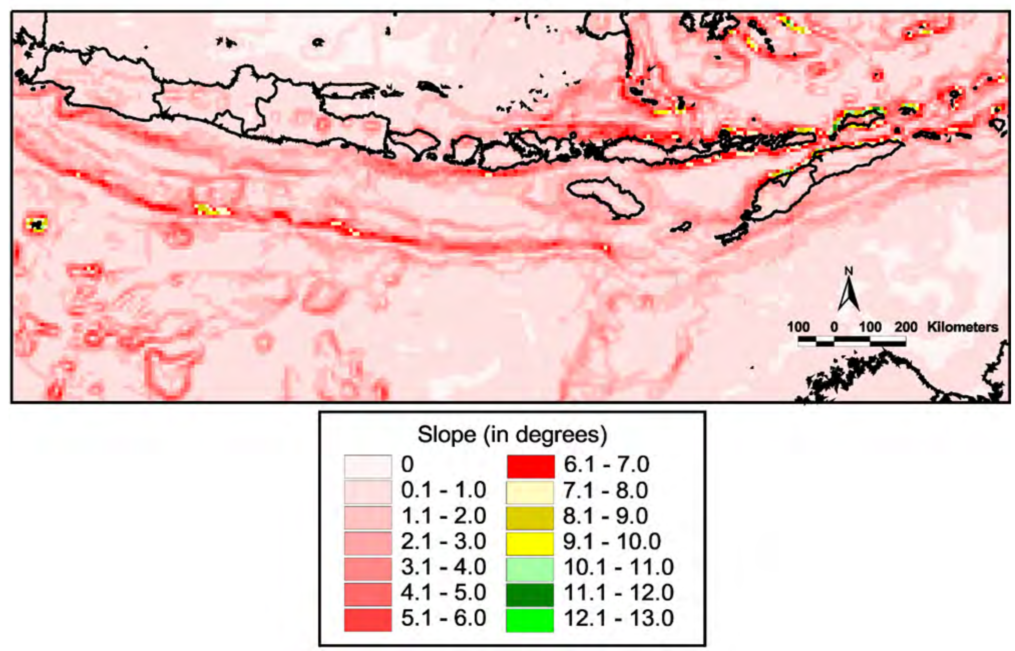
Cities at Greatest Risk to Tsunamogenic Events



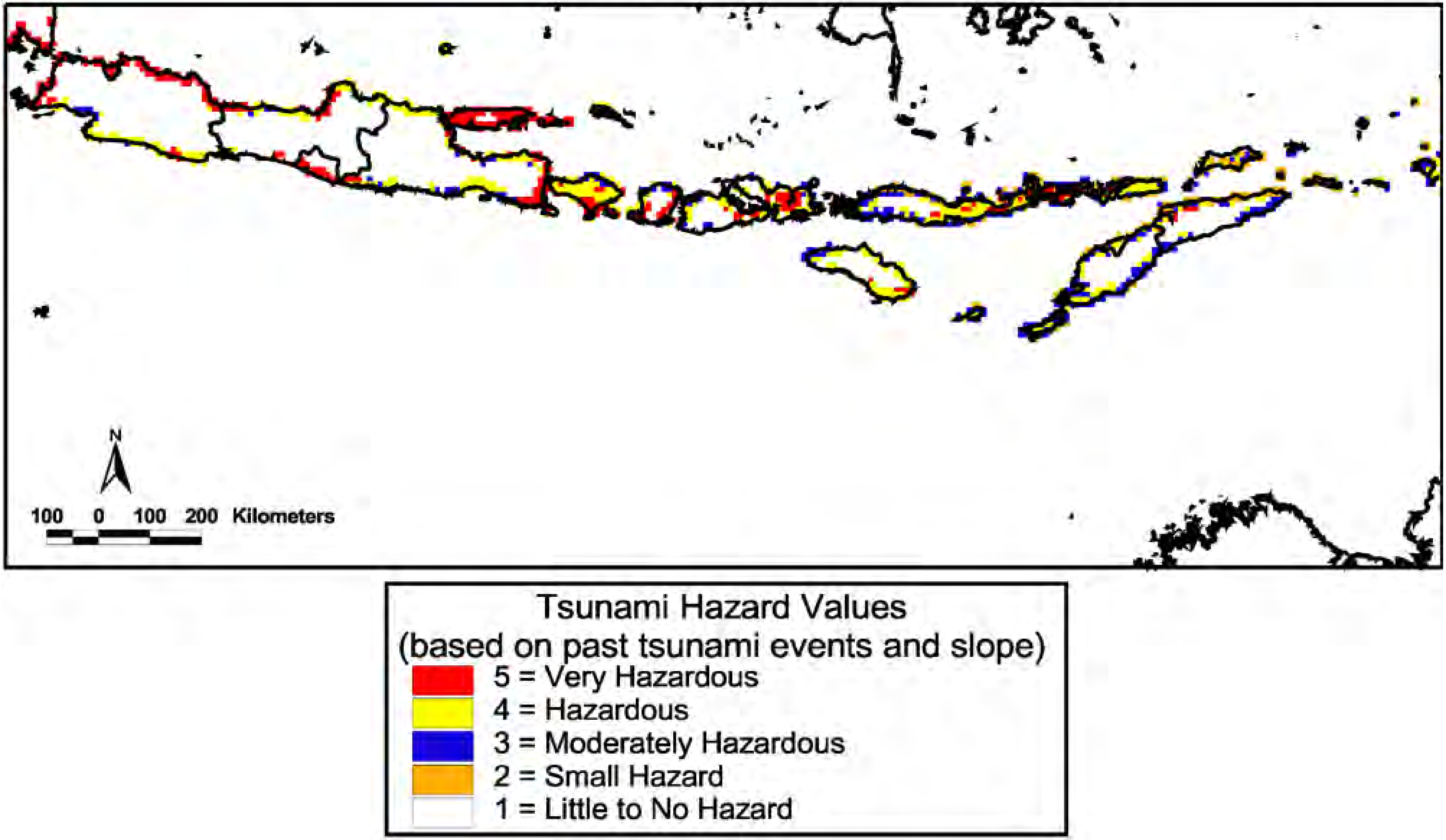
Bathymetry and Elevation

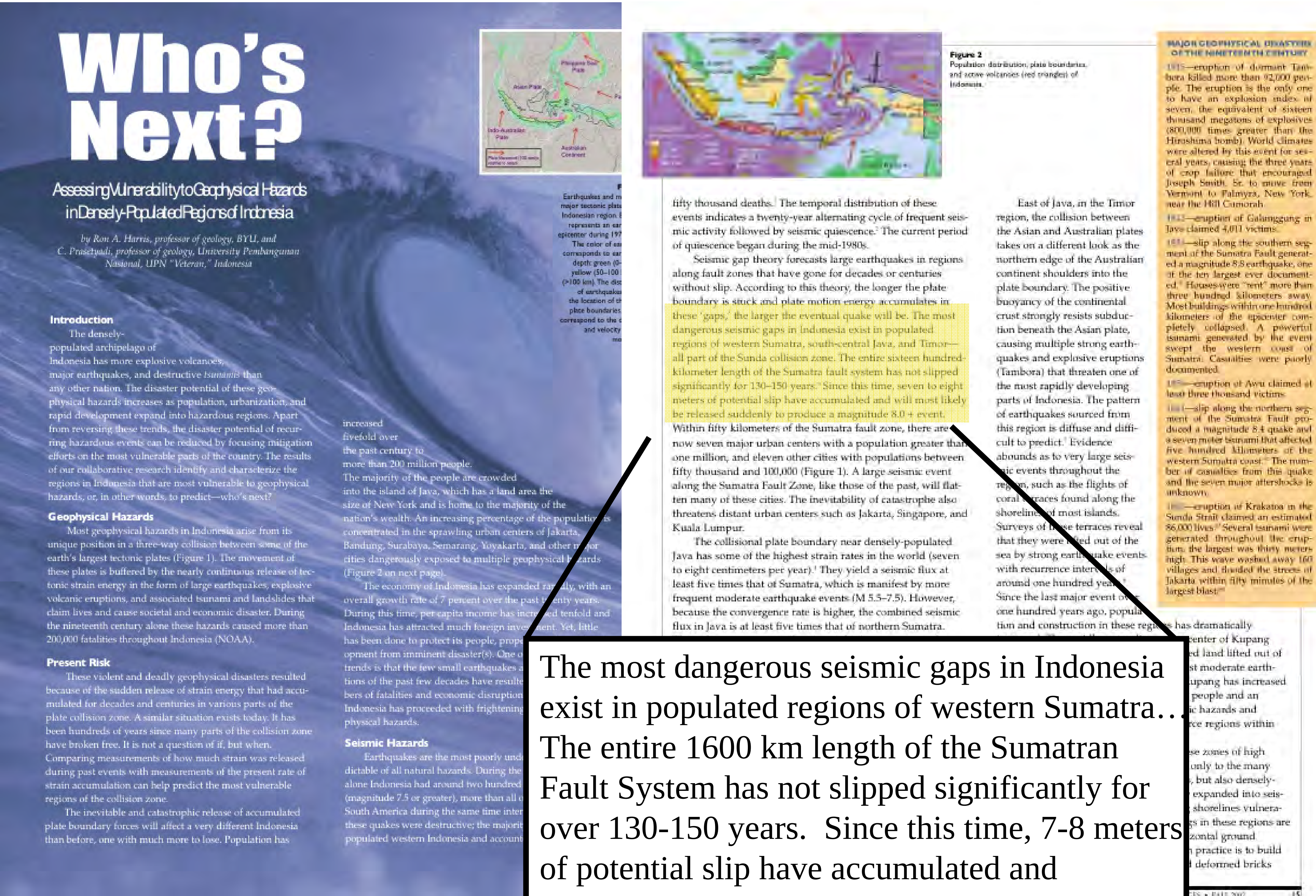


Slope



Tsunami Hazards





Who's Next?

Assessing Vulnerability to Geophysical Hazards in Densely-Populated Regions of Indonesia

by Ron A. Harris, professor of geology, BYU, and C. Prasetyadi, professor of geology, University Pembangunan Nasional, UPN "Veteran," Indonesia

Introduction

The densely-populated archipelago of Indonesia has more explosive volcanoes, major earthquakes, and destructive *tsunamis* than any other nation. The disaster potential of these geophysical hazards increases as population, urbanization, and rapid development expand into hazardous regions. Apart from reversing these trends, the disaster potential of recurring hazardous events can be reduced by focusing mitigation efforts on the most vulnerable parts of the country. The results of our collaborative research identify and characterize the regions in Indonesia that are most vulnerable to geophysical hazards, or, in other words, to predict—who's next?

Geophysical Hazards

Most geophysical hazards in Indonesia arise from its unique position in a three-way collision between some of the earth's largest tectonic plates (Figure 1). The movement of these plates is buffered by the nearly continuous release of tectonic strain energy in the form of large earthquakes, explosive volcanic eruptions, and associated tsunami and landslides that claim lives and cause societal and economic disaster. During the nineteenth century alone these hazards caused more than 200,000 fatalities throughout Indonesia (NOAA).

Present Risk

These violent and deadly geophysical disasters resulted because of the sudden release of strain energy that had accumulated for decades and centuries in various parts of the plate collision zone. A similar situation exists today. It has been hundreds of years since many parts of the collision zone have broken free. It is not a question of if, but when. Comparing measurements of how much strain was released during past events with measurements of the present rate of strain accumulation can help predict the most vulnerable regions of the collision zone.

The inevitable and catastrophic release of accumulated plate boundary forces will affect a very different Indonesia than before, one with much more to lose. Population has increased fivefold over the past century to more than 200 million people. The majority of the people are crowded into the island of Java, which has a land area the size of New York and is home to the majority of the nation's wealth. An increasing percentage of the population is concentrated in the sprawling urban centers of Jakarta, Bandung, Surabaya, Semarang, Yoyakarta, and other major cities dangerously exposed to multiple geophysical hazards (Figure 2 on next page).

The economy of Indonesia has expanded rapidly, with an overall growth rate of 7 percent over the past twenty years. ...

Seismic Hazards

Earthquakes are the most poorly understood and least predictable of all natural hazards. ...

Figure 2
Population distribution, plate boundaries, and active volcanoes (red triangles) of Indonesia.

fifty thousand deaths. The temporal distribution of these events indicates a twenty-year alternating cycle of frequent seismic activity followed by seismic quiescence. The current period of quiescence began during the mid-1980s.

Seismic gap theory forecasts large earthquakes in regions along fault zones that have gone for decades or centuries without slip. According to this theory, the longer the plate boundary is stuck and plate motion energy accumulates in these 'gaps,' the larger the eventual quake will be. The most dangerous seismic gaps in Indonesia exist in populated regions of western Sumatra, south-central Java, and Timor—all part of the Sunda collision zone. The entire sixteen hundred-kilometer length of the Sumatra fault system has not slipped significantly for 130–150 years. Since this time, seven to eight meters of potential slip have accumulated and will most likely be released suddenly to produce a magnitude 8.0 + event. Within fifty kilometers of the Sumatra fault zone, there are now seven major urban centers with a population greater than one million, and eleven other cities with populations between fifty thousand and 100,000 (Figure 1). A large seismic event along the Sumatra Fault Zone, like those of the past, will flatten many of these cities. The inevitability of catastrophe also threatens distant urban centers such as Jakarta, Singapore, and Kuala Lumpur.

The collisional plate boundary near densely-populated Java has some of the highest strain rates in the world (seven to eight centimeters per year). They yield a seismic flux at least five times that of Sumatra, which is manifest by more frequent moderate earthquake events (M 5.5–7.5). However, because the convergence rate is higher, the combined seismic flux in Java is at least five times that of northern Sumatra.

East of Java, in the Timor region, the collision between the Asian and Australian plates takes on a different look as the northern edge of the Australian continent shoulders into the plate boundary. The positive buoyancy of the continental crust strongly resists subduction beneath the Asian plate, causing multiple strong earthquakes and explosive eruptions (Tambora) that threaten one of the most rapidly developing parts of Indonesia. The pattern of earthquakes sourced from this region is diffuse and difficult to predict. Evidence abounds as to very large seismic events throughout the region, such as the flights of coral terraces found along the shorelines of most islands. Surveys of these terraces reveal that they were lifted out of the sea by strong earthquake events with recurrence intervals of around one hundred years. Since the last major event over one hundred years ago, population and construction in these regions has dramatically ...

MAJOR GEOPHYSICAL DISASTERS OF THE NINETEENTH CENTURY

1815—eruption of dormant Tambora killed more than 92,000 people. The eruption is the only one to have an explosion index of seven, the equivalent of sixteen thousand megatons of explosives (800,000 times greater than the Hiroshima bomb). World climates were altered by this event for several years, causing the three years of crop failure that encouraged Joseph Smith, Sr. to move from Vermont to Palmyra, New York, near the Hill Cumorah.

1822—eruption of Galunggung in Java claimed 4,011 victims.

1833—slip along the southern segment of the Sumatra Fault generated a magnitude 8.8 earthquake, one of the ten largest ever documented. Houses were "rent" more than three hundred kilometers away. Most buildings within one hundred kilometers of the epicenter completely collapsed. A powerful tsunami generated by the event swept the western coast of Sumatra. Casualties were poorly documented.

1856—eruption of Awu claimed at least three thousand victims.

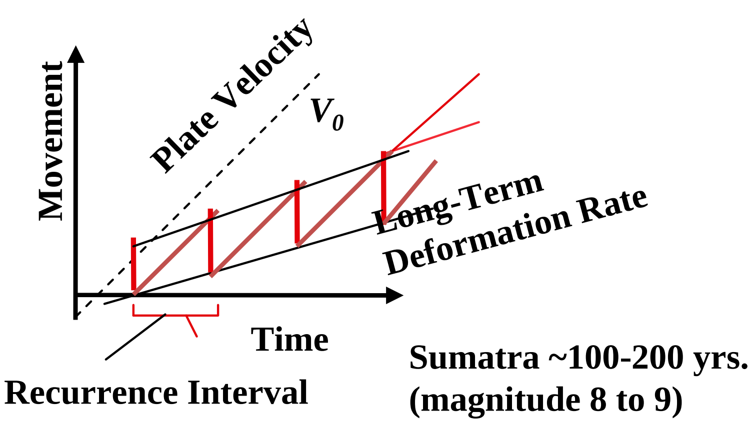
1861—slip along the northern segment of the Sumatra Fault produced a magnitude 8.4 quake and a seven meter tsunami that affected five hundred kilometers of the western Sumatra coast. The number of casualties from this quake and the seven major aftershocks is unknown.

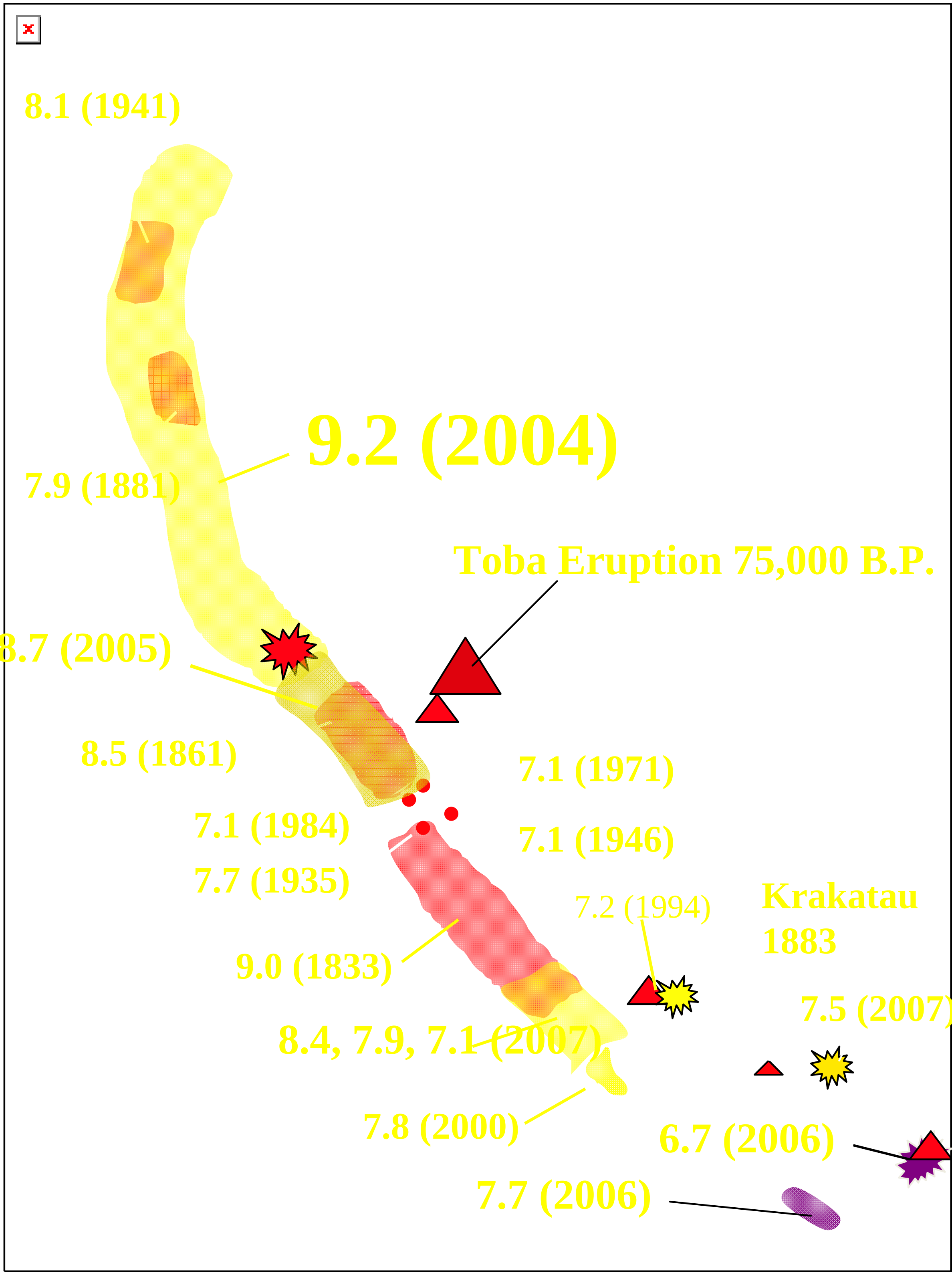
1883—eruption of Krakatoa in the Sunda Strait claimed an estimated 36,000 lives. Several tsunami were generated throughout the eruption, the largest was thirty meters high. This wave washed away 160 villages and flooded the streets of Jakarta within fifty minutes of the largest blast.

The most dangerous seismic gaps in Indonesia exist in populated regions of western Sumatra…
The entire 1600 km length of the Sumatran Fault System has not slipped significantly for over 130-150 years. Since this time, 7-8 meters of potential slip have accumulated and will most likely be released suddenly to produce a magnitude 8.0 + event!

Was the South Asian Tsunami a Surprise?

- Newcomb and McCann (1987)
- Ghose and Oike (1988)
- Sun and Pan (1995)
- Harris et al., (1997)
- Ortiz and Bilham (2003)





What is Our Responsibility?

- Fundamental research and monitoring of natural hazards

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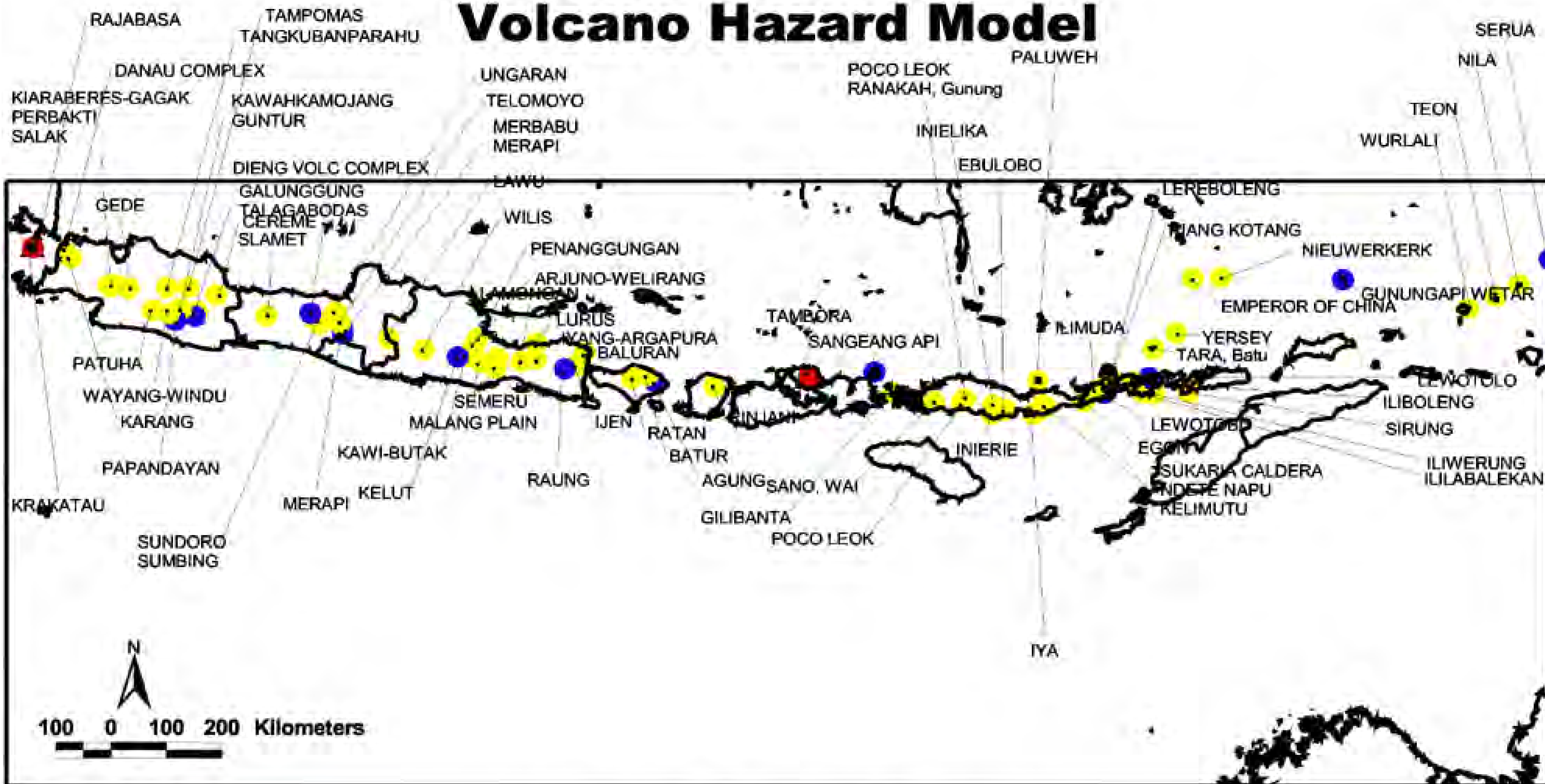
(EOS 11 Jan. 2005)

Volcano Hazard Model



Volcanic Hazard Scores

- **5** Very Hazardous (historic VEI of 5.1 - 7 and frequency of eruptions > 25)
- **3** Moderately Hazardous (historic VEI of 3.1 - 5 and frequency of eruptions between 15 and 24)
- **1** Small Hazard (historic VEI of 1 - 3 and frequency of eruptions between 1 and 15)
- **0** No Recorded Eruption or outside of volcano buffer area


The Dome of Death!


5 14'97

What would you do to protect the growing cities at the base of Merapi?



What about disaster mitigation here?

- Assessment (B)
  - Minimum estimate from paleoseismicity
  - Active faults vs. hazard (intra-plate setting)
- Communication (C - perception is reality)
  - Probabilities confusing to public
  - Deterministic vs. Probabilistic (Time dependent)
- Implementation (D)
  - Bogota schools

Assessment Problems: Lack of surface expression of seismogenic events

- Fault slip decreases upward
- No surface rupture
- Haiti earthquake was from a secondary, unknown fault.
- Known active fault nearest the capital is no more likely to rupture due to stress loading.
- In many places most surface ruptures do not show previous geomorphic evidence of Holocene activity
- In areas of low strain rates, the ‘most active’ fault may not be the most hazardous fault.

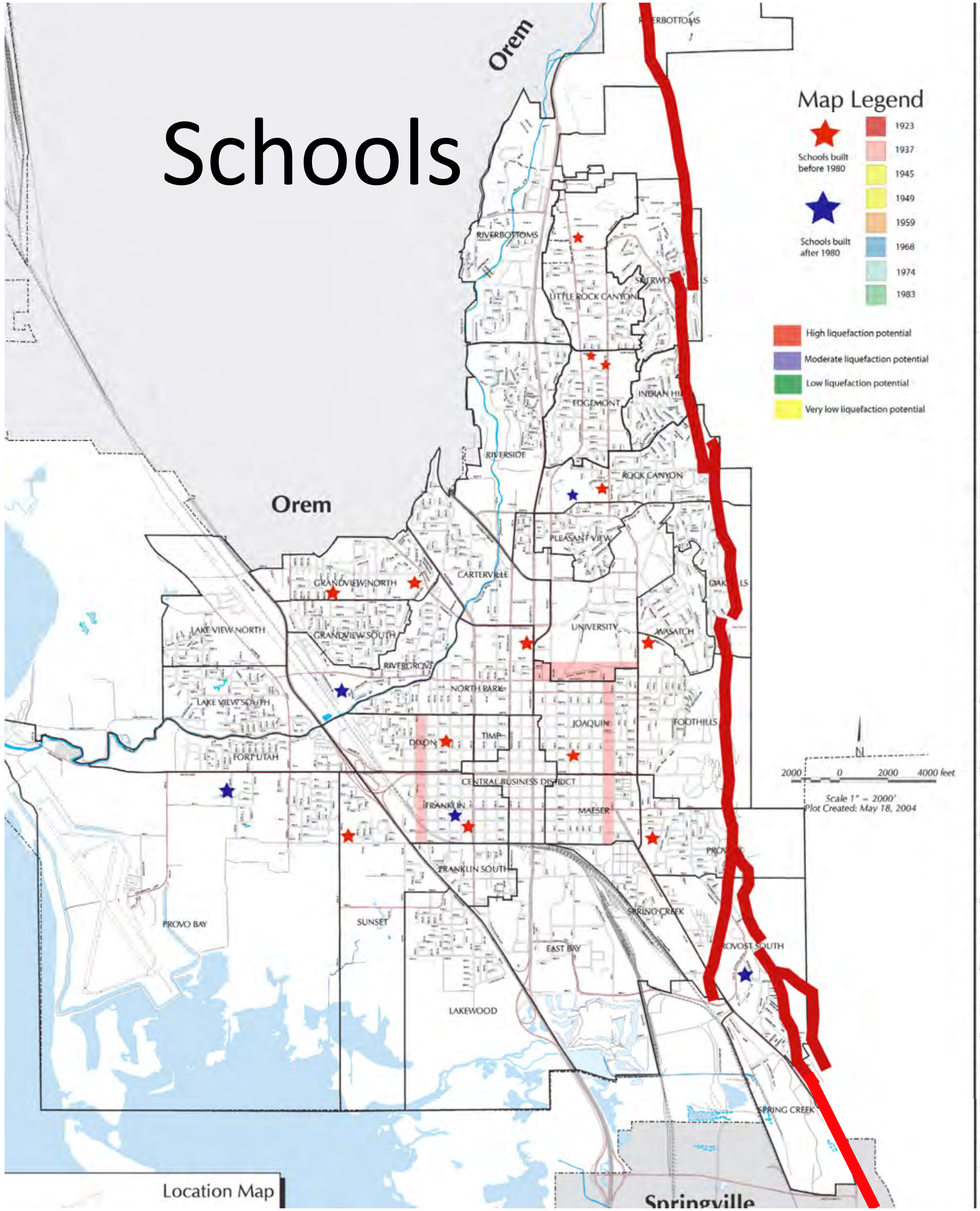
Implementation

- 2004-2008 Bogota retro-fitted all Hospitals
- 250 of 800 schools ($200 million).
- Cost Benefit analysis was presented to Mayor Bogota and he was most convinced by potential to improve school facilities.

Schools

Building	Date	Students	
Admin	1965	?	
Elementary Schools			
Amnelia	1999		651
Canyon Cr.	1982	554	
Edgemont	1955	488	
Farrer	1931	427	
Franklin	1901 (94)		532
Grandview	1949	532	
Provost	1949	441	
Rock Cany	1964	579	
Spring Cr.	2002	559	
Sunset V.	1959	637	
Timp.	1938	539	
Wasatch	1949	587	
Westridge	1979	800	
		6116	
Middle Schools			
Centinneal	1996	977	
Dixon	1931	934	
High Schools			
Provo	1956	1940	
Timpview	1974	1706	
	3646		

Students in Unreinforced Schools = 10,796



Recommendations

- Communication
  - Revision of UGS publication and greater access
  - Communication of probabilities
- Implementation
  - Quaternary Faults meeting session
  - Funding
  - Guidelines

UTAH GEOLOGICAL SURVEY

2012 UTAH QUATERNARY FAULT RESEARCH PRIORITIES

Trenching the Bear River fault, 2009

2010 FAULT PRIORITY LIST

2010 Highest Priority Faults/Fault Segments For Study

Fault/Fault Section	Priority	Investigation Status	Investigating Institution
Northern Salt Lake City segment WFZ	1	No activity	
West Valley fault zone	2	No activity	
Penultimate event Provo segment WFZ	3	Trench site reconnaissance	UGS
Washington fault zone	4	Reconnaissance study	UGS
Rozelle section, East Great Salt Lake fault	5	No activity	

Other Priority Faults/Fault Segments 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	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Bear River fault zone	2007	Scarp reconnaissance	USGS

Faults/Fault Segment 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/UVU study ongoing	UGS/USGS/UVU
Weber segment WFZ – most recent event	3	On going	UGS/USGS
Weber segment WFZ – multiple events	4	On going	UGS/USGS
Utah Lake faults and folds	5	Ongoing	UUGG
East Great Salt Lake fault zone	6	Ongoing	UUGG
Collinston and Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
East Cache fault zone	12	Ongoing	USU
Wasatch Range back-valley faults	14	Ongoing	USBR
Hurricane fault zone	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Ongoing	UGS/USGS

2011 FAULT PRIORITY LIST

2011 HIGHEST PRIORITY FAULTS/FAULT SECTIONS FOR STUDY			
Fault/Fault Section	**Priority**	**Investigation Status**	**Investigating Institution**
Warm Springs fault/East Bench fault subsurface geometry and connection (not a paleoseismic investigation)	1	No activity	
Penultimate event Provo segment WFZ	2	Trench site reconnaissance	UGS
Long-term earthquake record Nephi segment	3	No activity	
Washington fault	4	Two trenching investigations	UGS/Simon-Bymaster
Mid- to late-Holocene earthquake chronology southern part Weber segment WFZ	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	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (submerged beneath Great Salt Lake)	2007	No activity	
Rozelle section, EGSL fault (submerged beneath Great Salt Lake)	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 UVU study ongoing	UGS/USGS/UVU
West Valley fault zone	2	Study Funded	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Ongoing	UUGG
East Great Salt Lake fault zone	6	Ongoing?	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
East Cache fault zone	12	Ongoing	USU
Wasatch Range back-valley faults (Sufficient? – Main Canyon fault)	14	UGS Miscellaneous Pub 10-5	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Ongoing	UGS/USGS
Bear River fault zone	2007	Ongoing/No Recent Activity	USGS
Salt Lake City segment WFZ – north end	2009	Study Funded	UGS/USGS

Fault/Fault Segment	Original UQFPWG Priority (2005)
Nephi segment WFZ	1
West Valley fault zone*	2
Weber segment WFZ – most recent event	3
Weber segment WFZ – multiple events	4
Utah Lake faults and folds	5
Great Salt Lake fault zone*	6
Collinston & Clarkston Mountain segments WFZ	7
Sevier/Toroweap fault*	8
Washington fault	9
Cedar City-Parowan monocline/ Paragonah fault*	10
Enoch graben	11
East Cache fault zone	12
Clarkston fault	13
Wasatch Range back-valley faults*	14
Hurricane fault*	15
Levan segment WFZ*	16
Gunnison fault	17
Scipio Valley faults	18
Faults beneath Bear Lake	19
Eastern Bear Lake fault	20
Bear River fault zone	Added 2007
Brigham City segment WFZ – most recent event	Added 2007
Carrington fault (Great Salt Lake)	Added 2007
Northern Salt Lake City segment WFZ	Added 2009
Provo segment WFZ – penultimate event	Added 2007
Rozelle section – Great Salt Lake Fault	Added 2007
Warm Springs fault/East Bench fault subsurface geometry and connection	Added 2010
Long-term earthquake record Nephi segment	Added 2010
Mid- to late-Holocene earthquake chronology southern Weber segment	Added 2010

UQFPWG QUATERNARY FAULT STUDY PRIORITY LIST

*On Utah NSHM

UTAH GEOLOGICAL SURVEY

SUGGESTIONS FOR CONSIDERATION

- **Warm Springs fault/East Bench fault subsurface geometry and connection***
- **Long-term earthquake record Nephi segment***
- **Provo segment WFZ – penultimate event***
- **Mid- to late-Holocene earthquake chronology southern Weber segment***
- **Rozelle segment East Great Salt Lake fault zone**
- **West Valley fault zone – Taylorsville fault***
- **Northern end of Provo segment of WFZ***
- **Brigham City rupture extent (N and S ends)***
- **Collinston and Clarkston Mountain segments of WFZ***
- **Levan and/or Fayette segments of WFZ***
- **Hansel Valley faults***
- **Bear River fault zone***
- **Poorly studied faults that are currently earthquake sources on the National Seismic Hazard Maps***

***Existing/Former high priority**

***Derivative high priority**

***New – recommend reviewing the existing fault priority list before adding any more new faults.**

***Hansel Valley, Morgan, North Promontory, Paragonah, Stansbury, Strawberry, Taylorsville, and Wellsville faults**