UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP

Wednesday, February 13, 2008

WELCOME

UQFPWG HISTORY

- **Expert panel originally convened to evaluated paleoseismic-trenching data available for Utah's Quaternary faults.**

- **Used experience and best professional judgment to assign preferred consensus recurrence-interval and vertical slip-rate estimates, and "best estimate" confidence limits for faults under review.**

- **Resulting RI and VSR estimates and associated confidence limits represent the best available information regarding the faults/fault sections reviewed.**

- **Recommended additional paleoseismic study of 20 faults/fault sections to characterize Utah's earthquake hazard to "a minimally acceptable level."**

UQFPWG TODAY

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

2007 MEETING REVIEW

Presentations on work completed/in progress

- Nephi segment Santaquin trench study results – UGS
- Nephi segment Willow Creek trench study results – USGS
- Great Salt Lake fault zone study update – U of U
- Mapleton megatrench study update – URS Corp.
- East Canyon fault trenching – B of Rec
- Sevier fault paleoseismic reconnaissance update – UGS
- GPS studies of active tectonics in Utah – U of U
- New Weber segment paleoseismic data – UGS/USGS

Technical discussion items

- New Salt Lake City segment slip rate?
- Utah NSHM fault recommendations to the USGS
- BRPEWG recommendations and the 2007 update of the NSHMs

2008 FAULT PRIORITY LIST

Priority A – First Priority (listed alphabetically)

- Brigham City segment, Wasatch fault zone – timing of most recent event
- Carrington fault (Great Salt Lake)
- Provo segment, Wasatch fault zone – timing of penultimate event
- Rozelle section, northern Great Salt Lake fault
- Utah Lake faults and folds
- West Valley fault zone

Priority B – Second Priority (listed alphabetically)

- Bear River fault zone
- Cedar City-Parowan monocline/Paragonah fault
- Clarkston fault
- Eastern Bear Lake fault
- Enoch graben
- Faults beneath Bear Lake
- Gunnison fault
- Hurricane fault zone (Cedar City section)
- Levan segment, Wasatch fault zone – trench
- Scipio Valley faults
- Wasatch Range back-valley faults

Priority C (study in progress; need for further investigation to be determined)

- East Cache fault, southern section
- Nephi segment, Wasatch fault zone
- Promontory section, Great Salt Lake fault zone
- Sevier/Toroweap fault
- Washington fault
- Weber segment, Wasatch fault zone

2007 RESEARCH RECOMMENDATIONS

The Working Group considered several Utah-related BRPEWG research recommendations, but noted that in almost every instance those recommendations would benefit from additional detailed paleoseismic information on individual faults, both on and off the Wasatch Front, and therefore recommended that future Utah research efforts focus on obtaining additional paleoseismic data.

AGENDA
QUATERNARY FAULT PARAMETERS WORKING GROUP
Wednesday, February 13

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

8:20 Technical presentations of work completed or in progress

- 8:20 – Nephi segment, Spring Lake trenching update: Danny Horns, UVSC
- 8:40 – Weber segment, Rice Creek trenching results; Chris DuRoss, UGS
- 9:00 – East Cache fault zone trenching update; Stephanie Davi, USU
- 9:20 – East Canyon and Main Canyon fault trenching results; Larry Anderson, USBR
- 9:40 – Washington fault reconnaissance; Tyler Knudsen, UGS

10:00 Break

10:20 Technical presentations of work completed or in progress

- 10:20 – Upcoming Brigham City trenching; Greg McDonald, UGS
- 10:40 – Vertical displacement on the central segments of the Wasatch fault zone; Chris DuRoss, UGS
- 11:00 – Update on EarthScope/Lidar studies in Utah; Robert Smith, UofU
- 11:20 – New GPS data for the Wasatch and ideas on fault segment scale; Robert Smith, UofU.
- 11:40 – Sevier fault reconnaissance study update; Bill Lund, UGS

12:00 Lunch

1:00 Technical discussion items

1:00 – Levan segment slip-rate estimate; Mike Hylland, UGS

1:15 – Nephi segment slip-rate and recurrence-interval estimates; Chris DuRoss, UGS/Steve Personius, USGS

1:45 – UQFPWG fault priorities for 2009

2:15 Break

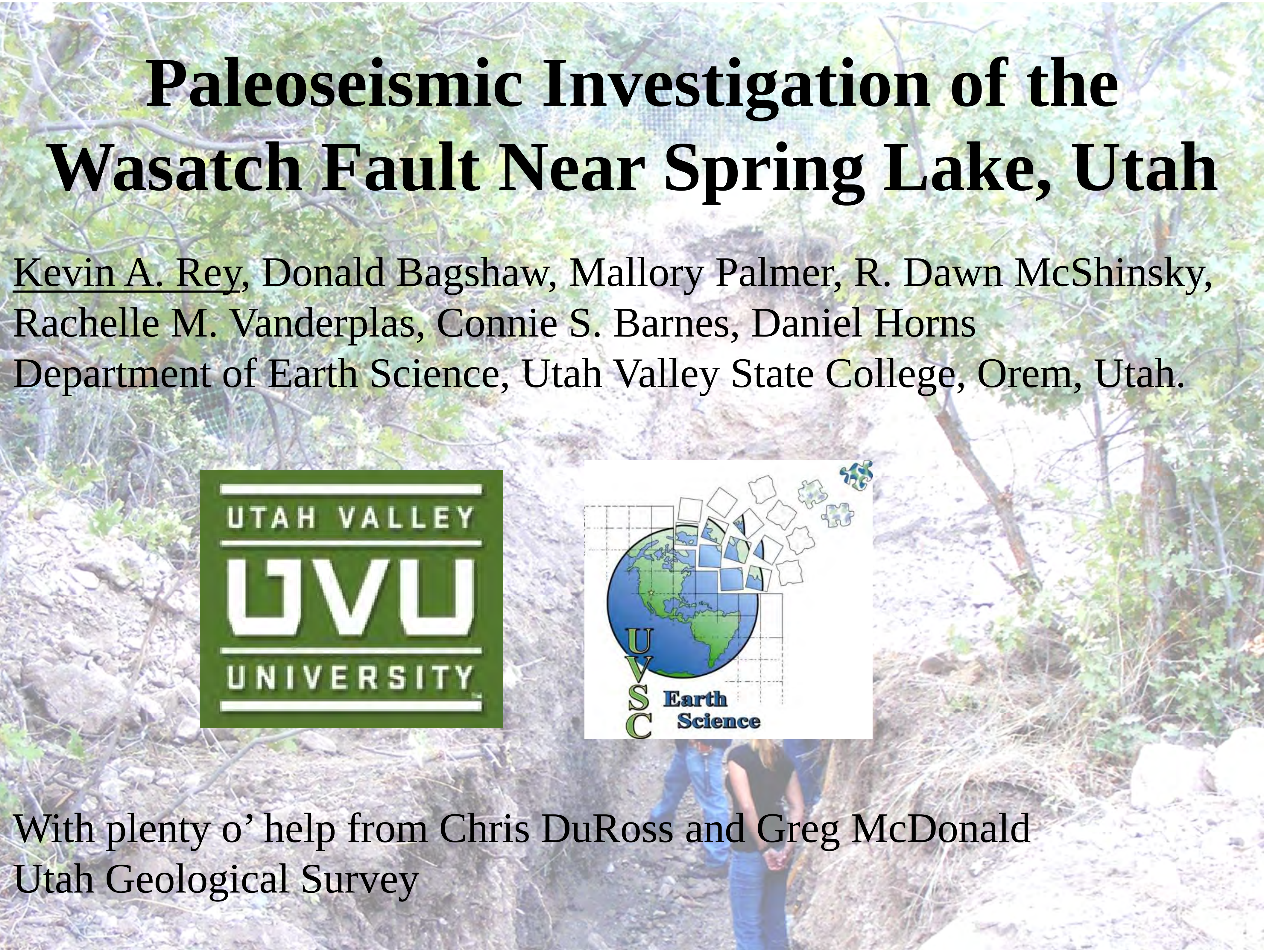
2:45 Technical discussion items

2:45 – Wasatch Front Community Fault Model; Mark Petersen, USGS, Bill Lund, UGS

- What is a CFM and what is it used for?
- Do we need a CFM for the Wasatch Front?
- Do we have the data to construct a WFCFM?
- If not, what new data do we need and how do we acquire it?
- If we need it and have/get the data, who should build and maintain it?

3:45 – Time dependent earthquake models – is the Wasatch fault a candidate? Susan Olig, URS Corp., Kathy Haller, USGS

4:45 Adjourn



Paleoseismic Investigation of the Wasatch Fault Near Spring Lake, Utah

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

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

Paleoseismic Investigation of the Wasatch Fault Near Spring Lake, Utah

1. Introduction to the Nephi segment of the Wasatch Fault

2. How UVSC students became involved

3. Results of work by two summer field classes

The three southern segments of the Wasatch Fault

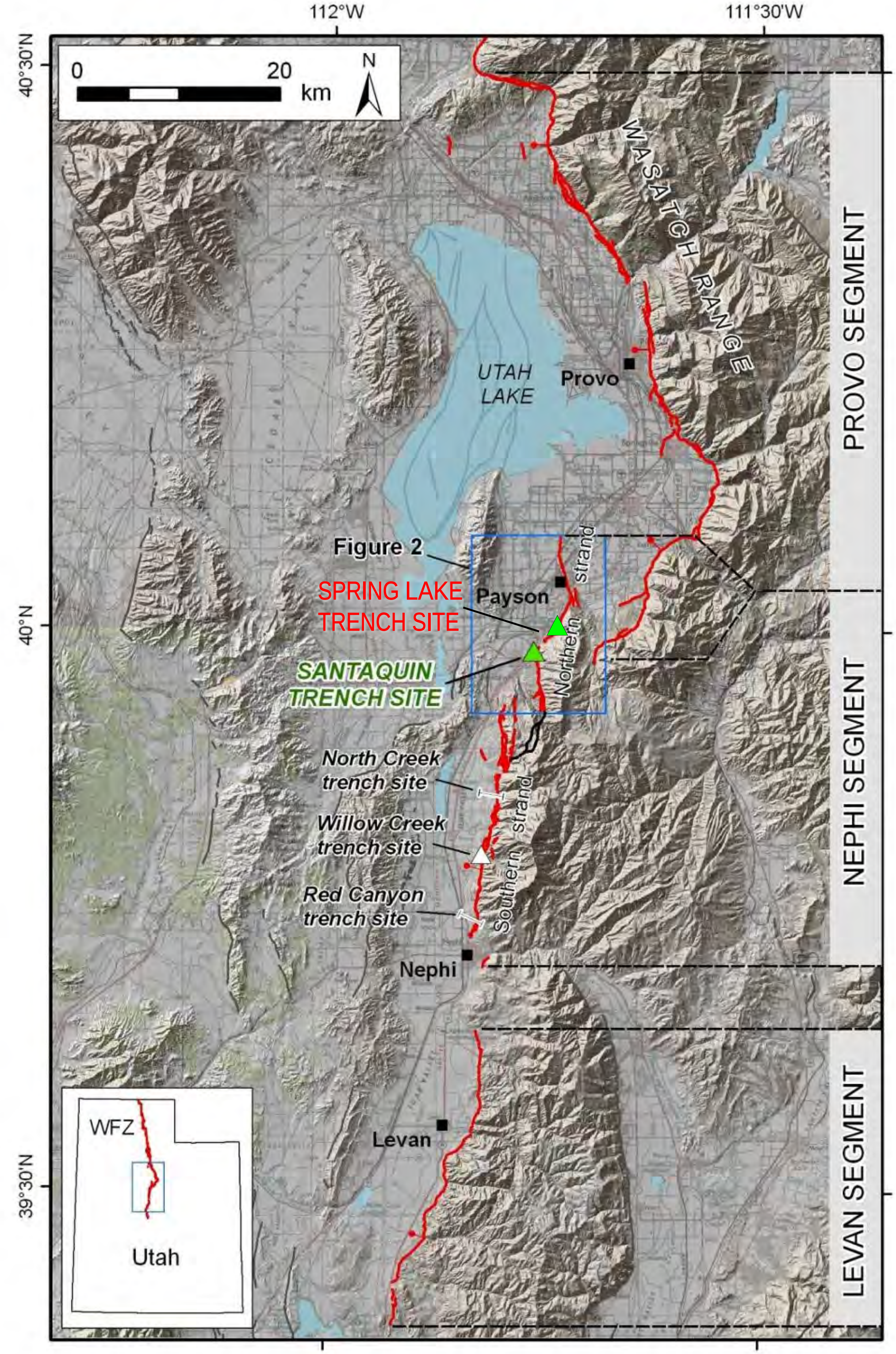


Figure from DuRoss and others, in prep.

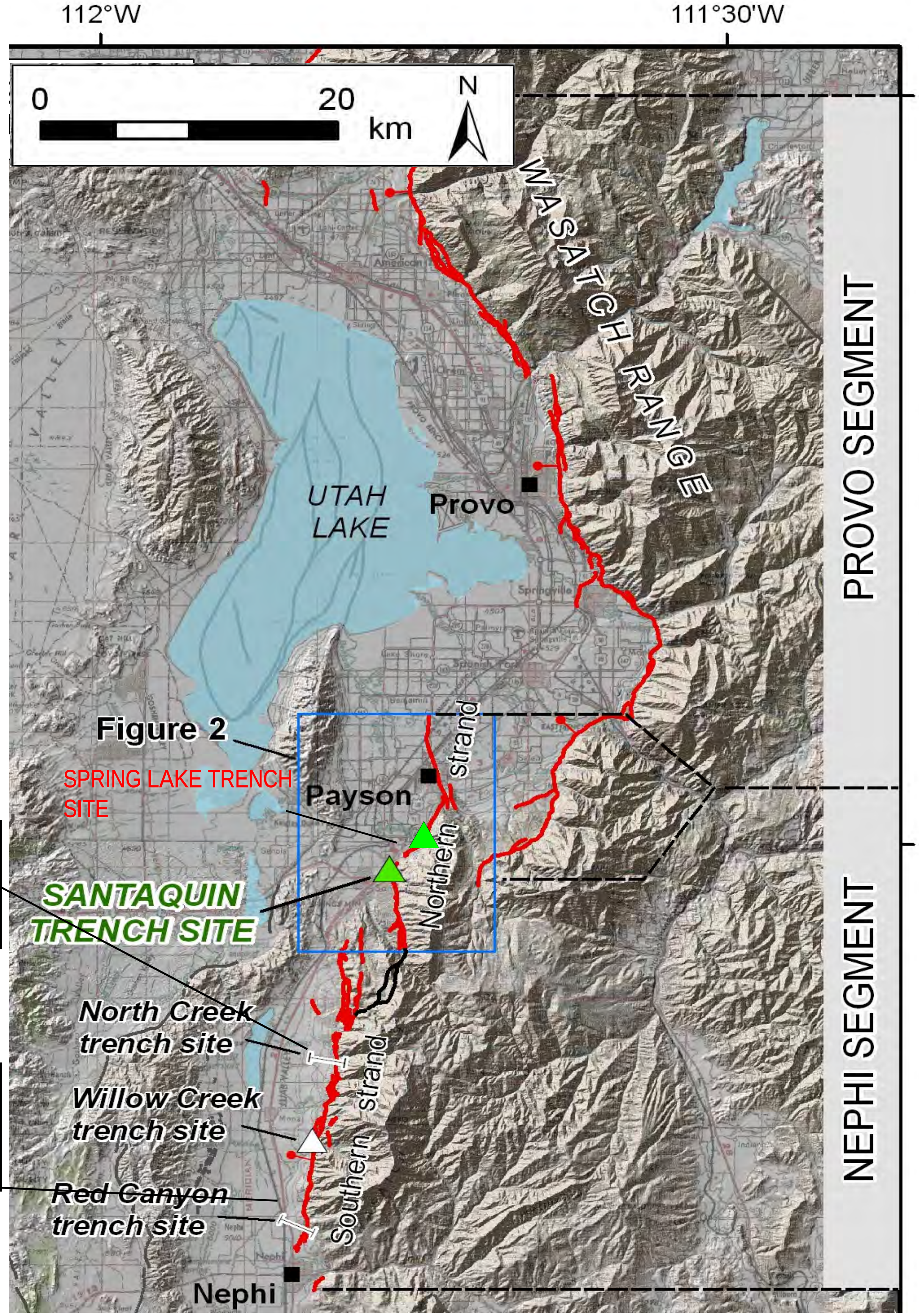
U T A H G E O L O G I C A L S U R V E Y

SURVEY NOTES

Volume 39, Number 1

January 2007

Previous investigations on the Nephi segment



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

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

Figure from DuRoss and others, in prep.

Previous investigations on the Nephi segment

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

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

Utah Quaternary Fault Parameters Working Group (2005)
P1: ≤1,000 ± 400 P2: 3,900 ± 500

- Based on poorly-constrained ages from previous studies…
- …and rapid urbanization along parts of the segment…
- …and the possibility that the northern and southern parts of the segment may behave independently…
- **The Nephi segment assigned <u>top priority</u> in Utah for additional paleoseismic studies**.

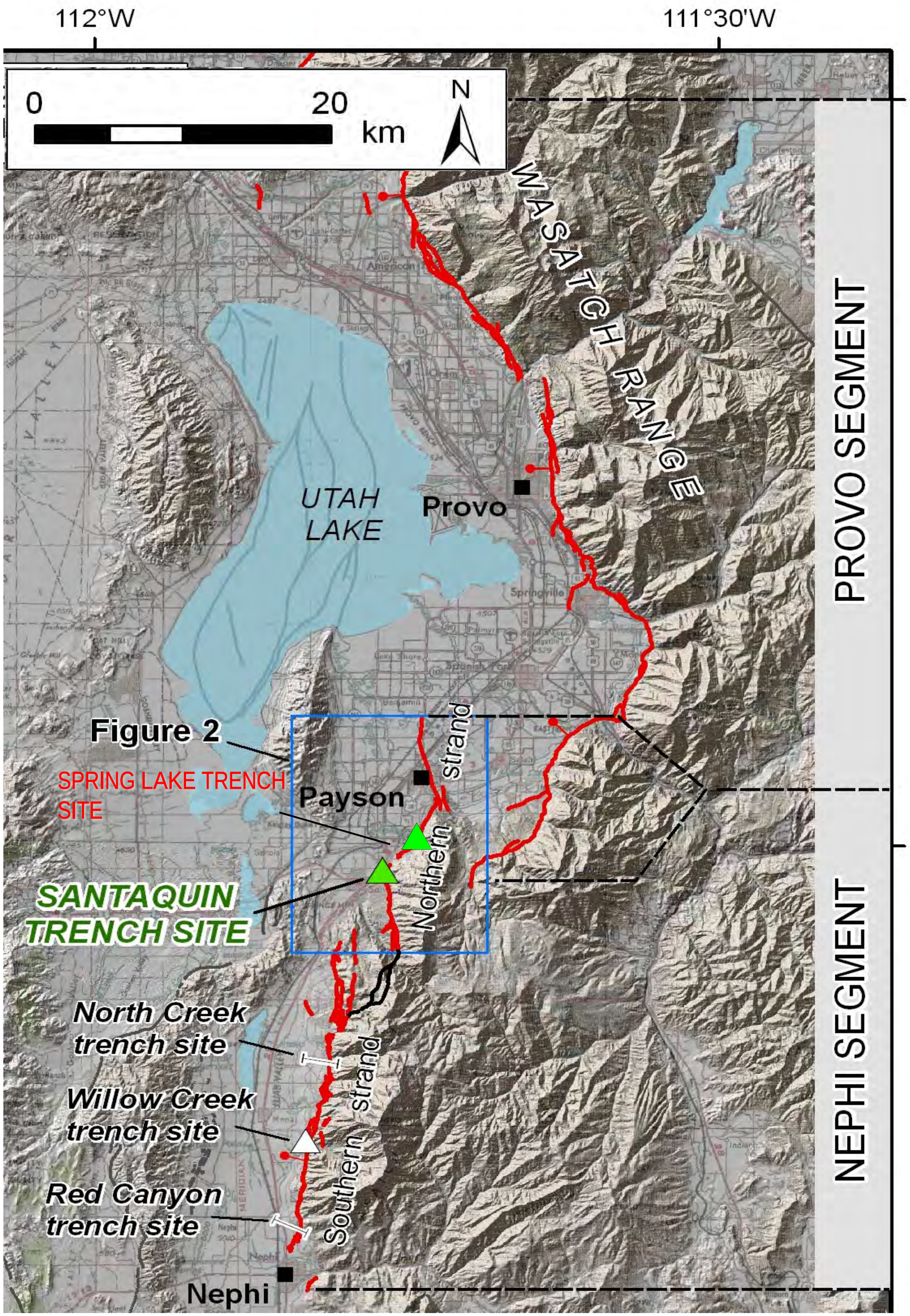


Figure from DuRoss and others, in prep.

Possibility that Provo and Nephi segments rupture concurrently

Utah Quaternary Fault Parameters Working Group (2005)

Provo Segment

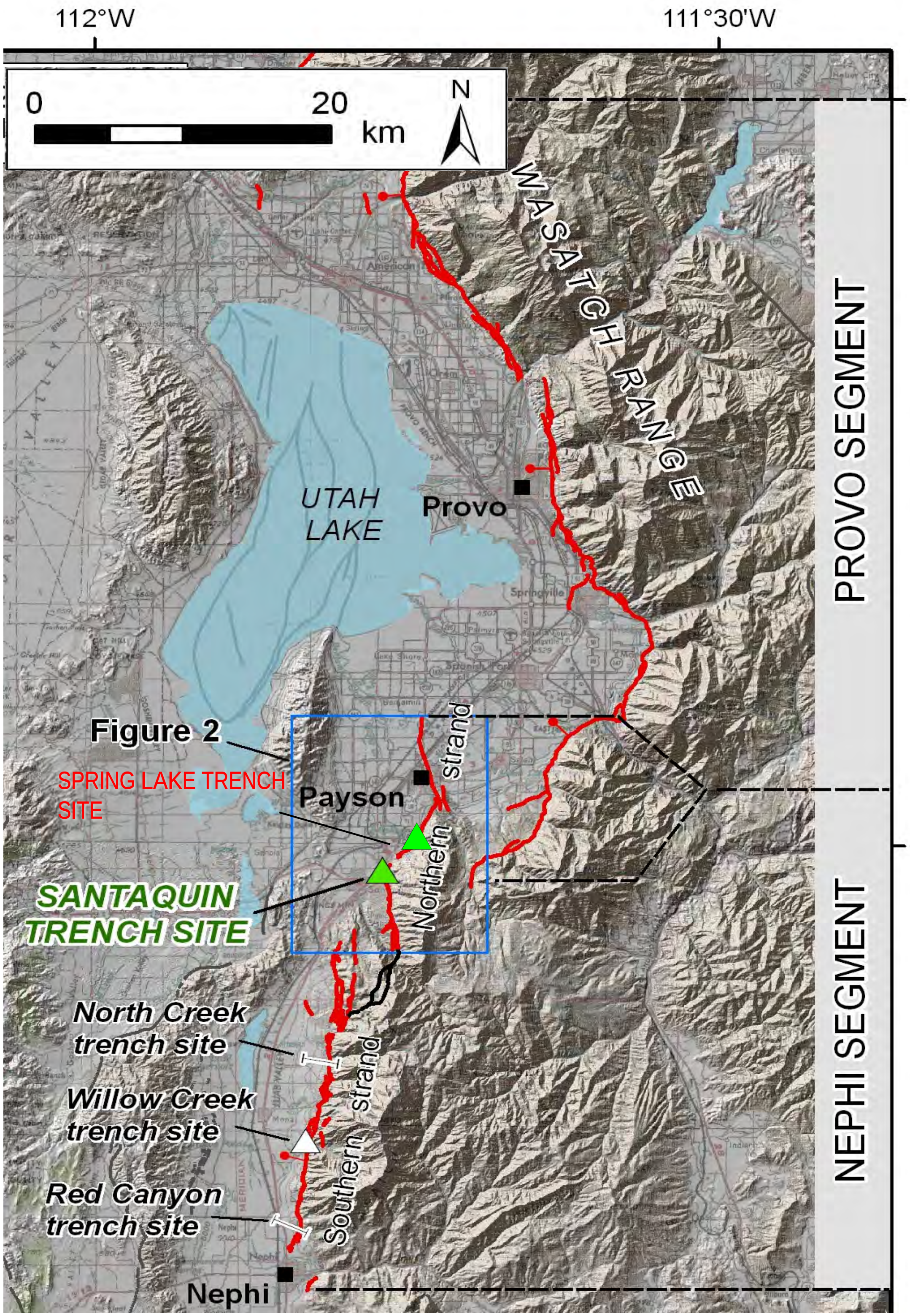
P1: 600 ± 350

Utah Quaternary Fault Parameters Working Group (2005)

Nephi Segment

P1: ≤1,000 ± 400

Figure from DuRoss and others, in prep.



The working group recommendation of additional study of the Nephi segment lead almost immediately to two more studies.

•Investigations were begun in 2005 at Santaquin and Willow Creek by the UGS and USGS.

•Early results indicated that significant uncertainties would remain.

Santaquin (DuRoss and others, in prep)

Willow Creek (Machette and others, 2007)

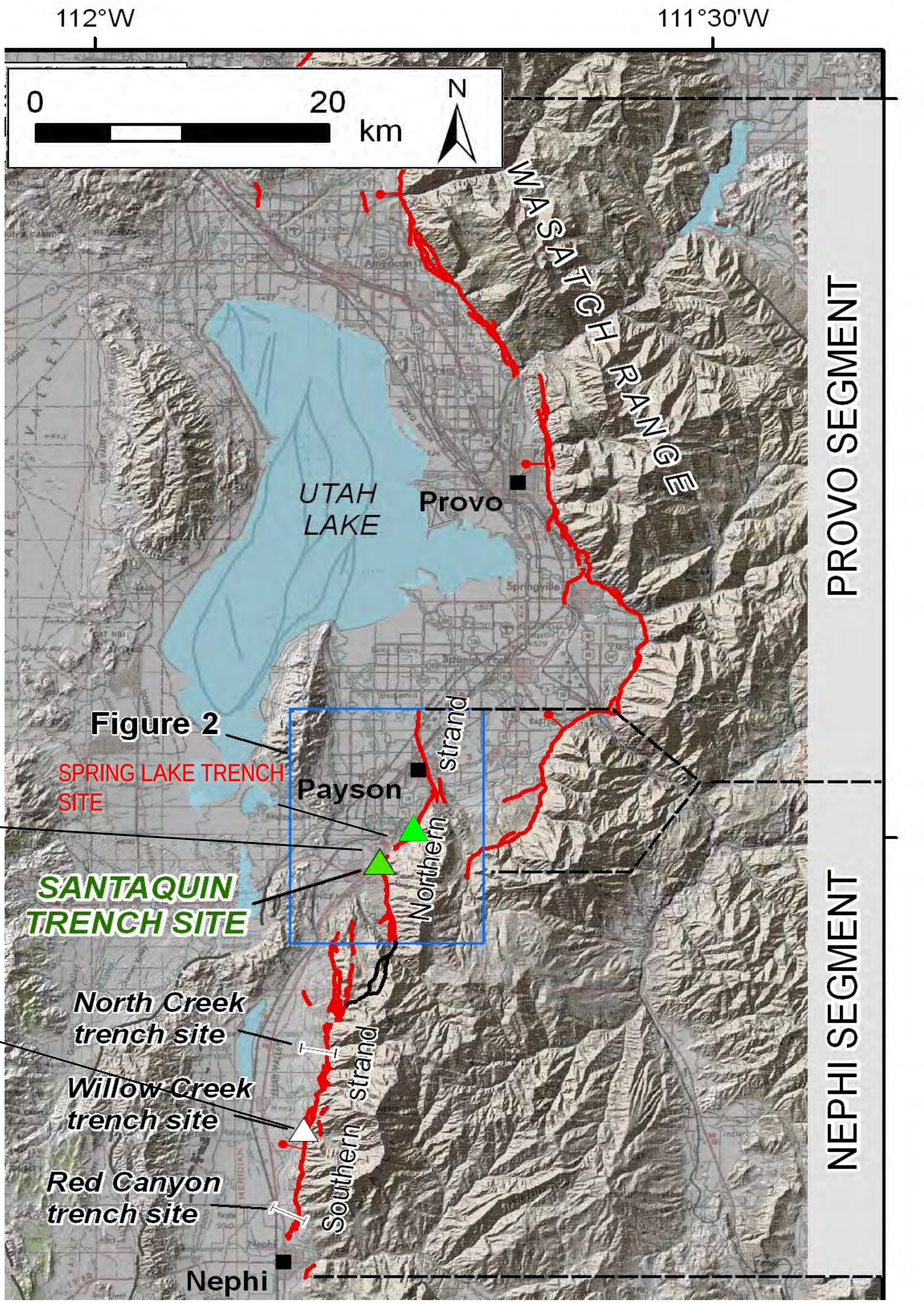


Figure from DuRoss and others, in prep.

Paleoseismic Investigation of the Wasatch Fault Near Spring Lake, Utah

1. Introduction to the Nephi segment
2. How UVSC students became involved
3. Results of work by two summer field classes

Summer field project for 2006?

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

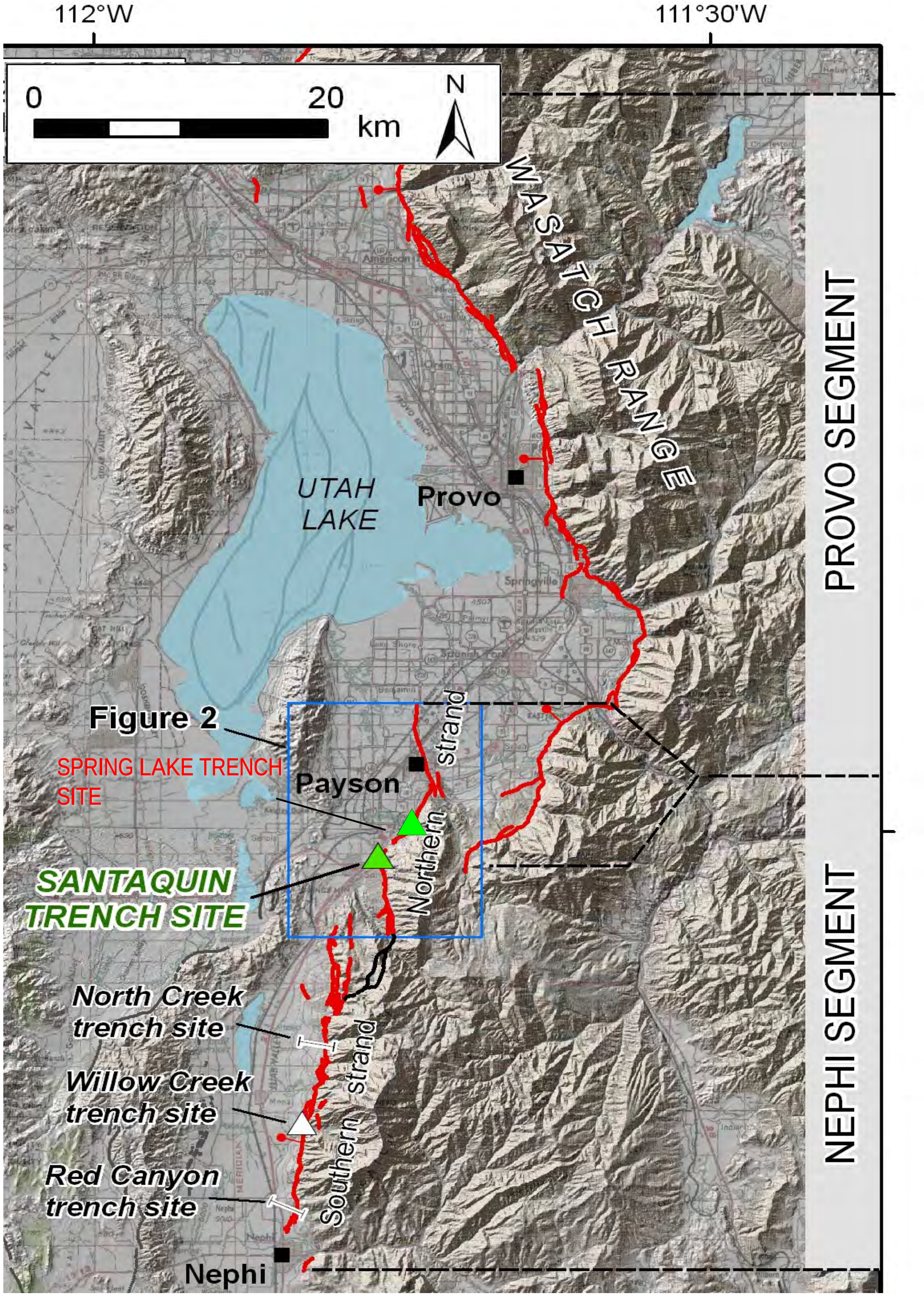


Figure from DuRoss and others, in prep.

Closeup of the northern strand of the Nephi segment

•Separated from the Southern Strand by a step-over

•Near the step-over to the Provo Segment

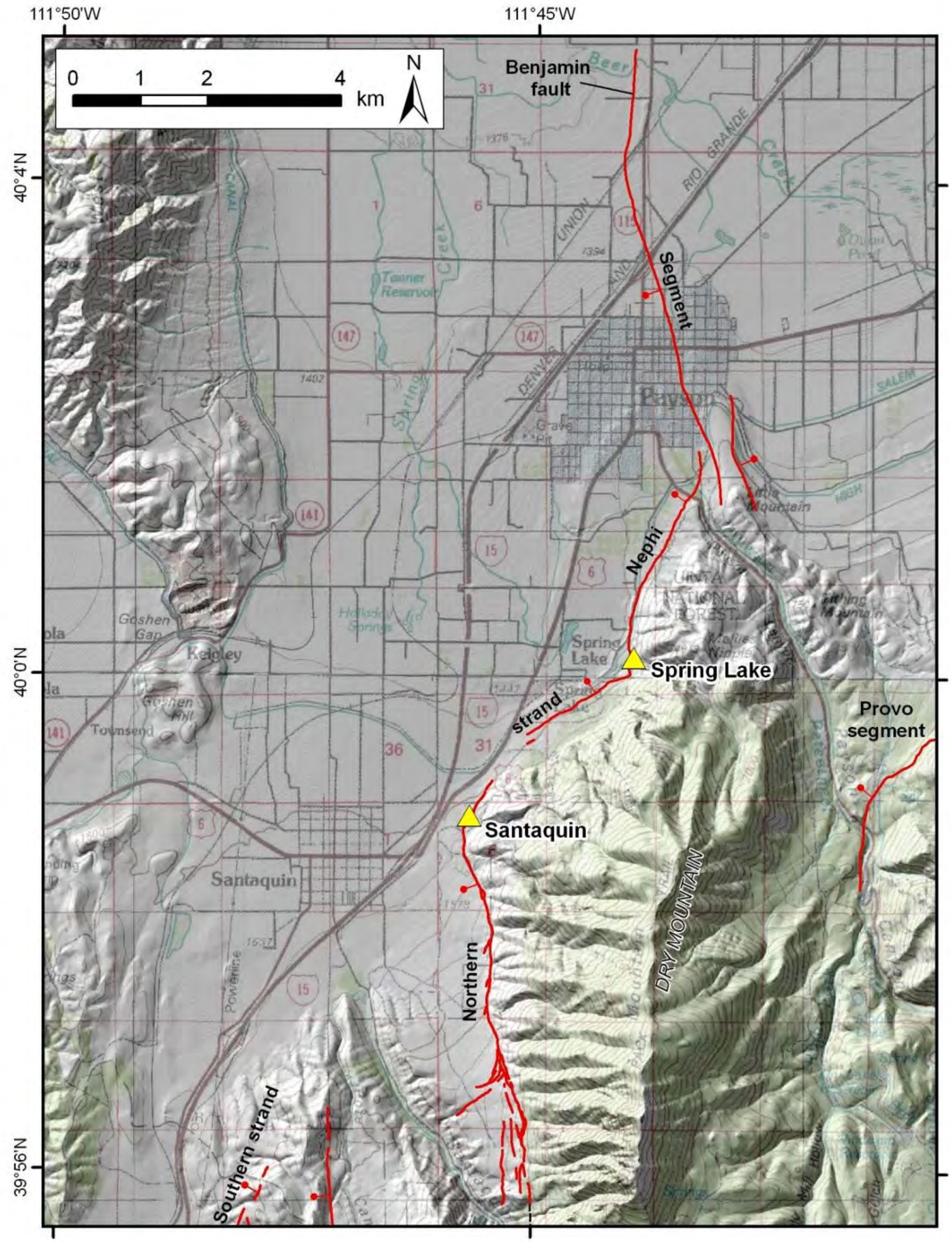
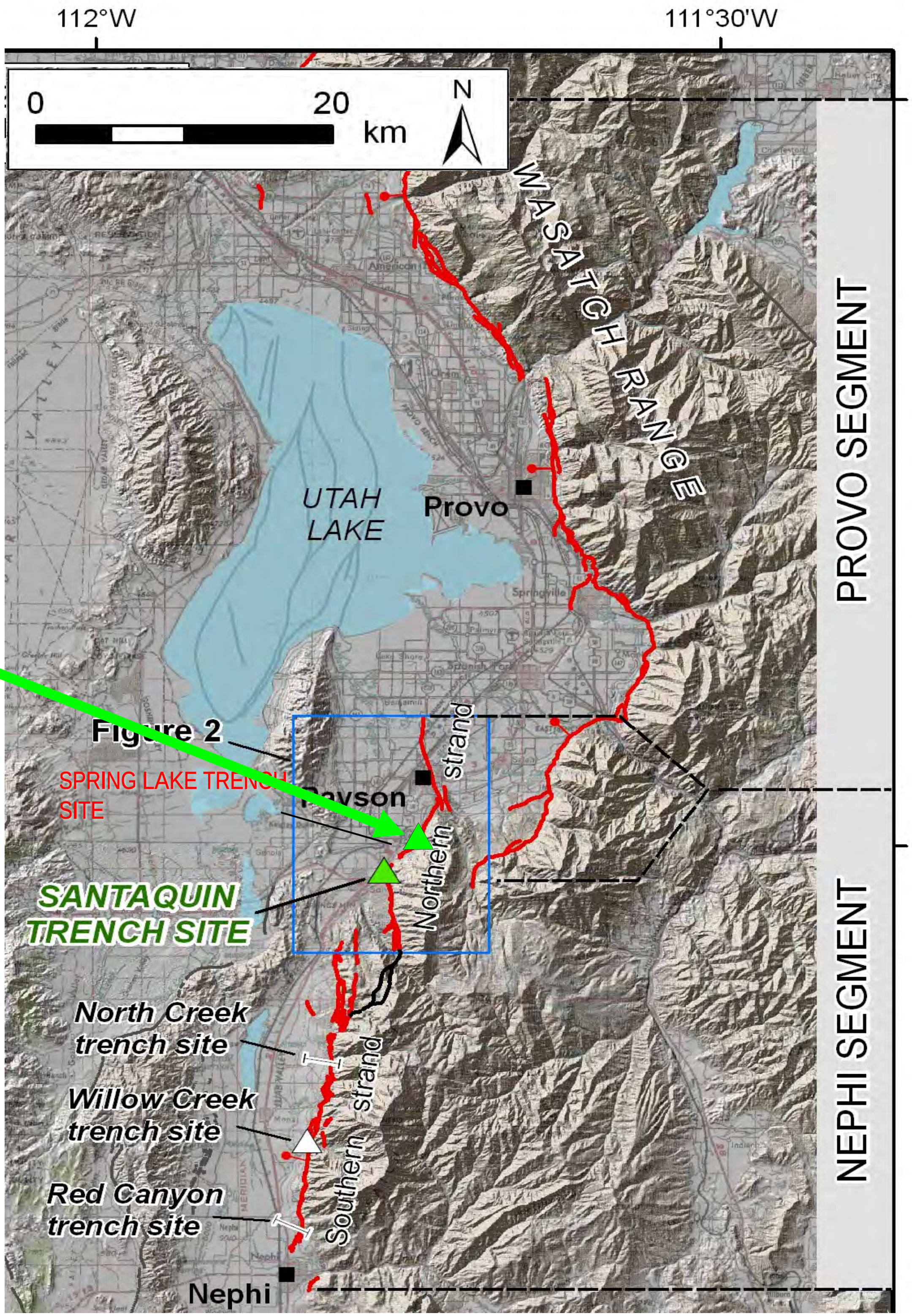


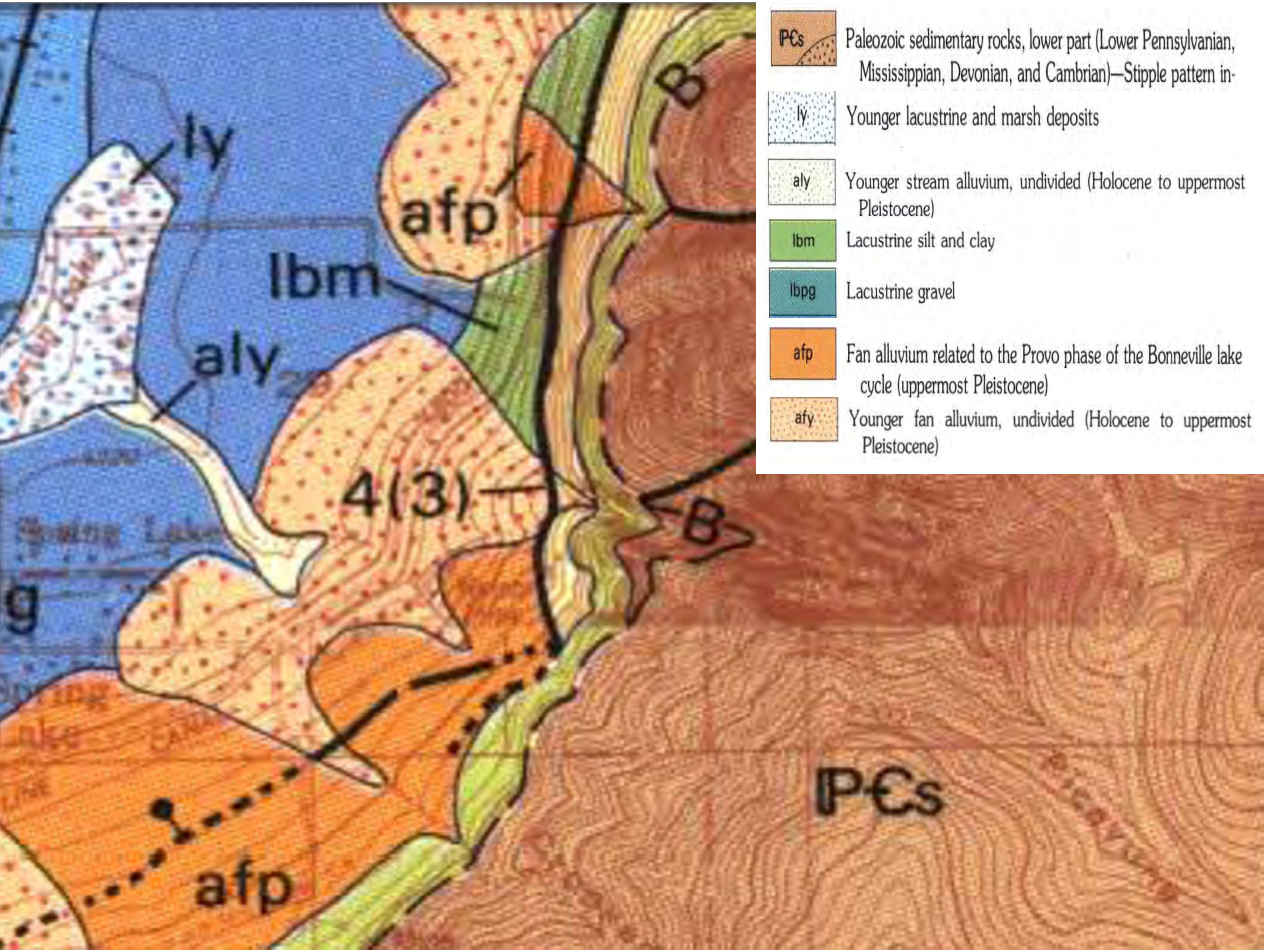
Figure from DuRoss and others, in prep.

Summer field project for 2006?

Focus on Spring Lake area



Spring Lake area on an old Woodward Clyde photo



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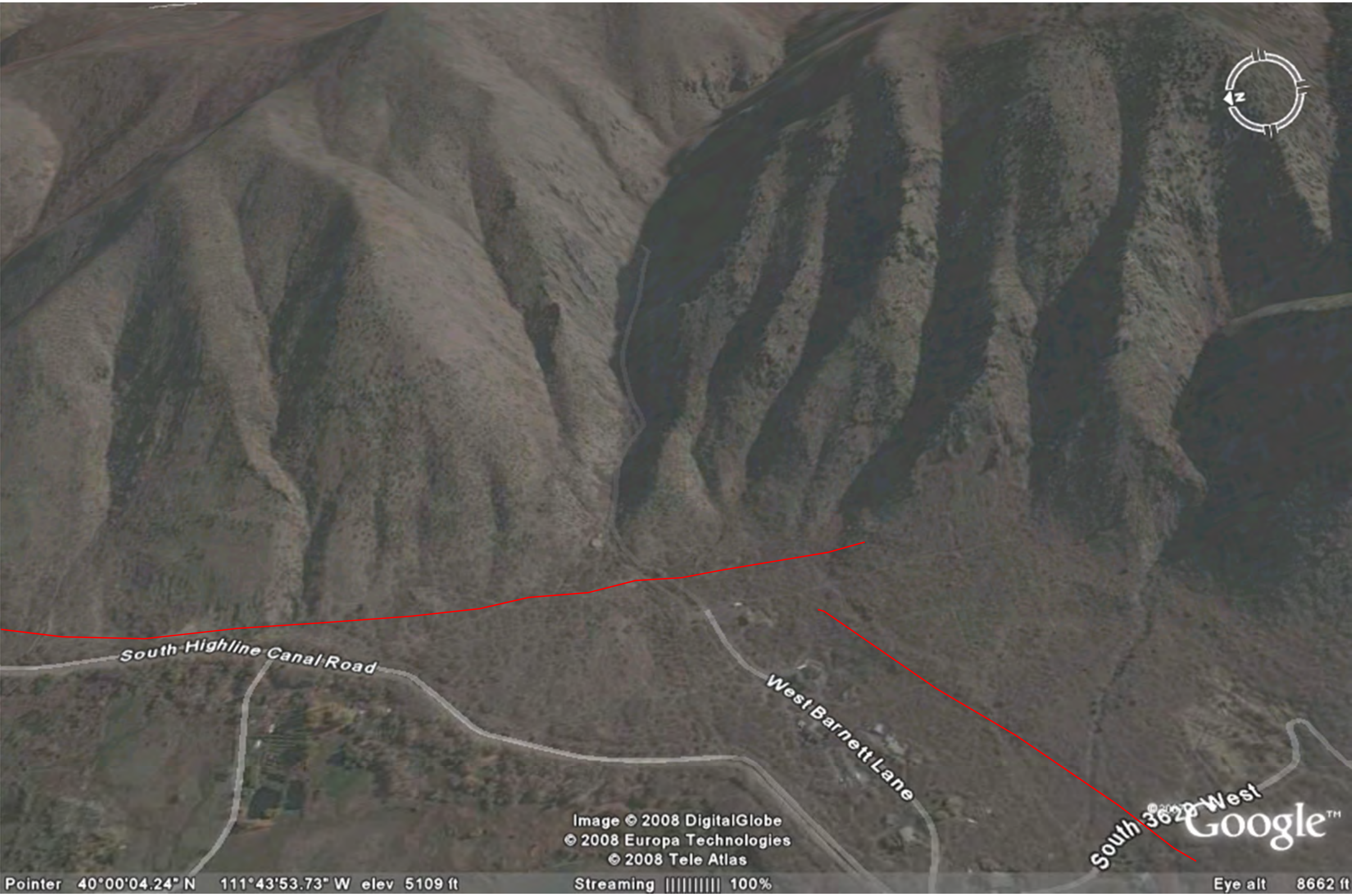
PЄs
Paleozoic sedimentary rocks, lower part (Lower Pennsylvanian, Mississippian, Devonian, and Cambrian)—Stipple pattern in-
ly
Younger lacustrine and marsh deposits
aly
Younger stream alluvium, undivided (Holocene to uppermost Pleistocene)
lbm
Lacustrine silt and clay
lbpg
Lacustrine gravel
afp
Fan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


South Highline Canal Road
West Barnett Lane
South 3620 West
Image © 2008 DigitalGlobe
© 2008 Europa Technologies
© 2008 Tele Atlas
Google™
Pointer 40°00'04.24" N 111°43'53.73" W elev 5109 ft
Streaming |||||||||| 100%
Eye alt 8662 ft

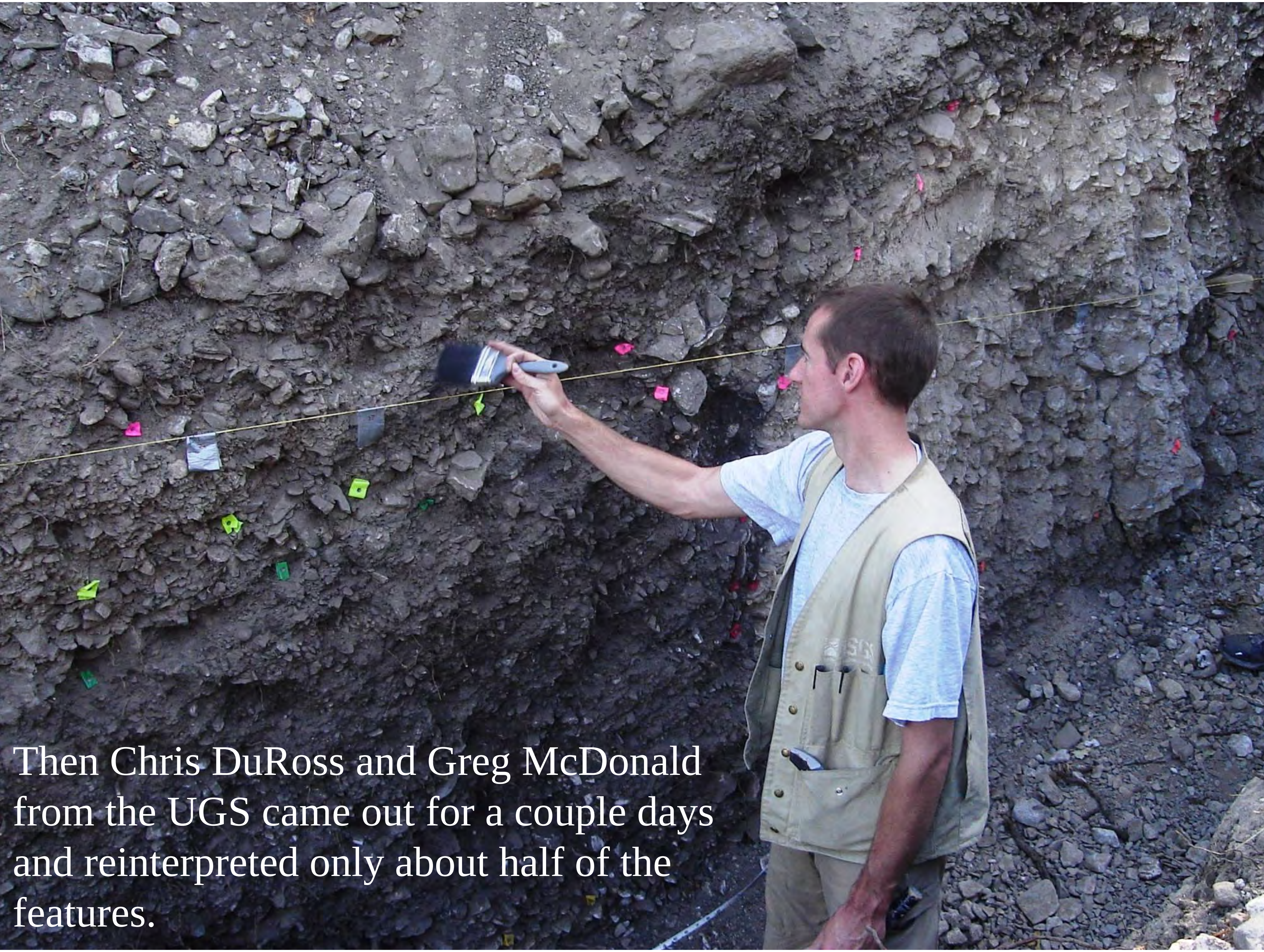
Summer field 2006: Mapping alluvial/debris-flow fans (Afp, Af1), lacustrine sediments (Lbg), and fault scarps (Fsc)-
Identification of preferred trenching location in the mouth of Picayune Canyon.

Summer field 2007:
Trenching

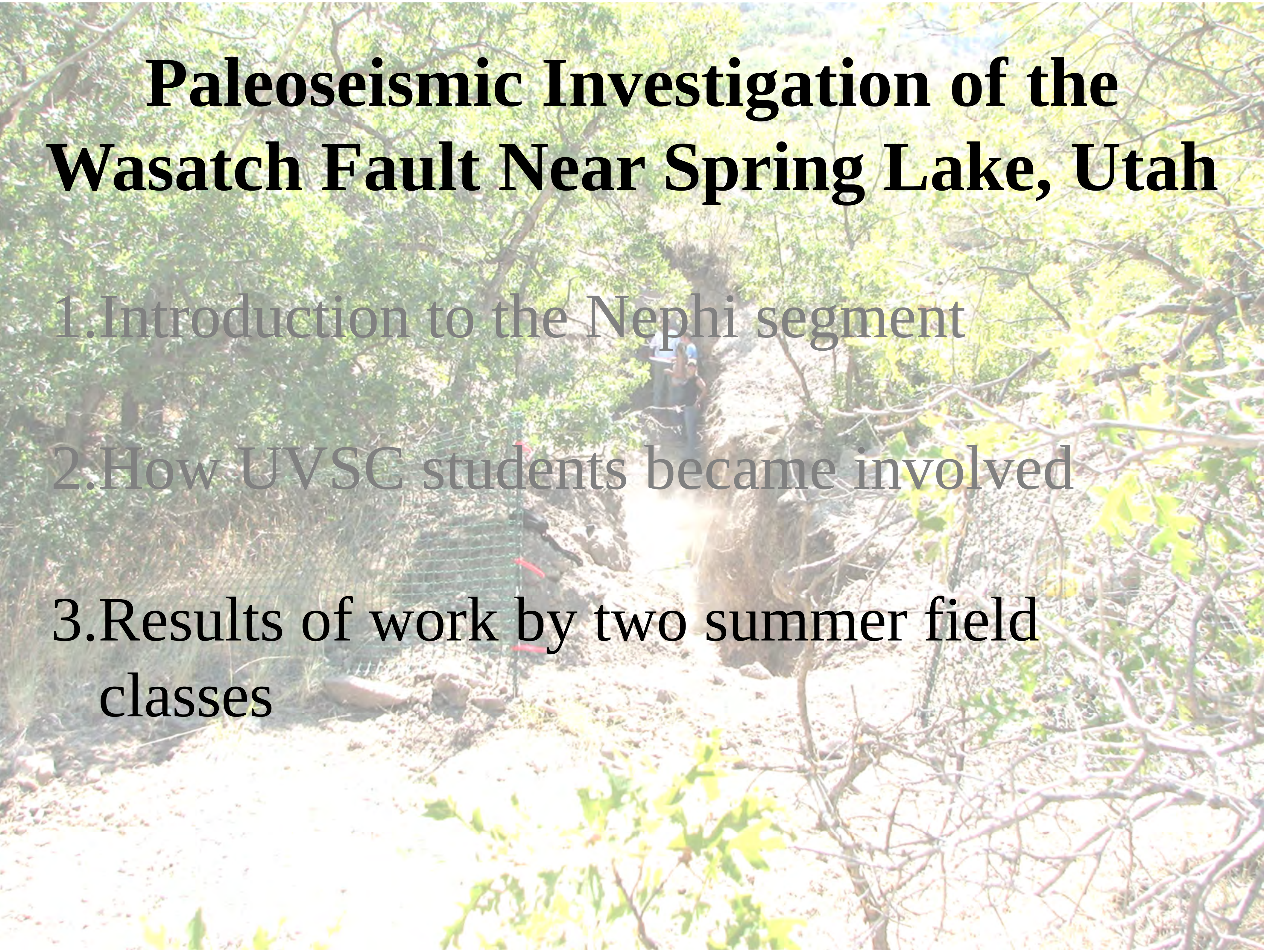
Agreement with forest service and budget constraints limit us to a single "5-foot" slot.

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

Students spent several days logging the north wall of the trench.



Then Chris DuRoss and Greg McDonald from the UGS came out for a couple days and reinterpreted only about half of the features.



Paleoseismic Investigation of the Wasatch Fault Near Spring Lake, Utah

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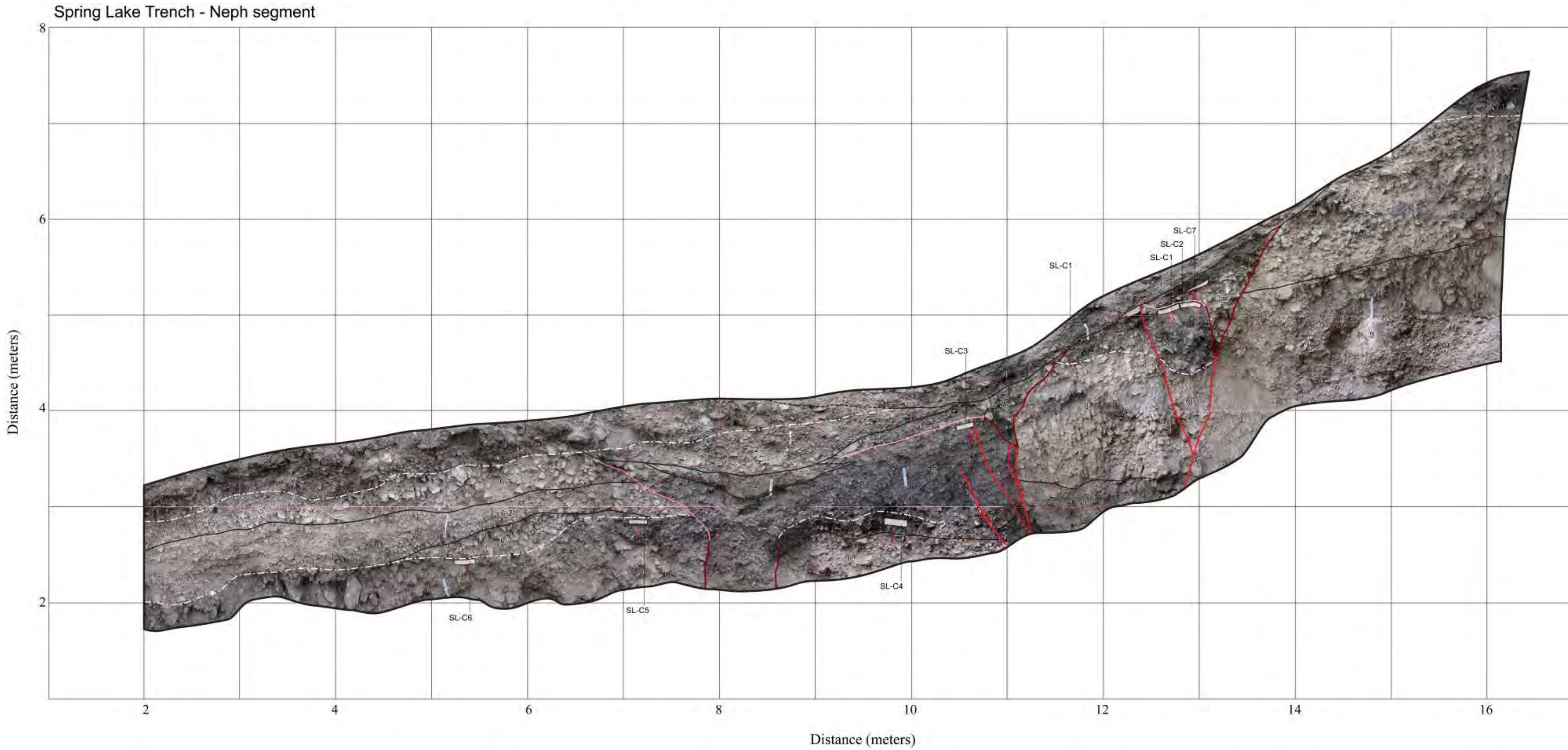
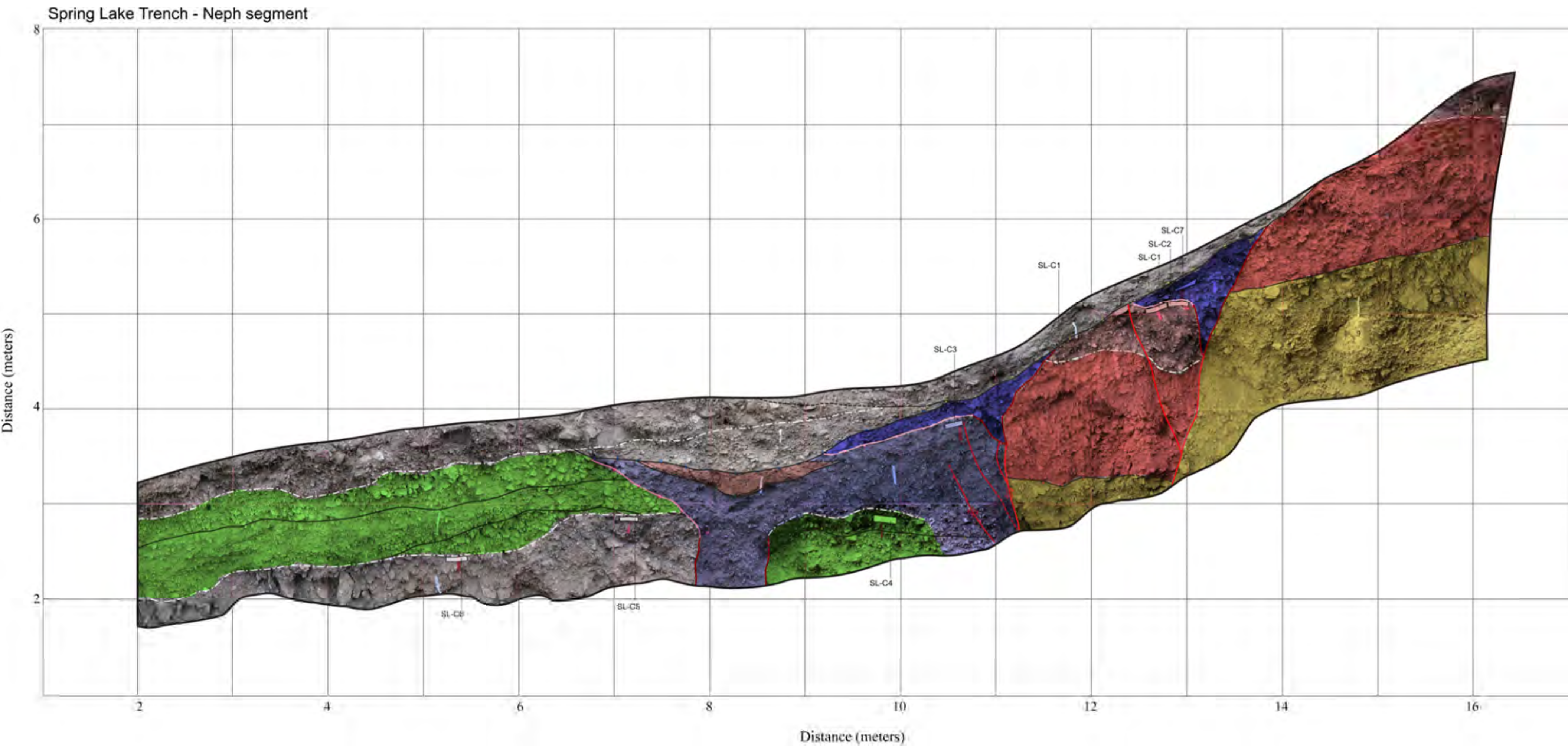


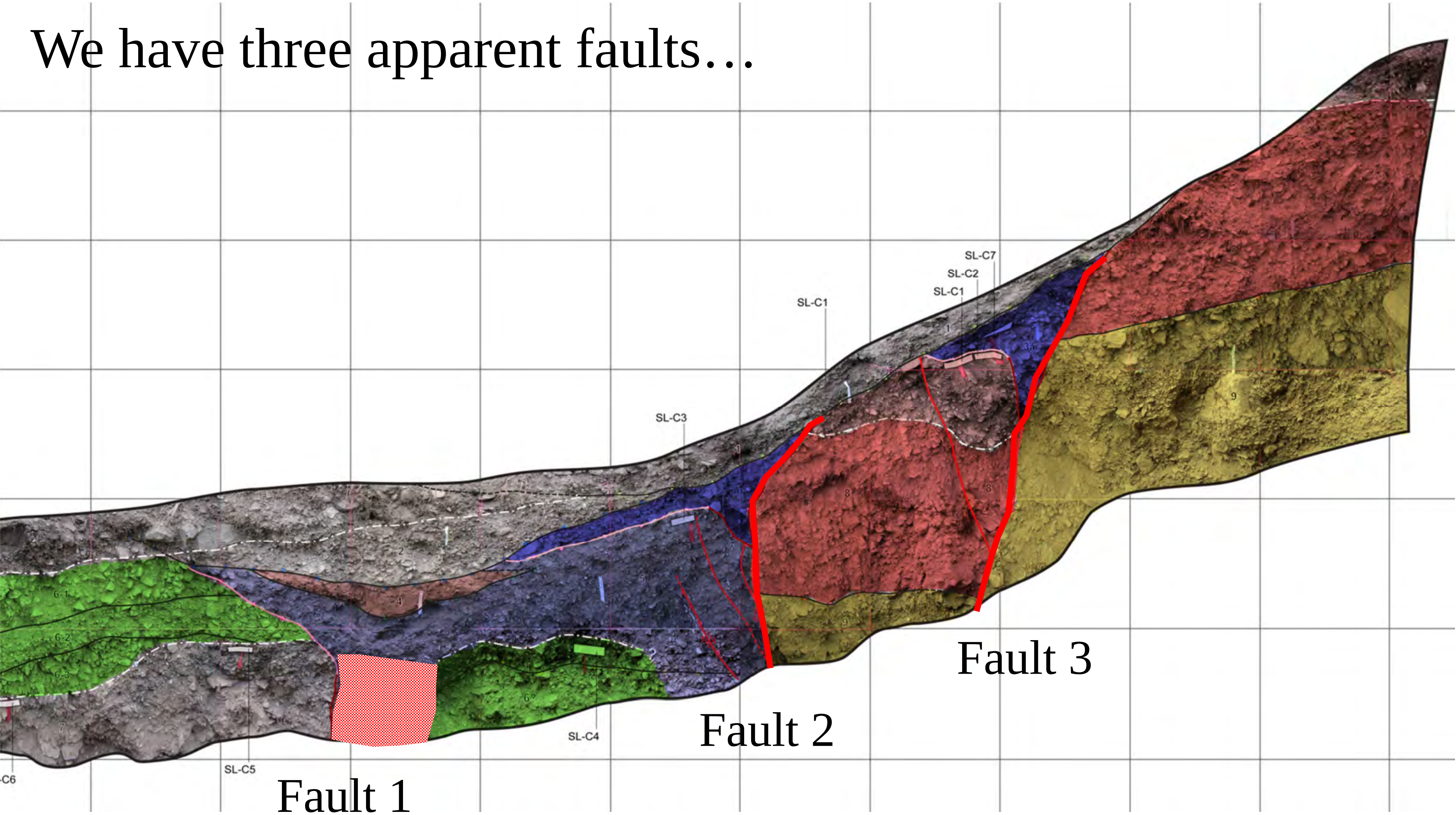
Photomosaic of the north wall (by Chris DuRoss) with interpretations of faults and sedimentary units.



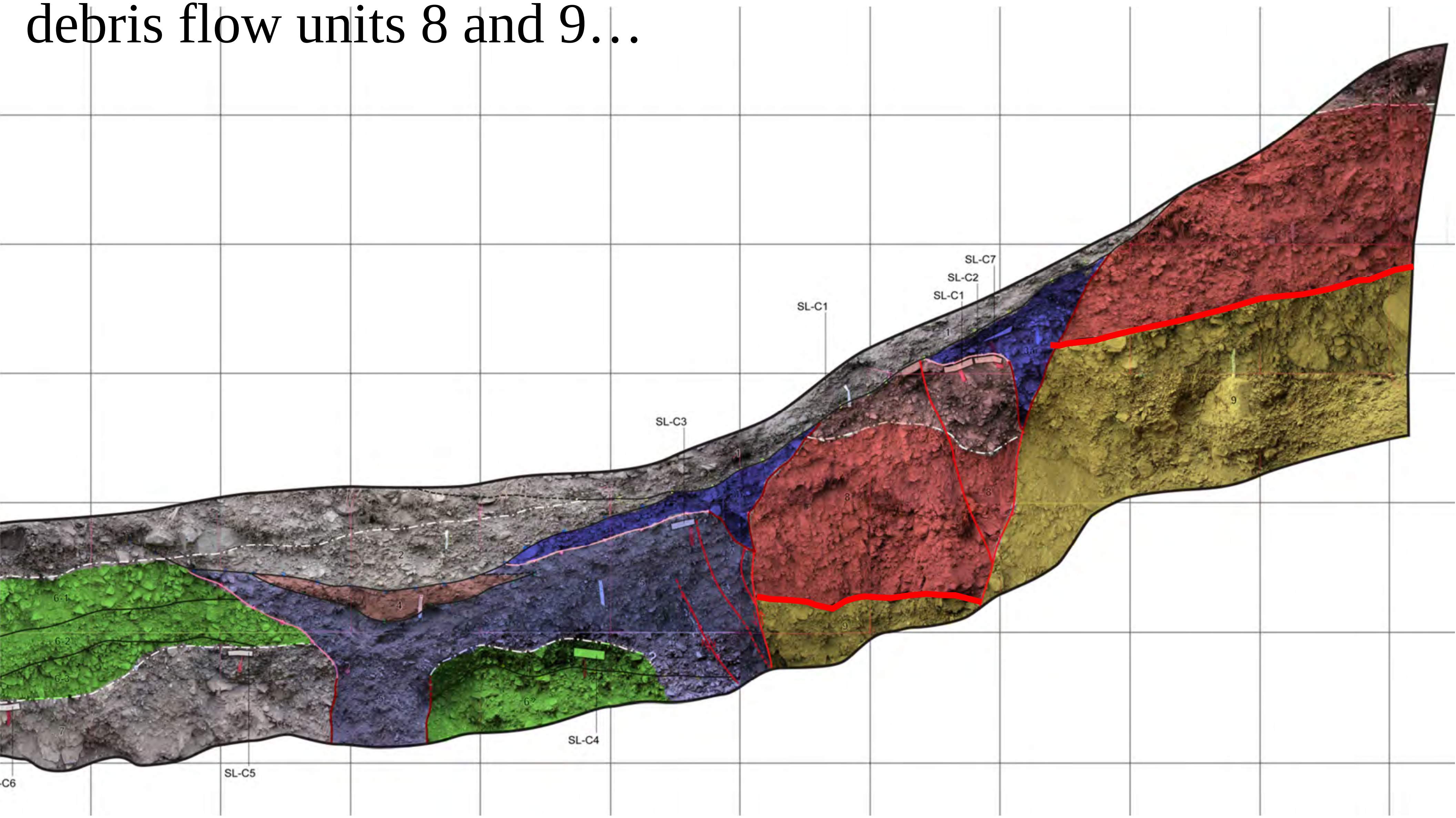
With map units colored-in.

Let's look at some key features:

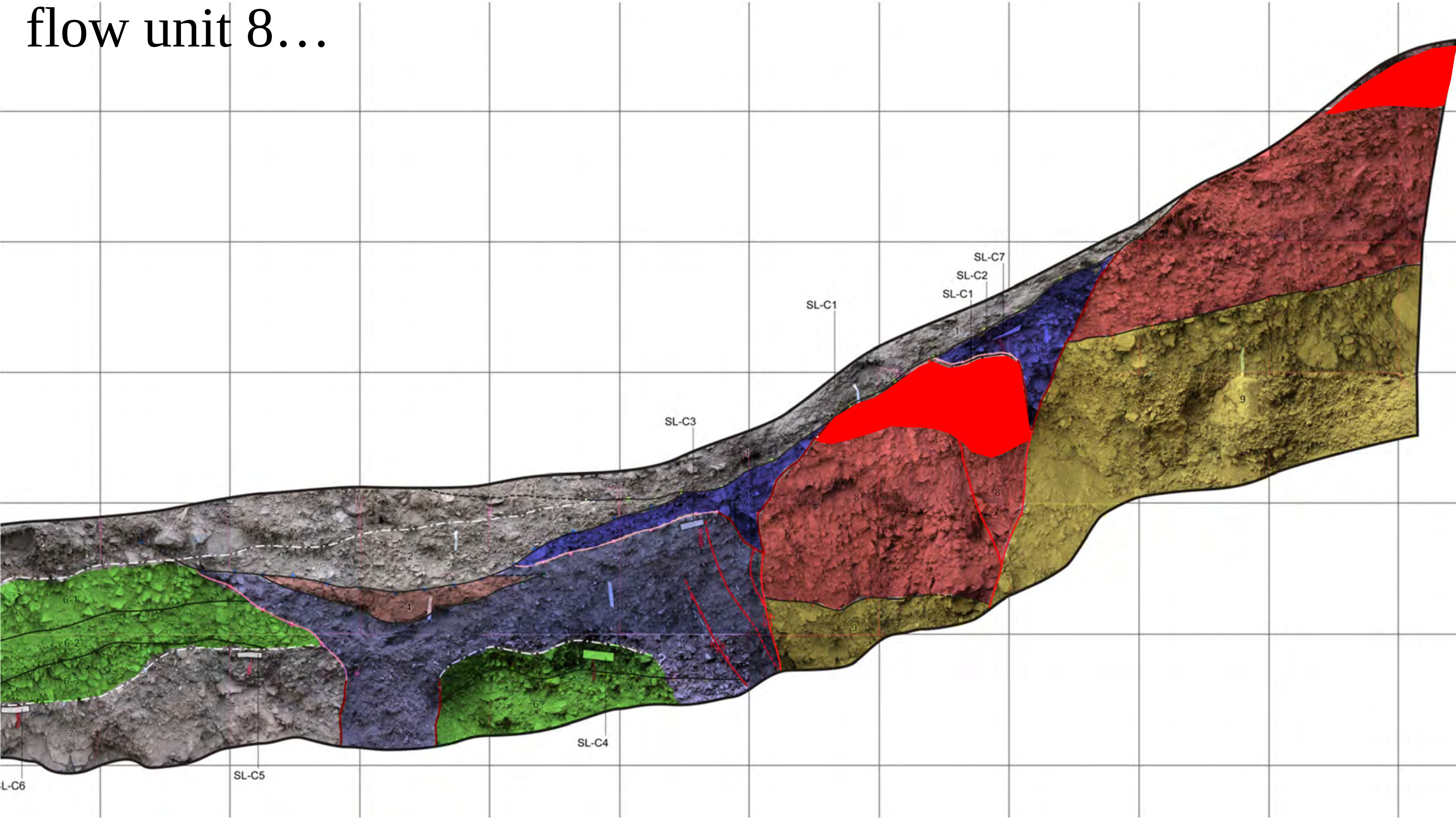
We have three apparent faults…



…a very well-defined contact between debris flow units 8 and 9…

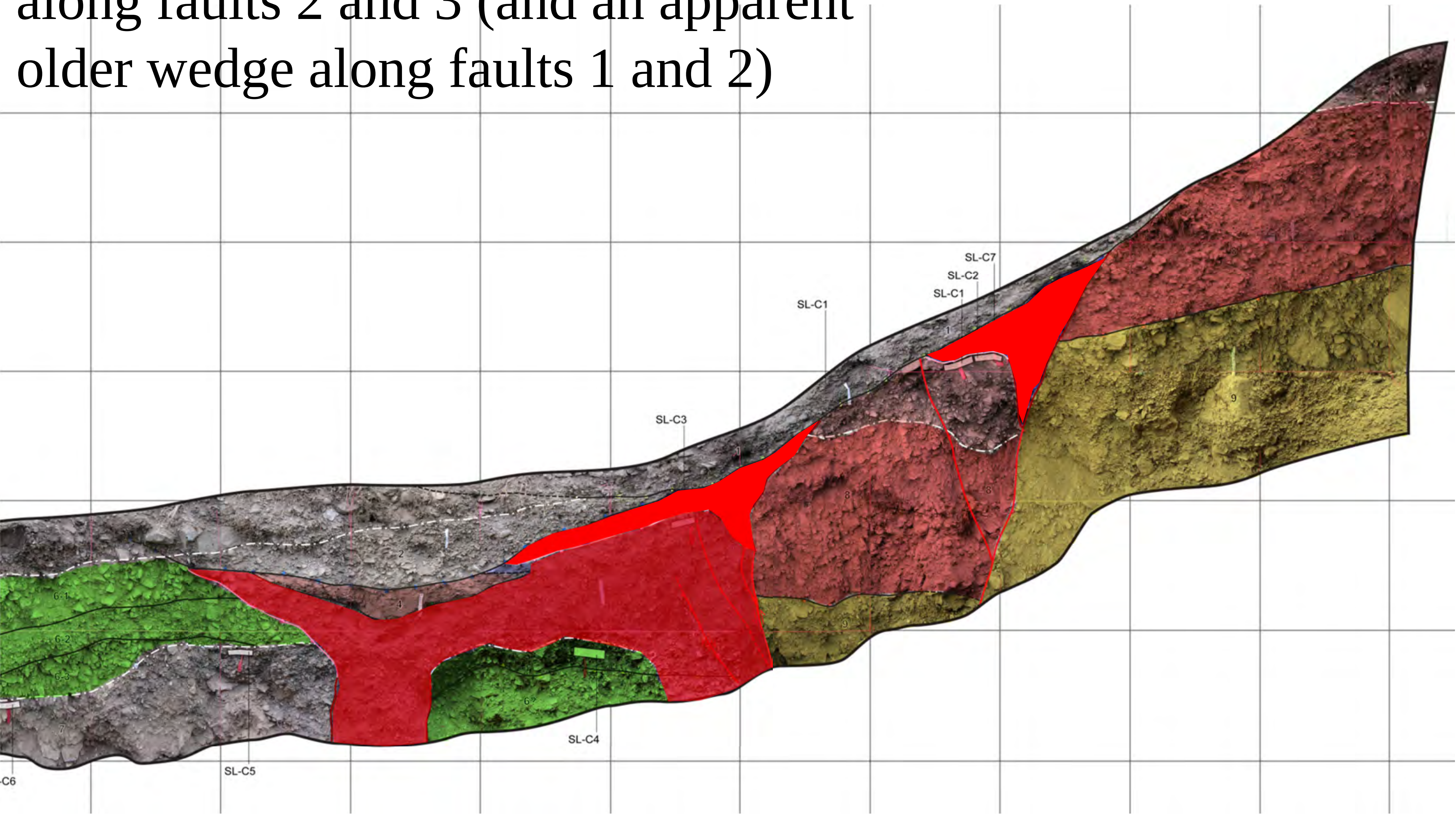


… a well-defined soil on top of debris flow unit 8…

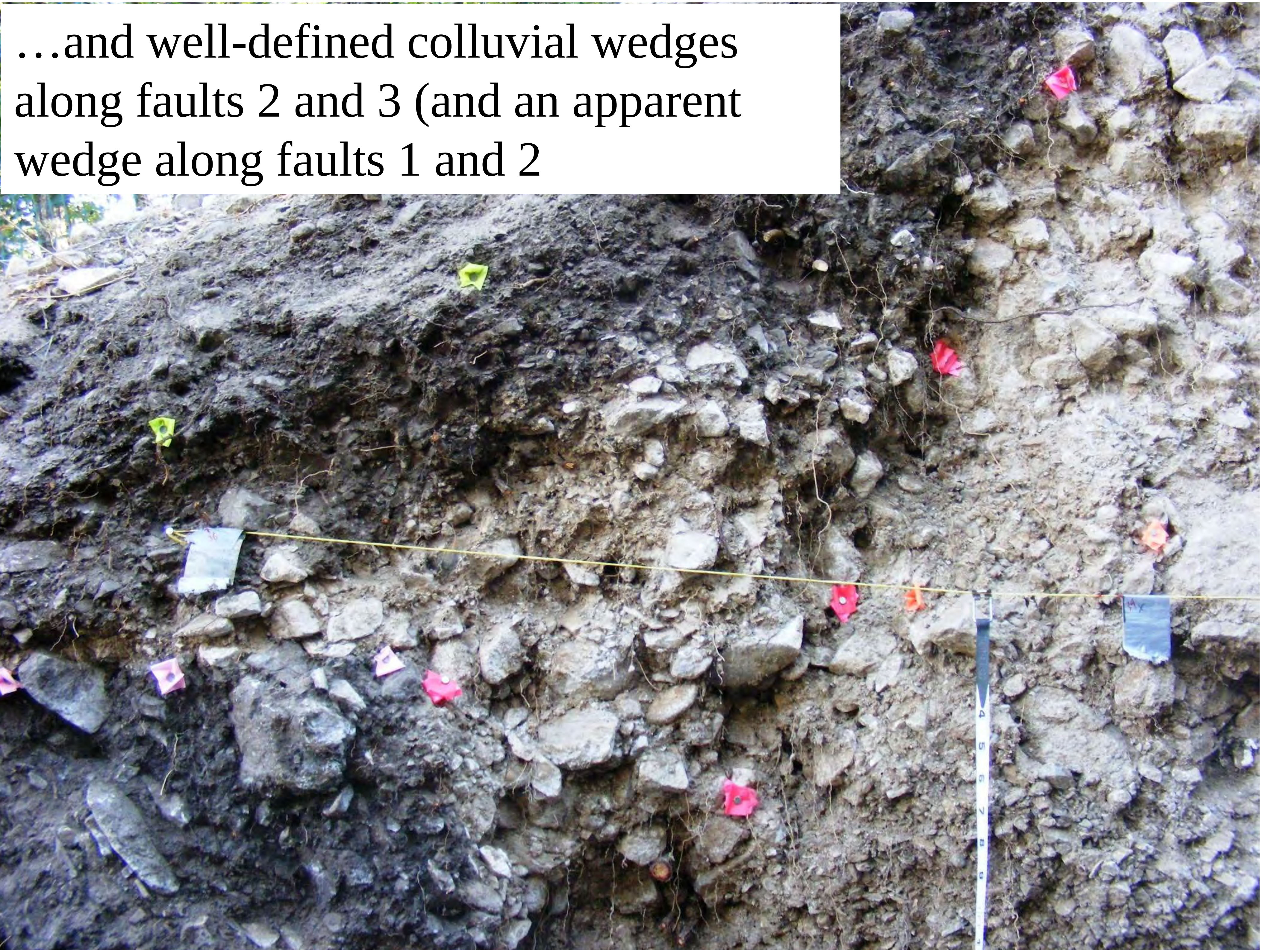


… a well-defined soil on top of debris flow unit 8…

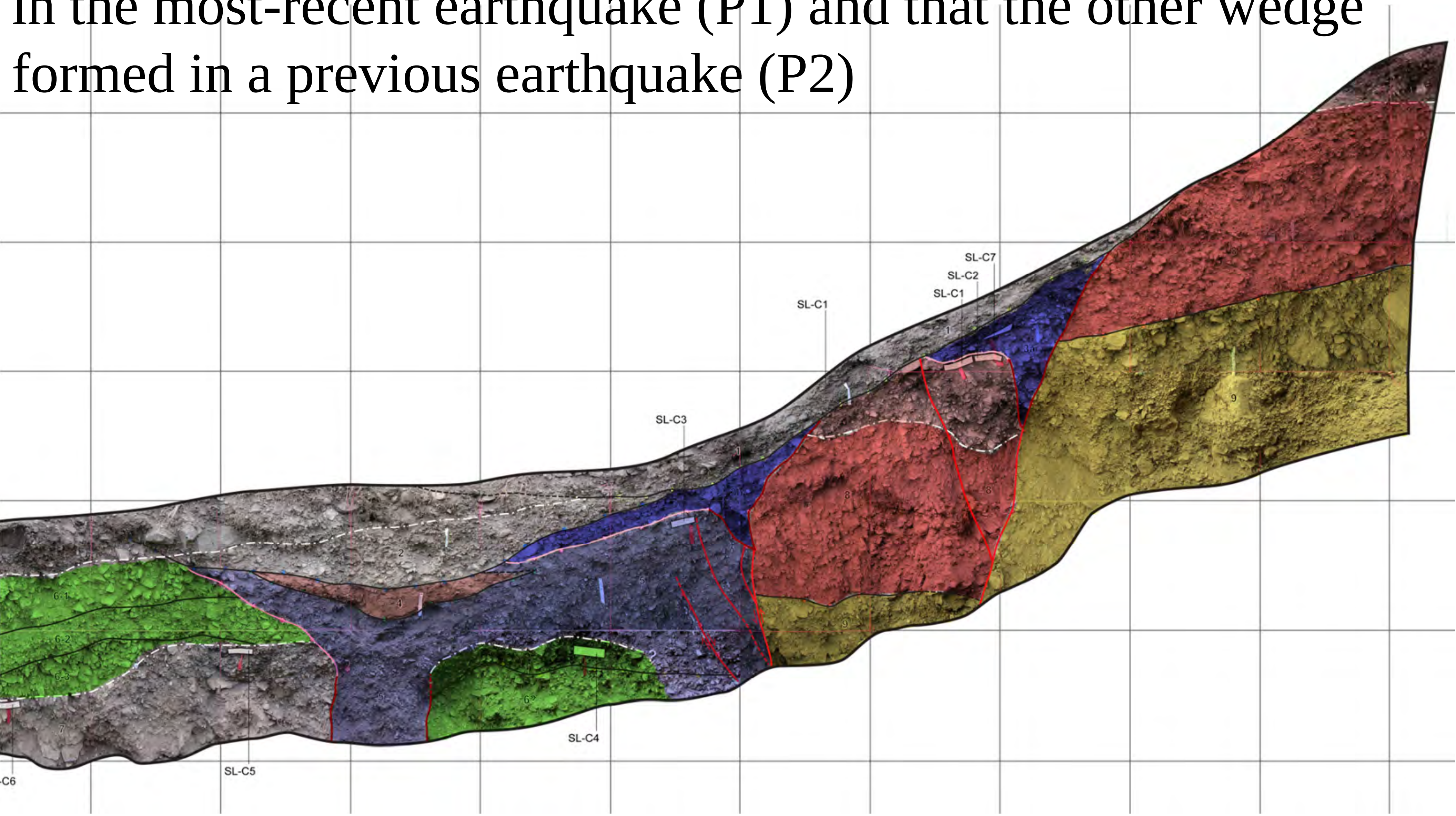
…and well-defined colluvial wedges along faults 2 and 3 (and an apparent older wedge along faults 1 and 2)

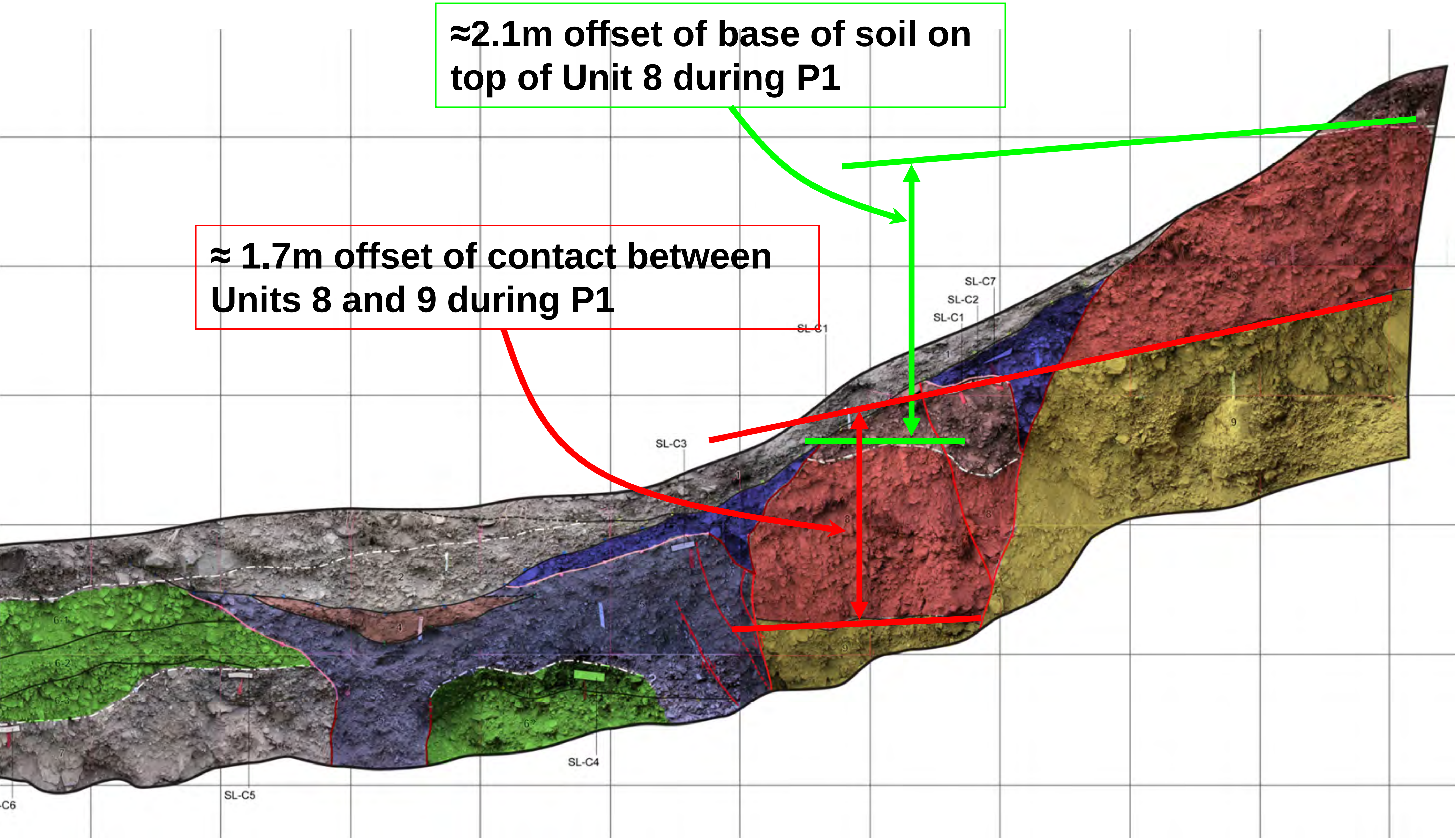


…and well-defined colluvial wedges along faults 2 and 3 (and an apparent wedge along faults 1 and 2

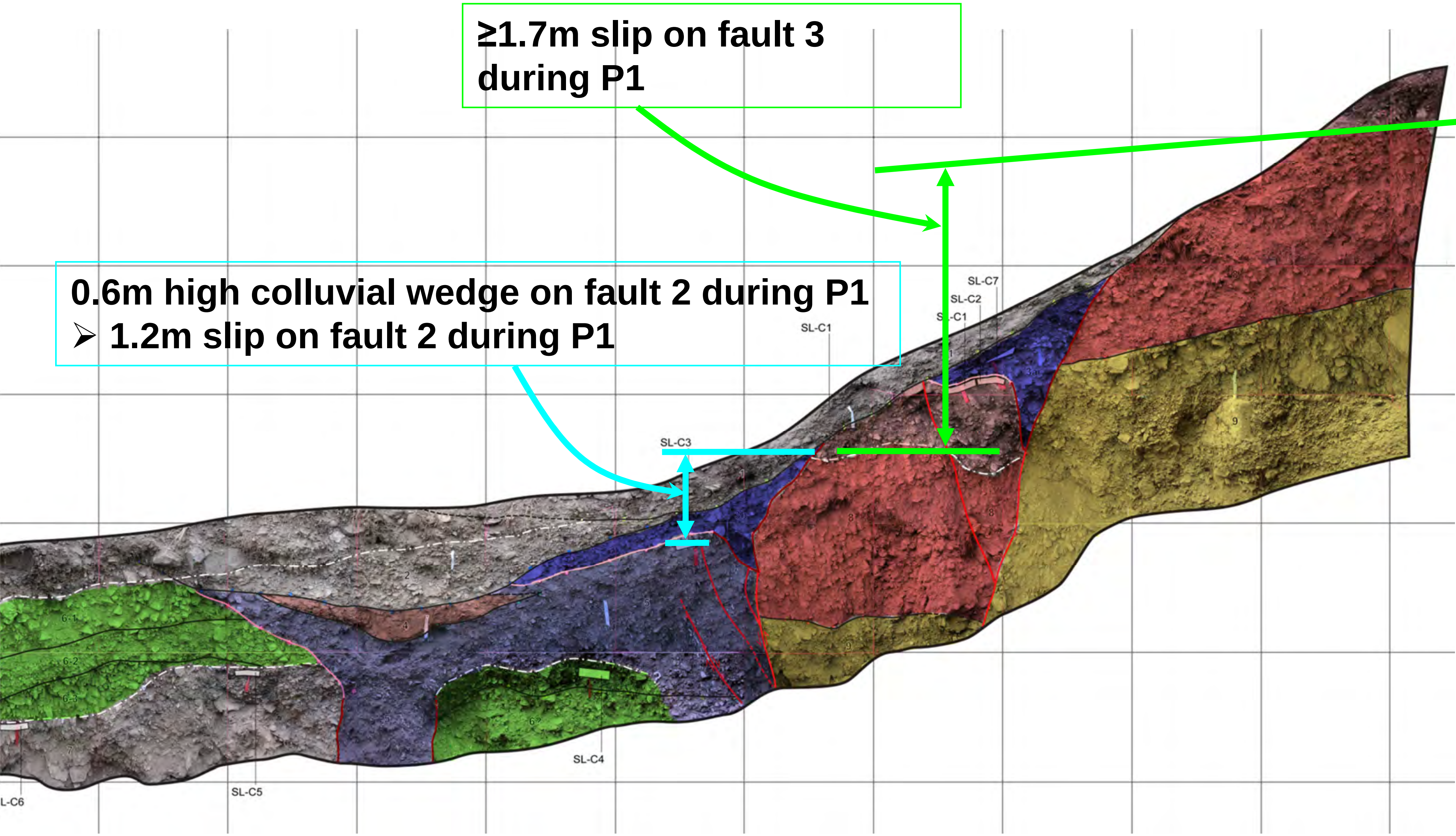


We think that the two well-defined colluvial wedges formed in the most-recent earthquake (P1) and that the other wedge formed in a previous earthquake (P2)



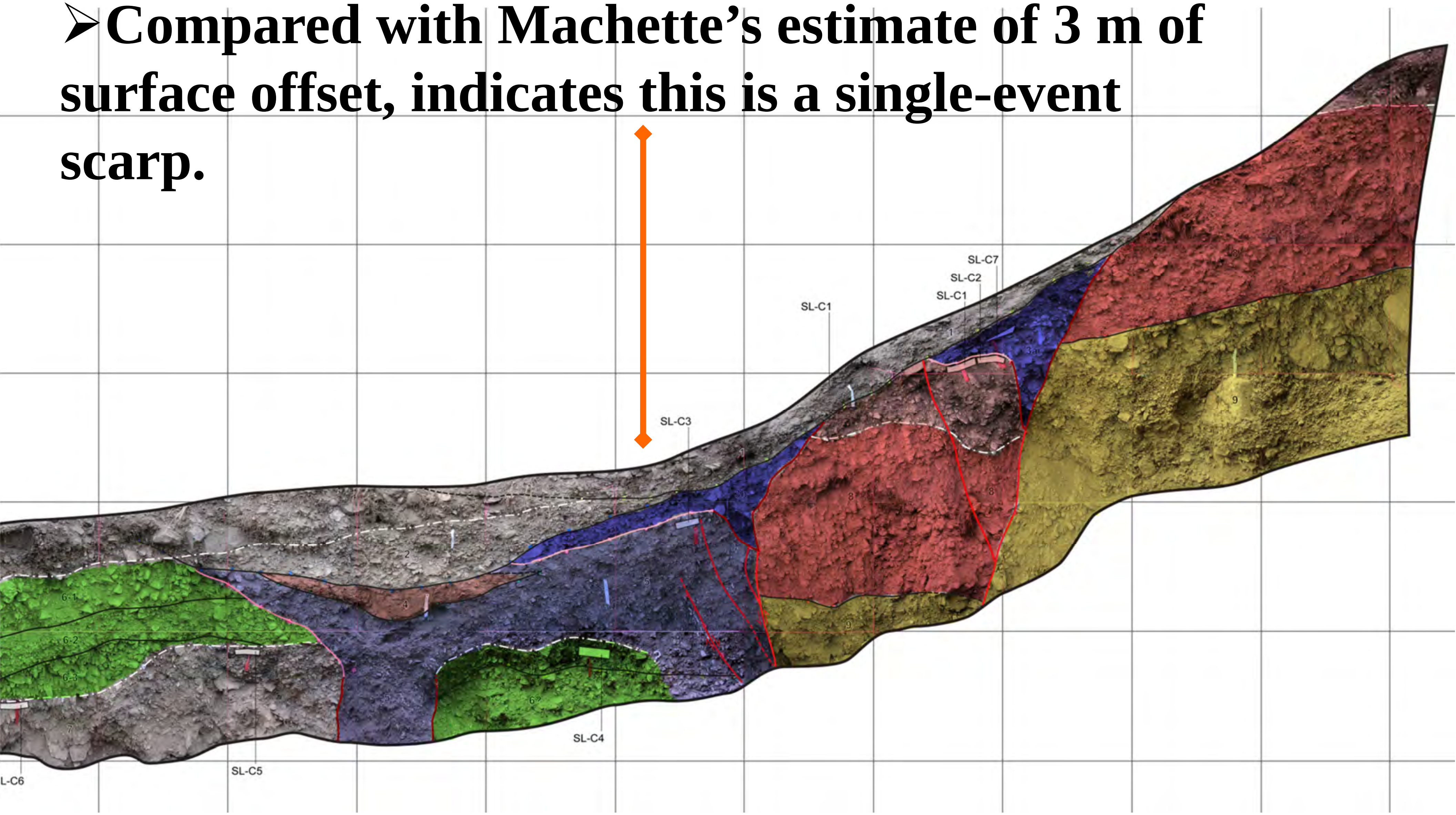


Estimating the amount of slip during P1


≥1.7m 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-C3
SL-C4
SL-C5
L-C6

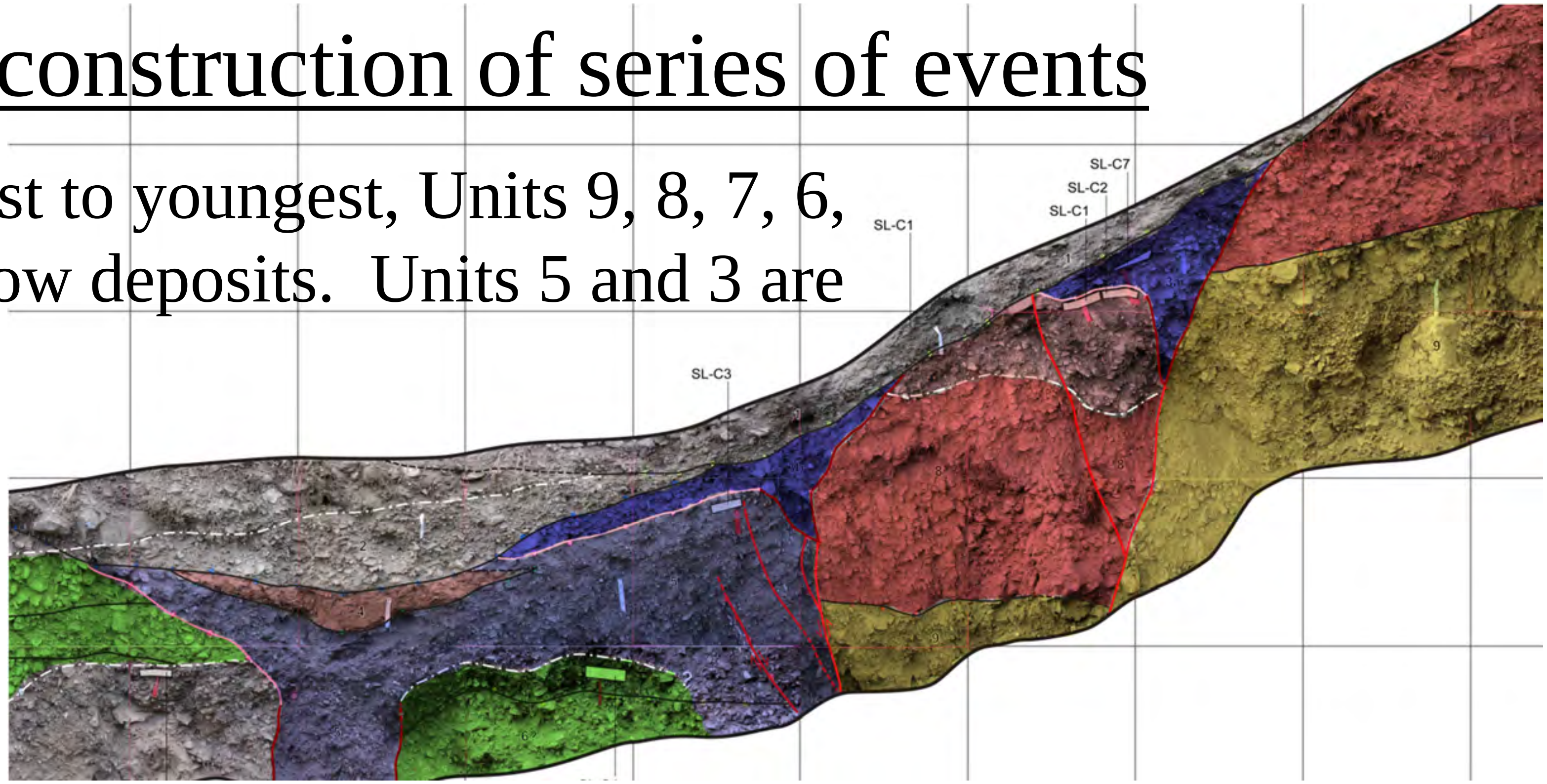
2.9m of slip during P1

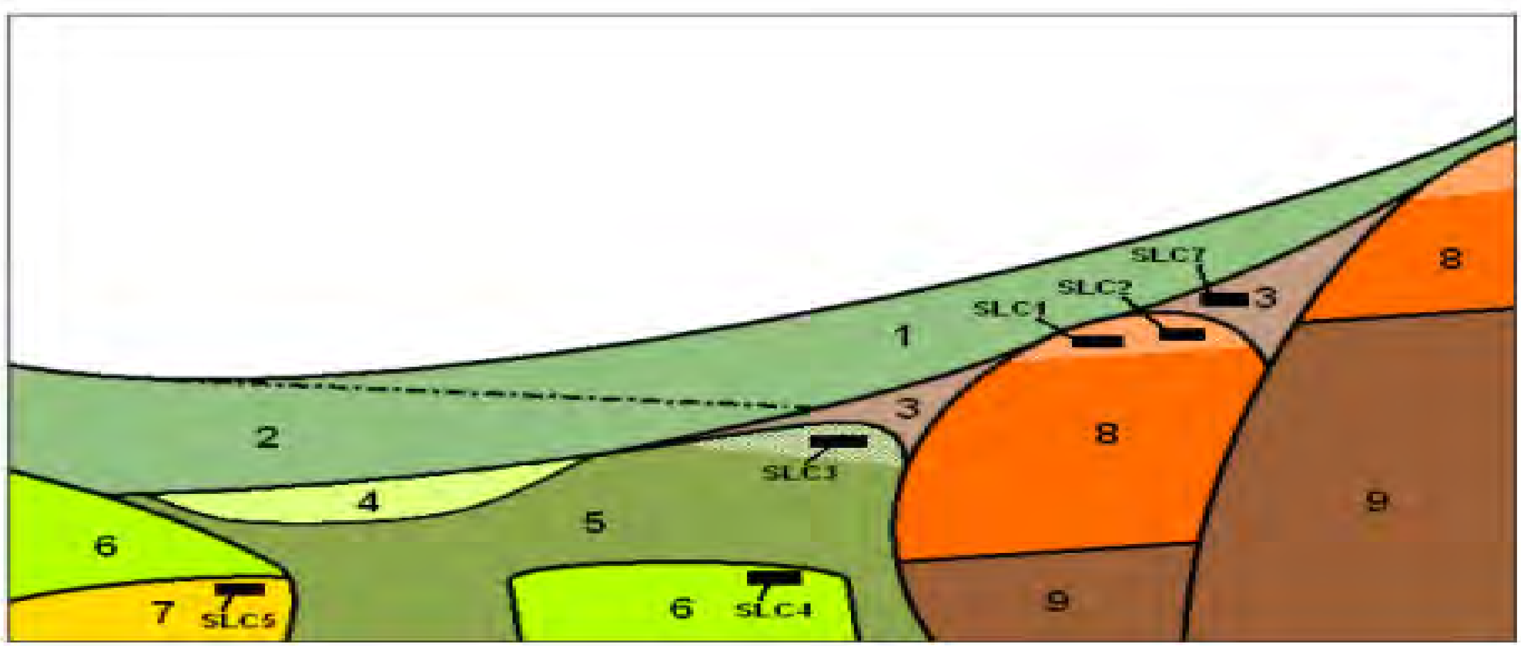
➢**Compared with Machette's estimate of 3 m of surface offset, indicates this is a single-event scarp.**



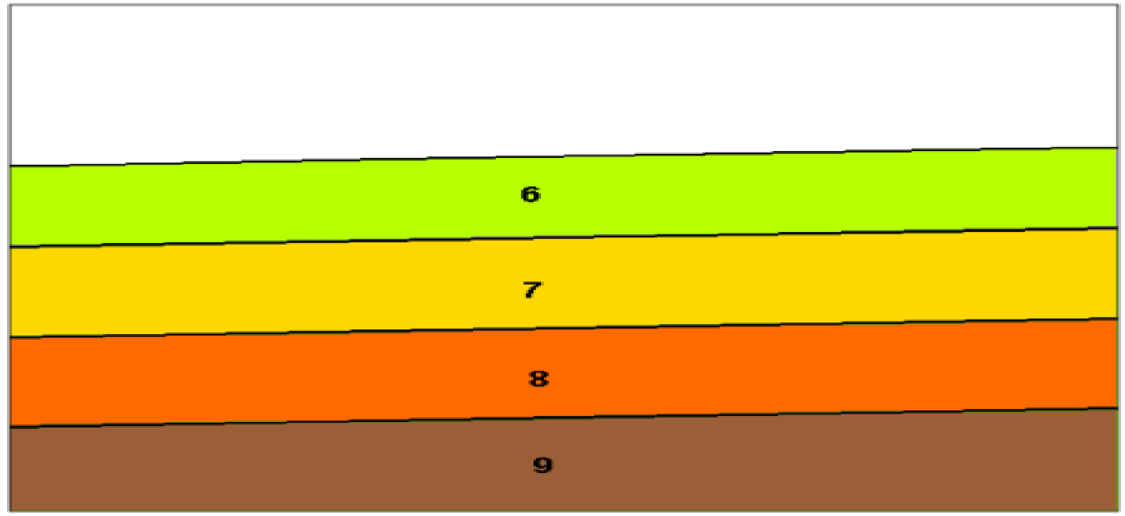
Interpreted reconstruction of series of events

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

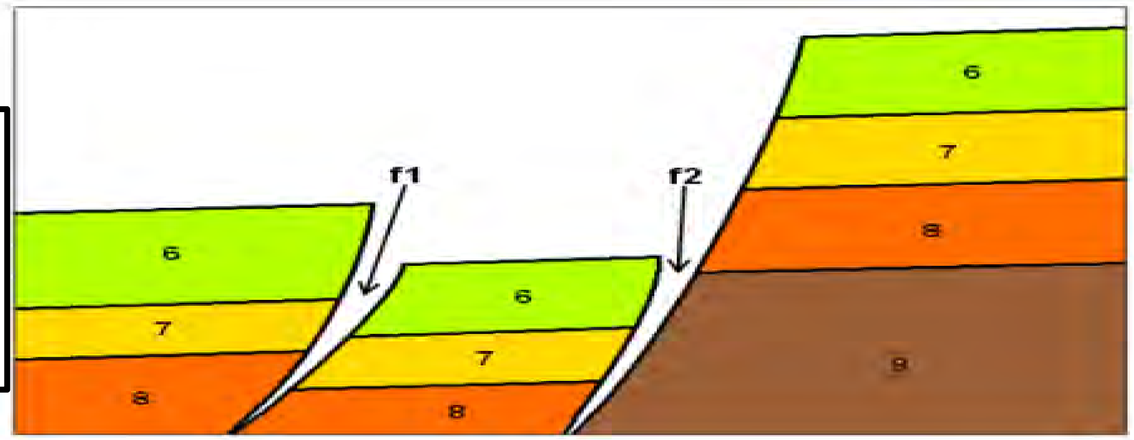




Time 1 – Deposition of multiple debris flows (6, 7, 8, 9). No faulting has occurred.



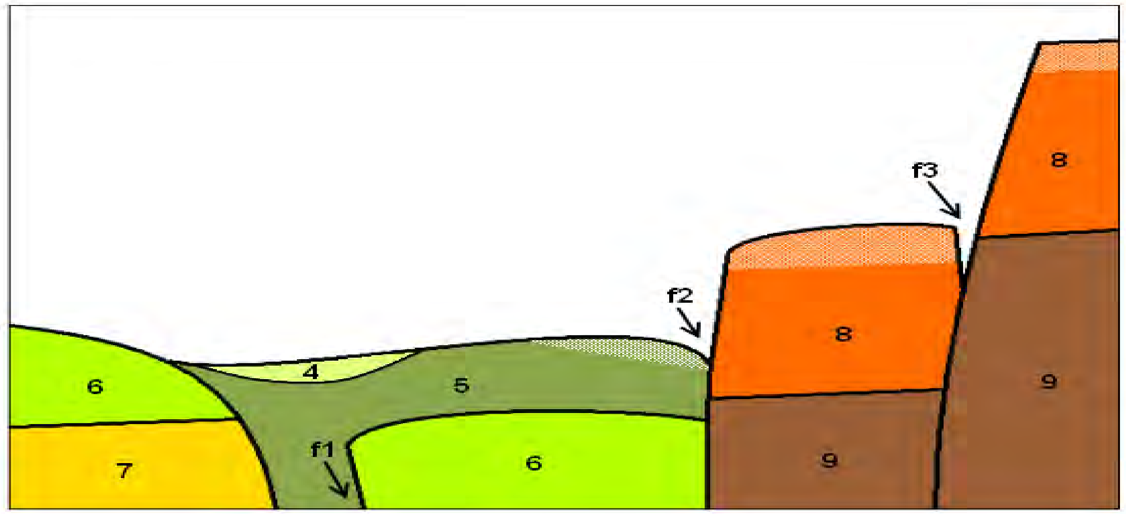
Time 2 – First faulting event (P2). Slip on faults f1 & f2; formation of graben.



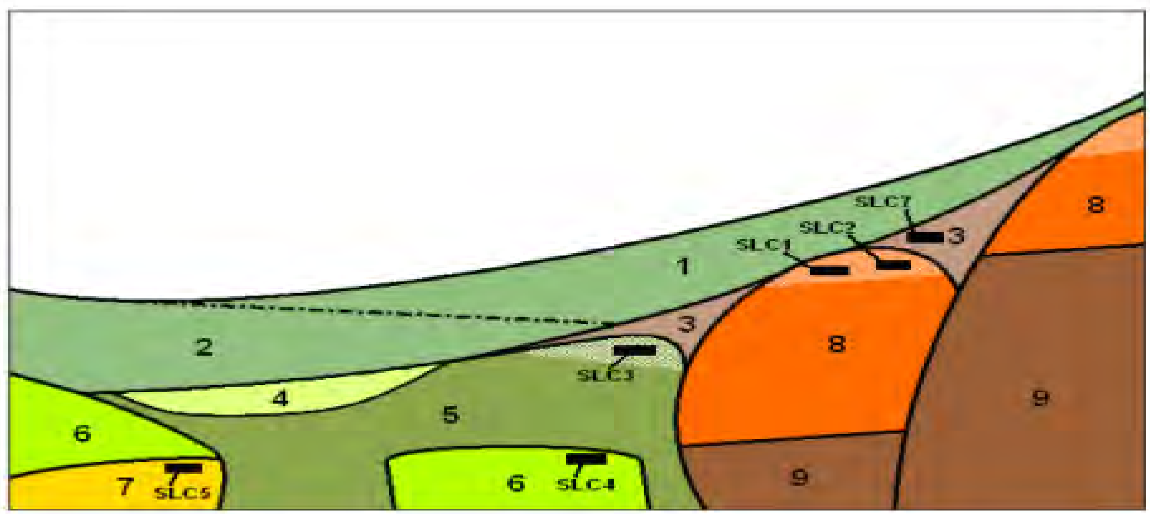
Time 3 – Unit 5 (colluvial wedge) deposited in graben. Soils form on units 5 & 8.

Time 3 – Unit 5 (colluvial wedge) deposited in graben. Soils form on units 5 & 8.

Time 4 – Second faulting event (P2). Reactivation of fault f2 and larger slip on fault f3.



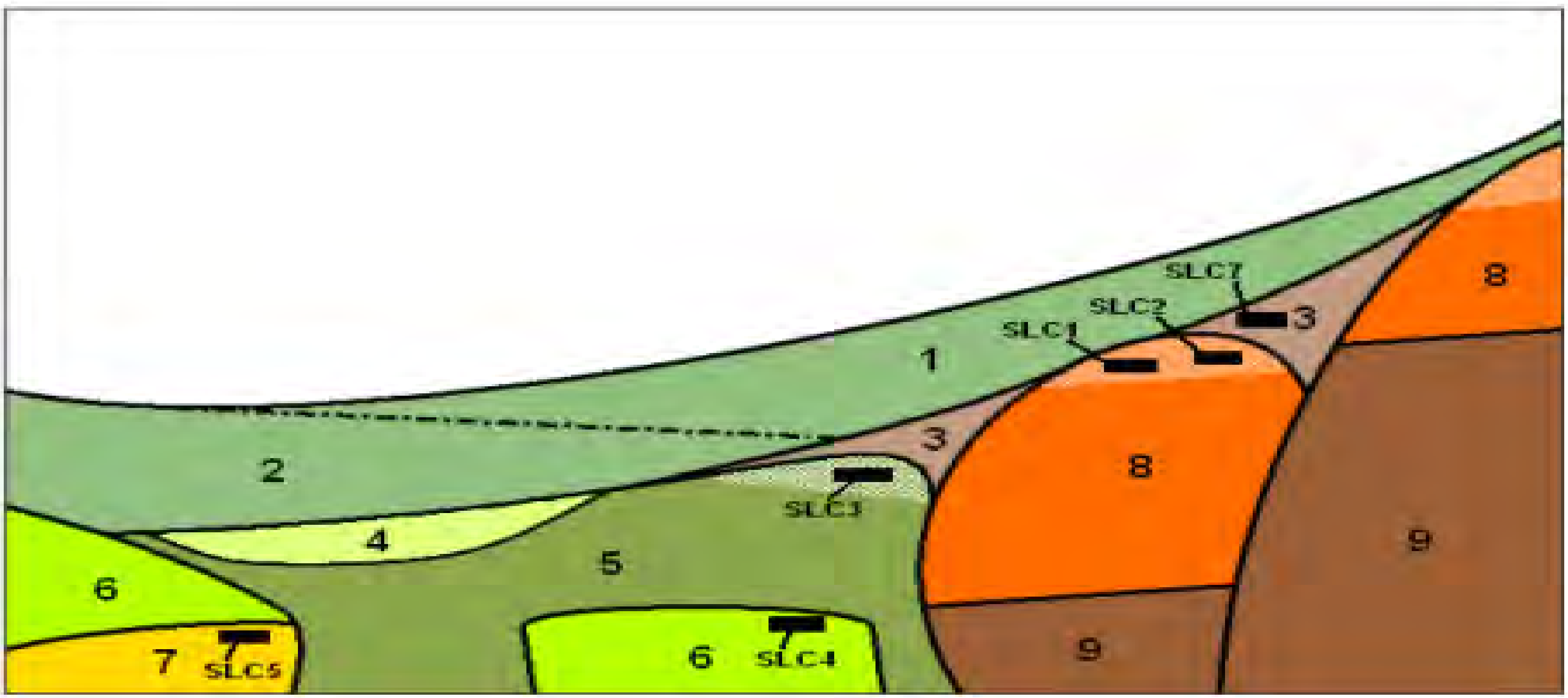
Time 5 – Present state—Unit 3 (colluvial wedge) deposited along P1 scarps. Unit 2 (debris flow) and unit 1 (slope wash) laid down.



Age constraints:

•Samples SL-C1, SL-C2, and SL-C3 will provide maximum limiting ages for P1.

•Sample SL–C4 will provide maximum limiting ages for P2.



What (we think) we can say so far:

- Two post-Bonneville surface-rupturing earthquakes evident in the trench (consistent with expectations from other trenches on the Nephi segment).
- About 2.9 m of slip distributed over two surface-rupturing faults in the most recent event (P1).
- Possible better constraints on the ages of these events will depend on the quality of dates that come from the samples

(once we get funds to run them…Gary???).

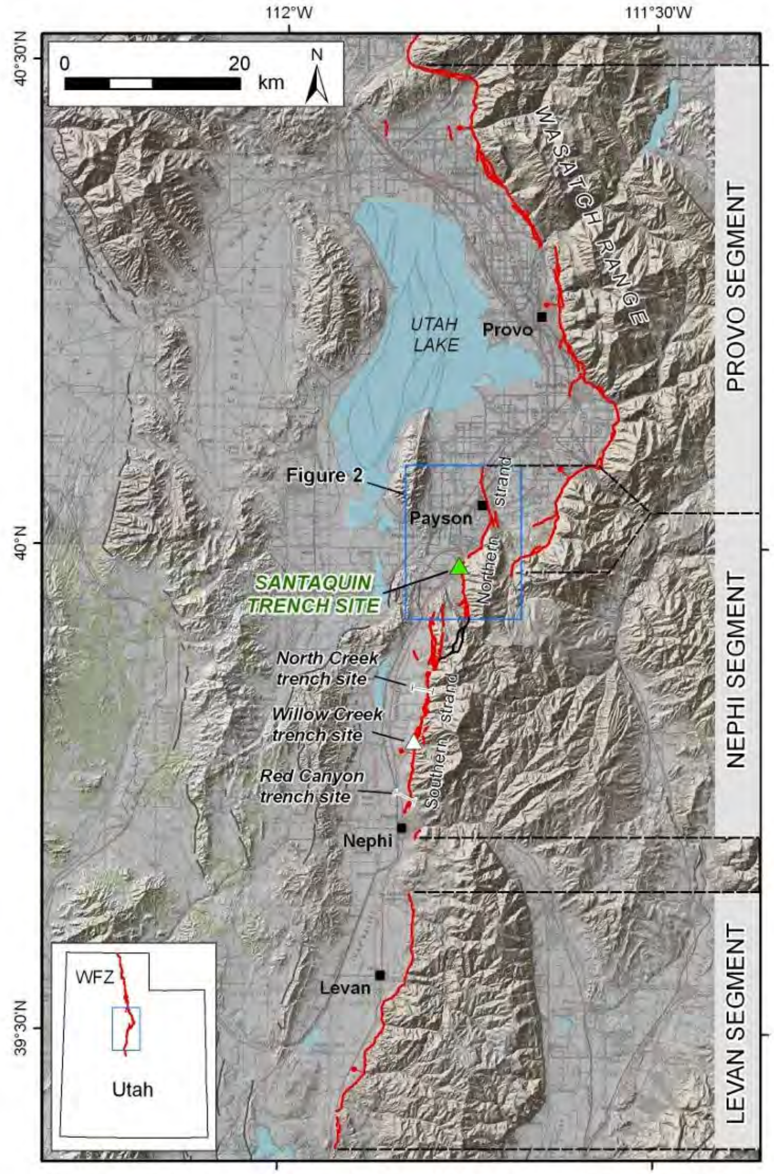
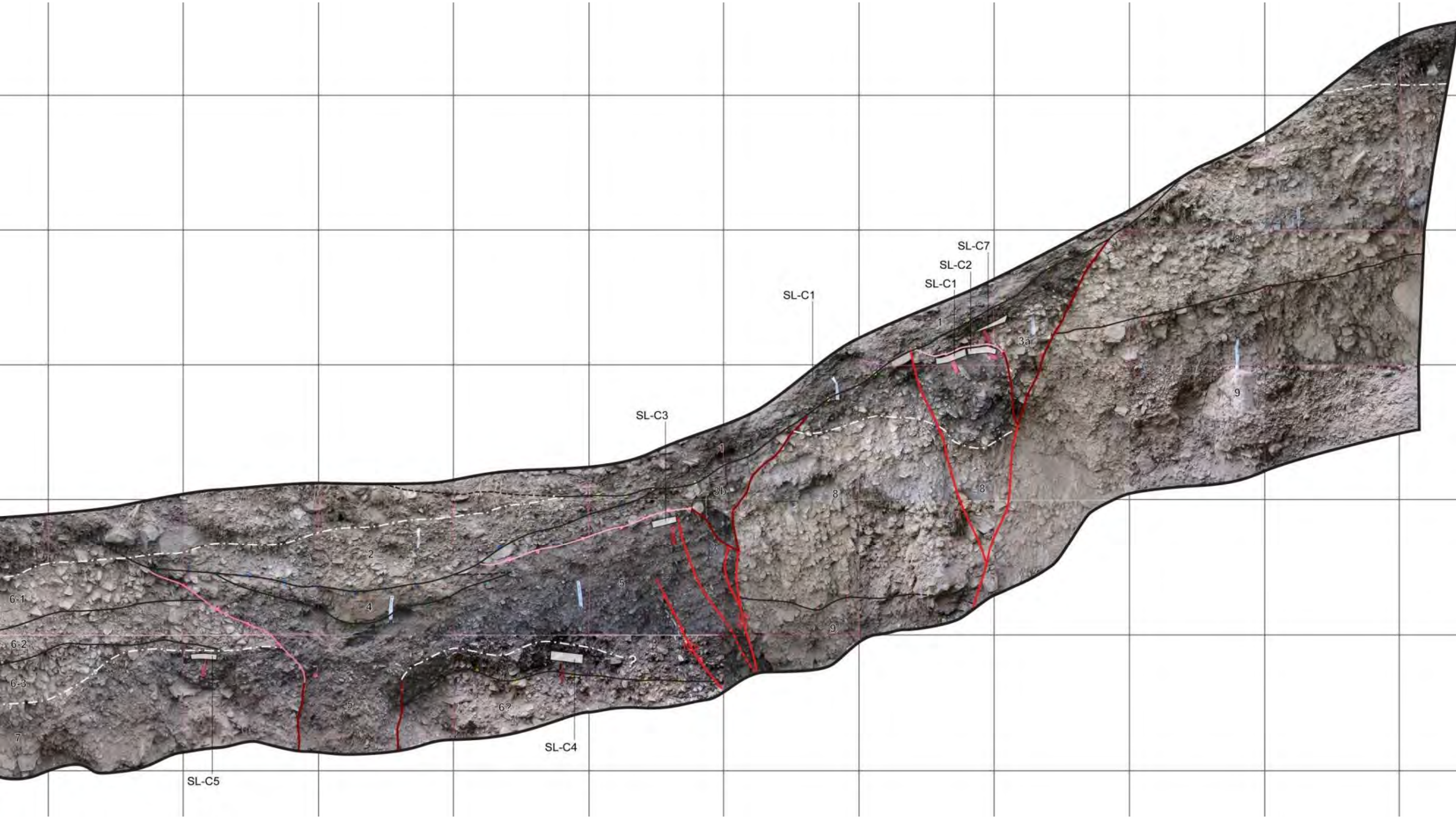
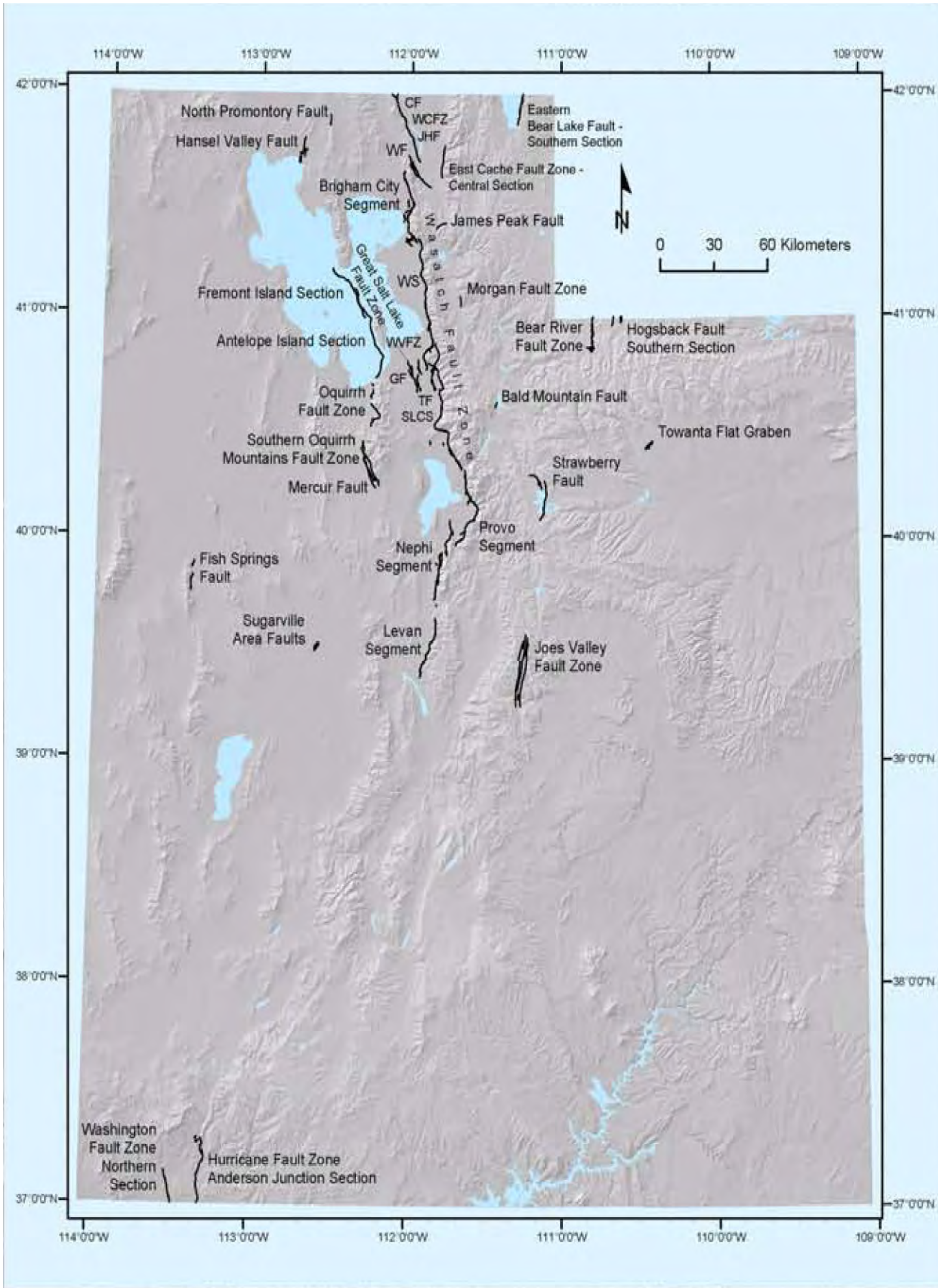


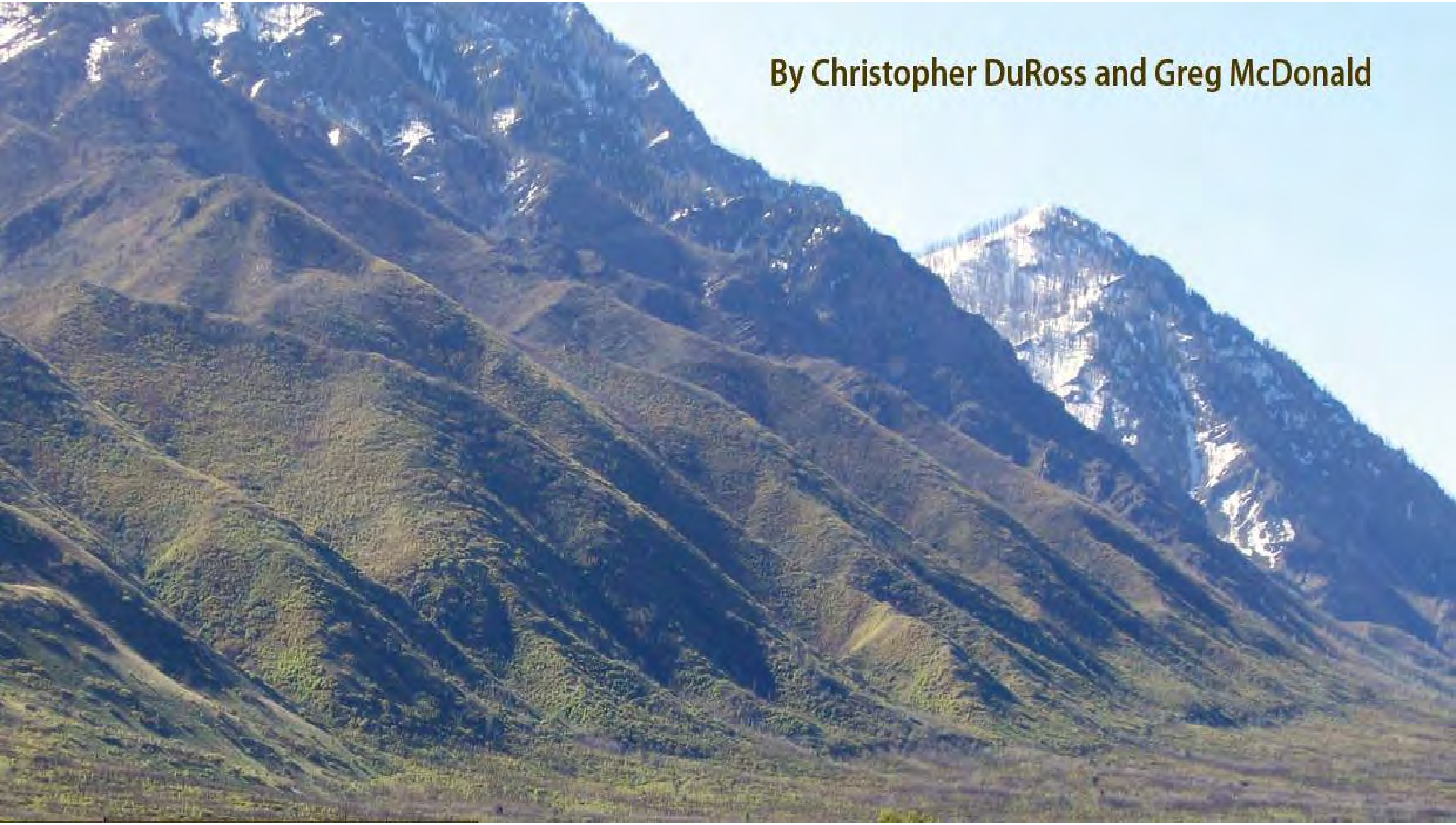
Figure 1. Surface trace of the Provo, Nephi, and Levan segments of the Wasatch fault zone (WFZ; inset) showing northern and southern strands of the Nephi segment, and locations of the Santaquin trench site, Willow Creek trench site (USGS), and pre-2005 trench sites (I shapes). Trace of WFZ (red) and other Quaternary faults (gray) from Black and others (2003); ball and bar on downthrown side. Cross fault (black) between northern and southern strands of Nephi segment modified from Harty and others (1997) and DuRoss (unpublished data, 2004). Blue box is area of figure 2. Basemaps: scanned USGS 1:250,000-scale topographic map and 30-m digital elevation model.



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

Fault/Fault Section[1]	Length[2] (km) Straight Line	Surface Trace	Earthquake Timing[3]	Consensus Preferred Recurrence Interval[4]	Consensus Preferred Vertical Slip Rate[5]
			W 5300±750 cal yr B.P. V ~7.5 ka (after 8.8-9.1 ka but before 5.1-5.3 ka) U ~9 ka (shortly after 9.5-9.9 ka) T ~17 ka S (?) 17–20 ka	V-W and U-V intervals are each roughly 2 kyr; the T-U mean interevent interval is ~8 kyr, indicating surface-faulting quiescence during earliest Holocene and latest Pleistocene time (McCalpin, 2002). Working Group Preferred Recurrence Interval 500-**1300**-2400 yr	Cottonwood Canyon. Scott (1989) reports the age of the moraine as 18-26 ka, resulting in a late Pleistocene slip rate of: 0.4-0.7-1.4 mm/yr Working Group Preferred Vertical Slip Rate 0.6-**1.2**-4.0 mm/yr
Provo segment	59	69.5	Z 600±350 cal yr B.P. Y 2850±650 cal yr B.P. X 5300±300 cal yr B.P.	Two most recent (X to Z) interevent interval average recurrence: 2400[6]±300[7] cal yr Working Group Preferred Recurrence Interval 1200-**2400**-3200 yr	Hobble Creek: Post-Provo time 0.68-0.76-0.83 mm/yr Post-Bonneville time 2.2-2.4-2.7 mm/yr American Fork Canyon: Post-Bonneville time 0.8-1.1-1.4 mm/yr Spanish Fork Canyon: Post-Provo time 0.18-0.19 mm/yr East of Provo between Slate and Slide Canyons: Post-Bonneville time ≤ 1.1-1.2 mm/yr Working Group Preferred Vertical Slip Rate 0.6-**1.2**-3.0 mm/yr
Nephi segment	37.5	42.5	Z ≤1.0±0.4 ka Y ~3.9±0.5 ka X >3.9±0.5 ka, <5.3±0.7 ka	Two most recent (X to Z) interevent interval average recurrence: ~2500[6]±2100[7] cal yr Working Group Preferred Recurrence Interval 1200-**2500**-4800 yr	North Creek (Schwartz and Coppersmith, 1984): Middle Holocene 1.27-1.36±0.1 mm/yr Harty and others (1997) middle Holocene slip-rate estimates: North Creek 0.8-1.2 mm/yr Willow Creek 0.7-1.0 mm/yr Gardner Creek 0.5-0.7 mm/yr Red Canyon 0.6-1.0 mm/yr


114°0'0"W
113°0'0"W
112°0'0"W
111°0'0"W
110°0'0"W
109°0'0"W
42°0'0"N
41°0'0"N
40°0'0"N
39°0'0"N
38°0'0"N
37°0'0"N
North Promontory Fault
Hansel Valley Fault
CF
WCFZ
JHF
WF
Eastern Bear Lake Fault - Southern Section
East Cache Fault Zone - Central Section
Brigham City Segment
James Peak Fault
0 30 60 Kilometers
Great Salt Lake Fault Zone
Fremont Island Section
WS
Wasatch Fault Zone
Morgan Fault Zone
Antelope Island Section
WVFZ
Bear River Fault Zone
Hogsback Fault Southern Section
GF
Oquirrh Fault Zone
TF
SLCS
Bald Mountain Fault
Southern Oquirrh Mountains Fault Zone
Towanta Flat Graben
Strawberry Fault
Mercur Fault
Provo Segment
Nephi Segment
Fish Springs Fault
Sugarville Area Faults
Levan Segment
Joes Valley Fault Zone
Washington Fault Zone Northern Section
Hurricane Fault Zone Anderson Junction Section


By Christopher DuRoss and Greg McDonald

Update of Weber Segment Trenching Investigation at Rice Creek, North Ogden

Utah Quaternary Fault Parameters Working Group

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Greg McDonald
William Lund
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UTAH DNR GEOLOGICAL SURVEY

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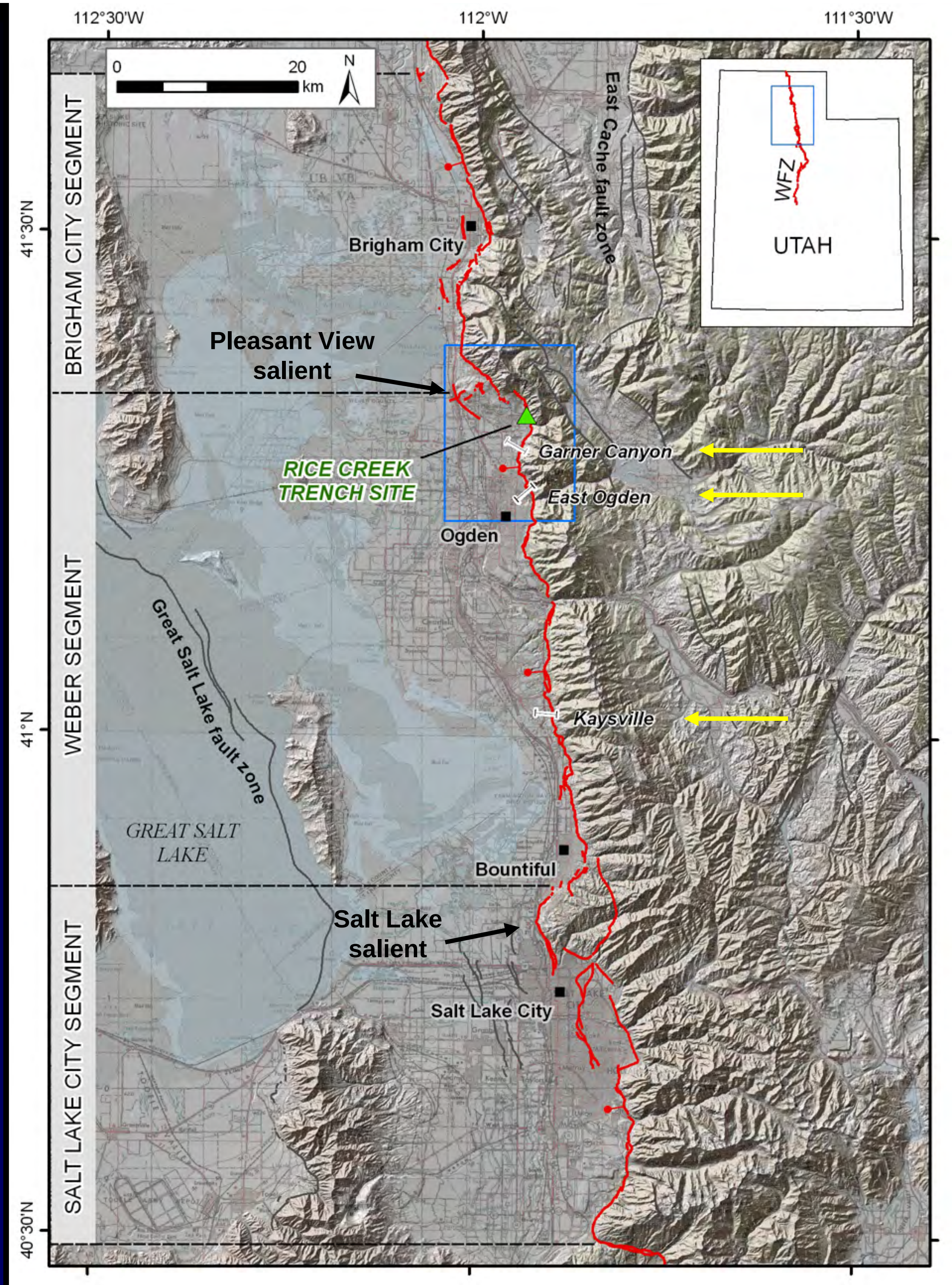
Introduction

- Purpose:
  - Address poorly constrained paleoearthquake parameters and evaluate the possibility of a 500-yr-old partial-segment rupture
- Objectives:
  - Develop a paleoseismic record at Rice Creek site
  - Extend length of paleoseismic record into early Holocene time, if possible
  - Refine event correlations between Weber segment trench sites
  - Refine earthquake recurrence and fault slip rate estimates for entire segment
  - Examine segmentation of northern WFZ, specifically between the Weber and Brigham City segments

Weber segment

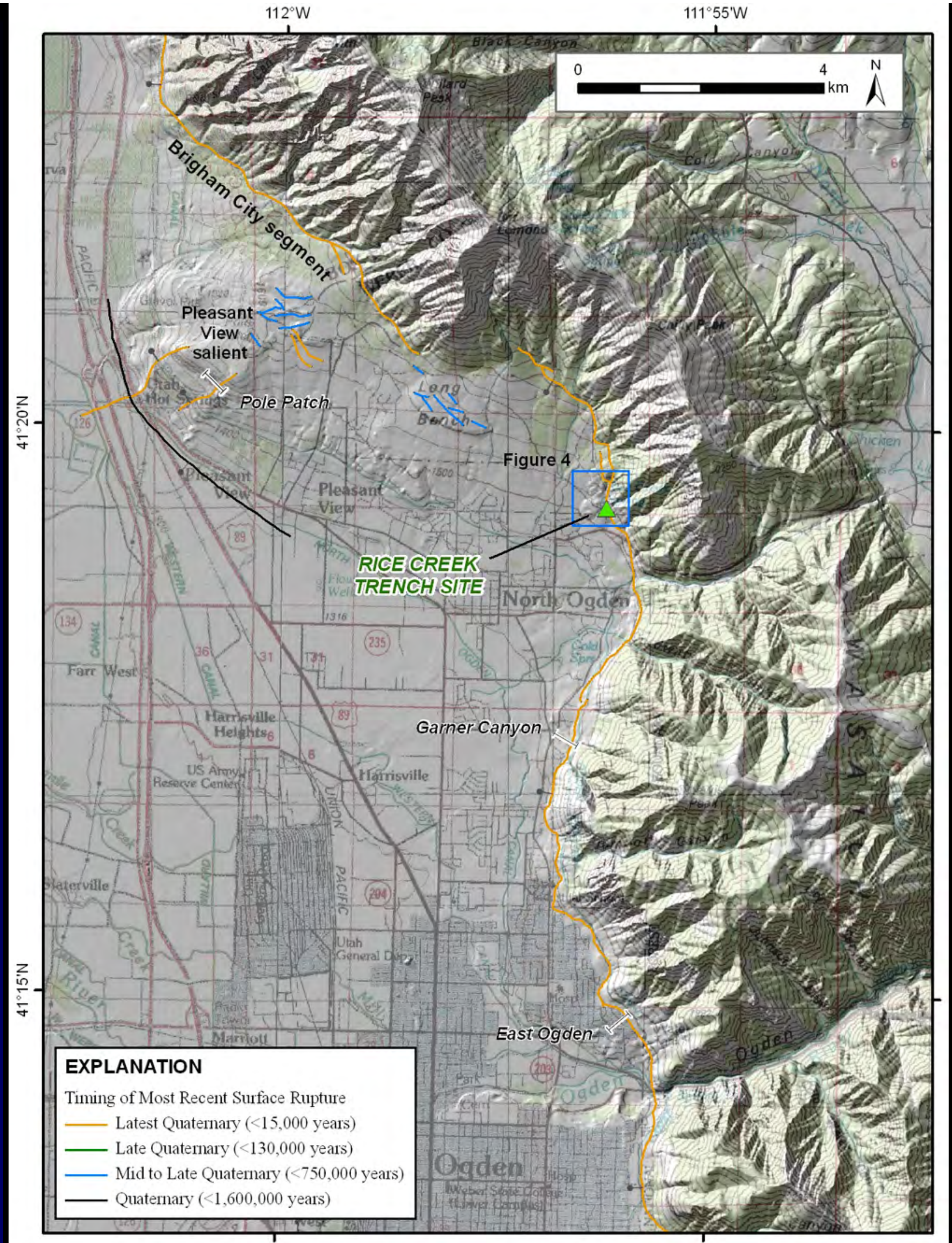
- 56 km long
  - Extends from Salt Lake salient on south to Pleasant View salient on north
- Sites of previous paleoseismic studies
  - Kaysville
    - Swan et al., 1980
    - McCalpin et al., 1994
  - East Ogden
    - Nelson et al., 2006
  - Garner Canyon
    - Nelson et al., 2006



Weber segment

Summary of paleoseismic data:

- Evidence of 3-4 events at each site
- UQFPWG consensus:
  - RI: 500-1400-2400 yr
  - SR: 0.6-1.2-4.3 mm/yr
- Vertical displacement: 2.1±1.28 m



Why trench the Weber segment?

1. Earthquake timing and correlation (among trench sites):

Event	***UQFPWG***	***Kaysville***		***East Ogden***		***Garner Canyon***
P1	500 ± 300	X		200-600		X
P2	950 ± 450	600-800	—	500-1700	—	600-1500
P3	3000 ± 700	2100-3500	—	2400-3900	—	1400-2800
P4	4500 ± 700	X	?	2800-4800	-?-	>2100-2800
P5	6100 ± 700	5700-6100 (3800-7900)		X		X

X: Evidence of an event of this age not found

Calendar ages rounded to nearest century

Why trench the Weber segment?

2. Fault parameters:

- RI, SR – variable, depending on event correlation
- Displacement per event – highly variable (0.5-4.2 m)

3. Segmentation Questions:

- Possibility of a 500-yr-old partial-segment rupture
- Brigham-City – Weber segment boundary?

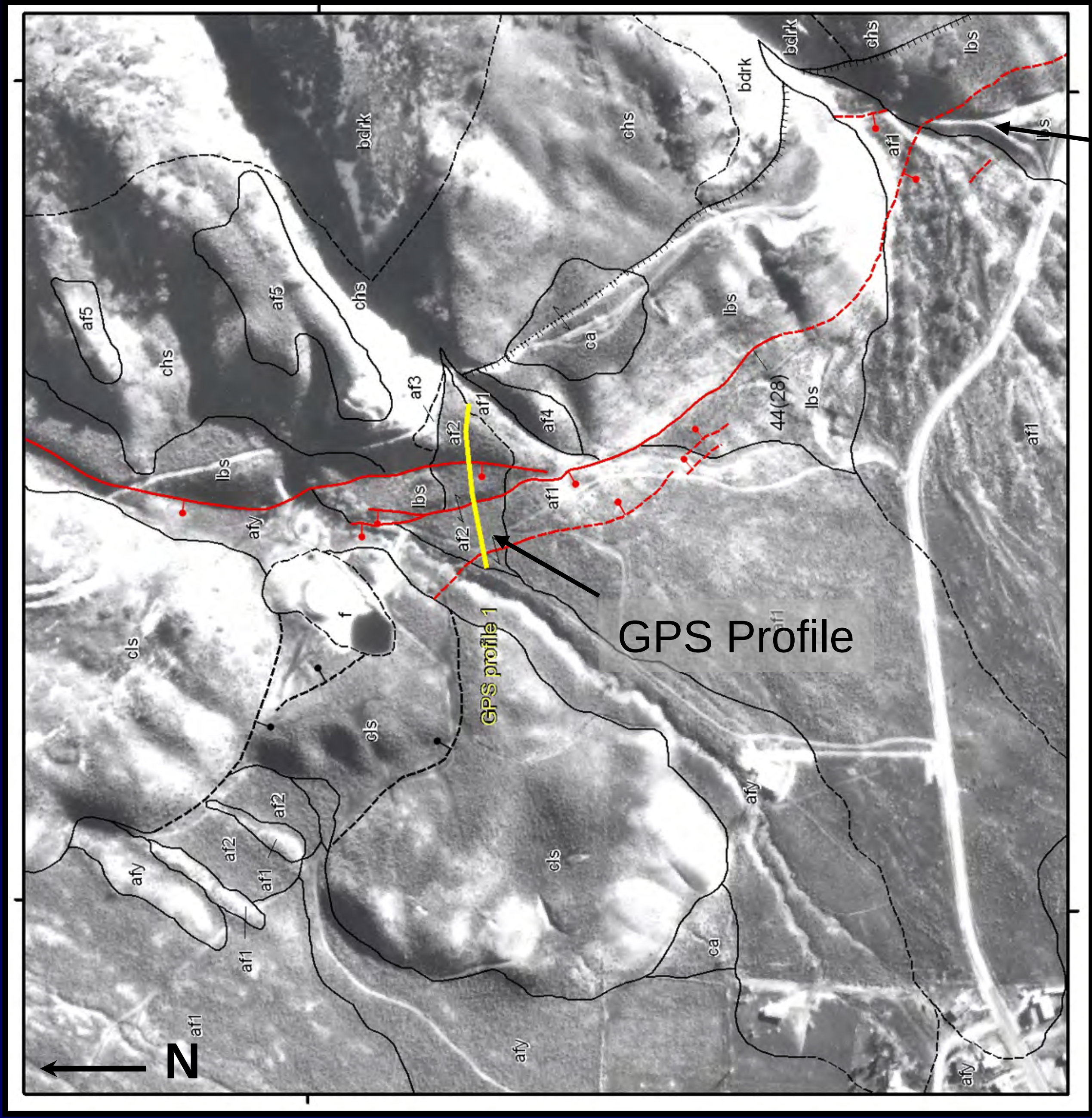
Why the Rice Creek site?

- Large, unmodified scarps on Holocene alluvial fan
- Narrow fault zone
- One of very few available sites where scarps are of workable size

But…

- Close to northern segment boundary
- Coarse material (on surface)

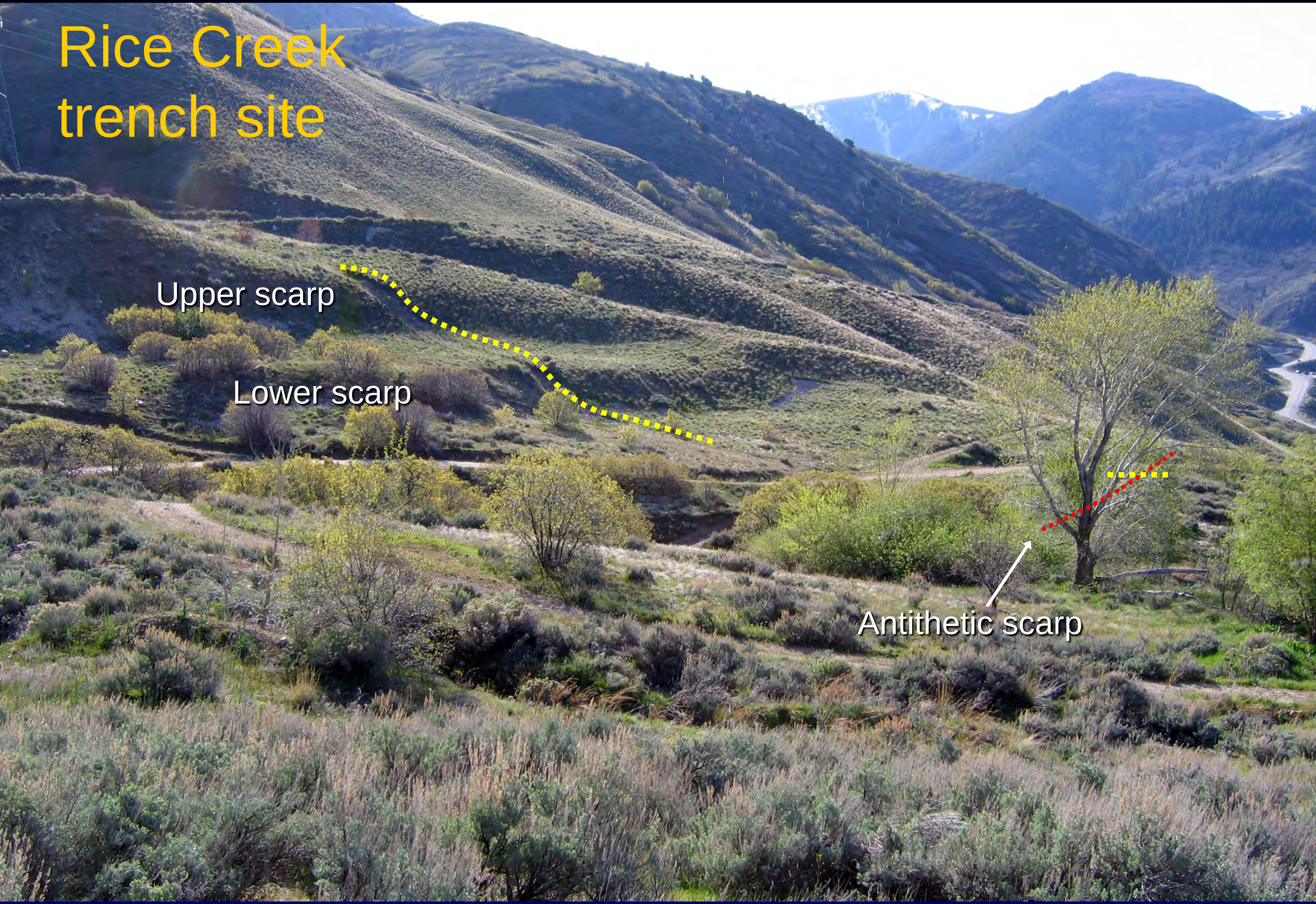
Rice Creek Trench Site



North Ogden Canyon

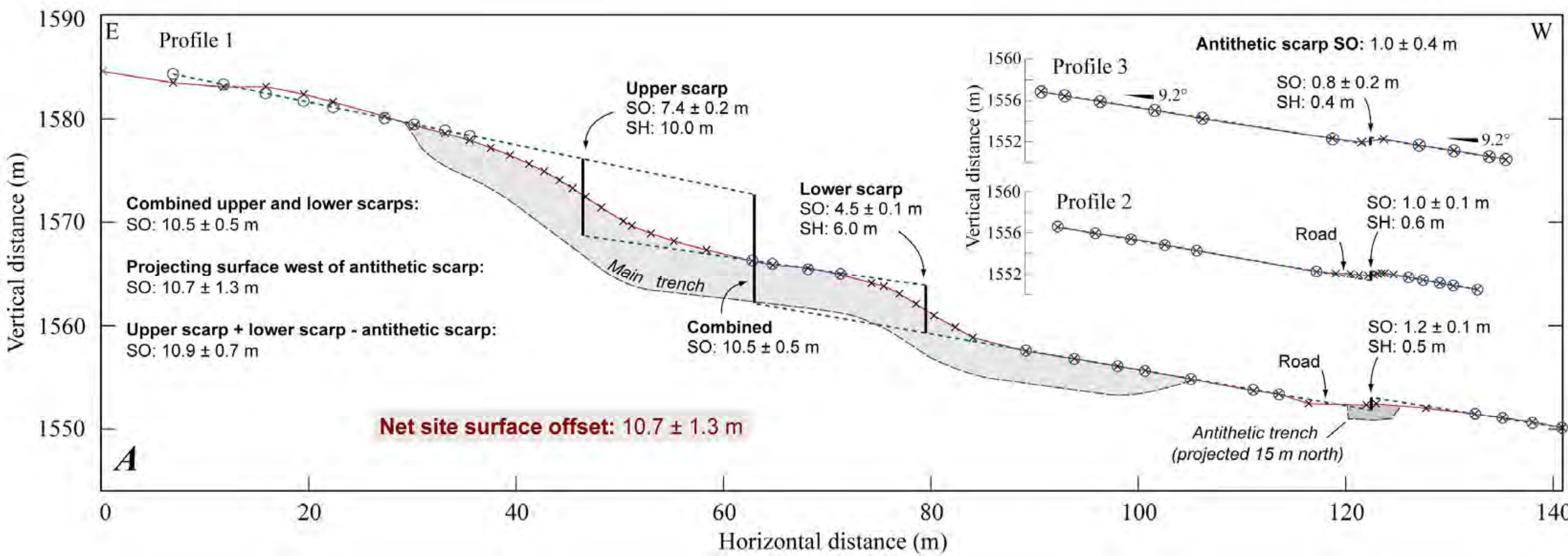
Woodward-Clyde photograph, circa 1975

Rice Creek trench site


Rice Creek
trench site
Upper scarp
Lower scarp
Antithetic scarp

Surface Offset

- Vertical surface offset
  - Upper scarp: 7.4 m
  - Lower scarp: 4.5 m
  - Antithetic scarp: 1.0 m
  - Site (net): 9.4-12.0 m

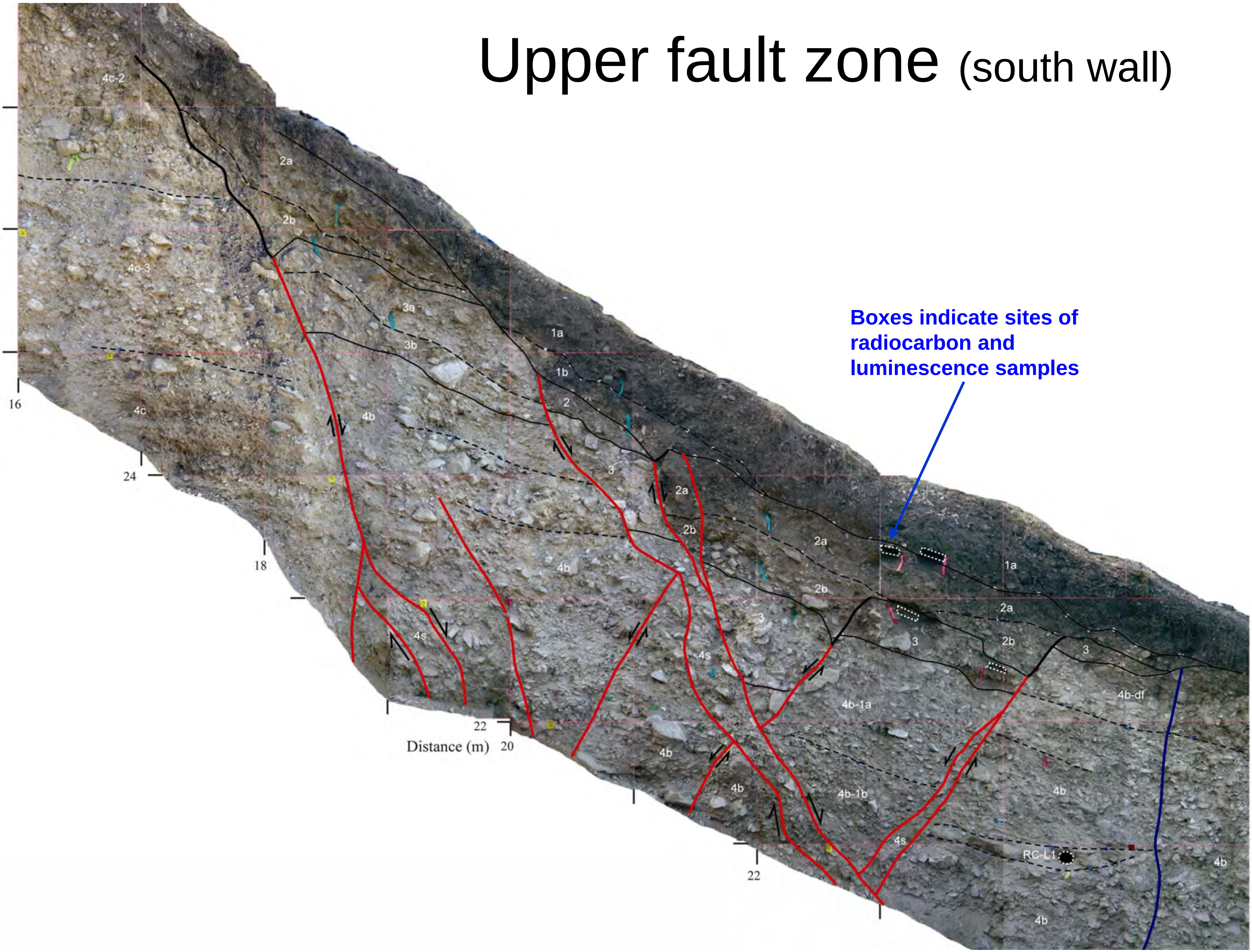



Rice Creek trench site
Upper scarp
Lower scarp

Main trench

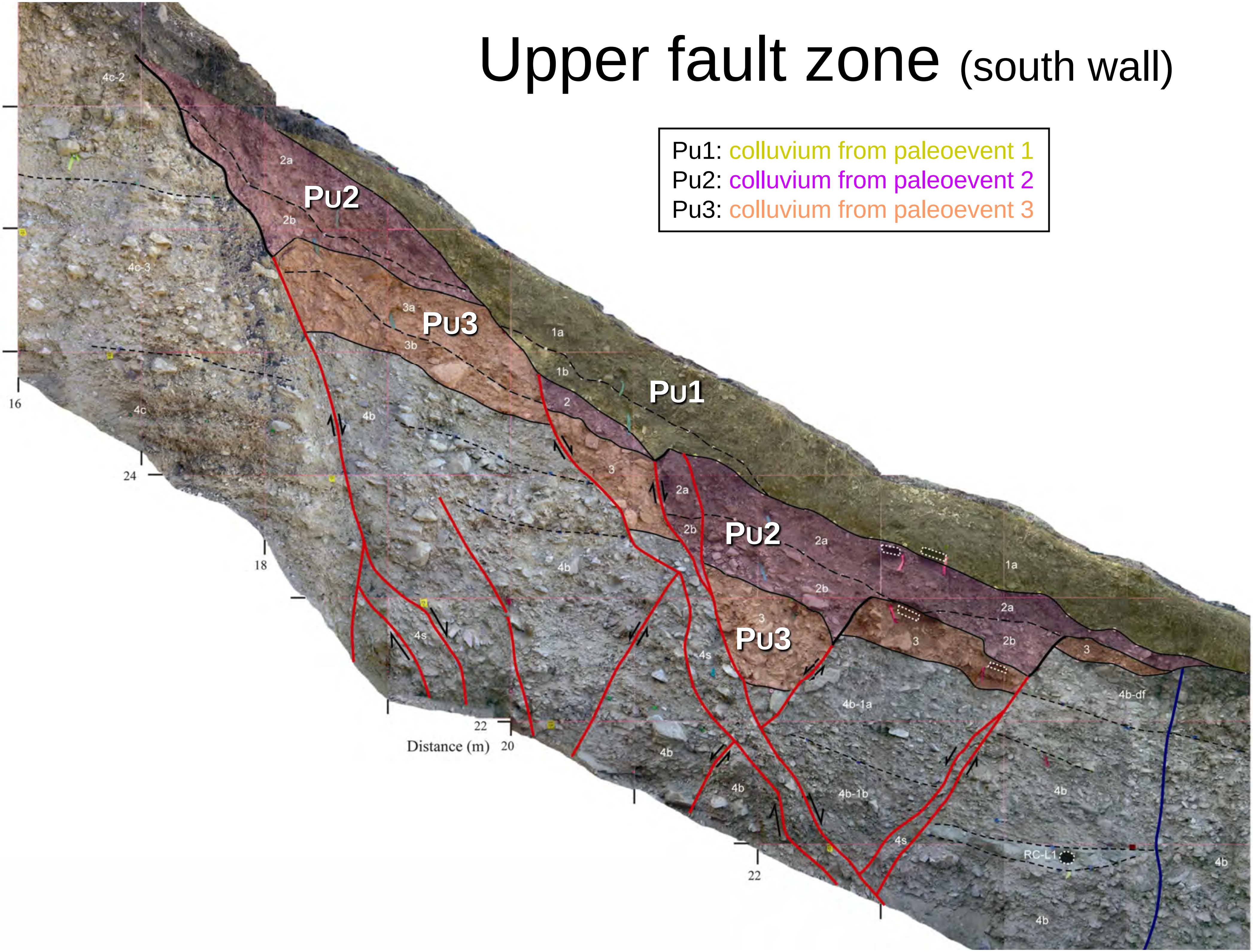
- 75 m long
- 2-4+ m deep
- Two main fault zones:
  - UFZ: upper scarp
  - LFZ: lower scarp

Upper fault zone (south wall)



Upper fault zone (south wall)

Pu1: colluvium from paleoevent 1
Pu2: colluvium from paleoevent 2
Pu3: colluvium from paleoevent 3



Upper fault zone (south wall)

Pu1: colluvium from paleoevent 1
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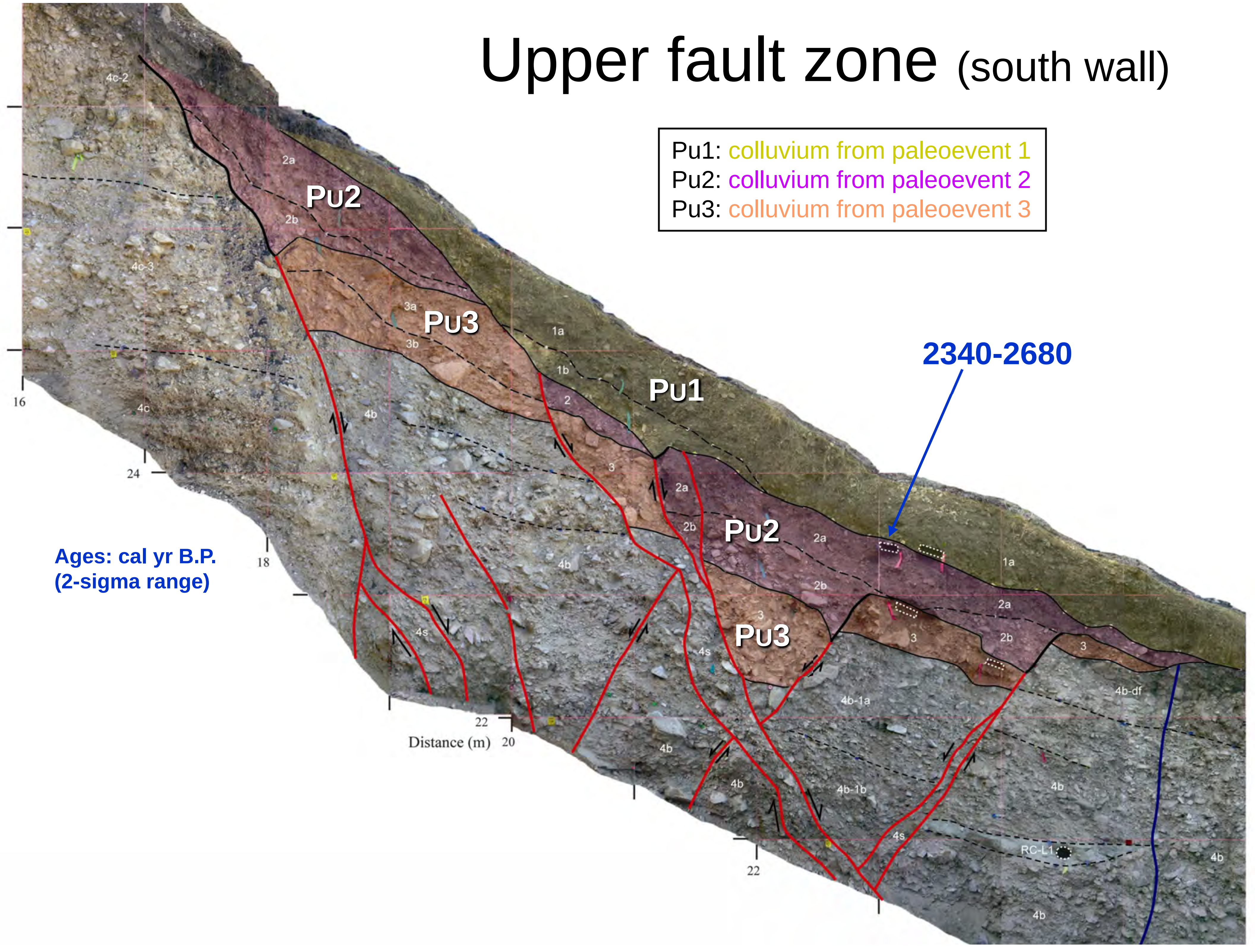
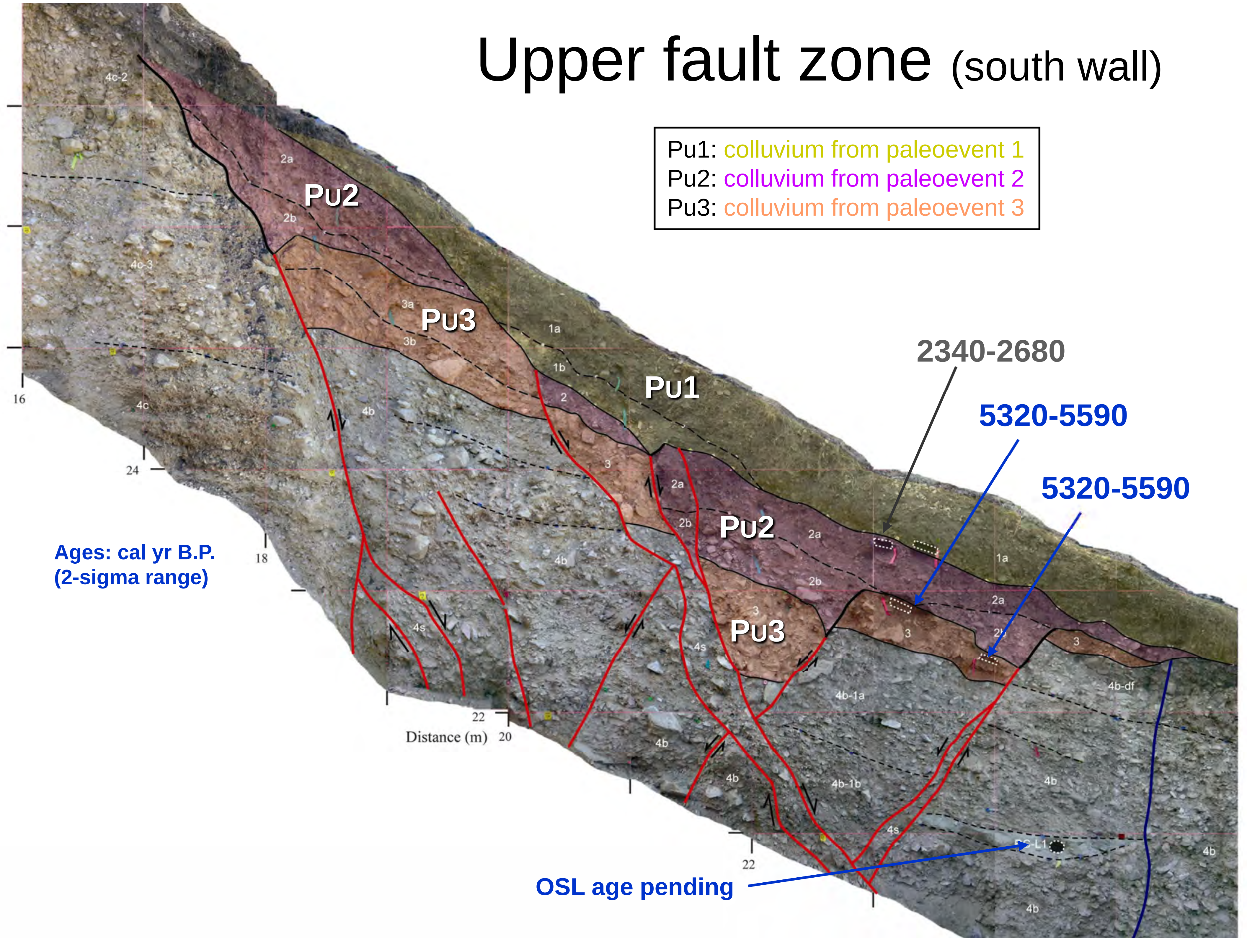
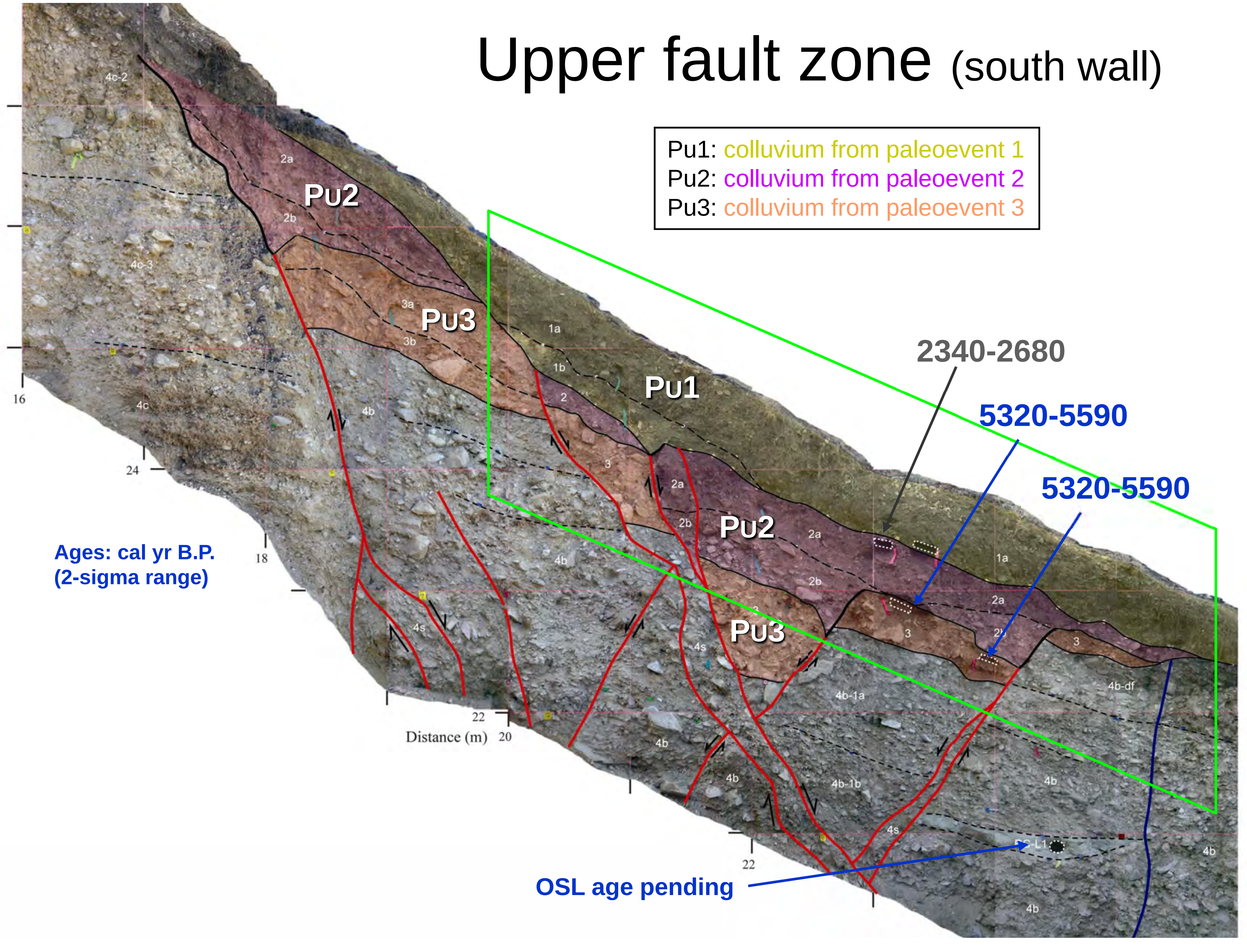


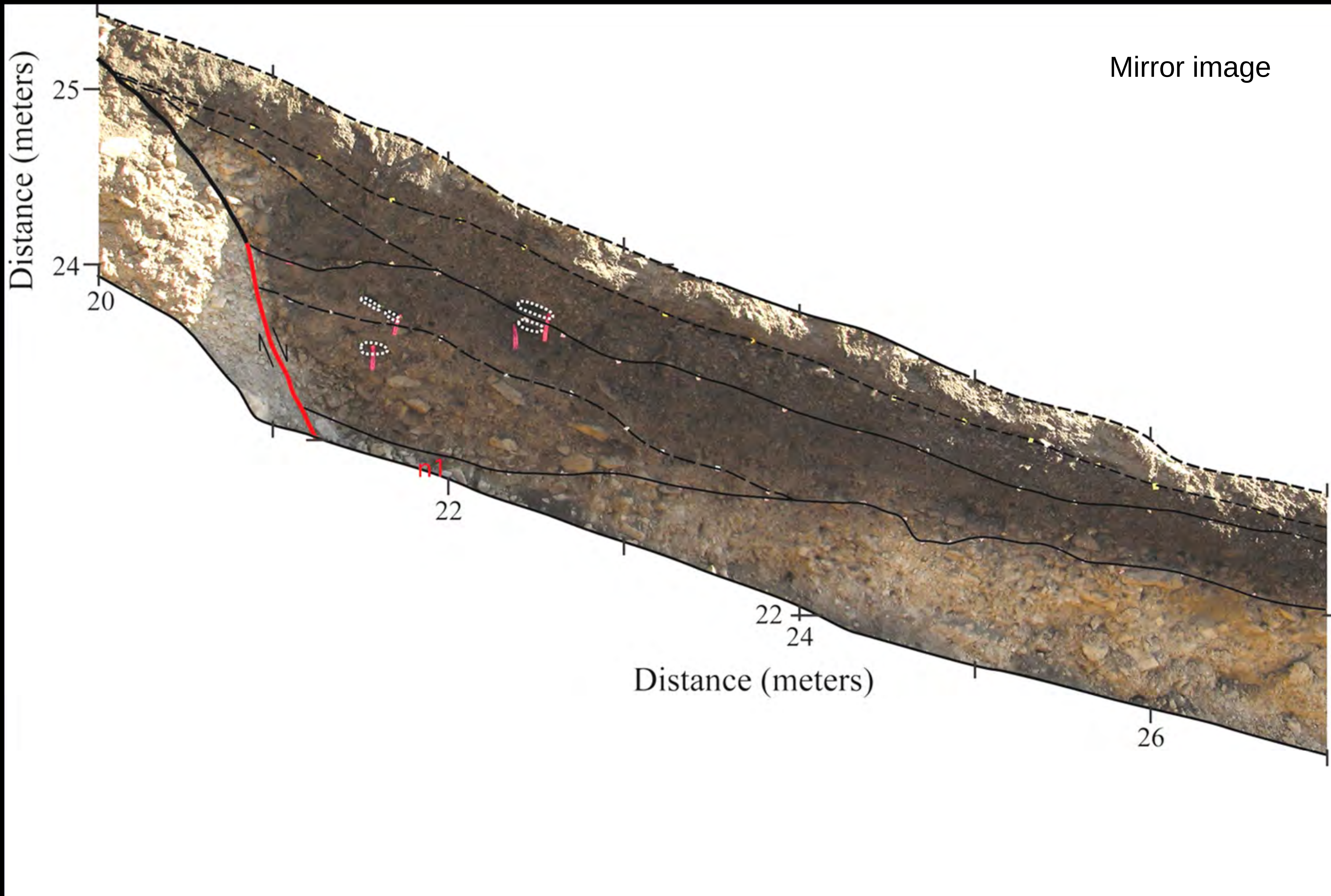
Upper fault zone (south wall)



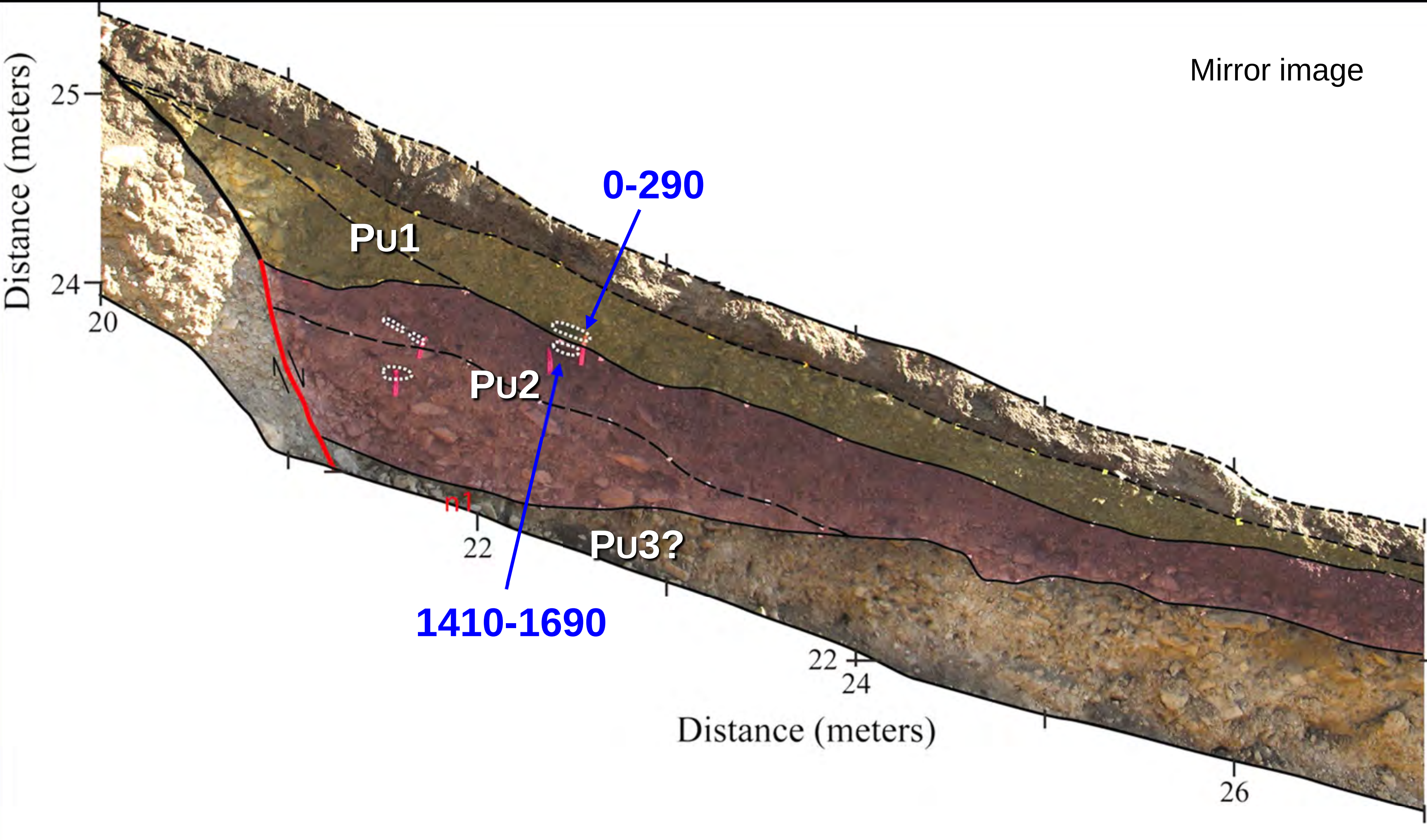
Upper fault zone (south wall)



Upper fault zone (north wall)

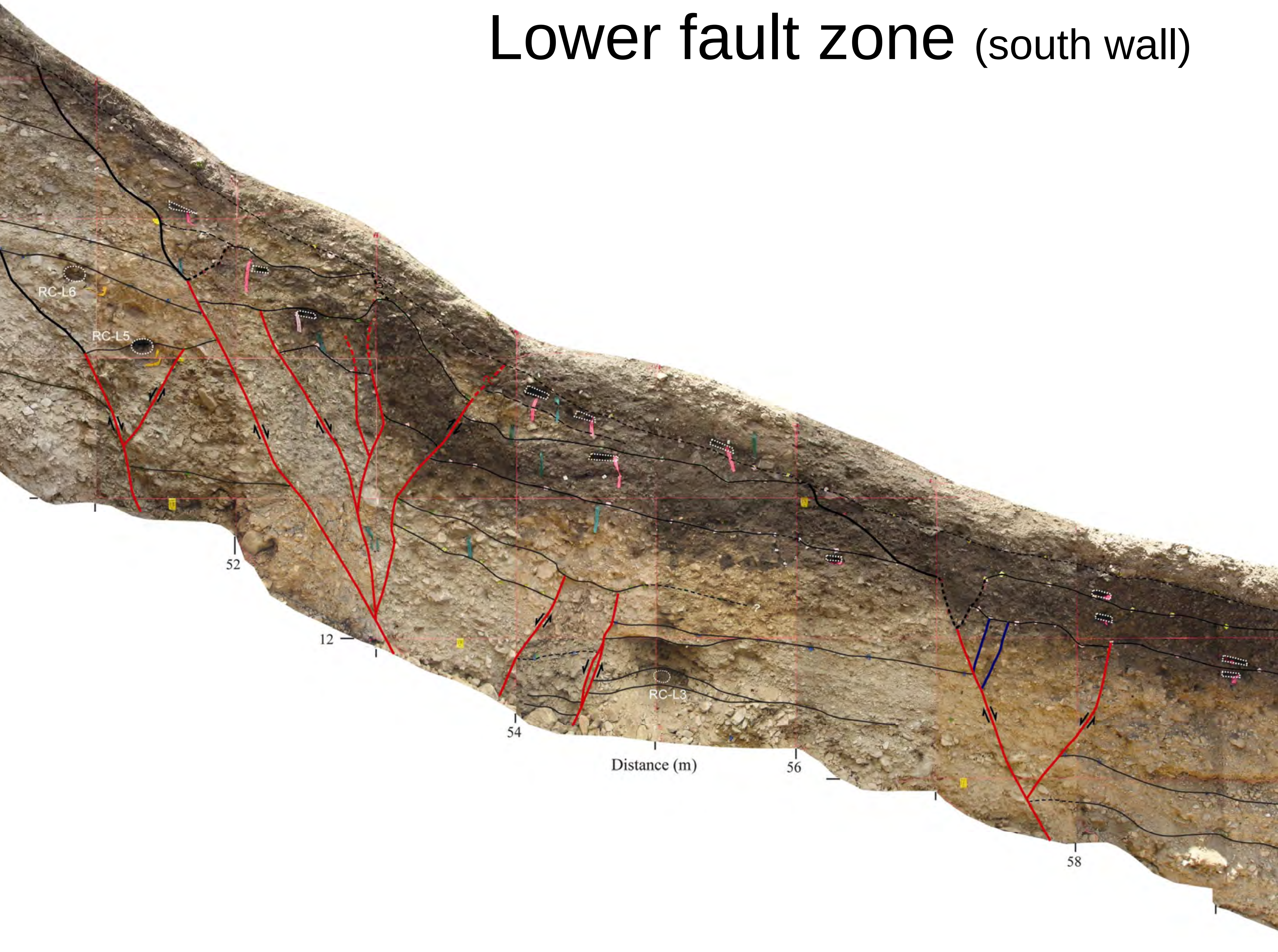


Upper fault zone (north wall)

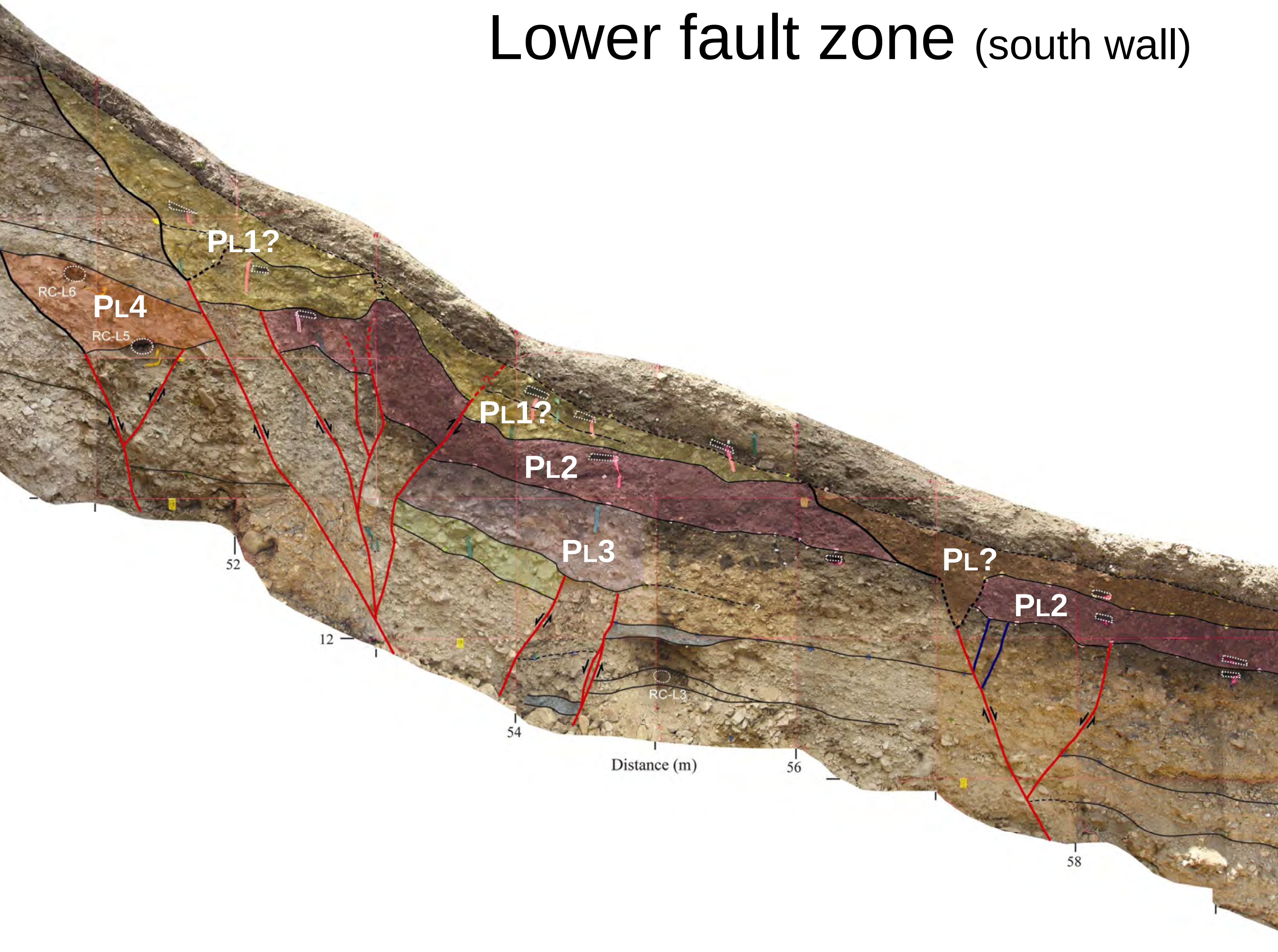


Ages: cal yr B.P.
(2-sigma range)

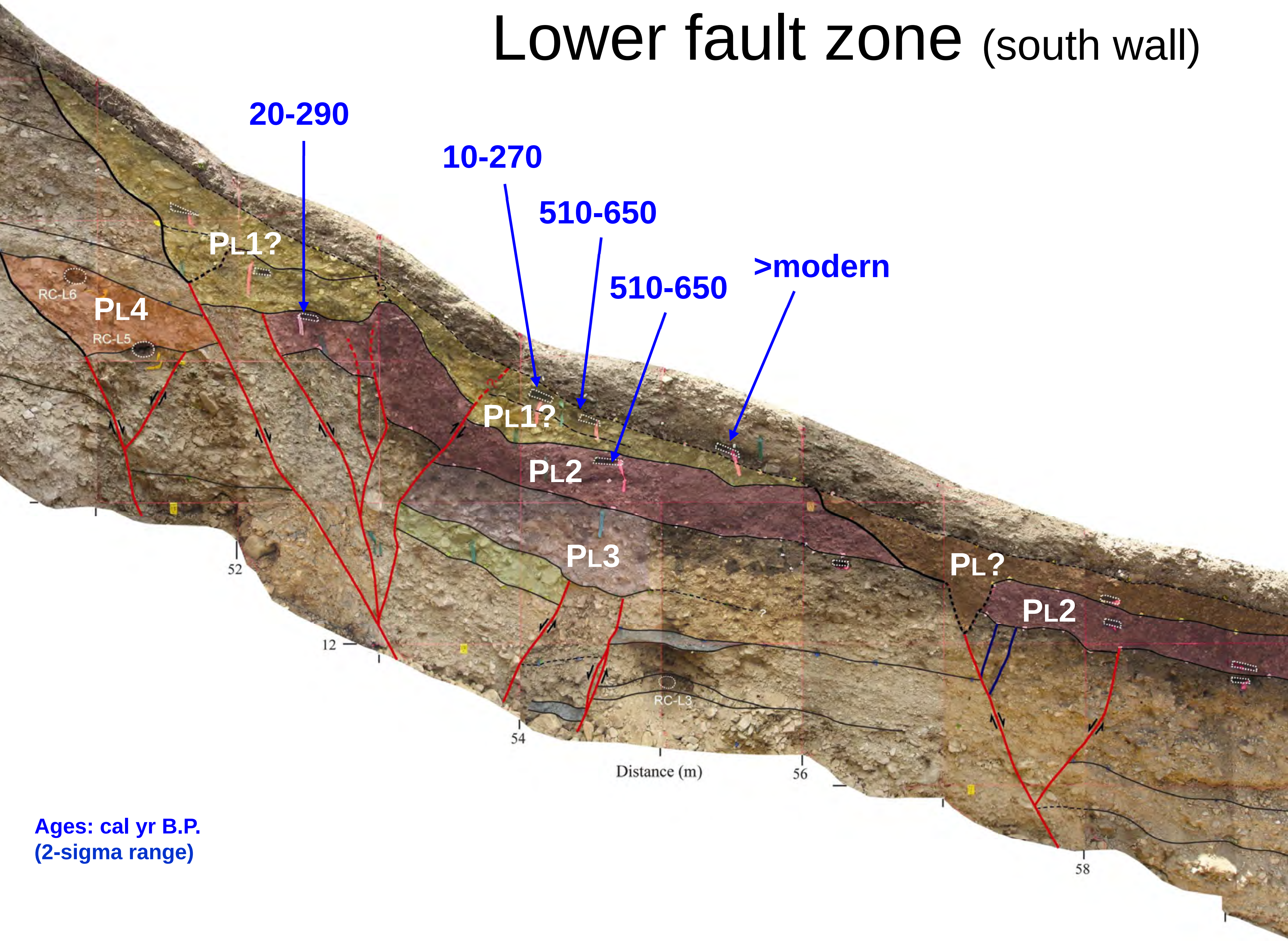
Lower fault zone (south wall)



Lower fault zone (south wall)

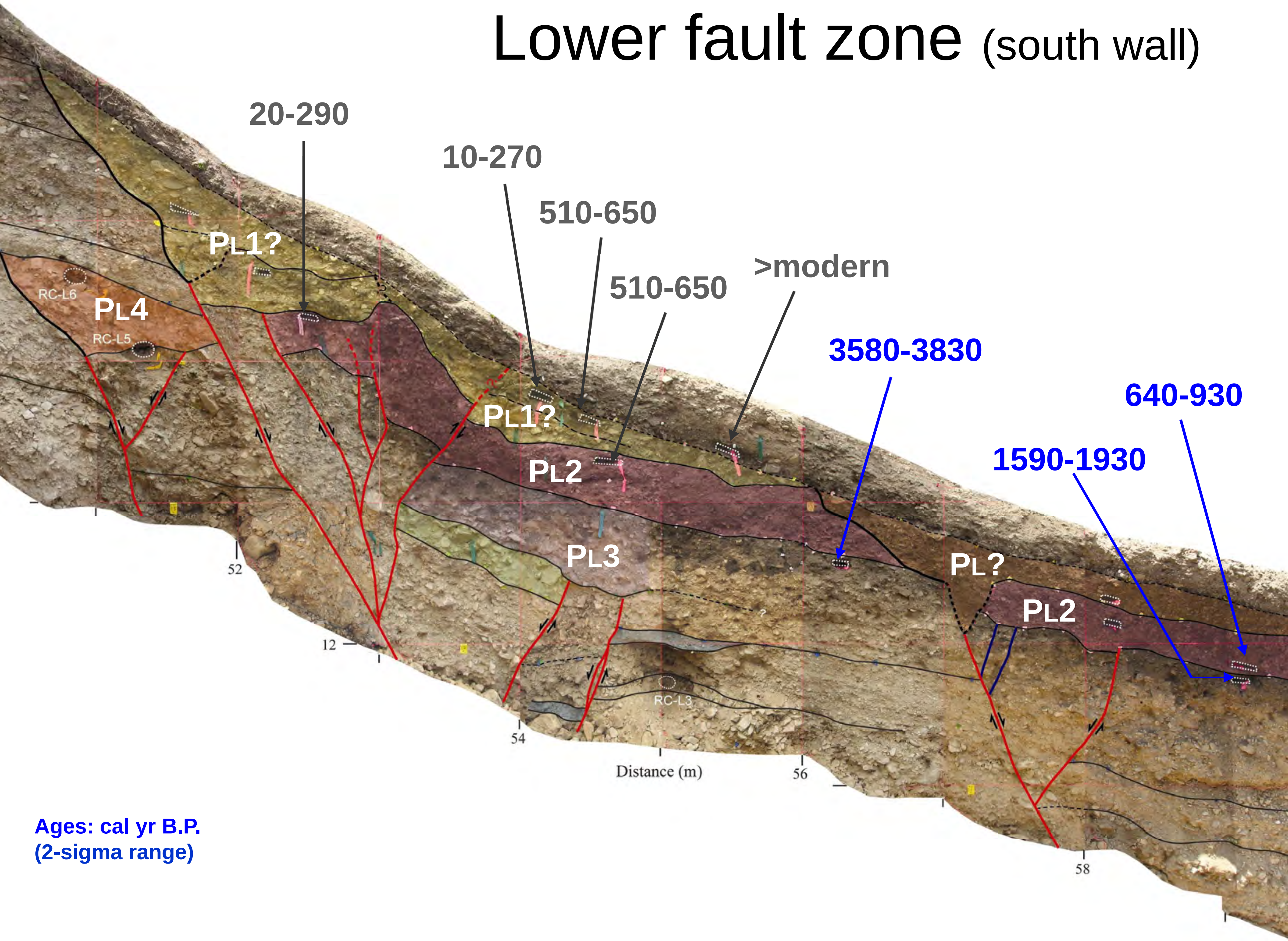


Lower fault zone (south wall)



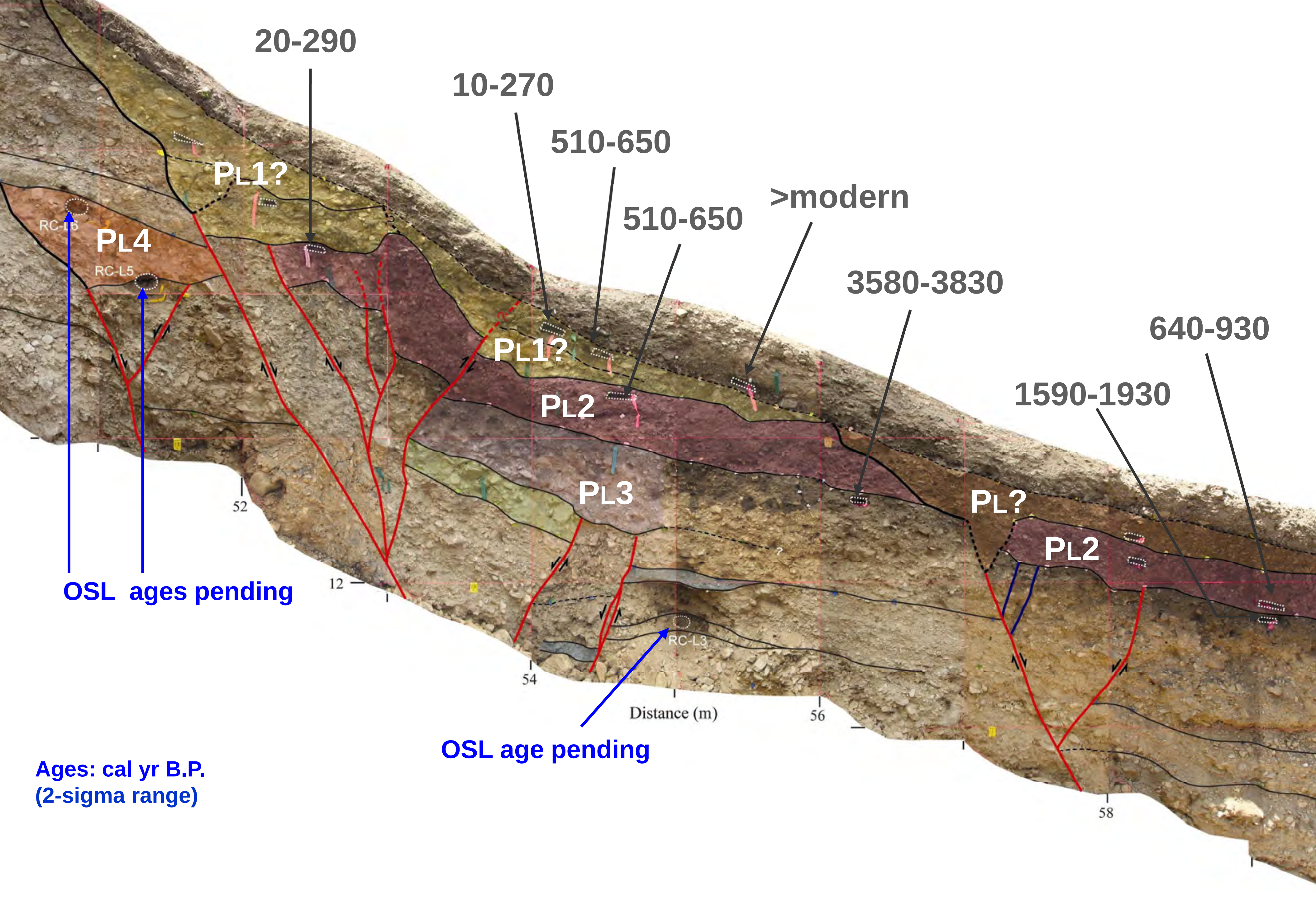
Ages: cal yr B.P.
(2-sigma range)

Lower fault zone (south wall)

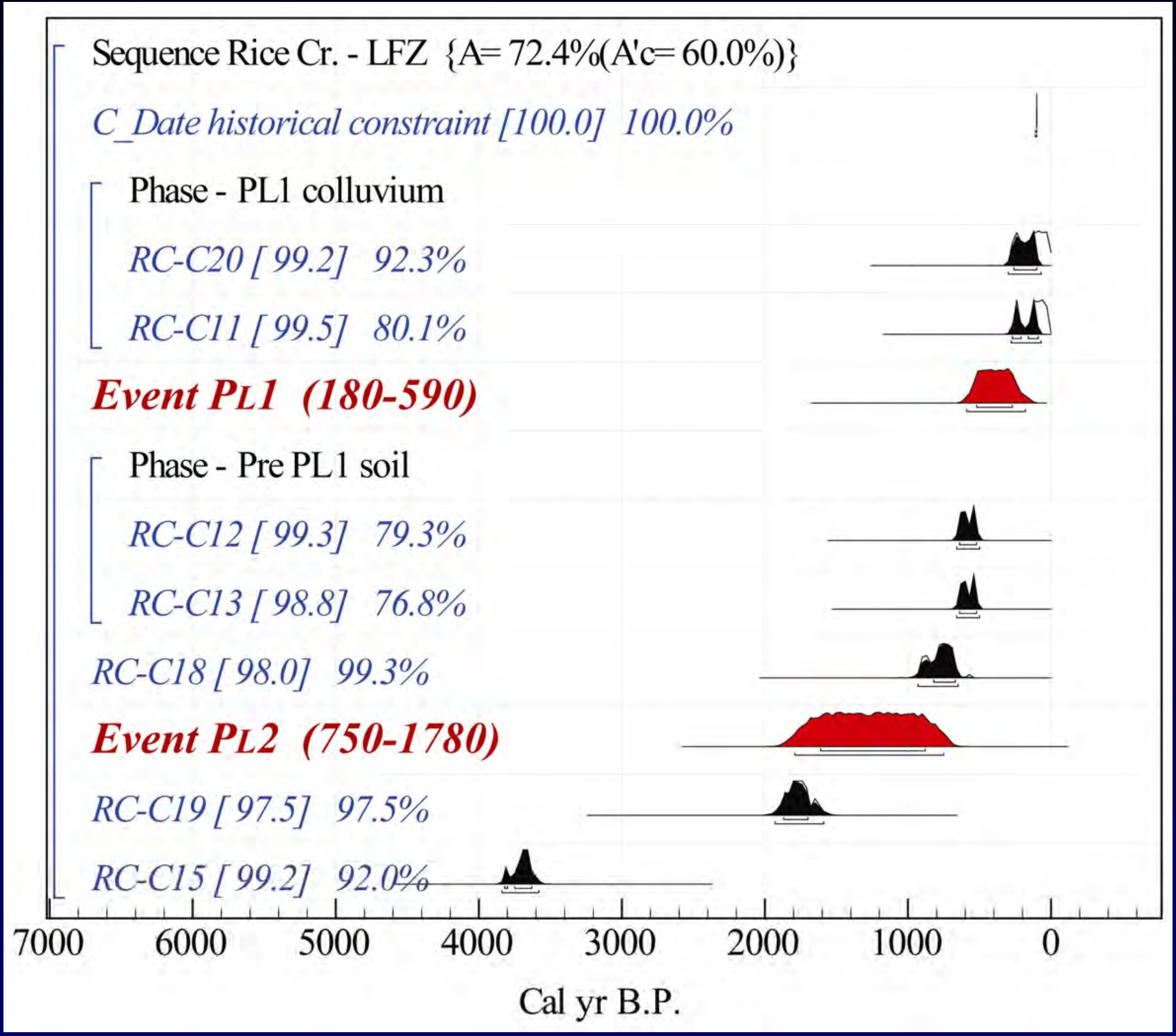


Ages: cal yr B.P.
(2-sigma range)

Lower fault zone (south wall)



Preliminary Oxcal modeling - LFZ



Preliminary results

- Evidence for at least 4 paleoearthquakes in upper & lower fault zones:
  - Three post-fan colluvial wedges in each fault zone
  - One intra-fan event associated with lower fault zone

- Upper FZ:
  - P_U1: 200-1550*
  - P_U2: <5300-5600
  - P_U3: ?

- Lower FZ:
  - P_L1: 200-600*
  - P_L2: 750-1800*
  - P_L3: ?
  - P_L4: ? (intra-fan event)

*Time range based on *preliminary* Oxcal modeling
Calendar ages rounded to nearest one-half century

Preliminary results

- Earthquake timing and correlation

Event	*UQFPWG*	*Kaysville*		*East Ogden*		*Garner Canyon*		*Rice Creek*
P1	500 ± 300	X		200-600		X	—	**200-600**
P2	950 ± 450	600-800	—	500-1700	—	600-1500	**-?-**	**200-1550**
P3	3000 ± 700	2100-3500	—	2400-3900	—	1400-2800		to
P4	4500 ± 700	X		2800-4800	**-?-**	>2100-2800		be
P5	6100 ± 700	5700-6100 (3800-7900)		X		X		determined

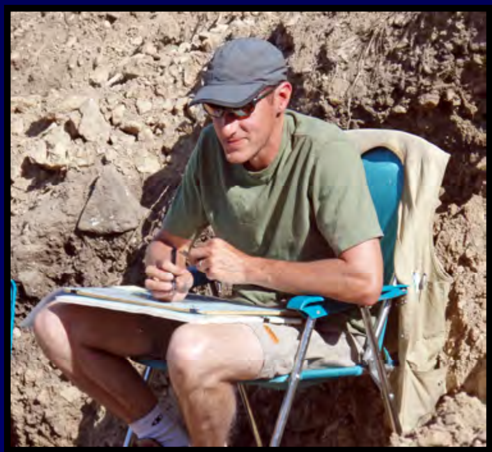
Preliminary results

- Slip rate:
  - Minimum: >0.6-0.7 mm/yr (9.4-12.0 m/<16.8 ka)
  - UQFPWG: 06.-1.2-4.3 mm/yr
- Recurrence interval:
  - 0.3-1.5 kyr*****
    (one interval in lower fault zone)
  - UQFPWG: 0.5-1.4-2.4 kyr
    (four intervals between 0.5 and 6.1 ka)

*****2-sigma interval based on *preliminary* Oxcal modeling

Remaining questions

- Refine event times - continue OxCal modeling
- Improve event correlation between trench sites
- Displacement per event
- Segmentation of the northern WFZ; Weber and Brigham City segments

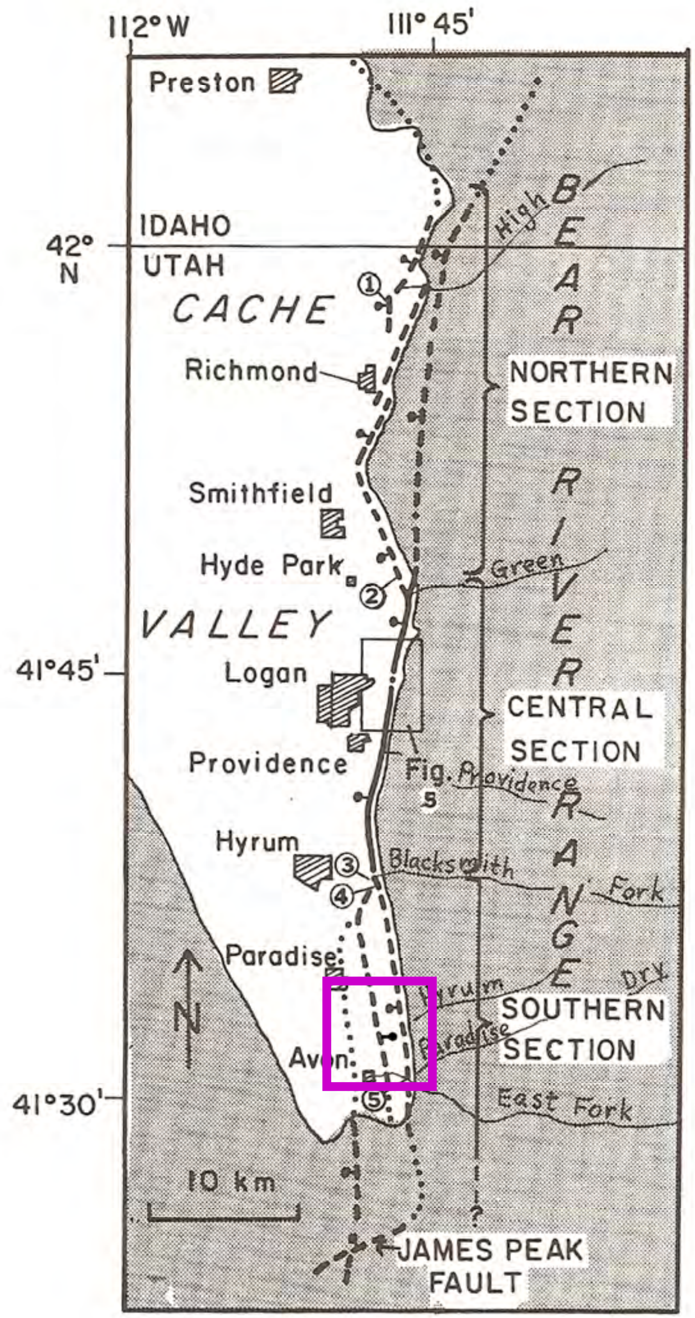


Paleoseismology of the Southern Segment of the East Cache Fault Zone, Cache Valley, Utah

1 mile

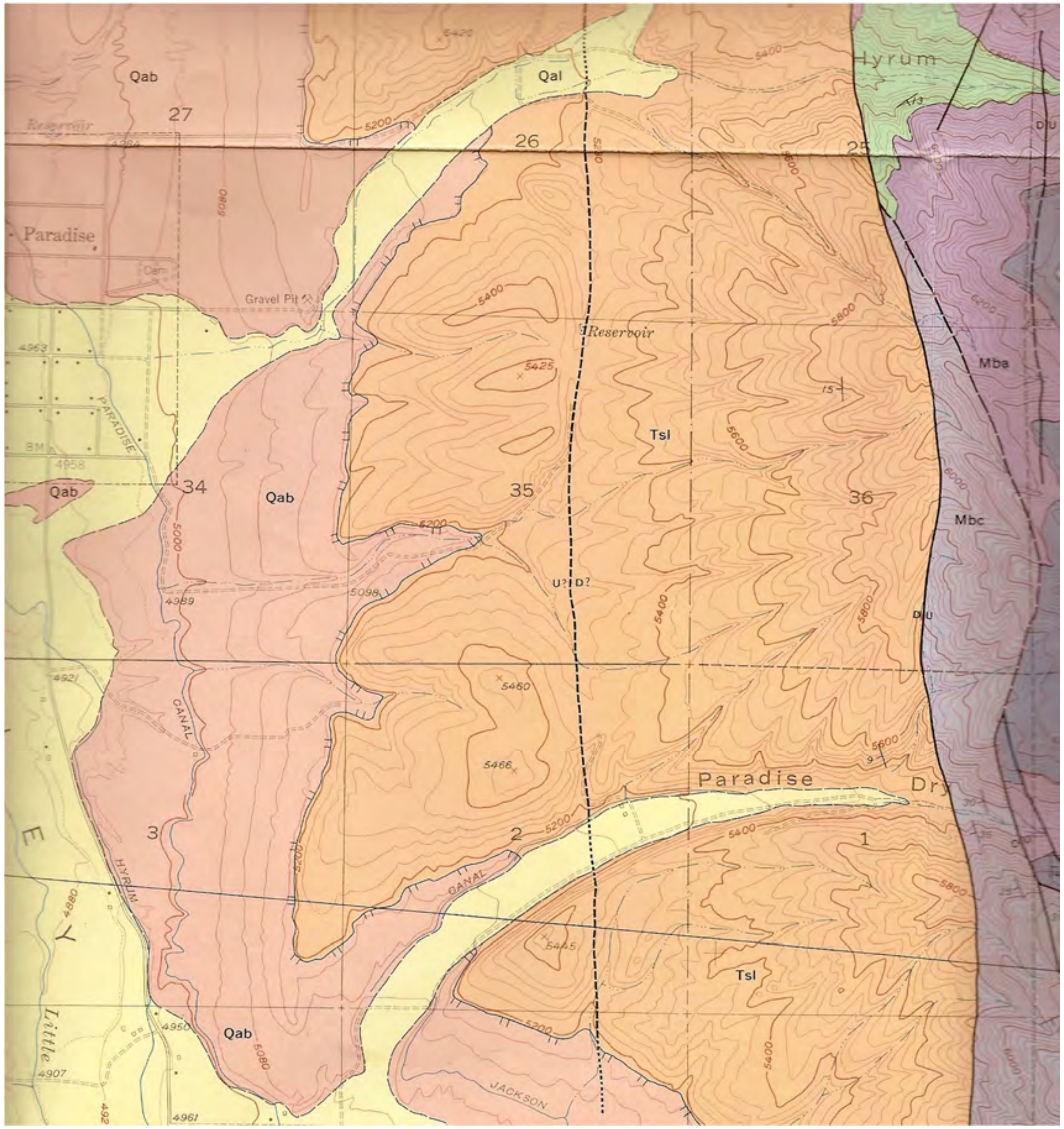
The East Cache Fault

- Divided into three segments
- 80 km long
- Separates Cache Valley from the Bear River range to the east



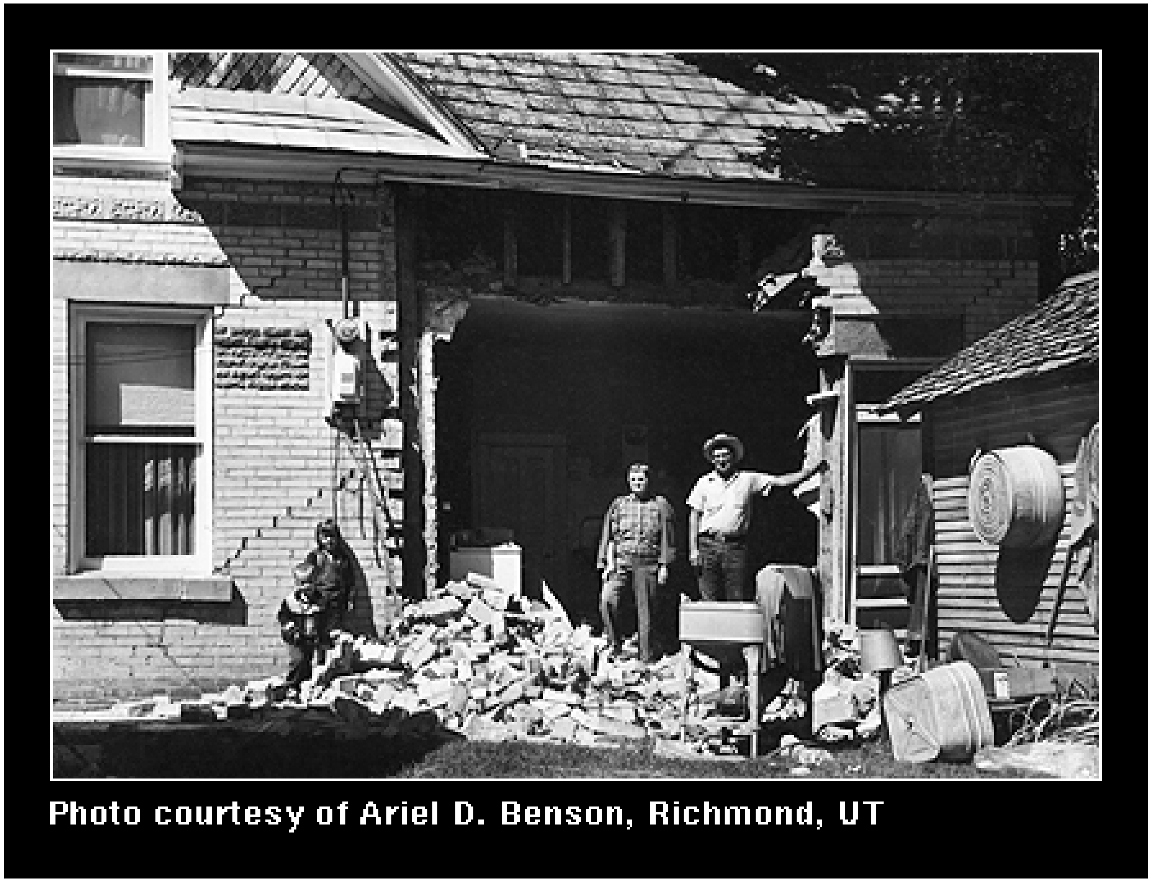
The Southern Section

- 14 km long
- Separated into three fault strands?
- Western strand originally mapped by Mullins and Izett to be the Bonneville highstand recently mapped as a western fault strand
- Eastern strand is a west dipping listric normal fault
- Antithetic central strand
- Generally poor fault trace expressions



Reason for Our Study

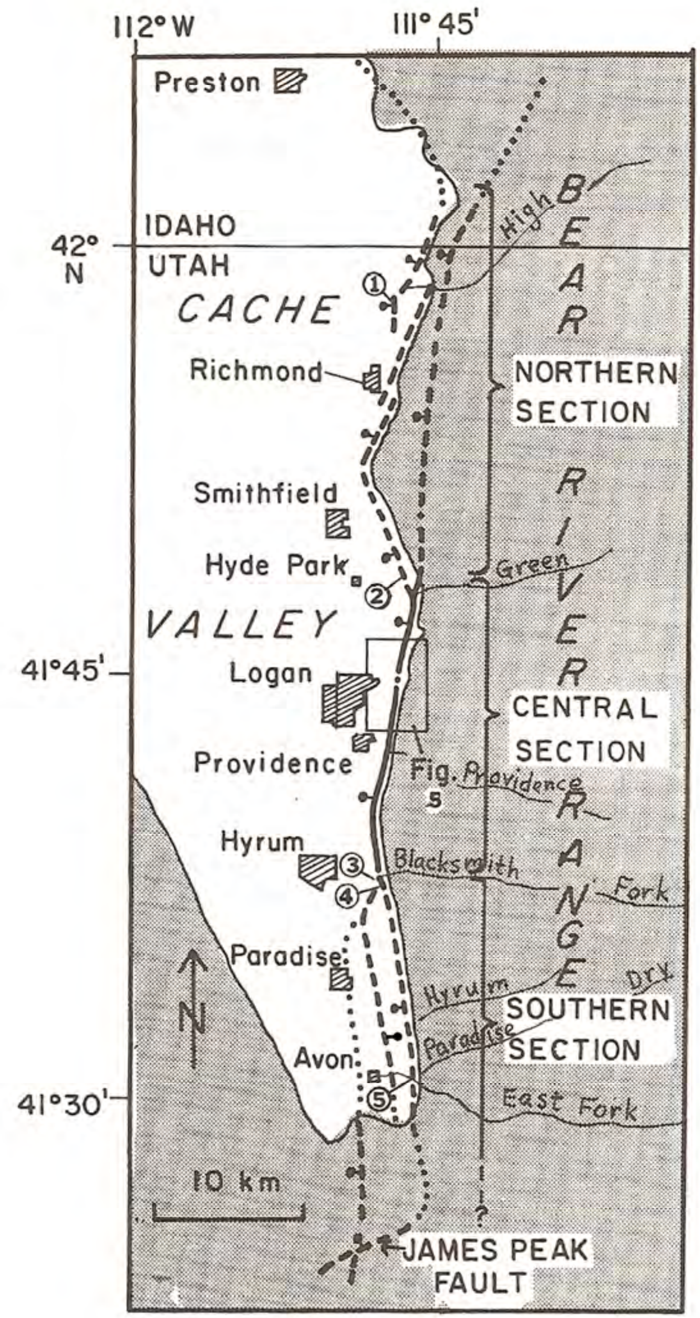
- Cache Valley population is expected to grow 275,000 – 300,000 by 2050.
- Few current building requirements to ID seismic hazards



Richmond 1962 Cache Valley Earthquake, M 5.7

Previous Investigations on the East Cache Fault

- Central segment extensively studied in 1994
- Two surface rupturing events
- First event:
  - 1.4 - 1.9 meters displacement
  - 13 – 15.5 k.a.
- Second event:
  - 0.5 – 1.2 meters displacement
  - 4000 years ago
- Magnitudes: 6.6 – 7.1
- Recurrence intervals: 9,000 – 11,500
- Slip rate: 0.22 mm/yr
- Northern and southern segments not studied in detail

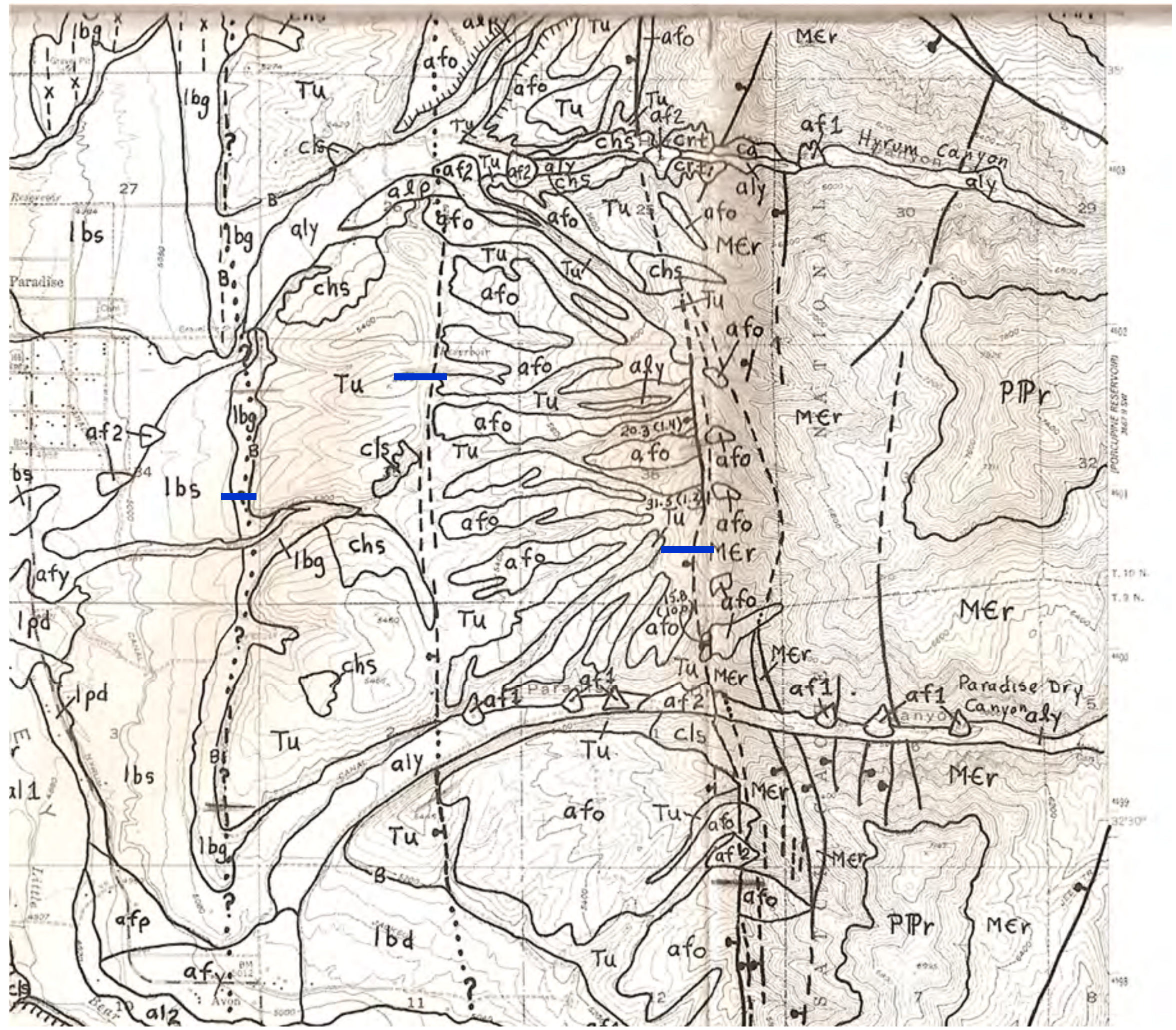


Project Objectives

- Verify where fault traces are mapped
- Determine the Quaternary rupture history
  - Calculate timing, magnitude, displacement, slip rates and recurrence intervals
- Compare our data with central segment data to determine fault behavior between segments (multi-segment ruptures?)
- Update the National Seismic Hazards Map

Methods

- Use GPR to determine fault location and thickness of colluvium
- Excavate three east –west trending trenches on each of the fault strands
- Log trenches using photo mosaic method
- Use OSL sampling methods to identify timing of events
- Conduct small seismic refraction survey to determine fault geometry and depth on eastern strand



Completed Work

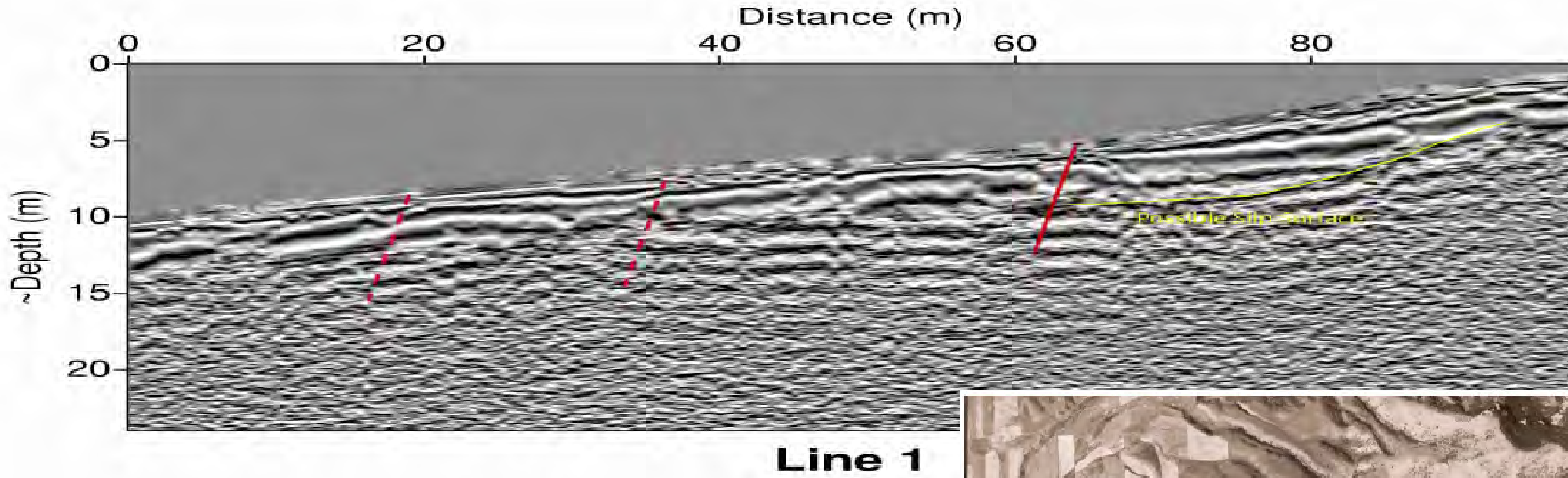
- Conducted GPR Survey
- Excavated trenches on the Western and Central fault strands

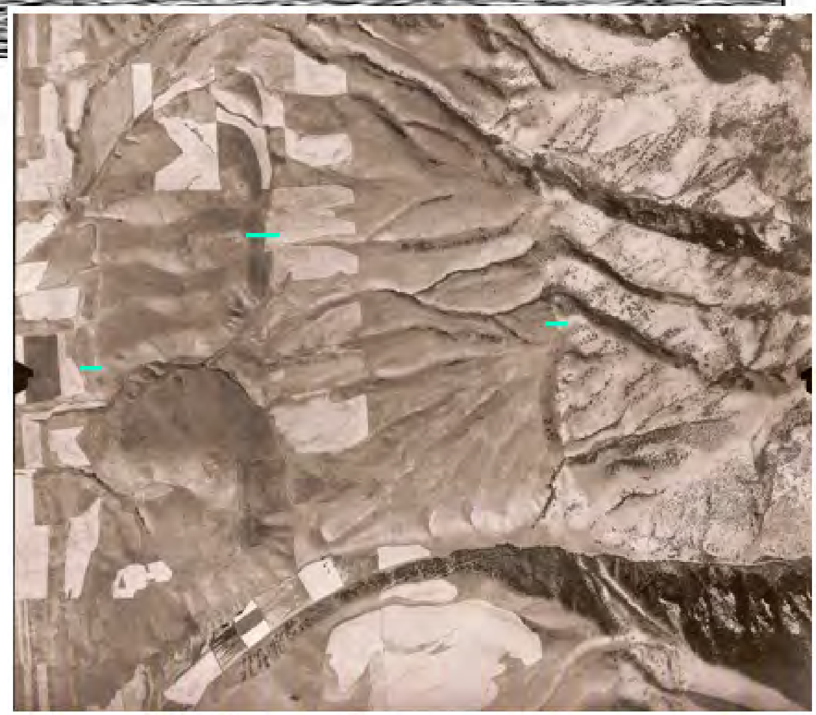
Project	Utah State Neotectonics GPR
Date of Acquisition	09/08/2007
GPR System	Sensors and Software PE Pro
Antennas	100 MHz
Transmitter	1000 V
Trace spacing	0.25 m
Polarization mode	Transverse electric
Trigger Method	Odometer Wheel
Sampling rate	0.8 ns
Recording time	500 ns
Stacks /trace	16
Collected by	John Bradford, Boise State Univ.

GPR Data

West

East



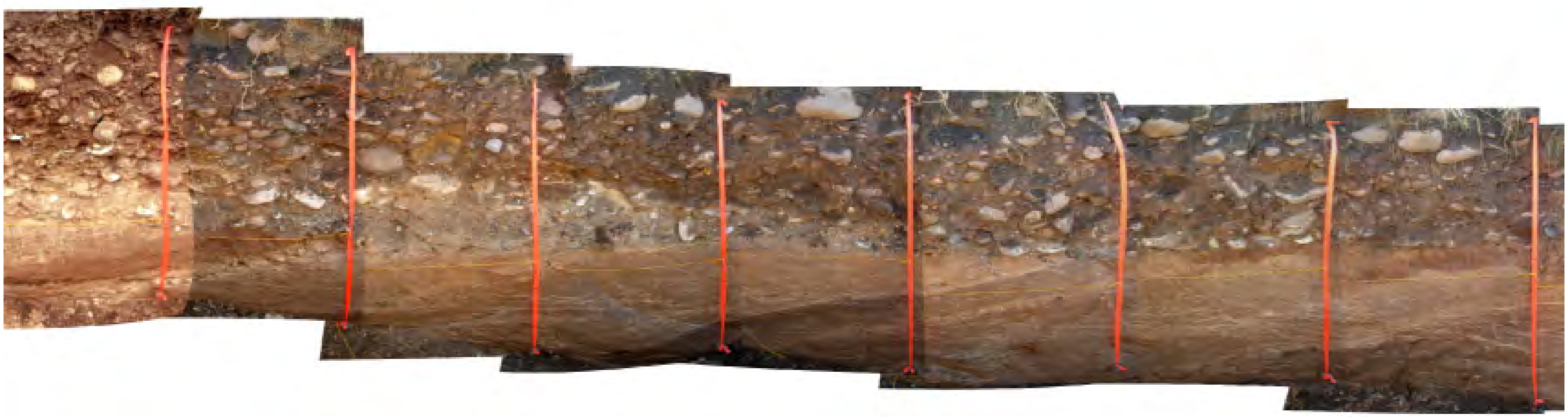


Western fault strand

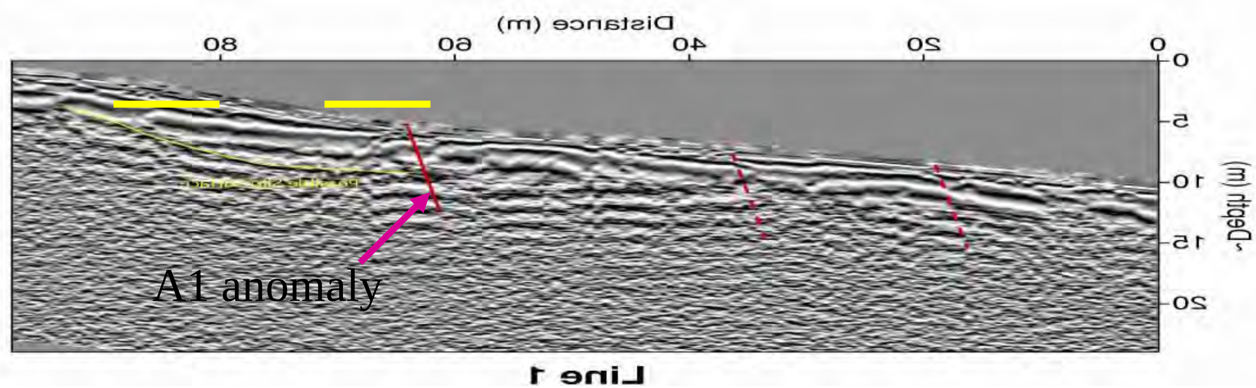
East

West

GPR anomaly at A1

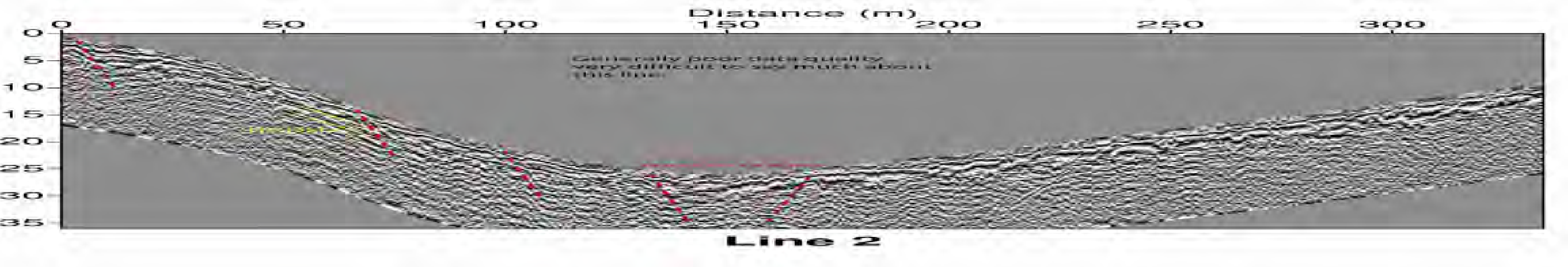


East dipping layers of the Tertiary Salt Lake Formation (TSL)

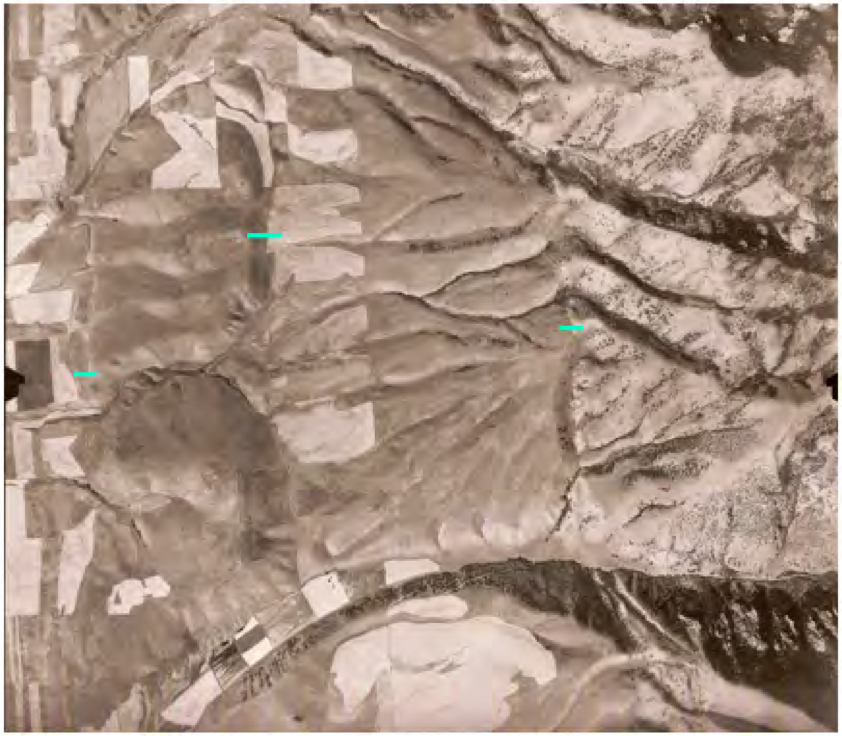


West

East

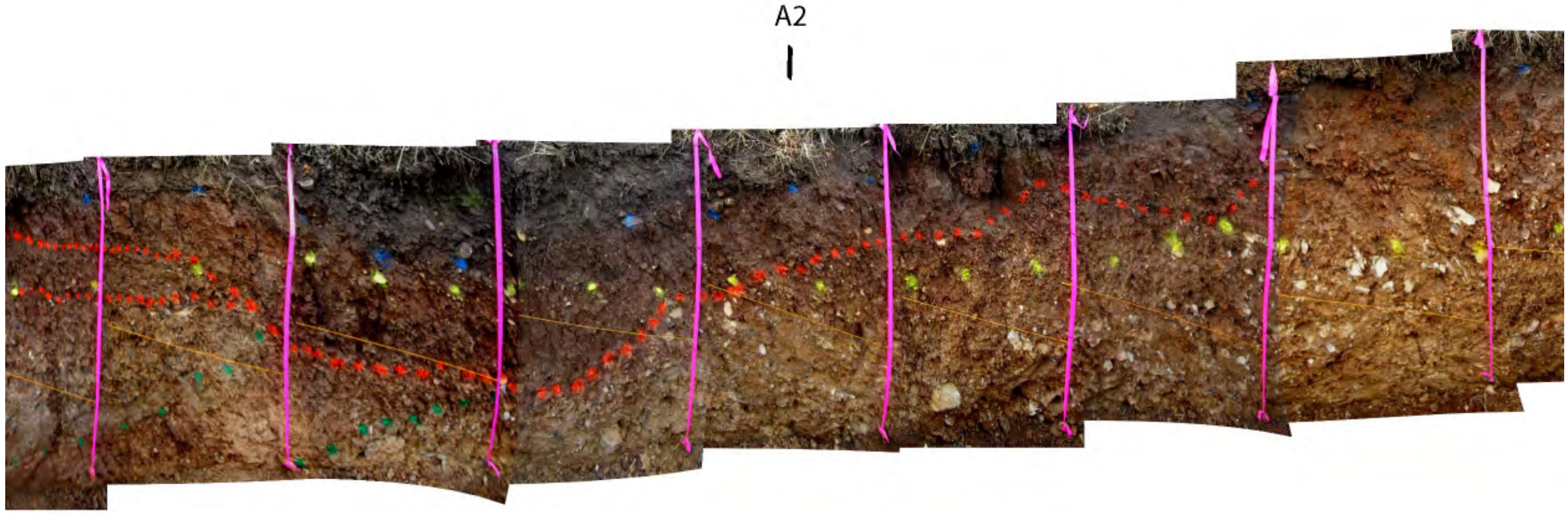


Central fault strand

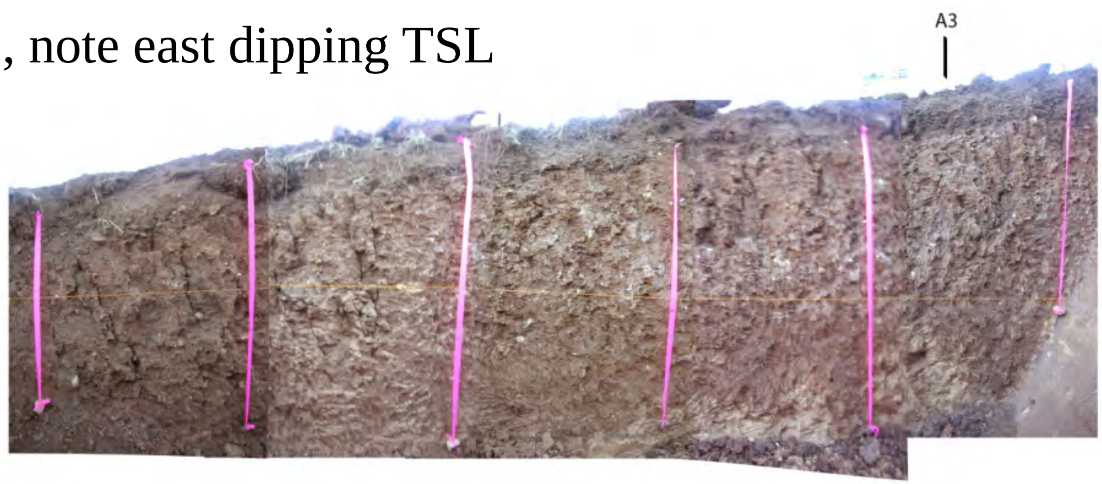


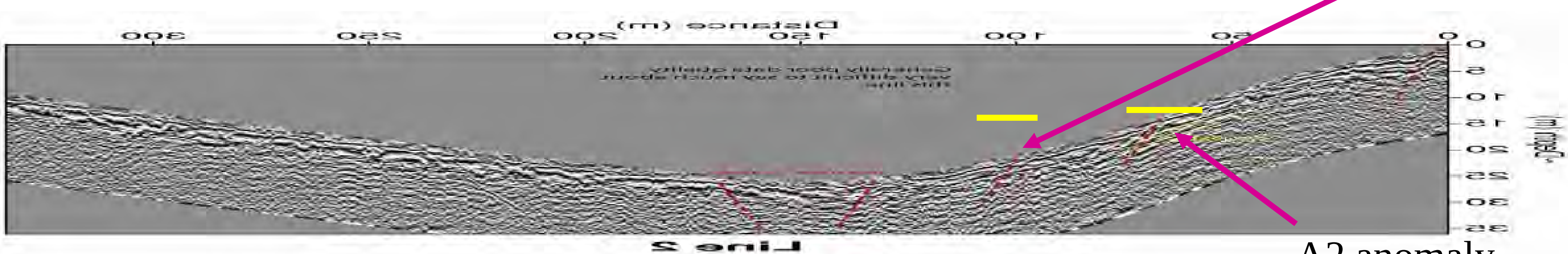
East

West



Anomaly at A2, note east dipping TSL



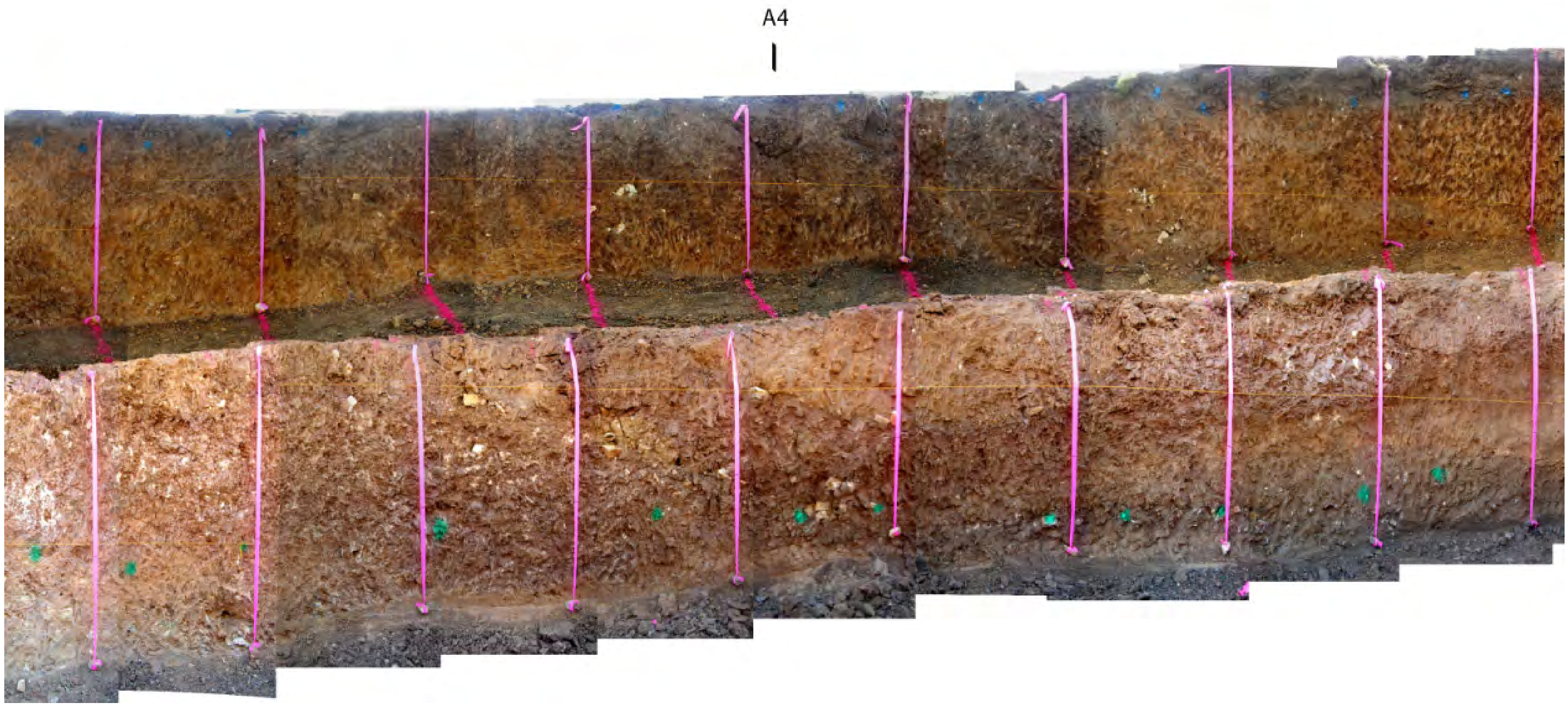


A3 anomaly

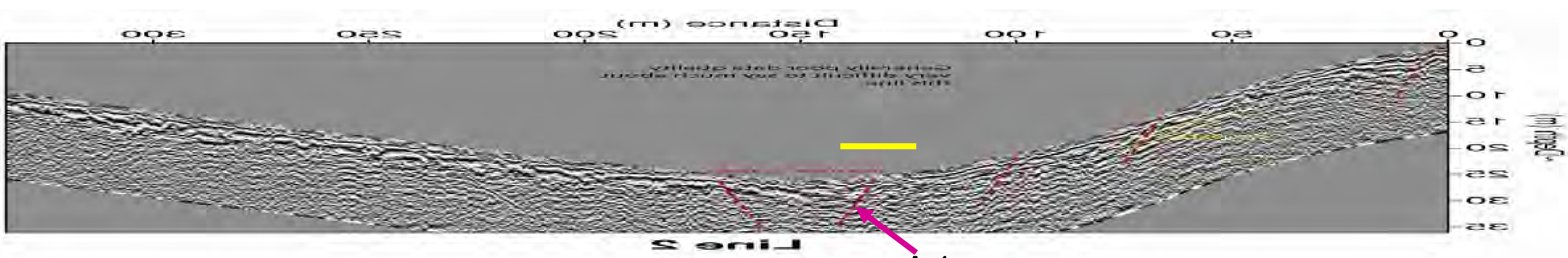
A2 anomaly

East

West



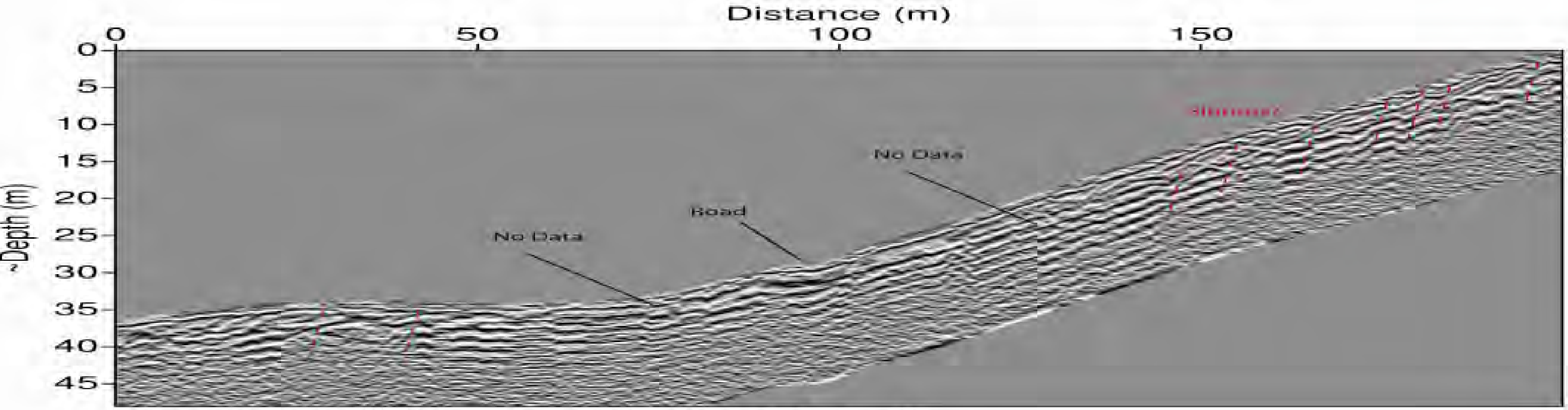
A4 Anomaly, no more eastward dips!



A4

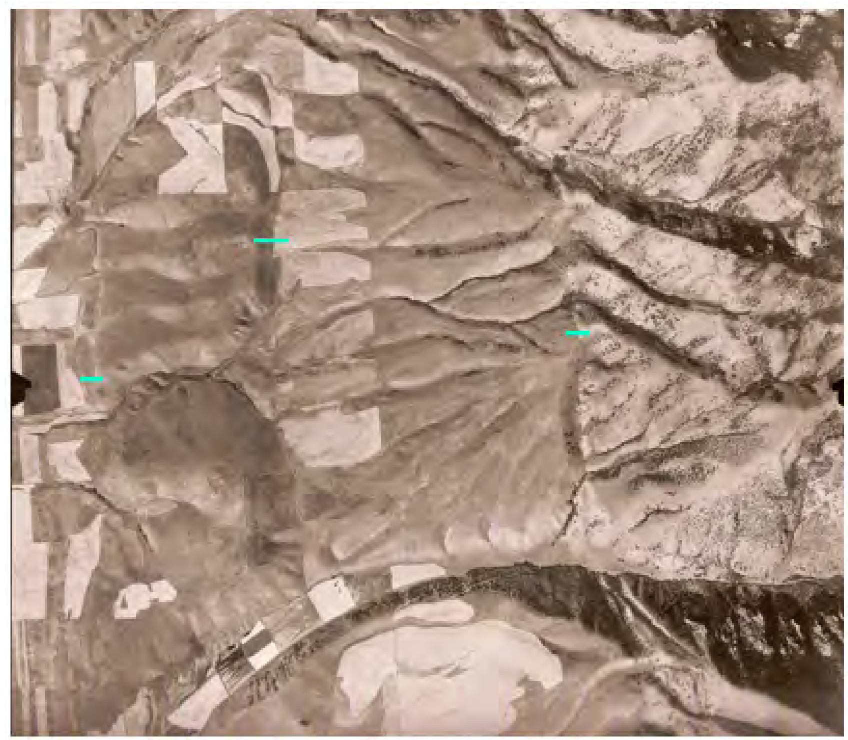
West

East



Line 4

Eastern fault strand



Conclusions

- No faults found during this investigation so far
- Western fault strand is most likely a Bonneville feature rather than a fault
- Possible syncline excavated at central fault strand (as noted in Oaks et al 1999)

Work left to do

- Conduct seismic survey on the eastern strand
- Excavate trench on the eastern strand
- Secure permission and excavate trench in area connecting two trenches on central strand
  - If no colluvial wedge or fault exposure in this gap
    - Then last rupture may be to old and is buried under colluvium

RECLAMATION

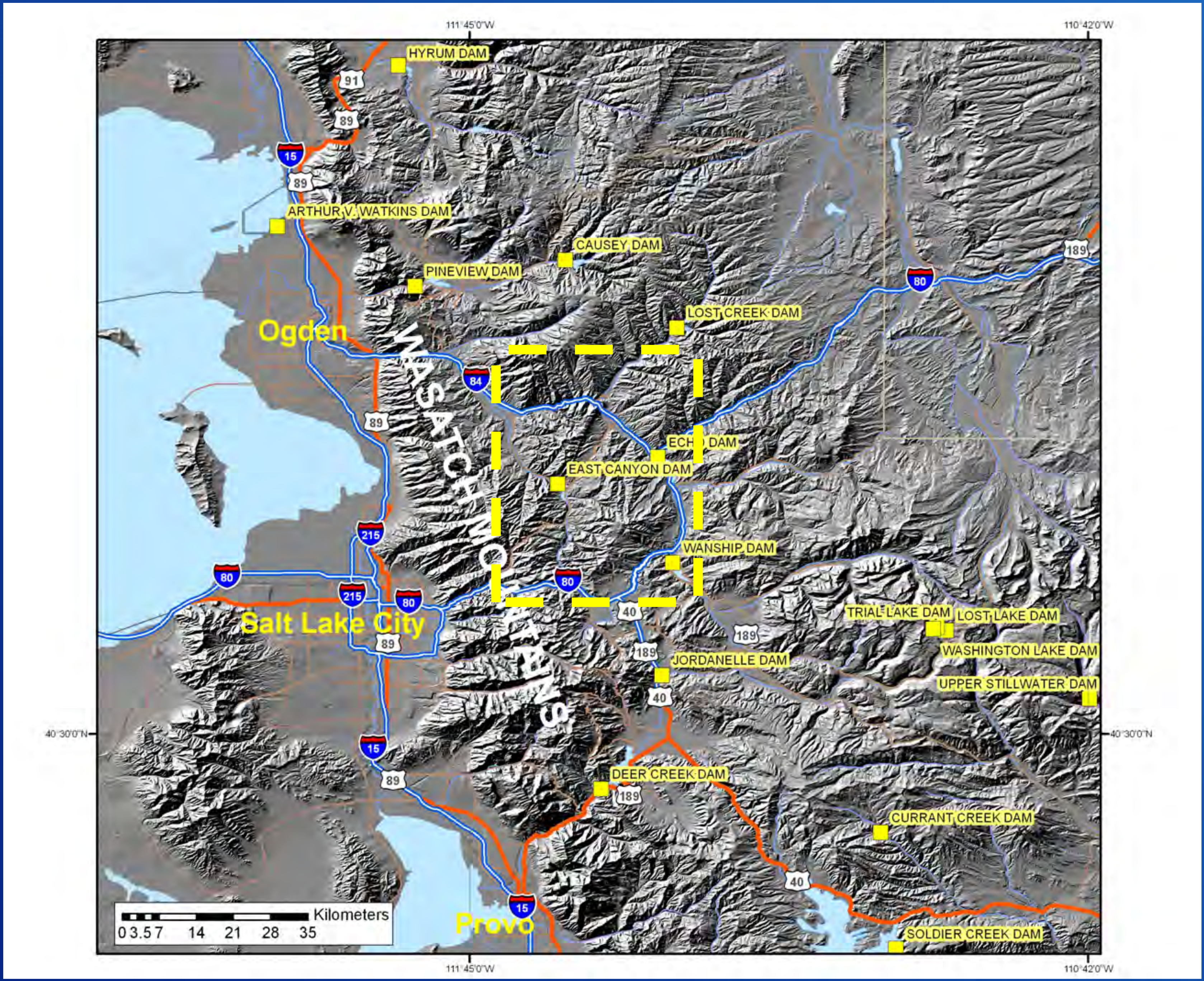
Managing Water in the West

EAST CANYON & MAIN CANYON FAULT STUDIES

Larry W. Anderson

Seismotectonics & Geophysics Group

February 13, 2008

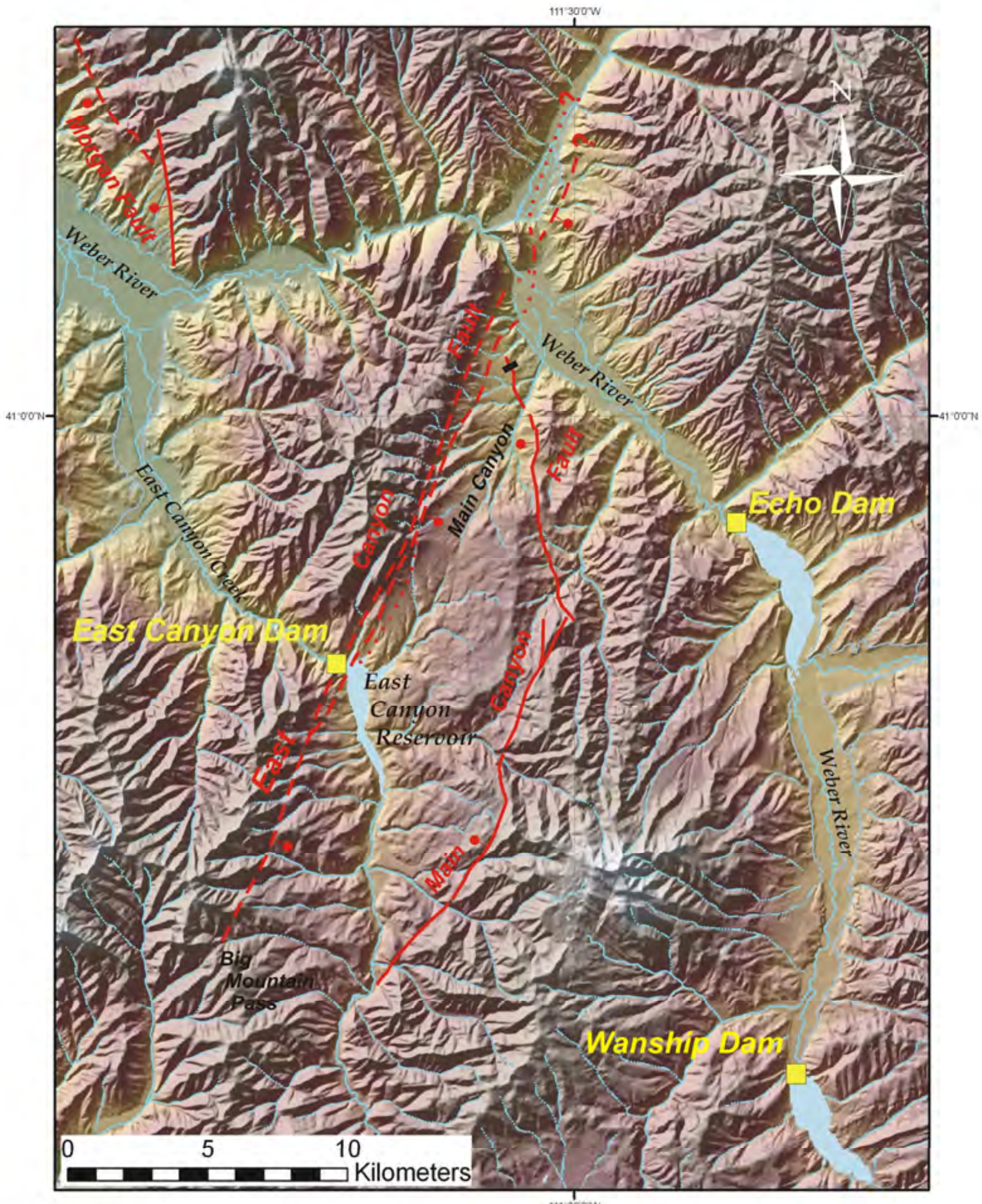


RECLAMATION

Reclamation Studies

- Sullivan et al., 1988 – Central Utah Regional Study
- Coogan (2007) – Stratigraphic, Structural, and Velocity Interpretation, East Canyon
- Piety and Anderson (in review) – Late Quaternary Faulting in East Canyon Valley

RECLAMATION



RECLAMATION

East Canyon Fault

28-km-long, no fault scarps identified. 2 “segments” – 18-km-long <u>Northern</u> and 10-km-long <u>Southern</u> –

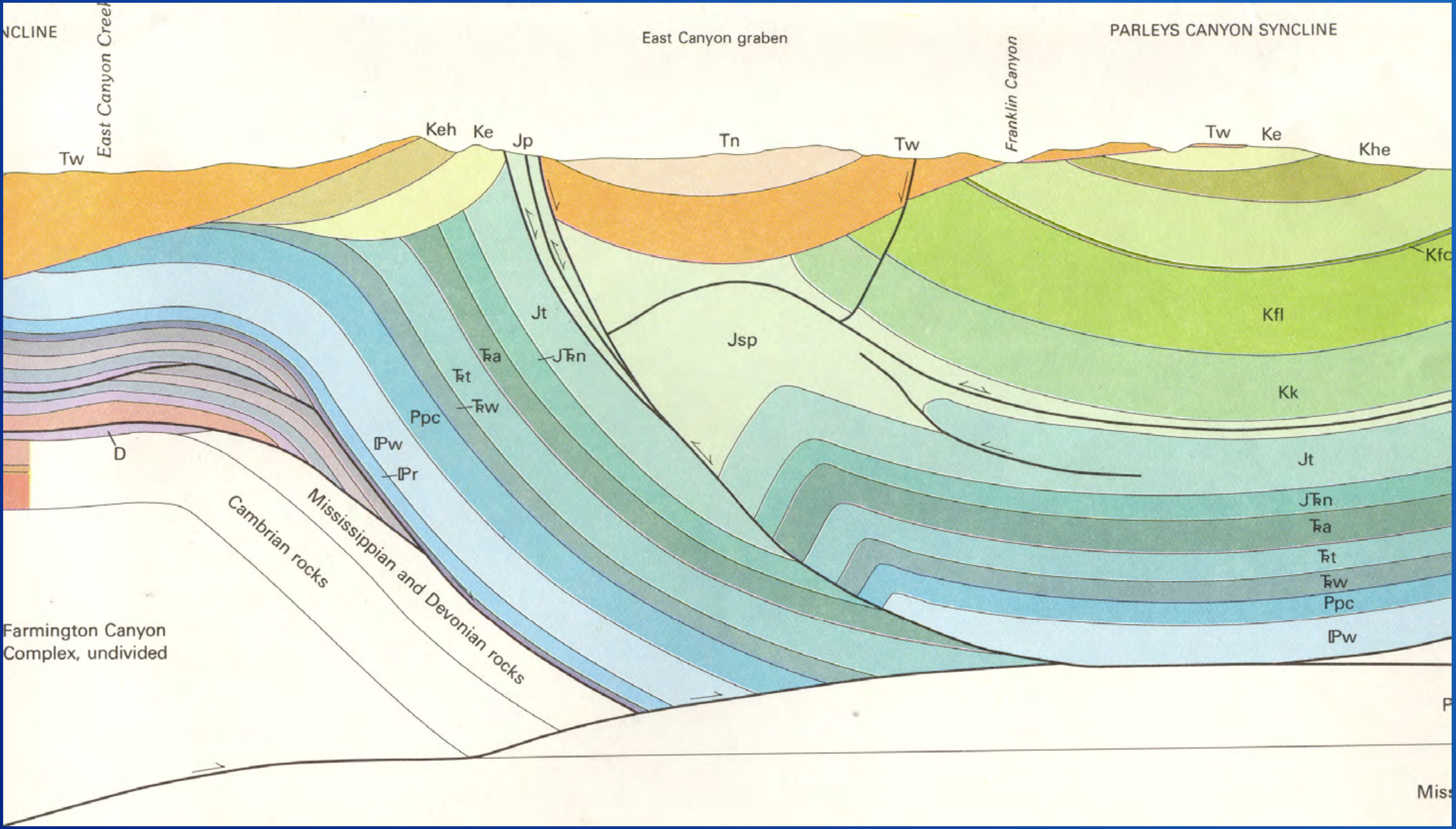
Based on similarities to the Morgan fault, assumed to be late Quaternary active (Sullivan, 1988)

Main Canyon Fault

Formerly referred to as “East” of East Canyon Fault

Recognized in the 1980s; shown on Sullivan et al., 1988 and Bryant, 1990. Antithetic to the East Canyon fault or it soles into Pruess Formation (salt)

i.e., not a *SOURCE*



From Bryant, 1990

RECLAMATION

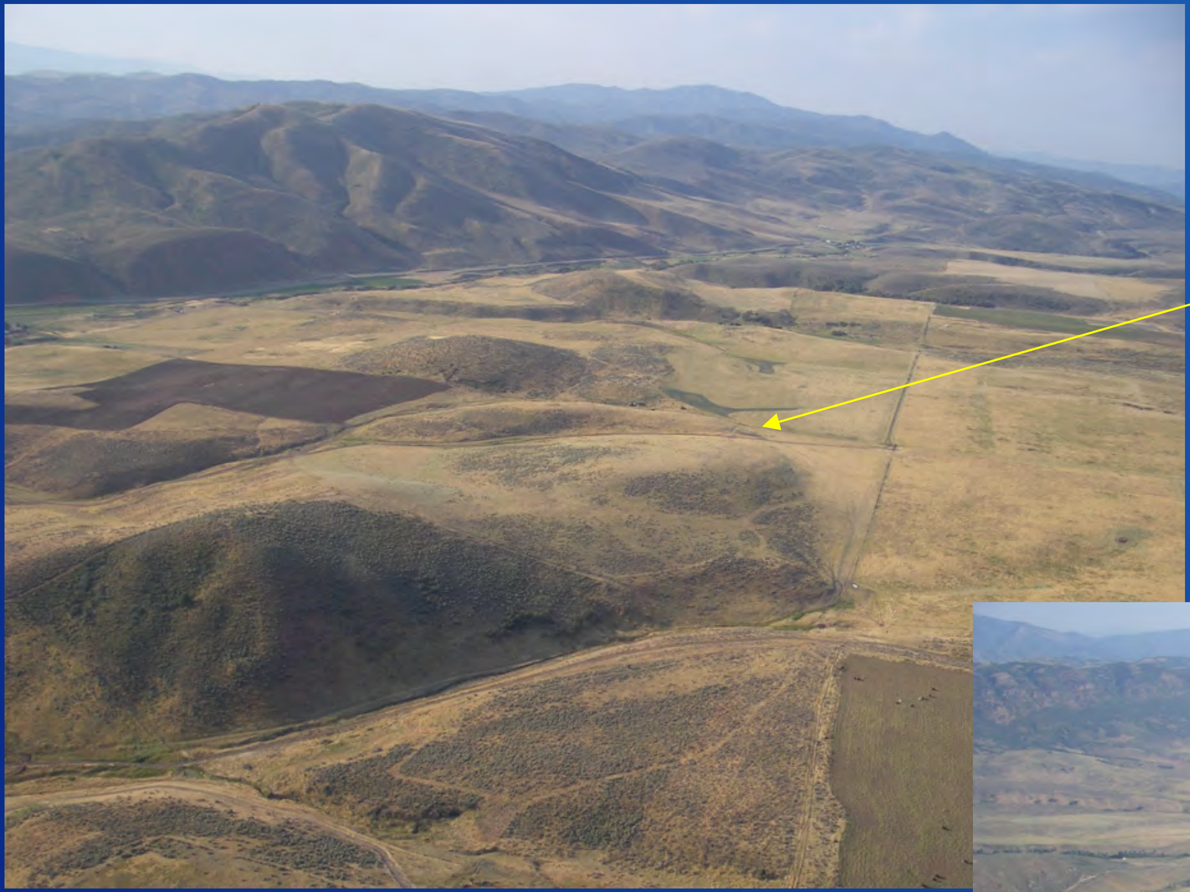
2006 – 2007 Studies

- Part of detailed evaluation (PHA, ground motion, site response, etc) for East Canyon and Echo dams
- East Canyon fault - Closest and controlling fault source to either dam (see Wong et al., 2004 for Echo Dam)
- Focus shifted to E of E (Main) Canyon fault due to geomorphic expression and suggestion of late Quaternary displacement
- Trenching, acquisition and interpretation of geophysical data

RECLAMATION

East Canyon Fault

RECLAMATION



Trench Site

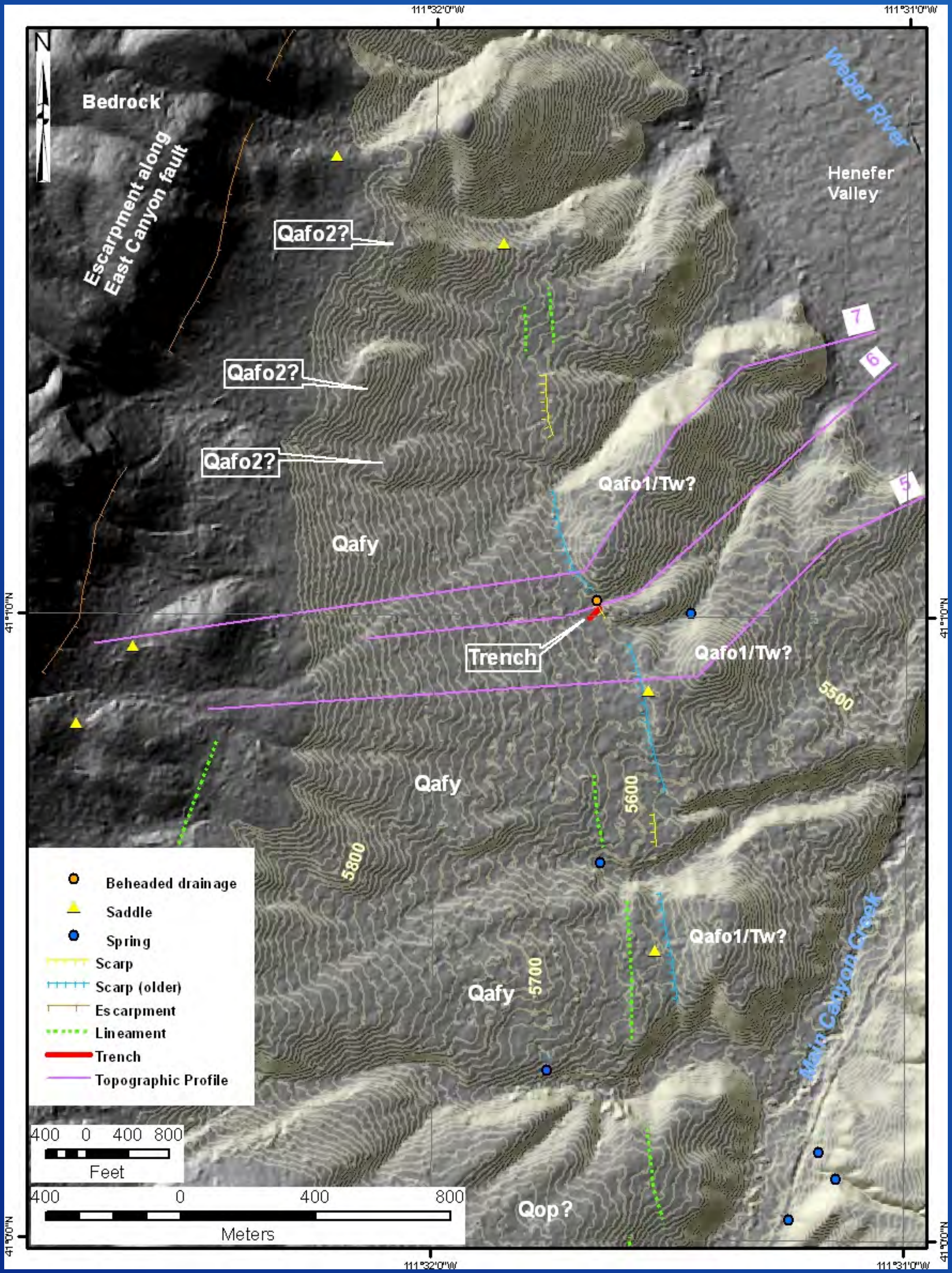
Main Canyon Fault

RECLAMATION

Main Canyon Fault

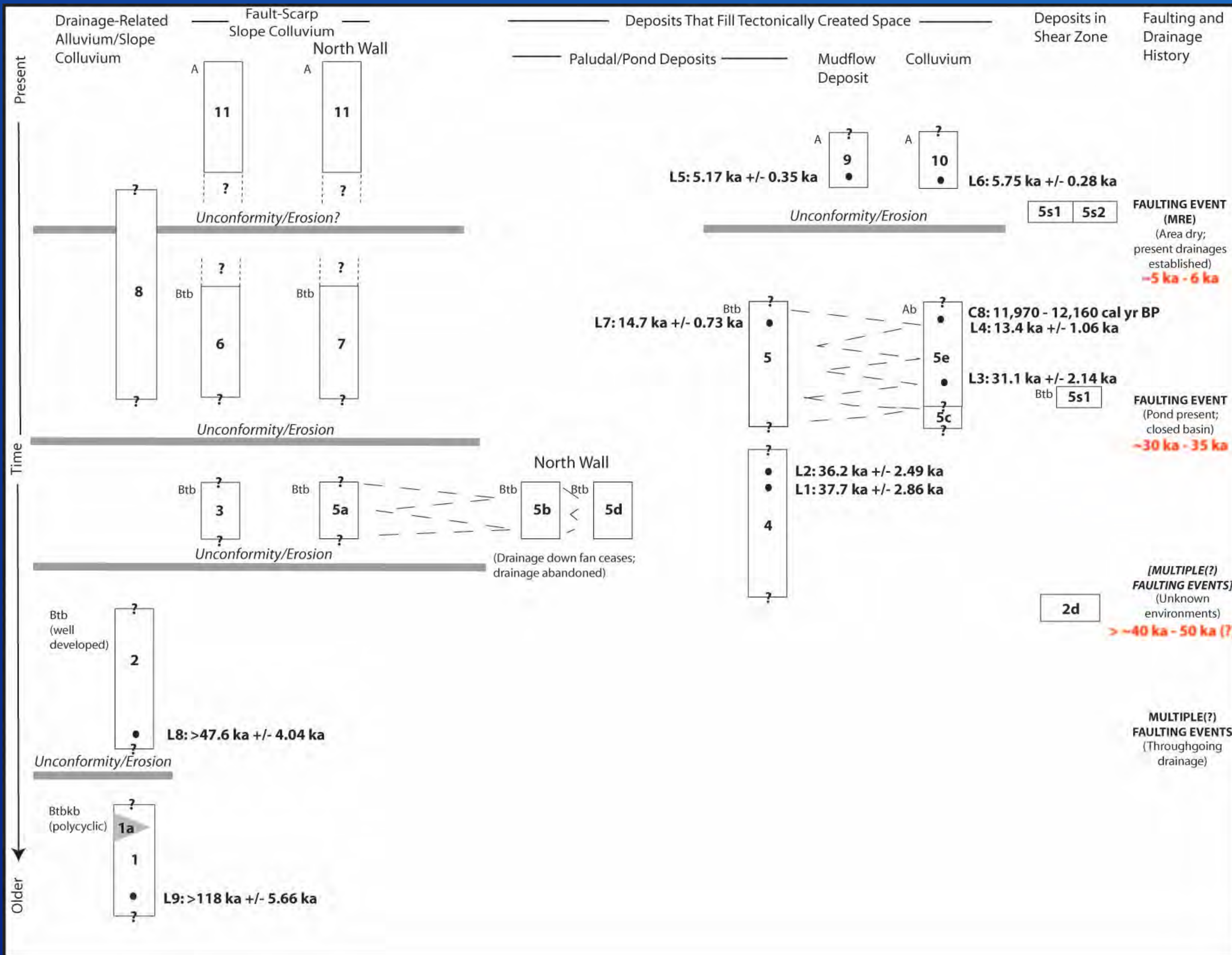
Morgan Fault

RECLAMATION



RECLAMATION

RECLAMATION



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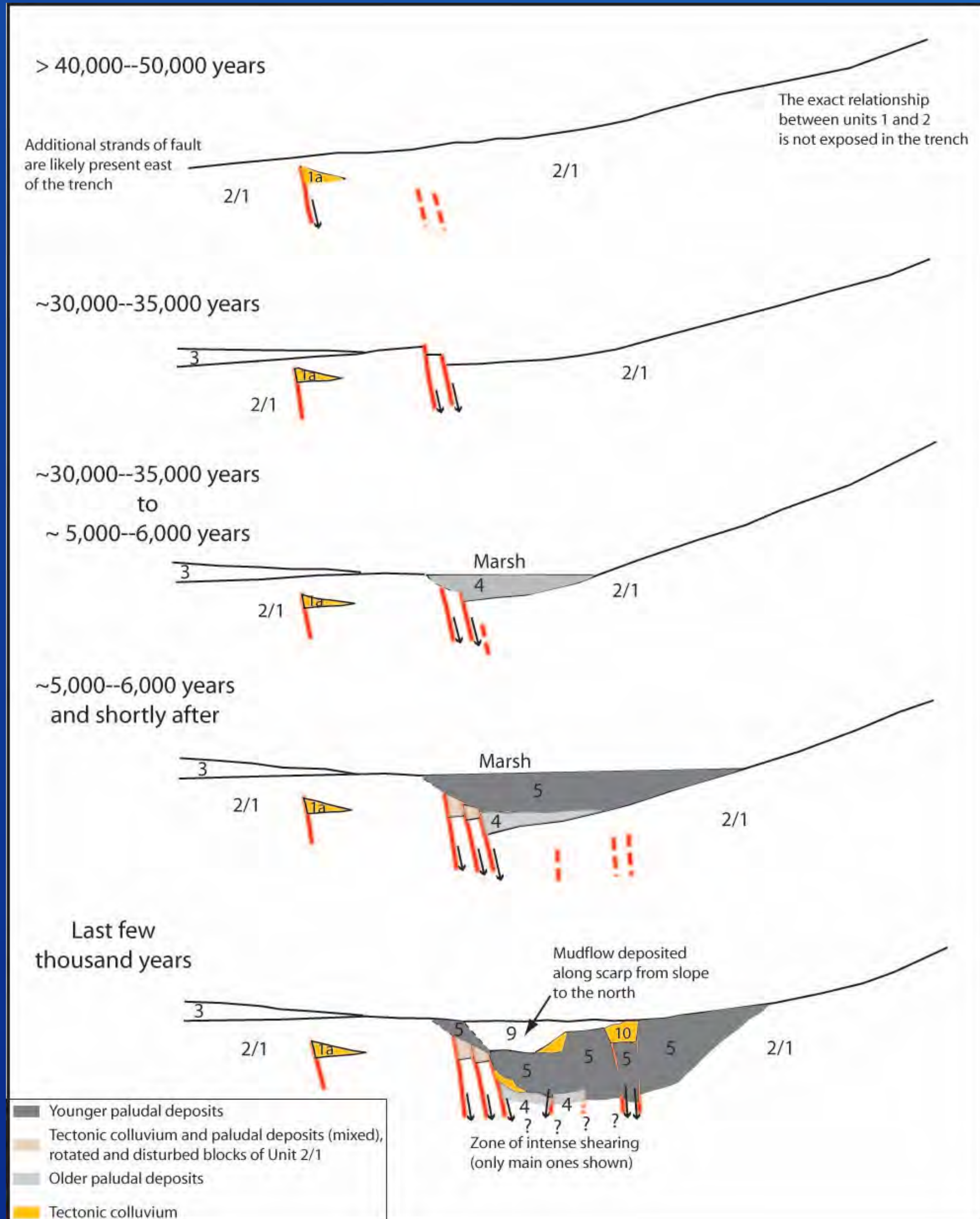
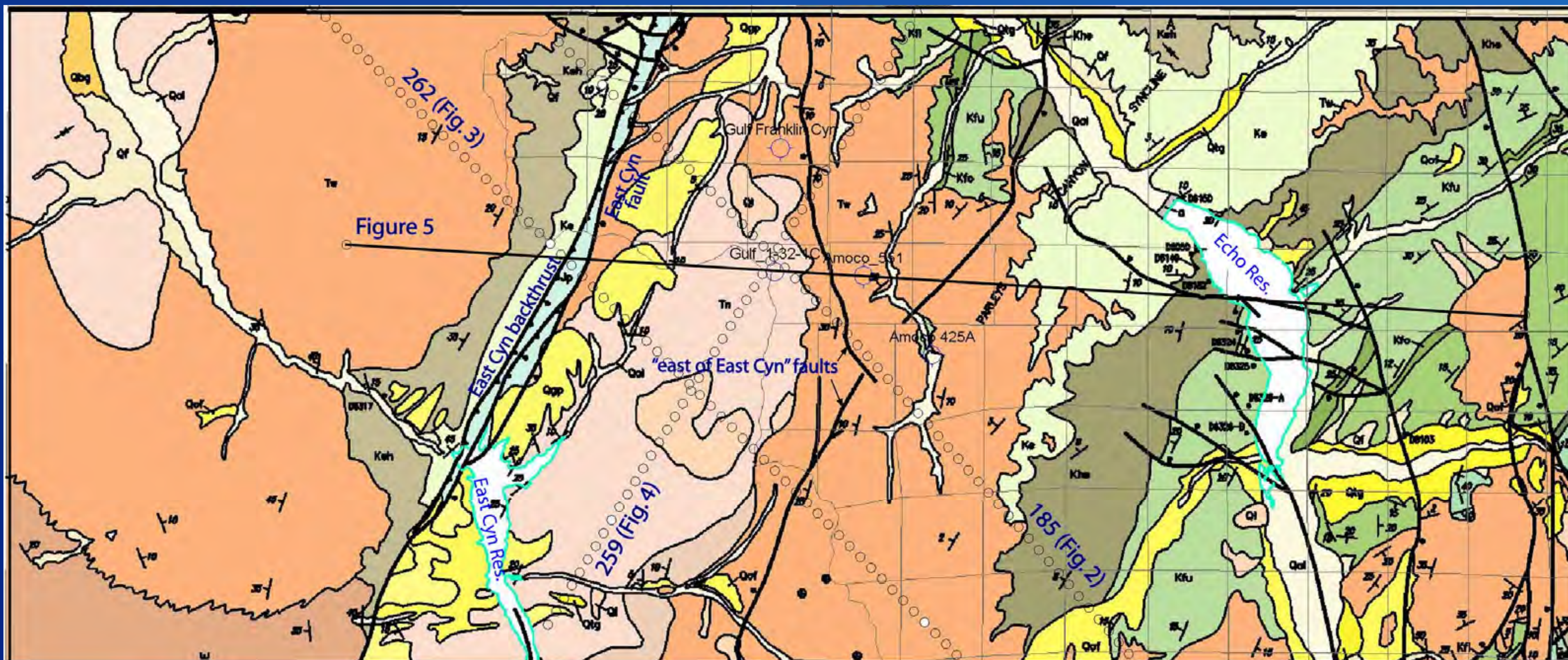
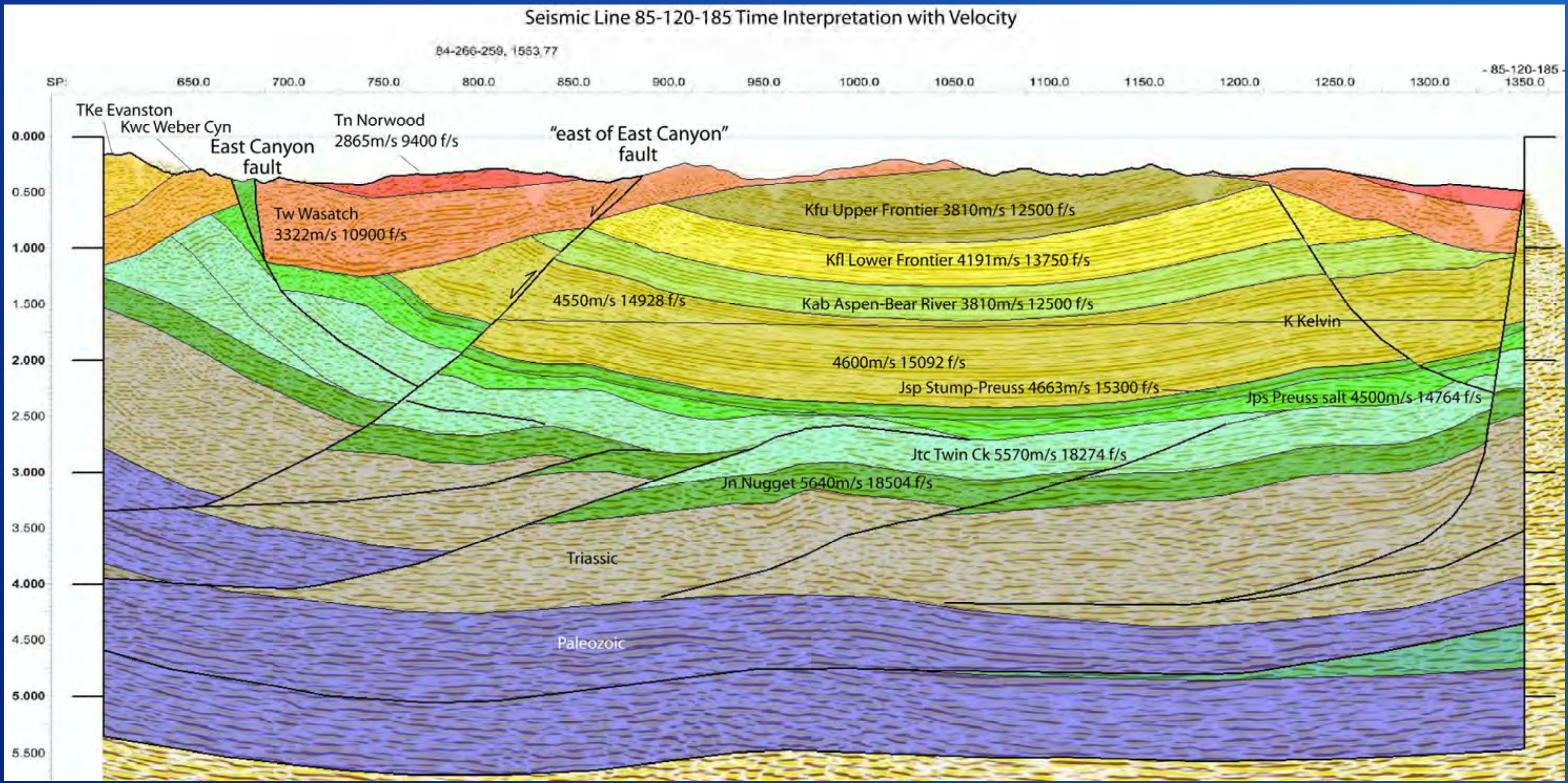


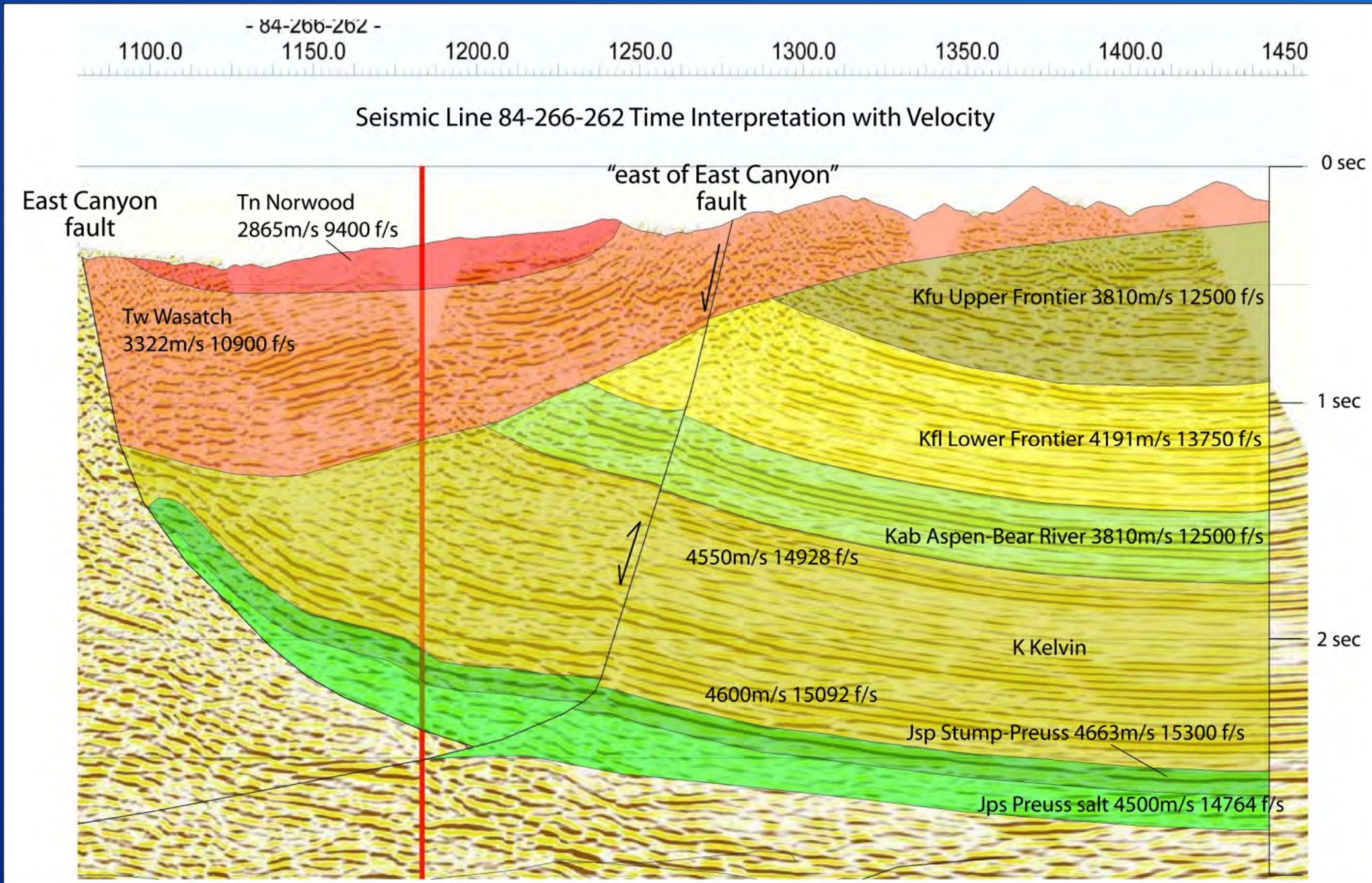
RECLAMATION



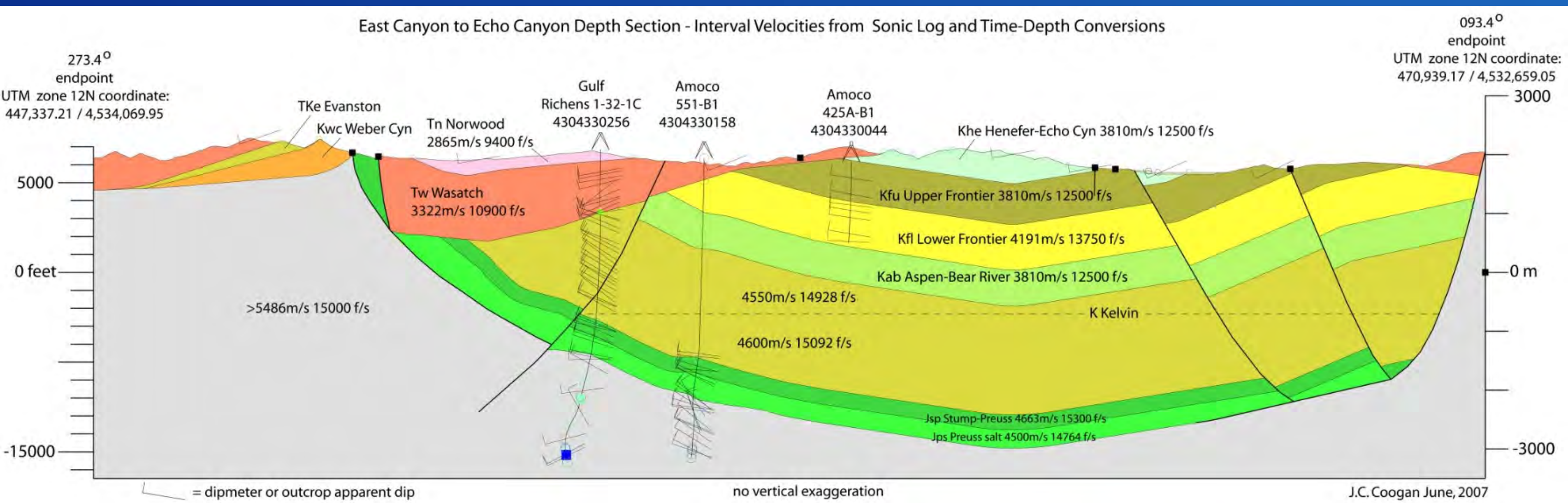
RECLAMATION



RECLAMATION



RECLAMATION



RECLAMATION

Main Canyon Fault

- Prominent geomorphic feature on the landscape – Even though only ~ 200 m of normal displacement
- Faulting history interpreted from the trench (multiple late Quaternary SR events) agrees with overall geomorphic expression
- West-facing, down-to-the-west fault, similar to other identified late Cenozoic back-valley faults in the trust belt
- Probability of “activity” or being the dominant seismic source – **0.9**
- Slip Rate: **0.01 to 0.1**mm/yr; preferred of **0.02 to 0.06** mm/yr

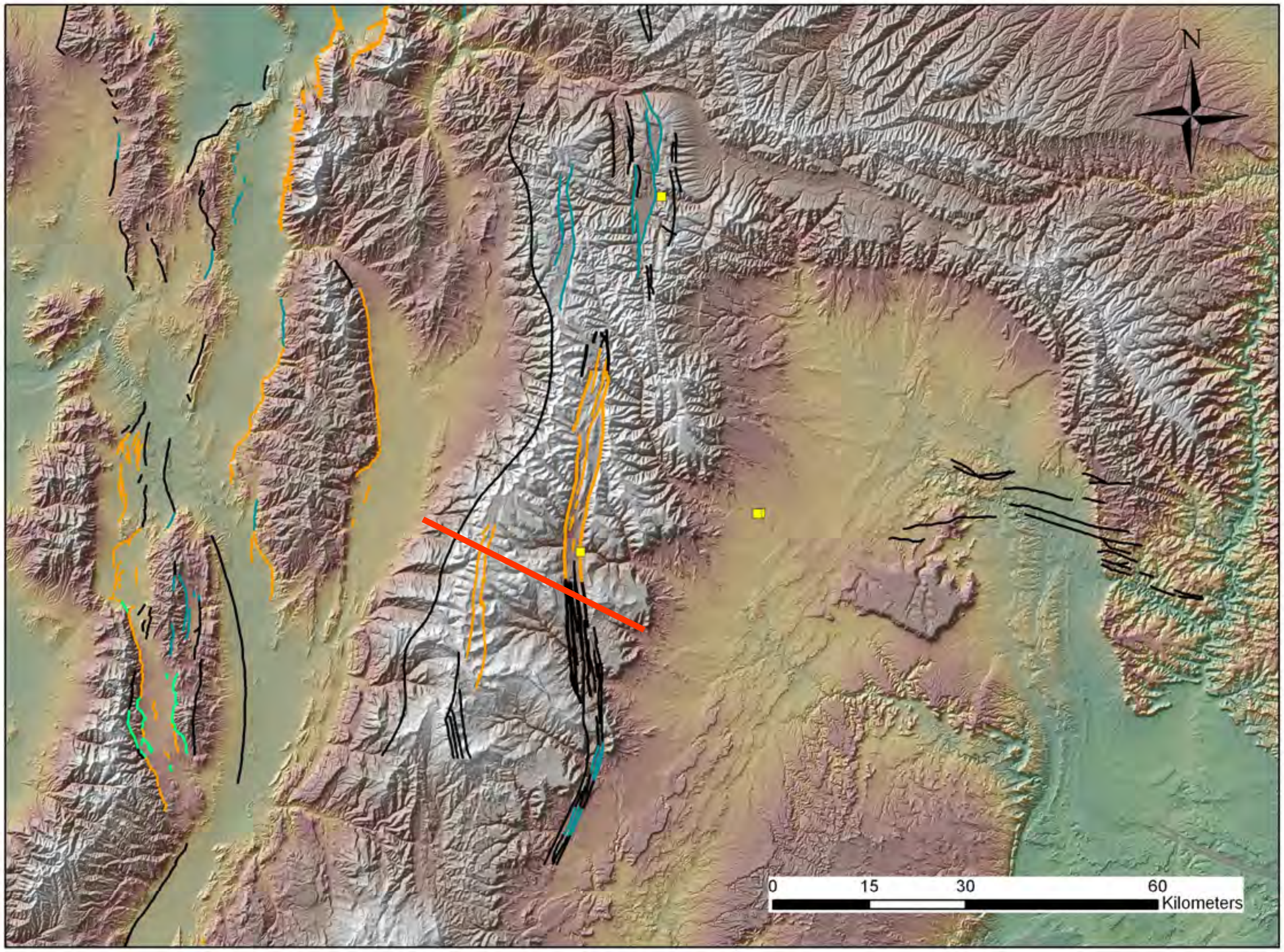
RECLAMATION

East Canyon Fault

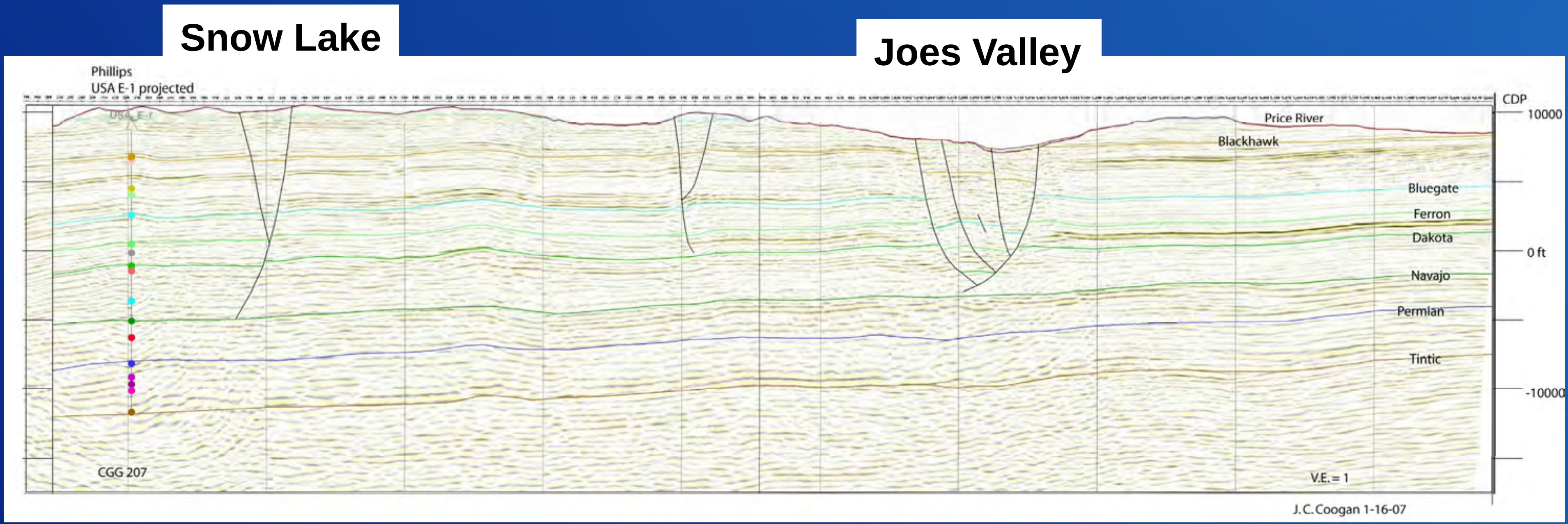
- Normal slip displacement ~ 1900 -2900 m
- Major escarpment- Fault line scarp
- No identified scarps in un-consolidated deposits
- Probability of “activity” or the dominant seismic source – **0.1**
- Slip Rate: **0.005 to 0.05** mm/yr

RECLAMATION

JOES VALLEY



RECLAMATION



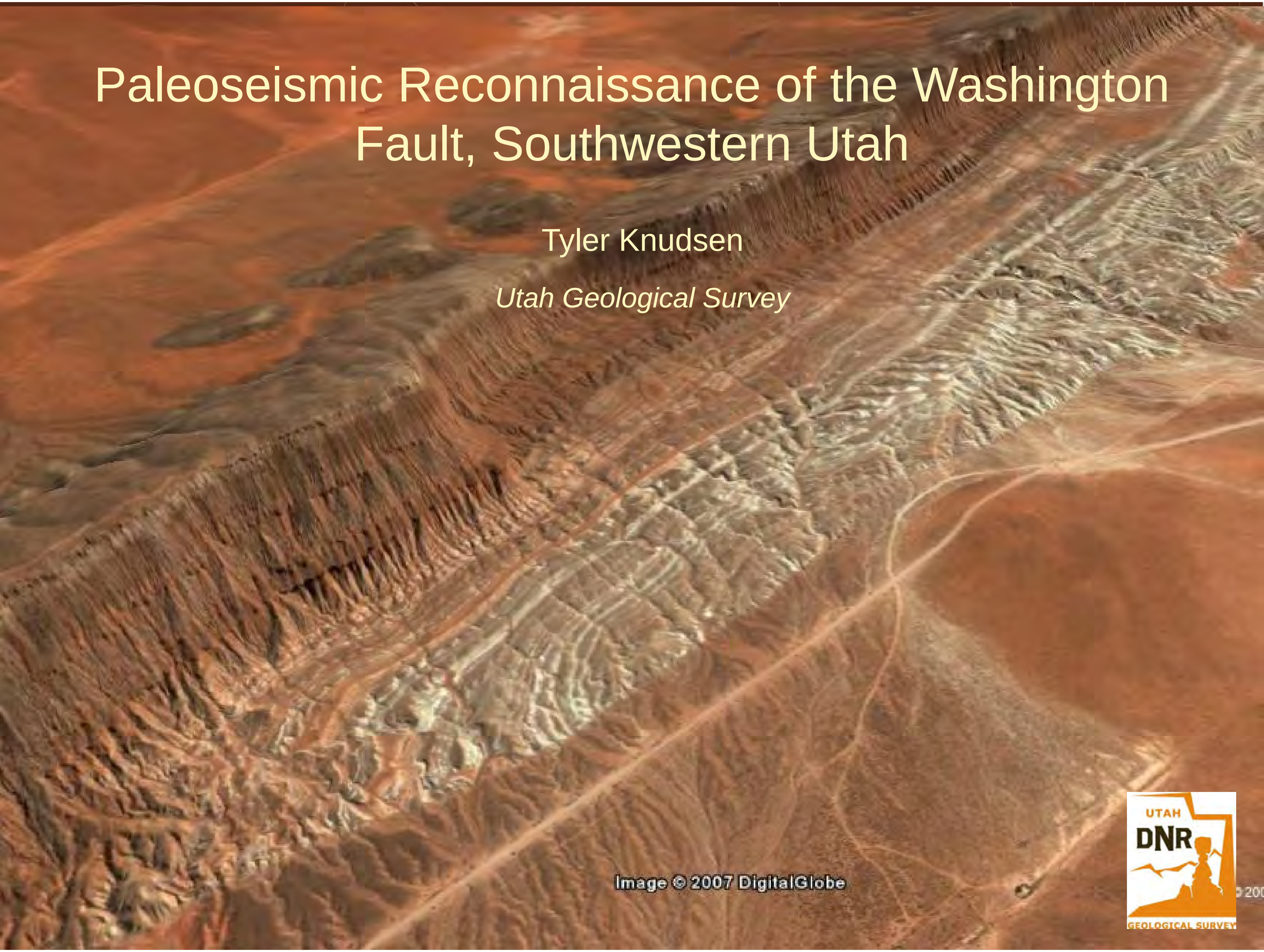
J. Coogan, 2008

RECLAMATION

Paleoseismic Reconnaissance of the Washington Fault, Southwestern Utah

Tyler Knudsen

Utah Geological Survey

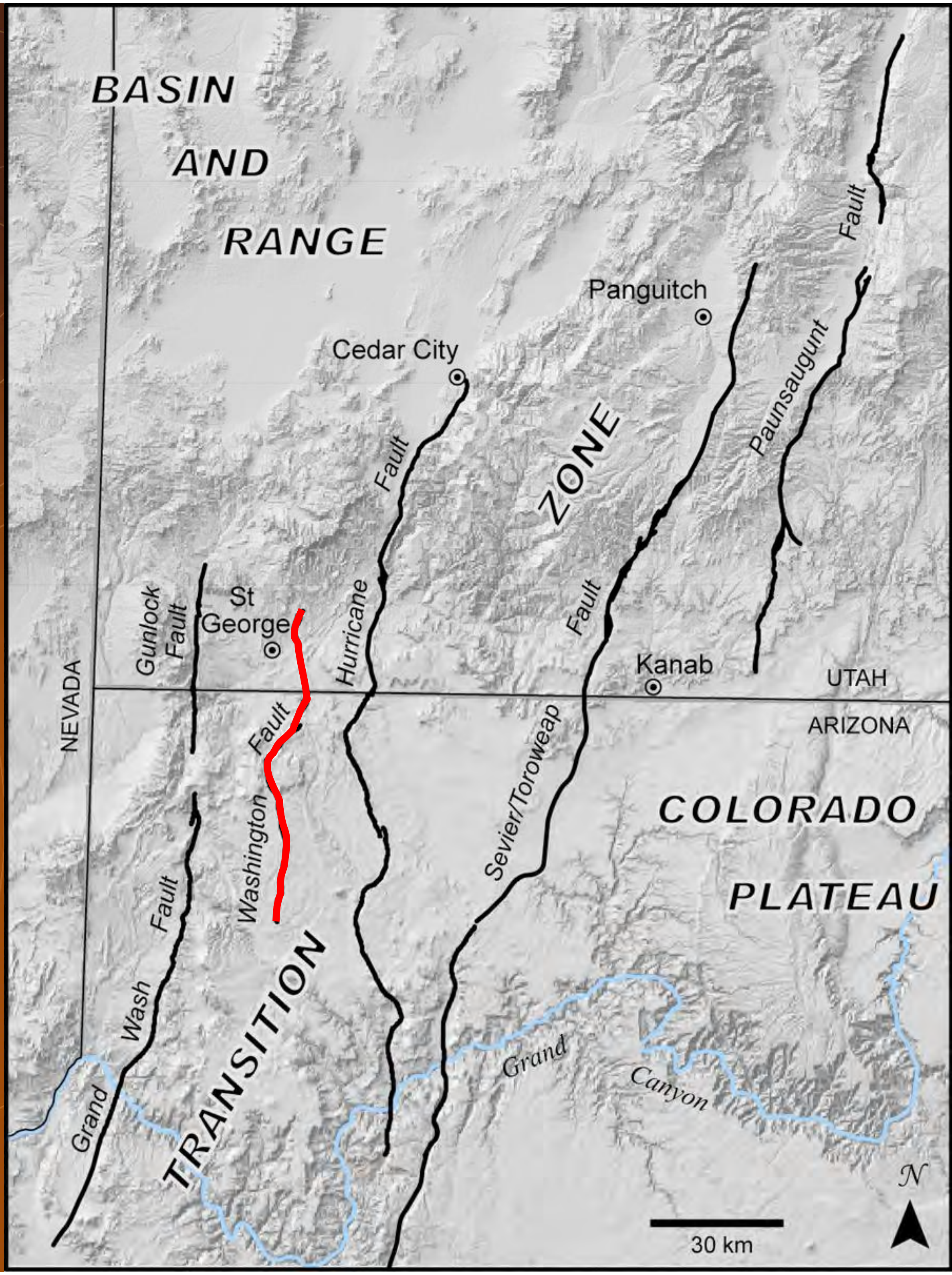


UTAH DNR GEOLOGICAL SURVEY

Washington Fault

- Within Basin & Range/Colorado Plateau transition zone
- Considered relatively minor compared to nearby faults
- ~75 km long
- Max displacement (~750 m) 6 km south of UT-AZ border
- Has received only cursory study despite proximity to booming St. George-Washington metro area

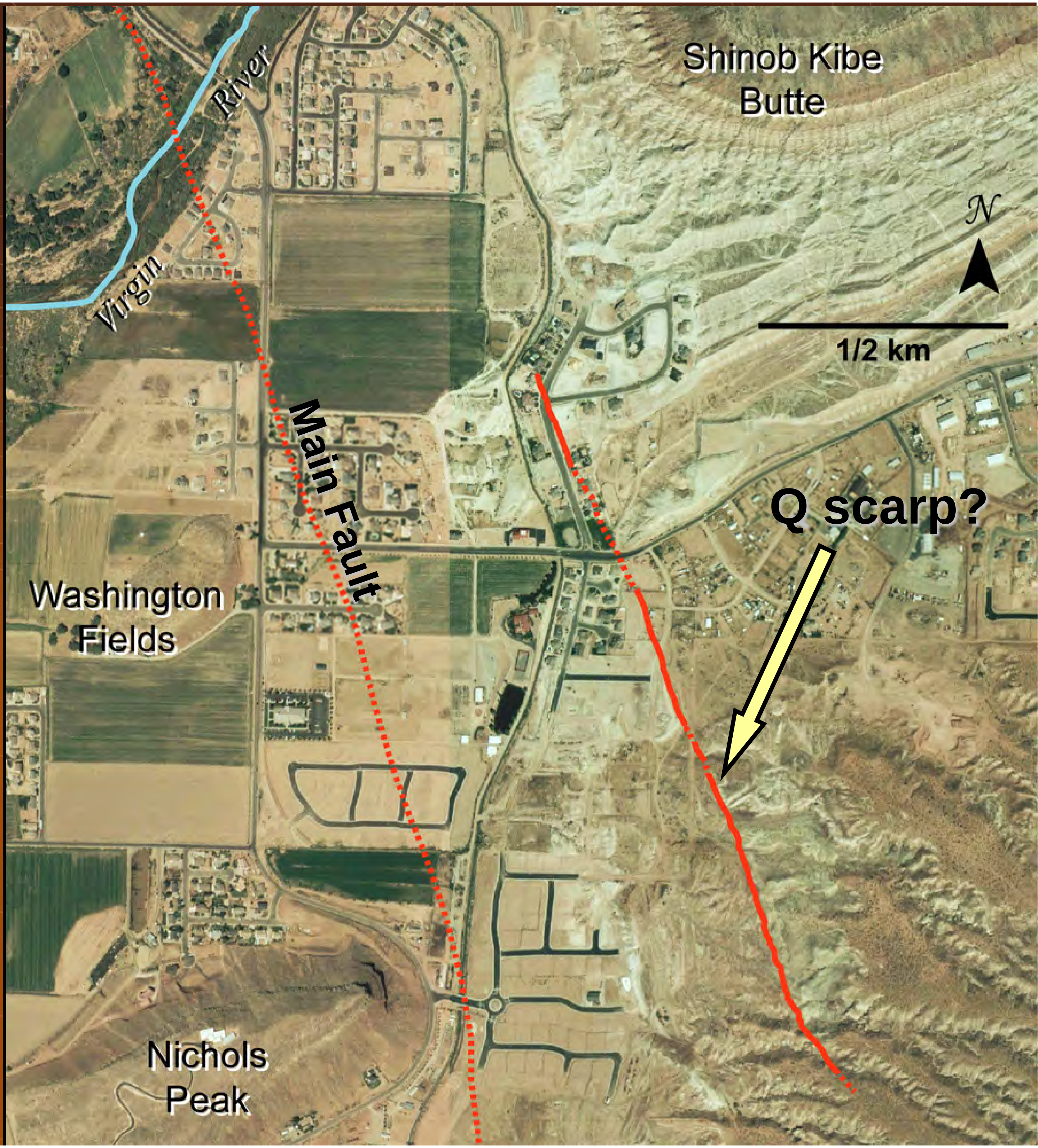
YEAR	POPULATION
2000	91,104
2005	125,010
2010	162,544
2020	251,896
2030	353,922
2040	472,355
2050	607,334



Rapid Urbanization

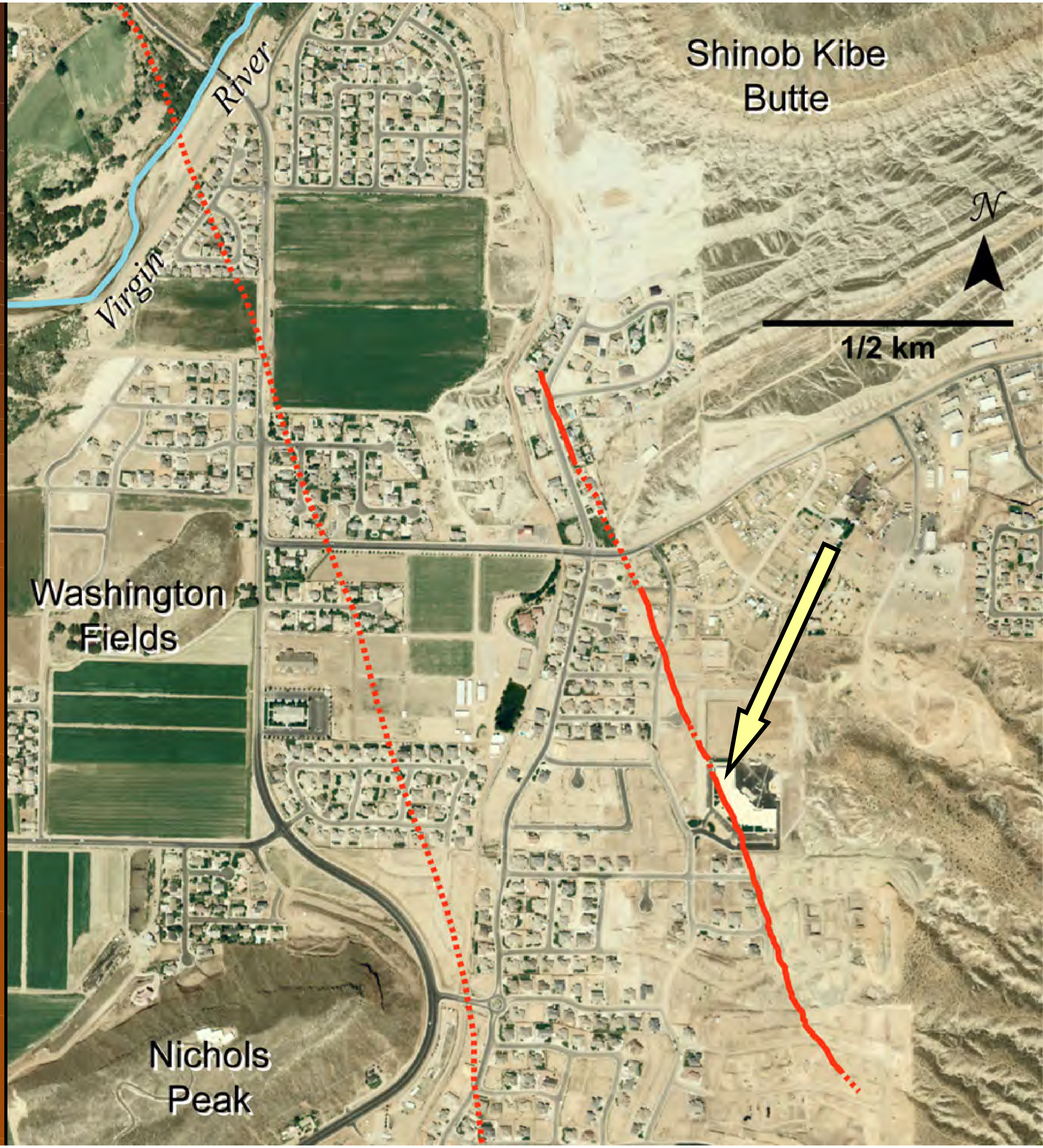
- Possible scarp in Quaternary unconsolidated deposits on subsidiary fault

2004



Rapid Urbanization

2006




Jkm
Jku

Goals

- Better assess seismic hazard to the St. George metro area
  - Develop new information on earthquake timing, recurrence, displacement, vertical slip rate, and segmentation
- Use these data to update the USGS National Seismic Hazard Maps

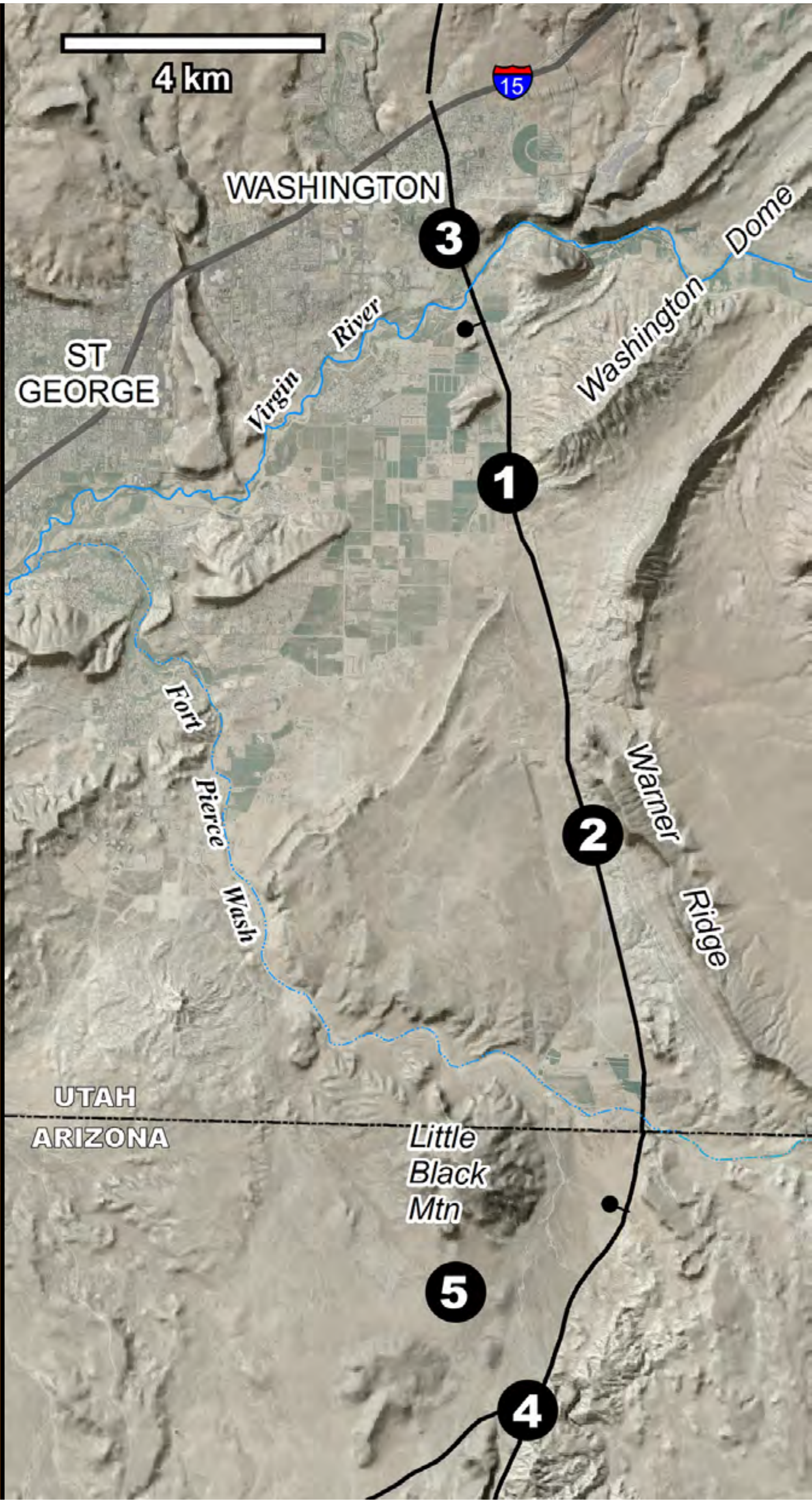
Methods

- Literature review (complete)
- Air photo interpretation (complete)
- Trenching
  - Suitable scarps all in Arizona
  - AGEC trenches: reconnaissance-level study
- Scarp profiling
- Sampling of displaced basalt flows
  - Geochemistry
  - Paleomagnetics
  - $^{40}Ar/^{39}Ar$ dating

Overview

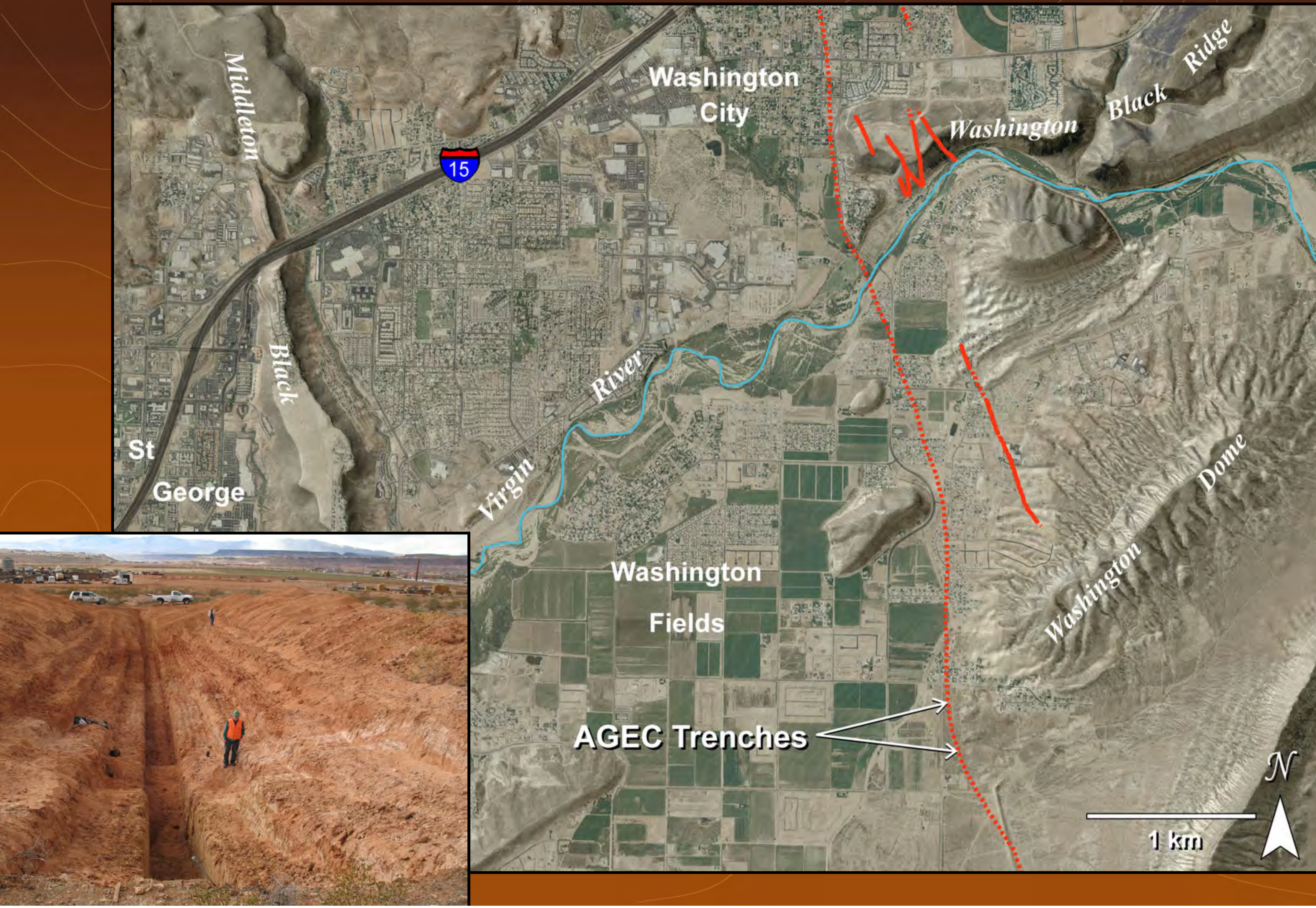
5 Key Sites That May Help Determine Fault Timing

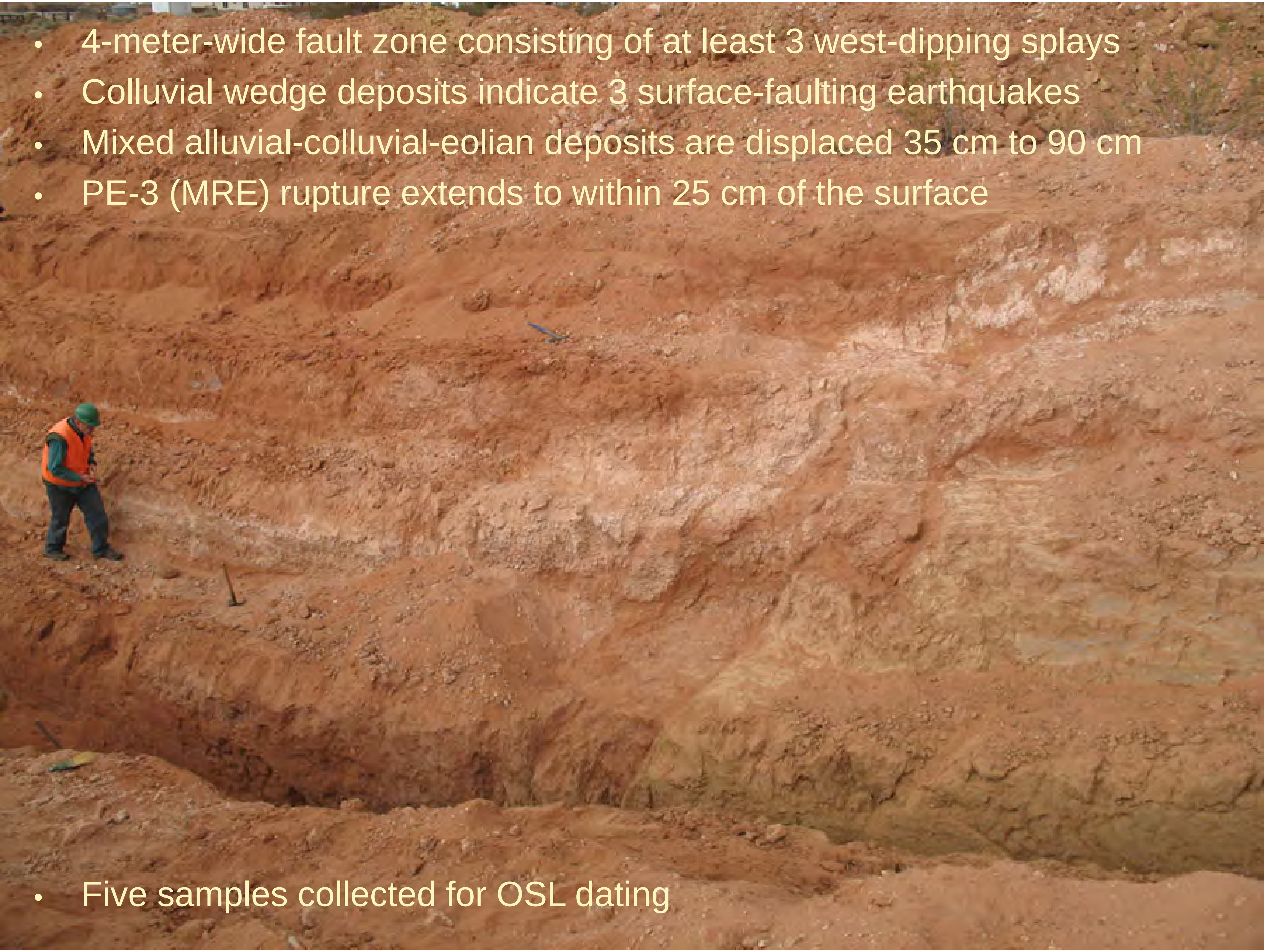
1. AGEC trench site
2. Faulted pediment deposit (Anderson and Christenson, 1989)
3. Displaced Washington Flow (Anderson and Christenson, 1989)
4. Possible trench site in Arizona
5. Displaced flows in Arizona

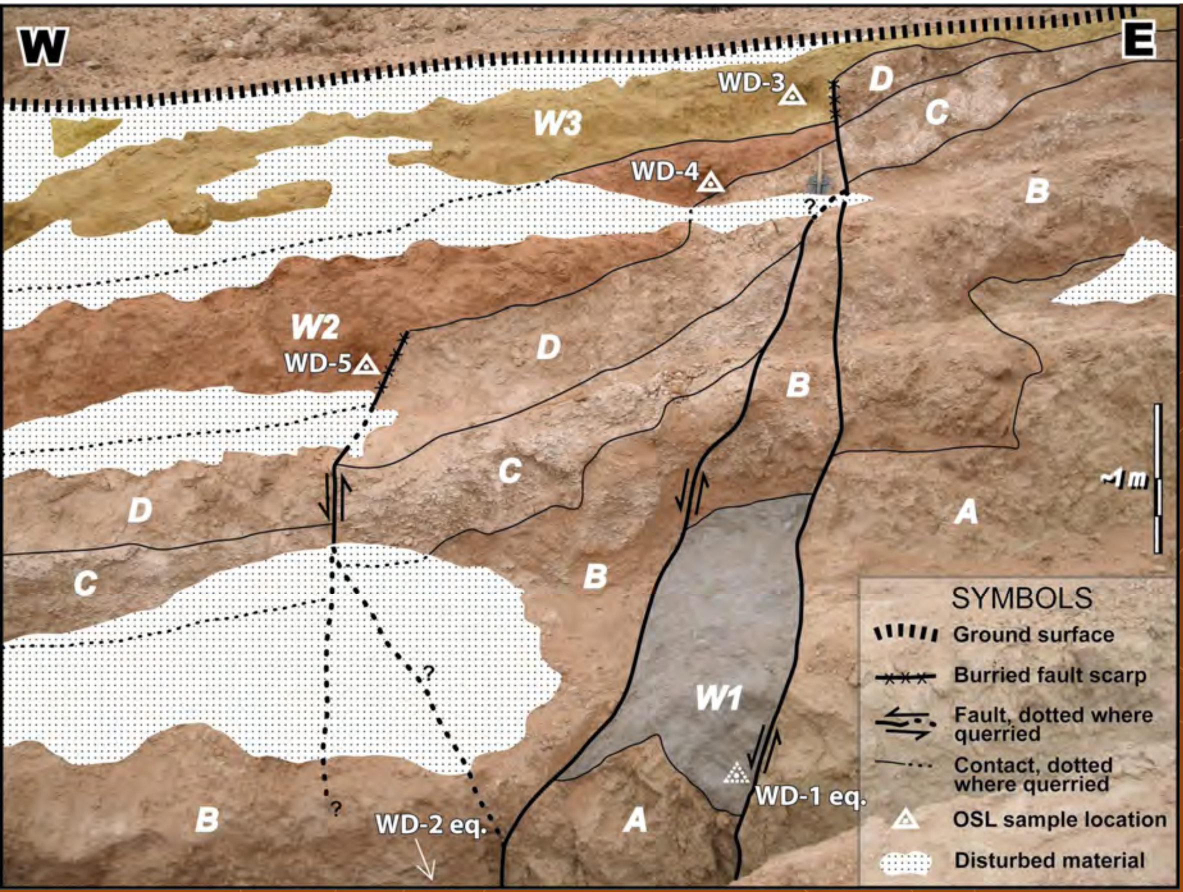


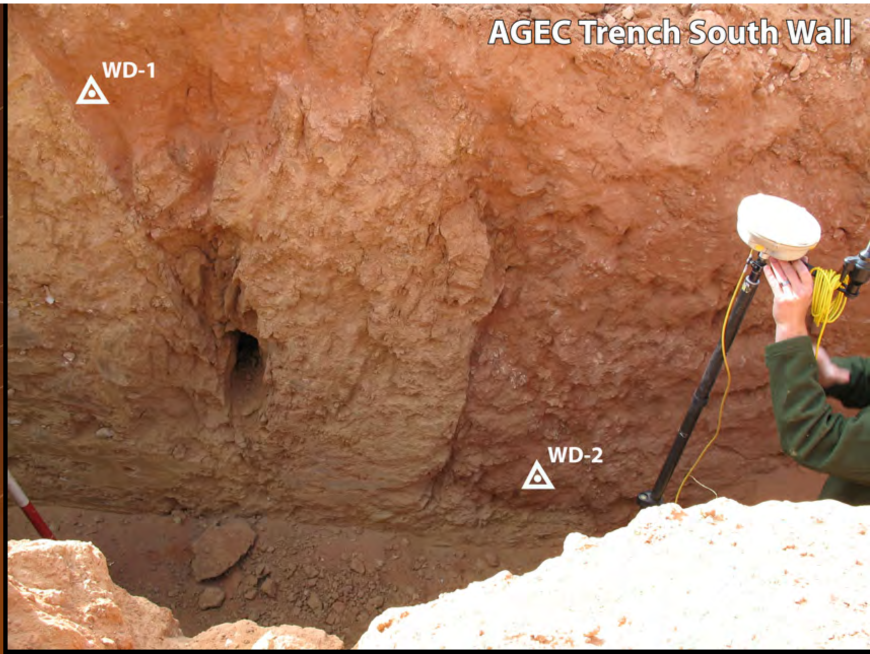
2007 AGEC Trenches

Reconnaissance Investigation




• 4-meter-wide fault zone consisting of at least 3 west-dipping splays
• Colluvial wedge deposits indicate 3 surface-faulting earthquakes
• Mixed alluvial-colluvial-eolian deposits are displaced 35 cm to 90 cm
• PE-3 (MRE) rupture extends to within 25 cm of the surface
• Five samples collected for OSL dating



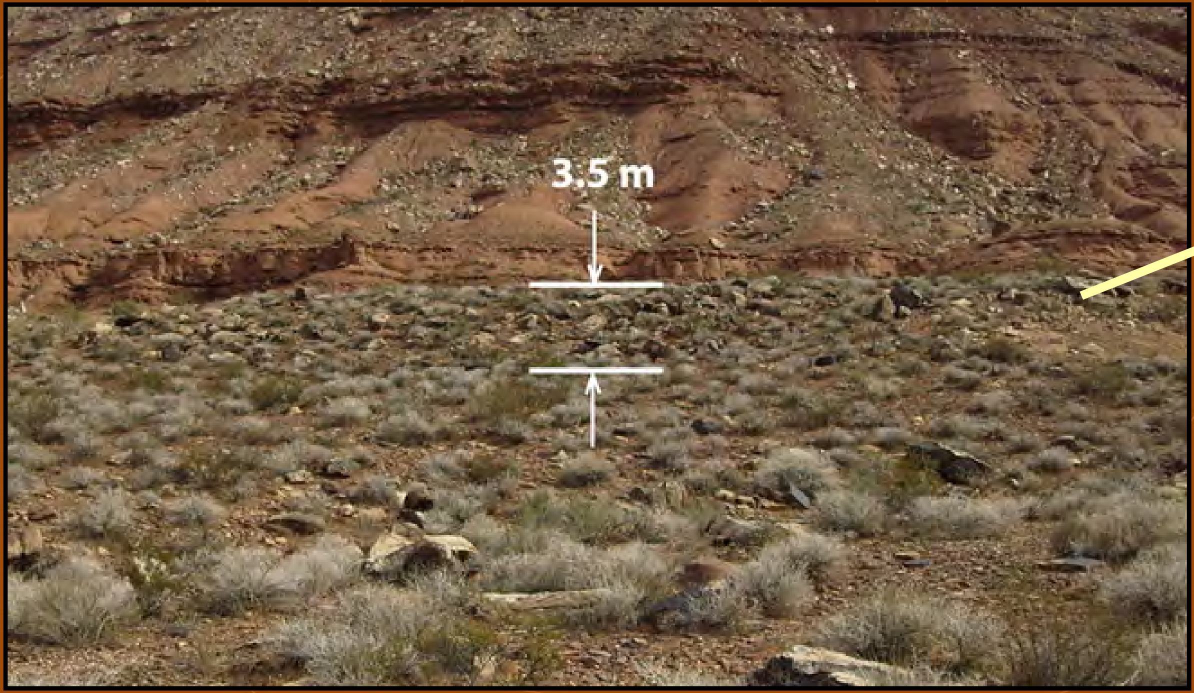


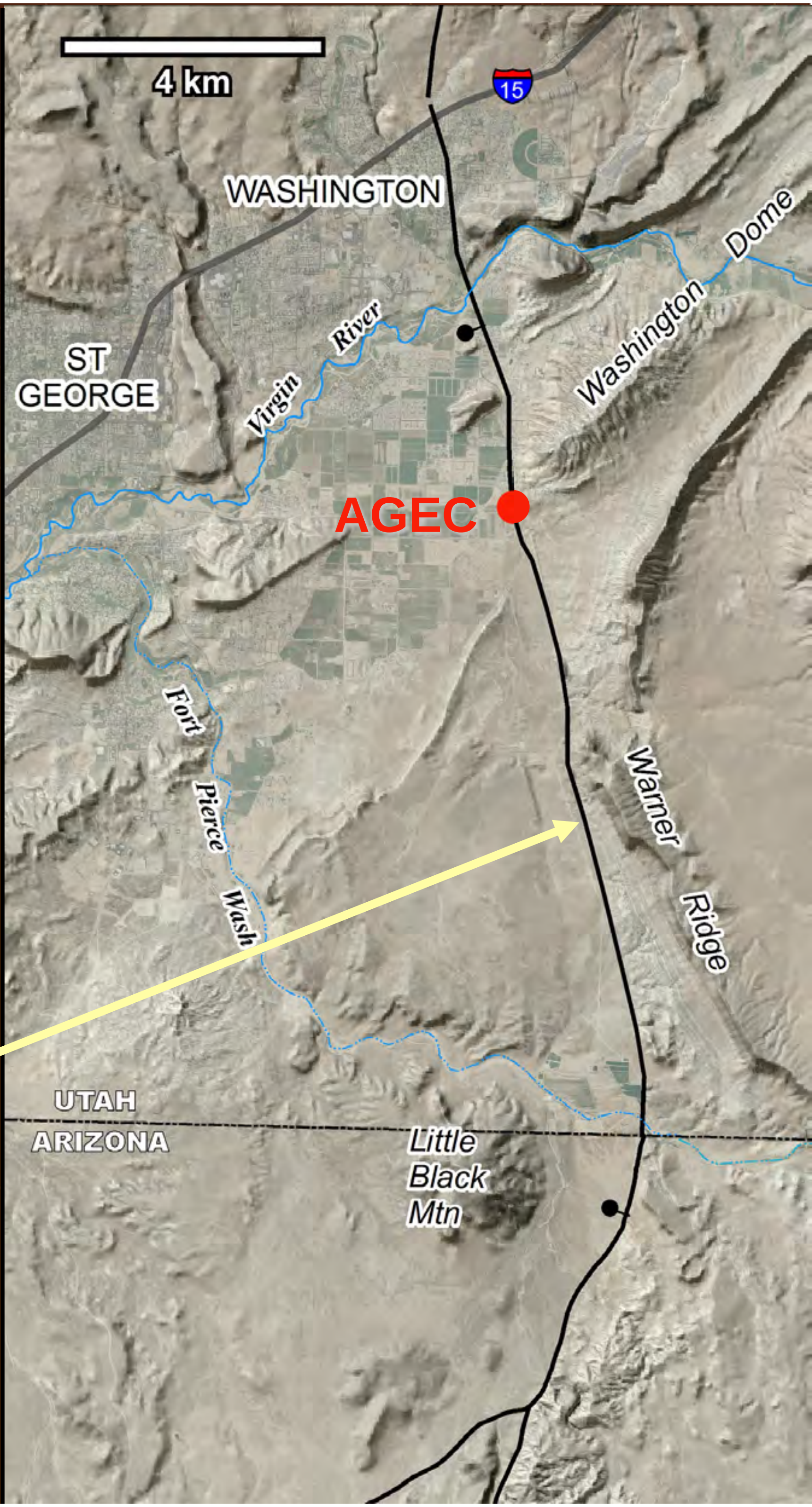
OSL AGE ESTIMATES		
Sample No.	**Age (ka)**	**Remarks**
WD-1	67.75 ± 4.56	PE-1 colluvial wedge
WD-2	75.57 ± 5.13	Pre-PE-1 basin-fill deposits
WD-3	18.59 ± 1.16	PE-3 colluvial wedge
WD-4	30.59 ± 2.10	PE-2 colluvial wedge
WD-5	30.81 ± 2.11	PE-2 colluvial wedge

- Three post-76-ka earthquakes
  - PE-1 shortly before ~68 ka (RI ~ 37 kyr)
  - PE-2 shortly before ~31 ka (RI ~ 12 kyr)
  - PE-3 shortly before ~19 ka
- Late Pleistocene MRE is more consistent with other studies

Faulted Pediment Apron

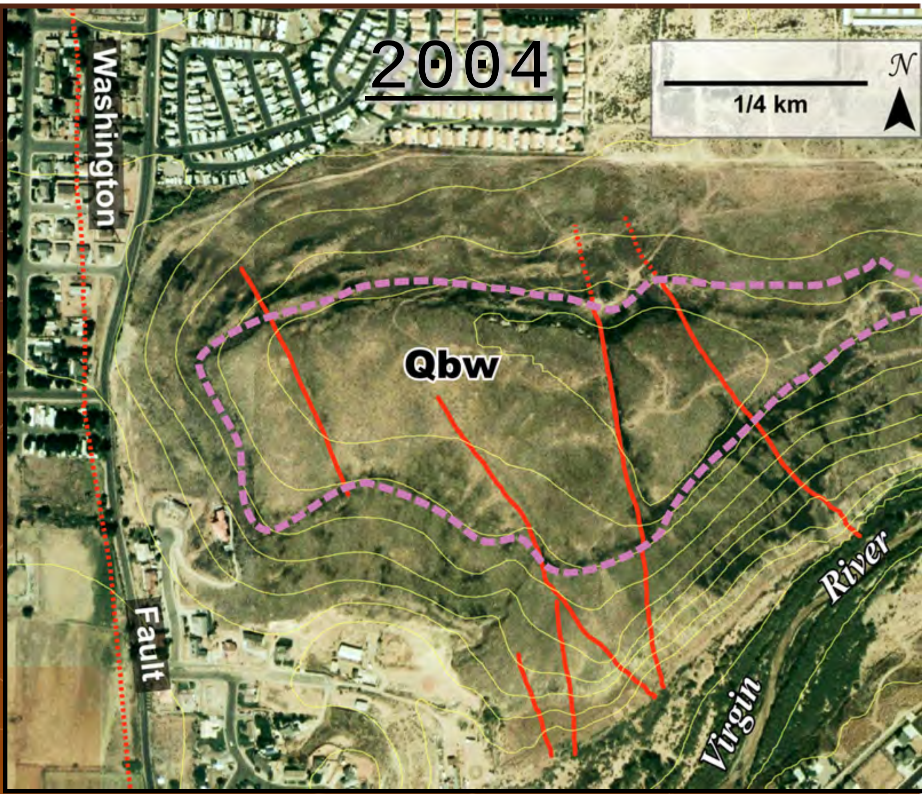
- Anderson and Christenson Study (1989)
  - < 3 miles south of the AGEC trench site
  - Faulted alluvial/colluvial pediment apron
  - Estimate a late Pleistocene age based a comparison of scarp profile to dated scarps elsewhere

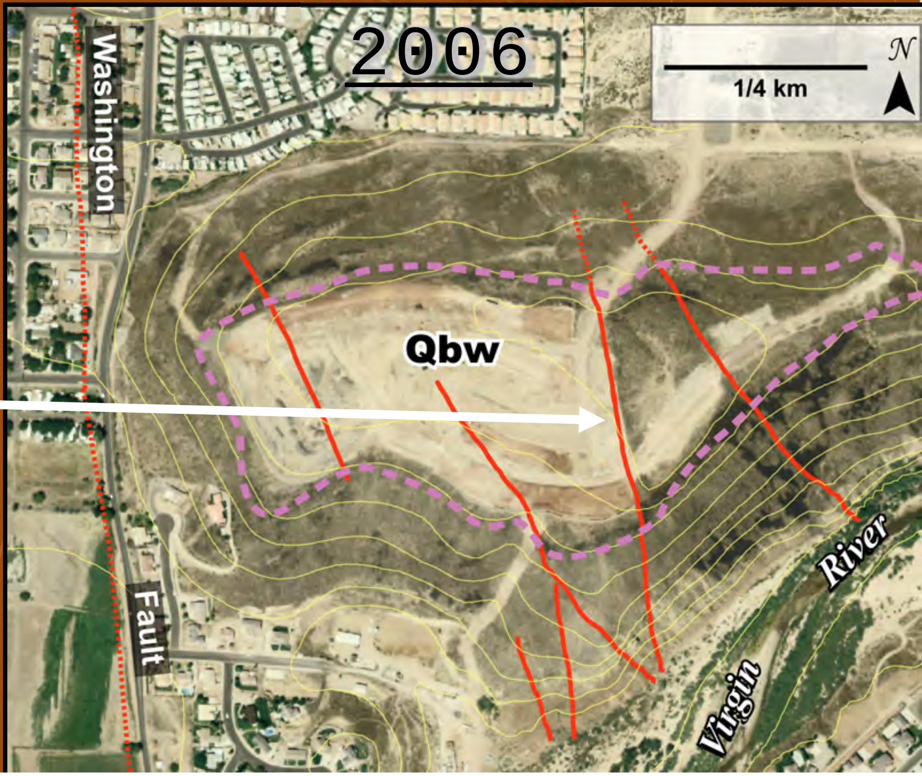


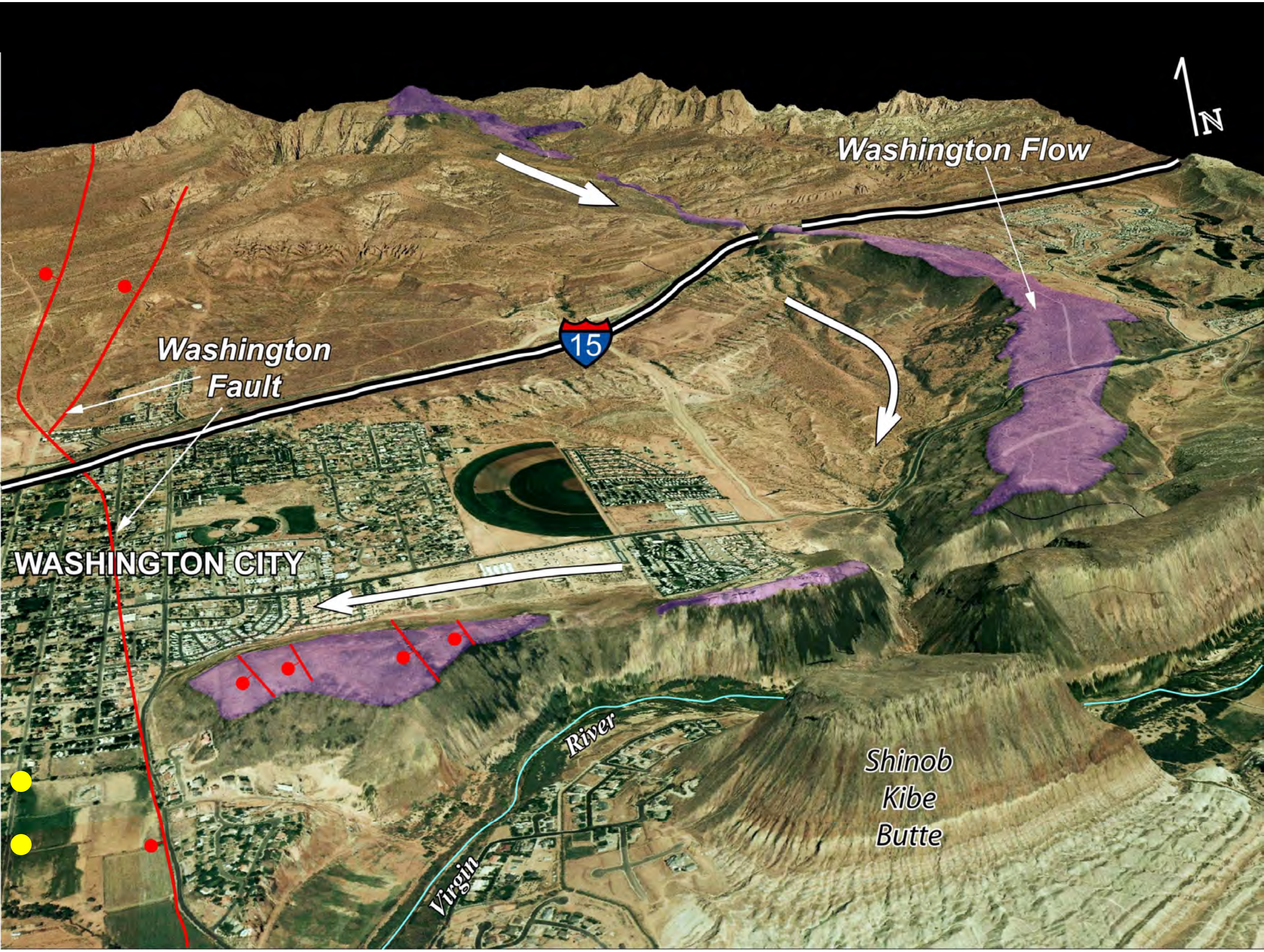


Washington Flow

- Only place in UT where related faults cut a basalt flow (900 ka [Biek, 2003])
- Maximum throw = 4.5 meters



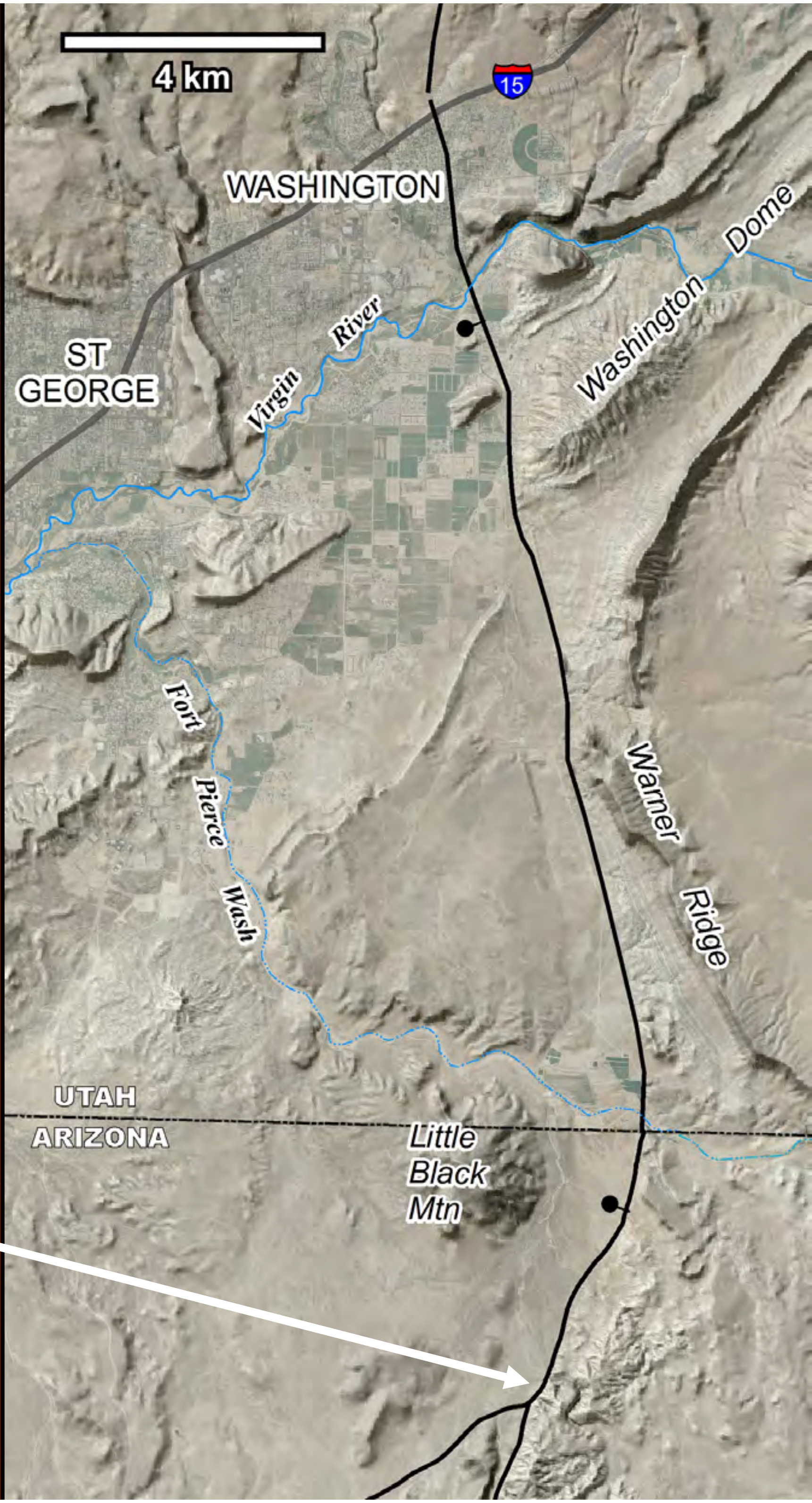




N
Washington Flow
Washington Fault
15
WASHINGTON CITY
River
Virgin
Shinob
Kibe
Butte

Possible Trench Site (AZ)

- 4.5 km south of state line
- 4-m-high scarp developed in a weakly consolidated, moderately dissected alluvial fan
- Best chance to collect additional paleoearthquake information applicable to the WF in Utah



Displaced Basalts

- Critical for deter-mining slip rates

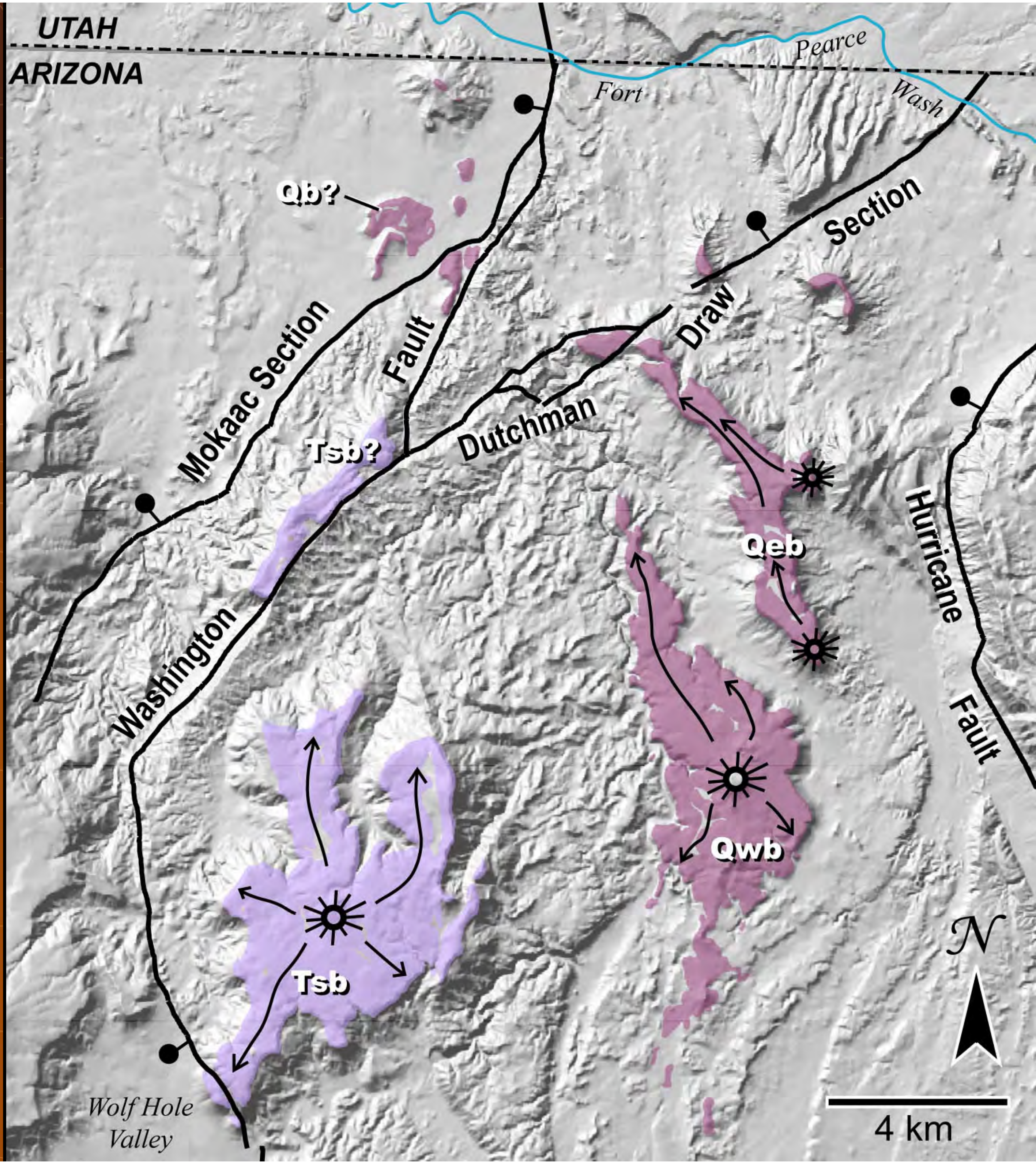
Reynolds and others (1986):

Qeb – East Mesa Basalt
~1.4 Ma (K-Ar)

Qwb – West Mesa Basalt
~1.6 Ma (K-Ar)

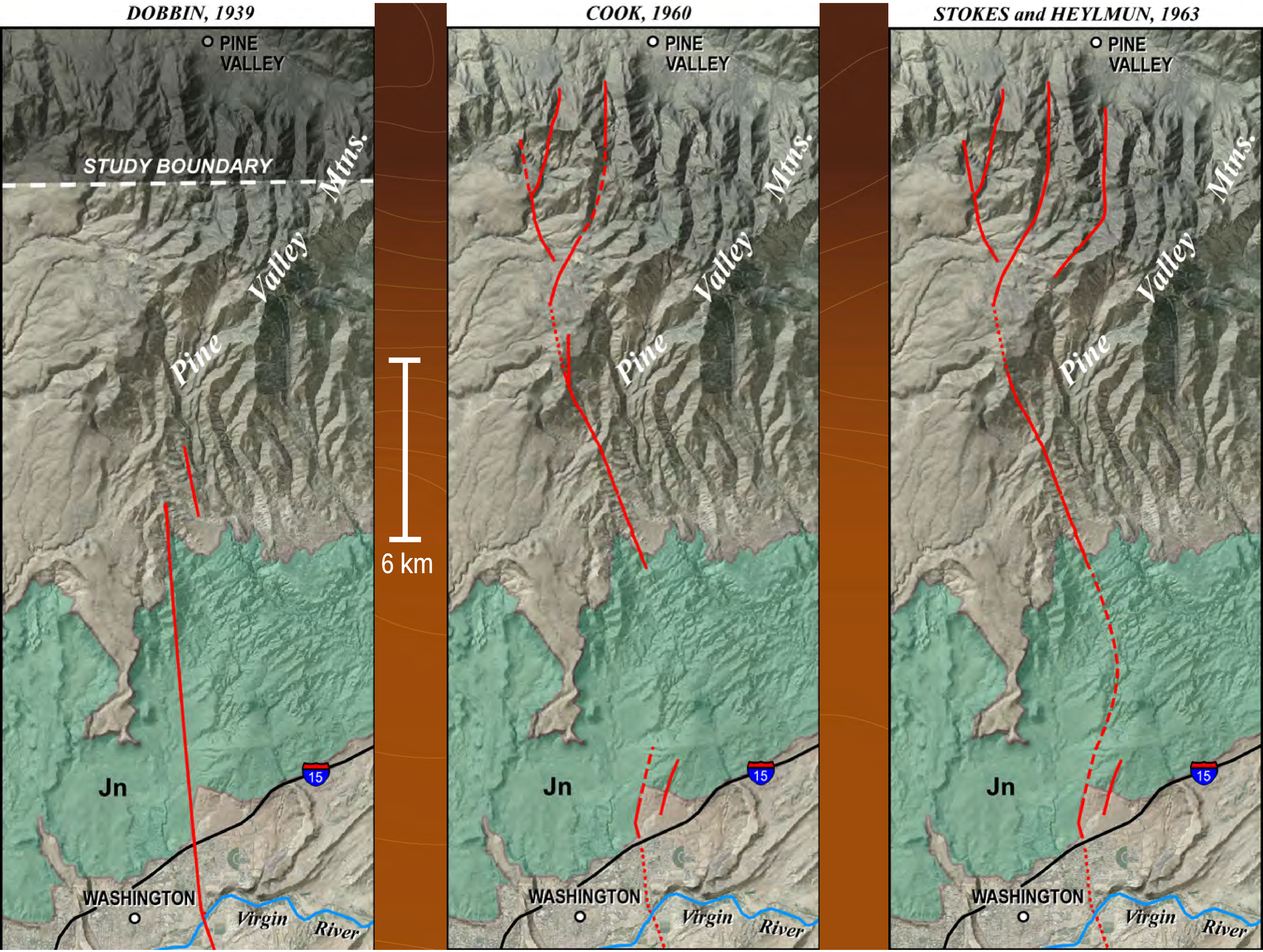
Tsb – Seegmiller Mtn.Basalt
~2.4 Ma (K-Ar)

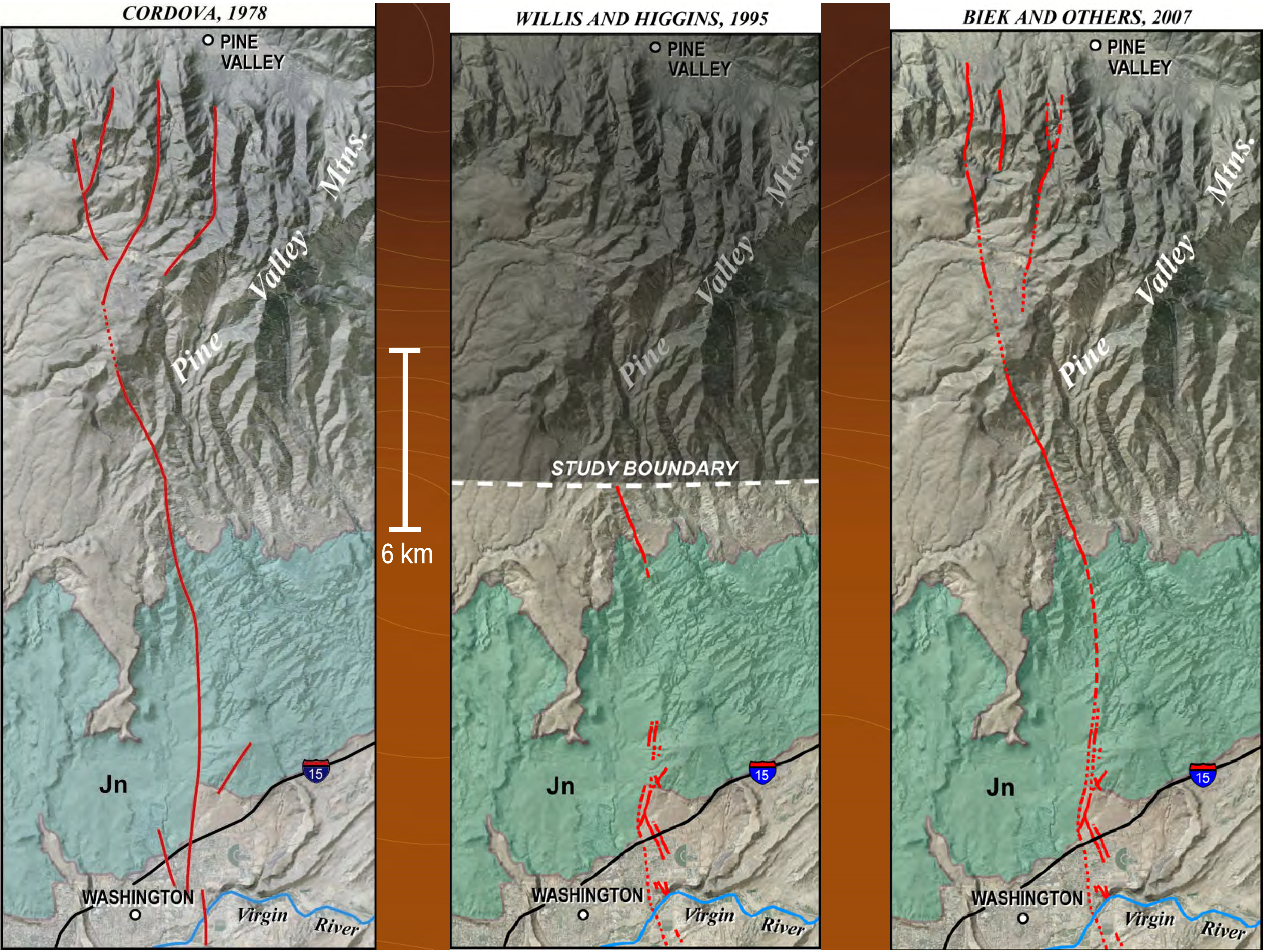
- Poor accuracy of K-Ar ages
- Poor correlation across the fault



Northern Termination

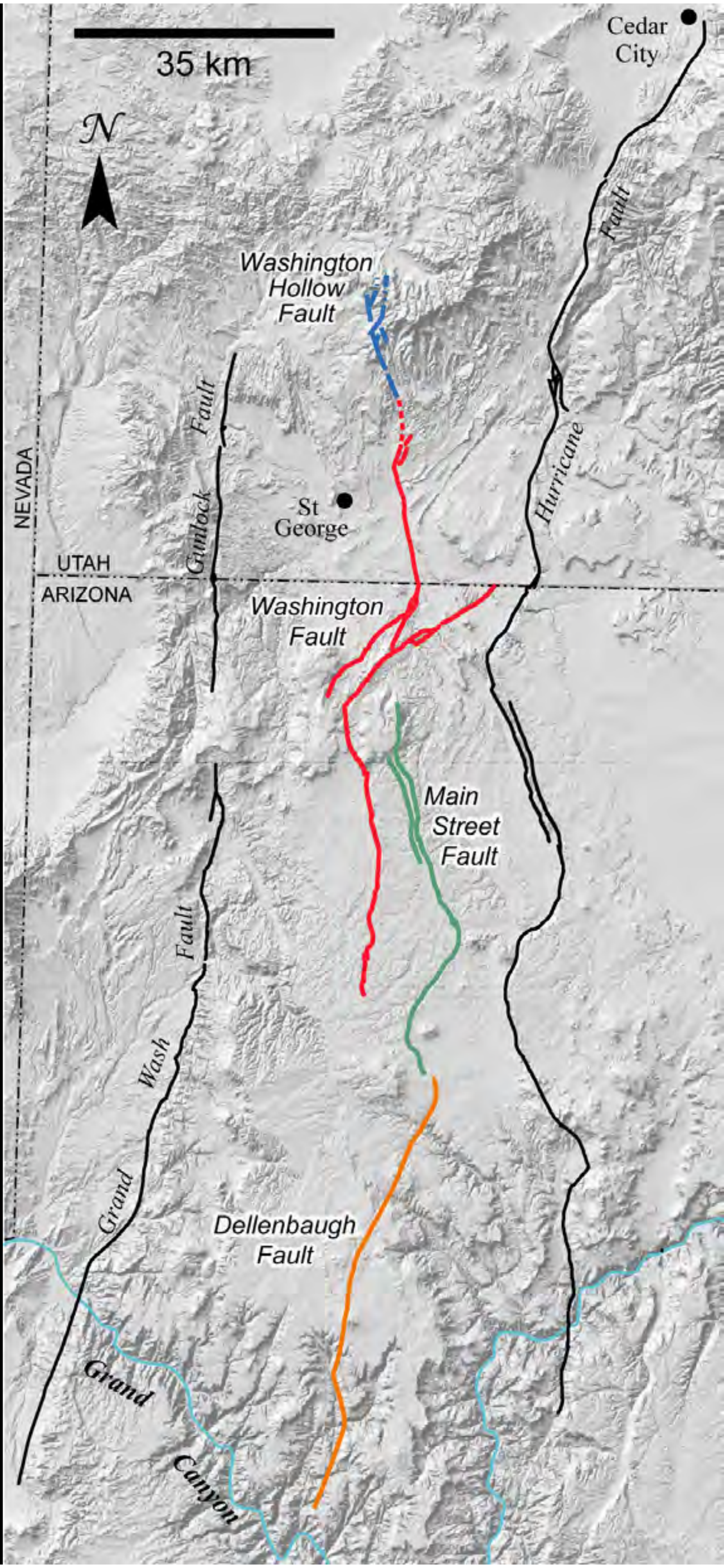
- Difficult to follow through thick Navajo section
- Connection to Washington Hollow fault?


DOBBIN, 1939
PINE VALLEY
STUDY BOUNDARY
Pine Valley Mtns.
Jn
15
WASHINGTON
Virgin River
6 km
COOK, 1960
PINE VALLEY
Pine Valley Mtns.
Jn
15
WASHINGTON
Virgin River
STOKES and HEYLMUN, 1963
PINE VALLEY
Pine Valley Mtns.
Jn
15
WASHINGTON
Virgin River


CORDOVA, 1978
PINE VALLEY
Pine Valley Mtns.
Jn
15
WASHINGTON
Virgin River
6 km
WILLIS AND HIGGINS, 1995
PINE VALLEY
Pine Valley Mtns.
STUDY BOUNDARY
Jn
15
WASHINGTON
Virgin River
BIEK AND OTHERS, 2007
PINE VALLEY
Pine Valley Mtns.
Jn
15
WASHINGTON
Virgin River

Southern Termination

- Main Street Fault
  - en echelon (Hamblin, 1970)
  - Similar geometry, offset, & timing
- Dellenbaugh Fault
  - Narrow left step with Main Street fault
  - Similar geometry, offset, & timing
- If considered the same fault system, this would add another 70 km
- WHF + WF + MSF + DF = 160 km!



Preliminary Conclusions

- Late Pleistocene (pre 18 ka) MRE near Washington City in UT
- Three surface-faulting earthquakes in the last 76 kyr
- Irregular recurrence interval (12 to 37 kyr)
- Length of fault may need to be revised

Future Work

- Additional trenching studies
- Scarp profiling
- Sample basalts for age-dating analysis and correlation
- With new timing, slip rate, and offset amounts, develop a segmentation model

WFZ - Brigham City Segment

- Refine MRE timing and uncertainty
- Investigate multi-seg/spill-over rupture with Weber segment
- Refine vertical displacement and slip-rate data

- Trenching Spring 2008 (UGS/USGS)

Previous Work

- Personius (1991) Bowden Cyn, Pole Patch
  - events Y, X, W,
- McCalpin and Forman (1993, 2002)
  - trenched 7 scarps Provo delta SE Brig City
  - events Z, Y, W, V, U?, T

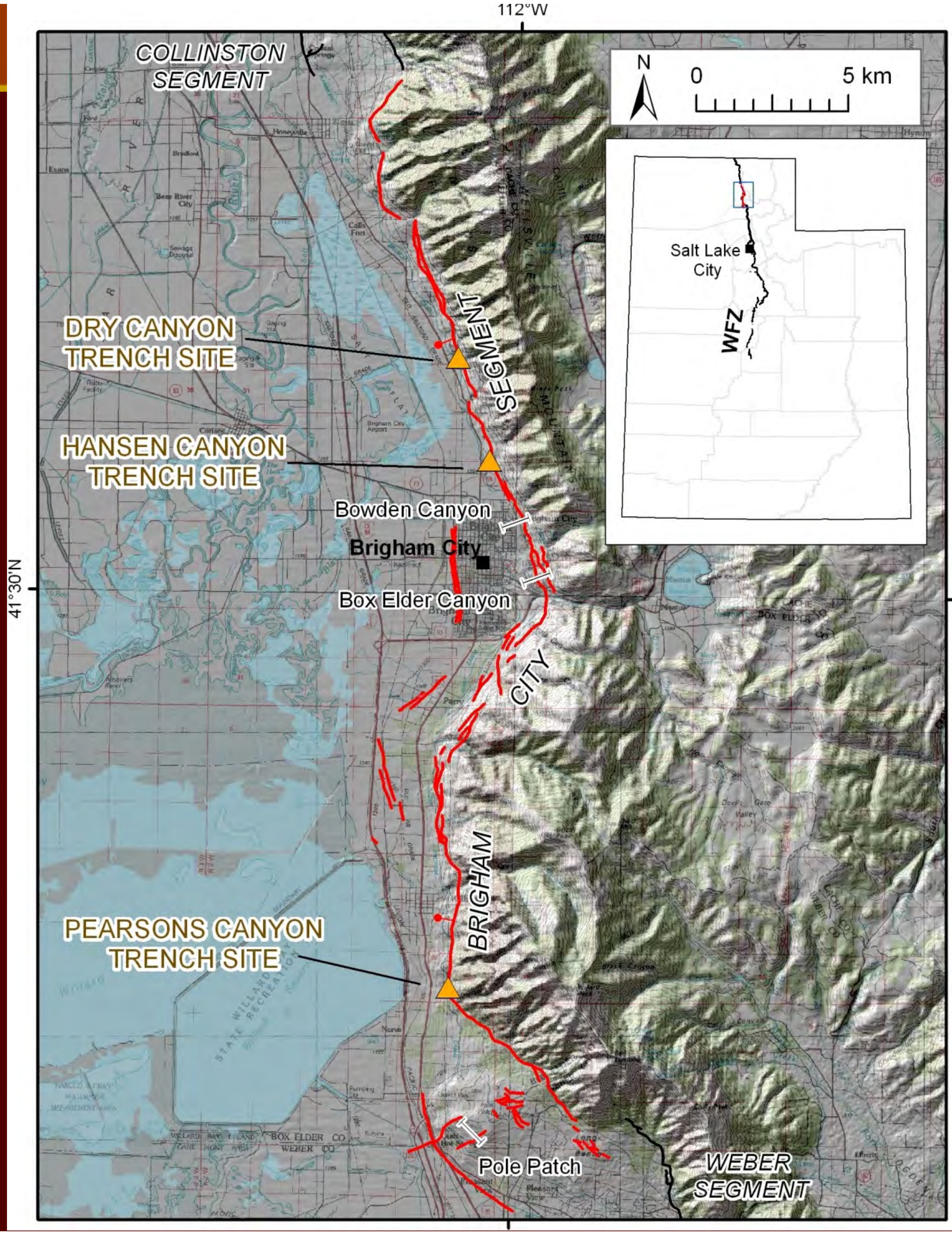
Z	2100+-800 cal yr BP
Y	3450+-300
X	4650+-500
W	5950+-250
V	7500+-1000
U	8500+-1500
T	>14800+-1200 <17000

UTAH GEOLOGICAL SURVEY

Preferred sites

Hanson South

Pearsons North

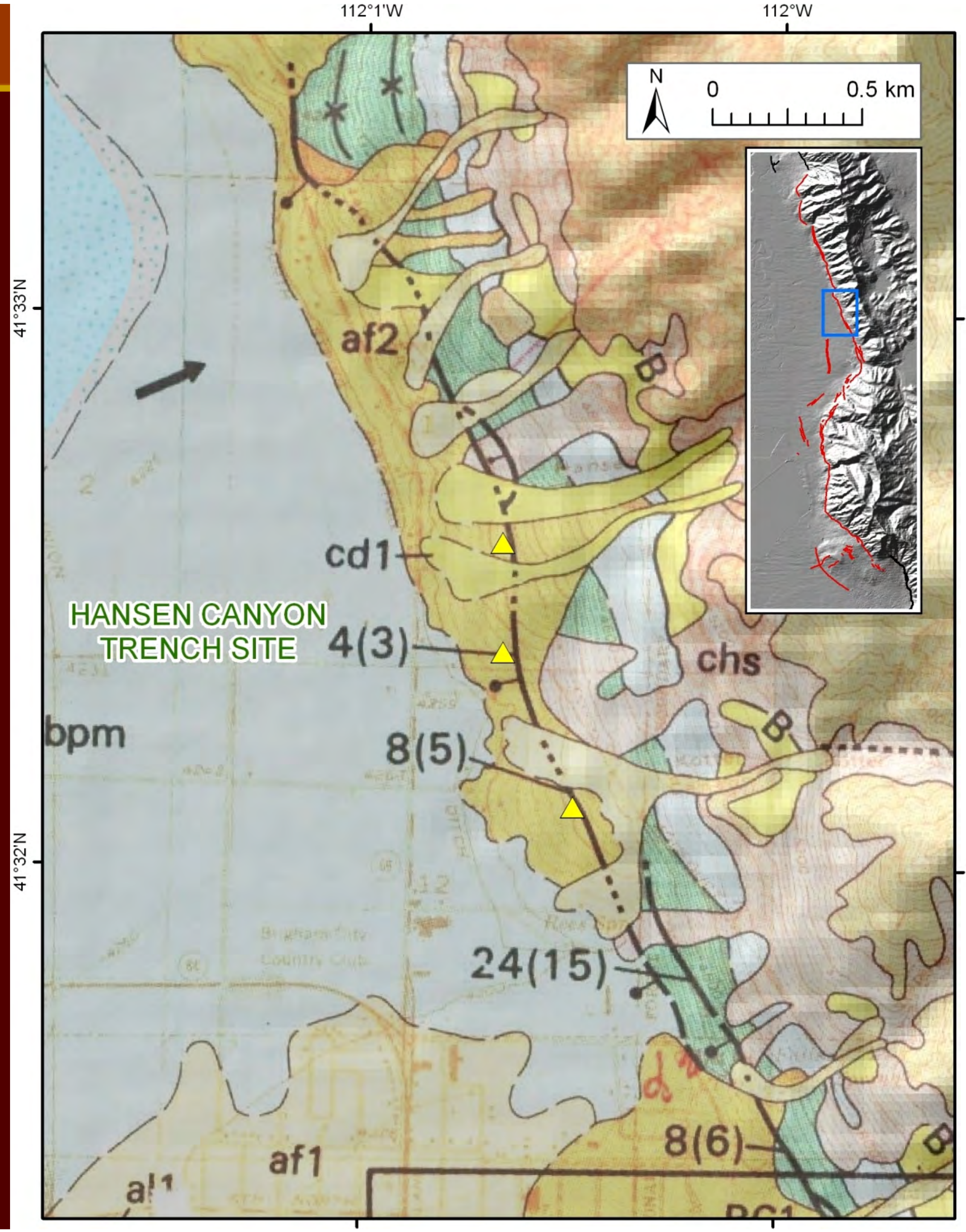


UTAH GEOLOGICAL SURVEY

Hanson South

~2 m scarp on af2

<1m antithetic scarp



Hansen Canyon S - af2
Hansen Canyon S - af2
Image © 2008 DigitalGlobe
©2007 Google™
Pointer 41°32'20.36" N 112°00'29.61" W elev 4510 ft
Streaming |||||||||| 100%
Eye alt 6952 ft

h.gov

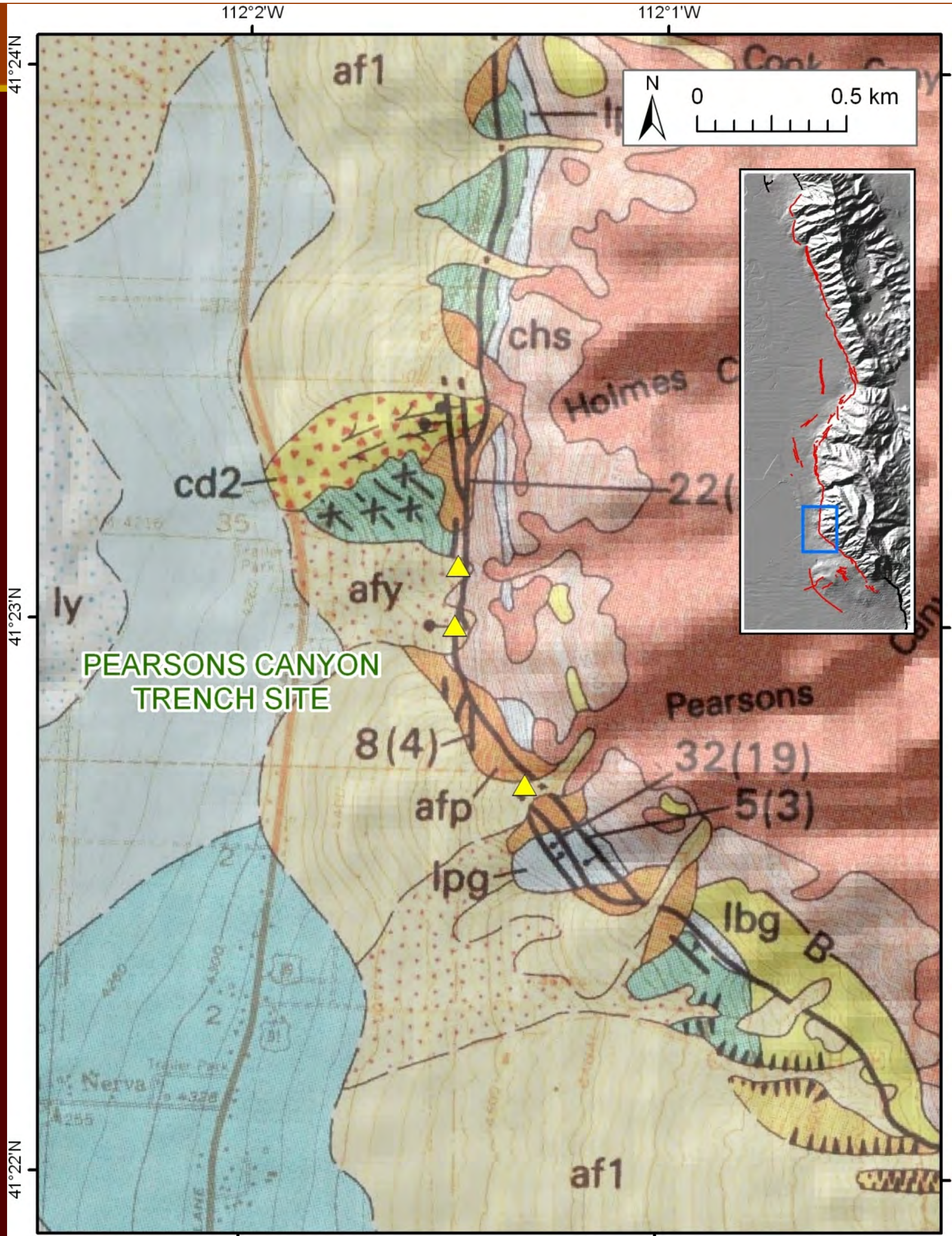
Hansen South

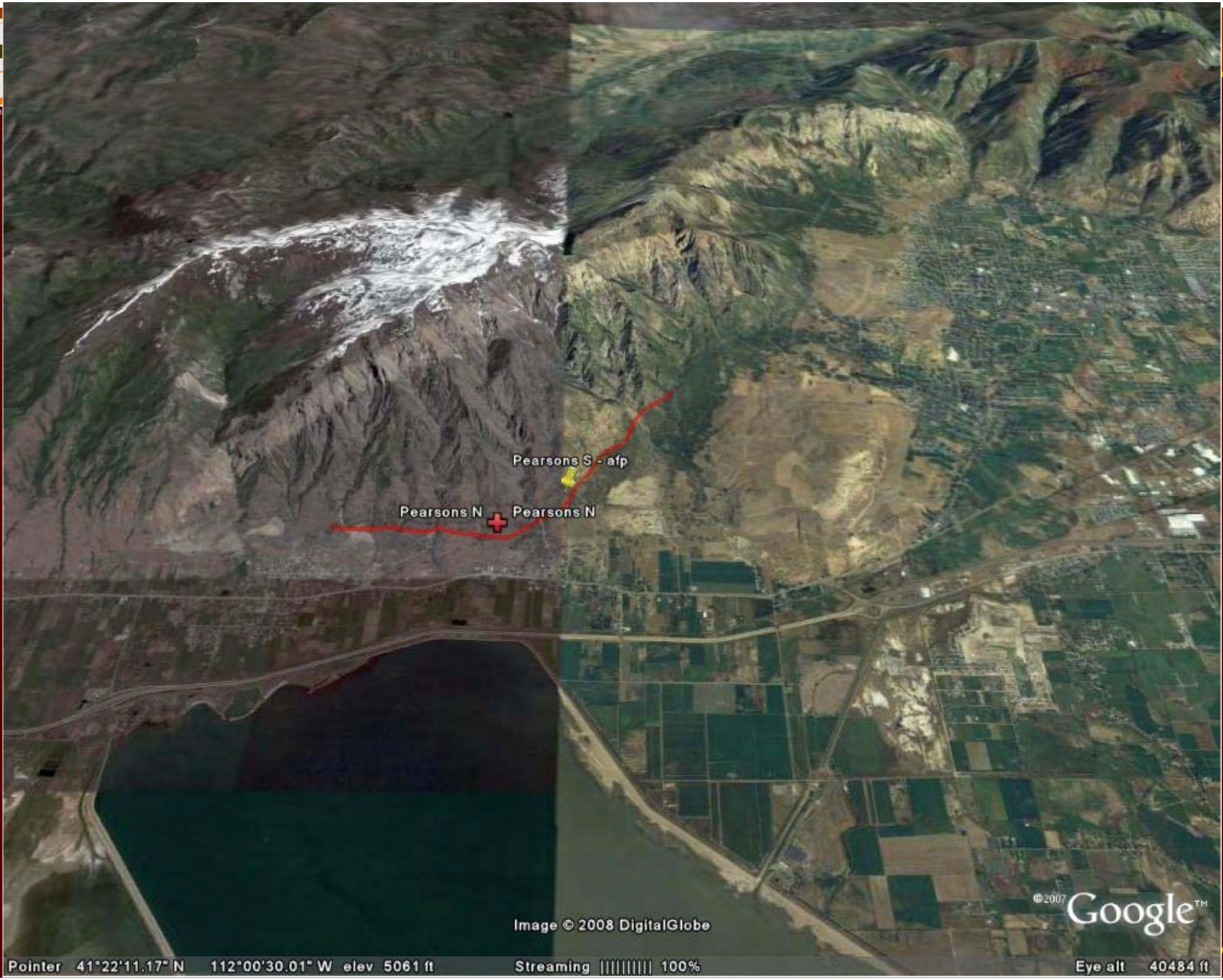
UTAH GEOLOGICAL SURVEY

Pearsons North

1-2 m scarp on afy

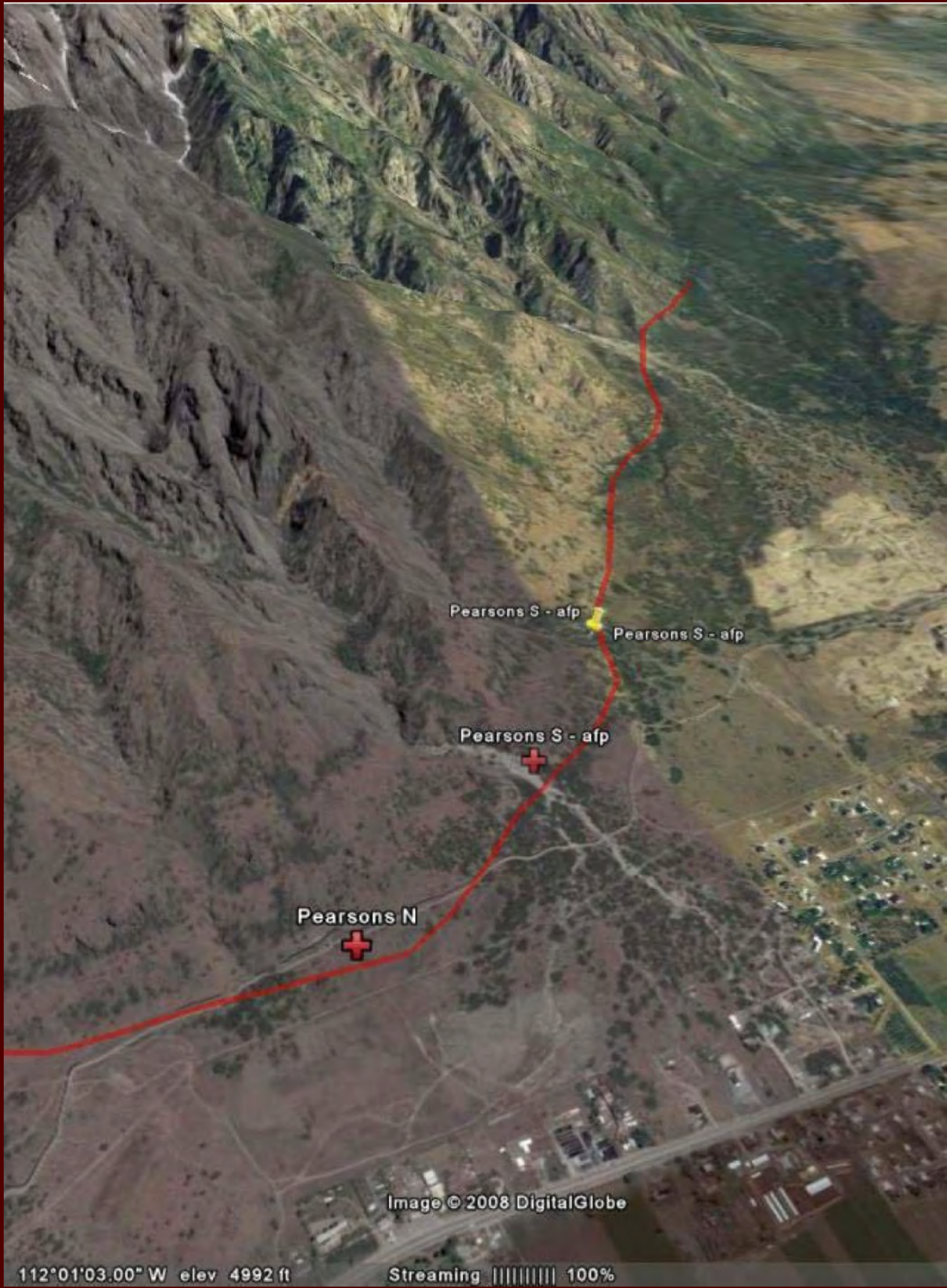
~1 m antithetic scarp




Pearsons S - afp
Pearsons N
Pearsons N
Image © 2008 DigitalGlobe
©2007 Google™
Pointer 41°22'11.17" N 112°00'30.01" W elev 5061 ft
Streaming |||||||||| 100%
Eye alt 40484 ft


Pearsons North site

Antimony Canyon - af2
Unnamed - af2
Unnamed - af2
Hansen Canyon S - af2
Hansen Canyon S - a
Hansen Canyon S - af2
Hansen
Image © 2008 DigitalGlobe
112°01'05.95" W elev 4345 ft
Streaming 100%



Pearsons S - afp
Pearsons S - afp
Pearsons S - afp
Pearsons N
Image © 2008 DigitalGlobe
112°01'03.00" W elev 4992 ft
Streaming 100%

Vertical Displacement on the central segments of the Wasatch fault zone

Chris DuRoss (UGS)

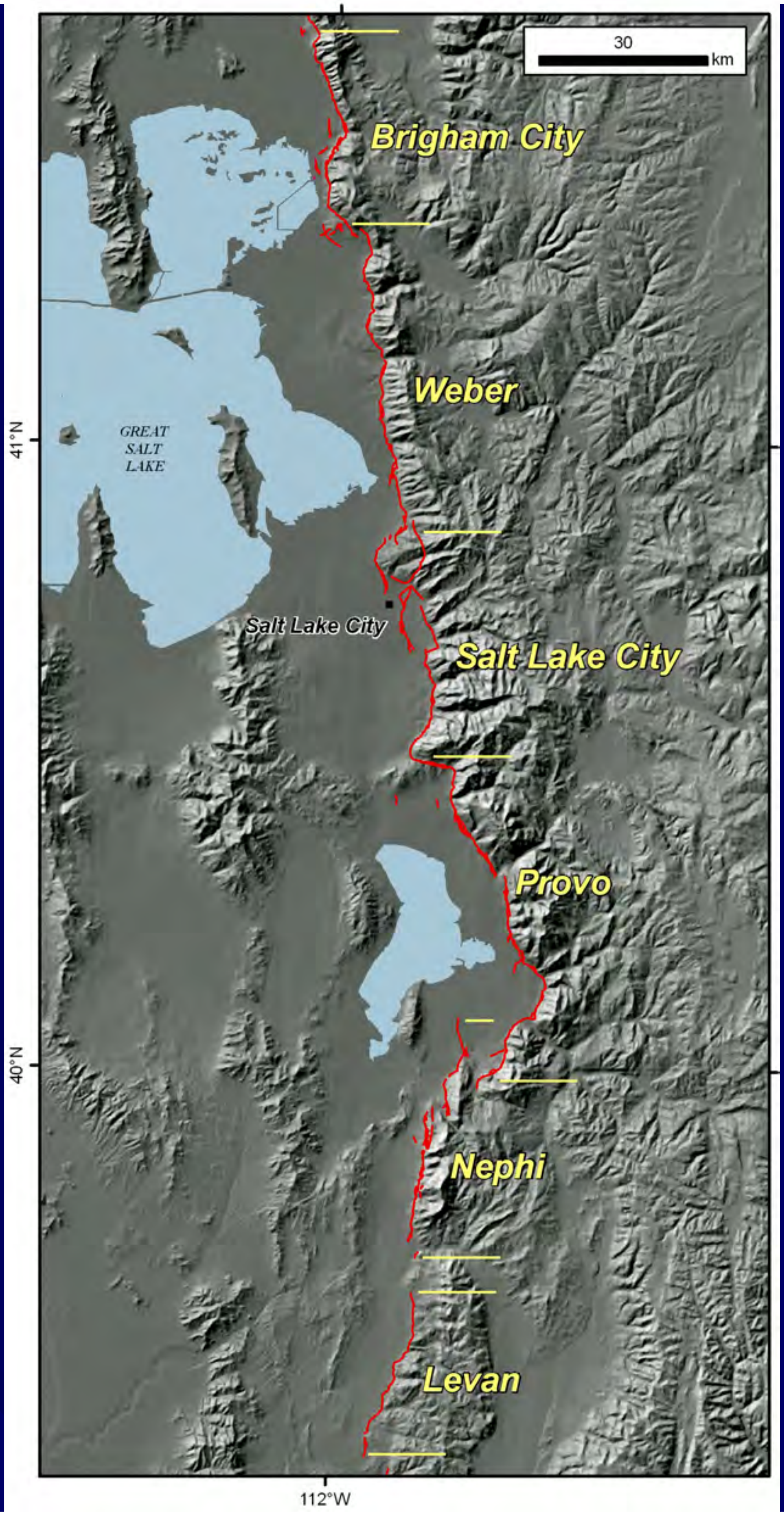
Utah Quaternary Fault Parameters Working Group

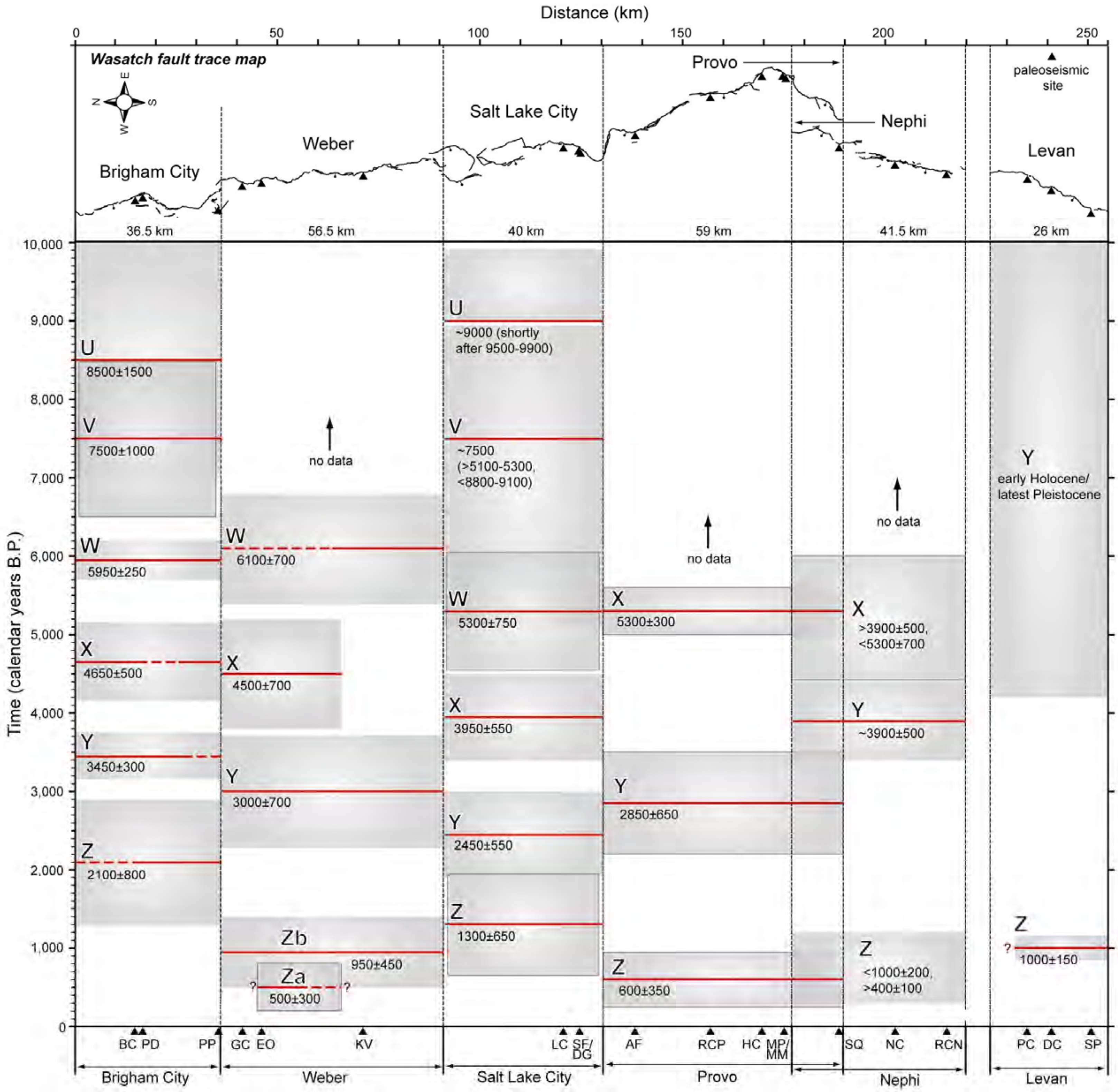
Introduction

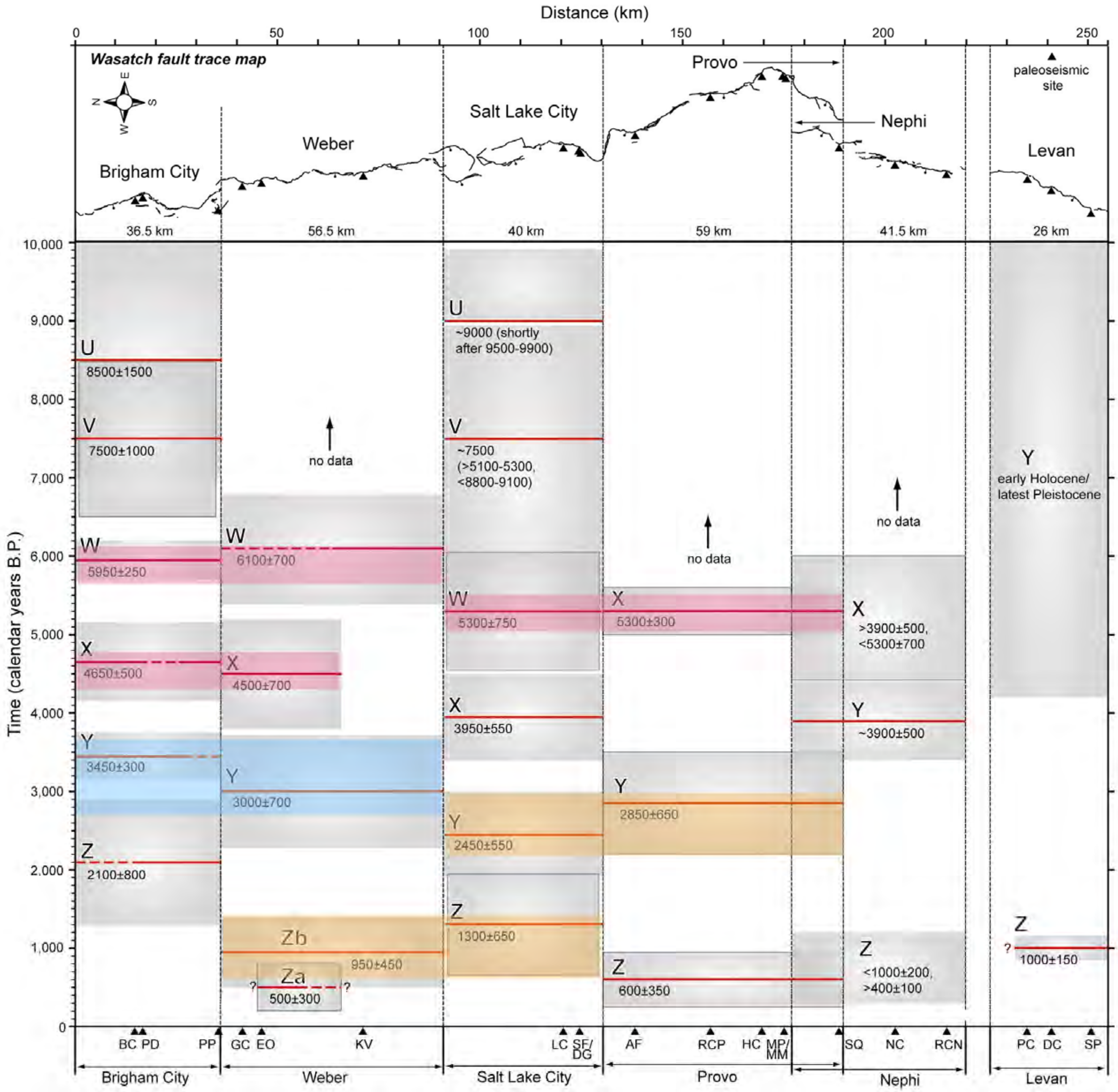
- BRPEWG:

  What is the potential for multi-segment rupture on the WFZ?

- Importance:
  - Fault parameters (SRL, SR, RI),
  - Hazard calculations (MSRs result in larger EQs, lower RIs, and reduced hazard)




Distance (km)
Wasatch fault trace map
Brigham City
Weber
Salt Lake City
Provo
Nephi
Levan
paleoseismic site
36.5 km
56.5 km
40 km
59 km
41.5 km
26 km
Time (calendar years B.P.)
U
8500±1500
V
7500±1000
W
5950±250
X
4650±500
Y
3450±300
Z
2100±800
no data
W
6100±700
X
4500±700
Y
3000±700
Zb
950±450
Za
500±300
U
~9000 (shortly after 9500-9900)
V
~7500 (>5100-5300, <8800-9100)
W
5300±750
X
3950±550
Y
2450±550
Z
1300±650
X
5300±300
Y
2850±650
Z
600±350
X
>3900±500, <5300±700
Y
~3900±500
Z
<1000±200, >400±100
Y
early Holocene/ latest Pleistocene
Z
1000±150
BC PD PP GC EO KV LC SF/DG AF RCP HC MP/MM SQ NC RCN PC DC SP



Distance (km)
Wasatch fault trace map
paleoseismic site
Brigham City
Weber
Salt Lake City
Provo
Nephi
Levan
36.5 km
56.5 km
40 km
59 km
41.5 km
26 km
Time (calendar years B.P.)
U
8500±1500
V
7500±1000
W
5950±250
X
4650±500
Y
3450±300
Z
2100±800
no data
W
6100±700
X
4500±700
Y
3000±700
Zb
950±450
Za
500±300
U
~9000 (shortly after 9500-9900)
V
~7500 (>5100-5300, <8800-9100)
W
5300±750
X
3950±550
Y
2450±550
Z
1300±650
X
5300±300
Y
2850±650
Z
600±350
X
>3900±500, <5300±700
Y
~3900±500
Z
<1000±200, >400±100
Y
early Holocene/ latest Pleistocene
Z
1000±150
BC PD PP GC EO KV LC SF/DG AF RCP HC MP/MM SQ NC RCN PC DC SP

Introduction

- Vertical Displacement data useful?

- Rephrase question: What do WFZ VD data reveal about prehistoric fault-rupture processes?

  (Do the data support the characteristic earthquake model?)

Characteristic Review

- Characteristic earthquake model (SC84):
  - Individual faults/segments behave “as discrete units through a significant period of time”
  - Produce similar-sized earthquakes having similar rupture areas, displacements at a point, and along-strike displacement distributions

- Displacements not supporting model:
  - Variable displacement at a point over time
  - Significantly different along-strike distributions between EQs
  - Large values near segment boundaries

Characteristic Review

- For the WFZ:
  - Segments – EQ timing, fault geomorph & geometry
  - 7 displacement measurements from 5 sites
  - Consistently large displacements: 1.6-2.6 m
  - Similar displacements at a point between events
- ***14 additional paleoseismic investigations…***

Approach

- To address questions:
  - Compiled and qualified 36 single-event vertical displacement observations
  - 17 paleoseismic sites

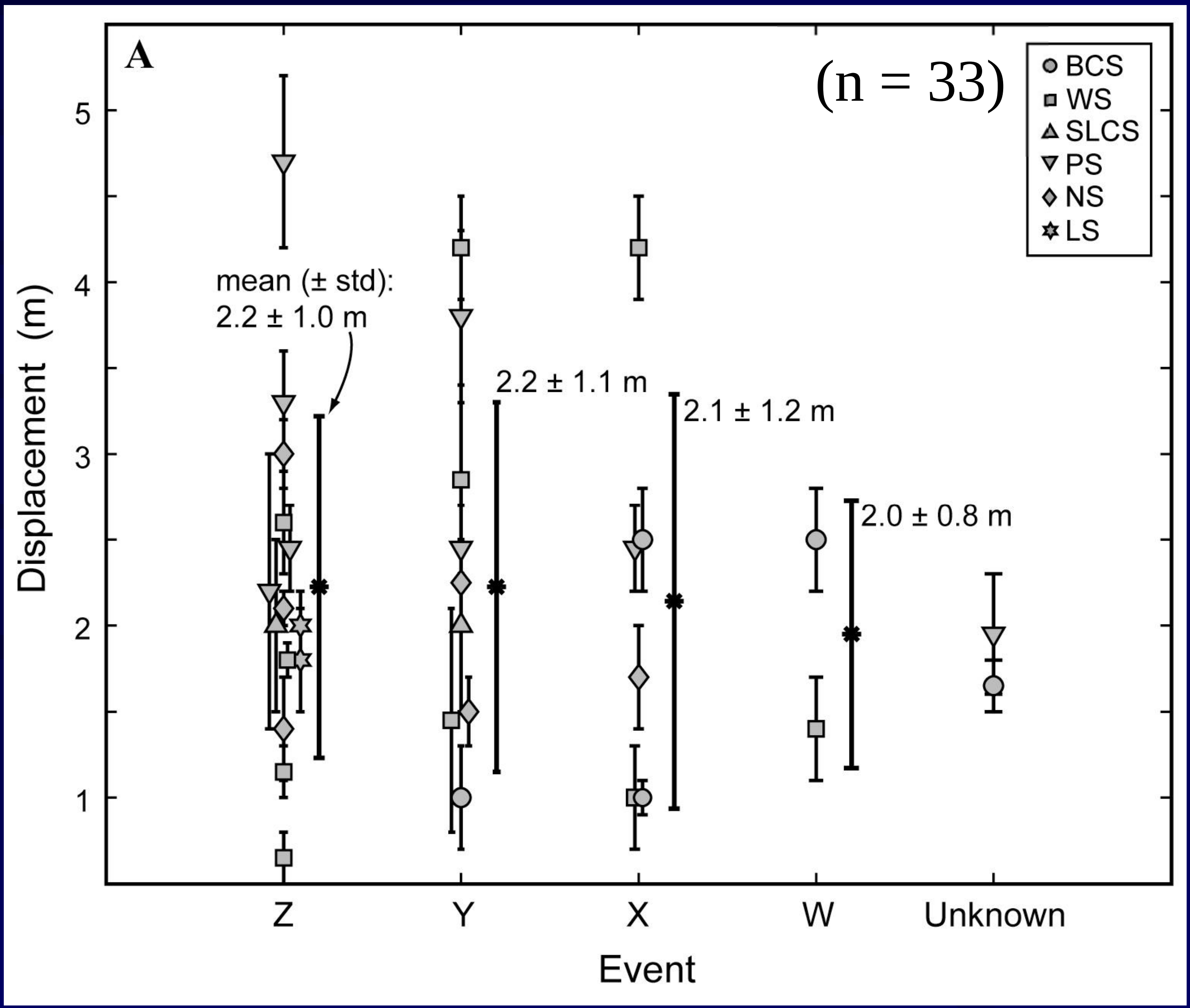
- Data are sparse and of variable quality, but do reveal important trends in displacement along the WFZ

WFZ Displacement Data

- Quality varies along the WFZ:
  - 2 (Levan, SLC) to 10 (Weber) observations per segment

- Measurement types:
  - 11% – stratigraphic displacement
  - 89% – some combination of colluvial-wedge thickness, relative/average displacement, retrodeformation

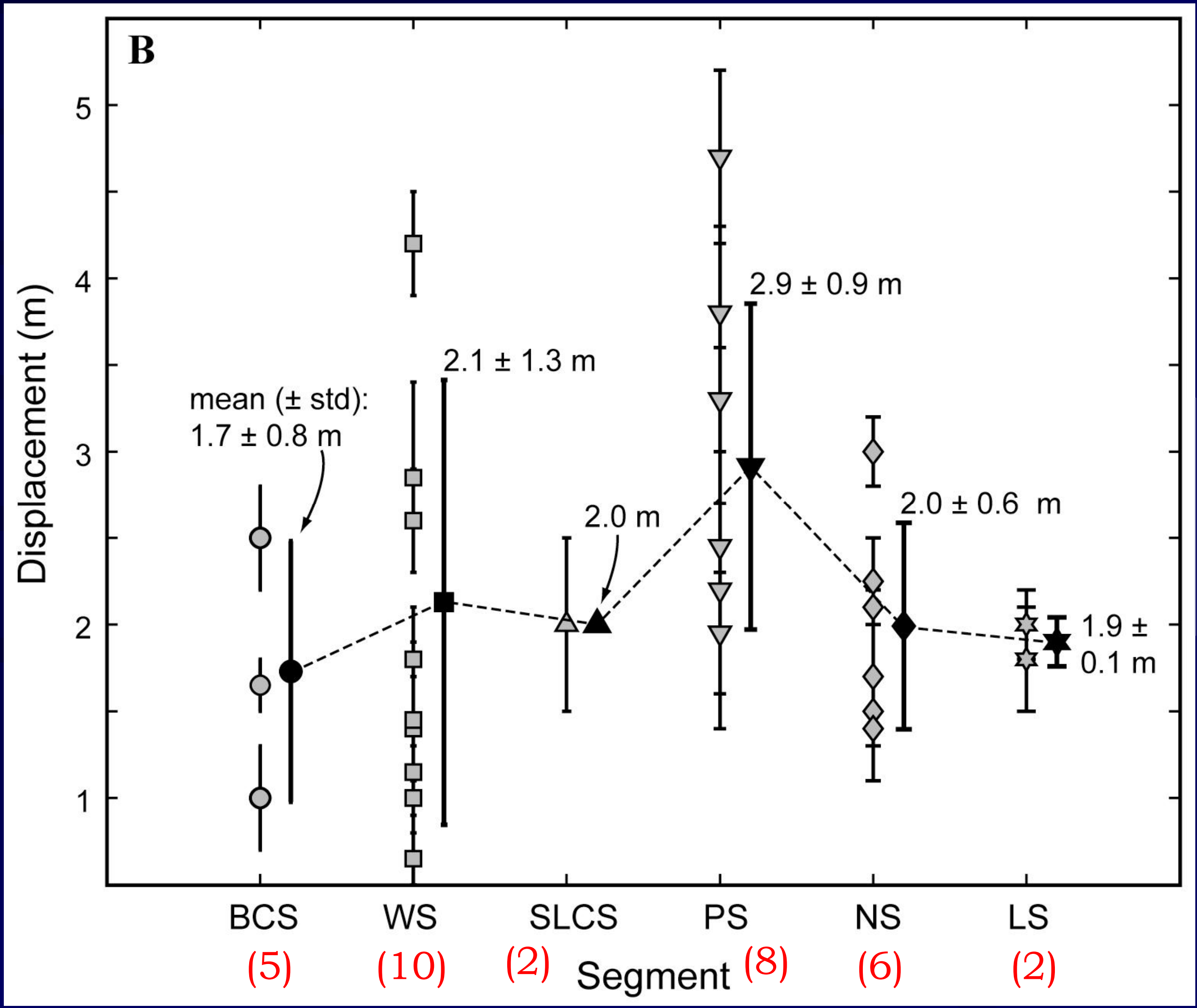
WFZ Displacement Data



Older events Poorly represented

Mean displacement – per **event**

WFZ Displacement Data



Mean WFZ displacement: 2.2 ± 0.98 m

SC84: 2.0 ± 0.35 m

Mean displacement – per **segment**

Displacement Distributions

- What about displacement along the fault?

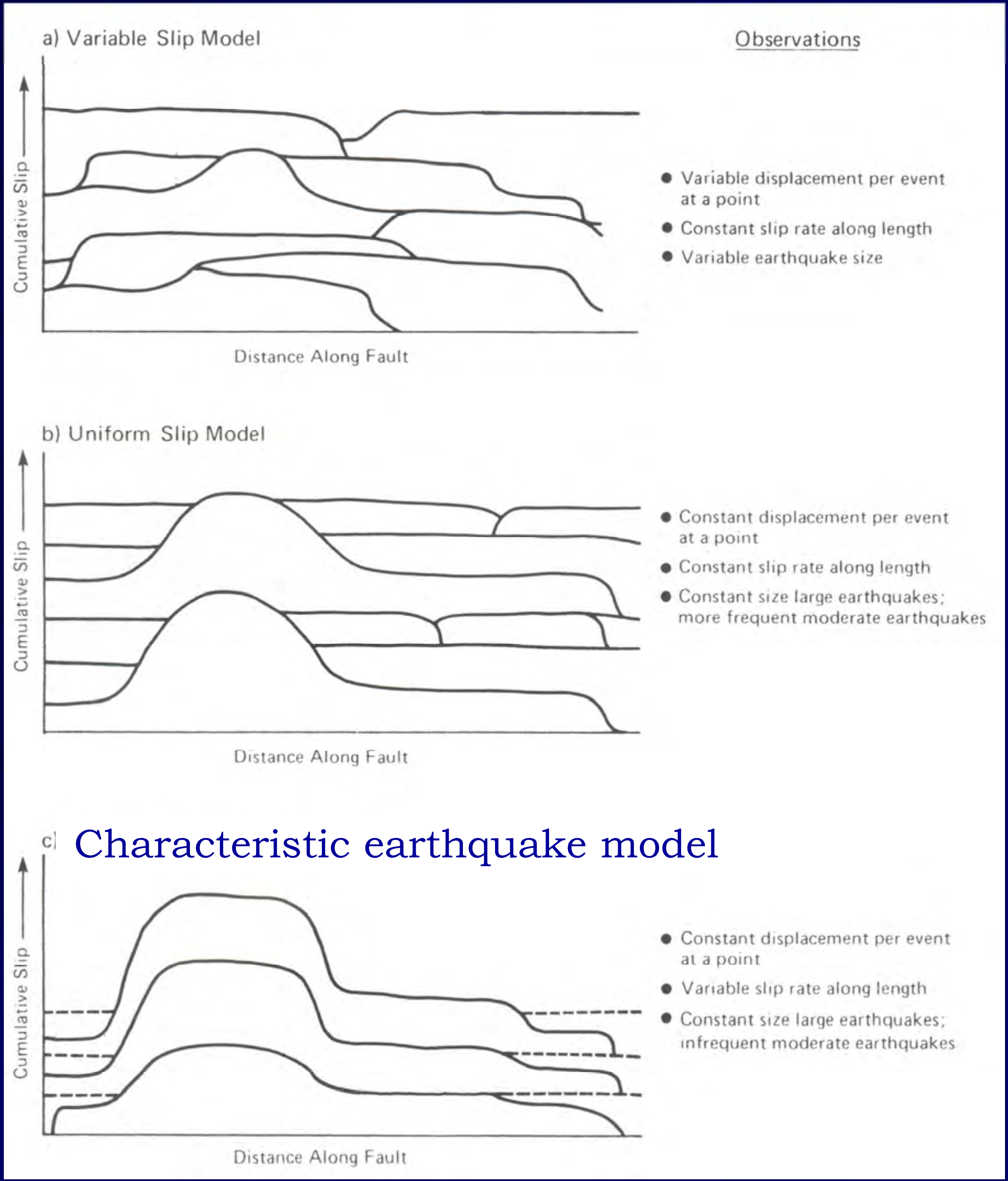
- Displacement distribution: basic characteristic of faulting that reflects growth, interaction, and segmentation

  – SC84: displacement at a point and along strike (distribution) – characteristic?

  – Willemse: geometry (skewed?) can indicate segment interaction

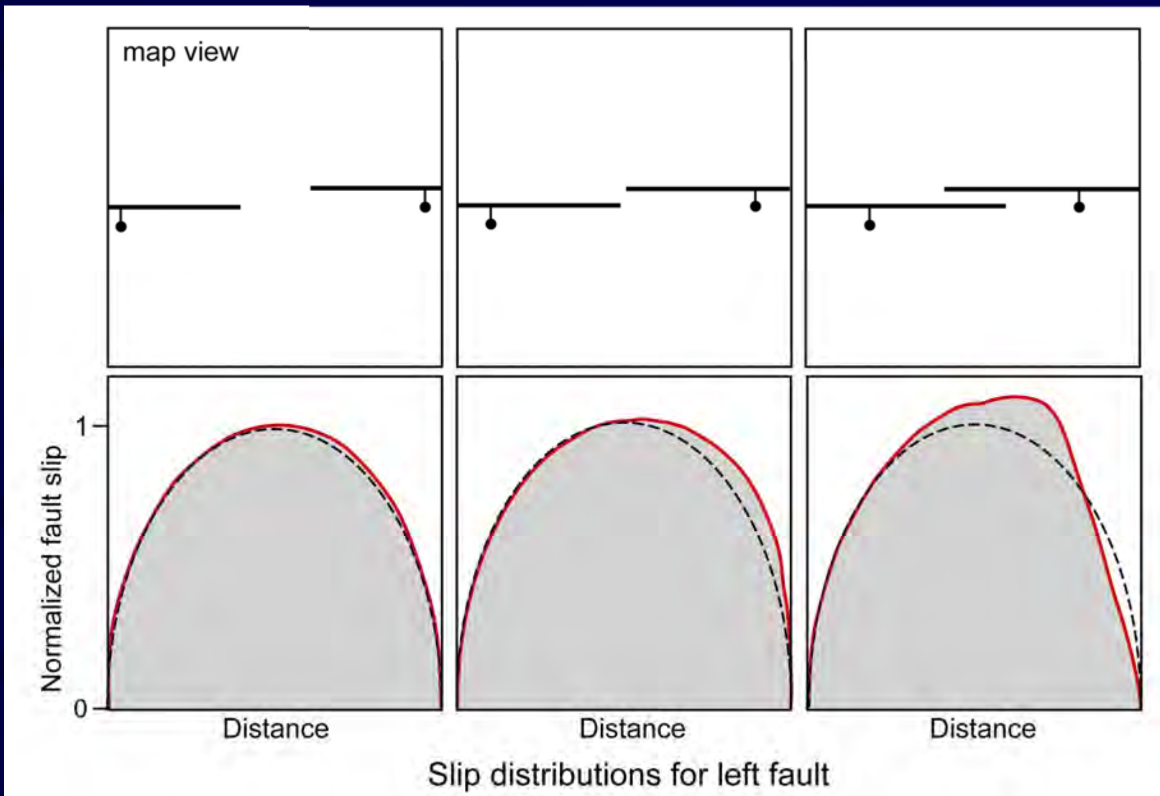
  – Ward: geometry at segment boundary shows rupture termination style

Displacement Distributions



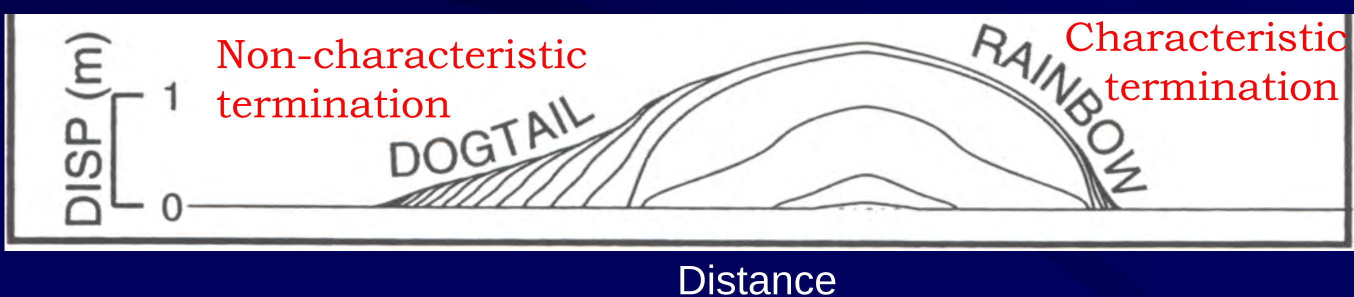
Schwartz and Coppersmith, 1984

Displacement Distributions



Overlapping faults: greater slip; skewed toward overlap

(Willemse et al., 1996)



"A rupture, like a car with failed brakes, can stop only in two ways…hit something hard [e.g., a segment boundary] or coast to a halt."

(Ward, 1997)

Displacement Distributions

- But historical distributions are complex!

- Characteristic distributions in an ideal world:
  - Similar distributions per EQ & through time
  - Long-term distribution = per-earthquake distribution
  - Concave down, terminating at segment boundary
  - Or at least **not** concave up, uniform, or random

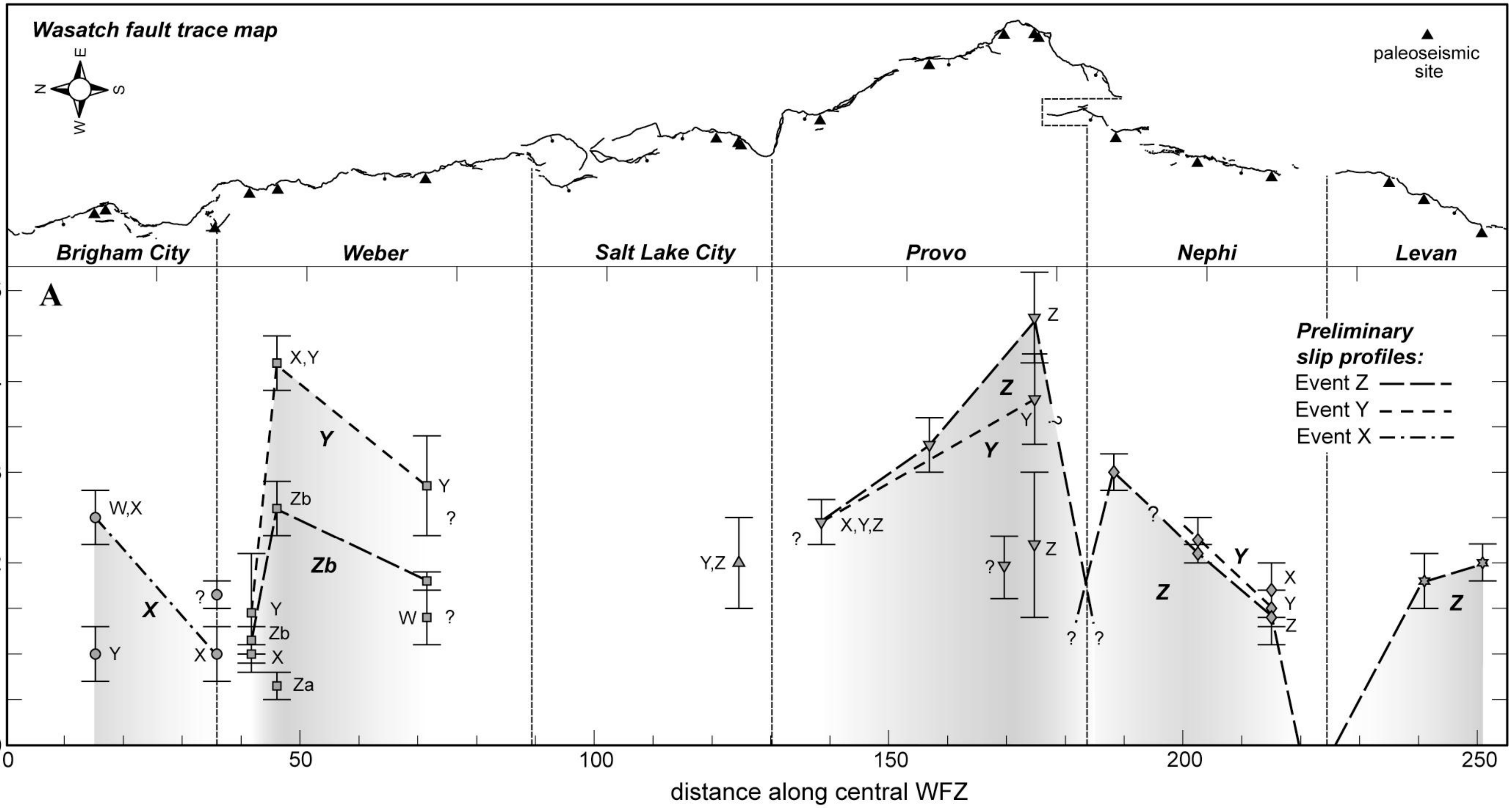
Displacement Distributions

WFZ: Insufficient data

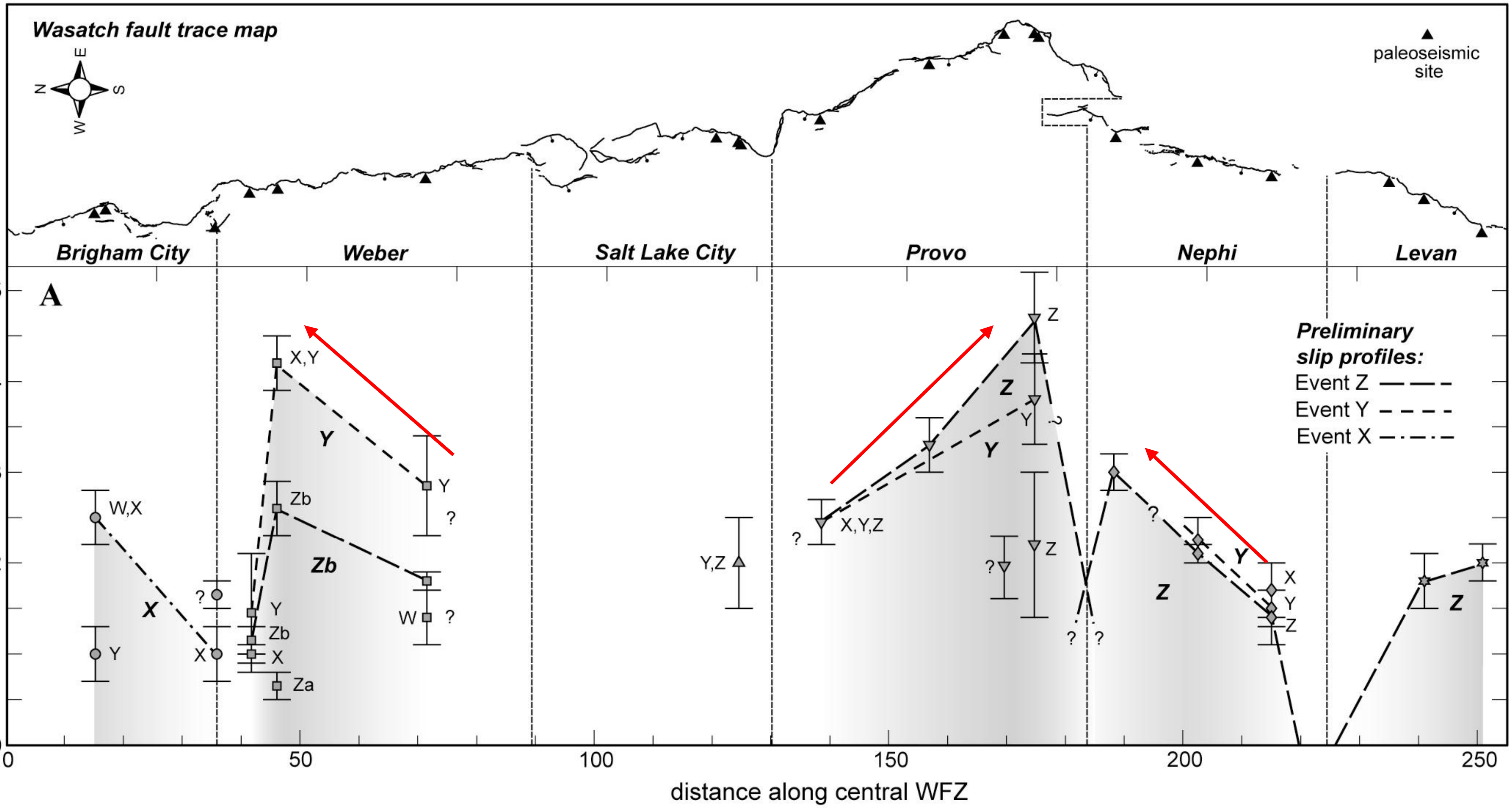
- 2-10 observations per segment
- Limited data near segment boundaries
- Per-earthquake: 2-3 points per earthquake distribution

- Combine displacements into "composite" distribution for WFZ

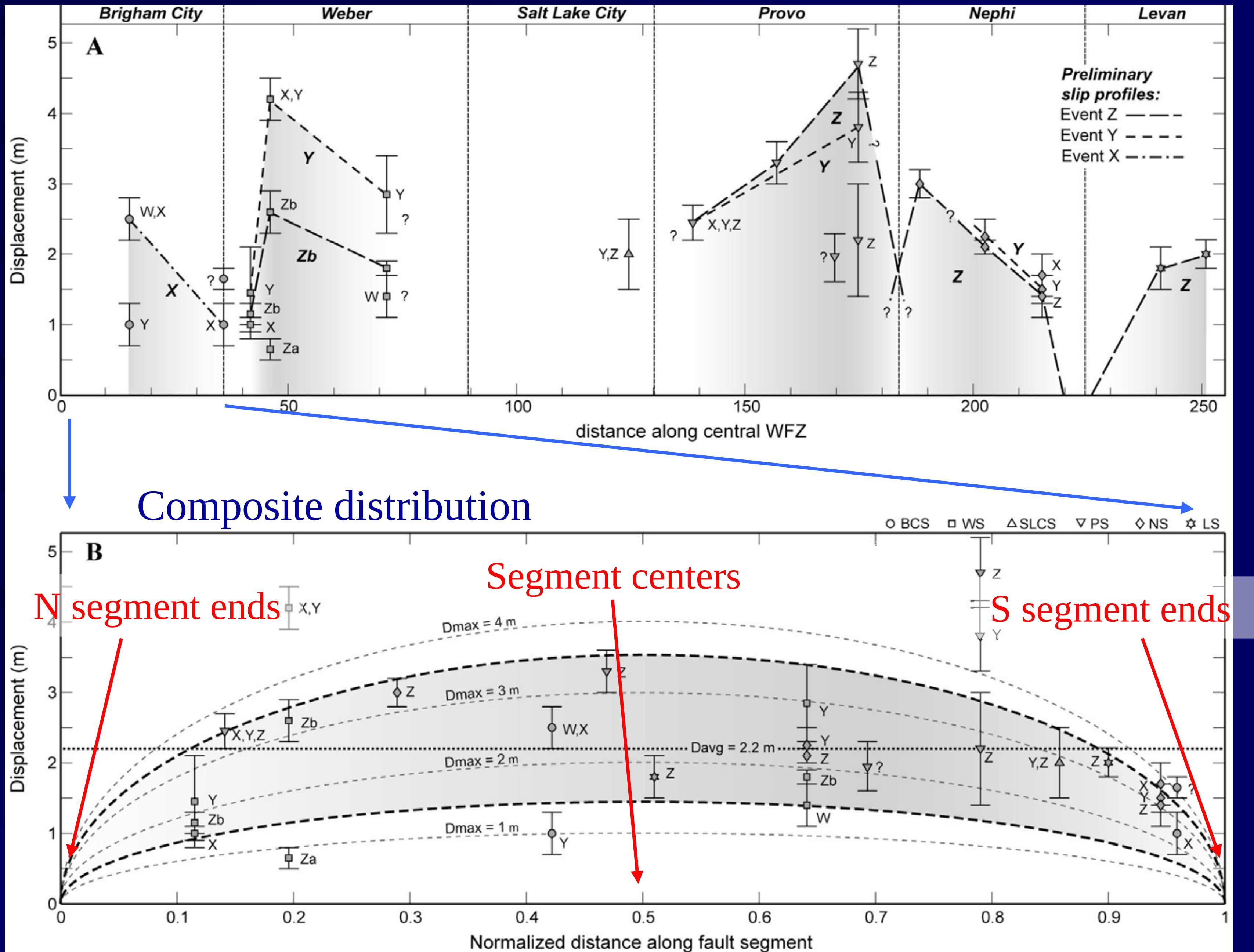
Displacement Distributions



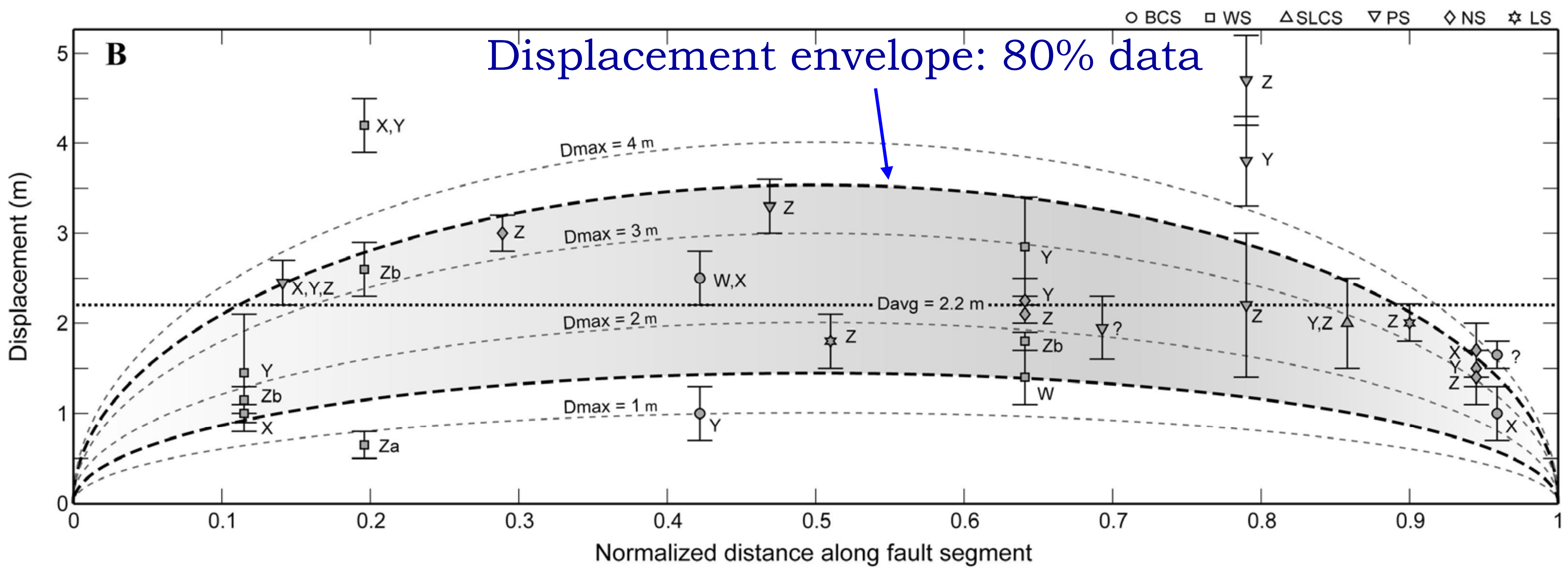
Displacement Distributions



Composite Distribution

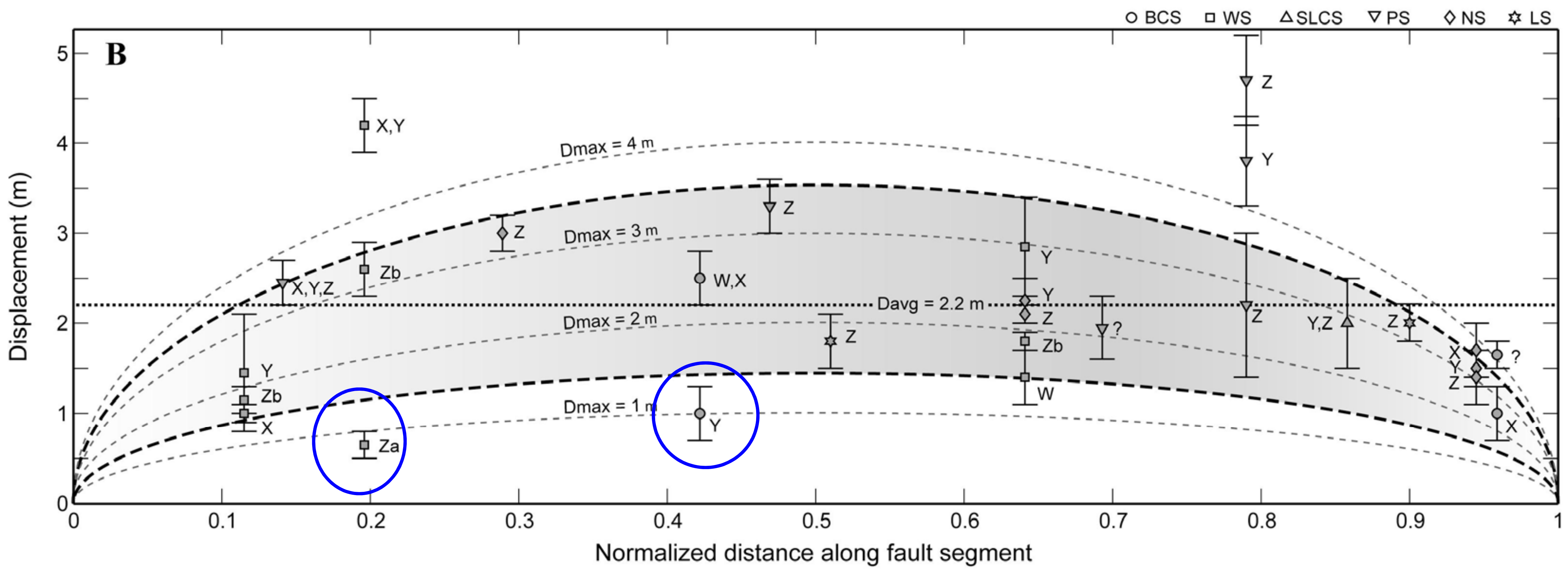


Composite Distribution



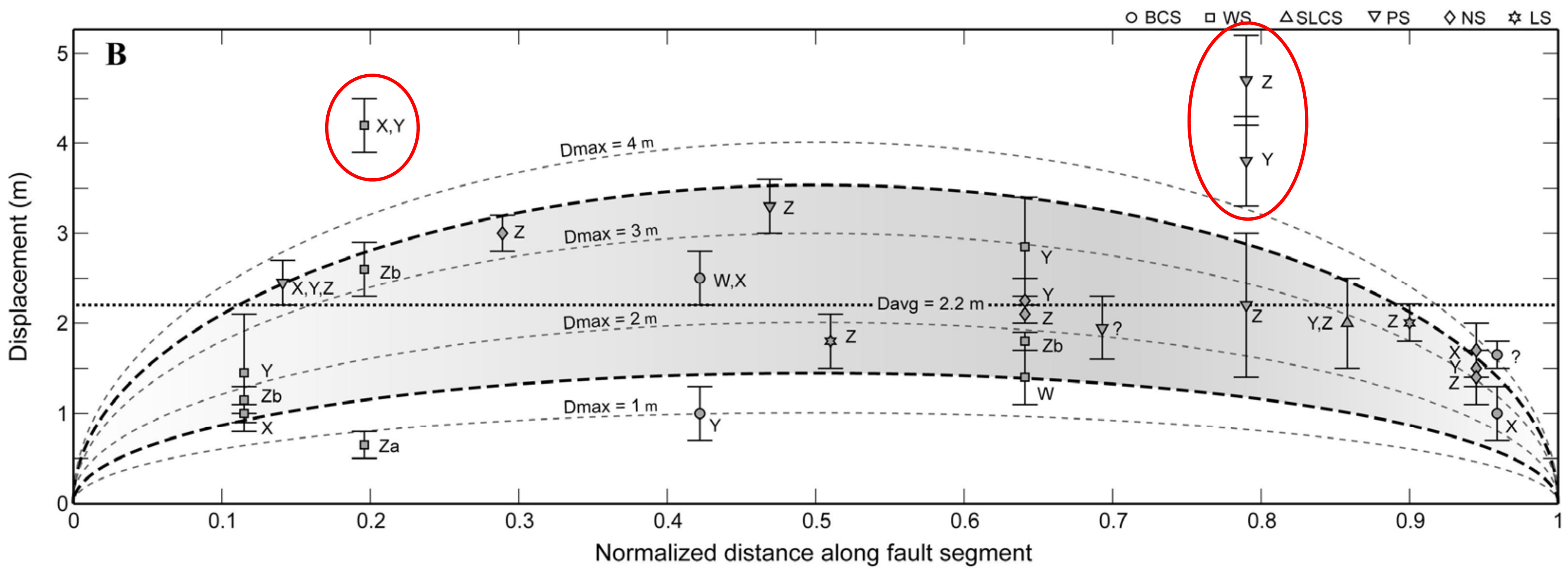
- Displacement envelope: half-ellipse shape, 1.4-3.5 m – center, tapering to 0.6-2.5 m near the segment boundaries

Composite Distribution



- <u>Small displacements</u>: minimum estimates or evidence of partial-segment rupture?

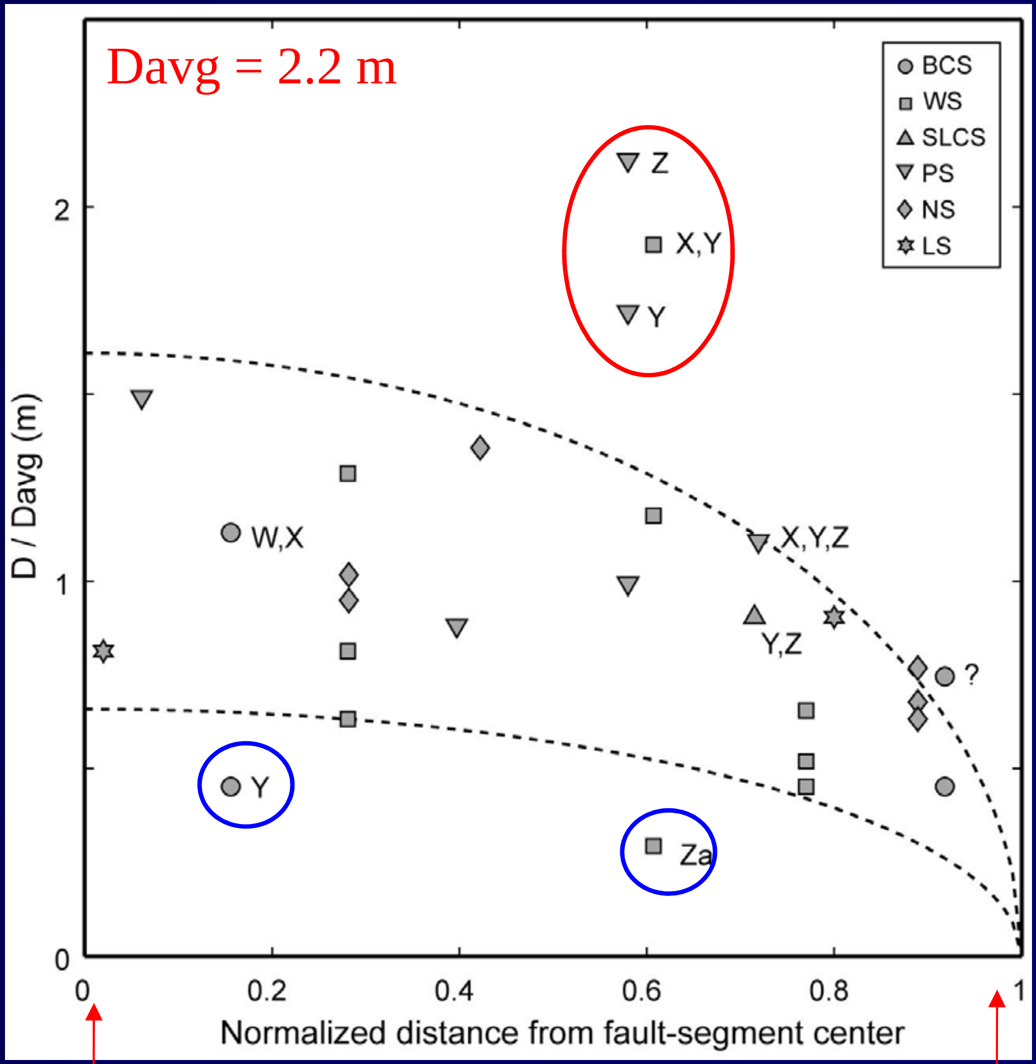
Composite Distribution



- Large displacements near segment boundaries: missed events, site bias, evidence for slip interaction between adjacent segments, or just natural variability?

Normalized Displacement

- Displacements decrease toward segment ends
- Dashed lines: 0.6-1.6 x Davg at segment centers (correspond with displacement envelope)
- Large displacements?



Centers of segments

Ends of segments

Fault-Parameter Regressions

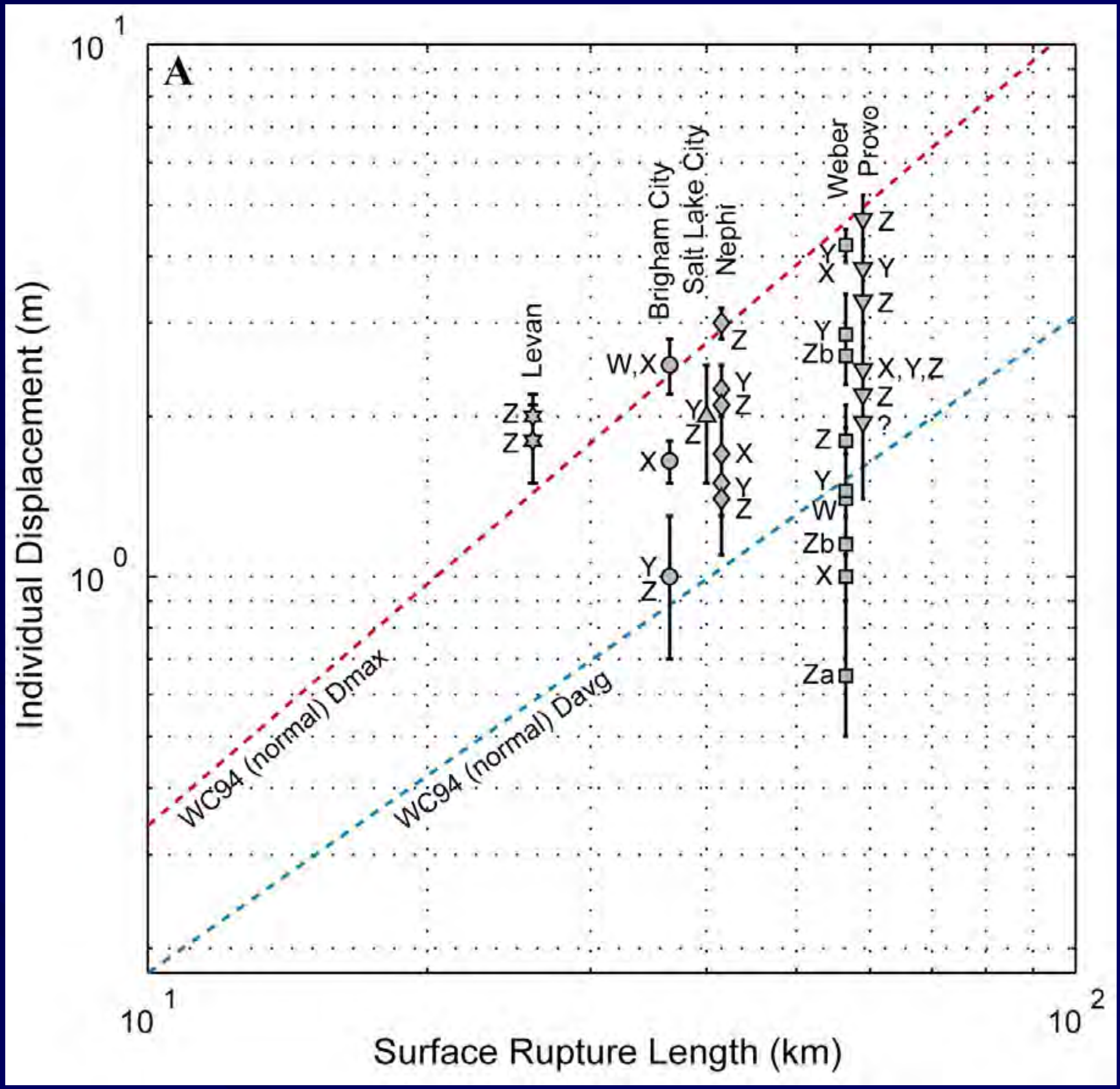
- Are observed displacements smaller or larger than predicted?

- Larger than predicted – SRLs longer than the mapped segment lengths?

- Smaller than predicted – partial-segment rupture?

Fault-Parameter Regressions

- 85% of observed displacements > average displacement predicted by regression



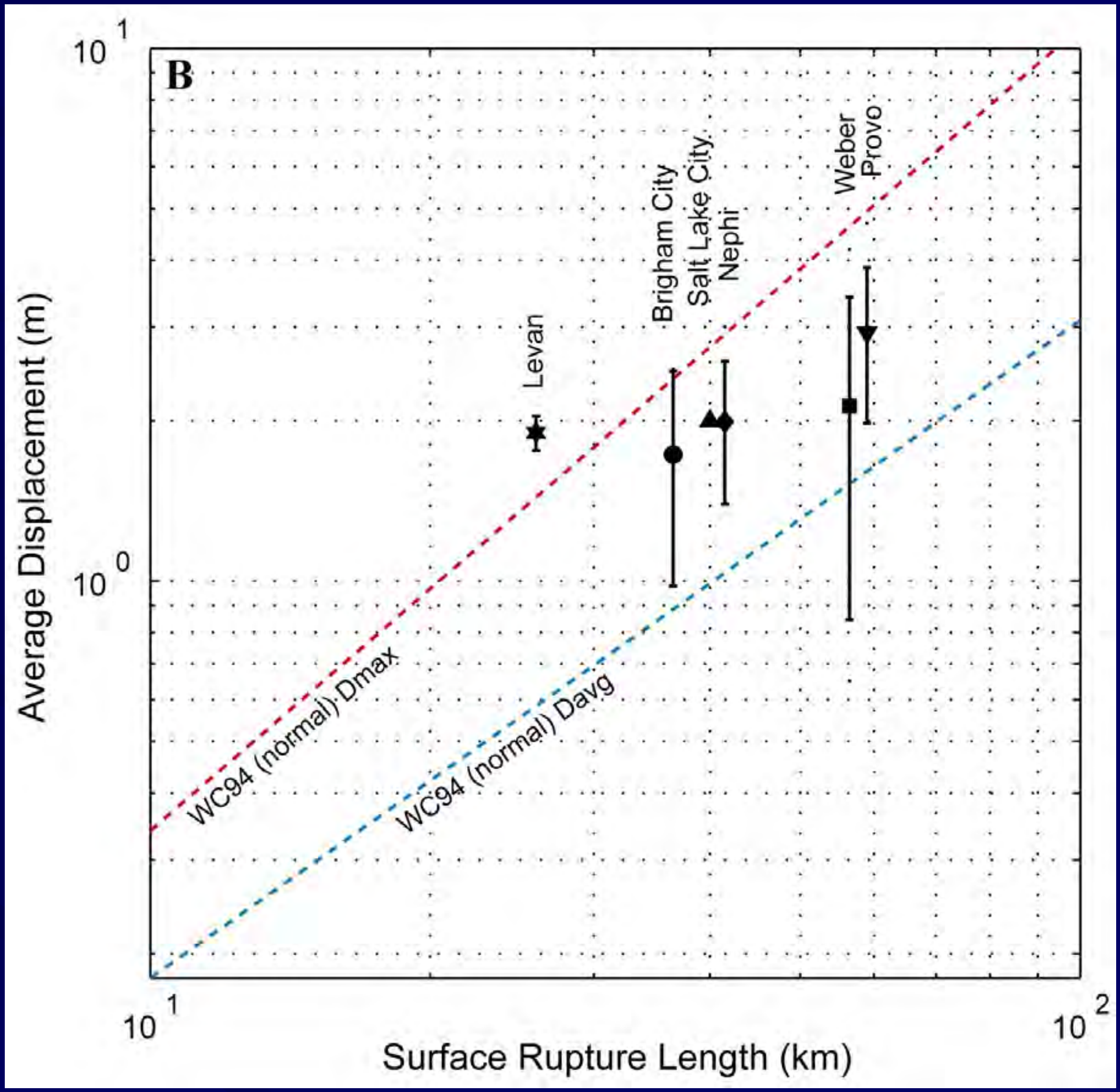
WC94 normal-fault type

Maximum D regression

Average D regression

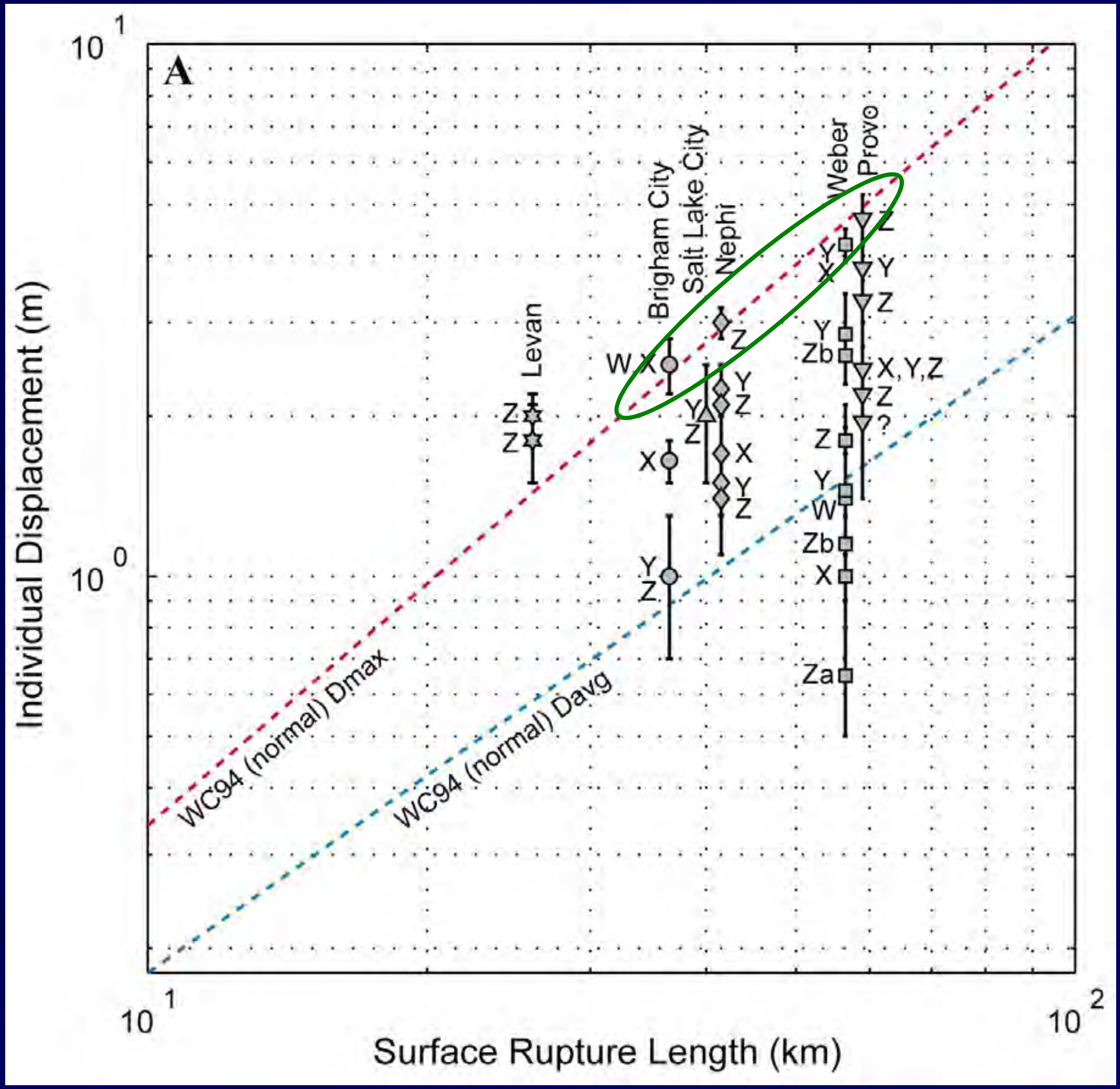
Fault-Parameter Regressions

- Also, observed averages per segment are > predicted averages
- Bias toward selecting largest scarps to trench?



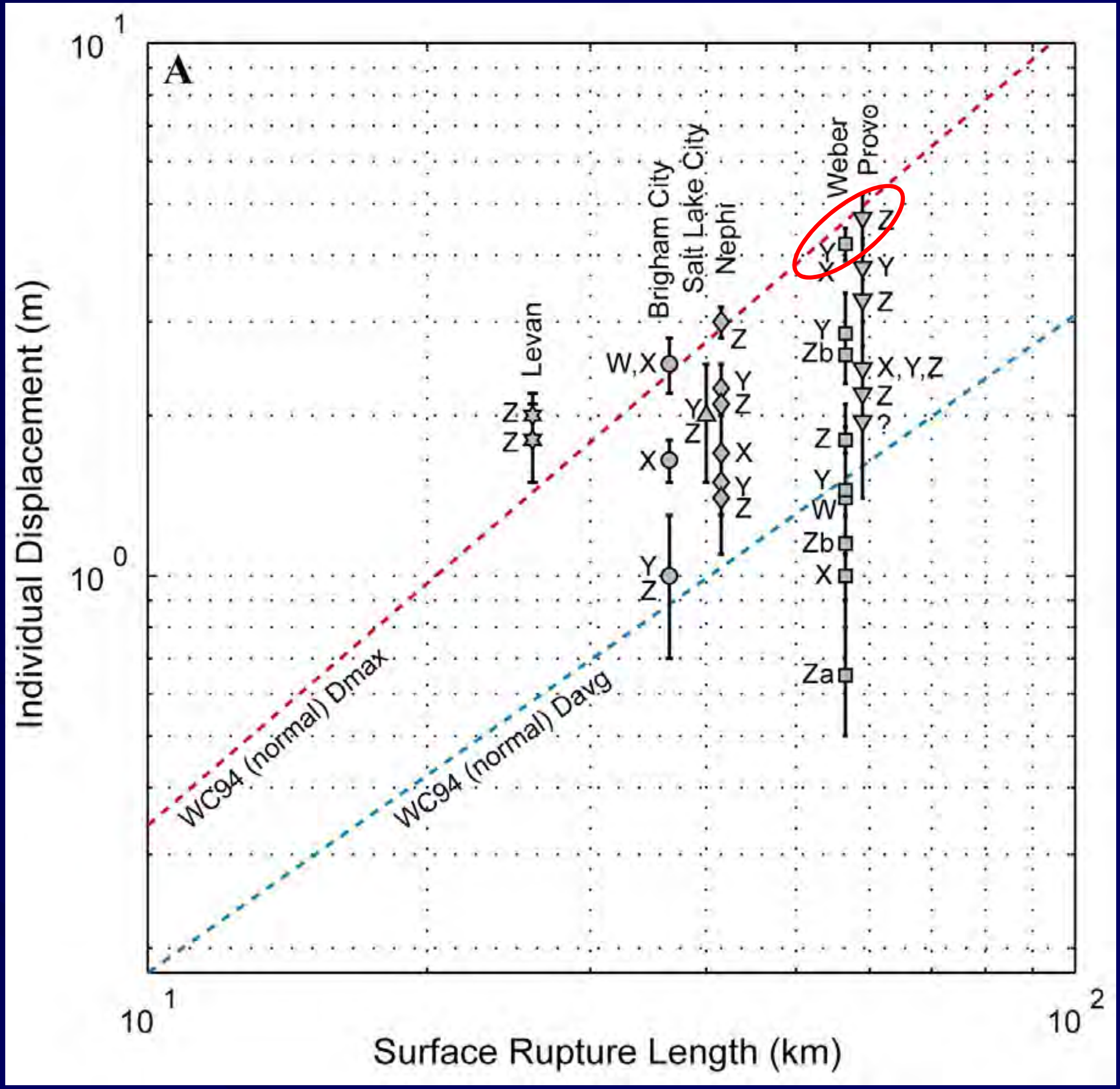
Fault-Parameter Regressions

- Largest observed displacements correspond well with maximum regression



Fault-Parameter Regressions

- 4-5 m displacements (Weber, Provo) = upper-bound displacement per segment?



Magnitude

- Moderate variability in Mw despite large displacements

Table 3. Moment-magnitude estimates for the central Wasatch fault zone segments.

Segment	SRL (km)[1]	D_{avg} (m)[2]	D_{max} (m)[3]	M_w (SRL)[4]	M_w (D_{avg})[5]	M_w (D_{max})[5]	Preferred M_w[5]
Brigham City	36.5	1.7	2.5	6.9	6.9	6.9	6.9 ± 0.1
Weber	56.5	2.1	4.2	7.2	7.0	7.1	7.1 ± 0.1
Salt Lake City	40	2.0	2.0?	7.0	7.0	6.8	7.0 +0.1/-0.2
Provo	59	2.9	4.7	7.2	7.1	7.1	7.1 ± 0.1
Nephi	41.5	2.0	3.0	7.0	7.0	6.9	7.0 ± 0.1
Levan	26	1.9	2.0	6.7	7.0	6.8	6.9 ± 0.2

Magnitude based on: SRL Average D Maximum D

Magnitude

- Moderate variability in M_W despite large displacements

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Magnitude based on: SRL Average D Maximum D

Discussion

- Data gaps:
  - Per-earthquake distributions (older events)
  - Segment boundaries
  - Salt Lake City area (50-km length from Kaysville to Little Cottonwood Canyon trench sites)
  - Levan segment

- Bias:
  - Largest scarps trenched? Using SRL and $D_{(max)}$ may provide more accurate M_W estimates

Discussion

Displacement data reasonably support the characteristic model:

- ***Displacement:***
  - Large average WFZ displacement (2.2 m)
  - Repeated, large displacements at a point (e.g., Weber, Provo, Nephi)

Discussion

Displacement data reasonably support the characteristic model:

Displacement distributions:

- Similar through time (Weber, Provo, Nephi), also Weber: long-term slip ≅ earthquake distribution
- Composite distribution: most data fit in half-ellipse-shaped displacement envelope
- Displacement decreases significantly toward SBs

Discussion

Displacement data reasonably support the characteristic model:

- ***Fault-Parameter regressions:***
  - SRL-D(max) regressions suggest that maximum displacements are not anomalously large

- ***Magnitude:***
  - Minimal variability in M_W despite large displacements

Discussion

Opposition to the characteristic model:

- ***Displacement variability:***
  - E.g., Weber segment: 0.5-4.2 m
  - High-valued displacements suggest SRLs longer than segment lengths (using Biasi and Weldon, 2006)
  - Small displacements suggest partial-segment ruptures

Discussion

Opposition to the characteristic model:

- ***Complex rupture processes:***
  - Skewed displacement distributions toward segment overlap zones

Conclusions

WFZ displacement data reasonably support a model of characteristic slip, *but variable displacements also indicate more complex patterns of strain release.*

- E.g., large and variable displacements may stem from a more random distribution of earthquake sizes than predicted
- Infrequent multi-segment, partial-segment, and spill-over rupture?

Conclusions

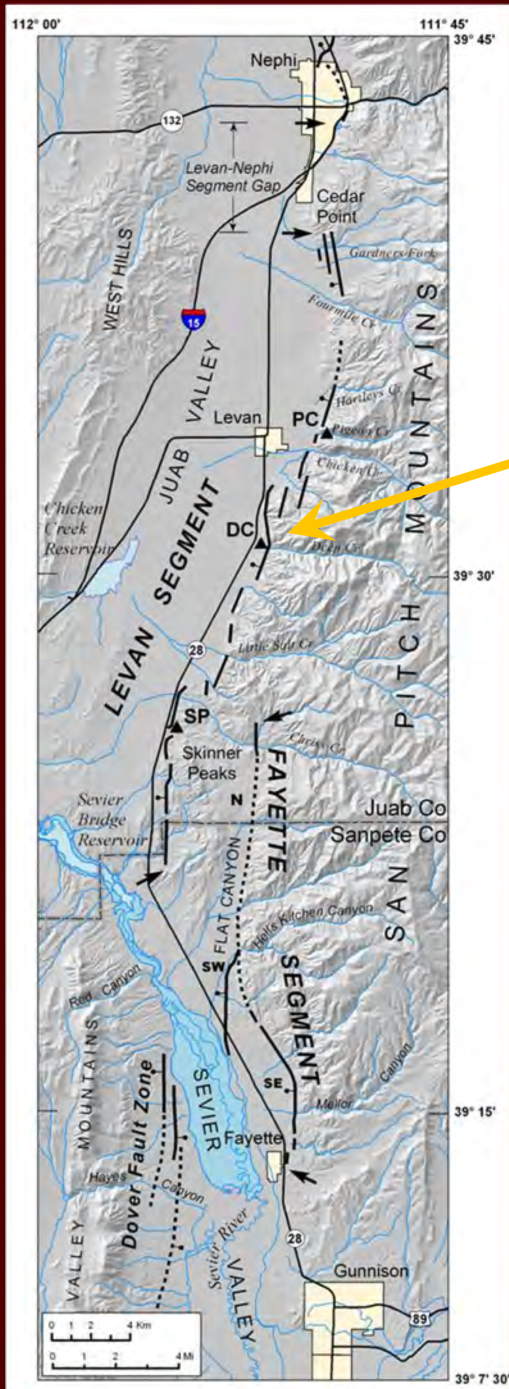
- However, regressions and M_W estimates suggest anomalous observations represent the natural variability in characteristic displacement at a point
- Thus, some degree of displacement variability in the model necessary to account for large upper- and lower-bound displacements
- Site biases and poor data coverage are significant issues – addressed by more trenching(!)

Levan-Segment Slip-Rate Estimate

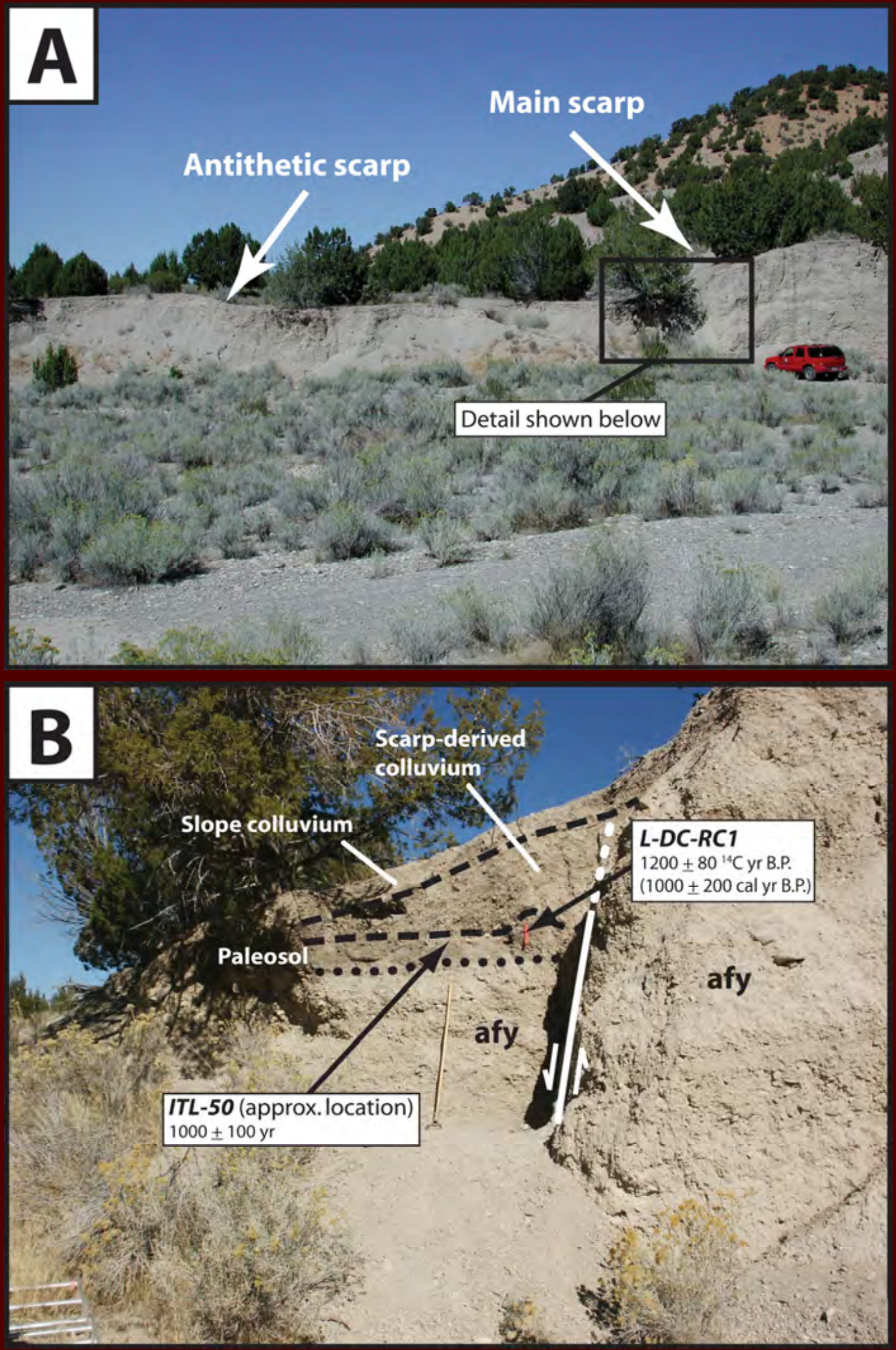
- Previously published slip rate: < 0.3 mm/yr (Hecker, 1993; Black and others, 2003)
- UQFPWG consensus slip rate: 0.1–0.6 mm/yr
- Published rate based on data from Deep Creek natural exposure (Schwartz and Coppersmith, 1984; Jackson, 1991)
- NVTD and MRE timing well constrained, but PE timing:
  - based on detrital charcoal ^{14}C age
  - stratigraphic/structural context of sample uncertain
  - ^{14}C age not calendar calibrated
  - reported uncertainty ± 1000 yr

To re-evaluate Levan-segment slip rate:

- Calendar-calibrated charcoal age
- Incorporated charcoal-age uncertainty into slip-rate calculation
- Calculated slip rate using data from Skinner Peaks trench (Jackson, 1991)



Deep Creek site



Deep Creek Data

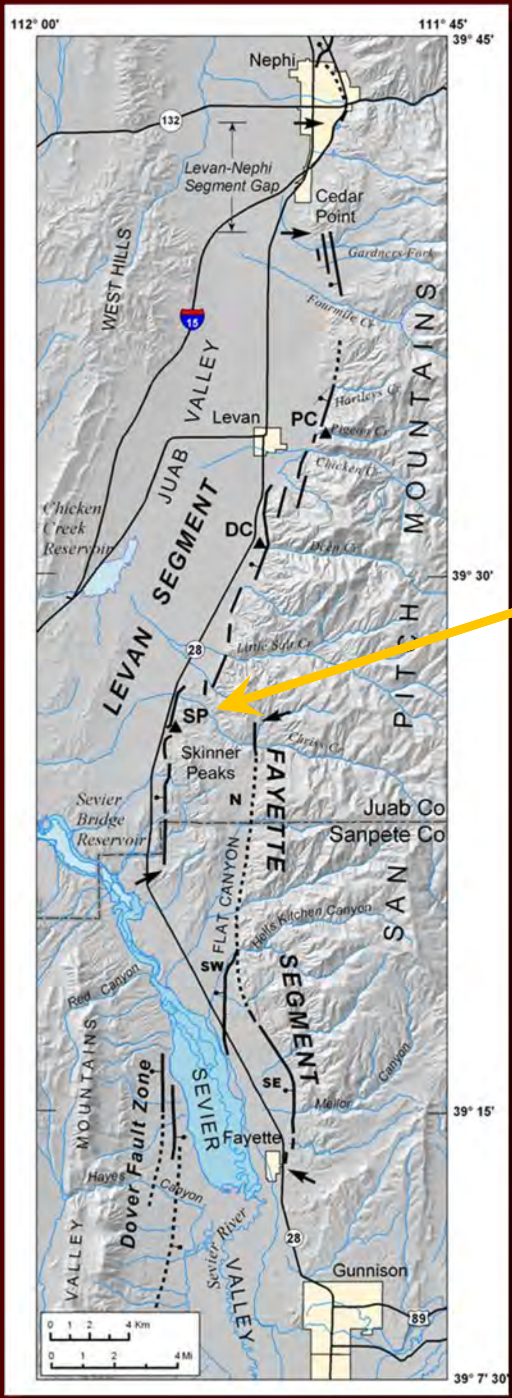
(Schwartz and Coppersmith, 1984; Jackson, 1991; Hylland and Machette, in press)

- Main scarp 3.2 m high
- Antithetic scarp 0.5 m high
- NVTD = 1.8 m
- Evidence for one event
- Paleosol beneath colluvial wedge dated at 1000 ± 200 cal yr B.P. (TL, ^{14}C)
  - close max. limit on MRE timing
- AMS dating of detrital charcoal from footwall deposits: 7300 ± 1000 yr B.P.
  - min. limit on PE timing

7300 ± 1000 yr B.P.:

- Calendar calibrated using CALIB 5.0.1 (INTCAL04 calibration dataset)
- 2σ range: 5985–10,586 BP
- Median and uncertainty (rounded to nearest 100 yr):

8300 ± 2300 cal yr B.P.



Skinner Peaks trench site

Skinner Peaks Data

(Jackson, 1991)

- Main scarp 3.3 m high
- Net surface offset ~3 m
- Evidence for two events
- Buried "burn layer" on footwall dated using TL, ^{14}C
  - TL: 2000 ± 300 yr
  - radiometric: 1700 ± 200 cal yr B.P.
  - max. limit on MRE timing est. 1000-1500 cal yr B.P.
- Buried "incipient A horizon" on hanging wall dated using TL, ^{14}C
  - TL: 3100 ± 300 yr
  - radiometric: 3900 ± 300 cal yr B.P.
  - min. limit on PE timing

3900 ± 300 cal yr B.P. (3720 ± 90 yr B.P.):

- (Re-) calendar calibrated using CALIB 5.0.1 (INTCAL04 calibration dataset)
- 2σ range: 3838–4300 BP
- Subtracted 100 yr MRTC (per Jackson, 1991)
- Median and uncertainty (rounded to nearest 100 yr):

4000 ± 300 cal yr B.P.

NVTD Calculations at Skinner Peaks Trench

(Jackson, 1991)

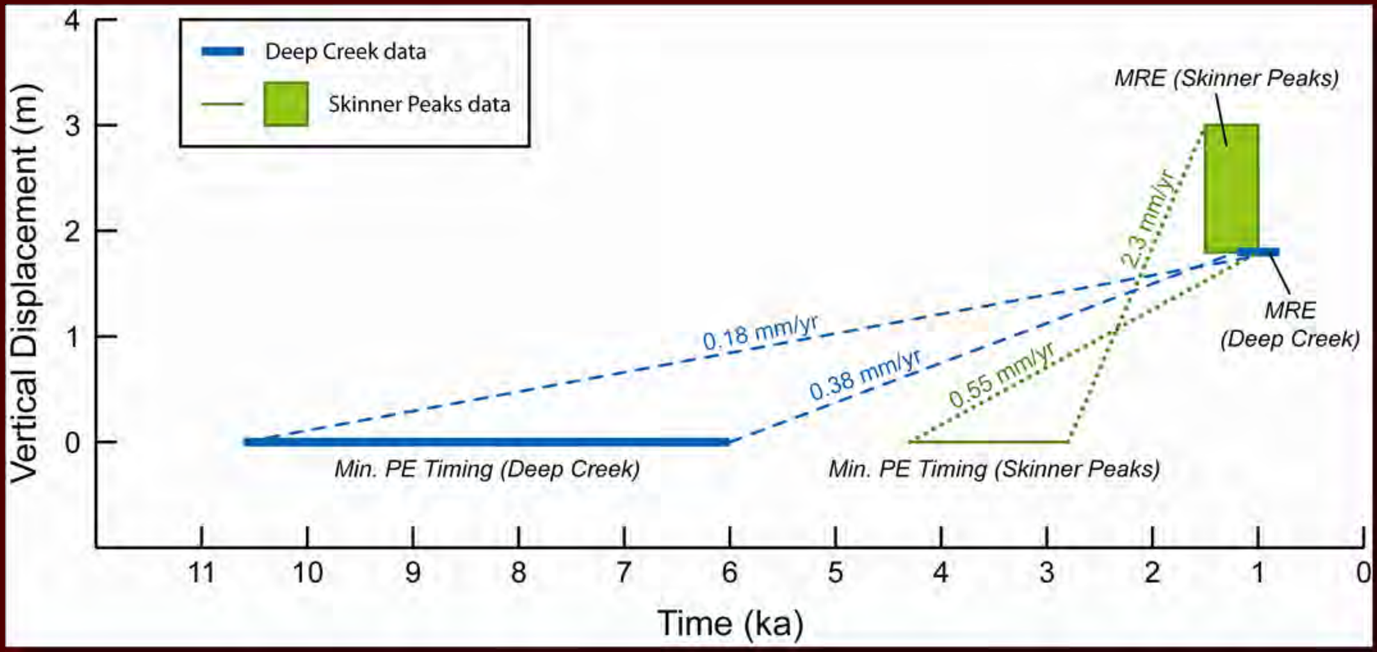
NVTD for MRE estimated from offset of former and current ground surfaces

- Footwall buried burn layer (projected) to “base of the colluvial-wedge package”
  - min. NVTD 2.0 ± 0.2 m
- Footwall modern fan surface (projected) to “base of the colluvial-wedge package”
  - max. NVTD 2.8 ± 0.2 m
- NVTD: 1.8–3.0 m

Levan-Segment Slip Rate

Site	NVTD (m)	MRE Timing (cal yr B.P.)	PE Timing (cal yr B.P.)	Inter-event Time (yr)	Slip Rate (mm/yr)
Deep Creek	1.8	< 800–1200	> 6000–10,600	> 4800–9800	< 0.18–0.38
Skinner Peaks	1.8–3.0	1000–1500	> 2800–4300	> 1300–3300	< 0.55–2.3

Yikes!!



Levan-Segment Slip Rate

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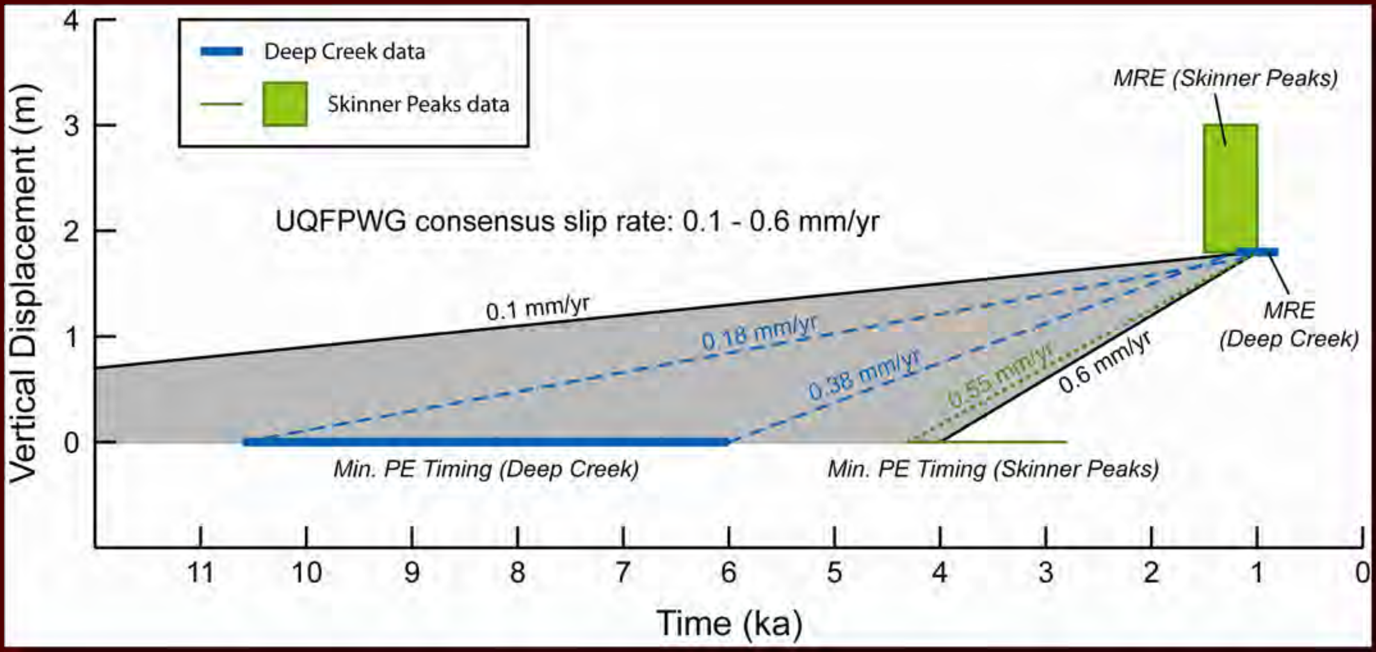
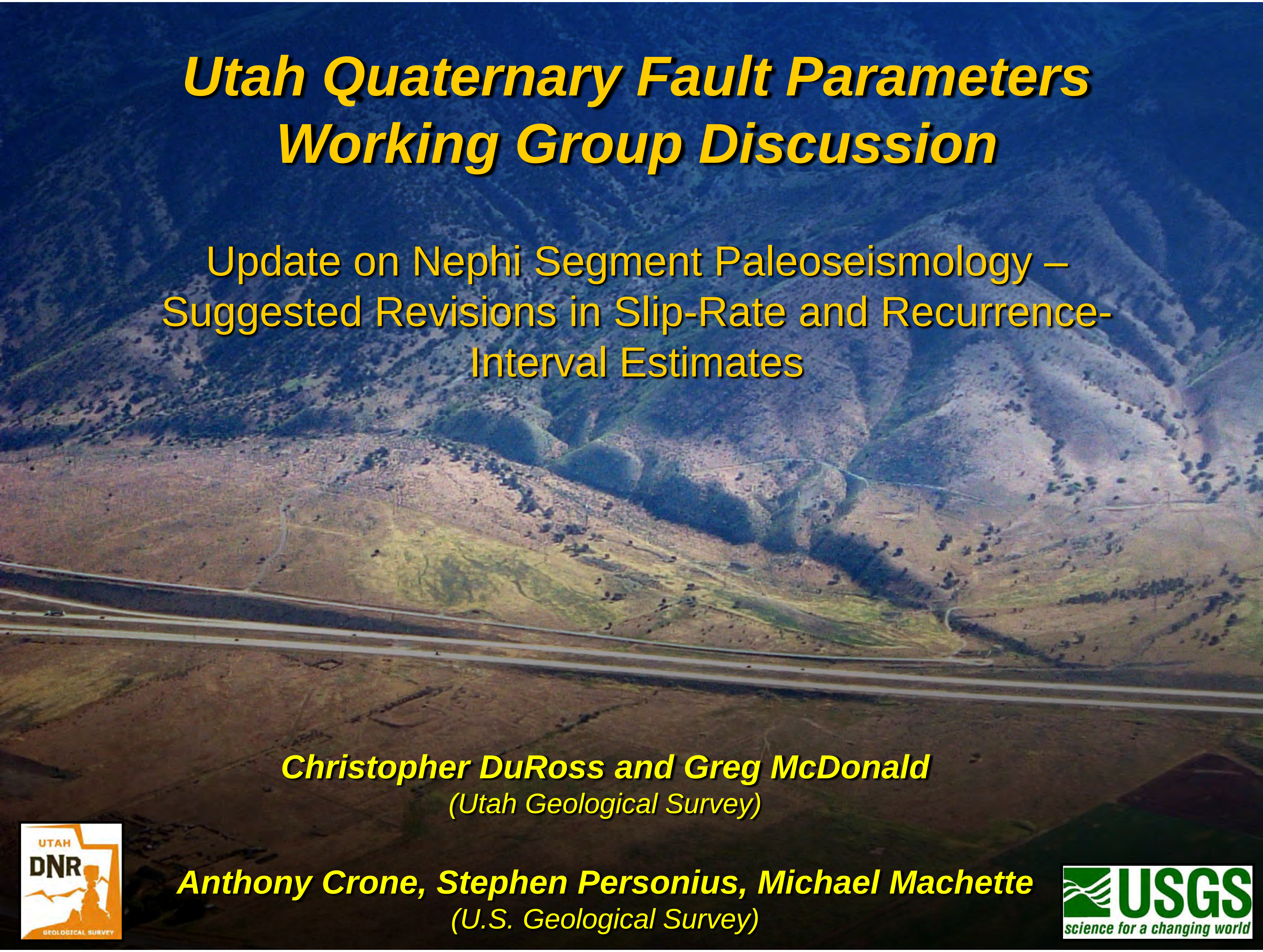


Levan-Segment Slip Rate

Conclusions and Recommendations

- Slip rate calculated from Deep Creek data (< 0.18–0.38 mm/yr) seems reasonable
  - open seismic cycle (PE undated), so max. rate
- Slip rate calculated from Skinner Peaks data (< 0.55–2.3 mm/yr) seems unreasonably high
  - open seismic cycle (PE undated), so max. rate
  - min. limit on PE timing may not be close
  - range of calculated NVTD may be problematic
- UQFPWG consensus slip rate: 0.1–0.6 mm/yr
- New numbers do not warrant change to consensus rate at present time



Utah Quaternary Fault Parameters Working Group Discussion

Update on Nephi Segment Paleoseismology – Suggested Revisions in Slip-Rate and Recurrence-Interval Estimates

Christopher DuRoss and Greg McDonald

(Utah Geological Survey)

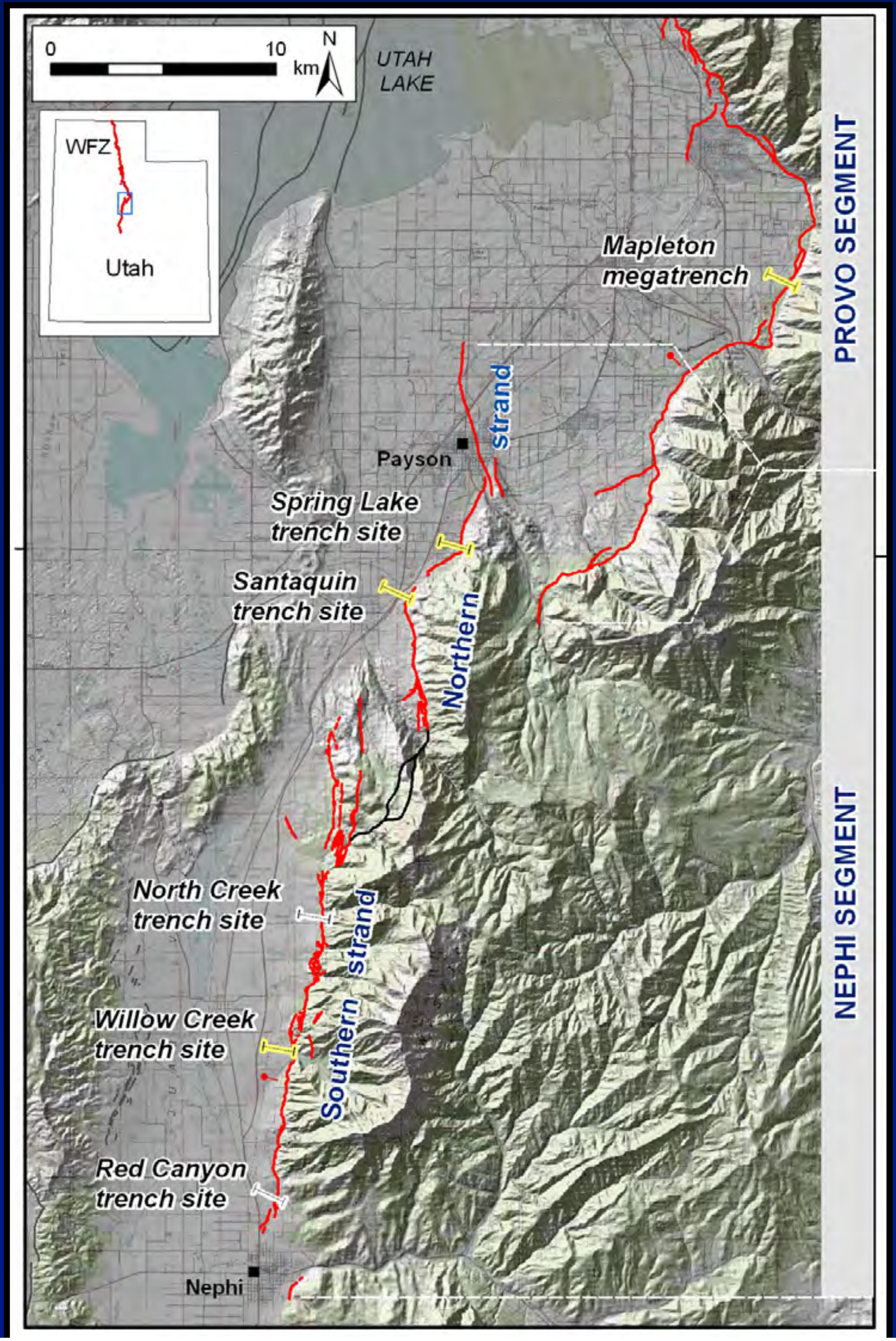
Anthony Crone, Stephen Personius, Michael Machette

(U.S. Geological Survey)

Nephi Segment, Wasatch Fault Zone

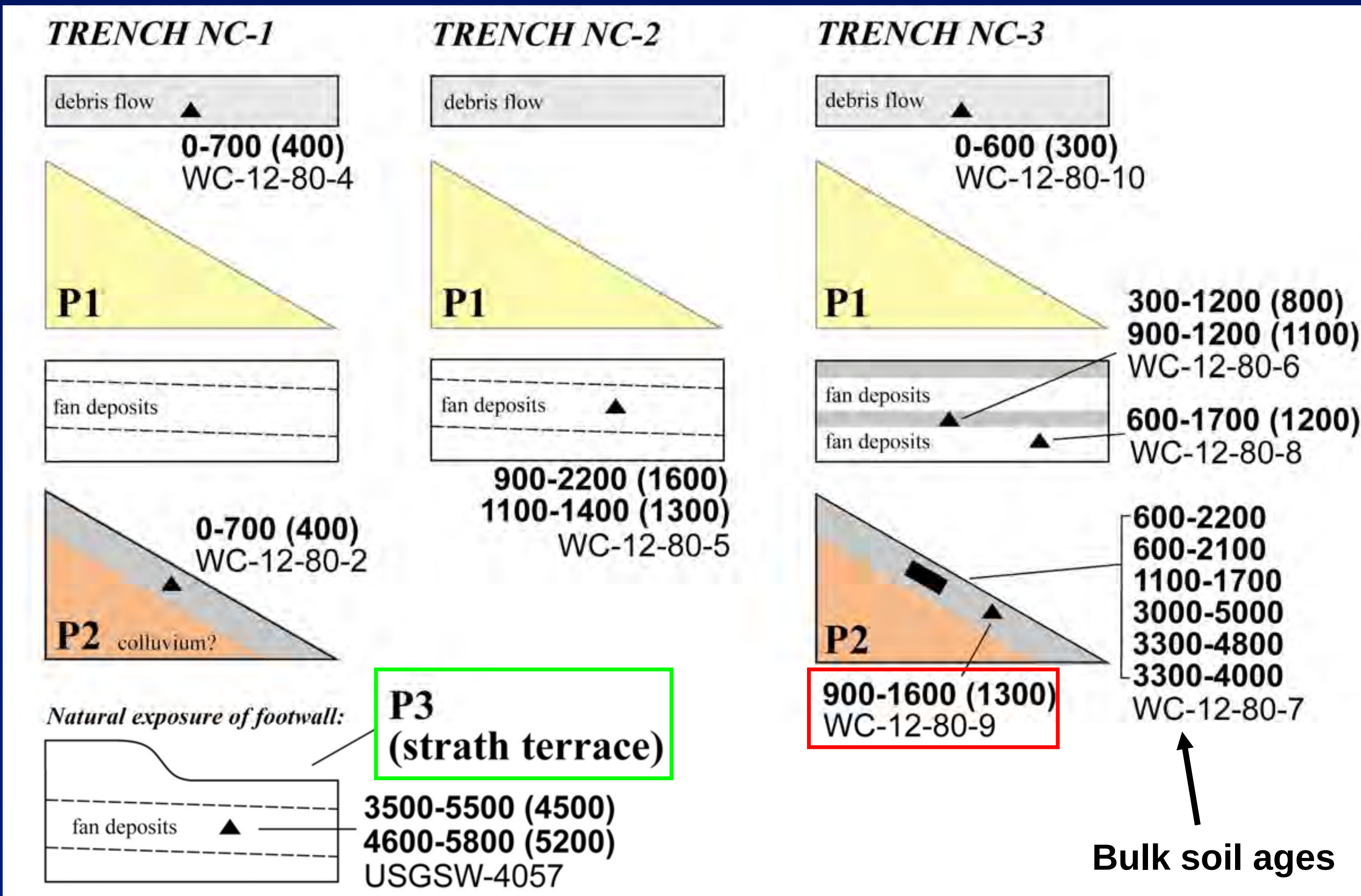
- ***Composed of two strands:***
  - ✓ Northern: 17 km long
  - ✓ Southern: 25 km long

- ***Locations of paleoseismic studies:***
  - ✓ North Creek
    - Hanson et al., 1981
  - ✓ Red Canyon
    - Jackson, 1991
  - ✓ Willow Creek
    - Machette et al., 2005
  - ✓ Santaquin
    - DuRoss et al., 2005, in press
  - ✓ Spring Lake
    - Horns, in progress



North Creek Earthquake Chronology

(Southern Strand)



Ages: cal yr B.P.

Times of prehistoric earthquakes
(cal. yr B.P.)

P1 *(MRE)*	*>300-400* *<800-1600*
P2	*>1300-1400* *>3700-4100*
P3	*<4500-5200*

P = paleoearthquake

North Creek Earthquake Summary

- ***Three events in less than about 5 ka***
- ***Original interpretation of earthquake chronology:***
  - ✓ P1: <1100, possibly 300-500 cal yr B.P. Did not give great credibility to younger constraining ages (>300-400 and <800 cal yr B.P.)
  - ✓ P2: 4000-4500 cal yr B.P.
    Credibility given to older (bulk soil) ages (>3700-4100 cal yr B.P.). Event also constrained by younger (charcoal and bulk soil) ages (1200-1600 cal yr B.P.)
  - ✓ P3: <5200 cal yr B.P.
    Poor age control for event; evidence not based on relations between stratigraphic units and faults

North Creek Earthquake Summary

- ***Earthquake Recurrence:***
  - ✓ P1-P2: <3800 yr
  - ✓ P2-P3: <3900 yr

- ***Slip Rate:***
  - ✓ 1.3-1.7 mm/yr (7.0±0.5 m in 4.5-5.2 kyr)
  - ✓ 0.8-1.6 mm/yr (4.0-4.7 m in 2.9-4.9 kyr)

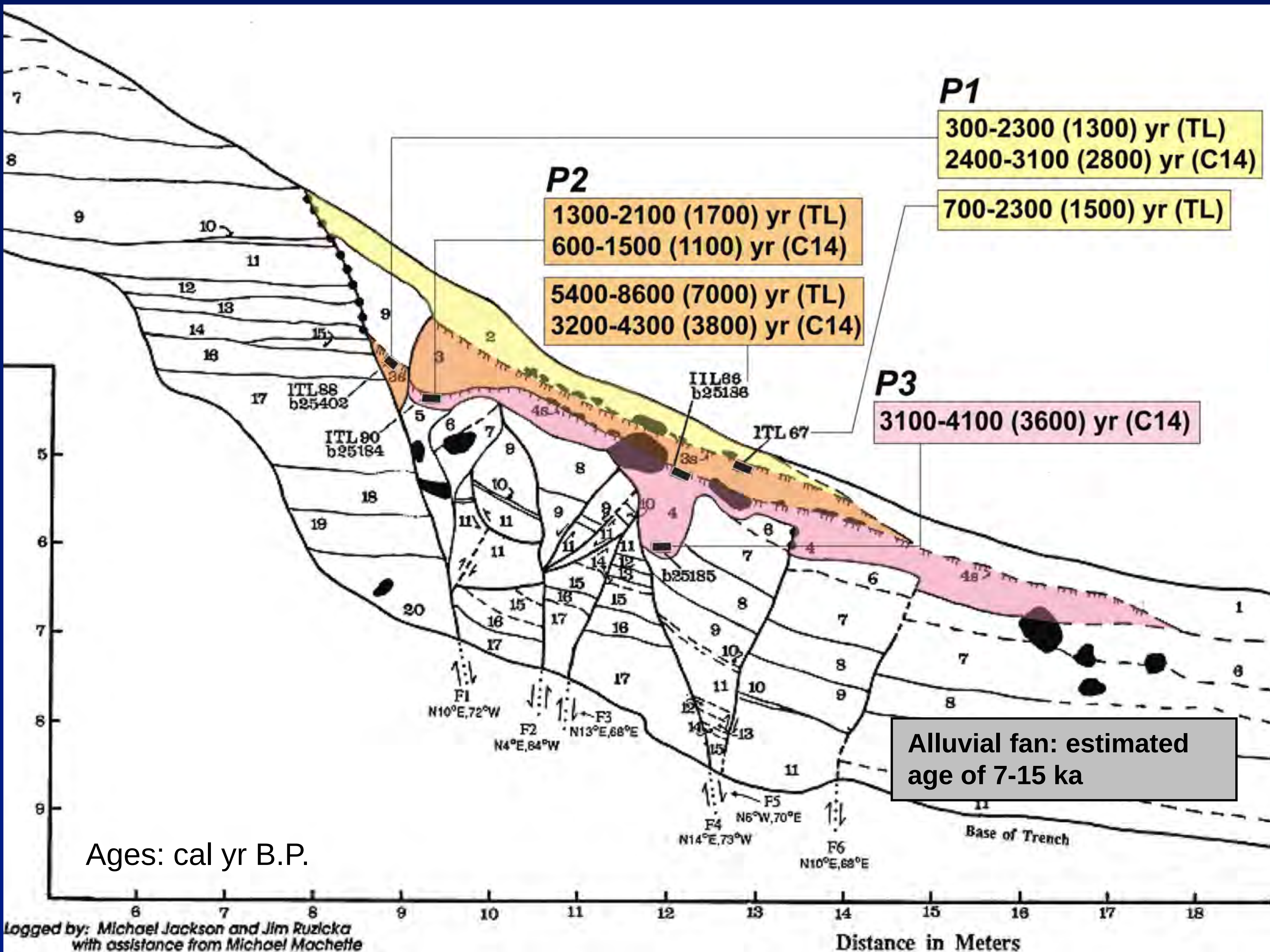
    (P1+P2 m) ÷ (P3-P1 kyr)

Times of prehistoric earthquakes
(cal. yr B.P.)

P1 (MRE)	*>300-400* *<800-1600*
P2	*>1300-1400* *>3700-4100*
P3	*<4500-5200*

Red Canyon Earthquake Chronology

(Southern Strand)



Three events younger than estimated age of alluvial fan: <7 ka

Red Canyon Earthquake Summary

- ***Three events in less than about ~3.6-7 ka***
- ***Original interpretation of earthquake chronology:***
  - ✓ P1: 1000-1200 cal yr B.P.
    Timing of event relies on younger TL ages
  - ✓ P2: 3000-3500 cal yr B.P.
    Credibility given to old set of ^{14}C ages (3600-3800 cal yr B.P.). Young ages also constrain event (<1100 [^{14}C]/1700 [TL])
  - ✓ P3: >4000-4500 cal yr B.P.
    Based on 3600 and 3800 ages

Times of prehistoric earthquakes
(cal. yr B.P.)

P1 (MRE)	*<1300-1500 (must be **<1100**)*
P2	*<1100-1700 <3800*
P3	*>3600 or 3800*

Red Canyon Earthquake Summary

- ***Earthquake Recurrence***:
  - ✓ P1-P2: <2500 yr?
  - ✓ P2-P3: <2500 yr?
- ***Slip Rate:***
  - ✓ 1.1-1.4 mm/yr (5.4±0.3 m in 4-4.5 kyr)
  - ✓ <1.4-1.6 mm/yr (5.4±0.3 m in 3.6 kyr)
  - ✓ <1.0-1.6 mm/yr (2.4-3.4 m in 2.1-2.3 kyr)

    (P1+P2 m) ÷ (P3-P1 kyr)

Times of prehistoric earthquakes
(cal. yr B.P.)

P1 *(MRE)*	*<1300-1500* *(must be **<1100**)*
P2	*<1100-1700* *<3800*
P3	*>3600 or 3800*

Nephi Segment Chronology

(pre-2005)

- ***UQFPWG Consensus Chronology:***

  ✓ Earthquake Timing:

  P1: <1000±400 cal yr B.P., possibly as young as 400±100

  P2: ~3900±500 cal yr B.P.

  P3: >3900±500, <5300±700 cal yr B.P.

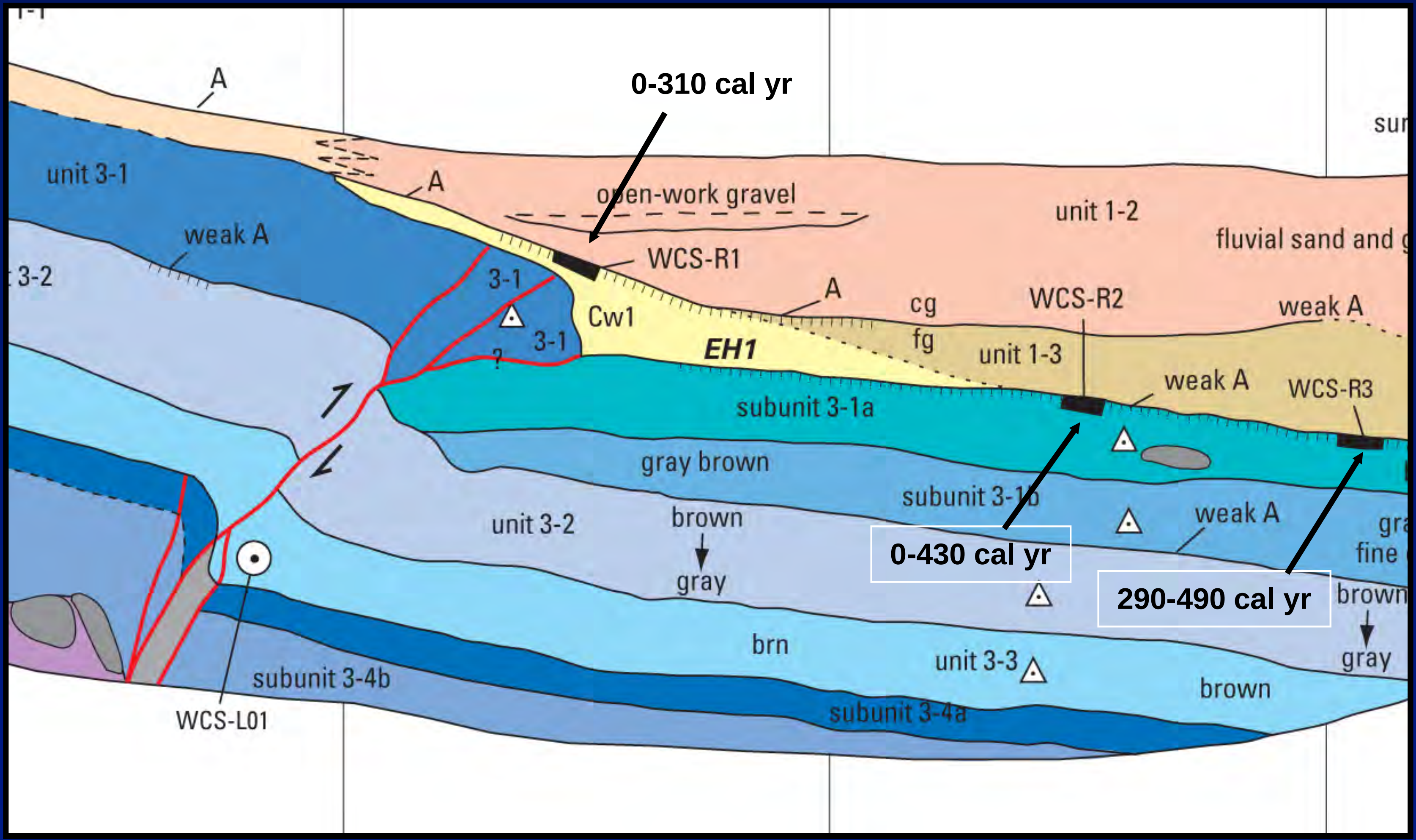
  ✓ Recurrence Interval: 1200-2500-4800 (three events in 5 ka)

  ✓ Slip Rate: 0.5-1.1-3.0 mm/yr

Willow Creek Trench Site

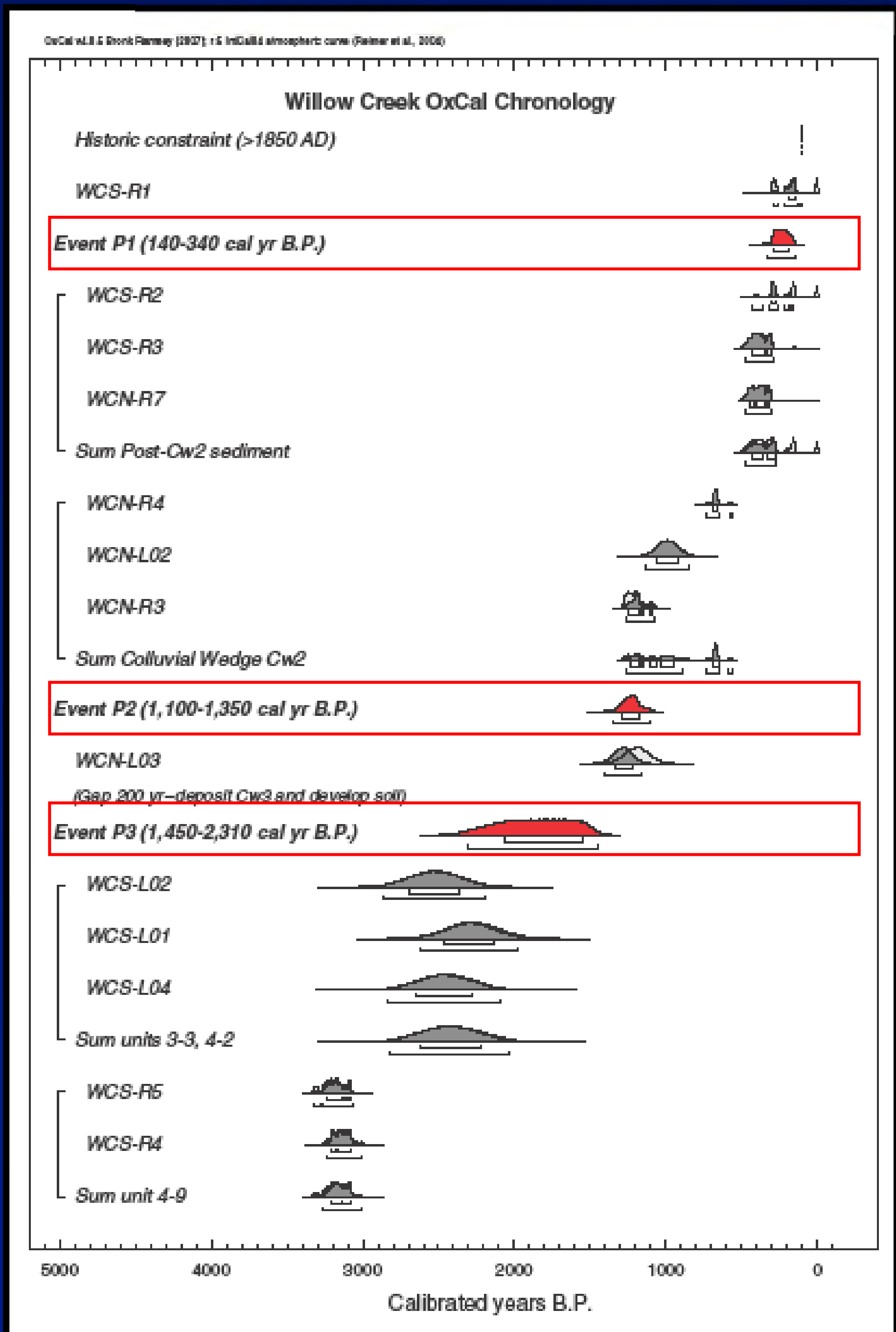
(Southern Strand)

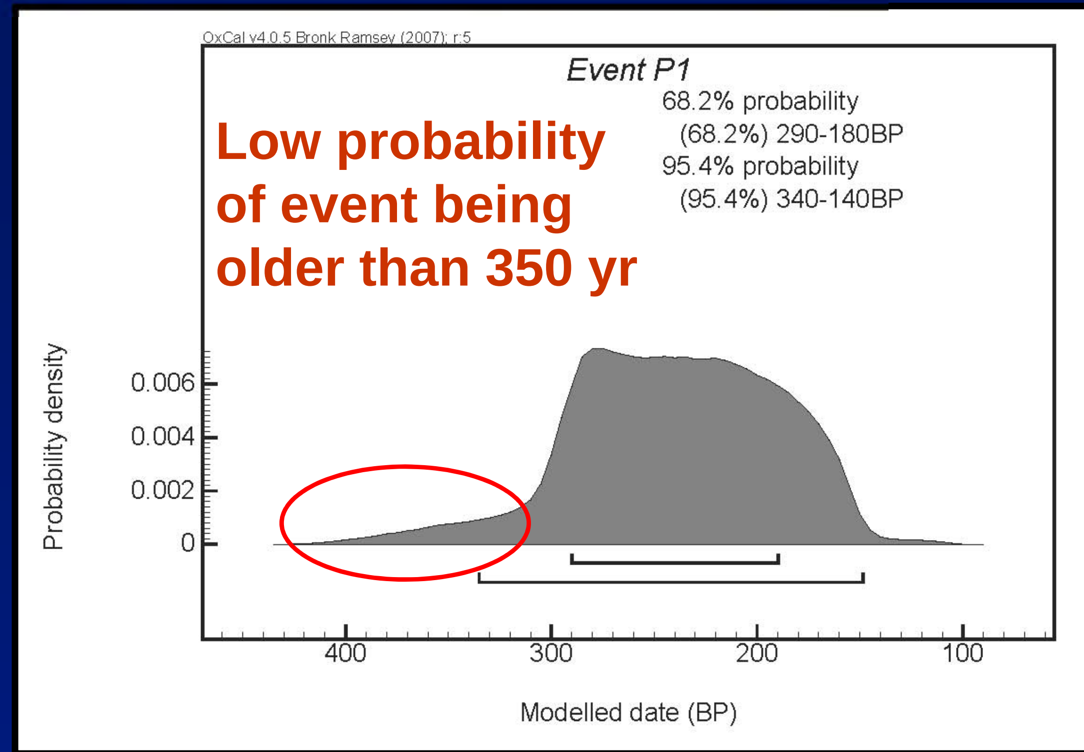
Example - Willow Creek Stratigraphy



OxCal analysis brackets P1 as having an age of 140-340 cal yr B.P.

Willow Creek Earthquake Summary





Willow Creek Earthquake Summary

- ***Three events in less than 2.5 ka:***
  - ✓ P1: 140-340 cal yr B.P.
  - ✓ P2: 1100-1350 cal yr B.P.
  - ✓ P3: 1450-2310 cal yr B.P.

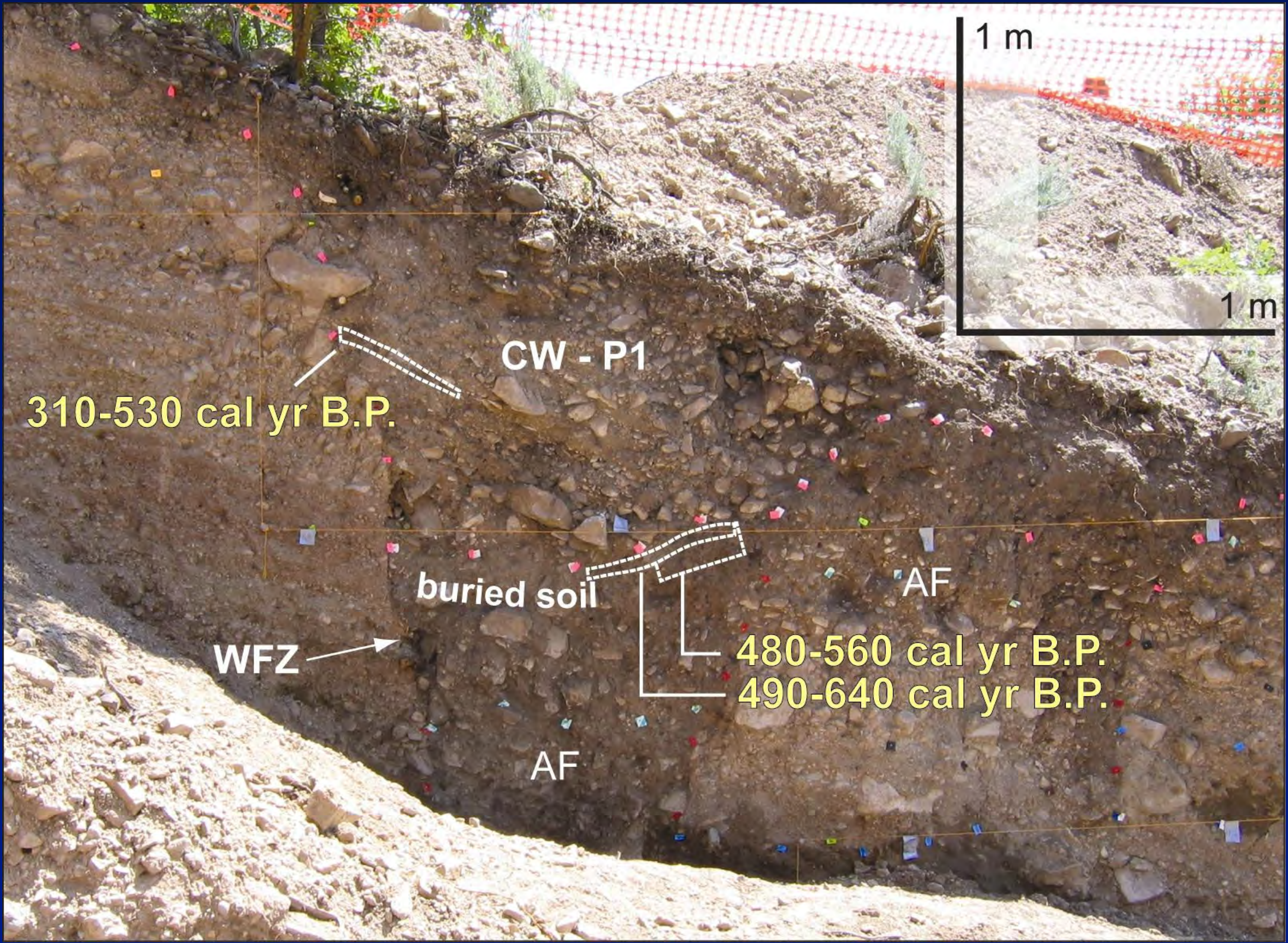
- ***Recurrence:***
  - ✓ P1-P2: 830-1150 yr
  - ✓ P2-P3: 220-1070 yr
  - ✓ P1-P3: 595-1045 yr

- ***Slip Rate:***
  - ✓ 2.6 mm/yr (6 m/2.3 ka)

Times of events are 2-sigma values
determined using OxCal v. 4.0

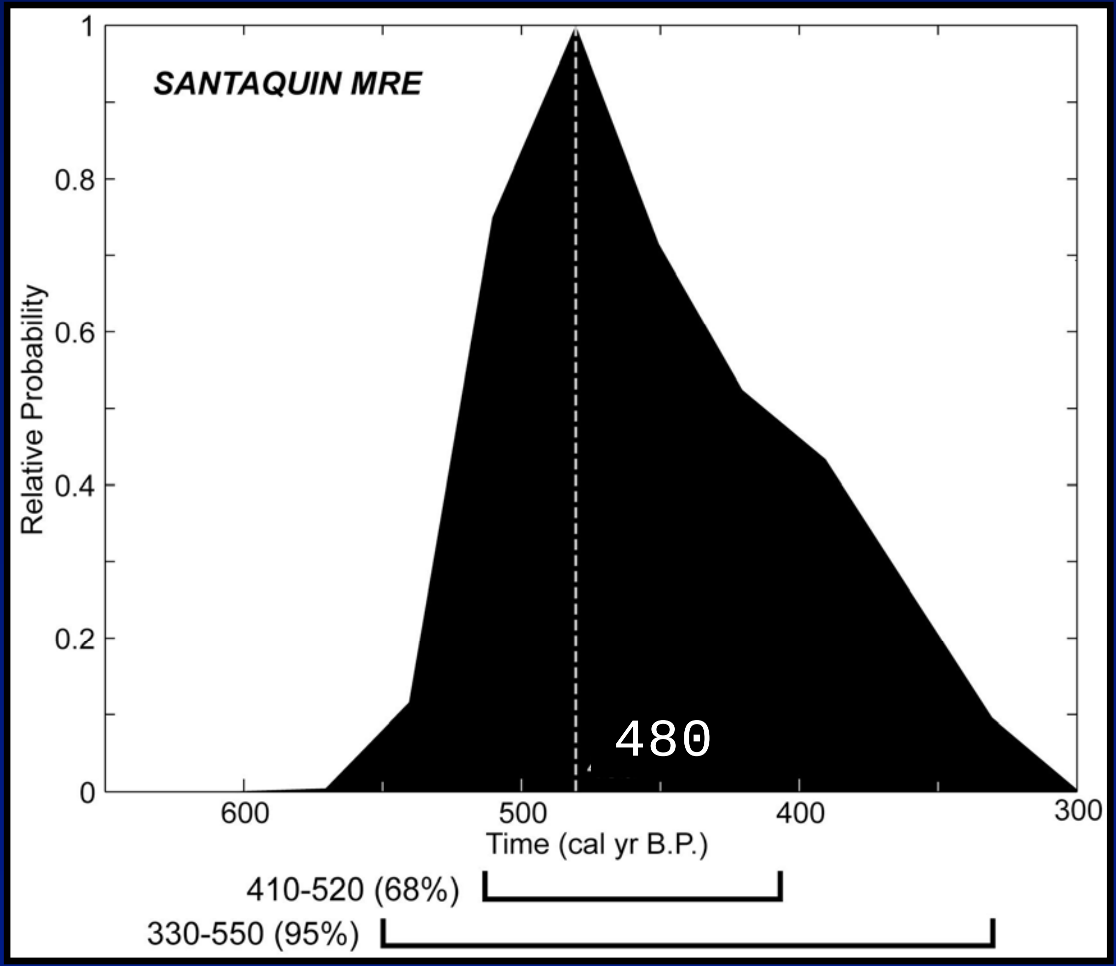
Santaquin Earthquake Chronology

(Northern Strand)



Santaquin Earthquake Summary

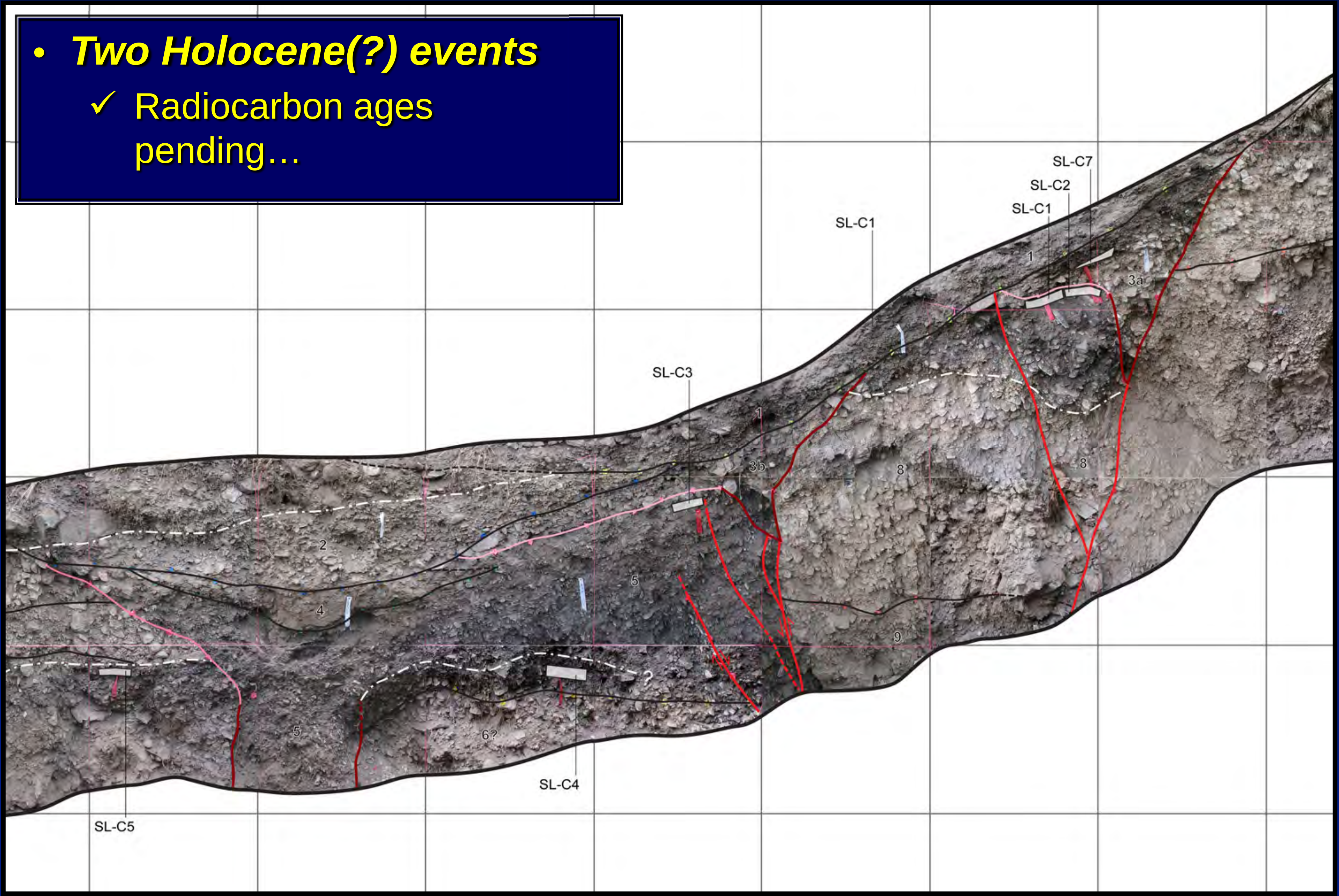
- ***One event in less than 6-7 ka***
  - ✓ P1: 330-550 cal yr B.P.
  - ✓ P2?: >6-7 ka
- ***Recurrence:***
  - ✓ Indeterminate at present
- ***Slip Rate:***
  - ✓ 0.5 mm/yr; based on vertical offset of Bonneville shoreline



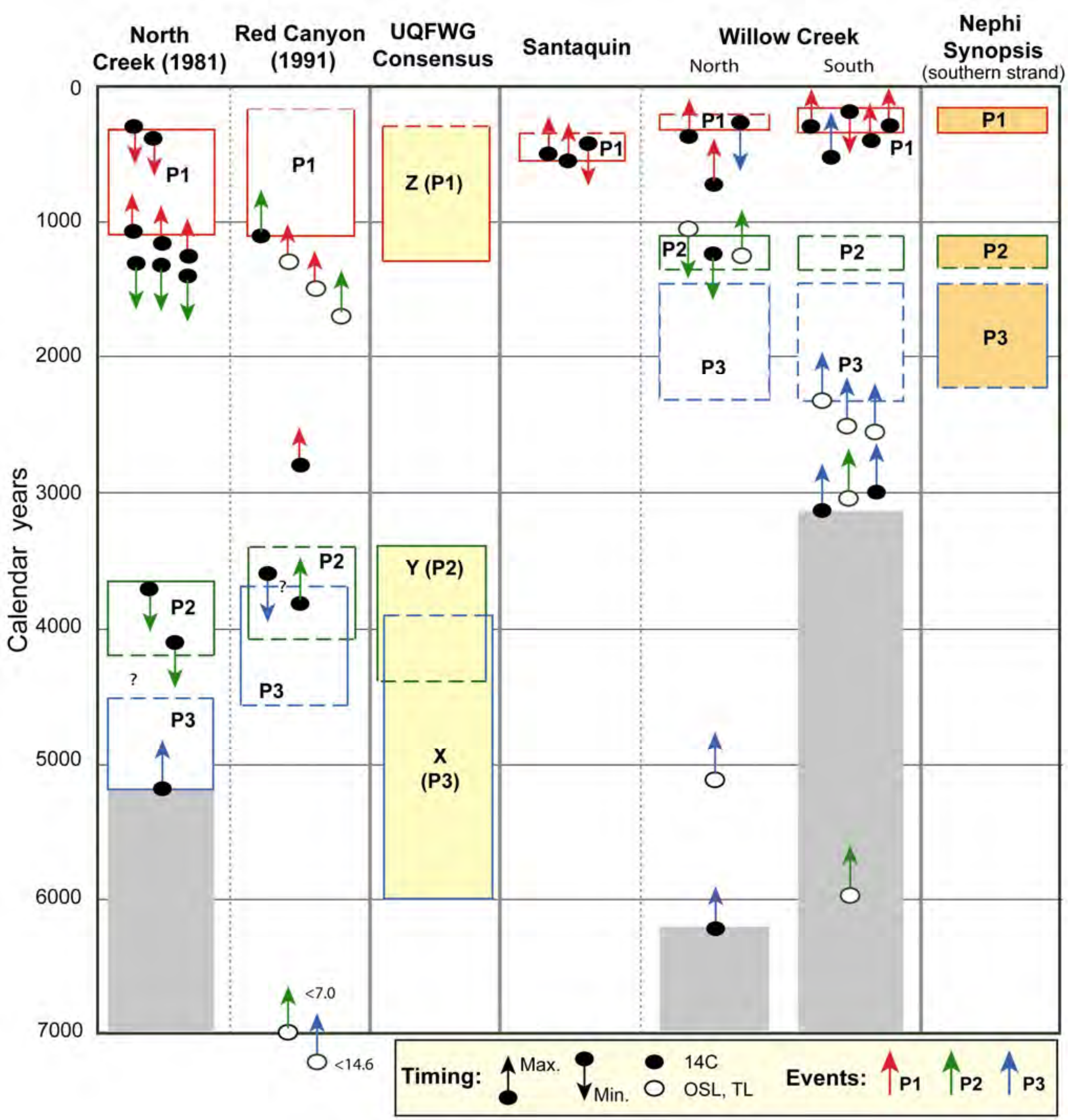
Spring Lake Trench Site

(Northern Strand)

- ***Two Holocene(?) events***
  - ✓ Radiocarbon ages pending…



Nephi Segment Summary



UQFPWG Summary – Nephi segment

P1: ≤1.0±0.4 ka (possibly 0.4±0.1 ka) (WC P1)

P2: ~3.9±0.5 ka

P3: >3.9±0.5 ka; <5.3±0.7 ka

Proposed Revised Event Chronology – Southern strand

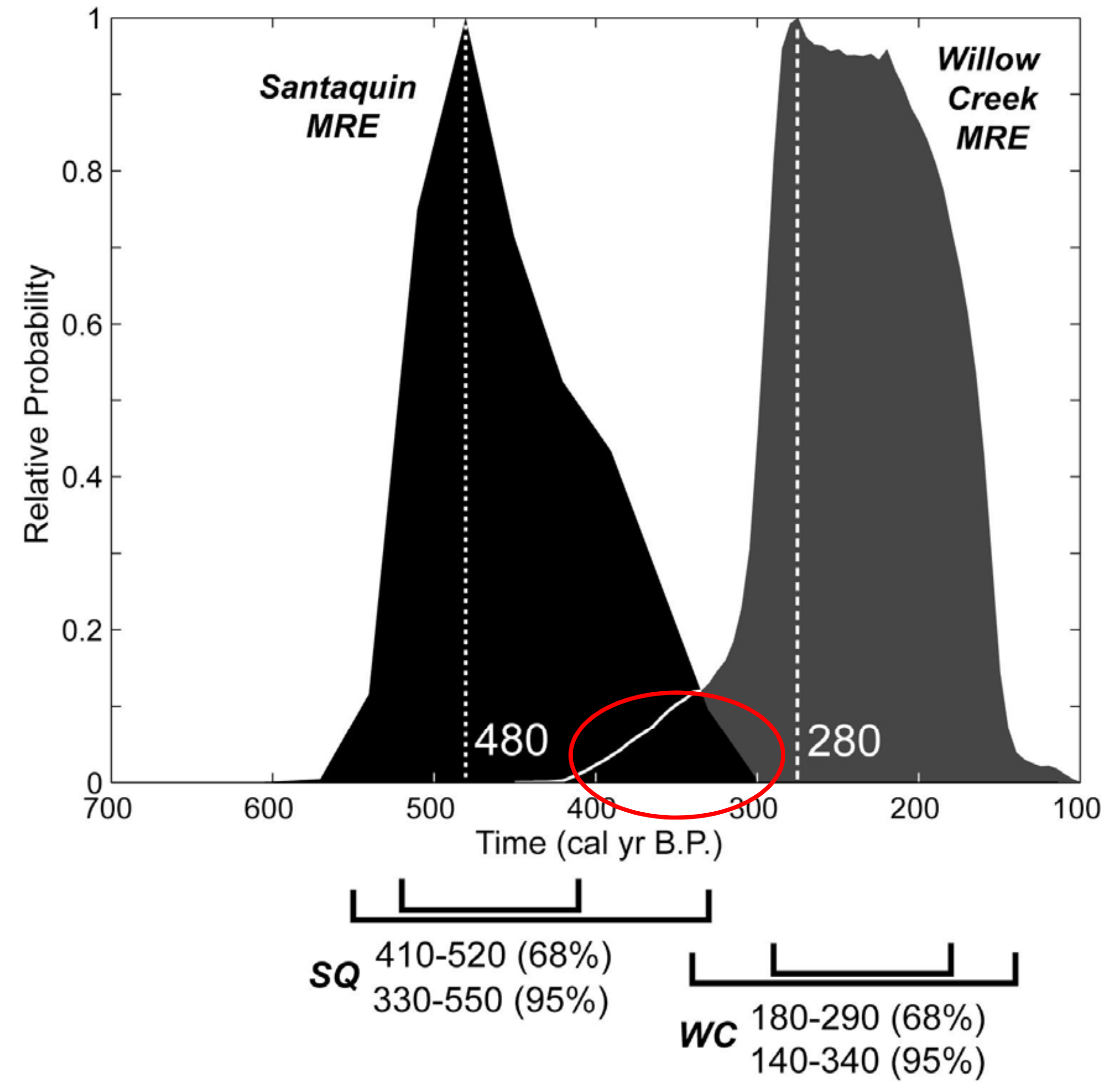
P1: 140-340 cal yr B.P.

P2: 1100-1350 cal yr B.P.

P3: 1450-2310 cal yr B.P.

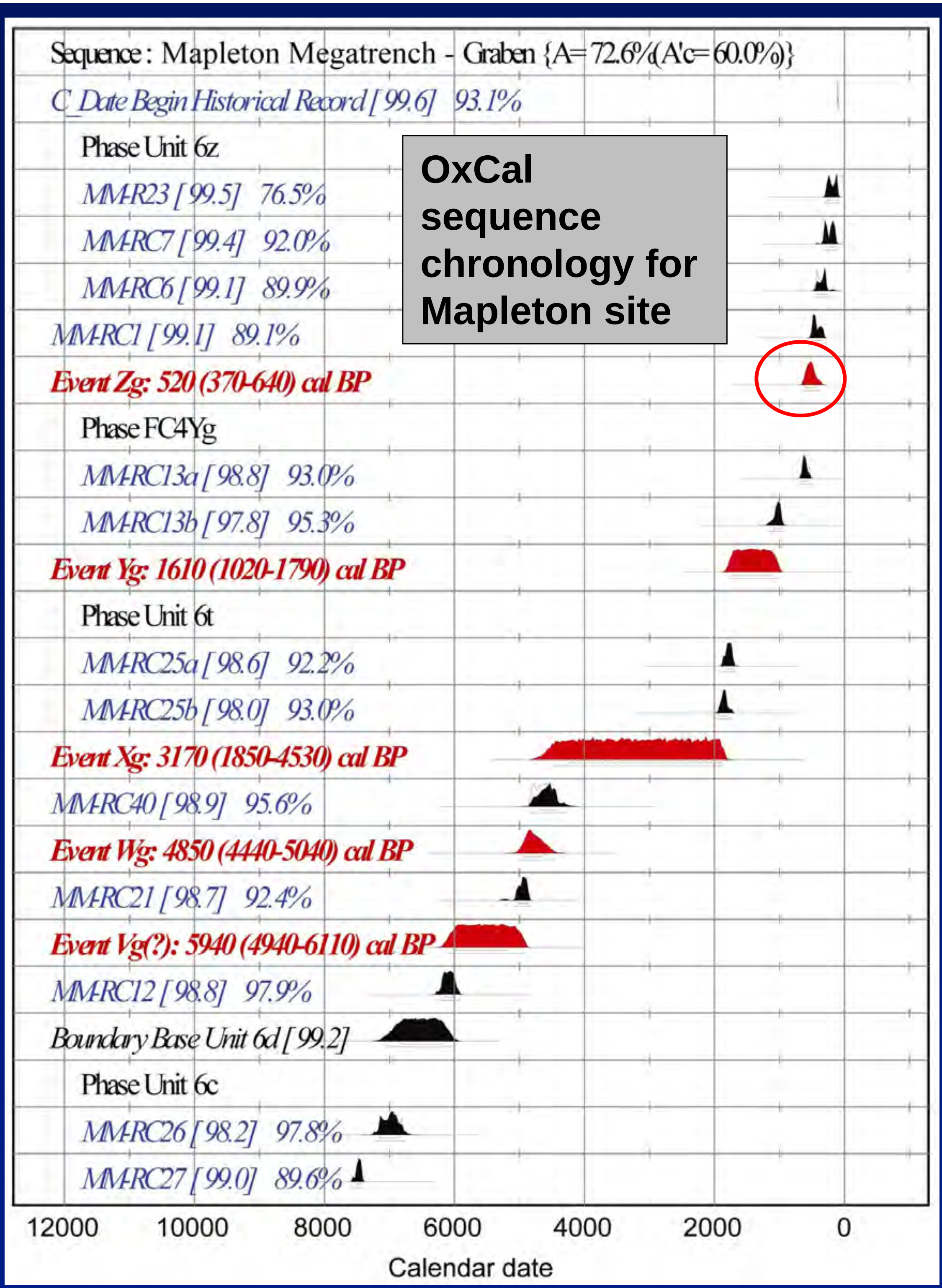
Segmentation scenarios

- ***Scenario One:***
  - ✓ Assume P1 at Santaquin is same event as P1 at Willow Creek (~300-400 cal yr)
  - ✓ Not considered likely: Limited overlap in probability distributions
  - ✓ Modal value is 280 cal yr at Willow Creek versus 480 cal yr at Santaquin



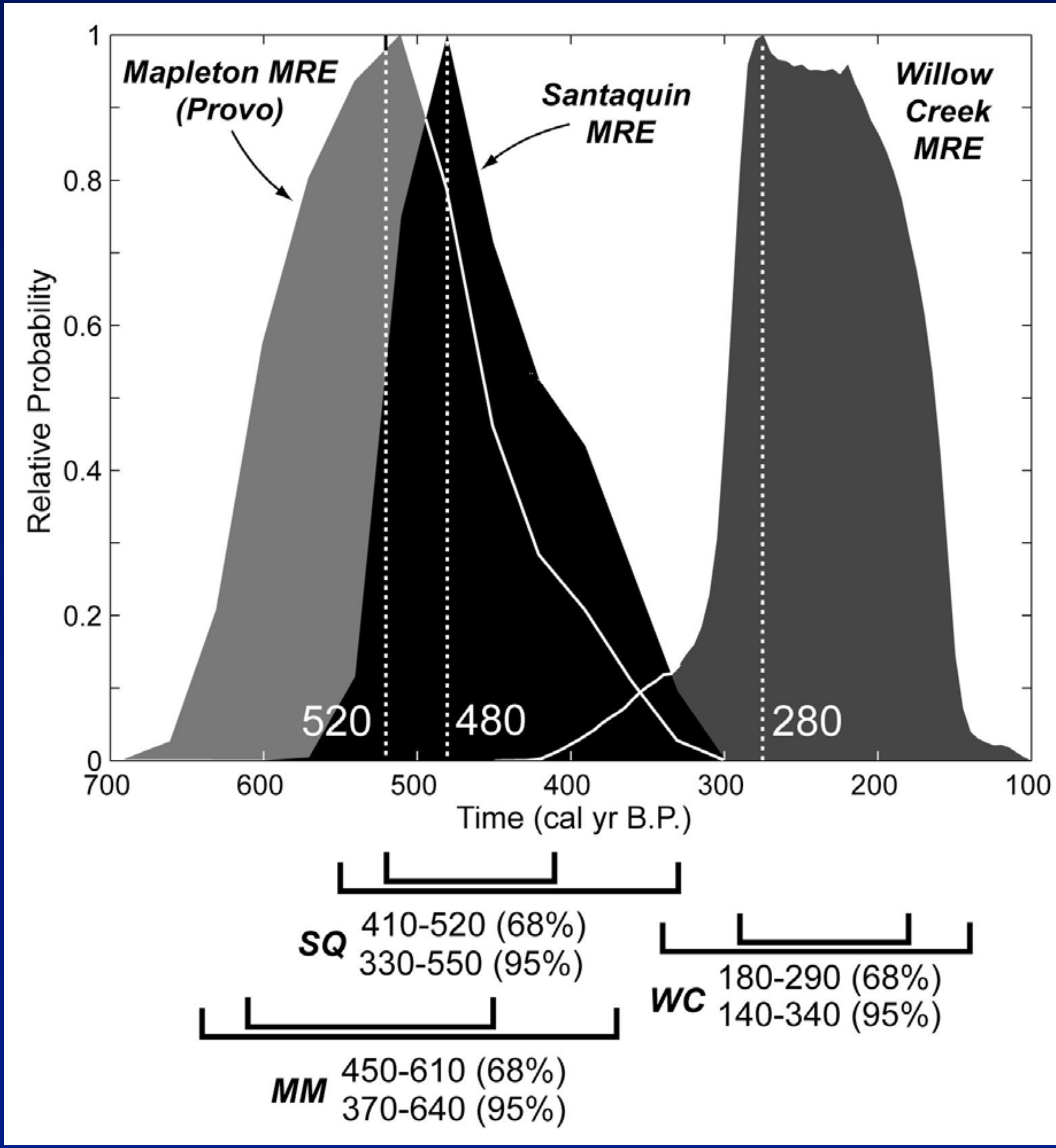
Segmentation Scenarios

- ***Scenario Two:***
  - ✓ Assume that P1 at Santaquin correlates with P1 on Provo segment (~500 cal yr)
  - ✓ Mapleton Site: Four events in <5 ka (S. Olig):
    - P1: 520 (370-640) cal yr B.P.
    - P2: 1610 cal yr B.P.
    - P3: 3170 cal yr B.P.
    - P4: 4850 cal yr B.P.



Segmentation Scenarios

- ***Scenario Two:***
  - ✓ P1 at Santaquin is similar in age to P1 on Provo segment (~500 cal yr)
  - ✓ P1 on southern strand of Nephi segment is ~300 cal yr based on data at Willow Creek only



Proposed Revised Slip-Rate and Recurrence-Interval Values

1. ***Consider Willow Creek and Santaquin values as upper and lower bounds for Nephi segment.***

   Slip Rate: 0.5-?-2.6 mm/yr

   Recurrence Interval: 600-?-6000 yr

   [WG: 0.5-1.1-3.0]

   [WG: 1200-2500-4800]

2. ***Apply Willow Creek values to entire segment (pending Spring Lake results).***

   Slip Rate: 2.6 ± 0.2 mm/yr

   Recurrence Interval: 600-?-1200 yr

3. ***Apply Willow Creek values to southern strand and Santaquin/Spring Lake values to northern strand.***

WASATCH FRONT COMMUNITY FAULT MODEL

- **What is a CFM and what is it used for?**
- **Do we need a CFM for the Wasatch Front?**
- **How do we define “Wasatch Front”?**
- **Do we have the necessary data to construct a WFCFM?**
- **If not, what new data do we need, and how do we acquire it?**
- **If we need it and have the data, who should build and maintain it?**

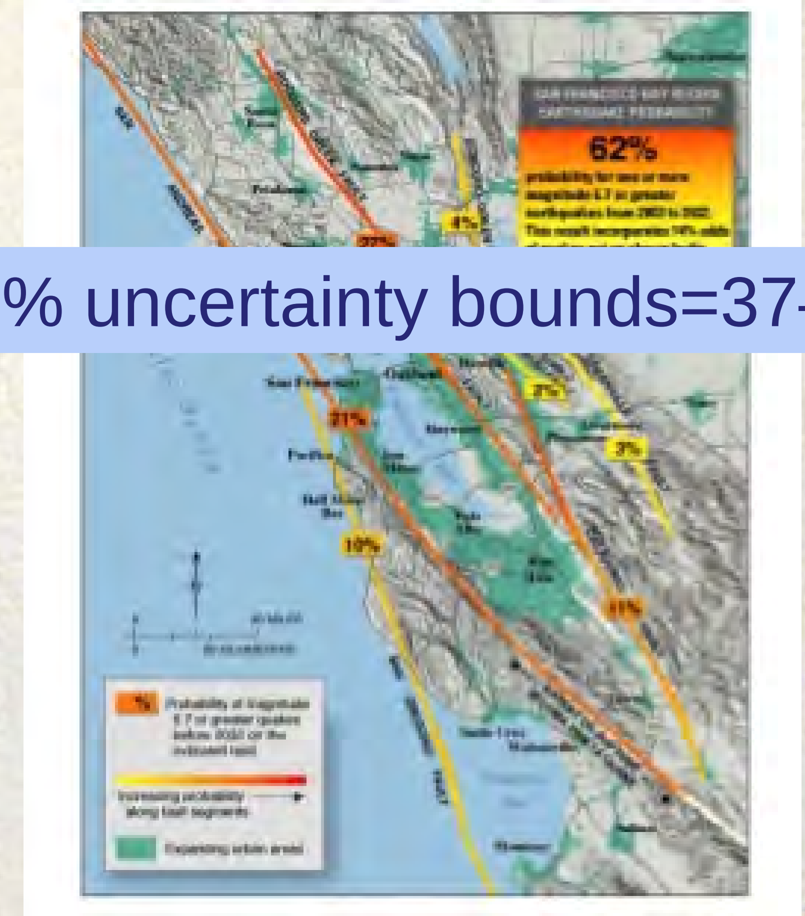
USGS time-dependent earthquake models

Kathy Haller

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

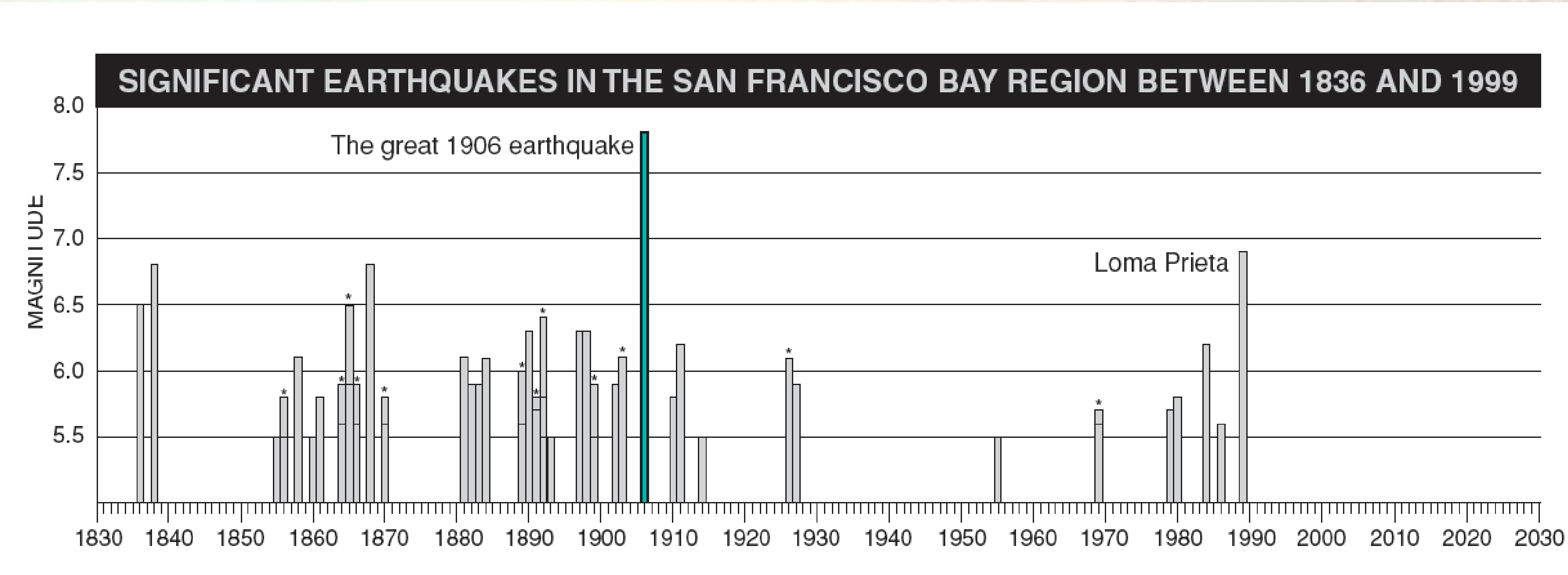
Working Group On California Earthquake Probabilities

- **"Drawing on new data and new methodologies, we have concluded that there is a 0.62 probability (i.e., a 62% probability) of a major, damaging earthquake M≥6.7) striking the greater San Francisco Bay Region over the next 30 years (2002–2031)."**



95% uncertainty bounds=37–87%

USGS Open-File Report 03-214

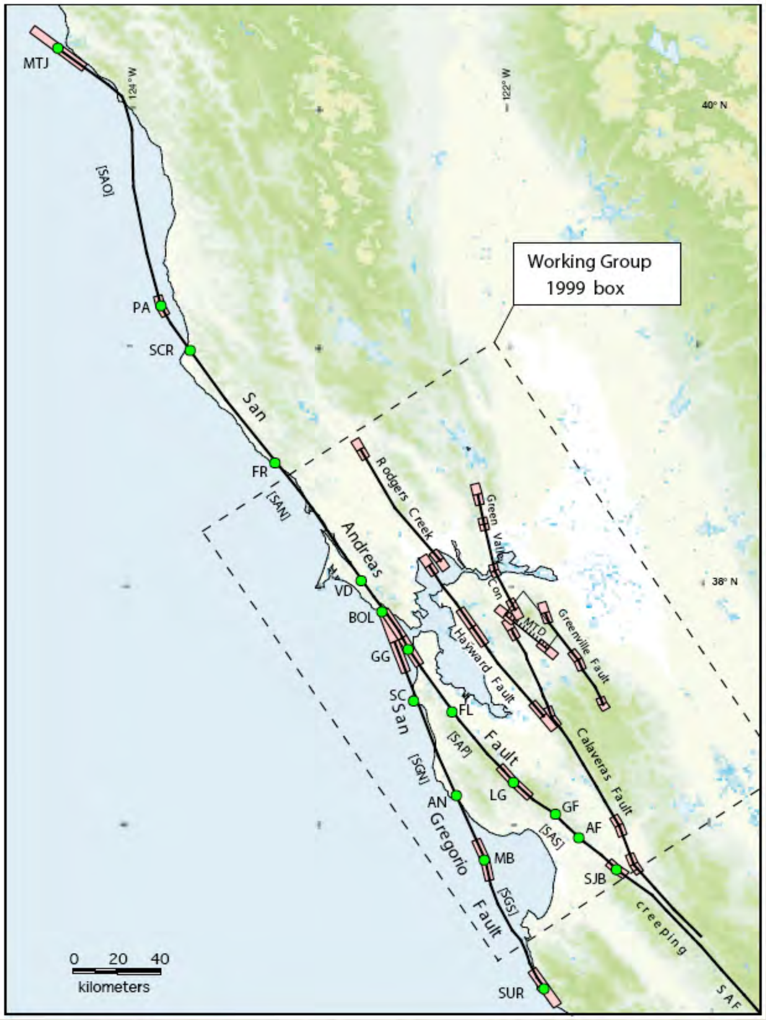

SIGNIFICANT EARTHQUAKES IN THE SAN FRANCISCO BAY REGION BETWEEN 1836 AND 1999
MAGNITUDE
8.0
7.5
7.0
6.5
6.0
5.5
The great 1906 earthquake
Loma Prieta
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030

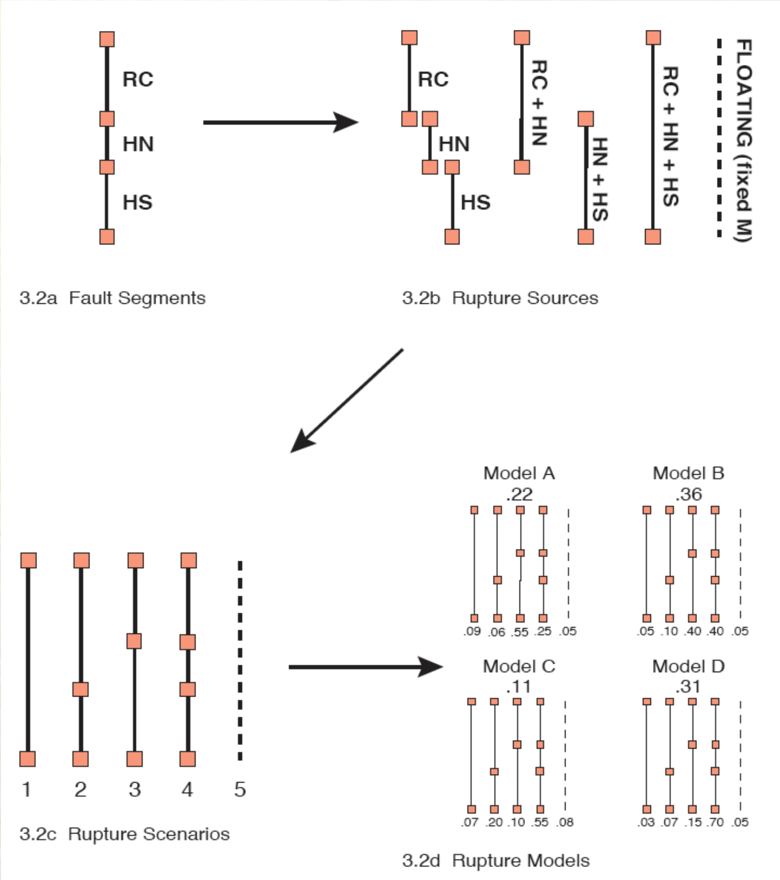
20-yr history

- WG88: San Andreas and Hayward faults
  - the 30-yr probability (1988 to 2018) of **M**≥7 earthquakes on each fault was 0.5
- WG90: Rodgers Creek fault added
  - the 30-yr probability (1990 to 2020) of **M**≥7 earthquakes was 0.67

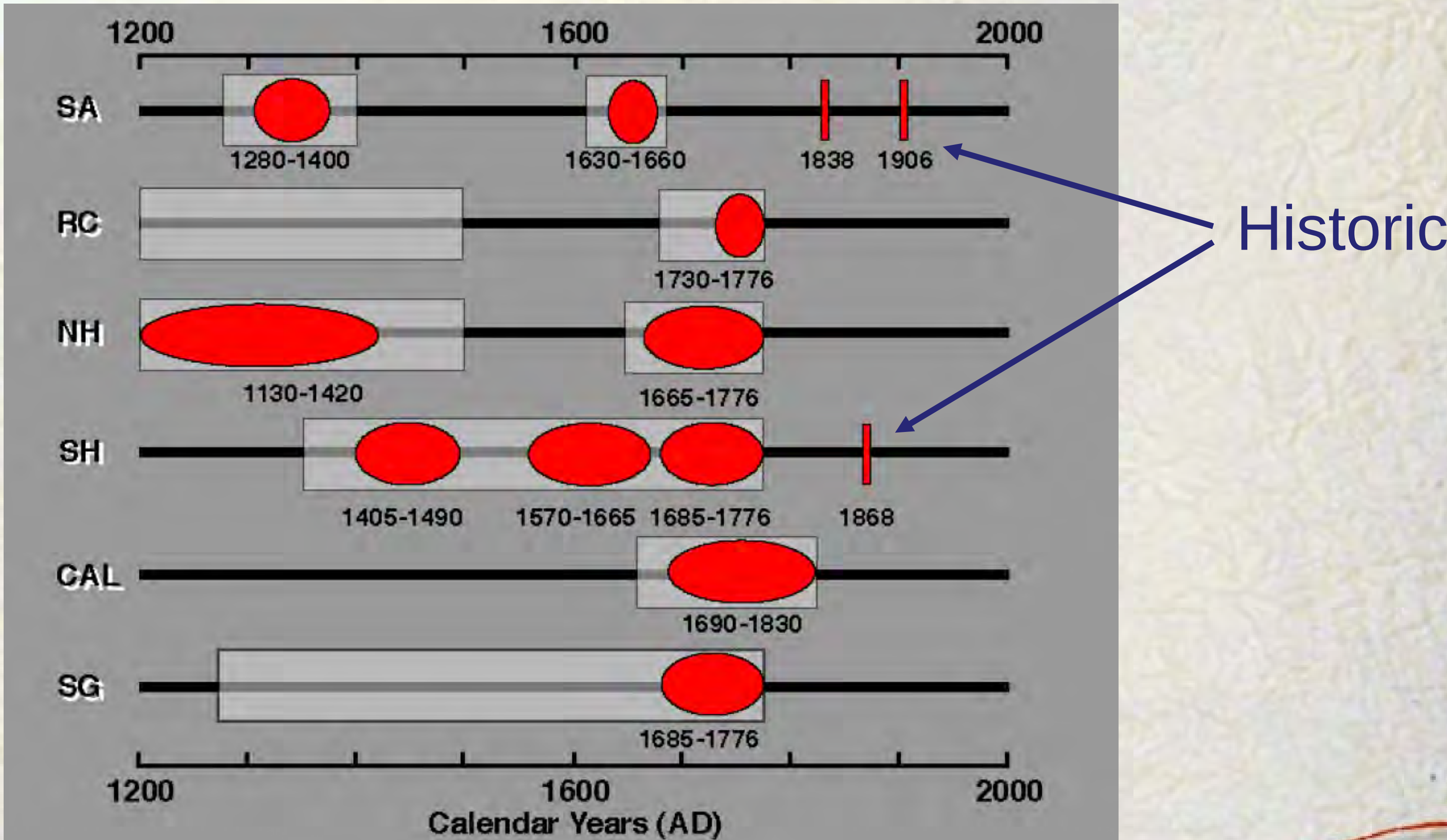
- WG99: constrained overall moment budget for the region and introduced alternative probability models
  - the 30-yr probability (1999 to 2029) of **M**≥6.7 earthquakes was 0.70
- WG02: added five additional faults and background seismicity to the model
  - Produced a broader regional perspective—one in which earthquake potential is more dispersed throughout the SFBR
  - the 30-yr probability (2002 to 2031) of **M**≥6.7 earthquakes was 0.62

Example of fault model



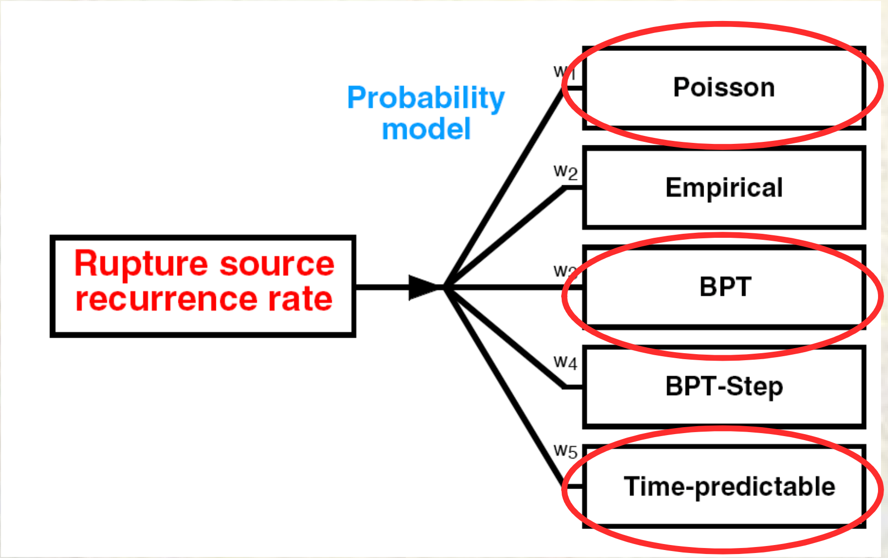


Timing of large earthquakes on SFBR faults



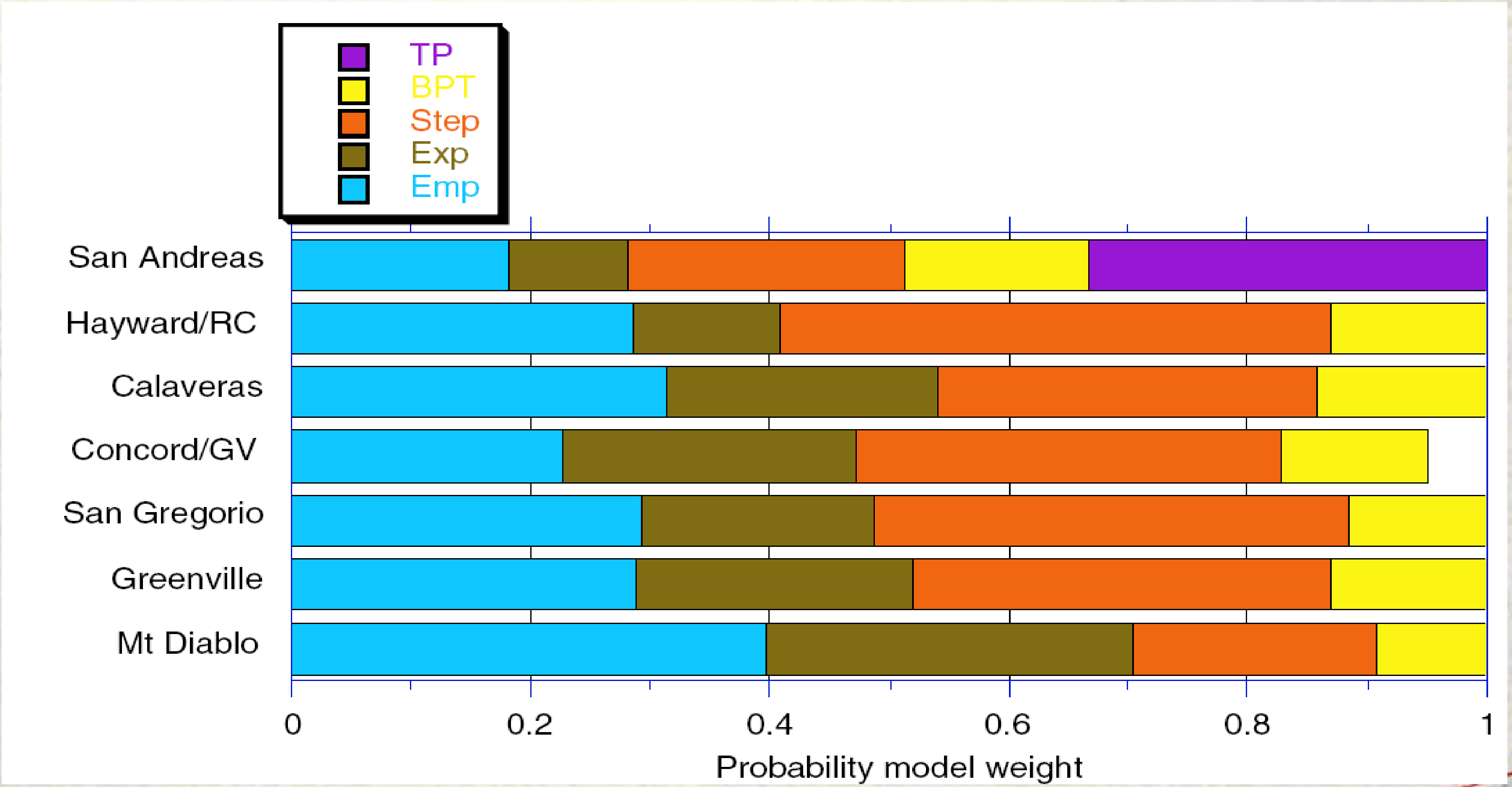
WG02 probability models

WG88
WG99

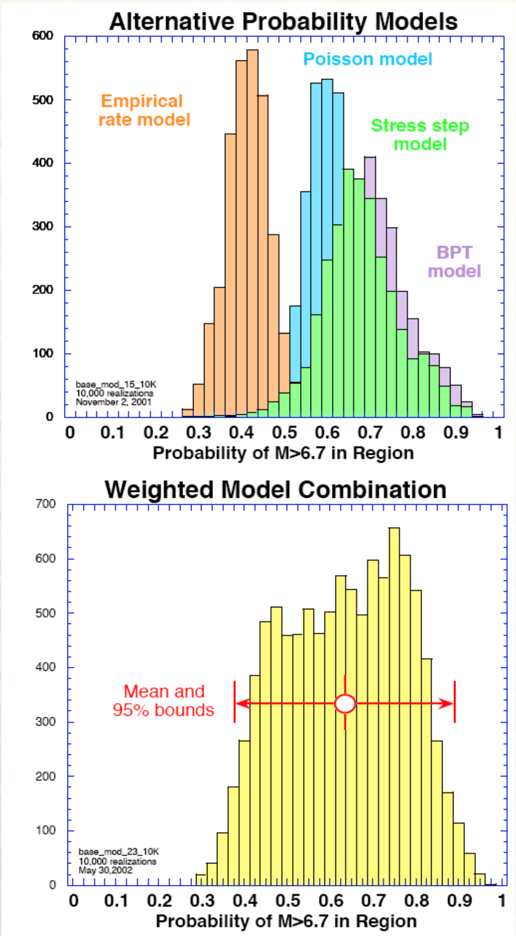


- Included a **suite** of probability models in their calculations
  - Time Predictable (TP)
  - Brownian Passage Time (BPT) and BTP-step
  - Poisson (Exp)–time independent
  - Empirical–variant of Poisson

WG02 probability model weights



Example of WG02 probability-model results

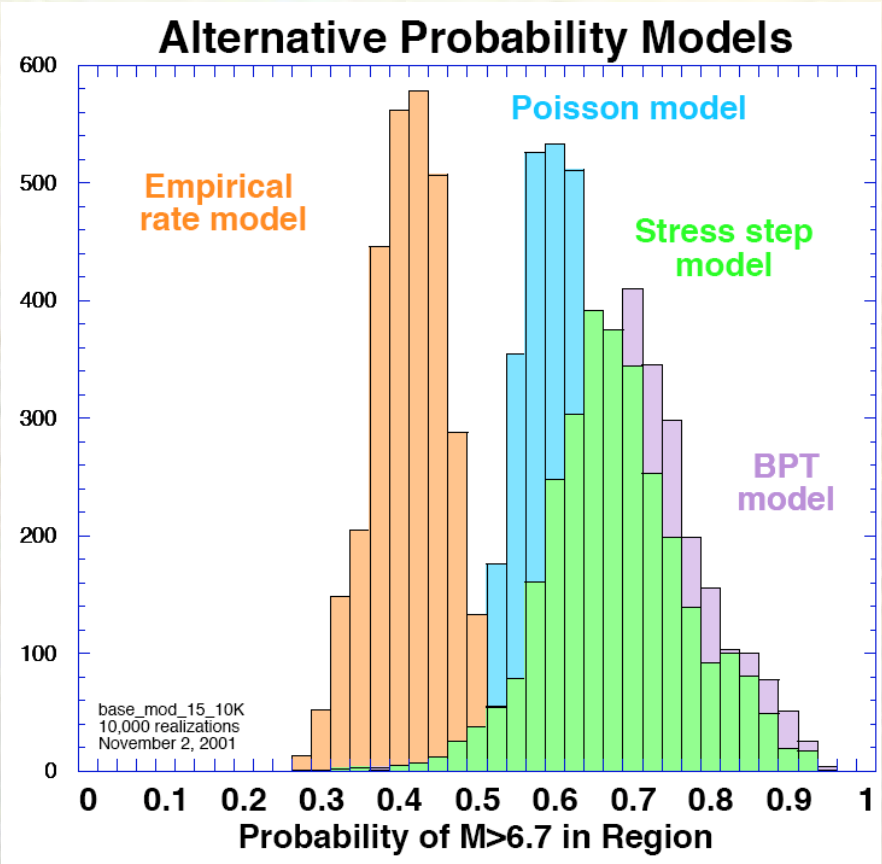


- Results reflect weighted averages of these models
- The broad shape reflects the combination of the distinct behaviors of the alternative models.

Time Predictable model

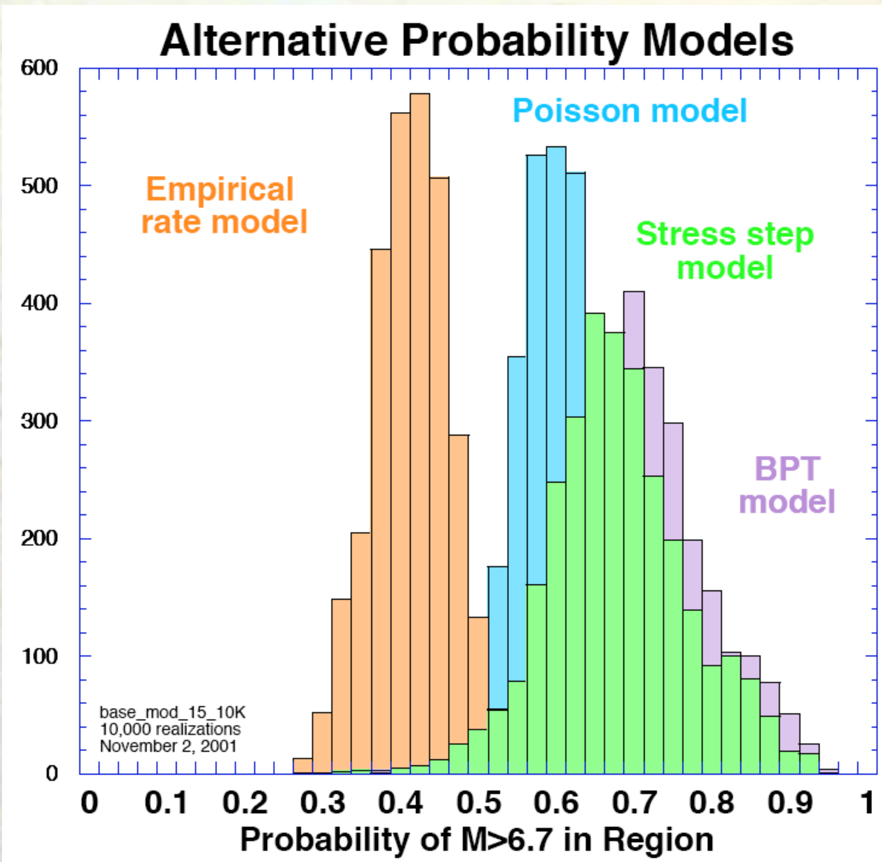
- Used in WG88, WG90, and WG99
- Time of next earthquake varied about the expected time according to lognormal distribution
- Differences between this and BPT are small compared to uncertainty
- WG02 used this only for SA because the information available for the remainder of the SFBR faults was either lacking or too uncertain

Poisson model



- Used in WG99
- In WG02 Empirical rate model added

Time-dependent renewal

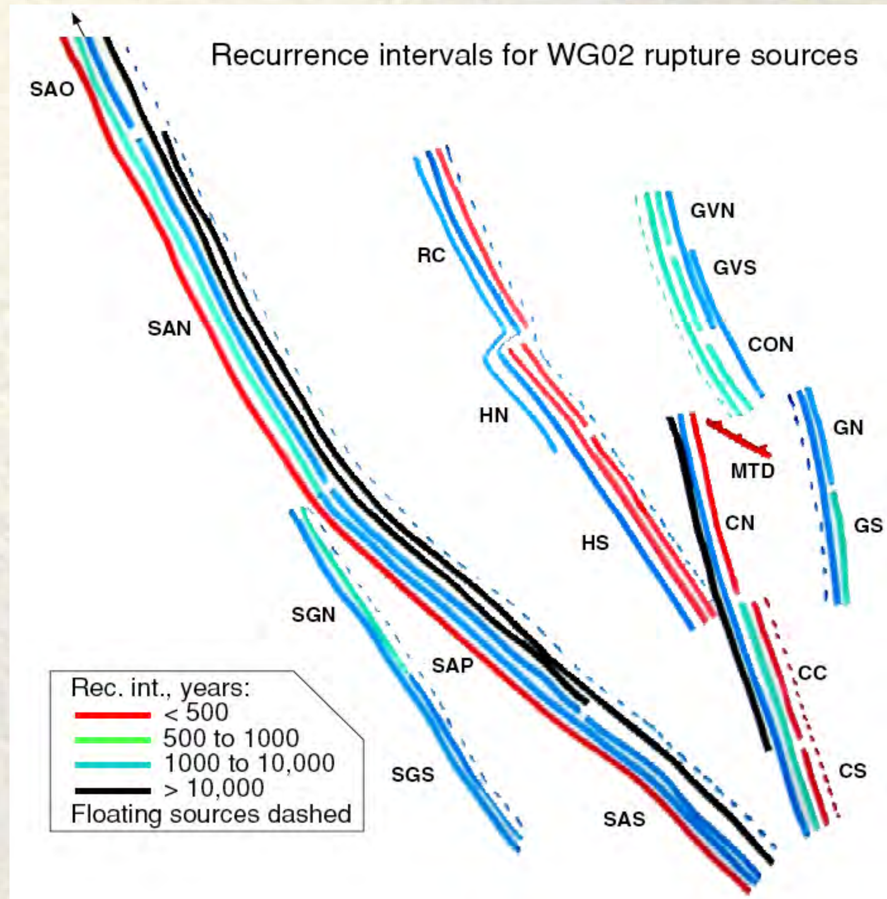


- "In contrast to the Poisson model, a time-dependent renewal process model embodies the expectation that after one earthquake on a fault segment, another earthquake on that segment is unlikely until sufficient time has elapsed for stress to gradually re-accumulate."
- Such

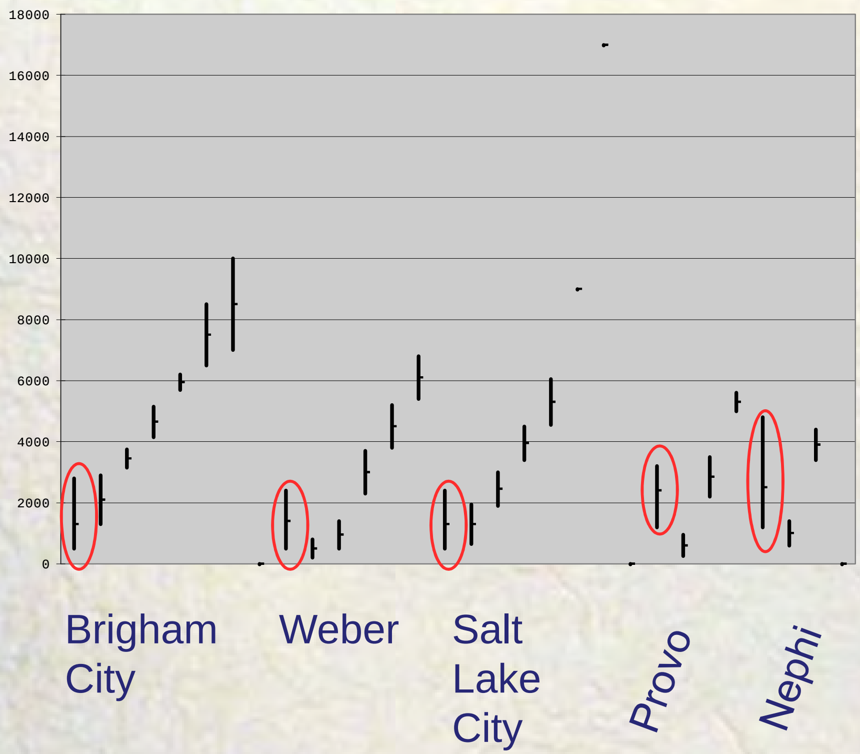
Results

Table ES.1. Probabilities of one or more $\mathbf{M} \geq 6.7$ earthquakes in the SFBR, 2002–2031.

Source fault	Probability	95% Confidence Bounds
SFBR region	0.62	[0.37 to 0.87]
San Andreas	0.21	[0.02 to 0.45]
Hayward/Rodgers Crk	0.27	[0.10 to 0.58]
Calaveras	0.11	[0.03 to 0.27]
Concord/Green Valley	0.04	[0.00 to 0.12]
San Gregorio	0.10	[0.02 to 0.29]
Greenville	0.03	[0.00 to 0.08]
Mt. Diablo thrust	0.03	[0.00 to 0.08]
Background	0.14	[0.07 to 0.37]



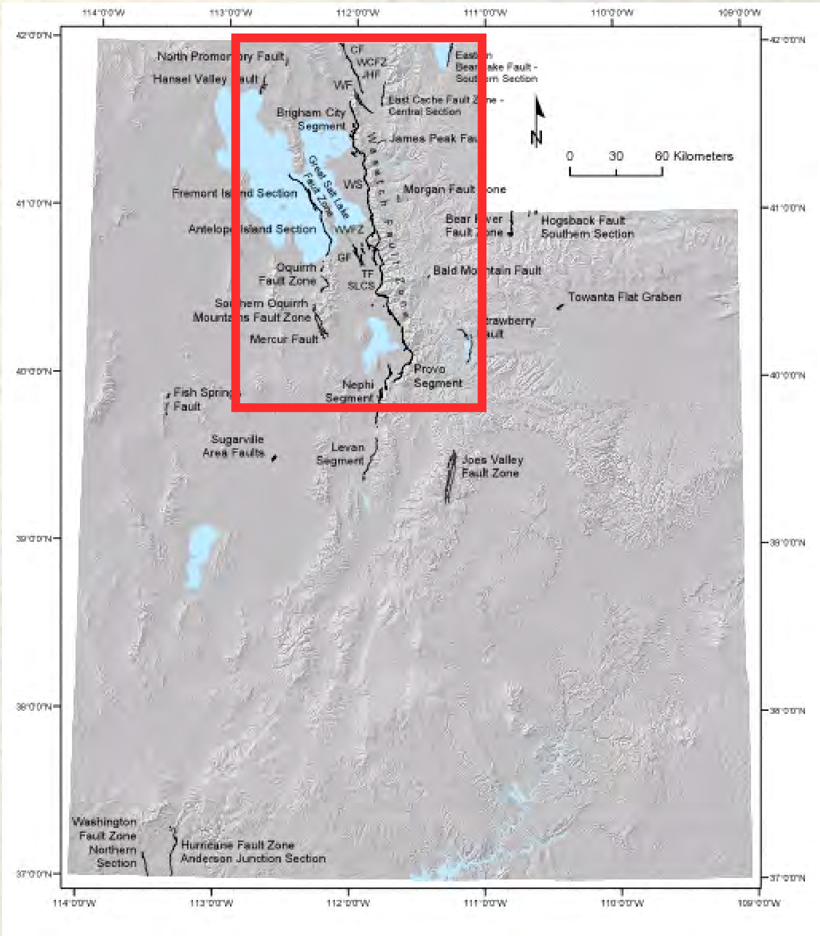
Wasatch fault



- Best-studied major fault in the Intermountain West
- Consensus fault parameters can contribute to a preliminary time-dependent model
- Recent studies refine mean recurrence and timing of last event

Lessons learned

- exercise caution in use of unvetted research results to form the basis of public-policy decisions
- the larger the spatial and temporal scale, the more reliable the results

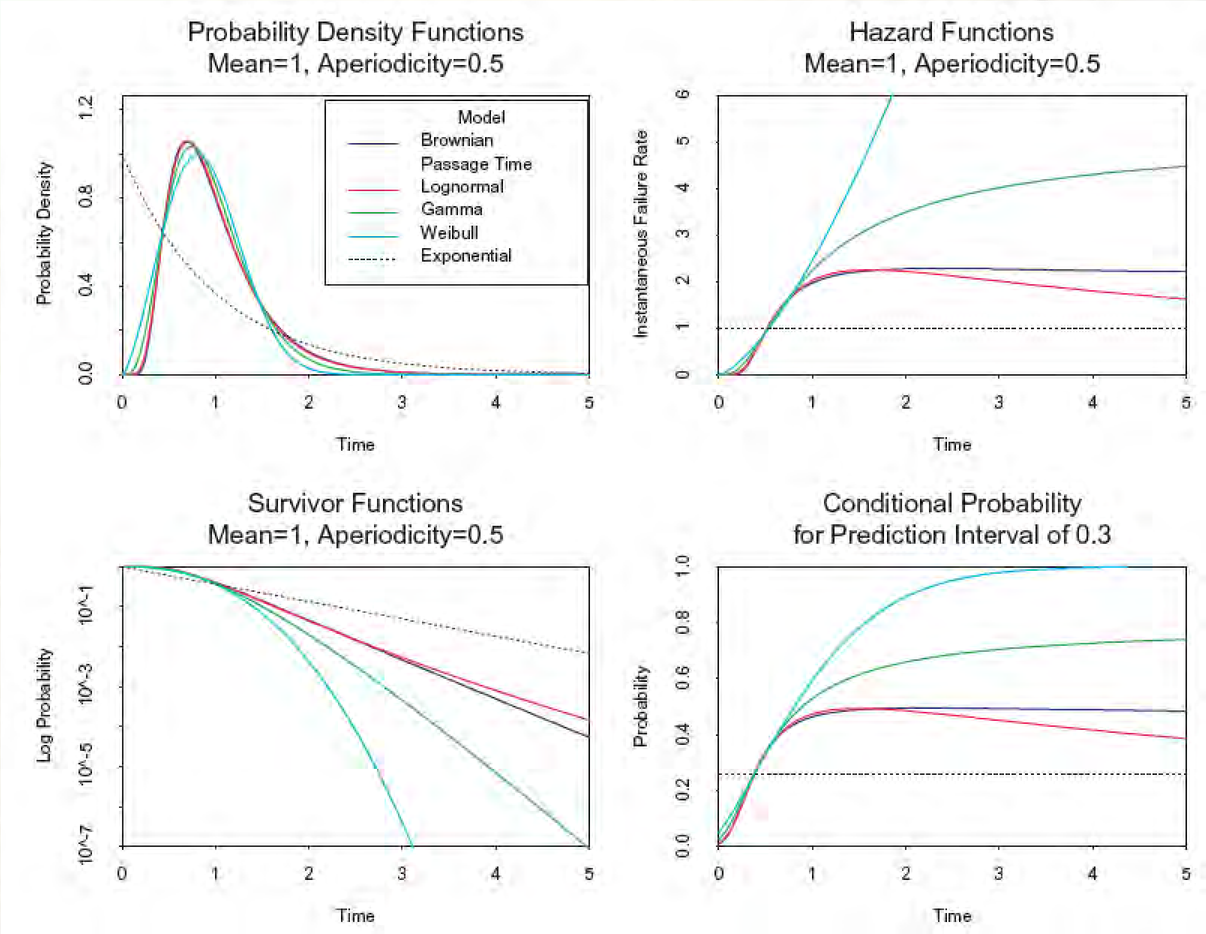


Future improvements

UGS PIS 40, 1996

- Improve M estimates
- Define rupture scenerios
- Obtain longer records
- Incorporate regional faults

Effect of aperiodicity on the behavior of BPT model



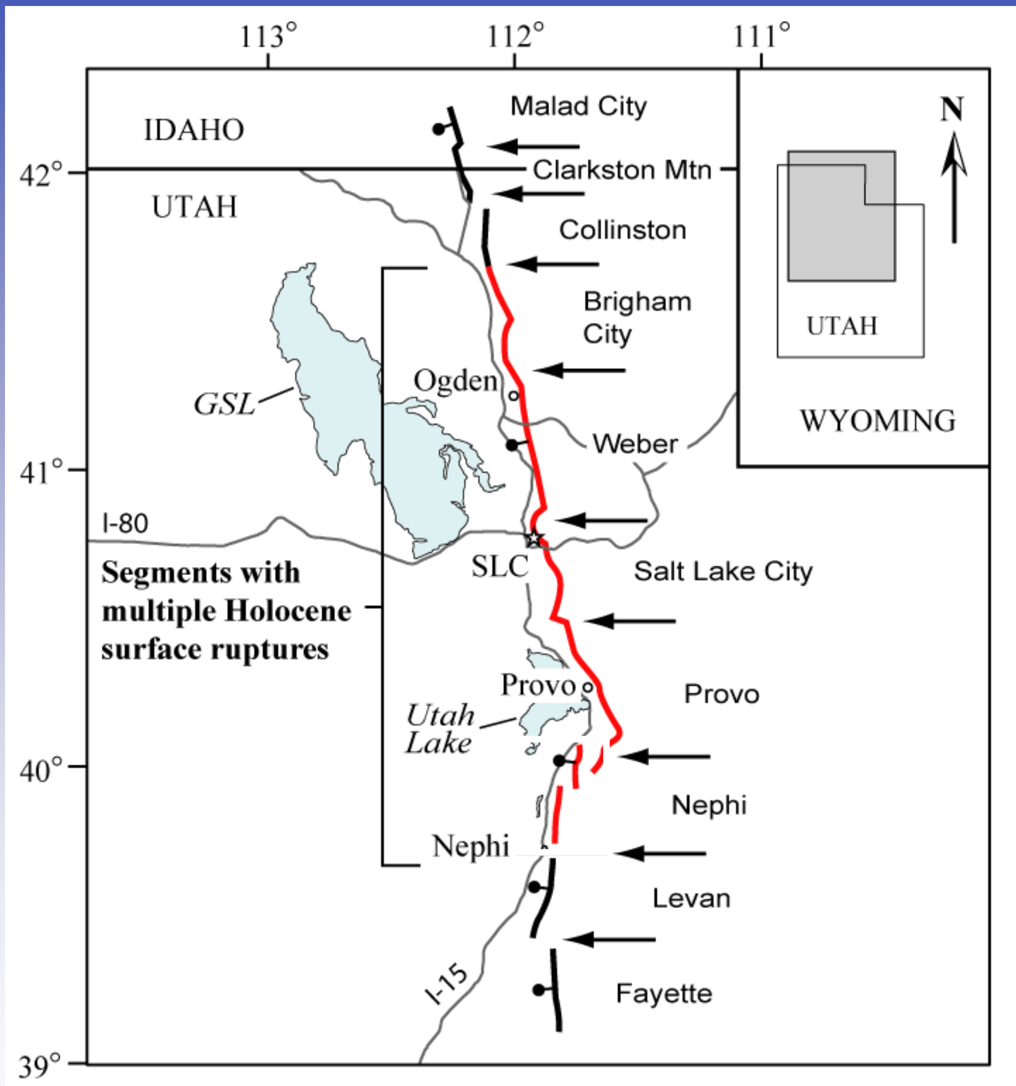
Time-Dependent Probabilistic Seismic Hazard Analyses for the Wasatch Fault: The Latest Twist

Susan Olig and Ivan Wong
Seismic Hazards Group
URS Corporation
1333 Broadway, Suite 800
Oakland, CA 94612

February 13, 2008

URS

Wasatch Fault Zone



After Machette et al., 1992

- **Longer paleoseismic records on:**
  - **Salt Lake City Segment**
  - **Brigham City Segment**
  - **Provo Segment**

Time-Dependent Model of Working Group on California Earthquake Probabilities

- Lognormal renewal model
- Time period of interest - 50 years
- Calculated equivalent Poisson recurrence intervals (or Time-dependent recurrence intervals) to use in PSHA

Input Needed to Calculate Time-Dependent Recurrence Intervals

- **Mean Recurrence (From UQFPWG)**
- **Elapsed Time (FROM UQFPWG)**
- **Coefficient of Variation (or aperiodicity)**

Coefficient of Variation (COV)

- **Important factor that measures the periodicity of earthquake occurrence**
- **COV** $= \dfrac{\sigma}{\mu}$
- **Small COV (< 0.3) → very periodic behavior (recurrence intervals are relatively consistent)**

versus

Large COV (> 1.0) → not periodic behavior (recurrence intervals vary considerably)

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COV Analysis

- Used a Monte Carlo simulation
- Conducted 1,000 simulations
- Used paleoearthquake ages (with 2 σ) from UQFPWG and Olig et al. (2006) that defined 15 seismic cycles on 4 segments
- COV = 0.42 (compared to 0.27 with no uncertainty in event ages)

Input and Resulting Time-Dependent Recurrence Intervals for the Brigham City Segment, Wasatch Fault Zone

	Preferred (weighted 0.6)	Maximum (weighted 0.2)	Minimum (weighted 0.2)
Elapsed time (yrs)[1]	2100	2100	2100
Mean recurrence (yrs)[1]	**1300**	**2800**	**500**
COV[2]	0.4	0.7	0.3
Time-dependent (or equivalent-Poisson) recurrence interval (yrs)	**430**	**1850**	**120**

1 From UQFPWG (Lund, 2005)

2 Range from WGCEP (1999) but the preferred value is based on a COV of 0.42 calculated for this study using Wasatch fault data.

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Input and Resulting Time-Dependent Recurrence Intervals for the Provo Segment, Wasatch Fault Zone

	Preferred (weighted 0.6)	Maximum (weighted 0.2)	Minimum (weighted 0.2)
Elapsed time (yrs)[1]	550	550	550
Mean recurrence (yrs)[1]	**1450**	**2800**	**500**
COV[2]	0.4	0.7	0.3
Time-dependent (or equivalent-Poisson) recurrence interval (yrs)	**5080**	**10,160**	**140**

[1] From Olig et al. (2006).

[2] Range from WGCEP (1999) but the preferred value is based on a COV of 0.42 calculated for this study using Wasatch fault data.

Input and Resulting Time-Dependent Recurrence Intervals for the Salt Lake City Segment, Wasatch Fault Zone

	Preferred (weighted 0.6)	Maximum (weighted 0.2)	Minimum (weighted 0.2)
Elapsed time (yrs)[1]	1300	1300	1300
Mean recurrence (yrs)[1]	**1300**	**2400**	**500**
COV[2]	0.4	0.7	0.3
Time-dependent (or equivalent-Poisson) recurrence interval (yrs)	**560**	**1880**	**110**

1 From Lund (2005)

2 Range from WGCEP (1999) but the preferred value is based on a COV of 0.42 calculated for this study using Wasatch fault data.

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Recurrence Comparison

Fault Segment	Weighted Mean Recurrence Intervals (yrs)		
	Time-Dependent	Poisson	Hazard Implications
Brigham City	**660**	1,440	↑
Salt Lake City	**730**	1,360	↑
Provo	**5,120**	1,530	↓

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UTAH GEOLOGICAL SURVEY

2009 RESEARCH PRIORITIES

2008 FAULT PRIORITY LIST

Priority A – First Priority (listed alphabetically; *added in 2007)

- Brigham City segment, Wasatch fault zone – timing of most recent event*
- Carrington fault (Great Salt Lake)*
- Provo segment, Wasatch fault zone – timing of penultimate event*
- Rozelle section, northern Great Salt Lake fault*
- Utah Lake faults and folds
- West Valley fault zone

Priority B – Second Priority (listed alphabetically)

- Bear River fault zone*
- Cedar City-Parowan monocline/Paragonah fault
- Clarkston fault
- Eastern Bear Lake fault
- Enoch graben
- Faults beneath Bear Lake
- Gunnison fault
- Hurricane fault zone (Cedar City section)
- Levan segment, Wasatch fault zone – trench
- Scipio Valley faults
- Wasatch Range back-valley faults

Priority C (study in progress; need for further investigation to be determined)

- East Cache fault, southern section
- Nephi segment, Wasatch fault zone
- Promontory section, Great Salt Lake fault zone
- Sevier/Toroweap fault
- Washington fault
- Weber segment, Wasatch fault zone

*Added at 2007 UQFPWG meeting

Fault/Fault Section	UQFPWG Priority	Investigation Status	Investigating Institution
Nephi segment WFZ[1,2]	1	In press (Special Study 124)	UGS/USGS/UVSC
West Valley fault zone	2	No activity	
Weber segment WFZ[1]	3	On going	UGS/USGS
Weber segment WFZ – multiple event[1]	4	On going	UGS/USGS
Utah Lake faults and folds[3]	5	No activity	
Great Salt Lake fault zone[1]	6	On going	U of U
Collinston & Clarkston Mountain segments WFZ[1]	7	Special Study 121	UGS
Sevier/Toroweap fault[1]	8	Special Study 122	UGS
Washington fault	9	On going	UGS
Cedar City-Parowan monocline/ Paragonah fault	10	No activity	
Enoch graben	11	No activity	
East Cache fault zone[1]	12	On going	USU
Clarkston fault	13	No activity	
Wasatch Range back-valley faults	14	No activity	
Hurricane fault[1]	15	Special Study 119	UGS
Levan segment WFZ[1]	16	In press (Map 231)	UGS
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Bear River fault zone	Added 2007	No activity	
Brigham City segment WFZ, most recent event[1]	Added 2007	Study to begin summer 2008	UGS/USGS
Carrington fault (Great Salt Lake)	Added 2007	No activity	
Provo segment WFZ – penultimate event	Added 2007	No activity	
Rozelle section, Great Salt Lake fault	Added 2007	No activity	

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

2005

- The West Valley fault zone has high relevance to seismic hazards in the Salt Lake Valley and its relation to the Salt Lake City segment of the WF needs to be determined.
- Utah's Quaternary faults should be classified (A through D) in a manner similar to the faults included on the USGS Quaternary Faults and Folds Database of the United States.
- Studies should be performed to resolve the seismogenic vs. nonseismogenic nature of certain Utah faults.

2006

- Look for trench sites between the Kaysville and South Fork Dry Creek sites on the Weber-Salt Lake City segments.
- Perform a reconnaissance of lesser known Utah faults outside the Wasatch Front that may be important to the NSHMs.
- Make a comprehensive review of new geologic literature, and if necessary conduct aerial photograph analysis and field reconnaissance studies, to ensure that all major Utah Quaternary faults have been identified.

BRPEWG RESEARCH RECOMMENDATIONS

- Compile long-term paleoseismic records for BRP faults and determine VSR and RI distributions, timing, and possible causes for clustering. Identify and trench faults that have the potential to produce long-term paleoseismic records (regardless of proximity to urban areas) to improve databases and provide insight into time-dependent fault behavior and modeling.

- Investigate how to recognize and characterize fault–rupture segments, and the quality and quantity of paleoseismic data needed to support earthquake-segmentation models along BRP faults.

- Construct earthquake-segmentation models for important, presently unsegmented BRP faults (based chiefly on field mapping and ultimately trenching).

- Compare SRL and displacement data for Utah faults where both are available to identify discrepancies among magnitude regressions.