UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP

Wednesday, February 28, 2007

WELCOME

UQFPWG HISTORY

- Expert panel convened to evaluated the 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 presently 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 four 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 when necessary.

- Provides advice/insight regarding technical issues related to fault behavior in Utah/BRP.

- Identifies and prioritizes future Utah Quaternary fault studies – NEHRP or otherwise.

2006 MEETING REVIEW

Presentations on work completed/in progress

- Latest Provo segment megatrench results
- Collinston & Clarkston Mountain segments paleoseismic reconnaissance
- Nephi segment trenching study
- Northern Weber segment paleoseismic study
- Corner Canyon fault trenching study
- Robert Smith discussion items
- BRPEWG update

Discussion items

- Updating the UQFPWG consensus slip-rate and recurrence-interval database
- Wasatch fault multi-segment rupture model
- Should additional Utah faults be included on NSHMs?

2006 UQFPWG
RESEARCH RECOMMENDATIONS

Priority Faults for Additional Study

- West Valley fault zone
- Weber segment – MRE
- Weber segment – multi-event
- Faults and folds beneath Utah Lake
- Washington fault
- East Cache fault zone

Additional Recommendations

- Expand the DuRoss draft Wasatch fault multi-segment rupture model to: (a) incorporate the methodology of Weldon and others (2005), and (b) moment balance the model.
- The UGS should make a recommendation to the USGS regarding which, if any, additional Utah Quaternary faults should be included on the 2007 update of the NSHMs.

A FEW WORDS ABOUT THE BASIN AND RANGE PROVINCE EARTHQUAKE WORKING GROUP

- WSSPC recommended convening a technical Basin and Range Province Earthquake Working Group (BRPEWG) to develop scientific consensus regarding fault behavior, ground-shaking and ground-failure modeling, and research priorities relevant to seismic policy and the USGS National Seismic Hazards Maps in the Basin and Range Province.

- The BRPEWG was convened in March, 2006, under the auspices of WSSPC, the UGS, and the USGS NSHM project; BRPEWG presented its recommendations to the USGS in June, 2006.

BRPEWG GOALS

- Bring together subject-matter experts from around the Basin and Range Province to discuss evidence, evaluate issues, and define strategies for resolving those issues.
- Establish consensus on issues wherever possible to advise the USGS regarding the next (2007) update of the NSHMs.
- Where consensus is not possible, outline research programs to resolve outstanding technical issues that the USGS can use when setting research priorities.

SEISMIC-POLICY ISSUES CONSIDERED BY BRPEWG

1. Use and relative weighting of time-dependent, Poisson, and clustering models to characterize BRP fault behavior.
2. Proper magnitude-frequency distributions (Gutenberg-Richter vs. characteristic earthquake models) for BRP faults.
3. **Use of length vs. displacement relations to estimate earthquake magnitudes.**
4. **Probabilities and magnitudes of multi-segment ruptures on BRP faults.**
5. Resolving discrepancies between horizontal geodetic extension rates and vertical geologic slip rates.

2007 UQFPWG MEETING

Meeting format

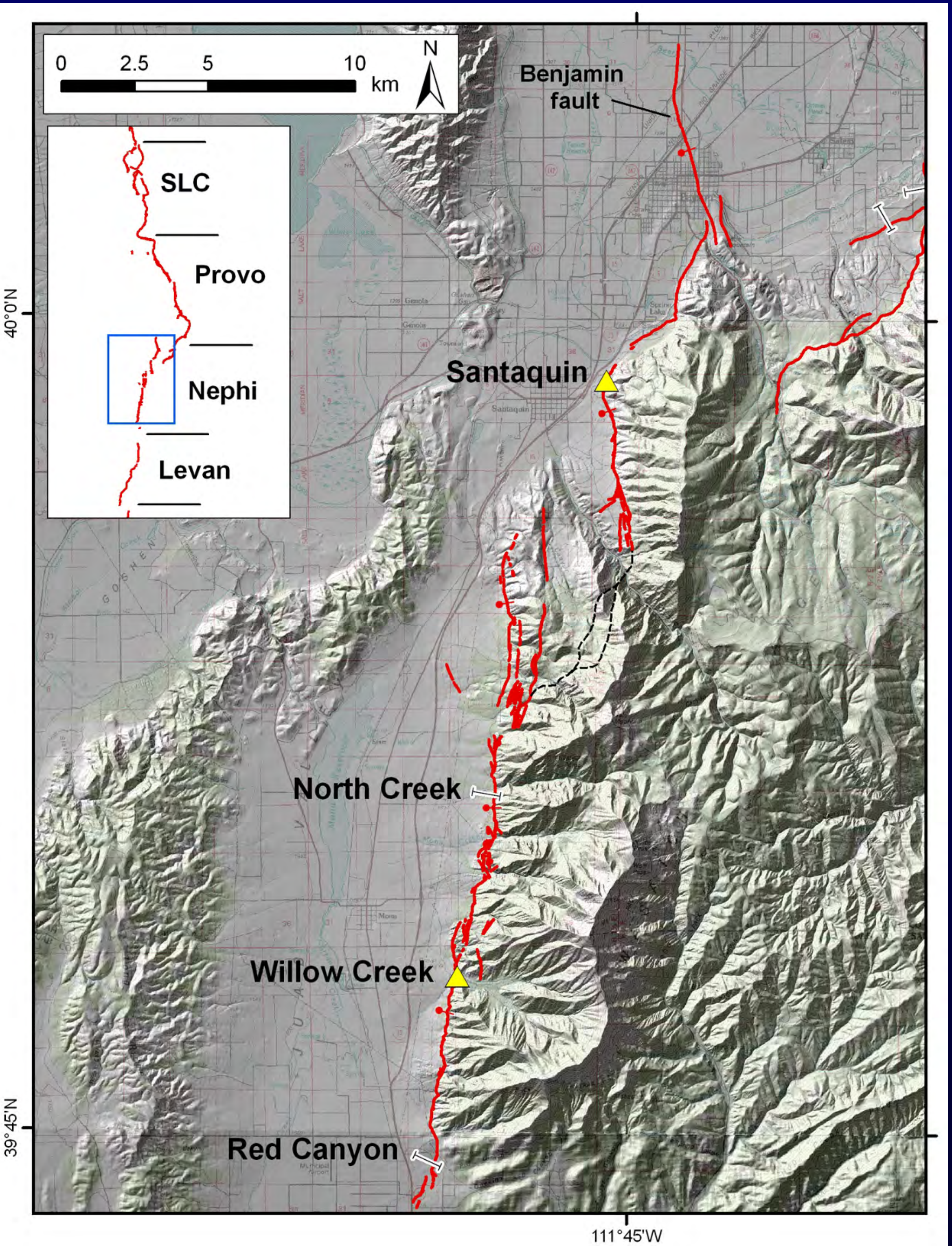
1. Technical presentations – 8:15 to Noon
2. Lunch – working if necessary
3. Technical discussion items – 1:00 to 2:00
4. 2007 fault study priorities – 2:00 to 2:45
5. Possible projects that address NEHRP and/or BRPEWG research priorities – 3:00 to 4:30

RESULTS OF NEPHI SEGMENT TRENCHING AT SANTAQUIN

C.B. DuRoss, G.N. McDonald, and W.R. Lund

Santaquin trench review - Fall 2005

UTAH DNR GEOLOGICAL SURVEY

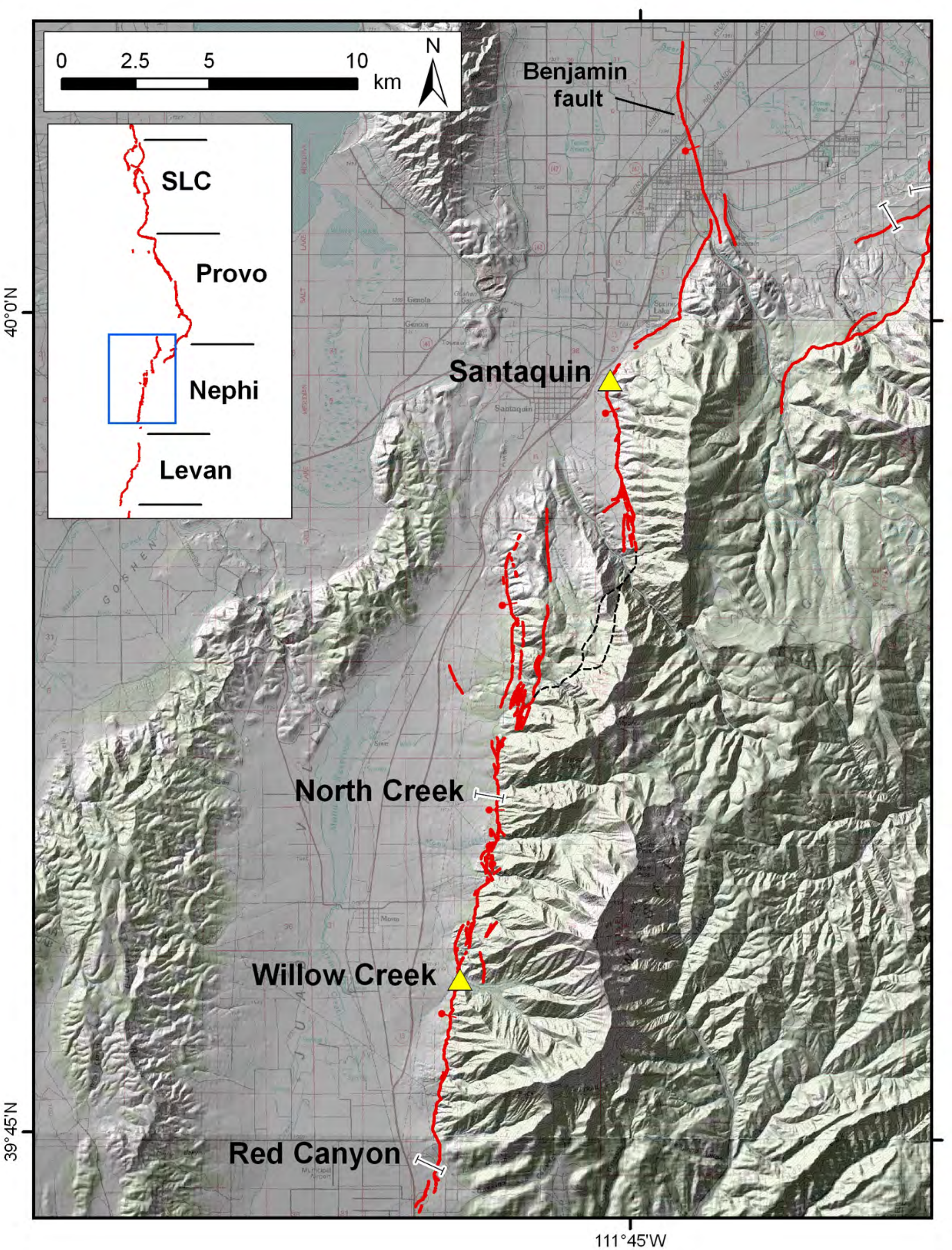


NEPHI SEGMENT

Two new trench sites:

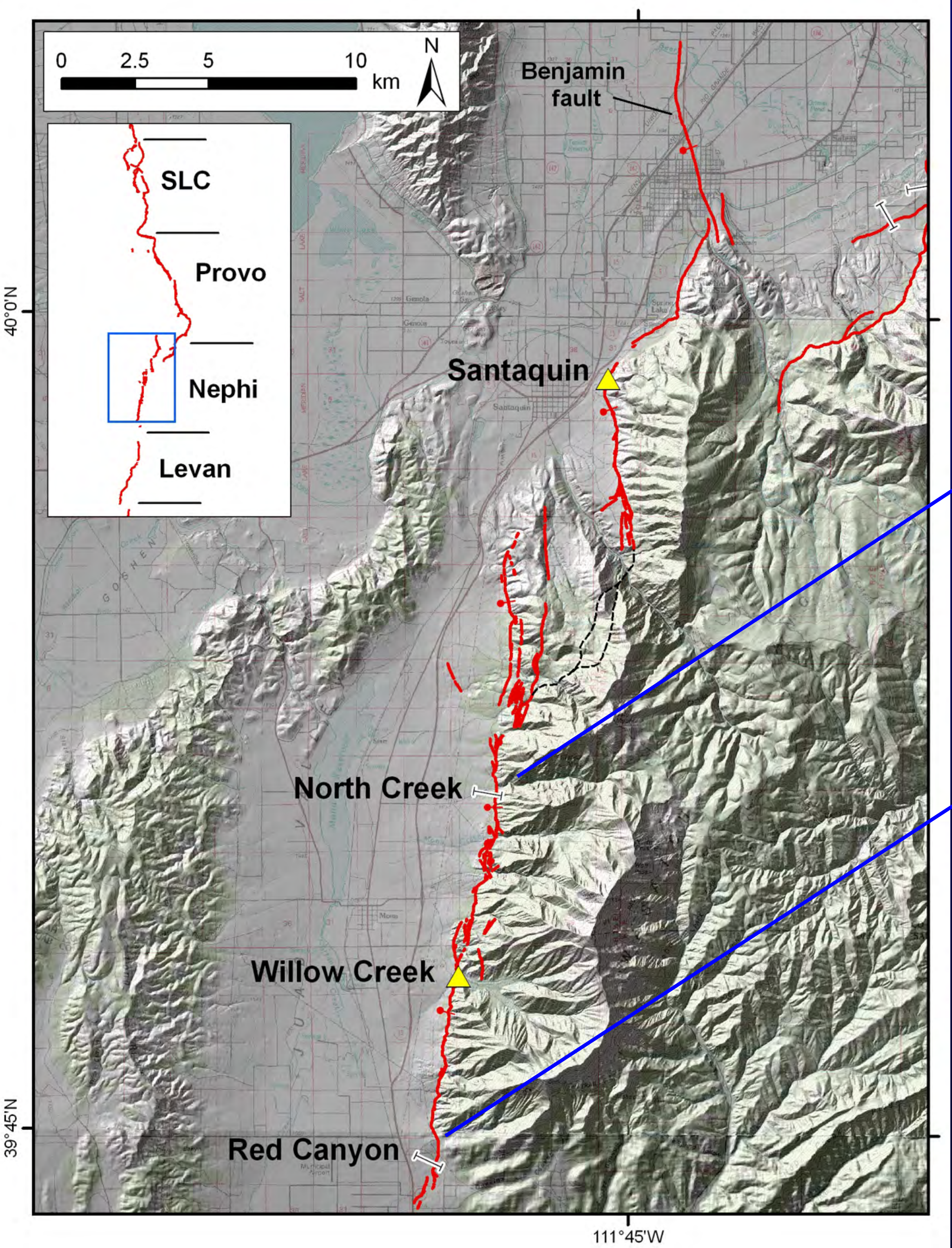
UGS – Santaquin

USGS – Willow Creek



Why trench Nephi segment?

1. **Holocene earthquake chronology - poorly constrained**



Why trench Nephi segment?

Existing sites:

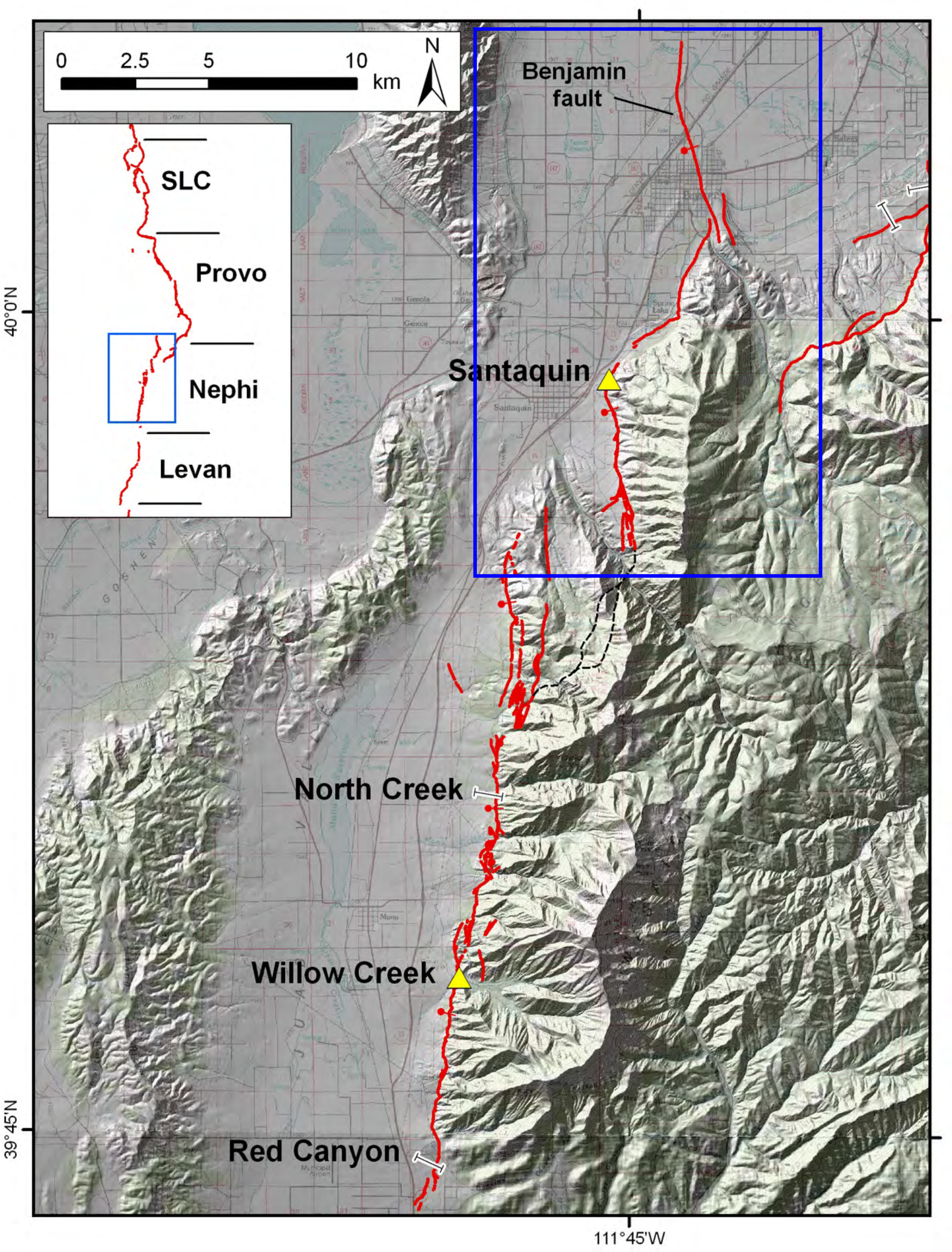
North Creek

- ***MRE*** >300-400, <800-1600
- ***PE*** >1300-1400(4), >3700-4100(3)
- ***APE*** <4500-5200

Red Canyon

- ***MRE*** <1300-1500
- ***PE*** <1100-1700(2), <3800-7000(2)
- ***APE*** >3600

(cal yr B.P.)



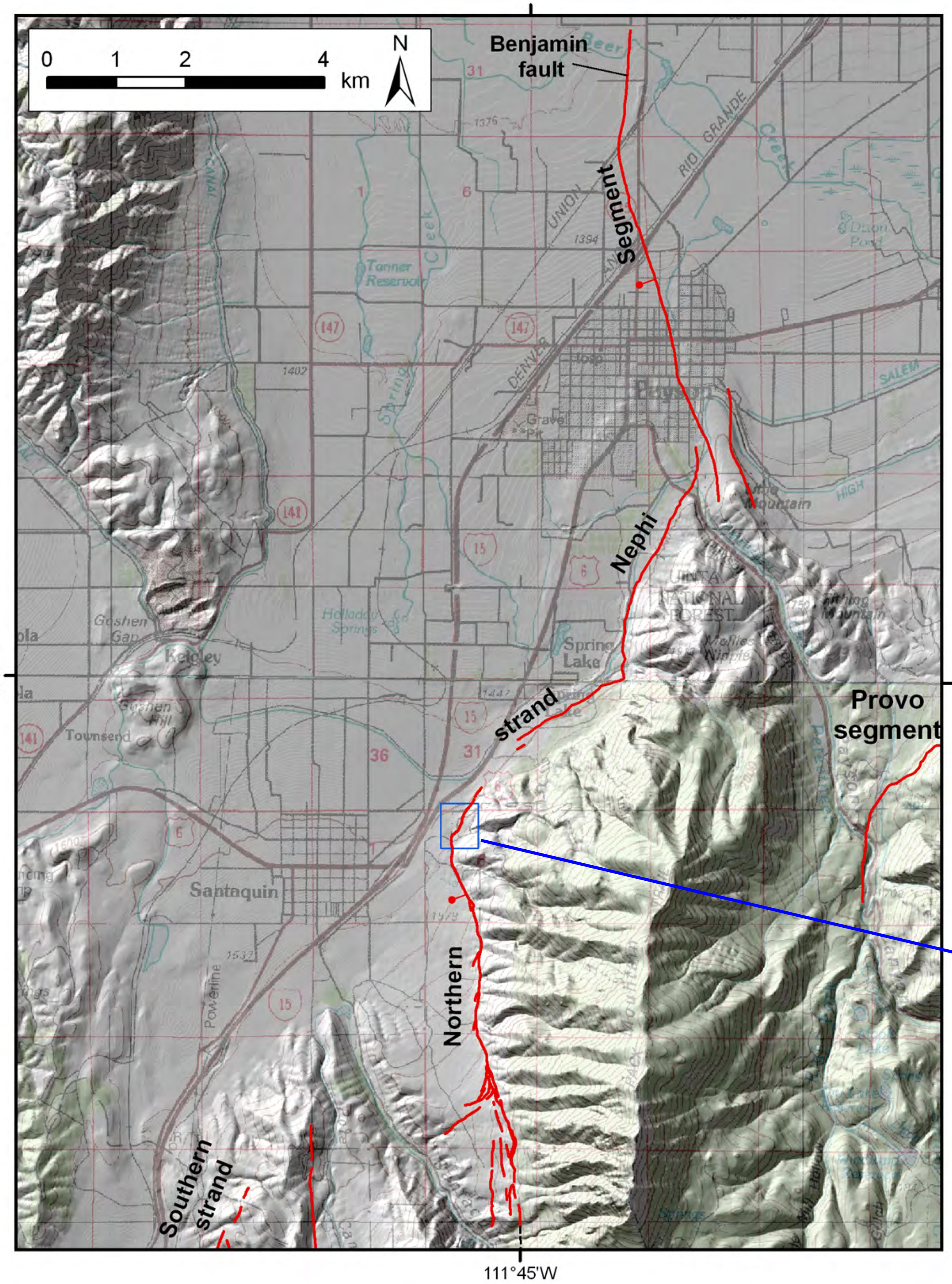
Why trench Nephi segment?

2. **Northern strand:**

   Holocene surface-faulting, <u>no paleoseismic data</u>

Why trench Nephi segment?

Holocene fault scarps along Northern strand, near Santaquin (view to SE)



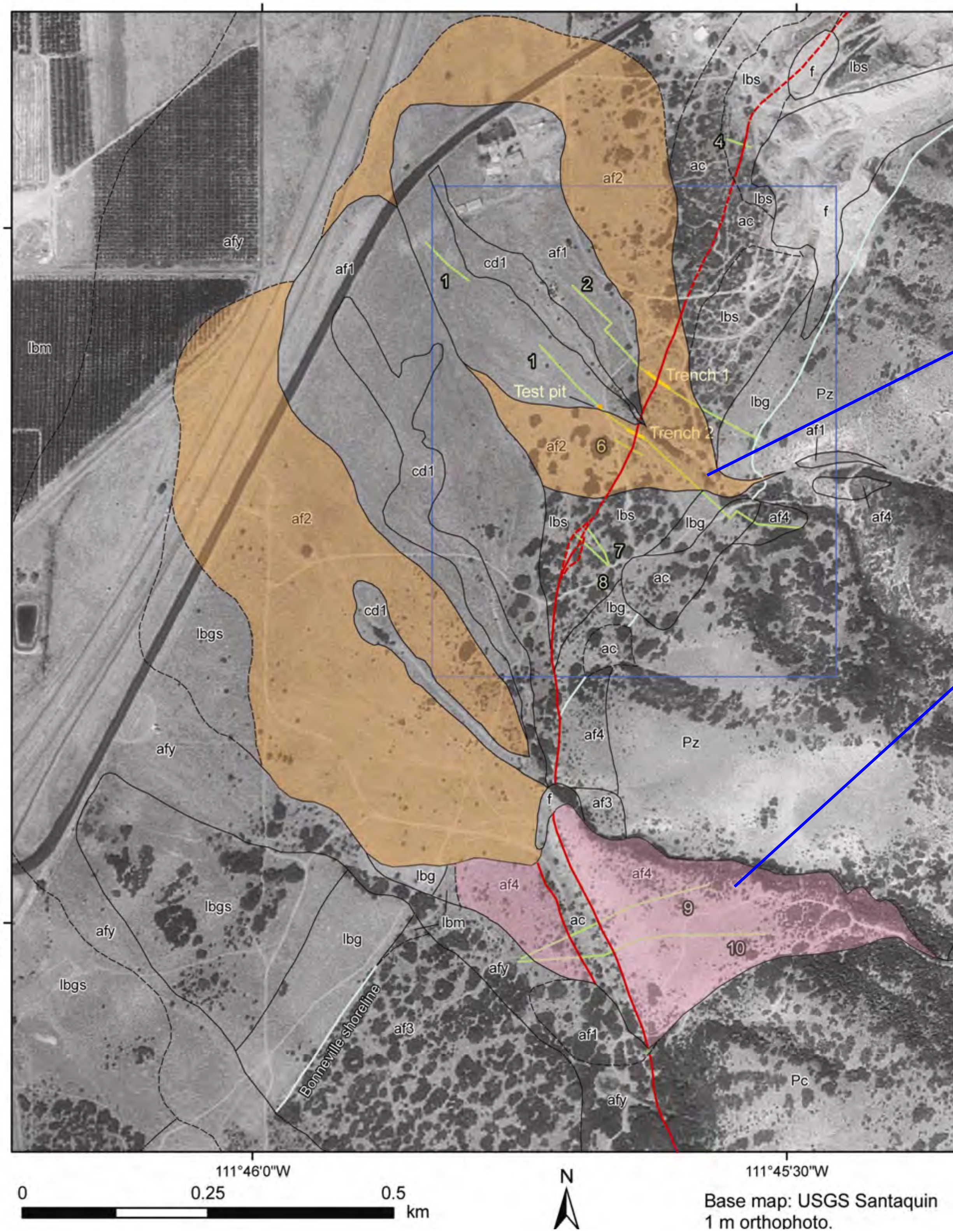
Why trench Nephi segment?

3. **Segmentation issues:**

- Entire segment rupture?
- Relation to Provo segment?

SANTAQUIN TRENCH SITE

SURFICIAL GEOLOGY

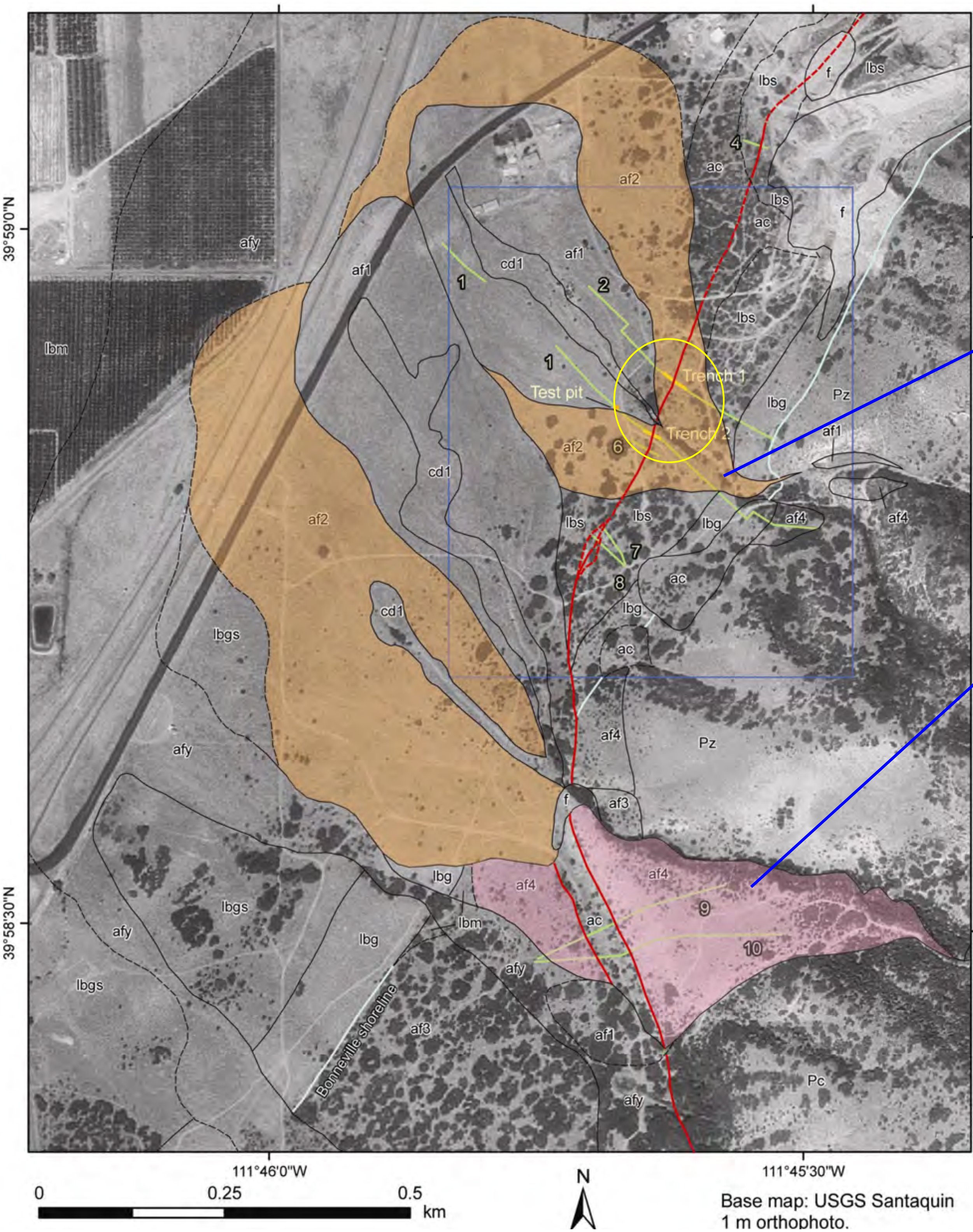


Post-Bonneville

Surface offset:
2.2-3.3 m

Pre-Bonneville

Surface offset:
16-22 m



SURFICIAL GEOLOGY

Post-Bonneville

Surface offset:
2.2-3.3 m

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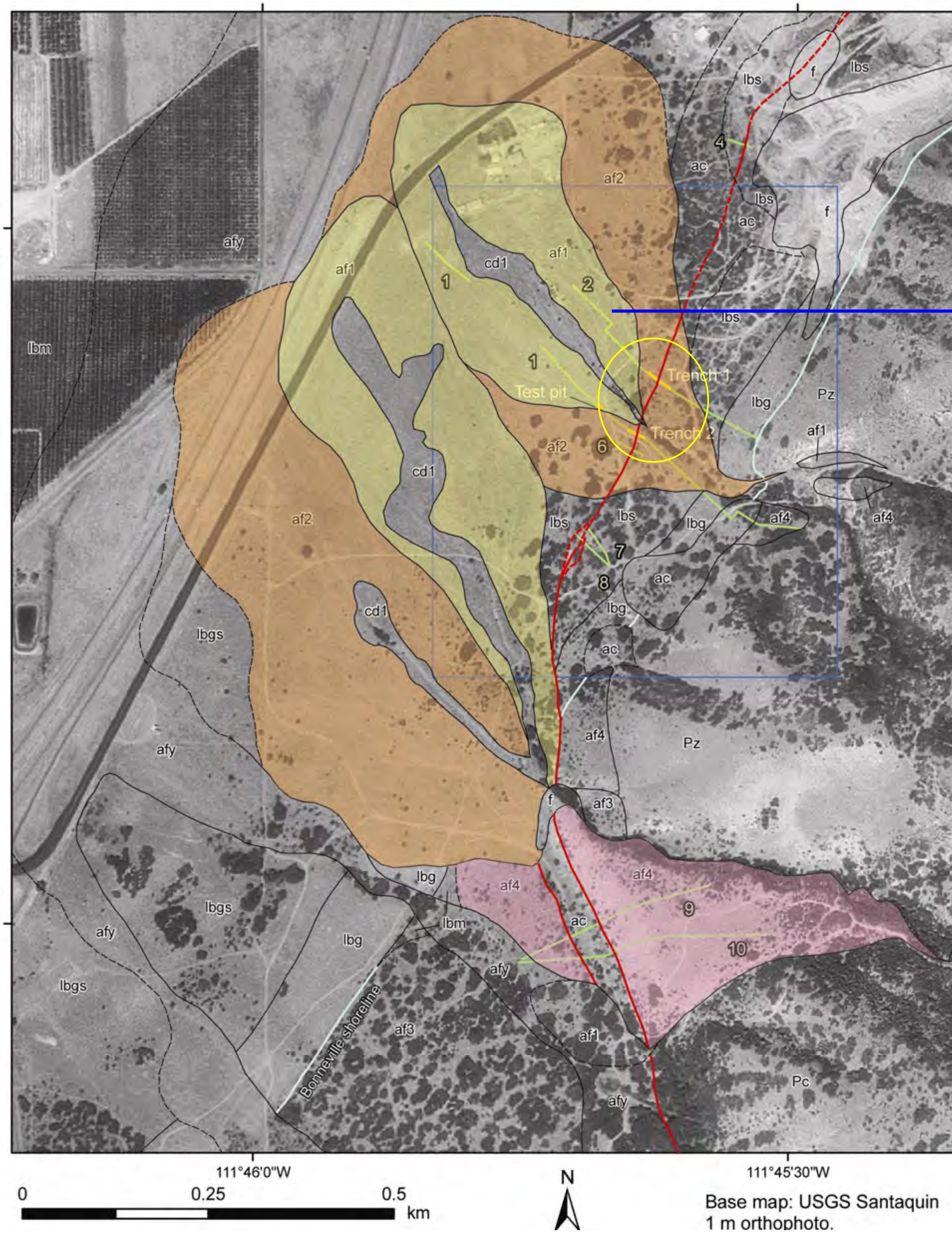
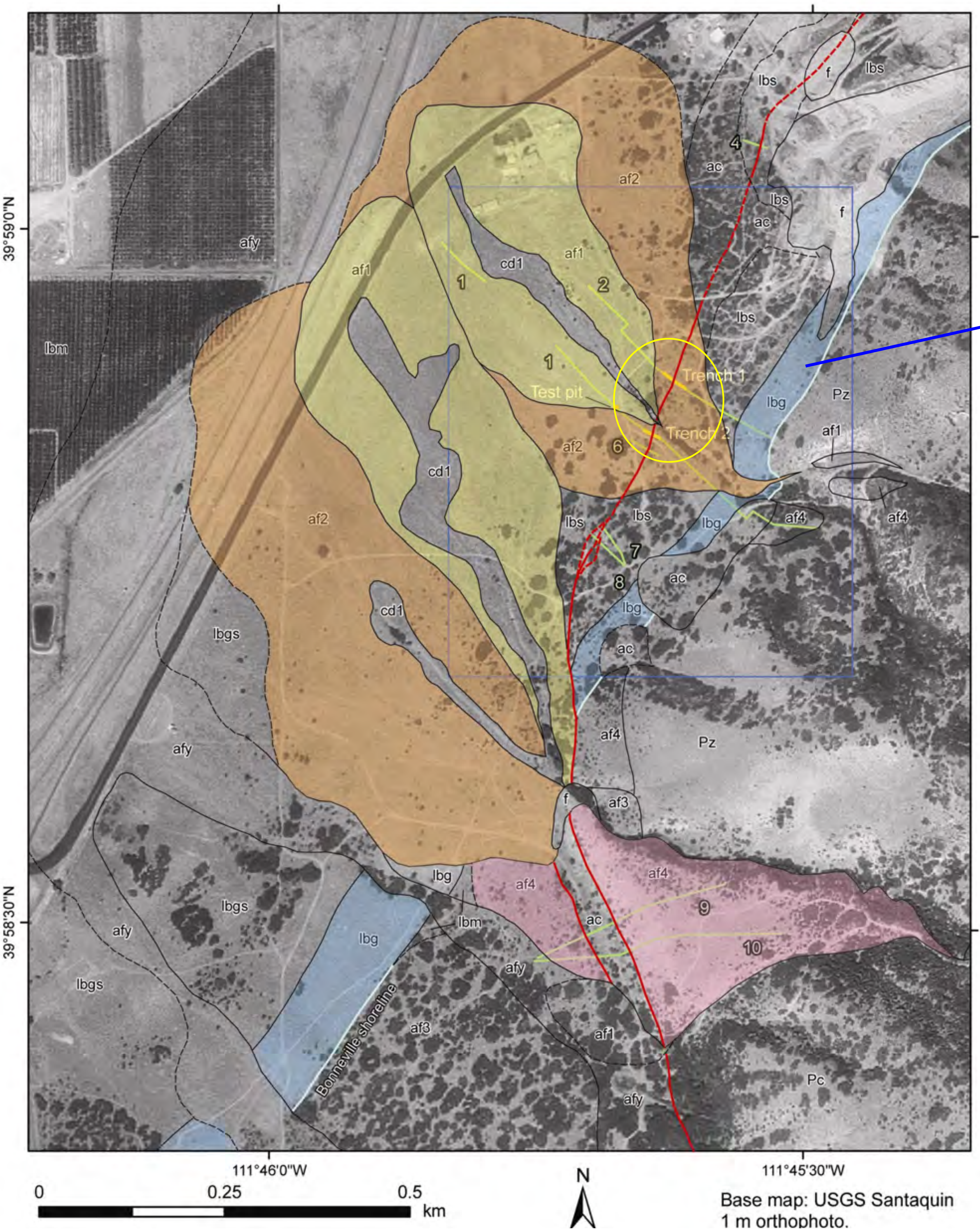


SURFICIAL GEOLOGY

Post-Bonneville (late Holocene):

Not displaced



SURFICIAL GEOLOGY

Bonneville shoreline:

Elevation difference across fault (~surface offset): 9 m


SANTAQUIN TRENCH SITE
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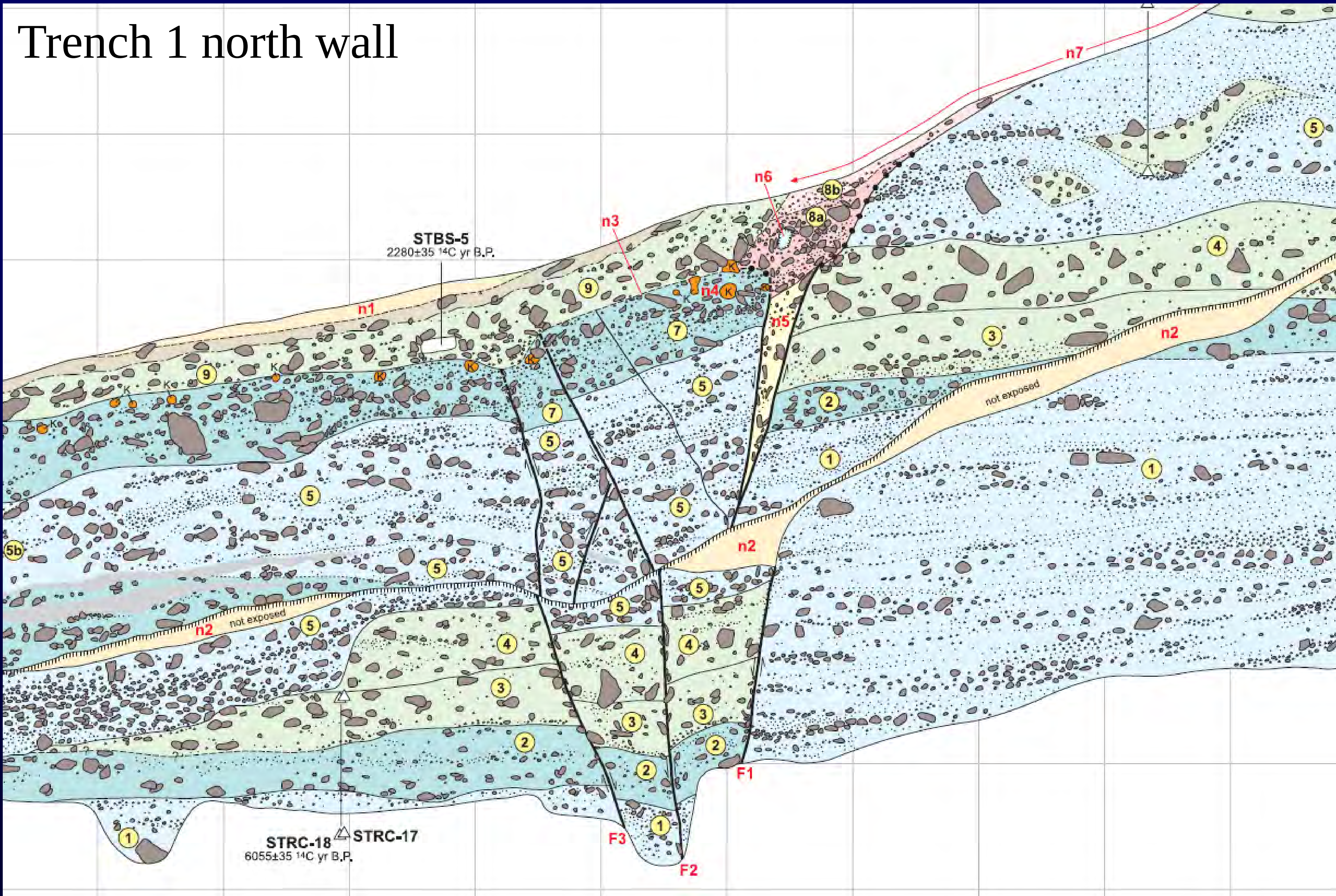
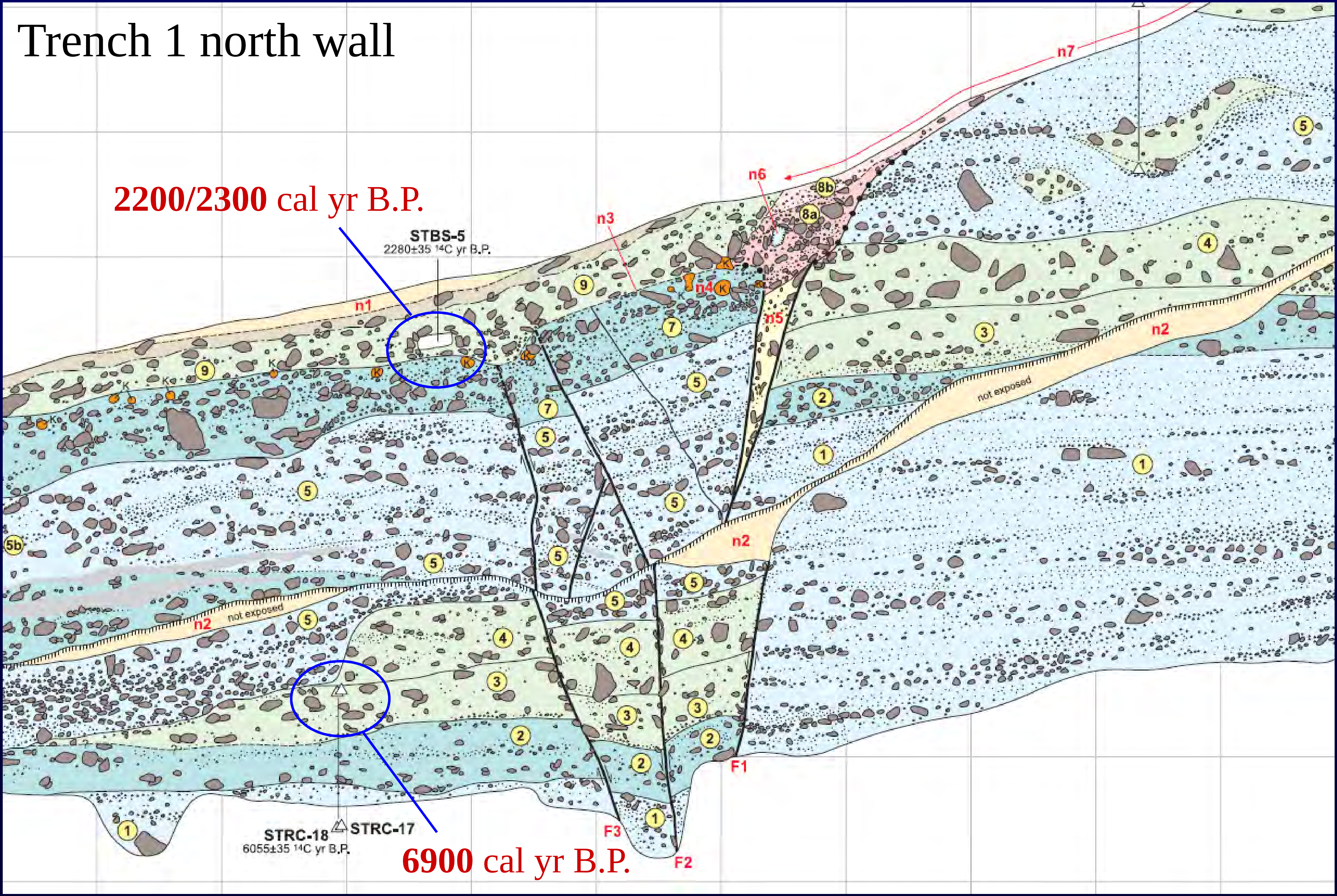
SANTAQUIN TRENCH SITE


PALEOSEISMIC INVESTIGATION

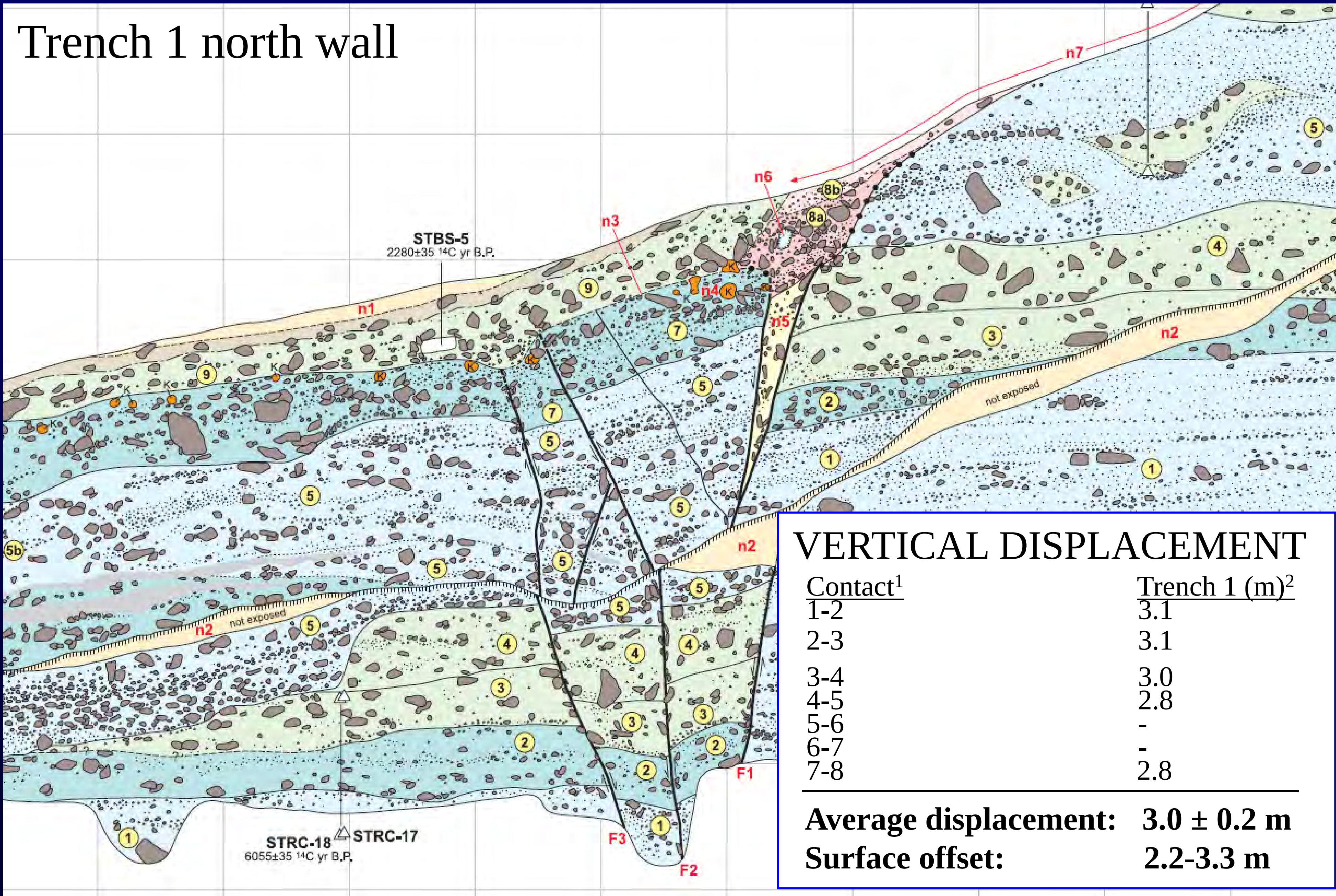
Trench 1 north wall



Trench 1 north wall



Trench 1 north wall



VERTICAL DISPLACEMENT

Contact[1]	Trench 1 (m)[2]
1-2	3.1
2-3	3.1
3-4	3.0
4-5	2.8
5-6	-
6-7	-
7-8	2.8

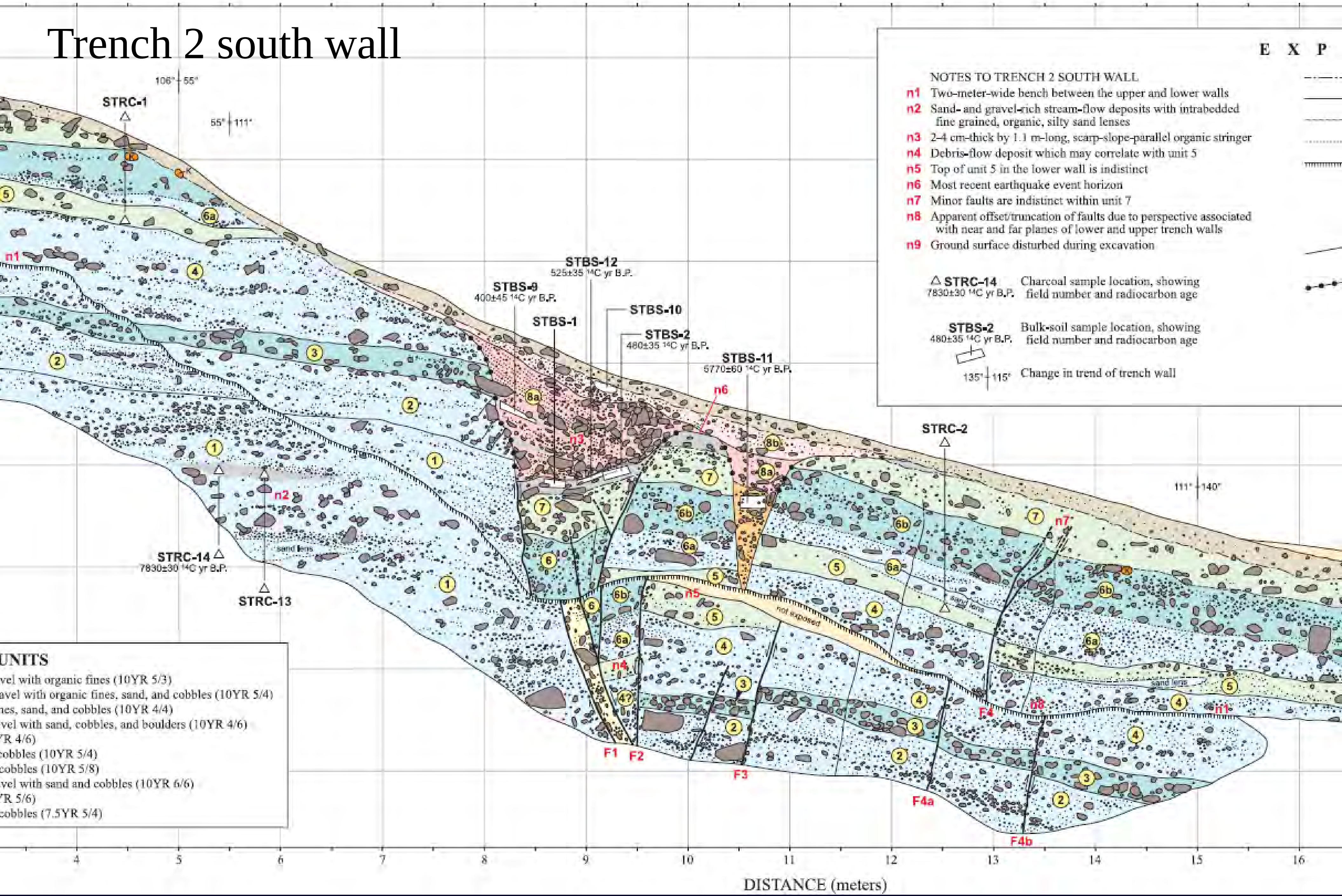
Average displacement: 3.0 ± 0.2 m

Surface offset: 2.2-3.3 m

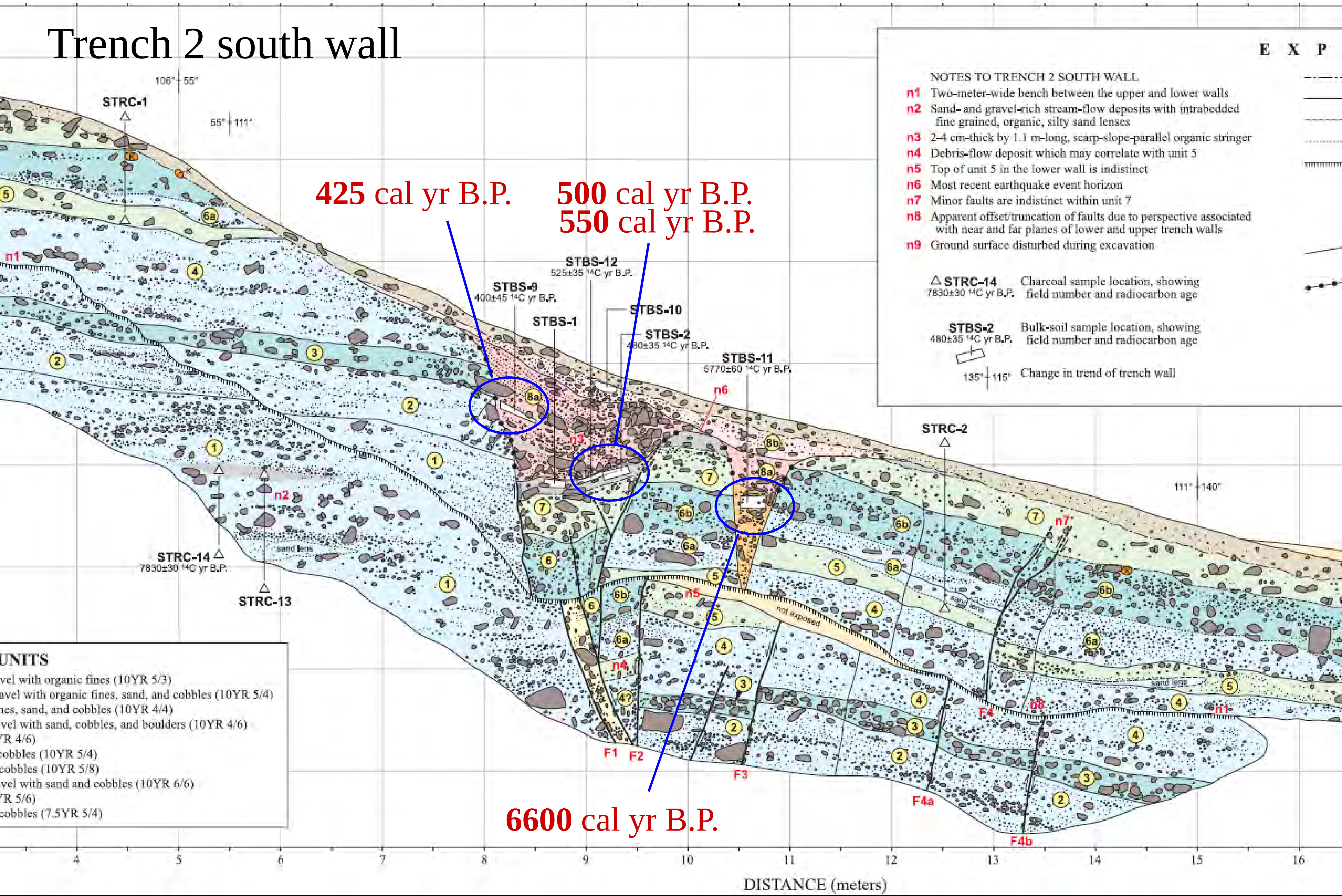
Trench 1 north wall

Trench 1
south wall

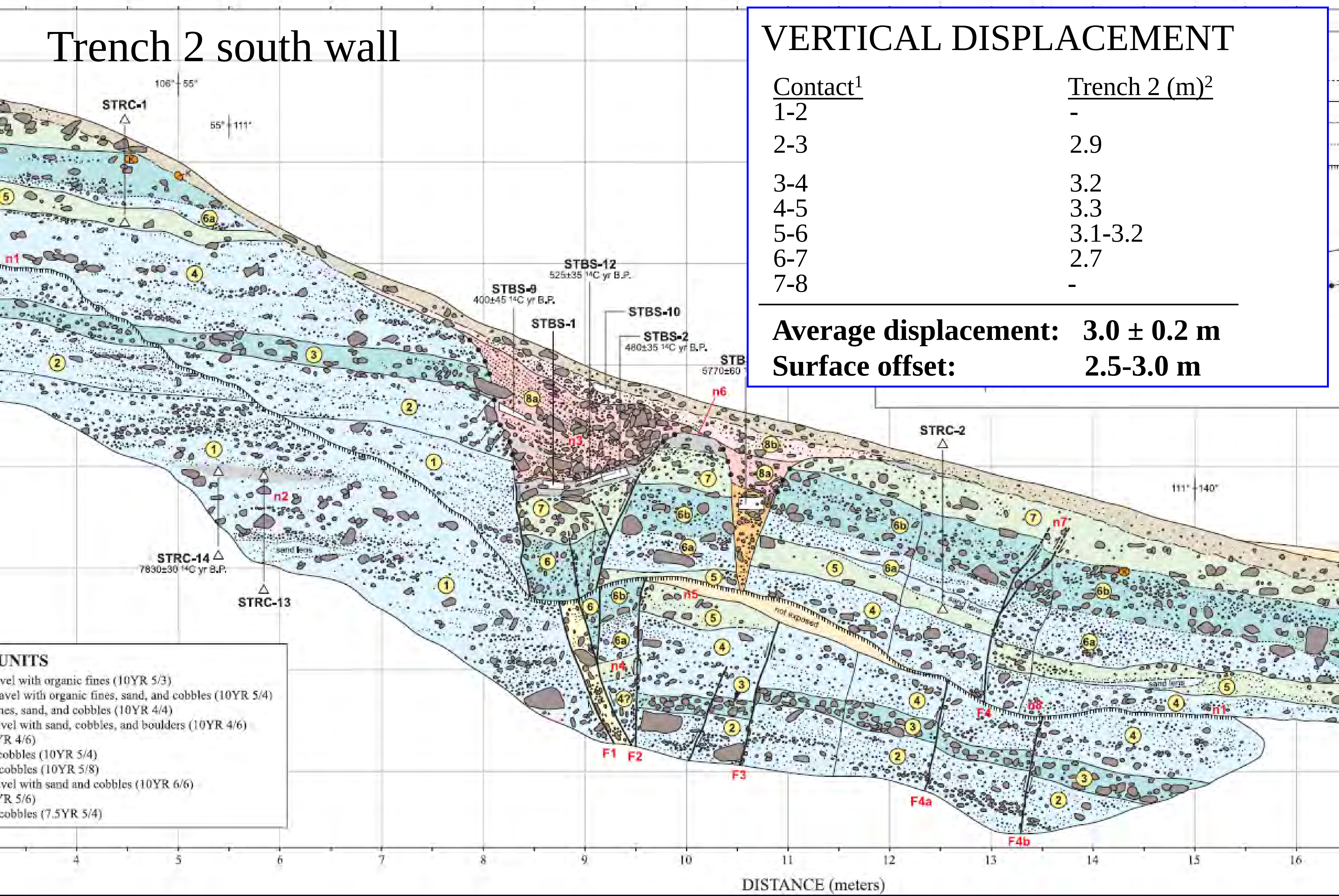
Trench 2 south wall



Trench 2 south wall



Trench 2 south wall



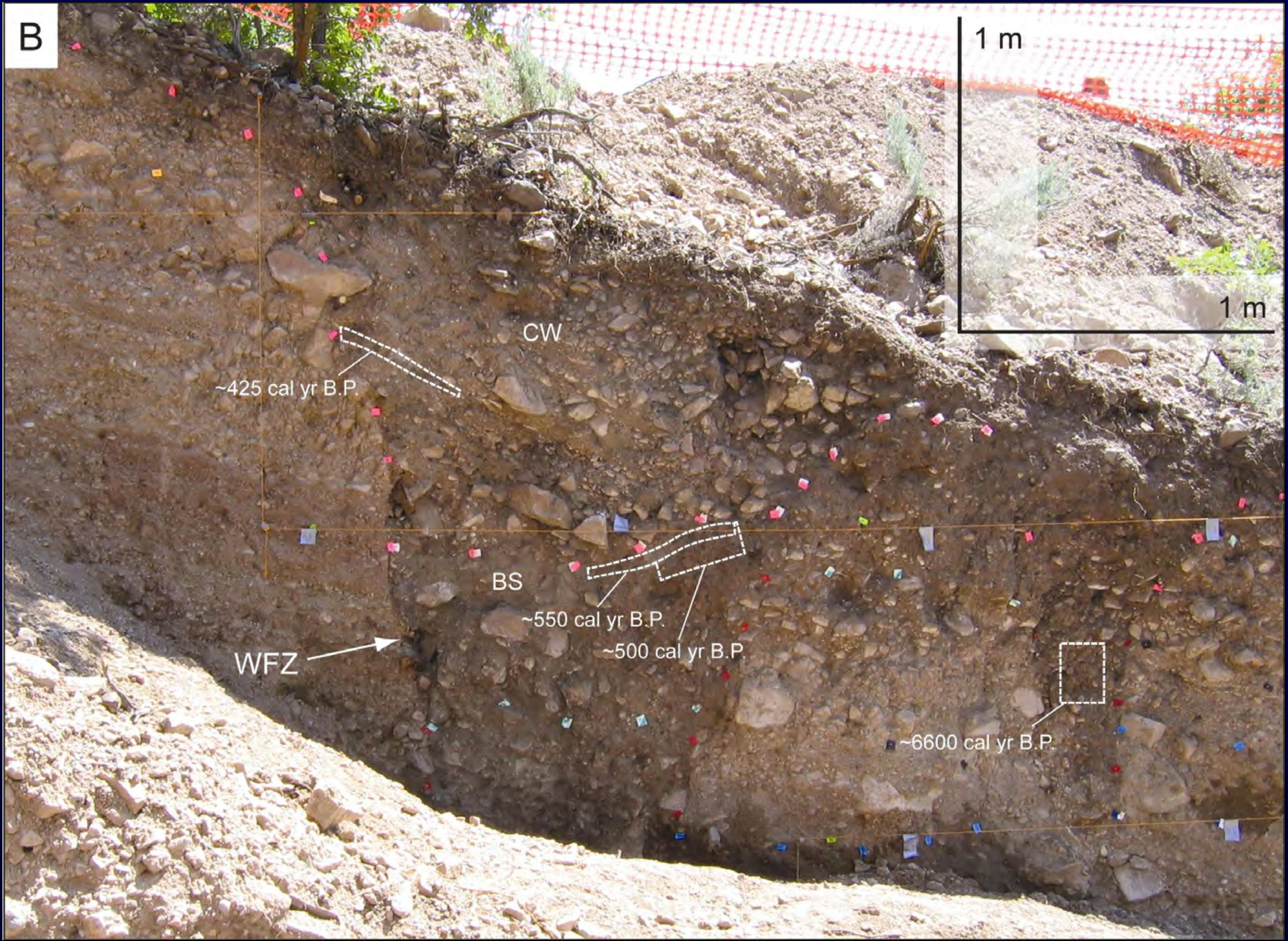
VERTICAL DISPLACEMENT

Contact[1]	Trench 2 (m)[2]
1-2	-
2-3	2.9
3-4	3.2
4-5	3.3
5-6	3.1-3.2
6-7	2.7
7-8	-

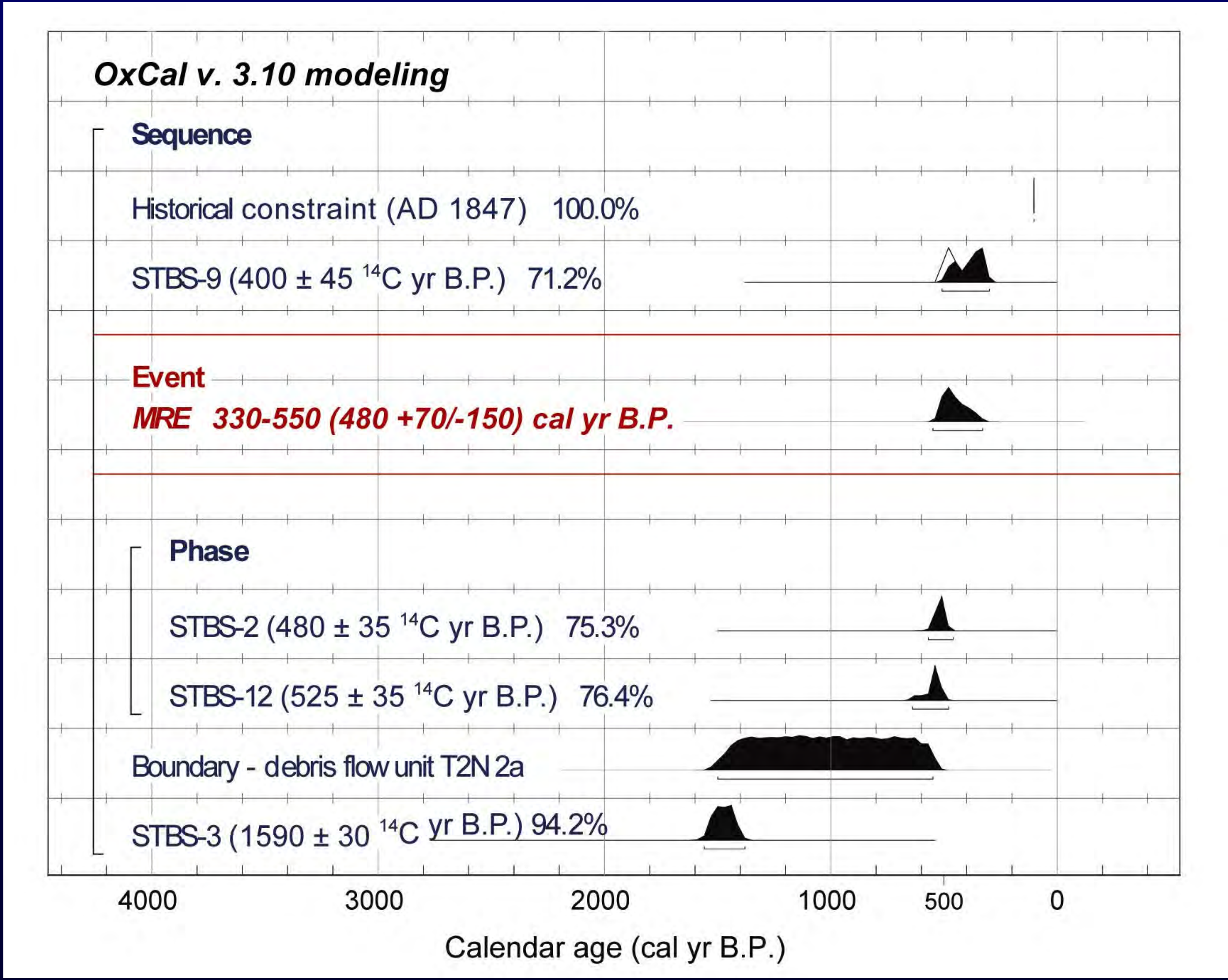
Average displacement: 3.0 ± 0.2 m

Surface offset: 2.5-3.0 m

Trench 2 south wall



Chronological control



PALEOSEISMIC RESULTS

SANTAQUIN

MRE 500 +100/-150 cal yr B.P. (3.0 ± 0.2 m displacement)

PE >**6100-7000** (?) cal yr B.P. (not exposed)

Slip Rate

- **0.5** mm/yr
  (using Bonneville shoreline)

Average Recurrence Interval

- **5600-6400 years**
  (2.8-3.2 m/0.5 mm/yr)

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UQFPWG

Slip rate

- 0.5-**1.1**-3.0 mm/yr

Recurrence interval

- 1200-**2500**-4800 years

PALEOSEISMIC RESULTS

<u>SANTAQUIN</u>

SRL

- **17 km** – northern strand
- **42 km** – entire segment
- **>50 km** –using 3-m displacement; Biasi and Weldon (2006) method

Magnitude

- **7.0 ± 0.3**
  - 6.5-7.0 (SRL)
  - 7.0-7.3 (displacement)

PALEOSEISMIC RESULTS

NEPHI	*MRE (cal yr)*	*VD (m)*
UQFPWG	<1000 ± 400 (400 ± 100?)	
North Creek	>300-400, <800-1600	2.0-2.2
Red Canyon	<1300-1500	1.1-1.7
Santaquin	500 +100/-150	3.0 ± 0.2

PALEOSEISMIC RESULTS

NEPHI	*MRE (cal yr)*	*VD (m)*
UQFPWG	<1000 ± 400 (400 ± 100?)	
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Red Canyon	<1300-1500	1.1-1.7
Santaquin	500 +100/-150	3.0 ± 0.2

PROVO	*MRE (cal yr)*	*VD (m)*
UQFPWG	650 ± 350	
American Fork	500 ± 200	2.2-2.7
Rock Creek	650 +50/-100	3.3
Mapleton (Lund)	600 ± 80	1.4-3.0
Mapleton (Olig)	500 ± 150	4.7 ± 0.5

Paleoseismology of the Nephi Segment, Wasatch Fault at Willow Creek, Juab County, Utah

by
Michael N. Machette, Anthony J. Crone, Stephen F. Personius
Shannon A. Mahan, Richard L. Dart, David J. Lidke, and Susan Olig

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Earthquake Chronology at Willow Creek–Nephi Segment

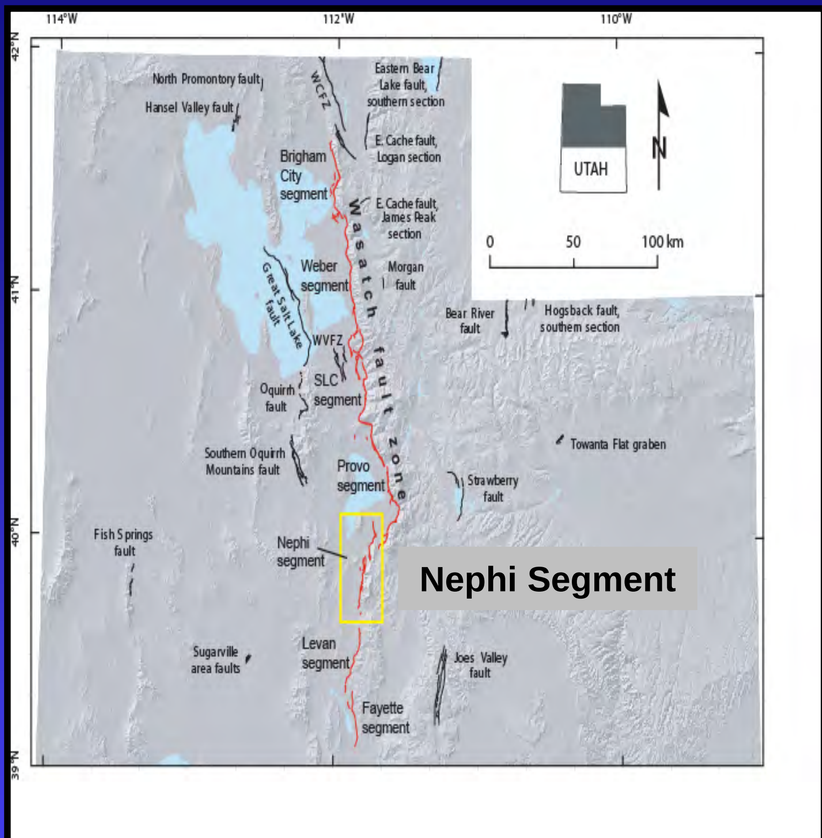
Purpose:

Address UQFPWG observation that Nephi segment is highest priority fault segment in Utah that warrants further study (Lund, 2005).

Objectives:

1. Develop chronology of prehistoric earthquakes at Willow Creek near center of Nephi segment–apply modern dating techniques.
2. Compare results with chronologies from previous studies–North Creek (Hanson and others, 1981, 1982; Schwartz and others, 1983, 1984) and Red Canyon (Jackson, 1991).
3. Refine chronology of events for the entire segment.

Segmentation of the Wasatch Fault Zone, Utah



Nephi segment has a precipitous range front
Mt. Nebo—11,928'; Juab Valley—4875'

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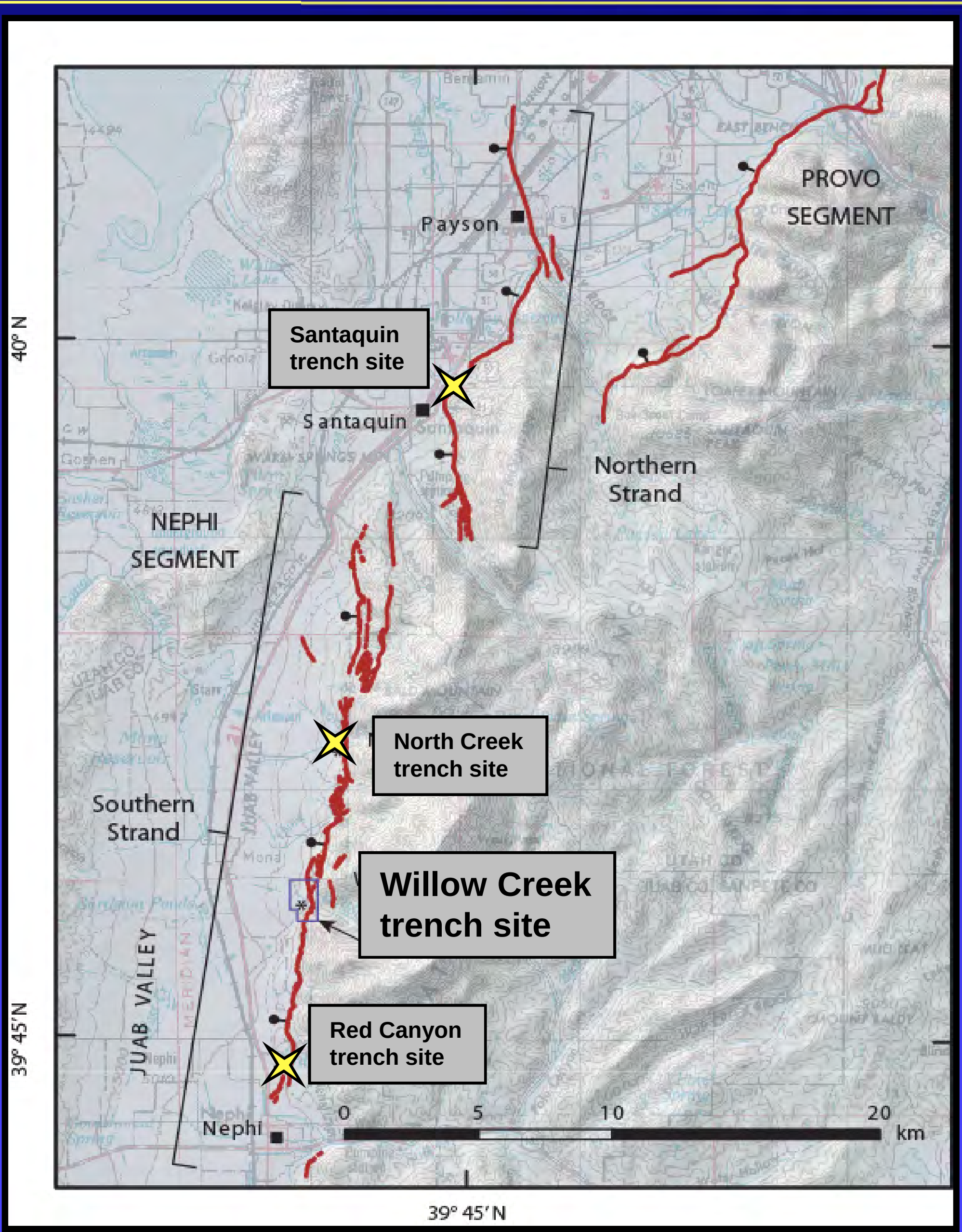
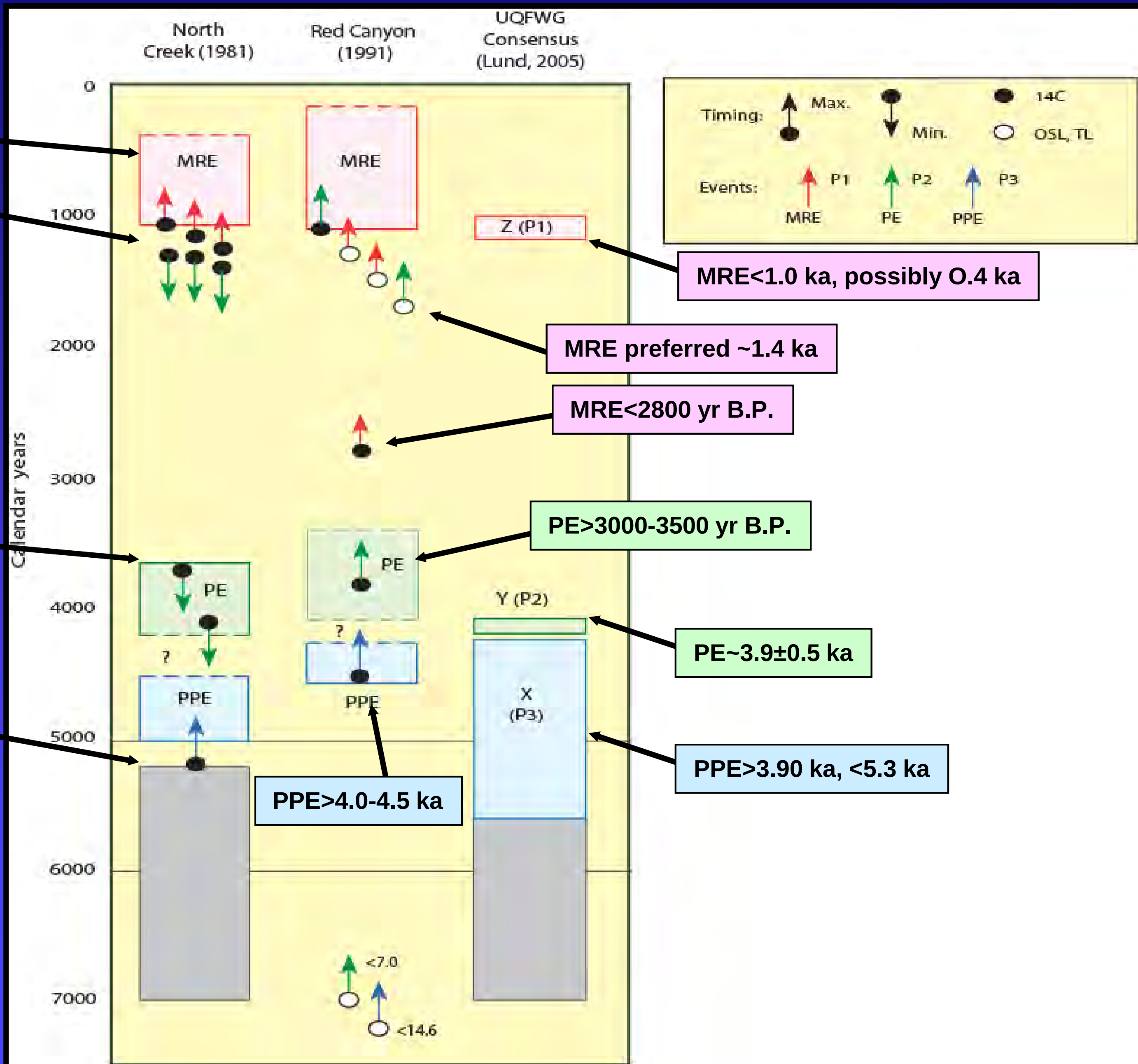
Location: Willow Creek–Nephi Segment



- **Willow Creek site is located near center of segment and approximately equidistant between North Creek and Red Canyon sites.**
- **Much of central part of segment is in the Mt. Nebo Wilderness Study area (WSA)–unavailable for excavations.**

Earthquake Chronology for the Nephi Segment–2005



Preferred 0.3-0.5 ka

MRE<1.1-1.3 ka

MRE<1.0 ka, possibly O.4 ka

MRE preferred ~1.4 ka

MRE<2800 yr B.P.

PE>3.7-4.1 ka

PE>3000-3500 yr B.P.

PE~3.9±0.5 ka

PPE>4.5-5.2 ka

PPE>4.0-4.5 ka

PPE>3.90 ka, <5.3 ka

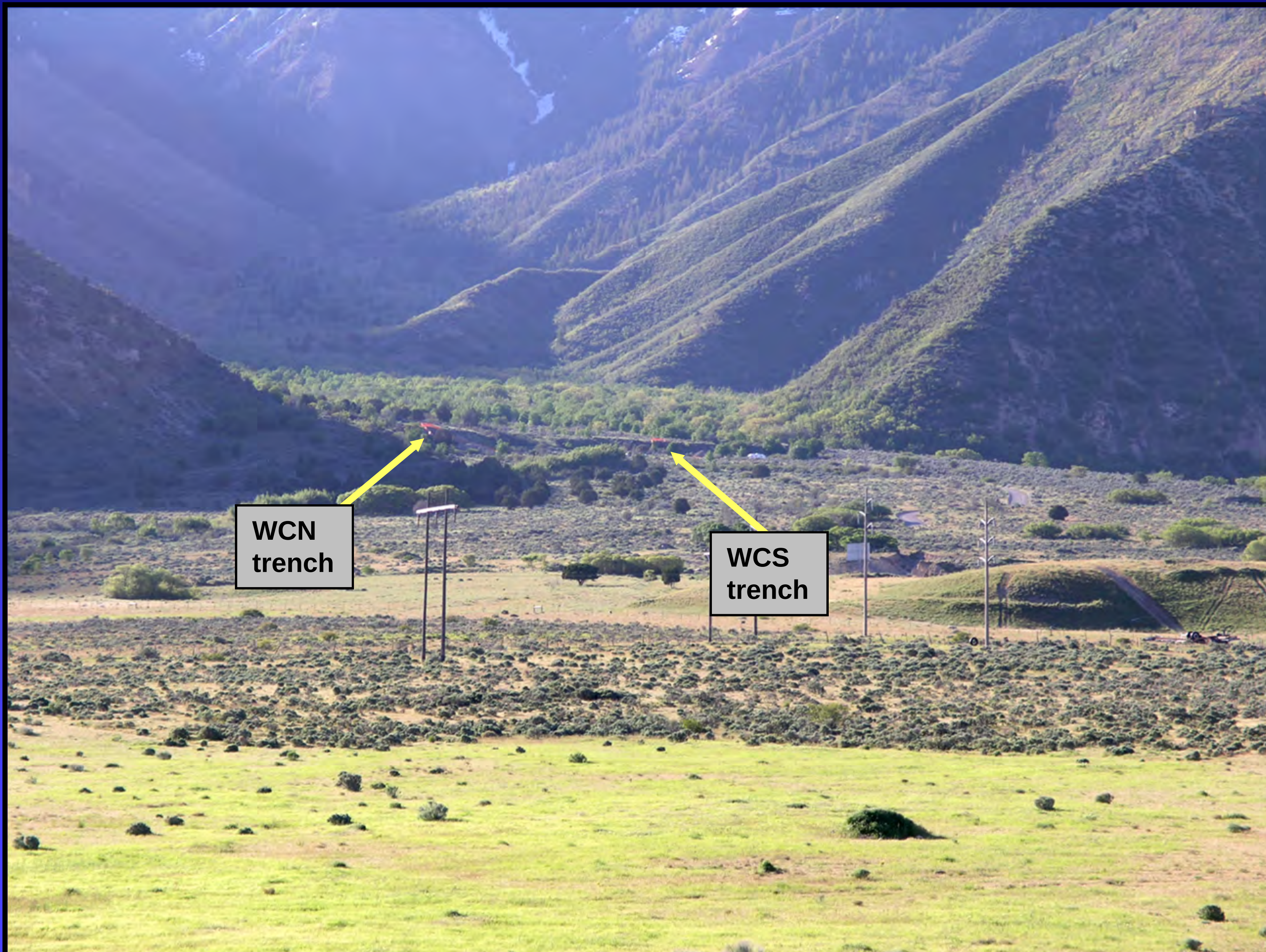
Fault Scarps–Nephi Segment

Large, impressive scarps

Oblique View: Willow Creek Trench Site

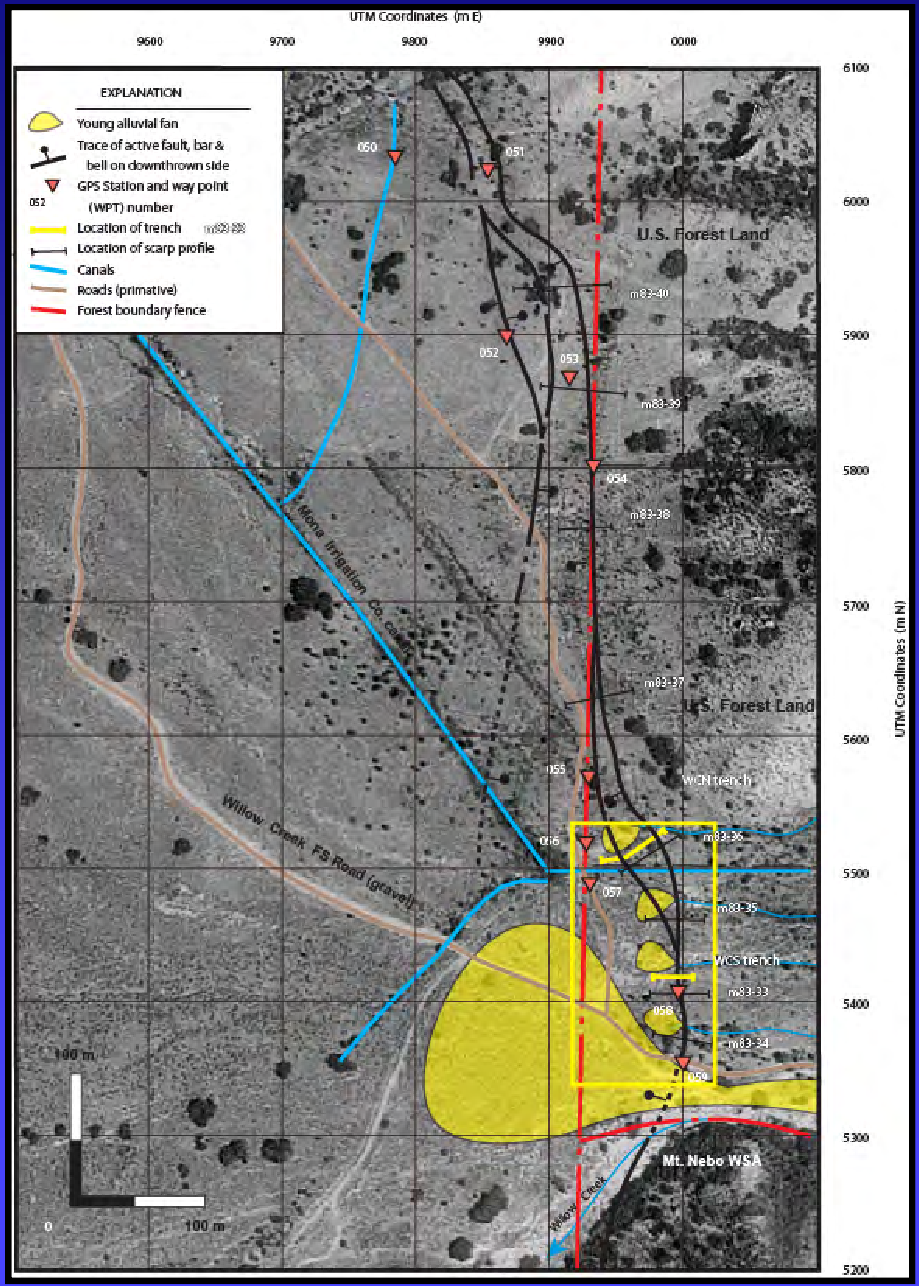
- **Willow Creek South (WCS) trench located on main Willow Creek alluvial fan.**
- **Willow Creek North (WCN) trench located on fan from subsidiary side valley.**

Willow Creek Trench Site



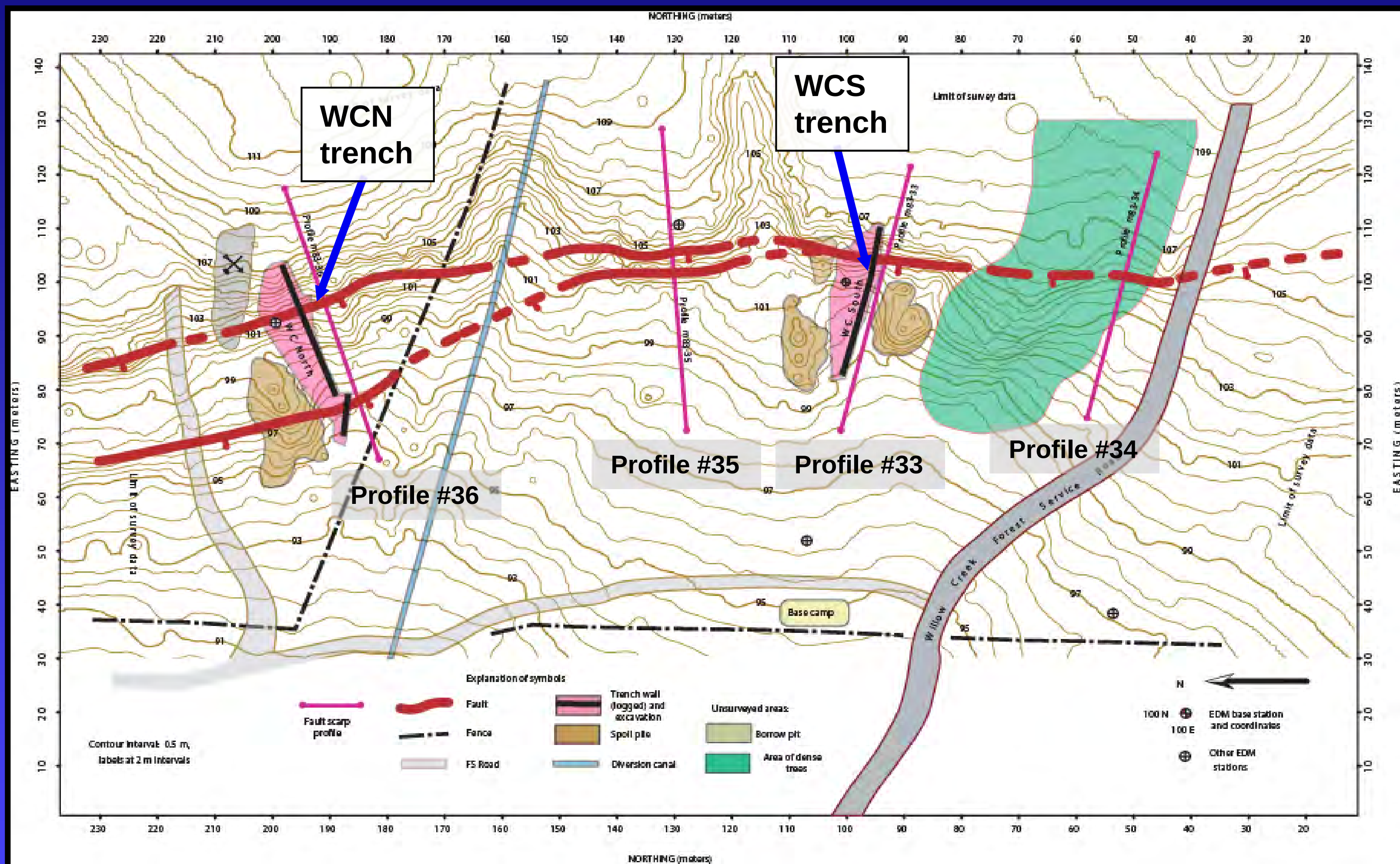
Willow Creek Trench Site

Willow Creek Trench Site



Locally, young alluvial fans have buried the hanging wall of the fault.

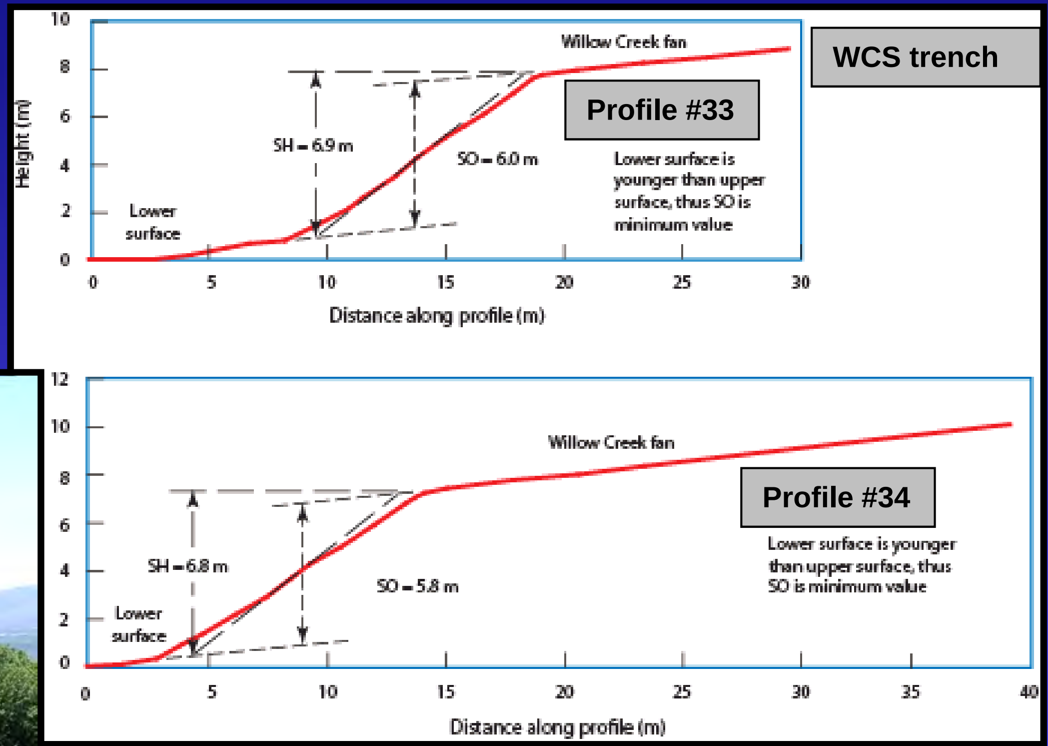
Site Topography: Willow Creek Trench Site



- **Willow Creek South (WCS) trench crosses a single scarp.**
- **Willow Creek North (WCN) trench crosses main scarp and smaller scarp downslope.**

Scarp Profiles: Willow Creek South

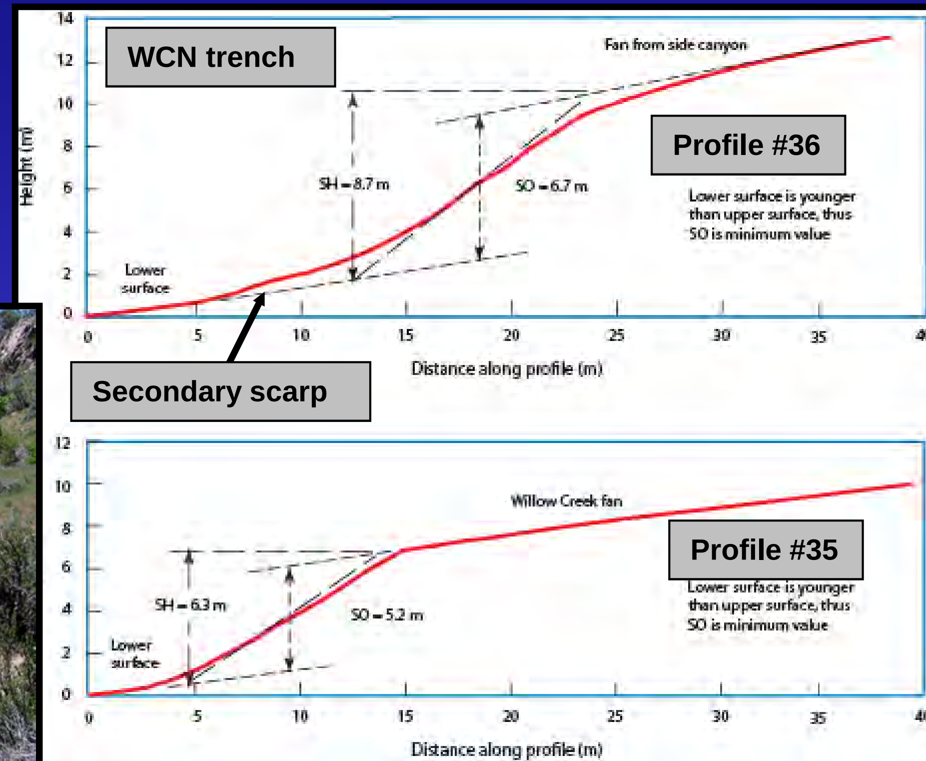
- Scarp heights (SH): 6.8–6.9 m
- Surface offsets (SO): 5.8–6.0 m
- Lower surface is younger than upper surface; SO is minimum value



View to south

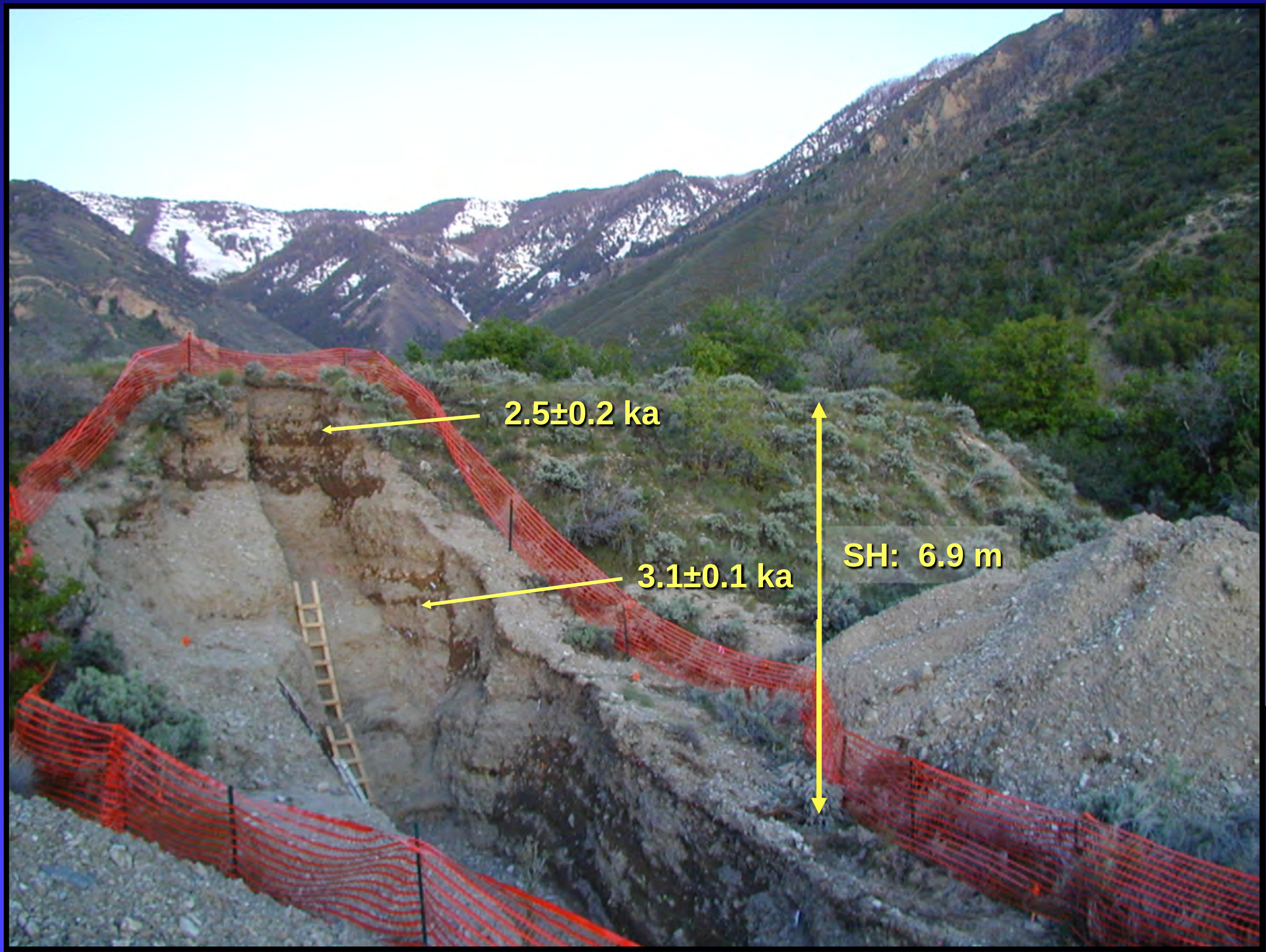
Scarp Profiles: Willow Creek North

- **Scarp heights (SH): 8.7 m**
- **Surface offsets (SO): 6.7 m**
- **Lower surface is younger than upper surface; SO is minimum value**



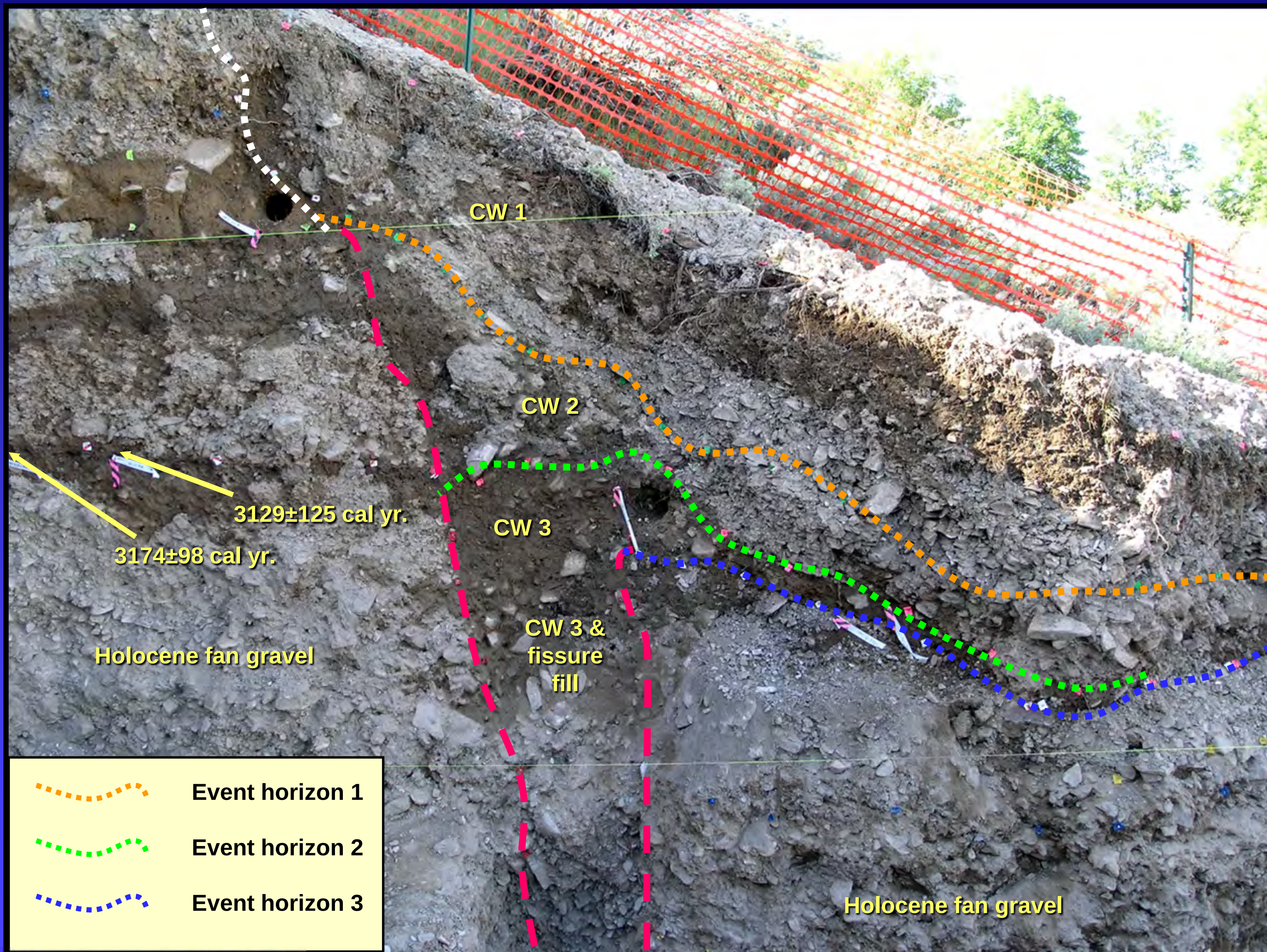
View to north

Willow Creek South (WCS) trench



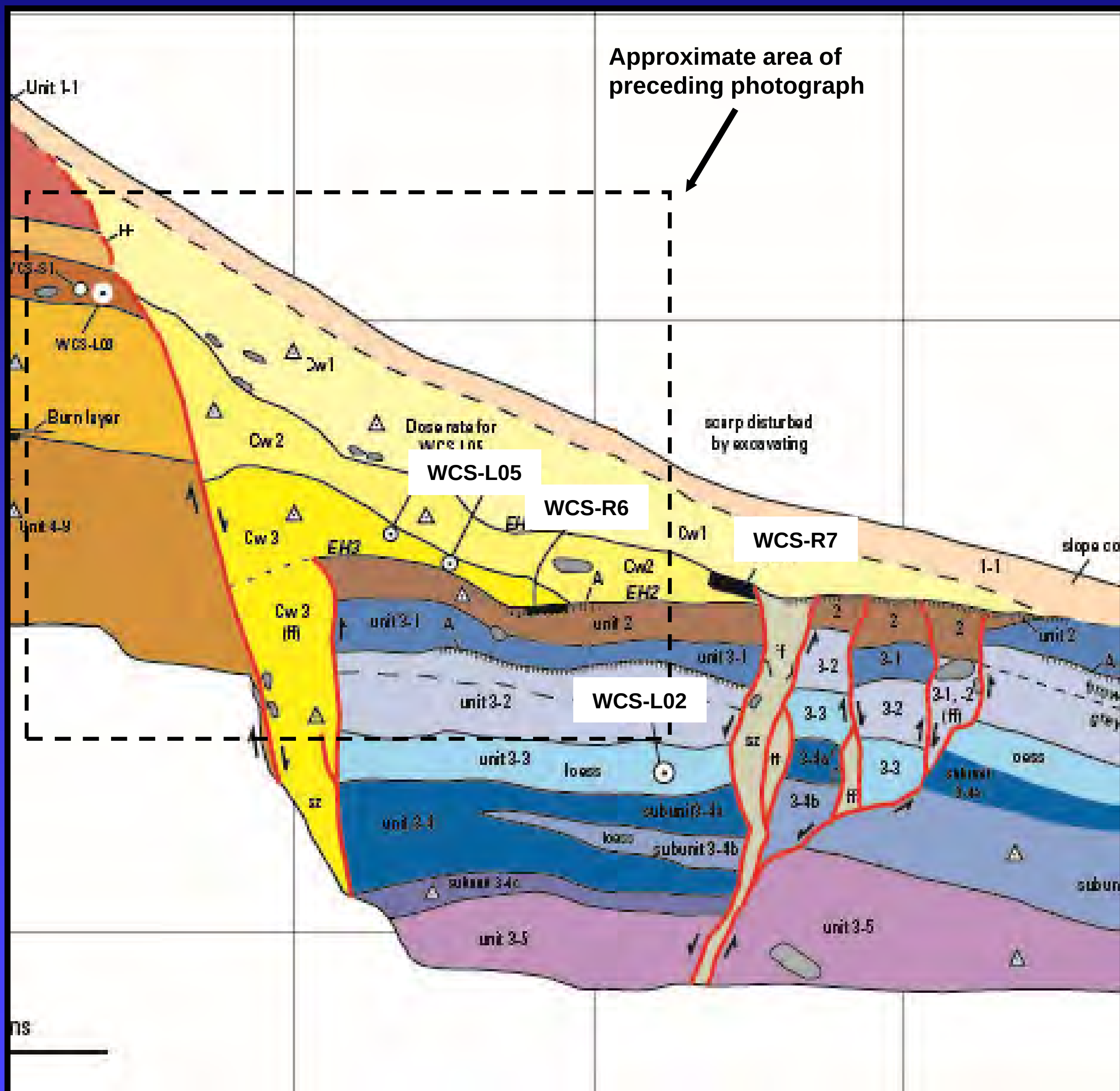
Scarp is formed on mid- to late Holocene alluvial-fan deposits

Willow Creek South Trench



Main fault zone

Willow Creek South Trench Map



Main fault zone

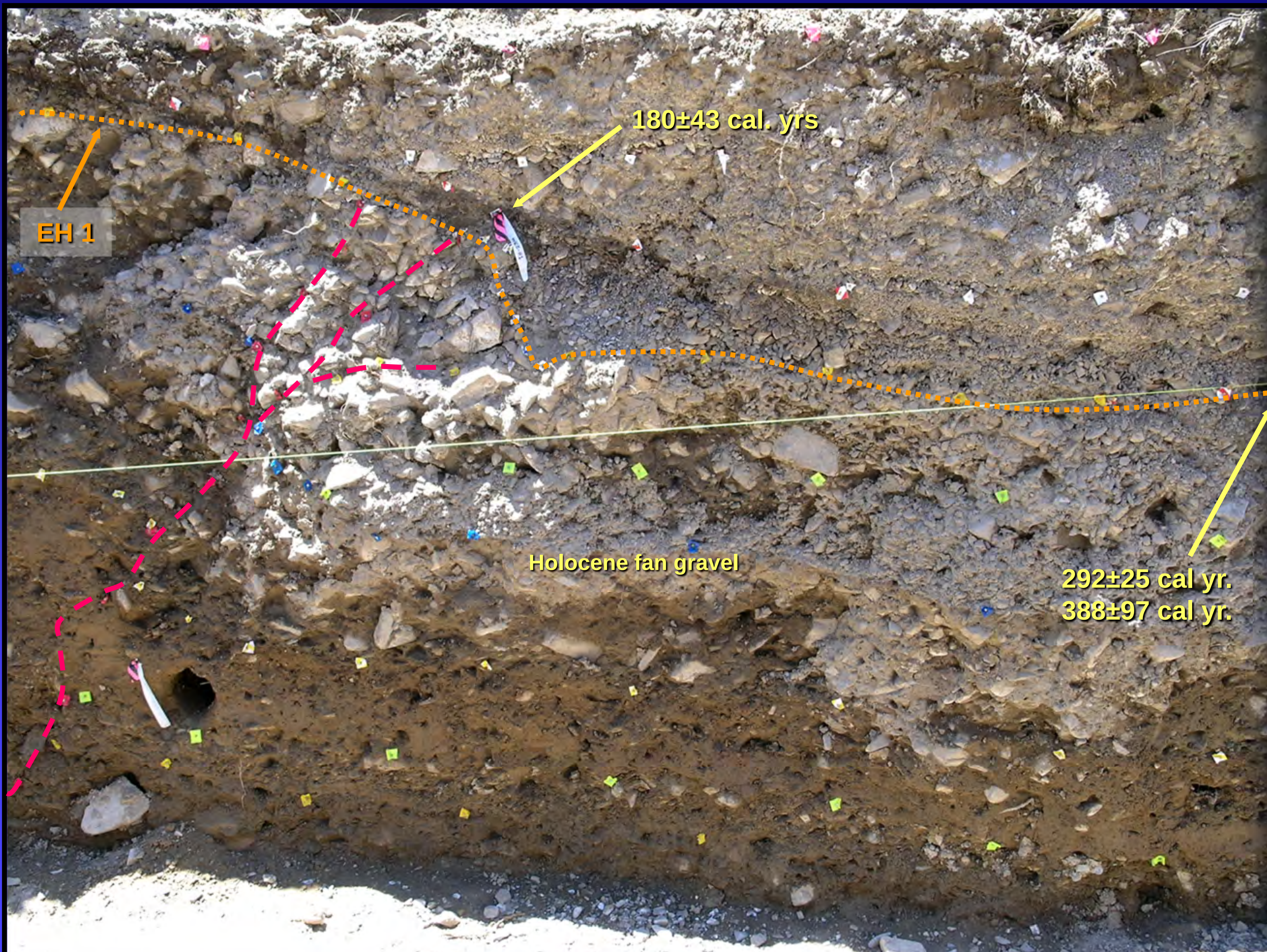
WCS-R7: 282±26 cal yr. (max. for MRE)

WCS-R6: 513±59 cal yr. (too young)

WCS-L05: 3.05±0.15 ka (not fully reset?)

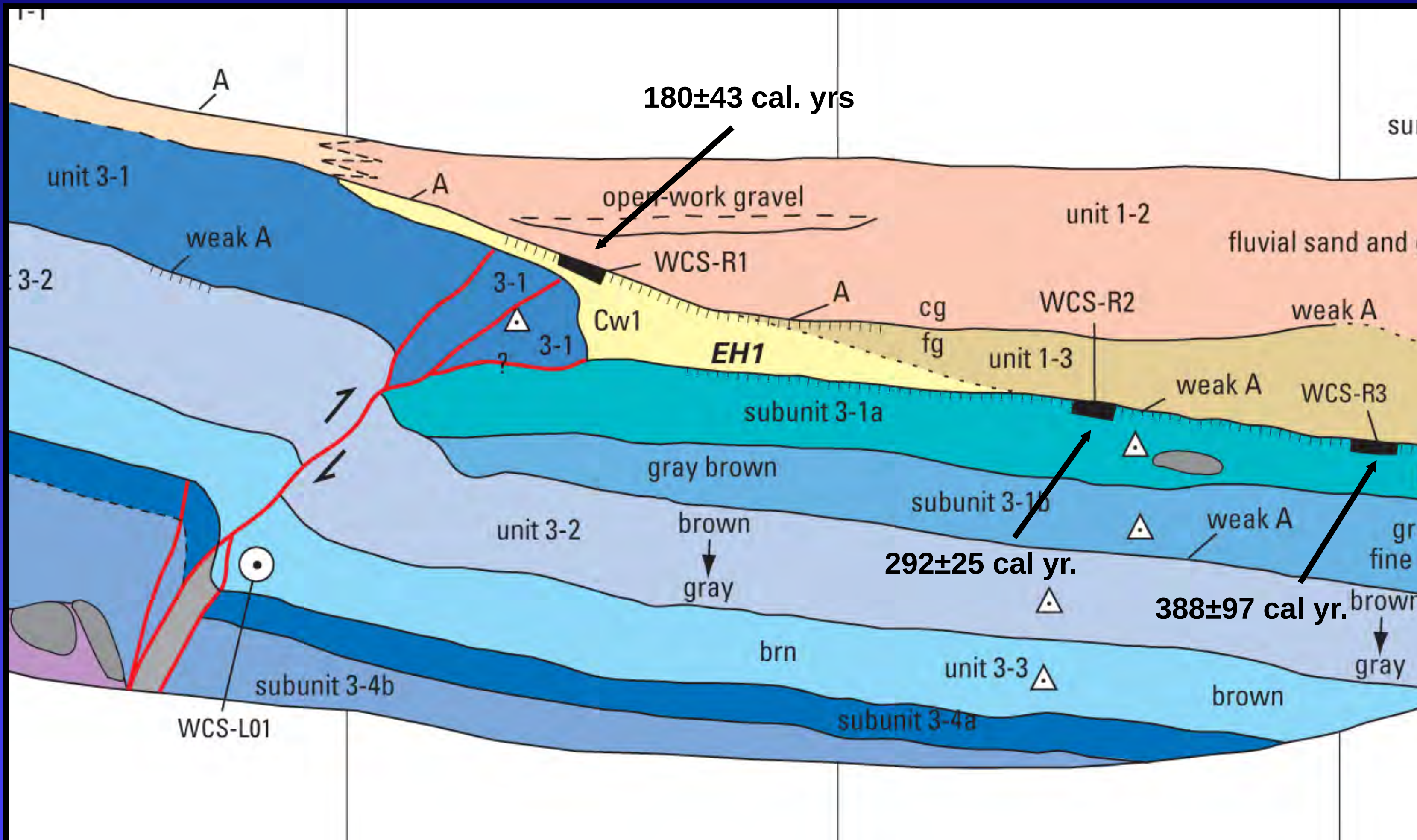
WCS-L02: 2.57±0.12 ka. (loess? in alluvial fan)

Willow Creek South Trench



Reverse fault zone

Willow Creek South Trench Map



Reverse fault zone

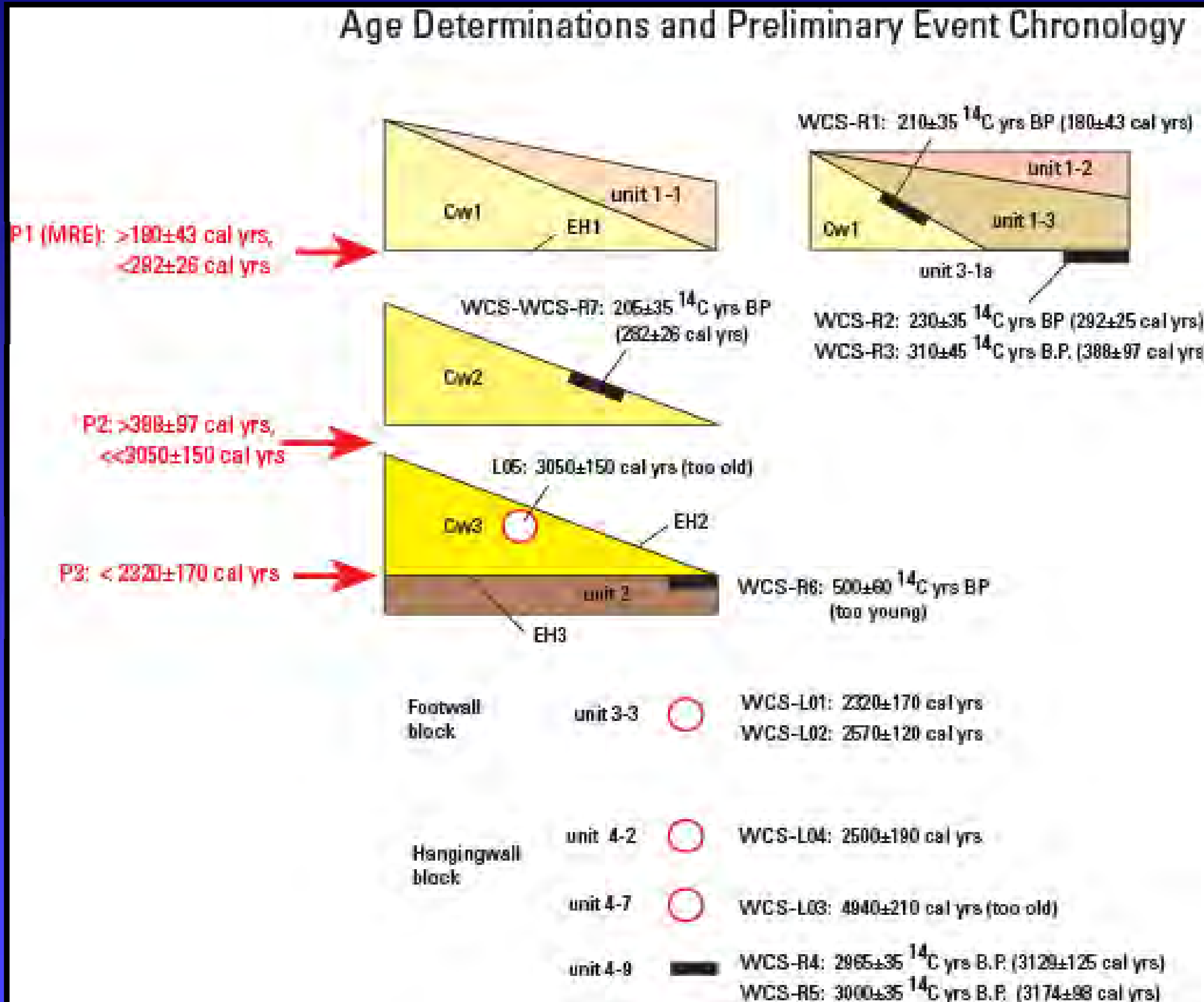
Radiocarbon ages bracket the most recent event to be between about 150-400 years old.

Event Chronology: Willow Creek South Trench

P1: well-constrained age

P2: poorly constrained age

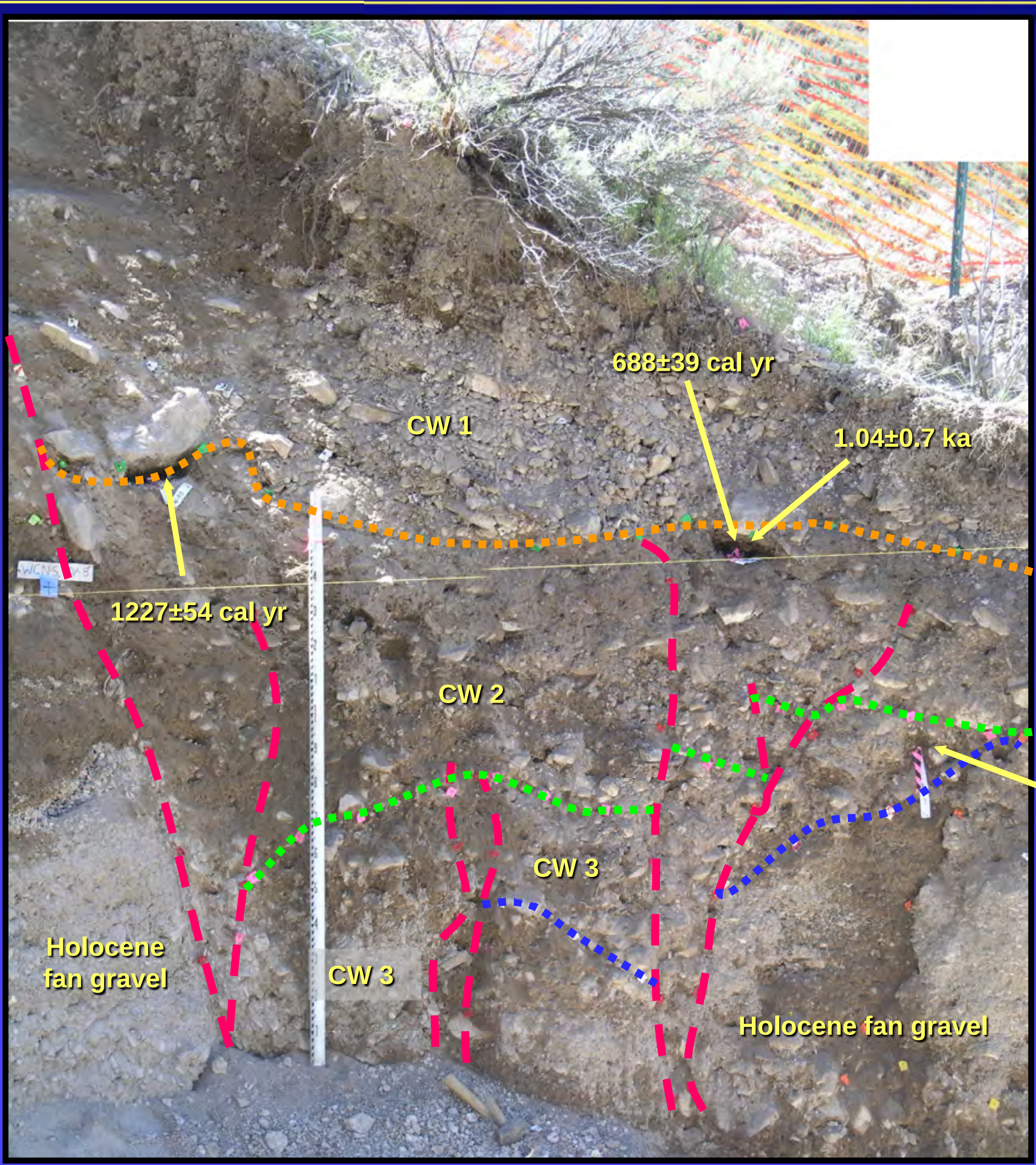
P3: poorly constrained age



Willow Creek North (WCN) trench

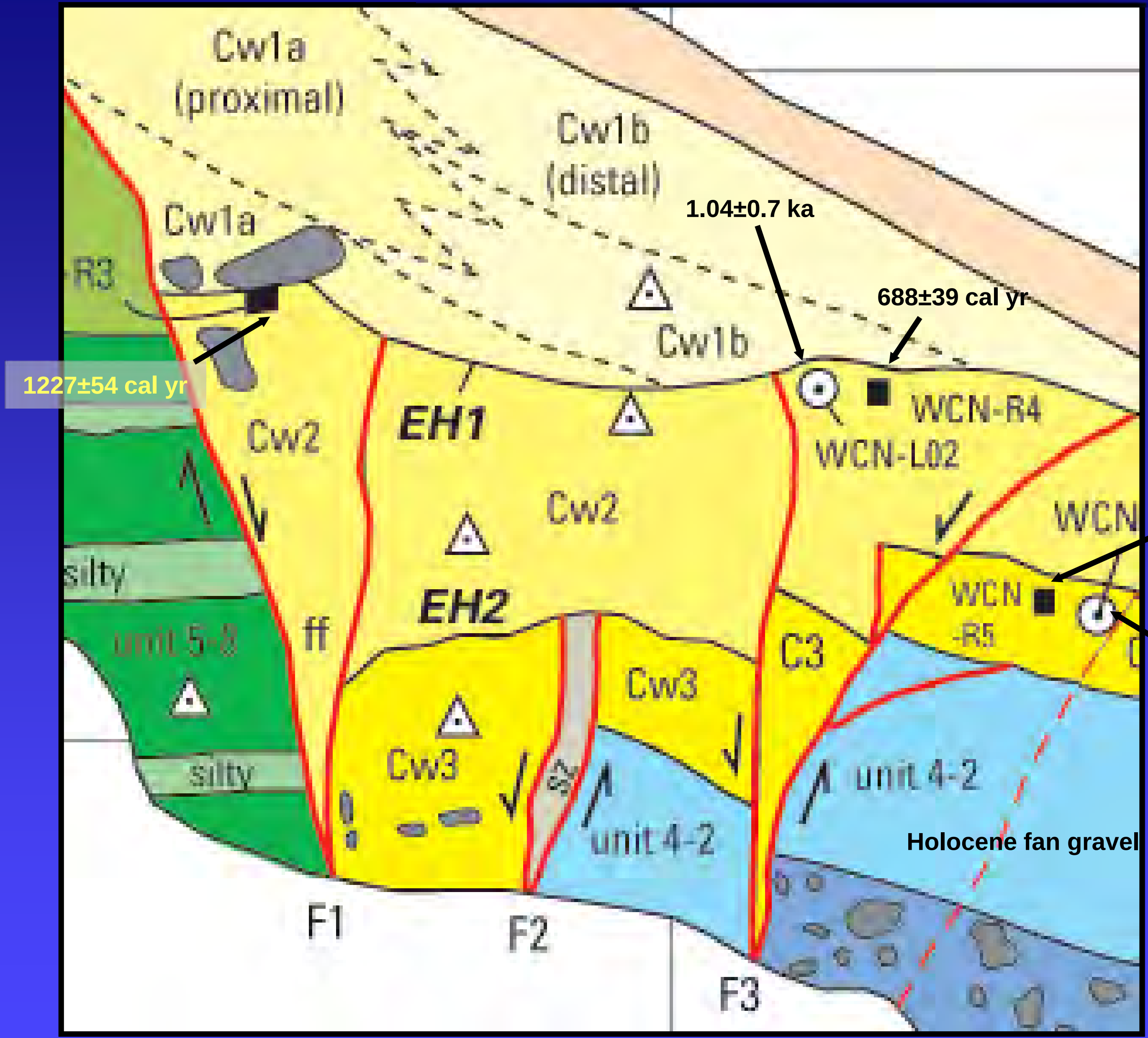
Alluvial-fan gravels at WCN site are older (~6.2 ka) than at WCS site.

Willow Creek North (WCN) trench



Main fault zone

Willow Creek North Trench Map

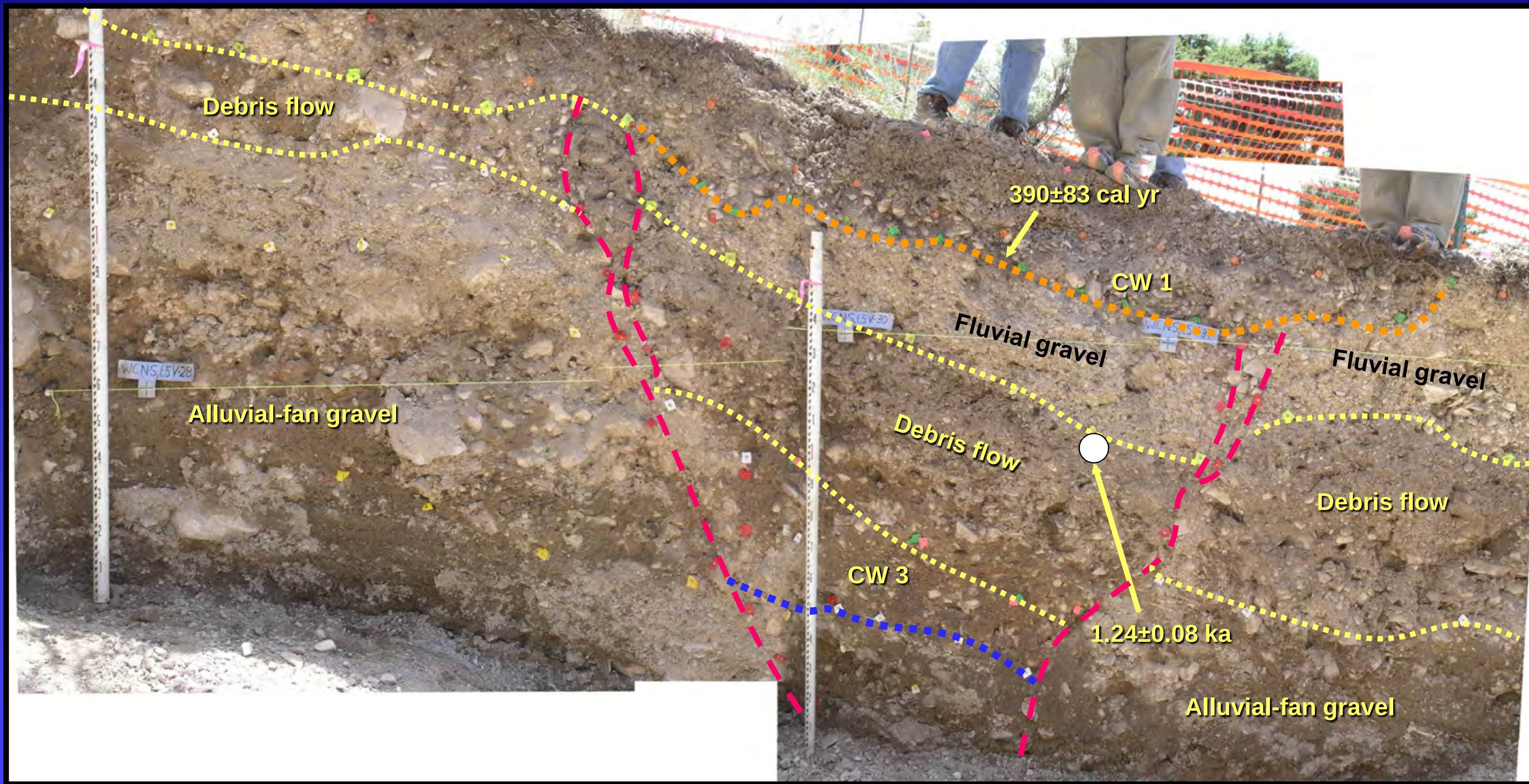


Main fault zone

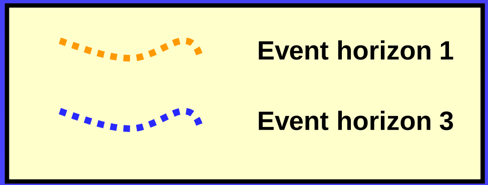
403±53 cal yr.
(too young)

5.79±0.3 ka
(not reset)

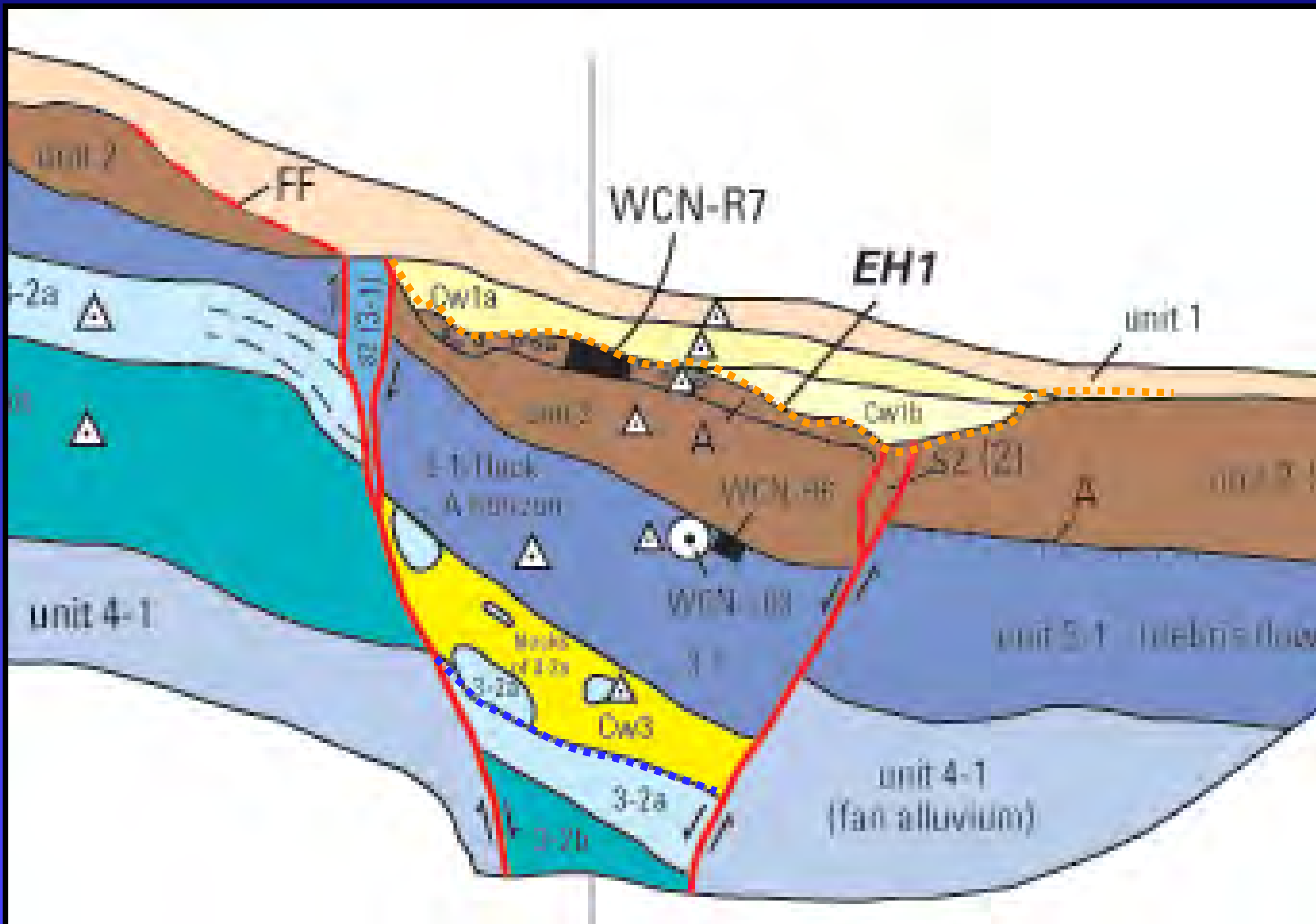
Willow Creek North (WCN) trench



Western fault zone



Willow Creek North Trench Map



Western fault zone

	Event horizon 1
	Event horizon 3

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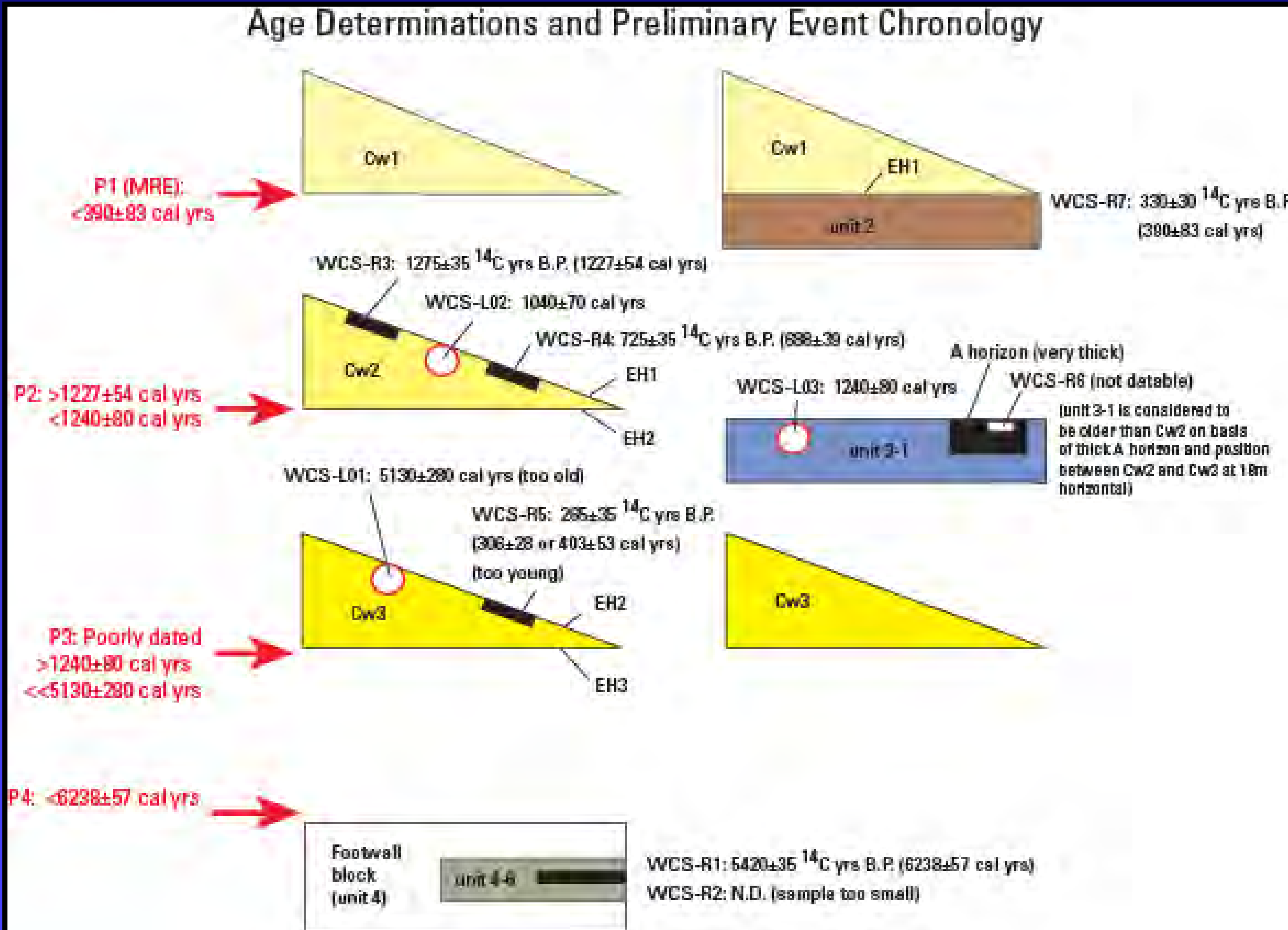
Event Chronology: Willow Creek North Trench

P1: consistent with WCS age

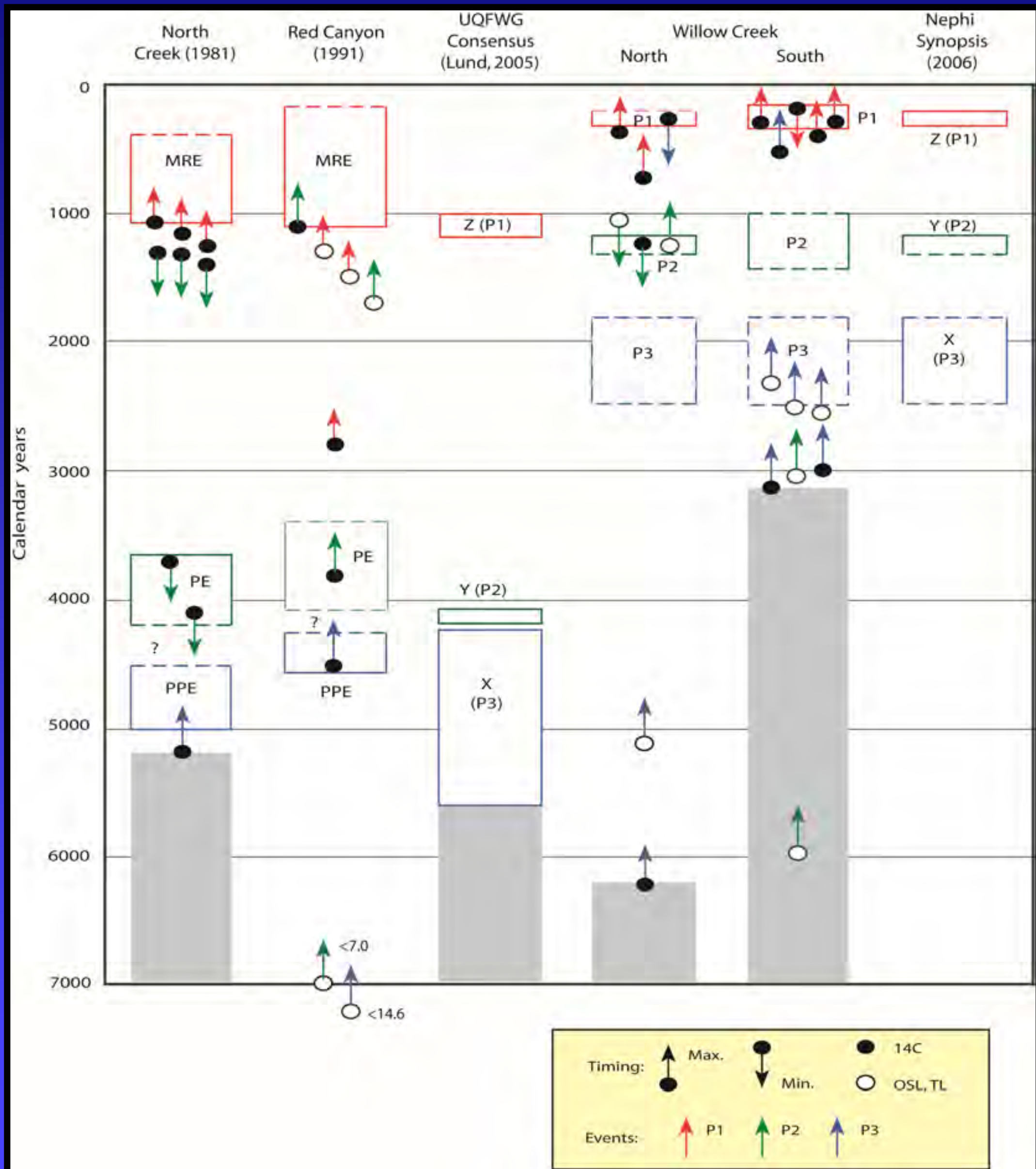
P2: well constrained age

P3: poorly constrained age

P4: older events younger than fan gravels



Revised Event Chronology: Nephi Segment



Preferred Ages of Events– Nephi Segment

P1: 150-390 yrs ago

P2: 1100-1370 yrs ago

P3: 1590-2450 yrs ago

P4: older than about 6.2 ka

UQFPWG Ages of Events– Nephi Segment

P1: ≤ 1.0±0.4 ka (0.4±0.1 ka)

P2: ~ 3.9±0.5 ka

P3: >3.9±0.5 ka; < 5.3±0.7 ka

P4: no data

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Revised Event Chronology: Nephi Segment

Significant Results:

- Event P1: likely is only a few hundred years old—slightly prehistoric.
- Event P2: substantially younger than the age previously interpreted by the UQFPWG.
- Event P3: range of possible ages for this event still relatively broad but improved.

Preferred Ages of Events–Nephi Segment

P1: 150-390 yrs ago

P2: 1100-1370 yrs ago

P3: 1590-2450 yrs ago

P4: older than about 6.2 ka

Remaining Questions:

- Age of event P3 need to be further refined.
- What is the significance and implications of the differing ages of the two alluvial-fan deposits?
- Our age determinations showed that individual samples yield erroneous results—multiple age determinations using multiple techniques needed to identify problems and produce viable results.

UQFPWG Ages of Events–Nephi Segment

P1: ≤ 1.0±0.4 ka (0.4±0.1 ka)

P2: ~ 3.9±0.5 ka

P3: >3.9±0.5 ka; < 5.3±0.7 ka

P4: no data

Segmentation and Holocene Displacement History of the Great Salt Lake Fault Zone

David A. Dinter, James C. Pechmann

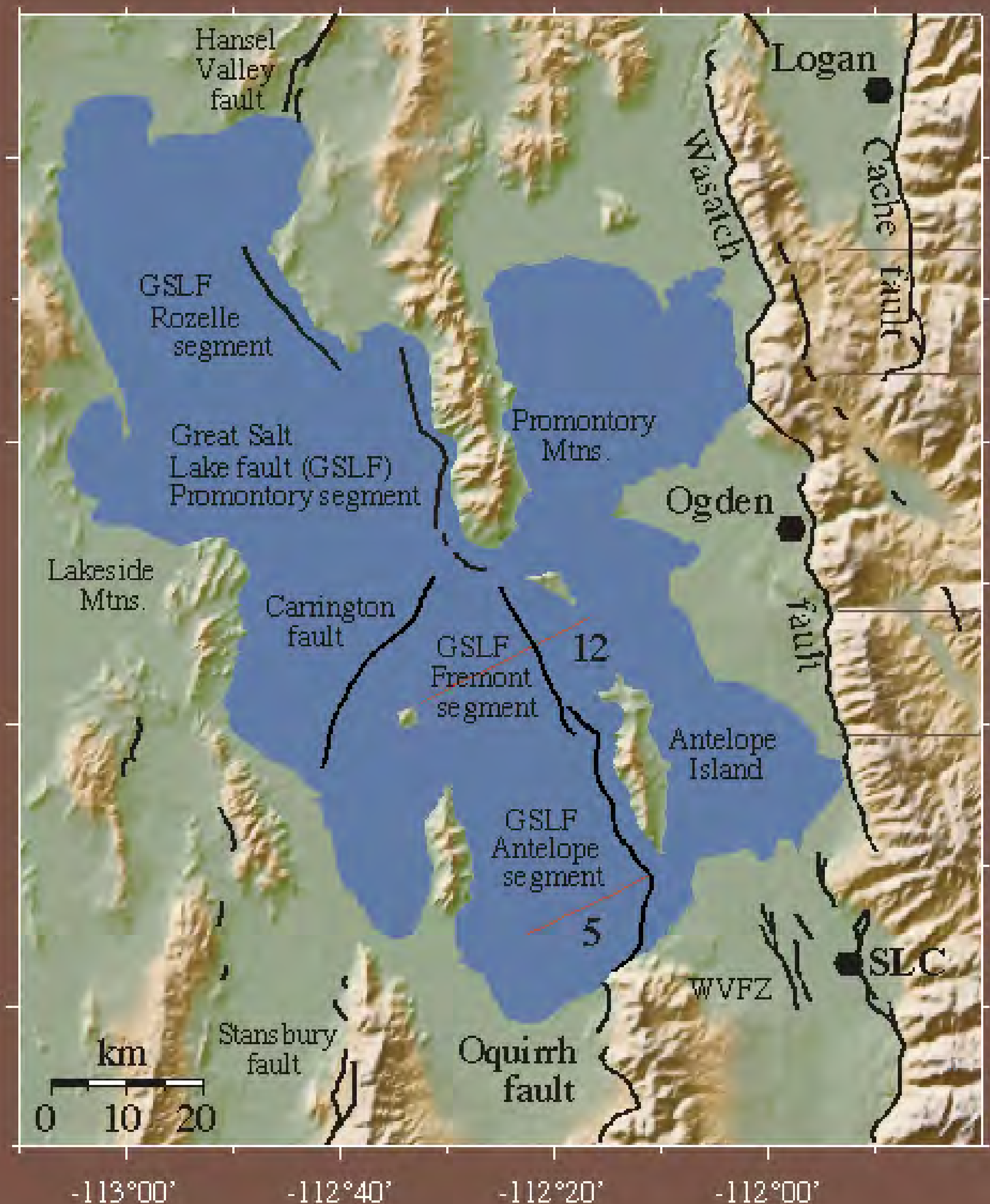
Department of Geology and Geophysics

University of Utah

February 28, 2007

Goal: Assess seismic risk posed by Great Salt Lake fault (GSLF) to Ogden–Salt Lake City urban corridor

Major active normal faults in the Great Salt Lake region, northern Utah



Approach: Analogous to trenching

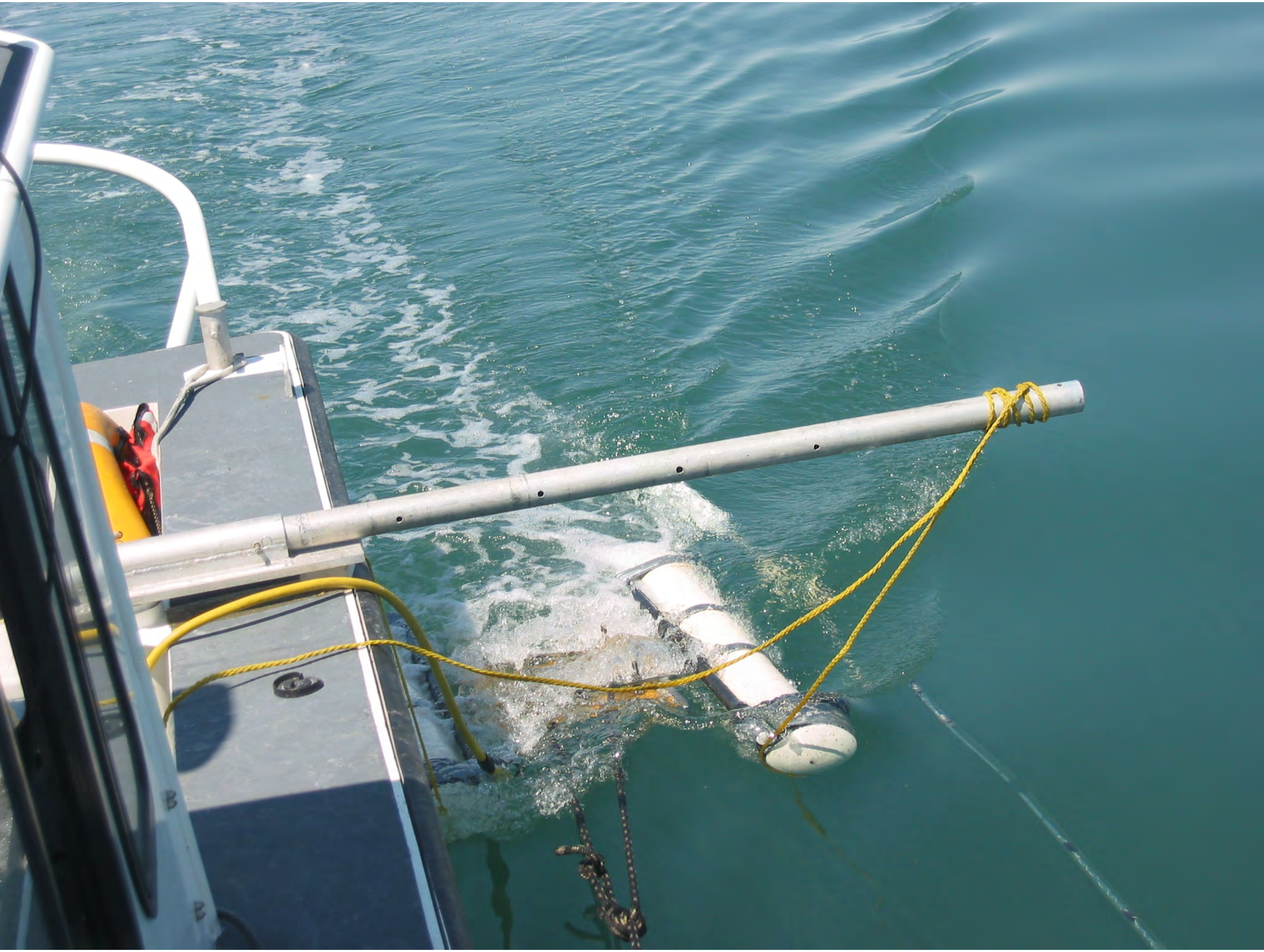
- Map active fault trace to determine length, segmentation
- Measure net vertical tectonic displacement from cross sections of fault and identify seismic event horizons
- Date event horizons to obtain EQ recurrence intervals

Sublacustrine paleoseismology (fault is submerged):

- Profile active fault traces using high-resolution marine seismic reflection systems (Geopulse and Chirp)
- Obtain continuous cores from hanging wall
- Sample and date seismic event horizons (radiocarbon)


SB-216S
EZ LOADER


EZ LOADER
MERCURY



Active faults in the south arm, Great Salt Lake, Utah

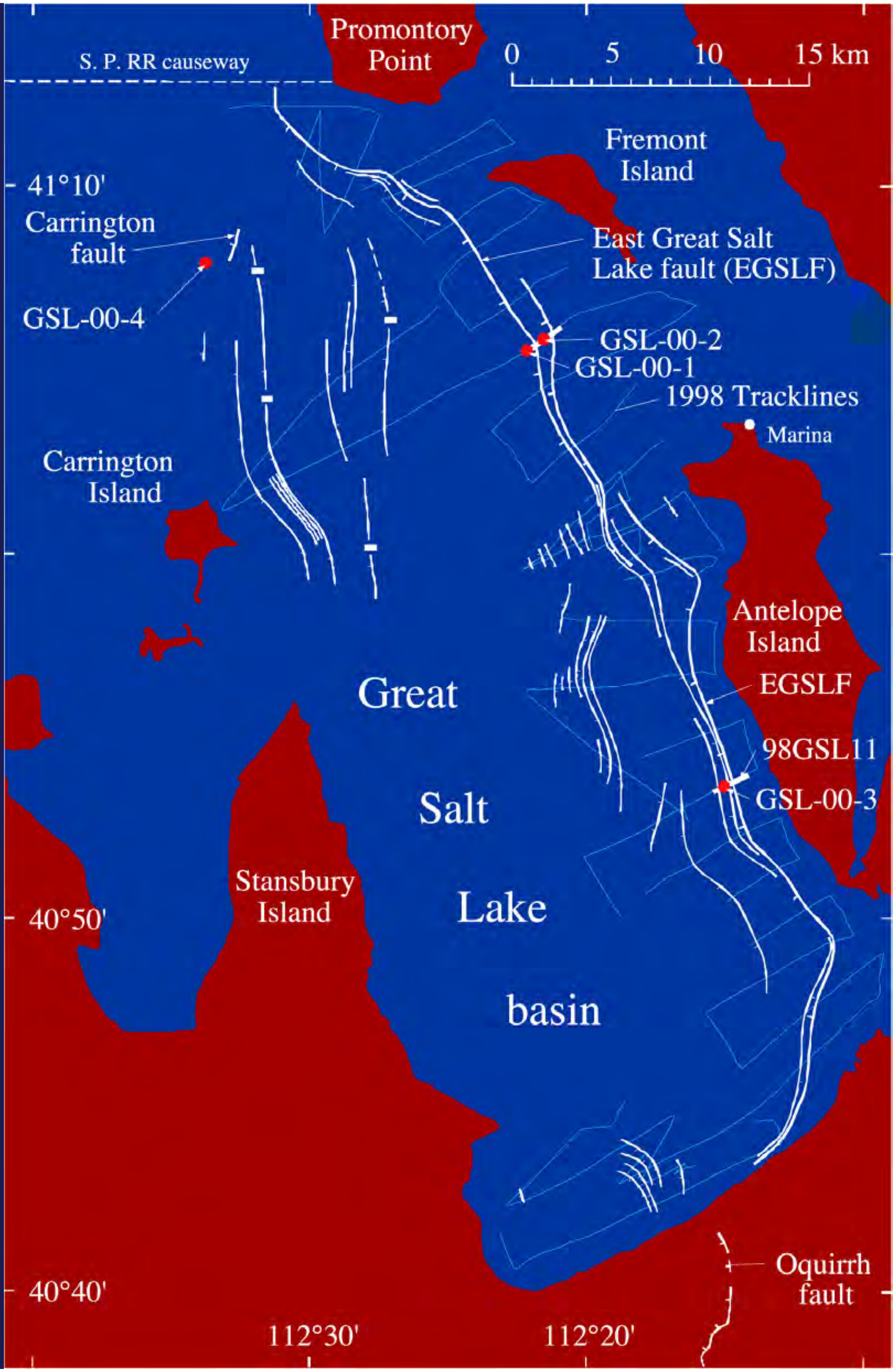
- Two major segments of the Great Salt Lake normal fault south of Promontory Point

- Segment boundary is a 2-km left step west of White Rock Bay, northern Antelope Island

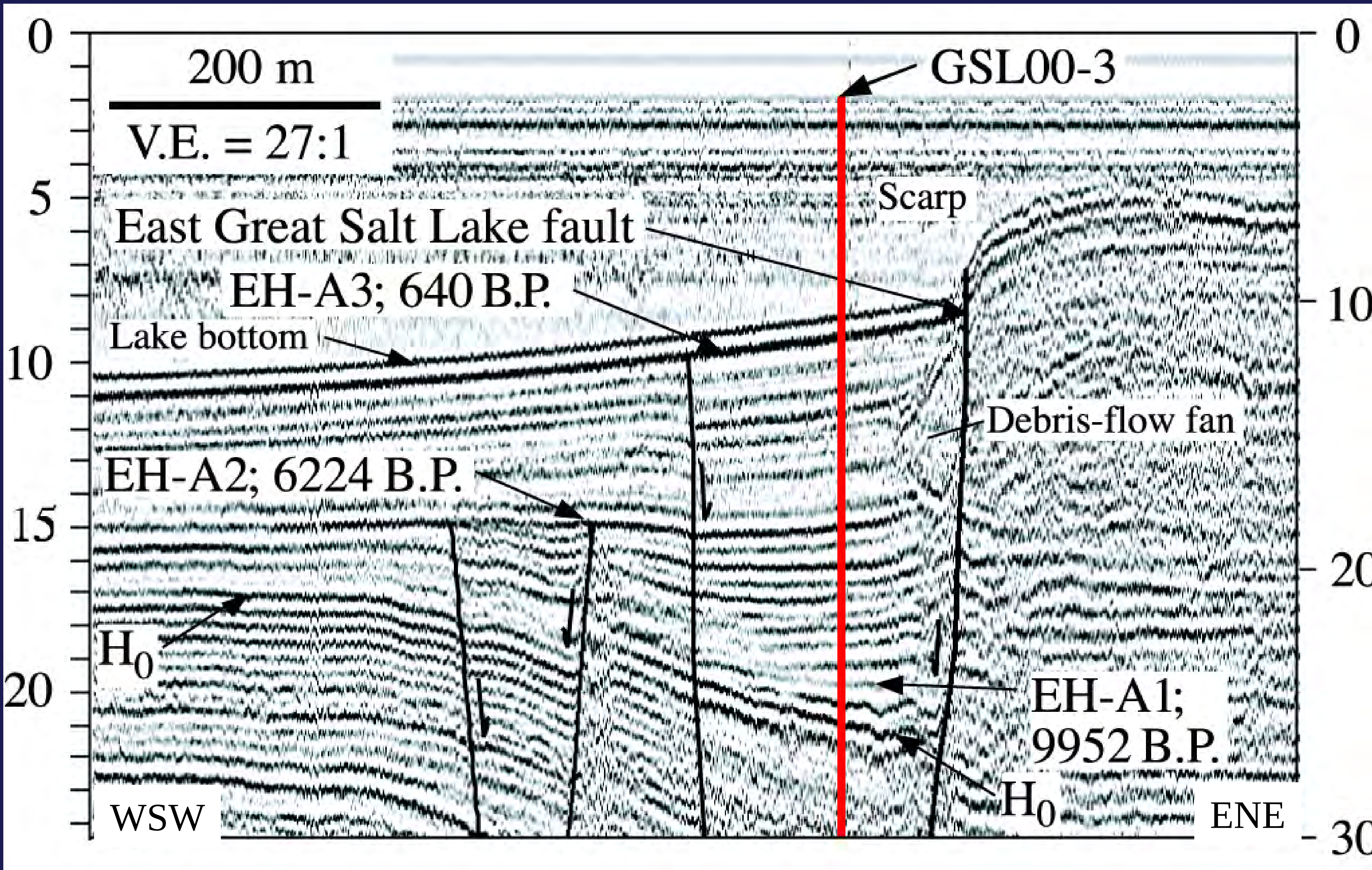
- Fremont Island segment:
  30 km long (revised: ~ 20 km)
  No lakebed scarp (buried)

- Antelope Island segment:
  35 km long
  Lakebed scarp with up to 3.3 m relief
  Bends sharply SW at south end
  Appears to merge with Oquirrh fault

- Numerous active intrabasin normal faults
  Strikes oblique to GSLF
  Lakebed scarps with up to 1.8 m relief
  Probably coseismic with GSLF

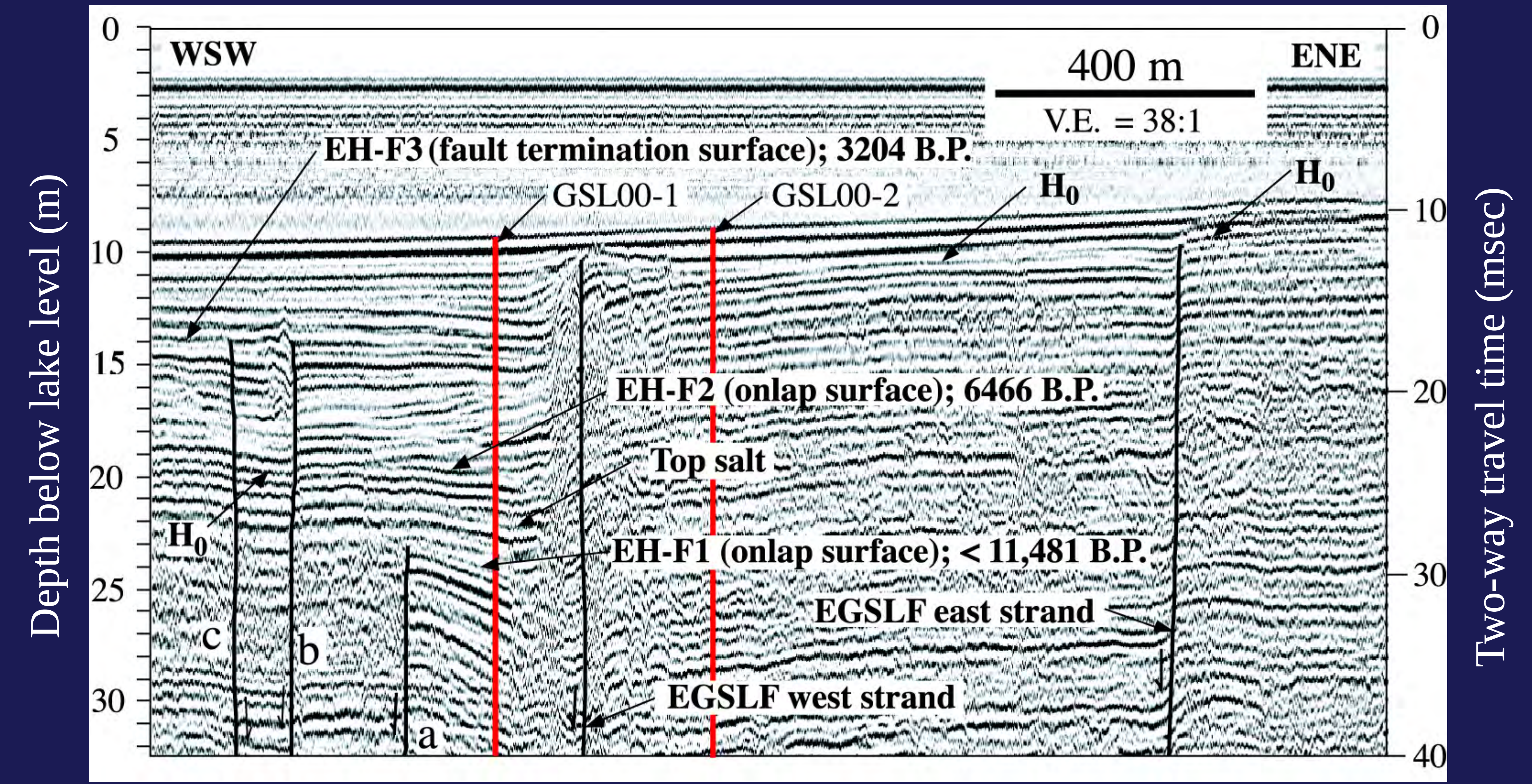


Great Salt Lake fault, Antelope Island segment



Geopulse Line 98GSL11

Great Salt Lake fault, Fremont Island segment

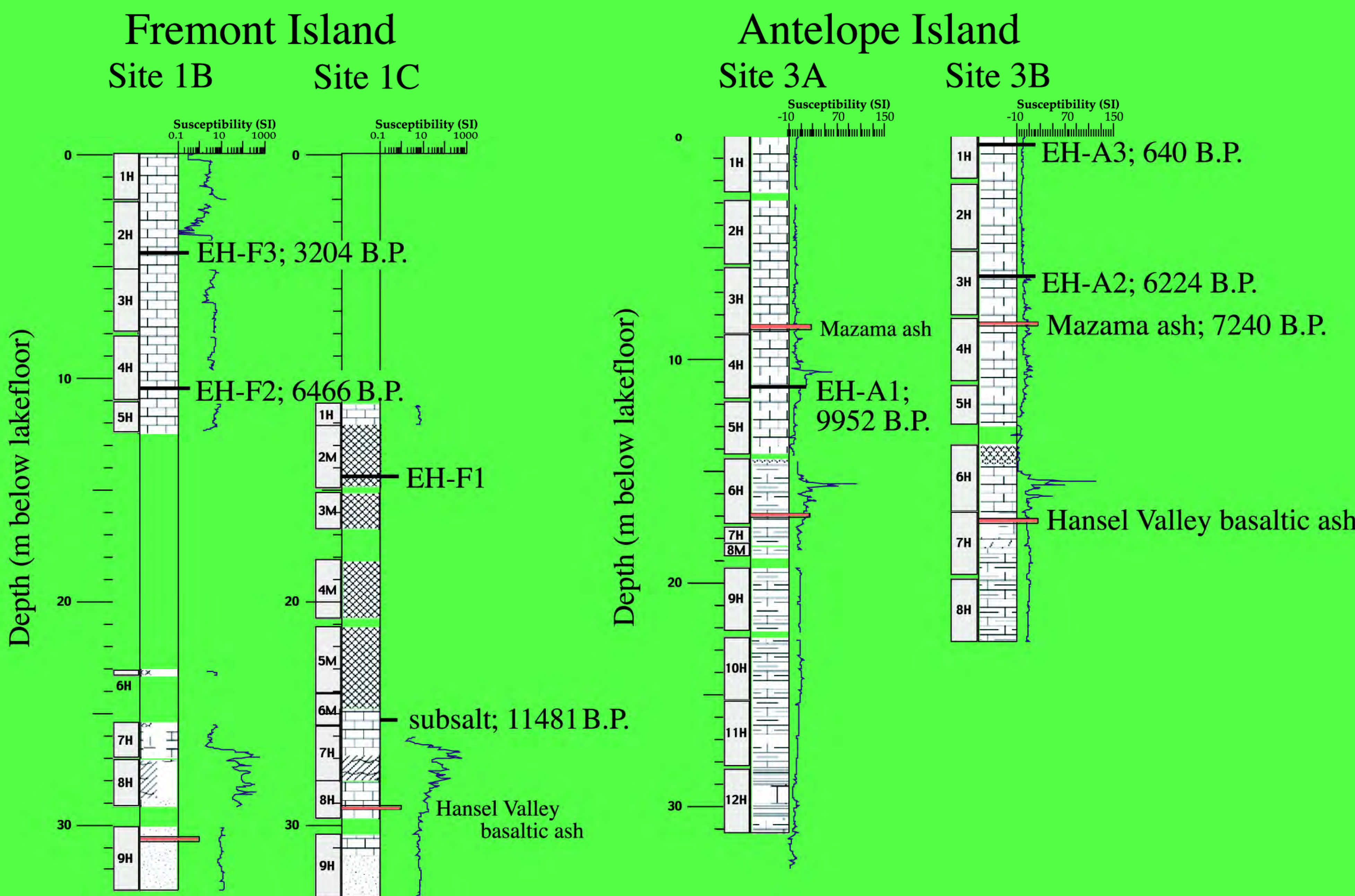


Geopulse Line 98GSL36

Maximum Magnitude Estimates, Great Salt Lake Fault

(from empirical relationships in Wells and Coppersmith, 1994)

Faulting Parameter	Antelope Segment	Fremont Segment
Surface Rupture Length	6.9 ± 0.3	6.8 ± 0.3
Rupture Area	6.9 ± 0.3	6.8 ± 0.3



Fremont Island
Site 1B
Site 1C
Antelope Island
Site 3A
Site 3B
Susceptibility (SI)
0.1
10
1000
-10
70
150
Depth (m below lakefloor)
0
10
20
30
1H
2H
3H
4H
5H
6H
7H
8H
9H
10H
11H
12H
2M
3M
4M
5M
6M
8M
EH-F3; 3204 B.P.
EH-F2; 6466 B.P.
EH-F1
subsalt; 11481 B.P.
Hansel Valley basaltic ash
Mazama ash
EH-A1; 9952 B.P.
EH-A3; 640 B.P.
EH-A2; 6224 B.P.
Mazama ash; 7240 B.P.
Hansel Valley basaltic ash

Earthquake dates, Great Salt Lake fault

Earthquake	^{14}C yr BP (before 1950)[1]	Calendar yr BP (before 1950)[2]; Stuiver et al., 1998 terrestrial calibration	Residence-corrected[3] calendar years BP **(before 1950)**[2]	Residence-corrected[3] calendar years **before 2004**[2]
Antelope Island segment				
EH-A3	> 804 ± 38 < 1027 ± 44	> 706 +81/-40 < 944 +106/-147	586 +201/-241	640 +201/-241
EH-A2	5,711 ± 50	6491 +163/-135	6170 +236/-234	6224 +236/-234
EH-A1	9,068 ± 66	10,219 +178/-234	9898 +247/-302	9952 +247/-302
Fremont Island segment				
EH-F3	3,269 ± 47	3471 +161/-90	3150 +235/-211	3204 +235/-211
EH-F2	5,924 ± 44	6733 +121/-90	6412 +209/-211	6466 +209/-211
EH-F1	<10,155 ± 72	<11,748 +580/-406	<11,427 +605/-449	<11,481 +605/-449

Earthquake recurrence intervals, Great Salt Lake fault

Earthquake pairs	Dates of occurrence (residence-corrected cal yr before 2004)	Recurrence interval (yr)
Antelope Island segment (M_{max} = 6.9)		
EH-A3 **EH-A2**	640 +201/-241 6224 +236/-234	5584 $^{+219/-172}$
EH-A2 **EH-A1**	6224 +236/-234 9952 +247/-302	3728 $^{+204/-351}$
Fremont Island segment (M_{max} = 6.8)		
EH-F3 **EH-F2**	3204 +235/-211 6466 +209/-211	3262 $^{+151/-184}$
EH-F2 **EH-F1**	6466 +209/-211 < 11,481 +605/-449	< 5015 $^{+587/-424}$

Average single-segment recurrence interval
= 4191 ± 1418 years

South arm update:

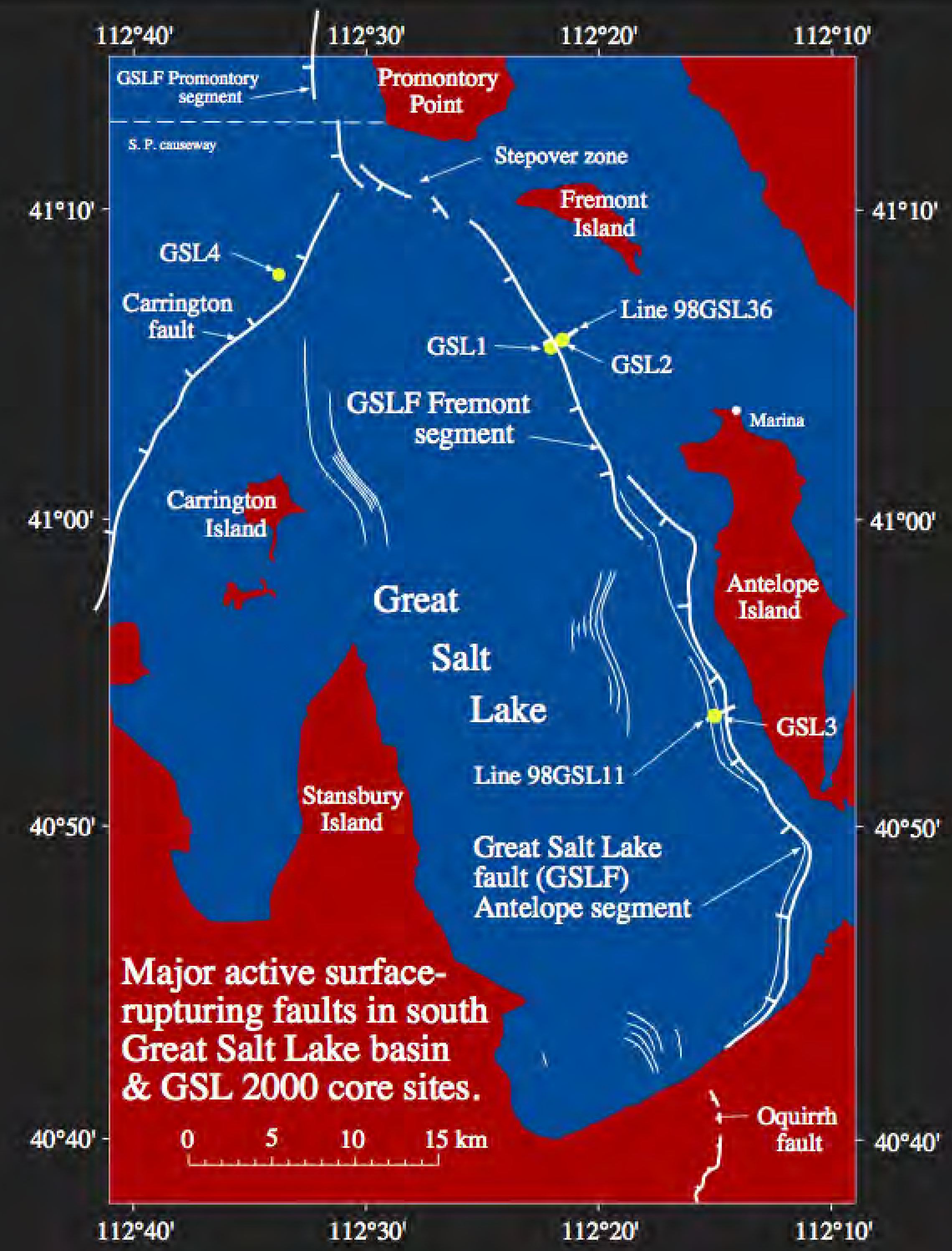
• Acquired new south arm seimic data in 2005, primarily north of Carrington Island to Promontory Point stepover zone.

• Carrington fault is an independent seismogenic structure ~30 km long.

Does *not* merge with GSL
Events as large as M 6.8
Fresh scarp = recent earthquake

• GSLF Fremont segment is shorter than previously mapped (~20 km)

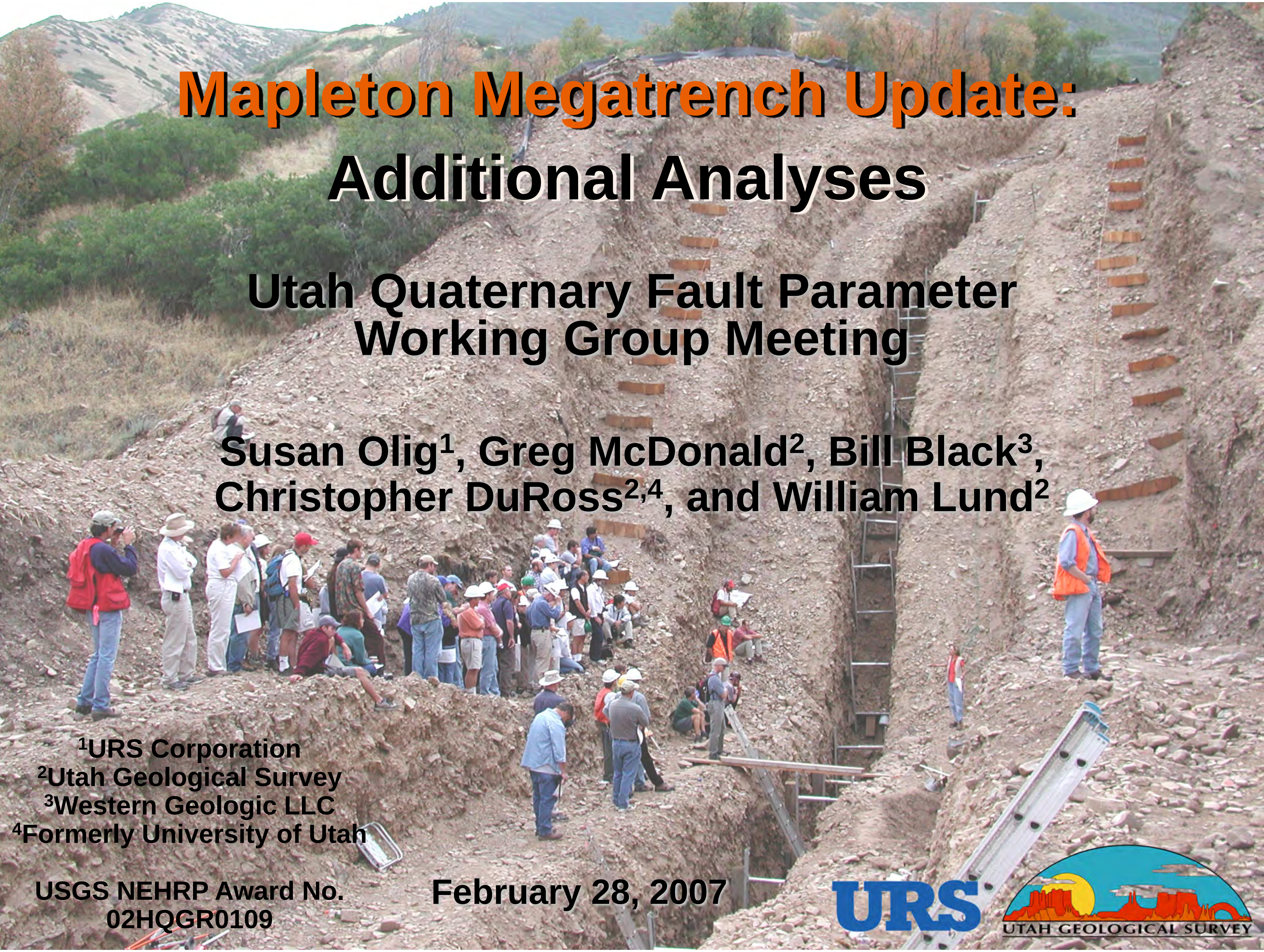
Does not curve NW to merge with Promontory segment.
Left stepover zone ~ 7 km wide contains short faults probably coseismic with Promontory segment.



North Arm preliminary results

- Obtained 15 north arm crossings of GSLF in May, 2006
- Data as yet unprocessed; no detailed map
- But, raw field records indicate:

Two additional segments in the north arm.
Promontory segment has a young scarp.
Stepover faults at south end of Promontory Point
also have fresh scarps; may be coseismic.
Rozelle segment is largely buried, and is northernmost
segment of GSLF system.
Hansel Valley fault to north has opposite vergence.
There is likely a tear-fault system in Spring Bay.



Mapleton Megatrench Update:
Additional Analyses

Utah Quaternary Fault Parameter Working Group Meeting

Susan Olig[1], Greg McDonald[2], Bill Black[3], Christopher DuRoss[2,4], and William Lund[2]

[1]URS Corporation
[2]Utah Geological Survey
[3]Western Geologic LLC
[4]Formerly University of Utah

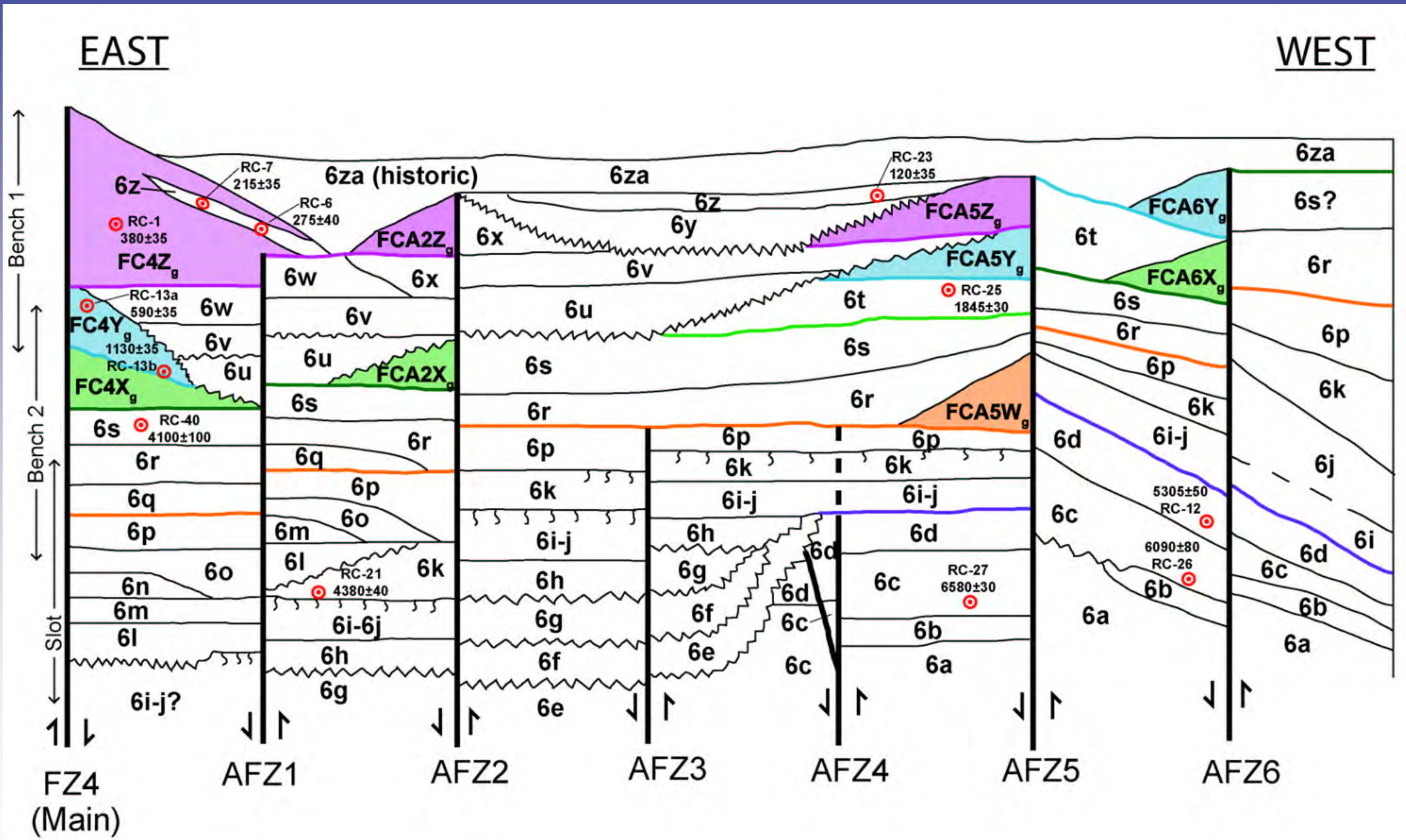
USGS NEHRP Award No. 02HQGR0109

February 28, 2007

URS

UTAH GEOLOGICAL SURVEY

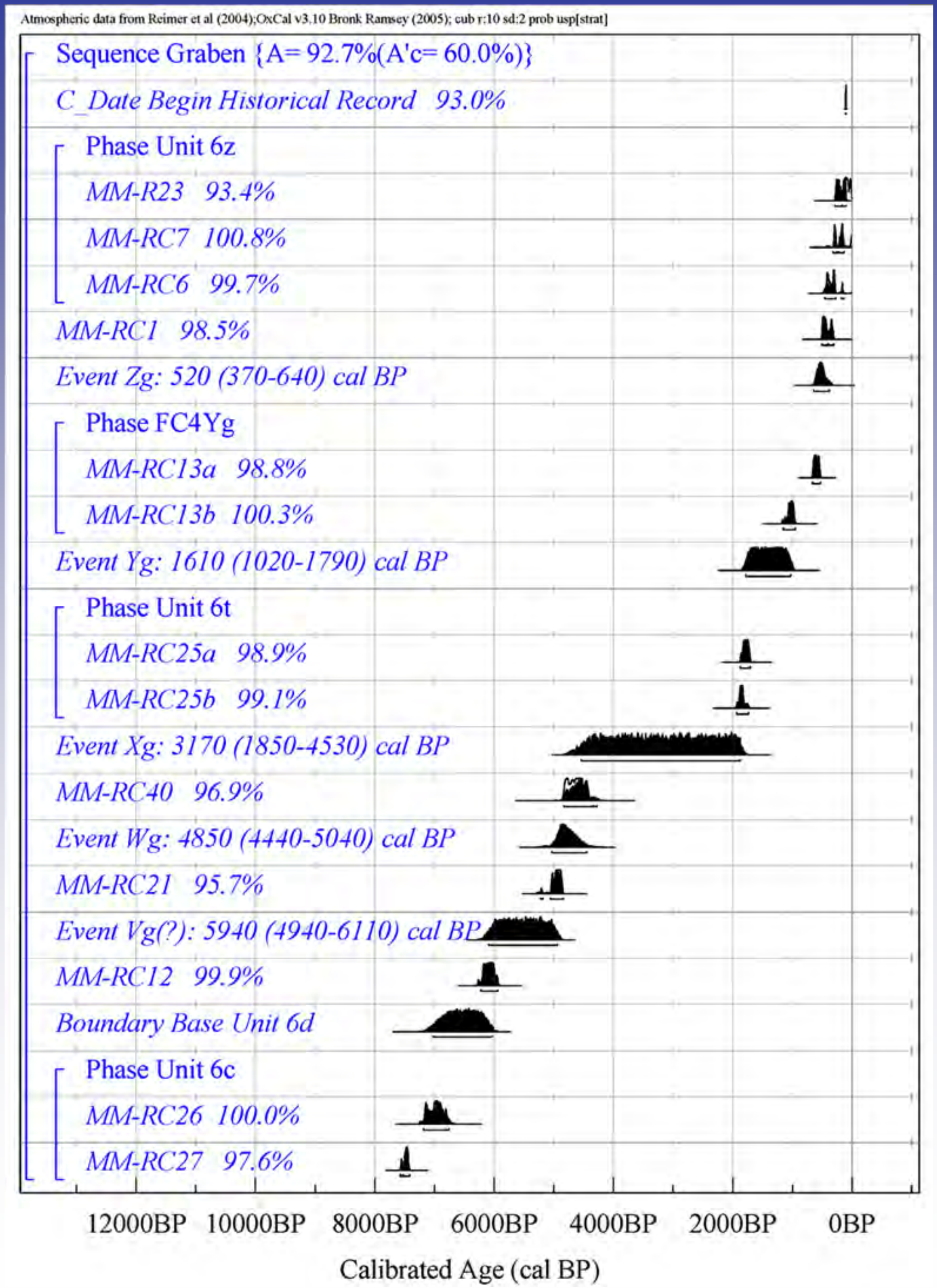
Graben Surface-Faulting Event Horizons Events Z_g Through V_g (?)



At least 4, possibly 5 separate events occurred since 6,100 cal BP

URS

Age Analysis of Graben Faulting Events



- **13 AMS radiocarbon analyses of charcoal samples**
- **Ages were calibrated and analyzed using OxCal v 3.10 (Bronk Ramsey, 2005) with IntCal04 calibration curve (Reimer et al., 2004)**
- **Slightly revised since UQFPWG '06**

Comparison With Previous Studies

<table>
<tr><th rowspan="2">Event</th><th rowspan="2">This Study
MN</th><th rowspan="2">UQFPWG
(Lund, 2005)
Entire
Segment</th><th rowspan="2">Lund et al. (1991)
MN and MS</th><th rowspan="2">Machette et al. (1992)
American
Fork</th><th rowspan="2">Swan et al.
(1980);
Schwartz et
al. (1983)
Hobble Creek</th><th colspan="2">Ostenaa (1990)[1]
Water Canyon</th></tr>
<tr><th>WC1</th><th>WC2</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td><540</td><td></td></tr>
<tr><td>Z</td><td>500 (350 to 650)</td><td>600 ± 350</td><td>600 ± 80</td><td>500 ± 200</td><td rowspan="5">6 or 7 events
since Provo
delta formed
(Provo Phase
ended 13,700
to 14,000)</td><td>700
(500 to 900)</td><td rowspan="2">1,300

(500 to 2,000)</td></tr>
<tr><td>Y</td><td>1,600
(1,000 to 1,800)</td><td></td><td>MS – Not Exposed?
MN – Not Dated</td><td>Not
Exposed?</td><td rowspan="4">Not
Exposed</td></tr>
<tr><td>X</td><td>3,150
(1,850 to 4,550)</td><td>2,850 ± 650</td><td>2,820
+150/-130</td><td>2,650 ± 250</td><td>3,500
(1,600 to 4,400)</td></tr>
<tr><td>W</td><td>4,850
(4,450 to 5,050)</td><td rowspan="2">5,300 ± 300</td><td rowspan="2">Not Exposed</td><td>5,300 ± 300</td><td rowspan="2">4,700
(3,700 to 5,600)</td></tr>
<tr><td>V (?)</td><td>5,950
(4,950 to 6,100)</td><td>5.3 to 8.1 ka</td></tr>
</table>

[1] Based on radiocarbon ages and relations provided by D. Ostenaa, USBR, pers. comm. (1/11/2006). Recalibrated using OxCal 3.10 (Bronk Ramsey, 1995; 2001) and IntCal04 calibration curve (Reimer et al., 2004)

Summary of Graben Surface-Faulting Events

- At least 4, possibly 5, events occurred since ≈ 6 ka (more events)
- 4 events occurred between 500 (± 150) cal BP and 4,850 (-400, +200) cal BP
- This indicates a **shorter** preferred average mid to late Holocene recurrence interval of **1,450 ± 250 years**
- Preferred estimates of individual recurrence intervals range from **1,100 to 1,700 years**
- Compared to previous consensus values of 2,400 (+800, -1200) years by UQFPWG (Lund, 2005)

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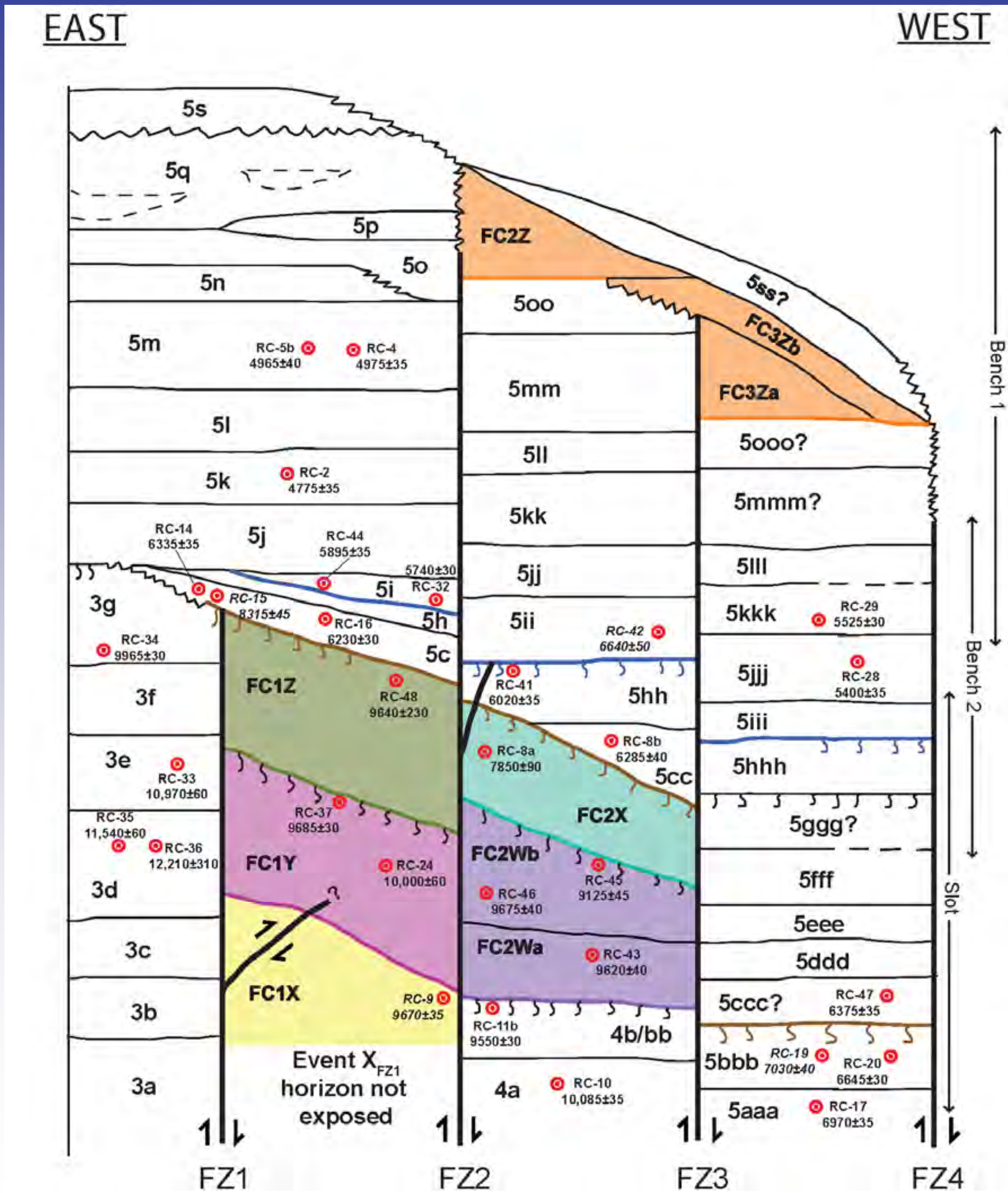
Footwall Surface-Faulting Events Horizons



- Evidence for at least 4, possibly as many as 7 surface faulting events

Preliminary Summary of Surface-Faulting Events

Footwall Faults			Graben Faults							
FZ1	FZ2	FZ3	FZ4 (main graben)	AFZ1	AFZ2	AFZ3	AFZ4	AFZ5	AFZ6	Graben Event Age
			Z_g	Z_g	Z_g			Z_g		500 (350 to 650)
			Y_g	Y_g				Y_g	Y_g	1600 (1000 to 1800)
			X_g		X_g				X_g	3150 (1850 to 4550)
	Z_{FZ2} < 5600	Z_{FZ3} < 5600				W_g		W_g		4850 (4450 to 5050)
			Not Exposed				V_g (?)			5950 (4950 to 6100)
	Y_{FZ2} (?) (just slumping?) 6450 to 7600	Y_{FZ3} (?) 7250 to 7600	Not Exposed							
	X_{FZ2} 8450 to 10,400	Not Exposed	Not Exposed							
Z_{FZ1} 10,300 to 11,200	W_{FZ2} 10,800 to 11,950	Not Exposed	Not Exposed							
Y_{FZ1} 11,250 to 13,550		Not Exposed	Not Exposed							
X_{FZ1} 11,250 to 13,550		Not Exposed	Not Exposed							

At least 7, possibly 11 or more events occurred since 13,550 cal BP

Planned Additional Analyses:

- Construct a trench retrodeformation sequence (for entire trench)
- Conduct OxCal analysis of radiocarbon ages for footwall sequence

URS

RECLAMATION

Managing Water in the West

PRELIMINARY RESULTS - "EAST" OF EAST CANYON FAULT

Larry W. Anderson

Seismotectonics & Geophysics Group

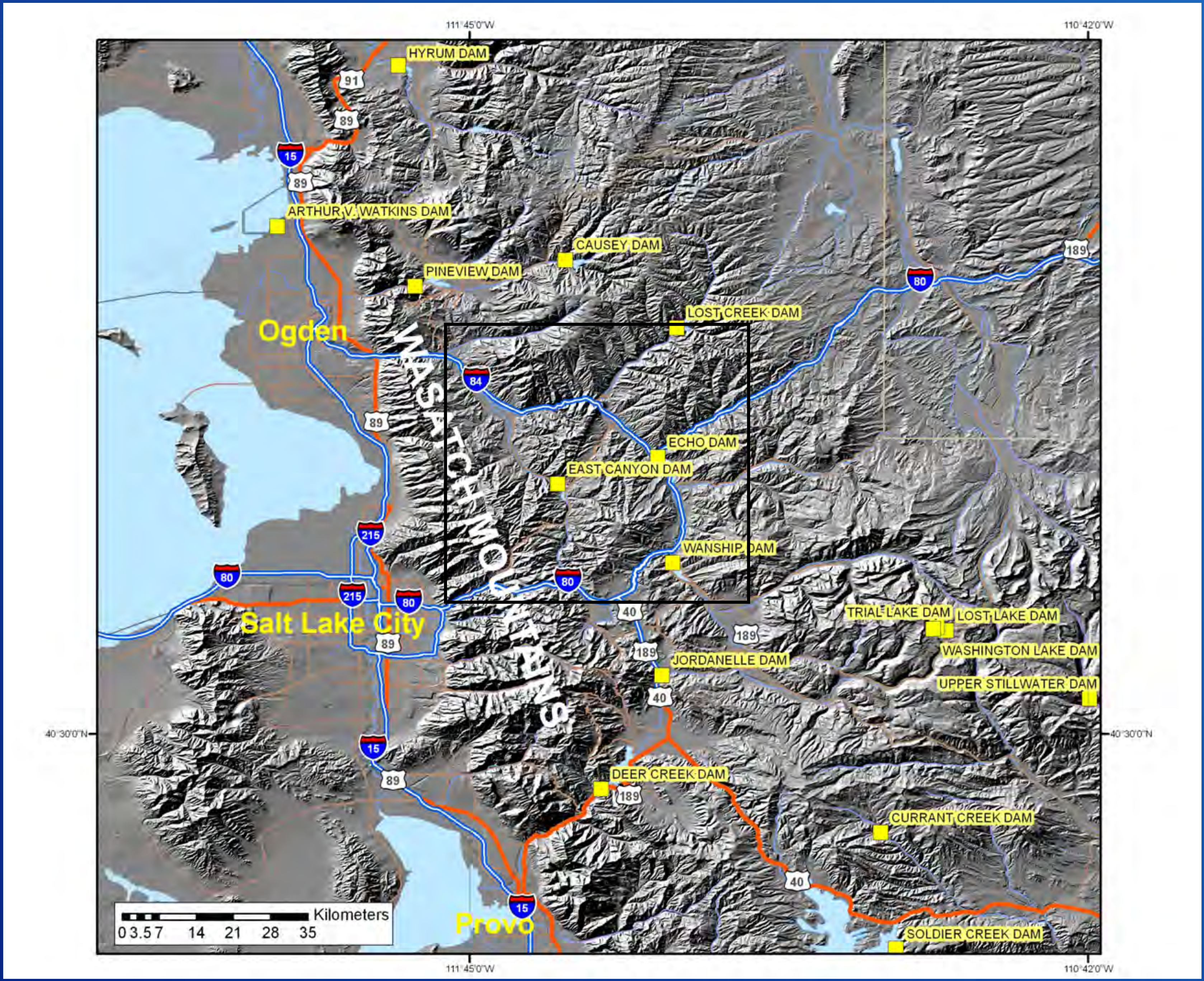
U.S. DEPARTMENT OF THE INTERIOR · BUREAU OF RECLAMATION

U.S. Department of the Interior
Bureau of Reclamation

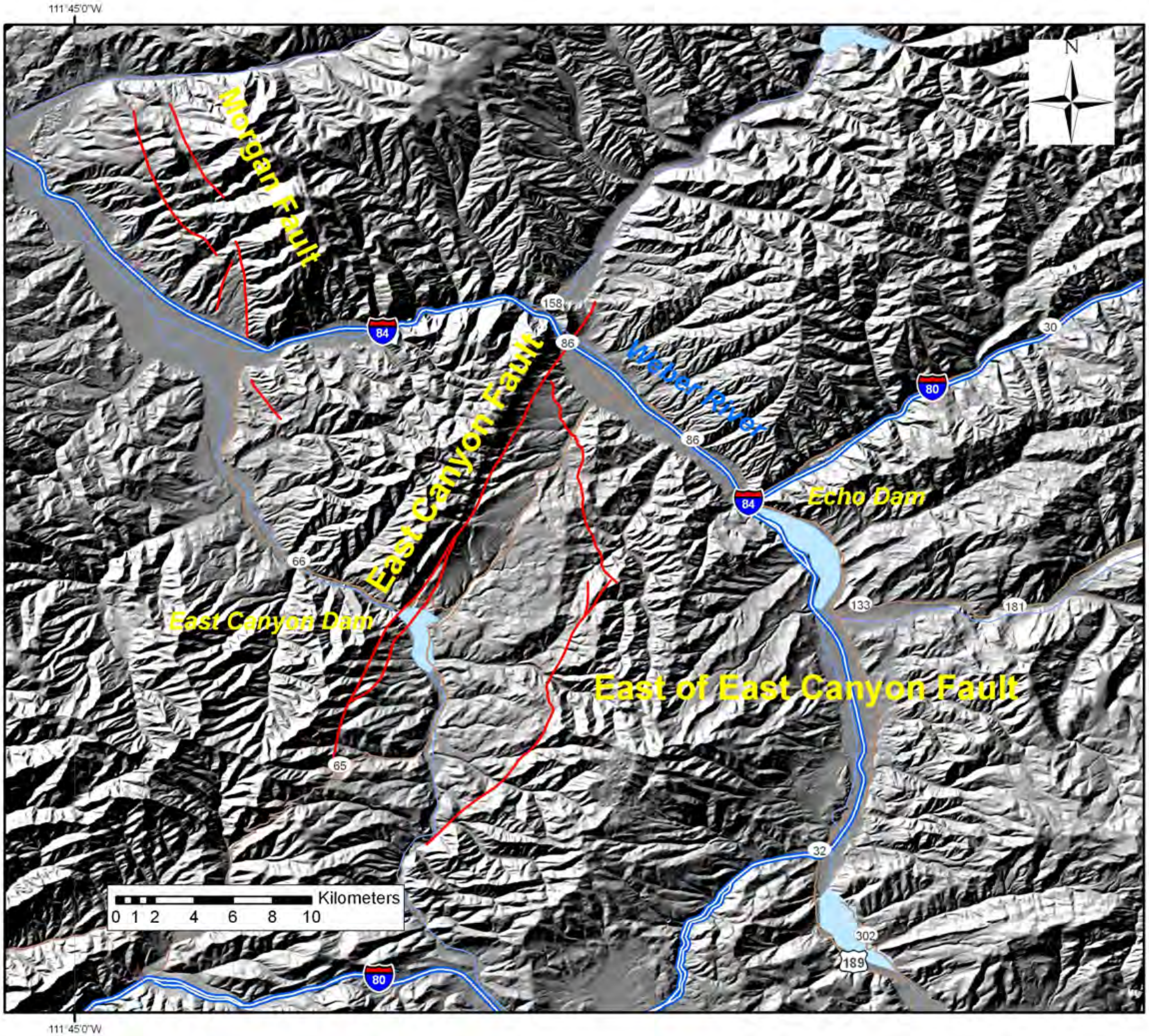
Reclamation Studies

- Sullivan et al., 1988 – Central Utah Regional Study
- Ostenaa, Piety, and O'Connell (in progress) – Seismic Source Characterization and Ground Motion Studies for Echo and East Canyon Dams

RECLAMATION



RECLAMATION



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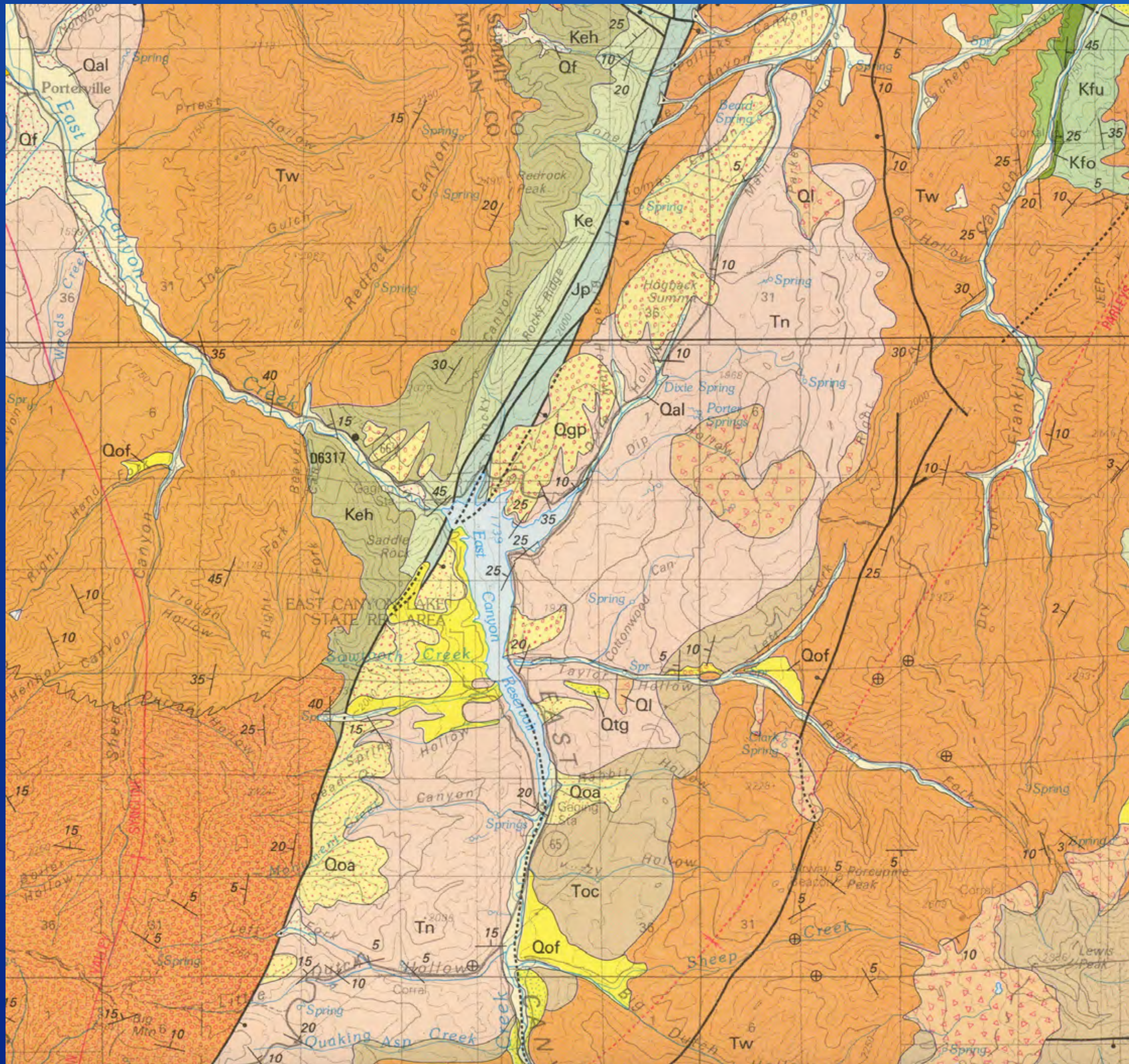


From Bryant, 1990

RECLAMATION

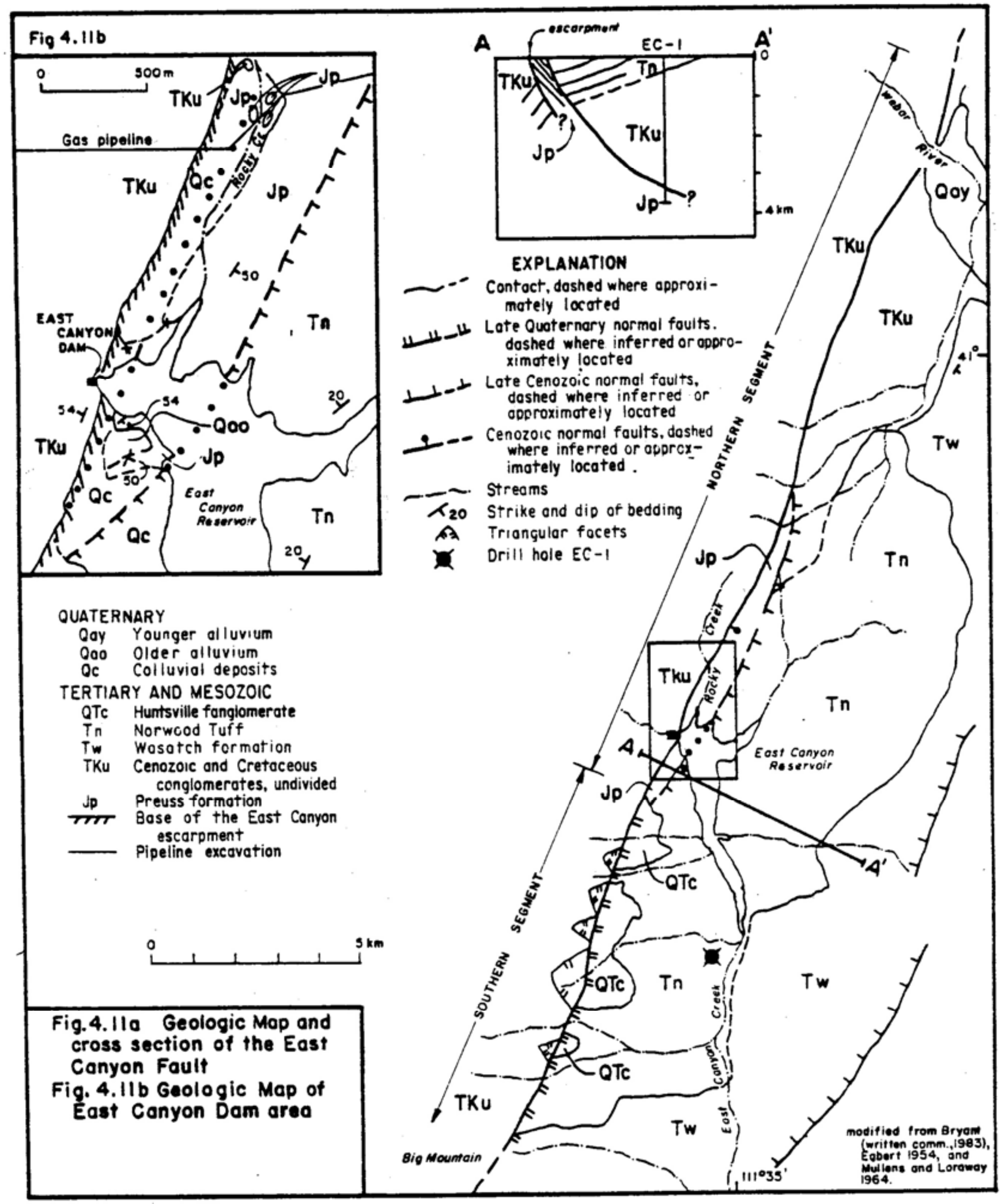


Fig. 4.11a Geologic Map and cross section of the East Canyon Fault
Fig. 4.11b Geologic Map of East Canyon Dam area

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>
- <u>Southern</u> – Based on similarities to the Morgan fault, assumed to be late Quaternary active

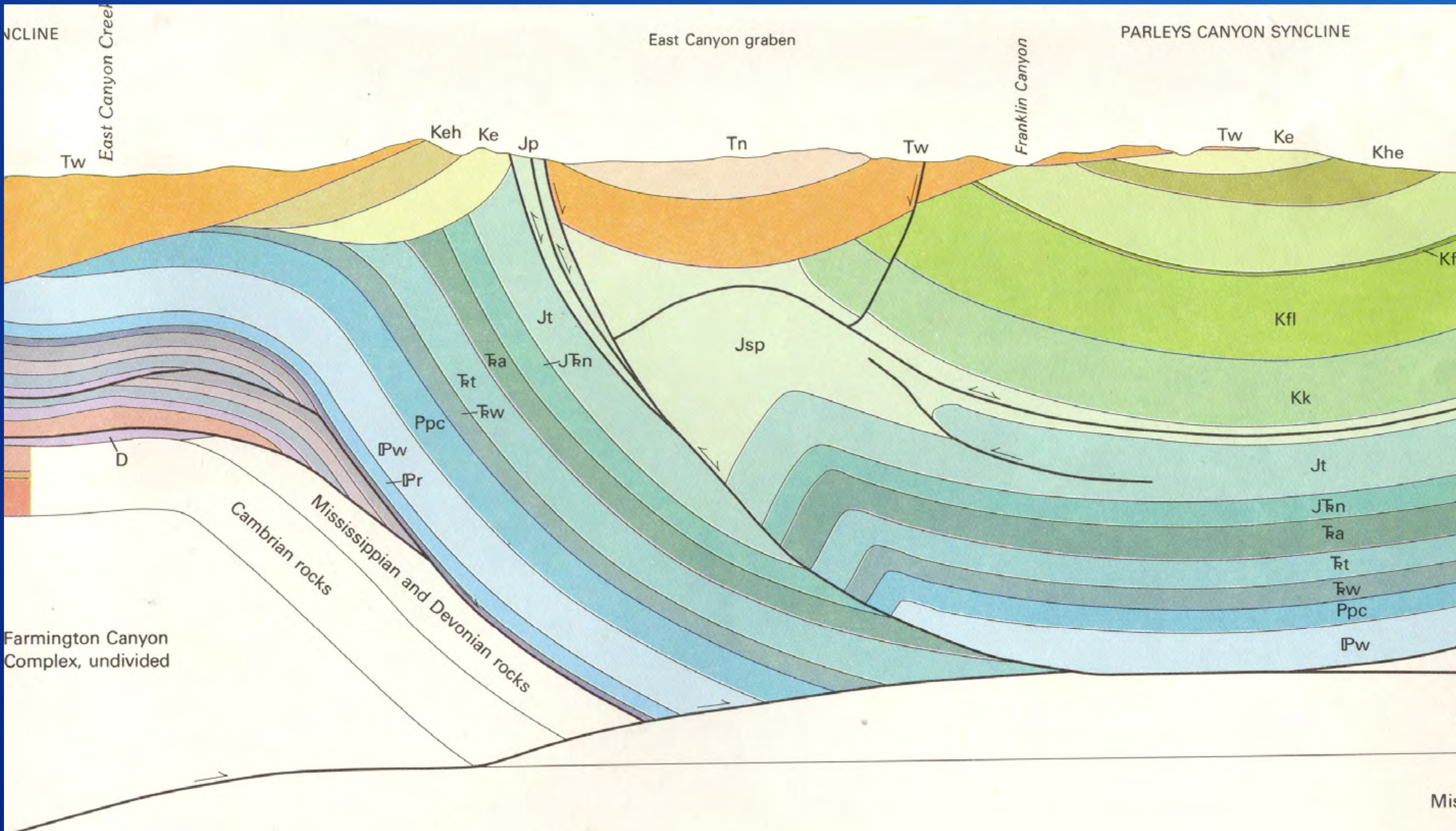
Sullivan et al., 1988

RECLAMATION

“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*

RECLAMATION



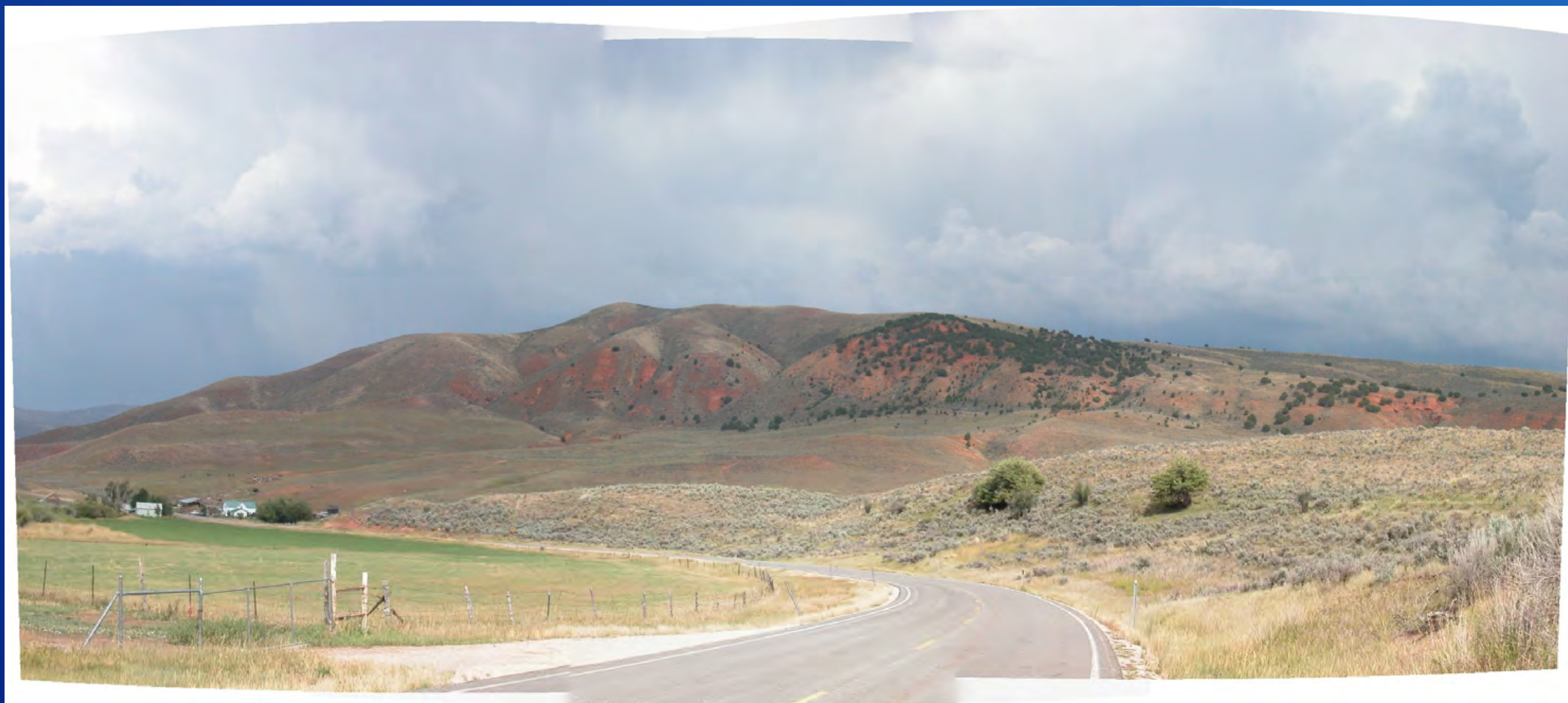
From Bryant, 1990

RECLAMATION

2006 – 2007 Studies

- 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 Canyon fault due to geomorphic expression and suggestion of late Quaternary displacement
- Trenching, acquisition and interpretation of geophysical data

RECLAMATION



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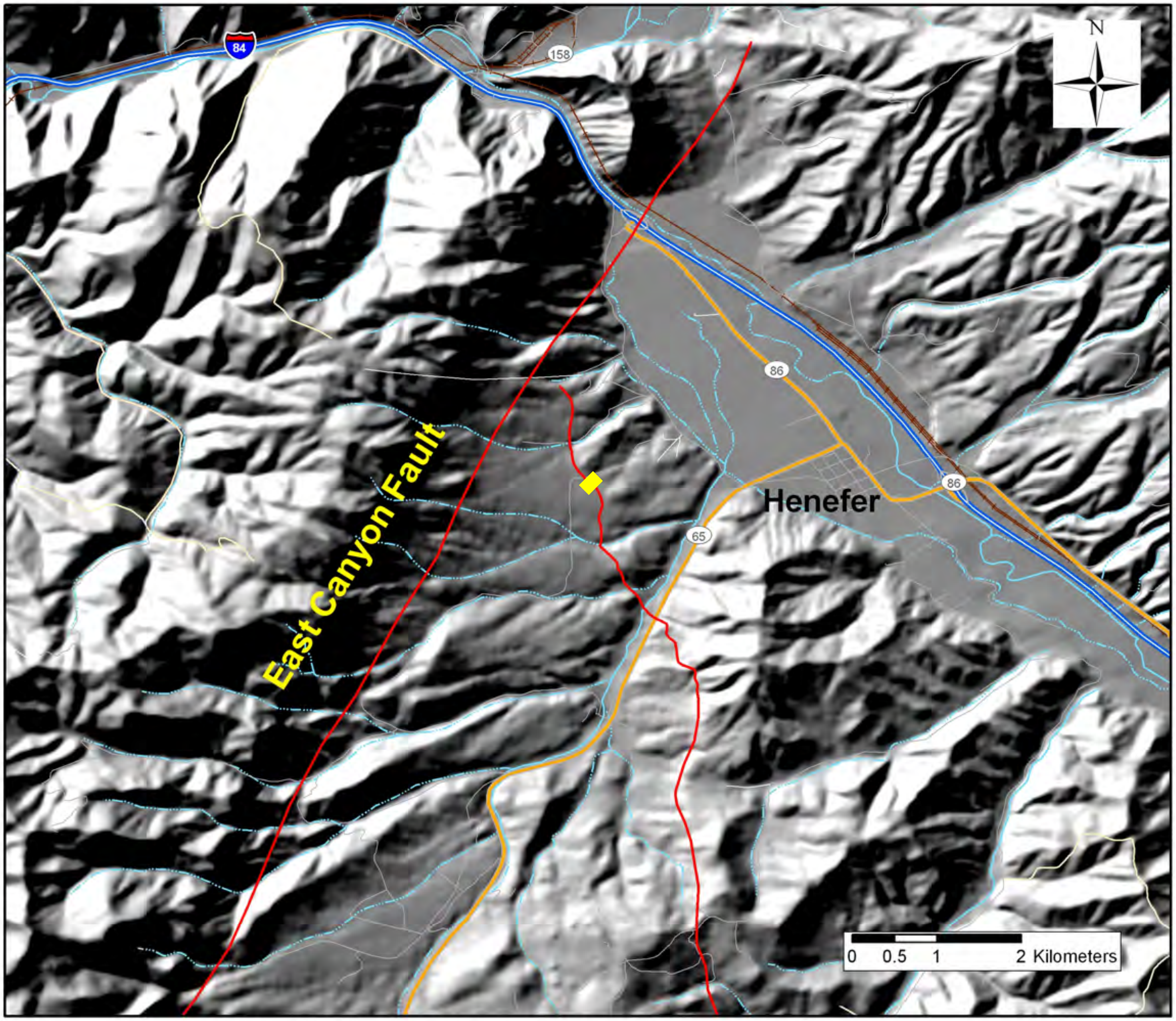

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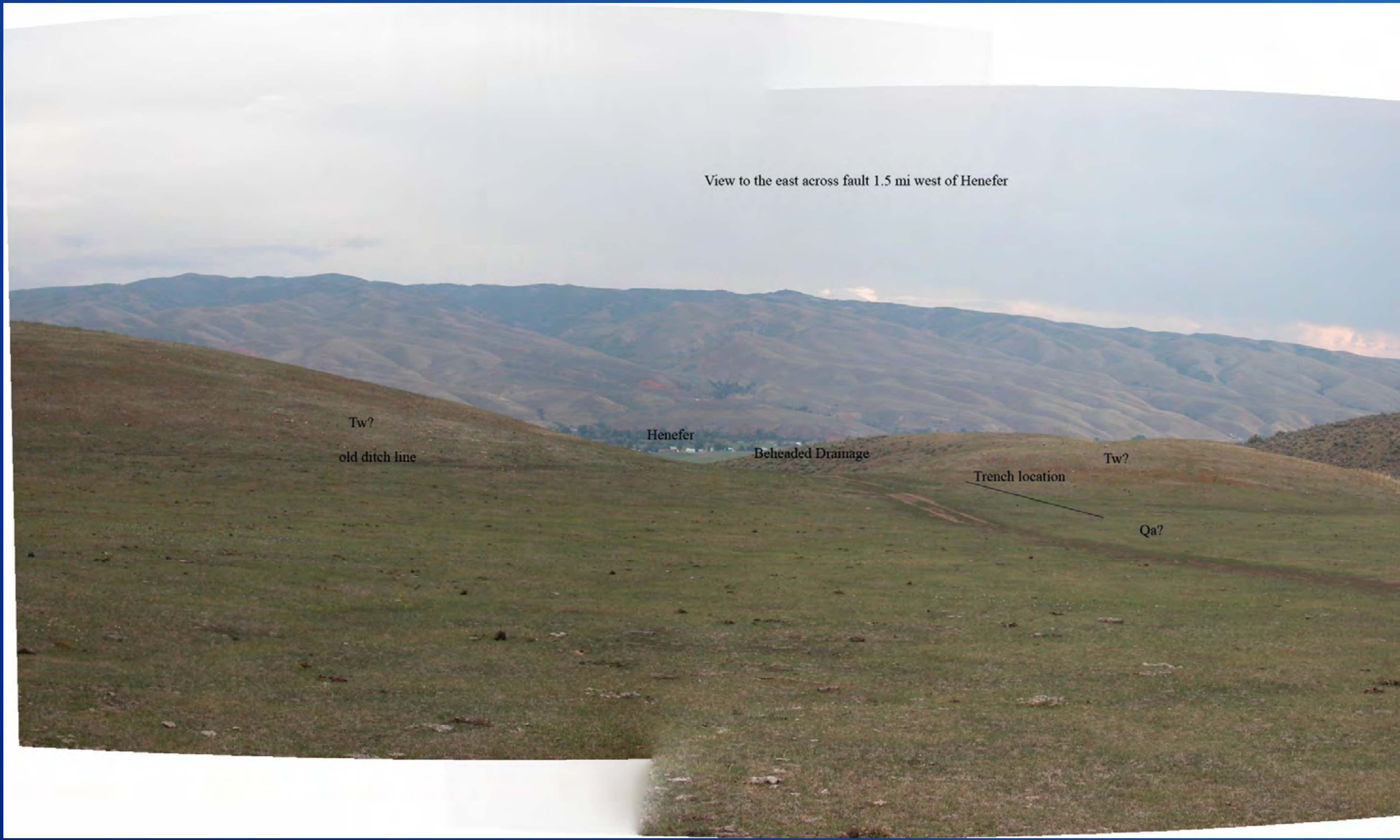

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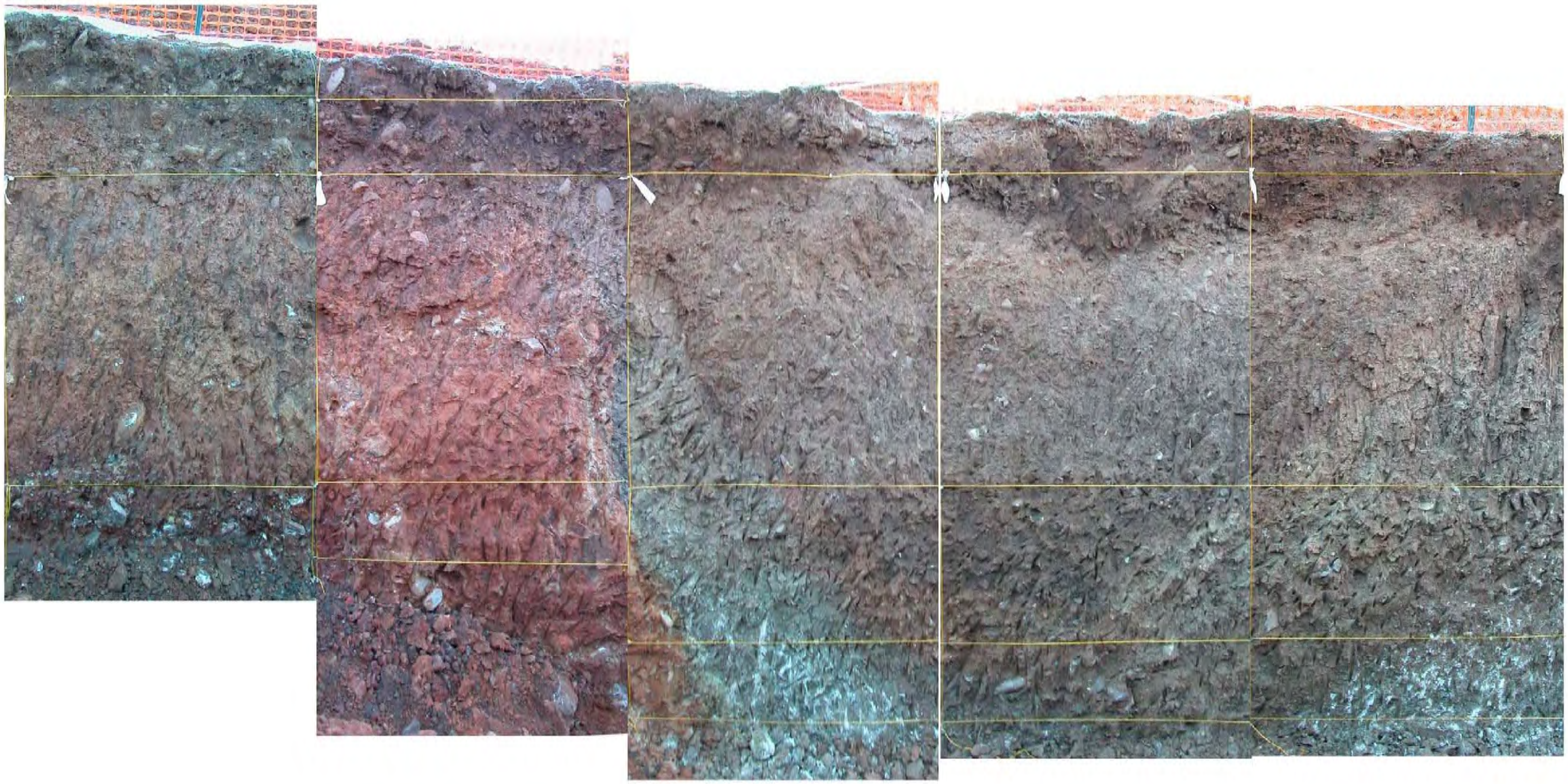

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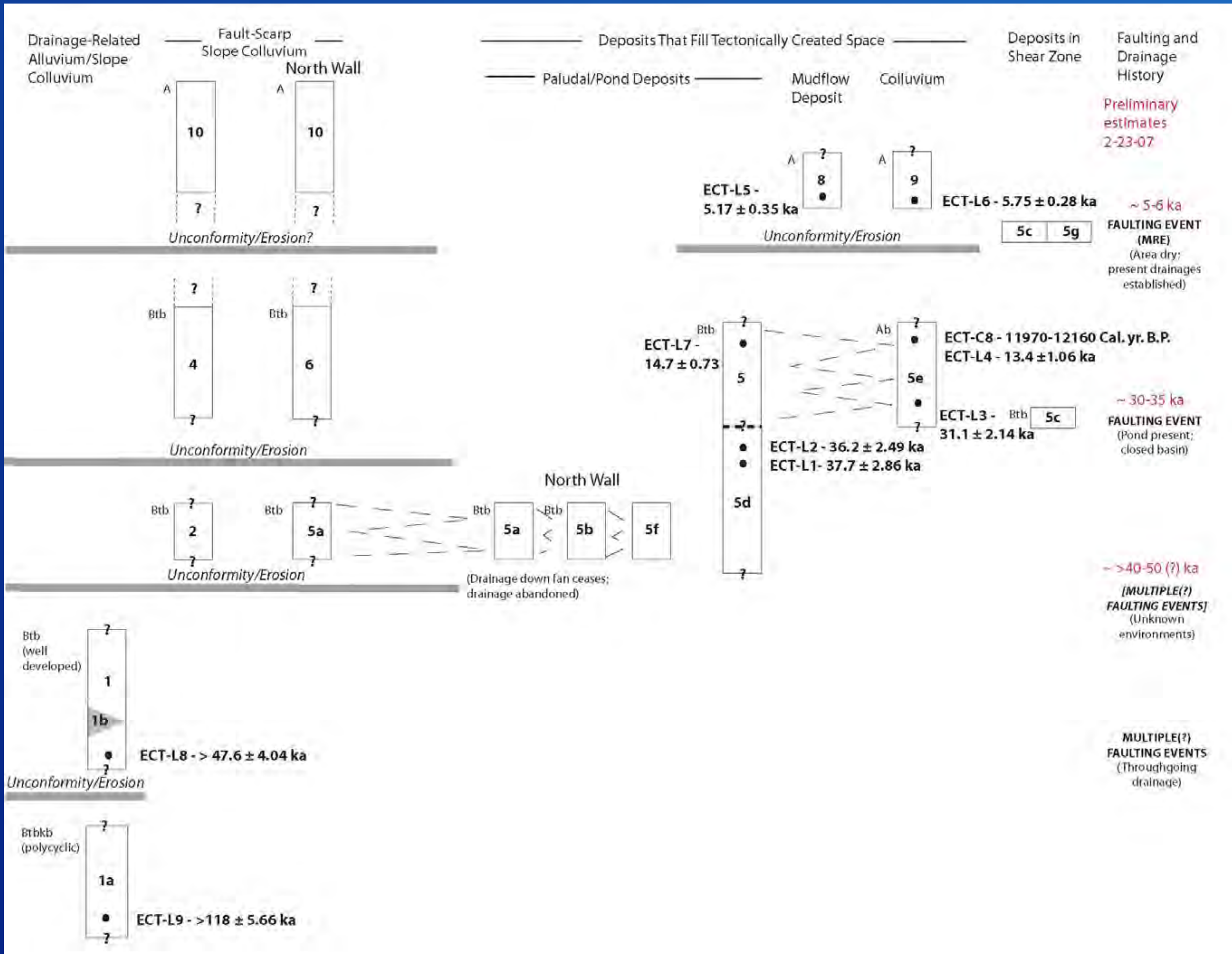


RECLAMATION

Preliminary Results
East of East Canyon Fault

- MRE: ~5-6 ka
- Penultimate event: ~30-35 ka
- Multiple events: > 40-50 ka
- Slip Rate: ~ 0.02-0.03 mm/yr

RECLAMATION

East Canyon Fault

- Past characterizations of slip rate based on comparisons to “high” values for Morgan fault
- Still no solid evidence for late Quaternary faulting
- Seismic reflection data suggests fault dip is on the order 30-45 degrees; might not go to seismogenic depths

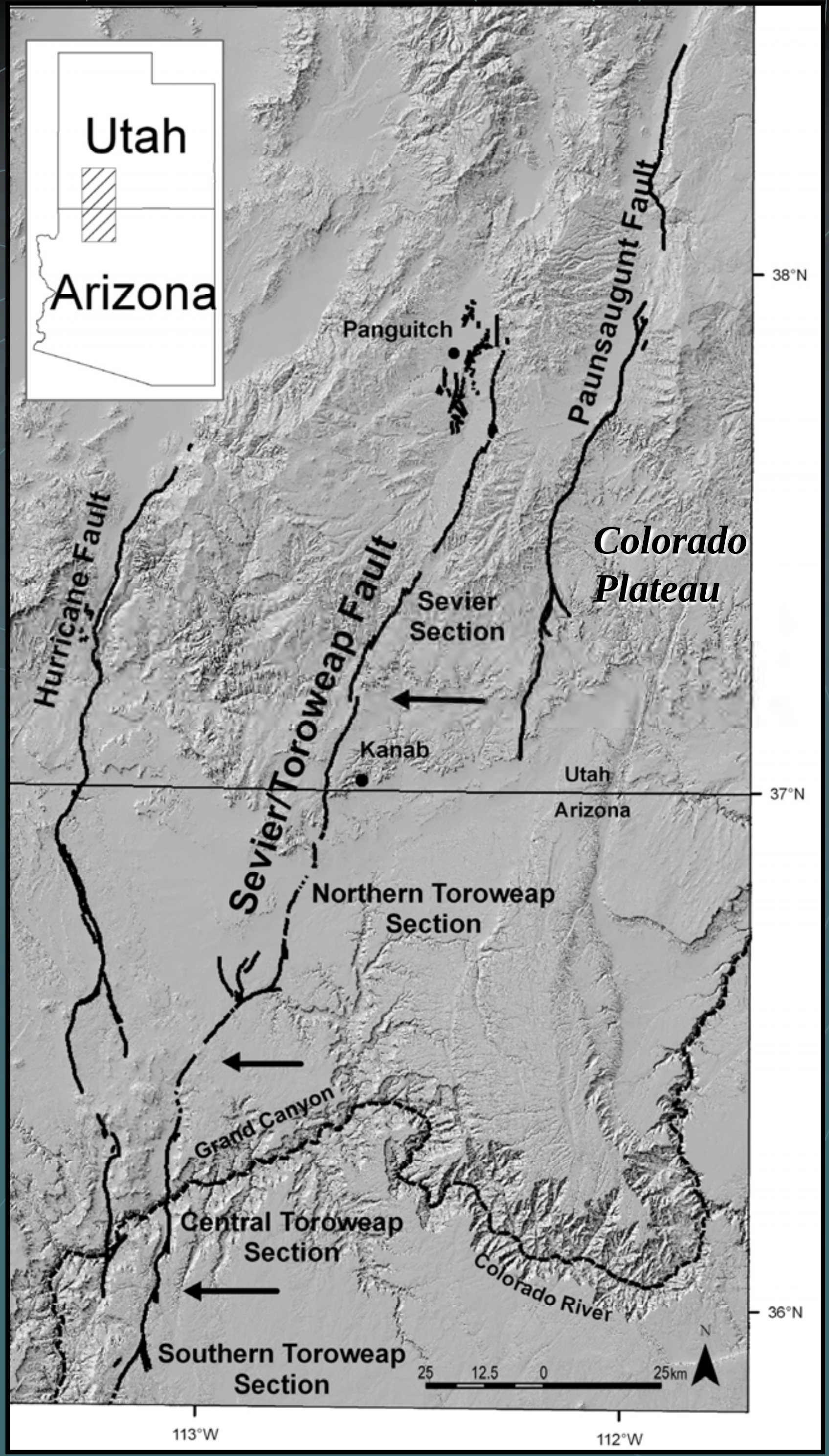
RECLAMATION

Paleoseismology and Segmentation of the Sevier Fault, Southwestern Utah

Tyler R. Knudsen
William R. Lund
Garrett S. Vice
Utah Geological Survey

Sevier/Toroweap Fault

- Normal, west-dipping
- Within Basin & Range-Colorado Plateau transition zone
- ~250 km long, 108 km in Utah
- Displacement increases northward
- Toroweap fault in AZ, Sevier fault in UT
- Four fault sections



Purpose

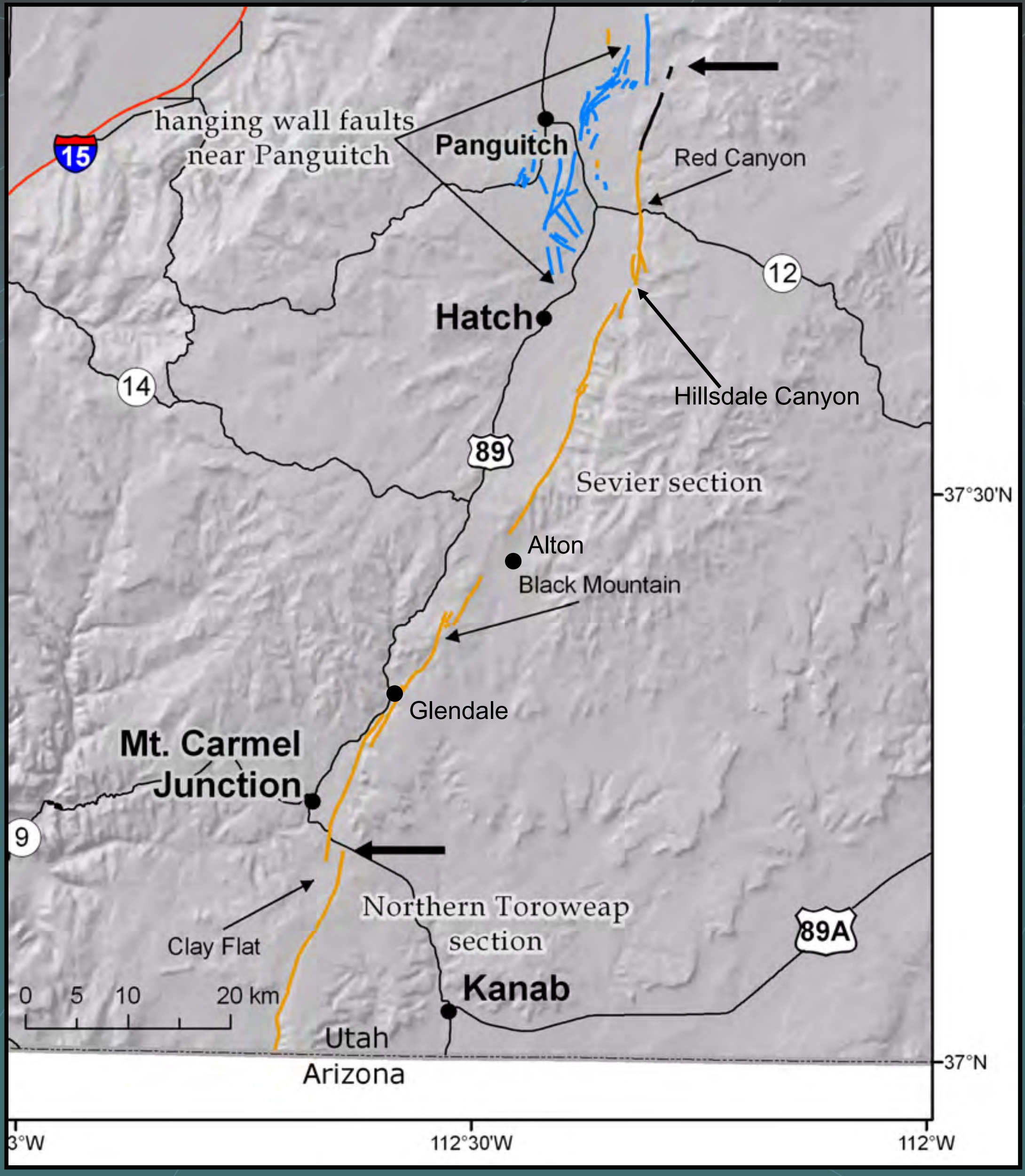
- Earthquake timing, recurrence, displacement, vertical slip rate, and segmentation
- Better assess seismic hazard
- Update the USGS Quaternary fault database
- Determine fault's importance to the USGS National Seismic Hazard Maps (NSHMs)

Methods

- Literature review
- Aerial photograph interpretation
- Field reconnaissance
- Sampling of displaced Quaternary volcanic rocks
  - $^{40}Ar/^{39}Ar$ radiometric dating
  - Geochemical analysis for correlation of flows
- Earthquake epicenter distribution

Results

- No scarps in unconsolidated deposits-no trench sites
- Quaternary volcanic rocks displaced at Black Mountain and Red Canyon
- Scarps on hanging-wall faults near Panguitch
- Three possible seismogenic segment boundaries

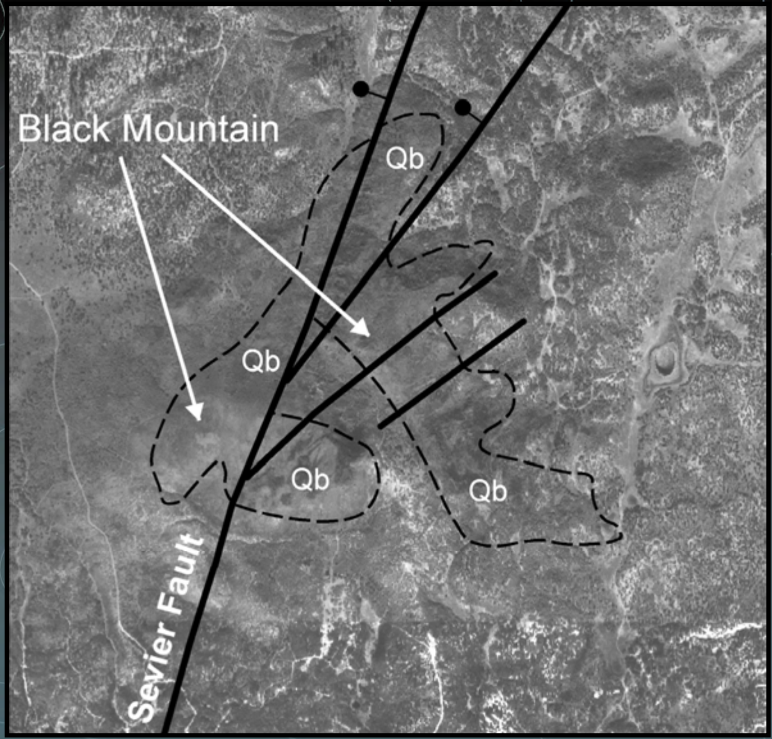


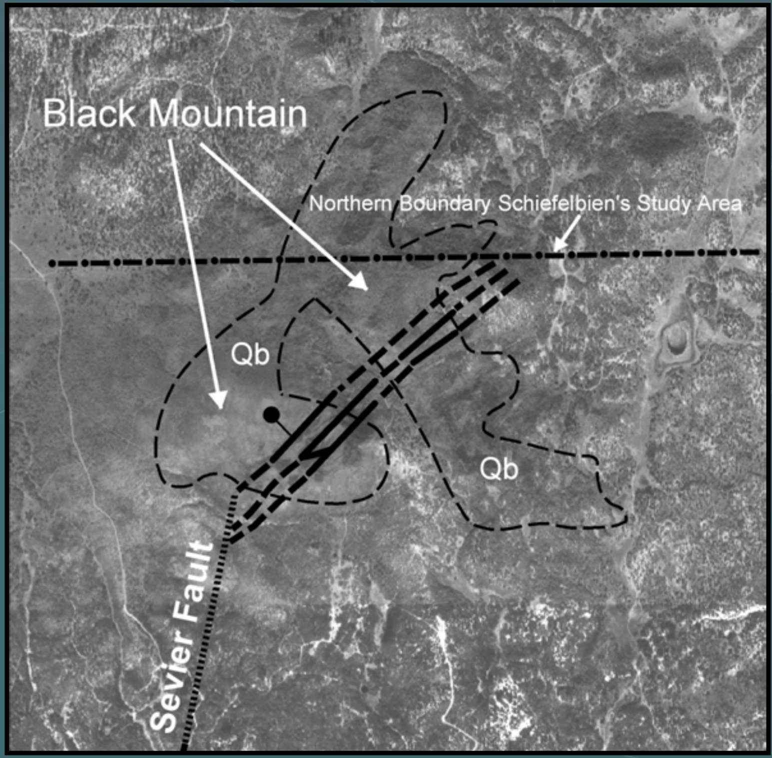
Black Mountain

- Sevier fault cuts 0.57 Ma volcanic rocks ($^{40}Ar/^{39}Ar$; Schielfelbein, 2002)
- Geologic relations are poorly exposed; difficult to attribute which scarps are due to surface faulting, landslides or preflow topography

Black Mountain

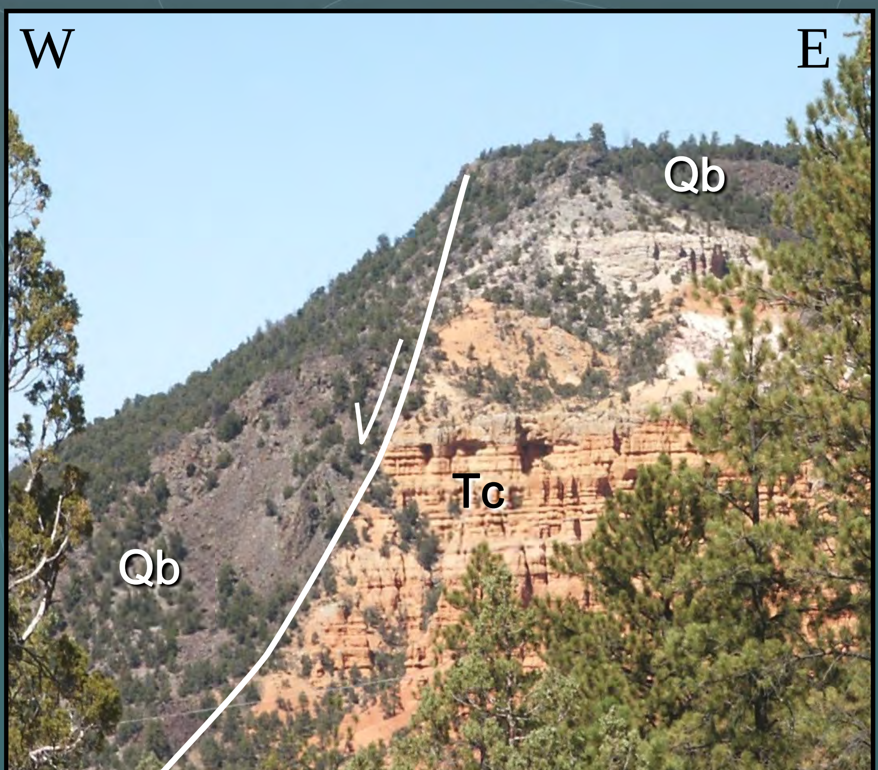
- Cashion (1967)
  - Volcanic rocks displaced 23 m
  - Vertical slip rate of **0.04 mm/yr**
- Schiefelbein (2002)
  - Volcanic rocks displaced 10 m
  - Vertical slip rate of **0.018 mm/yr**
- This Study
  - In agreement with Anderson and Christenson (1989) – too complex to estimate late Quaternary slip rate
  - Long term slip rate: 472-869 m stratigraphic offset (schiefelbein) and a 12-15 Myr age for the SF (Davis, 1999) = **0.03-0.07 mm/yr**
  - This slip rate likely has been consistent through the late Quaternary

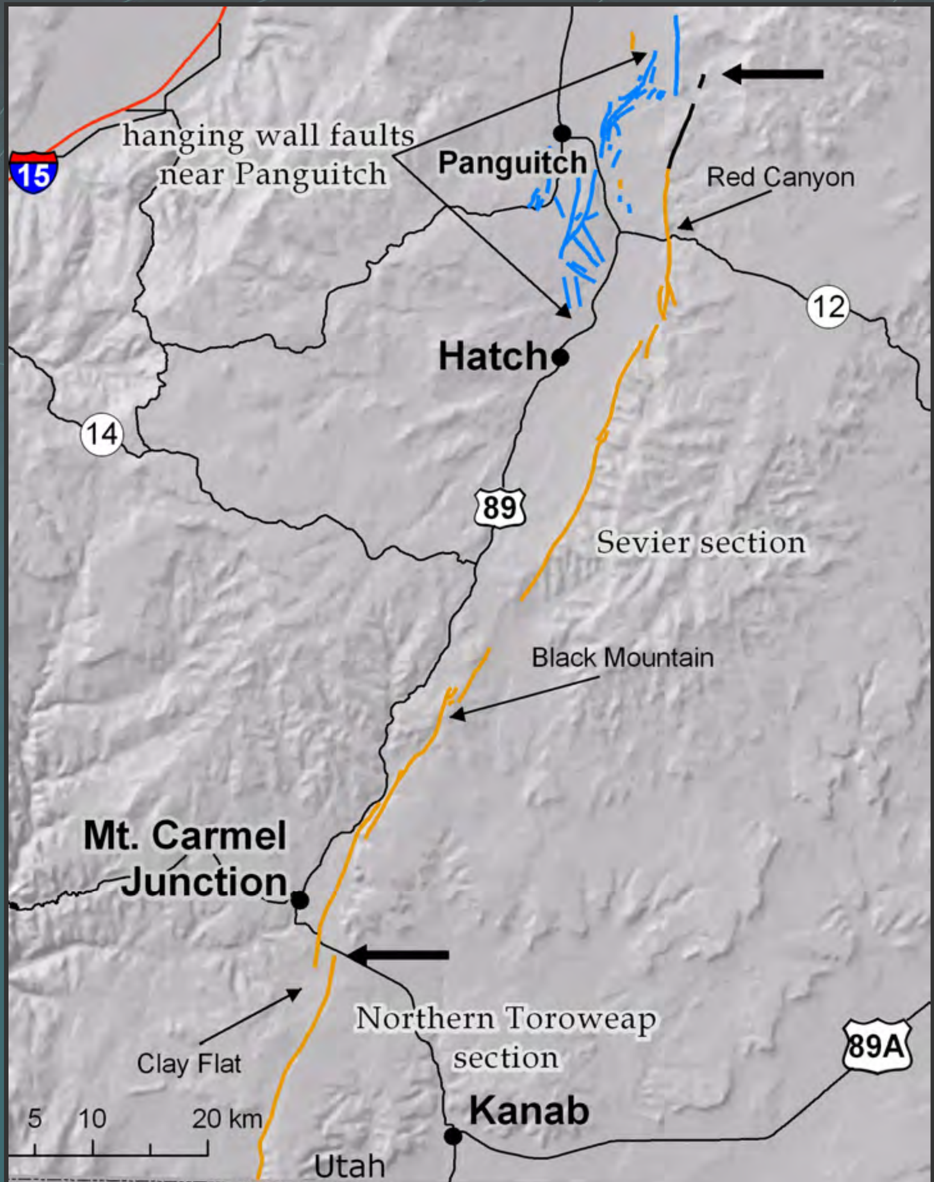




Red Canyon

Sevier Fault is well exposed along HWY 12 displacing Quaternary Volcanic rocks next to the Eocene Claron Formation



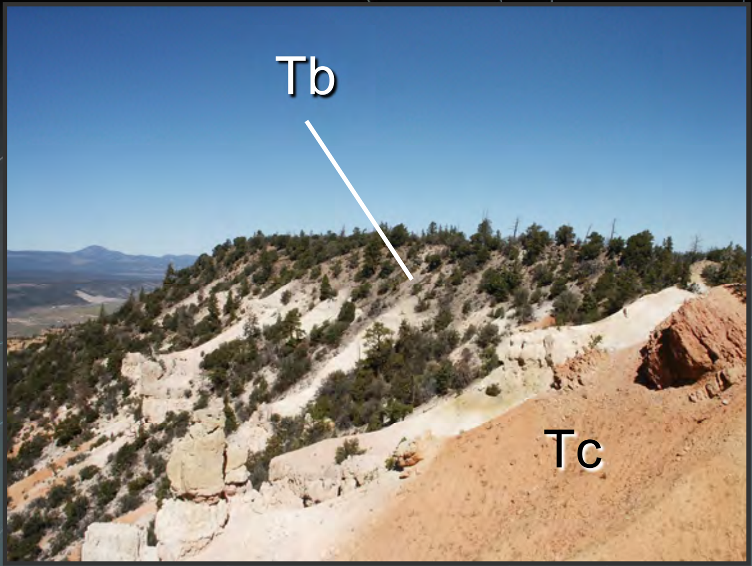


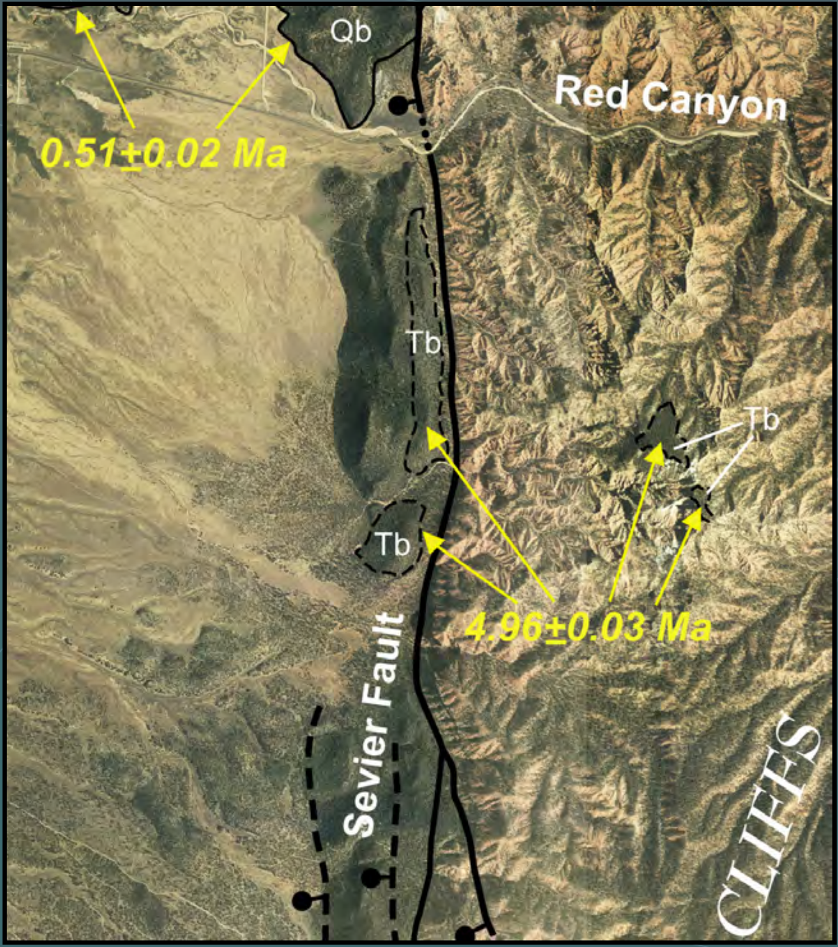
Red Canyon

- $^{40}Ar/^{39}Ar$ ages
  - 0.5 Ma flow north of canyon
  - 5 Ma flow south of canyon
- Geochemical Analysis
  - Flows are correlative across the fault
- True displacement?
  - Must know source location
  - Cinder/spatter cones on HW

Red Canyon

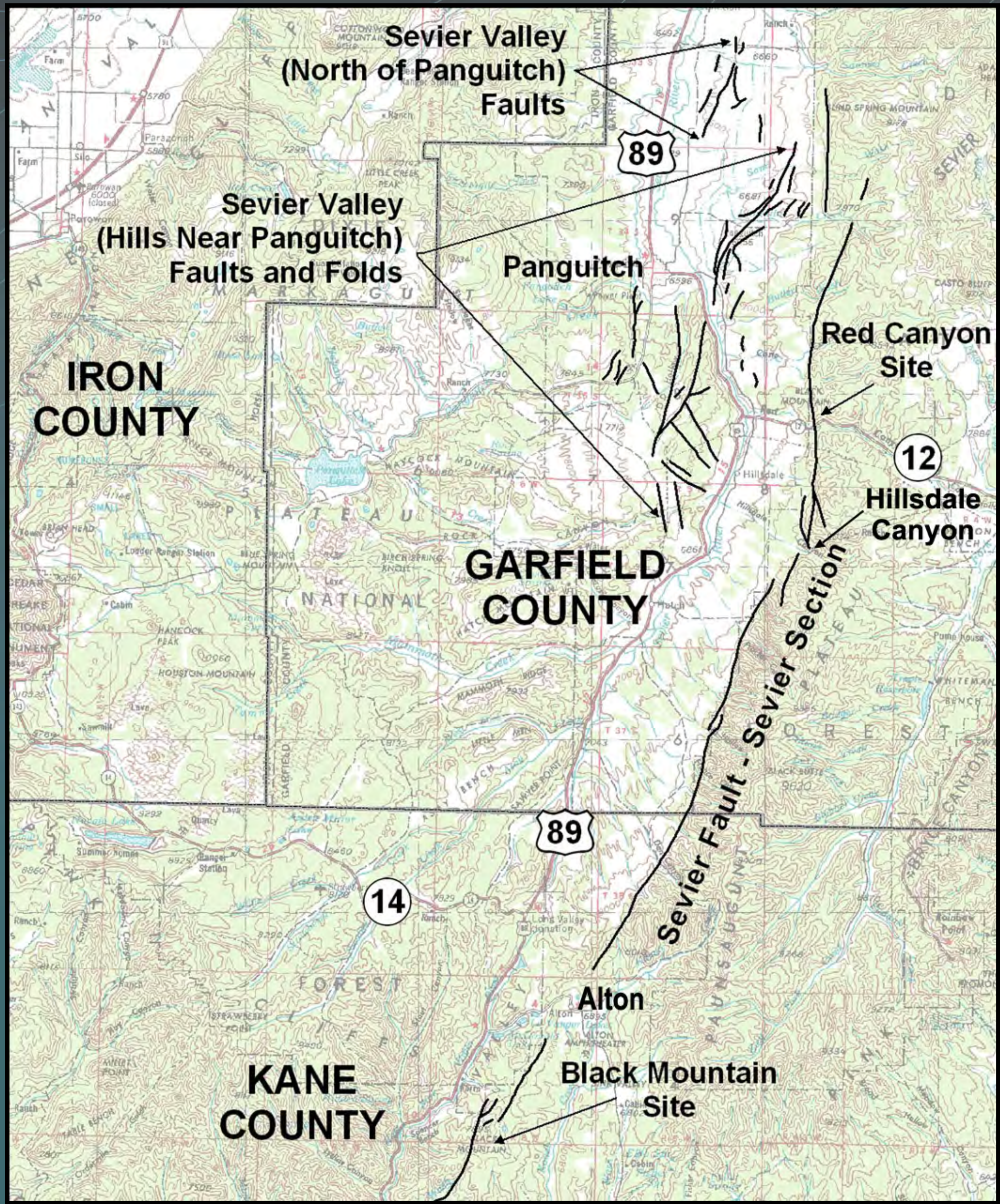
- 5 Ma flow south of canyon
  - Likely western source (Markagunt Plateau)
- Late Quaternary slip rate
  - 192-225 m displacement of 0.5 Ma rocks
  - VSR = 0.38-0.44 mm/yr
- Early Pliocene to present
  - 237-344 m displacement of 5 Ma rocks
  - VSR = 0.05-0.07 mm/yr
- Mid Miocene to present
  - 900 m displacement of basement
  - 12-15 Myr initiation age
  - VSR = 0.06-0.08 mm/yr
- Key notes
  - 6 X faster late Quaternary VSR
  - Late Quaternary slip rate much faster than that at Black Mountain





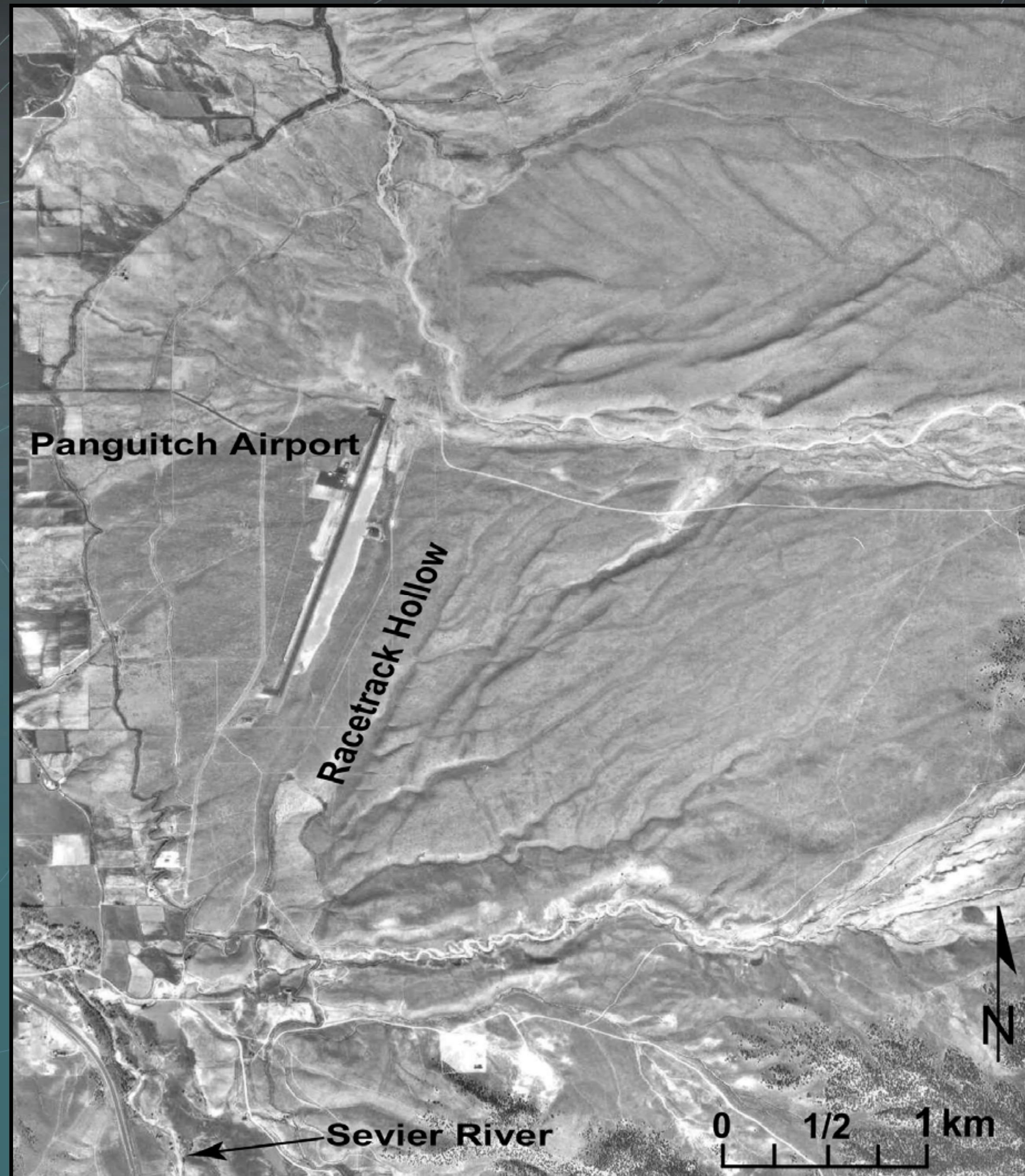
Hanging-Wall Faults Near Panguitch

- 23-km-long fold and fault belt in SF hanging wall near Panguitch
- Shorter (~6-km-long) belt north of Panguitch
- Deform middle to late Pleistocene alluvial deposits
- Scarps range from <1 m to ~25 m high



Hanging-Wall Faults Near Panguitch

- Genetic relation to main Sevier fault?
- Surface faulting or aseismic folding?
- No trenching of scarps
  - This would reveal little about surface faulting on main trace



Hanging-Wall Faults Near Panguitch

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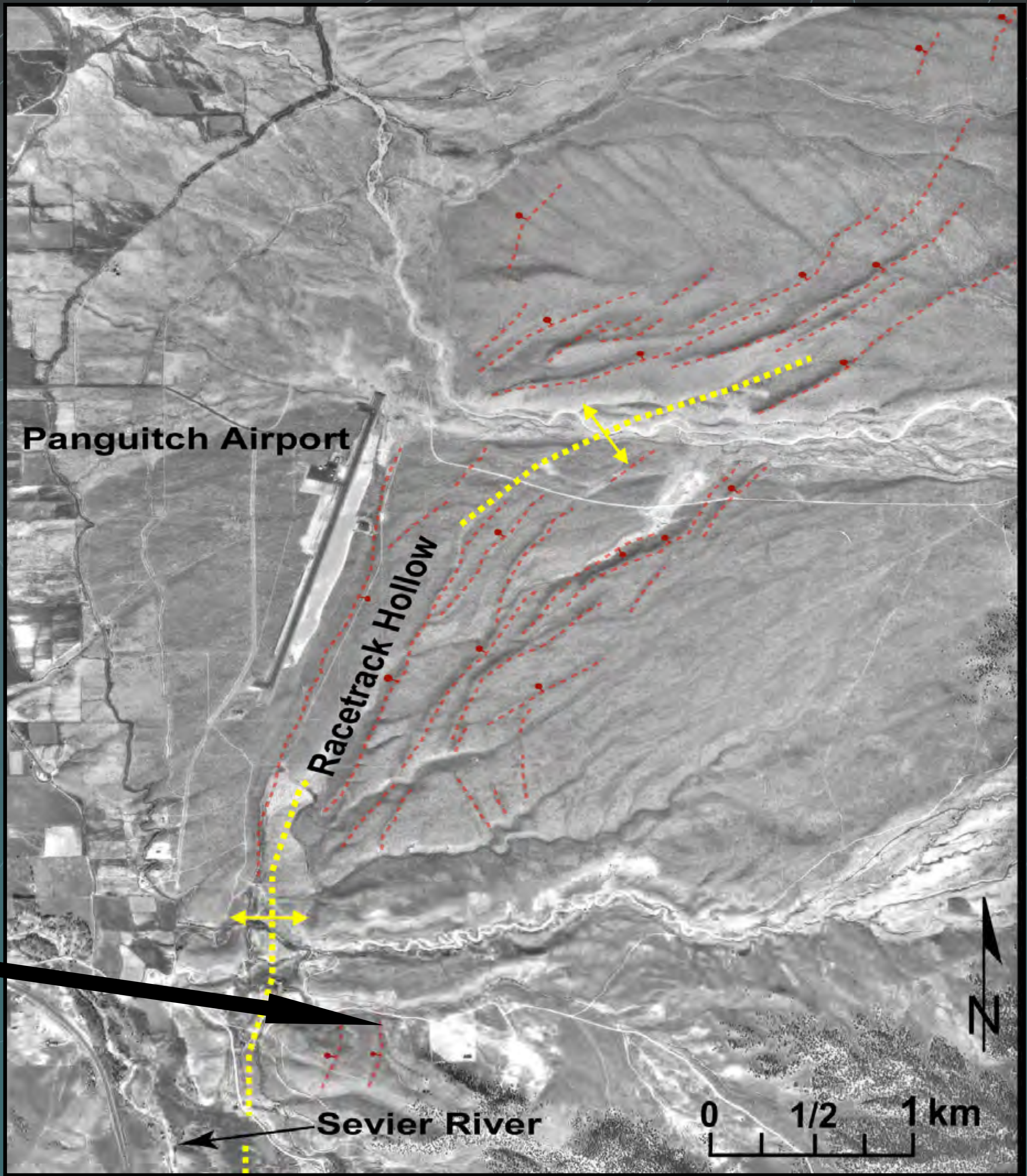
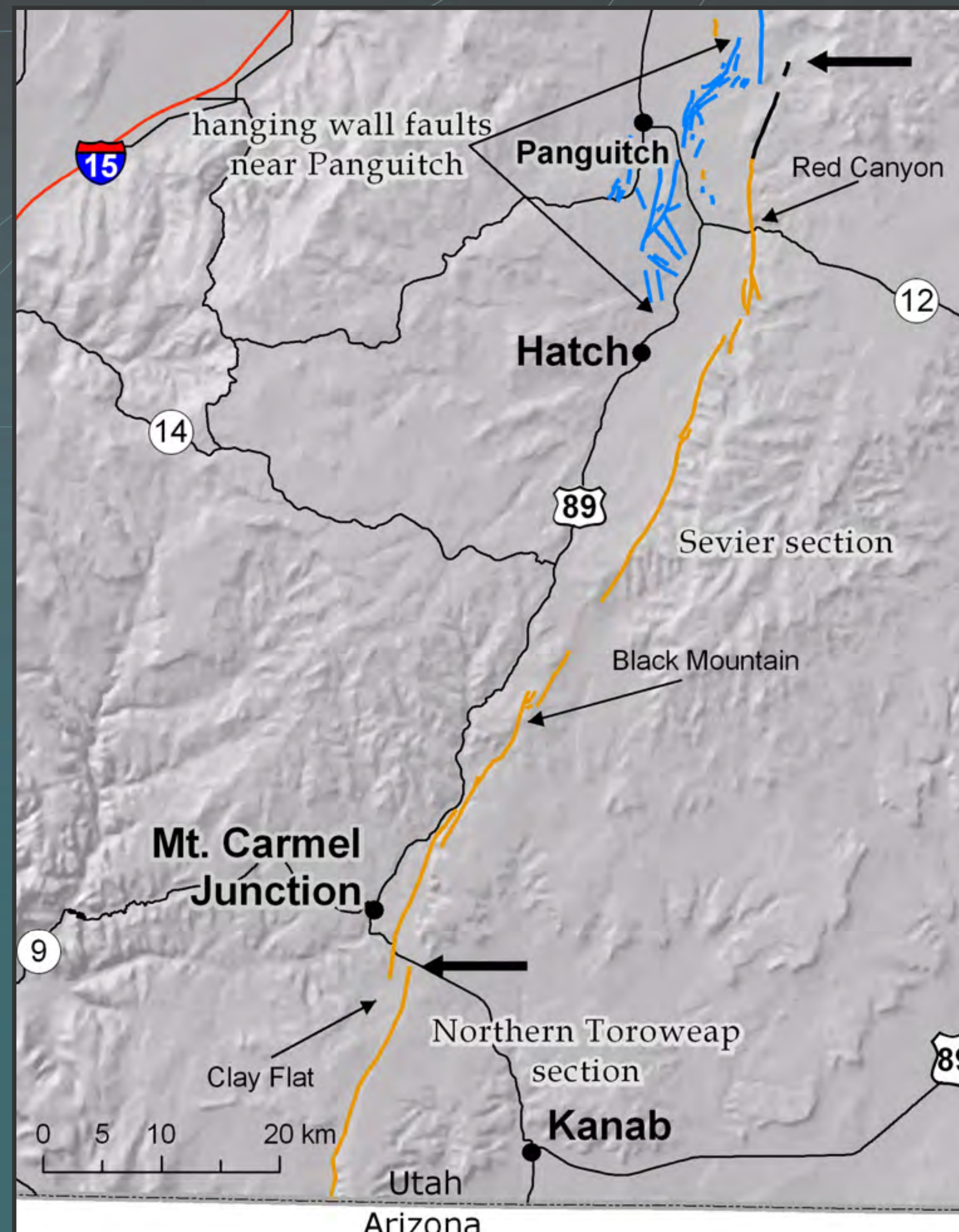
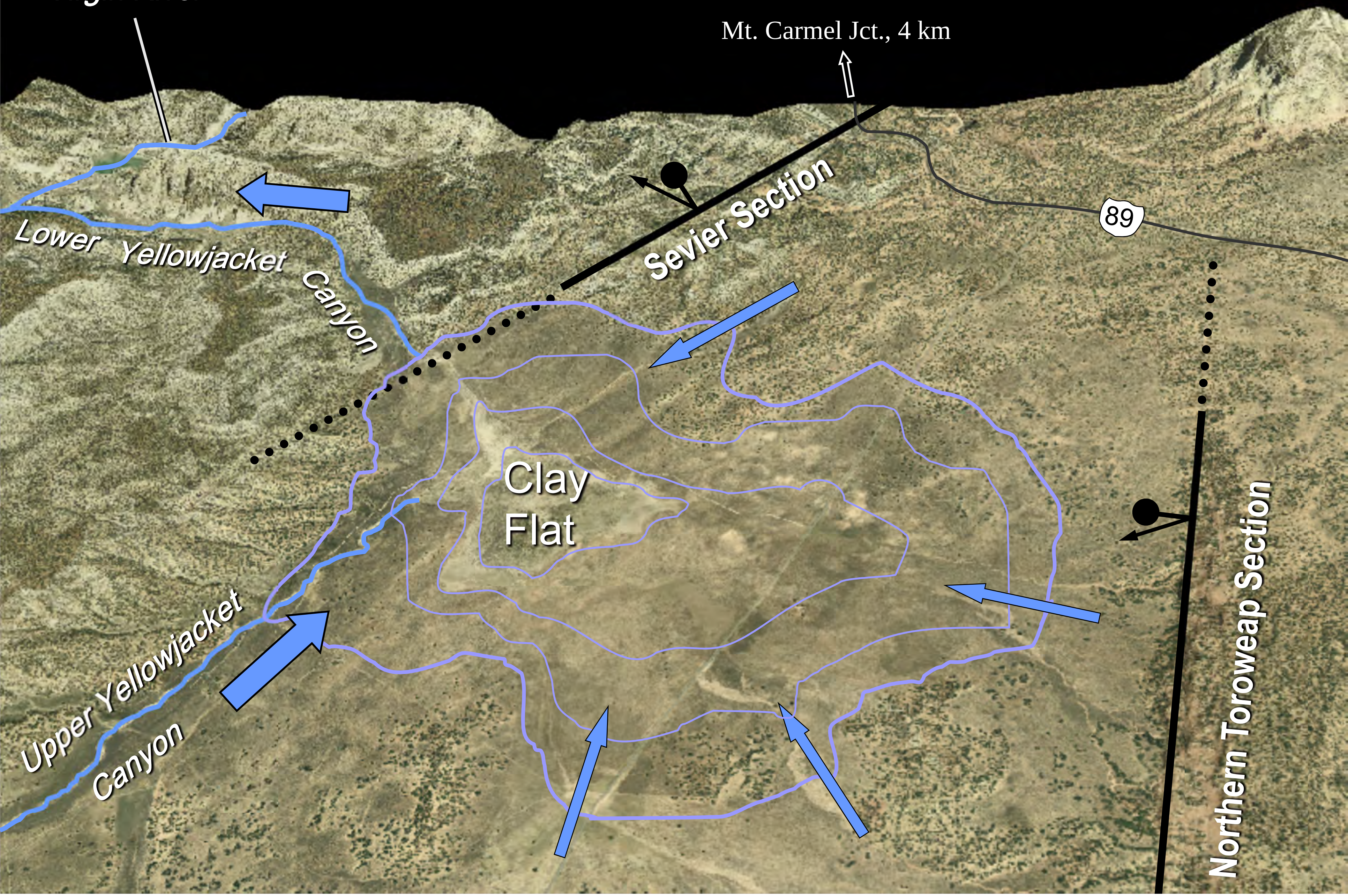


Clay Flat

- Sevier/Northern Toroweap section boundary
- Pull-apart basin (Clay Flat)
- 2.5-km-wide left step-over
- Left-oblique slip

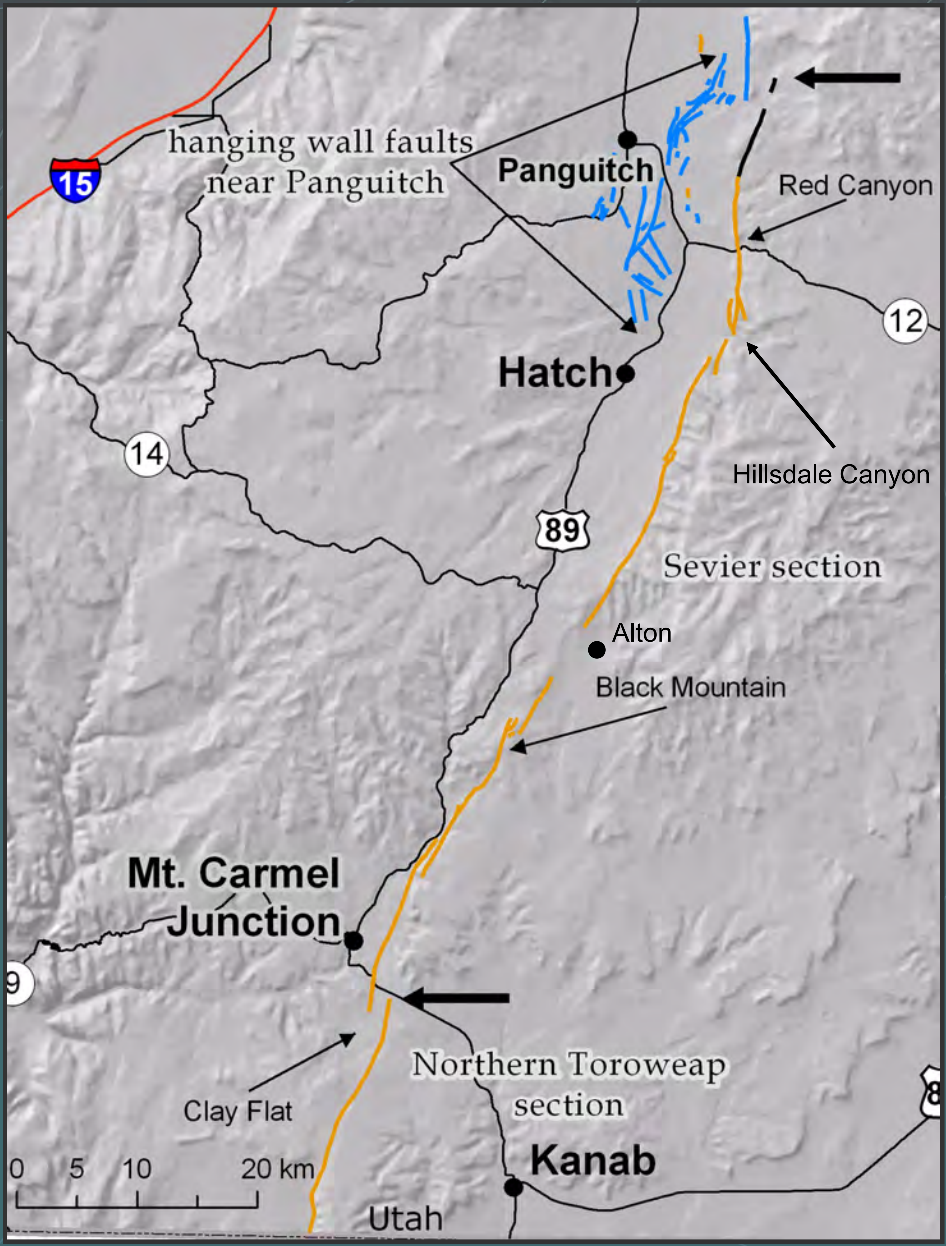


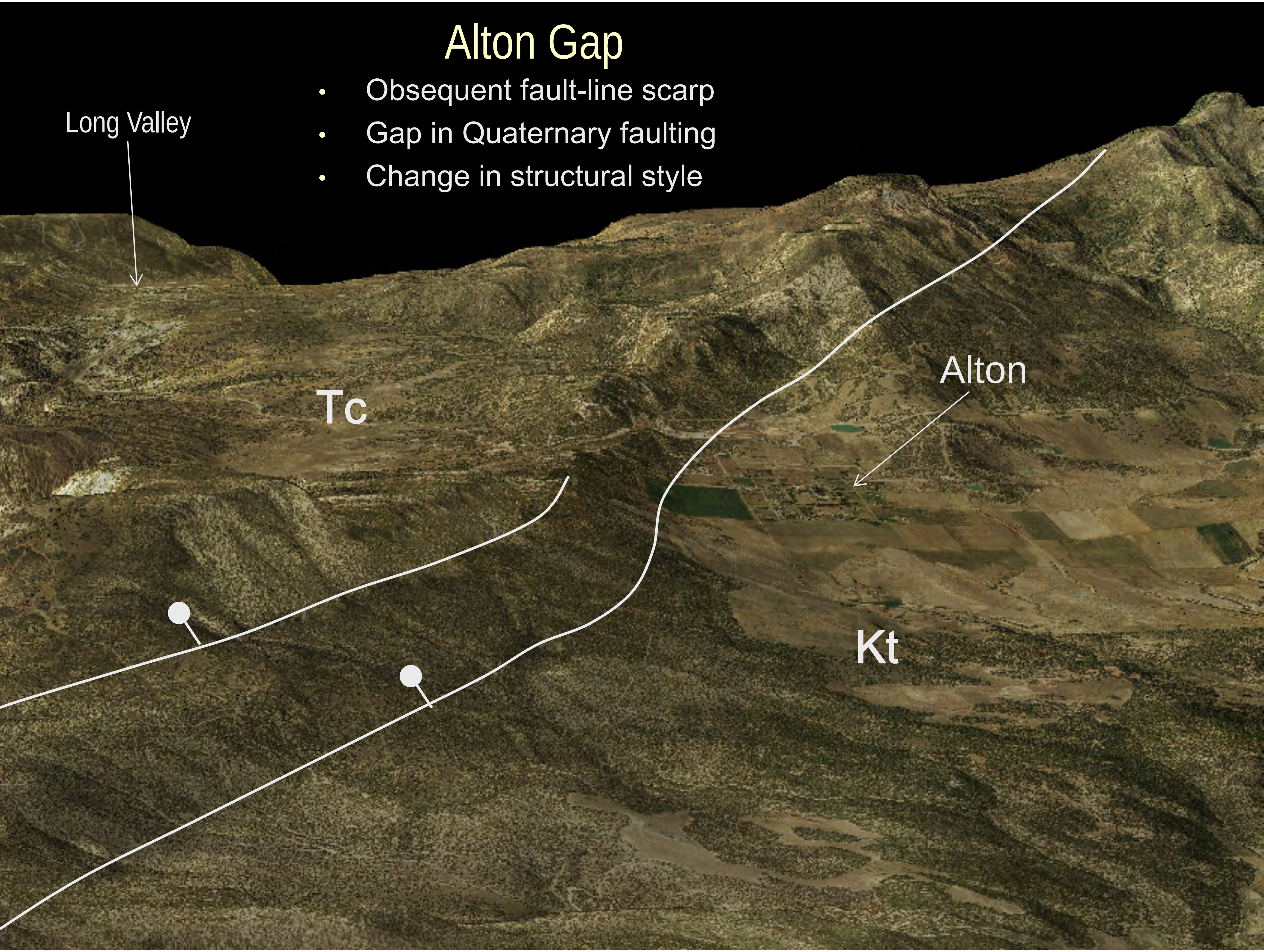
Clay Flat Closed Basin Depocenter



Segmentation

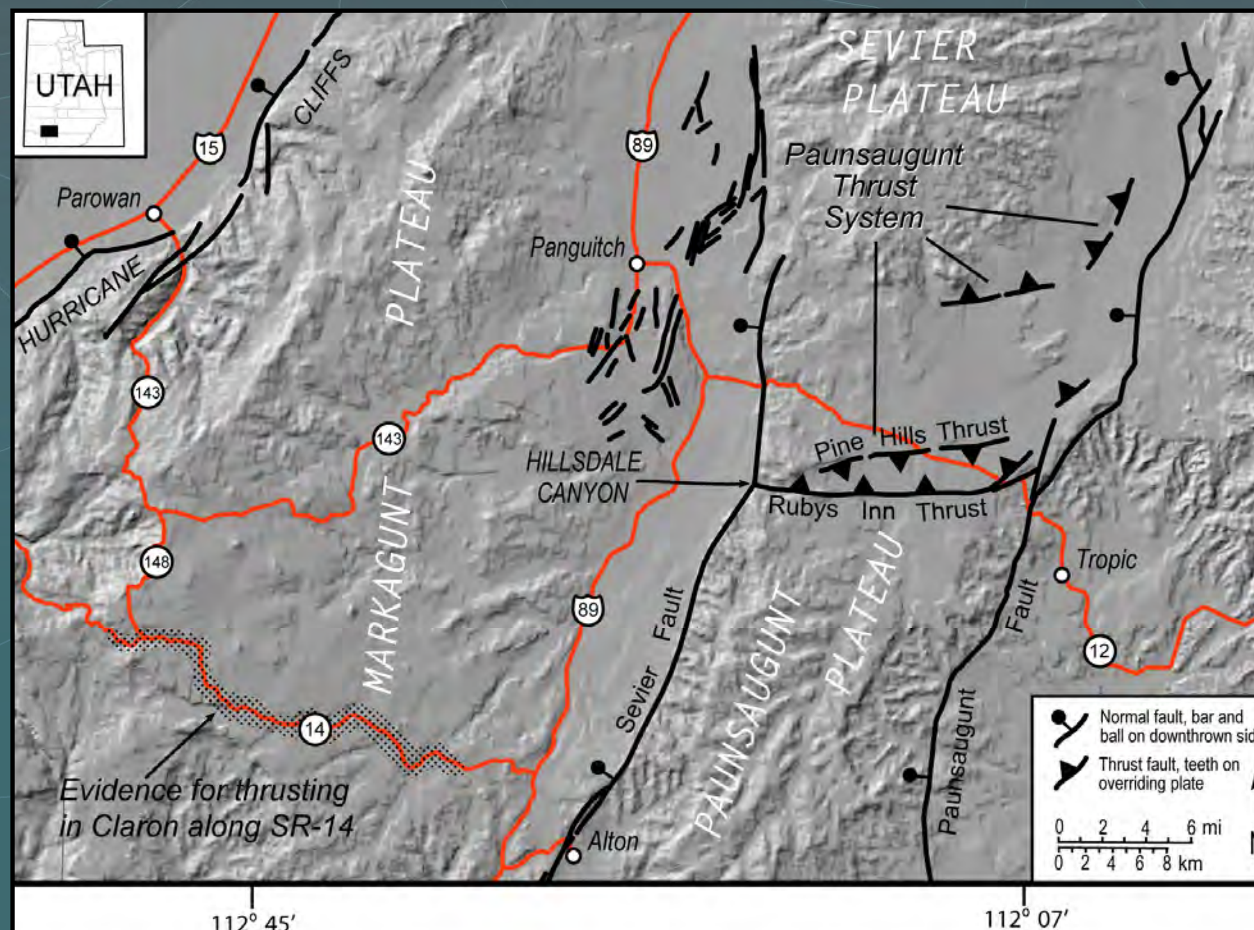
- Other long Basin & Range faults are composed of smaller (11-70 km) seismogenic segments
- Left step-over at Clay Flat
  - Scarps in fill deposits on the Northern Toroweap section in AZ
  - No scarps to the north on the Sevier section
- Sevier section = 88 km
- Two additional possible segment boundaries
  - Alton
  - Hillsdale Canyon




Alton Gap
• Obsequent fault-line scarp
• Gap in Quaternary faulting
• Change in structural style
Long Valley
Tc
Alton
Kt

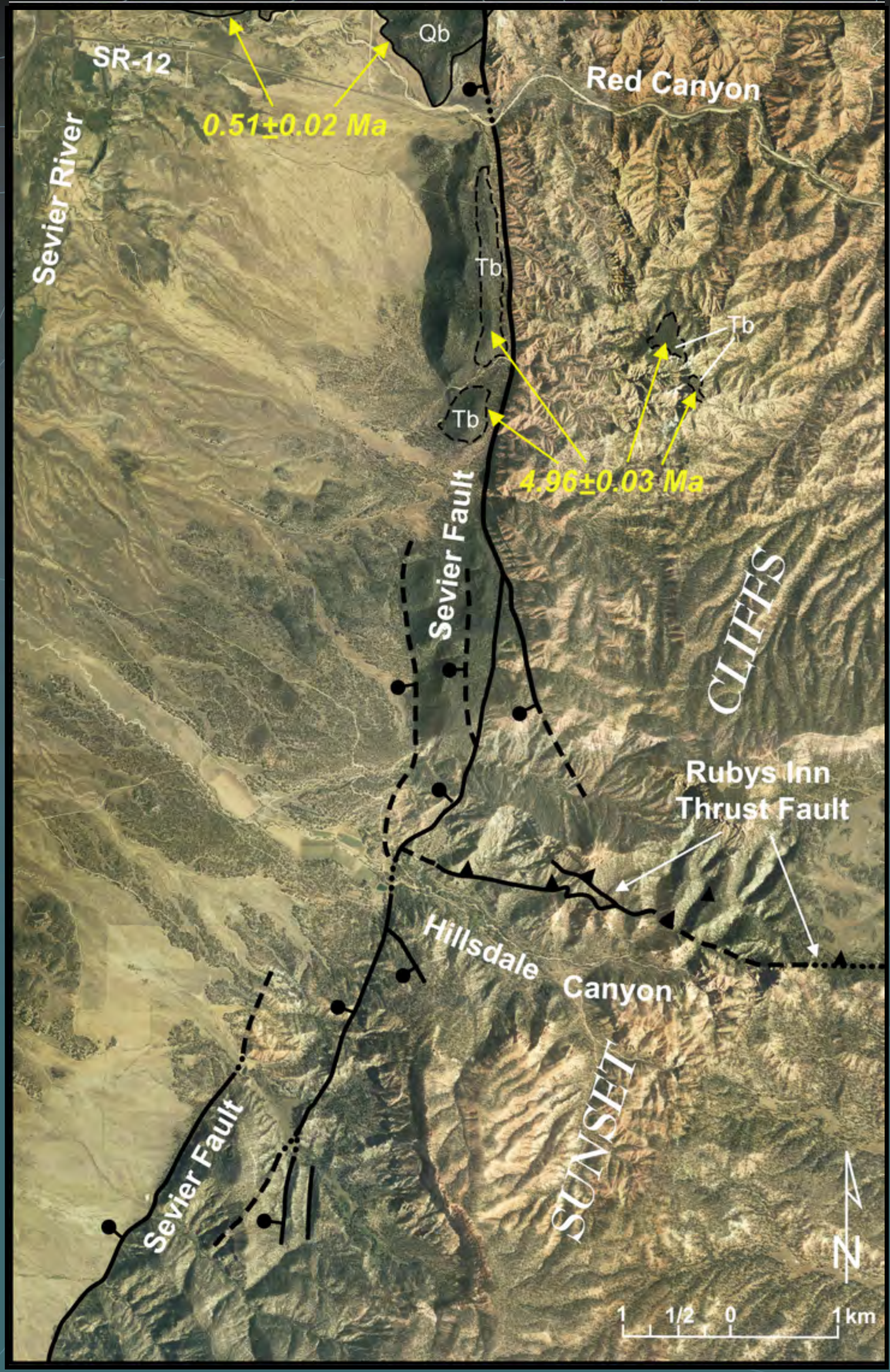
Hillsdale Canyon

- 30º fault bend
- Intersection with Paunsaugunt thrust system
- Segment Boundary?
- Ruby's Inn thrust fault is thin-skinned, soles out at only 2 km depth
- Decoupling cross-faults should extend to 12-15 km depth
- Thrust system active from ~30-20 Ma (Davis, 1999)
- Sevier fault initiated at ~15 Ma
- Evidence for thrusting to the west



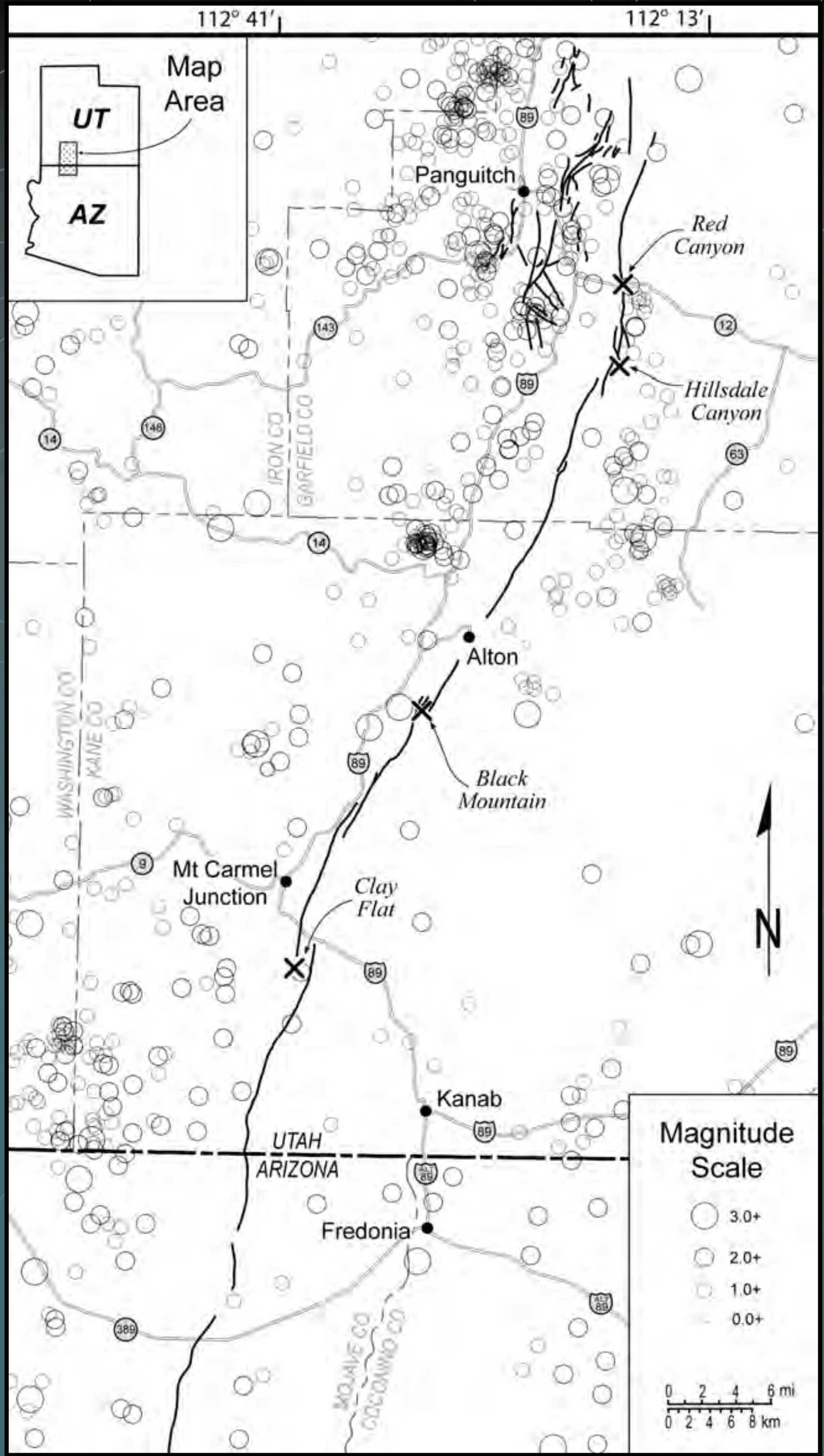
Hillsdale Canyon

- Intersection of the two is not exposed but evidence suggests the SF cuts and displaces the older thrust fault
- Conclusion: no structural link
- But there still may be a segment boundary here
- Paunsaugunt system may have deflected incipient SF trajectory
- Regardless of the bend's origin, slip vectors may not be conserved (nonconservative barrier; Bruhn & others, 1992)
- These barriers are typified by structural complexities
  - 3rd direction of faulting
  - Hanging-wall breakup



Seismicity

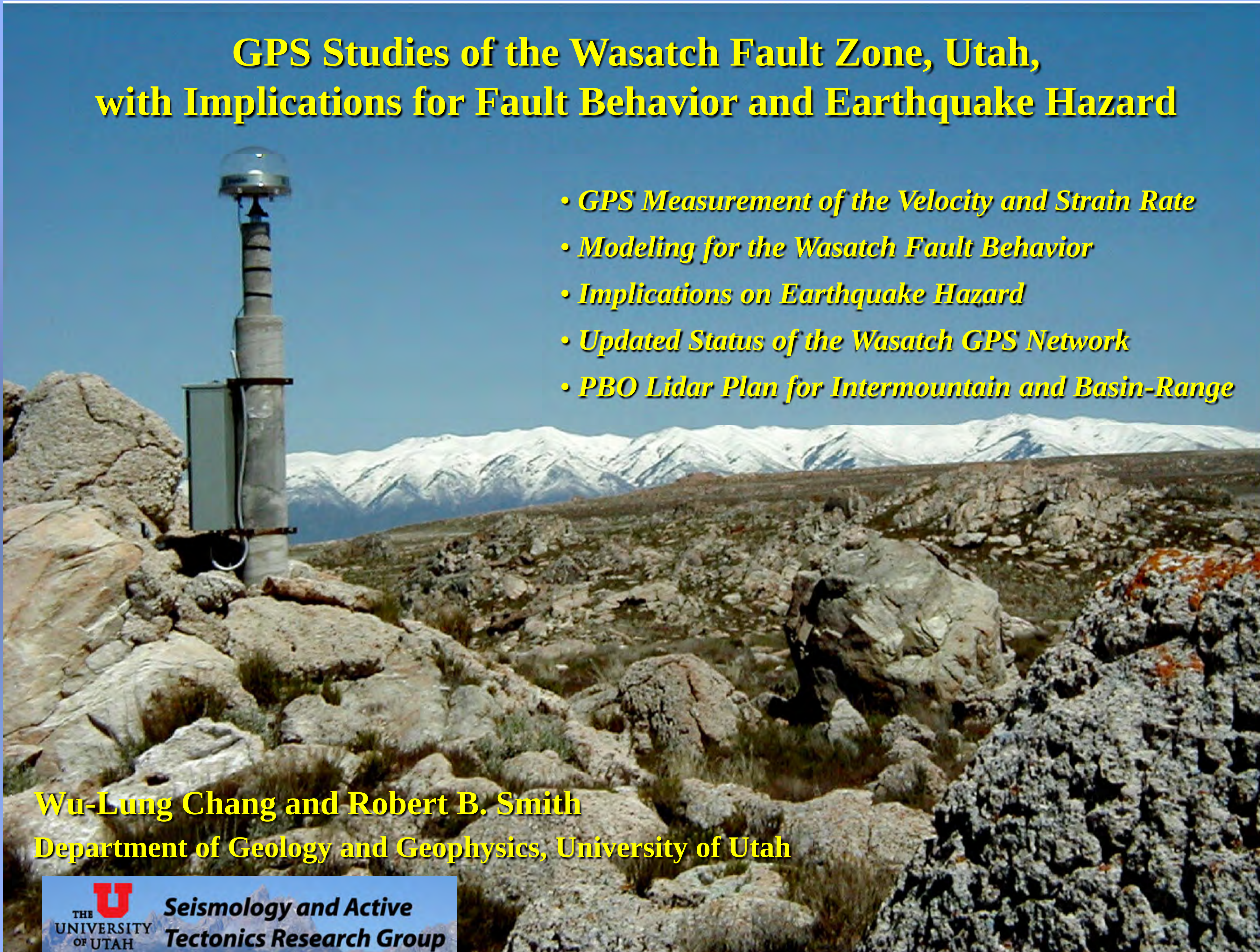
- Epicenters from 1962-2006 (University of Utah Seismograph Stations)
- Supports segmentation hypothesis
- Decrease in activity north of Clay Flat
- Quiescence at Alton
- Increase in activity north of Alton
- Big increase north of Hillsdale Canyon

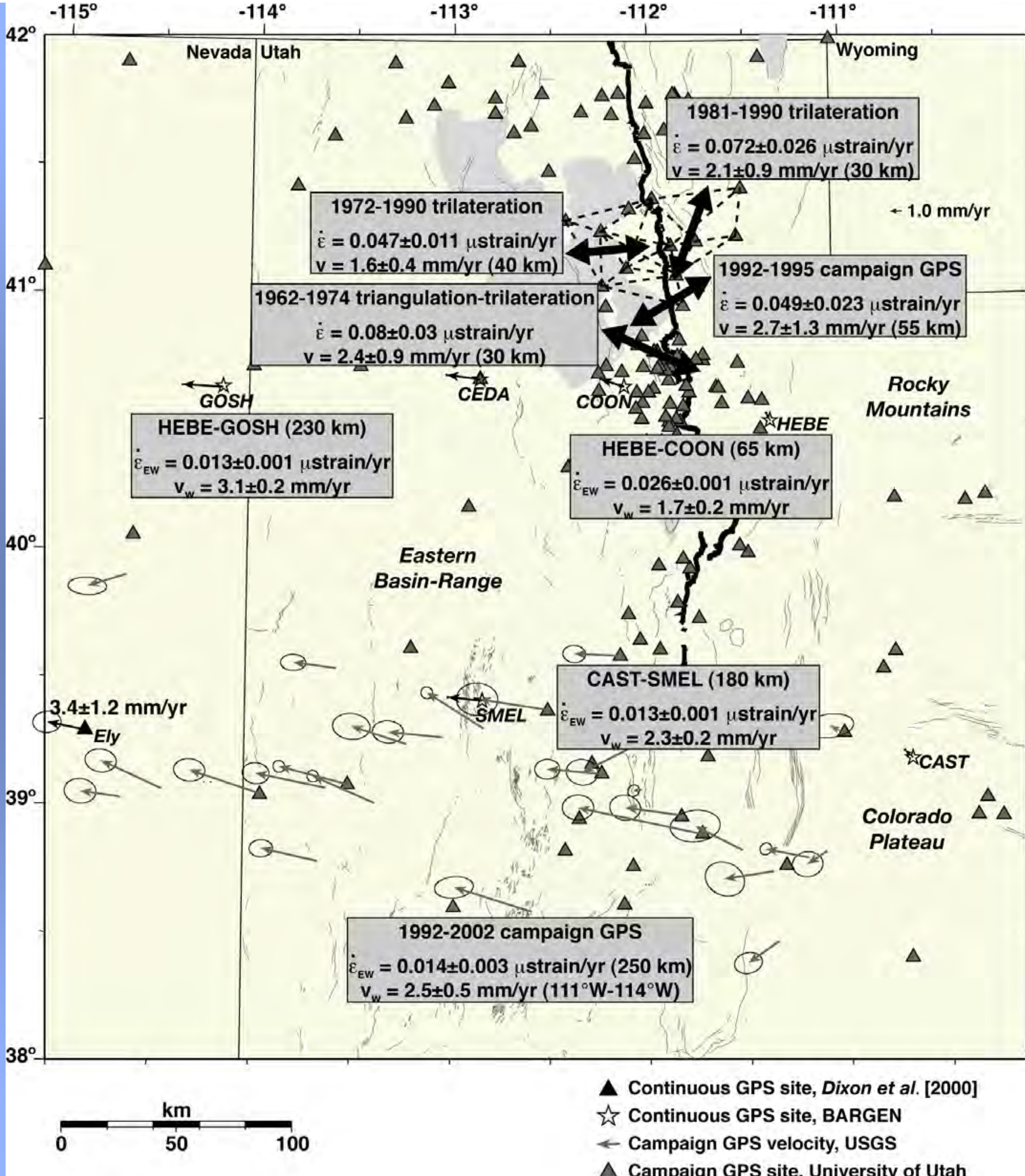


Conclusions

- More active northern part in late Quaternary
  - Current VSR at Red Canyon is 0.38-0.44 mm/yr [RI = 4.4-5.3 kyr]
  - Long term VSR at Red Canyon is 0.06-0.08 mm/yr [RI = 25-33 kyr]
  - Current VSR elsewhere in Utah is < 0.1 mm/yr [RI $\geq$ ~30 kyr]
  - This is consistent with young hanging-wall scarps near Panguitch and increased seismicity to the north

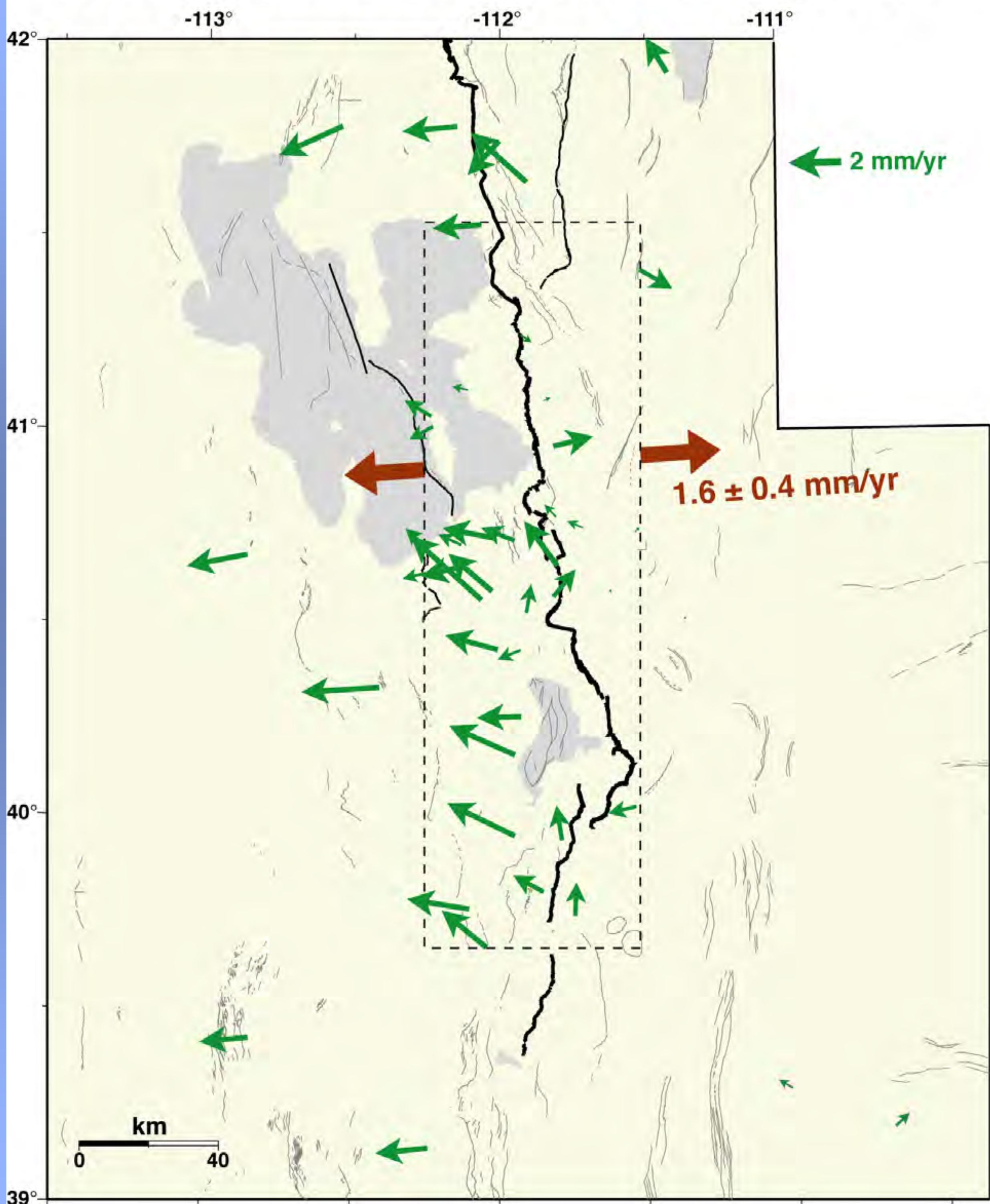
- Segmentation
  - Left step-over and pull-apart basin at Clay Flat
  - Gap in Quaternary surface faulting near Alton
  - Geometric bend, structural complexities near Hillsdale Canyon

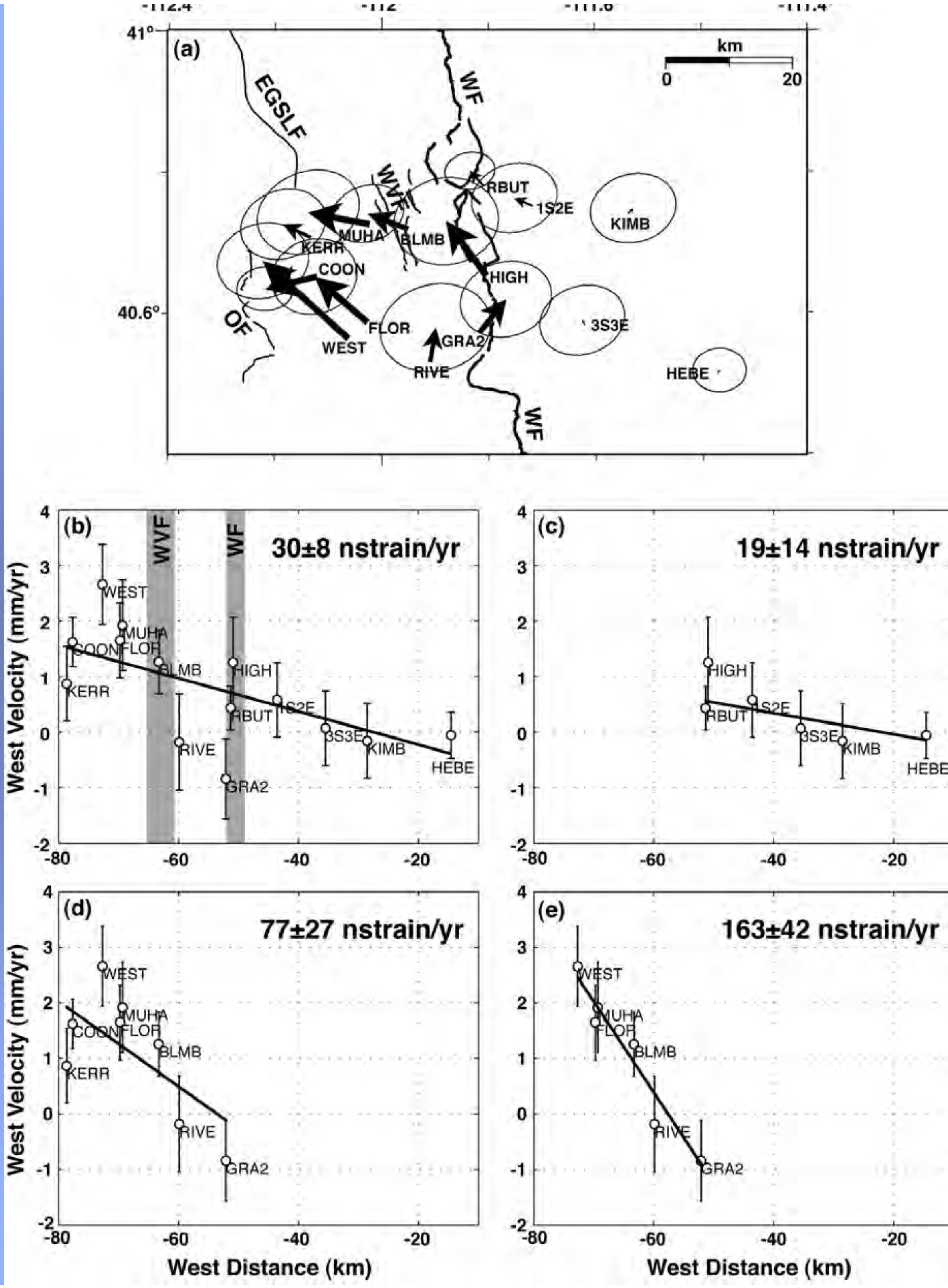

GPS Studies of the Wasatch Fault Zone, Utah,
with Implications for Fault Behavior and Earthquake Hazard
• GPS Measurement of the Velocity and Strain Rate
• Modeling for the Wasatch Fault Behavior
• Implications on Earthquake Hazard
• Updated Status of the Wasatch GPS Network
• PBO Lidar Plan for Intermountain and Basin-Range
Wu-Lung Chang and Robert B. Smith
Department of Geology and Geophysics, University of Utah
THE UNIVERSITY OF UTAH
Seismology and Active Tectonics Research Group



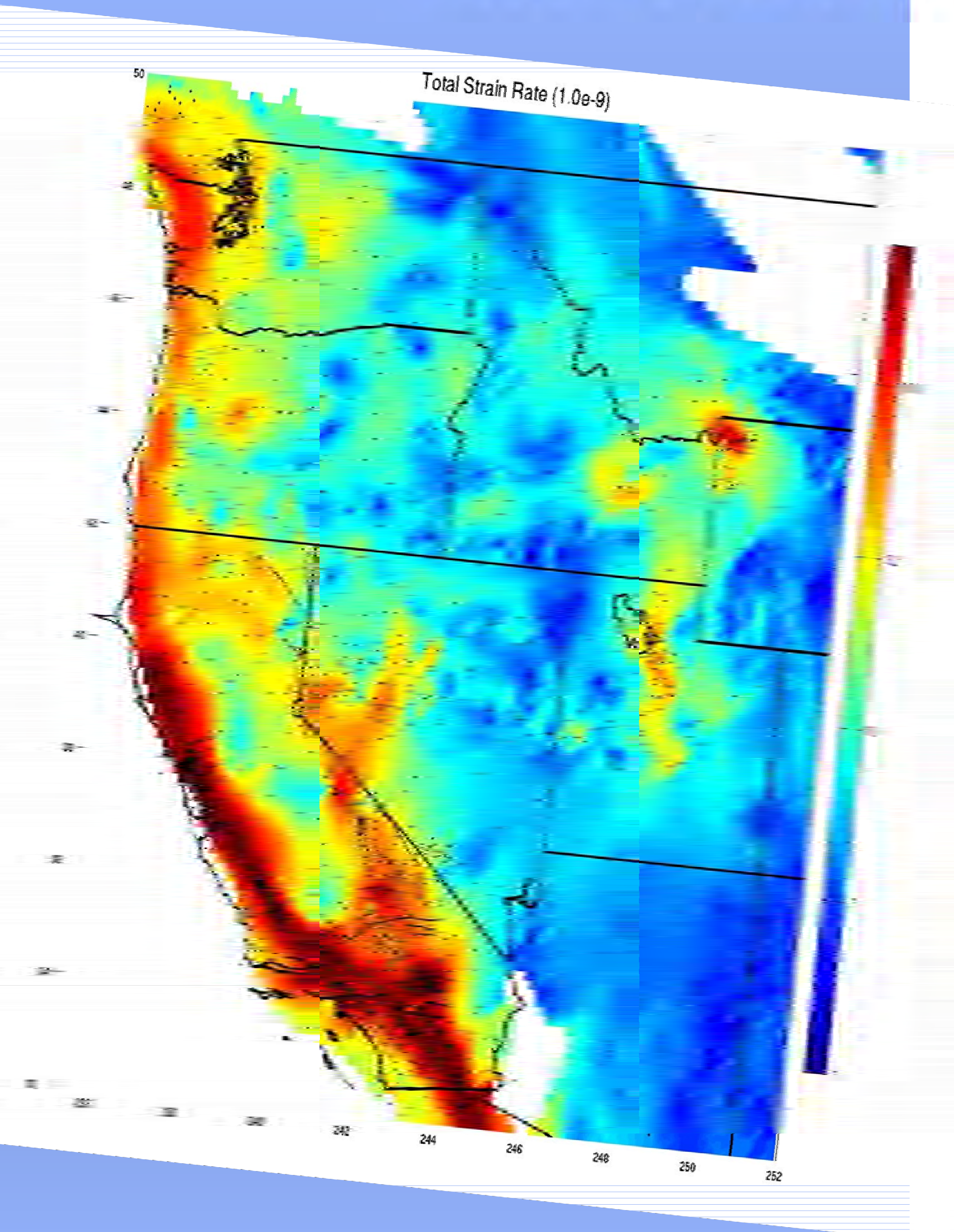
-115°
-114°
-113°
-112°
-111°
42°
41°
40°
39°
38°
Nevada
Utah
Wyoming
1981-1990 trilateration
$\dot{\varepsilon}$ = 0.072±0.026 μstrain/yr
v = 2.1±0.9 mm/yr (30 km)
1972-1990 trilateration
$\dot{\varepsilon}$ = 0.047±0.011 μstrain/yr
v = 1.6±0.4 mm/yr (40 km)
1.0 mm/yr
1992-1995 campaign GPS
$\dot{\varepsilon}$ = 0.049±0.023 μstrain/yr
v = 2.7±1.3 mm/yr (55 km)
1962-1974 triangulation-trilateration
$\dot{\varepsilon}$ = 0.08±0.03 μstrain/yr
v = 2.4±0.9 mm/yr (30 km)
GOSH
CEDA
COON
HEBE
Rocky Mountains
HEBE-GOSH (230 km)
$\dot{\varepsilon}_{EW}$ = 0.013±0.001 μstrain/yr
v_w = 3.1±0.2 mm/yr
HEBE-COON (65 km)
$\dot{\varepsilon}_{EW}$ = 0.026±0.001 μstrain/yr
v_w = 1.7±0.2 mm/yr
Eastern Basin-Range
CAST-SMEL (180 km)
$\dot{\varepsilon}_{EW}$ = 0.013±0.001 μstrain/yr
v_w = 2.3±0.2 mm/yr
3.4±1.2 mm/yr
Ely
SMEL
CAST
Colorado Plateau
1992-2002 campaign GPS
$\dot{\varepsilon}_{EW}$ = 0.014±0.003 μstrain/yr (250 km)
v_w = 2.5±0.5 mm/yr (111°W-114°W)
km
0
50
100
Continuous GPS site, *Dixon et al.* [2000]
Continuous GPS site, BARGEN
Campaign GPS velocity, USGS
Campaign GPS site, University of Utah

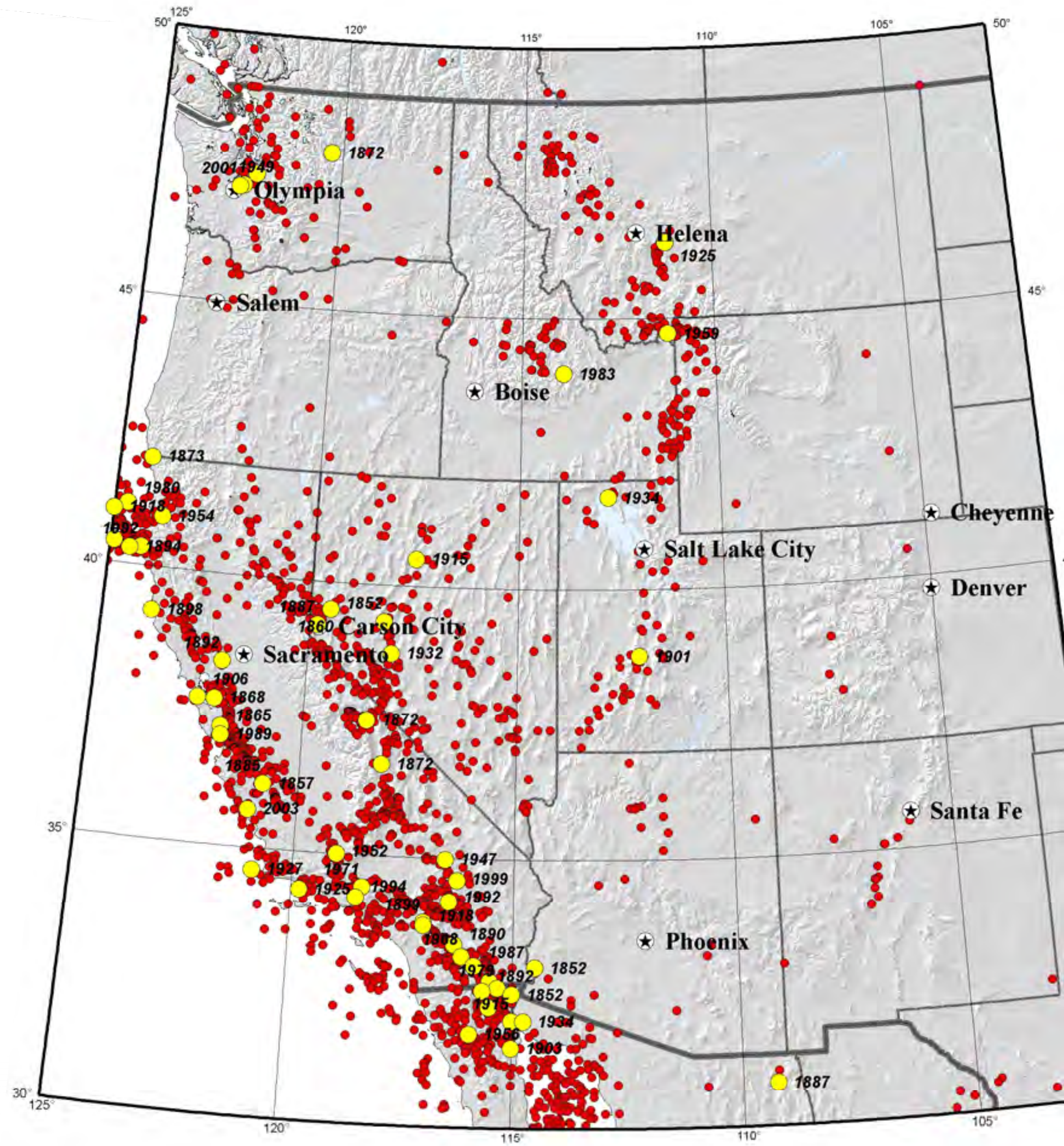
Wasatch GPS Network and Velocity Field



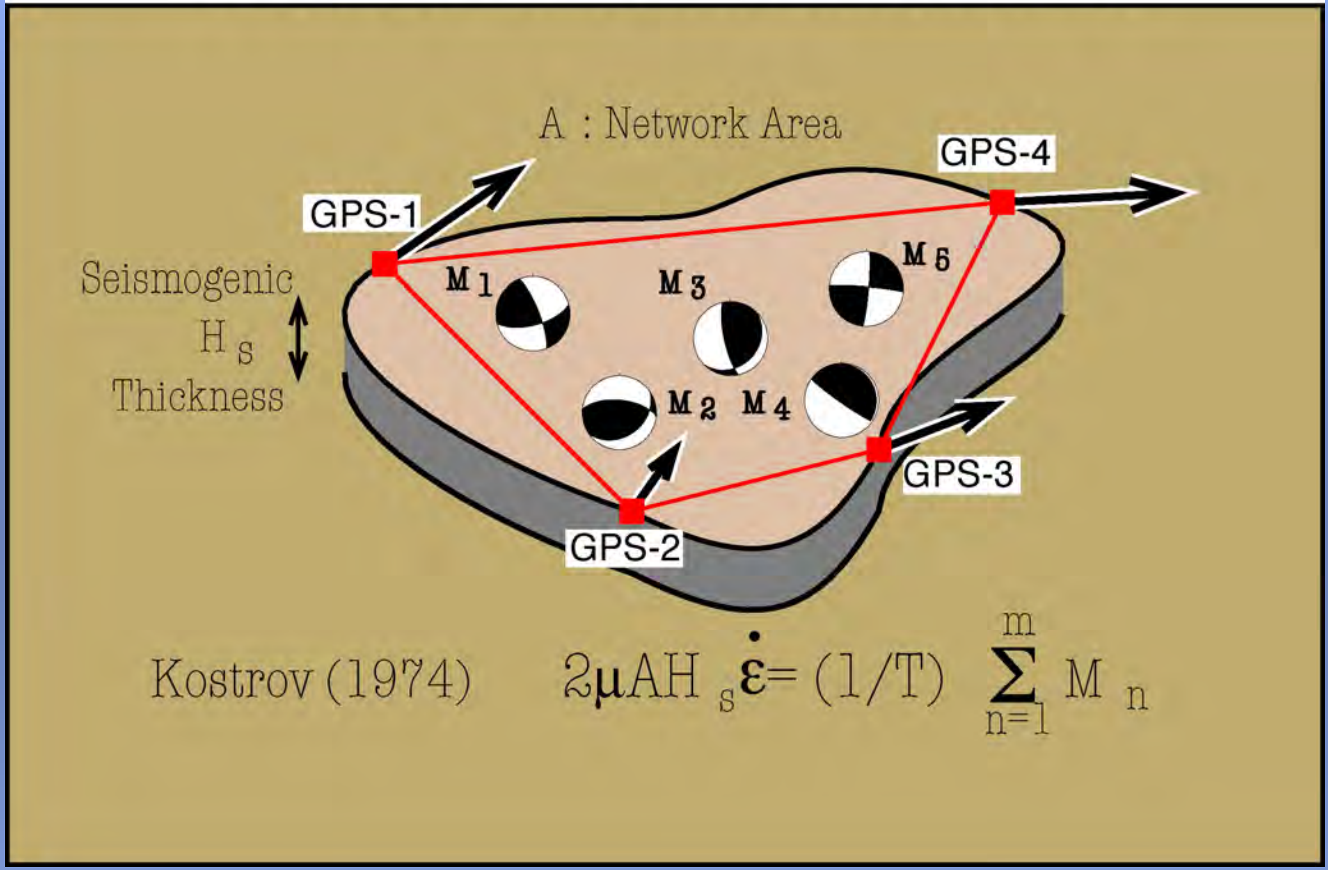

(a)
km
0
20
41°
40.6°
-112.4
-112
-111.6
-111.4
EGSLF
WF
WVF
OF
RBUT
1S2E
KIMB
MUHA
BLMB
KERR
COON
HIGH
FLOR
WEST
GRA2
RIVE
3S3E
HEBE
(b)
WVF
WF
30±8 nstrain/yr
(c)
19±14 nstrain/yr
(d)
77±27 nstrain/yr
(e)
163±42 nstrain/yr
West Velocity (mm/yr)
West Distance (km)

Western US kinematics from GPS and seismicity





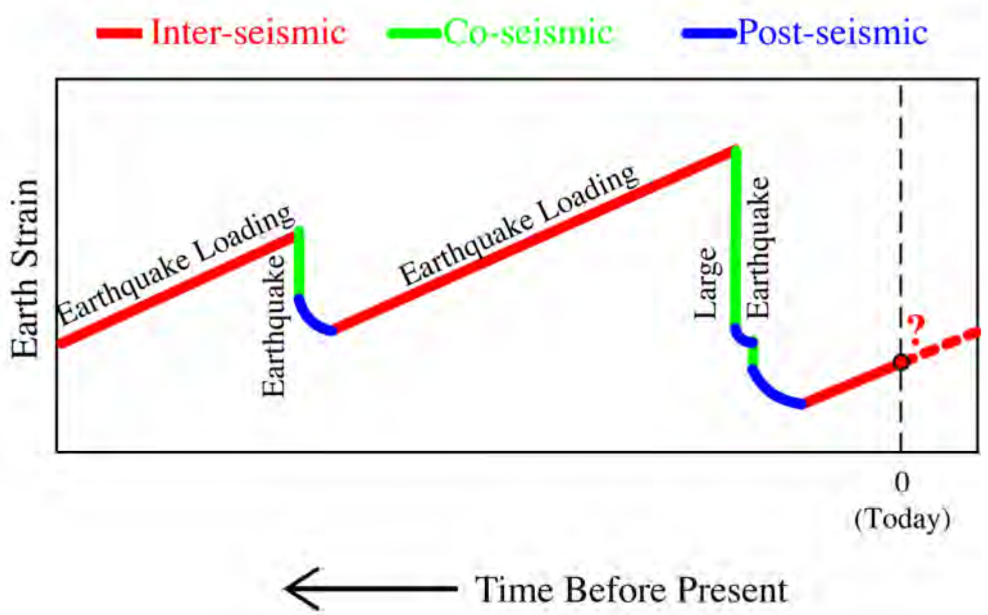
Geodetic Moment Rate from GPS



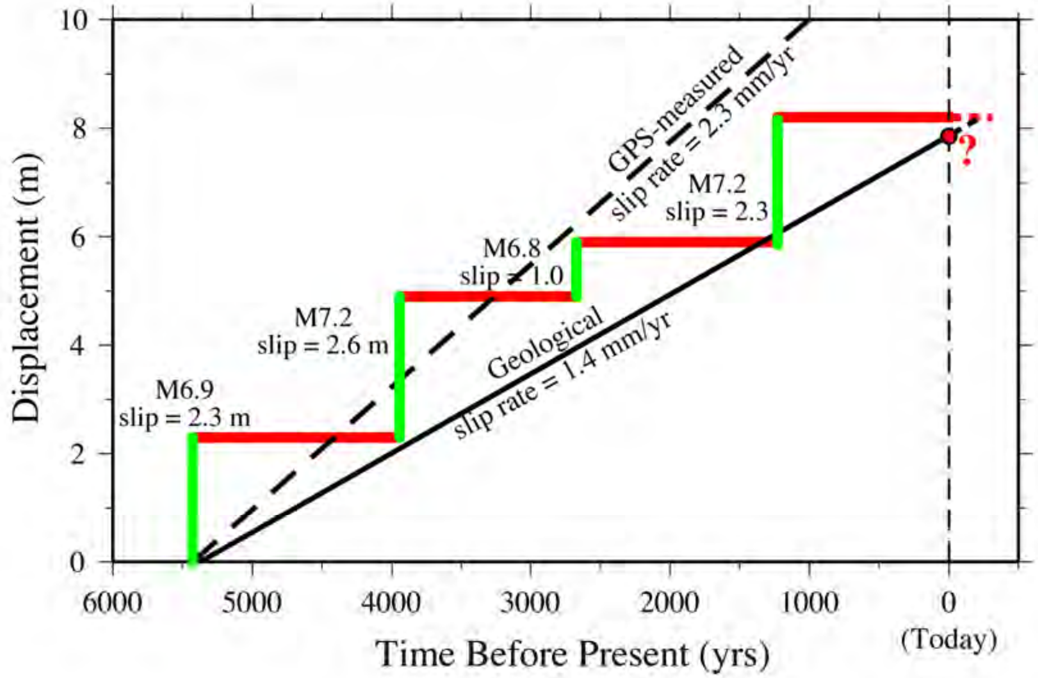
Strain rate from historic seismic moment rate ~ 1 to 4 nstrain/yr [*Eddington et al*., 1987]
GPS horizontal strain rate = 24 ± 6 nstrain/yr [*Chang et al*., 2006]

Earthquake Cycle

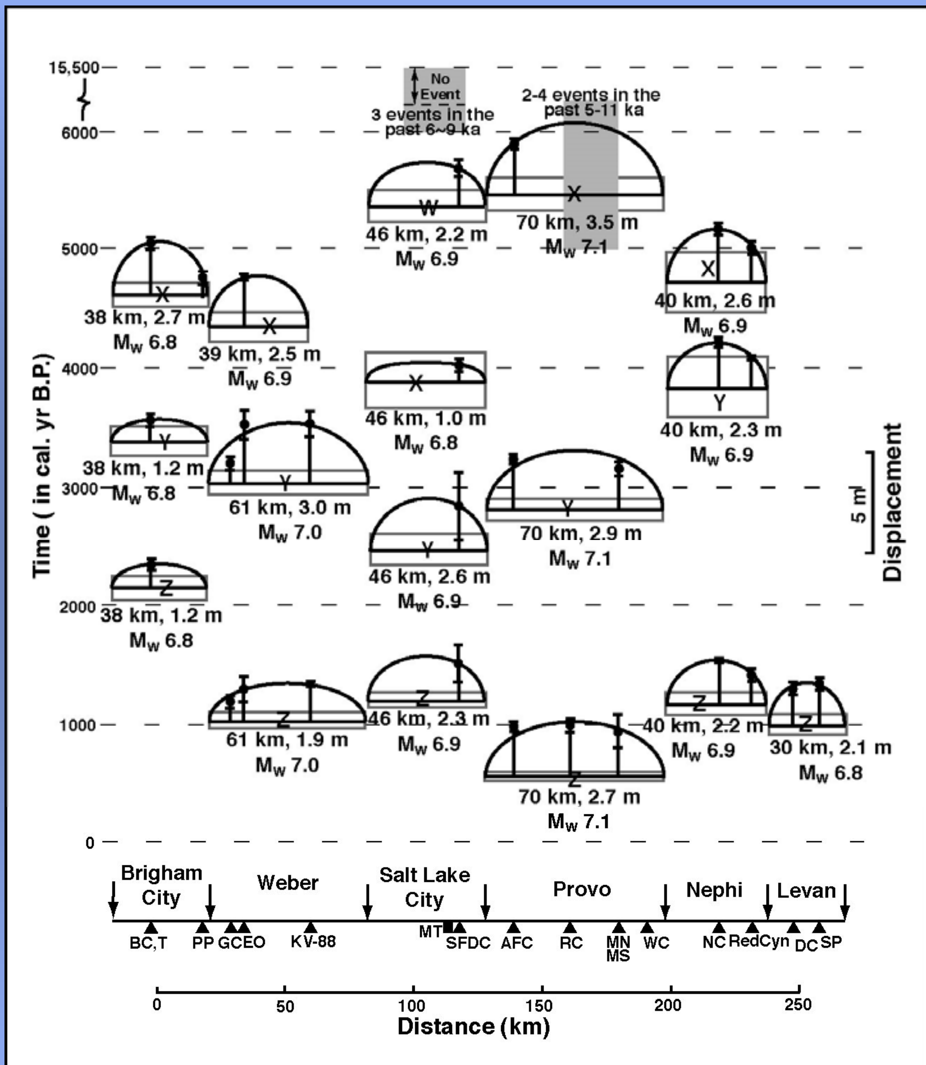
History of earthquakes and earthquake loading



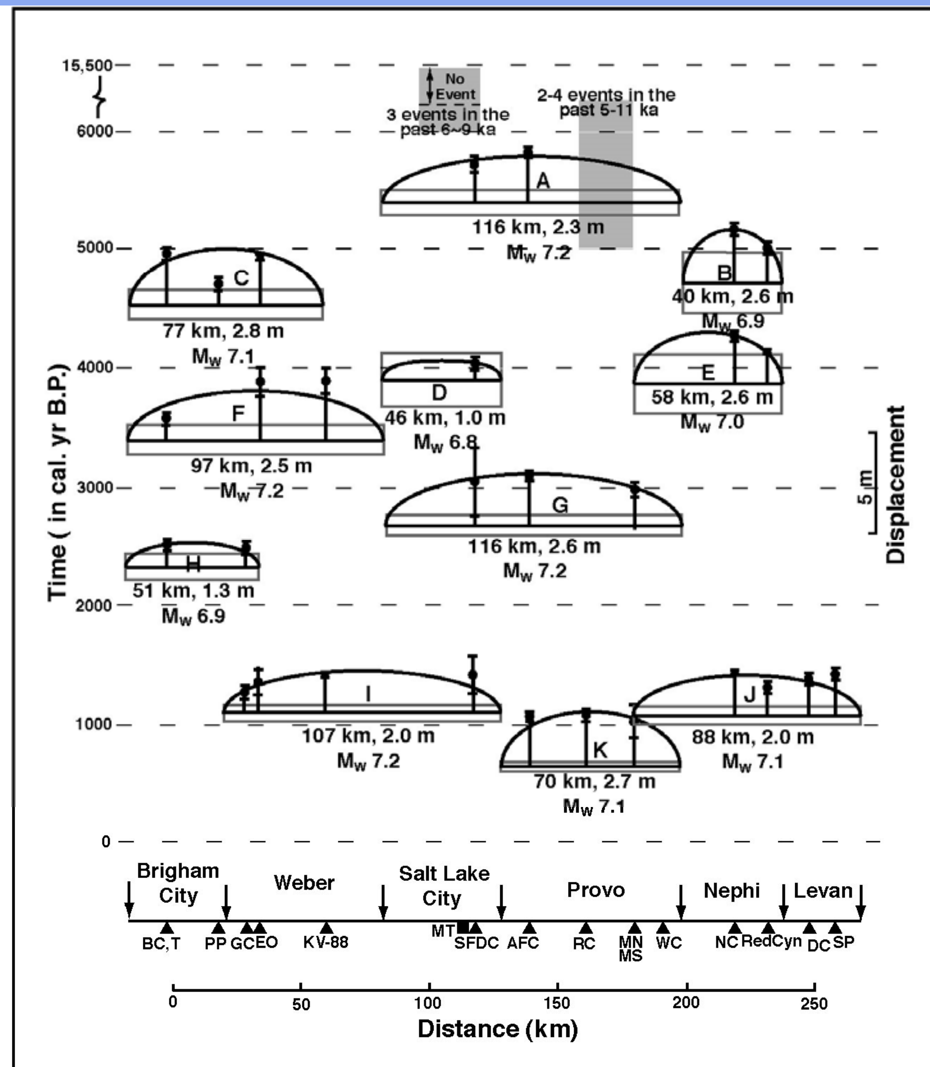
Wasatch fault earthquake history



Single- and Multi-segment Model for the Wasatch Paleoearthquakes

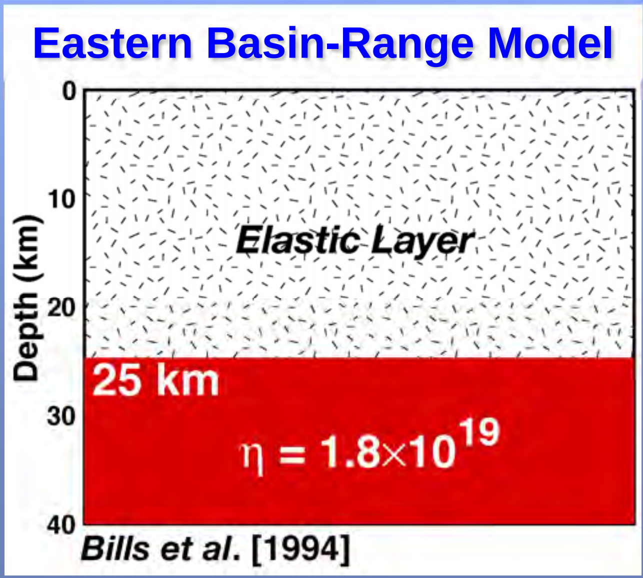


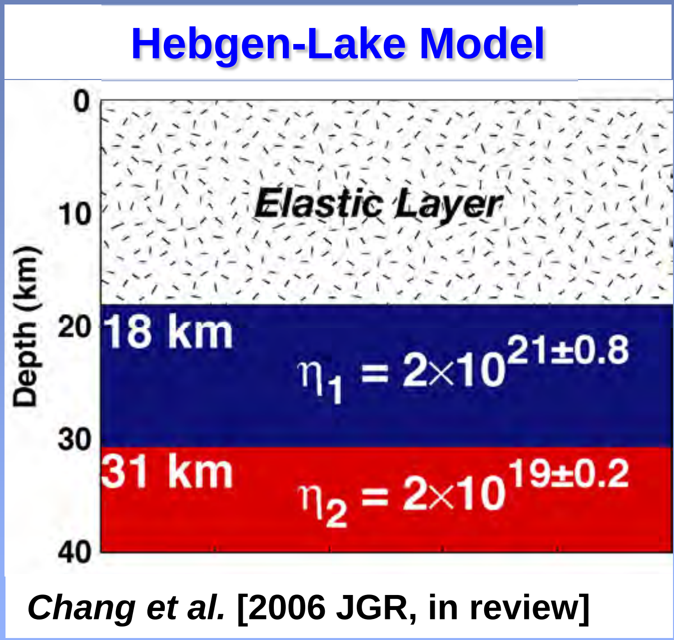
after McCalpin and Nishenko [1996]

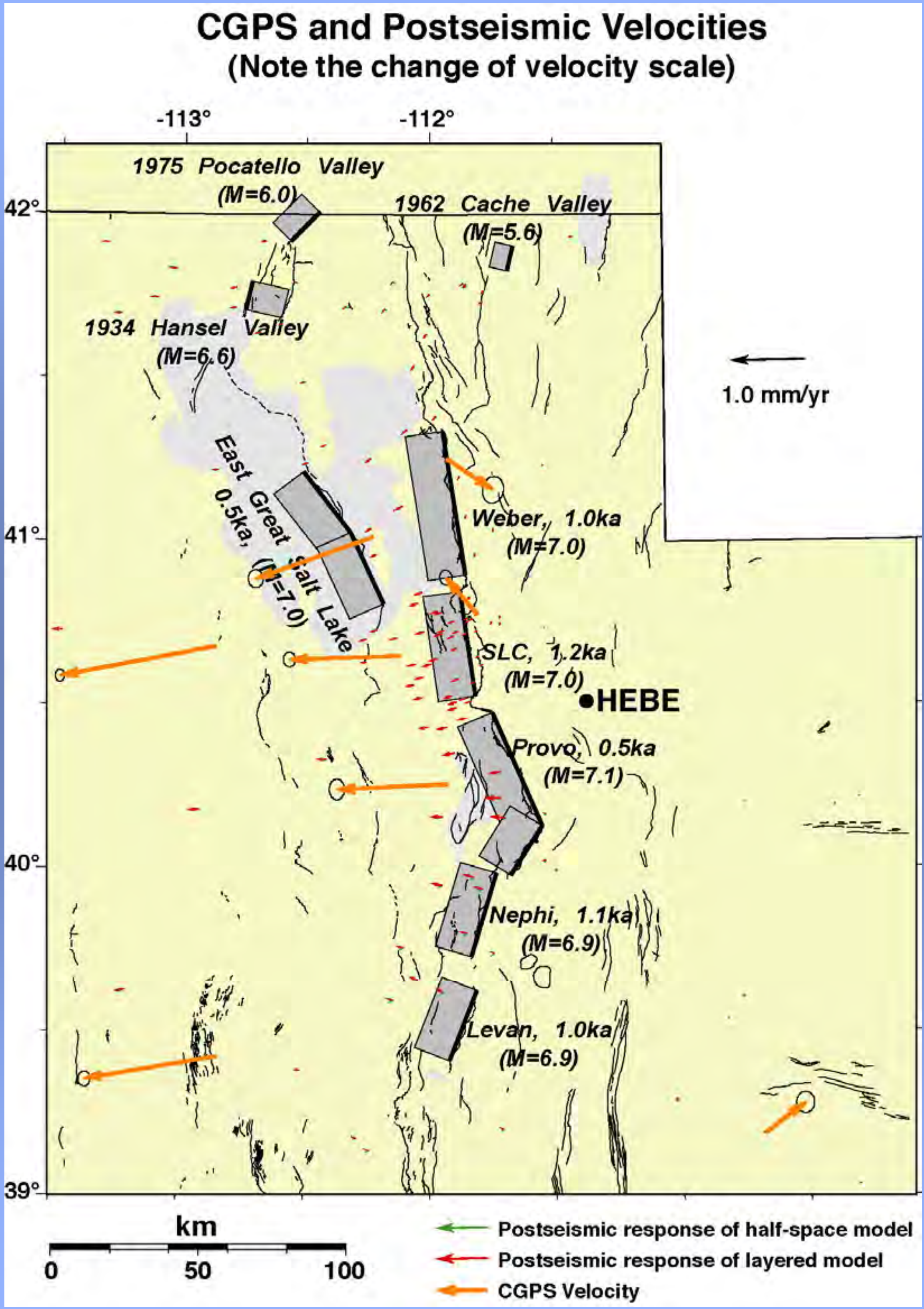


Chang and Smith [2002]

Rheologic Models for Estimating Postseismic Deformation

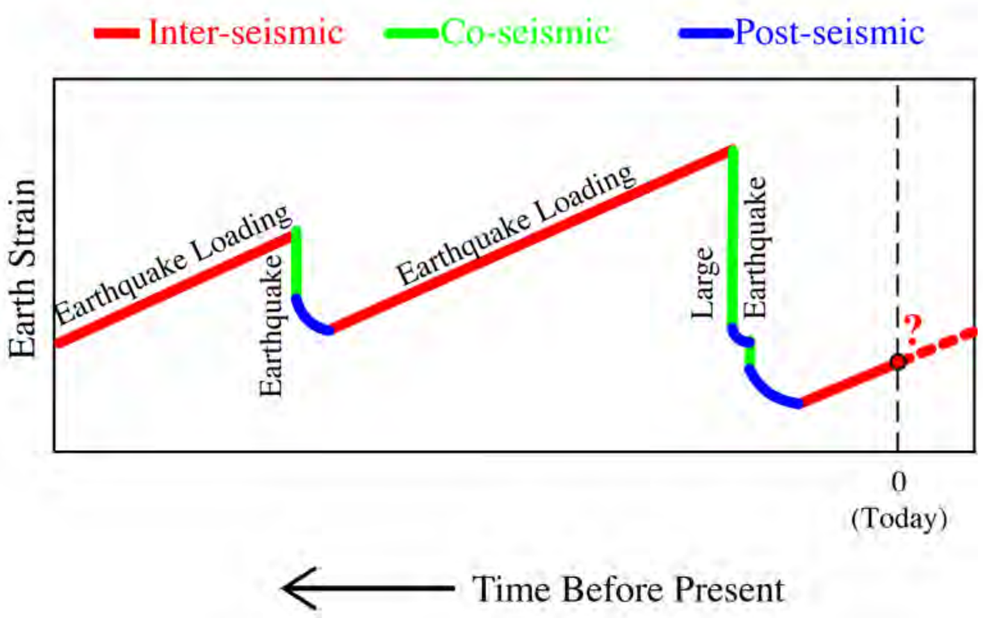




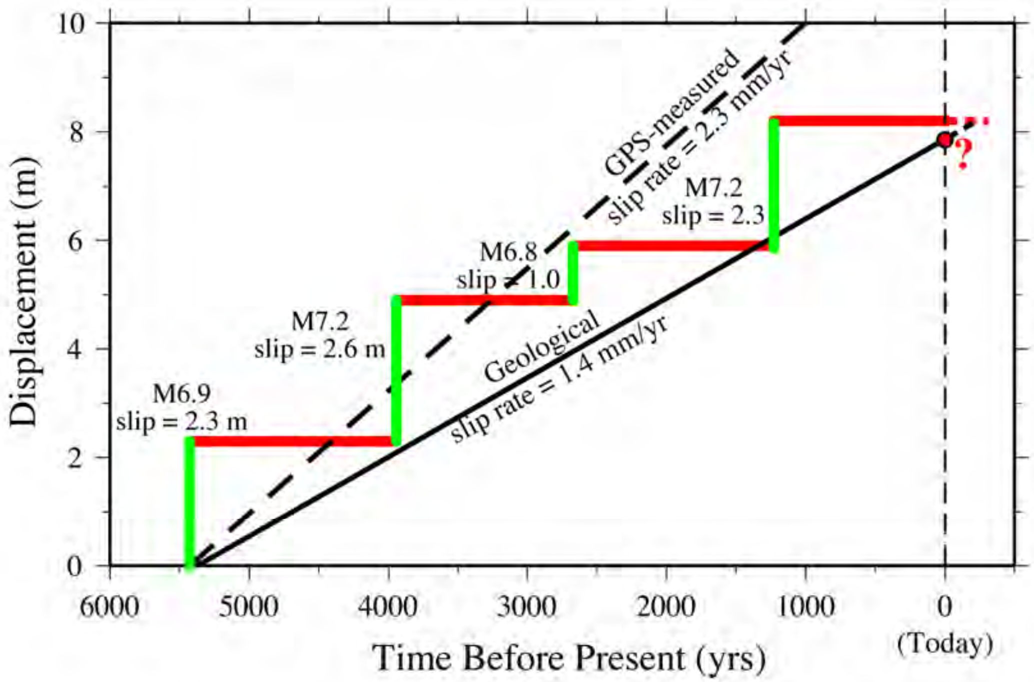


Earthquake Cycle

History of earthquakes
and earthquake loading

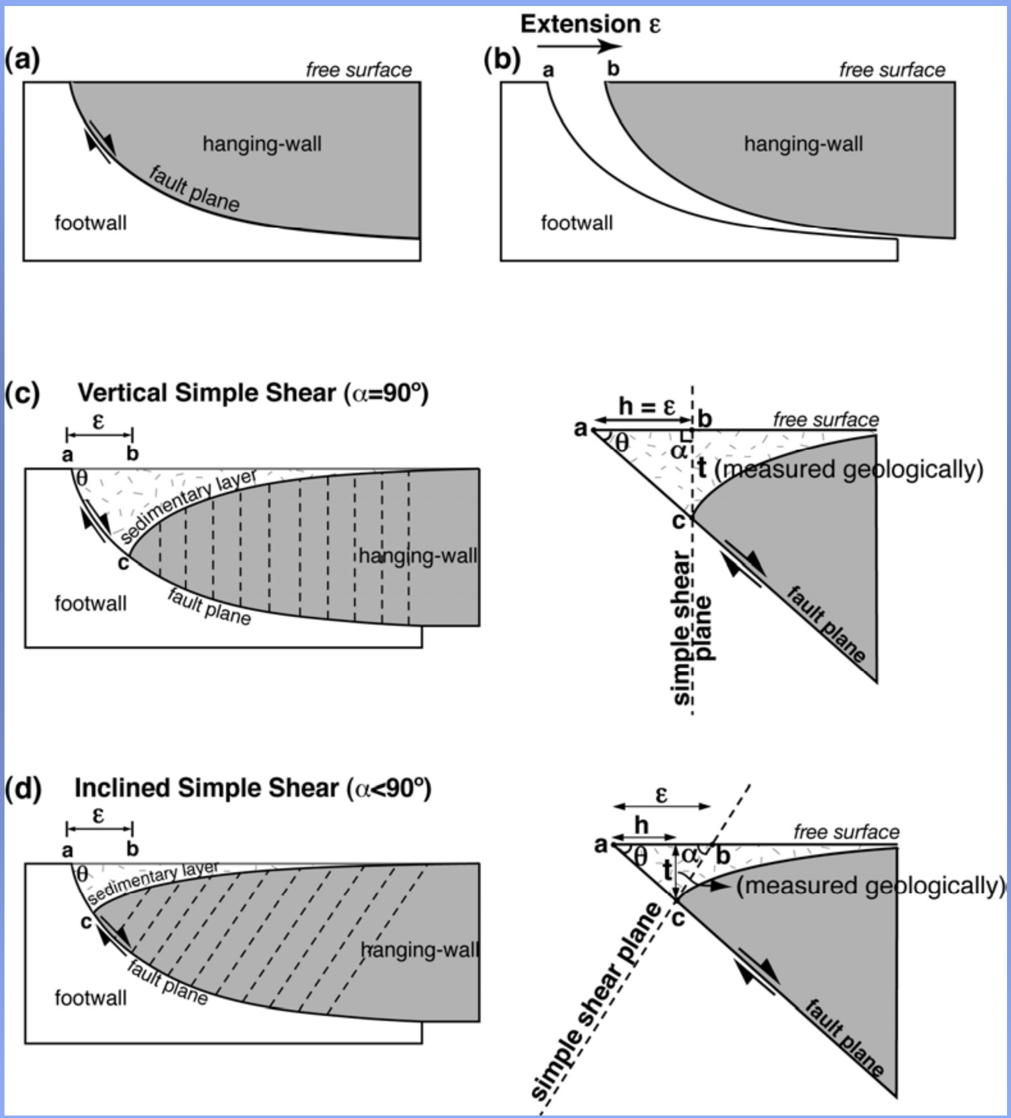


Wasatch fault earthquake history



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

Simple-Shear Model for Converting Geologic Vertical Displacement to Geodetic Horizontal Extension for Normal Fault

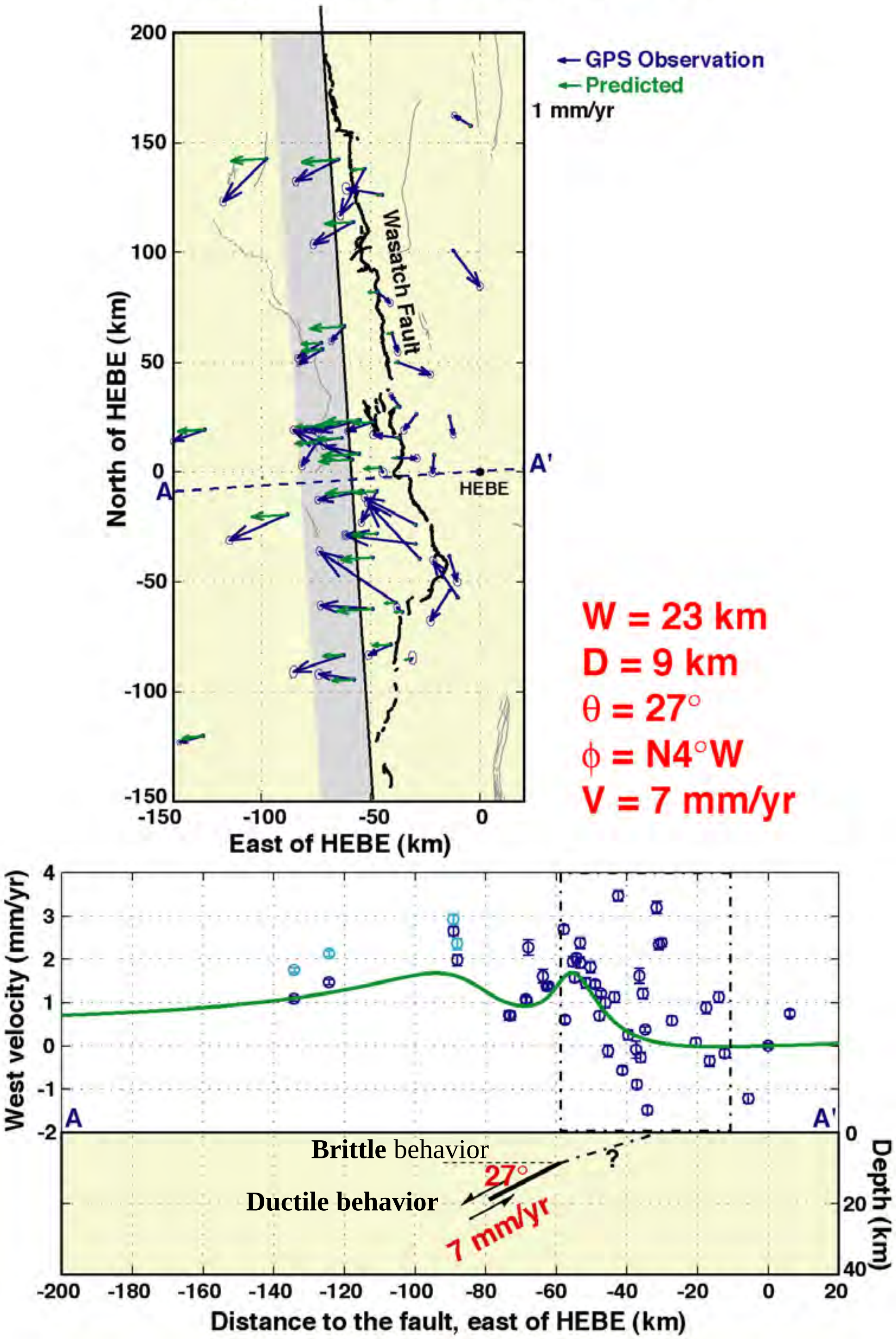


Comparison of Deformation Rates Across the Wasatch Fault From GPS and Geologic Determinations

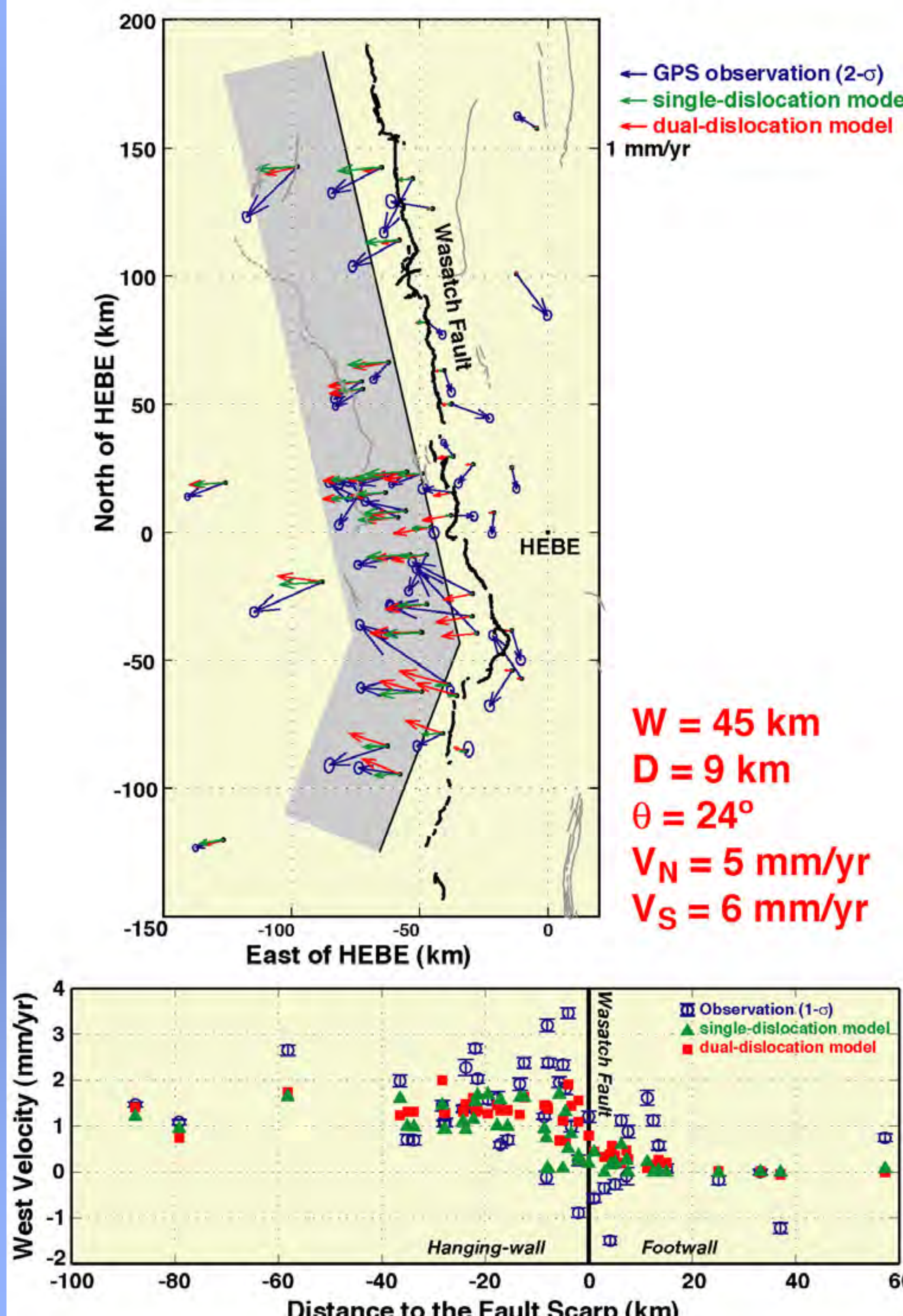
Dip of the Wasatch Fault	Dip of Simple-Shear Plane (Antithetic Fault)	Vertical Displacement Rate from GPS Data, mm/yr	Geologic Fault Slip Rate (0-10 ka), mm/yr	Comparison of GPS Rate with Geologic Rate
θ = 30°	**α = 55°E-80°E**	0.5 - 1.0	1.7 ± 0.5	**GPS < Geologic**
	α = 90°	0.7 - 1.2	1.7 ± 0.5	**GPS < Geologic**
θ = 55°	**α = 55°E-80°E**	0.9 - 2.3	1.7 ± 0.5	**Consistent**
	α = 90°	1.7 - 2.9	1.7 ± 0.5	**Consistent**
θ = 70°	**α = 55°E-80°E**	1.1 - 3.7	1.7 ± 0.5	**Consistent**
	α = 90°	3.3 - 5.5	1.7 ± 0.5	**GPS > Geologic**

Chang et al. [2006]

Single-dislocation model

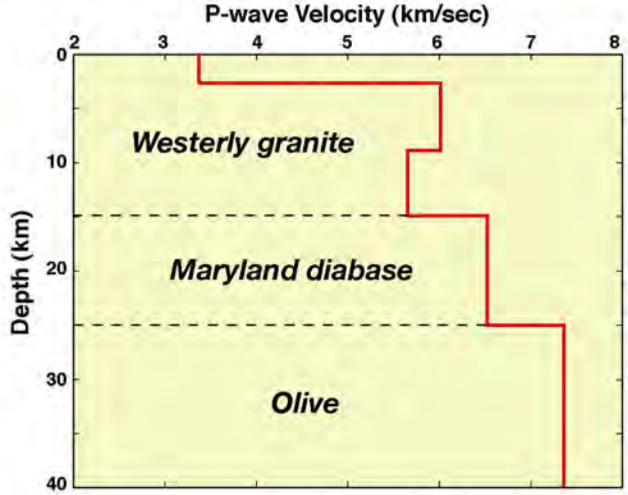


Dual-dislocation model

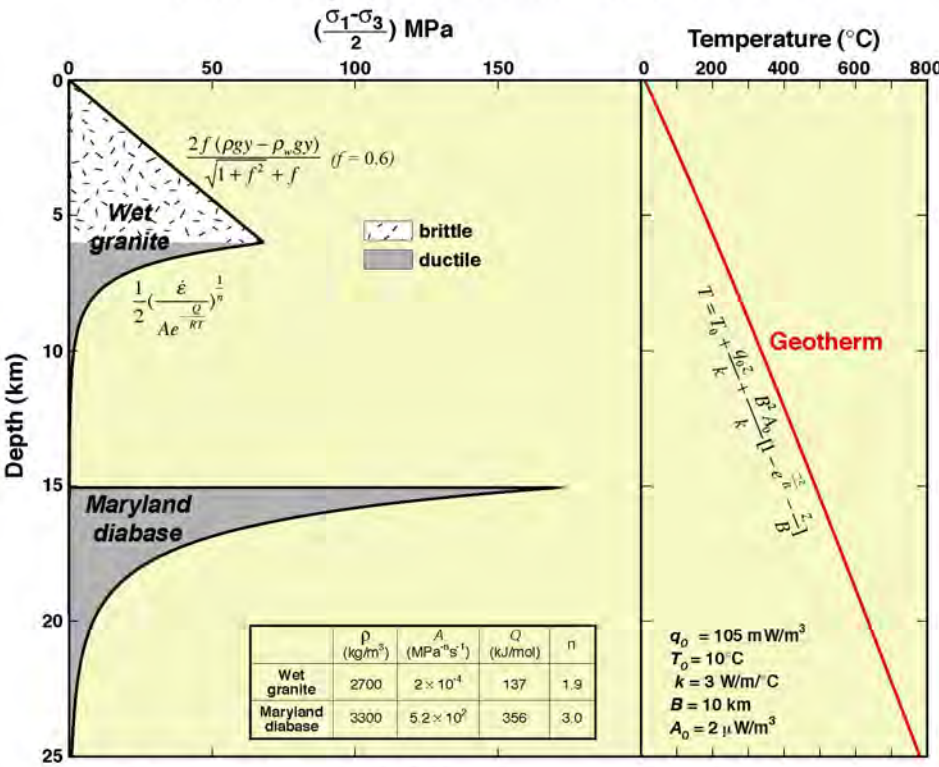


Chang et al., 2006

P-wave Velocity Structure for Basin-Range



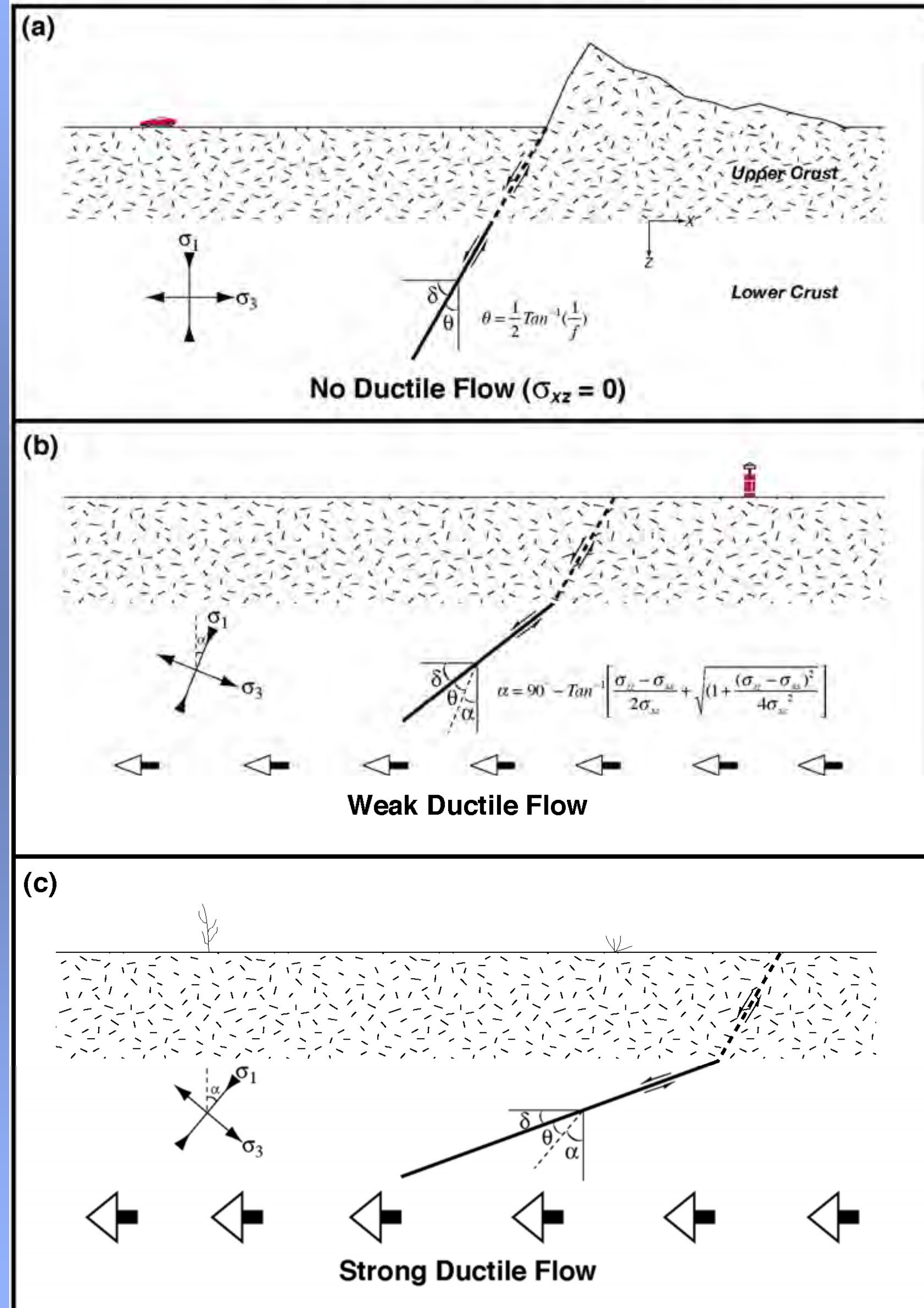
Crustal Rheological Model and Geotherm



	ρ (kg/m^3)	A (MPa^{-n}s^{-1})	Q (kJ/mol)	n
Wet granite	2700	2×10^{-4}	137	1.9
Maryland diabase	3300	5.2×10^{2}	356	3.0

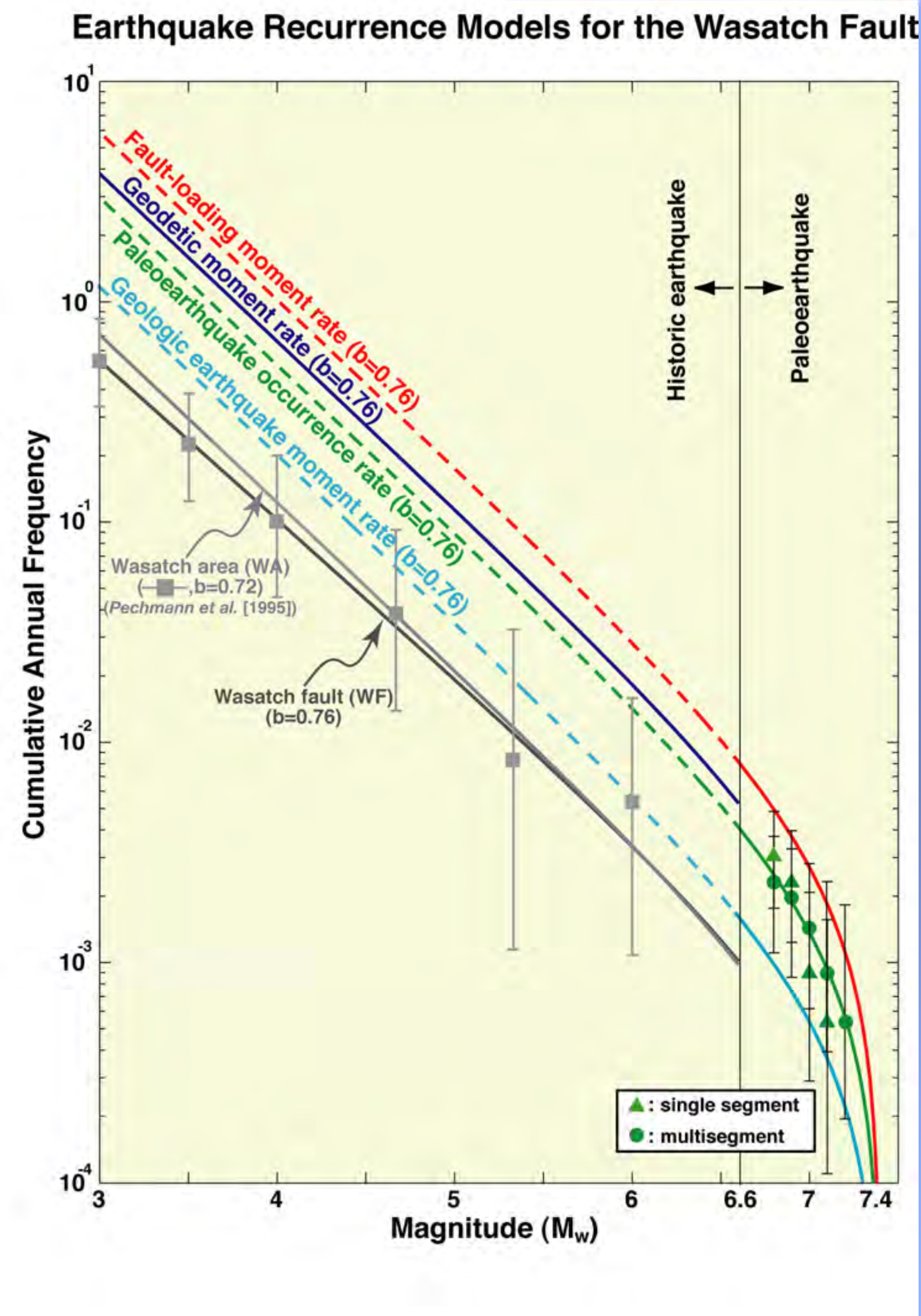
after *Smith and Bruhn* [1984]

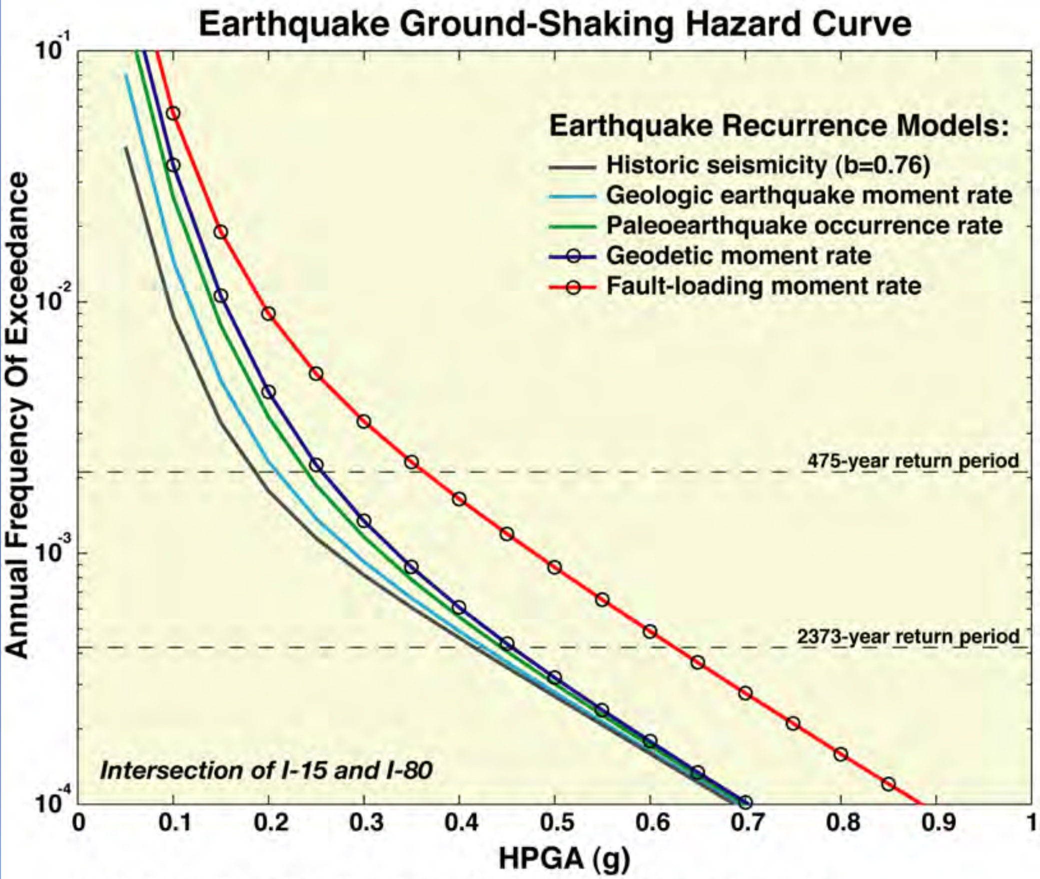
Changes of Normal-fault Dip and the Strength of Ductile Flow in the Lower Crust



(after *Westaway* [1998])

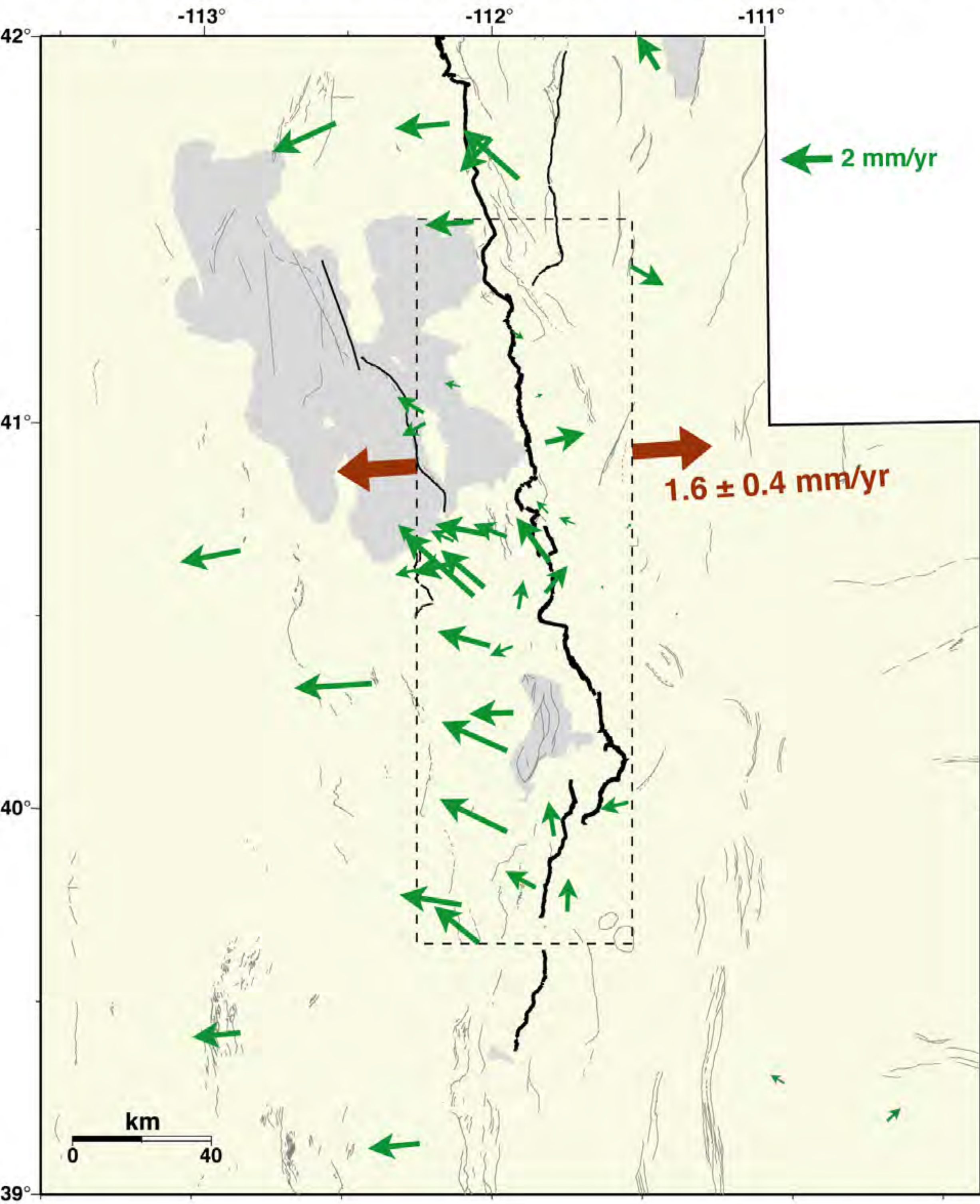
Integrated Earthquake Hazard Analysis

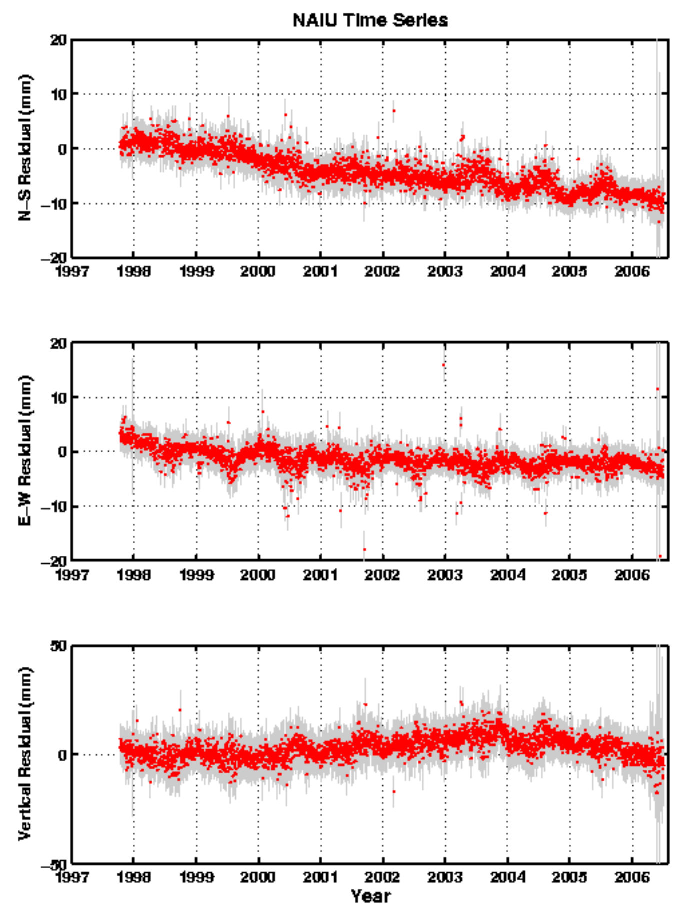




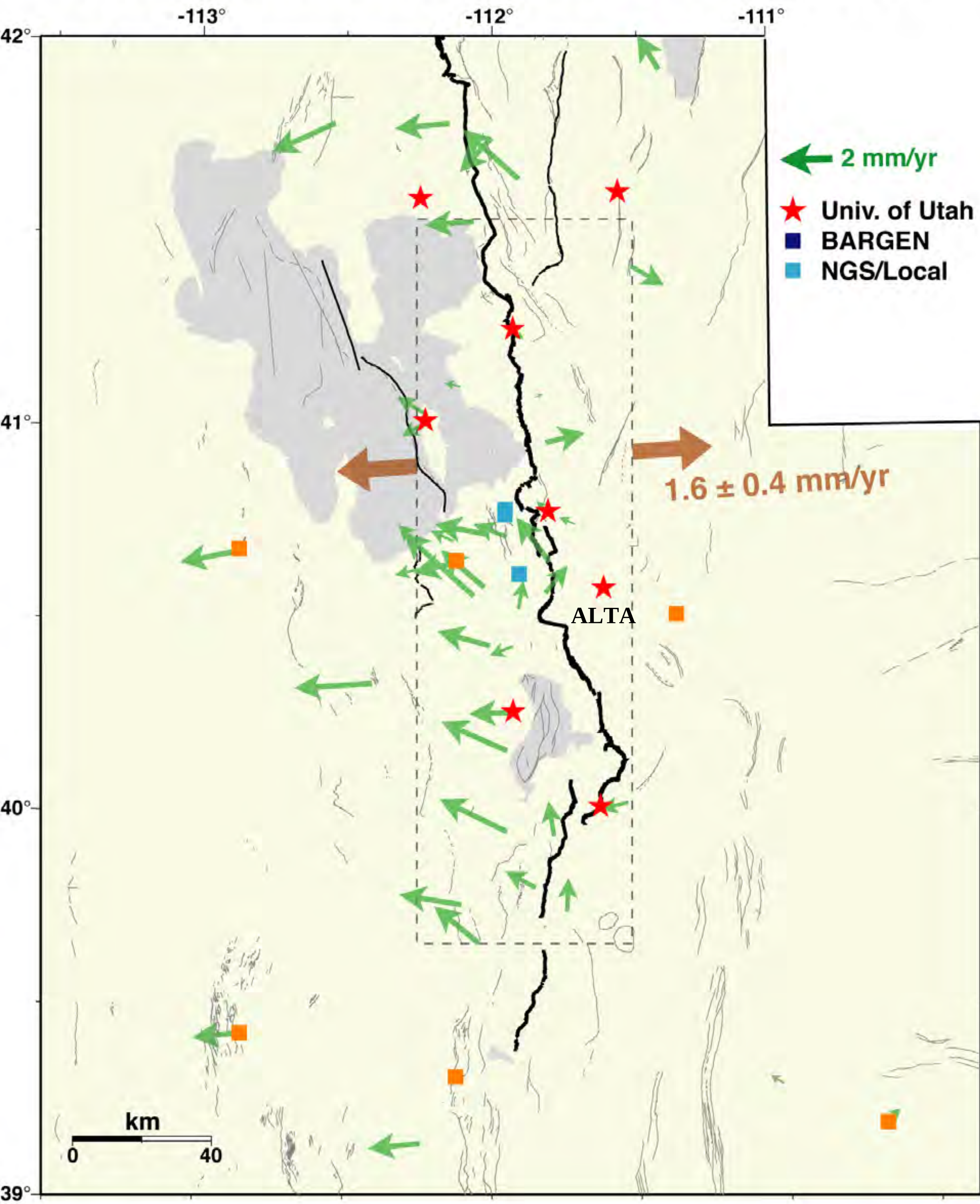
HPGA attenuation: *Spudich et al.* [1999] for extensional regimes

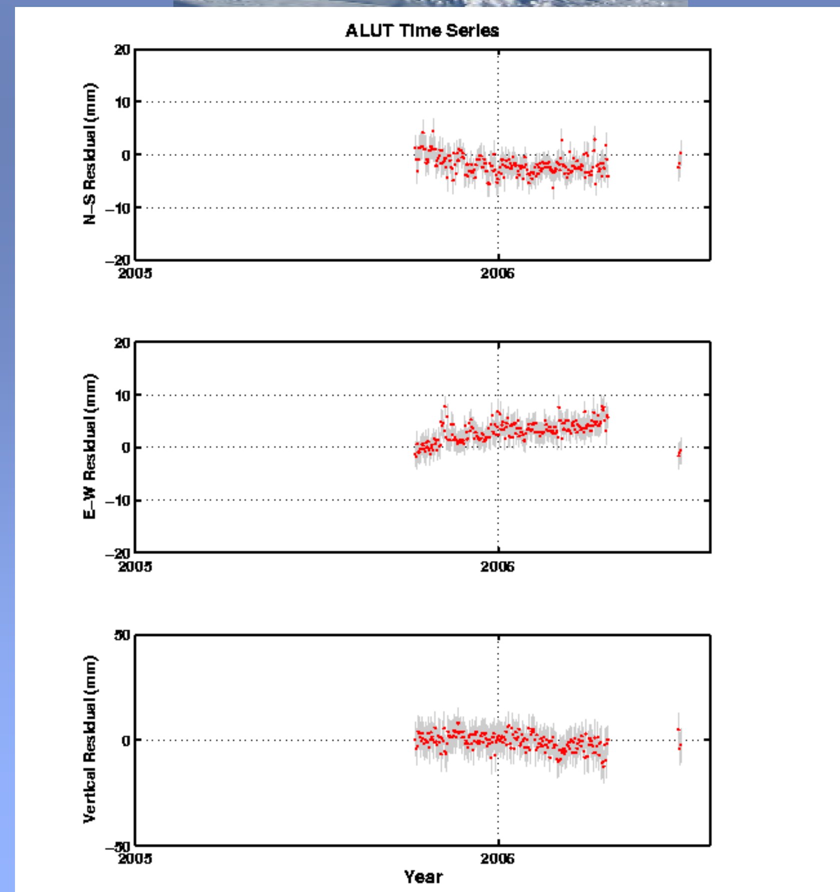
Wasatch GPS Network and Velocity Field



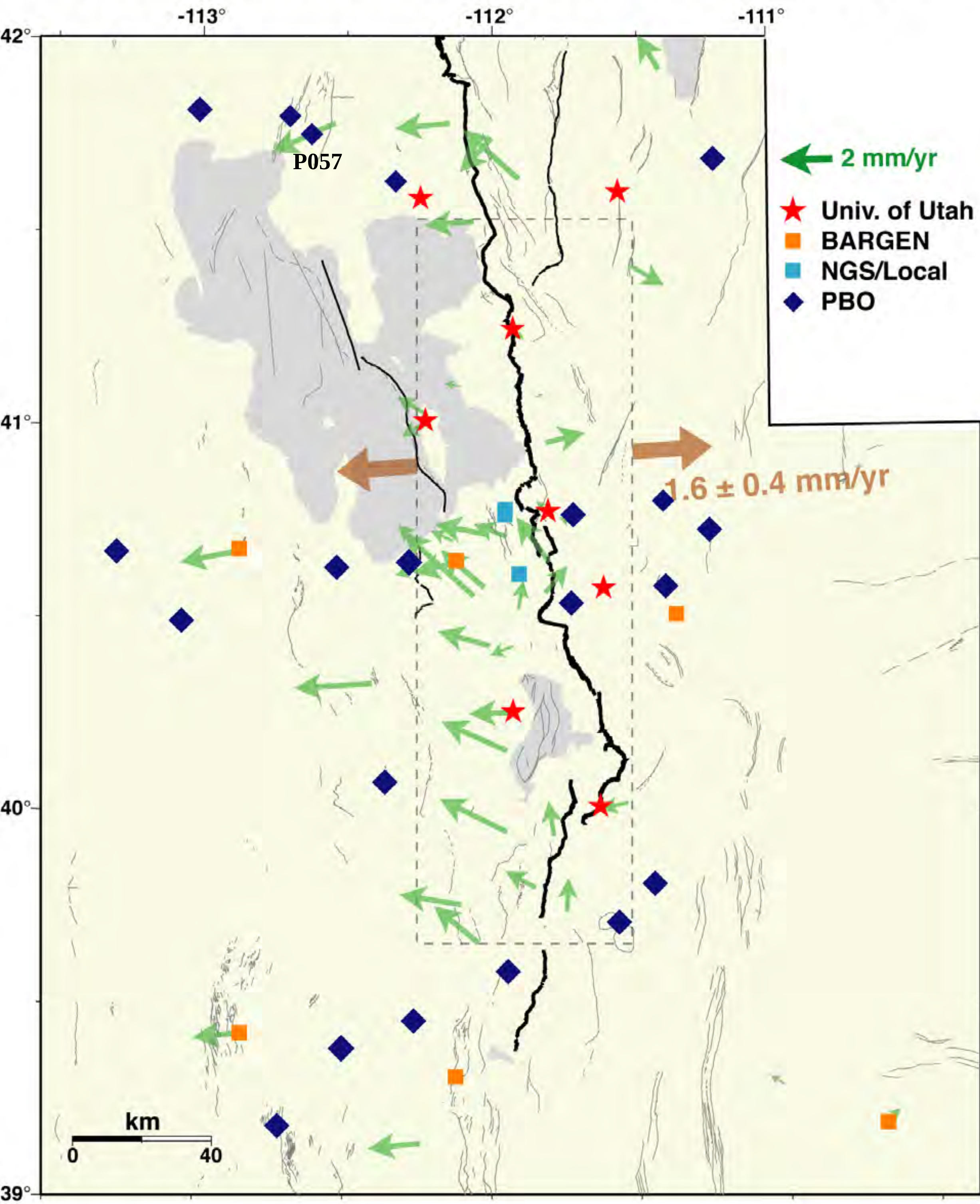


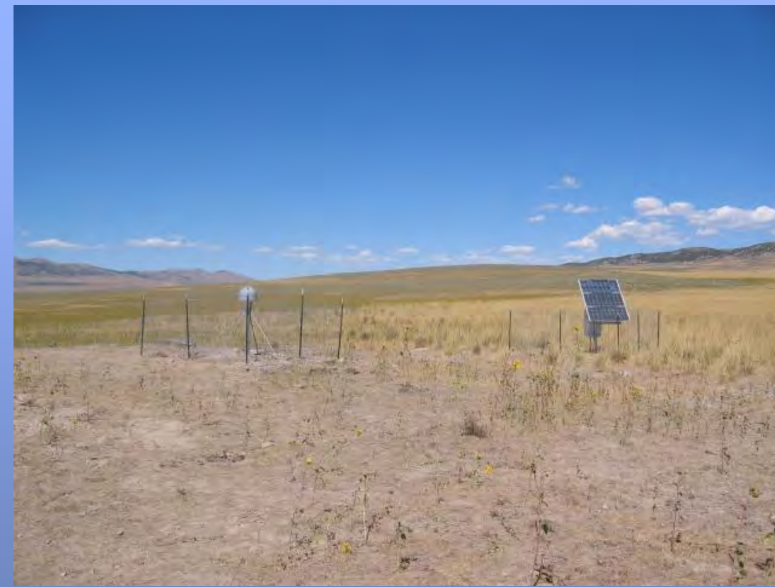
Wasatch GPS Network and Velocity Field

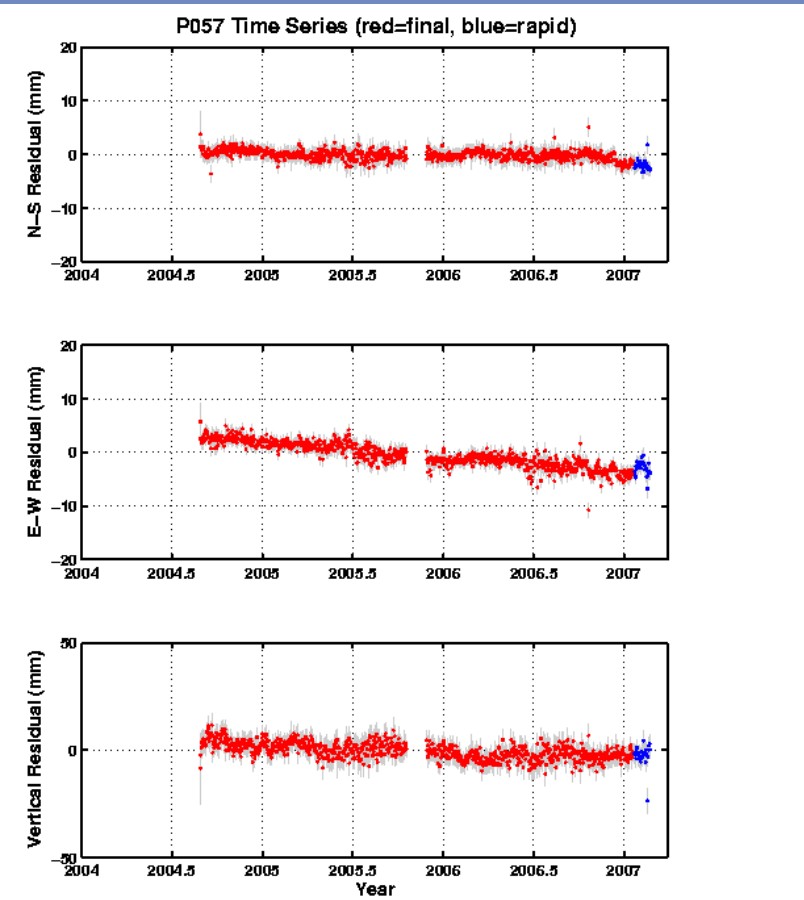




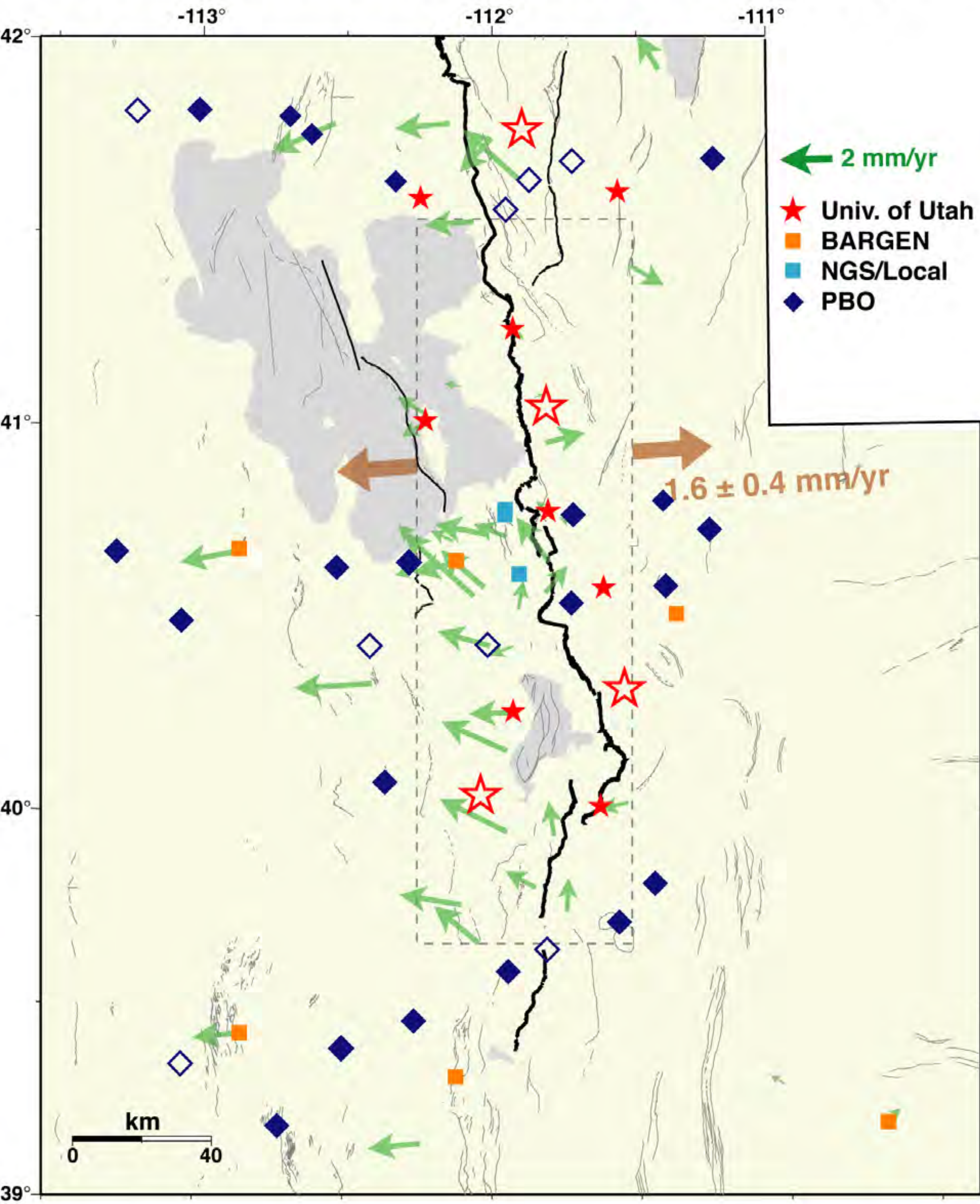
Wasatch GPS Network and Velocity Field







Wasatch GPS Network and Velocity Field



All GPS data are available at UNAVCO:
http://facility.unavco.org/data/data.html

GPS time series are available at our website:
http://www.mines.utah.edu/~ggcmpsem/UUSATRG/GPS/time_series.html

GeoEarthScope LiDAR Acquisition Targets

LiDAR acquisition is a key component of the GeoEarthScope Initiative that will provide data with a range of applications that will advance many of the EarthScope goals

Within each target region, specific faults and fault systems were identified for LiDAR data acquisition as part of GeoEarthScope; each target was ranked according to priority; with a provisional timetable.

Regional Targets:

a. Northern California
Priority 1 Data Acquisition: ~ 1370 km2 beginning Fall 2006

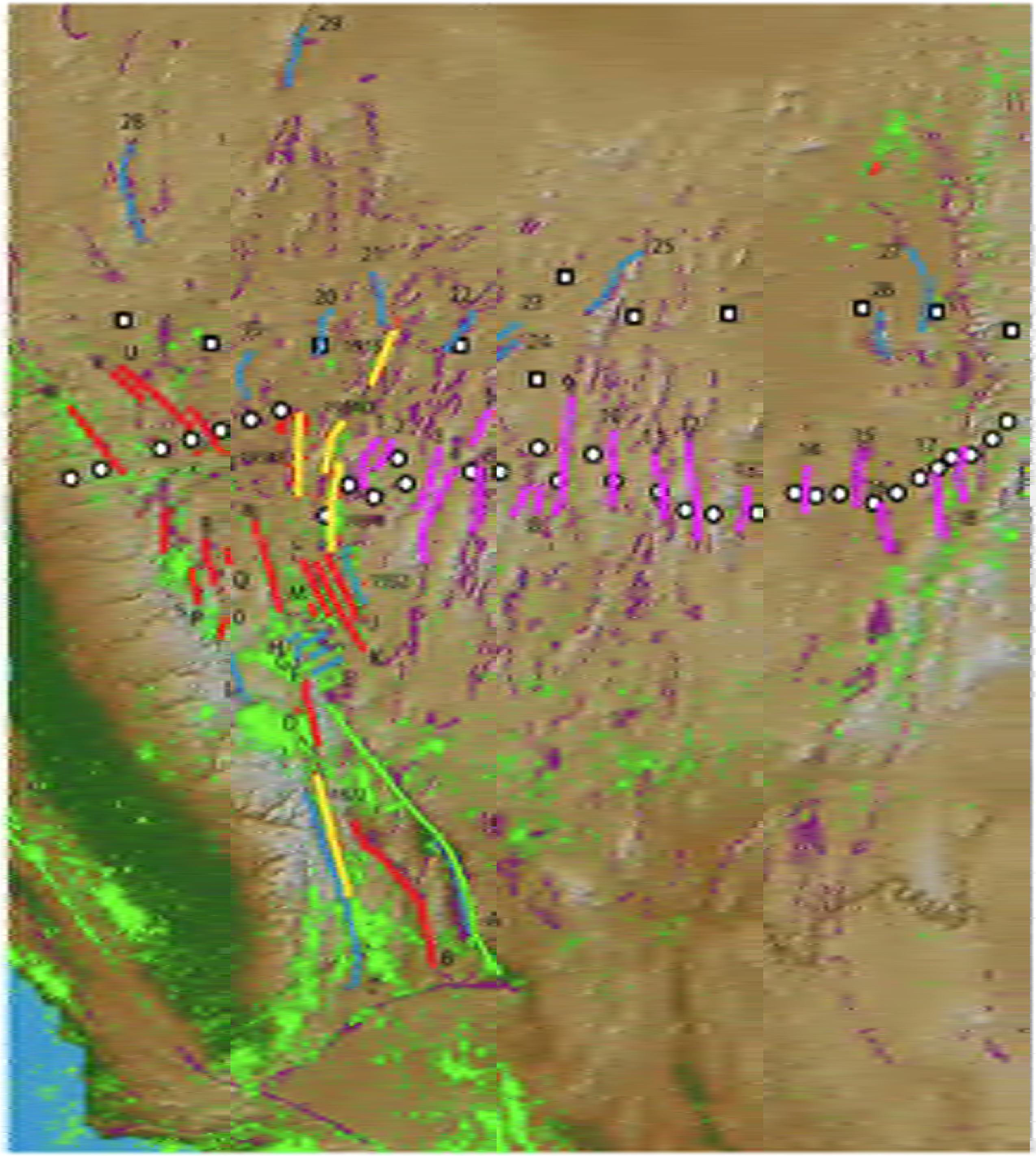
b. Southern California
Priority 1 Data Acquisition: ~ 1953 km2 beginning Spring 2007

c. Intermountain Seismic Belt
Including the Wasatch Fault, Teton Fault, Yellowstone Park area, and northern extensions of the system through Idaho and Montana, *beginning Fall 2007*
Priority 1 Data Acquisition: ~ 1513 km2

d. Eastern California, Walker Lane, and Basin and Range fault systems
Proposed Priority 1 Data Acquisition: ~ 2010 km2, beginning summer 2008

Data will be archived at the UNAVCO facility for all interested users

Research on LIDAR projects will be though competitive science proposals through regular NSF channels.



Basin & Range I-50 Transect

1. Clan Alpine
2. Desatoya
3. Toiyabe E.
4. Toiyabe W.
5. Simpson Park
6. Toquima
7. Monitor W.
8. Monitor E.
9. Diamond
10. Butte
11. Egan
12. Schell Creek
13. Snake Range
14. Utah - House Range
15. Utah - Drum Mountains
16. Utah - Clear Lake
17. Utah - Scipio-Little Valley
18. Utah - Wasatch - Levan

Basin & Range I-80 Transect

19. Shawave
20. Humboldts
21. Sonoma
22. Shoshone
23. Dry Hills
24. Cortez
25. Rubys
26. Stansbury Utah
27. E Salt Lake Utah

Historical Earthquakes

1872. Owens Valley
1932. Cedar
1954 F. Fairview
1954 D. Dixie
1954 R. Fallon Rainbow
1915. Pleasant Valley

Basin & Range Northwest:

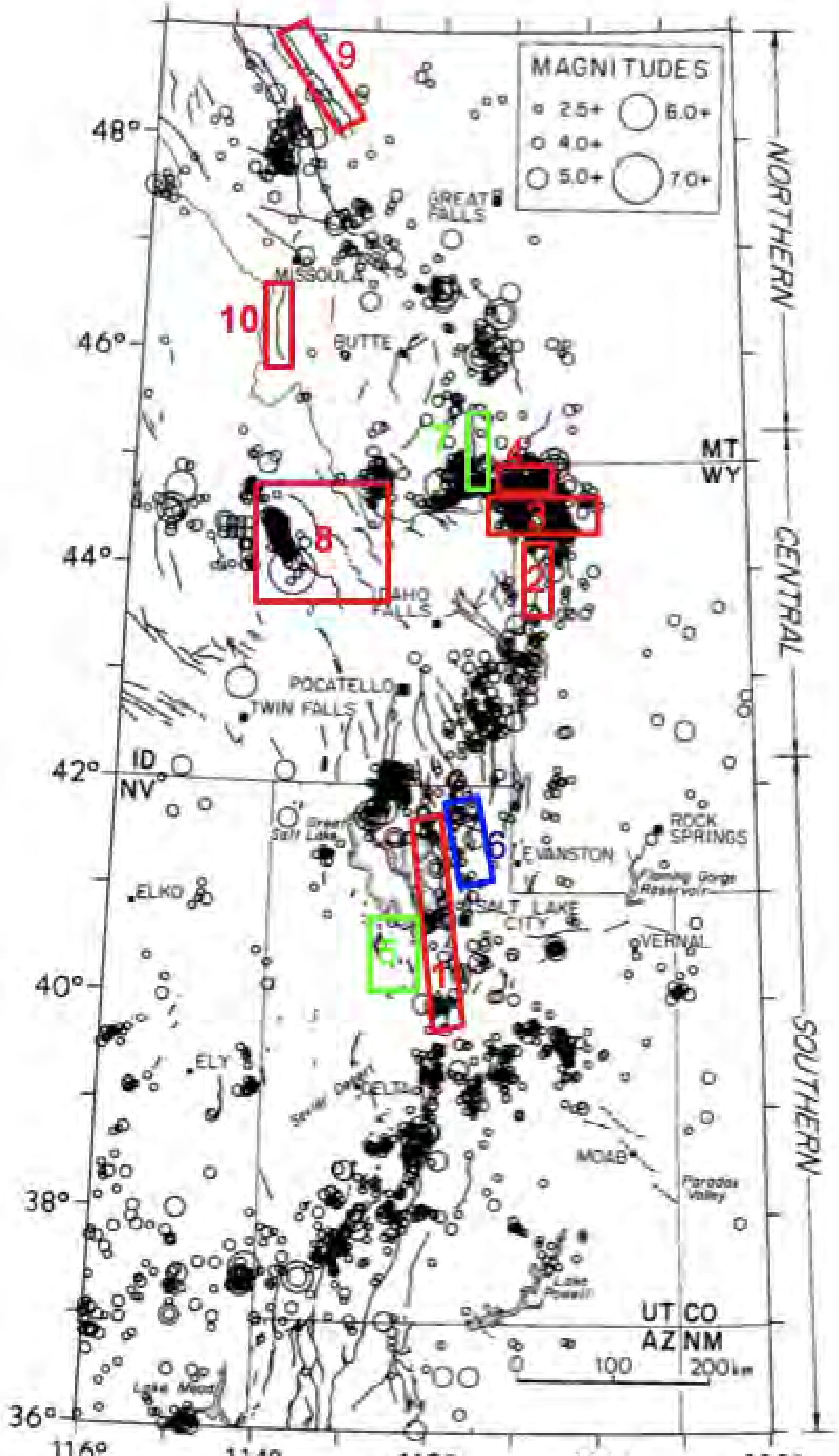
28. Surprise Valley, CA
29. Steens

Walker Lane

A. Death Valley -Furnace - Fish Lake
B. Panamint-Hunter-Saline
C. South Sierra Range front
D. White Mtns
E. Coaldale
F. Candelaria
G. Teels Marsh
H. Rattlesnake
I. Mono-Hilton
J. Petrified-Bettles
K. Benton Springs
L. Gumdrop
M. Indian Head
N. Wassuk
O. Bridgeport
P. Antelope V.-Topaz
Q. Mason Valley
R. Smith Valley
S. Genoa-Carson
T. Pryamid
U. Warm Spring
V. Honey Lake
W. Mohawk Valley
X. Olinghouse

Figure Caption

Location of faults (bold color lines) planned for LIDAR acquisition on physiographic fault. Also shown in thin lines are other Quaternary faults in Region. Priority 1 faults in Walker Lane, across Basin and Range, and historical ruptures are colored red, purple, and yellow, respectively. Priority 2 faults are colored blue. Green faults are already being acquired. Dots and squares are planned distribution of PBO GPS sites across Basin and Range. Squares are locartion of current BARGEN network. Green dots are background seismicity



MAGNITUDES
2.5+
4.0+
5.0+
6.0+
7.0+
NORTHERN
CENTRAL
SOUTHERN
GREAT FALLS
MISSOULA
BUTTE
IDAHO FALLS
POCATELLO
TWIN FALLS
ID
NV
MT
WY
Great Salt Lake
ELKO
EVANSTON
ROCK SPRINGS
Flaming Gorge Reservoir
SALT LAKE CITY
VERNAL
ELY
DELTA
Sevier Desert
MOAB
Paradox Valley
Lake Powell
Lake Mead
UT
CO
AZ
NM
100
200km
48°
46°
44°
42°
40°
38°
36°
116°
114°
112°
110°
108°
1
2
3
4
5
6
7
8
9
10

REVISE CONSENSUS SLIP RATE FOR THE SALT LAKE CITY SEGMENT OF THE WASTCH FAULT ZONE?

NEW CRONOLOGY OF LATE PLEISTOCENE GLACIERS, WASATCH MOUNTAINS

UTAH DNR

GEOLOGICAL SURVEY

PREVIOUS SLIP-RATE DATA FOR THE SALT LAKE CITY SEGMENT

- **Based on data from a single location at the mouth of Little Cottonwood Canyon (LCC) in the SE corner of the Salt Lake Valley.**
- **Swan and others (1981) reported 14.5 +10/-3 m of net vertical slip in the crest of the Bells Canyon moraines.**
- **Scott (1988) reported an age for the moraines of 18-26 ka.**
- **Calculated slip rate:**

$$\frac{14.5\ {+10}/{-3}\ \text{m}}{18\text{-}26\ \text{kyr}}$$

0.4 – 0.7 – 1.4 mm/yr

CAVEATS

- 26 ka maximum limiting age is a total organics ^{14}C age from the Majestic paleosol, which developed on the Bull-Lake-age moraine at LCC, and directly underlies the Pinedale-age moraine (Madsen and Currey,1979).

- 18 ka minimum limiting age is based on relations between the Pinedale-age moraine and high-stand deposits and geomorphic features of Lake Bonneville.

- Latest Pleistocene time (post 18-26 ka) likely included a period of quiescence on the WF (McCalpin, 2002), followed by shorter earthquake recurrence intervals during the Holocene.

- Therefore, most Pinedale-age moraine displacement likely occurred during the Holocene.

- The UQFPWG concluded that the reported slip rate for the SLC segment was too low.

CURRENT UQFPWG CONSENSUS SLIP RATE FOR THE SALT LAKE CITY SEGMENT

Based upon the likelihood of a period of fault quiescence in the latest Pleistocene and comparison with slip-rate information from adjacent segments, the UQFPWG assigned a consensus vertical slip rate for the Salt Lake City segment of:

0.6 - 1.2 - 4.0 mm/yr

NEW INFORMATION ON THE AGE OF THE BELLS CANYON MORAINES

- **Lips, E.W., 2005, Revised chronology of late Pleistocene glaciers, Wasatch Mountains, Utah [abs.]: Geological Society of America Abstracts with Programs, v. 37,no. 7, p. 41**

- **Godsey, H.S., Atwood, G., Lips, E., Miller, D.M., Milliagan, M., and Oviatt, C.G., 2005, Don R. Currey memorial field trip to the shores of Pleistocene Lake Bonneville, *in* Pederson, J.L., and Dehler, C.M., editors, Interior western United States: Geological Society of America Field Guide 6, p. 419-448.**

  (Stop 3.3: Inspiration Point – Temporal Relation between Till of Bells Canyon and the Bonneville Highstand)

NEW AGE FOR WASATCH GLACIERS

- **The Pinedale till at LCC was previously interpreted as preceding the highstand of Lake Bonneville by 4-5 kyr (Madsen and Currey, 1979; Scott, 1988).**

- **New stratigraphic exposures show that the till is interfingered with, or deposited on lake sediments, suggesting that the glaciers were at their maximum either contemporaneously with, or after the Bonneville highstand (Lips, 2005; Godsey and others, 2005).**

- **New ^{10}Be cosmogenic exposure ages from boulders on the youngest moraines at LCC indicate a glacial advance at approximately 16.9 $\pm$ 0.4 to 15.2 $\pm$ 0.4 ^{10}Be ka (mean of 15.9 $\pm$ 0.7 ^{10}Be ka).**

NEW SLIP-RATE CALCULATION

- **15.9 <u>+</u> 0.7 ^{10}Be ka age estimate has 1-sigma error bars.**

- **To be conservative, Jim Pechmann and Susan Olig (original UQFPWG members) recommend using 2-sigma uncertainty, i.e. 15.9 <u>+</u> 1.4 ^{10}Be ka for any new slip-rate calculations.**

- **New slip rate:**

$$\frac{14.5\ +10/-3\ \text{m}}{17.3 - 15.9 - 14.5\ {}^{10}\text{Be ka}}$$

0.7 – 0.9 – 1.7 mm/yr

SLIP-RATE COMPARISONS

- **Old calculated rate: 0.4 – 0.7 – 1.4 mm/yr**

- **New calculated rate: 0.7 – 0.9 – 1.7 mm/yr**

- **UQFPWG consensus rate: 0.6 - 1.2 - 4.0 mm/yr**

In light of the new age for the young moraine at LCC, does the UQFPWG need to revise the consensus slip rate for the Salt Lake City segment?

REVISED WEBER SEGMENT PALEOSEISMIC DATA

Revisit UQFPWG Consensus Slip-Rate and Recurrence Interval Estimates for the Weber Segment?

REVISED
WEBER SEGMENT PALEOSEISMIC DATA NOW AVAILABLE

Nelson, A.R., Lowe, M., Personius, S., Bradley, L.-A., Forman, S.L., Klauk, R., and Garr, J., 2006*, Holocene earthquake history of the northern Weber segment of the Wasatch fault zone, Utah: Utah Geological Survey Miscellaneous Publication 0 5-8, 39 p., 2 plates, CD-ROM.

*Report summarizes, in more detail than previously published, a cooperative investigation between the UGS and the USGS of the earthquake history at two sites on the northern part of the Weber segment of the Wasatch fault zone, largely completed between 1985 and 1990.

HOWEVER

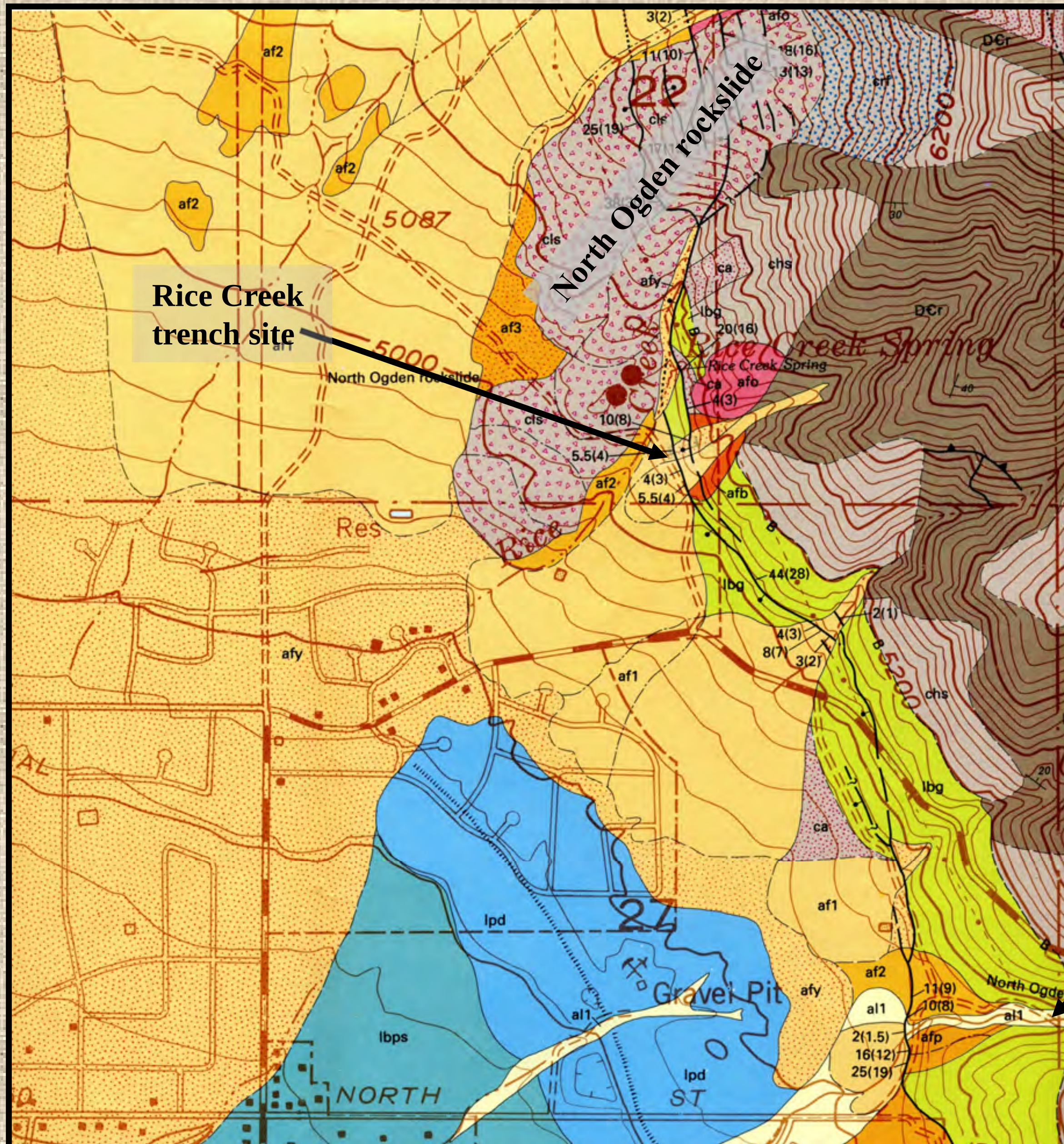
SIGNIFICANT QUESTIONS REMAIN REGARDING THE WEBER SEGMENT

- Chronology of WS Holocene surface-faulting earthquakes is the most poorly understood of the central WFZ segments (UQFPWG, 2006).
- Earthquakes identified in WS trench exposures are difficult to correlate between paleoseismic sites; Nelson and others (2006) could only correlate two of four earthquakes with confidence between all three sites.
- Estimates of mid-Holocene to present WS average recurrence are highly variable depending on different earthquake correlation schemes and inclusion of a possible young partial-segment rupture.
- Previous trench investigations only extend the paleoseismic record to the mid-Holocene.
- Total site displacement and displacement-per-event information are poorly quantified, and large uncertainties remain in WS paleoearthquake magnitudes and vertical slip rate.
- Evidence for both partial- and multi-segment rupture exists along the segment (Nelson and others, 2006), but further refining of the WS earthquake chronology is necessary to test segmentation models.

PLANS TO ADDRESS THESE QUESTIONS

- Because of urbanization and development, few unmodified scarps remain, severely limiting the number of possible study sites.
- Virtually all of central and southern parts of segment are developed.
- Of the remaining sites, best option is a site located about 150 m south of Rice Creek springs in North Ogden.
- UGS in cooperation with the USGS will excavate a trench across two parallel scarps at the site.
- Challenges:
  - Large scarps: lower scarp–5.5 m high; upper scarp–10 m high.
  - Very coarse debris-flow deposits.
  - Excavate deep enough to extend paleoseismic record beyond mid-Holocene time?
- Field Schedule: May 9-24, 2007.

Rice Creek Surficial Geology



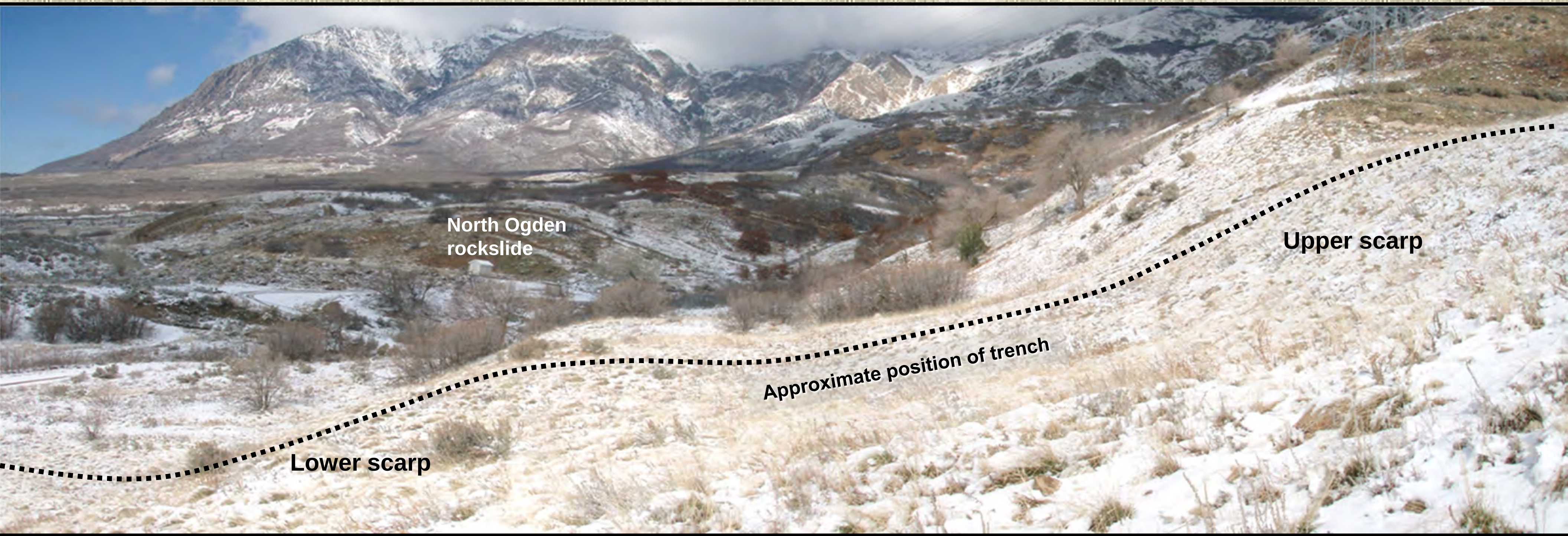
from Nelson and Personius, 1993, USGS Map I-2199

Rice Creek Location

Rice Creek Location

Rice Creek Location

Rice Creek Site



view to north

Rice Creek Site

Rice Creek Site

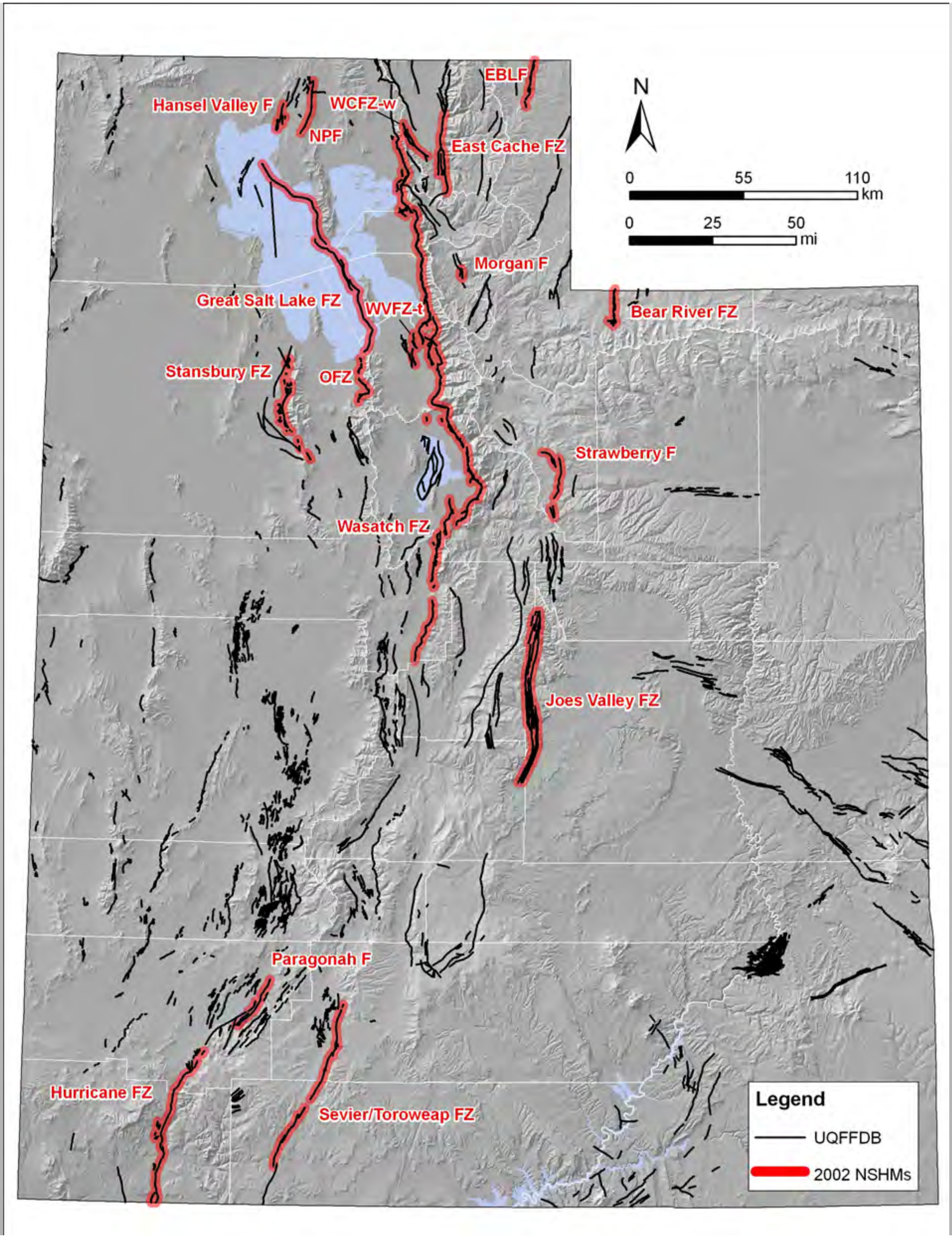
UTAH QUATERNARY FAULTS RECOMMENDED FOR THE 2007 UPDATE OF THE NATIONAL SEISMIC HAZARD MAPS

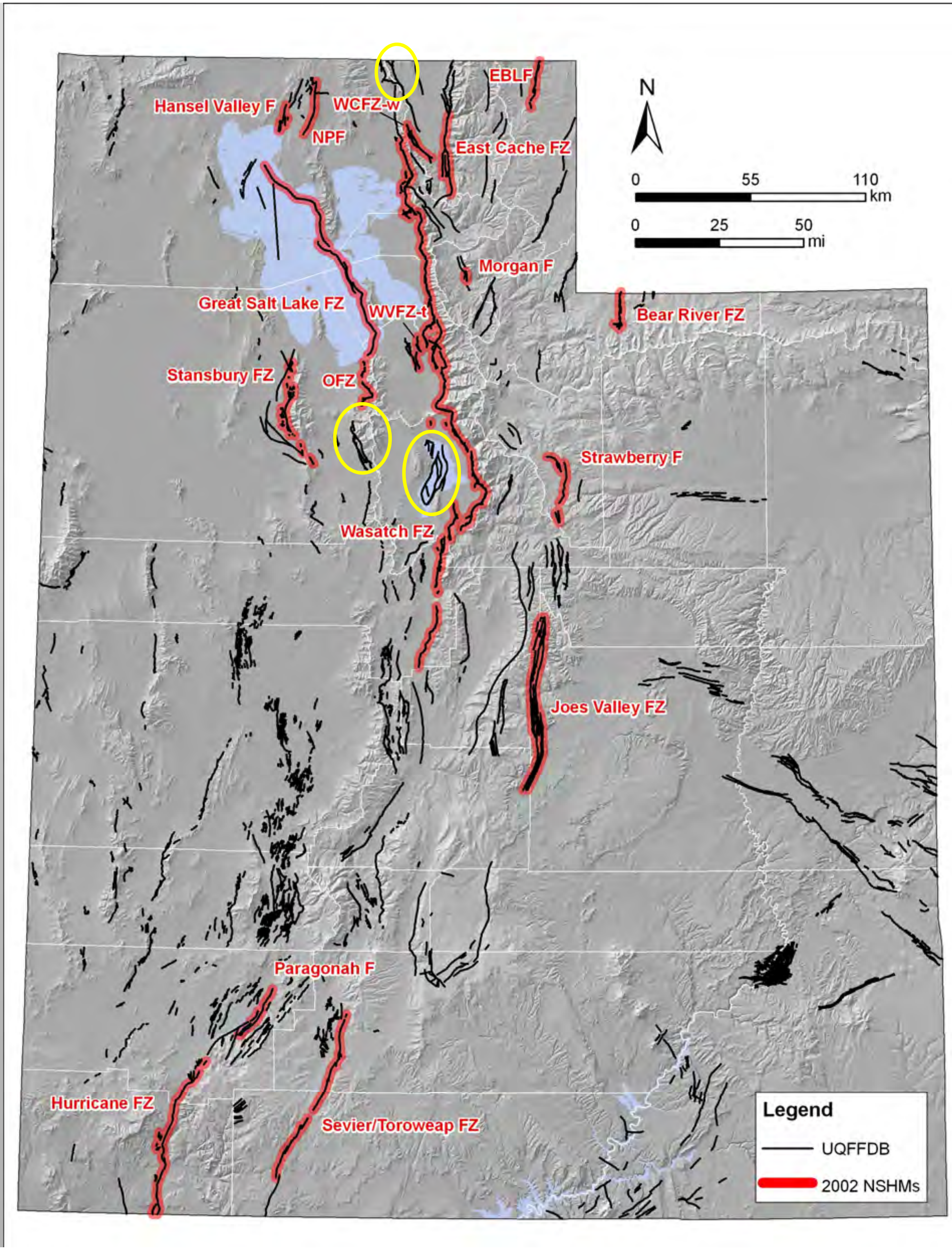
Christopher B. DuRoss, William R. Lund, Gary E. Christenson, and Michael D. Hylland

Utah Geological Survey

2002 NSHMs

23 Quaternary faults





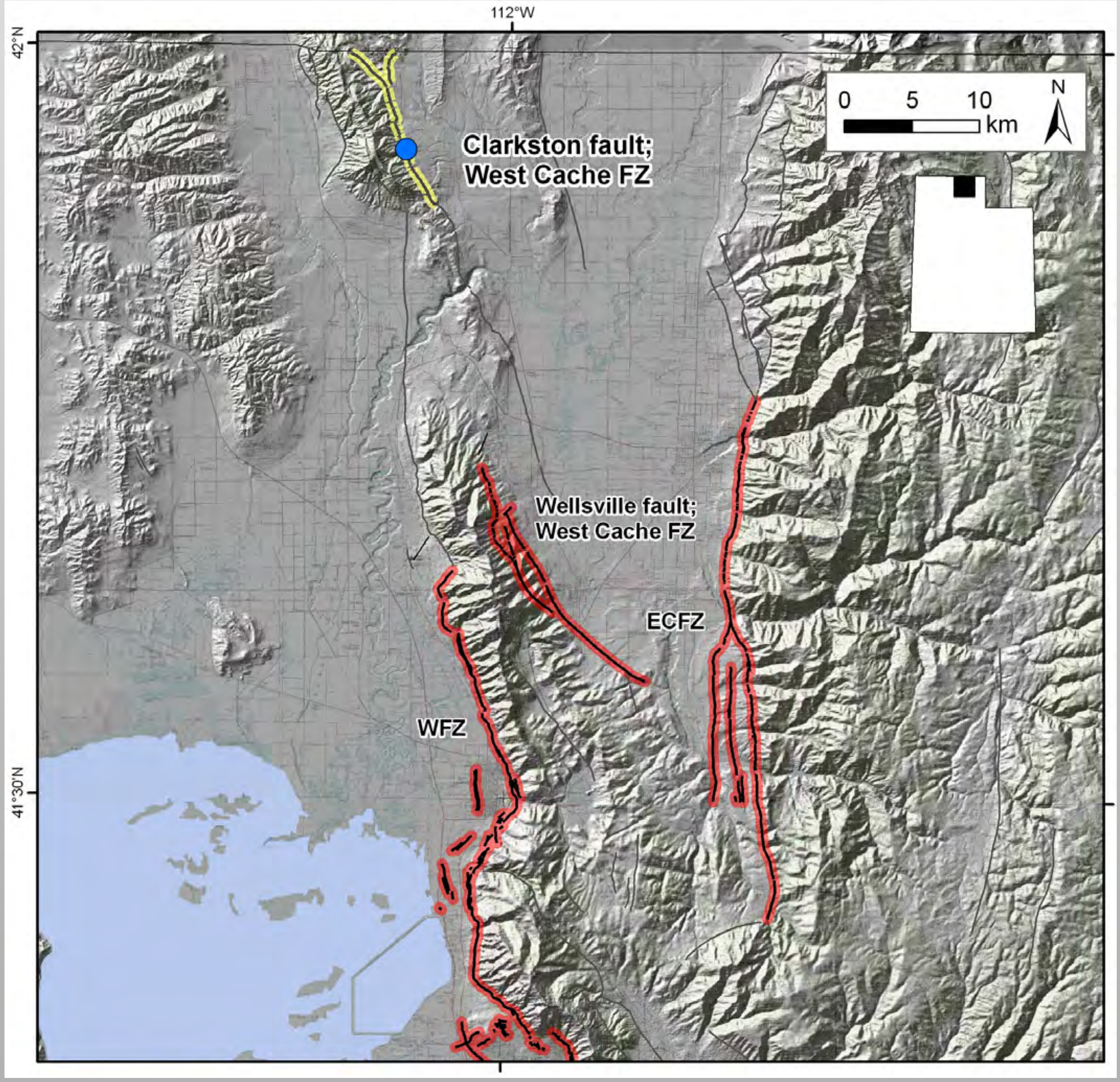
2002 NSHMs

23 Quaternary faults

Recommendations:

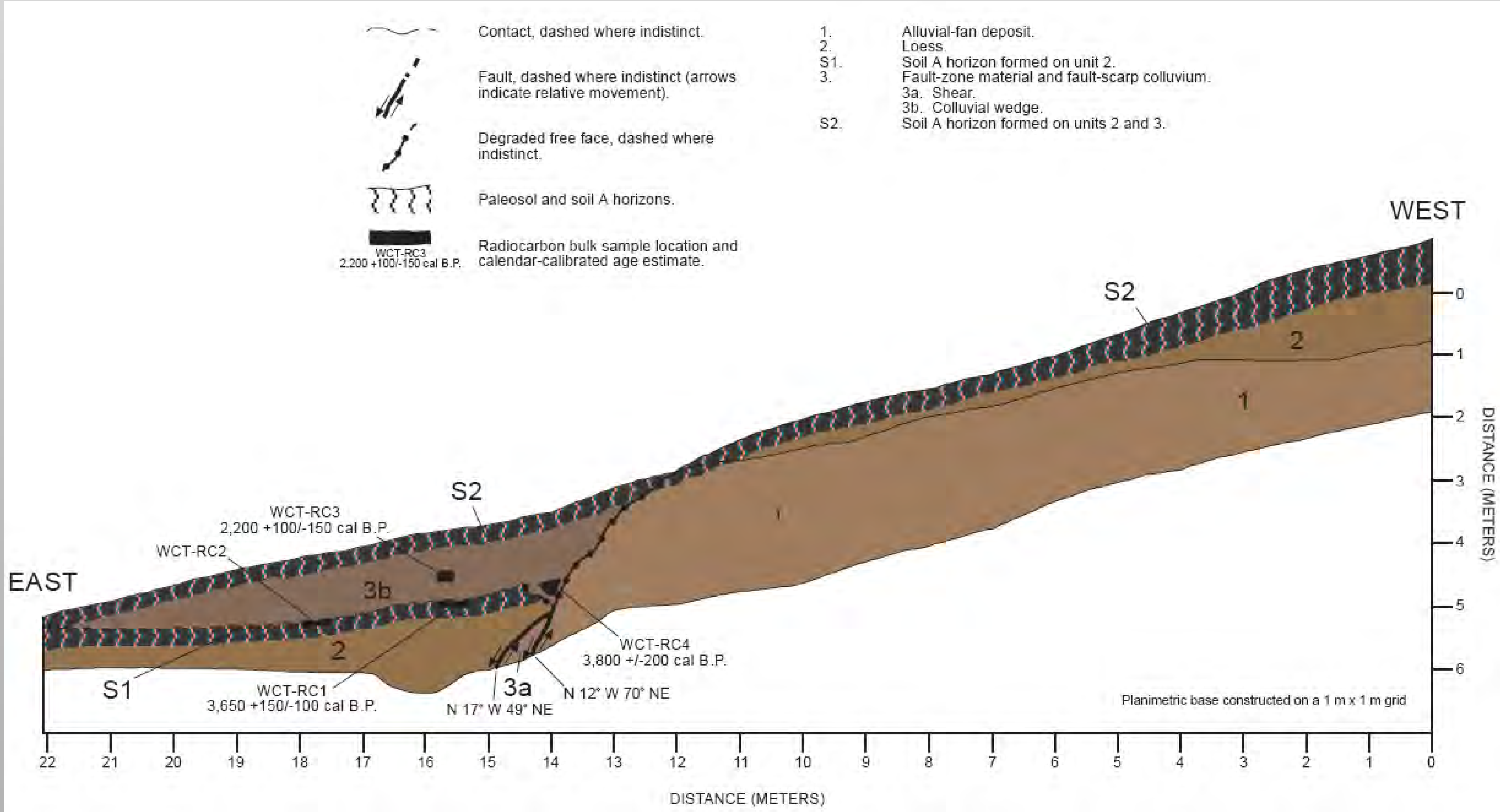
- West Cache fault zone
- Southern Oquirrh Mountains fault zone
- Utah Lake faults and folds

WEST CACHE FAULT ZONE
Clarkston Fault



WEST CACHE FAULT ZONE
Clarkston Fault

(Black and others, 2000)



WEST CACHE FAULT ZONE
Clarkston Fault

2002 NSHMs - not included

Summary

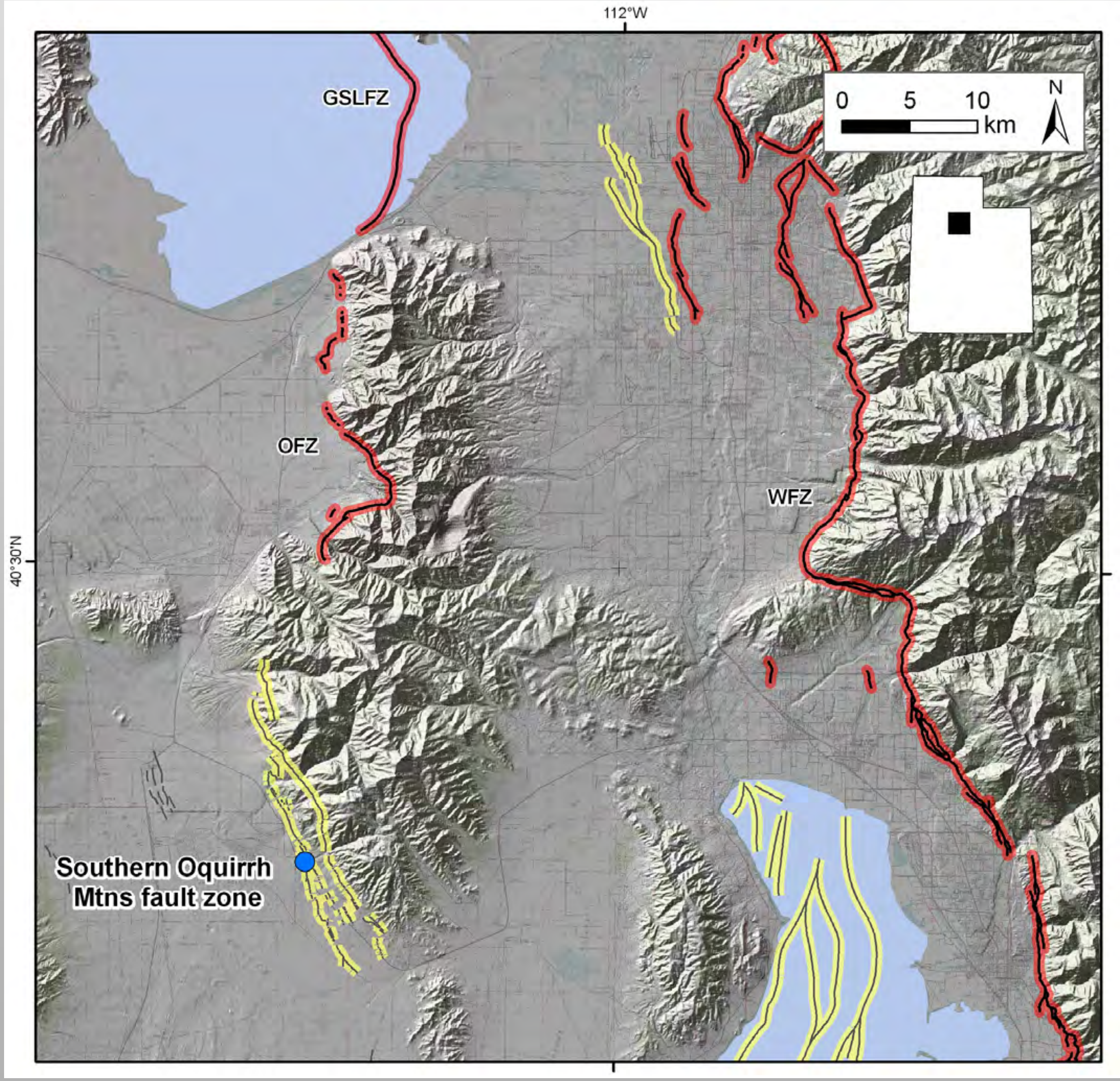
- Large-magnitude surface faulting: 3600-4000 cal yr
- 9 m displacement / 3.8-16.8 ka: long-term SR 0.7 mm/yr

  Black and others (2000)

Recommendation

- **UQFPWG** (Lund, 2005) SR: 0.1-**0.4**-0.7 mm/yr

SOUTHERN OQUIRRH MTNS



SOUTHERN OQUIRRH MTNS

SOUTHERN OQUIRRH MTNS

SOUTHERN OQUIRRH MTNS

2002 NSHMs - not included; **OFZ**: SR - 0.2 mm/yr, SRL 27 km

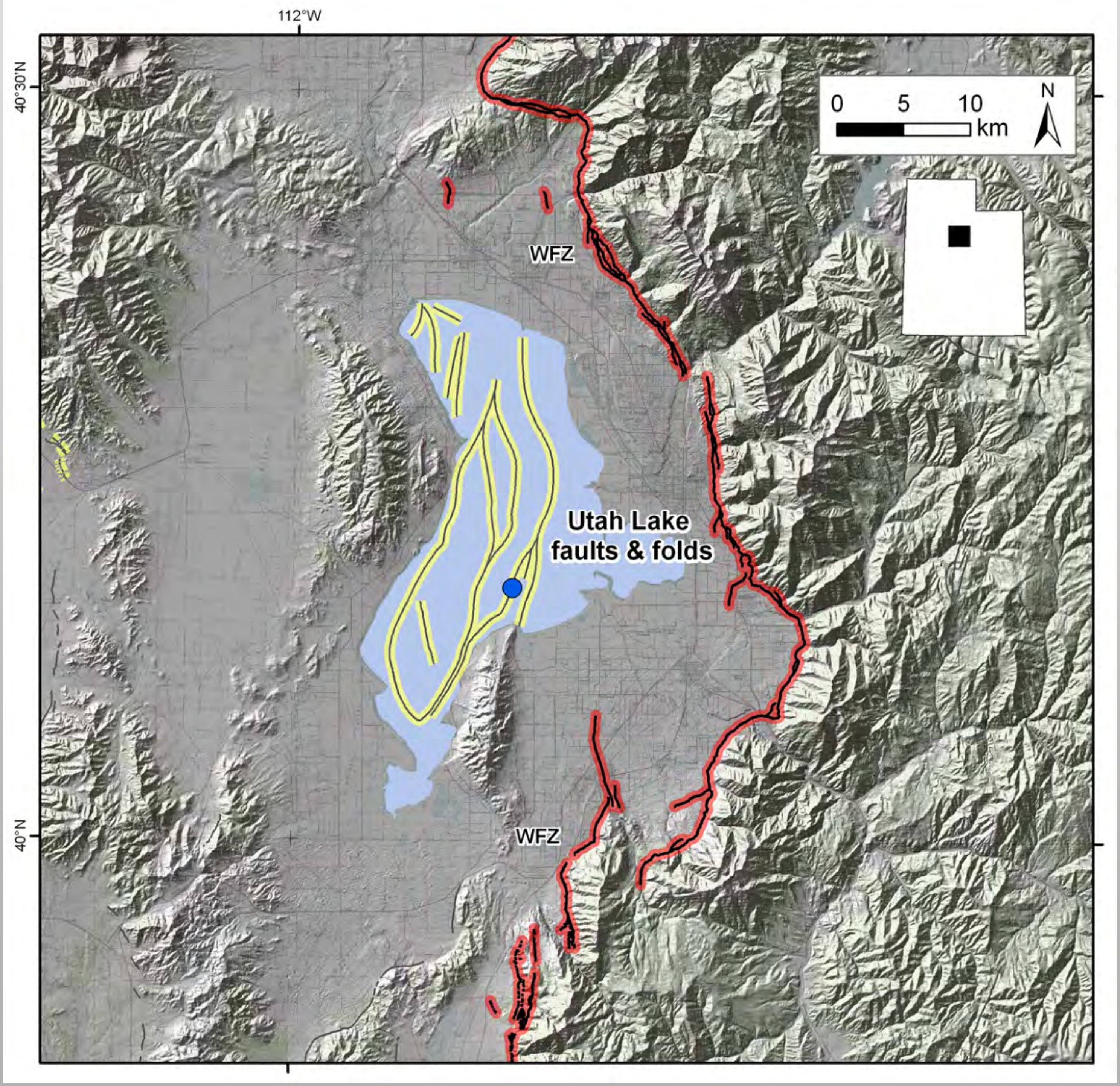
Summary

- 5-7 earthquakes between 4.6 and 92 ka (1.3-2.2 m per event)
- SR: 0.09-0.14 mm/yr (using seismic intervals)
  (Olig and others, 2001)

Recommendation

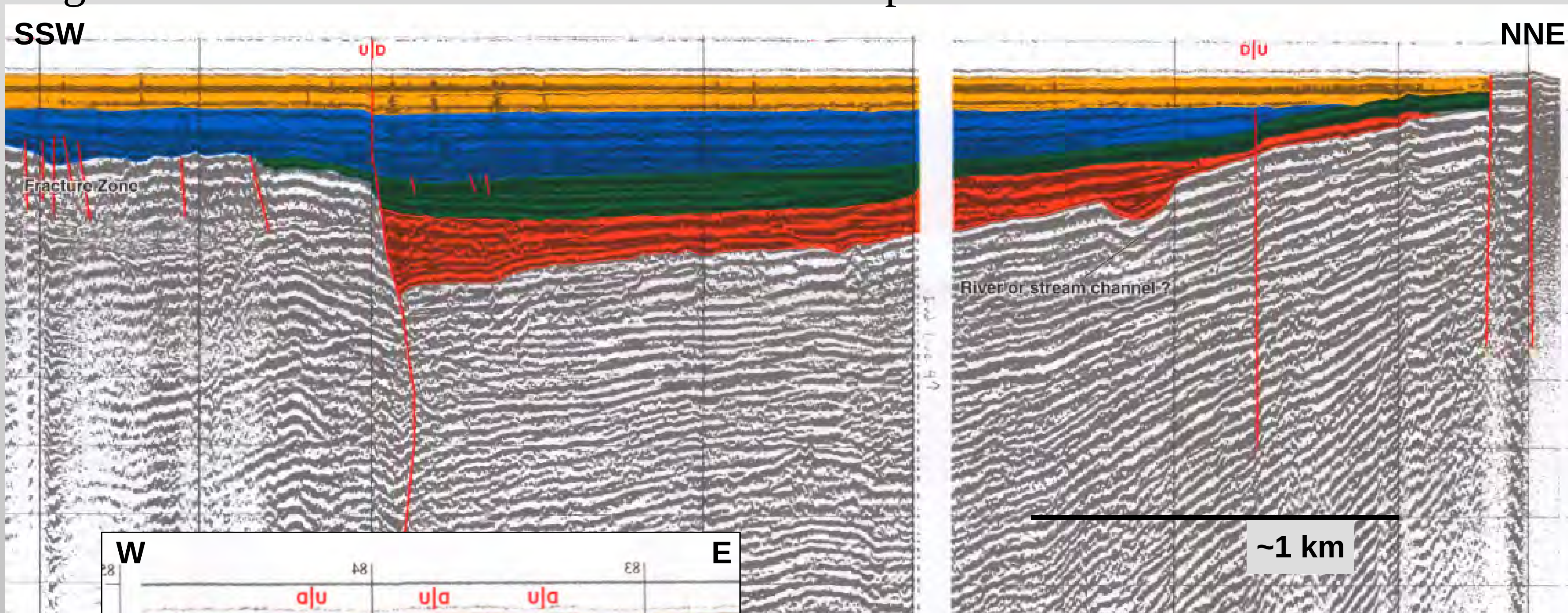
- 1) Model separately or 2) combine with Oquirrh fault zone
- **UQFPWG** SR: 0.05-**0.2**-0.4 mm/yr

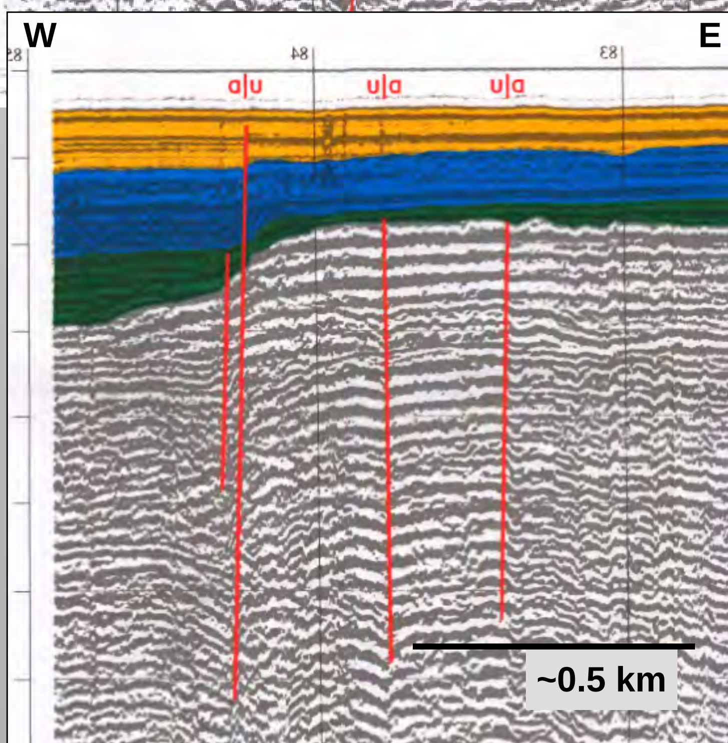
UTAH LAKE FAULTS

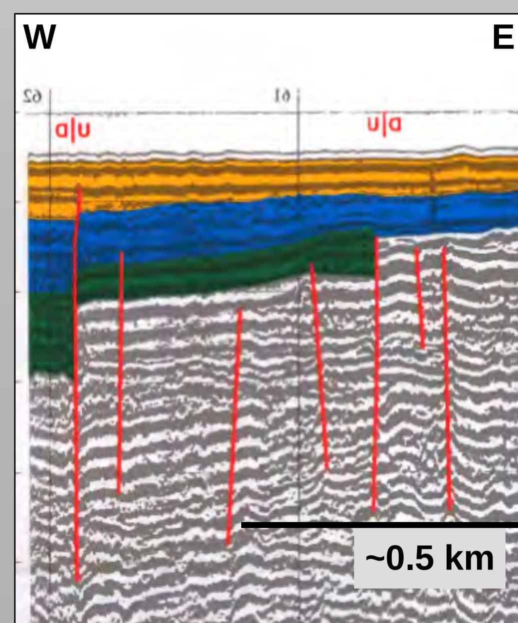


UTAH LAKE FAULTS

High-resolution continuous seismic-reflection profiles







Baskin and Berryhill (1998)

UTAH LAKE FAULTS

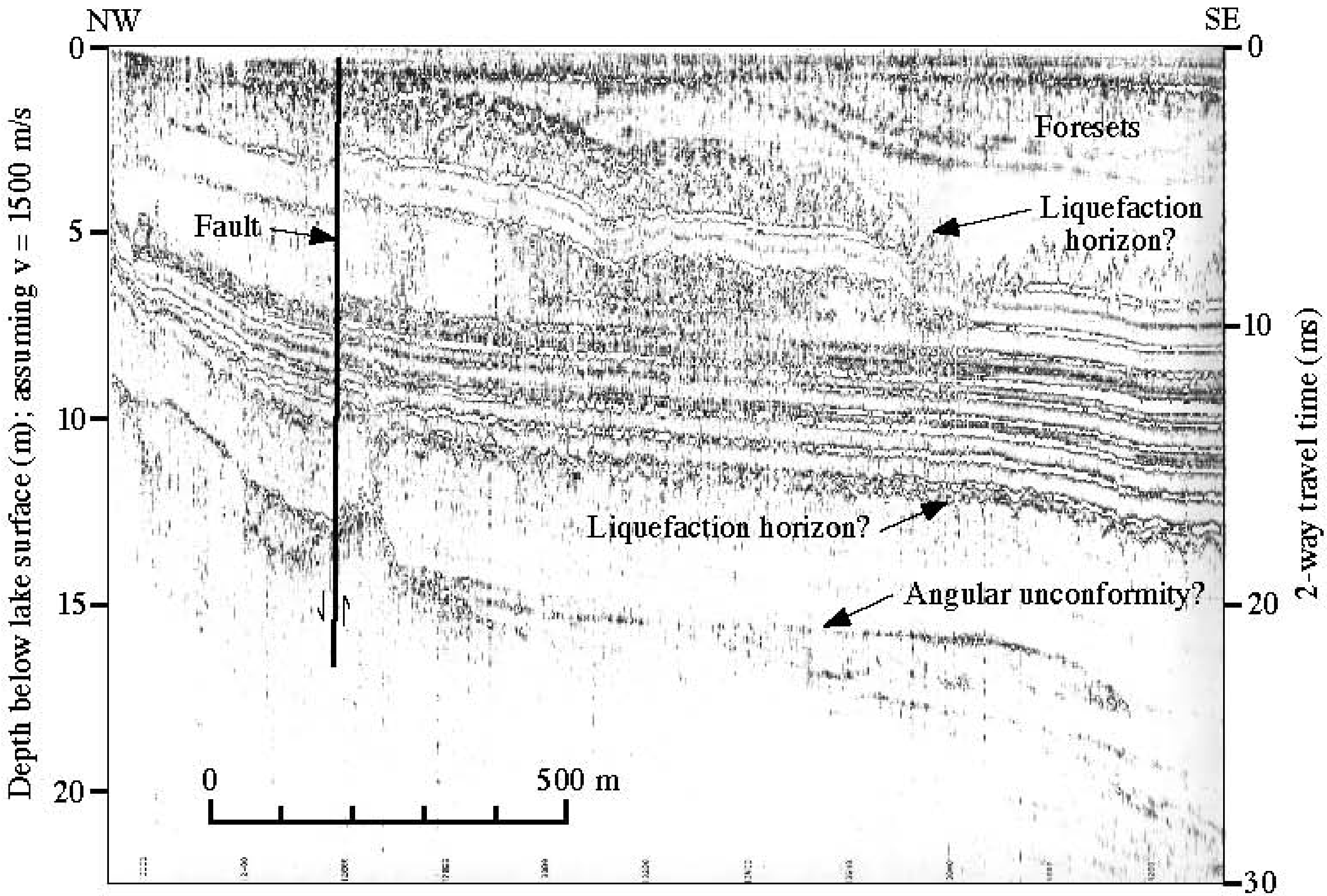


Figure 6. Chirp Line 04UTL-A in Utah Lake near northwest shore. Note down-to-NW normal fault cutting nearly to lakebed, concave-upward foresets near top of section, possible angular unconformity, and two possible liquefaction horizons that may record large earthquakes either generated within the lake or on Provo segment of Wasatch fault. See Fig. 2 for location.

UTAH LAKE FAULTS

2002 NSHMs - not included

Summary

- <2-5 m of displacement across Bonneville sediments (Brimhall and others, 1976).
- SR: <0.1-0.4 mm/yr (Black and others, 2003)
- Recent seismic reflection data: prominent west-dipping fault – 6-8 m ~Holocene displacement:
- SR 0.6-0.8 mm/yr

Recommendation

- Consider independently seismogenic
- SR: 0.1-**0.4**-0.7 mm/yr

SUMMARY OF RECOMMENDATIONS

Fault name	Section	SRL (km)	SR (mm/yr)	Comments
WCFZ	Clarkston fault	22	0.1-0.4-0.7	
SOMFZ	-	24	0.05-0.2-0.4	Separate source
OFZ-SOMFZ	-	54	0.05-0.2-0.4	Combined source
ULFF	-	31	0.1-0.4-0.7	

WSSPC recommendations Status Report

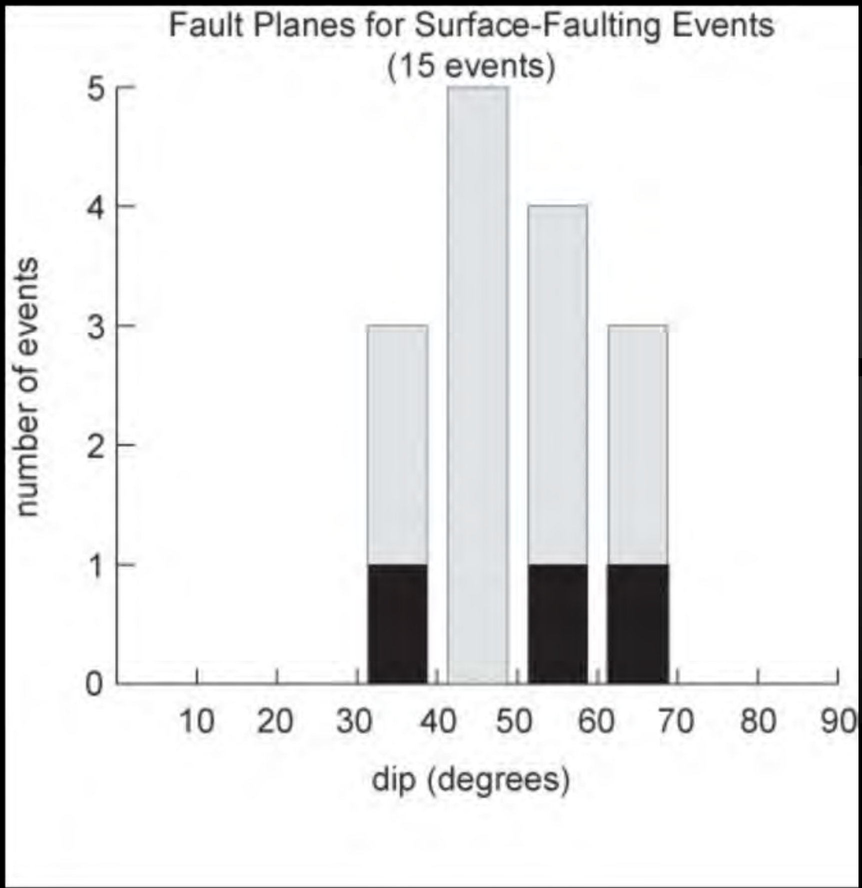
Kathy Haller

Salt Lake City, Utah
February 28, 2007

Issue 5

Resolving Discrepancies between Geodetic Extension and Geologic Slip Rates

Change default fault dip



(from Jackson, J.A., 2002, Active faulting and crustal extension: Key Issues in Earth Sciences, v. 2, p. 135-149.)

- ✓ Recommended change from 60° to 50±10°
- ✓ No real consensus in literature on issue
- ✓ Similar results as Zoback (1983)

Reducing fault dip raises hazard

- Non-linear. 50º to 40º has greater effect than 60º to 50º reduction
- There may be a SA period-dependent effect due to saturation at various magnitudes

Geodetic Extension rates

- Use the province-wide kinematic (GPS) boundary condition (12-14 mm/yr) as a constraint on the sum of geologic slip rates.
- Modify the boundaries of the geodetic zones in the western Great Basin used in the 1996 NSHMs to better reflect the areas of high strain depicted on the GPS-based strain-rate map.

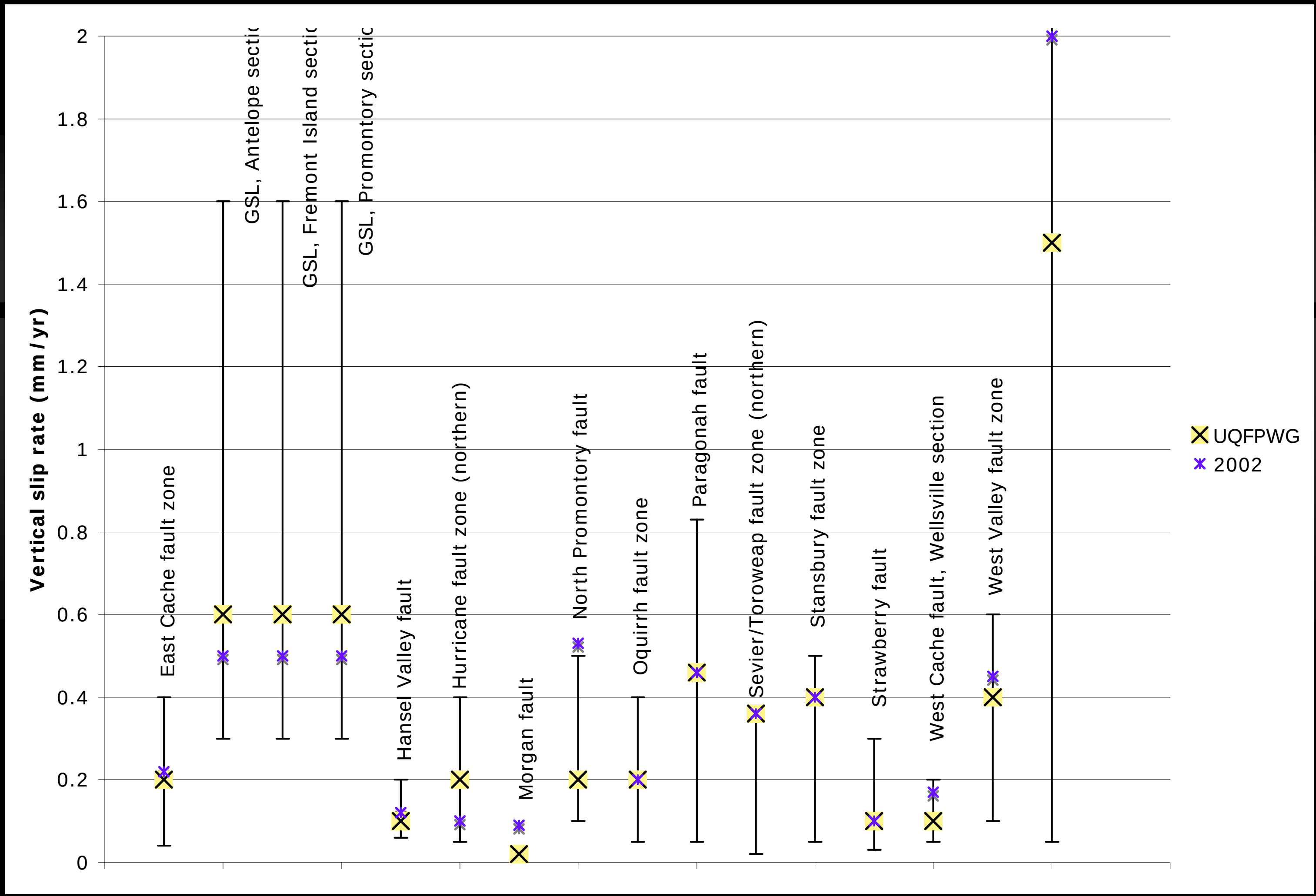
Issue 1

Use and Relative Weighting of Time-dependent, Poisson, and Clustering Models in Characterizing Fault Behavior

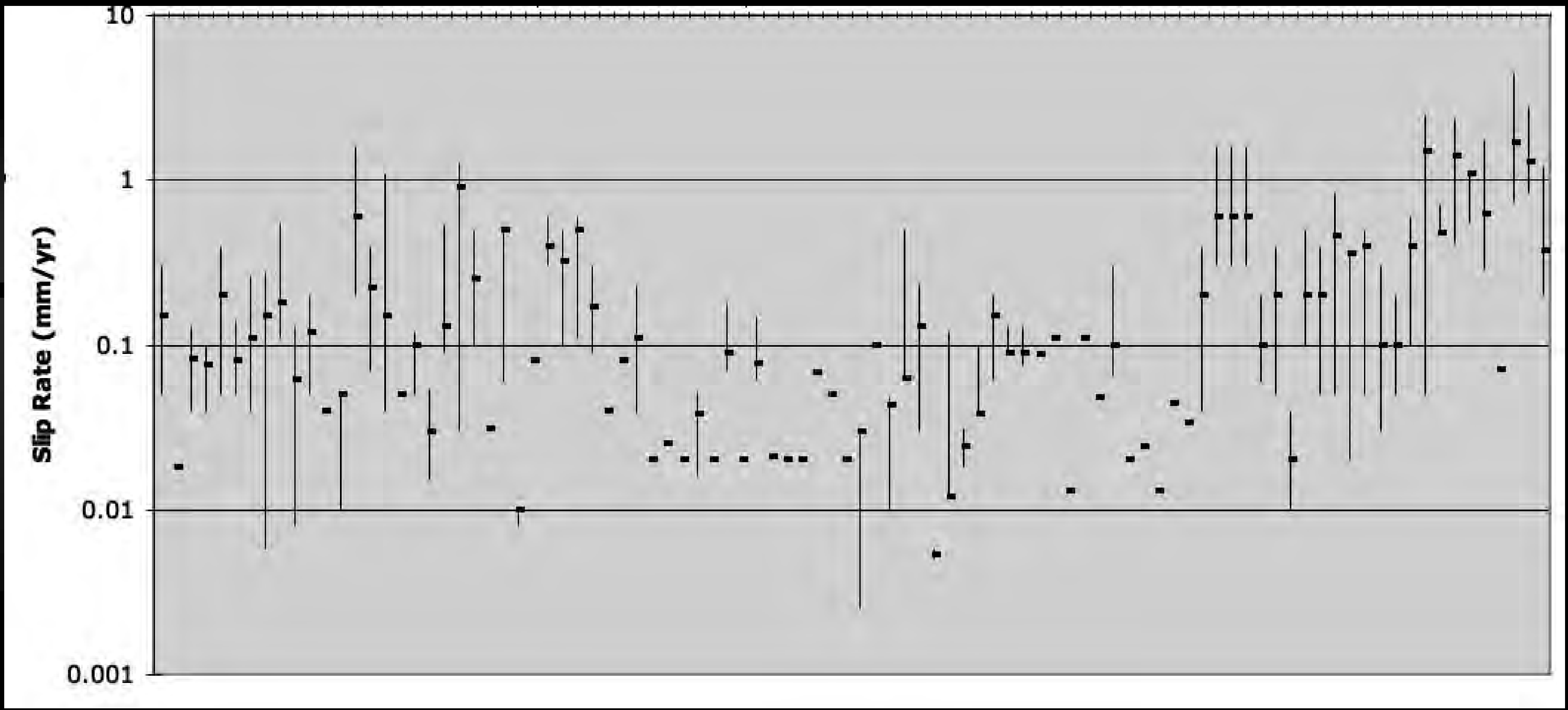
Fault Characterization

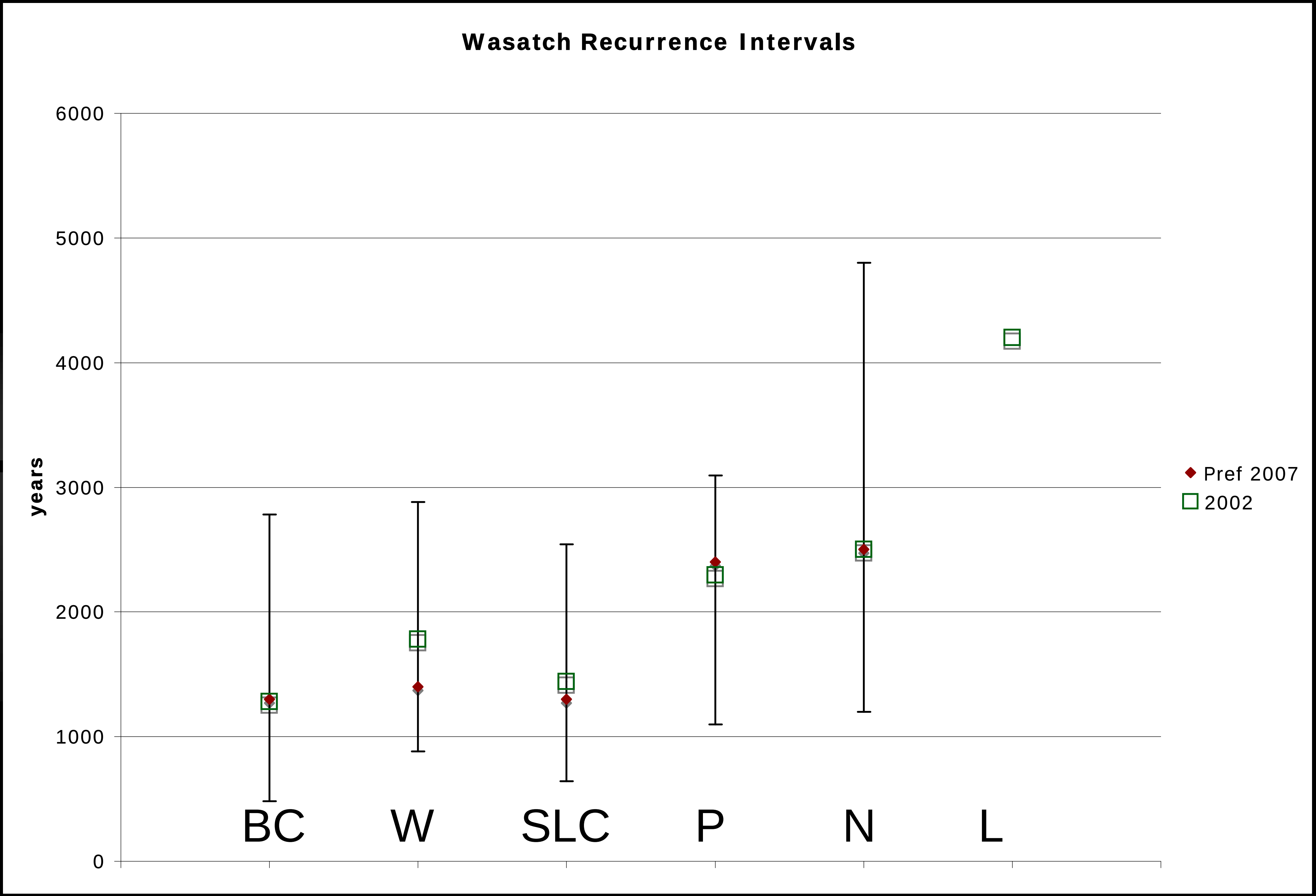
- The USGS should incorporate uncertainties in slip rates and recurrence intervals for the more significant BRP faults.

UQFPWG recommendations



Slip-rate uncertainties for IMW faults




Wasatch Recurrence Intervals
years
6000
5000
4000
3000
2000
1000
0
BC
W
SLC
P
N
L
Pref 2007
2002

Additions

- West Cache fault zone, Clarkston fault
- Southern Oquirrh Mountains fault zone
- Utah Lake faults

Deletions

- Two Joes Valley fault sources combined into one

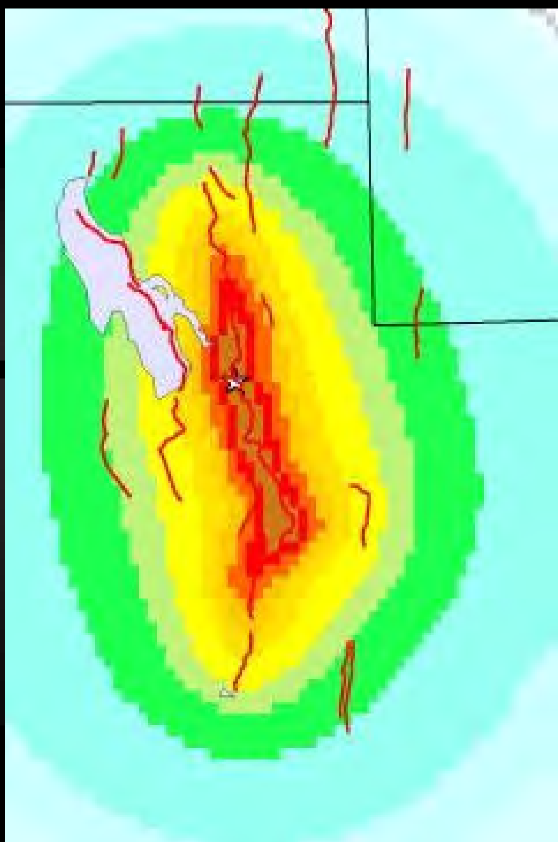
Issue 4

Probabilities and Magnitudes of Multi-Segment Ruptures

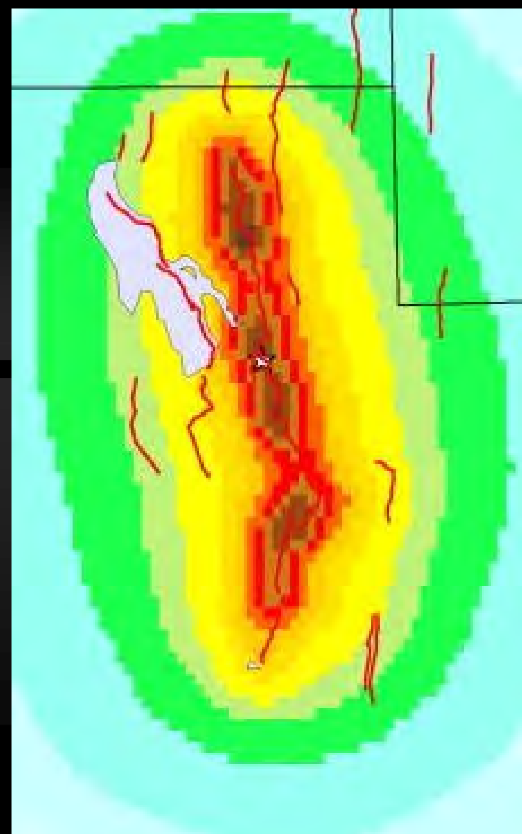
Multi-Segment ruptures

- Hazard calculation for the NSHMs should consider the possibility of multi-segment ruptures on BRP faults.
- The two faults that ruptured together in the 1959 Hebgen Lake earthquake should be treated as a single seismic source.

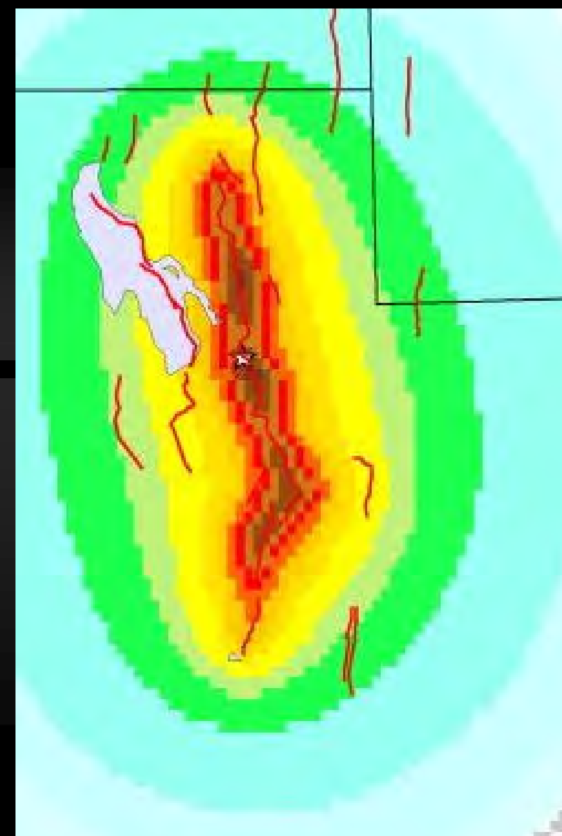
Wasatch 1-Hz Spectral Acceleration 2% in 50 years



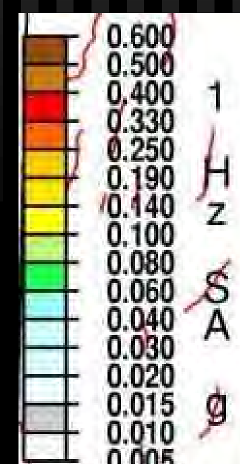
Floating M7.4
10% of the moment



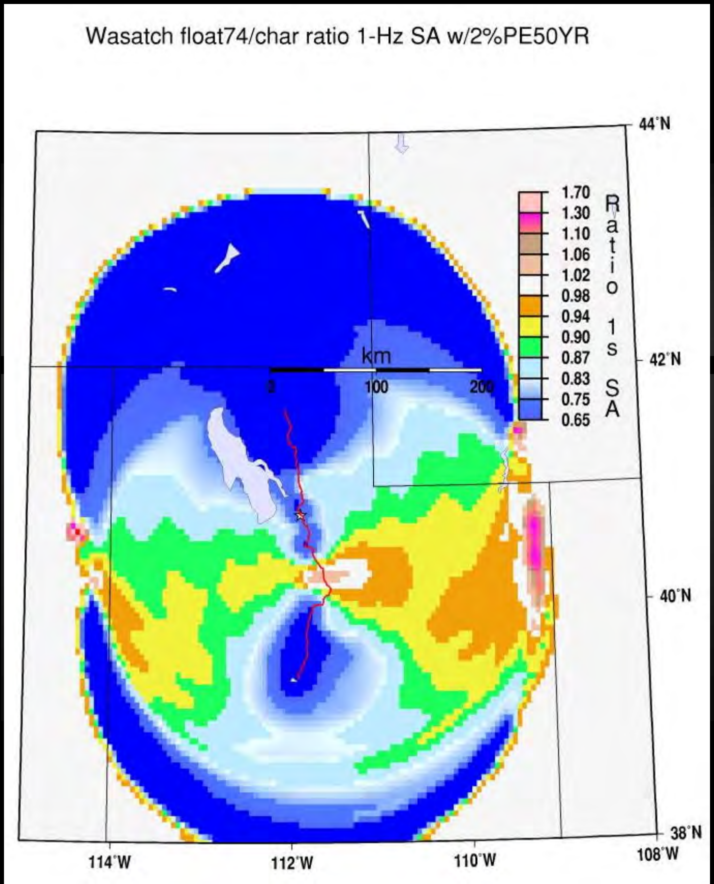
Mmax based on
segmentation



GR based on
1.2 mm/yr slip rate



Multi-segment vs. single-segment



- ✓ 1-hz spectral acceleration is about same along Provo segment
- ✓ SA up to 30% lower elsewhere

Issue 3

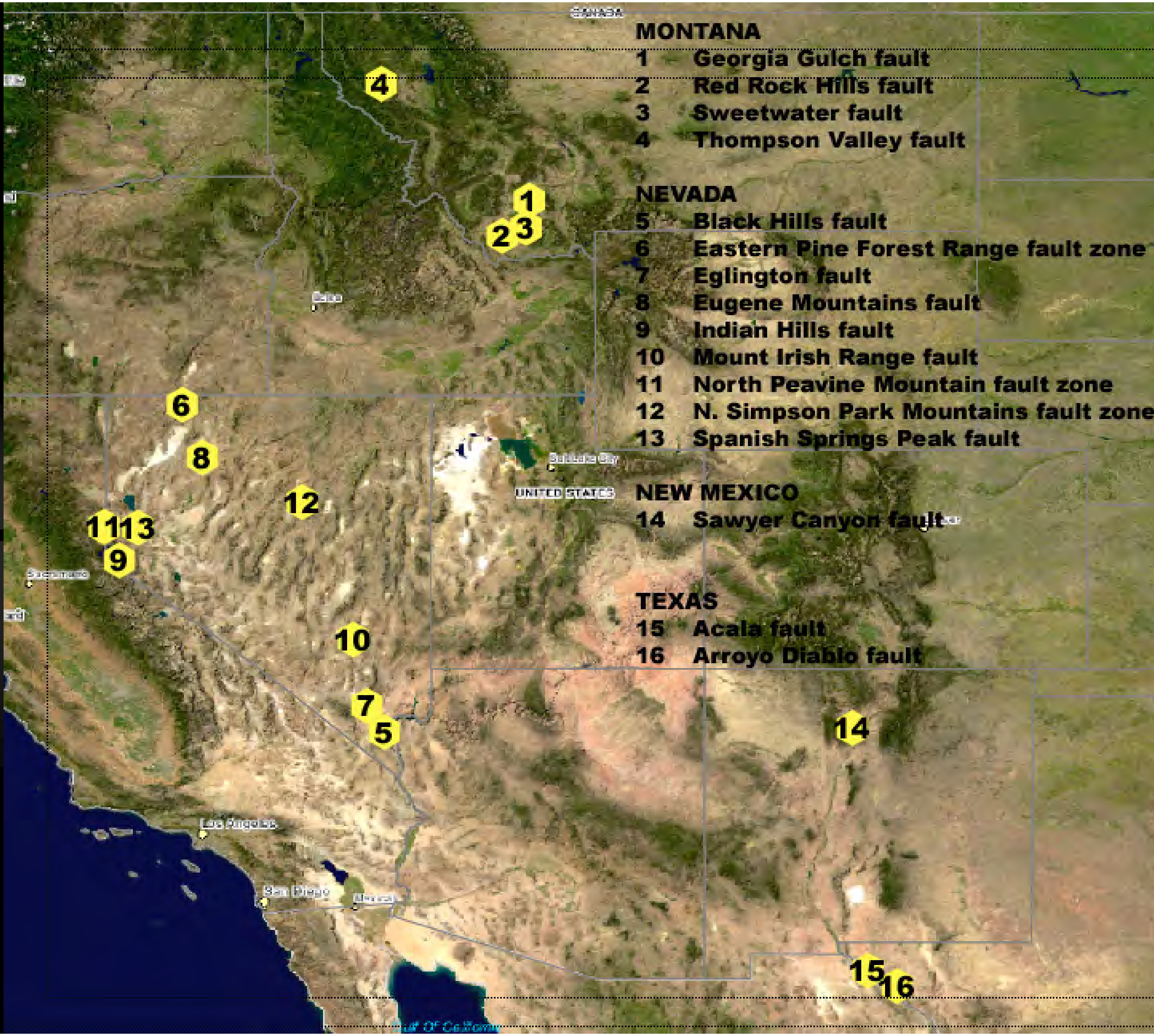
Use of Length versus Displacement Relations to Estimate Earthquake Magnitude

Estimating Earthquake Magnitude

- Include uncertainty in surface rupture length (SRL) and its consequences for magnitude.
- Use magnitude-displacement regressions to improve magnitude estimates where the magnitude from SRL appears inconsistent.

Minimum M constrained to 6.5

- ✓ Constrain the minimum magnitude assigned to surface-faulting earthquakes to M 6.5 to be consistent with the hazard set by background seismicity.


MONTANA
1 Georgia Gulch fault
2 Red Rock Hills fault
3 Sweetwater fault
4 Thompson Valley fault
NEVADA
5 Black Hills fault
6 Eastern Pine Forest Range fault zone
7 Eglington fault
8 Eugene Mountains fault
9 Indian Hills fault
10 Mount Irish Range fault
11 North Peavine Mountain fault zone
12 N. Simpson Park Mountains fault zone
13 Spanish Springs Peak fault
NEW MEXICO
14 Sawyer Canyon fault
TEXAS
15 Acala fault
16 Arroyo Diablo fault
UNITED STATES
Los Angeles
San Diego

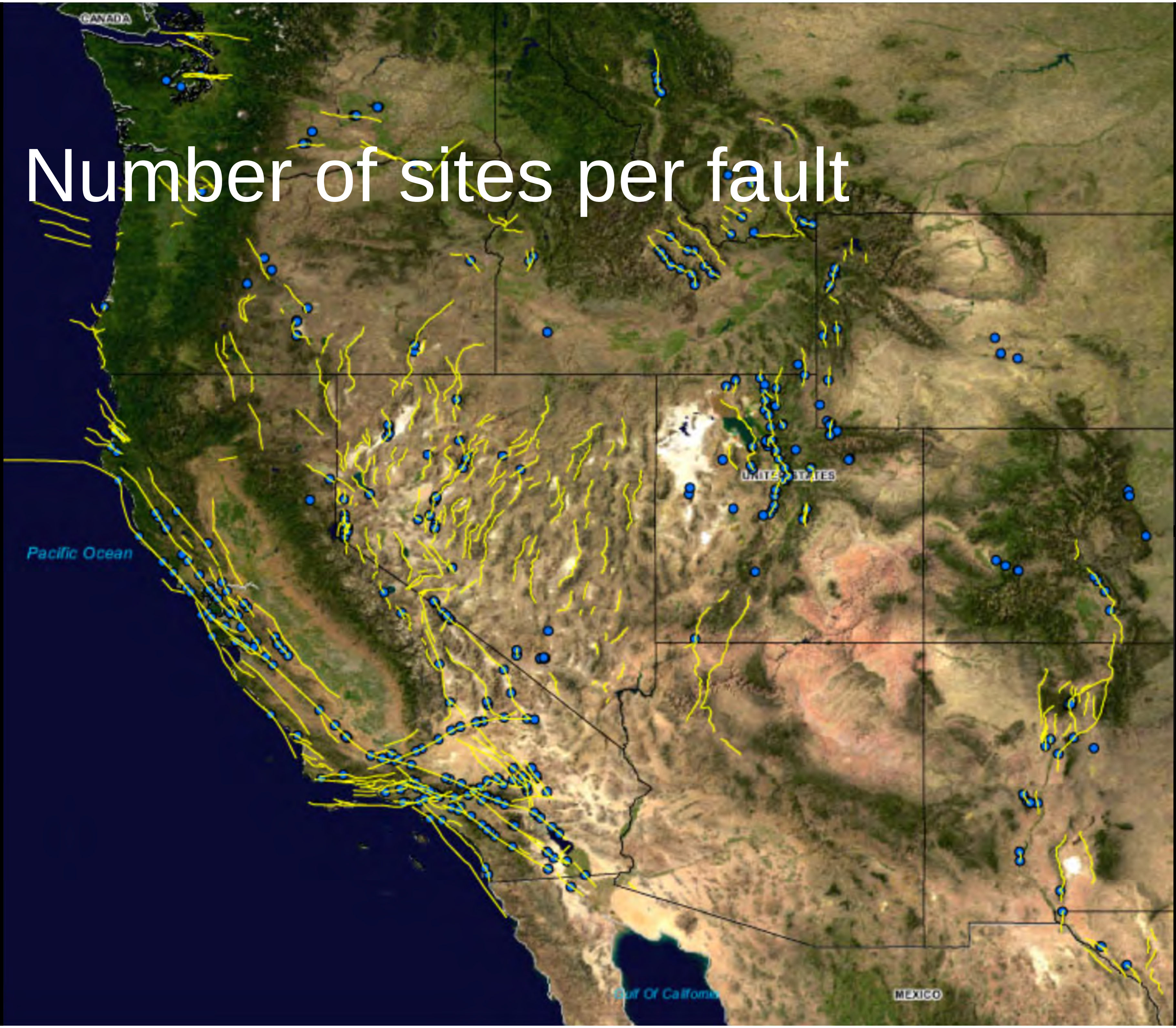
Issue 2

Proper Magnitude-Frequency Distributions (Gutenberg-Richter versus Characteristic Earthquake Models) for BRP Faults

Magnitude-Frequency Distribution

- Weights assigned to the maximum magnitude and “floating exponential” models used for the 2007 NSHMs should, at a minimum, have the same weights as those used in California (2/3 - 1/3) unless there is a technical basis for deviating from this characterization.

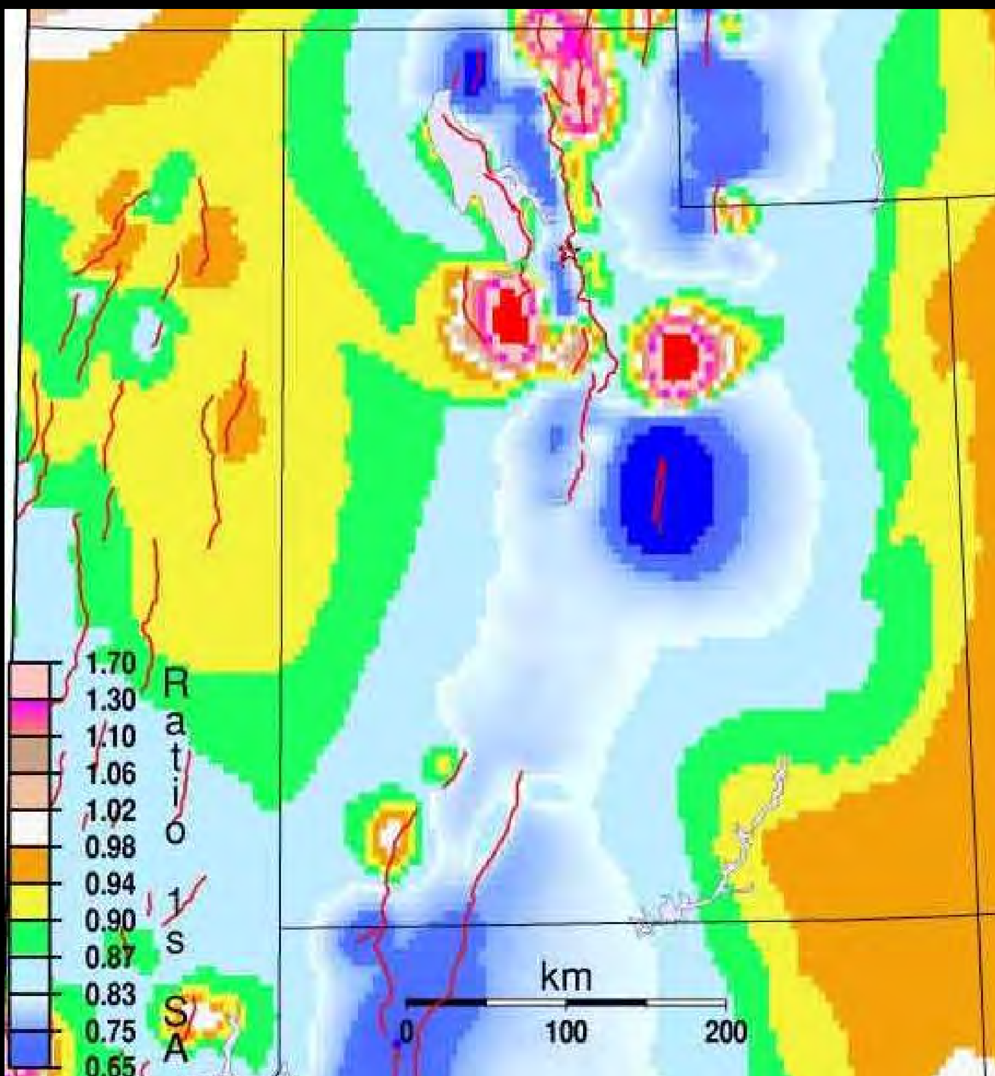
Number of sites per fault

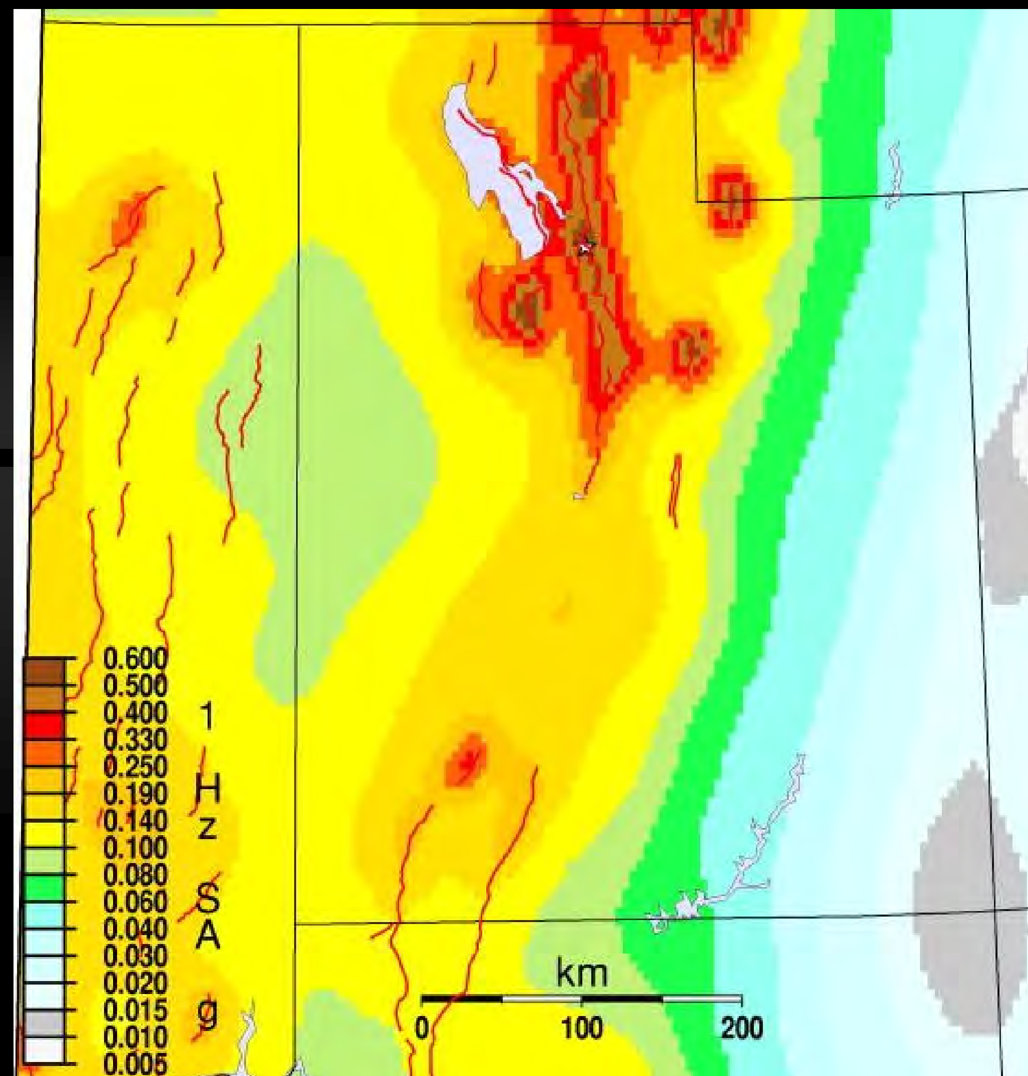


Progress on some long-term goals

- ✓ Nevada working group is being established
- ✓ Alaska time-dependent map as research project
- ✓ Compared results from using fault area instead of fault length to determine M

Results—1-Hz Spectral Acceleration 2% in 50 years





2007/2002 ratio

Wasatch Recurrence Intervals

	Min	2007 PREF	Max	2002
Brigham City	500	1300	2800	1282
Weber	500	1400	2500	1782
Salt Lake City	500	1300	2400	1441
Provo	1200	2400	3200	2297
Nephi	1200	2500	4800	2500
Levan				4200

2008 UTAH FAULT RESEARCH PRIORITIES

UQFPWG FAULTS RECOMMENDED FOR FURTHER STUDY IN 2005

Nephi segment (1)

Great Salt Lake fault zone (6)

Collinston & Clarkston Mtn. seg. (7)

Sevier/Toroweap fault (8)

Levan segment (16)

Weber segment - MRE (2007; 3)

Weber segment – MET (2007; 4)

Washington fault zone (9)

East Cache fault zone (2007; 12)

West Valley fault zone (2007; 2)

Utah Lake faults (2007; 5)

CC/Parowan monocline (10)

Enoch graben (11)

Clarkston fault (13)

WR back-valley fault (14)

Hurricane fault zone (15)

Gunnison fault (17)

Scipio Valley faults (18)

Faults beneath Bear Lake (19)

Eastern Bear Lake fault (20)

PREVIOUS UQFPWG RECOMENDATIONS

- Look for the new ~1600-yr Provo segment PE at other locations along the Provo segment.
- Look for possible trench sites between Kaysville (Weber segment) and South Fork Dry Creek (Salt Lake City segment).
- Perform a reconnaissance of lesser known Utah faults outside of the Wasatch Front that may be important to the NSHMs.
- Make a comprehensive review of new geologic literature, and if necessary conduct an aerial photograph analysis and field reconnaissance studies to ensure that all major Utah Quaternary faults have been identified.
- Excavate another trench on the Brigham City segment to confirm the timing of most recent surface faulting.

PRIORITTY FAULTS

UQFPWG	OTHERS?
West Valley fault zone (2007; 2)[1]	Brigham City segment - MRE
Utah Lake faults (2007; 5)[1]	Beaver Basin faults

CC/Parowan monocline\Paragonah fault (10)

Enoch graben (11)

Clarkston fault (13)[1]

WR back-valley fault (14)

Hurricane fault zone (15)[2]

Gunnison fault (17)

Scipio Valley faults (18)

Faults beneath Bear Lake (19)

Eastern Bear Lake fault (20)

[1]Recommended addition to NSHMs

[2]Only viable if landowner permission is forthcoming, which isn't likely any time soon.

NEHRP 2008 IMW RFP

General

- Prepare accurate and precise, digital Quaternary fault data sets for the western and eastern margins of the Great Basin as a step toward developing a three-dimensional Community Fault Model and eventually integrated geodetic/geologic model *(BRPEWG recommendation)*.

Utah Fault Specific

- Studies of faults in Utah should focus on those structures that have been identified as priority by the Utah Quaternary Fault Parameters Working Group (link to UGS web page)
- In and adjacent to the urbanized areas of Utah, studies that are designed to better characterize the paleoseismic histories of major faults whose rupture histories will affect time-dependent models of Utah's seismic hazards.
- Evaluate utility of newly acquired LIDAR imagery for the Wasatch Front for detailed mapping of faults, landslides, and areas of ground deformation.
- Investigate whether geodesy can identify specific faults in Utah where strain is being localized as an indicator of high seismic hazard.
- Investigate the dip of normal faults in Utah (using chiefly geophysics) to determine the best dip value(s) for converting fault slip rates to extensional rates for consistency with GPS data.

BRPEWG RESEARCH RECOMENDATIONS

- **Compile long-term paleoseismic records for BRP faults and determine SR 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 segmented earthquake 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.**
- **Prepare consistent-resolution Quaternary fault maps for the western margin of the Great Basin as a step toward developing a CFM and eventually an integrated geodetic/geologic model.**