Extending the Paleoseismic Record of the Provo Segment of the Wasatch Fault: Preliminary Results from the Mapleton Megatrench

THE SEQUEL

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

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

March 3, 2005

URS

Contributors

<u>URS Corporation</u>

Susan Olig

Eliza Nemser

Ivan Wong

<u>Utah Geological Survey</u>

Greg McDonald

Bill Lund

Gary Christenson

Mike Hylland

Rich Giraud

Justin Johnson

Chris Busch

Scott Cragen

<u>Western Geologic LLC</u>

Bill Black

Craig Nelson

<u>U.S. Geological Survey (Award No. 02HQGR0109)</u>

Mark Petersen

Dave Schwartz

<u>University of Utah</u>

Ronald Brunh

Gerald Schuster

Chris DuRoss

Ann Mattson

Maike Buddensiek

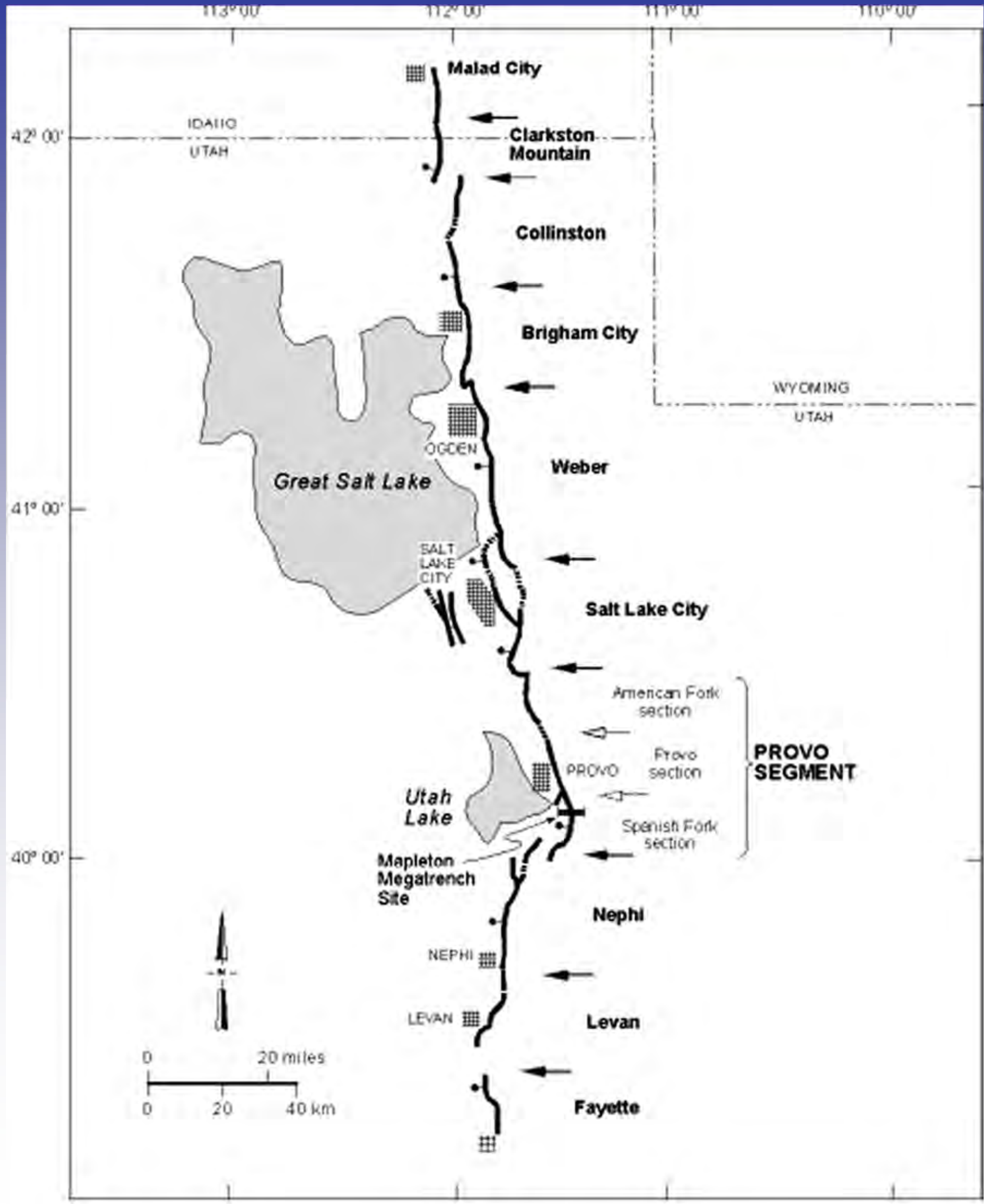
David Simon (Simon-Bymaster Inc.)

Mike Hozik (Richard Stockton College of New Jersey)

Gordon Seitz (UCSD)

Also thanks to: Division of Wildlife Resources, Suburban Land Reserve, Don White (Zion Securities), Mapleton City, Joergen Pilz (AMEC), Bob Gunnell (RB&G)

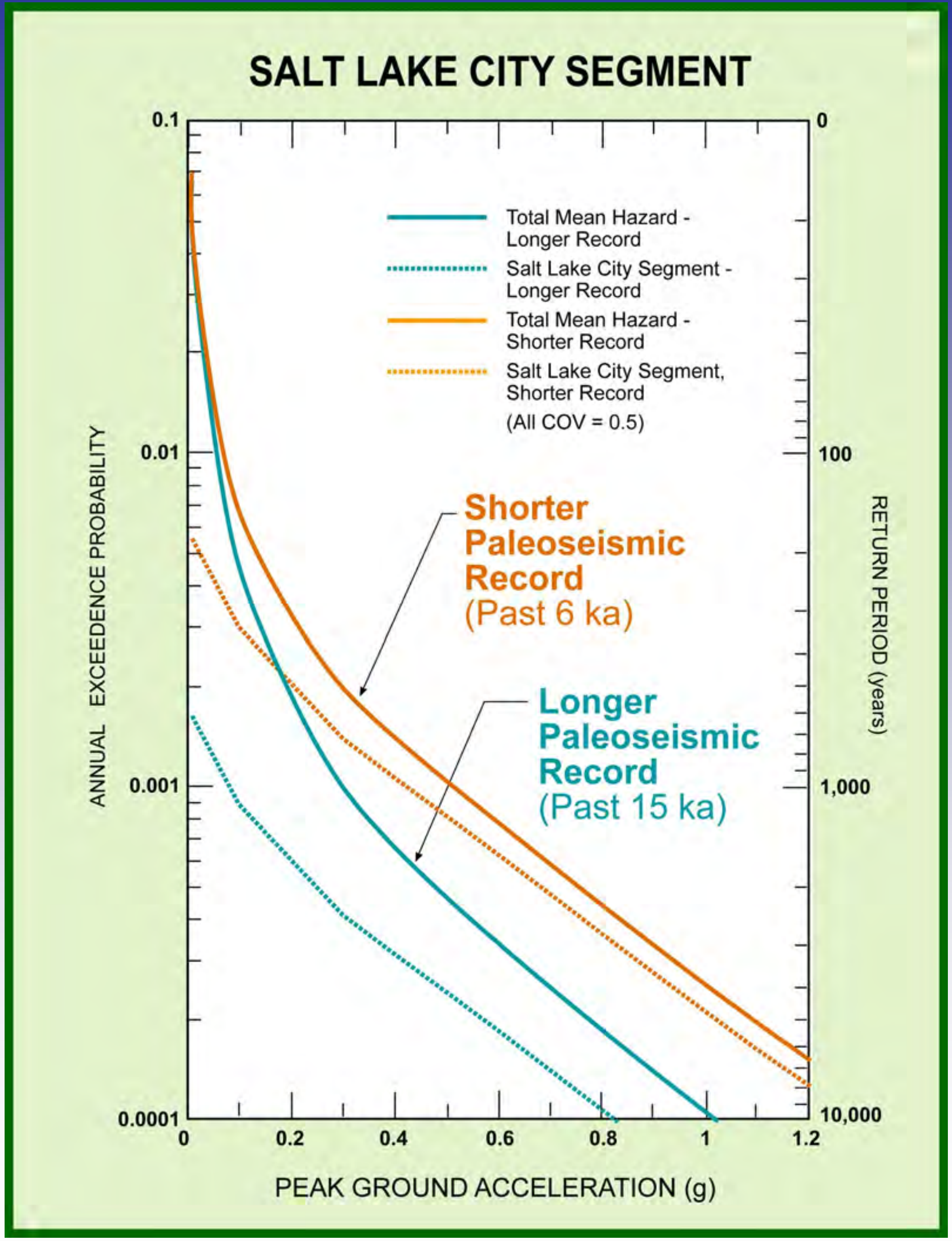
Wasatch Fault Zone



PALEOSEISMIC DATA

Brigham City Segment		Salt Lake City Segment	
EVENT	Age ± 2 σ (cal yr BP)	EVENT	Age ± 2 σ (cal yr BP)
Z (most recent)	2,130 ± 100	Z (most recent)	1,230 ± 60
Y	3,430 ± 140	Y	2,500 ± 140
X	4,670 ± 110	X	3,940 ± 220
W	5,970 ± 40	W	5,380 ± 140
V	7,300 ± 350	V	~ 7,500
U(?)	8,520 ± 340	U	9,300 ± 500
T	13,010 ± 340	T	> 17,200

Data Sources:
McCalpin and Nishenko, 1996 Black et al., 1996 McCalpin, 2002



From Olig et al., 2001

Mapleton Megatrench Site

(Photo from R. Bruhn)

Mapleton Megatrench Site

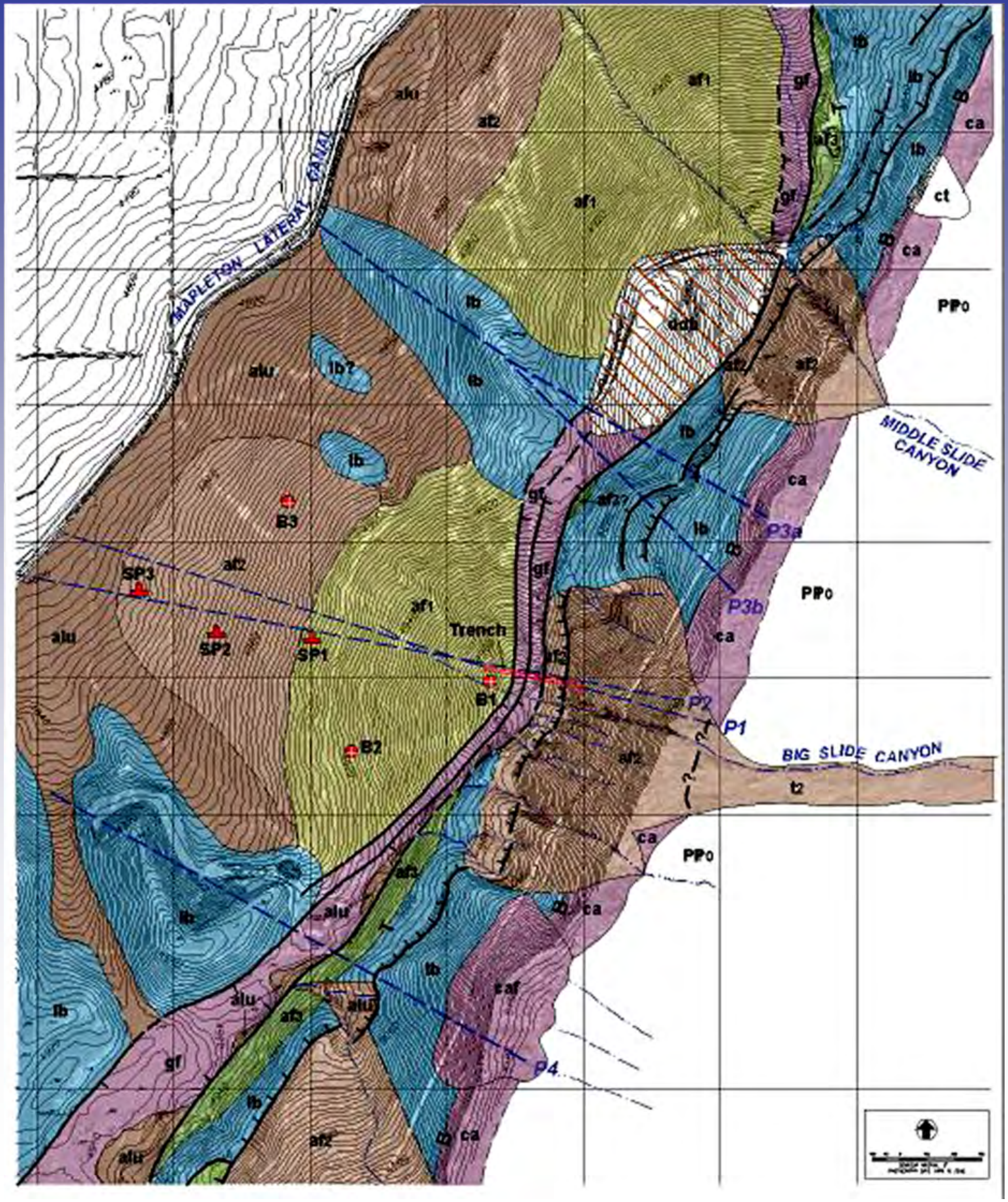
(Photo from R. Bruhn)

Trench Locations

(Photo from R. Bruhn)

Surficial Geology of the Mapleton Megatrench Site

- **Topographic Profiles (P1, P2, P3, P4)**
- **Boreholes (B1, B2, B3)**
- **Soil Pits (SP1, SP2, SP3)**



URS


CAT
325B
CAT


CAT

(Photo from W. Case)

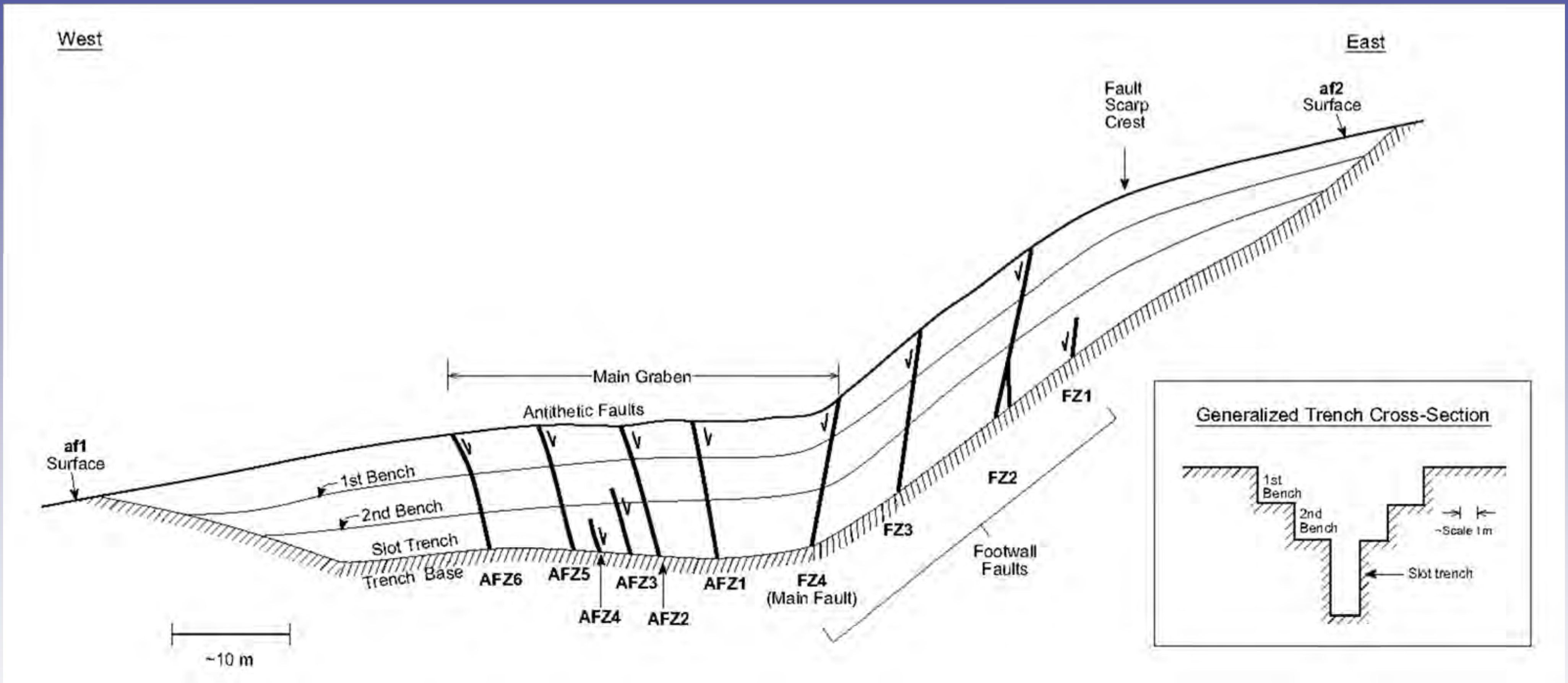
FOOTWALL:

- **4 significant west-dipping fault zones FZ1 through FZ4 (E to W)**

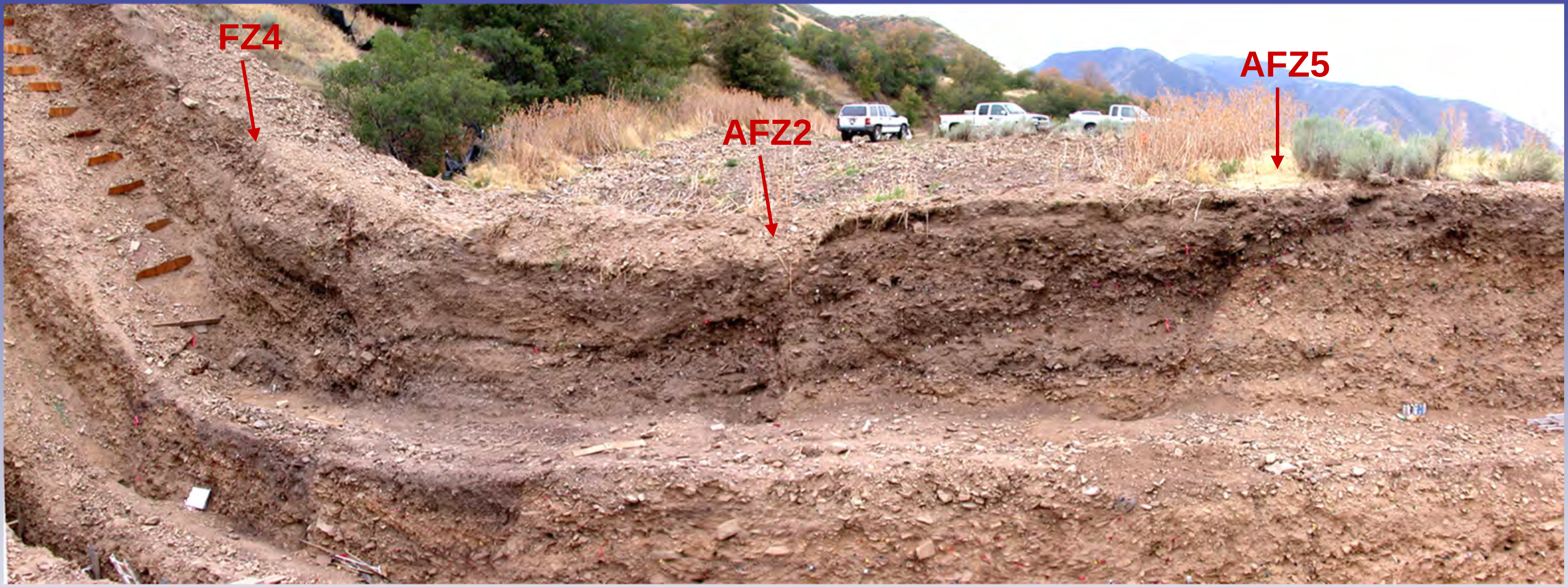
HANGING WALL:

- **6 significant east-dipping antithetic fault zones AFZ1 through AFZ6 (E to W)**

Significant Faults in the Mapleton Megatrench



Hanging Wall Stratigraphy



(Photo from W. Case)

- 35-m-wide graben (from FZ4 to AFZ6)
- Mid to late Holocene debris flows, channel alluvium, and colluvium (6100 RCYBP to historic)
- Able to correlate stratigraphy across antithetic faults

URS

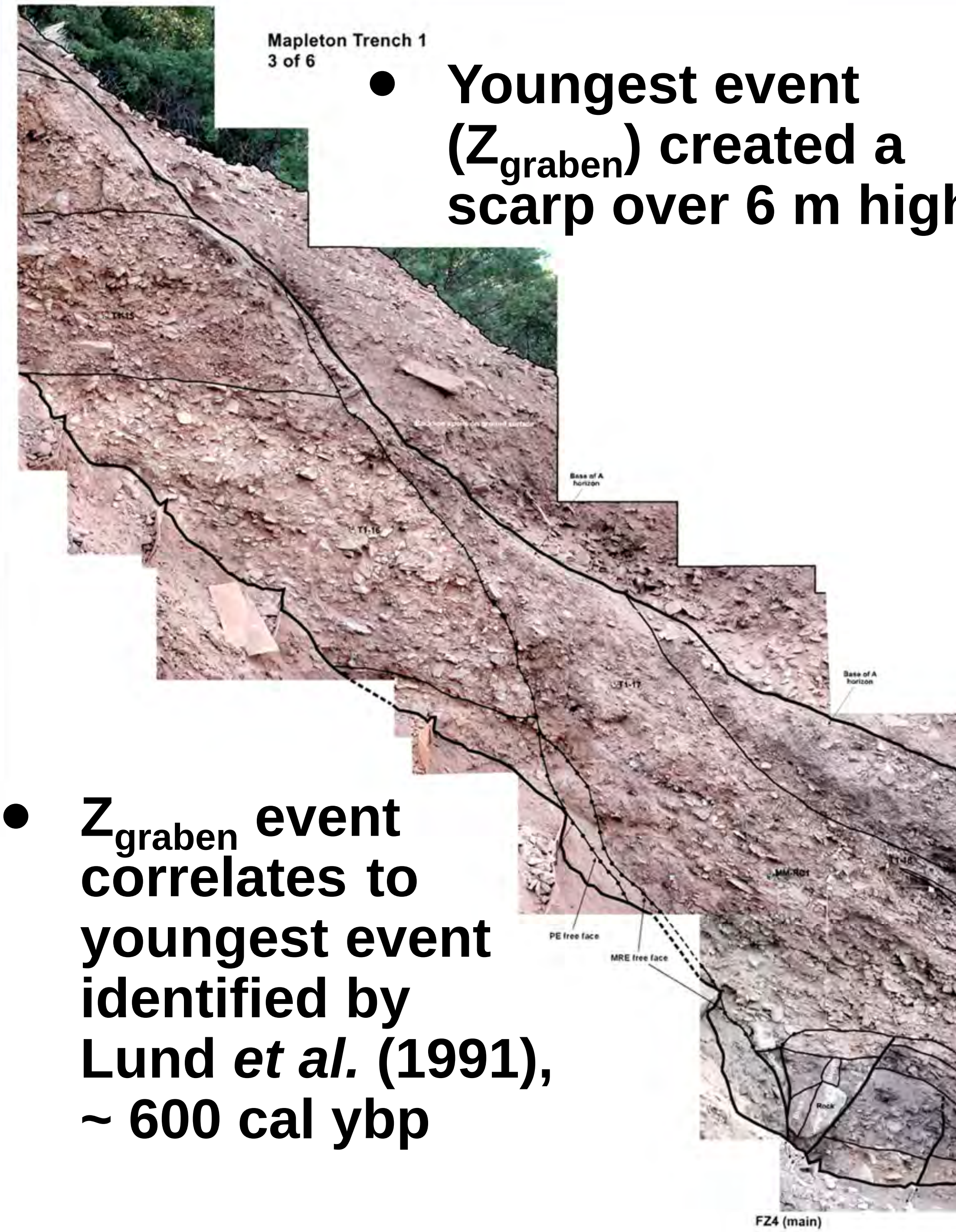
Footwall Stratigraphy

- **Latest Pleistocene to Holocene debris flows and colluvium (≤ 12,100 RCYBP)**
- **At least 3 pulses of alluvial fan deposition**
  - **11 to 12 ka (≈ af 2)**
  - **9 to 10 ka**
  - **4 to 6 ka (≈ af 1)**

Radiocarbon Dating

- **Analyses done – 26 samples (charcoal)**
- **Analyses pending – 17 samples (charcoal)**
- **Need to be sent – 4 to 6 samples (bulk soil and charcoal)**

FZ4 Bench 1



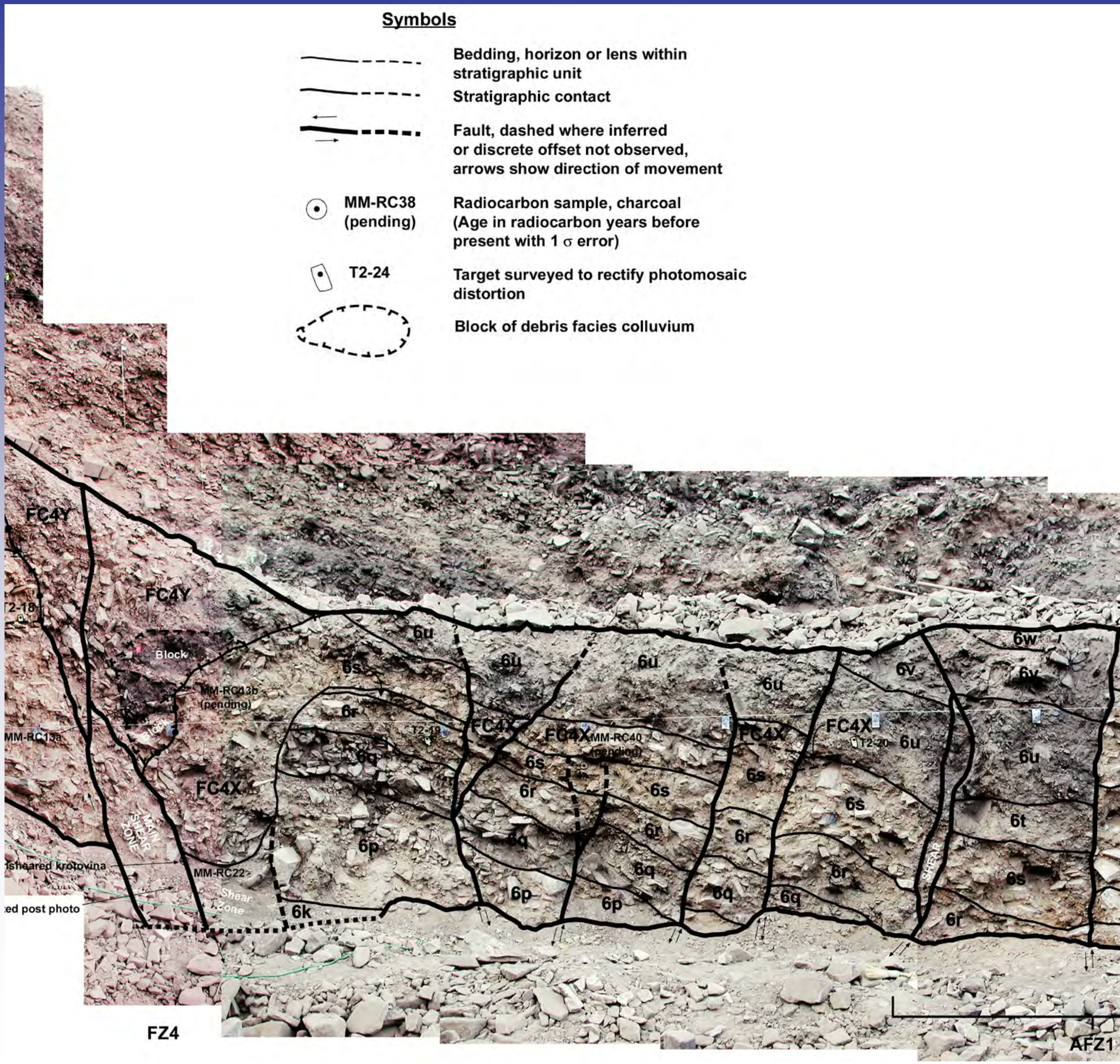
- **Youngest event (Z_{graben}) created a scarp over 6 m high**

- **Z_{graben} event correlates to youngest event identified by Lund *et al.* (1991), ~ 600 cal ybp**

FZ4 Benches 1 and 2

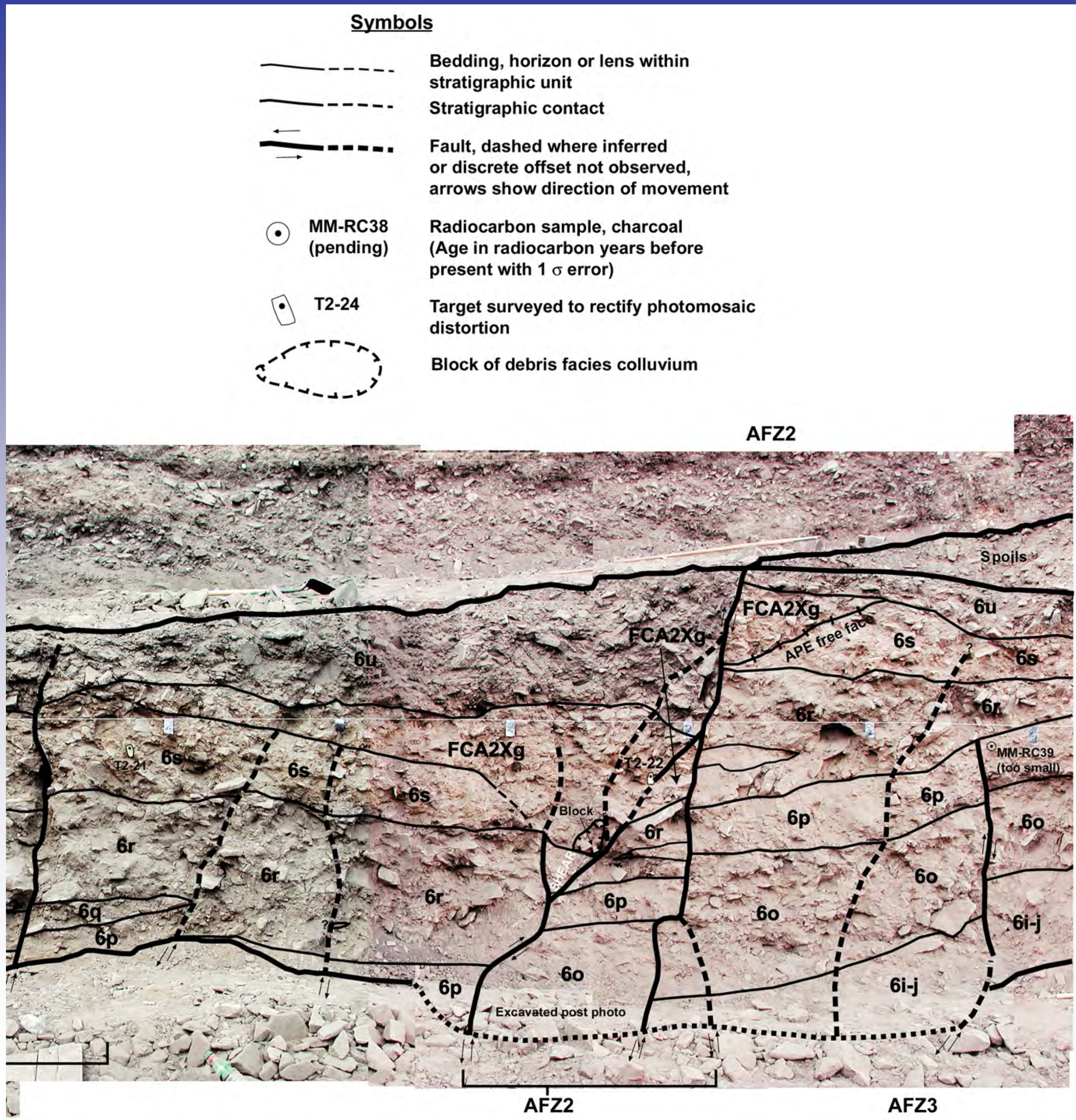
- **Evidence for 3 surface-faulting events < 4,380 RCYBP**
- **Record of older events eroded away by channels**

FZ4 Bench 2



Symbols
Bedding, horizon or lens within stratigraphic unit
Stratigraphic contact
Fault, dashed where inferred or discrete offset not observed, arrows show direction of movement
MM-RC38 (pending)
Radiocarbon sample, charcoal (Age in radiocarbon years before present with 1 σ error)
T2-24
Target surveyed to rectify photomosaic distortion
Block of debris facies colluvium
FC4Y
FC4Y
Block
MM-RC13b (pending)
MM-RC13a
FC4X
MAIN SHEAR ZONE
sheared krotovina
MM-RC22
Shear Zone
ed post photo
6k
6p
6q
6r
6s
6u
T2-19
FC4X
FC4X
MM-RC40 (pending)
FC4X
FC4X
T2-20
6v
6w
6t
SHEAR
FZ4
AFZ1

AFZ2 Bench 2


Symbols
Bedding, horizon or lens within stratigraphic unit
Stratigraphic contact
Fault, dashed where inferred or discrete offset not observed, arrows show direction of movement
MM-RC38 (pending)
Radiocarbon sample, charcoal (Age in radiocarbon years before present with 1 σ error)
T2-24
Target surveyed to rectify photomosaic distortion
Block of debris facies colluvium
AFZ2
Spoils
FCA2Xg
FCA2Xg
APE free face
6u
6u
6s
6s
6r
6r
T2-21
6s
6s
FCA2Xg
6s
T2-22
MM-RC39 (too small)
Block
6p
6p
6o
6r
6r
6r
6r
6o
6q
6p
6p
6o
6i-j
6o
6p
6i-j
Excavated post photo
AFZ2
AFZ3

Antithetic Faults

- Faults AFZ1 through AFZ6
- Evidence for 4 to 5 separate surface-faulting events, Z_{graben} through V_{graben}, since 5,300 RCYBP
- Activity jumps around between antithetic faults

AFZ5 – Benches 1 & 2

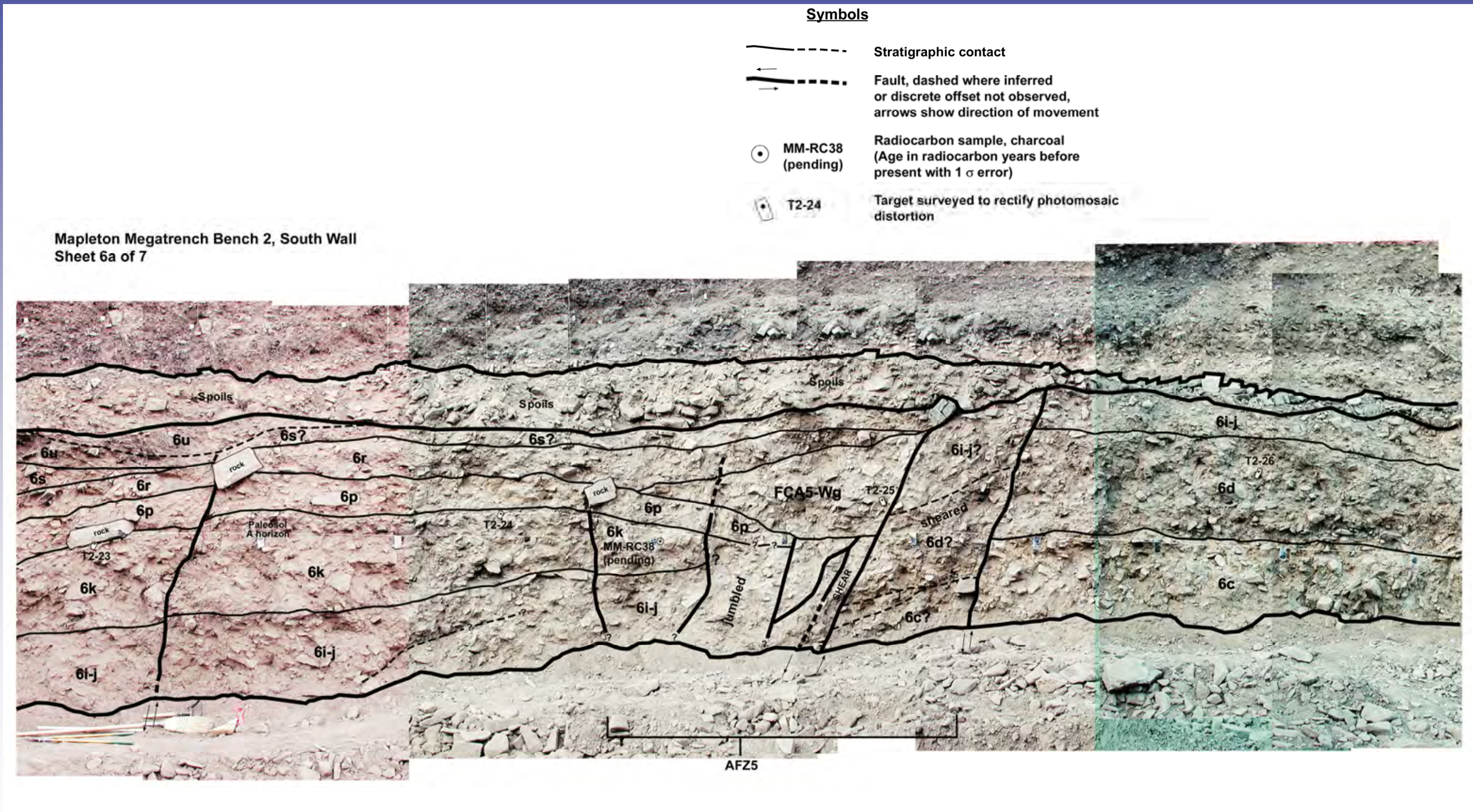
3 Surface-faulting events:

Z_{graben} - 600 years ago

Y_{graben} - ages pending

W_{graben} - < 5, 305 RCYBP

Faulting Event W_{graben} on AFZ5 – Bench 2



Graben Fault Summary*

Surface Faulting Event	FZ4	AFZ1	AFZ2	AFZ3	AFZ4	AFZ5	AFZ6
Z_{graben} ~600 cal YBP	- wedge - fault term. - buried free face - strat. offsets	- fault term. - strat. offsets	- wedge - fault term. - strat. offsets			- wedge - buried free face - strat. offsets	- wedge -buried free face - strat. offsets
Y_{graben}	- wedge - fault term. - buried free face - strat. offsets	- diff. offsets - fault term.				- wedge on soil - buried free face - fault term. - diff. offsets	
X_{graben} < 4,400 RCYBP	- strat. offsets - wedge/ fissure - fault term.		- wedge - diff. offsets - fault term. - buried free face				- fissure/ wedge - diff. offsets - fault term. - buried free face
W_{graben}	? (eroded)	? (eroded)		- diff. offsets - fault term. at soil		- wedge on soil - fault term. -diff. offsets	
V_{graben} (?) < 5,300 RCYBP	? (not exposed?)	? (not exposed?)			- diff. offset		

At least 4, Possibly 5 Separate Events

Between ≈ 600 and 5,300 RCYBP

* Purple indicates radiocarbon ages still pending

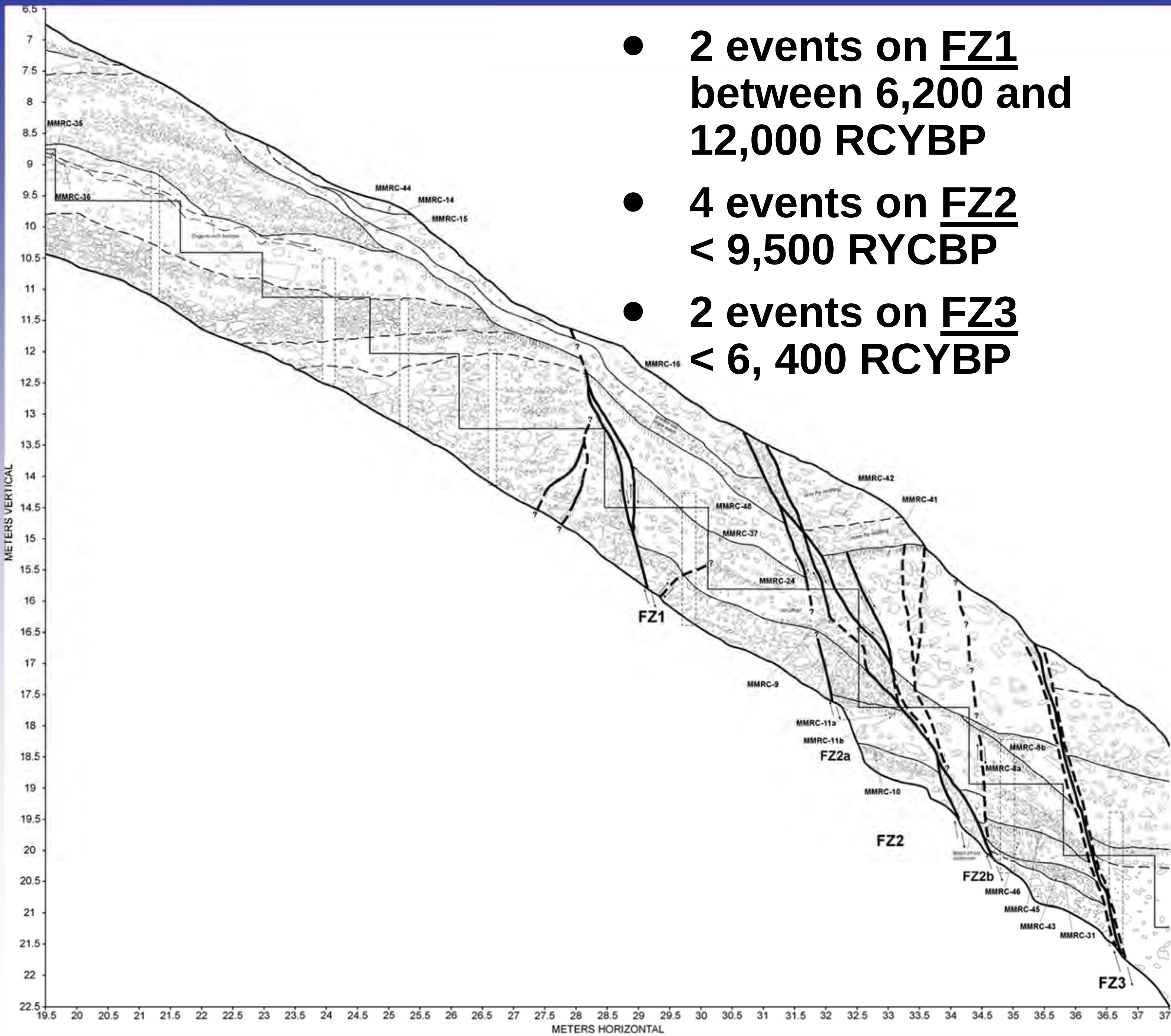
Footwall Faults

FZ2 Uppermost Colluvial Wedge

- Event Z_{FZ2} occurred shortly after 4,770 RCYBP
- 2.8 m throw
- May correlate to Event Z_{FZ3} with ~ 4½ m of throw

URS

Slot Trench Log - FZ1 Through FZ3



- 2 events on <u>FZ1</u> between 6,200 and 12,000 RCYBP
- 4 events on <u>FZ2</u> < 9,500 RYCBP
- 2 events on <u>FZ3</u> < 6, 400 RCYBP

URS

Footwall Fault Summary*

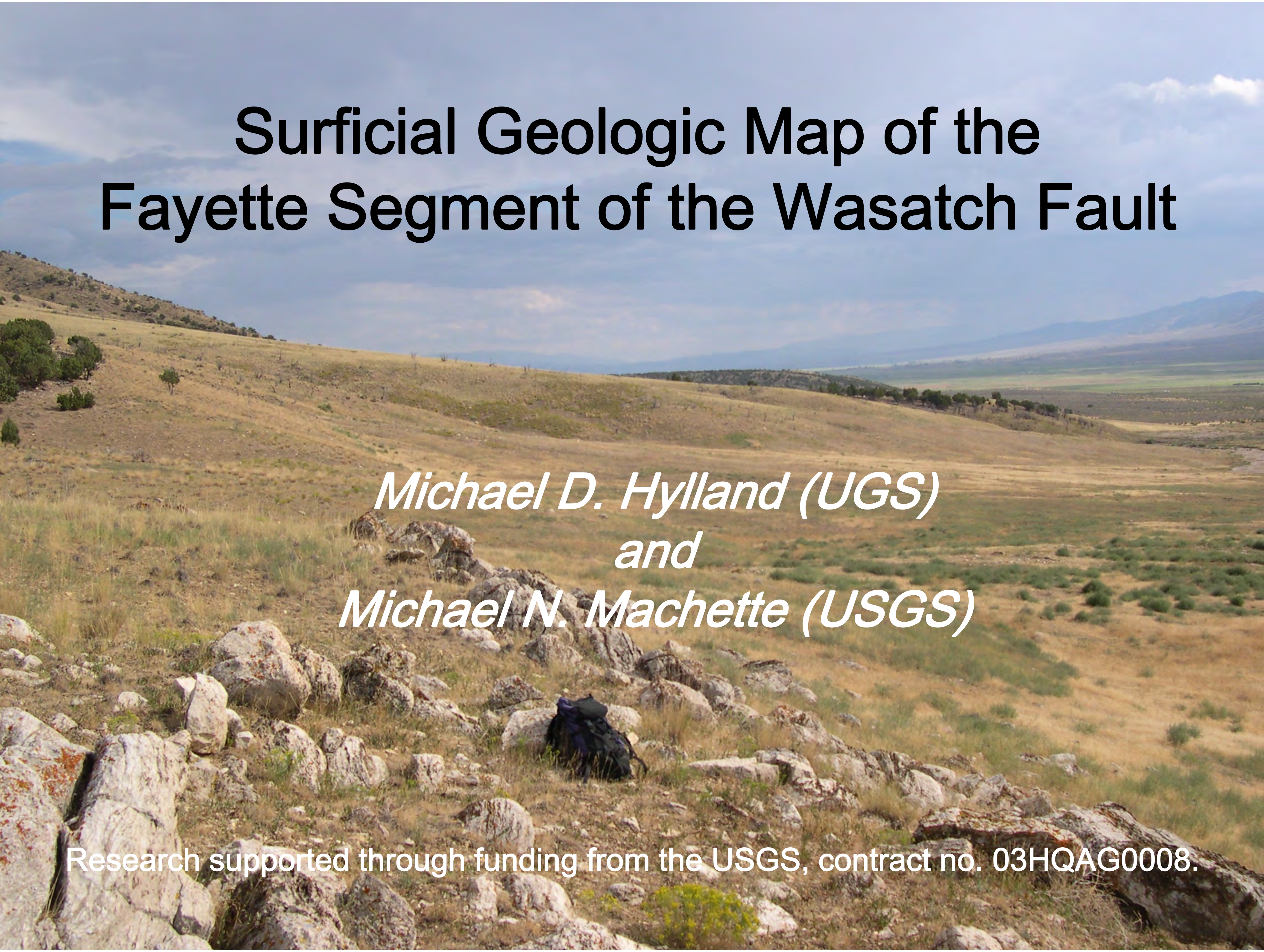
FZ1	FZ2	FZ3
	Z_{FZ2} < 4, 800 RCYBP	Z_{FZ3} < 4, 800 RCYBP
	Y_{FZ2} Slumping? 5,900 to 6,100 RCYBP	Y_{FZ3} Slumping? < 6,400 RCYBP (~ 2 ¾ m offset)
	X_{FZ2} 7,850 to 9,100 RCYBP	Not Exposed
Z_{FZ1} 6,200 to 9,700 RCYBP	W_{FZ2} 9,100 to 9,500 RCYBP	
Y_{FZ1} 9,700 to 12,000 RCYBP	Not Exposed	

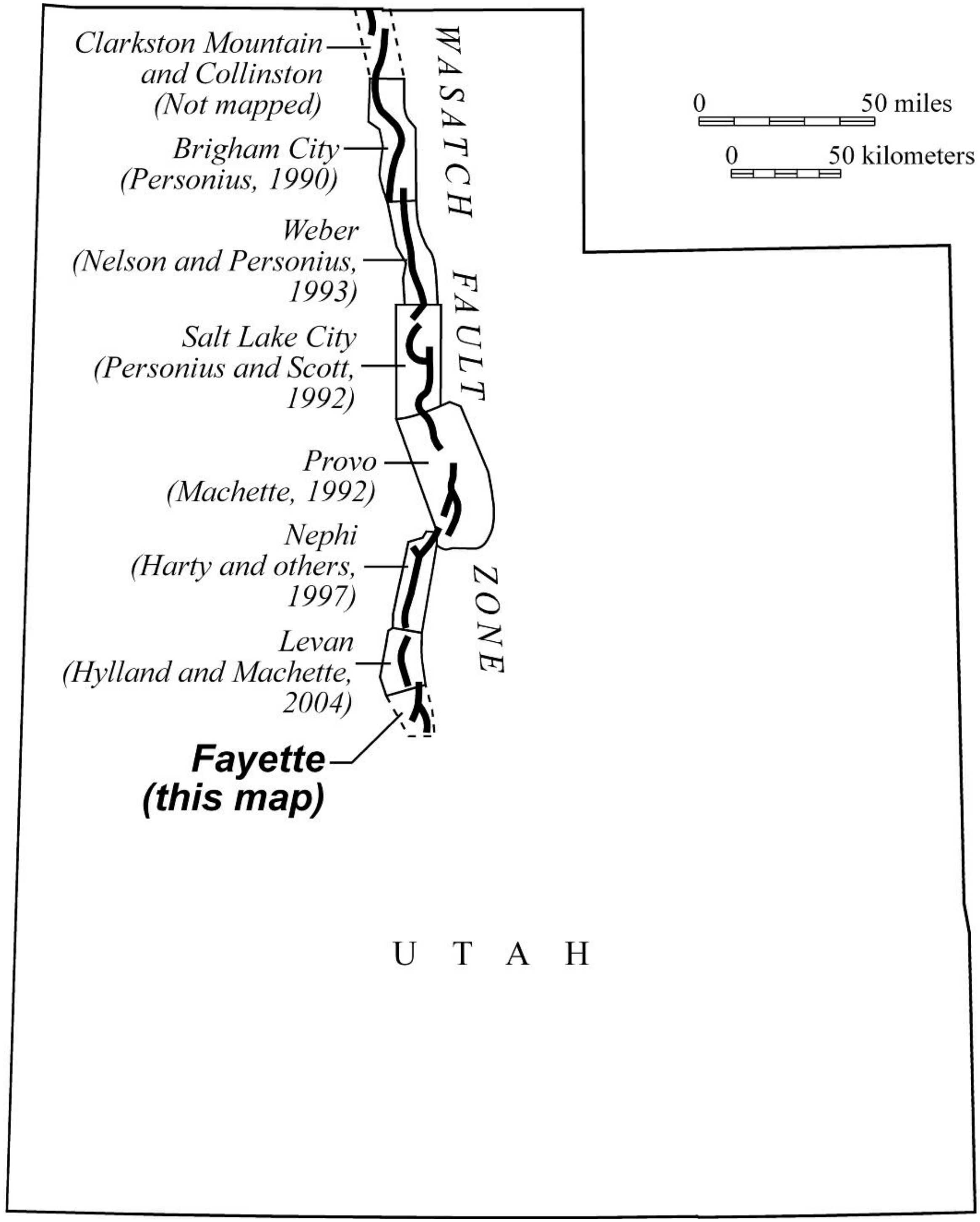
*** Purple indicates radiocarbon ages still pending**

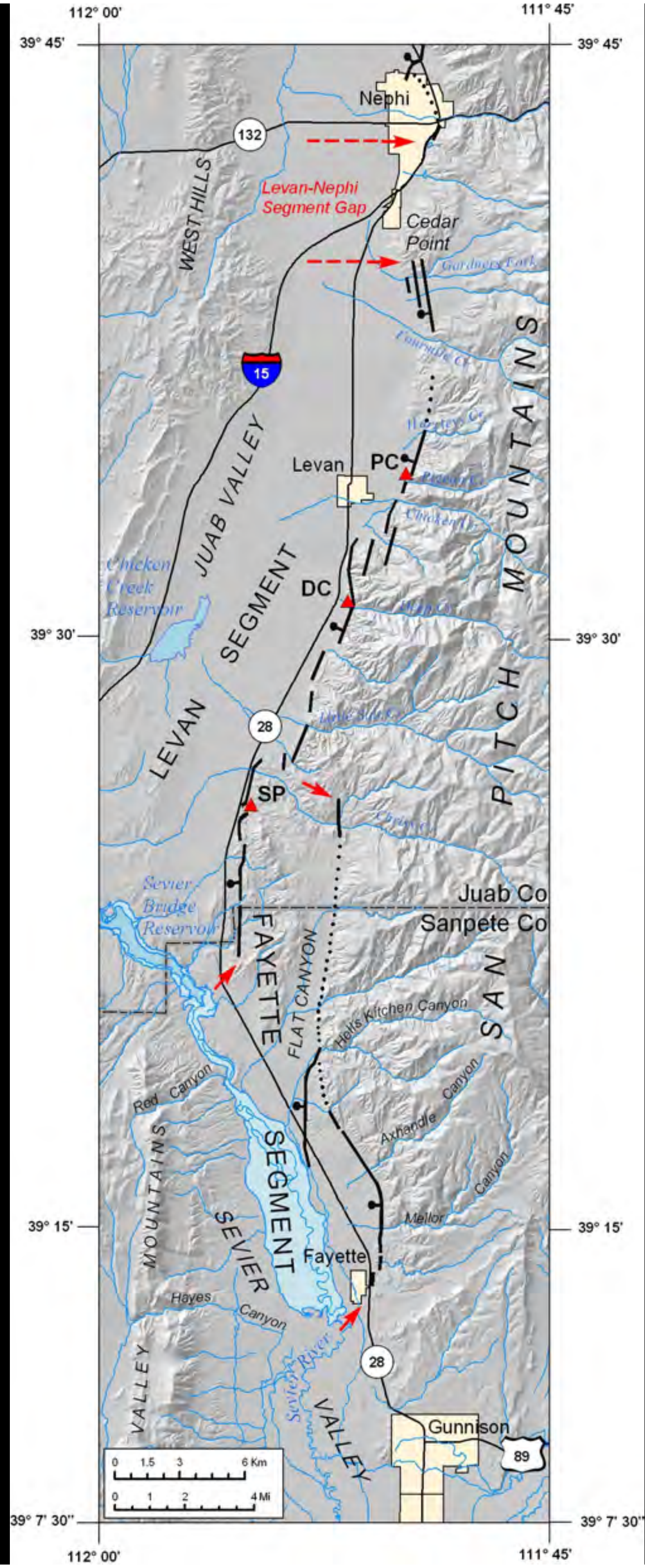
Mapleton Megatrench Summary for UQFPWG

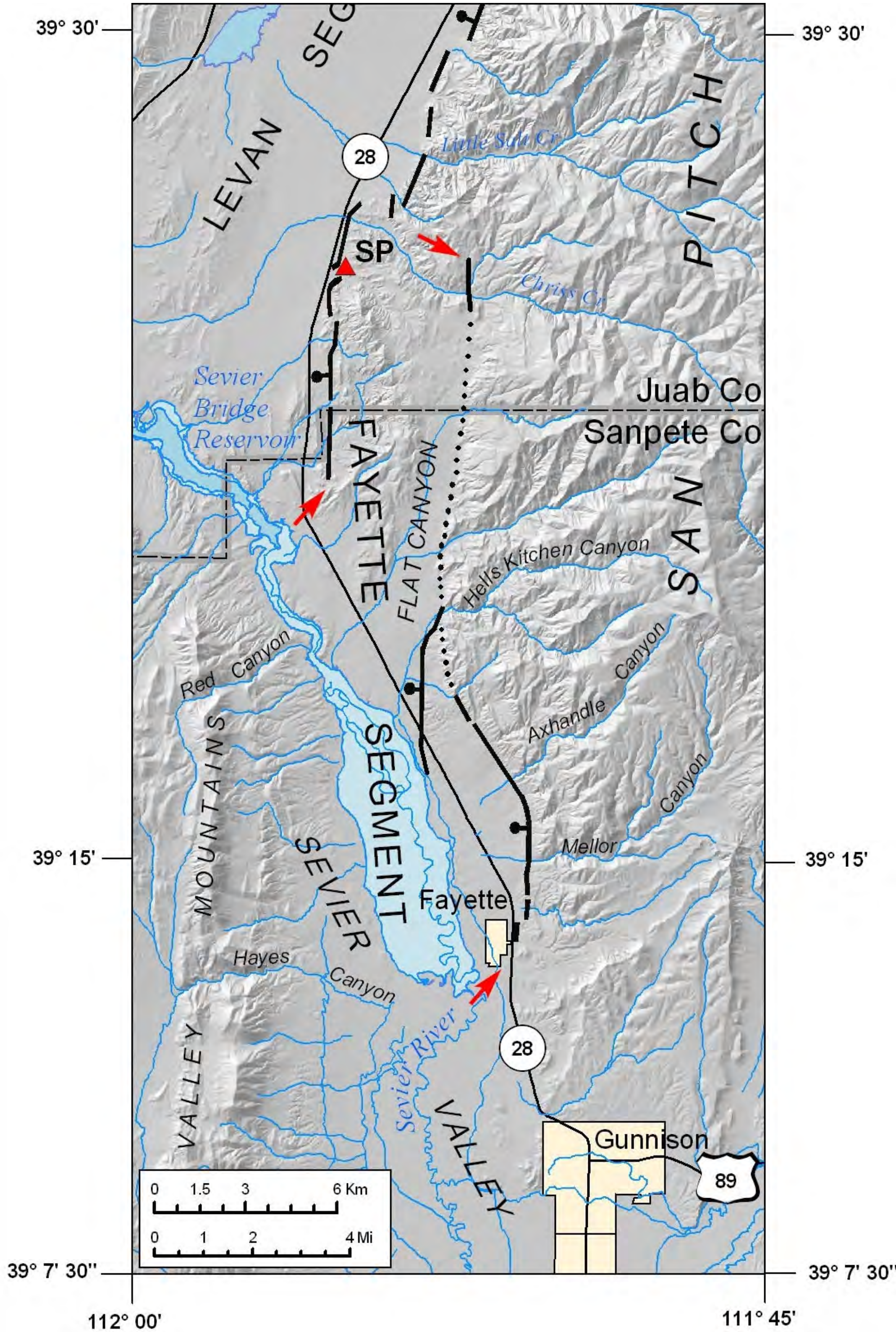
- At least 4 events, probably 5, occurred since 5,300 RYCBP
- At least 7 events, probably 9, possibly 12, occurred since 12,000 RYCBP
- This implies recurrence intervals of 1,200 to 2,800 years, preferred – 1,400 to 1,800 years
- Compared to the Working Group's recurrence intervals of 1,200 to 3,200 years, preferred – 2,400 years
- We anticipate being able to compare short term (< 6 ka) vs. long term (< 14ka) slip rates

URS


Surficial Geologic Map of the
Fayette Segment of the Wasatch Fault
Michael D. Hylland (UGS)
and
Michael N. Machette (USGS)
Research supported through funding from the USGS, contract no. 03HQAG0008.


Clarkston Mountain
and Collinston
(Not mapped)
Brigham City
(Personius, 1990)
Weber
(Nelson and Personius,
1993)
Salt Lake City
(Personius and Scott,
1992)
Provo
(Machette, 1992)
Nephi
(Harty and others,
1997)
Levan
(Hylland and Machette,
2004)
Fayette
(this map)
WASATCH FAULT ZONE
0 50 miles
0 50 kilometers
U T A H


112° 00'
111° 45'
39° 45'
39° 30'
39° 15'
39° 7' 30"
Nephi
132
Levan-Nephi
Segment Gap
Cedar
Point
WEST HILLS
15
JUAB VALLEY
Levan
PC
DC
Chicken
Creek
Reservoir
LEVAN
SEGMENT
PITCH MOUNTAINS
28
SP
Sevier
Bridge
Reservoir
Juab Co
Sanpete Co
FAYETTE
FLAT CANYON
Hells Kitchen Canyon
SAN
Red Canyon
Axhandle Canyon
SEGMENT
MOUNTAINS
SEVIER
Mellor Canyon
Fayette
Hayes Canyon
Sevier River
VALLEY
VALLEY
Gunnison
89
0 1.5 3 6 Km
0 1 2 4 Mi

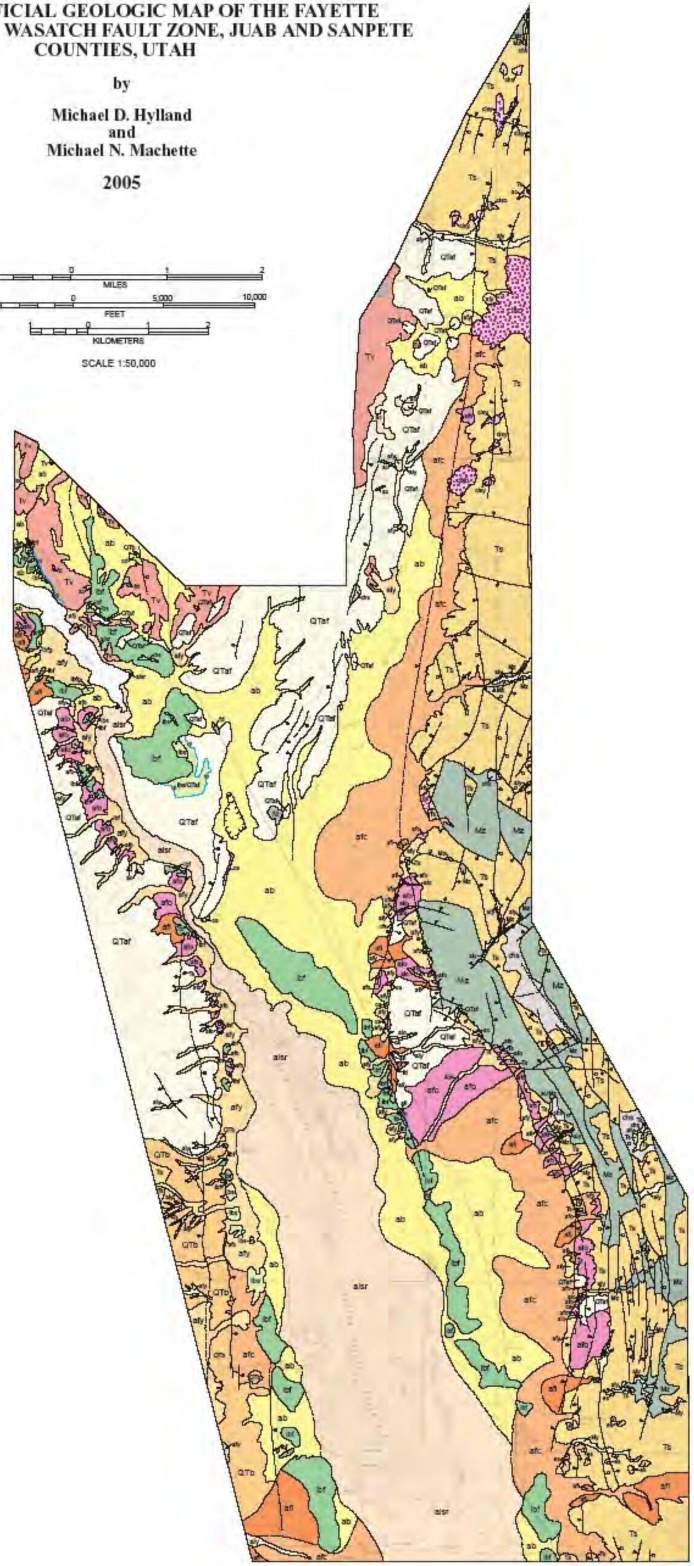

39° 30'
39° 30'
LEVAN SEG
28
Little Salt Cr
SP
Chriss Cr
PITCH
Sevier
Bridge
Reservoir
Juab Co
Sanpete Co
FAYETTE
FLAT CANYON
SAN
Hells Kitchen Canyon
Red Canyon
Axhandle Canyon
Canyon
MOUNTAINS
SEGMENT
Mellor
39° 15'
39° 15'
SEVIER
Fayette
Hayes
Canyon
28
Sevier River
VALLEY
VALLEY
Gunnison
89
0 1.5 3 6 Km
0 1 2 4 Mi
39° 7' 30''
39° 7' 30''
112° 00'
111° 45'

INTERIM SURFICIAL GEOLOGIC MAP OF THE FAYETTE SEGMENT OF THE WASATCH FAULT ZONE, JUAB AND SANPETE COUNTIES, UTAH

by

Michael D. Hylland
and
Michael N. Machette

2005

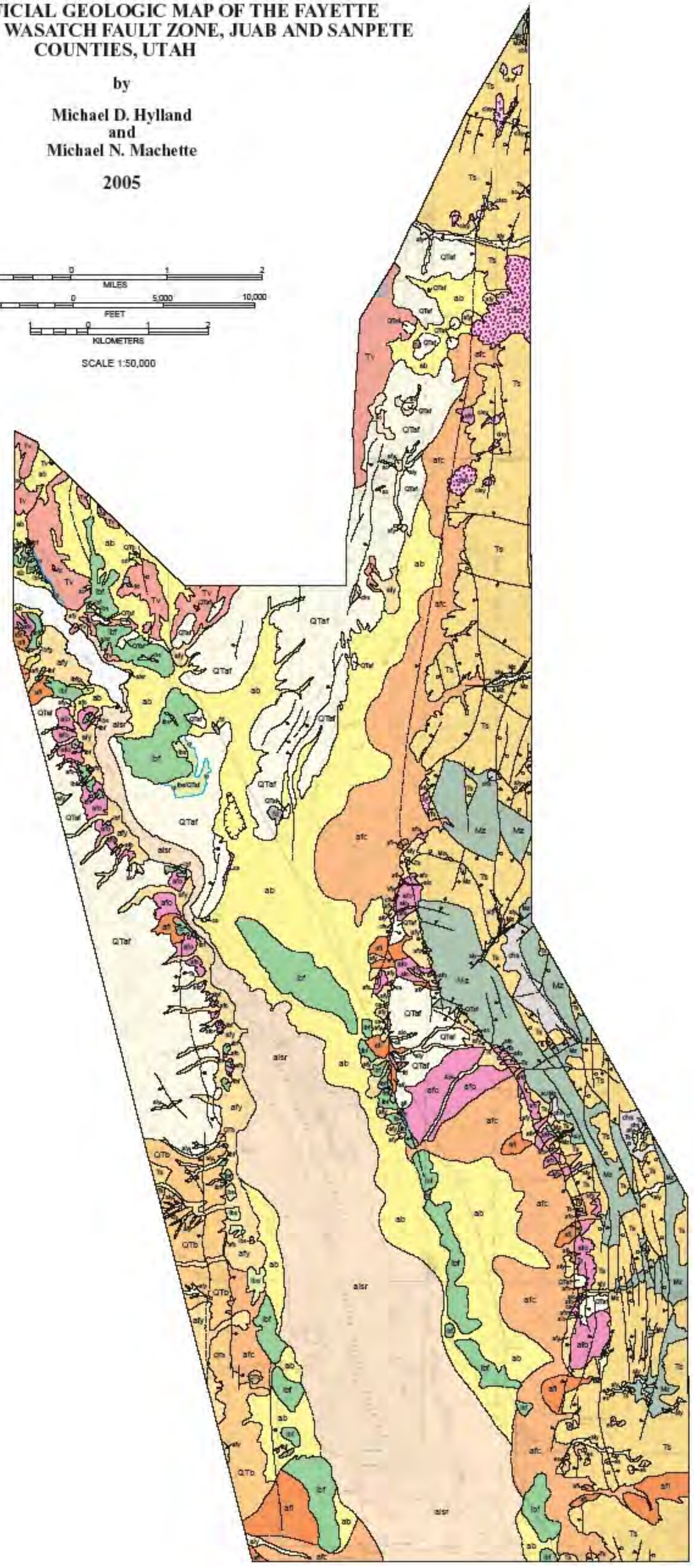


INTERIM SURFICIAL GEOLOGIC MAP OF THE FAYETTE SEGMENT OF THE WASATCH FAULT ZONE, JUAB AND SANPETE COUNTIES, UTAH

by

Michael D. Hylland
and
Michael N. Machette

2005




SAFETY GOGGLES

INTERIM SURFICIAL GEOLOGIC MAP OF THE FAYETTE SEGMENT OF THE WASATCH FAULT ZONE, JUAB AND SANPETE COUNTIES, UTAH

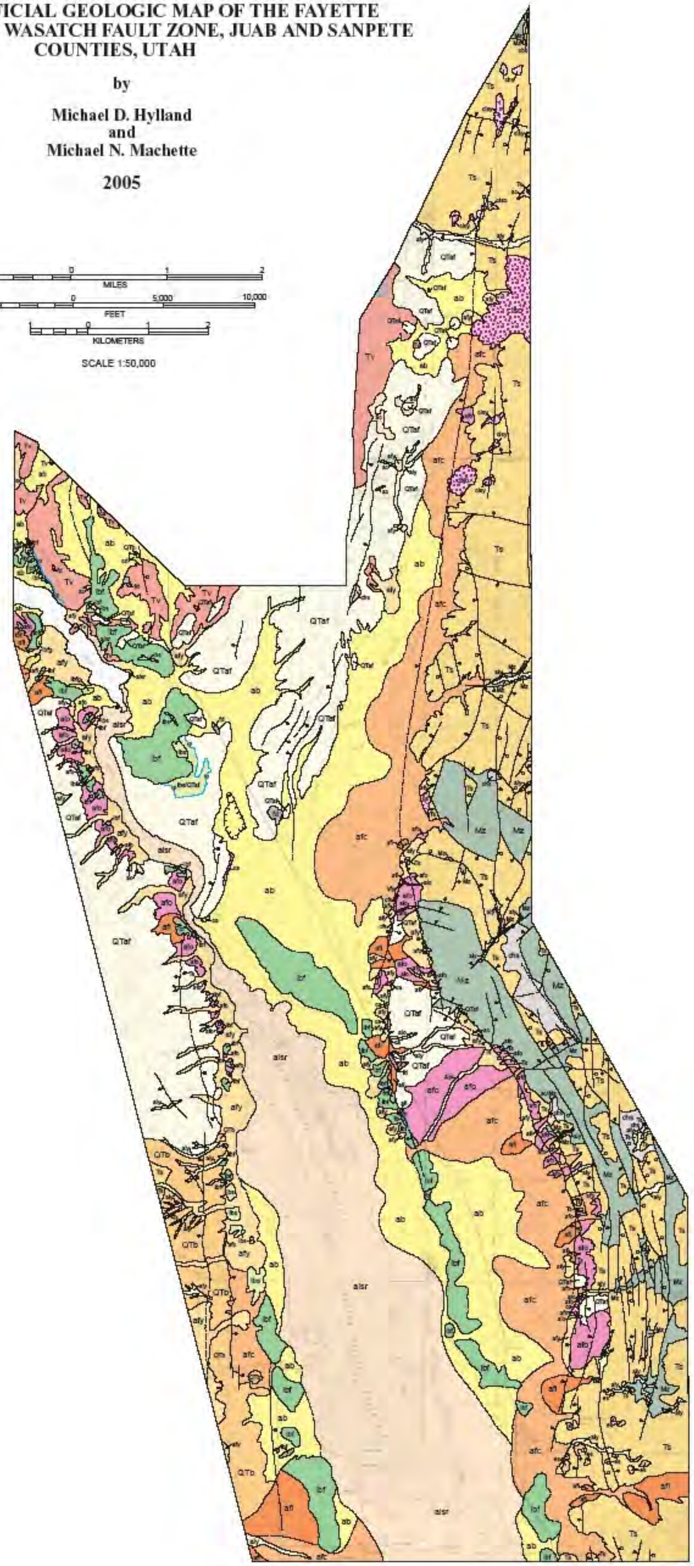
by

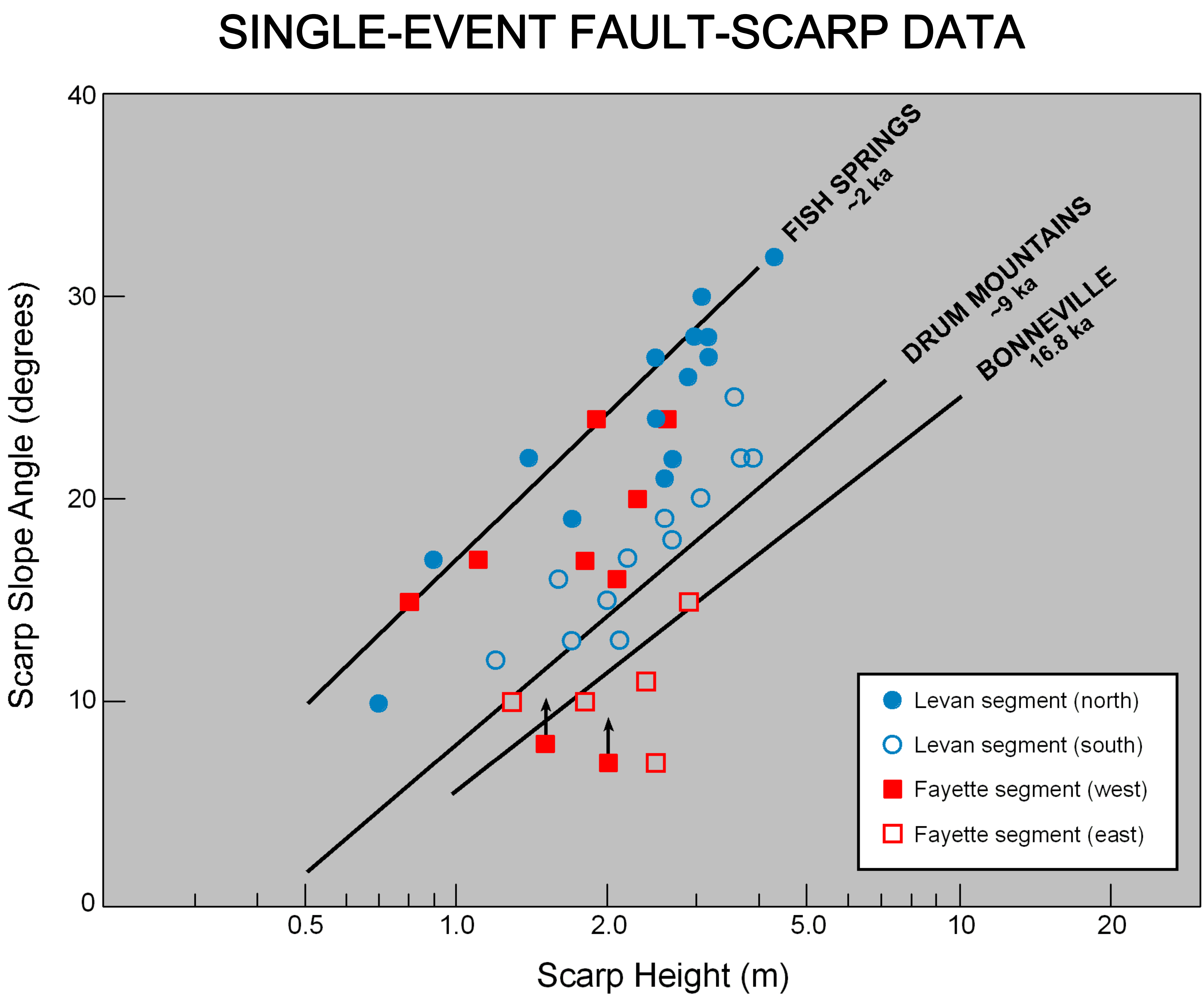
Michael D. Hylland
and
Michael N. Machette

2005

1 0 1 2
MILES
5,000 0 5,000 10,000
FEET
1 0 1 2
KILOMETERS

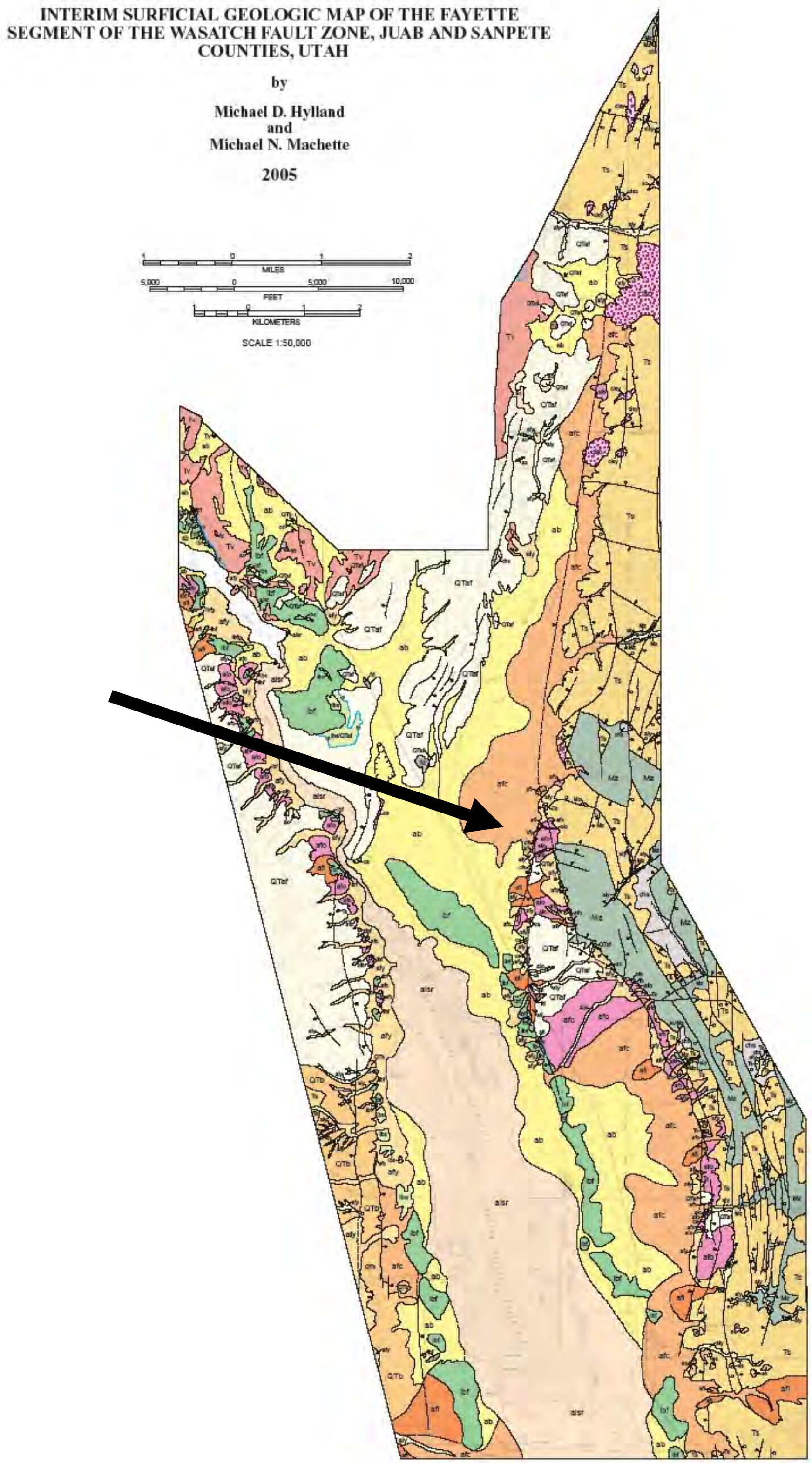
SCALE 1:50,000




SINGLE-EVENT FAULT-SCARP DATA
FISH SPRINGS
~2 ka
DRUM MOUNTAINS
~9 ka
BONNEVILLE
16.8 ka
Levan segment (north)
Levan segment (south)
Fayette segment (west)
Fayette segment (east)
Scarp Slope Angle (degrees)
Scarp Height (m)
0
10
20
30
40
0.5
1.0
2.0
5.0
10
20

Late Quaternary Geologic Slip Rates

Segment	NVTD (m)	Deposit Age (ka)	Slip Rate (mm/yr)
Fayette	$\geq$14	100-250	0.06-0.1 (min.)
Fayette	2.8	100-250	0.01-0.03
Fayette	$\geq$3.2	100-250	0.01-0.03 (min.)
Levan	4.8	100-250	0.02-0.05



Higher Slip Rate:

- Spillover of Levan-segment ruptures
- Additive slip from separate eastern- and western-strand ruptures
- Effects of subsurface evaporite beds

CONCLUSIONS

- Holocene MRE on western strand
- Late Pleistocene MRE on eastern strand
- No late Quaternary movement on northern strand
- 10 km overlap between Fayette and Levan segments
- Displacement transferred between Fayette and Levan segments along subsidiary faults in area of overlap

CONCLUSIONS (cont.)

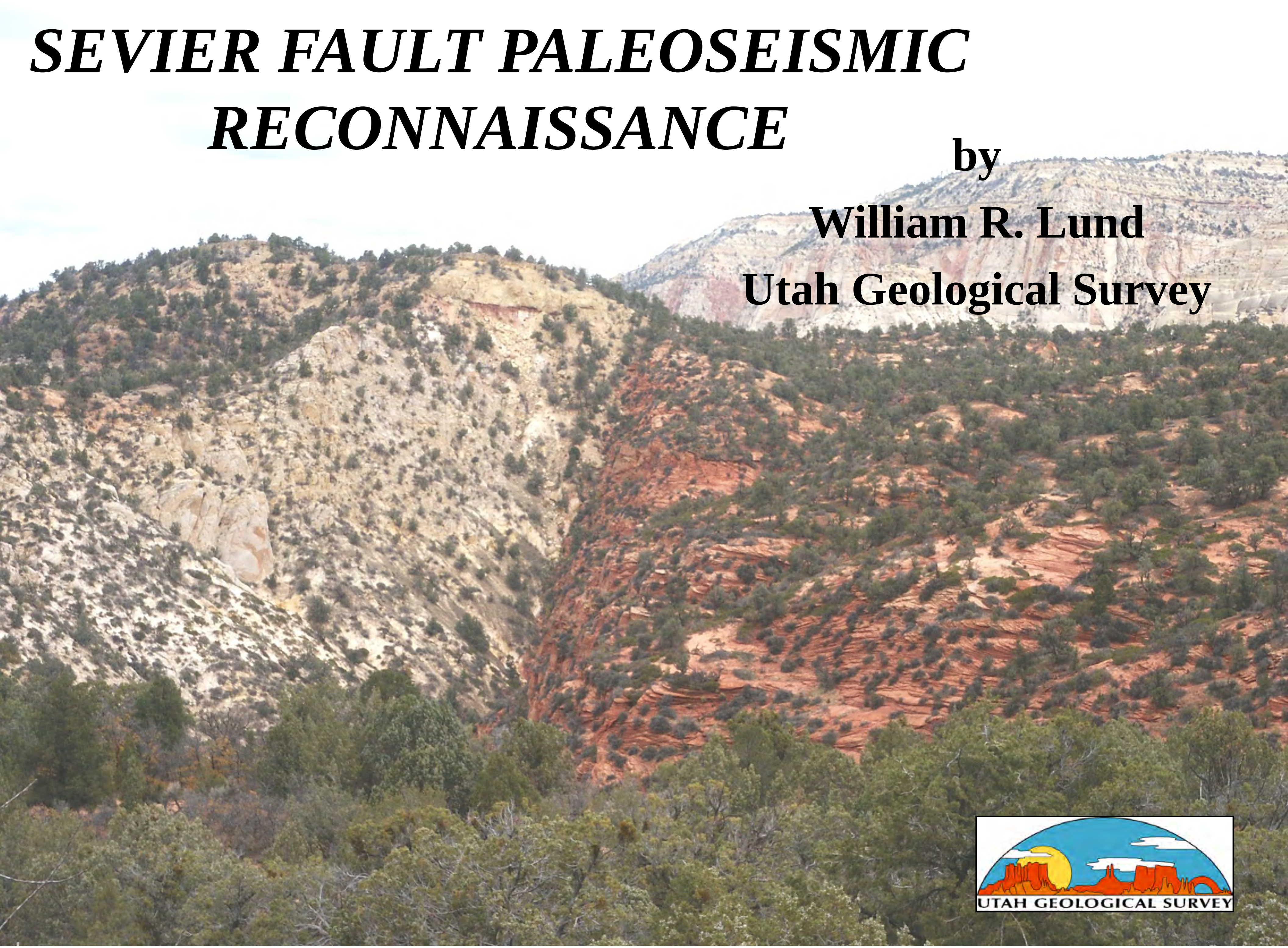
- Long-term (since ~250 ka) geologic slip rate is low (generally 0.01-0.03 mm/yr)
- Higher long-term geologic slip rate (0.06-0.1 mm/yr) may be due to:
  - Spillover of Levan-segment ruptures
  - Additive slip from separate eastern- and western-strand ruptures
  - Possible effect of local diapirism or dissolution-induced subsidence

SEVIER FAULT PALEOSEISMIC RECONNAISSANCE

by

William R. Lund

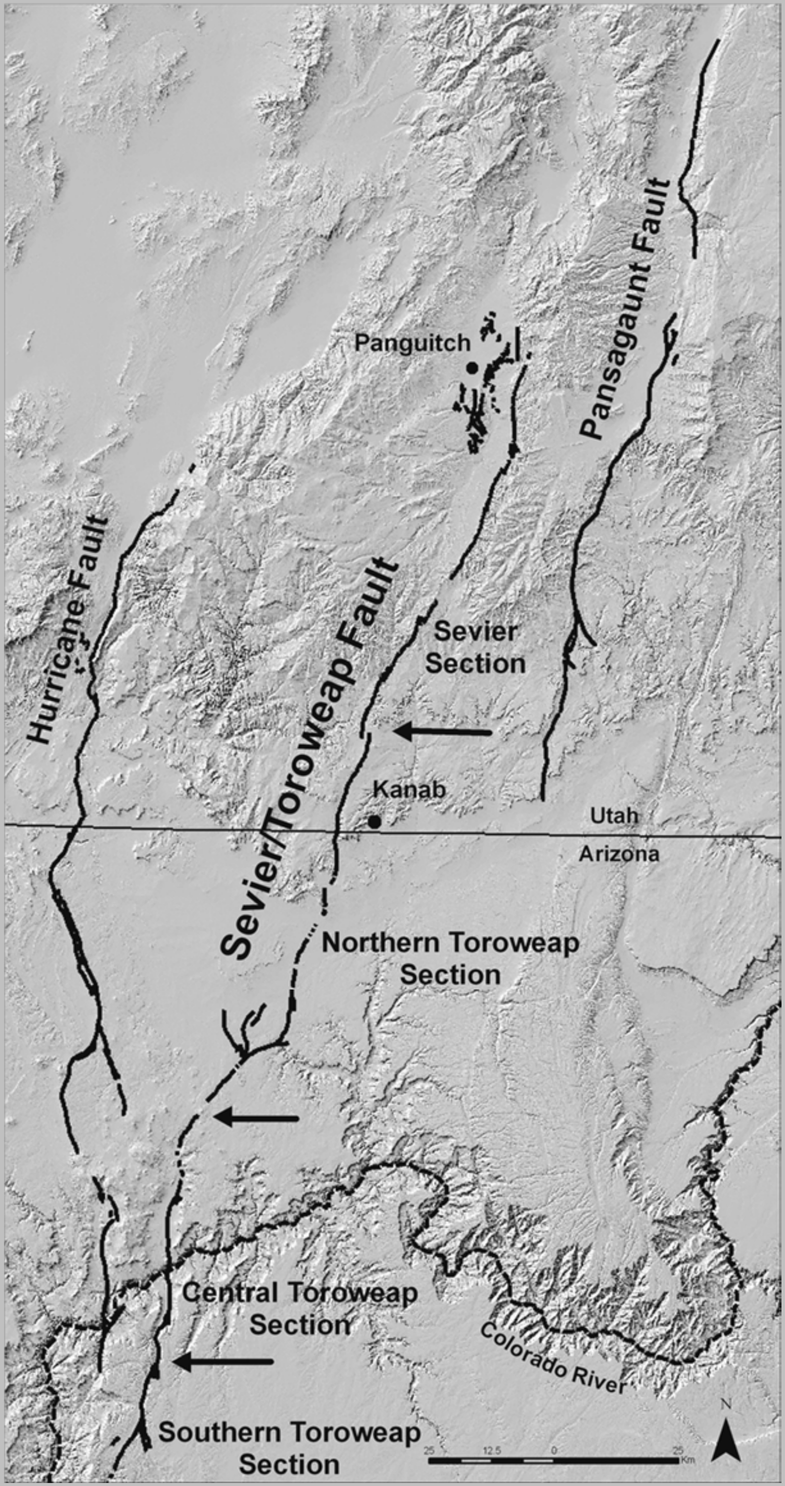
Utah Geological Survey



The UGS conducted a NEHRP-funded reconnaissance of the Sevier fault (SF) in southwestern Utah to identify sites where future paleoseismic investigations may provide information on earthquake timing, recurrence, displacement, and vertical slip rate.

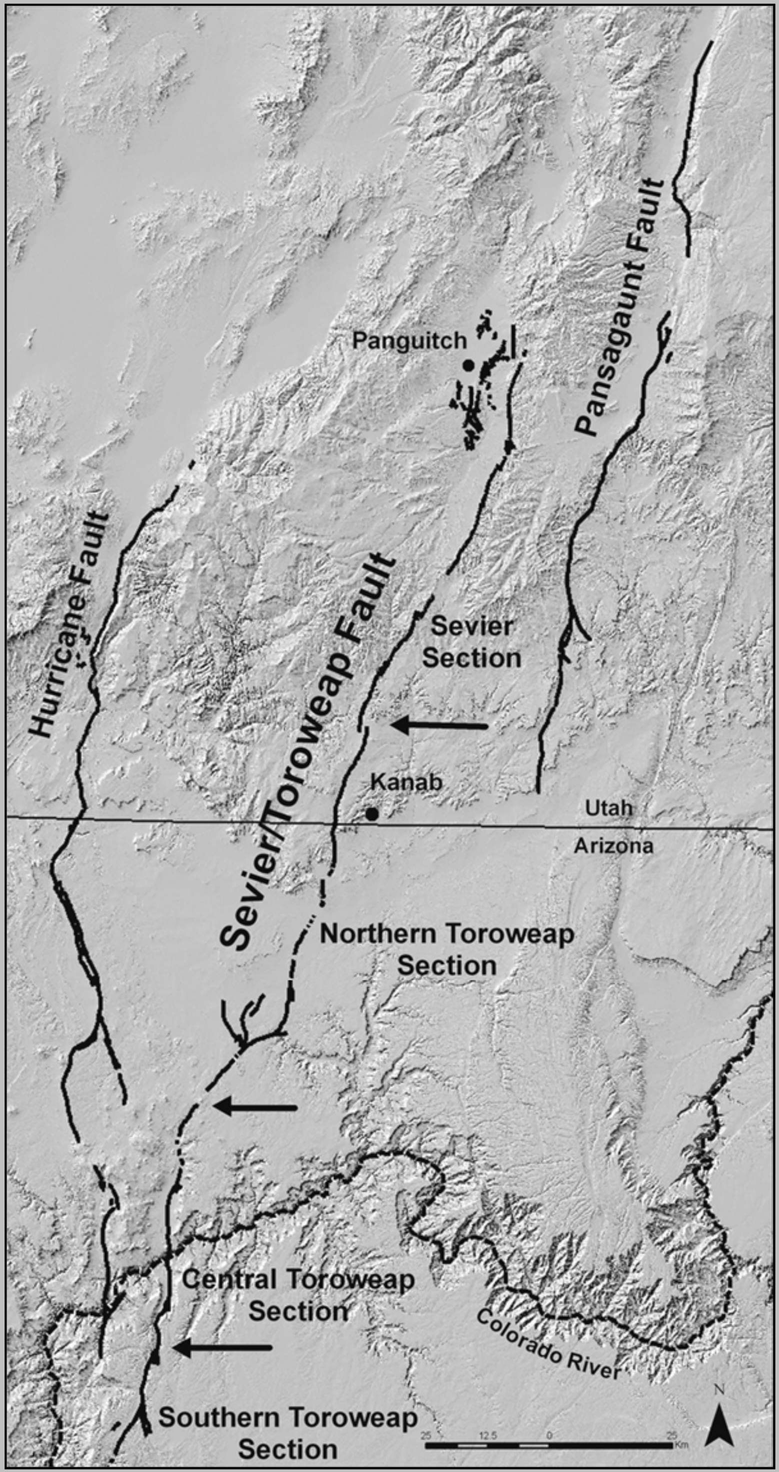
Determining these paleoseismic parameters will allow the UGS to (1) more accurately characterize the SF's importance to the National Seismic Hazard Maps, (2) include these data in the UGS and U.S. Geological Survey Quaternary fault databases, and (3) determine the level of seismic hazard presented by the SF to southwestern Utah.

The reconnaissance included a literature review, aerial-photograph interpretation (chiefly 1:40,000-scale with 1:20,000-scale stereoscopic photos of select areas), field verification of fault features and geologic units, and sampling of mafic volcanic flows for $^{40}Ar/^{39}Ar$ radiometric dating.



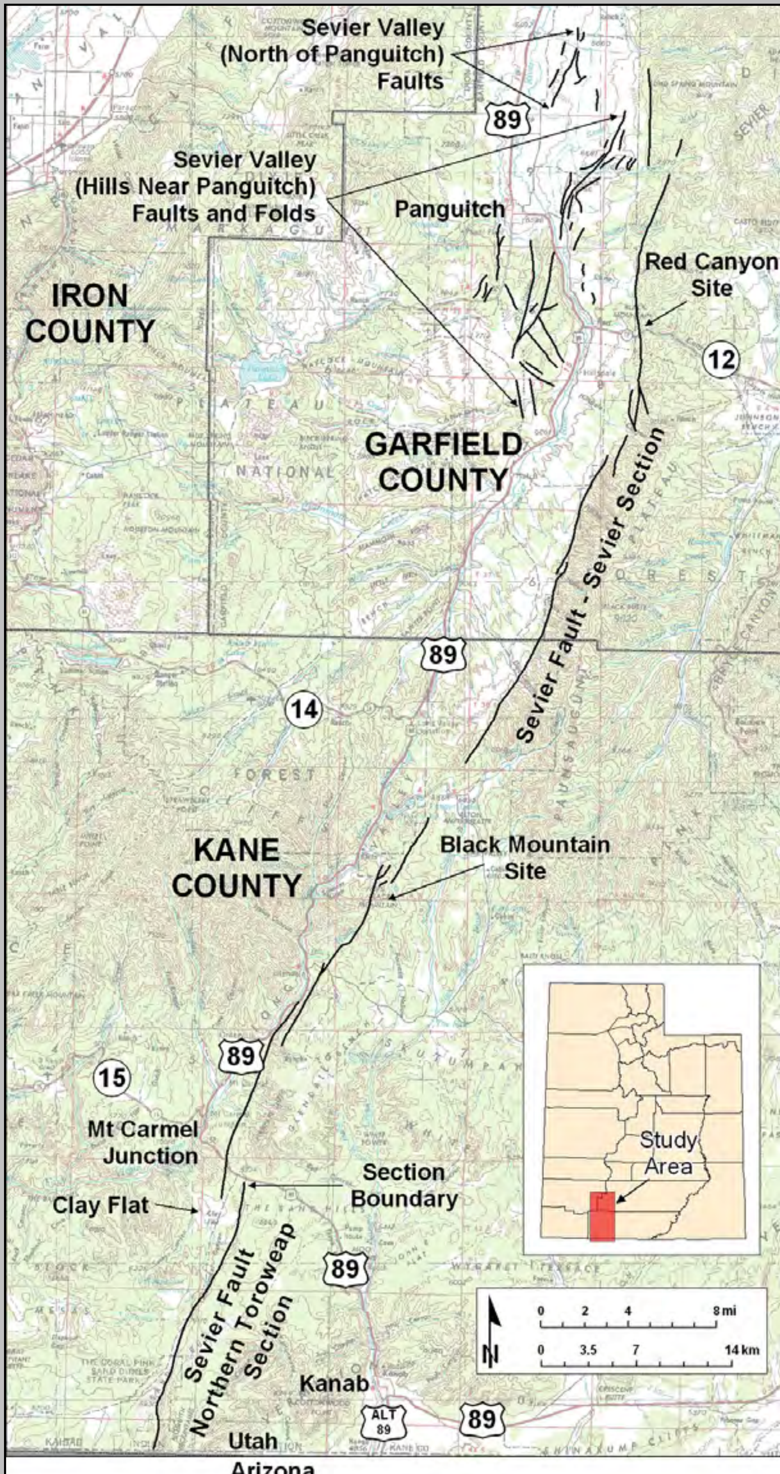
The Sevier/Toroweap fault is one of three major sub-parallel, generally north-trending faults (along with the Hurricane fault to the west and Paunsaugunt fault to the east) in northwestern Arizona and southwestern Utah that define the transition between the Basin and Range Province to the west and the Colorado Plateau to the east.

Although a continuous structure that is almost 250 km long, by convention the Sevier/Toroweap fault is named the Toroweap fault in Arizona and the Sevier fault in Utah.



Displacement across the Sevier/Toroweap fault is variable, but generally increases to the north. Near the Grand Canyon there is as much as 300 m of Cenozoic displacement, while in Utah 450 m of displacement is reported near Mt. Carmel Junction and 900 m at Red Canyon.

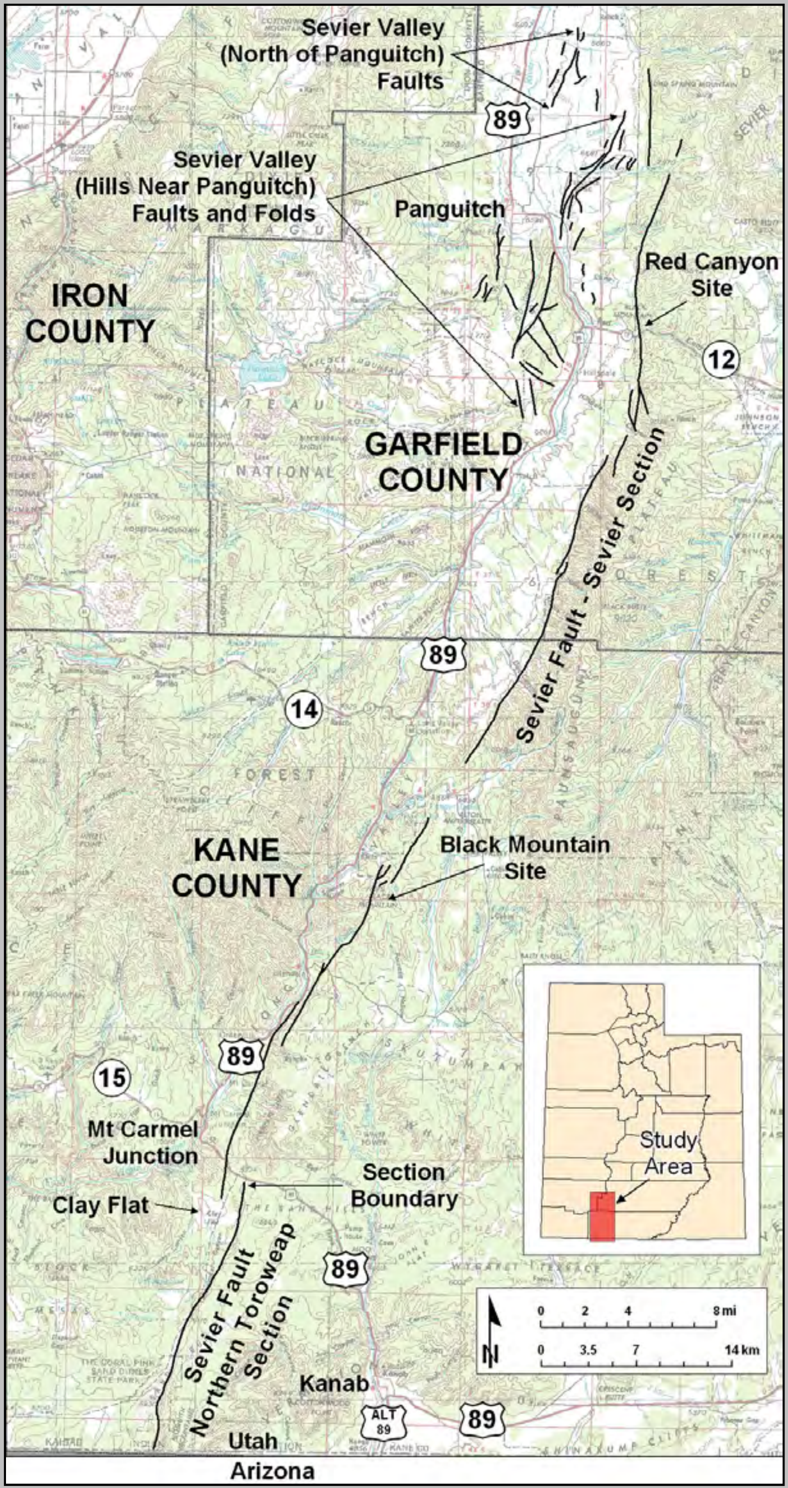
The Sevier/Toroweap fault is tentatively subdivided into four sections, two of which, the Northern Toroweap (partial) and Sevier lie within Utah



Sevier Fault in Utah

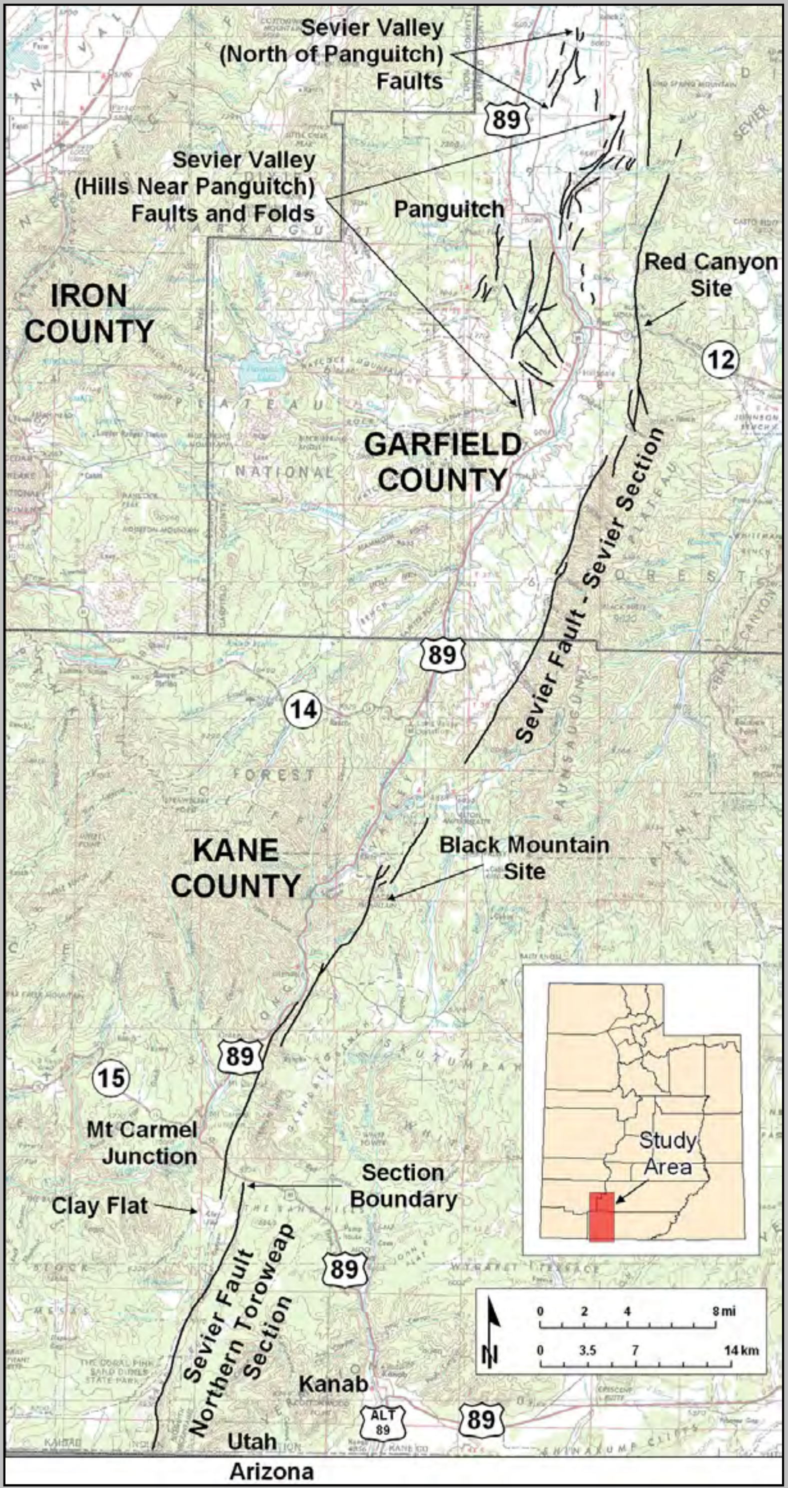
This paleoseismic reconnaissance included the main trace of the SF from the Utah/Arizona border to where the fault terminates north of Panguitch, Utah; end-to-end length of the SF in Utah is 108 km, which includes the northern 20 km of the NTS and the 88-km-long SS.

The reconnaissance also included two groups of faults and folds in the SF hanging wall near Panguitch: (1) the Sevier Valley (Hills Near Panguitch) Faults and Folds, and (2) the Sevier Valley (North of Panguitch) Faults.



Northern Toroweap Section

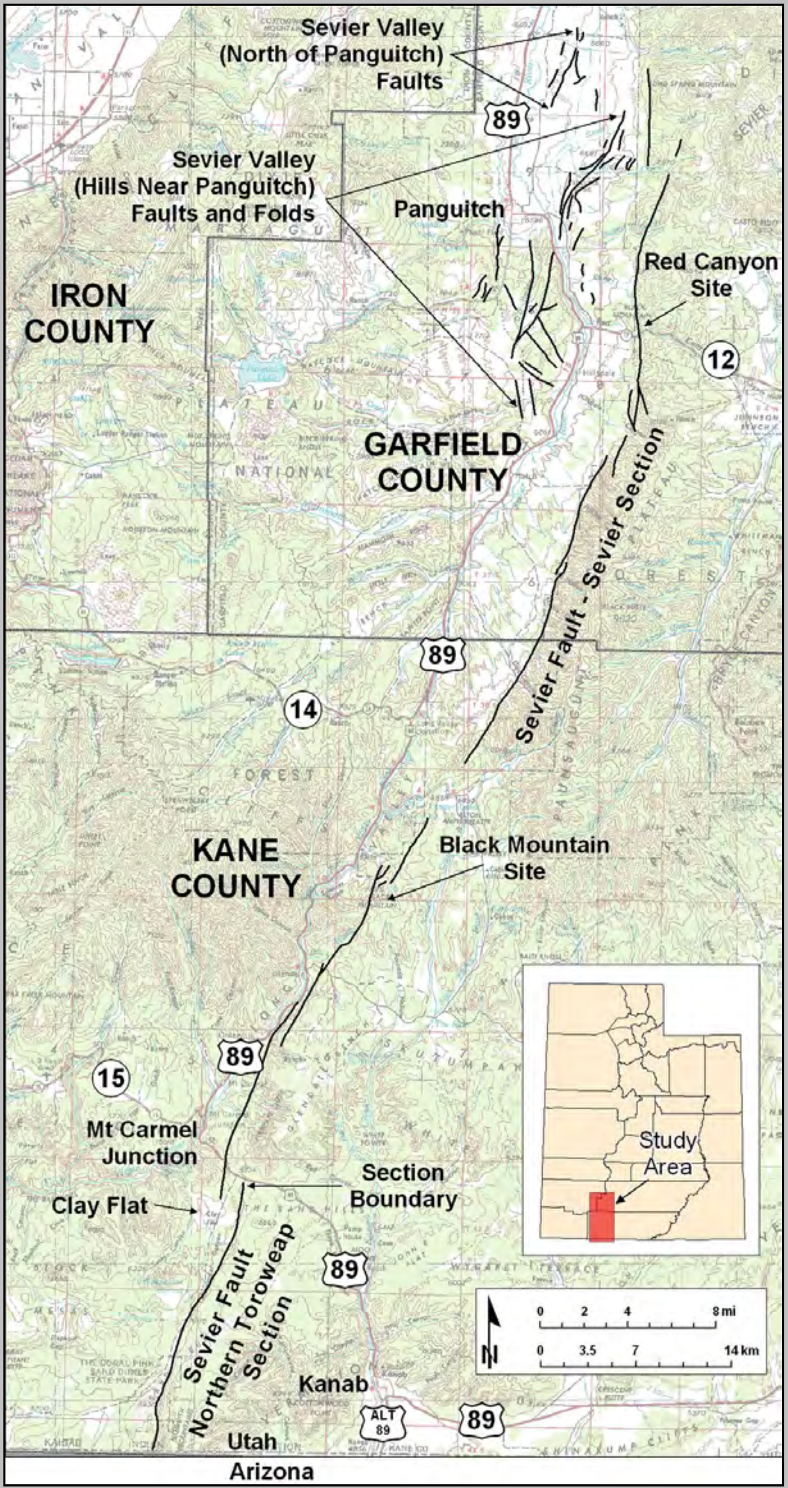
Scarps formed on Quaternary deposits are absent on the NTS in Utah. Where exposed in bedrock, the NTS defines a zone up to a km wide of overlapping and anastomosing fault strands.



Clay Flat

Clay Flat forms a small (1 km^2) closed basin where the SF makes a left en echelon step between the NTS on the east and the SS on the west . Left-lateral oblique slip documented on the NTS south of Clay Flat combined with a left step in the fault trace form a pull-apart basin at Clay Flat.

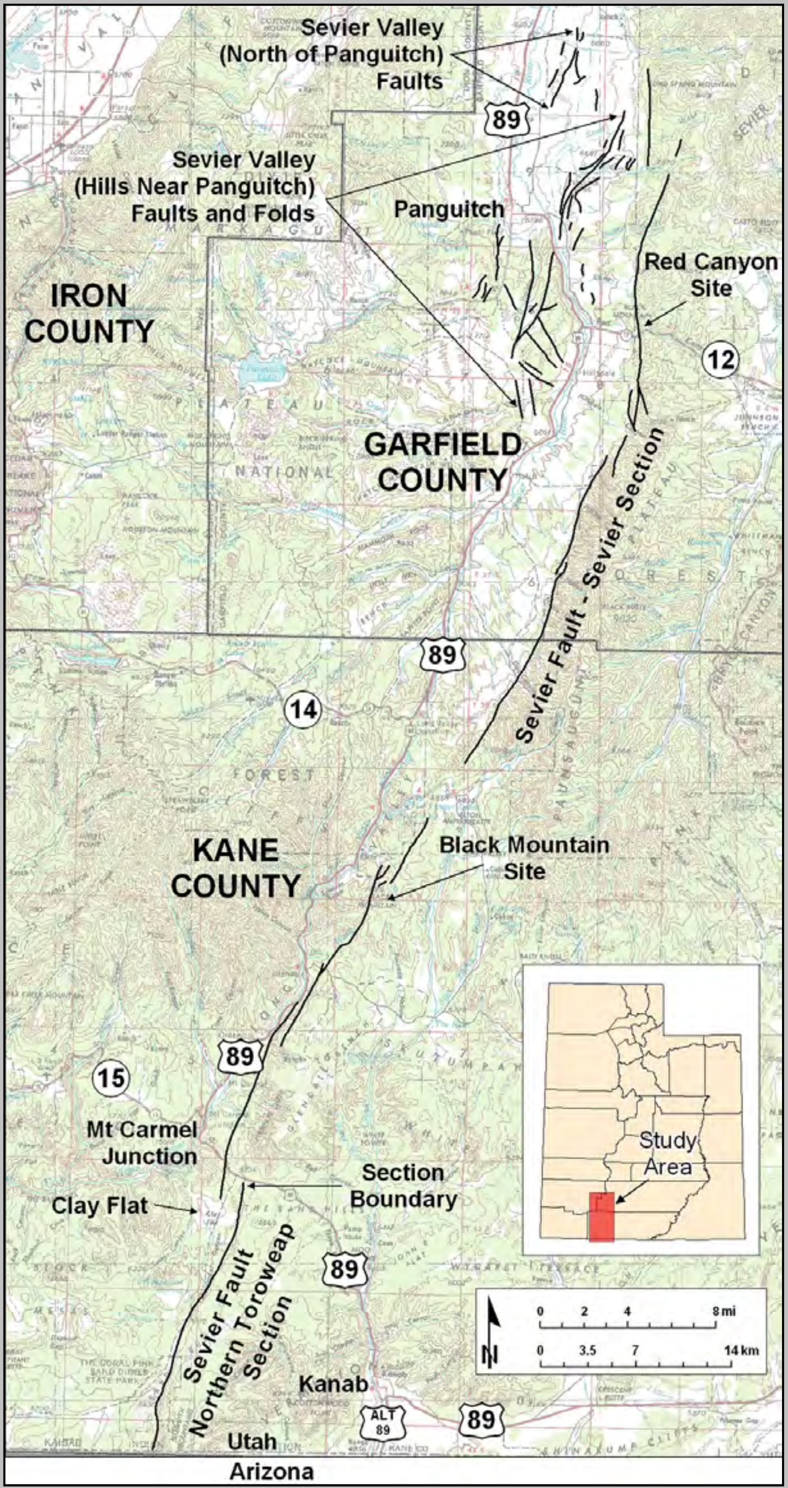
Anderson and Christenson (1989) state that maintaining a sediment depocenter that is receiving sediment from two large drainages likely requires active late Pleistocene subsidence.



Clay Flat

However, undeformed Holocene basin-fill deposits overlie the Sevier fault in the immediate vicinity of Clay Flat, indicating no Holocene deformation and masking possible evidence of Pleistocene tectonic activity.

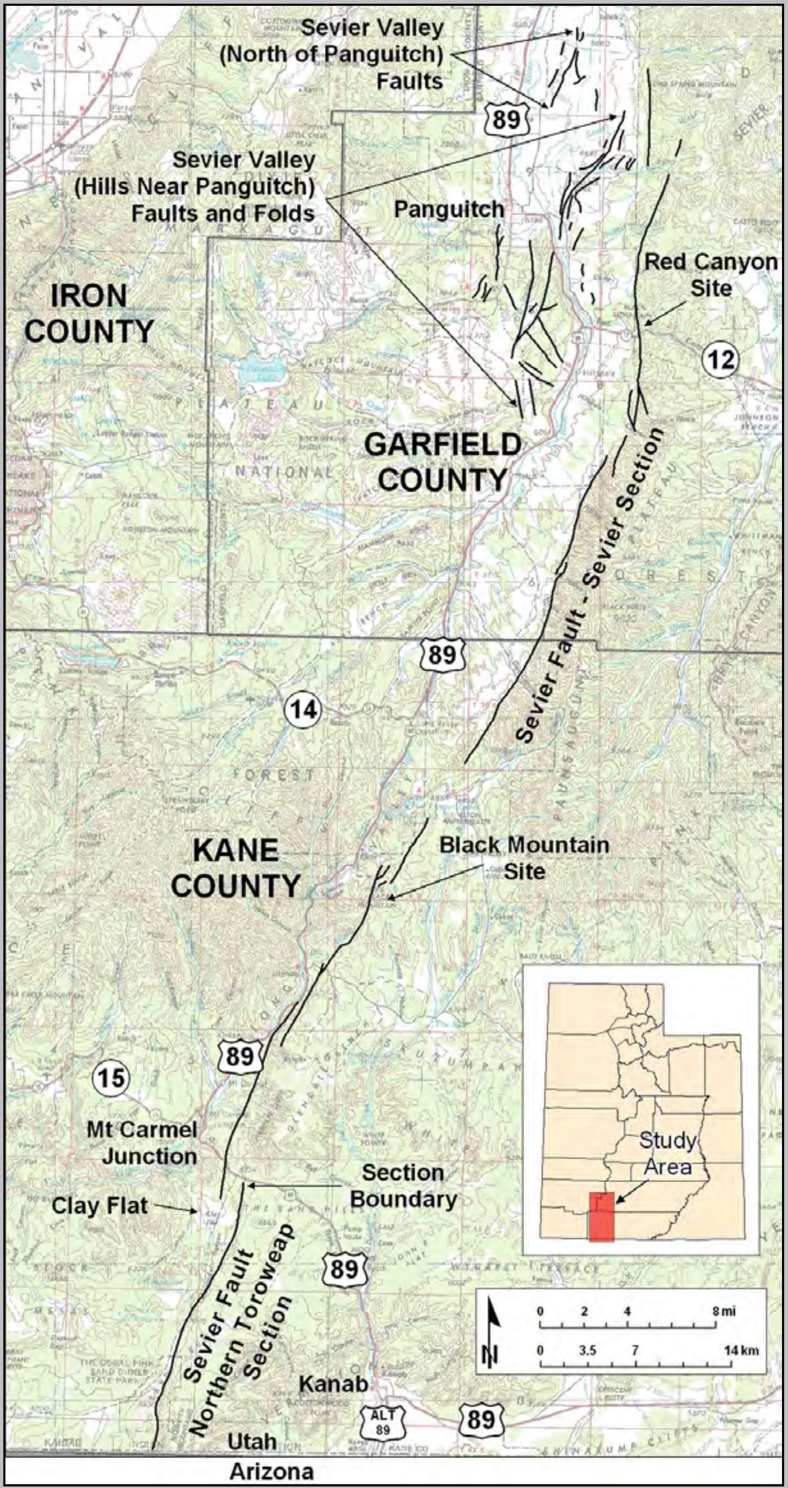
Black and others (2003) identified the left step at Clay Flat as the boundary between the Northern Toroweap and Sevier sections of the Sevier fault.



Sevier Section

The SS extends from Clay Flat to northeast of Panguitch. The section exhibits a complex pattern of right stepping, overlapping faults, relay ramps, and local folds from Clay Flat to near Black Mountain, a distance of about 28 km.

North of Black Mountain the fault trace shows less complexity, and has been mapped as a single strand in many areas. However, the SF has not been mapped in detail north of the Kane County/Garfield County line, so complexities may exist, which are as yet unrecognized.



Sevier Section

No fault scarps are formed on unconsolidated deposits along the SS. However, the fault does displace mafic volcanic rocks at two locations, Black Mountain in Kane County, and Red Canyon in Garfield County.

In the absence of scarps on unconsolidated deposits, the displaced volcanic rocks at Black Mountain and Red Canyon provide the only opportunity to determine vertical slip rates for the SF in Utah.

Sevier Fault at Red Canyon

The SF is well exposed at the mouth of Red Canyon where basalt is displaced 200 m down-to-the-west across the fault.

Best and others (1980) obtained a K-Ar age of 0.56 ± 0.07 Ma for the basalt.

Using those data, Hecker (1993) calculated a vertical slip rate of 0.36 mm/yr at Red Canyon.

Red Canyon

Slip rate calculations using displaced volcanic flows requires that the source of the flows be known. Flows erupting on the fault footwall may cascade over a pre-existing fault escarpment, and create the impression of greater displacement than has actually occurred due to faulting.

A priority of this reconnaissance was to determine the source and true tectonic displacement of the volcanic rocks at Red Canyon. The reconnaissance identified a previously unrecognized eroded cinder cone on the SF hanging wall north of Utah SR-12 immediately adjacent to the Red Canyon site.

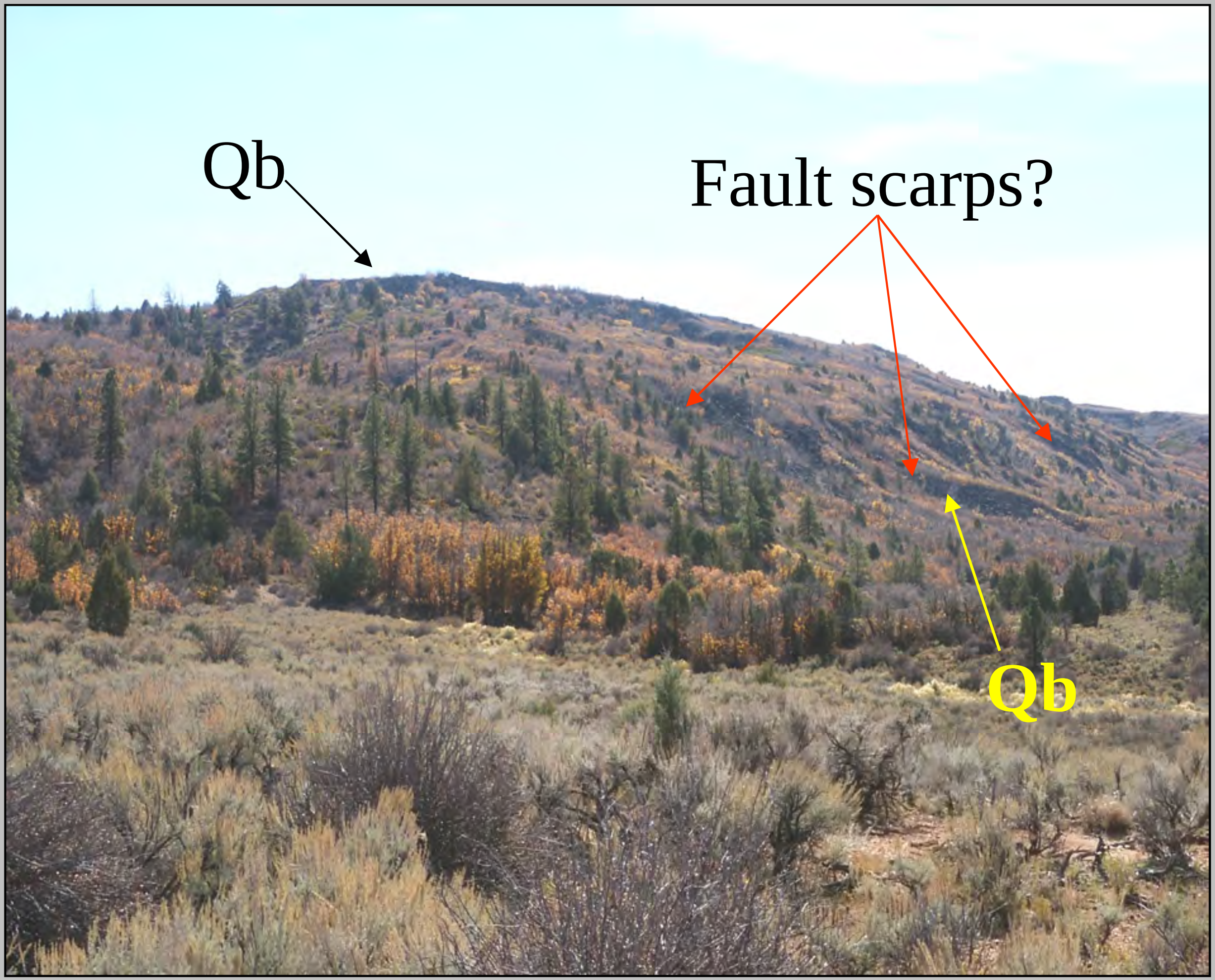
Identification of a hanging-wall source for the volcanic rocks indicates that the 200 m elevation difference between the volcanic rocks on either side of the SF is likely a true measure of post-eruption surface faulting at Red Canyon.

Red Canyon

The UGS has submitted basalt samples from the fault footwall and hanging wall for $^{40}Ar/^{39}Ar$ radiometric age analysis to refine the vertical slip rate at Red Canyon.

The dates will be reported when they become available in mid-2005. Until that time, the Hecker (1993) slip-rate estimate of 0.36 mm/yr appears reasonable and is the best available data for Red Canyon.

Sevier Fault at Black Mountain



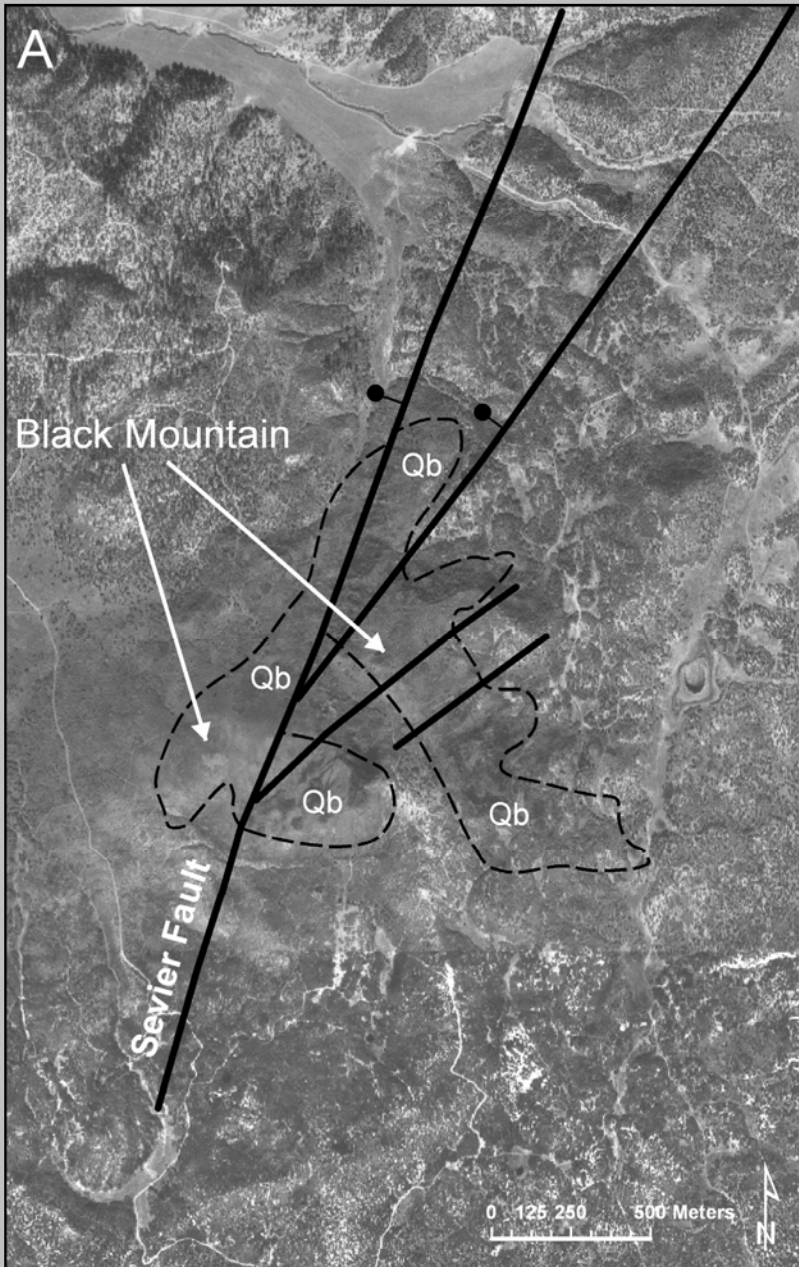
Mafic volcanic rocks cap Black Mountain and are displaced across the SF. The source of the volcanics has not been identified; however, it must be at or close to Black Mountain because a flow extends westward from the base of the mountain to the East Fork of the Virgin River.

Black Mountain

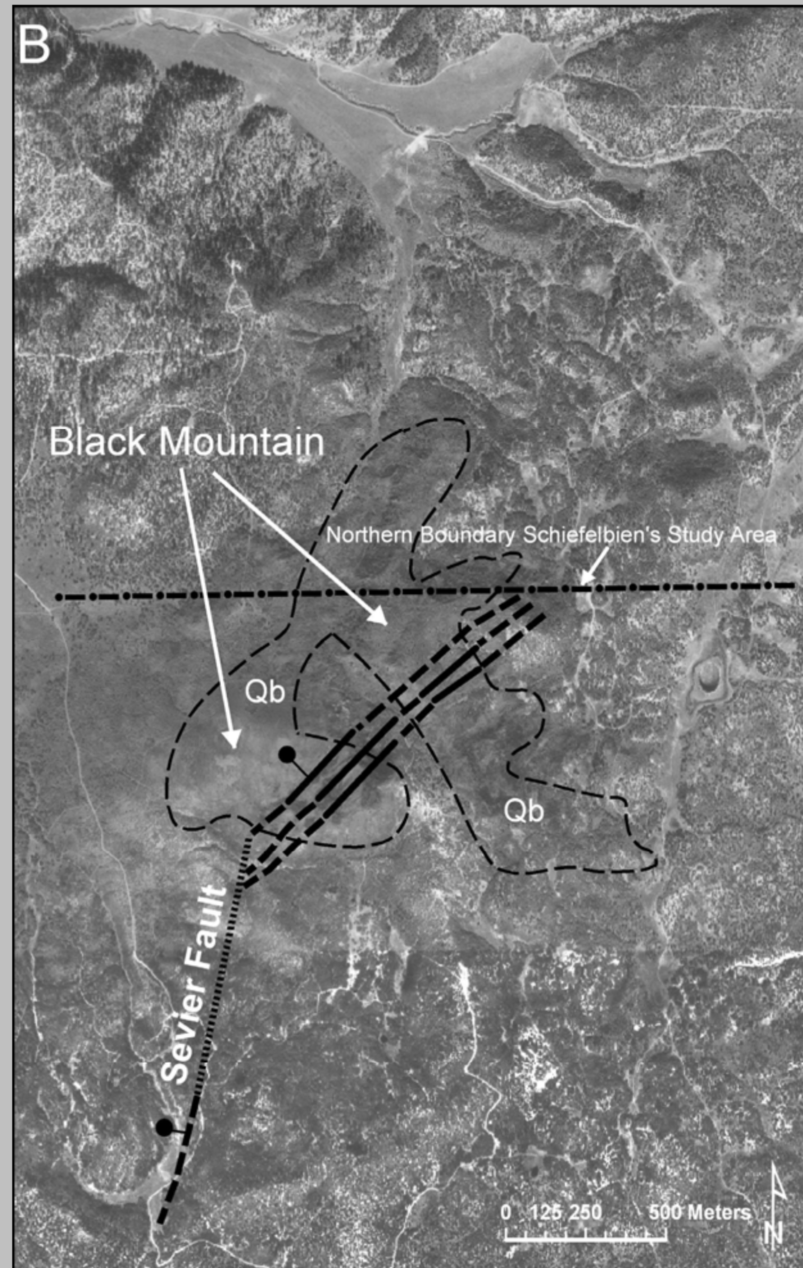
Geologic relations at Black Mountain are complex and poorly exposed. Reported fault displacements in basalt of 23 and ~21 m, and a new $^{40}Ar/^{39}Ar$ age for the basalt of 0.57 Ma support a late Quaternary vertical slip rate of about 0.04 mm/yr.

However, if landsliding and lava cascading are largely discounted as a cause of the difference in basalt elevations across the SF, the difference of 229 m results in a vertical slip rate of 0.40 mm/yr, which is compatible with the 0.36 mm/yr vertical slip rate reported by Hecker (1993) in volcanic rocks of essentially the same age at Red Canyon.

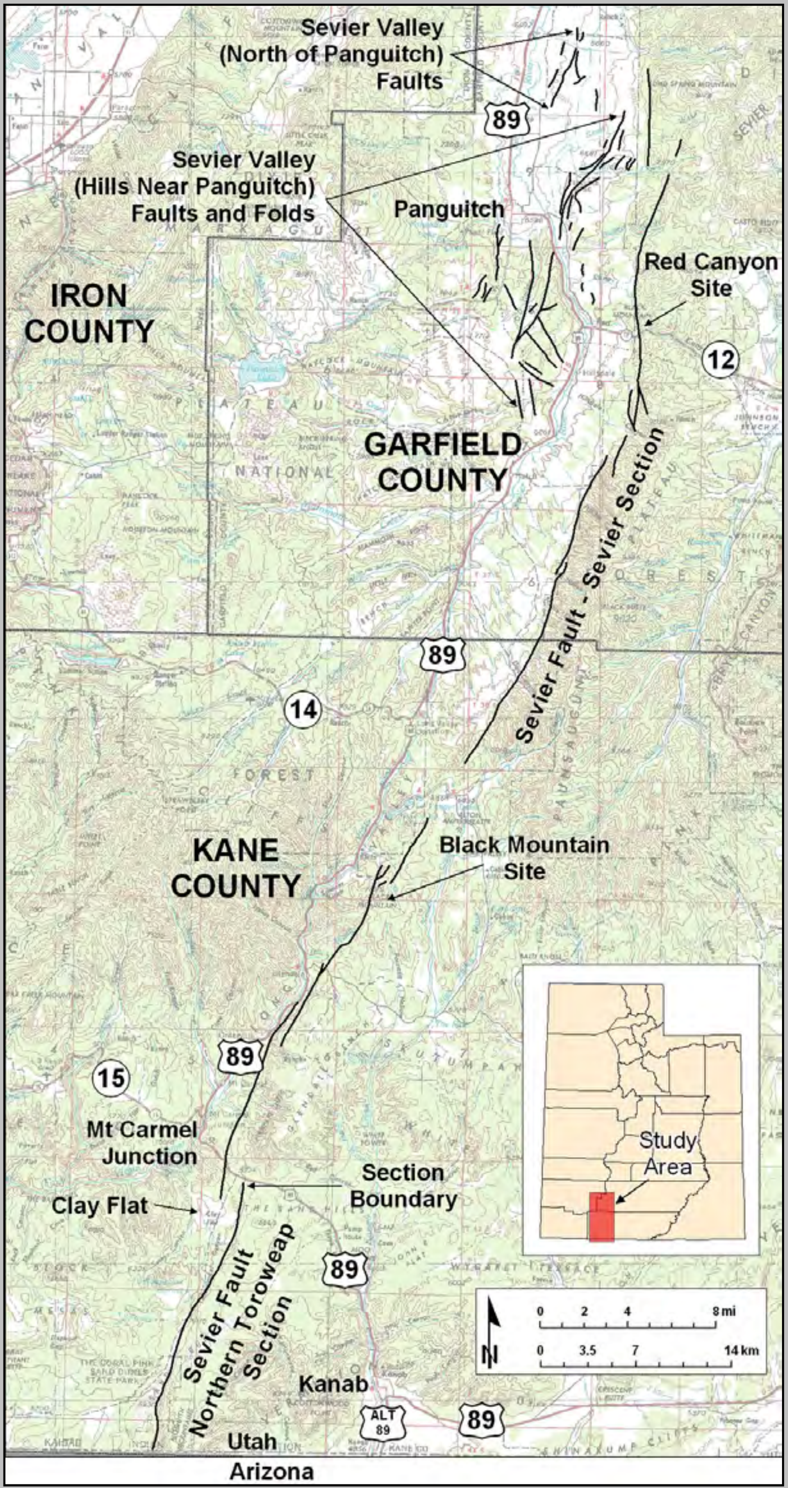
Black Mountain



Cashion (1967)



Schiefelbein (2002)



Hanging-Wall Faults

Scarps on unconsolidated basin-fill deposits in the SF hanging wall include a zone of faults and folds that extends from the hills directly south of Panguitch northeastward across the Sevier River to east of Panguitch, and a short, north-south trending fault zone on the east side of the Sevier River north of Panguitch. The scarps displace deposits ranging in age from late Pleistocene to late Tertiary and vary in height from less than a meter to 25 m high.

Hanging-Wall Faults

The southern group of faults and folds may be related to Holocene (ongoing) aseismic folding in the SF hanging wall. The northern faults are likely seismogenic, but are short (6 km) compared to the height of some scarps (12 m).

Sites suitable for trenching exist on both single- and multiple-event fault scarps in the SF hanging wall. However, in the absence of a viable trench site on the SF for comparison, it is unclear what relation surface faulting on those scarps may have to the main SF several km to the east.

Reconnaissance Results

Earthquake Timing, Recurrence, and Displacement

The absence of scarps on unconsolidated deposits on the SF in Utah precludes trenching to determine paleoseismic data for individual paleoearthquakes. Trenching scarps on unconsolidated Quaternary deposits in the SF hanging wall near Panguitch is possible, but what relation, if any, surface faulting there has to the SF is, and would likely remain, unknown.

Trenching scarps formed on unconsolidated deposits on the NTS in Arizona provides an opportunity to develop paleoseismic data relevant to the NTS in Utah. No scarps are present on the SS; so individual paleoearthquake timing and displacement data will remain unavailable for that fault section.

Reconnaissance Results

Vertical Slip Rate

The possibility of a roughly ten-fold difference in late Quaternary vertical slip rates between Black Mountain (0.04 mm/yr) and Red Canyon (0.36 mm/yr) in volcanic rocks of essentially the same age implies that the rate of seismogenic activity at the two sites may be fundamentally different. Conversely, if the vertical slip rates at Red Canyon and Black Mountain are 0.36 and 0.40 mm/yr, respectively, the difference between them is small and the two locations may have experienced similar surface-faulting histories.

Which scenario is in fact true cannot be determined with presently available data. In the absence of scarps suitable for trenching, resolving an accurate vertical slip rate at Black Mountain using displaced basalt flows is critical to gaining a better understanding of the SF’s behavior in Utah.

Reconnaissance Results

Segmentation

Long normal faults in the BRP typically rupture in shorter segments during surface-faulting earthquakes. Seismogenic segment lengths of 60 to 70 km are not unknown, but are not the norm. For example, the average length of the six Wasatch fault segments with Holocene surface faulting is 48 km.

In contrast, as presently defined the NTS and SS are 80 and 88 km long, respectively. Therefore, it seems unlikely that the NTS and SS represent single seismogenic segments, and is more likely that the SF ruptures in shorter, and presently poorly defined, increments in a manner similar to other long BRP faults.

Reconnaissance Results

Segmentation

In the absence of fault scarps on unconsolidated deposits along the SF in Utah, determining an accurate vertical slip rate at Black Mountain is key to gaining a better understanding of seismogenic segmentation of the SF.

Recommendations for Future Paleoseismic Study

1. Detailed geologic mapping of Black Mountain and vicinity to (1) determine the net vertical displacement of volcanic rocks across the SF, and (2) determine if a seismogenic segment boundary exists close to Black Mountain.

2. If net vertical displacement between Black Mountain and Red Canyon proves significantly different and no segment boundary is identified near Black Mountain, then map the SF in detail between Black Mountain and Red Canyon to determine if a possible segment boundary exists between those two locations.

3. Trench an alluvial scarp on the NTS in Arizona to collect surface-faulting information that can be applied to the SF in Utah.

Recommendations for Future Paleoseismic Study

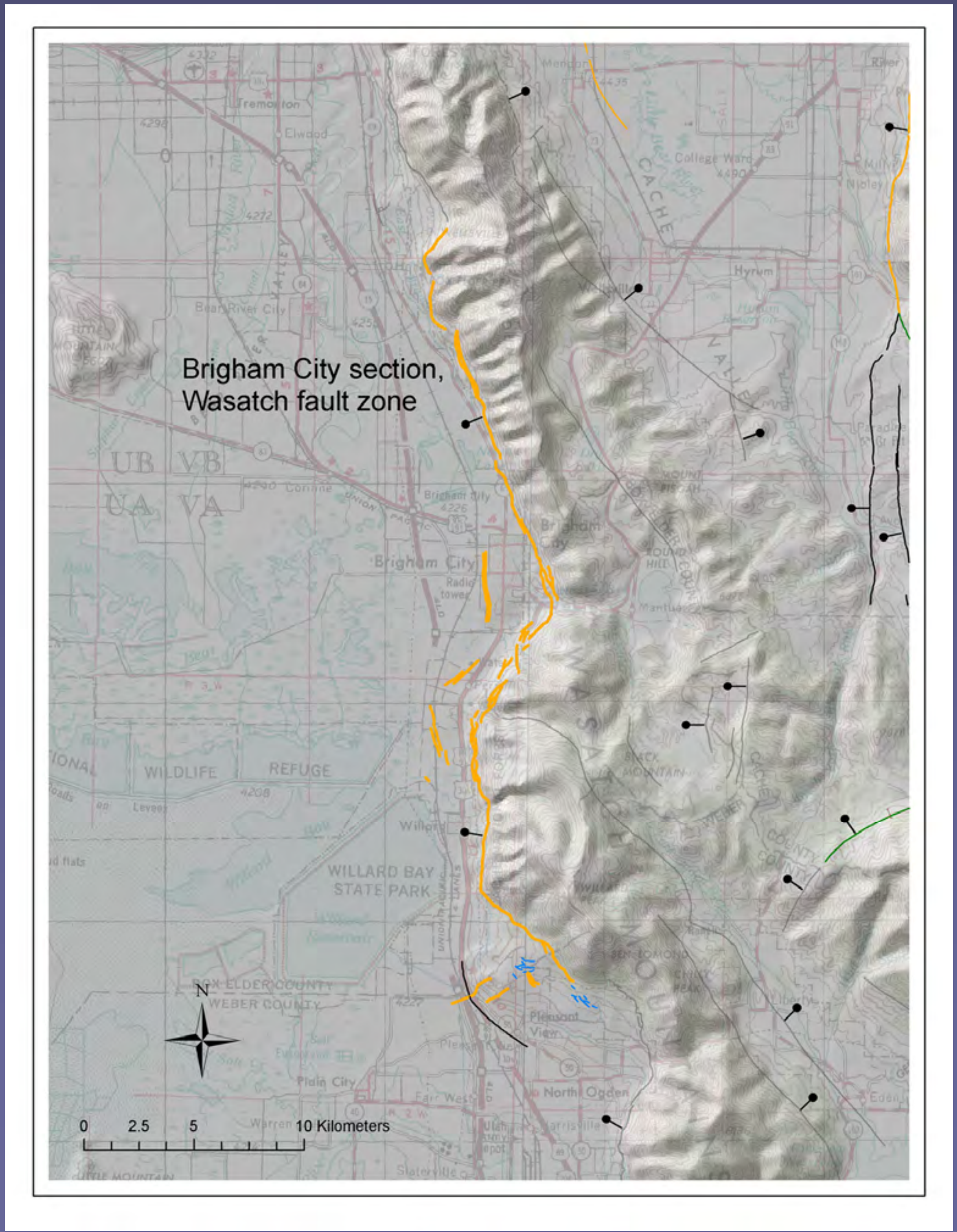
4. Trench a minimum of one probable single-event and one multiple-event scarp in the fault and fold belt near Panguitch to determine if those scarps are the result of surface faulting or aseismic folding.
5. Trench a single-event and a multiple-event scarp in the short fault zone north of Panquitch to better constrain the timing and magnitude of paleoearthquakes on those faults.

2004 Utah Quaternary Fault and Fold Database Update

DuRoss and Hylland

Database update:

1. Results of new fault studies
   (completed prior to 12/31/04)
2. UQFPWG consensus values
3. Informal review of slip-rate estimates



1. New fault studies

- Most recent updates (Black and others, 2003):
  - Wasatch fault zone 2001
  - Hurricane fault zone 2001
  - Great Salt Lake fault zone 2000
  - West Cache fault zone 2000
  - East Cache fault zone 1999
  - Joes Valley fault zone 1999
  - Majority of “other” faults 1999

1. New fault studies

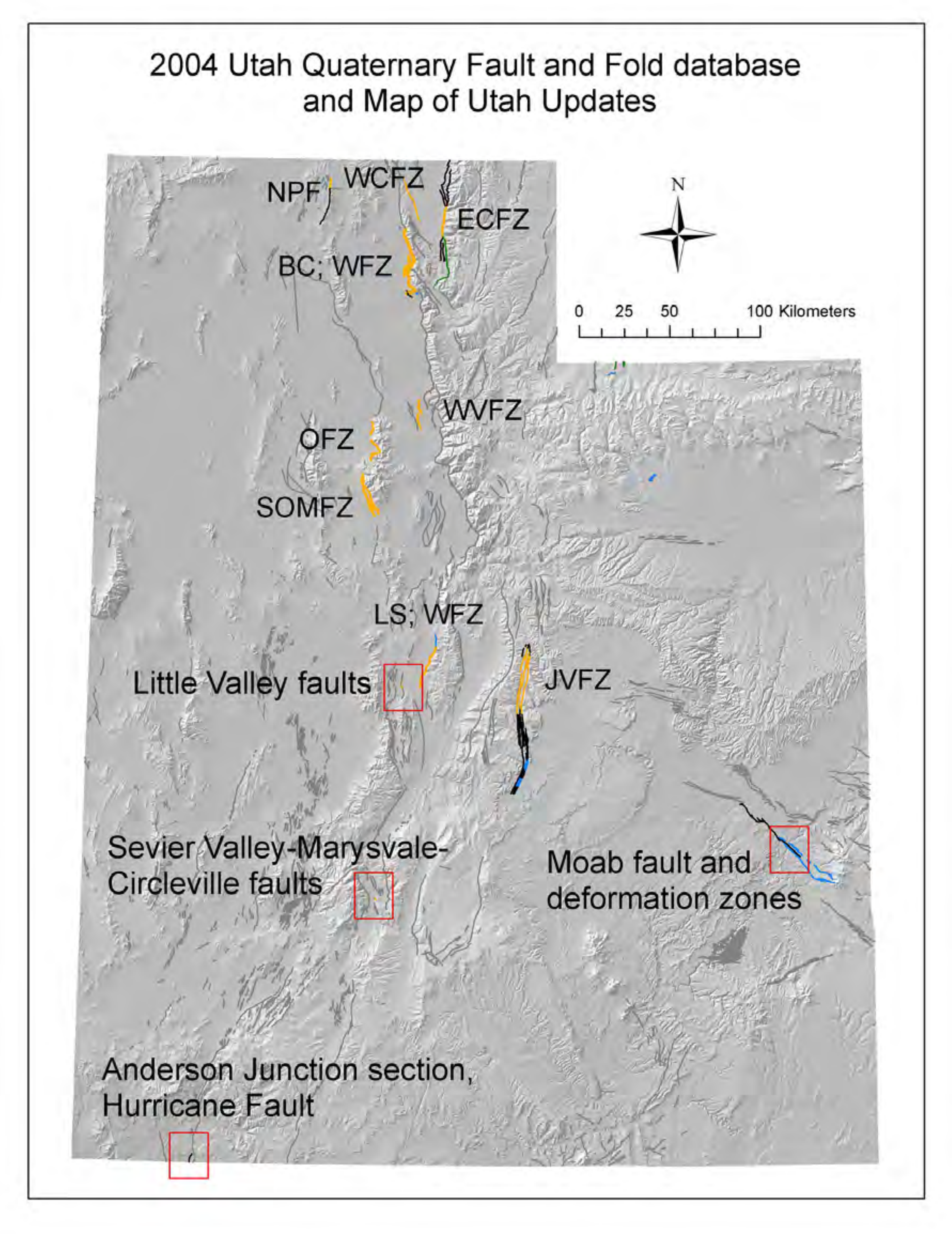
- Updated 33 database entries
  - Hintze and Davis; Millard Co. geologic mapping
  - Biek, Hayden, Stenner; WFZ, HFZ geologic mapping
  - Hylland & Machette, McCalpin; WFZ
  - Dinter & Pechmann; GSLFZ
  - Olig and others; Oquirrh fault zone
  - Also, Moab, Bear Lake (E and W), Duchesne-Pleasant Valley, and Needles faults

1. New fault studies

- Renamed 3 database entries
  - Moab fault and deformation zones
    (previously Moab fault and Spanish Valley faults)
  - Great Salt Lake fault zone
    (previously East GSLFZ)
  - East Cache fault zone sections: Richmond, Logan, Paradise
    (previously northern, central, and southern sections)

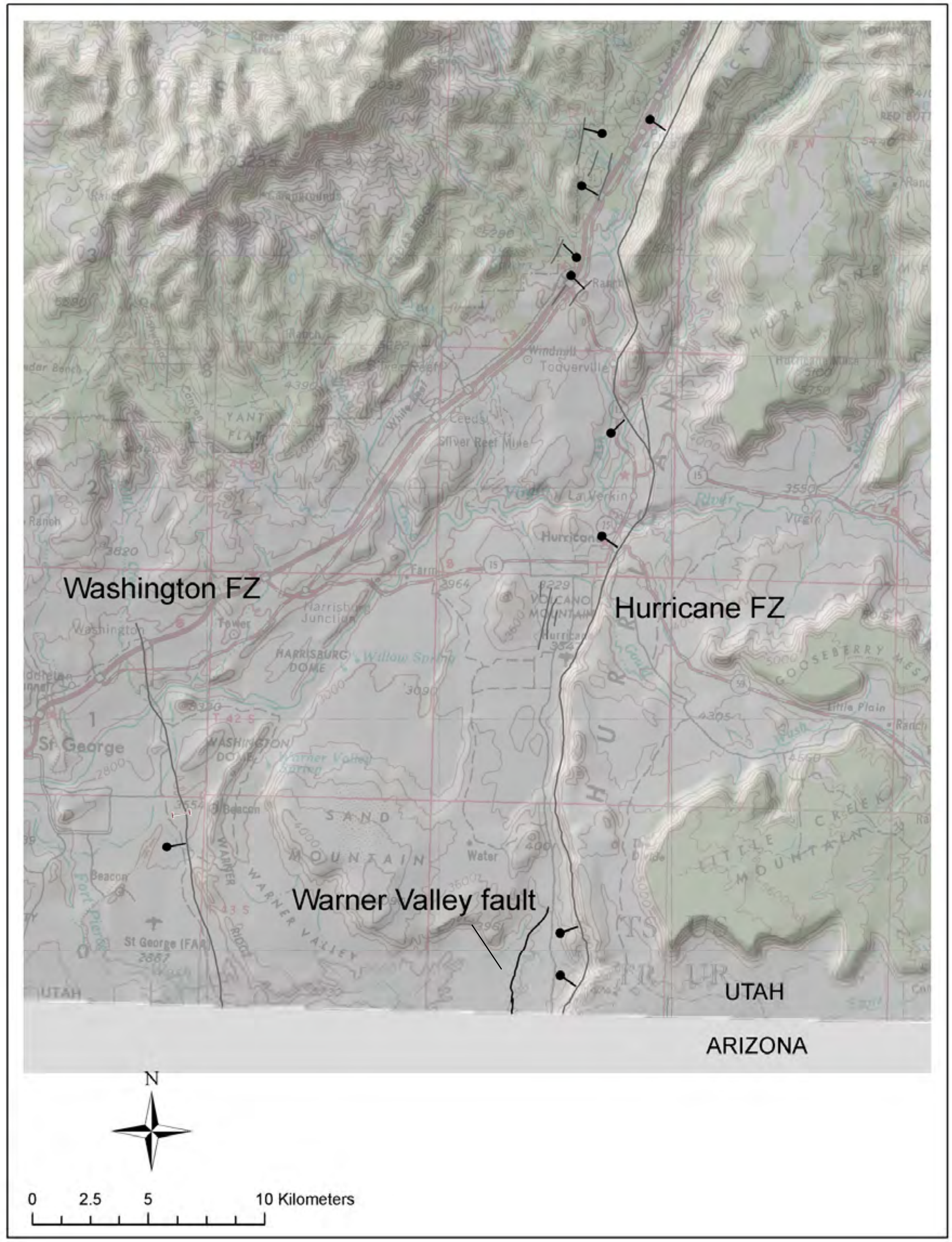
1. New fault studies

- Added 4 fault new fault traces
  - Little Valley
  - Sevier Valley-Marysvale-Circleville (SVMC) area
  - Hurricane fault
  - Moab fault



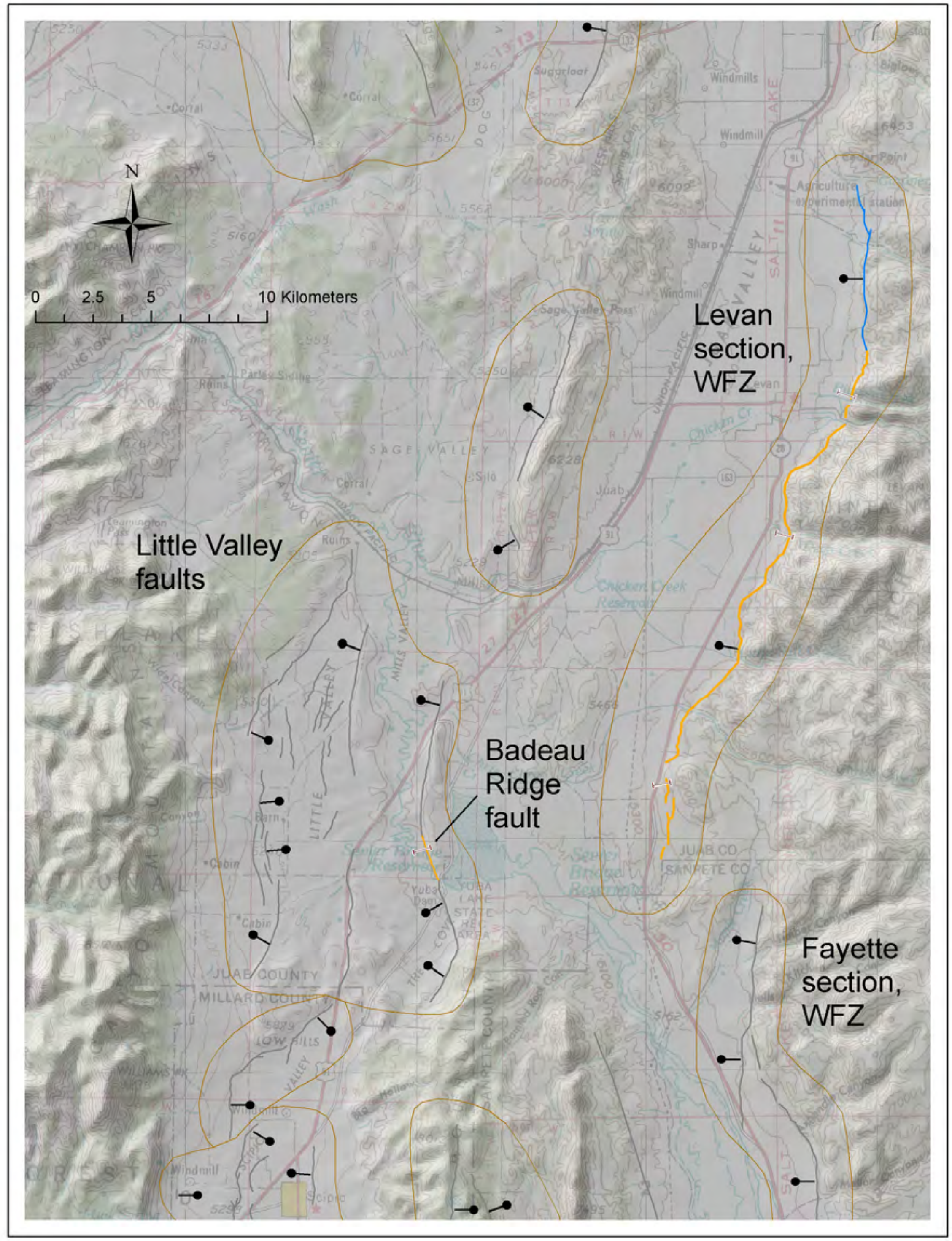
1. New fault studies

- Warner Valley fault
  - Anderson Junction section, HFZ (Hayden, 2004)
  - 5 km, down-to-W
  - MRE: Quaternary
  - SR: unknown



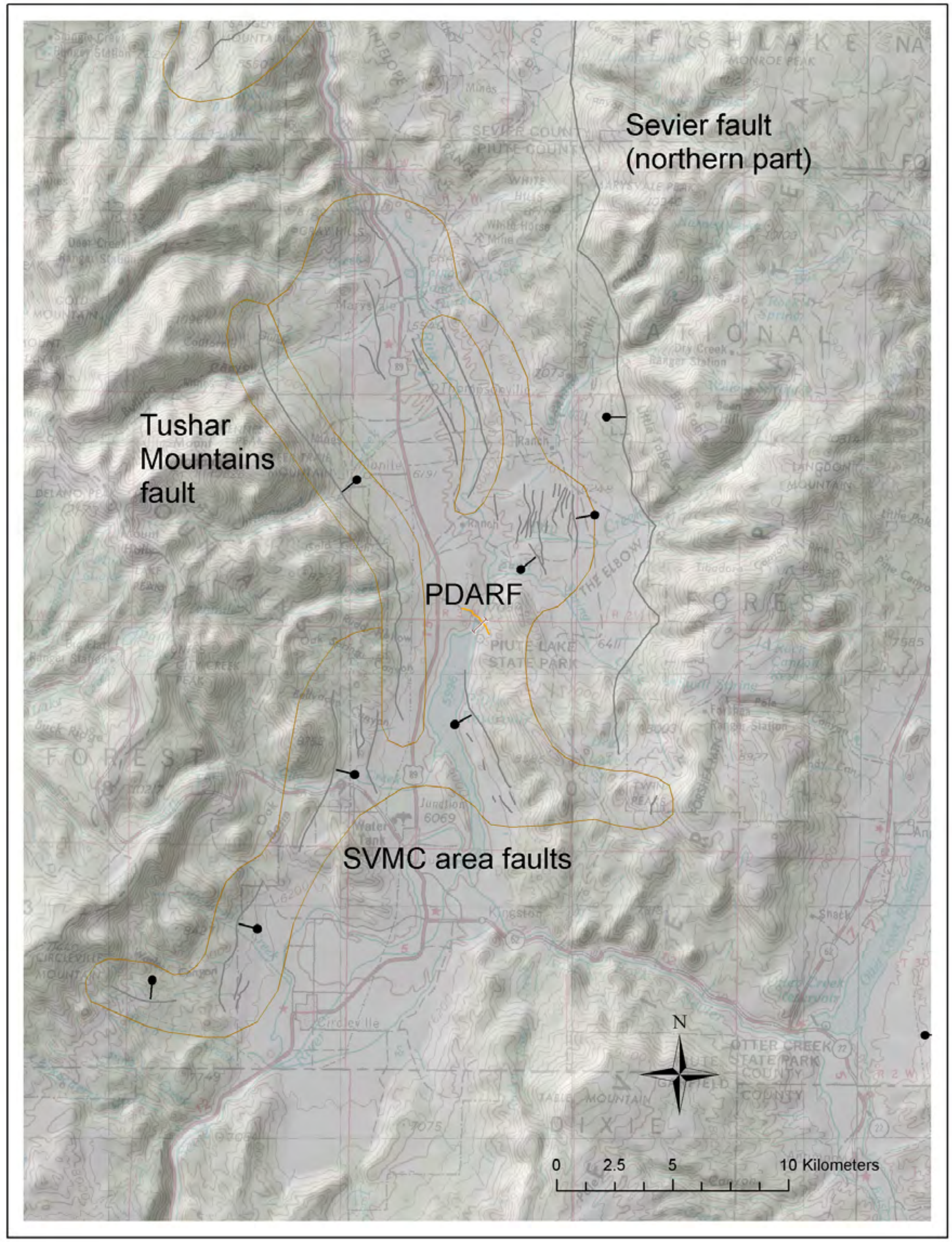
1. New fault studies

- Badeau Ridge fault
  - LVF (Gerhart Consultants, Inc., 2003)
  - 2 km, down-to-W
  - MRE: Holocene
  - SR: unknown



1. New fault studies

- PDARF
  - SVMC area faults (Simon-Bymaster, Inc., 2001)
  - 1.7 km, down-to-NE
  - MRE: Holocene
  - SR: unknown

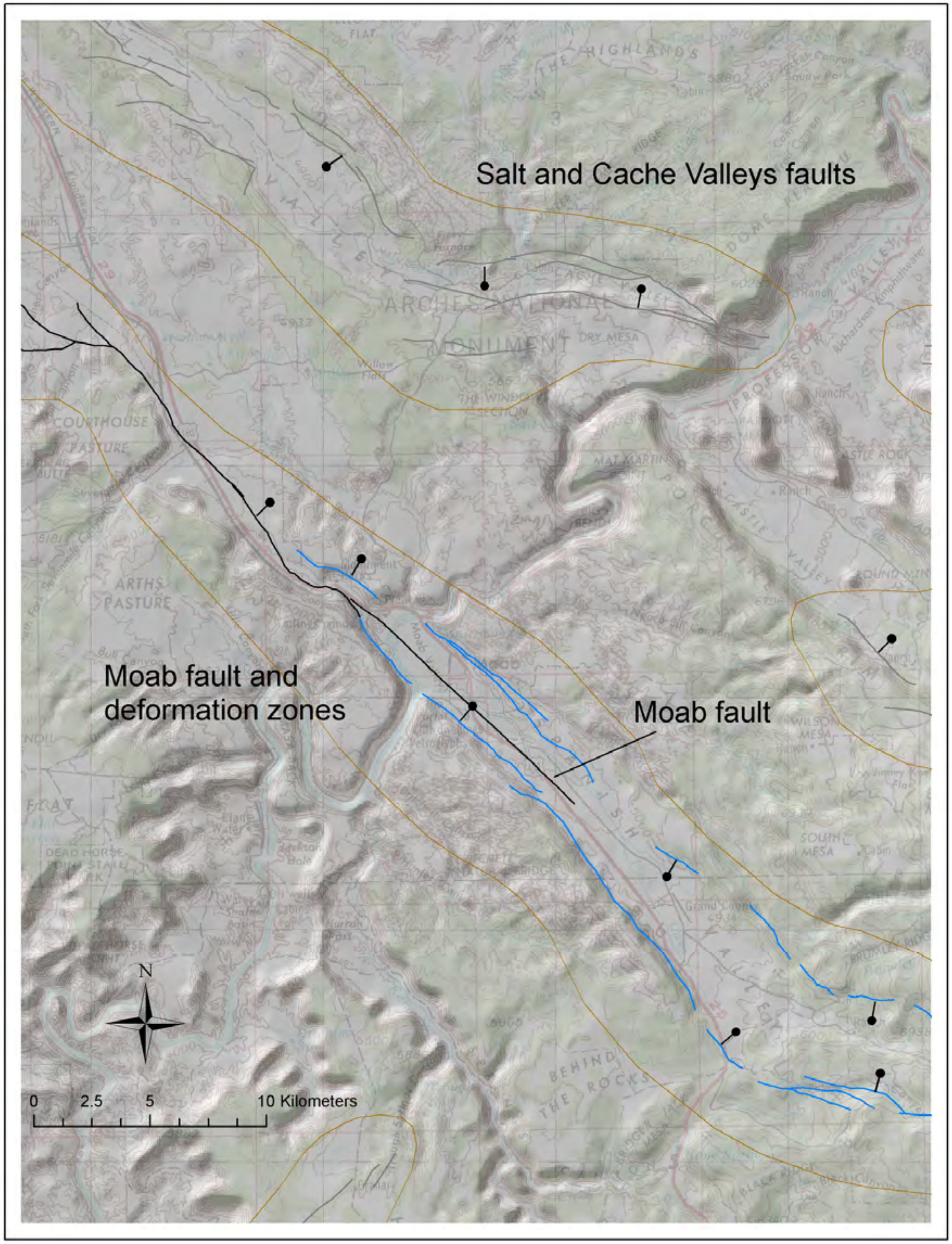


1. New fault studies

Moab fault and deformation zones

- New trace
  - (Doelling and others, 2004)
  - 13 km
  - MRE: Quaternary
  - SR: unknown

- Updated MRE timing
  - MRE: Middle and late Quaternary



2. UQFPWG

- 22 database updates (30 fault/fault-section updates)
  - WG's consensus values; format identical to Lund (2004)
  - Explanation of what values represent
  - Example: Anderson Junction section, Hurricane FZ:

    Lund (2004) reports the following earthquake chronology, based on two paleoseismic trench investigations…

Z	5-10 ka
Y	>5-10 ka, and <25-50 ka
X	>25-50 ka?

2. UQFPWG

- 10 map updates
  - Line weight change based on SR
- 2 reclassifications
  - James Peak fault:
    "James Peak" section, ECFZ
  - Reclassified 4 Joes Valley fault zone entries:
    Suspected Joes Valley fault zone
- Miscellaneous
  - Trench renumbering

3. Slip-Rate Review

- Added slip-rate qualifiers

- “Paleoseismic” SR
  - SR calculated using closed seismic cycles

  - Example:

    MRE displacement / elapsed time between MRE and previous event

3. Slip-Rate Review

- "Geologic" SR
  - SR calculated using open-ended time intervals
  - Example:

    SR based on displaced geomorphic feature or geologic deposit (e.g., Bonneville shoreline)

3. Slip-Rate Review

- 49 slip-rate updates
  - 36 geologic slip rates noted
  - 13 paleoseismic slip rates noted
  - Identified 21 faults/fault sections where additional fieldwork may help to resolve SR
  - Examples: Sevier/Toroweap FZ, Paragonah F, Scipio Valley F, Gunnison F

Summary of Updates

- 95 fault or fault sections updated
- Fewer faults/fault sections in Utah!
  - 209 (2004) versus 212 (2003)

Table 1. Summary of 2004 Quaternary Fault and Fold Database and Map of Utah Updates

Fault No.	Fault Name	2004 Update[1]	Comments[2]	References
730	Bear River fault zone[3]	RI: 1-100 ky Noted paleoseismic, geologic slip rates	-	Lund (2004)
732b	Unnamed (south) section, Hogsback fault[3,4]	SR: unknown, probably <0.2 mm/yr	-	Lund (2004)
997a	Sevier section, Sevier/Toroweap fault zone	Noted geologic slip rate.	-	-
997b	Northern Toroweap section, Sevier/Toroweap fault zone	Noted geologic slip rate.	-	-
998a	Cedar City section, Hurricane fault zone	Noted geologic slip rate.	-	-
998b	Ash Creek section, Hurricane fault zone	Noted geologic slip rate.	-	-
998c	Anderson Junction section, Hurricane fault zone[3,4]	Referenced and incorporated data (e.g., fault dip) from recently published quadrangles. Added trace of Warner Valley fault to map (Hayden, 2004). RI: 5-50 ky SR: unknown, probably <0.2 mm/yr MRE: 5 Noted geologic slip rate.	-	Stenner and others (2003), Hayden (2004), Lund (2004)

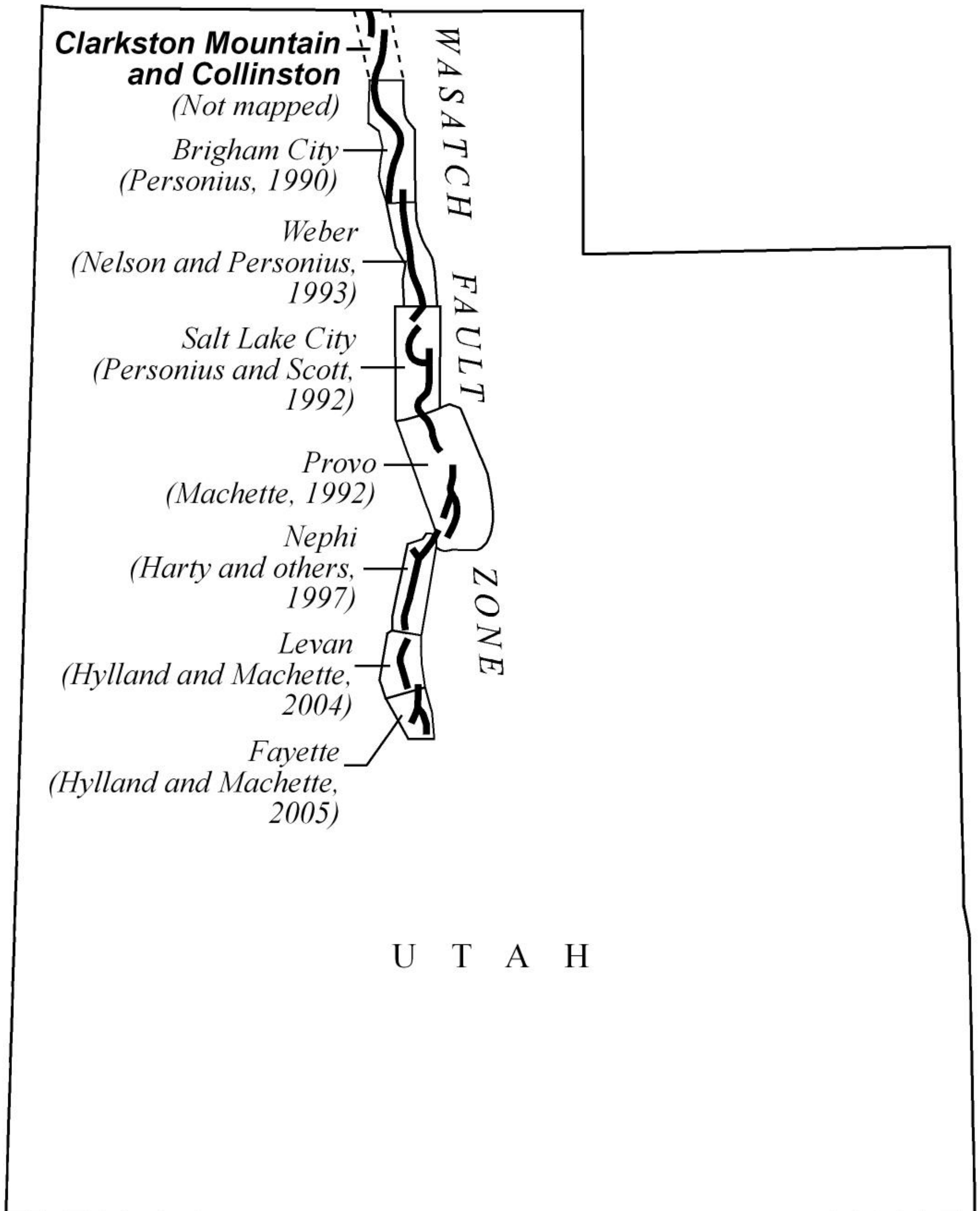
2004 Utah Quaternary Fault and Fold Database Update

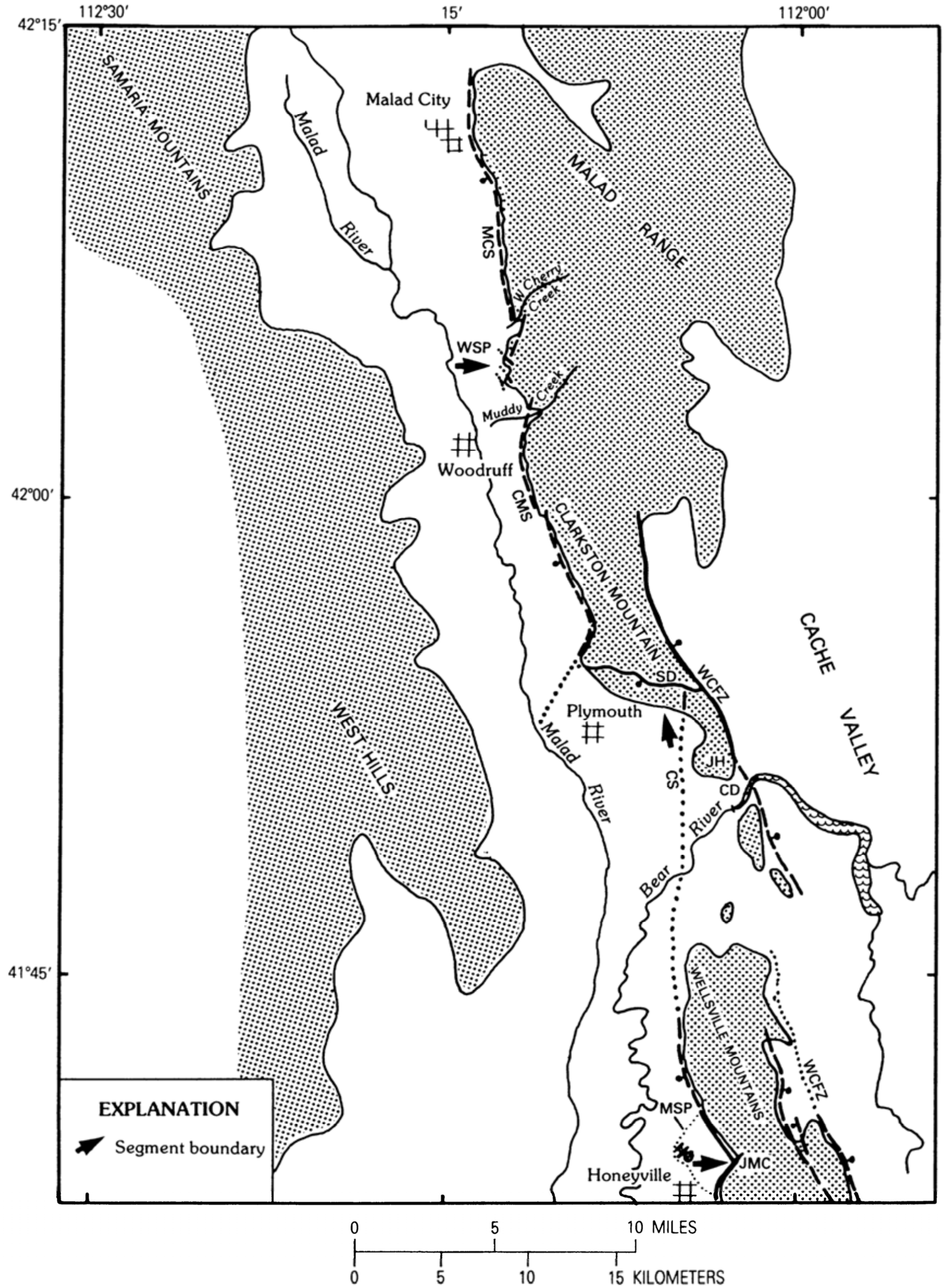
Future work

- USGS: update Utah part of QFFDB Web site
- UGS: update UQFFDB Web site
- Database review (work in progress):
  - Estimate Activity classes (AC); AC map
  - Identify faults where additional (non-trenching) studies could resolve unknown AC
- Update database as necessary

Current and Suggested Future Paleoseismic Studies on the North and South Ends of the Wasatch Fault Zone in Utah

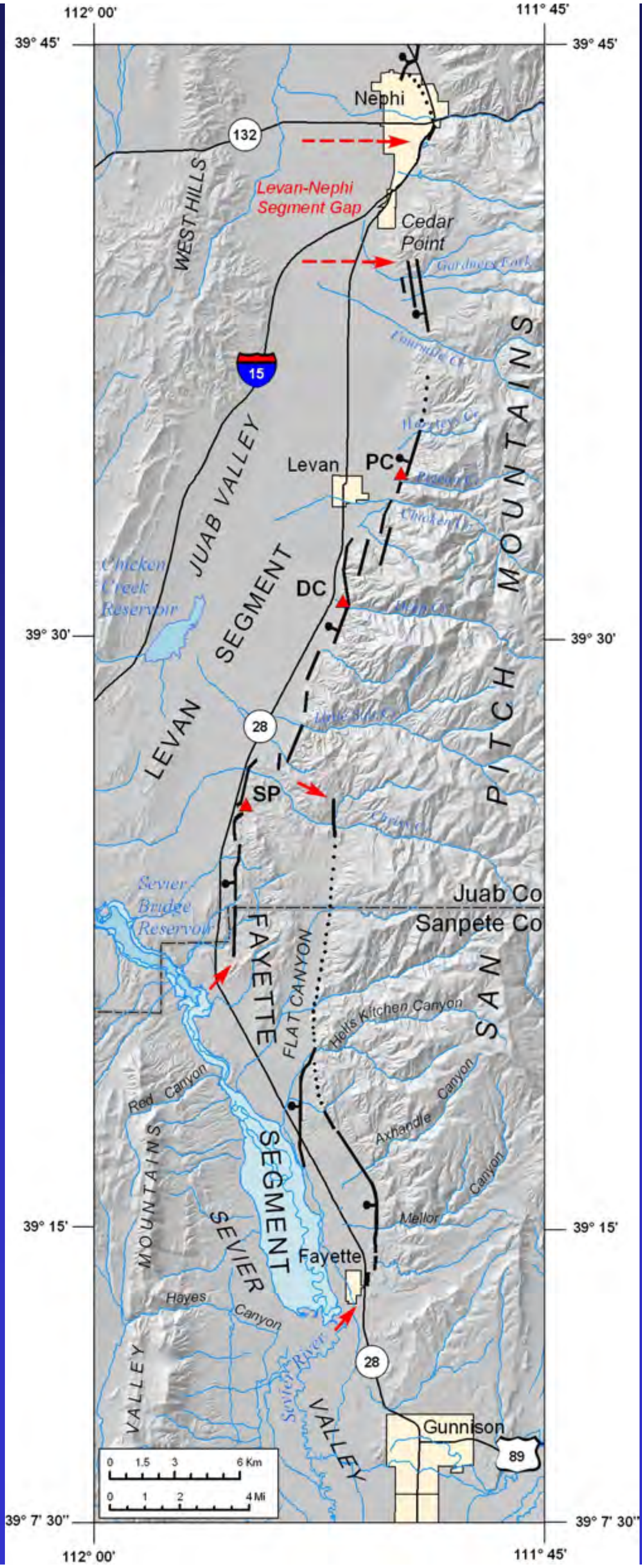
- Paleoseismic reconnaissance of the Collinston and Clarkston Mountain segments (funded for 2005)
- Paleoseismic trenching on the Levan and Fayette segments (suggested future work)


Clarkston Mountain
and Collinston
(Not mapped)
Brigham City
(Personius, 1990)
Weber
(Nelson and Personius, 1993)
Salt Lake City
(Personius and Scott, 1992)
Provo
(Machette, 1992)
Nephi
(Harty and others, 1997)
Levan
(Hylland and Machette, 2004)
Fayette
(Hylland and Machette, 2005)
WASATCH FAULT ZONE
UTAH



Collinston and Clarkston Mtn. segments

- Large-scale mapping of selected areas
- Scarps: fault vs. shoreline vs. landslide
- Geometry of segment boundary



Levan & Fayette segments

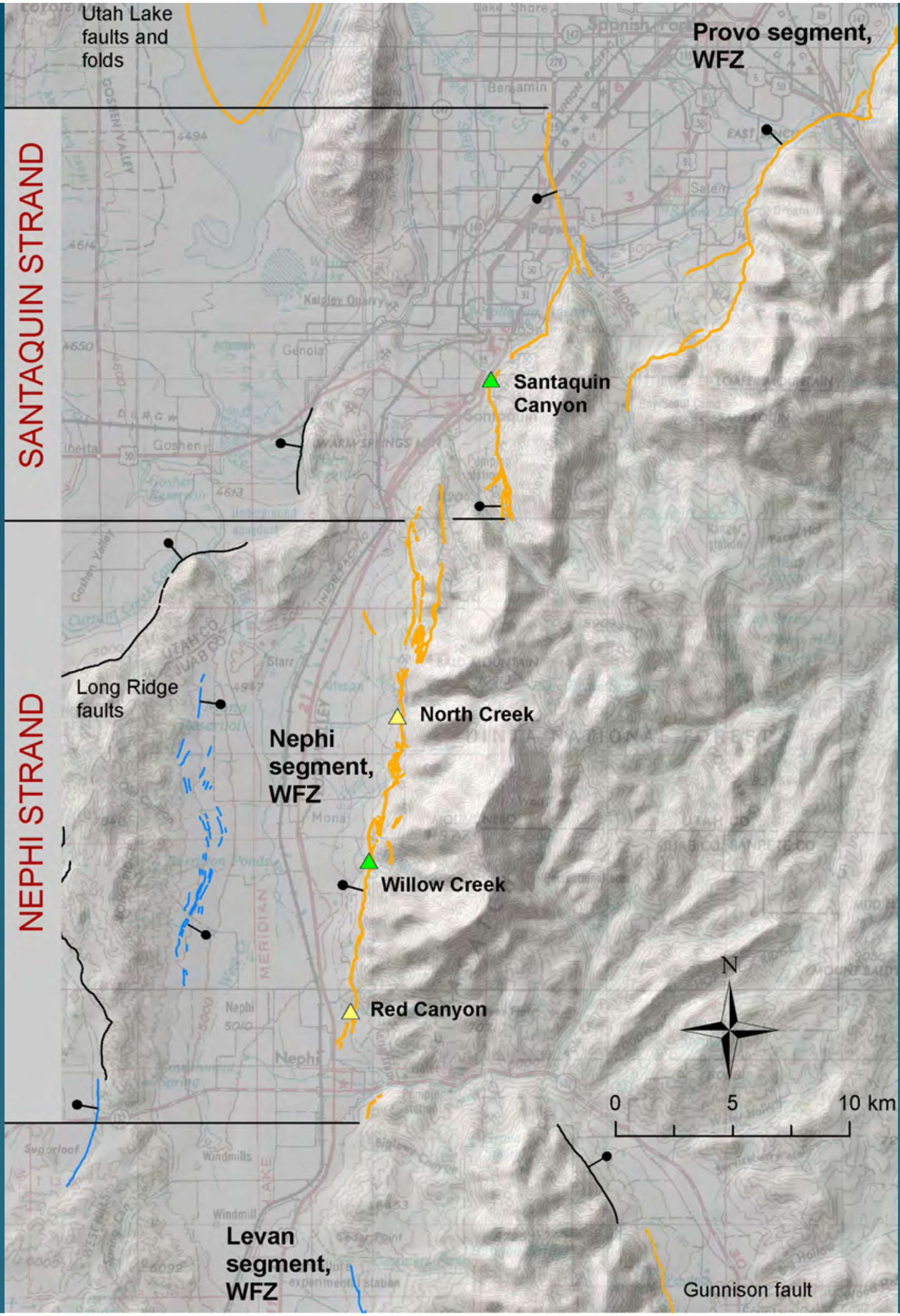
- What is timing of Levan PE?
- Is timing of Levan PE the same at N and S ends?
- What is timing of Fayette MRE and PE?
- Are Fayette E- and W-strand chronologies the same?
- How do Levan and Fayette chronologies compare?

If either the Levan or Fayette segment ruptured, would anyone notice?

- Trench sites unrestricted by development
- Single- and multiple-event scarps
- Generally simple fault zone (single trace)
- Wide temporal spacing of events

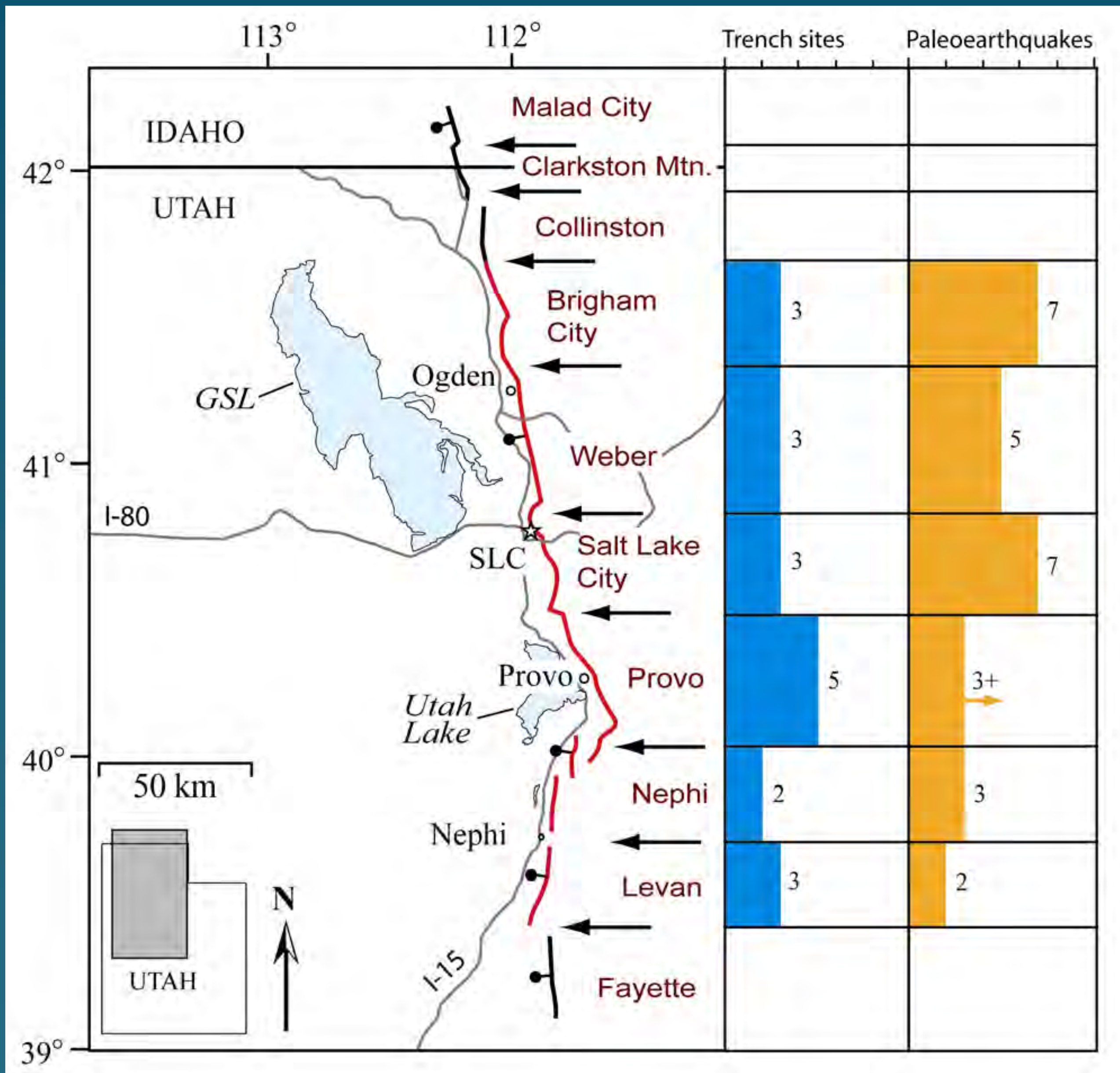
2005 NEHRP Trenching along the Nephi Segment

- 2 new trench sites:
  - Santaquin Canyon (UGS)
  - Willow Creek (USGS)
- May 2005
- GSA field trip: October 15, 2005



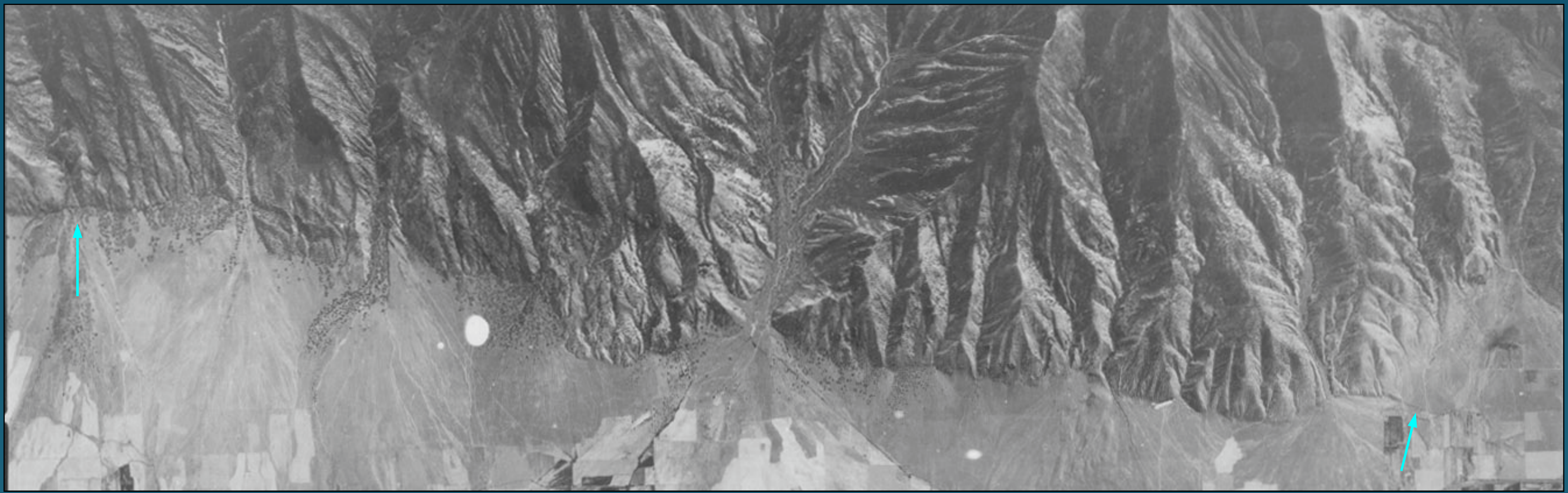
Why trench the Nephi segment?

1. Poorly constrained earthquake timing



Why trench the Nephi segment?

1. Poorly constrained earthquake timing



North Creek:

Z: >400, <1000-1300 cal yr B.P.

Y: >1300-1600, >3900-4300 cal yr B.P.

X: <5200 cal yr B.P.

(Hanson and others, 1981)

Red Canyon:

Z: <1300-1500 cal yr B.P.

Y: <4000-7000 cal yr B.P.

X: <3800 cal yr B.P.

(Jackson, 1991)

Why trench the Nephi segment?

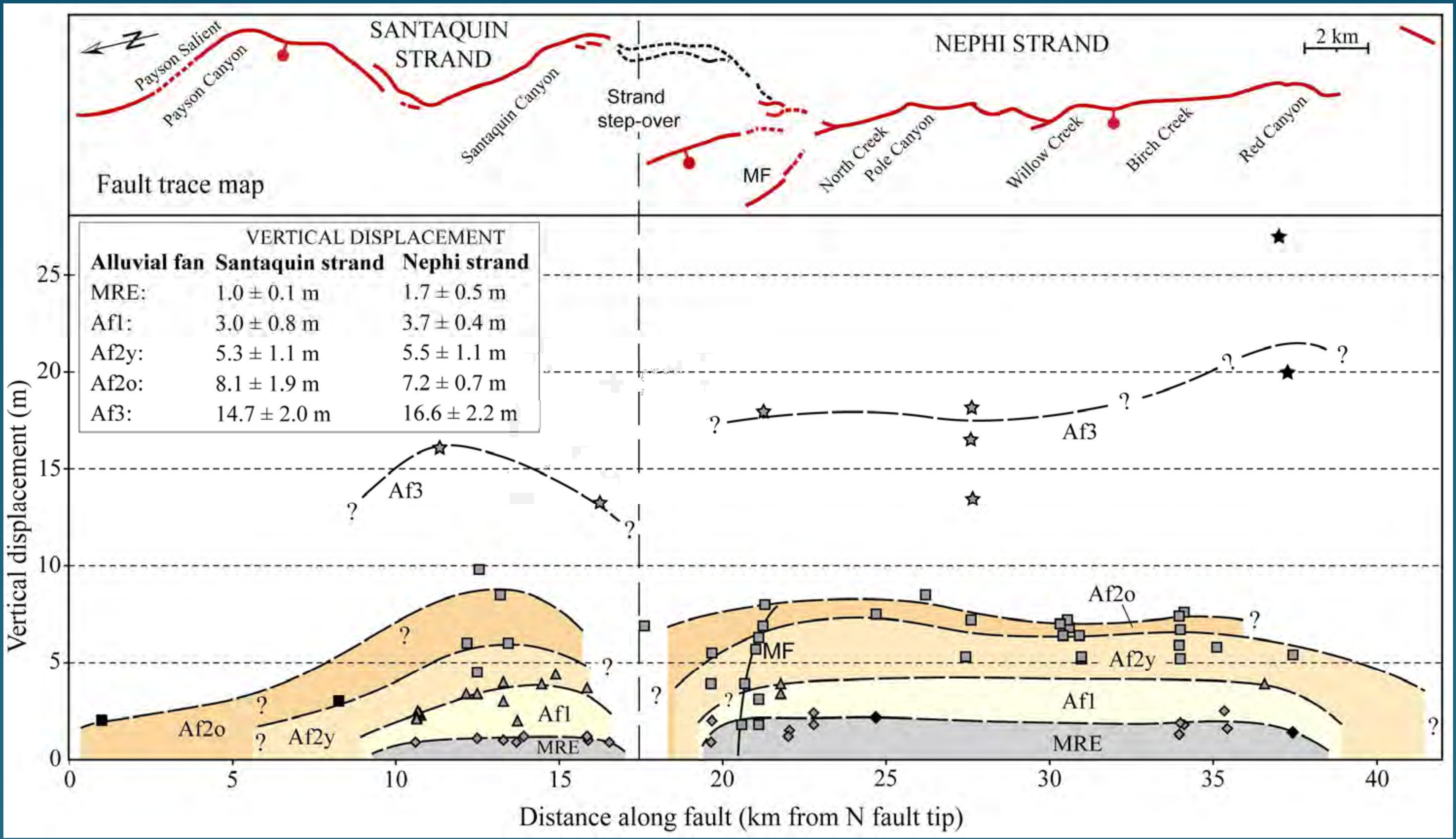
1. Poorly constrained earthquake timing

Event	Timing
Z:	<1.0 ± 0.4 ka, possibly as young as 0.4 ± 0.1 ka
Y:	~3.9 ± 0.5 ka
X:	>3.9 ± 0.5 ka, < 5.3 ± 0.7 ka

(Lund, 2004)

Why trench the Nephi segment?

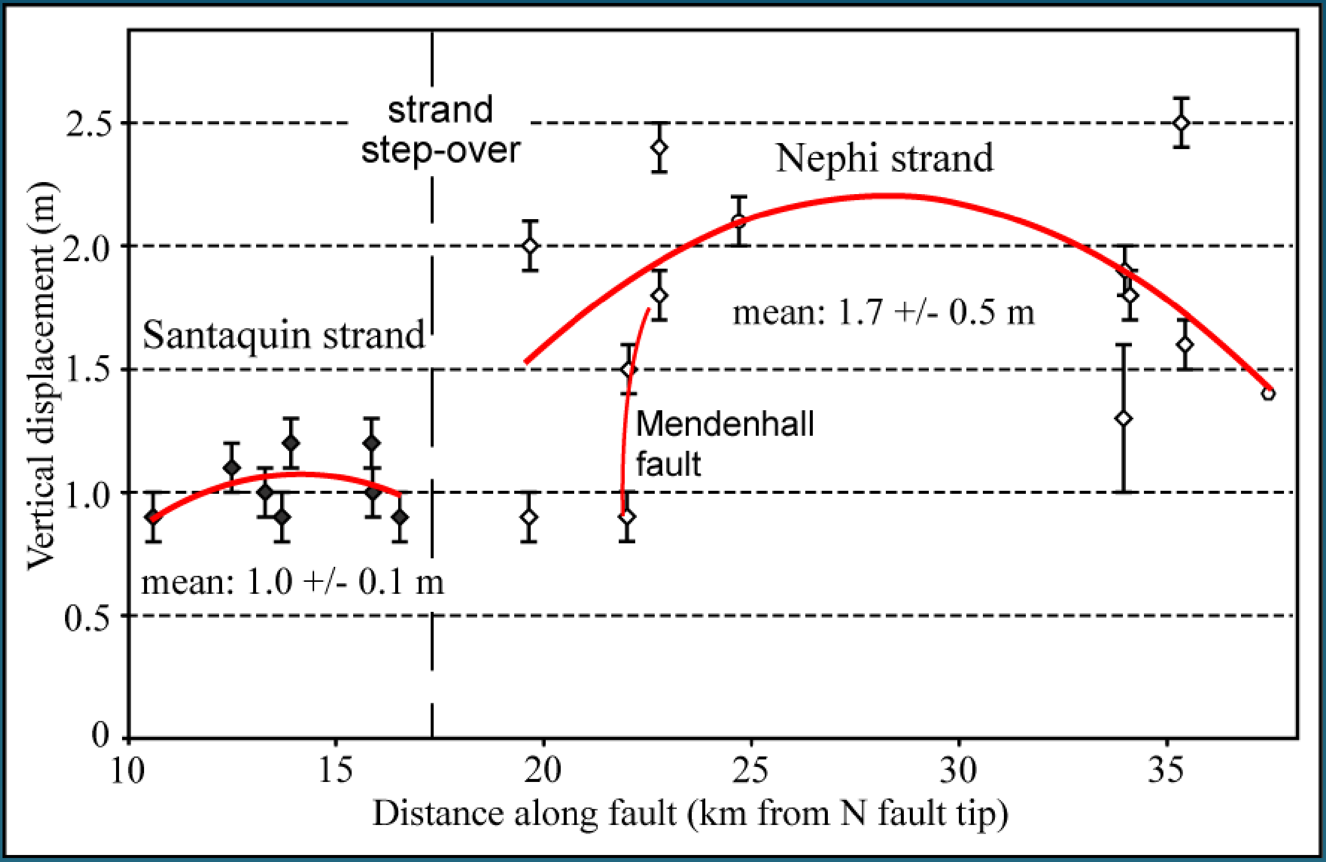
2. Multiple Holocene surface ruptures



Why trench the Nephi segment?

3. Scarp morphology

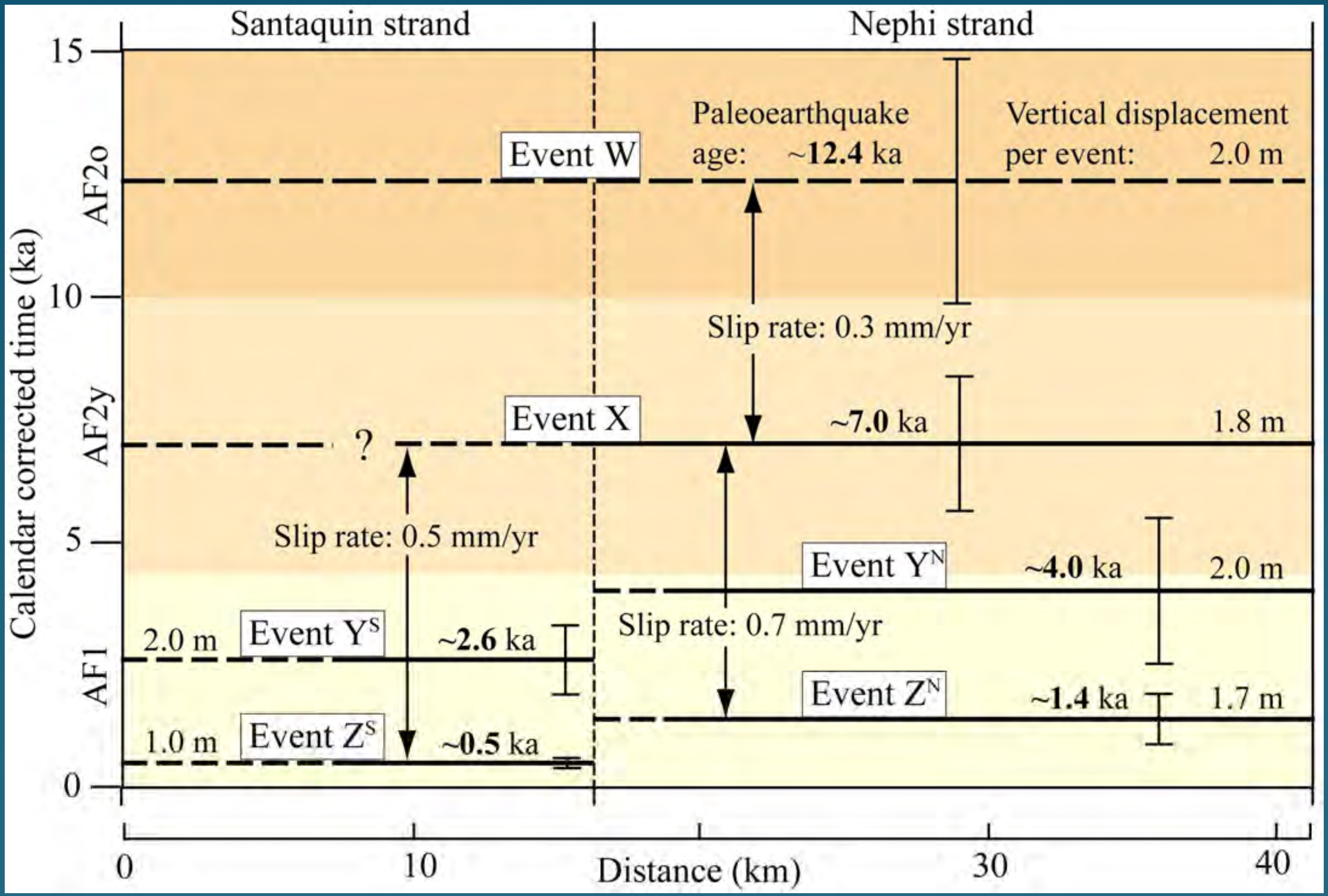
- Along-strike change in MRE displacement



Why trench the Nephi segment?

3. Scarp morphology

- Separate rupturing of fault strands?
- Short-term vs. long-term slip rate

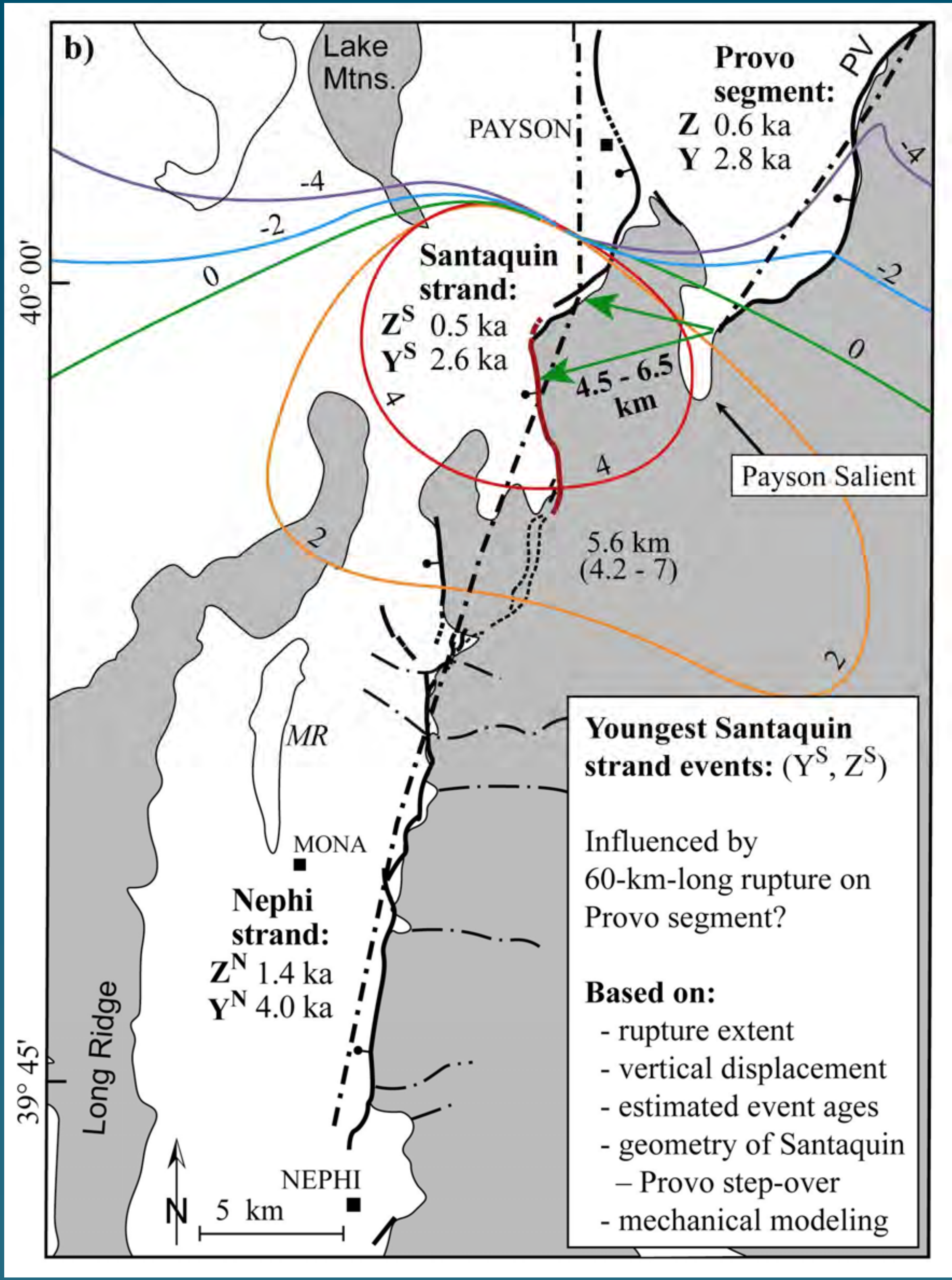


Why trench the Nephi segment?

4. Non-characteristic behavior?

- Provo segment earthquakes influence Santaquin strand?
  - Need paleoseismic data from Nephi and Santaquin strands

Contours: Coulomb failure stress change (bars) at 10 km (Chang, 1998; Chang and Smith, 2002)



Why trench the Nephi segment?

"Other" reasons:

5. WFZ segmentation, MSR model development

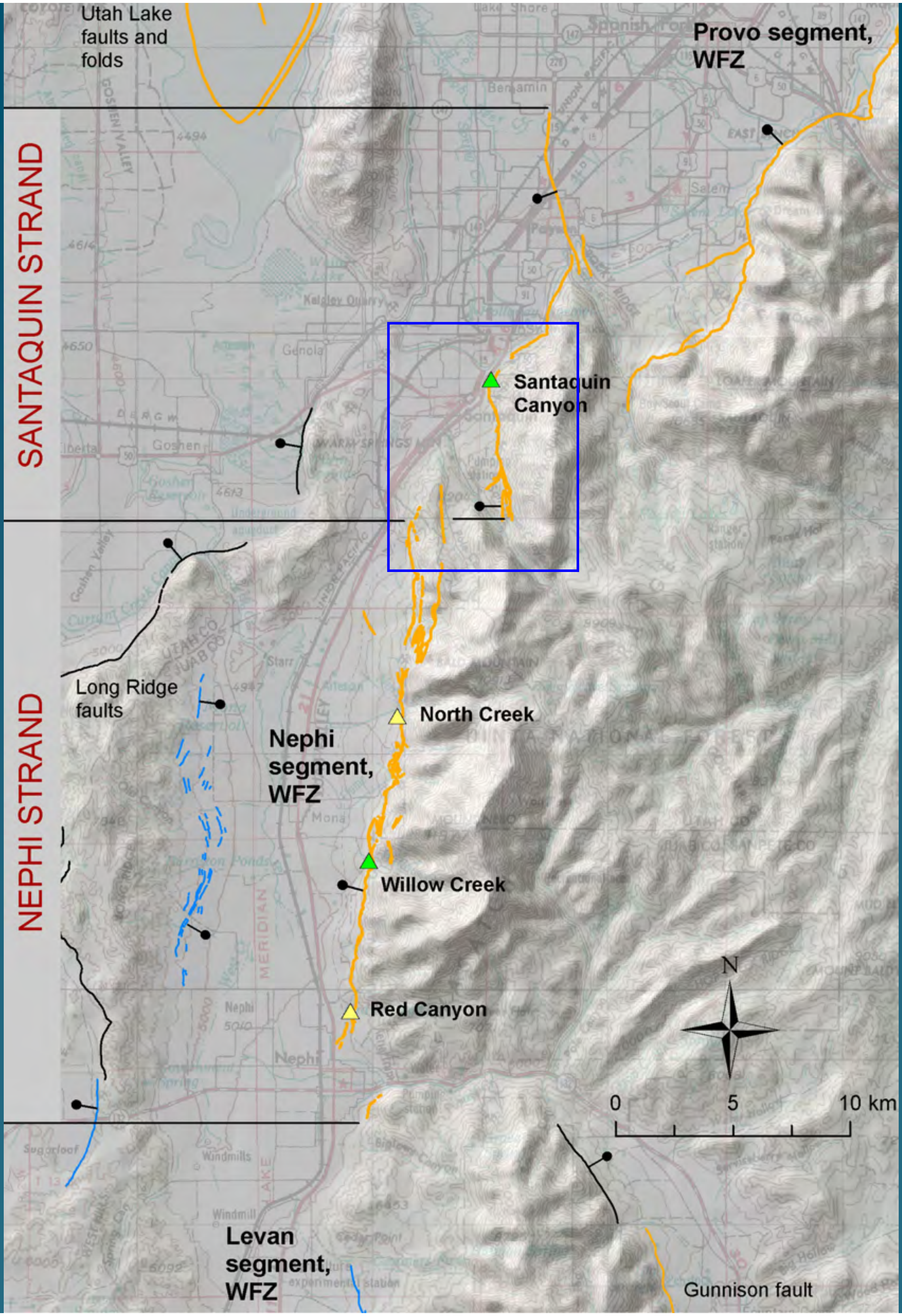
6. Rapid urban/suburban development

7. Fault-rupture and earthquake parameters along the southern WFZ

Nephi segment trenching

Santaquin Canyon site

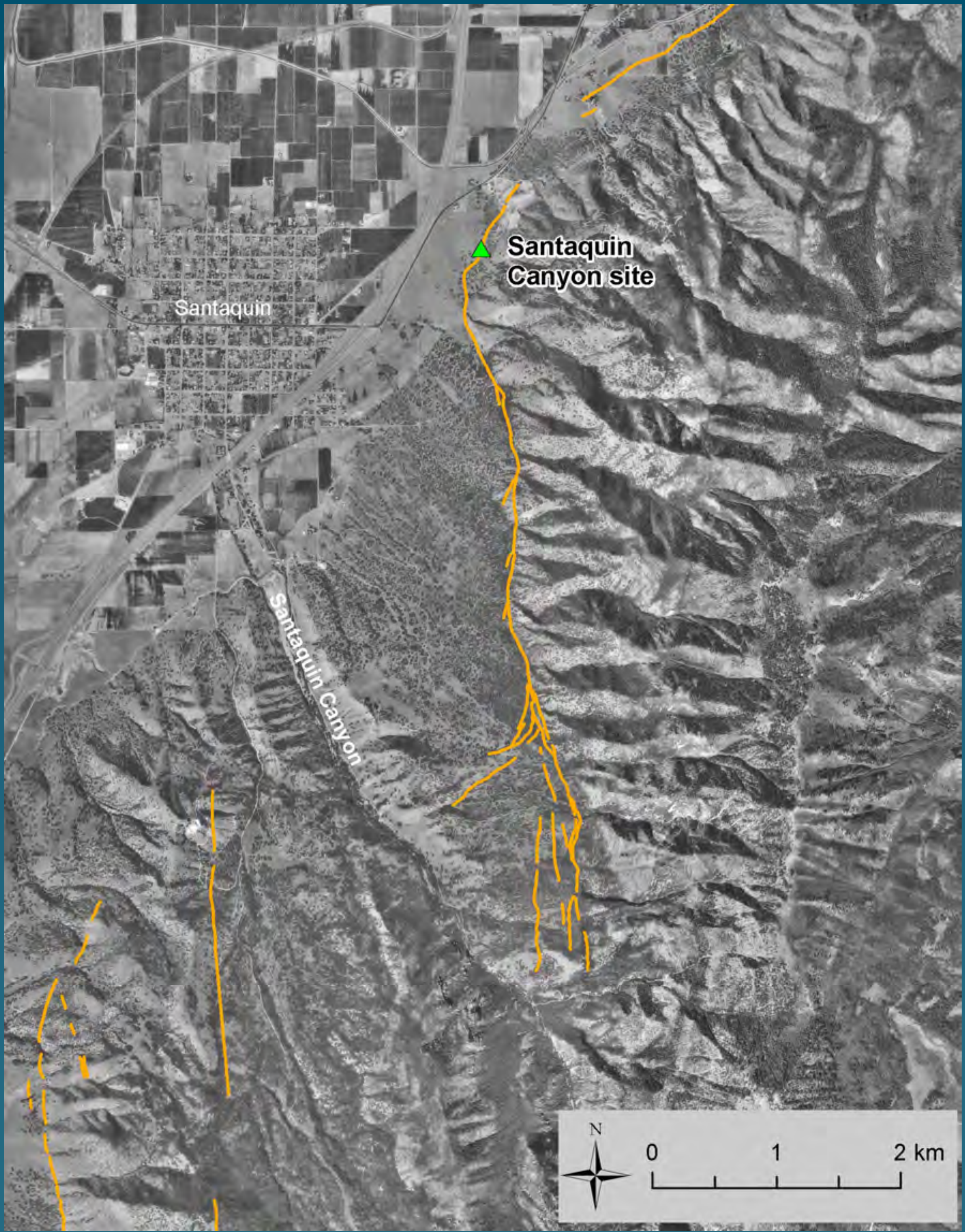
- 2-3 trenches
- 2 most-recent events
- Late Holocene alluvial fan



Nephi segment trenching

Why trench at Santaquin?

- Santaquin strand:
  - Unknown rupture history
  - Leaky PV-NP segment boundary?
- Investigate timing of MREs; compare with:
  - Provo segment
  - Nephi strand

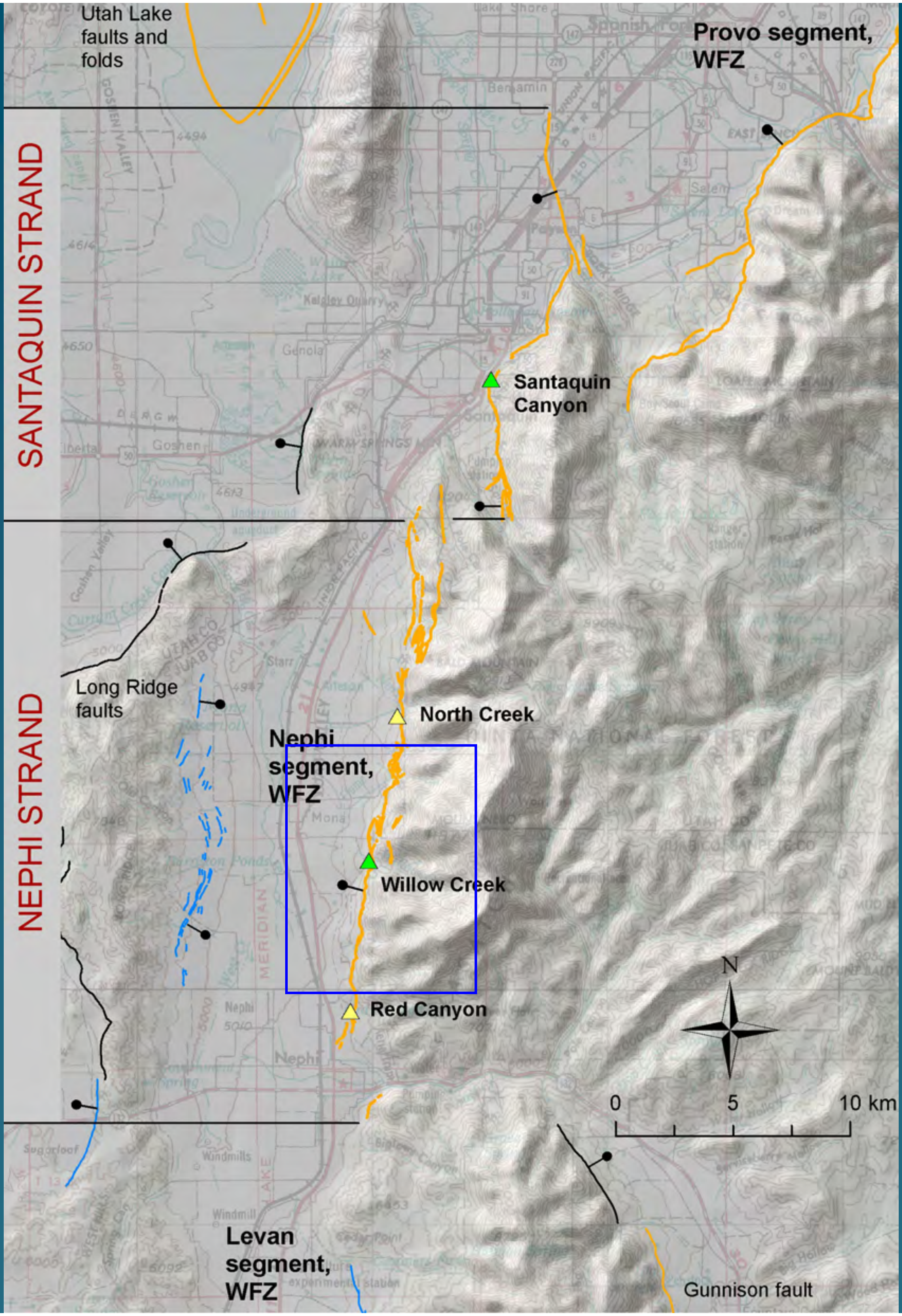


Santaquin Canyon site

Nephi segment trenching

Willow Creek site

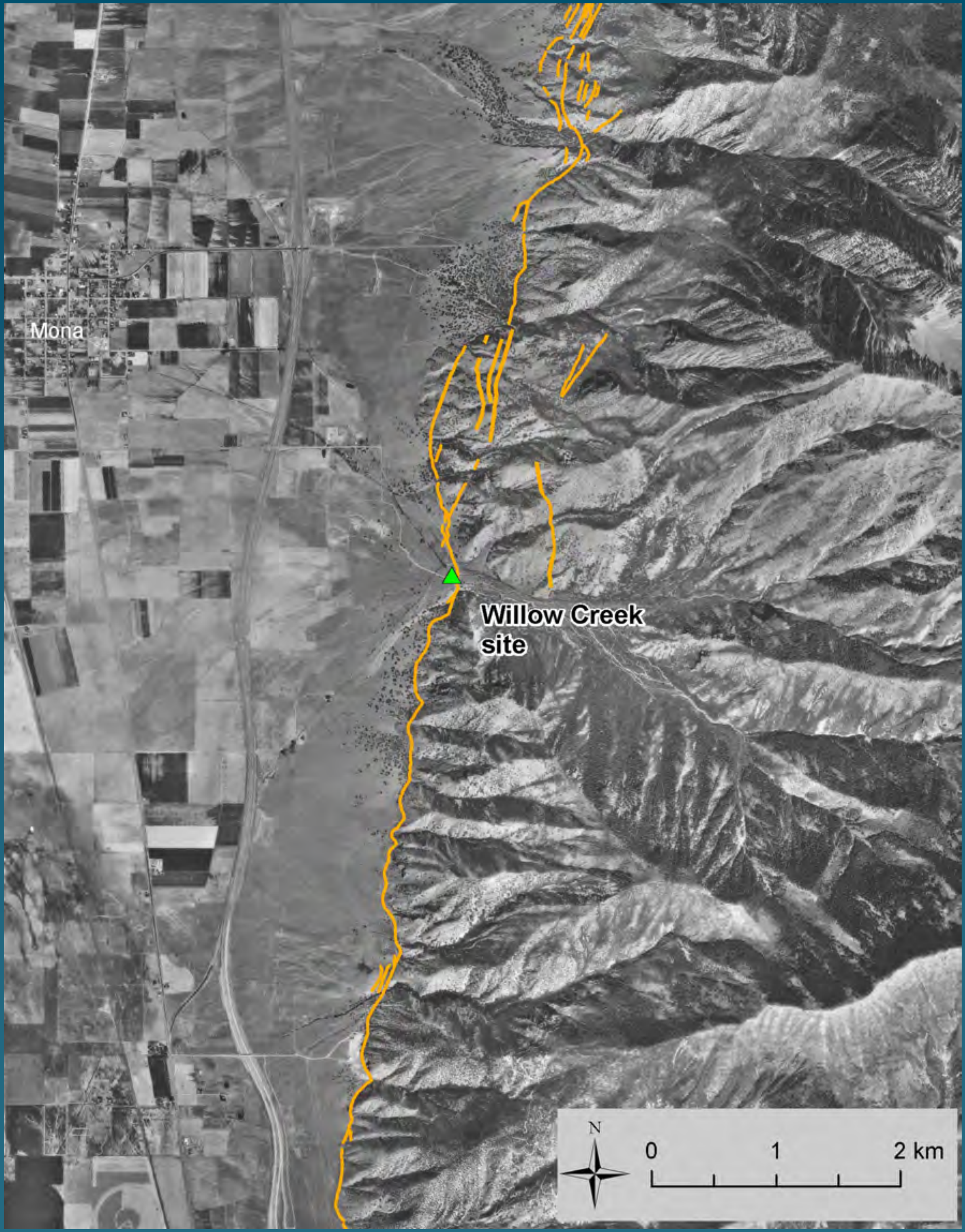
- 2-3 trenches
- 3-4 most-recent events
- Mid- to early Holocene alluvial fan



Nephi segment trenching

Why trench at Willow Creek?

- Nephi strand:
  - Last 3 events poorly constrained
  - Center of fault has not been trenched
- Resolve Holocene EQ history; compare with:
  - Santaquin strand
  - Provo and Levan segments



Willow Creek Site

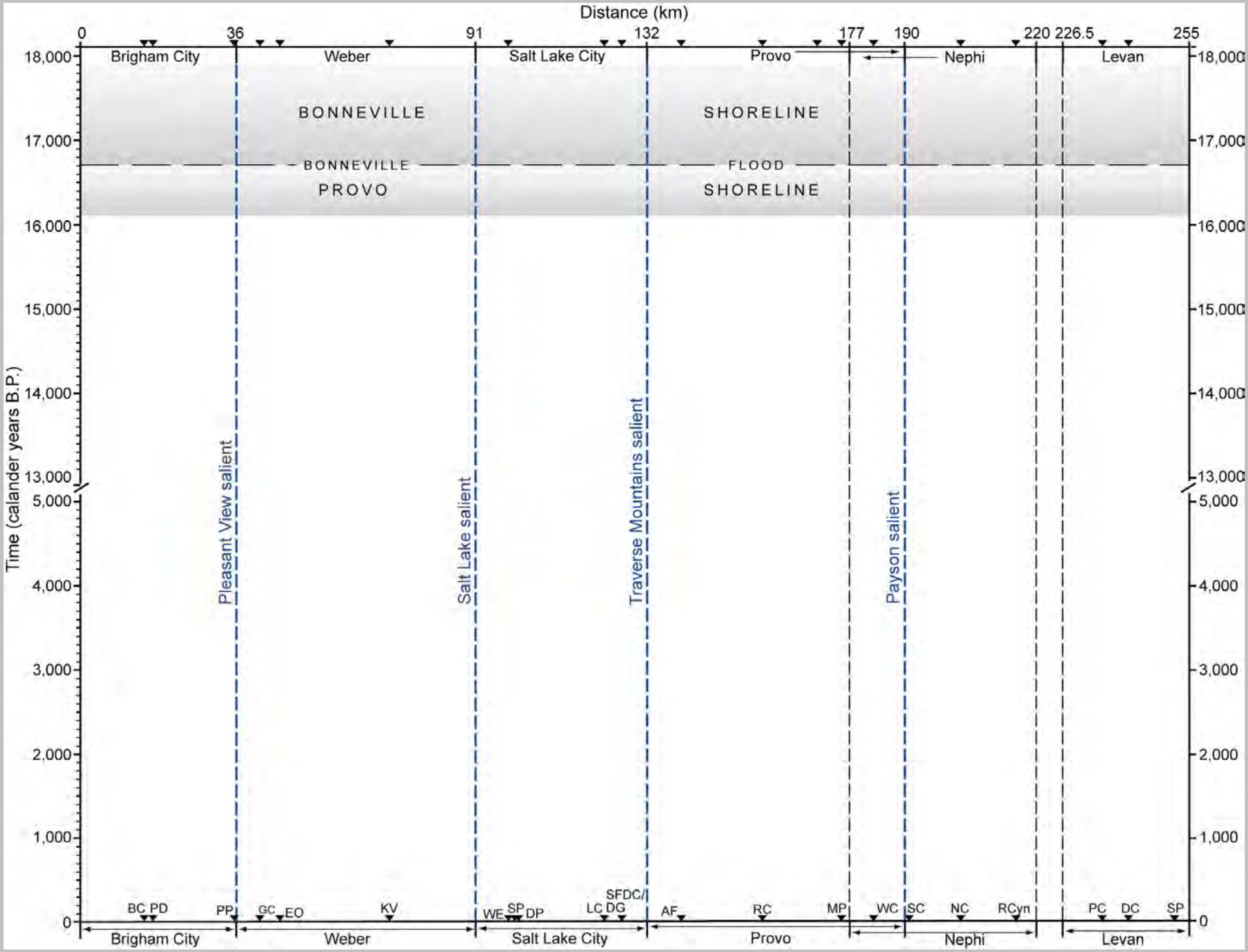
Wasatch Fault Zone Multi-Segment Rupture Model

DuRoss and Lund

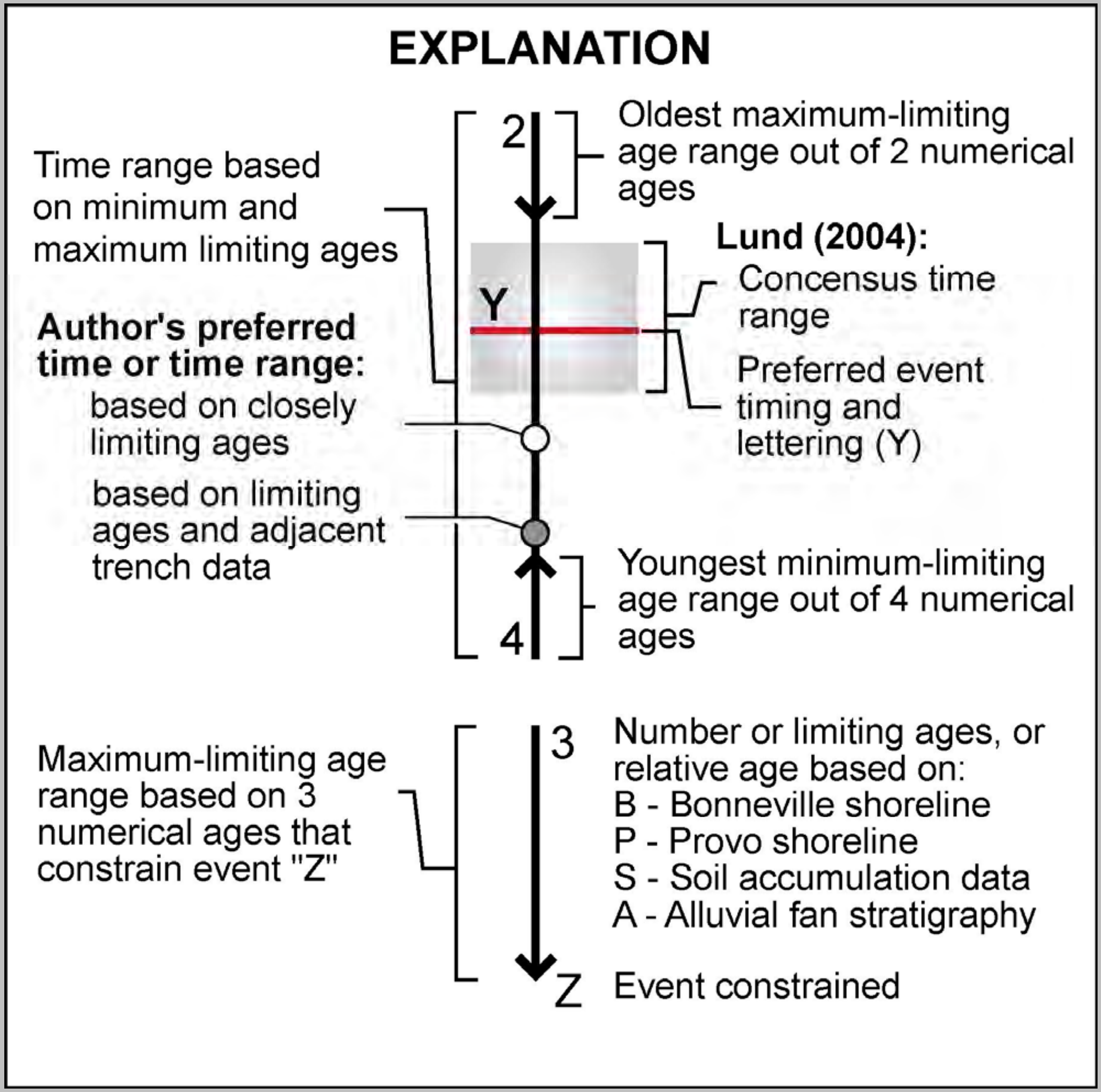
- Are multi-segment ruptures (MSRs) possible along the WFZ?
  - If so, for which segments?
  - Based on what data? (trench data, fault characteristics, expert opinion)
  - Methods to formulate and quantify MSR models?

- Fault characteristics for formulating MSR scenarios?
  - Earthquake timing
  - Fault displacement
  - Fault trace complexity
  - Geology/geophysics
  - Footwall topography/structure
  - Scarp geomorphology
  - Long- v. short-term data
  - Rupture propagation
  - Stress interaction
  - Seismicity

1. Space and time range

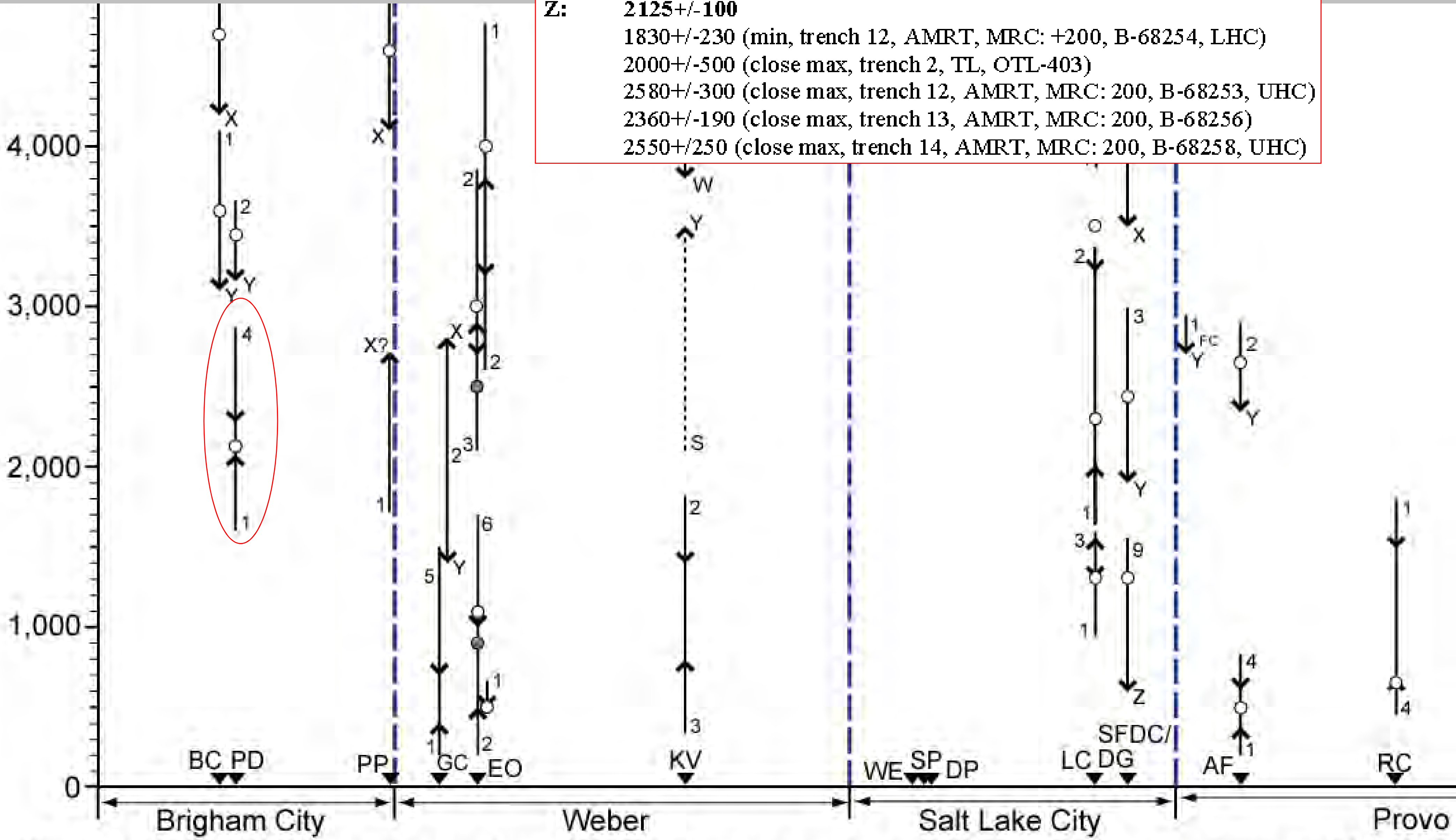


2. Summarizing and adding fault trench data



2. Summarizing and adding fault trench data

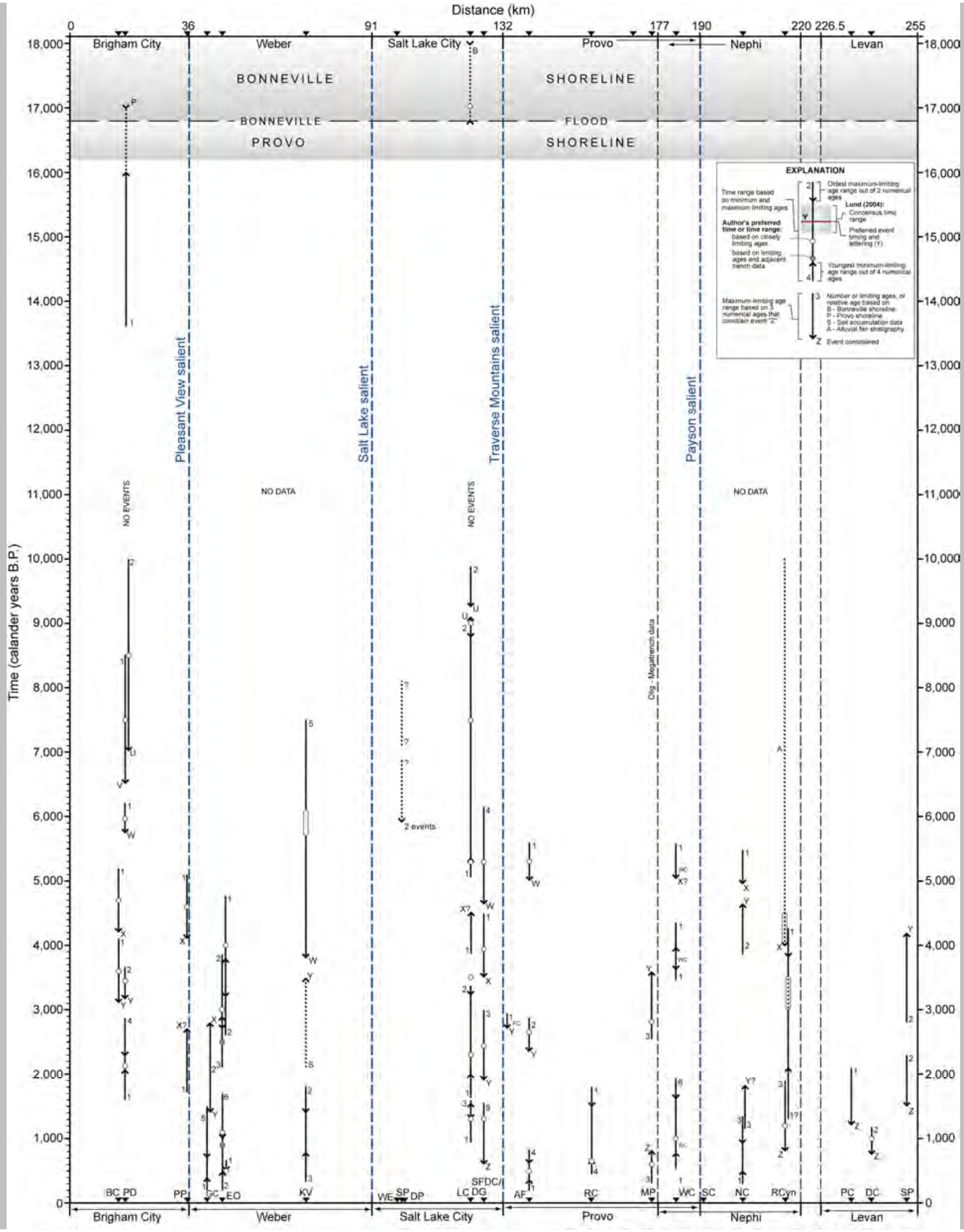
Z: **2125+/-100**
1830+/-230 (min, trench 12, AMRT, MRC: +200, B-68254, LHC)
2000+/-500 (close max, trench 2, TL, OTL-403)
2580+/-300 (close max, trench 12, AMRT, MRC: 200, B-68253, UHC)
2360+/-190 (close max, trench 13, AMRT, MRC: 200, B-68256)
2550+/250 (close max, trench 14, AMRT, MRC: 200, B-68258, UHC)



Wasatch fault zone paleoearthquake space-time diagram based on paleoseismic trench data. Trench-site abbreviations (north to south): BC - Brigham
(construction-related excavation), EO - East Ogden, KV - Kaysville, WE - Washington Elementary, SP - Salt Palace, DP - Dresden Place, LC - Little Cottonw
Fort Canyon (unpublished data), AF - American Fork, RC - Rock Creek (stream cut)/Rock Canyon, HC - Hobble Creek, MP - Mapleton north and south (Maple
pending), NC - North Creek, RCyn - Red Canyon, PC - Pigeon Creek, DC - Deep Creek (stream cut), and SP - Skinner Peaks.

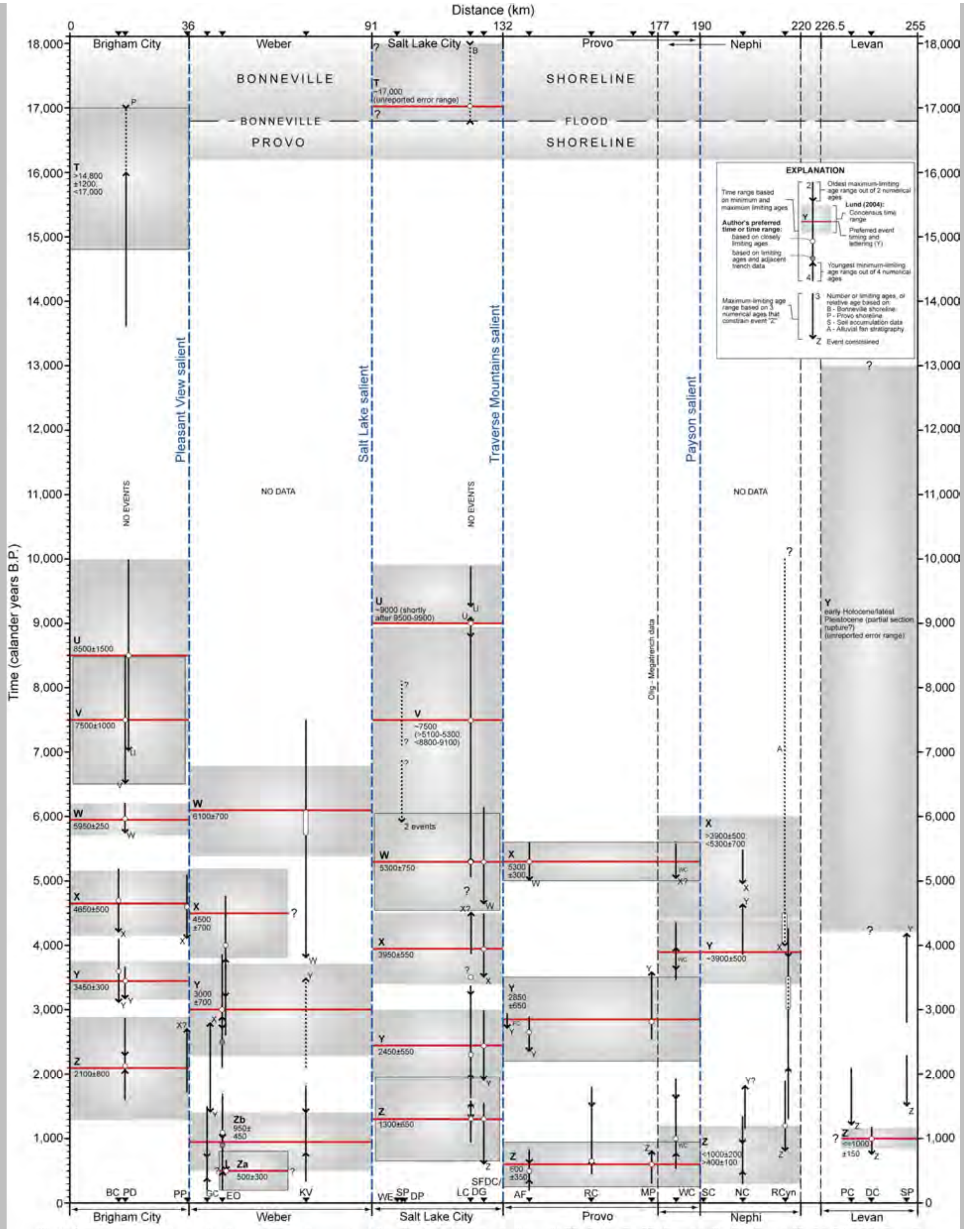
3. WFZ space-time diagram

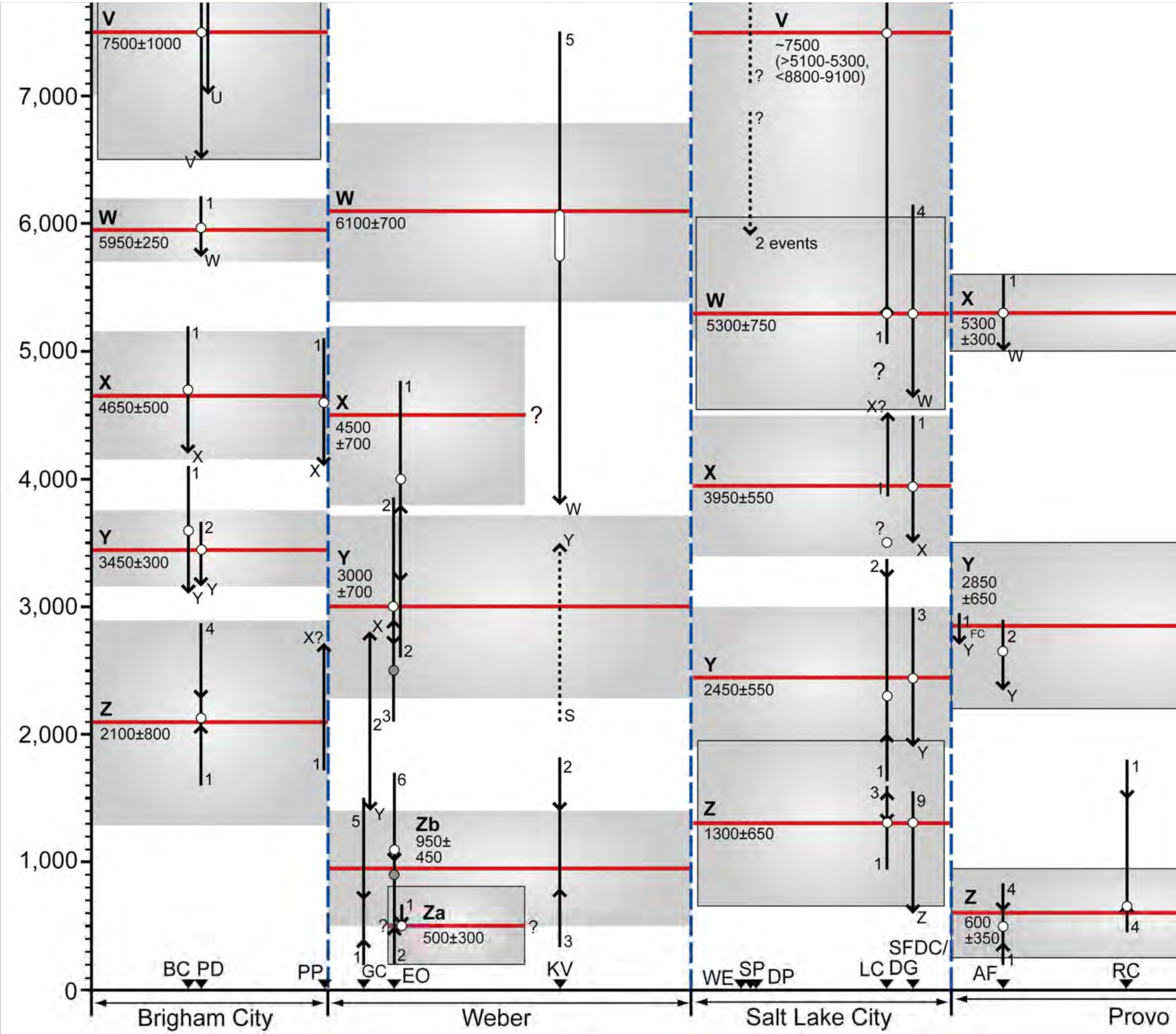
- Limiting ages



3. WFZ space-time diagram

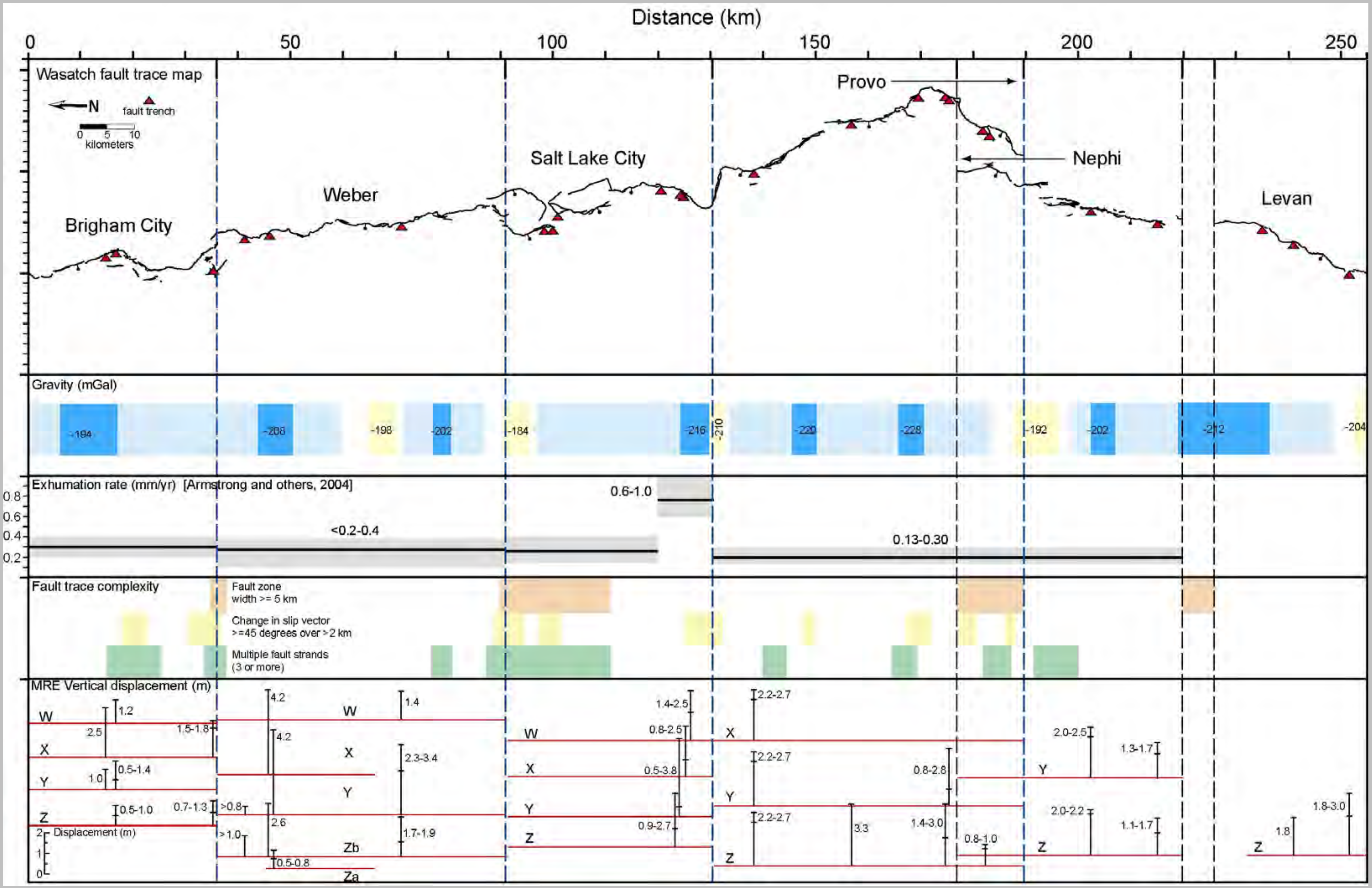
- UQFPWG consensus values

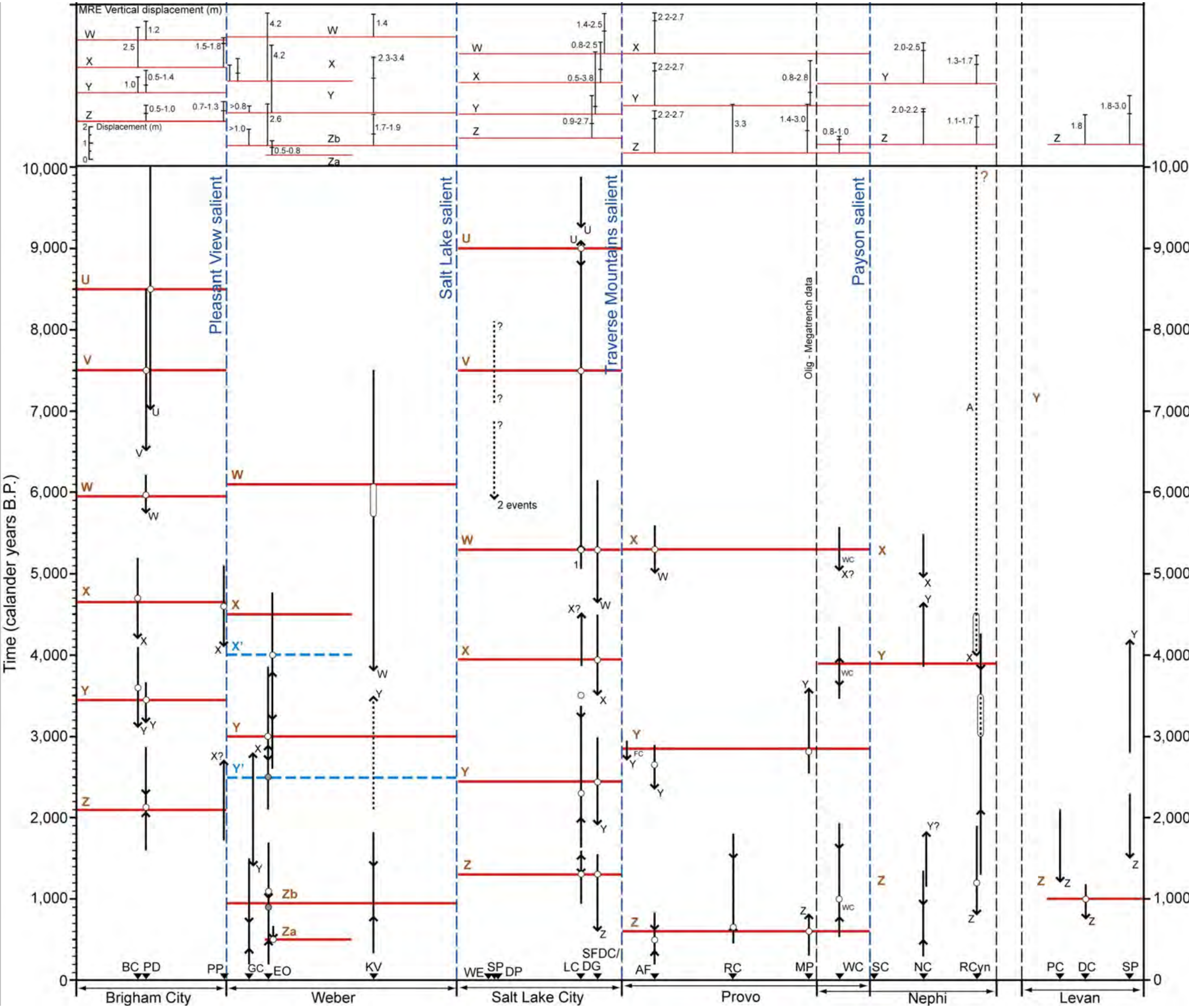




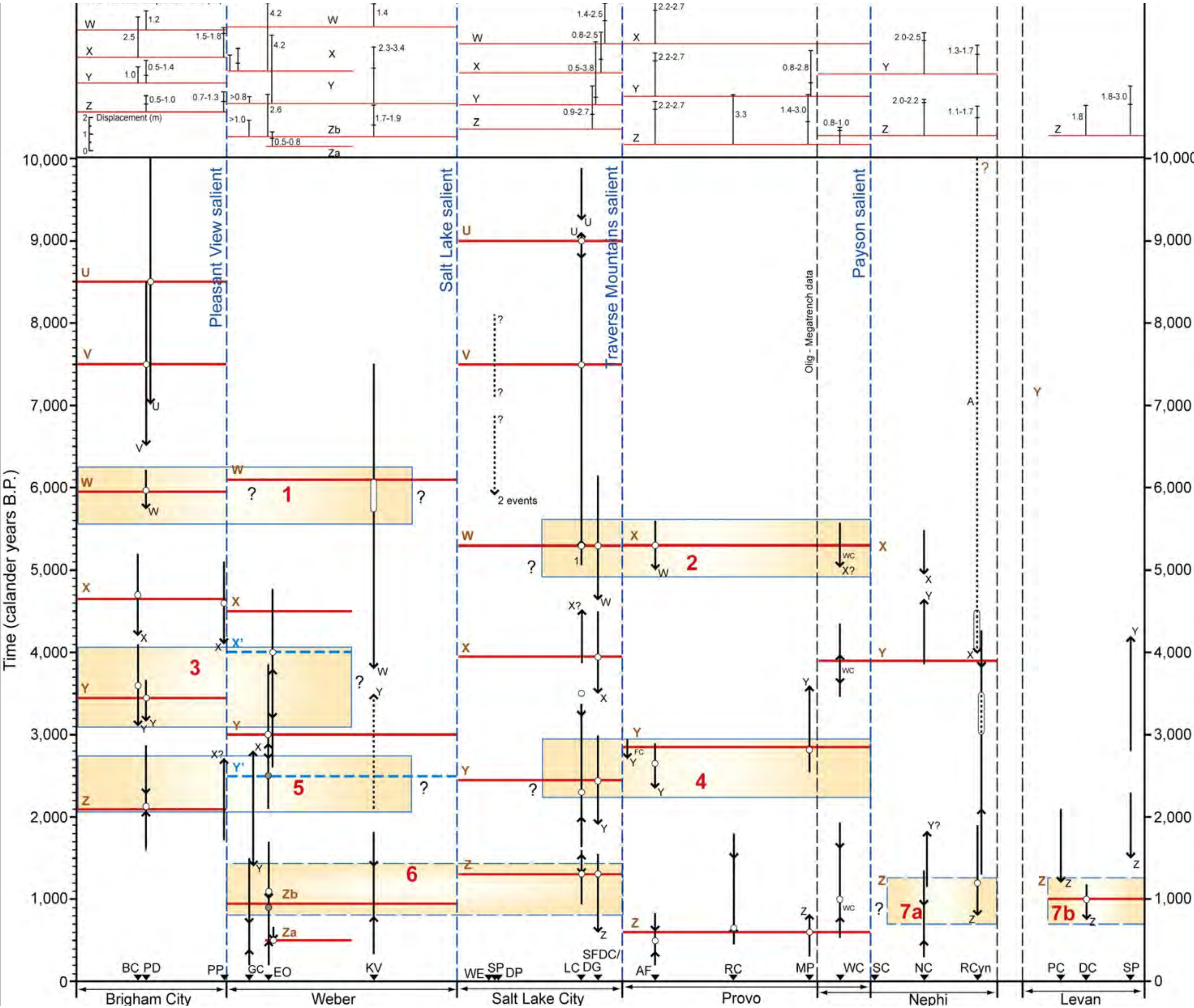
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
V
7500±1000
W
5950±250
X
4650±500
Y
3450±300
Z
2100±800
W
6100±700
X
4500
±700
Y
3000
±700
Zb
950±
450
Za
500±300
V
~7500
(>5100-5300,
<8800-9100)
2 events
W
5300±750
X
3950±550
Y
2450±550
Z
1300±650
X
5300
±300
Y
2850
±650
Z
600
±350
FC
BC PD
PP
GC
EO
KV
WE SP DP
LC
SFDC/
DG
AF
RC
Brigham City
Weber
Salt Lake City
Provo

3. Fault characteristics

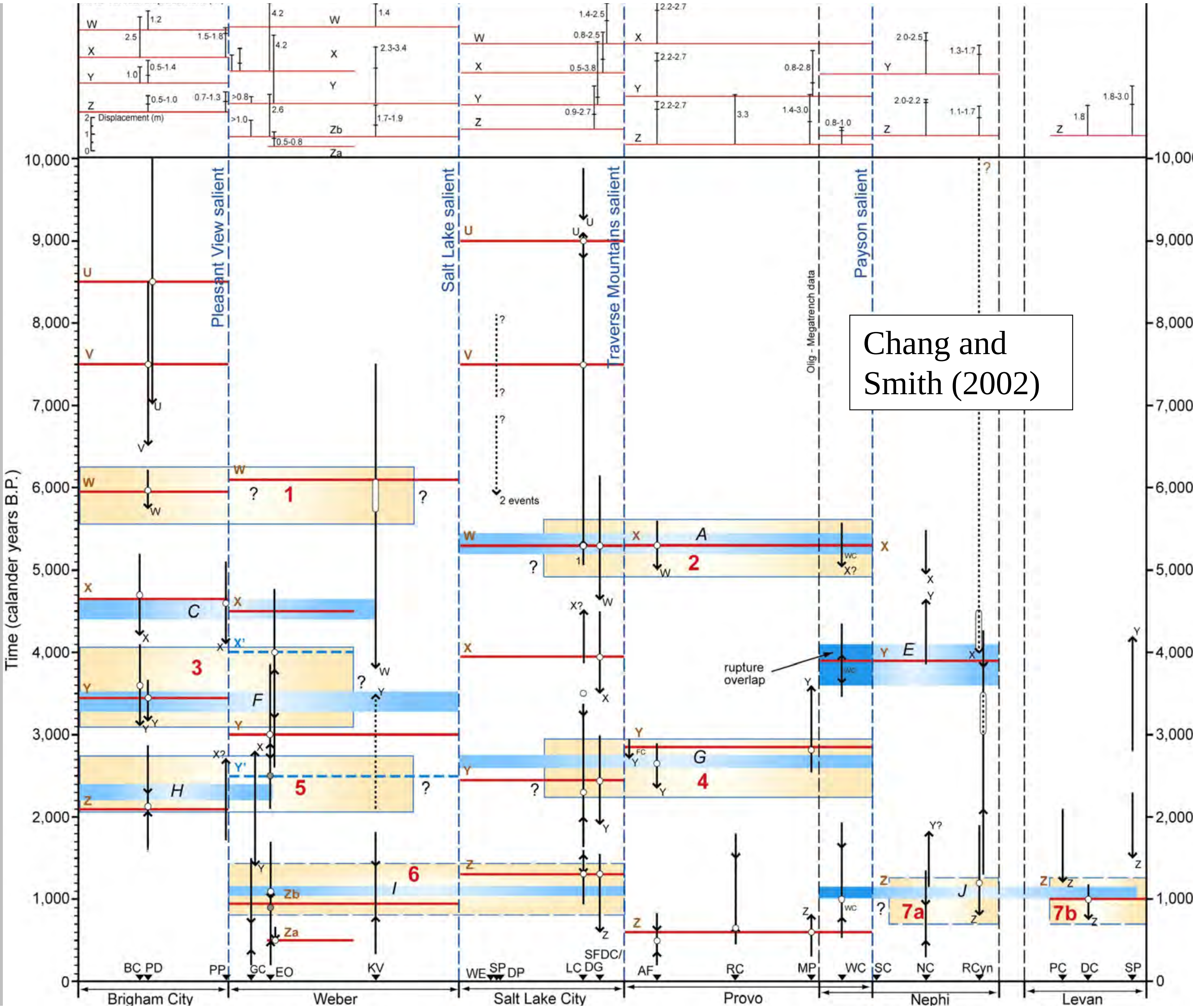




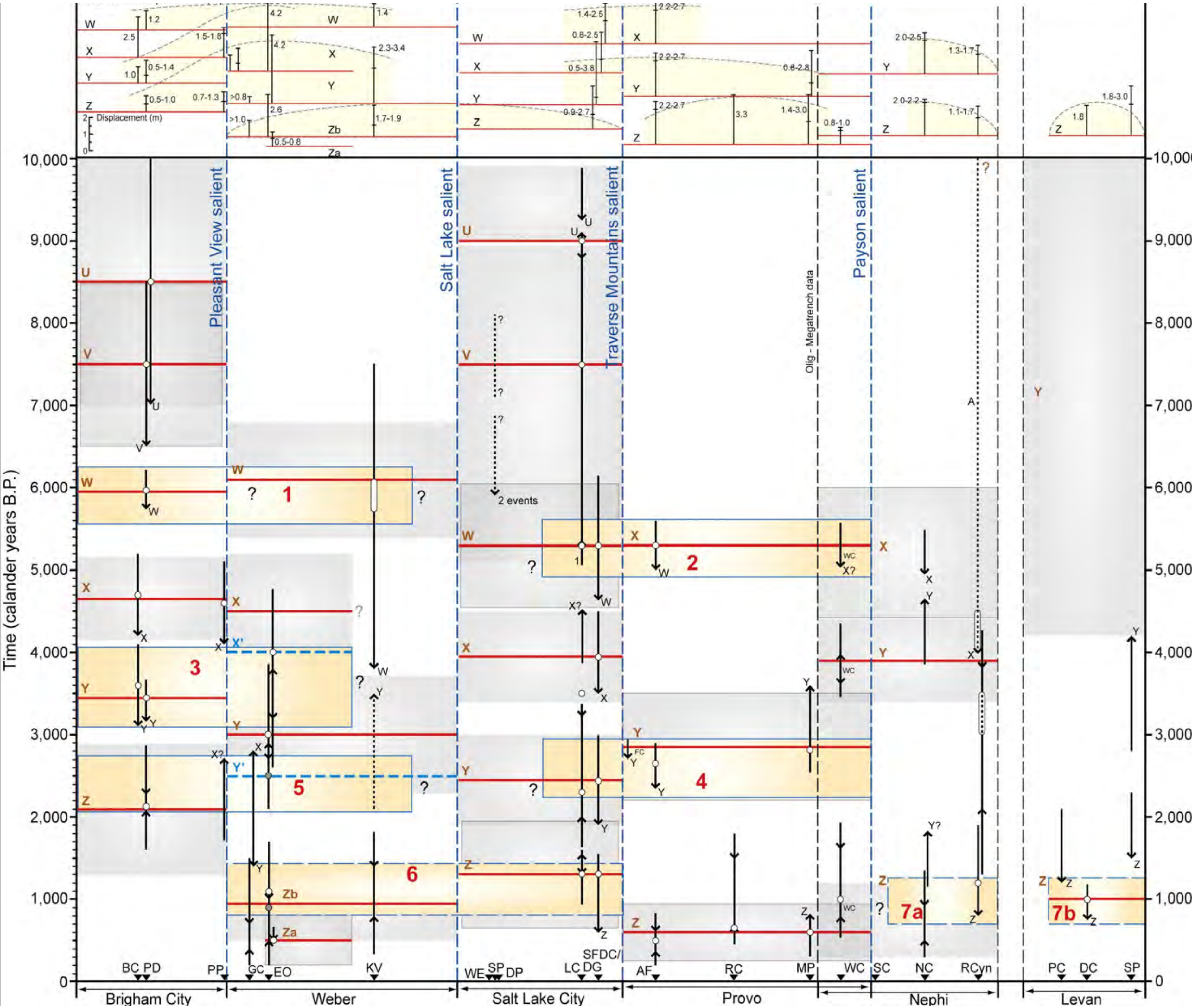
MRE Vertical displacement (m)
Displacement (m)
Time (calander years B.P.)
Pleasant View salient
Salt Lake salient
Traverse Mountains salient
Olig - Megatrench data
Payson salient
2 events
BC PD
PP
GC
EO
KV
WE SP DP
LC DG
SFDC/
AF
RC
MP
WC
SC
NC
RCyn
PC
DC
SP
Brigham City
Weber
Salt Lake City
Provo
Nephi
Levan



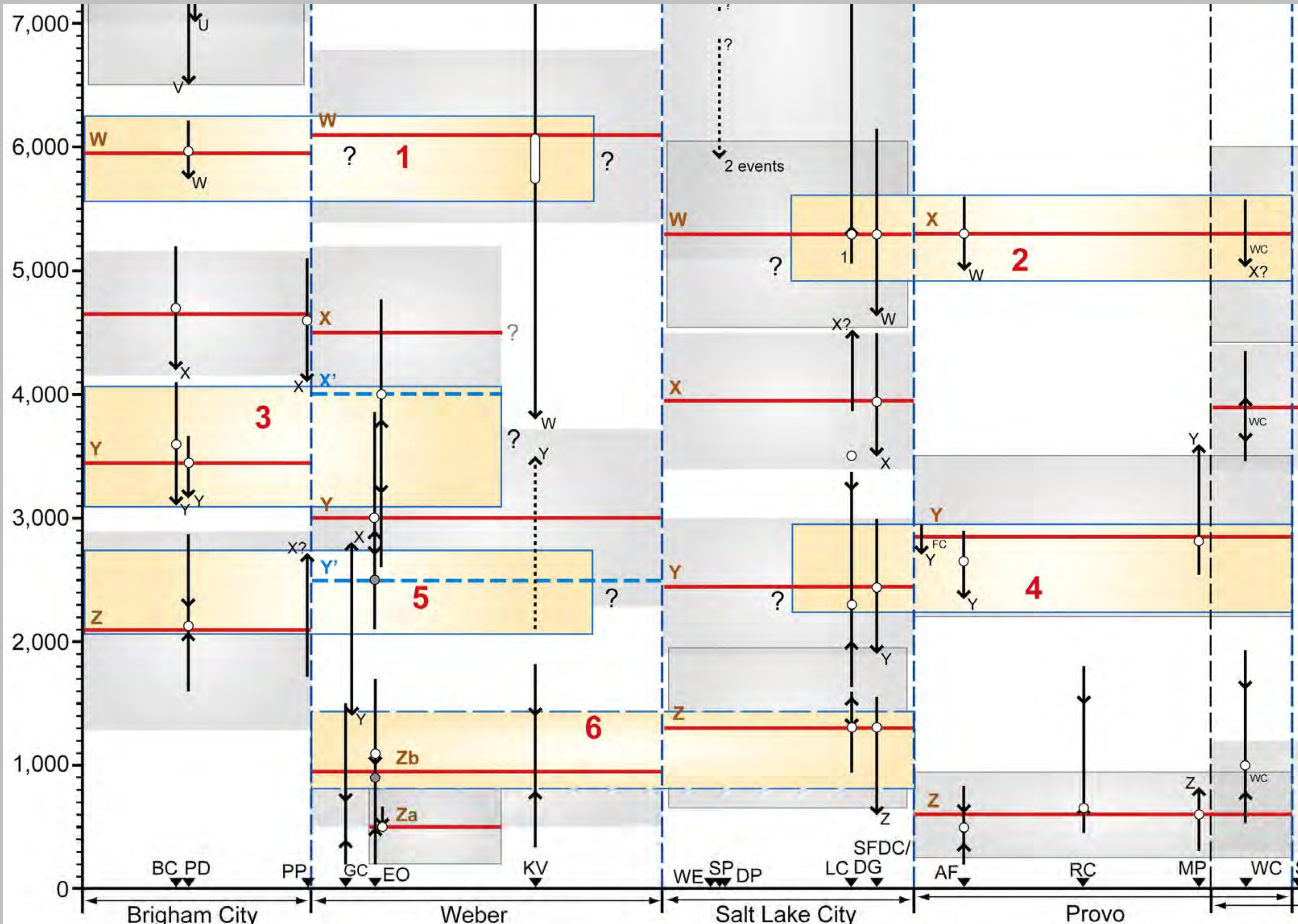
Displacement (m)
Time (calander years B.P.)
Pleasant View salient
Salt Lake salient
Traverse Mountains salient
Olig - Megatrench data
Payson salient
2 events
BC PD PP GC EO KV WE SP DP LC SFDC/ DG AF RC MP WC SC NC RCyn PC DC SP
Brigham City
Weber
Salt Lake City
Provo
Nephi
Levan



Chang and Smith (2002)
Time (calander years B.P.)
Displacement (m)
Pleasant View salient
Salt Lake salient
Traverse Mountains salient
Payson salient
Olig - Megatrench data
rupture overlap
2 events
Brigham City
Weber
Salt Lake City
Provo
Nephi
Levan
BC PD
PP
GC EO
KV
WE SP DP
LC DG
SFDC/
AF
RC
MP
WC
SC
NC
RCyn
PC
DC
SP



Time (calander years B.P.)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Displacement (m)
Pleasant View salient
Salt Lake salient
Traverse Mountains salient
Payson salient
Olig - Megatrench data
2 events
1
2
3
4
5
6
7a
7b
U
V
W
X
X'
Y
Y'
Z
Za
Zb
BC
PD
PP
GC
EO
KV
WE
SP
DP
LC
SFDC/
DG
AF
RC
MP
WC
SC
NC
RCyn
PC
DC
SP
Brigham City
Weber
Salt Lake City
Provo
Nephi
Levan

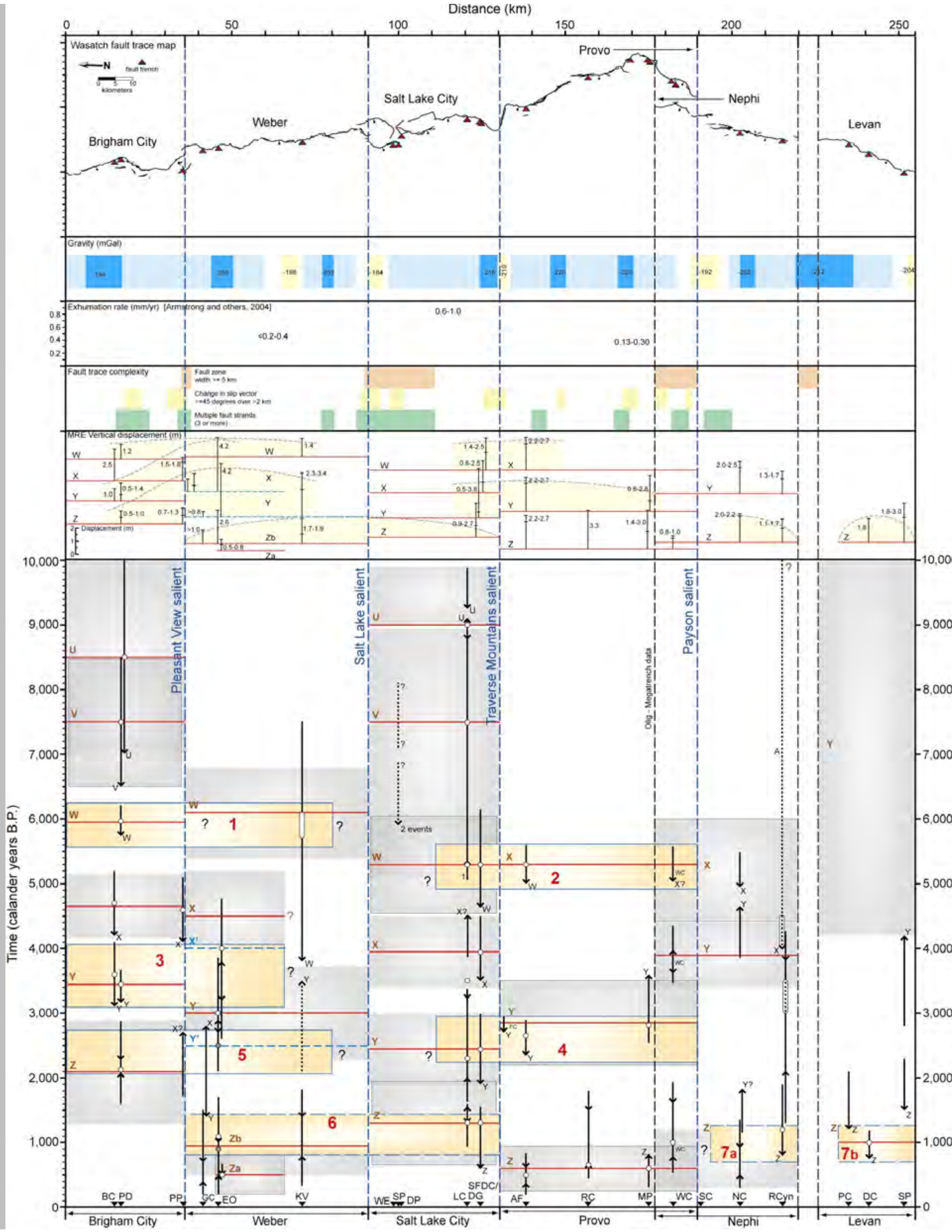


7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
W
X
Y
Z
X'
Y'
Zb
Za
1
2
3
4
5
6
2 events
BC PD
PP
GC
EO
KV
WE
SP
DP
LC
DG
SFDC/
AF
RC
MP
WC
Brigham City
Weber
Salt Lake City
Provo

4. WFZ MSR model

Segment boundaries:

- Strong:
  - WB-SL
- Weak:
  - BC-WB
  - SL-PV?
- Unknown:
  - PV-NP
  - NP-LV



Wasatch Fault Zone Multi-Segment Rupture Model

How California handles MSRs (WGCEP, 2003)

- Rupture source: single segment or combination of segments that may produce an earthquake

- WFZ (center 4 segments): 7 possible sources
  - BC, WB, SL, PV
  - BC + WB
  - WB + SL
  - SL + PV

Wasatch Fault Zone Multi-Segment Rupture Model

How California handles MSRs (WGCEP, 2003)

- Rupture scenario: combination of rupture sources – describing possible mode of failure of an entire fault/fault zone

- WFZ: 5 rupture scenarios
  - BC, WB, SL, PV
  - BC + WB, SL, PV
  - BC, WB + SL, PV
  - BC, WB, SL + PV
  - BC + WB, SL + PV

Wasatch Fault Zone Multi-Segment Rupture Model

How California handles MSRs (WGCEP, 2003)

– Fault-rupture model: weighted combination of multiple rupture scenarios, representing long-term behavior

– WFZ rupture scenarios / Fault-rupture models

WFZ rupture scenarios	Fault-rupture models		
BC, WB, SL, PV	100%	80%	20%
BC + WB, SL, PV	0%	5%	20%
BC, WB + SL, PV	0%	5%	20%
BC, WB, SL + PV	0%	5%	20%
BC + WB, SL + PV	0%	5%	20%

Summary & Discussion

Yes, MSRs are possible along the WFZ

- Where, when?
- WFZ MSR model is one possibility

Multiple rupture scenarios/models for the WFZ?

- Include partial-segment rupture and triggered slip?
    1. Partial-segment — 0.3WB, 0.8LV
    2. Single-segment — WB, SL, PV…
    3. Spill-over — BC+0.5WB, SL+0.3PV
    4. Triggered slip — NP(+LV), SL(+PV)
    5. MSR — BC+WB, SL+PV…
- Defining and weighting scenarios/models – WG consensus?

Incorporate scenarios/models into the NSHMs?