UTAH GEOLOGICAL SURVEY

WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
MEETING #4

One strand of the complex Drum Mountain fault zone

February 16 & 17, 2011

www.geology.utah.gov

WELCOME
&
INTRODUCTIONS

WGUEP Members

Walter Arabasz, UUSS
Tony Crone, USGS
Chris DuRoss, UGS
Nico Luco, USGS
Bill Lund, UGS (Coordinator)
Susan Olig, URS
Jim Pechmann, UUSS
Steve Personius, USGS
Mark Petersen, USGS
David Schwartz, USGS
Bob Smith, UUGG
Ivan Wong, URS (Chair)

With assistance from
Steve Bowman and Mike Hylland, UGS; Patricia Thomas, URS; Christine Puskas, UUGG

WGUEP AGENDA
Wednesday, February 16, 2011

7:30 – 8:00	Continental Breakfast	
8:00 – 8:15	Welcome	Bill
8:15 – 8:30	Overview of Agenda	Ivan
8:30 – 9:15	WGUEP Strawman Logic Tree and Products	Ivan
9:15 – 10:00	Recurrence Models	Ivan
10:00 – 10:15	Break	
10:15 – 10:30	Final Wasatch Central Segment Recurrence Rates	Chris
10:30 – 10:45	Final Recurrence Rates for Wasatch Fault End Segments	Mike
10:45 – 11:30	Methods for Estimating Mmax	Susan/David
11:30 – 12:15	Time-Dependent Models	Patricia
12:15 – 1:15	Lunch	
1:15 – 2:15	Comparison of Paleoseismic, Seismicity, and Geodetic Moment Rates	Christine/Bob
2:15 – 3:00	Horizontal Strain Rates From Slip Rate and Geodetic Data	Mark
3:00 – 3:15	Break	
3:15 – 4:00	Moment Balancing the Wasatch Fault	Mark
4:00 – 4:45	Consensus Wasatch Front Earthquake Catalog	Walt/Jim
4:45 – 5:15	Wrap-up Discussion	All
5:15	Adjourn	

WGUEP AGENDA
Thursday, February 17, 2011

7:30 – 8:00	Continental Breakfast	
8:00 – 8:30	Strawman Rupture Scenarios for the Fault	Jim
8:30 – 10:00	Final Wasatch Front Fault Model	Bill
10:00 – 10:15	Break	
10:15 – 11:30	Discussion on Calculating Time-Dependent and Time-Independent Rates	All
11:30 – 12:30	Lunch	
12:30 – 1:30	Discussion on Final Products and Report	All
1:30 – 2:00	Meeting 5 Schedule	
2:00	Adjourn	

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

Working Group on Utah Earthquake Probabilities

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Salt Lake City, UT 15 February 2011

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With assistance from Patricia Thomas (URS) and
Steve Bowman and Mike Hylland (UGS)

Approach

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

Products

- The WGUEP will calculate the probability of a range of moderate to large earthquakes (M $\geq$ 5.5) in the Wasatch Front Region for a range of intervals varying from annually to 100 years.

- The earthquake probabilities that will be estimated are:
  1. Segment-specific for the Wasatch fault
  2. Total for the Wasatch fault
  3. Fault-specific for other major faults in the area
  4. Total for the Wasatch Front region.

Products (cont.)

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

Accomplishments

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

Accomplishments

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

Remaining Issues

1. GPS moment rate versus geologic and seismicity data

2. Moment balancing the Wasatch fault

Next Steps

1. Historical seismicity catalog update and calculation of background earthquake rates.

2. Update West Valley rupture scenarios (including coseismic rupture with Salt Lake City segment).

3. Calculate time-dependent and/or time-dependent rates for all faults.

4. Develop forecast.

Next Steps (cont.)

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

Analysis of ANSS Data for Stress Drop, Q(f), and Kappa

Utah Ground Motion Working Group

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Seismic Hazards Group
URS Corporation
Oakland, CA

Jim Pechmann
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Salt Lake City, UT

Walt Silva and Bob Darragh
Pacific Engineering & Analysis
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Tian Yu
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China Earthquake Administration
Harbin, China

Salt Lake City, UT
14 February 2011

Introduction

- Objective: To evaluate the critical factors that control ground shaking hazard along the Wasatch Front: stress drop, kappa, and crustal attenuation.
- Some previous studies have suggested that ground motions in an extensional regime such as the Basin and Range Province may be lower than in California for the same magnitude and distance.
- The inference was that this difference may be due to the lower stress drops of extensional earthquakes compared to compressional earthquakes as first suggested by McGarr (1984).

Background

- No systematic evaluation of earthquake stress drops has been performed for earthquakes along the Wasatch Front.
- No studies have been performed to evaluate the variability in kappa in the central Wasatch Front. Kappa can have a very significant effect on high-frequency ground motions with lower values of kappa resulting in larger high-frequency ground motions.
- Only a few studies to estimate Q(f) for the Wasatch Front (Brockman and Bollinger, 1992; Jeon and Herrmann, 2004) have been performed.

Scope of Work

- To analyze the available strong motion and broadband data from ANSS stations in the central Wasatch Front region for stress drop, kappa, and Q(f).

- The approach uses an inversion scheme developed by Walt Silva. In the inversion scheme, earthquake source, path and site parameters are obtained by using a nonlinear least-squares inversion of Fourier amplitude spectra.

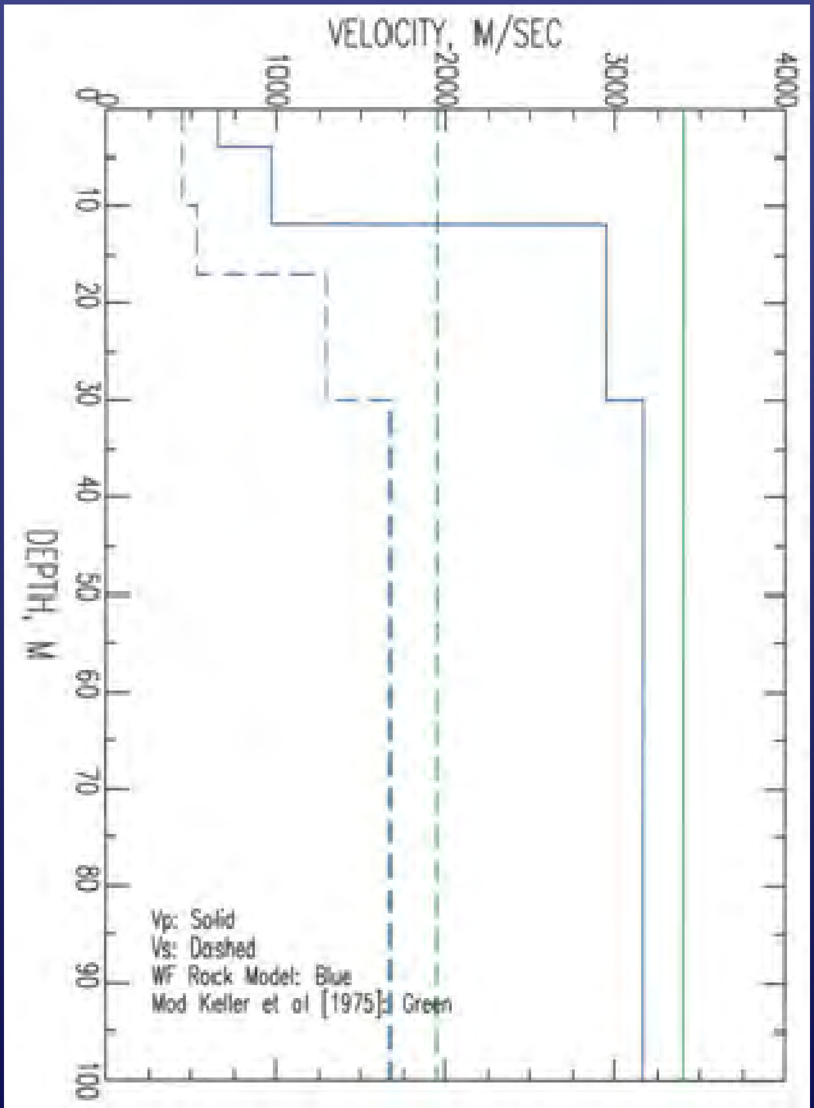
Earthquakes to be Analyzed

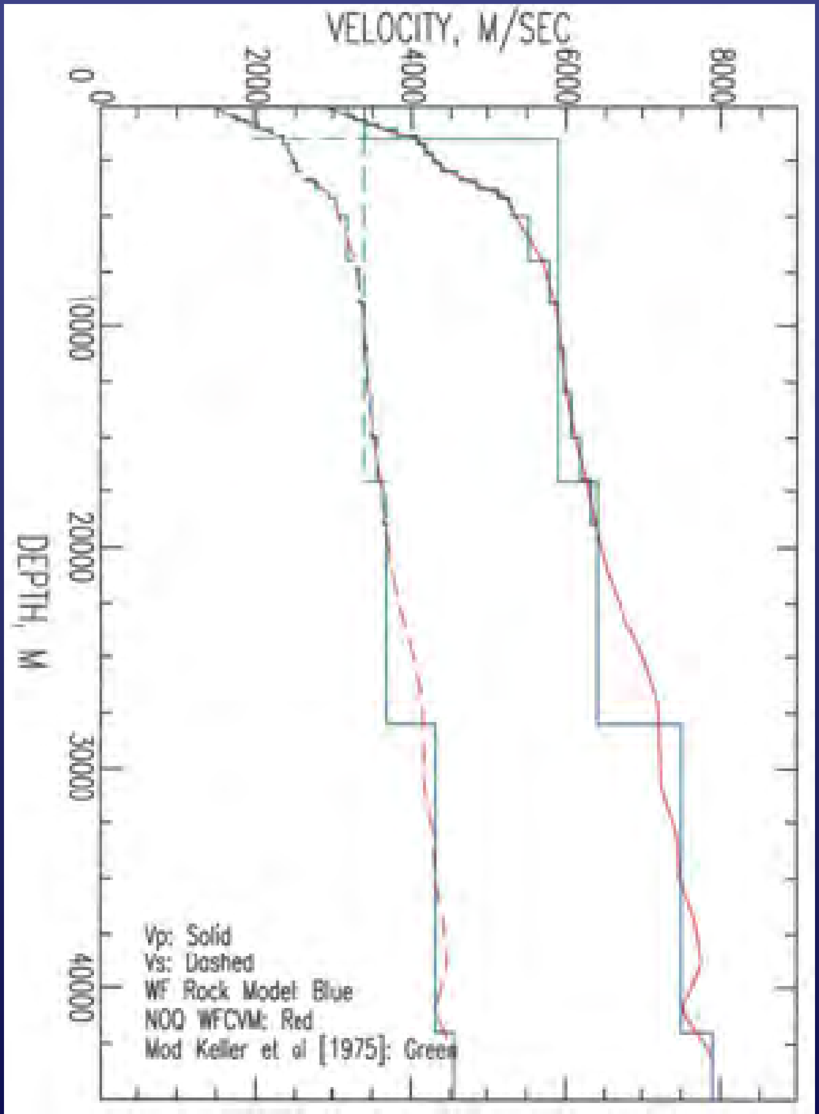
- Total of 17 events
- Period: May 2001 to November 2007
- Magnitude Range: **M** 3.0 to 4.2
- Number of stations recording events: 18 to 68

Scope of Work

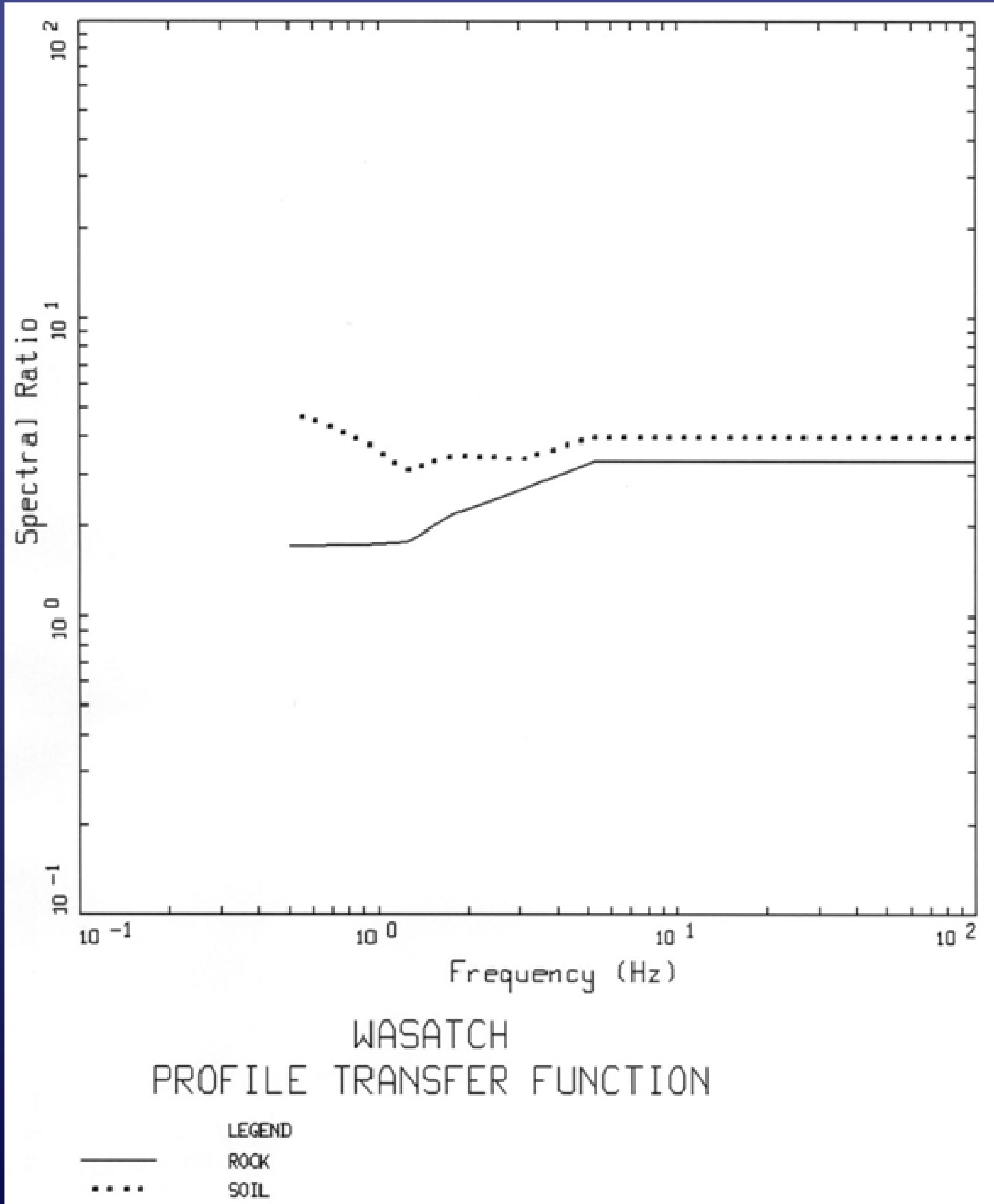
- Steps involved in analyses are:
  1) Inversions with rock amp factors using rock recordings.
  2) Results from Step 1 used to invert soil recordings to obtain an average set of amp factors for soil sites.
  3) Rock and soil amp factors are used to invert both rock and soil recordings.
  4) Inversions were performed fixing Q_0 and R0 fixed to values in Step 3 and rock and soil amp factors to obtain station κ and stress drop.

Hard Rock V_S and V_P Profiles

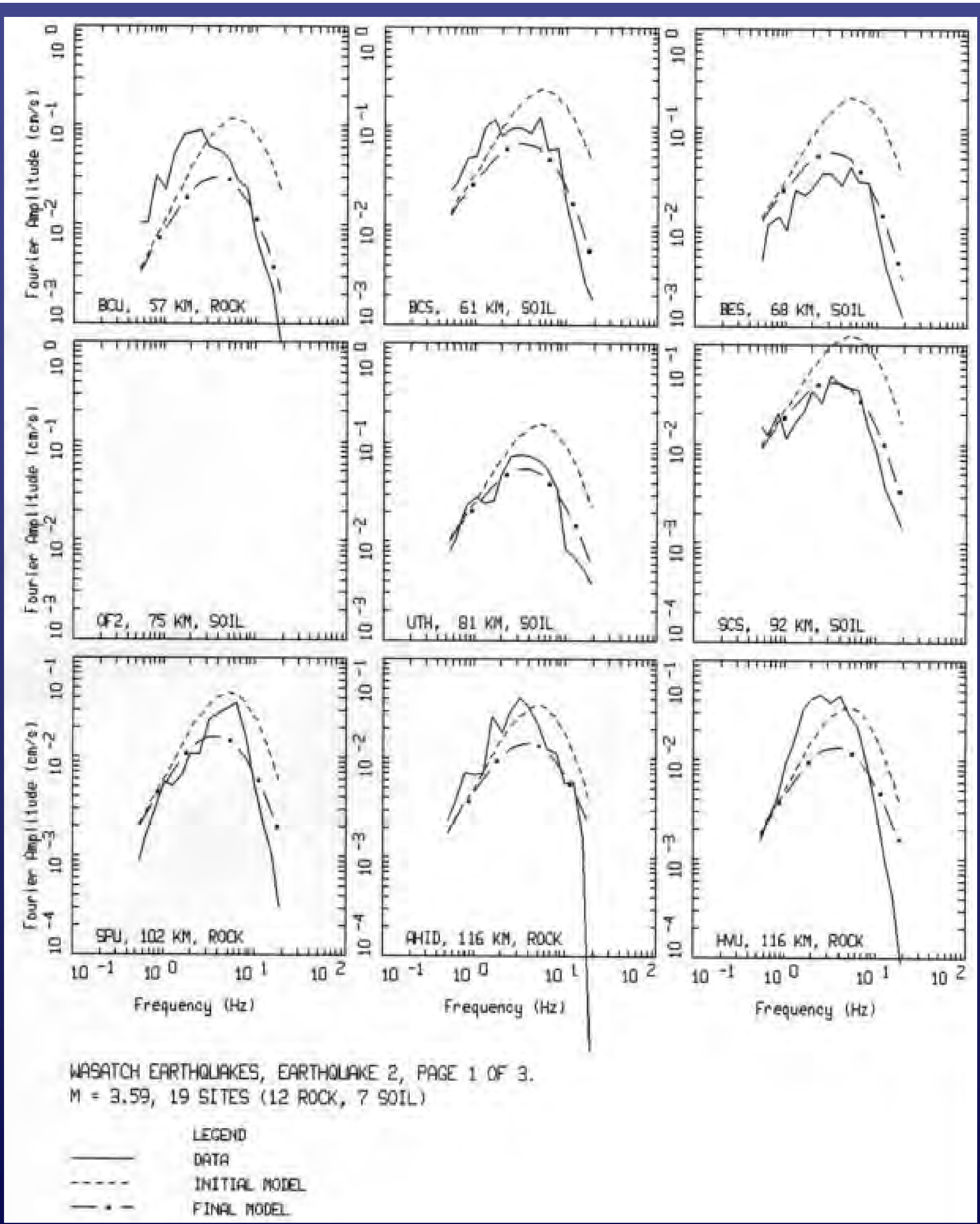




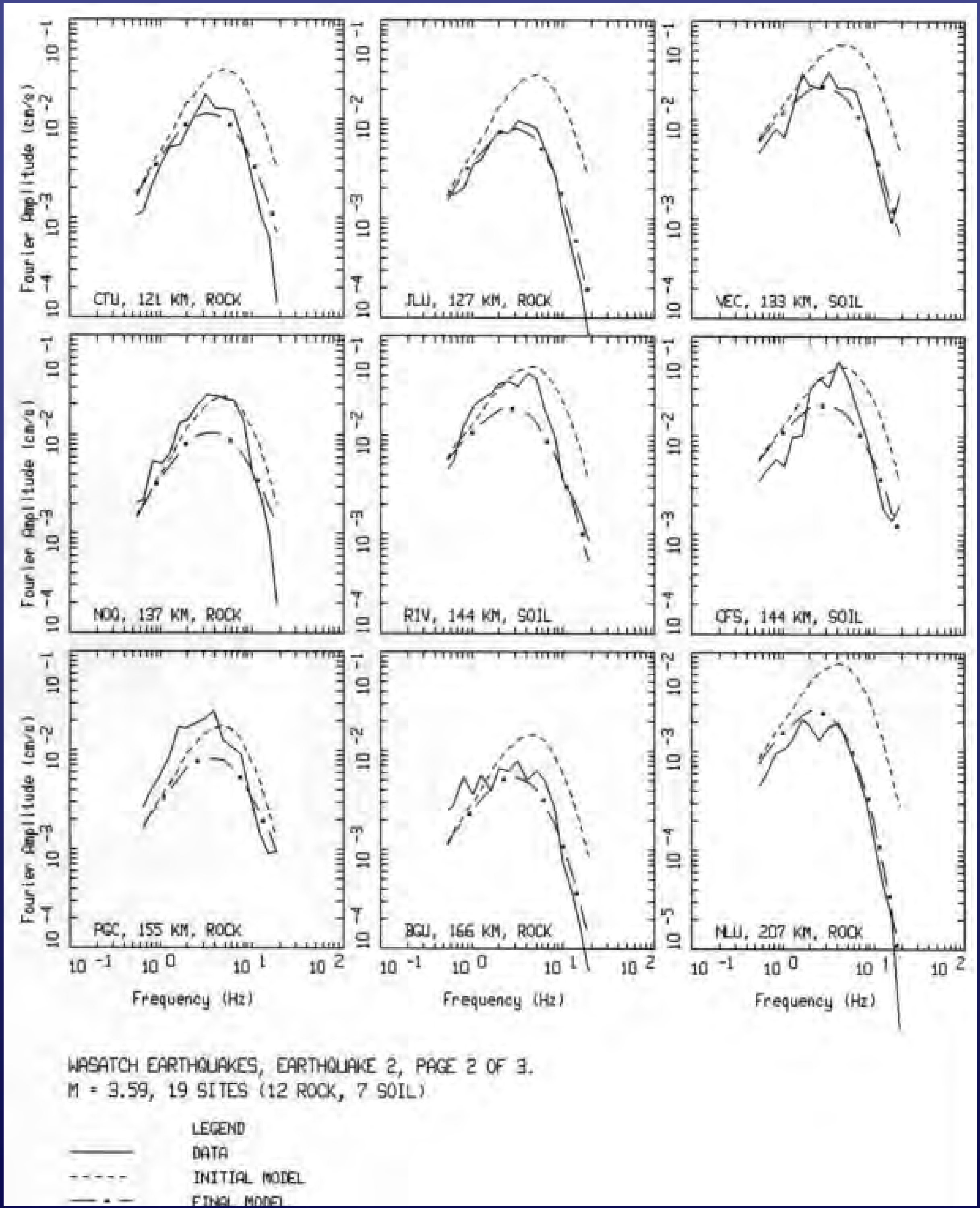
Frequency-Dependent Amplification Factors



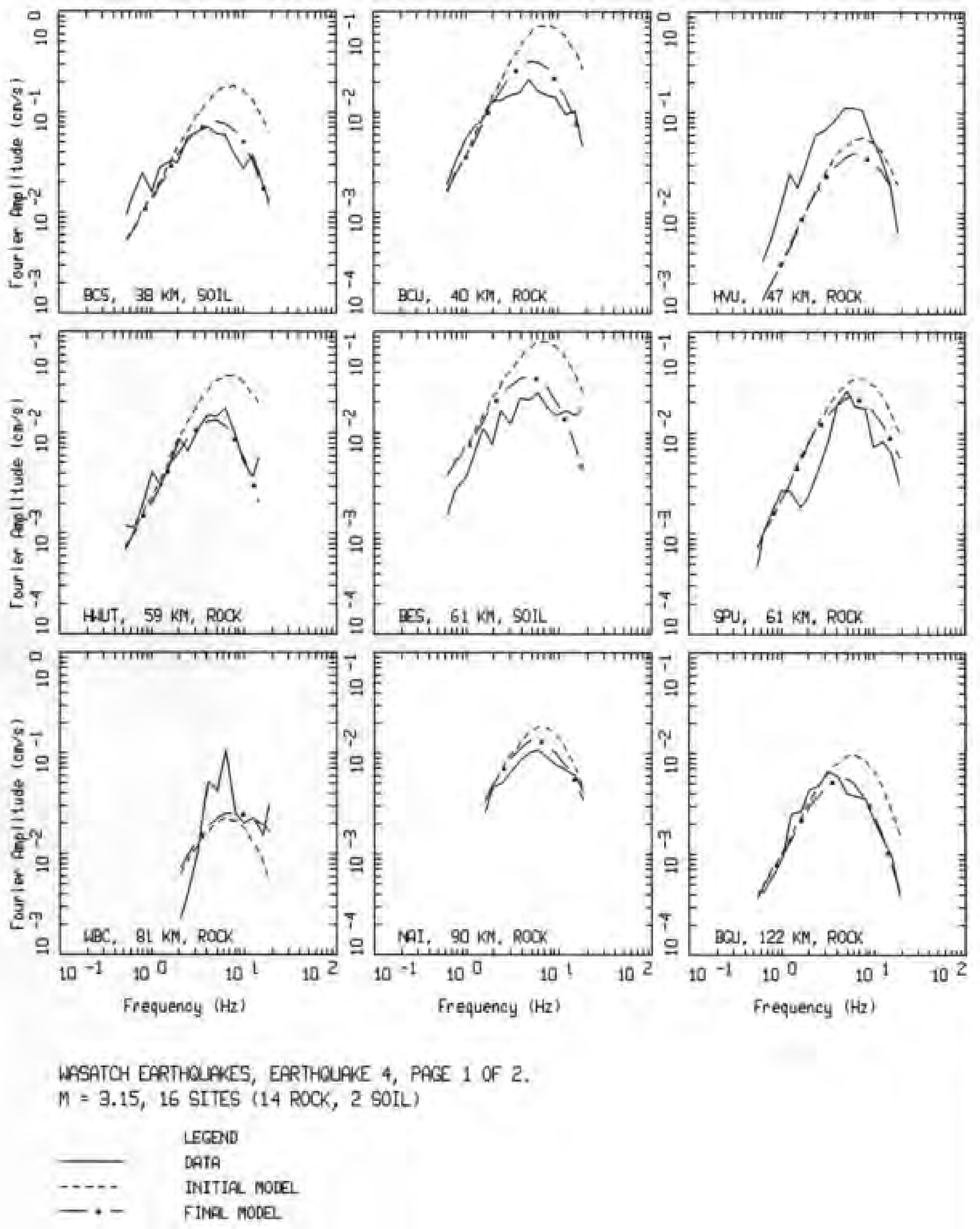
Spectral Inversion Results for Event #2



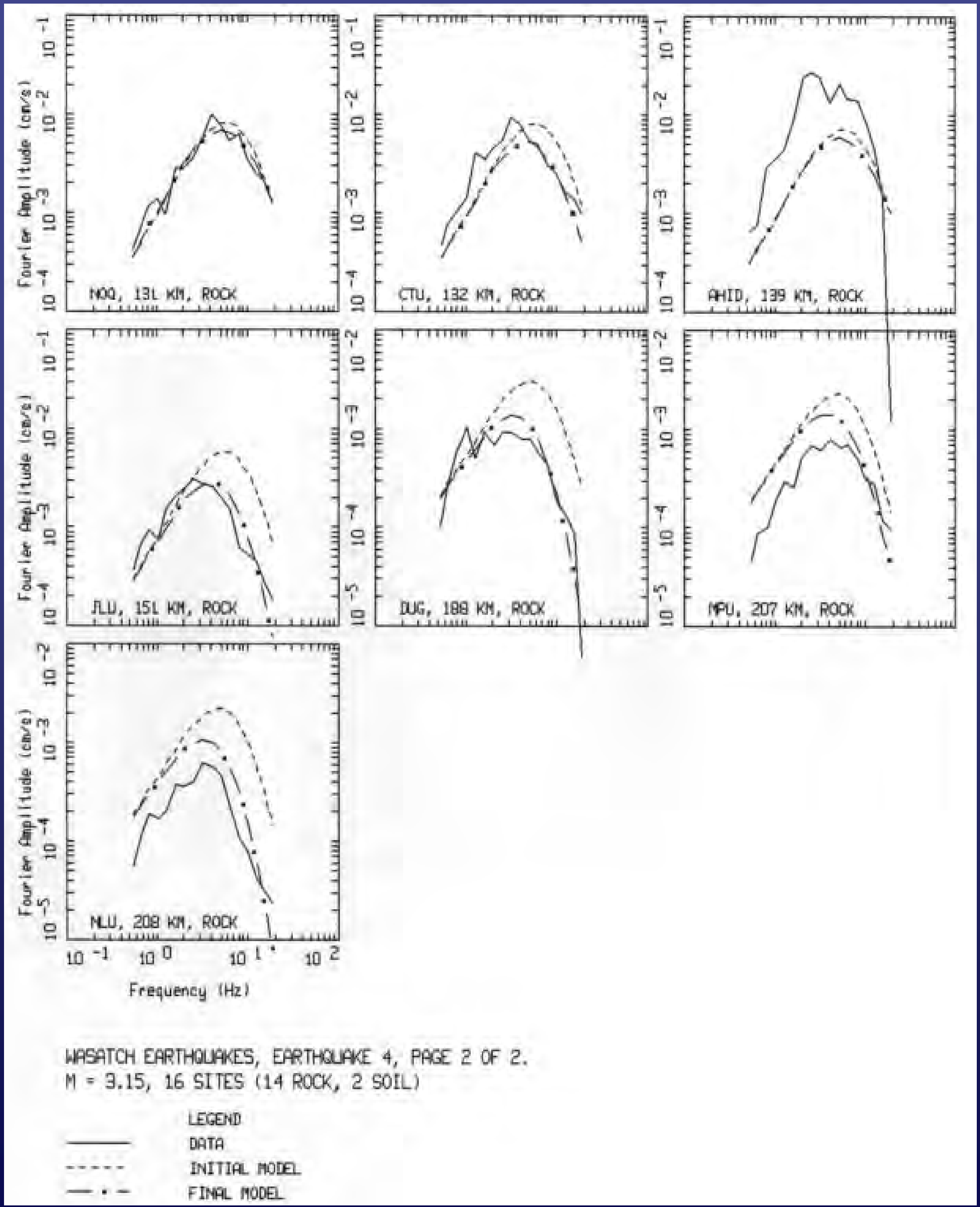
Spectral Inversion Results for Event #2



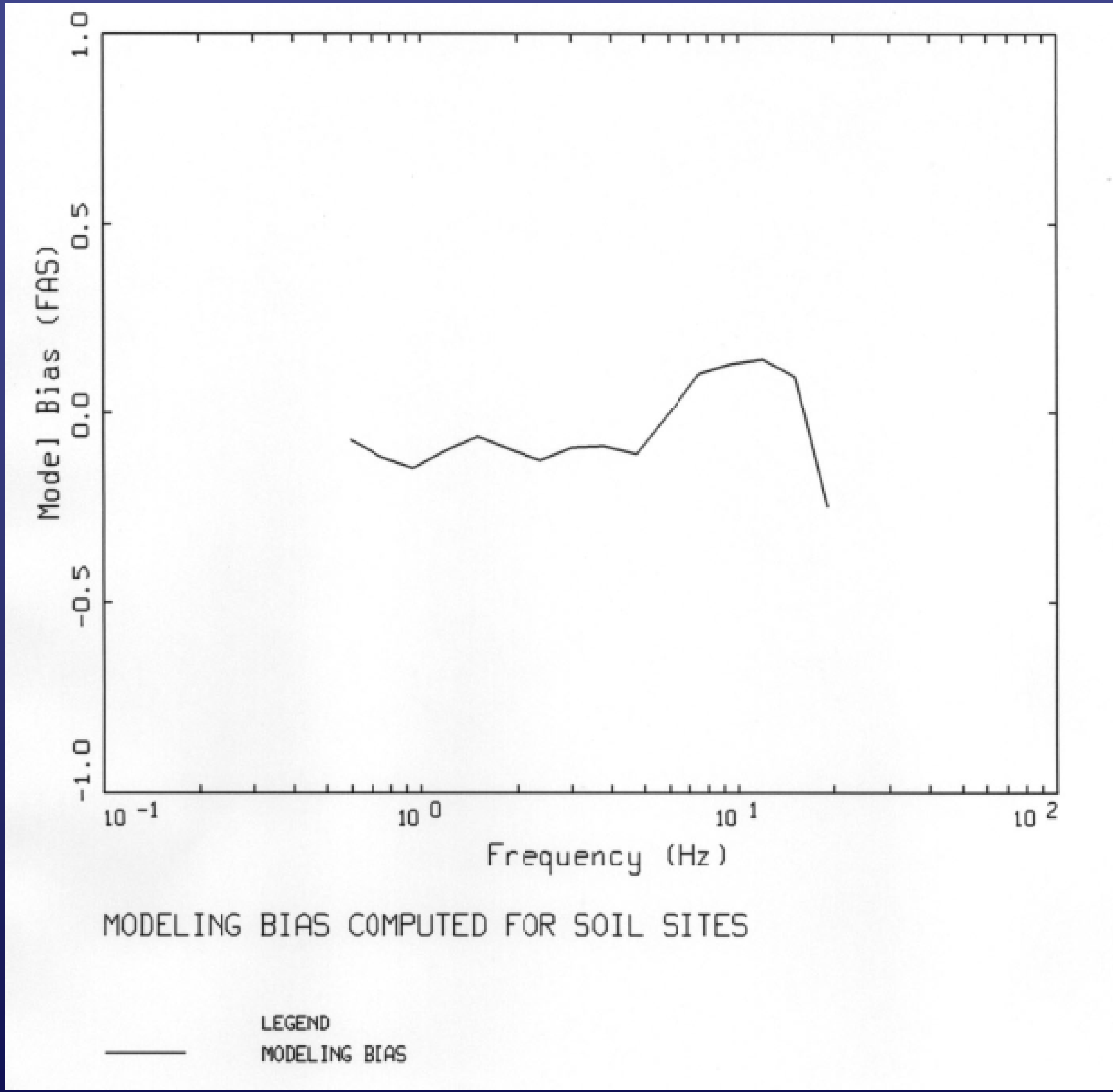
Spectral Inversion Results for Event #4



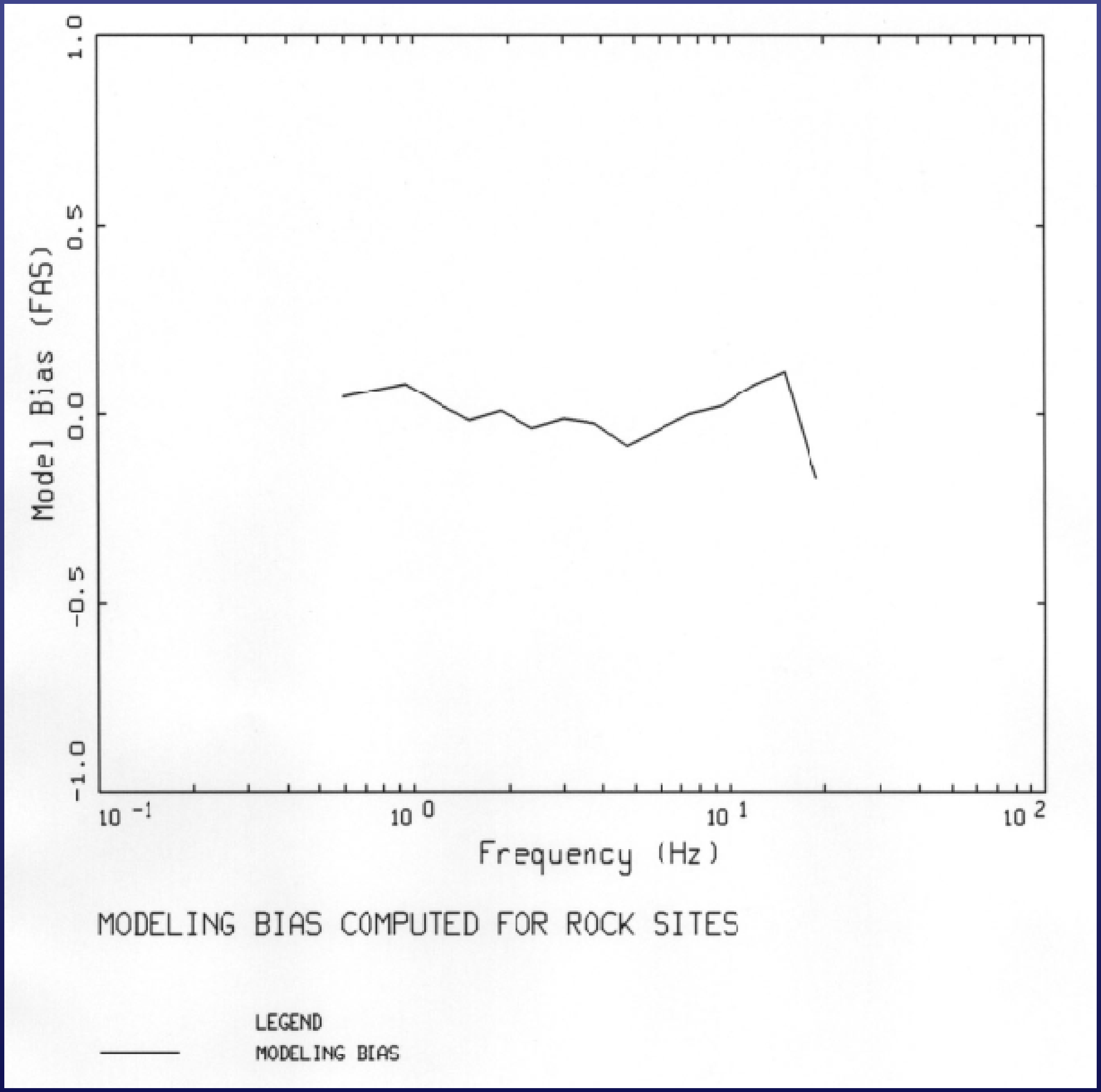
Spectral Inversion Results for Event #4



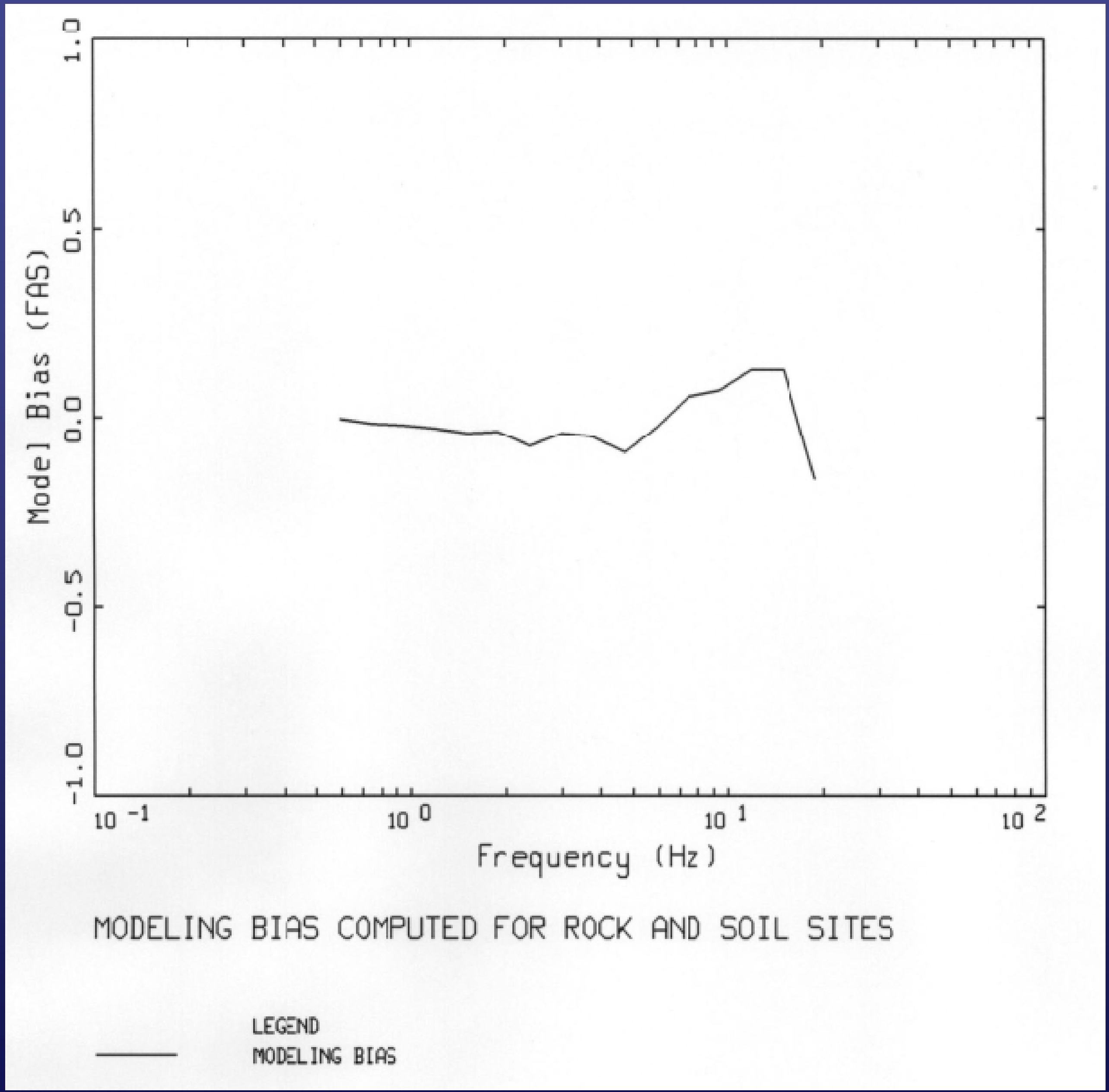
Model Bias for Soil Sites



Model Bias for Rock Sites



Model Bias for All Sites (Rock and Soil)



Final Preliminary Results

Event	Date	Event ID	Magnitude (M)	Latitude (degrees)	Longitude (degrees)	Depth (km)	Δσ (bars)
1	20010524	10224024041	3.30	40.3777	-111.9307	5.9	10.62
2	20020728	20728193840	3.59	41.7445	-111.3802	9.3	5.84
3	20030103	30103050212	3.62	41.2745	-111.8020	11.70	22.52
4	20030201	30201203731	3.15	41.8288	-112.2120	0.22	12.38
5	20030417	30417010419	4.24	39.5095	-111.8962	0.08	2.83
6	20030712	30712015440	3.50	41.2855	-111.6148	8.97	38.98
7	20031227	31227003924	3.64	39.6480	-111.9430	0.88	15.43
8	20040225	40225004104	3.38	41.9977	-111.8182	1.68	44.00
9	20040313	40313130447	3.17	39.6572	-111.9377	1.77	13.19
10	20050518	50518192147	3.29	41.4245	-111.0898	1.56	11.43
11	20050723	50723053748	3.30	41.8835	-111.6325	11.07	147.27
12	20050905	50905093155	3.00	41.0222	-111.3568	7.41	27.26
13	20051120	51120102429	2.62	41.3672	-111.6910	2.77	132.13
14	20060611	60611100150	3.41	40.2468	-111.0733	10.37	15.11
15	20061220	61220181536	3.35	41.1270	-111.5745	7.94	89.78
16	20070901	70901183202	3.92	41.6423	-112.3185	5.61	6.07
17	20071105	71105214801	3.91	39.3458	-111.6475	5.50	16.81

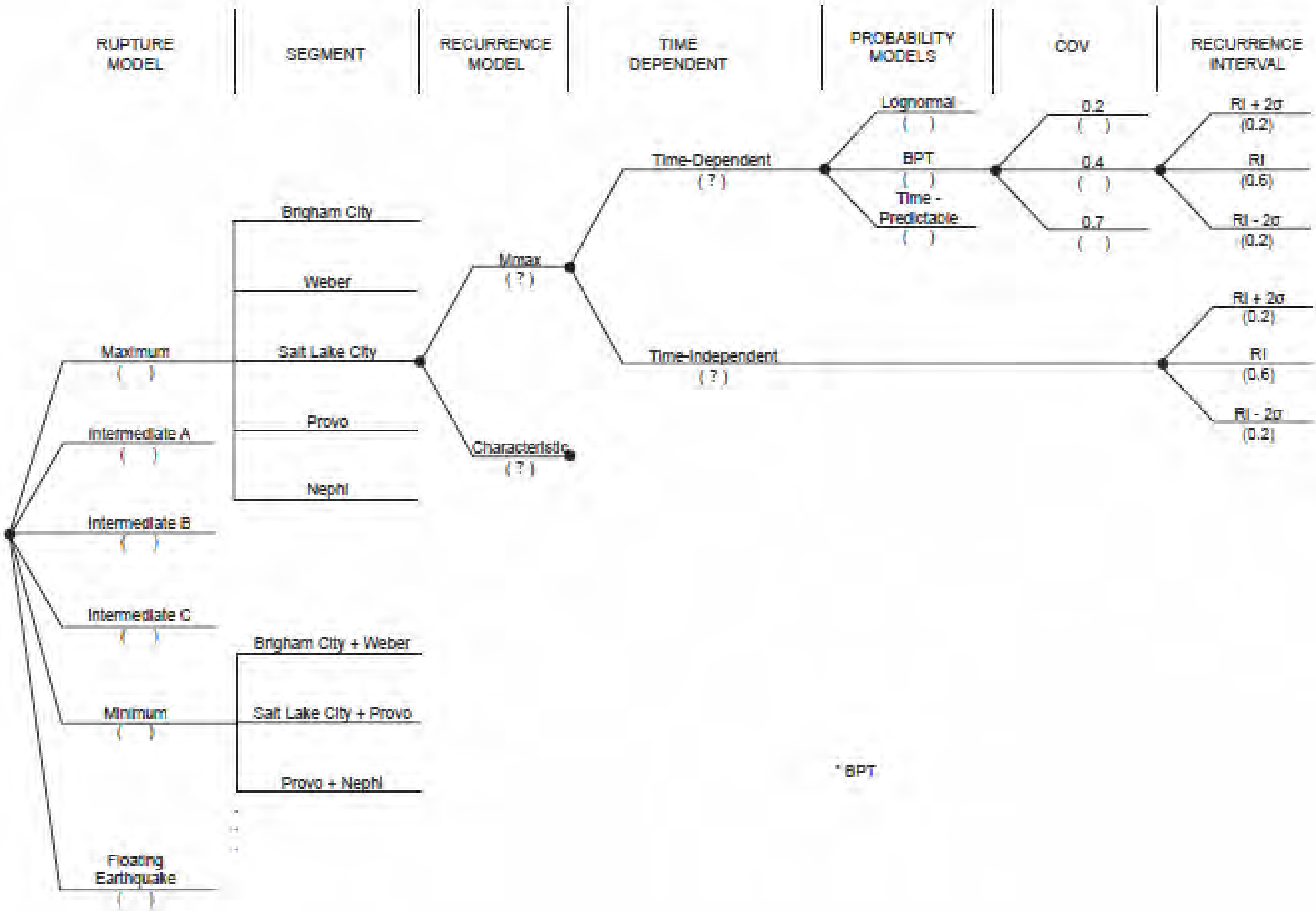
Final Inversion Results

Q_0	137.05
η	0.56
$\overline{\Delta\sigma}$ (bars)	20.1
$\overline{\kappa}$ (sec)	0.034
$\overline{\kappa}$ for rock sites (sec)	0.030
$\overline{\kappa}$ for soil sites (sec)	0.036
R0 (km)	59.88

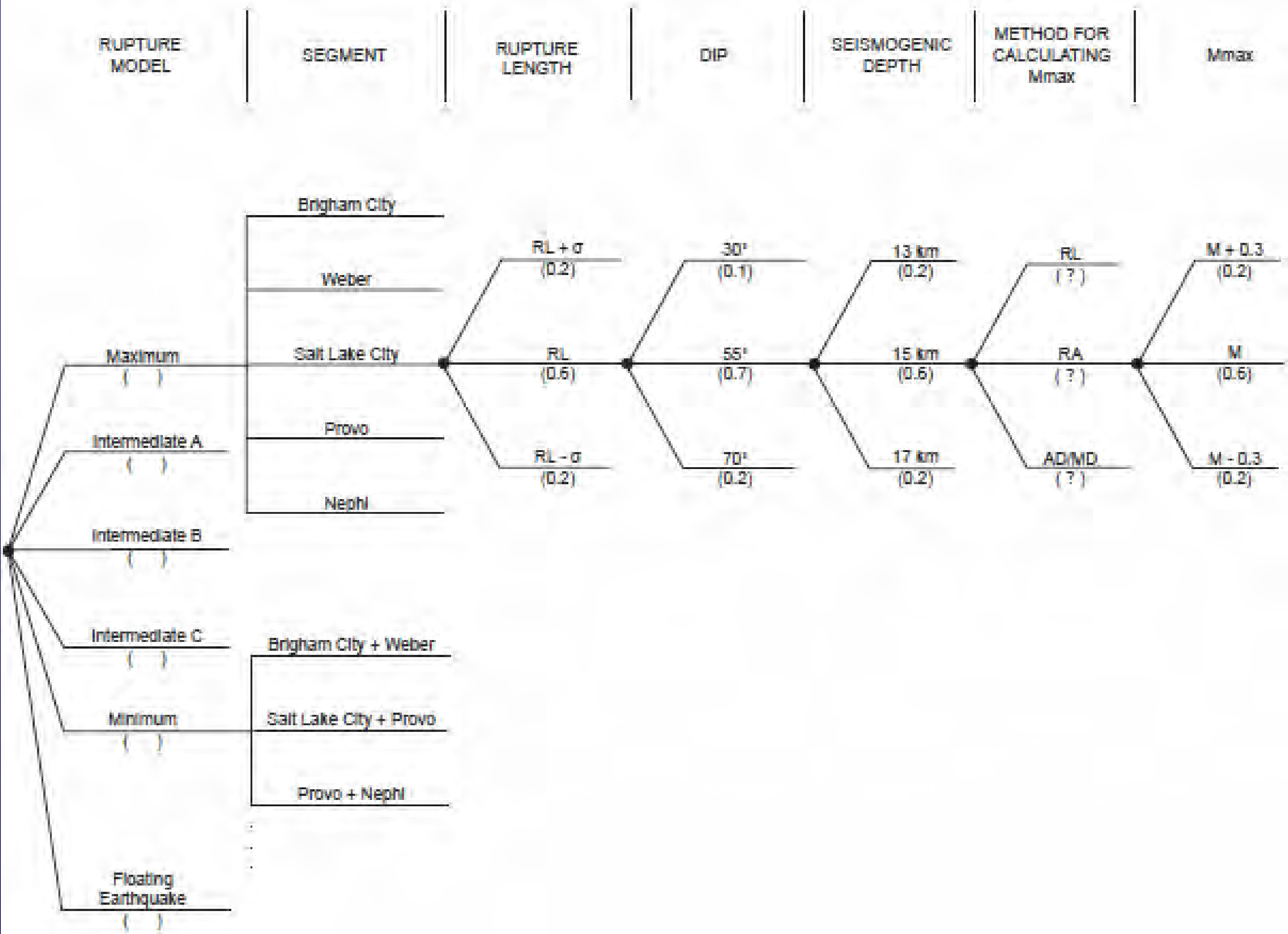
Comparison of Stress Drops

Source	Region	Magnitude	Stress Drop
Becker and Abrahamson (1997)	Worldwide	5.1 – 6.9	16 – 93 bars 29 bars (median)
WCFS et al. (1996)	Basin and Range	2.8 – 6.0	8 – 114 bars 40 bars (mean)
This study	Wasatch Front	3.0 – 4.2	3 – 147 bars 20 bars (mean)
Silva et al. (1997)	California	5.7 – 7.3	59 bars (mean)

Wasatch Fault Central Segments Logic Tree for Recurrence



Wasatch Fault Central Segments Logic Tree for Mmax



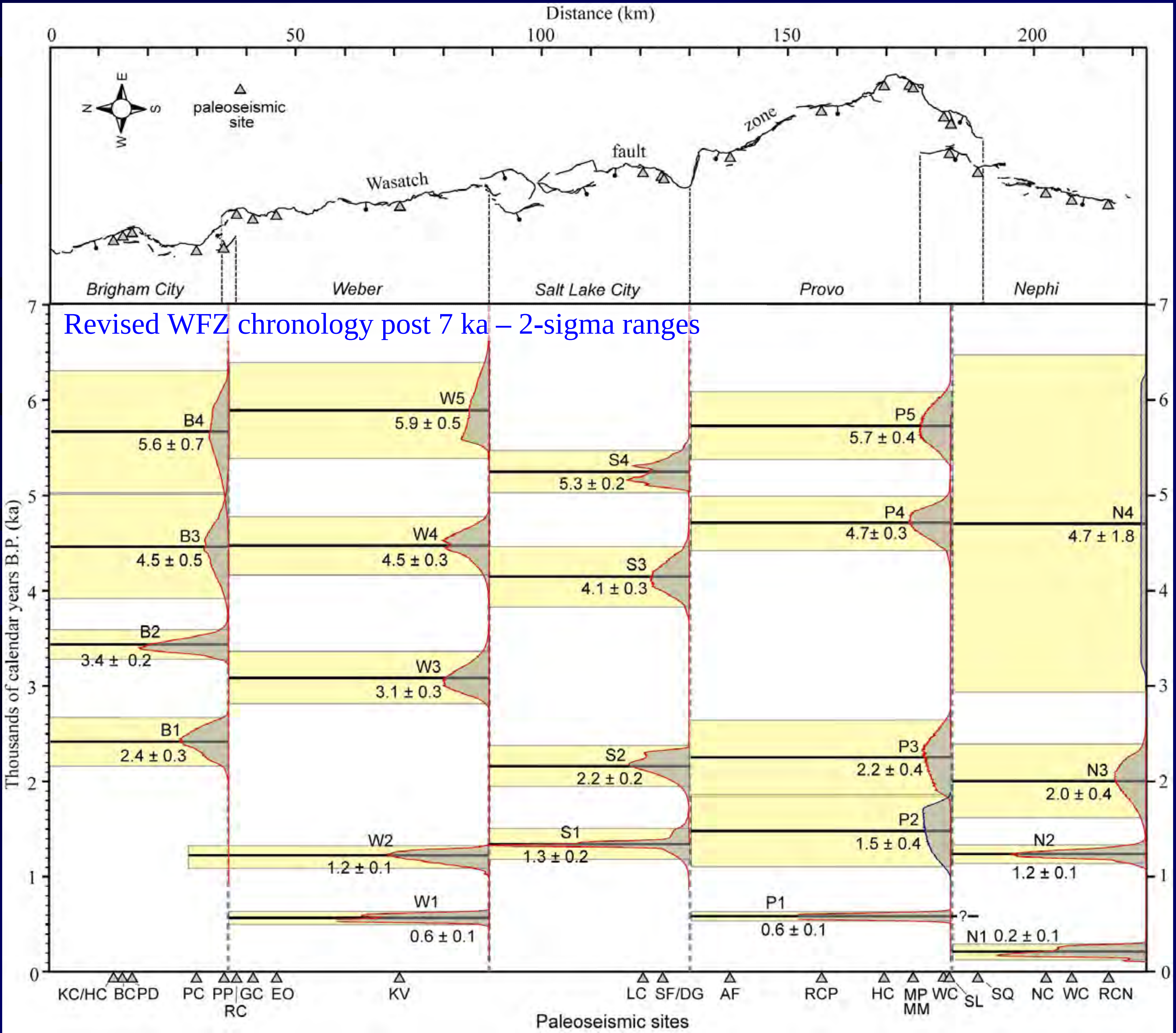
Strawman Rupture Models for the Central Wasatch Fault

Paleoseismology Subgroup

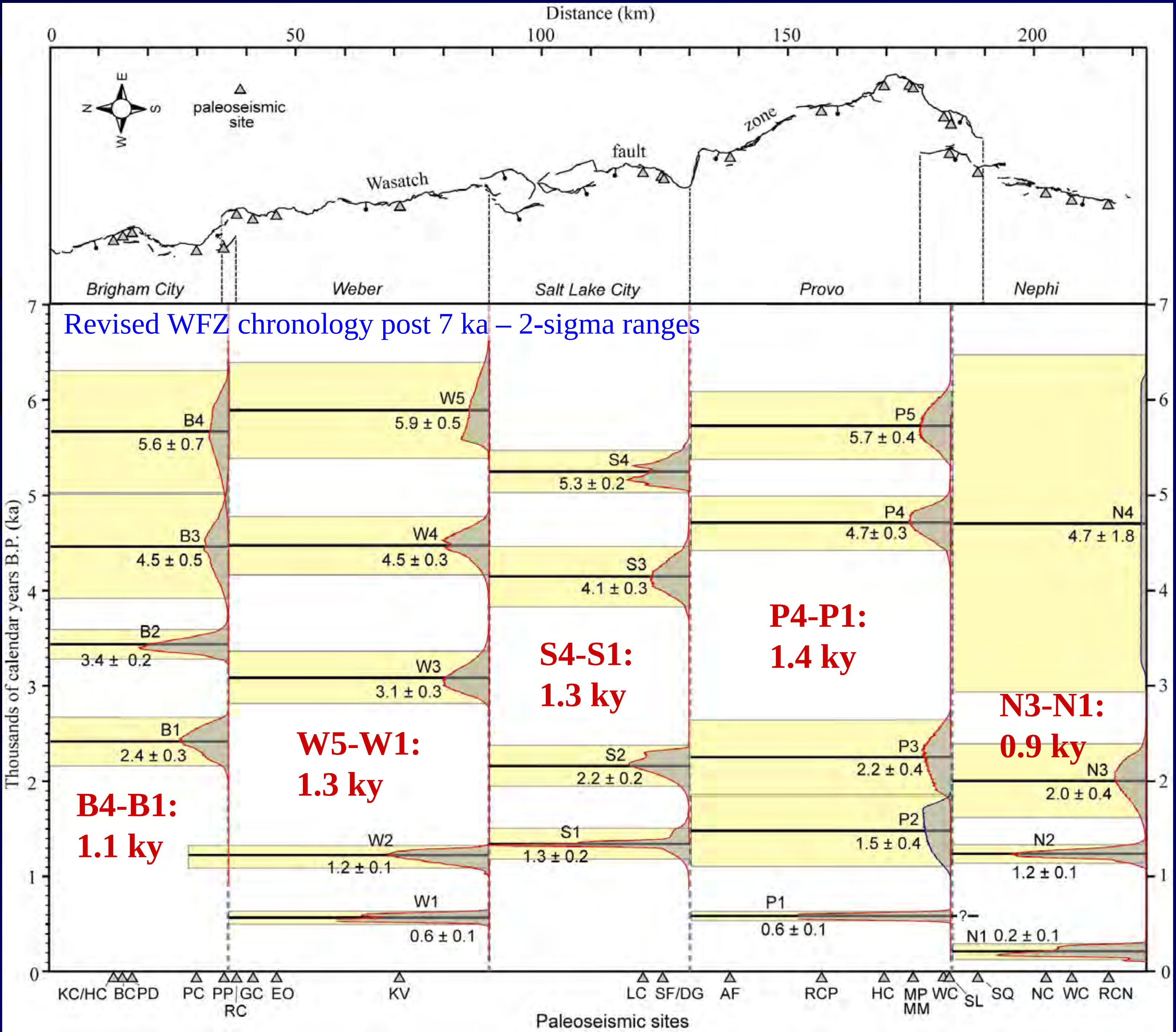
(Chris DuRoss, Steve Personius, Tony Crone, Susan Olig, and Bill Lund)

Working Group on Utah Earthquake Probabilities, Feb. 2011

Final WFZ Chronology



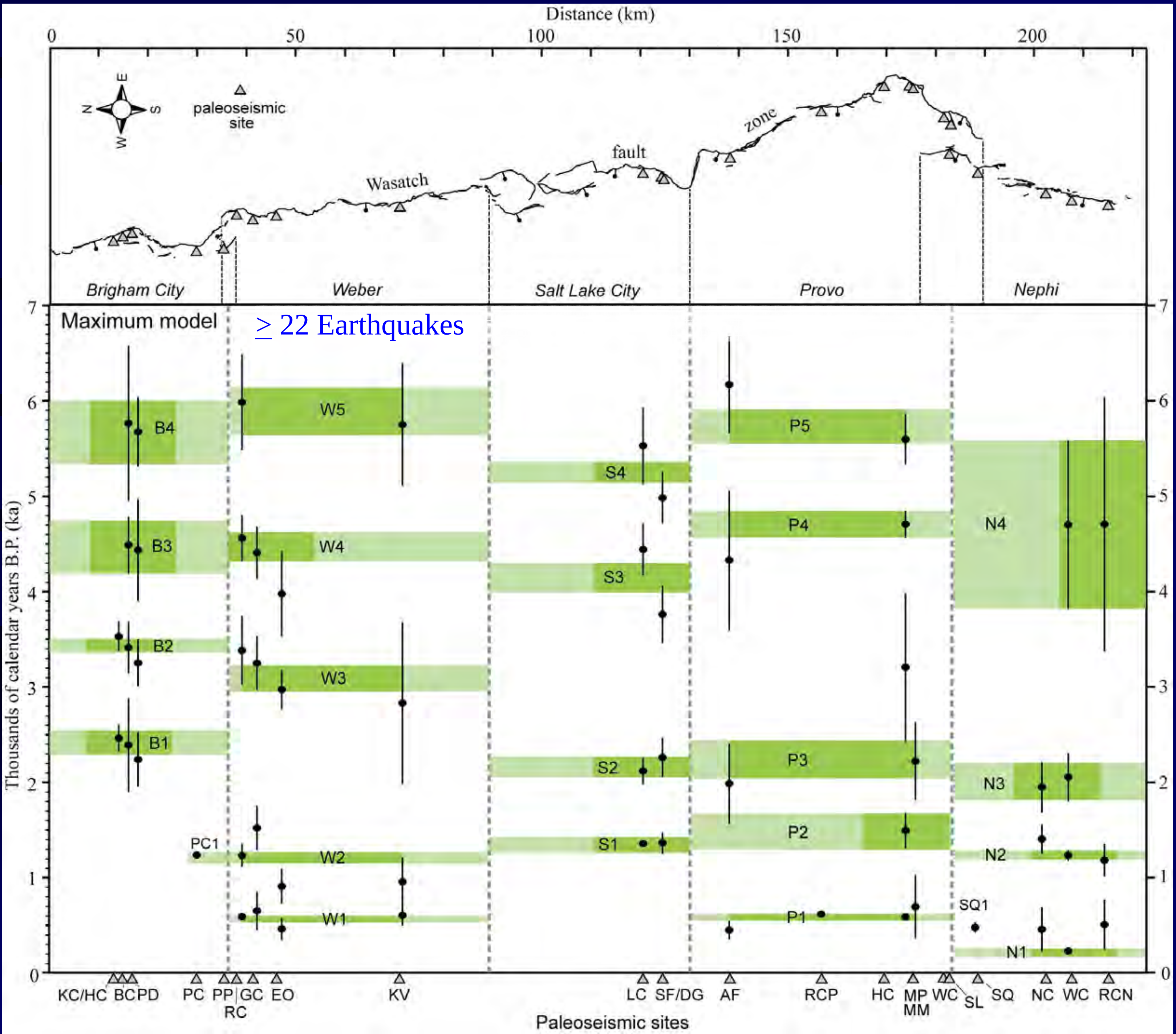
Final WFZ Chronology



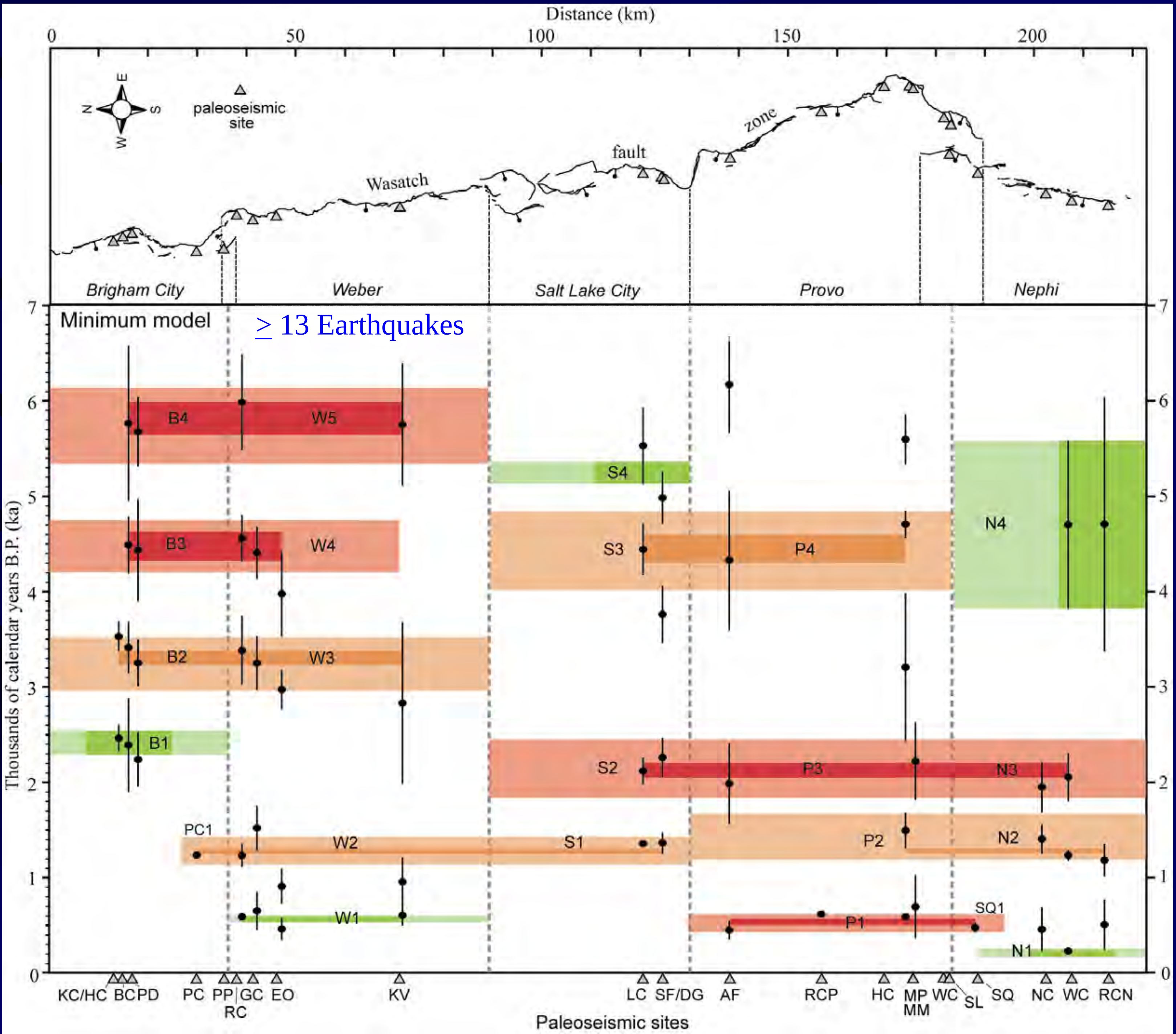
Strawman Rupture Models

- Maximum. 22 single-segment ruptures. Uncertainties in segment-boundary locations (± 3–8.5 km) allow for leaky-boundary (spill-over) ruptures. Minimum rupture lengths based on paleoseismic sites.
- Minimum. 13 earthquakes: 7 multi-segment, 6 single-segment. Fewest possible ruptures generally based on earthquake timing (PDF overlap). Generally considered two-segment ruptures (with exception).
- Intermediate. 19-20 earthquakes. Mostly single-segment ruptures, keeping "preferred" multi-segment ruptures B3+W4 and B4+W5 based on earthquake timing data (PDF overlap), large per-event displacements, and segment boundary. Variations:
  - Intermediate A: **S2+P3**; N3
  - Intermediate B: S2; **P3+N3**
  - Intermediate C: S2; P3; N3

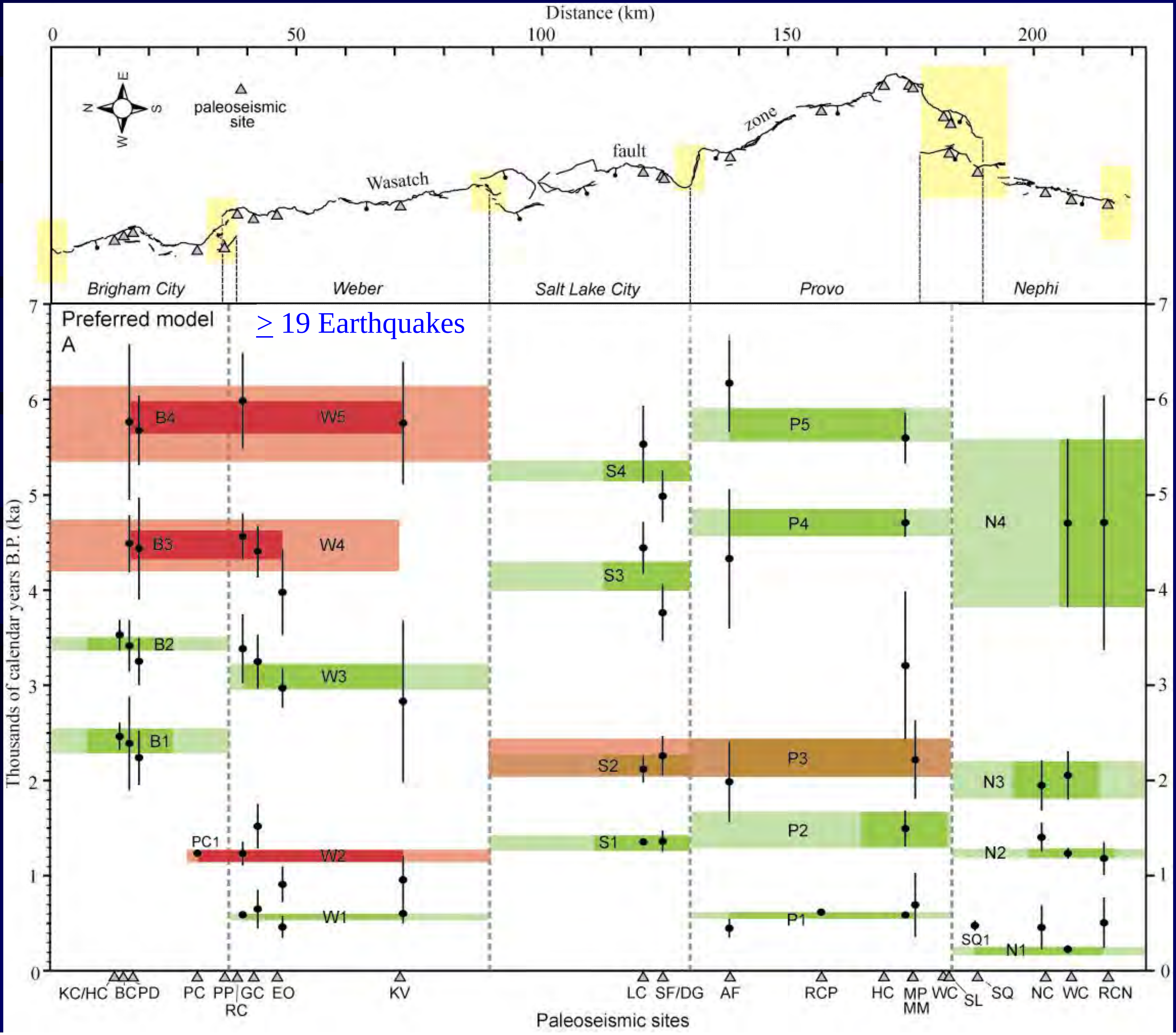
Maximum Rupture Model



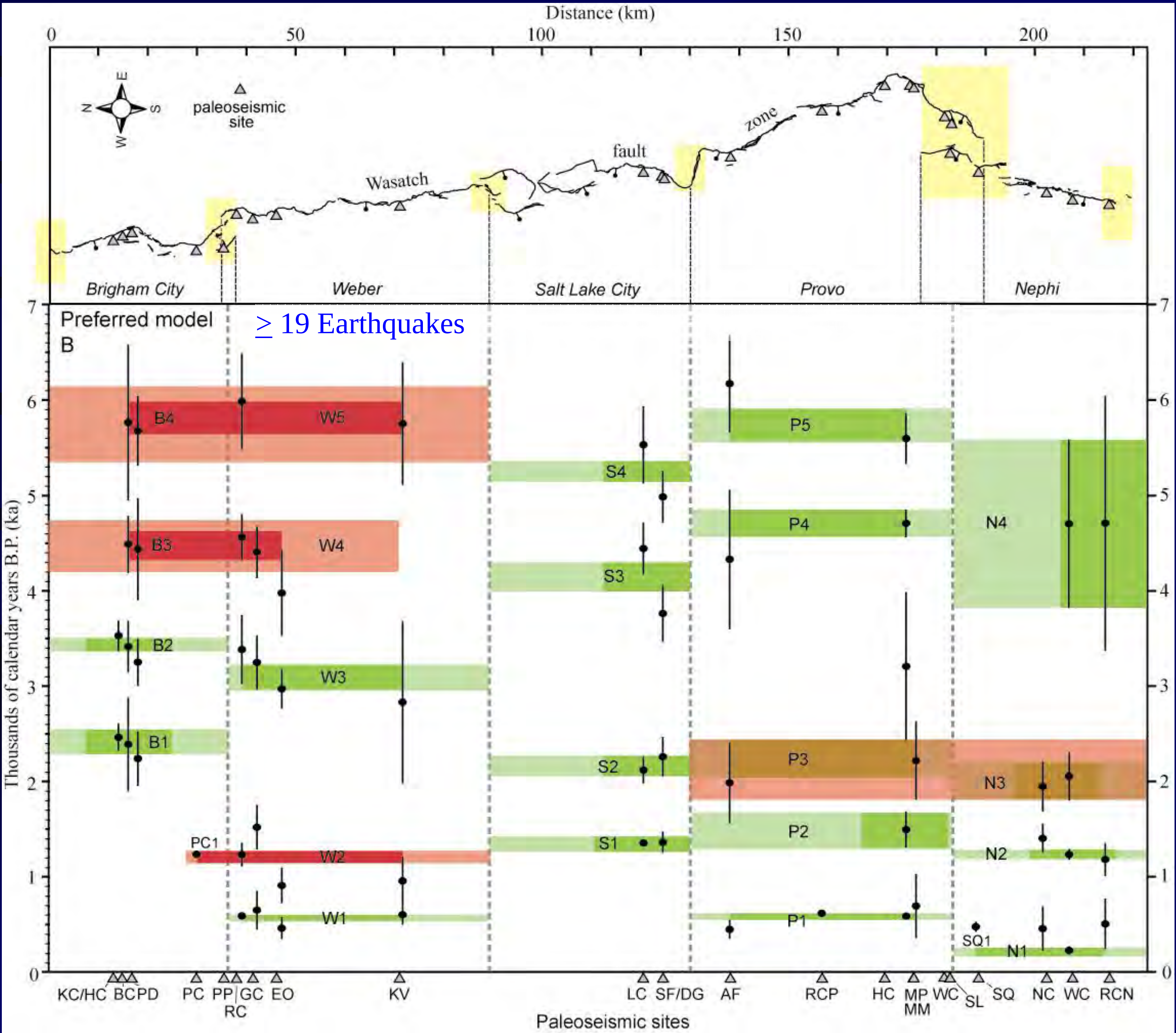
Minimum Rupture Model



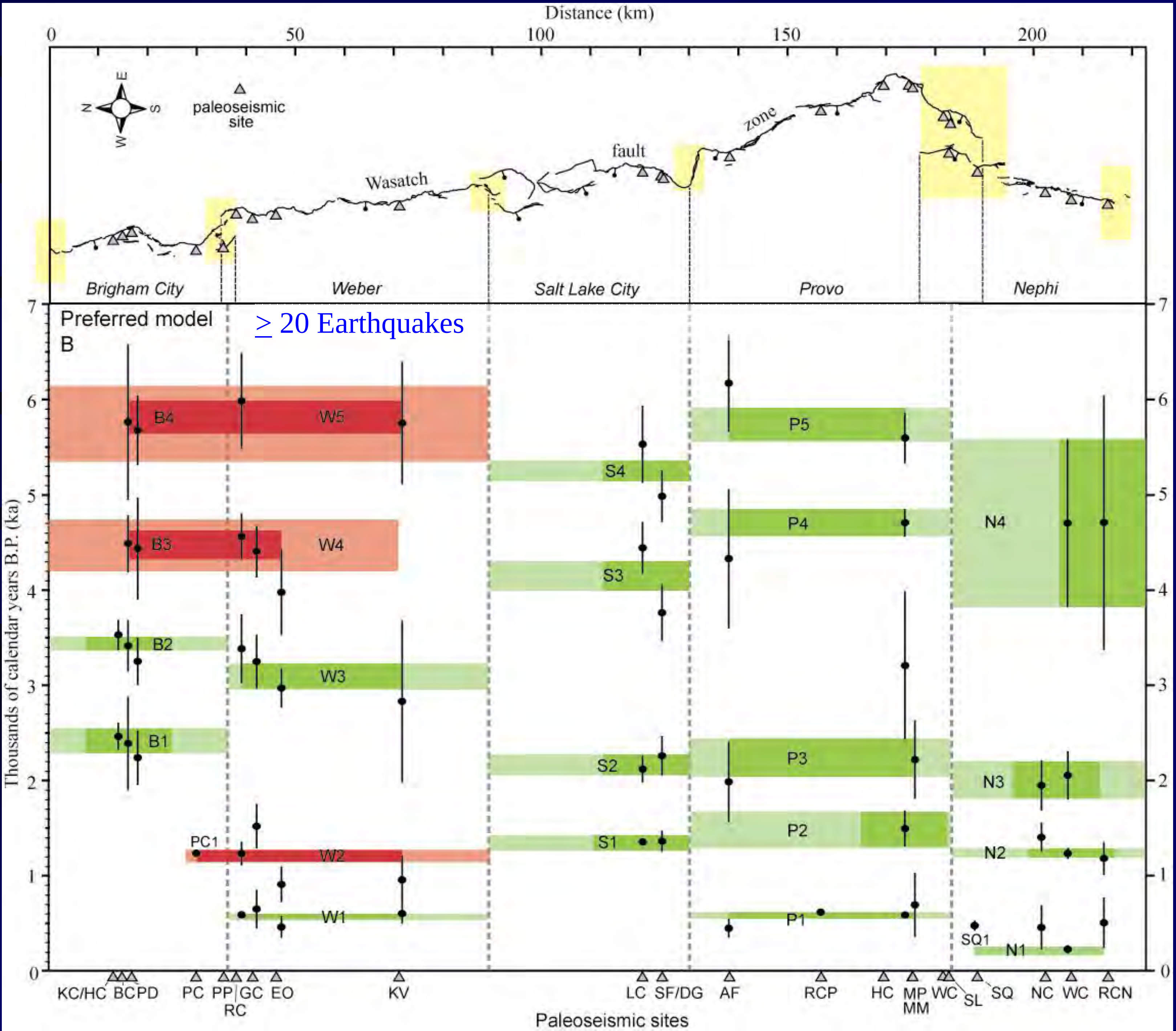
Intermediate Model A



Intermediate Model B



Intermediate Model C



Path Forward

Rupture Scenario	Weight
Maximum Rupture Model (22 EQs <6.4 ka)	___%
Minimum Rupture Model (13 EQs <6.4 ka)	___%
Intermediate Rupture Model A (S2-P3 combined (19 EQs <6.4 ka)	___%
Intermediate Rupture Model B (P3-N3 combined (19 EQs <6.4 ka)	___%
Intermediate Rupture Model C (S2/P3/N3 separate (20 EQs <6.4 ka)	___%

- -

Unsegmented Earthquake Model(?)	___%

Path Forward

Rupture Scenario	Weight
Maximum Rupture Model (22 EQs <6.4 ka)	**60%**

- Long term history of fault; displacement and timing data do support multi-segment ruptures, but not convincing; spill-over ruptures probably more common, which can be addressed by uncertainty in segment-boundary locations

Minimum Rupture Model (13 EQs <6.4 ka) 5%

- Unlikely scenario(?); 7 of 13 ruptures greater than 70 km long (M_{SRL} 7.2–7.5); conflicts with prominent segment boundaries (unless slip still decreases at segment ends) and along-strike changes in fault-scarp character (size, geomorphology)

Intermediate Rupture Model A (S2-P3 combined (19 EQs <6.4 ka) **10%**

Intermediate Rupture Model B (P3-N3 combined (19 EQs <6.4 ka) **5%**

Intermediate Rupture Model C (S2/P3/N3 separate (20 EQs <6.4 ka) **20%**

- B4-W5 and B3-B4 have compelling evidence (displacements, similarity in event times, PDF overlap), but given broad timing uncertainties (± 500 –700 yr) still prefer individual-segment ruptures (with spill over). Prefer S2/P3/N3 as separate events (C), over 85-99-km-long ruptures in A and B. Prefer P3-S2 (but maybe not full SLCS rupture?) over P3-N3 considering lack of evidence for P3 on northern Nephi.

Path Forward

Olig

Rupture Scenario	Weight
Maximum Rupture Model (22 EQs <6.4 ka)	50%
Minimum Rupture Model (13 EQs <6.4 ka)	10%
Intermediate Rupture Model A (S2-P3 combined (19 EQs <6.4 ka)	5%
Intermediate Rupture Model B (P3-N3 combined (19 EQs <6.4 ka)	5%
Intermediate Rupture Model C (S2/P3/N3 separate (20 EQs <6.4 ka)	10%

- -

Unsegmented Earthquake Model(?)	___%

Path Forward

Crone

Rupture Scenario	Weight
Maximum Rupture Model (22 EQs <6.4 ka)	40%
Minimum Rupture Model (13 EQs <6.4 ka)	5%
Intermediate Rupture Model A (S2-P3 combined (19 EQs <6.4 ka)	10%
Intermediate Rupture Model B (P3-N3 combined (19 EQs <6.4 ka)	20%
Intermediate Rupture Model C (S2/P3/N3 separate (20 EQs <6.4 ka)	25%

- -

Unsegmented Earthquake Model(?) ___%

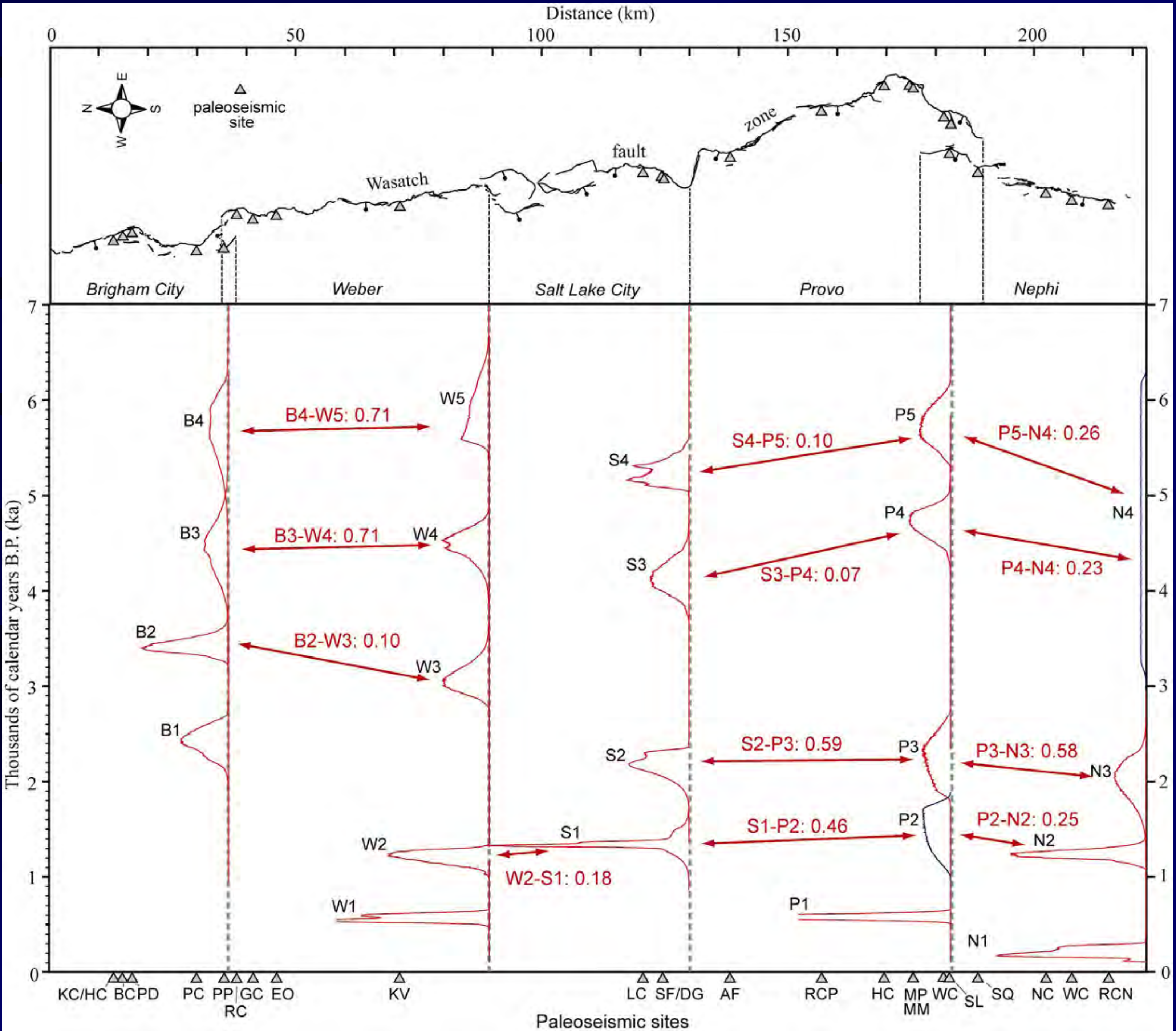
Path Forward

Rupture Scenario	Weight
Maximum Rupture Model (22 EQs <6.4 ka)	40-60%
Minimum Rupture Model (13 EQs <6.4 ka)	5-10%
Intermediate Rupture Model A (S2-P3 combined (19 EQs <6.4 ka)	5-10%
Intermediate Rupture Model B (P3-N3 combined (19 EQs <6.4 ka)	5-20%
Intermediate Rupture Model C (S2/P3/N3 separate (20 EQs <6.4 ka)	10-20%

- -

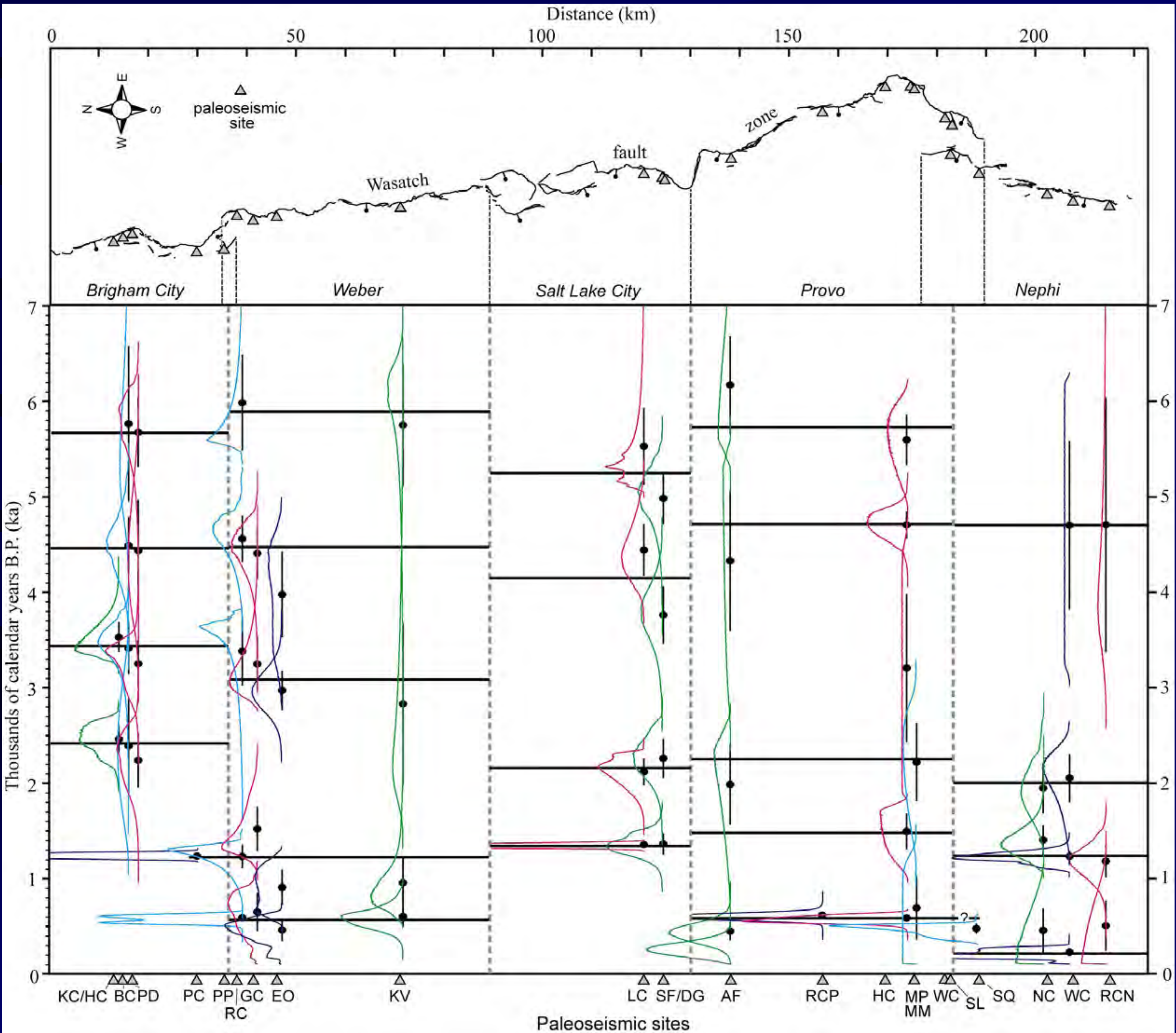
Unsegmented Earthquake Model(?)	___%

PDF Overlap

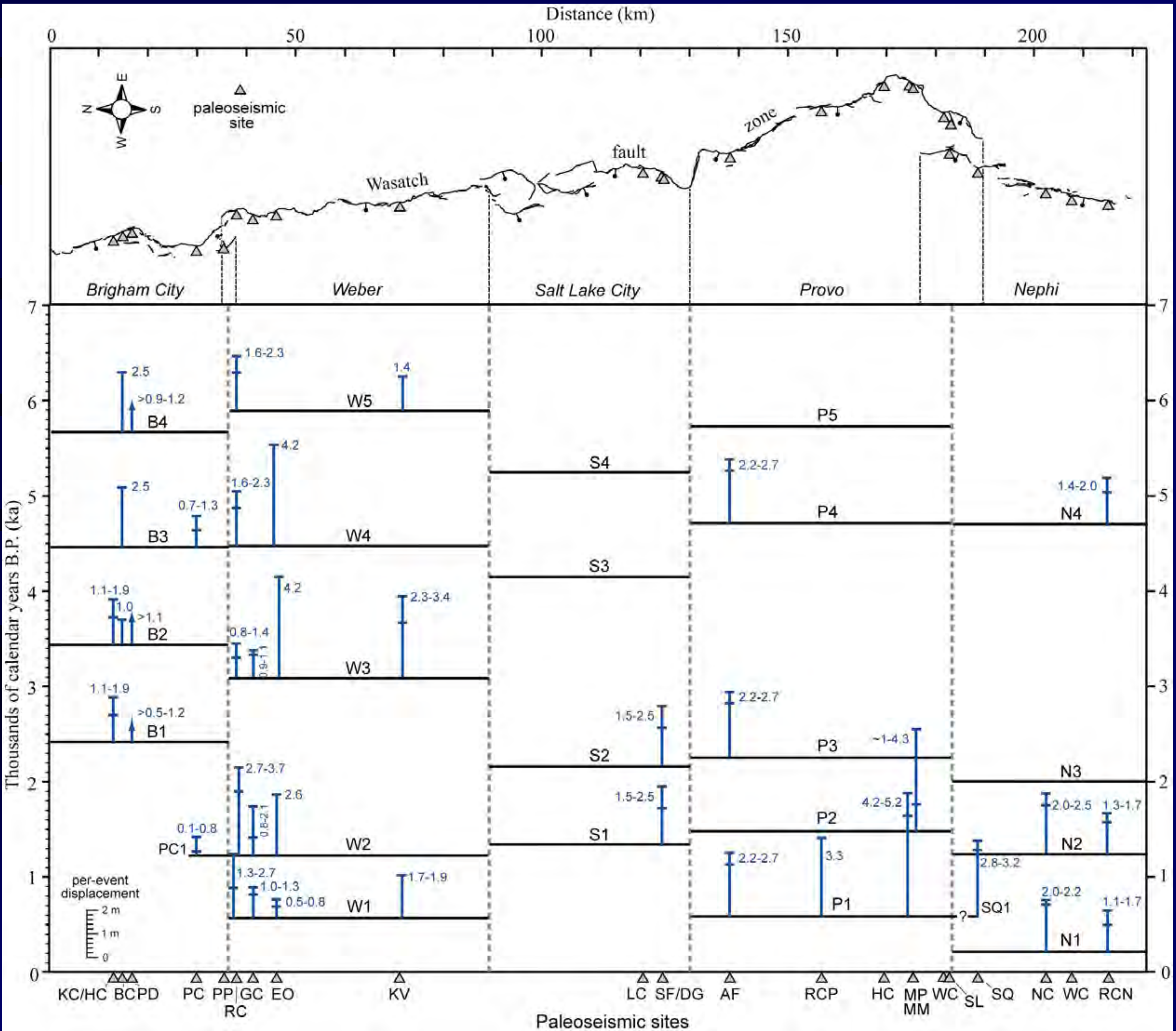


Distance (km)
0
50
100
150
200
paleoseismic site
N
S
E
W
Wasatch
fault
zone
Brigham City
Weber
Salt Lake City
Provo
Nephi
Thousands of calendar years B.P. (ka)
B4
B3
B2
B1
W5
W4
W3
W2
W1
S4
S3
S2
S1
P5
P4
P3
P2
P1
N4
N3
N2
N1
B4-W5: 0.71
B3-W4: 0.71
B2-W3: 0.10
W2-S1: 0.18
S4-P5: 0.10
S3-P4: 0.07
S2-P3: 0.59
S1-P2: 0.46
P5-N4: 0.26
P4-N4: 0.23
P3-N3: 0.58
P2-N2: 0.25
KC/HC
BC
PD
PC
PP
RC
GC
EO
KV
LC
SF/DG
AF
RCP
HC
MP
MM
WC
SL
SQ
NC
WC
RCN
Paleoseismic sites

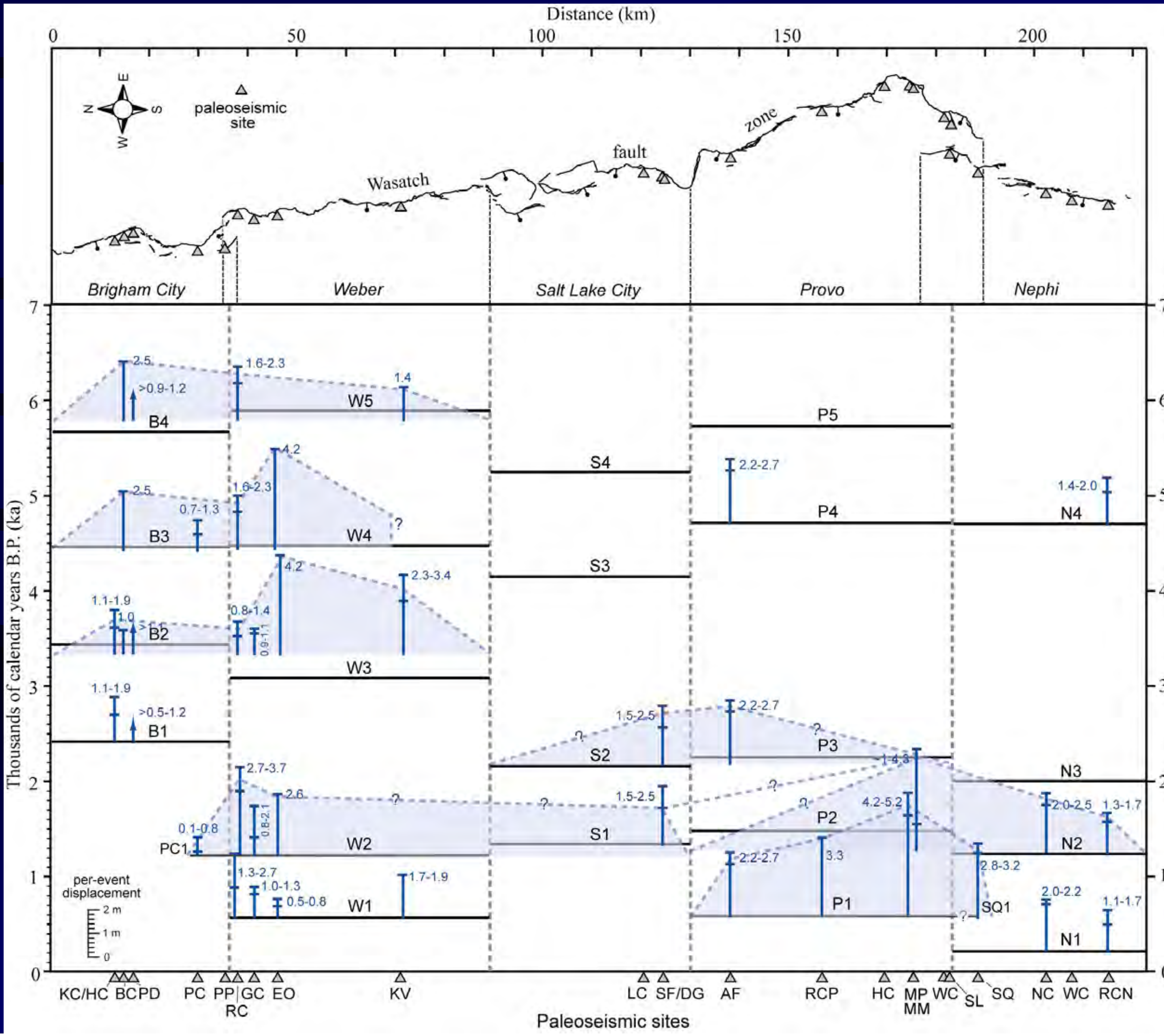
Site PDFs (OxCal)



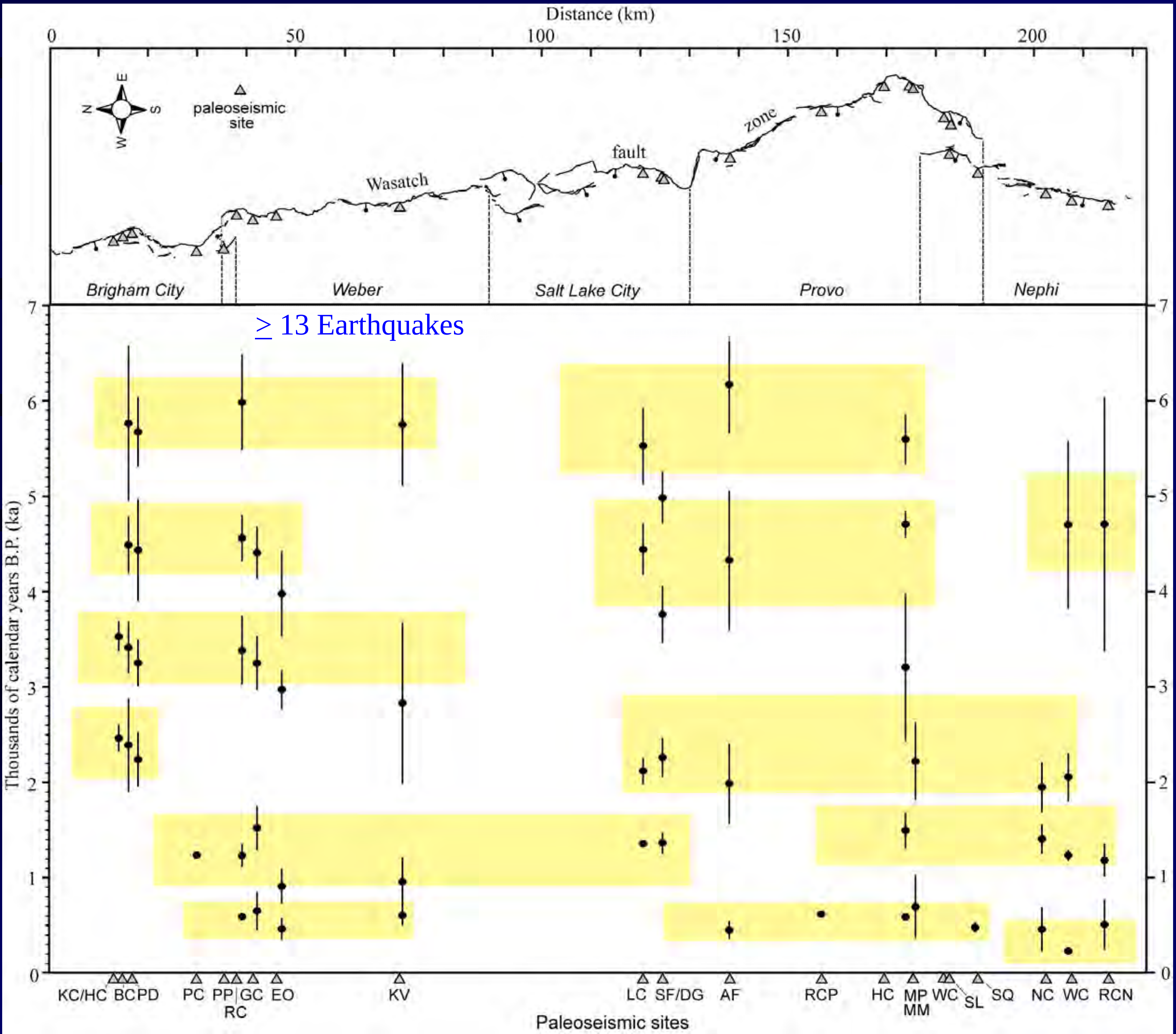
Per-event Displacements



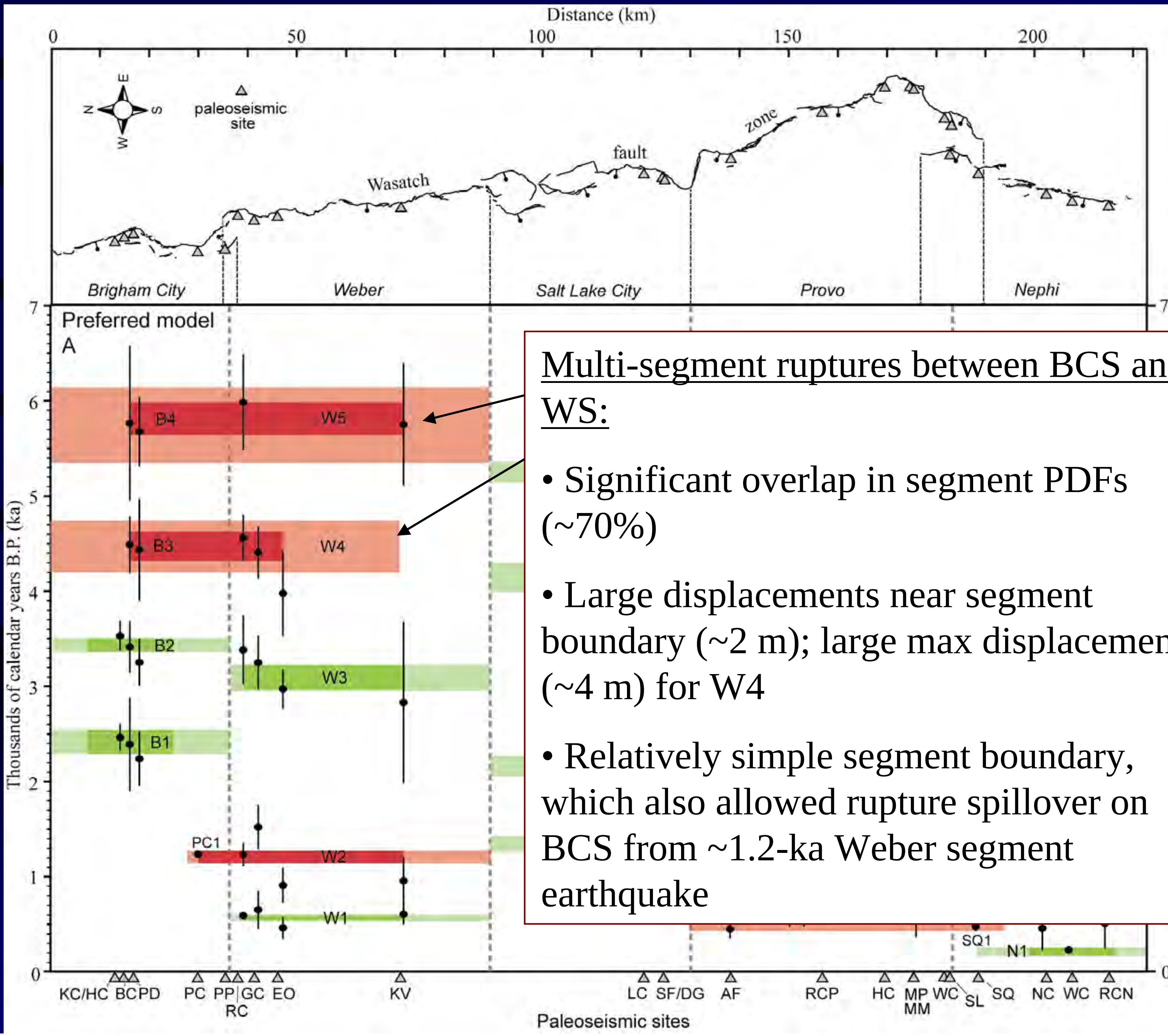
Along-Strike Displacement



Floating Earthquake Model (test)



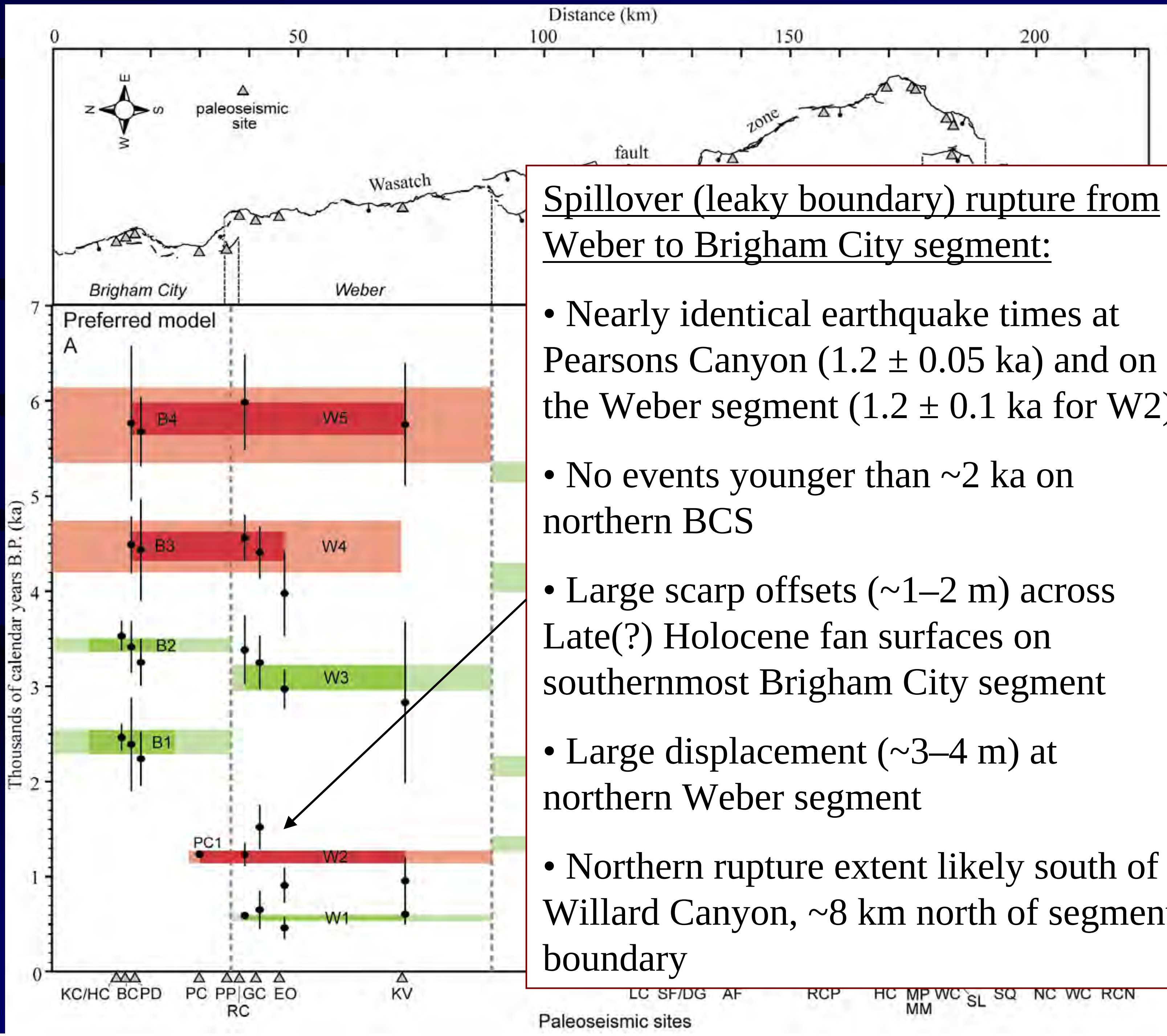
Intermediate Rupture Model



Multi-segment ruptures between BCS and WS:

- Significant overlap in segment PDFs (~70%)
- Large displacements near segment boundary (~2 m); large max displacement (~4 m) for W4
- Relatively simple segment boundary, which also allowed rupture spillover on BCS from ~1.2-ka Weber segment earthquake

Intermediate Rupture Model



Spillover (leaky boundary) rupture from Weber to Brigham City segment:

- Nearly identical earthquake times at Pearsons Canyon (1.2 ± 0.05 ka) and on the Weber segment (1.2 ± 0.1 ka for W2)
- No events younger than ~2 ka on northern BCS
- Large scarp offsets (~1–2 m) across Late(?) Holocene fan surfaces on southernmost Brigham City segment
- Large displacement (~3–4 m) at northern Weber segment
- Northern rupture extent likely south of Willard Canyon, ~8 km north of segment boundary

The Wasatch Fault Zone End Segments

(Malad City, Clarkston Mountain, Collinston, Levan, & Fayette)

Geologic and Paleoseismic Constraints on Displacement, Slip Rate, and Recurrence

Michael Hylland
Utah Geological Survey

Working Group on Utah Earthquake Probabilities – February 2011

Northern Segments

Malad City Segment

Paleoseismic data: none

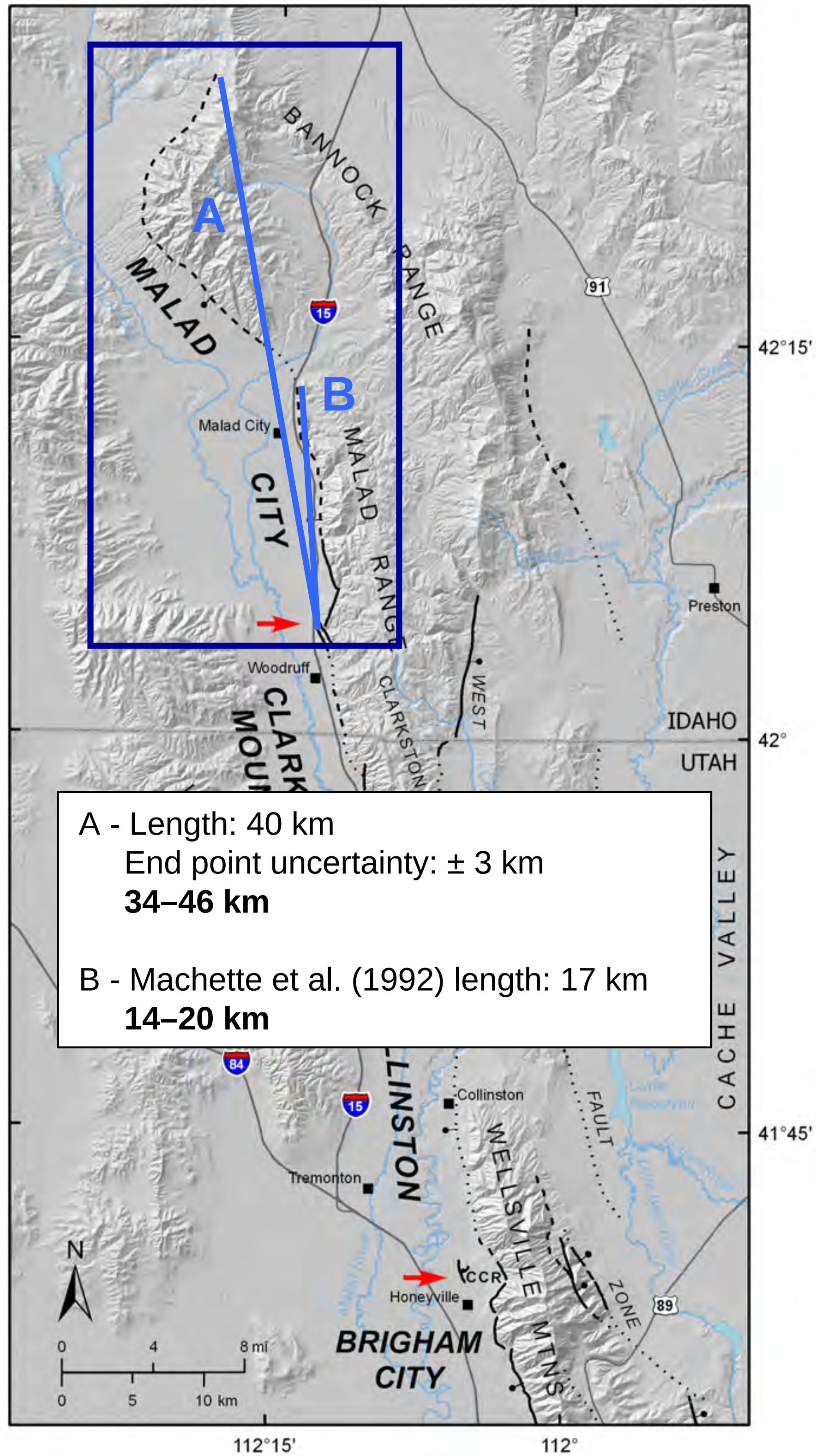
Geologic constraints:
•Bonneville lake-cycle deposits are not faulted
•Fault scarps are present on late Quaternary deposits (“older” alluvium)
•Steep range-front geomorphology
•Steep, linear gravity gradients

Earthquake timing:
Geologic data suggest active faulting during the late Pleistocene (pre-Bonneville)

Slip rate:
•Database slip rate category: <0.2 mm/yr
•Slip rate estimate:
≤1.5 m in >18,000 yr = 0.08 mm/yr (max)

Recurrence interval: NA (no individual earthquake timing data)

Sources:
Cluff et al. (1974), Machette et al. (1992), Pope et al. (2001)

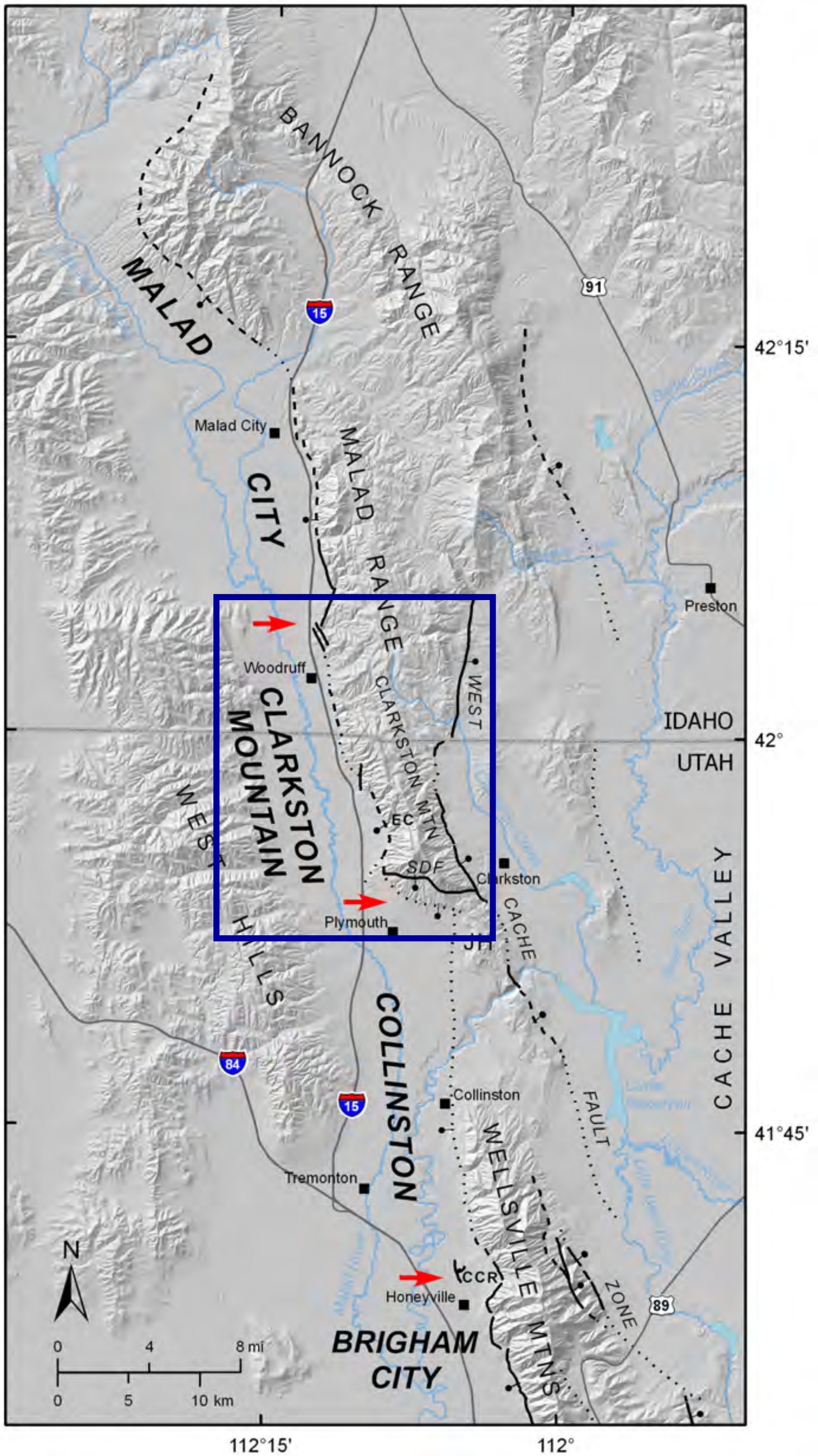


Northern Segments

Clarkston Mountain Segment

Paleoseismic data:
•Field reconnaissance
•Scarp profiling and empirical analysis
    •Elgrove Canyon
    •Composite scarp (2 or perhaps 3 events)
    •MRE & PE surface offset ≈2 m

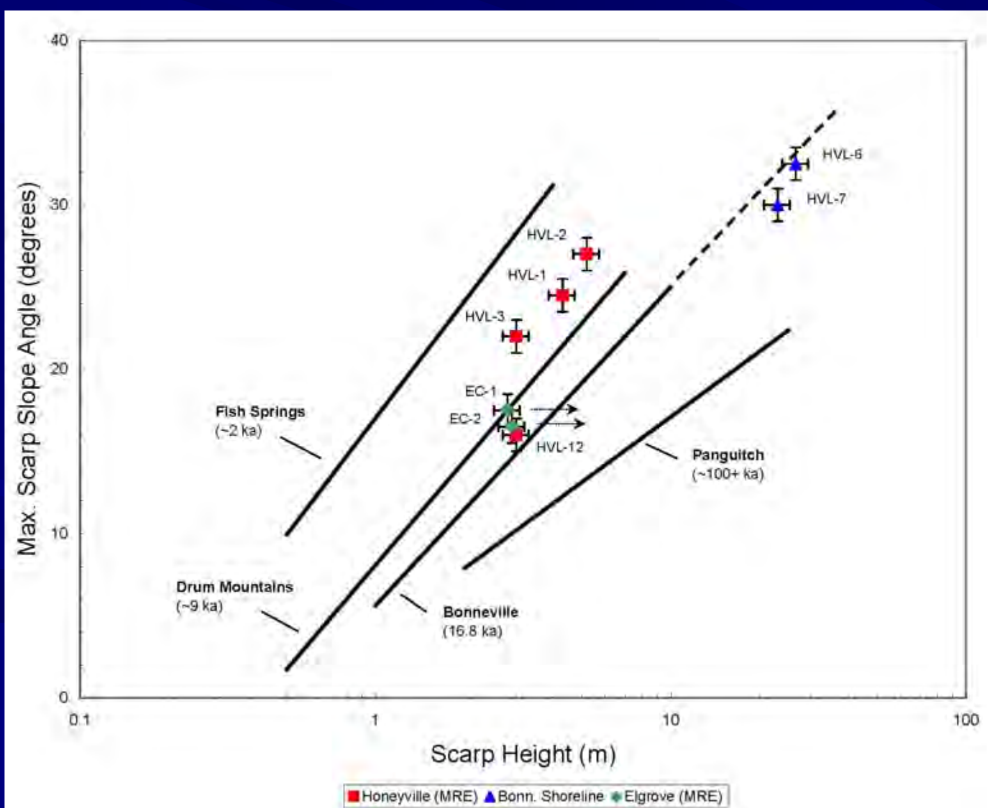
Geologic constraints:
•Bonneville lake-cycle deposits are not faulted
•Fault scarps are present on late Quaternary deposits ("Bonneville and older" alluvium)
•Steep range-front geomorphology
•Steep, linear gravity gradients

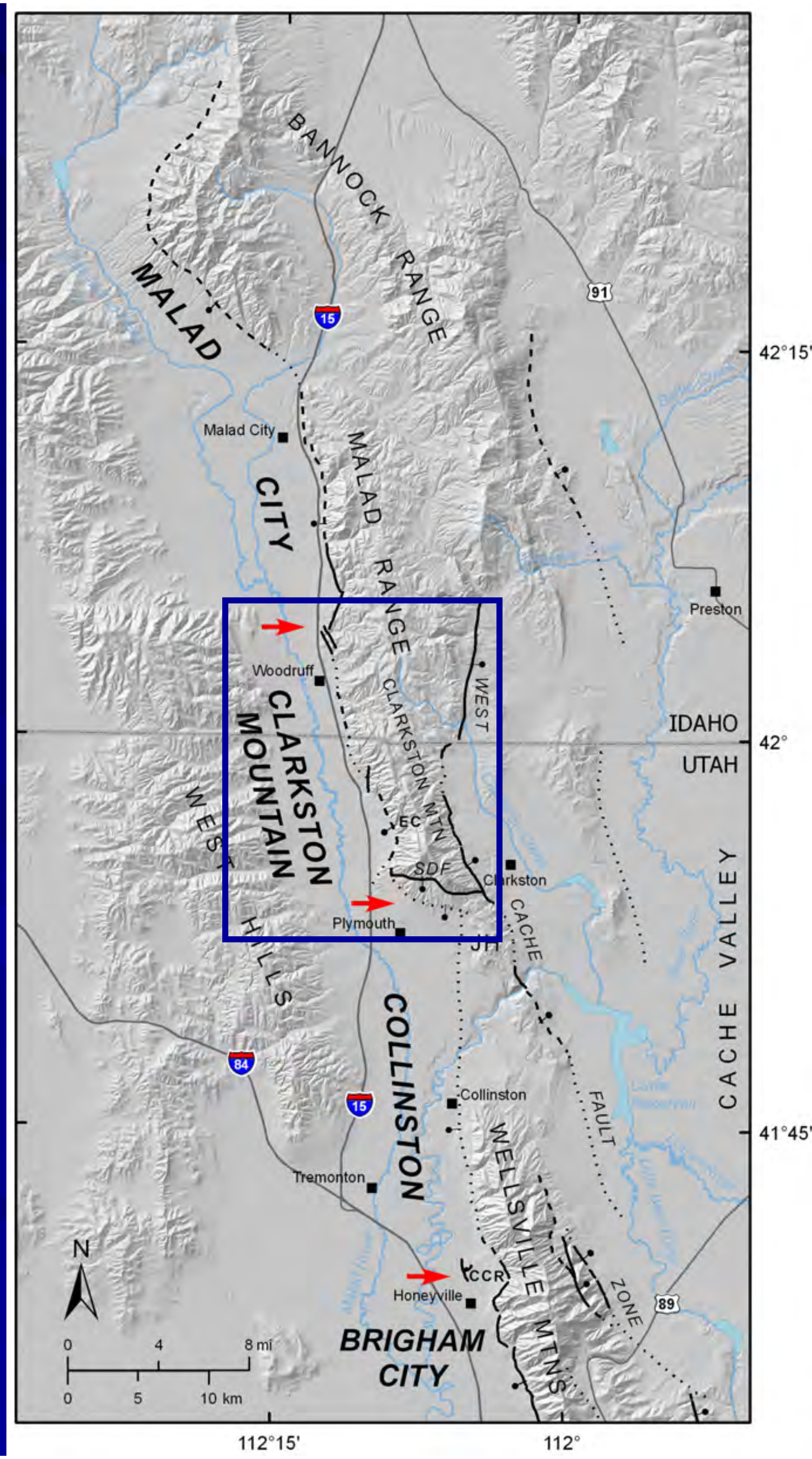


Northern Segments

Clarkston Mountain Segment

Earthquake timing:
•MRE—empirical scarp profile analysis indicates early Holocene (likely a minimum age estimate)
•PE timing unknown
•Geologic data suggest active faulting during the late Pleistocene (during or before end of Bonneville lake cycle)





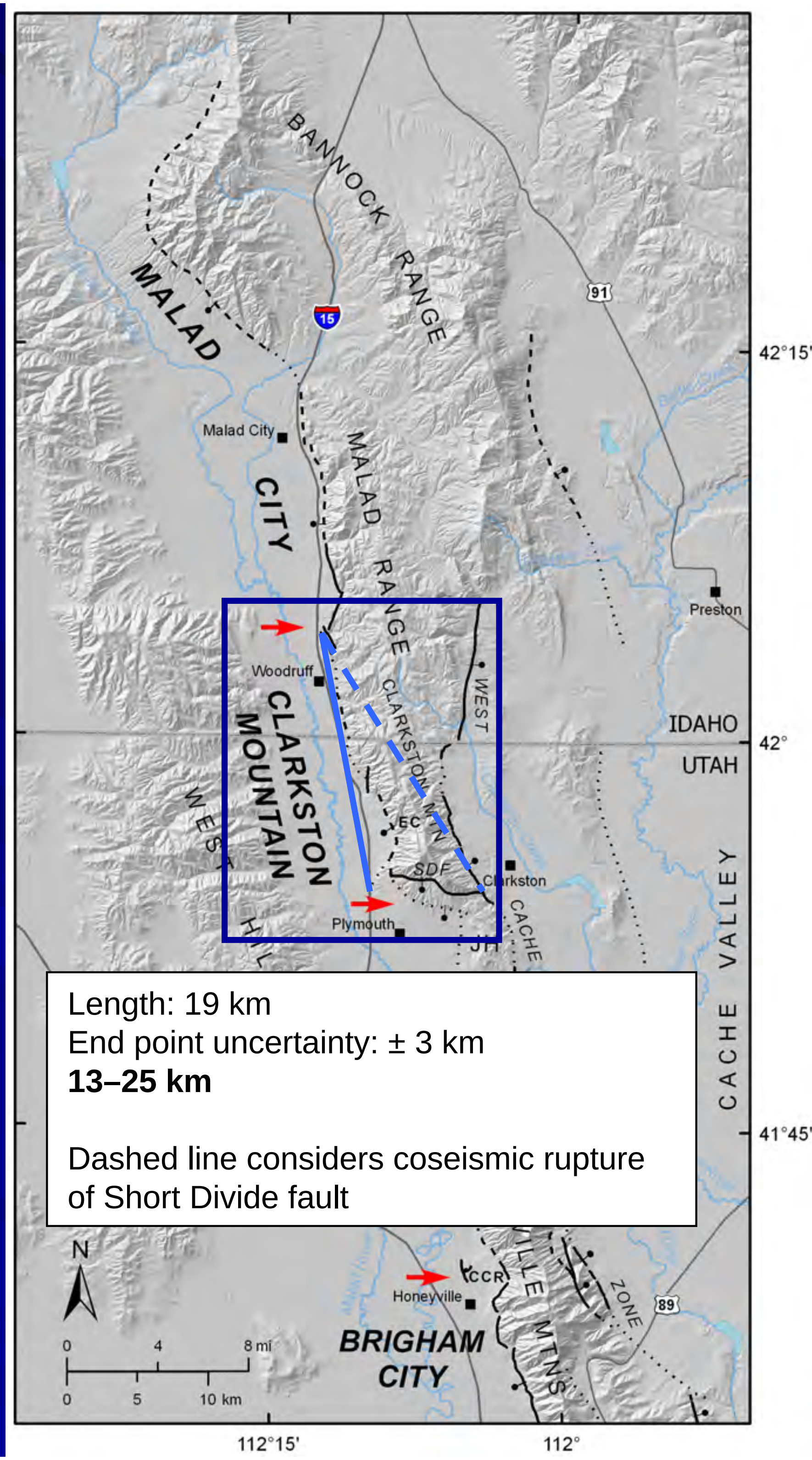
Northern Segments

Clarkston Mountain Segment

Slip rate:
•Database slip rate category: <0.2 mm/yr
•Slip rate estimate:
2 m in >18,000 yr = 0.1 mm/yr (max)

Recurrence interval: NA (MRE timing poorly constrained, no timing data for the PE)

Sources:
Machette et al. (1992), Biek et al. (2003), Hylland (2007)

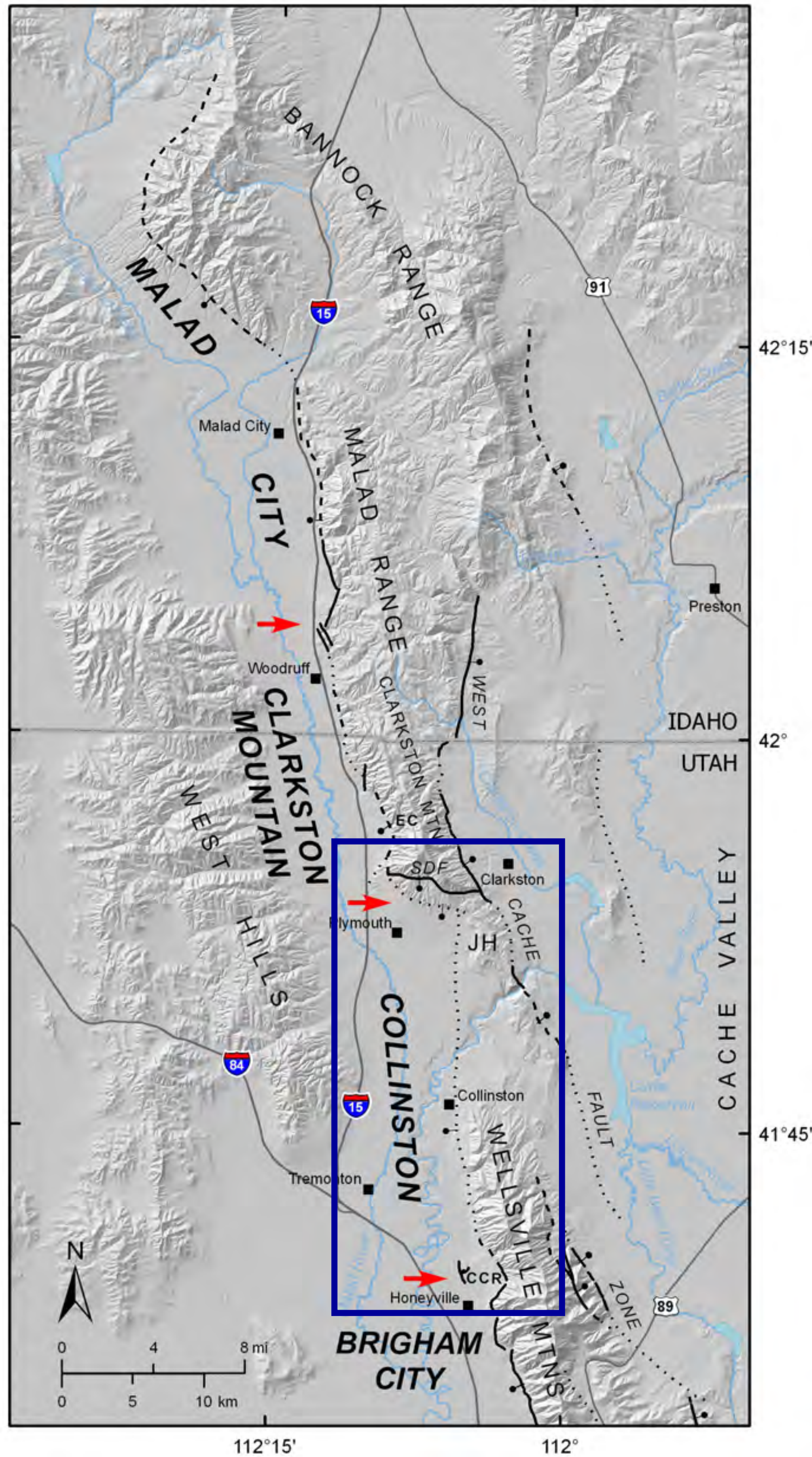


Northern Segments

Collinston Segment

Paleoseismic data:
•Field reconnaissance
•Scarp profiling and empirical analysis
  •Coldwater Canyon reentrant (S segment boundary)
  •Small single-event to large composite scarps

Geologic constraints:
•Bonneville lake-cycle deposits are faulted, but only in CCR (unfaulted to the N)
•Steep range-front geomorphology S, topographic saddle N (West Cache fault may be a factor; Holocene faulting)
•Steep, linear gravity gradients



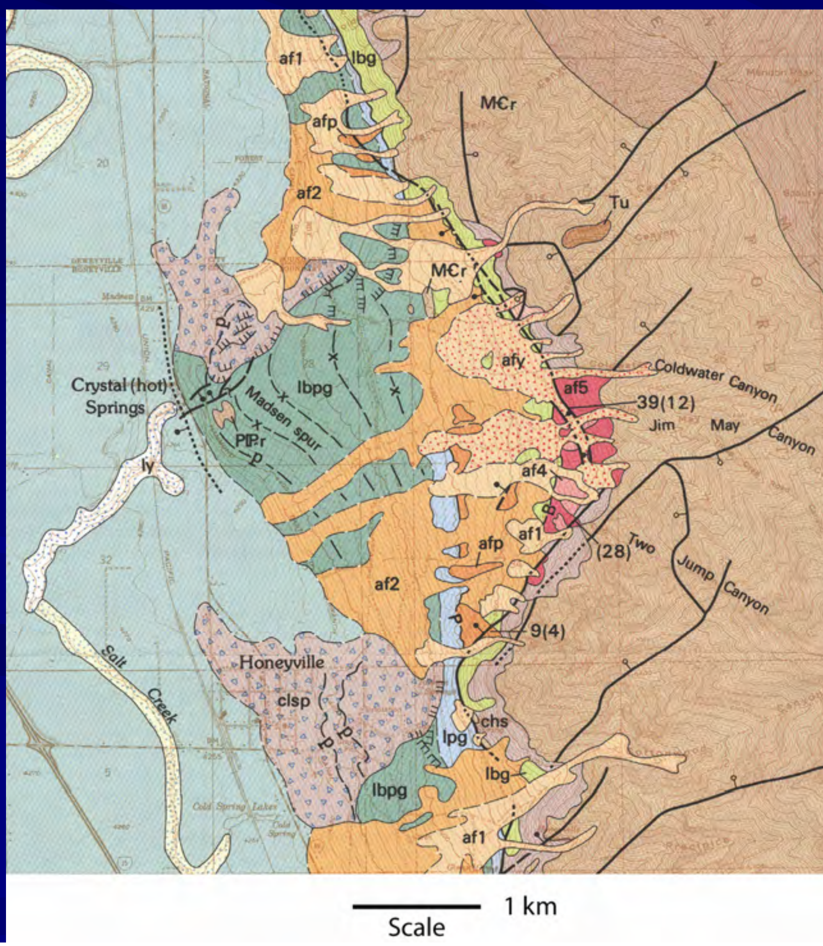
Northern Segments

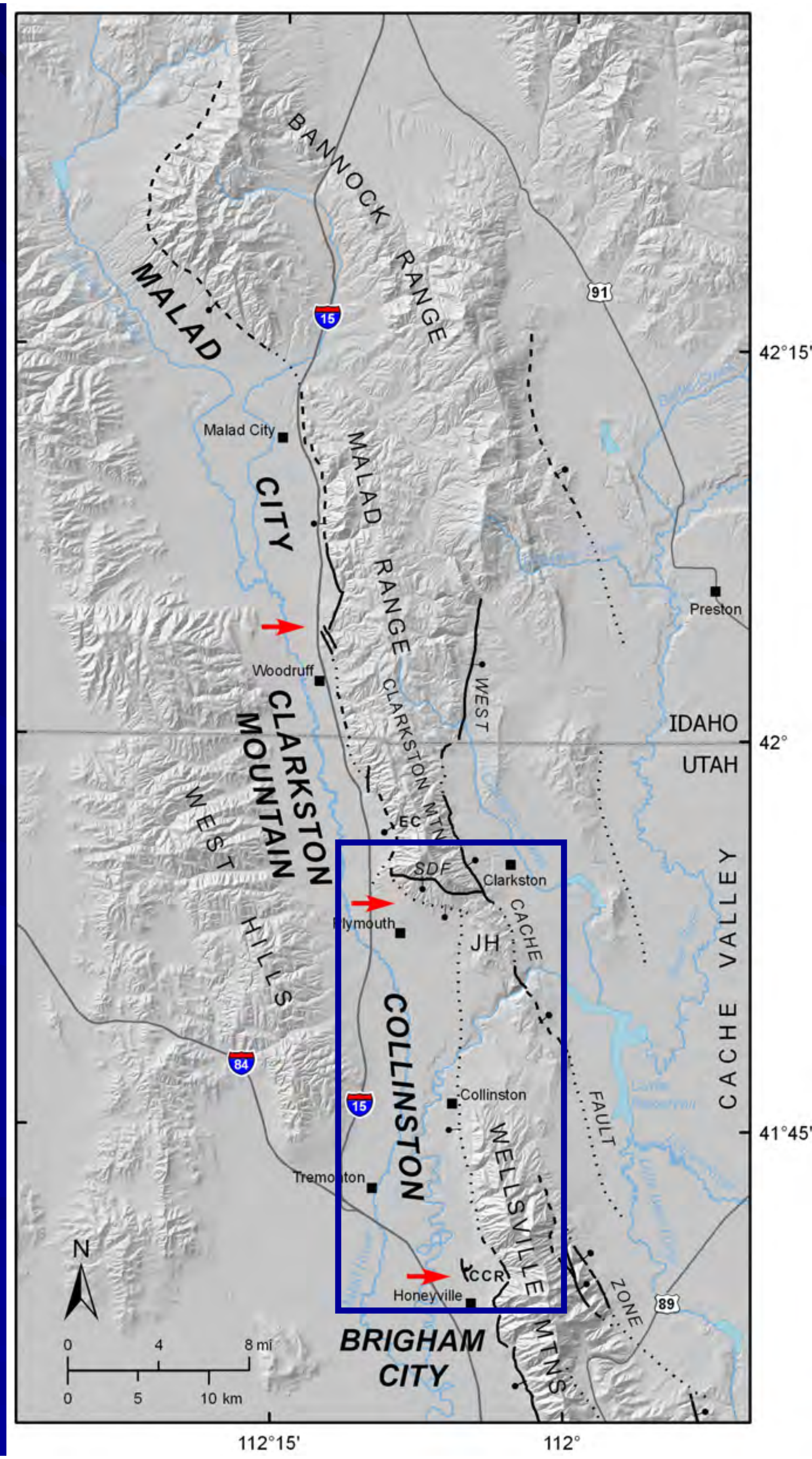
Collinston Segment

Earthquake timing:

•Holocene and latest Pleistocene events, but only in CCR (likely northern end of ruptures on Brigham City segment)

•Geologic data suggest active faulting during the late Pleistocene (pre-Bonneville)





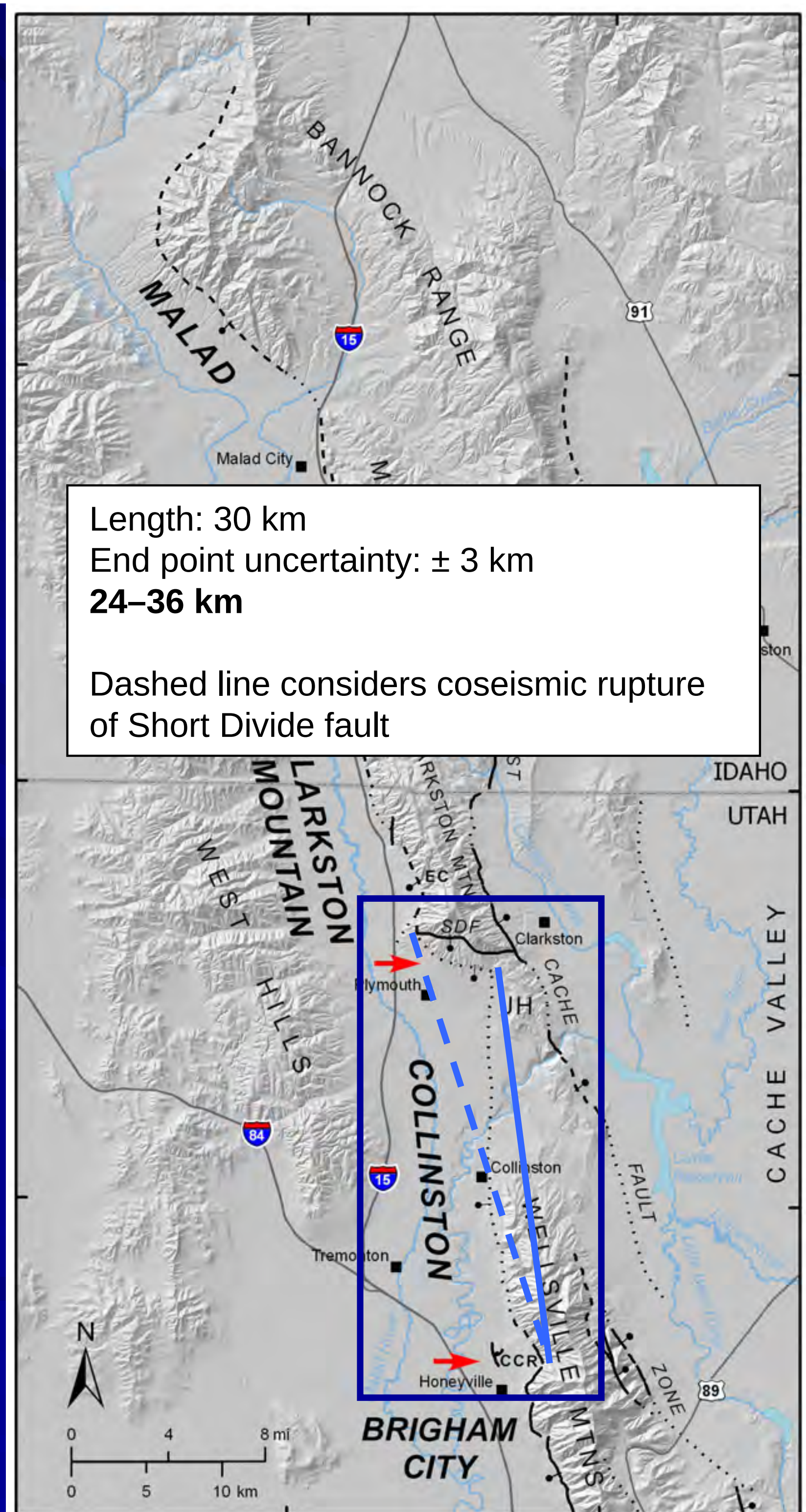
Northern Segments

Collinston Segment

Slip rate:
- Database slip rate category: <0.2 mm/yr
- Slip rate estimate:
  ≤2 m in >18,000 yr = 0.1 mm/yr (max)
- Long-term average slip rate:
  <12 m in ~300,000 yr = 0.04 mm/yr (max)

Recurrence interval: NA (no individual earthquake timing data)

Sources:
Oviatt (1986a, b), Personius (1990), Machette et al. (1992), Hylland (2007)



Length: 30 km
End point uncertainty: ± 3 km
24–36 km

Dashed line considers coseismic rupture of Short Divide fault

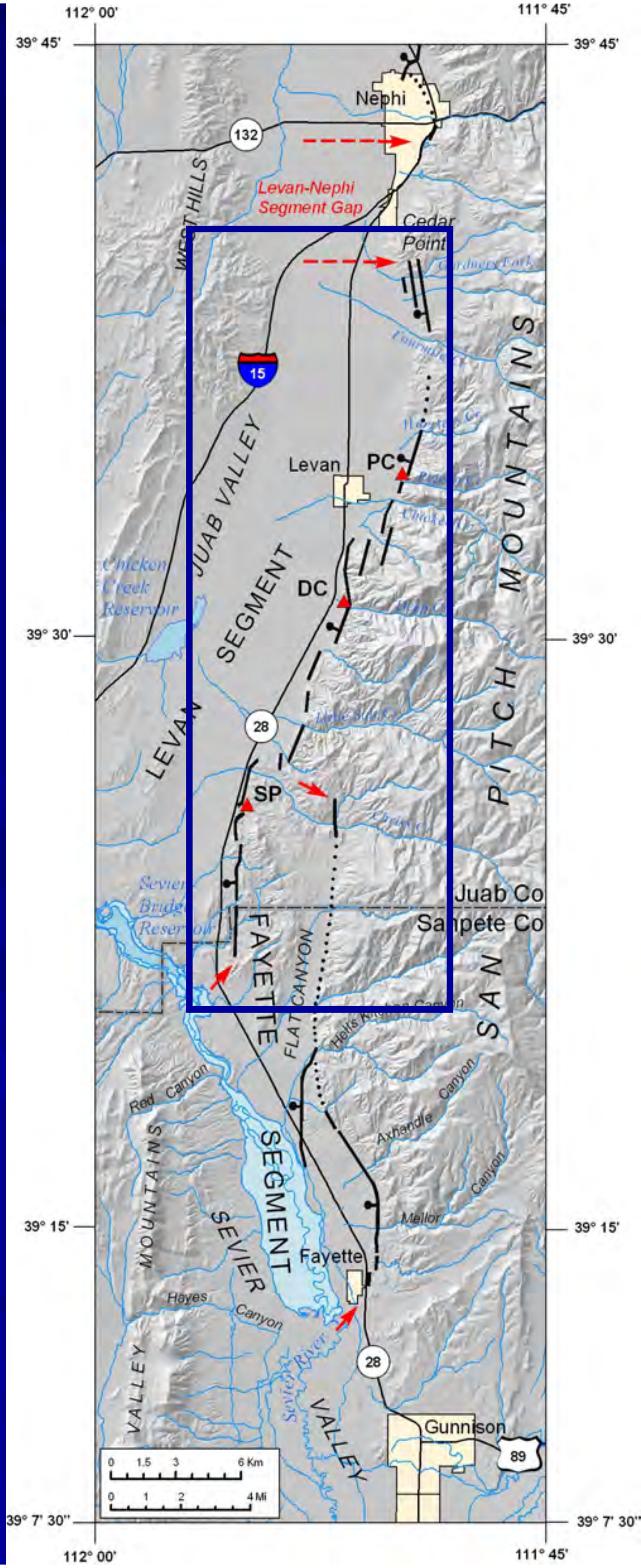
Southern Segments

Levan Segment

Paleoseismic data:
•Scarp profiling and empirical analysis
•Diffusion equation modeling
•Dated charcoal from faulted fan alluvium (Pigeon Creek)
•Natural exposure of fault—displacement and timing data (Deep Creek)
•Fault trench (Skinner Peaks)

Geologic constraints:
Fault scarps are present on late Quaternary deposits
•Faulted late Holocene alluvium
•Large (12 m) fault scarps on late to middle Pleistocene alluvium

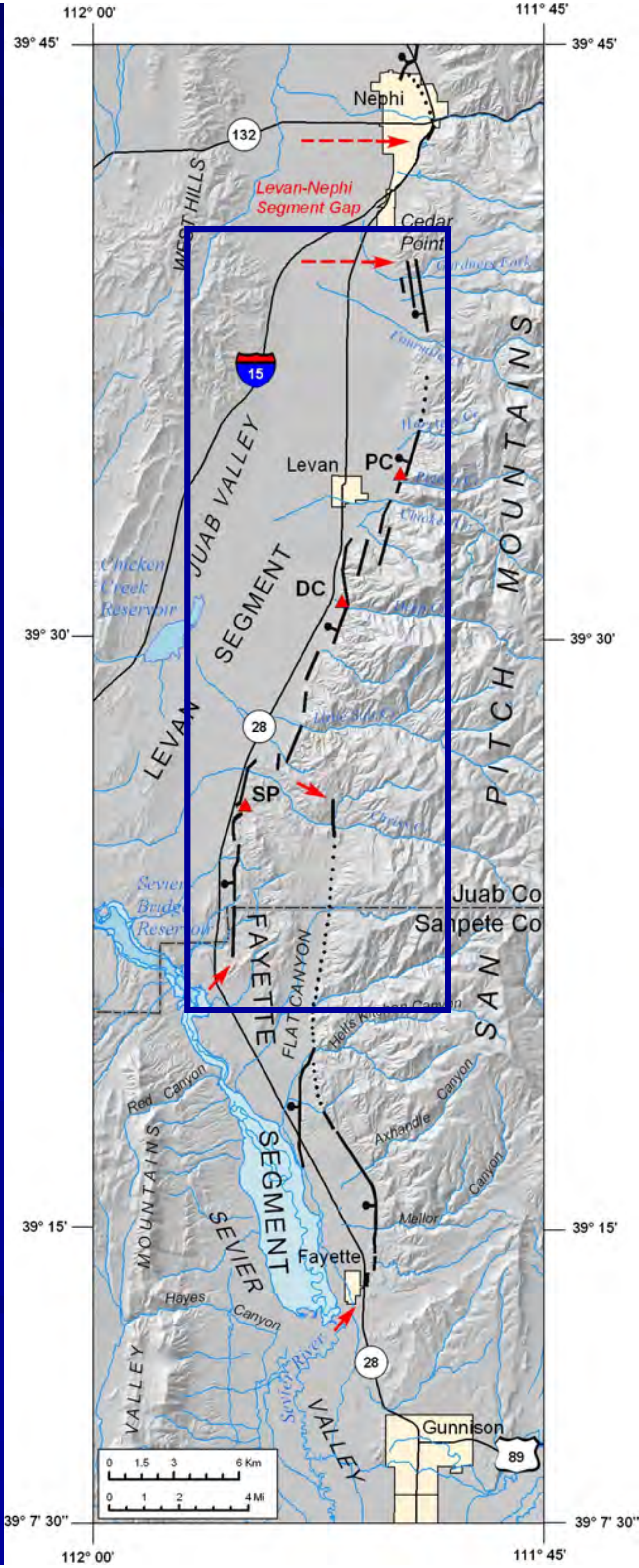
Earthquake timing:
Pigeon Creek:
•MRE postdates fan alluvium containing charcoal dated at 2100 ± 300 yr B.P. (1410–2760 cal yr B.P.) and 1750 ± 350 yr B.P. (950–2490 cal yr B.P.)



Southern Segments

Levan Segment

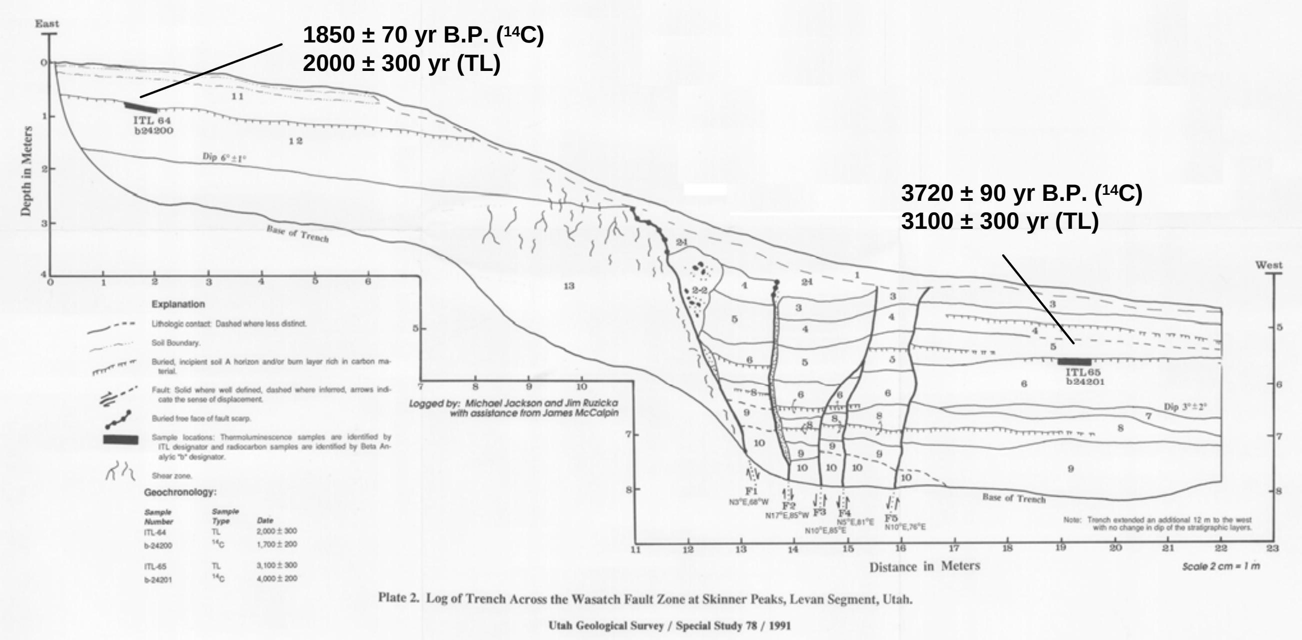
Earthquake timing (cont.):
Deep Creek:
- •MRE closely postdates age of buried soil, dated at:
  - •1200 ± 80 yr B.P. (870–1180 cal yr B.P.; bulk sample, 100 yr MRT correction)
  - •1000 ± 100 yr (TL)
- •PE predates(?) fan alluvium containing charcoal dated at 7300 ± 1000 yr B.P. (5980–10,590 cal yr B.P.)

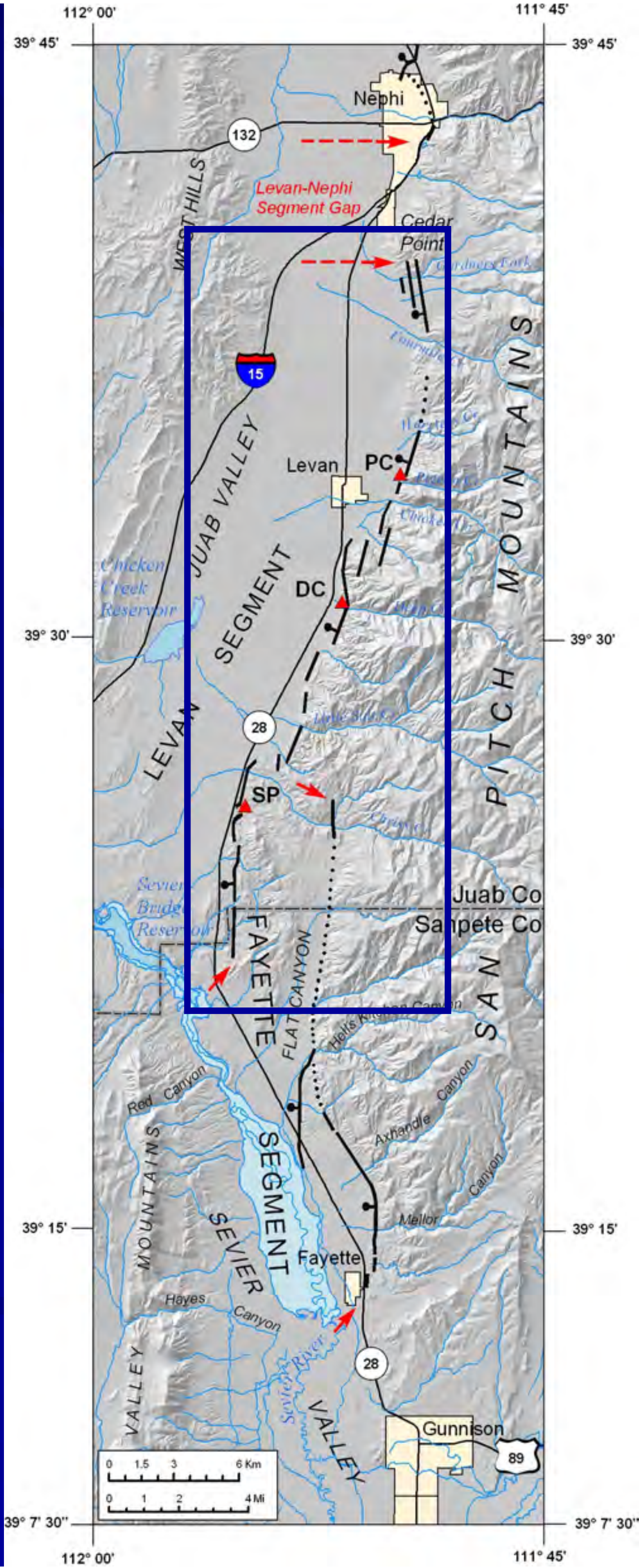


Southern Segments

Levan Segment

Earthquake timing (cont.):
Skinner Peaks:
- MRE postdates age of "burn layer" on footwall, dated at:
  - 1850 ± 70 yr B.P. (1610–1940 cal yr B.P.; charcoal)
  - 2000 ± 300 yr (TL)
  - Jackson (1991) preferred range: 1000–1500 cal yr B.P.
- PE likely predates hanging-wall alluvium containing buried "incipient A horizon" dated at:
  - 3720 ± 90 yr B.P. (3740–4200 cal yr B.P.; charcoal concentrate, 100 yr MRT correction)
  - 3100 ± 300 yr (TL)



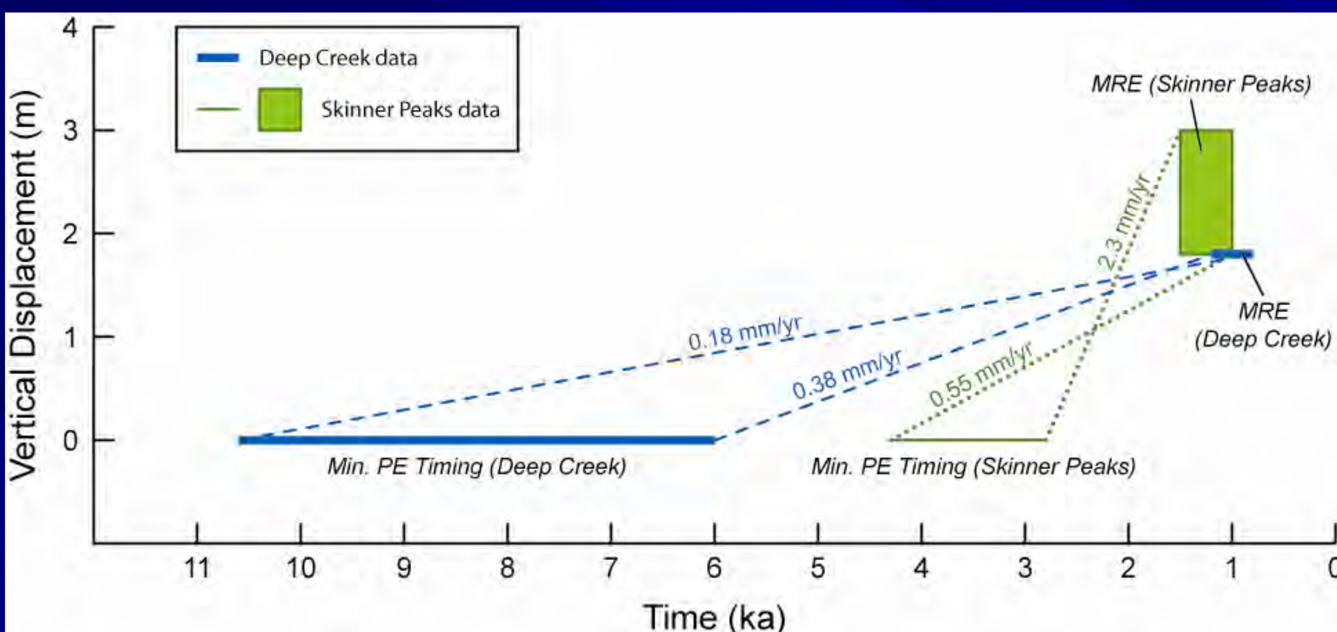


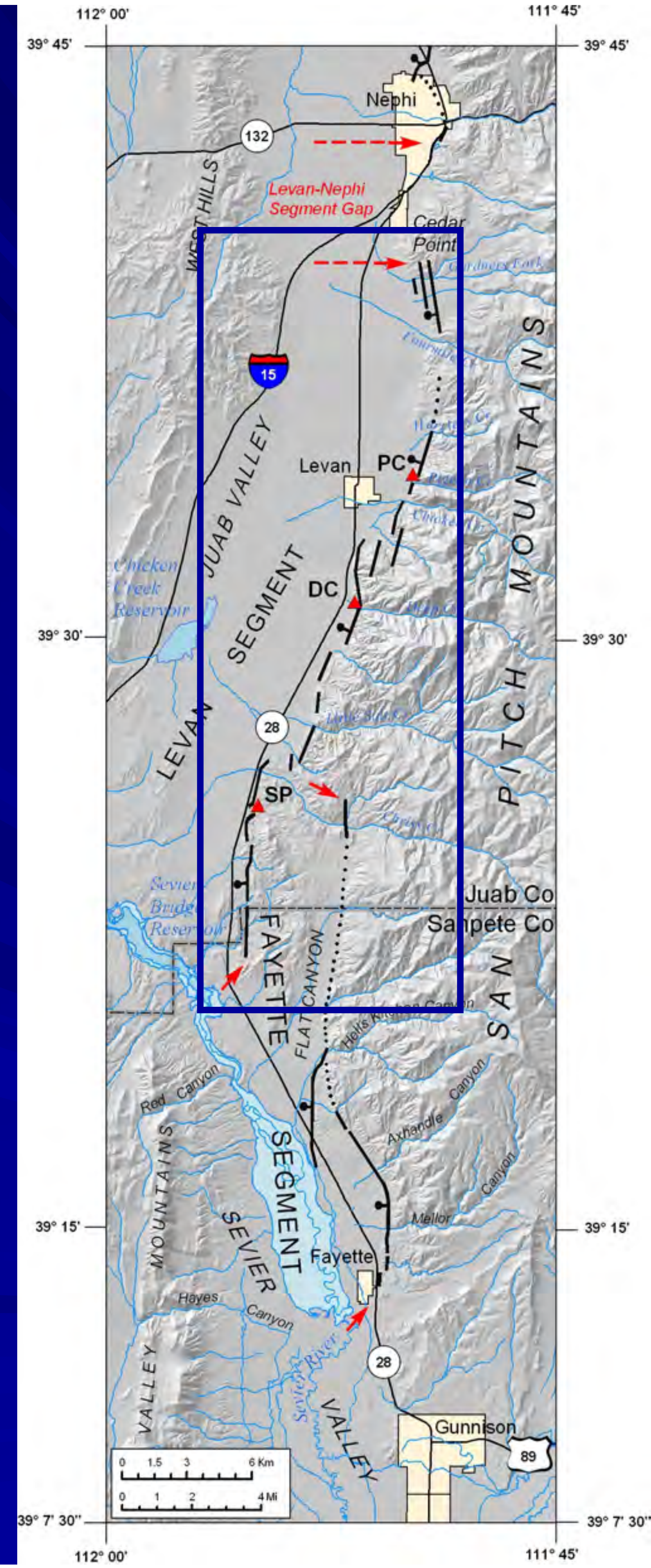
Southern Segments

Levan Segment

Slip rate:
•Database slip rate category: <0.2 mm/yr
•Slip rate estimate:

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



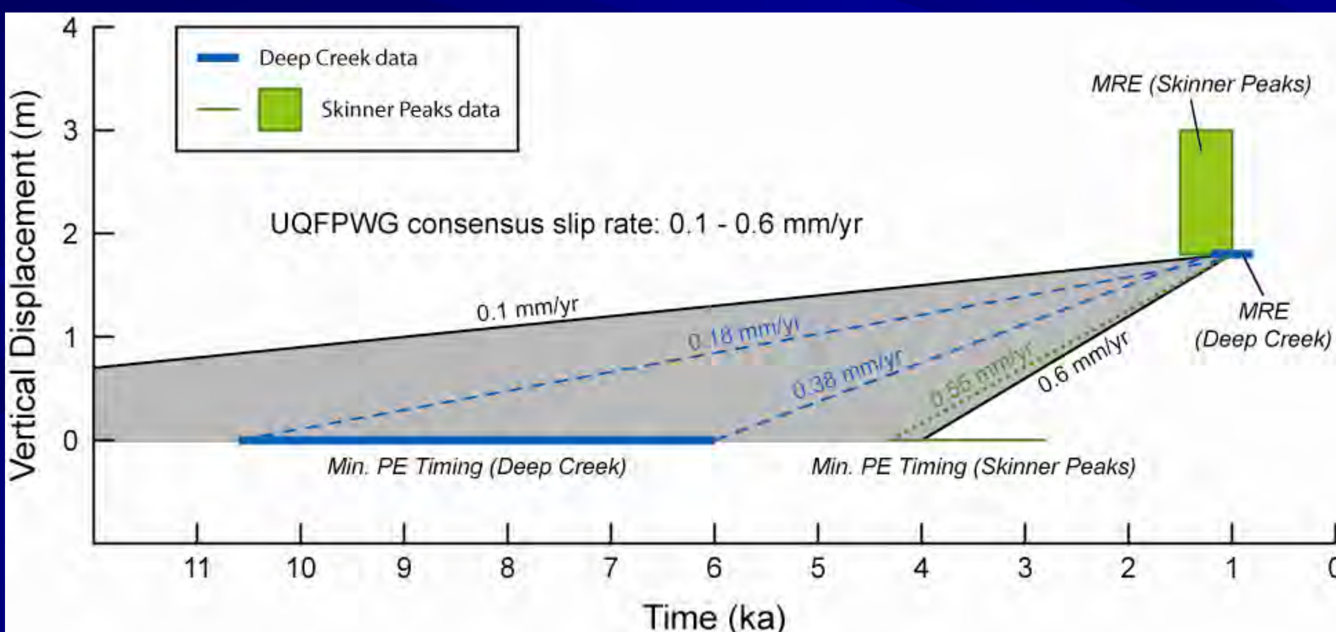


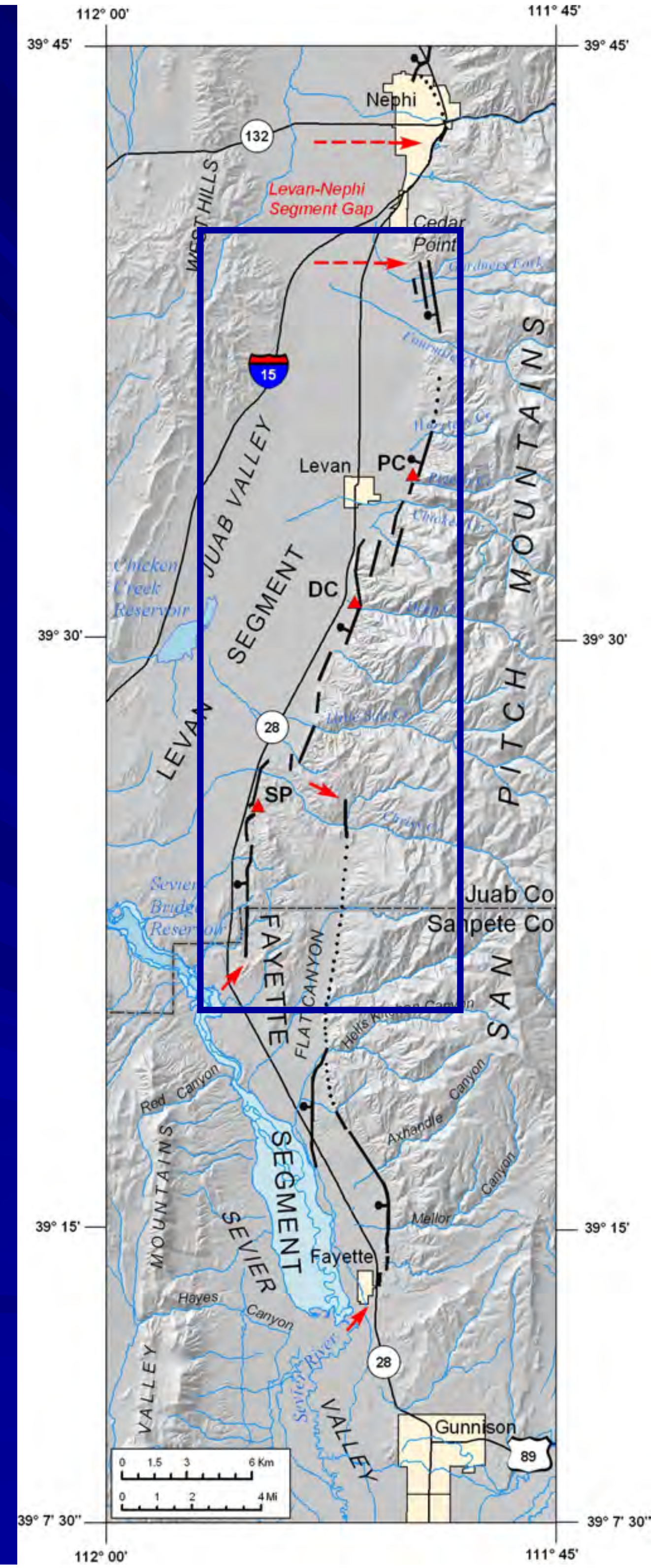
Southern Segments

Levan Segment

Slip rate:
•Database slip rate category: <0.2 mm/yr
•Slip rate estimate:

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





Southern Segments

Levan Segment

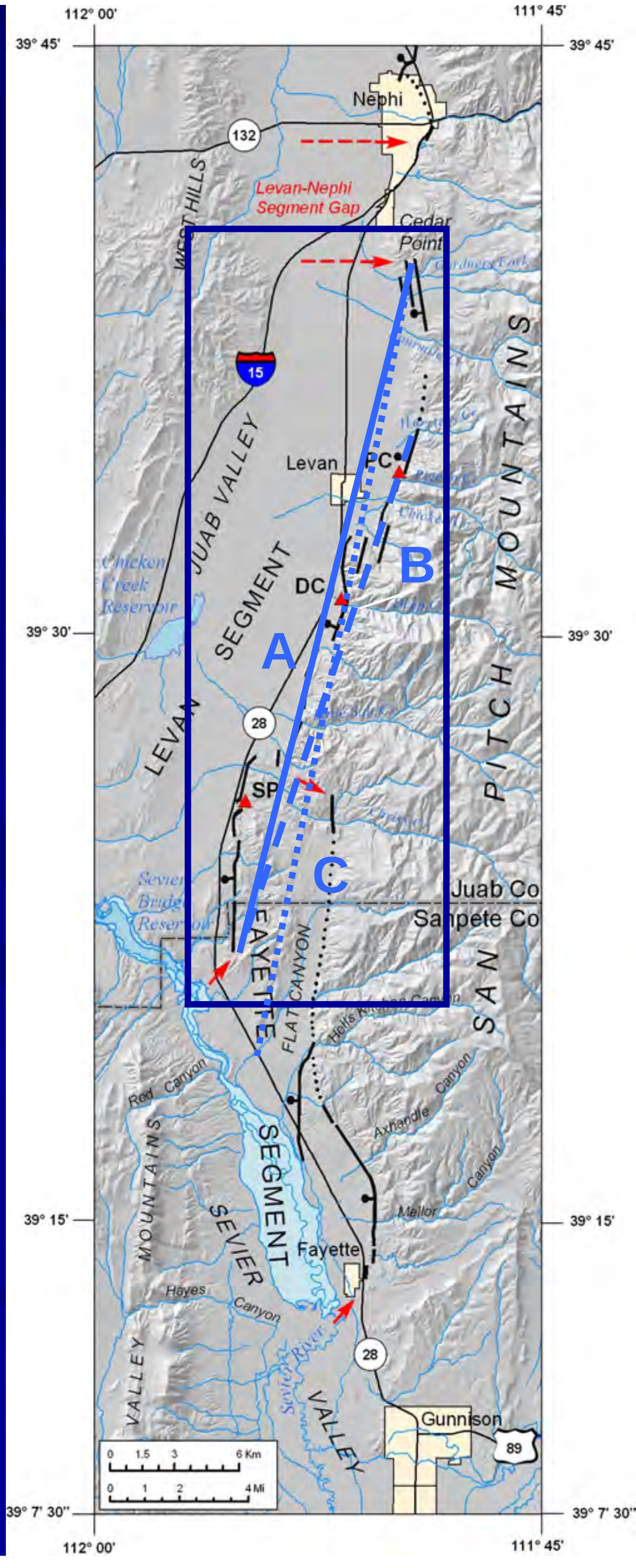
Slip rate (cont.):
•Database slip rate category: <0.2 mm/yr
•Hylland and Machette (2008) preferred value: 0.3 ± 1 mm/yr (max)
•UQFPWG consensus range: 0.1–0.6 mm/yr
•Long-term average slip rate:
4.8 m in 100–250 kyr = 0.02–0.05 mm/yr

Recurrence interval:
•Recurrence interval not calculated because timing of PE is poorly constrained
•UQFPWG consensus range: >3000 and <12,000 yr
(based on 2 Holocene events and approximate 2σ confidence limits)

Sources:
Crone (1983), Schwartz and Coppersmith (1984), Jackson (1991), Machette et al. (1992), Hylland (2007), Hylland and Machette (2008)

A - Length: 32 km
End point uncertainty: ± 3 km
26–38 km
B - Mapped Holocene rupture: 25 km
19–31 km
C - Including coseismic rupture of subsidiary faults in step-over: 37 km
31–43 km

Length range to consider: **19–43 km**

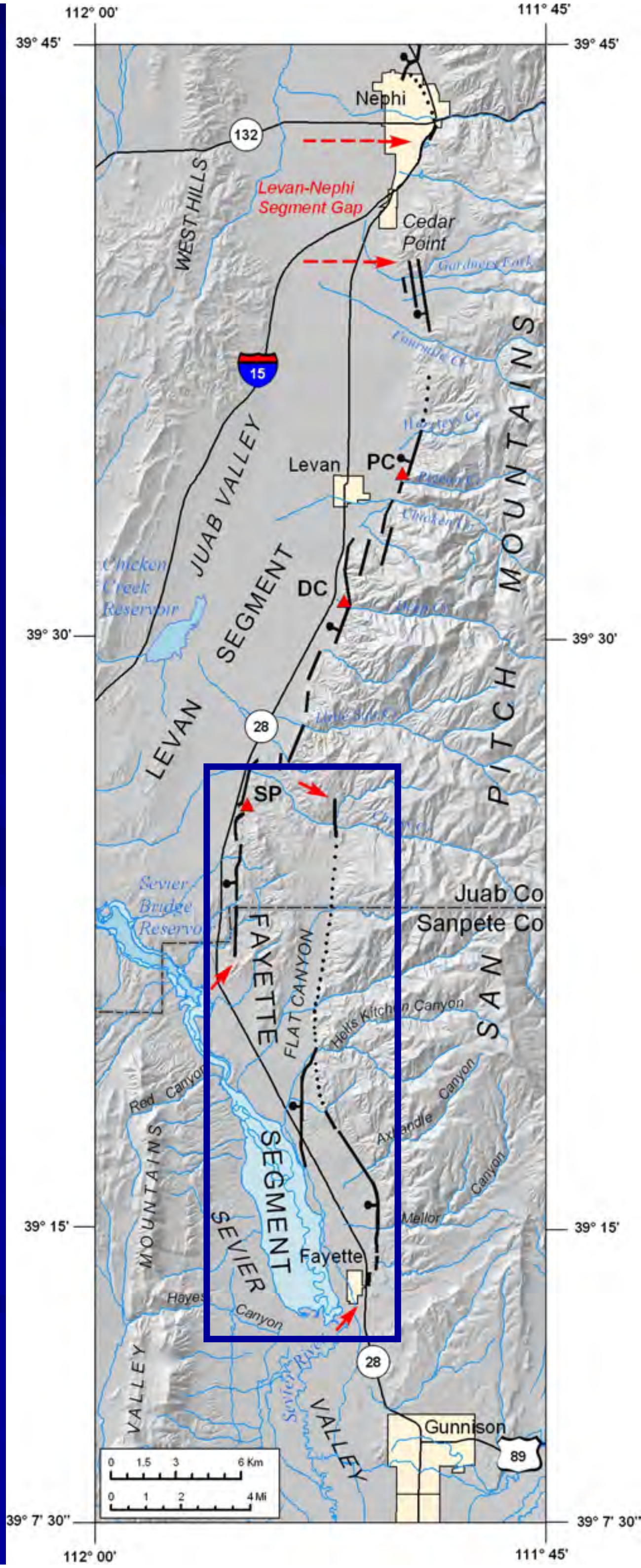


Southern Segments

Fayette Segment

Paleoseismic data:
•Scarp profiling and empirical analysis
•Diffusion equation modeling

Geologic constraints:
•Fault scarps are present on late Quaternary deposits
•Holocene to late Pleistocene alluvium is faulted, but late Holocene alluvium is not
•Scarps on late to middle Pleistocene alluvium typically 4–6 m high
•Anomalously high scarps (~20 m) at north end of SW strand



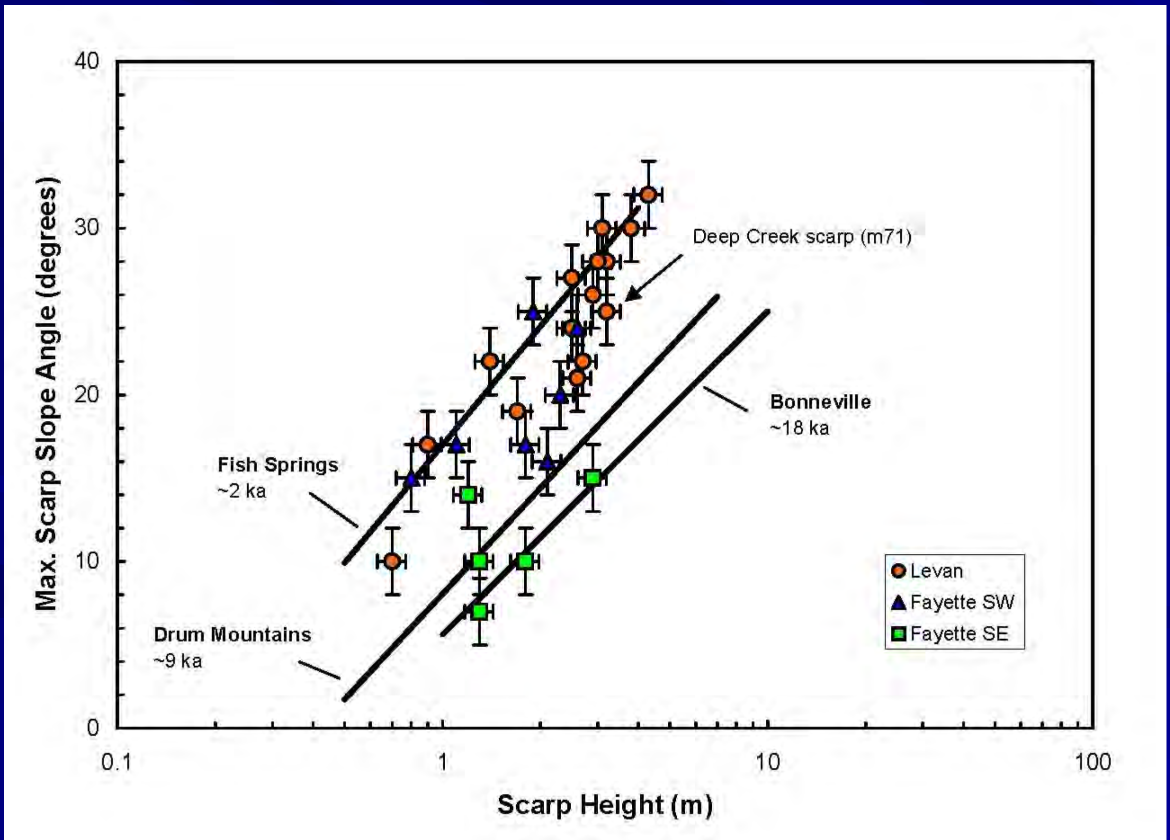
Southern Segments

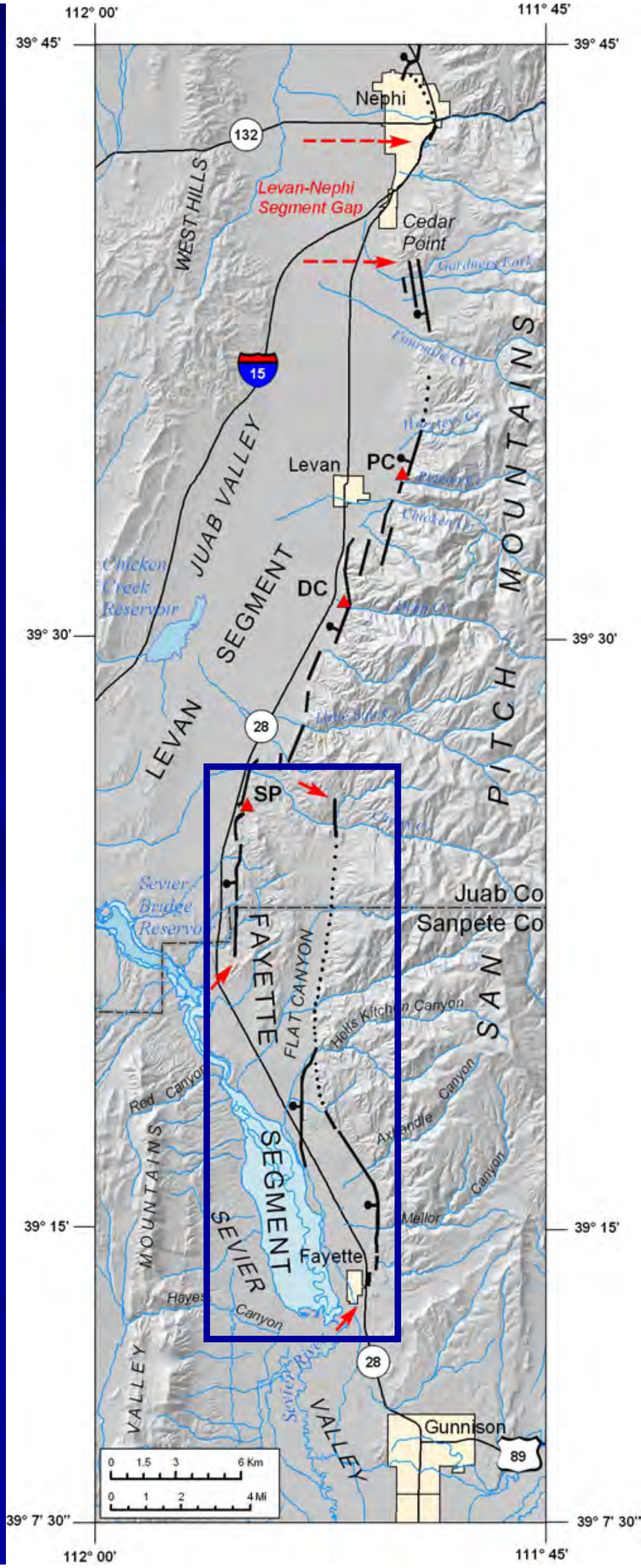
Fayette Segment

Earthquake timing:

•MRE—cross-cutting relations and empirical scarp profile analysis indicates:

- •Early or middle Pleistocene(?) (N strand)
- •Latest Pleistocene (SE strand)
- •Holocene (SW strand)





Southern Segments

Fayette Segment

Slip rate:

•Database slip rate category: <0.2 mm/yr

•Slip rate estimates:

0.8–1.6 m in <11,500 yr = 0.07–0.1 mm/yr (min) (SW strand)

0.5–1.3 m in <18,000 yr = 0.03–0.07 mm/yr (min) (SE strand)

3 m in 100–250 kyr = 0.01–0.03 mm/yr

Recurrence interval: NA (MRE timing poorly constrained, no timing data for the PE)

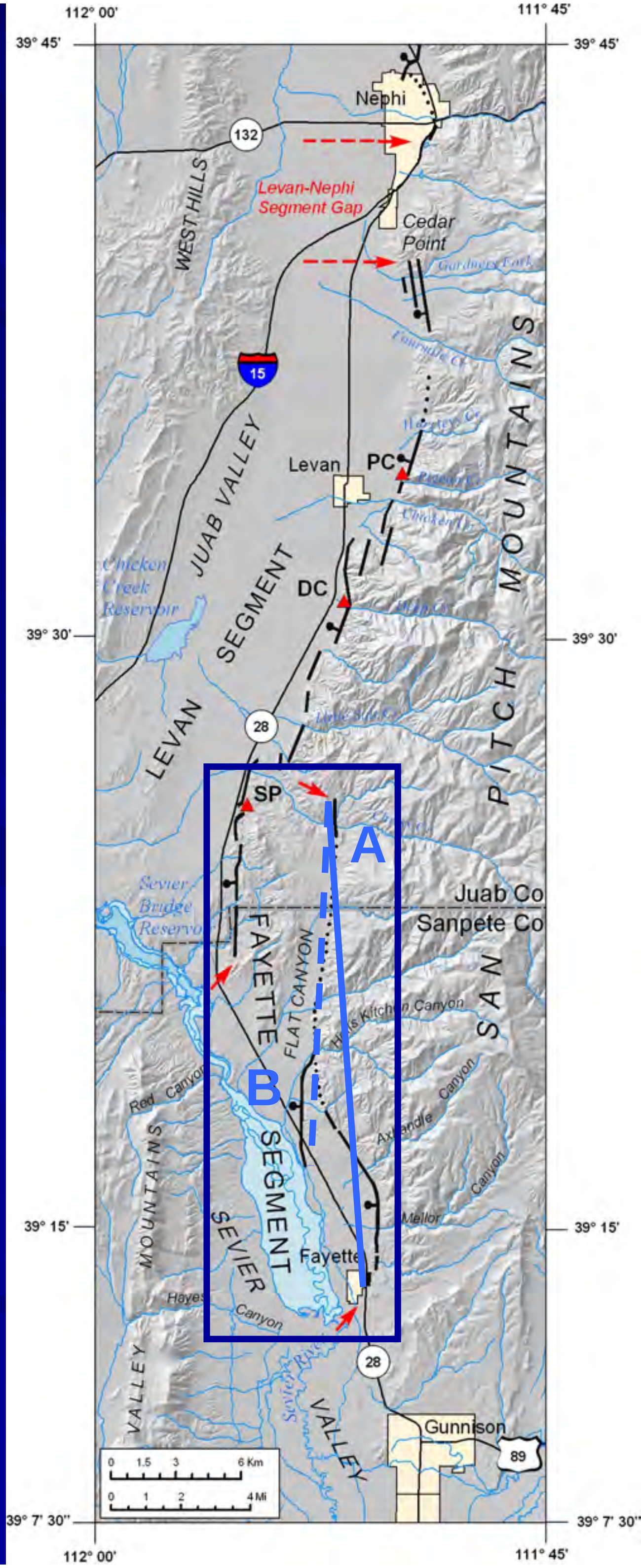
Sources:

Machette et al. (1992), Hylland (2007), Hylland and Machette (2008)

A - Length: 22 km
End point uncertainty: ± 3 km
16–28 km

B - Fayette (N) + Fayette (SW): 18 km
12–24 km

Length range to consider: **12–28 km**

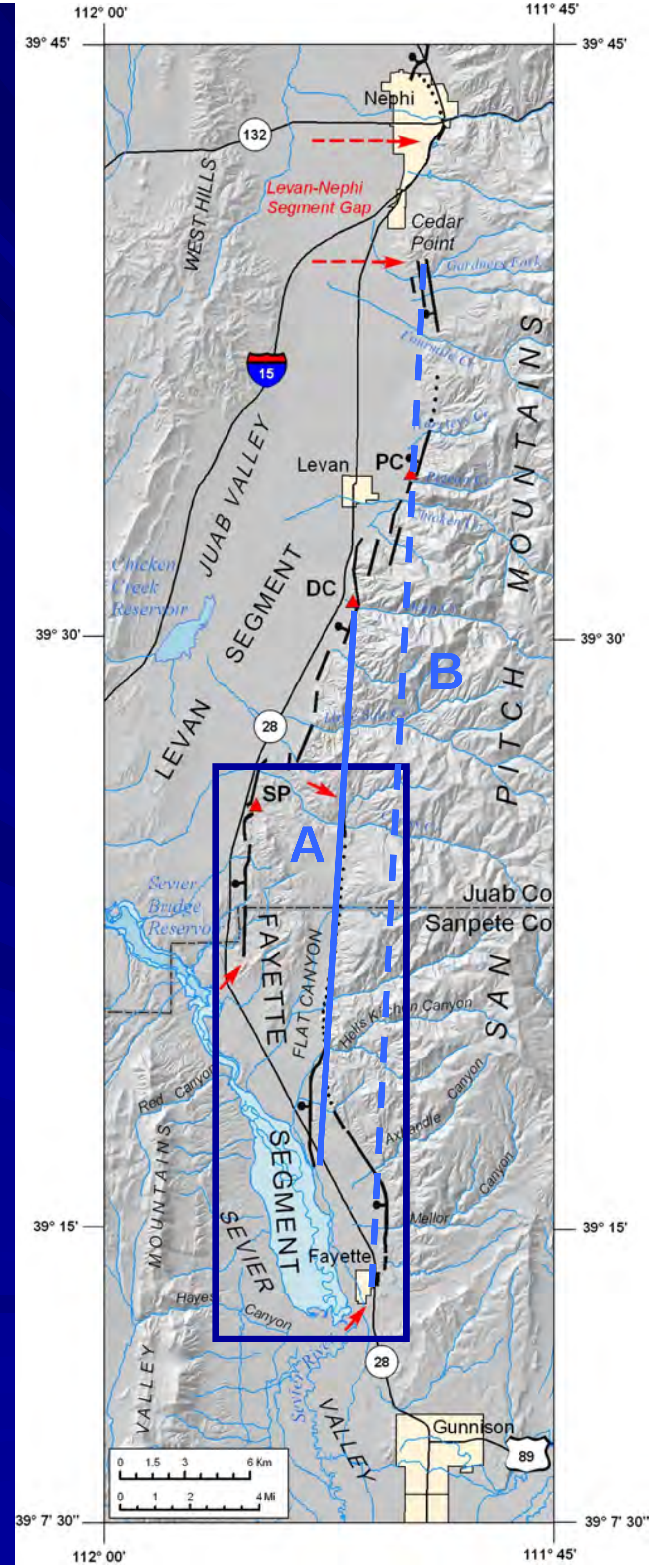


Levan–Fayette combined:

A - Levan (S) + Fayette (SW): 26 km
20–32 km (similar to Levan Holocene rupture: 19–31 km)

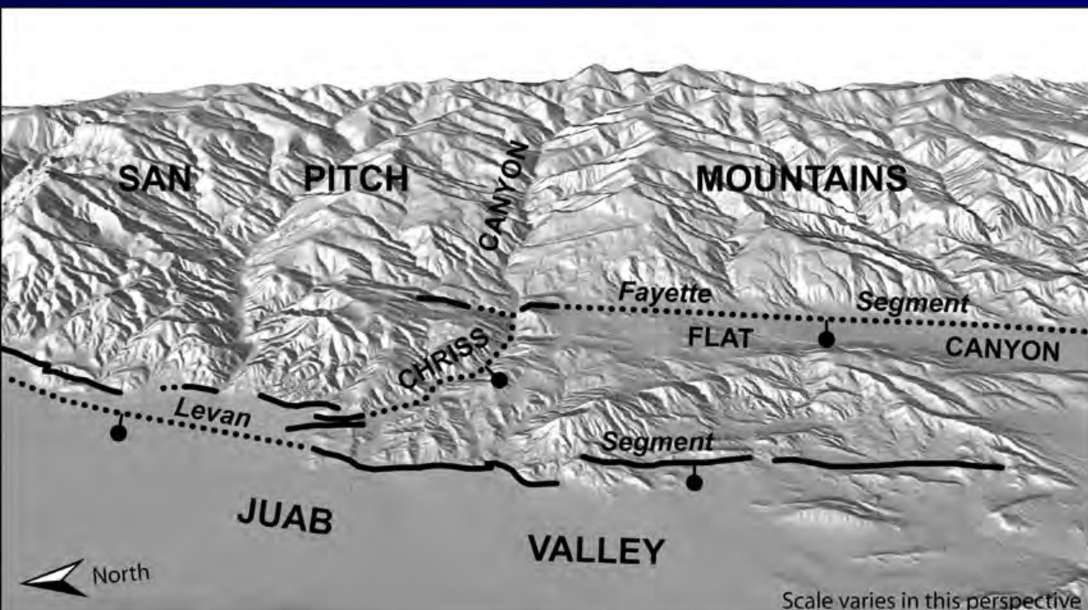
B - Levan + Fayette (original Schwartz & Coppersmith model): 46 km
40–52 km

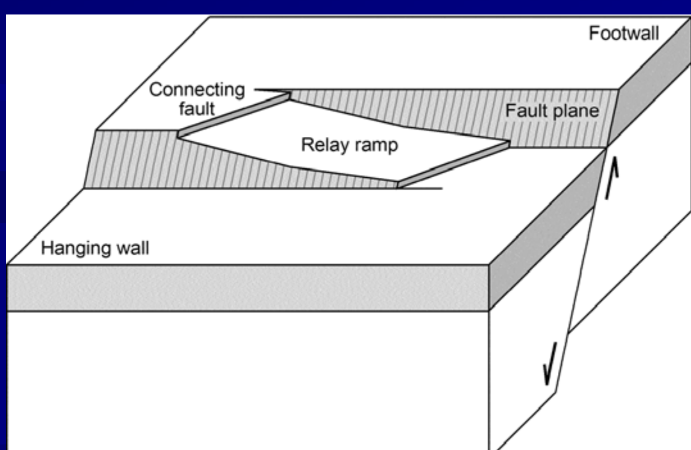
So, length range to conside for Levan: **19–52 km**

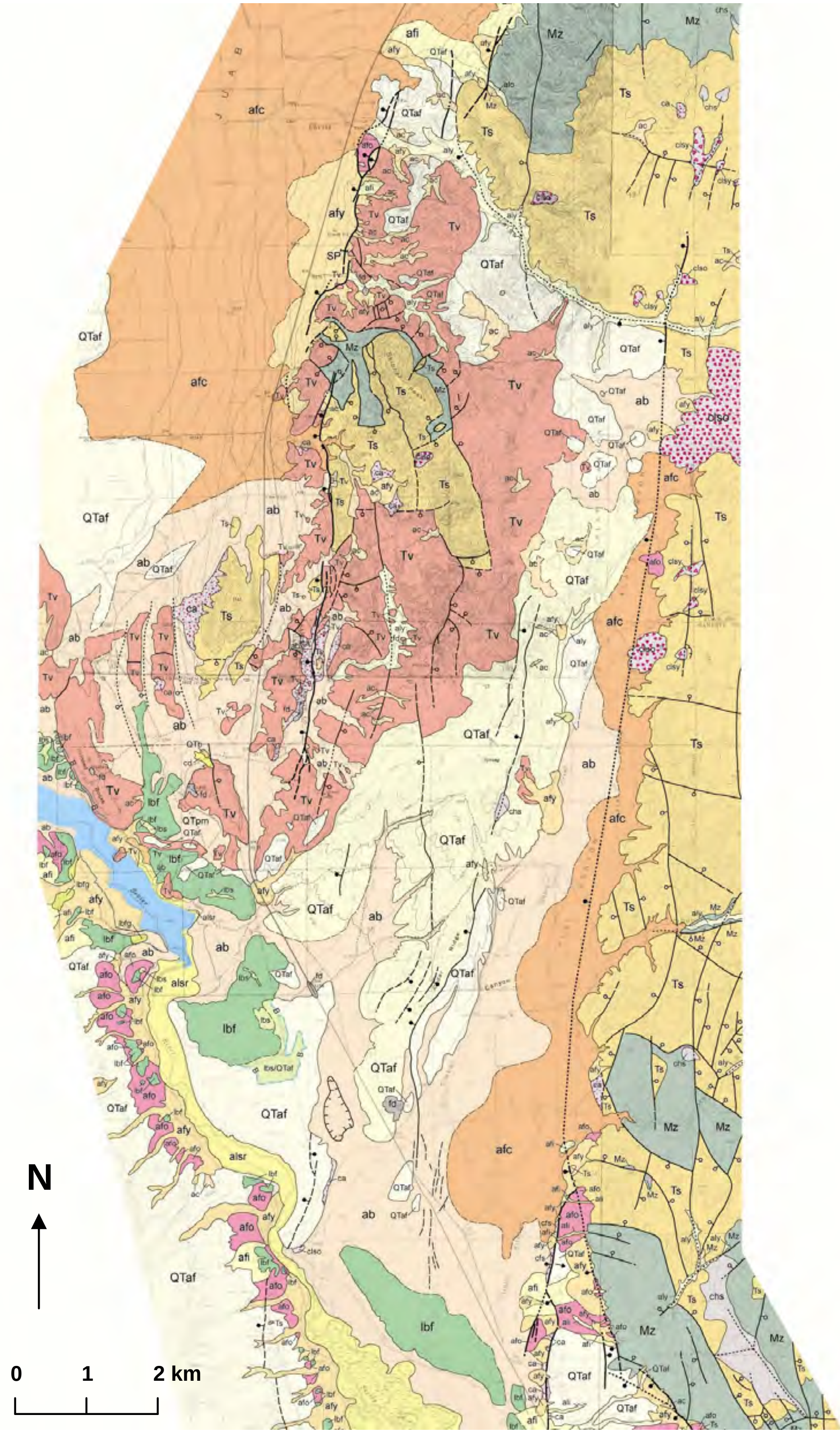


Southern Segments

Levan–Fayette Segment Boundary







The Wasatch Fault Zone End Segments

Summary of Earthquake Parameters

Segment	***MRE Timing***	***Displacement/ Surface Offset (m)***	***Time Interval (kyr)***	***Est. SR (mm/yr)***	***Recommended SR (mm/yr)***	***RI (kyr)***
Malad City	Late Pleistocene	≤1.5 (est.)	>18	<0.08	0.01–0.1	NA
Clarkston Mountain	Late Pleistocene	2	>18	<0.1	0.01–0.1	NA
Collinston	Late Pleistocene	≤2 (est.) <12	>18 300	<0.1 <0.04	0.01–0.1	NA
Levan	≤1000 cal yr B.P. 1000–1500 cal yr B.P.	1.8 1.8–3.0 4.8	>4.8–9.8 >1.3–3.3 100–250	<0.2–0.4 <0.5–2.3 <0.3±0.1* 0.1–0.6** 0.02–0.05	0.1–0.6	>3 & <12**
Fayette	Early(?) Holocene (SW strand) Latest Pleistocene (SE strand)	0.8–1.6 0.5–1.3 3	<11.5 <18 100–250	>0.07–0.1 >0.03–0.07 0.01–0.03	0.01–0.1	NA

*Hylland and Machette, 2008

** UQFPWG (Lund, 2005)

Estimating Maximum Magnitudes for Faults – Take 2

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WGUEP Meeting, Salt Lake City, UT

16 February 2011

Empirical Relations for WGUEP Model

- **Wells and Coppersmith (1994) – all fault types**
  - **Area (A); $M = 4.07 + (0.98 \times \log A)$; $\sigma = 0.24$**
  - **Surface rupture length (L); $M = 5.08 + (1.16 \times \log L)$; $\sigma = 0.28$**
  - **Average slip (AD); $M = 6.93 + (0.82 \log AD)$; $\sigma = 0.39$**
- **Hemphill Haley and Weldon (1999)**
  - **AD (from trench sites) and MVCDS, which is a mode value statistic based on n and the percent of fault length that the n samples cover; $M = 6.93 + 0.82 \log (AD \times MVCDS)$**
- **Hanks and Kanamori (1979)**
  - **Seismic moment (M_O); $M = (2/3 \times \log M_O) - 10.7$**

URS

Strawman Approach

1. **Categorize faults according to available data**

   A. **Well-mapped with 3 or more trench sites (segmented with alternative rupture models; have D data)**

   B. **Well-mapped with 1 or 2 trench sites (may or may not be segmented; have minimal D data)**

   C. **Mapped and no trench sites (likely not segmented; no D data)**

2. **Use different empirical relations (and uncertainties) according to available data and rupture models**

Strawman Approach (continued)

- For category A faults use:
  - Wells and Coppersmith – A (0.25)
  - Wells and Coppersmith – L (0.25)
  - Hemphill-Haley and Weldon – AD (0.25)
  - Hanks and Kanamori – M_O (0.25)
- For category B faults use (with ± 1 σ depending on epistemic uncertainty):
  - Wells and Coppersmith – A (0.3)
  - Wells and Coppersmith – L (0.3)
  - Hanks and Kanamori – M_O (0.2)
  - Wells and Coppersmith – AD (0.2)
- For category C faults use (with ± 1 σ):
  - Wells and Coppersmith – L (0.5)
  - Wells and Coppersmith – A (0.5)
- Truncate all distributions at M 7.8 maximum. Use aleatory uncertainty of ± 0.12. Review resulting distributions and adjust as needed.

URS

Example Category A Fault: Provo Segment (Single segment/ Multiple segment)

W & C – L	→	M 7.1 [7.3]
W & C – A	→	M 7.0 [7.2]
H-H & W – AD	→	M 7.3 [7.2]
H & K – M_o	→	M 7.4 [7.4]

- Single segment input: L = 59 km; AD = 3.56 m; A = 1080 km^2 (dip = 55° and depth = 15 km)
- Use ± 0.12 for aleatory uncertainty
- Multiple segment (Provo + Nephi) input: L = 86 km; AD = 3 m; A = 1574 km^2 (dip = 55° and depth = 15 km)

Example Category B Fault: Bear River Fault Zone

H & K – M_O	→	M 7.2 (0.2)
W & C – L	→	M 6.9 (0.3)
W & C – A	→	M 6.9 (0.3)
W & C – AD	→	M 7.3 (0.2)

- Input: AD = 3 m; L = 40 km; (West, 1994) A = 732 km^2 (dip = 55° and depth = 15 km)
- Use ± 1 σ for additional epistemic uncertainty(?)
- Use ± 0.12 for aleatory uncertainty

URS

Example Category C Fault: Carrington Fault

W & C – L (σ = 0.28) → M 6.8 (L = 28 km) (0.5)

W & C – A (σ = 0.24) → M 6.7 (A = 512 km) (0.5)

- Use ± 0.12 for aleatory uncertainty
- Above is for dip = 55° and depth = 15 km;
  For dip = 70º and depth of 12 km→ M 6.5;
  For dip = 30º and depth of 18 km→ M 7.0.
- Use ± 1 σ for additional epistemic uncertainty?

URS

Time-Dependent Probability Models

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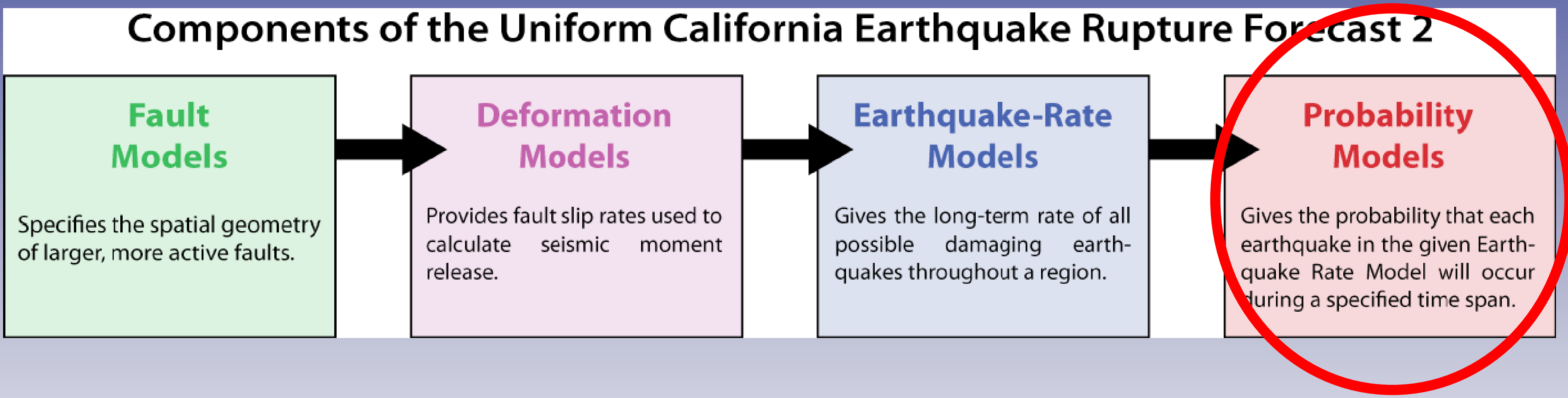
16 February 2011

WGCEP (2003) and UCERF METHODOLOGY



Probability Models

How are earthquakes distributed in time?

How to incorporate the physics of earthquake cycles and fault interactions?

URS

Probability Models

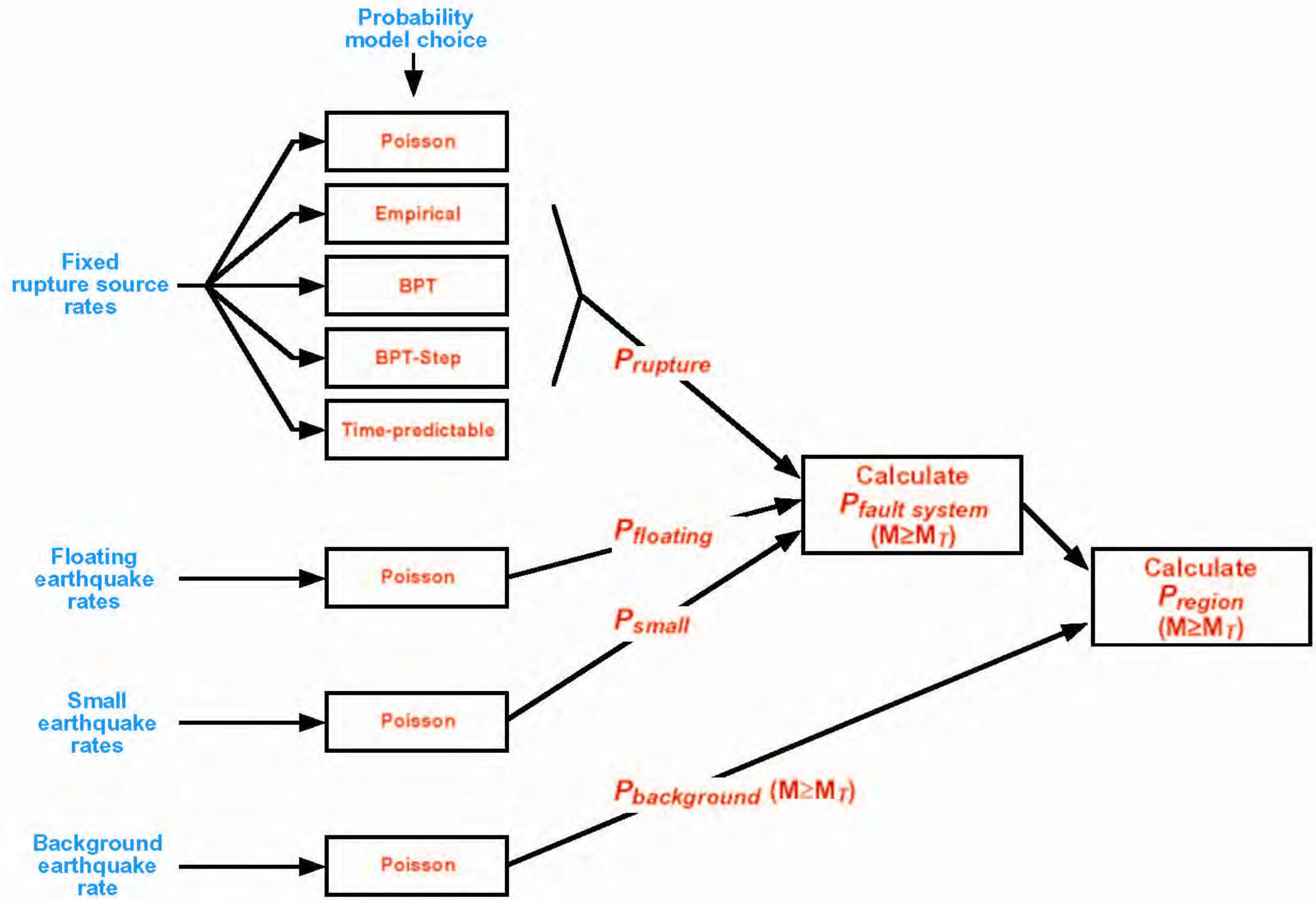
- **Earthquakes are modeled as a renewal process (Cornell and Winterstein, 1988)**
  - ***Time between events are independent and identically distributed random variables***
  - ***Expected time of next event does not depend on any details of last event except the time it occurred***
  - ***A rupture on a segment resets the renewal process to its initial state***

Sample of Probability Models

- Poisson – random process, probability does not vary in time
- Empirical – variation of Poisson, long term mean rupture rate is modulated by an extrapolation of the recent regional rate of earthquakes
- Lognormal and BPT
  - Uses time since last event
  - Failure condition of fault is described by a state variable that rises from a ground state to the failure state during the earthquake cycle
  - Movement toward failure is governed by a deterministic parameter (mean recurrence interval) and a stochastic parameter describing variability of recurrence intervals (aperiodicity or COV)
- Time-Predictable
  - Uses time and amount of slip in the most recent event
  - expected time of next event is equal to time required to restore the fault to the same state when the preceeding event occurred

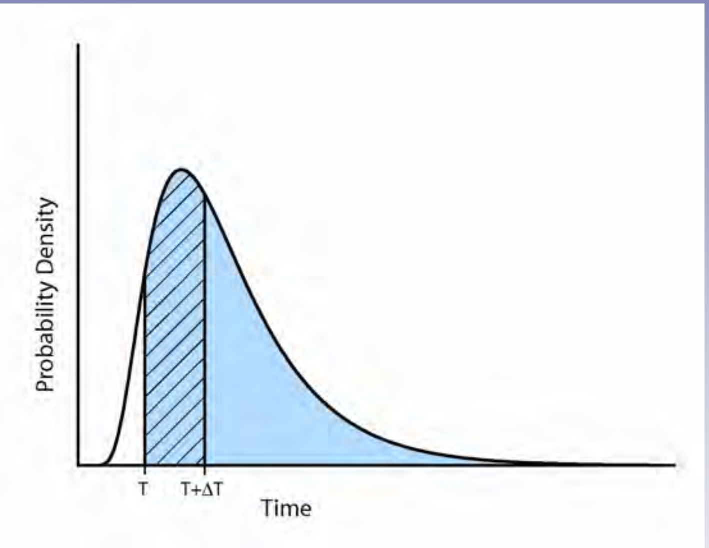
URS

WGCEP 2003 Methodology



Mathematical Model

Probability Density Function, *f*(*t*), defines the chance that failure will occur in the interval from *t* to *t* + Δ*t*, where *t* is time since last event



- Survivor function, $\boldsymbol{F(T)}$
  - ➢ gives probability that at least time T will elapse between events
- Hazard function, $\boldsymbol{h(t)}$
  - ➢ $\boldsymbol{h(t)} = \boldsymbol{f(t)}/\boldsymbol{F(t)}$ gives instantaneous rate of failure at time t conditional on no event occurring up to time t

Conditional probabilities give probability of an event during an interval of interest, conditional on it not having occurred prior to the start of the interval

$$P(T \le t \le T + \Delta T \mid t > T) = [\ F(T) - F(T + \Delta T\ )\ ] \ /\ F(T)$$

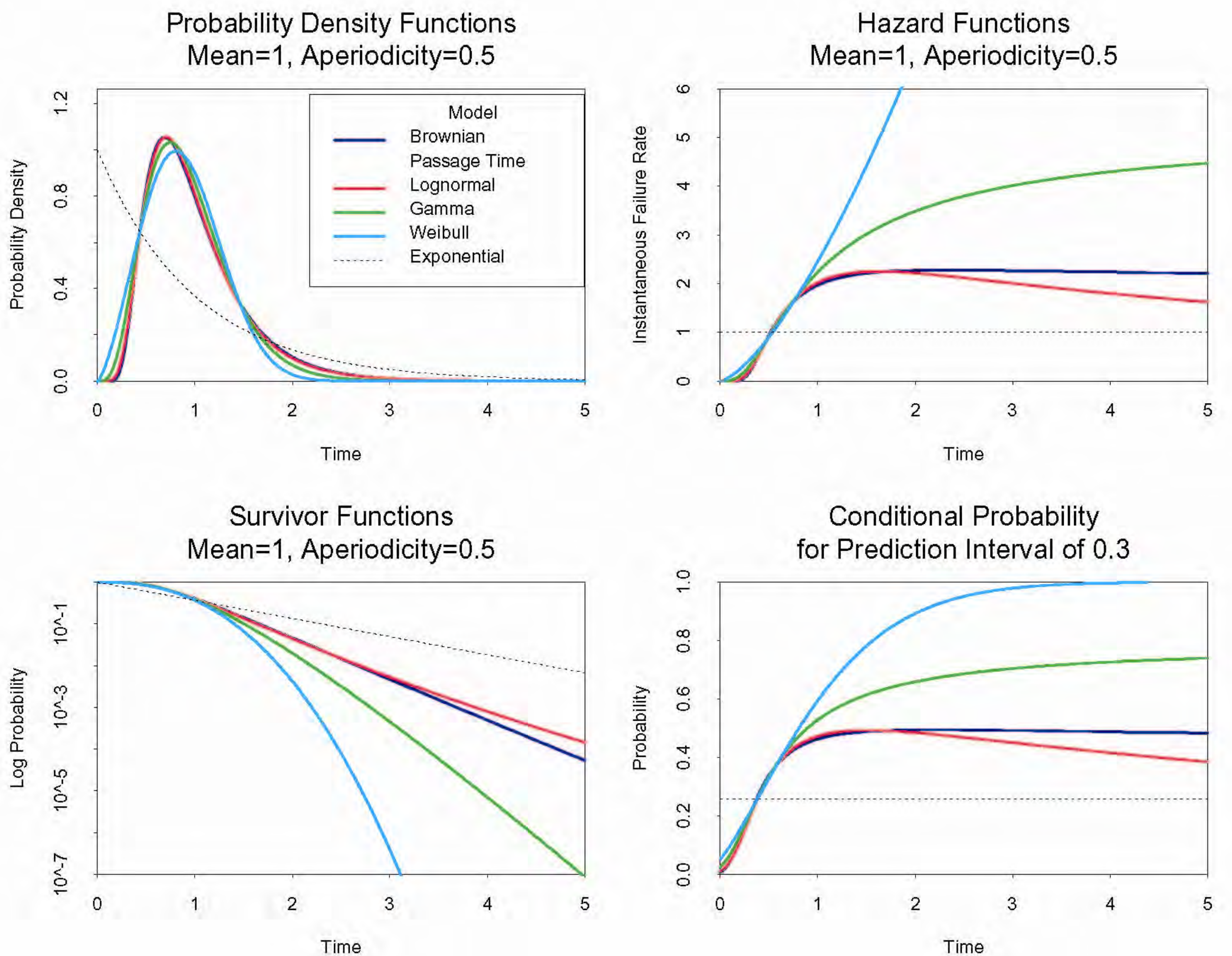
Brownian Passage Time (BPT) Model

- **Inputs**
  - **mean recurrence interval, $\mu = 1/\lambda$**
  - **aperiodicity, α, or variability of recurrence intervals**
    - $\alpha = \sigma / \mu$
- **Probability density function**

$$f_{BPT}(t) = \sqrt{\frac{\mu}{2\pi\alpha^2 t^3}}\, e^{-\frac{(t-\mu)^2}{2\mu t\alpha^2}}$$

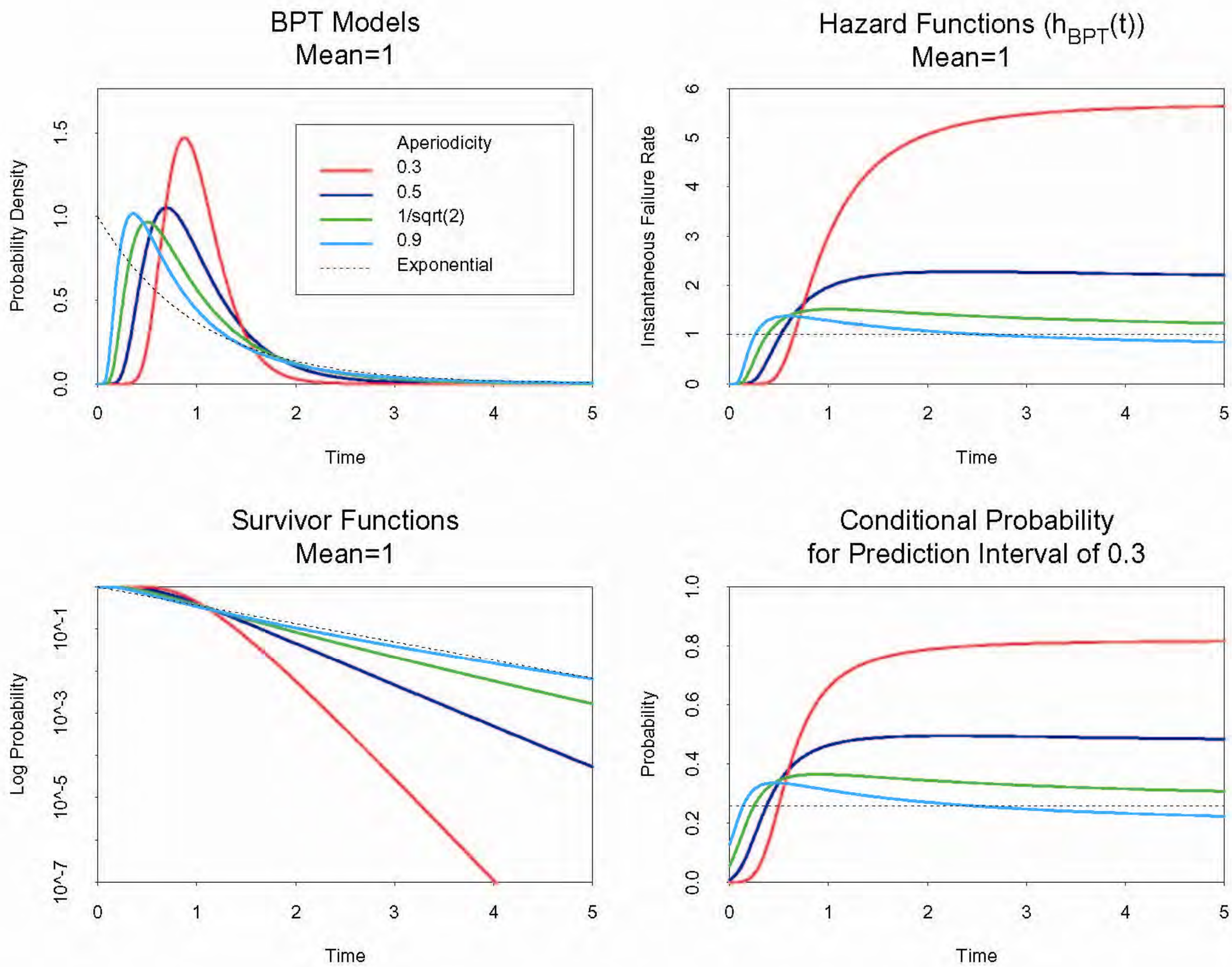
- **Hazard function increases from zero to a maximum and the decreases toward an asymptotic value of 1/(2 μ α^2)**
  - ***When $\alpha = 1/\sqrt{2}$, the asymptotic failure rate is 1/ μ, which is the same as the poisson process with the same μ***

URS



Probability Density Functions
Mean=1, Aperiodicity=0.5
Probability Density
0.0
0.4
0.8
1.2
0
1
2
3
4
5
Time
Model
Brownian
Passage Time
Lognormal
Gamma
Weibull
Exponential
Hazard Functions
Mean=1, Aperiodicity=0.5
Instantaneous Failure Rate
0
1
2
3
4
5
6
Time
Survivor Functions
Mean=1, Aperiodicity=0.5
Log Probability
10^-1
10^-3
10^-5
10^-7
Time
Conditional Probability
for Prediction Interval of 0.3
Probability
0.0
0.2
0.4
0.6
0.8
1.0
Time

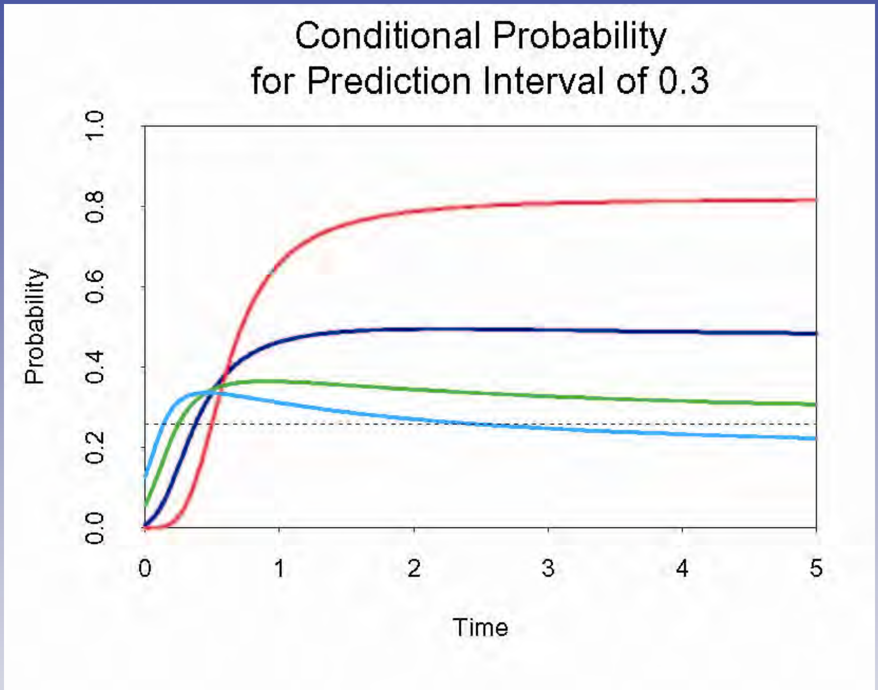
INFLUENCE OF α



URS

INFLUENCE OF α

- **Smaller α (0.3)**
  - ***pdf* is strongly peaked and remains close to zero longer (more periodic)**
  - **Larger conditional probabilities in long-term quasi-stationary state**



- **Larger α (0.7)**
  - **Delay time is shorter, closer to poisson-like behavior**
  - **Conditional probabilities close to poisson in long-term quasi-stationary state**

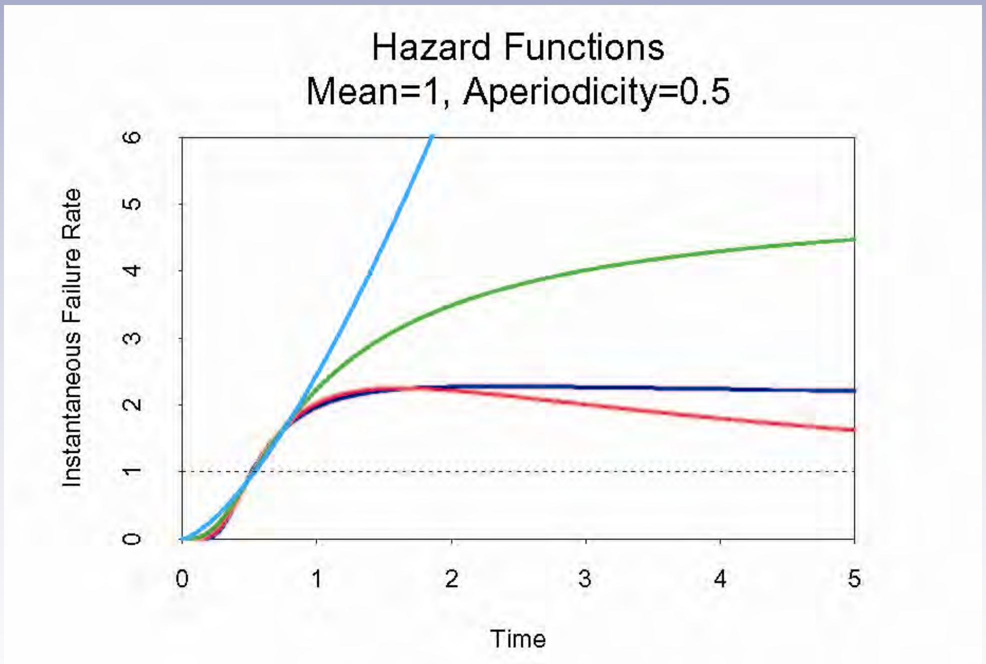
- **UCERF: 0.3 (0.2), 0.5 (0.5), 0.7 (0.3)**
  - **Ellsworth et al. (1999) 37 sequences of events**
  - **Branches for segment specific and for constant value for all segments.**

WASATCH ?

URS

LOGNORMAL MODEL

- Shape of pdf very close to BPT model
- However,
  - Hazard function increases from zero initially, but goes to zero as $t \to \infty$



➢Long term behavior does not fully satisfy geologic intuition or earthquake renewal process

Time-Predictable Model

- Inputs
  - Slip during most recent event
  - Fault slip rate

- Provides expected time of next event, not the size

- Implemented by WGCEP 2003 for Northern San Andreas
  - BPT model used to describe variation about expected time

- Not implemented in UCERF 2
  - *"Slip-predictable methods of computing earthquake probabilities from long-term rates significantly overpredict event rates and moment rates"* (Field and Gupta, 2008)
  - Data on average slip from previous events sparse and uncertain

Time-Predictable Model Implemented by WGCEP 2003

1. **Compute slip in most recent event**
2. **Determine slip rate on each segment**
3. **Expected return time for segment is slip / slip rate**
4. **Compute probability of event starting on segment**
   - ***BPT model with α***
5. **Compute probability that an epicenter on a segment will lead to one of the rupture fault sources using slip-predictable model**
   - ***What is the probability for each rupture source that there is enough stored moment since last event?***
6. **Compute rupture source probabilities**
   - ***Probability of epicenter on each segment * Probability that epicenter will lead to a rupture source***

URS

Issues Relating to Multi-segment Rupture Models

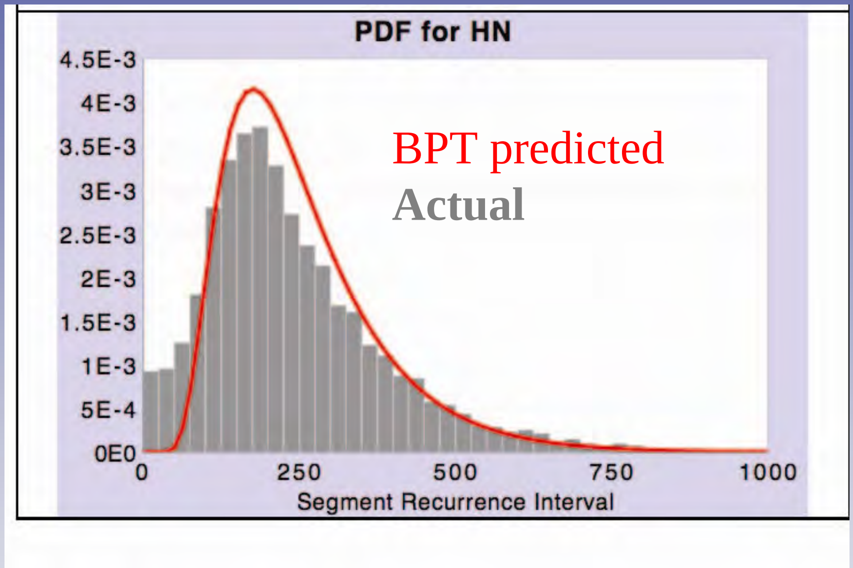
Inconsistency with segment rates implied by BPT distribution and actual segment rates produced by the model

$$P(rup) = \sum_{segs\_in\_rup} P(seg) \frac{R(rup)}{R(seg)} \frac{\dot{M}o(seg)}{\sum_{segs\_in\_rup} \dot{M}o(seg)}$$

$$P(rup) \approx P_{pois}(rup) \frac{\sum_{seg\_in\_rup} \frac{P(seg)}{P_{pois}(seg)} \dot{M}o(seg)}{\sum_{seg\_in\_rup} \dot{M}o(seg)}$$

- First, probabilities of segment rupture are computed, then distributed to rupture sources containing that segment.

Issues Relating to Multi-segment Rupture Models (continued)



- Final segment probabilities aggregated from the rupture source probabilities are **not** the same as the BPT computed probabilities
- Probability of segment rupturing and taking it's neighbor has nothing to do with when it's neighbor ruptured last
- Problem increases with increasing number of segments (S. SAF worse than N. SAF)

"WGCEP (2003) methodology remains the best available science"
(Field and Gupta, 2008) and was adopted for UCERF2.

URS

Analysis of Moment Rates from GPS, Historic Earthquakes, and Paleoearthquakes on the Wasatch Fault

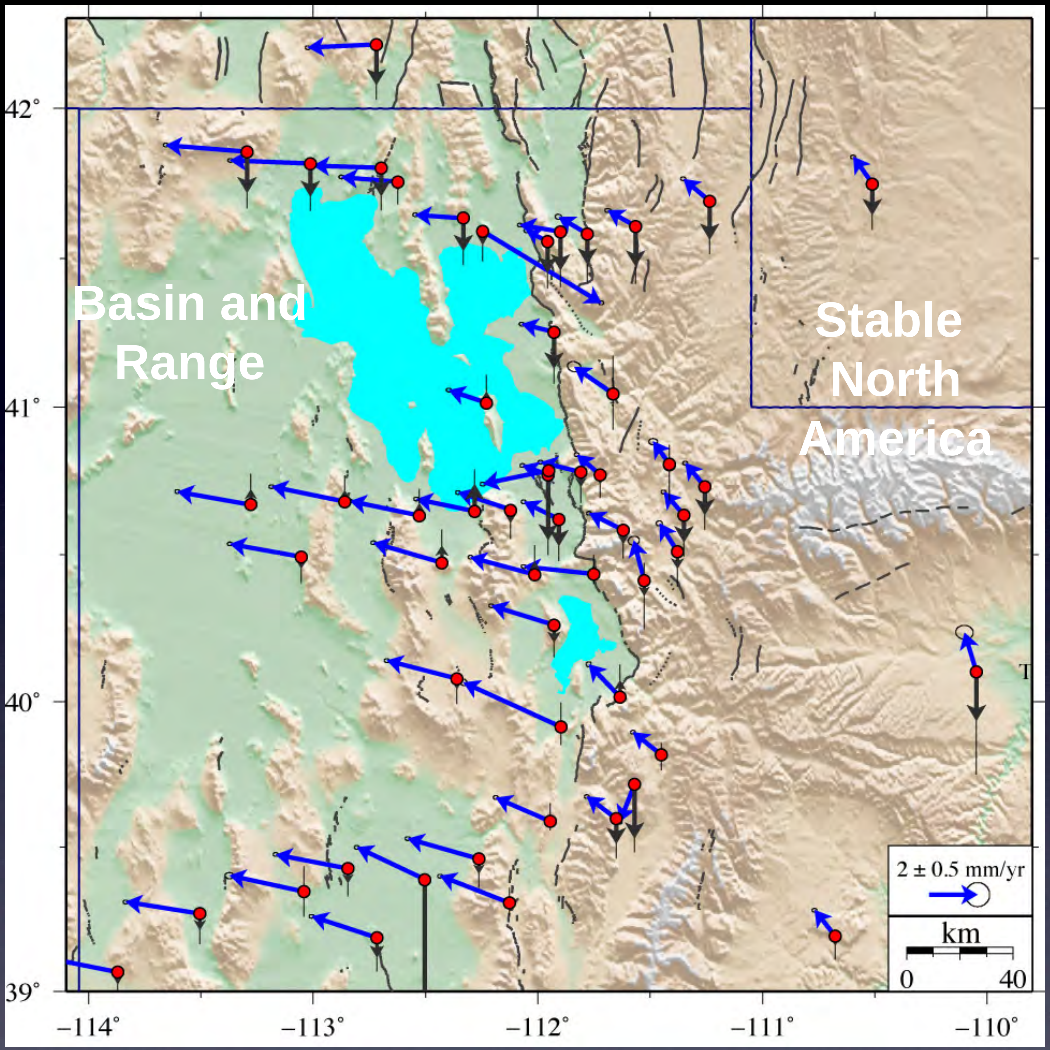
Christine Puskas
Robert B. Smith
Dept of Geology and Geophysics

THE UNIVERSITY OF UTAH
Seismology and Active Tectonics Research Group

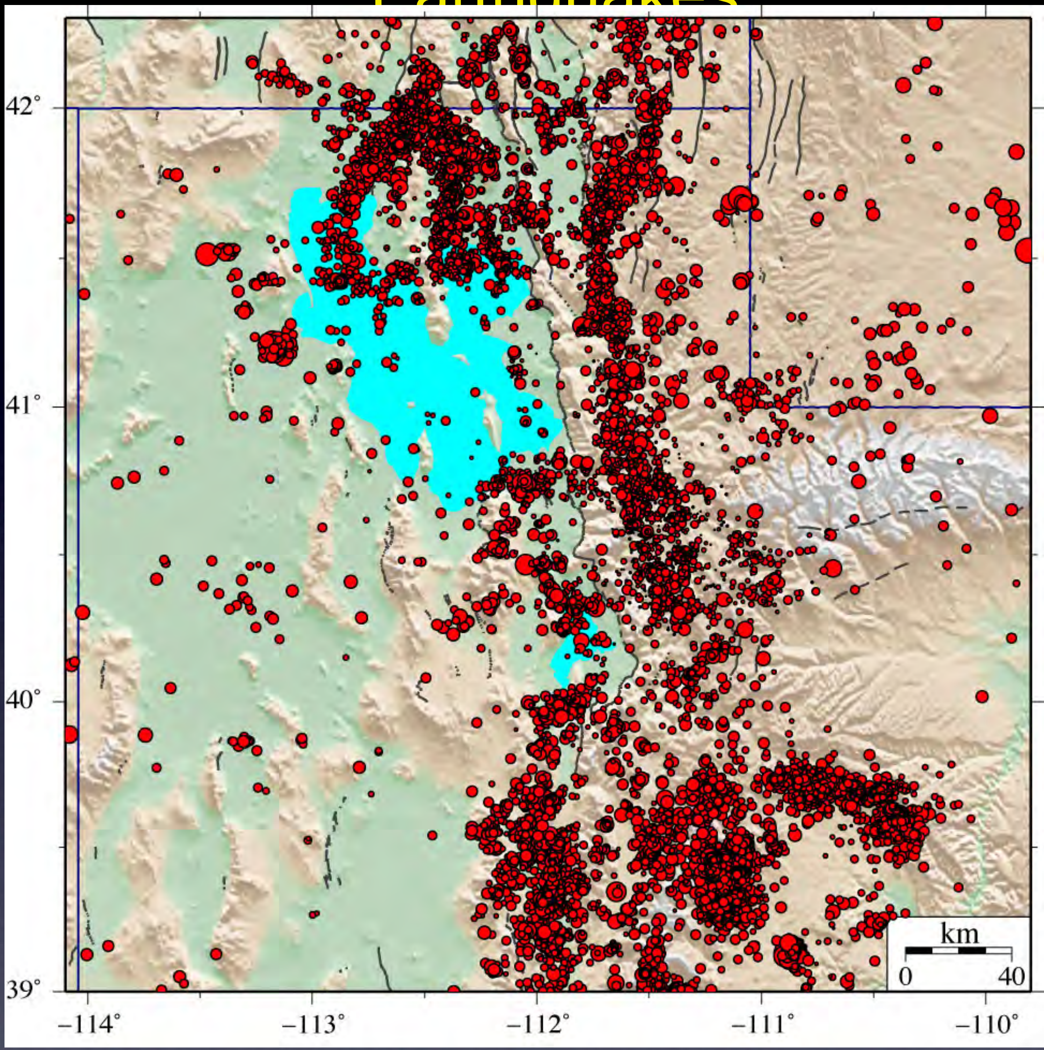
Moment: measure of energy required for deformation

$$M_o = \mu \dot{u} A$$

2007-2010 Wasatch GPS Velocities



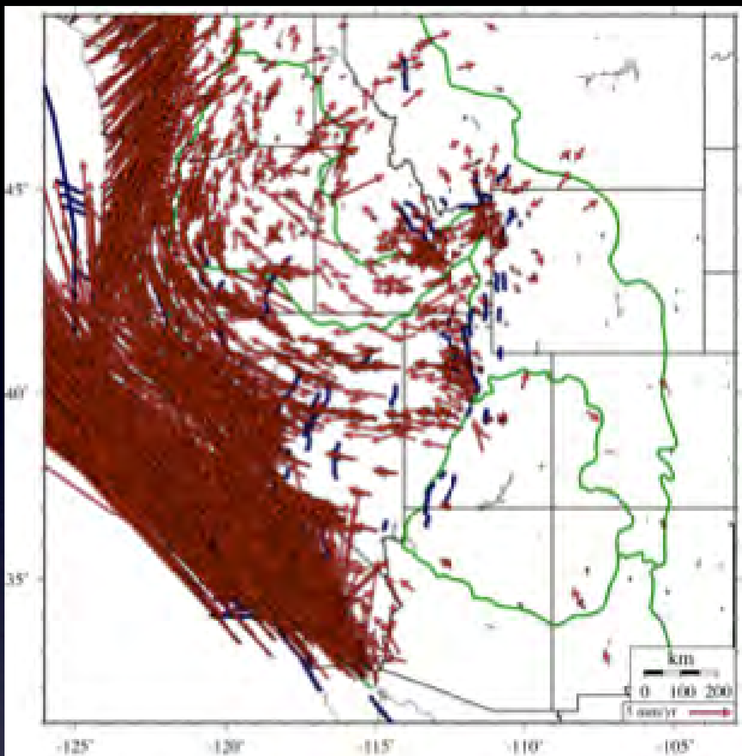
1981-2011 Wasatch Earthquakes

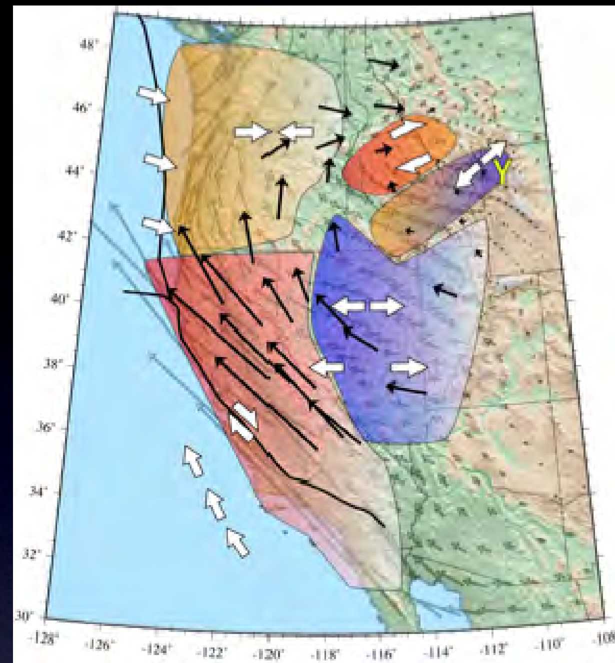


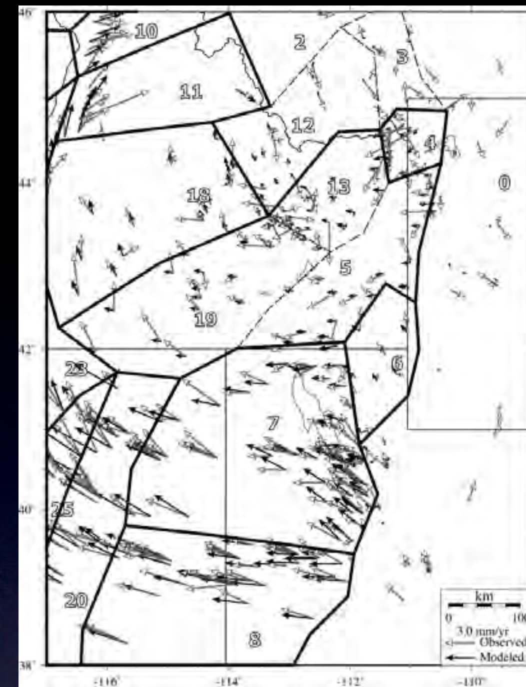
- Basin-Range/Rocky Mountain boundary (stable North America)
- Central Intermountain Seismic Belt

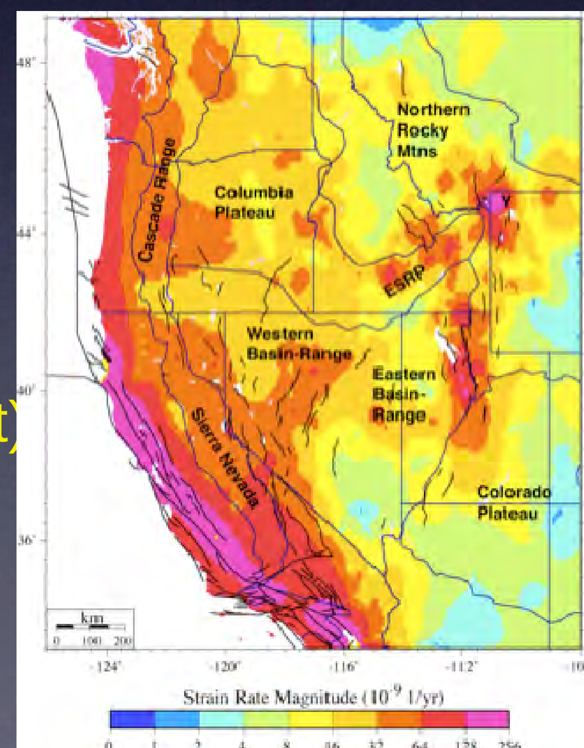
Deformation Models

Western U.S. GPS Data



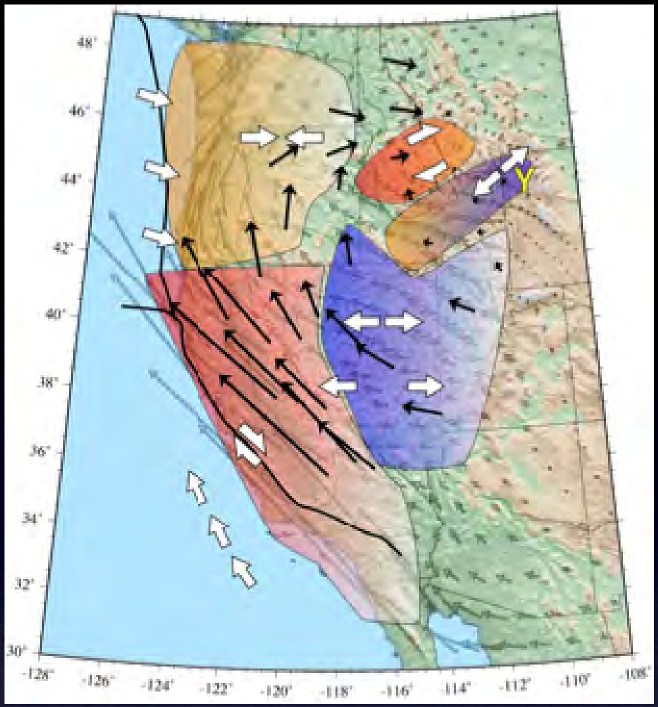






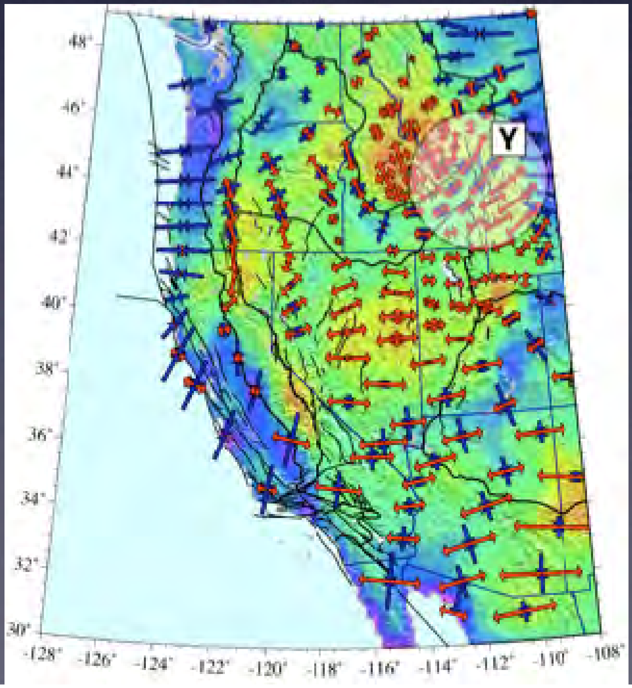
- Western U.S. rotation in velocity field
- Extensional Basin-Range (including Wasatch Front)
- Locally high deformation rates at Wasatch fault

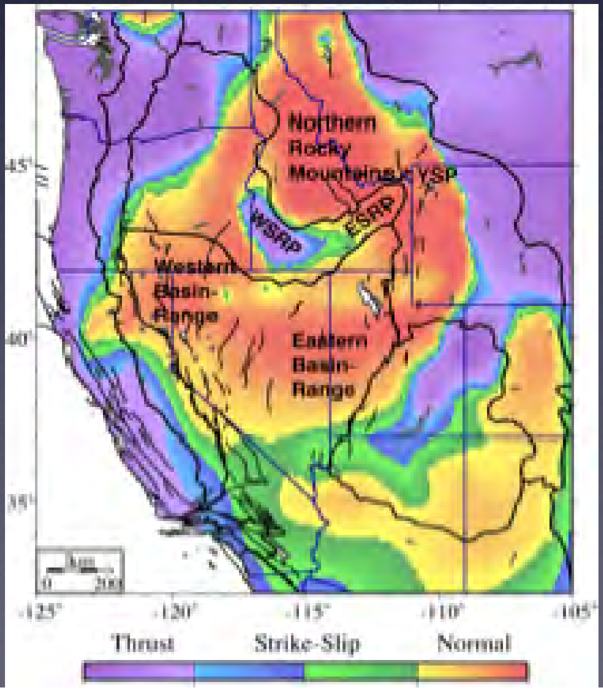
Deformation Model



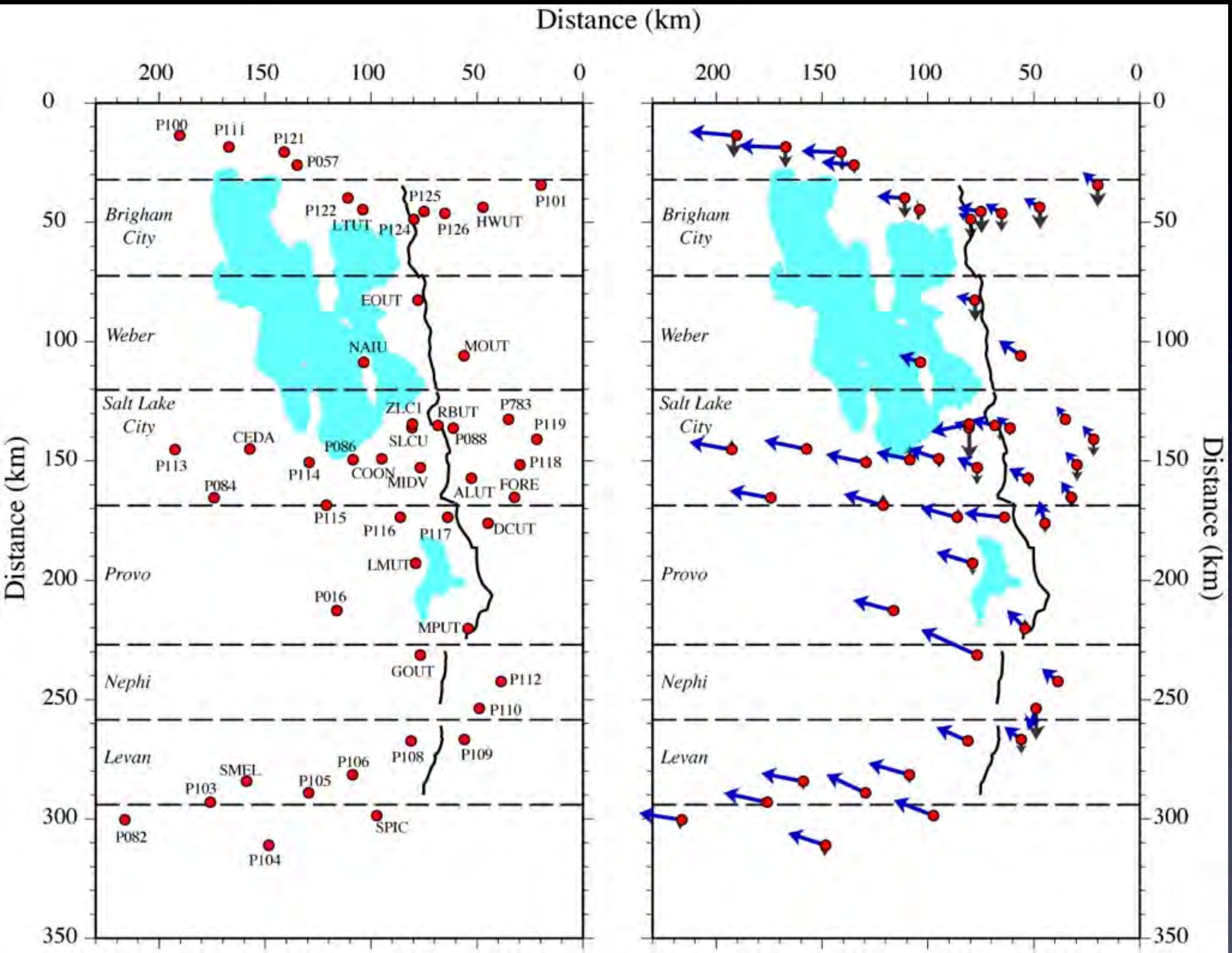
- Tectonic stresses drive deformation
- Stress modeling reveals regional tectonics
  - High elevation and high potential energy cause tensional stress (Intermountain West)
  - North America-Pacific-Juan de Fuca plate interaction cause compression and shear (California and Pacific Northwest)
- Inferred stresses account for observed rotation in GPS data

Western U.S. Stress Model



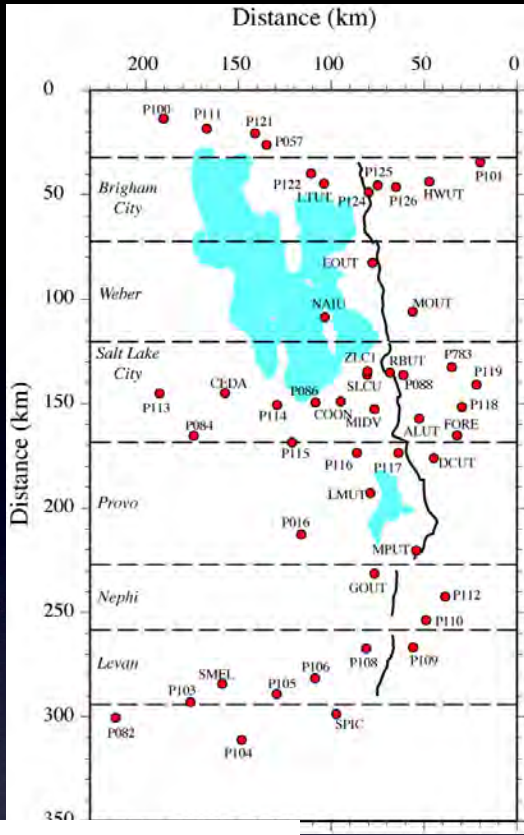


2007-2010 Wasatch GPS Network

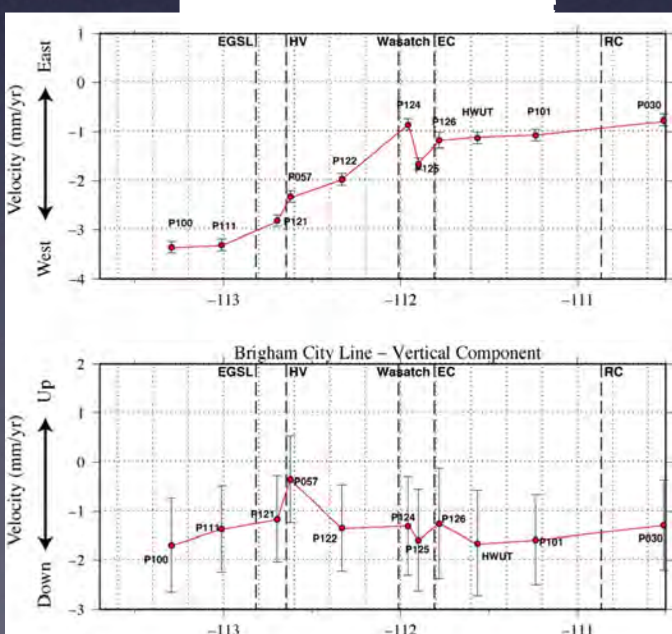


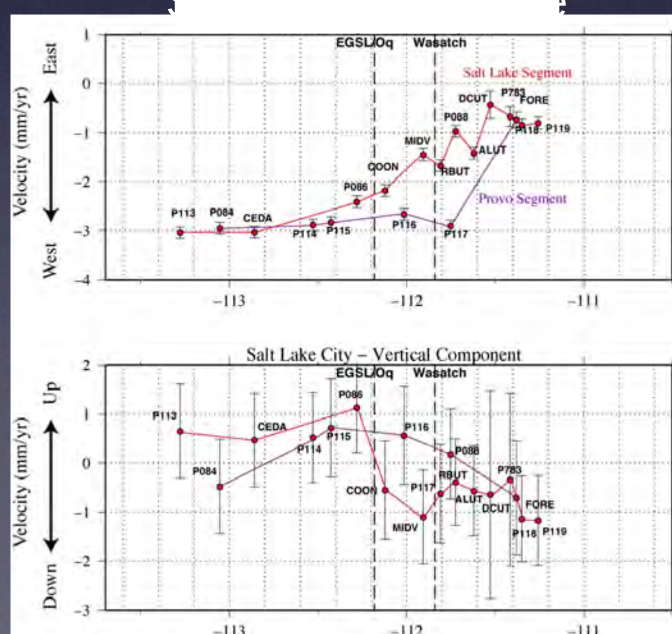
- 68 permanent GPS stations
- Operated by University of Utah and Plate Boundary Observatory
- Profiles across Wasatch fault and other faults to measure contemporary deformation
- Monitoring since 1996

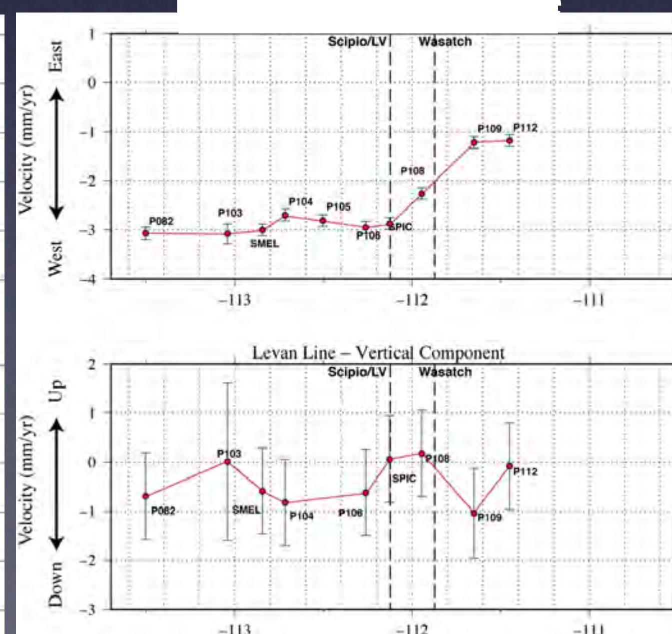
Velocity Profiles



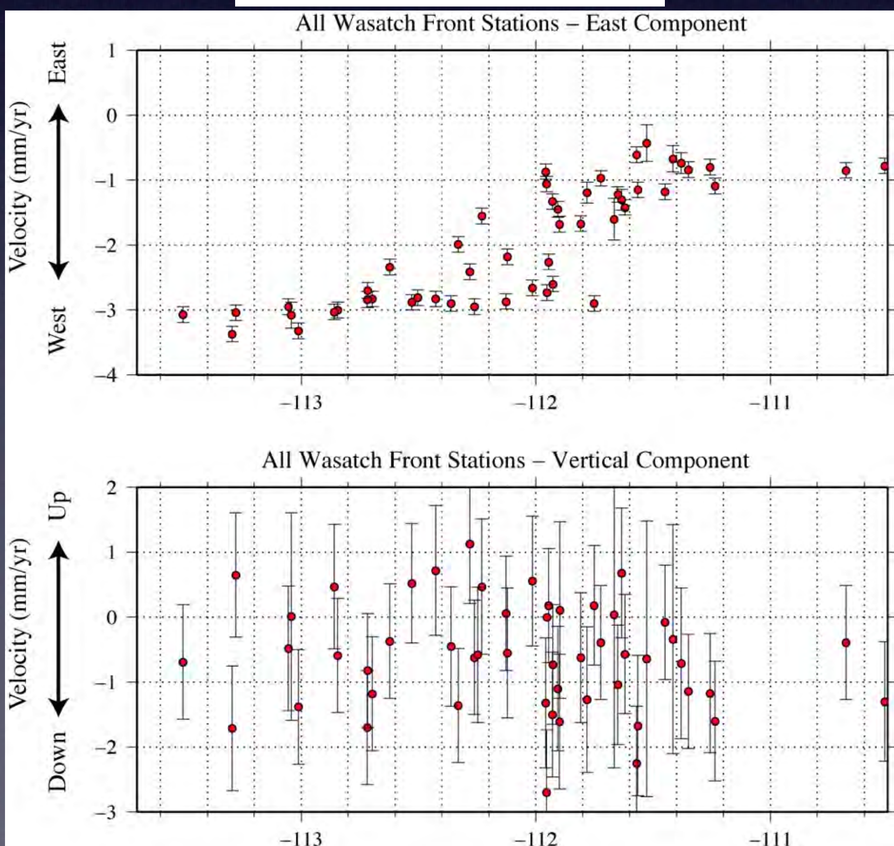
- 2007-2010 velocities
- Velocities increase rapidly across the fault zone
- Profiles cross multiple fault systems
  - Wasatch
  - East Cache
  - East Great Salt Lake/Oquirrh
  - Hansel Valley
  - Scipio/Little Valley



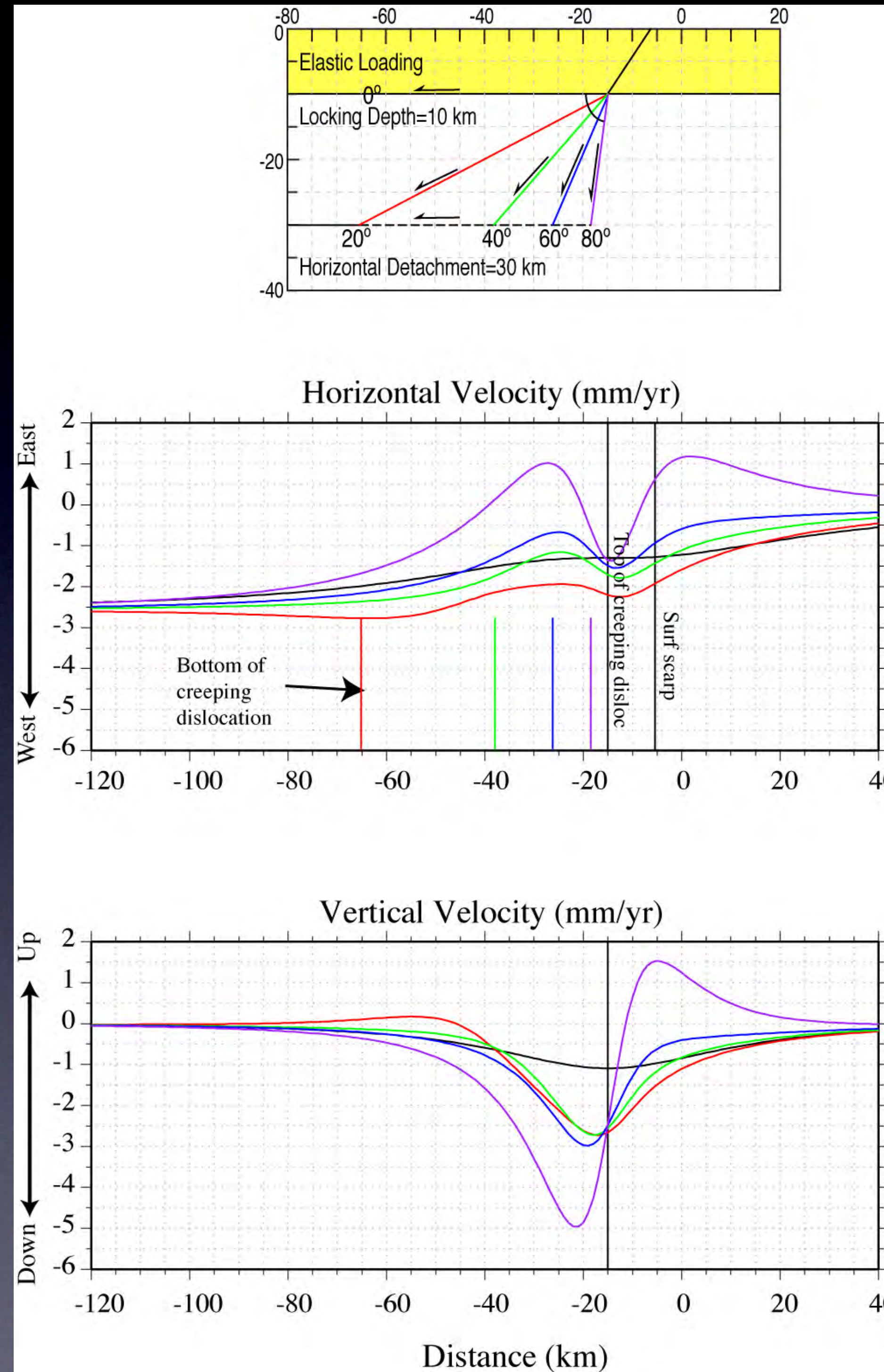


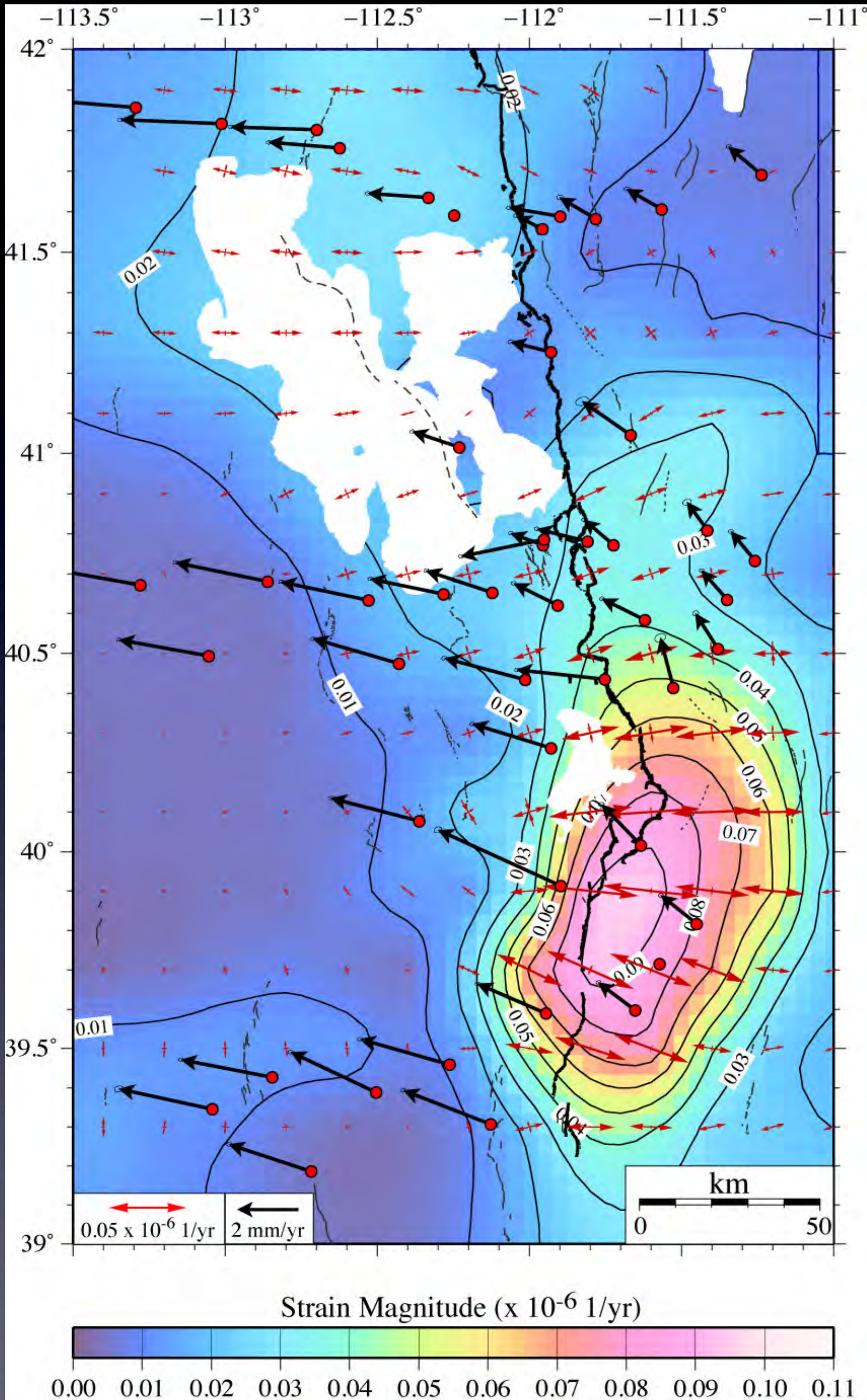


- Locked elastic seismogenic layer over creeping lower crustal layer
- Horizontal dislocation to simulate far-field deformation on a detachment
- GPS profiles more closely resemble modeled rates from low-dip (<40º) creeping dislocation

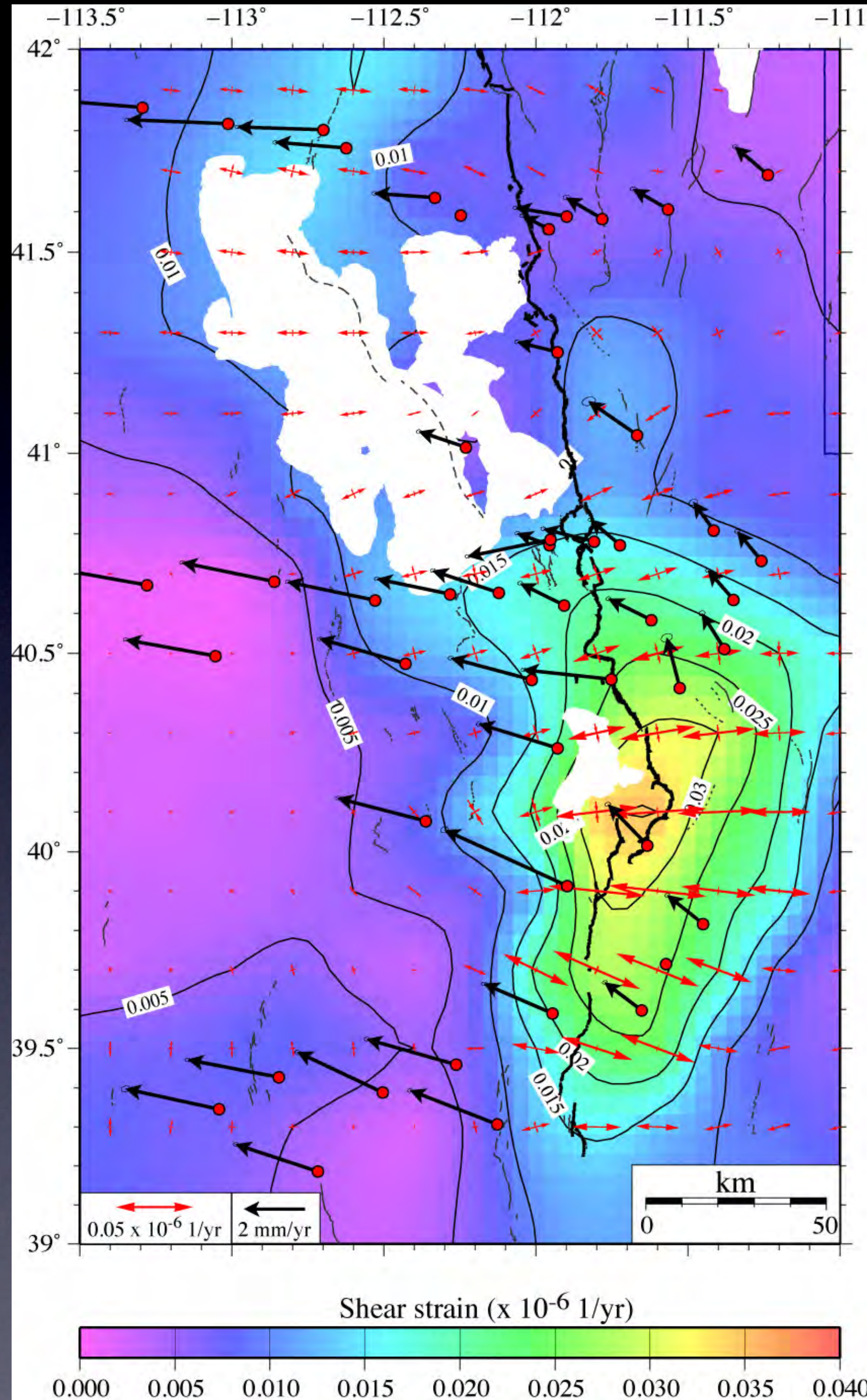


Fault Plane Dislocation Models

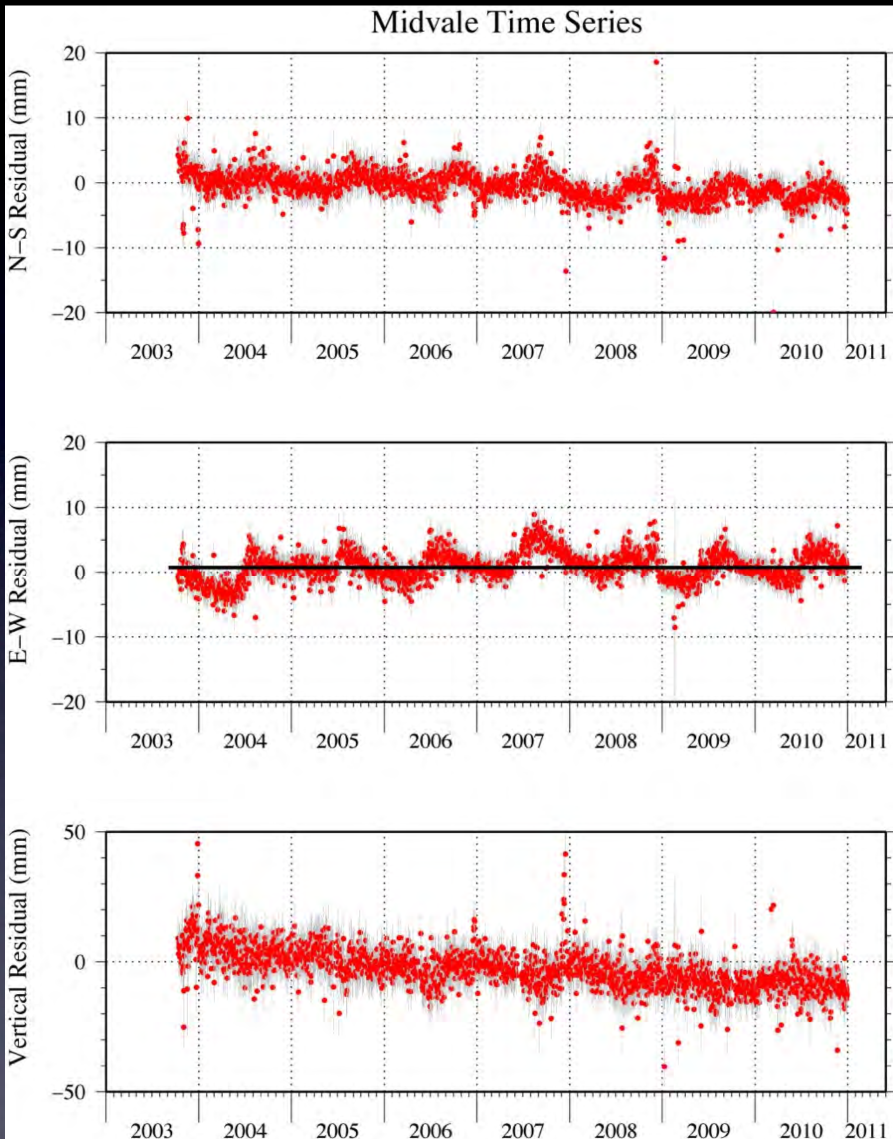


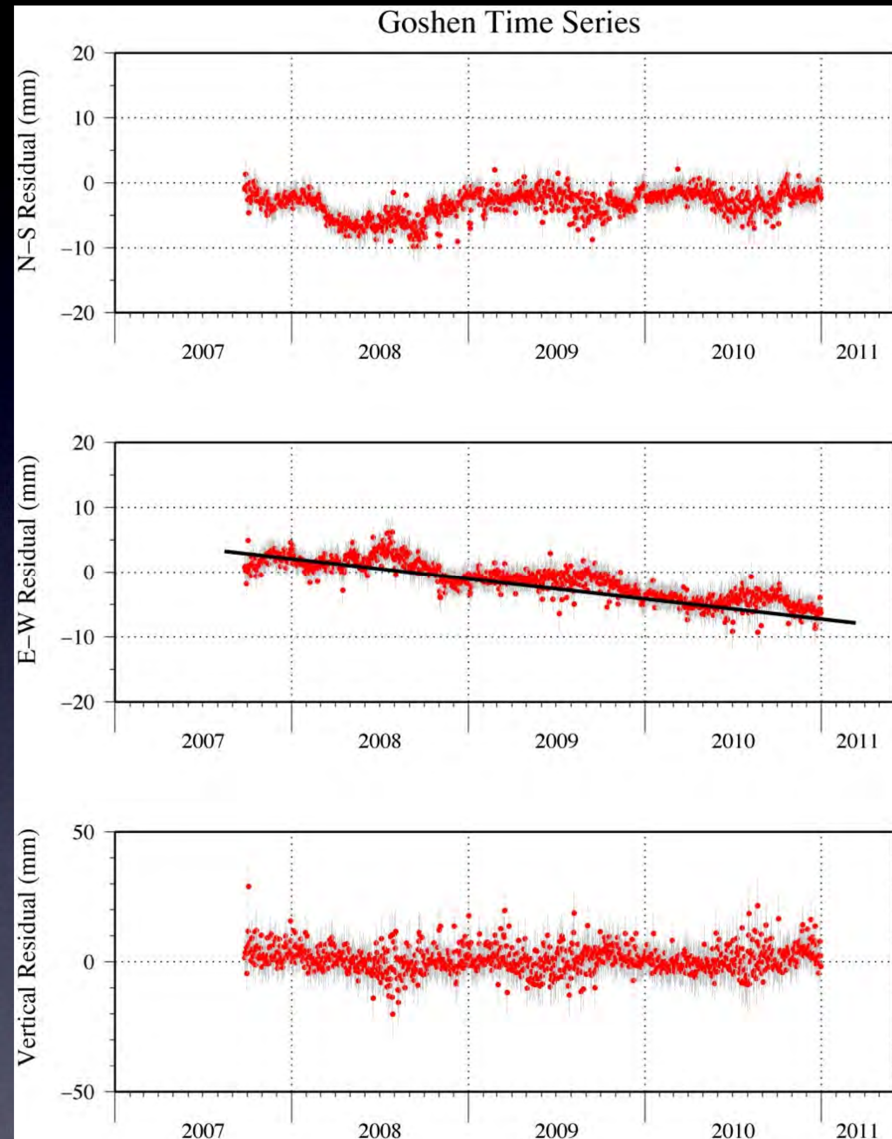


0.05 x 10-6 1/yr
2 mm/yr
km
0
50
Strain Magnitude (x 10-6 1/yr)
0.00 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10 0.11

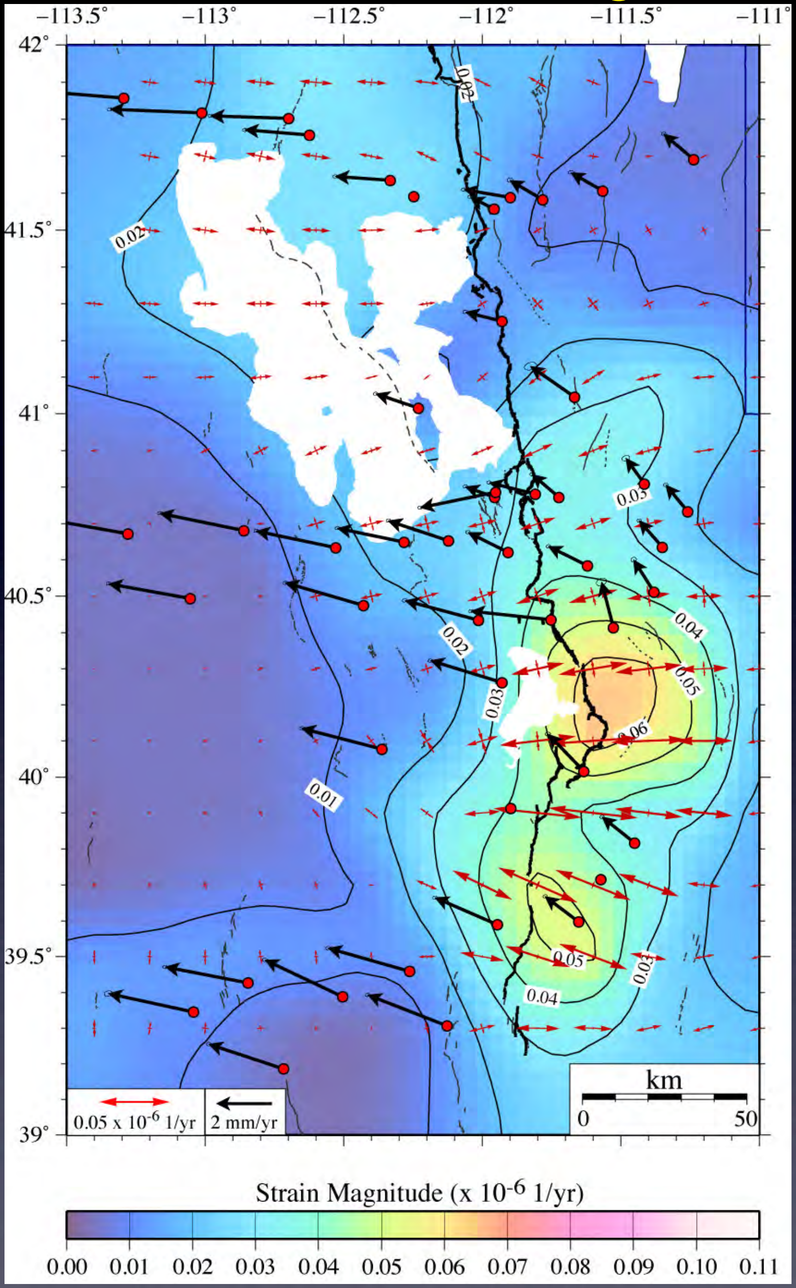


0.05 x 10-6 1/yr
2 mm/yr
km
0
50
Shear strain (x 10-6 1/yr)
0.000 0.005 0.010 0.015 0.020 0.025 0.030 0.035 0.040

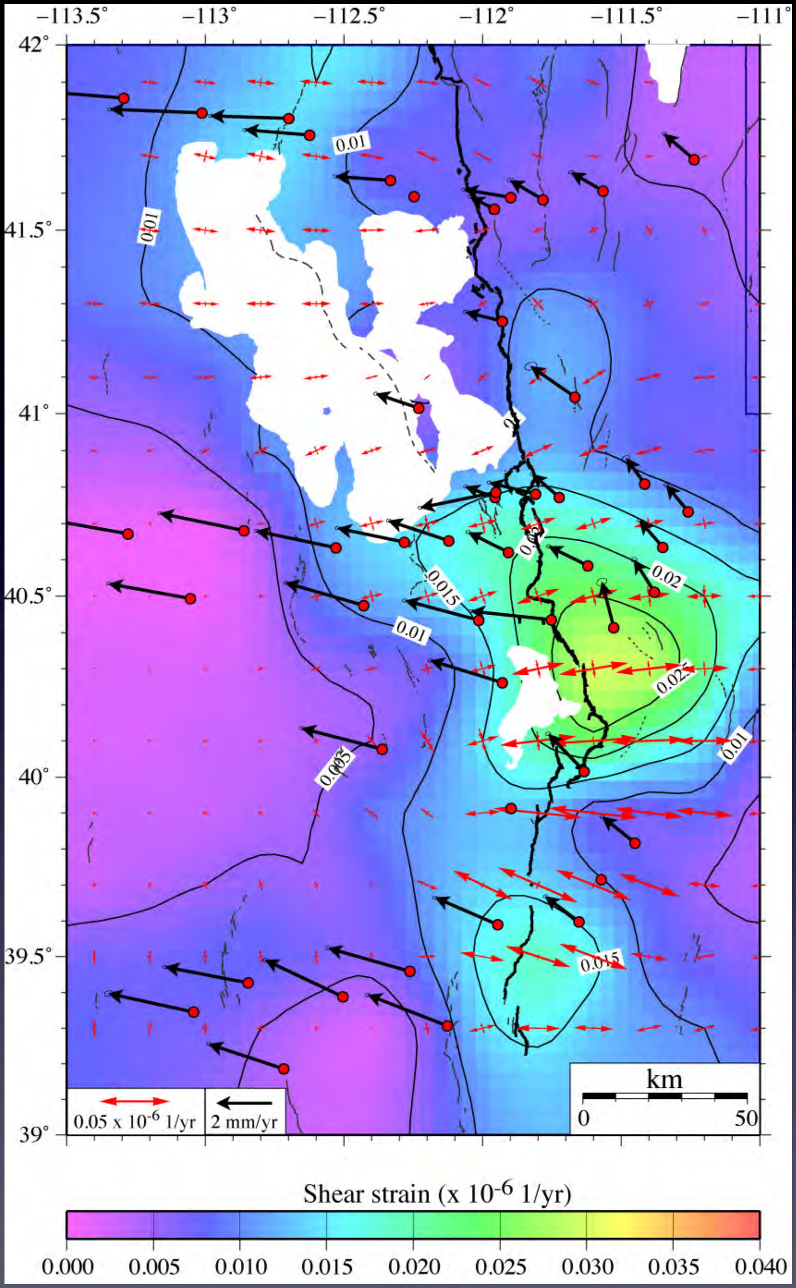

Midvale Time Series
N–S Residual (mm)
E–W Residual (mm)
Vertical Residual (mm)
20
10
0
−10
−20
50
0
−50
2003
2004
2005
2006
2007
2008
2009
2010
2011


Goshen Time Series
N–S Residual (mm)
E–W Residual (mm)
Vertical Residual (mm)
20
10
0
−10
−20
50
0
−50
2007
2008
2009
2010
2011

Strain Rates and Magnitude



Strain Rates and Shear Stress

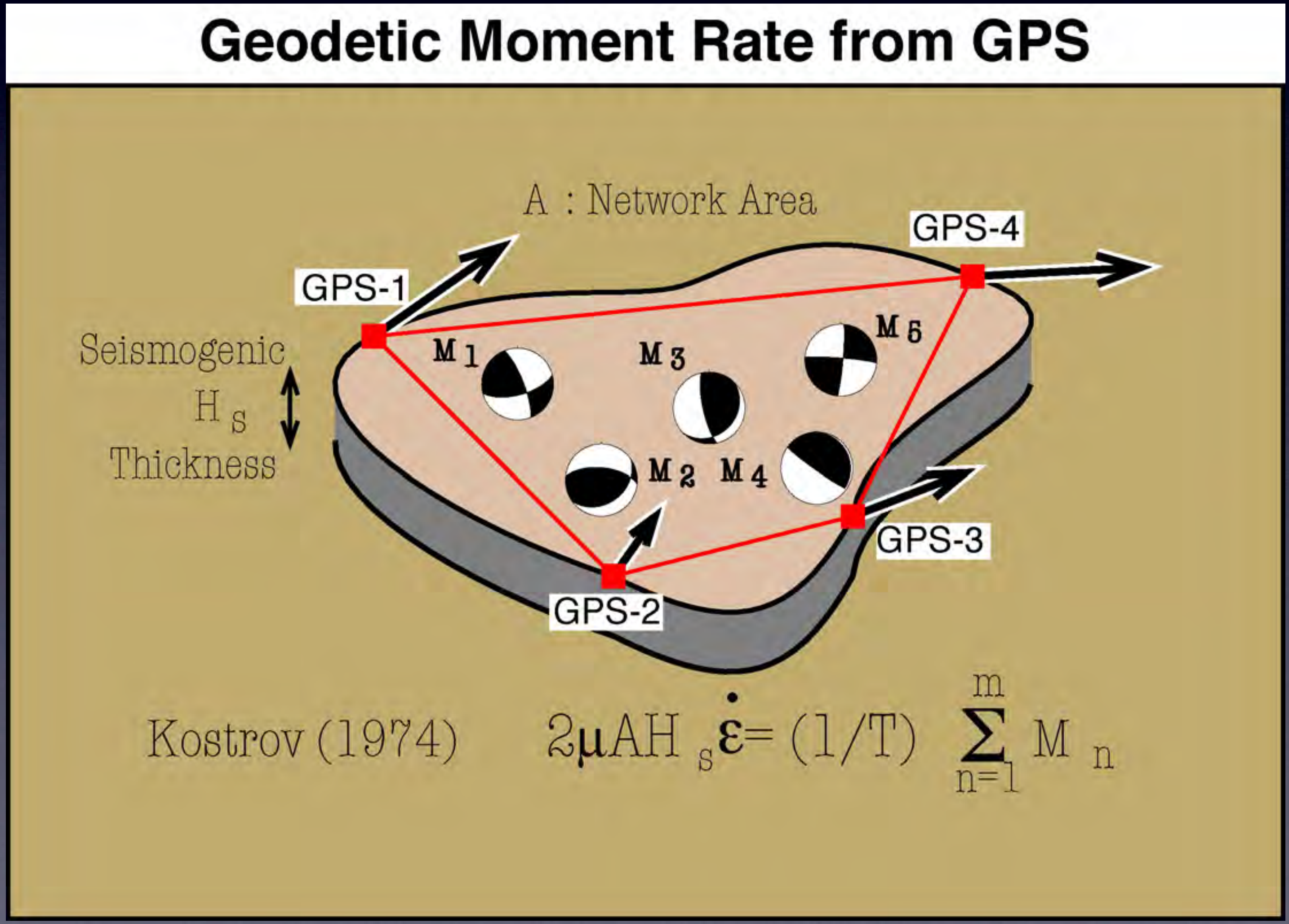


- Interpolate GPS velocities to strain rate grid
- Greatest changes in deformation at Wasatch fault

- Use Kostrov formula to estimate geodetic loading rate

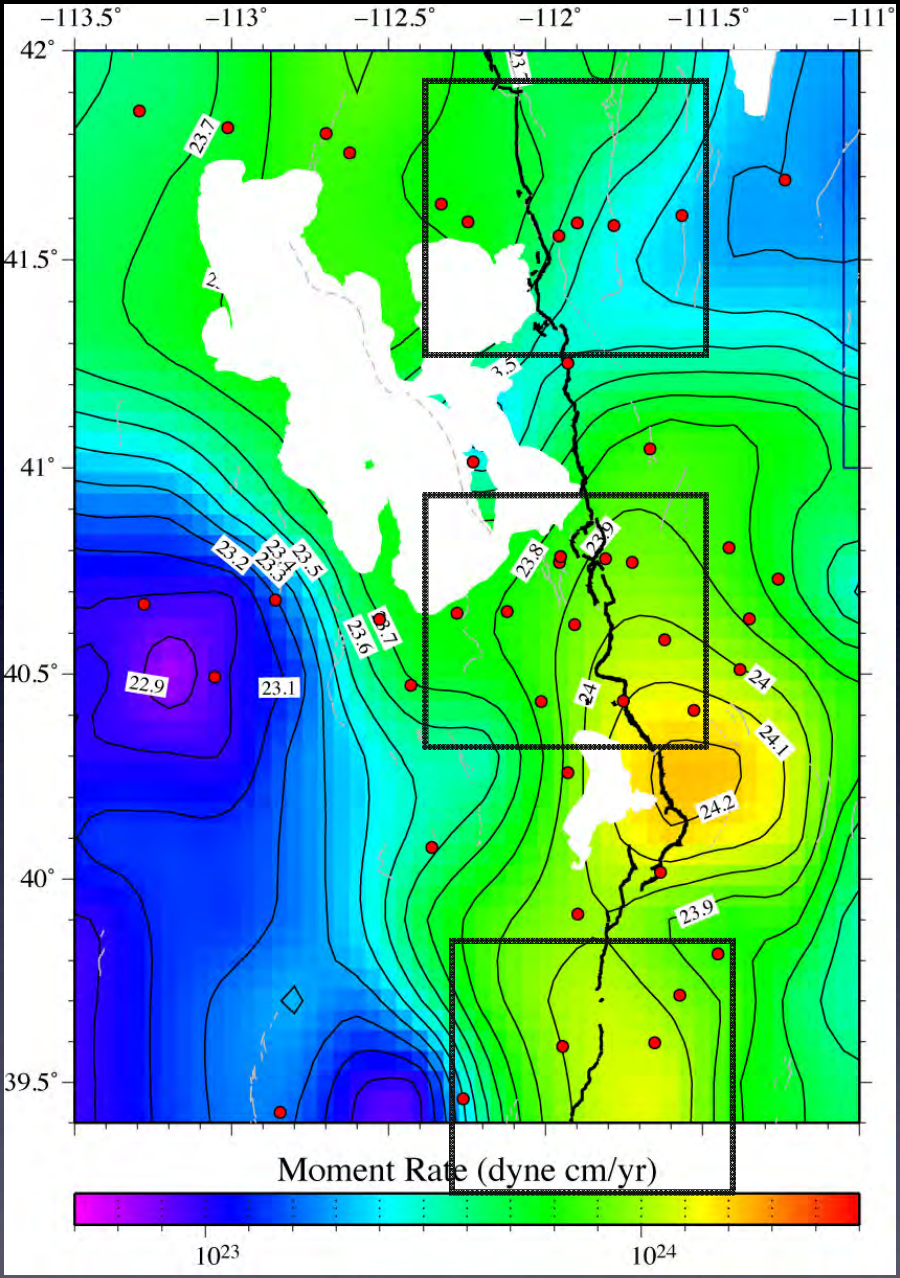
- Moment available for earthquakes depends on:
  - Seismogenic volume (network area x maximum earthquake depth)
  - Strain (deformation rate) for area

- Average surface strain assumed proportional to volume strain



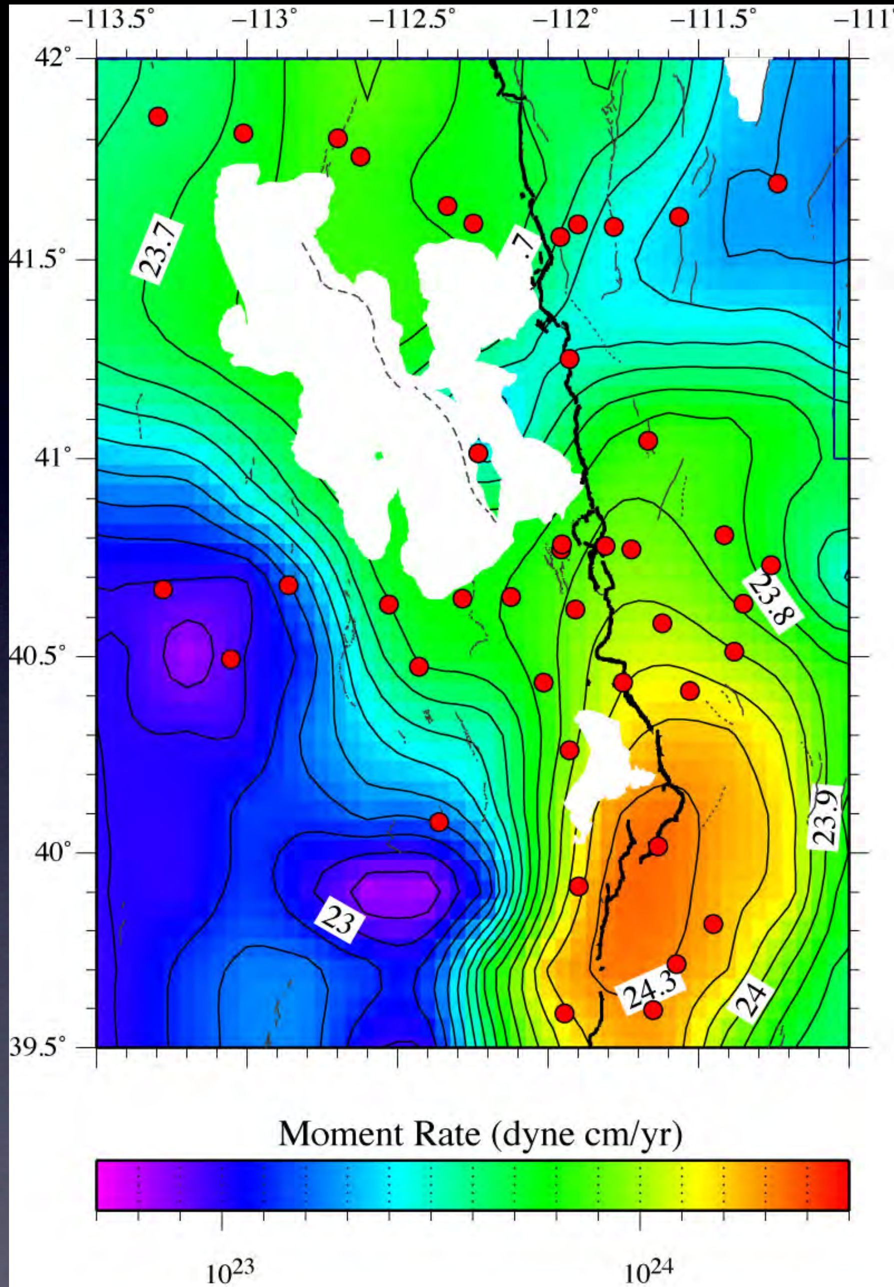
(Ward, 1998)

Geodetic Moment Loading Rates



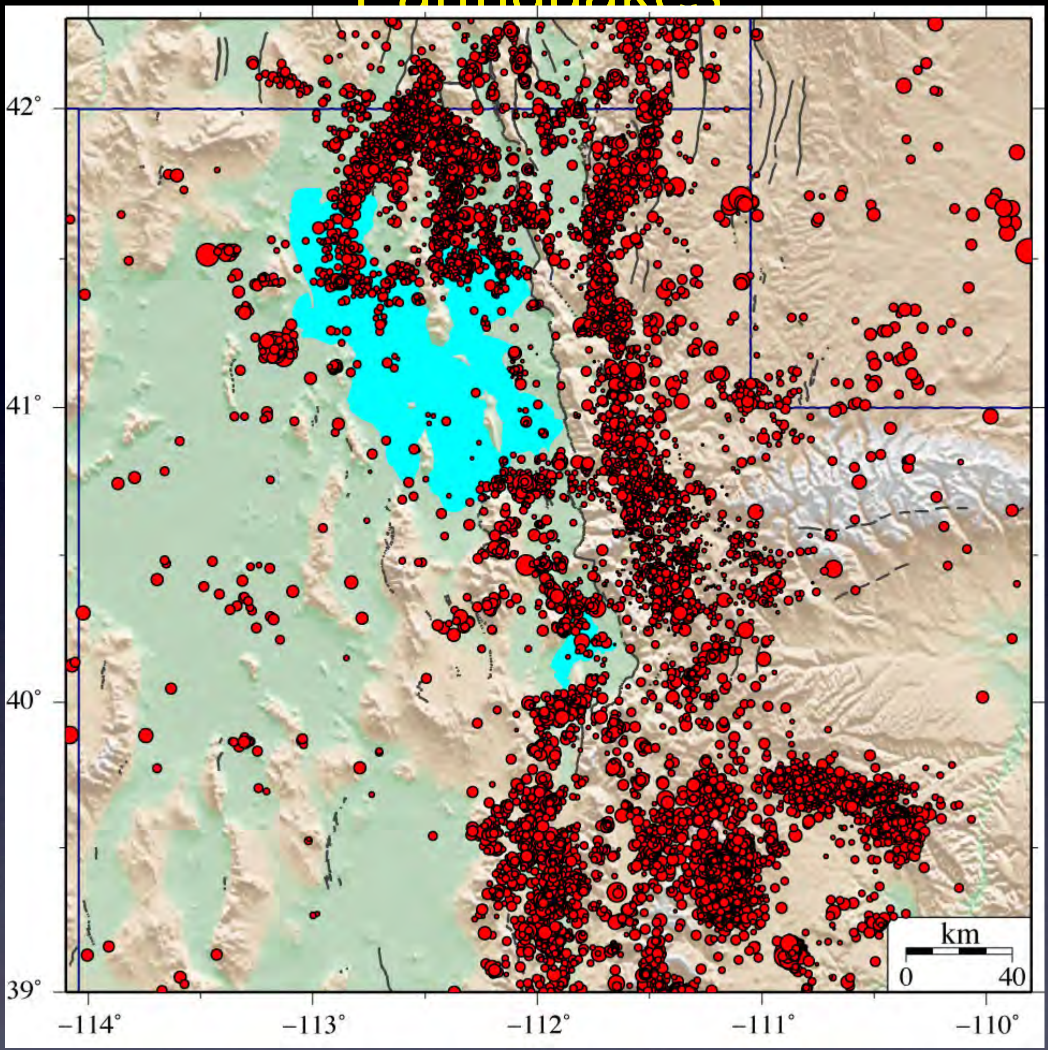
- Convert strain rates to moment rates
- Moment rates reflect deformation rates
- Geodetic loading rates are 10^{23} to 10^{24} dyne cm/yr in 0.2° grid areas
- Greatest loading in south-central Wasatch
- Calculate profile moment rates from single interpolated strain rate in selected area

Area	Moment Rate (dyne cm/yr)
Northern GPS profile	6.7E+24
Central GPS profile	9.1E+24
Southern GPS profile	1.1E+25



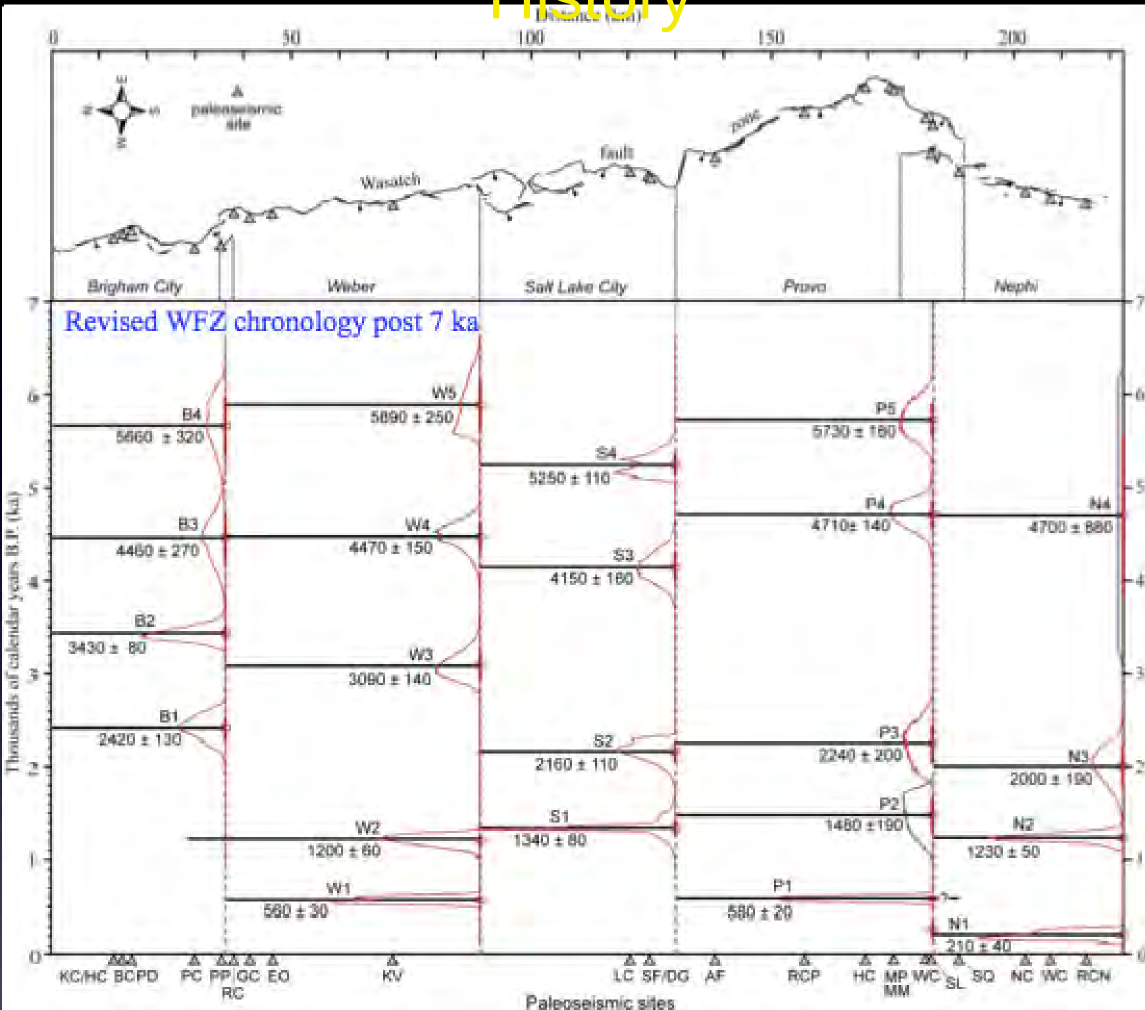
−113.5°
−113°
−112.5°
−112°
−111.5°
−111°
42°
41.5°
41°
40.5°
40°
39.5°
23.7
.7
23.8
23.9
23
24.3
24
Moment Rate (dyne cm/yr)
10^{23}
10^{24}

1981-2011 Wasatch Front Earthquakes



- Historic earthquakes
  - Wasatch fault quiescent for M$\geq$3
  - Notable N-S zone of seismicity east of Wasatch fault
- Convert magnitude to seismic moment
  - 40,000+ earthquakes for 1981-2011
  - Catalog contains local and coda magnitudes
  - Use empirical relation (Bott et al., 1997)
- Average seismic moment release rate is 8.6E+22 dyne cm/yr - one order of magnitude less than geodetic rates

Wasatch Fault Paleoearthquake History

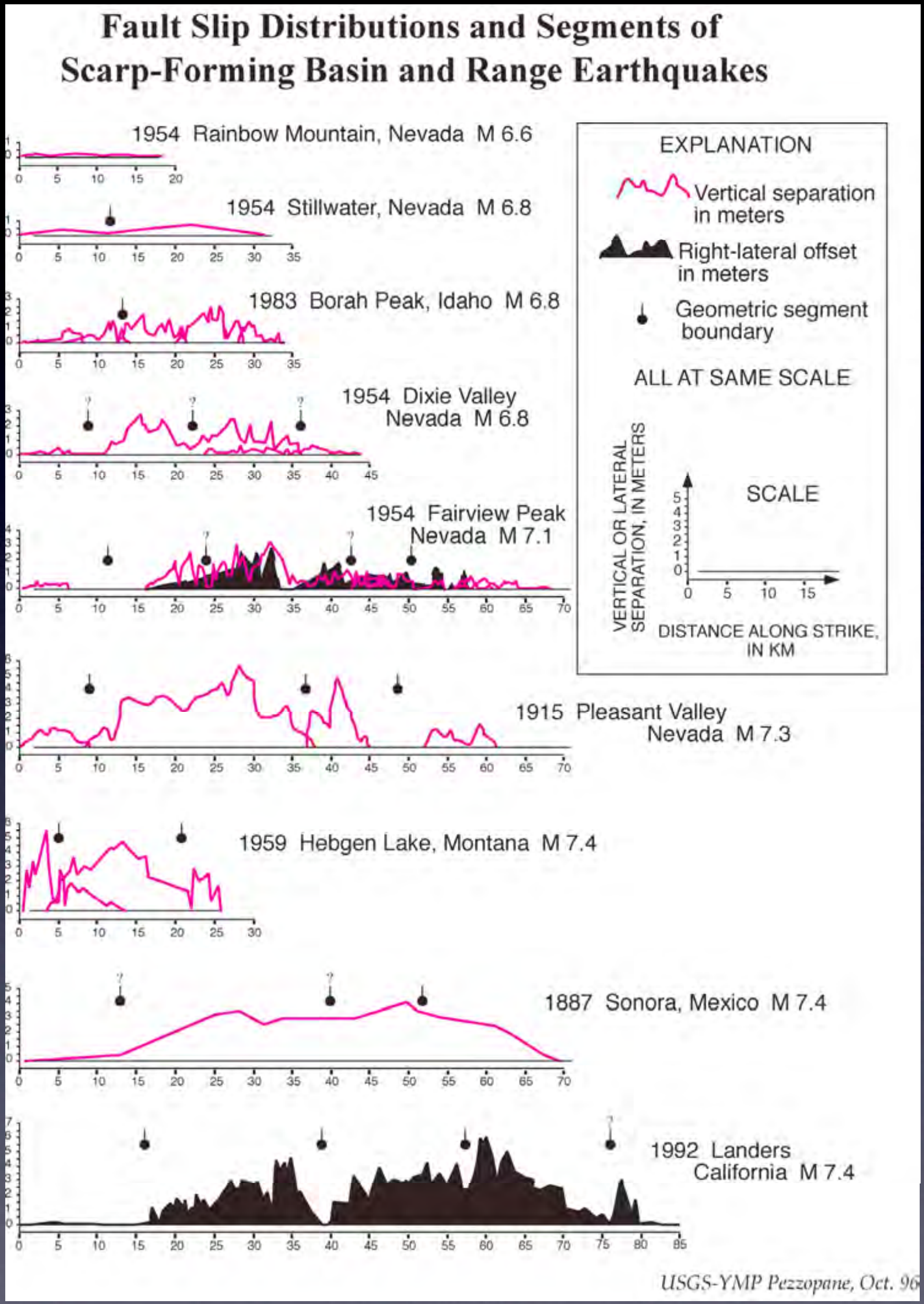


(Working Group on Utah Earthquake Probabilities, 2010)

- Identify Late Quaternary paleo-earthquakes from Wasatch fault trenching
  - Each segment has had 4-5 ruptures
- Data: offset, surface rupture length
  - Moment related to rupture area, slip
  - Surface displacement varies along strike
  - Rupture area depends fault geometry, rupture length, seismogenic depth
- Use empirical scaling to obtain moment magnitude (Wells and Coppersmith, 1994)
  - Preferred moment magnitudes from surface rupture length relation

$$M=5.08 + 1.16 \cdot \log(SRL)$$

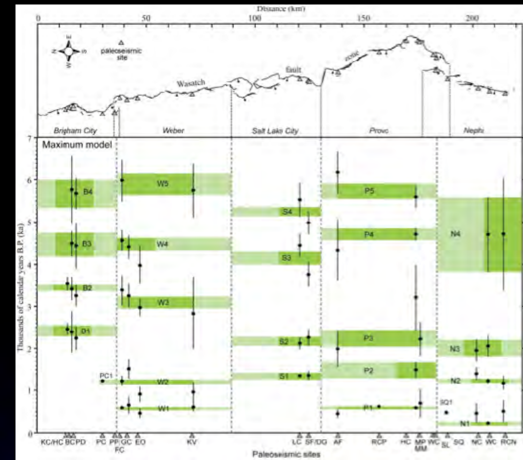
Historic Multi-Segment Earthquakes

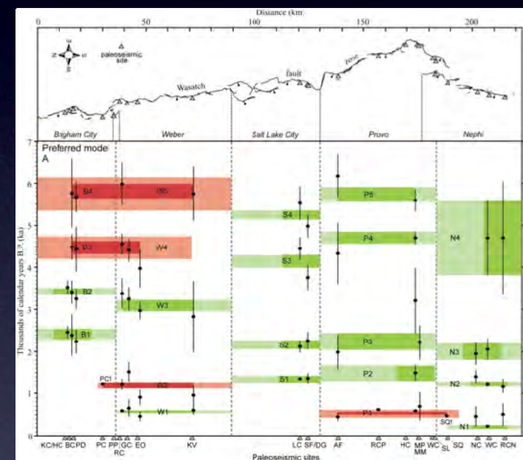


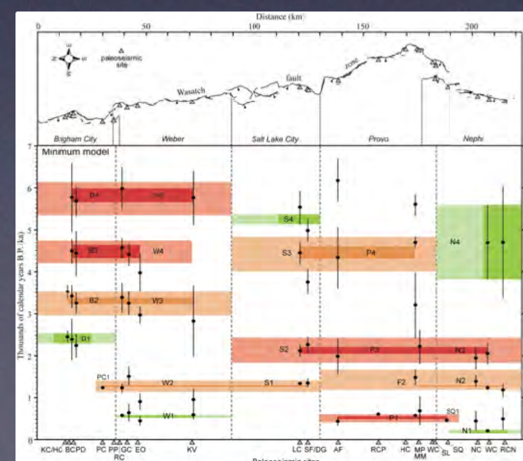
(Pezzopane and Dawson, 2010)

Scenario Earthquake Models

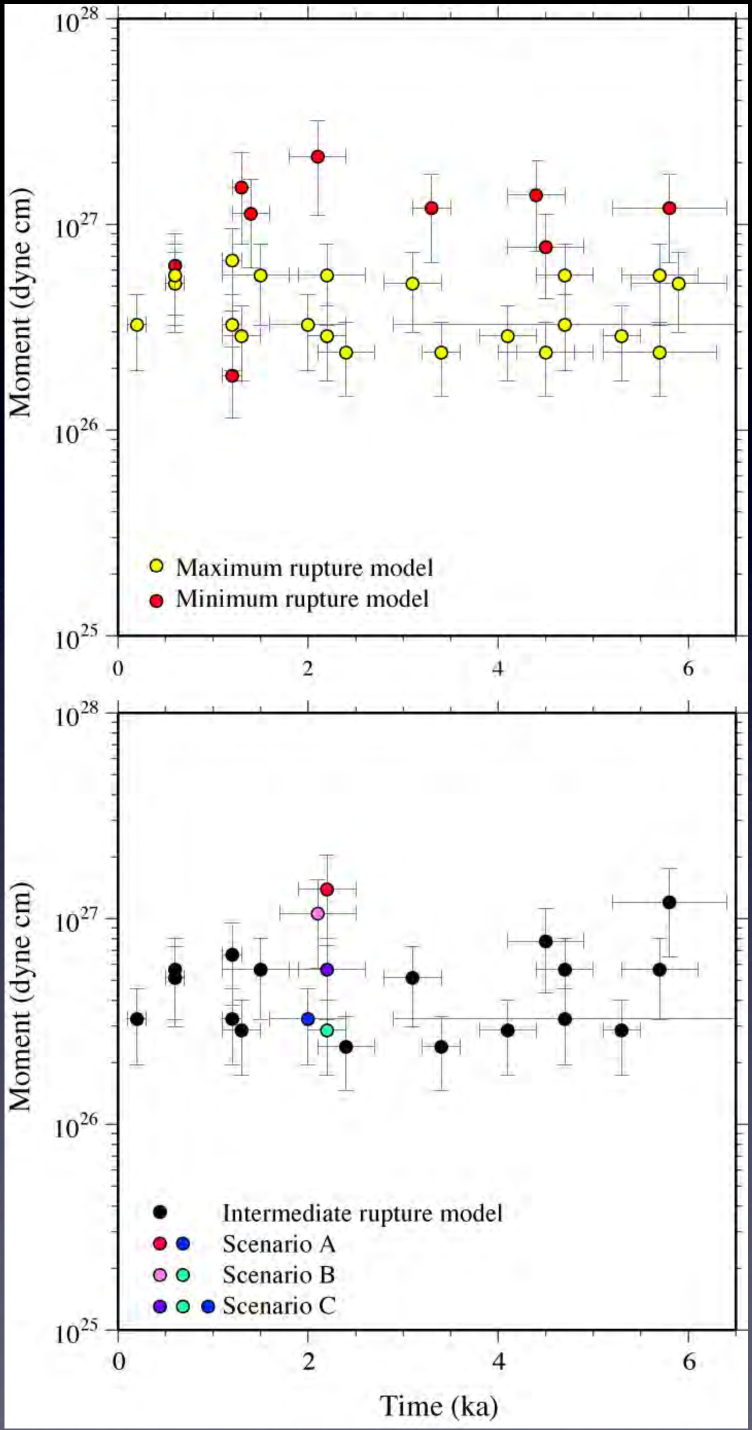
- Developed by Working Group on Utah Earthquake Probabilities
- Divide paleoearthquakes into various single and multisegment combinations
- Maximum Rupture Model - single segment ruptures + one leaky-boundary rupture (22 events)
- Intermediate Rupture Model - mostly single-segment with some multisegment scenarios (variations A, B, C) (19-20 events)
- Minimum Rupture Model - multisegment ruptures where possible (13 events)







Distribution of Paleoearthquakes



- Multisegment earthquakes release more moment
- Significant uncertainties in timing and magnitude
- No clear patterns in timing, magnitude

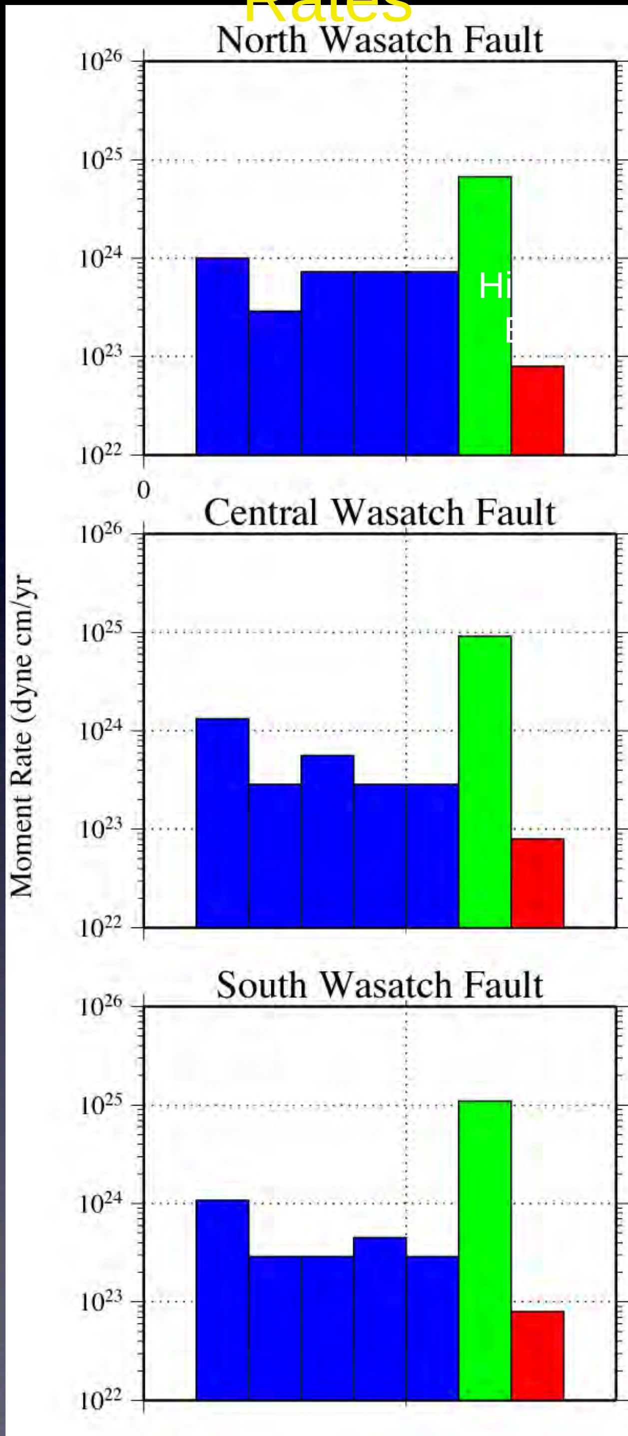
Comparison of Moment Rates

	Source	Moment Rate (dyne cm/yr)
Paleoearthquakes (all Wasatch Front)	Minimum rupture model	1.9E+24
	Maximum rupture model	1.5E+24
	Intermediate model A	1.7E+24
	Intermediate model B	1.6E+24
	Intermediate model C	1.6E+24
GPS	Northern GPS profile	6.7E+24
	Central GPS profile	9.1E+24
	Southern GPS profile	1.1E+25
Historic Earthquakes	1981-2011 Historic Earthquake catalog	8.6E+22

Comparison of Moment Rates

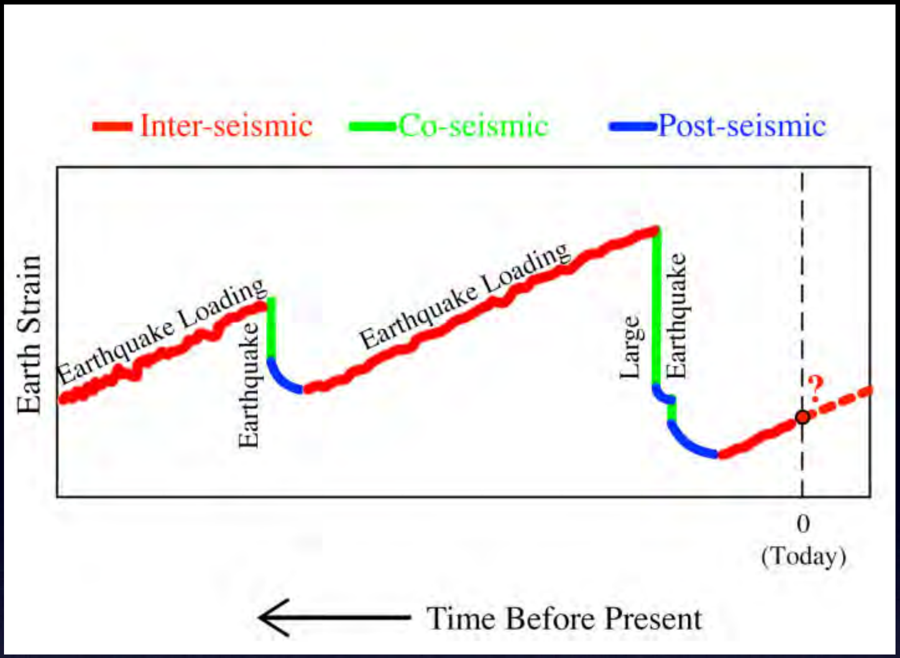
	Source	Moment Rate (dyne cm/yr)	North	Center	South
Paleoearthquakes (all Wasatch Front)	Minimum rupture model	1.9E+24	1.0E+24	1.3E+24	1.0E+24
	Maximum rupture model	1.5E+24	2.9E+23	2.9E+23	2.9E+23
	Intermediate model A	1.7E+24	7.2E+23	5.6E+23	2.9E+23
	Intermediate model B	1.6E+24	7.2E+23	2.9E+23	4.5E+23
	Intermediate model C	1.6E+24	7.2E+23	2.9E+23	2.9E+23
GPS	Northern GPS profile	6.7E+24			
	Central GPS profile	9.1E+24			
	Southern GPS profile	1.1E+25			
Historic Earthquakes	1981-2011 Historic Earthquake catalog	8.6E+22			

Moment Loading Rates

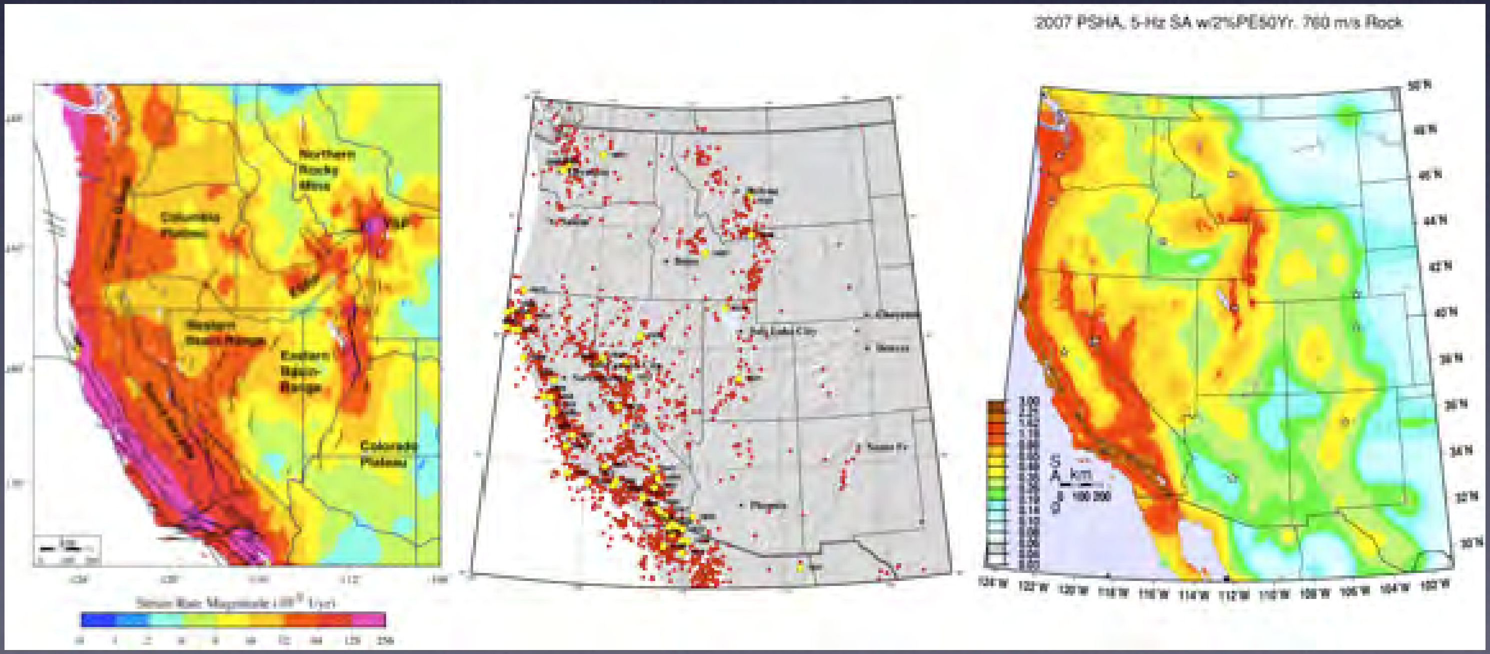


- Paleoearthquake models and GPS disagree by one order of magnitude
  - Problems with M-SLR relation for paleoearthquakes?
  - Overestimate GPS network area?
  - Not all accumulated moment released in earthquake?
  - Some elastic strain recovered during earthquake?
  - Ongoing aseismic deformation?
  - Time-varying loading rate?
  - More/bigger multisegment ruptures?

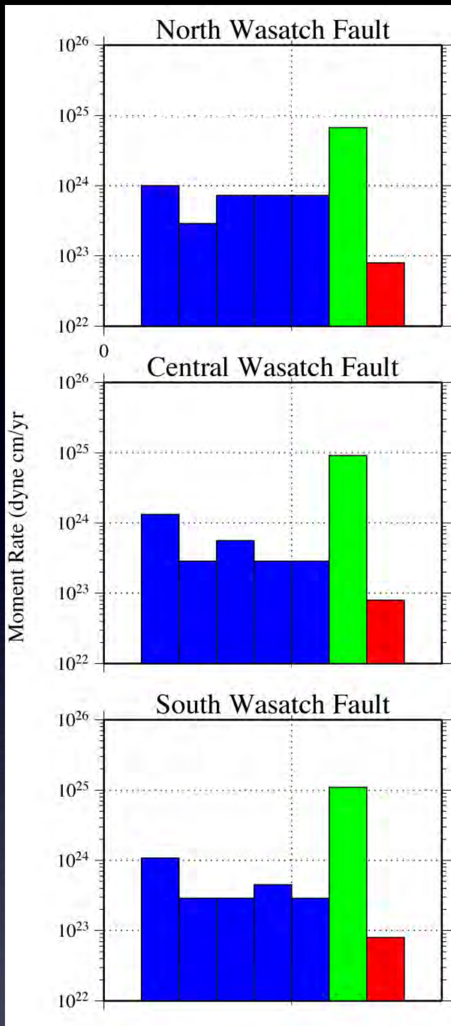
- Other paleoseismic parameters (average, max offset) not readily available as alternate sources for magnitude

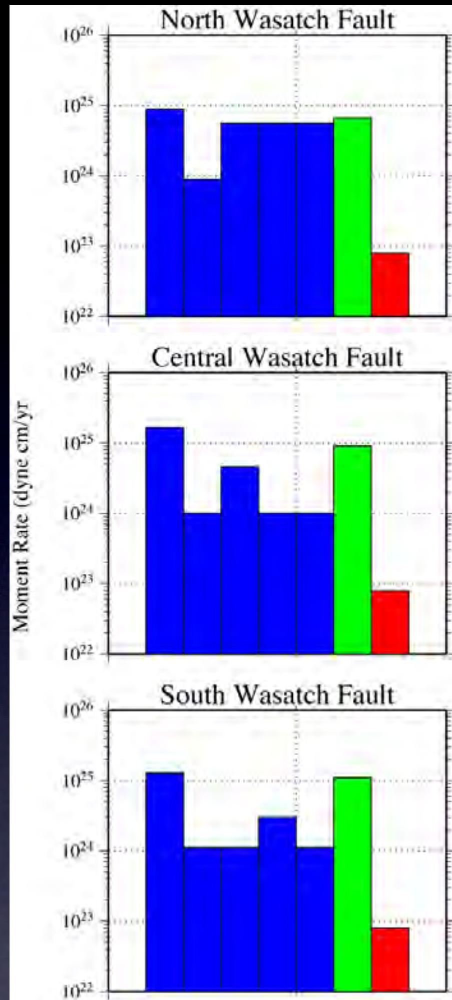


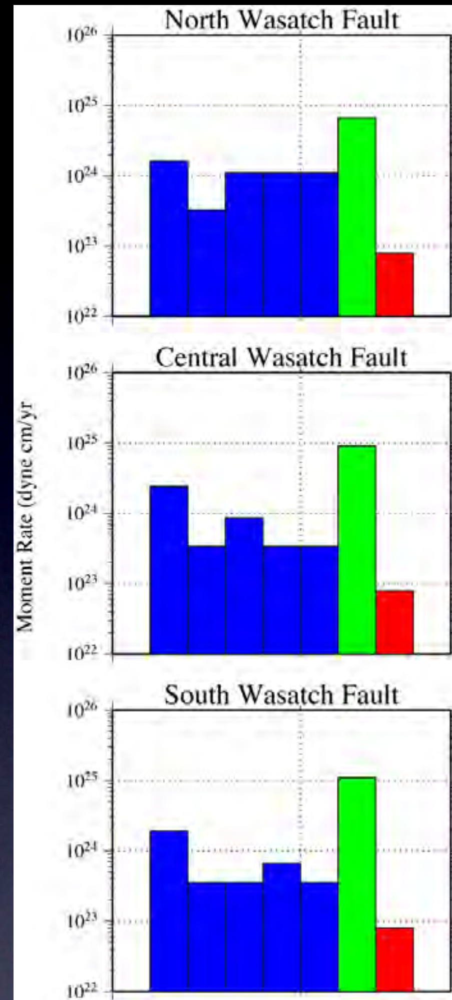
- GPS advantages
  - Measure contemporary deformation
  - Good spatial, time coverage - not just Wasatch fault
- GPS and paleoseismic rates won't match
  - Uncertainties in moment calculations
  - Loading rates not necessarily uniform
  - Other processes may affect rates

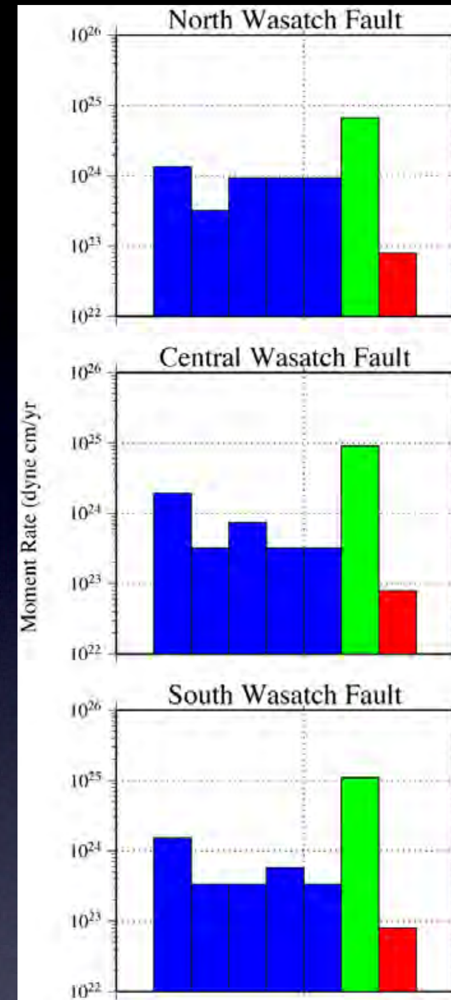


M=5.08 + 1.16•log(SRL) log(SRL)=-2.01+0.5•M log(SRL)=-3.22+0.69•MM=4.86 + 1.32•log(SRL



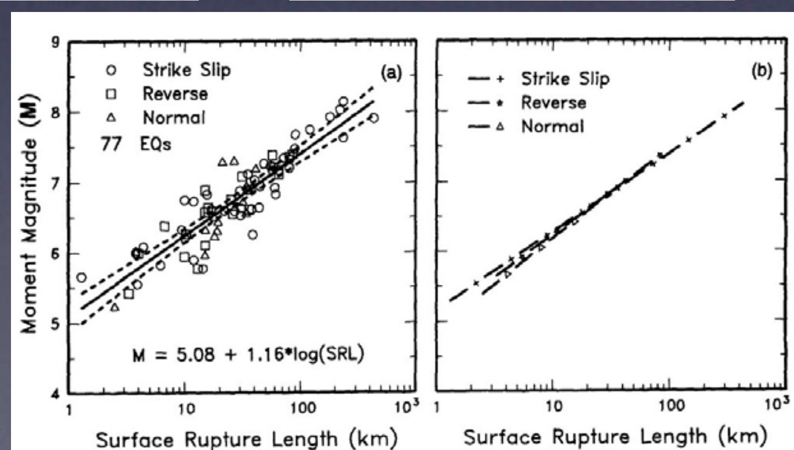






Default relation

Multiple expressions for M-SLR relation



(Wells and Coppersmith, 1994)

Moment Rate for Utah

Mark Petersen, Stephen Harmsen, Yuehua Zeng, Tony Crone, Kathy Haller

Parameters to calculate moment/moment rate

1. Moment = rigidity*area*displacement

2. Moment rate = rigidity*area*slip rate

3. Slip rate = Moment rate/(rigidity*area)

4. Kostrov's formula converts strain rate to Moment rate:
   Moment rate~rigidity X length X width X strain rate
   (dependent on fault geometry)

We assume a 3X 10^10 rigidity constant
M_0=10**(1.5*M+9.05)
Lengths (l) are based on segmentation model

Parameters to calculate moment/moment rate

For USGS NSHMs we assume a 15 km vertical depth and a planar fault:

1. 50 degree dip (0.6 wt) –> 19.6 km down-dip width
2. 60 degree dip (0.2 wt) –> 17.3 km down-dip width
3. 40 degree dip (0.2 wt) –> 23.3 km down-dip width

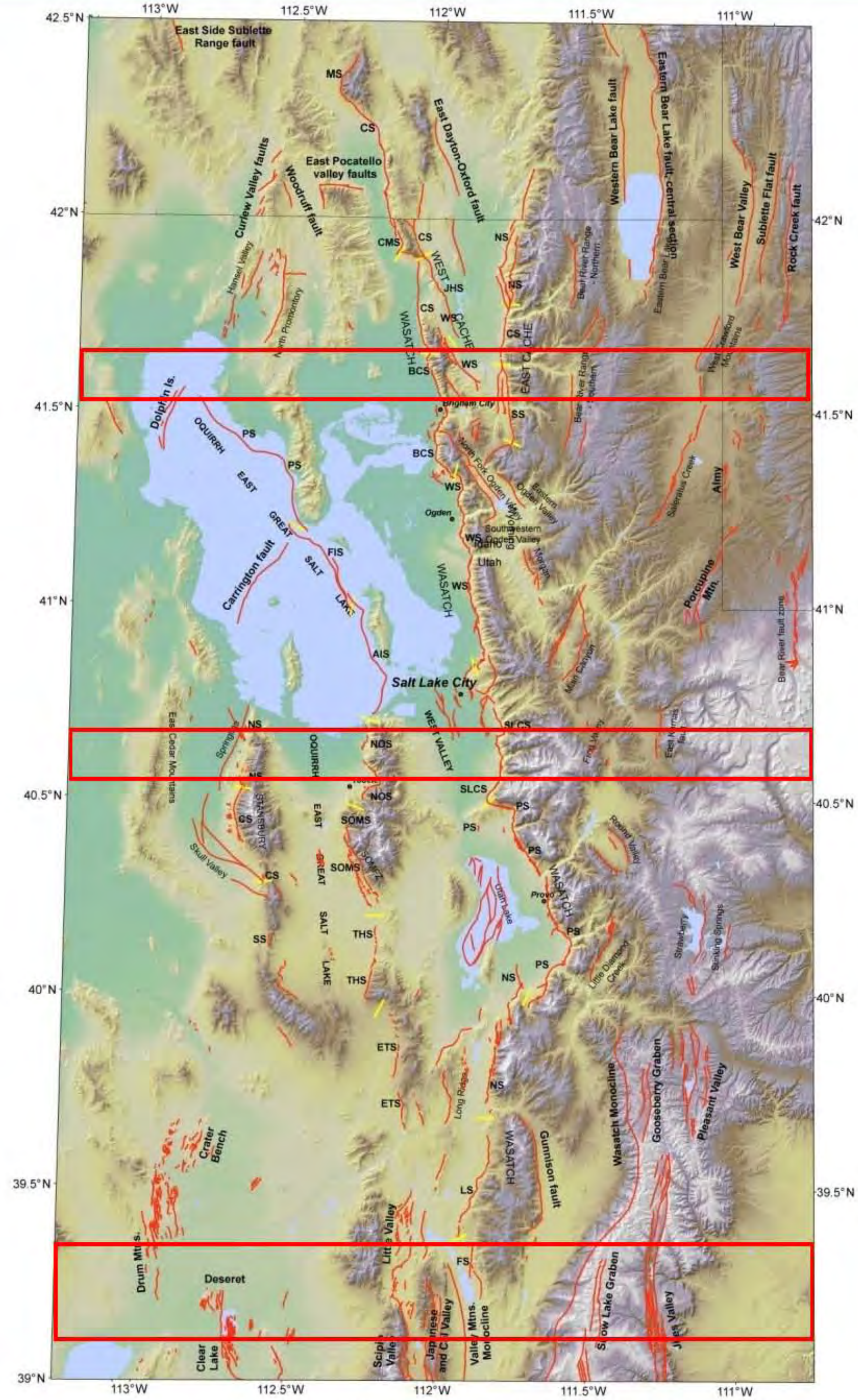
Other models - Wulung Chang and Bob Smith: (approximate numbers shown)

1. listric fault with 10 degree dip between 13-35 km (5 mm/yr)
2. listric fault with 38 degree dip between 7-24 km (8 mm/yr)
3. listric fault with ~40 degree Wasatch 8-20 km (8 mm/yr), Oquirrh 5-20 km (2 mm/yr), and Stansbury 5-20 km (2 mm/yr)
4. listric fault 27 degree dip between 9-20 km (7 mm/yr)

Wasatch Lengths and Magnitudes

Segment	Length (km)	USGS Assigned Magnitude	Calculated Magnitude
all	305	7.4	7.97
Brigham City	41	6.9	6.95
Weber	63	7.2	7.17
Salt Lake City	48	7.0	7.04
Provo	77	7.4	7.27
Nephi	44	7.0	7.02
Levan	32	6.8	6.84

Puskas and Smith suggest that Wasatch is capable of producing M 7.5 earthquakes
Based on paleoseismic studies of fault slip (McCalpin and Nishenko, 1996 and Chang and Smith, 2002)



WGUEP WASATCH FRONT REGION

(latitude 39.00° - 42.50°, longitude 110.75° - 113.25°)

PROFILE 1:

a. East Great Salt Lake Fault (dips west) 0.78 mm/yr (downdip), 0.6 mm/yr (vertical), 0.5 (horizontal)

b. Brigham City Wastatch (dips west) 1.5 mm/yr geologic, M 6.9 at 7.7X10-4/yr, this gives equivalent rate of between 1-3 mm/yr (downdip), 2 mm/yr vert→1.29 horiz

c. East Casche (dips west) 0.26 mm/yr (downdip), 0.20 mm/yr (vertical), 0.17 (horizontal)

NET SLIP TO WEST 0.5, 1.3, 0.17

PROFILE 2:

a. Stansbury (dips west) 0.52 mm/yr (downdip), 0.4 mm/yr (vertical), 0.34 (horizontal)

b. Oquirrh (dips west) 0.26 mm/yr (downdip), 0.20 mm/yr (vertical), 0.17 mm/yr (horizontal)

c. West Valley (dips east) 0.52 mm/yr (downdip), 0.4 mm/yr (vertical), 0.34 mm/yr (horizontal)

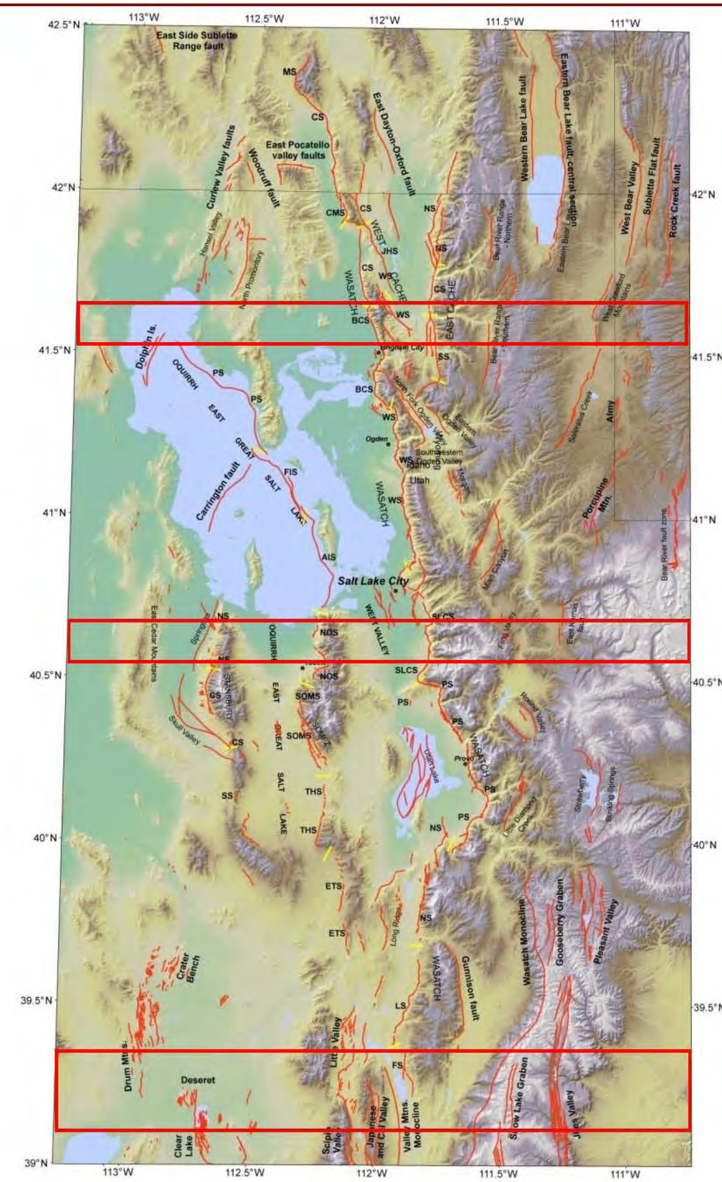
d. SLC Wasatch (dips west) 1.5 mm/yr geologic, M 7.0 at 7.7X10-4/yr, this gives equivalent rate of 1-3 mm/yr

NET SLIP TO WEST 0.34, 0.17, 0.34, 1.3

PROFILE 3:

a. Joes Valley (dips west) 0.26 mm/yr (downdip), 0.20mm/yr (vertical), 0.17 mm/yr (horizontal)

NET SLIP TO WEST 0.17 mm/yr



WGUEP WASATCH FRONT REGION

(latitude 39.00° - 42.50°, longitude 110.75° - 113.25°)

Characteristic earthquakes

Characteristic	M	wt(M)	MoRate	Rate*10**-4	length		moment ratet*wt	Moment (eq)	Moment rate	50deg SR	60degSR	40degSR
Provo	7.4	0.6	5.93	4.2	77		3.56E+16	1.41E+20	5.93E+16	1.31	1.48	1.10
	7.2	0.2	2.97	4.2			5.95E+15	7.08E+19	2.97E+16	0.66	0.74	0.55
	7.6	0.2	11.8	4.2			2.37E+16	2.82E+20	1.18E+17	2.61	2.96	2.20
Nephi	7	0.6	1.42	4	44		8.52E+15	3.55E+19	1.42E+16	0.55	0.62	0.46
	6.8	0.2	0.71	4			1.42E+15	1.78E+19	7.11E+15	0.27	0.31	0.23
	7.2	0.2	2.83	4			5.66E+15	7.08E+19	2.83E+16	1.09	0.71	0.92
Levan	6.8	0.6	0.42	2.37	32		2.53E+15	1.78E+19	4.21E+15	0.22	0.25	0.19
	6.6	0.2	0.21	2.37			4.22E+14	8.91E+18	2.11E+15	0.11	0.13	0.09
	7	0.2	0.84	2.37			1.68E+15	3.55E+19	8.41E+15	0.45	0.51	0.38
Brigham City	6.9	0.6	1.93	7.7	41		1.16E+16	2.51E+19	1.93E+16	0.80	0.91	0.67
	6.7	0.2	0.97	7.7			1.94E+15	1.26E+19	9.69E+15	0.40	0.46	0.34
	7.1	0.2	3.86	7.7			7.72E+15	5.01E+19	3.86E+16	1.60	1.81	1.35
Weber	7.2	0.6	5.03	7.1	63		3.02E+16	7.08E+19	5.03E+16	1.36	1.54	1.14
	7	0.2	2.52	7.1			5.04E+15	3.55E+19	2.52E+16	0.68	0.77	0.57
	7.4	0.2	10.03	7.1			2.01E+16	1.41E+20	1.00E+17	2.71	3.07	2.28
Salt Lake City	7	0.6	2.73	7.7	48		1.64E+16	3.55E+19	2.73E+16	0.97	1.10	0.81
	7.2	0.2	5.45	7.7			1.09E+16	7.08E+19	5.45E+16	1.93	2.19	1.62
	6.8	0.2	1.37	7.7			2.74E+15	1.78E+19	1.37E+16	0.49	0.55	0.41
						SUM	1.92E+17					

Floating and GR

Float 7.4 (10% weight-1.2 mm/yr slip rate)	Dip	wt(dip)	MoRate	Rate*10**-3		Wasatch floating large-eq (7.4+-) branches	Weighted Moment rate	Moment of M7.4	Moment rate	50 degree downdip slip rate	60 degree downdip slip rate	40 degree downdip slip rate
7.4	50	0.6	28.16	2	305	19.6	1.70E+17	1.41E+20	2.83E+17	1.58	1.78	1.33
	40	0.2	42.77	3.03	305	23.3	8.56E+16	1.41E+20	4.28E+17	2.39	2.70	2.01
	60	0.2	15.5	1.1	305	17.3	3.11E+16	1.41E+20	1.55E+17	0.87	0.98	0.73
						SUM	2.86E+17					
Gutenberg-Richter (18% weight, M 5-Max mag)	dip	wt(dip)	MoRate	Dwndip SR	Vert SR	Horiz SR	Weighted Moment rate	RI(yrs)				
Provo	50	0.6	7.1	1.57	1.2	1	4.26E+16					
	40	0.2	10.08	1.87	1.2	1.4	2.02E+16					
	60	0.2	5.55	1.39	1.2	7	1.11E+16					
Nephi	50	0.6	3.92	1.44	1.1	0.9	2.35E+16					
	40	0.2	5.57	1.71	1.1	1.3	1.11E+16					
	60	0.2	3.07	1.27	1.1	0.6	6.14E+15					
Levan	50	0.6	0.75	0.39	0.3	0.25	4.50E+15					
	40	0.2	1.06	0.47	0.3	0.36	2.12E+15					
	60	0.2	0.58	0.35	0.3	0.17	1.16E+15					
Brigham City	50	0.6	4.38	1.83	1.4	1.2	2.63E+16					
	40	0.2	6.22	2.18	1.4	1.7	1.24E+16					
	60	0.2	3.42	1.62	1.4	0.8	6.84E+15					
Weber	50	0.6	5.76	1.57	1.2	1	3.46E+16					
	40	0.2	8.18	1.87	1.2	1.4	1.64E+16					
	60	0.2	4.51	1.39	1.2	0.7	9.02E+15					
Salt Lake City	50	0.6	4.45	1.57	1.2	1	2.67E+16	262				
	40	0.2	6.32	1.87	1.2	1.4	1.26E+16	185				
	60	0.2	3.48	1.39	1.2	0.7	6.96E+15	337				
						WT SUM	2.74E+17					
									M7.4	M 7		
						TOTAL M	2.16E+17		653 yrs	164 yrs		

Comparison (downdip slip rates)

Segment	Geologic slip rate (mm/yr +/- 15%)	RI based slip rate (mm/yr +/- 15%)	Geodetic slip rate (Zeng)	Geodetic slip rate (Chang and Smith)
Brigham City	1.83	0.80	2.2	5-12
Weber	1.57	1.36	2.6	5-12
Salt Lake City	1.57	0.97	4.1	5-12
Provo	1.57	1.31	4.3	5-12
Nephi	1.44	0.55	4.3	5-12
Levan	0.39	0.22	3.3	5-12

Geodetic data analysis

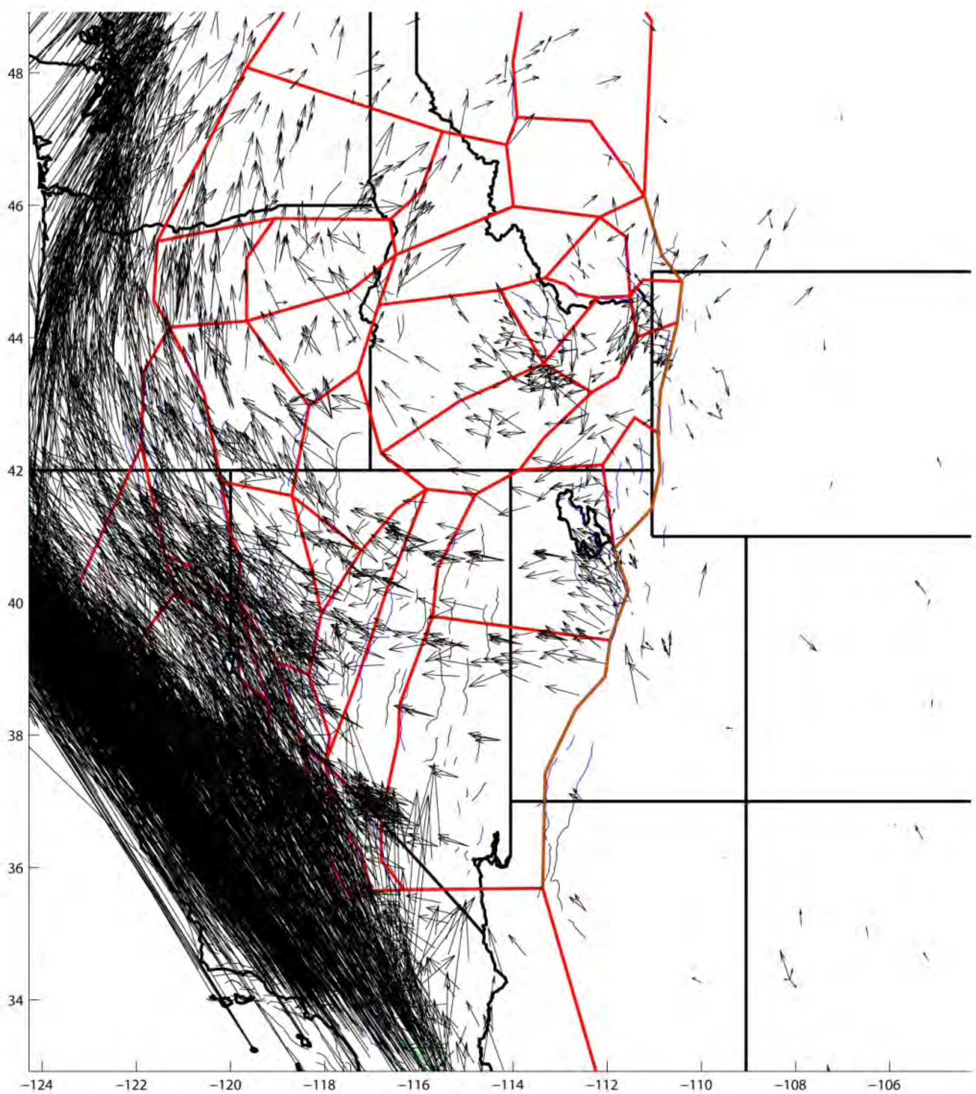
Mark Petersen and Yuehua Zeng

(data and zones from Puskas and Smith)

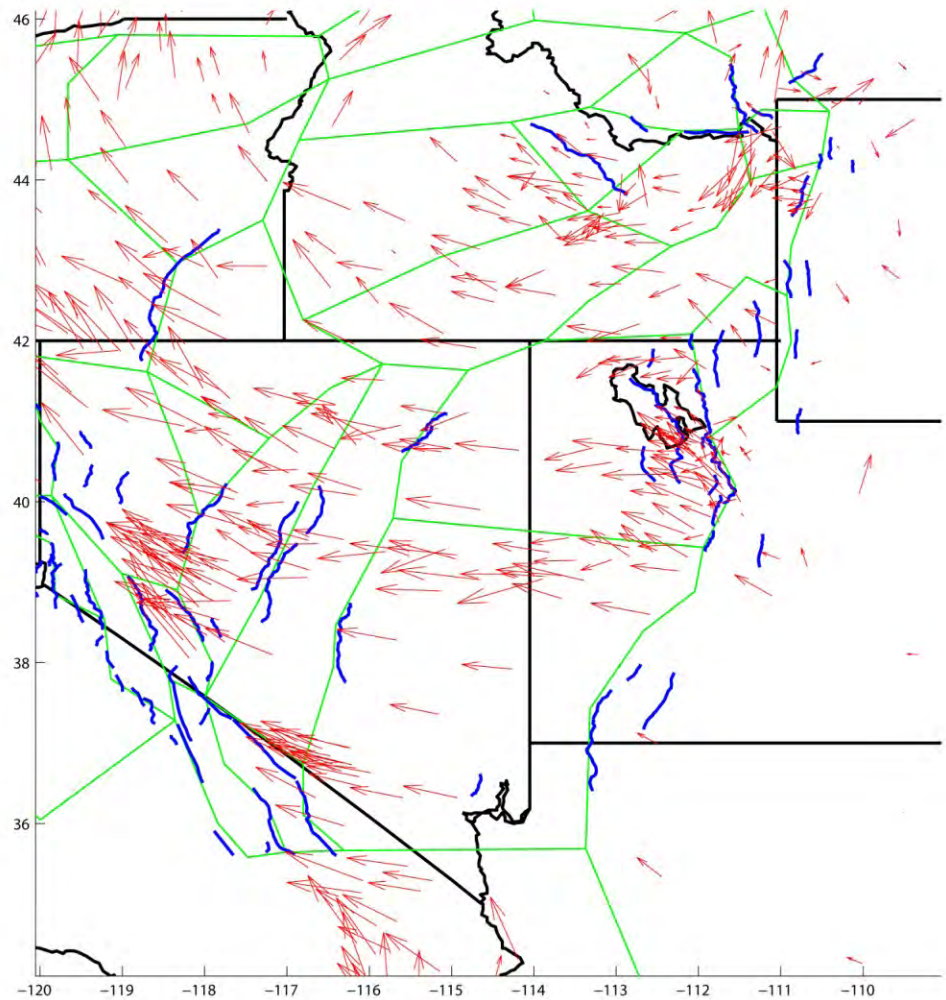
Methodology (Zeng)

- Started with GPS data from Puskas and Smith
- Cleaned out the spurious data
- Extrapolated to make strain rate maps
- Modified Puskas and Smith block model (not continuum model, use buried fault model)
- Inverted for slip rate on Wasatch Fault using block model of elastic upper layer and creeping lower layer

GPS velocity field

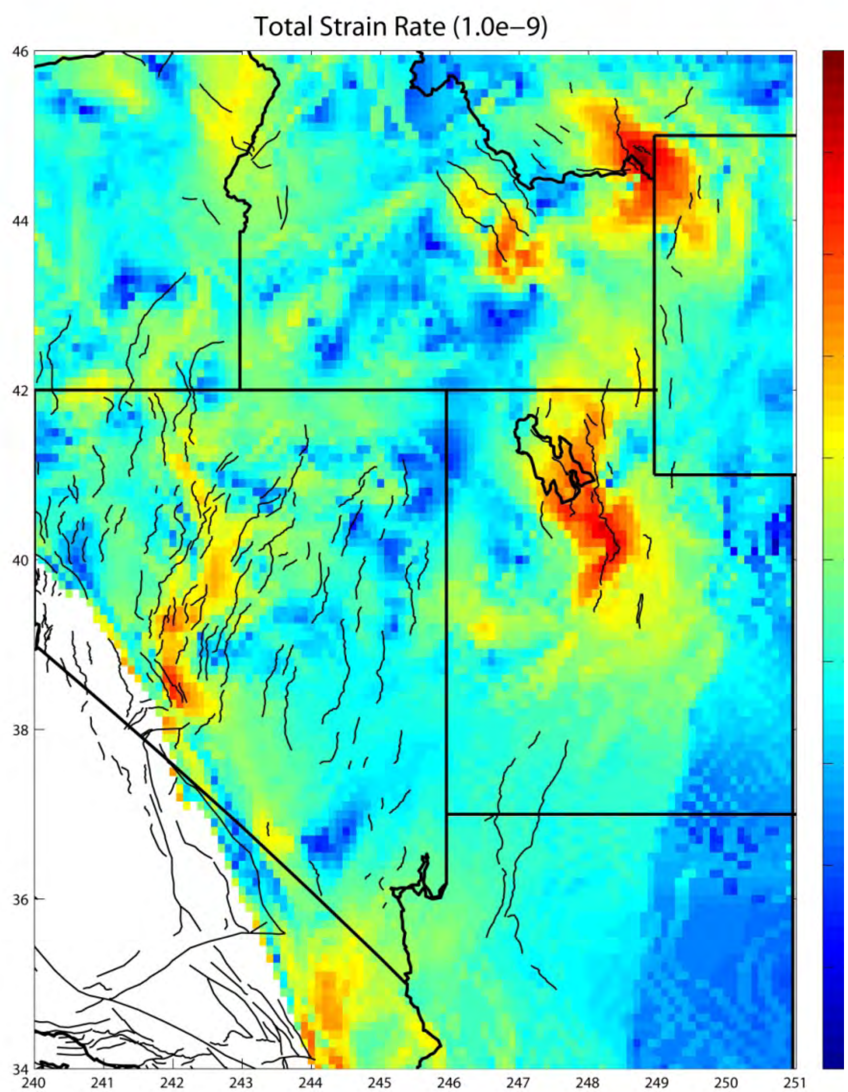


Processed GPS data

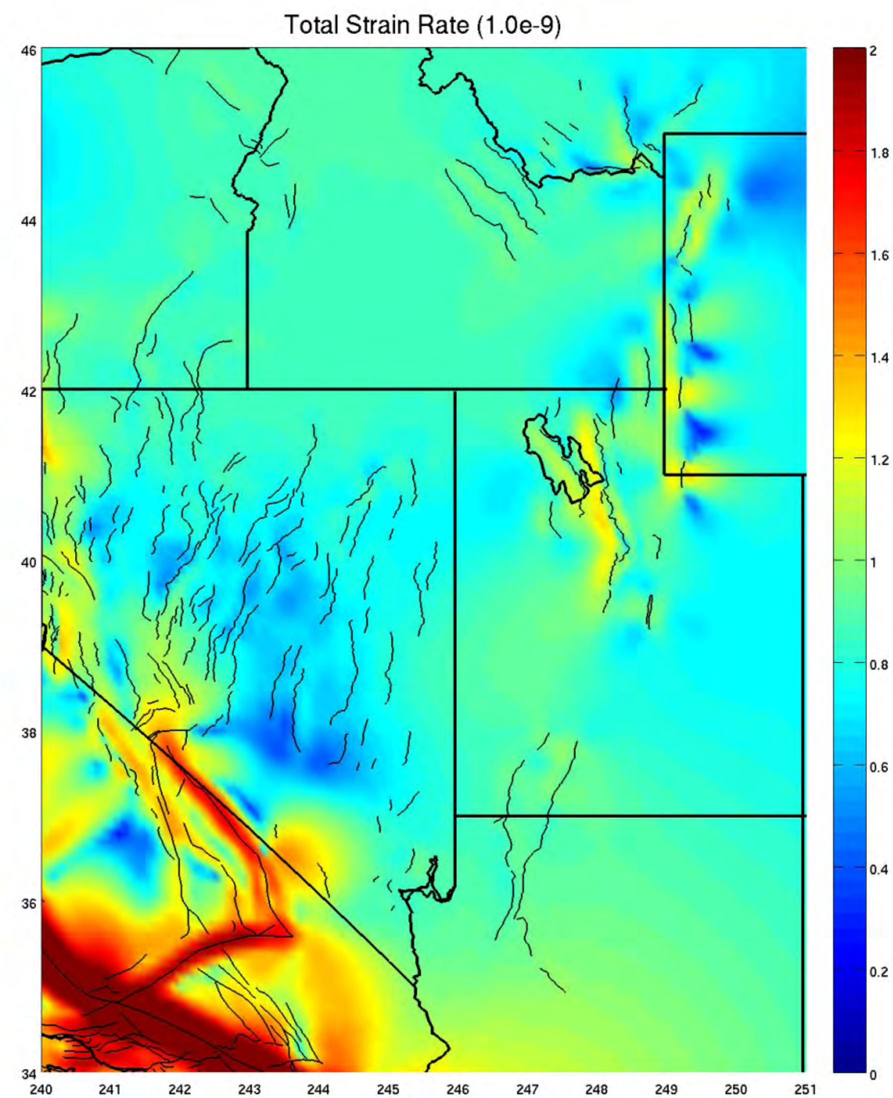


Comparison of GPS and Geology strain rates

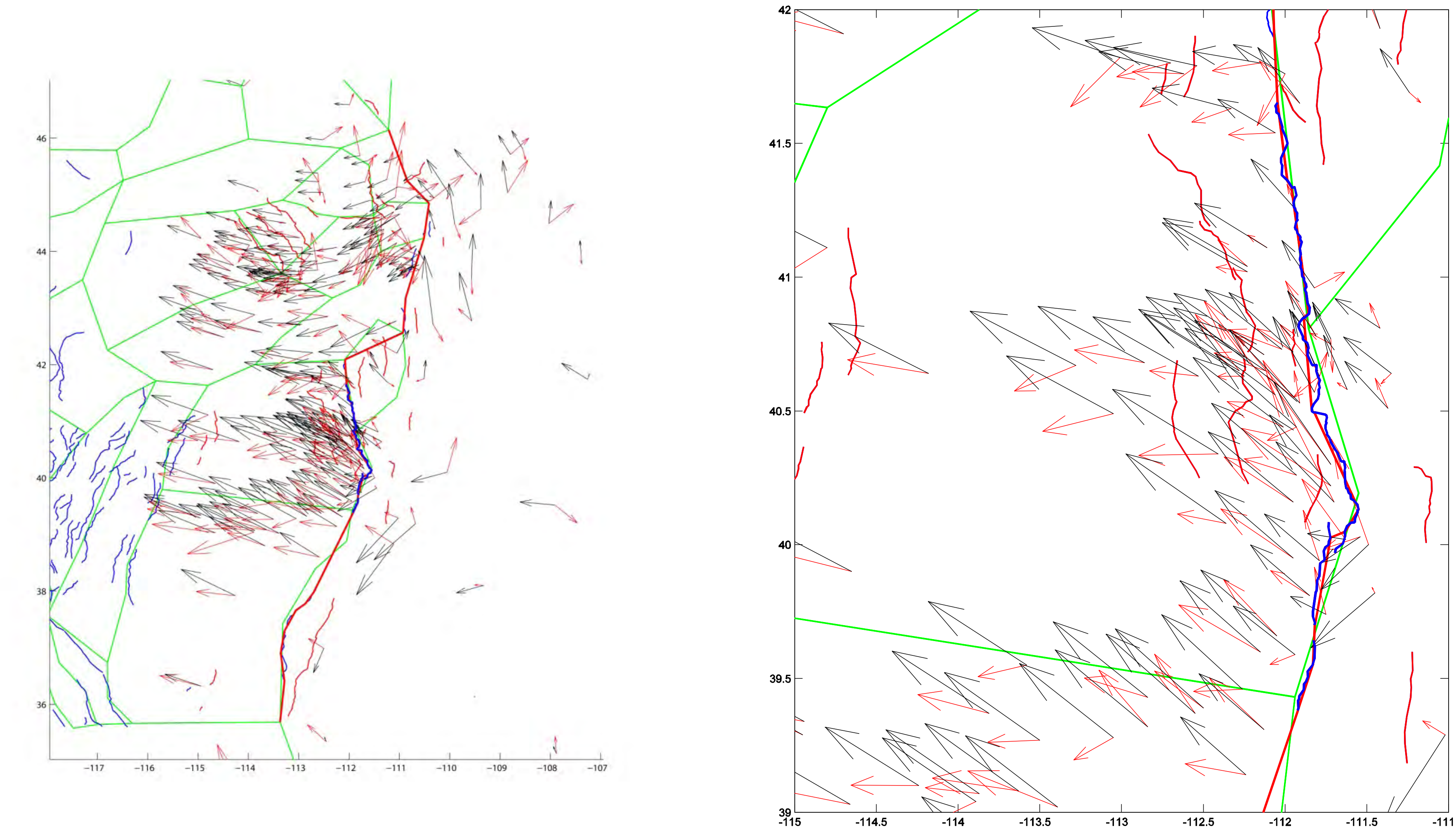
GPS strain rate



Geology strain rate



Block Model



Red: data, Black predicted

Chang Thesis

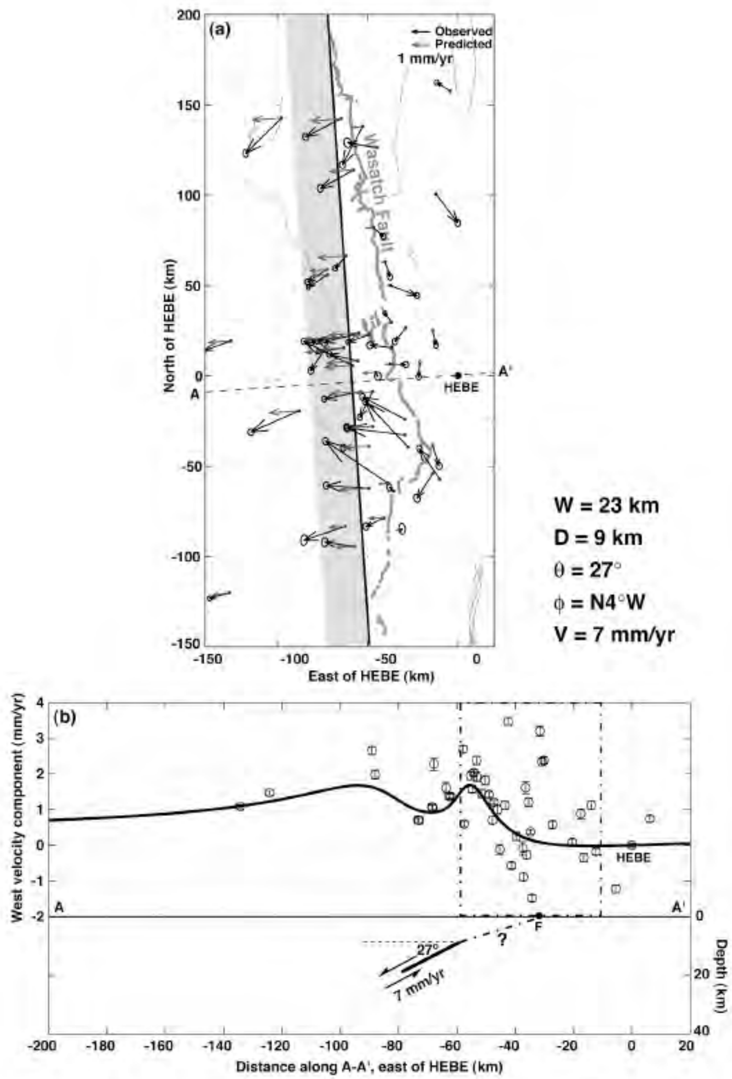


Figure 4.9. A narrow-dislocation model for the Wasatch fault, with the EBAR background extension removed. See Figure 4.6 for detailed discriptions.

Chang thesis

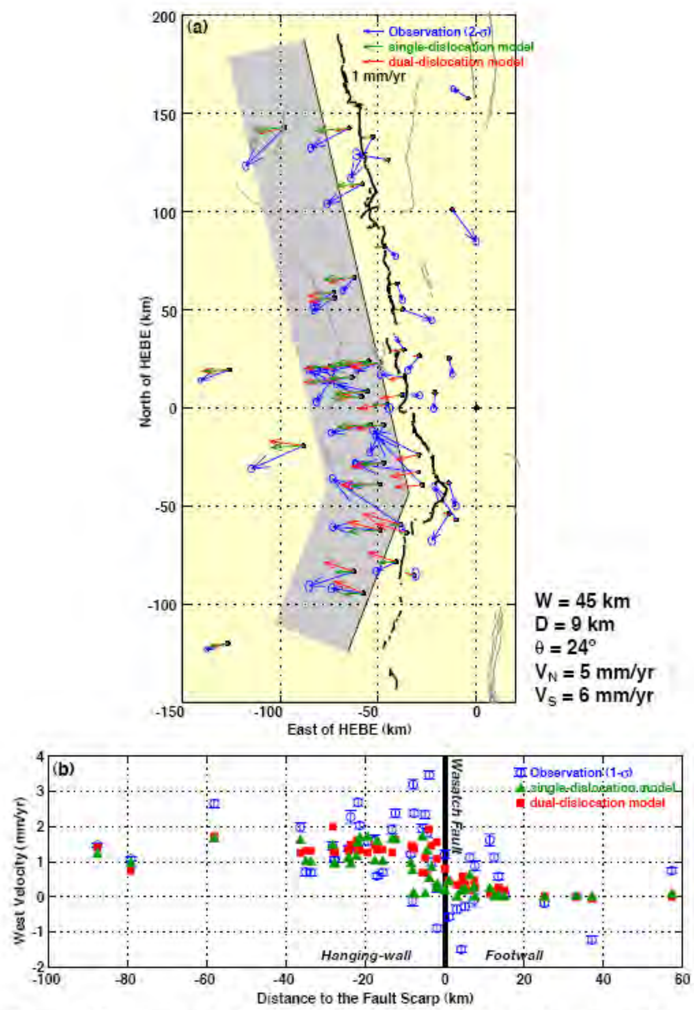


Figure 4.15. Inverted dual-dislocation model that best fits the horizontal GPS velocities. (a) The predicted (red arrows) and observed (blue arrows) velociy vectors are plotted with that derived from the single-dislocation model shown in Figure 4.9 (green arrows). V_N and V_S are the loading rates of the northern and southern fault patches, rspectively. (b) The west velocity components are plotted with respect to the distances from GPS sites to the Wasatch fault scarp (bold line).

Comparison of Slip Rates

Segment	Geologic slip rate (mm/yr +/- 15%)	RI based slip rate (mm/yr +/- 15%)	Geodetic slip rate (Zeng)	Geodetic slip rate (Chang and Smith)
Brigham City	1.83	0.80	2.2	5-12
Weber	1.57	1.36	2.6	5-12
Salt Lake City	1.57	0.97	4.1	5-12
Provo	1.57	1.31	4.3	5-12
Nephi	1.44	0.55	4.3	5-12
Levan	0.39	0.22	3.3	5-12

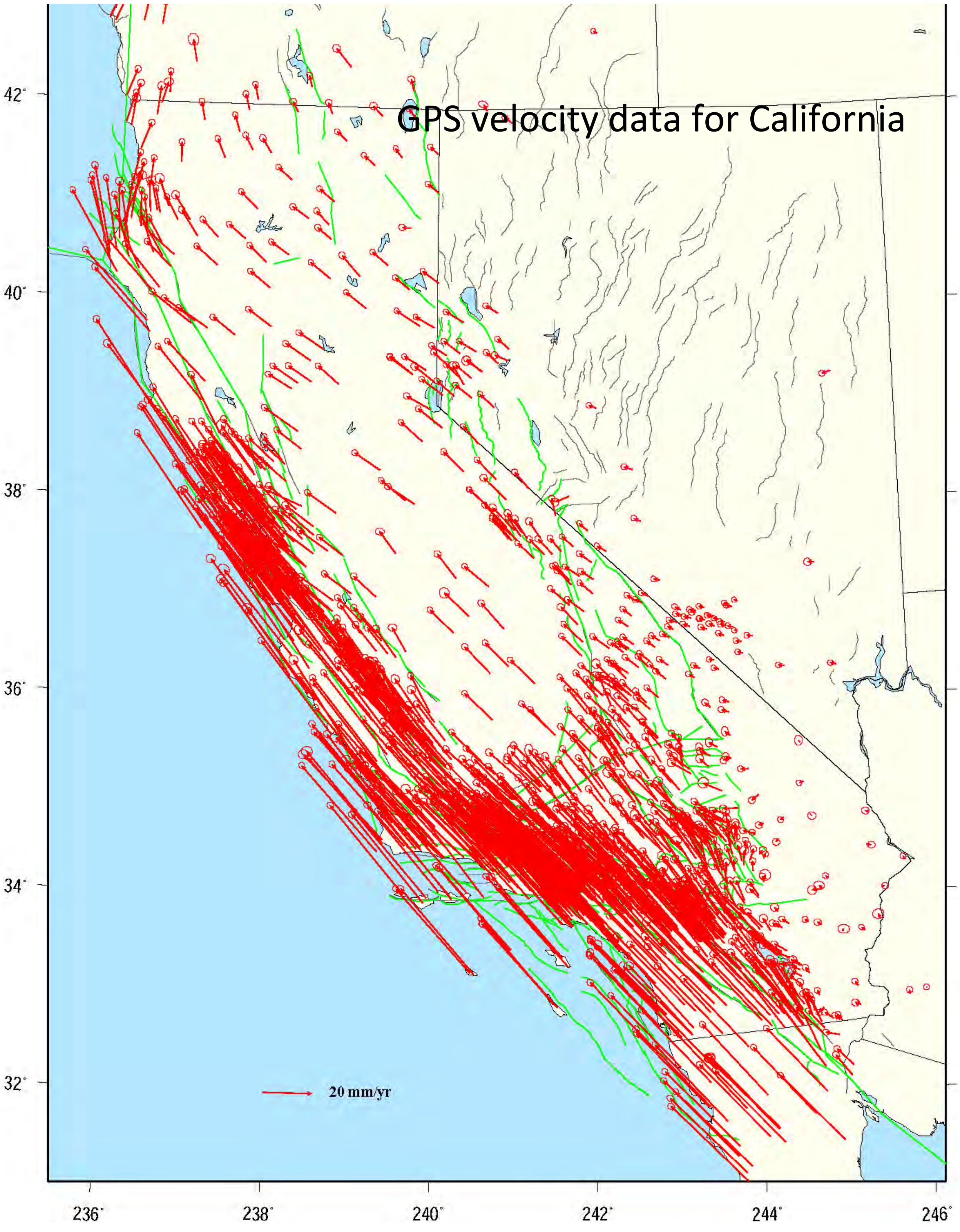
Comparisons of geodetic and geologic data

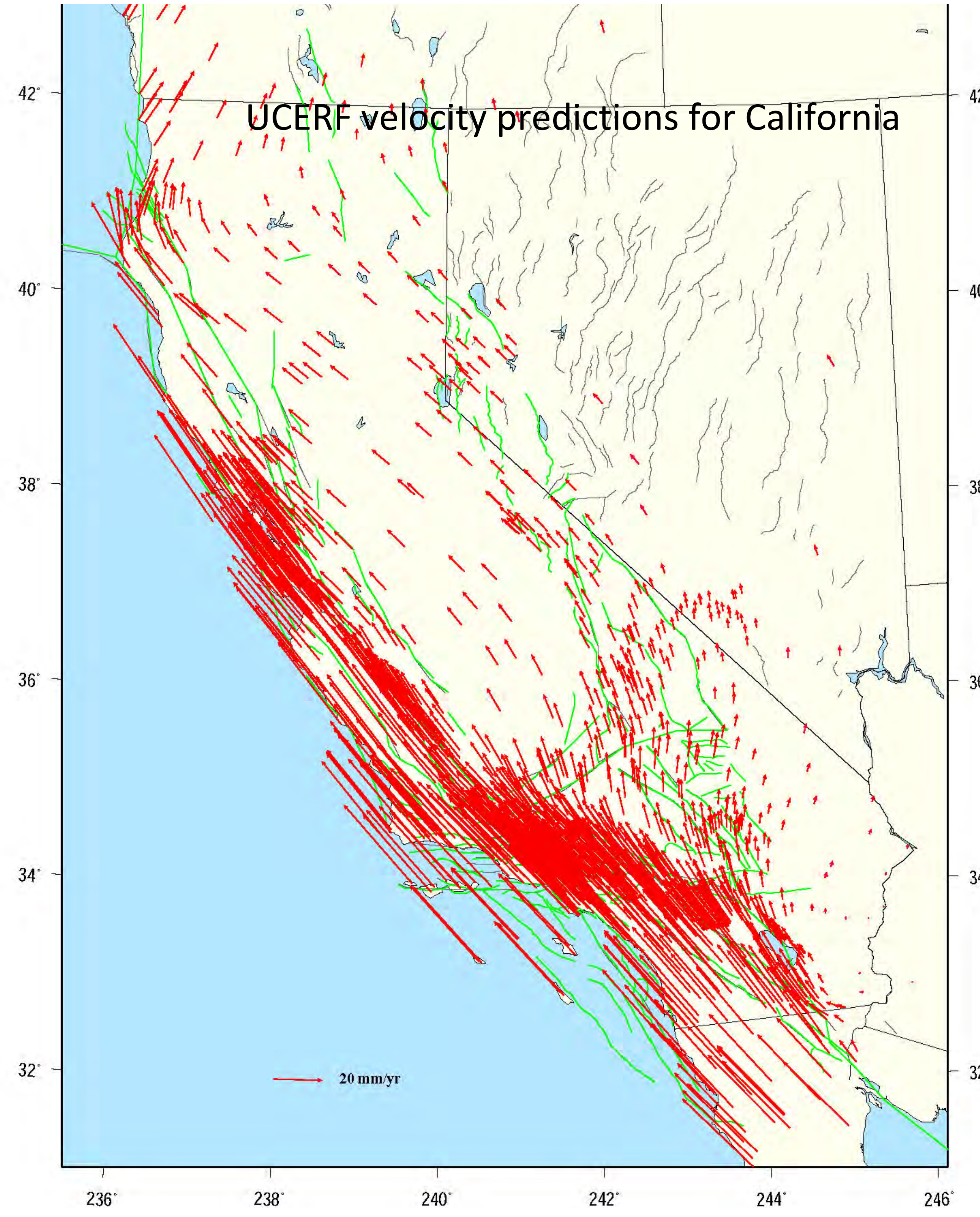
Segment	Geologic slip rate (mm/yr +/- 15%)	RI based slip rate (mm/yr +/- 15%)	Geodetic slip rate (Zeng)	geologic sr/recur	geol sr/geodetic	
Brigham City	1.83	0.8	2.2	2.3	0.8	1.2
Weber	1.57	1.36	2.6	1.2	0.6	1.7
Salt Lake City	1.57	0.97	4.1	1.6	0.4	2.6
Provo	1.57	1.31	4.3	1.2	0.4	2.7
Nephi	1.44	0.55	4.3	2.6	0.3	3.0
Levan	0.39	0.22	3.3	1.8	0.1	8.5

A Kinematic Fault Network Model of Crustal Deformation for California and Its Application to the Seismic Hazard Analysis

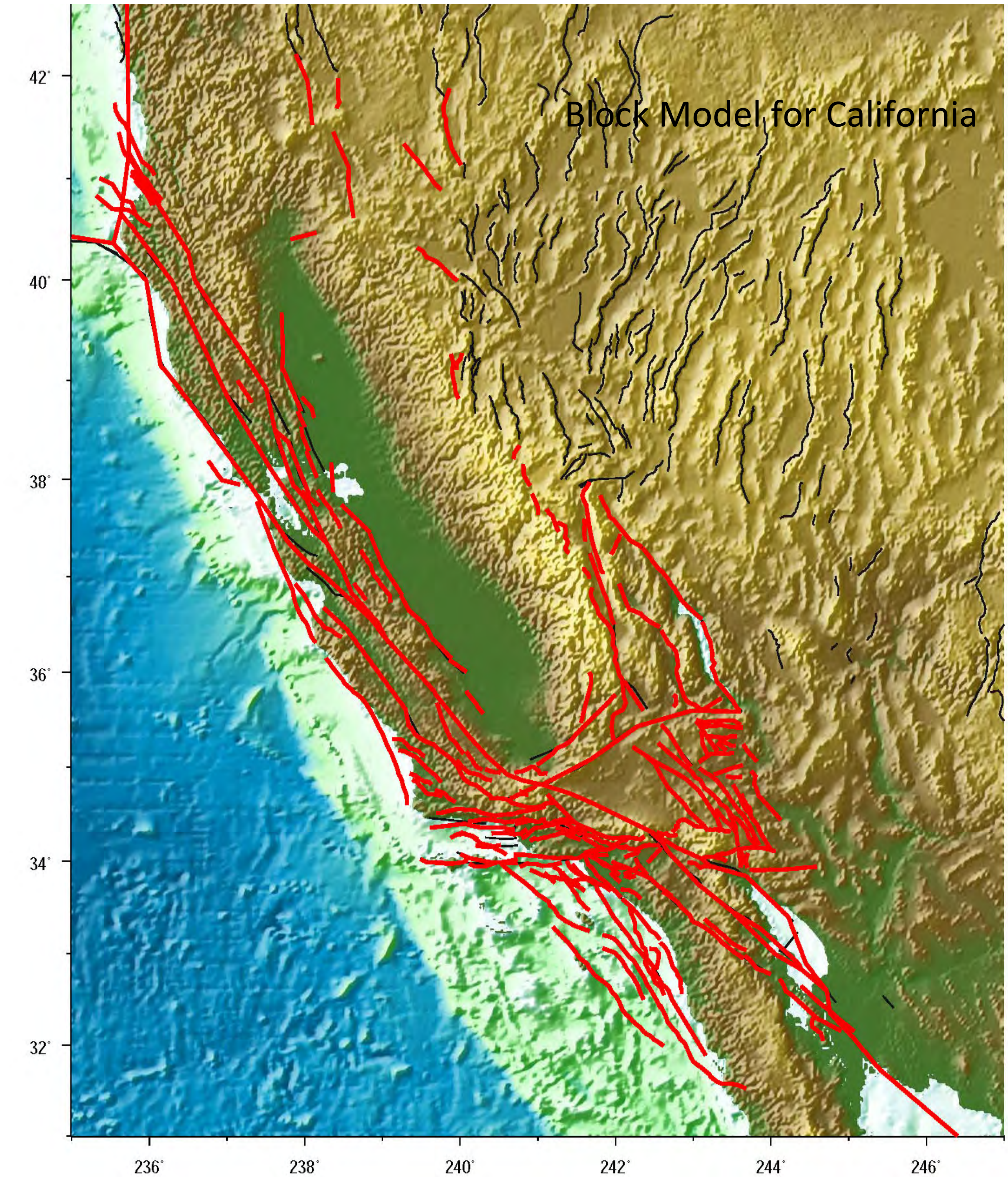
Yuehua Zeng[1], Zhengkang Shen[2], Steve Harmsen[1], and Mark Petersen[1]

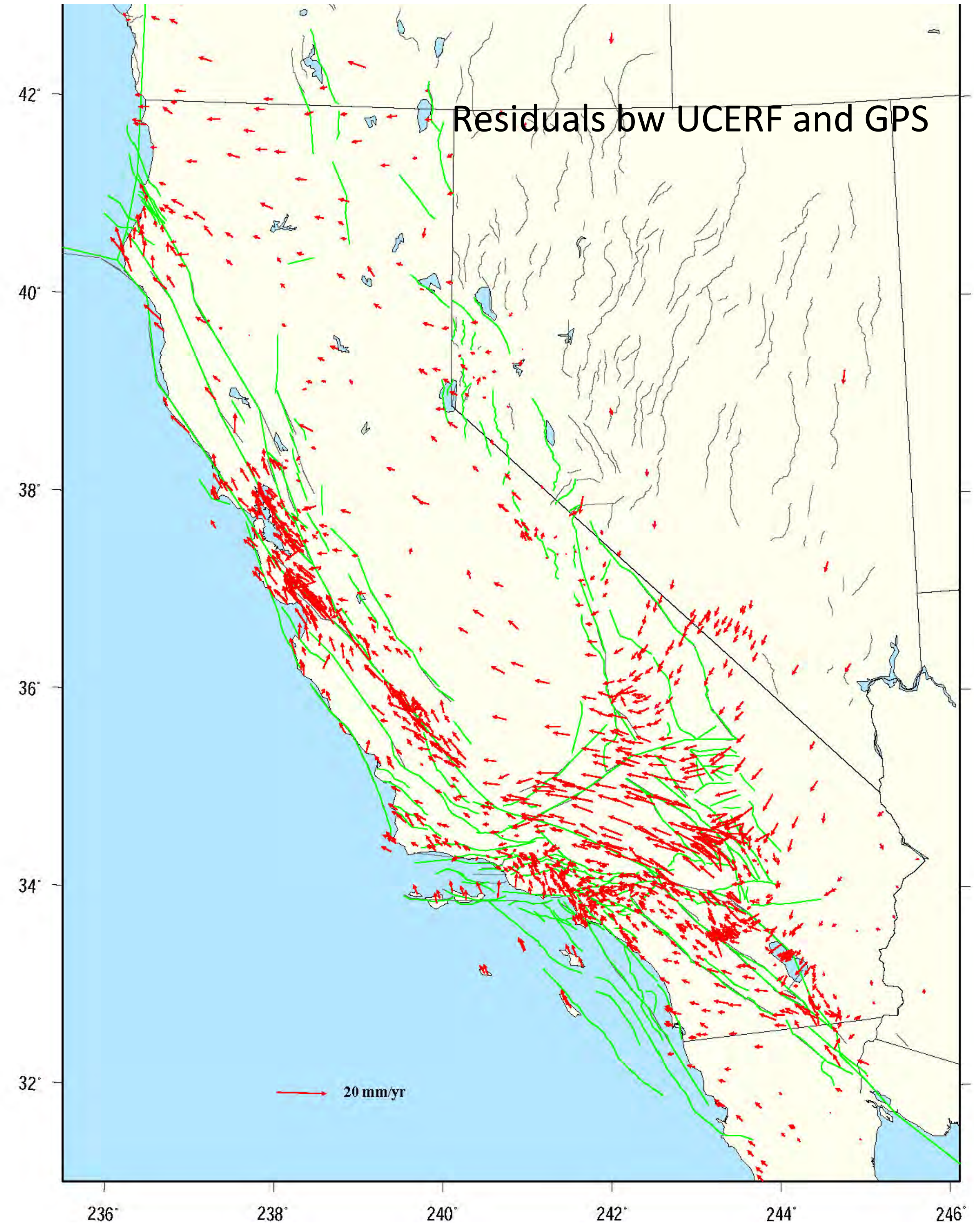
1.US Geological Survey, Golden, CO
2.Dept of Earth and Space Sciences, UCLA


GPS velocity data for California
20 mm/yr
42°
40°
38°
36°
34°
32°
236°
238°
240°
242°
244°
246°

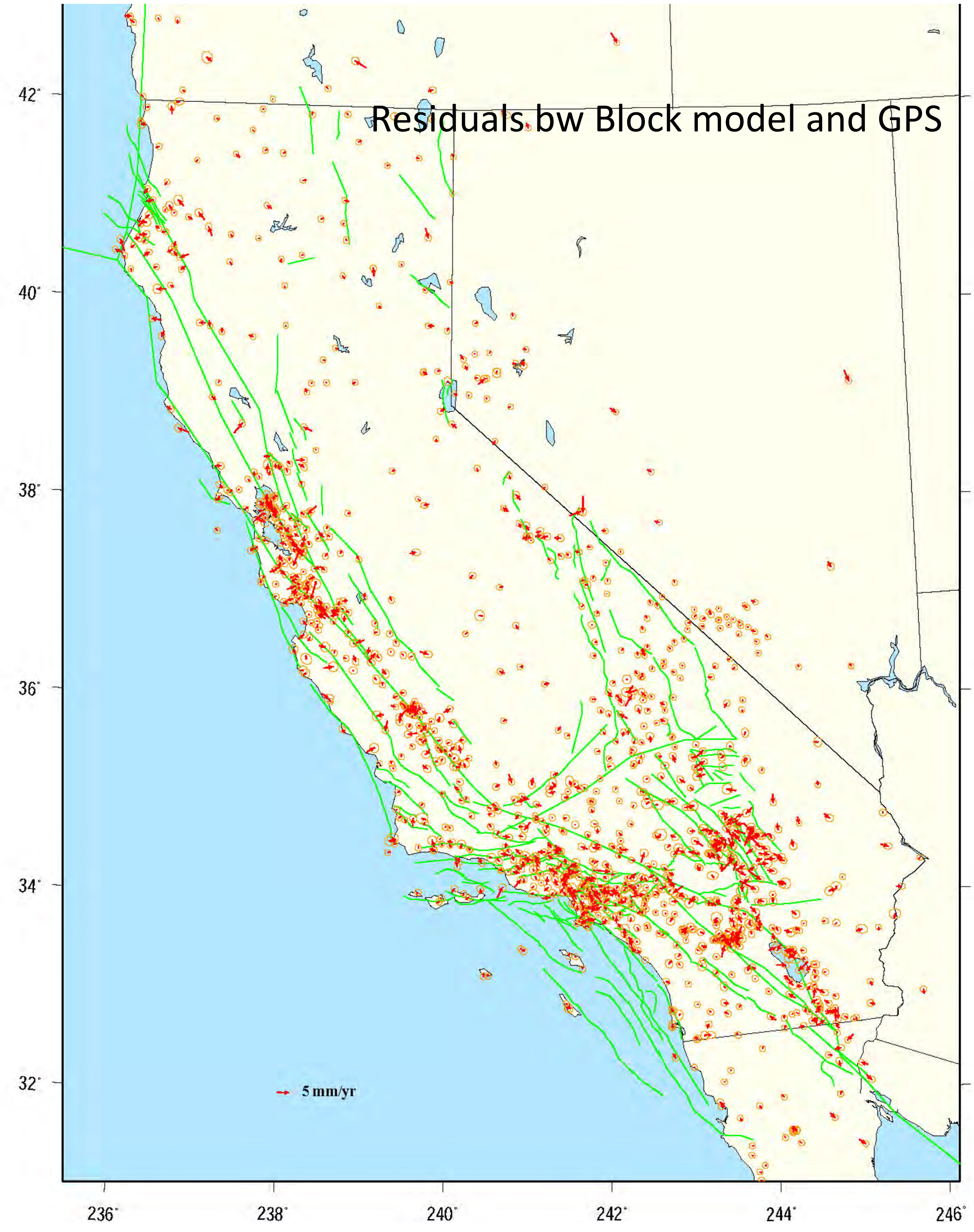


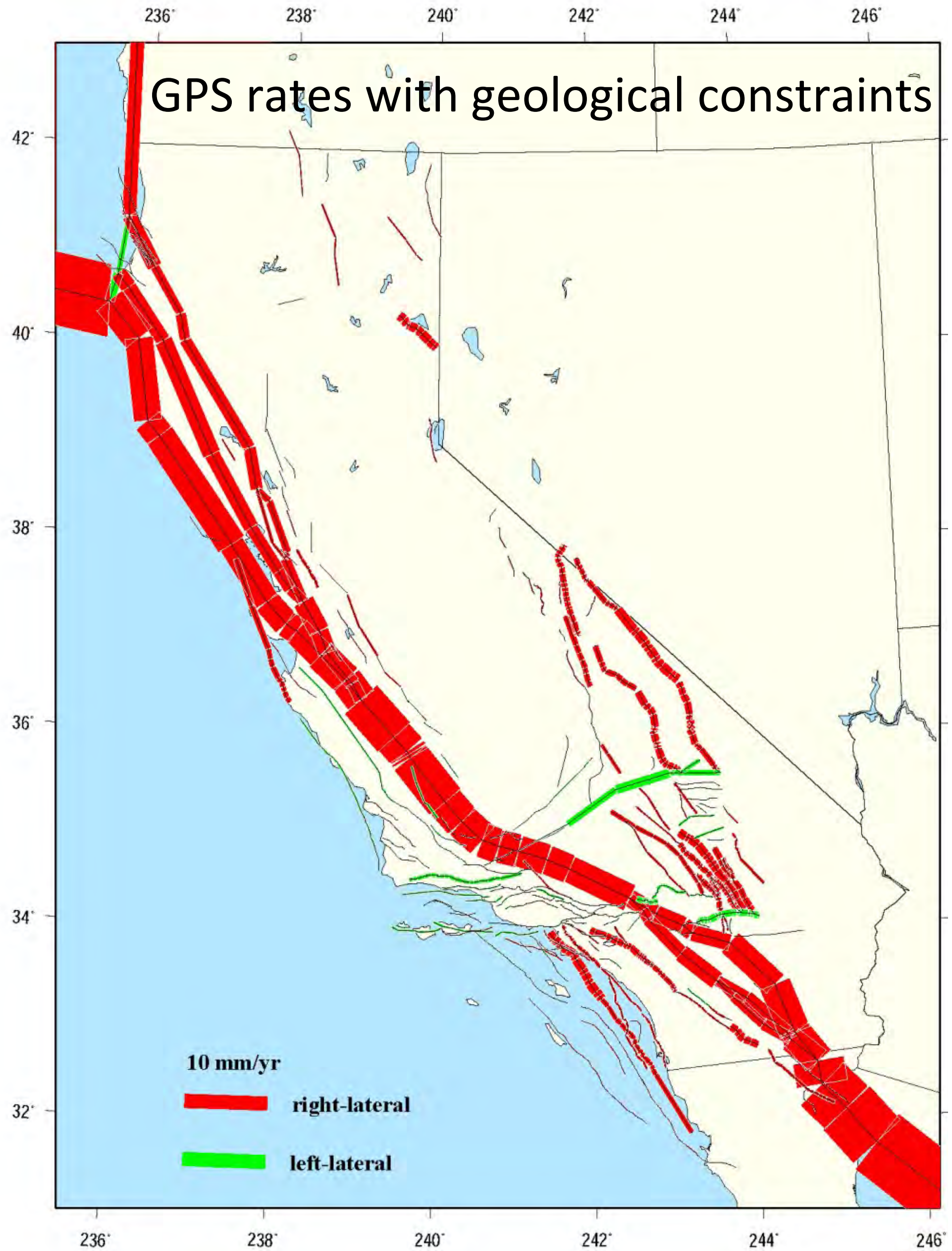
UCERF velocity predictions for California
20 mm/yr
42°
40°
38°
36°
34°
32°
236°
238°
240°
242°
244°
246°

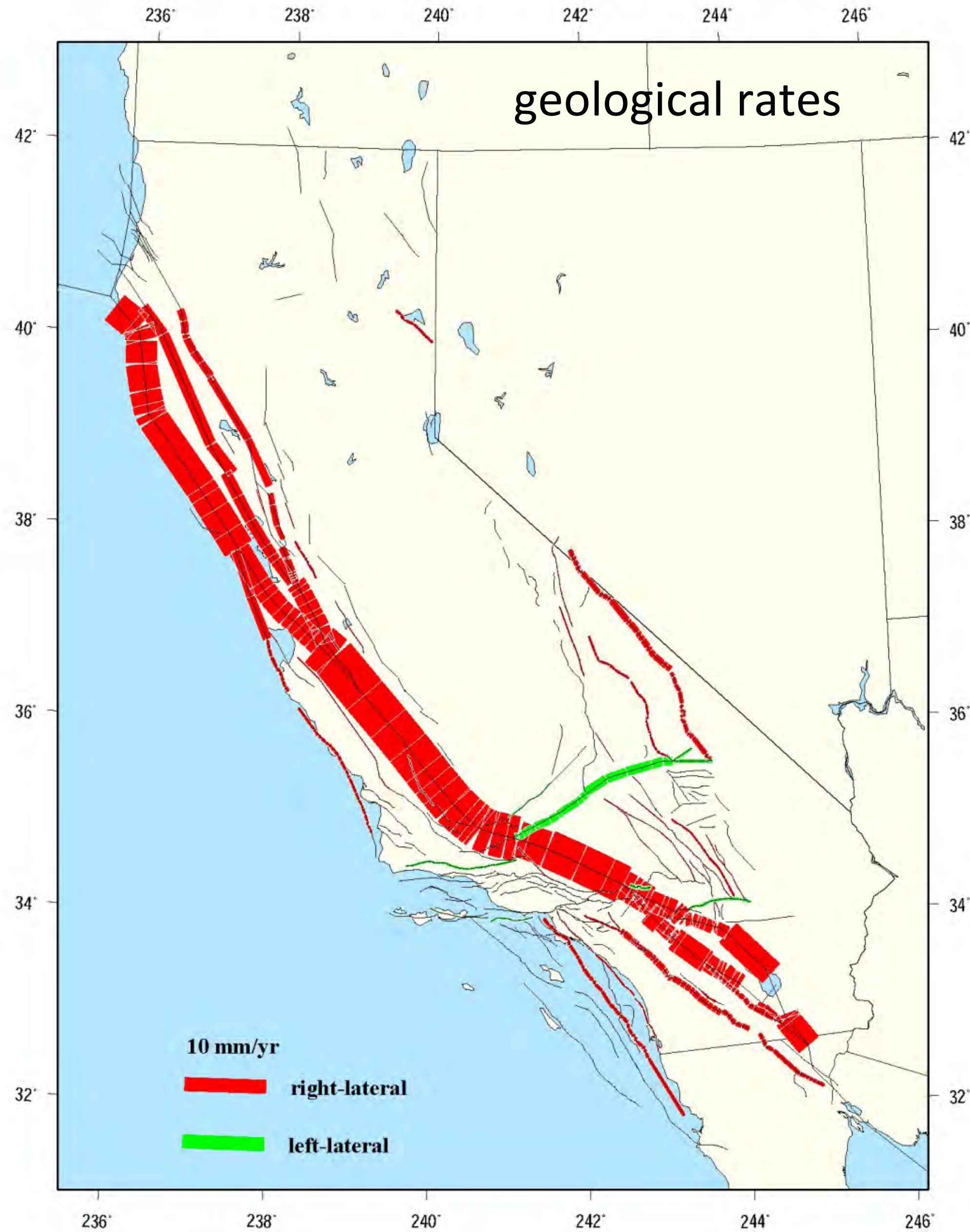

Block Model for California
42°
40°
38°
36°
34°
32°
236°
238°
240°
242°
244°
246°

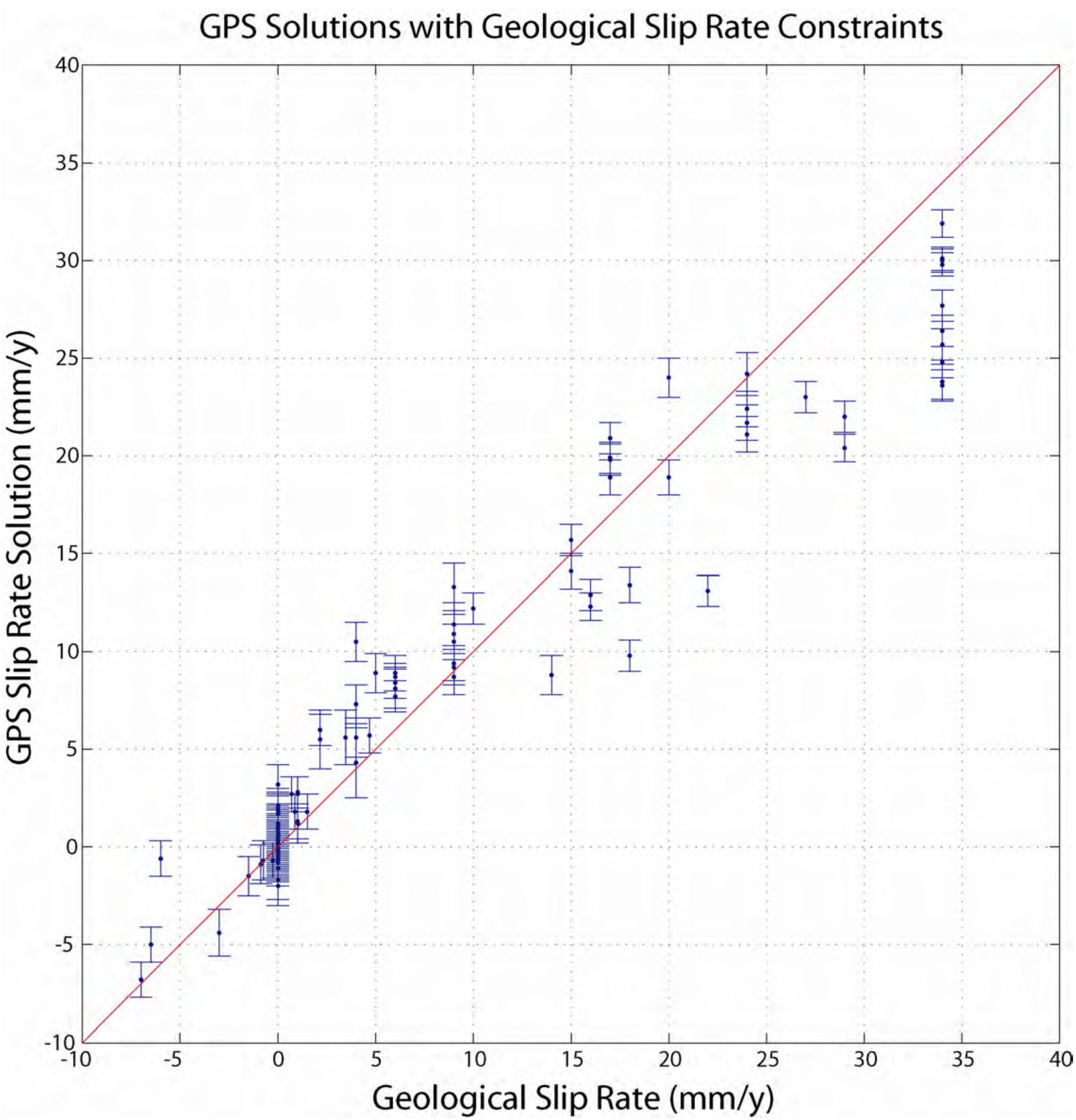


Residuals bw UCERF and GPS
20 mm/yr
42°
40°
38°
36°
34°
32°
236°
238°
240°
242°
244°
246°


Residuals bw Block model and GPS
5 mm/yr
42°
40°
38°
36°
34°
32°
236°
238°
240°
242°
244°
246°

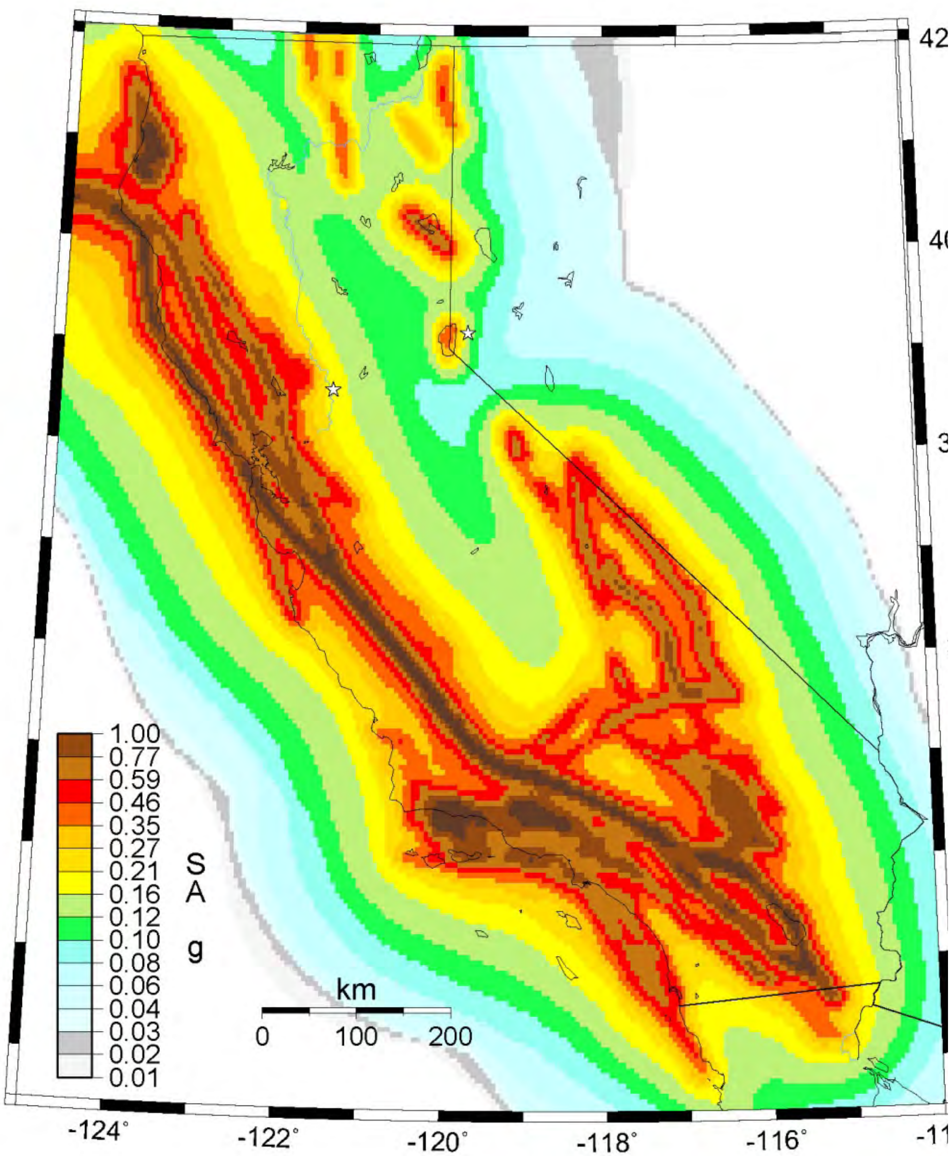

GPS rates with geological constraints
10 mm/yr
right-lateral
left-lateral


geological rates
10 mm/yr
right-lateral
left-lateral



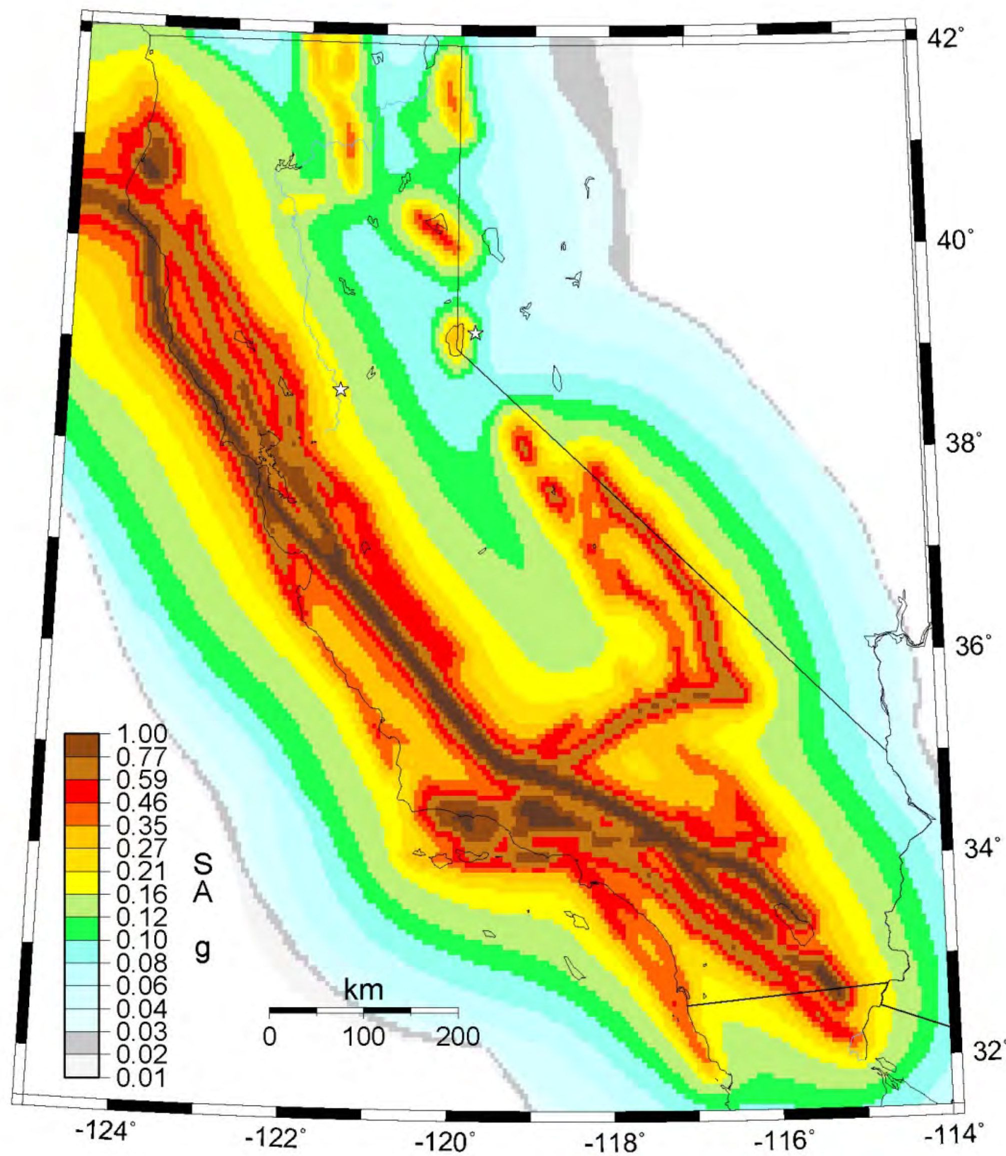
GPS Solutions with Geological Slip Rate Constraints
GPS Slip Rate Solution (mm/y)
Geological Slip Rate (mm/y)
40
35
30
25
20
15
10
5
0
-5
-10
-10
-5
0
5
10
15
20
25
30
35
40

CA Geodetic 1-Hz SA w/2%PE50Y. 760 m/s Rock



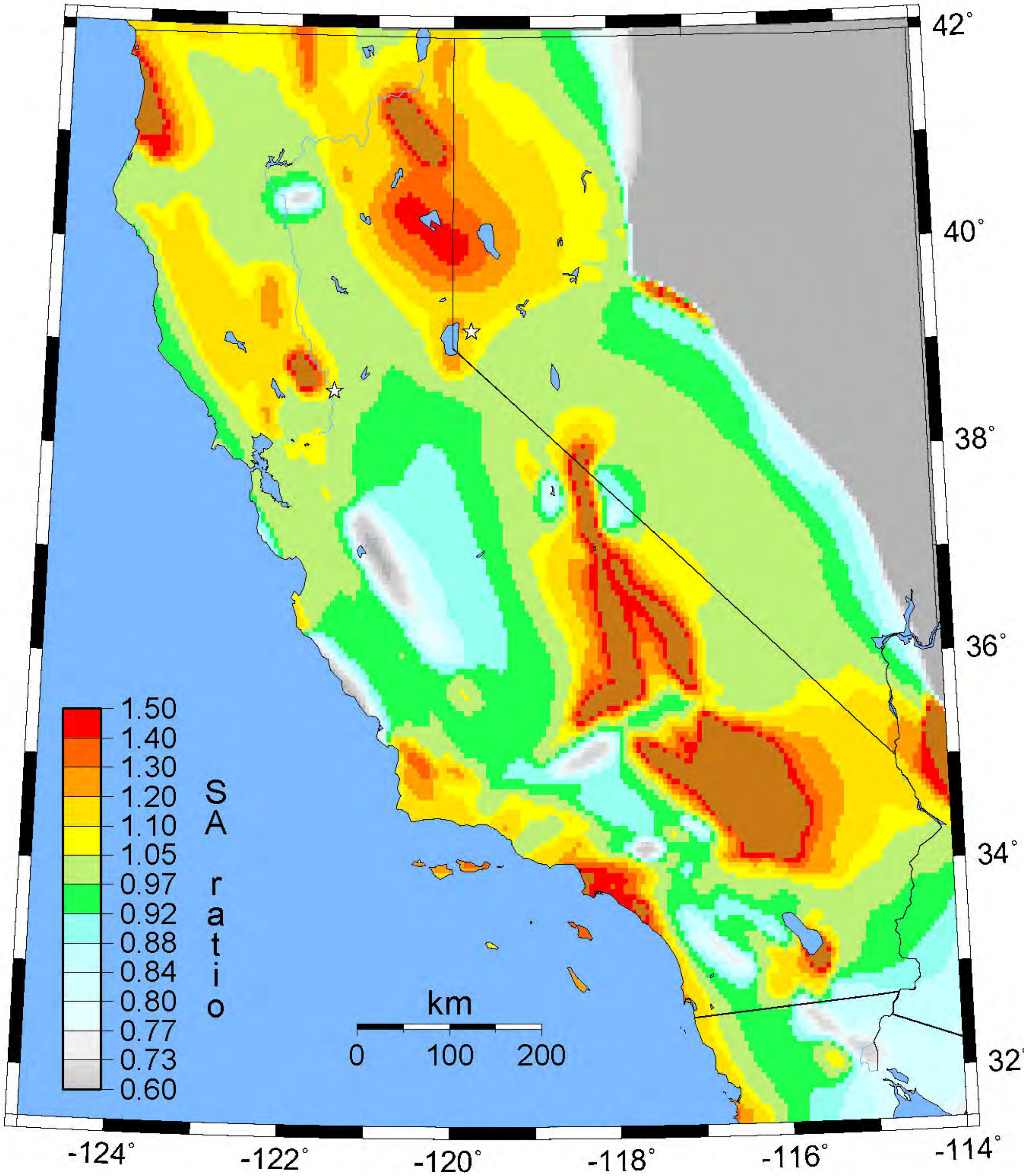
2010 Apr 16 11:34:41 PSHA CA fault sources only. Site Vs30 760 m/s. 1 Hz 2%50 yr PE. Sliprate from geodesy model, characteristic & GR ruptures 2:1

CA Geologic 1-Hz SA w/2%PE50Yr. 760 m/s Rock



GMT 2010 Apr 16 11:36:31 PSHA CA fault sources only. Site Vs30 760 m/s. 1 Hz 2%50 yr PE. Sliprate from UCERF geology model, characteristic & GR ruptures 2:1

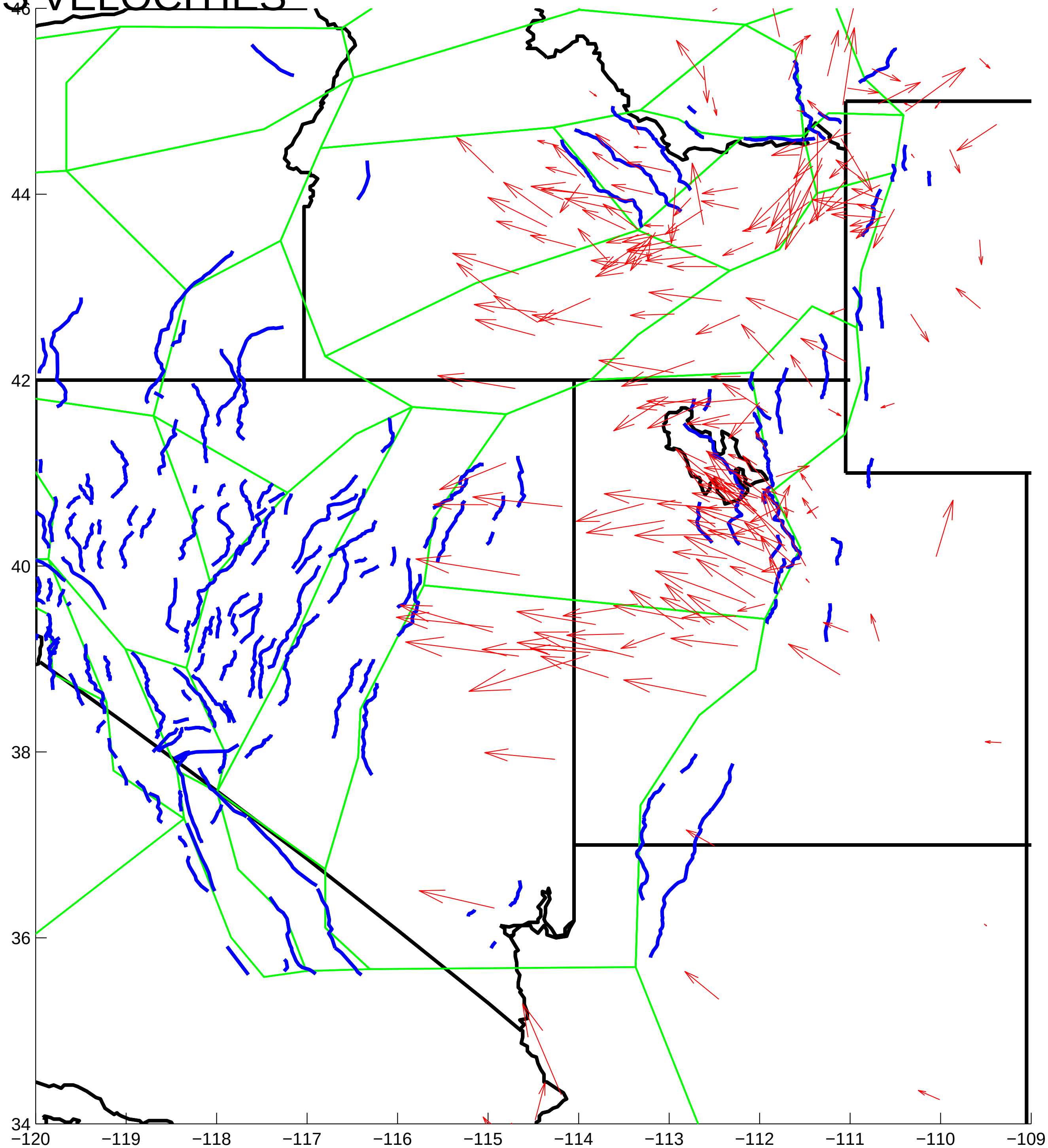
CA Geodetic/Geologic 1-Hz SA w/2%PE50Yr. 760 m/s Rock

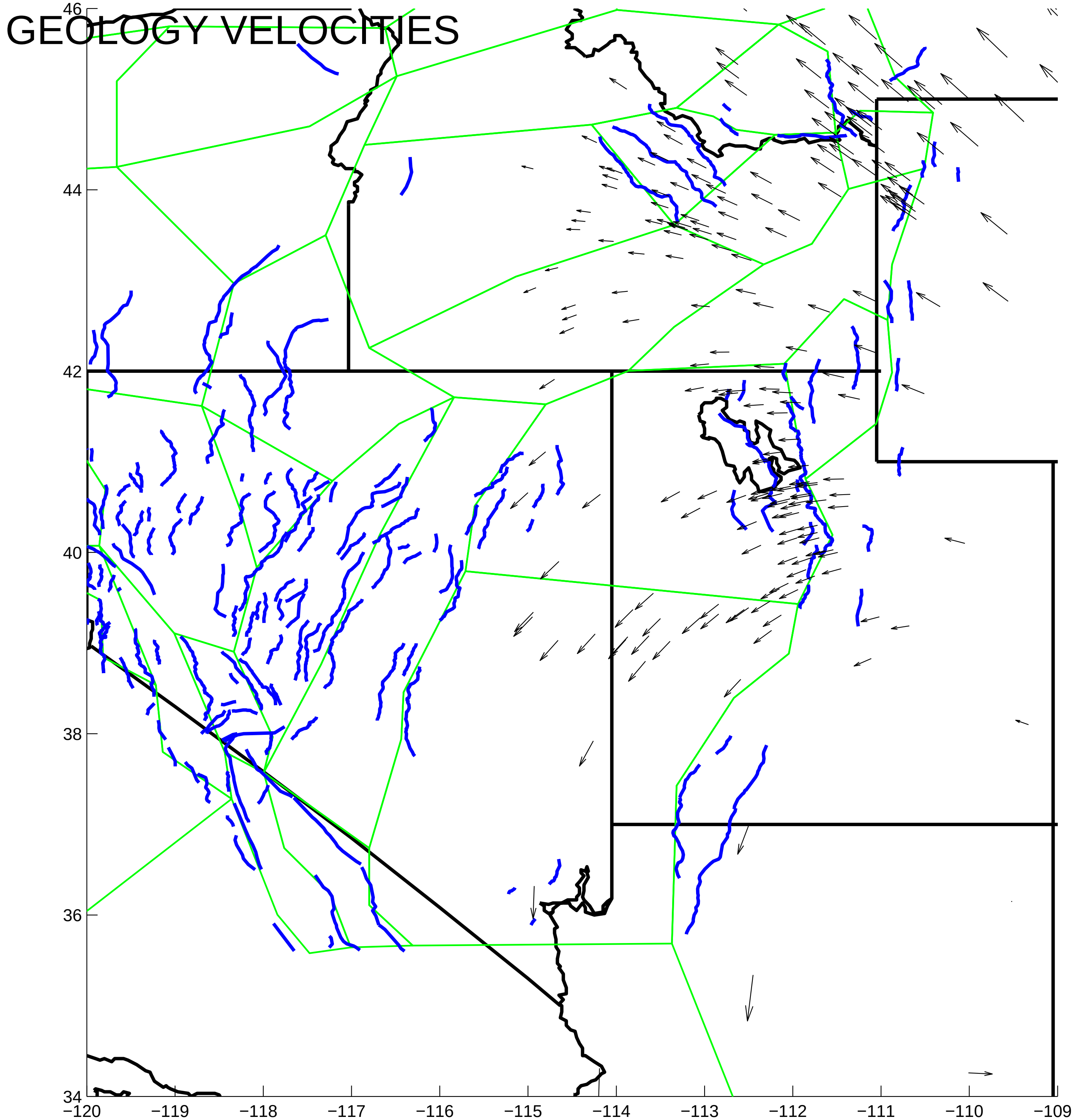


Part of the WUS - GPS and geological model comparison

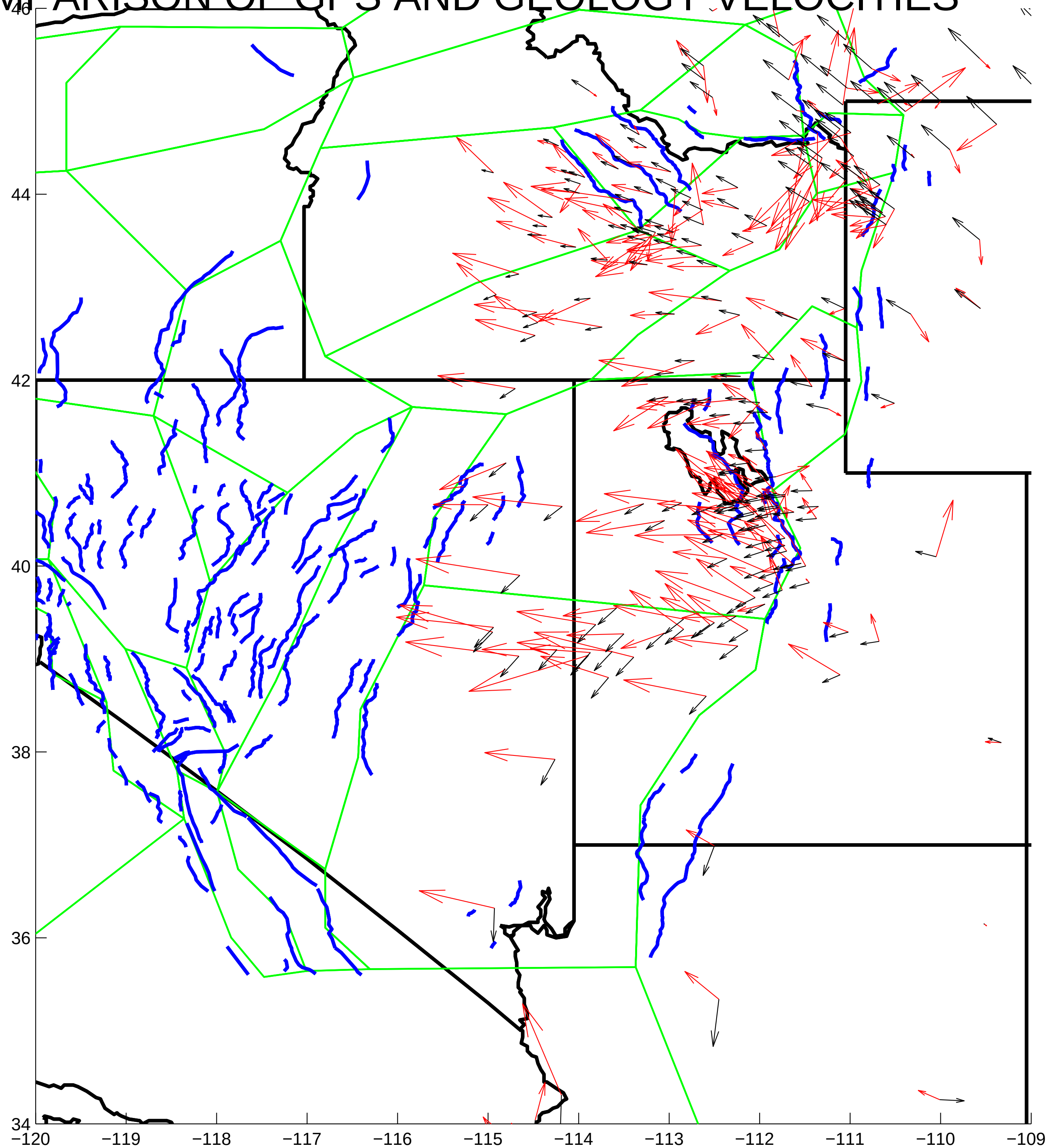
- We do not have the WUS block model completed however we have the Wasatch
- Geologic model based on 2008 slip rates
- Processed GPS observations

GPS VELOCITIES

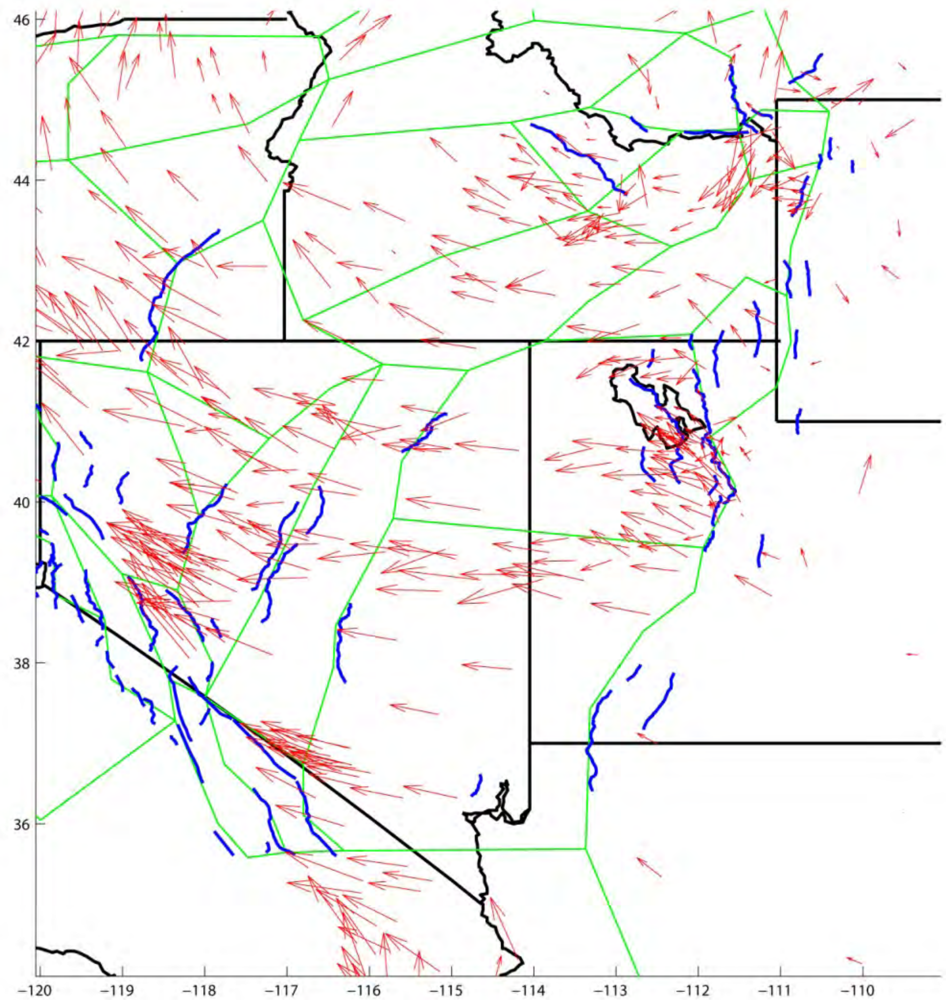



GEOLOGY VELOCITIES
46
44
42
40
38
36
34
−120
−119
−118
−117
−116
−115
−114
−113
−112
−111
−110
−109

COMPARISON OF GPS AND GEOLOGY VELOCITIES



Processed GPS data



Conclusions

- GPS working groups strongly advise using the GPS data to constrain slip rates in the hazard maps.
- For California the GPS and Geology models are similar but the moment rate for gps is about 15% higher than the geology.
- For Utah the GPS and Geology models are differ by a factor of more than 1-3 .
- The difference increase to the South
- Should we use the GPS data? This would imply higher hazard on the Southern Wasatch.

Background Earthquakes and Consensus Wasatch Front Earthquake Catalog

Walter Arabasz and Jim Pechmann

Working Group on Utah Earthquake Probabilities
February 16, 2010

Discussion Points

- Collaboration with USGS on a consensus earthquake catalog
- Thinking through how to handle “background” earthquakes vis-à-vis fault sources
- Planned steps (redux)

Collaboration with USGS

Catalog compilation (1850 through 2010)

- Discussions started with Chuck Mueller in January, still shaping plans
- Scoping the bounds (larger than WGUEP area?) and magnitude threshold for unifying UUSS and USGS catalog entries, accounting for special studies of some mainshocks
- Eventual comparison of declustering: Gardner Knopoff method used by USGS vs. Veneziano and Van Dyck stochastic method

Steps (redux)

1. Conversion to Moment magnitude, M_W

- Instrumentally-determined M_W
- Conversion from macroseismic measure (e.g., I_0)
- Conversion from other instrumental magnitudes

Steps (redux)

2. Uniform Magnitude Catalog

- Veneziano (EPRI, 1988) showed that earthquake recurrence rates can be biased due to uncertainties relating to the magnitude conversion process
- In a rigorous analysis, M* (an adjusted magnitude) is used to correct this bias and produce a “uniform magnitude catalog” for recurrence calculations

Steps (redux)

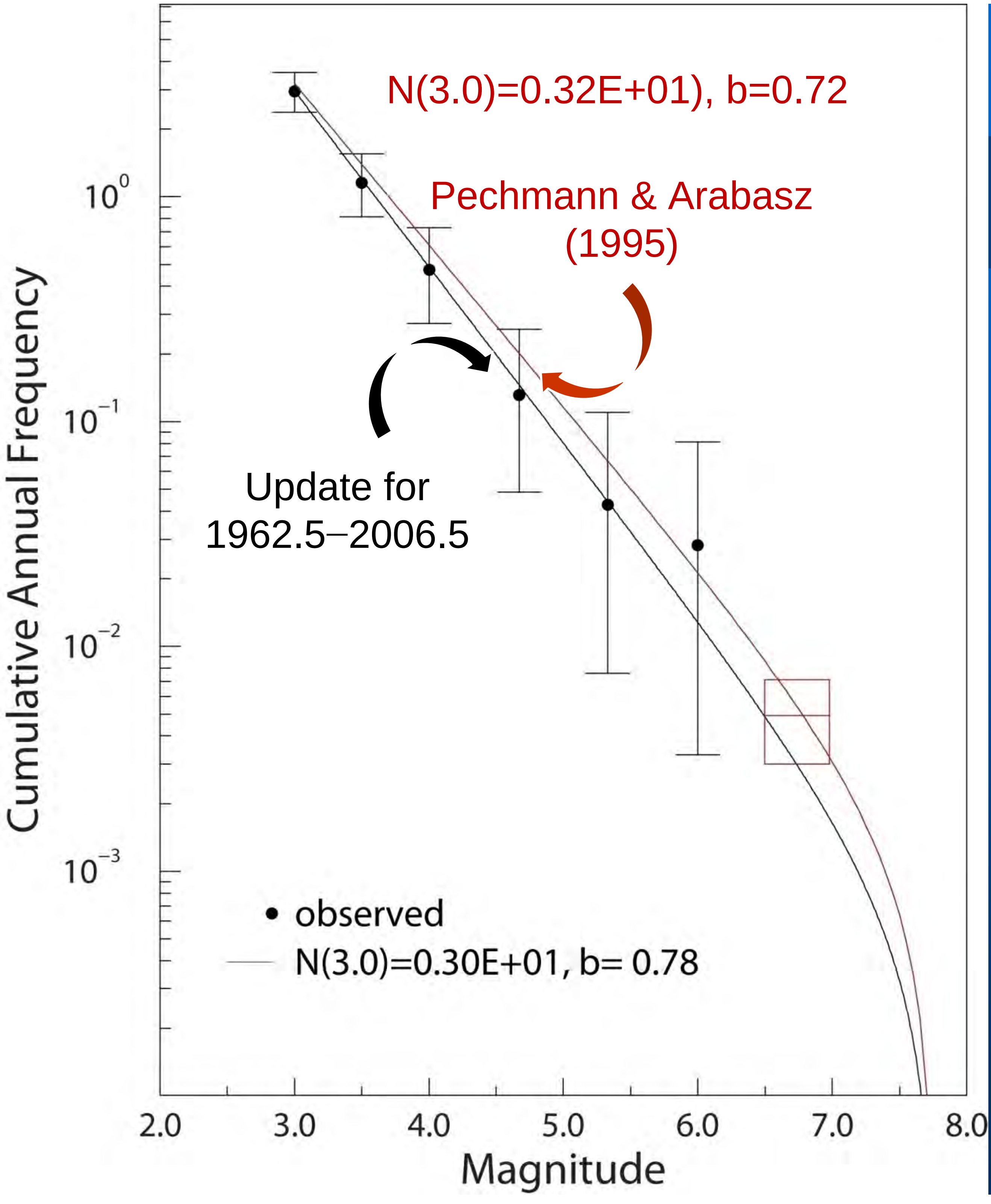
3. Catalog Declustering

- Gardner & Knopoff (1974) — uses simple time and distance windows to remove foreshocks and aftershocks
- EPRI (1986) [Veneziano & Van Dyck] — stochastic approach

Steps (redux)

5. Earthquake Recurrence Calculations

- State of practice is to use a maximum-likelihood approach (e.g., Weichert, 1980)



(for reference)

Example recurrence calculation using Weichert approach

(from Feb 2010 WGUEP meeting)

Path Forward (for discussion)

1. Need to decide/agree on scope and rigor of steps for analysis
2. At least basic attempt to move in direction of a consensus catalog with USGS
3. Revisit whether probability of $M \geq 5.0$ background earthquake is to be computed for entire WGUEP study region or on some gridded basis (as being done on USGS Web site)
4. Complete steps and analysis

end

EARTHQUAKE TIMING (ka ± 2 sigma)

Event	Brigham City	Weber	Salt Lake City	Provo	Nephi
E1	2.4 ± 0.3	0.6 ± 0.1	1.3 ± 0.2	0.6 ± 0.0	0.2 ± 0.1
E2	3.4 ± 0.2	1.2 ± 0.1	2.2 ± 0.2	1.5 ± 0.4	1.2 ± 0.1
E3	4.5 ± 0.5	3.1 ± 0.3	4.1 ± 0.3	2.2 ± 0.4	2.0 ± 0.4
E4	5.6 ± 0.7	4.5 ± 0.3	5.3 ± 0.2	4.7 ± 0.3	4.7 ± 1.8
E5		5.9 ± 0.5		5.7 ± 0.4	

RECURRENCE (ky ± 2 sigma)

	Brigham City	Weber	Salt Lake City	Provo	Nephi
Closed mean recurrence	**1.1 ± 0.2** E4-E1	**1.3 ± 0.1** E5-E1	**1.3 ± 0.1** E4-E1	**1.4 ± 0.1** E4-E1	**0.9 ± 0.2** E3-E1
Open mean recurrence	1.4 ± 0.2 E4-present	1.2 ± 0.1 E5-present	1.3 ± 0.1 E4-present	1.2 ± 0.1 E4-present	0.7 ± 0.1 E3-present
UQFPWG RI	1.3	1.4	1.3	2.4	2.5

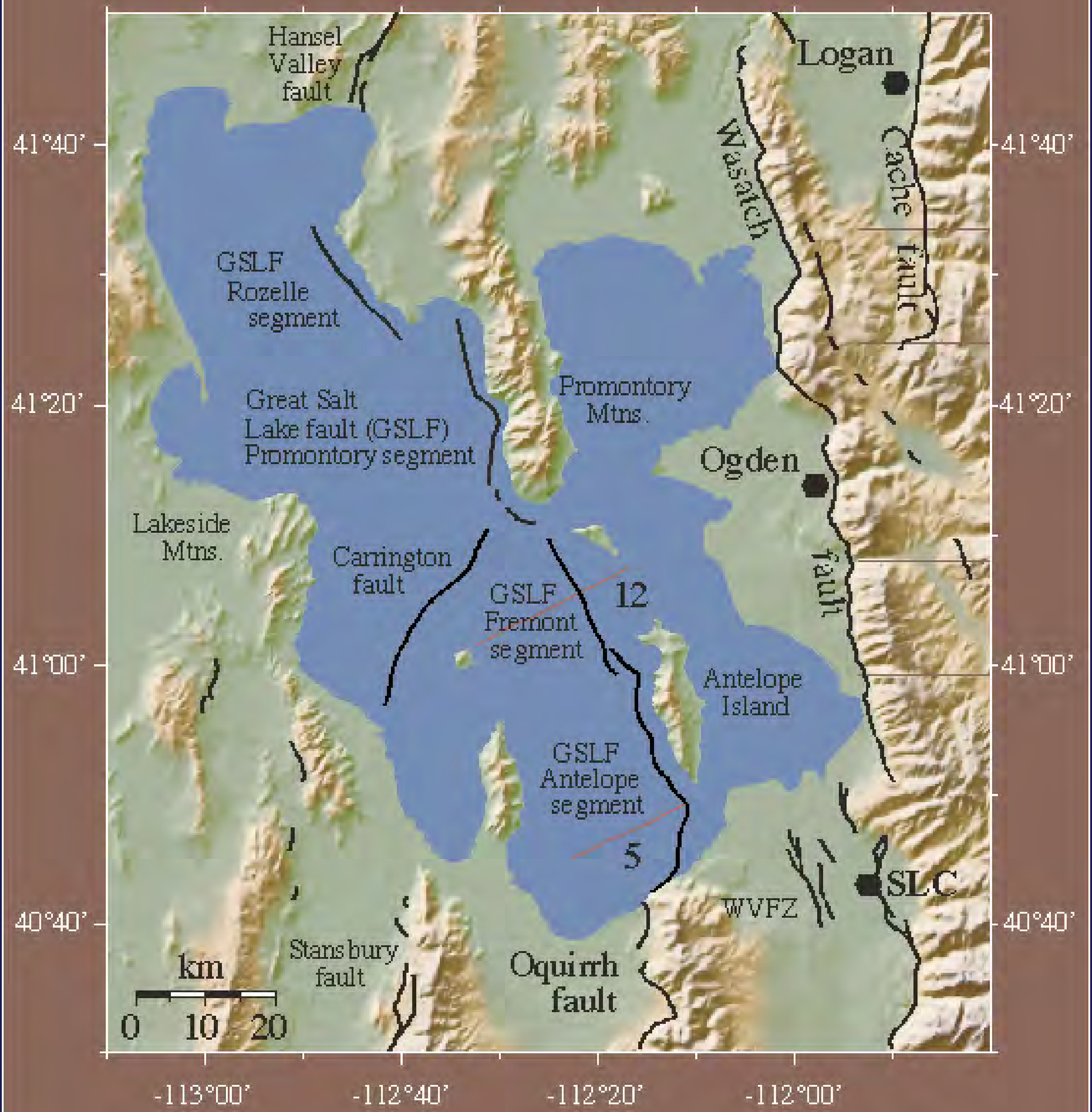
SLIP RATE (mm/yr)

	Brigham City	Weber	Salt Lake City	Provo	Nephi
Mean per-event displacement	2.0	2.2	2.0	2.4	1.8
Mean slip rate	**1.9**	**1.6**	**1.5**	**1.8**	**2.0**
UQFPWG SR	1.4	1.2	1.2	1.2	1.1

Should the WGUEP Compute Time-Dependent Probabilities for Large Earthquakes on the Great Salt Lake Fault?

David A. Dinter and James C. Pechmann
Department of Geology and Geophysics
University of Utah

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



Approach – Analogous to trenching:

• Map active fault traces to determine lengths and identify segments

• Measure net vertical tectonic displacement from lake bottom topography and/or cross sections across fault

• Identify seismic event horizons

• Date event horizons to obtain earthquake

In our surveys, we typically use two seismic reflection syste
Simultaneously deployed from either side of a small boat.

The Geopulse “boomer” diaphragm,
mounted on a pontoon sled,
emits pulses at energies up to
280 joules with frequency content
in the 700- to
1200-Hz range.

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

- Two major segments of the GSL norma
fault south of Promontory Point
- Segment boundary is a 1-2-km left ste
W of White Rock Bay, N Antelope Island
- Fremont Island segment:
  20 km long (revised from 30 km)
  No lakebed scarp along half of it (buried)
- Antelope Island segment:
  35 km long
  Lakebed scarp, up to 3.6 m relief
  Bends sharply SW at south end
  Appears to merge with Oquirrh faul
- Numerous active intrabasin normal fault
  Strikes oblique to GSLF
  Lakebed scarps, up to 1.8 m relief
  Probably coseismic with GSLF

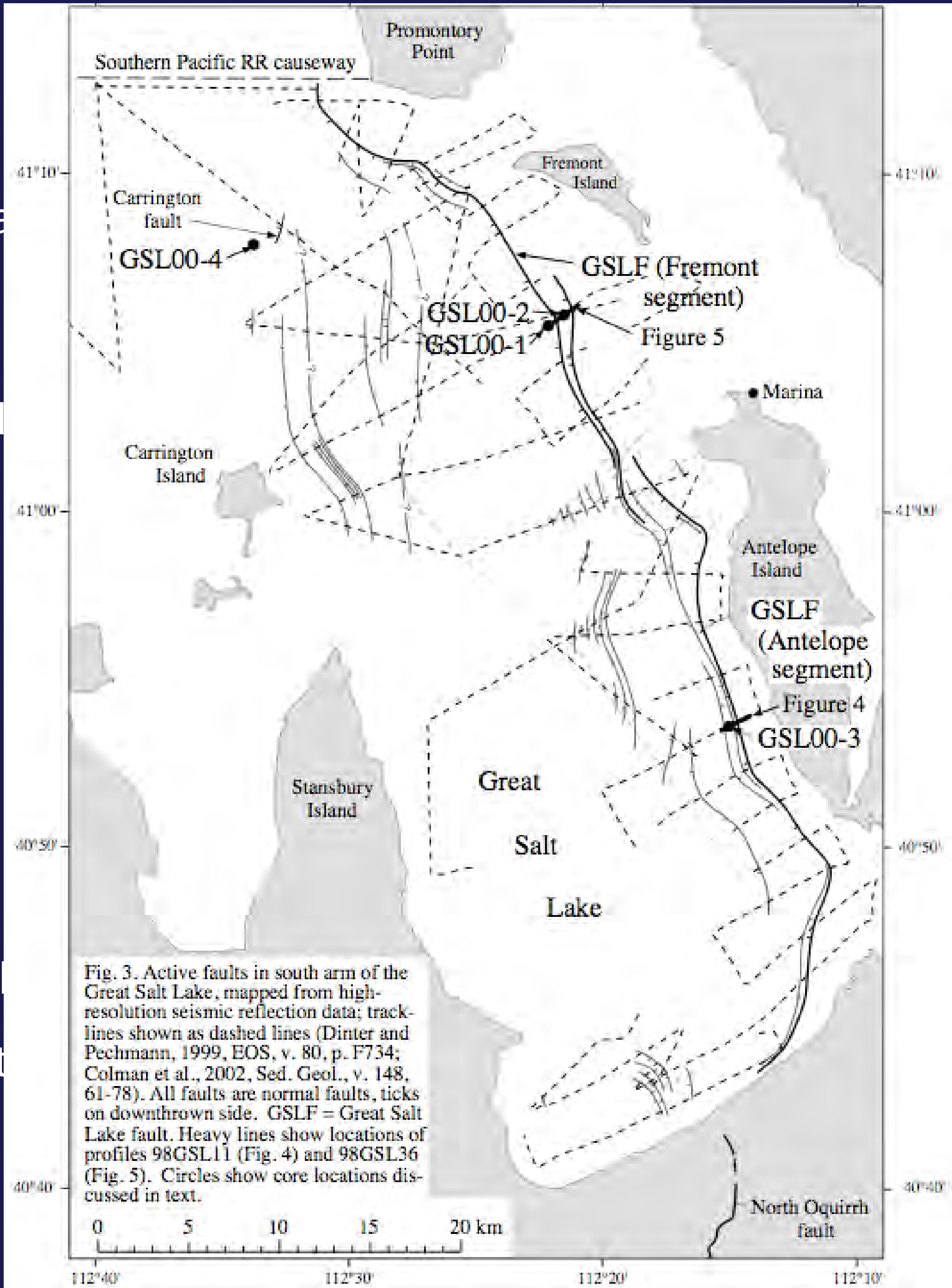


Fig. 3. Active faults in south arm of the Great Salt Lake, mapped from high-resolution seismic reflection data; track-lines shown as dashed lines (Dinter and Pechmann, 1999, EOS, v. 80, p. F734; Colman et al., 2002, Sed. Geol., v. 148, 61-78). All faults are normal faults, ticks on downthrown side. GSLF = Great Salt Lake fault. Heavy lines show locations of profiles 98GSL11 (Fig. 4) and 98GSL36 (Fig. 5). Circles show core locations discussed in text.

South arm update:

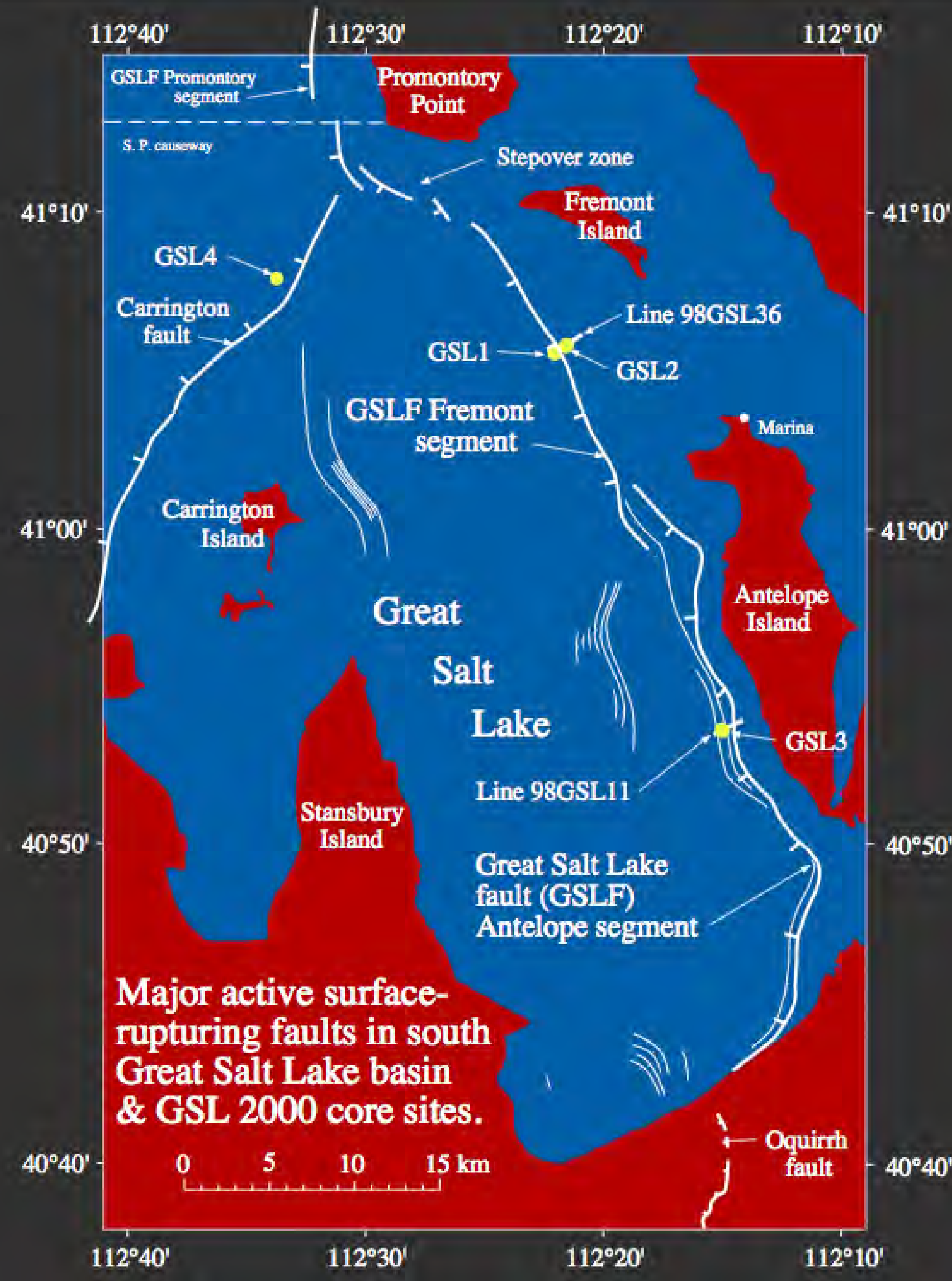
• Acquired new south arm seismic data in 2005-6, primarily north of Carrington Island to Promontory Point stepover zone.

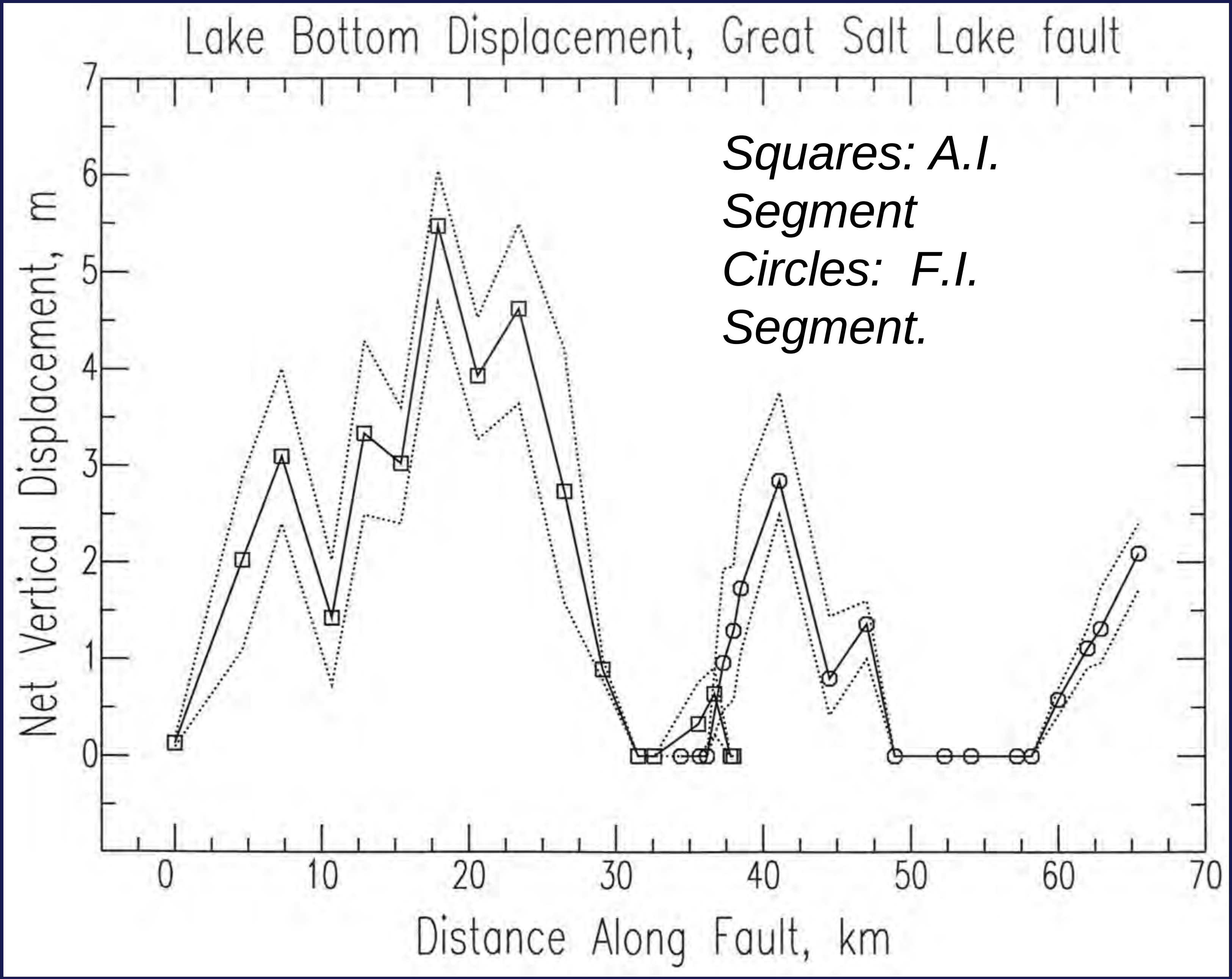
• Carrington fault is an independent seismogenic structure ~30 km long.

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)

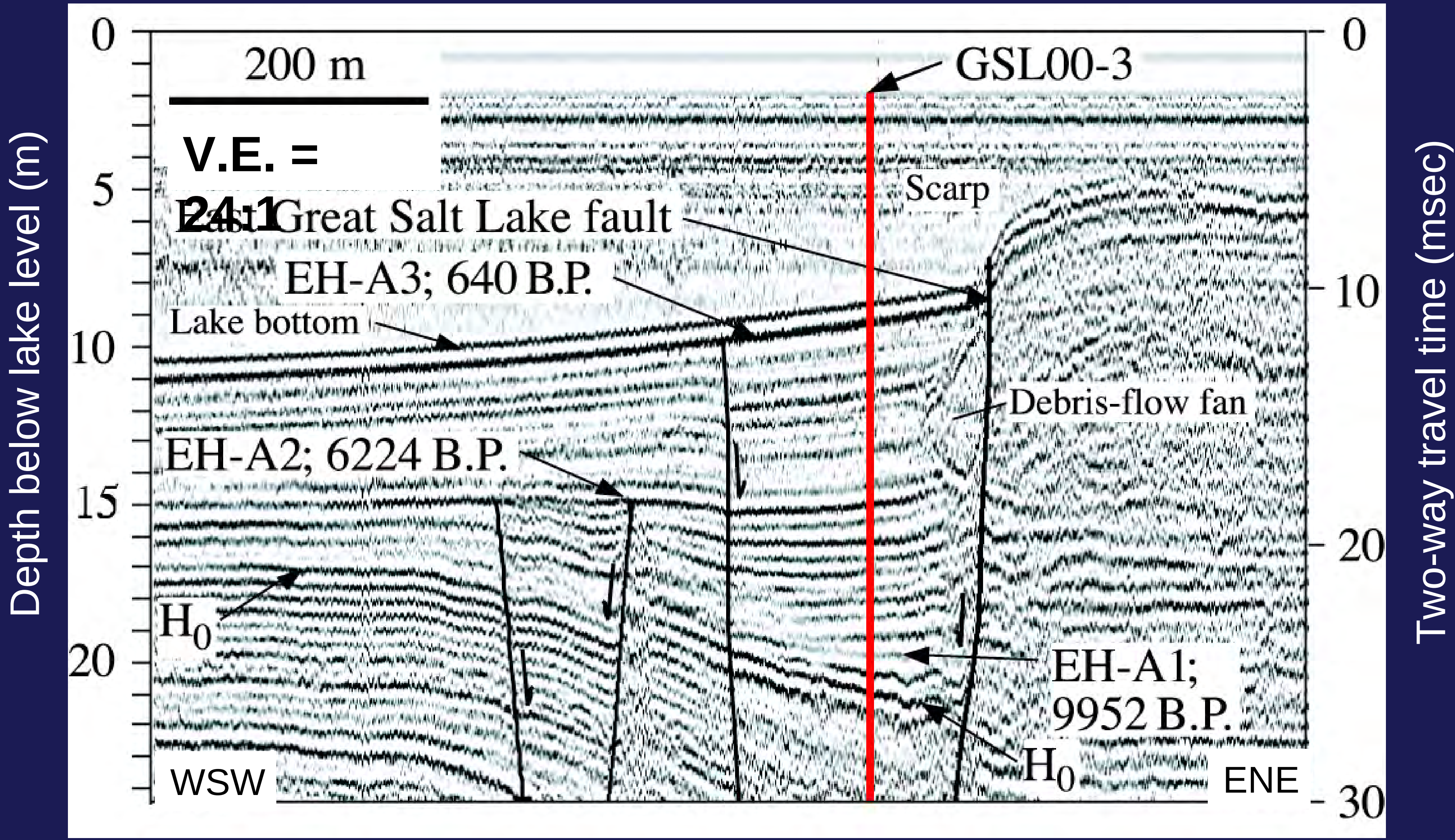
Does not curve NW to merge with Promontory segment.
Left stepover zone ~ 7 km wide contains short faults probably coseismic with Promontory segment.





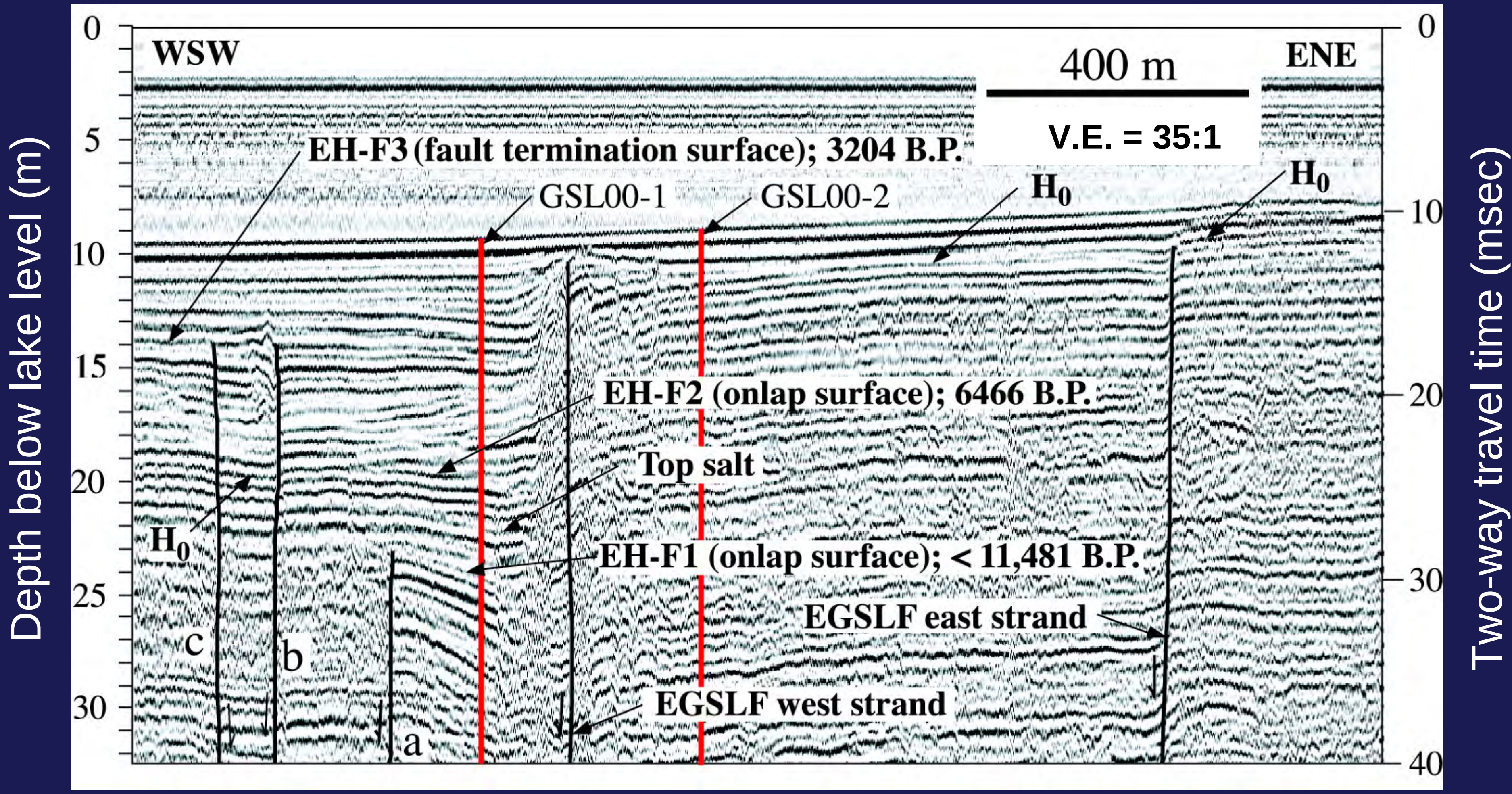
A.I. segment average vertical slip rate = 0.55 +0.5/-0.25 mm/yr (max)

Great Salt Lake fault, Antelope Island segment



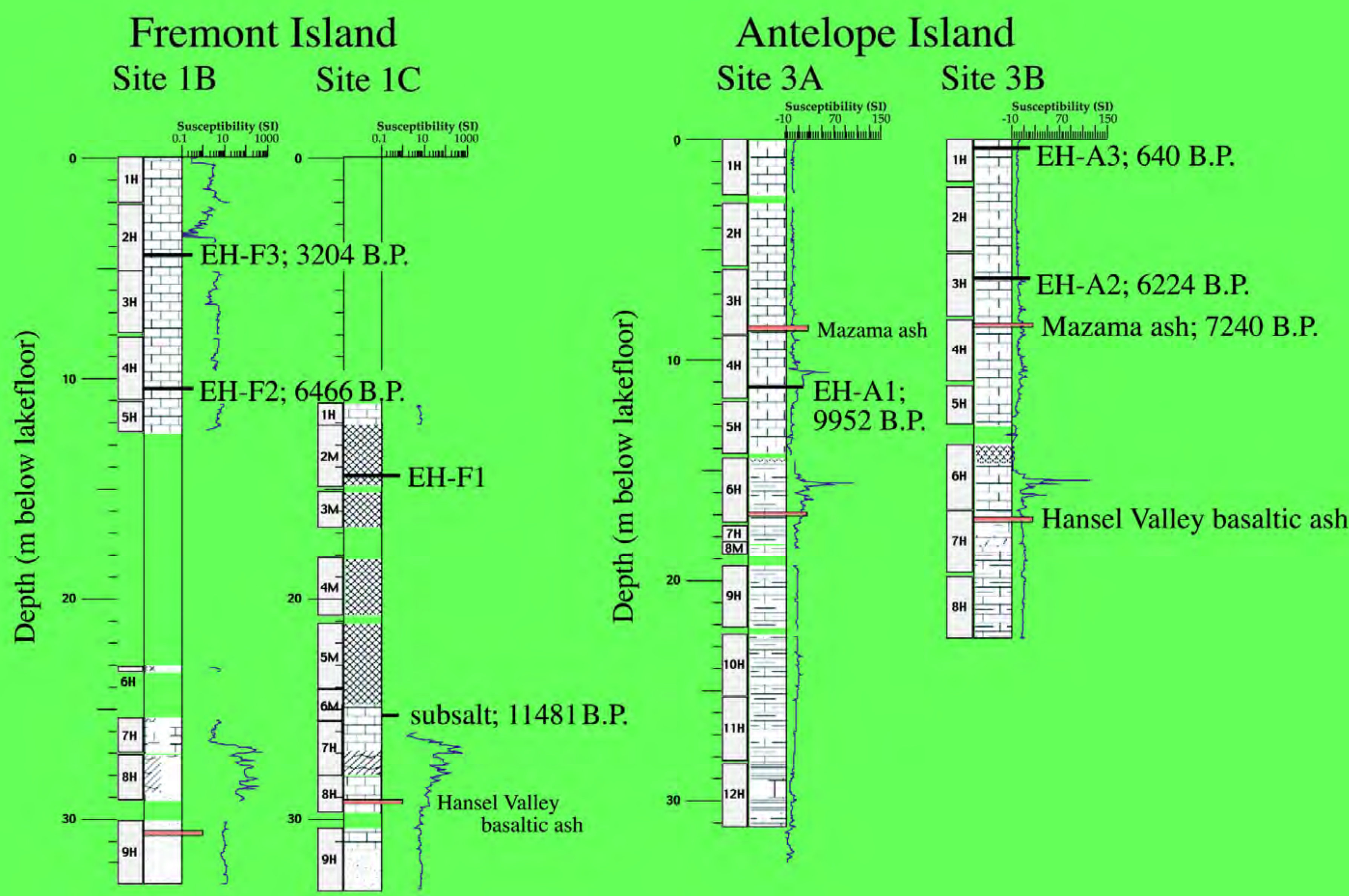
Geopulse Line 98GSL11

Great Salt Lake fault, Fremont Island segment



Geopulse Line 98GSL36

The DOSECC GLAD-1 mobile lacustrine drilling platform, 2000



Fremont Island
Site 1B
Site 1C
Antelope Island
Site 3A
Site 3B
Susceptibility (SI)
Depth (m below lakefloor)
EH-F3; 3204 B.P.
EH-F2; 6466 B.P.
EH-F1
subsalt; 11481 B.P.
Hansel Valley basaltic ash
EH-A3; 640 B.P.
EH-A2; 6224 B.P.
Mazama ash; 7240 B.P.
Mazama ash
EH-A1; 9952 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 2007**[2]
Antelope Island segment				
EH-A3	> 804 ± 38 < 1027 ± 44	> 706 $^{+81/-40}$ < 944 $^{+106/-147}$	586 $^{+201/-241}$	643 $^{+201/-241}$
EH-A2	5,711 ± 50	6491 $^{+163/-135}$	6170 $^{+236/-234}$	6227 $^{+236/-234}$
EH-A1	9,068 ± 66	10,219 $^{+178/-234}$	9898 $^{+247/-302}$	9955 $^{+247/-302}$
Fremont Island segment				
EH-F3	3,269 ± 47	3471 $^{+161/-90}$	3150 $^{+235/-211}$	3207 $^{+235/-211}$
EH-F2	5,924 ± 44	6733 $^{+121/-90}$	6412 $^{+209/-211}$	6469 $^{+209/-211}$
EH-F1	<10,155 ± 72	<11,748 $^{+580/-406}$	<11,427 $^{+605/-449}$	<11,484 $^{+605/-449}$

Earthquake recurrence intervals, Great Salt Lake fault

Earthquake pairs	Dates of occurrence (residence-corrected cal yr before 1950)	Recurrence interval (yr)
Antelope Island segment (M_{max} = 6.9)		
EH-A3 **EH-A2**	596 +201/-241 6170 +236/-234	5584 +219/-172
EH-A2 **EH-A1**	6170 +236/-234 9898 +247/-302	3728 +223/-285
Fremont Island segment (M_{max} = 6.6-6.7)		
EH-F3 **EH-F2**	3150 +235/-211 6412 +209/-211	3262 +151/-184
EH-F2 **EH-F1**	6412 +209/-211 < 11,427 +605/-449	< 5015 +587/-424

Average single-segment recurrence interval = 4200 ± 1400 years

North Arm provisional results

- Obtained 40 north arm crossings of GSLF in 2009, 2010
- Detailed active fault map in preparation
- Preliminary interpretation indicates:

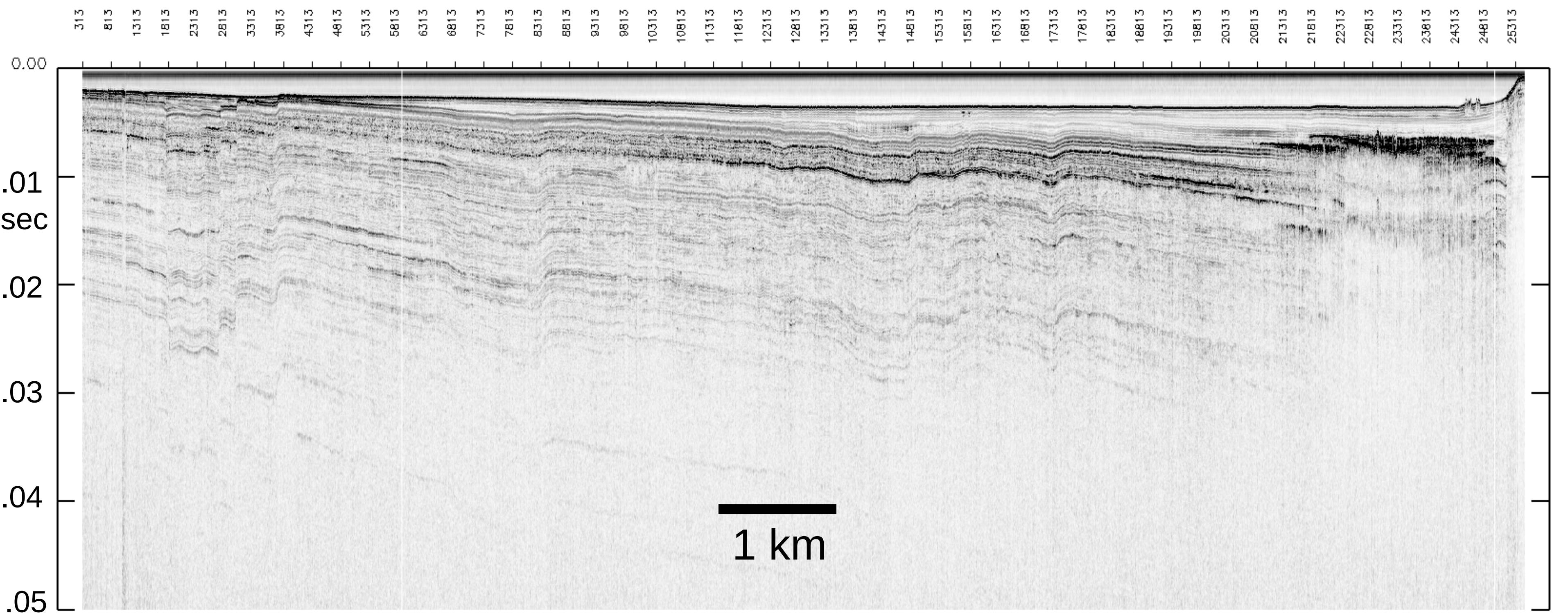
  Two additional segments in the north arm:

  Promontory segment has a young scarp.
  Stepover faults at south end of Promontory Point also have fresh scarps; may be coseismic.
  Rozelle segment is partly buried, and is the northernmost segment of GSLF system.

  Hansel Valley fault to north has opposite dip direction.

  There is likely a tear-fault system in Spring Bay.

Example of North Arm Data, Great Salt Lake



Raw plot of “Ultrachirp” Line 09GSL2a, E-W crossing of GSLF Promontory segment in Great Salt Lake north arm. Note Holoc
scarp at far right, auxiliary faults throughout basin.


Hansel Valley fault
Logan
Wasatch
Cache fault
41°40'
GSLF Rozelle segment
Promontory Mtns.
41°20'
Great Salt Lake fault (GSLF) Promontory segment
Ogden
Lakeside Mtns.
Carrington fault
GSLF Fremont segment
12
fault
41°00'
Antelope Island
GSLF Antelope segment
5
SLC
WVFZ
40°40'
km
0 10 20
Stansbury fault
Oquirrh fault
-113°00'
-112°40'
-112°20'
-112°00'

Launching the survey boat in the Great Salt Lake north a

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	6.6 ± 0.3
Rupture Area	6.9 ± 0.3	6.7 ± 0.3

Strawman Rupture Scenarios for the Great Salt Lake Fault

James C. Pechmann and David A. Dinter

Department of Geology and Geophysics

University of Utah

(with help from Susan S. Olig, URS Corp.)

End-to-End Segment Lengths

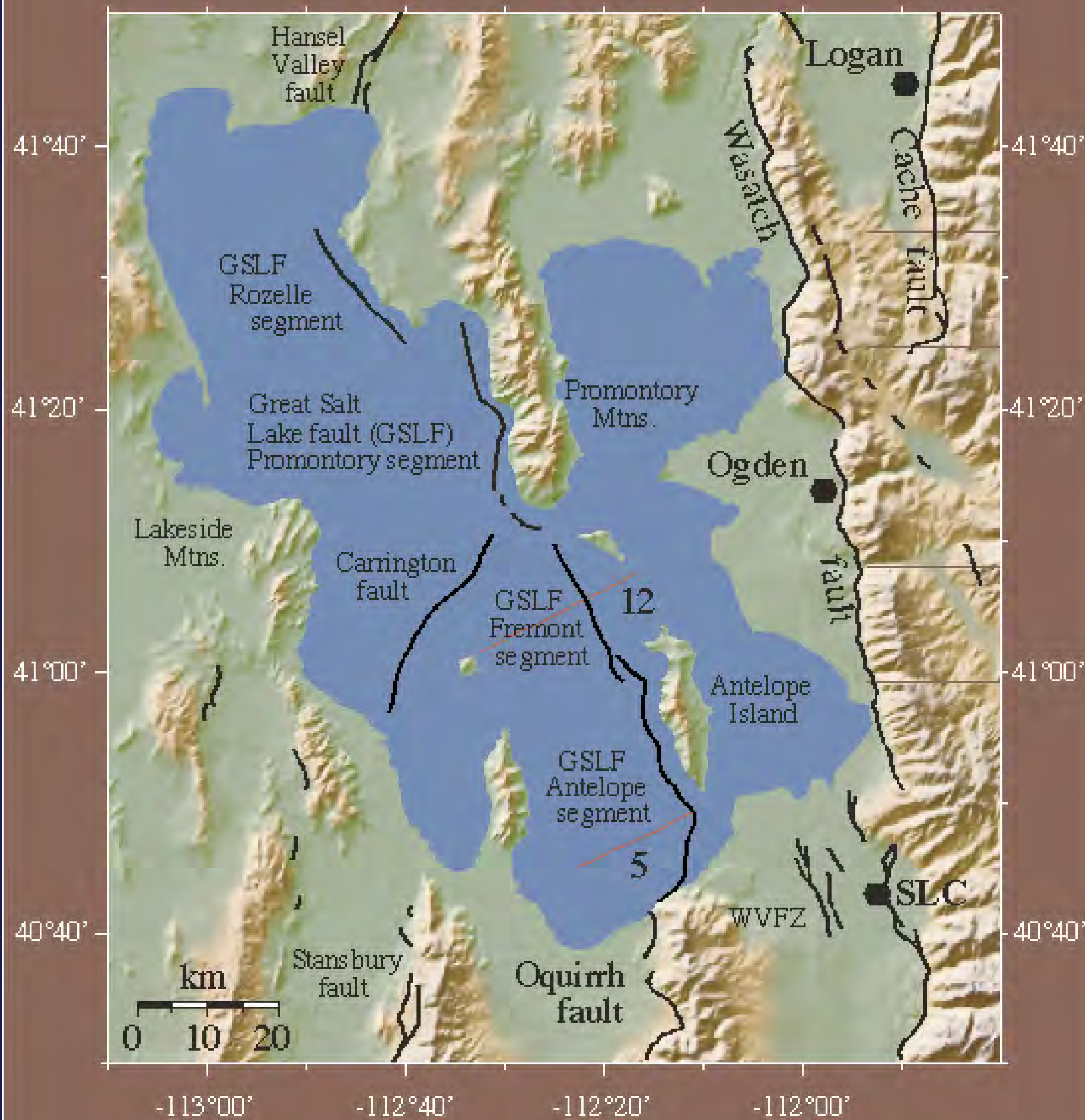
Antelope Island (AI)
35 (30-37) km
Large lakebed scarp

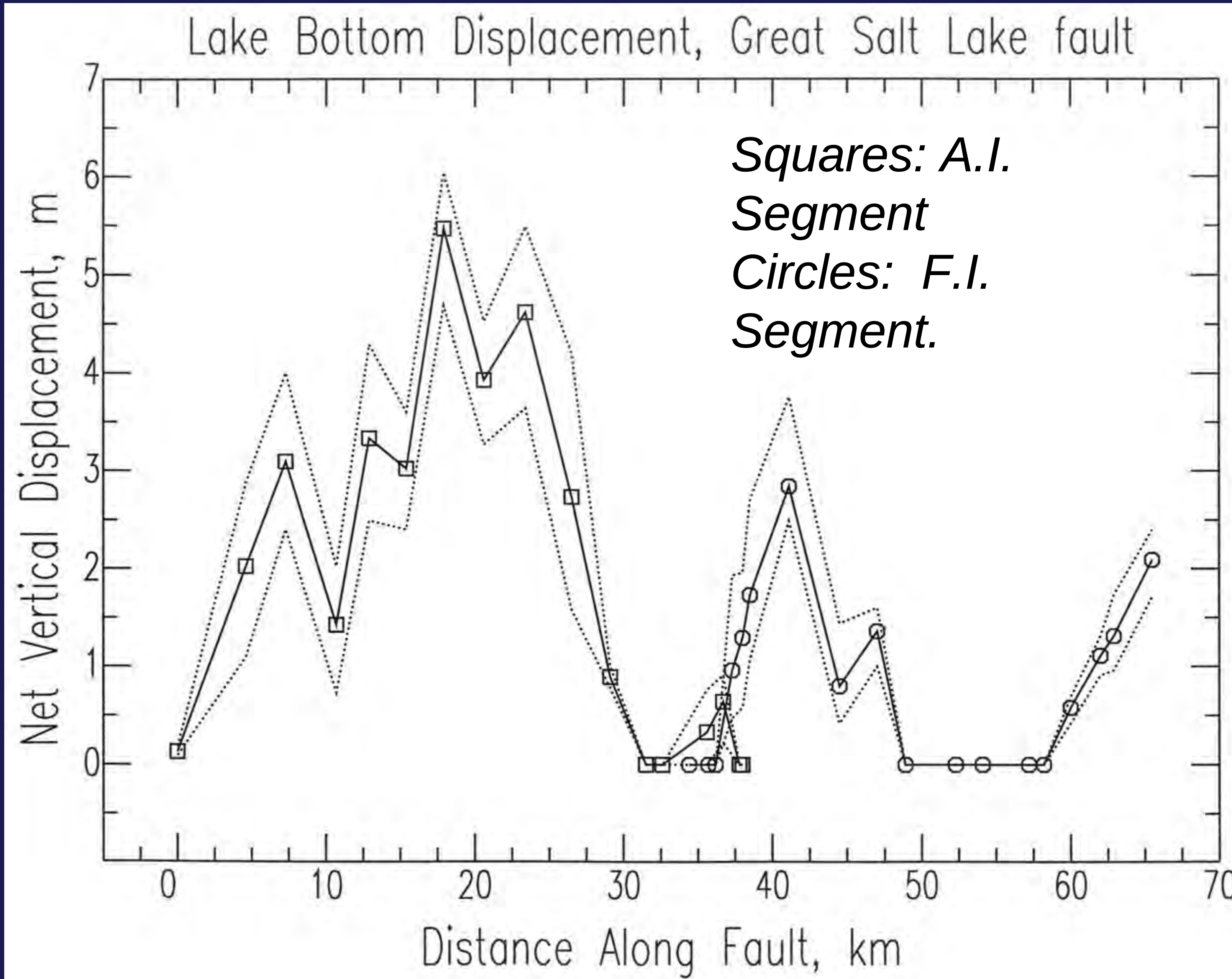
Fremont Island (FI)
22 (18-28) km
Half buried scarp

Promontory (P)
32 (28-36) km
Young scarp

Rozelle (R)
23 (19-27) km
Partly buried scarp

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





A.I. segment avg vertical slip rate = 0.55 +0.5/-0.25 mm/yr (max)

Maximum Magnitude Estimates, Great Salt Lake Fault (from M vs. SRL relations for normal faults, Wells and Coppersmith, 1994)

Single-Segment Ruptures			Multi-Segment Ruptures		
Fault Segment	Length (km)	M_w	Fault Segments	Length (km)	M_w
Rozelle (R)	23	6.7	R + P	53	7.1
Promontory (P)	32	6.8	P + FI	56	7.2
Fremont Island (FI)	22	6.6	FI + AI	52	7.1
Antelope Island (AI)	35	6.9	R + P + FI + AI	108	7.5

South arm update:

• Acquired new south arm seismic data in 2005-6, 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
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Fresh scarp -> recent earthquake

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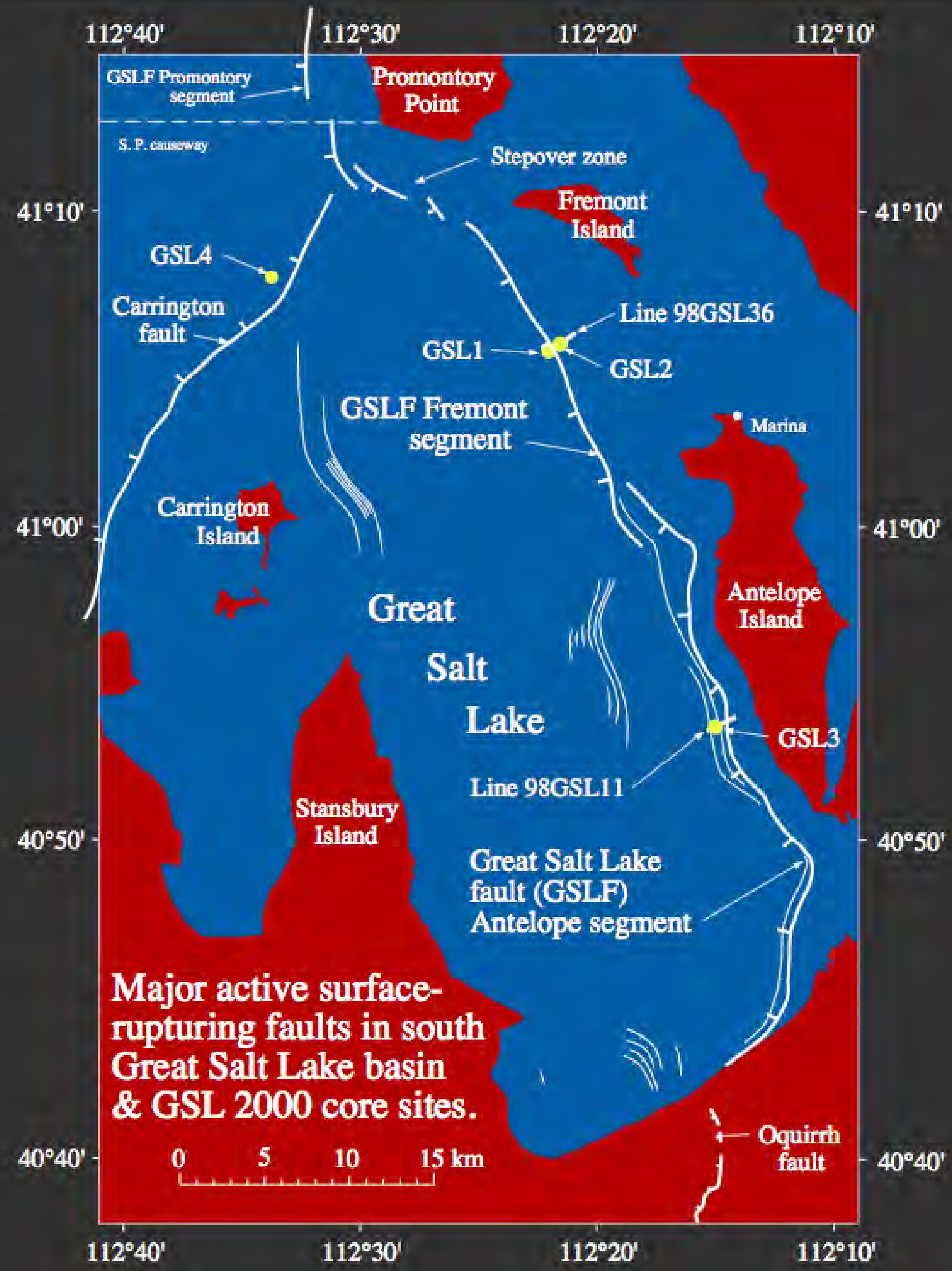
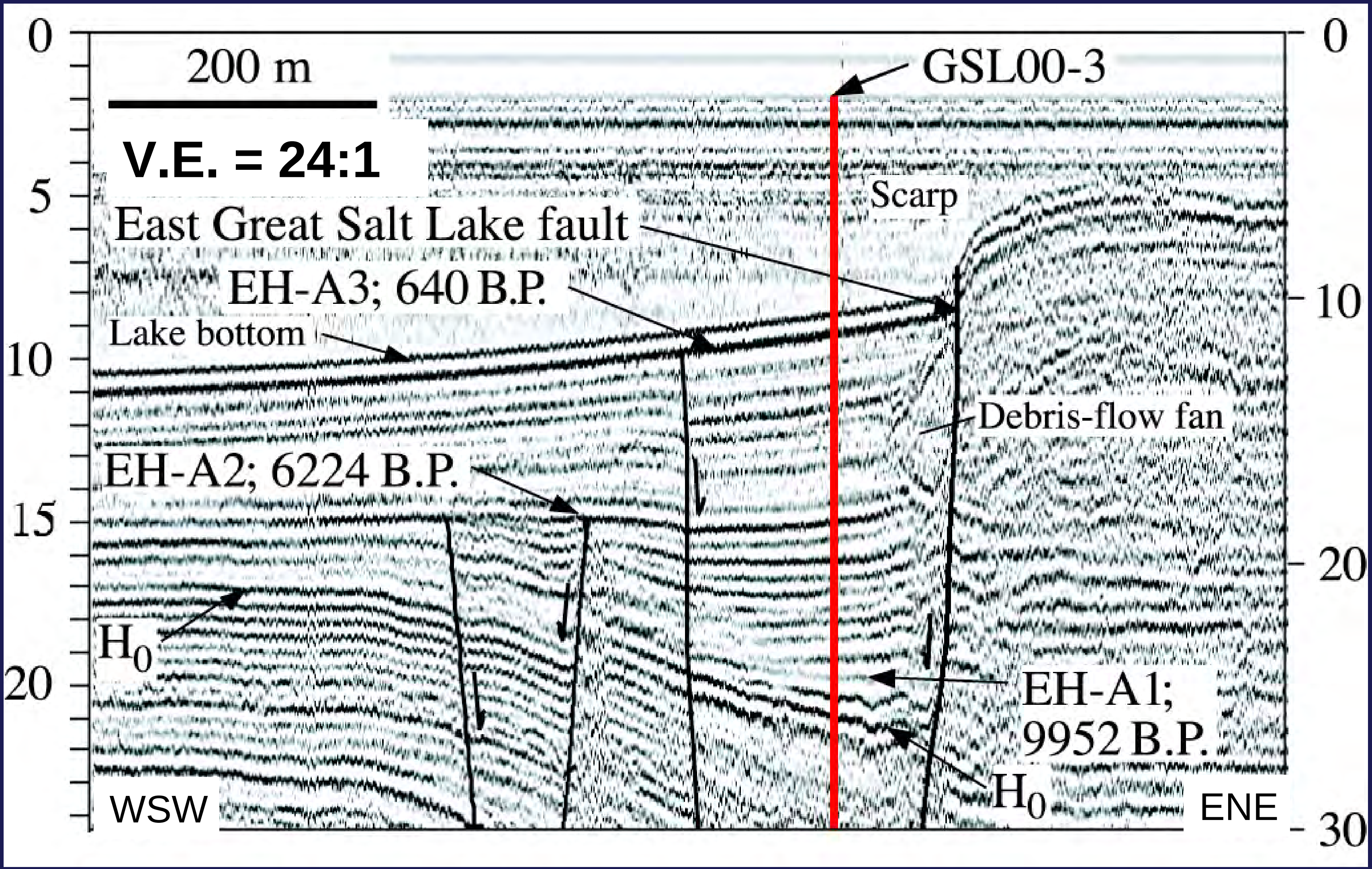
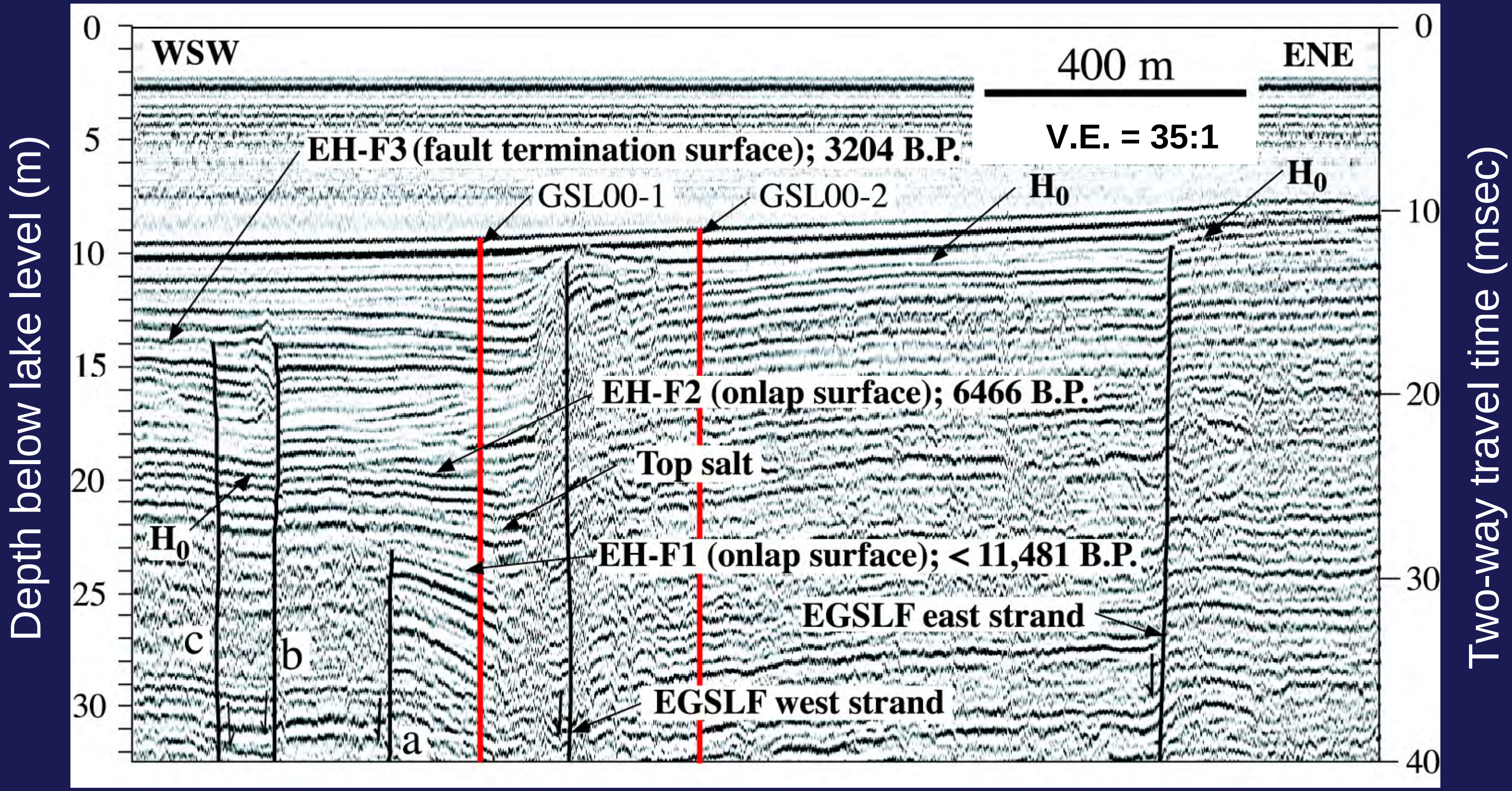


Great Salt Lake fault, Antelope Island segment



Geopulse Line 98GSL11

Great Salt Lake fault, Fremont Island segment



Geopulse Line 98GSL36

Earthquake dates, Great Salt Lake fault

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Earthquake recurrence intervals, Great Salt Lake fault

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EH-F3 **EH-F2**	3150 +235/-211 6412 +209/-211	3262 +151/-184
EH-F2 **EH-F1**	6412 +209/-211 < 11,427 +605/-449	< 5015 +587/-424

Average single-segment recurrence interval = 4200 ± 1400 years

Considerations Favoring Single-Segment Ruptures

- Fault geometry
- Rupture lengths of most recent events
- Relatively uniform offsets in each event

Considerations Favoring Multi-Segment Ruptures

- Some relatively short segment lengths
- Dates permit two combined ruptures of the Fremont Island and Antelope Island segments

Rupture Scenarios

				COMMENTS
R	P	FI	AI	MRE ruptures
R + P		FI	AI	Speculative
R	P + FI		AI	Unlikely
R	P	FI + AI		Allowed by dates for S half
R + P		FI + AI		Allowed by dates for S half

Unsegmented

Rupture Scenarios

				WS1	WS2
R	P	FI	AI	0.75	0.68
R + P		FI	AI	0.05	0.08
R	P + FI		AI	0.00	0.00
R	P	FI + AI		0.05	0.08
R + P		FI + AI		0.05	0.08
Unsegmented				0.10	0.08


Hansel
Valley
fault
Logan
Wasatch
Cache
fault
GSLF
Rozelle
segment
Promontory
Mtns.
Great Salt
Lake fault (GSLF)
Promontory segment
Ogden
Lakeside
Mtns.
Carrington
fault
GSLF
Fremont
segment
12
fault
Antelope
Island
GSLF
Antelope
segment
5
SLC
WVFZ
Stansbury
fault
Oquirrh
fault
km
0
10
20
41°40'
41°20'
41°00'
40°40'
-113°00'
-112°40'
-112°20'
-112°00'

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	6.6 ± 0.3
Rupture Area	6.9 ± 0.3	6.7 ± 0.3

Table 1. Source Parameters For Working Group on Utah Earthquake Probabilities "Other" Faults

FAULT NO.[1]	FAULT NAME	RUPTURE MODEL	MAXIMUM RUPTURE LENGTH[2] (km)	MAXIMUM MAGNITUDE[3] (M)	DIP[4] (degrees)	APPROXIMATE AGE OF YOUNGEST OFFSET	PROBABILITY OF ACTIVITY[5]	RATE OF ACTIVITY[6] (mm/yr)	COMMENTS
730	*Bear River fault zone*	Independent (1.0)	40 (35)	6.8 (0.2) 7.1 (0.6)[7] 7.4 (0.2)	30 W (0.3) 55 W (0.6) 70 W (0.1)	Holocene	1.0	0.05 (0.2) 1.5 (0.6) 2.5 (0.2)	Detailed trenching and mapping revealed evidence for at least two large, late Holocene surface-faulting earthquakes on this apparently new normal fault with no associated range front (West, 1994). Preferred slip rate based on an average vertical offset of 3 m per event and a recurrence interval of 2,250 to 2,370 years (West, 1994). Maximum and minimum rates are after the 5th and 95th percentiles assigned by the UQFPWG (Lund, 2005). Length and geometry from Plate 1 of West (1994). The west-dipping normal faults are inferred to merge into a ramp of the Laramide-age Darby-Hogsback thrust fault at a depth of about 5-7 km. There is no evidence, at this time, that the fault zone has discrete rupture segments.
2432 2433	*Drum Mountains fault zone and Crater Bench faults*	Independent (0.2) Unsegmented – coseismic (0.8)	Drum Mountains fault zone - 52 Crater Bench faults - 16 52 (two fault zones overlap completely)	?		Holocene Latest Quaternary	0.5	0.01 (0.3) 0.04 (0.6) 0.2 (0.08) 1.0 (0.02)	Comments from Tony Crone: In the absence of better data, I'd favor leaving the Drum Mountains fault zone in the current low slip rate category (<0.2 mm/yr) for two reasons. First our knowledge of the actual net slip across the entire zone is imperfect. The net slip could actually be very small. With current GPS technology we have an opportunity to efficiently and accurately measure profiles several kilometers long; so we could obtain the net slip. However, this work hasn't been done yet, so we don't have a basis for saying the slip rate across the entire zone should be higher. Second, I'm not totally convinced about the seismogenic potential of the Drum Mountains fault scarps. The complex, widely distributed zone of scarps is unusual for tectonic faults, and the scarps are spread out a fair distance east of the Drum Mountains range front, which lacks the morphology of a classic active range front. A possible issue is the role of subsurface evaporite deposits in forming the Drum Mountain scarps. Deep wells in the region report [thick accumulations of] subsurface salt and gypsum. Considering the complex pattern of the scarps and the possible presence of significant amounts of subsurface evaporites, the possibility that the Drum Mountain scarps could be halokinetic features related to salt/evaporite movement cannot be ruled out. If this is the case, then they would not be seismogenic, and would not be a factor in seismic hazard assessments. I think that this possibility needs to be considered carefully when assigning some level of seismic hazard to these faults. Also note a possible connection of these two fault zones with the Sevier detachment fault.
Not Applicable	Carrington fault	Independent (1.0)	28 (~30)	6.5 (0.2) 6.8 (0.6) 7.1 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Holocene	1.0	1,800 (0.2) 4,200 (0.6) 6,800 (0.2)	Dinter and Pechmann (2005) first identified the Carrington fault based on offsets observed in high-resolution seismic reflection profiles in the Great Salt Lake. Our depiction of this northeast-striking, 28-km-long, down-to-the-northwest normal fault, which is northwest of Carrington Island, is based on the scarp being clearly visible on recent bathymetry data of Great Salt Lake (Buskin and Allen, 2005). This scarp is as high as 1.5 m, and likely has experienced multiple Holocene surface-faulting events, similar to the Antelope and Fremont Island segments of the East Great Salt Lake fault zone. However, absolute event ages remain unconstrained (D. Dinter, University of Utah, written communication, 2010). Based on the apparent similarities of the lakebed scarps, we assigned a recurrence interval distribution (in years and shown in bold) similar to the Antelope Island segment of the East Great Salt Lake fault (see Oquirrh-East Great Salt Lake fault zone entry).
2346	Crawford Mountains (west side) fault	Independent (1.0)	25	6.4 (0.2) 6.7 (0.6) 7.0 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Late Quaternary	1.0	0.01 (0.3) 0.04 (0.4) 0.2 (0.3)	Although Everitt (1995) included scarps on alluvium south of the Bear River, Black *et al.* (2003) included these with the Saleratus Creek fault and we follow that depiction here. However, further study is needed to resolve the relation between the Crawford Mountains (west side) and Saleratus Creek faults. Due to a lack of data, we assumed a slip rate distribution similar to the Morgan fault.

Table 1. Source Parameters For Working Group on Utah Earthquake Probabilities "Other" Faults (continued)

FAULT NO.[1]	FAULT NAME	RUPTURE MODEL	MAXIMUM RUPTURE LENGTH[2] (km)	MAXIMUM MAGNITUDE[3] (M)	DIP[4] (degrees)	APPROXIMATE AGE OF YOUNGEST OFFSET	PROBABILITY OF ACTIVITY[5]	RATE OF ACTIVITY[6] (mm/yr)	COMMENTS
3504	Curlew Valley faults	Independent single plane (1.0)	20	6.3 (0.2) 6.6 (0.6) 6.9 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Latest Quaternary	1.0	0.1 (0.4) 0.4 (0.4) 1.0 (0.2)	These post-Bonneville northeast-trending *en echelon* faults mapped along the eastern margin of Curlew Valley by Allmendinger (1983) are the southern portion of the much longer East side of Arbon Valley fault of Witkind (1975), which included faults with pre-Quaternary movement to the north. Cress (1983) observed fault scarps as high as 24 m on undifferentiated Lake Bonneville sediments that could be associated with the Little Valley cycle (> 130 ka) or the Bonneville cycle (12 to 30 ka). Our maximum slip rate assumes 24 m of offset occurred since 30 ka, whereas other rates assume 20 m occurred since 60 and 150 ka (20 m accounts for some antithetic faulting and backtilting that is likely).
2352a, 2352b, 2352c, 2378, 2377	*East Cache fault zone* (includes the James Peak and Broadmouth Canyon faults)	Unsegmented (0.3) Segmented (0.7)	84 Northern Segment - 37 Central Segment - 18 Southern Segment - 29	7.0 (0.2) 7.3 (0.6) 7.6 (0.2) 6.6 (0.2) 6.9 (0.6) 7.2 (0.2) 6.5 (0.2) 6.8 (0.6)[8] 7.1 (0.2) 6.6 (0.2) 6.9 (0.6)[9] 7.2 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Holocene Mid Pleistocene Holocene Late Pleistocene	1.0 (same for all segments)	0.05 (0.2) 0.2 (0.6) 1.0 (0.2) 0.05 (0.3) 0.12 (0.4) 0.6 (0.3) Slip Rate: (0.8): 0.05 (0.2) 0.24 (0.6) 1.0 (0.2) Recurrence Interval (0.2): 4000 (0.3) 10,000 (0.4) 15,000 (0.3) 0.04 (0.3) 0.08 (0.4) 0.6 (0.3)	We modeled the northern end extending into Idaho, as mapped by Westaway and Smith (1989). We included the James Peak and Broadmouth Canyon faults at the southern end as mapped by Nelson and Sullivan (1992). The segmentation model is after McCalpin and Forman (1991). Slip rate distributions used by Wong *et al.* (2002) were slightly modified here based on consensus rates determined by the UQFPWG (Lund, 2005). Slip rate estimates based on: (1) 4.2 m of vertical offset of 15.5 ka deposits along the central segment; (2) 1.65 m of vertical offset during the penultimate earthquake cycle (10.3 ky long) on the central segment (McCalpin, 1994); (3) 400 to 500 m of vertical offset of 1 to 2 Ma deposits, and 20 m of vertical offset of 200 to 400 ka deposits along the northern segment (McCalpin, 1994); (4) 10 m of vertical offset of 150 to 1000 ka deposits on the southern segment (McCalpin and Forman, 1991); and, (5) 4.2 m of vertical offset of ~140 ka deposits on the James Peak fault (Nelson and Sullivan, 1992). The maximum slip rate (1mm/yr) assumes activity on the East Cache fault zone increases to approach slip rates of nearby faults to alleviate a possible late Pleistocene slip deficit on the East Cache fault zone (McCalpin and Forman, 1991).
2354a, 2354b	East Canyon fault (includes northern [12-16] and southern [12-17] sections)	Linked (1.0)	26	6.4 (0.2) 6.7 (0.6) 7.0 (0.2)	30 E (0.2) 55 E (0.6) 70 E (0.2)	Late Quaternary	0.3	0.005 (0.5) 0.05 (0.5)	The east-dipping East Canyon fault and the west-dipping Main Canyon fault bound the asymmetric Neogene basin that forms East Canyon Valley (Bryant, 1990). The structural relationship between these faults is poorly understood, but their close spatial proximity to each other suggests that they likely intersect or merge at depth. As the East Canyon fault is marked by a prominent topographic escarpment and has a thicker section of Neogene sedimentary and volcanic rock associated with the hanging wall block, it has typically been considered the primary fault or seismic source in previous studies (e.g., Sullivan *et al*., 1988; Hecker, 1993; Black *et al*., 2003; Wong *et al*., 2004). However, recent mapping along the East Canyon fault suggests a lack of latest Quaternary activity, whereas a trench across the Main Canyon fault revealed evidence that two latest Quaternary surface-faulting earthquakes occurred since 35 ka (Piety *et al.*, 2010). Our revised characterization here is based on these studies and a simplification of the model of Thomas *et al.* (2010).
3509	East Dayton – Oxford faults	Independent (1.0)	23		30 W (0.2) 55 W (0.6) 70 W (0.2)	Late Quaternary	1.0	0.01 (0.3) 0.04 (0.6) 0.2 (0.1)	This north-trending, high-angle, down-to-east, normal fault bounds the eastern margin of the Bannock Range, and has been considered to be a northward extension of the West Cache Valley fault, which is known to displace Quaternary age Lake Bonneville sediments farther south in Utah. These two faults overlap across an 8- to 10-km-wide step. There is no documented evidence of late Quaternary fault scarps. Recent mapping by Carney and others (2002) shows the trace of the fault as entirely covered, but adjacent to the abrupt termination of various Quaternary deposits, suggesting but not proving Quaternary deformation.

Table 1. Source Parameters For Working Group on Utah Earthquake Probabilities "Other" Faults (continued)

FAULT NO.[1]	FAULT NAME	RUPTURE MODEL	MAXIMUM RUPTURE LENGTH[2] (km)	MAXIMUM MAGNITUDE[3] (M)	DIP[4] (degrees)	APPROXIMATE AGE OF YOUNGEST OFFSET	PROBABILITY OF ACTIVITY[5]	RATE OF ACTIVITY[6] (mm/yr)	COMMENTS
2364c-Southern Segment, 2364b-Central Segment, 2364a-Northern Segment	*Eastern Bear Lake fault*	Segmented (0.7)	Southern section – 32	6.8 (0.2) 7.1 (0.6)[10] 7.4 (0.2)	30 W (0.4) 50 W (0.4) 60 W (0.2)	Late Holocene	1.0	0.4 (0.2) 1.0 (0.6) 2.0 (0.2)	Segmentation model and lengths from McCalpin (1993). Dips based on cross-sections of Evans (1991). Slip rate distribution based on data from McCalpin (1993). Due to the scarcity of data for the central and northern segments, the same slip rates were assumed for all segments and the unsegmented model.
			Central section - 26	6.8 (0.2) 7.1 (0.6)[11] 7.4 (0.2)	(same for all segments)	Holocene (?)	1.0		
			Northern section – 57? (19)	6.9 (0.2) 7.2 (0.6)[11] 7.5 (0.2)		Late Quaternary (?) Middle and late Quaternary (<750 ka)?	1.0	(Same for all segments)?	
		Unsegmented (0.3)	58 (1.5 times average segment length)	6.9 (0.2) 7.2 (0.6) 7.5 (0.2)		Holocene	1.0		
2471, 2443, 2442, 2441, 2440	Faults along the western margin of Scipio Valley (from south to north includes: Red Canyon fault scarps, Maple Grove faults, Pavant Range fault, Scipio fault zone, and Scipio Valley faults) Add Little Valley faults?	Linked (1.0)	45 (0.3) (total length) 30 (0.3) (partial floating rupture) 20 (0.4) (partial floating rupture)	6.7 (0.2) 7.0 (0.6) 7.3 (0.2) 6.5 (0.2) 6.8 (0.6) 7.1 (0.2) 6.3 (0.2) 6.6 (0.6) 6.9 (0.2)	30 E (0.2) 55 E (0.6) 70 E (0.2)	Latest Quaternary (≤ 15 ka)	1.0	0.02 (0.2) 0.1 (0.6) 0.4 (0.2)	These north-striking, down-to-the-east normal faults are all individually short, lie along the boundary between the Pavant Range to the west and Scipio Valley to the east and all show evidence for scarps on latest Quaternary deposits (Bucknam and Anderson, 1979; Anderson and Bucknam, 1979). Therefore, we linked these faults together, but also allowed for shorter partial ruptures. Scarps vary from 2 to 11 m on unconsolidated deposits, but ages generally are not well constrained. Our preferred slip rate assumes 3 to 4 m of slip occurred since 30 ka whereas our minimum assumes 2 m of slip occurred since 130 ka and our maximum rate assumes 11 m of slip occurred since 30 ka.
2445	*Gunnison fault*	Independent (1.0)	42	6.7 (0.2) 7.0 (0.6) 7.3 (0.2)	30 E (0.2) 55 E (0.6) 70 E (0.2)	Holocene (?)	0.8	0.05 (0.3) 0.1 (0.4) 0.3 (0.3)	This north-striking normal fault separates the San Pitch Mountains to the west from Sanpete Valley to the east. This fault likely initially formed during Neogene extension along a zone of weakness in imbricate reverse faults (Weiss and Sprinkel, 2002). Alternatively, it may be a subsidence feature related to salt dissolution (Witkind, 1981). Based on this, and that the fault may possibly sole into a detachment in the upper 5 km (Strandlee, 1982), we assigned a slightly lower probability of activity. Little is known about rates of activity, but scarps in unconsolidated alluvium are somewhat similar to the East Tintic and Long Ridge faults, except for the anomalous deformation at Birch Canyon (Hecker, 1989). Therefore, we assumed a similar slip rate distribution to the East Tintic fault for the Gunnison fault.
2358, 2359	Hansel Valley fault (includes the east Hansel Mountains fault – Hansel Valley [valley bottom] faults?)	Linked (1.0)	27	6.6 (0.2)[12] 6.8 (0.6)[13] 7.1 (0.2)	30 E (0.2) 55 E (0.6) - ? 70 E (0.2)	Historic (1934) Middle and late Quaternary (<750 ka)	1.0	0.07 (0.2) 0.18 (0.7) 0.7 (0.1) – high?	Although the M 6.6 1934 event was roughly only 10 km long and did not rupture the east Hansel Mountains fault, large (2.6 m) displacements per event for prehistoric ruptures of the Hansel Valley fault (McCalpin *et al*., 1992) imply longer maximum rupture lengths than 10 km. Based on this, their along-strike association, and similar dip direction, we linked these faults. Slip rate distribution based on data from McCalpin *et al*. (1992).
2439	Little Valley faults (link with Scipio faults, etc.?)	Independent (1.0)	20	6.3 (0.2) 6.6 (0.6) 6.9 (0.2)	70 W (0.3) 90 (0.4) 70 E (0.3)	Latest Pleistocene (≤ 30 ka)	1.0	0.06 (0.5) 0.3 (0.5)	This wide zone of north-striking faults in Little Valley bounds both the east and west sides of the valley (Oviatt, 1992). Although scarp morphology suggests an age < 15 ka, scarps are truncated by the Lake Bonneville high stand indicating an older age (Bucknam and Anderson, 1979). Scarps as high as 8 m on Pleistocene sediments (Bucknam and Anderson, 1979), suggesting slip rates between 0.06 (8 m/130 ky) and 0.3 (8 m/30 ky) mm/yr. The event forming the Little Valley fault scarps may be similar in age to the pre-Holocene event on the Scipio Valley [2440] faults to the south, but the scarps show no evidence of the younger (late Holocene) earthquake evident on the latter faults.

Table 1. Source Parameters For Working Group on Utah Earthquake Probabilities "Other" Faults (continued)

FAULT NO.[1]	FAULT NAME	RUPTURE MODEL	MAXIMUM RUPTURE LENGTH[2] (km)	MAXIMUM MAGNITUDE[3] (M)	DIP[4] (degrees)	APPROXIMATE AGE OF YOUNGEST OFFSET	PROBABILITY OF ACTIVITY[5]	RATE OF ACTIVITY[6] (mm/yr)	COMMENTS
2350	Main Canyon fault (formerly referred to as "fault east of East Canyon," or East Canyon [east side] fault" in USGS database)	Independent (1.0)	26	6.4 (0.2) 6.7 (0.6) 7.0 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Holocene	0.9	Recurrence Intervals (0.7): 12,000 (0.2) 24,000 (0.3) 30,000 (0.3) 60,000 (0.2) Slip Rate (0.3): 0.01 (0.3) 0.04 (0.4) 0.1 (0.3)	Although identified and mapped by Bryant (1990) and Coogan and King (1999), this fault is not included in Black *et al.* (2003) and was only recently included in the USGS Quaternary Fault and Fold Database. The Main Canyon fault bounds the east side of East Canyon Valley and the East Canyon fault bounds the west side. Previous studies had considered the nearby East Canyon fault to be the more active and dominant fault primarily based on thicker late Cenozoic deposits along the west side of the basin, and the geomorphic expression of bedrock scarps (Sullivan *et al.*, 1988). However, in a recent paleoseismic study by Piety *et al.* (2008), they found evidence for three (or more?) late Quaternary faulting events occurring on the Main Canyon fault at 5-6 ka, 30-35 ka, and >40-50 ka. In contrast, Piety *et al.* (2008) found no evidence for late Quaternary faulting on the East Canyon fault, although the age of youngest activity remains unconstrained, and the relation of the two faults remains ambiguous. Our characterization here is simplified after Anderson (2009) and considers the Main Canyon fault likely to be the dominant fault, but our slightly lower probability of activity acknowledges the small possibility the East Canyon may be dominant.
2353a, 2353b, 2353c	Morgan fault (includes northern, central, and southern sections)	Linked (1.0)	17	6.4 (0.2) 6.7 (0.6)[14] 7.0 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Holocene	1.0	0.01 (0.3) 0.04 (0.4) 0.2 (0.3)	We grouped the northern, central, and southern sections defined by Sullivan and Nelson (1992) based on: (1) short section lengths; (2) along-strike patterns of topographic profiles; and (3) similar geomorphic expression (Sullivan *et al.*, 1988). Slip rates based on data of Sullivan and Nelson (1992) and Sullivan *et al.* (1988).
2361	North Promontory fault	Independent (1.0)	26	6.5 (0.2) 6.8 (0.6)[15] 7.1 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Latest Quaternary	1.0	0.02 (0.2) 0.25 (0.6) 1.0 (0.2)	Range-front fault bounding eastern Hansel Valley showing evidence for Holocene movement and multiple late Pleistocene events. Slip rate distribution based on data in McCalpin *et al.* (1992)
2369, 2398, 2399, 2407, 2420	Oquirrh-Great Salt Lake fault zone (modified from Wong *et al*., 2002; includes the East Great Salt Lake, Oquirrh, South Oquirrh Mountains, Topliff Hills, and East Tintic faults)	Unsegmented (0.2) Segmented (0.8)	50 (1.5 times weighted-mean average segment length) Segmentation Model A (0.65): Rozelle Segment-25 Promontory Segment-25 Fremont Island Segment-25 (20) *Antelope Island Segment*-35	6.8 (0.2) 7.1 (0.6) 7.4 (0.2) 6.4 (0.2) 6.7 (0.6) 7.0 (0.2) 6.4 (0.2) 6.7 (0.6) 7.0 (0.2) 6.7 (0.2) 7.0 (0.6)[16] 7.3 (0.2) 6.8 (0.2) 7.1 (0.6)[17] 7.4 (0.2)	30 W (0.2) 45 W (0.6) 70 W (0.2) 30 W (0.2) 45 W (0.6) 70 W (0.2) 30 W (0.3) 40 W (0.4) 50 W (0.3) 30 W (0.3) 40 W (0.4) 50 W (0.3) 30 W (0.2) 40 W (0.6) 50 W (0.2)	Holocene Holocene Latest Quaternary Holocene Holocene	1.0 1.0 1.0 1.0 1.0	0.05, *0.5* (0.2) 0.2, *0.9* (0.6) 1.0, *2.5* (0.2) 1,800 (0.2) 4,200 (0.6) 6,600 (0.2) 1,800 (0.2) 4,200 (0.6) – broad 6,600 (0.2) 1,800 (0.2) 4,200 (0.6) 6,600 (0.2) 1,800 (0.2) 4,200 (0.6) 6,600 (0.2)	Rupture lengths and segmentation models A and B revised from Wong *et al.* (2002) based on new data from Dinter and Pechmann (2005) and Olig *et al.* (2001). Note that the South Oquirrh Mountains fault includes the Mercur fault (No. 7-14 of Hecker, 1993) as well as other associated Quaternary faults as mapped by Olig *et al.* (1999a). Note also that Dinter and Pechmann (2005) and Lund (2005) refer to the former East Great Salt Lake fault zone (#2369) as just the Great Salt Lake fault zone, and we use that nomenclature here. Recent revised mapping of the Great Salt Lake fault based on additional seismic reflection profiles in the northern arm of the lake indicate a newly identified segment boundary near the north end of Indian Cove that defines the Rozelle segment to the north (D. Dinter, University of Utah, written and digital communication, 2010). Shallower dips considered for the Great Salt Lake fault (i.e., the Rozelle Promontory, Antelope Island, and Fremont Island segments) based on seismic reflection and drill-hole data (Pechmann *et al.*, 1987; Vivieros, 1986; Smith and Bruhn, 1984; Mohapatra and Johnson, 1998). Slip rate distributions are after consensus values of the UQFPWG (Lund, 2005) wherever available. Slip rates are based on data in Pechmann *et al.* (1987), Olig *et al.* (1994), Barnhard and Dodge (1988), Everitt and Kaliser (1980), Olig *et al.* (1999a and 1999b), and Dinter and Pechmann (1999; 2004). We used two slip rate distributions for the unsegmented model, with the higher rates (shown in italics) applying to the more active portion along the Great Salt Lake fault. Recurrence intervals (in years, and shown in bold) are after consensus values of the UQFPWG (Lund, 2005) and are based on seismic and drill hole data along the Great Salt Lake fault that indicates at least 3 events occurred since about 10 ka and 12 ka along both the Antelope and Fremont Island segments, respectively (Dinter and Pechmann, 2004), and that the Promontory and Rozelle segments likely have a similar rate of activity (D. Dinter, University of Utah, verbal communication, 2010).

Table 1. Source Parameters For Working Group on Utah Earthquake Probabilities "Other" Faults (continued)

FAULT NO.[1]	FAULT NAME	RUPTURE MODEL	MAXIMUM RUPTURE LENGTH[2] (km)	MAXIMUM MAGNITUDE[3] (M)	DIP[4] (degrees)	APPROXIMATE AGE OF YOUNGEST OFFSET	PROBABILITY OF ACTIVITY[5]	RATE OF ACTIVITY[6] (mm/yr)	COMMENTS
			Northern Oquirrh - South Oquirrh Segment-61	6.9 (0.2) 7.2 (0.6)[18] 7.5 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Holocene	1.0	0.05 (0.3) 0.2 (0.4) 0.4 (0.3)	
			Topliff Hills Segment-26	6.4 (0.2) 6.7 (0.6) 7.0 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Holocene - ?	1.0	0.05 (0.3) 0.1 (0.4) 0.3 (0.3)	
			East Tintic Segment-35	6.6 (0.2) 6.9 (0.6) 7.2 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Mid to late Pleistocene	1.0	0.05 (0.3) 0.1 (0.4) – high? 0.3 (0.3)	
			Segmentation Model B (0.35):						
			Rozelle Segment-25	6.4 (0.2) 6.7 (0.6) 7.0 (0.2)	30 W (0.2) 45 W (0.6) 70 W (0.2)	Holocene	1.0	1,800 (0.2) 4,200 (0.6) 6,600 (0.2)	
			Promontory Segment-25	6.4 (0.2) 6.7 (0.6) 7.0 (0.2)	30 W (0.3) 40 W (0.4) 50 W (0.3)	Holocene	1.0	1,800 (0.2) 4,200 (0.6) 6,600 (0.2)	
			Fremont Island Segment-25	6.7 (0.2) 7.0 (0.6)[16] 7.3 (0.2)	30 W (0.3) 40 W (0.4) 50 W (0.3)	Holocene	1.0	1,800 (0.2) 4,200 (0.6) 6,600 (0.2)	
			Antelope Island Segment-35	6.8 (0.2) 7.1 (0.6)[17] 7.4 (0.2)	30 W (0.3) 40 W (0.4) 50 W (0.3)	Holocene	1.0	1,800 (0.2) 4,200 (0.6) 6,600 (0.2)	
			Northern Oquirrh Segment-30	6.7 (0.2) 7.0 (0.6)[19] 7.3 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Holocene	1.0	0.05 (0.3) 0.2 (0.4) 0.4 (0.3)	
			South Oquirrh Mountains Segment-31	6.7 (0.2) 7.0 (0.6)[20] 7.3 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Holocene	1.0	0.05 (0.3) 0.2 (0.4) 0.4 (0.3)	
			Topliff Hills Segment-26	6.4 (0.2) 6.7 (0.6) 7.0 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Late Pleistocene	1.0	0.05 (0.3) 0.1 (0.4) 0.3 (0.3)	
			East Tintic Segment-25	6.6 (0.2) 6.9 (0.6) 7.2 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Mid to late Pleistocene	1.0	0.05 (0.3) 0.1 (0.4) – high? 0.3 (0.3)	
2380	Porcupine Mountain faults	Independent (1.0)	36	6.6 (0.2) 6.9 (0.6) 7.2 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Late Quaternary	1.0	0.01 (0.3) 0.04 (0.4) 0.2 (0.3)	Fault geometry and length from Coogan and King (1999) and Bryant (1990). Note that even though Machette *et al.* (2001) measure an end to end length of 34.6 km from the same sources as used here, this shorter length would still result in the same preferred maximum magnitude of M 6.9. This fault offsets apparently young (Holocene-latest Pleistocene?) alluvial fans (J. King, UGS, personal communication, 4-3-00). Due to a lack of slip rate data, we assumed a distribution similar to the Morgan fault.

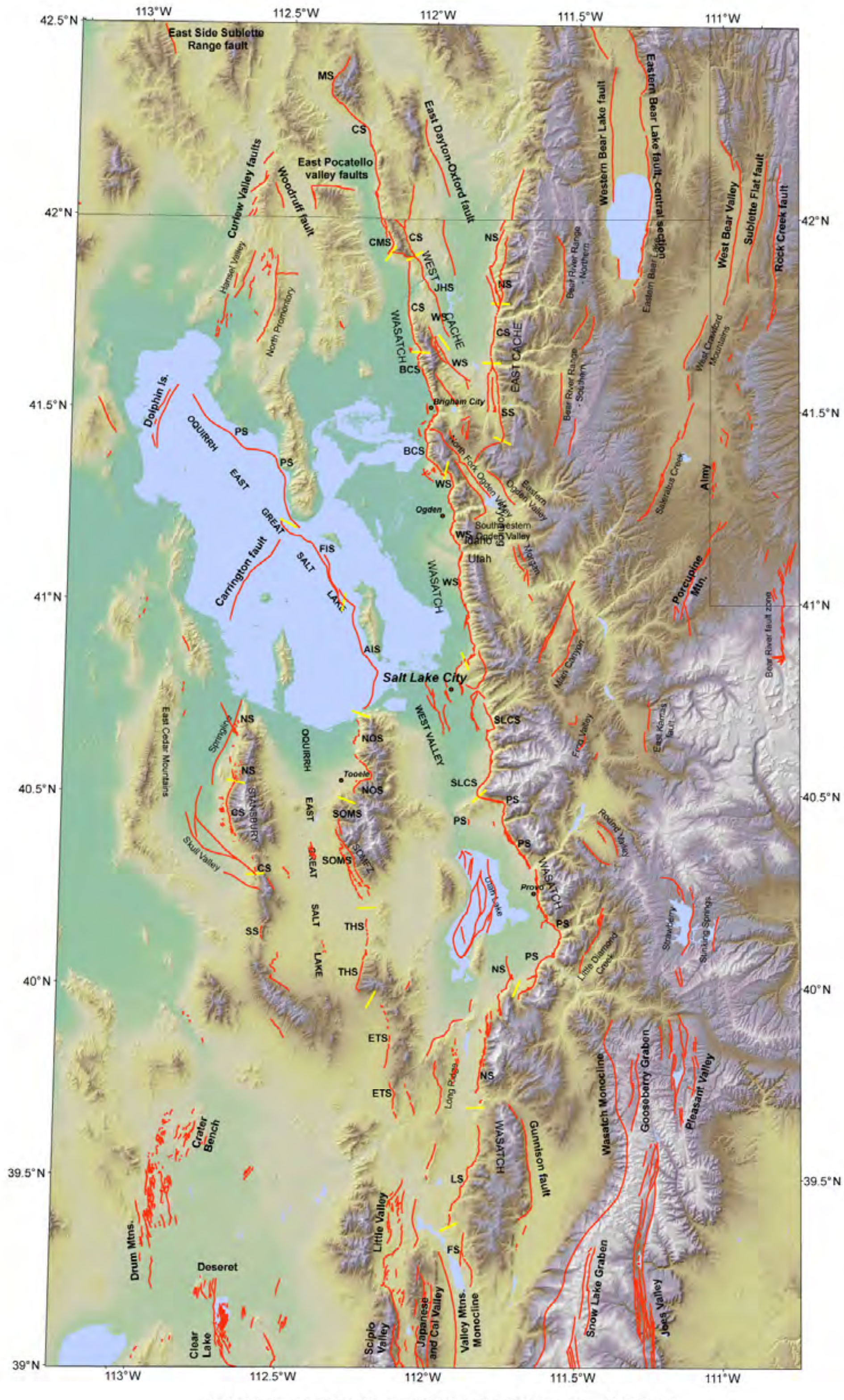
FAULT NO.[1]	FAULT NAME	RUPTURE MODEL	MAXIMUM RUPTURE LENGTH[2] (km)	MAXIMUM MAGNITUDE[3] (M)	DIP[4] (degrees)	APPROXIMATE AGE OF YOUNGEST OFFSET	PROBABILITY OF ACTIVITY[5]	RATE OF ACTIVITY[6] (mm/yr)	COMMENTS
731	Reactivated Section of the Absaroka Thrust fault	Independent (1.0)	15	6.1 (0.2) 6.4 (0.6) 6.7 (0.2)	30 W (0.3) 55 W (0.6) 70 W (0.1)	Holocene	0.7	0.4 (0.3) 0.7 (0.6) - ? 1.5 (0.1)	Length and location based on mapping of West (1994), which includes the Martin Ranch scarp. We assigned a slightly lower p (a) to account for the possibility that this structure may not be seismogenic and capable of independent rupture from the Bear River fault zone, as suggested by West (1994). Preferred slip rate based on West's (1994) 0.5 to 0.7 mm/yr vertical estimate, even though this is not for a complete seismic cycle.
729	*Rock Creek fault*	Independent (1.0) Shorter length floating earthquake?	41		Listric?	Holocene	1.0	0.2 (0.1) 0.7 (0.6) 1.0 (0.3) 0.6-1.5 ky?	The Rock Creek fault is a high-angle, down-to-west normal fault within the Tunp Range; it may sole into the Laramide-age Tunp thrust fault. Most of fault length is characterized by scarps on steep colluvial slopes. McCalpin (1993) stated that some scarps are as much as 25 m high. He excavated one trench across the fault. The most recent event is bracketed by radiocarbon ages of 3,280±70 and 3,880±60 14C yr BP (McCalpin and Warren, 1992), or roughly 3.6±0.3 ka, whereas the penultimate (older) event is about 4.6±0.2 ka. McCalpin (1993) provided these minimum and maximum recurrence intervals based on the occurrence of the two most recent paleoearthquakes. This equates to a permissible recurrence interval of about 0.6-1.5 ky. However, the late Quaternary recurrence interval must be quite variable: it has been about 3.6±0.3 ky since the last event and it was at least 10 ky before the penultimate event (15 ka is the inferred time of deposition of older faulted deposit at trench site).
2405	Sheeprock fault zone	Independent (1.0)	12		30 W (0.2) 55 W (0.6) 70 W (0.2)	Latest Quaternary – Holocene?	1.0	0.05 (0.3) 0.1 (0.4) 0.3 (0.3)	Range-front scarps along the eastern side of the Sheeprock Mountains and Red Pine Mountain. The southern half of the fault zone is a single, continuous, northwest-trending fault trace paralleling the range front. At East Government Creek, the fault zone and range front change trend to the north-northeast, and the fault zone changes from a single trace without antithetic faulting to an en-echelon fault zone accompanied by antithetic faulting. Diffusion-equation modeling of the scarps, which probably represent multiple earthquakes (cumulative displacement <11.5 m), yielded an age of about 53 ka (Hanks and others, 1984). In contrast, Everitt and Kaliser (1980) concluded that scarp morphology suggests a possible Holocene age for the latest faulting event. The embayed character of the range front suggests a long period of inactivity preceding the recent episode of faulting (Everitt and Kaliser, 1980). The relatively low scarp height in deposits probably much older than the scarp age, as determined by diffusion modeling, indicate a slip rate much less than 0.2 mm/yr. Due to a lack of data, we assumed a slip rate distribution similar to the Topliff and East Tintic faults.
2387	Skull Valley (mid valley) faults	Linked (1.0)	32	6.5 (0.2) 6.8 (0.6) 7.1 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Latest Quaternary	0.9	0.06 (0.2) 0.3 (0.6) 0.5 (0.2)	For simplicity these faults were modeled as a single, linked plane. Similar to the Springline fault, these faults may be dependent on the Stansbury fault. Therefore, a slightly lower p(a) was assigned although Geomatrix Consultants (1999) found definite evidence for repeated late Pleistocene offsets. Lower bound slip rate is based on analogy with the Stansbury fault. Other rates are based on late Pleistocene vertical slip rates of 0.2 (±0.1) and 0.06 (±0.01) mm/yr for the East and West faults, respectively (Geomatrix Consultants, 1999).
Not Applicable	Springline fault (of Helm, 1995). Now incorporated into the Skull Valley (mid valley) faults on the USGS database.	Independent (1.0) Or combine with Skull Valley faults above?	18	6.2 (0.2) 6.5 (0.6) 6.8 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Quaternary (?)	0.7	0.06 (0.2) 0.2 (0.6) – High? 0.5 (0.2)	Although this postulated fault may actually be dependent on the Skull Valley faults (East and West faults of Geomatrix Consultants, 1999), and/or the Stansbury fault, for simplicity and because of its distance, we considered it only as an independent source and assigned a relatively lower p(a). Geometry, location, and slip rates based on data and estimates of Geomatrix Consultants (1999).

FAULT NO.[1]	FAULT NAME	RUPTURE MODEL	MAXIMUM RUPTURE LENGTH[2] (km)	MAXIMUM MAGNITUDE[3] (M)	DIP[4] (degrees)	APPROXIMATE AGE OF YOUNGEST OFFSET	PROBABILITY OF ACTIVITY[5]	RATE OF ACTIVITY[6] (mm/yr)	COMMENTS
2395	Stansbury fault	Unsegmented (0.3)	69	6.9 (0.2) 7.2 (0.6)[21] 7.5 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Holocene (?)	1.0	0.06 (0.2) 0.5 (0.6) 1.0 (0.2)	Segmentation model modified after Helm (1995) and Geomatrix Consultants (1999). Maximum rupture lengths measured on Plate 6 of Geomatrix Consultants (1999). Slip rate distribution based on long-term (Miocene) vertical slip rates of 0.07 (± 0.02) mm/yr (Helm, 1995), late-Pleistocene vertical slip rates of 0.4 (± 0.1) mm/yr (Geomatrix Consultants, 1999) and comparison with the Oquirrh-East Great Salt Lake fault for the maximum.
		Segmented (0.7)	Northern Segment (Section A of Geomatrix Consultants, 1999) – 24	6.4 (0.2) 6.7 (0.6) 7.0 (0.2)	(same for all segments)	Late Pleistocene (?)	(same for all segments)	0.06 (0.2) 0.5 (0.6) 1.0 (0.2)	The surface trace of the Stansbury fault is simple in the southern half of the fault (south of Pass Canyon) but complex to the north, suggesting the fault may consist of two independent sections. A down-to-the-south cross-fault at Pass Canyon forms the boundary between the sections (Helm, 1994 #4517). In the south, a single fault strand consisting of a main fault and a subsidiary antithetic fault cuts Quaternary alluvial fans and forms a narrow (about 20-m-wide) graben along most of the fault trace (Helm, 1994 #4517). North of Pass Canyon, the trace is a complex fault zone consisting of multiple synthetic and antithetic fault traces showing evidence of Quaternary movement. Based on scarp morphology and observation of stream knickpoints a short distance from the fault trace, Everitt and Kaliser (1980 #4524) concluded that the most recent movement was during the Holocene. Helm (1994 #4517) reports maximum scarp angle vs. scarp height plots suggest the Stansbury fault is generally older than the highstand of Lake Bonneville. However, Geomatrix Consultants, Inc. (1999 #4513) states that the southern section of the fault is inferred to have moved in a single event during the early to middle Holocene. From scarp-profile data collected by Geomatrix Consultants, Inc. (1999 #4513) the Stansbury scarps of the southern section appear younger than the Sheeprock [2405], Topliff Hill [2407] and Mercur [2399] fault scarps. Measured scarp heights are from 3.9 to 49.5 m.
			Central Segment (Sections B and C of Geomatrix Consultants, 1999) - 29	6.7 (0.2) 7.0 (0.6)[21] 7.3 (0.2)		Holocene (?)		0.06 (0.2) 0.5 (0.6) – high? 1.0 (0.2)	
			Southern Segment (Section D of Geomatrix Consultants, 1999) – 17	6.2 (0.2) 6.5 (0.6) 6.8 (0.2)		Quaternary?		0.06 (0.2) 0.2 (0.6) 1.0 (0.2)	
2413	Stinking Springs fault	Independent (1.0)	11	6.0 (0.2) 6.3 (0.6) 6.6 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Late Quaternary	1.0	0.04 (0.2) 0.2 (0.6) 0.5 (0.2)	Slip rate data are lacking for this poorly understood fault as much of the central portion lies underwater, so we assumed a slip rate distribution similar to the Strawberry fault based on a similar geomorphic expression (Nelson and Martin, 1982).
2412	*Strawberry fault*	Independent (1.0)	32	6.7 (0.2) 7.0 (0.6)[22] 7.3 (0.2)	30 W (0.2) 55 W (0.6) 70 W (0.2)	Holocene	1.0	0.04 (0.2) 0.2 (0.6) 0.5 (0.2)	Maximum rupture length includes the southernmost suspected Quaternary fault trace of Hecker (1993). Trenches across a subsidiary fault exposed evidence for 2 to 3 earthquakes offsetting fan deposits estimated to be 15 to 30 ky based on soil development (Nelson and Martin, 1982; Nelson and Van Arsdale, 1986). Slip rate distribution based on data in Nelson and VanArsdale (1986), with vertical offsets of 1 to 2 m per event and average recurrence of 5,000 to 15,000 years during the latest Quaternary, and longer-term Quaternary (<150 to 300 ka) vertical slip rates of 0.03 to 0.06 mm/yr. Specifically, maximum rate of 0.5 mm/yr assumes 2 m of vertical slip and a recurrence interval of 5,000 years (adjusted to net slip for a 55° dip). Preferred rate of 0.2 mm/yr assumes 1.5 m of vertical slip and a recurrence interval of 10,000 years (also adjusted to net slip for a 55° dip). Minimum rate of 0.04 mm/yr based on longer term rate estimates. In contrast, the UQFPWG (Lund, 2005) assigned 5th, 50th, and 95th percentile slip rate values of 0.03, 0.1, and 0.3 mm/yr, but we consider this distribution to underestimate the large uncertainties of the limited paleoseismic data from a subsidiary fault (i.e., absolute age constraints for events and estimates of total slip are lacking, as well as data are for a subsidiary fault).

FAULT NO.[1]	FAULT NAME	RUPTURE MODEL	MAXIMUM RUPTURE LENGTH[2] (km)	MAXIMUM MAGNITUDE[3] (M)	DIP[4] (degrees)	APPROXIMATE AGE OF YOUNGEST OFFSET	PROBABILITY OF ACTIVITY[5]	RATE OF ACTIVITY[6] (mm/yr)	COMMENTS
2409	Utah Lake faults	Zone (1.0)	31	6.5 (0.2) 6.8 (0.6) 7.1 (0.2)	55 W (0.4) 90 (0.3) 55 W (0.3)	Latest Pleistocene to Holocene (?)	0.7	0.1 (0.3) 0.35 (0.4) 0.5 (0.3)	This complex anastomosing system of east and west dipping faults generally strikes north-south, but individual fault traces are poorly located. Because of this, we modeled the Utah Lake faults as a zone. Although seismic airgun surveys suggest offset of <2 to 5 m of Lake Bonneville deposits (Brimhall and Merritt, 1981), we assigned a slightly lower p(a) to account for the possibility that the Utah Lake faults rupture dependently on the Provo segment of the Wasatch fault zone, given the geometric and possible seismogenic relation of the faults. Slip rates are based on <2 to 5 m of vertical offset of regressive lake Bonneville deposits (Machette, 1992) (assumed to be 12 to 14.5 ka for these elevations).
2521b, 2521a, 2374, 2521c	West Cache fault zone	Unsegmented (0.3) Segmented (0.7)	80 (includes the Hyrum fault) Clarkston fault-37 Junction Hills fault - 24 Wellsville fault - 20	7.0 (0.2) 7.3 (0.6) 7.6 (0.2) 6.7 (0.2) 7.0 (0.6)[23] 7.3 (0.2) 6.7 (0.2) 7.0 (0.6)[24] 7.3 (0.2) 6.6 (0.2) 6.9 (0.6)[25] 7.2 (0.2)	30 E (0.2) 55 E (0.6) 70 E (0.2) (same for all segments)	Holocene Holocene Early Holocene Holocene	1.0 (same for all segments)	0.06 (0.3) 0.3 (0.4) 0.9 (0.3) 0.1 (0.3) 0.5 (0.4) 0.9 (0.3) Slip Rate (0.8): 0.04 (0.3) 0.12 (0.5) 0.9 (0.2) Recurrence Interval (0.2): 10,000 (0.5) 25,000 (0.5) Slip Rate (0.8): 0.06 (0.3) 0.12 (0.5) 0.9 (0.2) Recurrence Interval (0.2): 10,000 (0.5) 25,000 (0.5)	Seismic reflection data indicates that the West Cache fault zone has significantly less cumulative offset than the East Cache fault zone (Evans, 1991; Evans and Oaks, 1996), suggesting that the former is antithetic to the latter (Sullivan *et al.*, 1988). However, subsequent detailed mapping and trenching studies have shown that the latest Quaternary behavior of the two faults is distinctly different, implying generally independent behavior (Black *et al.*, 2000). Therefore, we assigned a p(a) of 1.0. Fault trace geometry and lengths are after Black *et al.* (2003). Segmentation model is after Black *et al.* (2000). We included the Hyrum fault as a southern extension of the Wellsville segment in the unsegmented model (Black *et al*., 2000; Figure 1). Rate distributions used by Wong *et al.* (2002) were slightly modified here based on consensus rates of the UQFPWG (Lund, 2005). Slip rate distributions based on: (1) 9 m of vertical offset since 16.8 ka on the Clarkston segment (Solomon, 1999); (2) 2.9 m of vertical offset since 22.5 ka (Black *et al.*, 2000), and 600 to 1200 m of vertical offset since the Miocene (Evans, 1991) on the Junction Hills segment; (3) 13.2 m of vertical offset of 100 to 200 ka deposits, and 4.4 m of vertical offset since 15.1 to 25 ka on the Wellsville segment (Black *et al*., 2000).
2386b, 2386a	*West Valley fault zone* (includes the Granger and Taylorsville faults)	Independent (0.3) Linked synchronous rupture with Salt Lake City segment of the Wasatch fault zone (0.7)	16 Granger section – 16 Taylorsville section - 15	6.4 (0.2) 6.7 (0.6)[26] 7.1 (0.2)	55 E (0.3) 70 E (0.4) 80 E (0.3)	Holocene	1.0	0.03 (0.2) 0.2 (0.6) – Low? 0.7 (0.2)	Due to their close proximity, similar dip, and for simplicity, we assumed that the Granger and Taylorsville faults of the West Valley fault zone merge at a shallow depth and that the primary moment release occurs on the Granger fault as it appears to have the greatest cumulative offset (Keaton *et al.*, 1993). The West Valley fault zone is antithetic to, and is 3 to 13 km west of, the more-active Salt Lake City segment of the Wasatch fault zone. We allowed for both independent and dependent (linked or coseismic) rupture of the West Valley fault zone with the Salt Lake City segment of the Wasatch fault zone. We favored the latter in light of recent dates from trenches that suggest overlapping ages for: the youngest events on the Granger fault and the Salt Lake City segment, and the youngest event on the Taylorsville fault and the penultimate event on the Salt Lake City segment (Solomon, 1998; B.D. Black, UGS, written communication, 8-9-99). Steeper dips than typical range-bounding faults were assumed for this intrabasin graben-bounding fault zone. Slip rate distribution is based on data in Keaton *et al.* (1993) for a variety of time periods.
622	Western Bear Lake fault	Independent (single plane)	26 (versus total fault length of about 80 km)	6.6 (0.2) 6.9 (0.6)[27] 7.2 (0.2)	40 E (0.4) 50 E (0.4) 60 E (0.2)	Late Holocene	0.6	0.2 (0.9) 1.0 (0.1)	Maximum rupture length based on total extent of scarps on unconsolidated sediments (McCalpin, 1993). Probability of activity considers possibility that the western Bear Lake fault is dependent on the eastern Bear Lake fault and is not an independent seismic source, based on kinematic and geometric relations (Evans, 1991; Skeen, 1975; McCalpin et al., 1990). Dips based on cross-sections of Evans (1991). Slip rates based on data in McCalpin (1993).

1. Fault number and nomenclature after Hecker (1993) with number in parentheses after Black *et al.* (2003) unless noted otherwise.
2. Measured straight-line, end to end on Hecker (1993) unless noted otherwise. Note that the same maximum seismogenic depth distribution of 12 km (0.2), 15 km (0.7), and 18 km (0.1) was assumed for all fault sources.
3. Preferred values estimated using the empirical relation of Wells and Coppersmith (1994) for all fault types. Unless otherwise noted, values are estimated based on maximum surface rupture length.
4. Average crustal dips. Most faults are assumed to be simple planes except those that are italicized, where a curvilinear model was used. Preferred dips are based on available subsurface data for Wasatch Front faults and basin geometries (e.g., Zoback 1983, 1992; Smith and Bruhn, 1984; Bruhn *et al.*, 1992; Mabey, 1992; Mohapatra and Johnson, 1998). Ranges are based on focal mechanisms for large normal faulting earthquakes worldwide (Jackson and White, 1989).
5. Probability of activity, p(a), the likelihood that a fault is an independent seismogenic structure and is still active within the modern stress field.
6. Rates of fault activity are typically average net slip rates (in mm/yr) except values shown in **bold**, which are recurrence intervals (in years). Recurrence models included characteristic, maximum moment, and exponential, with weights depending on the type of seismic source and rupture model (as shown in column 3). For longer, segmented faults the distribution is: characteristic – 0.7, maximum moment – 0.2, and truncated exponential – 0.1. For shorter, single-plane, independent faults the distribution is: characteristic – 0.6, maximum moment – 0.2, truncated exponential – 0.2. For faults modeled as zones, characteristic and truncated exponential models are equally weighted (0.5/0.5).
7. Based on the average of expected magnitudes estimated from: surface rupture length, and 3 m of average displacement per event (West, 1994). Note that although Machette *et al.* (2001) measured an end to end fault length of only 33.2 km based on mapping by West (1989), this would still result in the same average expected magnitude of **M** 7.1 as calculated here.
8. Based on average of expected magnitudes estimated from: rupture length, and average displacements per event of 0.85 and 1.65 m (McCalpin, 1994).
9. Based on average of expected magnitudes estimated from: rupture length, and inferred average displacements per event of 0.5 to 1.5 m (McCalpin and Forman, 1991) for the southern East Cache fault, and an average displacement per event of 1.8 to 2.4 m for the James Peak fault (Nelson and Sullivan, 1992).
10. Based on average of expected magnitudes estimated from: rupture length, and average displacements per event of 2.6 to 5.6 (McCalpin, 1993)
11. Although displacement data are not available for this segment, maximum magnitudes were estimated similar to the southern segment assuming that behavior is analogous to the southern segment and other active faults in the region that show large displacements relative to segment or fault lengths (McCalpin, 1993).
12. Based on the **M** 6.6 1934 earthquake (Smith and Arabasz, 1991).
13. Based on the average of expected magnitudes estimated from: rupture length, and maximum displacements per event of 2.6 m (McCalpin *et al*., 1992)
14. Based on the average of expected magnitudes estimated from: rupture length, and average displacements per event of 0.5 to 1.0 m (Sullivan *et al*., 1988; Sullivan and Nelson, 1992).
15. Based on the average of expected magnitudes estimated from: rupture length, and maximum displacements per event of 2.5 m (McCalpin *et al*., 1992).
16. Based on the average of expected magnitudes estimated from: rupture length, and average displacement per event of ~2 m (Dinter and Pechman, 2005).
17. Based on the average of expected magnitudes estimated from: rupture length, and a maximum displacement per event of 5.5 m per event (Dinter and Pechmann, 2005).
18. Based on the average of expected magnitudes estimated from: rupture length, and a maximum displacement of 2.7 m (Olig *et al*., 1994; 2001) and the empirical displacement relation of Hemphill-Haley and Weldon (1999).
19. Based on the average of expected magnitudes estimated from: rupture length, and average displacements per event of 2.4 m (Olig *et al*., 1994).
20. Based on the average of expected magnitudes estimated from: rupture length, and an average displacement of 1.3 to 2.4 m per event (Olig *et al.*, 2001).
21. Based on the average of expected magnitudes estimated from: rupture length, and an average displacement per event of 2 to 3 m (Geomatrix Consultants, 1999).
22. Based on the average of expected magnitudes estimated from: rupture length, and an average displacement per event of 1 to 2 m (Nelson and Van Arsdale, 1986).
23. Based on the average of expected magnitudes estimated from: rupture length, and a maximum displacement per event of 3.7 m (Black *et al*., 2000).
24. Based on the average of expected magnitudes estimated from: rupture length, and an average displacement per event of 2.9 m (Black *et al*., 2000).
25. Based on the average of expected magnitudes estimated from: rupture length, and an average displacement per event of 2.2 m (Black *et al*., 2000).
26. Based on the average of expected magnitudes estimated from: rupture length, and an average displacement per event of 0.5 to 1.5 m (Solomon, 1998; Keaton *et al*., 1993).
27. Based on the average of expected magnitudes estimated from: rupture length, and average displacements per event of 1.5 to 2.0 m (McCalpin, 1993).

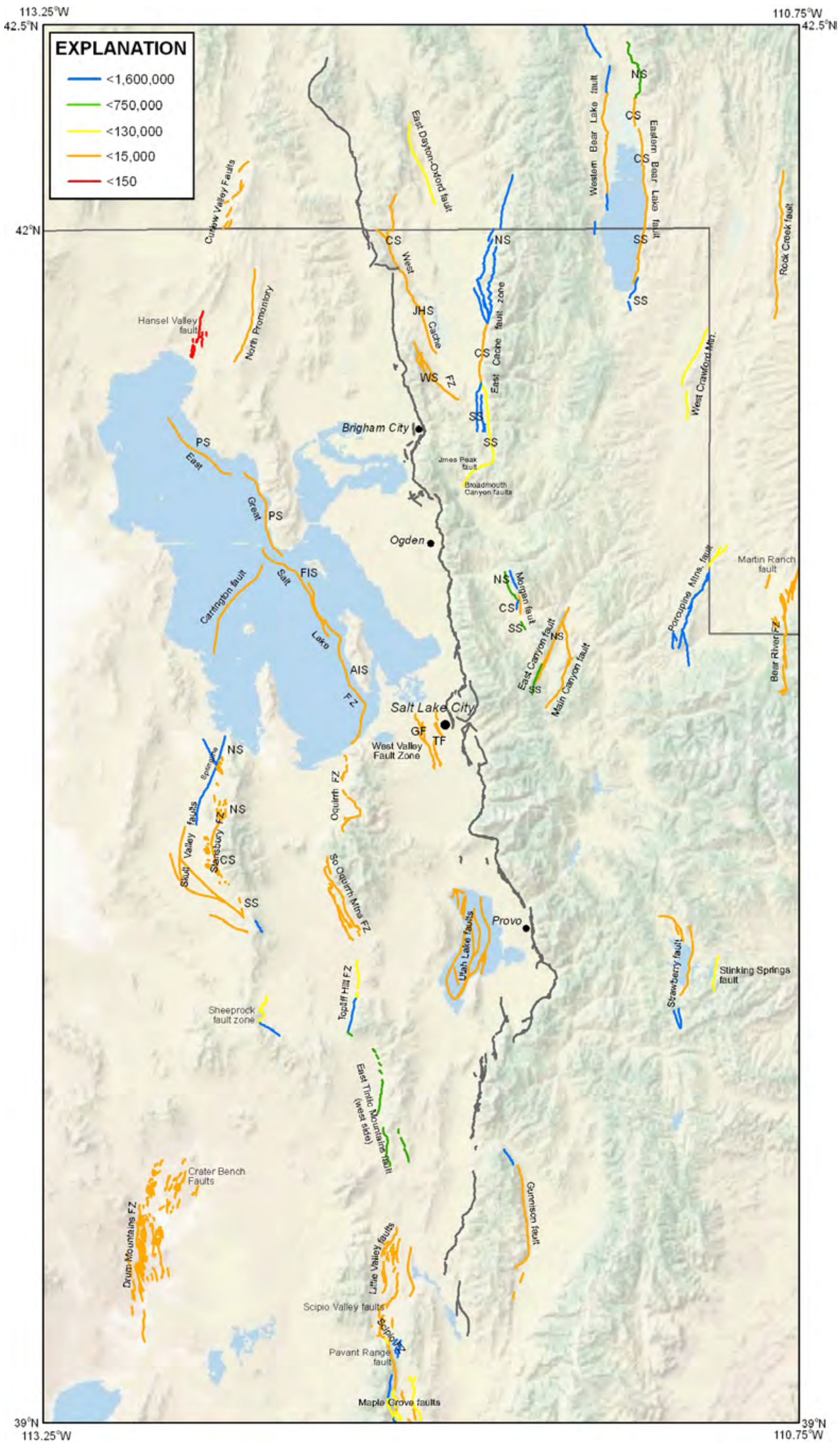
IN THE BEGINNING 122 FAULTS/FAULT SEGMENTS



WGUEP WASATCH FRONT REGION

(latitude 39.00° - 42.50°, longitude 110.75° - 113.25°)

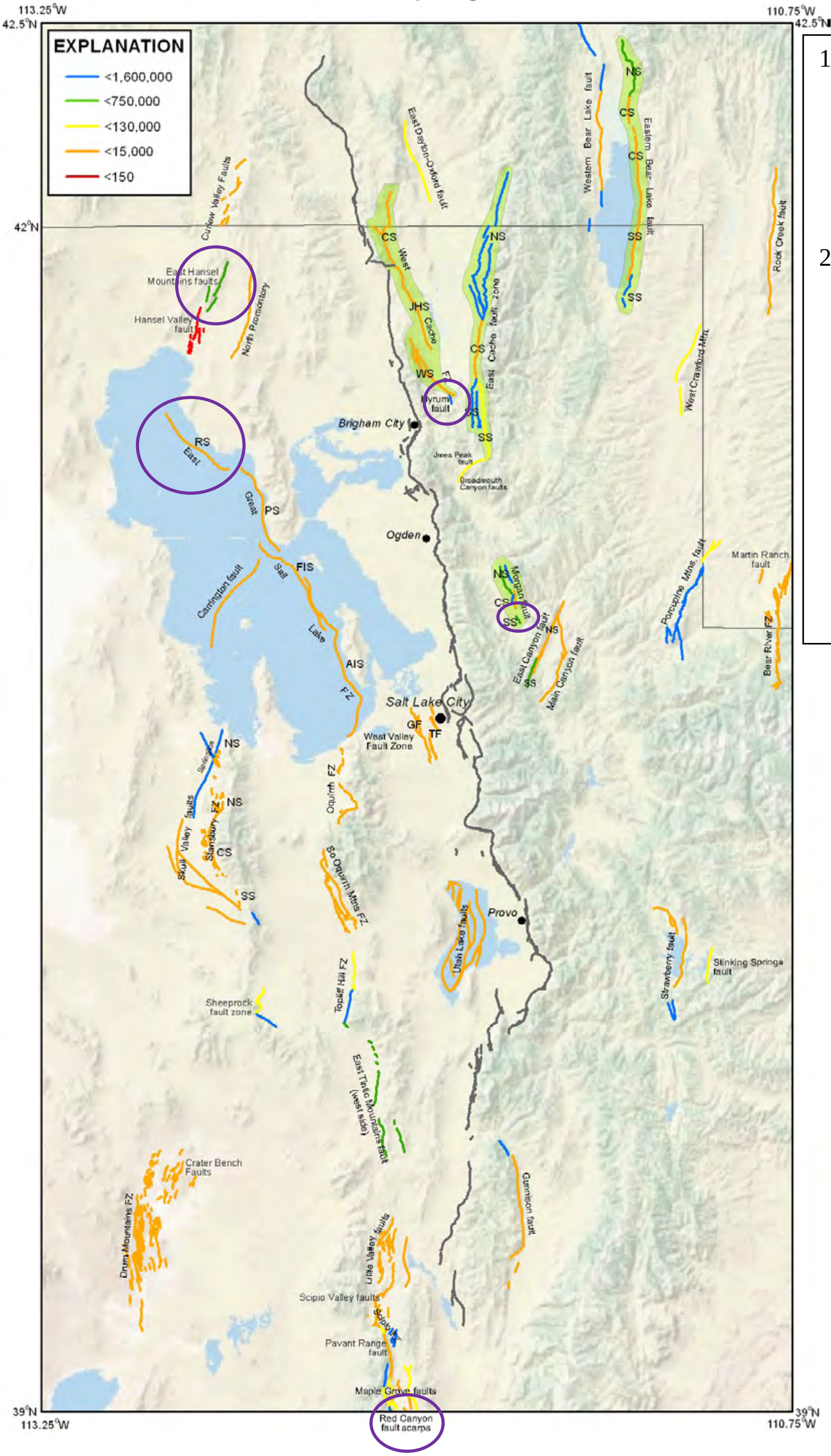
TODAY'S WGUEP WASATCH FRONT REGION "OTHER" FAULTS



1. Total of 49 faults/fault segments
2. Age of most recent deformation color coded.
3. Wasatch fault zone shown in black for reference.

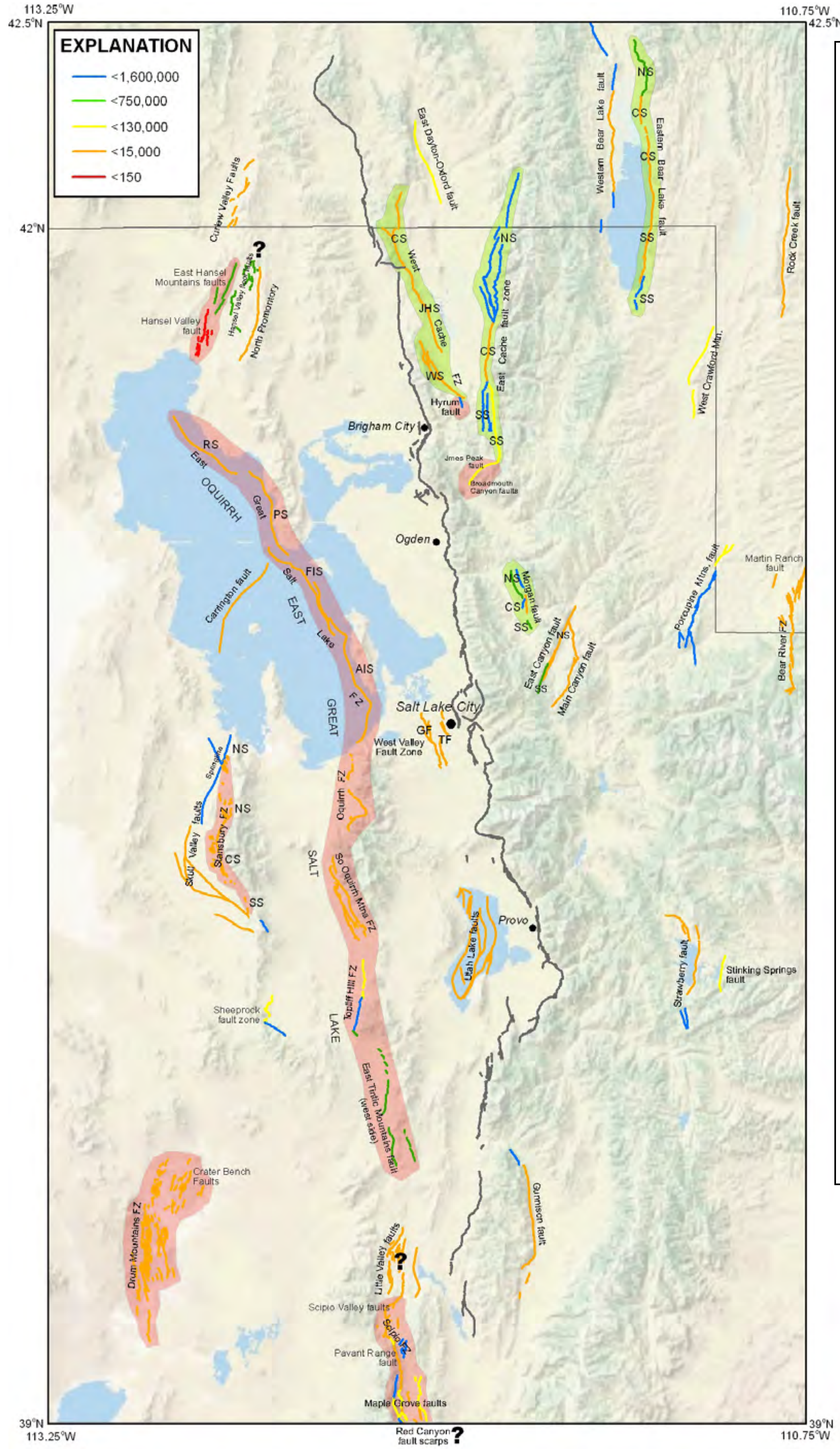
WGUEP "OTHER" FAULTS + URS ADDITIONS

Previously Segment Faults Outlined in Green



1. Four faults previously recognized as segmented:
   a. East Bear Lake
   b. East Cache
   c. West Cache
   d. Morgan
2. URS, Inc. included the following closely related faults in their fault characterization table:
   a. East Hansel Mountains faults
   b. Hyrum fault
   c. EGSLFZ Rozelle segment (new)
   d. Morgan fault southern segment
   e. Red Canyon fault scarps

POSSIBLE ADDITIONAL FAULT GROUPINGS
CHIEFLY AFTER URS



1. Combine East Hansel Mountains faults with the Hansel Valley fault.
2. Add Hyrum fault to the West Cache fault zone.
3. Combine the James Peak and Broadmouth Canyon faults with the East Cache fault zone.
4. Combine the EGSLF, Oquirrh fault zone, Southern Oquirrh fault zone, Topliff fault zone, and East Tintic Mountains fault into a single very long fault zone.
5. Segment the Stansbury fault zone after Geomatrix Inc.
6. Combine the Scipio Valley faults, Scipio fault, Pavant Range fault, Maple Grove fault, and the Red Canyon fault scarps into a single fault zone.
7. Combine the Drum Mountains fault zone with the Crater Bench faults.

QUESTIONS

What about the:

1. Hansel Valley (valley floor) faults?
2. Little Valley faults?
3. Red Canyon fault scarps (just outside Wasatch Front Region boundary)

WGUEP "OTHER" FAULTS LIST

Bear River fault zone
Broadmouth Canyon faults
Carrington fault
Crater Bench faults
Crawford Mountains fault (west side)
Curlew Valley faults
Drum Mountains fault zone
East Dayton – Oxford faults
East Canyon fault
East Tintic Mountains fault (west side)
East Cache fault zone
- Northern section
- Central section
- Southern section

East Great Salt Lake fault zone
- Promontory section
- Fremont section
- Antelope Island section

Eastern Bear Lake Fault
- Northern section
- Central section
- Southern section

Gunnison fault
Hansel Valley fault
James Peak fault
Little Valley faults
Main Canyon fault (East Canyon east side faults)
Maple Grove faults
Martin Ranch fault (Reactivated Section of the Absaroka Thrust fault)
Morgan fault
- Northern section
- Central section

North Promontory fault
Oquirrh fault zone
Pavant Range fault
Porcupine Mountains fault
Rock Creek fault
Scipio fault zone
Scipio Valley faults
Sheeprock fault zone
Skull Valley (mid valley) faults
Southern Oquirrh Mountains fault zone
Stansbury fault zone
Stinking Springs fault
Strawberry fault
Topliff Hill fault zone
Utah Lake faults
West Cache fault zone
- Clarkston fault
- Junction Hills fault
- Wellsville fault

Western Bear Lake fault
West Valley fault zone
- Granger fault
- Taylorsville fault

***Not characterized by URS**

WGUEP EXPANDED "OTHER FAULTS" LIST

Bear River fault zone
Broadmouth Canyon faults
Carrington fault
Crater Bench faults
Crawford Mountains fault (west side)
Curlew Valley faults
Drum Mountains fault zone
East Dayton – Oxford faults
East Canyon fault
East Tintic Mountains fault (west side)
East Cache fault zone
- Northern section
- Central section
- Southern section

East Great Salt Lake fault zone
- **Rozelle segment**
- Promontory segment
- Fremont segment
- Antelope Island segment

Eastern Bear Lake Fault
- Northern section
- Central section
- Southern section

Gunnison fault
Hansel Mountains (east side) fault
Hansel Valley fault
Hyrum fault
James Peak fault
Little Valley faults
Main Canyon fault (East Canyon east side faults)
Maple Grove faults
Martin Ranch fault (Reactivated Section of the Absaroka Thrust fault)
Morgan fault
- Northern section
- Central section
- **Southern section**

North Promontory fault
Oquirrh fault zone
Pavant Range fault
Porcupine Mountains fault
Red Canyon fault scarps
Rock Creek fault
Scipio fault zone
Scipio Valley faults
Sheeprock fault zone
Skull Valley (mid valley) faults
Southern Oquirrh Mountains fault zone
Stansbury fault zone
Stinking Springs fault
Strawberry fault
Topliff Hill fault zone
Utah Lake faults
West Cache fault zone
- Clarkston fault
- Junction Hills fault
- Wellsville fault

Western Bear Lake fault
West Valley fault zone
- Granger fault
- Taylorsville fault

WGUEP GROUPED "OTHER FAULTS" LIST

Bear River fault zone
Carrington fault
Crater Bench faults
Drum Mountains fault zone
Crawford Mountains fault (west side)
Curlew Valley faults
East Dayton – Oxford faults
East Canyon fault
East Cache fault zone
  Northern section
  Central section
  Southern section
James Peak fault
Broadmouth Canyon faults
East Great Salt Lake fault zone
  Rozelle segment
  Promontory segment
  Fremont segment
  Antelope Island segment
Oquirrh fault zone
Southern Oquirrh Mountains fault zone
Topliff Hill fault zone
East Tintic Mountains fault (west side)
Eastern Bear Lake Fault
  Northern section
  Central section
  Southern section
Gunnison fault
Hansel Mountains (east side) fault
Hansel Valley (valley floor) faults?
Hansel Valley fault
Little Valley faults?
Scipio fault zone
Scipio Valley faults
Pavant Range fault
Maple Grove faults
Red Canyon fault scarps?
Main Canyon fault (East Canyon east side faults)
Martin Ranch fault (Reactivated Section of the Absaroka Thrust fault)
Morgan fault
  Northern section
  Central section
  Southern section
North Promontory fault
Porcupine Mountains fault
Rock Creek fault
Sheeprock fault zone
Skull Valley (mid valley) faults
Stansbury fault zone
Stinking Springs fault
Strawberry fault
Utah Lake faults
West Cache fault zone
  Clarkston fault
  Junction Hills fault
  Wellsville fault
  Hyrum fault
Western Bear Lake fault
West Valley fault zone
  Granger fault
  Taylorsville fault

WGUEP STUDY AREA "OTHER" FAULTS

Fault Name	Fault Number	State	Rate of Activity	Recurrence Interval	Approximate Age of Youngest Offset	Rupture Length	Additional Information Link	Fault Maps
Bear River fault zone	730	UT/WY	Between 1.0 and 5.0 mm/yr	y	Latest Quaternary (<15 ka)	35	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=2507&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
Broadmouth Canyon faults	2377	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	3	http://geohazards.cr.usgs.gov/cfusion/qfault/qf_web_disp.cfm?qfault_or=1075&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
Carrington (Dinter, per. comm. to URS Corp)	No data	UT	Similar to EGSLFZ AI section	y	Similar to GSLFZ Antelope Island section	~28		
Crater Bench faults	2433	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	16	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1132&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/del.html
Crawford Mountains (west side) fault	2346	UT	<0.2 mm/yr	y	Late Quaternary (<130 ka)	25	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1030&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
Curlew Valley faults	3504	ID	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	20	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1261&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/id.poc.html
Drum Mountains fault zone	2432	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	52	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1131&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/del.html
East Dayton-Oxford fault	3509	ID	<0.2 mm/yr	y	Late Quaternary (<130 ka)	23	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1266&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/id.poc.html
East Cache fault zone, central section	2352b	UT	Between 0.2 and 1.0 mm/yr	y	Latest Quaternary (<15 ka)	17	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1043&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
East Cache fault zone, northern section	2352a	UT/ID	<0.2 mm/yr		Quaternary (<1.6 Ma)	41	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5000&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
East Cache fault zone, southern section	2352C	UT	<0.2 mm/yr	y	Late Quaternary (<130 ka)	22	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1044&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
East Canyon fault - Southern East Canyon sec.	2354b	UT	<0.2 mm/yr	y	Middle and late Quaternary (<750 ka)	8	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1049&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/slc.html
East Tintic Mountains (west side) faults	2420	UT	<0.2 mm/yr	y	Middle and late Quaternary (<750 ka)	41	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1119&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/del.html
Eastern Bear Lake fault, central section	2364b	UT/ID	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	24	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1060&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/wy/prs.html
Eastern Bear Lake fault, northern section	2364a	ID	<0.2 mm/yr	y	Middle and late Quaternary (<750 ka)	19	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1059&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/wy/prs.html
Eastern Bear Lake fault, southern section	2364C	UT	Between 0.2 and 1.0 mm/yr	y	Latest Quaternary (<15 ka)	35	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5004&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
EGSLF Rozelle section (Dinter, per. comm.)	NA	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	25	NA	NA
EGSLFZ, Antelope Island section	2369c	UT	Between 0.2 and 1.0 mm/yr	y	Latest Quaternary (<15 ka)	35	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5040&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/too.html
EGSLFZ, Fremont Island section	2369b	UT	Between 0.2 and 1.0 mm/yr	y	Latest Quaternary (<15 ka)	30	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5006&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/bri.html
EGSLFZ, Promontory section	2369a	UT	Between 0.2 and 1.0 mm/yr	y	Latest Quaternary (<15 ka)	49	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5005&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/bri.html
Gunnison fault	2445	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	42	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1144&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/prj.html
Hansel Valley fault	2358	UT	<0.2 mm/yr	y	1934 - Hansel Valley earthquake	13	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5002&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/bri.html
Hansell Mountains (east side) faults	2359	UT	<0.2 mm/yr	y	Middle and late Quaternary (<750 ka)	15	http://geohazards.usgs.gov/cfusion/qfault/qf_web_disp.cfm?disp_cd=C&qfault_or=1054&ims_cf_cd=cf	http://earthquake.usgs.gov/hazards/qfaults/ut/bri.html
Hansell Valley (valley floor) faults	2360	UT	<0.02 mm/yr	y	Middle and late Quaternary (<750 ka)	20	http://geohazards.usgs.gov/cfusion/qfault/qf_web_disp.cfm?disp_cd=C&qfault_or=1055&ims_cf_cd=cf	http://earthquake.usgs.gov/hazards/qfaults/ut/bri.html
Hyrum fault	2374	UT	<0.2 mm/yr	y	Quaternary (<1.6 Ma)	3	http://geohazards.usgs.gov/cfusion/qfault/qf_web_disp.cfm?disp_cd=C&qfault_or=1072&ims_cf_cd=cf	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
James Peak fault	2378 ?	UT	<0.2 mm/yr	y	Late Quaternary (<130 ka)	6	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1076&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
Little Valley faults	2439	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	20	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1138&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/del.html
Main Canyon = East Canyon east side faults	2350	UT	None reported	y	Latest Quaternary (<15 ka)	26	Piety, L.A., Anderson, L.W., and Ostenaa, D.A., 2010, Late Quaternary faulting in East Canyon Valley, northeastern Utah:	USBR Seismotectonic Report 2008-1, variously paginated
Maple Grove faults	2443	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	17	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=2543&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/del.html
Martin Ranch fault	731	WY	Between 0.2 and 1.0 mm/yr	y	Latest Quaternary (<15 ka)	15	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1561&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
Morgan fault, central section	2353b	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	5	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5001&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
Morgan fault, northern section	2353a	UT	<0.2 mm/yr	y	Middle and late Quaternary (<750 ka)	8	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1045&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
Morgan fault, southern section	2353c	UT	<0.2 mm/yr	y	Middle and late Quaternary (<750 ka)	2	http://geohazards.usgs.gov/cfusion/qfault/qf_web_disp.cfm?disp_cd=C&qfault_or=1047&ims_cf_cd=cf	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
North Promontory fault	2361	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	26	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5003&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/bri.html
Oquirrh fault zone	2398	UT	Between 0.2 and 1.0 mm/yr	y	Latest Quaternary (<15 ka)	21	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5021&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/too.html
Pavant Range fault	2442	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	14	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=2544&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/del.html
Porcupine Mountain faults	2380	UT/WY	<0.2 mm/yr	y	Late Quaternary (<130 ka)	35	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1078&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
Red Canyon faul scarps	2471	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	9	http://geohazards.usgs.gov/cfusion/qfault/qf_web_disp.cfm?disp_cd=C&qfault_or=1167&ims_cf_cd=cf	http://earthquake.usgs.gov/hazards/qfaults/ut/ric.html
Rock Creek fault	729	WY	Between 0.2 and 1.0 mm/yr	y	Latest Quaternary (<15 ka)	41	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1559&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
Scipio fault zone	2441	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	13	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=2545&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/del.html
Scipio Valley faults	2440	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	7	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=2546&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/del.html
Sheeprock fault zone	2405	UT	<0.2 mm/yr	y	Late Quaternary (<130 ka)	12	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1104&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/too.html
Skull Valley (mid valley) faults	2387	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	55	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1086&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/too.html
Southern Oquirrh Mountains fault zone	2399	UT	Between 0.2 and 1.0 mm/yr	y	Latest Quaternary (<15 ka)	24	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5060&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/too.html
Stansbury fault zone	2395	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	50	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1093&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/too.html
Stinking Springs fault	2413	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	10	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1112&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/slc.html
Strawberry fault	2412	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	32	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1111&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/slc.html
Topliff Hill fault zone	2407	UT	<0.2 mm/yr	y	Late Quaternary (<130 ka)	20	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1106&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/too.html
Utah Lake faults	2409	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	31	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1108&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/slc.html
West Cache fault zone - Clarkston fault	2521a	UT/ID	Between 0.2 and 1.0 mm/yr	y	Latest Quaternary (<15 ka)	21	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=2524&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/bri.html
West Cache fault zone - Junction Hills fault	2521b	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	24	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=2525&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/bri.html
West Cache fault zone - Wellsville fault	2521c	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	20	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=2526&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/ogd.html
West Valley fault zone Granger section	2386b	UT	Between 0.2 and 1.0 mm/yr	y	Latest Quaternary (<15 ka)	16	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5010&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/slc.html
West Valley fault zone Taylorsville section	2386a	UT	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	15	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=5009&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/ut/slc.html
Western Bear Lake fault	622	ID	<0.2 mm/yr	y	Latest Quaternary (<15 ka)	59	http://gldims.cr.usgs.gov/webapps/cfusion/sites/qfault/qf_web_disp.cfm?qfault_or=1411&ims_cf_cd=cf&disp_cd=C	http://earthquake.usgs.gov/hazards/qfaults/wy/prs.html