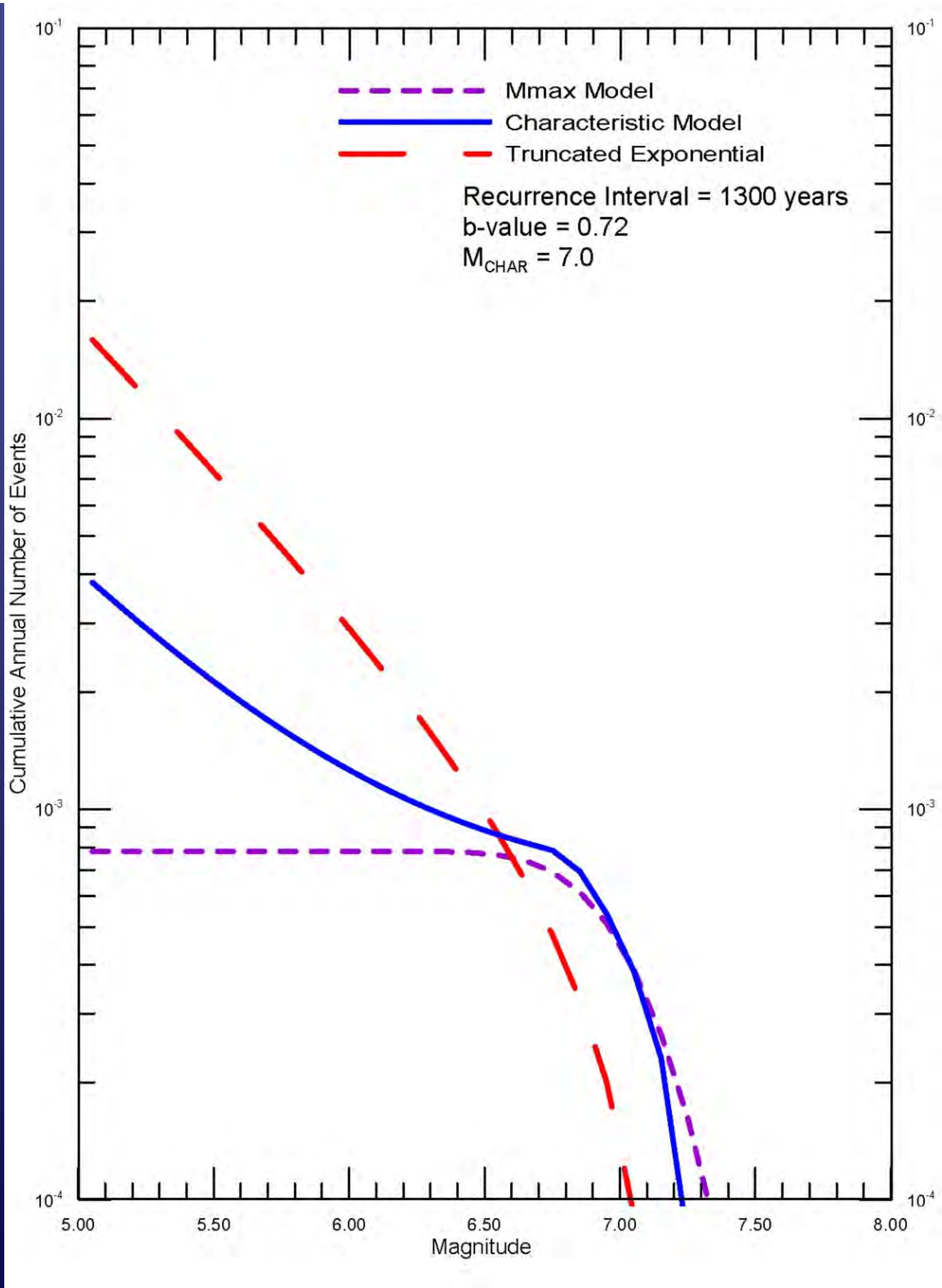
Strawman Recurrence Models

Working Group on Utah Earthquake Probabilities

Ivan G. Wong
Seismic Hazards Group
URS Corporation
Oakland, CA

Salt Lake City, UT 17 November 2011

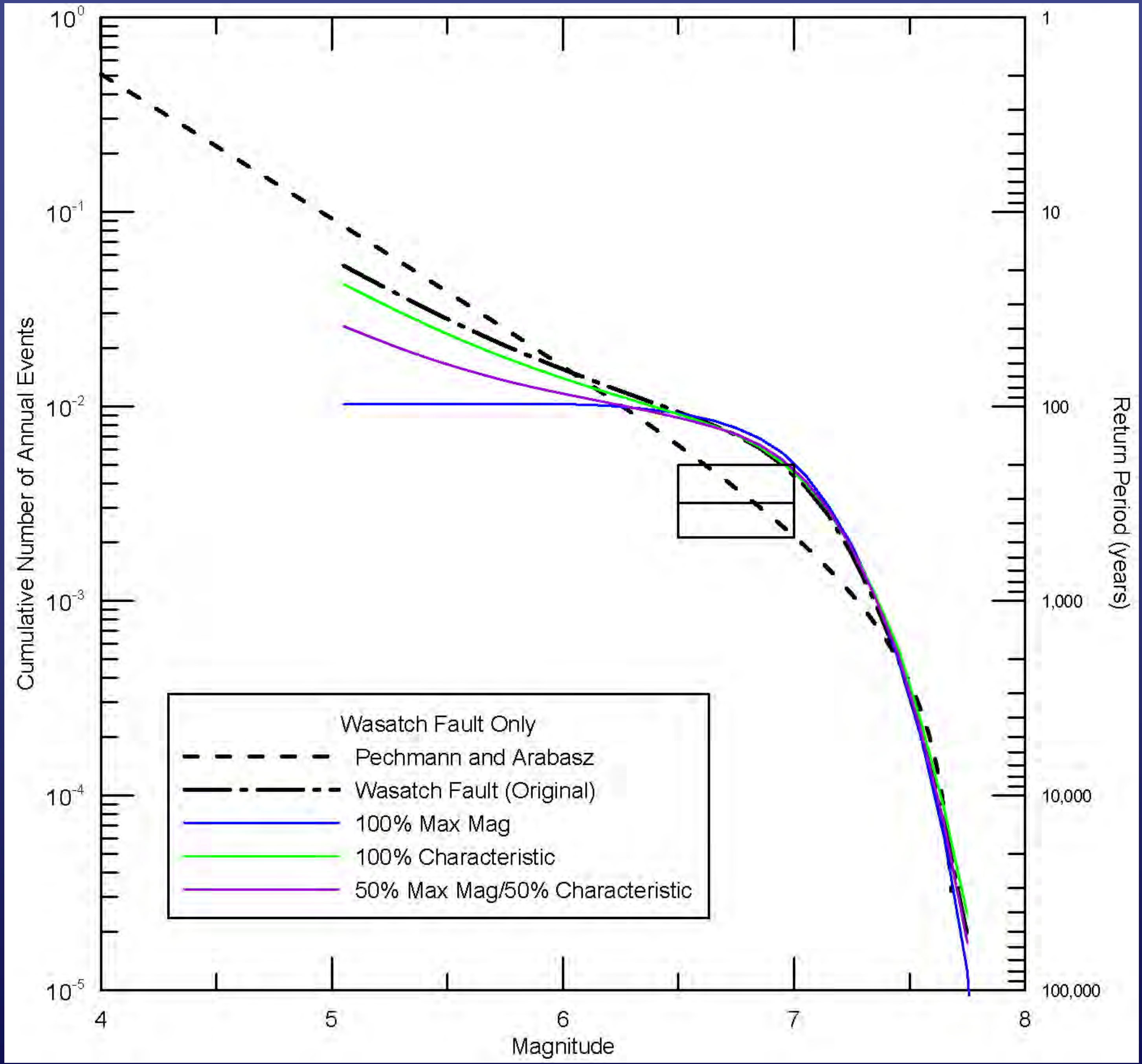
Earthquake Recurrence Models



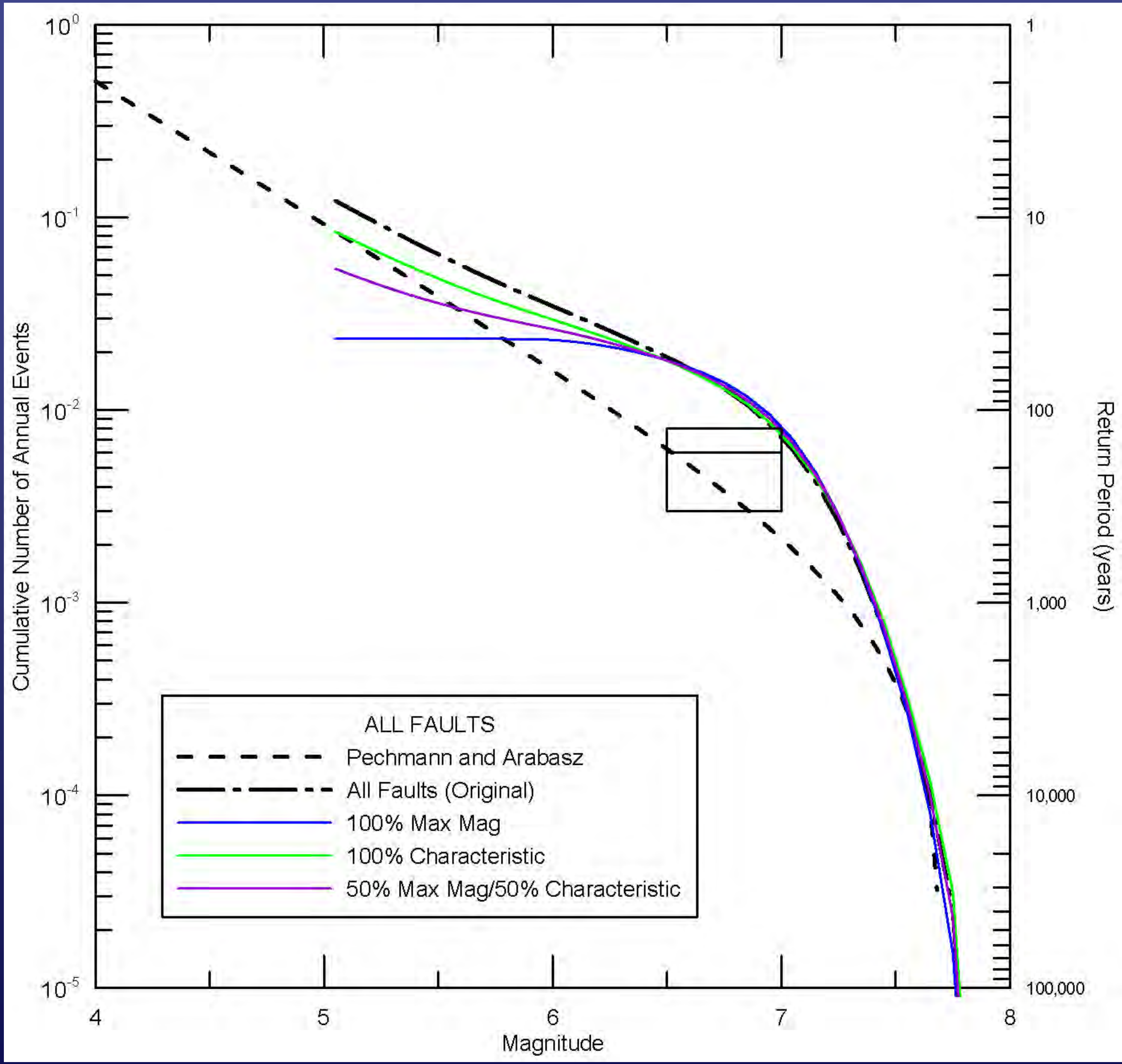
USGS Recurrence Model Approach

- Use both "characteristic" (actually Maximum Magnitude) and Gutenberg-Richter models.
- Both models have their Mmin at **M** 6.5 for faults.
- Mmin 6.5 came about because of mismatch of **M** 4-5 in southern California.
- Background earthquakes events are accommodated by smoothed seismicity. Gutenberg-Richter model has a Mmax of **M** 6.5.
- Mmax for gridded seismicity is lowered over dipping faults to avoid overlap.

Recurrence for the Wasatch Front



Recurrence for the Salt Lake City Fault



Return Periods

Wasatch Fault	Return Period (years)		
	100% Mmax	100% Char	50% Mmax / 50% Char
M5 and greater	98	24	39
M6 and greater	98	72	86
M7 and greater	200	222	215

Strawman Models

- Wasatch and Oquirrh-Great Salt Lake Faults
  0.9 maximum magnitude (Mmin 6.75?)
  0.1 truncated exponential (Mmin 6.75?)
- Other Faults
  0.8 maximum magnitude (Mmin 6.75?)
  0.2 truncated exponential (Mmin 6.75?)
- Background Seismicity
  1.0 truncated exponential (**M** 5.0 to Mmin)

Update on Consensus Wasatch Front Catalog

Walter Arabasz

University Of Utah
Seismograph Stations
The University of Utah

WGUEP
November 17, 2011

Outline*

I. Methodology preview: magnitude uncertainties and rate calculations from seismicity

II. UUSS magnitudes
(historical: $M_{L\ (I_o)}$; instrumental: M_L, M_C, and M_w)

III. More on comparison between UUSS and NSHM catalogs (and magnitudes)

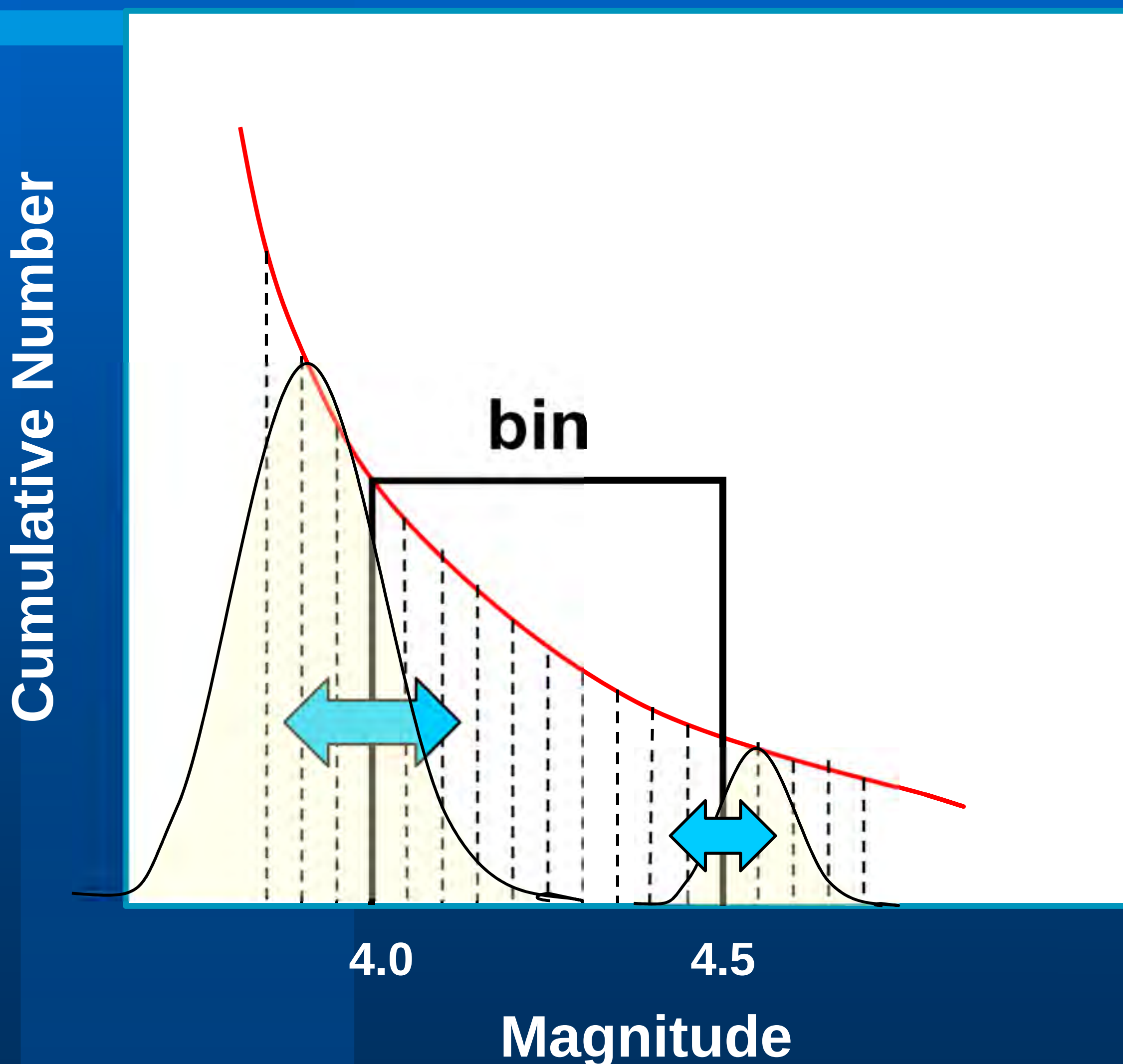
IV. Next steps to closure

** Presentation borrows heavily from one given at BRPEWG II workshop on 11/16/2011; slides marked with a ★ are specific to today's meeting*

Why are magnitude uncertainties important?

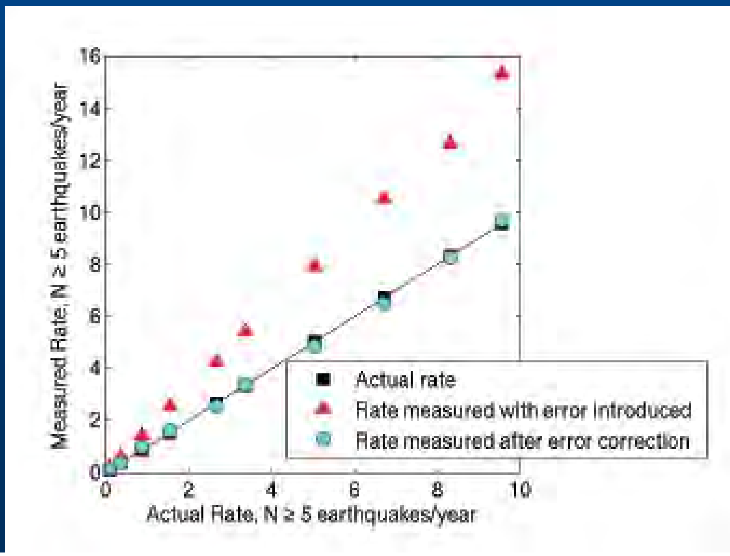
- Recurrence calcs for rigorous hazard and risk analyses require an adjustment for magnitude uncertainties because they introduce bias (*a*-values are systematically overestimated)
- Bias arises because errors in magnitude estimates are normally distributed while earthquake counts in magnitude bins are exponentially distributed
- Magnitude uncertainties come from: (1) statistical average of measurements made at a number of stations and (2) conversion from one magnitude scale to another; errors also from rounding

“observed” counts > true counts

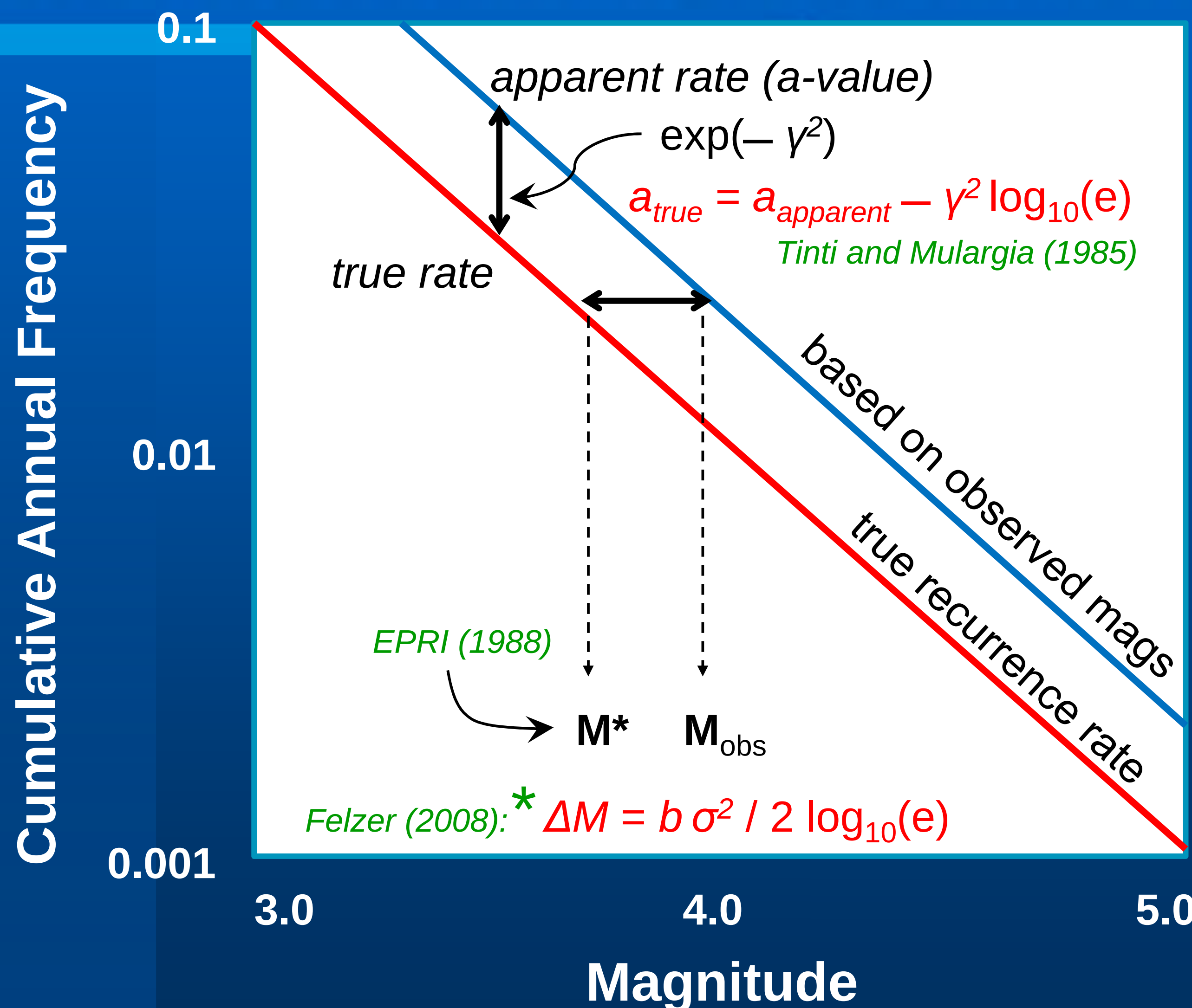


If Gaussian error is added to true magnitudes, **a net increase in the observed counts in a bin** results due to relative change in counts across the left-hand side of the bin compared to the right-hand side

Example from Felzer (2008) →



Equivalent approaches to ensuring unbiased recurrence rates



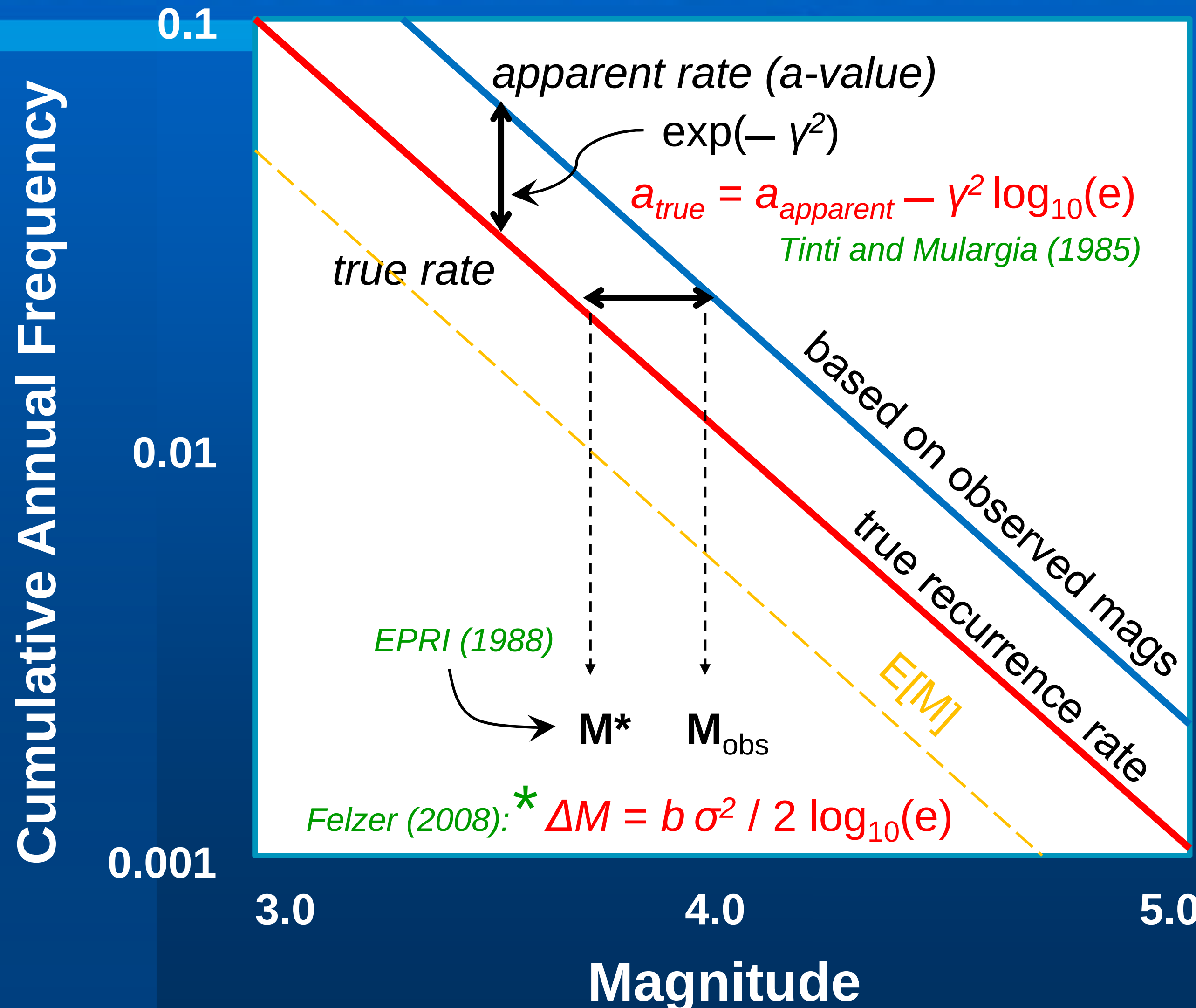
$\gamma^2 = \beta^2 \sigma^2 / 2$

where $\beta = b / \log_{10}(e)$

Adapted from Youngs (2011)

**** Published equation incorrectly shows b^2***

Equivalent approaches to ensuring unbiased recurrence rates



$\gamma^2 = \beta^2 \sigma^2 / 2$

where $\beta = b / \log_{10}(e)$

Fine point:
E[M] = expected value of the true magnitude

Adapted from Youngs (2011)

**** Published equation incorrectly shows b^2***

Need σ and *b*-value for the bias correction

- For an adopted scale (say M_W or $M_L \approx M_W$) and for observed magnitudes: need to know $\boldsymbol{\sigma}_{\textit{stations}}$, the standard error of estimate of magnitude based on measurements at multiple stations.
- When converting from one magnitude scale to another, need to know $\boldsymbol{\sigma}_{\textit{regression}}$, the std error of estimate for the regression.

In this case, for the normally-distributed magnitude errors

$$\sigma = \sqrt{\boldsymbol{\sigma}_{\textit{regression}}^{\,2} - \boldsymbol{\sigma}_{\textit{stations}}^{\,2}}$$

Magnitudes in UUSS Catalog

- **Historical Catalog** (1850– June1962)
  - —Most magnitudes estimated from maximum Modified Mercalli Intensity (INT) using
    M_{I_o} = (2/3) INT + 1 (Gutenberg and Richter, 1956; validated for Utah by USGS, 1976)
- **Instrumental Catalog** (July 1962 – present)
  - —Preferred magnitude is local magnitude, M_L , determined from maximum peak-to-peak amplitudes on Wood-Anderson seismograms
  - —The vast majority of the magnitudes are coda magnitudes, M_C, determined from signal durations on short-period vertical records
  - —M_W now routinely determined for M ~ 3.4 and larger

Magnitude-Intensity Relation for Utah

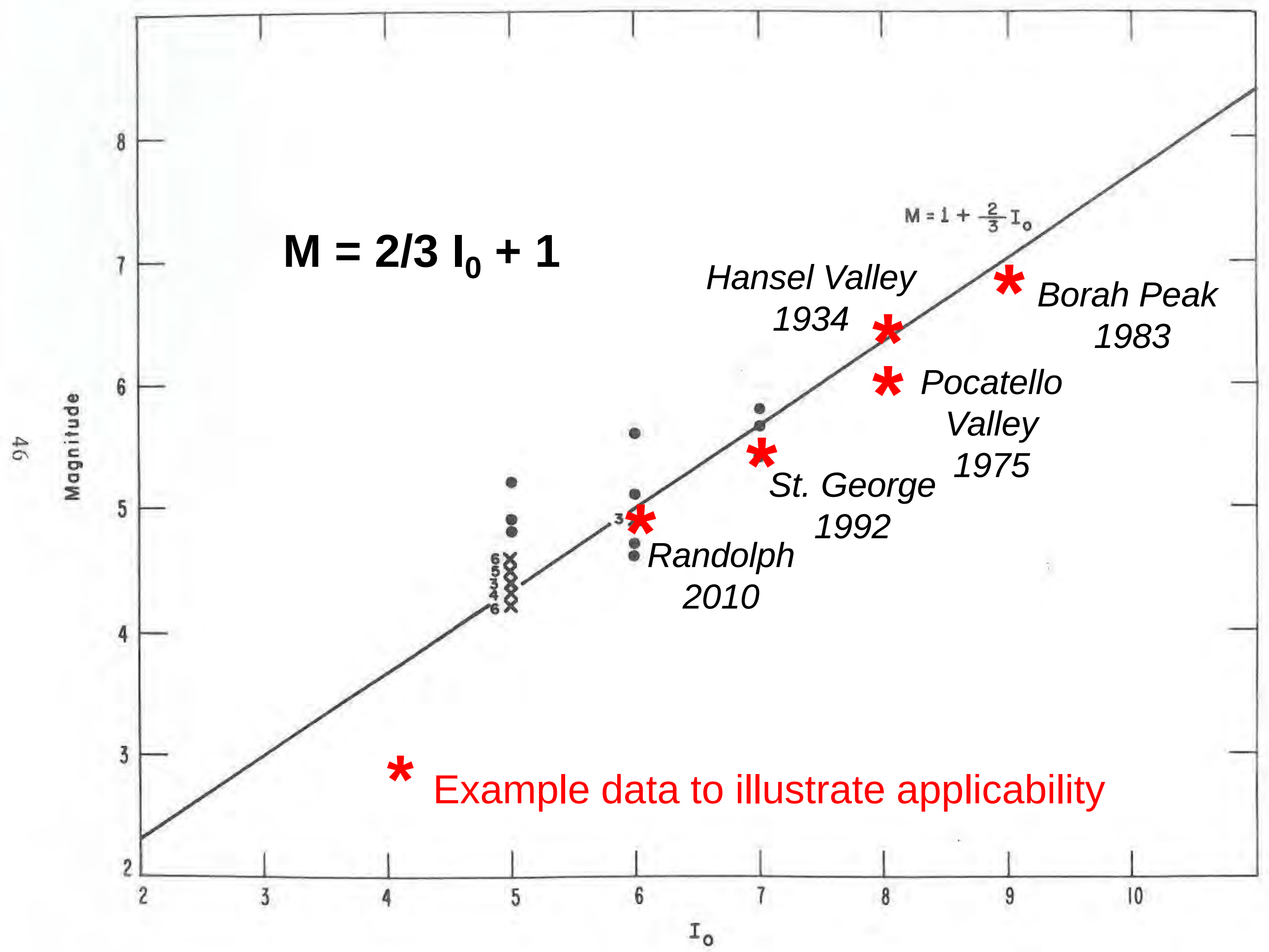
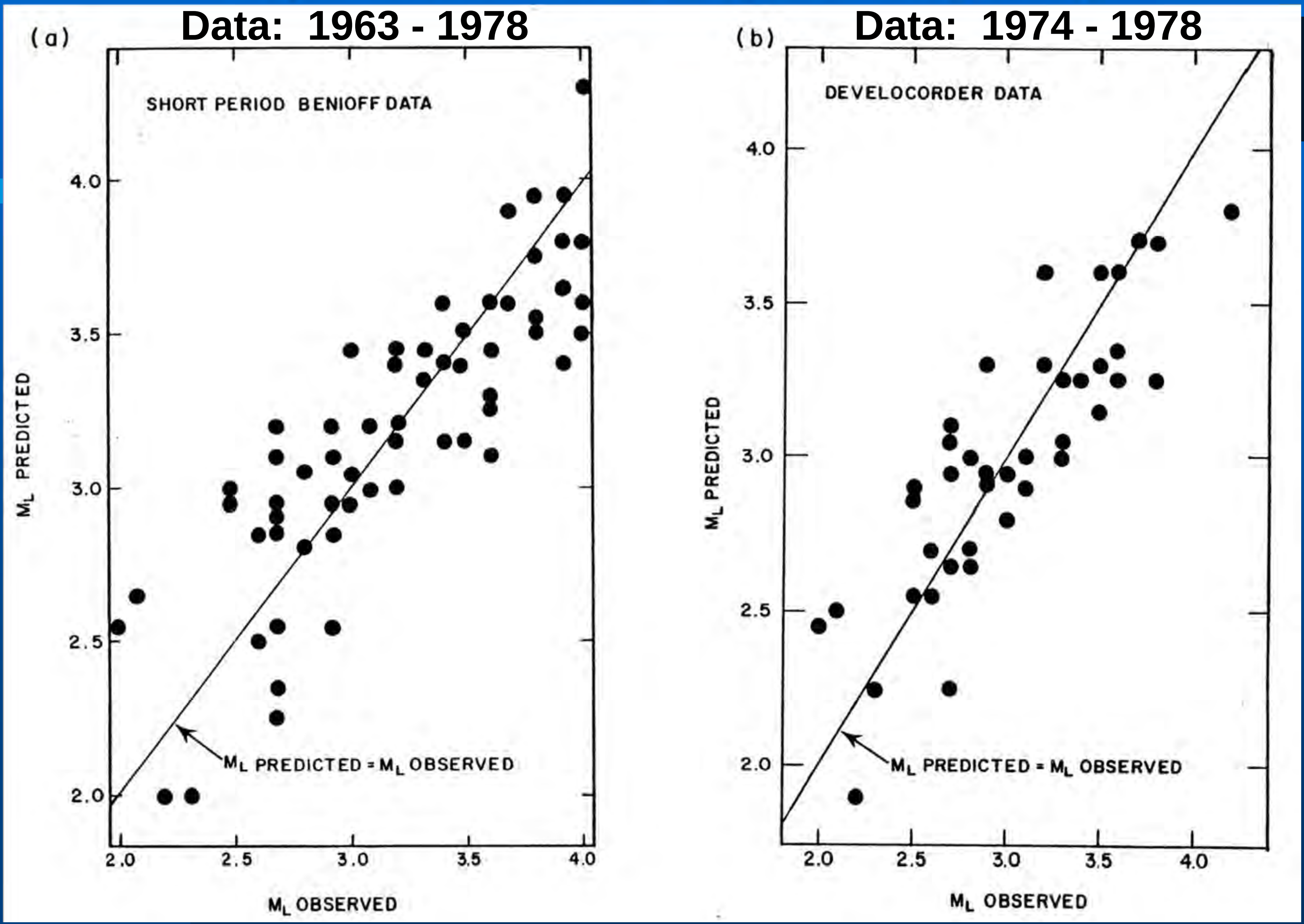


Figure 11.--Graph showing magnitude versus maximum intensity for Utah earthquakes. The line shows the Gutenburg-Richter relation. The numbers indicate the number of overlapping data points.

Base figure from Rogers et al. (USGS Open-file Rept. 76-89, 1976)

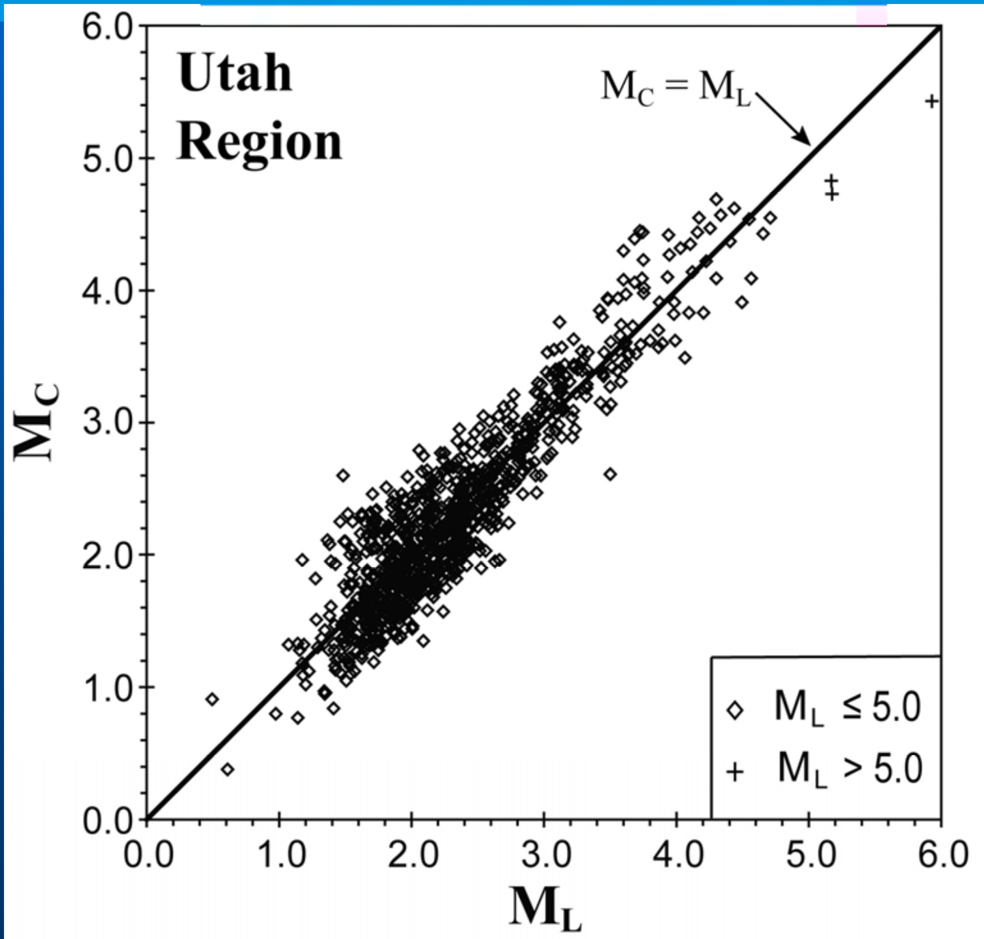
M_C Calibrations (pre-digital)



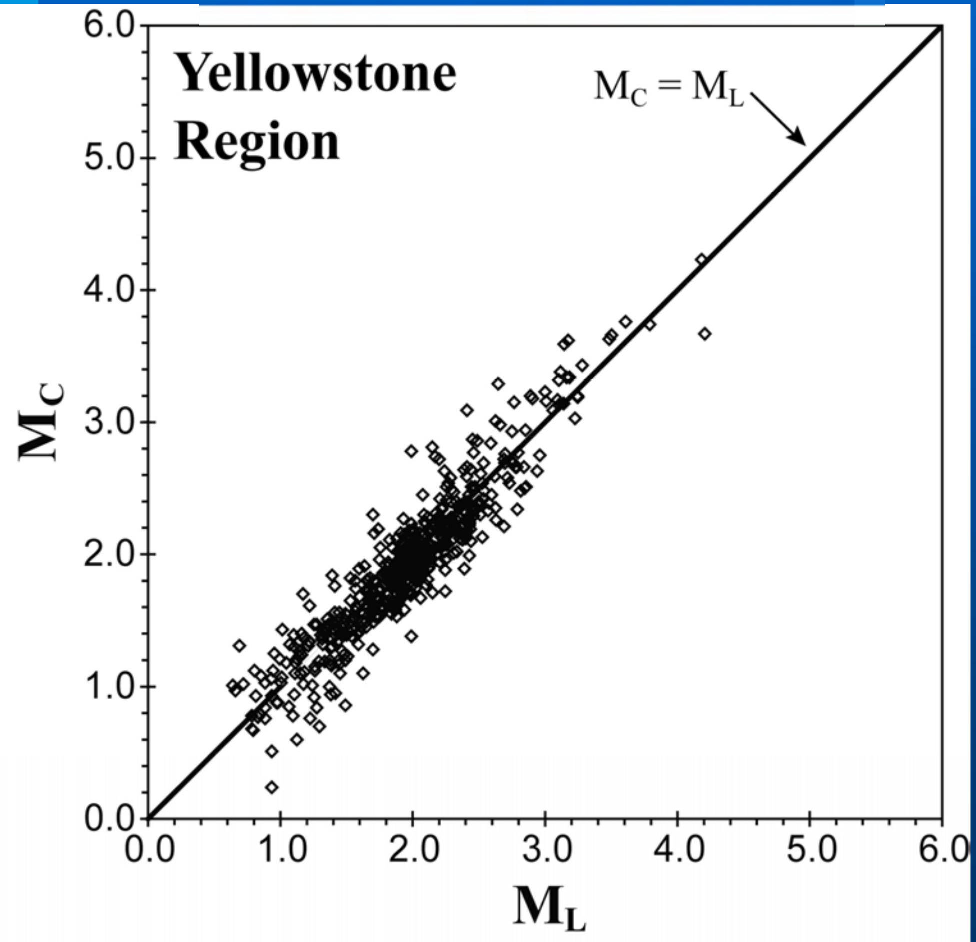
From Griscom and Arabasz (1979)

M_C Calibrations (digital)

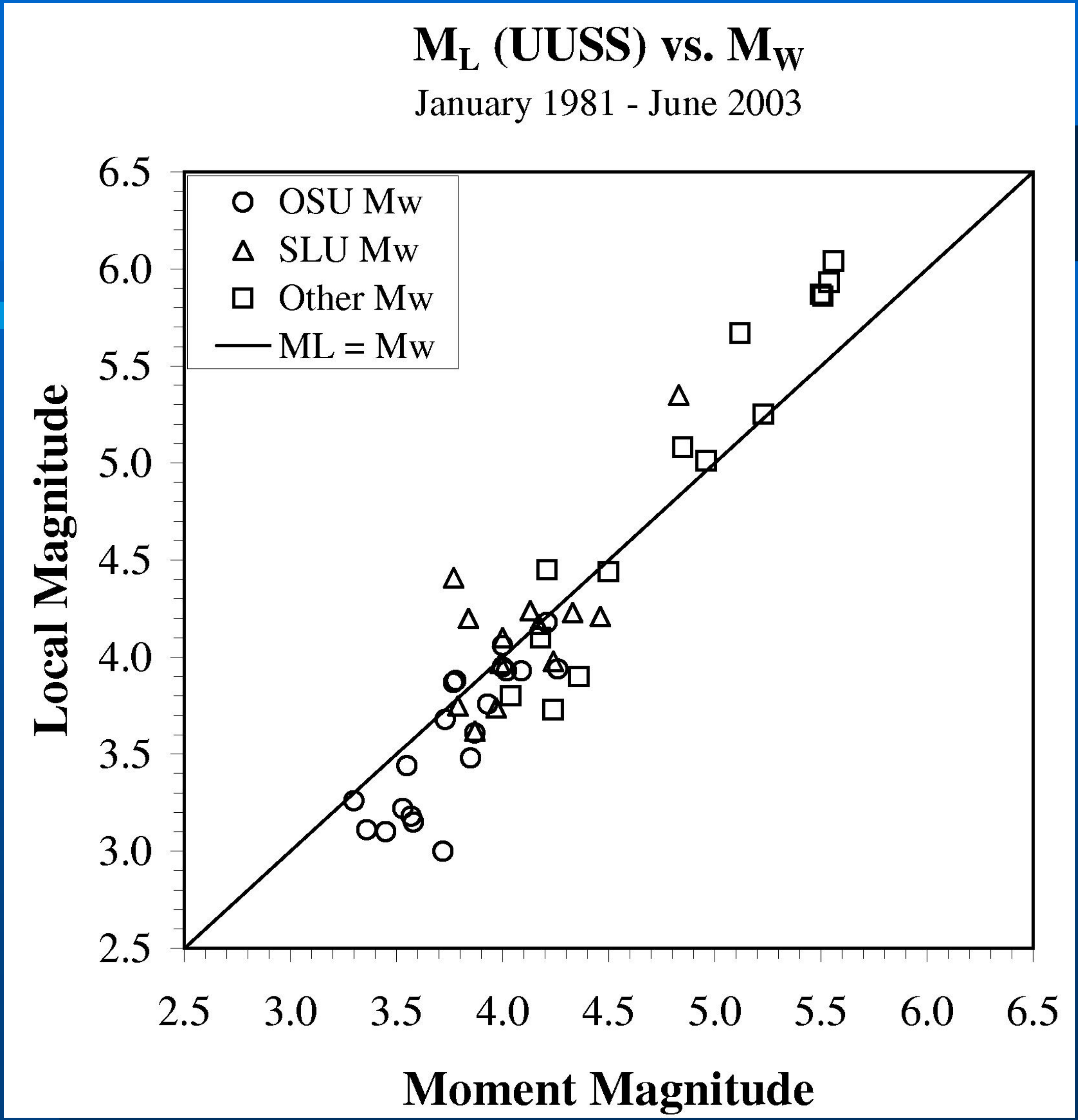
Data: 1981 - 2001



Data: 1995 - 2001



From Pechmann et al. (2007)



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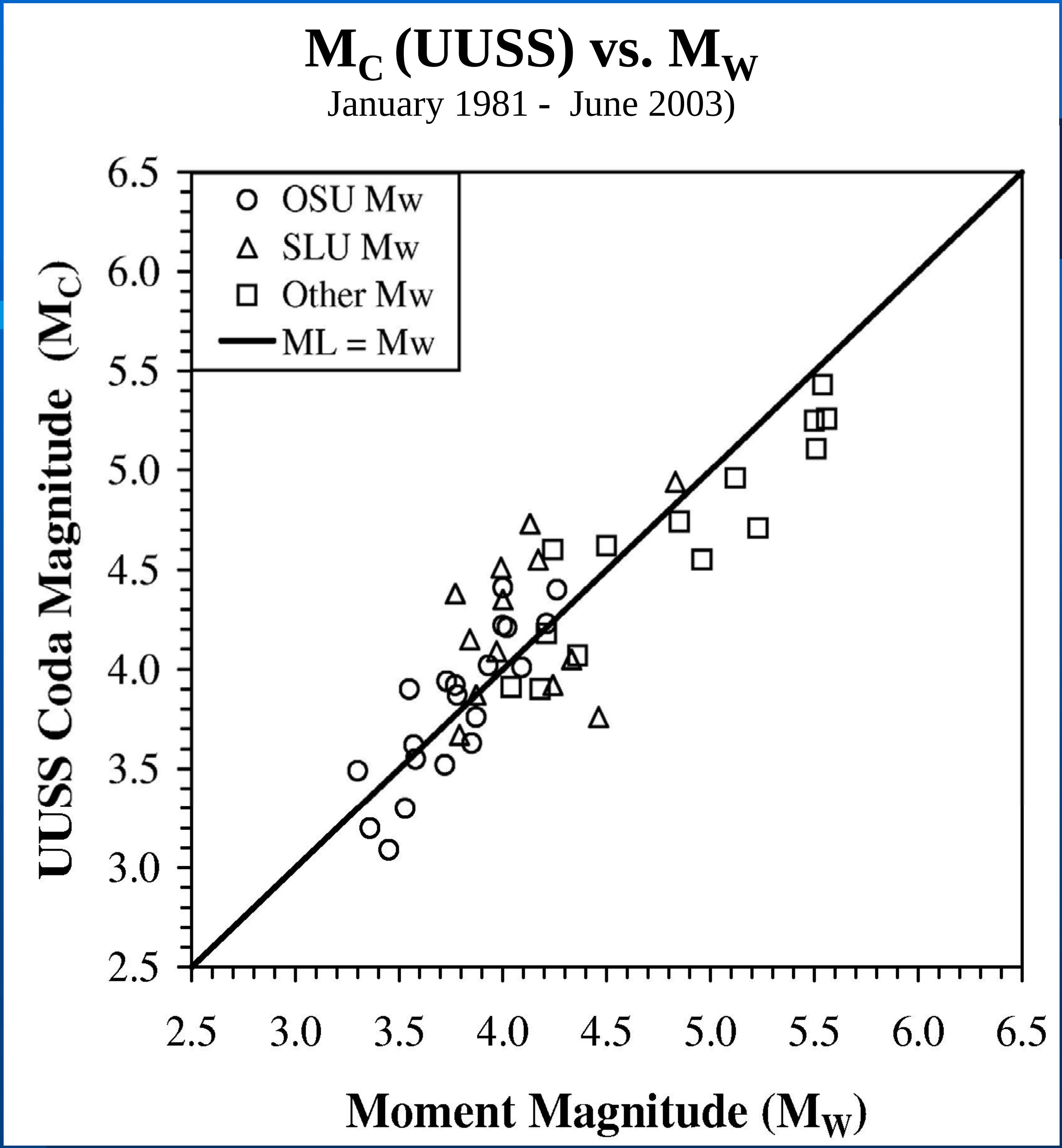
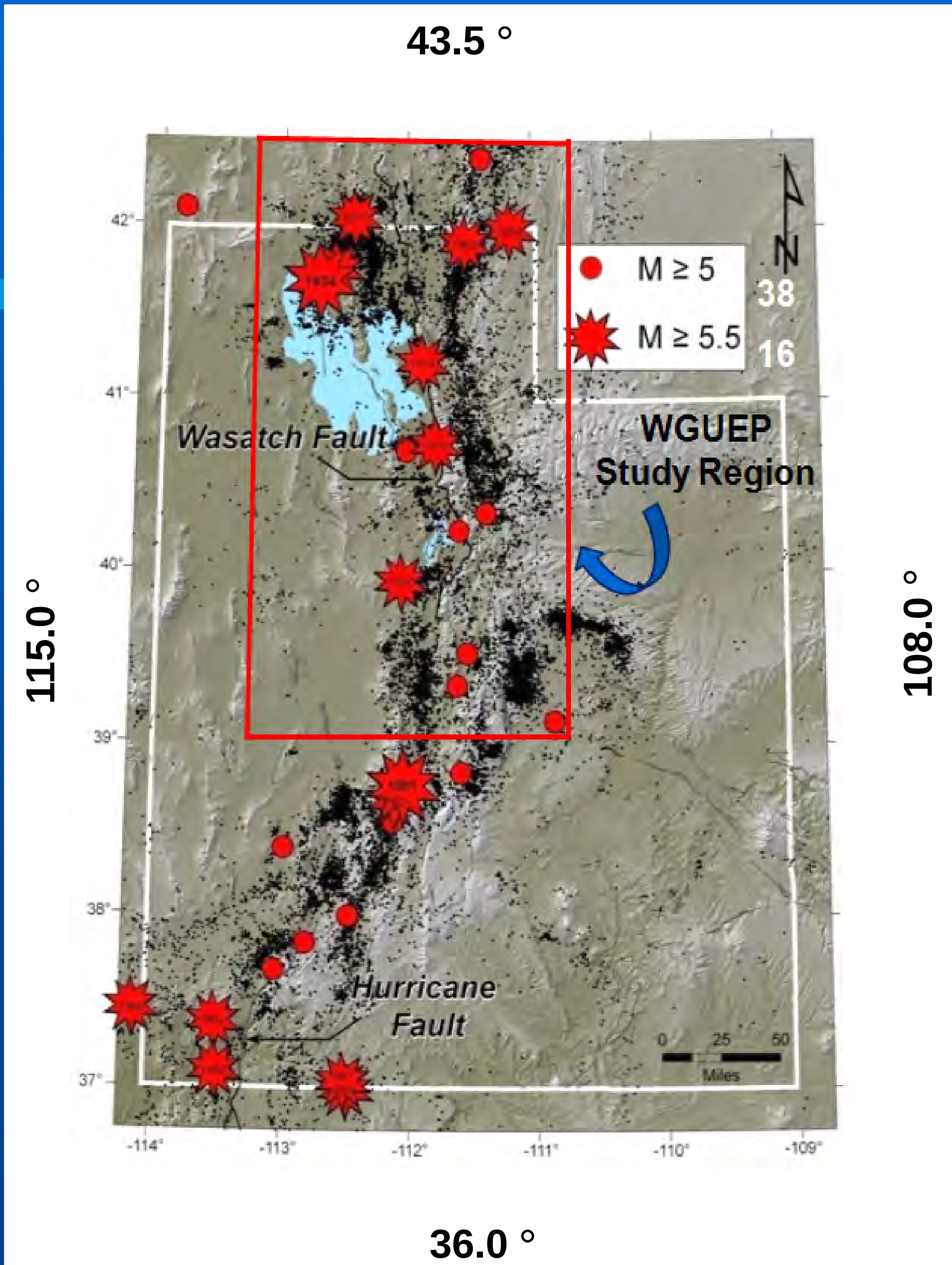


from Pechmann et al. (2007)

Methodology Status

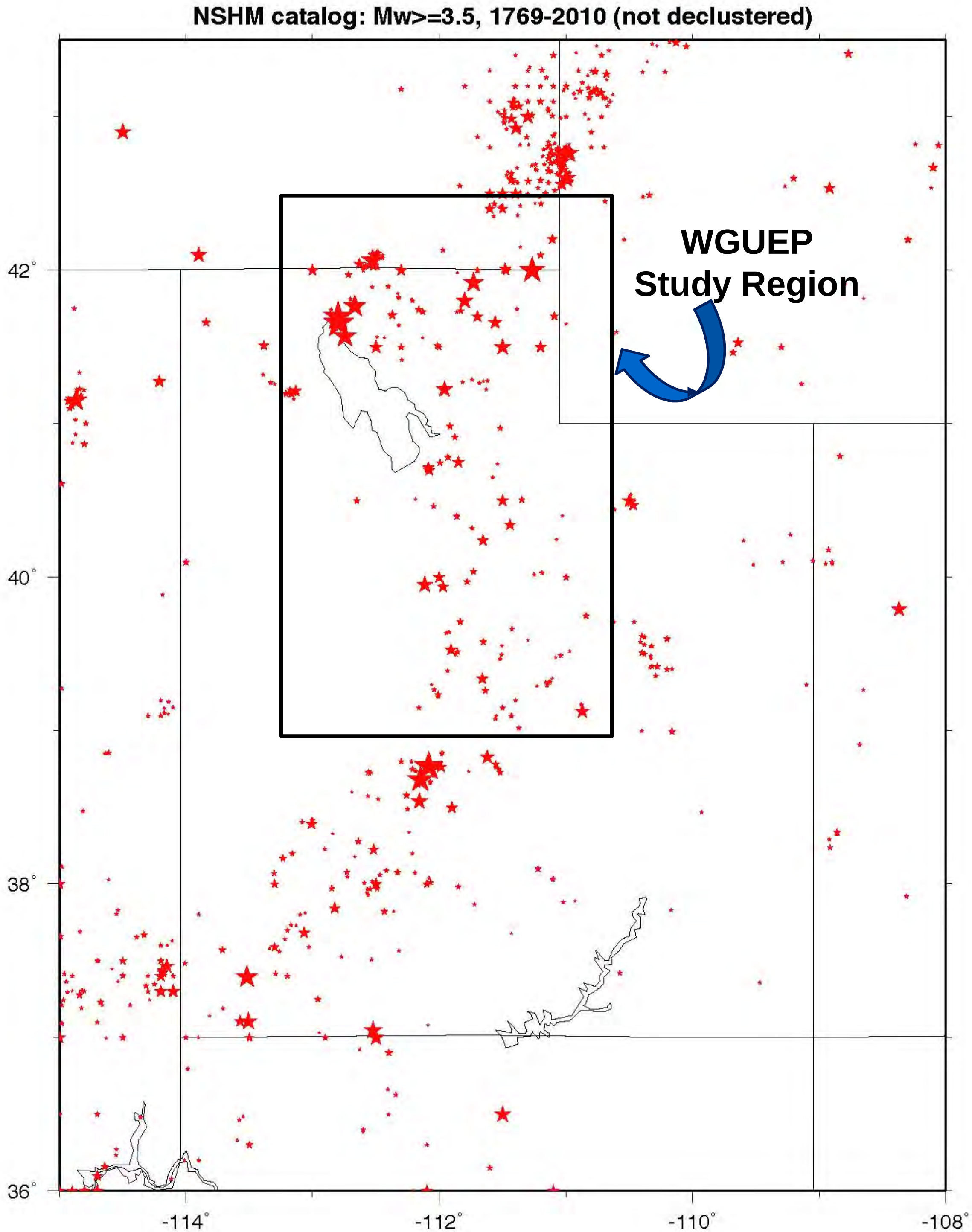
- Standard errors for magnitude estimates in UUSS catalog can be provided for M_{I_o}, M_L, and M_C, and rounding values can be provided
- Have to decide on approach to uniform magnitude (M_W) — Event-by-event conversion to M_W? Assume M_L and M_C sufficiently equivalent to M_W?
- Size estimates for pre-instrumental shocks (M_{I_o}) have relatively largest uncertainty; intensity-magnitude relation will be examined with added data, and sizes of larger events re-examined
- Assumption is that WGUEP earthquake catalog will be turned over to URSCorp/USGS "analysts" for bias-correcteced rate calculations and probabilities

“extended Utah region”



NSHM catalog request

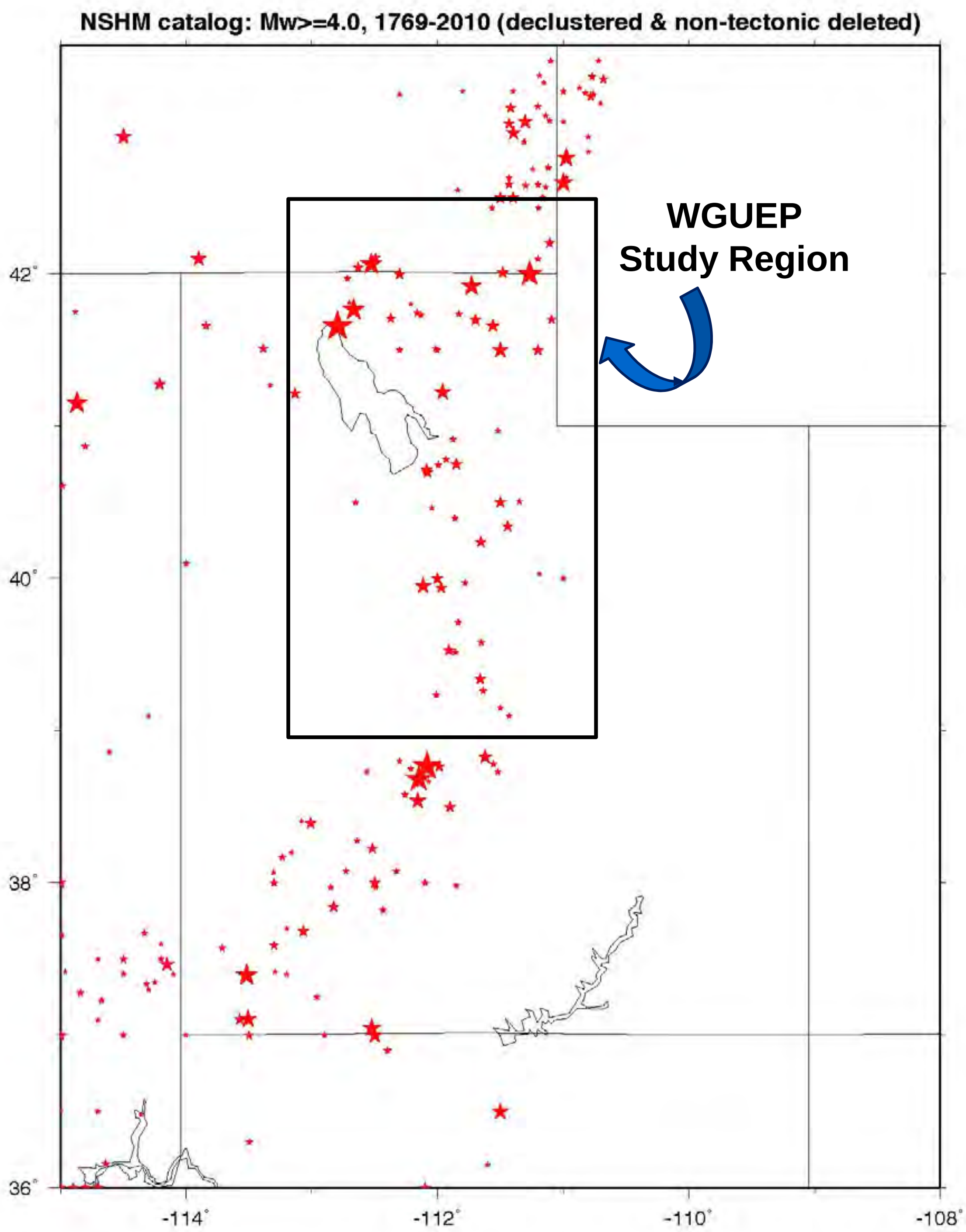
lat 36.0° – 43. 5° N
long 108.0° – 115.0° W



NSHM Catalog
Mw ≥ 3.5
1769 [1880]−2010
Not declustered

N *total area* = 788

N *WGUEP region* = 203



NSHM Catalog

Mw ≥ 4.0
1769 [1880]−2010
Declustered
Non-tectonic events deleted

N *total area* = 202

N *WGUEP region* = 67

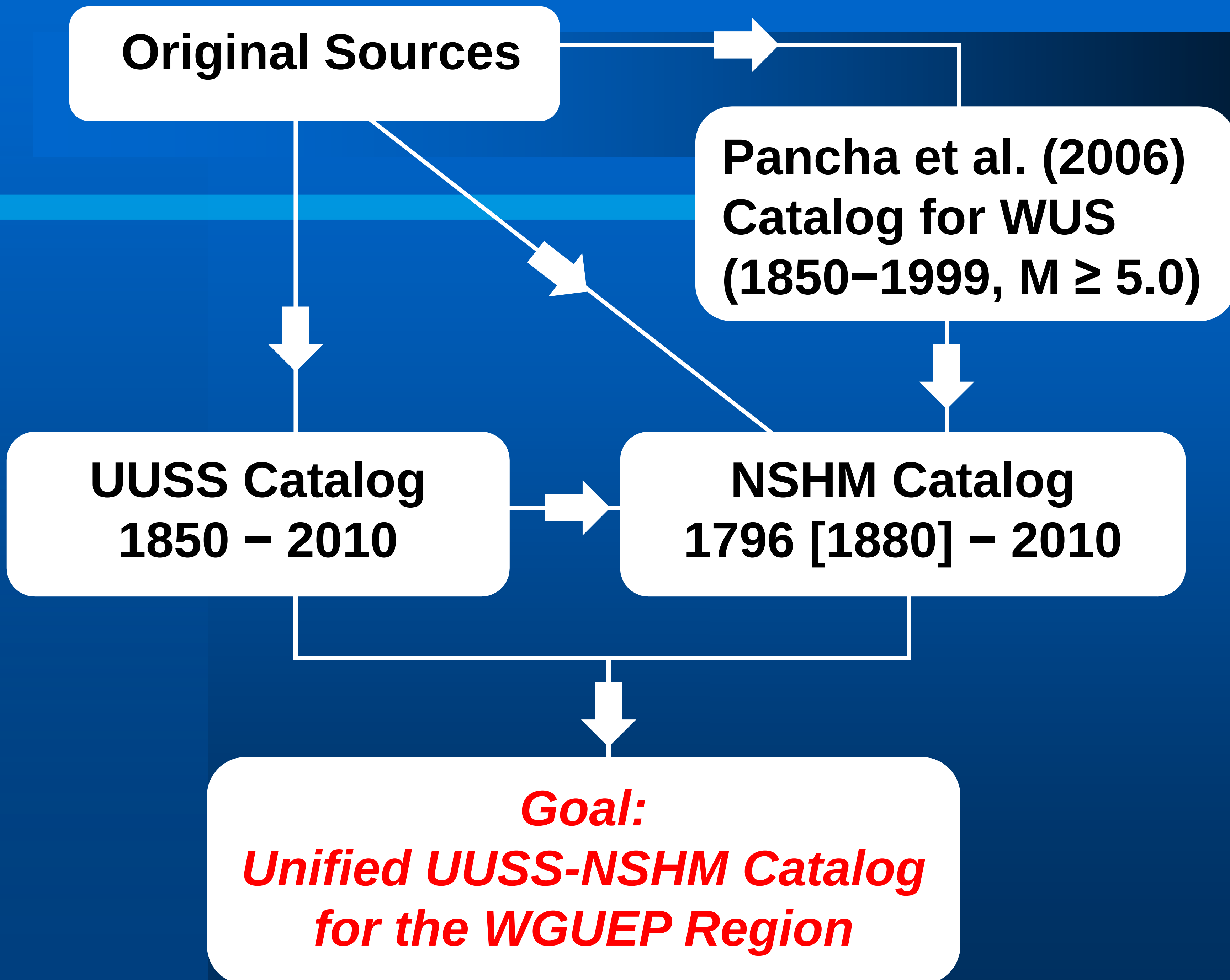
Comparison of UUSS and NSHM catalogs for the WGUEP region . . .

(1880 through 2010; independent mainshocks M ≥ 4.0, non-tectonic events removed)

Magnitude Range	UUSS Catalog	NSHM Catalog
$4.0 \leq M < 4.5$	45	34
$4.5 \leq M < 5.0$	5	4
$5.0 \leq M < 5.5$	10	21
$5.5 \leq M < 6.0$	4	4
$6.0 \leq M < 6.5$	3	3
$6.5 \leq M < 7.0$	1	1
Total Number	68	67

Comparison of independent mainshocks ($M \geq 4.0$) in the UUSS and NSHM catalogs for the WGUEP Region — *accounting for completeness periods*

Magnitude Range	Completeness Period	Yrs	Number UUSS Catalog	Number NSHM Catalog
$4.00 \leq M < 4.67$	July 1962−Dec 2010	48.5	17	16
$4.67 \leq M < 5.33$	Jan 1950−Dec 2010	61.0	7	17
$5.33 \leq M < 6.00$	Jan 1938−Dec 2010	73.0	1	2
$6.00 \leq M < 6.67$	Jan 1900−Dec 2010	111.0	3	2


Original Sources
Pancha et al. (2006) Catalog for WUS (1850−1999, M ≥ 5.0)
UUSS Catalog 1850 − 2010
NSHM Catalog 1796 [1880] − 2010
Goal:
Unified UUSS-NSHM Catalog for the WGUEP Region

Example Comparison of NSHM and UUSS Catalogs

	NSHM→	← Pancha et al. (2006)			UUSS		
1966	5.21 UNR|mw	5.20899001	Mw	D&S 1982	4.6	ML	
1963	5.03 UNR|mw	5.03230178	Mw Surf	Patton 85	4.4	ML	
1964	5.02 UNR|mw	5.01883286	Mw	D&S 1982	4.1	ML	
1950	5.00 UNR|mw	5	MLEPB	EPB	3.0	X	NOAA (no mag)
1953	5.00 UNR|mw	5	MLEPB	EPB	4.3	I	
1957	5.00 UNR|mw	5	MLEPB	EPB	3.0	X	NOAA (no mag)
1958	5.00 UNR|mw	5		UTHist	5.0	I	
1960	5.00 UNR|mw	5	MLEPB	EPB	3.0	X	NOAA (no mag)
1961	5.00 UNR|mw	5		UTHist	5.0	I	
1962	5.00 UNR|mw	5.00470666	Mw	D&S 1982	5.2	ML	
1980	5.00 UNR|mw	5	mb GS	PDE	4.4	Mc	
1988	5.00 UNR|mw	5	mb GS	USHIS	4.32	Mc	
1987	4.99 UNR|mw	4.99	Mw SorB	W&C	4.71	Mc	
1973	4.95 UNR|mw	4.94900929	Mw	D&S 1982	4.2	Mc	
1987	4.80 UNR|mw	4.8	Mc	CNSS UW			Duplicate
1989	4.80 UNR|mw	4.8	*W	Utregion	4.8	ML	

Next Steps to Closure

- Identify parts of the WGUEP catalog (a) that will come directly from the UUSS instrumental catalog and (b) that will represent a unified blending of UUSS and NSHM catalogs
- Verify periods of completeness using “Stepp” plots
- Revise or confirm intensity-magnitude relation for pre-instrumental shocks in the Utah region with added data
- Decide on approach to achieving “uniform M_W” in the catalog
- Determine values of σ and rounding errors for various magnitude estimates in the WGUEP catalog that will be needed by the analysts for bias corrections
- Reconcile differences in magnitudes between NSHM and UUSS catalogs — based on careful checking of sources, compilation of available size estimates, and assessment of a preferred magnitude — to achieve a unified catalog

end

Data Needs for Probability Calculations and Input Sensitivites

Patricia Thomas

Seismic Hazards Group, URS Corporation
1333 Broadway, Suite 800
Oakland, CA 94612

WGUEP Meeting, Salt Lake City, UT

17 November 2011

Overall Approach

PART 1: Define fault segment attributes

PART 2: Define rupture sources and compute rates

PART 3: Define background seismicity

PART 4: Define probability model parameters

PART 5: Probability calculations

PART 1: Fault segment attributes

- Segment endpoints
  - Calculate segment lengths
- Seismogenic crust thickness
  - Correlated across region (thin, med, thick)
- Dip
  - Correlated within fault system (shallow, med, deep)
- Long-term segment slip rate
  - Correlated within fault system (low, med, high)

PART 2: Define rupture sources and rates

- For each rupture source, compute MCHAR and rate of rupture, $\lambda_{Rupture}$
- Inputs:
  - SRL, Area, AD
  - M_{CHAR} Model
  - A-priori (data driven) rupture rates
  - Segment slip rates
  - Slip distribution for multisegment ruptures

PART 2: M_{CHAR} Calculations

M_{CHAR} RELATIONS

Wells and Coppersmith – A

Wells and Coppersmith – SRL

Hemphill-Haley and Weldon – AD

Hanks and Kanamori – M_O

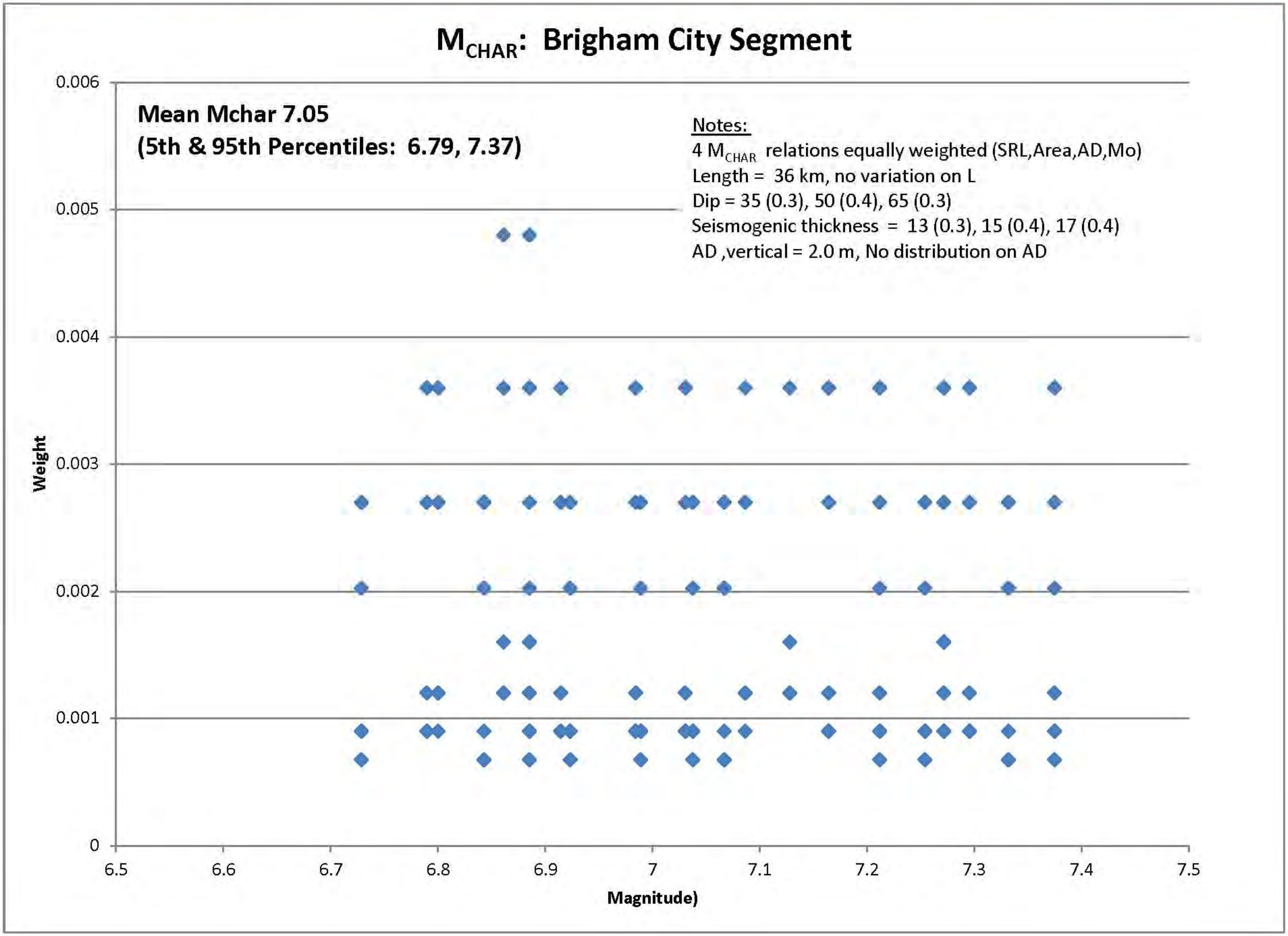
Aleatory Uncertainty

0.12 mag units truncated at +/- 2sigma

Epistemic Uncertainty:

Covered by logic tree approach (distribution on L, Dip, thickness, M_{CHAR} model)

M_{CHAR} Example: Brigham City Segment



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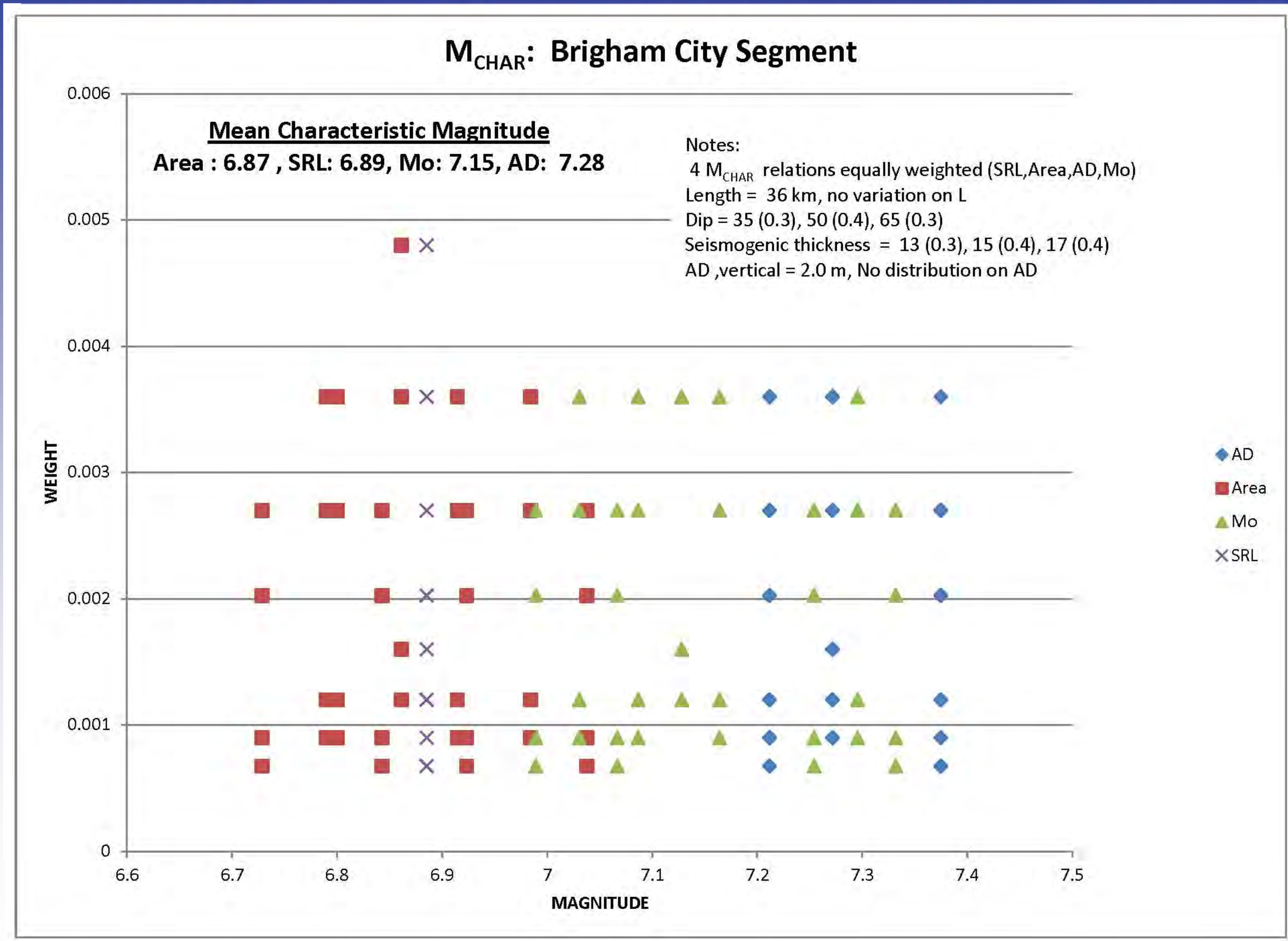
M_{CHAR} Example: Brigham City Segment



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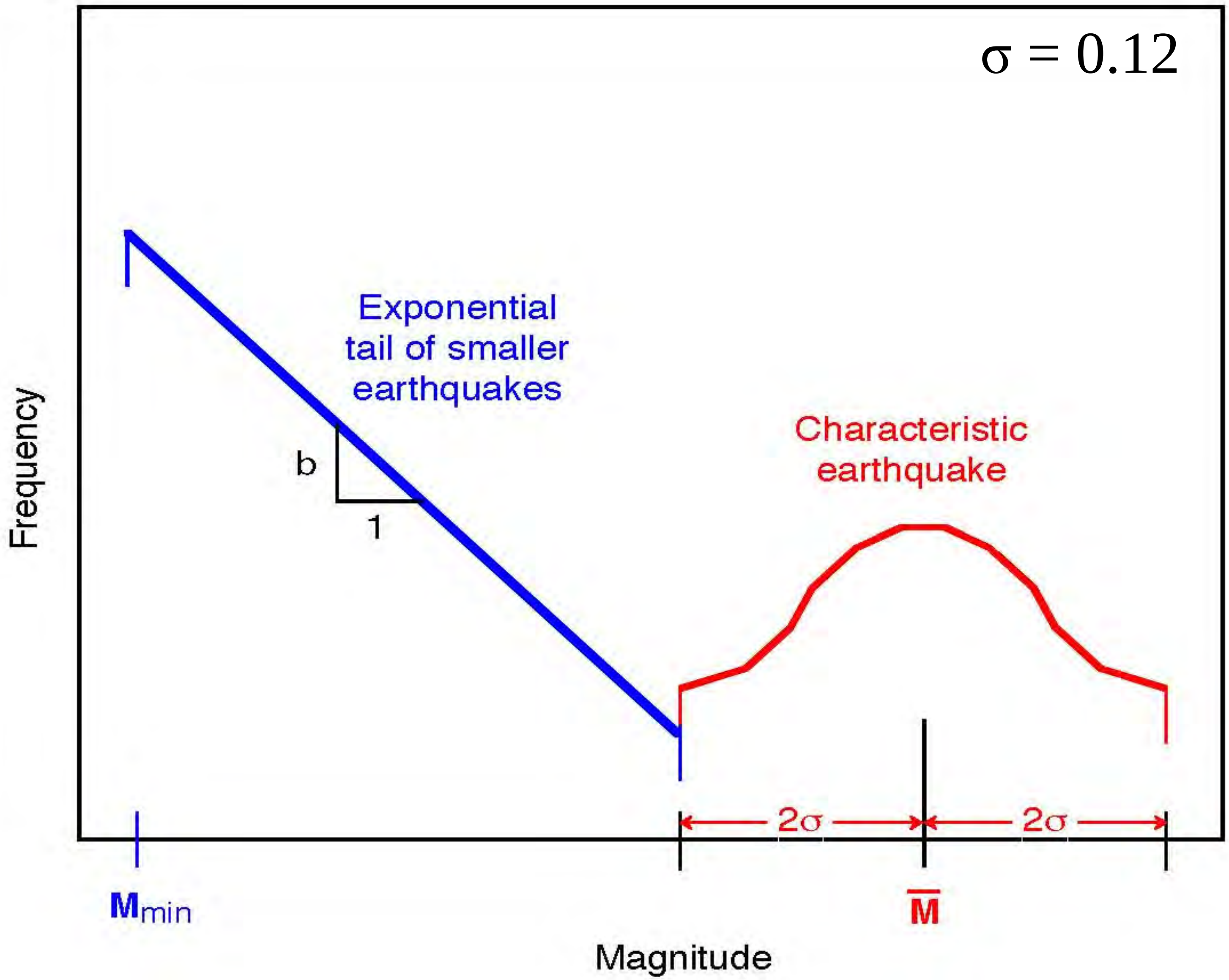
M_{CHAR} Aleatory Uncertainty



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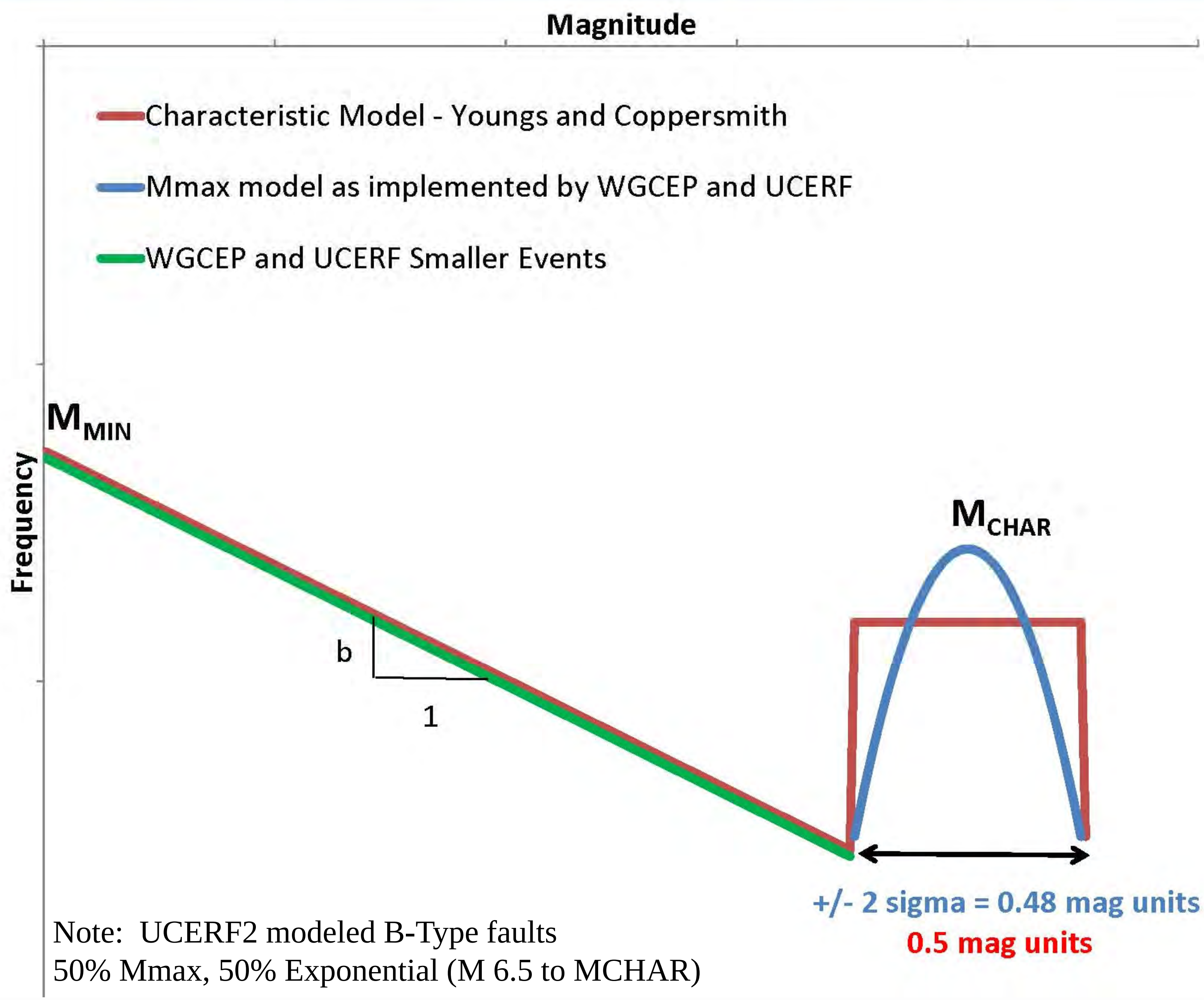
Comparison of Magnitude Recurrence Models



Note: UCERF2 modeled B-Type faults
50% Mmax, 50% Exponential (M 6.5 to MCHAR)

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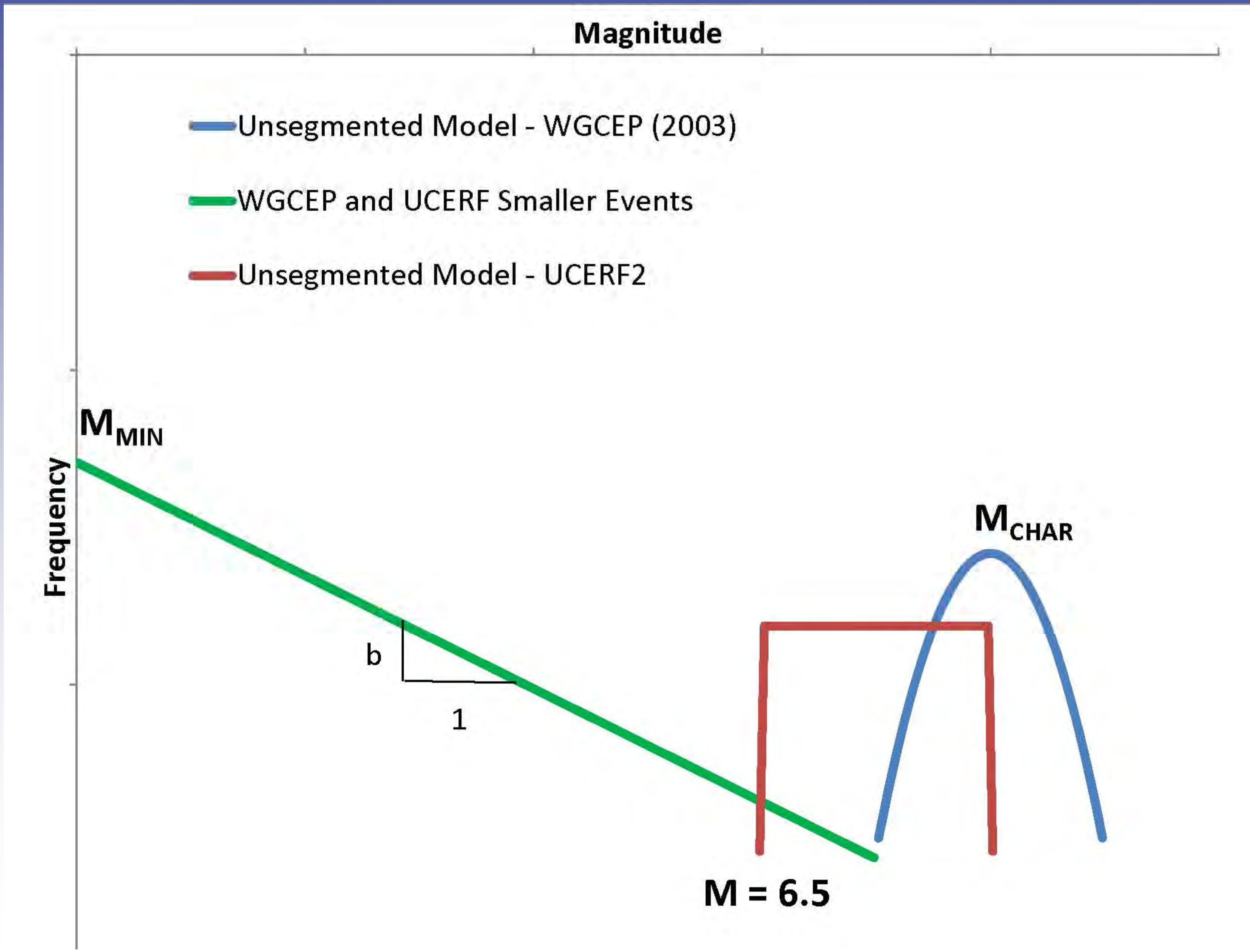
Magnitude Recurrence Models for Unsegmented Fault Models



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Example: Wasatch Single Segment Model

Segment	Wt. Mean M_{CHAR}	5^{th} Percentile M_{CHAR}	95^{th} Percentile M_{CHAR}
Brigham City	7.05	6.79	7.37
Weber	7.20	6.98	7.45
Salt Lake City	7.08	6.83	7.38
Provo	7.23	7.00	7.49
Nephi	7.10	6.87	7.34

Inputs:

4 MCHAR relations equally weighted (SRL, Area, AD, Mo)

Lengths (km): B = 36, W = 56, S = 40, P = 59, N = 43.

No distribution on Length

Dip = 35 (0.3), 50 (0.4), 65 (0.3)

Seismogenic thickness (km) = 13 (0.3), 15 (0.4), 17 (0.4)

AD ,vertical (m): B = 2.00, W = 2.18, S = 2.05, P = 2.40, N = 1.98.

No distribution on AD

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Example: Wasatch Single Segment Model

Segment	M_{CHAR} - SRL	M_{CHAR} - Area	M_{CHAR} - AD	M_{CHAR} - Mo
Brigham City	6.89	6.87	7.28	7.15
Weber	7.11	7.06	7.32	7.30
Salt Lake City	6.94	6.92	7.29	7.19
Provo	7.13	7.08	7.35	7.34
Nephi	6.97	6.95	7.28	7.20

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PART 2: Rupture source rates

- A-priori (Data Driven) rupture rates
  - λ_{CHAR} defined as 1/RI
- Moment-balanced rupture rates
  - Inversion to compute moment-balanced rupture rates, λ_{CHAR}, which honor segment slip rates. A-priori rates used as initial guess in inversion.
  - Slip distribution for multisegment ruptures required
- λ_{SMALL} computed from magnitude recurrence model (% moment in smaller events, b-value)

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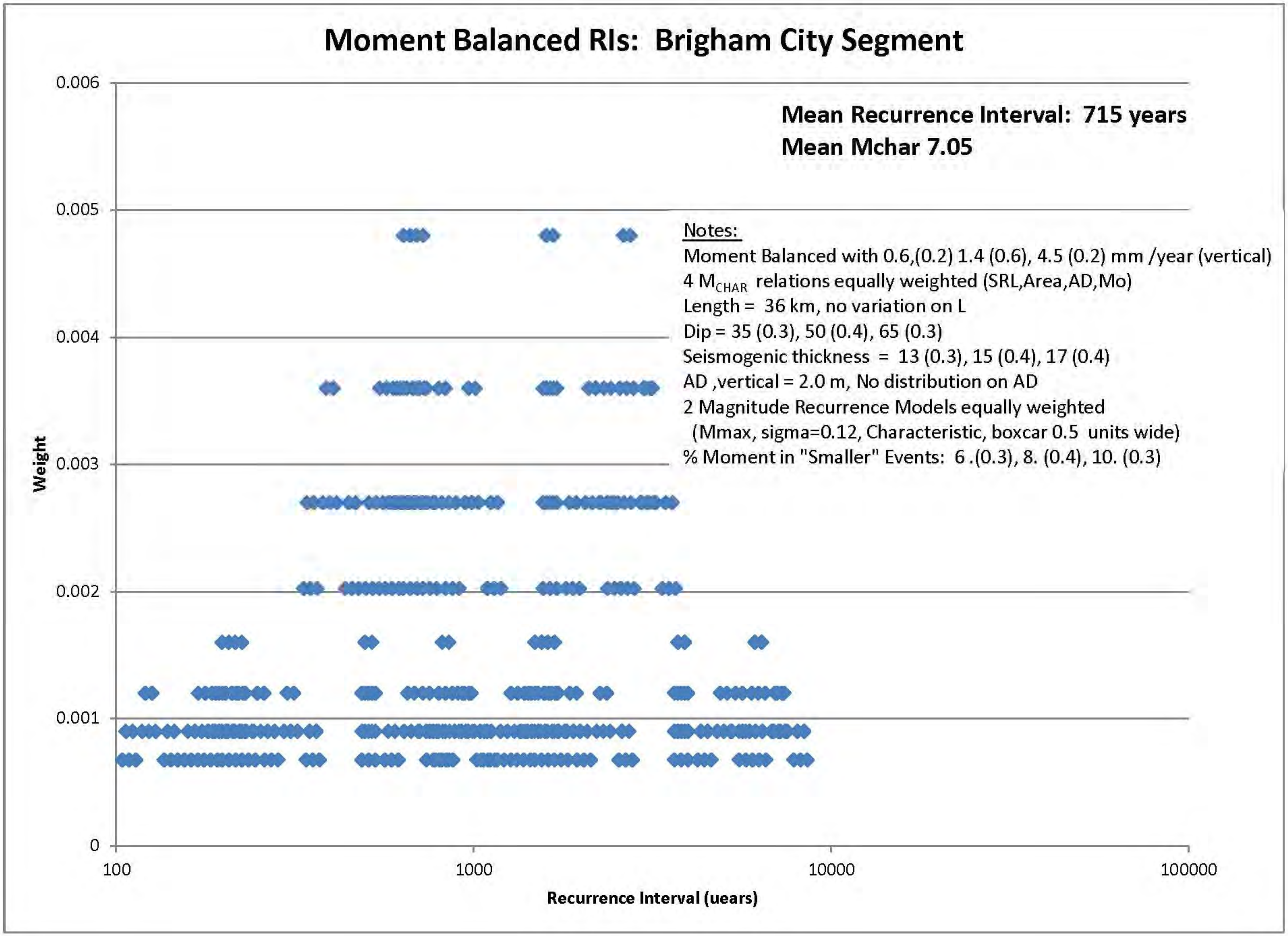
Example: Moment-Balanced RIs for Wasatch Single Segment Model



Example: Moment-Balanced RIs for Wasatch Single Segment Model

Segment	Wt. Mean RI*	5th Percentile RI*	95th Percentile RI*
Brigham City	715	206	4232
Weber	924	272	4154
Salt Lake City	848	244	4080
Provo	1143	401	4573
Nephi	1037	339	4729

*Wt. Mean RI computed as 1/Wt. Mean Rate

Notes on Moment Balanced RIs:

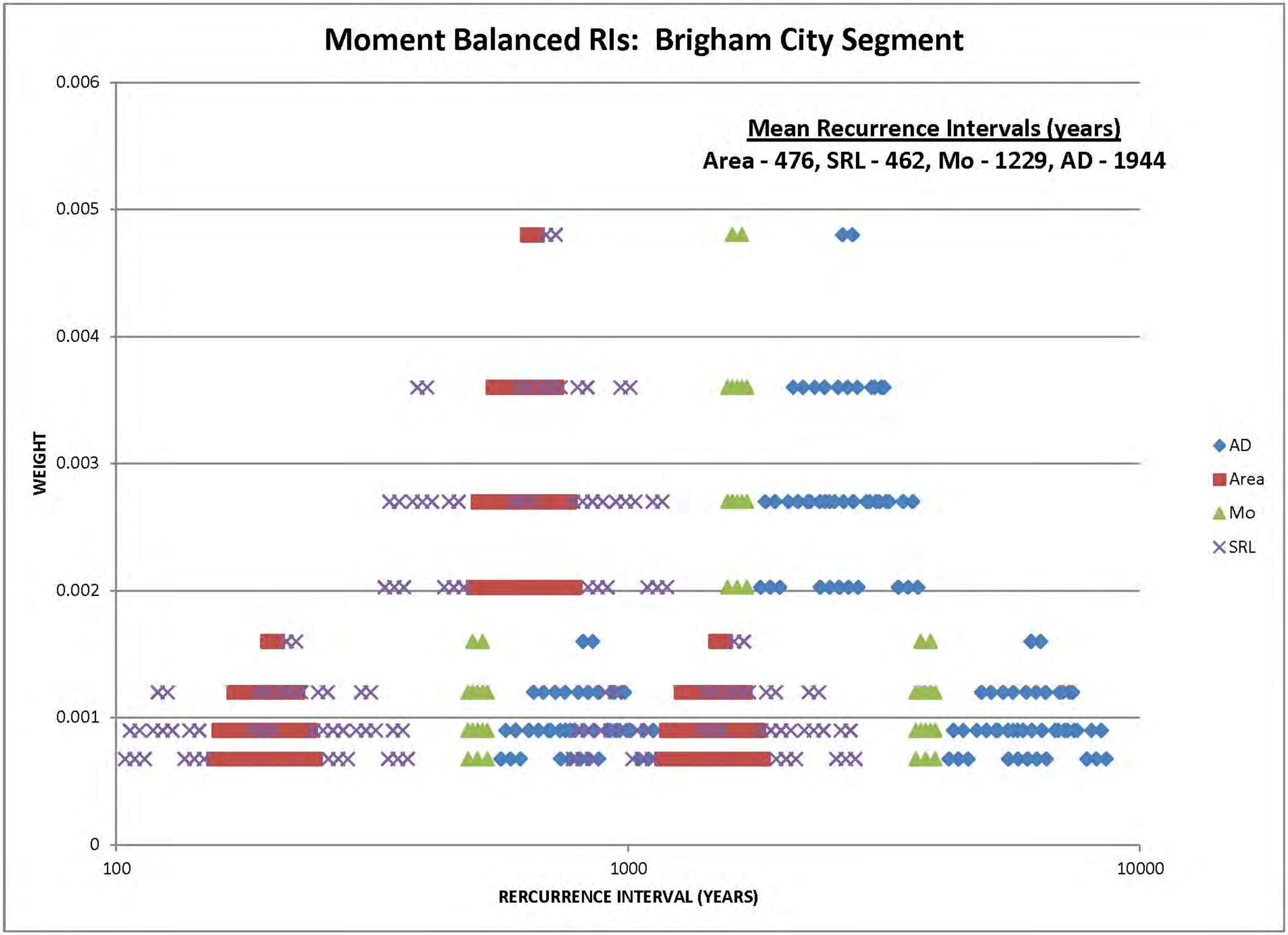
Moment Balanced with UQFPWG Slip Rates weighted 0.2, 0.6, 0.2

2 Magnitude Recurrence Models equally weighted
(Mmax, sigma=0.12, Characteristic, boxcar 0.5 magnitude units wide)

% Moment in "Smaller" Events: 6. (0.3), 8. (0.4), 10. (0.3)

Little sensitivity to Magnitude Recurrence Model and % Moment in Smaller Events (Exp. Tail)

Example: Moment-Balanced RIs for Wasatch Single Segment Model



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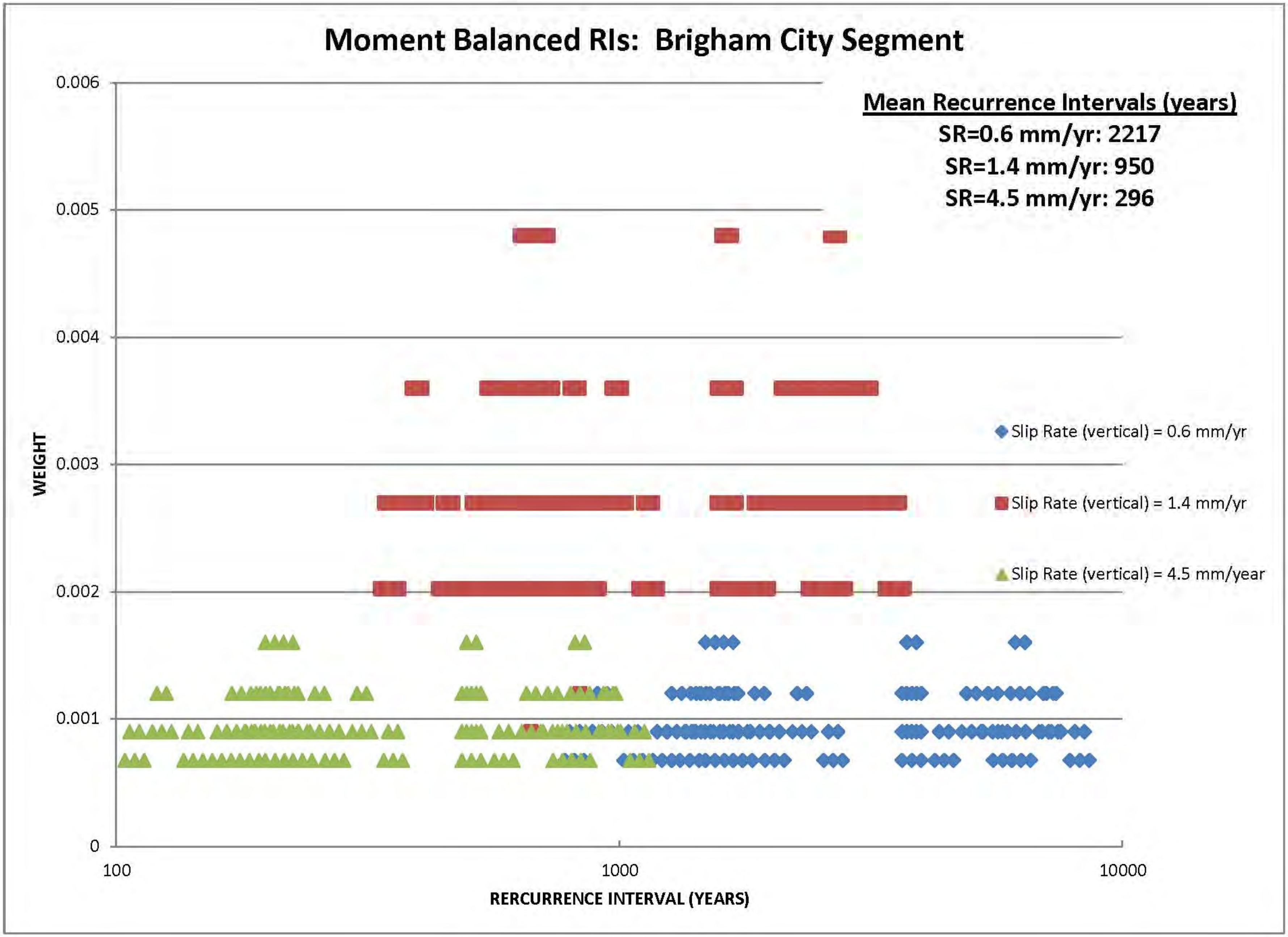
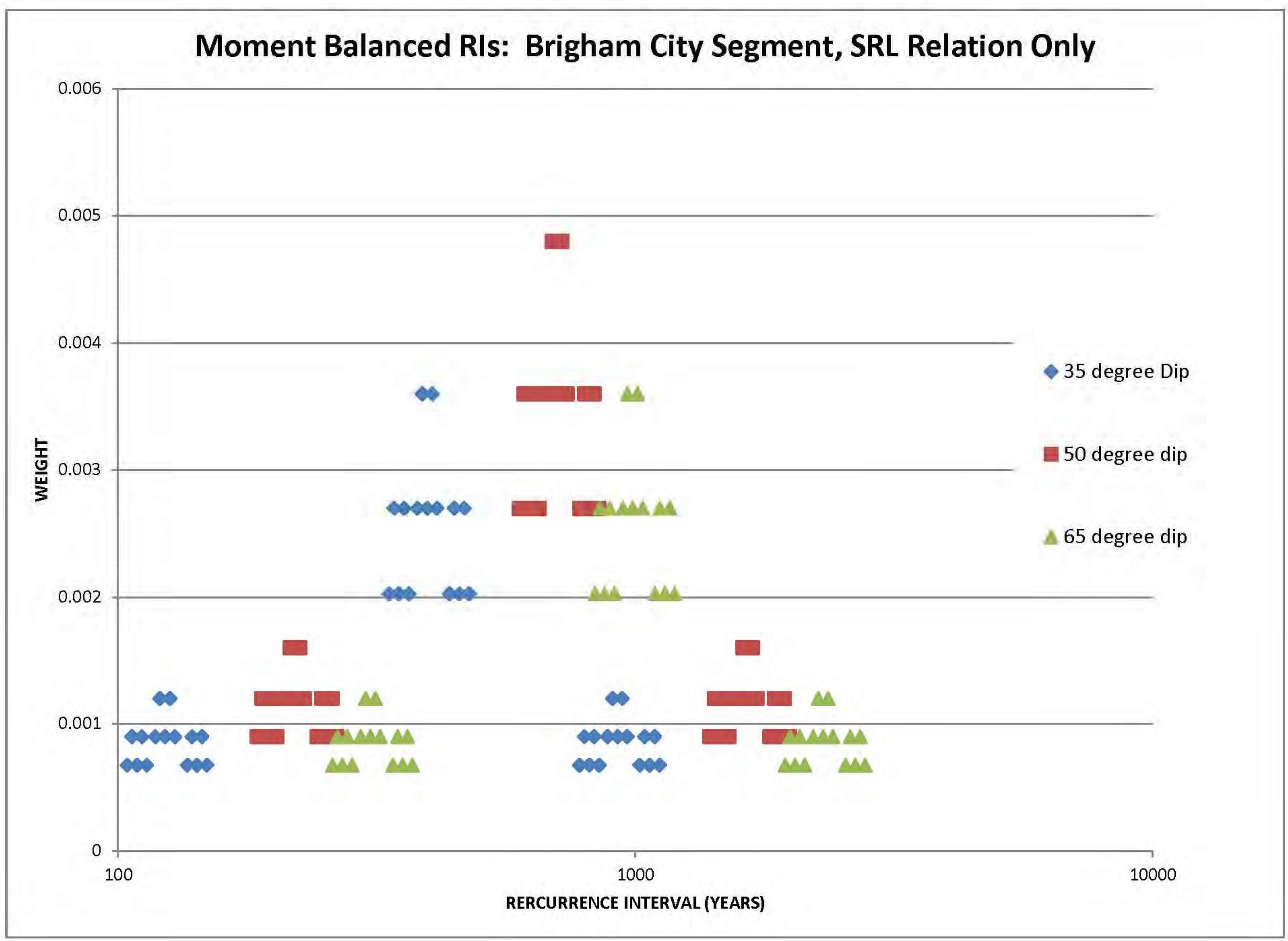
Example: Moment-Balanced Ris for Wasatch Single Segment Model



Example: Moment-Balanced Ris for Wasatch Single Segment Model



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Example: Moment-Balanced RIs for Wasatch Single Segment Model

Sensitivity to MCHAR Relation

Segment	RI - SRL	RI - Area	RI - AD	RI - Mo
Brigham City	462	476	1944	1229
Weber	701	640	1520	1465
Salt Lake City	567	567	2045	1428
Provo	861	1905	1917	1905
Nephi	721	1664	2199	1664

Sensitivity to Slip Rate Relation

Segment	Mean SR	Low SR	High SR
Brigham City	950	2217	296
Weber	1310	2619	365
Salt Lake City	1159	2318	348
Provo	1372	2744	549
Nephi	1282	2821	470

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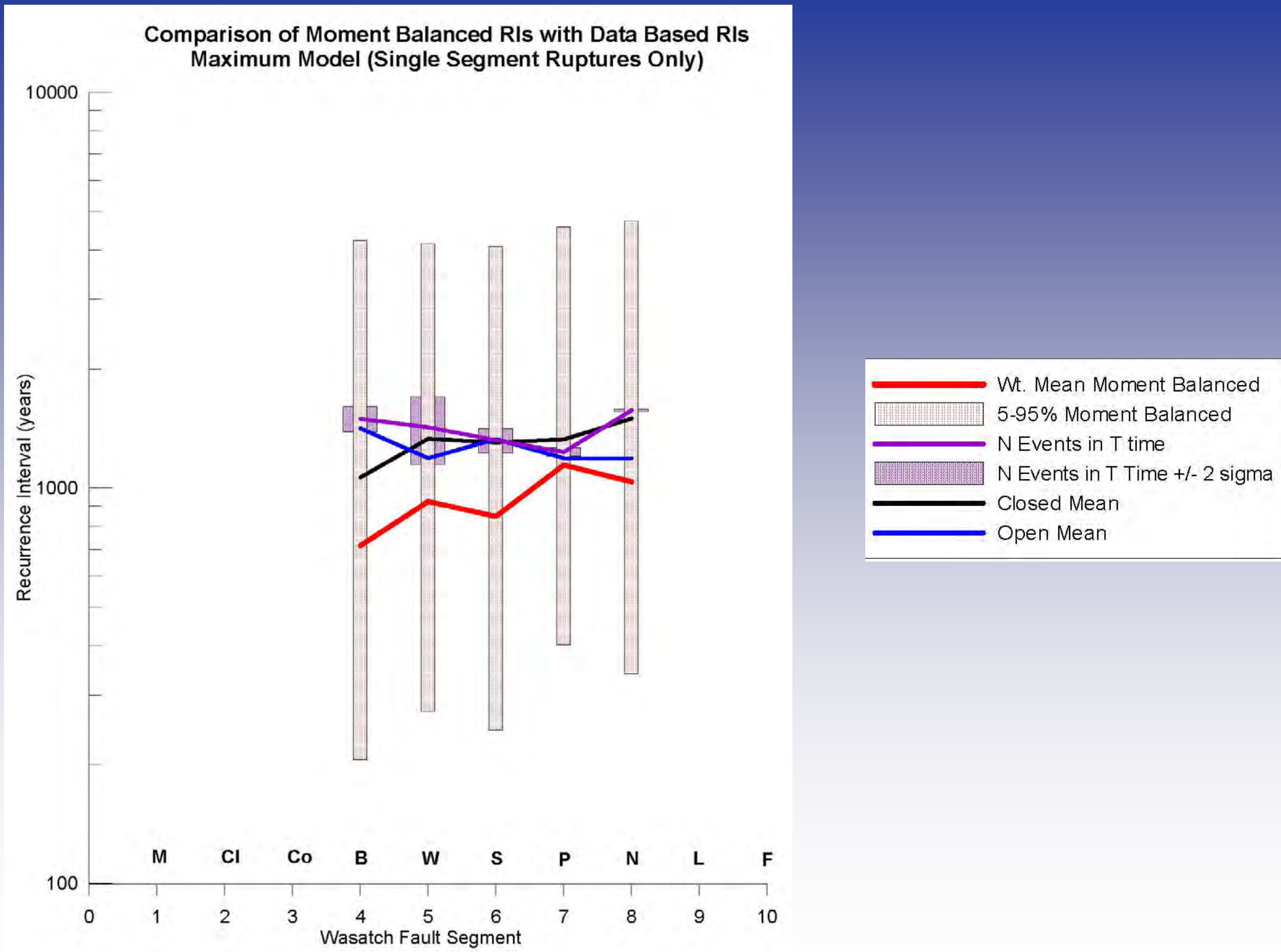
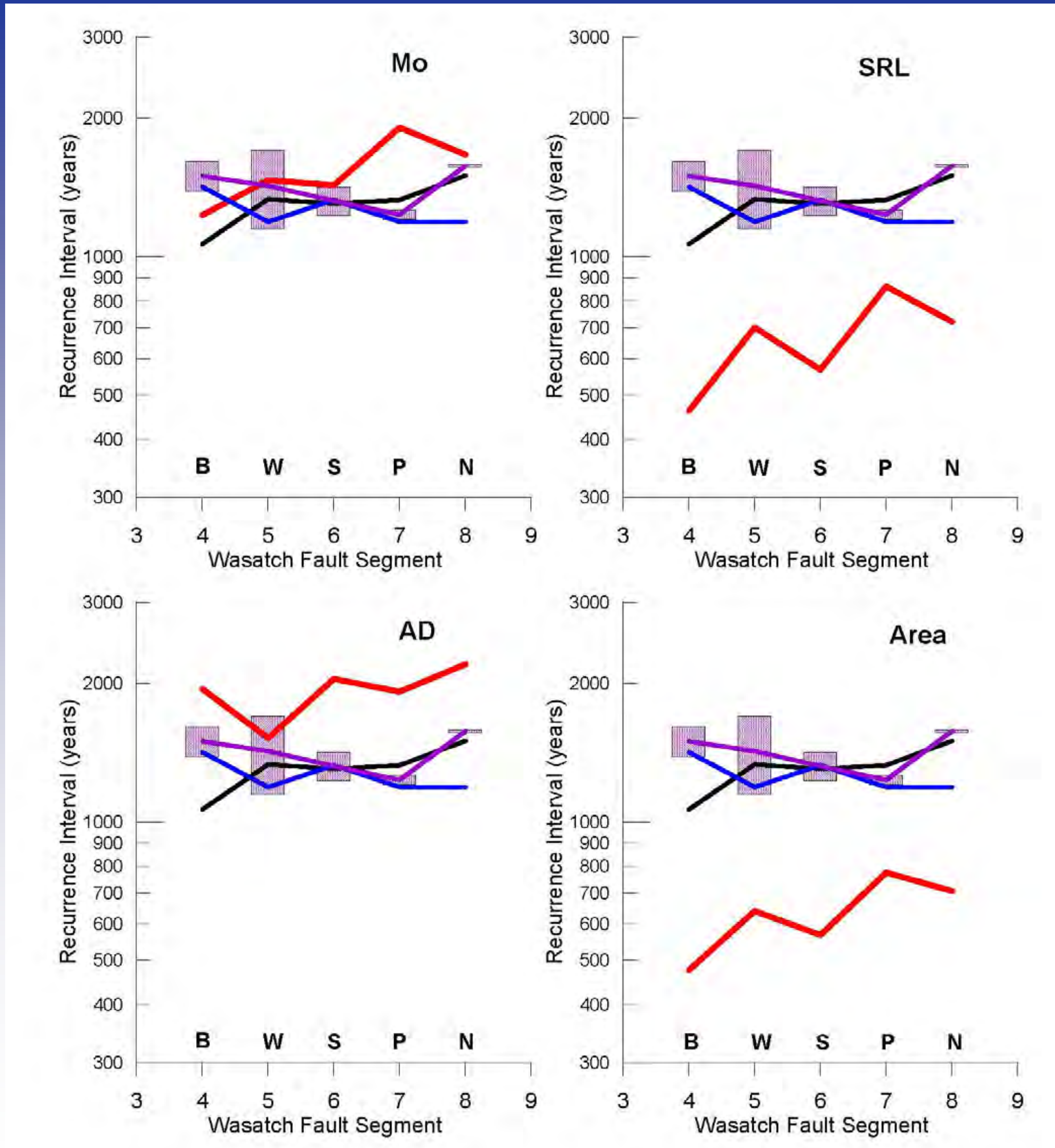


Comparison of Moment Balanced RIs with Data Based RIs
Maximum Model (Single Segment Ruptures Only)
Recurrence Interval (years)
10000
1000
100
M
Cl
Co
B
W
S
P
N
L
F
0
1
2
3
4
5
6
7
8
9
10
Wasatch Fault Segment
Wt. Mean Moment Balanced
5-95% Moment Balanced
N Events in T time
N Events in T Time +/- 2 sigma
Closed Mean
Open Mean



Mo
SRL
AD
Area
Recurrence Interval (years)
3000
2000
1000
900
800
700
600
500
400
300
B
W
S
P
N
3
4
5
6
7
8
9
Wasatch Fault Segment

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Implied Slip Rates from A-priori rates

Segment	Wt. Mean Slip Rate	Wt. Mean UQFWG Slip Rate
Brigham City	1.35	1.86
Weber	1.37	1.70
Salt Lake City	1.51	1.64
Provo	1.69	1.44
Nephi	1.21	1.36

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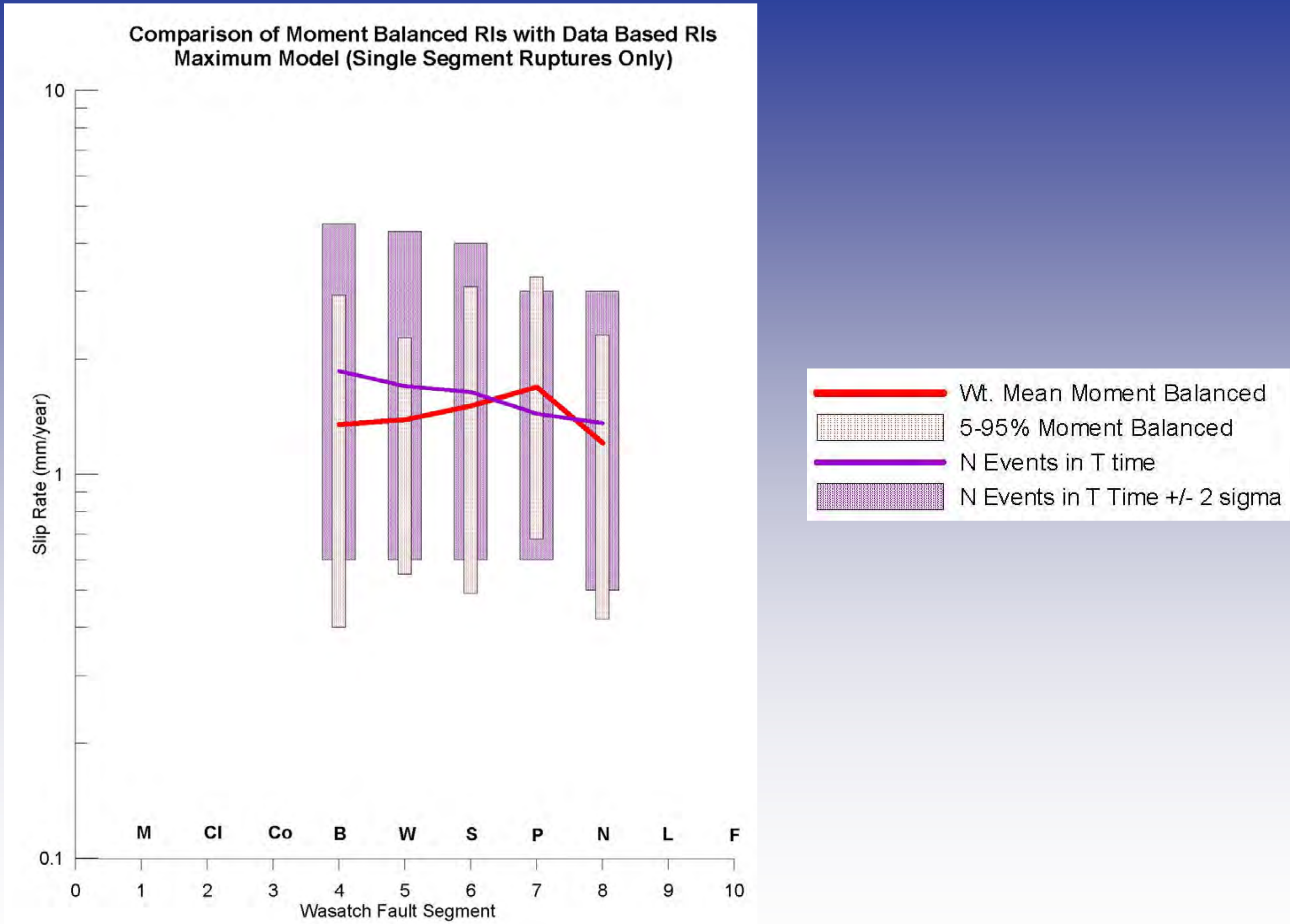
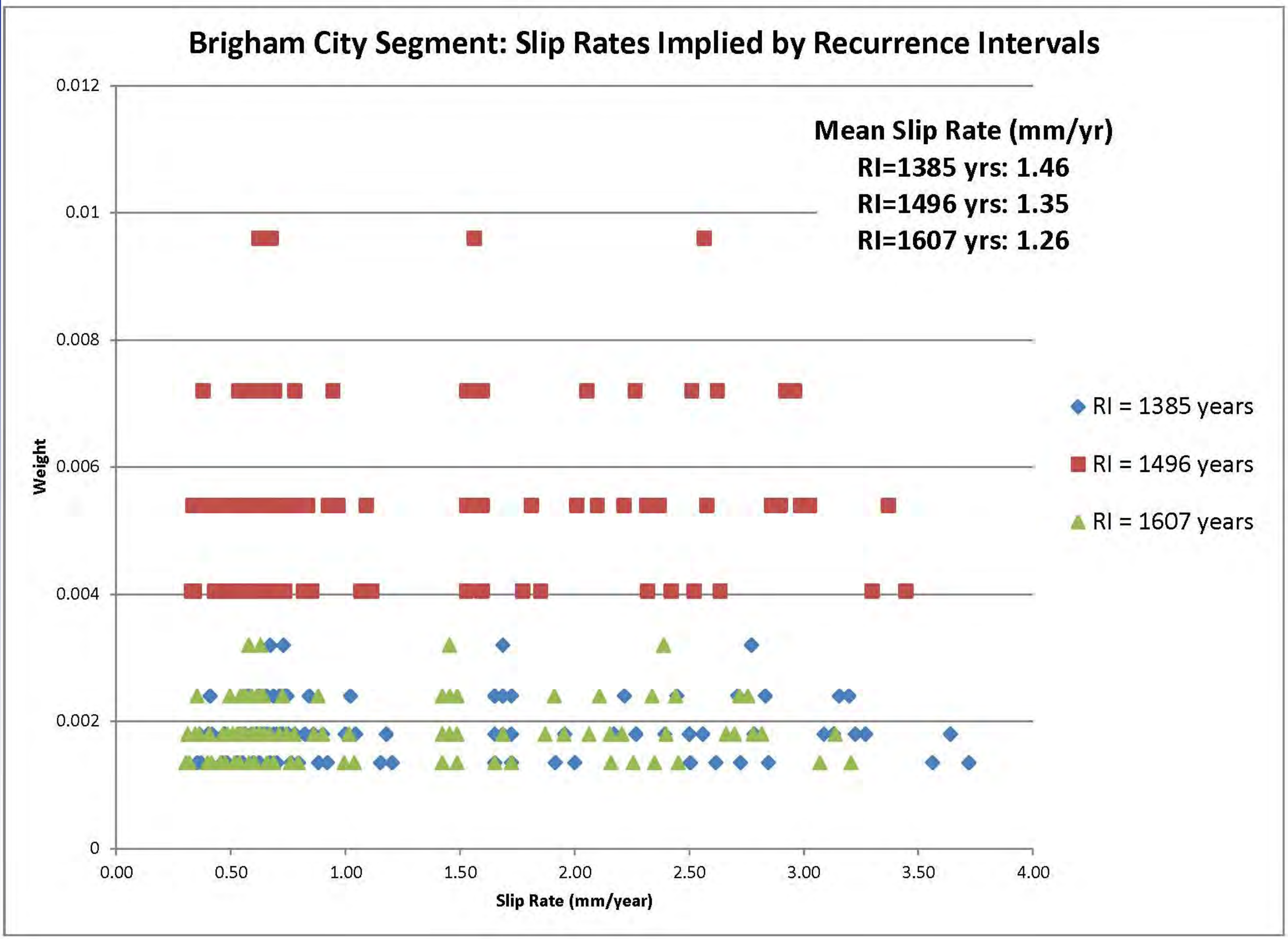
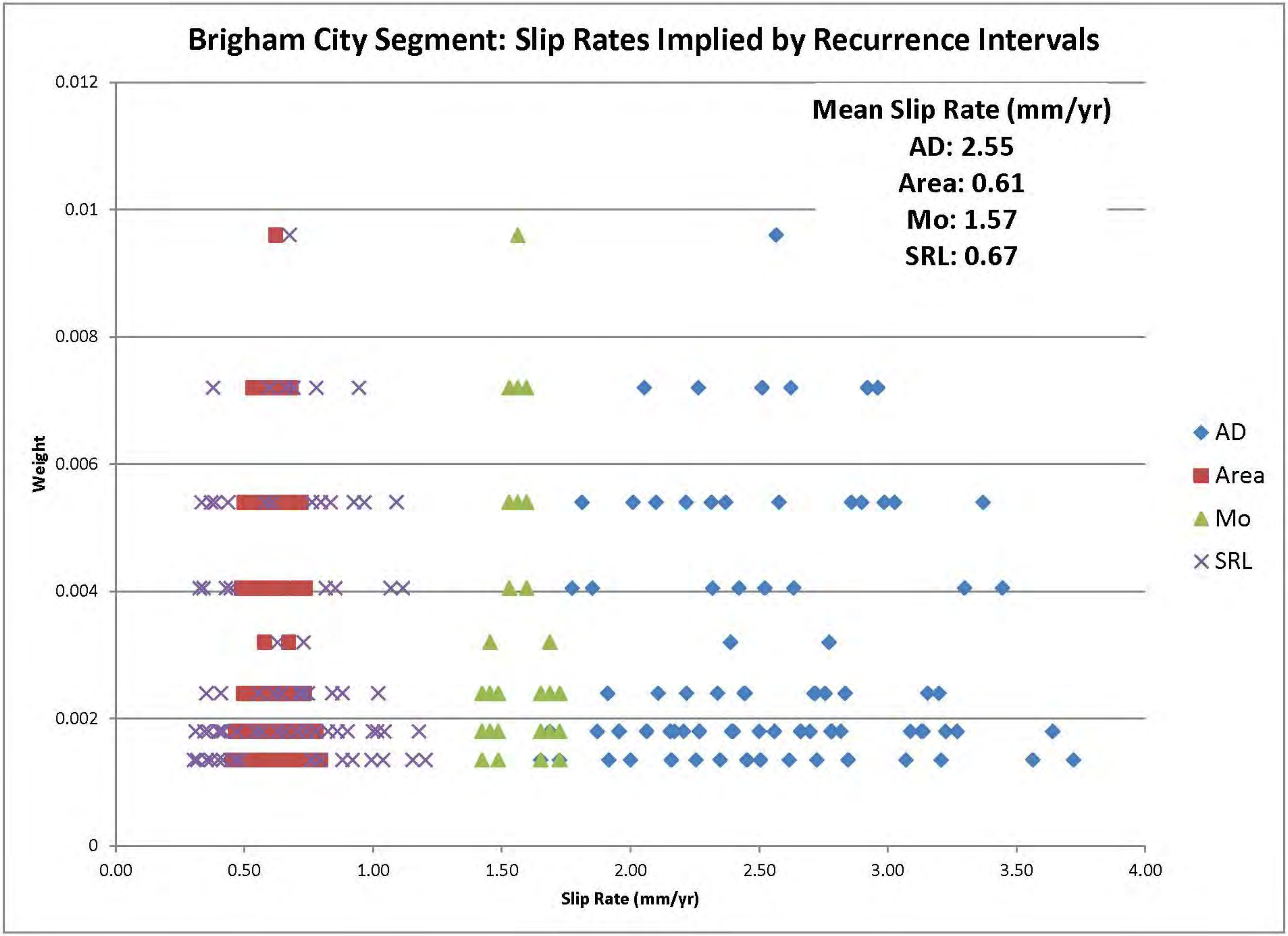

Comparison of Moment Balanced RIs with Data Based RIs
Maximum Model (Single Segment Ruptures Only)
10
1
0.1
Slip Rate (mm/year)
M
Cl
Co
B
W
S
P
N
L
F
0
1
2
3
4
5
6
7
8
9
10
Wasatch Fault Segment
Wt. Mean Moment Balanced
5-95% Moment Balanced
N Events in T time
N Events in T Time +/- 2 sigma



Brigham City Segment: Slip Rates Implied by Recurrence Intervals
Mean Slip Rate (mm/yr)
RI=1385 yrs: 1.46
RI=1496 yrs: 1.35
RI=1607 yrs: 1.26
RI = 1385 years
RI = 1496 years
RI = 1607 years
Weight
0.012
0.01
0.008
0.006
0.004
0.002
0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Slip Rate (mm/year)



Brigham City Segment: Slip Rates Implied by Recurrence Intervals
Mean Slip Rate (mm/yr)
AD: 2.55
Area: 0.61
Mo: 1.57
SRL: 0.67
Weight
0.012
0.01
0.008
0.006
0.004
0.002
0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Slip Rate (mm/yr)
AD
Area
Mo
SRL

PART 2: Multisegment Rupture Source Rates

- **A-priori (Data Driven) rupture rates**
  - *Is there enough data to determine RIs?*
- **Moment-balanced rupture rates**
  - *Slip distribution for multisegment ruptures required*
    - *Characteristic Slip (WGCEP 1995)* $D_{sr} = D_s$
    - *WG2002 Model* $D_{sr} \propto SR_s$
    - *Uniform Slip* $D_{sr} = D_r$
    - *Tapered Slip* $[\mathrm{Sin}(x)]^{0.5}$ *(UCERF2)*

PART 2: Other Faults: M_{CHAR} and Rupture Rates

- M_{CHAR}
  - Wells and Coppersmith – A *(B, C Faults)*
  - Wells and Coppersmith – SRL *(B, C Faults)*
  - Hemphill-Haley and Weldon – AD *(B Faults)*
  - *Distribution on Length, dip, seismogenic thickness, AD?*
- Rupture Rates
  - A-priori rates (1/RI)
    - *RIs provided for very few faults, weighting?*
  - Moment-balanced rates using slip rates

URS

PART 4: Probability Inputs

- **Poisson Model –** *Other faults, Unsegmented Model for Wasatch, EGSL*
  - ***Rupture rates***
- **BPT Model –** *Wasatch , EGSL Segmented Models*
  - **COV**

    Used for each rupture source; Is there enough data for independent COVs for each rupture source?
  - **MRE**

PART 5: Probability Calculations

Example: Wasatch Single Segment Model Using Moment-Balanced Rates

Segment	Poisson	BPT, a=0.7	BPT, a=0.5	BPT, a=0.3
Brigham City	6.5 %	7.7%	11.6%	18.1%
Weber	5.7 %	6.2 %	7.3 %	10.0 %
Salt Lake City	5.7 %	7.1%	10.0 %	16.0%
Provo	4.7 %	5.0%	5.5 %	6.9%
Nephi	4.8 %	3.8 %	3.1 %	3.0 %
5 Central Segments	24.1 %	26.5%	32.5 %	44.1 %

MRE (years): B = 2478, W = 622, S = 1404, P = 637, N = 267

Wt. Mean RI* (years): B = 715, W = 924, S = 848, P = 1143, N = 1037

URS

PART 5: Probability Calculations

Example: Wasatch Single Segment Model Using A-priori Rates (1/RIs)

Segment	Poisson	BPT, a=0.7	BPT, a=0.5	BPT, a=0.3
Brigham City	3.4 %	4.6 %	6.9 %	14.0 %
Weber	4.0 %	4.1 %	2.8 %	0.7 %
Salt Lake City	4.0 %	5.6 %	7.3 %	11.8 %
Provo	4.6 %	5.2 %	4.3 %	1.5 %
Nephi	3.4 %	0.5 %	0.02 %	0.0 %
5 Central Segments	17.9 %	18.5 %	19.8 %	25.9 %

MRE (years): B = 2478, W = 622, S = 1404, P = 637, N = 267

Wt. Mean RI (years): B = 1496, W = 1423, S = 1321, P = 1233, N = 1572

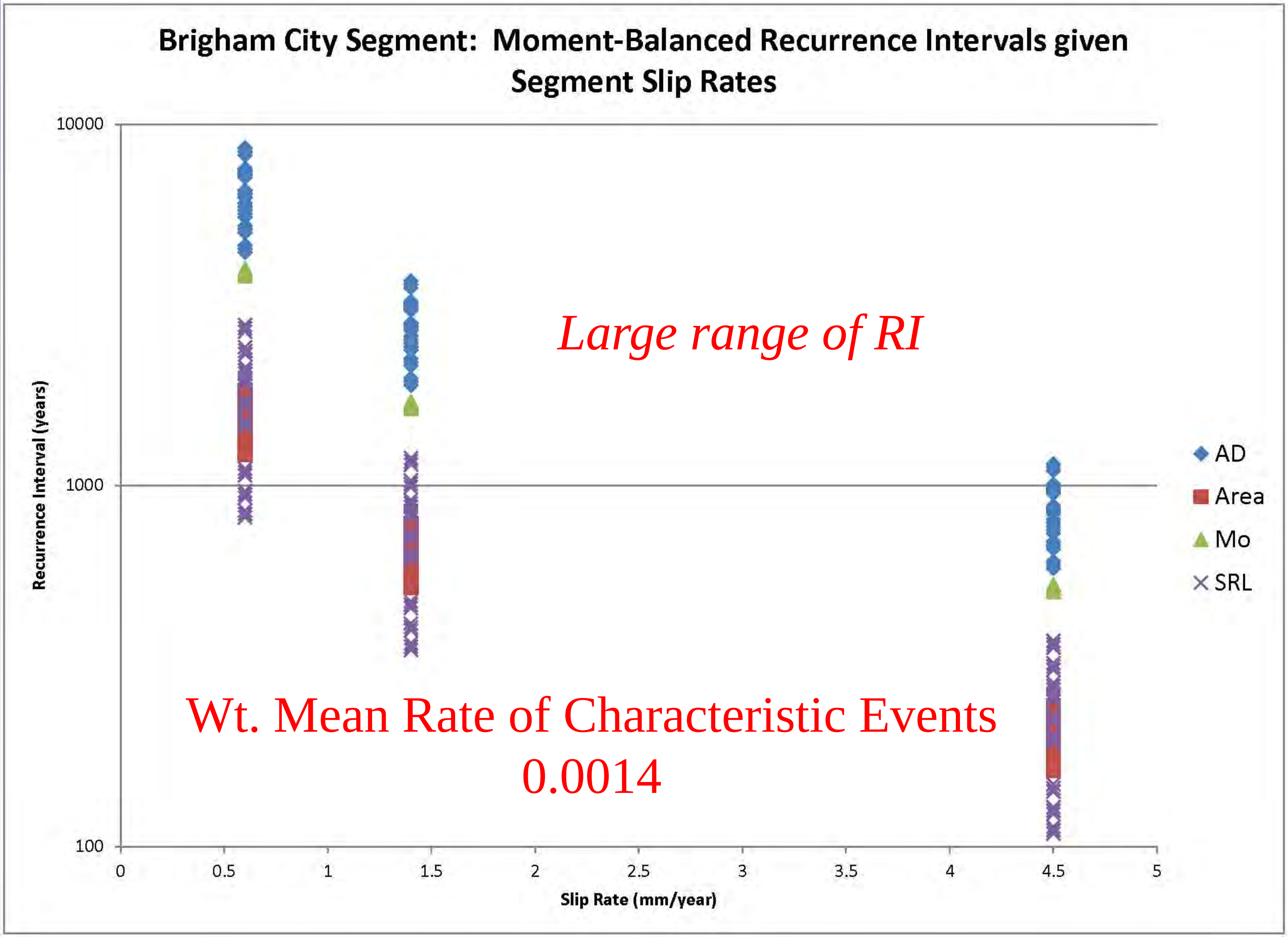
Wasatch Single Segment Model : A Closer Look

Brigham City Segment	Slip Rate (mm/yr)	RI (years)	Poisson Probability (%)
Moment-Balanced Rates – Wt. Mean Inputs Only	1.86	1037	6.0
Moment-Balanced Rates – All Branches (Wt. Mean)	1.86	715	6.5
A-priori Rates (1/RI) – Wt. Mean Inputs Only	1.36	1496	3.4
A-priori Rates (1/RI) – All Branches (Wt. Mean)	1.35	1496	3.4

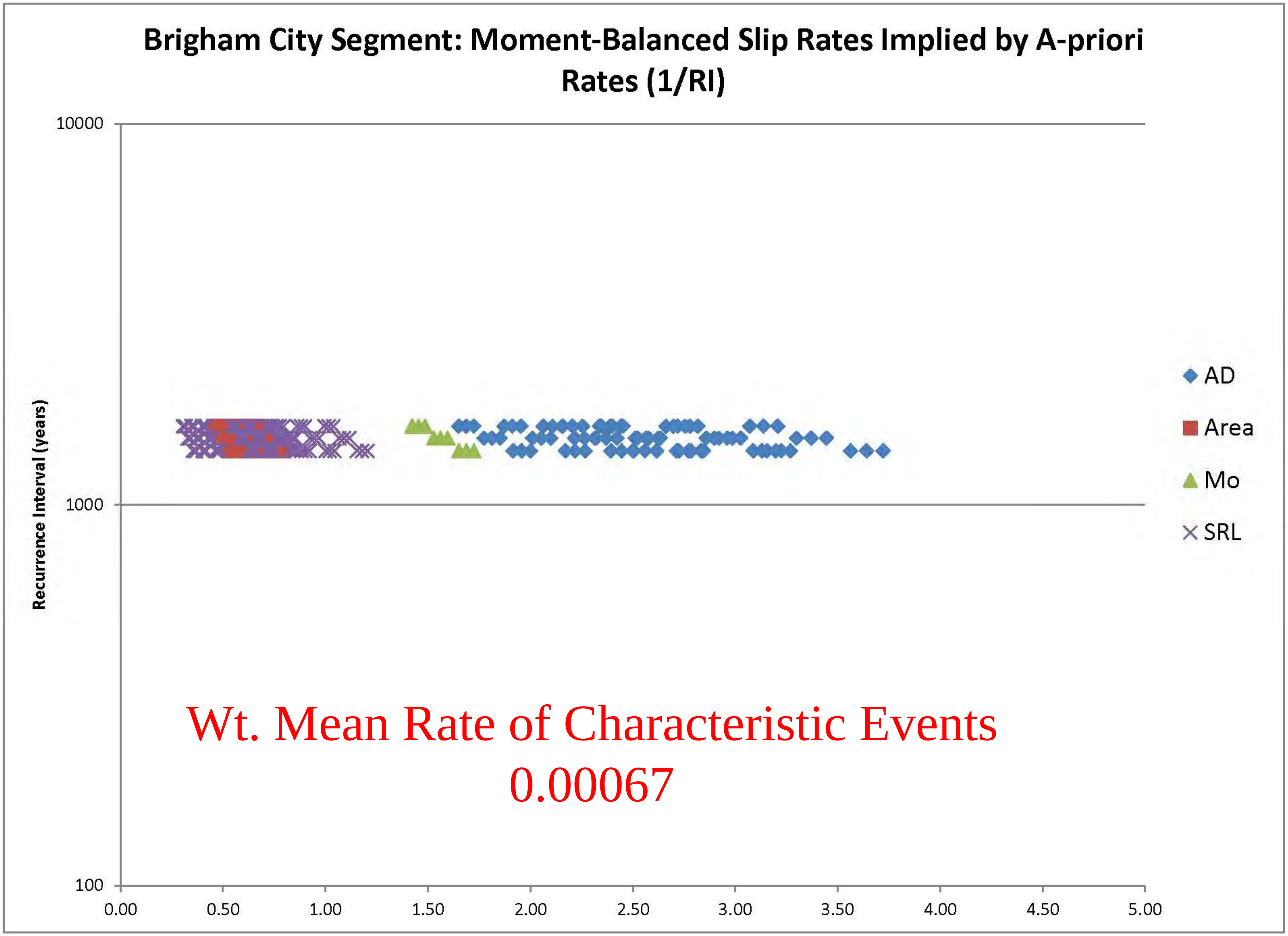
Provo Segment	Slip Rate (mm/yr)	RI (years)	Poisson Probability (%)
Moment-Balanced Rates – Wt. Mean Inputs Only	1.44	1490	3.9
Moment-Balanced Rates – All Branches (Wt. Mean)	1.44	1143	4.7
A-priori Rates (1/RI) – Wt. Mean Inputs Only	1.70	1233	4.5
A-priori Rates (1/RI) – All Branches (Wt. Mean)	1.69	1233	4.5

URS

Wasatch Single Segment Model : A Closer Look



Wasatch Single Segment Model : A Closer Look



Summary of Inputs Required

- Geometry
  - Segment endpoints
  - Seismogenic thickness
  - Dip
- Regional moment rate constraint?
- Mean Characteristic Magnitude models
- Average displacement for rupture sources

URS

Summary of Inputs Required

- Magnitude Probability Density models
- Fault rupture models (rupture sources, models, weights)
- Distribution of Slip for multisegment ruptures
- Background seismicity parameters
- Probability models and weights
- Probability model parameters
  - Time since last event, COV

WGUEP
Paleoseismology Subgroup Update

Christopher B. DuRoss
Anthony J. Crone
Stephen F. Personius
Susan Olig
William R. Lund

Working Group on Utah Earthquake Probabilities June, 2011

Tasks

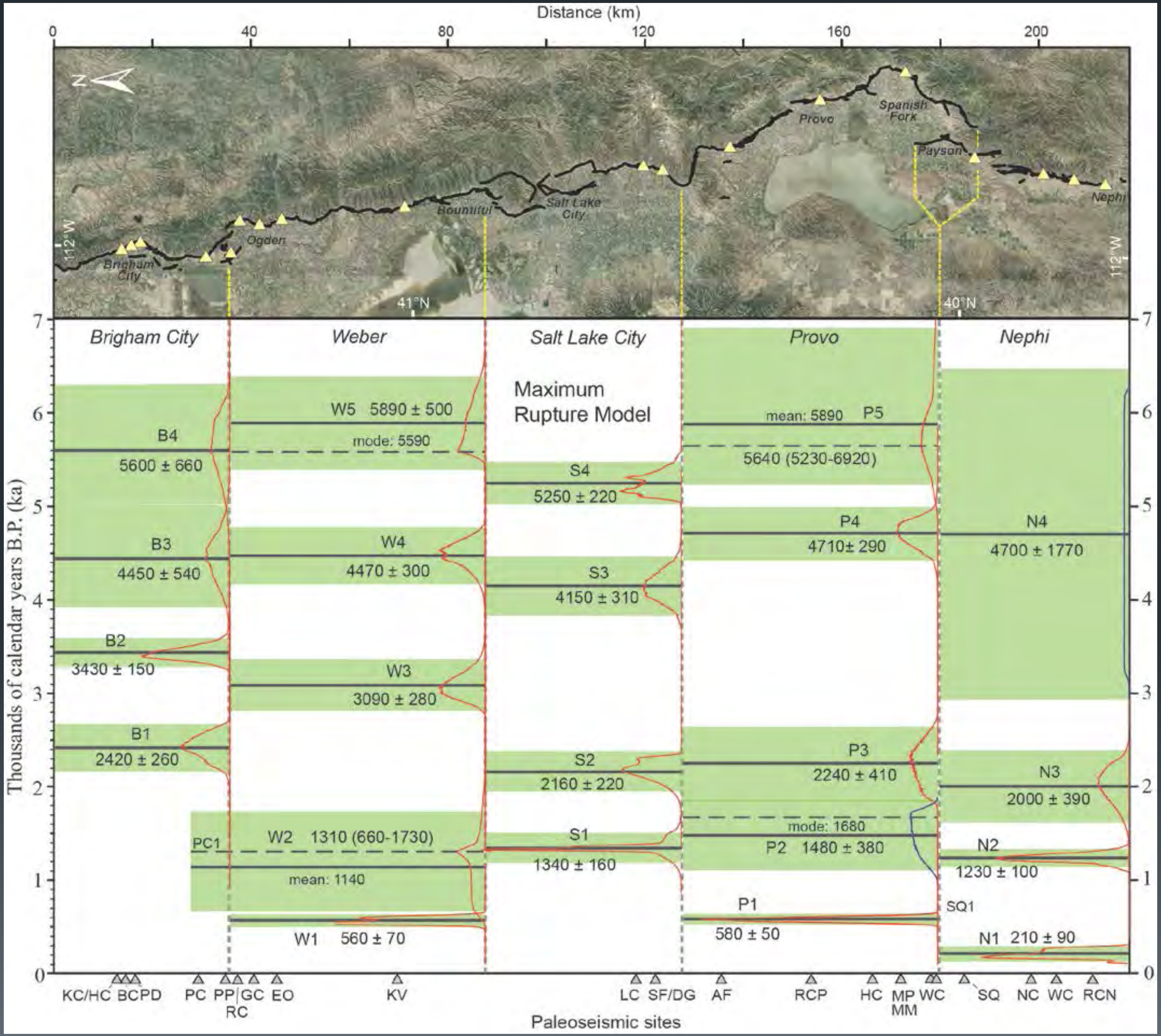
1. Weight WFZ rupture scenarios
2. Sum moment release per segment per scenario
3. Plot magnitude frequency distributions for rupture scenarios
4. COV's (?)

1. Weight WFZ Rupture Scenarios

Central WFZ Rupture Scenarios

- Maximum Rupture Model (22 EQs)
- Minimum Rupture Model (14 EQs)
- Intermediate Rupture Model A (19 EQs)
- Intermediate Rupture Model B (19 EQs)
- Intermediate Rupture Model C (20 EQs)
- Unsegmented Earthquake Model

Maximum Rupture Model



- **Mean** – solid horiz. line
- **Mode** –dashed, if >100-yr from mean
- **Box** is 2σ range

Earthquake Recurrence

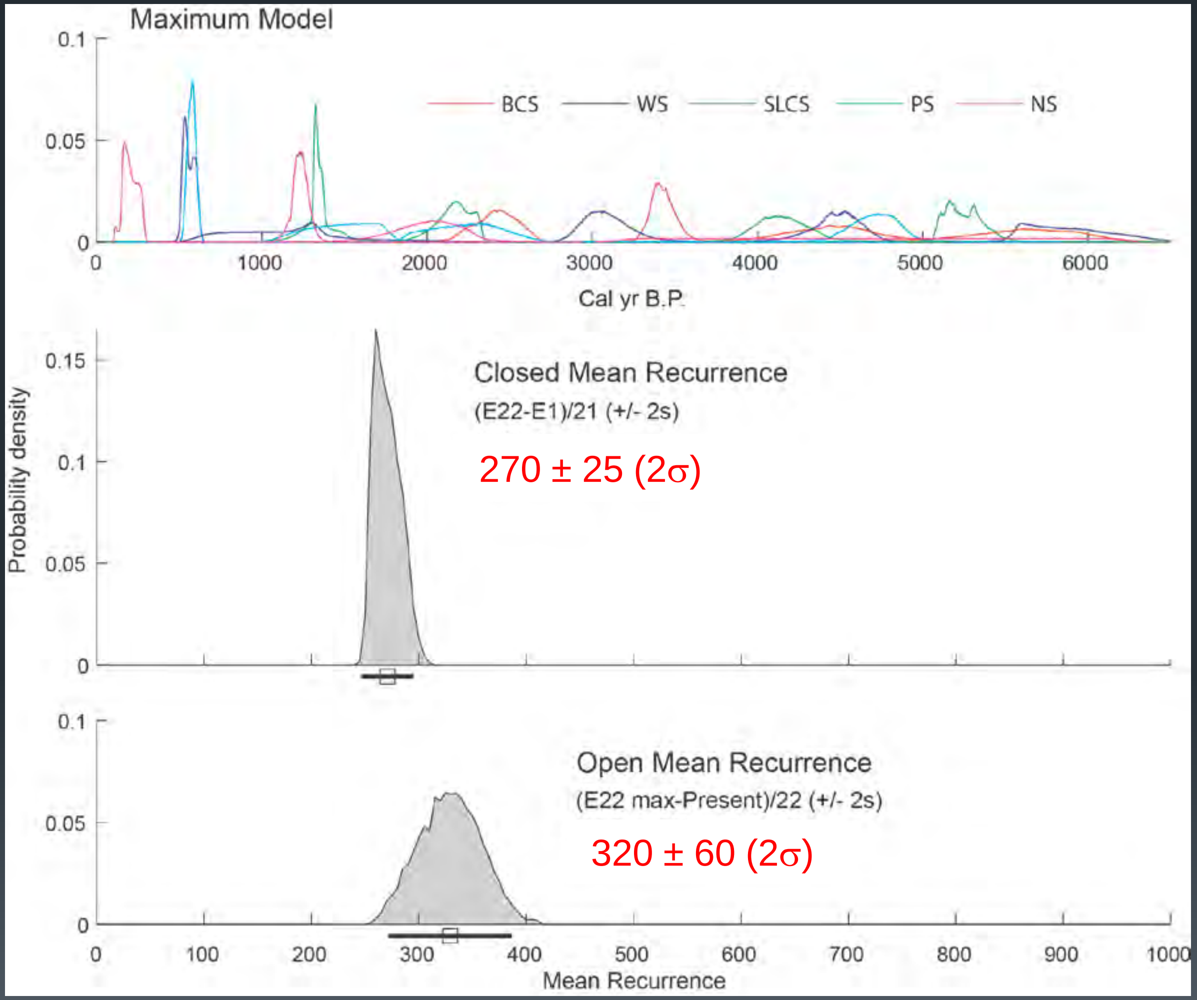
- Closed mean: intervals between observed events
- N events in T time: number of events in observed time window (elapsed time from maximum age for oldest event to present)

	Closed mean	N events/T time	MRE elapse time
BCS (E4-E1)	1060 ± 240 yr	1500 ± 110 yr (<5.9 ka)	2480 ± 260 yr
WS (E5-E1)	1330 ± 120 yr	1420 ± 270 yr (<7.1 ka)	620 ± 70 yr
SLCS (E4-E1)	1300 ± 90 yr	1320 ± 90 yr (<5.2 ka)	1400 ± 160 yr
PS (E5-E1)	1330 ± 250 yr	1233 ± 0 yr (<6.1 ka)	640 ± 50 yr
NS (E3-E1)	900 ± 200 yr	1080 ± 20 yr (<3.2 ka)	270 ± 90 yr
NS (E4-E1)	1500 ± 590 yr	1570 ± 10 yr (<6.2 ka)	270 ± 90 yr

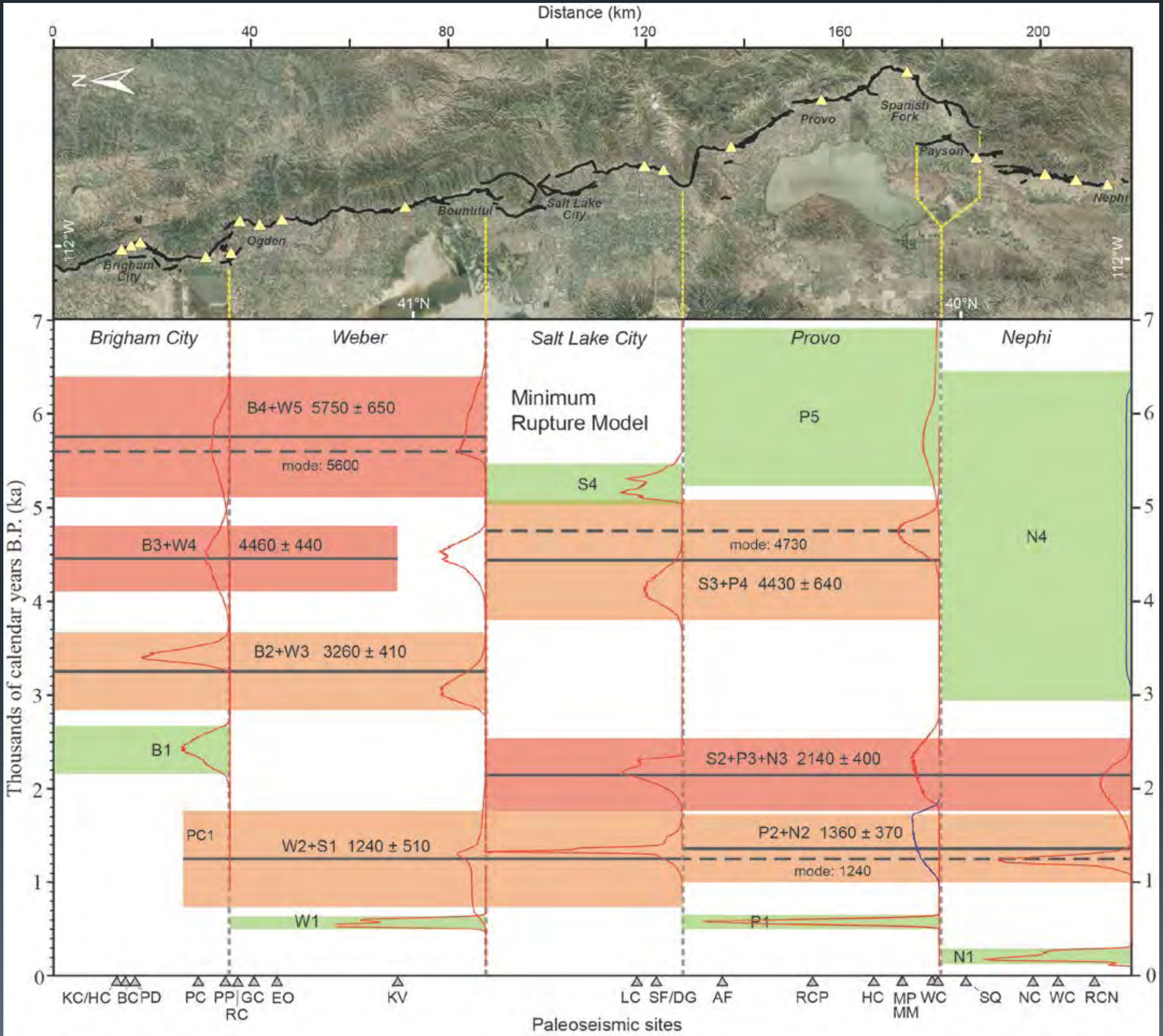
all uncertainties ± 2 sigma

Maximum Rupture Model

- 22 Earthquakes
  - All one-segment, but including leaky-boundary rupture from W2 to PC1 (southern Brigham City seg.)
- Recurrence:
  - Closed mean recurrence: 270 ± 25 yr (2σ)
  - N events in T time (open mean): 320 ± 60 yr (22 events in 7.3 ky)



Minimum Rupture Model

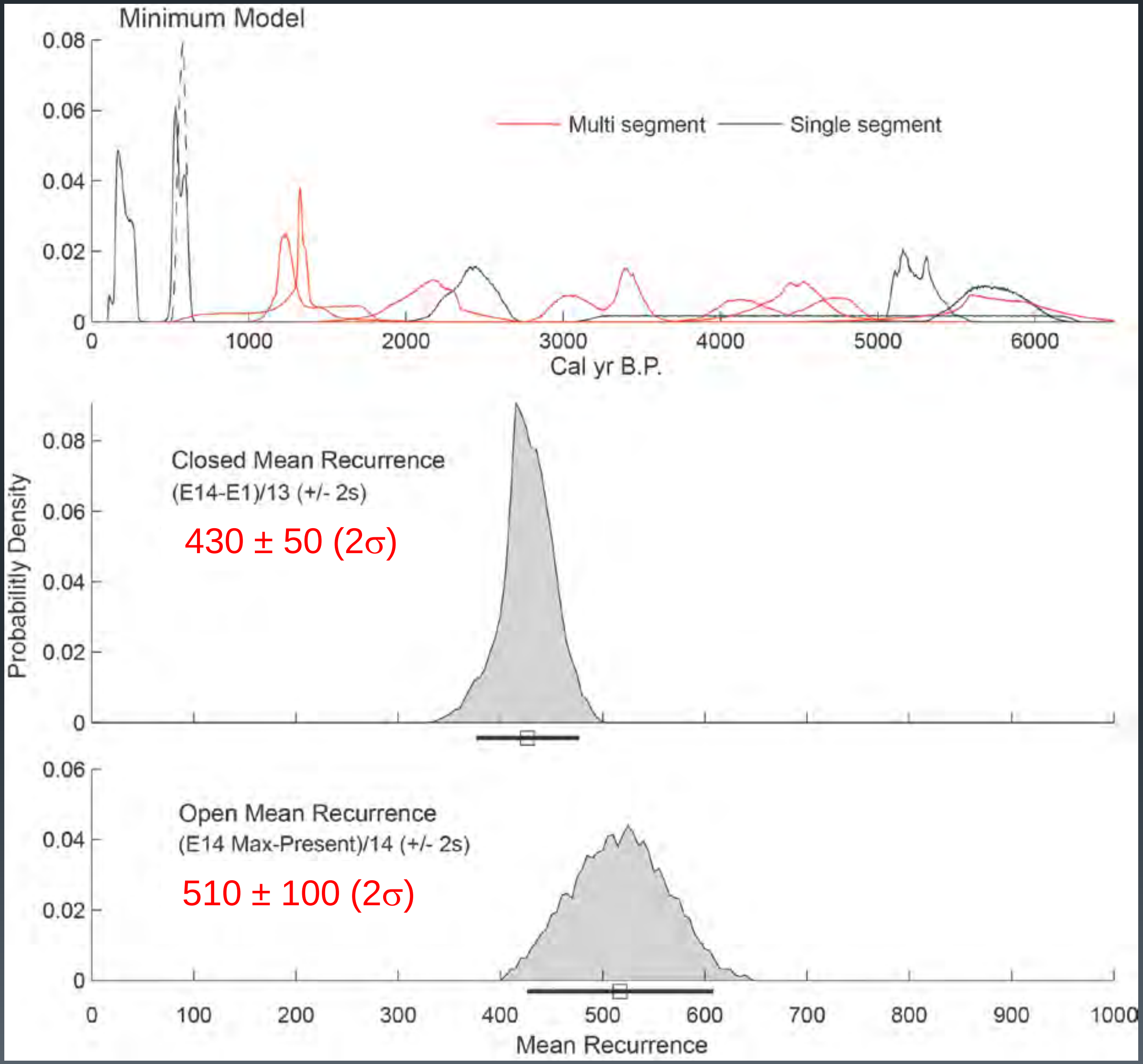


- **Red** – PDF overlap > 0.5
- **Orange** – PDF overlap < 0.5

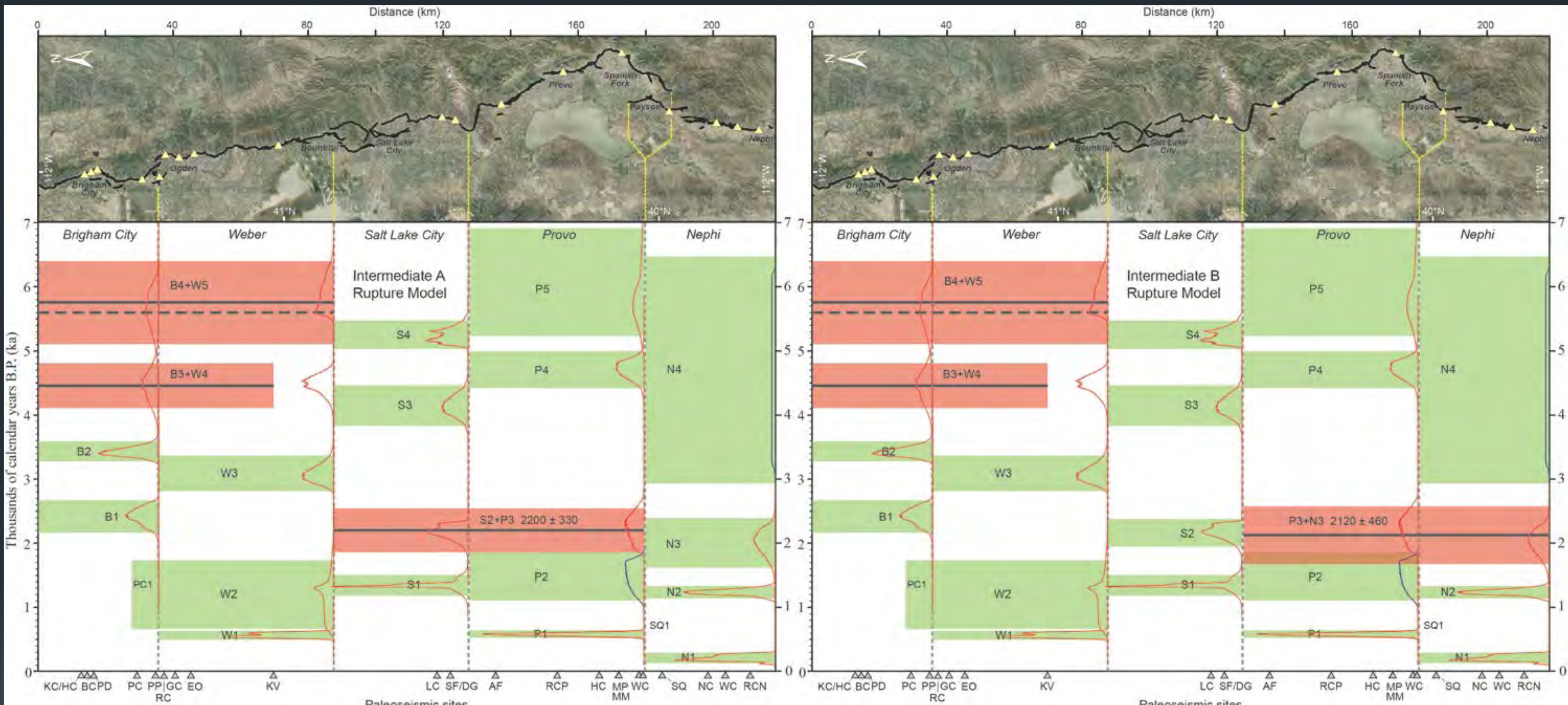
- **Mean** – solid horiz. line
- **Mode** –dashed, if >100-yr from mean
- **Box** is 2σ range

Minimum Rupture Model

- 14 Earthquakes
  - 7 one-segment (previously 6 – excluding P5)
  - 6 two-segment
  - 1 three-segment
- Recurrence:
  - Closed mean recurrence: 430 ± 50 yr (2σ)
  - N events in T time: 510 ± 100 yr (14 events in 7.3 ky)



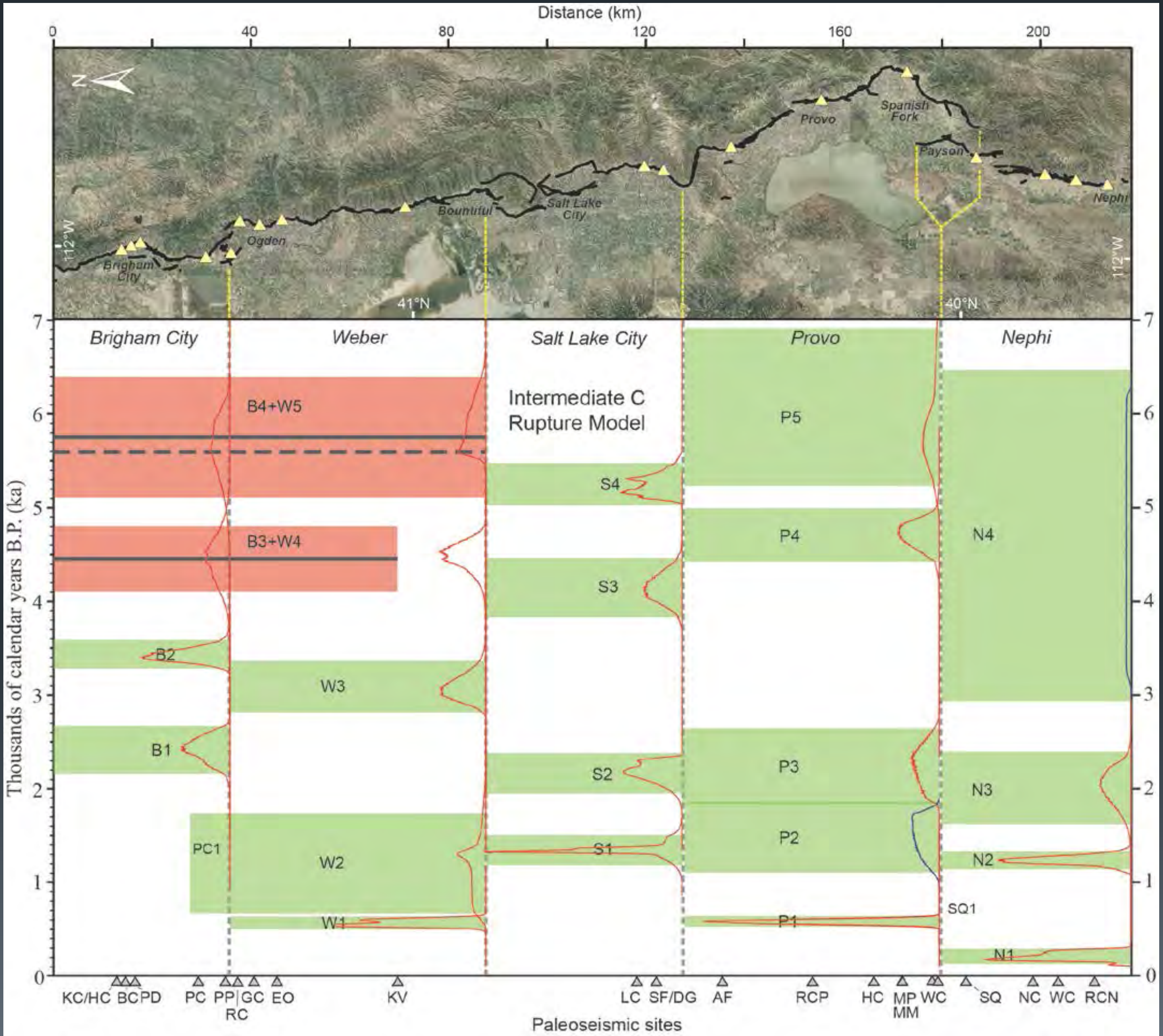
Intermediate Rupture Models



- Model A
  - B4+W5, B3+W4
  - S2+P3, N3
- Model B
  - B4+W5, B3+W4
  - S2, P3+N3

Intermediate Rupture Models

- Model C
  - B4+W5
  - B3+W4
  - S2
  - P3
  - N3



- **Mean** – solid horiz. line
- **Mode** –dashed, if >100-yr from mean
- **Box** is 2σ range

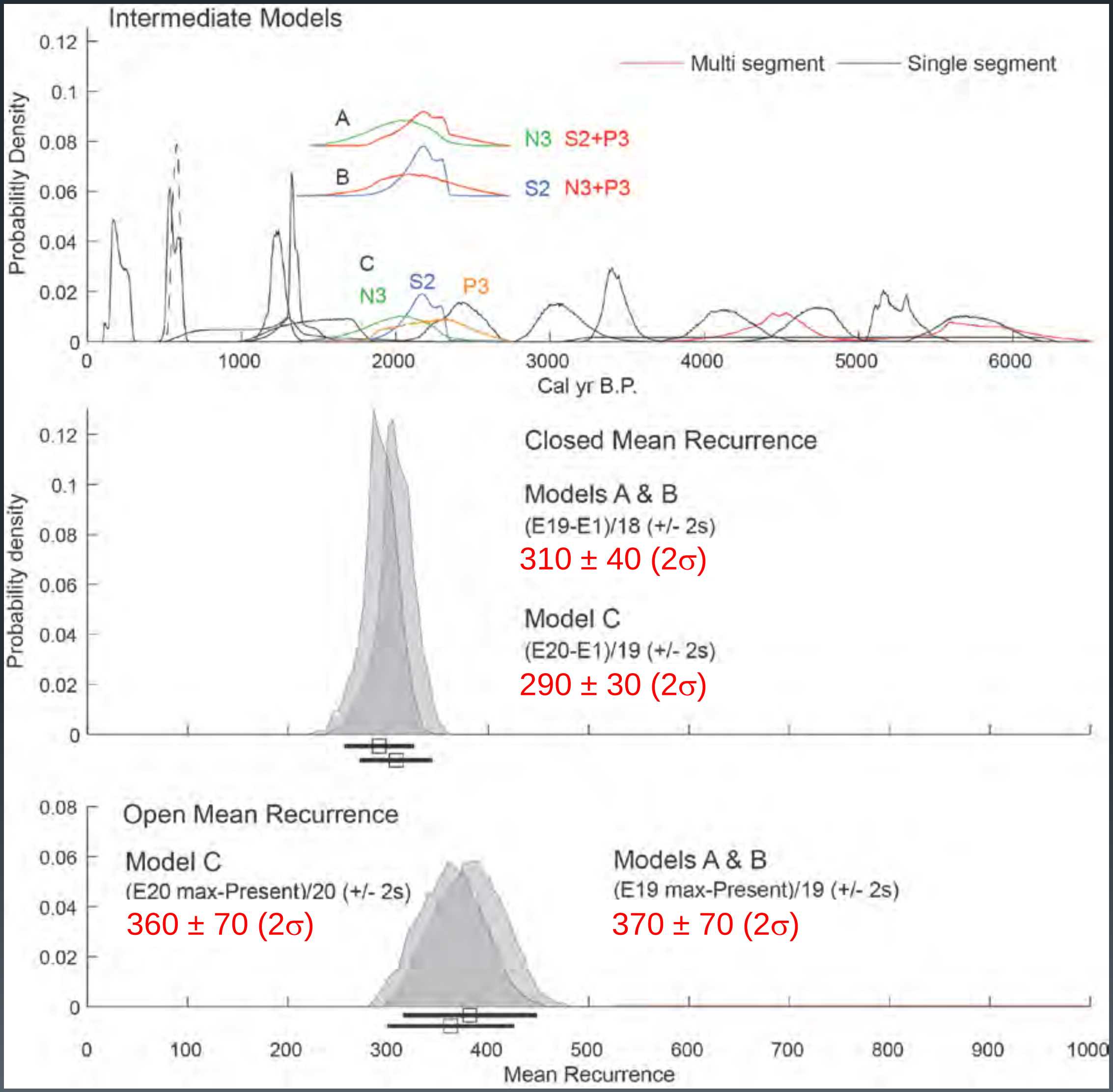
Intermediate Rupture Models

Models A & B

- 19 Earthquakes
  - 16 one-segment
  - 3 two-segment
- Recurrence:
  - Closed mean recurrence: 310 ± 40 yr (2σ)
  - N events in T time: 370 ± 70 yr (19 events in 7.3 ky)

Model C

- 20 Earthquakes
  - 18 one-segment
  - 2 two-segment
- Recurrence:
  - Closed mean recurrence: 290 ± 30 yr (2σ)
  - N events in T time: 360 ± 70 yr (20 events in 7.3 ky)



1. WFZ Rupture Scenarios

Central WFZ Rupture Scenarios

➢ Maximum Rupture Model (22 EQs)	50%
➢ Minimum Rupture Model (14 EQs)	5%
➢ Intermediate Rupture Model A (19 EQs)	10%
➢ Intermediate Rupture Model B (19 EQs)	10%
➢ Intermediate Rupture Model C (20 EQs)	15%
➢ Unsegmented Earthquake Model	10%

1. WFZ Rupture Scenarios

Central WFZ Rupture Scenarios

- Maximum Rupture Model (22 EQs) 50%

Our preference is for single-segment ruptures on the WFZ (maximum rupture model),

- Differences in earthquake timing
- Per-event displacements roughly taper toward segment boundaries
- Persistent segment boundaries: structural, geophysical, and topographic data indicate less cumulative displacement at salients

Multiple-segment ruptures are plausible considering the data, but we consider single-segment and spill-over (leaky-boundary) ruptures to be more likely as these modes of rupture are clearly observed along the fault.

Spill-over ruptures (e.g., Provo–northern Nephi) are addressed by uncertainty in segment-boundary locations (± 3–8.5 km)

1. WFZ Rupture Scenarios

Central WFZ Rupture Scenarios

- Minimum Rupture Model (14 EQs) 5%

We consider the minimum rupture model to be an unlikely scenario

- 7 of 13 ruptures have SRLs in excess of 70 km long (Mw-SRL 7.2–7.5)
- Dominant multi-segment rupturing conflicts with the prominent segment boundaries along the fault and along-strike changes in fault-scarp character (size, geomorphology) (unless slip consistently decreases at salients in multi-segment ruptures).

Finally, the most probable multi-segment ruptures are included in the intermediate models.

1. WFZ Rupture Scenarios

Central WFZ Rupture Scenarios

- Intermediate Rupture Model A (19 EQs) 10%
- Intermediate Rupture Model B (19 EQs) 10%
- Intermediate Rupture Model C (20 EQs) 15%

We prefer the intermediate models over the minimum model as they include only those multi-segment ruptures with the most compelling timing and displacement evidence (e.g., B4+W5 and B3+W4).

But given the broad earthquake timing uncertainties (± 500–700 yr), we still prefer the Maximum model (with spill-over) over the Intermediate models.

Between the Intermediate A, B, and C models, we prefer S2/P3/N3 as separate events (C), over 85–99-km-long ruptures in A and B.

1. WFZ Rupture Scenarios

Central WFZ Rupture Scenarios

- Unsegmented Earthquake Model 10%

The unsegmented scenario accounts for random ruptures on the WFZ irrespective of segment boundaries. This accounts for ruptures with spill over onto an adjacent segment that is greater than that allowed by the segment-boundary uncertainties (± 3.0–8.5 km).

Relatively low weight (10%) is given to the unsegmented model since prominent segment boundaries and paleoseismic data suggest SRLs are not completely random.

Unsegmented M_W distribution: M 7 ± 0.5 (0.2–0.6–0.2: M 6.5–7.0–7.5) (?)

West Valley fault zone

WVFZ Rupture Models

1. WVFZ ruptures independently 50%
2. WVFZ ruptures coseismically with SLCS (adds M_0) 45%
3. WVFZ is non-seismogenic 5%

SLCS

1. Ruptures without WVFZ (SLCS only contributes M_0) 55%
2. Coseismic rupture with WVFZ (both contribute M_0) 45%

West Valley fault zone

WVFZ Rupture Models

1. WVFZ ruptures independently 50%
2. WVFZ ruptures coseismically with SLCS (adds M_0) 45%
3. WVFZ is non-seismogenic 5%

SLCS

1. Ruptures without WVFZ (SLCS only contributes M_0) 55%
2. Coseismic rupture with WVFZ (both contribute M_0) 45%

There are insufficient data to settle the issue of the dependence/independence of the WVFZ.

Scenario 1 is given slight preference considering (1) the 1934 Hansel Valley earthquake, (2) differences in preliminary Penrose Drive (SLCS) and Baileys Lake (Granger fault, WVFZ) earthquake chronologies, and (3) that this scenario includes events on the WVFZ triggered by (but not coseismic with) an SLCS earthquake.

2. Moment Release

- M_0
  - M_0 (μAD) = rigidity(μ) * A * AD(net) (dyne-cm; Hanks and Kanamori, 1979);
  - A = Down-dip rupture width (DDW) * surface rupture length (SRL)
  - Rigidity (μ) = 3.3×10^{11}
  - DDW = **20 km** (14–30 km), based on fault dip = **50°** (35–65°) and seismogenic depth = **15 km** (13–17 km range)
  - AD(net) = Average net (fault-parallel) displacement per event
  - Other M_0 calculation: Log M_0 = 3/2 [M_W(SRL)] + 16.05 (Hanks and Kanamori, 1979)

- Sum of M_0 release
  - Per segment. For multi-segment ruptures, M_0 apportioned according to SRL. E.g., B4+W5 M_0 is split between BCS (39%) and WS (61%) using segment lengths.
  - Per scenario – sum of all moment released (sum for central WFZ)

Along-Strike Displacement Profiles

- Displacement data
  - DuRoss (2008) + new trench data (Brigham City, Provo)
  - Measurements range from total scarp offset divided by # events, to max. colluvial wedge thickness, to stratigraphic displacement.

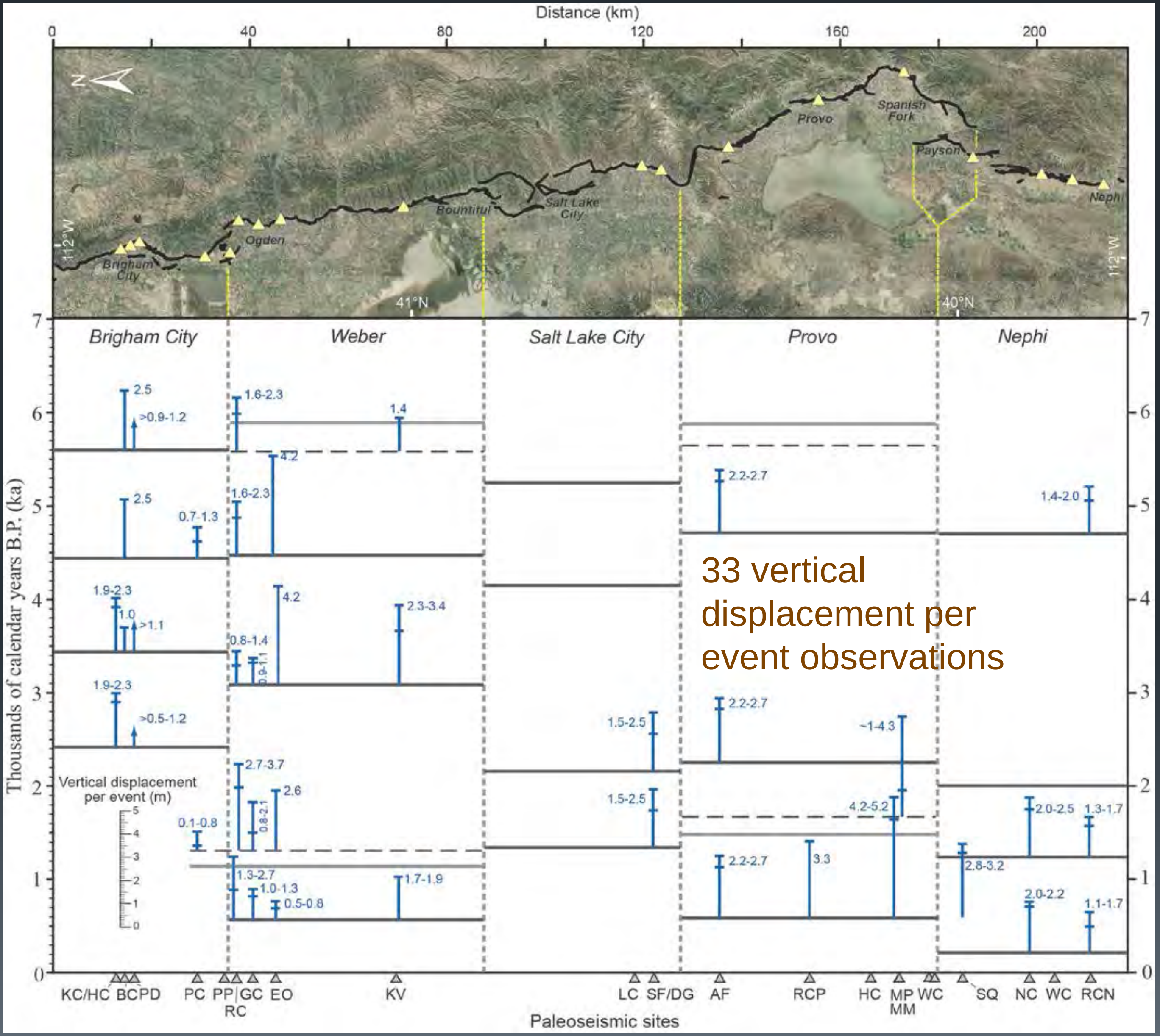
- Simple method for calculation AD(net)
  - AD(net) = average of displacement observations from trenches
  - No assumptions about rupture profile/slip decreasing at rupture ends
  - Advantage: ideal if have numerous displacement observations
  - Disadvantages: displacement tapering at rupture ends well documented (Ward, 1997; Pezzopane and Dawson, 1996; Hemphill-Haley and Weldon, 1999 ; Biasi and Weldon, 2009), if have few data, large/small displacements may skew average displacement

Along-Strike Displacement Profiles

- Analytical method for calculating AD(net)
  - AD(net) based on analytical half-ellipse distribution fit to observed data
  - Half-ellipse shape: square root of sin(L). L is normalized distance along rupture (1-km spacing). Height scaled according to observed data.
  - Supported by literature (Chang and Smith, 2002; Biasi and Weldon, 2009), used by UCERF2 (height scaled using average displacement from a SRL-AD regression) (also Great Salt Lake fault)
  - Advantage: Can determine AD, max D with only 1–2 observations
  - Disadvantages: Half-ellipse profile likely far from reality; large observed displacements near segment boundaries or small observed displacements near rupture centers won't correspond well with profile.

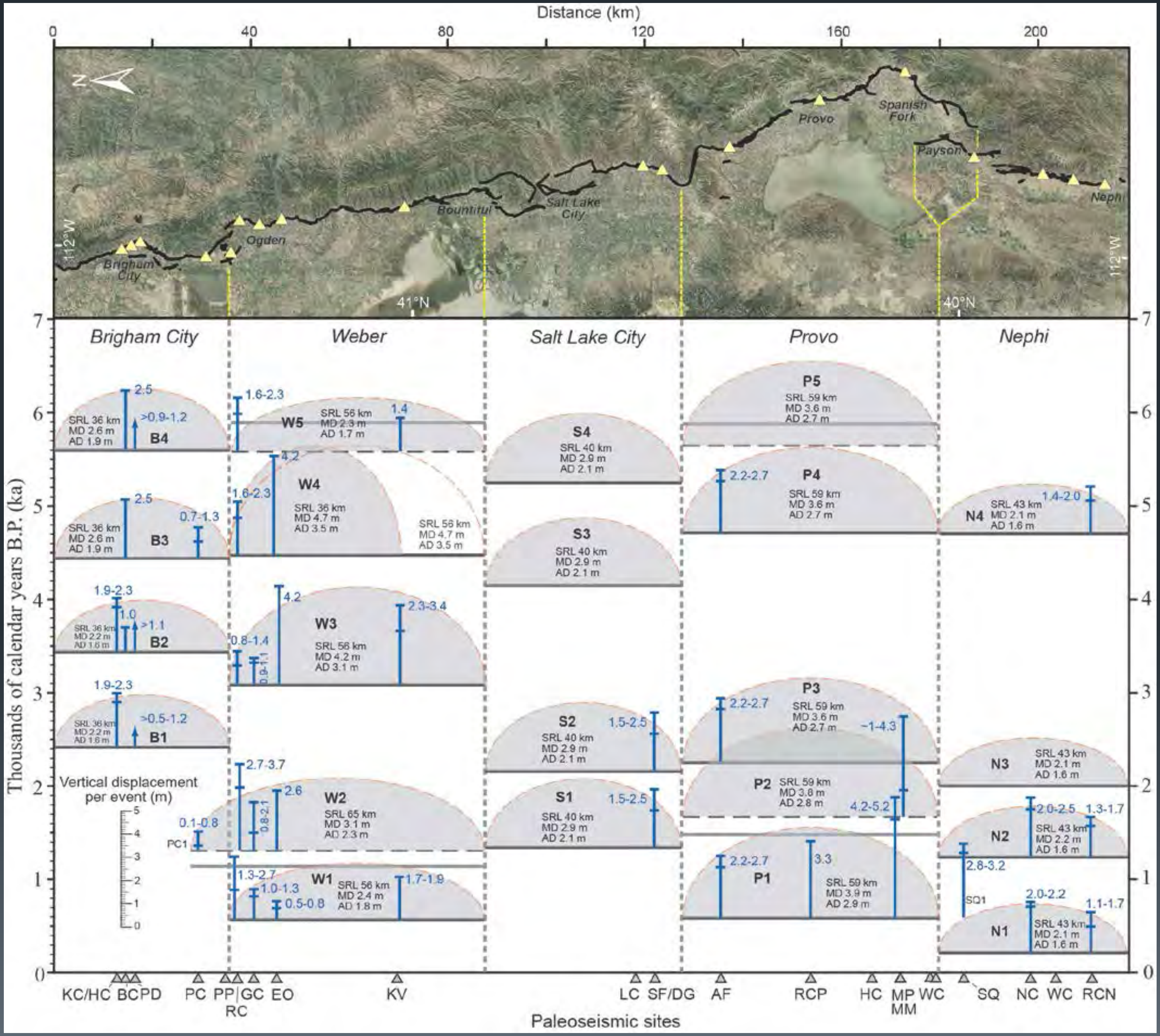
- Other
  - Characteristic: average displacement for segment is independent of whether it is included in a single- or multi-segment rupture.
  - Uniform/Boxcar: constant displacement along rupture

Observed Displacement (Maximum Model)



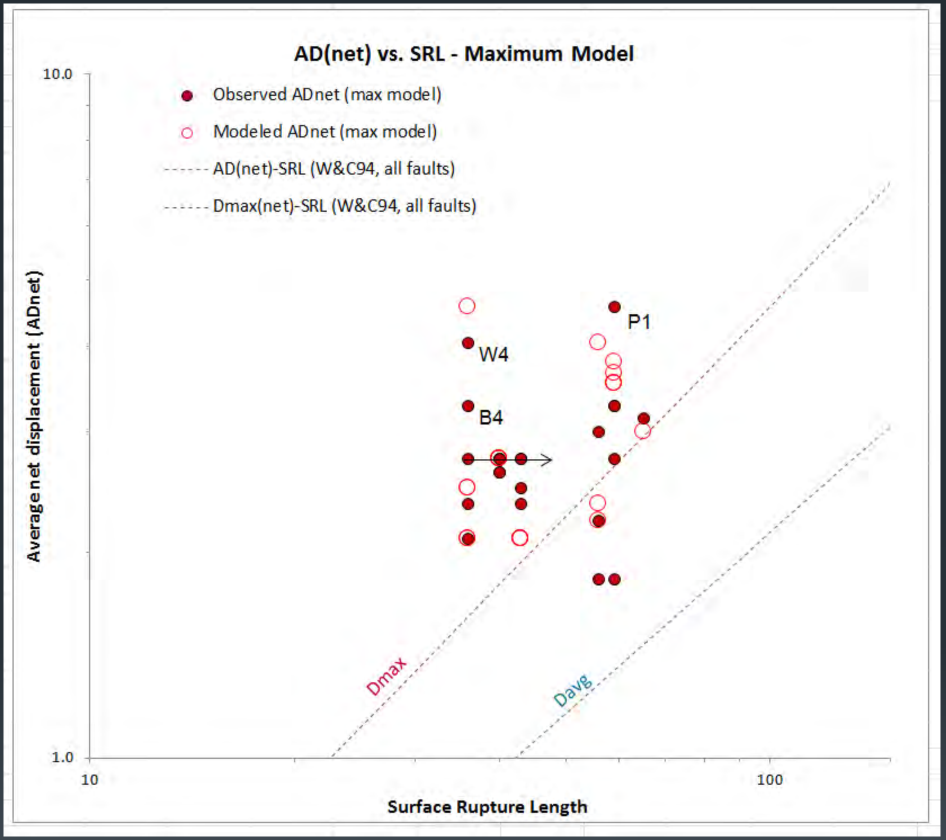
33 vertical displacement per event observations

Modeled Displacement – Maximum Model

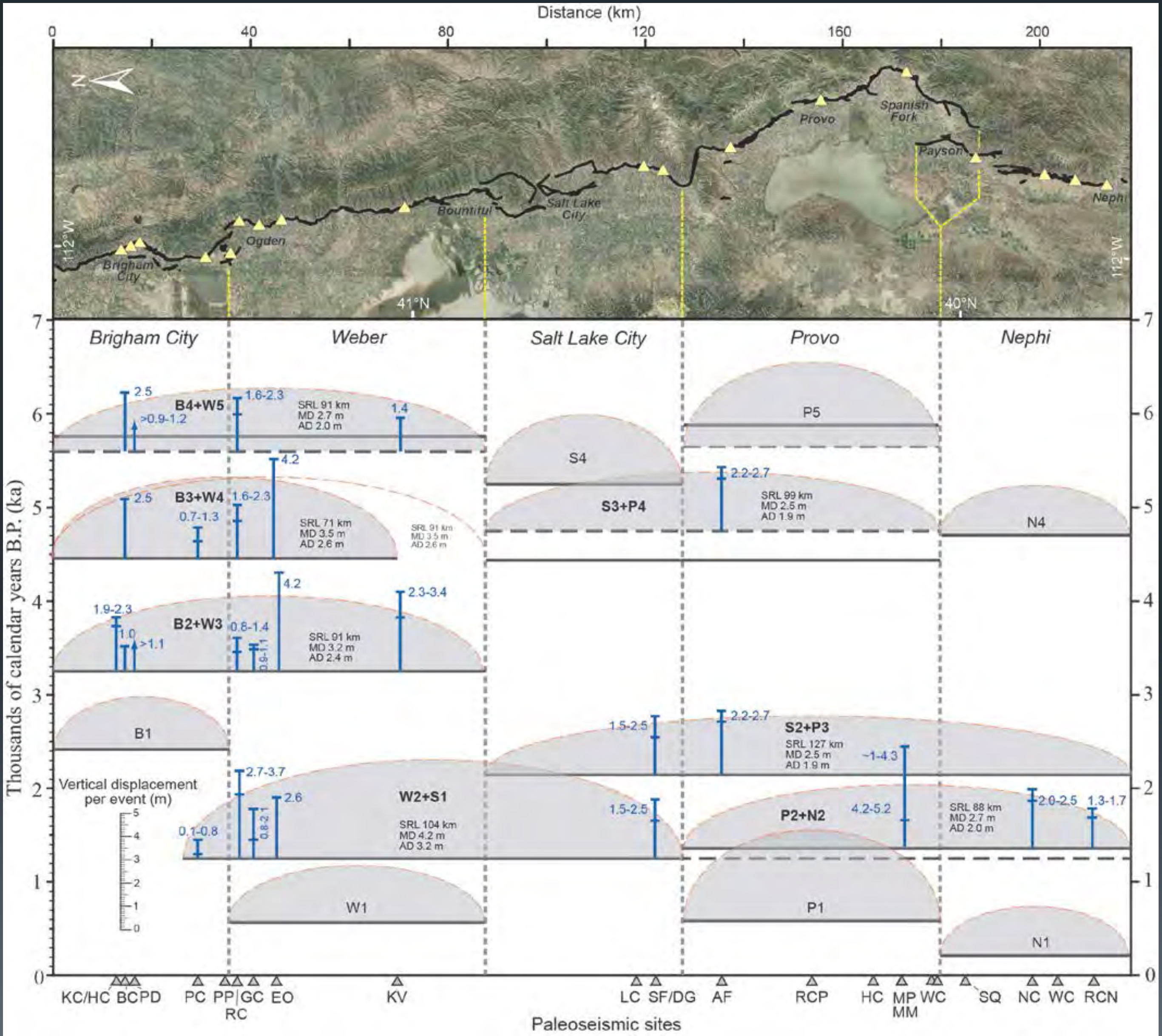


Modeled Displacement – Maximum Model

- Observed (trenches)
  - Mean of AD(net): 2.8 ± 1.3 m
    (2σ)
- Modeled (half ellipses)
  - Mean of AD(net): 2.8 ± 1.5 m
- Single-segment ruptures have more displacement per SRL than suggested by the historical D-SRL regressions
  - Site bias? (bias toward trenching large scarps)
  - Underestimated SRLs?

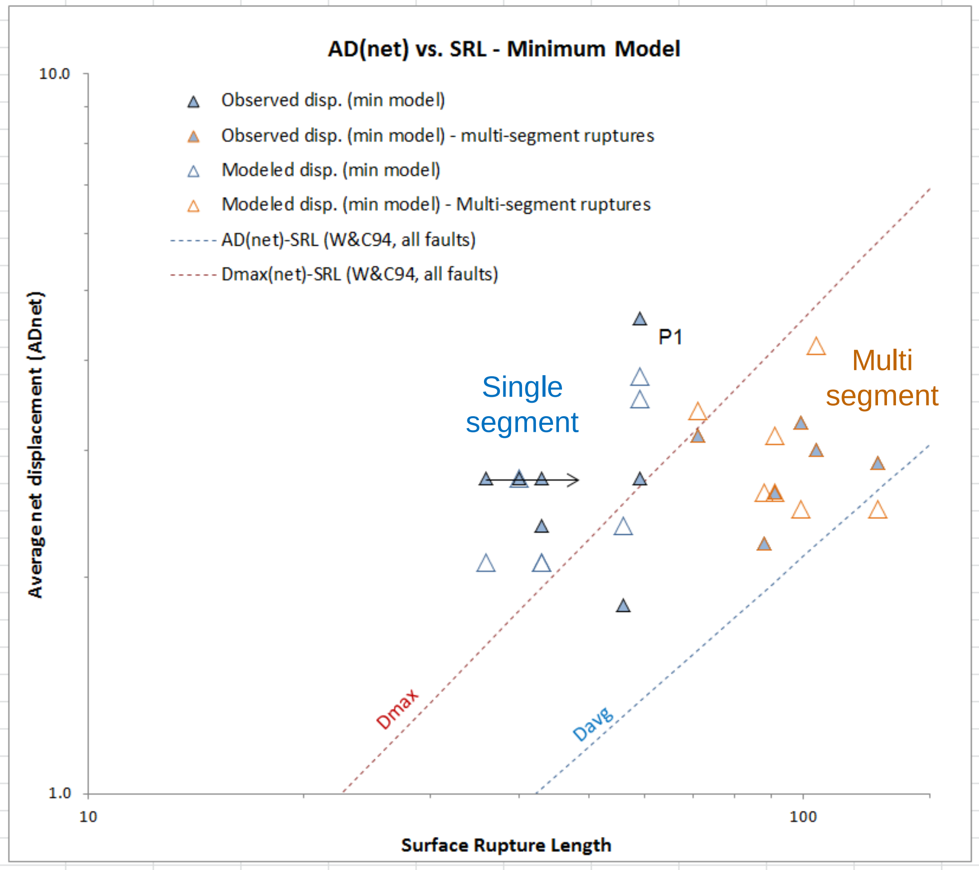


Modeled Displacement – Minimum Model



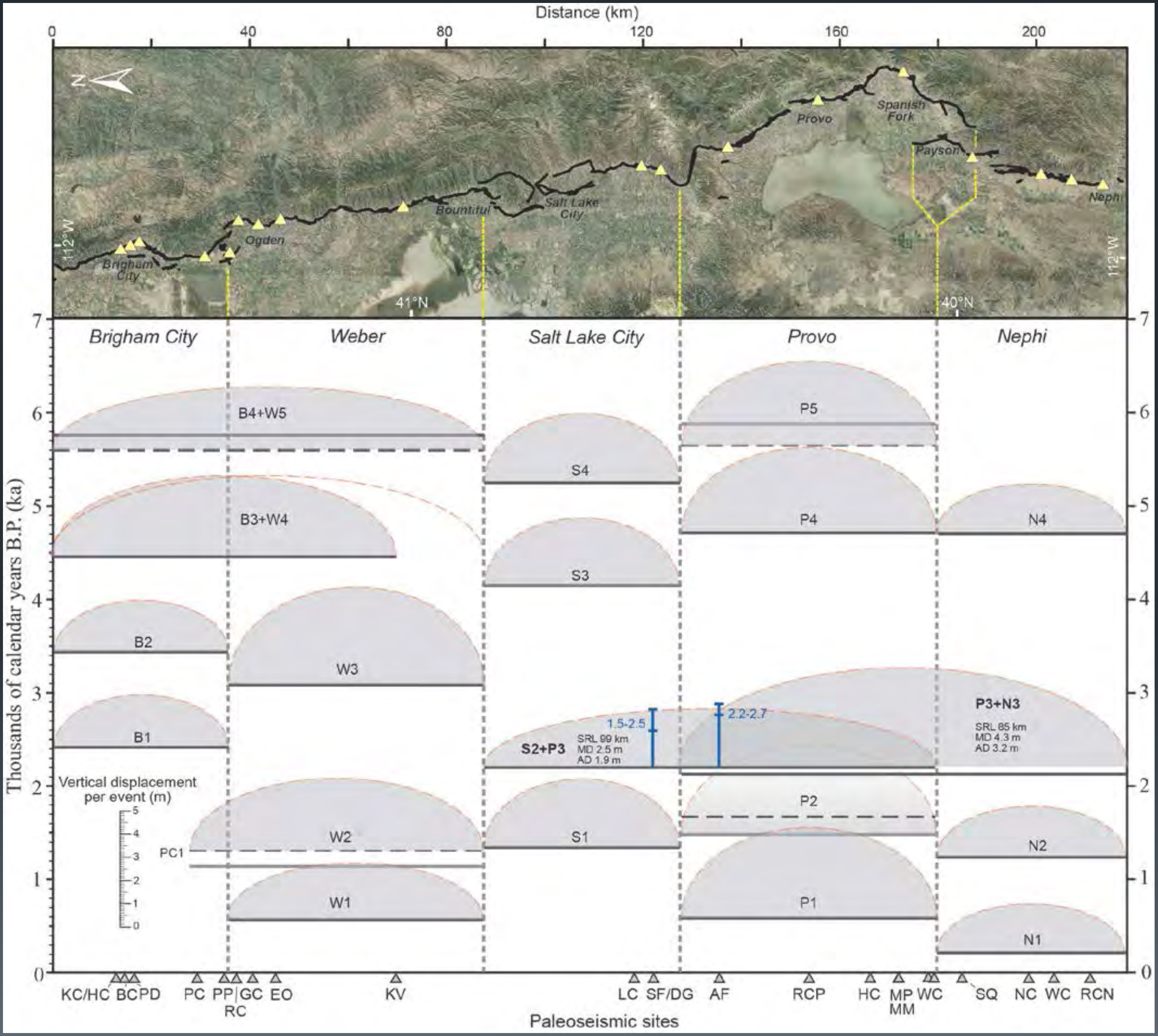
Modeled Displacement – Minimum Model

- Observed (trenches)
  - Mean AD(net): 2.8 ± 1.2 m *(2σ)*
- Modeled (half ellipses)
  - Mean of AD(net): 2.8 ± 1.3 m
- Multi-segment ruptures (orange) have displacements that are closer to that predicted by historical D-SRL regressions



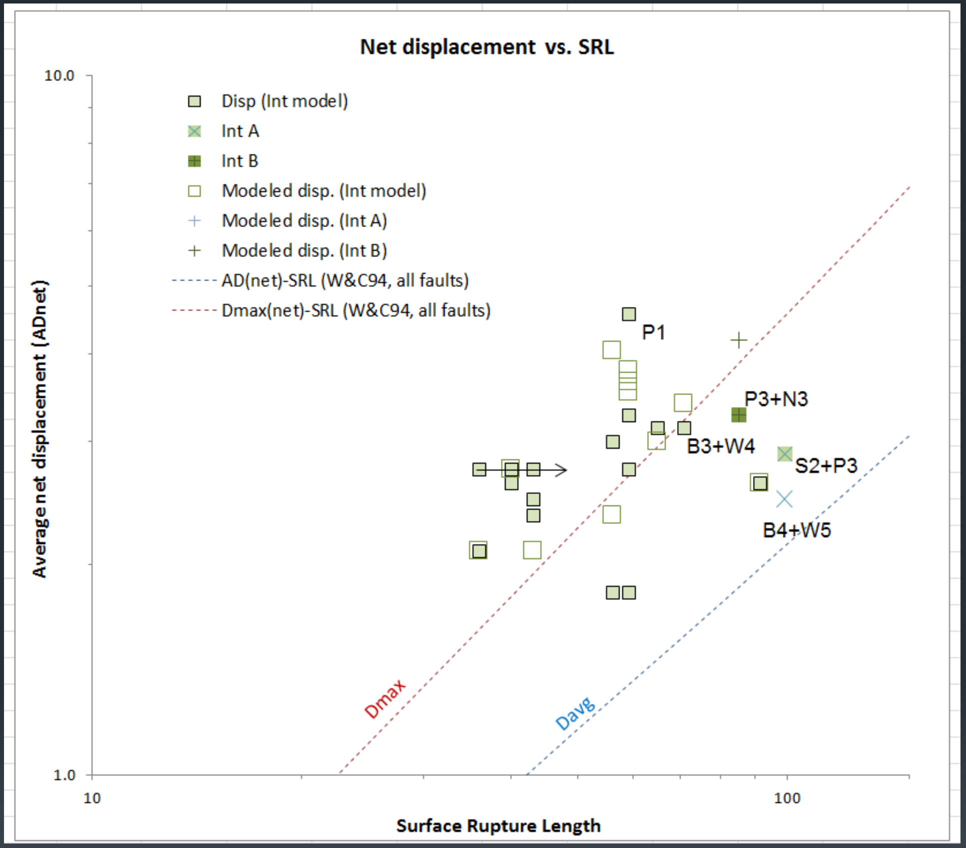
Values are mean ± 2σ

Modeled Displacement – Intermed. Models



Modeled Displacement – Intermed. Models

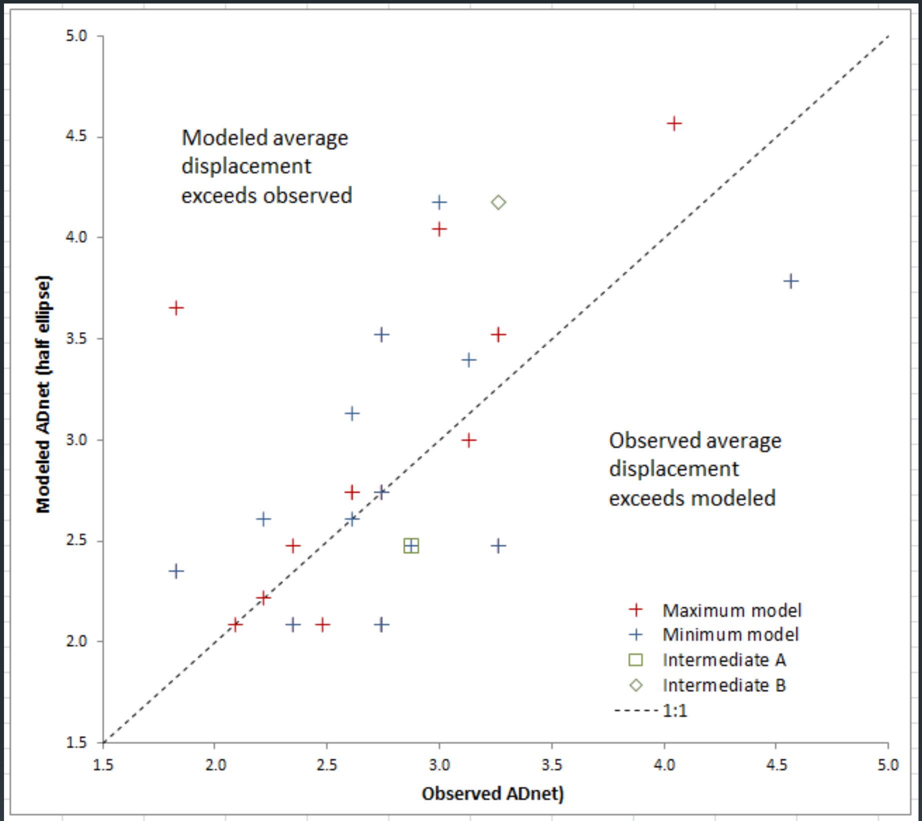
- Observed (trenches)
  - Mean AD(net): 2.8 ± 1.2 m
    (2σ)
- Modeled (half ellipses)
  - Mean of AD(net): 2.8 ± 1.3 m



Values are mean ± 2σ

Displacement Conclusions I

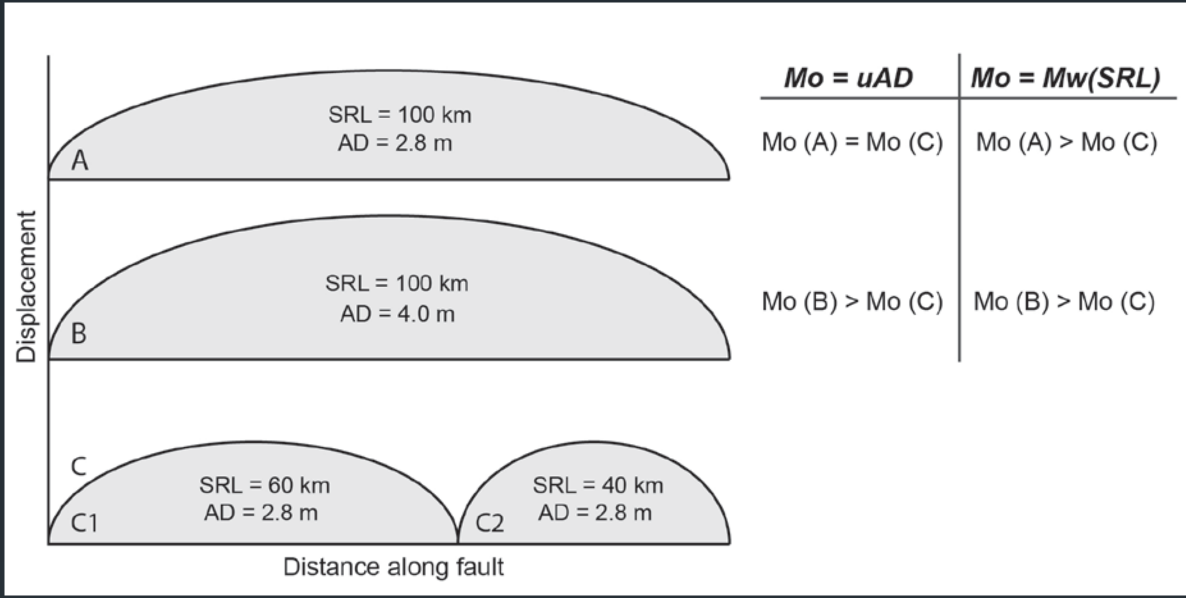
- Per-event displacements are consistently large (site bias?, longer SRLs?)
- For modeled profiles: observed displacements adequate to constrain half ellipses (rather than using historical regression)
- Some significant differences in observed and modeled displacements, but as a whole, AD(net) consistent between methods



Use half-ellipse method, which is well supported in literature?

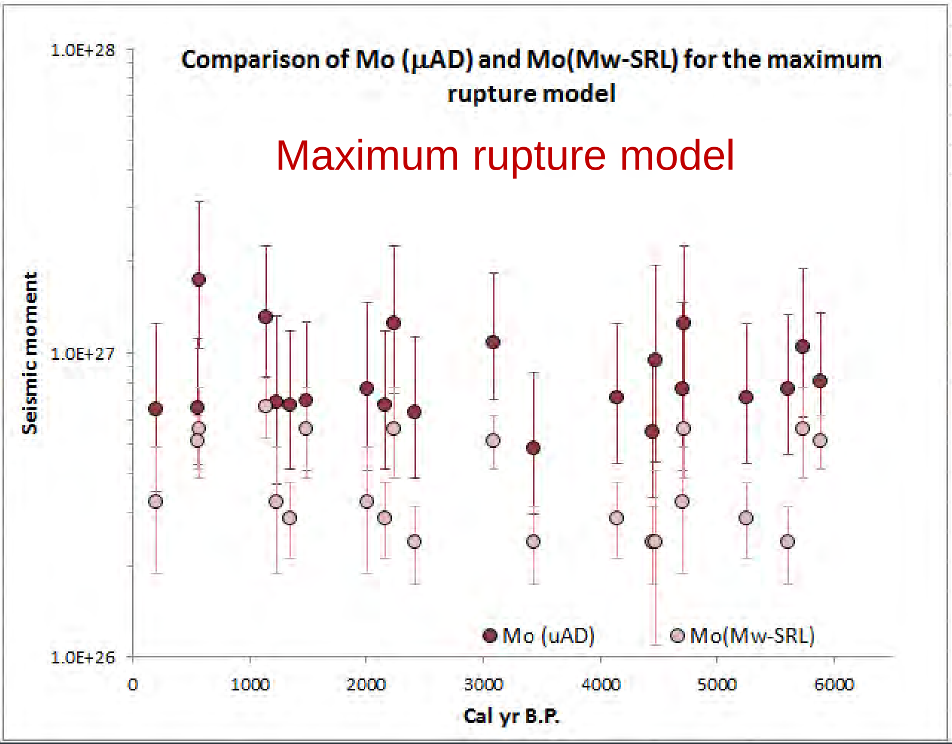
Displacement Conclusions II

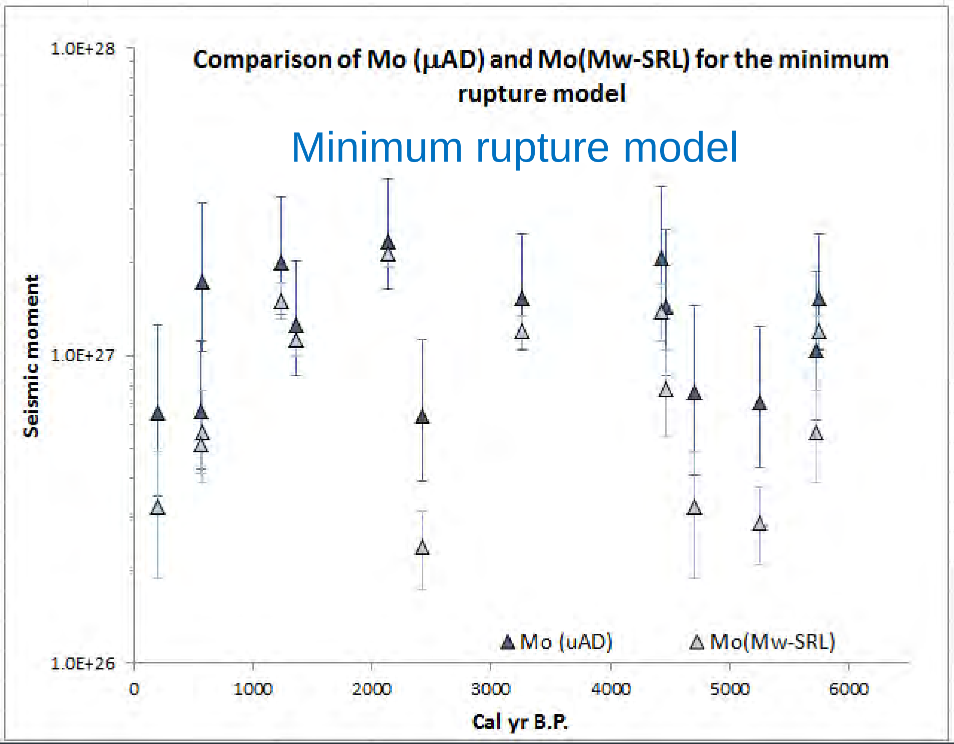
- Possible that displacement does not scale significantly with SRL for larger ruptures…
  - Both single-segment and multi-segment rupture profiles moderately well constrained by observed data
  - For example, B2 – 1.6 m, W3 – 3.1 m, B2+W3 – 2.4 m (ADnet)



Based on half-ellipse modeling, multi-segment rupture profile A is more likely than B for multi-segment ruptures.

Comparison of M_0(μAD) and M_0(M_W-SRL)

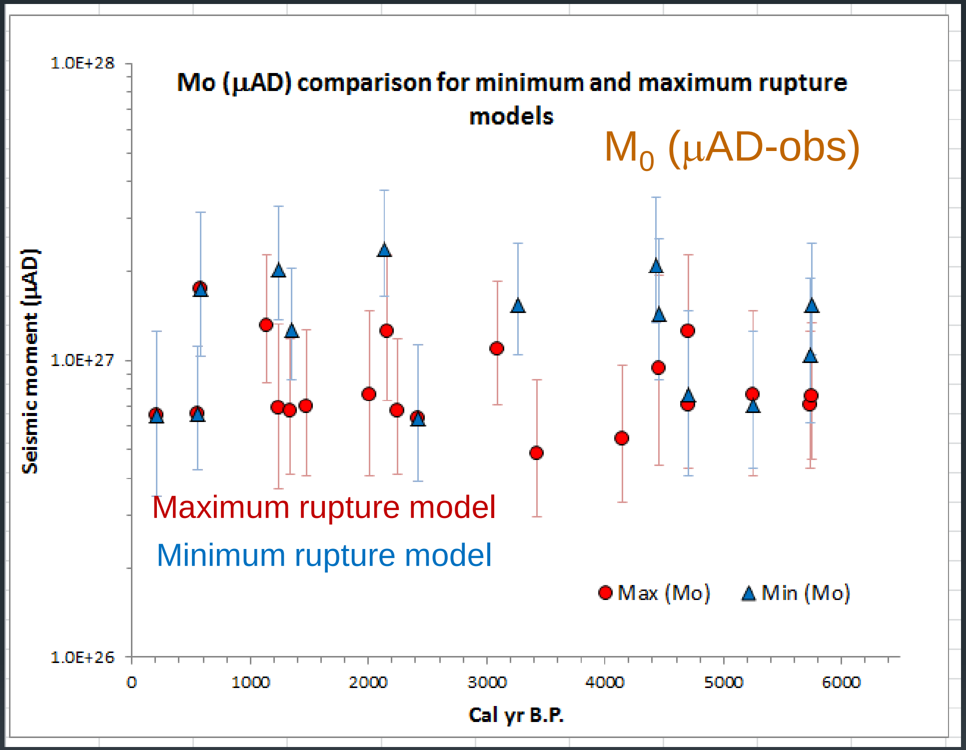




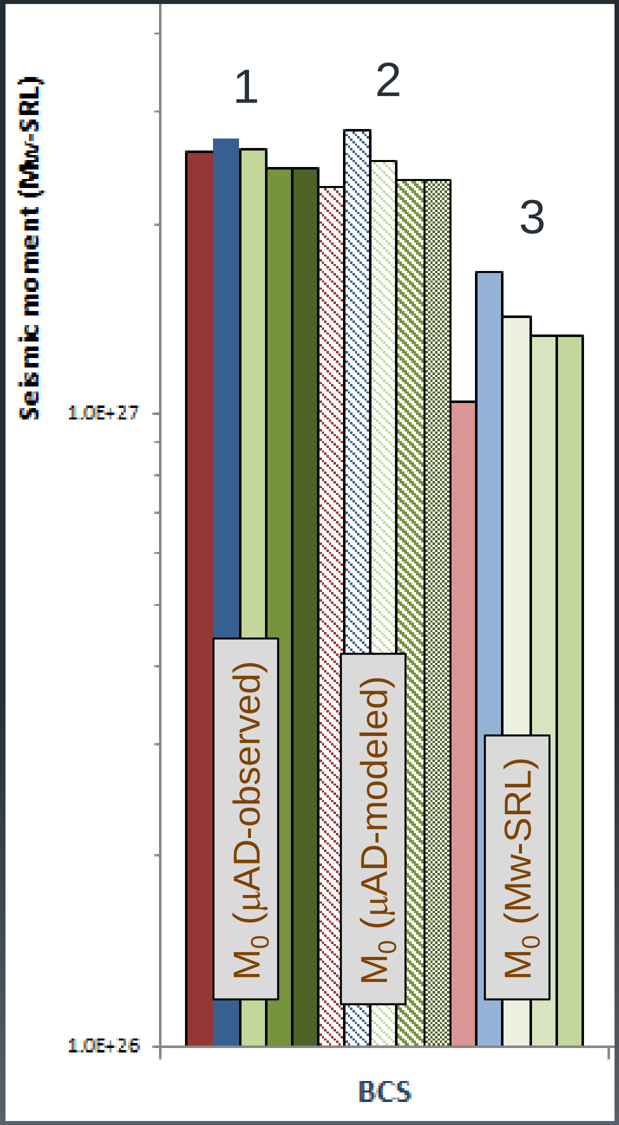
- M_0 (μAD) (darker color) consistently greater than M_0 (Mw-SRL) (lighter color)
  - M_0 (μAD) is 2.3 ± 0.6 times greater than M_0 (Mw-SRL) for maximum model
  - M_0 (μAD) is 1.8 ± 0.6 times greater than M_0 (Mw-SRL) for minimum model
- Differences related to large net displacements (~2.8 m avg.)

M_0 Release in Min and Max Models

- Greater <u>M_0 release per earthquake</u> in Minimum rupture model (blue), but fewer earthquakes
  - M_0 sum for maximum model approximately equal to sum for minimum model
  - More significant difference in sums for max/min models if M_0 based on Mw-SRL max (max < min)



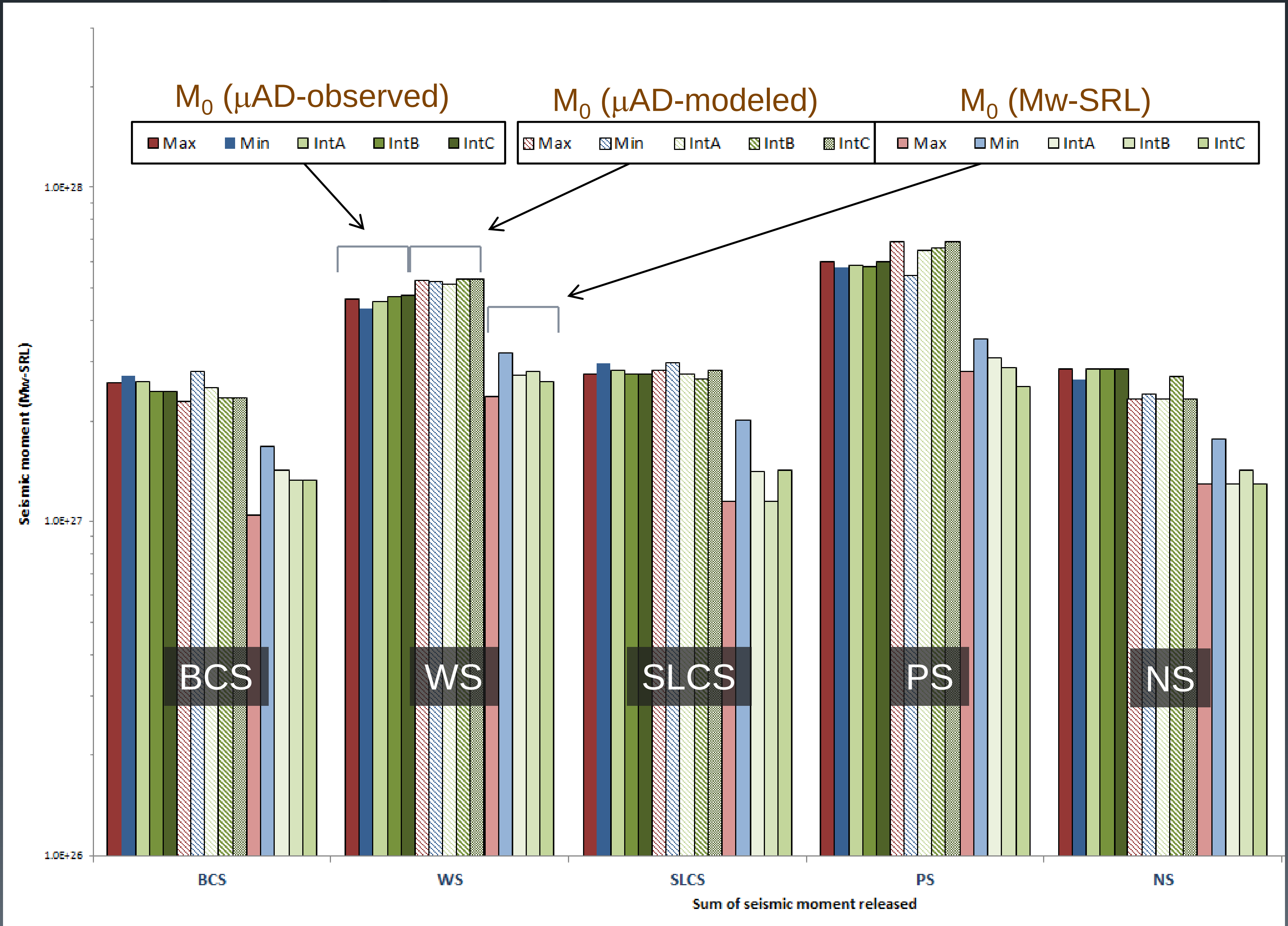
Moment Comparison



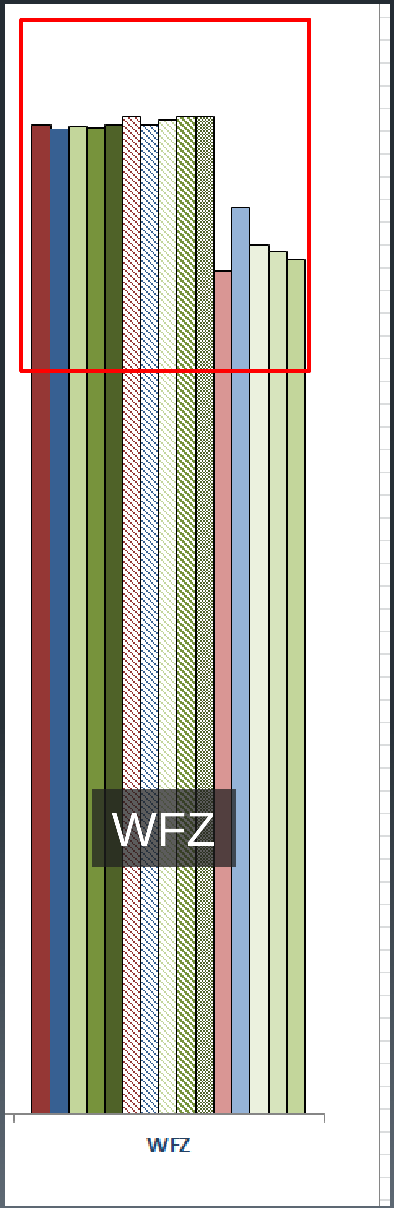
- Sum of M_0 per segment
  1. M_0 (μAD-observed) – dark colors
  2. M_0 (μAD-modeled) – hachured
  3. M_0 (Mw-SRL) – light colors

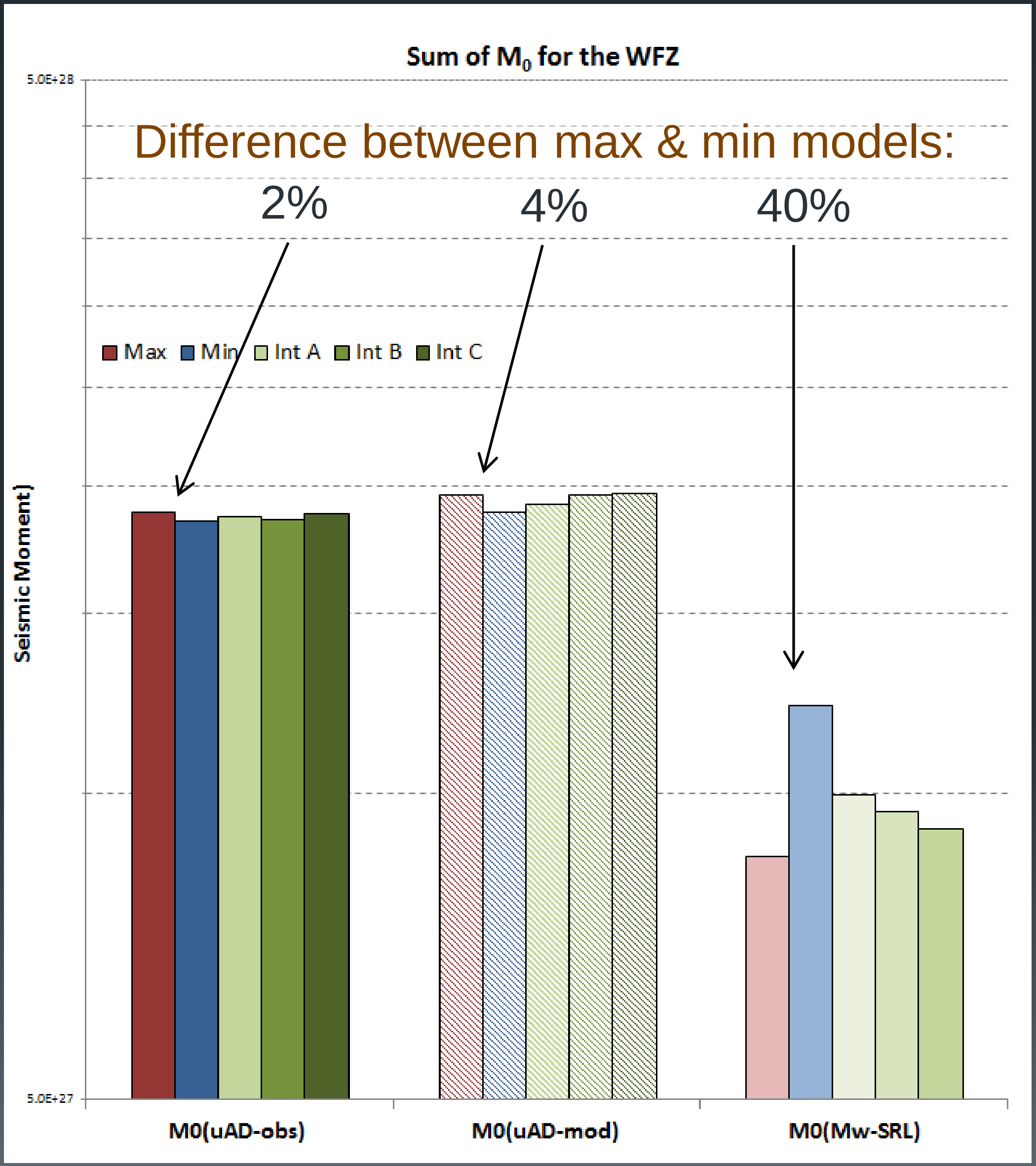
- Rupture models:
  - Maximum
  - Minimum
  - Intermediate A
  - Intermediate B
  - Intermediate C

Moment Comparison



Moment Comparison - WFZ





M_0 Conclusions

- Using M_0 (μAD), the five rupture scenarios have similar amounts of moment release (summed per segment and for the WFZ)
  - Consistent results with observed vs. modeled average displacement
  - Not likely that M_0 (μAD) underestimates moment release for larger ruptures (displacements are not significantly larger in multi-segment ruptures, and we're probably not missing the largest displacements)
  - However, possible that M_0 (μAD) overestimates M_0 for smaller (single-segment) ruptures (longer SRLs than mapped, site bias?)

- M_0 (μAD) consistently yields more moment release (per earthquake, segment, and rupture model) than M_0 (M_W-SRL)
  - Given large WFZ displacements, M_0-μAD better portrays moment release than M_0–SRL (more M_0 released in single- and multi-segment ruptures than indicated by M_0–SRL regression)

Next Steps

<u>Moment balancing?</u>

1. UQFPWG consensus slip rates (per segment)
   - 1.1–1.4 mm/yr vertical SR
   - 1.4–1.8 mm/yr net SR (using 50° fault dip)
2. UQFPWG consensus SR adjusted for revised earthquake times
3. Long-term (e.g., post-Bonneville) slip rates
   - ~0.7–2.5 mm/yr vertical SR
   - ~0.9–3.3 mm/yr net SR
4. Geodetic extension rates
   - 1.2–2.0 mm/yr horizontal SR *(Chang et al., 2006)*
   - 1.9–3.1 mm/yr net SR

➢ Single rate for WFZ, or segment specific?

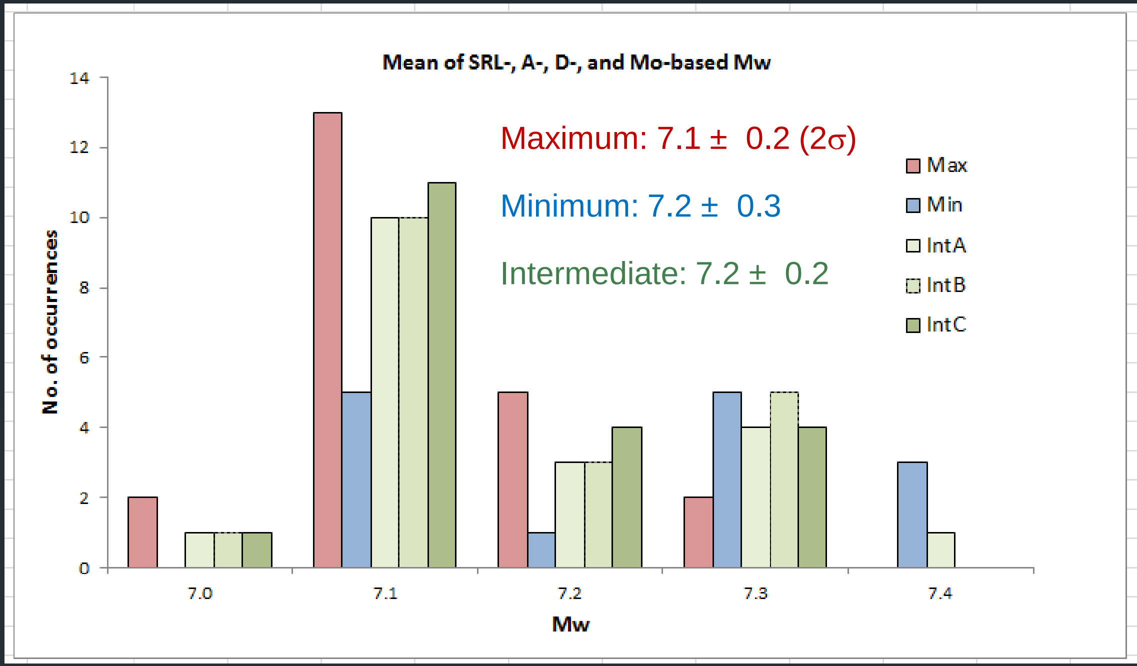
3. Moment Magnitude

- M_W
  - M_W (SRL) = 1.16* LOG*SRL+5.08 (W&C94–all-fault-types); range based on SRL uncertainty
  - M_W (A) = 4.07+0.98*LOG(DDW*SRL) (W&C94–all-fault-types); range based on DDW and SRL uncertainties
  - M_W (AD–HH&W99) (in progress…)
  - M_W (AD–W&C94): M_W (AD[net]) = 0.82*(LOG(AD[net]))+6.93 (all-fault-types)
  - M_W (M_0) = (2/3)*(LOG(M_0)) - 10.7 (H&K79)

- Mean M_W
  - M_W (SRL) – 0.25 wt
  - M_W (A) – 0.25 wt
  - M_W (AD–W&C94) – 0.25 wt
  - M_W (M_0) – 0.25 wt

Moment Magnitude

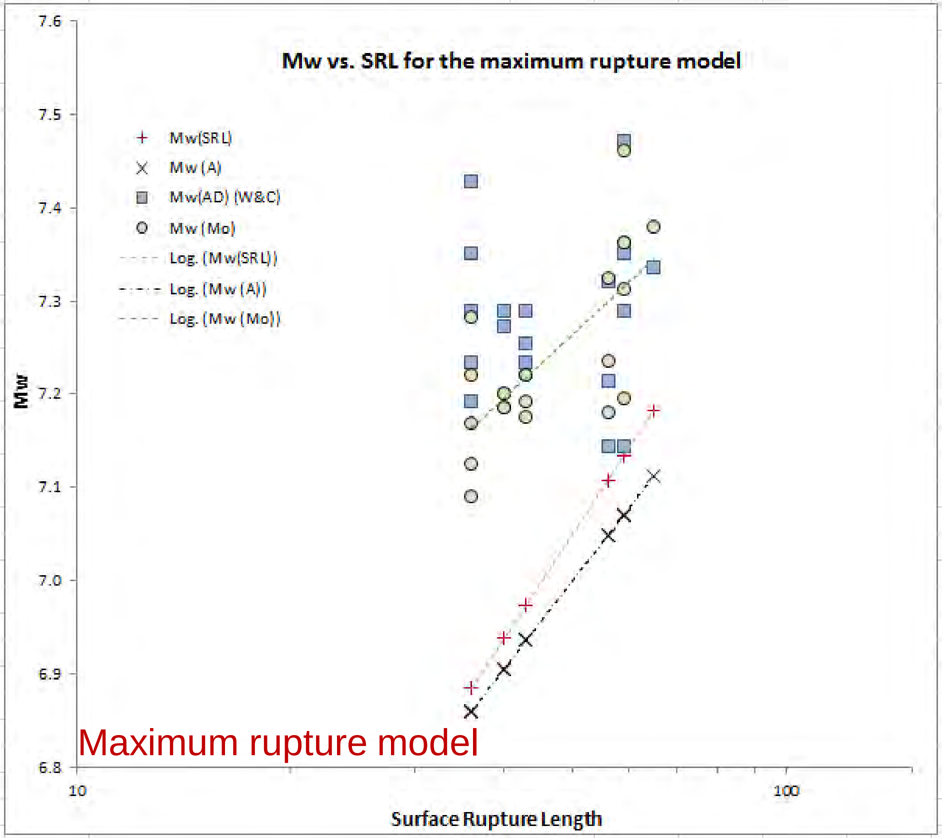
- Maximum model
  - M_W (SRL): <u>7.0 ± 0.2</u> (6.9 ± 0.2 – 7.1 ± 0.2)
  - M_W (A): <u>7.0 ± 0.2</u> (6.7 ± 0.2 – 7.2 ± 0.2)
  - M_W (AD): 7.3 ± 0.2
  - M_W (M_0-μAD): 7.2 ± 0.2
  - Mean M_W: 7.1 ± 0.2

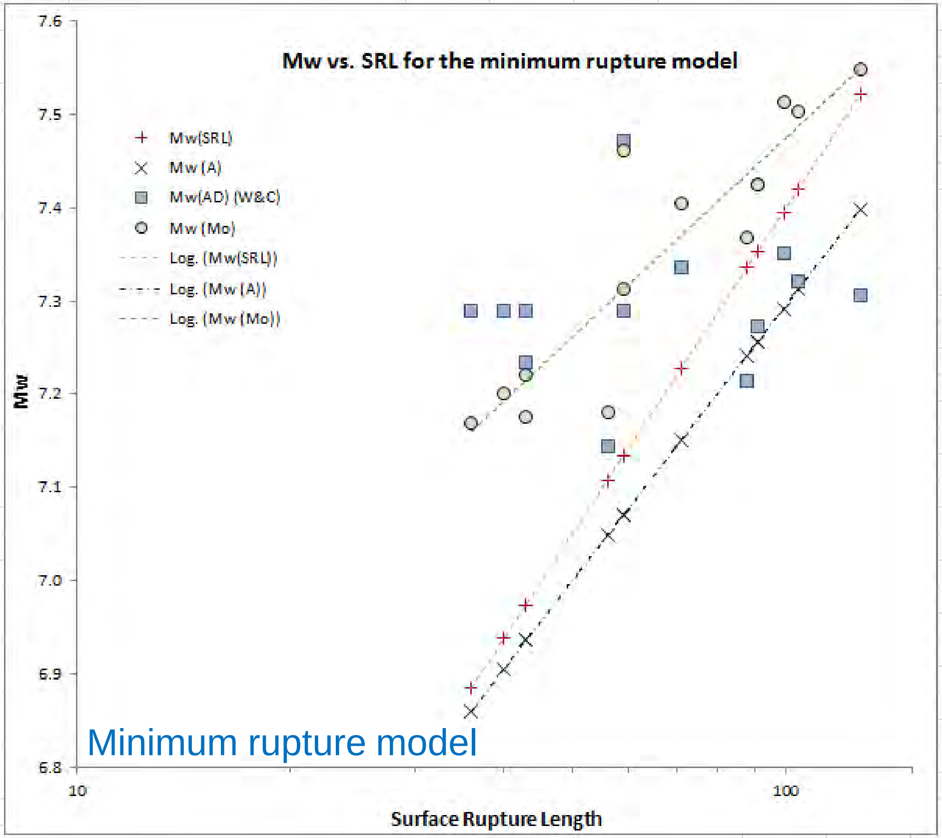


M_W values rounded to nearest 10th

- Minimum model
  - M_W (SRL): <u>7.2 ± 0.4</u> (7.1 ± 0.5 – 7.3 ± 0.4 using SRL uncert.)
  - M_W (A): <u>7.1 ± 0.3</u> (6.9 ± 0.4 – 7.4 ± 0.3 using A uncert)
  - M_W (AD): 7.3 ± 0.1
  - M_W (M_0-μAD): 7.4 ± 0.3
  - Mean M_W: 7.2 ± 0.3

M_W vs. SRL



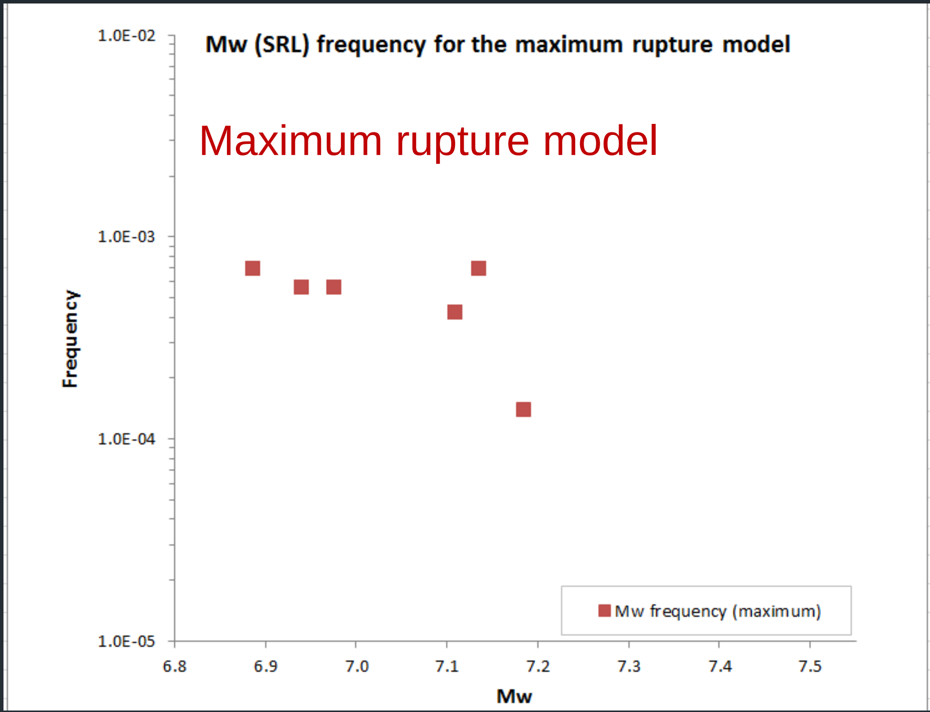


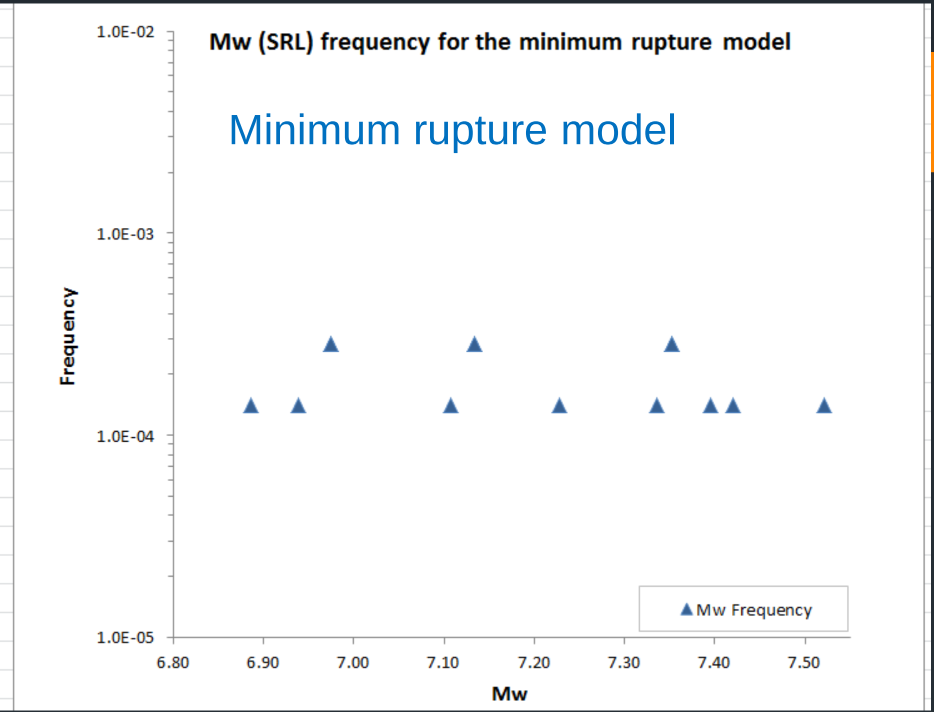
<u>Maximum model</u>

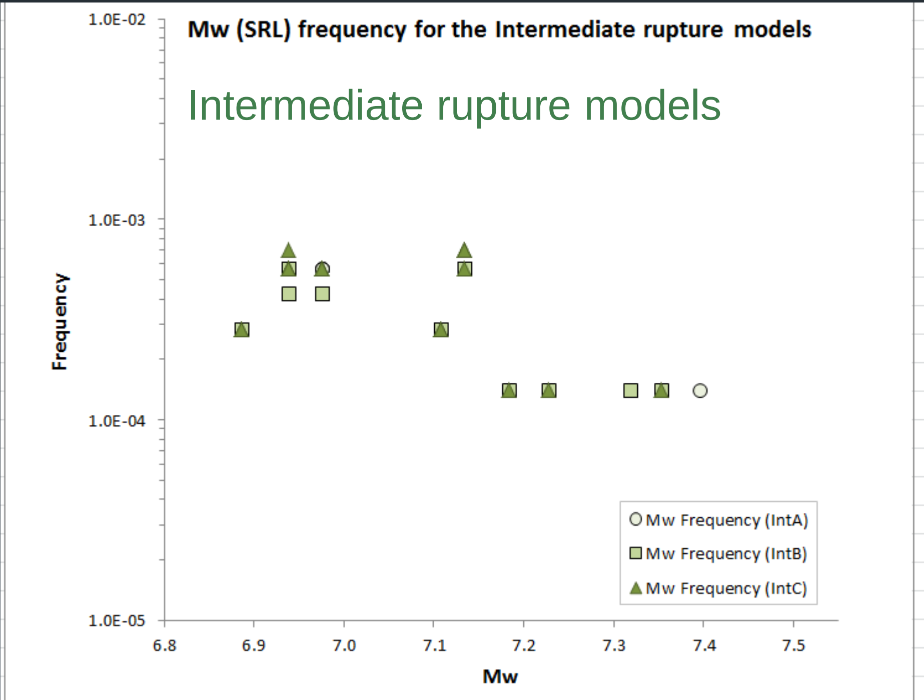
- M_W (D or M_0) consistently greater than M_W (SRL or A)

<u>Minimum model</u>

- M_W (D or M_0) generally greater than M_W (SRL or A)







- M_W Frequency
  - Number of occurrences of earthquakes of a particular SRL divided by the total elapsed time (7.1-ka max constraint for W5 to present)
  - E.g., in the max model a 43-km-SRL earthquake occurs 4 times in 7.1 yr.

COV

1. Determine earthquake times per segment (one out of 10,000 scenarios). Using the Brigham City model, simulation1 has the following earthquake times:
   - E4: 5615
   - E3: 4355
   - E2: 3500
   - E1: 2225

2. Compute recurrence intervals (RIs):
   - E4-E3: 1260
   - E3-E2: 855
   - E2-E1: 1275

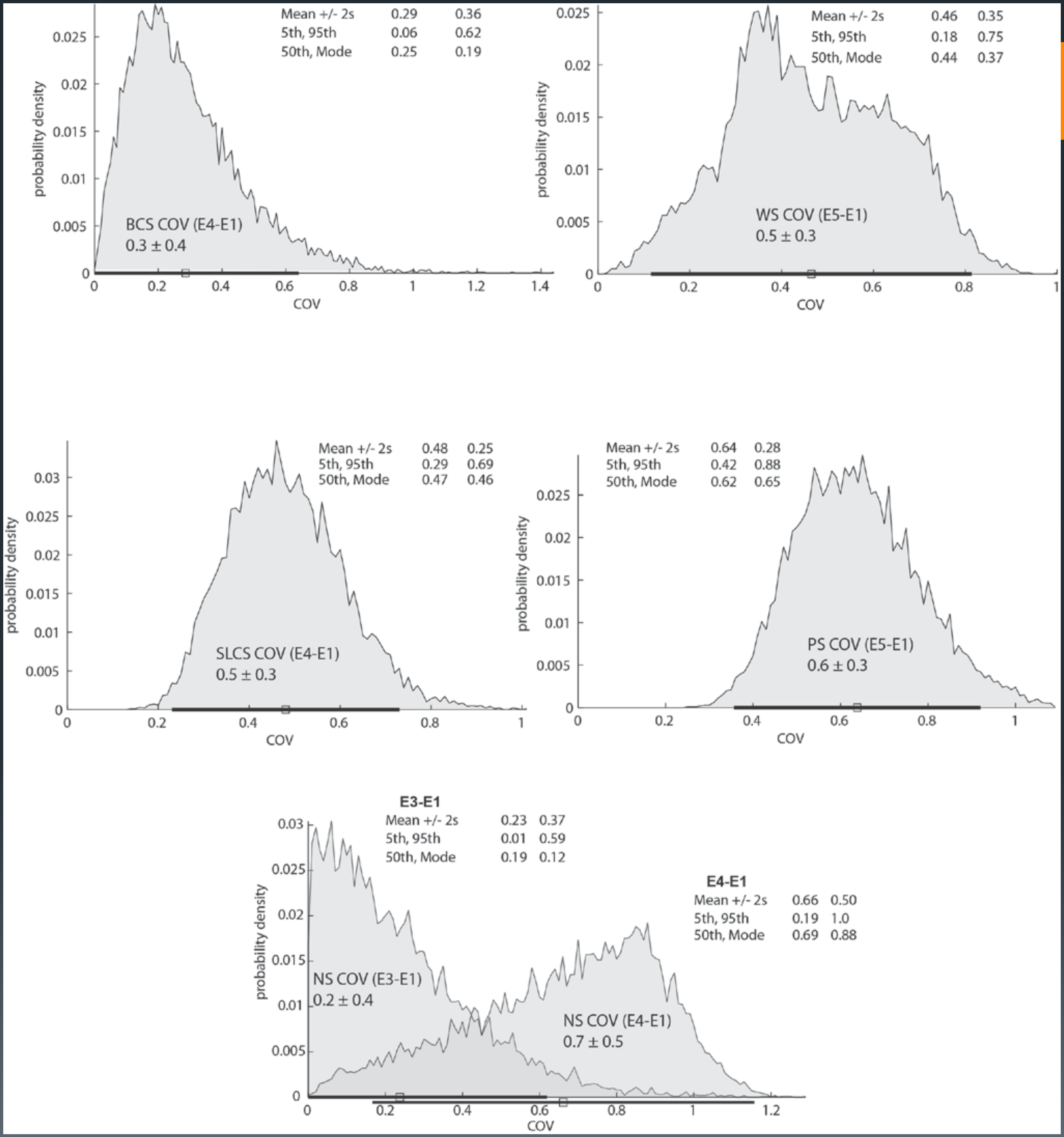
3. Calculate COV = standard deviation of RIs (138 yr) divided by the mean of them (1130 yr):
   - COV = 138/1130 = 0.12

4. Repeat, and then compile and plot EQ times, RIs, and COVs

COV

- Brigham City
  0.3 ± 0.4 (2σ)
- Weber and Salt Lake City
  0.5 ± 0.3 (WS)
  0.5 ± 0.2 (SLCS)
- Provo
  0.6 ± 0.3
- Nephi
  - 0.7 ± 0.5 (E4-E1)
  - 0.2 ± 0.4 (E3-E1)

- **<u>Next step:</u>**
  calculate COV for each rupture model



WGUEP:
WFZ Recurrence Rates and COVs

Christopher B. DuRoss

[Anthony J. Crone
Stephen F. Personius
Susan Olig
William R. Lund]

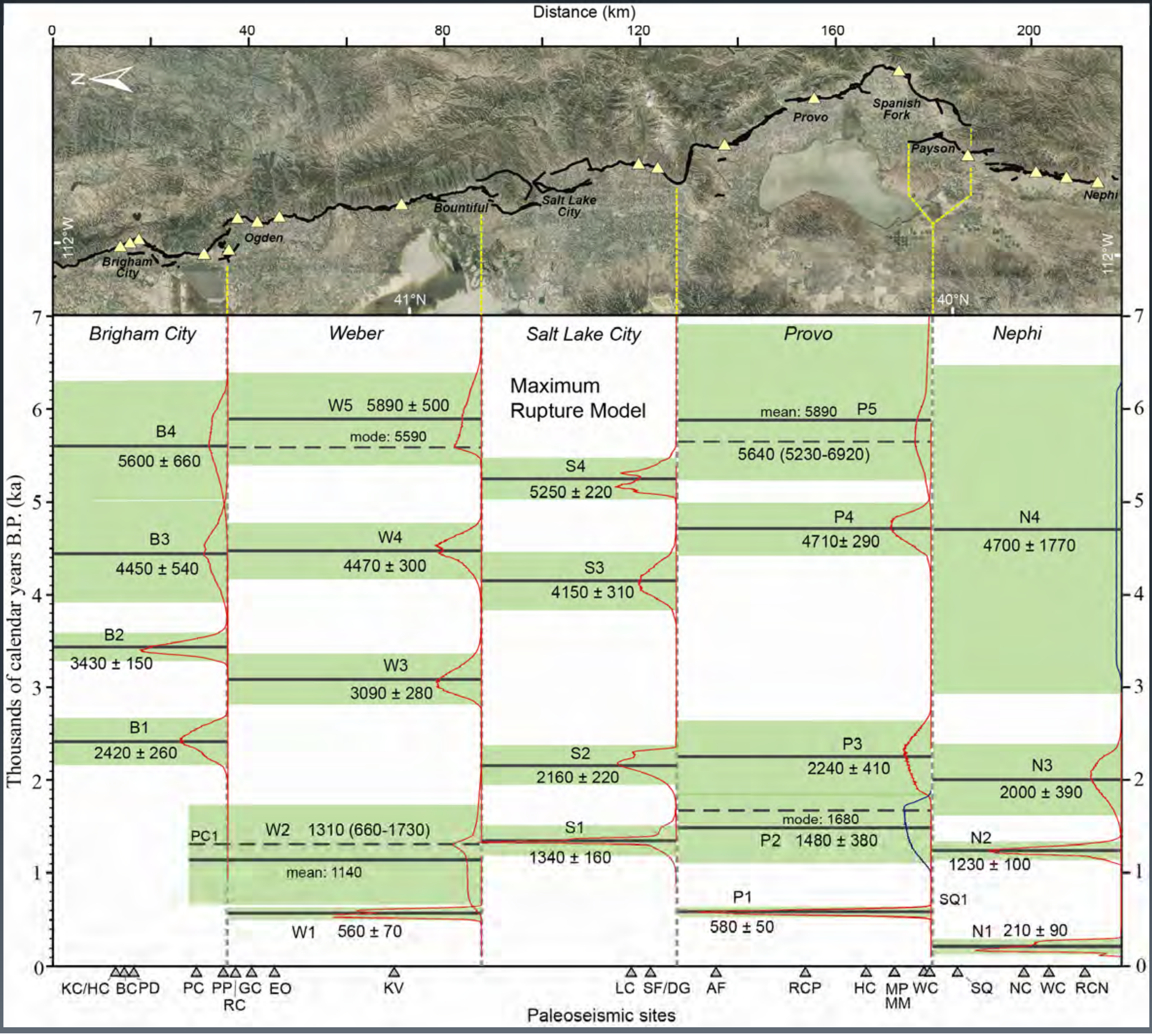
Working Group on Utah Earthquake Probabilities June, 2011

Tasks

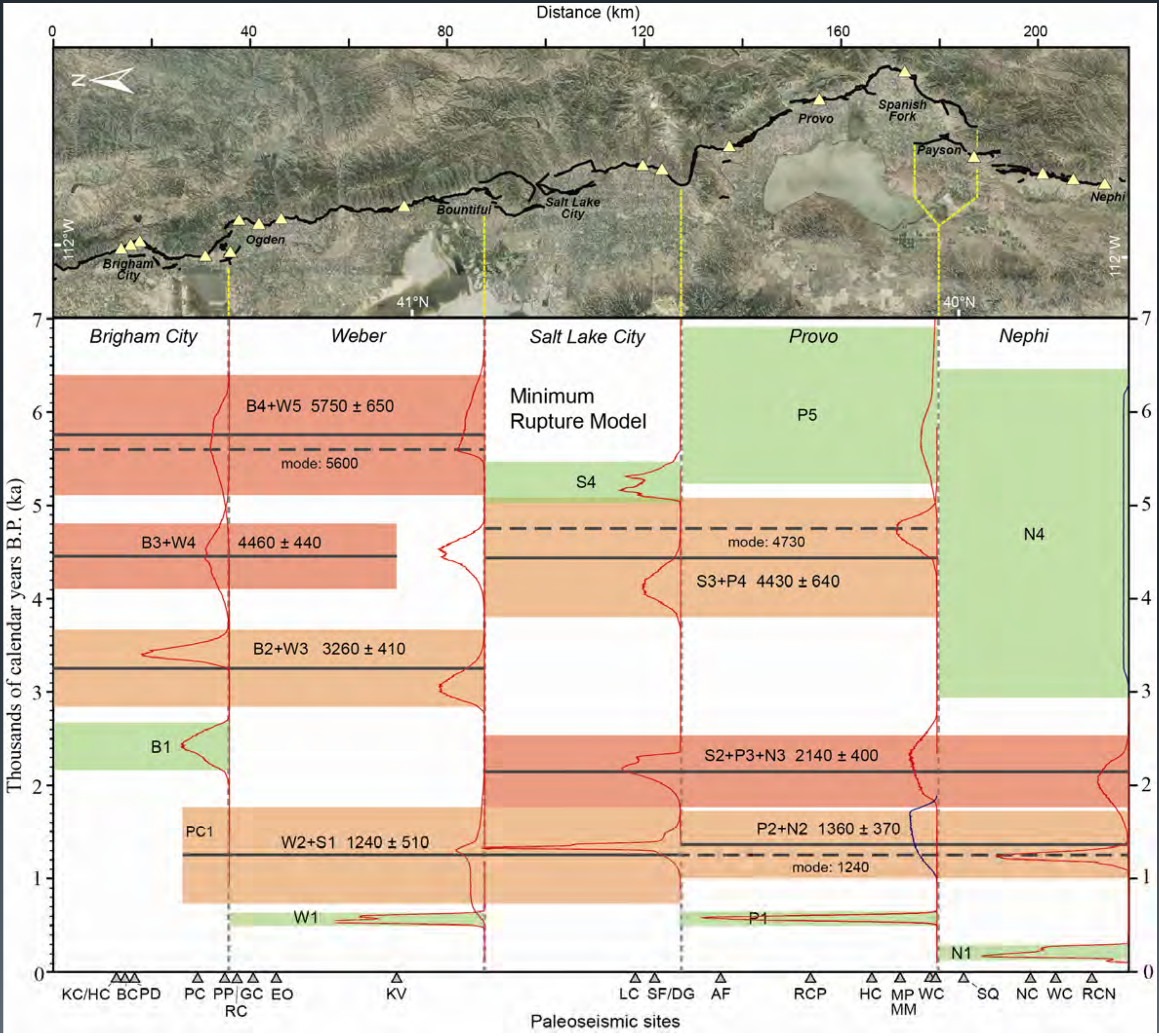
- Paleoseismology subgroup tasks:
  - ✓Review of all WFZ paleoseismic data
  - ✓Integration/modeling of paleoseismic data per segment to develop segment earthquake chronologies
  - ✓Development of multi-segment rupture models, consensus weighting
  - ✓Final recurrence intervals for single-segment rupture model
  - ✓Displacement models, **M** estimates, sum of M_0 (first cut)
  - ✓COV estimates (per-segment and composite)

- WGUEP tasks
  - Determine earthquake-source recurrence rates
  - Finalize COV for modeling
  - Address **M** discrepancy/M_0 sum issues *[to be discussed later…]*
  - Slip rate for moment balancing

Single-Segment Rupture (SSR) Model (50%)

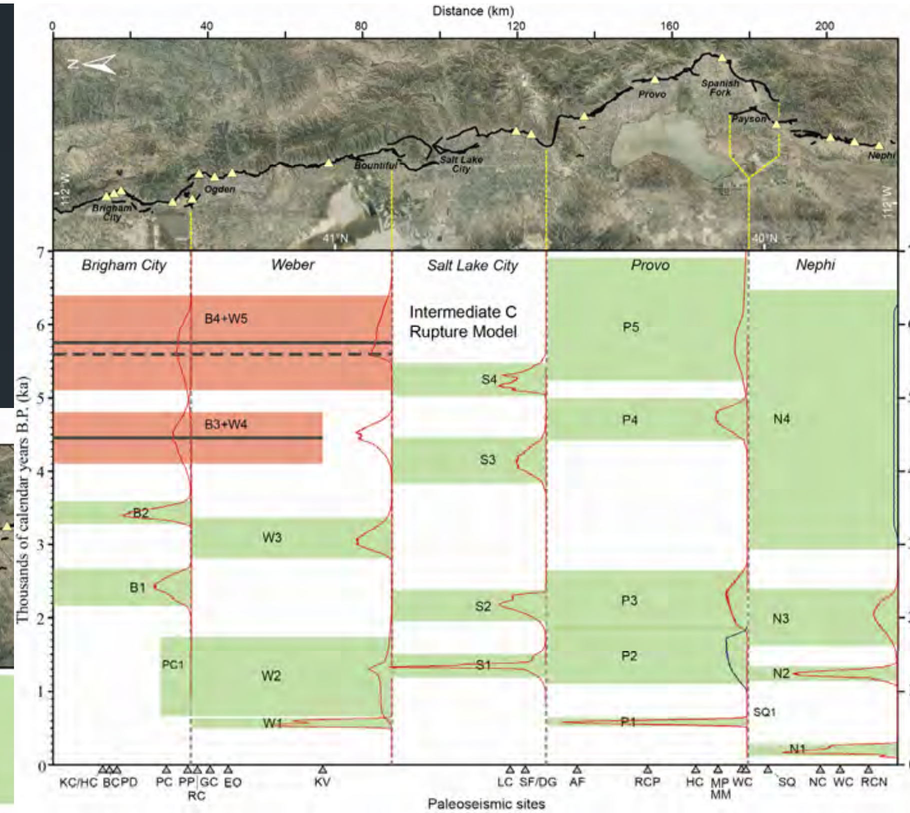


Multi-Segment Rupture (MSR) Model (5%)

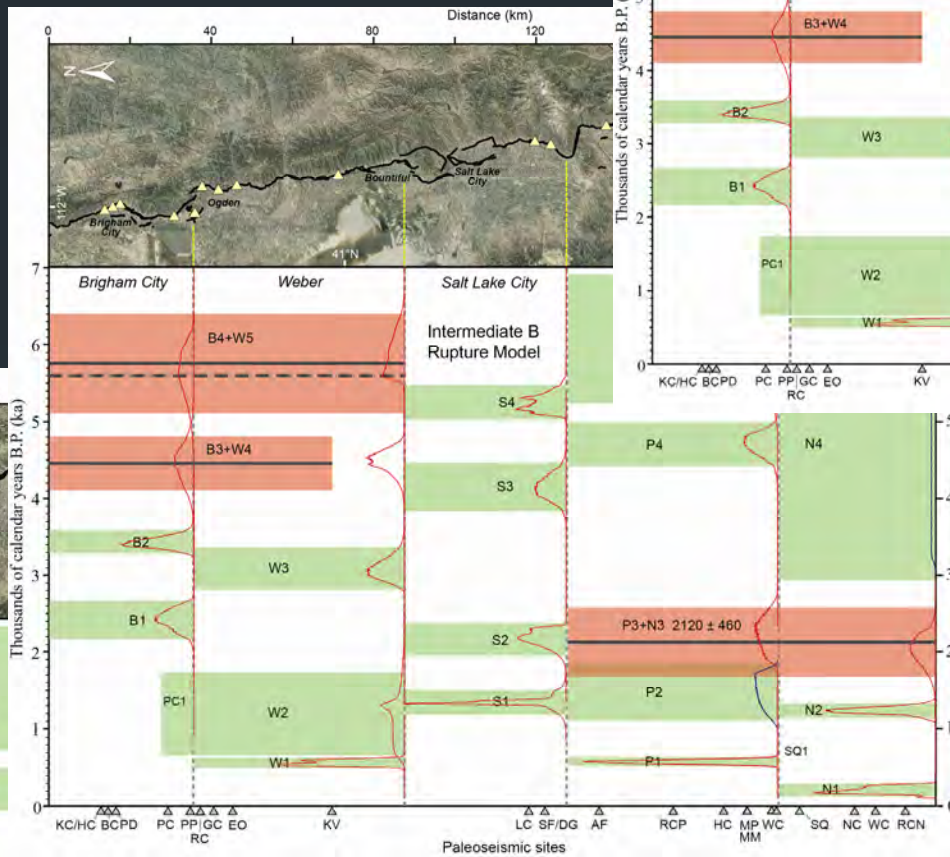


Intermediate Rupture Models (35%)

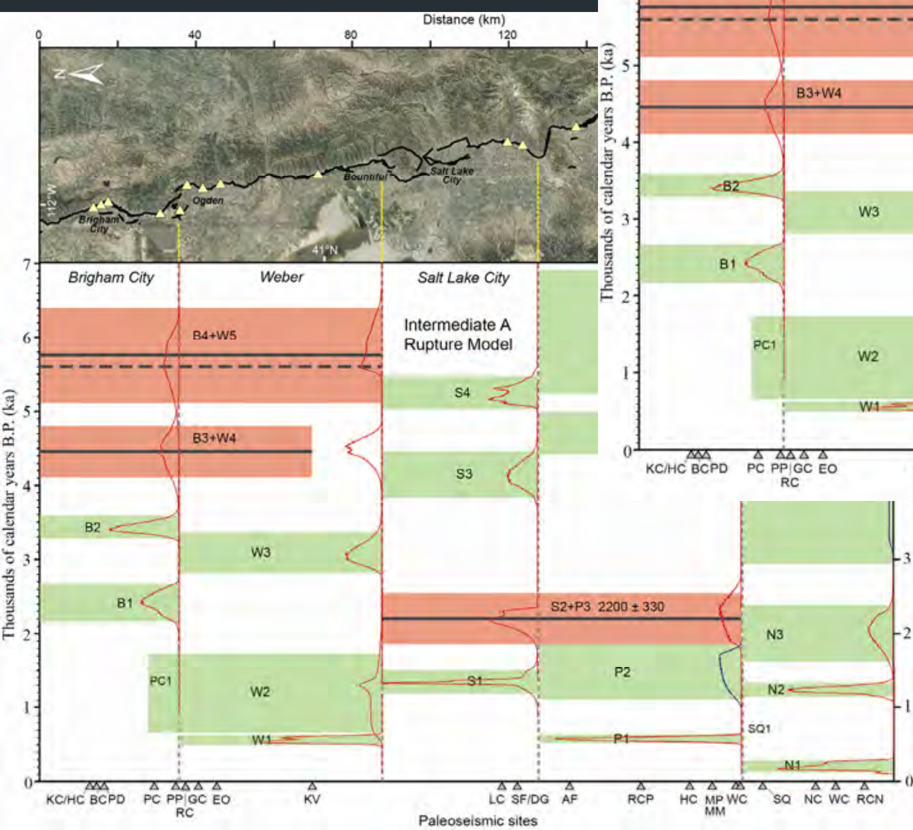
Model C (15%)



Model B (10%)



Model A (10%)



Unsegmented Rupture Model (10%)

Earthquake Recurrence Rates

- Single-segment ruptures (SSRs)
  - Closed mean (and open mean) recurrence intervals

- Multi-segment ruptures (MSRs)
  - Issue of MSR sources having 0–1 recurrence intervals
  - Maximum likelihood estimation?

- Path forward:
  - Volunteer to calculate recurrence rates using MLE?

COV – June 2011

In each of 10,000 simulations:

1. Determine set of earthquake times per segment (using PDFs)

2. Compute inter-event recurrence intervals (RIs) from earthquake times

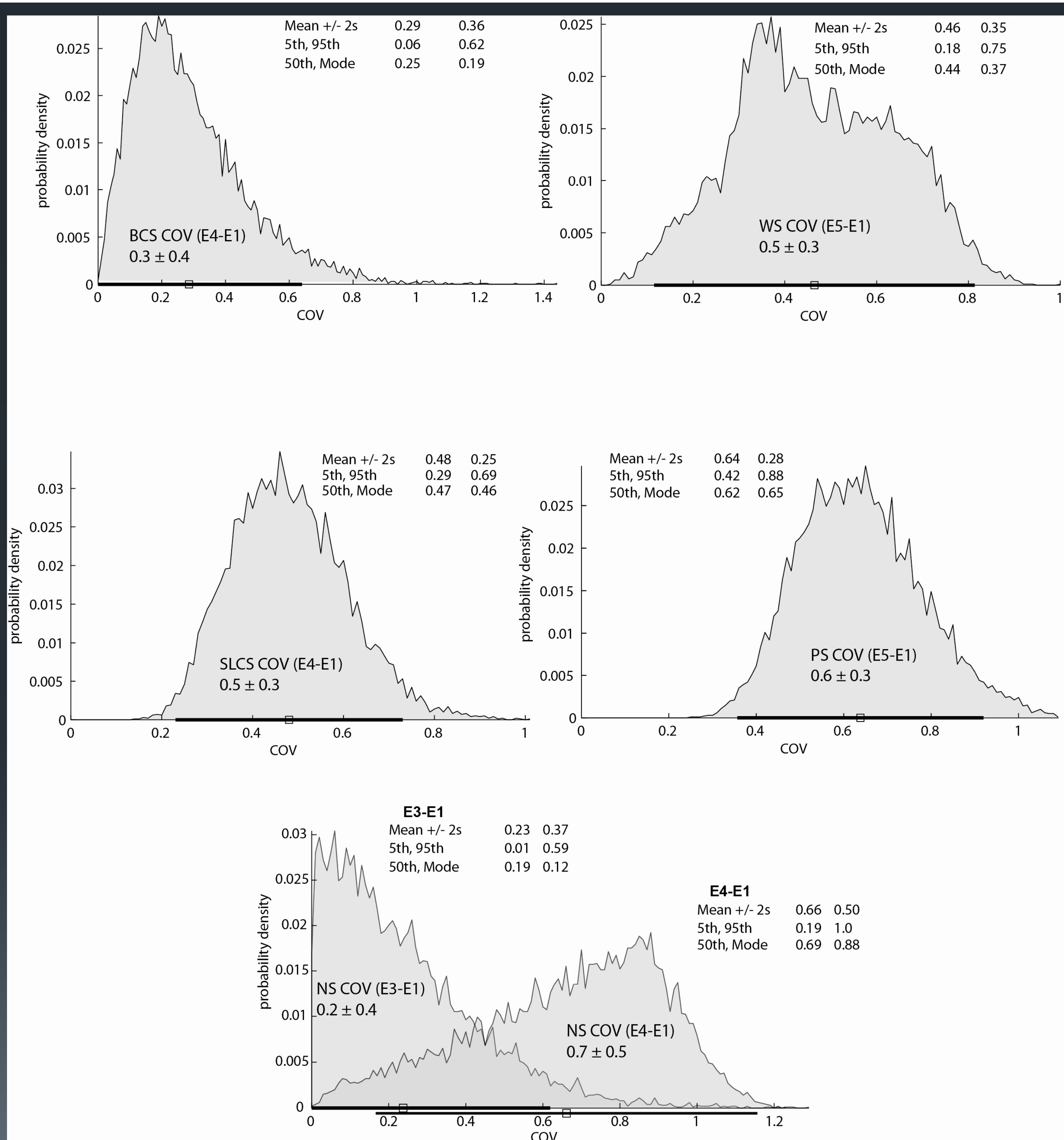
3. Calculate COV = standard deviation of RIs / mean of them

4. Repeat, and then compile and plot COVs

- Issues:
  - Insufficient data per segment (2–4 RIs)
  - RIs not filtered for negative or near-zero recurrence
  - How combine into single value for central WFZ?

COV

- BCS: 0.3 ± 0.4 (2σ)
- WS: 0.5 ± 0.3
- SLCS: 0.5 ± 0.2
- P: 0.6 ± 0.3
- N:
  - 0.7 ± 0.5 (E4-E1)
  - 0.2 ± 0.4 (E3-E1)



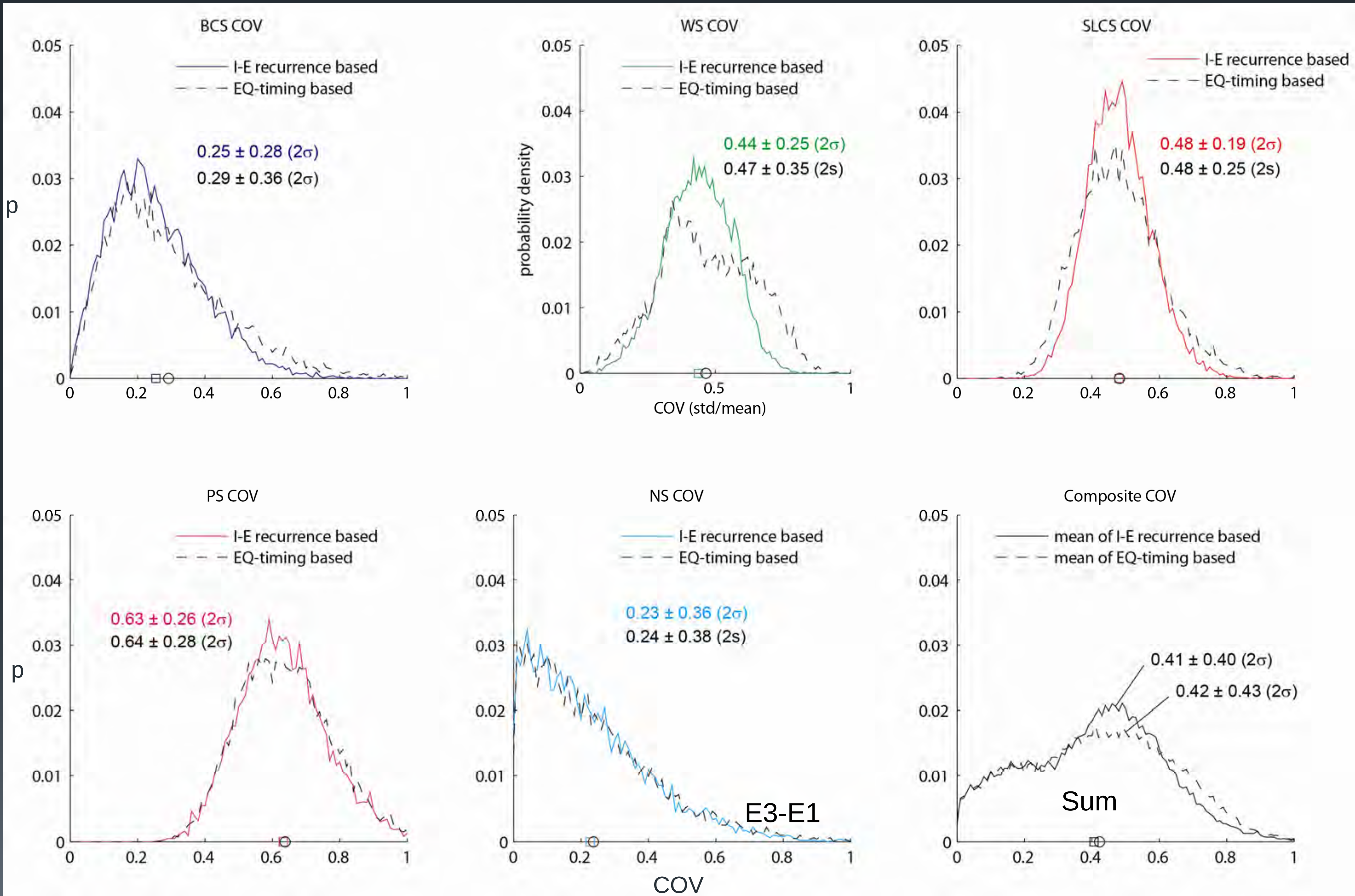
Composite COV

1. Compile inter-event recurrence PDFs in one place.
   - Brigham City B4-B3, B3-B2, B2-B1, Weber segment W4-W3, etc. (n = 16)
   - RI PDFs filtered for some minimum value (important)
   - Not including elapsed time since MRE as a recurrence interval

2. Sample recurrence data. In each simulation (n = 10k):
   - Randomly select single recurrence value from each inter-event PDF (e.g., B4-B3) and add to group of recurrence values
   - Each simulation results in a set of 16 inter-event RIs
   - COV (per sim) = standard dev. (stdev) of RIs / mean of Ris
   - COV (per sim, per seg.) = stdev BCS-RIs / mean BCS-RIs

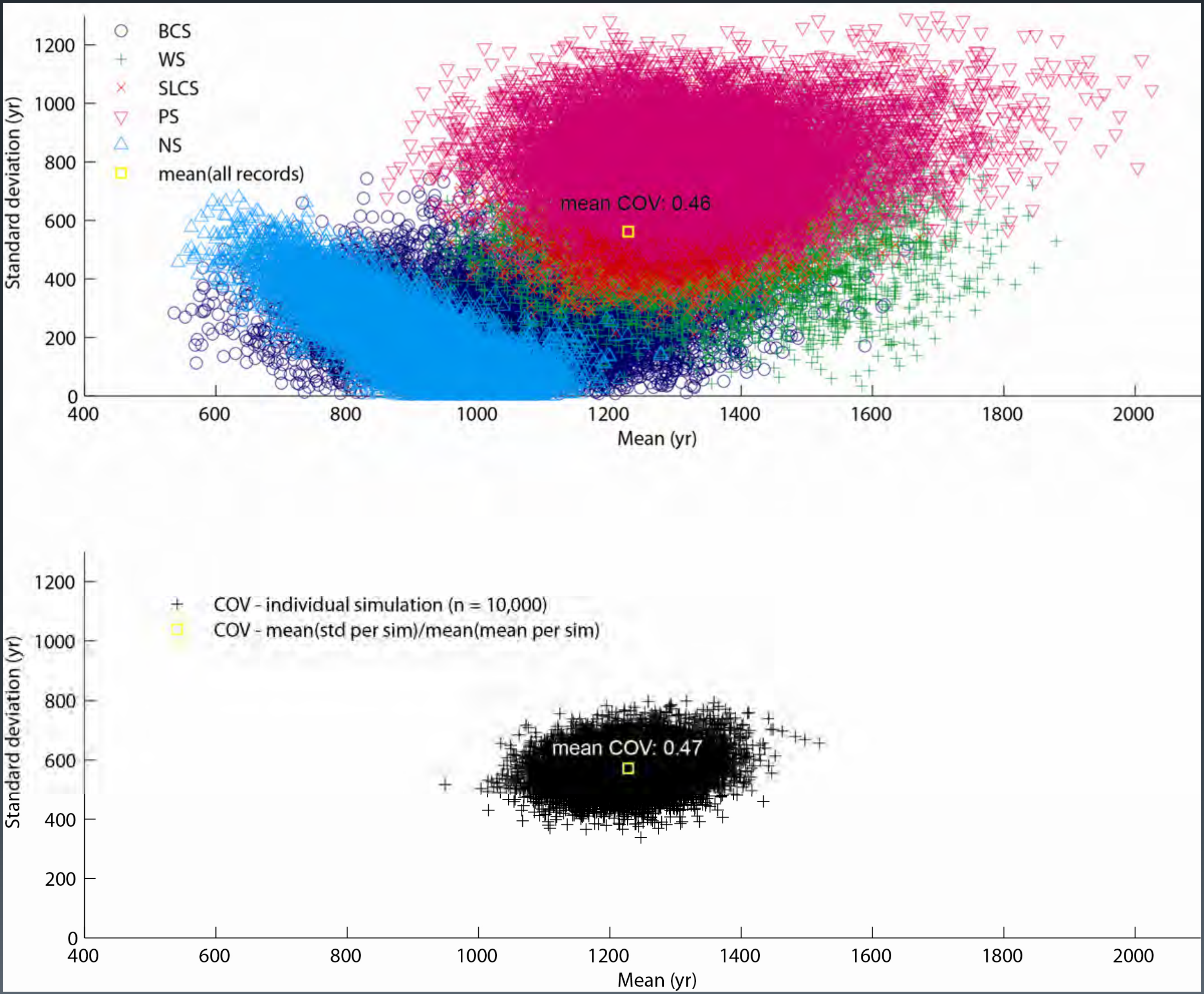
➢ The COV values computed in each simulation are then compiled and plotted in probability space.

Comparison of COV per Segment

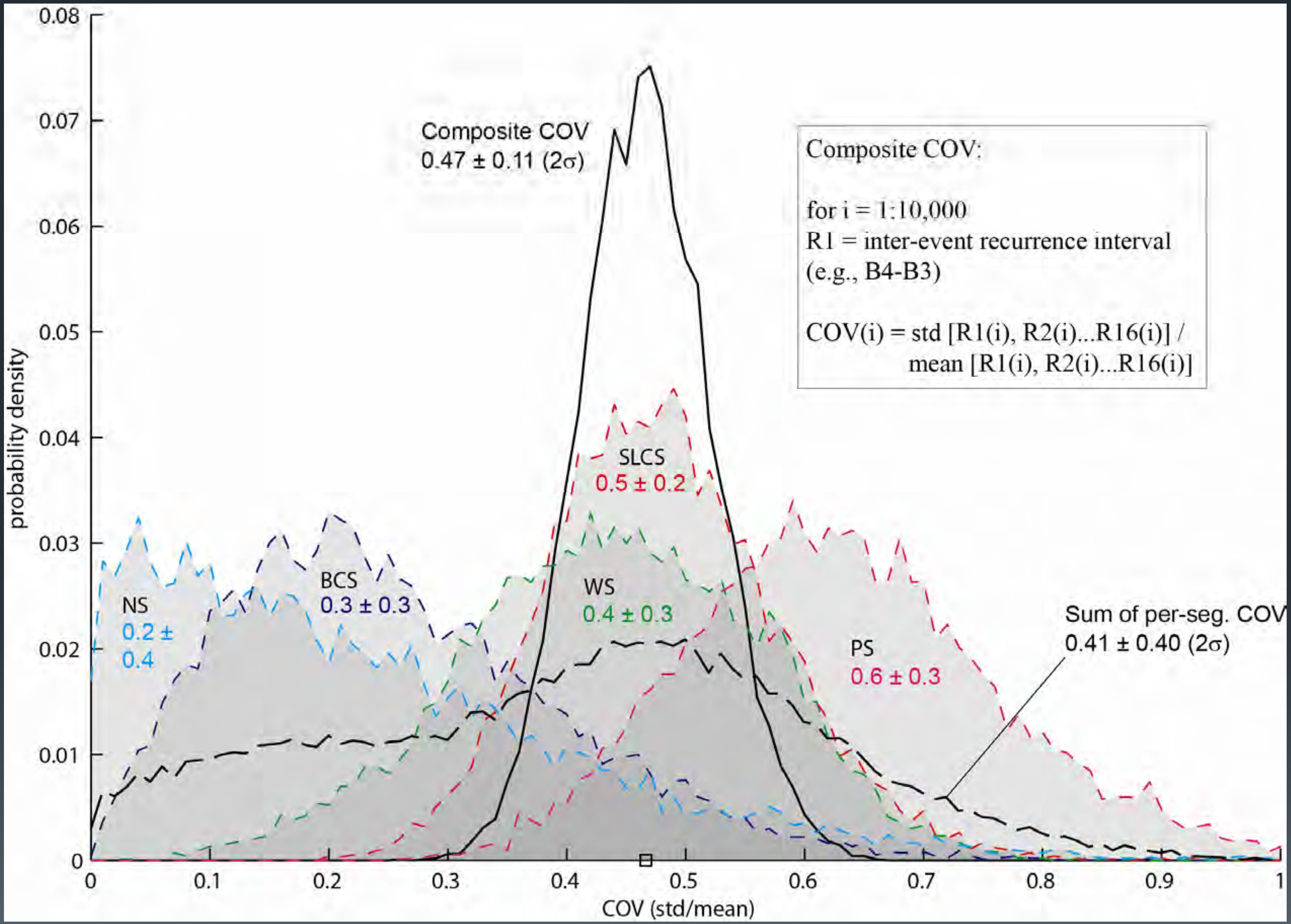


Per-Segment vs. Composite COV

- COVs per segment
  - Ea. Shape is one COV calculated using seg.-specific RI data
- Composite COV
  - Ea. + is one COV from 16 inter-event RIs



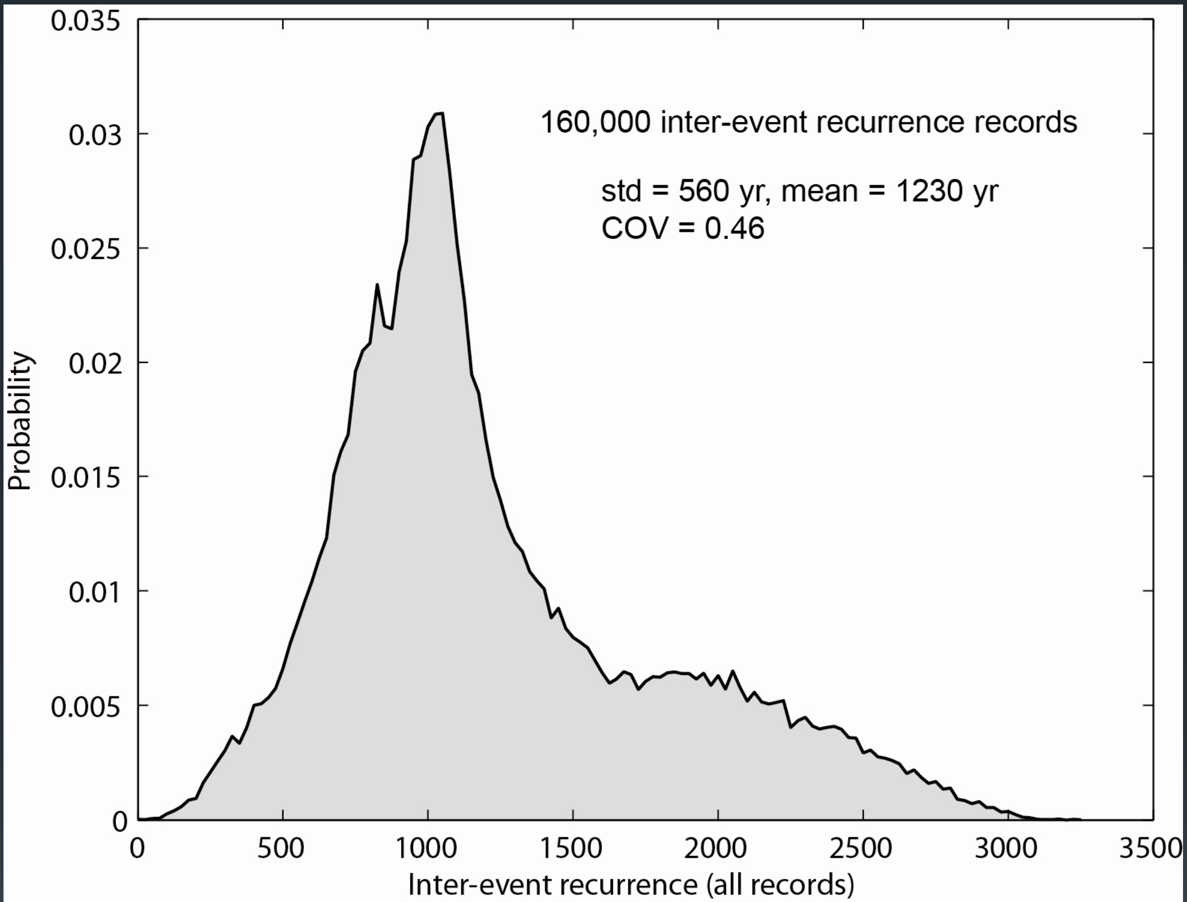
Composite COV



Alternate Approach – Mean of all records

1. Compile all inter-event recurrence values sampled in each scenario in one group
   - Brigham City B4-B3, B3-B2, B2-B1, Weber segment W4-W3, etc. (n = 16 x 10k sim)

➢ COV = stdev. (all records) / mean (all records = 0.46



COV Conclusions

- Different methods yield similar results, but different uncertainties
- Sum of per-segment COVs (based on EQ times and Inter-event RIs)
  - COV: 0.4 ± 0.4 (2σ)
  - Large uncertainty driven by limited data/variability per segment
    - NS COV ~0.2 *(poorly defined – 3 events)* = 1/5 records or 20%
    - WS COV ~0.4 *(better defined – 5 events)* = 1/5 records or 20%
- Composite
  - 0.5 using all records, **0.5 ± 0.1 (2σ)** sampling each of 16 inter-event recurrence intervals; possible range: 0.3–0.7
  - Compiling all data limits influence of individual segments, reduces uncertainty
    - NS COV ~0.2 = 2/16 records or 12.5%
    - WS COV ~0.4 = 4/16 records or 25%

Path Forward?

1. Composite COV: 0.5 ± 0.1 (2σ).
   - Composite value taking into account all RIs calculated for WFZ.
   - Assumption: central segments have similar earthquake behavior, similar recurrence intervals.
   - Nephi only possible exception.

2. Composite COV: 0.5 ± 0.2 (full range)
   - Full range of possible COVs using all WFZ RIs

3. Composite COV, but including elapsed times since MREs

4. Sum COV: 0.4 ± 0.4.
   - Mean value and uncertainty strongly influenced by Nephi, Brigham City

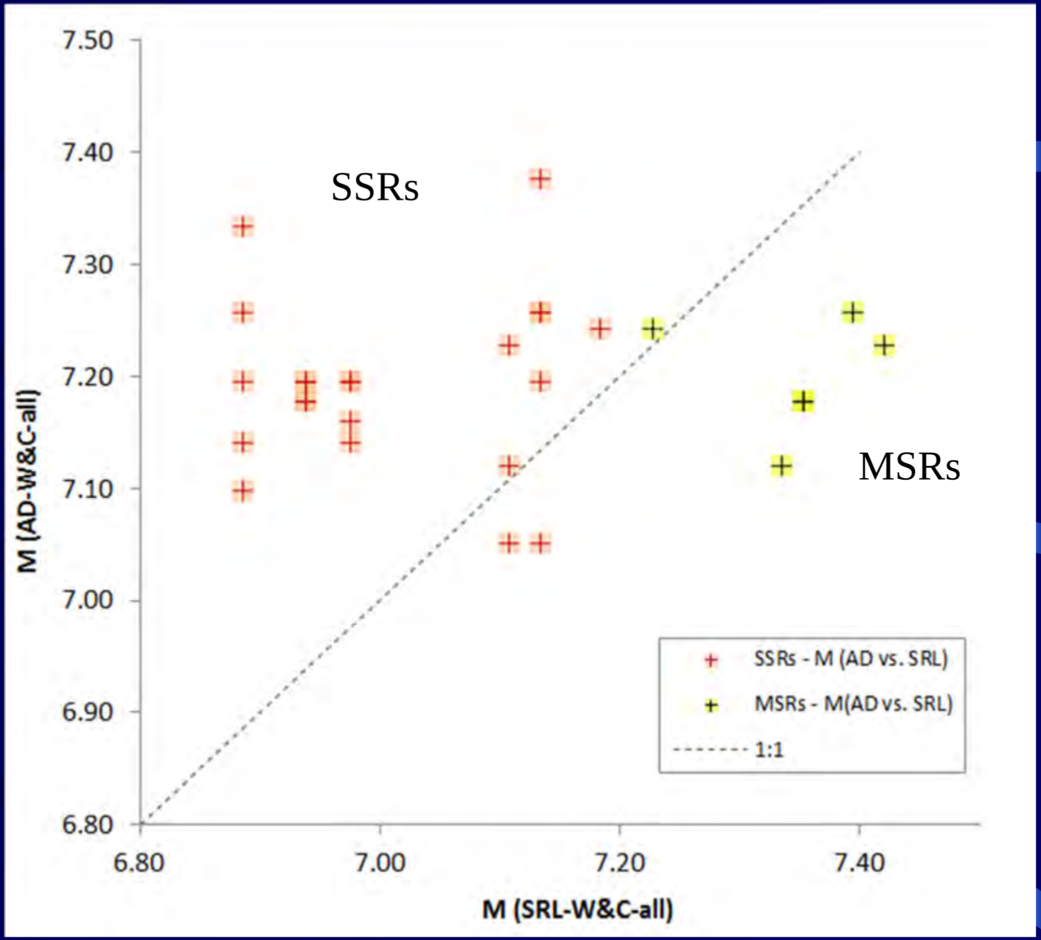
Update on calculating **M** and M_0 for the Wasatch Fault Zone

Susan Olig
Chris DuRoss

Working Group on Utah Earthquake Probabilities; November, 2011

Conclusions (from BRPEWG II – WFZ Discussion)

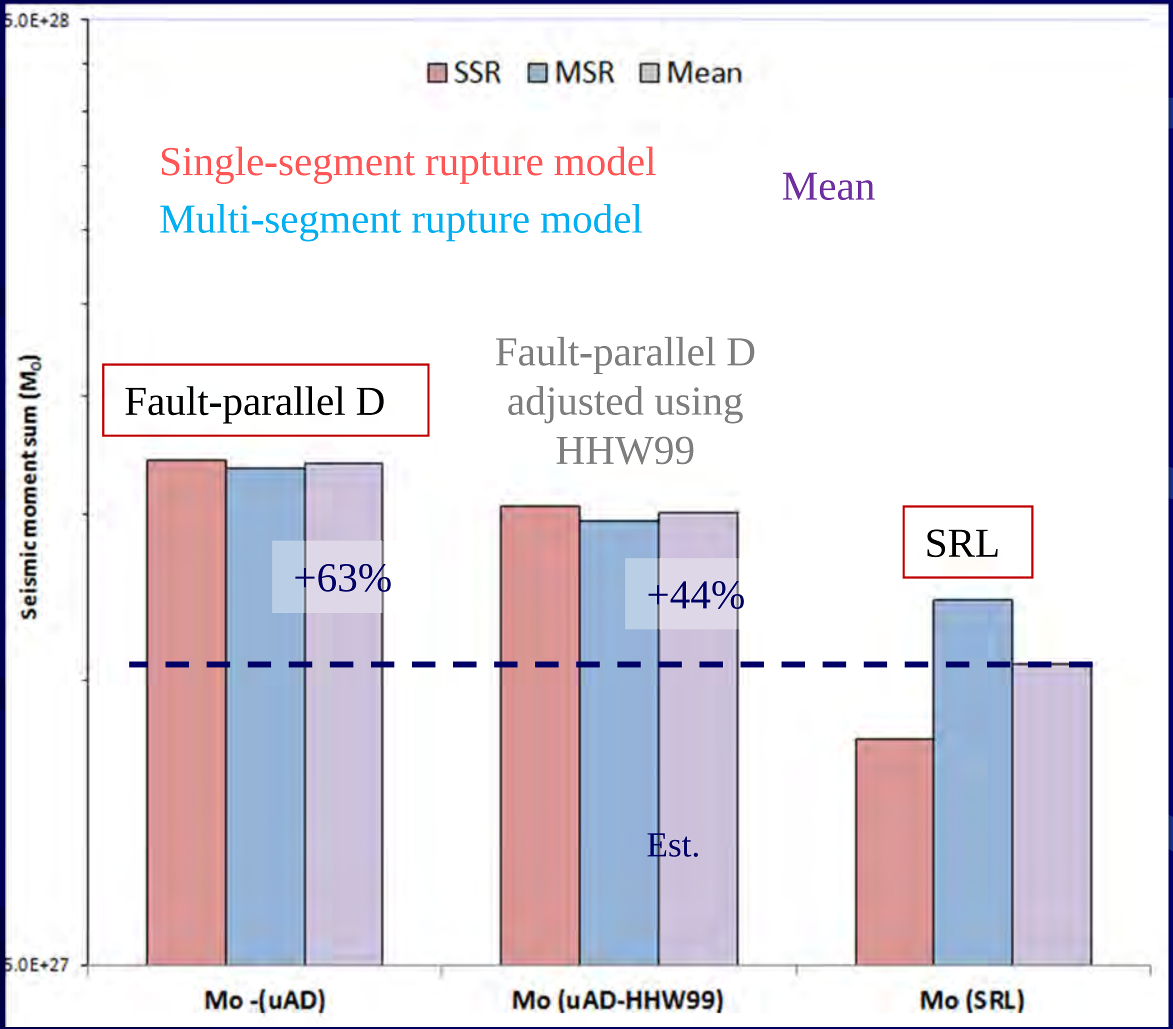
- **M** discrepancy
  - For single-segment ruptures, **M**(AD/M_0) > **M**(SRL/A), especially for shorter segments



- Difficult to consistently reduce the **M** discrepancy
  - Insufficient data to consistently apply HHW99 (and has limited effect)
  - Increasing SRL helps (especially for shorter segments), but hard to justify
  - Using normal-fault-type regressions helps reduce discrepancy for shorter SRLs, but for longer segments **M**(SRL) > **M**(AD)
  - <u>Best approach</u>: equal weighting of different **M** regressions?

M_0 Sum

- 60% more moment release on WFZ using AD ($M_0 = \mu * A * AD$) compared to only using SRLs



Sum of M_0 release for single- and multi-segment rupture models (WGUEP)

November 2011 Update

- Using vertical displacements in empirical M regressions (compared to fault-parallel displacement in M_0 calculations)
  - Minor reduction in M (SRL vs. AD) discrepancy

- Considering alternative **M** relations (BRPEWG II):
  - Stirling et al. (2002) – M(SRL-censored instrumental/W&C94-all)
  - Anderson et al. (1996) – M(SR)
  - Wells & Coppersmith (1994) – M(SRL-normal-fault-type)

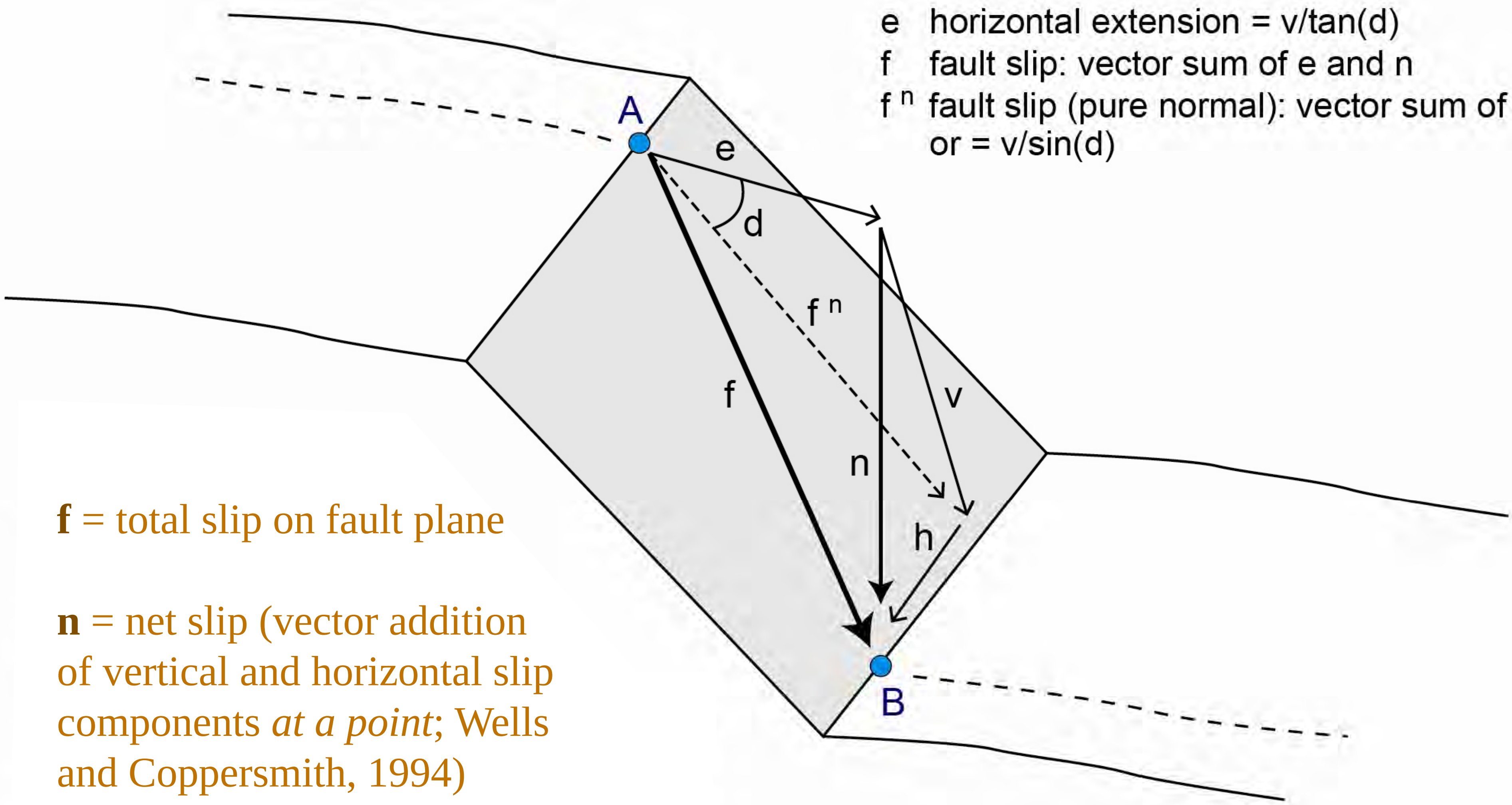
- **M** discrepancy likely related to empirical relations (related to EQ size, slip-type, region), not issue with displacement data.
  - No longer use W&C94(AD)
  - Use $M(M_0)$ to incorporate displacement (D) data where available
  - Use M(SRL-Stirling etal. 2002) to address uncertainties and for faults with little/no D data

November 2011 Update – Slip Vectors

M_0 relation uses **f** (if d <90°)

M regressions use **n** (or v, h)

v vertical component of displacement
h horizontal (lateral) component of displacement
n net slip: vector sum of v and h (W&C, 1994)
d fault dip
e horizontal extension = v/tan(d)
f fault slip: vector sum of e and n
f^n fault slip (pure normal): vector sum of e and v, or = v/sin(d)

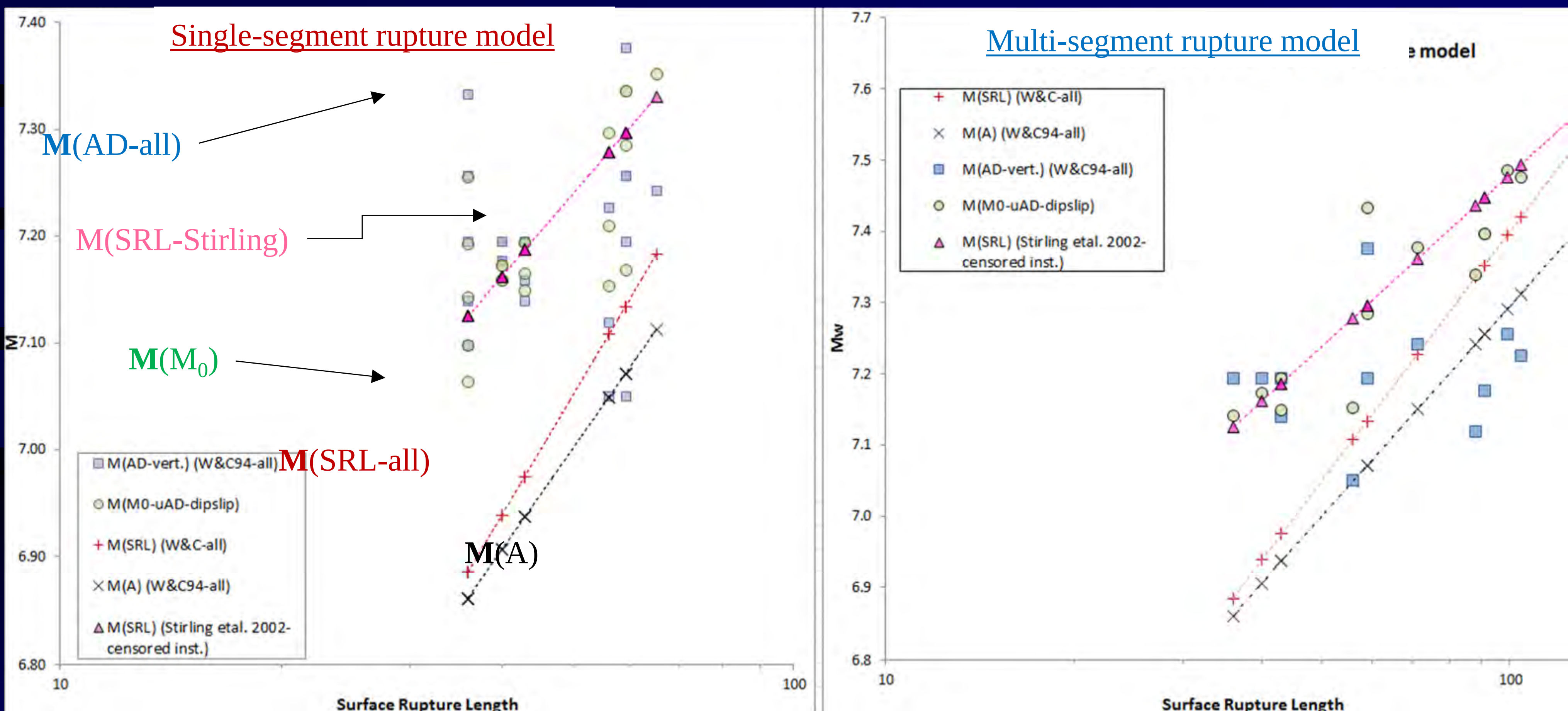


f = total slip on fault plane

n = net slip (vector addition of vertical and horizontal slip components *at a point*; Wells and Coppersmith, 1994)

Alternative M Relations

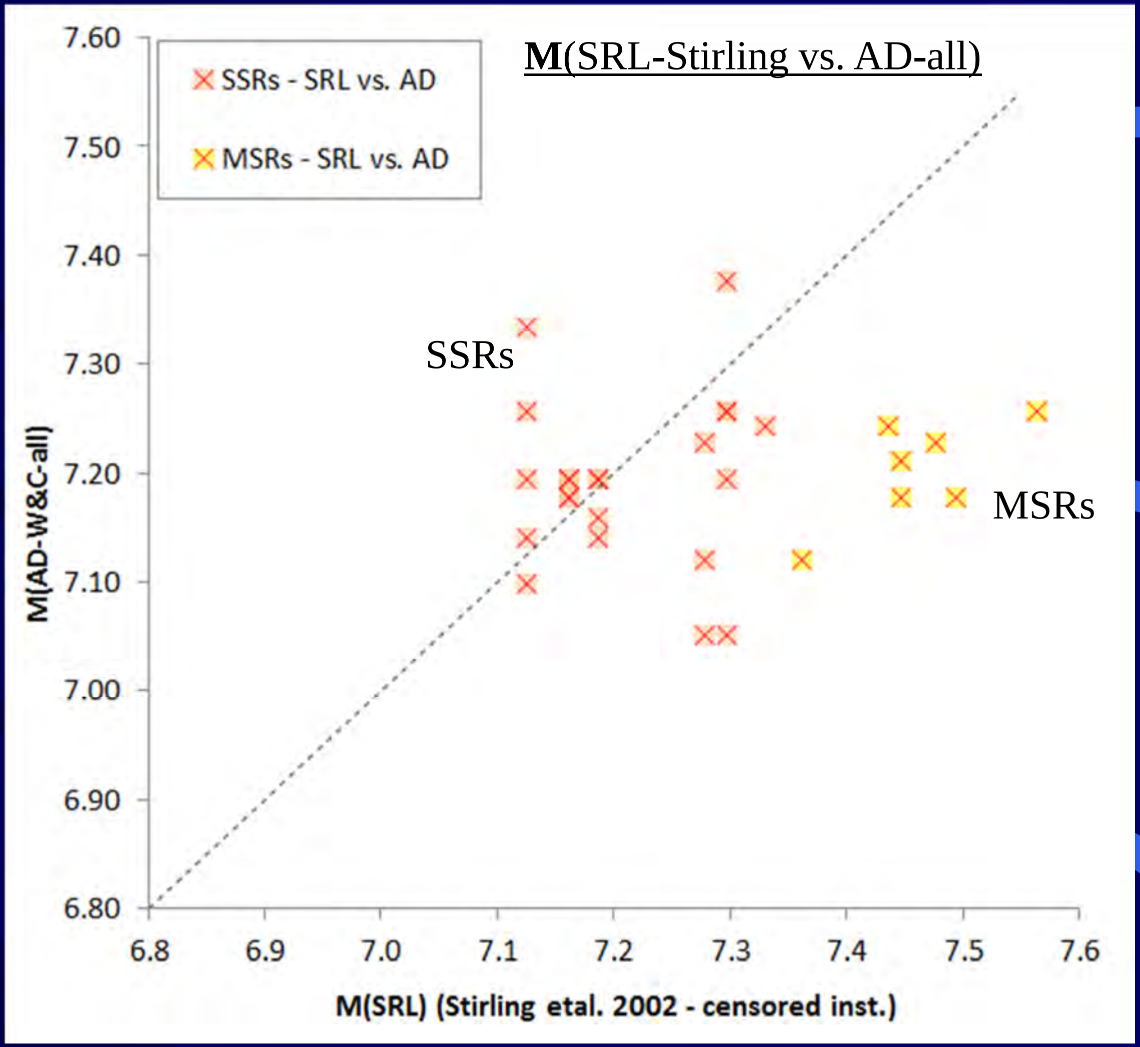
- Stirling et al. (2002) M(SRL) using censored instrumental (W&C94-all) data: <u>best fit to M for WFZ single-segment based on AD or M_0</u>



Alternative M Relations

- Stirling et al. (2002) **M**(SRL) using censored instrumental (W&C94-all) data:
- For SSRs, mod. good agreement between **M**(SRL-censored) and **M**(AD)
- For MSRs, **M**(SRL-censored) > **M**(AD) (**M**/AD not scaling with SRL)

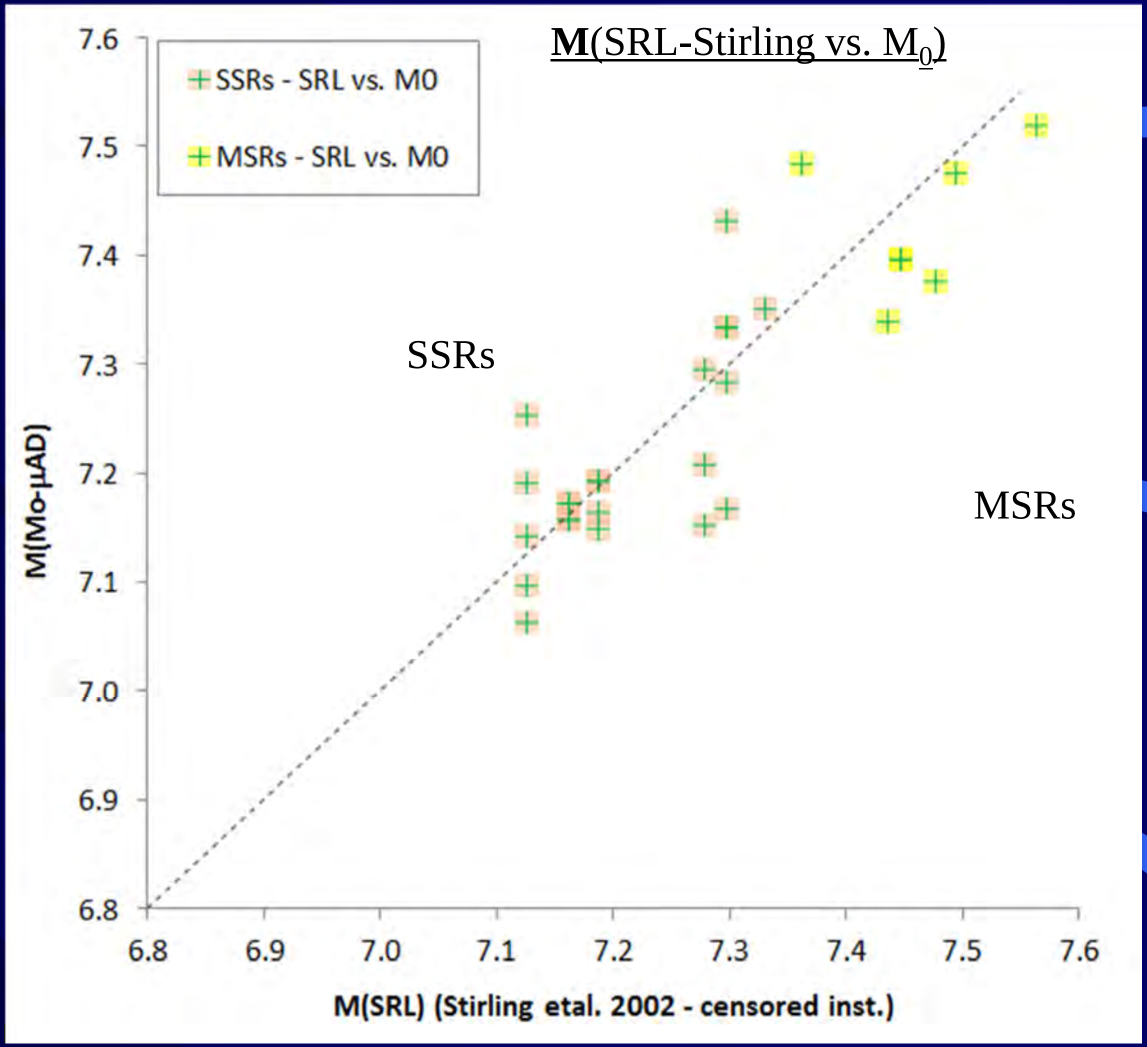
M(SRL-censored) vs. **M**(AD):



Alternative M Relations

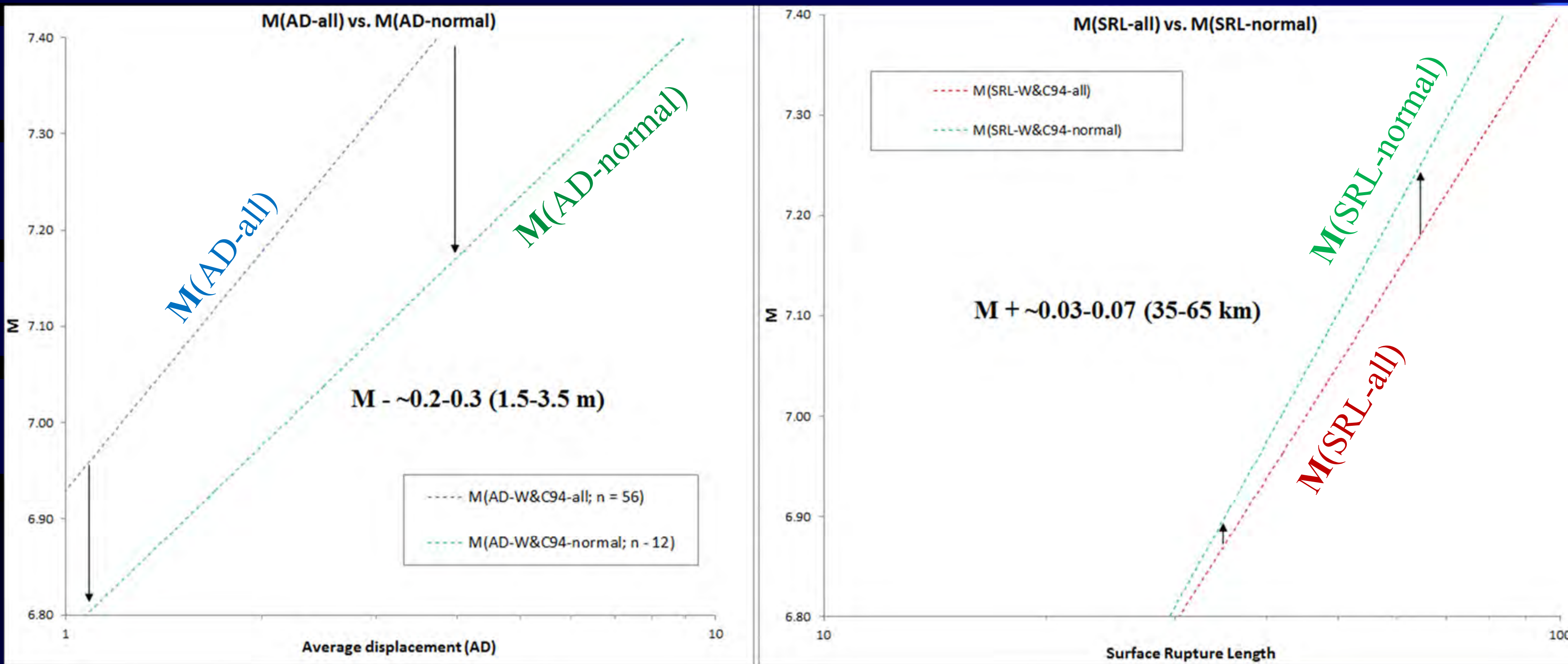
- Stirling et al. (2002) M(SRL) using censored instrumental (W&C94-all) data:
- For SSRs and MSRs, good agreement between **M**(SRL-censored) and **M**(AD)
- For MSRs, **M**/M_0 accounts for longer SRLs, but also AD (not scaled with SRL)

M(SRL-censored) vs. **M**(M_0):



Alternative M Relations

- W&C94 – Normal-fault regressions



BRPEWG II Conclusions

Strawman 1

- WGUEP A (3+ sites)
  - W&C94(SRL-all) 0.25
  - W&C94(A-all) 0.25
  - W&C94(AD-HHW) 0.25
  - H&K79(M_0) 0.25
- WGUEP – B (1-2 sites)
  - W&C94(SRL-all) 0.3
  - W&C94(A-all) 0.3
  - W&C94(AD-all?) 0.2
  - H&K79(M_0) 0.2
- WGUEP – C (no sites)
  - W&C94(SRL-all) 0.5
  - W&C94(A-all) 0.5

BRPEWG II

- M relations for BRP faults
  - W&C94(SRL-all)
  - W&C94(A-all)
  - W&C94(SRL-normal)
  - Anderson et al.(SR)
  - Stirling et al.(SRL-cen. inst.)

BRPEWG II Conclusions

Strawman 2

- WGUEP A (3+ sites)
  - W&C94(SRL-all) 0.25
  - W&C94(A-all) 0.25
  - W&C94(AD-HHW) 0.25
  - H&K79(M_0) 0.25
- WGUEP – B/C (0-2 sites)
  - W&C94(SRL-all) 0.5
  - W&C94(A-all) 0.5

BRPEWG II

- M relations for BRP faults
  - W&C94(SRL-all)
  - W&C94(A-all)
  - W&C94(SRL-normal)
  - Anderson et al.(SR)
  - Stirling et al.(SRL-cen. inst.)

BRPEWG II Conclusions

Strawman 3

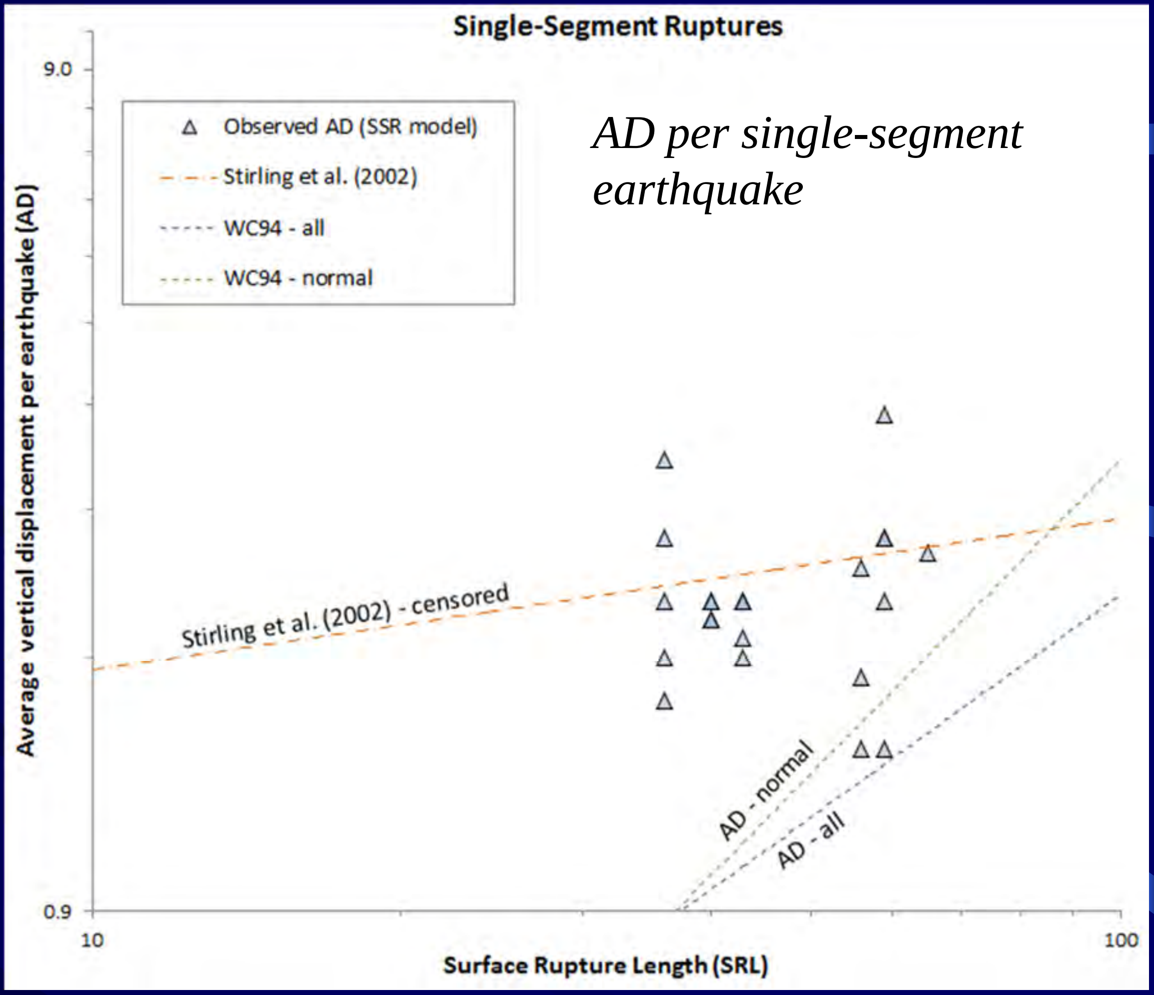
- WGUEP A (2+ sites)
  - H&K79(M_0) 0.30
  - W&C94(SRL-all) 0.20
  - Stirling et al.(SRL-cen. inst.) 0.30
  - W&C94(A-all) 0.20
- WGUEP – B/C (all others)
  - W&C94(SRL-all) 0.3
  - Stirling et al.(SRL-cen. inst.) 0.25
  - W&C94(SRL-normal) 0.15
  - W&C94(A-all) 0.15
  - Anderson et al.(SR) 0.15

BRPEWG II

- M relations for BRP faults
  - W&C94(SRL-all)
  - W&C94(A-all)
  - W&C94(SRL-normal)
  - Anderson et al.(SR)
  - Stirling et al.(SRL-cen. inst.)

Conclusions from June 2011 WGEUP

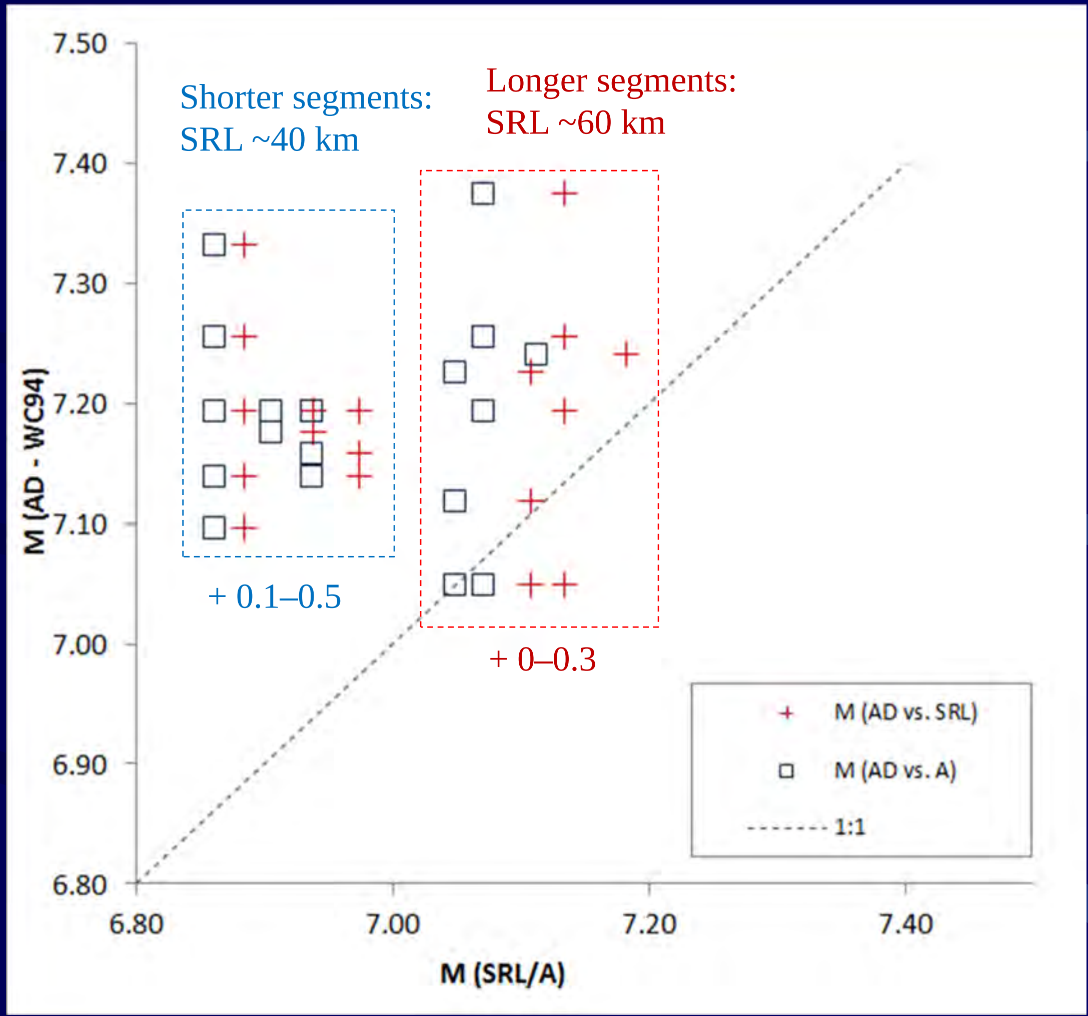
- Average displacement (AD) per WFZ earthquake is large
  - Similar results if averaged or modeled (half ellipse)
  - Vertical D converted to fault-parallel D
  - Overestimated displacement? Underestimated SRLs?
  - Greater discrepancy for shorter segments and single-segment rupture model



SRL

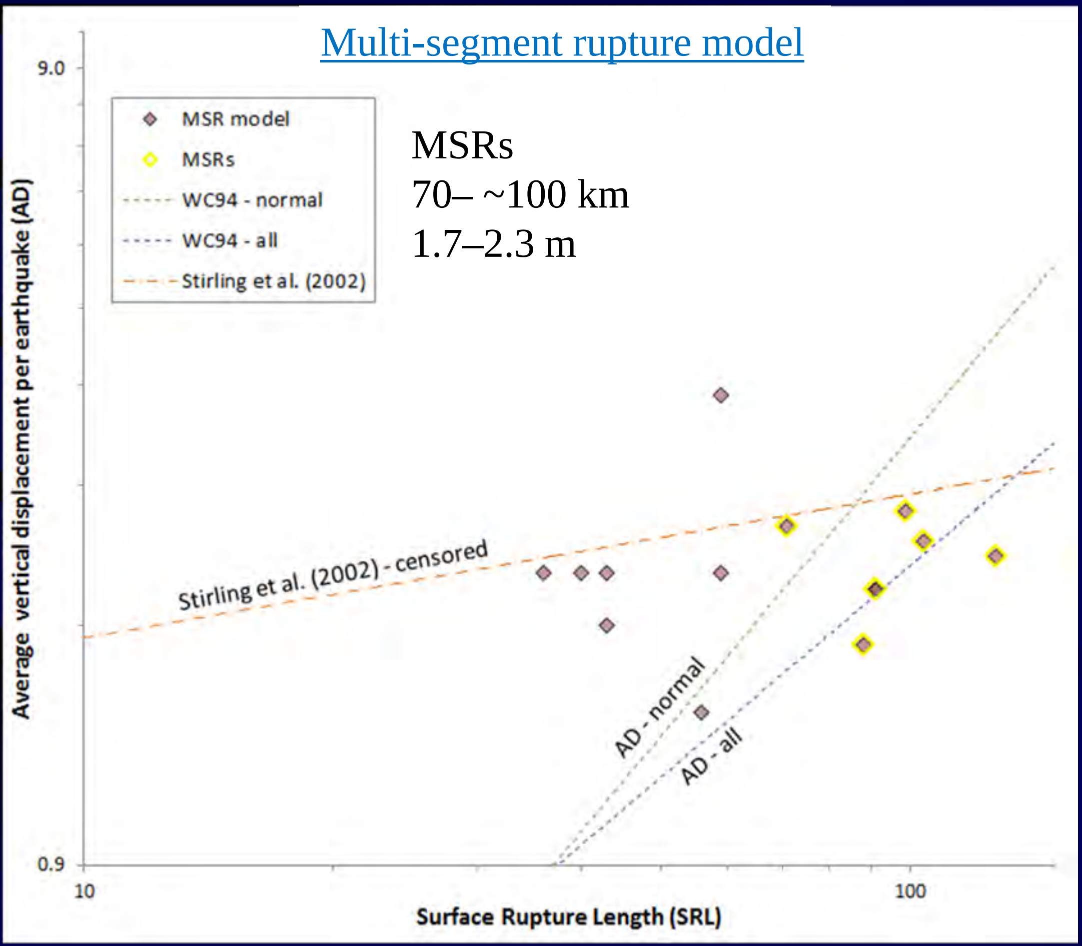
M Discrepancy – Single-Segment Ruptures

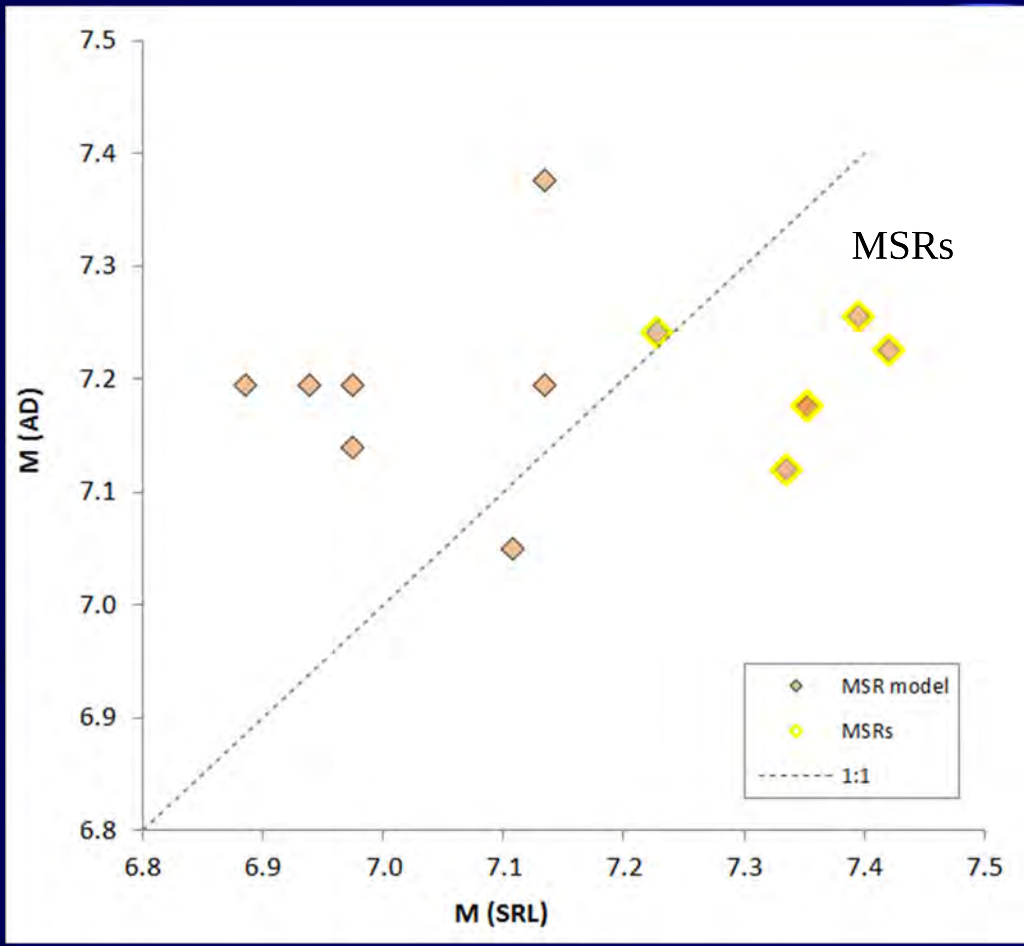
- For single-segment earthquakes, **M**(AD) consistently greater than **M**(SRL or A)
  - Discrepancy greatest for shorter segments



Multi-Segment Ruptures

- **M** discrepancy less of an issue for MSRs (using observed displacements)

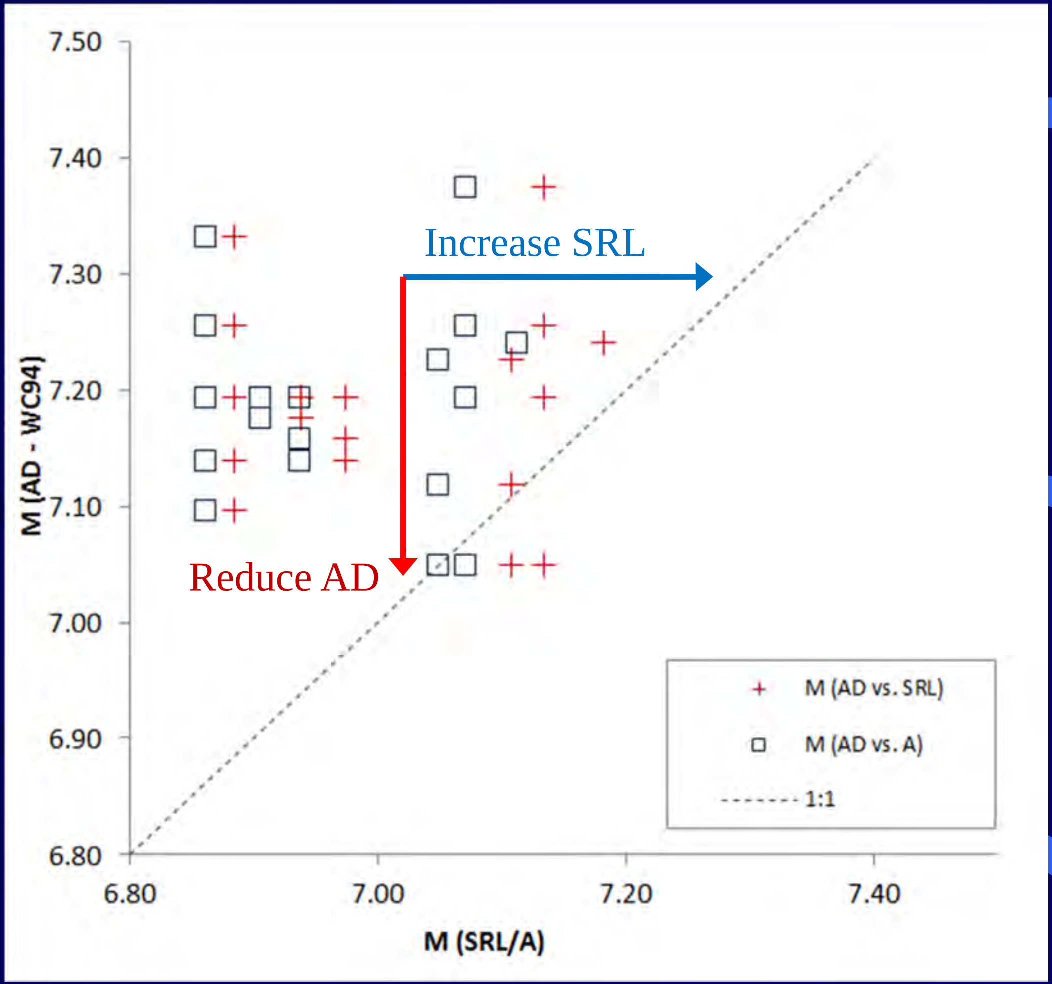




Reducing the **M** Discrepancy

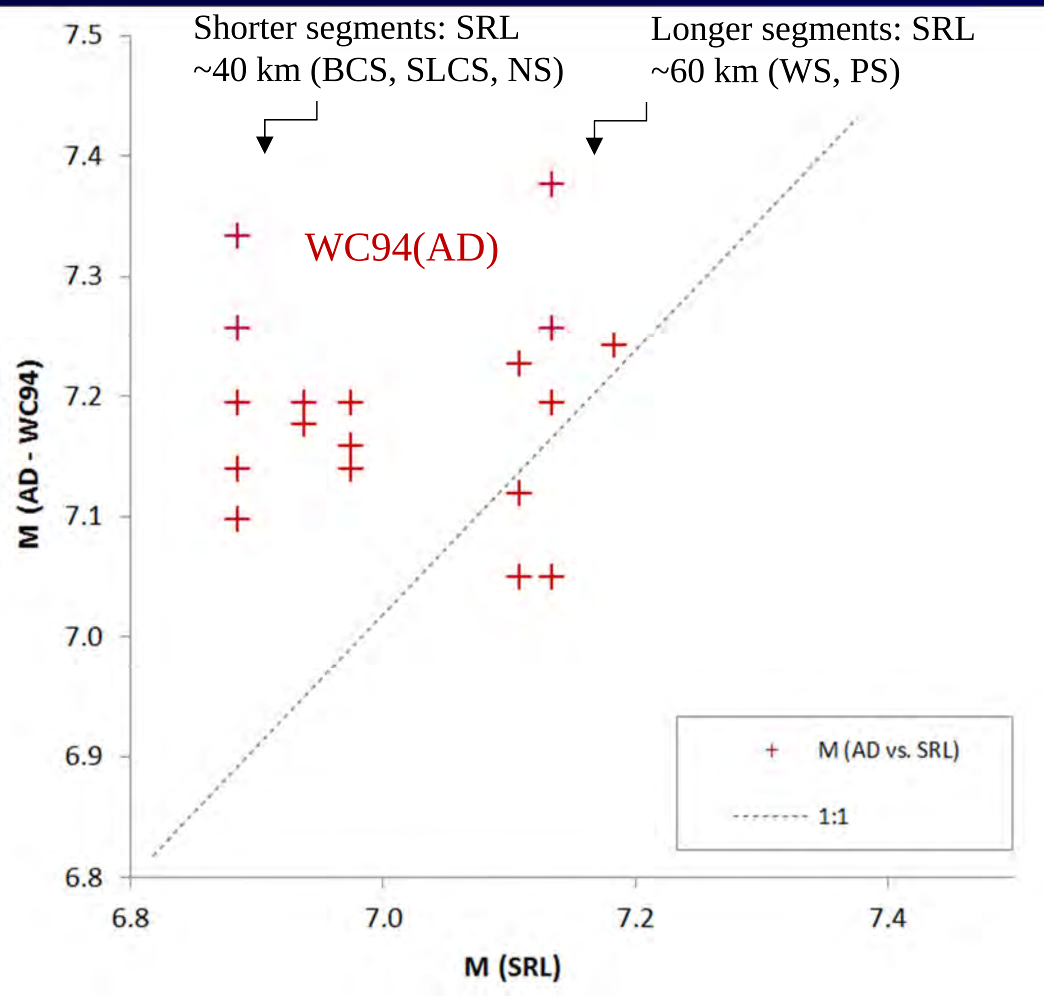
- Ways to reduce the **M** discrepancy
  - Reduce AD
  - Increase SRL

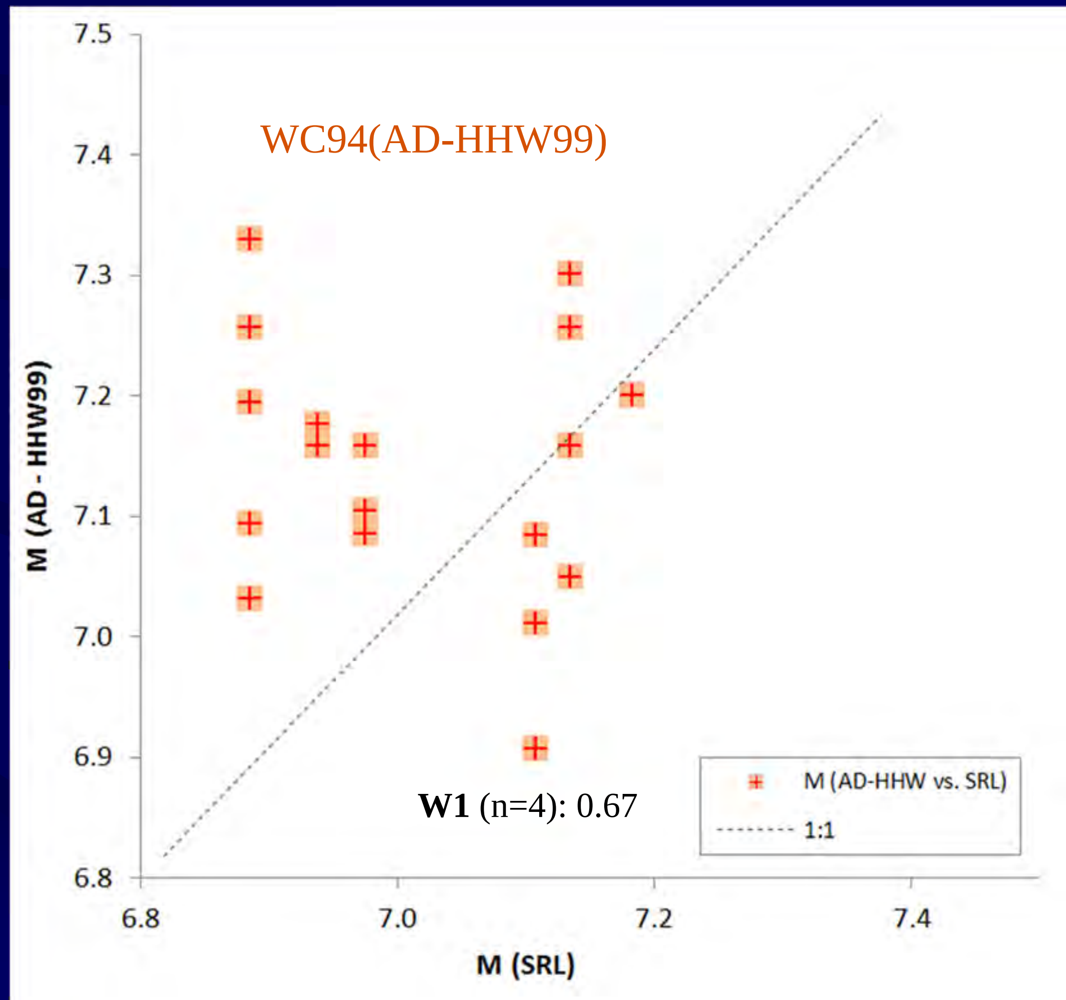
- Other options
  - Ignore (cite large stress drops)
  - Take mean of all available **M** estimates
  - Use different or acquire new regressions



Revising Displacement

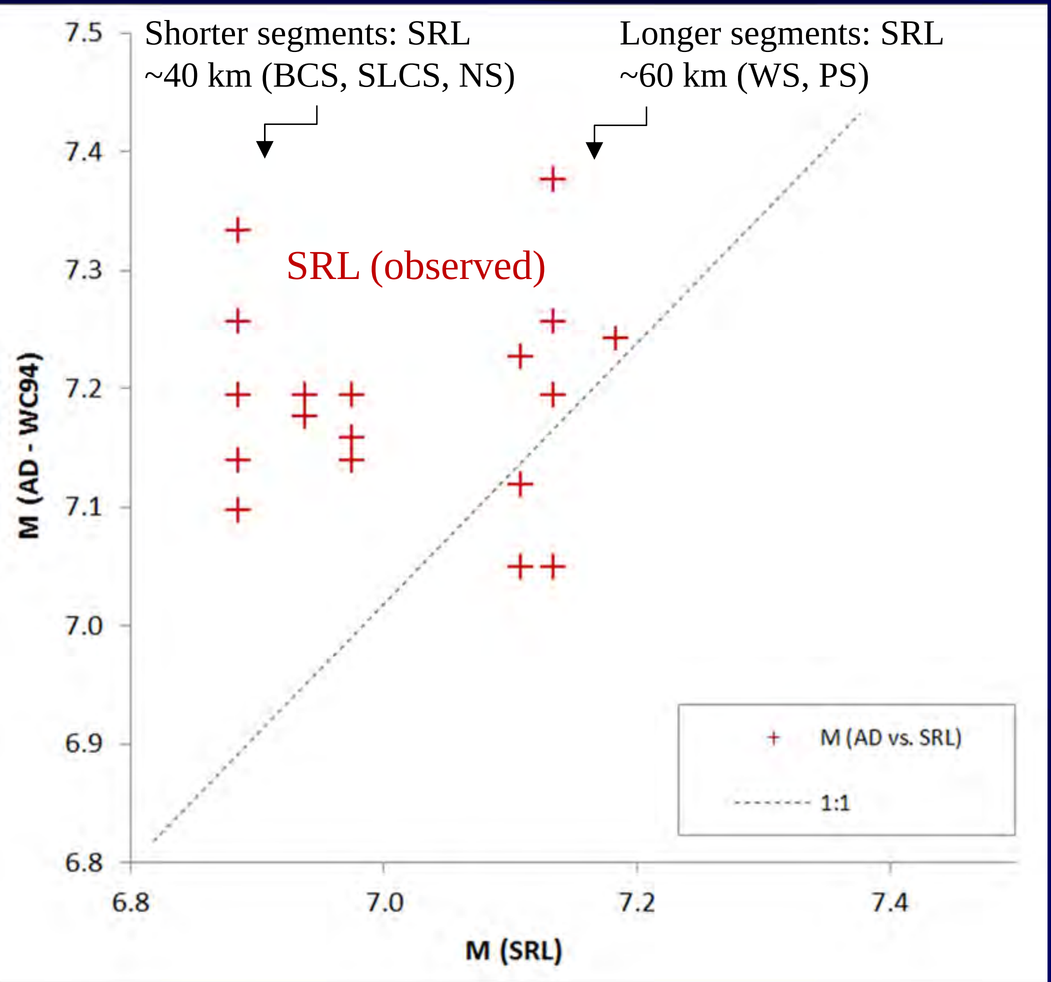
- HHW99 AD correction has minor effect on **M** discrepancy
  - Most significant change: W1 (1.4 to 0.9 m), W3 (2.3 to 1.5 m)
  - Minor to no change with shorter SRL segments (BCS, SLCS, NS)

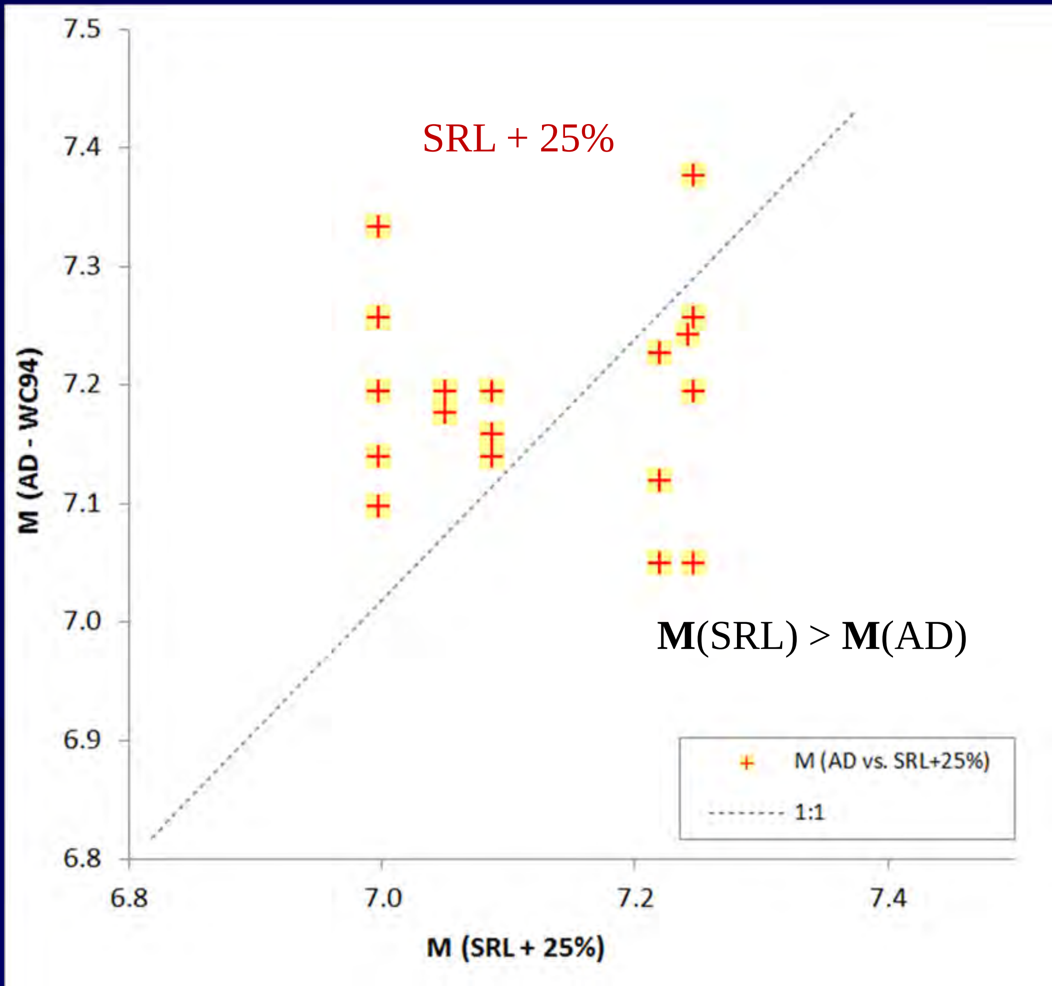




Revising SRL

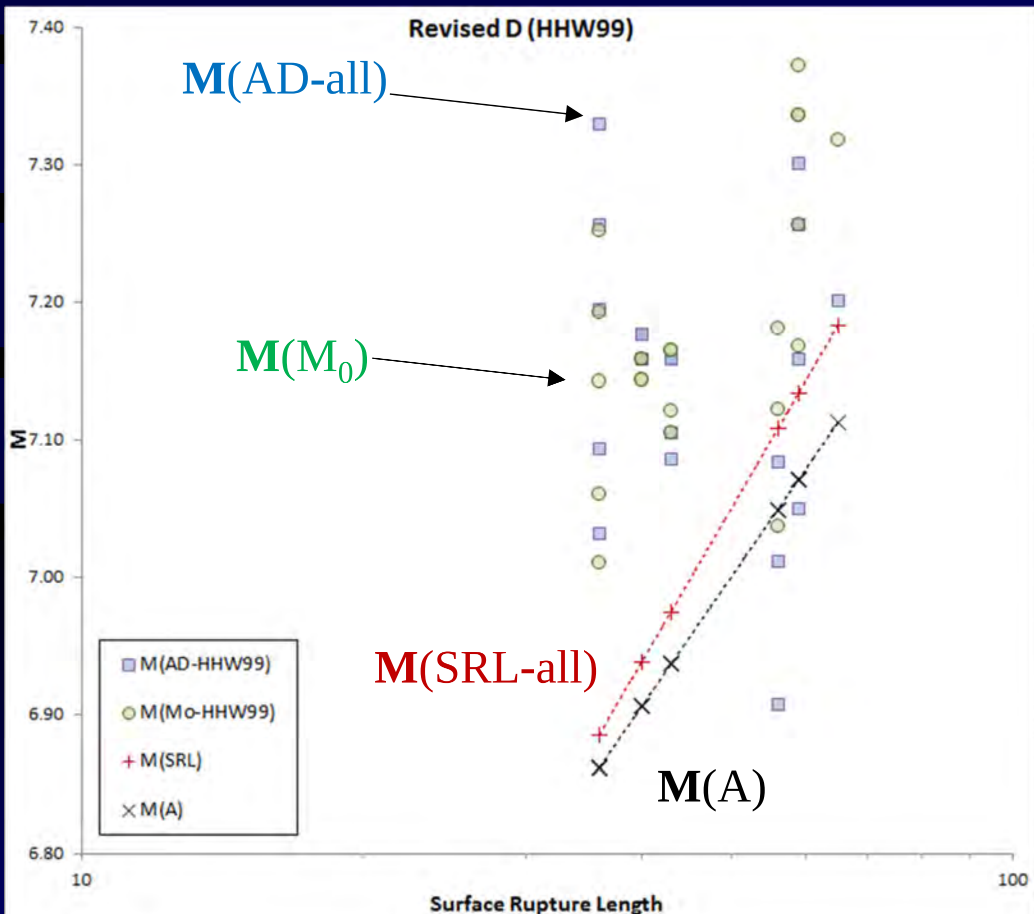
- What if we underestimated single-segment SRLs by 25%?
  - Double the Weber-Brigham City segment spill over = ~27%
  - McCalpin and Slemmons (1996): underestimate SRL by ~25% if scarps having 0–10% of maximum displacement (~0–40 cm) are removed, buried, or obscured

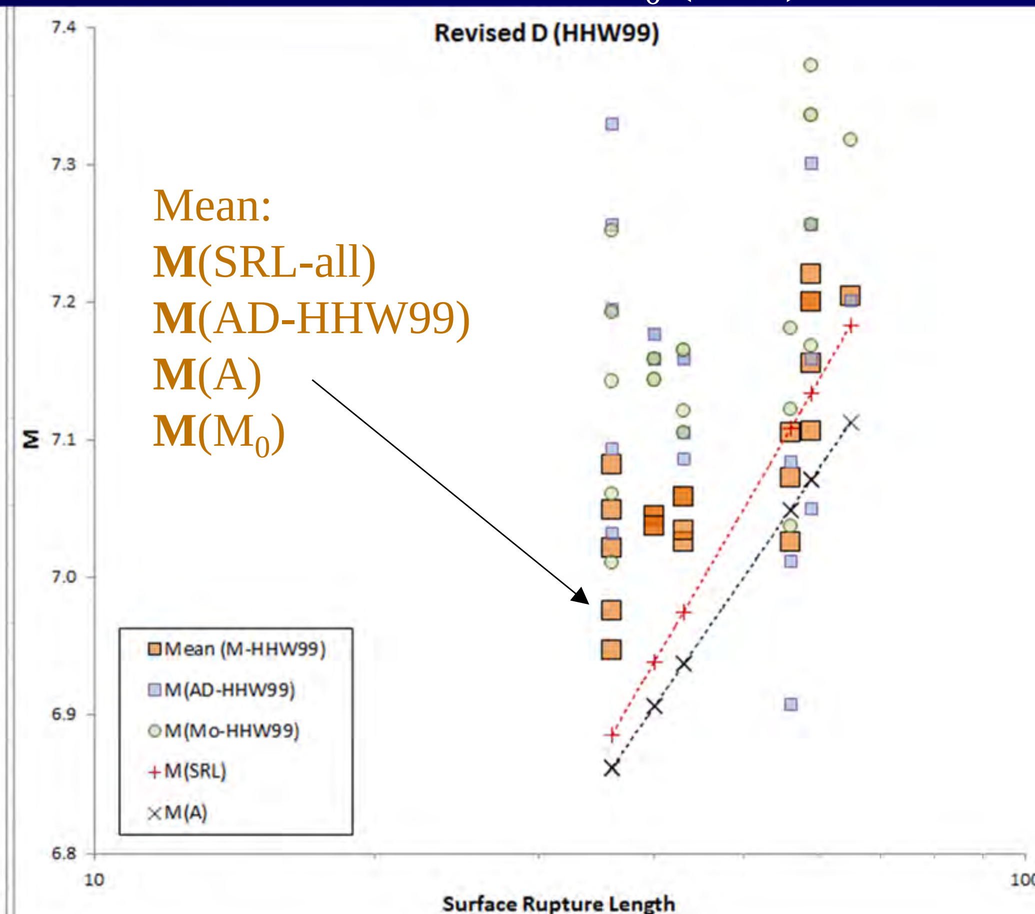




Other Options

- Weighting Scheme (using revised AD):
  - W&C94 – A (0.25)
  - W&C94 – SRL-all (0.25)
  - HHW99 – AD (0.25)
  - Hanks and Kanamori – M_0 (0.25)*

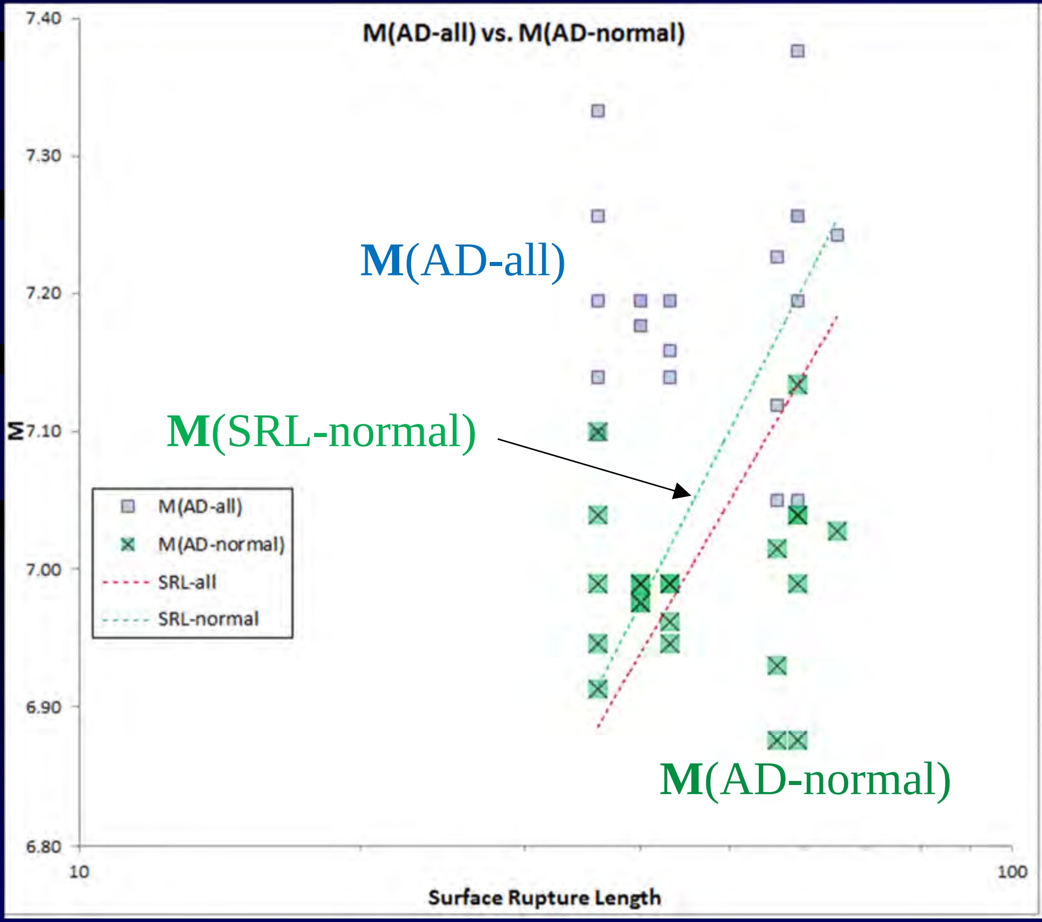


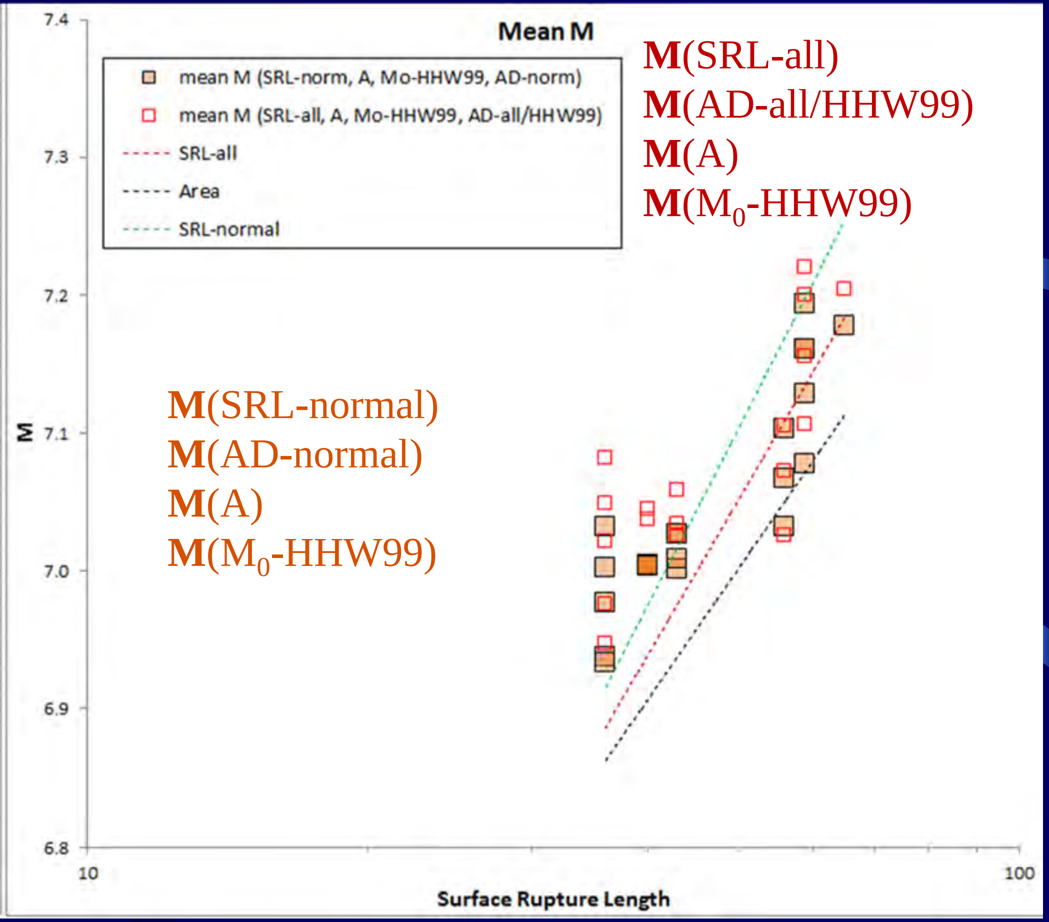


***M** (M_0) = 2/3 log(M_0) – 10.7; M_0 = μ*A(SRL*W)*AD (AD converted to fault-parallel slip)

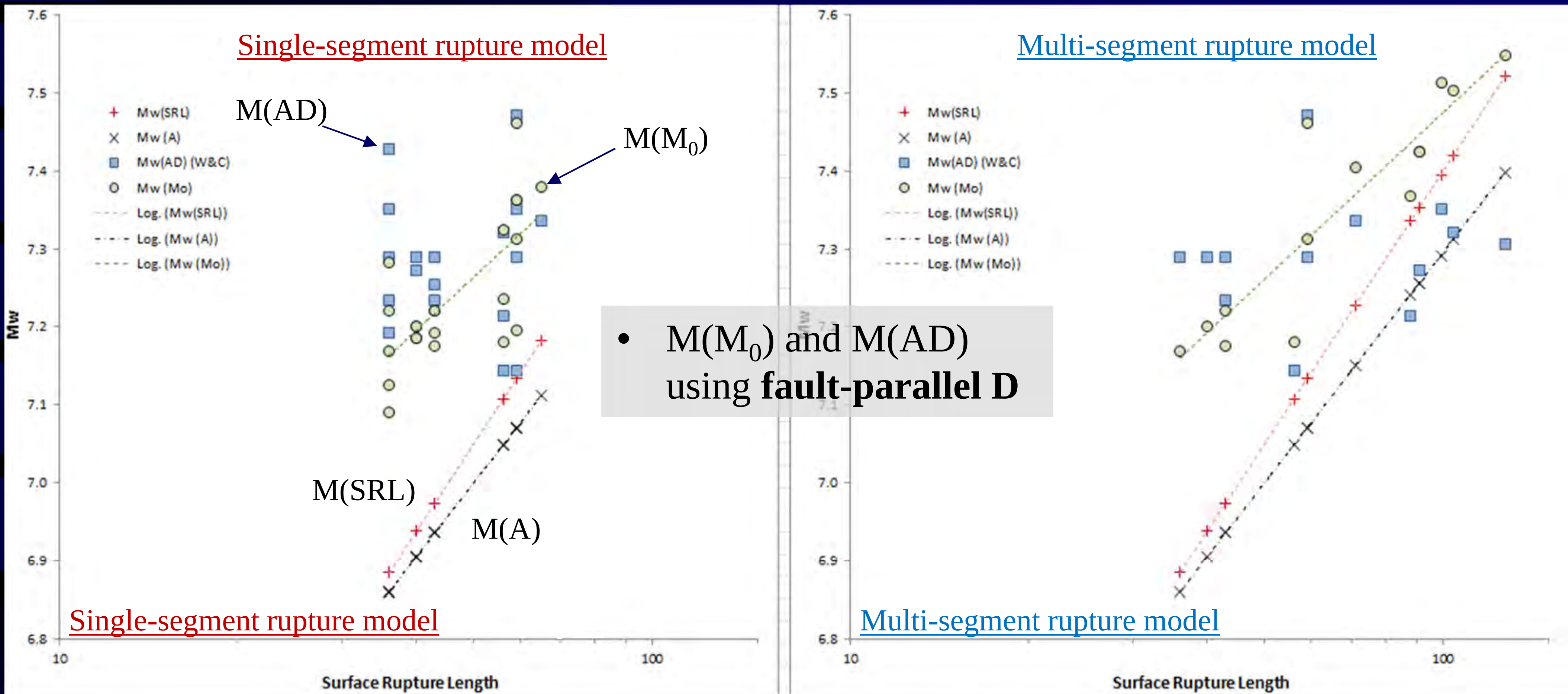
Other Options

- Other regressions? W&C94 – Normal-fault regressions?
  - Discrepancy reduced for shorter segments
  - M(SRL) > M(AD) for longer segments, larger displacements





M vs. SRL – June 2011



- M(M_0) and M(AD) using **fault-parallel D**

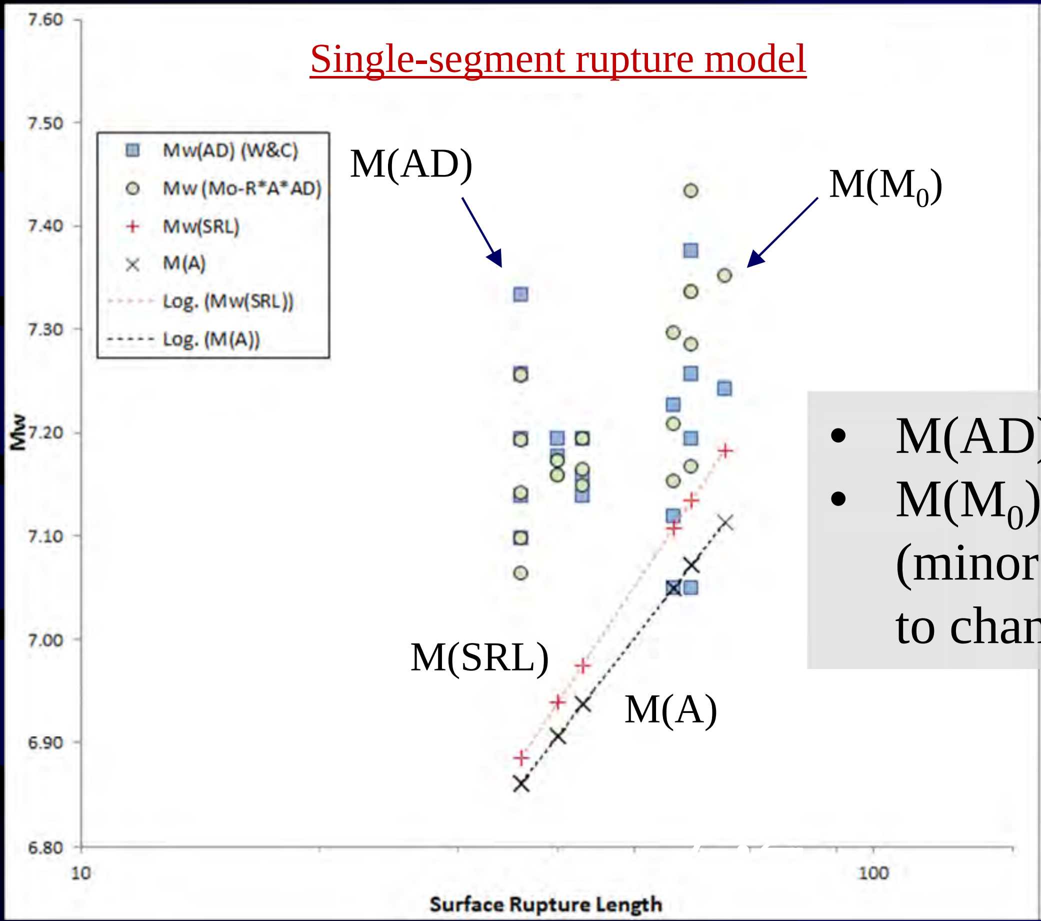
Single-segment rupture model

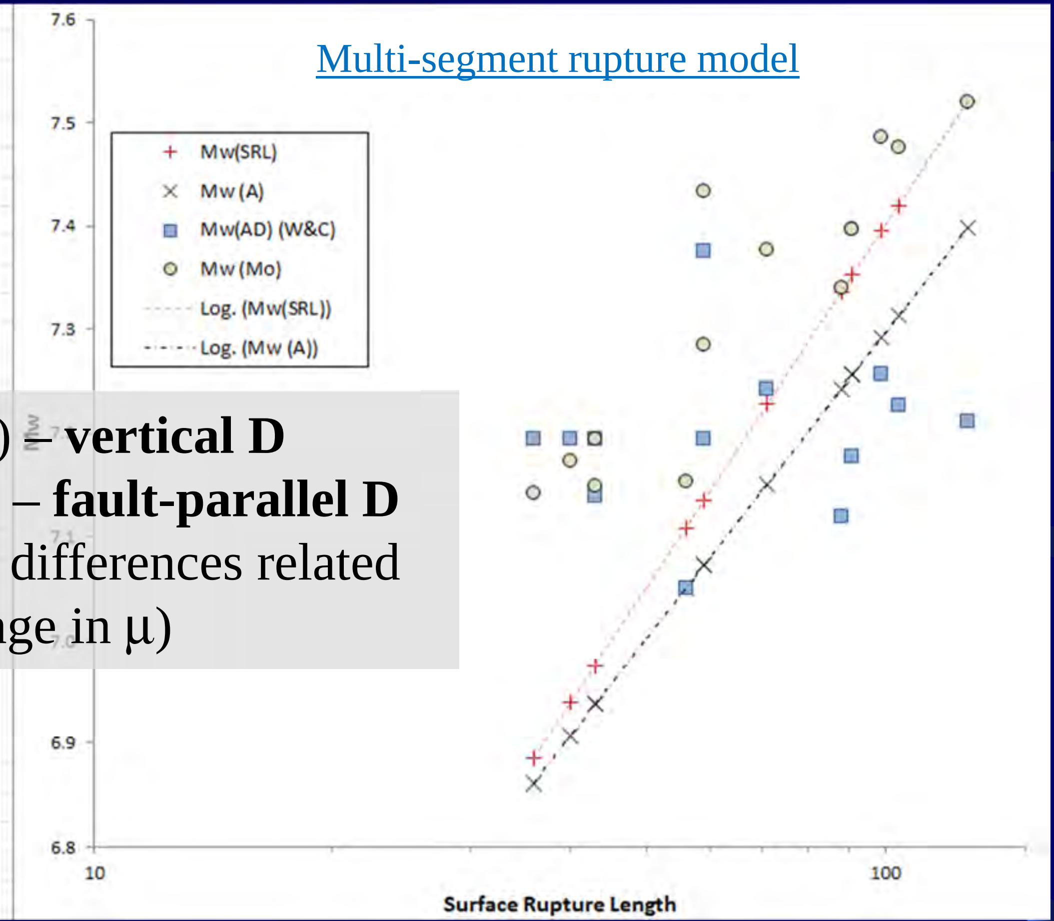
- M_W (D or M_0) consistently greater than M_W (SRL or A)

Multi-segment rupture model

- M_W (D or M_0) generally greater than M_W (SRL or A)

M vs. SRL – Revised





- M(AD) – **vertical D**
- M(M_0) – **fault-parallel D** (minor differences related to change in μ)

Single-segment rupture model

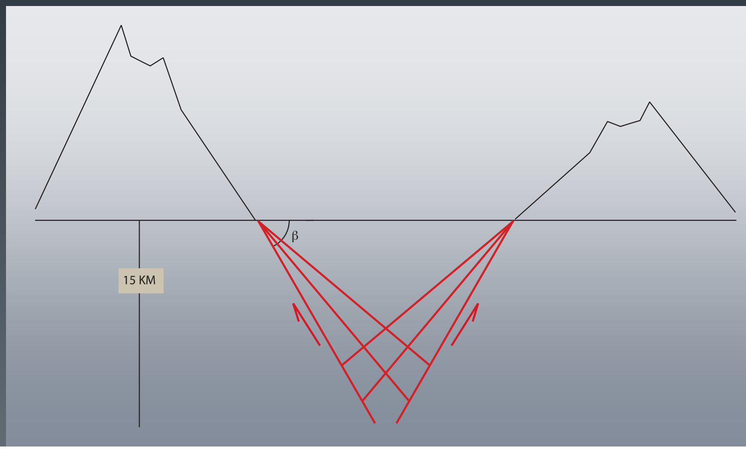
- ➢ Discrepancy still present

Multi-segment rupture model

- ➢ No discrepancy

Modeling Graben-bounding Faults in the NSHMs

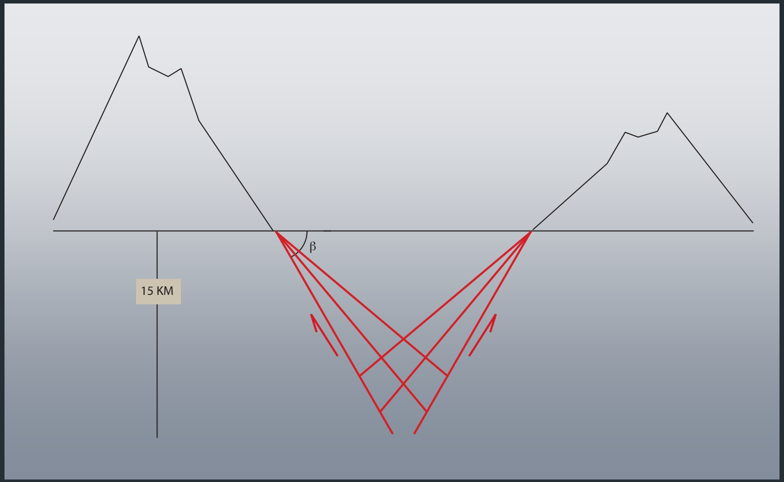
BRPEWGII Meeting
Issue G2
Discussion Leaders: Kathy Haller and Mike Hylland



The question:

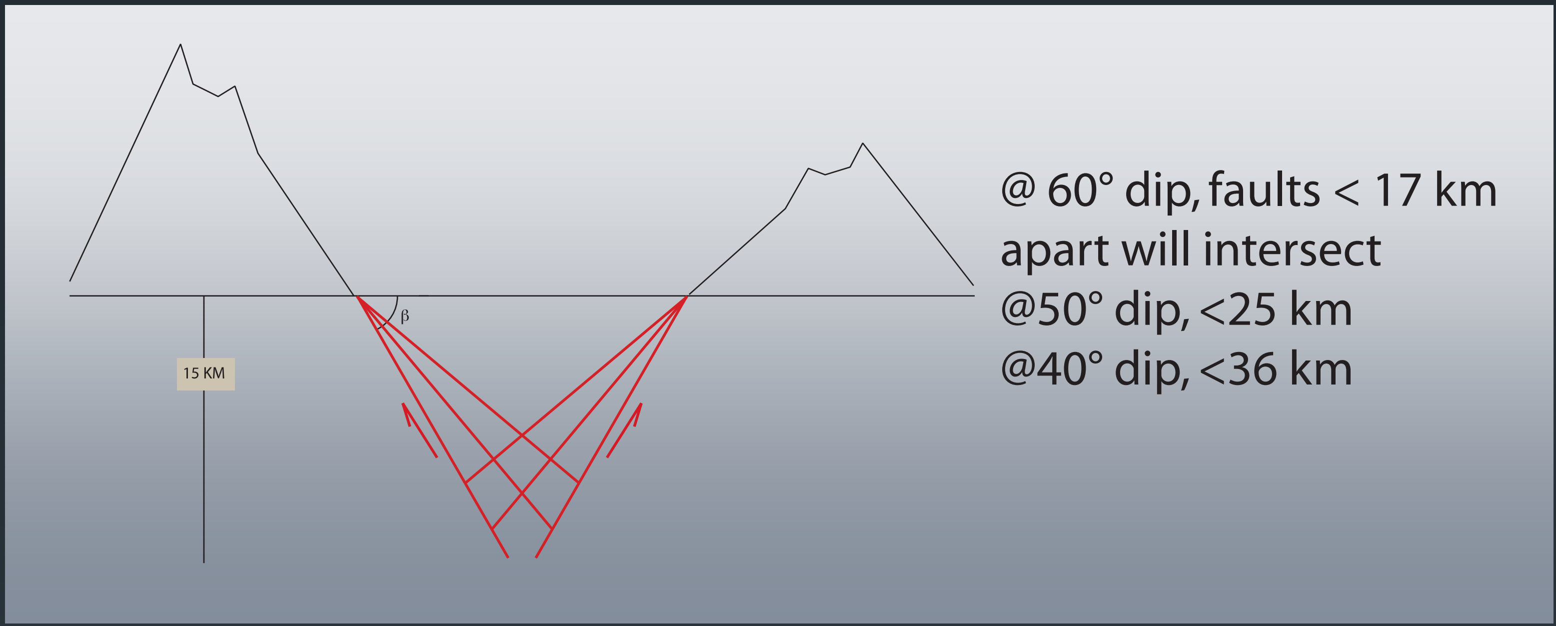
- How should antithetic fault pairs be modeled in the NSHMs? For example, what is the relation and seismogenic significance of fault pairs such as the East and West Cache faults, and strands of the Salt Lake City segment of the Wasatch fault and the West Valley fault zone?

The problem:



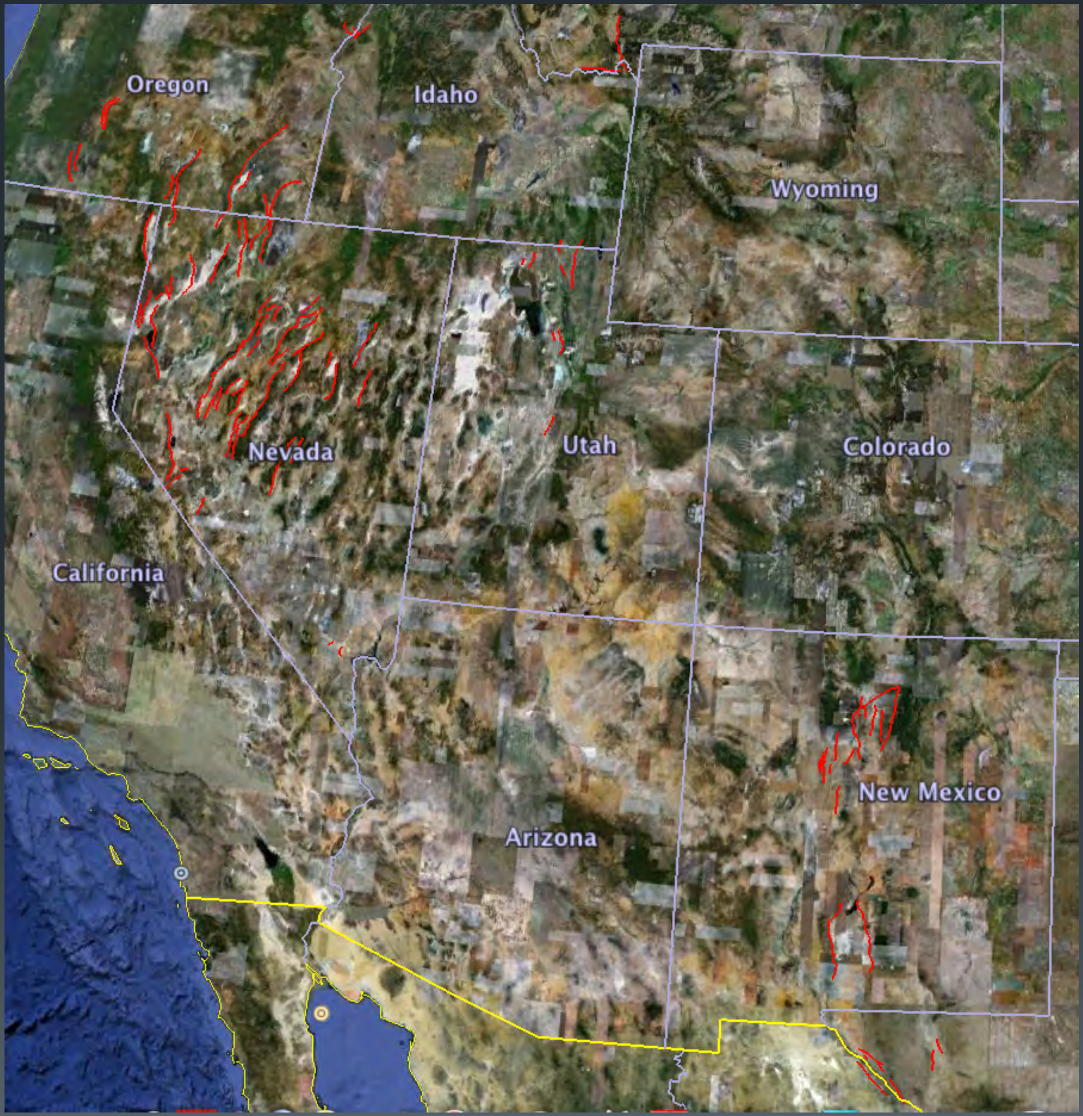
- Graben-bounding pairs are too close to avoid faults intersecting at depth
  - faults closer than 17 km will intersect if both dip 60°
  - faults closer than 25 km will intersect if both dip 50°
  - faults closer than 36 km will intersect if both dip 40°
- Both sources were projected below their intersection to a depth of 15 km in prior hazard maps
- Some source pairs that dip 40° in the 2008 model intersect at depths as shallow as 1.6 km

How we got here:



- Change in modeling assumptions in the 2008 maps to include dip uncertainty for normal faults increased the number of intersecting fault pairs (currently 52 pairs in NSHMs)

Intersecting pairs in 2008 model

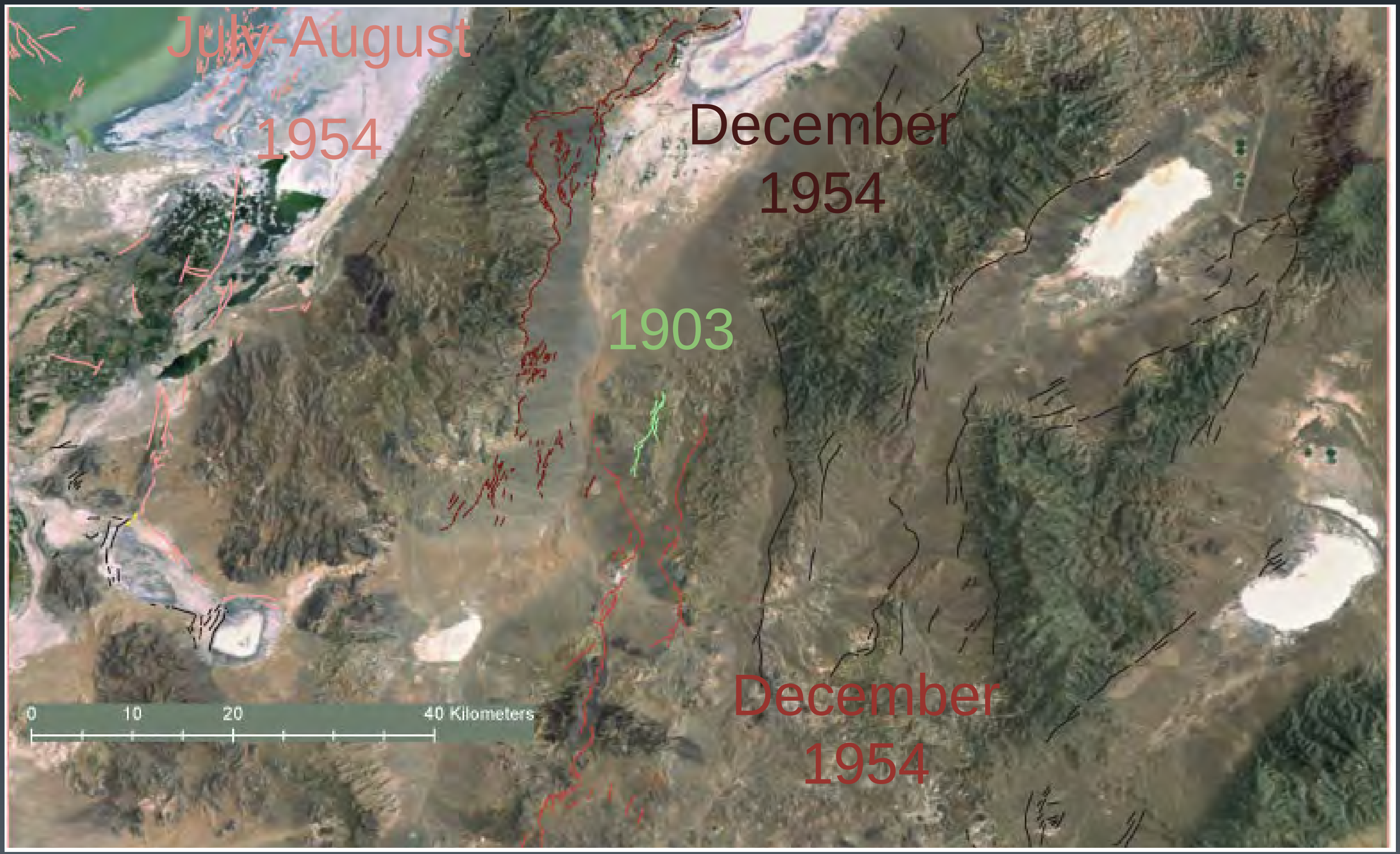


Key questions:

- Do graben-bounding fault pairs move together, separately, or both?
- Can we tell which fault is the master fault?
- Are some alternatives unviable--what is the minimum width for a fault to be considered capable of generating independent earthquakes?
- What method do we use to determine M on truncated faults?

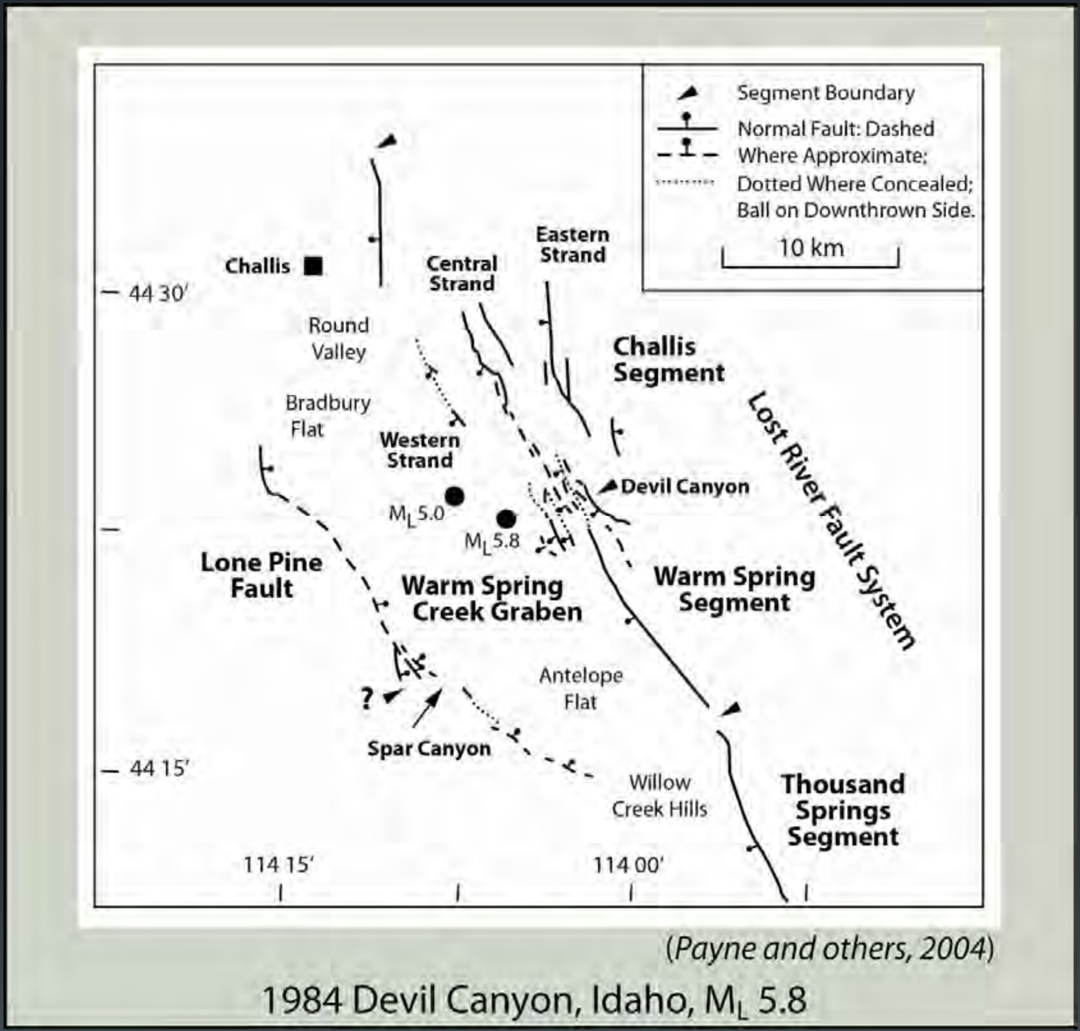
Historical Analogs for Antithetic Faulting in the Basin and Range

Central Nevada Seismic Zone (1903 and 1954)



Historical Analogs for Antithetic Faulting in the Basin and Range

Devil Canyon, Idaho (August 1984)



M 5.8 main shock considered a late aftershock of the M 7.3 Borah Peak earthquake (Oct. 1983)

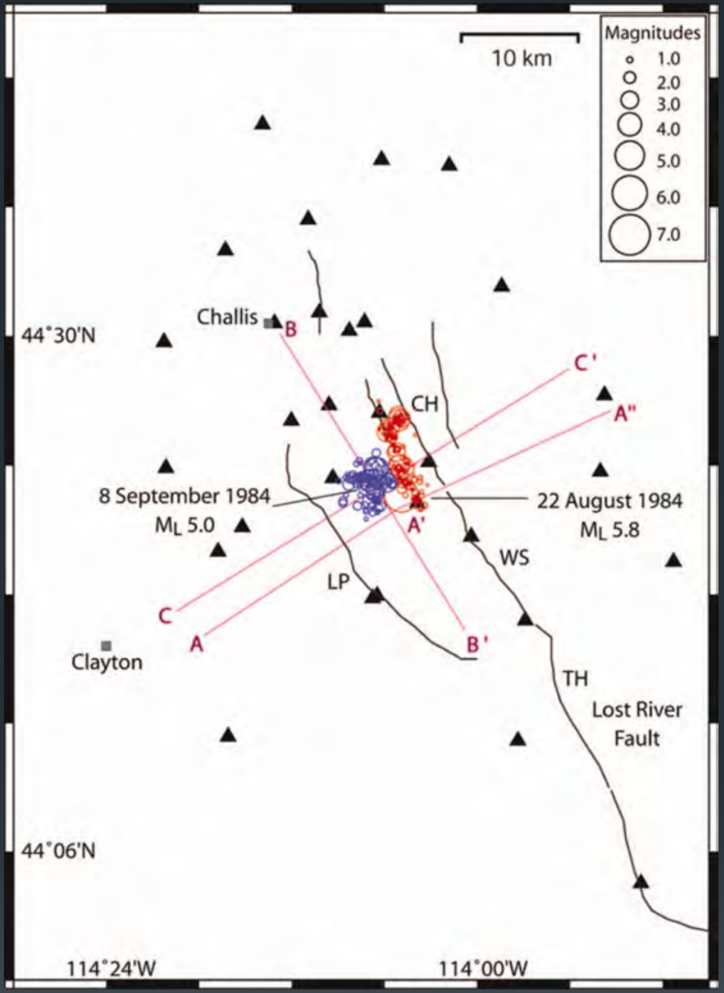
- Down-to-southwest normal slip on Challis segment of Lost River fault

M 5.0 aftershock occurred 17 days after the M 5.8 main shock

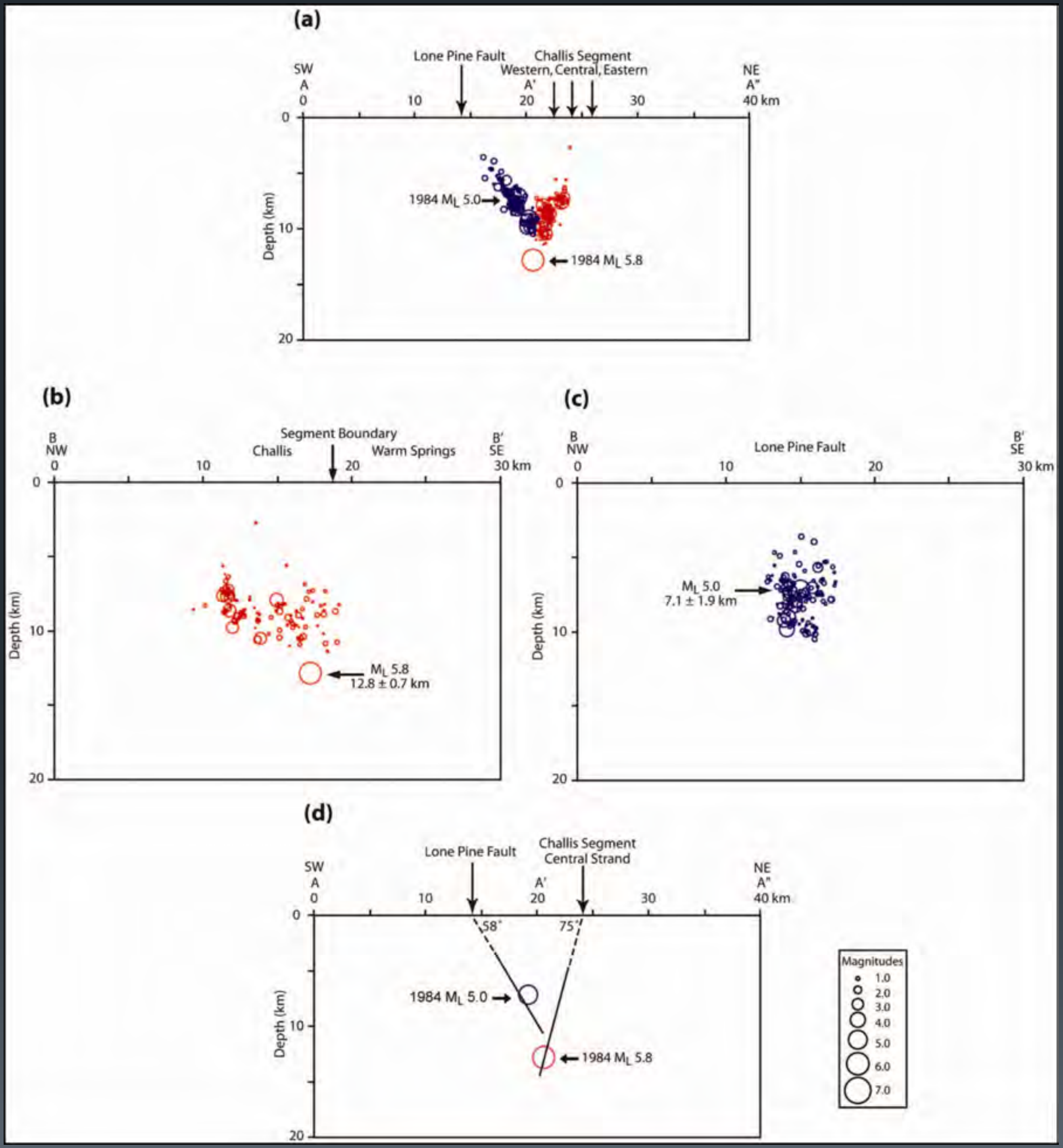
- Involved normal slip on antithetic Lone Pine fault

Historical Analogs for Antithetic Faulting in the Basin and Range

Devil Canyon, Idaho (August 1984)



(Payne and others, 2004)



(Payne and others, 2004)

Antithetic faulting considered triggered slip

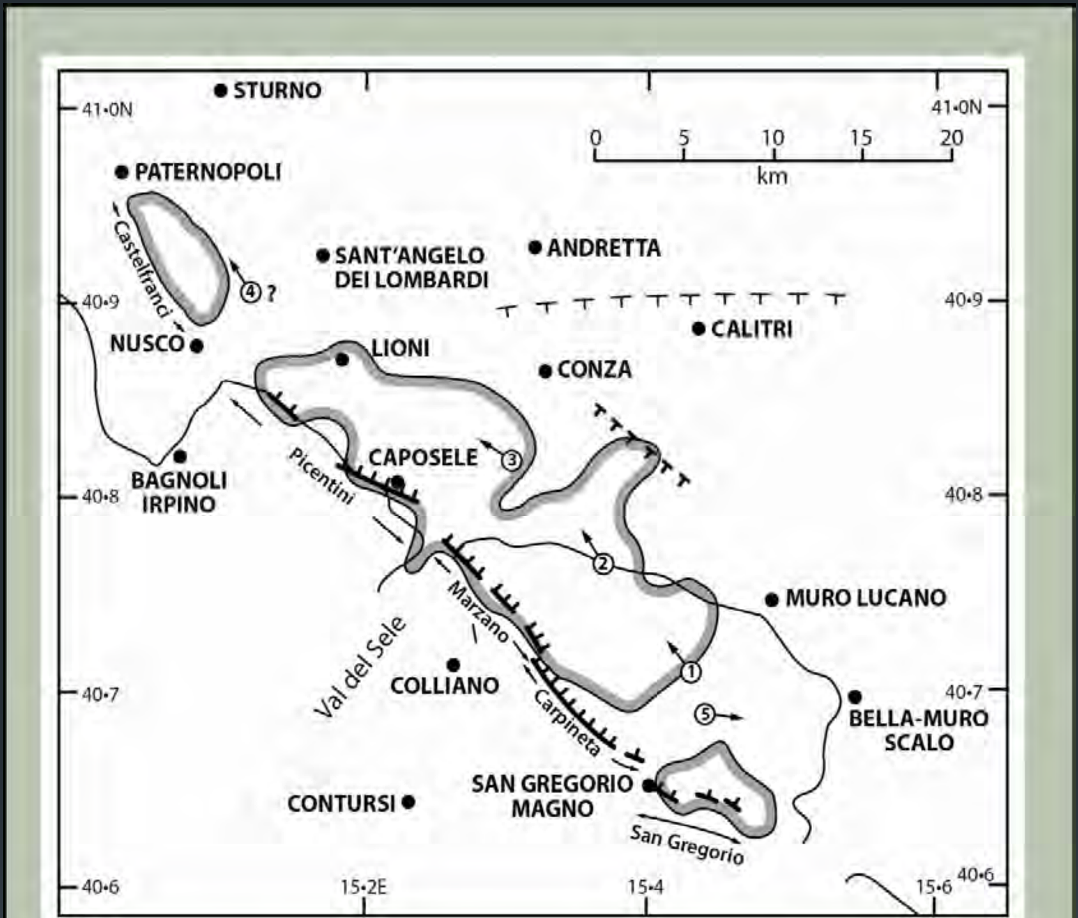
- separate earthquake with its own moment release

Antithetic slip restricted to Challis fault hanging wall

Small earthquake (M5), no surface rupture

Historical Analogs for Antithetic Faulting in the Basin and Range

Irpinia (Campania-Basilicata), Italy (November 1980)



1980 Irpinia (Campania-Basilicata), Italy, M_S 6.9

M 6.9 earthquake comprising numerous sub-events

- Rupture initiated as down-to-northeast normal slip on Carpineta fault
- At ~40 s, normal slip occurred on antithetic intrabasin fault

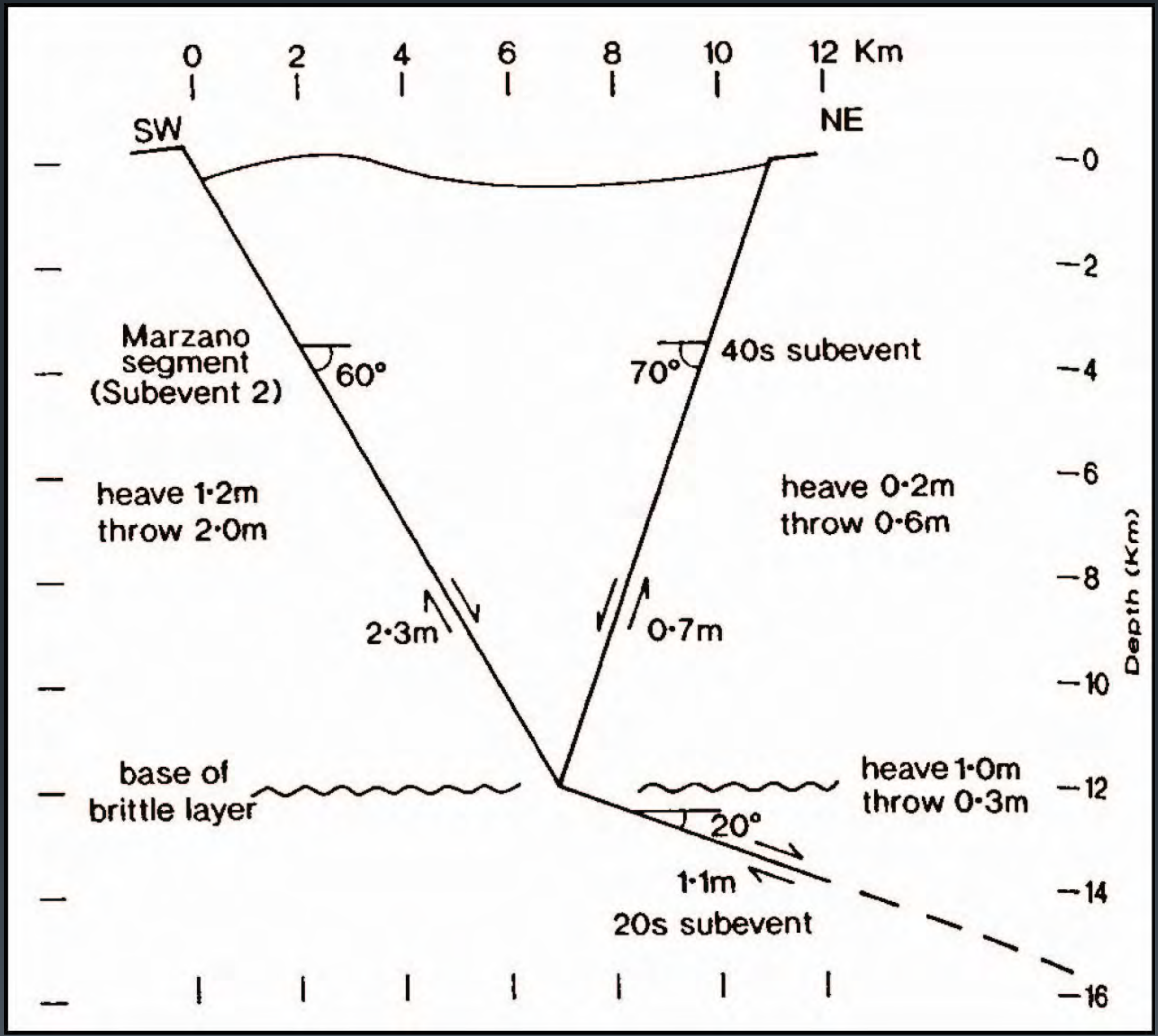
Historical Analogs for Antithetic Faulting in the Basin and Range

Irpinia (Campania-Basilicata), Italy (November 1980)

Antithetic faulting considered coseismic

- contributed moment (~12%) to the earthquake as a whole

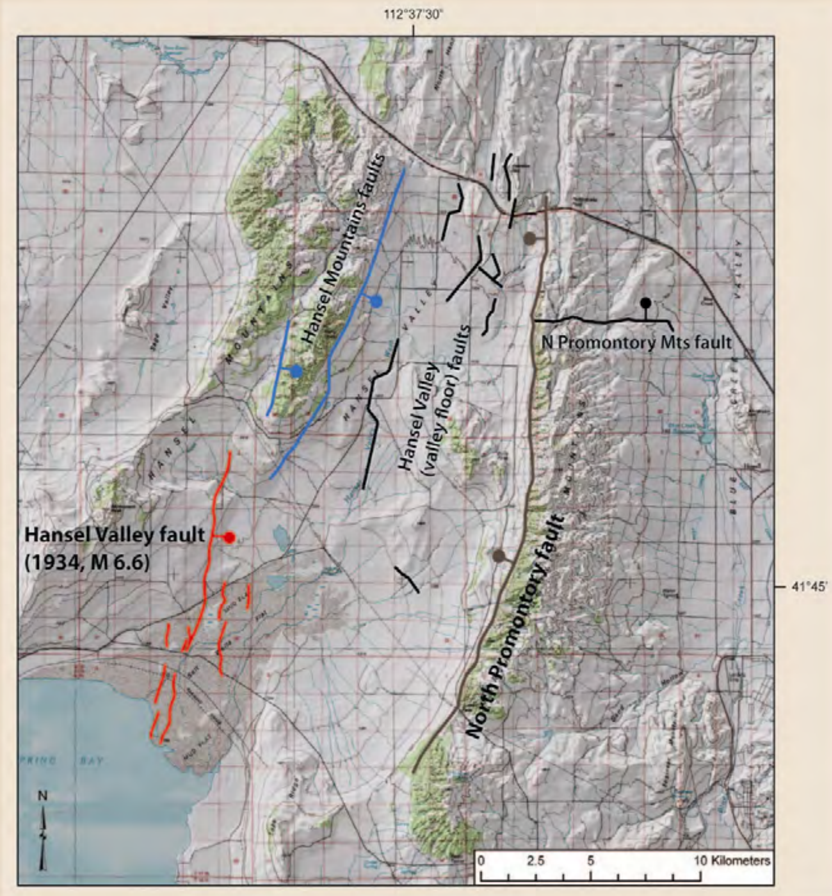
No surface rupture associated with antithetic faulting



(Westaway, 1992)

Historical Analogs for Antithetic Faulting in the Basin and Range

Hansel Valley, Utah (March 1934)



1934 Hansel Valley, Utah, M 6.6

M 6.6 earthquake involving mostly down-to-east surface faulting (but strike-slip focal mechanism)

- No rupture documented along North Promontory fault, to which Hansel Valley fault is antithetic

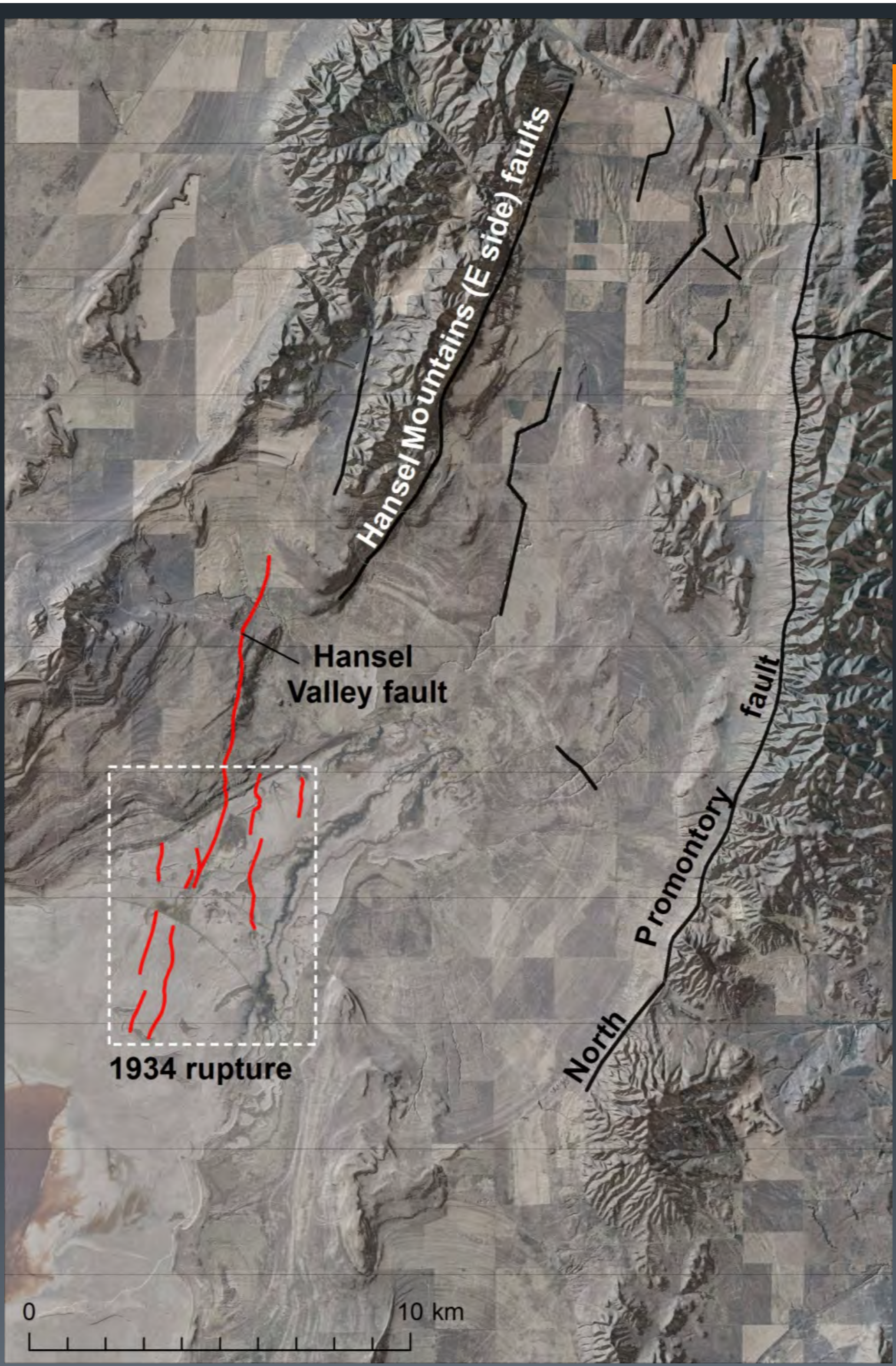
Antithetic faulting appears to have been independent

- Absence of movement of the main range-bounding fault

1934 M 6.6 Hansel Valley Earthquake: Analog for Antithetic Fault Rupture?

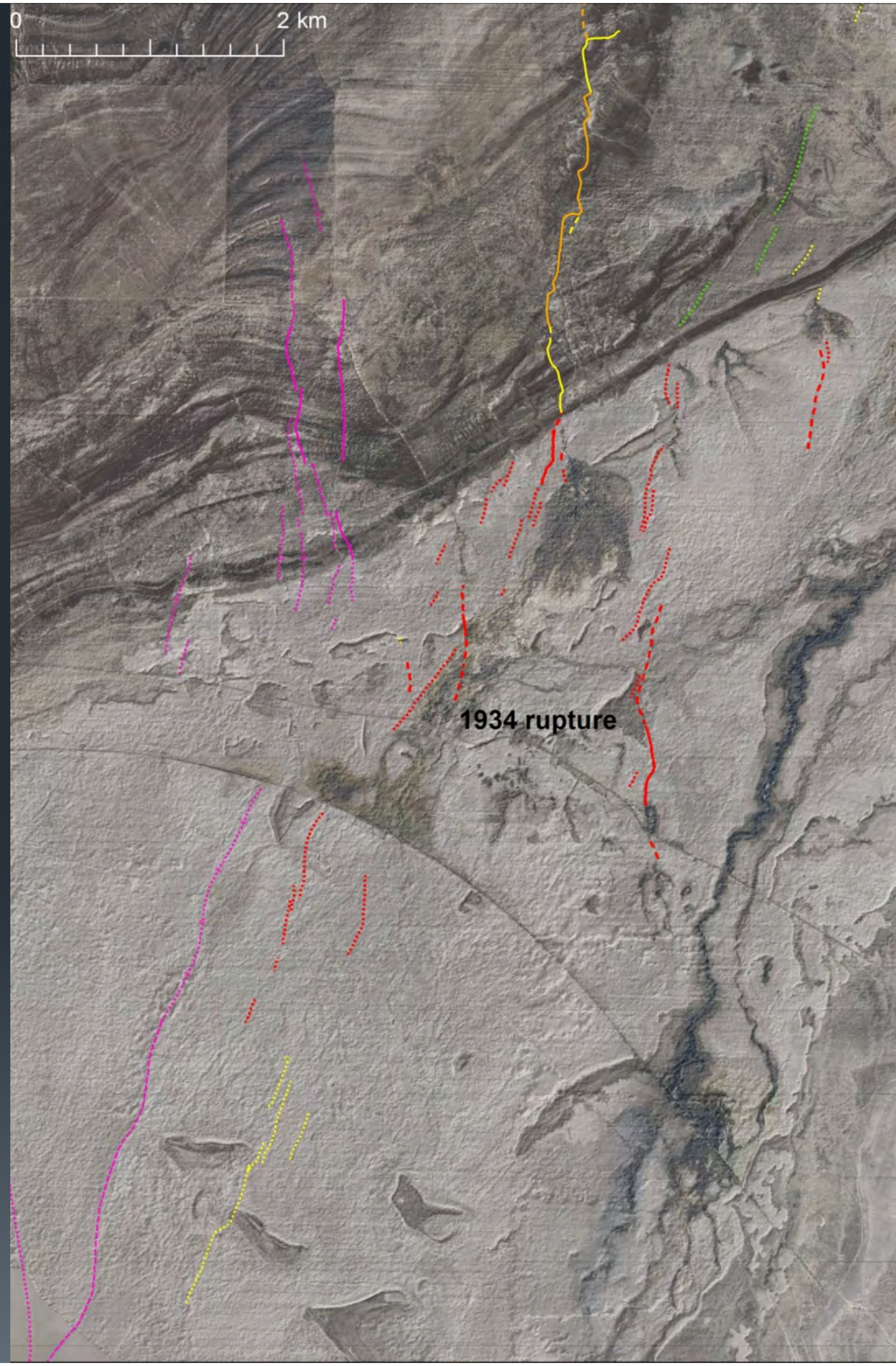
Chris DuRoss
Mike Hylland

BRPEWGII Meeting
November 2011



Geologic Observations

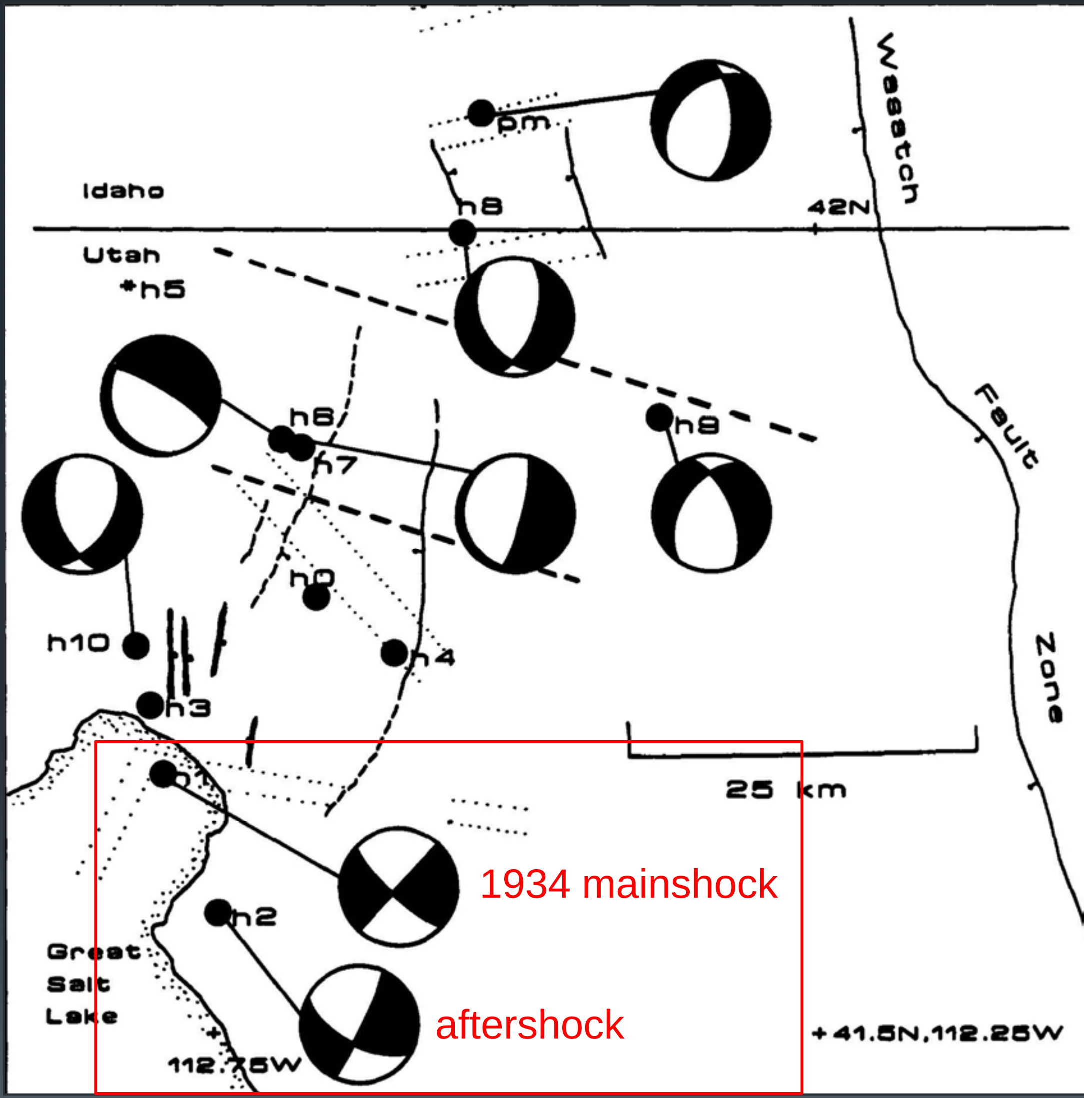
- 5–8-km-long, NE-oriented zone of ground cracks and minor surface faulting
- Down-to-the-east scarps related to 1934 earthquake
  - Maximum vertical displacement: ~50 cm, mostly down to the east
  - Maximum strike-slip displacement: ~25 cm (poorly documented)
- No reports of rupture along prehistoric rupture to the north, which has evidence of larger displacements (1+ m)




0
2 km
1934 rupture

Seismologic Observations

- Left-lateral strike-slip on near-vertical, NE oriented fault
- Rupture length: ~11 km using rupture time and velocity; NE propagation?
- Average horizontal slip: 2.3 m using seismic moment (M_0 = rigidity*area*slip)
- Average vertical slip: 20–25 cm using focal mechanism



Doser (1989)

Other puzzle pieces

- Bathymetry and shoreline data (1850–1934):
  - 1-m increase in water depth, no change to south
  - ~2-m decrease in relative shoreline elevation

- Re-leveling of railroad grade (after 1934)
  - ~0.3–0.4 m of subsidence east of rupture.

Other puzzle pieces

- 1909 M ~6 Hansel Valley earthquake
  - No report of surface rupture, but newspaper report of waves passing over 3.5-m high railroad trestle
  - A: Bathymetry & shoreline data (1850–1934) could include displacement from this event
  - B: Linear shoreline south of 1934 rupture (and epicenter) suggests down-to-the-west faulting.
  - C: Lineaments and down-to-the-west scarps east of 1934 rupture related to 1909 earthquake?

Remaining Questions

- Was the1934 M 6.6 earthquake a normal or strike slip event?
  - Normal surface rupture (~5–8-km L, 0.5 m vertical D)
  - Strike-slip focal mechanism (~11-km L, ~2 m horizontal D)

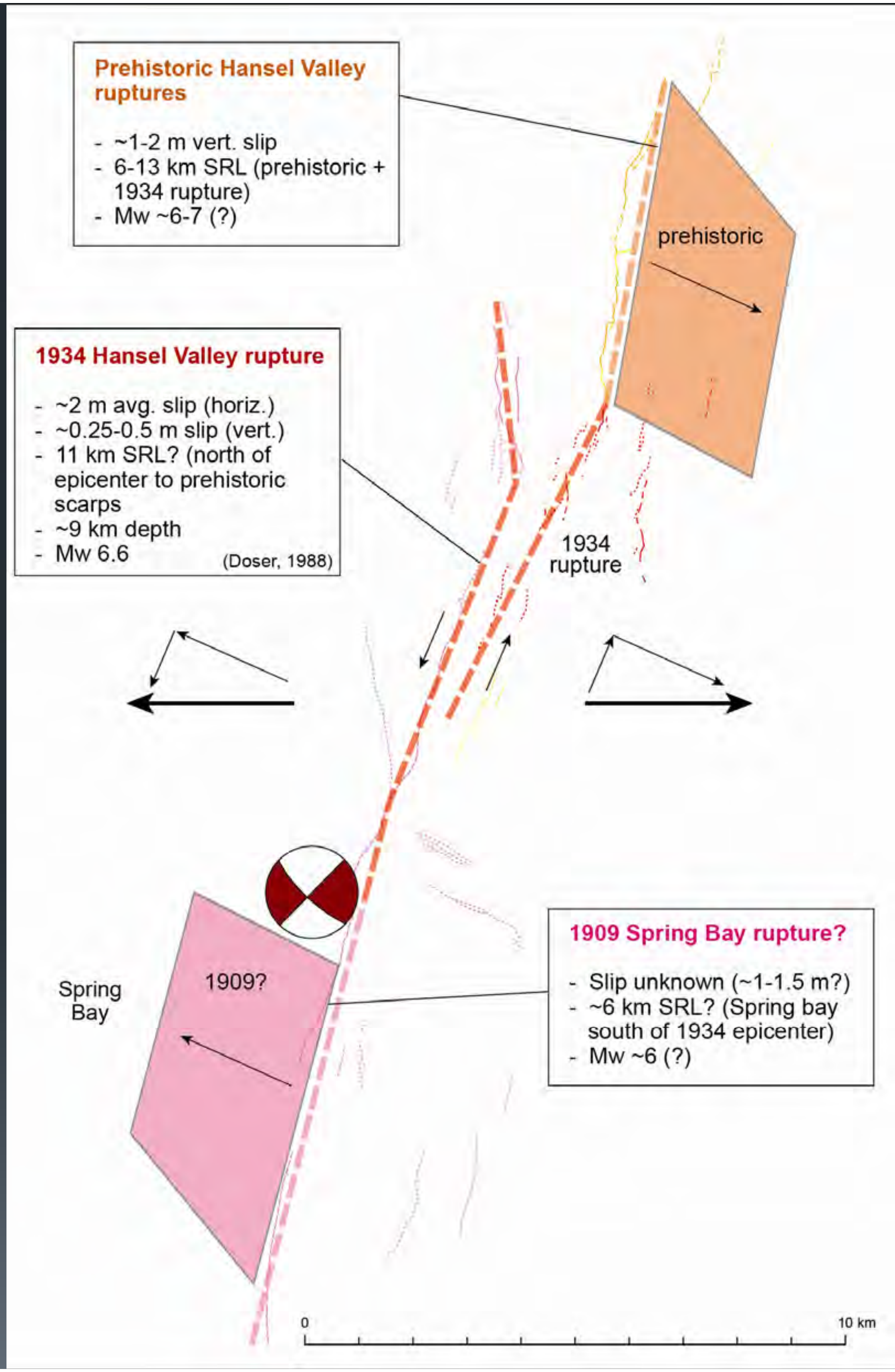
- Did the 1934 event occur as a strike slip event, only initiating normal faulting (or non-tectonic slip?) near the northern end of the rupture?

- How does the 1909 M~6 earthquake fit in? Did this event rupture faults in Spring Bay?

Speculation…

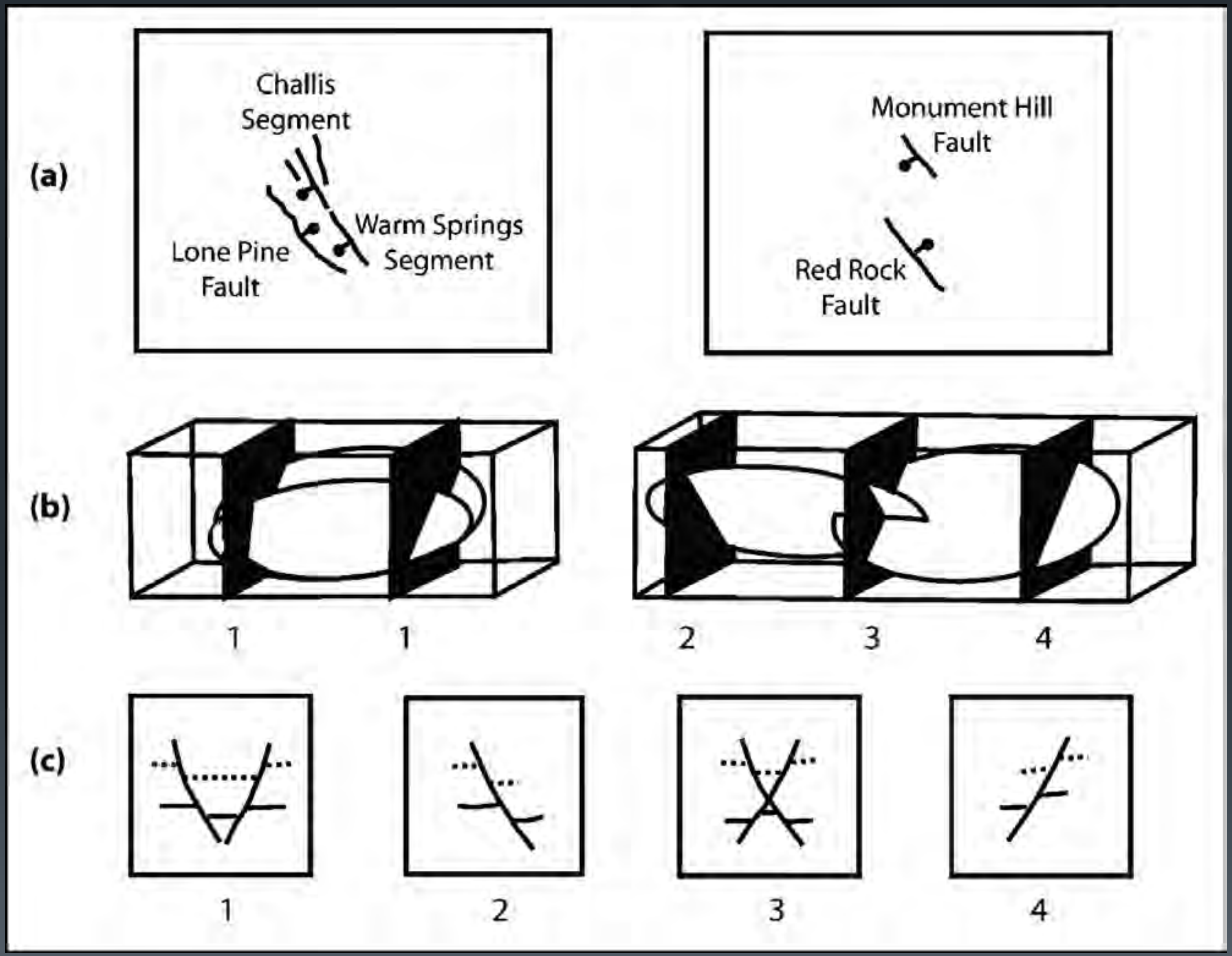
- Possible kinematic model: the 1934 earthquake was a dominantly strike-slip event that released strain accumulated between two normal faults.

- Bottom line: The 1934 earthquake has too many remaining questions to be a well-behaved poster child for antithetic-fault rupture.



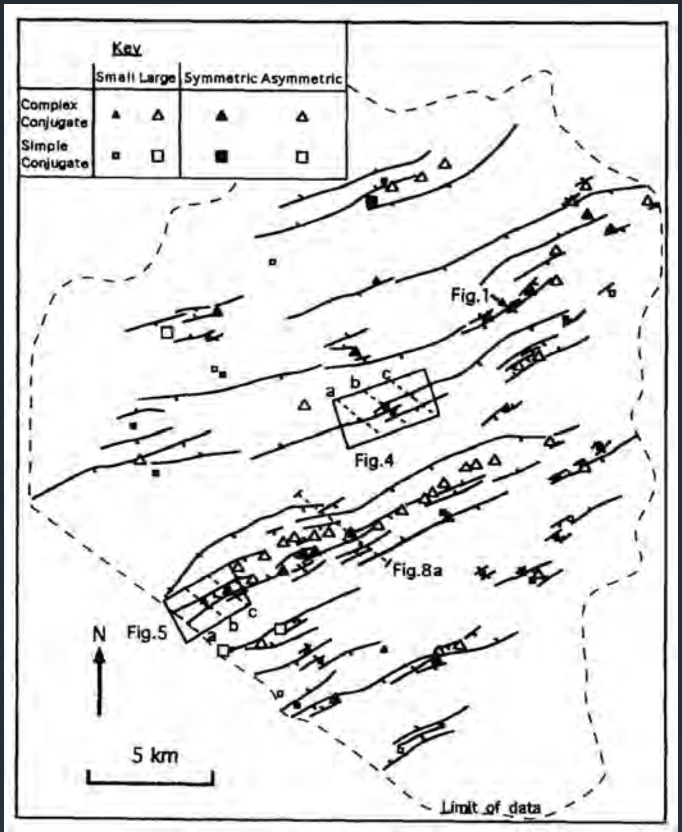
Conjugate Normal Fault Systems
Insights from 2D, 3D Modeling and Lab Experiments

How is strain accommodated on conjugate normal fault systems, particularly near fault terminations and in overlap zones?



(Payne and others, 2004, after Nicol and others, 1995)

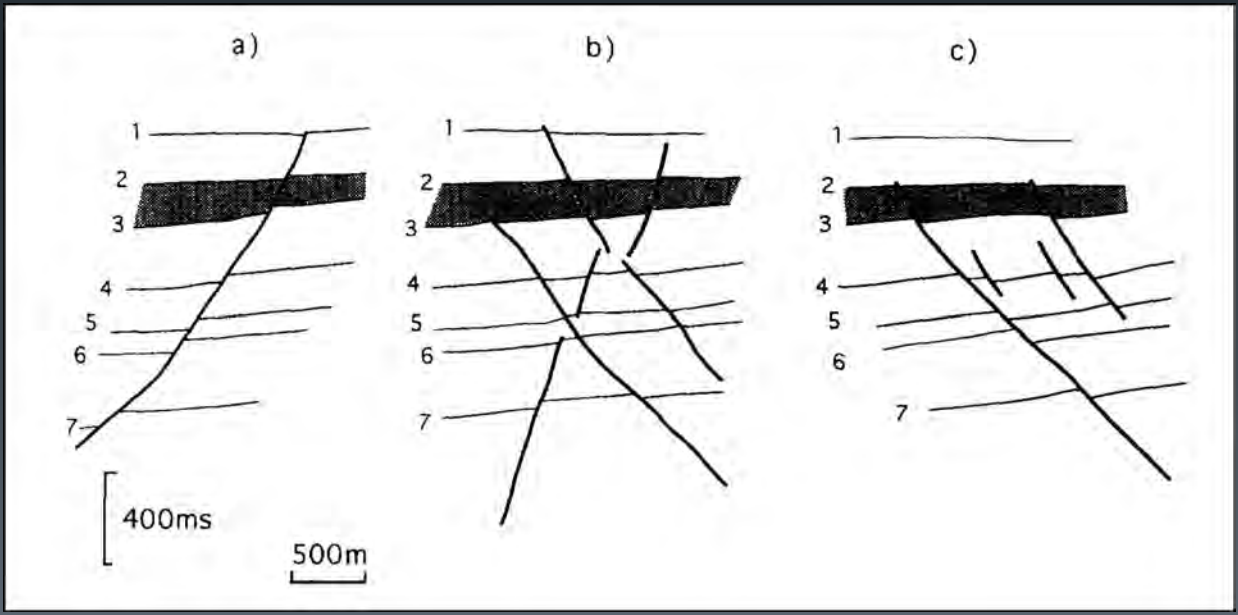
Conjugate Normal Fault Systems
Insights from 2D, 3D Modeling and Lab Experiments



(Nicol and others, 1995)

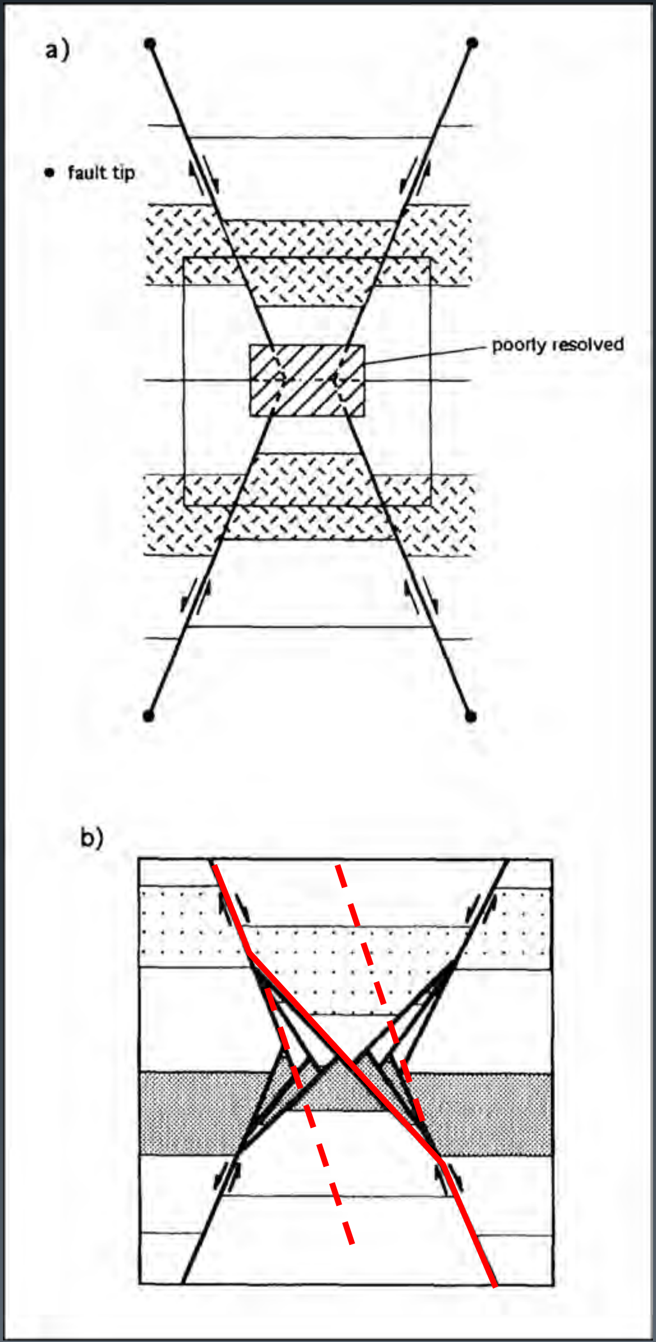
Example: Timor Sea

- Normal faults, up to 10s of kilometers long, throws up to 400 m
- Crossing conjugate normal faults imaged by 2D, 3D seismic reflection in upper 3.5 km of crust
- Faults accommodate extension associated with subduction of Australian plate
- Many larger faults originated by reactivation and upward propagation of Late Jurassic normal faults



(Nicol and others, 1995)

Conjugate Normal Fault Systems
Insights from 2D, 3D Modeling and Lab Experiments



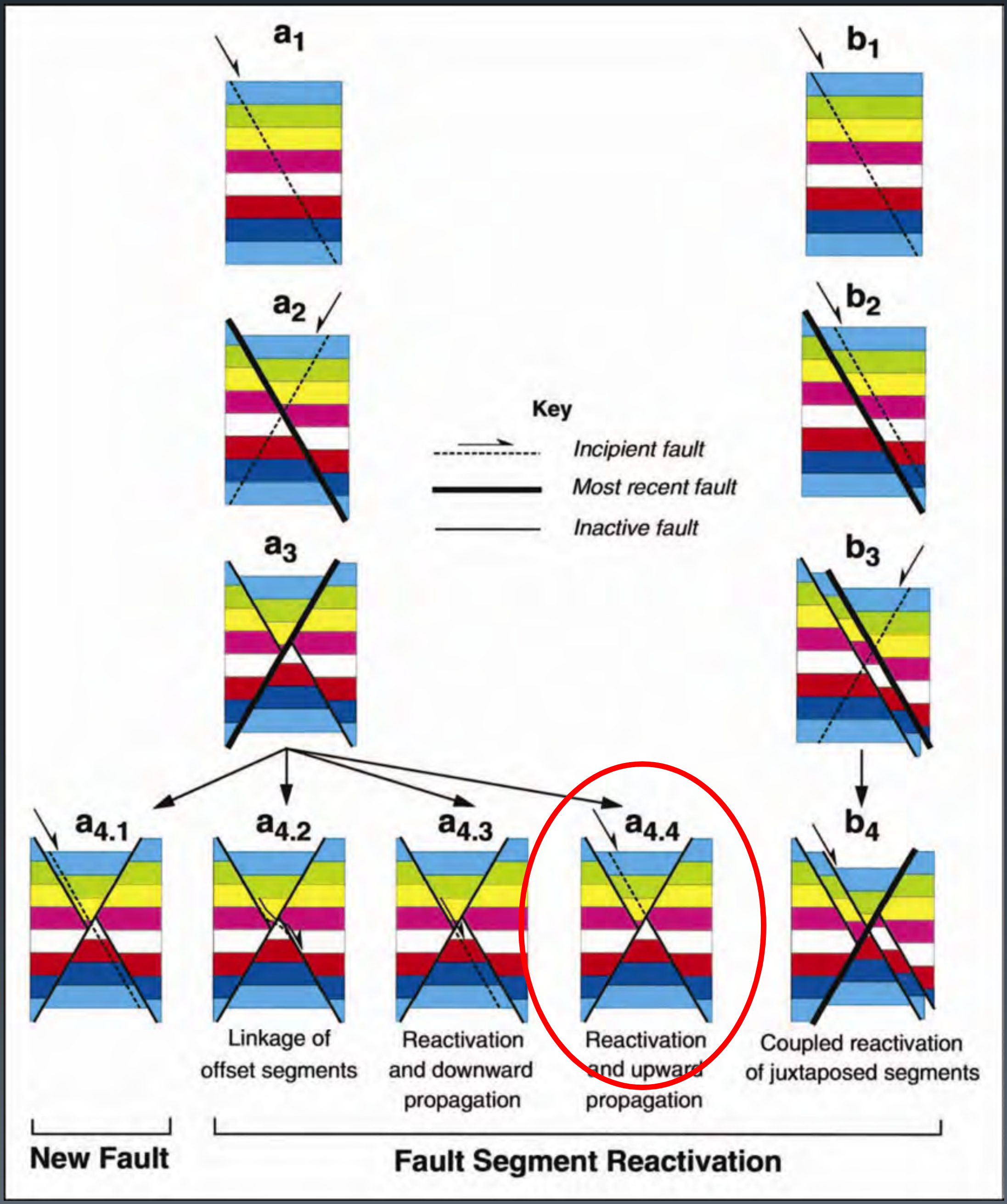
(Nicol and others, 1995)

Kinematic Model (Nicol and others, 1995, after Horsfield, 1980)

- Inter-fault volumes undergo significant ductile strain
- "Ductile" is scale-dependent term
    - "Concept of brittle deformation (rigid blocks translated along faults) is valid only for the microscopic scale"
- In intersection zone, cumulative displacement is distributed among numerous individual slip surfaces; new surface generated in each slip event
- Radius of curvature of bends in fault surface is limiting factor; i.e., eventually new fault will form
- Slip on main faults considered simultaneous (on geologic time scale)

Conjugate Normal Fault Systems

Insights from 2D, 3D Modeling and Lab Experiments



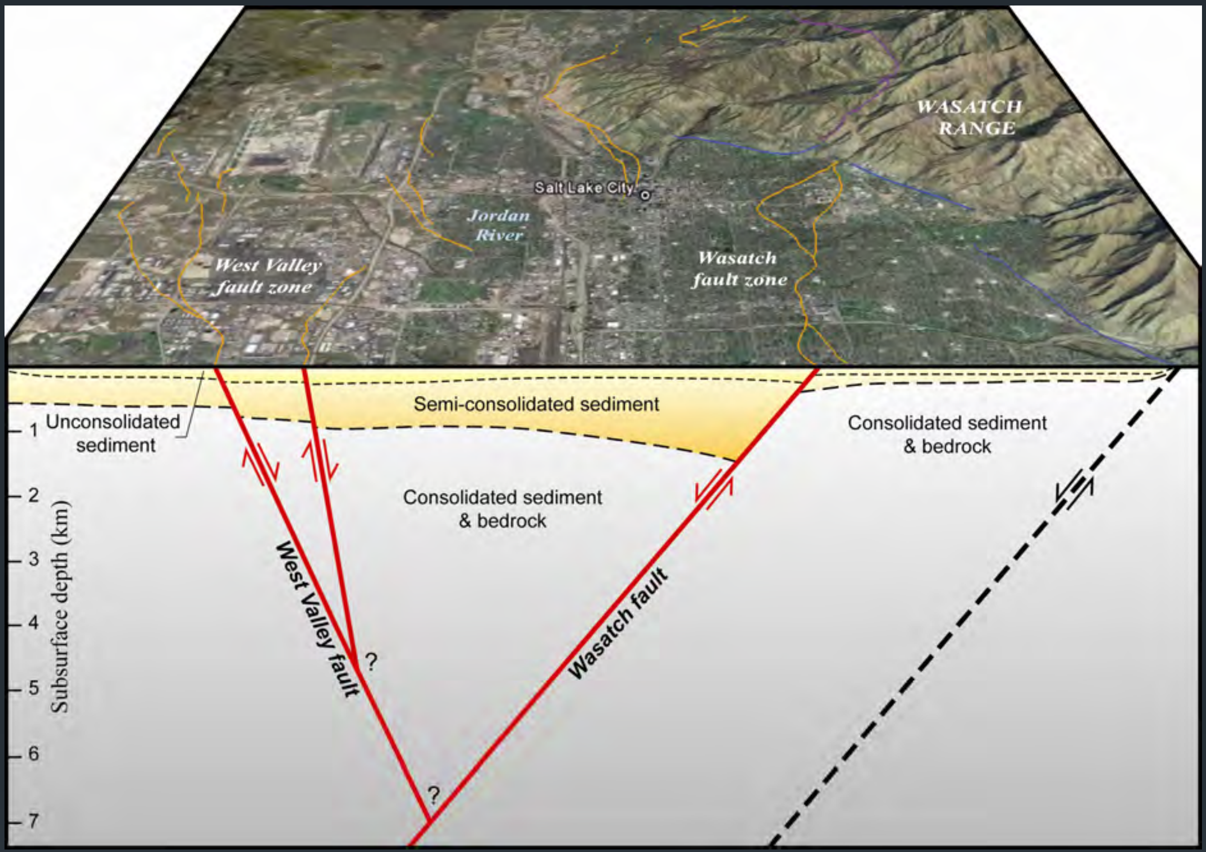
(Ferrill and others, 2000)

2D Modeling of Ferrill and others (2000)

- Simultaneous movement of conjugate fault pairs requires volume change in intersection area
- Alternating sequential movement is preferred model
- Several outcrop-scale examples provided

Conjugate Normal Fault Systems

Insights from 2D, 3D Modeling and Lab Experiments

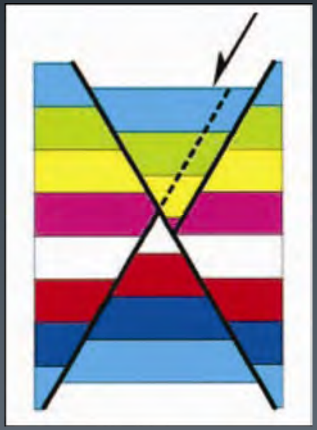


West Valley Fault Zone – Salt Lake City Segment

Crossing conjugate normal faults, or listric master fault (with splays) and truncated antithetic fault in hanging wall?

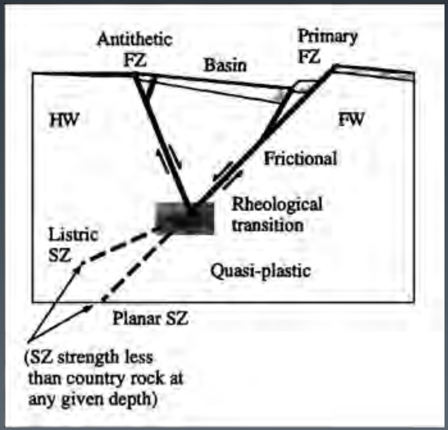
Pertinent questions:

- Fault dip
- Depth to intersection zone
- Horizontal separation of fault traces vs. vertical offset of faults
- Reactivation of pre-existing structure
- Map patterns of fault traces



(Ferrill and others, 2000)

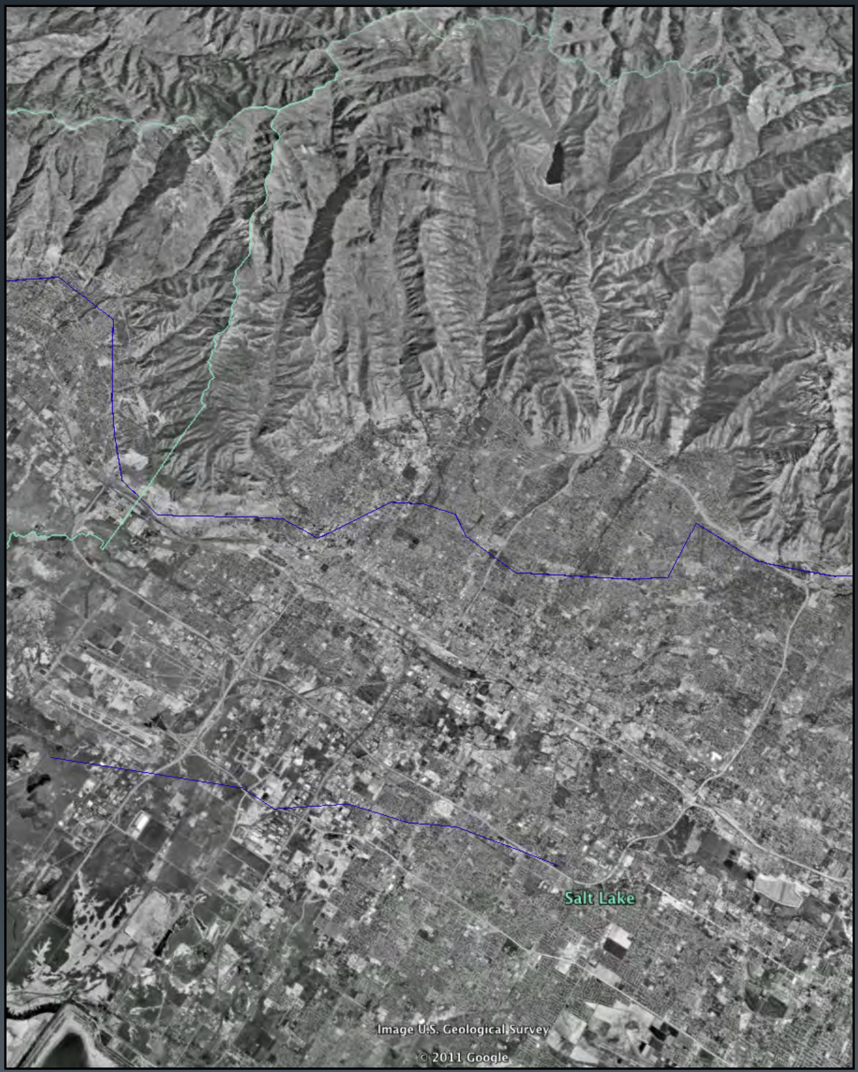
Or?



(Bruhn and Schultz, 1996)

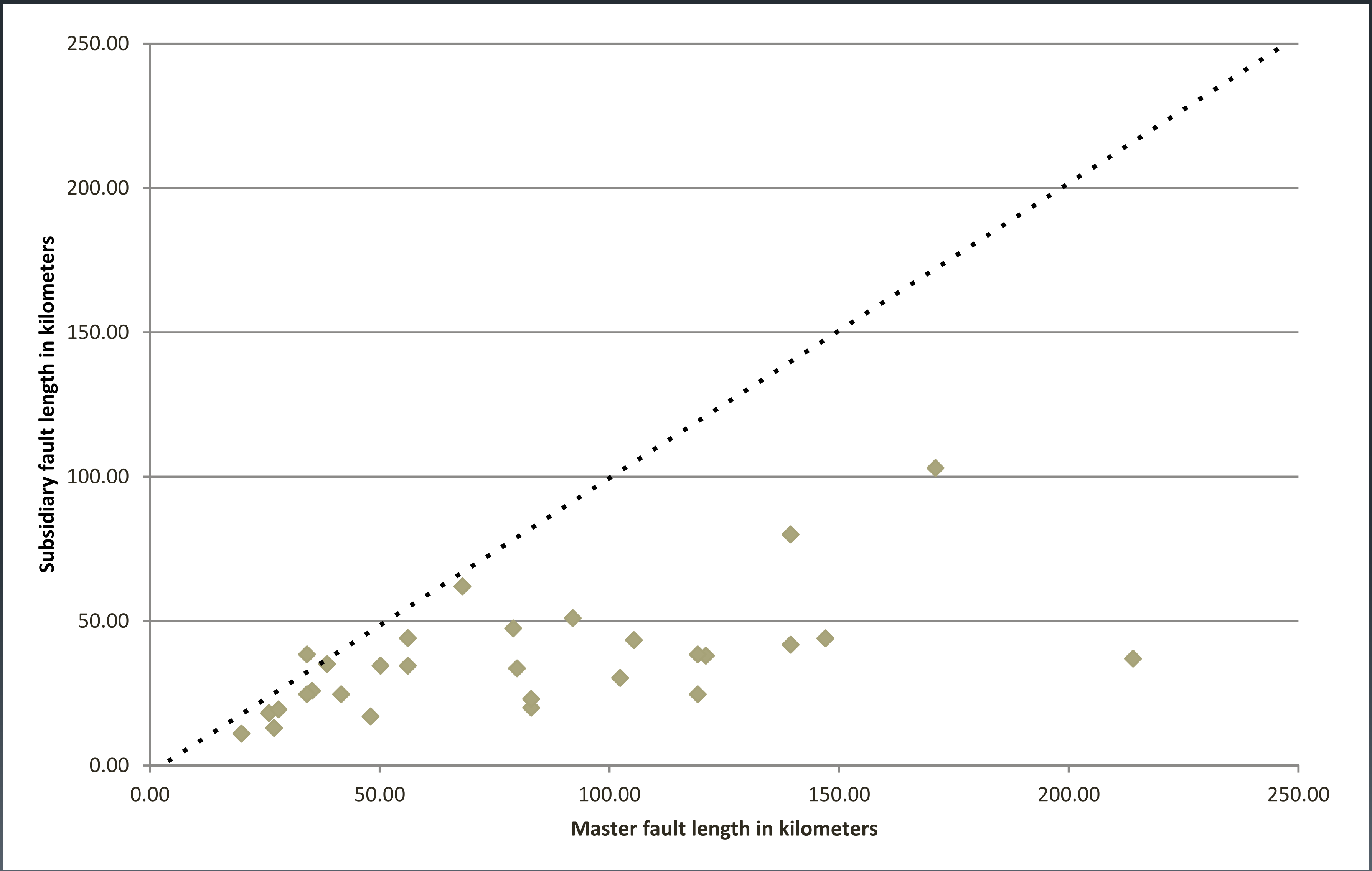
Metrics to differentiate master and subsidiary faults

- Fault length
- Percent of along-strike overlap
- Topographic relief
- Short-term slip rate based on paleoseismology is not always diagnostic

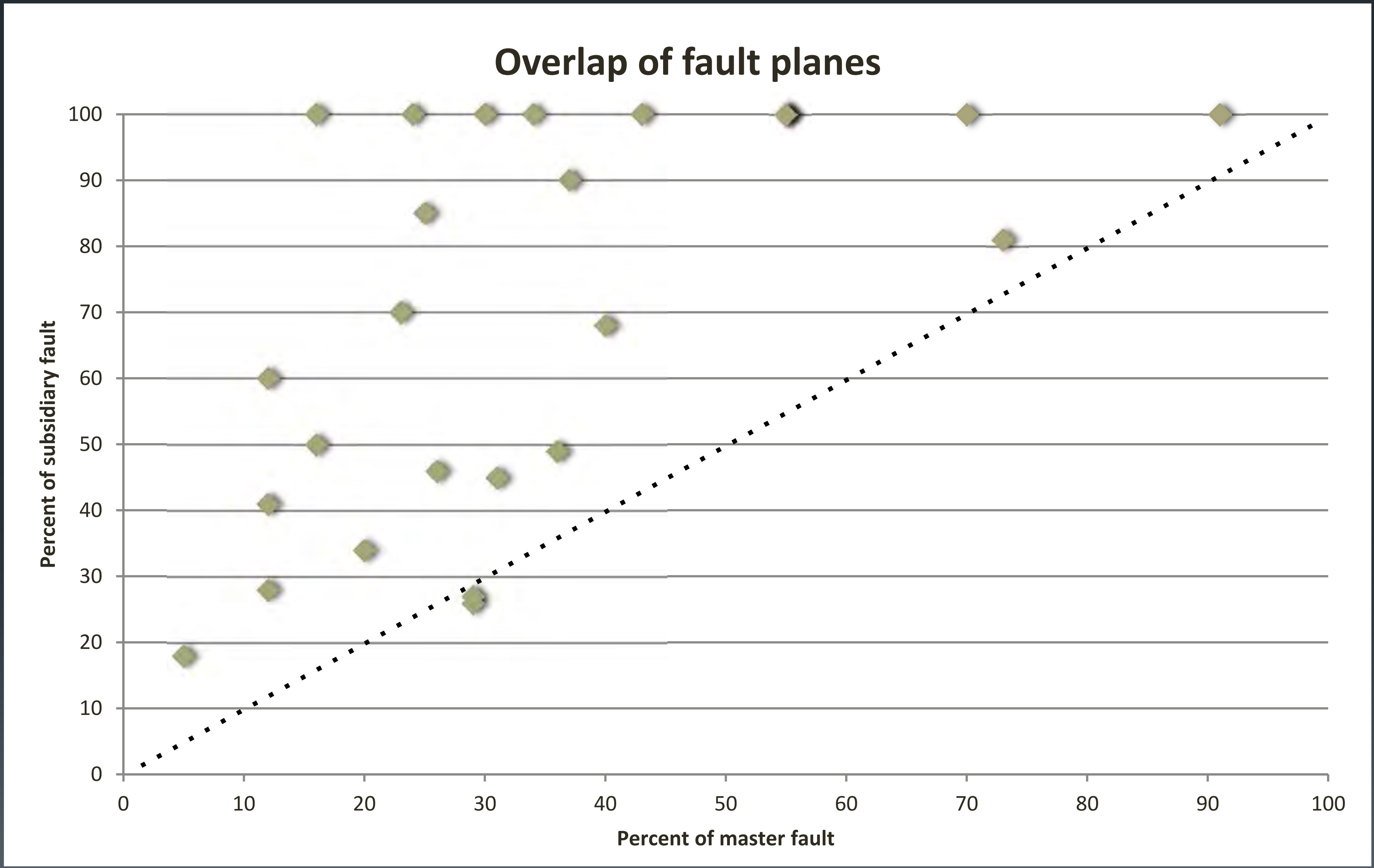


SLC segment of the Wasatch and West Valley sources

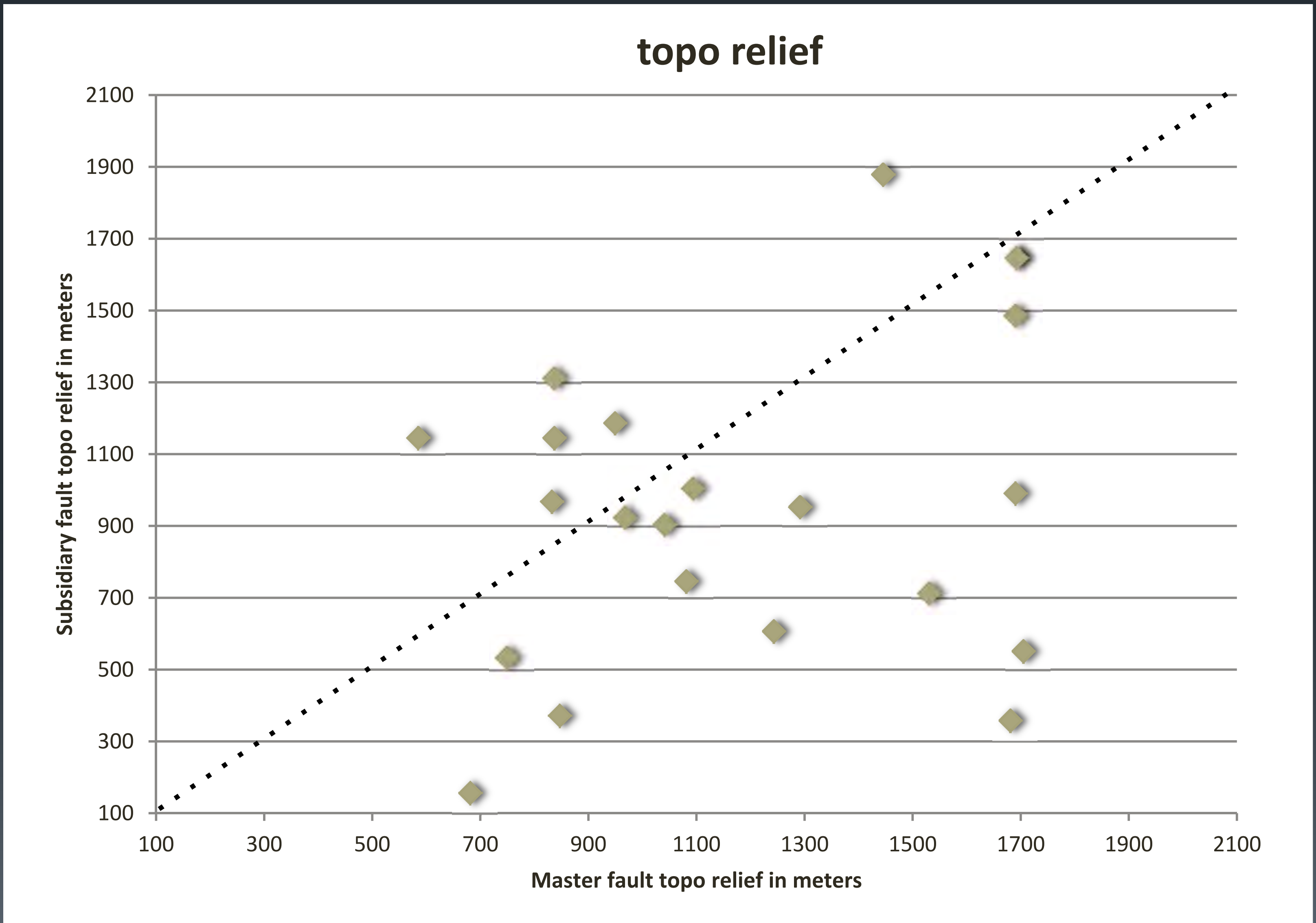
Fault length



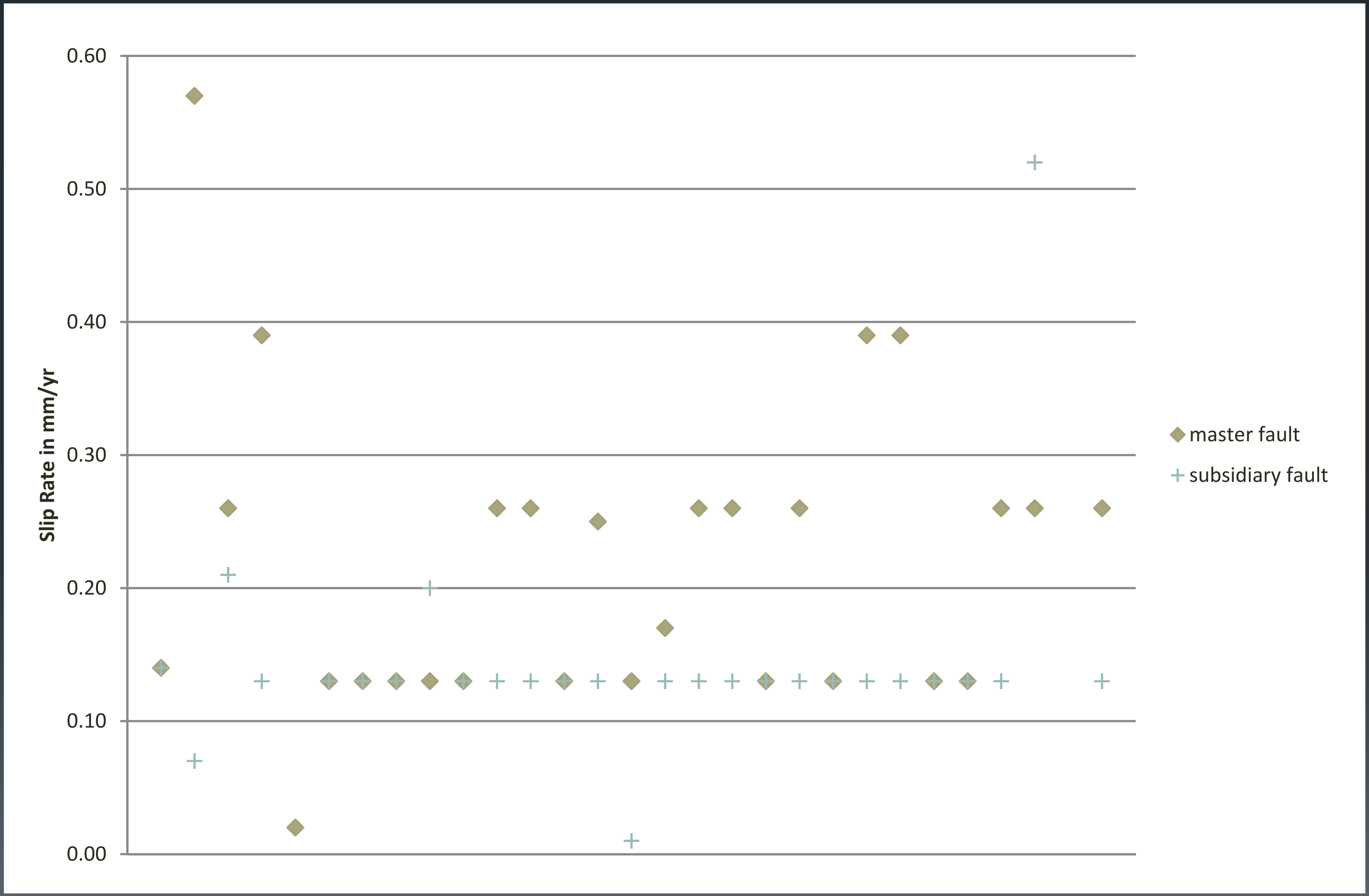
Overlap of fault planes



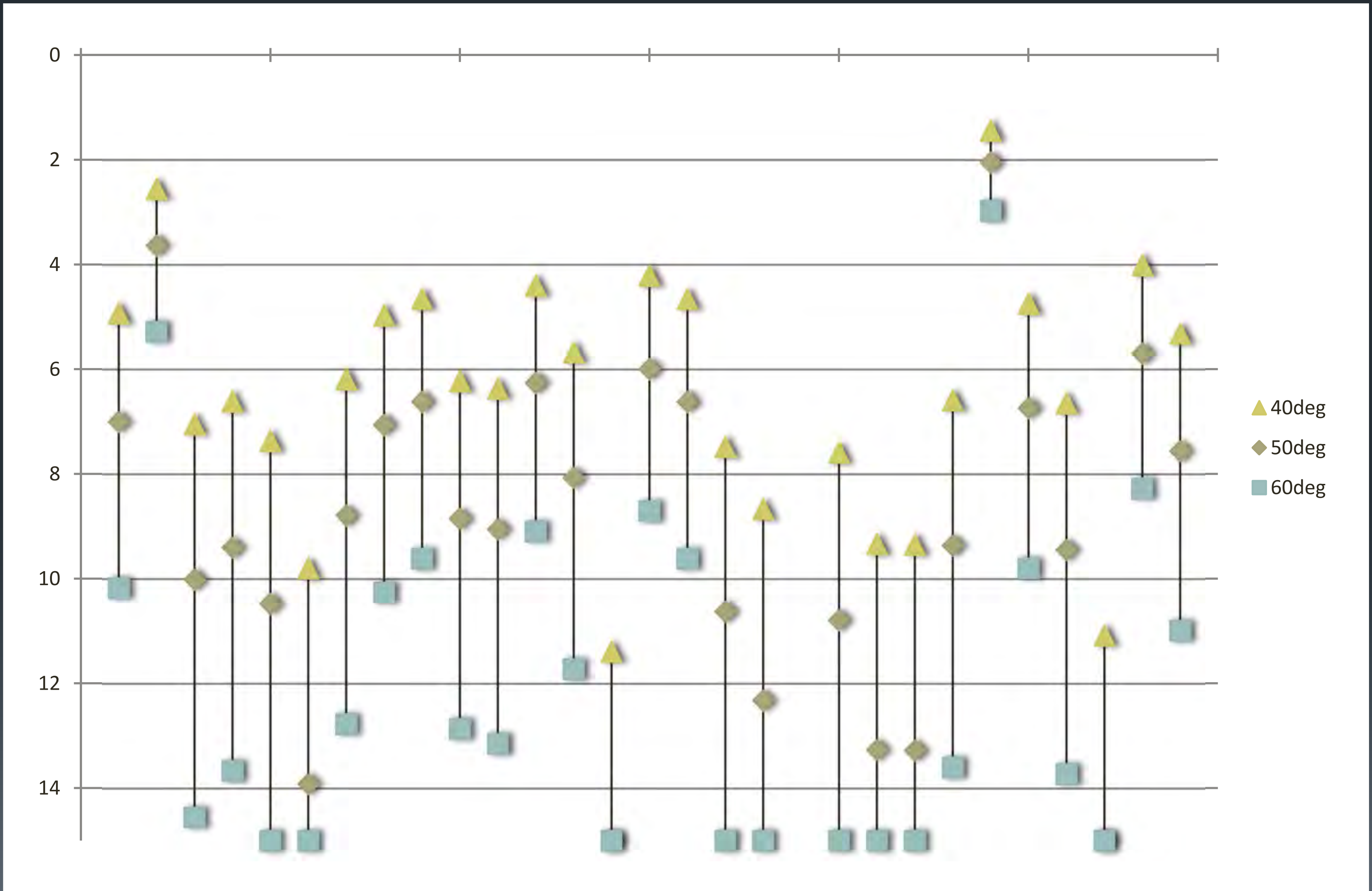
Topographic relief



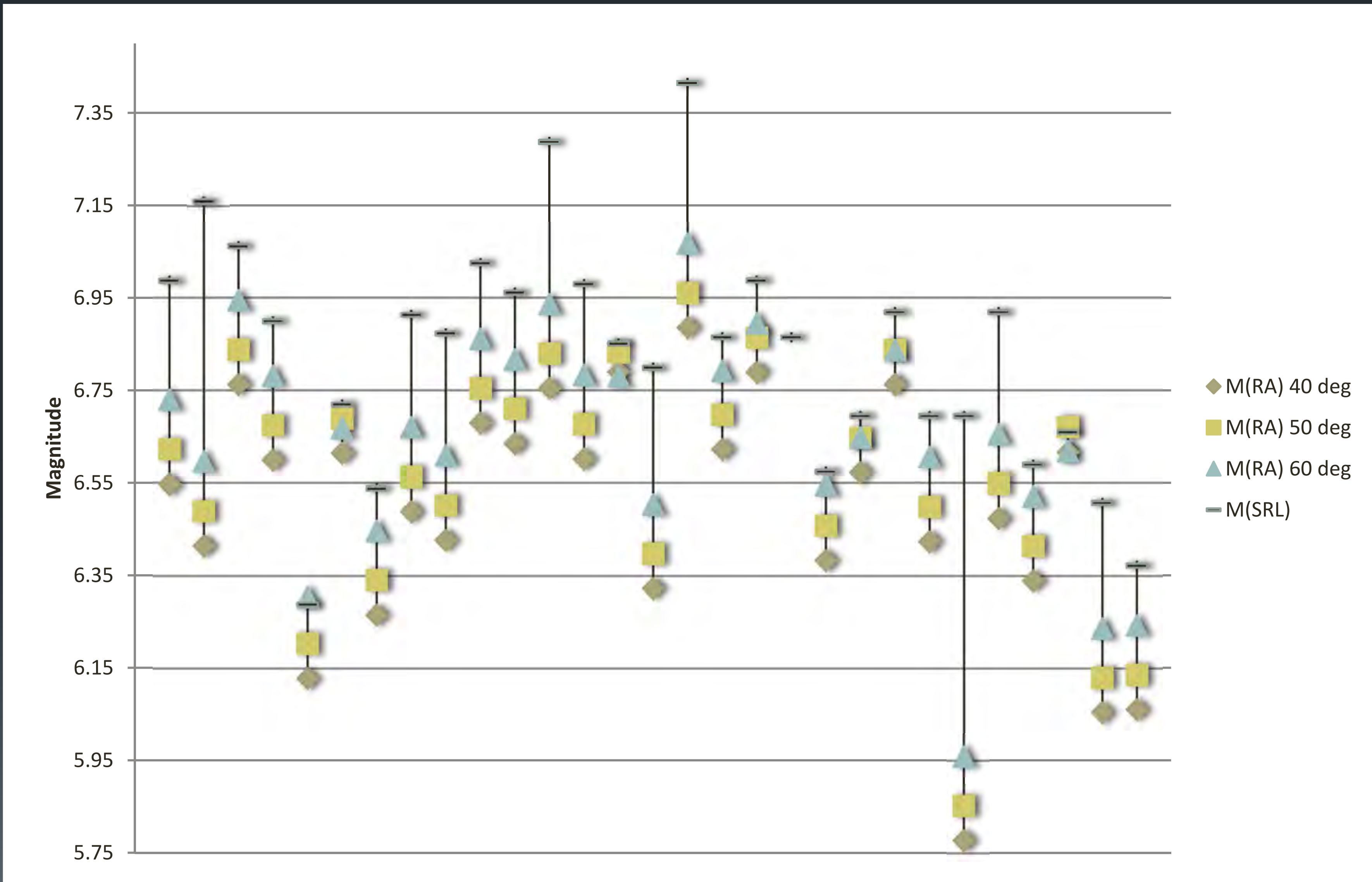
Assigned slip rate



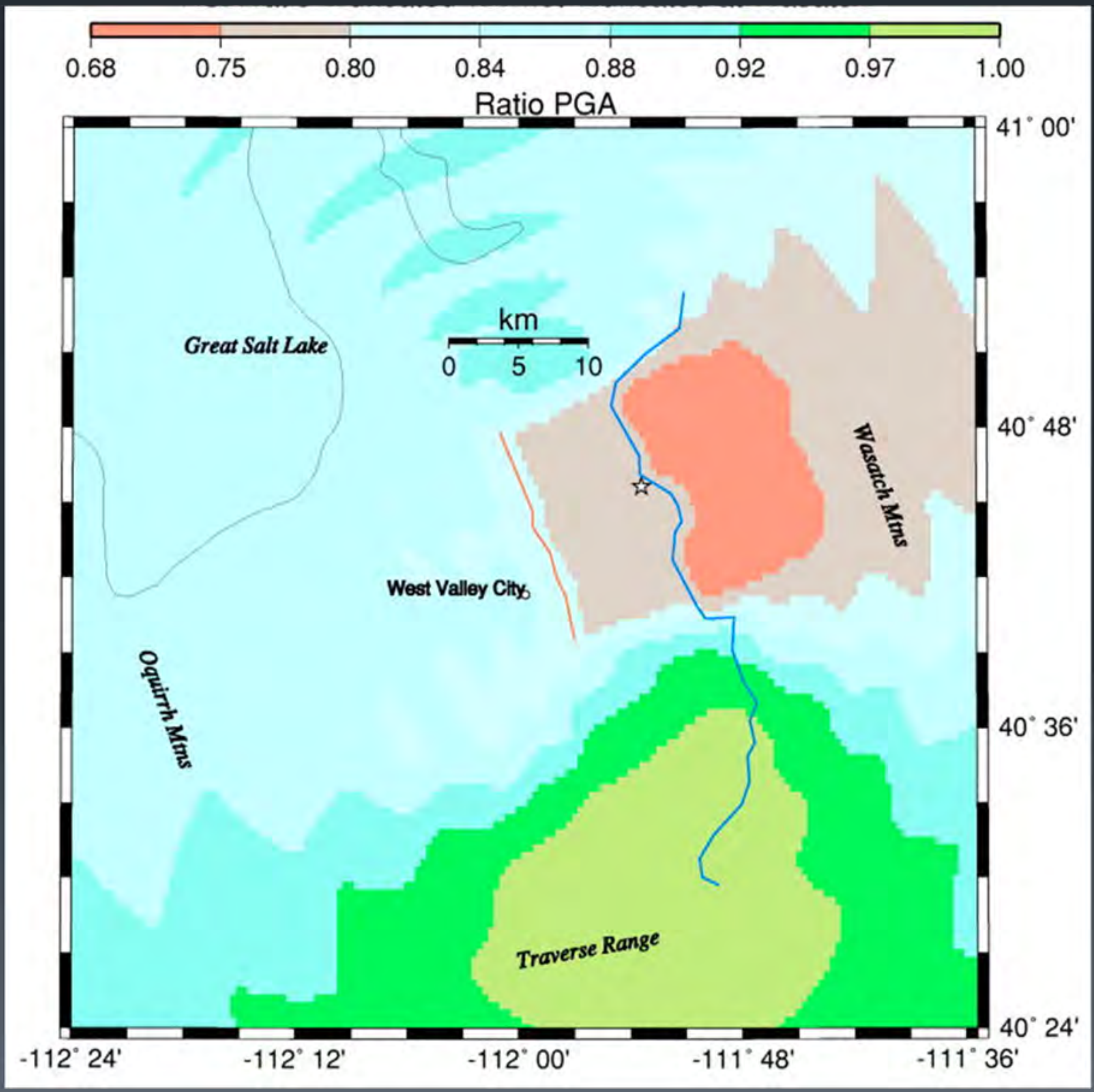
Depth of truncation



Magnitude comparison



Sensitivity study
SLC segment and West Valley fault zone



Conclusions

- Historical record suggests that graben-bounding faults do not behave in a predictable manner
- It is possible that none of these historic earthquakes provide an analogy for the seismic potential of the West Valley fault
- If one source is truncated, the hazard will noticeably decrease in the surrounding area

Discussion

- Are graben-bounding pairs properly modeled in the NSHMs?
- What other sensitivity studies are needed?
- Should the USGS modify how M is assigned to the truncated fault?
- Should there be a minimum M?

The question:

- How should antithetic fault pairs be modeled in the NSHMs? For example, what is the relation and seismogenic significance of fault pairs such as the East and West Cache faults, and strands of the Salt Lake City segment of the Wasatch fault and the West Valley fault zone?

Consensus recommendations to the USGS

USGS should explore using metrics (such as Length, Topographic Relief, Overlap) to guide selection of master and subsidiary faults.

- Evaluate dataset for overlapping relations to select master fault based on Length
- Evaluate using aspect ratio (Length/Width) for individual fault pairs
- Where data allow, structural throw should be used rather than Topo. Relief
- Evaluate using Length X Throw as a parameter for selecting master fault

Subsurface data (e.g., seismic reflection) should be used to guide master fault selection, where available.

Where available data do not give a clear indication of master vs. subsidiary fault, model both alternatives using a logic tree approach.

For truncated faults, use rupture area (rather than SRL) to determine M.

Consensus recommendations to the USGS

The USGS should conduct sensitivity studies on the impact on ground motions of graben-bounding fault pairs in urban areas.

The USGS should develop and test methodology for modeling graben-bounding pairs and present results at the IMW workshop in summer 2012.

WGUEP STUDY AREA FAULTS

Fault Name	Fault ID #	State	Slip Rate Category	Average Recurrence	Time of Most Recent Deformation	Length (km)
Almy	742	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	11
Bald Mountain	2390	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	2
Bear River fault zone	730	UT/WY	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	35
Bear River Range faults	2410	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	63
Blue Springs Hills faults	2363	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	2
Carrington (Dinter, per. comm. to URS Corp)	No data	UT	Similar to GSLFZ AI section		Similar to GSLFZ Antelope Island section	~28
Cedar Mountains - East side	2385	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	10
Cedar Valley - South side	2408	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	3
Clover fault zone	2396	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	4
Crater Bench faults	2433	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	16
Crawford Mountains - West side	2346	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	25
Cricket Mountains - North end	2434	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	3
Curlew Valley faults	3504	ID	<0.2 mm/yr		Latest Quaternary (<15 ka)	20
Deseret	2435	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	7
Dolphin Island fracture zone	2367	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	19
Drum Mountains fault zone	2432	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	52
Duncomb Hollow	743	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	2
East Cache fault zone	2352	UT				
ECFZ Northern section	2352a	UT/ID	<0.2 mm/yr		Quaternary (<1.6 Ma)	41
ECFZ Central section	2352b	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	17
ECFZ Southern section	2352c	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	22
James Peak fault/section?	2378	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	6
Broadmouth Canyon faults	2377	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	3
East Canyon - Northern/Southern sections	2354	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	26
East Dayton-Oxford faults	3509	ID	<0.2 mm/yr		Late Quaternary (<130 ka)	23
Great Salt Lake fault zone	2369	UT	—			
GSLFZ Antelope Island section	2369c	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	35
GSLFZ Fremont Island section	2369b	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	30
GSLFZ Promontory section	2369a	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	49
GSLF Rozelle section		UT	—			23 (19-27)
East Kamas	2391	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	15
East Lakeside Mountains fault zone	2368	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	36
East Tintic Mountains - West side	2420	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	41
East Side Sublette Range faults	3505	ID	<0.2 mm/yr		Quaternary (<1.6 Ma)	9
Eastern Bear Lake fault	2364	UT				
EBLF Northern section	2364a	ID	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	19
EBLF Central section	2364b	UT/ID	<0.2 mm/yr		Latest Quaternary (<15 ka)	24
EBLF Southern section	2364C	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	35
Elk Mountain	736	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	8
Frog Valley	2389	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	5
Gooseberry graben	2424	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	23
Gunnison	2445	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	42
Hansel Mountains - East side	2359	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	15
Hansel Valley fault	2358	UT	<0.2 mm/yr		1934 - Hansel Valley earthquake	13
Hansel Valley - Valley floor	2360	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	20
Hyrum	2374	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	3
Japanese and Cal Valley faults	2447	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	30
Joes Valley fault zone (combined)	2455	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	57
Lakeside Mountains - West side	2384	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	4

Little Diamond Creek	2411	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	20
Little Valley faults	2439	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	20
Long Ridge Northwest side	2422	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	21
Long Ridge West side	2421	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	15
Lookout Pass	2404	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	4
Main Canyon = East Canyon east side faults	2350	UT	—		Latest Quaternary (<15 ka)	26
Mantua area faults	2373	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	21
Martin Ranch	731	WY	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	4
Maple Grove faults	2443	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	17
Morgan	2353	UT				
MF Northern section	2353a	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	8
MF Central section	2353b	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	5
MF Southern section	2353c	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	2
North Bridger Creek	737	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	4
North Promontory	2361	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	26
North Promontory Mountains	2362	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	6
Ogden Valley North Fork	2376	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	26
Ogden Valley NE Margin faults	2379	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	13
Ogden Valley SW Margin faults	2375	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	18
Oquirrh fault zone	2398	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	21
Pavant faults	2438	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	30
Pavant Range fault	2442	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	14
Pleasant Valley fault zone - Dry Valley graben	2427	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	12
Pleasant Valley fault zone - graben	2426	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	18
Pleasant Valley fault zone - unnamed faults	2425	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	31
Porcupine Mountain faults	2380	UT/WY	<0.2 mm/yr		Late Quaternary (<130 ka)	35
Puddle Valley fault zone	2383	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	7
Raft River Mountains	2448	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	2
Red Canyon fault	2471	UT	<0.02 mm/yr		Latest Quaternary (<15 ka)	9
Rock Creek	729	WY	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	41
Round Valley faults	2400	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	13
Ryckman Creek	740	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	5
Sage Valley	2444	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	11
Saint John Station fault zone	2397	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	5
Saleratus Creek	2365	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	38
Scipio Valley faults	2440	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	7
Scipio fault zone	2441	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	13
Sheeprock fault zone	2405	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	12
Sheeprock Mountains	2419	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	7
Simpson Mountains faults	2418	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	11
Skull Valley (mid valley) faults	2387	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	55
Snow Lake graben	2452	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	26
Southern Joes Valley fault zone	2456	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	47
Southern Oquirrh Mountains fault zone	2399	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	24
Spring Creek	738	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	2
Stansbury fault zone	2395	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	50
Stinking Springs	2413	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	10
Strawberry	2412	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	32
Sublette Flat	733	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	36
Sugarville Area faults	2437	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	5
The Pinnacle	739	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	2
Topliff Hill fault zone	2407	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	20

Utah Lake faults	2409	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	31
Valley Mountains monocline	2449	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	39
Vernon Hills fault zone	2406	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	4
Wasatch fault zone	2351					
WFZ Malad City section	2351a	ID	<0.2 mm/yr		Late Quaternary (<130 ka)	40
WFZ Clarkston Mountain section	2351b	UT/ID	<0.2 mm/yr		Late Quaternary (<130 ka)	19
WFZ Collinston section	2351c	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	30
WFZ Brigham City section	2351d	UT	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	37
WFZ Weber section	2351e	UT	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	56
WFZ Salt Lake City section	2351f	UT	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	43
WFZ Provo section	2351g	UT	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	59
WFZ Nephi section	2351h	UT	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	43
WFZ Levan section	2351i	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	30
WFZ Fayette section	2351j	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	16
Wasatch monocline	2450	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	104
West Cache fault	2521	UT				
WCF Clarkston fault	2521a	UT/ID	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	21
WCF Junction Hills fault	2521b	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	24
WCF Wellsville fault	2521c	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	20
West Pocatello Valley	3506	ID	<0.2 mm/yr		Quaternary (<1.6 Ma)	8
West Valley fault zone	2386	UT				
WVFZ Granger section	2386b	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	16
WVFZ Taylorsville section	2386a	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	15
Western Bear Lake	622	ID	<0.2 mm/yr		Latest Quaternary (<15 ka)	59
Western Bear Valley faults	735	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	12
White Mountain Area faults	2451	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	17
Whitney Canyon	741	WY	<0.2 mm/yr		Latest Quaternary (<15 ka)	5
Woodruff	3508	ID	<0.2 mm/yr		Quaternary (<1.6 Ma)	13

					WGUEP STUDY AREA FAULTS NOT CONSIDERED	
Fault Name	**Fault ID #**	**State**	**Slip Rate Category**	**Average Recurrence**	**Time of Most Recent Deformation**	**Length (km)**
Almy	742	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	11
Bald Mountain	2390	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	2
Bear River Range faults	2410	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	63
Blue Springs Hills faults	2363	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	2
Cedar Mountains - East side	2385	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	10
Cedar Valley - South side	2408	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	3
Clover fault zone	2396	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	4
Cricket Mountains - North end	2434	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	3
Deseret	2435	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	7
Dolphin Island fracture zone	2367	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	19
Duncomb Hollow	743	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	2
East Kamas	2391	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	15
East Lakeside Mountains fault zone	2368	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	36
East Side Sublette Range faults	3505	ID	<0.2 mm/yr		Quaternary (<1.6 Ma)	9
Elk Mountain	736	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	8
Frog Valley	2389	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	5
Gooseberry graben	2424	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	23
Hyrum	2374	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	3
Japanese and Cal Valley faults	2447	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	30
Lakeside Mountains - West side	2384	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	4
Little Diamond Creek	2411	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	20
Long Ridge Northwest side	2422	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	21
Long Ridge West side	2421	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	15
Lookout Pass	2404	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	4
Mantua area faults	2373	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	21
North Bridger Creek	737	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	4
North Promontory Mountains	2362	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	6
Ogden Valley North Fork	2376	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	26
Ogden Valley NE Margin faults	2379	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	13
Ogden Valley SW Margin faults	2375	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	18
Pavant faults	2438	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	30
Pleasant Valley fault zone - Dry Valley graben	2427	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	12
Pleasant Valley fault zone - graben	2426	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	18
Pleasant Valley fault zone - unnamed faults	2425	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	31
Puddle Valley fault zone	2383	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	7
Raft River Mountains	2448	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	2
Round Valley faults	2400	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	13
Ryckman Creek	740	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	5
Sage Valley	2444	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	11
Saint John Station fault zone	2397	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	5
Saleratus Creek	2365	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	38
Sheeprock Mountains	2419	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	7
Simpson Mountains faults	2418	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	11
Snow Lake graben	2452	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	26
Southern Joes Valley fault zone	2456	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	47
Spring Creek	738	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	2
Sublette Flat	733	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	36
Sugarville Area faults	2437	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	5
The Pinnacle	739	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	2
Valley Mountains monocline	2449	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	39
Vernon Hills fault zone	2406	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	4
Wasatch monocline	2450	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	104
Western Bear Valley faults	735	WY	<0.2 mm/yr		Quaternary (<1.6 Ma)	12
West Pocatello Valley	3506	ID	<0.2 mm/yr	n	Quaternary (<1.6 Ma)	38
White Mountain Area faults	2451	UT	<0.2 mm/yr		Quaternary (<1.6 Ma)	17
Whitney Canyon	741	WY	<0.2 mm/yr		Latest Quaternary (<15 ka)	5
Woodruff	3508	ID	<0.2 mm/yr		Quaternary (<1.6 Ma)	13

WGUEP STUDY AREA FAULTS RETAINED						
Fault Name	**Fault ID #**	**State**	**Slip Rate Category**	**Average Recurrence**	**Time of Most Recent Deformation**	**Length (km)**
Bear River fault zone	730	UT/WY	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	35
Carrington (Dinter, per. comm. to URS Corp)	No data	UT	Similar to GSLFZ AI section		Similar to GSLFZ Antelope Island section	~28
Crater Bench faults	2433	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	16
Crawford Mountains - West side	2346	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	25
Curlew Valley faults	3504	ID	<0.2 mm/yr		Latest Quaternary (<15 ka)	20
Drum Mountains fault zone	2432	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	52
East Cache fault zone	2352	UT				
ECFZ Northern section	2352a	UT/ID	<0.2 mm/yr		Quaternary (<1.6 Ma)	41
ECFZ Central section	2352b	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	17
ECFZ Southern section	2352C	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	22
James Peak fault/section?	2378 ?	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	6
Broadmouth Canyon faults	2377	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	3
East Canyon - Southern/Northern sections	2354b	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	26
East Dayton-Oxford faults	3509	ID	<0.2 mm/yr		Late Quaternary (<130 ka)	23
Great Salt Lake fault zone	2369	UT				
GSLFZ Antelope Island section	2369c	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	35
GSLFZ Fremont Island section	2369b	UT	—		Latest Quaternary (<15 ka)	30
GSLFZ Promontory section	2369a	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	49
GSLF Rozelle section			—			
East Tintic Mountains - West side	2420	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	41
Eastern Bear Lake fault	2364	UT				
EBLF Northern section	2364a	ID	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	19
EBLF Central section	2364b	UT/ID	<0.2 mm/yr		Latest Quaternary (<15 ka)	24
EBLF Southern section	2364C	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	35
Gunnison	2445	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	42
Hansel Mountains - East side	2359	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	15
Hansel Valley fault	2358	UT	<0.2 mm/yr		1934 - Hansel Valley earthquake	13
Hansel Valley - Valley floor	2360	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	20
Joes Valley fault zone zone (combined)	2455	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	57
Little Valley faults	2439	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	20
Main Canyon = East Canyon east side faults	2350	UT	—		Latest Quaternary (<15 ka)	26
Martin Ranch	731	WY	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	4
Maple Grove faults	2443	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	17
Morgan	2353	UT				
MF Northern section	2353a	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	8
MF Central section	2353b	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	5
MF Southern section	2353c	UT	<0.2 mm/yr		Middle and late Quaternary (<750 ka)	2
North Promontory	2361	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	26
Oquirrh fault zone	2398	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	21
Pavant Range fault	2442	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	14
Porcupine Mountain faults	2380	UT/WY	<0.2 mm/yr		Late Quaternary (<130 ka)	35
Red Canyon fault	2471	UT	<0.02 mm/yr		Latest Quaternary (<15 ka)	9
Rock Creek	729	WY	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	41
Scipio Valley faults	2440	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	7
Scipio fault zone	2441	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	13
Sheeprock fault zone	2405	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	12
Skull Valley (mid valley) faults	2387	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	55
Southern Oquirrh Mountains fault zone	2399	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	24
Stansbury fault zone	2395	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	50

Stinking Springs	2413	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	10
Strawberry	2412	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	32
Topliff Hill fault zone	2407	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	20
Utah Lake faults	2409	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	31
Wasatch fault zone	2351					
WFZ Malad City section	2351a	ID	<0.2 mm/yr		Late Quaternary (<130 ka)	40
WFZ Clarkston Mountain section	2351b	UT/ID	<0.2 mm/yr		Late Quaternary (<130 ka)	19
WFZ Collinston section	2351c	UT	<0.2 mm/yr		Late Quaternary (<130 ka)	30
WFZ Brigham City section	2351d	UT	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	37
WFZ Weber section	2351e	UT	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	56
WFZ Salt Lake City section	2351f	UT	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	43
WFZ Provo section	2351g	UT	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	59
WFZ Nephi section	2351h	UT	Between 1.0 and 5.0 mm/yr		Latest Quaternary (<15 ka)	43
WFZ Levan section	2351i	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	30
WFZ Fayette section	2351j	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	16
West Cache fault	2521	UT				
WCF Clarkston fault	2521a	UT/ID	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	21
WCF Junction Hills fault	2521b	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	24
WCF Wellsville fault	2521c	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	20
West Valley fault zone	2386	UT				
WVFZ Granger section	2386b	UT	Between 0.2 and 1.0 mm/yr		Latest Quaternary (<15 ka)	16
WVFZ Taylorsville section	2386a	UT	<0.2 mm/yr		Latest Quaternary (<15 ka)	15
Western Bear Lake	622	ID	<0.2 mm/yr		Latest Quaternary (<15 ka)	59

“OTHER” FAULT SUMMARY TABLE

Parameters	Retained Faults[1]	Deleted Faults
Total 112	55	57
<0.2 mm/yr	39	57
> 0.2 mm/yr < 1.0 mm/yr	12	–
> 1.0 mm/yr < 5.0 mm/yr	1	–
Unknown	3	–
Historical	1	–
Latest Quaternary < 15 ka	37	4
Late Quaternary < 130 ka	9	4
Middle Quaternary < 750 ka	7	20
Quaternary < 1.8 Ma	1	29
0 – 10 km	10	26
11 – 20 km	16	15
21– 30 km	13	7
31 – 40 km	6	6
> 40 km	10	3

[1]Does not include the ten Wasatch fault zone segments.

Evaluation of the Seismogenic Potential of the Joes Valley Fault Zone - Joes Valley Dam, Emery County Project - Utah

This Technical Memorandum presents the results of these additional studies. Basically, these new data and interpretations by Dr. James Coogan (Attachment A) strongly suggest that the faults of the Joes Valley fault zone, and similar north-striking normal faults within the Wasatch Plateau, sole into weak rocks of the Jurassic Carmel Formation or Arapien Shale at depths of about 3 km, and do not penetrate the underlying Navajo Sandstone. Since these faults do not appear to penetrate the Navajo Sandstone, this further indicates that the Wasatch Plateau faults probably do not extend to the seismogenic depths (10-20 km) necessary to produce large damaging earthquakes (**M** 6 to 7 ½). Thus, the results for **Case 2** of O'Connell and others (2005) is probably the preferred interpretation for representing the seismic hazard at Joes Valley Dam.

Conclusions

The geophysical data and report by Dr. Coogan has been reviewed by Reclamation staff, Dr. Dan O'Connell (formerly of the Seismotectonics and Geophysics Group; Attachment B), and Doug Sprinkel of the UGS. Based on the new seismic reflection data, as well as the reviews of this data, it is our conclusion that the model where the Joes Valley faults extend to seismogenic depths and are the potential sources of large-magnitude earthquakes appears to be the least likely of all the four models presented by Foley and other (1986) and O'Connell and others (2005). Thus, the faults of the Joes Valley graben and similar Wasatch Plateau faults probably are not potential sources of large-magnitude earthquakes (**M** $\geq$ 6.5). In a new PSHA for Joes Valley Dam, these faults would be given a very low probability of activity (Pa 0.05 to 0.1?). Surface rupture or offset is still obviously a potential hazard, but given the limited width (i.e., down dip extent) of the faults (2 to 4 km) earthquakes associated with the Joes Valley faults would be of relatively small magnitude (**M** 5 $\pm$). Finally, **Case 2** (Figure 4), probably represents a close approximation of the seismic hazard at Joes Valley Dam.

4. East Canyon/Main Canyon Fault Conclusions

Exposures in the trench confirm that the scarps along the northern Main Canyon fault have a tectonic origin, and were likely formed by recurrent surface-faulting earthquakes. Stratigraphic units, ages, and tectonic events interpreted from the trench are summarized in Figure 1. Dating of faulted and unfaulted deposits exposed in the trench suggests that two surface-rupturing earthquakes have occurred since about 30,000 to 38,000 years ago. The MRE likely occurred shortly before 5000 to 6000 years ago, but could be as old as 12,000 to 15,000 years. Characteristics of the sediment filling the graben and a distinct, buried A horizon preserved on unit 6 beneath the graben fill (unit 10) suggest that this earthquake occurred closer to the minimum bracketing age than to the maximum bracketing age. The orientation of the fault and its sense of displacement relative to the landscape resulted in fault scarps that face upslope. When scarps formed, the generally east-flowing drainages were blocked at least temporarily, and fine alluvial and eolian sediments were trapped in the resulting ponds and marshes. Consequently, the alluvial-fan and colluvial deposits that are preserved on the footwall were not exposed in the trench on the hanging wall, and neither the amount of offset nor a slip rate could be estimated. The penultimate faulting earthquake occurred between about 30,000 and 38,000 years ago, when a marsh also formed in response to scarp formation. Evidence for older surface-faulting earthquakes (older than 38,000 years ago) on the Main Canyon fault is present in the trench, but the timing of these events could not be estimated with any accuracy from the available exposures.

The geomorphic expression of the Main Canyon fault is consistent with the faulting history interpreted from the trench exposure. Although late Quaternary tectonic scarps have been recognized only at the north end of the fault, between Main Canyon and the Weber River valley, facets or bedrock scarps, saddles, and lineaments are present nearly continuously to Taylor Hollow, a distance of at least 20 km. The fault cuts across topography, and its geomorphic expression varies depending upon whether the offsets face upslope or downslope. The geomorphic expression of the southern about 6 km of the Main Canyon fault (south of Taylor Hollow) is more discontinuous than it is to the north, but is still present. Thus, the total length of late Quaternary rupture could be as long as 26 km. The lack of an escarpment or a late Cenozoic basin along the fault suggests that the fault did not experience surface ruptures during the entire Cenozoic, but has only been recently active.

The geomorphic expression of the East Canyon fault is quite different than that of the Main Canyon fault. The East Canyon fault has produced an eroded escarpment in resistant rocks at its north end, and facets/bedrock scarps along about 26 km of the fault. No obvious scarps on late Quaternary or Quaternary deposits have been observed associated with the East Canyon fault, in contrast to the Main Canyon fault. This expression, along with the pattern of Tertiary rocks preserved in East Canyon valley, suggests that displacements occurred earlier on the East Canyon fault than on the Main Canyon fault, beginning some time before the Norwood Tuff was deposited during the Oligocene and continuing for some time thereafter. The lack of evidence for late Quaternary or Quaternary activity associated with the East Canyon fault suggests that such activity has not occurred or has occurred at only a very low rate.

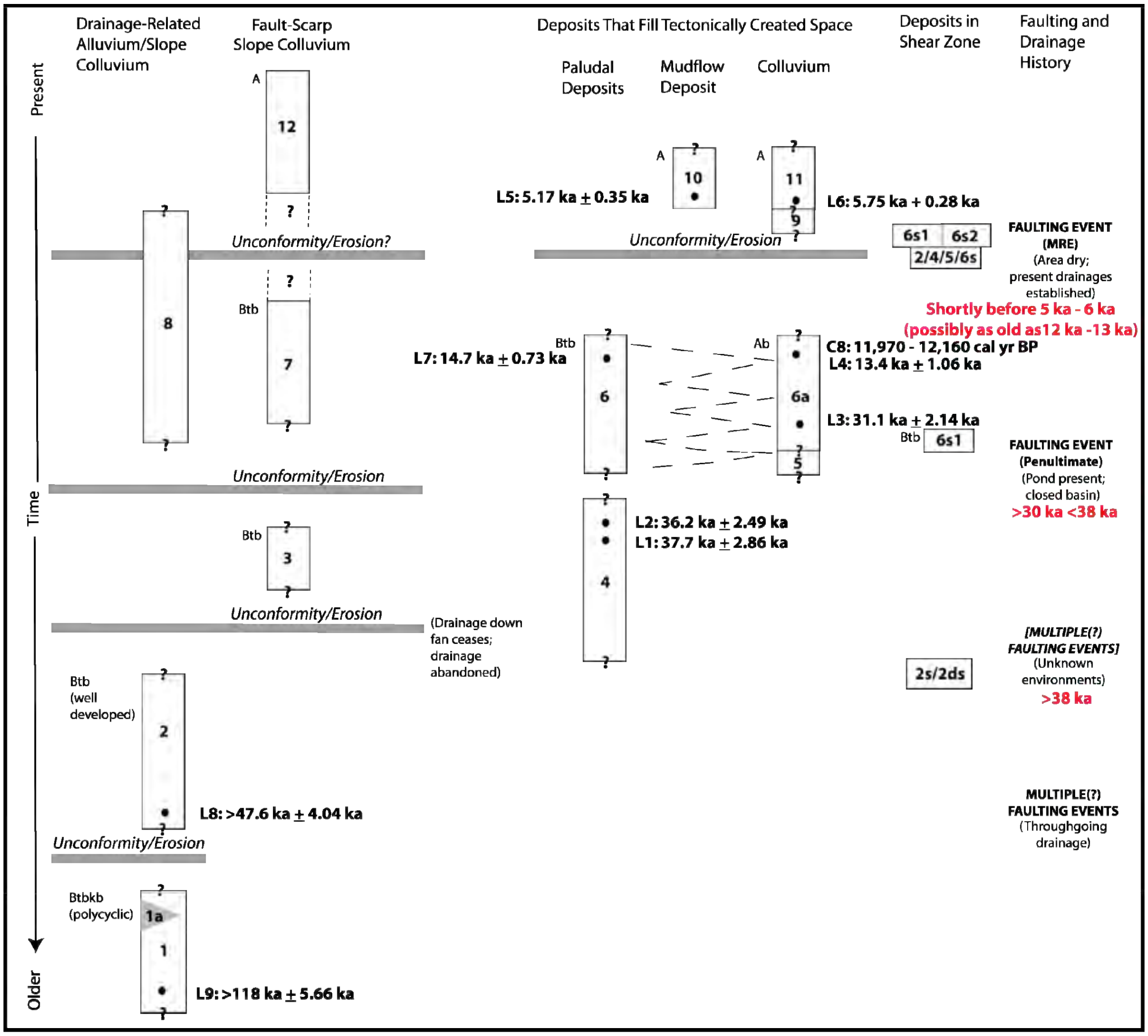


Figure 1. *Stratigraphic units, ages, and tectonic events interpreted from the trench excavated near the north end of the Main Canyon fault.*

Addressing Slip-Rate Uncertainty in the NSHM

BRPEWG II meeting
Issue G3
Discussion Leaders: Steve Wesnousky
Kathy Haller

The Question

- The USGS seeks guidance on how to estimate the uncertainty for the slip rates on BRP normal-slip faults, especially for faults that have little or no slip-rate data. The method used in California to estimate the uncertainty has varied the upper and lower bounds of the slip rate by plus-or-minus 50%. Thus the uncertainty bounds for a fault that has a slip rate of 5 mm/yr would be 7.5 mm/yr and 2.5 mm/yr. Do these bounding values encompass the fifth and ninety-fifth percentiles for this fault?

Outline

- Review UQFWG slip-rate uncertainties
- Sensitivity studies of UQFWG determinations
- Slip-rate uncertainties for IMW sources
- Examples of paleoseismic records suggesting clustering

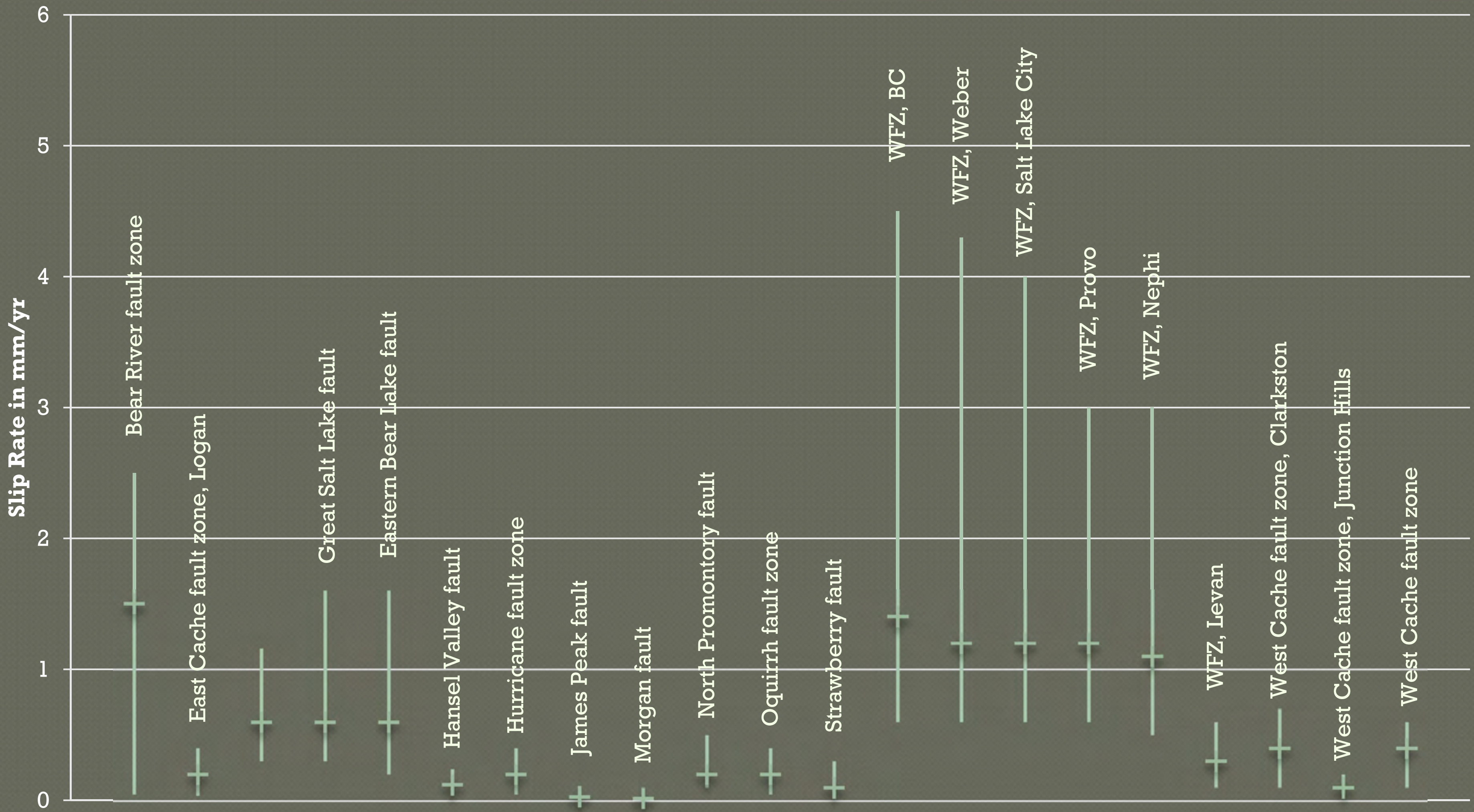
UQFWG uncertainties

- Working group reviewed all faults in Utah that had been trenched prior to 2003 and reported min, max, and preferred slip rates for 21 sources
- Slip rate uncertainty represents 5 and 95 percentiles
- The range of the model compares average slip rates that cover different time periods and/or different offset markers along a given fault

UQFWG uncertainties

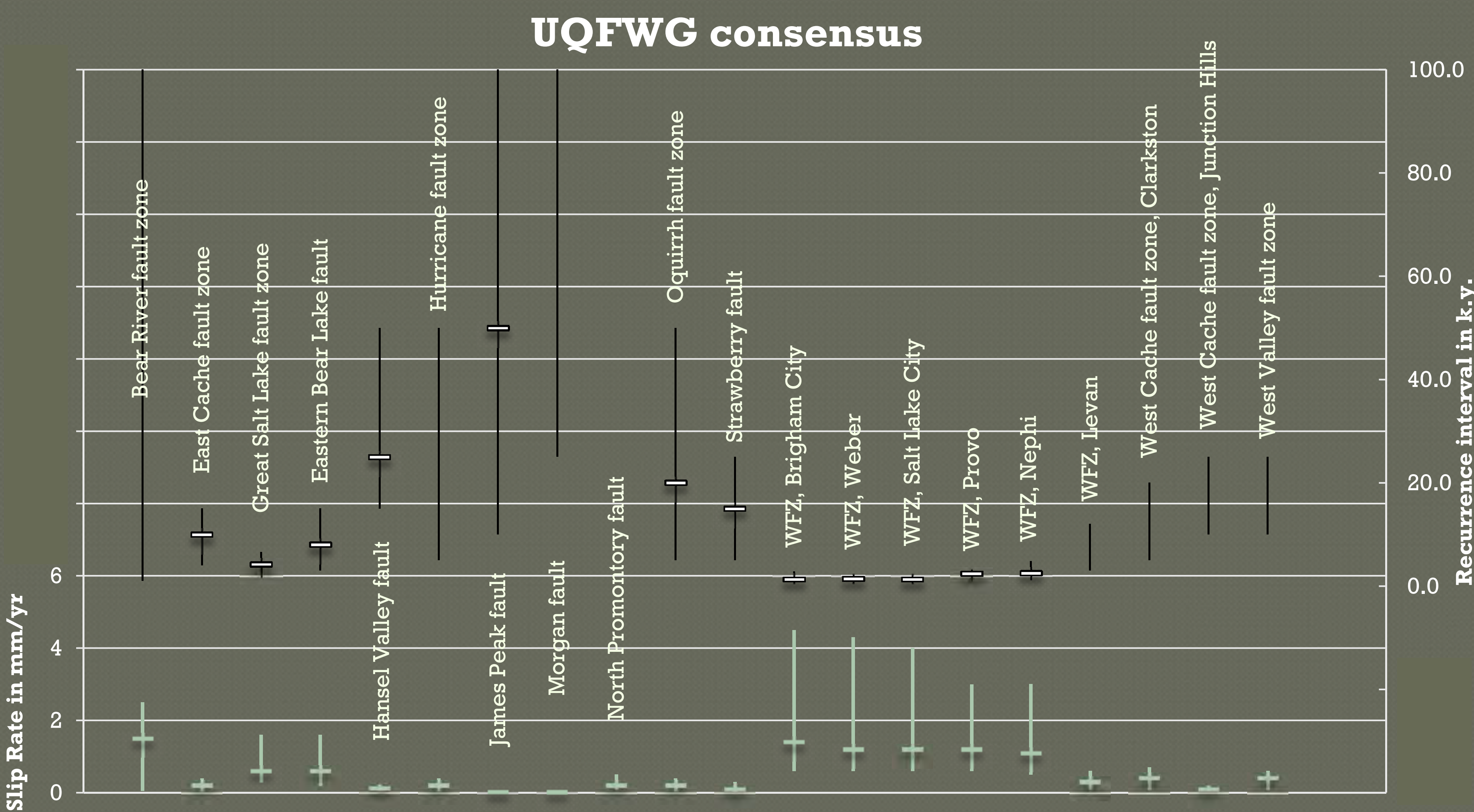
- Reported uncertainties reflect consensus view of clustering
- Minimum slip rates are from out of cluster series
- Maximum slip rate are from in-cluster series

UQFWG consensus slip rates



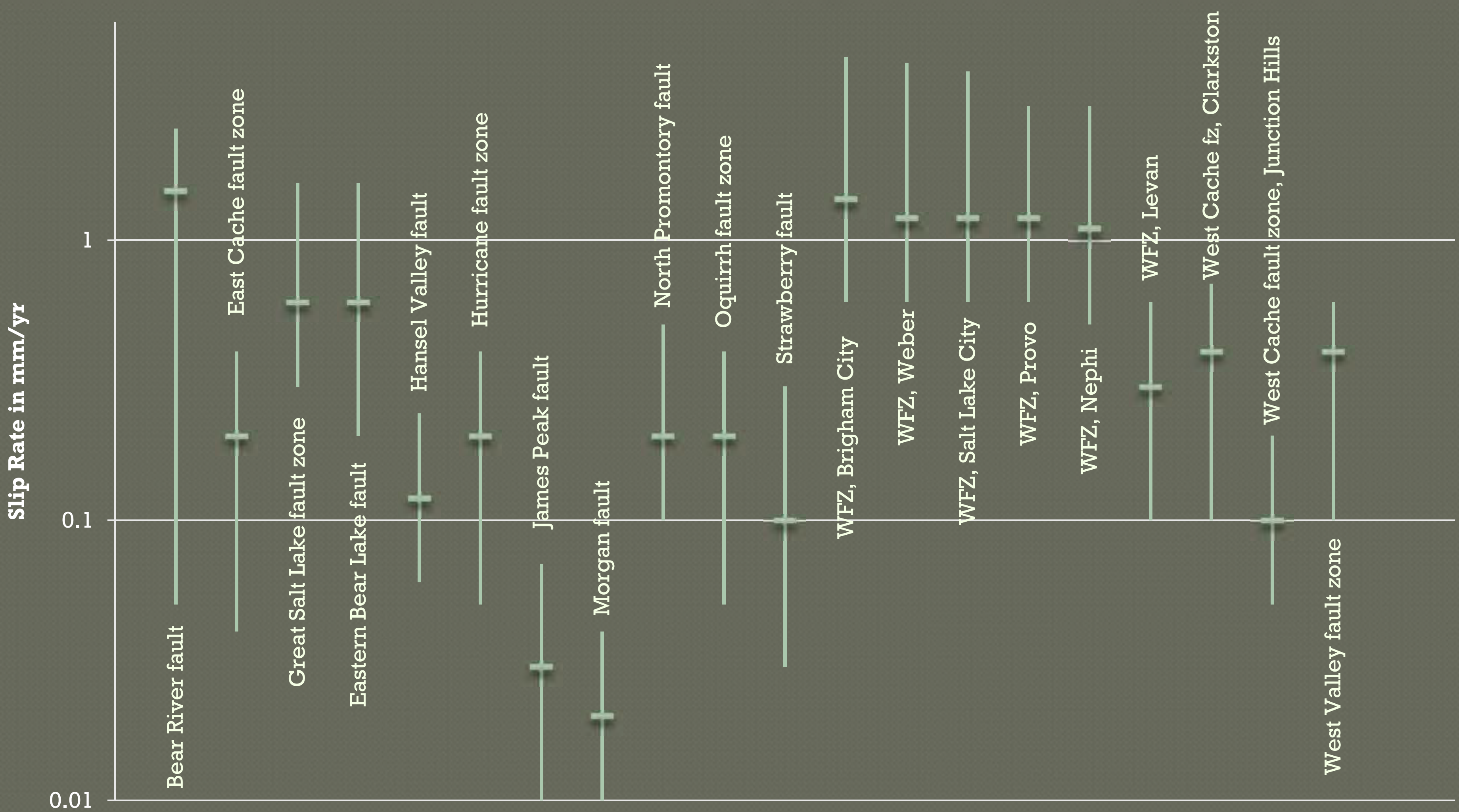
Data from Lund 2005

Consensus slip rate and recurrence intervals



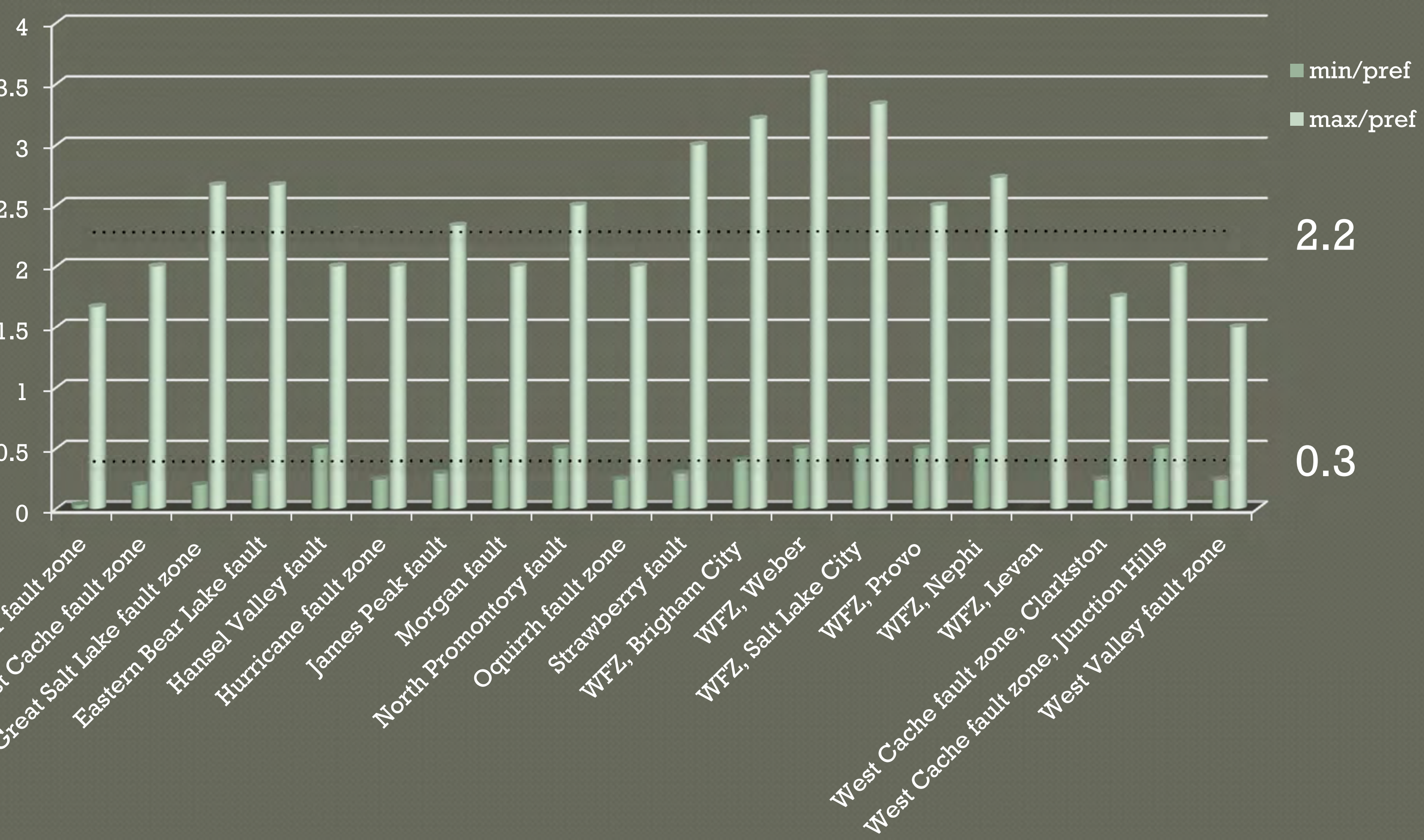
Data from Lund 2005

Log of slip rate

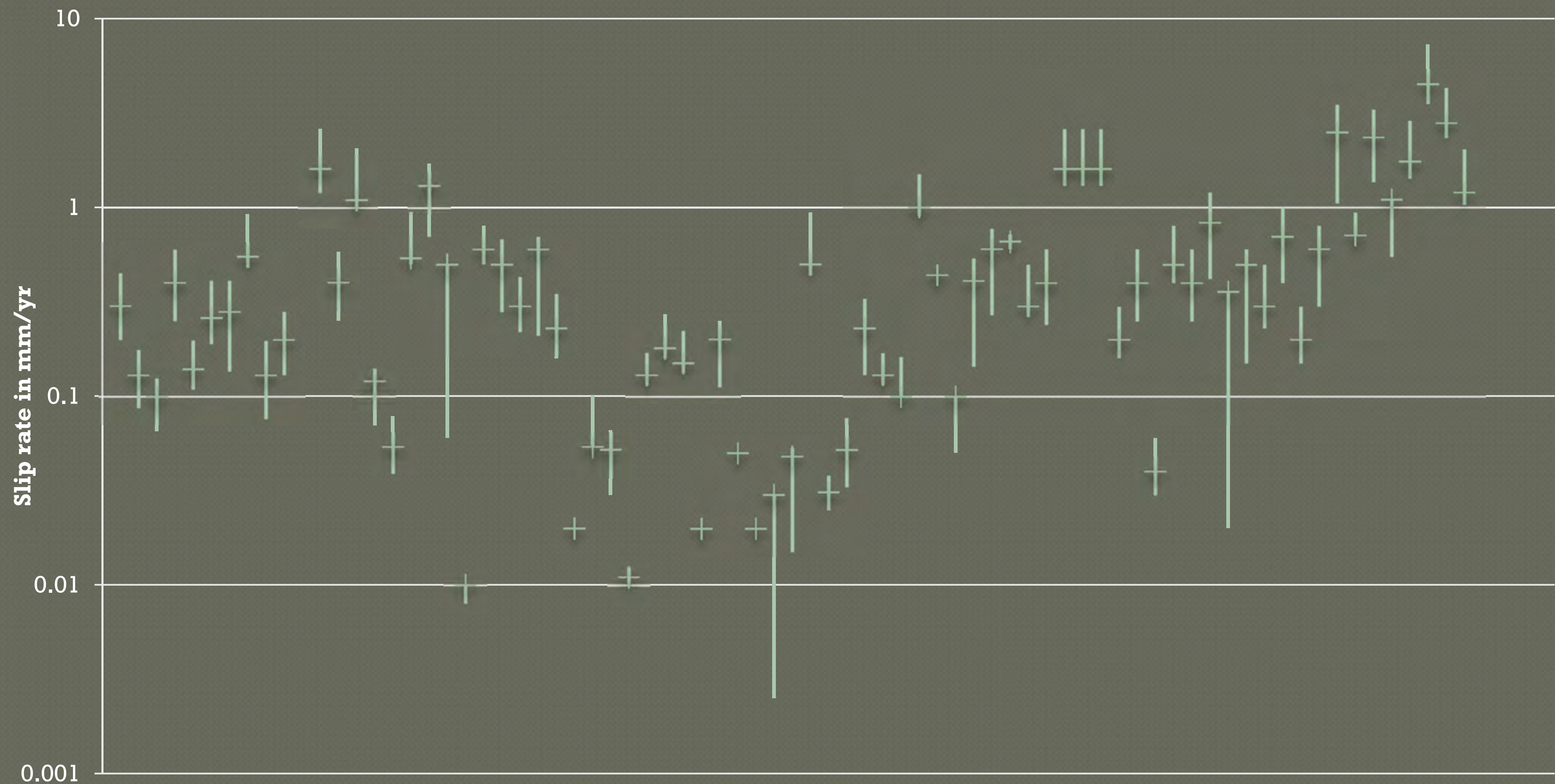


Data from Lund 2005

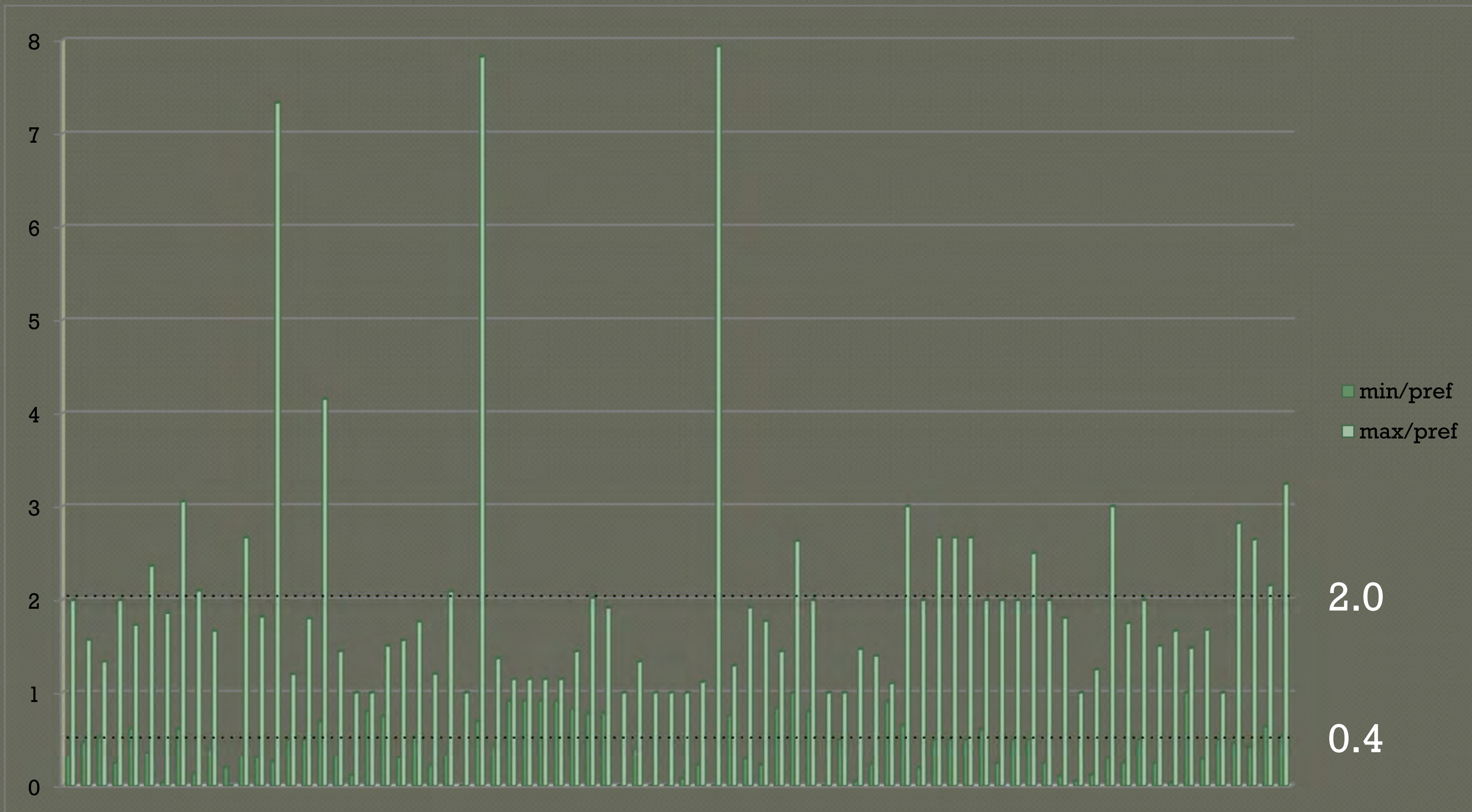
UQFWG slip-rate ratio



IMW slip-rate uncertainties



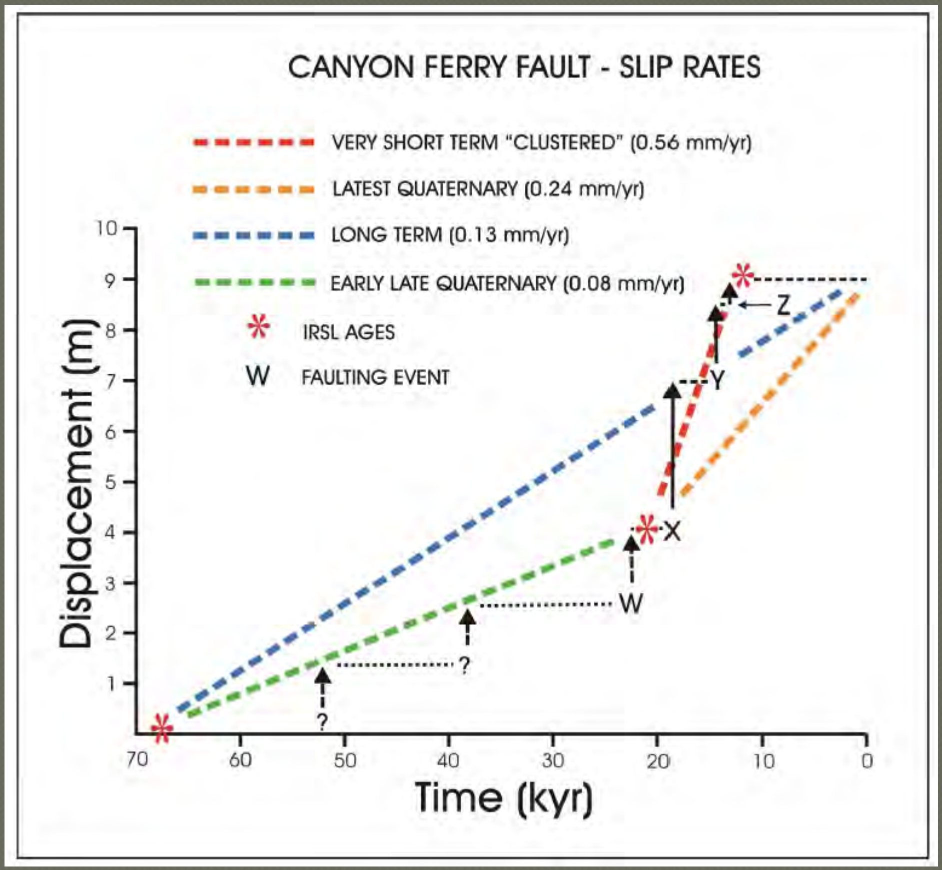
IMW slip-rate ratio



Clustering or Poisson

- "preponderance of evidence that some faults don't have regularly spaced events in time"—Zechar and Frankel 2009
- "For short series (fewer than 10 intervals) sample means tend to reflect the median of an asymmetric recurrence distribution possibly leading to an overestimate of the hazard.." –Parsons 2008
- Faults will yield different long-term slip rates depending on how far back (how many earthquakes) we are able to extend the paleoseismic record.

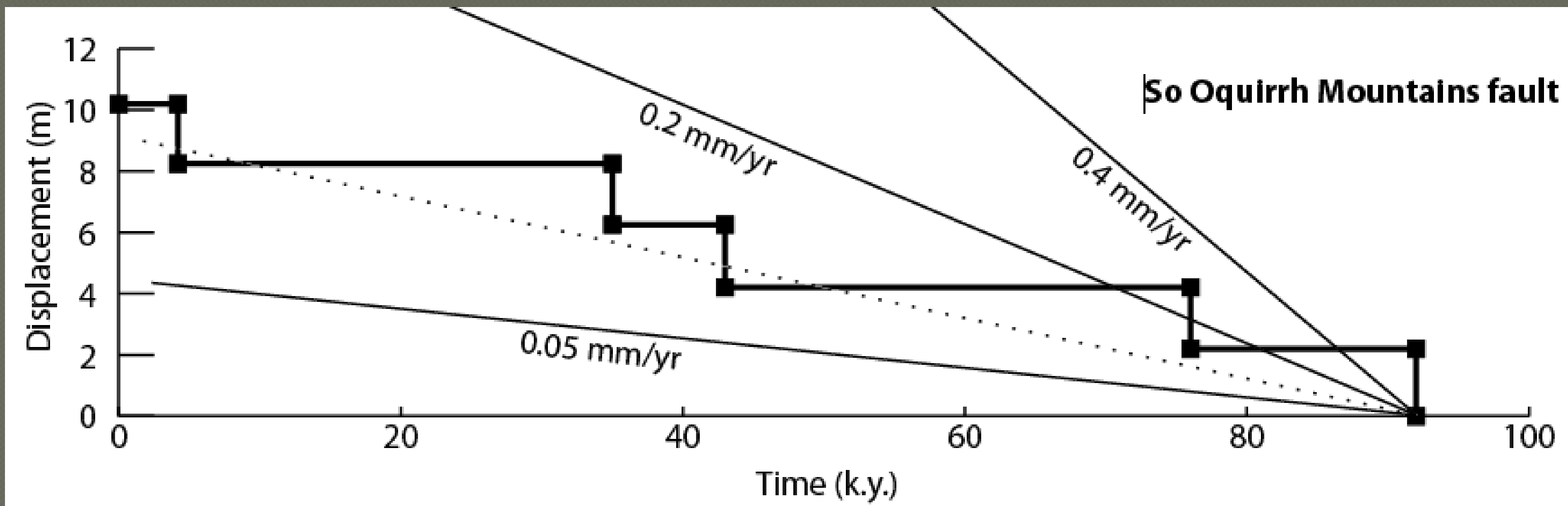
Clustering and slip rate



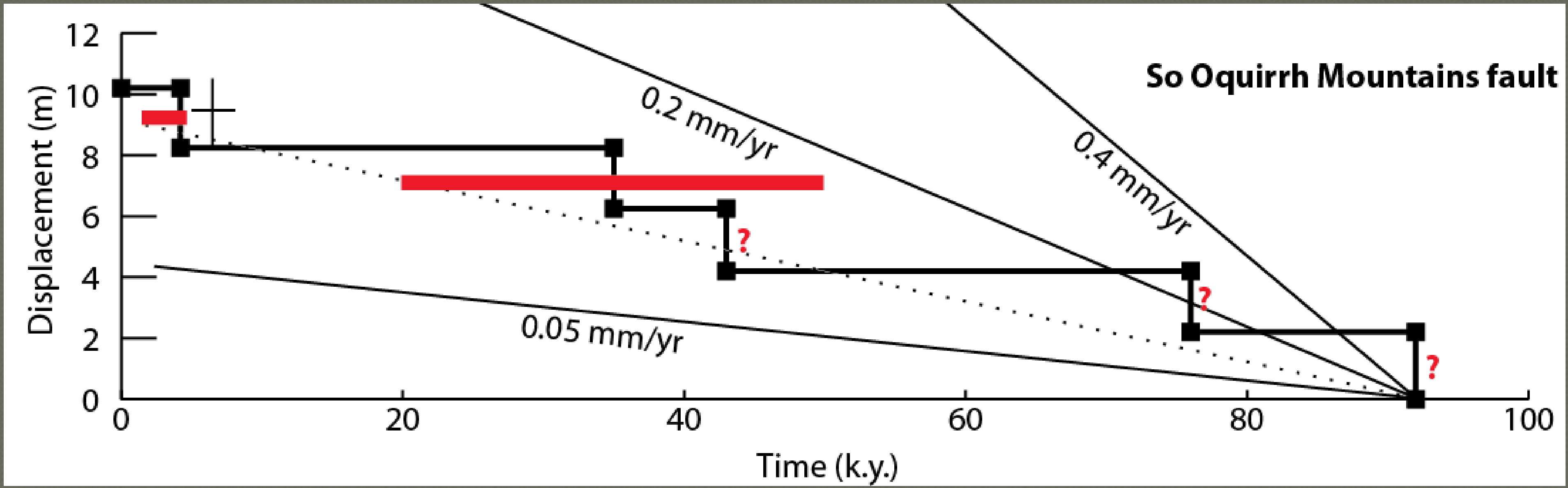
from Anderson and others 2004

- In cluster slip rate 0.56 mm/yr spanning 12% of the record
  2-3 events total offset 5 m
- Out of cluster slip rate 0.8 mm/yr spanning 70% of the record unknown number of events total offset 4.1 m

Slip-predictable model

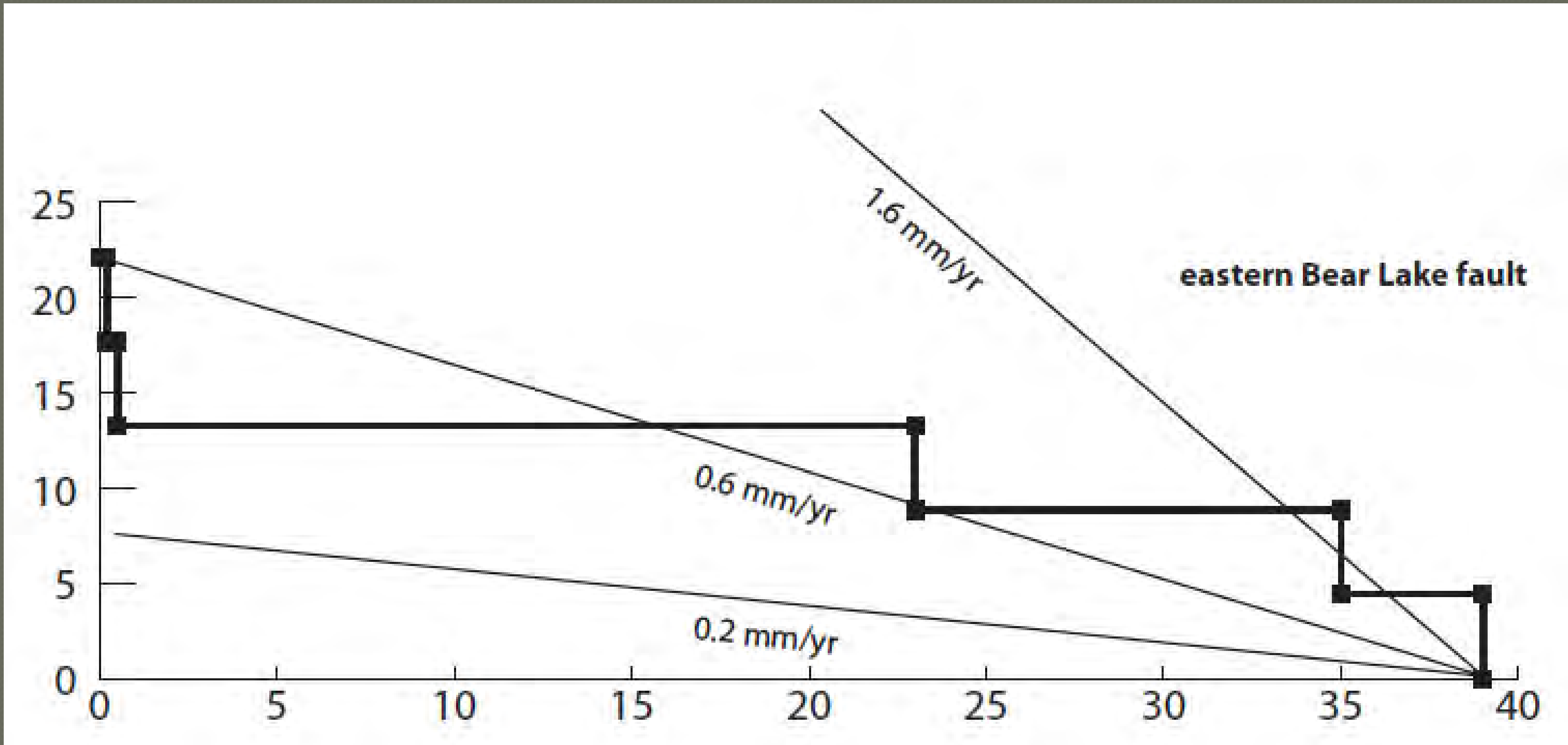


Data uncertainty



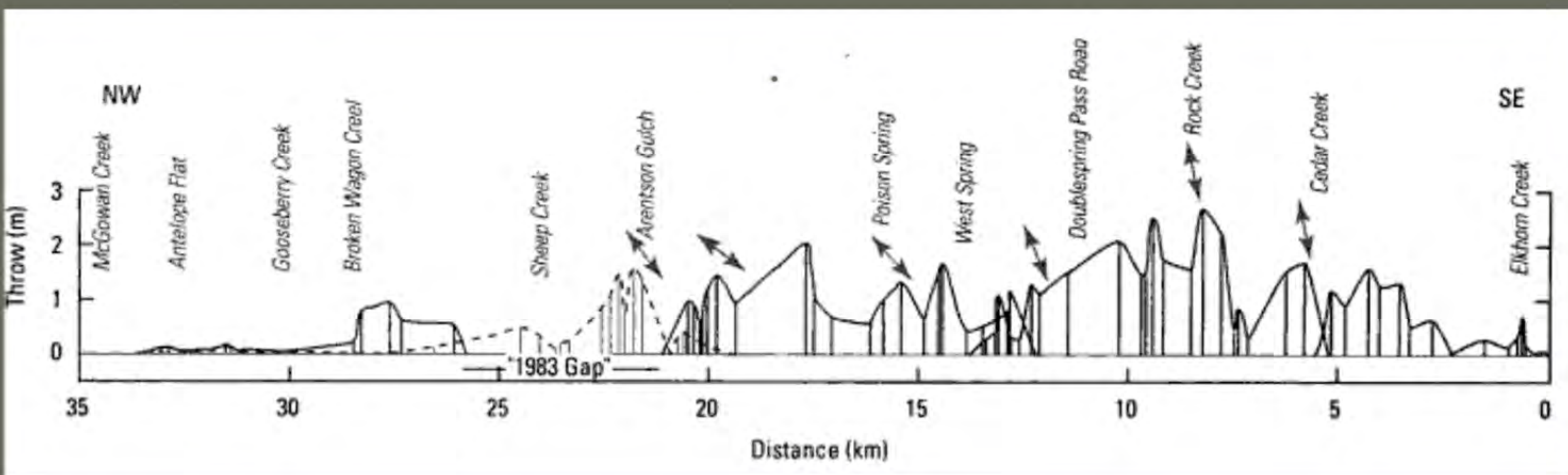
Event timing from Lund 2005

Another slip-predictable model



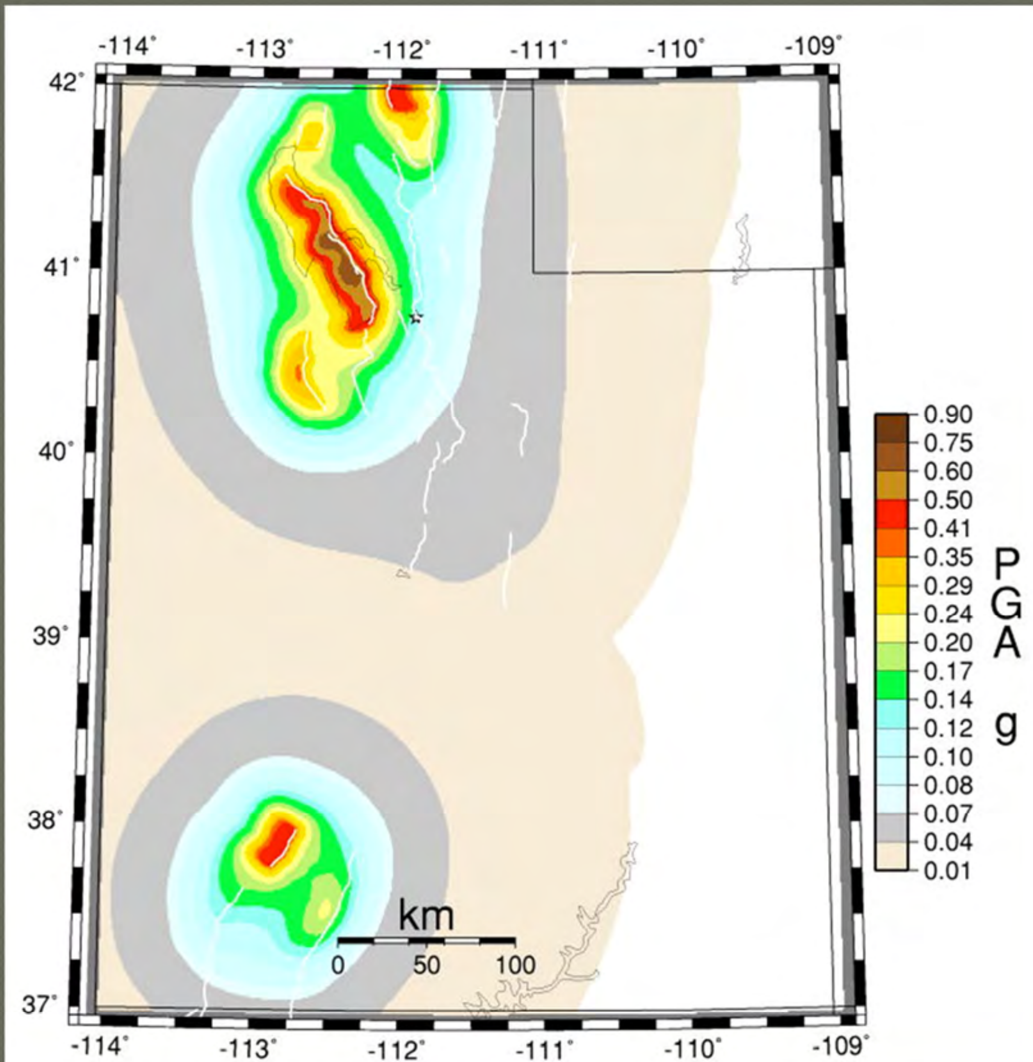
Event timing from Lund 2005

Have we addressed distribution of slip?



- “Skewed distributions are particularly common when mean values are low, variance is large, and values cannot be negative”
- “What is the difference between normal and log-normal variability? Both forms of variability are based on a variety of forces acting independently of one another. A major difference, however, is that the effects can be additive or multiplicative, thus leading to normal or log-normal distributions, respectively.”
- --Limpert, Stahel, and Abbt 2001

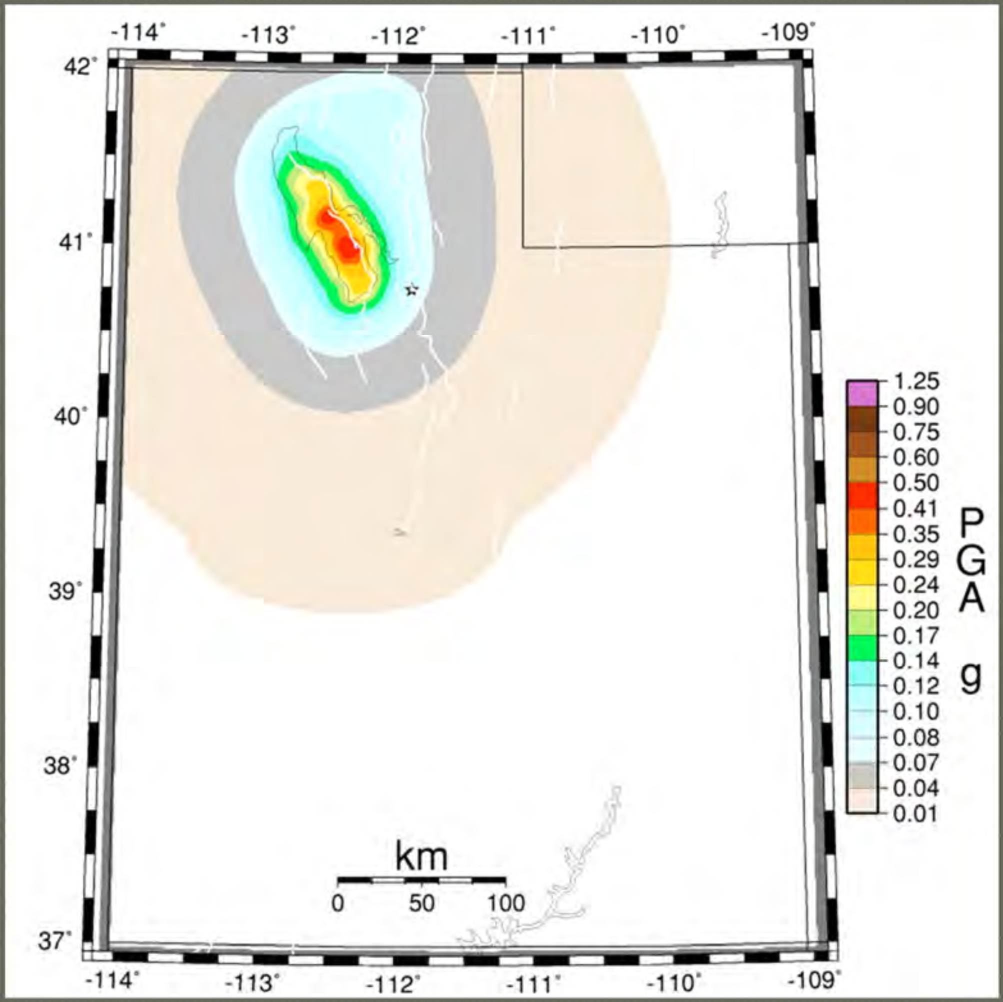
Preferred slip rates—UQFWG



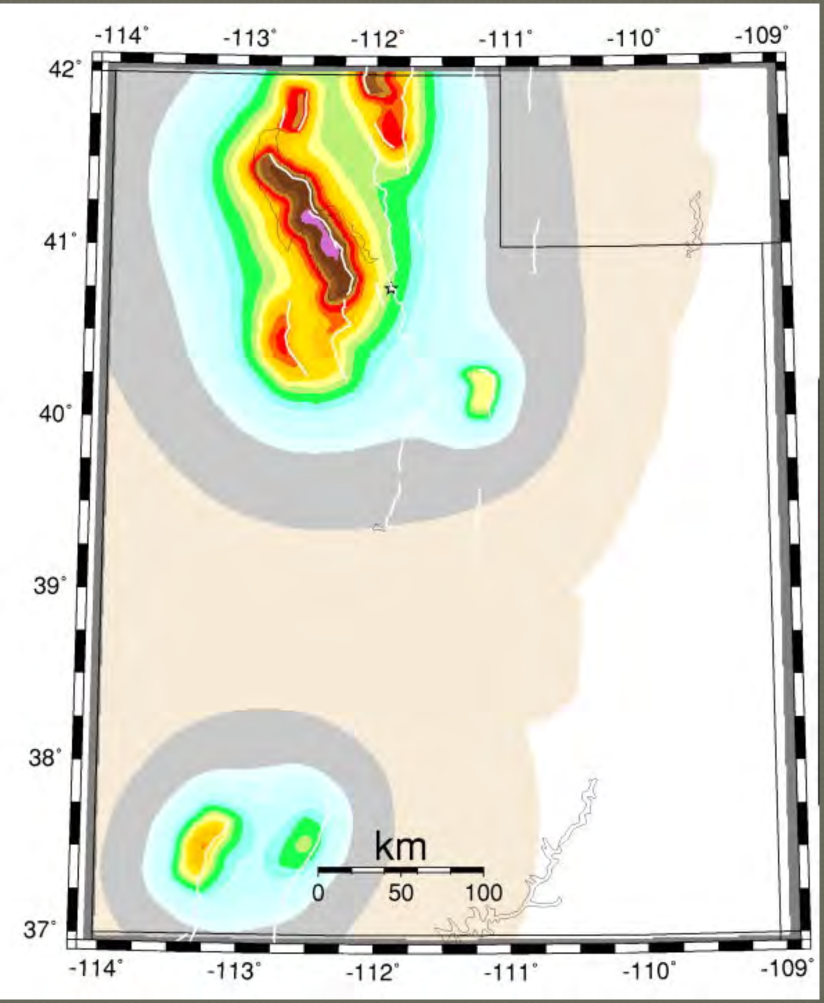
- PGA 2% in 50 yr
- Includes 1/3 GR and 2/3 Char
- 760 m/sec Vs30
- Sources (white lines) have ±10° dip uncertainty

Alternative slip rates—UQFWG

5 PERCENTILE SLIP RATE



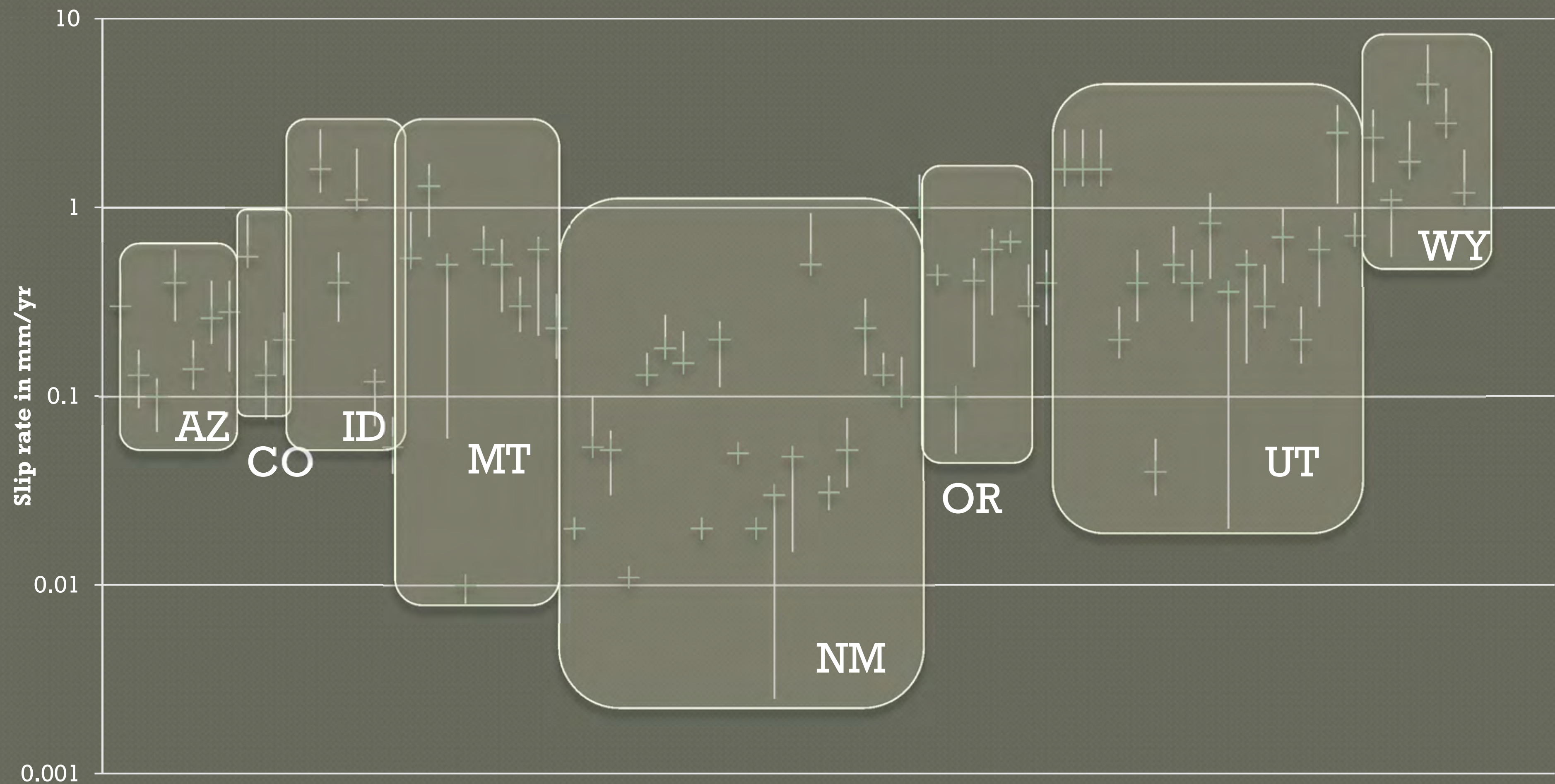
95 PERCENTILE SLIP RATE



Discussion

- Should we expect slip rate uncertainty to have normal distributions?
- UQFWG estimates and uncertainty compiled for surrounding states demonstrate considerable spread, but are in broad agreement. Does assigning ±50% make sense for IMW slip-rate uncertainties?
- Which paleoseismic records are long enough to evaluate clustering?

IMW slip-rate uncertainties



Addressing Slip-Rate Uncertainty in the NSHM

BRPEWG II meeting
Issue G3
Discussion Leaders: Steve Wesnousky
Kathy Haller

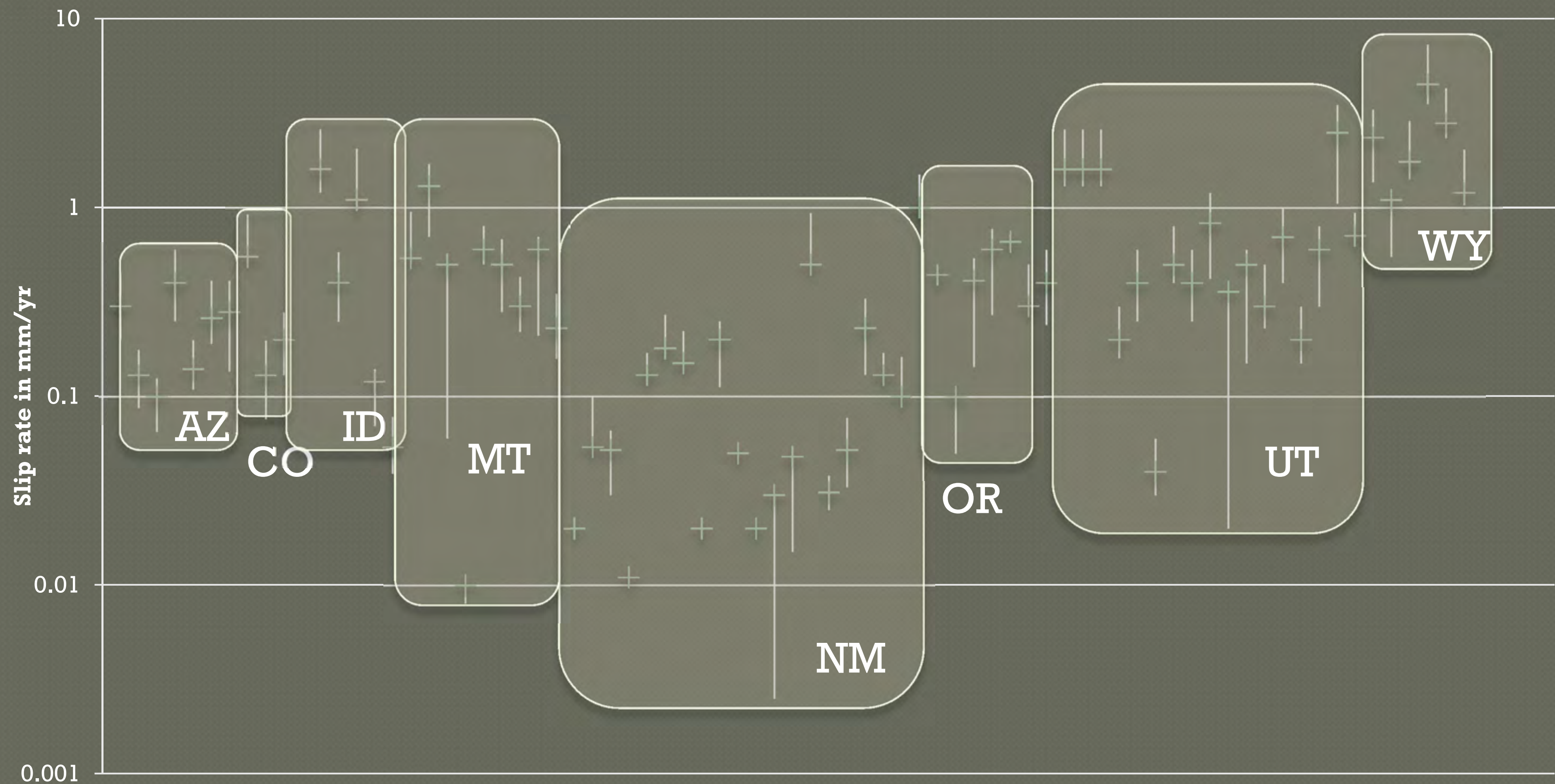
The Question

- The USGS seeks guidance on how to estimate the uncertainty for the slip rates on BRP normal-slip faults, especially for faults that have little or no slip-rate data. The method used in California to estimate the uncertainty has varied the upper and lower bounds of the slip rate by plus-or-minus 50%. Thus the uncertainty bounds for a fault that has a slip rate of 5 mm/yr would be 7.5 mm/yr and 2.5 mm/yr. Do these bounding values encompass the fifth and ninety-fifth percentiles for this fault?

Conclusions

- ±50 percent does not capture slip rate uncertainty
- Uncertainty is closer to ½ 2X of the preferred to reflect clustering in paleoseismic records to represent 5 and 95 percentiles

IMW slip-rate uncertainties

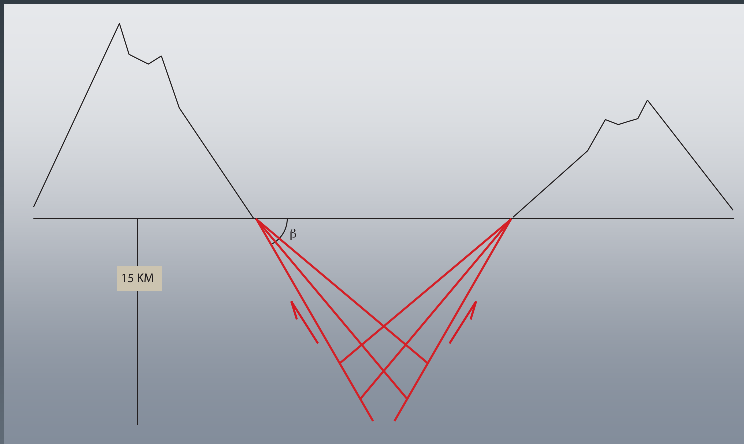


Recommendations

- The USGS should engage state survey scientists to contribute and review slip-rate uncertainty for IMW sources
- The USGS should conduct sensitivity studies of ground motions that incorporate assigned slip rates for sources in the IMW
- The USGS should test assigned parameters and present results at the IMW workshop in Summer of 2012

Modeling Graben-bounding Faults in the NSHMs

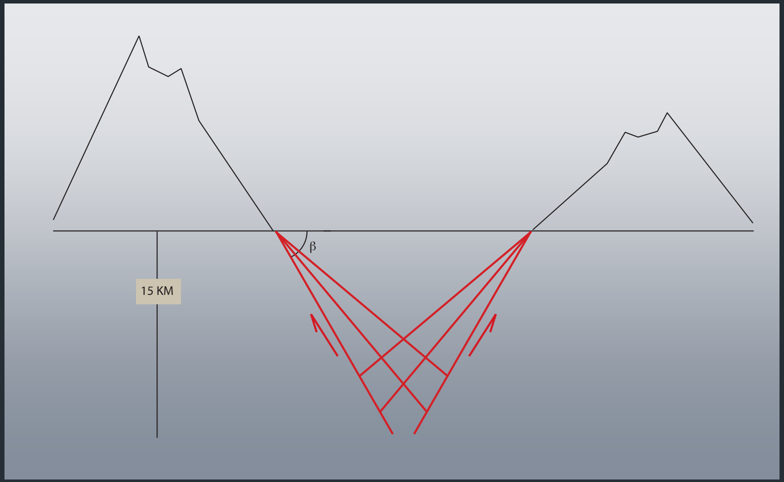
BRPEWGII Meeting
Issue G2
Discussion Leaders: Kathy Haller and Mike Hylland



The question:

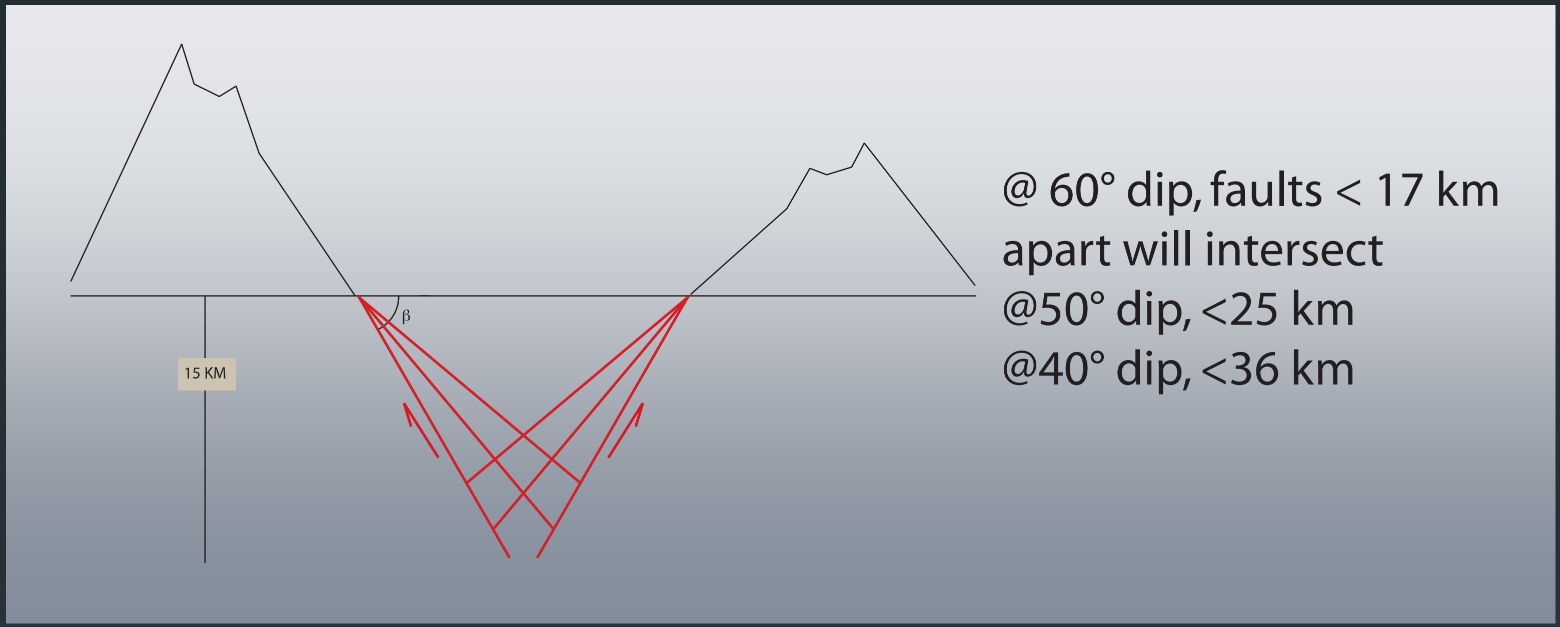
- How should antithetic fault pairs be modeled in the NSHMs? For example, what is the relation and seismogenic significance of fault pairs such as the East and West Cache faults, and strands of the Salt Lake City segment of the Wasatch fault and the West Valley fault zone?

The problem:



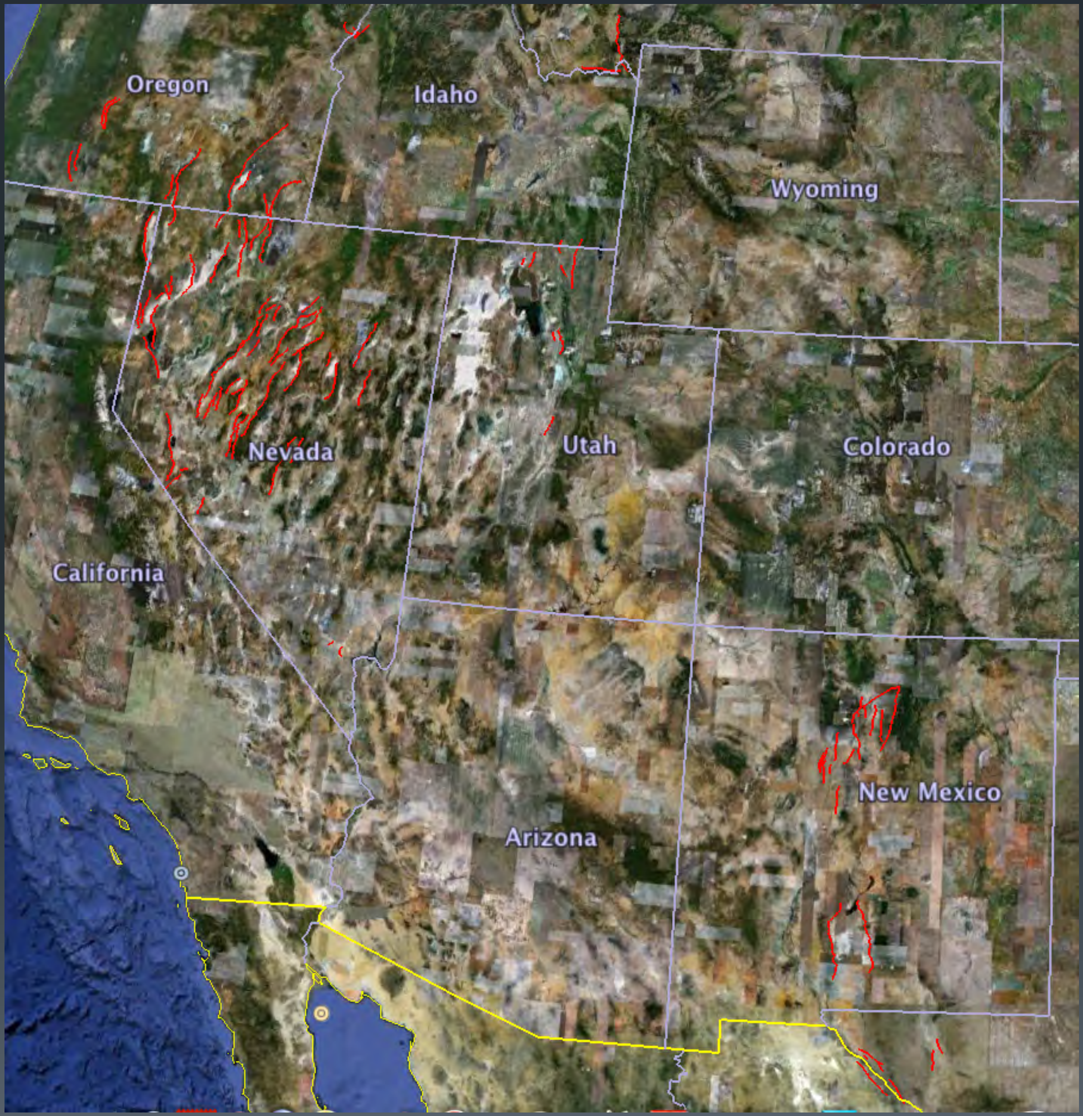
- Graben-bounding pairs are too close to avoid faults intersecting at depth
  - faults closer than 17 km will intersect if both dip 60°
  - faults closer than 25 km will intersect if both dip 50°
  - faults closer than 36 km will intersect if both dip 40°
- Both sources were projected below their intersection to a depth of 15 km in prior hazard maps
- Some source pairs that dip 40° in the 2008 model intersect at depths as shallow as 1.6 km

How we got here:



- Change in modeling assumptions in the 2008 maps to include dip uncertainty for normal faults increased the number of intersecting fault pairs (currently 52 pairs in NSHMs)

Intersecting pairs in 2008 model

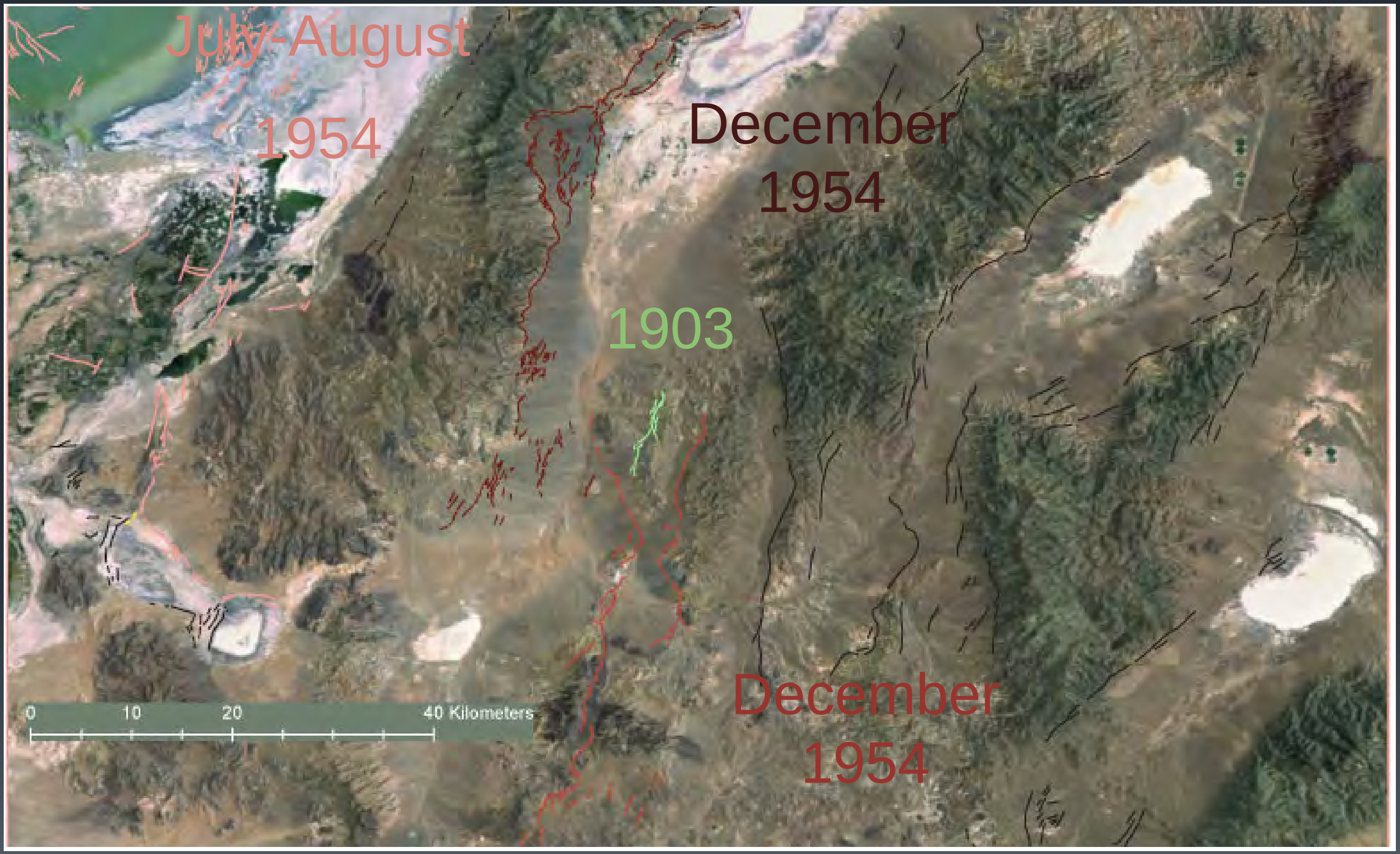


Key questions:

- Do graben-bounding fault pairs move together, separately, or both?
- Can we tell which fault is the master fault?
- Are some alternatives unviable--what is the minimum width for a fault to be considered capable of generating independent earthquakes?
- What method do we use to determine M on truncated faults?

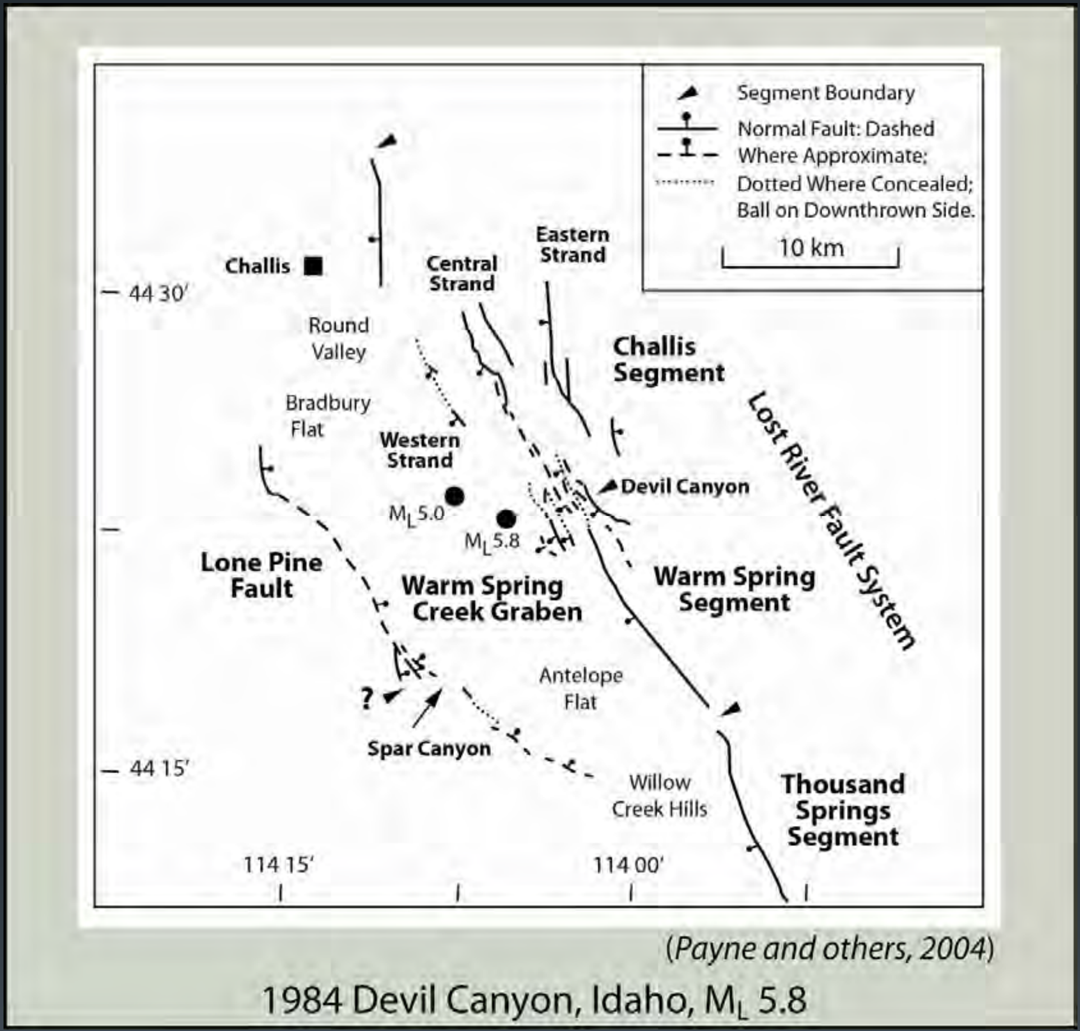
Historical Analogs for Antithetic Faulting in the Basin and Range

Central Nevada Seismic Zone (1903 and 1954)



Historical Analogs for Antithetic Faulting in the Basin and Range

Devil Canyon, Idaho (August 1984)



M 5.8 main shock considered a late aftershock of the M 7.3 Borah Peak earthquake (Oct. 1983)

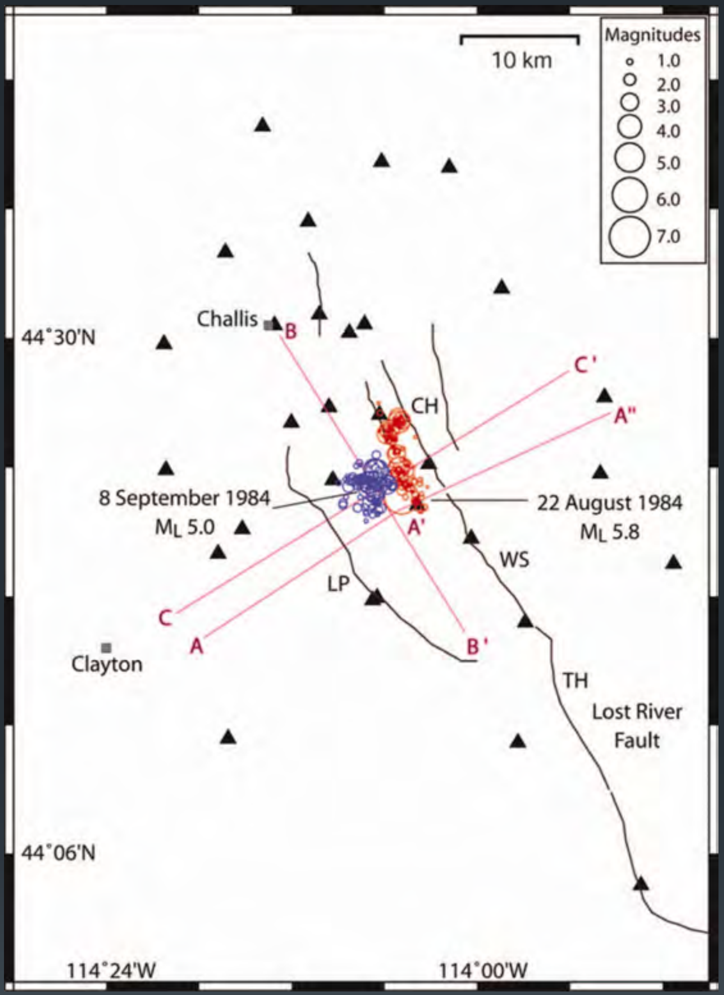
- Down-to-southwest normal slip on Challis segment of Lost River fault

M 5.0 aftershock occurred 17 days after the M 5.8 main shock

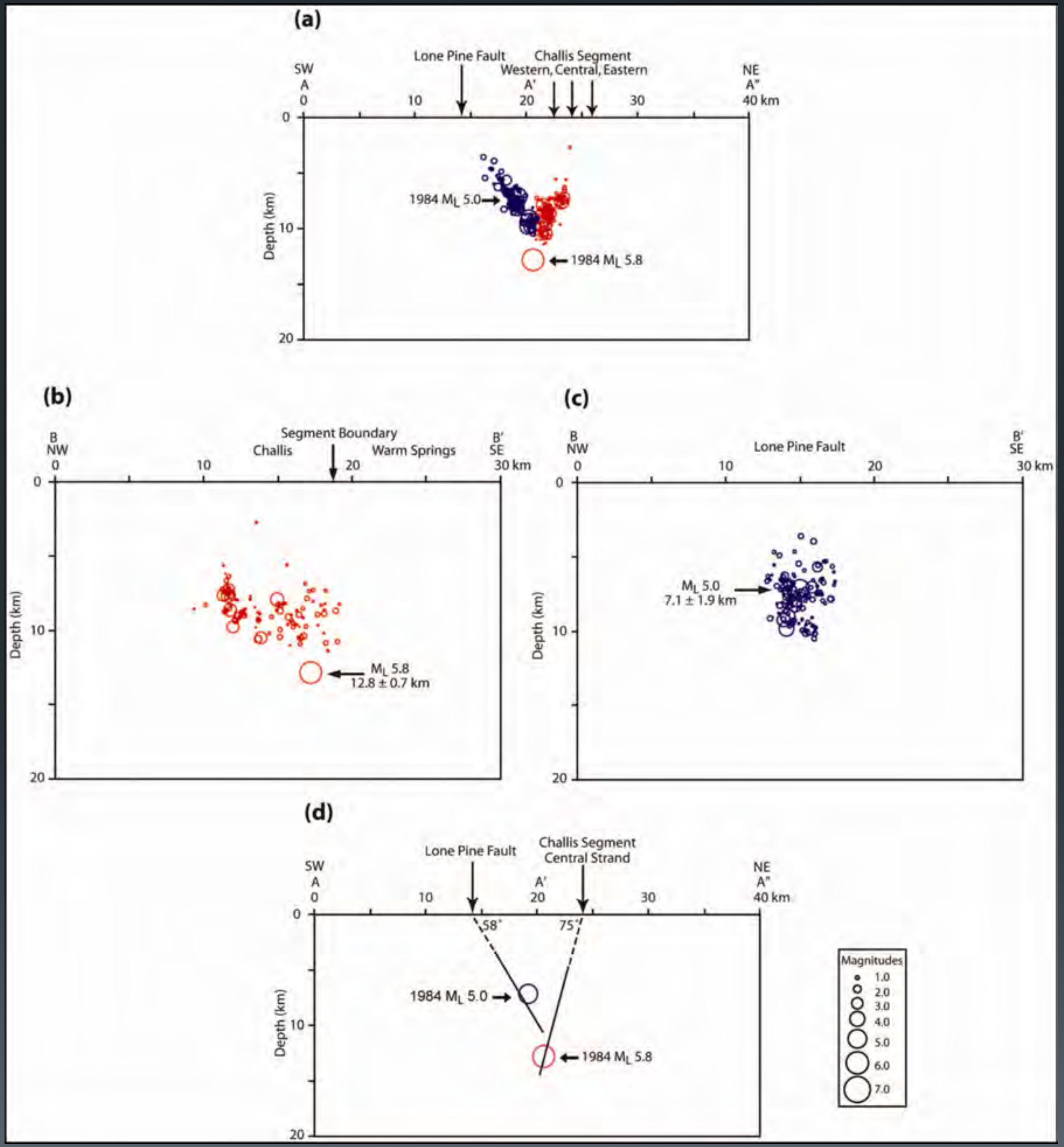
- Involved normal slip on antithetic Lone Pine fault

Historical Analogs for Antithetic Faulting in the Basin and Range

Devil Canyon, Idaho (August 1984)



(Payne and others, 2004)



(Payne and others, 2004)

Antithetic faulting considered triggered slip

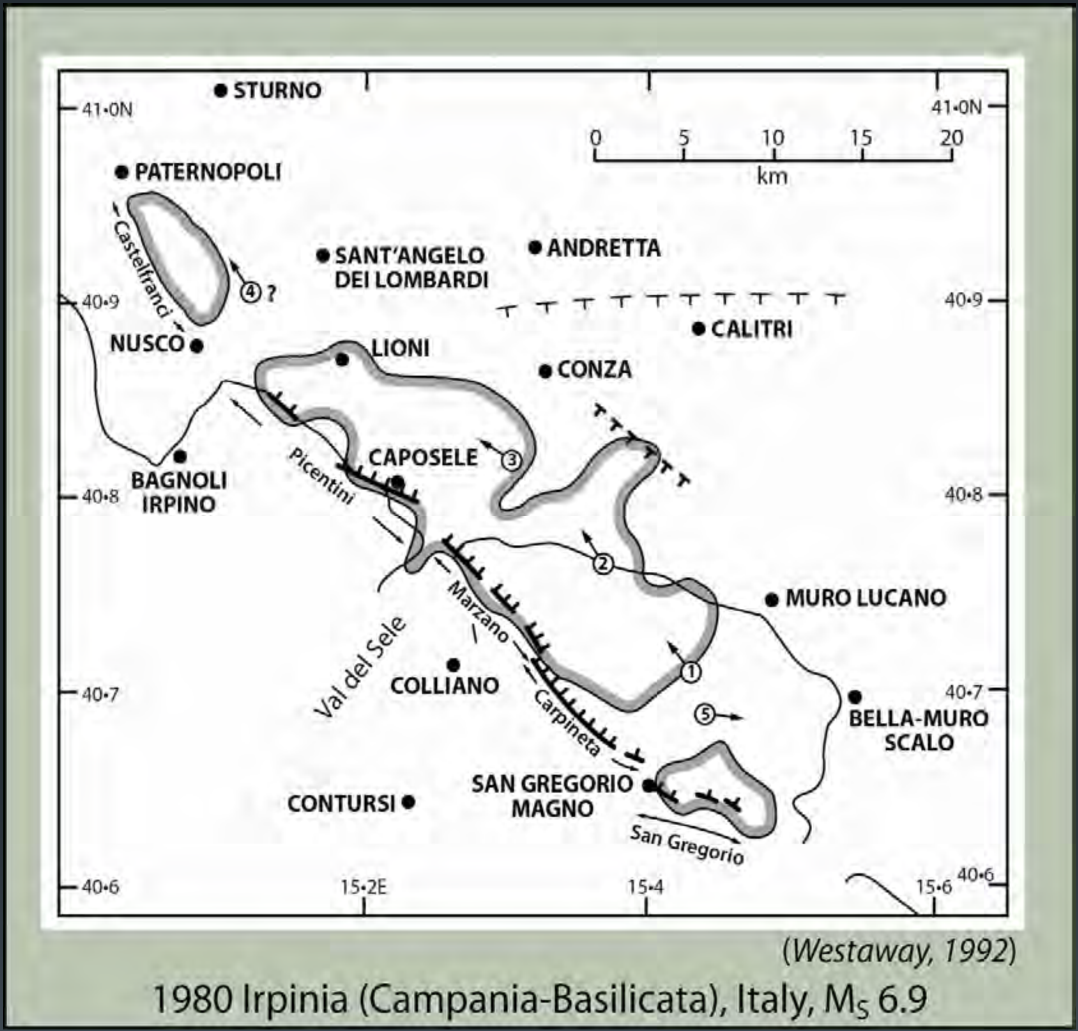
- separate earthquake with its own moment release

Antithetic slip restricted to Challis fault hanging wall

Small earthquake (M5), no surface rupture

Historical Analogs for Antithetic Faulting in the Basin and Range

Irpinia (Campania-Basilicata), Italy (November 1980)



(*Westaway, 1992*)

1980 Irpinia (Campania-Basilicata), Italy, M_S 6.9

M 6.9 earthquake comprising numerous sub-events

- Rupture initiated as down-to-northeast normal slip on Carpineta fault
- At ~40 s, normal slip occurred on antithetic intrabasin fault

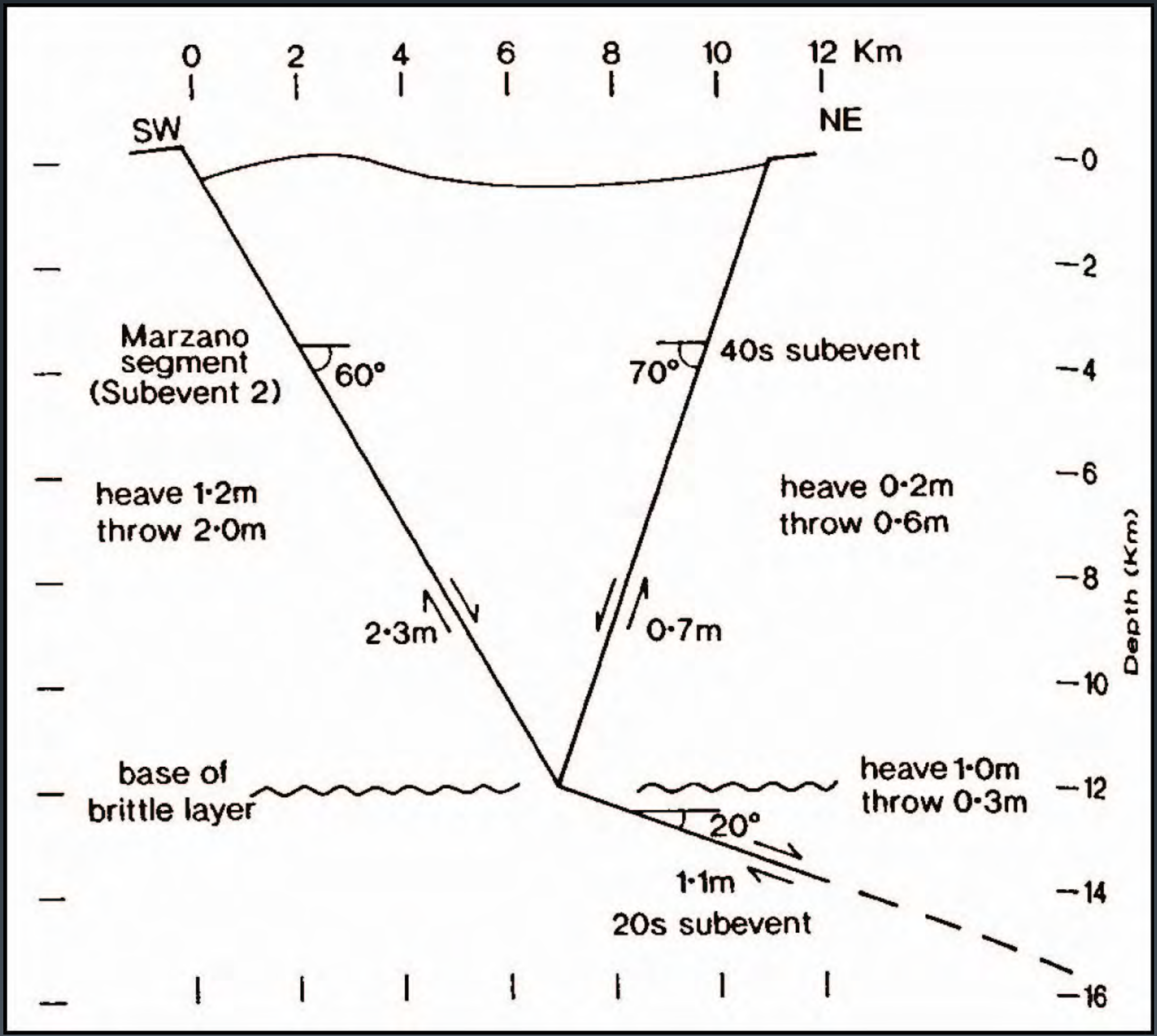
Historical Analogs for Antithetic Faulting in the Basin and Range

Irpinia (Campania-Basilicata), Italy (November 1980)

Antithetic faulting considered coseismic

- contributed moment (~12%) to the earthquake as a whole

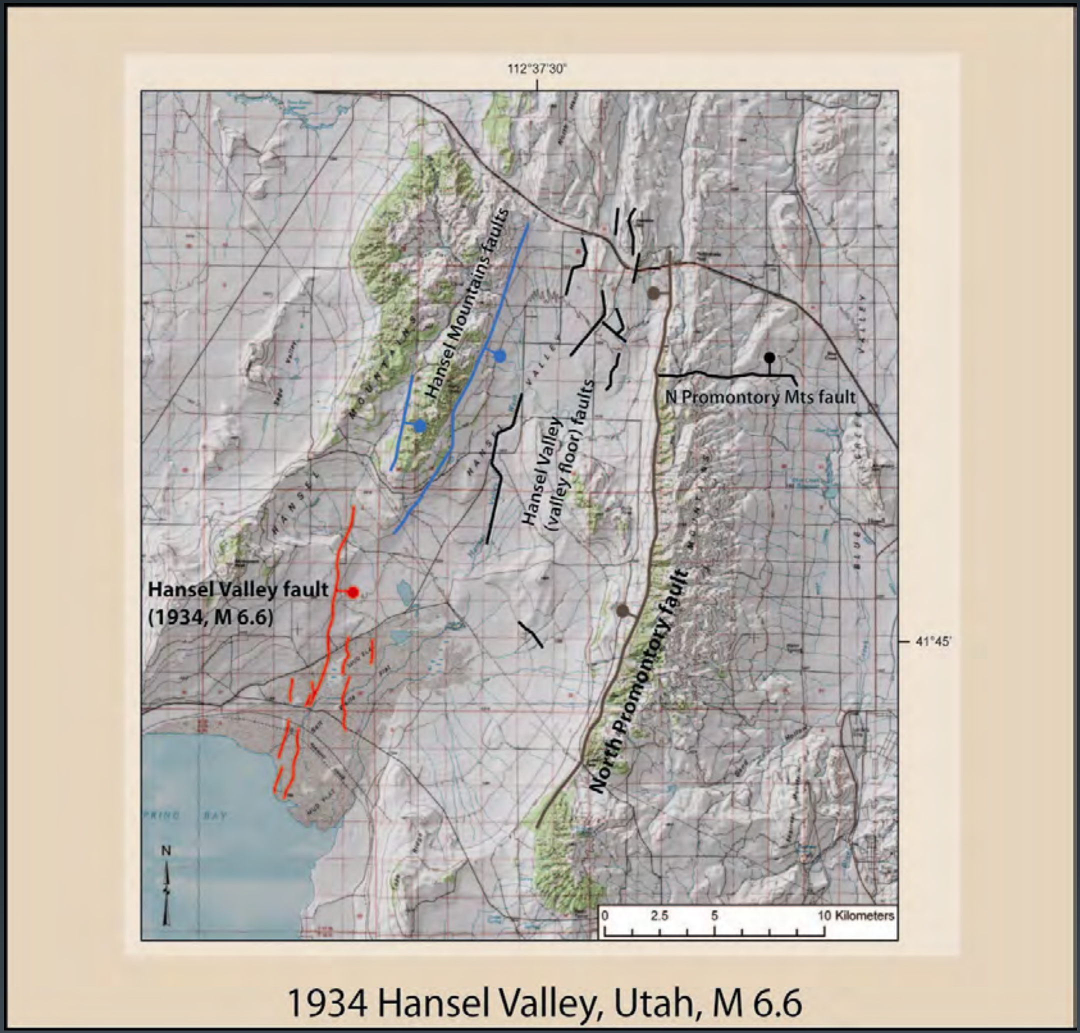
No surface rupture associated with antithetic faulting



(Westaway, 1992)

Historical Analogs for Antithetic Faulting in the Basin and Range

Hansel Valley, Utah (March 1934)



M 6.6 earthquake involving mostly down-to-east surface faulting (but strike-slip focal mechanism)

- No rupture documented along North Promontory fault, to which Hansel Valley fault is antithetic

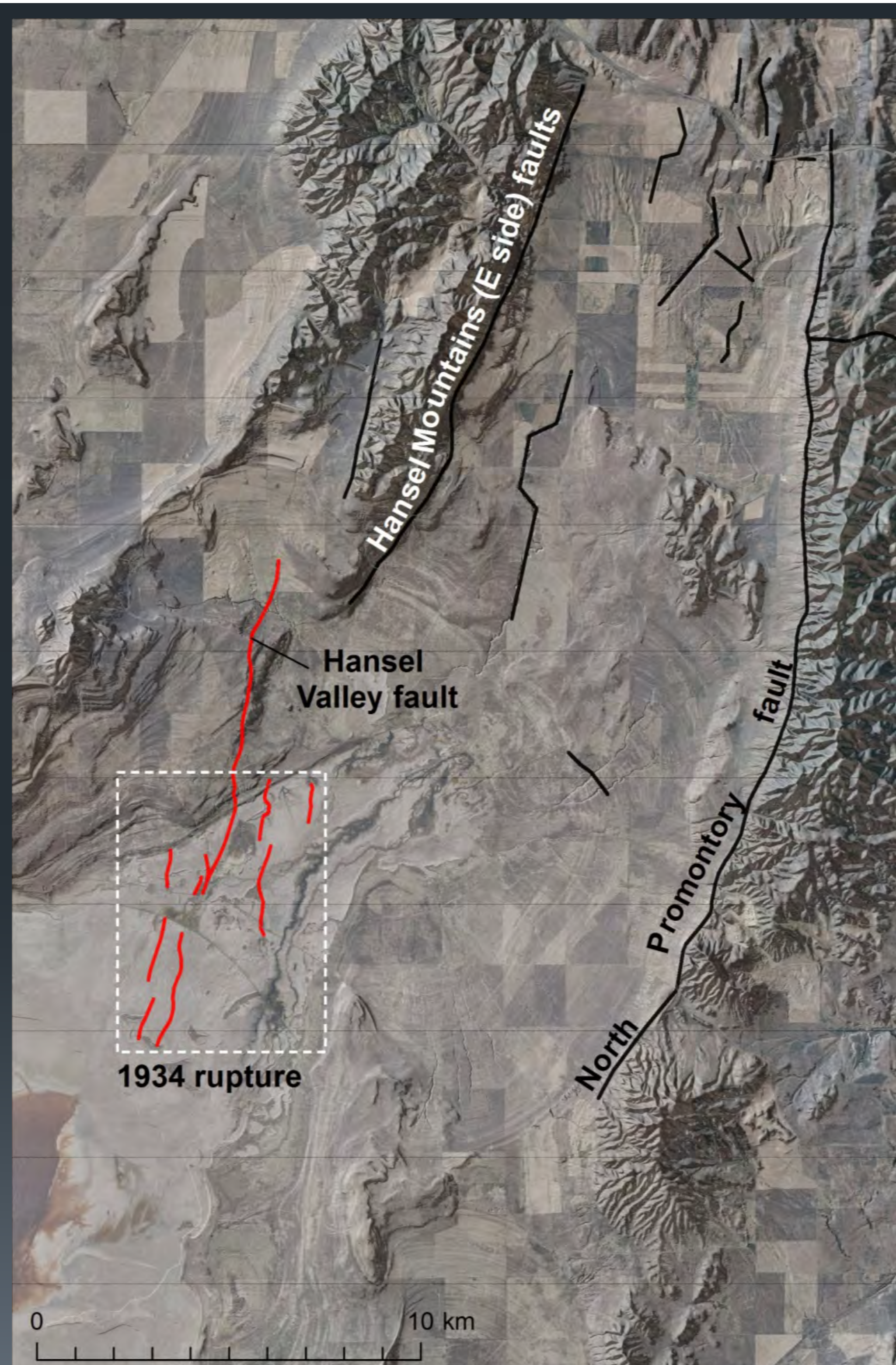
Antithetic faulting appears to have been independent

- Absence of movement of the main range-bounding fault

1934 M 6.6 Hansel Valley Earthquake: Analog for Antithetic Fault Rupture?

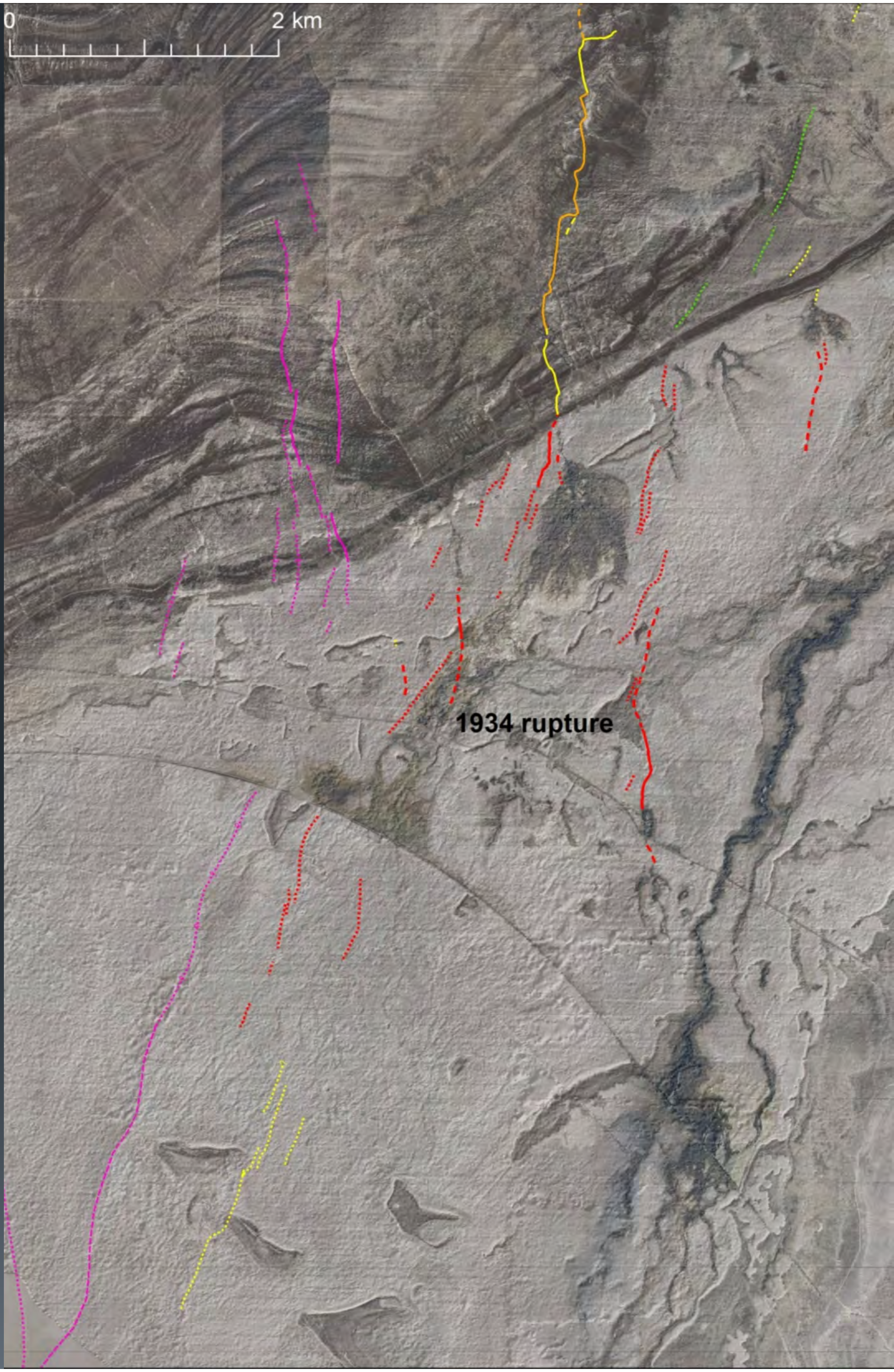
Chris DuRoss
Mike Hylland

BRPEWGII Meeting
November 2011



Geologic Observations

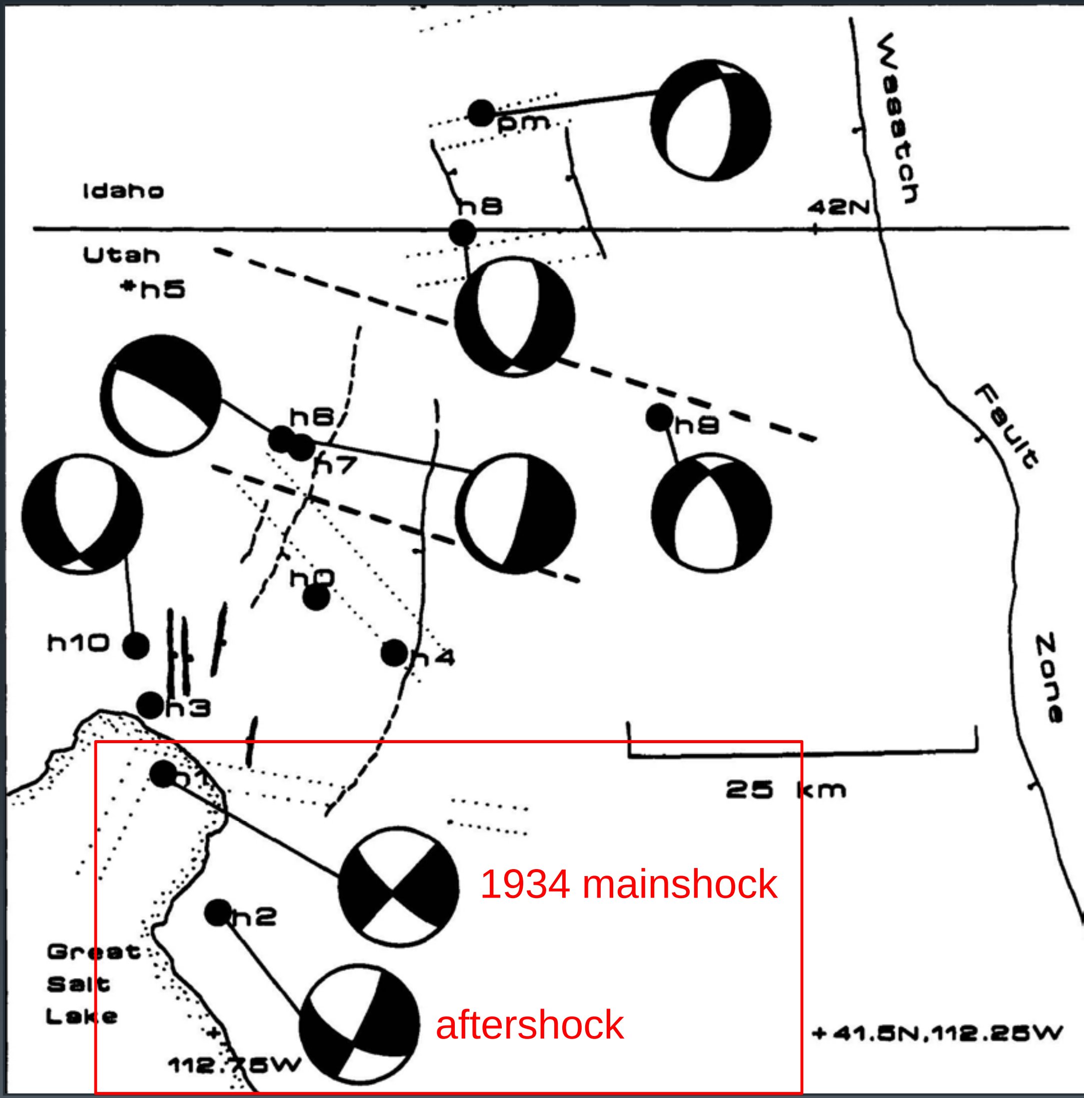
- 5–8-km-long, NE-oriented zone of ground cracks and minor surface faulting
- Down-to-the-east scarps related to 1934 earthquake
  - Maximum vertical displacement: ~50 cm, mostly down to the east
  - Maximum strike-slip displacement: ~25 cm (poorly documented)
- No reports of rupture along prehistoric rupture to the north, which has evidence of larger displacements (1+ m)



0
2 km
1934 rupture

Seismologic Observations

- Left-lateral strike-slip on near-vertical, NE oriented fault
- Rupture length: ~11 km using rupture time and velocity; NE propagation?
- Average horizontal slip: 2.3 m using seismic moment (M_0 = rigidity*area*slip)
- Average vertical slip: 20–25 cm using focal mechanism



Doser (1989)

Other puzzle pieces

- Bathymetry and shoreline data (1850–1934):
  - 1-m increase in water depth, no change to south
  - ~2-m decrease in relative shoreline elevation
- Re-leveling of railroad grade (after 1934)
  - ~0.3–0.4 m of subsidence east of rupture.

Other puzzle pieces

- 1909 M ~6 Hansel Valley earthquake
  - No report of surface rupture, but newspaper report of waves passing over 3.5-m high railroad trestle
  - A: Bathymetry & shoreline data (1850–1934) could include displacement from this event
  - B: Linear shoreline south of 1934 rupture (and epicenter) suggests down-to-the-west faulting.
  - C: Lineaments and down-to-the-west scarps east of 1934 rupture related to 1909 earthquake?

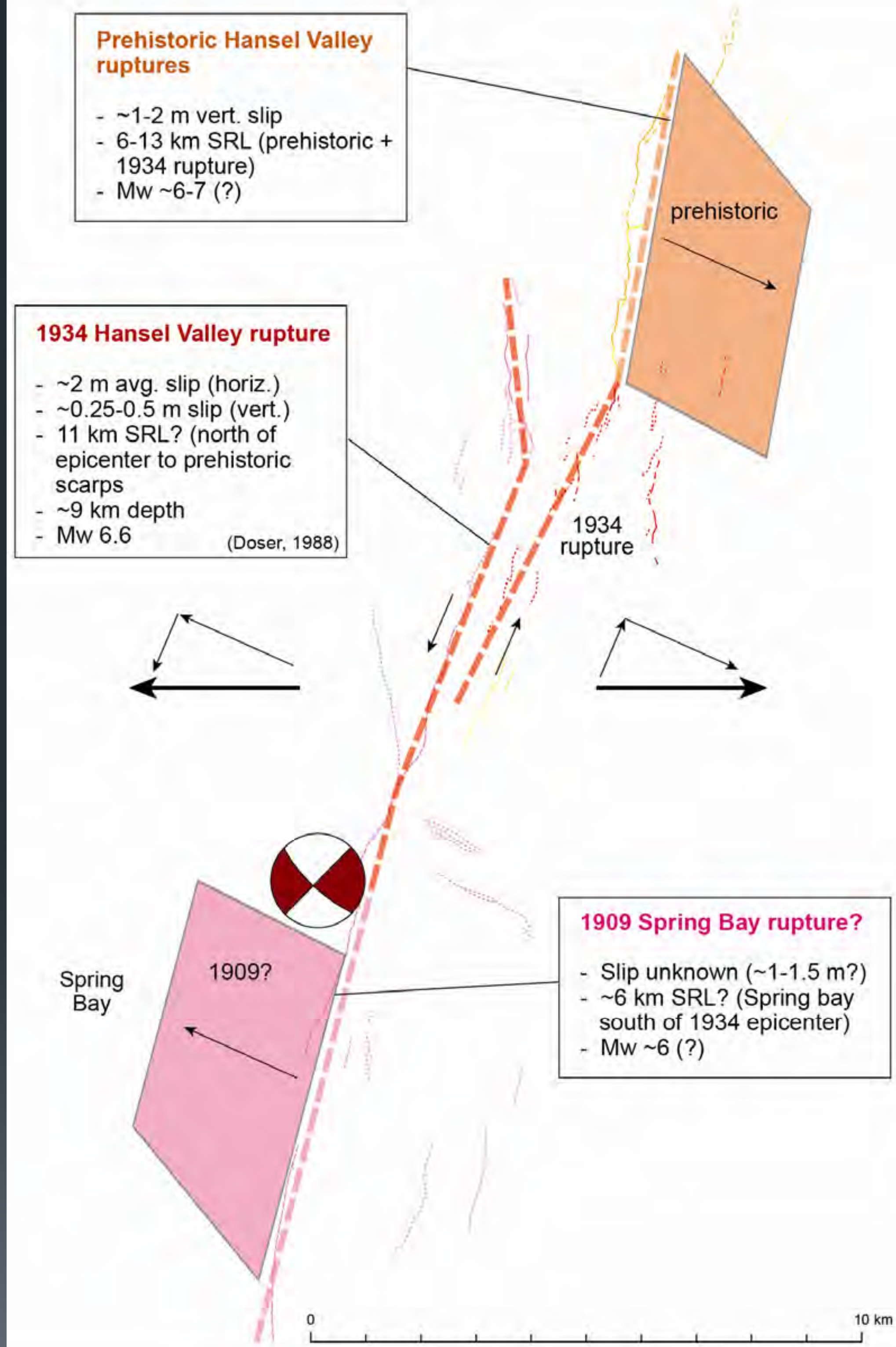
Remaining Questions

- Was the1934 M 6.6 earthquake a normal or strike slip event?
  - Normal surface rupture (~5–8-km L, 0.5 m vertical D)
  - Strike-slip focal mechanism (~11-km L, ~2 m horizontal D)
- Did the 1934 event occur as a strike slip event, only initiating normal faulting (or non-tectonic slip?) near the northern end of the rupture?
- How does the 1909 M~6 earthquake fit in? Did this event rupture faults in Spring Bay?

Speculation…

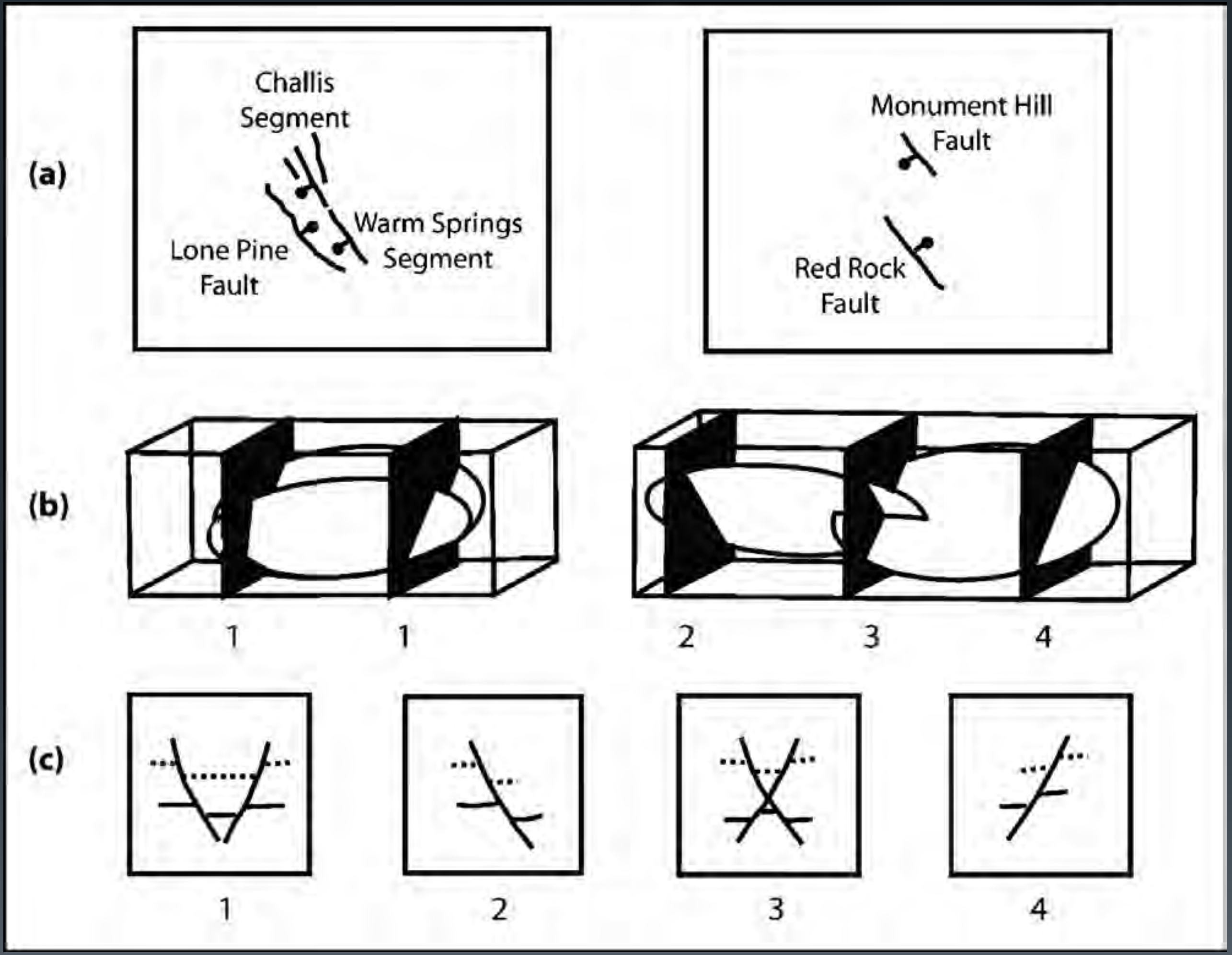
- <u>Possible kinematic model</u>: the 1934 earthquake was a dominantly strike-slip event that released strain accumulated between two normal faults.

- <u>Bottom line</u>: The 1934 earthquake has too many remaining questions to be a well-behaved poster child for antithetic-fault rupture.



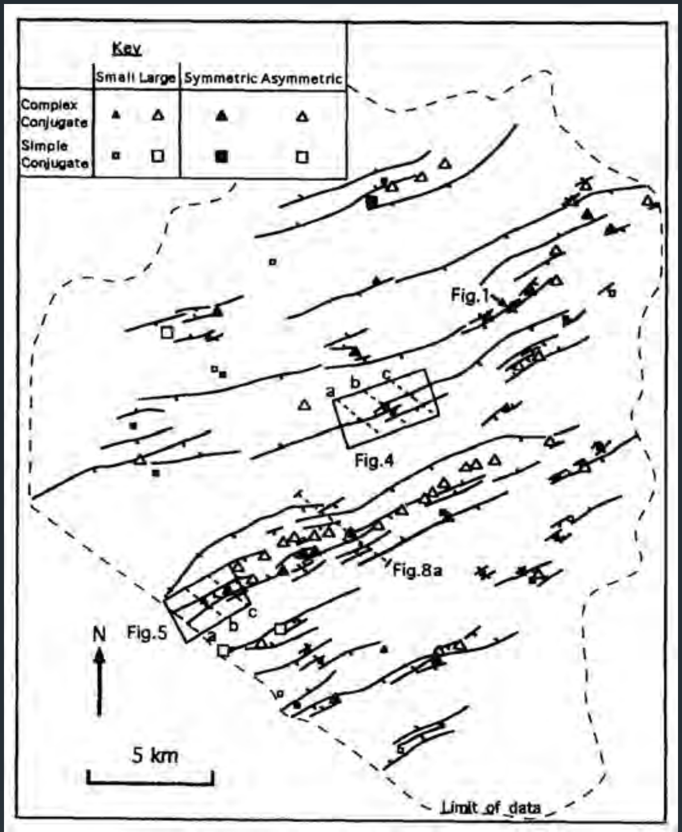
Conjugate Normal Fault Systems
Insights from 2D, 3D Modeling and Lab Experiments

How is strain accommodated on conjugate normal fault systems, particularly near fault terminations and in overlap zones?



(Payne and others, 2004, after Nicol and others, 1995)

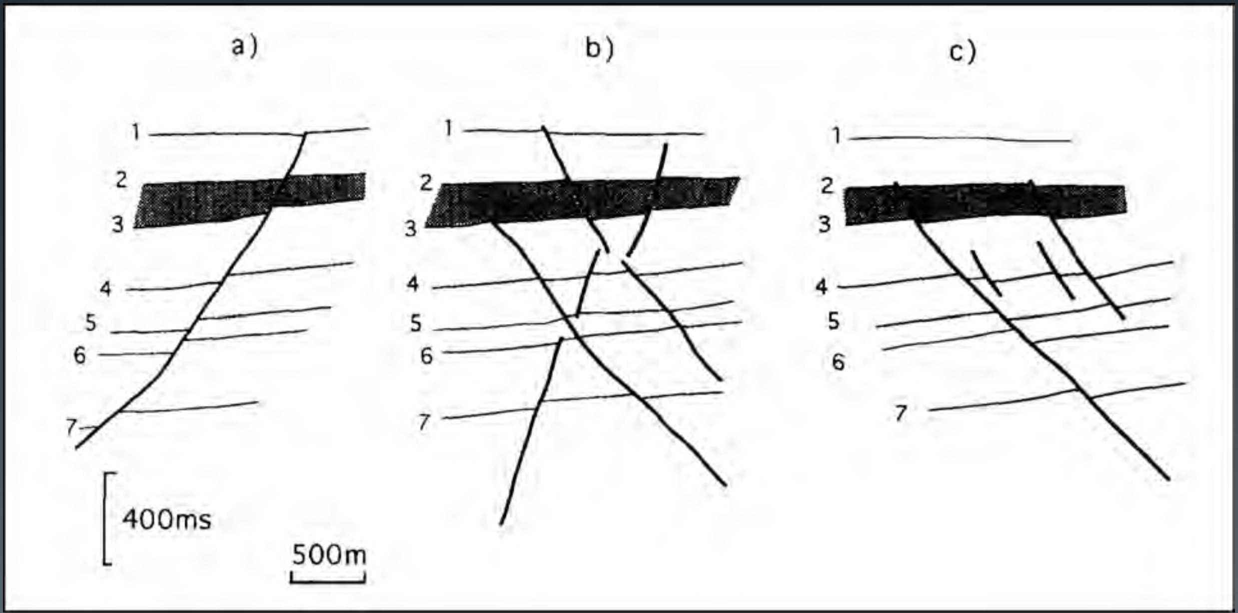
Conjugate Normal Fault Systems
Insights from 2D, 3D Modeling and Lab Experiments



(Nicol and others, 1995)

Example: Timor Sea

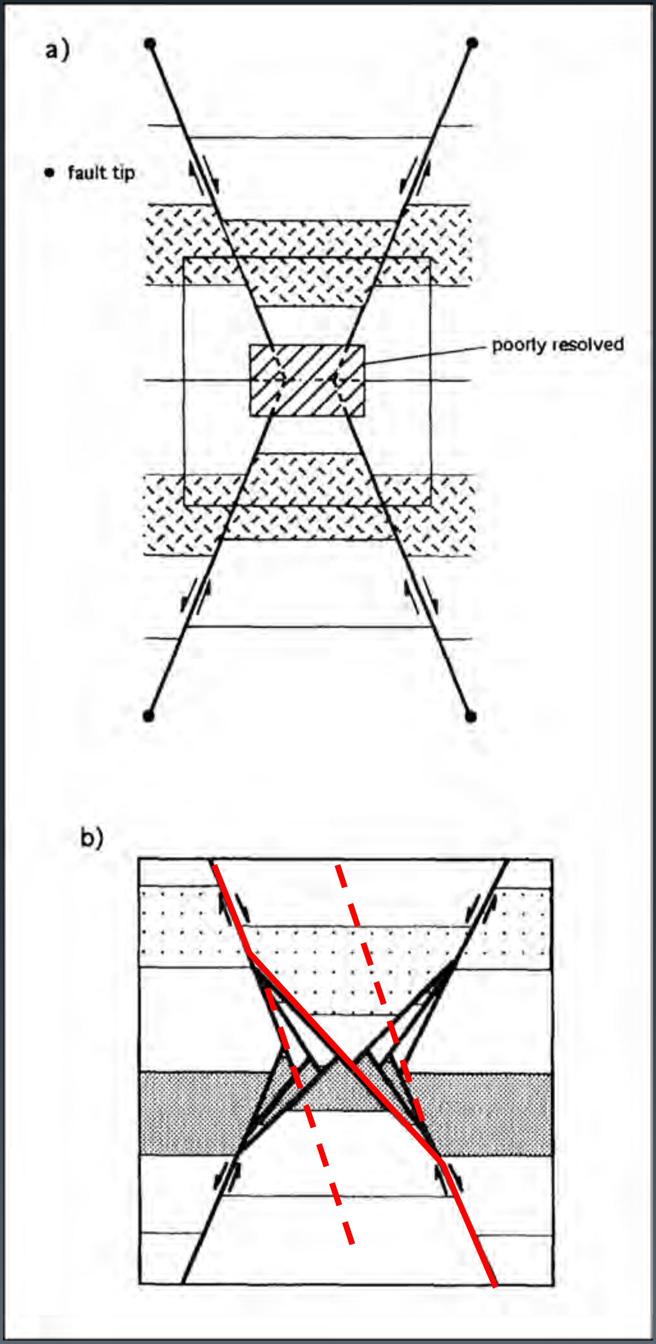
- Normal faults, up to 10s of kilometers long, throws up to 400 m
- Crossing conjugate normal faults imaged by 2D, 3D seismic reflection in upper 3.5 km of crust
- Faults accommodate extension associated with subduction of Australian plate
- Many larger faults originated by reactivation and upward propagation of Late Jurassic normal faults



(Nicol and others, 1995)

Conjugate Normal Fault Systems

Insights from 2D, 3D Modeling and Lab Experiments



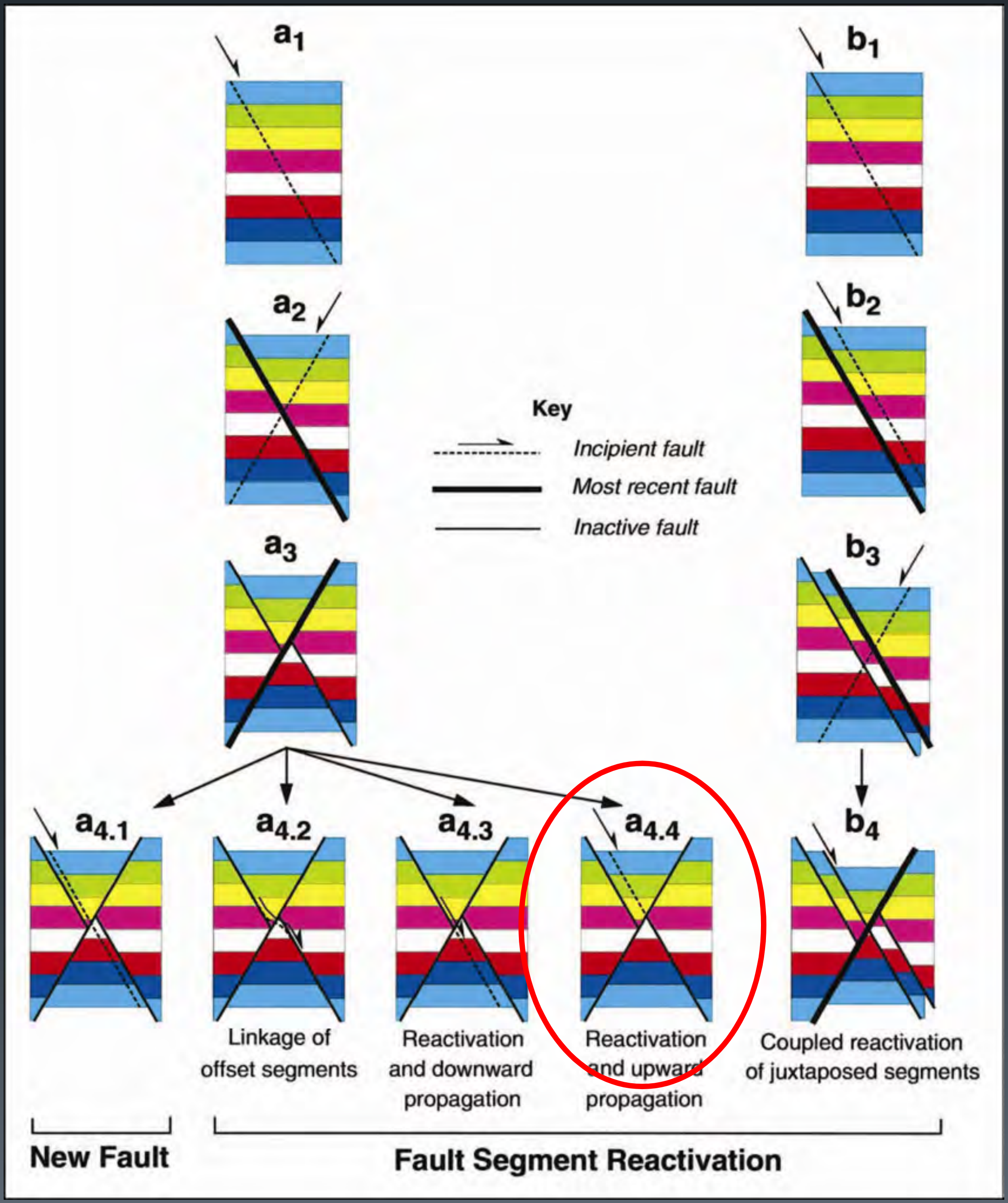
(Nicol and others, 1995)

Kinematic Model (Nicol and others, 1995, after Horsfield, 1980)

- Inter-fault volumes undergo significant ductile strain
- "Ductile" is scale-dependent term
  - "Concept of brittle deformation (rigid blocks translated along faults) is valid only for the microscopic scale"
- In intersection zone, cumulative displacement is distributed among numerous individual slip surfaces; new surface generated in each slip event
- Radius of curvature of bends in fault surface is limiting factor; i.e., eventually new fault will form
- Slip on main faults considered simultaneous (on geologic time scale)

Conjugate Normal Fault Systems

Insights from 2D, 3D Modeling and Lab Experiments

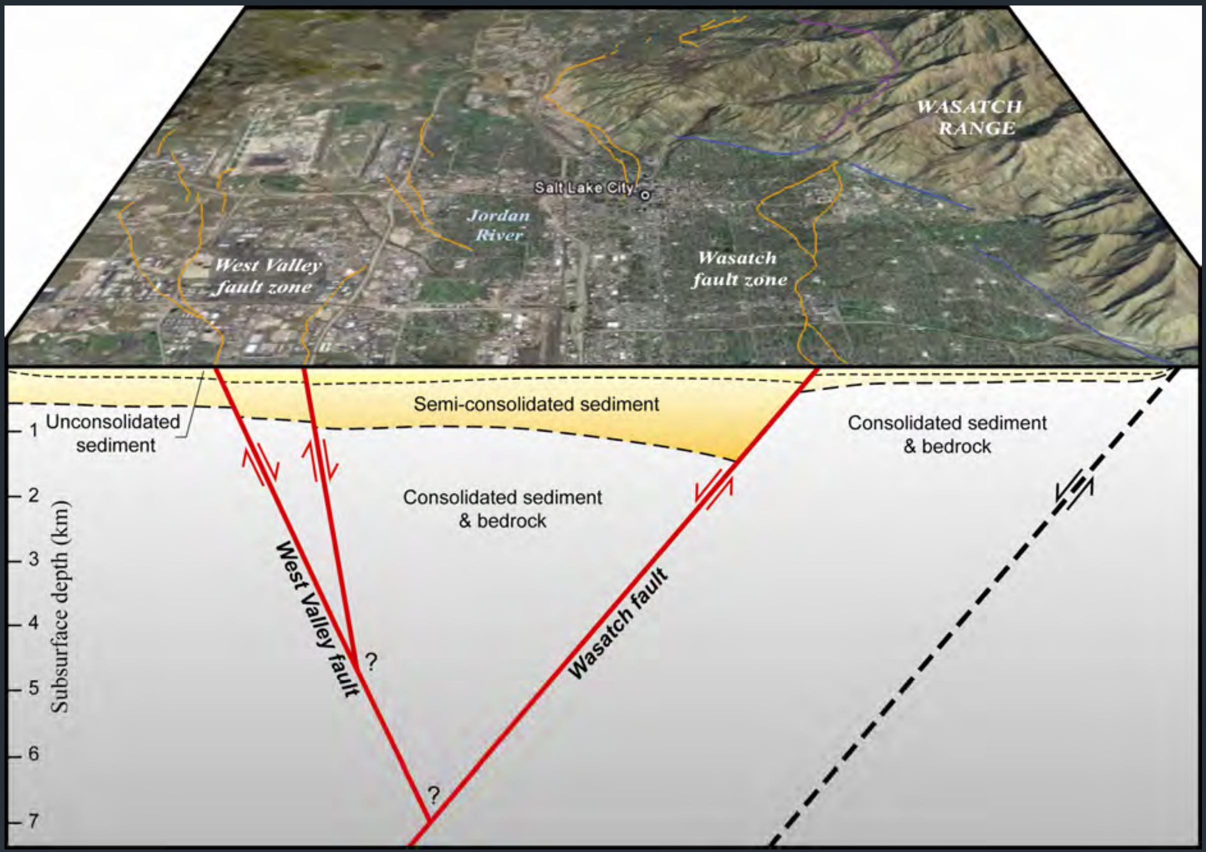


(Ferrill and others, 2000)

2D Modeling of Ferrill and others (2000)

- Simultaneous movement of conjugate fault pairs requires volume change in intersection area
- Alternating sequential movement is preferred model
- Several outcrop-scale examples provided

Conjugate Normal Fault Systems
Insights from 2D, 3D Modeling and Lab Experiments

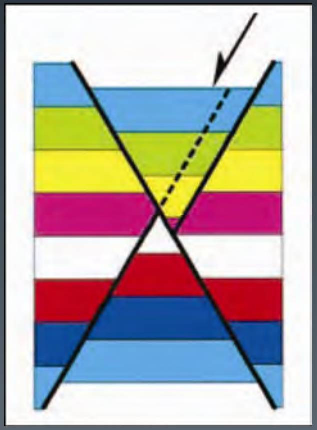


West Valley Fault Zone – Salt Lake City Segment

Crossing conjugate normal faults, or listric master fault (with splays) and truncated antithetic fault in hanging wall?

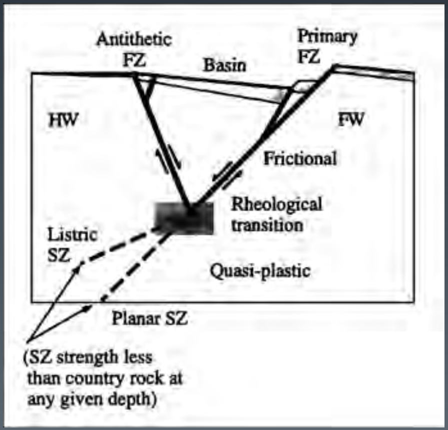
Pertinent questions:

- Fault dip
- Depth to intersection zone
- Horizontal separation of fault traces vs. vertical offset of faults
- Reactivation of pre-existing structure
- Map patterns of fault traces



(Ferrill and others, 2000)

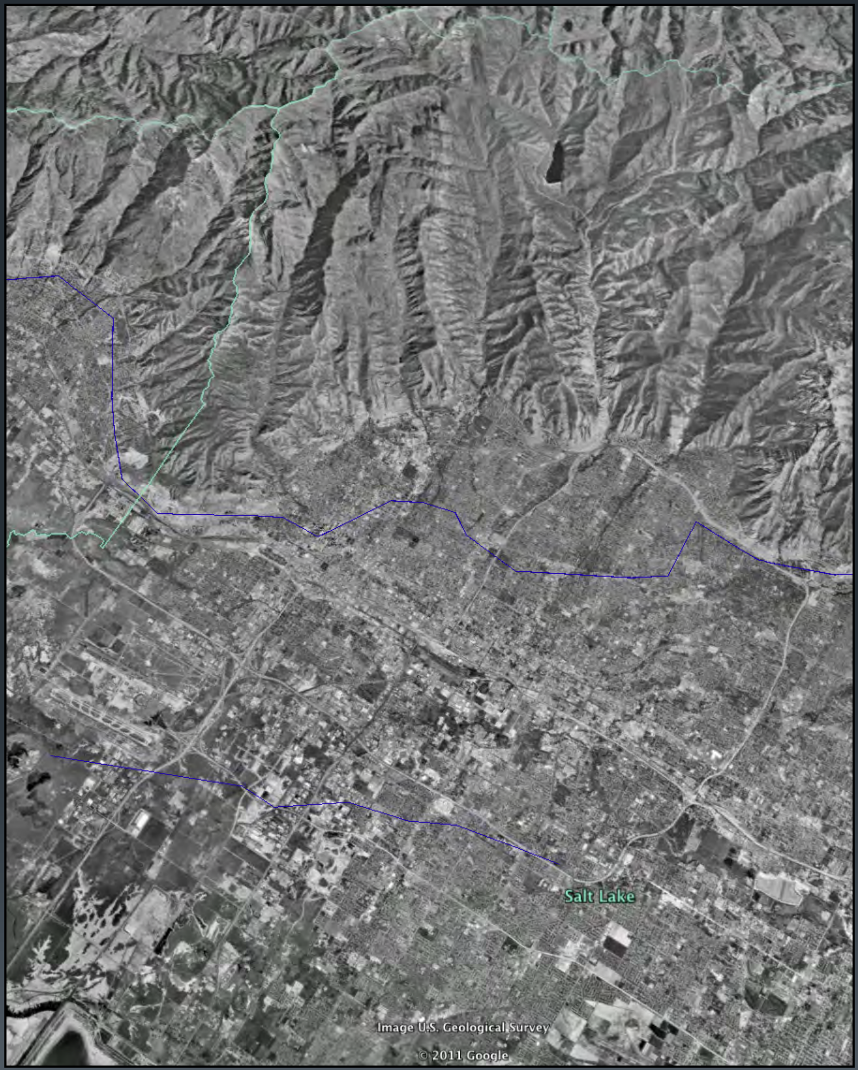
Or?



(Bruhn and Schultz, 1996)

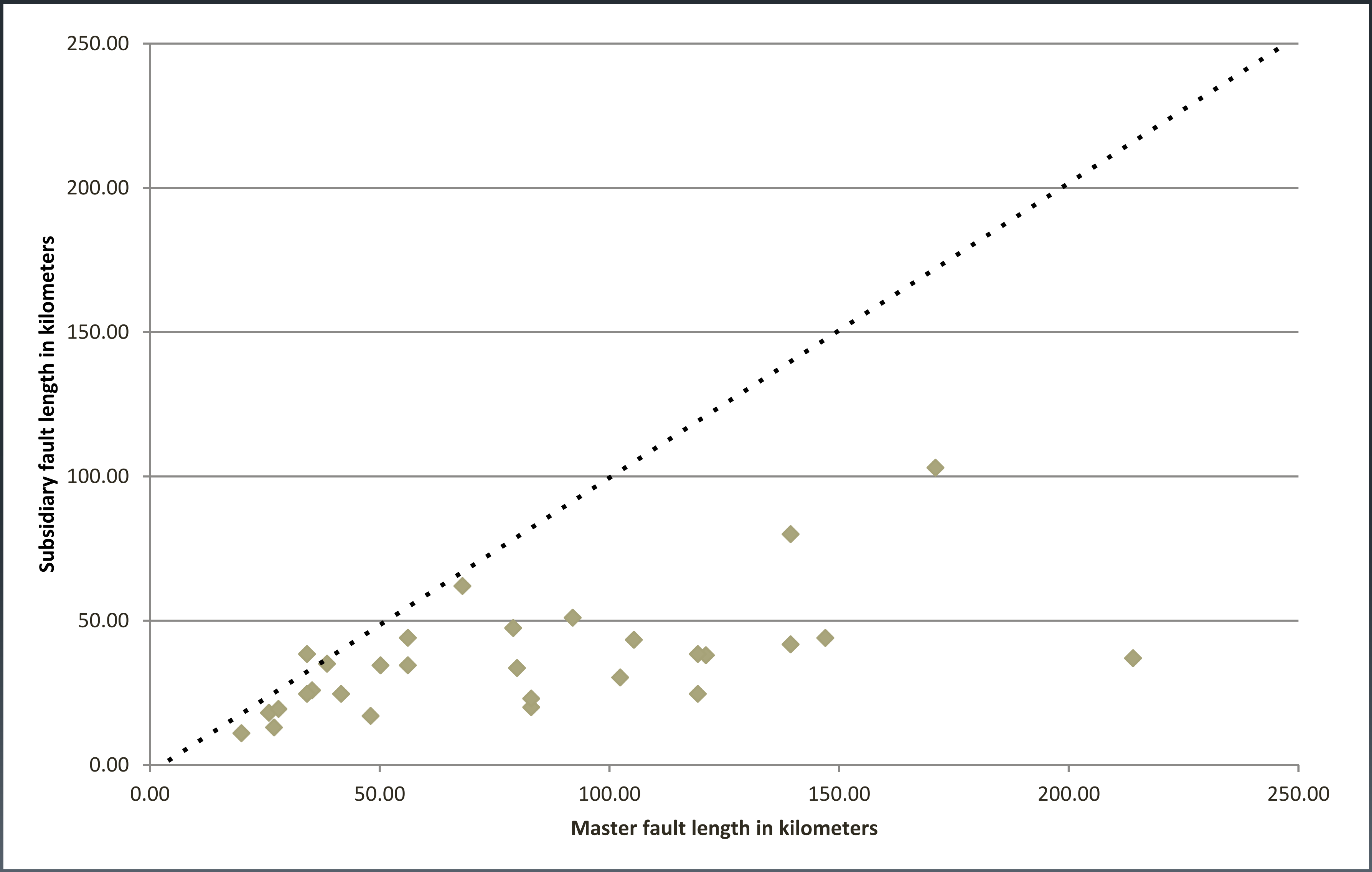
Metrics to differentiate master and subsidiary faults

- Fault length
- Percent of along-strike overlap
- Topographic relief
- Short-term slip rate based on paleoseismology is not always diagnostic

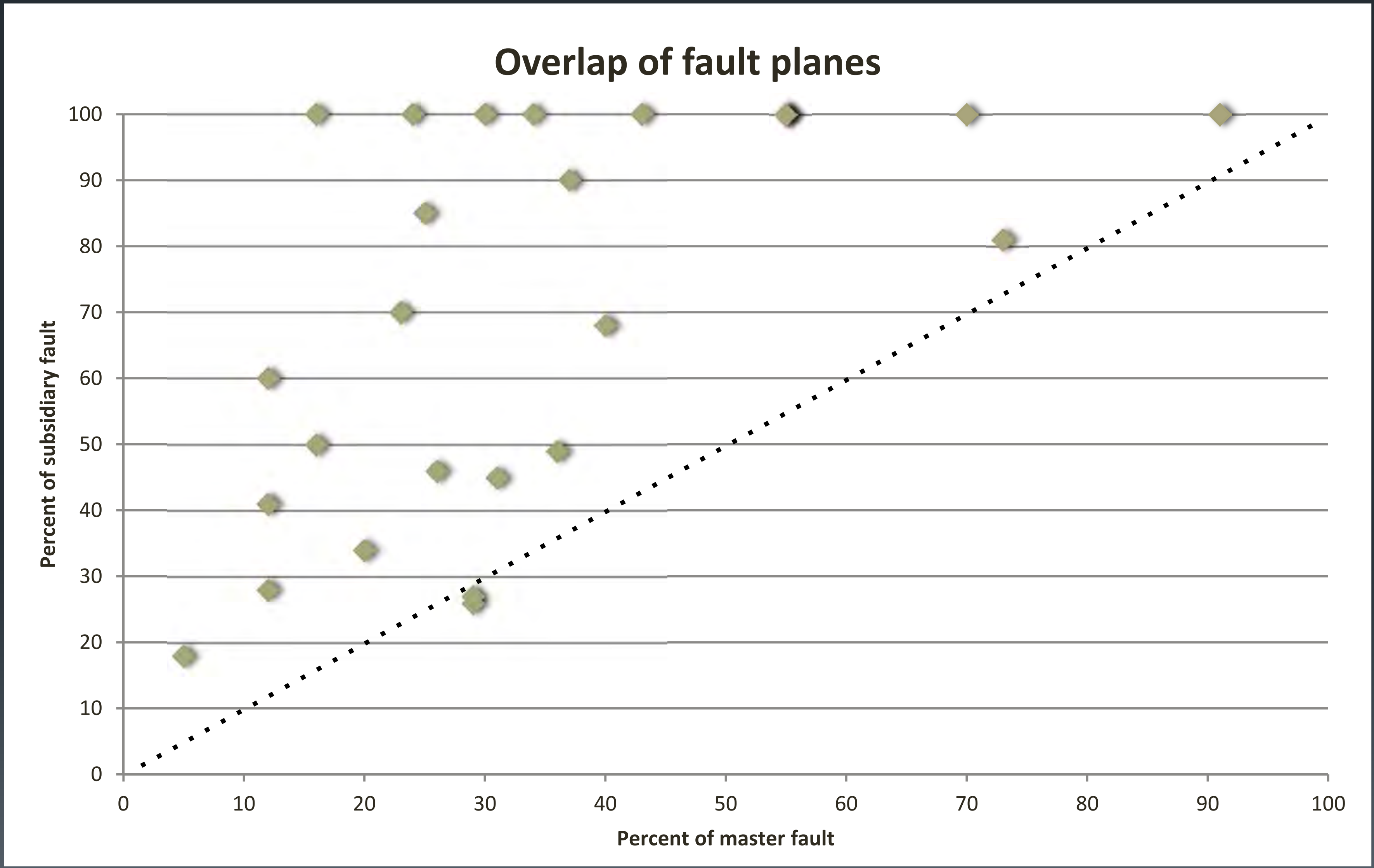


SLC segment of the Wasatch and West Valley sources

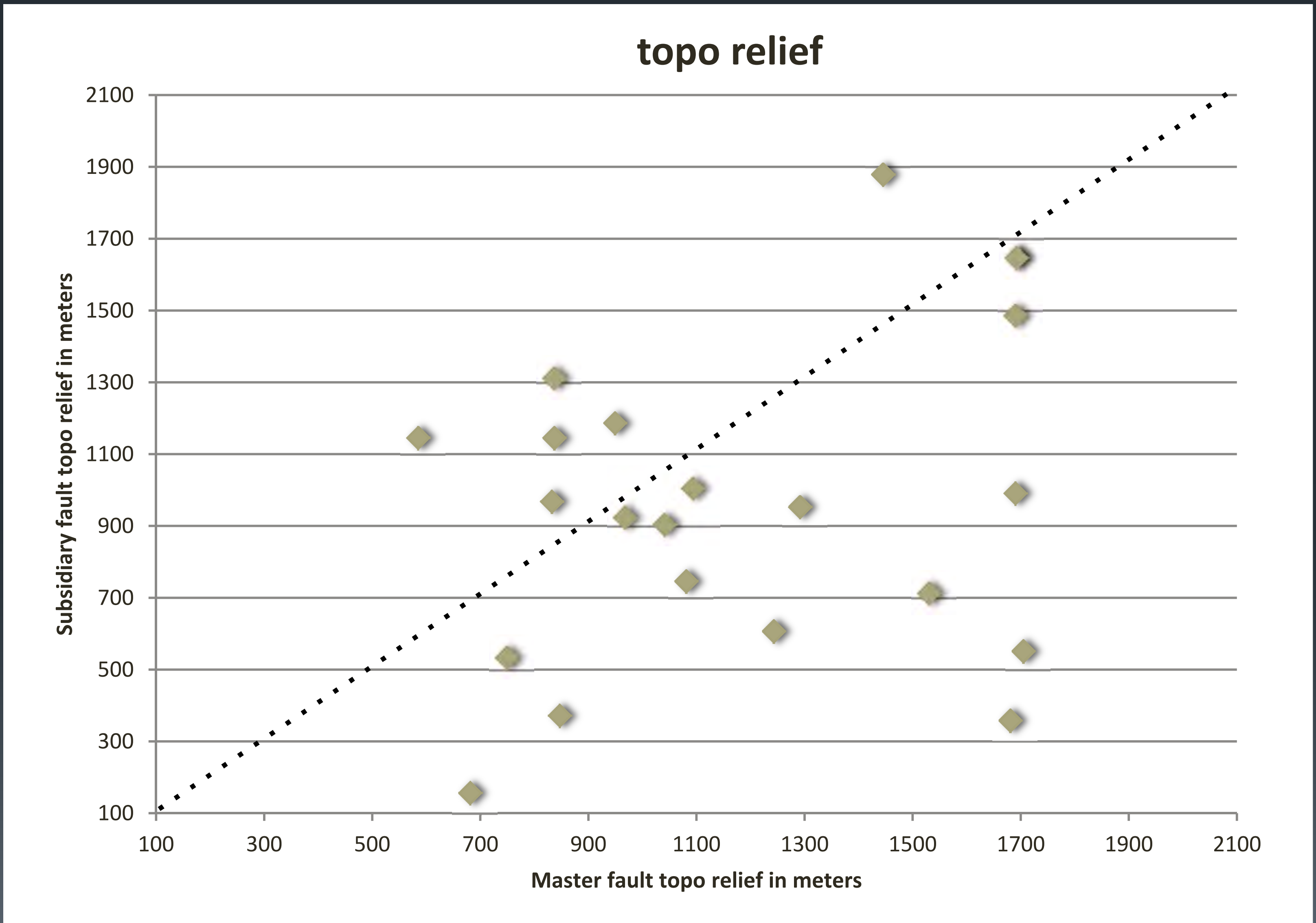
Fault length



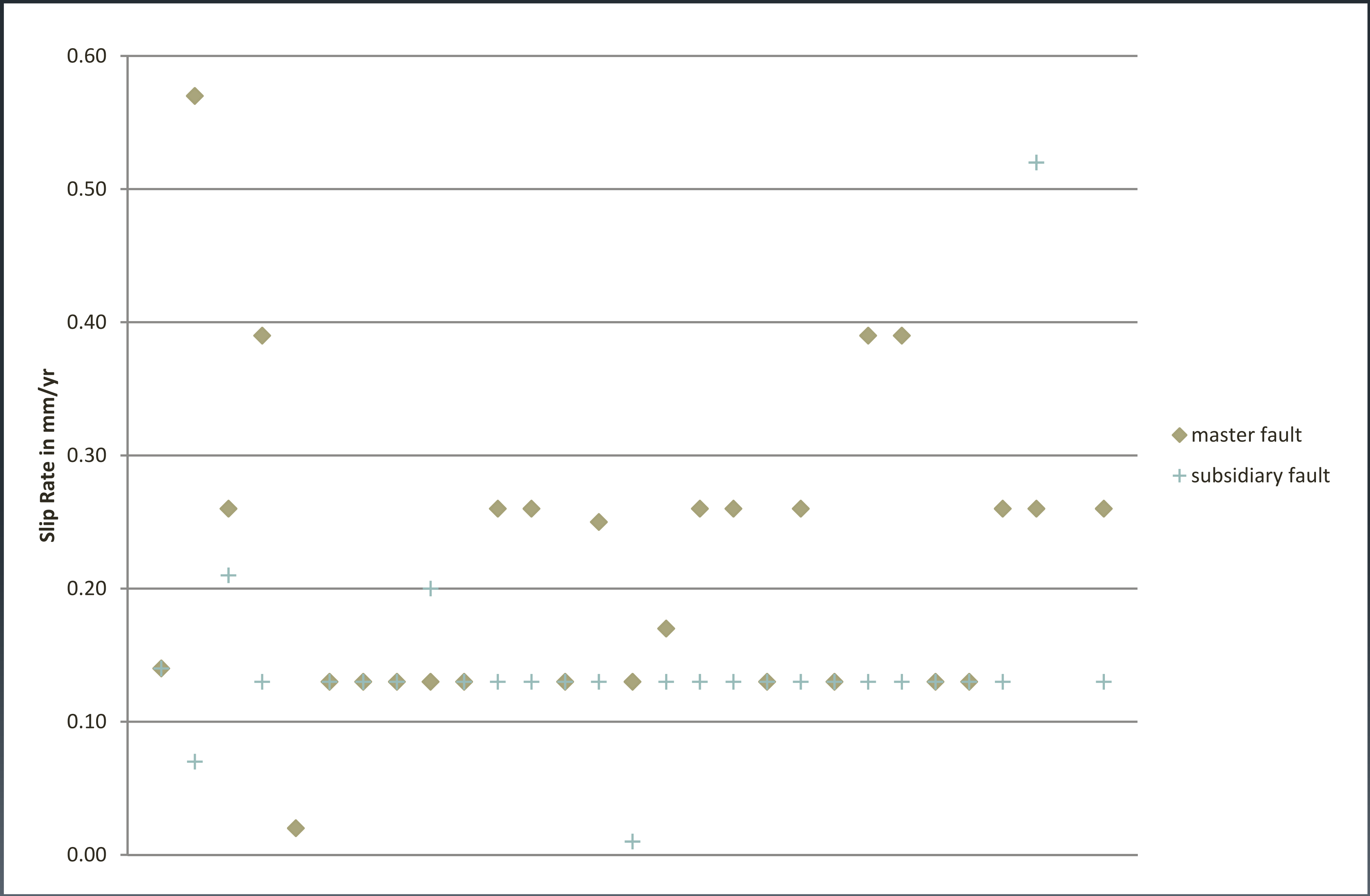
Overlap of fault planes



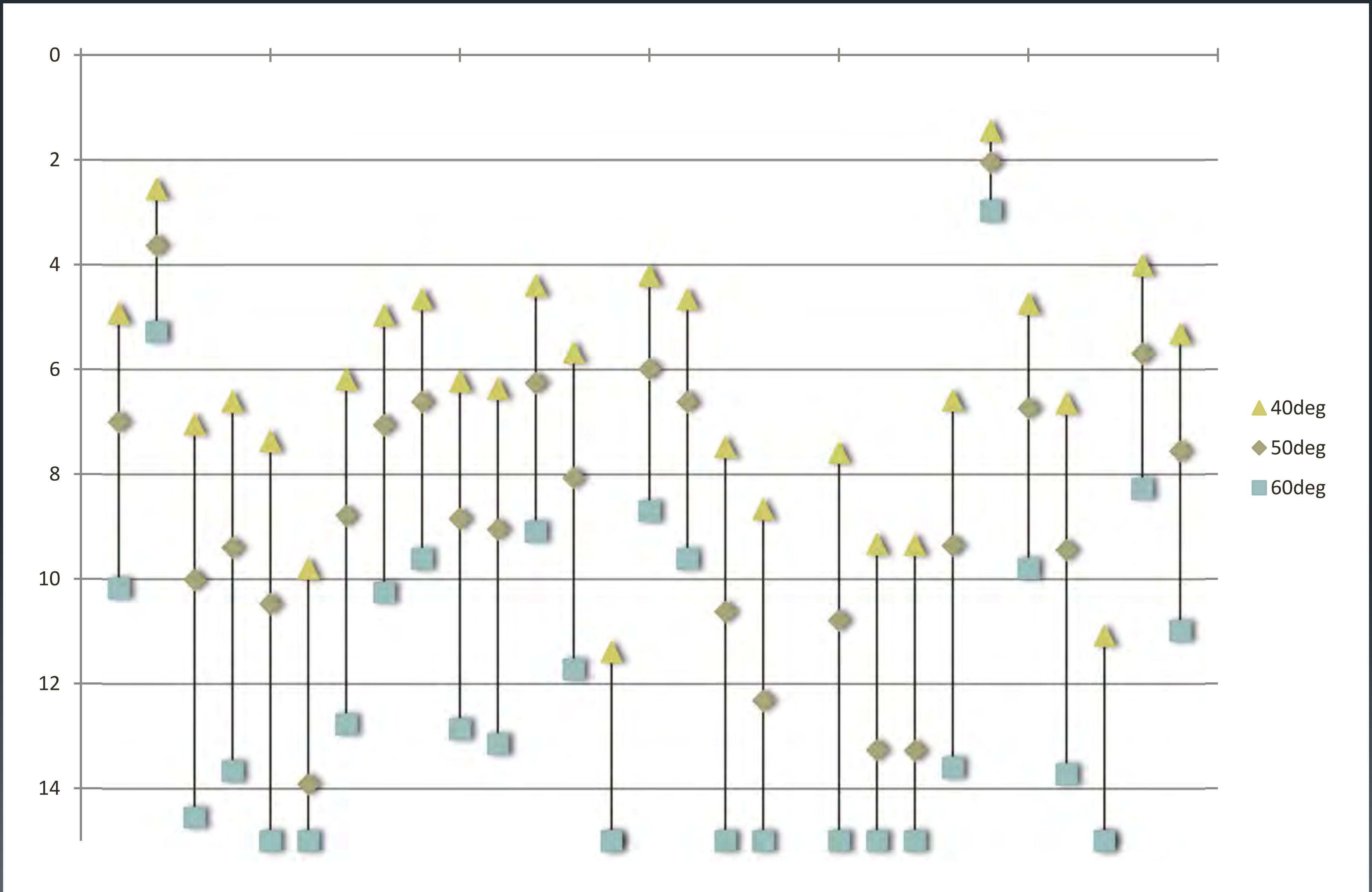
Topographic relief



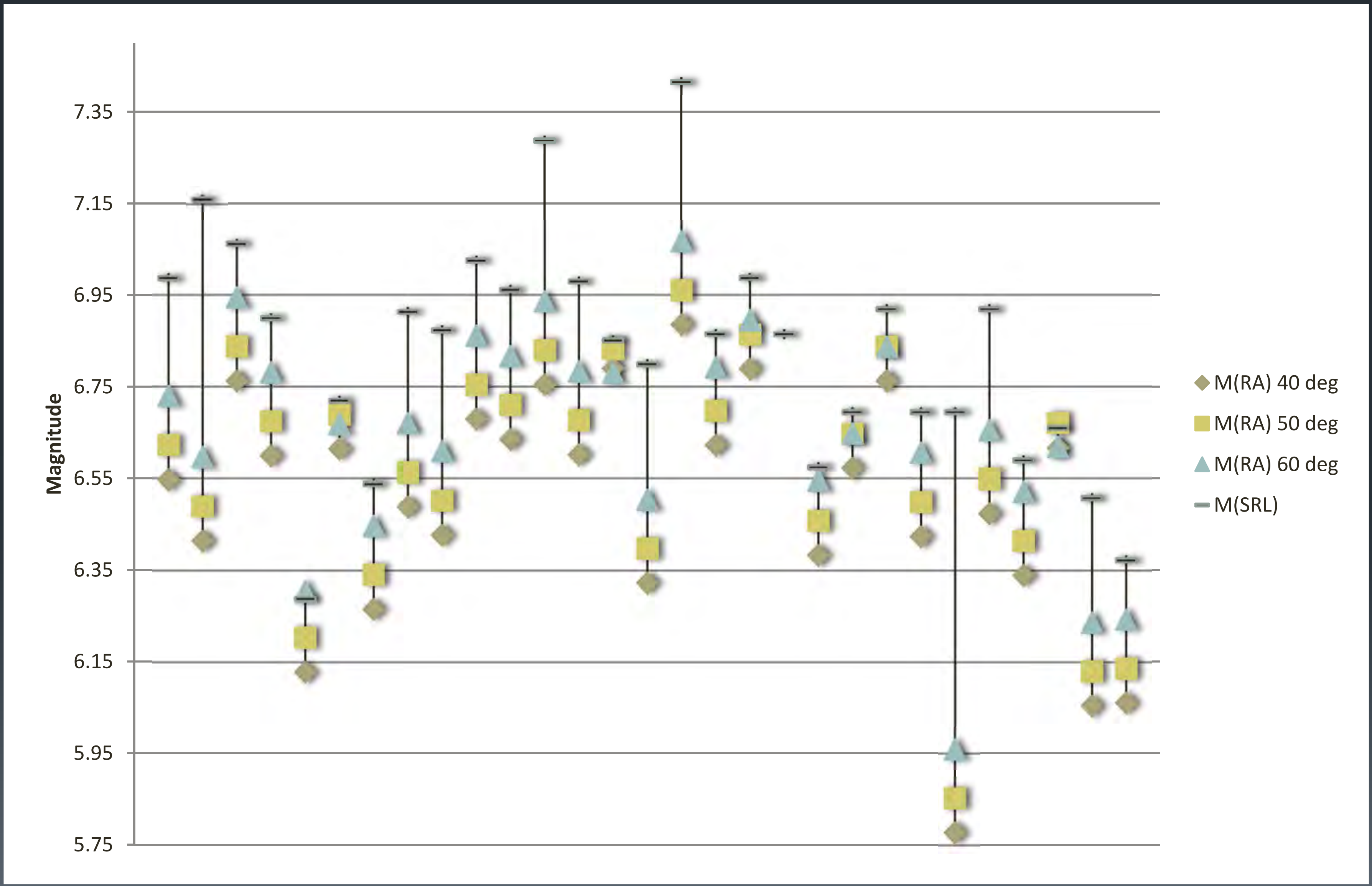
Assigned slip rate



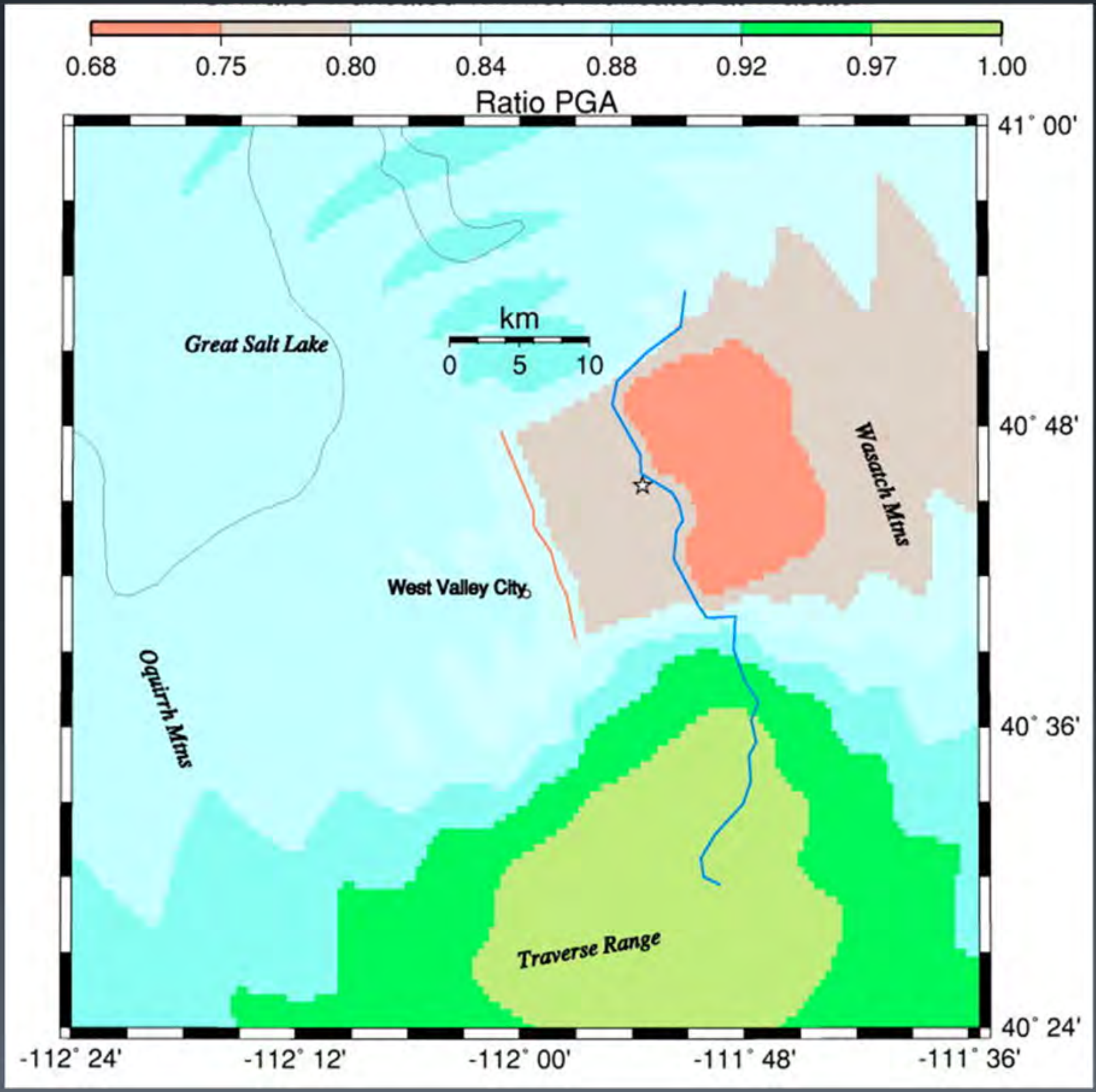
Depth of truncation



Magnitude comparison



Sensitivity study
SLC segment and West Valley fault zone



Conclusions

- Historical record suggests that graben-bounding faults do not behave in a predictable manner
- It is possible that none of these historic earthquakes provide an analogy for the seismic potential of the West Valley fault
- If one source is truncated, the hazard will noticeably decrease in the surrounding area

Discussion

- Are graben-bounding pairs properly modeled in the NSHMs?
- What other sensitivity studies are needed?
- Should the USGS modify how M is assigned to the truncated fault?
- Should there be a minimum M?

The question:

- How should antithetic fault pairs be modeled in the NSHMs? For example, what is the relation and seismogenic significance of fault pairs such as the East and West Cache faults, and strands of the Salt Lake City segment of the Wasatch fault and the West Valley fault zone?

Consensus recommendations to the USGS

USGS should explore using metrics (such as Length, Topographic Relief, Overlap) to guide selection of master and subsidiary faults.

- Evaluate dataset for overlapping relations to select master fault based on Length
- Evaluate using aspect ratio (Length/Width) for individual fault pairs
- Where data allow, structural throw should be used rather than Topo. Relief
- Evaluate using Length X Throw as a parameter for selecting master fault

Subsurface data (e.g., seismic reflection) should be used to guide master fault selection, where available.

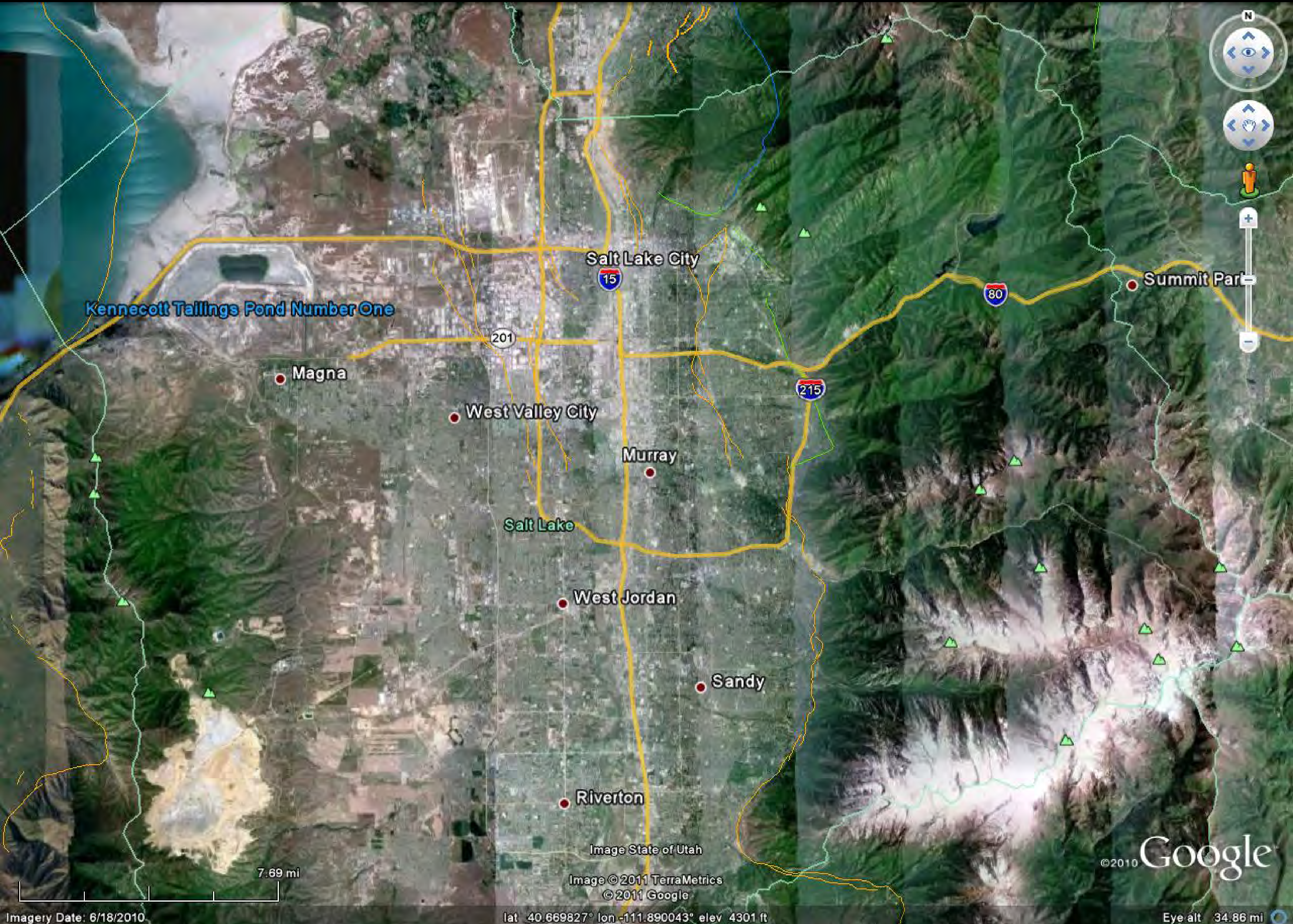
Where available data do not give a clear indication of master vs. subsidiary fault, model both alternatives using a logic tree approach.

For truncated faults, use rupture area (rather than SRL) to determine M.

Consensus recommendations to the USGS

The USGS should conduct sensitivity studies on the impact on ground motions of graben-bounding fault pairs in urban areas.

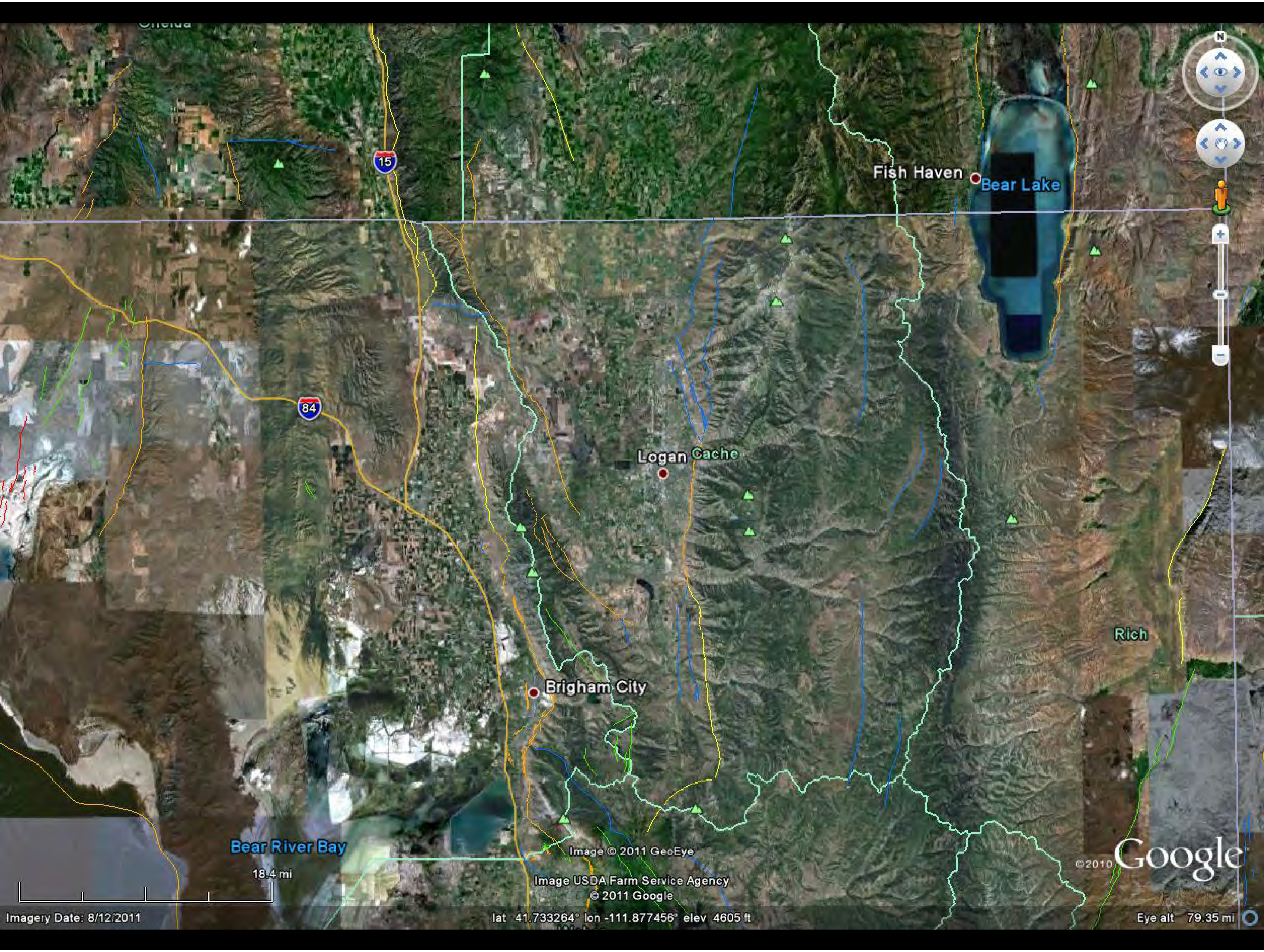
The USGS should develop and test methodology for modeling graben-bounding pairs and present results at the IMW workshop in summer 2012.



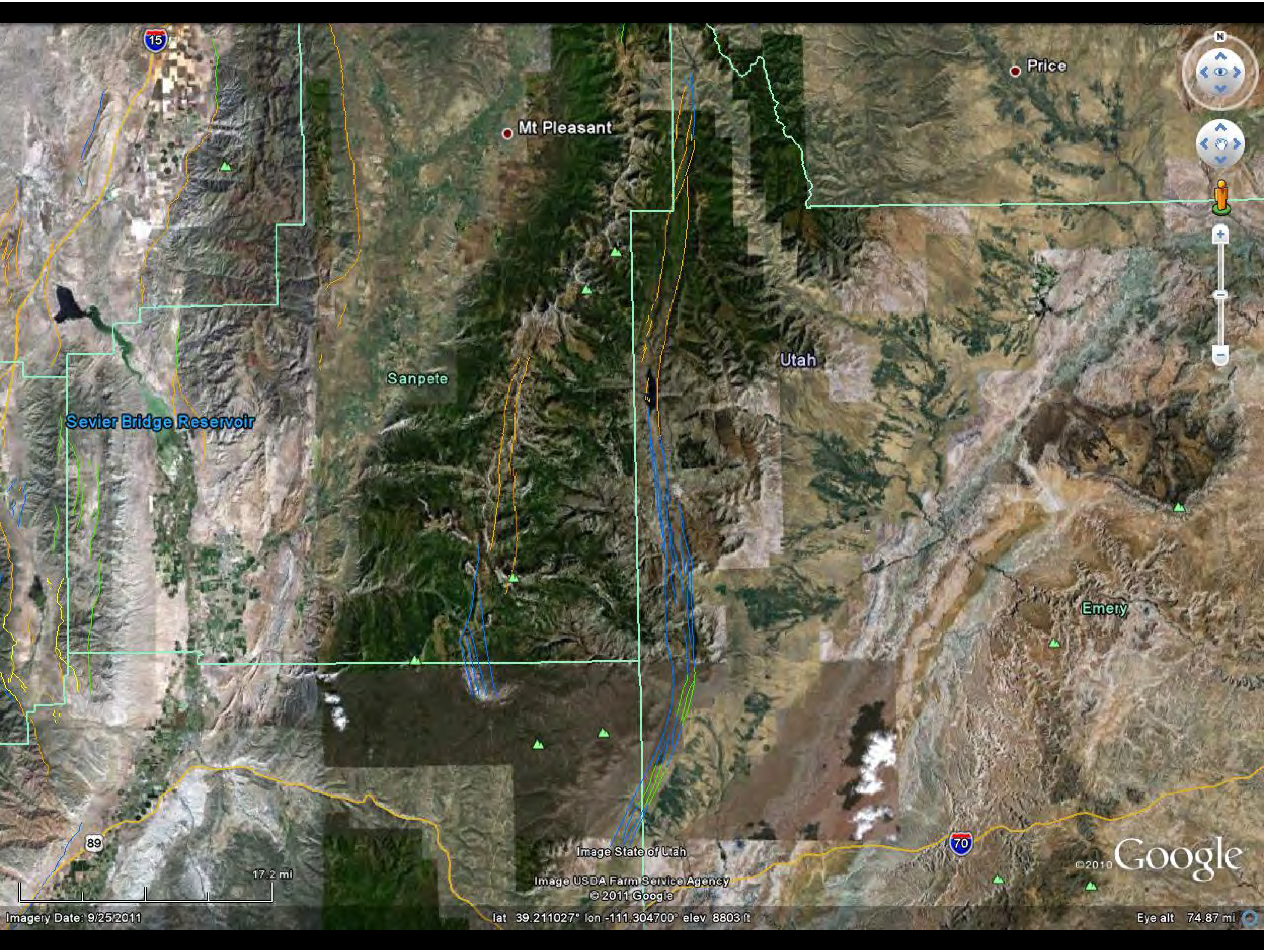
Salt Lake City
15
Kennecott Tailings Pond Number One
201
Magna
West Valley City
Murray
215
80
Summit Par
Salt Lake
West Jordan
Sandy
Riverton
Image State of Utah
Image © 2011 TerraMetrics
© 2011 Google
©2010 Google
7.69 mi
Imagery Date: 6/18/2010
lat 40.669827° lon -111.890043° elev 4301 ft
Eye alt 34.86 mi

Heber
Alpine
Deer Creek Reservoir
89
American Fork
Eagle Mountain
Orem
Provo
Utah Lake
Provo Bay
Springville
15
6
Utah
Payson
Woodland Hills
Santaquin
Eureka
Goshen
11.58 mi
Image © 2011 DigitalGlobe
© 2011 Google
Image State of Utah
©2010 Google
Imagery Date: 9/25/2011
lat 40.212335° lon -111.801605° elev 4498 ft
Eye alt 51.33 mi


N
84
Spring Bay
Image © 2011 GeoEye
Image USDA Farm Service Agency
© 2011 Google
7.23 mi
©2010 Google
Imagery Date: 8/12/2011
lat 41.770977° lon -112.620302° elev 4549 ft
Eye alt 31.95 mi



15
84
Fish Haven
Bear Lake
Logan
Cache
Brigham City
Rich
Bear River Bay
18.4 mi
Image © 2011 GeoEye
Image USDA Farm Service Agency
© 2011 Google
©2010 Google
Imagery Date: 8/12/2011
lat 41.733264° lon -111.877456° elev 4605 ft
Eye alt 79.35 mi


15
Mt Pleasant
Price
Sanpete
Utah
Sevier Bridge Reservoir
Emery
89
70
17.2 mi
Image State of Utah
Image USDA Farm Service Agency
© 2011 Google
©2010 Google
Imagery Date: 9/25/2011
lat 39.211027° lon -111.304700° elev 8803 ft
Eye alt 74.87 mi

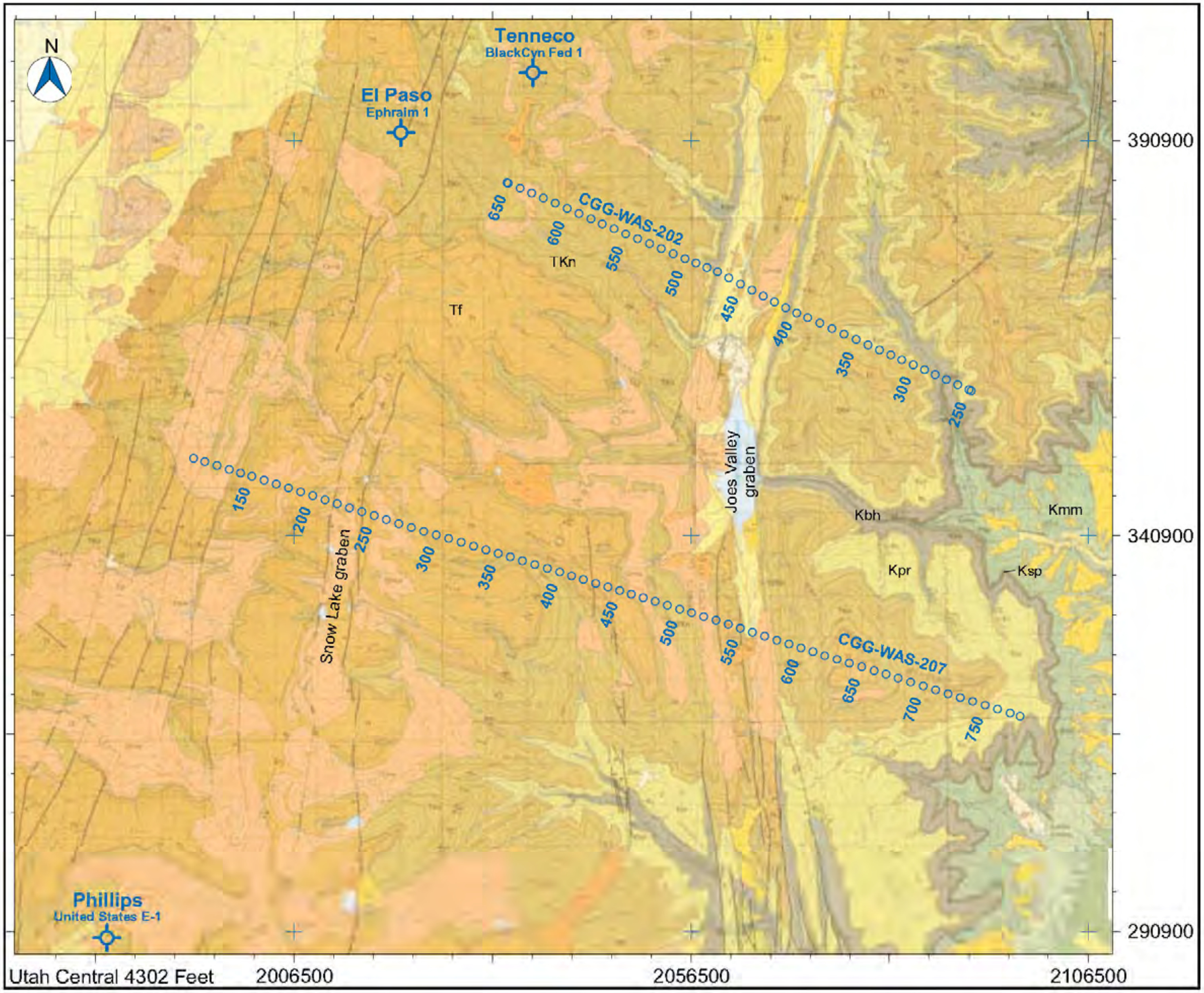


Figure 1. Geologic index map showing location of seismic lines CGG_WAS-202 and CGG-WAS-207 and wells in Figures 2,3,& 4 and Tables 1 & 2. Geologic base map from Witkind et al. (1987). Bedrock geologic units: Kmm - Masuk Member of Mancos Shale, Ksp - Star Point Sandstone, Kpr - Price River Formation, TKn - North horn Formation, Tf - Flagstaff Limestone. Quaternary units superceded by Foley et al. (1986). Margin scale is Utah State Plane feet, central zone 4302.

J.C. Coogan, in Anderson (2008)

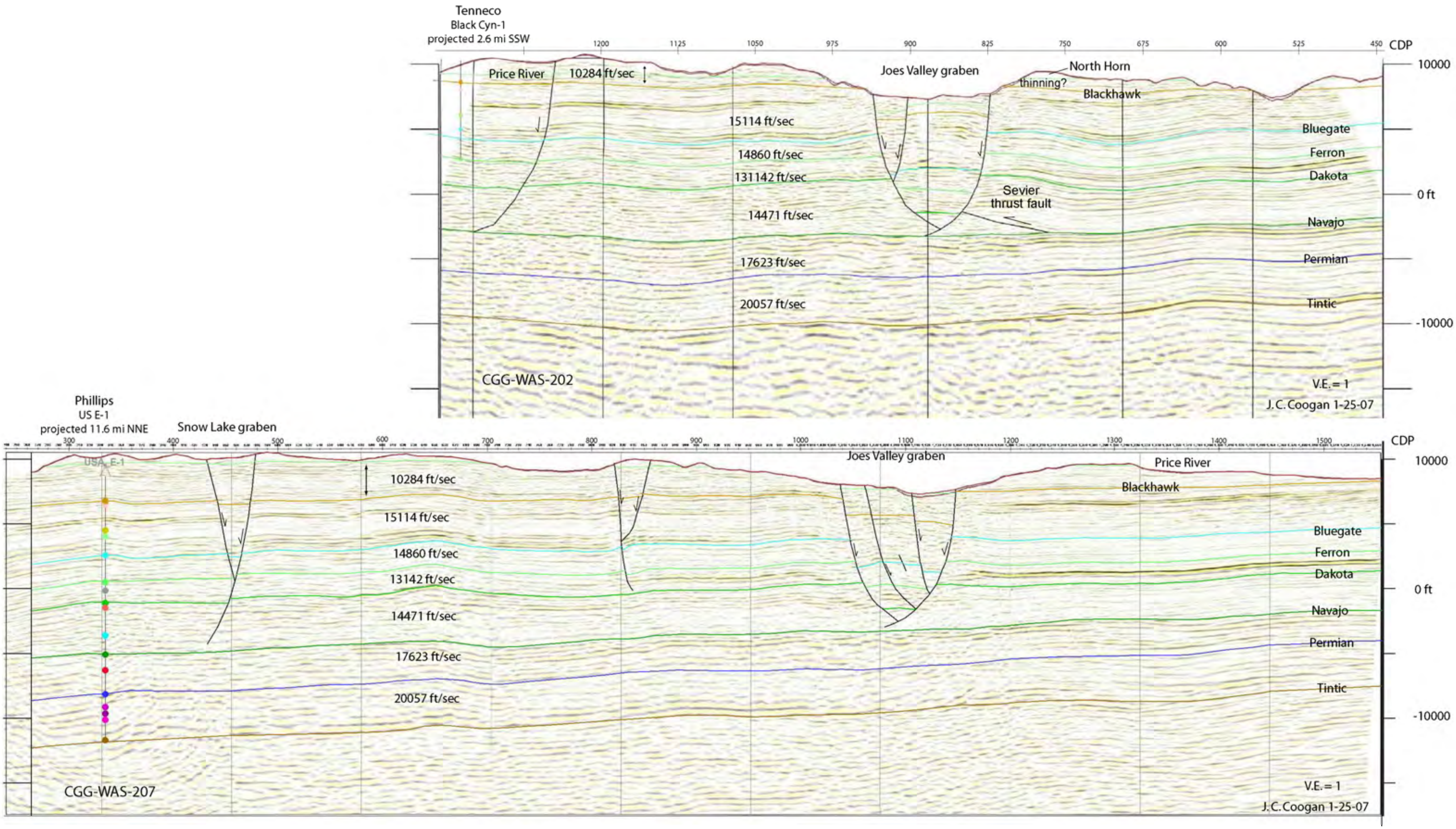


Figure 6. Depth cross sections superimposed on seismic depth images of CGG-WAS-202 (top) and CGG-WAS-207 (bottom). Seismic images are Excel Geophysical pre-stack depth migration rectified to correlative vertical-incidence depth-converted horizons. Horizon names are labeled. Interval velocities between horizons are from Table 2.

J.C. Coogan, in Anderson (2008)

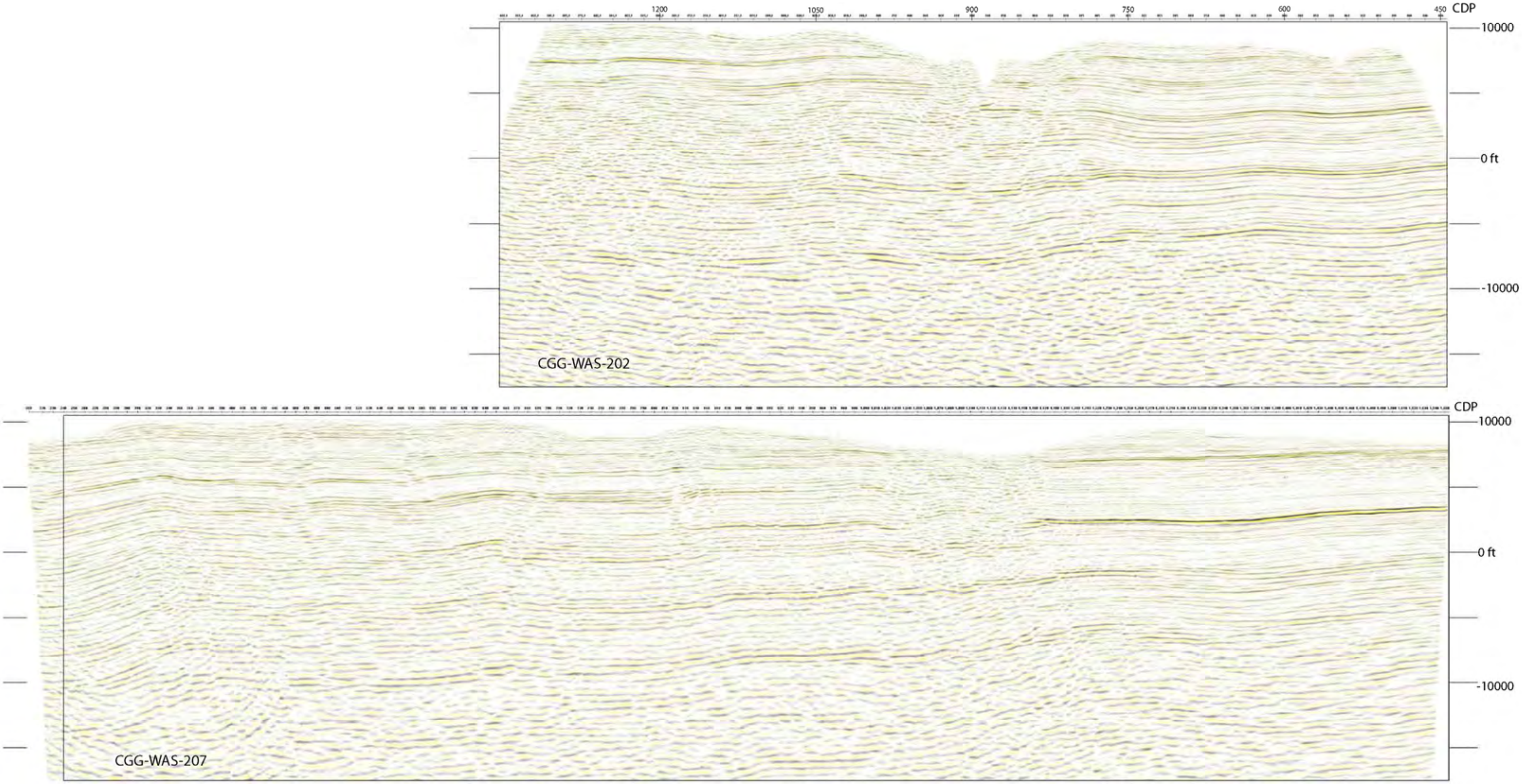


Figure 5. Uniterpreted pre-stack depth migration images of CGG-WAS-202 (top) and CGG-WAS-207 (bottom).

J.C. Coogan, in Anderson (2008)

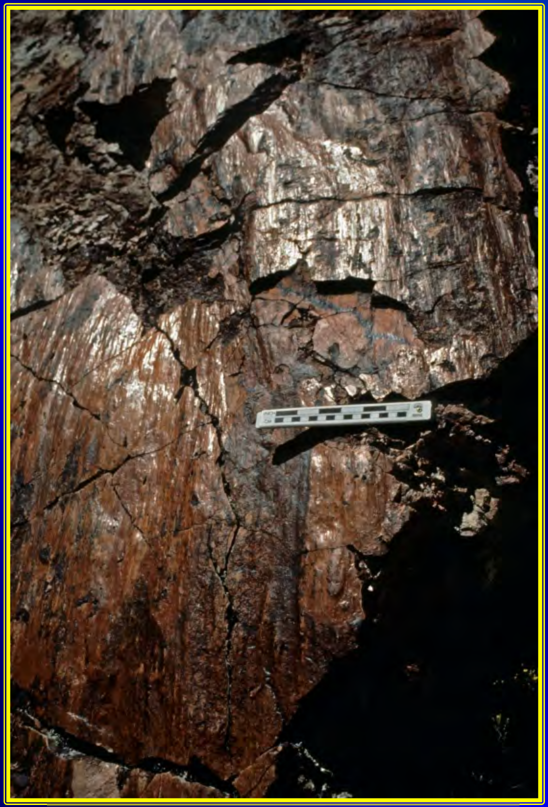
Dip Angles for Basin and Range Normal Faults

Yumu Shan fault, China

BRPEWG II

Discussion Topic Geology 4

Anthony Crone
U.S. Geological Survey
Denver, Colorado



Dixie Valley fault, Nevada

USGS science for a changing world

WGUEP 17 Nov. 2011

Historical Perspective:

NSHMs used value of 60° for dip of normal faults with no uncertainty range prior to 2008.

BRPEWG I Recommendation: "Convert vertical slip rates to extensional rates for consistency with GPS data. This involves resolving the question of dip of normal faults. The NSHMs currently use a dip of 60°; the Working Group recommends using a dip of 50°±10°."

B&R Province Earthquakes and Faults

1) Borah Peak, Idaho, Earthquake

Richins et al., 1987, BSSA; aftershocks: about 45°.

Stein and Barrientos, 1985, JGR; geodesy: 47° ± 2°.

2) Devils Canyon, Idaho, Earthquake

Payne et al., 2004, BSSA; Borah Peak aftershock: 75° on LRF, 58 ° on antithetic Lone Pine fault.

3) Hebgen Lake, Montana, Earthquake

Ryall, 1962, BSSA; P-waves: 54° ± 8°.

Doser, 1985, JGR; aftershocks: 60° ± 5° and 42° ± 5°(Laramide structure?).

Barrientos et al., 1987, BSSA; geodesy: 45°-50°.

USGS science for a changing world

B&R Province Earthquakes and Faults

1) Fairview Peak, Nevada, Earthquake

Romney, 1957, BSSA; P-waves: 62°.

Slemmons, 1957, BSSA; geology: 55°-75°.

2) Dixie Valley-Fairview Peak faults, Nevada, Earthquake

Caskey et al., 1996, BSSA; geology: 30°-70° on various faults.

3) Northern Dixie Valley, Nevada

Okaya and Thompson, 1985, Tectonics; geophysics: 50°.

4) Pocatello Valley, Idaho, Earthquake

Arabasz et al., 1980, BSSA; aftershocks: 39°-60°.

B&R Province Earthquakes and Faults

1) Wasatch Fault, Utah

Zoback, 1992, USGS Prof. Paper; geophysics: 50°-55°.

Bruhn et al., 1987, Geol. Soc. Spec. Pub. 28; geology: 35°-65°.

Smith and Bruhn, 1984, JGR; geophysics: steep to low-angle dips.

Chang and Smith, 2002, BSSA; geodesy: 55°.

Chang et al., 2006, J.GR; geodesy: 55°.

2) Western Cordillera, United State

Doser and Smith, 1989, BSSA; seismology: 40°-70° on various faults.

Global Earthquakes and Faults

1) Continental Crust

Jackson and White, 1992, J. Struct. Geol.; seismology: 30°-50°.

Collettini and Sibson, 2001, Geology; seismology: mode at 45°, range of 30°-65°.

Jackson, 2002, Int. Assoc. Seism. & Phys. Earth's Int.; seismology: mode at 40°-50°.

BRPEWG Topic G4:
Summary Recommendations

1. Following a review of published data summarizing the dips of normal faults in the Basin and Range Province and worldwide, the BRPEWG II Working Group (WG) concludes that a dip of 50°± 15° best represents the range of dips for normal faults in the Basin and Range Province (BRP). The WG recommends this range be used in updates of the NSHMs; the 50° value defines the mean dip value and the ±15° range represents the 5% and 95% percentiles.
2. For those faults having geological, geophysical, seismological, or geodetic data that constrains a specific fault's dip within seismogenic depth, the NSHMs should use these fault-specific data.
3. The WG recommends that the USGS evaluates the impact of increasing the range of recommended fault dips (from ±10° to ±15°) on the overall hazard.

USGS
science for a changing world

Oquirrh Great Salt Lake Fault Zone

Susan Olig (URS Corporation)
Jim Pechmann (UUSS)

Working Group Utah Earthquake Probabilities - November, 2011

OGSLFZ

Rozelle - 25 km

Promontory – 25 km

Fremont Is.- 25 km

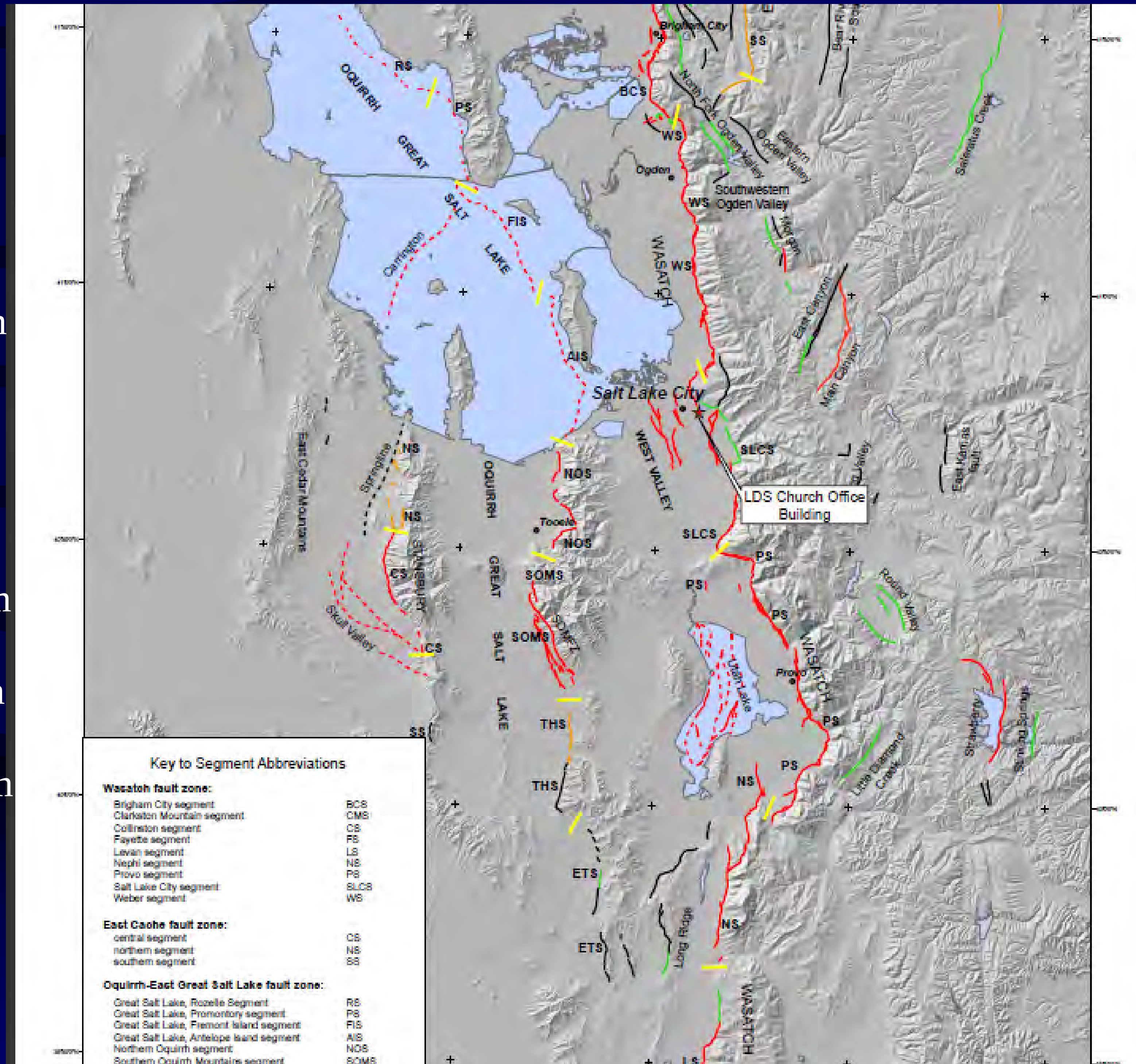
Antelope Is.- 35 km

No. Oquirrh – 30 km

So. Oquirrh – 31 km

Topliff Hills – 26 km

East Tintic - 35 km



Strawman Rupture Models for OGSLFZ

Table 2a. Great Salt Lake Fault Zone Rupture Scenarios and Weights from Meeting #4

Rupture Scenarios	WGUEP Weights
R, P, *FI, AI*	*0.75*
R, P, FI+AI	0.1
Unsegmented	0.15

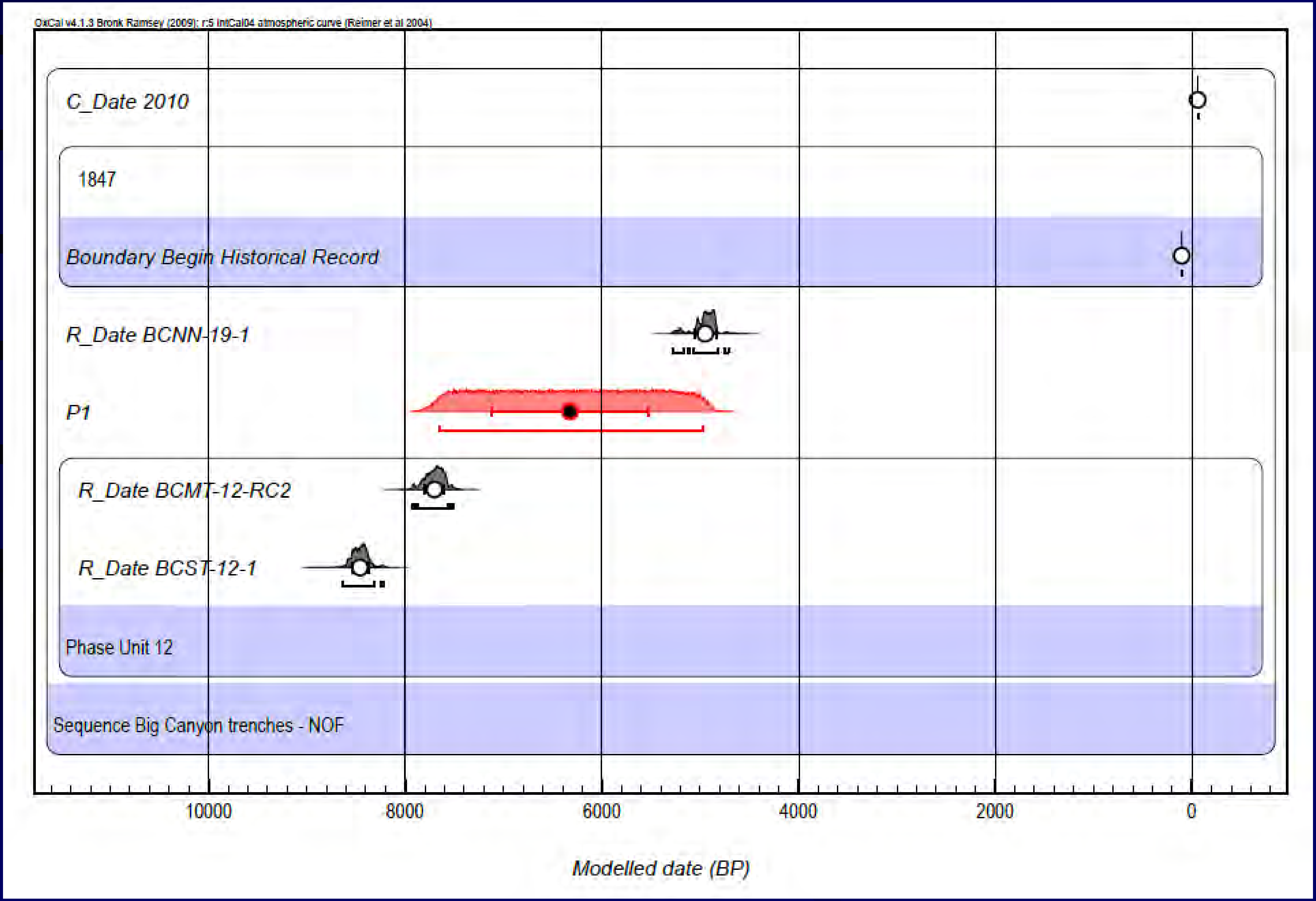
R = Rozelle segment, P = Promontory segment, FI = Fremont Island segment, AI = Antelope Island segment; italics indicates time-dependent model considered for that rupture source

Table 2b. Strawman Oquirrh-Great Salt Lake Fault Zone Rupture Model

Rupture Scenarios		Strawman 1 Weights	Strawman 2 Weights
1	RZ, PY, *FI, AI,* NO+SO, TH, ET	*0.40*	*0.25*
2	RZ, PY, *FI, AI,* NO, SO, TH, ET	*0.25*	*0.40*
3	RZ, PY, FI+AI, NO, SO, TH, ET	0.10	0.10
4	RZ, PY, *FI, AI,* NO, SO+TH, ET	0.10	0.10
5	Unsegmented (floating)	0.15	0.15

RZ = Rozelle segment, PY = Promontory segment, FI = Fremont Island segment, AI = Antelope Island segment, NO = Northern Oquirrh, SO = Southern Oquirrh, TH = Topliff Hills, ET = East Tintic; italics indicates time-dependent model considered for that rupture source

Revisiting Age of the MRE on Northern Oquirrh Fault



Paleoseismic Timing Data

Table 3

Ages of Youngest Surface-Faulting Along Segments of the Oquirrh-Great Salt Lake Fault Zone[1]

	Fault Segment	Youngest Event	Penultimate Event	Older Events?[3]
Great Salt Lake fault[2]	Rozelle (RZ)	Holocene?	?[3]	?[3]
Great Salt Lake fault[2]	Promontory (PY)	Holocene?	?[3]	?[3]
Great Salt Lake fault[2]	Fremont Island (FI)	3,150 (+240, -210)	6,410 (+210, -210)	< 11,430 (+610, -450)
Great Salt Lake fault[2]	Antelope Island (AI)	590 (+200, -240)	6,170 (+240, -230)	9,900 (+250, -300)
	Northern Oquirrh (NO)[4]	6330 (4960 to 7650)	20,300 - 26,400	> > 33,000
	Southern Oquirrh (SO)[5]	1,300 to **4,830**[6]	20 to 50 ka[6]	shortly after 42 ± 8; shortly after 75 ± 10 ka; ca. 92 ± 14 ka[6]
	Topliff Hills (TH)	> 15,000[7] or < 15,000[8]	?[3]	?[3]
	East Tintic (ET)	> > 15,000 (middle to late Pleistocene)[9]	?[3]	?[3]

Strawman Rupture Models for OGSLFZ

Table 2a. Great Salt Lake Fault Zone Rupture Scenarios and Weights from Meeting #4

Rupture Scenarios	WGUEP Weights
R, P, *FI, AI*	*0.75*
R, P, FI+AI	0.1
Unsegmented	0.15

R = Rozelle segment, P = Promontory segment, FI = Fremont Island segment, AI = Antelope Island segment; italics indicates time-dependent model considered for that rupture source

Table 2b. Strawman Oquirrh-Great Salt Lake Fault Zone Rupture Model

Rupture Scenarios		Strawman 1 Weights	Strawman 2 Weights
1	RZ, PY, *FI, AI,* NO+SO, TH, ET	*0.40*	*0.25*
2	RZ, PY, *FI, AI,* NO, SO, TH, ET	*0.25*	*0.40*
3	RZ, PY, FI+AI, NO, SO, TH, ET	0.10	0.10
4	RZ, PY, *FI, AI,* NO, SO+TH, ET	0.10	0.10
5	Unsegmented (floating)	0.15	0.15

RZ = Rozelle segment, PY = Promontory segment, FI = Fremont Island segment, AI = Antelope Island segment, NO = Northern Oquirrh, SO = Southern Oquirrh, TH = Topliff Hills, ET = East Tintic; italics indicates time-dependent model considered for that rupture source

INPUT	**Responsible Person**	**Completed?**
Wasatch RI –single central 5 segments	Chris/Nico	
Wasatch RI – multisegment ruptures on central 5 segments	Nico/Chris	
Wasatch RIs – end segments, single & multisegment ruptures		
Wasatch slip rates by segments	Mike/Chris	
Wasatch unsegmented model slip rates		
Wasatch COV	Done	
O-GSL COV	Same as Wasatch	
O-GSL RIs	Susan/Jim	
O-GSL slip rates		
Final MCHAR relations and weights A-Faults B/C-Faults Unsegmented Wasatch (6.5-7.0) Unsegmented O-GSL? Antithetic Faults – only Area?	Susan	
Final MagRecur Models A-Faults B/C-Faults Unsegmented	Ivan	Need Mmin for A/B/C faults
Seismogenic Thickness	Jim/Ivan	Done? 13 (0.3) 15 (0.4) 17 (0.3)
Fault Dips	Tony	Done 35 (0.3) 50 (0.4) 65 (0.3)
Other Faults length, dips, slip rates/RIs	Bill/Susan	
Antithetic Fault parameters geometry of antithetic faults with distribution, Wts of coseismic / independent branches	Mike/Bill	Need final parameters on Hansel Valley
Background Seismicity Final parameters for uniform and grid pts	Walter / Mark	
Wts on Time Dependent / Time Independent	Chris et. al	
Use of Geodetic Data	Jim/Mark/David	
Average displacement	Chris/Susan	