WGUEP Products

Working Group on Utah Earthquake Probabilities

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Products

- Segment-specific time-dependent and time-independent probabilities of the characteristic earthquake on the five central segments of the WFZ. (Note the time-dependent probabilities may be calculated with some weight given to a time-independent approach.)

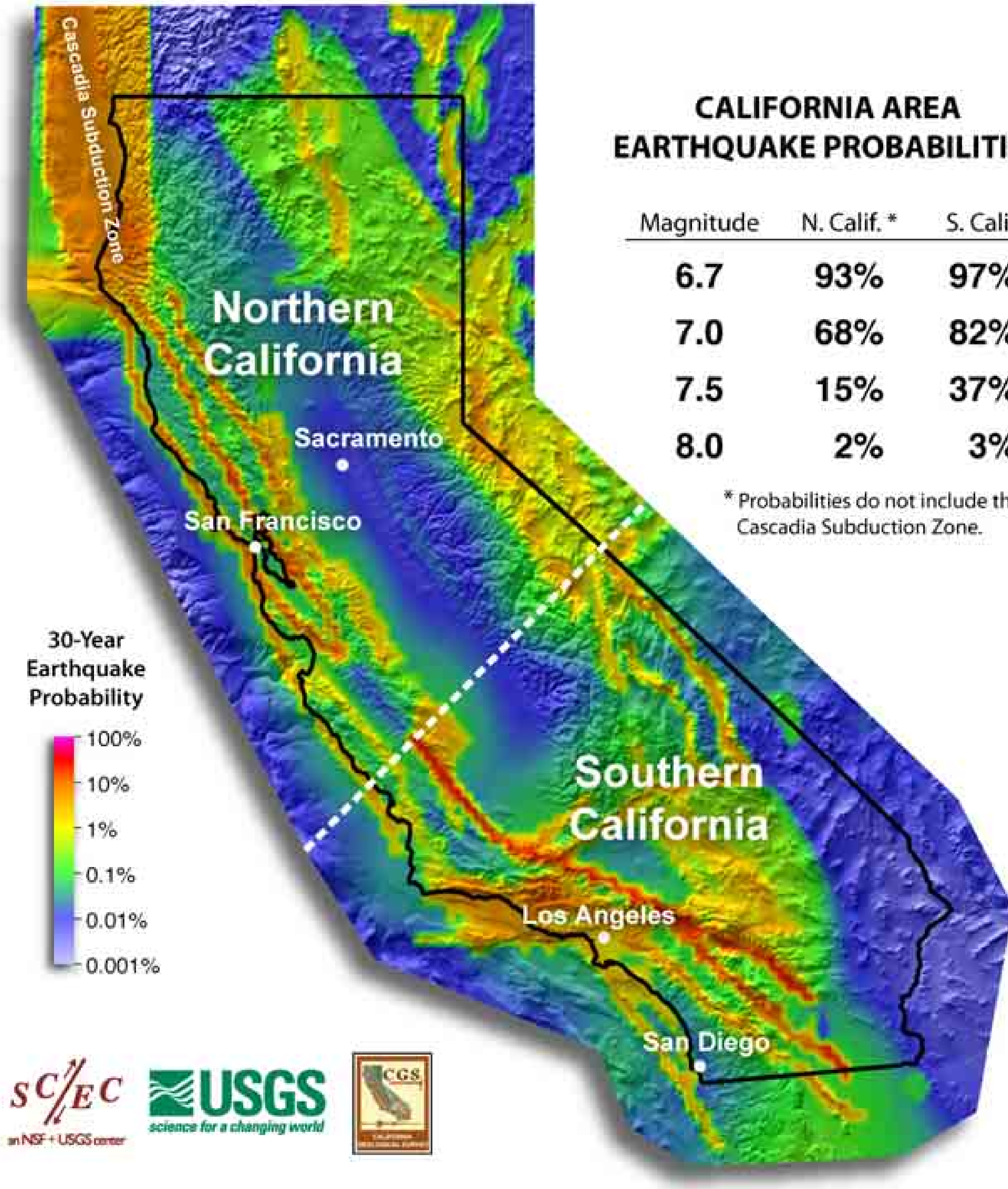
- Time-dependent and time-independent probabilities for the whole WFZ for **M** 6.5 and greater and **M** 7.0 and greater events.

- Segment-specific and fault-specific time-dependent and time-independent probabilities for the GSLFZ.

Products (cont.)

- Time-independent probabilities for each of the other faults in the Wasatch Front.
- Time-dependent and time-independent probabilities for the Wasatch Front for range of magnitudes starting at **M** ≥ 5.0.
- Time-independent probability for background earthquakes in the Wasatch Front for range of magnitudes starting at **M** ≥ 5.0.
- Map of time-dependent probabilities for Wasatch Front.

California Earthquake Probabilities

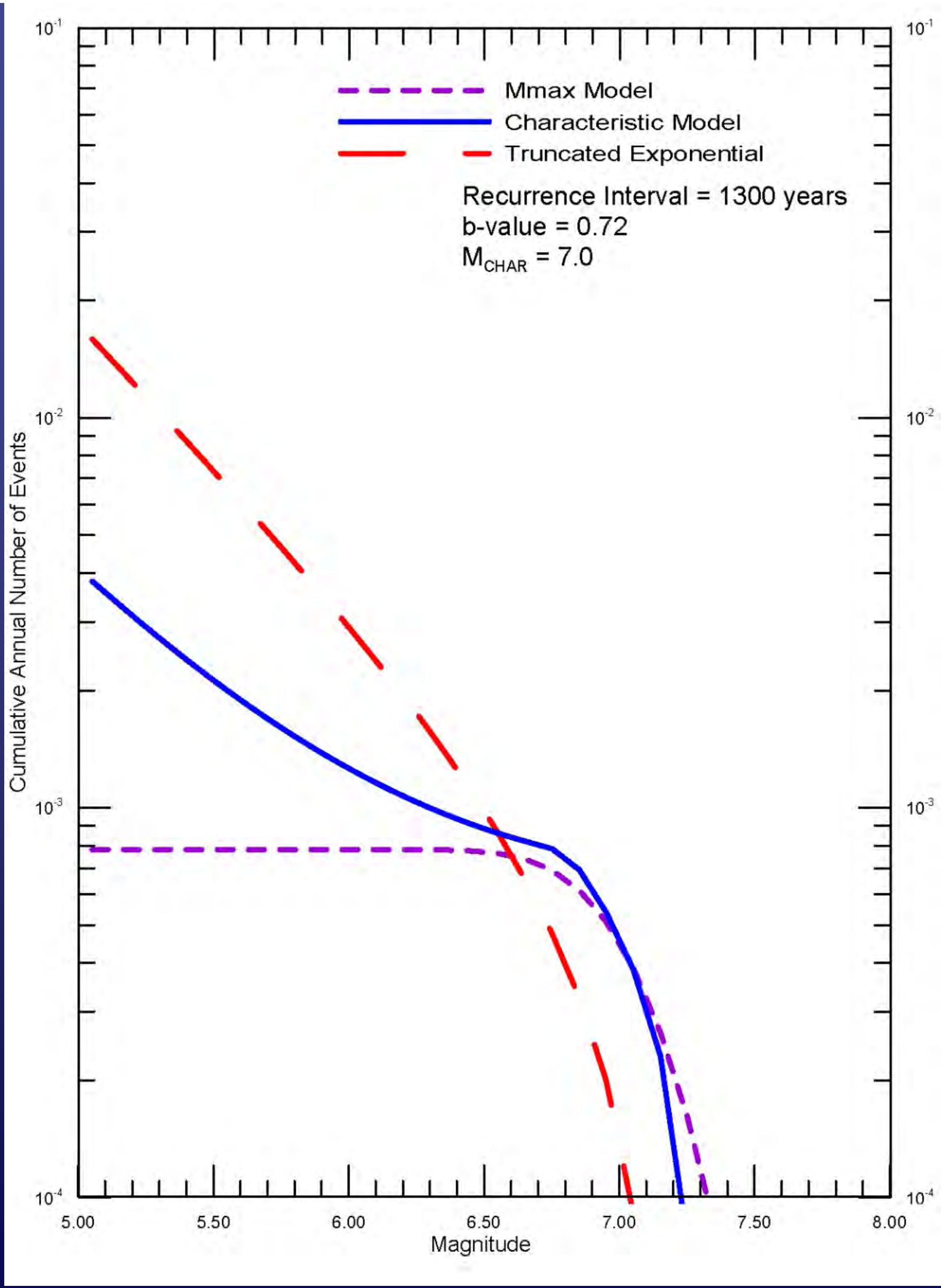


CALIFORNIA AREA EARTHQUAKE PROBABILITIES

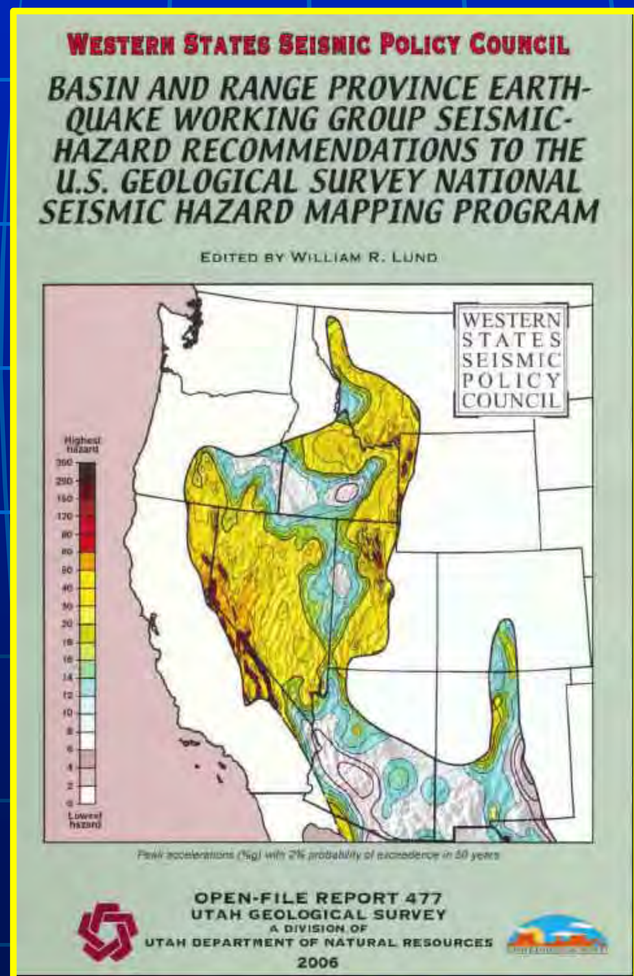
Magnitude	N. Calif. *	S. Calif.
6.7	93%	97%
7.0	68%	82%
7.5	15%	37%
8.0	2%	3%

* Probabilities do not include the Cascadia Subduction Zone.

Cumulative Recurrence Curves



Basin and Range Province Earthquake Working Group (BRPEWG) Meeting II



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Western States Seismic Policy Council WSSPC

BRPEWG I Meeting

Objective: Provide recommendations to the U.S. Geological Survey's Seismic Hazard Mapping Project in advance of the 2007 update of the National Seismic Hazard maps (NSHM).

•Identified six seismic-hazard issues in the Basin and Range Province that were considered important with respect to updates of the NSHM.

•Working Group met in SLC in March 2006.

•Offered sets of short-term and long-term recommendations.

•Released as: Lund, W.R. (ed.), 2006, Utah Geol. Survey Open-File Report 477.

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BRPEWG I Meeting

Discussion Topics:

1. Use and relative weighting of time-dependent, Poisson, and clustering models in characterizing fault behavior.
2. Appropriate attenuation relations, stress drop, and kappa in modeling ground motions, including consideration of evidence from precarious rock studies.
3. Proper magnitude-frequency distributions (Gutenberg-Richter vs. characteristic earthquake models) for BRP faults.
4. Use of length versus displacement relations to estimate earthquake magnitude.
5. Probabilities and magnitudes of multi-segment ruptures.
6. Resolving discrepancies between geodetic extension rates and geologic slip rates.

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BRPEWG II Meeting

Objective: Provide recommendations to the U.S. Geological Survey's Seismic Hazard Mapping Project in advance of 2013 update of the National Seismic Hazard maps (NSHM).

•Working Group will meet in SLC on Nov. 15–17. 2011.

•Participants from federal and state govt. agencies, academia, and private industry.

•Support from USGS and WSSPC.

•Discussions will focus on:
1) Seismological topics
2) Geological Evaluation of Seismic Sources

•Geodetic issues will be discussed in separate NSHM national workshop.

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BRPEWG II Meeting

Seismology Topics:

1. How can we quantify the sources of uncertainty in the earthquake magnitudes listed in catalogs used in the NSHMs?

2. Does the rate of historical earthquake have to match the rate of earthquakes represented in the NSHMs? If now, what level of mismatch is acceptable?

3. How should the “smoothing” of seismicity be handled in the NSHMs? The current maps use radial smoothing, but work related to precarious rocks suggest that anisotropic might be more appropriate.

4. What do frequency–magnitude relations look like for a single B&R fault, specifically below M 6.0–6.5? Does existing seismological data help define this relationship?

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BRPEWG II Meeting

Geologic Evaluation of Seismic Sources Topics:

1. How should antithetic fault pairs be modeled in the in the NSHMs?

2. Based on recommendations from BRPEWG I, the USGS uses a dip of 50° ±10° for B&R normal faults. Is this value and the ±10° uncertainty range valid and acceptable?

3. Should all long B&R faults be modeled as "segmented" faults? Does sufficient B&R data exist to determine how frequently multi-segment ruptures should be considered when modeling these normal faults? What is the appropriate Mmax for B&R faults?

4.The current NSHM needs guidance on how to estimate the uncertainty bounds for the slip rates on faults, especially for a fault that has little or no data on its slip rate. Add 50% to the upper and lower bounds of a slip rate?

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BRPEWG II Meeting

Many of the issues highlighted for BRPEWG II are similar to those identified in BRPEWG I meeting.

Answers aren't simple or clear.

Refining input into the NSHMs is an iterative process; goal is to assure that each update includes improved data and information, which yields a better representation of the seismic hazard at a national level.

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Recurrence Models

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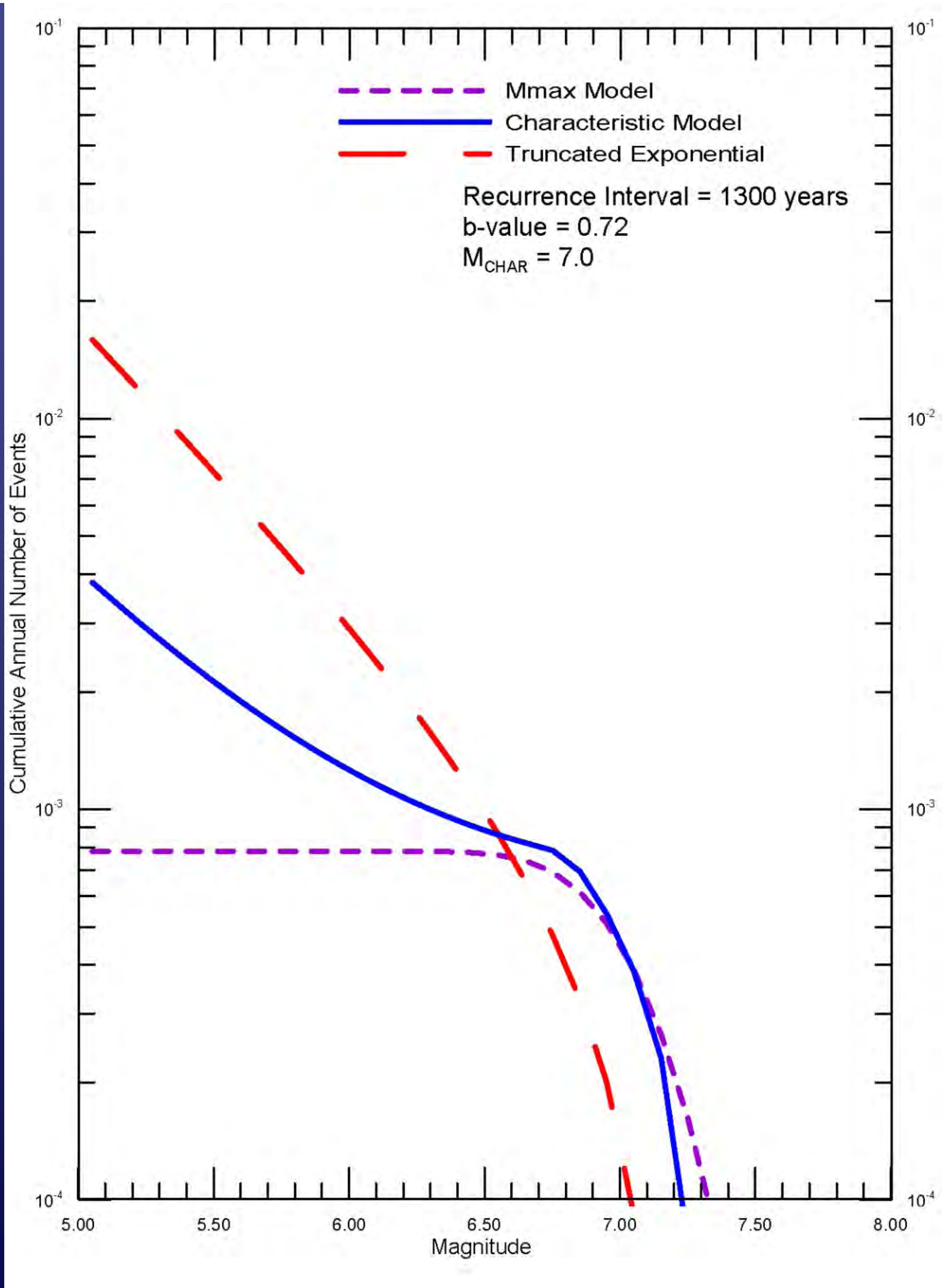
Earthquake Recurrence Models



USGS Recurrence Model Approach

- Use both “characteristic” (actually Maximum Magnitude) and Gutenberg-Richter models.
- Both models have their Mmin at **M** 6.5
- Mmin 6.5 came about because of mismatch of **M** 4-5 in southern California
- Smaller events are accommodated by the models; 1 (smoothed seismicity) and 2 (large background zone) and Gutenberg-Richter model above **M** 6.5

WGUEP
Paleoseismology Subgroup Update

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Working Group on Utah Earthquake Probabilities June, 2011

Tasks

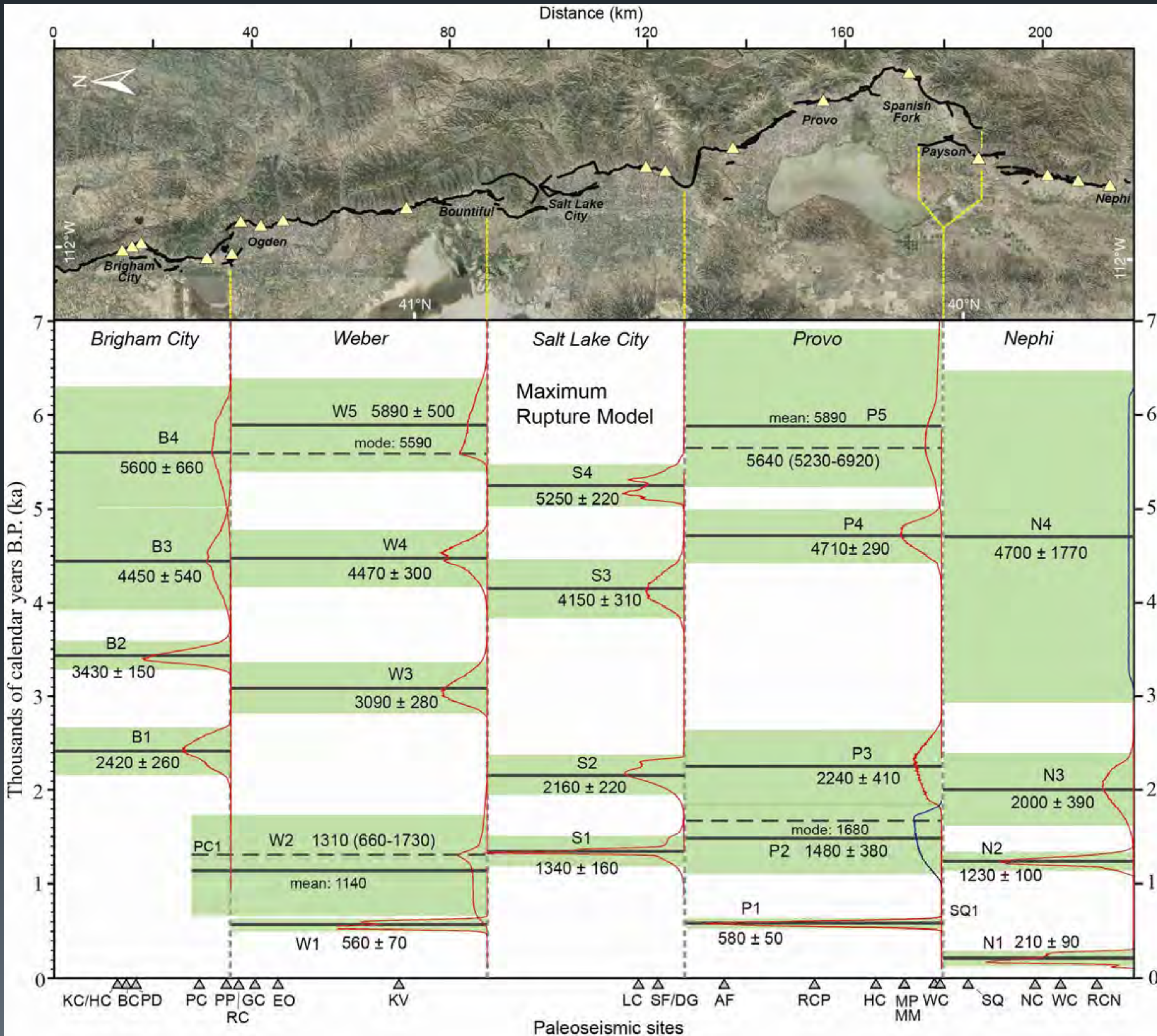
1. Weight WFZ rupture scenarios
2. Sum moment release per segment per scenario
3. Plot magnitude frequency distributions for rupture scenarios
4. COV’s (?)

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

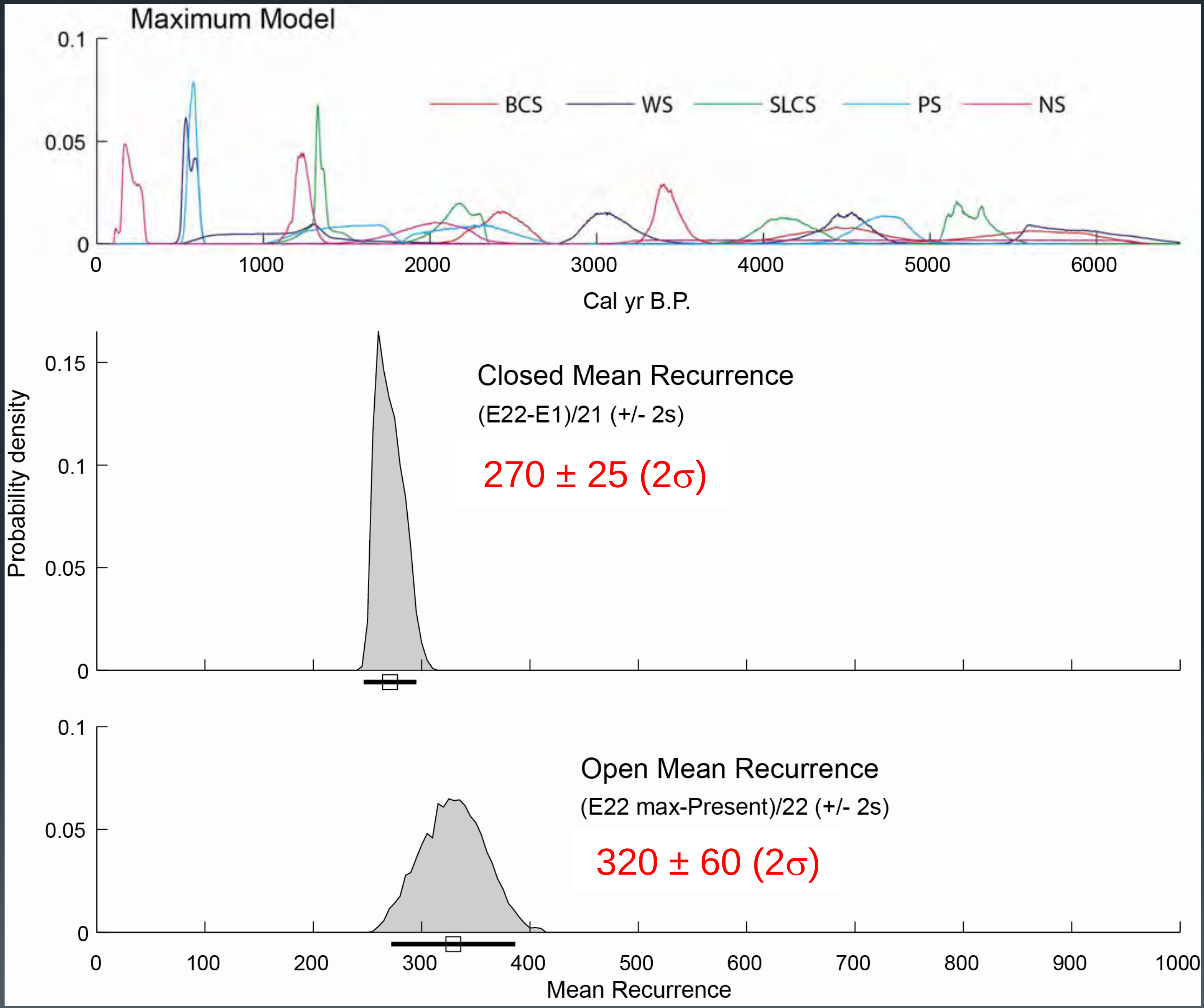
- Closed mean: intervals between observed events
- N events in T time: number of events in observed time window (elapsed time from maximum age for oldest event to present)

	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

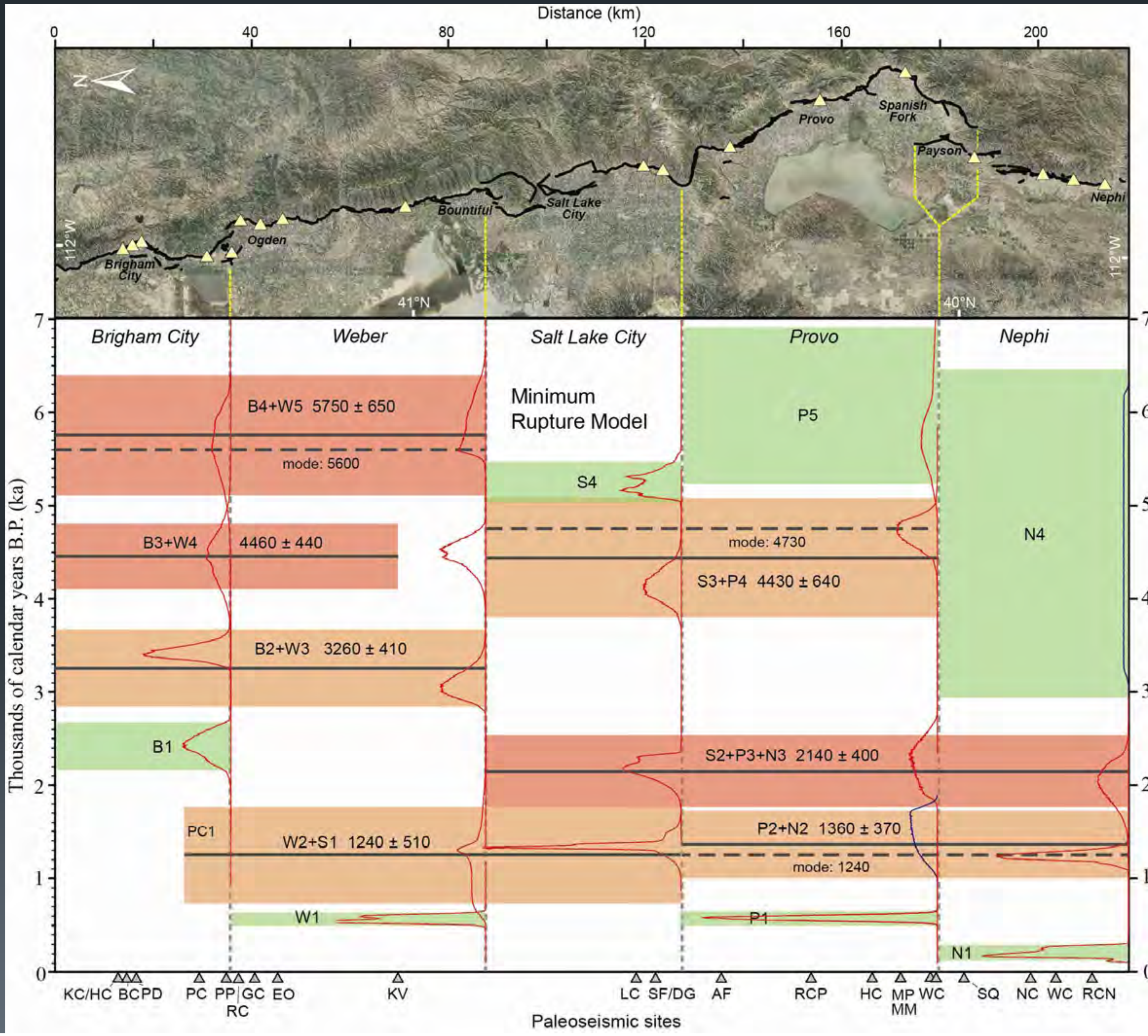
- 22 Earthquakes
  - All one-segment, but including leaky-boundary rupture from W2 to PC1 (southern Brigham City seg.)
- Recurrence:
  - Closed mean recurrence: 270 ± 25 yr (2σ)
  - N events in T time (open mean): 320 ± 60 yr (22 events in 7.3 ky)



Minimum Rupture Model

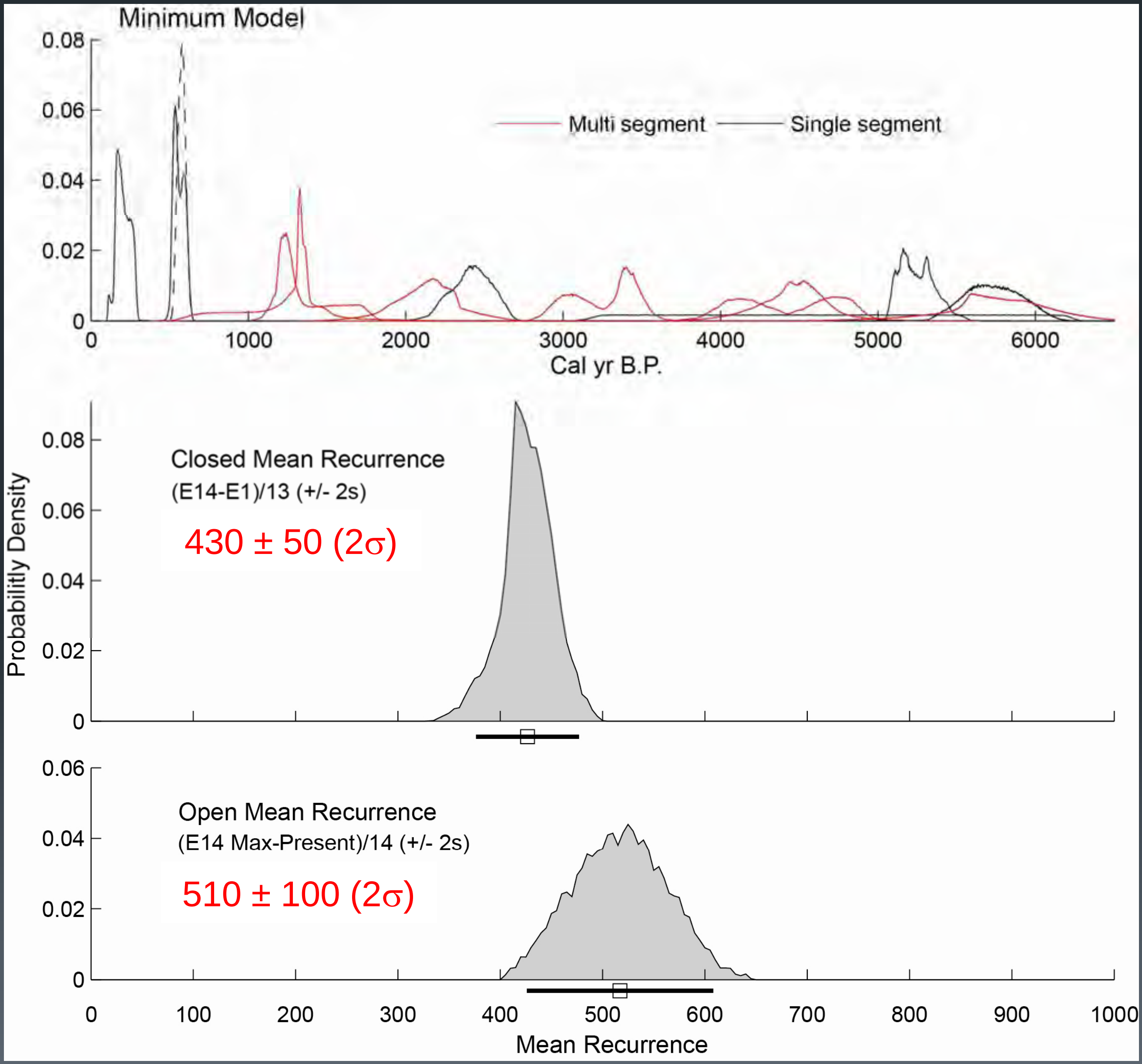
- **Red** – PDF overlap > 0.5
- **Orange** – PDF overlap < 0.5

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

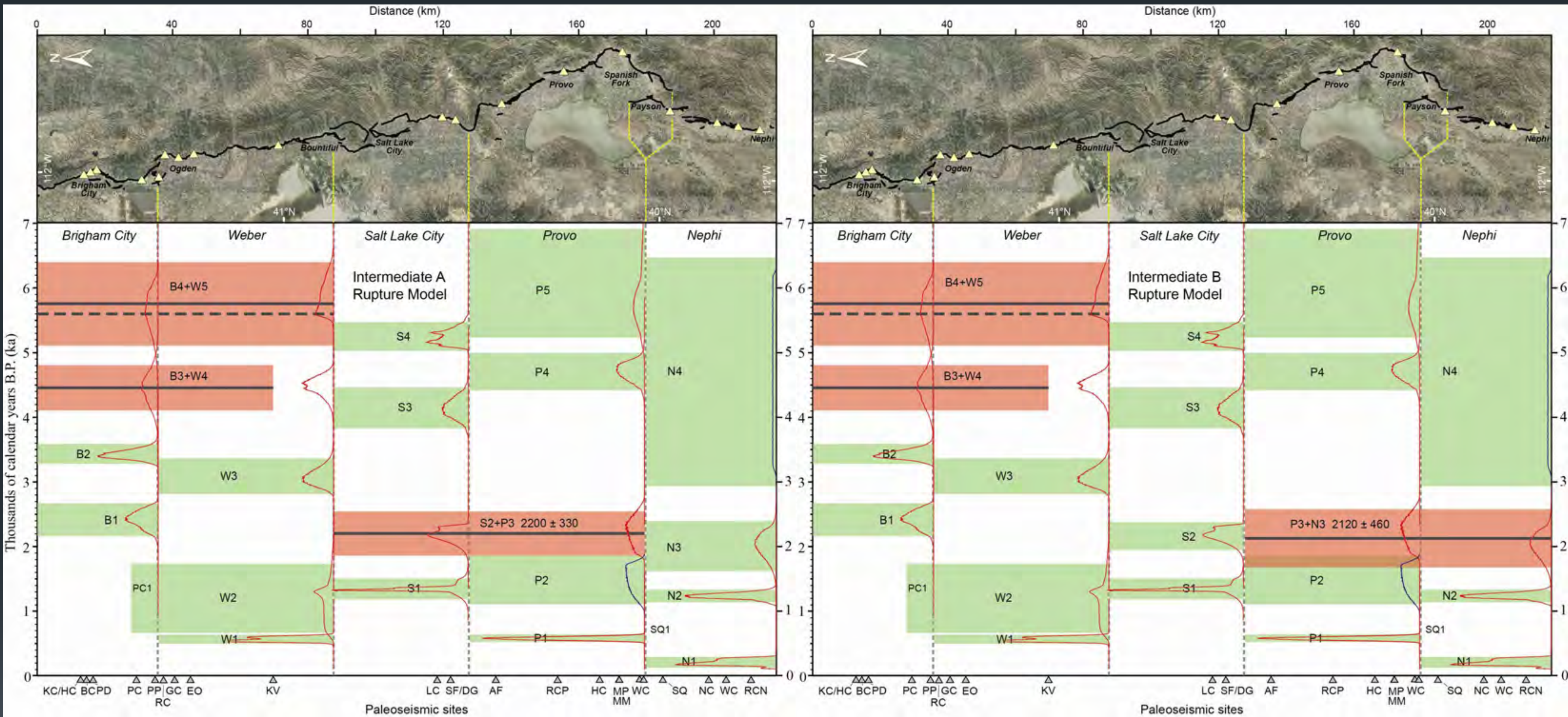


Minimum Rupture Model

- 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)



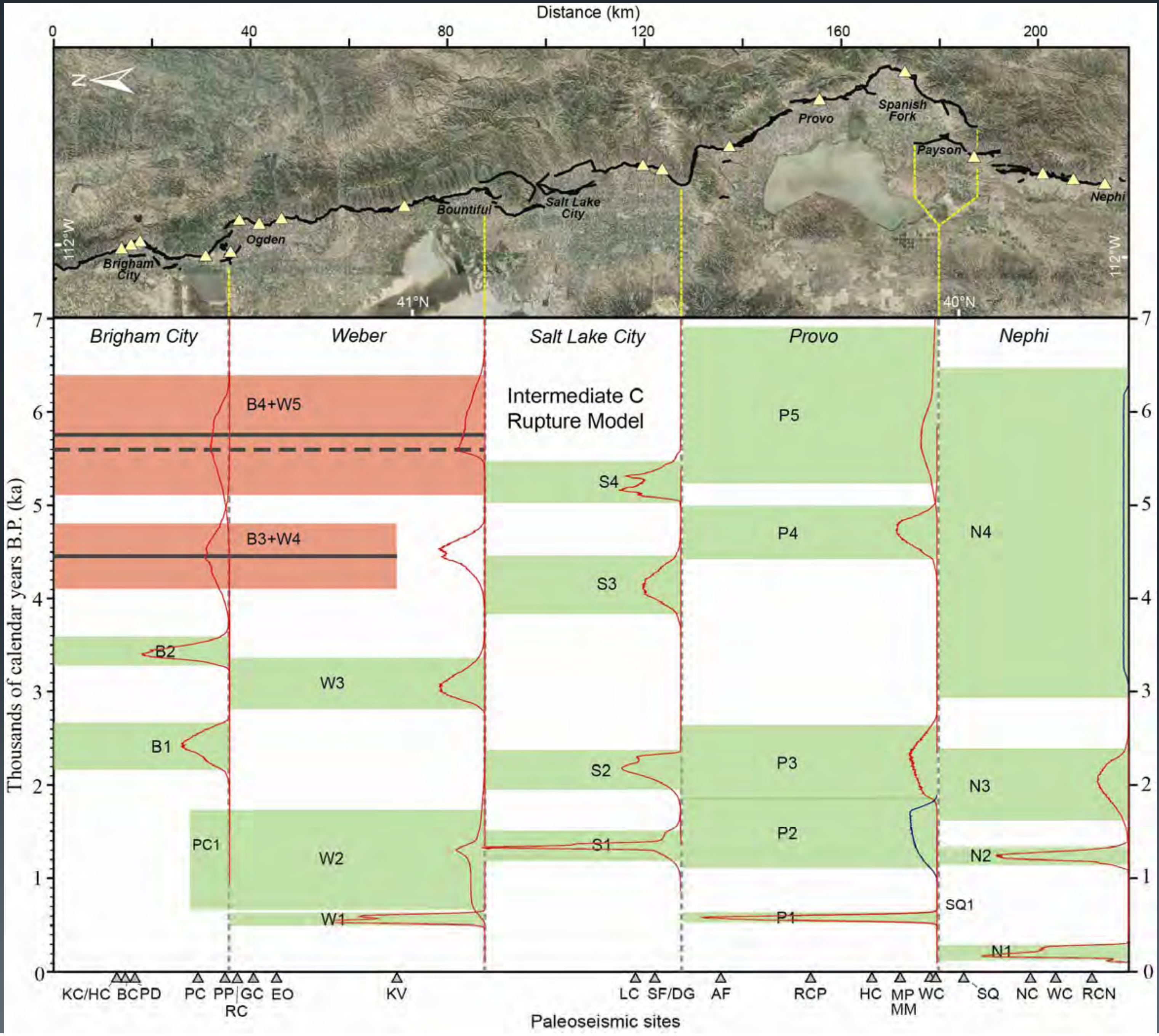
Intermediate Rupture Models



- 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

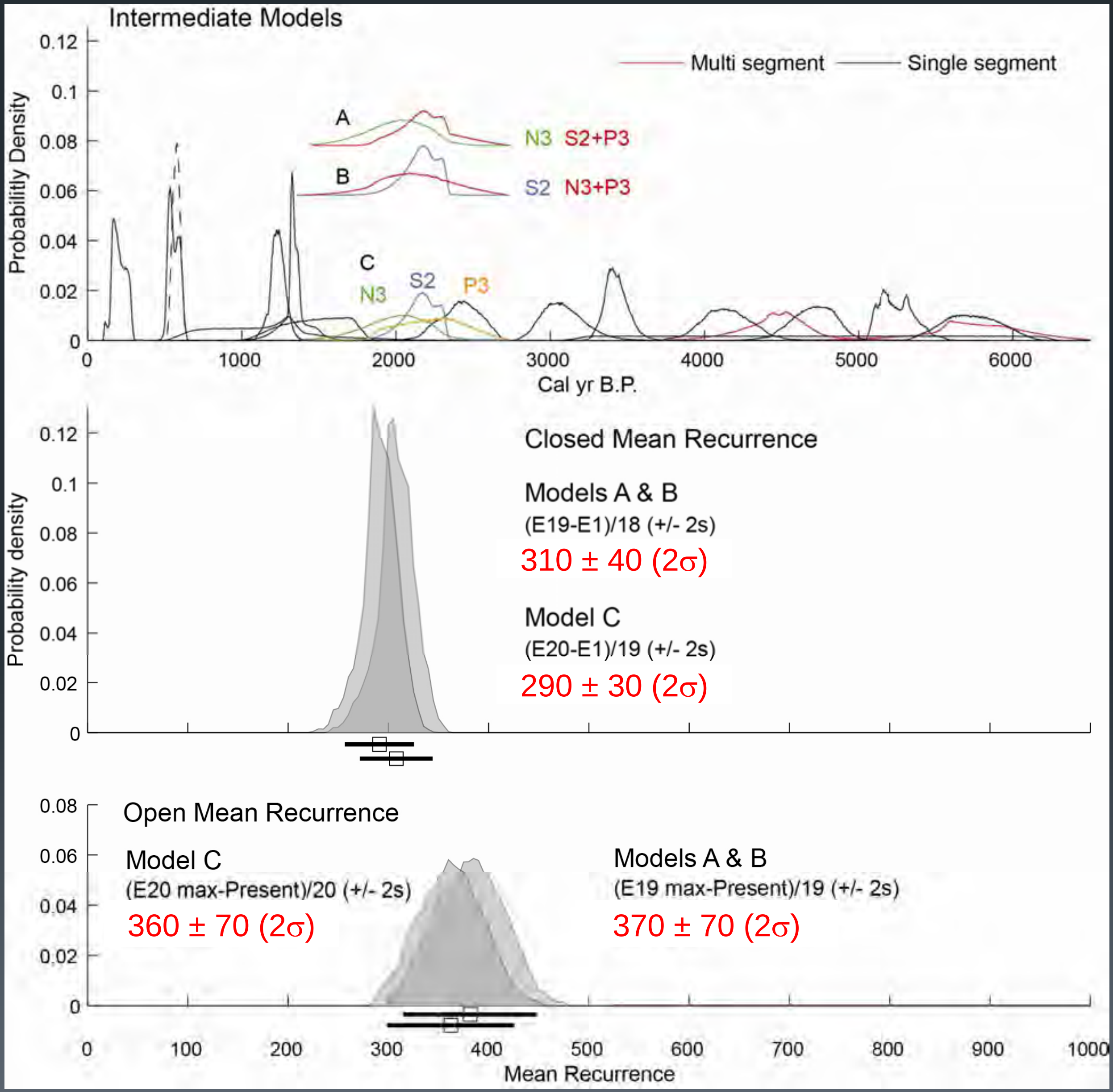
Intermediate Rupture Models

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 <u>slight</u> 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: $\log M_0 = 3/2\ [M_W(\mathrm{SRL})] + 16.05$ (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.

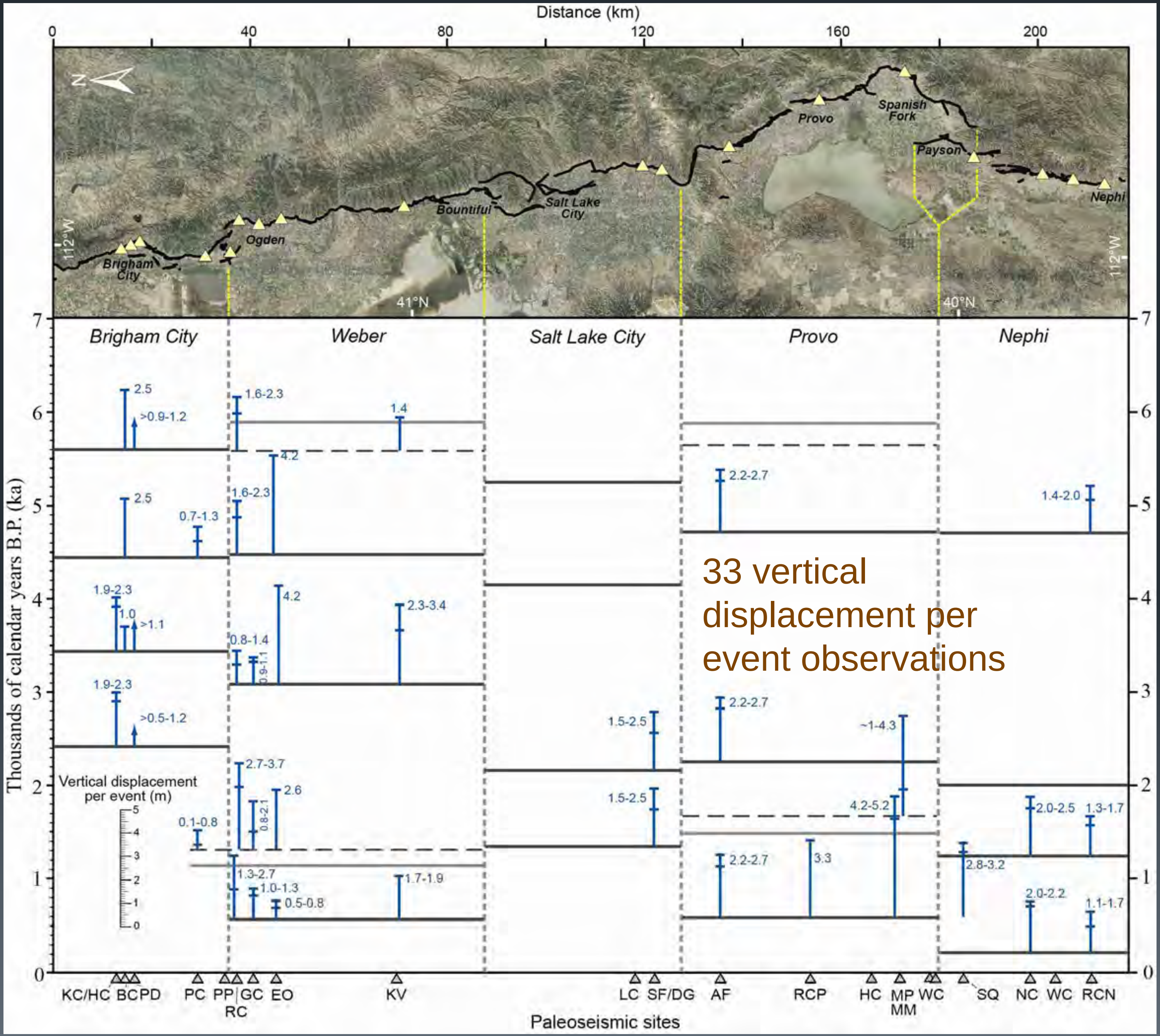
- Simple method for calculation AD(net)
  - <u>AD(net)</u> = average of displacement observations from trenches
  - No assumptions about rupture profile/slip decreasing at rupture ends
  - Advantage: ideal if have numerous displacement observations
  - Disadvantages: displacement tapering at rupture 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.

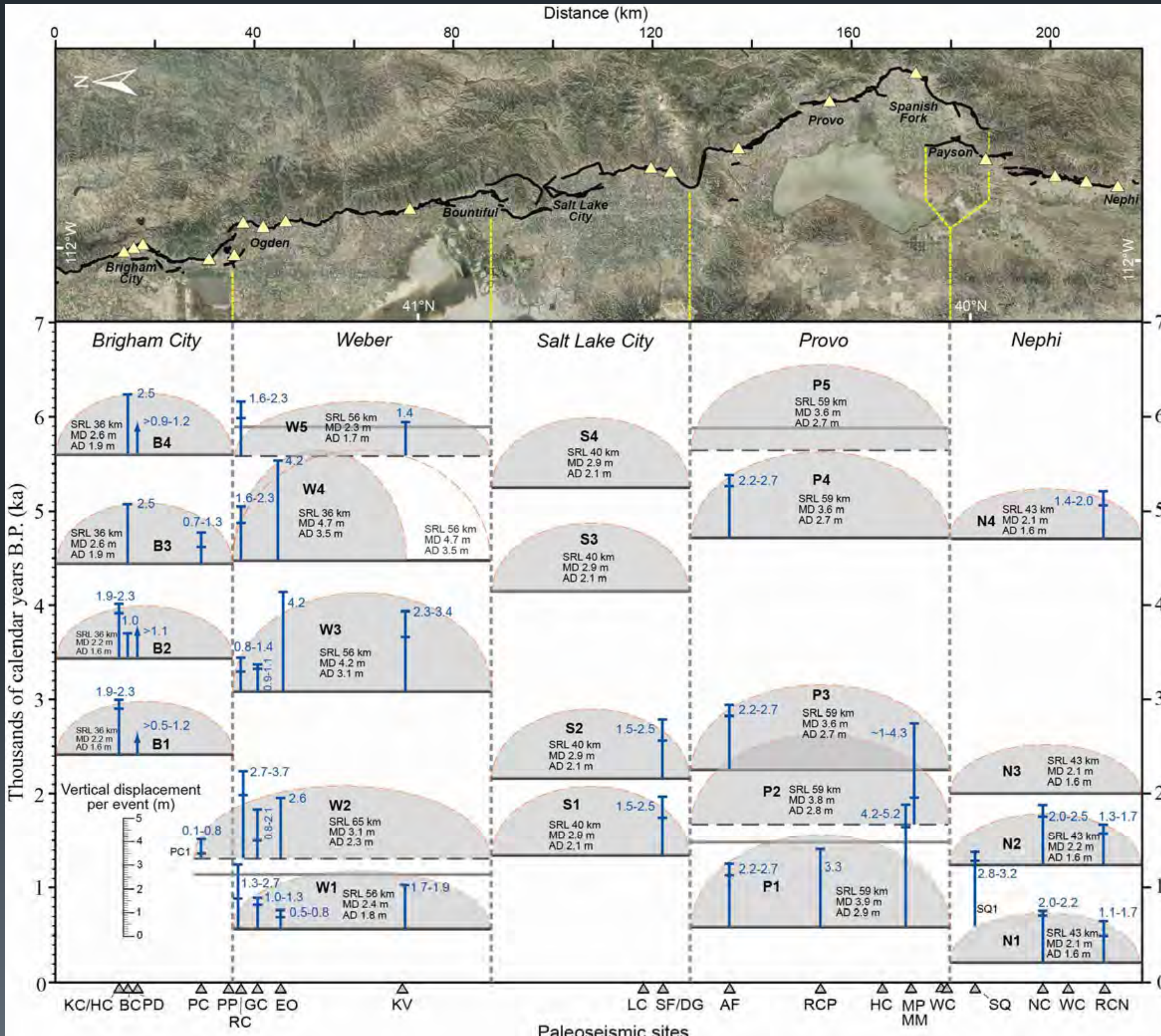
- Other
  - Characteristic: average displacement for segment is independent of whether it is included in a single- or multi-segment rupture.
  - Uniform/Boxcar: constant displacement along rupture

Observed Displacement (Maximum Model)



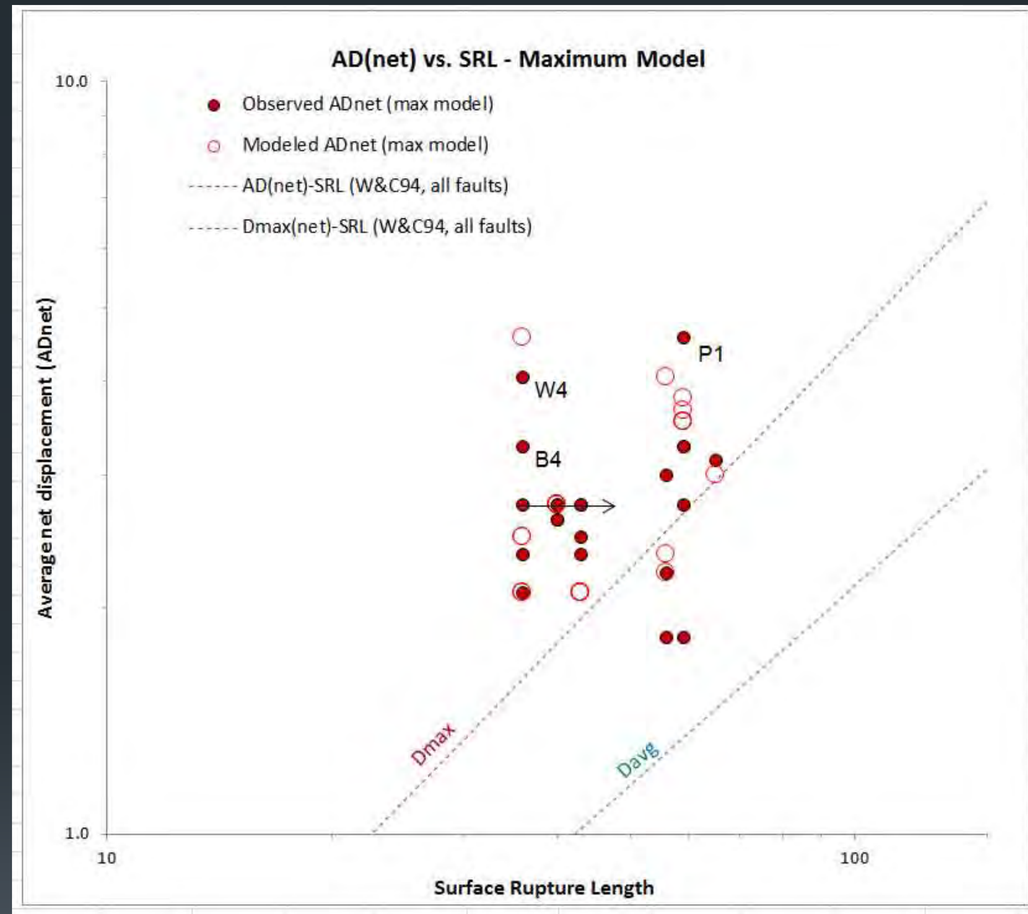
33 vertical displacement per event observations

Modeled Displacement – Maximum Model

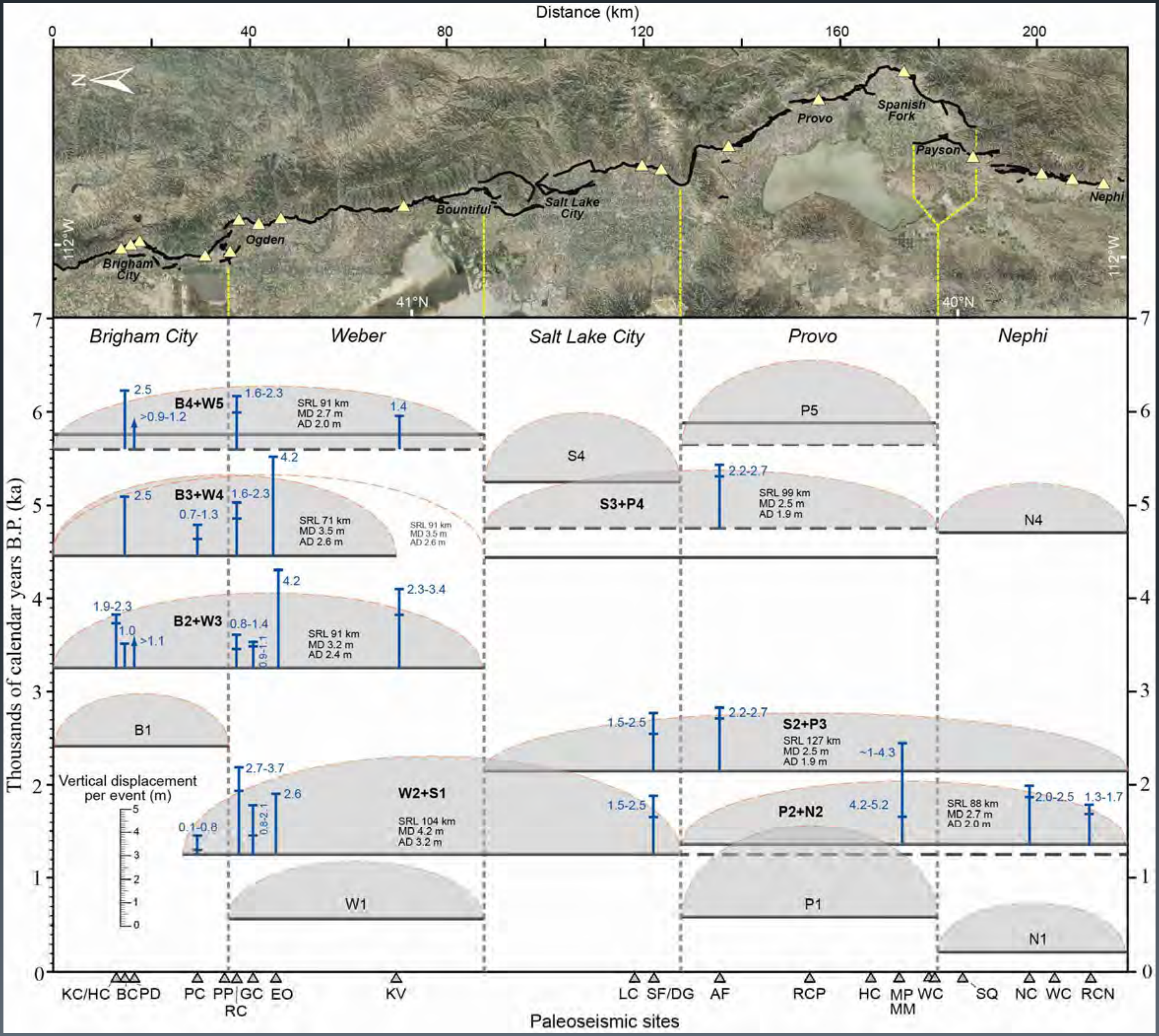


Modeled Displacement – Maximum Model

- 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?

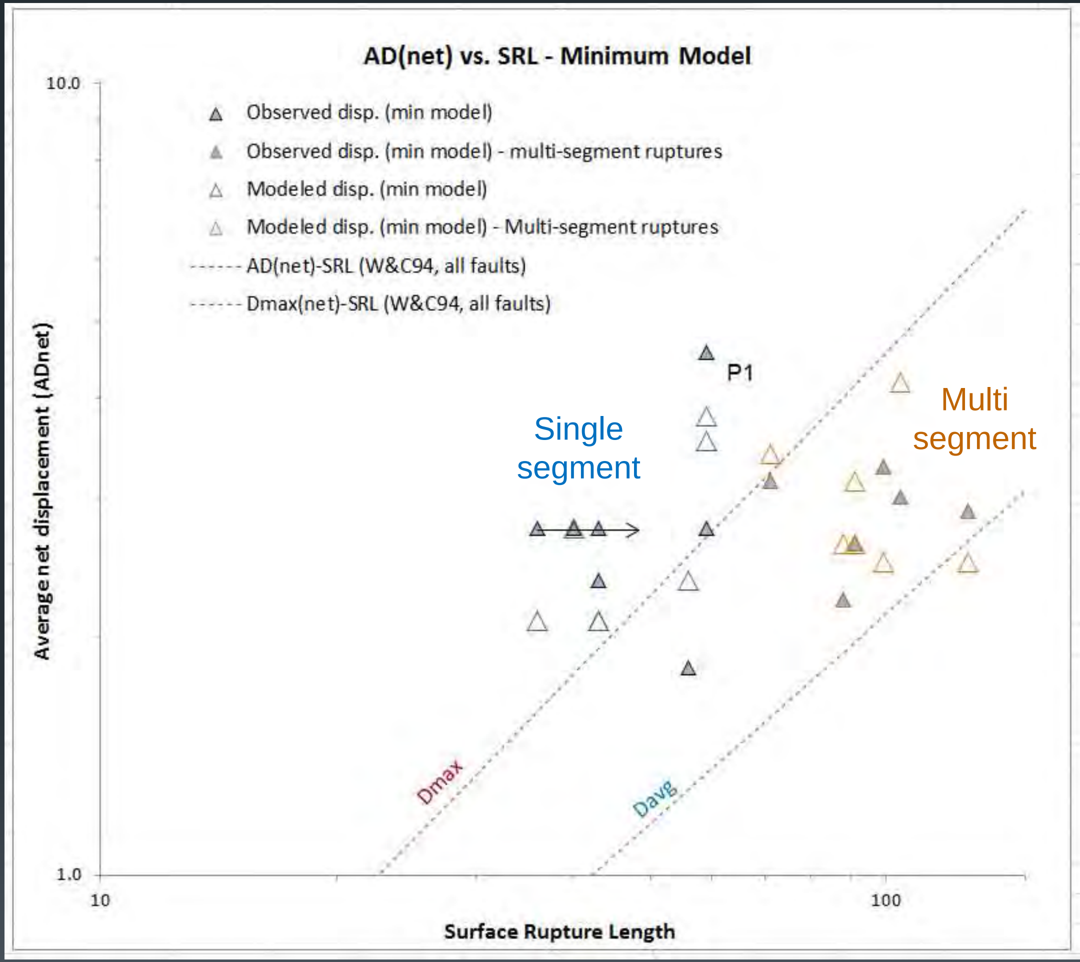


Modeled Displacement – Minimum Model



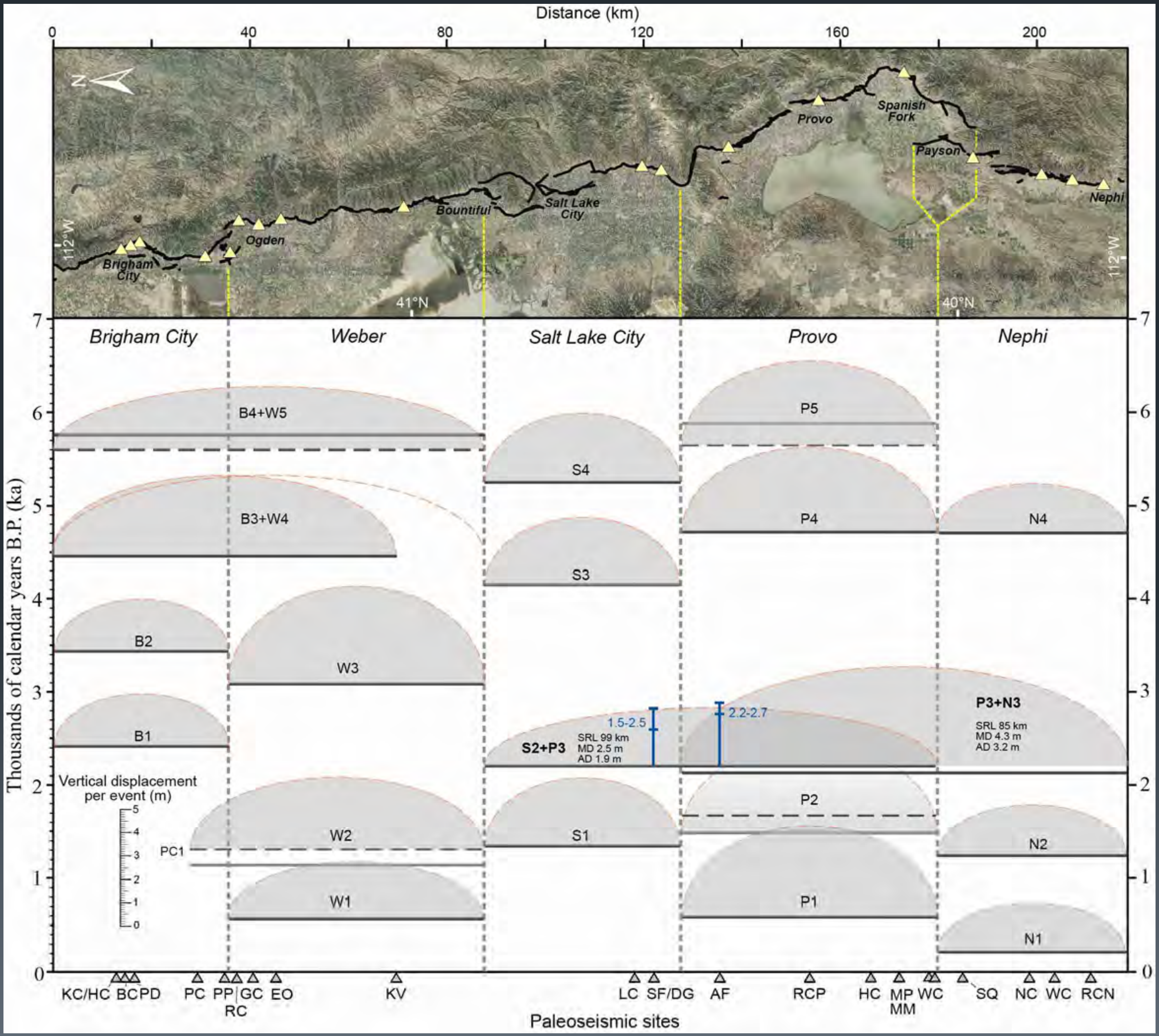
Modeled Displacement – Minimum Model

- 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



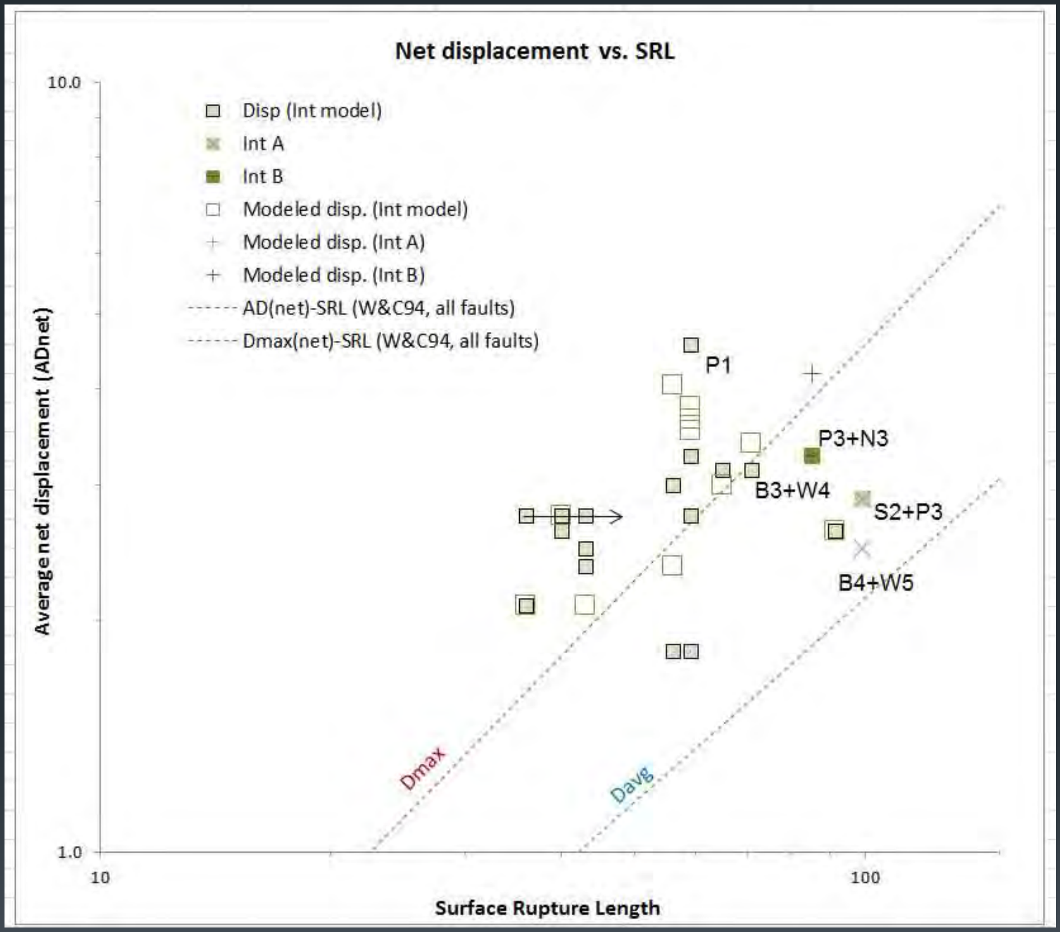
Values are mean ± 2σ

Modeled Displacement – Intermed. Models



Modeled Displacement – Intermed. Models

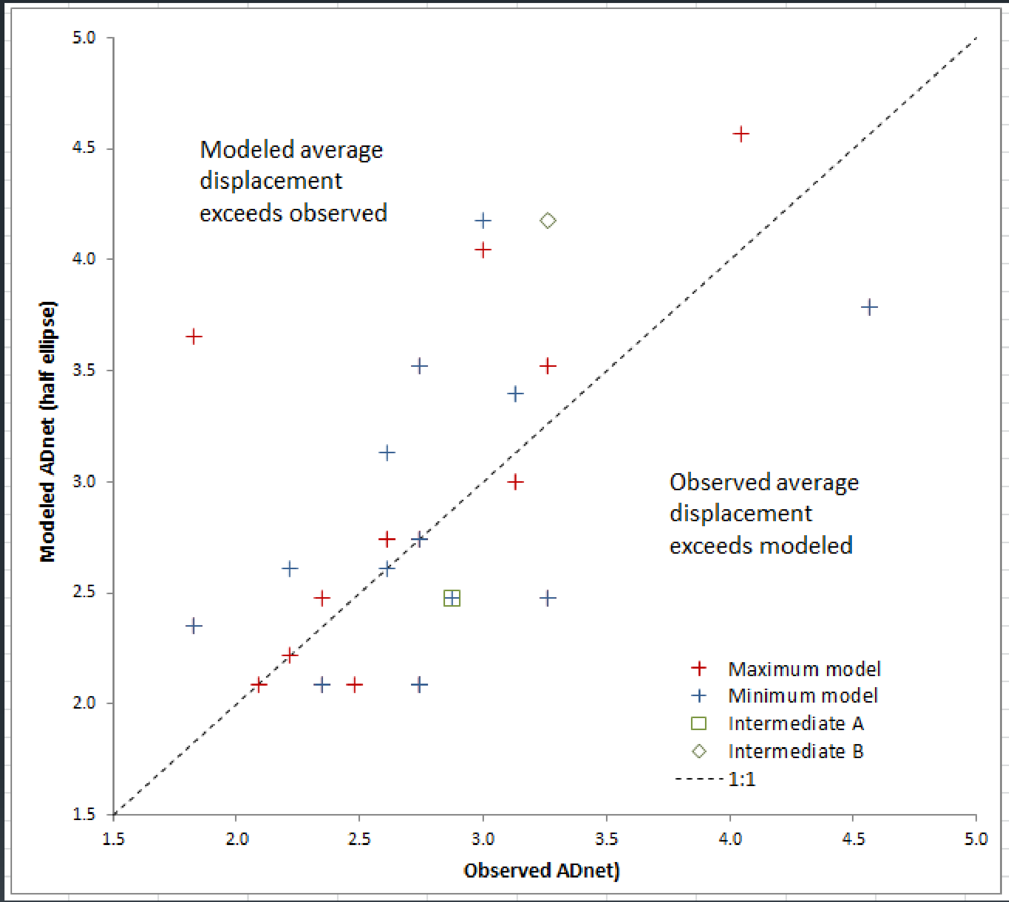
- Observed (trenches)
  - Mean AD(net): 2.8 ± 1.2 m *(2σ)*
- Modeled (half ellipses)
  - Mean of AD(net): 2.8 ± 1.3 m



Values are mean ± 2σ

Displacement Conclusions I

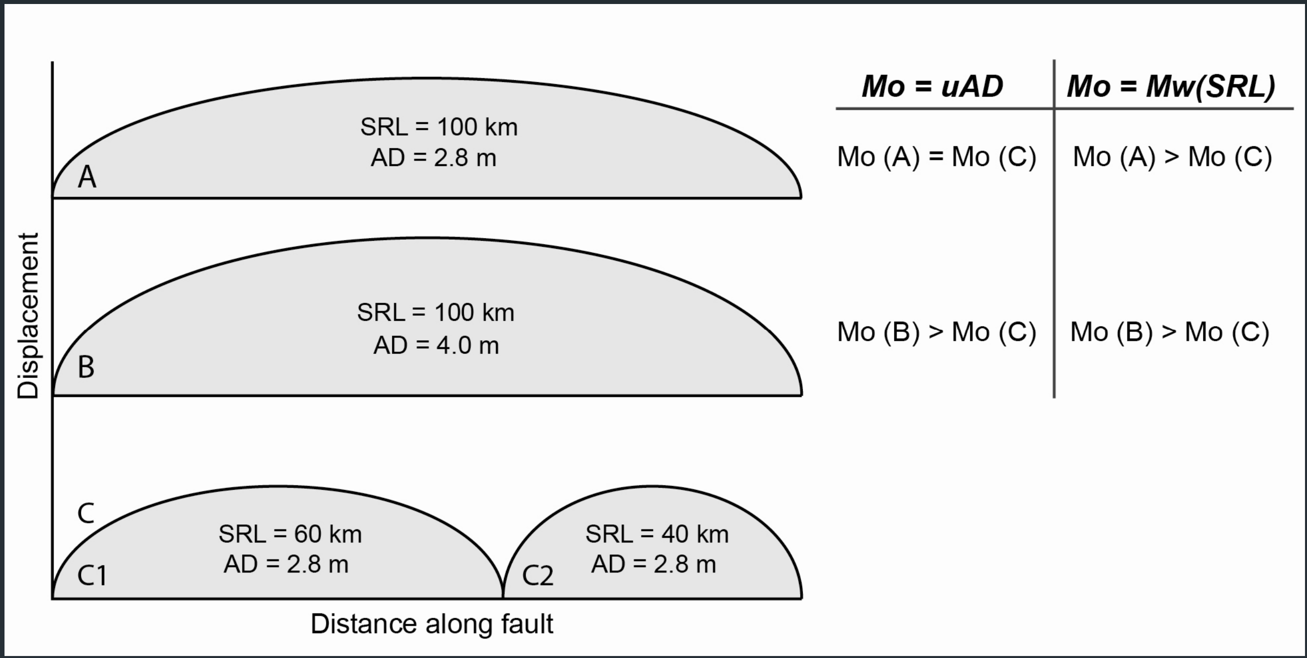
- Per-event displacements are consistently large (site bias?, longer SRLs?)
- For modeled profiles: observed displacements adequate to constrain half ellipses (rather than using historical regression)
- Some significant differences in observed and modeled displacements, but as a whole, AD(net) consistent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



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

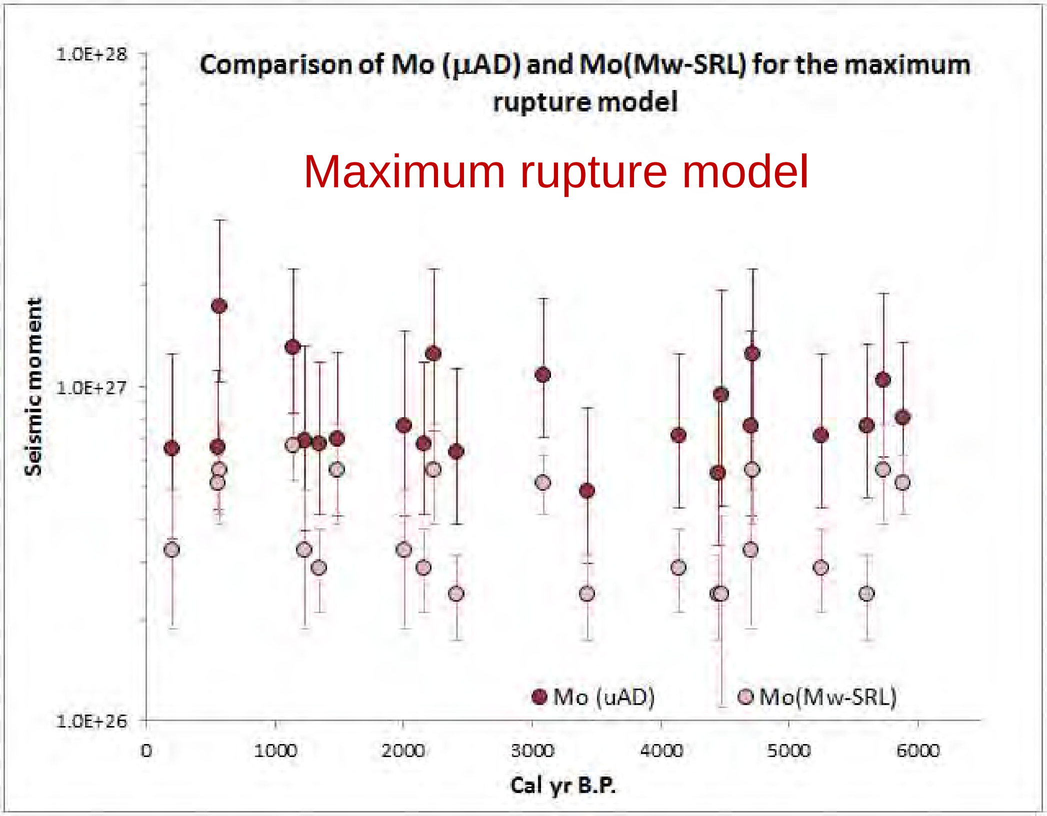
Displacement Conclusions II

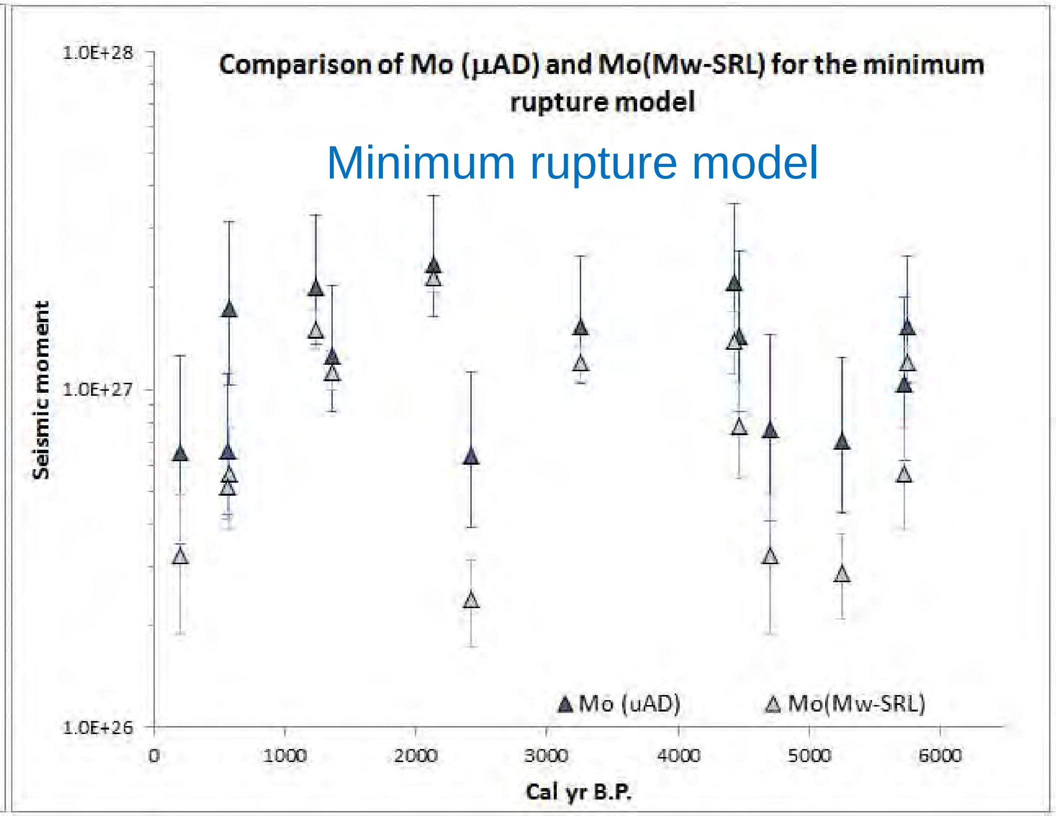
- Possible that displacement does not scale significantly with SRL for larger ruptures…
  - Both single-segment and multi-segment rupture profiles moderately well constrained by observed data
  - For example, B2 – 1.6 m, W3 – 3.1 m, B2+W3 – 2.4 m (ADnet)



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)

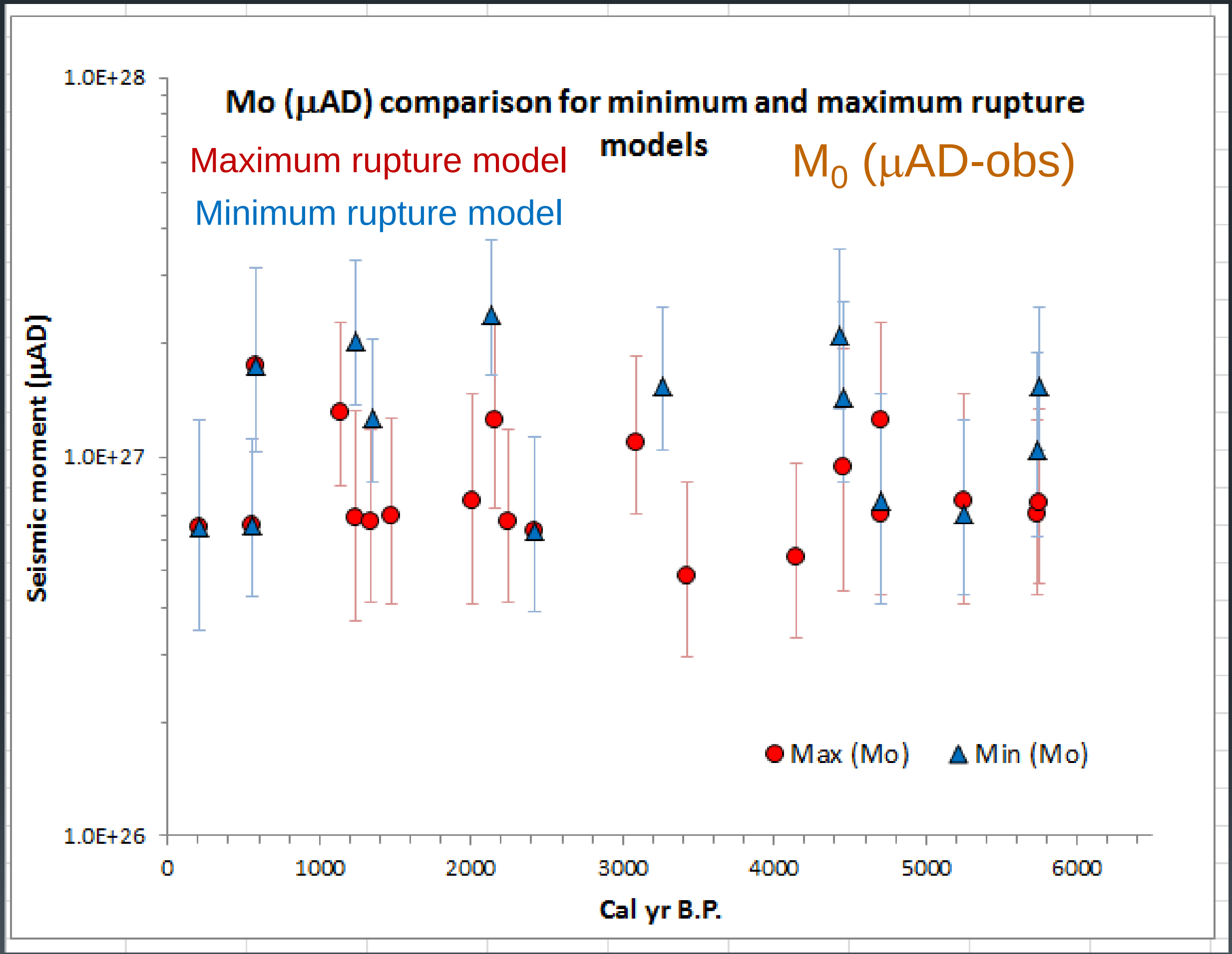




- M_0 (μAD) (darker color) consistently greater than M_0 (Mw-SRL) (lighter color)
  - M_0 (μAD) is 2.3 ± 0.6 times greater than M_0 (Mw-SRL) for maximum model
  - M_0 (μAD) is 1.8 ± 0.6 times greater than M_0 (Mw-SRL) for minimum model
- Differences related to large net displacements (~2.8 m avg.)

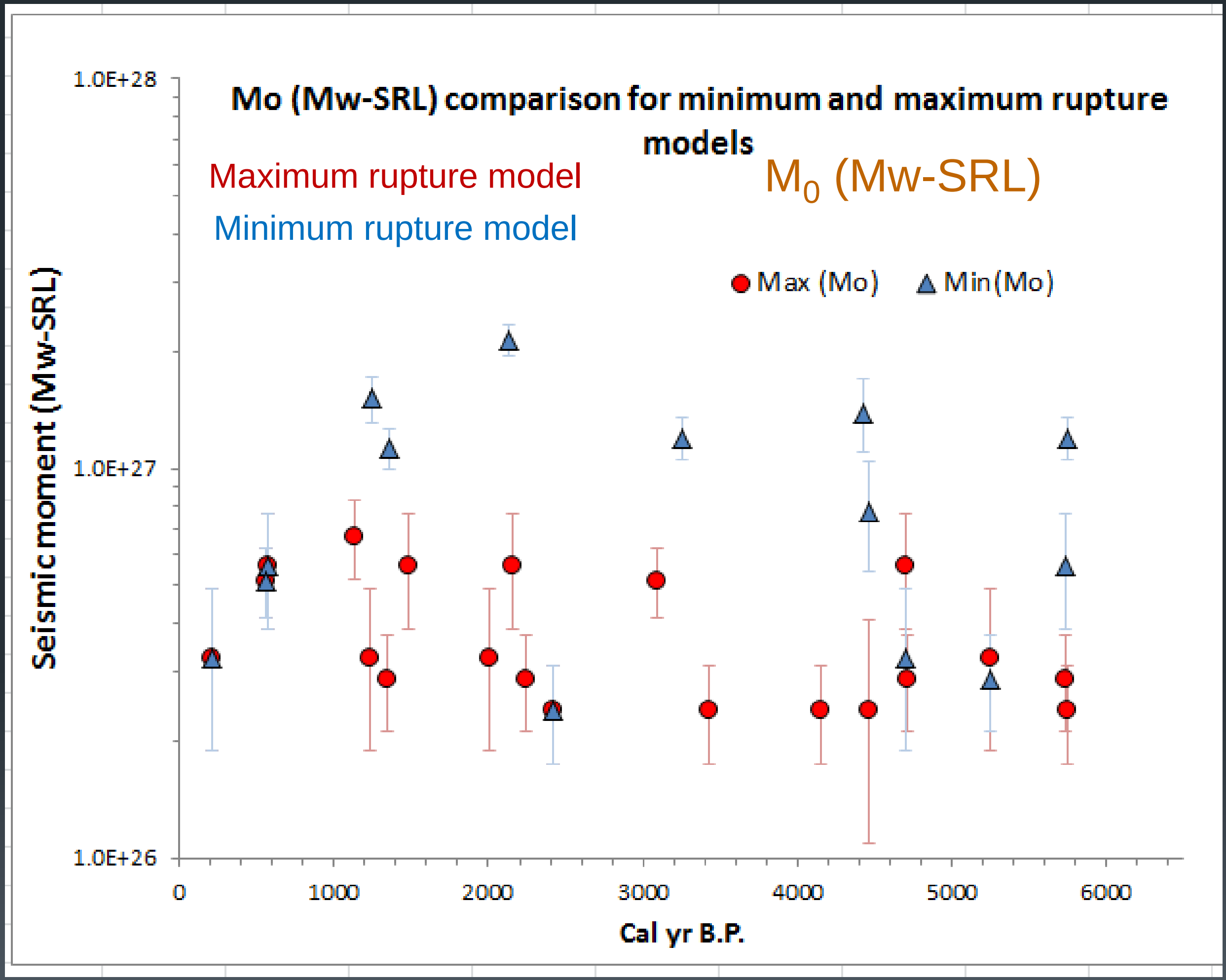
M_0 Release in Min and Max Models

- Greater M_0 release per earthquake in Minimum rupture model (blue), but fewer earthquakes
  - M_0 sum for minimum model approximately equal to sum for maximum model

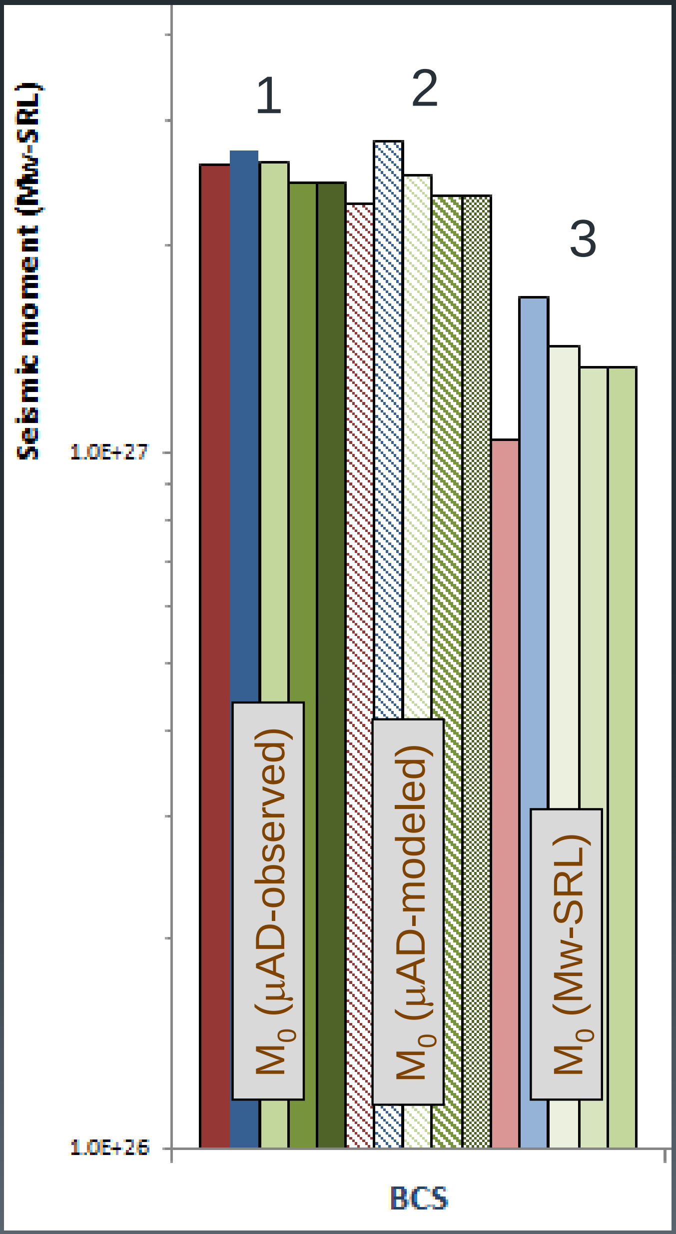


M_0 Release in Min and Max Models

- Greater M_0 release <u>per earthquake</u> in Minimum rupture model (blue), even though there are fewer earthquakes
  - M_0 sum for minimum model <u>40% greater</u> than moment sum for maximum model



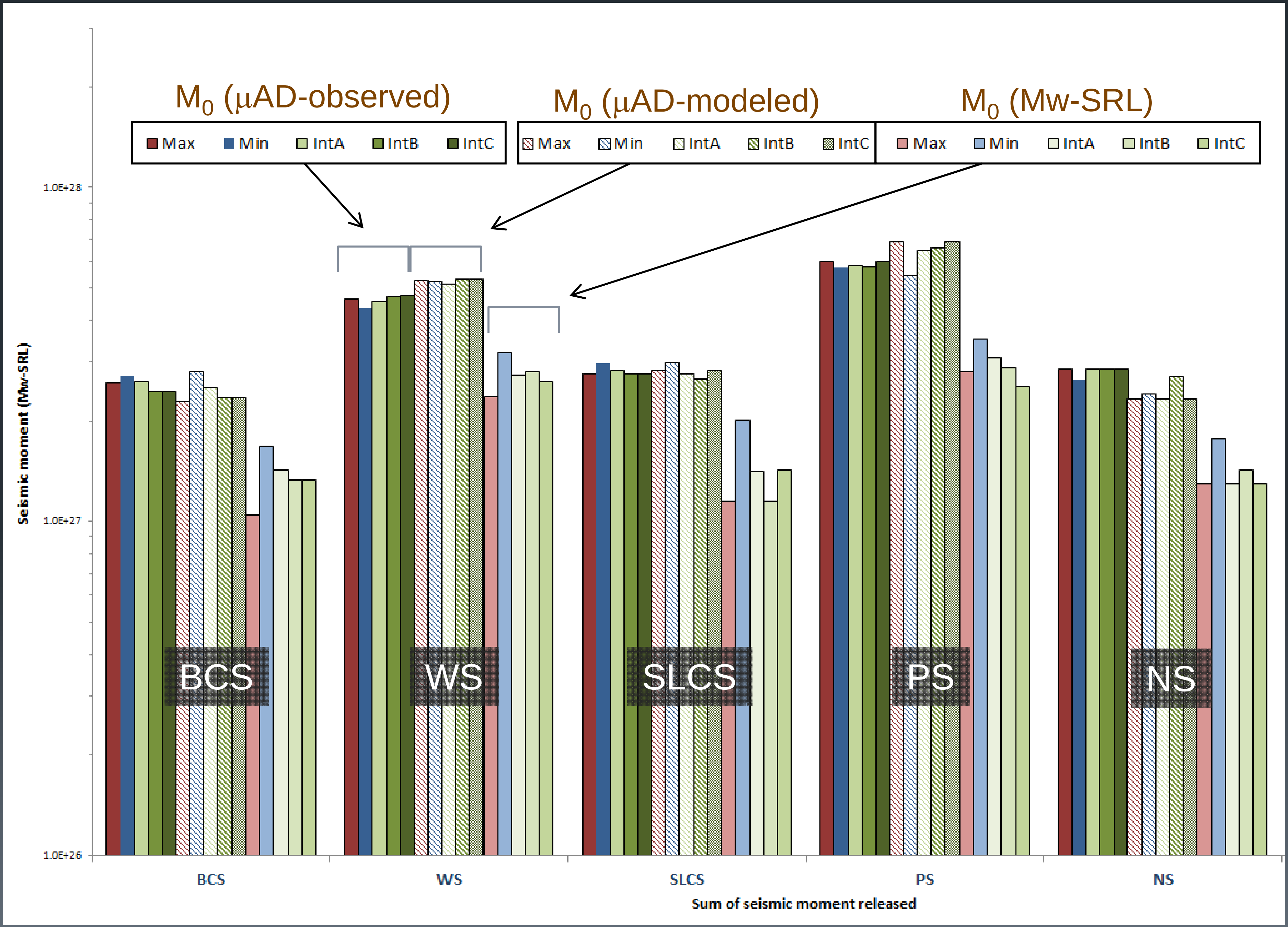
Moment Comparison



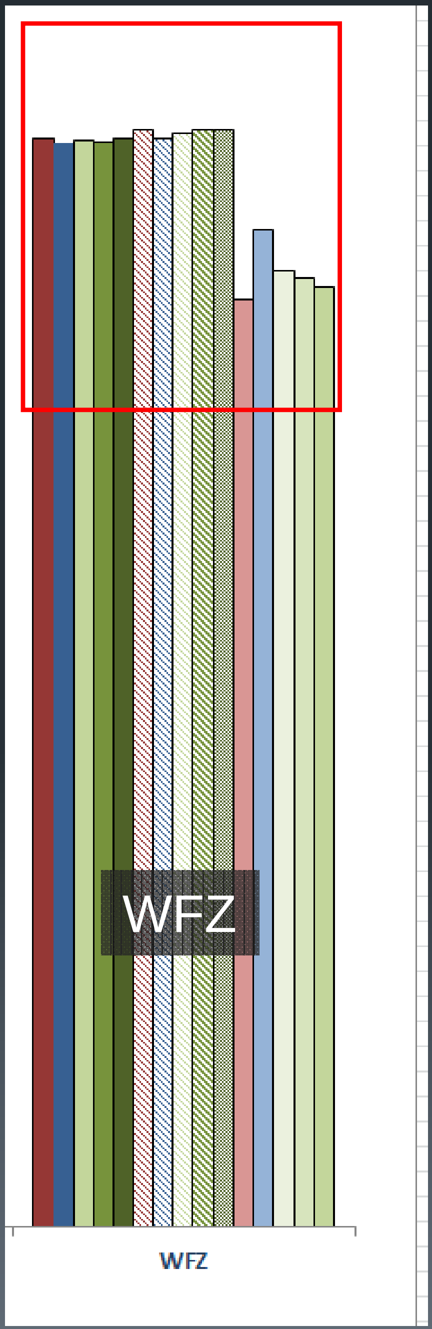
- Sum of M_0 per segment
  1. M_0 (μAD-observed) – dark colors
  2. M_0 (μAD-modeled) – hachured
  3. M_0 (Mw-SRL) – light colors

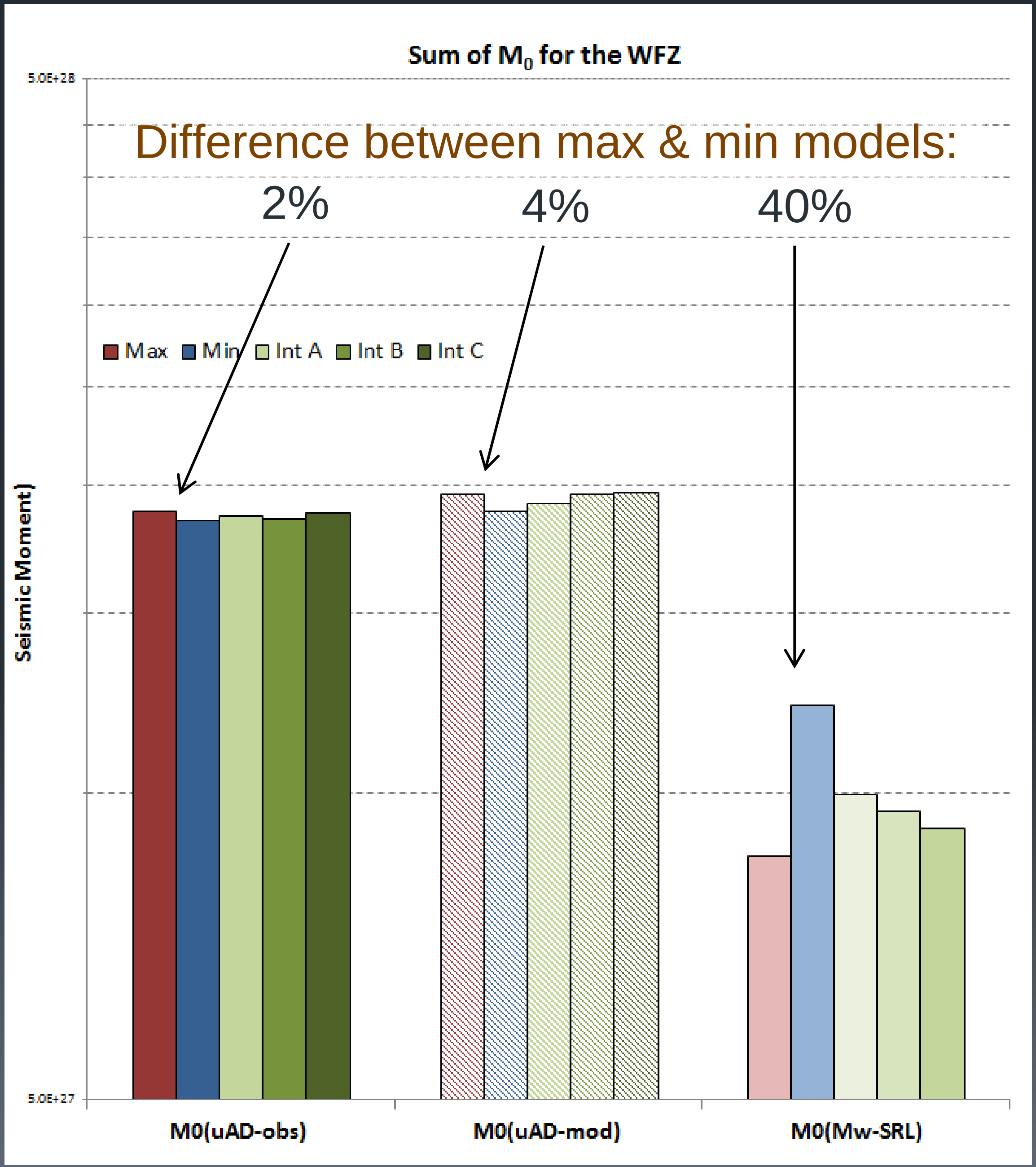
- Rupture models:
  - Maximum
  - Minimum
  - Intermediate A
  - Intermediate B
  - Intermediate C

Moment Comparison

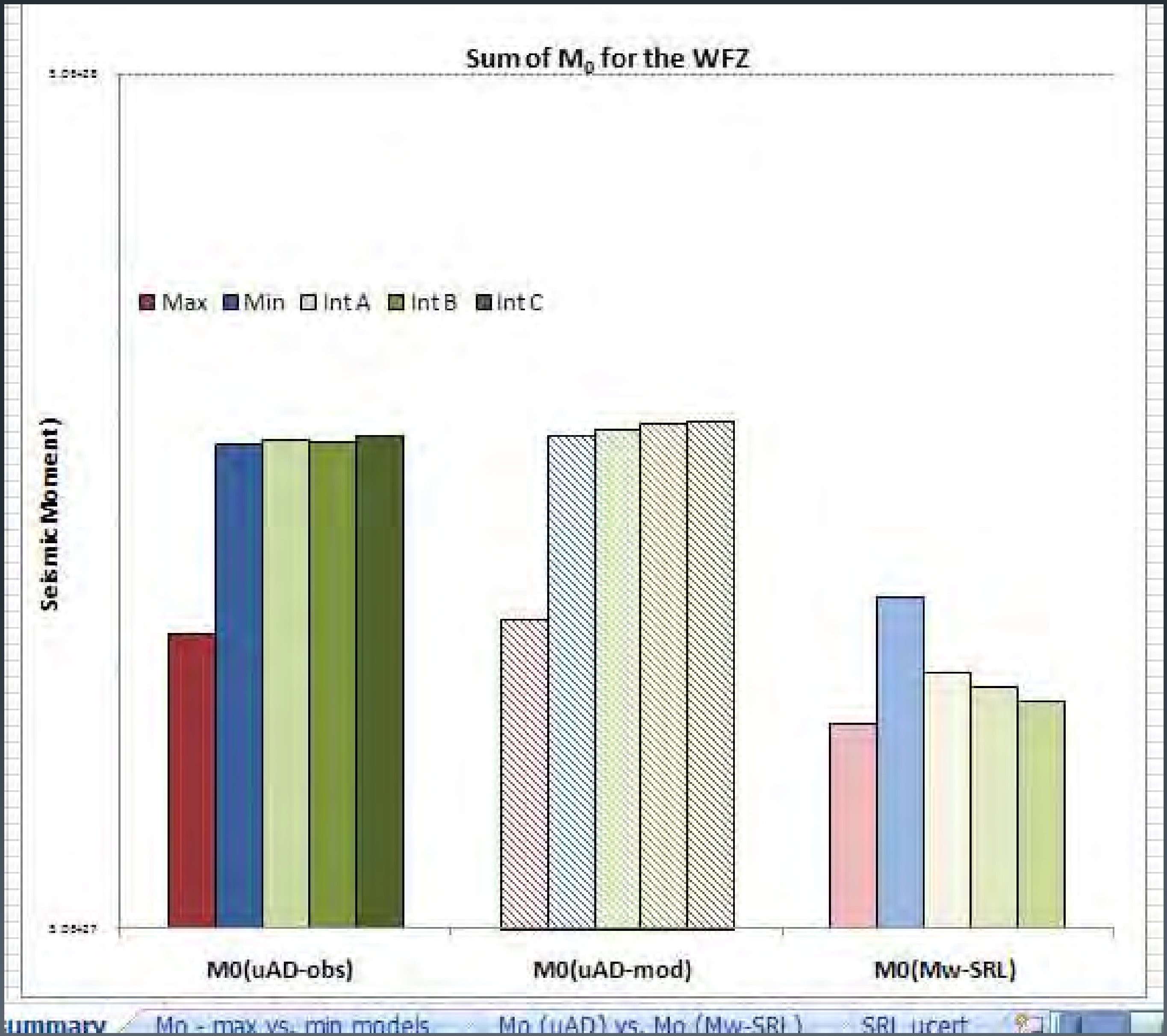


Moment Comparison - WFZ





➢ 90 degree dip



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

Moment balancing?

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

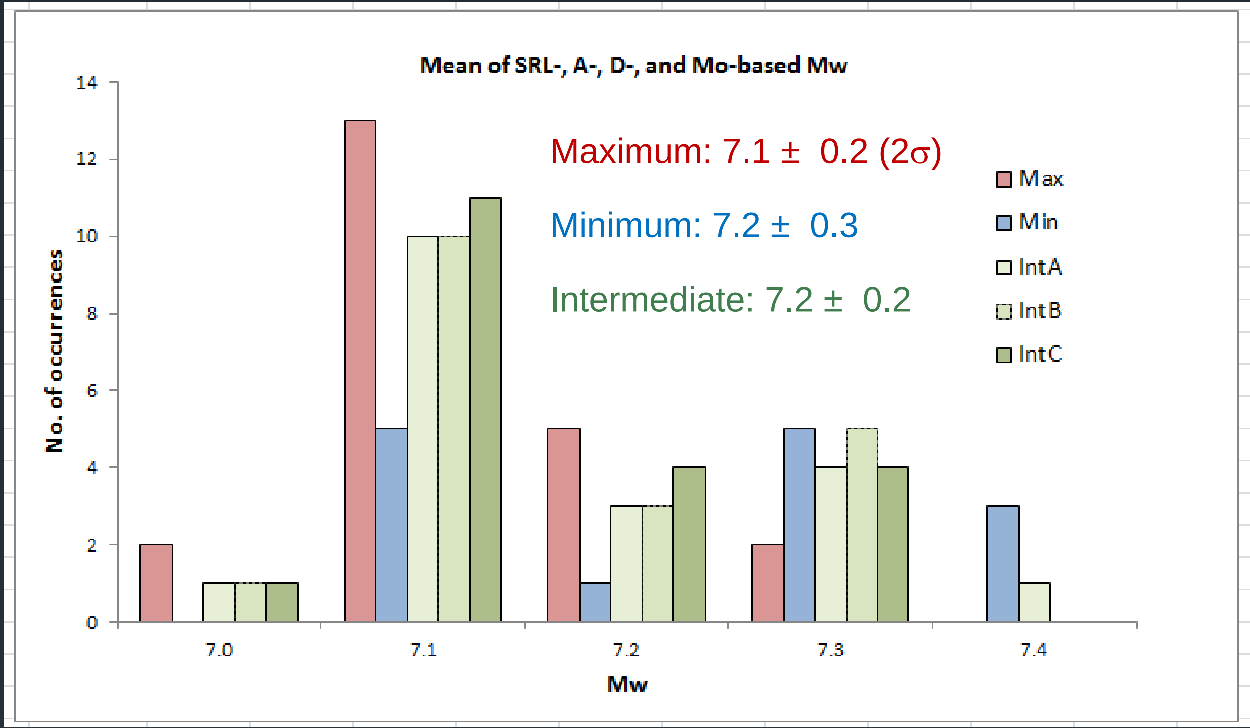
➢ Single rate for WFZ, or segment specific?

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

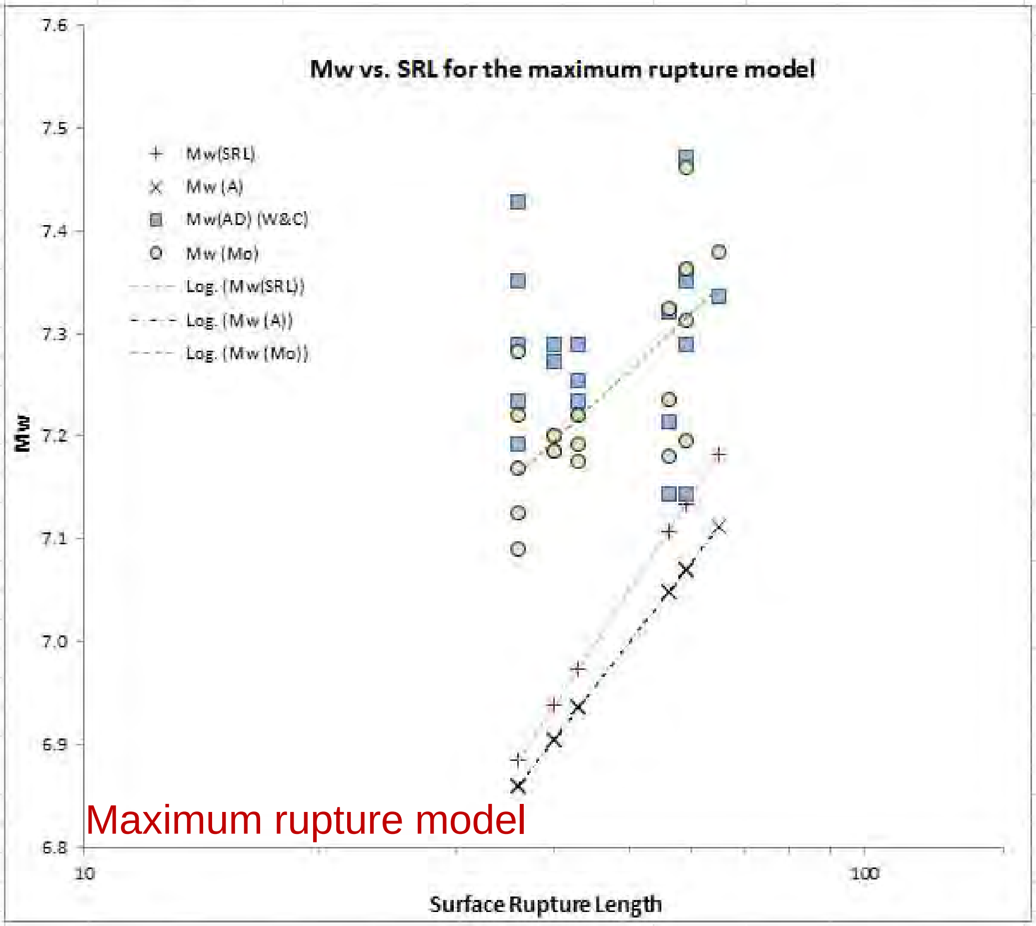
- Maximum model
  - M_W (SRL): 7.0 ± 0.2 (6.9 ± 0.2 – 7.1 ± 0.2)
  - M_W (A): 7.0 ± 0.2 (6.7 ± 0.2 – 7.2 ± 0.2)
  - M_W (AD): 7.3 ± 0.2
  - M_W (M_0-μAD): 7.2 ± 0.2
  - Mean M_W: 7.1 ± 0.2

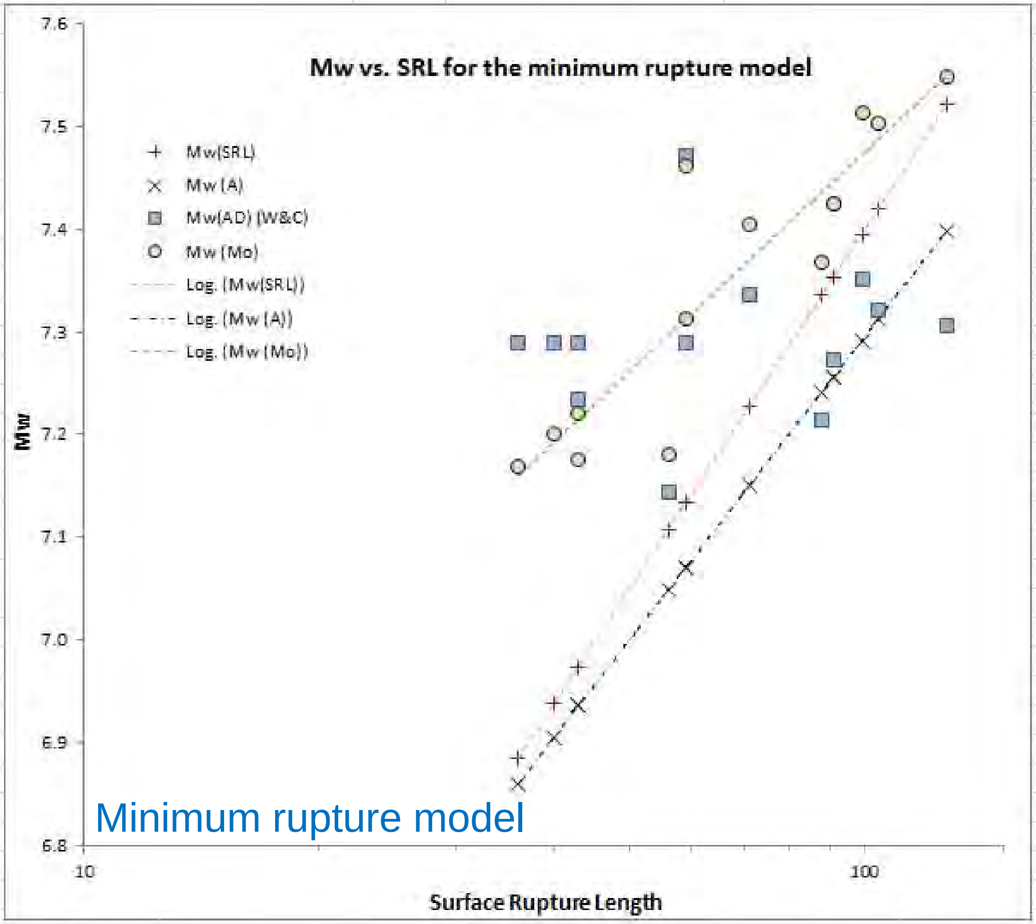


M_W values rounded to nearest 10th

- Minimum model
  - M_W (SRL): 7.2 ± 0.4 (7.1 ± 0.5 – 7.3 ± 0.4 using SRL uncert.)
  - M_W (A): 7.1 ± 0.3 (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



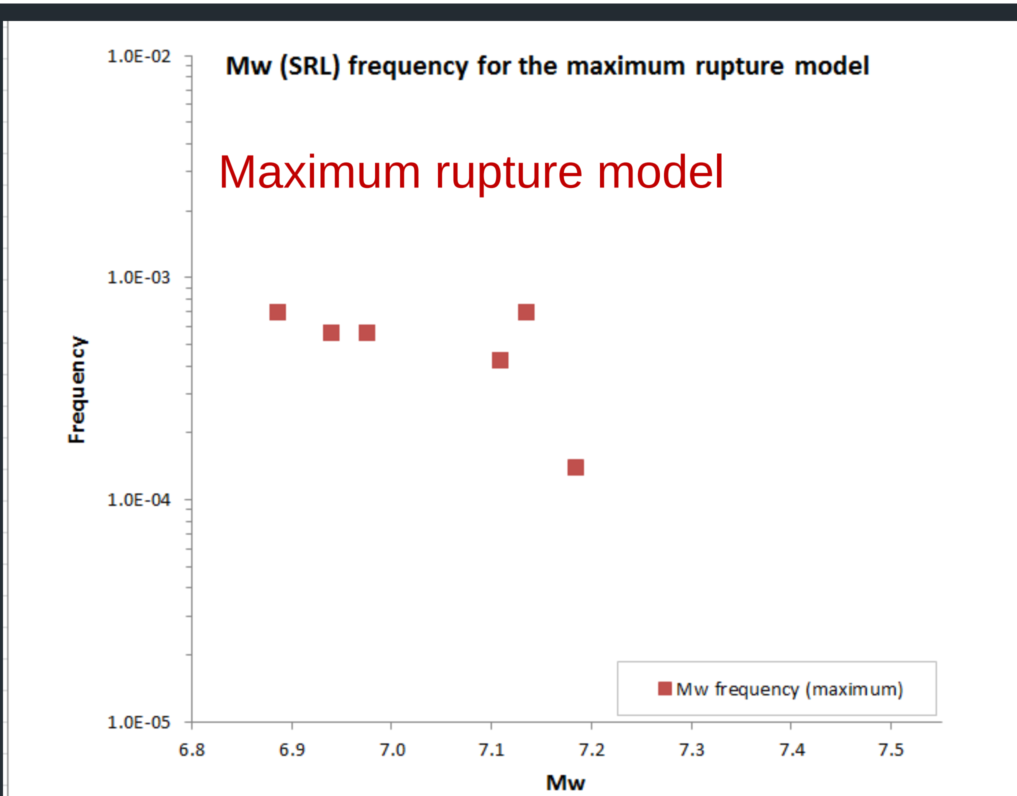


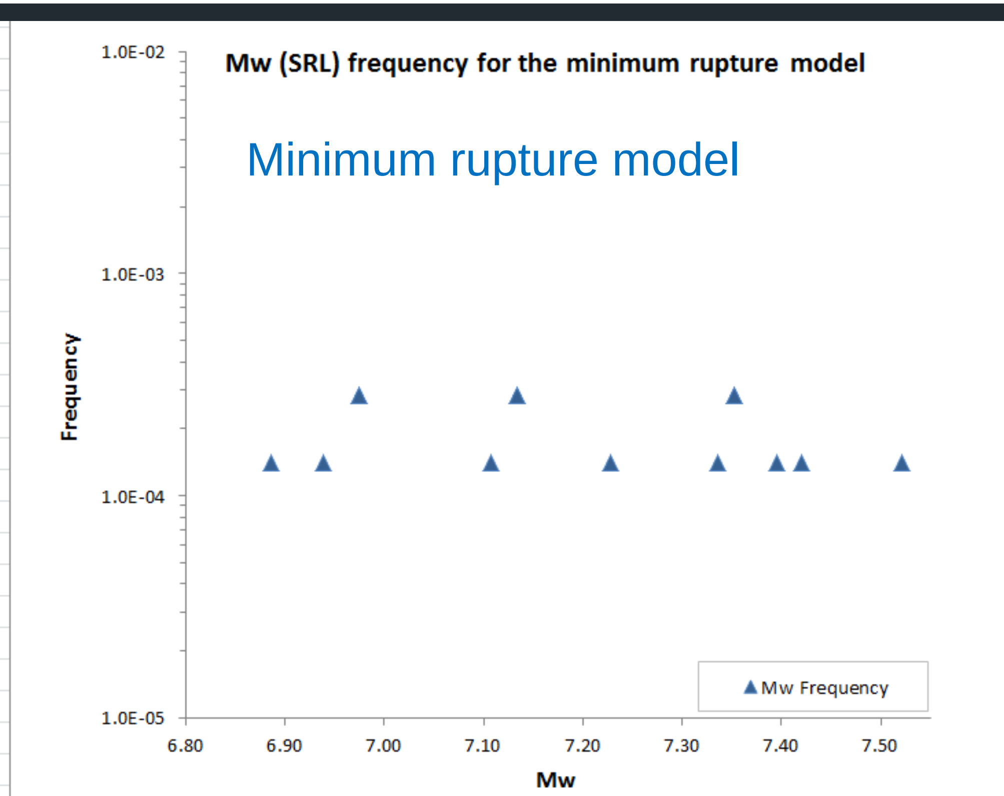
<u>Maximum model</u>

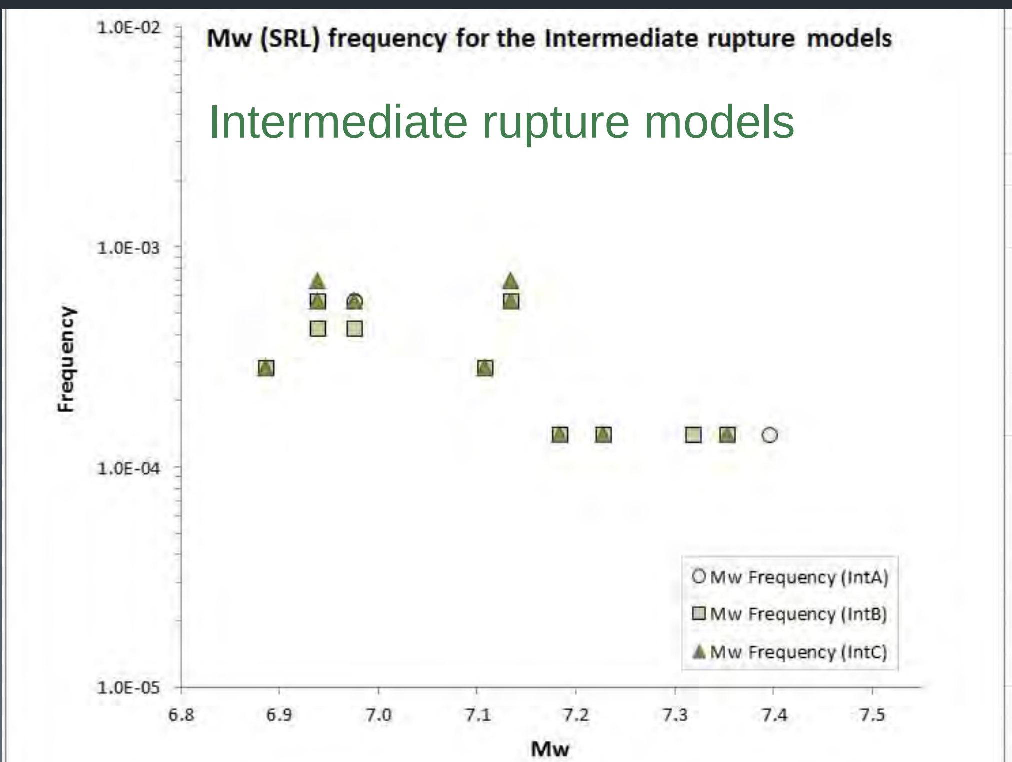
- M_W (D or M_0) consistently greater than M_W (SRL or A)

<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

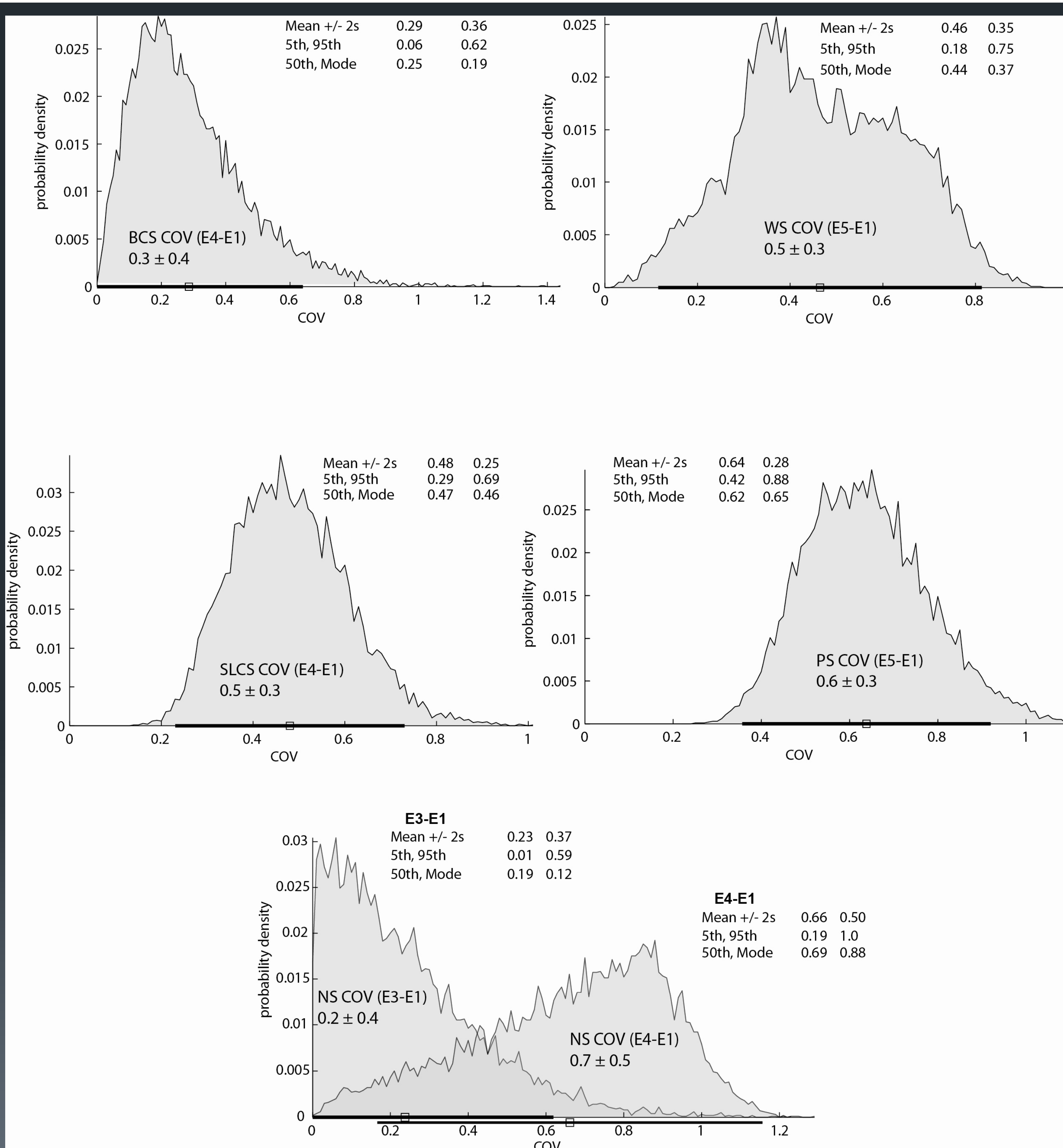
3. Calculate COV = standard deviation of RIs (138 yr) divided by the mean of them (1130 yr):
   - COV = 138/1130 = 0.12

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)

- **Next step:**
  calculate COV for each rupture model



Integration of Paleoseismic Data from Multiple Sites to Develop an Objective Earthquake Chronology:

Application to the Weber Segment of the Wasatch Fault Zone, Utah

Christopher B. DuRoss (UGS)

Stephen F. Personius (USGS)

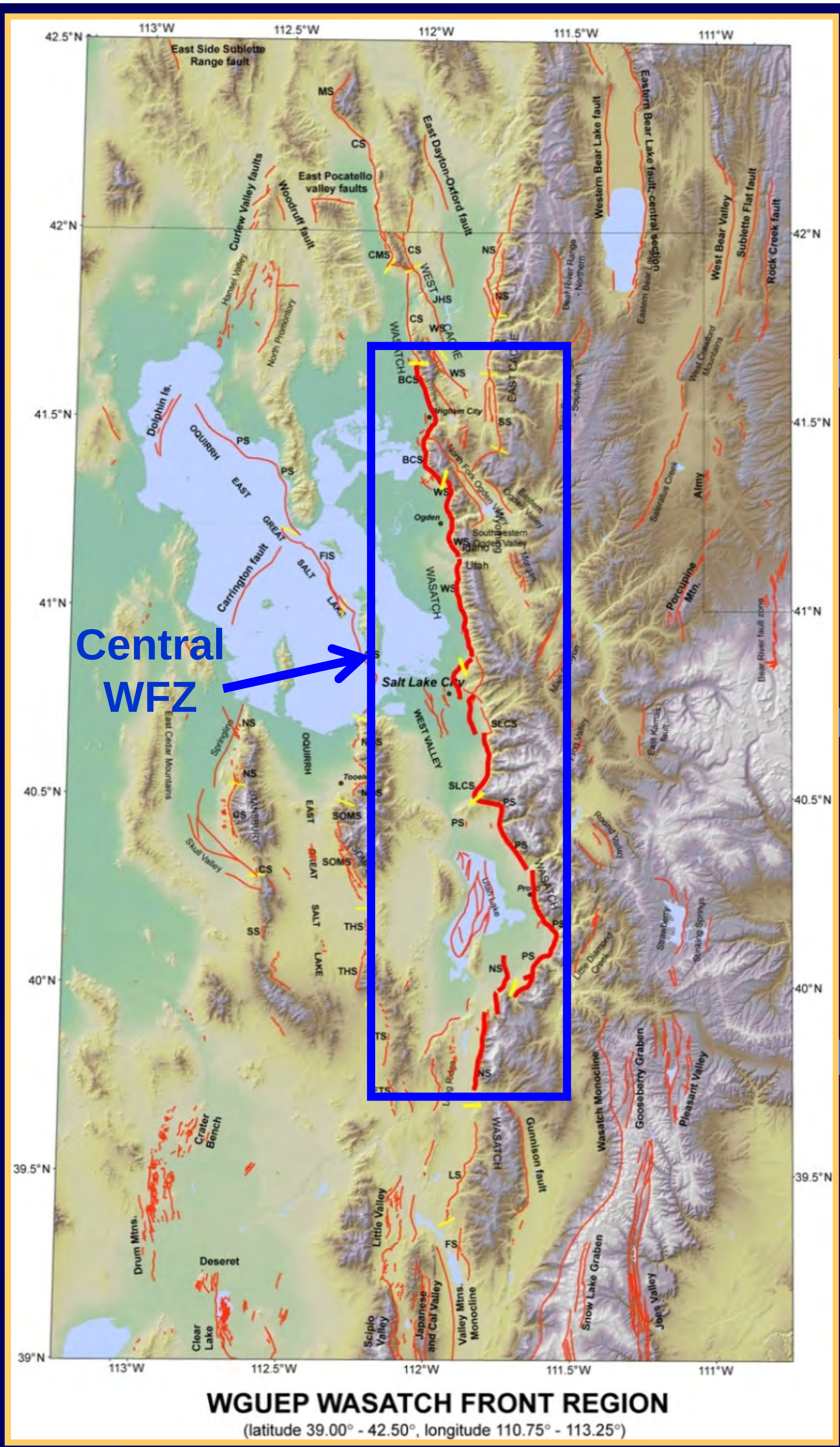
Anthony J. Crone (USGS)

Susan S. Olig (URS Corp.)

William R. Lund (UGS)

Introduction

- **Methodology:**
  - ✓ Integrate paleoseismic data from multiple sites on a segmented normal fault.
  - ✓ Yield a largely objective and reproducible chronology of earthquake times and recurrence estimates.
- **Motivation: Working Group on Utah Earthquake Probabilities (WGUEP) — developing a time-dependent earthquake forecast (M≥6.5) for the Wasatch Front region.**
- **Time-dependent element of forecast:**
  - ✓ Focus on five central segments of WFZ.
  - ✓ Earthquake timing information, including elapsed time since MRE.
  - ✓ Recurrence intervals for segments and entire fault.
  - ✓ Uncertainties in these values.

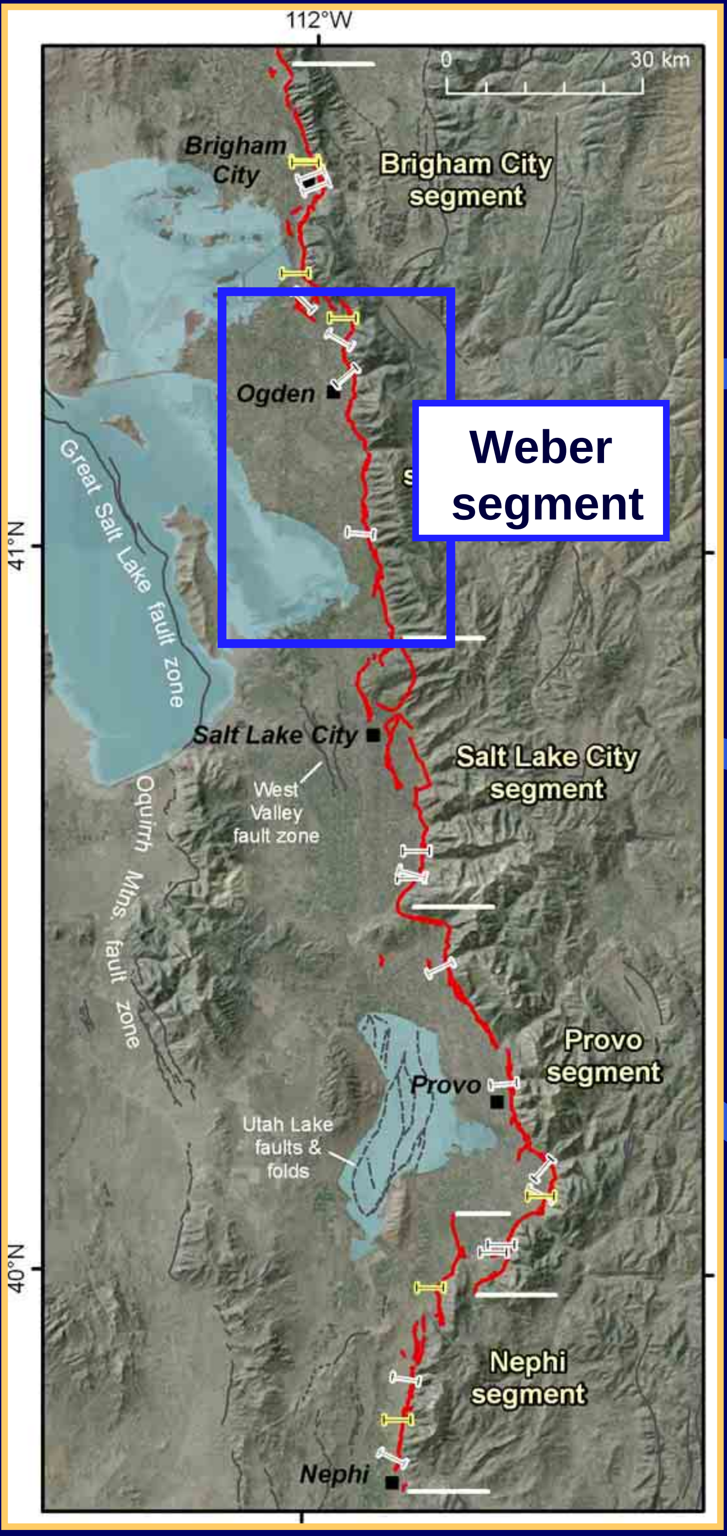


WGUEP study region

Issues with Paleoseismic Data

Abundant paleoseismic data collected for the WFZ over past 30 years, but still significant issues with these data:

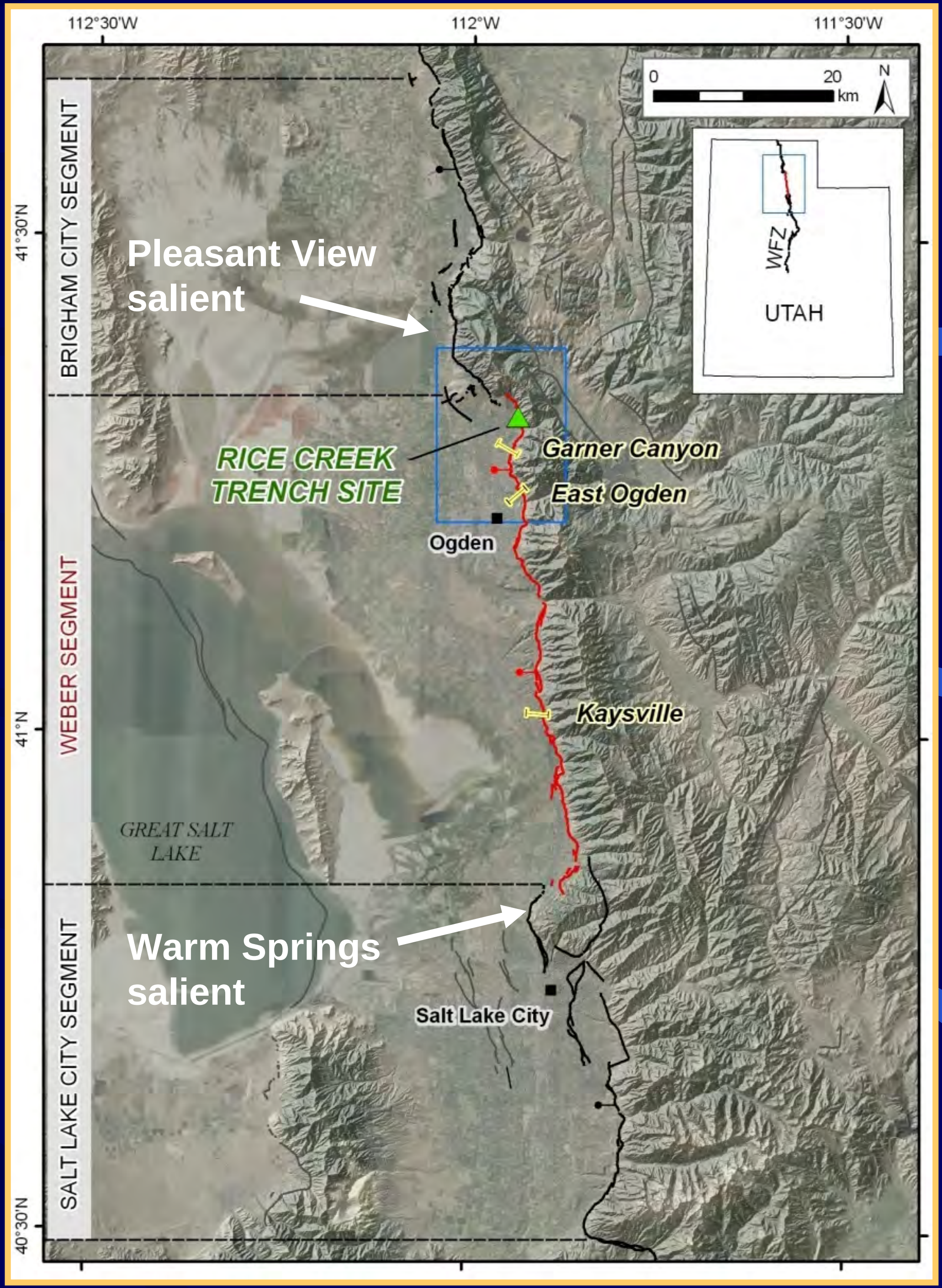
- **Trenching and dating methods have evolved.**
  - ✓ **Variable quality of data from site to site**
  - ✓ **Age constraints of events vary**
- **Correlating earthquakes between trench sites is not always obvious.**
- **Seven trench studies have been completed since the most recent review of WFZ paleoseismic data (2004 Utah Quaternary Fault Parameters Working Group).**
- **Apply our analysis to Weber segment of WFZ.**



WFZ trenches:
(I shapes; yellow I=post 2004)

Weber Segment

- **Paleoseismic studies:**
  - ✓ **Kaysville (K) – 1978/1988**
  - ✓ **Garner Canyon (GC) – 1985**
  - ✓ **East Ogden (EO) – 1986**
  - ✓ **Rice Creek (RC) – 2007**
- **Purpose of this work: integrate new Rice Creek data with previous paleoseismic data.**
- **Resolve questions:**
  - ✓ **Timing & extent of MRE?**
  - ✓ **Correlation of older earthquakes?**
  - ✓ **Holocene recurrence interval?**



Detailed map: Weber segment, Wasatch fault zone

The Problem

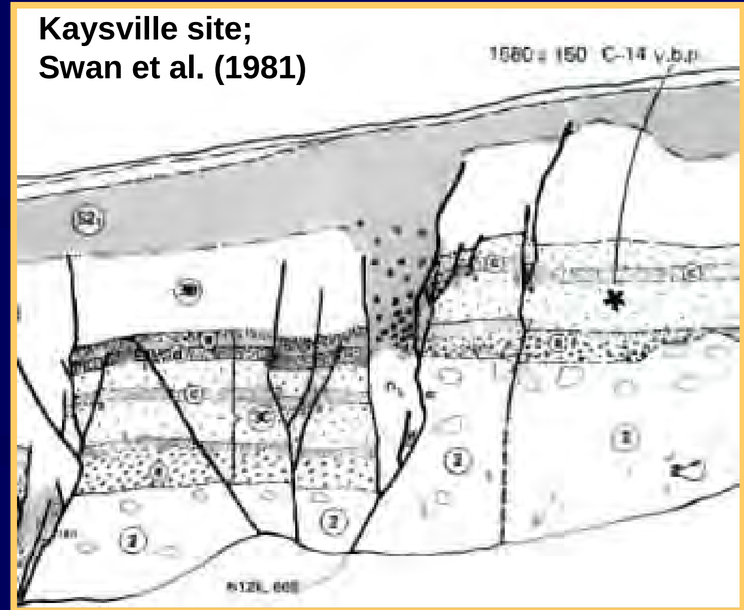
- How do we distill variable-quality paleoseismic data from multiple sites into an objective earthquake record that applies to the entire segment?

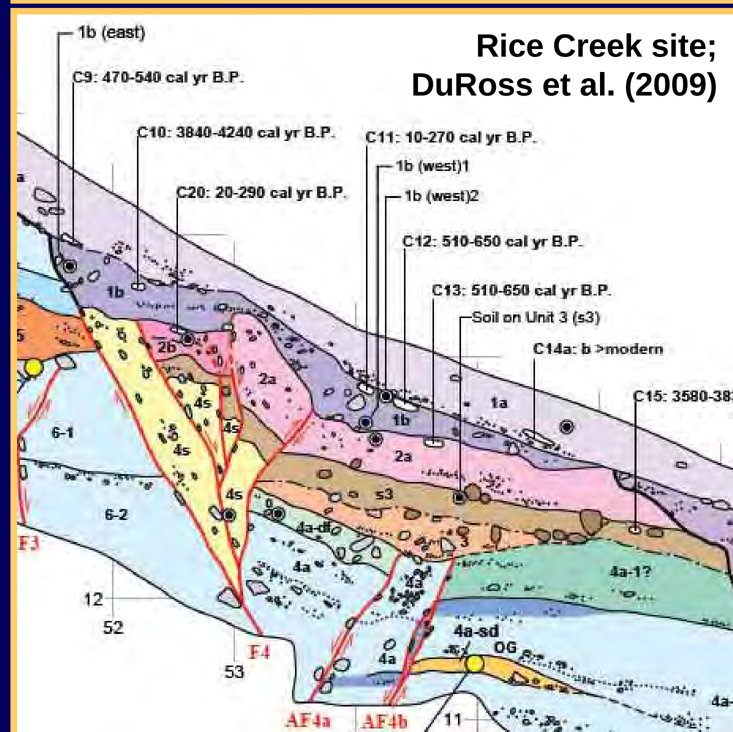
- <u>The Approach</u>:
  1. Systematically review all paleoseismic data, especially the stratigraphic evidence for earthquakes, evaluation of the dating, and interpretation of results.
  2. Construct time-stratigraphic OxCal models for each trench site.
  3. Correlate events between sites to develop a segment-wide history.
  4. Compute probability density functions (PDFs) for the time of each segment-wide earthquake (using Matlab).
  5. Use segment-wide earthquake data to objectively determine earthquake recurrence values.

1. Review Paleoseismic Data for Site

- **Systematically evaluate evidence for earthquakes (legacy studies and recent studies).**
  - ✓ **Stratigraphic framework for events.**
  - ✓ **Completeness of record**
    - o **All scarps trenched?**
    - o **Orphan (undated) colluvial wedges?**
    - o **Events missing, but expected?**

- **Considered limiting ages and uncertainties in the dating of events.**
  - ✓ **Sample locations and nature of dated material.**
  - ✓ **Mean-residence-time (MRT) correction(s) for bulk-soil ^{14}C ages.**

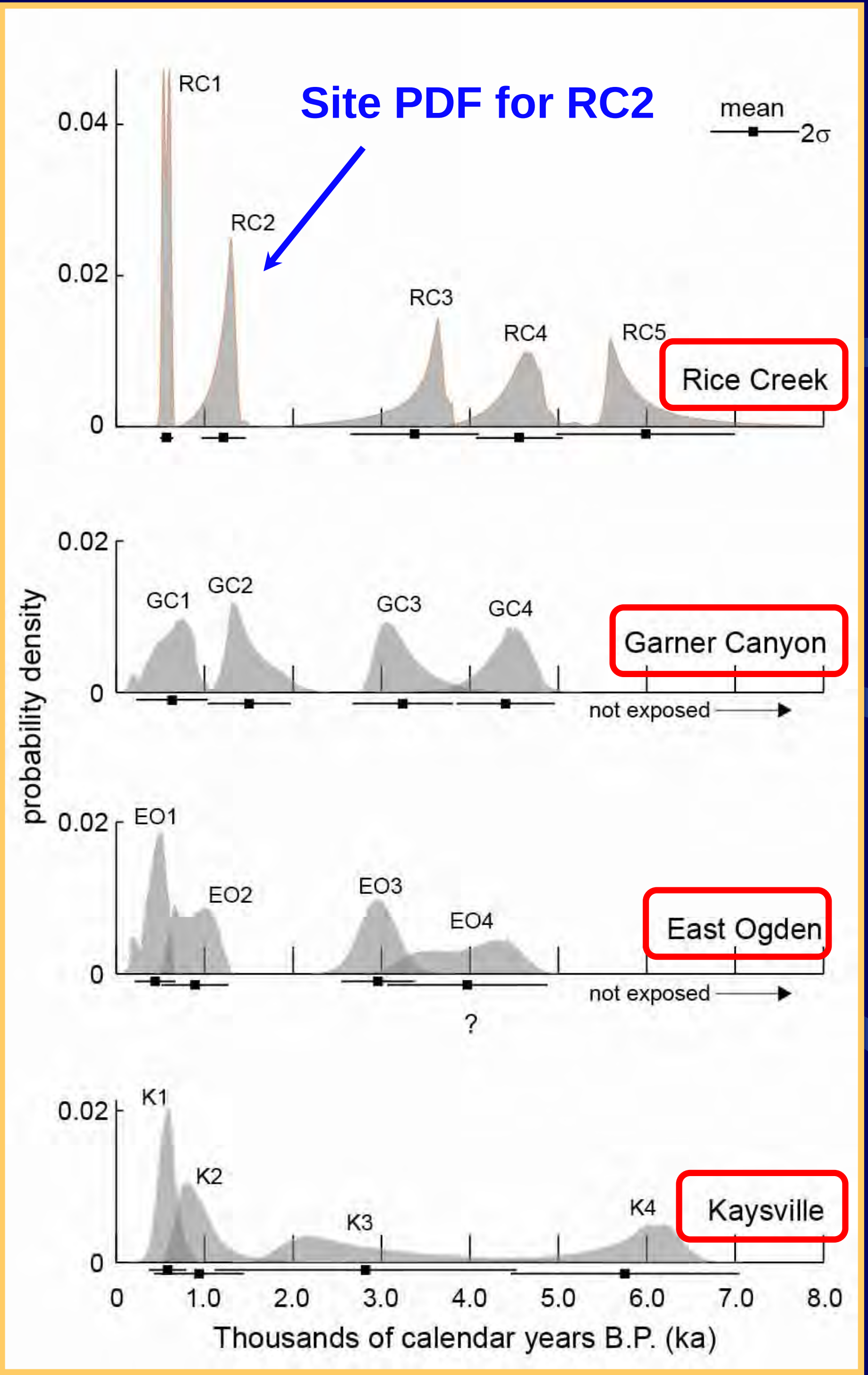

Kaysville site; Swan et al. (1981)



Rice Creek site; DuRoss et al. (2009)

2. OxCal Models

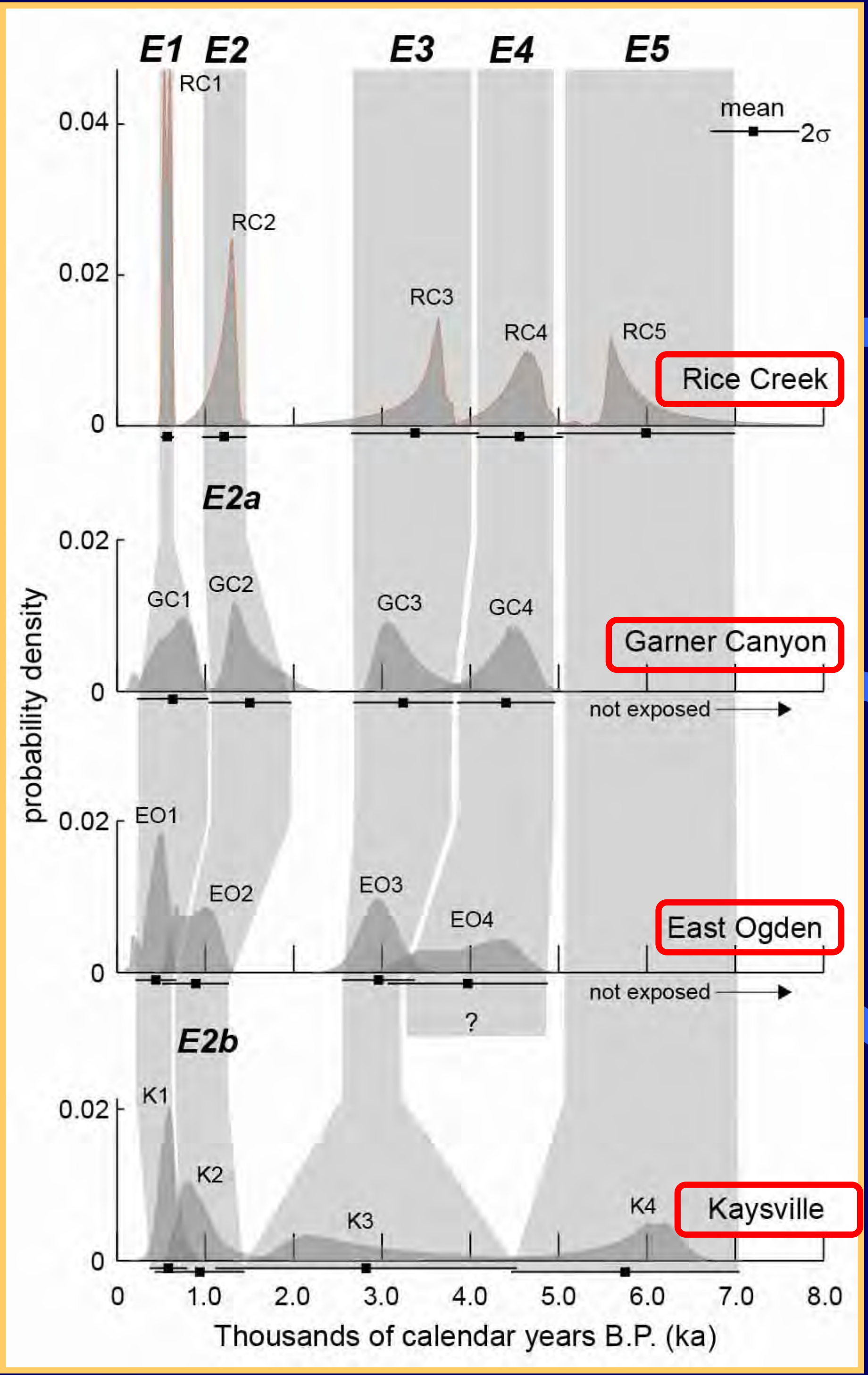
- OxCal (http://c14.arch.ox.ac.uk)
  - ✓ *"Radiocarbon calibration program OxCal provides paleoseismologists with a straightforward but rigorous means of estimating [paleoearthquake] ages and their uncertainties."* (Lienkaemper and Bronk Ramsey, Seism. Res.Lett., 2009)
  - ✓ Develop a model of sequence of depositional and faulting events based on stratigraphic relations at each site.
  - ✓ OxCal analysis yields the time distributions (PDFs) of undated events (e.g., earthquakes) based on the stratigraphic and chronological model.
  - ✓ Objectively evaluates paleoseismic data and yields a PDF of the time of events.
  - ✓ Export PDFs for each site earthquake (site PDFs).



OxCal results for Weber segment paleoseismic sites

3. Earthquake Correlation

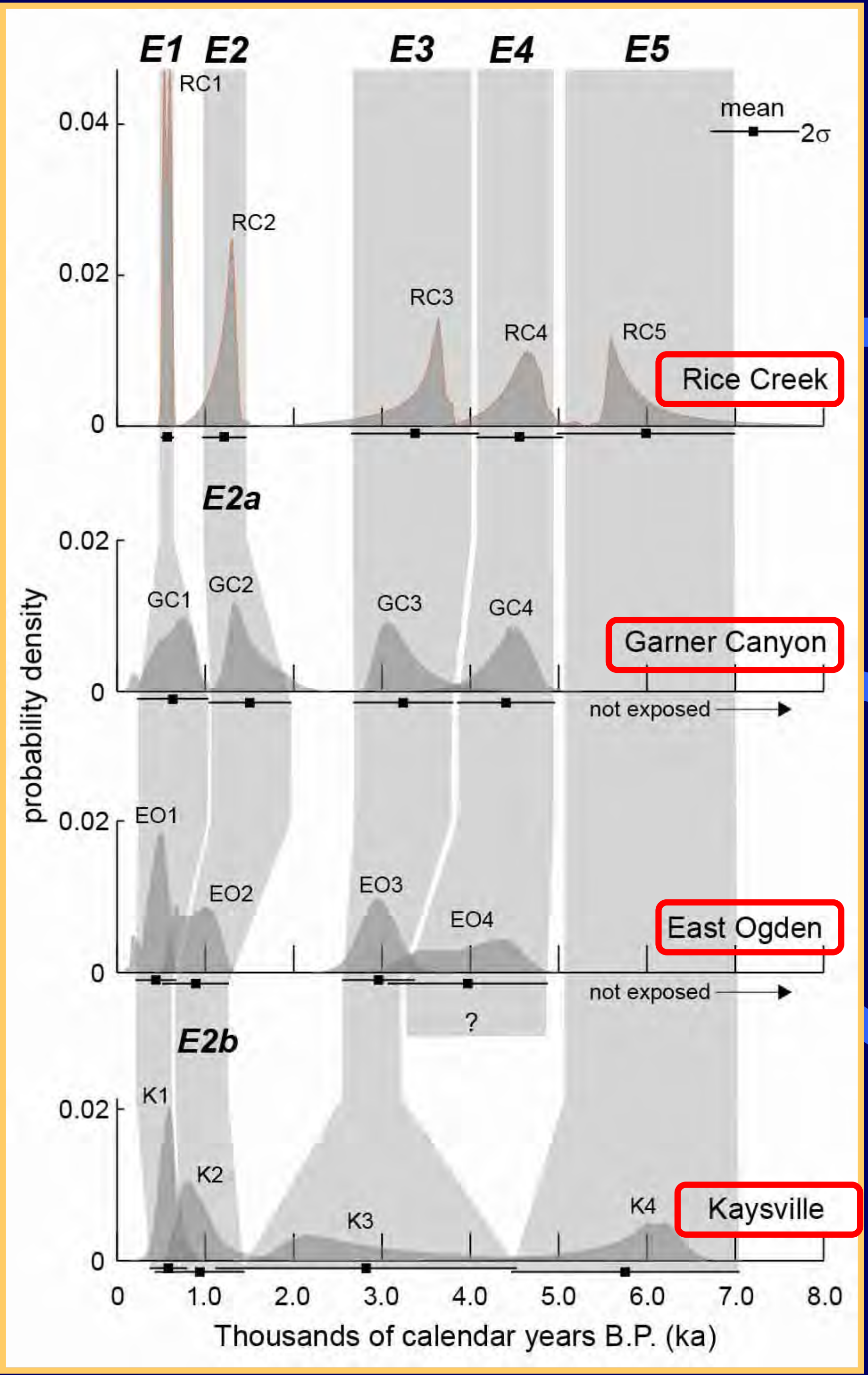
- **Correlate site PDFs to develop a segment-wide history.**
  - ✓ **MRE (E1) at 400–600 yr.**
  - ✓ **Possible that Weber segment ruptured in two separate earthquakes.**
    - **E2a at ~1.2-1.5 ka**
    - **E2b at ~0.9 ka**
  - ✓ **E4 not identified at Kaysville (Incomplete record?).**
  - ✓ **Oldest Kaysville event (~5.8 ka) likely corresponds with oldest Rice Creek event (~6 ka) to form E5.**



Subjective correlation of OxCal site PDFs

3. Earthquake Correlation

- **Caveats:**
  - ✓ We assume that the Weber segment behaves independently.
  - ✓ With exception, we do not consider partial- or multi-segment ruptures.
  - ✓ Supported by:
    - o Similar earthquake histories at the four paleoseismic sites (overlap in the site PDFs).
    - o Large per-event displacements (~2-m avg; 4-m max.).
    - o Prominent segment boundaries on the WFZ.

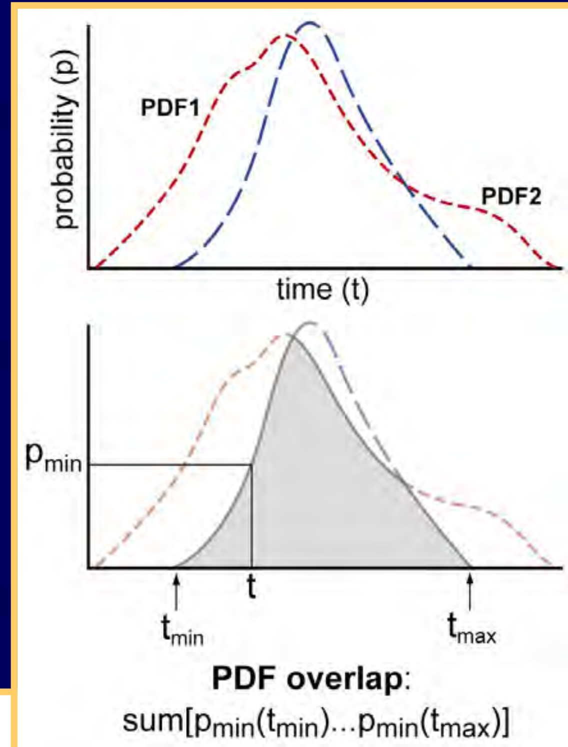


Subjective correlation of OxCal site PDFs

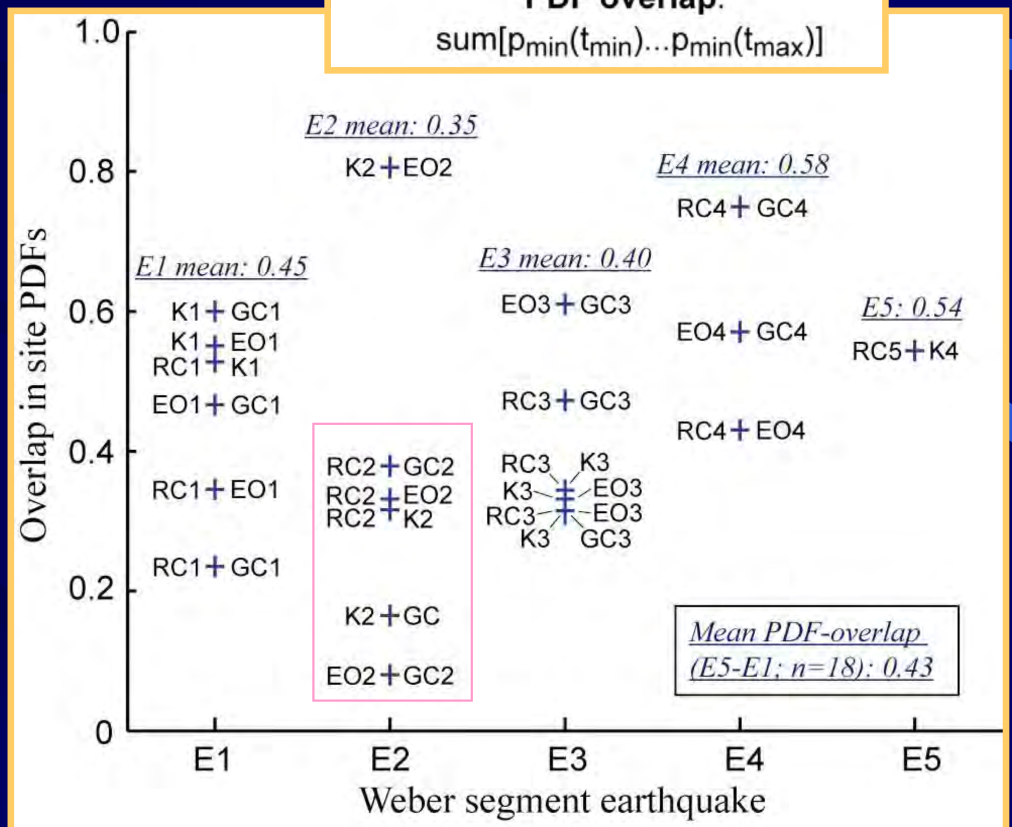
3. Earthquake Correlation

- **PDF overlap* quantifies the amount of site-PDF overlap, proxy for quality of correlation.**
  - ✓ **For two overlapping PDFs, sum of the minimum probabilities for each time bin in area of overlap (t_{min} to t_{max} in figure).**

PDF overlap



  - ✓ **0–1: zero to full overlap.**
  - ✓ **Mean PDF overlap per earthquake:**
    - o **E1: 0.45**
    - o **E2: 0.35 (some <0.2)**
    - o **E3: 0.40**
    - o **E4: 0.58**
    - o **E5: 0.54 (2 site PDFs)**



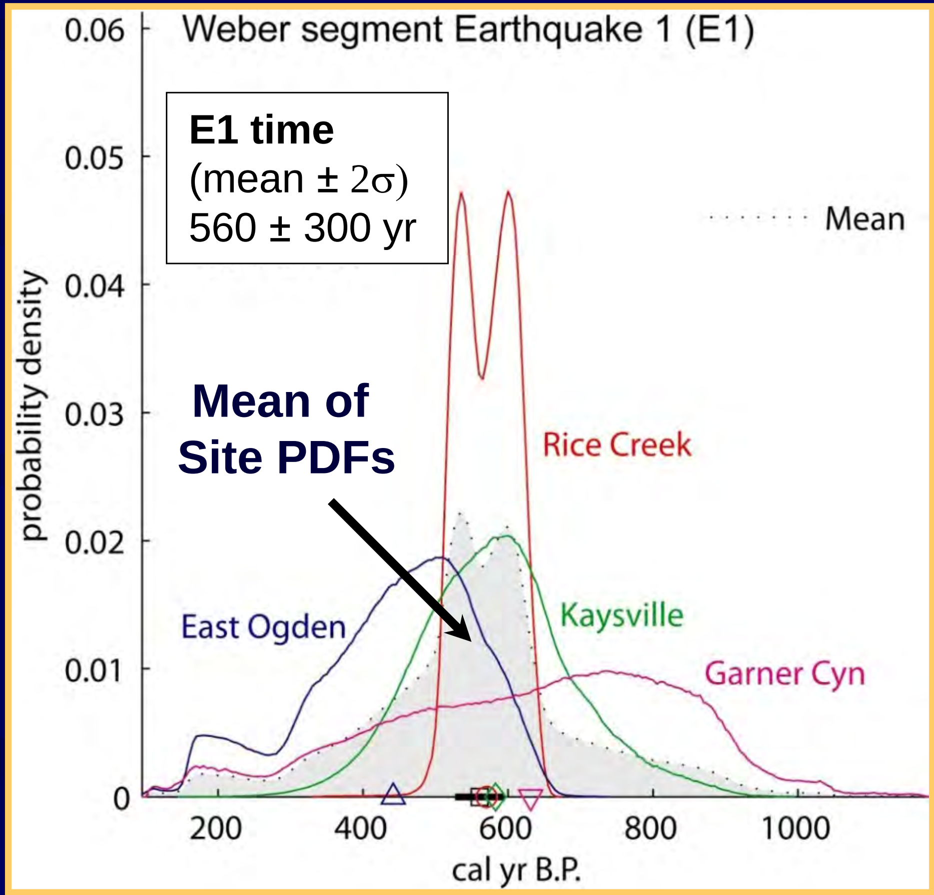
* from Biasi and Weldon (2009); BSSA, v. 99, no. 2A, p. 471–498

4. PDFs for Segment-wide Earthquakes

- **Combine OxCal models into segment chronology (Matlab).**
  - ✓ **Using correlation of events, combine correlative site PDFs to form single "segment PDF"**

***Simple Mean* of site PDFs (light gray)**

- ✓ **All site PDFs given equal weight.**
- ✓ **Mean earthquake time influenced by least well-constrained data (broadest PDFs).**
- ✓ **<u>E1 PDF</u> has long tails because of poorly constrained event age at Garner Canyon.**
- ✓ **Mean of PDFs is better suited to site PDFs with poor overlap or where correlation is uncertain.**



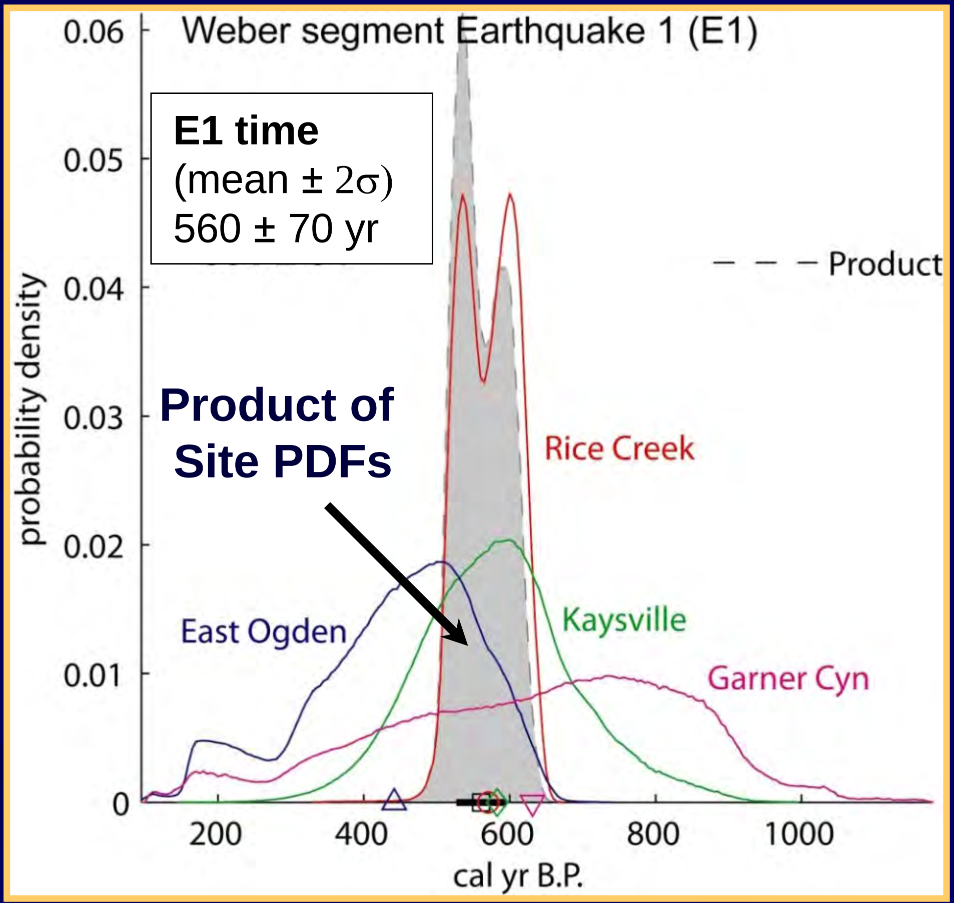
Site PDFs contributing to E1

4. PDFs for Segment-wide Earthquakes

- Combine OxCal models into segment chronology (Matlab).
  - ✓ Using correlation of events, combine correlative site PDFs to form single "segment PDF"

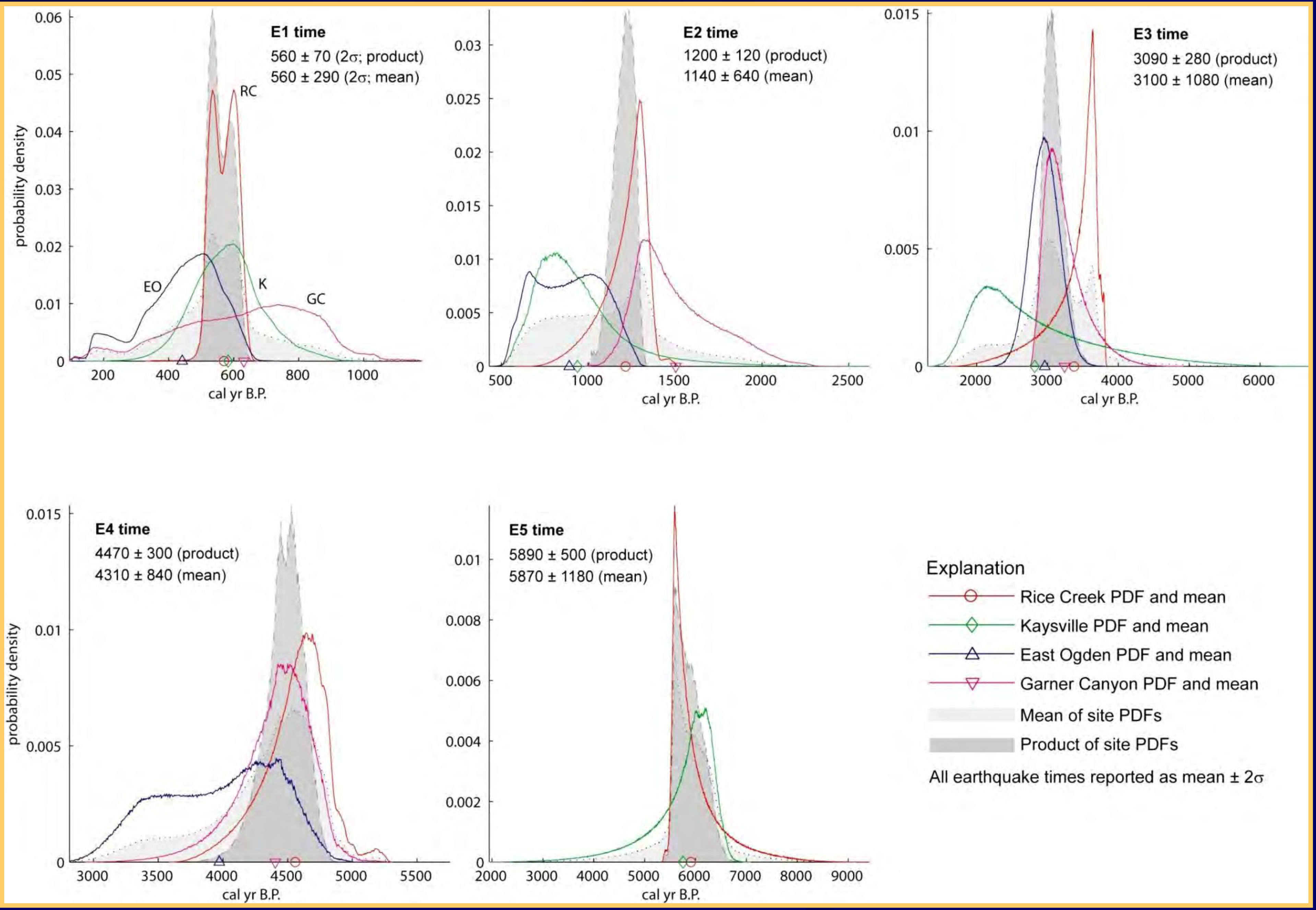
Product **of site PDFs (light gray)**

- ✓ For independent events A & B, probability of both events occurring at time t: $P(A \text{ and } B)_t = P(A)_t * P(B)_t$
- ✓ <u>Basis</u>: some paleoseismic sites better suited to constraining an earthquake time than others.
- ✓ <u>E1 PDF</u> based on overlap in site PDFs: best-constrained PDFs receive most weight.
- ✓ Best suited to overlapping site PDFs where correlation is well understood.

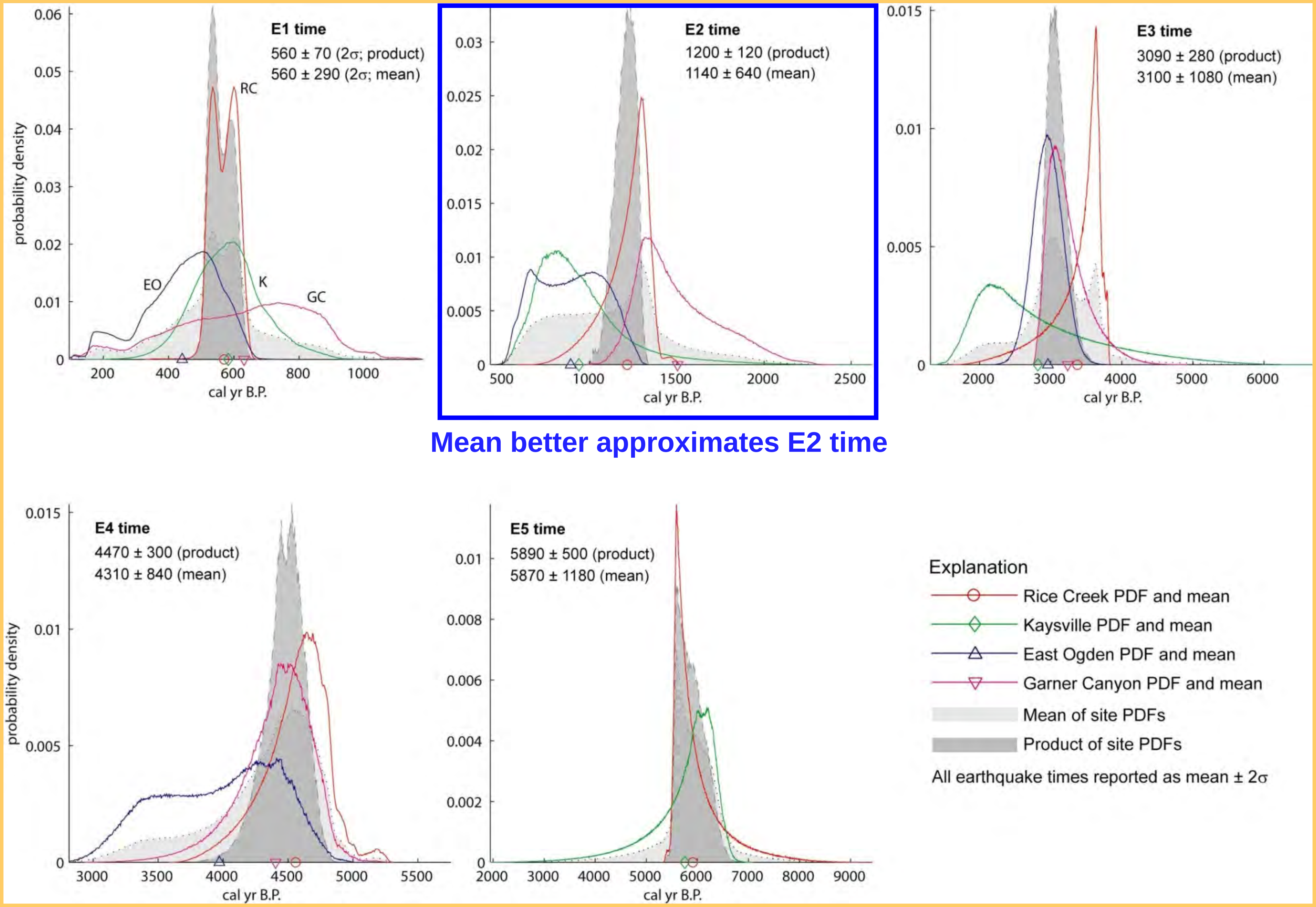


Site PDFs contributing to E1

4. PDFs for Segment-wide Earthquakes



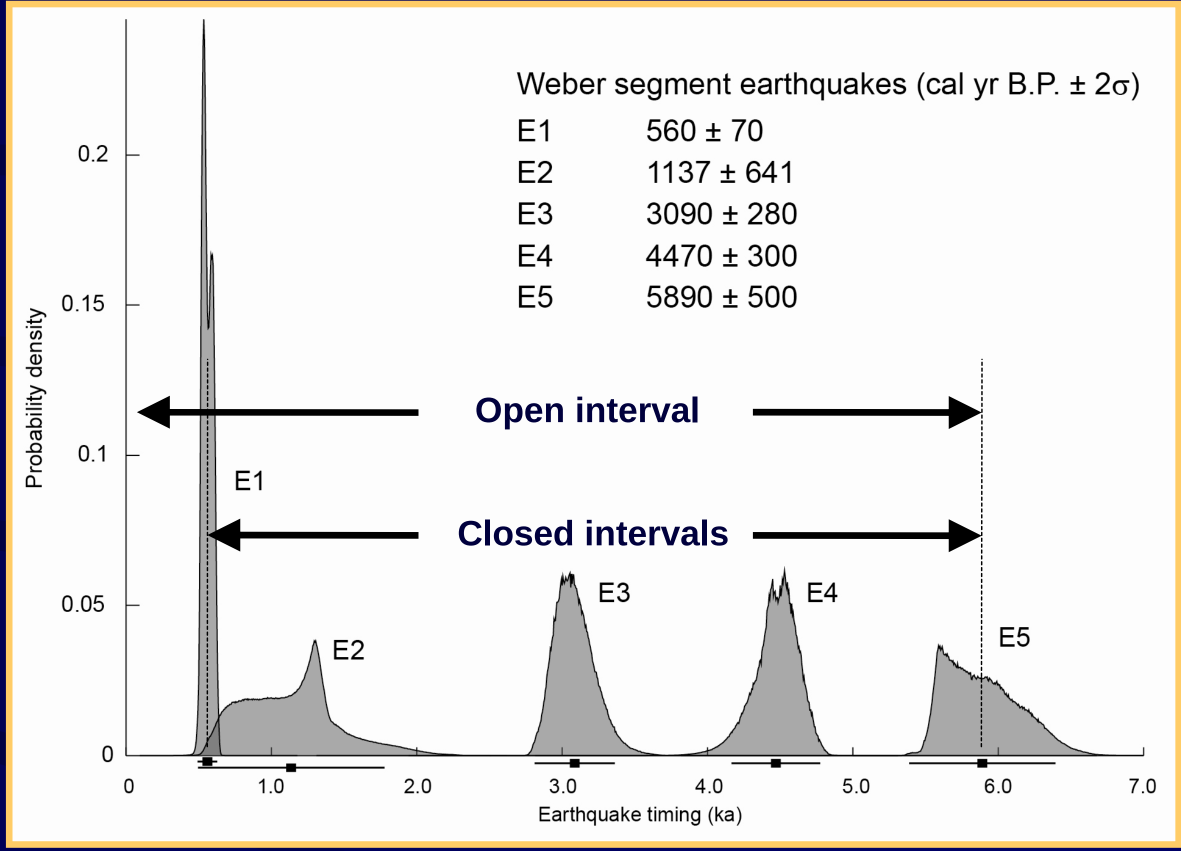
4. PDFs for Segment-wide Earthquakes



Mean better approximates E2 time

5. Earthquake Recurrence

- Recurrence intervals
  - Determined using <u>final earthquake PDFs</u> (mostly product PDFs)
  - <u>Closed recurrence</u> – between two or more earthquakes)
  - <u>Open recurrence</u> – including elapsed time since MRE

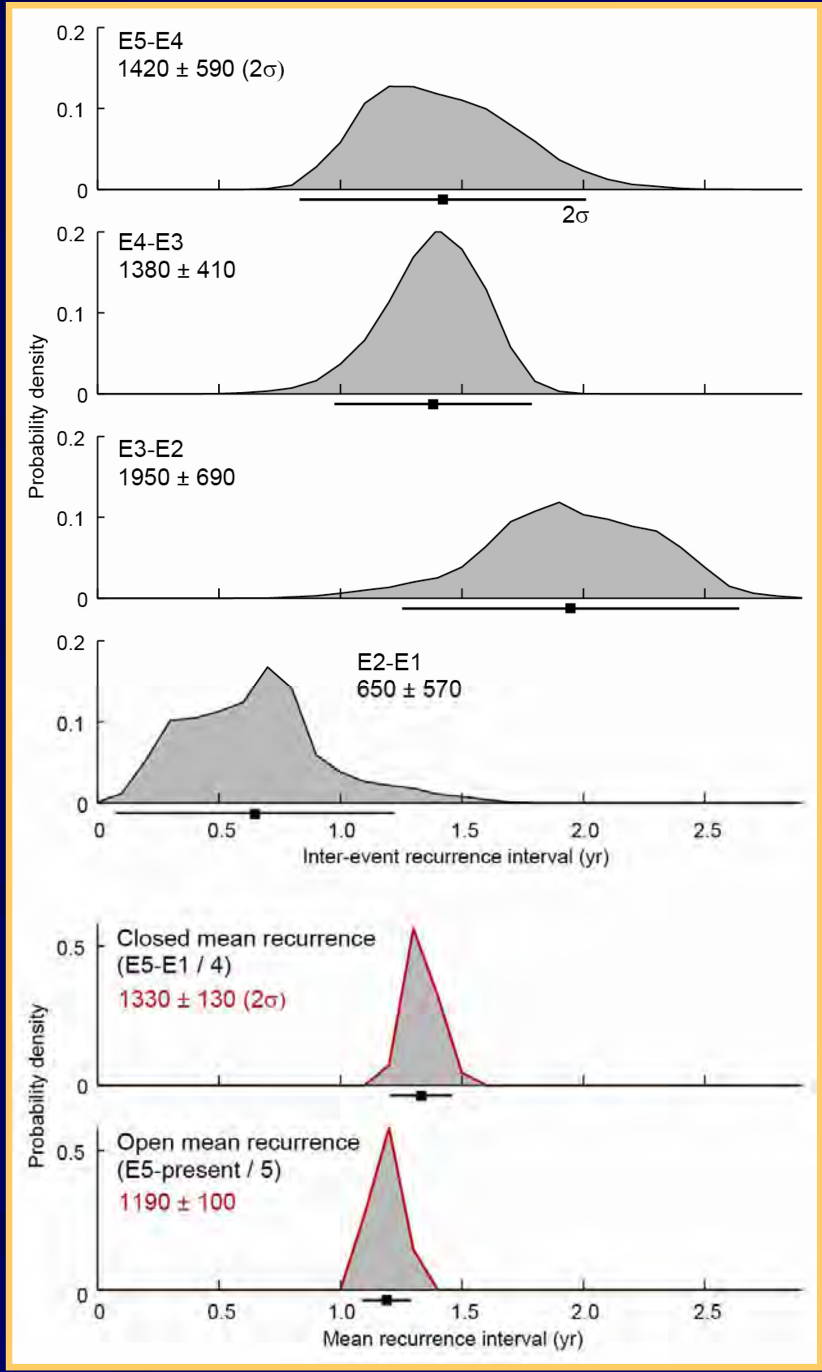


Final Weber segment earthquake chronology

- Monte Carlo model
  - In each scenario:
    1. Randomly sample earthquake PDFs.
    2. Compute inter-event (e.g., E5–E4) and mean (e.g., E5–E1/4) recurrence.
    3. Compile values and plot as PDFs.

5. Earthquake Recurrence

- Inter-event recurrence
  - ✓ Apparent aperiodicity:
    - o E3–E2: ~1.9 ky
    - o E2–E1: ~0.7 ky
- Mean recurrence
  - ✓ Close mean recurrence (4 intervals): ~1.3 ky
  - ✓ Open mean recurrence (5 intervals): ~1.2 ky
- Segment-wide recurrence:
  - ✓ 1.3 ± 0.6 ky (based on mean and inter-event results).
  - ✓ 2004 UQFPWG value: 0.5–1.4–2.4 ky



Conclusions

- Product method – reproducible method for refining earthquake times:
  - ✓ Integrates OxCal data from multiple sites
  - ✓ Focuses on the overlap in earthquake times at sites
  - ✓ Best where correlation of events is strong
  - ✓ Avoids subjectively weighting or excluding the least well-constrained data
- Simple-Mean method – most appropriate where:
  - ✓ Site PDFs have poor overlap
  - ✓ Correlation of events is uncertain or weak
- For Weber segment: improved our understanding of the segment's earthquake behavior by refining earthquake-timing and recurrence-interval estimates
  - Our results compare well with previous data, but our analyses utilize a more objective approach (vs expert opinion)
- Our analysis has important implications and application for the time-dependent earthquake forecast for central Wasatch fault zone

Key Points

- Five segment-wide earthquakes on the Weber segment
  - ✓ OxCal analyses and application of the product method help answer questions regarding Weber segment paleoseismic data, including:
    - o Timing and extent of the youngest and oldest earthquakes.
    - o Average Holocene recurrence interval.

- Product method is generally well suited to the Weber segment
  - ✓ Generally overlapping site PDFs have narrow to broad shapes depending on the vintage of the data.
  - ✓ Product method yields similar results, but smaller uncertainties compared to the simple mean method (e.g., E1).
  - ✓ Our results compare well with previous data, but our analyses include 2007 Rice Creek data and utilize a more objective approach.

Task List

1. Recurrence Model Subgroup (Ivan, Walter, and Jim) to develop a set of strawman recurrence models weights for the Working Group's consideration.

2. Validate comparison of geodetic, historical earthquake, and geologic moment rates and provide a recommendation of how to incorporate GPS horizontal extension data in the WGUEP probability forecast – Christine.

3. Weight WFZ rupture scenarios, sum moment release per segment per scenario, compute and plot magnitude frequency distributions for rupture scenarios – Paleoseismology Subgroup.

4. Evaluate software for running a Brownian Passage Time probability model/evaluate other probability models – Nico, Patricia.

Task List (cont.)

5. Revise historical earthquake catalog – Seismology Subgroup (Walter, Ivan, Jim, and Mark).

6. Decide on final WGUEP products (full model building or simplified product) – Ivan and Mark.

7. Recompute vertical slip rates and Mmax, and devise a reliability indicator for the paleoseismic data in the WGUEP “Other Fault” database.

8. Determine what to use as the maximum magnitude background earthquake (M 6.75 $\pm$, M 6.6 $\pm$ 0.2, other?) – Ivan, Mark.

Inputs Required for Probability Calculations

Patricia Thomas

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1333 Broadway, Suite 800

Oakland, CA 94612

WGUEP Meeting, Salt Lake City, UT

28 June 2011

Overall Approach

Code from WGCEP (2003) uses Monte Carlo scheme to sample the logic tree

PART 1: Define fault segment attributes

PART 2: Define rupture sources and rates

PART 3: Define background seismicity

PART 4: Define probability model parameters

PART 5: Probability calculations

URS

PART 1: Fault segment attributes

- Select segment endpoints
  - Calculate segment lengths
- Select seismogenic thickness
  - Correlated across region (thin, med, thick)
- Select dip
  - Correlated within fault system (shallow, med, deep)
  - Calculate segment areas

URS

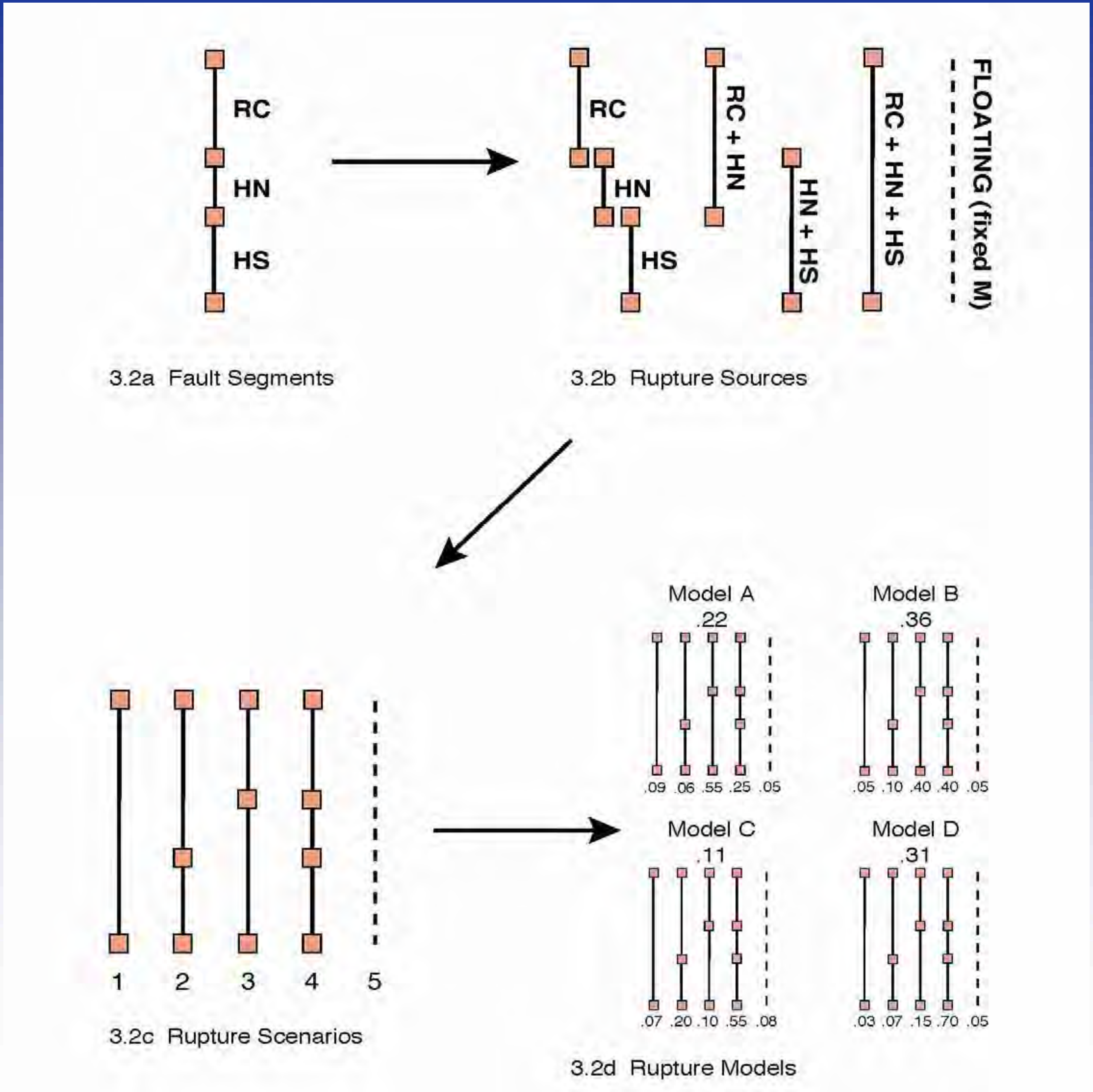
PART 1: Fault segment attributes

- Select long term segment slip rate
  - Correlated within fault system (low, med, high)
- Compute long term segment moment rates
  - segMomentRate = sliprate * SegArea * mu
- Apply regional slip rate constraint
  - In California, plate motion used to constrain slip rate across 3 transects in region
  - In Utah? Geodetic?

PART 2: Define rupture sources and rates

- **Select fault rupture model**
  - ***Rupture source is a single segment or combination of adjacent segments that produces an earthquake***
  - ***Rupture scenario is a combination of rupture sources that describes a possible mode of failure of the entire fault during one earthquake cycle***
  - ***Fault-rupture model is a weighted combination of fault rupture scenarios that represents long-term behavior of the fault***

"If entire length of a fault failed completely 100 times, what would be the frequency of each rupture scenario"



RC
HN
HS
3.2a Fault Segments
RC
HN
HS
RC + HN
HN + HS
RC + HN + HS
FLOATING (fixed M)
3.2b Rupture Sources
1
2
3
4
5
3.2c Rupture Scenarios
Model A
.22
.09 .06 .55 .25 .05
Model B
.36
.05 .10 .40 .40 .05
Model C
.11
.07 .20 .10 .55 .08
Model D
.31
.03 .07 .15 .70 .05
3.2d Rupture Models

PART 2: Define rupture sources and rates

- Compute rupture source lengths and areas
- Select Mean Characteristic Magnitude Model
  - Correlated for all faults and segments
- Select magnitude probability density function
  - Correlated for all faults and segments
  - Fraction of moment in characteristic and exponential parts defined
- Select fraction of moment in aftershocks
  - Available moment from long term slip rates reduced to account for aftershocks

PART 2: Define rupture sources and rates

- Compute mean Characteristic Magnitude, M_{CHAR}
- Compute mean moment for characteristic and exponential parts from magnitude pdf and M_{CHAR}
- Compute rupture source moment rates
  - Available segment moment rates are distributed using fault rupture model parameters (scenarios and wts) which are adjusted to balance long term segment moment rates
- Compute mean rate of characteristic EQs

  rupture source moment rate / mean moment of M_{CHAR}

URS

PART 2: Define rupture sources and rates

- In WGCEP, segment slip rates (moment rates) were partitioned onto rupture sources
  - Relative rates of rupture sources were determined from geologists estimate of rupture scenarios with weights and then moment-balanced against long term segment moment rates
- WGUEP “models” provide define rupture sources and recurrence intervals

What does moment-balancing mean in this framework?

URS

Wasatch Fault Rupture Models

Rupture sources: ***B, W, S, P, N, B+W, S+P, W+S, P+N, S+P+N***

Rupture scenarios:

All possible combinations of rupture sources that fail entire fault

1. ***B, W, S, P, N***

2. ***B+W, S, P, N*** 3. ***B+W, S+P, N*** 4. ***B+W, S, P+N***

5. ***B, W+S, P, N*** 6. ***B, W+S, P+N***

7. ***B, W, S+P, N***

8. ***B, W, S, P+N***

9. ***B, W, S+P+N*** 10. ***B+W, S+P+N***

URS

Wasatch Fault Rupture Models

Rupture model (Maximum): ***model wt: 0.6***

1. ***B, W, S, P, N wt = 1.0***

Rupture model (Intermediate A): ***model wt: 0.1***

1. ***B, W, S, P, N wt = __***

2. B+W, S, P, N wt = __

3. B+W, S+P, N wt = __

4*.* ***B, W, S+P, N wt = __***

Weights are relative frequencies of rupture scenarios

URS

Wasatch Fault Rupture Models

Rupture model (Intermediate B): ***model wt: 0.1***

1. ***B, W, S, P, N*** ***wt*** **= __**
2. ***B+W, S, P, N*** ***wt*** **= __**
3. ***B+W, S, P+N*** ***wt*** **= __**
4. ***B, W, S, P+N*** ***wt*** **= __**

Rupture model (Intermediate C): ***model wt: 0.15***

1. ***B, W, S, P, N*** ***wt*** **= __**
2. ***B+W, S, P, N*** ***wt*** **= __**

URS

Wasatch Fault Rupture Models

Rupture model (Minimum): ***model wt: 0.05***

1. ***B, W, S, P, N* wt = __**
2. ***B+W, S, P, N* wt = __**
3. ***B+W, S+P, N* wt = __**
4. ***B+W, S, P+N* wt = __**
5. ***B, W+S, P, N* wt = __**
6. ***B, W+S, P+N* wt = __**
7. ***B, W, S+P, N* wt = __**
8. ***B, W, S, P+N* wt = __**
9. ***B, W, S+P+N* wt = __**
10. ***B+W, S+P+N* wt = __**

PART 3: Define Background Seismicity

- Select set of parameters to define background seismicity (b_value, minMag, rate > MinMag)

- Select Mmax

- Compute rate at Mmin using truncated exponential model

PART 4: Define Probability Model Parameters

- Select probability model number
  - some correlation between faults if ordered the same.
- Select COV
  - correlated across region
- Select time of last rupture for each segment
  - Compute time since last event

PART 5: Probability Calculations

- Calculations computed for each threshold Magnitude, M_T
- Compute probability of magnitude of each rupture greater than M_T given magnitude probability density function, Pmag
  - done for characteristic and exponential parts
- Compute rupture probabilities for selected probability model
  - For Poisson model, inputs are simply rate of characteristic events and Pmag
  - For BPT model, compute segment probabilities (lapse times are for segments), then partition these to rupture sources according to relative rates in long term model
  - Combine probabilities from characteristic and exponential tail

PART 5: Probability Calculations

- Compute segment probabilities (aggregated from rupture source probabilities)
- Compute fault probabilities
- Compute background probabilities
- Compute regional probabilities

Summary of Inputs Required

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

Summary of Inputs Required

- **Magnitude Probability Density models**
- **Fault rupture models (rupture sources, scenarios, weights)**
- **Background seismicity parameters**
- **Probability models and weights**
- **Probability model parameters**
  - **Time since last event, COV**

Update on Fault Trenching at the Baileys Lake Site, West Valley Fault Zone

Mike Hylland, Chris DuRoss, Greg McDonald (UGS)
Susan Olig (URS)

Working Group on Utah Earthquake Probabilities
June 28, 2011

Research funded by the Utah Geological Survey and U.S. Geological Survey, National Earthquake Hazards Reduction Program

Ongoing studies:

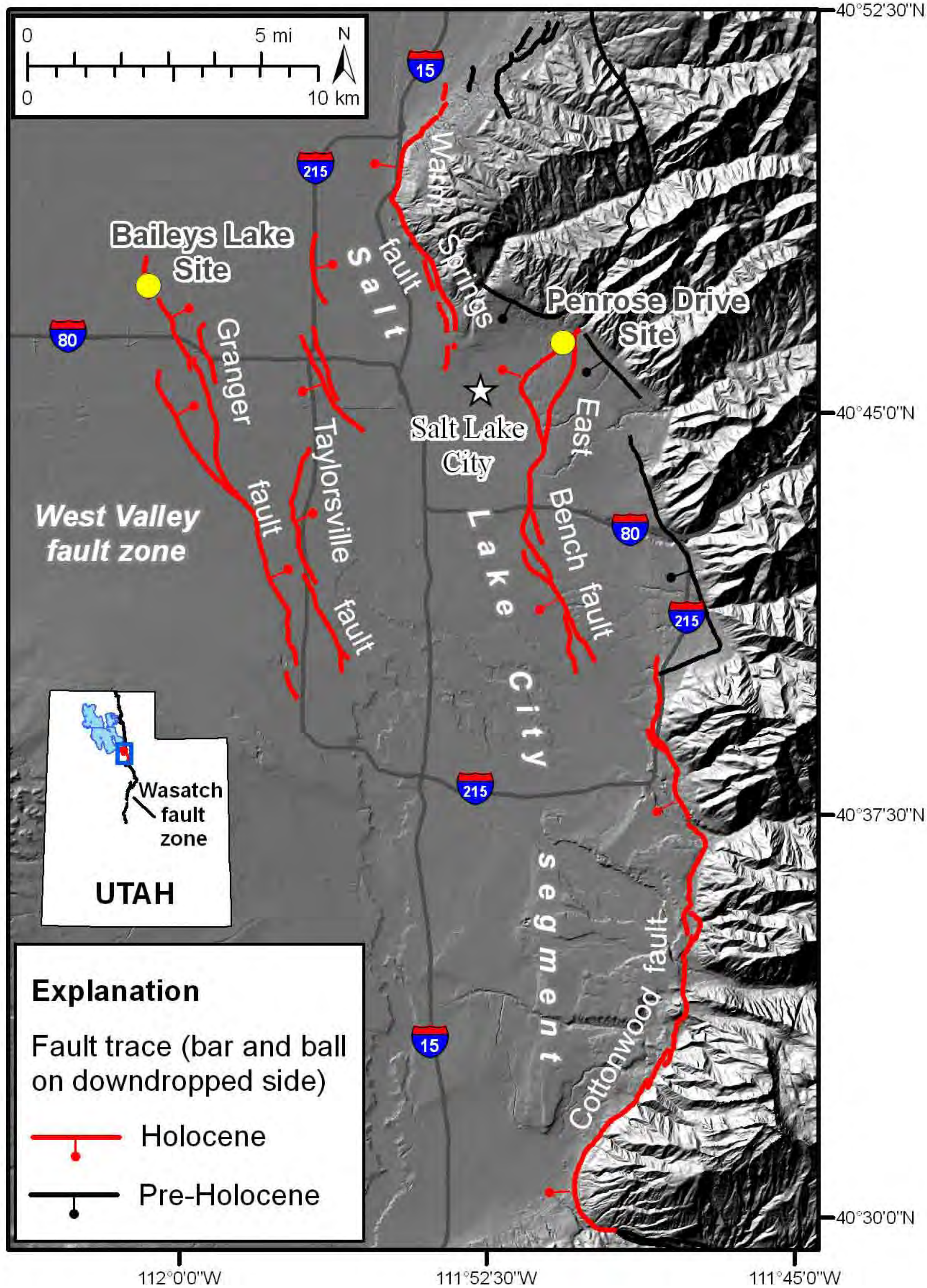
- Penrose Drive (SLCS)
- Baileys Lake (WVFZ)

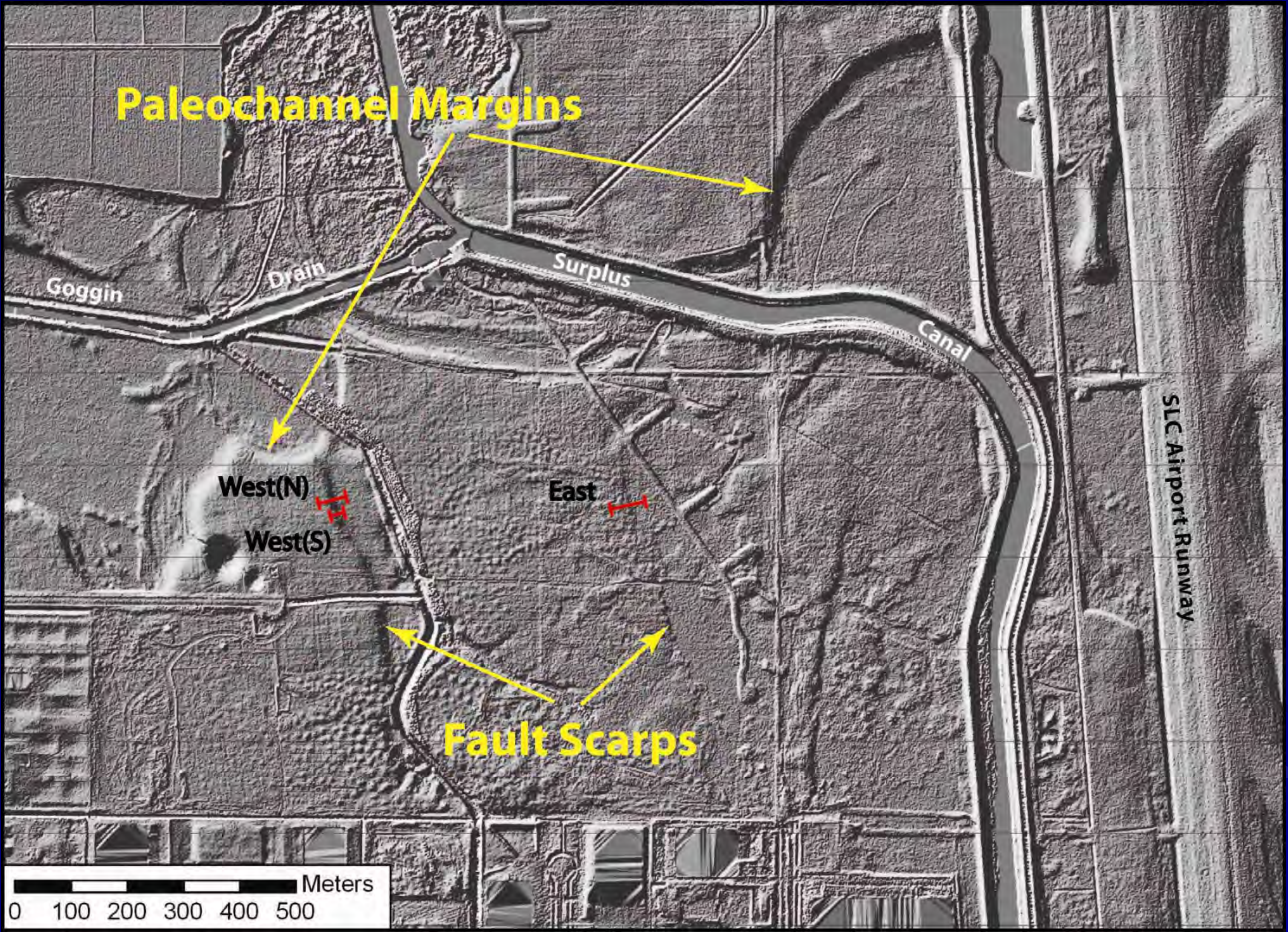
Primary goals:

- Resolve the timing and displacement of individual surface-faulting earthquakes on the northern part of the SLCS and the WVFZ
- Clarify the seismogenic relation (dependent or independent) between these two faults

Status of earthquake timing determinations:

- Radiocarbon dating complete
- Ostracode assemblages identified
- OSL dating in progress

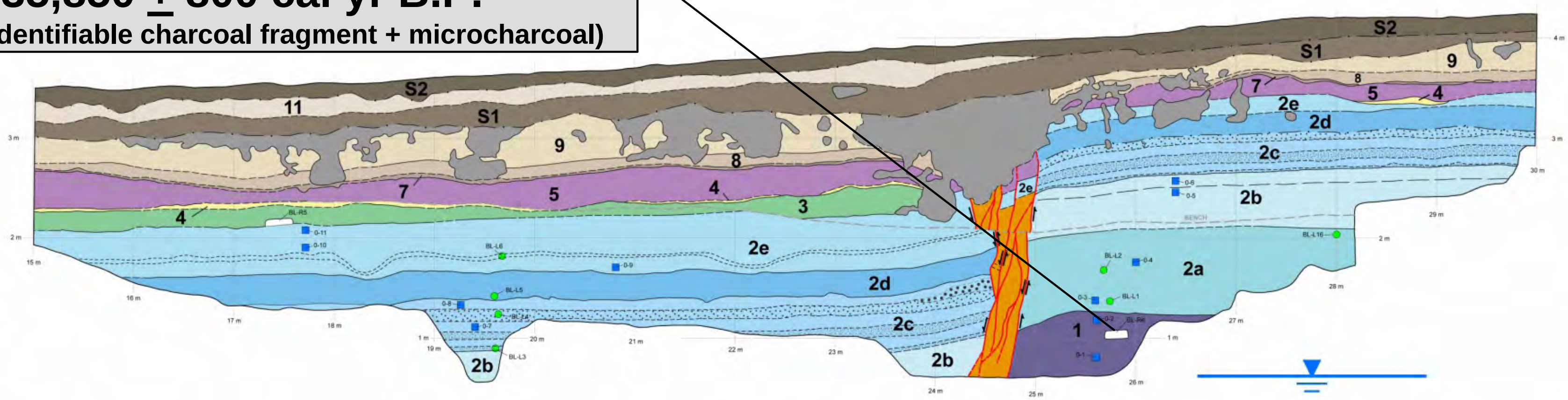




LiDAR image from Utah Automated Geographic Reference Center (2006; 2 m, illumination from NW)

Baileys Lake West(S) Trench
South Wall

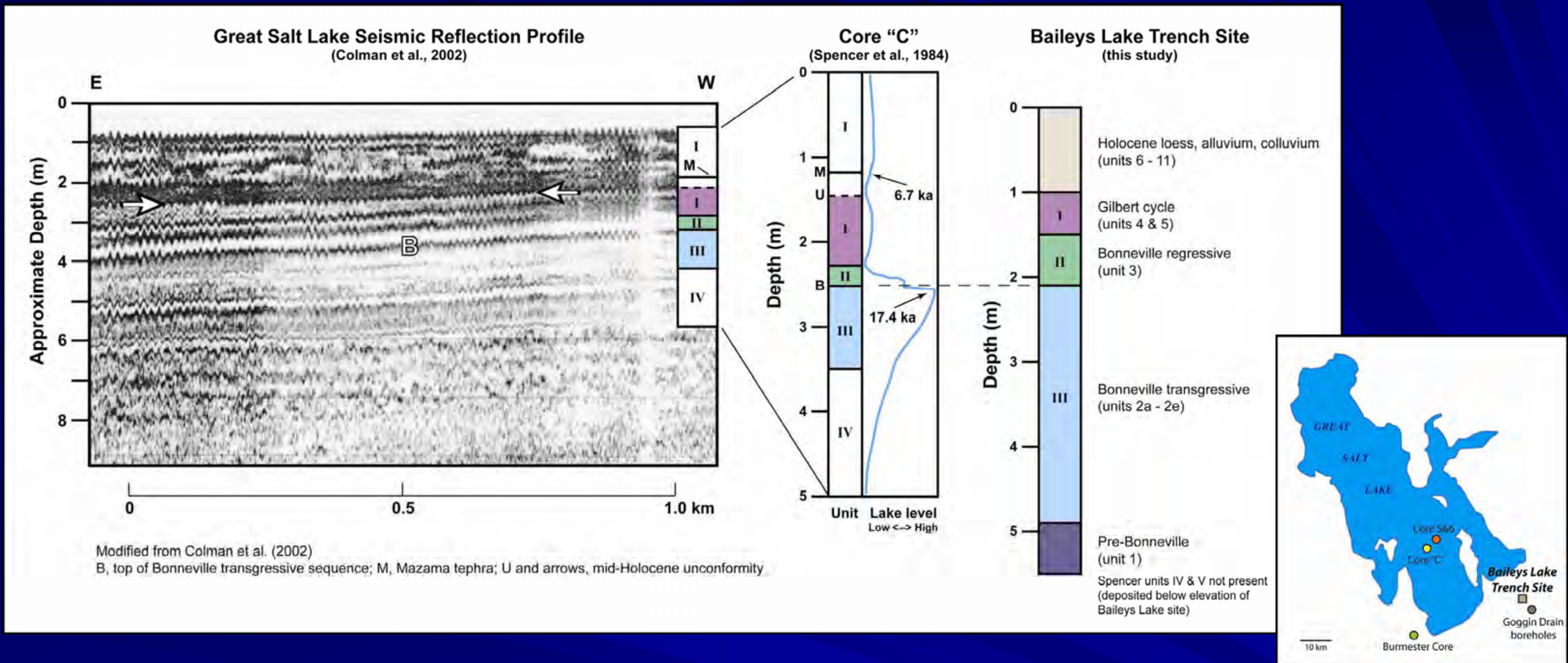
35,850 ± 800 cal yr B.P.
(small unidentifiable charcoal fragment + microcharcoal)



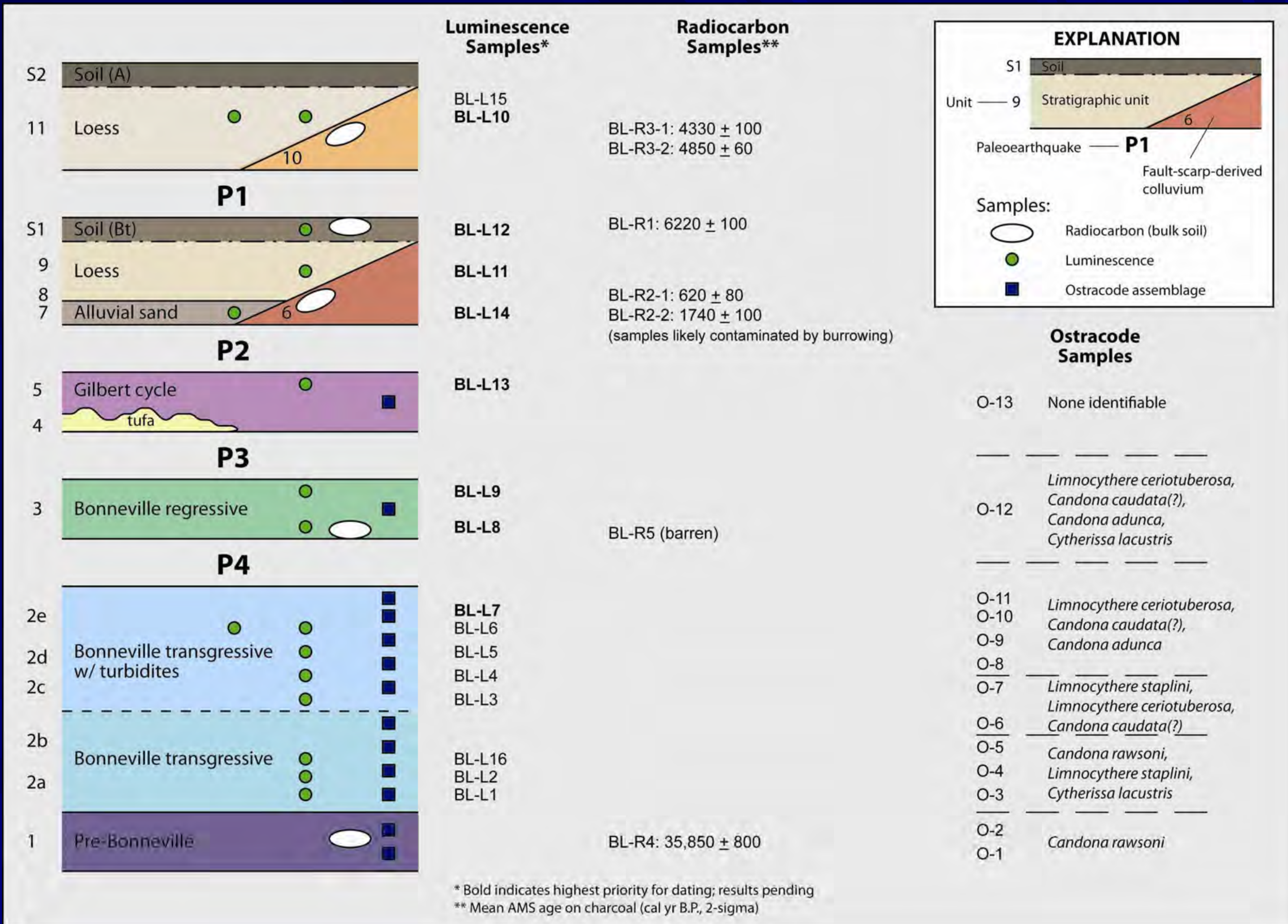
S2	Modern soil (A horizon)
S1	Buried soil (Bt horizon)
11	Loess (younger)
9	Loess (older)
8	Wetland/marginal lacustrine (marl)
7	Alluvial/fluvio-deltaic sand
5	Laminated marl (Gilbert lake cycle)
4	Shoreline tufa (Gilbert transgression)
3	Bonneville sandy laminated marl (regressive)
2e	Bonneville clay (mid- to late transgressive)
2d	Turbidite marker bed
2c	Bonneville clay with turbidites (transgressive)
2b	Bonneville clay (transgressive)
2a	Bonneville sand, silt, clay (early transgressive)
1	Wetland/alluvial marsh (pre-Bonneville)
	Sheared sediment
	Burrowed sediment

Note: Units 6 and 10 are scarp-derived colluvial wedges associated with the two most recent surface-faulting earthquakes; not mapped on this log.

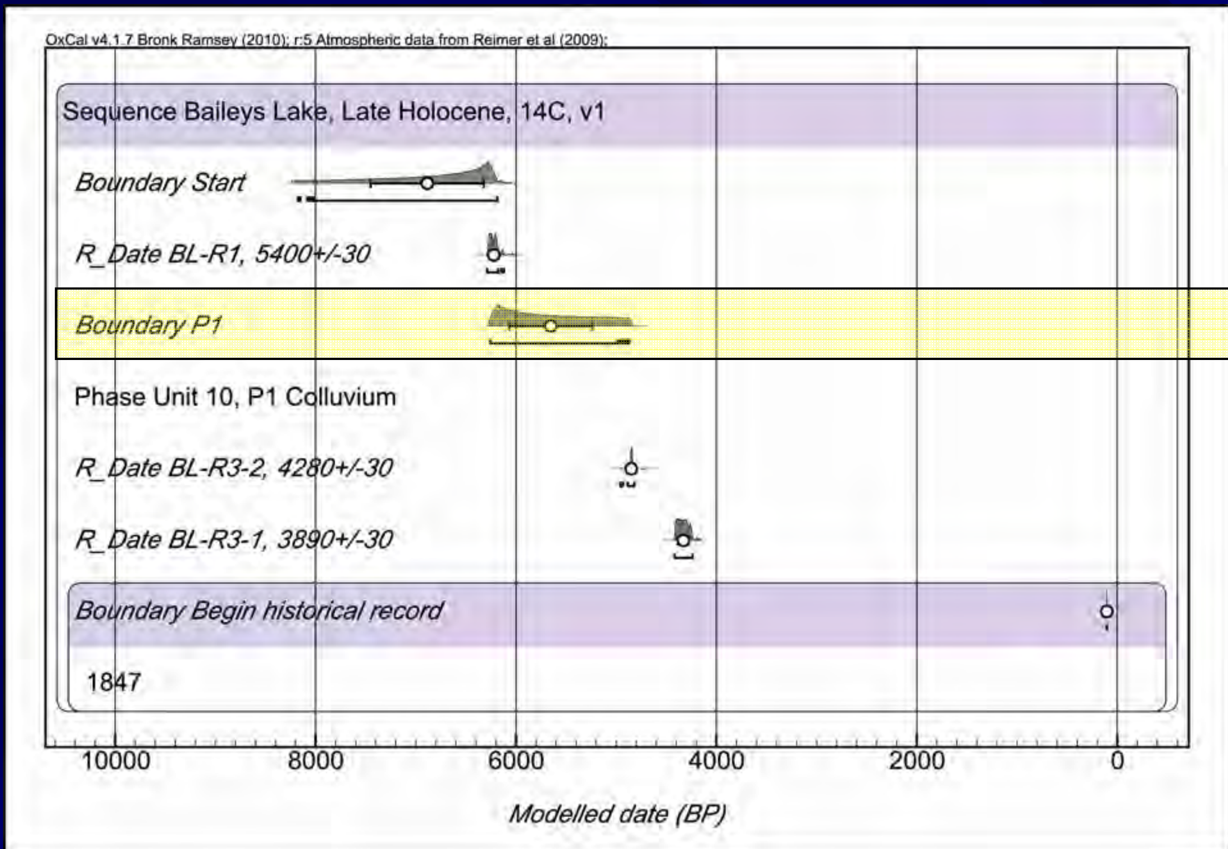
Comparison of Bonneville section at Baileys Lake site with nearby boreholes



	Baileys Lake (this study)	Core "C" (Spencer et al., 1984; Colman et al., 2002)	Core 5&6 (Oviatt and Thompson, unpublished data)	Burmester (Eardley et al., 1973; Oviatt et al., 1999)	Goggin Drain (Keaton and Currey, 1989)
Bonneville (total)	**2.5 – 3.9 m**	**2.6 – 3.1 m** (min., does not include Gilbert portion of unit I)	**2.3 m**	**<2 m** (based on position of Hansel Valley basaltic ash; ~26.5 ka)	**7.5 – 9.0 m**
Gilbert cycle	**0.05 – 0.5 m**	—	**0.4 m**	—	**1.5 – 2.0 m**
Bonneville (regressive)	**0.02 – 0.6 m** (min., overlain by erosional unconformity)	**0.2 – 0.5 m**	**0.7 m**	—	—
Bonneville (transgressive)	**2.4 – 2.8 m** (unit III)	**2.4 – 2.6 m** (units III & IV)	**1.2 m**	—	—


Luminescence Samples*
Radiocarbon Samples**
EXPLANATION
S1 Soil
Unit — 9 Stratigraphic unit
6
Paleoearthquake — P1
Fault-scarp-derived colluvium
Samples:
Radiocarbon (bulk soil)
Luminescence
Ostracode assemblage
S2 Soil (A)
11 Loess
10
BL-L15
BL-L10
BL-R3-1: 4330 ± 100
BL-R3-2: 4850 ± 60
P1
S1 Soil (Bt)
BL-L12
BL-R1: 6220 ± 100
9 Loess
BL-L11
8
7 Alluvial sand
6
BL-L14
BL-R2-1: 620 ± 80
BL-R2-2: 1740 ± 100
(samples likely contaminated by burrowing)
P2
Ostracode Samples
5 Gilbert cycle
4 tufa
BL-L13
O-13 None identifiable
P3
3 Bonneville regressive
BL-L9
BL-L8
BL-R5 (barren)
O-12 Limnocythere ceriotuberosa, Candona caudata(?), Candona adunca, Cytherissa lacustris
P4
2e
2d Bonneville transgressive w/ turbidites
2c
BL-L7
BL-L6
BL-L5
BL-L4
BL-L3
O-11
O-10
O-9
O-8
Limnocythere ceriotuberosa, Candona caudata(?), Candona adunca
O-7
O-6
Limnocythere staplini, Limnocythere ceriotuberosa, Candona caudata(?)
2b
2a Bonneville transgressive
BL-L16
BL-L2
BL-L1
O-5
O-4
O-3
Candona rawsoni, Limnocythere staplini, Cytherissa lacustris
1 Pre-Bonneville
BL-R4: 35,850 ± 800
O-2
O-1
Candona rawsoni
* Bold indicates highest priority for dating; results pending
** Mean AMS age on charcoal (cal yr B.P., 2-sigma)

Preliminary OxCal Modeling Results



Sample/ Event	Age (calendar-calibrated)	
	Mean (2 Sigma)	Mode (5th, 95th)
BL-R1	6.2 ± 0.1 ka	6.3 (6.0 - 6.3) ka
P1	*5.6 ± 0.8 ka*	*6.2 (4.9 - 6.3) ka*
BL-R3-2	4.8 ± 0.1 ka	4.8 (4.8 - 5.0) ka
BL-R3-1	4.3 ± 0.1 ka	4.4 (4.2 - 4.4) ka

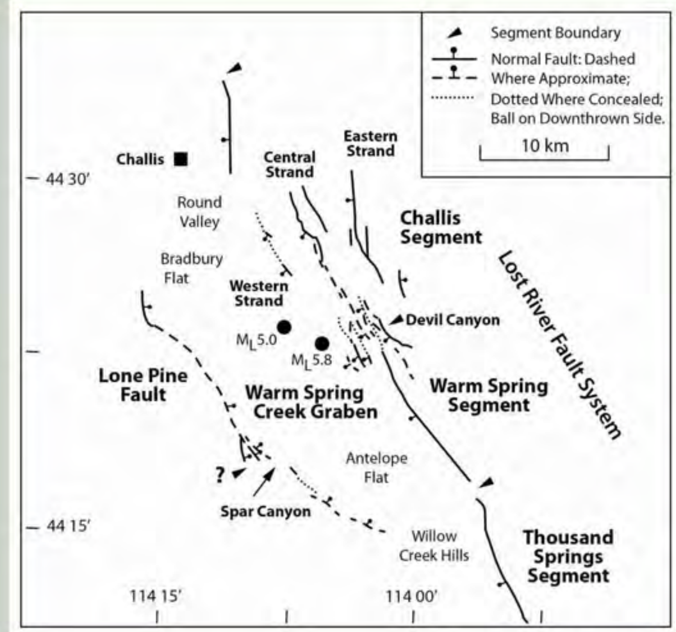
Salt Lake City Segment earthquake chronology:

Penrose Drive
E1 4.0 ± 0.5 ka
E2 5.7 ± 0.8 ka
E3 9.2 ± 2.1 ka (E3a 6.8 ± 0.5 ka)
(E3b 9.7 ± 1.1 ka)
E4 10.9 ± 0.2 ka
E5 12.1 ± 1.6 ka
E6 16.2 ± 1.8 ka

LCC/SFDC
E1 1.3 ± 0.2 ka
E2 2.2 ± 0.2 ka
E3 4.1 ± 0.3 ka
E4 5.2 ± 0.2 ka
E5 ~8 ka
E6 ~9 ka

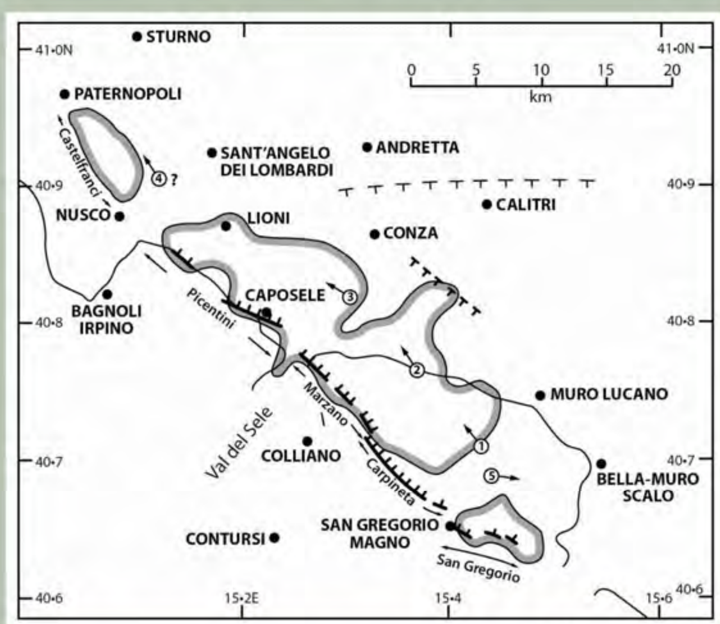
Historical Analogs for West Valley Fault Activity

West Valley fault zone, Utah



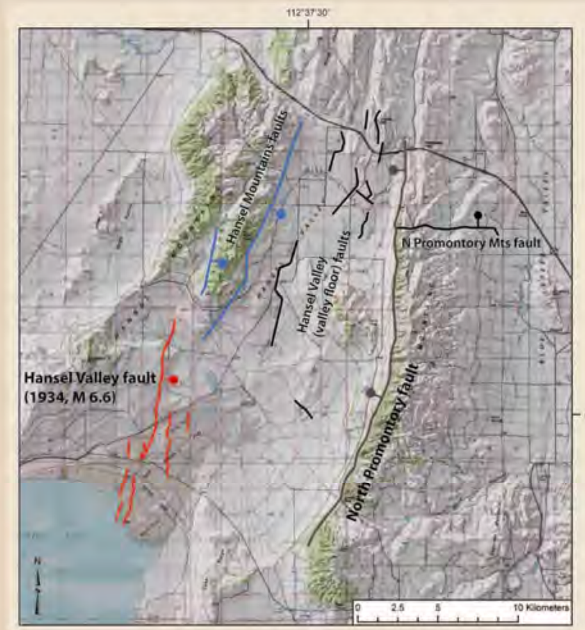
(*Payne and others, 2004*)

1984 Devil Canyon, Idaho, M_L 5.8



(*Westaway, 1992*)

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

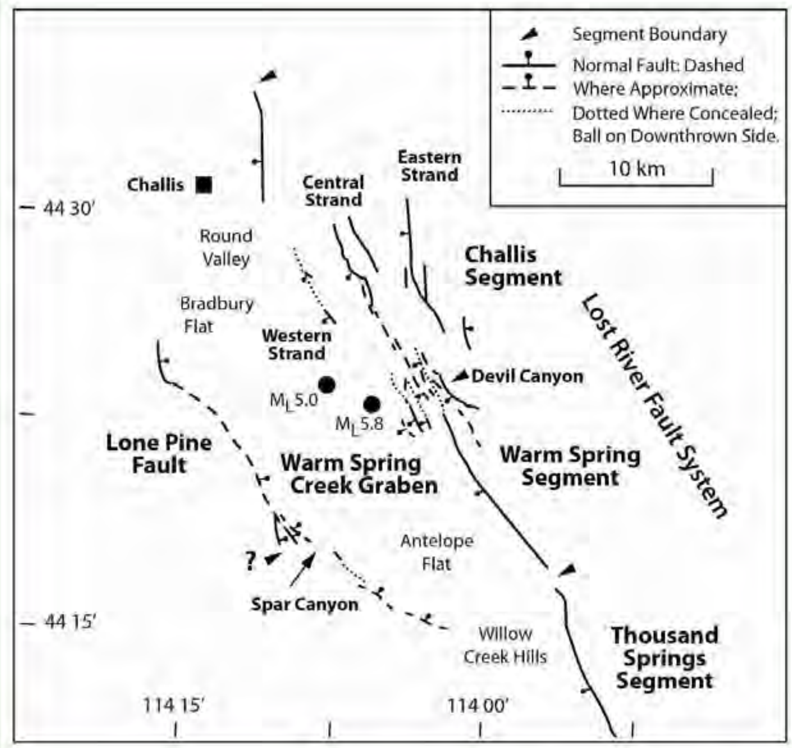


1934 Hansel Valley, Utah, M 6.6

Historical Analogs for West Valley Fault Activity

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
- Antithetic faulting considered triggered slip (separate earthquake with its own moment release)



(*Payne and others, 2004*)

1984 Devil Canyon, Idaho, M_L 5.8

Historical Analogs for West Valley Fault Activity

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

- 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

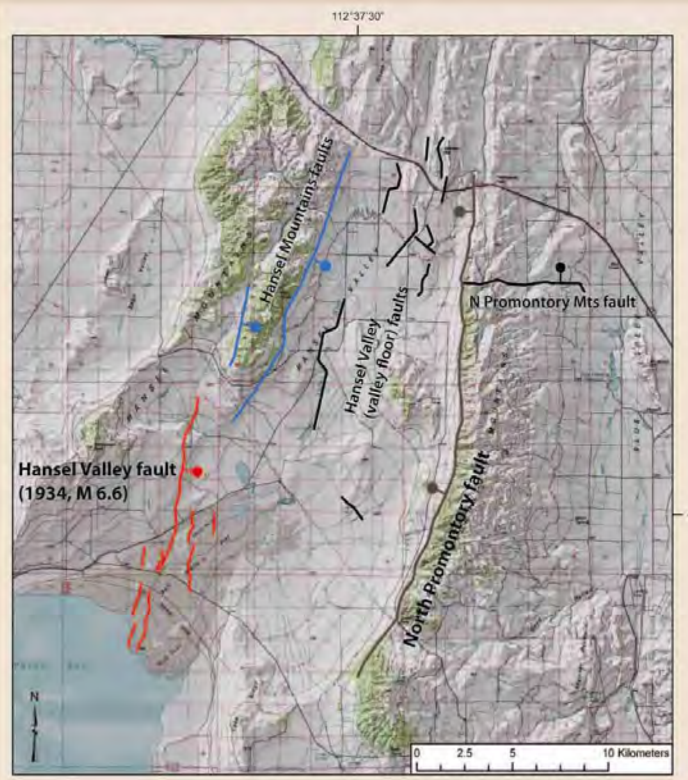
- Antithetic faulting considered coseismic, contributing moment (~12%) to the earthquake as a whole

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

Historical Analogs for West Valley Fault Activity

Hansel Valley, Utah (March 1934)

- M 6.6 earthquake involving mostly down-to-east normal and strike slip on intrabasin faults
    - No rupture documented along North Promontory fault, to which Hansel Valley fault is antithetic
- Antithetic faulting appears to have been independent (i.e., faulting in the absence of movement of the main range-bounding fault)



1934 Hansel Valley, Utah, M 6.6

Preliminary Results

Baileys Lake site shows evidence of at least 4 large earthquakes

Earthquake timing:
- P4 – Warping event around the time of the Bonneville highstand (~18 ka)
- P3 – Surface faulting during lake regression from the Provo shoreline, possibly during the period of very low lake level prior to the Gilbert transgression (~12 ka)
- P2 – Surface faulting sometime after the Gilbert lake cycle (early Holocene)
- P1 – Surface faulting during the mid-Holocene (5.6 ± 0.8 ka)

Vertical displacement:
- Average per-event vertical displacement ~0.5 m

Modeled timing of P1 is in very good agreement with timing of SLCS event E2 at Penrose Drive site

Current thoughts on weighting WVFZ activity (WGUEP Fault subgroup, 3/11):
- 0.50 independent (currently 0.25 in the NSHMs)
- 0.45 dependent (coseismic with SLCS, adds moment to SLCS earthquake)
- 0.05 non-seismogenic (space-accommodation structure)

Update on
Consensus Wasatch Front
Earthquake Catalog

Walter Arabasz and Jim Pechmann

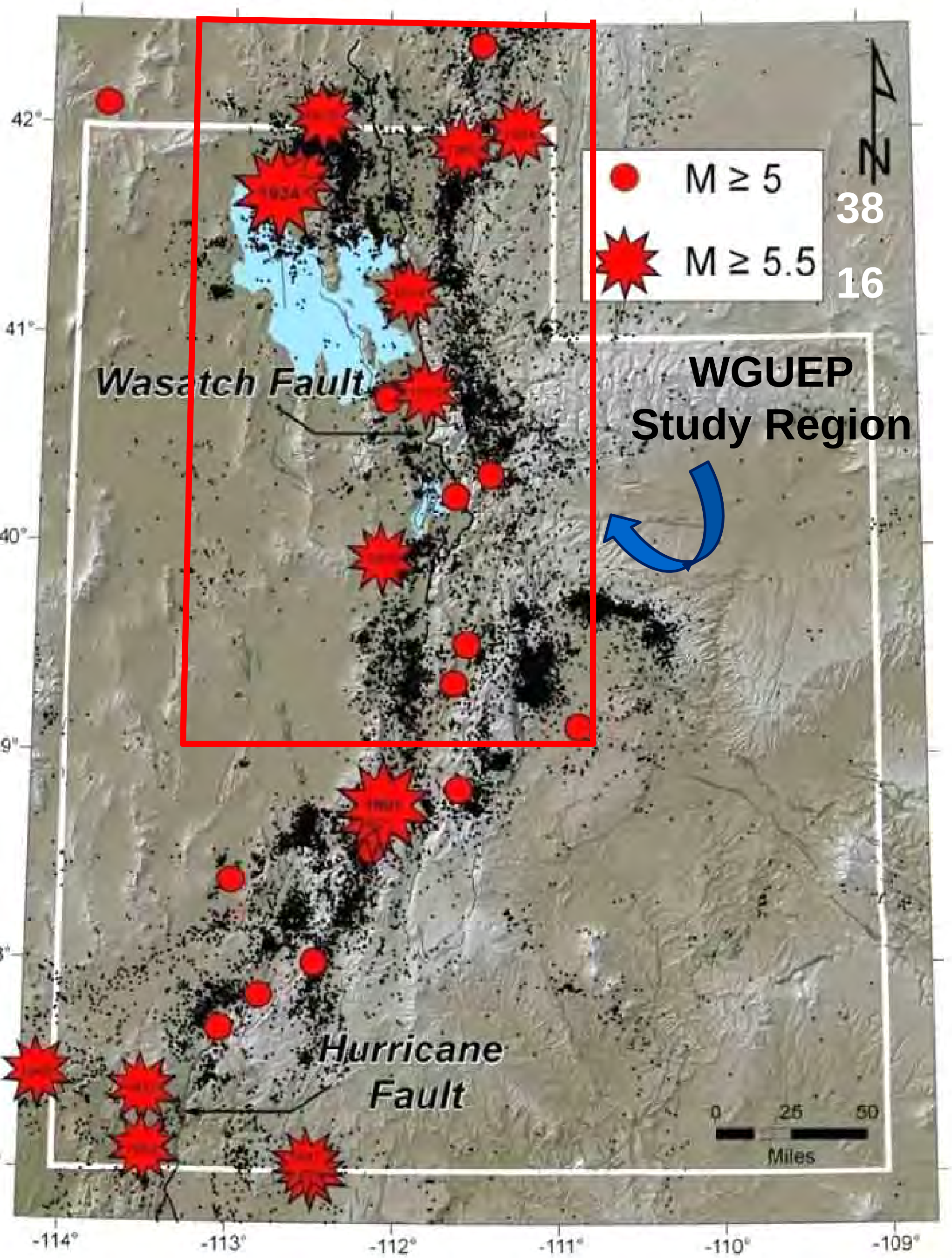
Working Group on
Utah Earthquake Probabilities
June 29, 2010

Collaboration with USGS

Catalog compilation (1850 through 2010)

- Discussions started with Chuck Mueller in January 2011
- Working group teleconference (Wong, Arabasz, Pechmann, Mueller, Petersen) on May 17, 2011
- USGS/NSHM catalog through 2010 for “extended Utah region” (36.0°–43.5° N, 108°–115° W) delivered by Chuck Mueller to Arabasz and Pechmann on June 6, 2011

HISTORICAL & INSTRUMENTAL SEISMICITY
IN THE UTAH REGION (1850-2008)

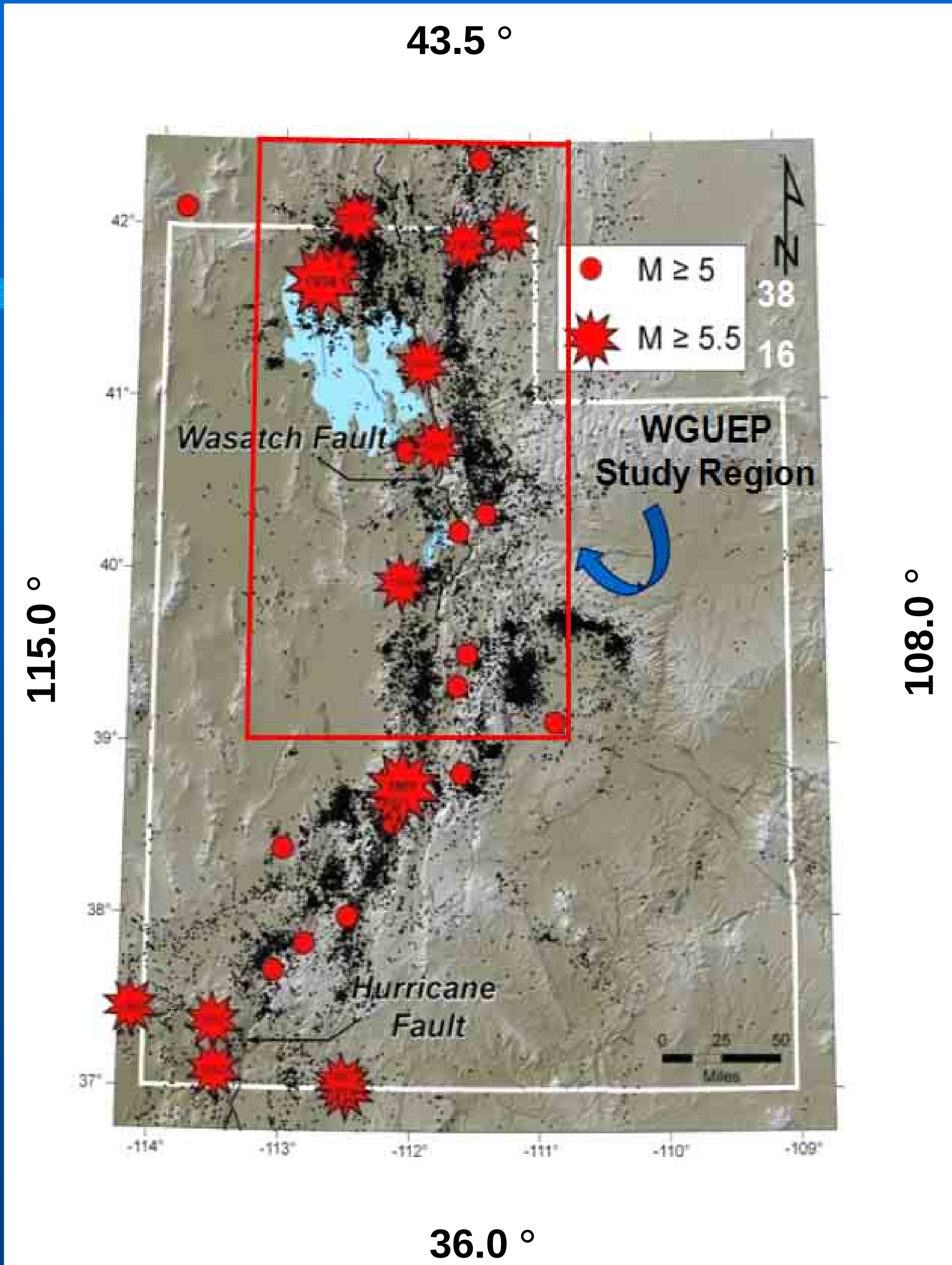


*Source: University of Utah Seismograph Stations earthquake catalog
(number of earthquakes = 44,634)

“Utah Region”

[bounds of standard UUSS earthquake catalog]

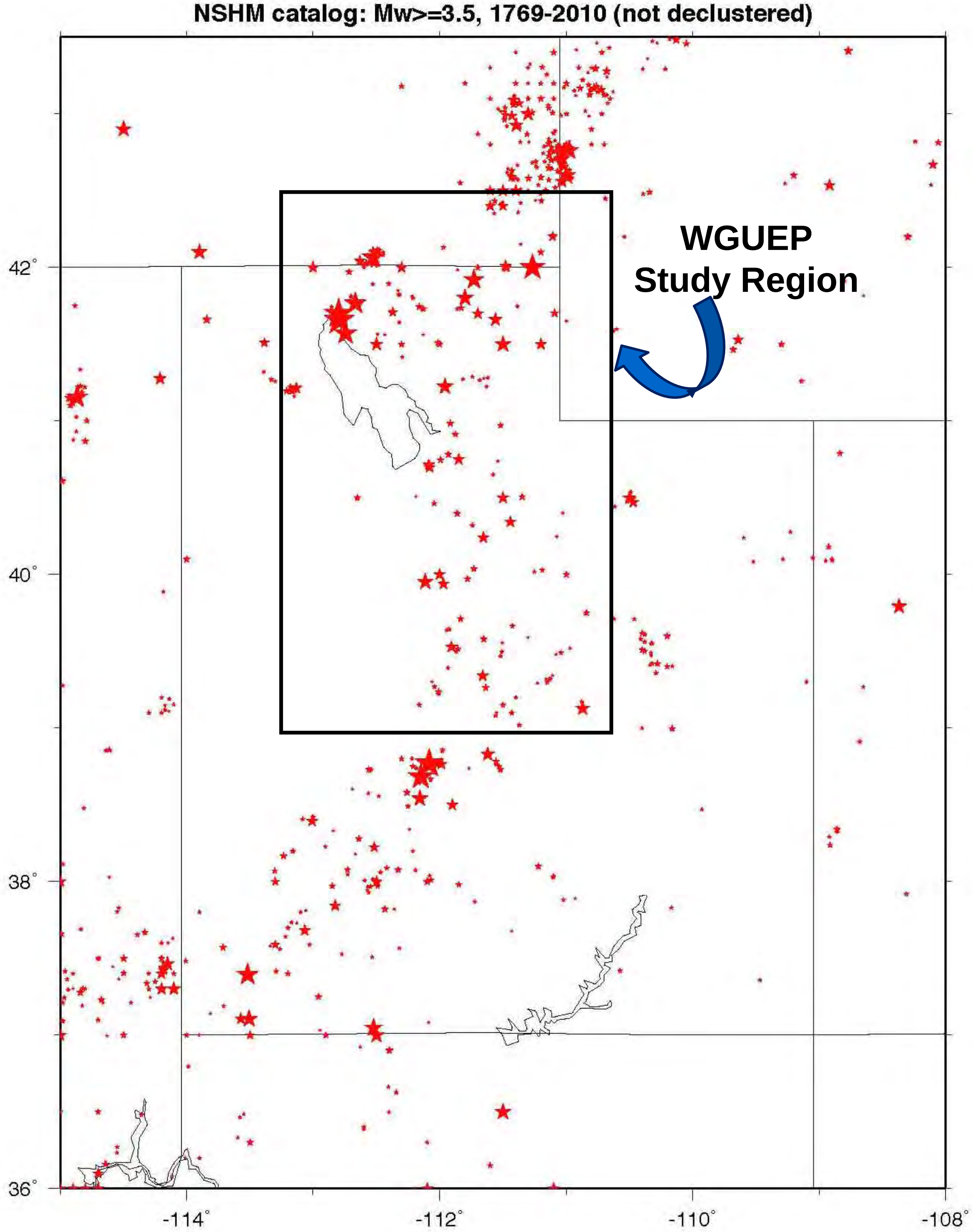
lat 36.75° – 42.50 ° N
long 108.75 ° – 114.25 ° W



"extended Utah region"

NSHM catalog request

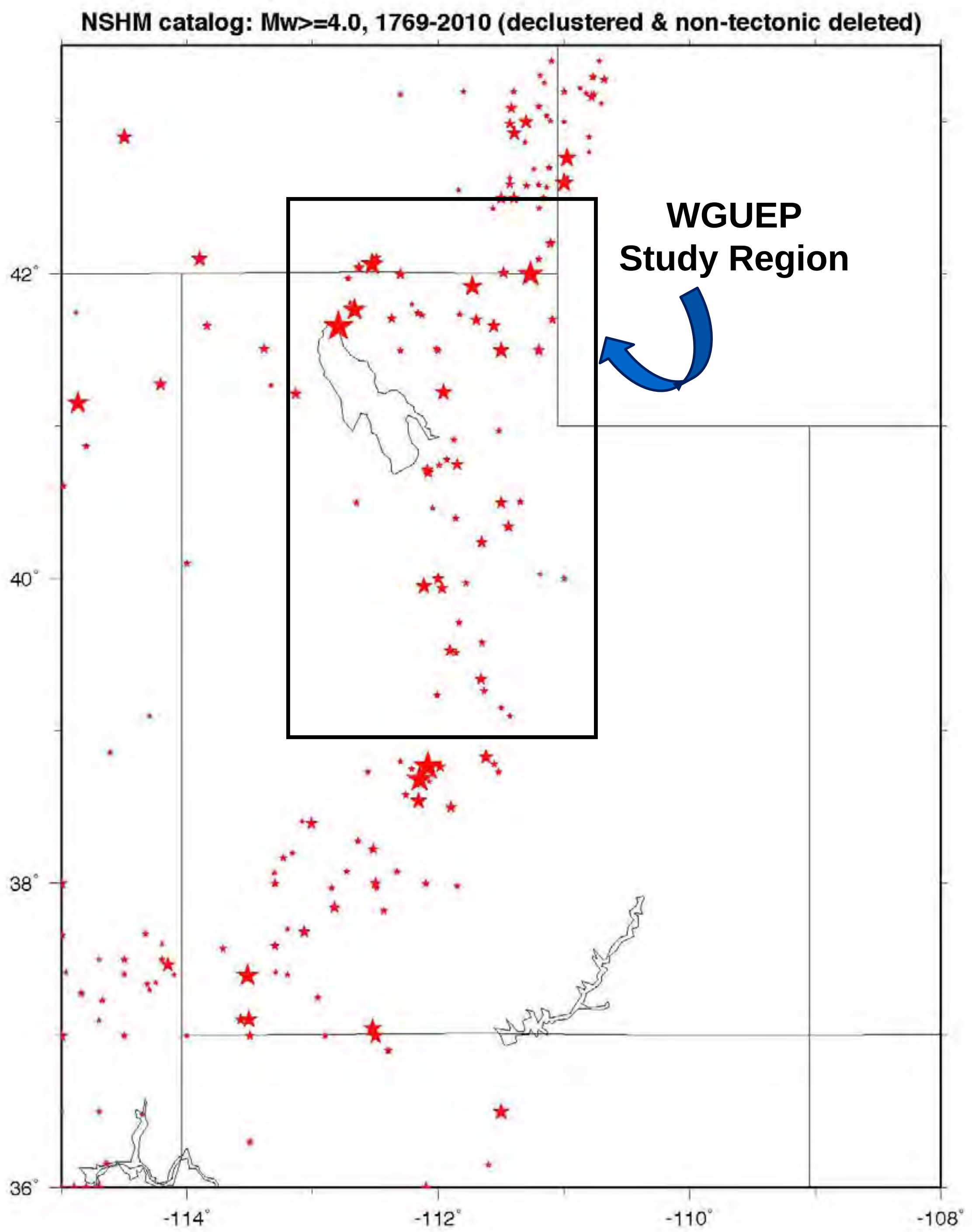
lat 36.0° – 43. 5° N
long 108.0° – 115.0° W



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 . . .

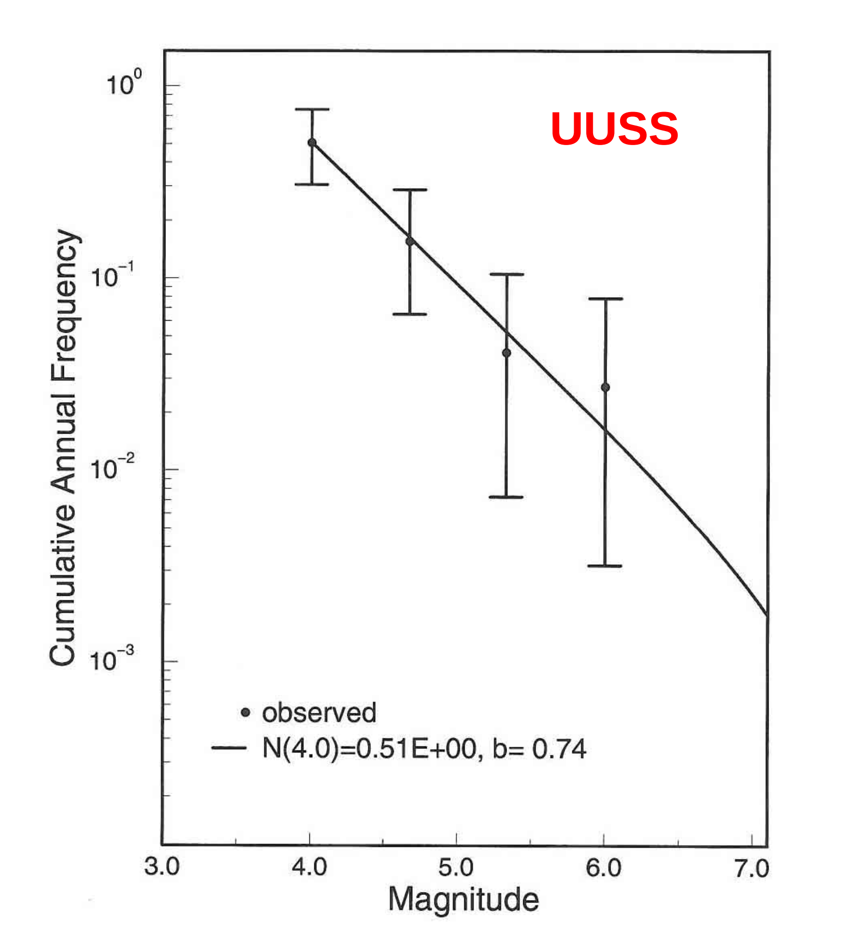
(1880 through 2010; independent mainshocks M ≥ 4.0, non-tectonic events removed)

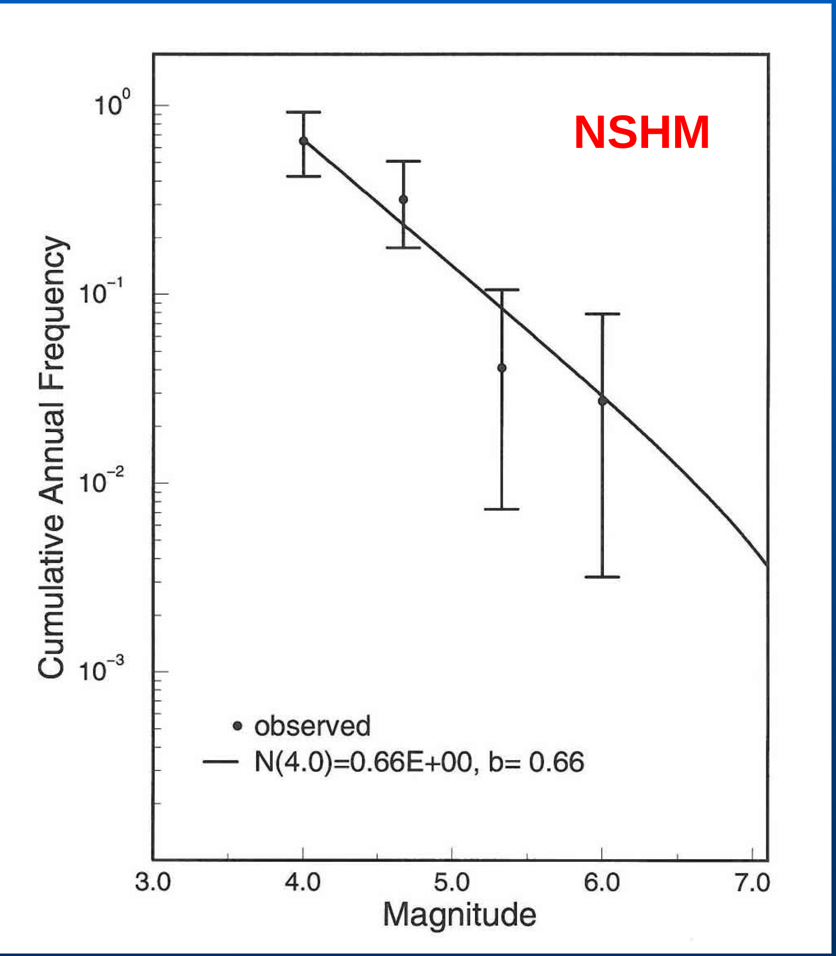
Magnitude Range	UUSS Catalog	NSHM Catalog
$4.0 \leq M < 4.5$	45	34
$4.5 \leq M < 5.0$	5	4
$5.0 \leq M < 5.5$	10	21
$5.5 \leq M < 6.0$	4	4
$6.0 \leq M < 6.5$	3	3
$6.5 \leq M < 7.0$	1	1
Total Number	68	67

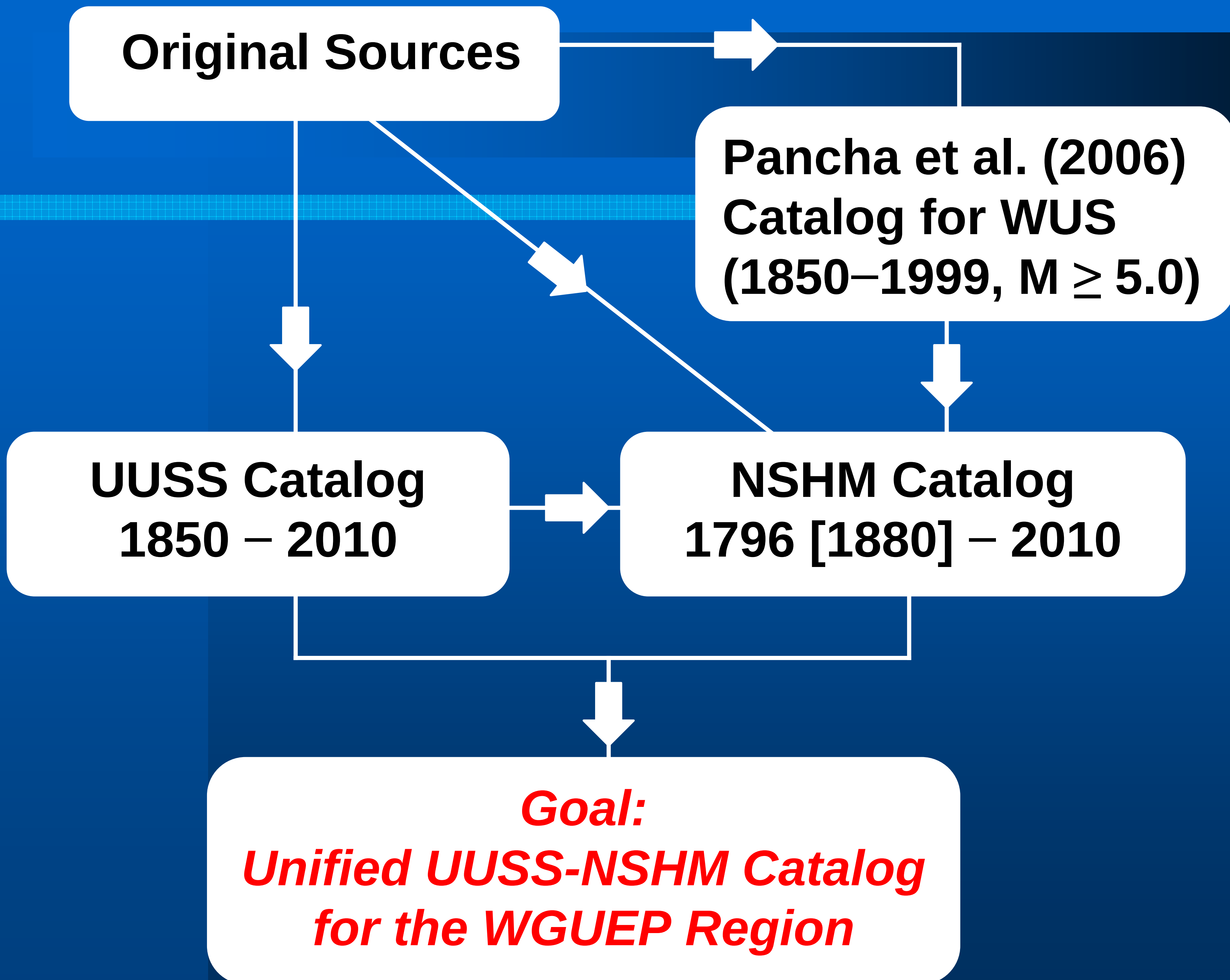
Comparison of independent mainshocks ($M \geq 4.0$) in the UUSS and NSHM catalogs for the WGUEP Region — *accounting for completeness periods*

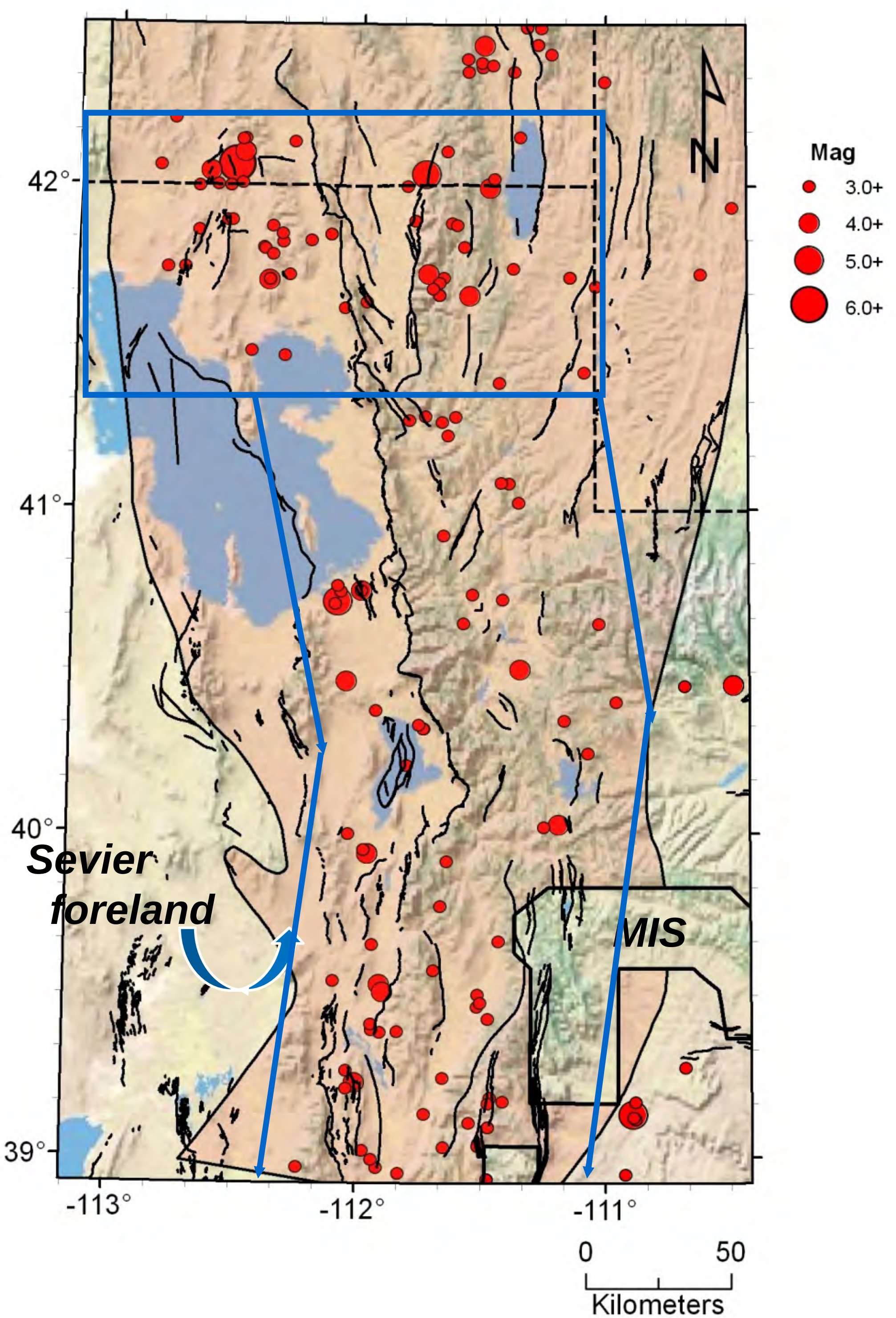
Magnitude Range	Completeness Period	Yrs	Number UUSS Catalog	Number NSHM Catalog
$4.00 \leq M < 4.67$	July 1962–Dec 2010	48.5	17	16
$4.67 \leq M < 5.33$	Jan 1950–Dec 2010	61.0	7	17
$5.33 \leq M < 6.00$	Jan 1938–Dec 2010	73.0	1	1
$6.00 \leq M < 6.67$	Jan 1900–Dec 2010	111.0	3	3

Maximum Likelihood Recurrence Calcs for WGUEP Region — UUSS vs. NSHM Catalogs






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

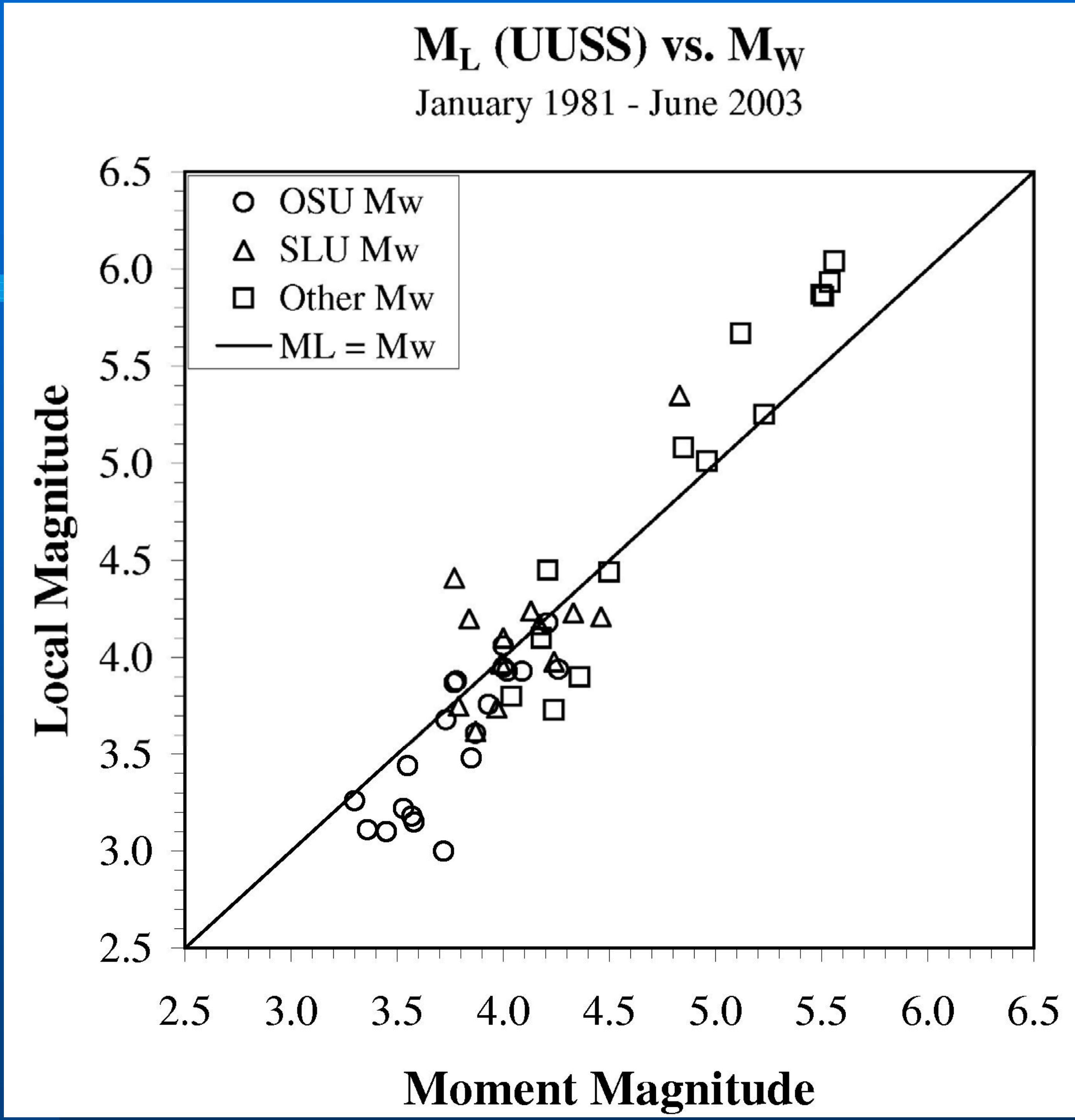


Revisiting Pechmann and Arabasz (1995)

Independent mainshocks
M ≥ 3.0
(1962.5–2006.5)
N = 128

Adequate data to calculate recurrence for sub-regions of WGUEP study region?

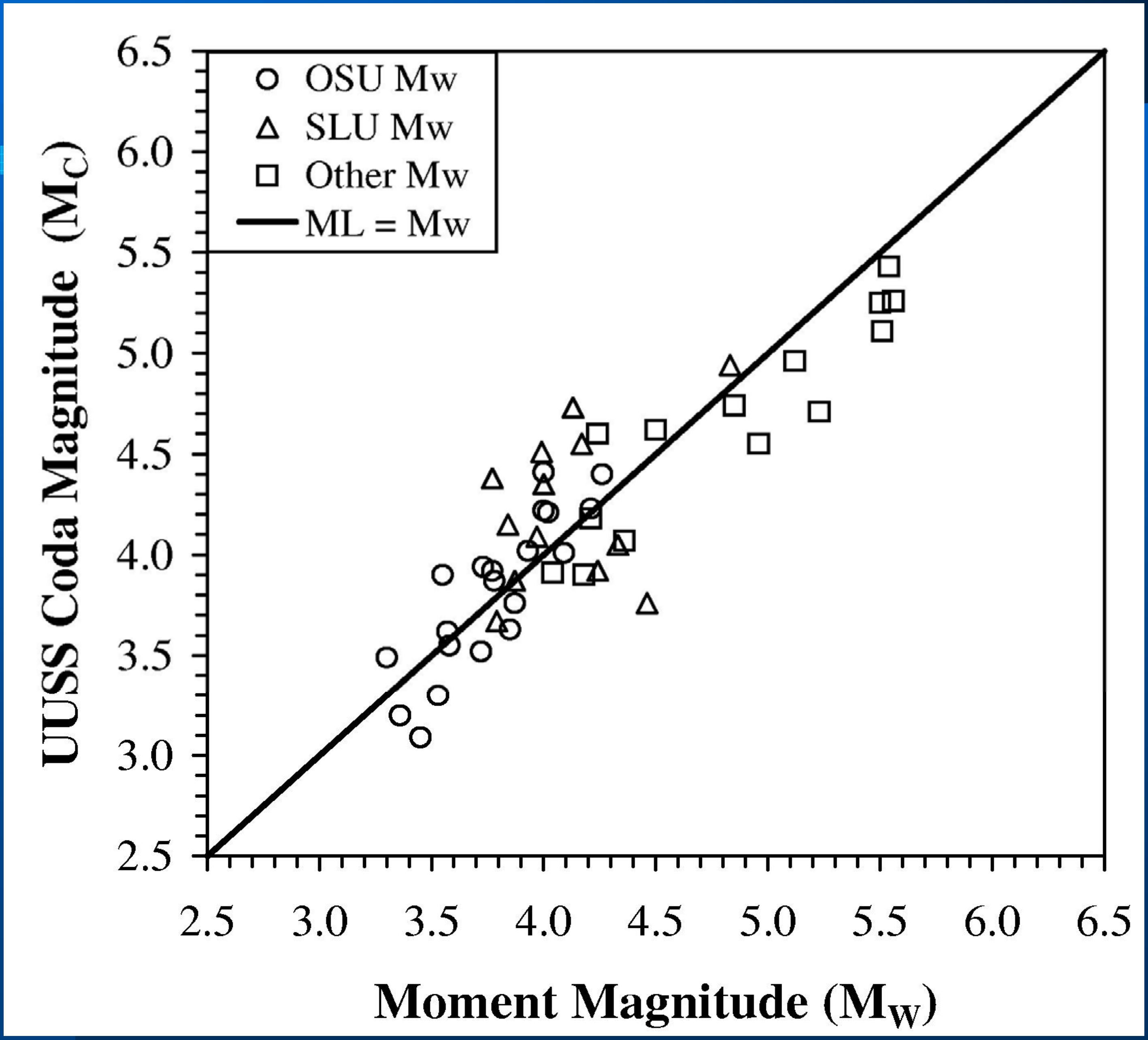
Some considerations from extensive work on magnitude revisions in the UUSS catalog by Pechmann et al. (2006, 2007) . . .



ML (UUSS) vs. MW
January 1981 - June 2003
OSU Mw
SLU Mw
Other Mw
ML = Mw
Local Magnitude
Moment Magnitude
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5

M_C (UUSS) vs. M_W

January 1981 - June 2003



end

strike−slip rates

McCaffrey, Johnson, Hammond/Bormann, Zeng, Bird

(color denotes median of the above 5)