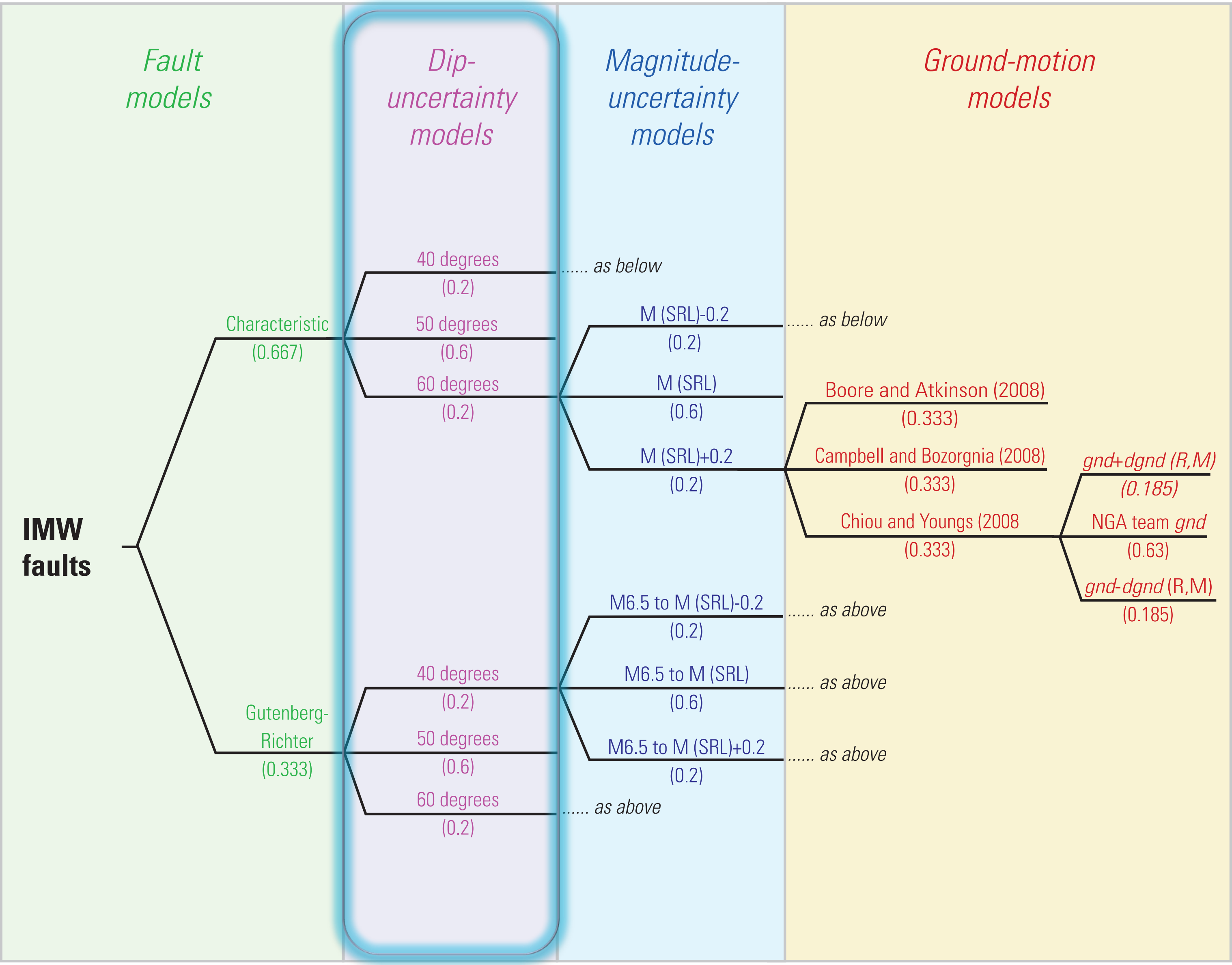
# Review of BRPEWG geology recommendations

- Uncertainty in source dip
- Characterization of source maximum M
- Slip-rate uncertainty
- Modeling antithetic sources

- Characterize the M–frequency distribution appropriately
- Test prediction by comparing the paleoseismic record to the model

# Dip uncertainty of normal sources in the IMW



Petersen et al. (2008)

# Discussion topics

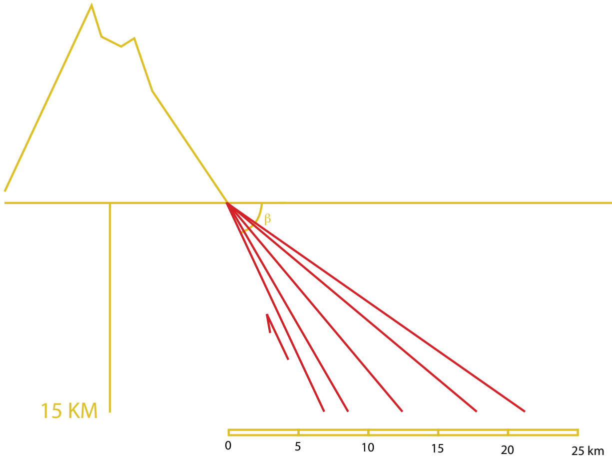
- Does the group still recommend that the assigned dip of normal sources in the IMW should be 50±15°?
- If so, should 40° and 60° dips be retained in the logic tree?

# Implications on hazard at a site by broadening dip uncertainty

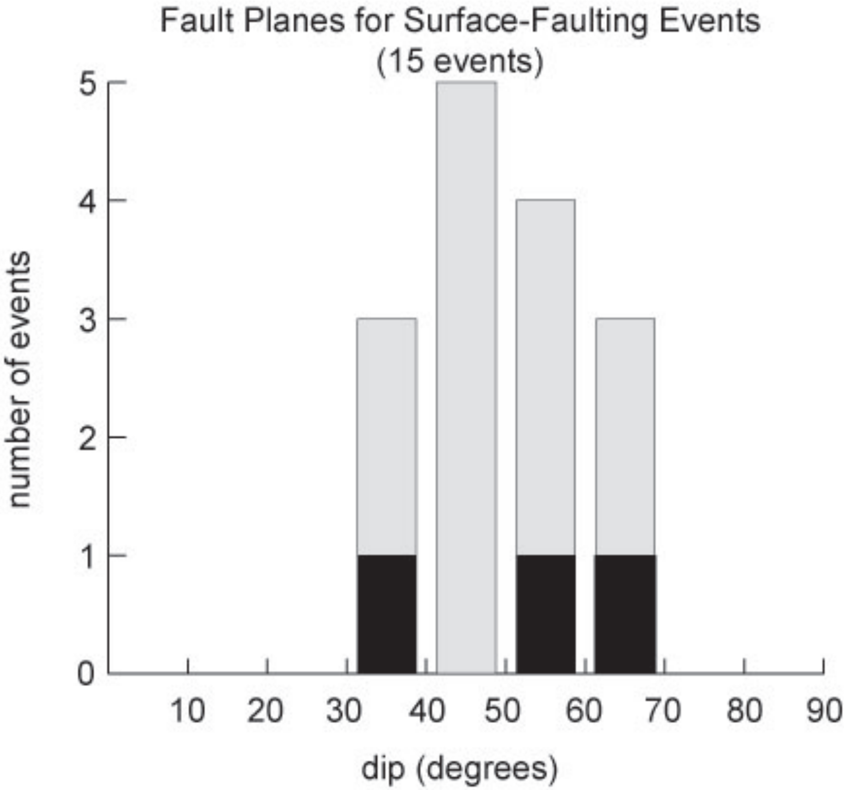
- Change in mean seismic moment rate $[1/\sin(\text{dip})]^2$

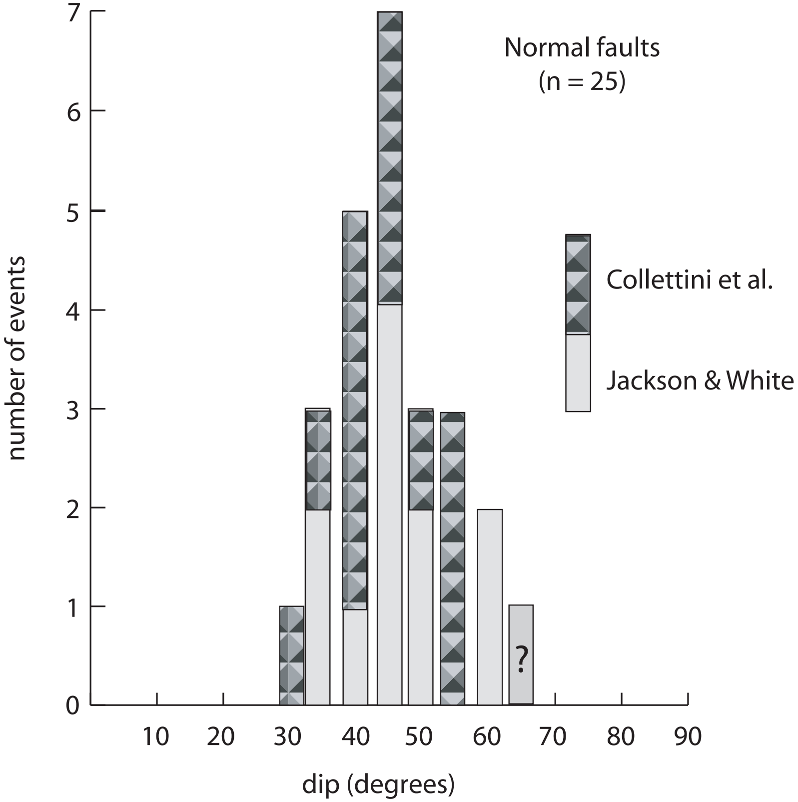
| 35° | 40° | 50° | 60° | 65° |
|---|---|---|---|---|
| 1.8x | 1.4x | 1.0 | 0.8x | 0.7x |

- Change in distance to rupture plane



# Historical normal-faulting earthquakes

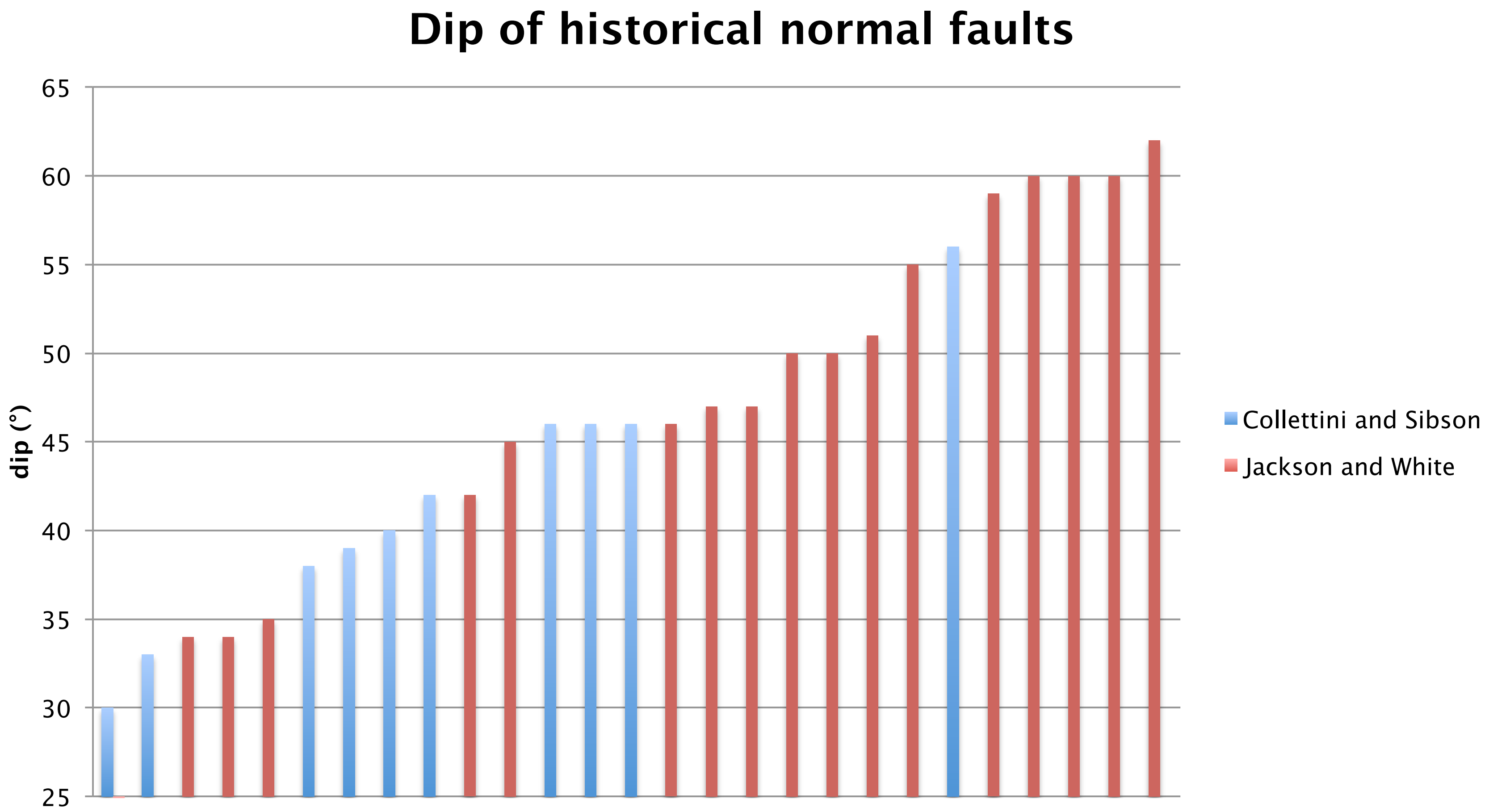




from Jackson and White, 1989

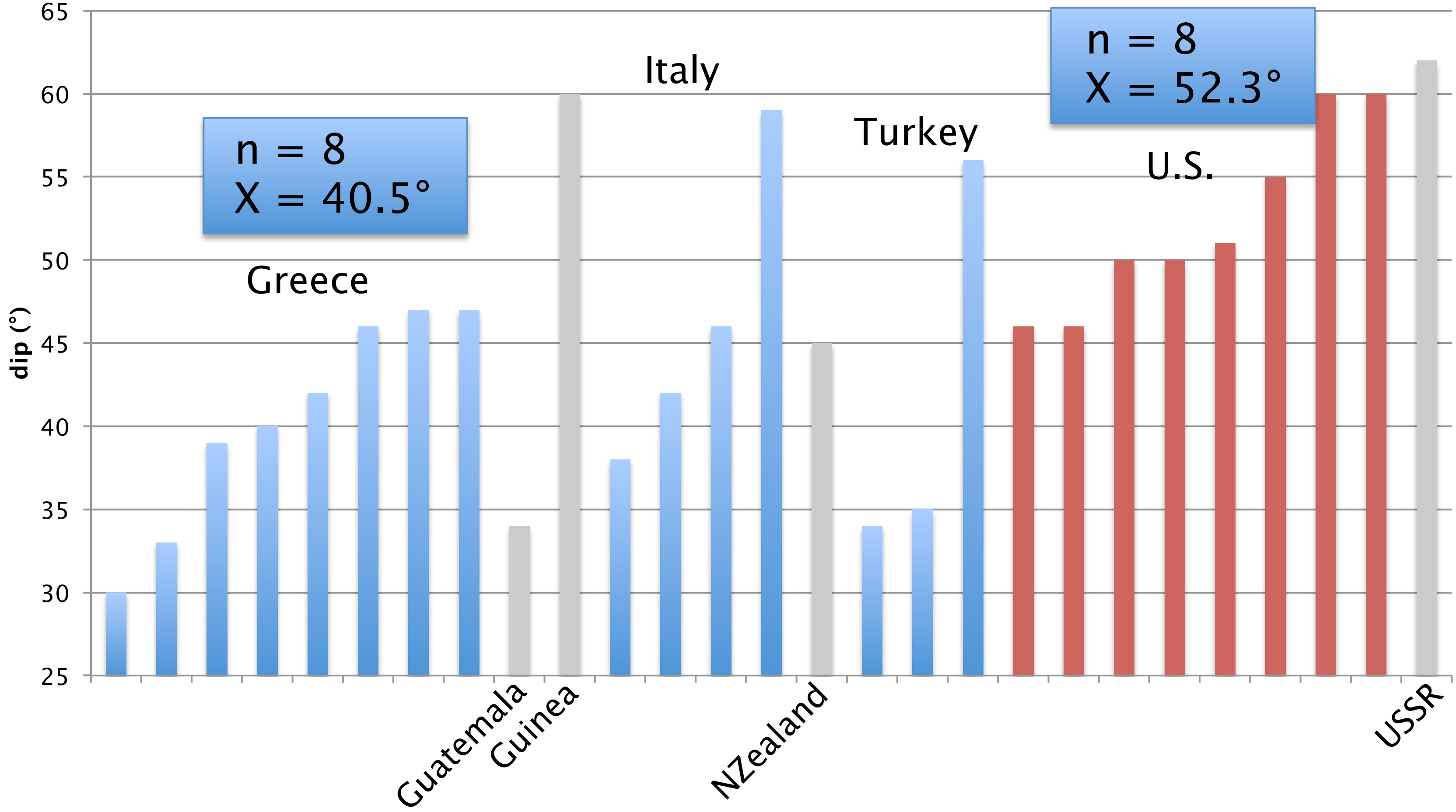
from Collettini and Sibson, 2001

# Source of dip attributed to historical normal fault

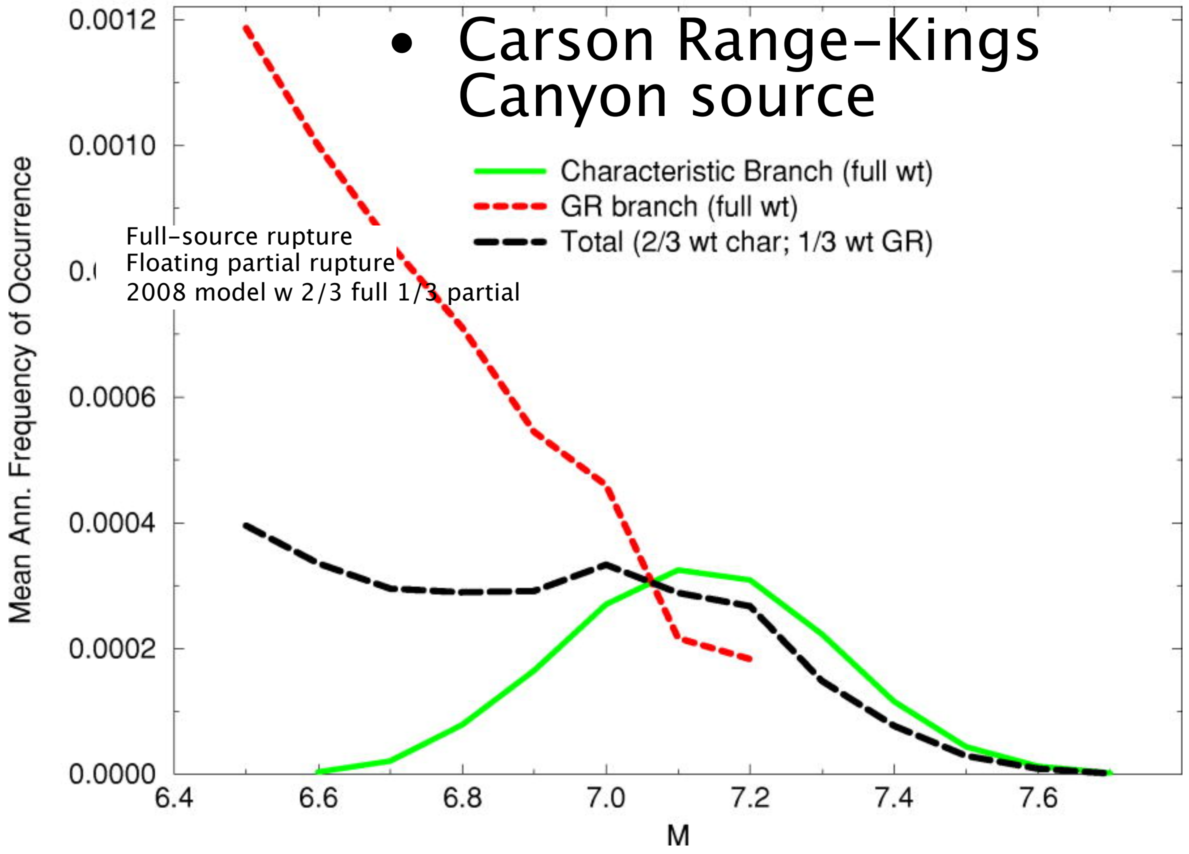


Dip of historical normal faults

# Location of historical normal-faulting earthquake



# 2008 annual frequency of full and partial ruptures

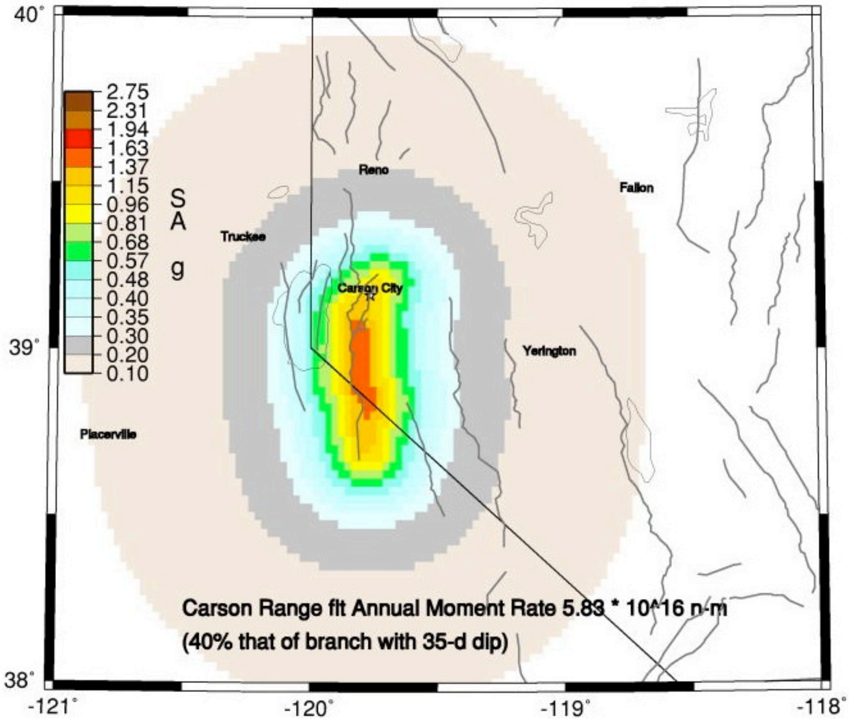


- Carson Range-Kings Canyon source

Full-source rupture
Floating partial rupture
2008 model w 2/3 full 1/3 partial

# 65-degree dipping sources

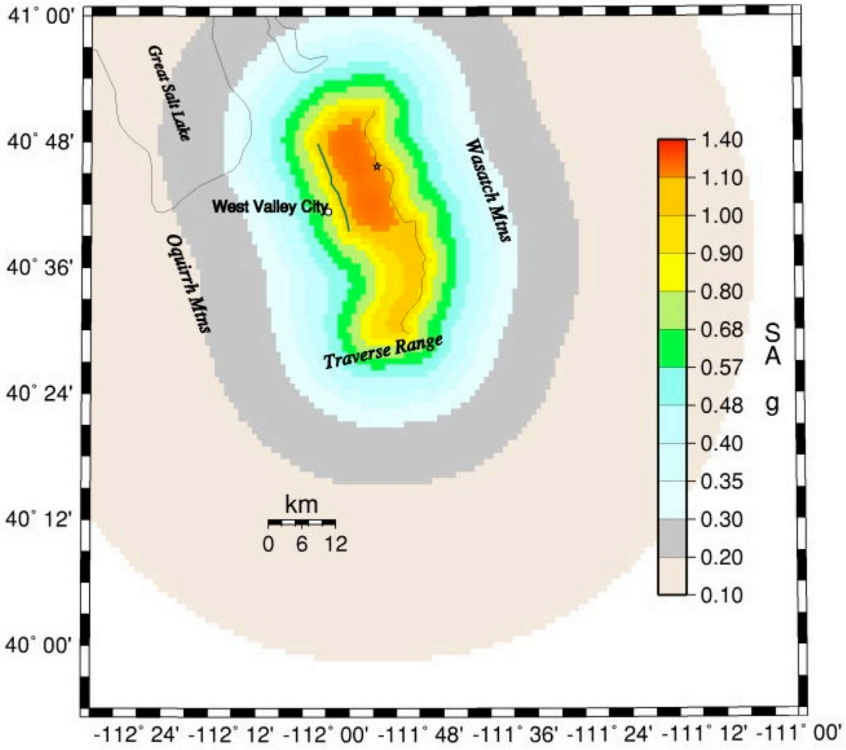
**Carson Range-Kings Canyon source 0.3s SA 2% PE in 50 yr**



Carson Range flt Annual Moment Rate 5.83 * 10^16 n-m
(40% that of branch with 35-d dip)

Maximum SA = 1.15-1.37

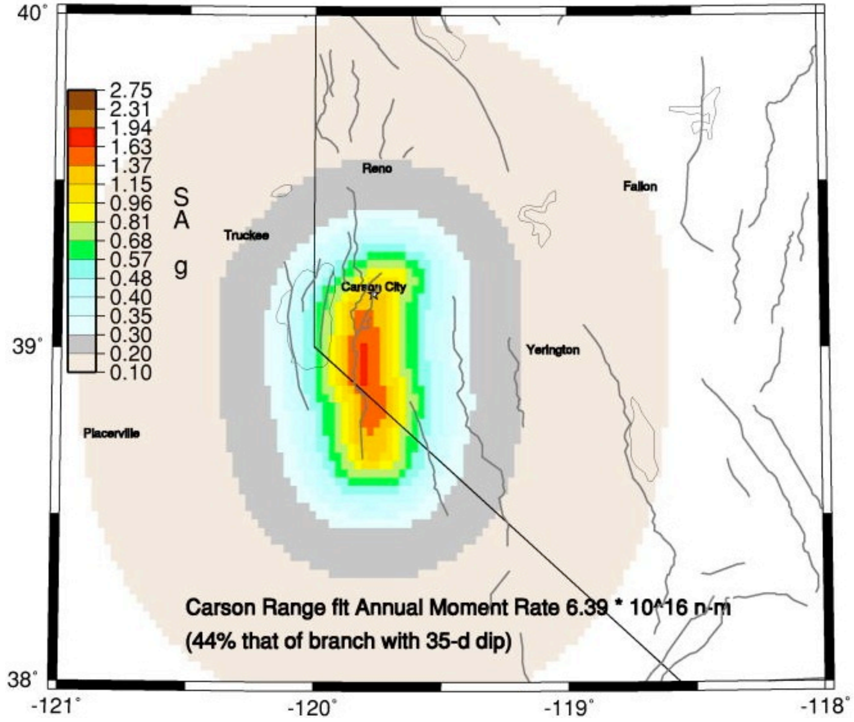
**Salt Lake City segment and West Valley sources 0.3s SA 2% PE in 50 yr**



Maximum SA = 1.1-1.40

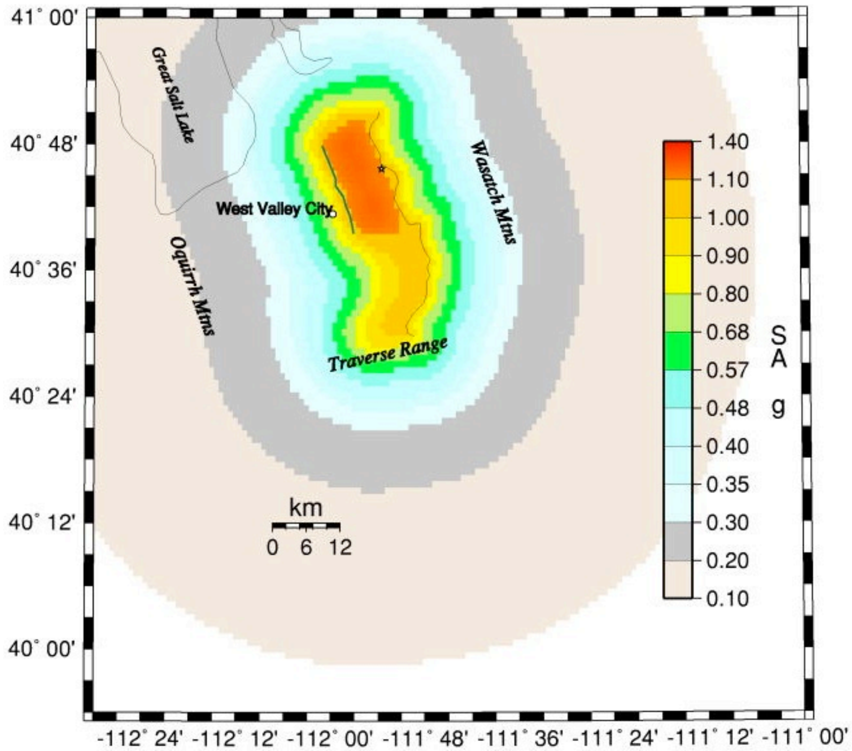
# 60-degree dipping sources

**Carson Range-Kings Canyon source 0.3s SA 2% PE in 50 yr**



Maximum SA = 1.63-1.94

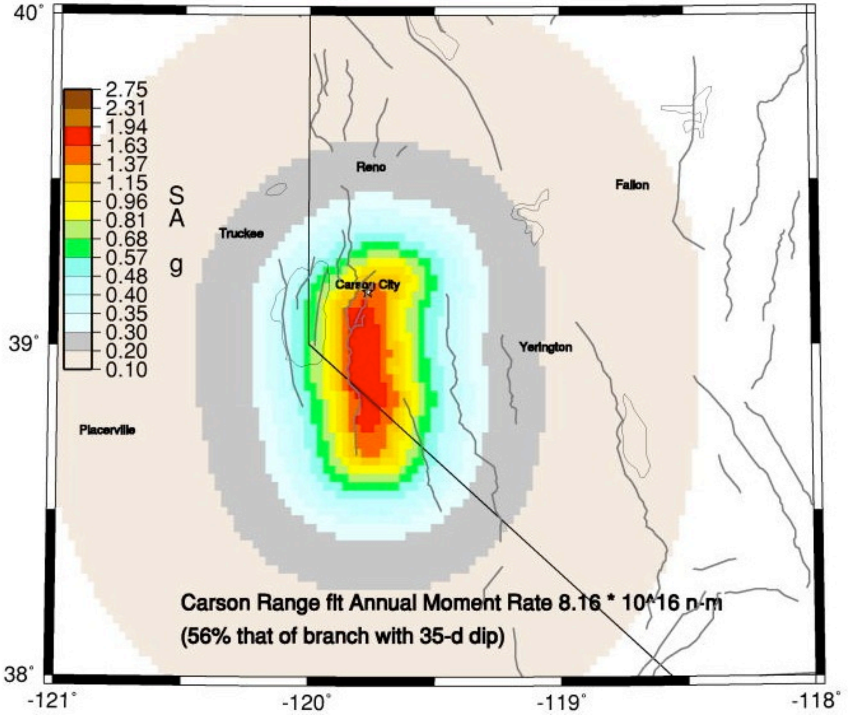
**Salt Lake City segment and West Valley sources 0.3s SA 2% PE in 50 yr**



Maximum SA = 1.10-1.40

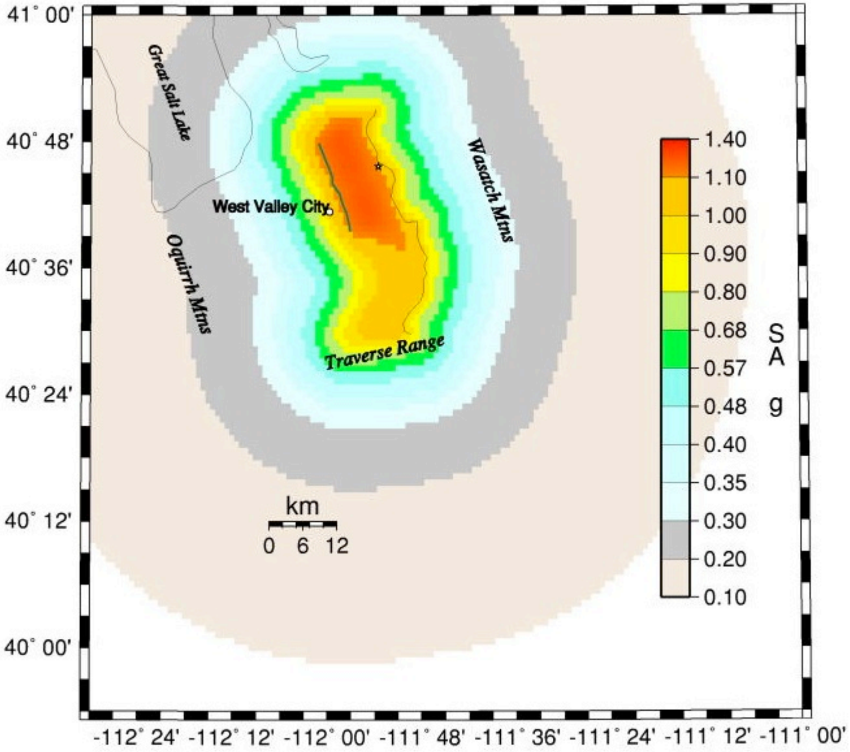
# 50-degree dipping sources

**Carson Range-Kings Canyon source 0.3s SA 2% PE in 50 yr**



Maximum SA = 1.63-1.94

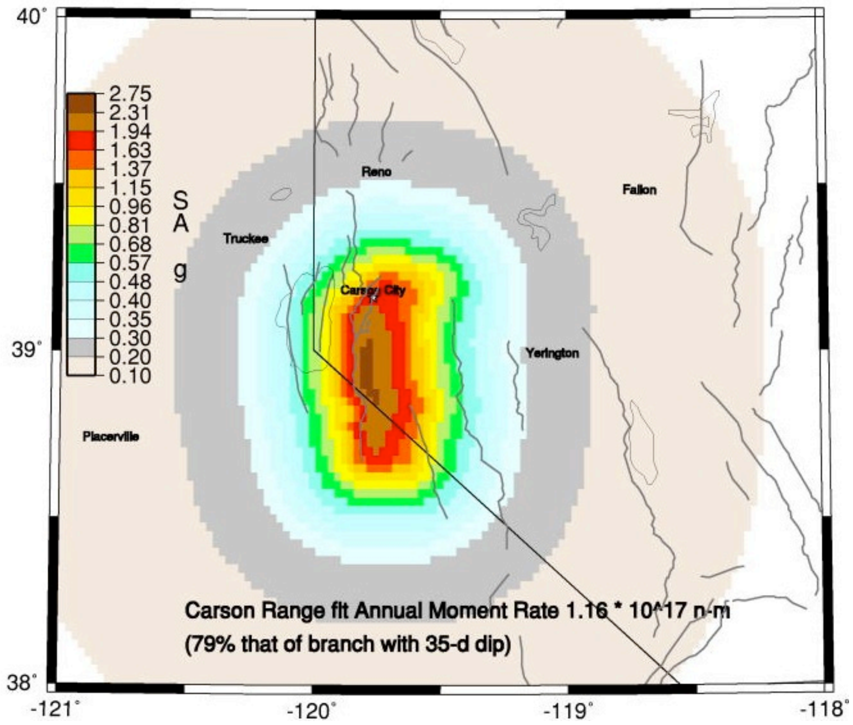
**Salt Lake City segment and West Valley sources 0.3s SA 2% PE in 50 yr**



Maximum SA = 1.10-1.40

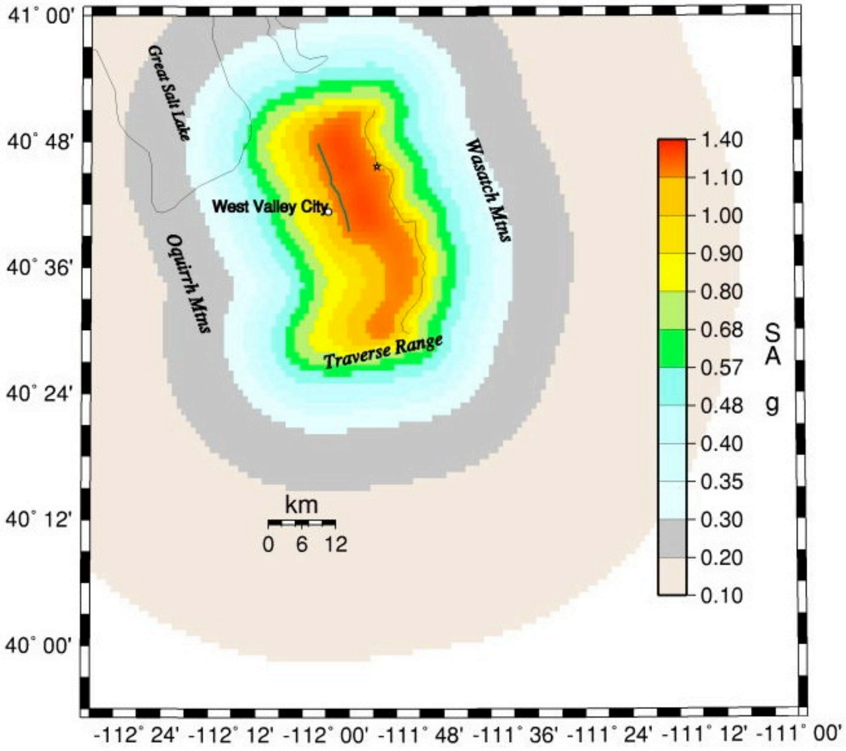
# 40-degree dipping sources

**Carson Range-Kings Canyon source 0.3s SA 2% PE in 50 yr**



Maximum SA = 2.31-2.75

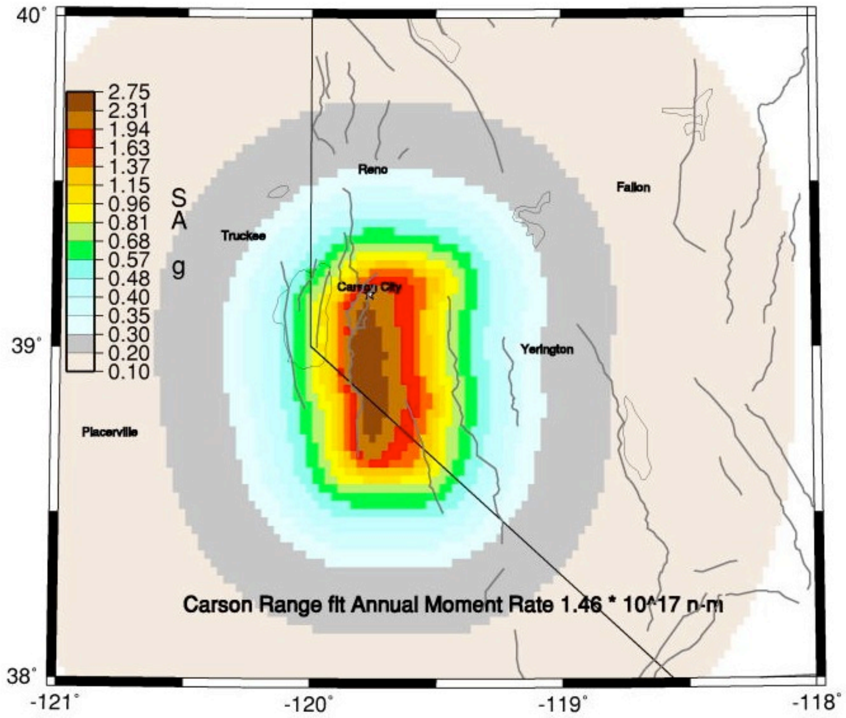
**Salt Lake City segment and West Valley sources 0.3s SA 2% PE in 50 yr**



Maximum SA = 1.10-1.40

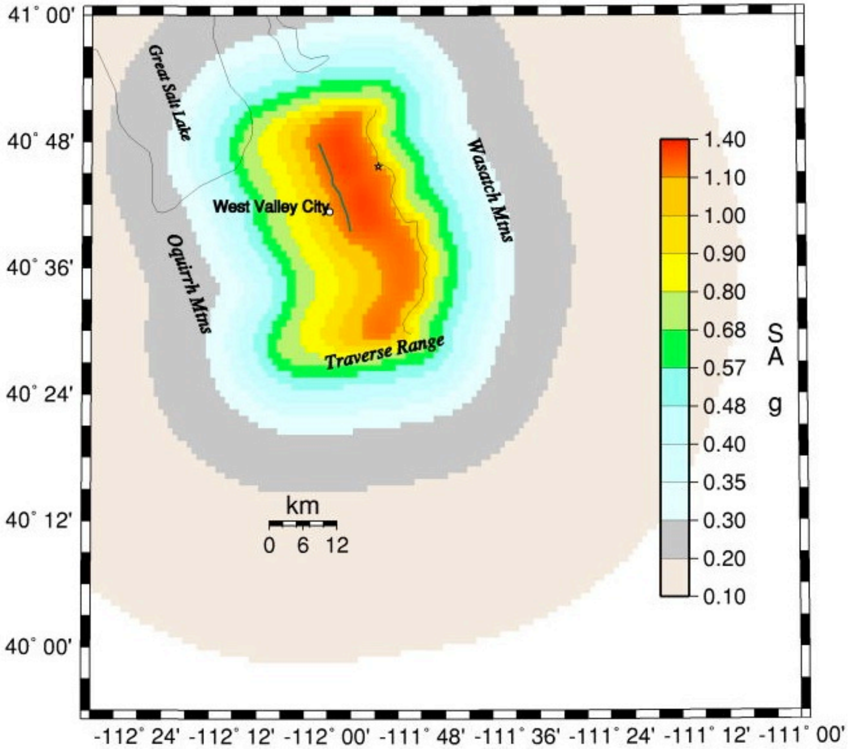
# 35-degree dipping sources

**Carson Range-Kings Canyon source 0.3s SA 2% PE in 50 yr**



Maximum SA = 2.31-2.75

**Salt Lake City segment and West Valley sources 0.3s SA 2% PE in 50 yr**

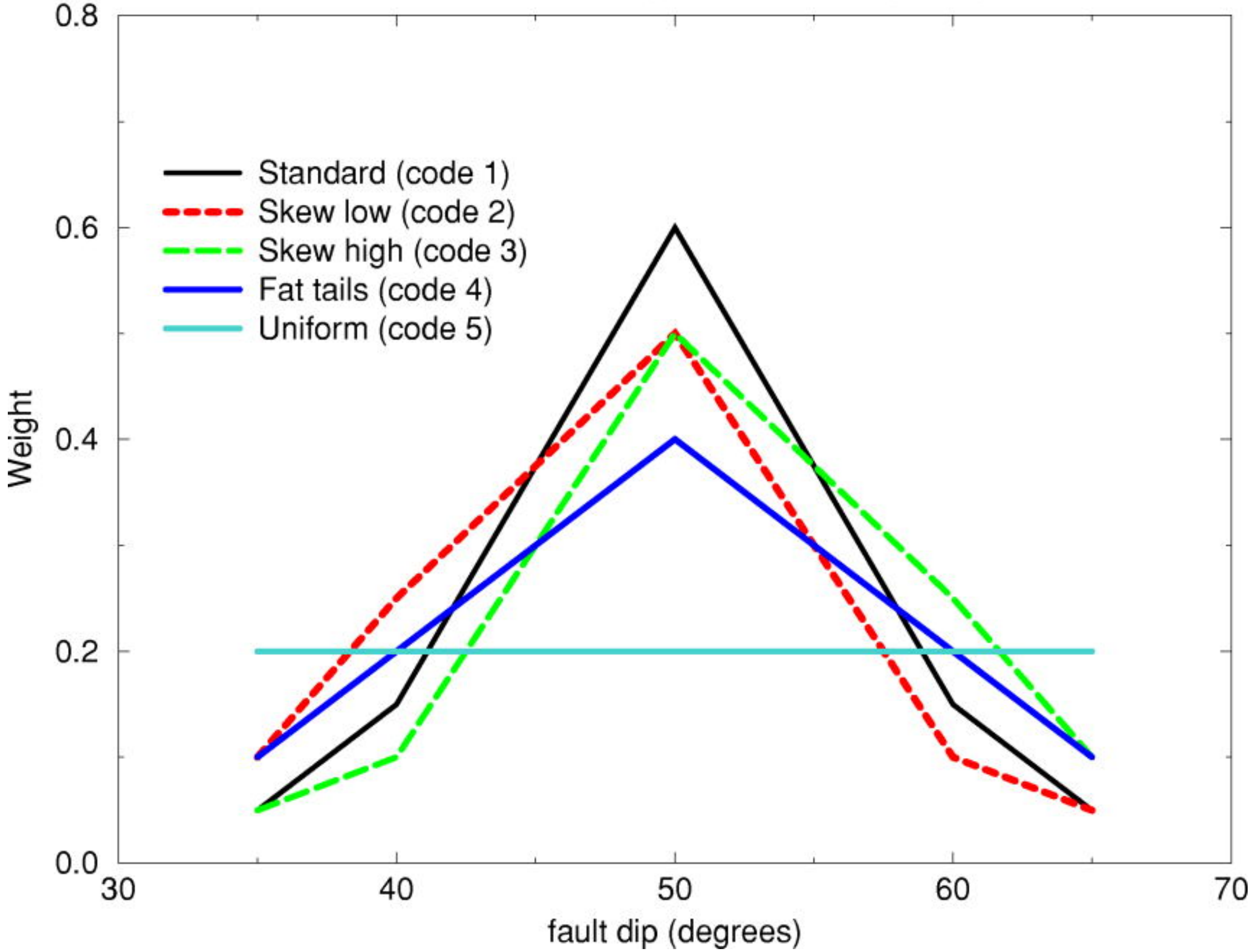


Maximum SA = 1.10-1.40

# Summary

- For slip rate constrained sources, increase mean seismic moment rate as $[1/\sin(\mathrm{dip})]^2$
- No similar change in rate for sources with fixed return times
- Hazard at Ssites above the fault are sensitive to distance to rupture
- How do alternative **M**–frequency fit the paleoseismic record?

# Possible dip distributions for normal sources



# References

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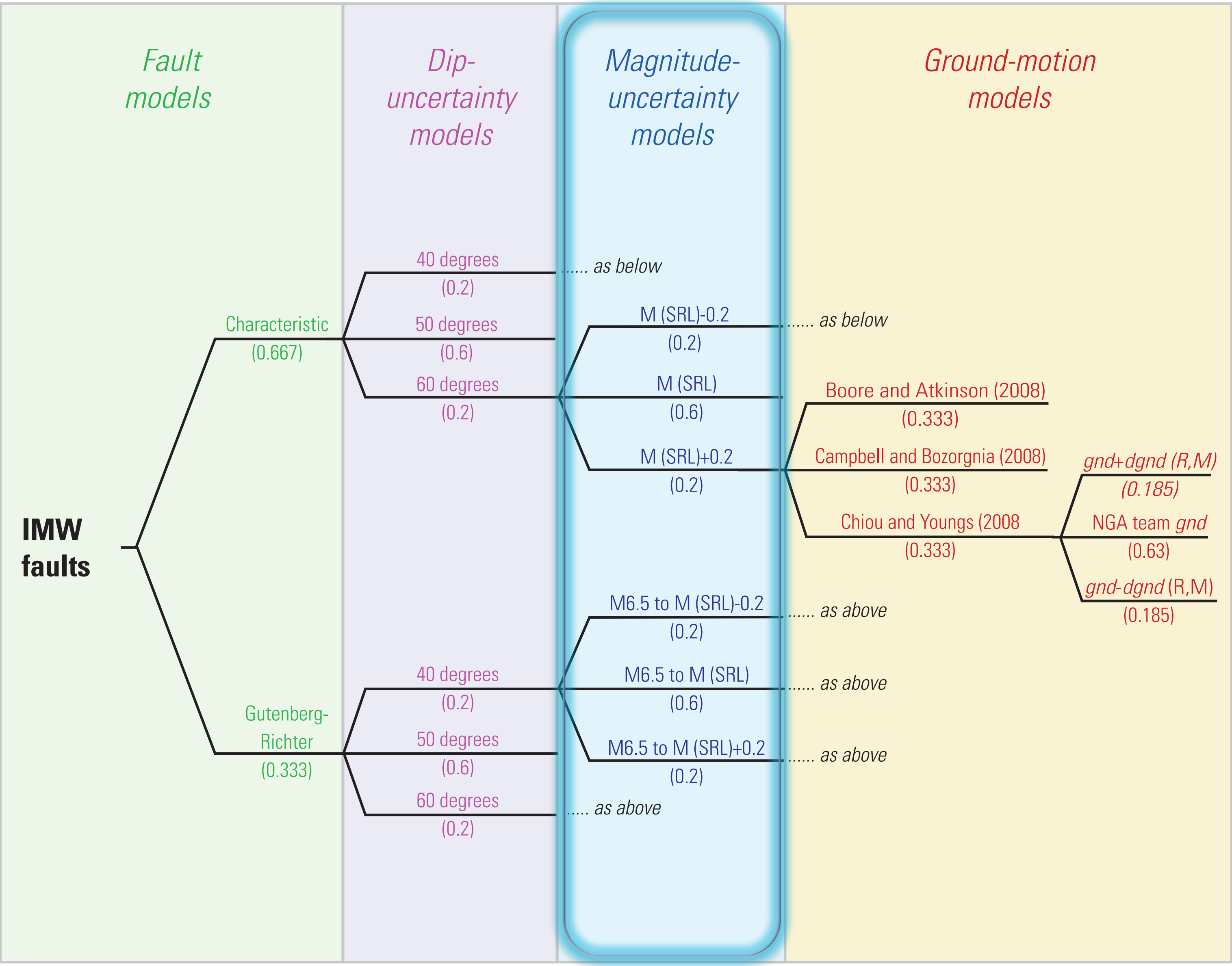
- DeCelles, P. G., and Coogan, J. C., 2006, Regional structure and kinematic history of the Sevier fold-and-thrust belt, central Utah: Geological Society of America Bulletin, v. 118, no. 7-8, p. 841-864.
- Jackson and White
- Koehler, R. D., and Wesnousky, S. G., 2011, Late Pleistocene regional extension rate derived from earthquake geology of late Quaternary faults across the Great Basin, Nevada, between 38.5 degrees N and 40 degrees N latitude: Geological Society of America Bulletin, v. 123, no. 3-4, p. 631-650.

# Analysis of scaling relations to constrain maximum **M** for fault sources in the IMW

# Outline

- Compare M–scaling relations for normal sources and their respective uncertainties
- Compare M–scaling relations for strike–slip sources
- Characterize the distribution of M in the IMW



*Fault models*

*Dip-uncertainty models*

*Magnitude-uncertainty models*

*Ground-motion models*

**IMW faults**

Characteristic
(0.667)

40 degrees
(0.2)
...... *as below*

50 degrees
(0.6)

60 degrees
(0.2)

M (SRL)-0.2
(0.2)
...... *as below*

M (SRL)
(0.6)

M (SRL)+0.2
(0.2)

Boore and Atkinson (2008)
(0.333)

Campbell and Bozorgnia (2008)
(0.333)

Chiou and Youngs (2008
(0.333)

*gnd+dgnd (R,M)*
*(0.185)*

NGA team *gnd*
(0.63)

*gnd-dgnd* (R,M)
(0.185)

Gutenberg-Richter
(0.333)

40 degrees
(0.2)

50 degrees
(0.6)

60 degrees
(0.2)
..... *as above*

M6.5 to M (SRL)-0.2
(0.2)
...... *as above*

M6.5 to M (SRL)
(0.6)
...... *as above*

M6.5 to M (SRL)+0.2
(0.2)
...... *as above*

Petersen et al. (2008)

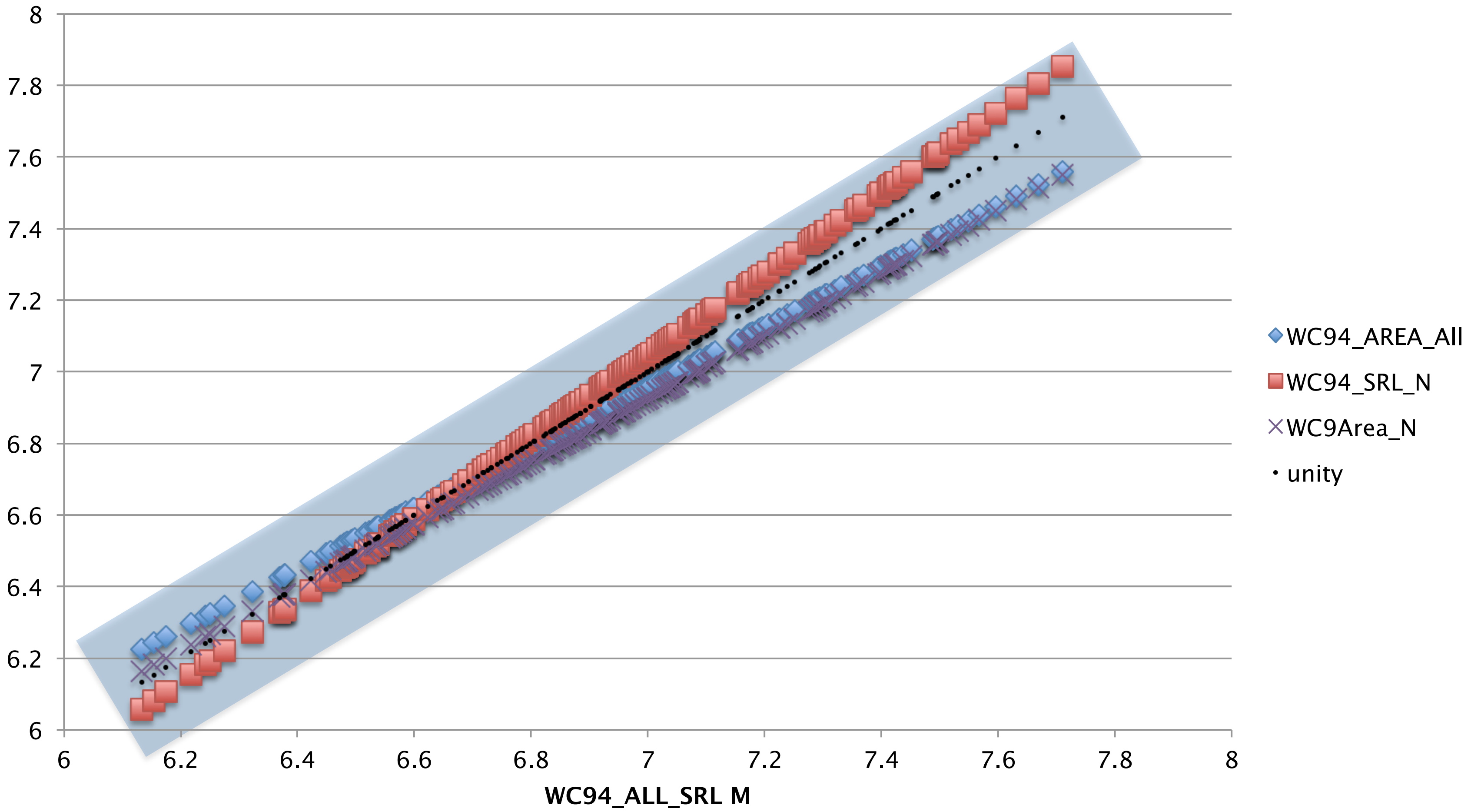
# BRPEWGII recommendation

- There are significant epistemic uncertainties in determining Mmax *[maximum source M]* for BRP normal faults due to possible scaling differences for the low-strain rate environment, normal slip earthquakes, and larger events. To better address these uncertainties, consider using multiple regression relations from the following list to determine Mmax for BRP faults in the NSHMs:

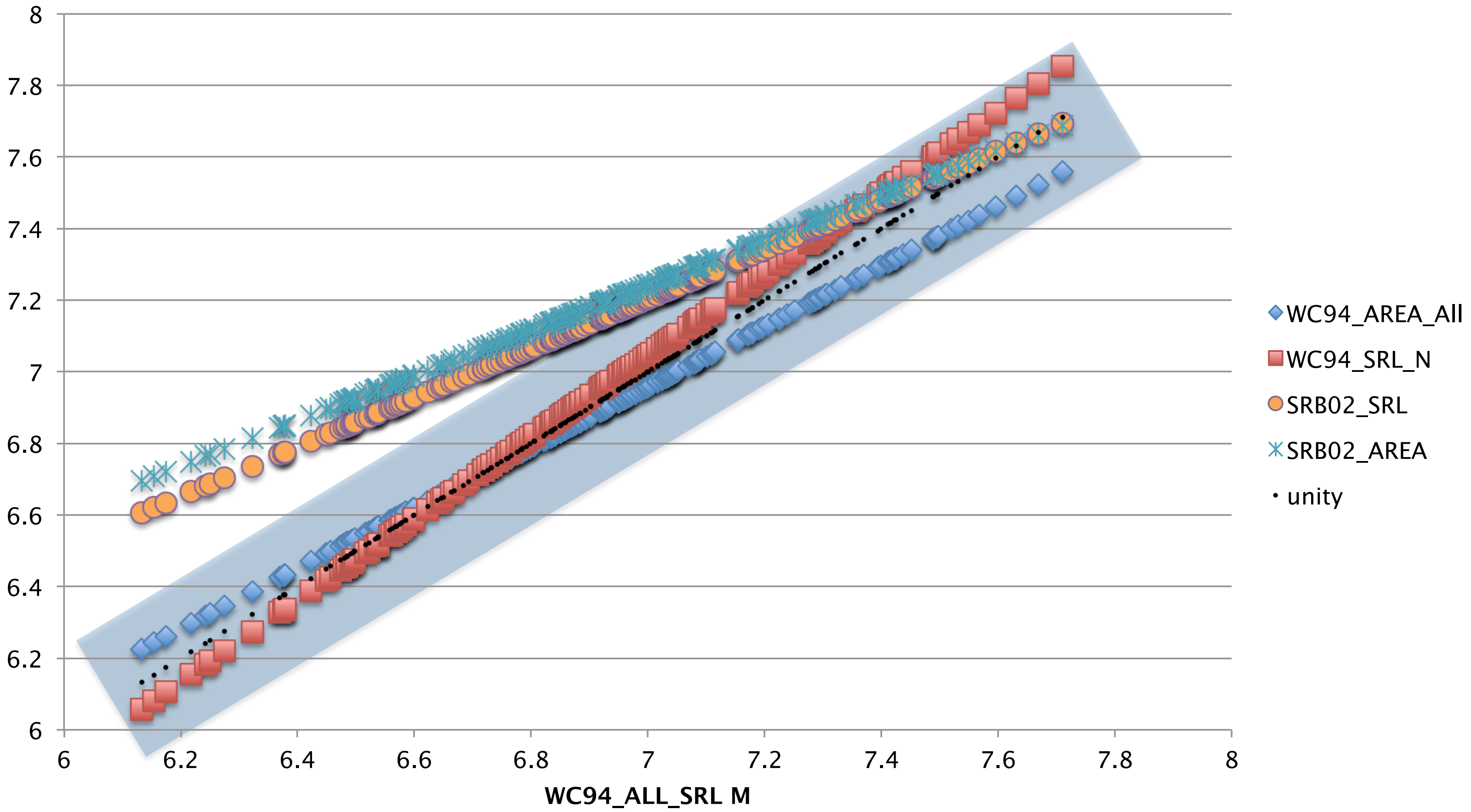
# Scaling relations

- Wells and Coppersmith (1994)
  $\mathbf{M} = (5.08\pm0.01)+(1.16\pm0.07)*\log(\mathrm{SRL})$ for all fault types
  $\mathbf{M} = (4.07\pm0.06)+(0.98\pm0.03)*\log(\mathrm{RA})$ for all fault types
  $\mathbf{M} = (4.86\pm0.34)+(1.32\pm0.26)*\log(\mathrm{SRL})$ for normal faults
  $\mathbf{M} = (3.93\pm0.23)+(1.02\pm0.1)*\log(\mathrm{RA})$ for normal faults
- Anderson et al. (1996)
  $\mathbf{M} = (5.12\pm0.12)+(1.16\pm0.07)*\log(\mathrm{SRL})-0.2*\log(\mathrm{SR})$
- Stirling et al. (2002) – censored instrumental (table 2)
  $\mathbf{M} = (5.88\pm0.17)+(0.8\pm0.1)*\log(\mathrm{SRL})$
  $\mathbf{M} = (5.09\pm0.21)+(0.73\pm0.07)*\log(\mathrm{RA})$

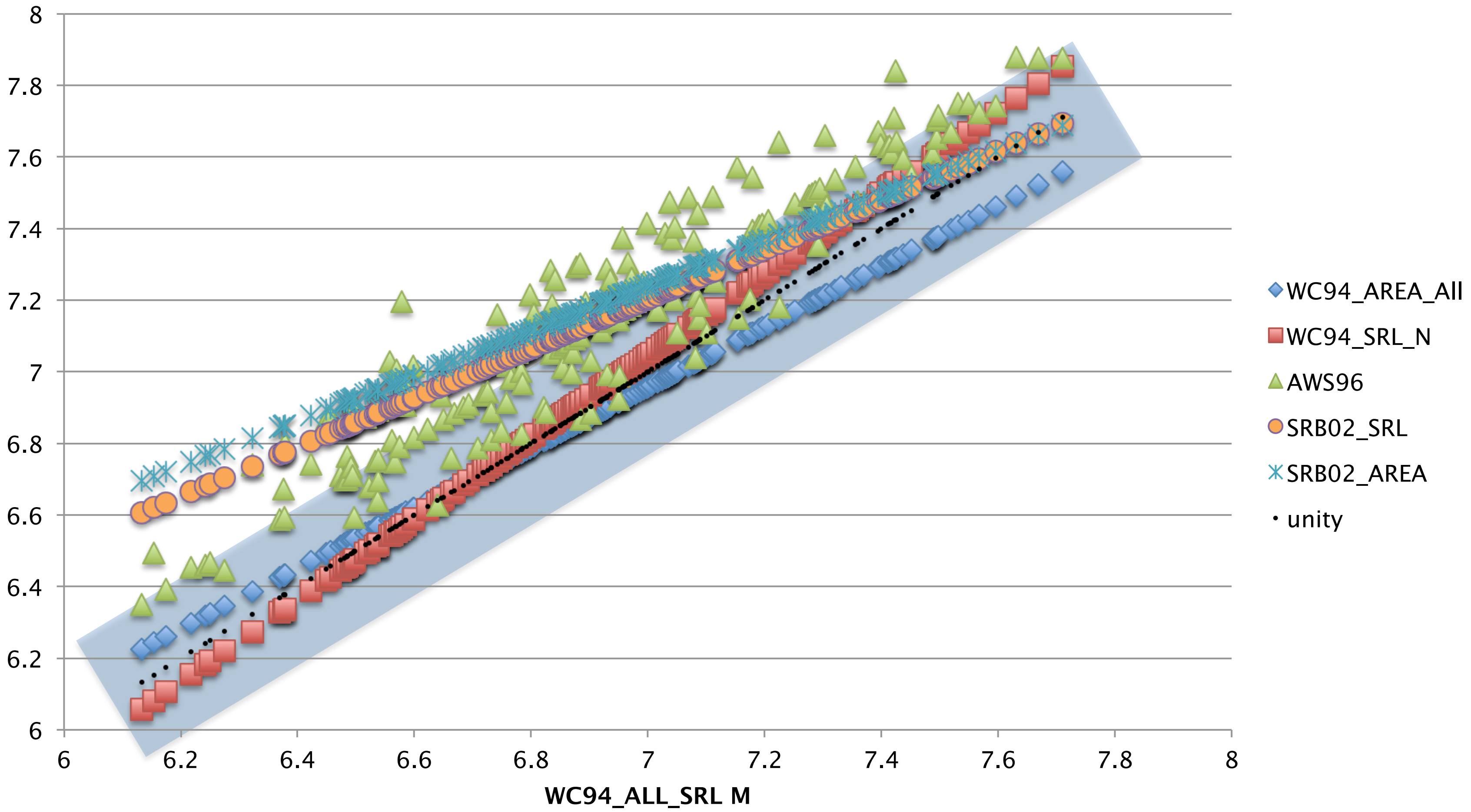
# Comparison of recommended scaling relations



# Compare recommended scaling relations to WC94_SRL_All

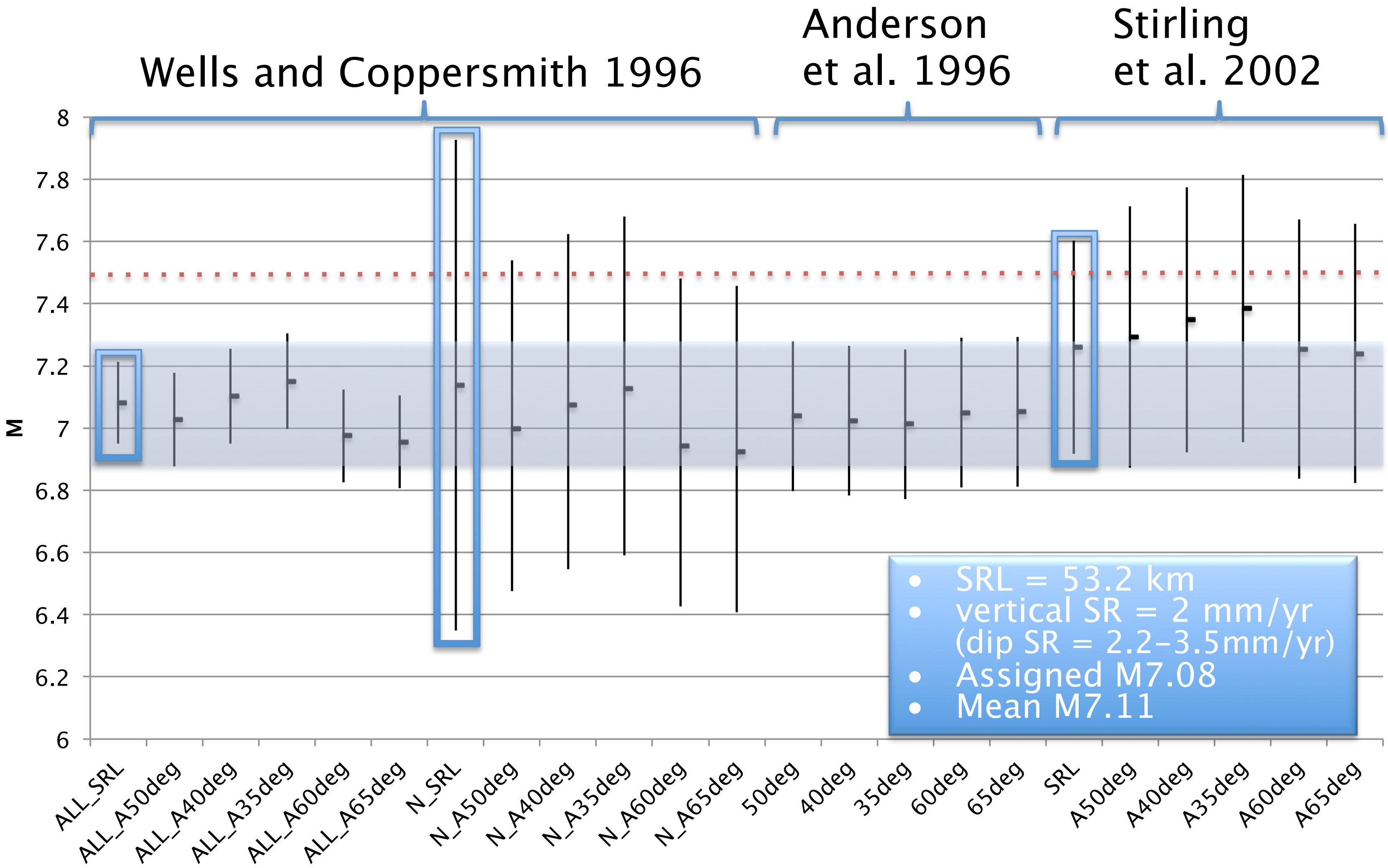


# Compare recommended scaling relations to WC94_SRL_All



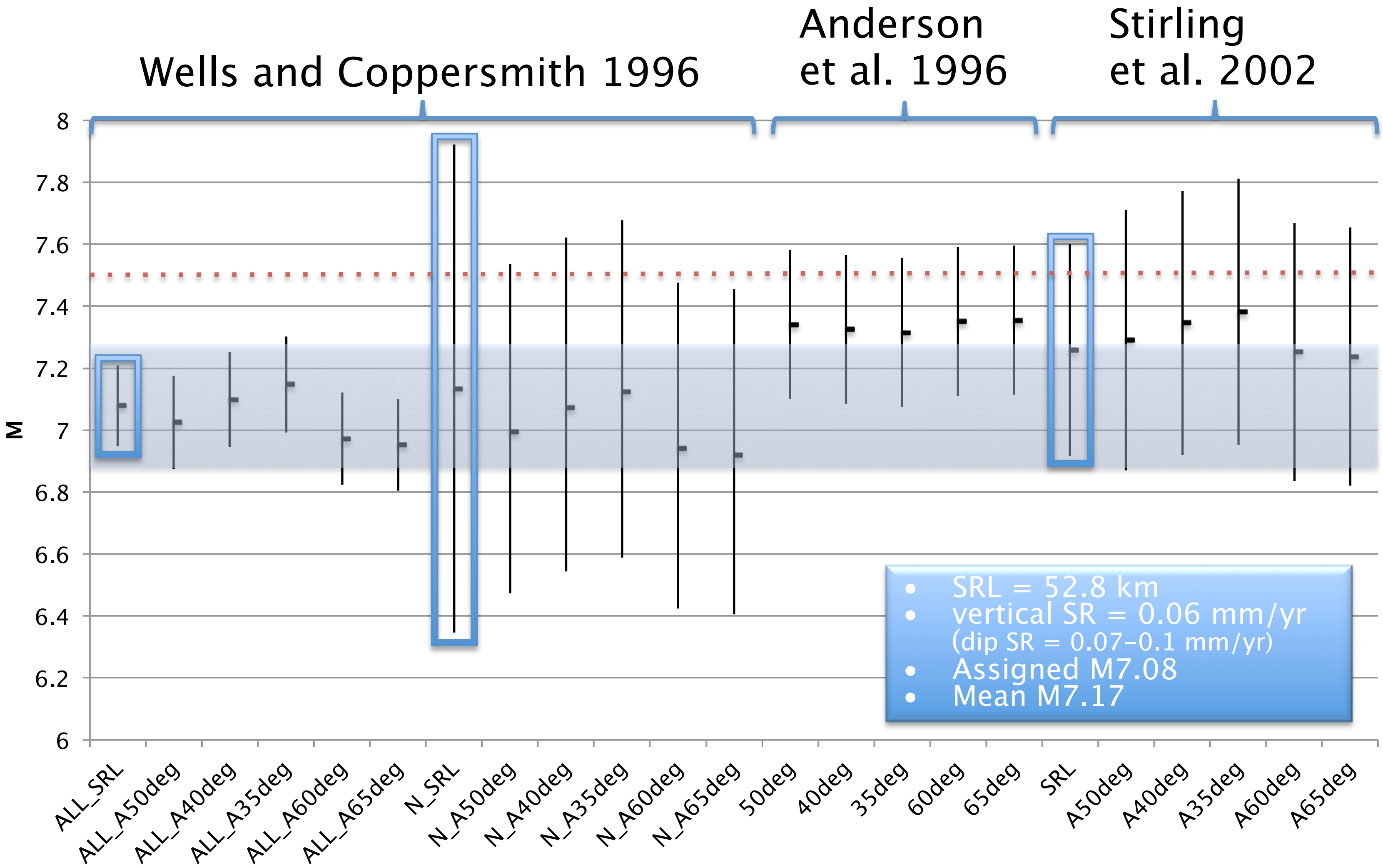
- Under estimate of M “will result in more numerous, smaller-magnitude earthquakes. This in turn will lead to correspondingly—and erroneously—higher mean annual rates of occurrence” for predicted earthquakes. __Hanks and Bakun (2002)

# Carson Range source



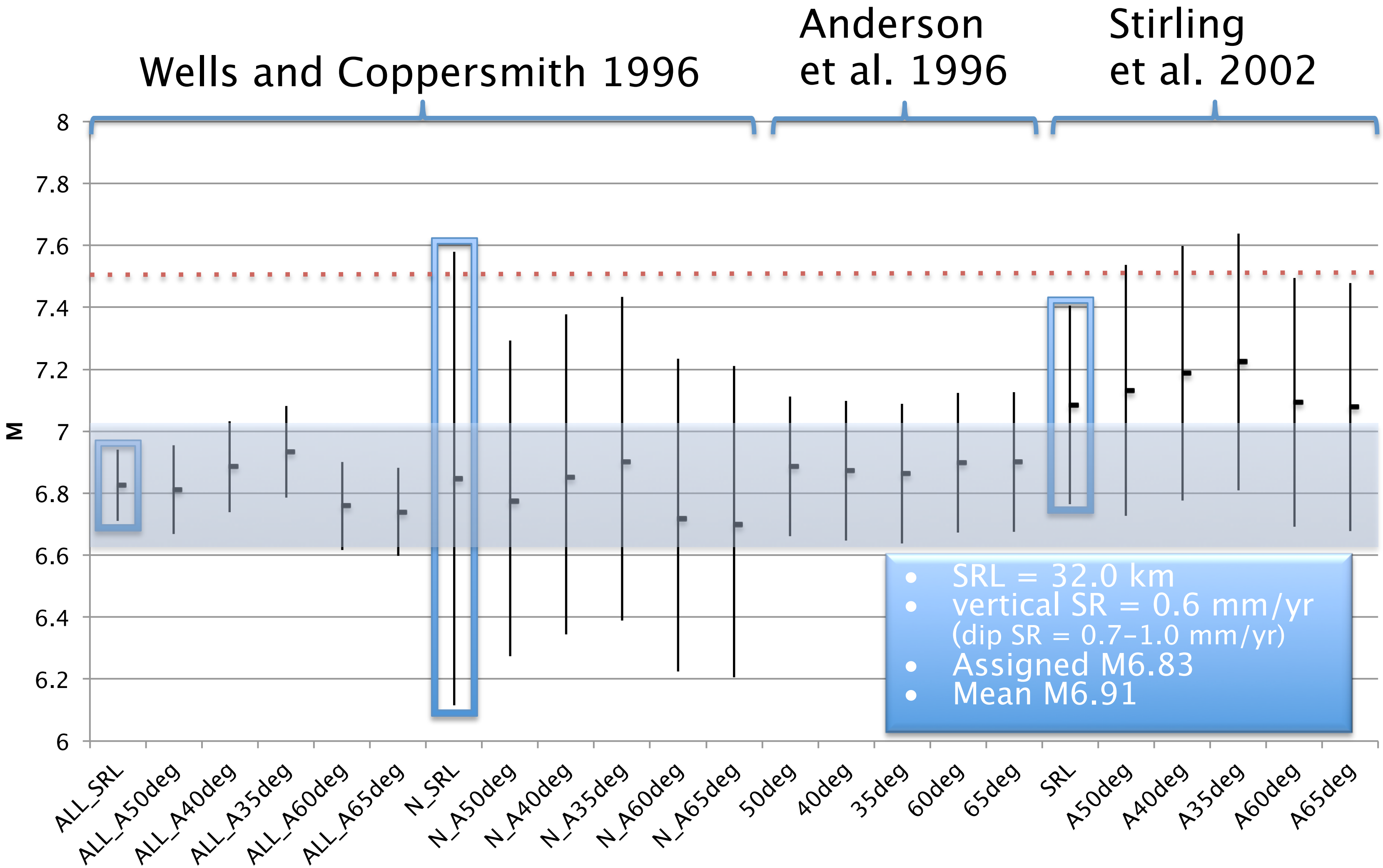
- SRL = 53.2 km
- vertical SR = 2 mm/yr (dip SR = 2.2-3.5mm/yr)
- Assigned M7.08
- Mean M7.11

# West Spring Mountains source



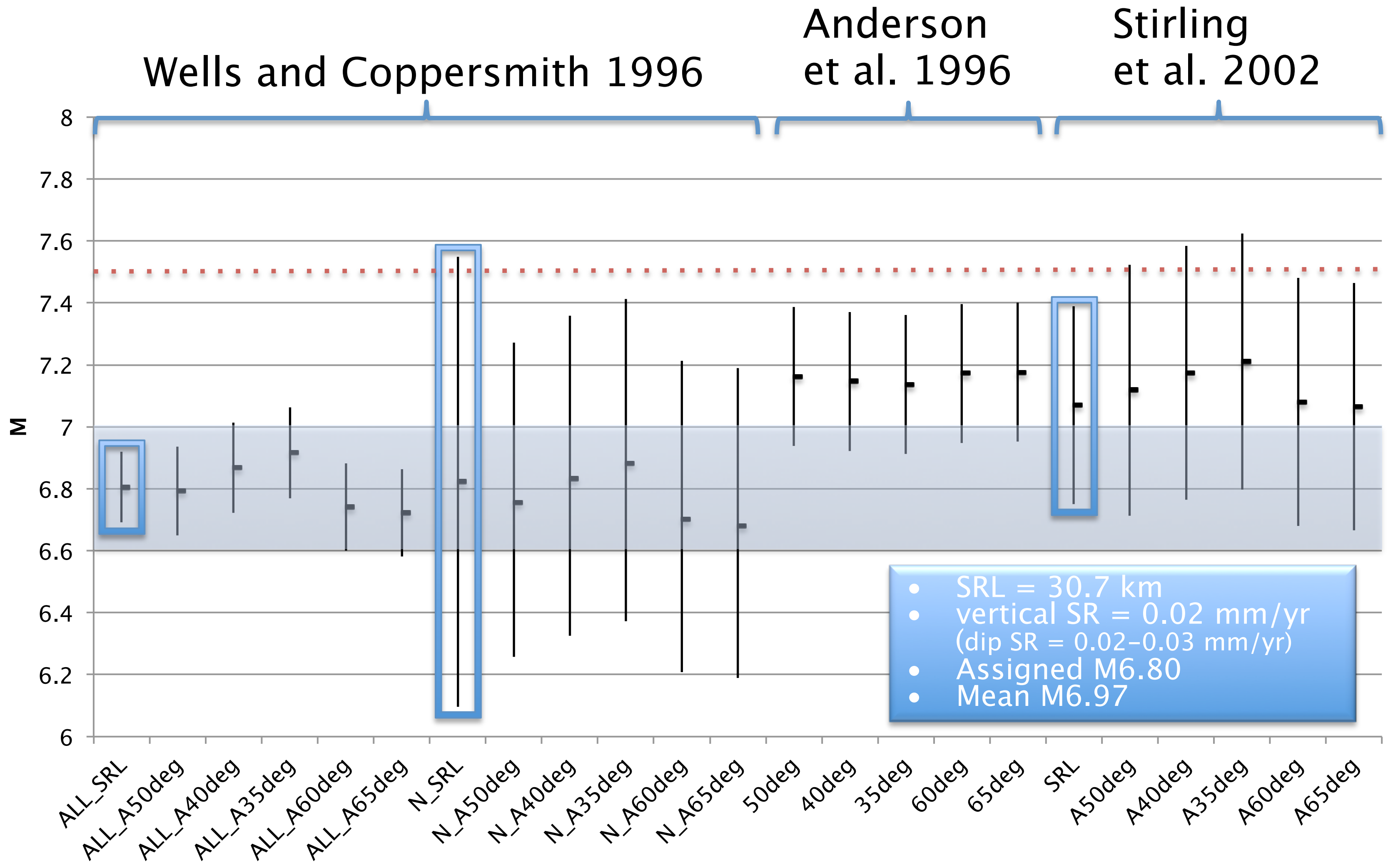
- SRL = 52.8 km
- vertical SR = 0.06 mm/yr
  (dip SR = 0.07-0.1 mm/yr)
- Assigned M7.08
- Mean M7.17

# GSL, Fremont Island source



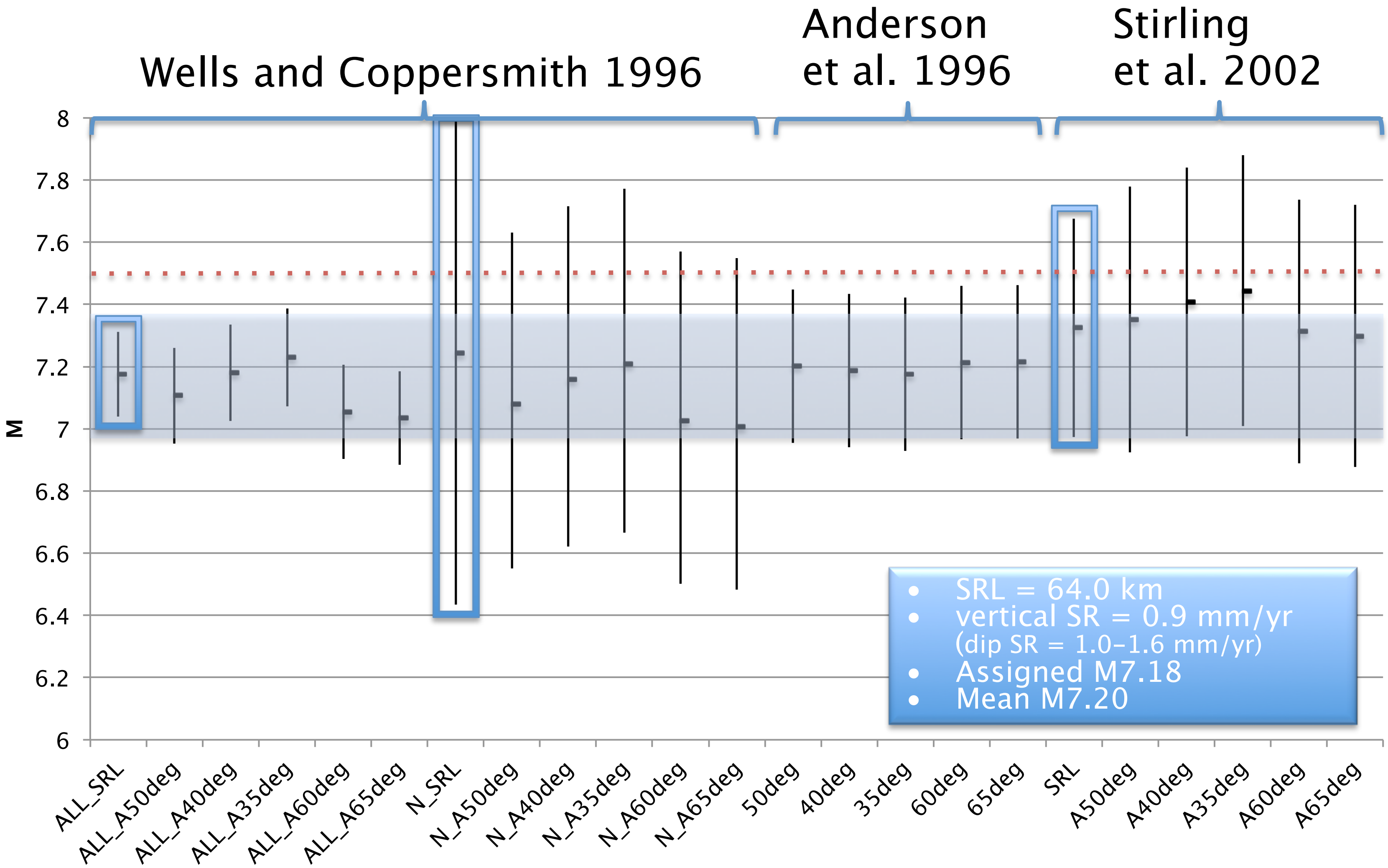
- SRL = 32.0 km
- vertical SR = 0.6 mm/yr
  (dip SR = 0.7-1.0 mm/yr)
- Assigned M6.83
- Mean M6.91

# Canones M_char



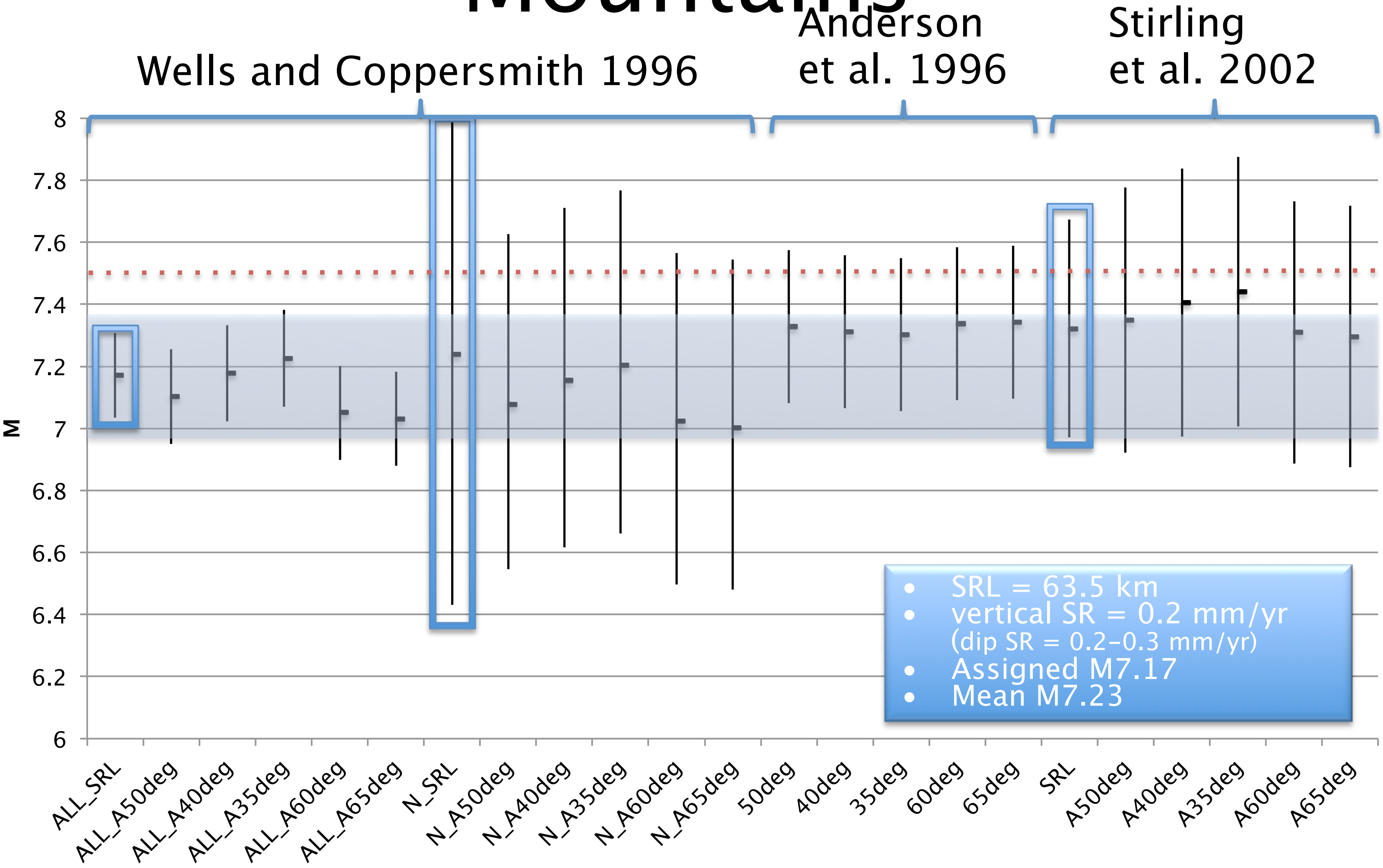
- SRL = 30.7 km
- vertical SR = 0.02 mm/yr
  (dip SR = 0.02-0.03 mm/yr)
- Assigned M6.80
- Mean M6.97

# Centennial M_char



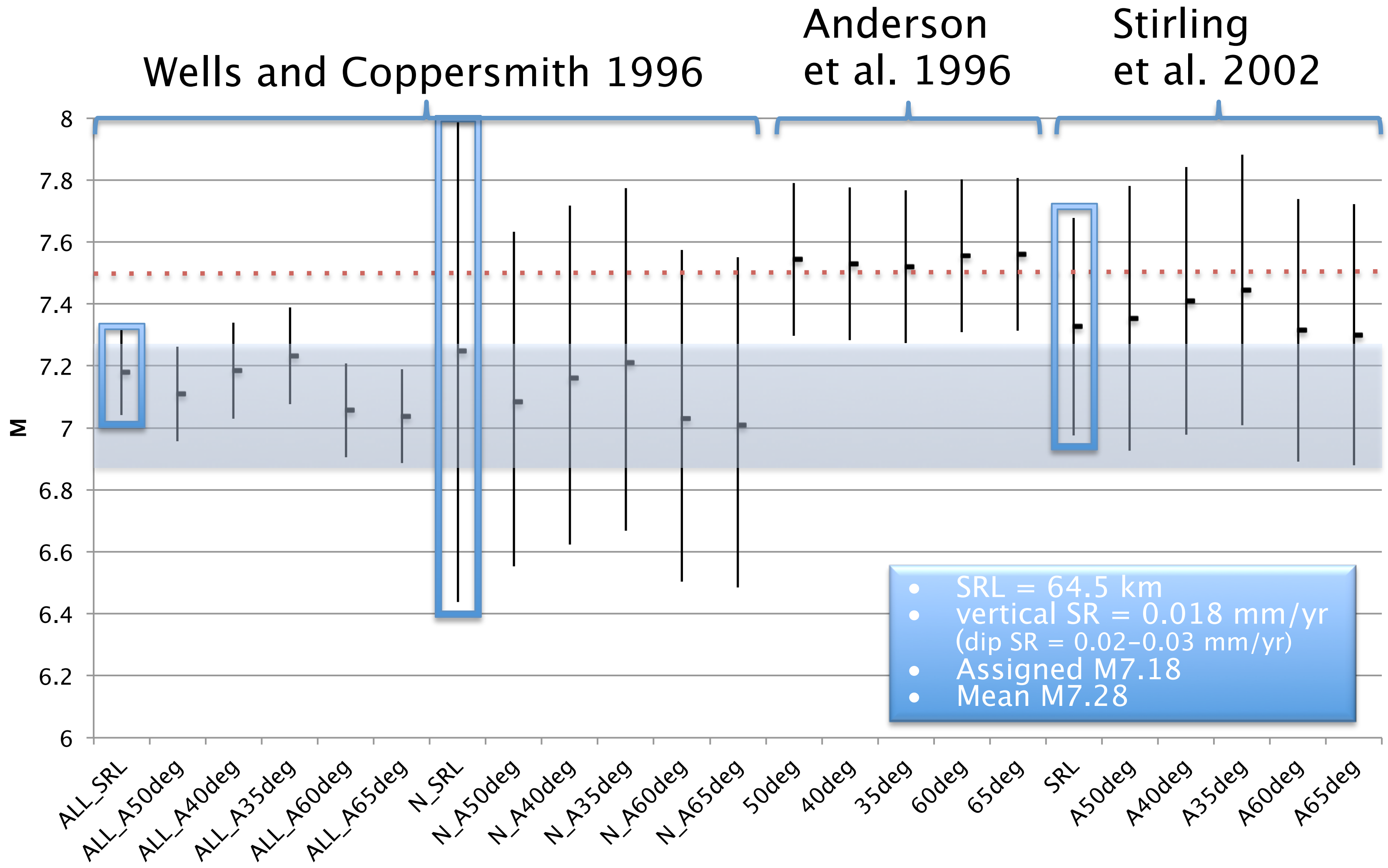
- SRL = 64.0 km
- vertical SR = 0.9 mm/yr
  (dip SR = 1.0-1.6 mm/yr)
- Assigned M7.18
- Mean M7.20

# Oquirrh–Southern Oquirrh Mountains



- SRL = 63.5 km
- vertical SR = 0.2 mm/yr
  (dip SR = 0.2–0.3 mm/yr)
- Assigned M7.17
- Mean M7.23

# Aubrey M_char



- SRL = 64.5 km
- vertical SR = 0.018 mm/yr (dip SR = 0.02-0.03 mm/yr)
- Assigned M7.18
- Mean M7.28

# Summary

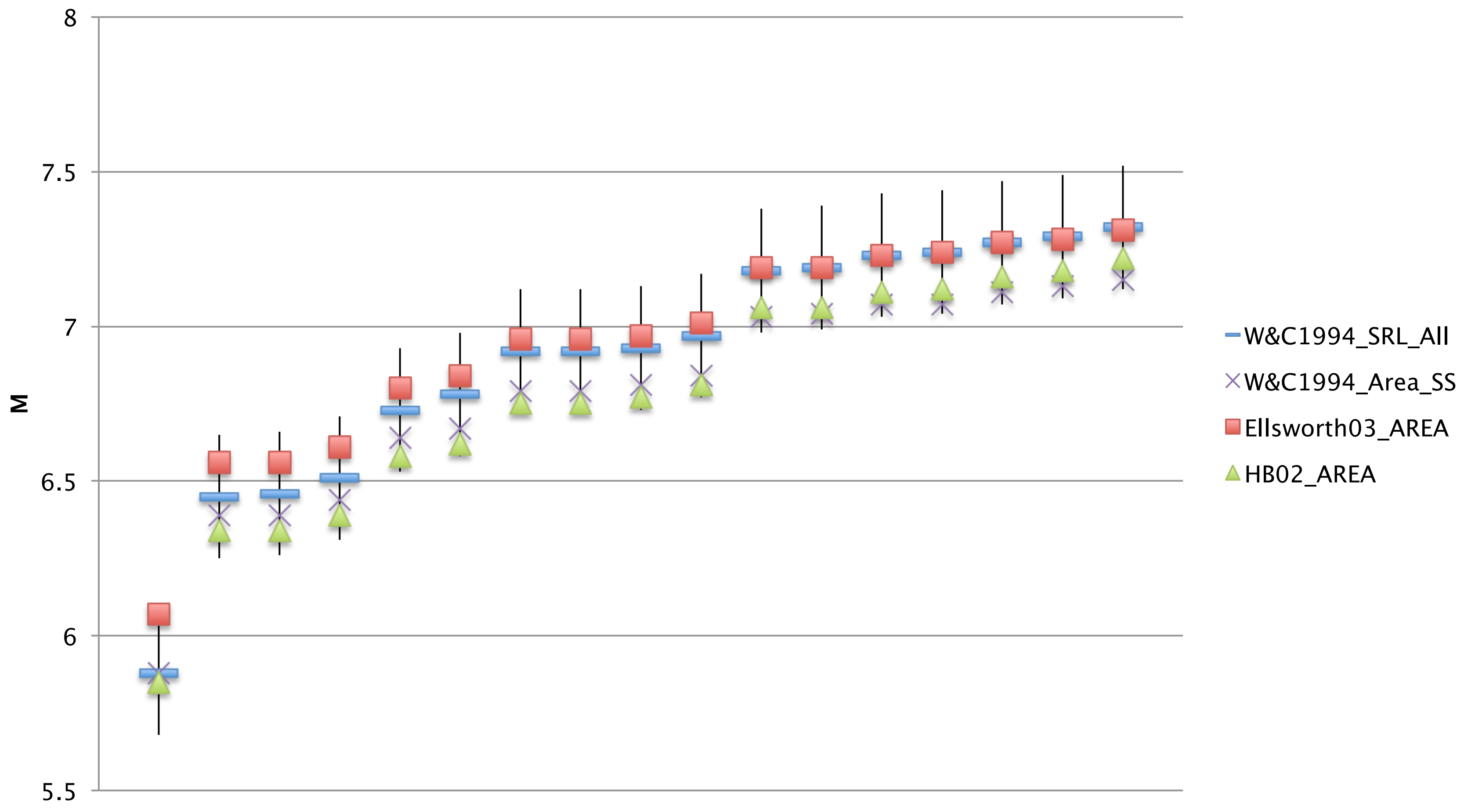
- Alternative relations yield larger **M** than WC94 relations
- All **M**–area and Anderson et al. (1996) scaling relations are sensitive to source dip
- Anderson et al. (1996) indicates larger M for slower slip faults

| | **SRL (km)** | **Vert SR (mm/yr)** | **Assigned M** | **M Range** | **Mean M** |
|---|---|---|---|---|---|
| Carson | 53.2 | 2.0 | 7.08 | 6.92–7.38 | 7.11 |
| West Spring | 52.8 | 0.06 | 7.08 | 6.92–7.38 | 7.17 |
| GSL, Fremont Is | 32.0 | 0.6 | 6.83 | 6.70–7.22 | 6.91 |
| Coones | 30.7 | 0.02 | 6.80 | 6.68–7.21 | 6.97 |
| Centennial | 64.0 | 0.9 | 7.18 | 7.00–7.44 | 7.20 |
| Oquirrh | 63.5 | 0.2 | 7.17 | 7.00–7.44 | 7.23 |
| Aubrey | 64.5 | 0.018 | 7.18 | 7.01–7.55 | 7.28 |

# BRPEWGII recommendation

- Use the same approach for determining Mmax for strike-slip faults in the BRP as is used for strike-slip faults in California (Petersen and others, 2008).

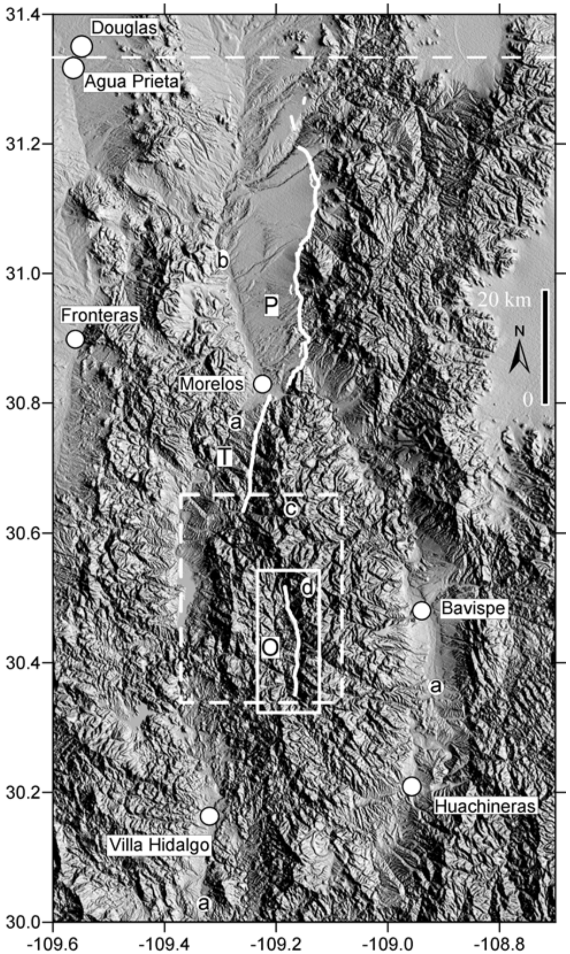
# M-scaling IMW strike-slip sources



# BRPEWGII recommendation

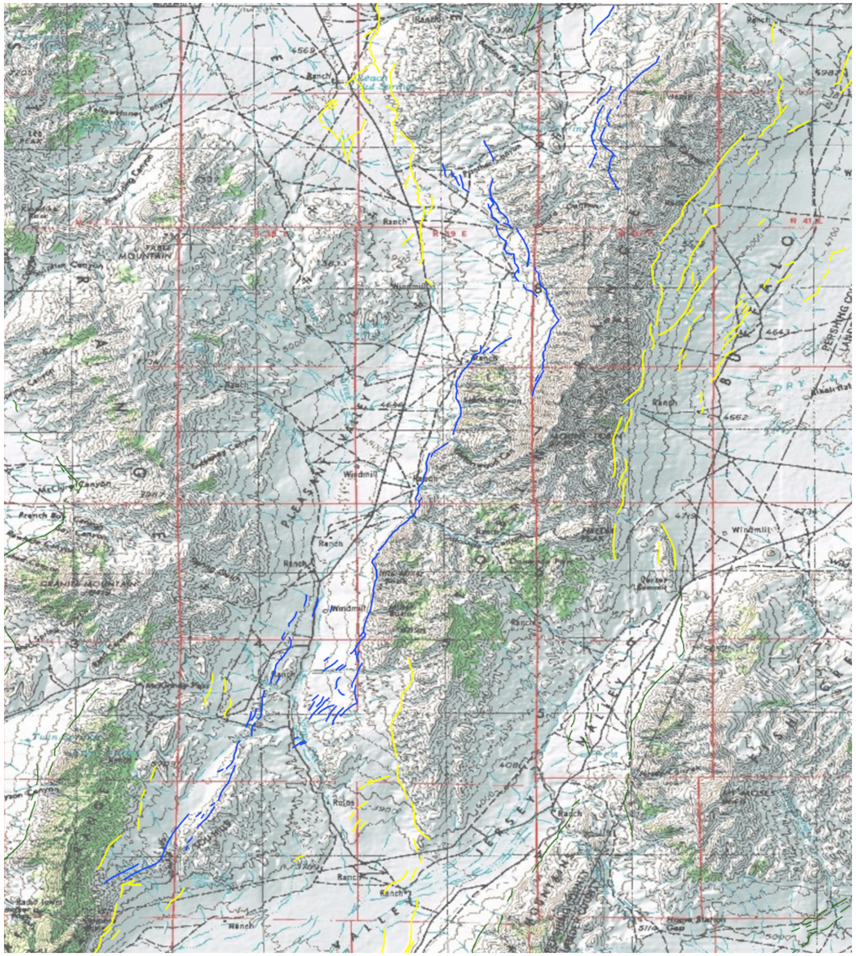
- Consider segmented or other alternative rupture models where paleoseismic studies provide good evidence for differences in rupture patterns and behavior along a fault (e.g., West Cache, Steens, Lost River, Lemhi, Mission, Sangre de Cristo, and others).

# May 03 1887 Sonora Mexico earthquake



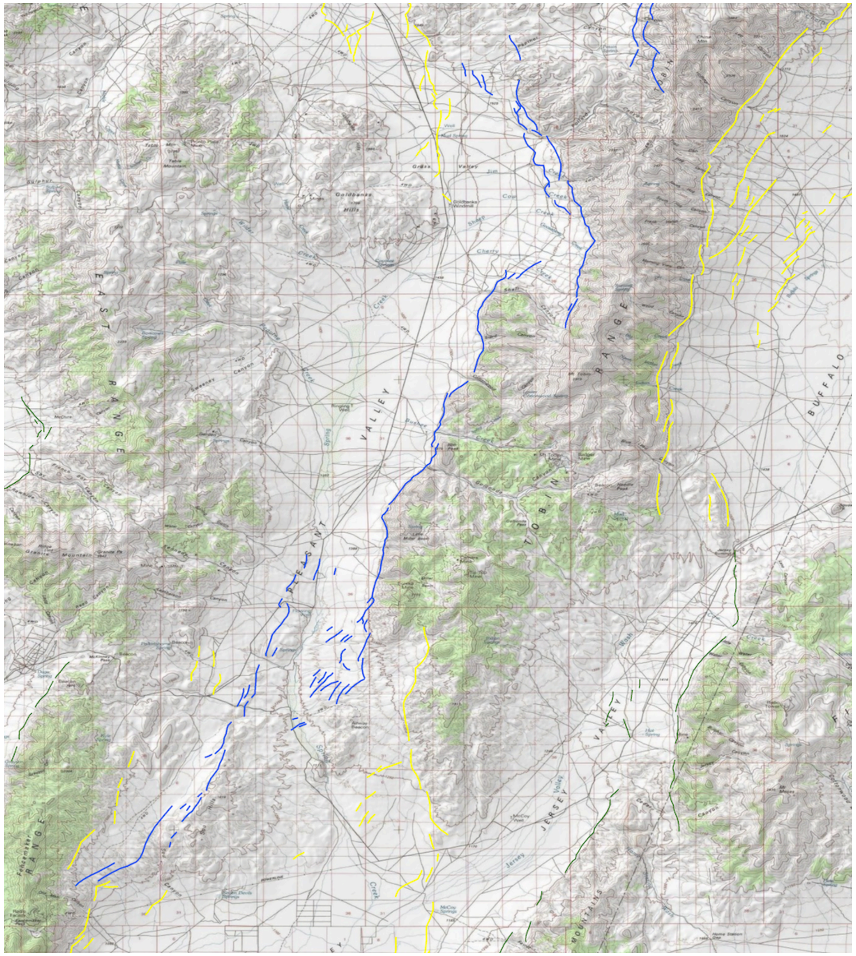
- ~M7.4
- 102 km rupture
- Three mapped faults
- Maximum rupture jump ~15 km

# October 3 1915 Pleasant Valley Nevada earthquake



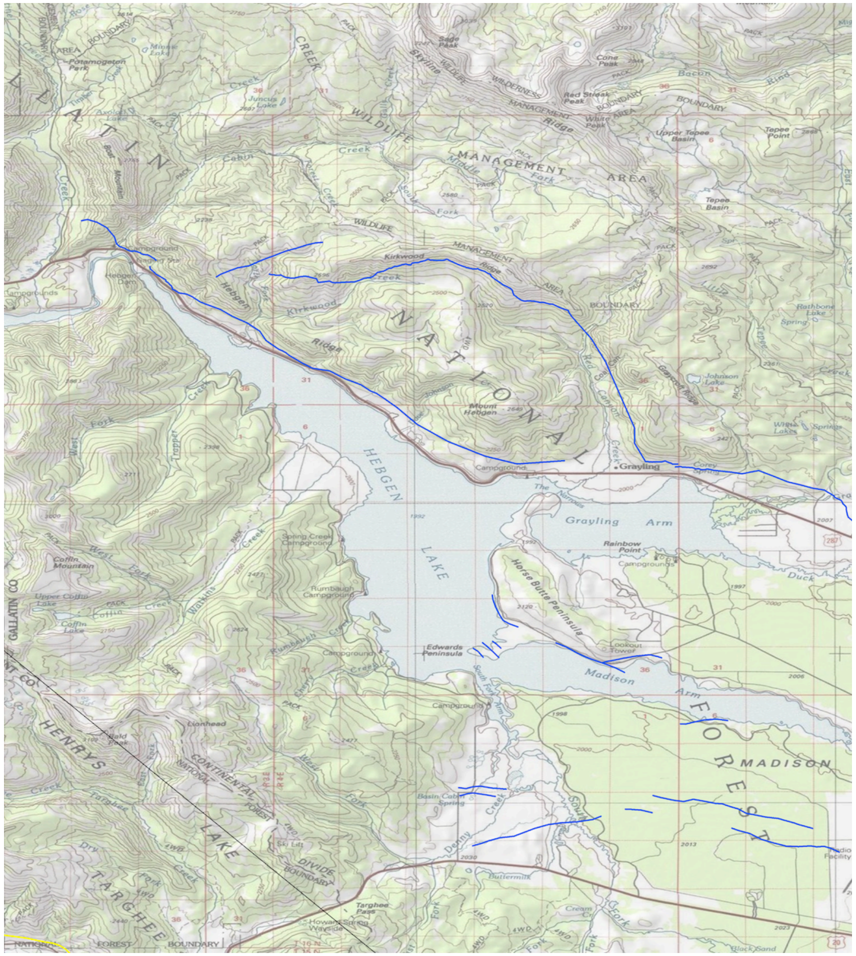
- ~M7.1
- 68 km rupture
- Four echelon surface ruptures
- Maximum rupture jump 6 km

# October 3 1915 Pleasant Valley Nevada earthquake



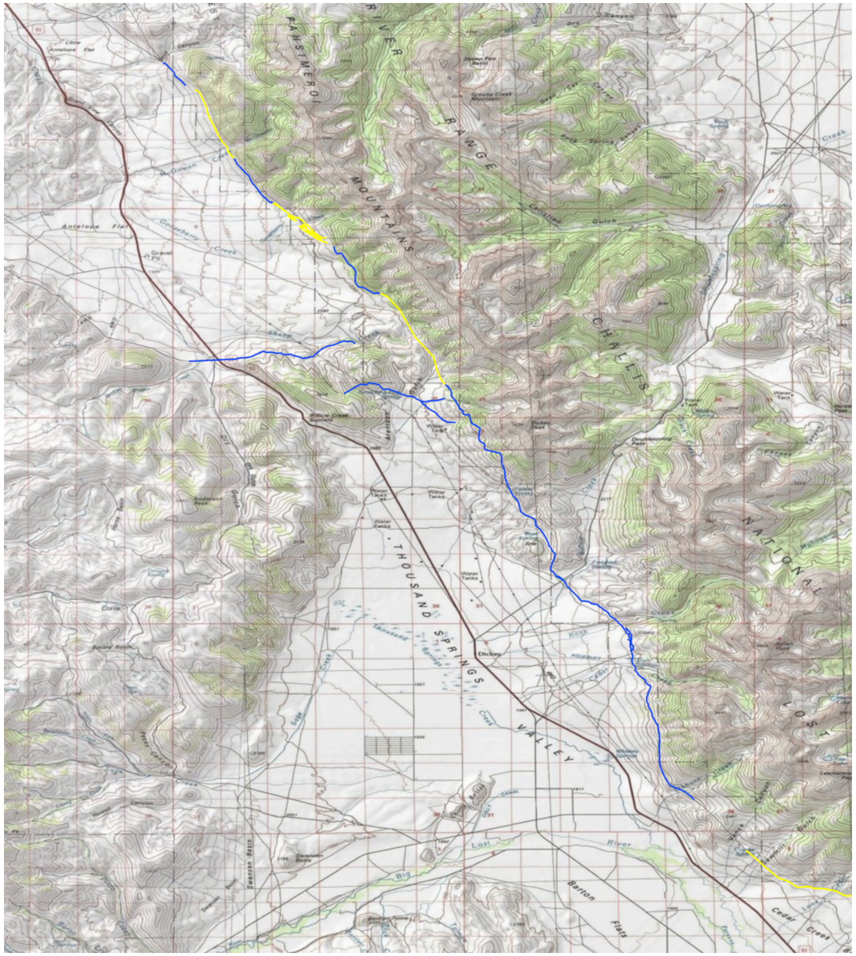
- ~M7.1
- 68 km rupture
- Four echelon surface ruptures
- Maximum rupture jump 6 km

# August 18 1959 Hebgen Lake Montana earthquake



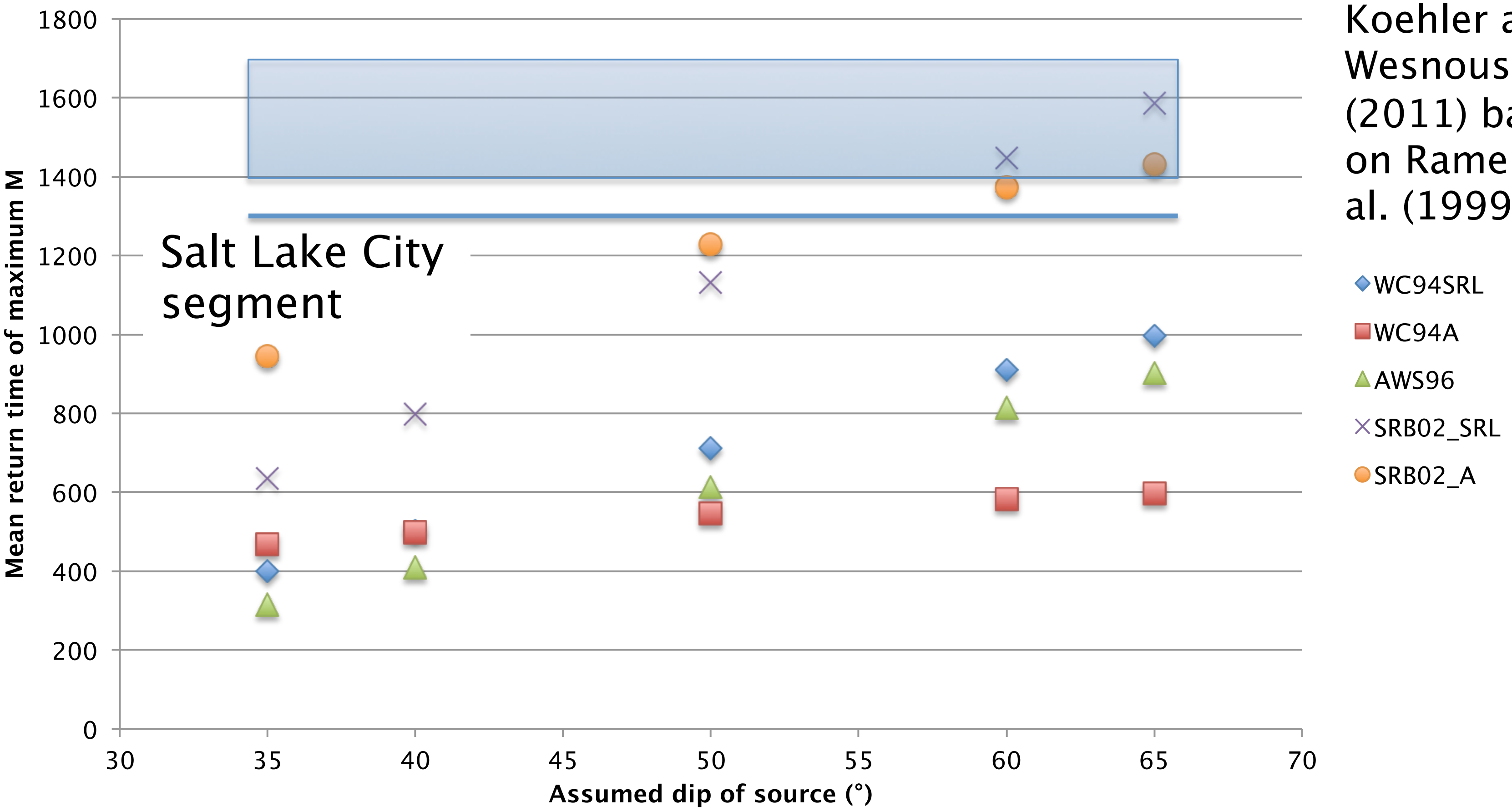
- M7.3
- 25 km rupture
- Three major echelon surface ruptures
- Maximum rupture jump 2 km

# October 28 1983 Borah Peak Idaho earthquake



- M6.9
- 34 km rupture
- Three mapped fault segments
- Maximum rupture jump 2 km

# Carson Range–Kings Canyon source



late Holocene recurrence interval from Koehler and Wesnousky (2011) based on Ramelli et al. (1999)

# References

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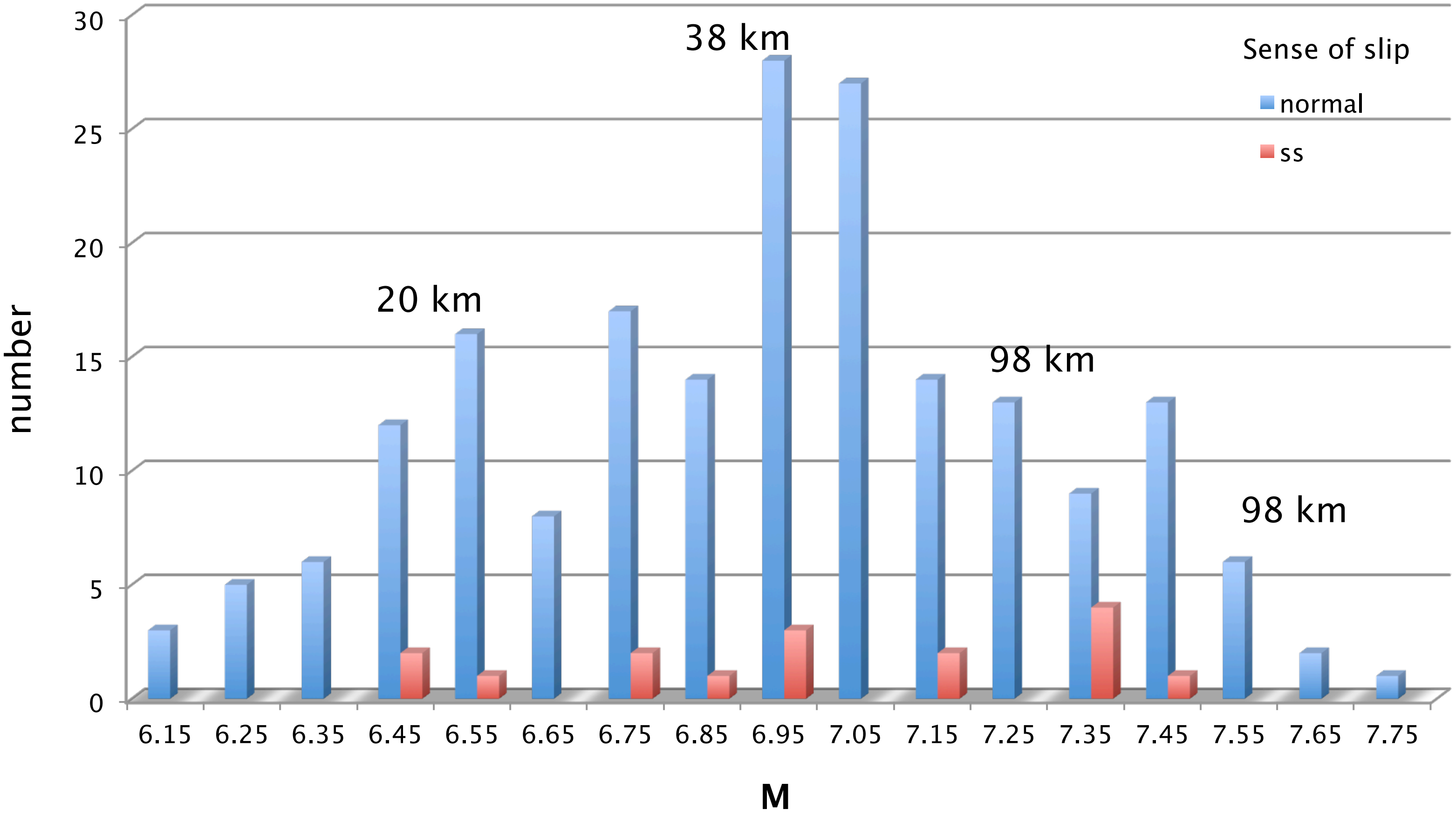
# Discussion topics

- Does the group still recommend that the assigned dip of normal sources in the IMW should be 50±15°?
- If so, should 40° and 60° dips be retained in the logic tree?
- What M-scaling relations are important to include in the 2014 model?
- Slip-rate uncertainty

# IMW maximum source M



# COCORP data

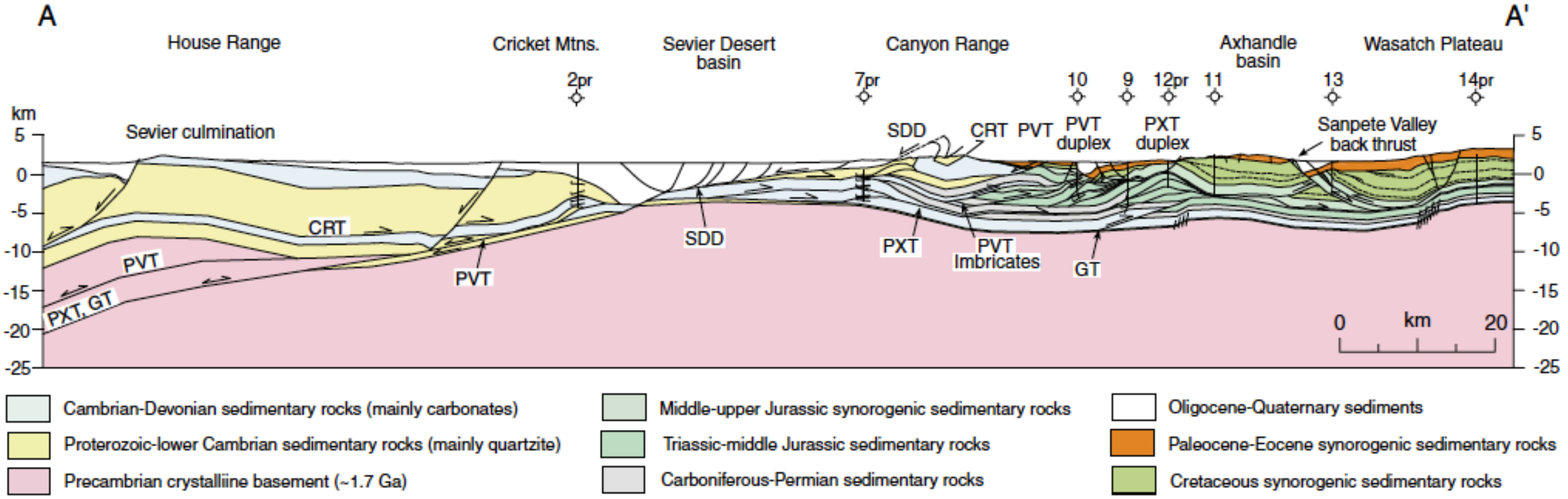
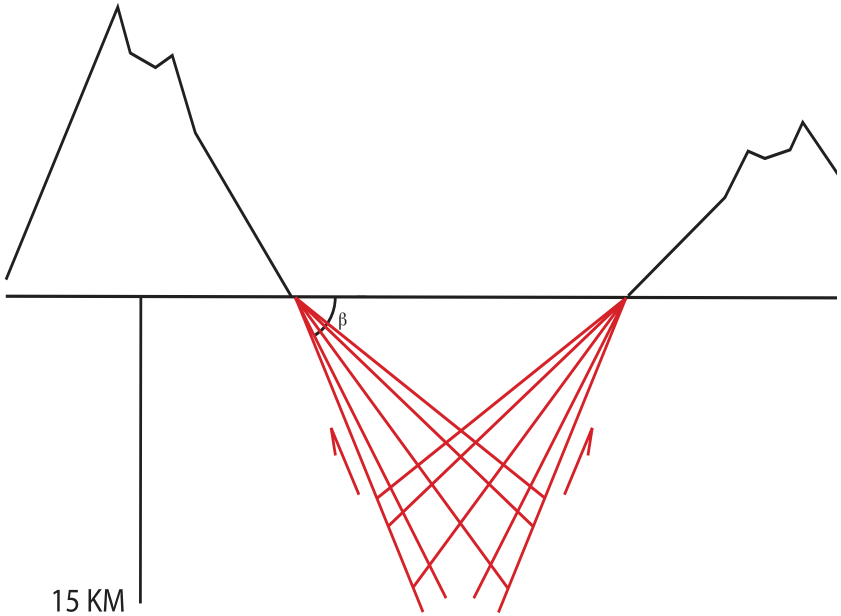


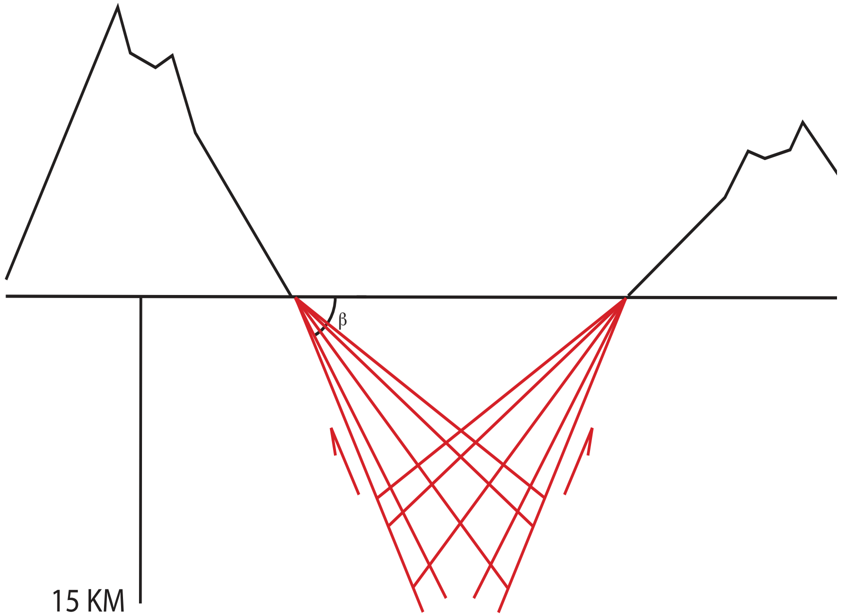
**Figure 3.** Regional balanced cross-section A–A′ of the Sevier fold-and-thrust belt in central Utah, based in part on Coogan et al. (1995), Royse (1993), Standlee (1984), and Consortium for Continental Reflection Profiling (COCORP) deep seismic-reflection profile (Allmendinger et al., 1983, 1986). Numerals indicate industry wells that were used to constrain the section. Letters (pr) after well numbers indicate where data were projected more than a few kilometers into the plane of the cross section. See Figure 2 for location of cross section and legend of industry wells. CRT—Canyon Range thrust; PVT—Pavant thrust; PXT—Paxton thrust; GT—Gunnison thrust; SDD—Sevier Desert detachment.

DeCelles and Coogan (2006)

# Modeled sources that intersect at depth

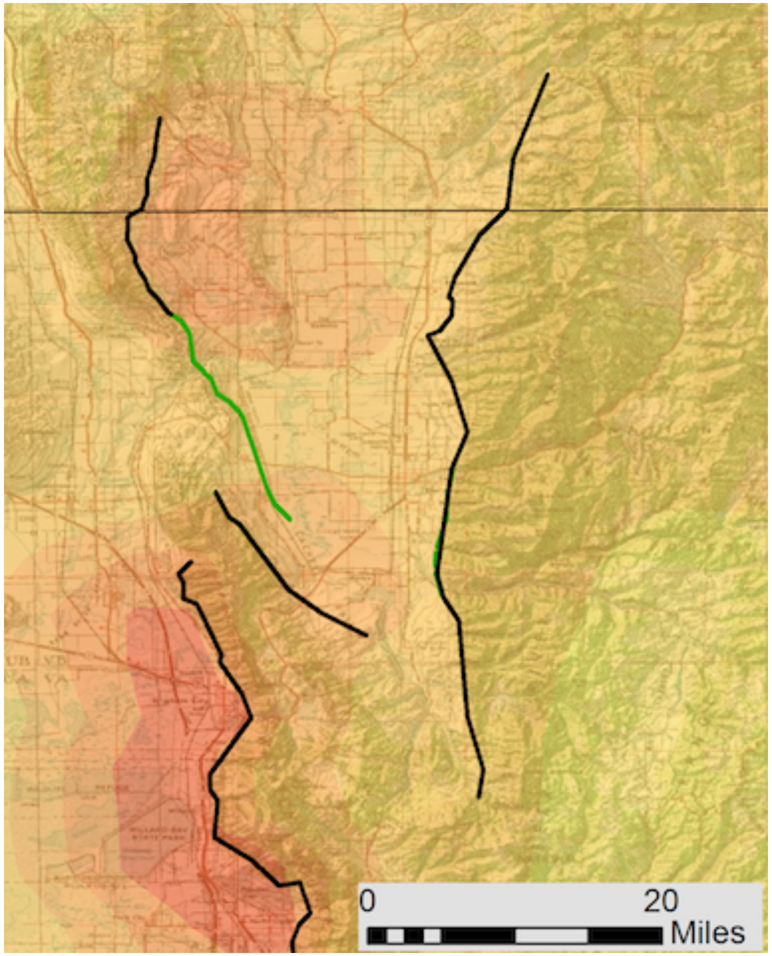


- Salt Lake City
- Las Vegas
- Cache Valley



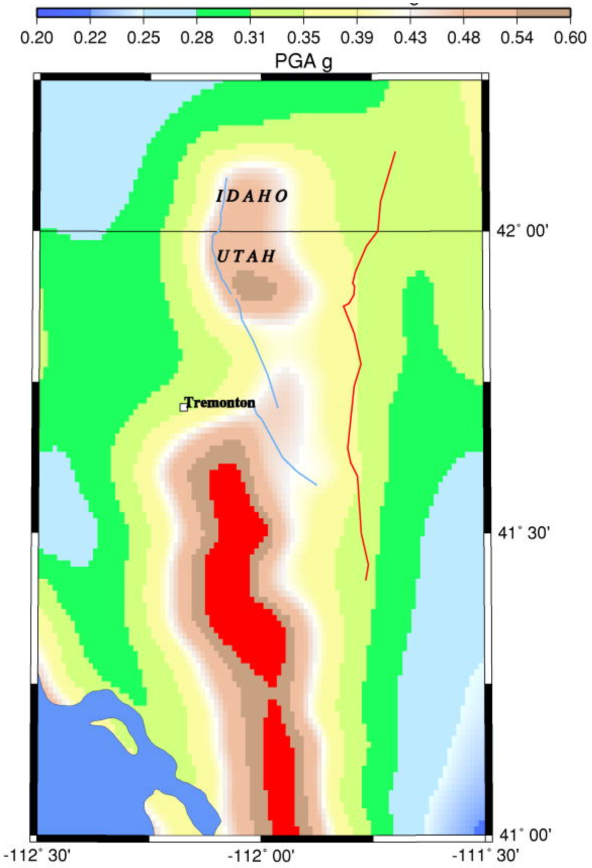
- 3 dip alternatives yield up to 9 possible branches
- 5 dip alternatives yields up to 25 possible branches
- 50 possible branches if master fault cannot be identified

# 2008 model for Cache Valley, Utah

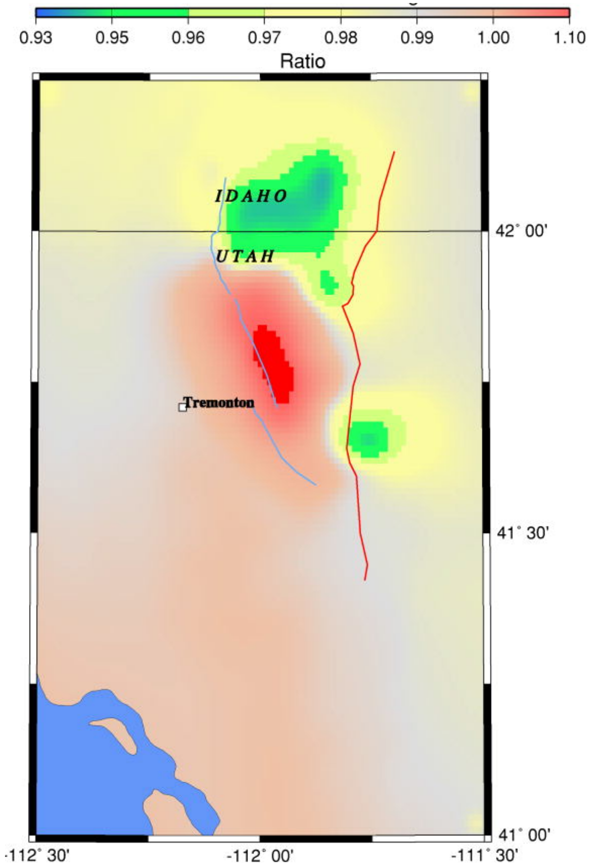


# 2008 model E Cache (master) W Cache (subsidiary)

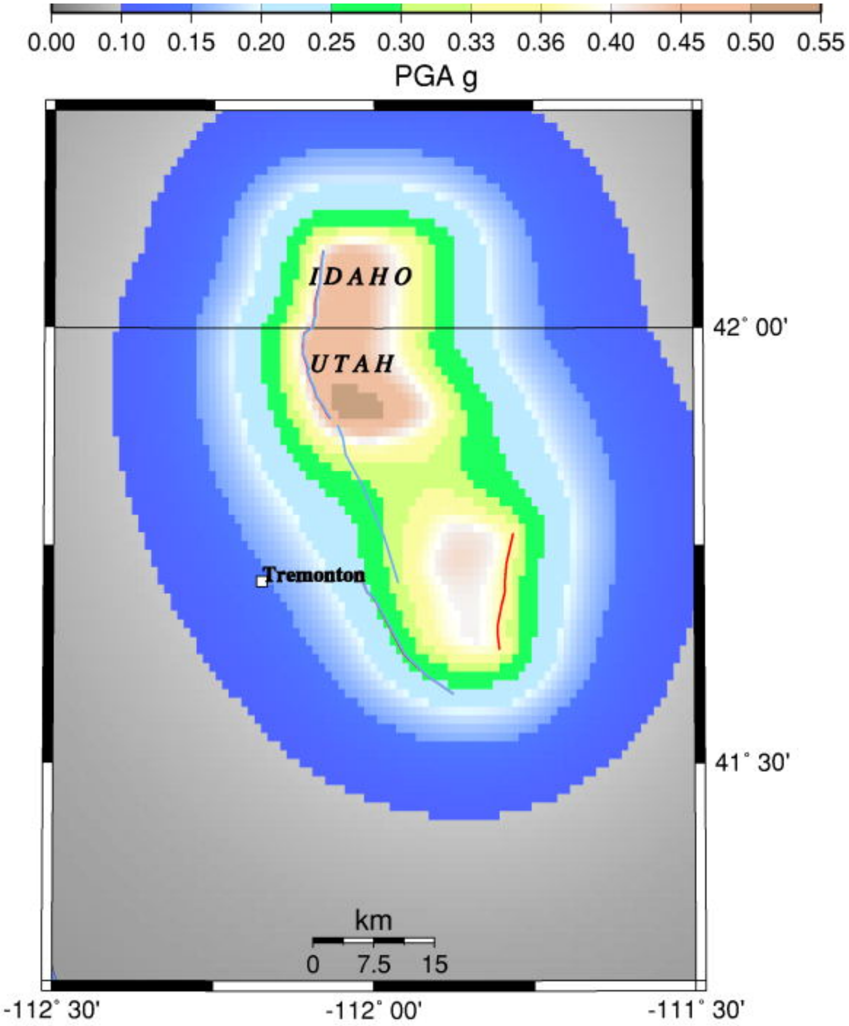
## PGA 2% PE in 50 yr



## 2008 model/truncated W Cache PGA ratio map



# PGA Ratio map of W Cache (master) central E Cache (subsidiary)



# Fault characteristics

| | MRE | Vertical slip rate (mm/yr) | Recurrence interval (k.y.) | Maximum M | Model rate (k.y.) |
|---|---|---|---|---|---|
| 2008 E Cache | | 0.28 | | 7.31 | 8.1 |
| E Cache central* | 4 | 0.2–1.0* | 8 | 6.93 | 5.2 |
| E Cache southern* | 26–46 | 0.01–0.03 | >26–46 | 6.6–6.9 | ____ |
| W Cache Clarkston** | 3.6–4 | <0.68 | <10 | 6.6 | 1.5 |
| W Cache Junction Hills** | 8.2–8.6 | <0.21 | >10 | 6.68 | 6.5 |
| W Cache Wellsville** | 4.4–4.8 | 0.11–0.21 | 10–20 | 6.6 | 5.7 |

# References

- Bill D. Black, B.D.,  Richard E. Giraud, R.E., and Bea H. Mayes, B.H., 2000, Paleosiesmic investigation of the Clarkston, Junction Wills, and Wellsville faults, West Cache fault zone, Cache County, Utah: Utah Geological Survey, Paleoseismology of Utah v. 9, 29 p.
- Evans, J.P., and McCalpin, J.P., 2012, Determination of paleoearthquake timing and magnitudes on the southern segment of the East Cache fault, Utah: Final Technical Report under Contract 07HQGR0079, 54 p.