Magnitude-Area Scaling of Strike-Slip Earthquakes

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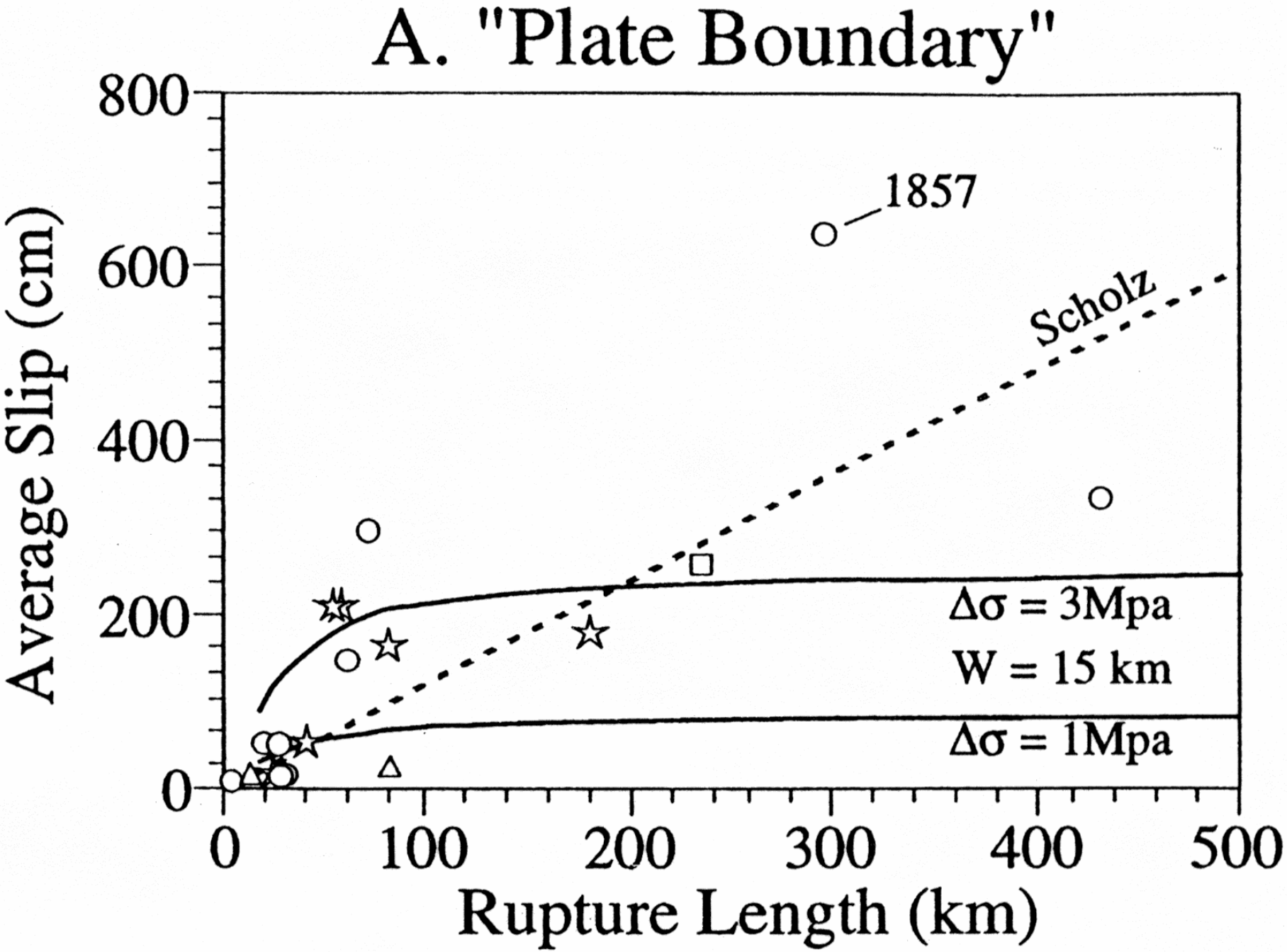

A. "Plate Boundary"
Average Slip (cm)
800
600
400
200
0
1857
Scholz
Δσ = 3Mpa
W = 15 km
Δσ = 1Mpa
0
100
200
300
400
500
Rupture Length (km)

Scaling Models of Large Strike-slip Earthquakes

L Model Scaling (Hanks & Bakun, 2002)

Displacement grows with L for L > > Wmax

M ~ 4/3 log A *(small L, large D)*

W Model Scaling (Romanowicz, 1992)

Displacement constant for L >> Wmax

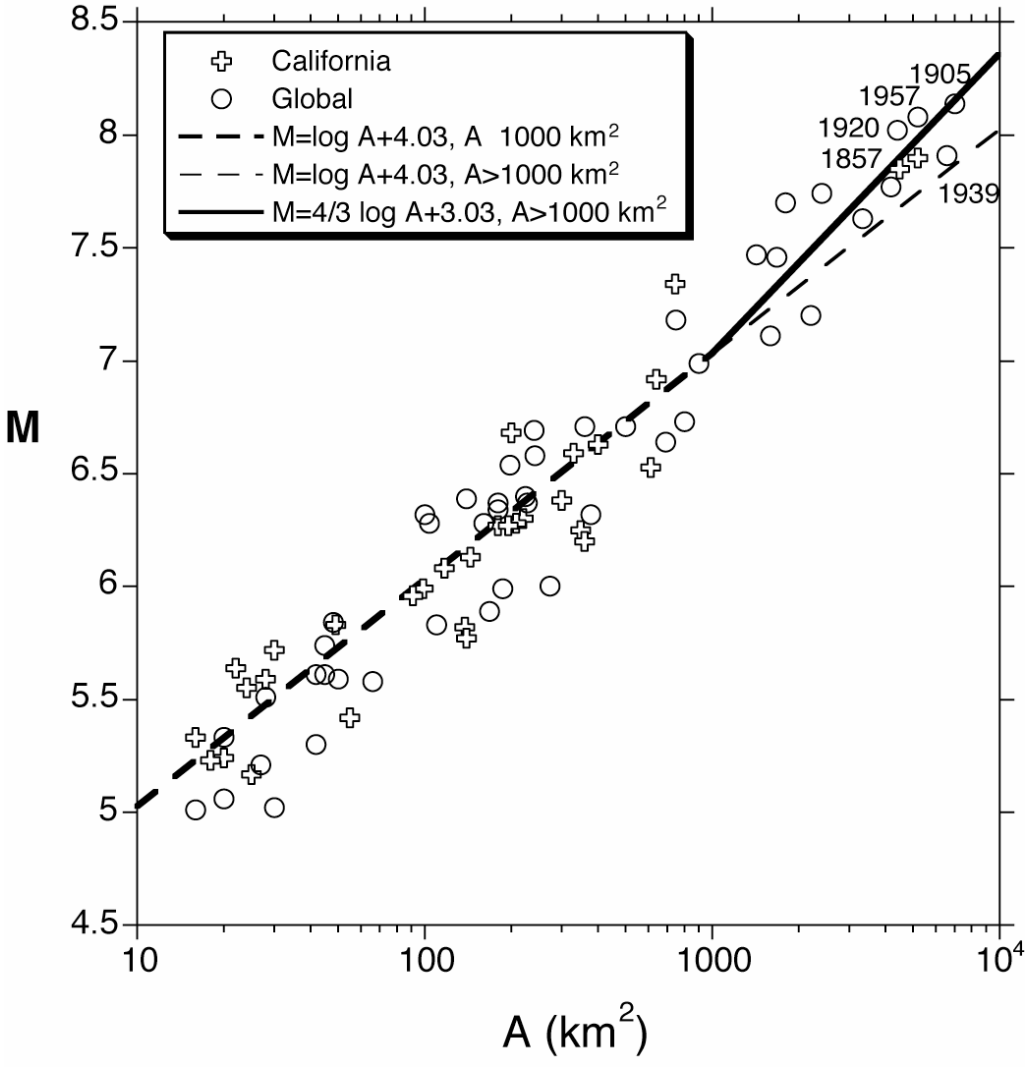
M ~ 2/3 log A *(large L, small D)*

Self Similar Area Scaling (Somerville, 2006)

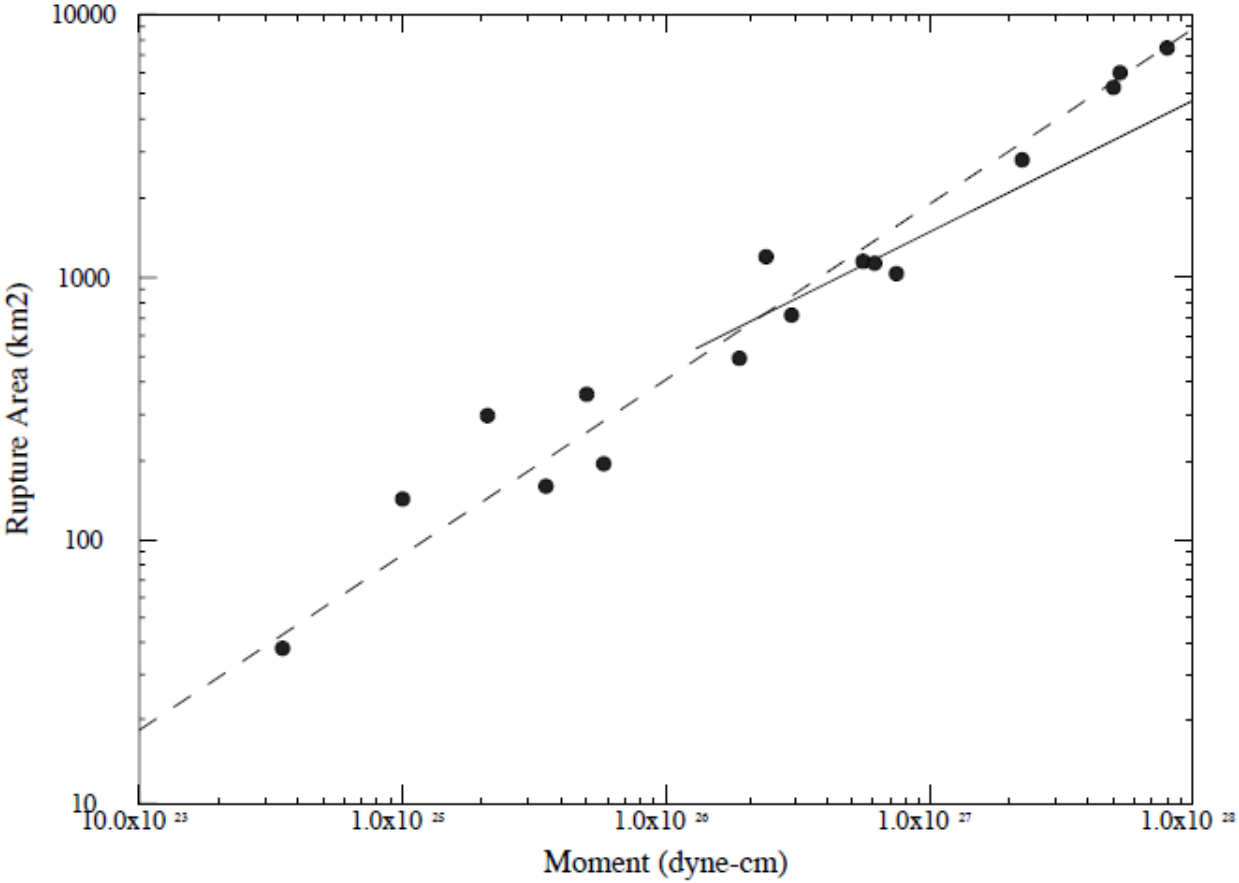
Displacement proportional to area

M ~ log A *(intermediate between L & W)*

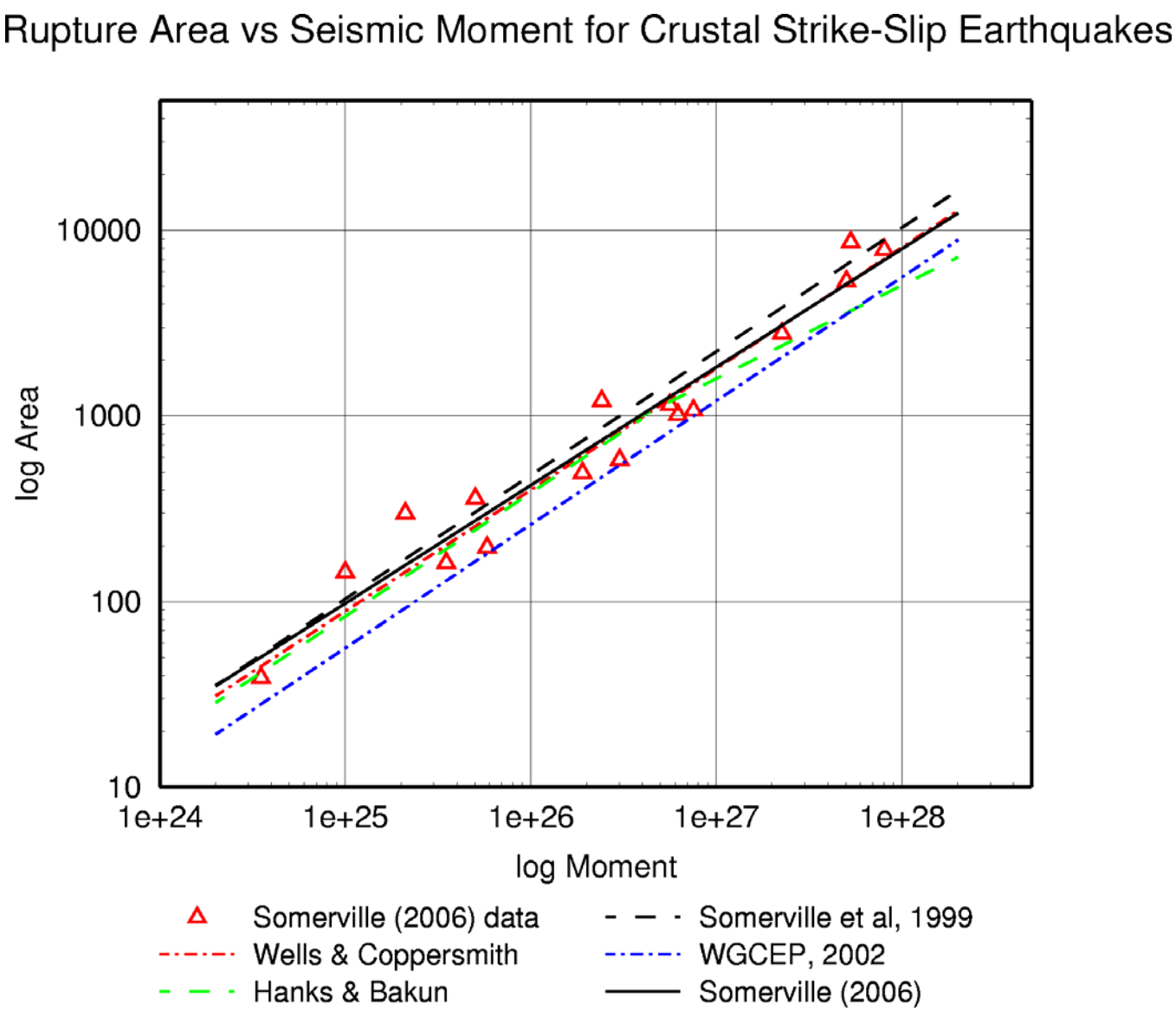
Hanks and Bakun (2002)



Somerville, 2006



Comparison of Moment – Area Scaling Relations

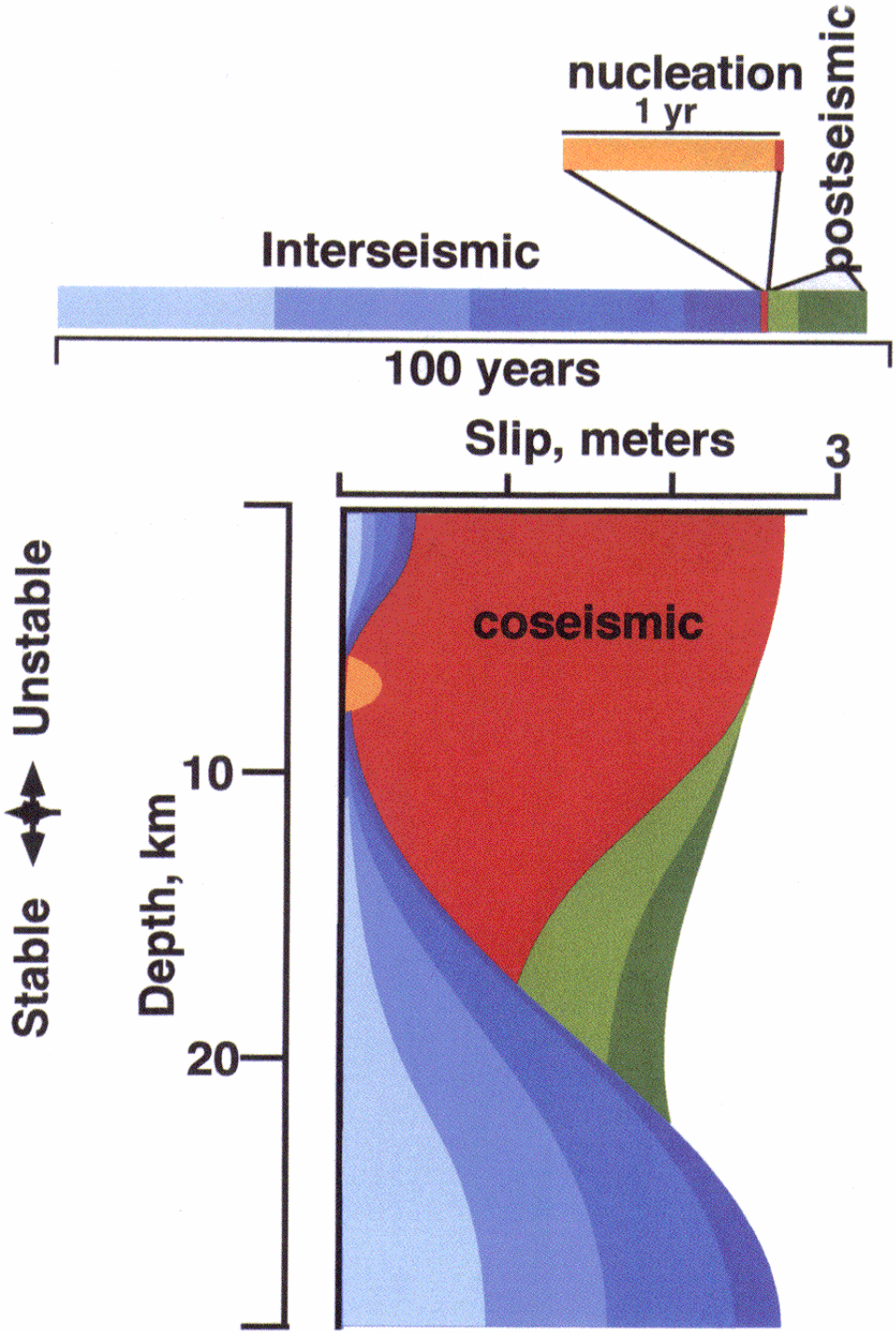


Data Types for Area Estimation

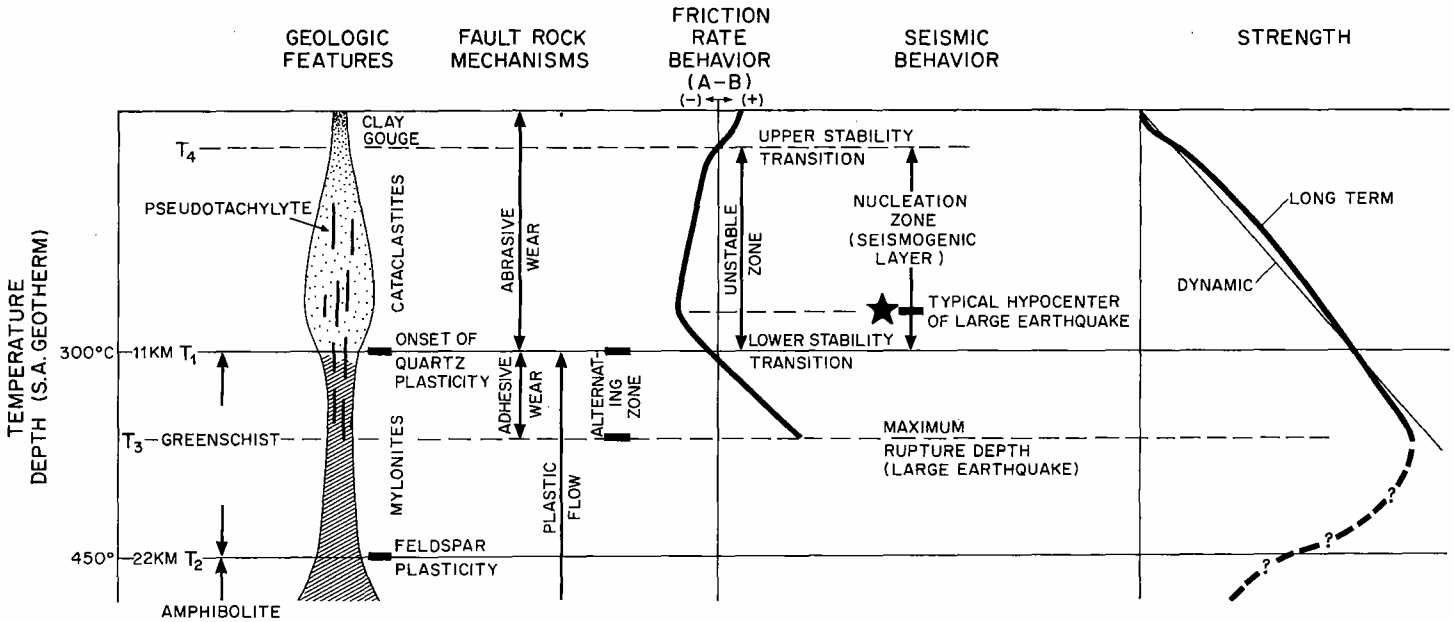
- Indirect measurements (aftershock zone; surface rupture length): Wells & Coppersmith (1994); Hanks & Bakun (2002); WGCEP(2002)
- Direct measurements from rupture models derived from seismic radiation: Somerville et al. (1999); Mai & Beroza (2000), Somerville (2006)

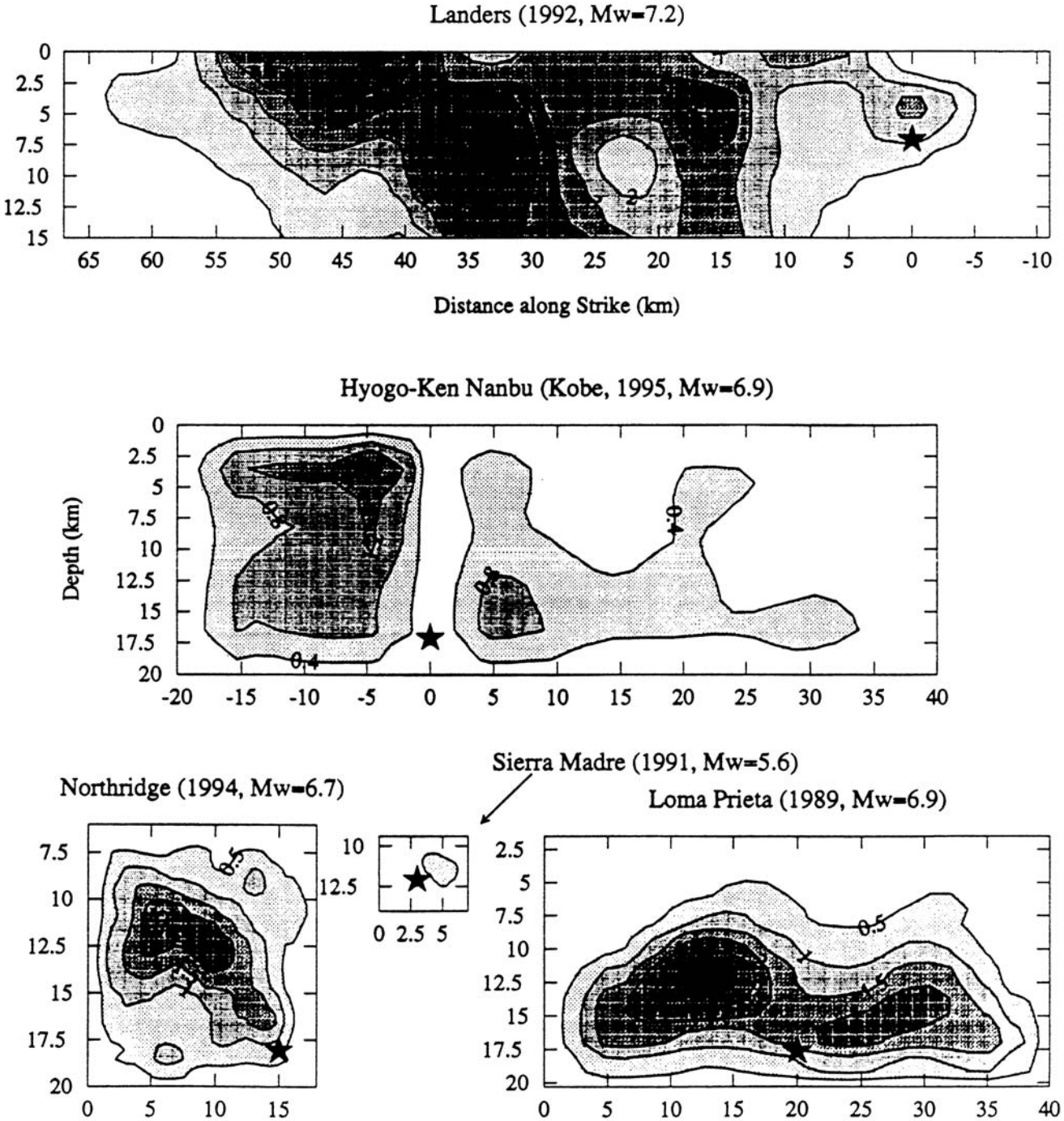
Comparison of Data used by WCGEP (2002) and Somerville (2006): 1999 Izmit Earthquake

AUTHOR	AREA		METHOD
	Untrimmed	Trimmed	
Delouis et al. (2002)	2550		Slip model inversion
Wright et al. (2001)	1700		INSAR
Yagi & Kikuchi (2000)	1050		Preliminary automated slip model inversion
AVERAGE - WGCEP	**1767**		
Bouchon et al. (2002)	2790	2790	Slip model inversion
Delouis et al. (2002)	3882	2700	Slip model inversion
Sekiguchi & Iwata (2002)	3285	2796	Slip model inversion
Thio et al (2004)	3040	2800	Slip model inversion
AVERAGE – Somerville	3249	**2772**	


nucleation
1 yr
postseismic
Interseismic
100 years
Slip, meters
3
coseismic
Unstable
Stable
Depth, km
10
20

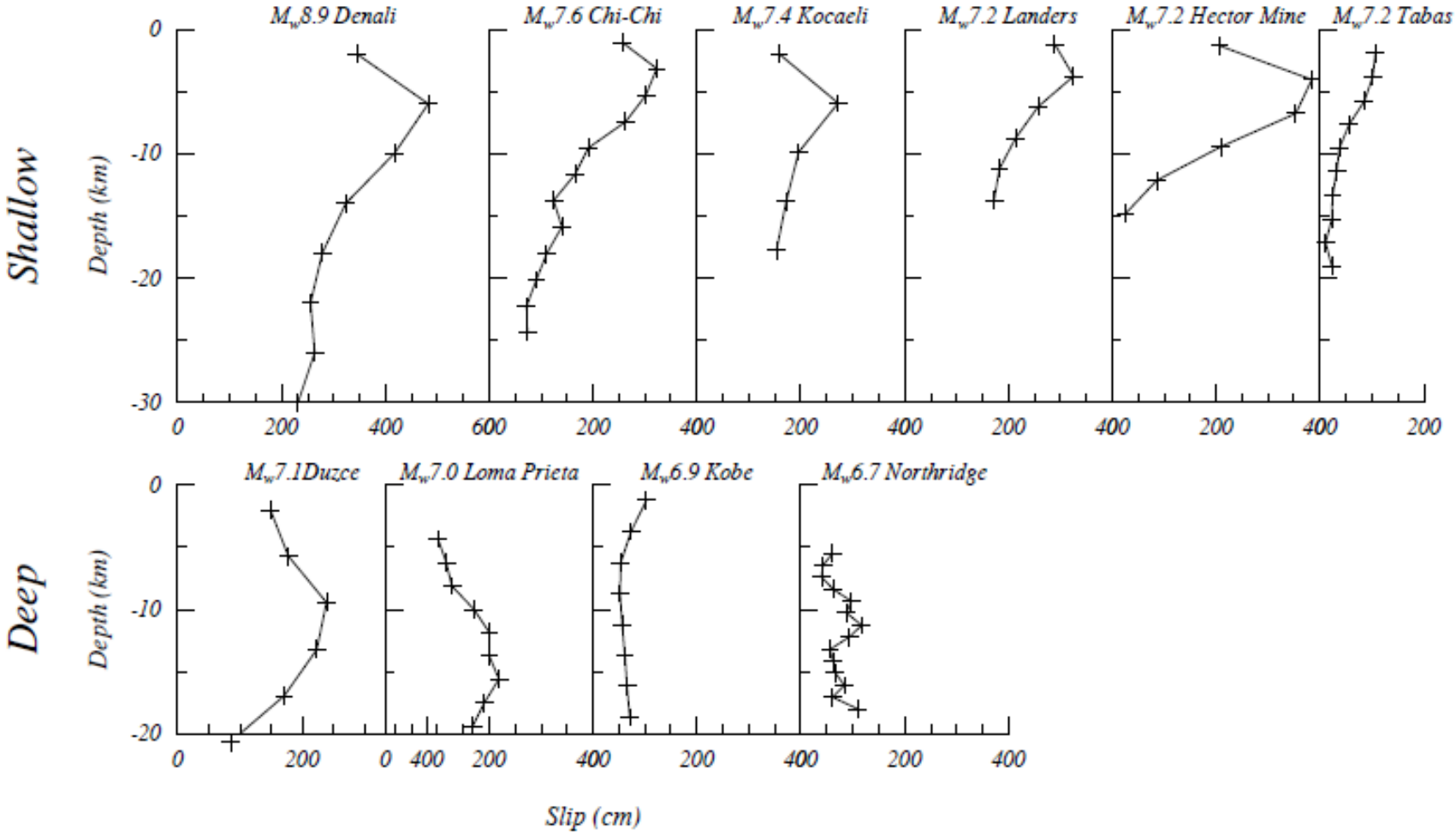
Synoptic model of a shear zone (Scholz, 1988)



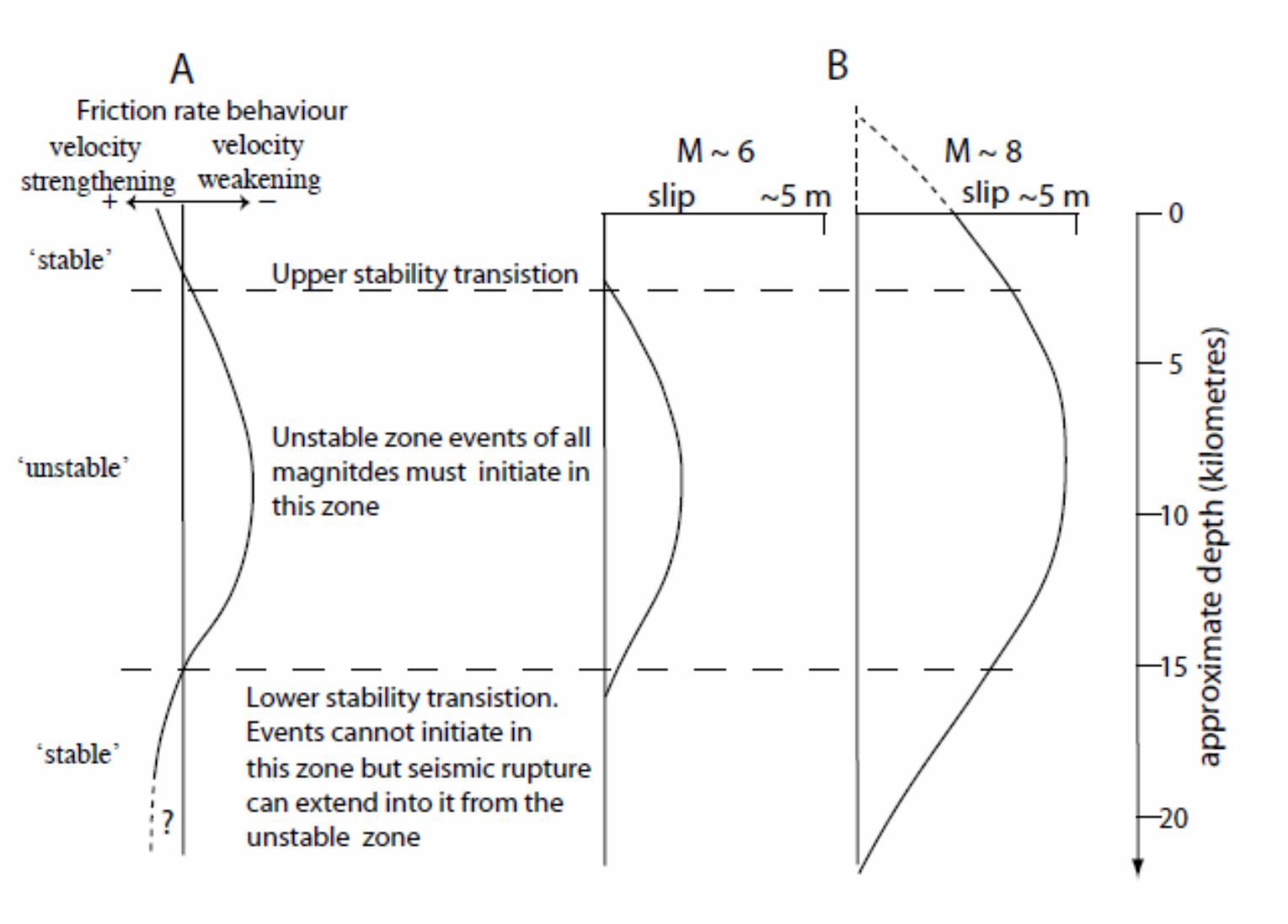

Landers (1992, Mw=7.2)
Distance along Strike (km)
Hyogo-Ken Nanbu (Kobe, 1995, Mw=6.9)
Depth (km)
Sierra Madre (1991, Mw=5.6)
Northridge (1994, Mw=6.7)
Loma Prieta (1989, Mw=6.9)

Slip model is derived by matching recorded and calculated seismograms, GPS, surface slip,….

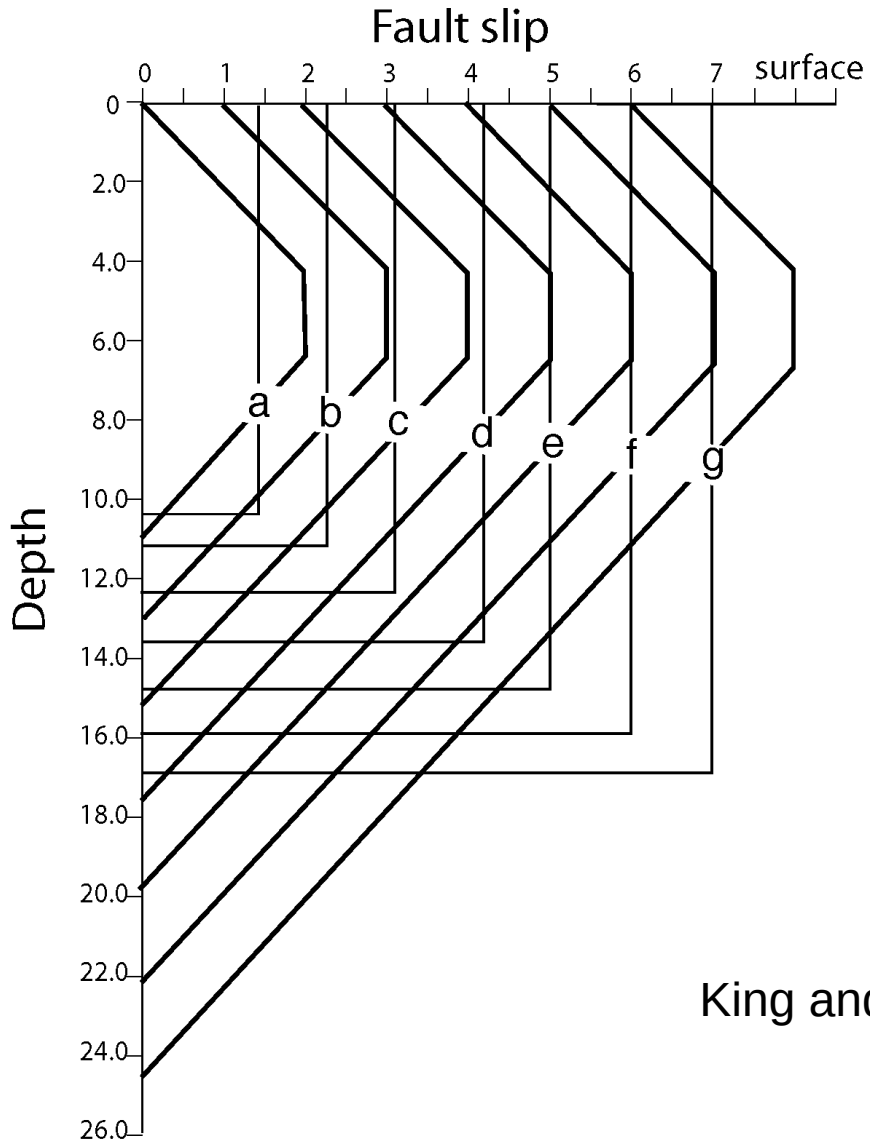
Depth Distribution of Slip



A. Conceptual model of frictional characteristics at depth, B. Expected coseismic slip distribution with depth (King and Wesnousky)



L model – strain drop increasing with magnitude (box)
SA model – constant strain drop (taper)



King and Wesnousky, 2007

Implications for Earthquake Forecast Models

- The main impact is on Mmax, which affects recurrence of smaller earthquakes
- UCERF found that SA models overpredict historical seismicity due to low Mmax (the “bulge”), and excluded them from consideration
- But many other factors could be responsible for causing the “bulge”

Factors that Influence Seismicity Rate

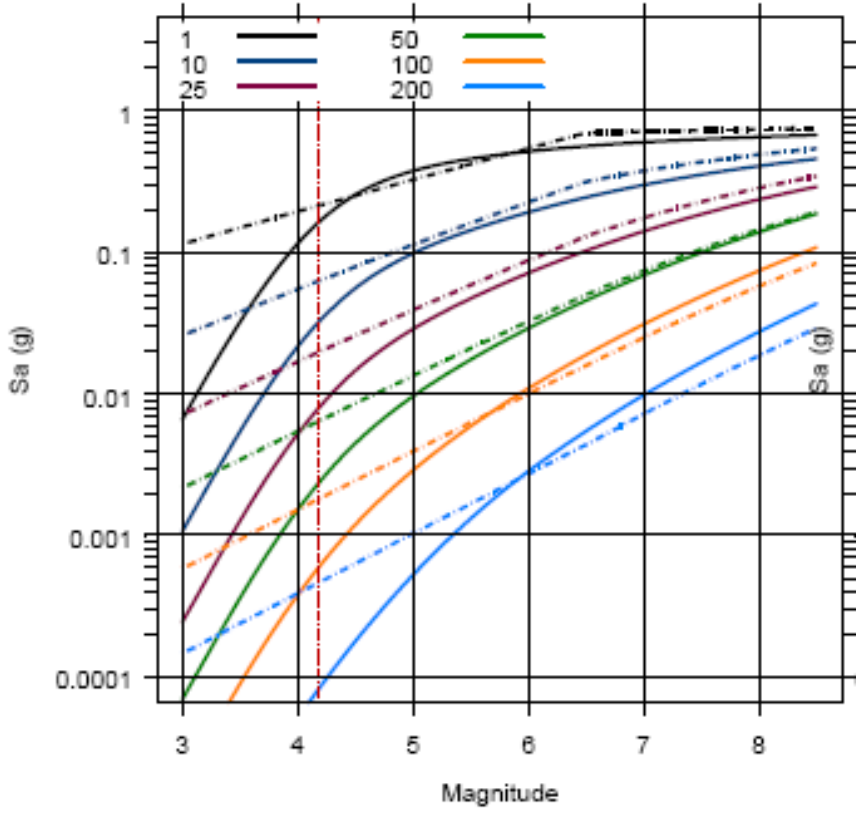
Field et al (1999): explaining deficit in S Cal Seismicity:

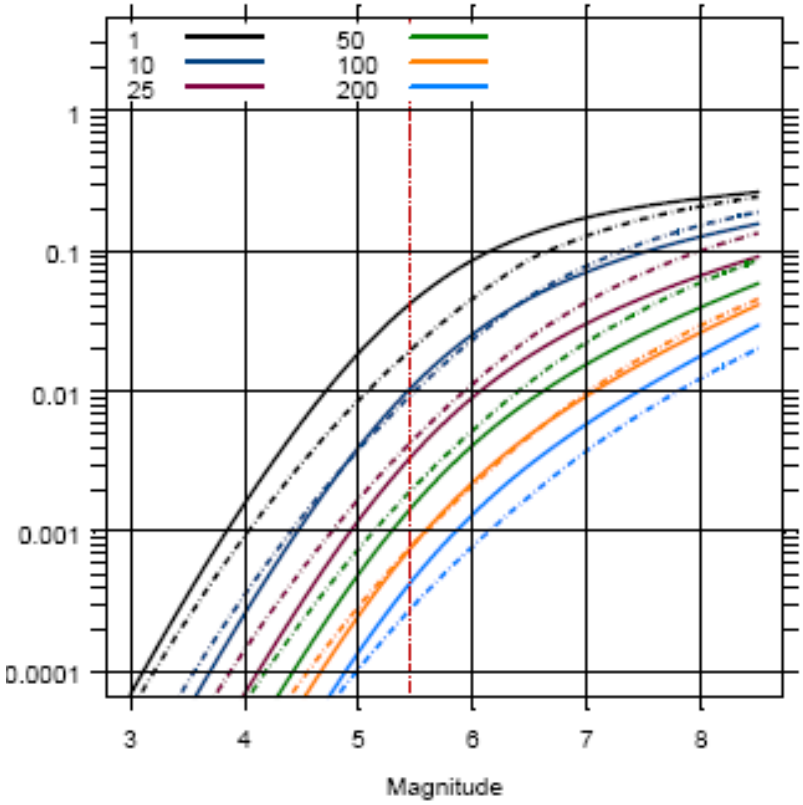
- The b-value and minimum magnitude applied to Gutenberg-Richter seismicity
- The percentage of moment released in characteristic earthquakes
- A round-off error in the moment magnitude definition
- Bias due to historical catalog completeness
- Careful adherence to the conservation of seismic moment rate
- Uncertainty in magnitude estimates obtained from empirical regressions
- Allowing multi-segment ruptures (cascades)
- The time dependence of recurrence rates.

Implications for Strong Motion Simulation

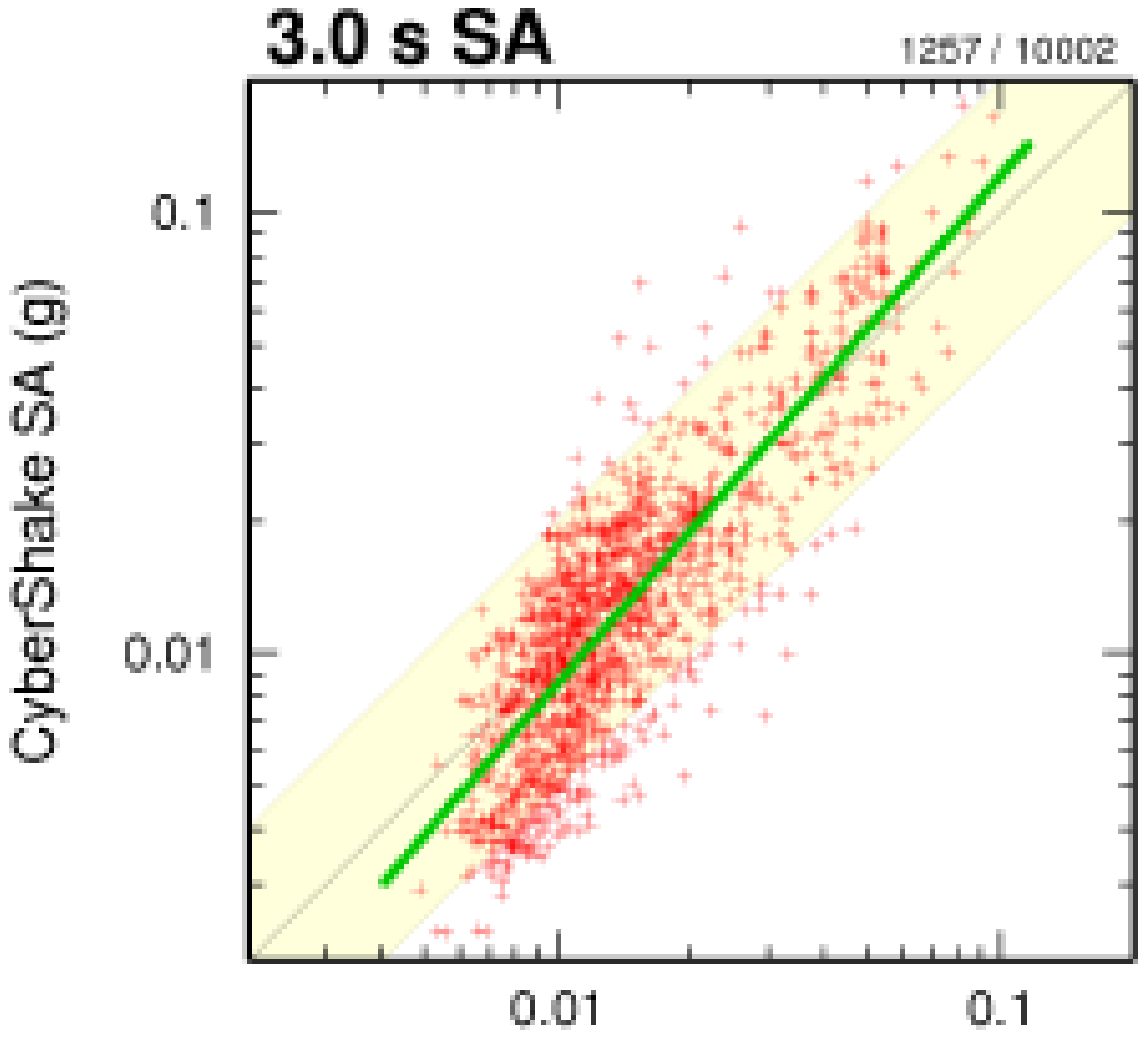
- SA models are compatible with recorded long period strong ground motion amplitudes, which tend to saturate with increasing magnitude
- L models are not – predict ground motions that increase rapidly with increasing magnitude, and are much too large

Magnitude scaling of response spectral acceleration (g) for peak acceleration (left) and 3 seconds period (right) for various distances, for the Chiou and Youngs (2008, solid lines) and Sadigh et al. (1997, dashed lines) ground motion models.





Comparison of Simulations with NGA Predictions using Somerville SA Mw-Area Relation



Summary

- The Hanks & Bakun and Ellsworth Mw-Area relations used in UCERF fault models underestimate fault area and may be incompatible with a gradual transition from brittle to ductile behavior at the base of the seismogenic zone
- These Mw-Area relations cause overprediction of recorded strong ground motions
- The SA Mw-Area model is compatible with both the gradual transition and with recorded motions

Table 4. Crustal Strike-slip Earthquakes used by Somerville (2006a)

Earthquake	Mw	Seismic Moment	Rupture Area	Sources
Denali	7.9	8.00E+27	7846	Asano et al. (2005), Ji (2005), Oglesby et al. (2004), Ozacar & Beck (2004), Thio (2005)
Kunlunshan	7.8	5.30E+27	8633	Antolik et al. (2004), Bouchon & Vallee (2004), Ozacar & Beck (2004), Velasco (2004)
San Francisco	7.8 (7.87)	5.00E+27 (7.00E+27)	5280 (5760)	Wald et al. (1996) Song and Beroza (2006)
Izmit	7.5	2.25E+27	2772	Bouchon et al. (2002), Delouis et al. (2002), Sekiguchi et al. (2002), Thio and Graves (2004)
Landers	7.2	7.50E+26	1072	Cotton & Campillo (1995), Hernandez et al (1999), Wald & Heaton (1994), Zeng & Anderson (1999)
Hector Mine		6.20E+26	1014	Ji et al. (2002), Kaverina et al. (2002), Salichon et al (2003)
Duzce	7.1	5.60E+26	1152	Thio et al. (2004)
Loma Prieta	7.0	3.00E+26	581	Beroza (1991), Steidl et al. (1991), Wald et al. (1991), Zeng & Anderson (2000)
Kobe	6.9	2.40E+26	1080	Ide & Takeo (1996), Sekiguchi et al. (1997), Wald (1996), Yoshida et al., Zeng & Anderson (2002).
Tottori	6.8	1.90E+26	598	Sekiguchi et al. (2003).
Yamaguchi	6.5	5.80E+25	196	Miyakoshi et al. (2000)
Imperial Valley	6.5	5.00E+25	360	Hartzell and Heaton (1983)
Superstition Hills	6.3	3.50E+25	161	Wald et al. (1990)
Morgan Hill	6.2	2.10E+25	312	Beroza & Spudich (1988), Hartzell & Heaton (1986)
Kagoshima	6.0	1.00E+25	144	Miyakoshi et al. (2000)
Coyote Lake	5.7	3.50E+24	39	Liu &Helmberger (1983)

Table 5. Fault Dimensions of Crustal Strike-slip Earthquakes used by Somerville (2006a)

Earthquake	Before Trimming			After Trimming			Reference
	Length	Width	Area	Length	Width	Area	
2002 Denali	261.00	18.00	4698.00	261.00	18.00	4698.00	Asan et al (2005)
	300.00	30.00	9000.00	288.75	30.00	8662.50	Oglesby et al (2004)
	290.00	20.00	5800.00	280.00	20.00	5600.00	Ji (2003)
	408.00	32.00	13056.00	386.00	32.00	12352.00	Oglesby et al (2004)
	376.00	30.00	11280.00	264.00	30.00	7920.00	Thio pers comm (2005)
2001 Kunlunshan	460.00	30.00	13800.00	460.00	30.00	13800.00	Antolik et al (2004)
1999 Izmit	155.00	18.00	2790.00	155.00	18.00	2790.00	Bouchon et al (2002)
	172.50	22.50	3881.25	150.00	18.00	2700.00	Delouis et al (2002)
	141.00	23.30	3285.30	120.00	23.30	2796.00	Sekiguchi and Iwata (2002)
	152.00	20.00	3040.00	140.00	20.00	2800.00	Thio pers comm (2005)
1992 Landers	80.00	15.00	1200.00	80.00	15.00	1200.00	Cotton and Campillo (1995)
	80.00	15.00	1200.00	70.00	15.00	1050.00	Hernandez et al (1999)
	78.00	15.00	1170.00	69.00	15.00	1035.00	Wald and Heaton (1994)
	77.00	15.00	1155.00	71.50	14.00	1001.00	Zeng and Anderson (1999)
1999 Hector Mine	54.00	16.00	864.00	45.00	13.30	598.50	Ji et al (2002)
	68.00	24.00	1632.00	68.00	24.00	1632.00	Kaverina et al (2002)
	54.00	18.00	972.00	45.00	18.00	810.00	Salichon et al (2003)
1989 Loma Prieta	40.00	14.00	560.00	38.00	14.00	532.00	Beroza 1991
	38.00	17.00	646.00	38.00	14.87	565.06	Steidle et al (1991)
	40.00	20.00	800.00	40.00	17.50	700.00	Wald et al (1991)
	40.00	14.00	560.00	37.50	14.00	525.00	Zeng and Anderson (1999)
2000 Tottori	34.00	17.60	598.40	34.00	17.60	598.40	Sekiguchi et al (2003)