Three-Stage Magnitude-Area Scaling Supported by Slip Inversions and Dynamic Rupture Simulations

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Abstract

Source scaling of seismic moment and rupture area is a fundamental issue to understand earthquakes. For the source scaling of seismic moment and fault length, the L-model (Scholz, 1982) and the W-model (Romanowicz, 1992) had been proposed for crustal earthquakes over the magnitude range of the circular-crack model. Recent development of slip inversions enabled us to improve quantitative estimates of the magnitude-area scaling.

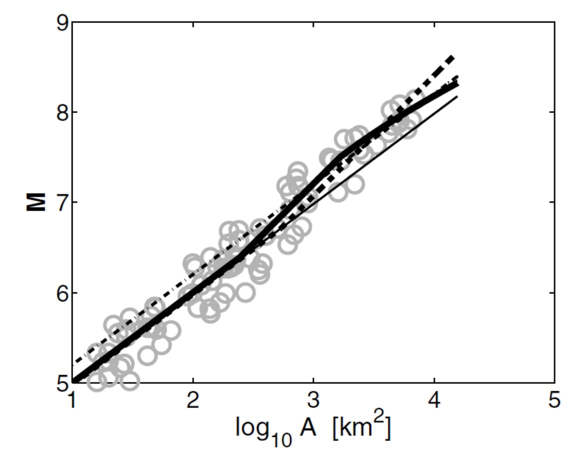
Three-Stage Mo-A Scaling and Stress Drop

1st Stage:
circular-crack model
M < 6.5
L ~ Wmax

2nd Stage:
L-model
6.5 < M < 7.9 (7.4)
L ~ 10Wmax (5 or 6Wmax)

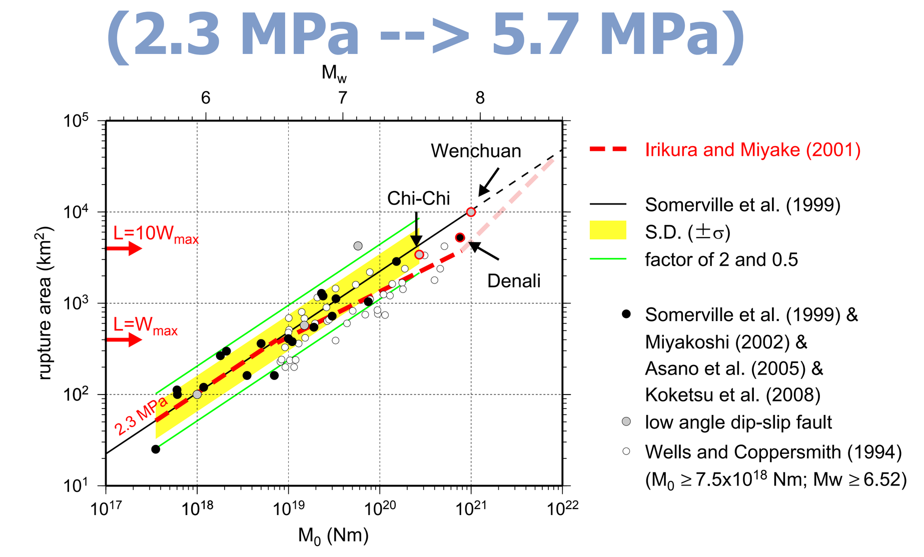
3rd Stage:
W-model
M > 7.9 (7.4)

Constant Stress Drop



Shaw (2009): bold line

Stress Drop with Increase (2.3 MPa --> 5.7 MPa)



Irikura and Miyake (2001, 2011)

Mo-A Scaling from Slip Inversions

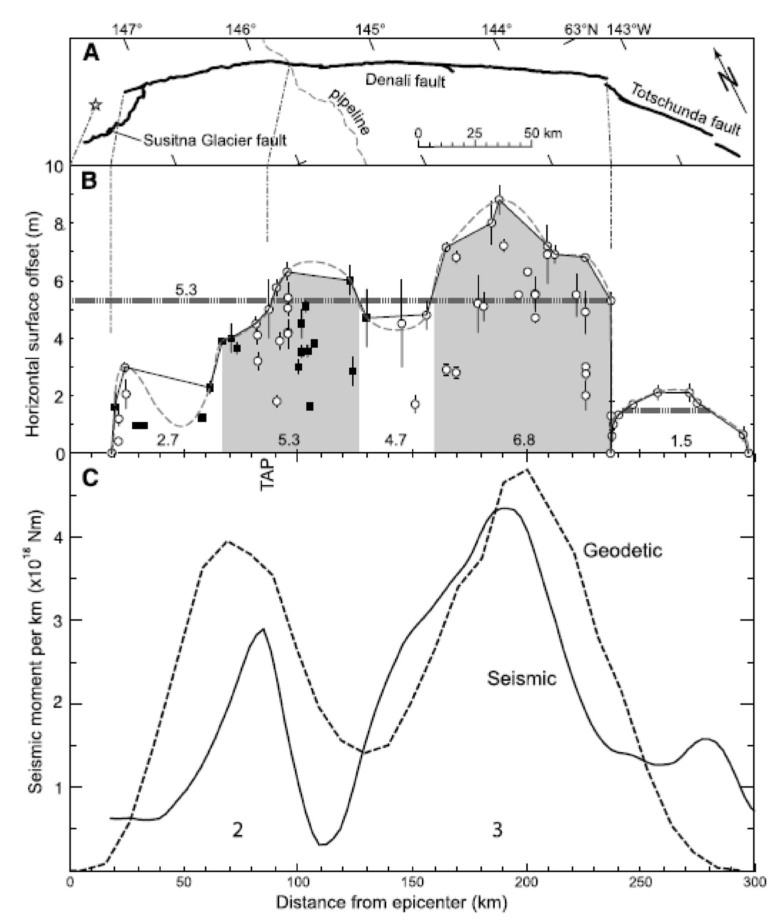
Based on the source characterization of slip inversions, the magnitude-area scaling for crustal earthquakes has been constructed:

The first circular-crack model stage of
S (km²) = 2.23 x 10^{-15} x (M_0 (Nm) x $10^7)^{2/3}$ (Somerville et al., 1999)
for M_0 < 7.5 x 10^{18} Nm,

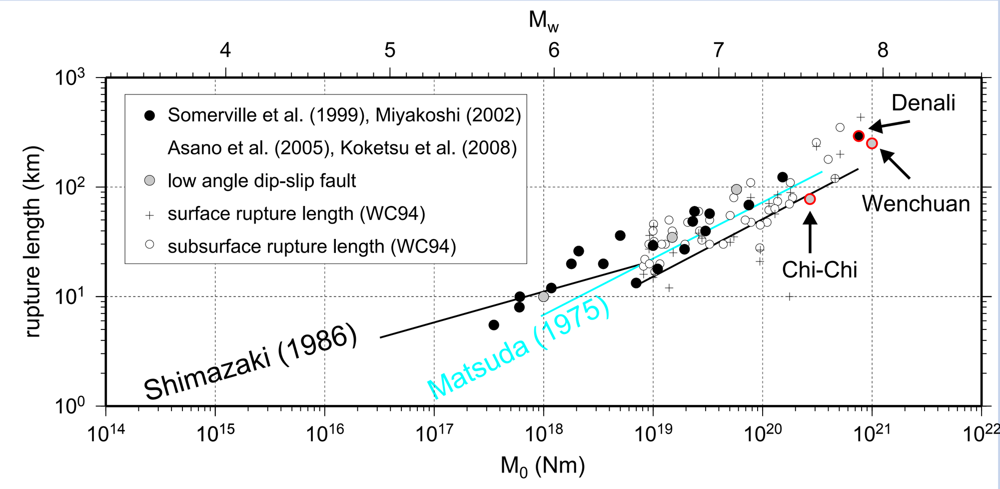
the second L-model stage of
S (km²) = 4.24 x 10^{-11} x (M_0 (Nm) x $10^7)^{1/2}$ (Irikura and Miyake, 2001, 2011)
for M_0 >= 7.5 x 10^{18} Nm,

and the third W-model stage of
S (km²) = 5.30 x 10^{-25} x (M_0 (Nm) x 10^7) (Irikura et al., 2004)
for M_0 >= 7.5 x 10^{20} Nm,
that was recently revised into
S (km²) = 1.0 x 10^{-17} x M_0 (Nm) (Murotani et al., 2010)
for M_0 >= 1.8 x 10^{20} Nm.

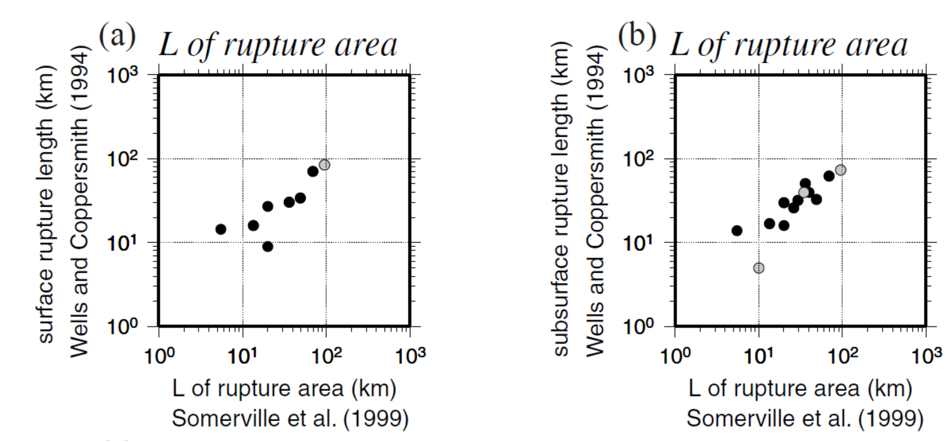
The above three-stage source scaling shows bending without significant gaps that pointed out by several 2-D numerical simulations. The scaling supports L ~ Wmax, not L = 2Wmax. There were less evidence of the differences seen in cascade and scaling earthquake ruptures. The second L-model stage is similar to Hanks and Bakun (2002) well constraint by megafault systems.



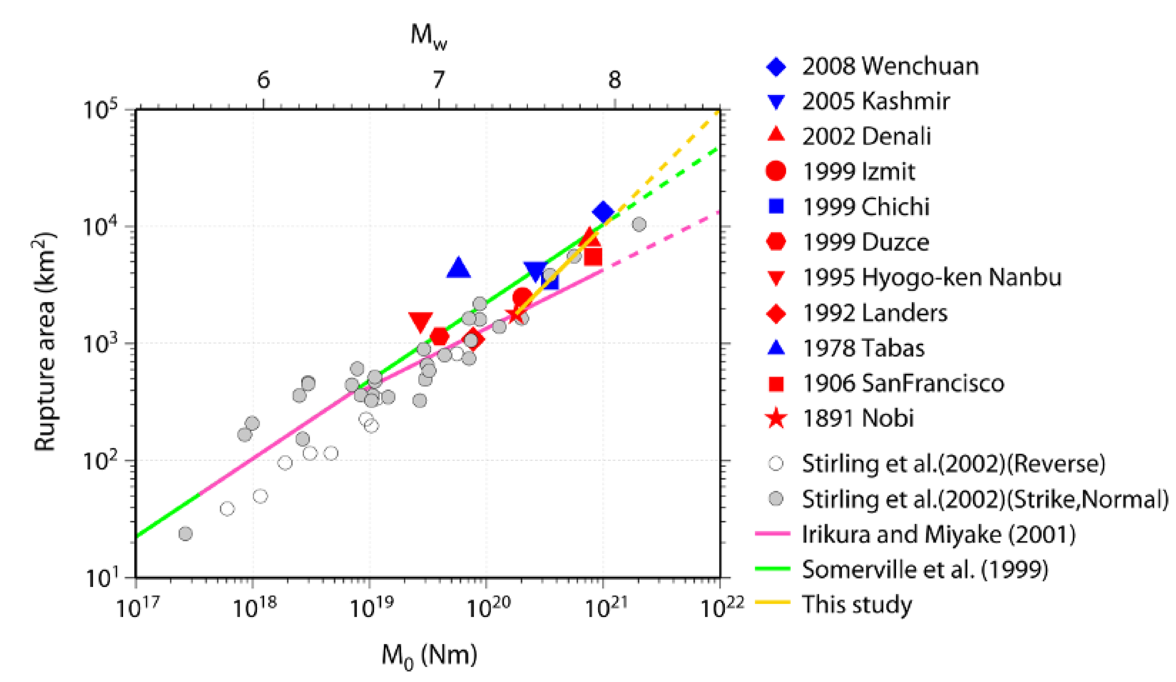
2002 Denali: Eberhart-Phillips et al. (2003)



Irikura and Miyake (2001, 2011)



Slip Inversions Prefer Earlier 2nd Bending (L = 100 km)

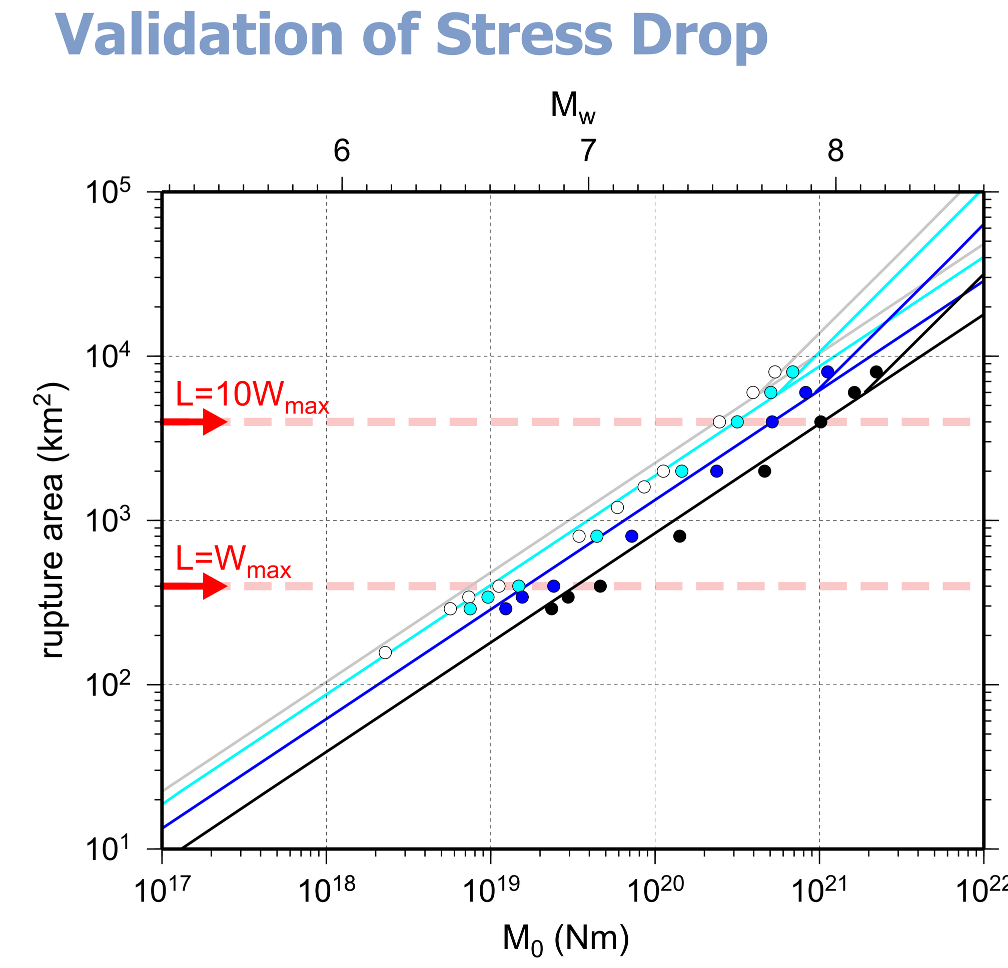


Murotani et al. (2010)

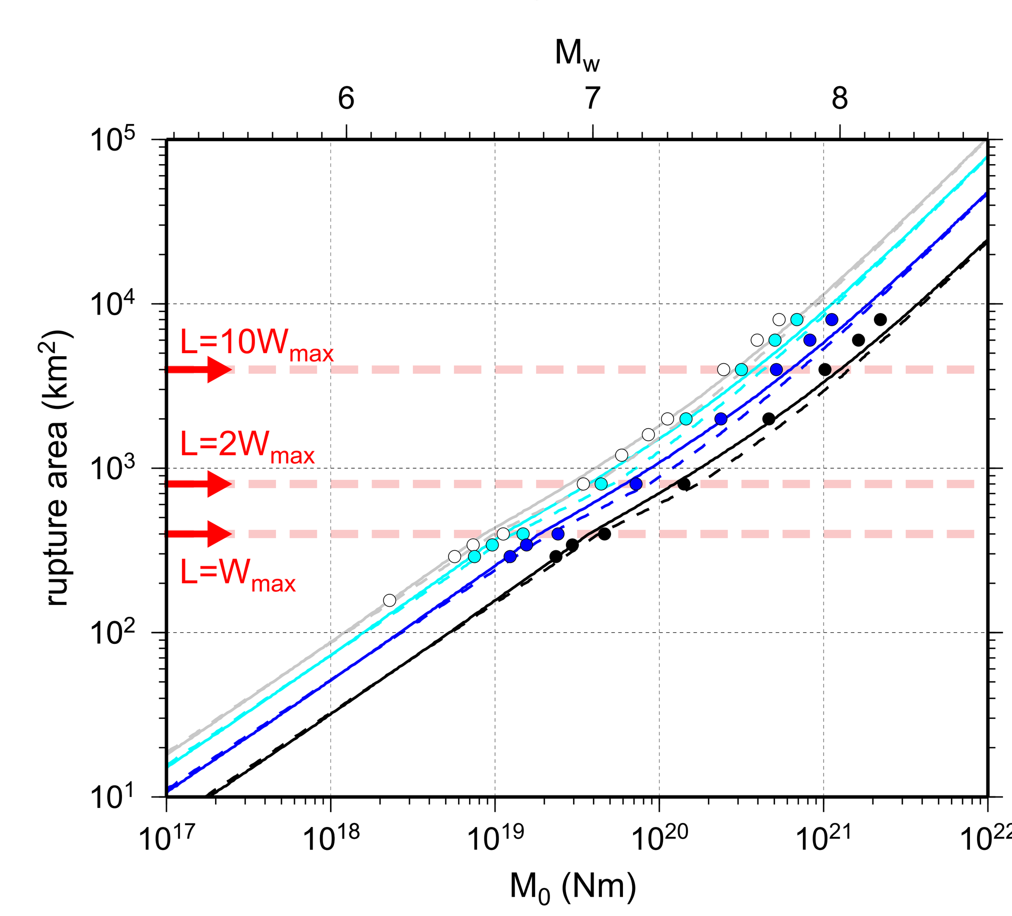
Mo-A Scaling from Dynamic Rupture Simulations

It is very important to quantify stress drop for the stages of the scaling. We performed a series of dynamic rupture simulations for strike-slip faulting using 3-D FDM of Dalguer et al. (2008). Stress drops were assumed for 2.3, 3.0, 5.0, and 10.0 MPa for rectangular crack models with maximum fault width Wmax of 20 km. Aspect ratios of the faults ranged 1 to 20. Our dynamic rupture simulations naturally reproduced the three-stage magnitude-area scaling. Those are compatible with the static models by Fujii and Matsu'ura (2000) and Shaw and Scholz (2001). To fit the scaling between slip inversions and dynamic rupture simulations, slight increase of stress drop from 2.3 to over 3.0 MPa is required in the second L-model stage, where the stress drop increases from 2.3 to 5.7 MPa for the circular-crack calculation by Eshelby (1957).

Validation of Stress Drop

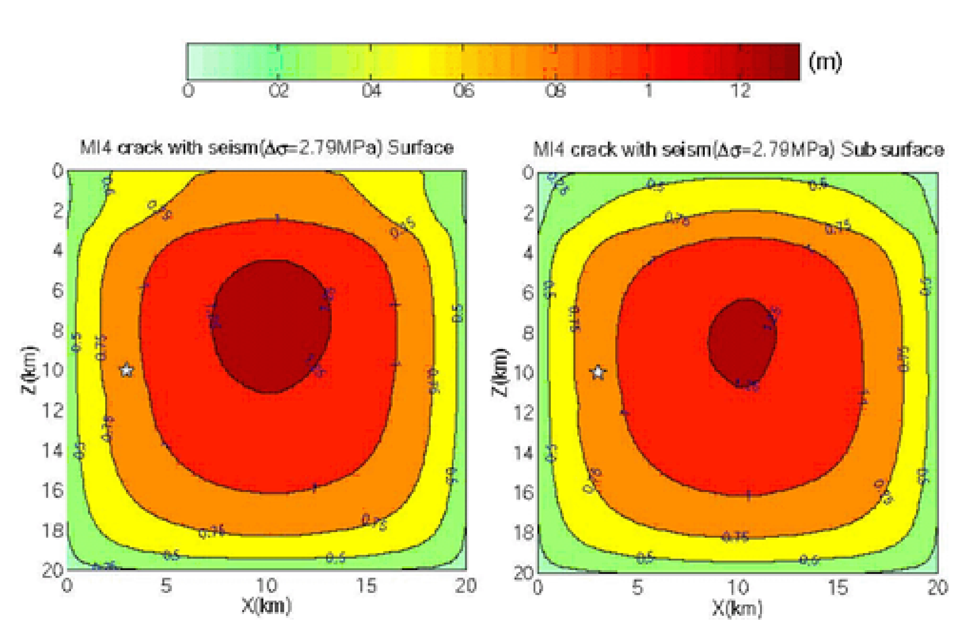


Dynamic rupture simulation vs. Eshelby crack model



Dynamic rupture simulation vs. Published bending models

Simulation for the 1st Bending (L = 20 km): Subsurface to Surface Rupture without Significant Gap of Dislocation



Dynamic Rupture Simulations Suggest

1st Stage:
Constant stress drop
2.3 MPa

2nd Stage:
Stress drop increase
2.3 MPa to over 3.0 MPa

3rd Stage:
Constant stress drop
over 3.0 MPa