Mechanics of Earthquakes and Faulting

Lecture 20, 13 Apr. 2021

www.geosc.psu.edu/Courses/Geosc508

- Seismic Spectra, Earthquake Scaling laws, Self-Similarity of Earthquake Rupture.

Aki, Scaling law of seismic spectrum, JGR, 72, 1217-1231, 1967.

Hanks, b Values and $\omega^{-\gamma}$ seismic source models: implications for tectonic stress variations along active crustal fault zones and the estimation of high-frequency strong ground motion, JGR, 84, 2235-2242, 1979.

Scholz, BSSA 1982

Pacheco, J. F. Scholz, C. H. Sykes, L. R. (1992). Changes in frequency-size relationship from small to large earthquakes, Nature 355, 71- 73.

Seismic Spectra, Earthquake Scaling laws and Self-Similarity of Earthquake Rupture

Implications for Rupture Dynamics and the Mode of Rupture Propagation

0 Self-similar:
Are small earthquakes 'the same' as large ones?
Do small ones become large ones or are large eq's different from the start?

1 Geometric self-similarity: aspect ratio of rupture area

2 Physical self-similarity: stress drop, seismic strain, scaling of slip with rupture dimension

3 Same physical processes operate during shear rupture of very small (lab scale, mining induced seismicity) and very large earthquakes?

4 Observation of constant b-value over a wide range of inferred source dimension.

5 Expectation of scaling break if rupture physics/dynamics change in at a critical size (or slip velocity, etc.). Shimazaki result. (Fig. 4.12). Length-Moment scaling and transition at L≈60km (Romanowicz, 1992; Scholz, 1994).

6 Gutenberg-Richter frequency-magnitude scaling, b-values.

7 G-R scaling, b-value data. Single-fault versus fault population. G-R versus characteristic earthquake model.

8 Crack vs. slip-pulse models

Circular ruptures (small)

$$M_o = GuA$$

$$\Delta\sigma =$$

$$M_o =$$

Scaling and Self-Similarity

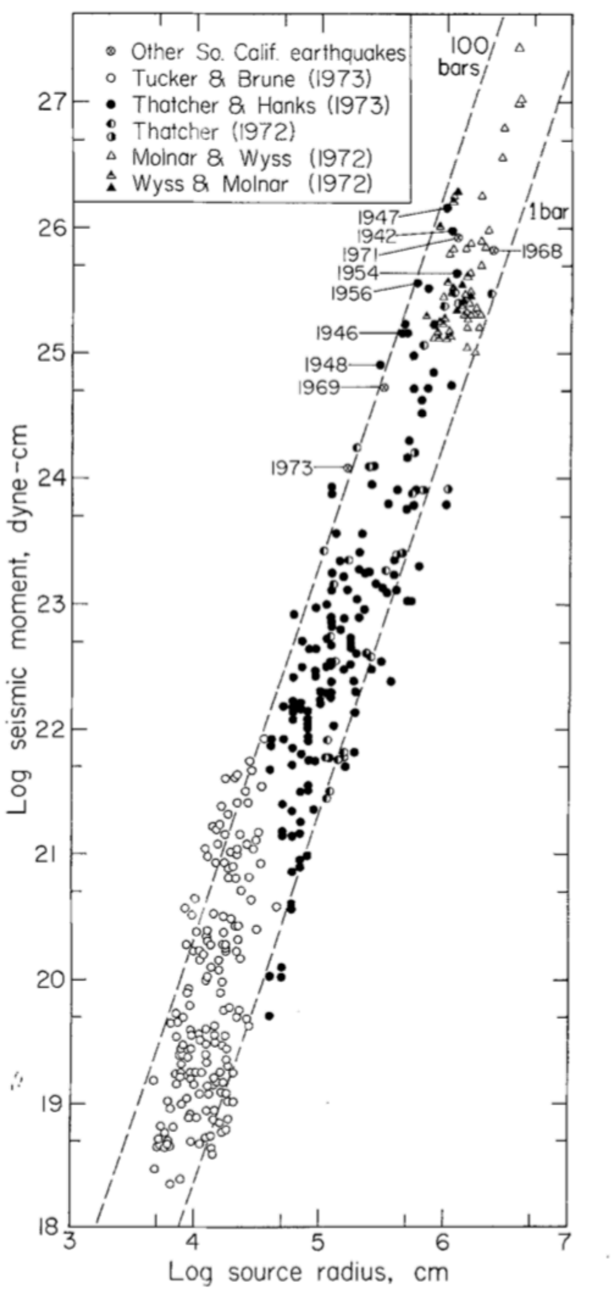
Are small earthquakes 'the same' as large ones?

1 Geometric self-similarity: rupture aspect ratio

2 Physical self-similarity: stress drop, seismic strain, scaling of slip with rupture dimension

3. Does stress drop scale with eq size, or are there scaling breaks that can be tied to a change in mechanism?

Thomas C. Hanks



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$$M_o = GuA$$

$$\Delta\sigma = C\,G\frac{u}{r}$$

$$M_o = C\,\Delta\sigma\,r^3$$

Scaling and Self-Similarity

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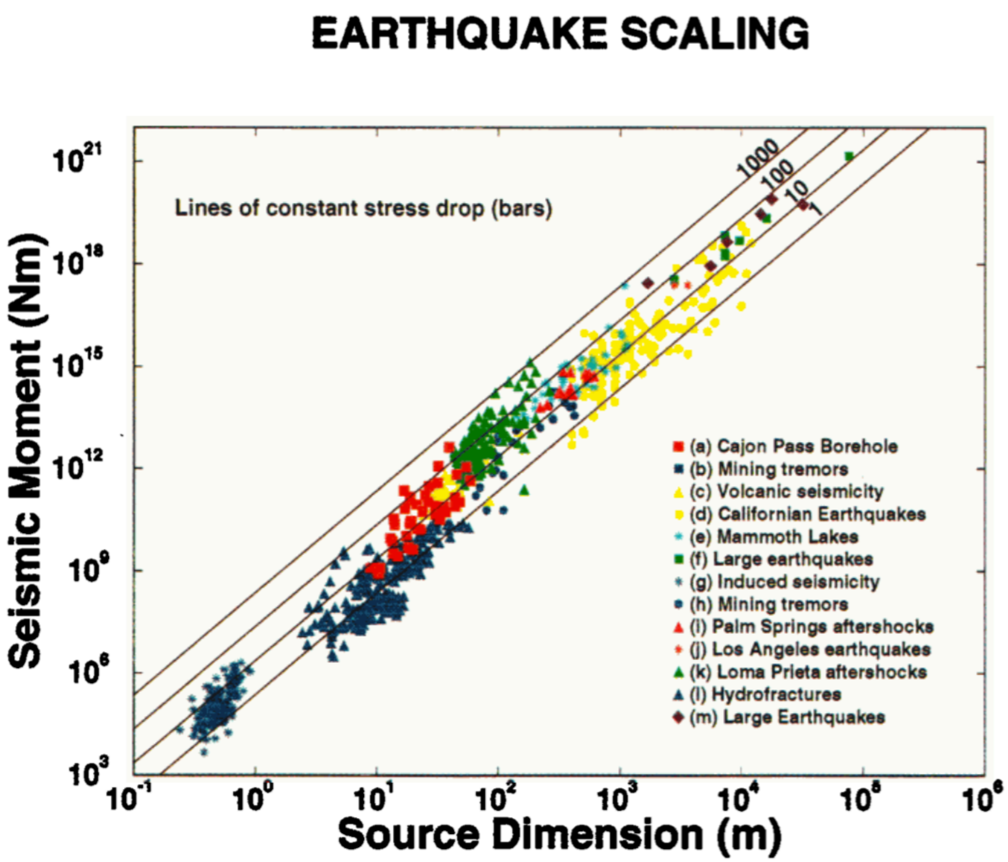

Abercrombie & Leary, 1993

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Bulletin of the Seismological Society of America

72 February 1982 No. 1

SCALING LAWS FOR LARGE EARTHQUAKES: CONSEQUENCES FOR PHYSICAL MODELS

BY CHRISTOPHER H. SCHOLZ

ABSTRACT

It is observed that the mean slip in large earthquakes is linearly proportional to fault length and does not correlate with fault width. This observation is interpreted in the light of the two possible classes of models for large earthquakes: *W* models, in which stress drop and slip are determined by fault width, and *L* models, in which these parameters are fundamentally determined by fault length. In the *W* model interpretation, stress drop systematically increases with *L*/*W*, the aspect ratio, and, as a consequence, seismic moment. The correlation of slip with length means that the rupture length is determined by the dynamic stress drop. This conflicts with the observation that the length of large earthquakes is often controlled by adjacent rupture zones of previous earthquakes or by tectonic obstacles. It also conflicts with the observations for small earthquakes that stress drop is nearly constant and does not correlate with source radius over a broad range. In the *L* model interpretation, the correlation between slip and length means that stress drop is constant, namely about 7.5, 12, and 60 bars for interplate strike-slip, thrust, and Japanese intraplate earthquakes, respectively. *L* models require that the fault be mechanically unconstrained at the base. *W* models predict that mean particle velocity increases with fault length, but rise time is constant. *L* models predict the opposite.

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Circular ruptures (small)

$$M_o = GuA$$

$$\Delta\sigma = C\,G\frac{u}{r}$$

$$M_o = C\,\Delta\sigma\,r^3$$

Rectangular ruptures (large)

Slip determined by W:

$$M_o = GuLW$$

$$\Delta\sigma =$$

$$M_o =$$

Slip determined by L

$$M_o = GuLW$$

$$\Delta\sigma =$$

$$M_o =$$

Scaling of Large Earthquakes: Is slip determined (limited) by W or L?

Rectangular ruptures (large)

Slip determined by W:

$$M_o = GuLW$$
$$\Delta\sigma = C\,G\frac{u}{W}$$
$$M_o = C\Delta\sigma LW^2$$

Slip determined by L

$$M_o = GuLW$$
$$\Delta\sigma = C\,G\frac{u}{L}$$
$$M_o = C\Delta\sigma W L^2$$

L model interpretation

u = α L

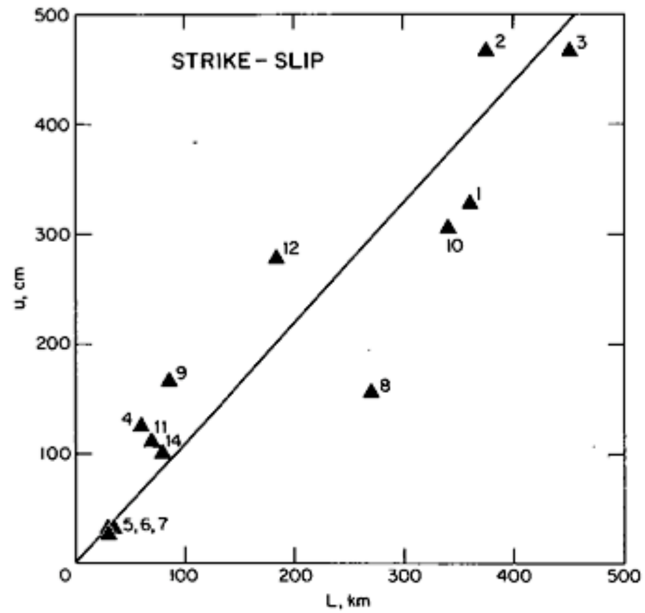


FIG. 1. A plot of mean slip, u versus fault length for the strike-slip events. The line drawn through the data has a slope of 1.25×10^{-5}. Numbers are references in Table 1.

W model interpretation: stress drop increases with L/W and seismic moment

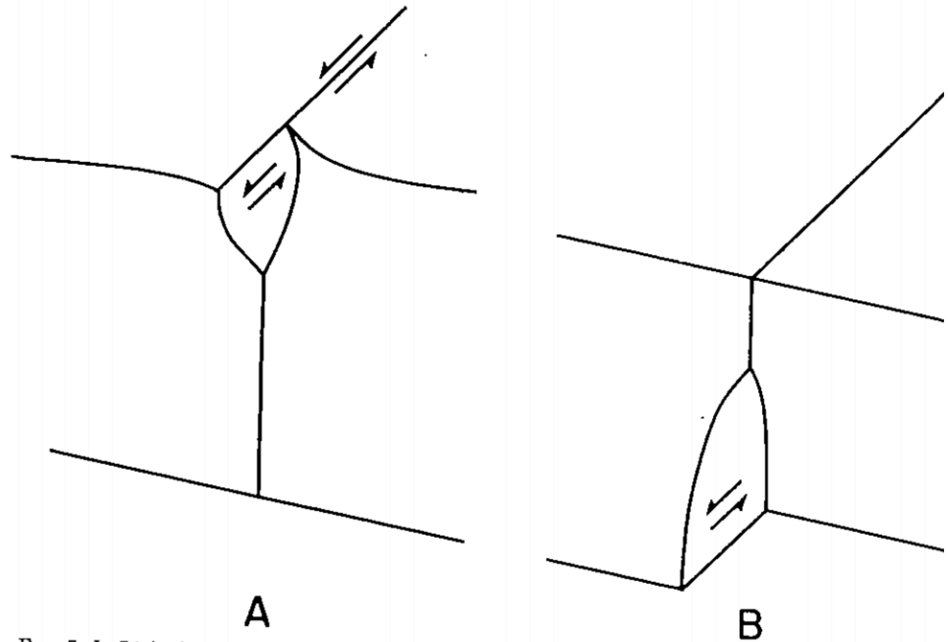


Fig. 7. In 7A is shown schematically a *W* model of a large earthquake, in which slip is constrained t be zero at the base of the fault. In 7B, we show a possible mechanism that may result in an *L* model. Th figure shows the situation just prior to a large earthquake. Aseismic slip has occurred beneath th seismogenic layer. If this preslip is larger than the slip in the earthquake, the earthquake may not b constrained at the base.

W model interpretation: stress drop increases with L/W and seismic moment

L model interpretation

$u = \alpha L$

Scaling of Large Earthquakes: Is slip determined (limited) by W or L?

GEOPHYSICAL RESEARCH LETTERS, VOL. 29, NO. 12, 1604, 10.1029/2001GL014479, 2002

On moment-length scaling of large strike slip earthquakes and the strength of faults

B. Romanowicz[1] and L. J. Ruff [2]

Received 29 November 2001; revised 8 March 2002; accepted 11 March 2002; published 29 June 2002.

Rectangular ruptures (large)

Slip determined by W:

$$M_o = C\Delta\sigma L W^2$$

Slip determined by L

$$M_o = C\Delta\sigma W L^2$$

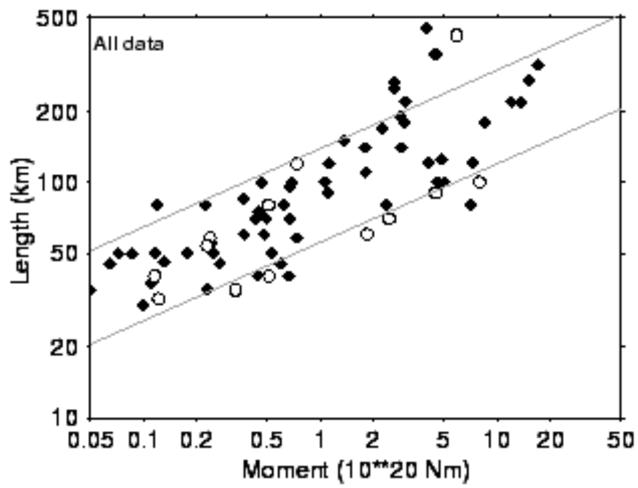


Figure 18.1: Moment-length plot for the dataset described. Lines corresponding to $n = 3$ bracketing most of the data have been drawn for reference. Circles correspond to recent data for which length was estimated from the NEIC catalog.

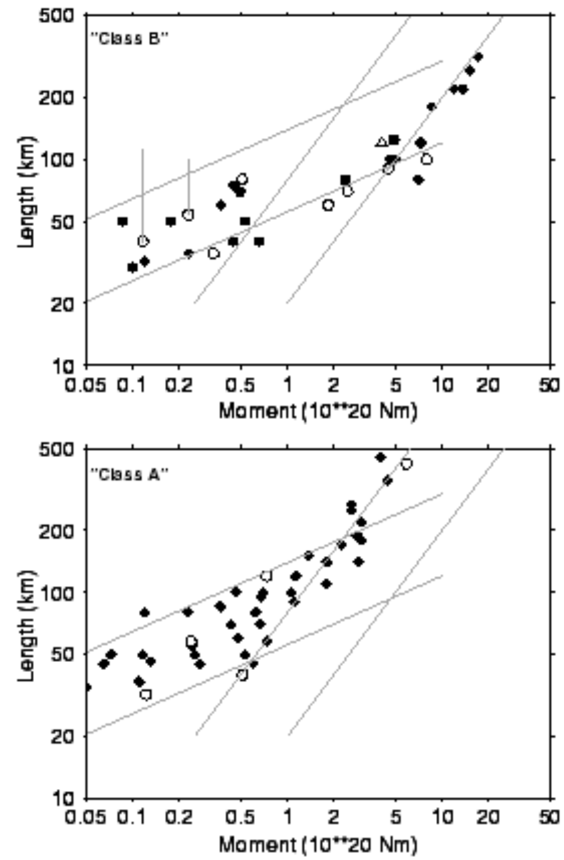
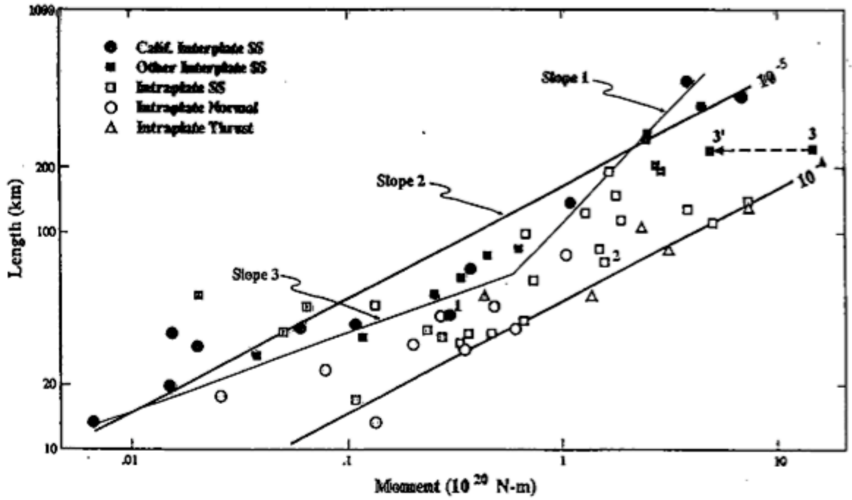


Figure 18.2: Moment-length plots for A (bottom) and B (top) events. Best fitting $n = 1$ trends are indicated for each subset of data. Circles as in Figure 1, diamonds from other sources. Triangle is Luzon'90 event. Vertical lines point to the length estimates of PD96 for Aegean Sea events

Scaling of Large Earthquakes: Is slip determined (limited) by W or L?



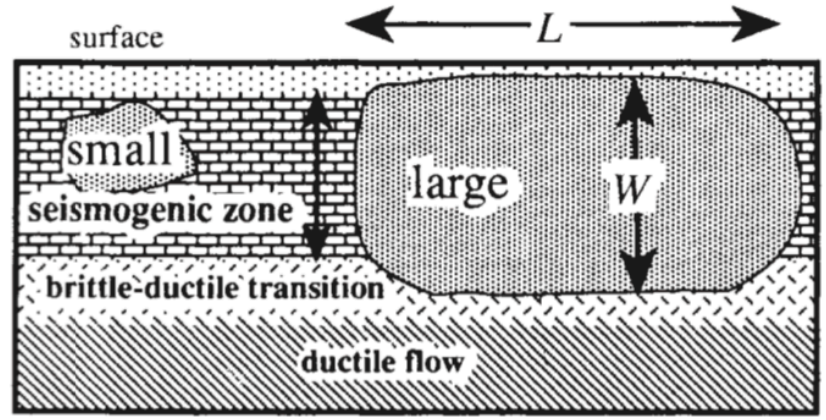


FIG. 1 Two types of earthquakes; small (unbounded) and large (bounded). *L* is rupture length, along strike of fault, *W* down-dip width of the rupture.

Changes in frequency–size relationship from small to large earthquakes

Javier F. Pacheco, Christopher H. Scholz & Lynn R. Sykes

Lamont-Doherty Geological Observatory and Department of Geological Sciences, Columbia University, Palisades, New York 10964, USA

THE constant '*b* value' observed in frequency–magnitude distributions of earthquakes has been taken as an indication of self-

Nature, 1992

Circular ruptures (small)

$$M_o = GuA$$

$$\Delta\sigma = C\,G\frac{u}{r}$$

$$M_o = C\,\Delta\sigma\,r^3$$

Transition from small to large eq's

Rectangular ruptures (large)

Slip determined by W:

$$M_o = GuLW$$

$$\Delta\sigma = C\,G\frac{u}{W}$$

$$M_o = C\Delta\sigma LW^2$$

Slip determined by L

$$M_o = GuLW$$

$$\Delta\sigma = C\,G\frac{u}{L}$$

$$M_o = C\Delta\sigma WL^2$$

SMALL AND LARGE EARTHQUAKES:
THE EFFECTS OF THE THICKNESS OF SEISMOGENIC LAYER AND THE FREE SURFACE

Kunihiko Shimazaki

Earthquake Research Institute, University of Tokyo, Bunkyo-ku, Tokyo, Japan 113

AGU Monograph, 1986

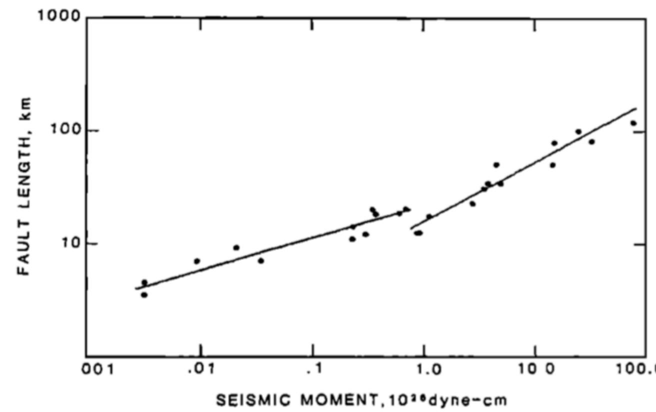


Fig. 1. A plot of logarithm of fault length against that of seismic moment. The whole dataset for Japanese intraplate earthquakes are divided into two at the seismic moment of 7.5×10^{25} dyne-cm and the linear regression analysis is applied to each dataset. This segmented fit is shown to be statiscally better than models shown in Figure 2.

Some Topics in the Mechanics of Earthquakes and Faulting

- What determines the size of an earthquake?
- What physical features and factors of faulting control the extent of dynamic earthquake rupture? --Fault Area, Seismic Moment
- What is the role of fault geometry (offsets, roughness, thickness) versus rupture dynamics ?
- What controls the amount of slip in an earthquake? Average Slip, Slip at a point
- What controls whether fault slip occurs dynamically or quasi-statically?
- Nucleation: How does the earthquake process get going?
- What is the size of a nucleation patch at the time that slip becomes dynamic? How do we define dynamic versus quasi-dynamic and quasi-static? Nucleation patch: physical size, seismic signature
- What controls dynamic rupture velocity?
- How do faults grow and evolve with time?