Earthquake Magnitude

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Earthquake Magnitude

Richter Magnitude (K. Wadati 1931, Richter 1935) of local earthquake (M_L) is:

Log_{10} (max. seismic wave amplitude (horizontal motion) in thousands of a millimeter, recorded on a standard Wood-Anderson (W-A) seismograph, at a distance of 100km from the earthquake epicenter).

W-A instruments were widely available at the time (not anymore).

Later allowance was made for measurements (based on data from California, Reiter page 18) at distances other than 100kms as shown in Box 7.1 (Bolt Book). In this figure note that S-P time-distance relations are based on experience from measurements in California (i.e., reflects rock properties in California).

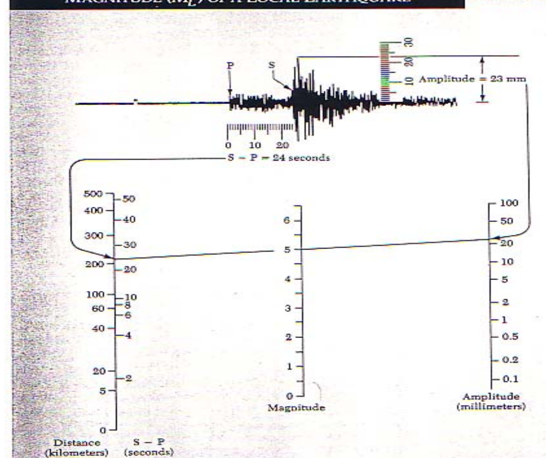
-This magnitude scale is based only on maximum recorded value, and this leaves out a lot of information.

- Increase in magnitude of one unit means increase in wave amplitude of 10 times (note that 0.1mm is 0.1x1000 = 100 in thousands of a mm), e.g.,

$M_L = 2 = \log_{10} (100)$ or 0.1 mm on the instrument

$M_L = 4 = \log_{10} (10,000)$ or 10 mm on the instrument

EXAMPLE OF THE CALCULATION OF THE RICHTER MAGNITUDE (M_L) OF A LOCAL EARTHQUAKE **Box 7.1**



Procedure for calculating the local magnitude, M_L

1. Measure the distance to the focus using the time interval between the S and the P waves (S – P = 24 seconds).
2. Measure the height of the maximum wave motion on the seismogram (23 millimeters).
3. Place a straight edge between appropriate points on the distance (left) and amplitude (right) scales to obtain magnitude M_L = 5.0.

[From Bruce A. Bolt's Earthquakes (New York: W. H. Freeman and Company, Copyright 1993)]

- W-A amplitudes can be easily correlated to magnitudes of other measuring instruments.

- Other similar M_L relations have been developed for other locations (other than California) worldwide (using available instruments to measure peak amplitude) and local rock properties for estimating distance.

- Many limitations, including that peak amplitude does not correlate in a straightforward way with EQ. Strength or size especially when you reach $M_L = 8$ and above

$M_L = 8 = \log_{10} (100,000,000)$

Where 100,000,000 is 100,000 mm = 100 m (can't be measured…)

- Very small tremors will result in a negative magnitude (e.g., amplitude in thousands of a millimeter of less than 1, will result in negative M_L and even $M_L = 1$ means amplitude is 10 in thousands of a mm which is 0.01mm and is too small to be measured).

- Peak shear wave amplitude is highly affected by local ground surface conditions and surface wave propagation characteristics (amplitude of Rayleigh and Love waves).

- Other magnitudes have been developed with the general form

$M = \log (A) + f(d, h) + C_s + C_R$

In which M = magnitude
A = actual amplitude of wave being measured (after removing instrument effects)
f(d,h) = function that accounts for epicentral distance and focal depth
C_s = station correction
C_R = regional correction

- If you use maximum amplitude (from the first few cycles) of P-wave (using the vertical motion trace; thought to be not affected much by focal depth), you get a Body Wave Magnitude (known as m_b), where

$m_b = \log A - \log T + 0.1\,\Delta + 5.9$

A is P-wave amplitude in microns, T = P-wave period, Δ (360 degrees is earth's circumference)

This magnitude is reliable for deep earthquakes.
This magnitude cannot be used to infer energy released from very large events.

m_b exists also in which amplitude of other body waves may be used (rarely used in US).

- For shallow EQs (< 70 km depth), the surface wave train can be used to measure the amplitude of largest swing (ground displacement A in microns; usually the Rayleigh wave) with a period near 20 seconds (known as **Surface Wave Magnitude** M_s)

$M_s = \log A + 1.66 \log \Delta + 2$ (25 degrees $< \Delta <$ 90 degrees)

Such waves can most easily be observed at distances 1000 kms from events with $M_s > 5$ (thus, not so good for small deep or local events).

- Empirical relations exist to correlate m_b to M_s (at least for moderate EQs).

- M_s correlates more closely with our concept of EQ size, more so than m_b (e.g., because large EQs generate surface waves of large amplitude whereas P-wave amplitude (used for m_b) does not increase as much for such events).

However, limitations still exist (i.e., surface wave amplitude does not tell the whole story).

- Measurements (estimates) of **released energy** for a given EQ yields

$\log E = 4.8 + 1.5\, M_s$ (implies that an increase of 1 in M_s leads to an increase of about 30 times (31.6 actually) in seismic energy E (in Joules, see Bolt), or

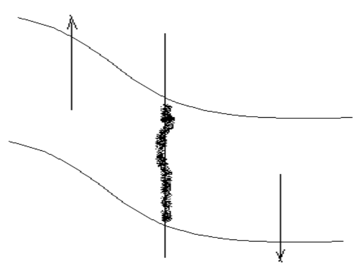
$\log E = 11.8 + 1.5\, M_s$ (Energy in Erg, see Reiter)

Seismic Moment (M_o)

-Favored by seismologists to estimate size of seismic source

- Yields a consistent scale of earthquake size

- Reflects influence of dislocation surface (see figure), friction force along fault and thus total energy released from seismic event



$$M_o = \mu\, A\, D$$

where μ = rigidity modulus (resistance to shearing motion)

A = fault rupture area (length x height of slip area on fault)

D = average relative movement between opposite sides f fault (page 20 in Reiter's book) measured indirectly from long period waves in a seismogram (long period end of spectrum waves).

Empirical Relation

Seismic Moment M_o (Newton Meters units)

$\log M_o = 10.92 + 1.11\, M_s$

Moment Magnitude M_w

$M_w = (2/3) \log M_o - 6$ (M_o in Newton Meter)

Or,

$M_w = (2/3)\ (10.92 + 1.11\, M_s\ ) - 6$ (M_o in Newton Meter)

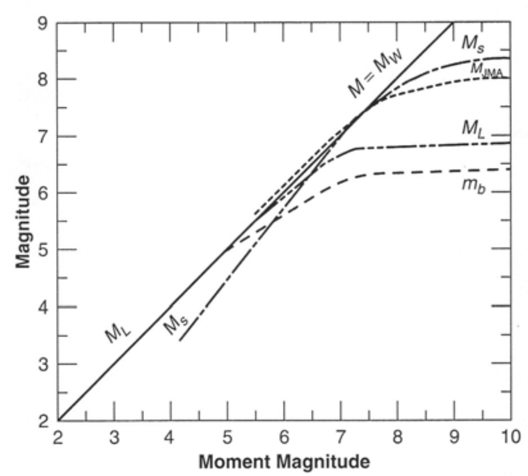


Figure 2.29 Saturation of various magnitude scales: M_w (moment magnitude), M_L (Richter local magnitude), M_s (surface wave magnitude), m_b (short-period body wave magnitude), m_B (long-period body wave magnitude), and M_{JMA} (Japanese Meteorological Agency magnitude). (After Idriss, 1985.)

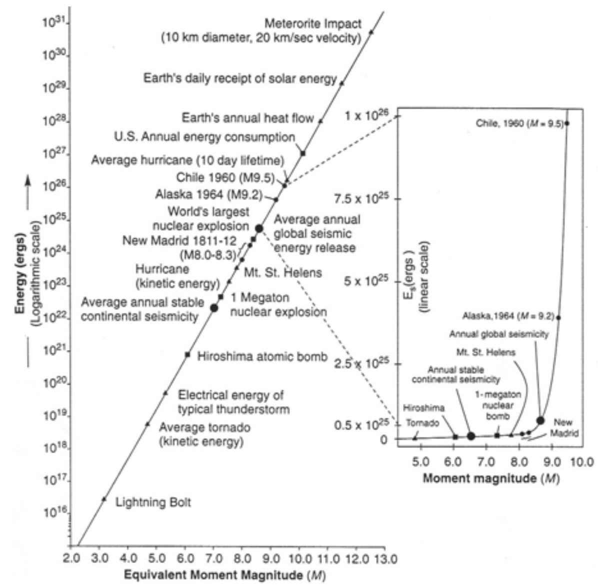


Figure 2.31 Relative energy of various natural and human-made phenomena. (After Johnston, 1990. Reprinted by permission of USGS.)

Table 2 Worldwide Earthquakes per Year

Magnitude M_s	Average Number Above M_s
8	2
7	20
6	100
5	3000
4	15,000
3	More than 100,000

[From Bruce A. Bolt's Earthquakes (New York: W. H. Freeman and Company, Copyright 1993)]