

Richter magnitude
Why magnitude?

Intensity

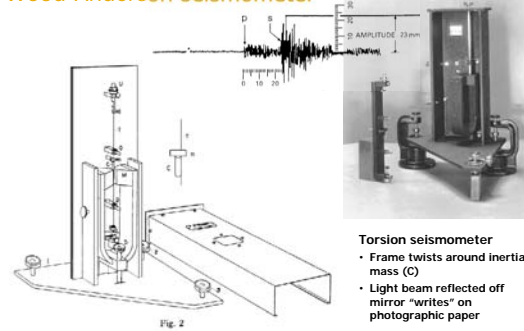
- varies spatially for a given earthquake
- subjective measure – depends on types of buildings
- ➔ need a measure of the “size” of an earthquake

Magnitude

- single number for an earthquake
- initially, a measure of the amplitude of ground shaking with respect to a reference event:

Richter magnitude: magnitude is \log_{10} of the maximum amplitude recorded on a Wood-Anderson seismometer at 100 km from the epicenter

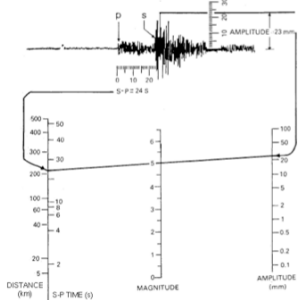
Richter magnitude
Wood-Anderson seismometer



Torsion seismometer
• Frame twists around inertial mass (C)
• Light beam reflected off mirror “writes” on photographic paper

Richter magnitude
Nonogram

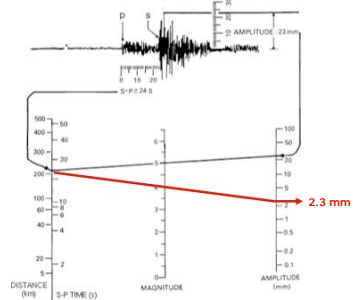
1. Measure S-P time. Provides distance
2. Measure amplitude in mm on Wood-Anderson seismometer
3. Draw line between the two points to obtain magnitude



Richter magnitude
Nonogram

How much smaller would the amplitude be if the earthquake was 1 mag unit smaller?

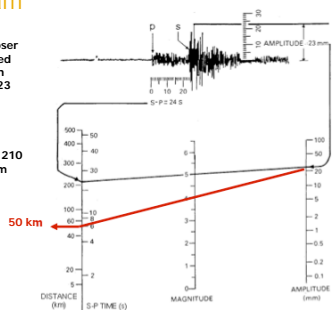
➔ factor of 10



Richter magnitude
Nonogram

How much closer would you need to be to get an amplitude of 23 mm for a magnitude 4 earthquake?

➔ move from 210 km to 50 km

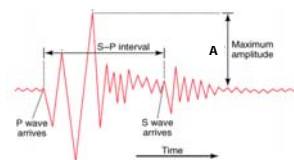


Richter magnitude
Today

Use different instruments and a distance correction factor:

$$M_L = \log A \cdot (\text{Distance correction factor})$$

$$M_L = \log A - 2.48 + 2.76 \log \Delta$$



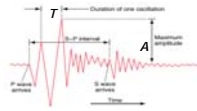
Obtain a magnitude estimate from every station waveform

➔ calculate average from all station for the final magnitude

Other magnitude scales
Body wave magnitude: m_b

Measured from P-wave amplitude of any waveform around the world

$$m_b = \log A - \log T + 0.01\Delta + 5.9$$



Alaskan earthquake recorded at Orville (see Bolt Appendix G)

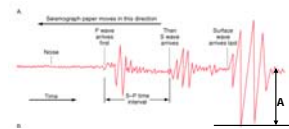
P-wave: $A = 1.4 \times 10^{-6} \text{ m}$ $T = 12 \text{ sec}$ $\Delta = 28^\circ$

$$m_b = 0.15 - 1.08 + 0.28 + 5.9 = 5.3$$

Other magnitude scales
Surface wave magnitude: M_s

Measured from surface-wave amplitude of any waveform around the world

$$M_s = \log A + 1.66 \log \Delta + 2.0$$



Alaskan earthquake recorded at Orville (see Bolt appendix G)

P-wave: $A = 1.4 \times 10^{-6} \text{ m}$ $T = 12 \text{ sec}$ $\Delta = 28^\circ$

$$m_b = 0.15 - 1.08 + 0.28 + 5.9 = 5.3$$

Rayleigh wave: $A = 4.3 \times 10^{-6} \text{ m}$

$$M_s = 0.63 + 2.40 + 2.0 = 5.0$$

Are you surprised the magnitude estimates are different?

Magnitude as a discriminator

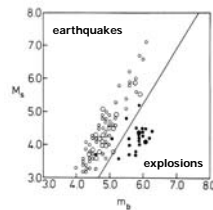
M_s and m_b estimates are usually different for a given earthquake

- m_b measures the amplitude of the P-wave
- M_s measures the amplitude of the surface wave

Nuclear explosions

- Do not excite surface waves very well
- Use m_b vs. M_s to discriminate

How else can we discriminate?



Magnitude-frequency relation

Gutenberg-Richter relation:

$$\log N = a - bM$$

Global average for b is -1

→ There are ten times as many magnitude 4 as there are magnitude 5

Earthquake magnitude	Number per year
2-8.0	0-1
7-7.9	18
6-6.9	120
5-5.9	800
4-4.9	6,200
3-3.9	49,000
2-2.9	~350,000
1-1.9	~3,000,000

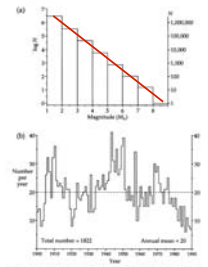
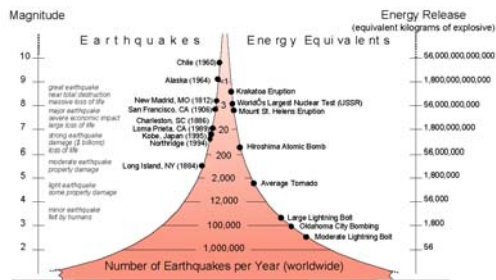


Fig. 3.43 Histogram of (a) the number (N) of earthquakes per year with magnitude M_s and (b) the annual number of earthquakes with magnitude M_s . (Data from 1960 based on data from the US Geological Survey National Earthquake Information Center.)

Magnitude and frequency



Earthquake energy

To measure all the energy released in an earthquake we must integrate over space and time ...difficult!

We can approximately relate magnitude to energy:

$$\log_{10} E = 11.8 + 1.5 M_s$$

see Bolt Appendix G

- A magnitude 5 earthquake releases about 30 times as much energy as a magnitude 4
- Even when you add together the energy release from all the small earthquakes, it is small compared to the one big event

Earthquake magnitude	Number per year	Annual energy (10^{13} joule yr^{-1})
2-8.0	0-1	0-600
7-7.9	18	200
6-6.9	120	43
5-5.9	800	12
4-4.9	6,200	3
3-3.9	49,000	1
2-2.9	~350,000	0.2
1-1.9	~3,000,000	0.1

Alaska earthquake at Orville

see Bolt appendix G

Rayleigh wave: $A = 4.3 \times 10^{-6} \text{ m}$
 $M_s = 0.63 + 2.40 + 2.0 = 5.0$

Estimate energy:

$$\log_{10} E = 11.8 + 1.5 M_s$$

$$E = 2.0 \times 10^{19} \text{ ergs}$$

Some comparisons:

- US annual energy consumption: 10^{26} ergs
- Annual heat flow out of the Earth: 10^{28} ergs
- Total annual seismic energy: $10^{25} - 10^{26}$ ergs

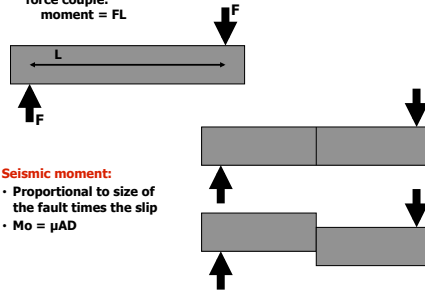
EP24 Earthquakes in your backyard

What's with the wiggles?

Best measure of earthquake "size" Seismic moment

a measure of the total mechanical energy

force couple:
moment = FL



Seismic moment:
 • Proportional to size of the fault times the slip
 • $M_o = \mu AD$

EP24 Earthquakes in your backyard

What's with the wiggles?

Best measure of earthquake "size" Moment magnitude

related to seismic moment: $M_w = \frac{2}{3} \log M_o - 10.7$

Alaskan earthquake recorded at Orville

$$M_o = 4 \times 10^{23} \text{ Nm}$$

therefore... $M_w = 4.9$

remember $m_b = 5.3$
 $M_s = 5.0$

Fault length scales with M_s

$$M_s = 6.10 + 0.70 \log L$$

therefore $L = 3 \text{ km}$

also from Bolt Appendix G

EP24 Earthquakes in your backyard

What's with the wiggles?

Other earthquakes

Pakistan Oct 8, 2005

M_b 6.7 *
 M_s 7.7
 M_o 2.9×10^{27} dyne-cm
 M_w 7.6

E 2.2×10^{23} ergs
 L 190 km



* m_b is not a good measure for large magnitude earthquake ($M > 6$)

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Other earthquakes

Pakistan Oct 8, 2005

M_b 6.7 *
 M_s 7.7
 M_o 2.9×10^{27} dyne-cm
 M_w 7.6

E 2.2×10^{23} ergs
 L 190 km

Loma Prieta Oct 17, 1989

M_b 6.5 *
 M_s 7.1

M_w 6.9

E 2.8×10^{22} ergs
 L 30 km



* m_b is not a good measure for large magnitude earthquake ($M > 6$)

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Other earthquakes

Pakistan Oct 8, 2005

M_b 6.7 *
 M_s 7.7
 M_o 2.9×10^{27} dyne-cm
 M_w 7.6

E 2.2×10^{23} ergs
 L 190 km

Loma Prieta Oct 17, 1989

M_b 6.5 *
 M_s 7.1

M_w 6.9

E 2.8×10^{22} ergs
 L 30 km



Sumatra Dec 26, 2004

M_b - *
 M_s 8.9
 M_o 1×10^{30} dyne-cm
 M_w 9.3

E 1.4×10^{25} ergs
 L 1000 km

* m_b is not a good measure for large magnitude earthquake ($M > 6$)

EP24 Earthquakes in your backyard

What's with the wiggles?