Corso di Laurea in Fisica - UNITS

ISTITUZIONI DI FISICA PER IL SISTEMA TERRA

SEISMIC SOURCES: EARTHQUAKE SIZE

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Earthquake size

Earthquake size

- intensity
- magnitude scales
- saturation
- energy concepts
- moment magnitude

How is Earthquake Size Determined?

(1) **Seismic Intensity**

"Dated" method

Does "not" use seismometers

Many problems

(2) **Magnitudes**

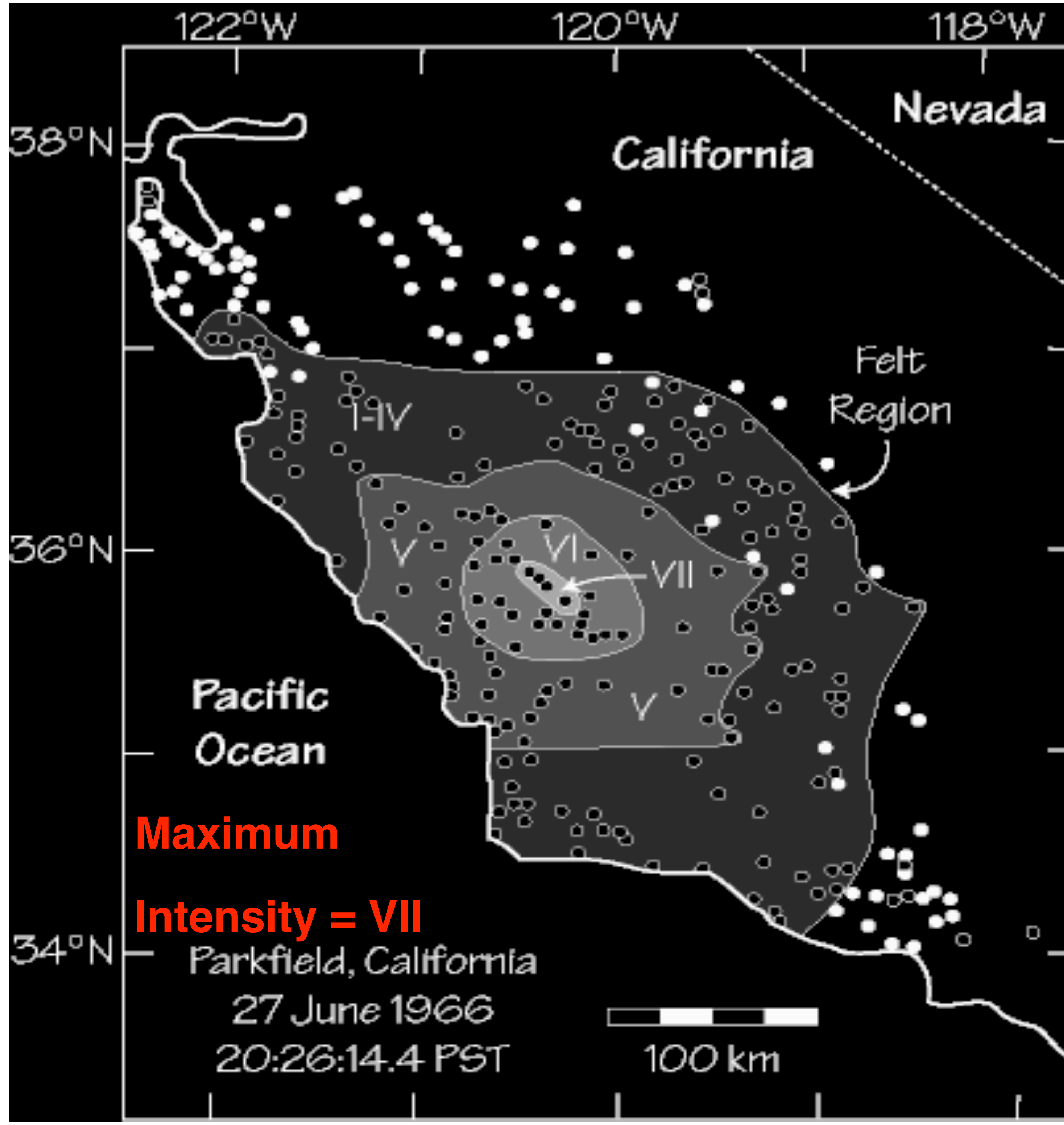
Modern method

Uses seismometers

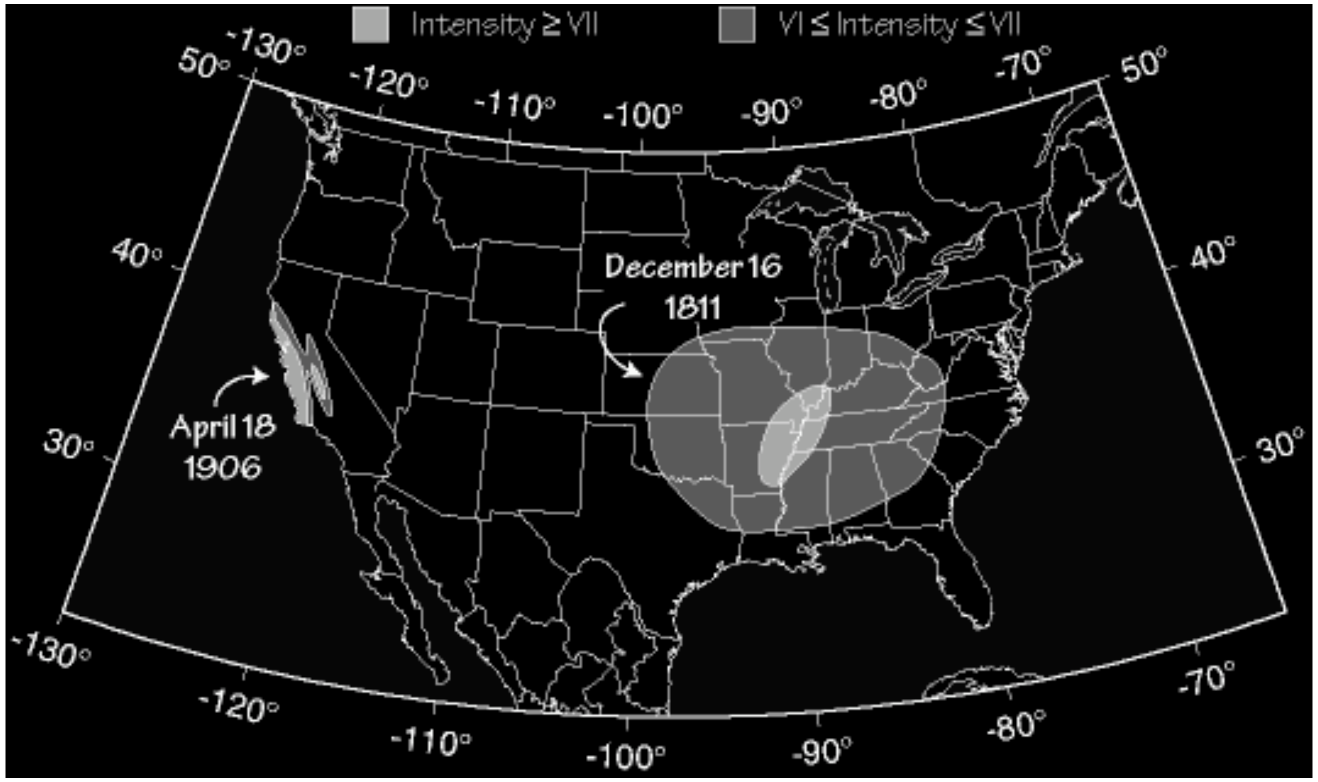
Fewer problems

Maximum Intensity

Maximum Intensity is used to estimate the size of historical earthquakes, but suffers from dependence on depth, population, construction practices, site effects, regional geology, etc.



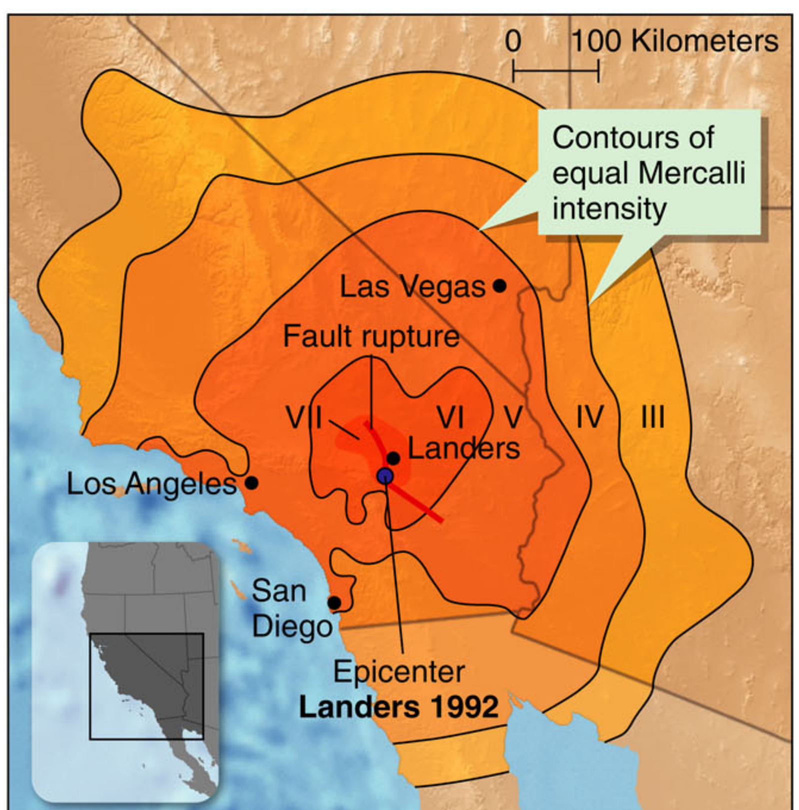
1906 SF and 1811-12 New Madrid

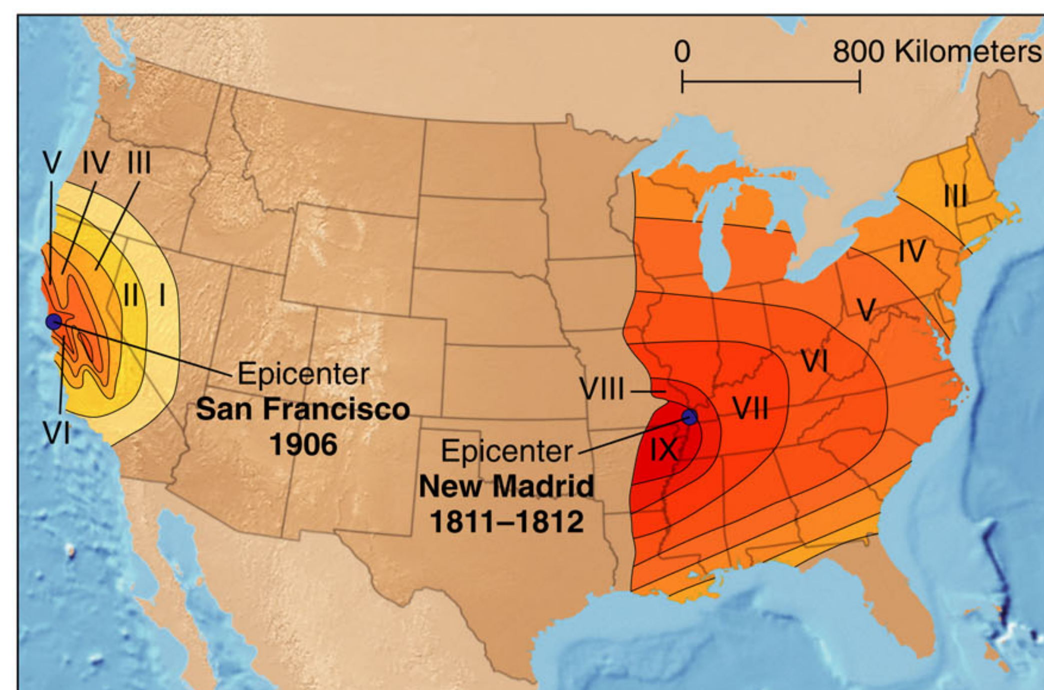


Intensity scales are based on the **observed** effects of the shaking, such as the degree to which people or animals were alarmed, and the extent and severity of **damage** to different typologies of structures or natural features.

The maximal intensity observed, and the extent of the area where shaking was felt (isoseismal maps), can be used to estimate the location and magnitude of the source earthquake; this is extremely useful for **historical** earthquakes where there is no instrumental record.

These earthquakes were roughly the same size, but the intensity patterns in the east are broader than in the west (wait for Q...)





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Intensity scales

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<tr><th>MM</th><th>RF</th><th>JMA</th><th>MCS</th><th>MSK</th></tr>
<tr><td rowspan="2">I</td><td rowspan="3">I</td><td></td><td rowspan="2">II</td><td rowspan="2">I</td></tr>
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<tr><td>XII</td></tr>
<tr><td>XI</td><td rowspan="2">VII</td><td rowspan="2"></td><td>XI</td></tr>
<tr><td>XII</td><td>XII</td></tr>
</table>

MM – Modified Mercalli; RF – Rossi-Forel; JMA – Japanese Meteorological Agency;
MCS – Mercalli-Cancani-Sieberg; MSK – Medvedev-Sponheuer-Karnik

EQ size

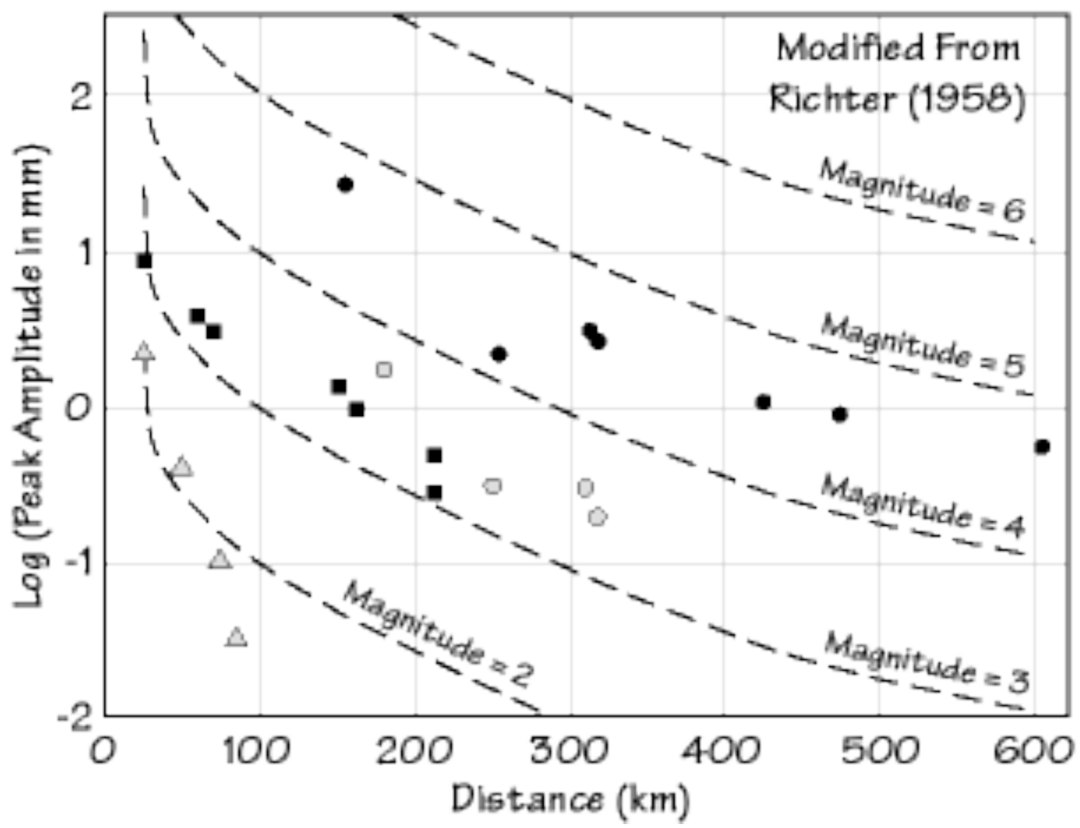
Earthquake Magnitude

Earthquake magnitude scales originated because of

- the desire for an objective measure of earthquake size
- Technological advances -> seismometers

Magnitude Scales - Richter

The concept of magnitude was introduced by Richter (1935) to provide an objective instrumental measure of the size of earthquakes. Contrary to seismic intensity, I, which is based on the assessment and classification of shaking damage and human perceptions of shaking, the magnitude M uses instrumental measurements of earth ground motion adjusted for epicentral distance and source depth.



The original Richter scale was based on the observation that the amplitude of seismic waves systematically decreases with epicentral distance.

Data from local earthquakes in California

The relative size of events is calculated by comparison to a reference event, with M_L=0, such that A_0 was 1 μm at an epicentral distance, Δ, of 100 km with a Wood-Anderson instrument:

$$\mathbf{M_L=\log(A/A_0)=\log A-2.48+2.76}\Delta.$$

Magnitude Scales - Richter

[CHAP. 22] MAGNITUDE, STATISTICS, ENERGY 341

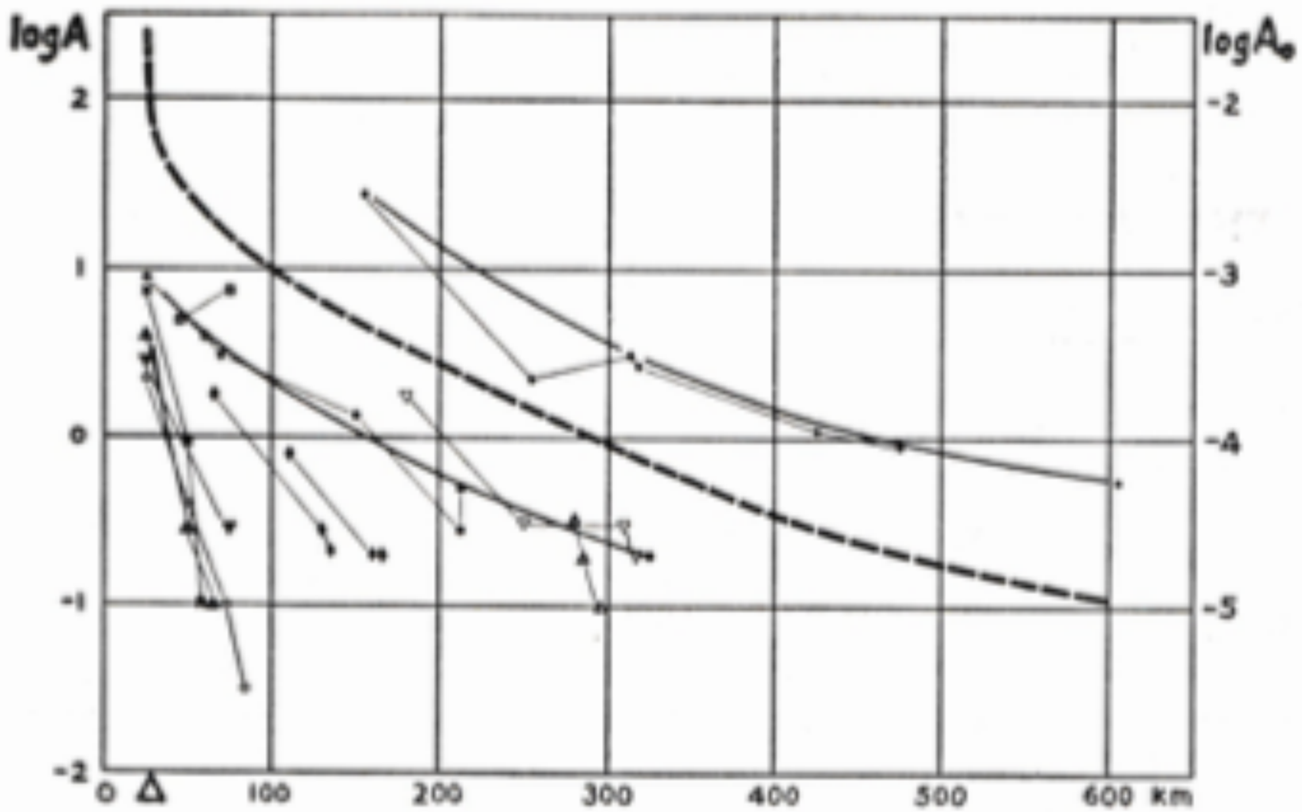
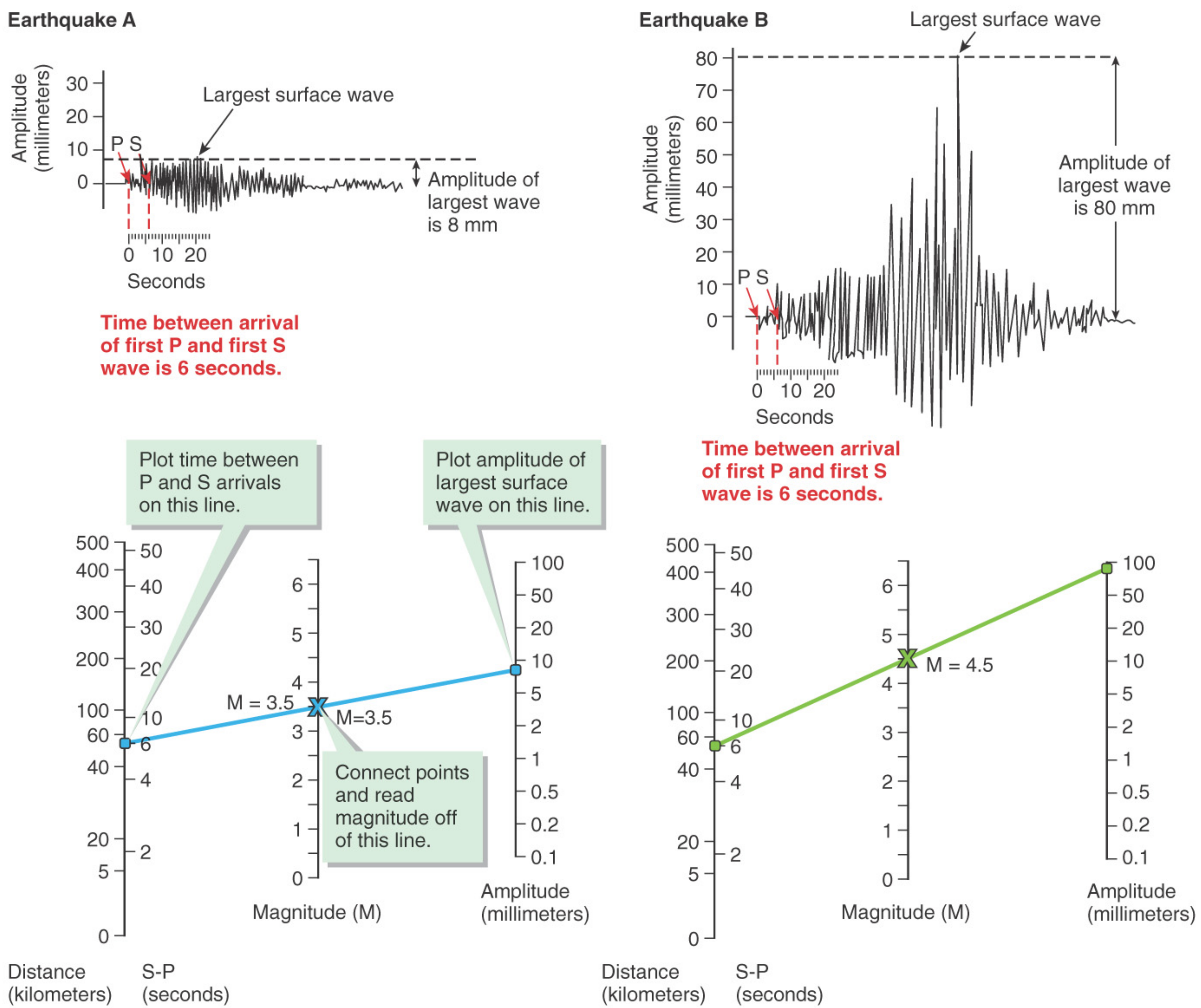


FIGURE 22-2 *Origin of the magnitude scale. Data for Southern California earthquakes of January, 1932. [Redrafted from the original notes.]*

"I found a paper by Professor K. Wadati of Japan in which he compared large earthquakes by plotting the maximum ground motion against distance to the epicenter. I tried a similar procedure for our stations, but the range between the largest and smallest magnitudes seemed unmanageably large. Dr. Beno Gutenberg then made the natural suggestion to plot the amplitudes logarithmically. I was lucky because **logarithmic plots are a device of the devil**. I saw that I could now rank the earthquakes one above the other. Also, quite unexpectedly the attenuation curves were roughly parallel on the plot. By moving them vertically, a representative mean curve could be formed, and individual events were then characterized by individual logarithmic differences from the standard curve. This set of logarithmic differences thus became the numbers on a new instrumental scale. Very perceptively, Mr. Wood insisted that this new quantity should be given a distinctive name to contrast it with the intensity scale. My amateur interest in astronomy brought out the term "magnitude," which is used for the brightness of a star."

Charles F. Richter - An Interview by Henry Spall, Earthquake Information Bulletin. Vol. 12, No. 1, January - February, 1980



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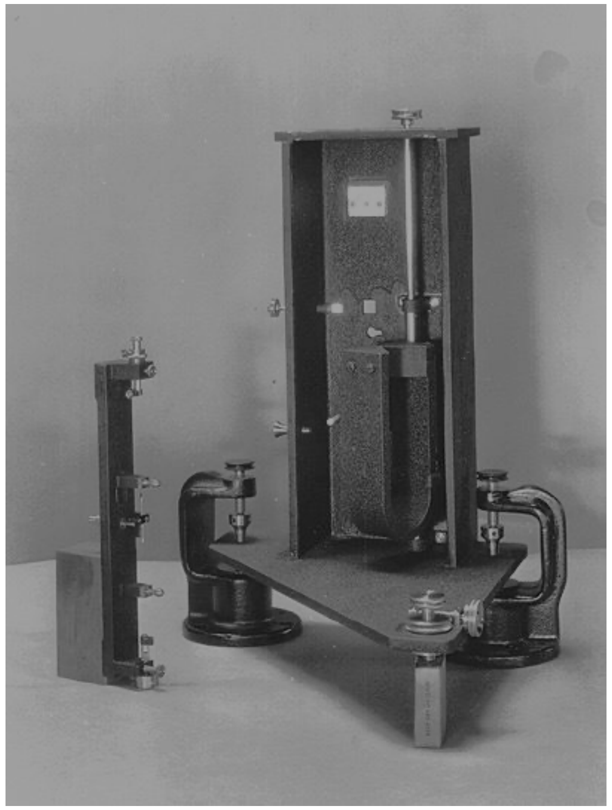
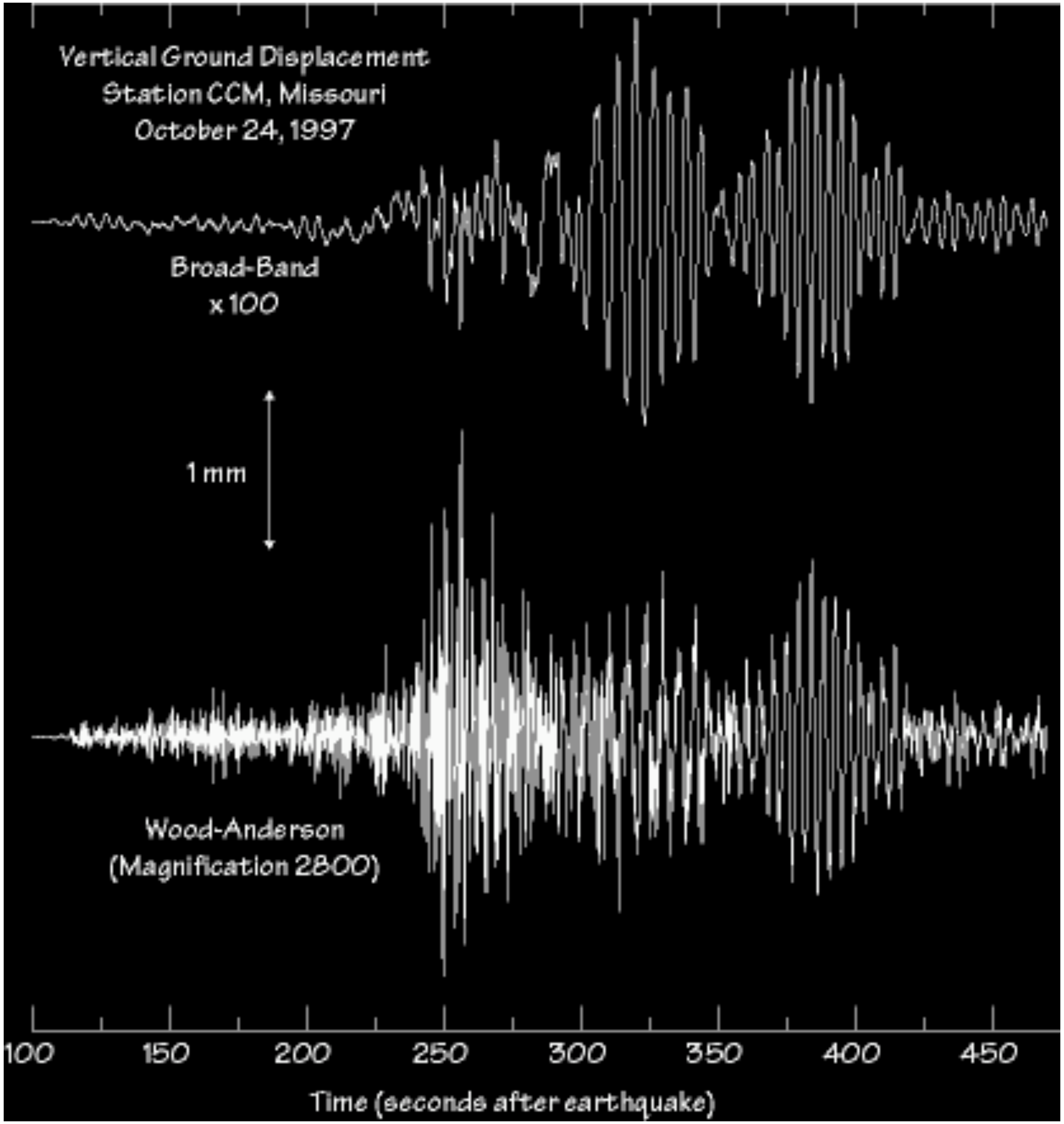
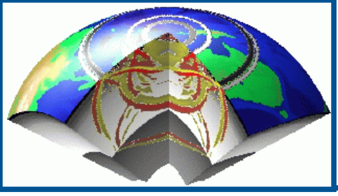
EQ size

Wood-Anderson Seismometer

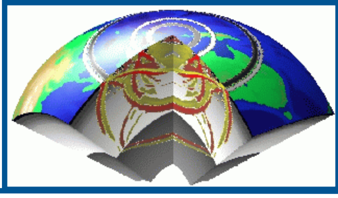
Richter also tied his formula to a specific seismic instrument







Mercalli Intensity and Richter Magnitude



Magnitude	Intensity	Description
1.0-3.0 Micro	I	**I.** Not felt except by a very few under especially favorable conditions.
3.0 - 3.9 Minor	II - III	**II.** Felt only by a few persons at rest, especially on upper floors of buildings. **III.** Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
4.0 - 4.9 Light	IV - V	**IV.** Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably. **V.** Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
5.0 - 5.9 Moderate	VI - VII	**VI.** Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight. **VII.** Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
6.0 - 6.9 Strong	VII - IX	**VIII**. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. **IX.** Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
7.0 and higher Major great	VIII or higher	**X.** Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent. **XI.** Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly. **XII.** Damage total. Lines of sight and level are distorted. Objects thrown into the air.

EQ size

Richter's Magnitude Scale

- Only valid for Southern California earthquakes
- Only valid for one specific type of seismometer
- Has not been used by professional seismologists in decades
- Is much abused by the press today

“Modern” Seismic Magnitudes

- Today seismologists use different seismic waves to compute magnitudes
- These waves have lower frequencies than those used by Richter
- These waves are generally recorded at distances of 1000s of kilometers instead of the 100s of kilometers for the Richter scale

Magnitude Scales

The original M_L is suitable for the classification of local shocks in Southern California only since it used data from the standardized short-period Wood-Anderson seismometer network. The magnitude concept has then been extended so as to be applicable also to ground motion measurements from medium- and long-period seismographic recordings of both surface waves (M_s) and different types of body waves (m_b) in the teleseismic distance range.

The general form of all magnitude scales based on measurements of ground displacement amplitudes A and periods T is:

$$M = \log\left(\frac{A}{T}\right) + f(\Delta, h) + C_r + C_s$$

M seismic magnitude
A amplitude
T period
f correction for distance and depth
C_s correction for site
C_r correction for source region

M_L **Local magnitude**

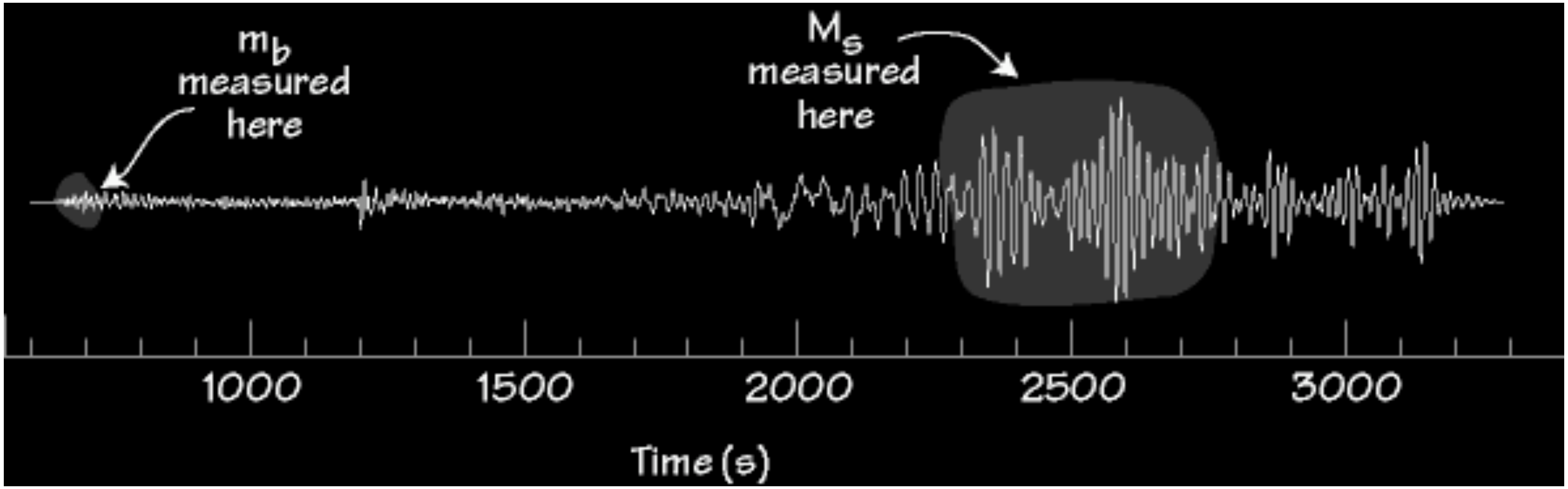
m_b **body-wave magnitude** (1s)

M_s **surface wave magnitude** (20s)

Teleseismic M_S and mb

The two most common modern magnitude scales are:

- M_S, Surface-wave magnitude (Rayleigh Wave, 20s)
- m_b, Body-wave magnitude (P-wave)



Magnitude Discrepancies

Ideally, you want the same value of magnitude for any one earthquake from each scale you develop, i.e.

$M_S = m_b = M_L$

But this does not always happen:

Turkey 8/17/99: $M_S = 7.8$, $m_b = 6.3$

Taiwan 9/20/99: $M_S = 7.7$, $m_b = 6.6$

Why Don't Magnitude Scales Agree?

Simplest Answer:

- Earthquakes are complicated physical phenomena that are not well described by a single number.

- Can a thunderstorm be well described by one number ? (No. It takes wind speed, rainfall, lightning strikes, spatial area, etc.)

Why Don't Magnitude Scales Agree?

More Complicated Answers:

- The distance correction for amplitudes depends on geology.
- Deep earthquakes do not generate large surface waves - M_S is biased low for deep earthquakes.
- Some earthquakes last longer than others, even though the peak amplitude is the same.

Why Don't Magnitude Scales Agree?

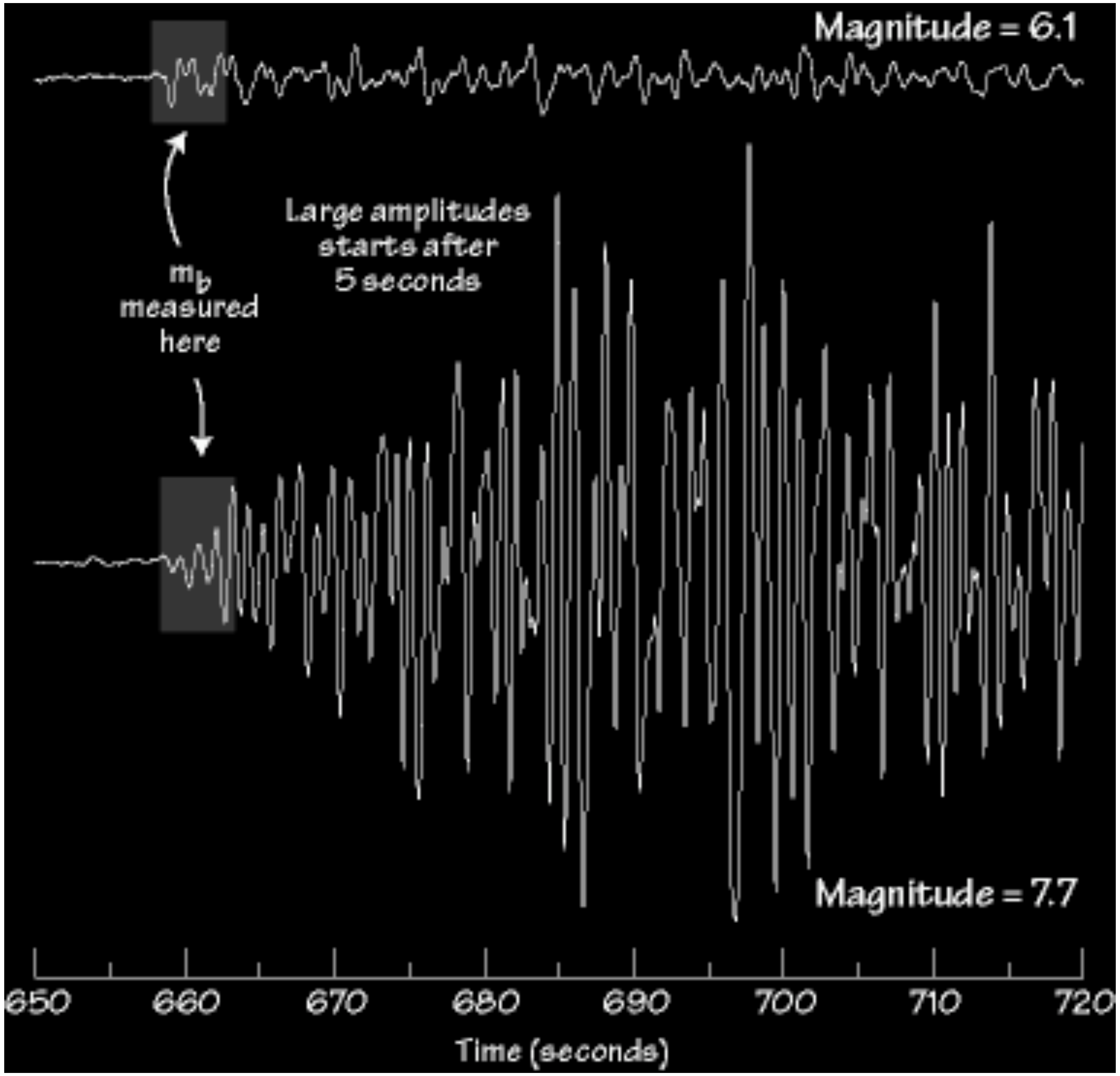
Most complicated reason:

- Magnitude scales **saturate**
- This means there is an upper limit to magnitude no matter how "large" the earthquake is
- For instance M_s (surface wave magnitude) never gets above 8.2–8.3

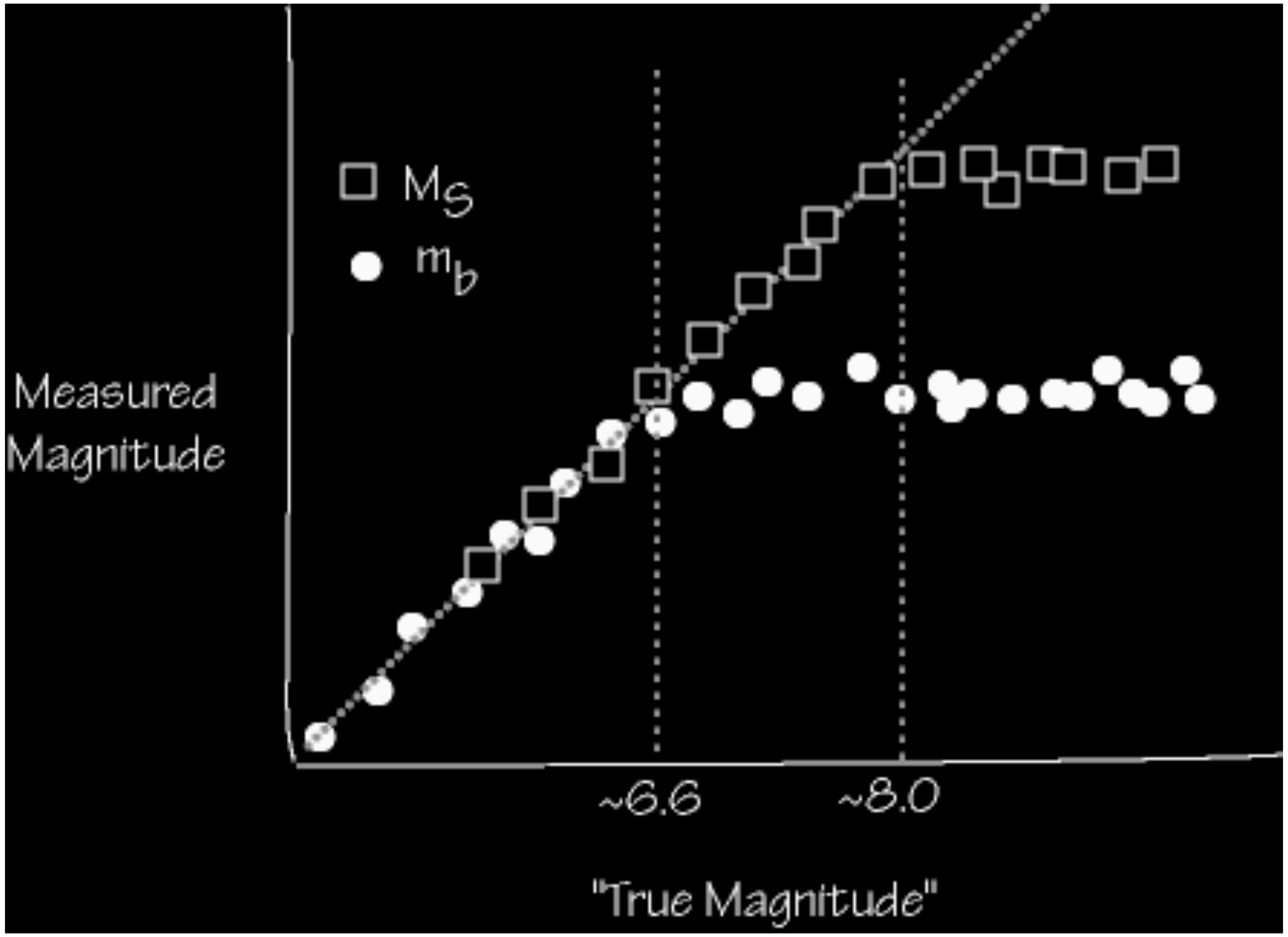
Example: mb "Saturation"

m_b seldom gives values above 6.7 – it "saturates".

m_b must be measured in the first 5 seconds – that's the rule.



Saturation

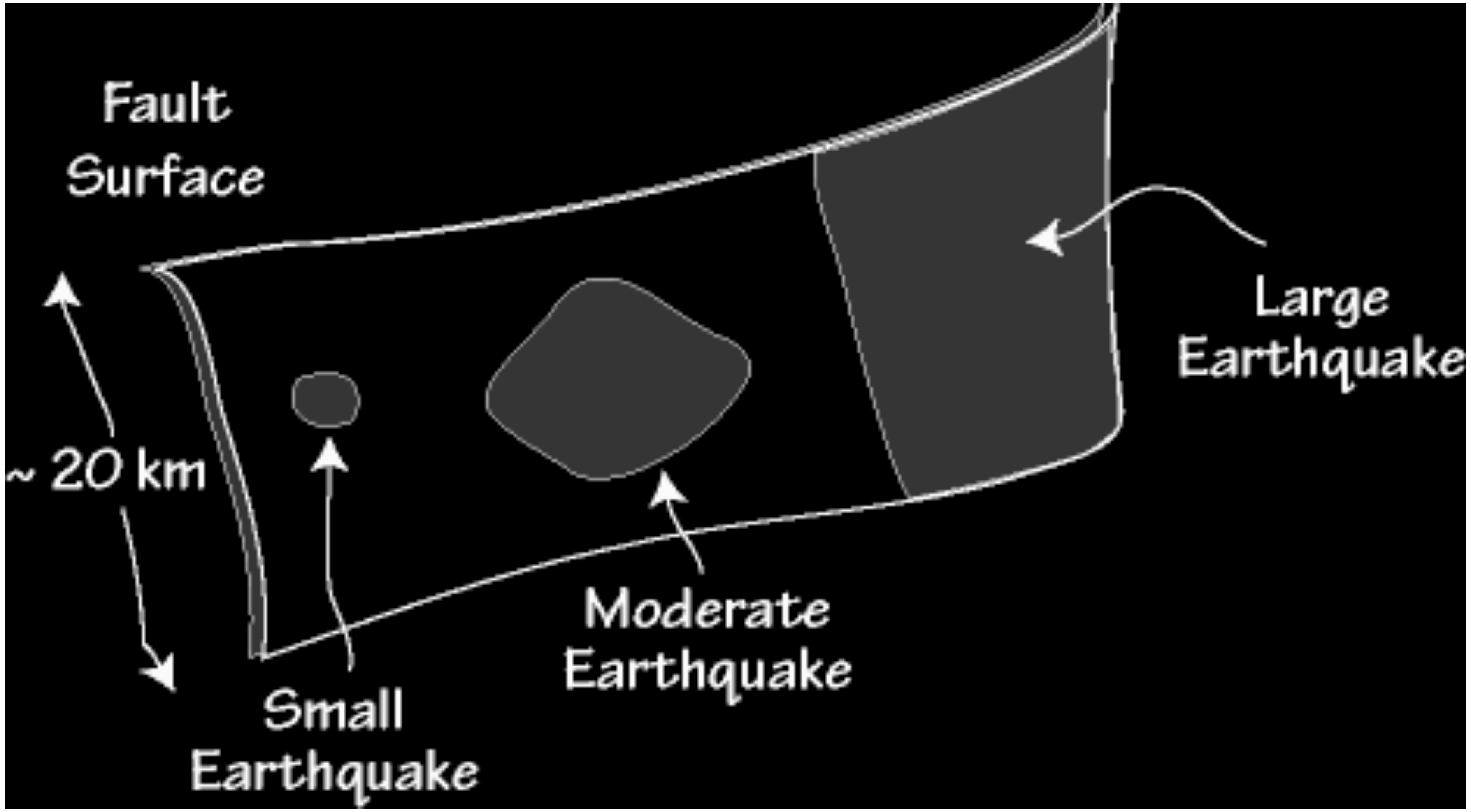


What Causes Saturation?

The rupture process.

Small earthquakes rupture small areas and are relatively enriched in short period signals.

Large earthquakes rupture large areas and are relatively depleted in high frequencies.



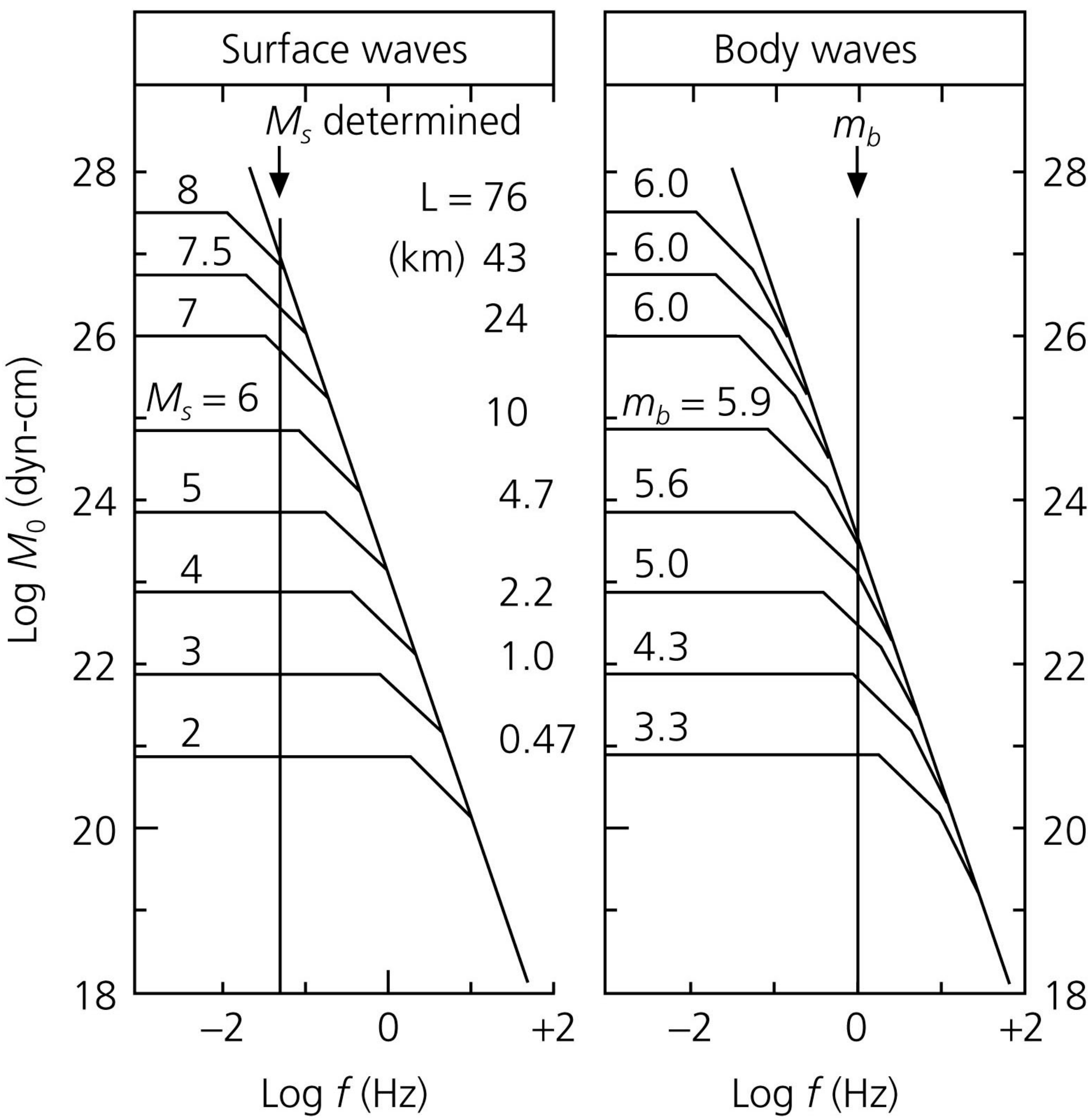
Are m_b and M_s still useful?

YES!

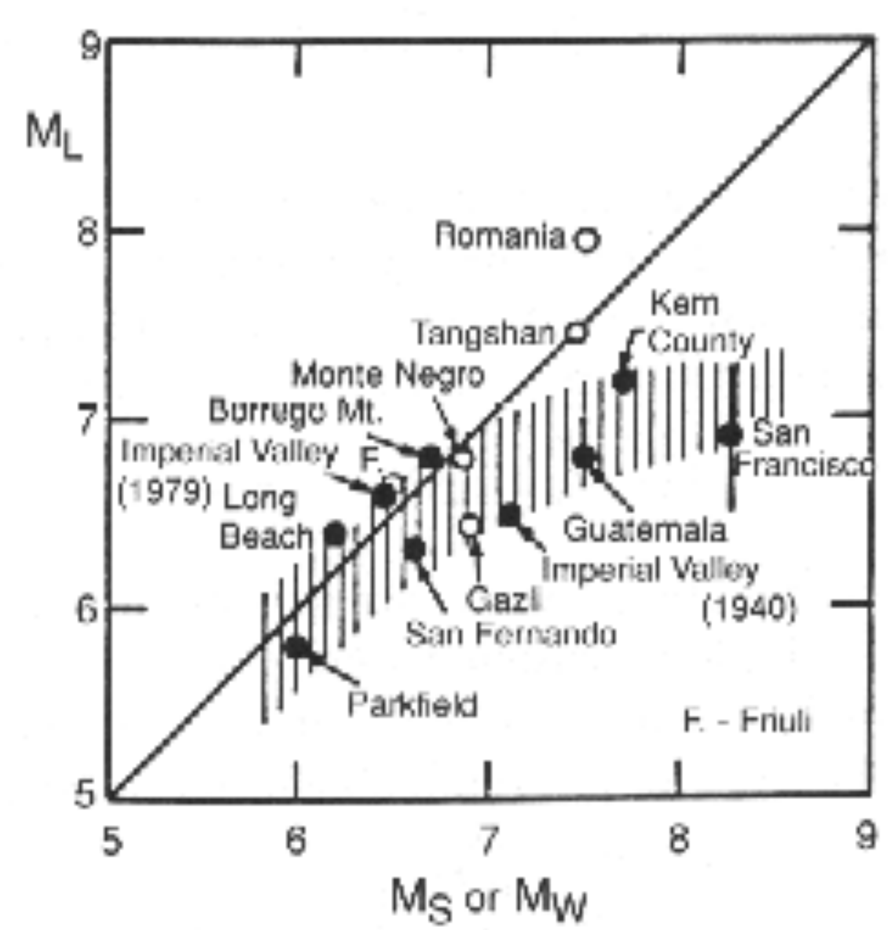
- Many (most) earthquakes are small enough that saturation does not occur
- Empirical relations between energy release and m_b and M_s exist
- The ratio of m_b to M_s can indicate whether a given seismogram is from an earthquake or a nuclear explosion (verification seismology)

Magnitude saturation

There is no a-priory scale limitation or classification of magnitudes as for macroseismic intensities. In fact, nature limits the maximum size of tectonic earthquakes which is controlled by the maximum size of a brittle fracture in the lithosphere. A simple seismic shear source with linear rupture propagation has a typical "source spectrum".



Ms is not linearly scaled with Mo for Ms > 6 due to the beginning of the so-called saturation effect for spectral amplitudes with frequencies f > fc. This saturation occurs already much earlier for mb which are determined from amplitude measurements around 1 Hz.



Moment magnitude

Empirical studies (Gutenberg & Richter, 1956; Kanamori & Anderson, 1975) lead to a formula for the released seismic energy (in Joule), and for moment, with magnitude:

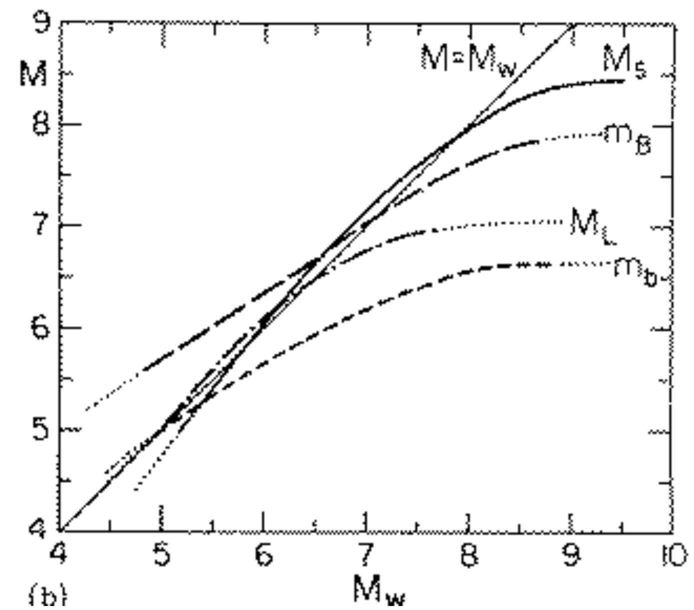
$$\log E = 4.8 + 1.5 M_s \quad \log M_0 = 9.1 + 1.5 M_s$$

resulting in

$$M_w = (2/3)\log M_0 - 6.07$$

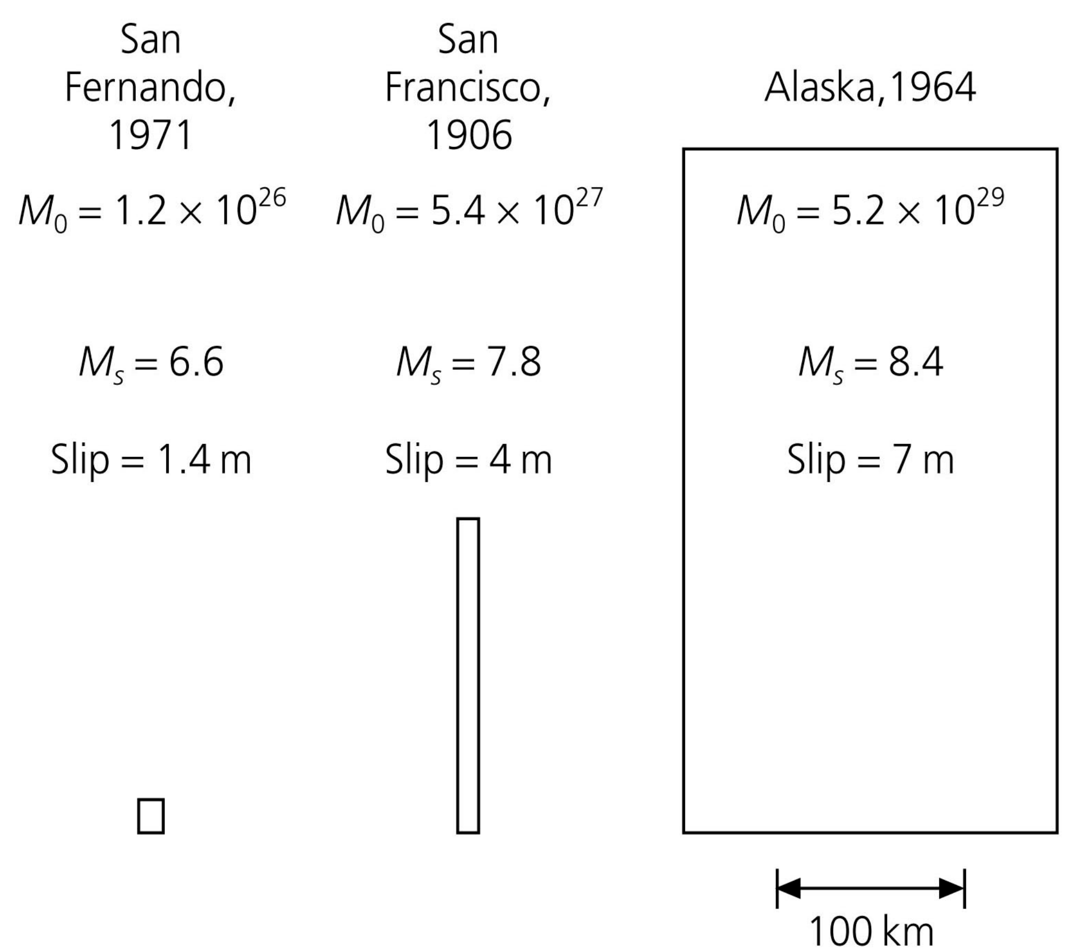
when the Moment is measured in N·m (otherwise the intercept becomes 10.73);

it is related to the final static displacement after an earthquake and consequently to the tectonic effects of an earthquake.



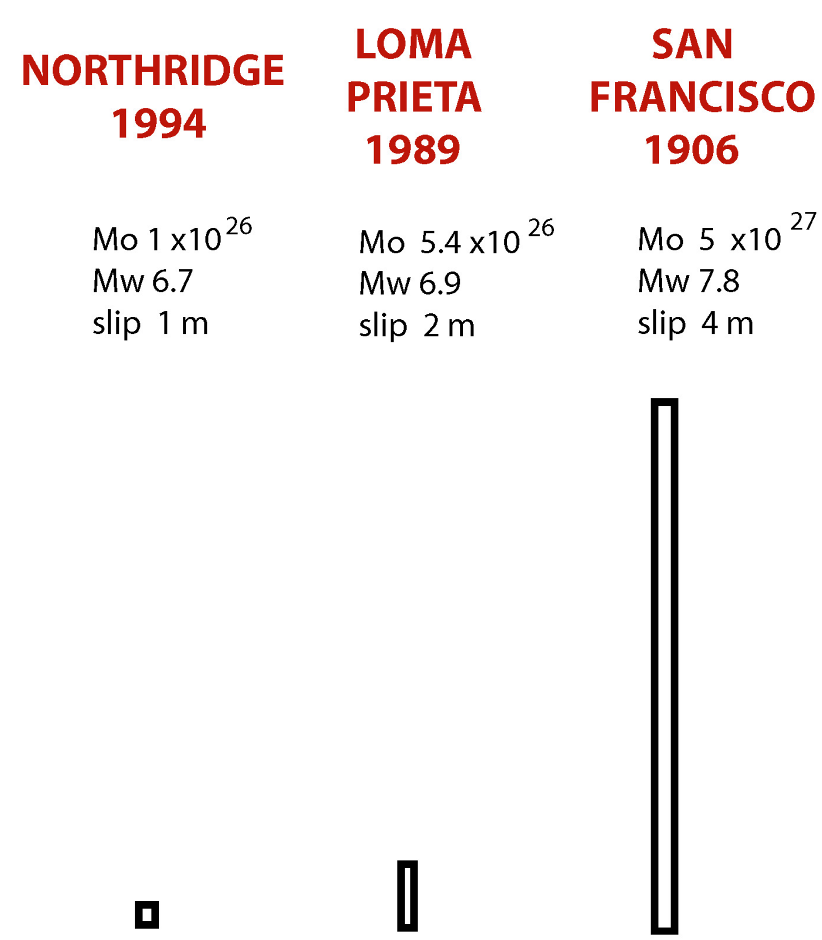
Earthquake	Body wave magnitude m_b	Surface wave magnitude M_s	Fault area (km^2) length × width	Average dislocation (m)	Moment (dyn-cm) M_0	Moment magnitude M_w
Truckee, 1966	5.4	5.9	10 × 10	0.3	8.3×10^{24}	5.8
San Fernando, 1971	6.2	6.6	20 × 14	1.4	1.2×10^{26}	6.7
Loma Prieta, 1989	6.2	7.1	40 × 15	1.7	3.0×10^{26}	6.9
San Francisco, 1906		8.2	320 × 15	4	6.0×10^{27}	7.8
Alaska, 1964	6.2	8.4	500 × 300	7	5.2×10^{29}	9.1
Chile, 1960		8.3	800 × 200	21	2.4×10^{30}	9.5

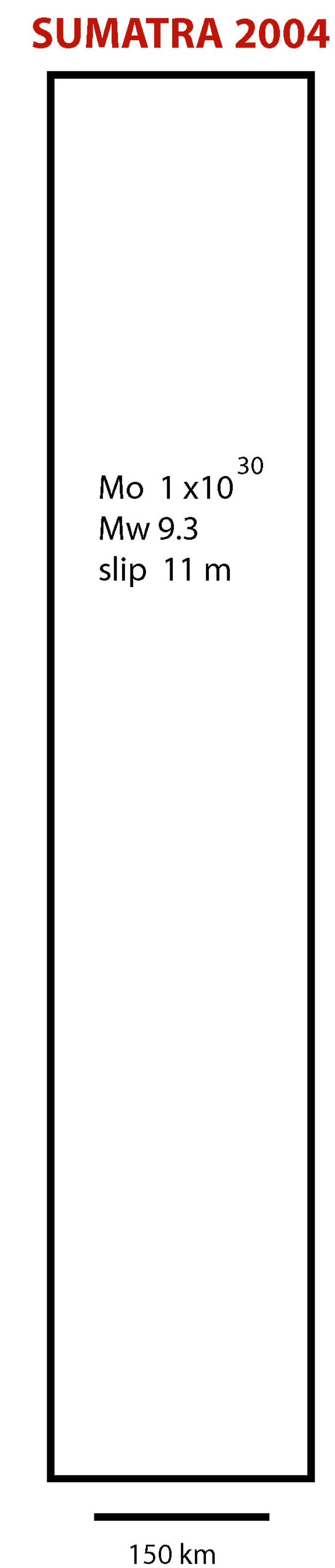
Moment, Magnitude and area



SEISMIC MOMENT Mo = fault area * slip * rigidity (dyn-cm)

MOMENT MAGNITUDE Mw = log Mo /1.5 - 10.73





The Largest Earthquakes