Basic Seismology

The Size of an Earthquake – Intensity and Magnitude

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The Size of an Earthquake

Robert Mallet

The first scientific field study of the effects of a great earthquake was conducted by an Irish man, **Robert Mallet**, who was recognized as the first true seismologist.

In his assessment of the effects of the Neapolitan Earthquake of 1857 in southern Italy, Mallet was using the oldest instruments in the world: his eyes, a compass and a measuring stick.

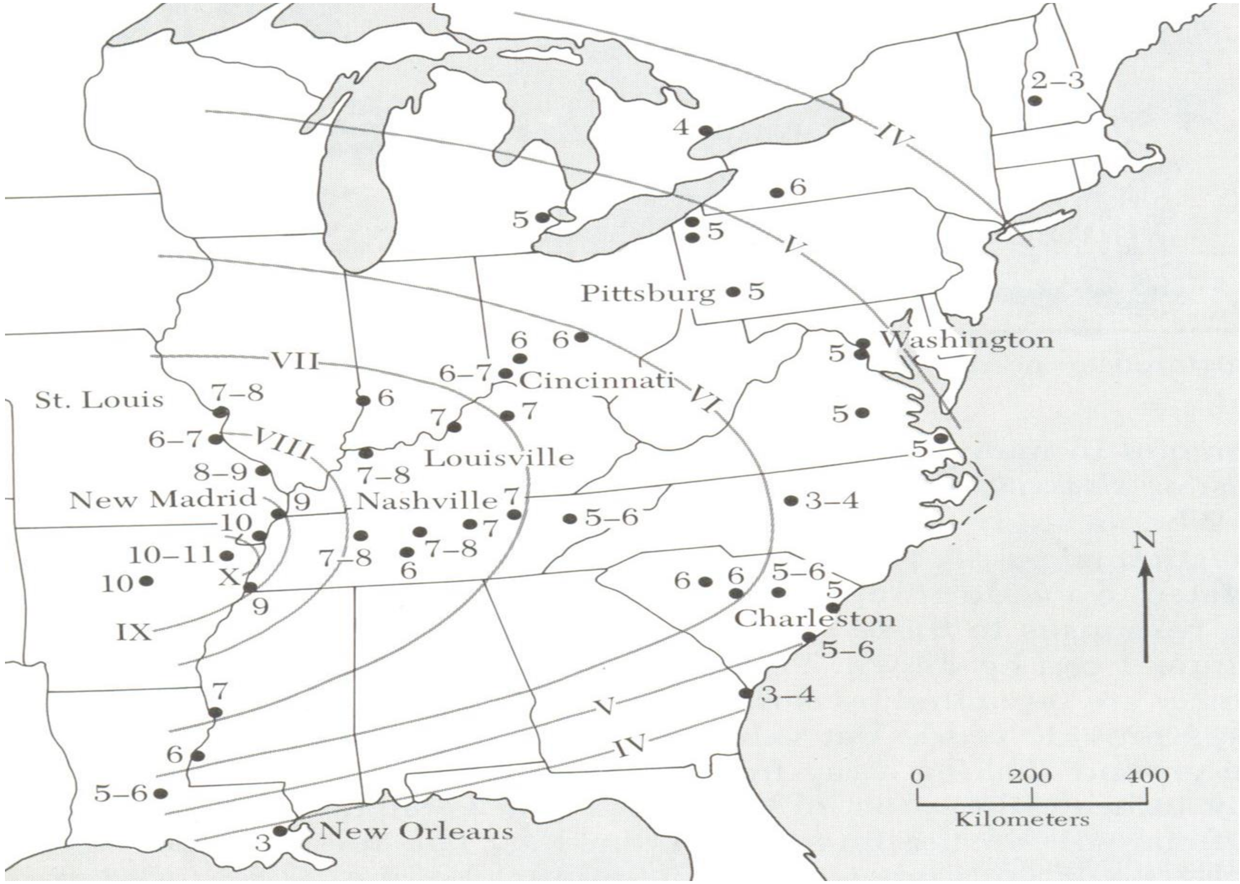
Mallet's method included detailed mapping and tabulation of felt reports and damage to buildings and geological movements.

In this way he was able to measure the strength and distribution of the earthquake ground motion.

The Size of an Earthquake

By drawing lines on a map between places of equal damage or of equal intensity (**isoseismal lines**), he determined the center of the earthquake shaking (the epicenter). Such maps are now called **isoseismal maps.**

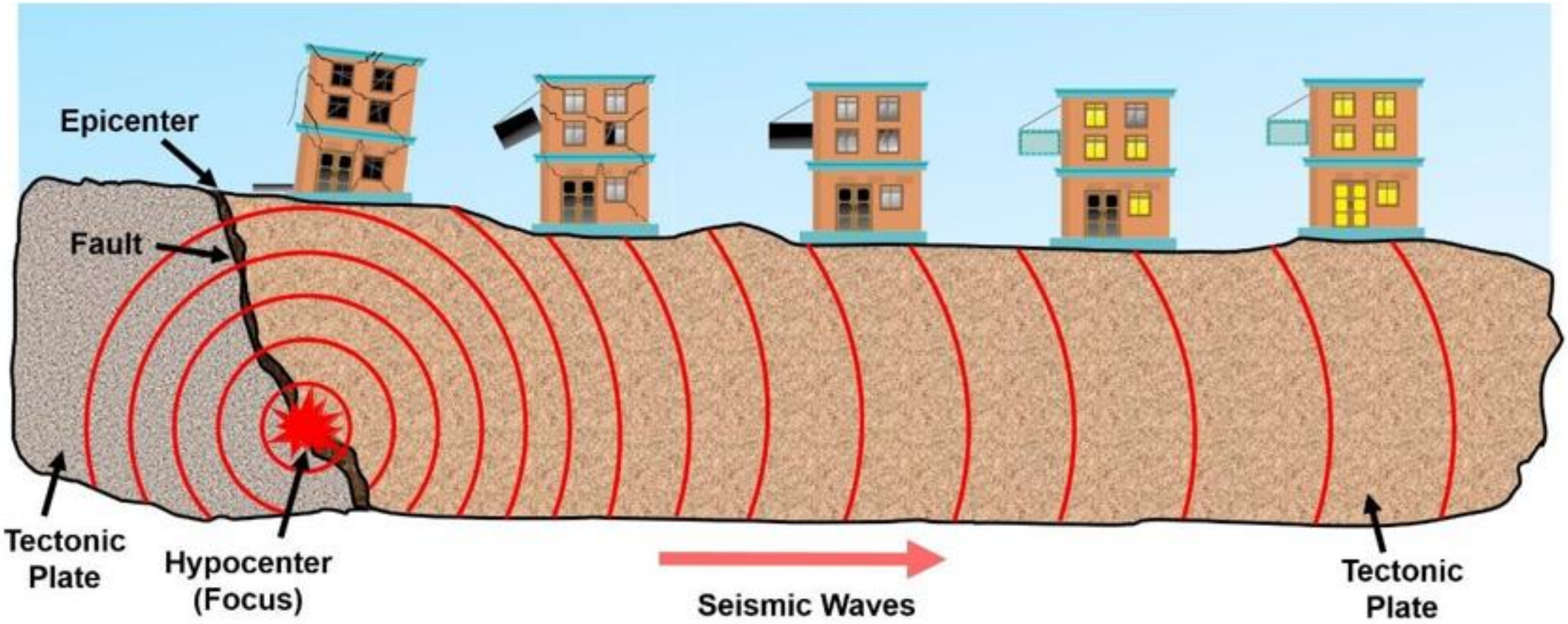
Isoseismal map of the 1811 New Madrid, Missouri, earthquake (MMI scale)



Intensity is measured by means of *the degree of damage to structures of human origin, the amount of disturbances to the surface of the ground, and the extent of animal and human reaction to the shaking, not by measuring the ground motion with instruments.*

Mallet used 4 degrees of intensity to prepare his isoseismal map.

The patterns of isoseismal lines also indicated to Mallet the rate at which the shaking effects diminished with distance and provide him with an estimate of the relative size of the earthquake.



Felt Intensity	X+	IX	VIII	VII	VI	V	IV	II-III	I
Damage	Very Heavy	Heavy	Moderate to Heavy	Moderate	Light	Very Light	None	None	None
Shaking	Extreme	Violent	Sever	Very Strong	Strong	Moderate	Light	Weak	Not Felt

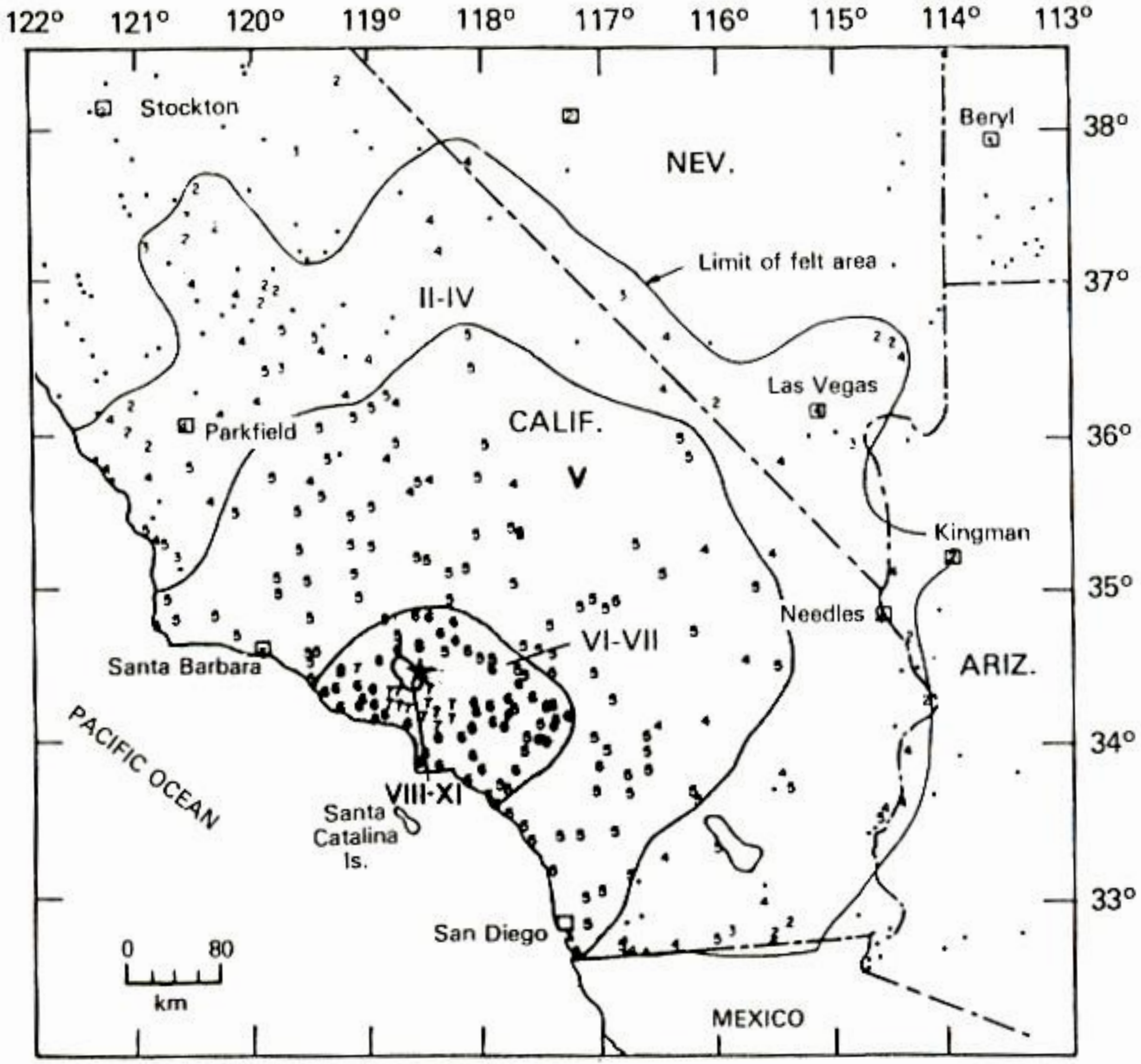


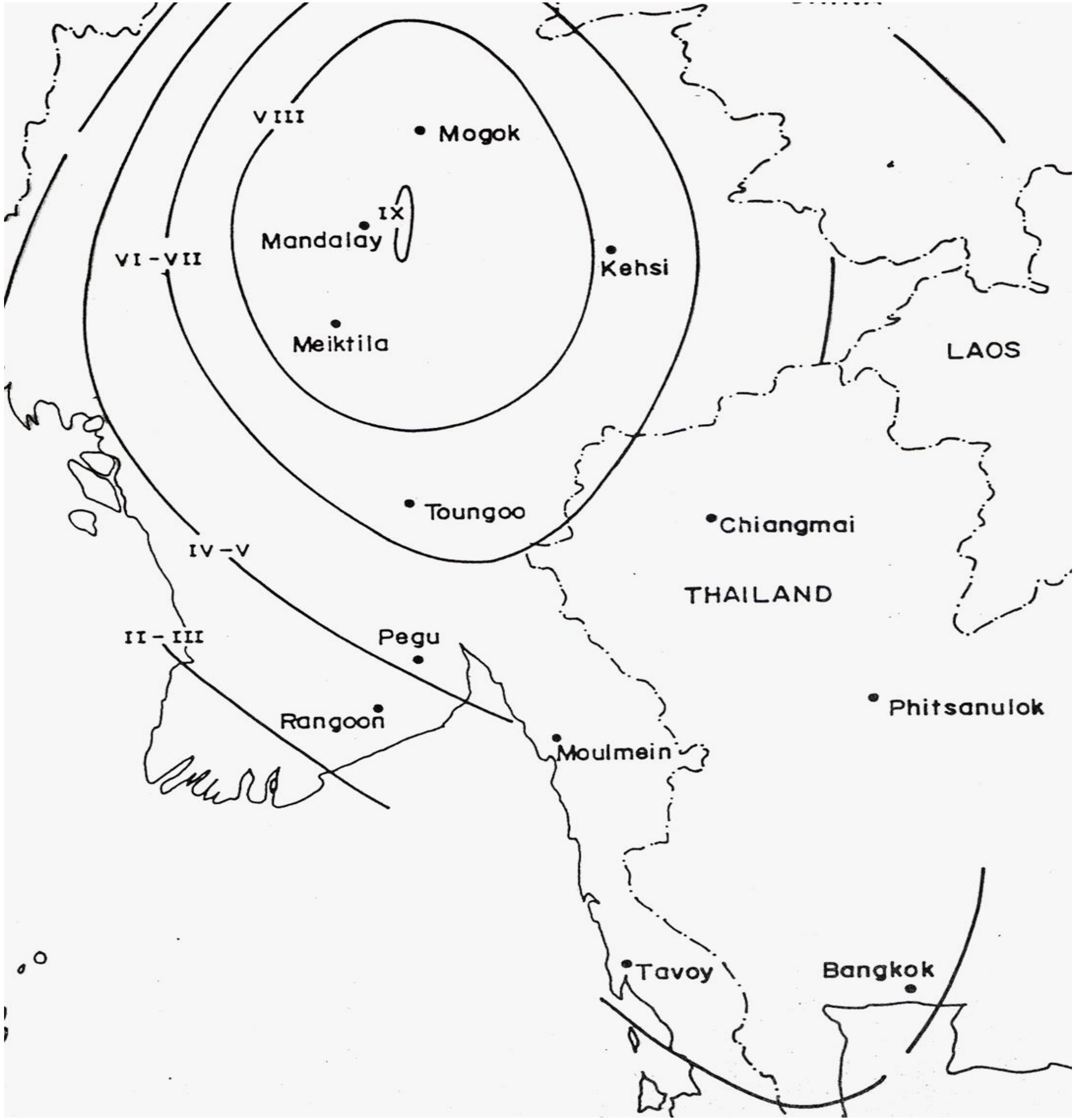
FIGURE 3.2 Generalized isoseismal map of the February 9, 1971 San Fernando, California earthquake. The epicenter is shown as a star. Roman numerals represent Modified Mercalli intensities between isoseismals. Arabic numerals represent Modified Mercalli intensities at specific cities. Dots represent locations where it was reported that the earthquake was not felt (after Coffman and Angel 1983).

Intensity Scale

- The first intensity scale of modern times was developed by M. S. de Rossi of Italy and Francois Forel of Switzerland in the 1880s. It was called the
- **Rossi-Forel Intensity Scale (I — X).**
- A more refined scale, with 12 values, was constructed in 1902 by the Italian seismologist and volcanologist **G. Mercalli.**
- A modified version of it, called the **Modified Mercalli Intensity (MMI) Scale**, was developed by H. O. Wood and Frank Neumann to fit construction conditions in California (and most of the United States).

- Alternative intensity scales have been developed and are widely used in other countries, notably in Japan (**the JMA Intensity Scale**) and the central and eastern European countries (**the Medvedev-Sponheuer-Karnik (MSK) Intensity Scale**), where conditions differ from those in California.

Isoseismal Map of the Mandalay earthquake of 23 May 1912 (after Brown, 1914)



Rossi-Forel Intensity Scale

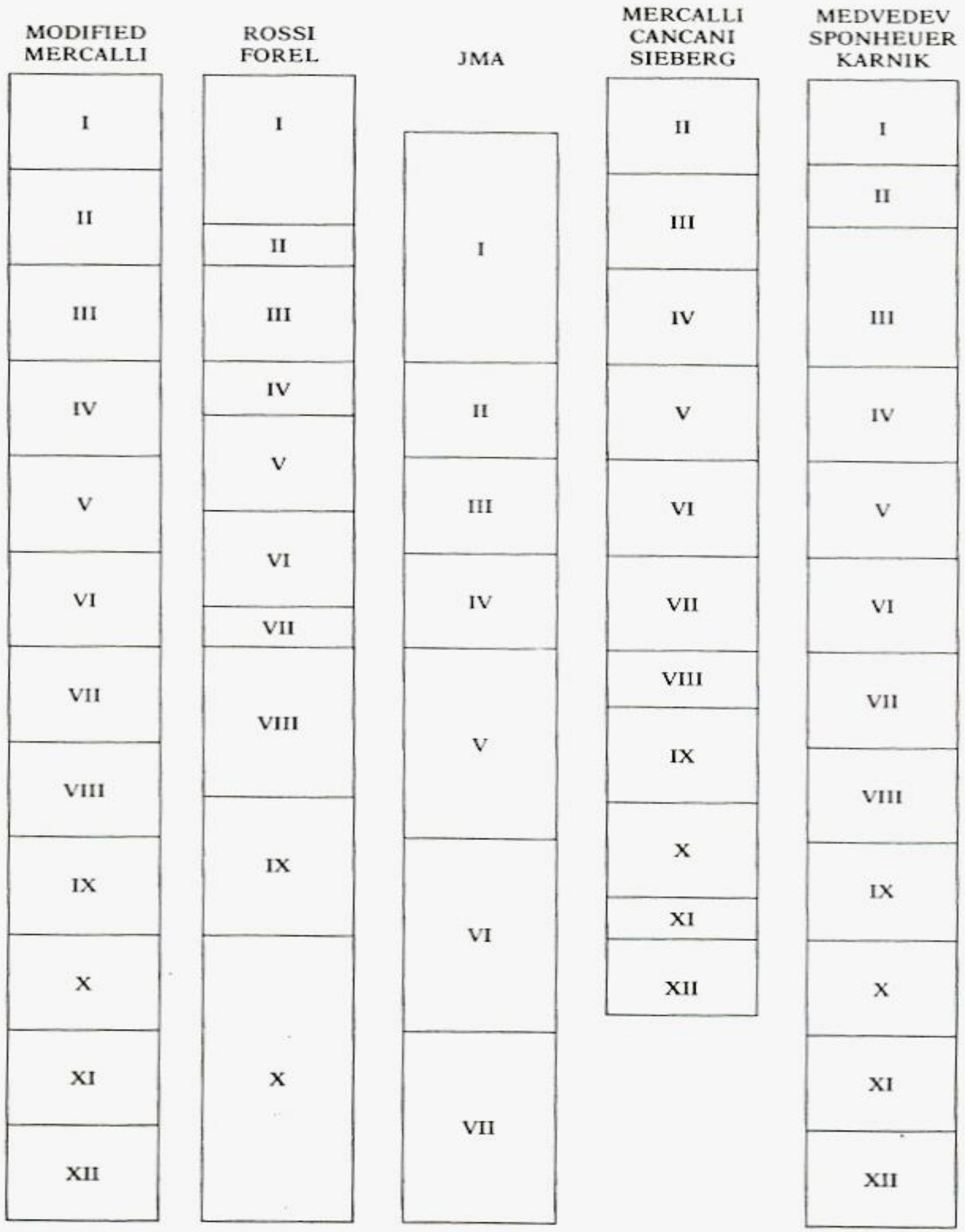
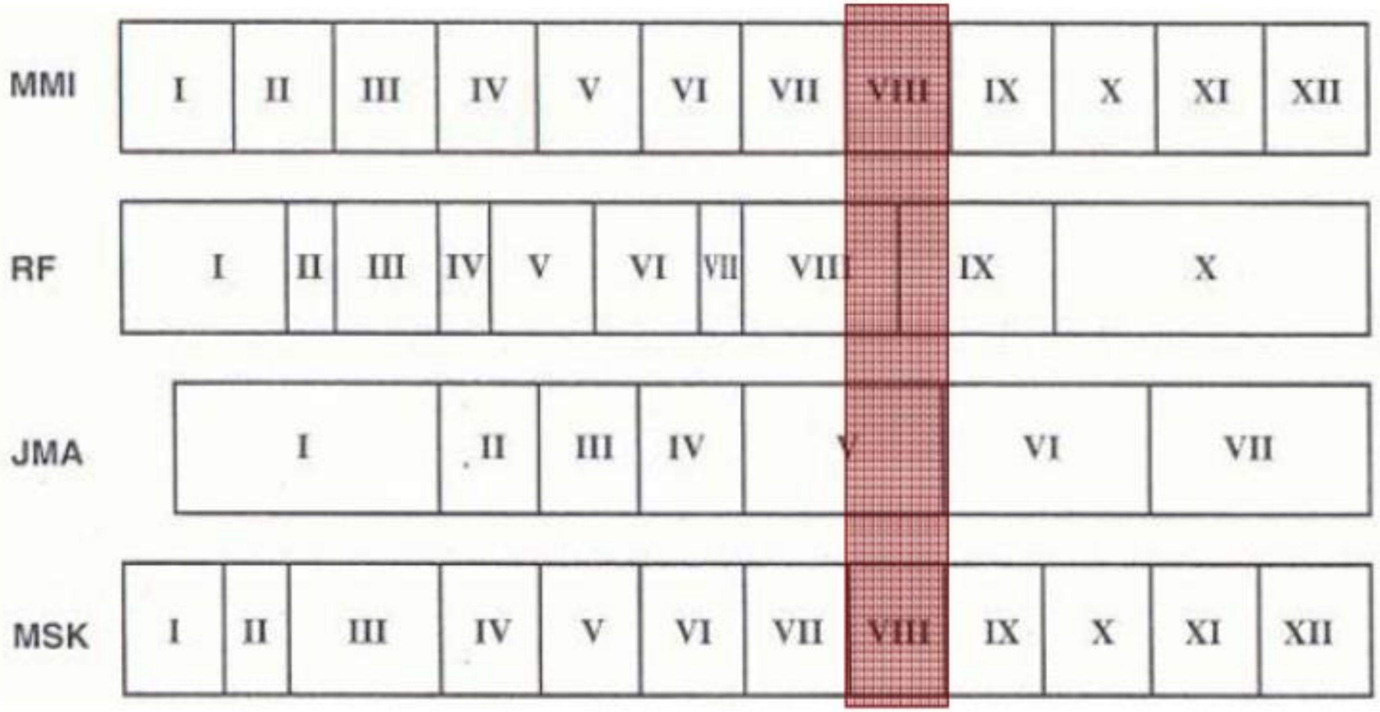
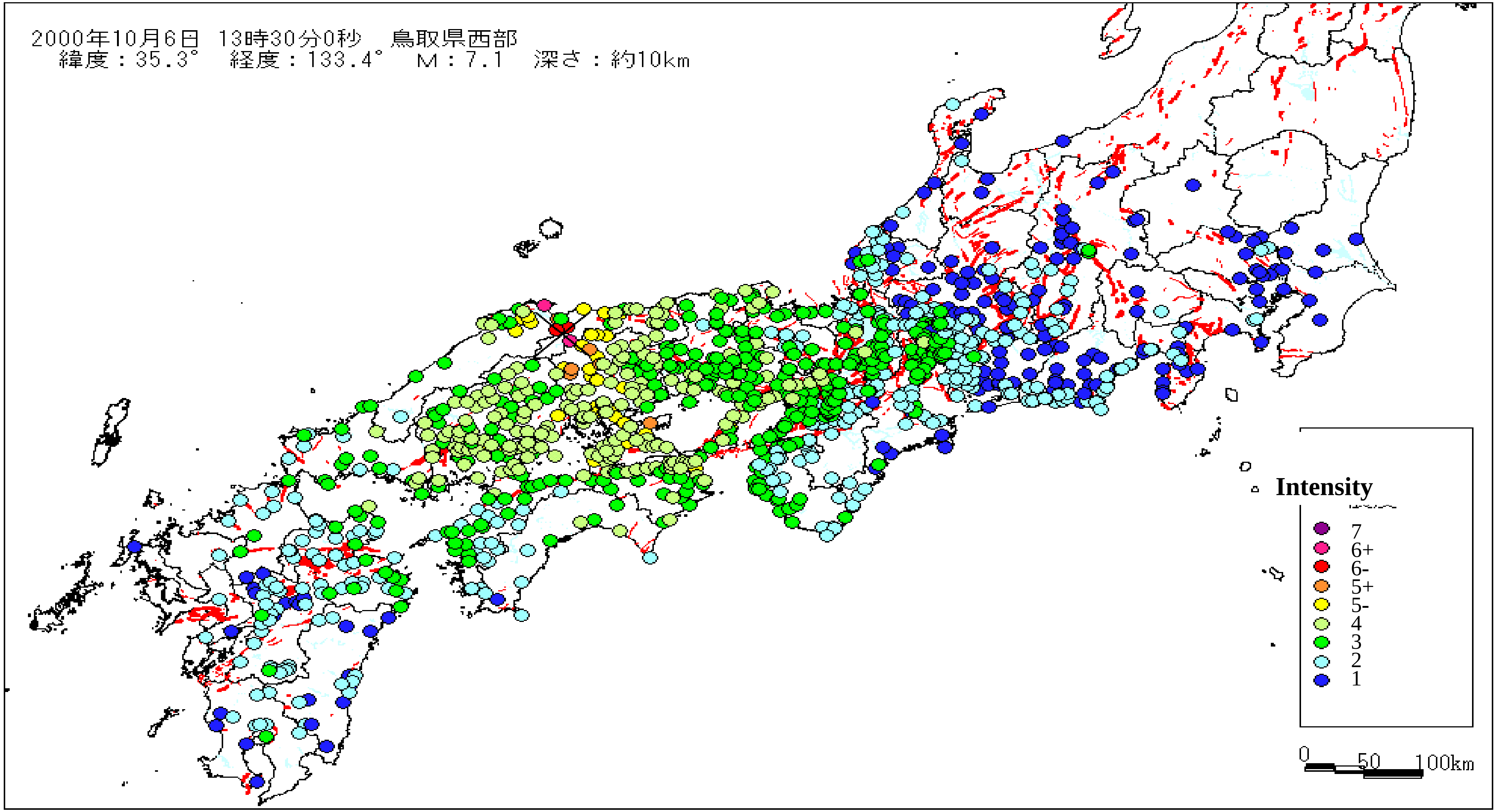


FIGURE 3.1 A comparison of seismic intensity scales (after Murphy and O'Brien 1977; and Richter,1958).

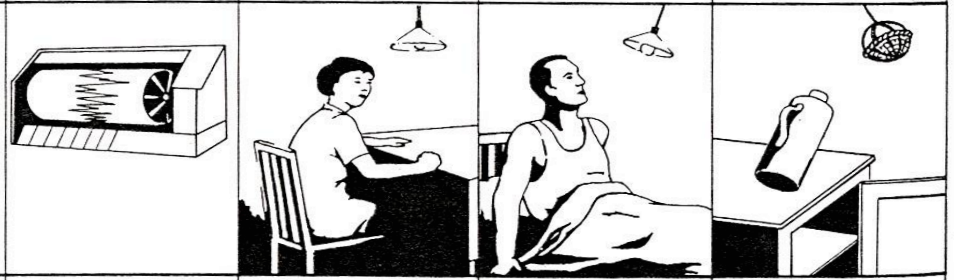
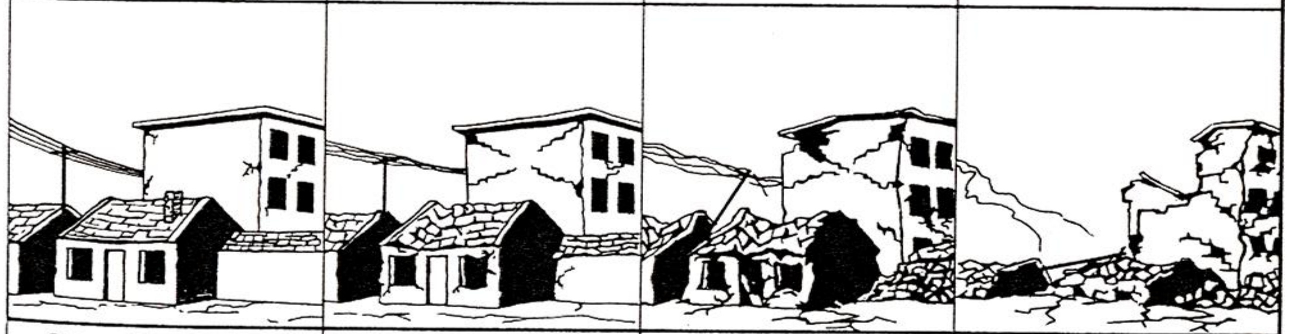
Comparison of the different intensity scales



JMA Instrumental Intensity in the 2000 Tottori EQ Measured by National Seismic Networks



Chinese Intensity Scale

Modified Mercalli scale	II	III	IV	V	V-VI	VI	VII	VIII and above
Chinese Classifi-cation	1-2	3	4-5	6	7	8	9	10 and above
								
Reaction of people and buildings.	Not felt by people generally. Just recordable by seismograph.	A few people indoors notice a slight vibration.	Sleeping persons wake. Hanging items like lamps swing.	Things indoors fall over.	Old buildings suffer considerable damage — houses generally some damage — old ones may collapse.	Many houses suffer damage. A few collapse.	Most houses damaged heavily or collapse.	Houses everywhere collapse.

Many nations use the Modified Mercalli scale of earthquake damage, but some countries employ their own. This is the Chinese version.

The Modified Mercalli Intensity Scale (Wood and Neumann, 1931)

I. Not felt—or, except rarely under especially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt: sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced; sometimes trees, structures, liquids, bodies of water, may sway—doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons. Also, as in grade I, but often more noticeably: sometimes hanging objects may swing, especially when delicately suspended; sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly; sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases. Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away. Hanging objects may swing slightly. Movements may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly.

IV. Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience. Vibration like that due to passing of heavy or heavily loaded trucks. Sensation like heavy body striking building or falling of heavy objects inside. Rattling of dishes, windows, doors; glassware and crockery clink and clash. Creaking of walls, frame, especially in the upper range of this grade. Hanging objects swung, in numerous instances. Disturbed liquids in open vessels slightly. Rocked standing motor cars noticeably.

V. Felt indoors by practically all, outdoors by many or most: outdoors direction estimated. Awakened many, or most. Frightened few—slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes, glassware, to some extent. Cracked windows—in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened, or closed, doors, shutters, abruptly. Pendulum clocks stopped, started, or ran fast, or slow. Moved small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees, bushes, shaken slightly.

VI. Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees, bushes, shaken slightly to moderately. Liquid set in strong motion. Small bells rang—church, chapel, school, etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks, chimneys in some instances. Broke dishes, glassware, in considerable quantity, also some windows. Fall of knick-knacks, books, pictures. Overturned furniture in many instances. Moved furnishings of moderately heavy kind.

VII. Frightened all—general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving motor cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amount, also some stucco. Broke numerous windows, furniture to some extent. Shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line (sometimes damaging roofs). Fall of cornices from towers and high buildings. Dislodged bricks and stones. Overturned heavy furniture, with damage from breaking. Damage considerable to concrete irrigation ditches.

VIII. Fright general—alarm approaches panic. Disturbed persons driving motor cars. Trees shaken strongly—branches, trunks, broken off, especially palm trees. Ejected sand and mud in small amounts. Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. Damage slight in structures (brick) built especially to withstand earthquakes. Considerable in ordinary substantial buildings, partial collapse: racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling. Fall of walls. Cracked, broke, solid stone walls seriously. Wet ground to some extent, also ground on steep slopes. Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers. Moved conspicuously, overturned, very heavy furniture.

IX. Panic general. Cracked ground conspicuously. Damage considerable in (masonry) structures built especially to withstand earthquakes: threw out of plumb some wood-frame houses built especially to withstand earthquakes; great in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs; underground pipes sometimes broken.

X. Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Shifted sand and mud horizontally on beaches and flat land. Changed level of water in wells. Threw water on banks of canals, lakes, rivers, etc. Damage serious to dams, dikes, embankments. Severe to well-built wooden structures and bridges, some destroyed. Developed dangerous cracks in excellent brick walls. Destroyed most masonry and frame structures, also their foundations. Bent railroad rails slightly. Tore apart, or crushed endwise, pipe lines buried in earth. Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many and widespread, varying with ground material. Broad fissures, earth slumps, and land slips in soft wet ground. Ejected water in large amounts charged with sand and mud. Caused sea-waves ("tidal" waves) of significant magnitude. Damage severe to wood-frame structures, especially near shock centers. Great to dams, dikes, embankments often for long distances. Few, if any (masonry) structures remained standing. Destroyed large well-built bridges by the wrecking of supporting piers, or pillars. Affected yielding wooden bridges less. Bent railroad rails greatly, and thrust them endwise. Put pipe lines buried in earth completely out of service.

XII. Damage total—practically all works of construction damaged greatly or destroyed. Disturbances in ground great and varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive. Wrenched loose, tore off, large rock masses. Fault slips in firm rock, with notable horizontal and vertical offset displacements. Water channels, surface and underground, disturbed and modified greatly. Dammed lakes, produced waterfalls, deflected rivers, etc. Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level. Threw objects upward into the air.

Earthquake Magnitude

- If the magnitudes of earthquakes are to be compared worldwide, a measure is needed that does not depend (as does intensity) on the density of population and type of construction.

Kiyoo Wadati

Such quantitative scale was originated in 1931 by **Kiyoo Wadati** in Japan and later on developed by **Dr. Charles Richter** in 1935 in California.

Charles Richter

- Richter defined the magnitude of an earthquake as *the logarithm to base 10 of the maximum seismic-wave amplitude (in micrometer) recorded on a standard Wood-Anderson short-period seismograph[1] at a distance of 100 km from the earthquake epicenter.*
- **Every time the magnitude goes up by 1 unit, the amplitude of the earthquake waves increases 10 times.**

[1] *The instrument has a natural period of 0.8 sec, critical damping ratio 0.8, magnification 2,800.*

Richter Magnitude Scale

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AN INSTRUMENTAL EARTHQUAKE MAGNITUDE SCALE*

By CHARLES F. RICHTER

The procedure may be interpreted to give a definition of the magnitude scale number being used, as follows: *The magnitude of any shock is taken as the logarithm of the maximum trace amplitude, expressed in microns, with which the standard short-period torsion seismometer ($T_0 = 0.8$ sec., $V = 2800$, $h = 0.8$) would register that shock at an epicentral distance of 100 kilometers.*

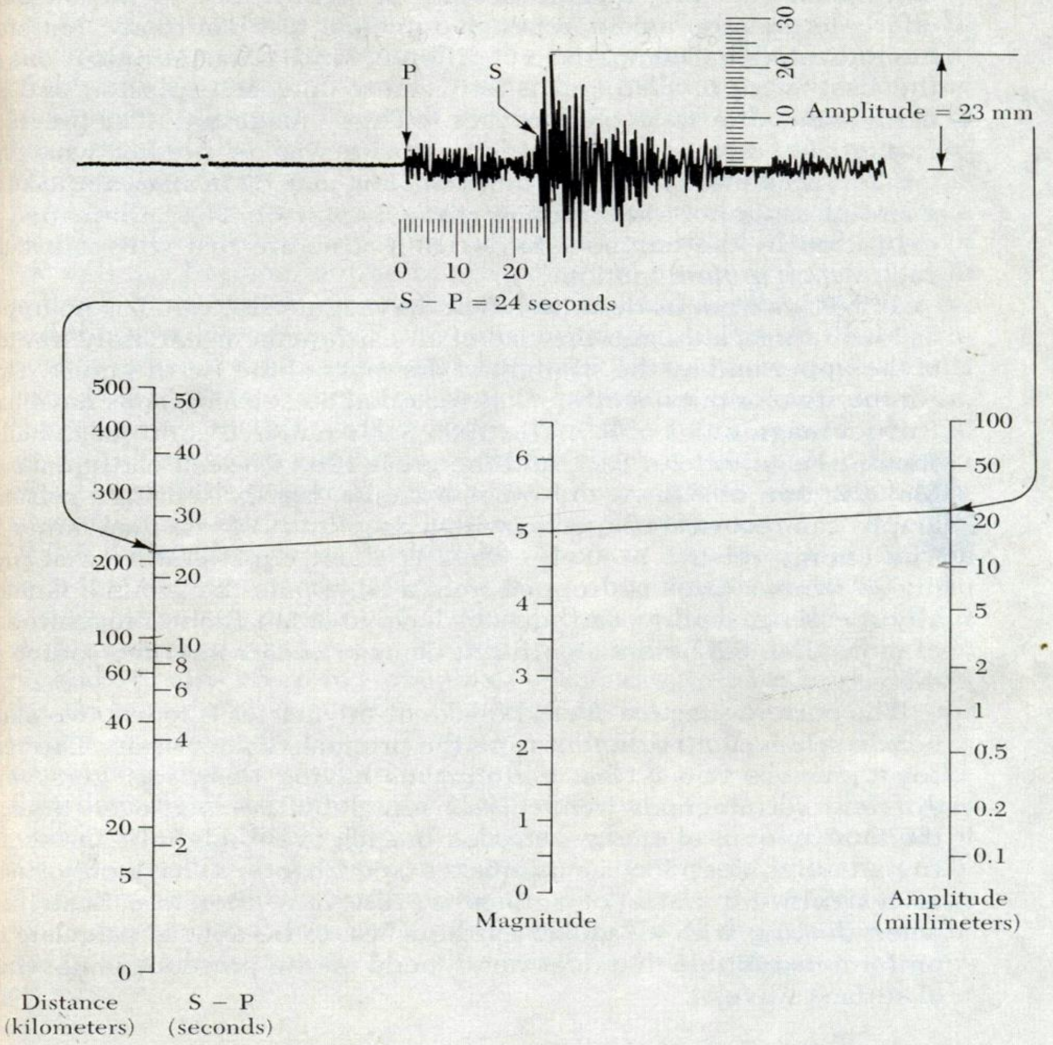
Charles Richter

Earthquake Magnitude

At first the scale was intended to deal with Californian earthquakes only, but with the cooperation of **Professor Beno Gutenberg** the scale was adapted to enable earthquakes to be classified worldwide.

The Richter magnitude scale is also called **Local Magnitude (M_L).**

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



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 $M_L = 5.0$.

Earthquake Magnitude

- At the present time there are several magnitude scales. The most used magnitude scales are **surface-wave magnitude (M_s), body-wave magnitude (m_b), and moment magnitude (M_w).**

- **M_s** is a world-wide scale determined from the maximum amplitude of Rayleigh waves with a period of about 20 seconds (between 18 s and 22 s) on a standard long-period seismograph[1]. It is most widely used magnitude scale for large damaging shallow earthquakes (less than 70 km deep).

- It was developed in 1950s by the same researchers who developed **M_L** (Gutenberg and Richter) in order to improve resolution on larger earthquakes.

- **m_b** is a world-wide scale determined from the maximum amplitude of the first few cycles of the P wave motion observed on the vertical component of seismogram. The waves measured typically have a period of about 1 second. It is widely used for characterizing deep earthquakes.

[1] *The instrument has a natural period of 15 sec.*

Saturation of Earthquake Magnitude

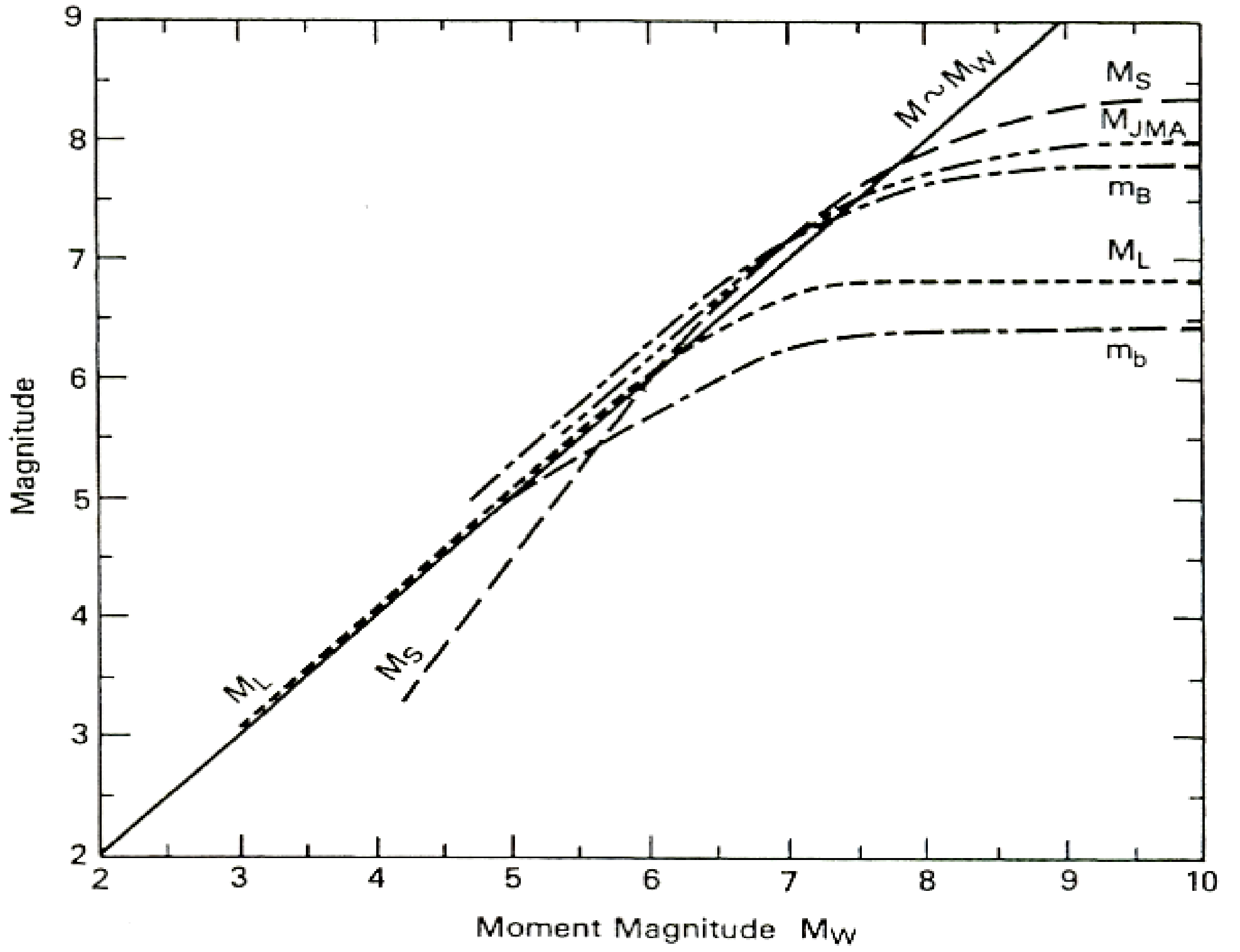


FIGURE 2.4 A comparison of moment magnitude with other magnitude scales (after Heaton, Tajima and Mori 1986).

It must be noted that most magnitude scales saturate, or stop increasing with increasing earthquake size.

This occurs because each magnitude scale is determined using a seismic wave of a particular period and wave length, which **at a certain level does not increase in amplitude as the earthquake source size and energy release increase**.

Moment Magnitude

- A more reliable and robust magnitude scale is moment magnitude (**M_w**). It was introduced by Hanks and Kanamori in 1979. It is based on the seismic moment (M_o), which is a measure of the whole dimension of the slipped fault:

$$M_W = (2/3).(\log_{10} M_o - 10.7)$$

Where M_o is seismic moment (in N.m). Geologically M_o is a description of the extent of deformation at the earthquake source. It is simply defined as:

$$M_o = \mu A D = 2 \mu E_S / Ds$$

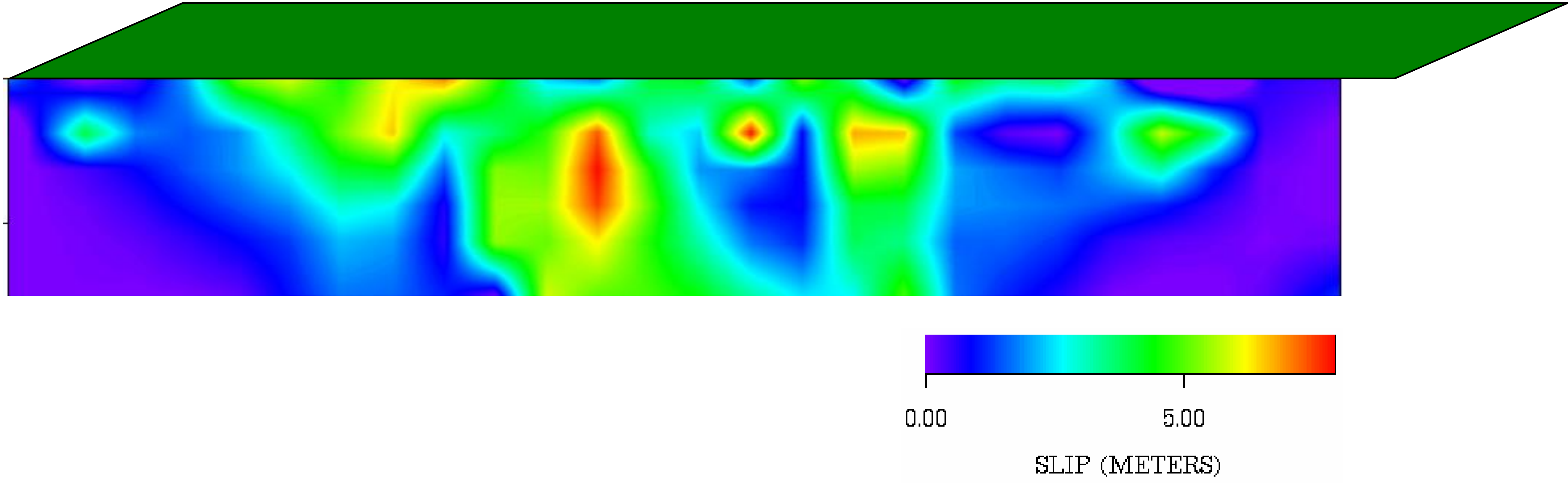
Where μ is the shear modulus of the rock in the source region (typically 30 GPa).

A is the fault rupture area.
D is the average dislocation or relative movement (slip) between the opposite sides of the fault.
E_S is radiated seismic energy.
Ds is stress drop.

- The definition based on A D allows M_o to be derived from geological faulting parameters that can be easily observed in the field for large surface-rupturing earthquakes. The definition based on E_S / Ds allows M_o to be derived from seismological measurements.

Rupture on a Fault

Total Slip in the M7.3 Landers Earthquake



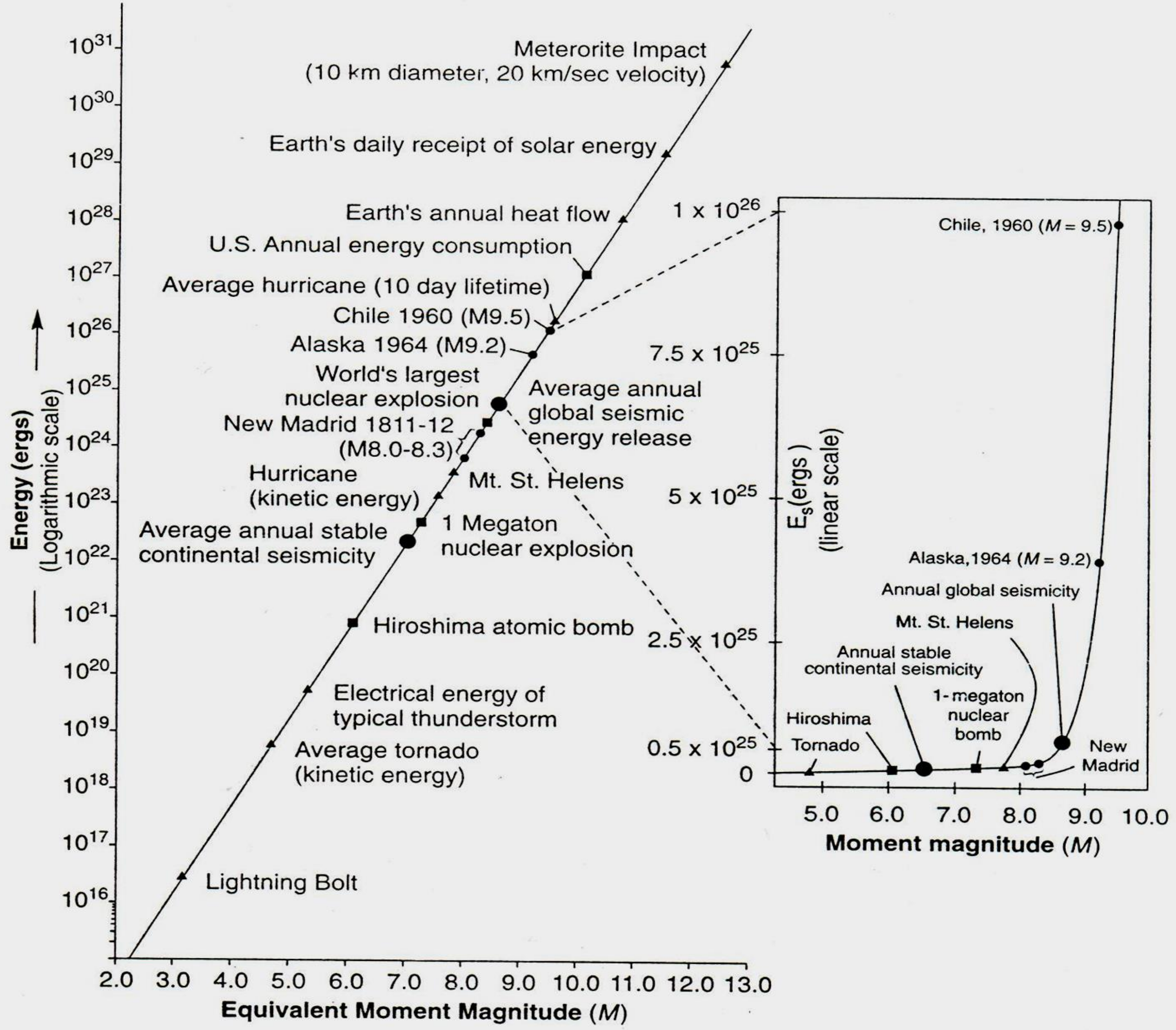


Figure 2.31 Relative energy of various natural and human-made phenomena. (After Johnston, 1990. Reprinted by permission of USGS.)

1 erg = 10^{-7} joules

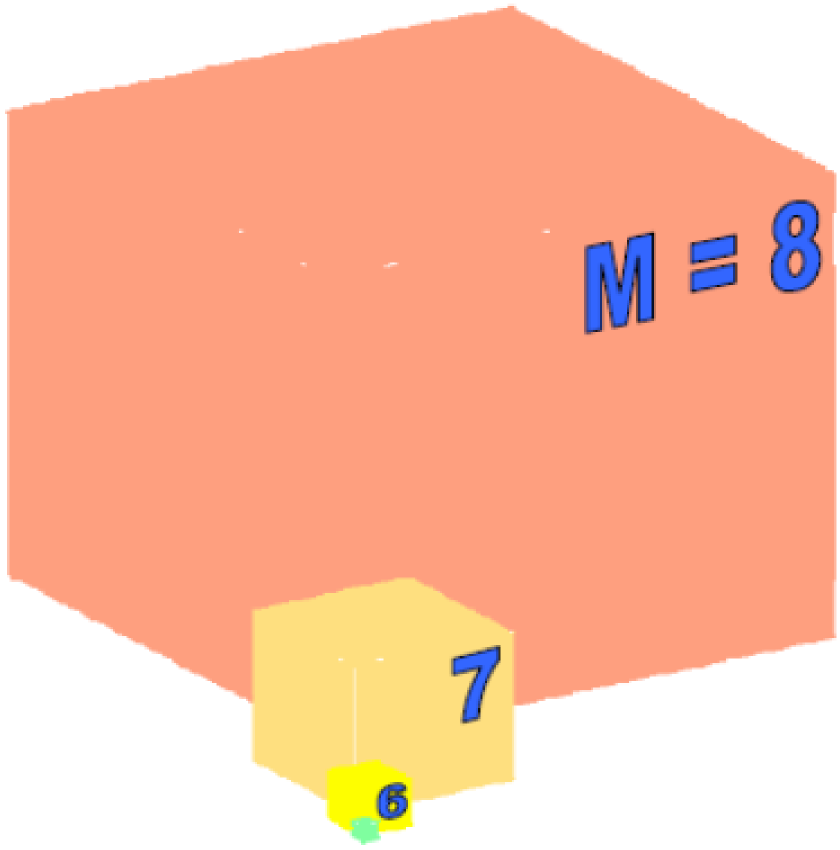
Earthquake Energy

- The total seismic energy (E, erg) released during an earthquake is often estimated from the following nonlinear relationship:

$$\log E = 11.8 + 1.5\, M_s$$

- This relationship is applicable to moment magnitude M_w as well.

- Each unit change in magnitude corresponds to a 32 fold increase in earthquake energy.



Thank you for your attention