CALIFORNIA GEOLOGICAL SURVEY

NOTE 32

HOW EARTHQUAKES AND THEIR EFFECTS ARE MEASURED

Vibrations produced by earthquakes are detected, recorded, and measured by instruments called **seismographs**. These devices may amplify ground motions beneath the instruments to over 1 million times, transcribing the ground motion into a zig-zag or wiggly trace called a **seismogram**. From the data expressed in seismograms, the time, epicenter, and focal depth of an earthquake can be determined. Also, estimates can be made of its relative size and amount of energy it released.

The point on the fault where rupture initiates is referred to as the **focus** or **hypocenter** of an earthquake. The hypocenter is described by its depth in kilometers, its map location in latitude and longitude, its date and time of occurrence, and its magnitude (a measure of the amount of energy radiated as seismic waves). The term **epicenter**, which is more commonly used to refer to an earthquake location, is the point on the earth's surface directly above the hypocenter. The description of an epicenter is the same as for a hypocenter except the depth is omitted.

The strength of an earthquake is generally expressed in two ways: **magnitude** and **intensity**. The magnitude is a measure that depends on the seismic energy radiated by the earthquake as recorded on seismographs. An earthquake's magnitude is expressed in whole numbers and decimals (e.g., 6.8). The intensity at a specific location is a measure that depends on the effects of the earthquake on people or buildings. Intensity is expressed in Roman numerals or whole numbers (e.g., VI or 6). Although there is only one magnitude for a specific earthquake, there may be many values of intensity (damage) for that earthquake at different sites.

Magnitude Scales

Several magnitude scales have been developed by seismologists. The original is the **Richter magnitude**, developed in 1932 by the late Dr. Charles F. Richter who was a professor at the California Institute of Technology (CalTech).

The Richter scale was designed to use the maximum trace amplitude registered on a seismogram from a standard instrument, called a Wood-Anderson torsion seismograph, as a measure of earthquake size. When an earthquake is recorded on the standard instrument, the greatest excursion of the wiggly trace is measured and compared with that of a reference magnitude 3.0 earthquake at the same epicenter-to-station distance. The result is a number that directly corresponds to the size of the earthquake relative to the reference earthquake. The reference magnitude 3.0 earthquake was defined by Richter to have a maximum trace amplitude of 1 millimeter on a standard Wood-Anderson seismograph at a distance of 100 kilometers from the epicenter. With appropriate distance corrections for the recorded amplitude (Figure 1), the magnitude value is constant and is an effective means of earthquake size classification.

The most commonly used scale today is the **Moment magnitude** (Mw) scale, jointly developed in 1978 by Dr. Thomas C. Hanks of the U.S. Geological Survey and Dr. Hiroo Kanamori, a professor at CalTech. Moment magnitude is related to the physical size of fault rupture and the movement (displacement) across the fault, and as such is a more uniform measure of the strength of an earthquake. The **seismic moment** of an earthquake is determined by the strength or resistance of rocks to faulting (shear modulus) multiplied by the area (length times width) of the fault that ruptures and by the average displacement that occurs across the fault during the earthquake. The seismic moment determines the energy that can be radiated by an earthquake and hence the seismogram recorded by a modern seismograph. A seismologist determines the seismic moment of an earthquake from a seismogram by using a computer to plot the seismo-gram's amplitude of motion as a function of period (wave length). The amplitude of the long period motions in a seismogram, when corrected for the distance from the earthquake, is a measure of the seismic moment for that earthquake. The Moment magnitude of an earthquake is defined relative to the seismic moment for that event.

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It is important to recognize that earthquake magnitude varies logarithmically with the wave amplitude or seismic moment recorded by a seismograph. Each whole number step in magnitude represents an increase of ten times in the amplitude of the recorded seismic waves. And the energy release increases by a factor of about 31 times. The size of the fault rupture and the fault's displacement (movement) also increase logarithmically with magnitude as shown in Figure 2.

Magnitude scales have no fixed maximum or minimum. Observations have placed the largest recorded earthquake (offshore from Chile in 1960) at Moment magnitude 9.6 and the smallest at -3. Earthquakes with magnitudes smaller than about 2 are called "micro-earthquakes." Magnitudes are not used to directly estimate damage. An earthquake in a densely populated area, which results in many deaths and considerable damage, may have the same magnitude as an earthquake that occurs in a barren, remote area, that may do nothing more that frighten the wildlife.

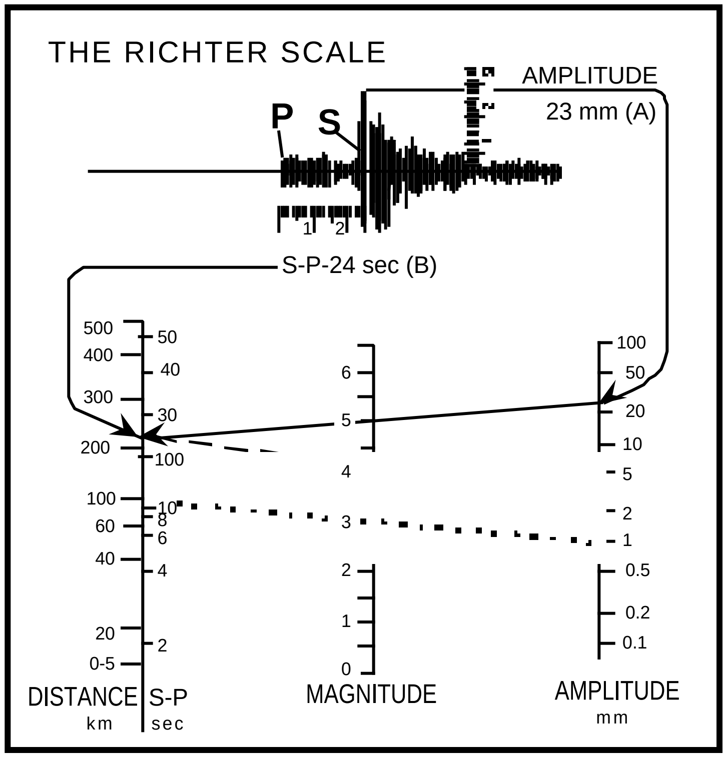


Figure 1. Diagram illustrating how seismologists determine earthquake magnitude using a Wood-Anderson Seismograph recording and a magnitude determination chart. Courtesy of California Institute of Technology.

EARTHQUAKE INTENSITY

The first scale to reflect earthquake intensities (damage) was developed by de Rossi of Italy and Forel of Switzerland in the 1880s and is known as the Rossi-Forel intensity scale. This scale, with values form I to X, was used for about two decades. A need for a more refined scale increased with the advancement of the science of seismology. In 1902, the Italian seismologist Mercalli devised a new scale on a I to XII range. The Mercalli intensity scale was modified in 1931 by American seismologists Harry O. Wood and Frank Neumann to take into account modern structural features.

The Modified Mercalli intensity scale measures the intensity of an earthquake's effects in a given locality, and is perhaps much more meaningful to the layperson because it is based on observations of earthquake effects at specific places (Photos 1 and 2). It should be noted that because the data used for assigning intensities is obtained from direct accounts for the earthquake's effects at numerous towns, considerable time (weeks to months) is sometimes needed before an intensity map can be assembled for a particular earthquake.

On the Modified Mercalli intensity scale, values range from I to XII. The most commonly used adaptation covers the range of intensities from the conditions of "I - not felt except by very few, favorably situated," to "XII - damage total, lines of sight disturbed, objects thrown into the air" (Table 2). While an earthquake has only one magnitude, it can have many intensities, which decrease with distance from the epicenter (Figure 3).

It is difficult to compare magnitude and intensity because intensity is linked with the particular ground and structural conditions of a given area, as well as distance from the earthquake epicenter, while magnitude depends on the energy released by earthquake faulting. But there is an approximate relation between magnitude and *maximum* expected intensity close to the epicenter (Table 1). The areas shaken at or above a given intensity increase logarithmically with earthquake magnitude (Figure 2).

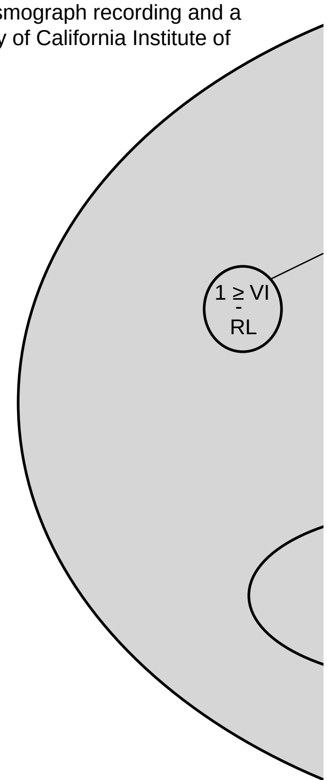
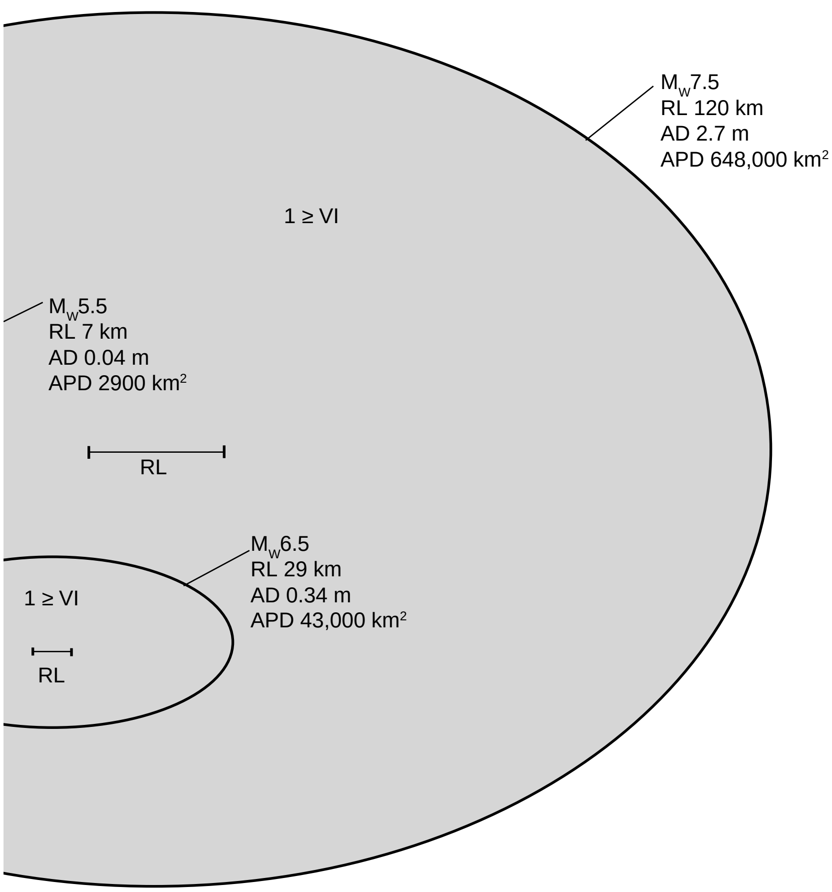


Figure 2. The relationship of earth
(intensity VI or greater) i

Table 1: COMPARISON OF RICHTER MAGNITUDE AND MODIFIED MERCALLI INTENSITY

Richter Magnitude	Expected Modified Mercalli Maximum Intensity (at epicenter)	
2	I-II	Usually detected only by instruments
3	III	Felt indoors
4	IV-V	Felt by most people; slight damage
5	VI-VII	Felt by all; many frightened and run outdoors; damage minor to moderate
6	VII-VIII	Everybody runs outdoors; damage moderate to major
7	IX-X	Major damage
8+	X-XI	Total and major damage

After Charles F. Richter, 1958, ***Elementary Seismology.***



arthquake magnitude (Mw) to rupture length (RL) and area of potential damage er) in California. Also listed are average displacements (AD) for each example magnitude.

TABLE 2: MODIFIED MERCALLI INTENSITY SCALE OF 1931

I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
IV	During the day felt indoors by many, outdoors by few. 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, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimeys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Board fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft gound. Rails bent greatly.
XII	Damage total. Practically all works of construction are damaged greatly or destroyed. Waves seen on ground surface. Lines of sight and level are destorted. Objects are thrown upward into the air.

Photo 1. *Single story wood frame houses usually stand up well to earthquake shaking. Even though fault rupture extends beneath this structure, it did not collapse during the 1971 San Fernando earthquake. The garage, however, with the large opening in the front, did yield to the horizontal shaking.* Photo by R. Castle, courtesy of U.S. Geological Survey.

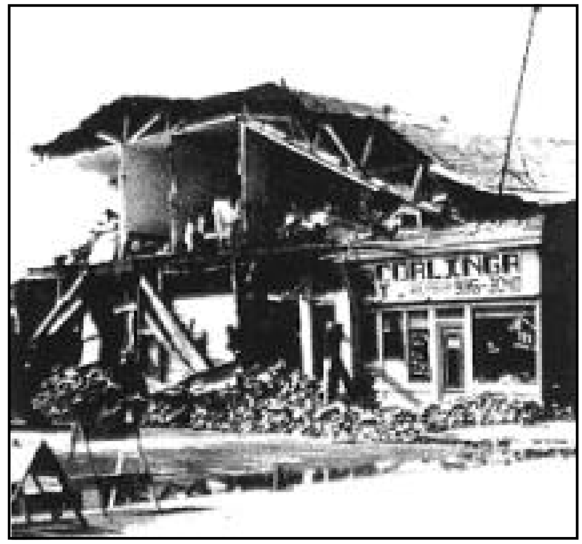


Photo 2. Masonry structures with little or no reinforcement, such as those in the Coalinga business district, usually sustain the greatest damage during an earthquake. *Photo by James Stratta.*

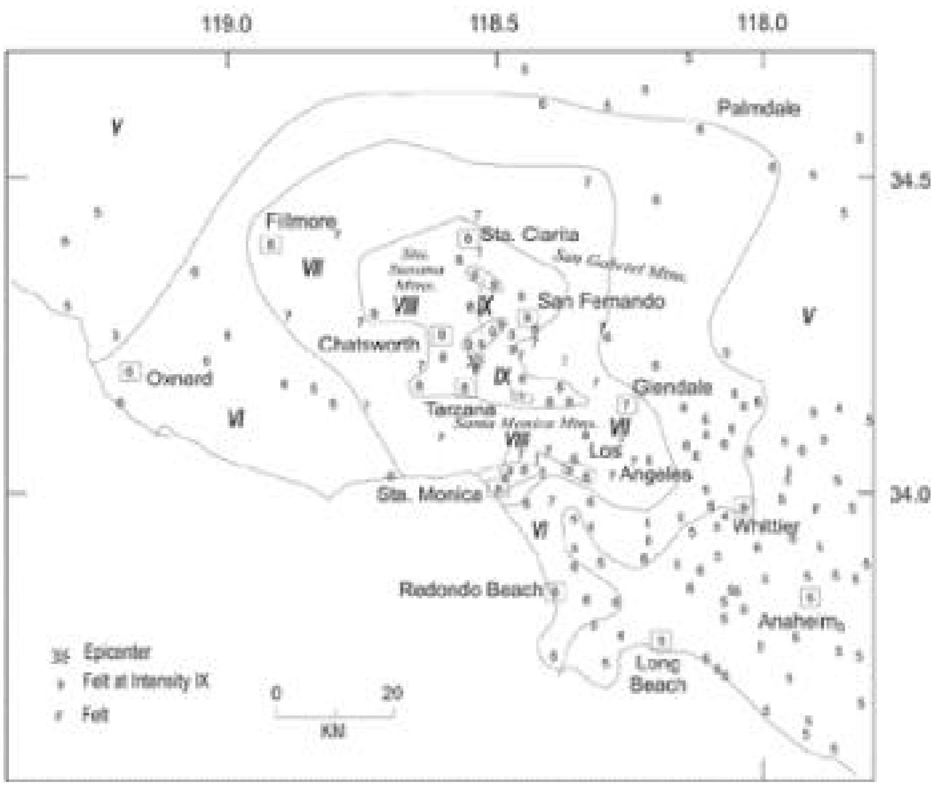


Figure 3. Distribution of Modified Mercalli Intensity (MMI) in the epicentral region. Roman numerals give average MMI. Arabic numerals represent intensities at specific locations. Squares denote towns labeled in the figure.

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