TEACHER FEATURE

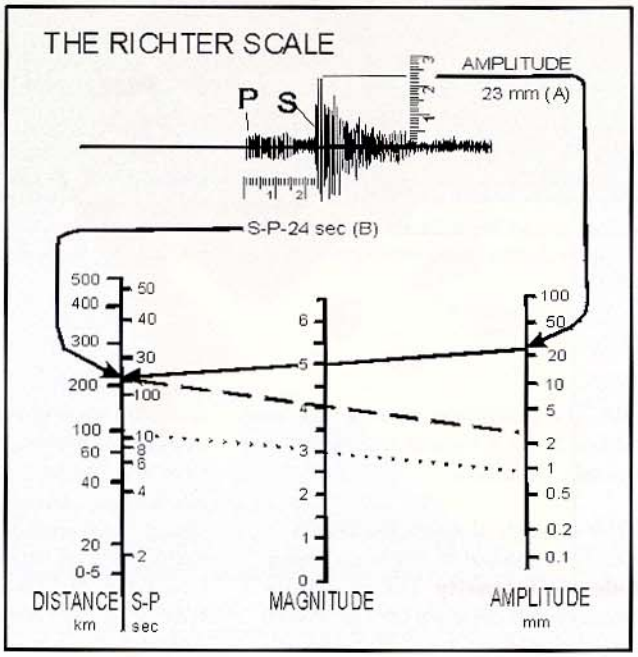
Sizing Up Earthquakes

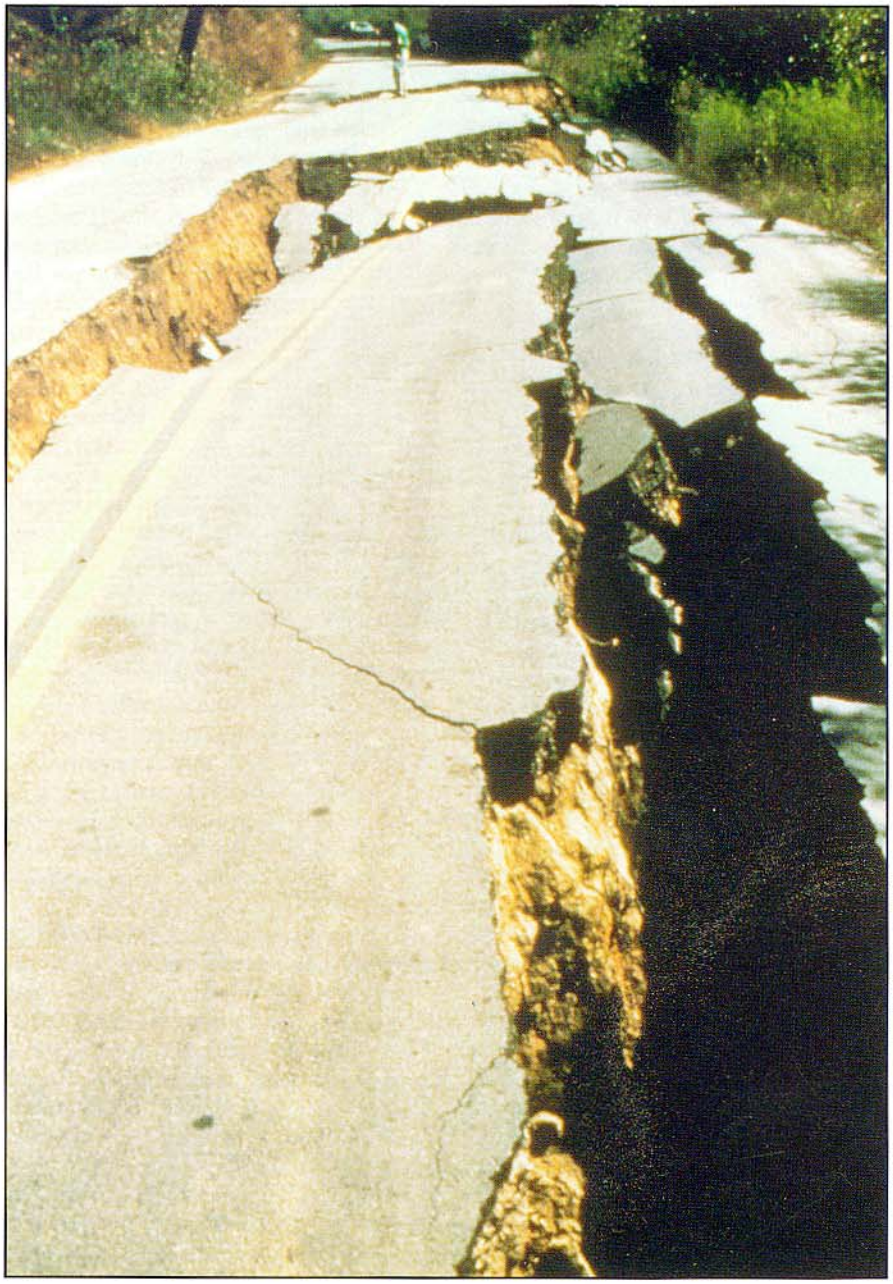
Damage caused by the 1906 earthquake in San Francisco. *California Department of Conservation, Division of Mines and Geology file photo.*

HOW THE EFFECTS OF EARTHQUAKES 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 of an earthquake 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 hypo-





Lateral spread into adjacent sag pond along San Andreas Fault. Santa Cruz County, California. Loma Prieta earthquake, October 1989. *Photo by M. Rymer, U.S. Geological Survey.*

center. The description of an epicenter is the same as for a hypocenter except that 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 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.

Several magnitude scales have been developed that measure the amplitude of different portions of a seismogram. The most widely known scale, the Richter scale, was originally 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 1millimeter on a standard Wood-Anderson seismograph at a distance of 100 kilometers from the epicenter. With appropriate distance corrections for the recorded amplitude (Figure), the magnitude value is constant and is an effective means of earthquake size classification.

A better measure of earthquake size is **seismic moment**. 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

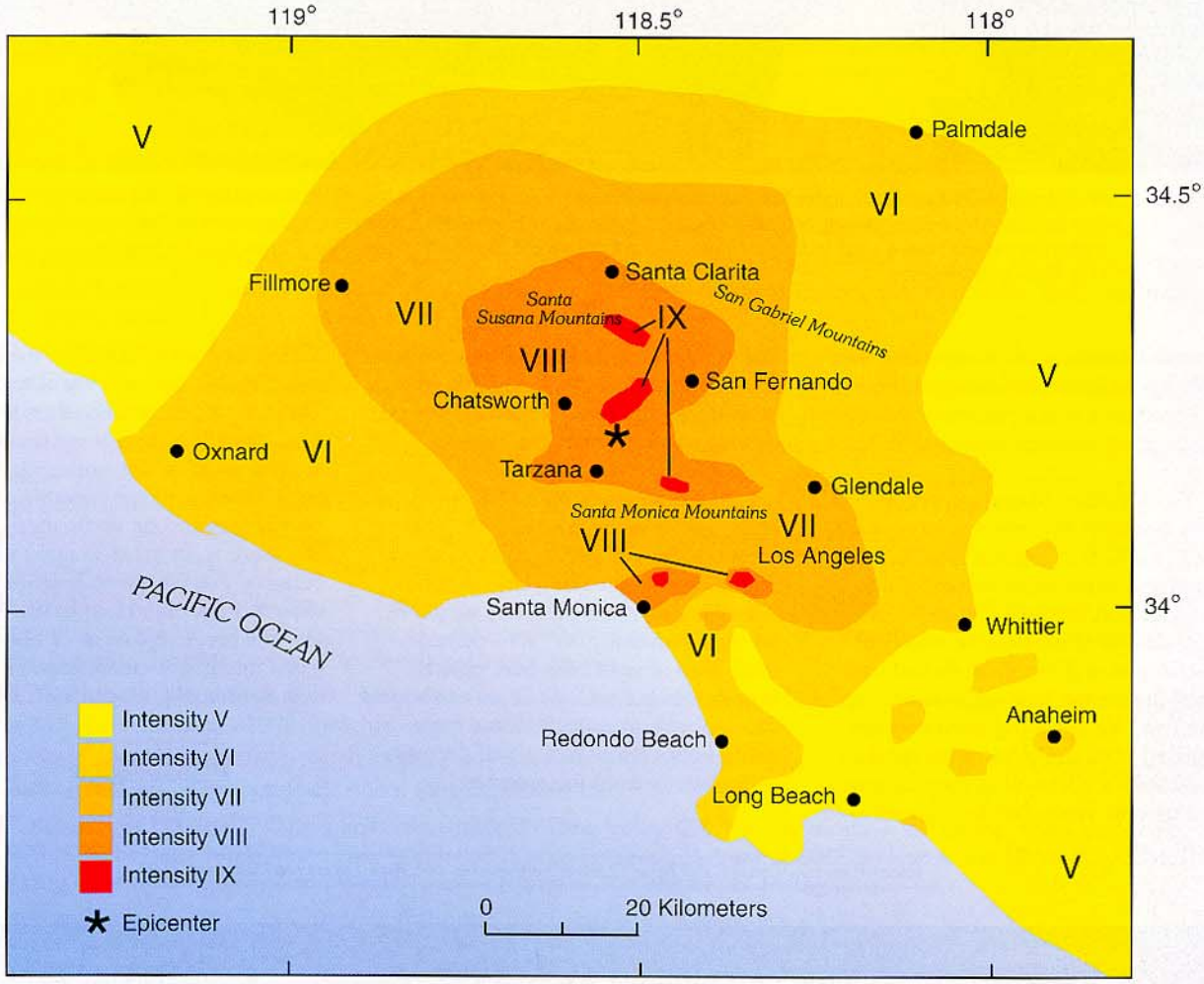
that occurs across the fault during the earthquake. The seismic moment determines the energy that can be radiated by an earthquake and hence the seismogram recorded by a modern seismograph. A seismologist determines that seismic moment of an earthquake from a seismogram by using a computer to plot the seismogram'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.

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.

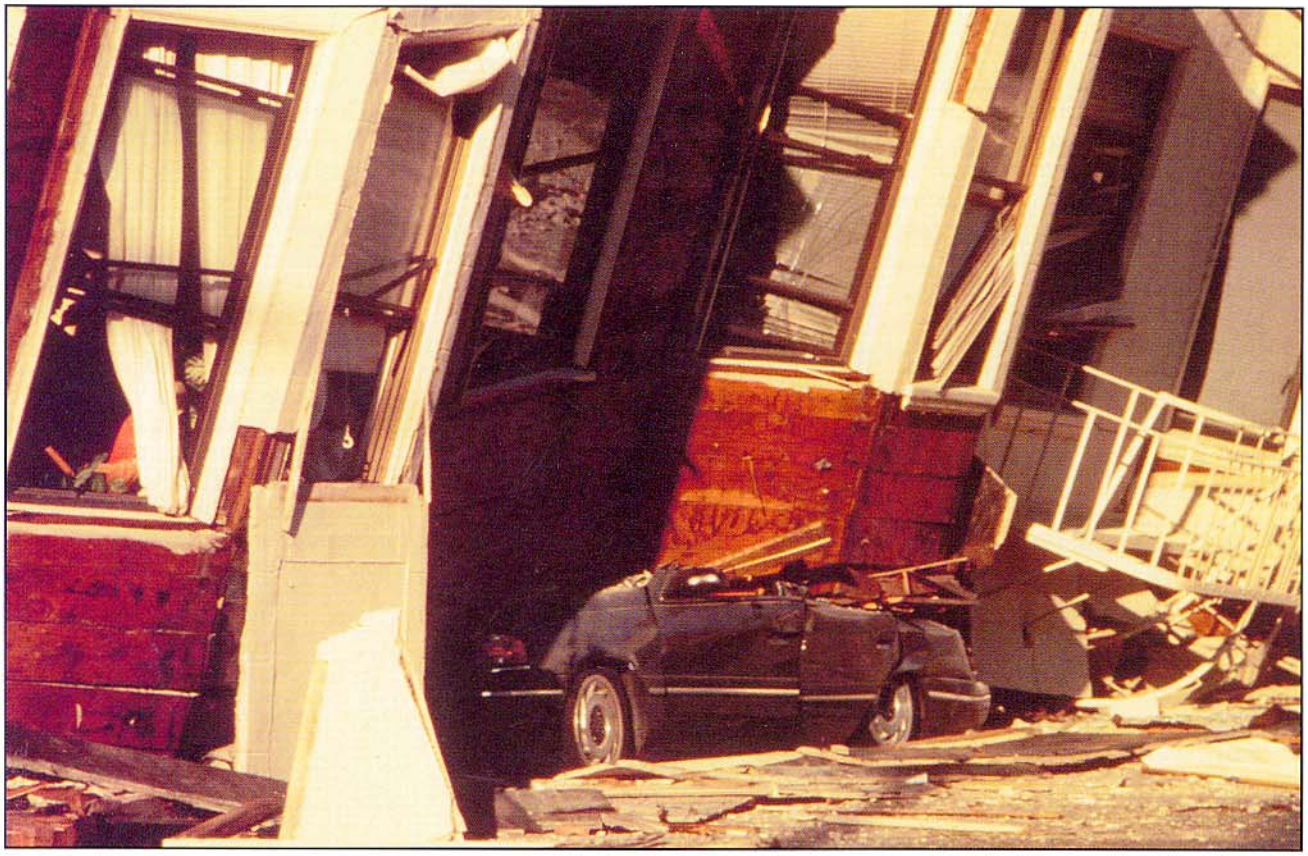
Magnitude scales have no fixed maximum or minimum. Observations have placed the largest recorded earthquake (offshore from Chile in 1960) at Moment magnitude 9.6 and the smallest at -3. Earthquakes with magnitudes smaller that about 2 are called "micro earthquakes." Magnitudes are not used to directly 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 animals.

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 from 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



Distribution of Modified Mercalli Intensity (MMI) in the epicentral region. Roman numerals give average MMI. This example shows what an intensity map might look like if an earthquake struck the Los Angeles area.



An automobile lies crushed under the third story of this apartment building in San Francisco's Marina District. The first two stories are no longer visible because of structural failure and sinking due to liquefaction, the transformation of the soil from a solid to a liquid state. Loma Prieta earthquake, October 1989. *Photo by John Nakata, U.S. Geological Survey.*

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). It should be noted that in the past because the data used for assigning intensities are obtained from direct accounts for the earthquake's effects at numerous towns, considerable time—weeks to months—was sometimes needed before an intensity map can be assembled for a particular earthquake. Now, responses can be quickly collected over the Internet.

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." While an earthquake has only one magnitude, it can have many (map) intensities, which decrease with distance from the epicenter.

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. The areas shaken at or above a given intensity increase logarithmically with earthquake magnitude.

Information taken from DMG Note 32. *How Earthquakes and Their Effects are Measured. 1997.*

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