

2.2_Earthquakes

Earthquakes demonstrate that the Earth continues to be a dynamic planet, changing every day by internal, tectonic forces. What causes earthquake activity, or seismicity? Scientific study associates seismicity with any of the following:

- the sudden formation of a new fault
- sudden slip on an existing fault
- a phase change, when the atoms in minerals suddenly rearrange
- movement of magma into, or explosive eruption of, a volcano
- a giant landslide
- a meteorite impact
- an underground nuclear-bomb test

When describing the location of an earthquake, seismologists use two terms. First, the point on a fault at which rock starts to rupture and slip is the *hypocenter*, or **focus**, of an earthquake. Simplistically, the focus is the place inside the Earth from which earthquake energy, in the form of vibrations, begins to propagate. Second, the point on the surface of the Earth that lies directly above the focus is the earthquake's **epicenter**.

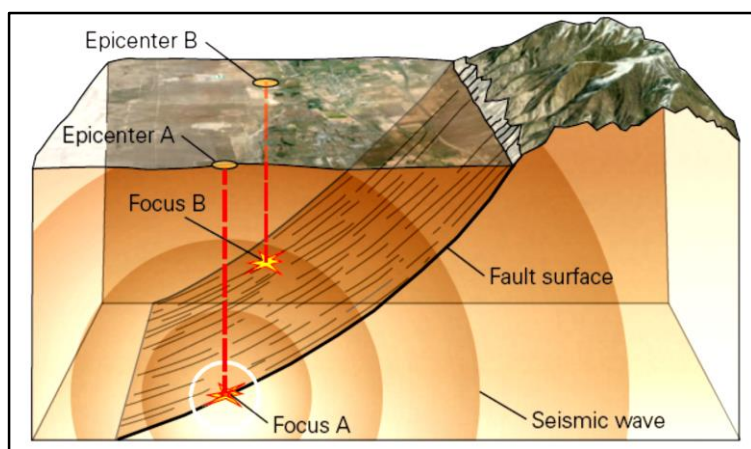


Figure 1: Earthquake hypocenters and epicenters.

Elastic-Rebound Theory

The origin of an **earthquake** can be illustrated by a simple experiment. Bend a stick until it snaps. Energy is stored in the elastic bending and is released if rupture occurs, causing the fractured ends to vibrate and send out sound waves. Detailed studies of active faults show that this model, known as the **elastic rebound theory**, applies to all major earthquakes.

Imagine a brick-shaped block of rock gripped on each side with a clamp and an upward push on one of the clamps and a downward push on the other is applied. By doing so, a stress to the rock is applied. At first, the rock bends slightly but doesn't break (**Fig. 2a**). In fact, the rock would return to its original shape if more stress is not applied. Geologists refer to such a phenomenon as elastic behavior—the same phenomenon happens when a spring is stretched and then let go. The change in shape due to elastic bending, stretching, or shortening is called *elastic strain*. Now by bending the rock even more will lead to the formation of a number of small cracks in the rock, typically in a diagonal zone. Eventually the cracks connect to one another to form a fracture (or rupture) that cuts across the entire block of rock (**Fig. 2b**). The instant that such a throughgoing fracture forms, the block breaks in two, and the rock on one side of the fracture suddenly slides past the rock on the other side. When sliding occurs, the fracture has become a fault. Any elastic strain that had built up in the rock gets released, so the

rock straightens out, or rebounds (**Fig. 2c**). Such fault formation in a previously intact rock releases energy and generates earthquake vibrations.

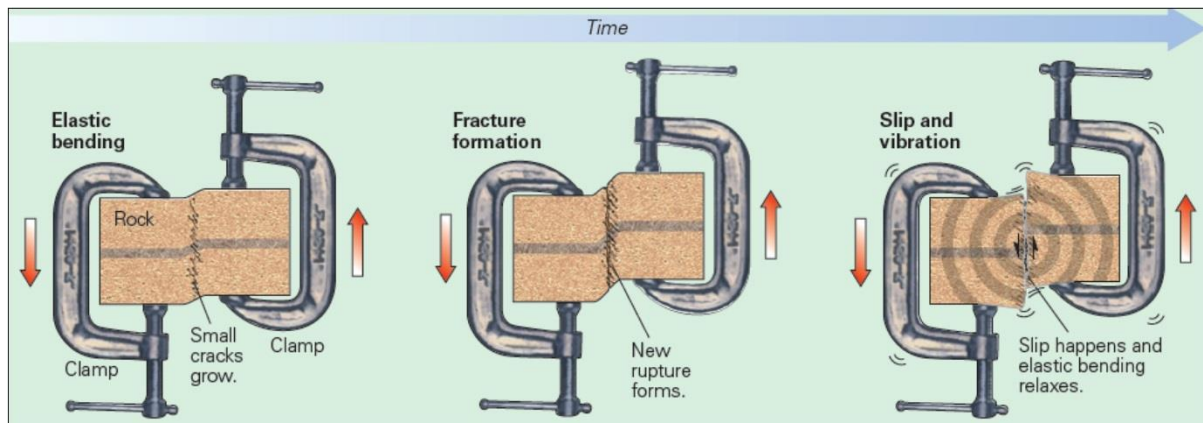


Figure 2: (a) Imagine a block of rock gripped by two clamps. Move one clamp up, and the rock starts to bend. Small cracks develop along the bend. (b) Eventually, the cracks link. When this happens, a throughgoing fracture forms. (c) The instant that the fracture forms, the rock breaks into two pieces that slide past each other. The energy that is released generates vibrations.

In sum, earthquakes happen because stresses build up, causing rock adjacent to the fault to develop elastic strain until either intact rock breaks or a pre-existing fault reactivates. When slip takes place, the once-bent rocks adjacent to the fault rebound back to their original, unbent shape, thereby relieving the elastic strain. Geologists refer to this overall concept as the **elastic-rebound theory** of earthquake generation. Notably, the stress necessary to reactivate a fault tends to be less than the stress necessary to break intact rock, so most earthquakes probably represent slip on pre-existing faults.

Defining the “Size” of Earthquakes

Some earthquakes shake the ground violently, whereas others can barely be felt—in other words, some earthquakes are bigger than others. Seismologists have developed two scales to define “size” in a meaningful way so that they can systematically describe and compare earthquakes. The first scale, called the **Mercalli Intensity Scale**, depends on human perception of ground shaking and the damage resulting from it at a given locality. The second scale, called the **magnitude scale**, focuses on the measured amount of ground motion, as recorded by a seismometer at a specified distance from the epicenter.

Mercalli Intensity Scale

The intensity of a given earthquake refers to the effect or consequence of its ground shaking at a locality on the Earth’s surface. In 1902, an Italian scientist named Giuseppe Mercalli devised a scale for defining intensity by systematically assessing human perception of shaking and of the damage that an earthquake caused. A version of this scale, called the **Modified Mercalli Intensity (MMI) scale**, continues to be used today (**Table 1**). The MMI scale uses Roman numerals ranging from I (low intensity) to XII (extremely high intensity).

To use the scale, seismologists visit the affected region to interview residents and observe the damage. For example, if an earthquake at a location causes everyone to notice shaking but does not damage buildings, then the earthquake had an intensity of III at that location. In contrast, if

ground shaking feels significant and destroys poorly constructed buildings, but causes only minor damage to substantial buildings, then the earthquake had an intensity of VIII.

Table 1: Modified Mercalli Intensity Scale

MMI	Destructiveness (Perceptions of the Extent of Shaking and Damage)
I	Detected only by seismic instruments; causes no damage.
II	Felt by a few stationary people, especially in upper floors of buildings; suspended objects, such as lamps, may swing.
III	Felt indoors; standing automobiles sway on their suspensions; it seems as though a heavy truck is passing.
IV	Shaking awakens some sleepers; dishes and windows rattle.
V	Most people awaken; some dishes and windows break, unstable objects tip over; trees and poles sway.
VI	Shaking frightens some people; plaster walls crack, heavy furniture moves slightly, and a few chimneys crack, but overall little damage occurs.
VII	Most people are frightened and run outside; a lot of plaster cracks, windows break, some chimneys topple, and unstable furniture overturns; poorly built buildings sustain considerable damage.
VIII	Many chimneys and factory smokestacks topple; heavy furniture overturns; substantial buildings sustain some damage, and poorly built buildings suffer severe damage.
IX	Frame buildings separate from their foundations; most buildings sustain damage, and some buildings collapse; the ground cracks, underground pipes break, and rails bend; some landslides occur.
X	Most masonry structures and some well-built wooden structures are destroyed; the ground severely cracks in places; many landslides occur along steep slopes; some bridges collapse; some sediment liquefies; concrete dams may crack; facades on many buildings collapse; railways and roads suffer severe damage.
XI	Few masonry buildings remain standing; many bridges collapse; broad fissures form in the ground; most pipelines break; severe liquefaction of sediment occurs; some dams collapse; facades on most buildings collapse or are severely damaged.
XII	Earthquake waves cause visible undulations of the ground surface; objects are thrown up off the ground; there is complete destruction of buildings and bridges of all types.

Earthquake Magnitude Scales

The magnitude of an earthquake indicates the maximum amplitude of ground motion recorded by a seismometer at a specific, standard distance from the focus. “Amplitude of ground motion,” means the amount of up-and-down or back-and-forth motion of the ground. The larger the ground motion, the greater the deflection of a seismometer pen tracing out a seismogram. Because the magnitude does not depend on distance, use of the magnitude scale allows seismologists to define the size of an earthquake objectively.

An American seismologist, Charles Richter, developed a method for defining and measuring earthquake magnitude. The scale he proposed, in 1935, came to be known as the Richter scale. It indicates the maximum amplitude of motion as it would be recorded at a seismic station 100 km from the epicenter. Because the amount of deflection on a seismogram depends on the distance between the seismometer and the epicenter, and since most seismic stations do not

happen to lie exactly 100 km from the epicenter, seismologists use a chart to adjust for distance of the station from the epicenter when calculating magnitude (**Fig. 3**).

Richter's scale became so widely used that news reports often include such wording as "The earthquake registered a 7.2 on the Richter scale." These days, however, seismologists actually use several different magnitude scales, not just the Richter scale, because the original Richter scale works well only for earthquakes whose focus lies close to the Earth's surface and whose epicenter lies fairly close to the seismometer station. Because of the distance limitation, seismologists now refer to a number on the original Richter scale as a **local magnitude (M_L)**.

The Richter scale cannot accurately define the sizes of extremely large earthquakes, because for an earthquake above a given size, the scale gives roughly the same magnitude regardless of how large the earthquake vibrations actually are. Because of this problem, seismologists developed the **moment magnitude scale (M_W)**, which provides the most accurate representation of an earthquake's size. To calculate the moment magnitude,

seismologists take into account the amplitude of several different seismic waves, the dimensions of the slipped area on the fault, and the amount of displacement that occurred. The largest recorded earthquake in history, the great 1960 Chilean quake, registered as an 8.5 on the M_L scale, but as a 9.5 on the M_W scale. The larger number makes more sense because this earthquake was indeed much larger than other known events for which $M_L = 8.5$. Of note, the catastrophic 2011 Tōhoku earthquake had a magnitude of $M_W = 9.0$.

What magnitude do modern news reports of earthquakes provide? For early reports, seismologists report a preliminary magnitude, typically an M_L , which can be calculated quickly.

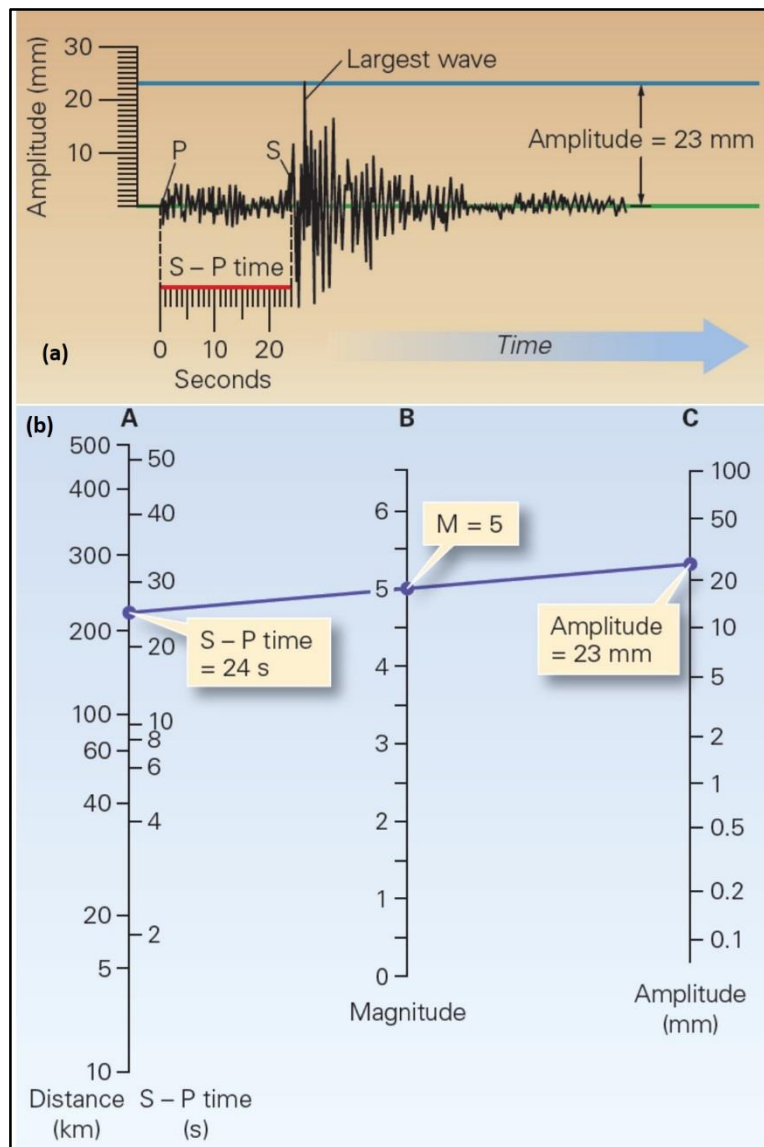


Figure 3: Using the Richter magnitude scale. (a) To calculate the Richter magnitude from a seismogram, first measure the S – P time to determine the distance to the epicenter. Then measure the amplitude of the largest wave. (b) Draw a line from the point on Column A representing the S – P time or the distance to the epicenter, to the point on Column C representing the wave amplitude. Read the Richter magnitude from Column B. (P = Primary wave; S = Secondary wave).

Later on, after they have had the chance to collect the necessary data, seismologists report an M_W , which becomes the number that appears in archival records.

All magnitude scales are logarithmic, meaning that an increase of one integer of magnitude represents a 10-fold increase in the maximum ground motion. Therefore, an M_W 8 earthquake results in ground motion that is 10 times greater than that of an M_W 7 earthquake, and 1,000 times greater than that of an M_W 5 earthquake. To make discussion easier, seismologists use familiar adjectives to describe the size of an earthquake, as listed in **Table 2**. Note that we can roughly correlate magnitude with the intensity at the epicenter for earthquakes that take place in the upper continental crust.

Table 2: Adjectives for Describing Earthquakes. *For upper-crustal earthquakes in continents.

Adjective	Magnitude	Approximate maximum intensity at epicenter*	Effects
Great	>8.0	X to XII	Major to total destruction
Major	7.0 to 7.9	IX to X	Great damage
Strong	6.0 to 6.9	VII to VIII	Moderate to serious damage
Moderate	5.0 to 5.9	VI to VII	Slight to moderate damage
Light	4.0 to 4.9	IV to V	Felt by most; slight damage
Minor	<3.9	III or smaller	Felt by some; hardly any damage

Earthquake Prediction

Can seismologists predict the next great earthquake? The answer depends on the time frame of the prediction. With their present understanding of the distribution of seismic belts and the frequencies at which earthquakes occur, seismologists can make *long-term predictions* (on a time scale of decades to centuries). For example, with some certainty, they can say that a major earthquake will probably rattle Jammu and Kashmir during the next 100 years and that a major earthquake probably won't strike Doda-Bhadarwah area during the next 10 years. But despite extensive research, seismologists cannot make *short-term predictions* (on a time scale of hours to weeks or even years). They cannot say, for example, that an earthquake will happen in Jammu next month. But new technologies may permit warnings to be sent seconds in advance of the arrival of seismic waves if an earthquake does happen. Seismologists refer to studies leading to predictions as seismic-risk assessment, or *seismic-hazard assessment*.

Long-Term Predictions

When making a prediction, we use the word *probability* because a prediction only gives the likelihood of an event. For example, a seismologist may say, "The probability of a major earthquake occurring in the next 20 years in this state is 20%." Civil engineers may use predictions to determine whether to build vulnerable structures such as nuclear power plants, hospitals, or dams in potentially seismic areas. Seismologists base long-term earthquake predictions on two kinds of information: the identification of seismic belts and the recurrence interval (the average time between successive events) of earthquakes along a given fault.

To identify a seismic belt (or zone), seismologists produce a map showing the epicenters of earthquakes that have happened during a set period of time (say, 30 years). Clusters of epicenters define a seismic belt. The basic premise of long-term earthquake prediction can be stated as follows: a region in which there have been many earthquakes in the past will probably

experience more earthquakes in the future. Seismic belts, therefore, are regions of greater seismic risk.

Geologists can help provide insight into seismic risk by examining landforms for evidence of recent faulting. For example, the presence of a distinct fault scarp in a landscape indicates that faulting has happened so recently that erosion has not yet had time to grind away the evidence.

To determine the recurrence interval for large earthquakes at a location, geologists determine when large earthquakes happened at the location in the past. This type of research, called *paleoseismology*, uses the historical record to identify earthquakes that occurred during the past several centuries.

Short-Term Predictions

Short-term predictions, which could lead to such precautions as evacuating dangerous buildings, shutting off gas and electricity, and readying emergency services, are not and may never be reliable. Seismologists have explored a number of possible clues to imminent earthquakes, but none have yet led to an accurate prediction, and often, possible clues can be recognized only in hindsight. For example, since rocks start to crack before a throughgoing rupture forms and slips, recognition of a “swarm” (a cluster of events during a short period) of foreshocks might be such a clue. But foreshocks do not always occur, and even if they do, they may be indistinguishable from other small earthquakes.

Recently, geologists have begun to use computer models of stress to predict where stress build-ups may lead to earthquakes, but these models have not yet proved to be a reliable predictor of events. Other changes that have been explored, but have not been confirmed as precursors of earthquakes, include changes in the water level in wells; the appearance of gases, such as radon or helium, in wells; changes in the electrical conductivity of rock underground; and unusual animal behavior. Believers in these proposed clues suggest that they all reflect the occurrence of cracking in the crust prior to an earthquake, but most researchers remain very skeptical.

Earthquake Early Warning Systems

Even though seismologists cannot provide weeks to years of advance notice that an earthquake will happen, they have successfully developed *earthquake early warning systems* in locations where there are enough seismic stations that some can detect the earthquake before the seismic waves have had time to reach populated areas.

An early warning system works as follows: When an earthquake happens, the seismic waves it produces start traveling through the Earth. The instant that multiple seismometer stations detect the earthquake, a computer approximates the epicenter location and then sends a signal to a control center, which automatically sends out emergency signals to areas that might be affected. Since broadcast warning signals travel at the speed of light, orders of magnitude faster than seismic waves, the signal arrives before the seismic waves. When the warning signal arrives, it activates electronic switches that automatically shut down gas pipelines, trains, nuclear reactors, power lines, and other vulnerable infrastructure. The signal also automatically activates sirens and alerts broadcasters to send out warnings on radio, TV, and cell phone networks to the public. Unless the focus lies directly under the city, the warning may precede the arrival of the first earthquake waves by several seconds—not a lot of time, but perhaps enough to prevent some infrastructure damage and to allow people to seek a safer location.

Some earthquake-prone regions, such as Japan and California, have already installed earthquake warning systems.

Seismic Zones of India

The Indian subcontinent has a history of number of devastating earthquakes over the past century. The major reason for the high frequency and intensity of the earthquakes primarily is the compression resulting from the northward push of the Indian subcontinent into Asia. Most of earthquakes occur along the Himalayan plate boundary. However, a number of intra-plate earthquakes have also occurred in the peninsular region.

Based on the past seismic activity, Bureau of Indian Standards [IS-1893 (Part- 1): 2002], grouped India into four seismic zones, viz. Zone-II, -III, -IV and -V.

The Modified Mercalli Intensity (MMI), broadly associated with various zones, is as follows:

<u>Seismic Zone</u>	<u>MMI</u>
II (Low intensity zone)	VI (or less)
III (Moderate intensity zone)	VII
IV (Severe intensity zone)	VIII
V (Very severe intensity zone)	IX (and above)

Broadly, **Zone-V** encompasses entire northeastern India, parts of Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Rann of Kutch in Gujarat, parts of North Bihar and Andaman & Nicobar Islands. **Zone-IV** includes remaining parts of Jammu & Kashmir and Himachal Pradesh, Union Territory of Delhi, Sikkim, northern parts of Uttar Pradesh, Bihar and West Bengal, parts of Gujarat and small portions of Maharashtra near the west coast and Rajasthan. Kerala, Goa, Lakshadweep islands, and remaining parts of Uttar Pradesh, Gujarat and West Bengal, parts of Punjab, Rajasthan,

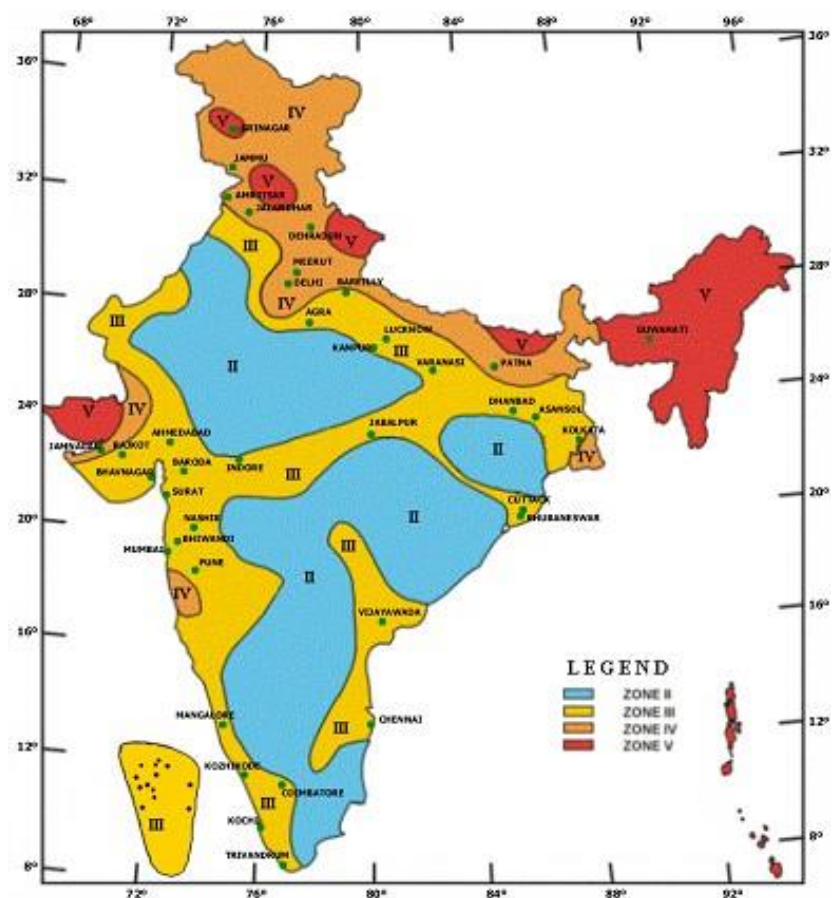


Figure 4: Seismic Zoning map of India

Madhya Pradesh, Bihar, Jharkhand, Chhattisgarh, Maharashtra, Orissa, Andhra Pradesh, Tamilnadu and Karnataka fall in ***Zone-III***. ***Zone-II*** covers remaining parts of the country. Since the current division of India into earthquake hazard zones does not use Zone I, no area of India is classed as ***Zone I***.

Source: Earth – Portrait of a Planet by Stephen Marshak
Government of India, Ministry of Earth Sciences
Earth's Dynamic Systems by Hamblin and Christiansen

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