Earthquakes

What is an earthquake?

An **earthquake** is what happens when two blocks of the earth suddenly slip past one another. The surface where they slip is called the **fault** or **fault plane**. The location below the earth's surface where the earthquake starts is called the **hypocentre**, and the location directly above it on the surface of the earth is called the **epicentre**. Sometimes an earthquake as **foreshocks**. These are smaller earthquakes that happen in the same place as the larger earthquake that follows. Scientists can't tell that an earthquake is a foreshock until the larger earthquake happens. The largest, main earthquake is called the **mainshock**. Mainshocks always have **aftershocks** that follow. These are smaller earthquakes that occur afterwards in the same place as the mainshock. Depending on the size of the mainshock, aftershocks can continue for weeks, months, and even years after the mainshock! To further define this, an **Earthquake** is any sudden shaking of the ground caused by the passage of seismic waves through Earth's rocks. Seismic waves are produced when some form of energy stored in Earth's crust is suddenly released, usually when masses of rock straining against one another suddenly fracture and "slip." Earthquakes occur most often along geologic faults, narrow zones where rock masses move in relation to one another. The major fault lines of the world are located at the fringes of the huge tectonic plates that make up Earth's crust.

Wikipedia defines an **earthquake** (also known as a **quake**, **tremor** or **temblor**) as the shaking of the surface of the Earth resulting from a sudden release of energy in the Earth's lithosphere that creates seismic waves. Earthquakes can range in size from those that are so weak that they cannot be felt to those violent enough to propel objects and people into the air, and wreak destruction across entire cities. The seismicity, or **seismic activity**, of an area is the frequency, type, and size of earthquakes experienced over a period of time. The word *tremor* is also used for non-earthquake seismic rumbling. At the Earth's surface, earthquakes manifest themselves by shaking and displacing or disrupting the ground. When the epicentre of a large earthquake is located offshore, the seabed may be displaced sufficiently to cause a tsunami. Earthquakes can also trigger landslides and occasionally, volcanic activity. In its most general sense, the word *earthquake* is used to describe any seismic event—whether natural or caused by humans—that generates seismic waves. Earthquakes are caused mostly by rupture of geological faults but also by other events such as volcanic activity, landslides, mine blasts, and nuclear tests. An earthquake's point of initial rupture is called its hypocentre or focus. The epicentre is the point at ground level directly above the hypocentre.

Naturally occurring earthquakes

Tectonic earthquakes occur anywhere in the earth where there is sufficient stored elastic strain energy to drive fracture propagation along a fault plane. The sides of a fault move past each other smoothly and aseismically only if there are no irregularities or asperities along the fault surface that increase the frictional resistance. Most fault surfaces do have such asperities, which leads to a form of stick-slip behavior. Once the fault has locked, continued relative motion between the plates leads to increasing stress and therefore, stored strain energy in the volume around the fault surface. This continues until the stress has risen sufficiently to break through the asperity, suddenly allowing sliding over the locked portion of the fault, releasing the stored energy. This energy is released as a combination of radiated elastic strain seismic waves, frictional heating of the fault surface, and cracking of the rock, thus causing an earthquake. This process of gradual build-up of strain and stress punctuated by occasional sudden earthquake failure is referred to as the elastic-rebound theory. It is estimated that only 10 percent or less of an earthquake's total energy is radiated as seismic energy. Most of the earthquake's energy is used to power the earthquake fracture growth or is converted into heat generated by friction. Therefore, earthquakes lower the Earth's available elastic potential energy and raise its temperature, though these changes are negligible compared to the conductive and convective flow of heat out from the Earth's deep interior.

Earthquake fault types

There are three main types of fault, all of which may cause an interpolate earthquake: normal, reverse (thrust), and strike-slip. Normal and reverse faulting are examples of dip-slip, where the displacement along the fault is in the direction of dip and where movement on them involves a vertical component. Normal faults occur mainly in areas where the crust is being extended such as a divergent boundary. Reverse faults occur in areas where the crust is being shortened such as at a convergent boundary. Strike-slip faults are steep structures where the two sides of the fault slip horizontally past each other; transform boundaries are a particular type of strike-slip fault. Many earthquakes are caused by movement on faults that have components of both dip-slip and strike-slip; this is known as oblique slip. Reverse faults, particularly those along convergent plate boundaries, are associated with the most powerful earthquakes, megathrust earthquakes, including almost all of those of magnitude 8 or more. Megathrust earthquakes are responsible for about 90% of the total seismic moment released worldwide. Strike-slip faults, particularly continental transforms, can produce major earthquakes up to about magnitude 8. Earthquakes associated with normal faults are generally less than magnitude 7. For every unit increase in magnitude, there is a roughly thirtyfold increase in the energy released. For instance, an earthquake of magnitude 6.0 releases approximately 32 times more energy than a 5.0 magnitude earthquake and a 7.0 magnitude earthquake releases 1,000 times more energy than a 5.0 magnitude of earthquake. An 8.6 magnitude earthquake releases the same amount of energy as 10,000 atomic bombs like those used in World War II.

This is so because the energy released in an earthquake, and thus its magnitude, is proportional to the area of the fault that ruptures and the stress drop. Therefore, the longer the length and the wider the width of the faulted area, the larger the resulting magnitude. The topmost, brittle part of the Earth's crust, and the cool slabs of the tectonic plates that are descending down into the hot mantle, are the only parts of our planet that can store elastic energy and release it in fault ruptures. Rocks hotter than about 300 °C (572 °F) flow in response to stress; they do not rupture in earthquakes. The maximum observed lengths of ruptures and mapped faults (which may break in a single rupture) are approximately 1,000 km (620 mi).

The nature of earthquakes

Causes of earthquakes

Earth's major earthquakes occur mainly in belts coinciding with the margins of tectonic plates. This has long been apparent from early catalogs of felt earthquakes and is even more readily discernible in modern seismicity maps, which show instrumentally determined epicentres. The most important earthquake belt is the Circum-Pacific Belt, which affects many populated coastal regions around the Pacific Ocean—for example, those of New Zealand, New Guinea, Japan, the Aleutian Islands, Alaska, and the western coasts of North and South America. It is estimated that 80 percent of the energy presently released in earthquakes comes from those whose epicentres are in this belt. The seismic activity is by no means uniform throughout the belt, and there are a number of branches at various points. Because at many places the Circum-Pacific Belt is associated with volcanic activity, it has been popularly dubbed the "Pacific Ring of Fire." A second belt, known as the Alpide Belt, passes through the Mediterranean region eastward through Asia and joins the Circum-Pacific Belt in the East Indies. The energy released in earthquakes from this belt is about 15 percent of the world total. There also are striking connected belts of seismic activity, mainly along oceanic ridges—including those in the Arctic Ocean, the Atlantic Ocean, and the western Indian Ocean—and along the rift valleys of East Africa. This global seismicity distribution is best understood in terms of its plate tectonic setting.

Natural forces

Earthquakes are caused by the sudden release of energy within some limited region of the rocks of the Earth. The energy can be released by elastic strain, gravity, chemical reactions, or even the motion of massive bodies. Of all these the release of elastic strain is the most important cause, because this form of energy is the only kind that can be stored in sufficient quantity in the Earth to produce major disturbances. Earthquakes associated with this type of energy release are called tectonic earthquakes.

Surface phenomena

Earthquakes often cause dramatic geomorphological changes, including ground movements—either vertical or horizontal—along geologic fault traces; rising, dropping, and tilting of the ground surface; changes in the flow of groundwater; liquefaction of sandy ground; landslides; and mudflows. The investigation of topographic changes is aided by geodetic measurements, which are made systematically in a number of countries seriously affected by earthquakes.

Earthquakes can do significant damage to buildings, bridges, pipelines, railways, embankments, and other structures. The type and extent of damage inflicted are related to the strength of the ground motions and to the behaviour of the foundation soils. In the most intensely damaged region, called the meizoseismal area, the effects of a severe earthquake are usually complicated and depend on the topography and the nature of the surface materials. They are often more severe on soft alluvium and unconsolidated sediments than on hard rock. At distances of more than 100 km (60 miles) from the source, the main damage is caused by seismic waves traveling along the surface. In mines there is frequently little damage below depths of a few hundred metres even though the ground surface immediately above is considerably affected. Earthquakes are frequently associated with reports of distinctive sounds and lights. The sounds are generally low-pitched and have been likened to the noise of an underground train passing through a station. The occurrence of such sounds is consistent with the passage of high-frequency seismic waves through the ground. Occasionally, luminous flashes, streamers, and bright balls have been reported in the night sky during earthquakes. These lights have been attributed to electric induction in the air along the earthquake source.

Tsunamis

Following certain earthquakes, very long-wavelength water waves in oceans or seas sweep inshore. More properly called seismic sea waves or tsunamis (*tsunami* is a Japanese word for "harbour wave"), they are commonly referred to as tidal waves, although the attractions of the Moon and Sun play no role in their formation. They sometimes come ashore to great heights—tens of metres above mean tide level—and may be extremely destructive.

The usual immediate cause of a tsunami is sudden displacement in a seabed sufficient to cause the sudden raising or lowering of a large body of water. This deformation may be the fault source of an earthquake, or it may be a submarine landslide arising from an earthquake. Large volcanic eruptions along shorelines, such as those of Thera and Krakatoa, have also produced notable tsunamis. The most destructive tsunami ever recorded occurred on December 26, 2004, after an earthquake displaced the seabed off the coast of Sumatra, Indonesia. More than 200,000 people were killed by a series of waves that flooded coasts from Indonesia to Sri Lanka and even washed ashore on the Horn of Africa.

Seiches.

Seiches are rhythmic motions of water in nearly landlocked bays or lakes that are sometimes induced by earthquakes and tsunamis. Oscillations of this sort may last for hours or even for a day or two. The great Lisbon earthquake of 1755 caused the waters of canals and lakes in regions as far away as Scotland and Sweden to go into observable oscillations. Seiche surges in lakes in Texas, in the southwestern United States, commenced between 30 and 40 minutes after the 1964 Alaska earthquake, produced by seismic surface waves passing through the area. A related effect is the result of seismic waves from an earthquake passing through the seawater following their refraction through the seafloor. The speed of these waves is about

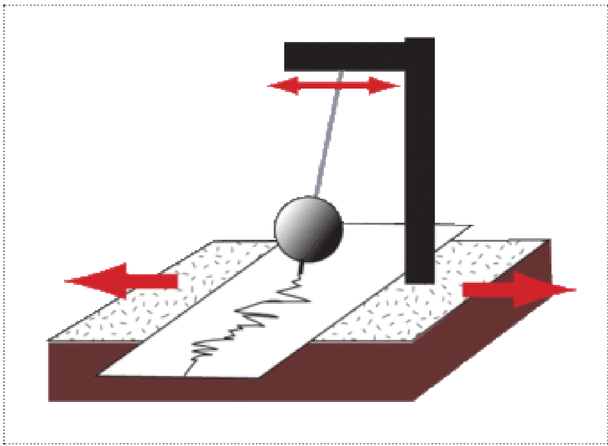
1.5 km (0.9 mile) per second, the speed of sound in water. If such waves meet a ship with sufficient intensity, they give the impression that the ship has struck a submerged object. This phenomenon is called a seaquake.

Why does the earth shake when there is an earthquake?

While the edges of faults are stuck together, and the rest of the block is moving, the energy that would normally cause the blocks to slide past one another is being stored up. When the force of the moving blocks finally overcomes the **friction** of the jagged edges of the fault and it unsticks, all that stored up energy is released. The energy radiates outward from the fault in all directions in the form of **seismic waves** like ripples on a pond. The seismic waves shake the earth as they move through it, and when the waves reach the earth's surface, they shake the ground and anything on it, like our houses and us!

How do scientists measure the size of earthquakes?

The size of an earthquake depends on the size of the fault and the amount of slip on the fault, but that's not something scientists can simply measure with a measuring tape since faults are many kilometres deep beneath the earth's surface. So how do they measure an earthquake? They use the **seismogram** recordings made on the **seismographs** at the surface of the earth to determine how large the earthquake was (figure below). A short wiggly line that doesn't wiggle very much means a small earthquake, and a long wiggly line that wiggles a lot means a large earthquake. The length of the wiggle depends on the size of the fault, and the size of the wiggle depends on the amount of slip. The size of the earthquake is called its **magnitude**. There is one magnitude for each earthquake. Scientists also talk about the *intensity* of shaking from an earthquake, and this varies depending on where you are during the earthquake.

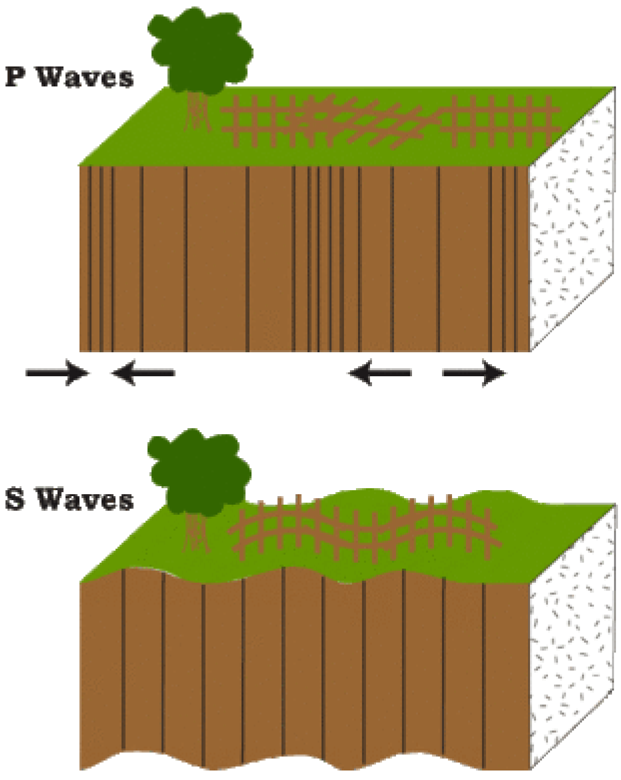


The cartoon sketch of the seismograph shows how the insrument shakes with the earth below it, but the recording device remains stationary (instead of the other way around). (Public domain.)

How can scientists tell where the earthquake happened?

Seismograms come in handy for locating earthquakes too, and being able to see the **P wave** and the **S wave** is important. You learned how P & S waves each shake the ground in different ways as they travel through it. P waves are also faster than S waves, and this fact is what allows us to tell where an earthquake was. To understand how this works, let's compare P and S waves to lightning and thunder. Light travels faster than sound, so during a thunderstorm you will first see the lightning and then you will hear the thunder. If you are close to the lightning, the thunder will boom right after the lightning, but if you are far away from the lightning, you can count several seconds before you hear the thunder. The further you are from the storm, the longer it will take between the lightning and the thunder.

P waves are like the lightning, and S waves are like the thunder. The P waves travel faster and shake the ground where you are first. Then the S waves follow and shake the ground also. If you are close to the earthquake, the P and S wave will come one right after the other, but if you are far away, there will be more time between the two.



P Waves alternately compress and stretch the crustal material parallel to the direction they are propagating. S Waves cause the crustal material to move back and forth perpendicular to the direction they are travelling. (Public domain.)

By looking at the amount of time between the P and S wave on a seismogram recorded on a seismograph, scientists can tell how far away the earthquake was from that location. However, they can’t tell in what direction from the seismograph the earthquake was, only how far away it was. If they draw a circle on a map around the station where the **radius** of the circle is the determined distance to the earthquake, they know the earthquake lies somewhere on the circle. But where?

Scientists then use a method called **triangulation** to determine exactly where the earthquake was. It is called triangulation because a triangle has three sides, and it takes three seismographs to locate an earthquake. If you draw a circle on a map around three different seismographs where the **radius** of each is the distance from that station to the earthquake, the intersection of those three circles is the **epicentre**!

Effects of earthquakes

Shaking and ground rupture

Shaking and ground rupture are the main effects created by earthquakes, principally resulting in more or less severe damage to buildings and other rigid structures. The severity of the local effects depends on the complex combination of the earthquake magnitude, the distance from the epicentre, and the local geological and geomorphological conditions, which may amplify or reduce wave propagation. The ground-shaking is measured by ground acceleration. Specific local geological, geomorphological, and geo-structural features can induce high levels of shaking on the ground surface even from low-intensity earthquakes. This effect is called site or local amplification. It is principally due to the transfer of the seismic motion from hard deep soils to soft superficial soils and to effects of seismic energy focalization owing to typical geometrical setting of the deposits. Ground rupture is a visible breaking and displacement of the Earth's surface along the trace of the fault, which may be of the order of several meters in the case of major earthquakes. Ground rupture is a major risk for large engineering structures such as dams, bridges, and nuclear power stations and requires careful mapping of existing faults to identify any that are likely to break the ground surface within the life of the structure.

Soil liquefaction.

Soil liquefaction occurs when, because of the shaking, water-saturated granular material (such as sand) temporarily loses its strength and transforms from a solid to a liquid. Soil liquefaction may cause rigid structures, like buildings and bridges, to tilt or sink into the liquefied deposits. For example, in the 1964 Alaska earthquake, soil liquefaction caused many buildings to sink into the ground, eventually collapsing upon themselves.

Human impacts

An earthquake may cause injury and loss of life, road and bridge damage, general property damage, and collapse or destabilization (potentially leading to future collapse) of buildings.

The aftermath may bring disease, lack of basic necessities, mental consequences such as panic attacks, depression to survivors, and higher insurance premiums.

Landslides.

Earthquakes can produce slope instability leading to landslides, a major geological hazard. Landslide danger may persist while emergency personnel are attempting rescue.

Fires

Earthquakes can cause fires by damaging electrical power or gas lines. In the event of water mains rupturing and a loss of pressure, it may also become difficult to stop the spread of a fire once it has started. For example, more deaths in the 1906 San Francisco earthquake were caused by fire than by the earthquake itself.

Tsunami

Tsunamis are long-wavelength, long-period sea waves produced by the sudden or abrupt movement of large volumes of water—including when an earthquake occurs at sea. In the open ocean the distance between wave crests can surpass 100 kilometres (62 mi), and the wave periods can vary from five minutes to one hour. Such tsunamis travel 600–800 kilometres per hour (373–497 miles per hour), depending on water depth. Large waves produced by an earthquake or a submarine landslide can overrun nearby coastal areas in a matter of minutes. Tsunamis can also travel thousands of kilometres across open ocean and wreak destruction on far shores hours after the earthquake that generated them.

Ordinarily, subduction earthquakes under magnitude 7.5 do not cause tsunamis, although some instances of this have been recorded. Most destructive tsunamis are caused by earthquakes of magnitude 7.5 or more.

Floods

Floods may be secondary effects of earthquakes, if dams are damaged. Earthquakes may cause landslips to dam rivers, which collapse and cause floods. The terrain below the Sarez Lake in Tajikistan is in danger of catastrophic flooding if the landslide dam formed by the earthquake, known as the Usoi Dam, were to fail during a future earthquake. Impact projections suggest the flood could affect roughly 5 million people.

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