Introduction

- Earthquakes represent the vibration of Earth because of movements on faults.
- The focus is the point on the fault surface where motion begins.
- The epicenter is the point on Earth's surface directly above the focus.

TABLE 11.4 Some Notable Earthquakes

Year	Location	Deaths (est.)	Magnitude†	Comments
1556	Shensi, China	830,000		Possibly the greatest natural disaster.
1755	Lisbon, Portugal	70,000		Tsunami damage extensive.
*1811–1812	New Madrid, Missouri	Few	7.9	Three major earthquakes.
*1886	Charleston, South Carolina	60		Greatest historical earthquake in the eastern United States.
*1906	San Francisco, California	1500	7.8	Fires caused extensive damage.
1908	Messina, Italy	120,000		
1923	Tokyo, Japan	143,000	7.9	Fire caused extensive destruction.
1960	Southern Chile	5700	9.6	Possibly the largest-magnitude earthquake ever recorded.
*1964	Alaska	131	9.2	Greatest North American earthquake.
1970	Peru	66,000	7.8	Great rockslide.
*1971	San Fernando, California	65	6.5	Damage exceeded $1 billion.
1975	Liaoning Province, China	1328	7.5	First major earthquake to be predicted.
1976	Tangshan, China	240,000	7.6	Not predicted.
1985	Mexico City	9500	8.1	Major damage occurred 400 km from epicenter.
1988	Armenia	25,000	6.9	Poor construction practices.
*1989	Loma Prieta, California	62	6.9	Damages exceeded $6 billion.
1990	Iran	50,000	7.3	Landslides and poor construction practices caused great damage.
1993	Latur, India	10,000	6.4	Located in stable continental interior.
*1994	Northridge, California	57	6.7	Damages in excess of $40 billion.
1995	Kobe, Japan	5472	6.9	Damage estimated to exceed $100 billion.
1999	Izmit, Turkey	17,127	7.4	Nearly 44,000 injured and more than 250,000 displaced
1999	Chi-Chi, Taiwan	2300	7.6	Severe destruction; 8700 injuries.
2001	El Salvador	1000	7.6	Triggered many landslides.
2001	Bhuj, India	20,000+	7.9	1 million or more homeless.

*U.S. earthquakes.
†Widely differing magnitudes have been estimated for some of these earthquakes. When available, moment magnitudes are used.
SOURCE: U.S. Geological Survey

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The deadly Izmit earthquake struck northwest Turkey on August 17, 1999, at 3 a.m. Over 14,000 residents of the region were killed as poorly constructed apartment complexes pancaked to the ground, each floor collapsing on the one below (Fig. 1). The death toll from this single event was greater than the average annual loss of life from all earthquakes worldwide.

Figure 1: Collapsed structures destroyed by the shallow 1999 Izmit, Turkey (left), and 1994 Northridge, California (right).

An earthquake occurs when Earth's surface shakes because of the release of seismic energy following the rapid movement of large blocks of the crust along a fault. Faults are breaks in the crust that may be hundreds of kilometers long and extend downward 10 to 20 km (6-12 miles) into the crust. The 1,200 km (750 miles) long San Andreas Fault that separates the North American and Pacific Plates in California is the most active fault system in the contiguous U.S. The Izmit earthquake occurred on the North Anatolian Fault, a fault that is of similar length and sense of movement as the San Andreas Fault. Unraveling the movement history of large faults that produce devastating but infrequent earthquakes can help predict the potential threat from similar faults elsewhere.

The point on the fault surface where movement begins, the earthquake source, is termed the **focus**.

Seismic waves radiate outward from the focus. Earthquake foci (plural of focus) occur at a range of depths. The majority of earthquakes occur at shallow depths that range from the surface down to 70 km (44 miles). Less frequent intermediate (70-300 km; 44-188 miles) and deep (300-700 km; 188-438 miles) earthquakes are generally associated with subduction zones where plates descend into the mantle.

Damage is greatest from shallow earthquakes because the seismic waves travel a shorter distance before reaching the surface. The earthquake effects, the type of damage associated with earthquakes, include changes in the natural environment such as landslides but most attention is focused on the impact on constructed structures. Building codes are in place in most earthquake-prone areas but they are of little use if enforcement is lax, as was the case in Turkey. Following the earthquake it was discovered that some contractors had cut corners in the construction of multistory apartment complexes. The poorly built structures were left as piles of rubble amongst other apartments that remained standing.

In contrast, on February 28, 2001, the strong Nisqually earthquake occurred below western Washington 56 km (35 miles) south of Seattle. Buildings in Seattle and the surrounding communities sustained relatively little structural damage, no one was killed, and only a handful of people received anything more than minor injuries. Seattle has enforced a stringent building code over the last 30 years that requires new structures to be able to withstand large earthquakes. In addition, over the last decade, many older buildings and bridges were retrofitted to ensure that they could endure the big earthquake predicted for the region. Residents in western Washington were doubly fortunate, not only did they have well-built structures but the earthquake occurred much further below the surface than the Izmit quake, further reducing the resulting ground shaking.

Seismic waves are captured by a recorder known as a **seismograph**. The relative arrival times of different types of seismic waves is used to determine the distance of the seismograph station from the origin of the earthquake.

Three or more records can be used to pinpoint the earthquake's **epicenter**, the geographic location of the point on the earth’s surface directly above the focus (Fig. 2). Earthquakes are named for the epicenter location, for example, the Nisqually earthquake occurred 53 km (33 miles) below the mouth of the Nisqually River in western Washington. Loss of life in the Turkish earthquake was greatest in the city of Izmit, located close to the earthquake's epicenter. **Earthquake distribution** is far from random. Earthquakes occur on faults that are preferentially located along plate boundaries. The largest earthquakes along convergent plate boundaries.

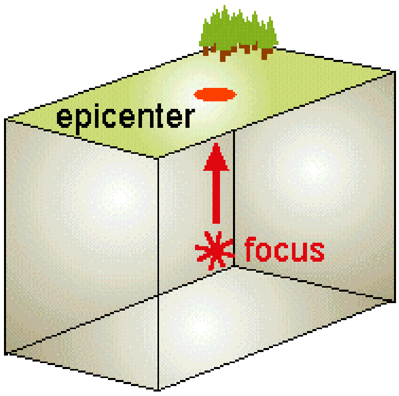


Figure 2: The focus is the source of the earthquake and the epicenter is the point on the surface directly above the focus.

Faults & Earthquakes

- Earthquakes represent the vibration of Earth because of movements on faults.
- Faults can be identified by the offset of rock layers on either side of the fault surface.
- Normal and reverse faults are types of dip-slip faults.
- Left-slip and right-slip faults are types of strike-slip faults.

An earthquake occurs when Earth shakes because of the release of seismic energy following the rapid movement of large blocks of the crust along a fault. A fault is a fracture in the crust. During the Izmit earthquake, the crust broke along the North Anatolian Fault in northern Turkey (Fig. 3). When fault movement occurs it may be slow and gradual and generate only small earthquakes, or it may be rapid and catastrophic causing widespread destruction. Ground shaking associated with most earthquakes is over in a matter of seconds but it involves such large regions of Earth's crust that tremendous amounts of energy are released. The ground shook for 45 seconds in the Izmit earthquake and affected a region of approximately 100,000 square kilometers.

Faults may be hundreds of kilometers in length but only part of longer faults typically break during an earthquake (Fig. 3). Fault segments that have not experienced a recent earthquake are termed seismic gaps and are considered potential sites for future events. The Izmit earthquake occurred in a 150 km (94 mile) long gap at the western end of the North Anatolian Fault.

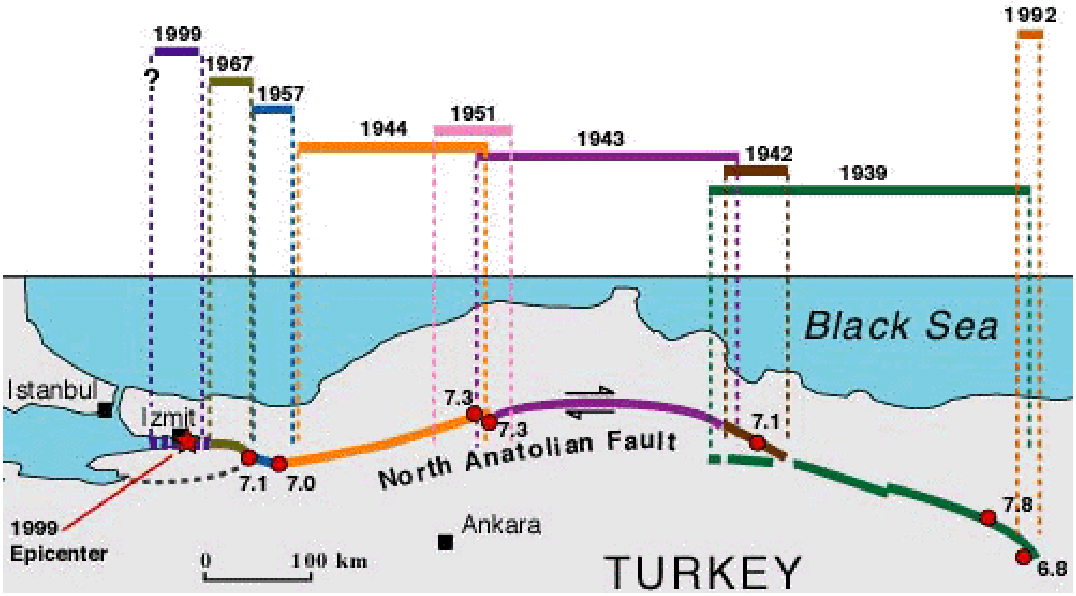


Figure 3: Earthquake sequence along the North Anatolian fault, Turkey, 1939-1999. A series of large earthquakes have occurred on the fault system; each resulting from only one segment of the fault breaking at a time.

Mechanism of earthquake generation

Elastic rebound

–Mechanism for earthquakes was first explained by H.F. Reid

»Rocks on both sides of an existing fault are deformed by tectonic forces

»Rocks bend and store elastic energy

»Slippage at the weakest point (the focus) occurs

»Vibrations (earthquakes) occur as the deformed rock releases the stored energy (elastic rebound)

Earthquakes most often occur along existing faults whenever the frictional forces on the fault surfaces are overcome (Fig. 4).

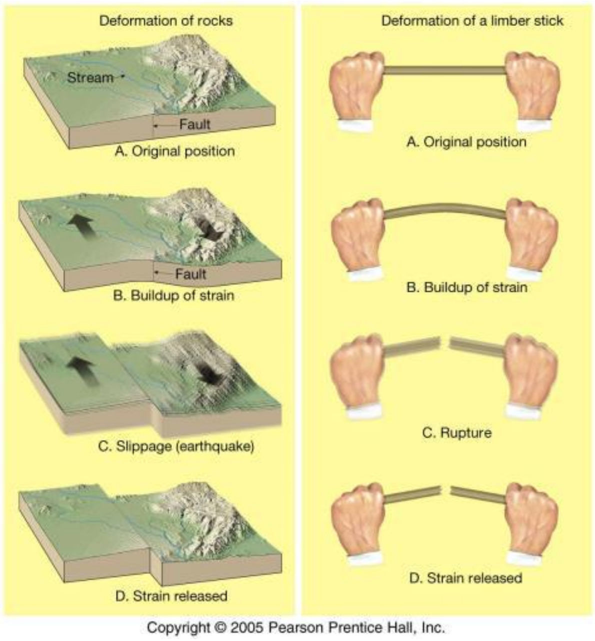


Figure 4: Mechanism of earthquake generation

Seismic Waves

• Seismic waves can be divided into surface waves that travel on Earth's surface and body waves that travel through Earth.

• Body waves are further divided into S waves and P waves.

• Seismic waves are recorded on a seismogram at a seismograph station.

• The distance of an earthquake epicenter from a seismograph station is determined by the difference in the arrival times of P and S waves at a seismograph station.

• Earthquake magnitude is calculated using the amplitude (height) of the S wave recorded on a seismogram.

Seismic waves represent the energy released from the earthquake focus. There are two types of seismic waves:

• **Surface waves** travel on Earth's surface and cause much of the destruction associated with earthquakes. Undulations of the land surface during an earthquake are a representation of surface waves (Fig. 5). Surface waves may result in vertical motions (**Rayleigh waves**), much like waves traveling through water, or sideways motions (**Love waves**) with no vertical component of movement.

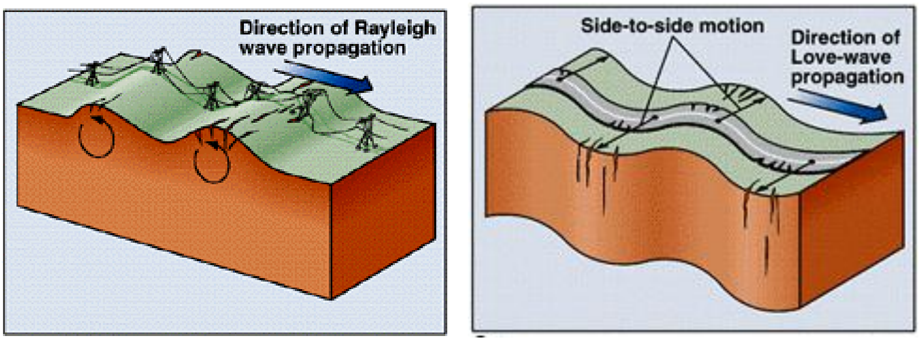


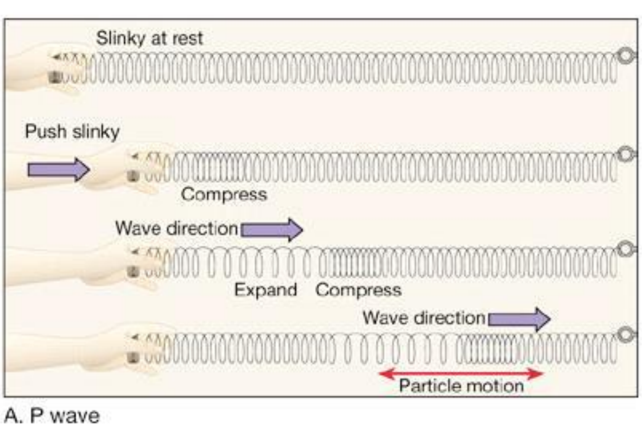
Figure 5: Rayleigh (right) and Love waves (left) are surface waves with contrasting motion directions generated during an earthquake.

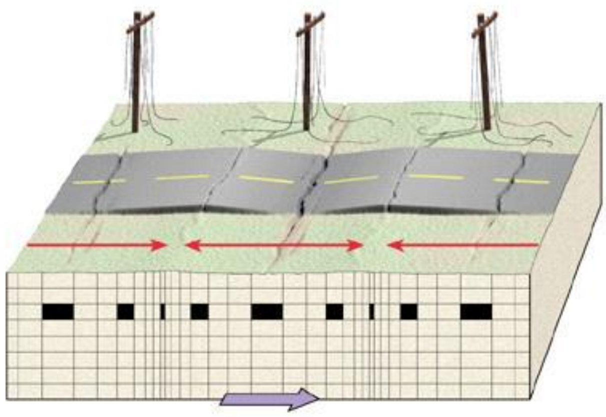
• **Body waves** travel through Earth's interior. These are further subdivided into P (primary) waves and S (secondary or shear) waves based upon their vibration direction and velocity. Variations in seismic wave velocity are used to infer the properties of Earth's interior.

P waves vibrate parallel to their travel direction in the same way a vibration passes along a slinky toy. P waves travel at speeds of 4 to 6 km per second (2.5-4 miles per second) in the uppermost part of the crust.

–Push-pull (compress and expand) motion, changing the volume of the intervening material

–Travel through solids, liquids, and gases



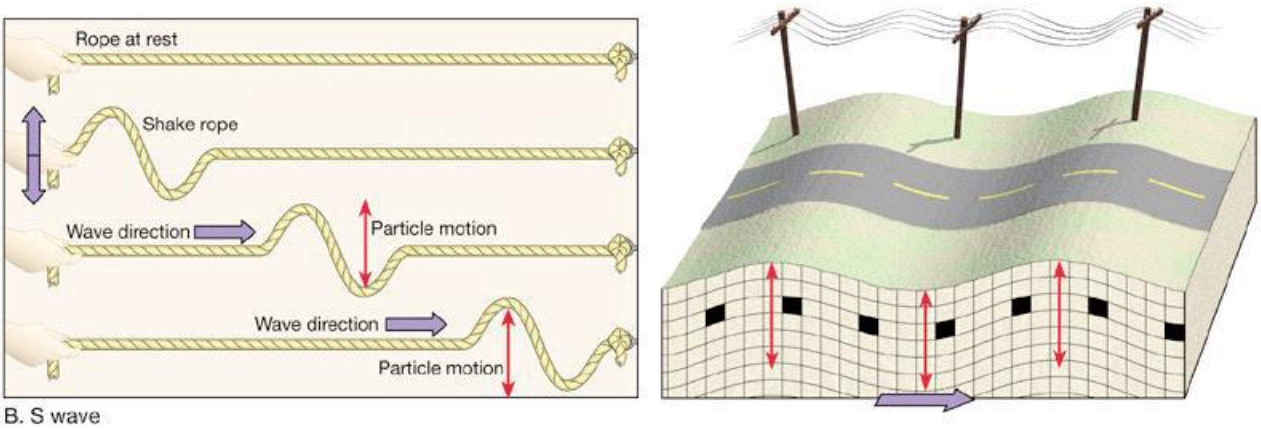


S waves vibrate perpendicular to their travel direction, like the wave that passes along a rope when it is given a sharp jerk. S wave velocity is 3 to 4 km per second (2-2.5 miles per second) in the shallow crust.

–Slower velocity than P waves

–Slightly greater amplitude than P waves

–Second to appear at recording station



B. S wave