

# Earthquakes

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## Introduction

Though we seldom feel them, earthquakes are not rare. Every 24 hours, more than 1,000 earthquakes occur around the world. Earthquakes are produced when rocks beneath the earth's surface suddenly move along **faults**, which are fractures that occur at weak points in the earth. This movement releases stress—energy that has been built up by forces inside the earth. The strength of the earthquake depends on the amount of stress released.

## Earthquakes and Plate Tectonics

To understand earthquakes, we need to know something about the theory of **plate tectonics**. According to this theory, the earth's **lithosphere**, a shell 120 miles (200 km) thick, is broken into several rigid slabs, or **plates**, that slide over the uppermost layer of the mantle (fig. 1). Seven major oceanic and continental plates have been identified, along with a number of smaller plates. Moving at rates of 10 to 130 millimeters (0.4 to 5 inches) per year, these plates interact with one another in various ways, producing mountain belts, volcanoes, and earthquakes.

Geologists have identified several types of plate movements associated with earthquakes. A well-known example is the movement of plates along the San Andreas fault in California. Here, the North American and Pacific Plates scrape past one another, the Pacific Plate moving to the northwest and the North American Plate moving in the opposite direction. Because friction prevents the plates from gliding easily past one another, enormous stresses build up and are periodically relieved by large earthquakes. The 1906 San Francisco and the 1989 "World Series" (Loma Prieta) earthquakes resulted

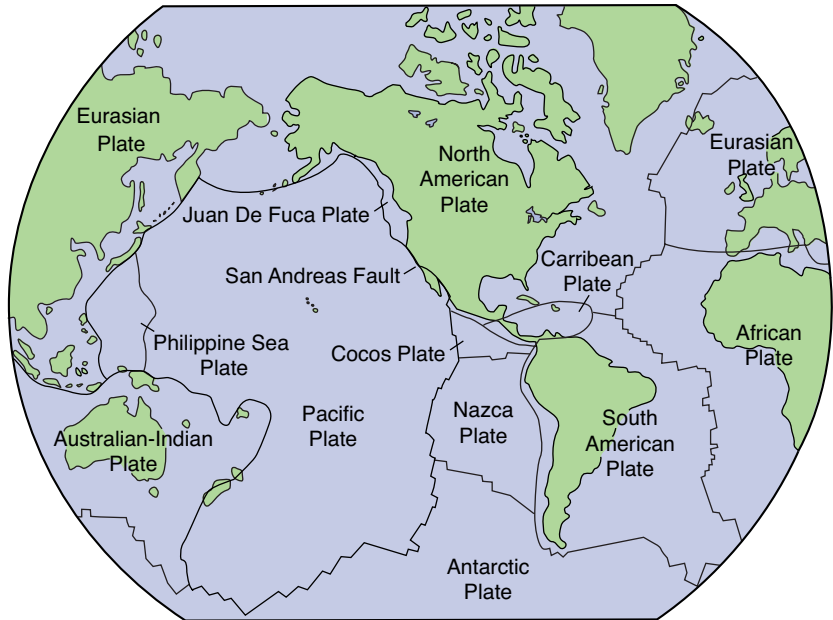


Figure 1—Simplified map of the earth's crustal plates (U.S. Geological Survey, 1990, Professional Paper 1515).

from sudden movement along this fault system.

Along the western coast of South America is an example of another type of plate movement associated with the collision of oceanic and continental plates. Here, in what is called a **subduction zone**, the Pacific plate is thrust, or subducted, under the South American plate, forming a deep oceanic trench. Earthquakes along this boundary are either shallow or deep, depending on where they occur on the downsloping plate. The oceanic plate eventually descends to a depth at which the mantle temperature is high enough to melt part of it into molten rock, or **magma**. This magma then

returns to the surface during volcanic activity, such as that which occurs around the rim of the Pacific Ocean, including the 1980 eruption of Mount St. Helens in Washington.

## Where Earthquakes Occur

About 98 percent of all earthquakes occur in well-defined zones around the world, corresponding with the boundaries of the tectonic plates (fig. 2). Seventy-five

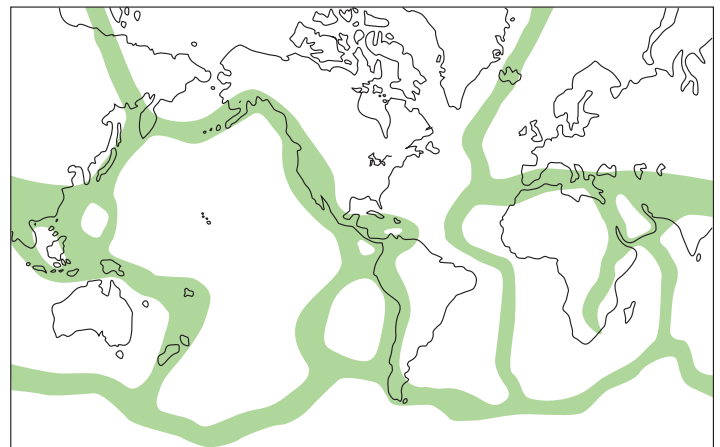


Figure 2—Principal earthquake zones of the earth (shaded in green). More than 98% of all earthquakes occur within these zones.

percent of the earthquakes occur in the zone around the Pacific Ocean. Twenty-three percent occur in a zone that ranges from the Mediterranean Sea through southern Asia and into China.

The remaining two percent of earthquakes, which occur in the interiors of the major plates, cannot be explained by plate tectonics. Notable examples of such earthquakes are the three very large New Madrid, Missouri, earthquakes that shook the eastern half of the United States in the winter of 1811–12. In terms of the amount of land shaken, these earthquakes were the largest in recorded U.S. history.

Seismologists classify areas of the United States according to the amount of earthquake damage they could expect to receive over several decades or more (fig. 3). Large areas of California, Nevada, Utah, Idaho, and Yellowstone National Park are in the major damage zone, as are smaller areas in Missouri, South Carolina, and New England. Kansas, for the most part, is classified as a minor damage zone, although a zone of moderate damage runs across the state from Nebraska to Oklahoma. Research results that provide information about seismic risk for a given area are incorporated into local building codes used by architects and engineers.

The amount of damage that occurs during an earthquake is closely related to the geology of an area. This relationship was first scientifically observed in the damage pattern of the 1906 San Francisco earthquake. The most severe damage occurred on “made land,” where people used fill to raise land in areas that were formerly below sea level. Similarly, the major damage in San Francisco from the 1989 Loma Prieta earthquake was on made land, showing people’s unfortunate tendency to ignore the lessons of history.

### Recording and Measuring Earthquakes

Earthquakes generate vibrations called **seismic waves** that travel through the earth in all directions from the **focus**, the point beneath the earth’s surface where the earthquake begins. The point on the earth’s surface directly above the focus, where the strongest shaking occurs, is called the **epicenter**. Shaking decreases with distance from the epicenter.

Seismologists use sensitive instruments called **seismometers** to record the waves. Seismometers can electronically amplify seismic waves more than 10,000 times and are sensitive enough to detect strong earthquakes originating anywhere in the world. The time, location, and magnitude of an earthquake can be determined from a graphical plot of the data called a **seismogram**.

To measure the strength of an earthquake, seismologists use two different types of scales: intensity scales and magnitude scales. The **Modified Mercalli Intensity scale** gauges earthquakes by their effect on people and structures. It was originally developed in 1902 in Italy and relies on newspaper and eyewitness reports. This scale also is used to estimate the size, or magnitude, of earthquakes that occurred before sensitive instruments existed to measure them. It has 12 levels designated by roman numerals, ranging from imperceptible shaking (I) to catastrophic destruction (XII) (fig. 4).

The most readily recognized magnitude scale is the **Richter magnitude scale**. It was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. Since then, other magnitude scales based on different mathematical formulas that overcome some of the Richter scale’s limitations have been developed. In the United States, the most commonly used scale today is the **moment magnitude scale**, which is based on a formula that more accurately measures medium and large earthquakes than Richter’s. Because the numbers on the Richter scale have become so universally familiar, all measurements calculated with the different formulas are converted into numbers comparable to those on the Richter scale.

Using records of seismic waves plotted on a seismogram, seismologists determine magnitude mathematically based on the size of the recorded waves and the calculated distance between the earthquake focus and the seismometer. Magnitude scales express magnitude in whole numbers and decimal fractions. Each increase in magnitude by one whole number represents a

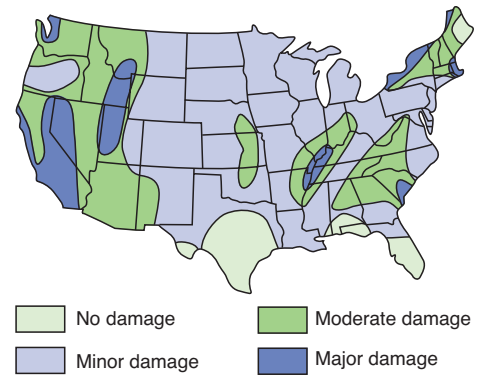


Figure 3 — Map of earthquake risk.

Modified Mercalli Scale		Richter Magnitude Scale
I	Detected only by sensitive instruments	1.5
II	Felt by few persons at rest, especially on upper floors; delicately suspended objects may swing	2
III	Felt noticeably indoors, but not always recognized as earthquake; standing autos rock slightly, vibration like passing truck	2.5
IV	Felt indoors by many, outdoors by few, at night some may awaken; dishes, windows, doors disturbed; motor cars rock noticeably	3
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects	3.5
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small	4
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of automobiles	4.5
VIII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed	5
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken	5.5
X	Most masonry and frame structures destroyed; ground cracked, rails bent, landslides	6
XI	Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rails bent	6.5
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up into air	7

Figure 4 — Approximate comparison for the U.S. Midcontinent of Modified Mercalli and Richter scales at locations very near the epicenter.

tenfold increase in measured wave size. In terms of energy, each whole-number increase represents 31 times more energy released. For example, a magnitude 5.3 earthquake releases 31 times more energy than a magnitude 4.3 earthquake.

The world averages about 20 earthquakes each year of magnitude 7.0 or larger. The largest earthquake

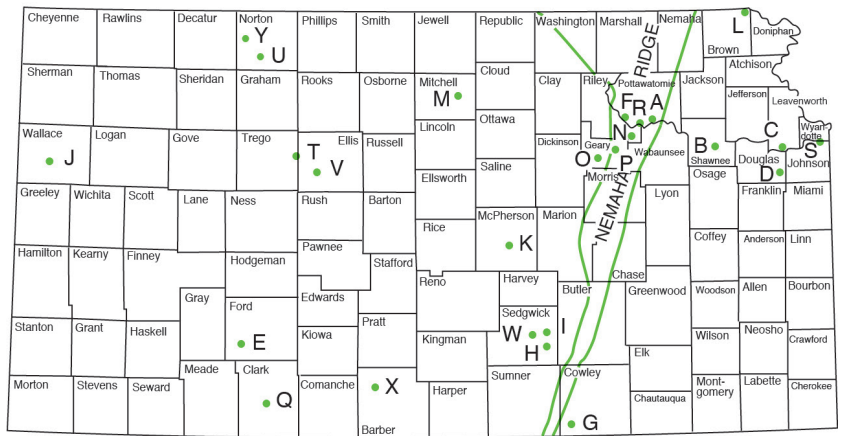
ever recorded in the world was a magnitude 9.5 in Chile in 1960. Sensitive seismometers are capable of recording nearby earthquakes of magnitudes  $-1.0$  or smaller. A person with a sledgehammer can generate the equivalent of a magnitude  $-4.0$  earthquake.

An earthquake's magnitude does not necessarily express the damage it caused. In a densely populated area, an earthquake may do far more damage than one of greater magnitude that occurs in a remote area. For example, the magnitude 6.8 earthquake that hit Kobe, Japan, on January 16, 1995, killed 6,308 people and injured thousands of others. Though it was the deadliest earthquake in 1995, its magnitude was lower than 25 other earthquakes recorded that year. Although magnitude scales and the Modified Mercalli Intensity scale are not strictly comparable, they can be roughly correlated for locations near the epicenter of an earthquake (fig. 4).

### Earthquakes in Kansas

Many Kansans have never felt so much as a tremor, but at least 25 earthquakes were felt in the state between 1867 and 1976 (fig. 5). The Kansas Geological Survey (KGS) also measured more than 100 earthquakes during a study of Kansas seismic activity between 1977 and 1989 (fig. 6). Most of the ones the KGS detected were **microearthquakes**, or earthquakes too small to feel. The largest recorded Kansas earthquake was centered near Wamego east of Manhattan in 1867. Measuring VII on the Modified Mercalli scale, it toppled chimneys, cracked foundations, and was felt as far away as Dubuque, Iowa. Estimating the magnitude based on the intensity near the epicenter, it probably measured between magnitude 5.0 and 5.5.

Some Kansas earthquakes are associated with the Nemaha Ridge, a buried mountain range that extends from roughly Omaha, Nebraska, to Oklahoma City (fig. 7). The ridge was formed about 300 million years ago and is bounded by faults that are still slightly active today, especially the Humboldt fault zone that forms the eastern boundary of the Nemaha Ridge and passes near Wamego, east of Manhattan, and El Dorado, east of Wichita. About 50 miles (80 km) west of the Nemaha Ridge is the Midcontinent rift, a zone of the earth's continental crust that was ripped apart and filled with oceanic-type crust (basaltic rocks) about 1.1 billion years ago. This zone of rifting extended from central Kansas near Salina, northeastward across Nebraska, Iowa, and Minnesota, and into the Lake Superior region. For unknown reasons, the rifting stopped after spreading only about 30 to 50 miles (50–80 km); if it had not stopped, eastern and western Kansas would likely be on different continents today.



A. 1867 VII	F. 1906 VII	K. 1927 V	P. 1929 V	U. 1933 V
B. 1875 V	G. 1907 IV	L. 1927 VI	Q. 1929 V	V. 1942 IV
C. 1881 III	H. 1919 IV	M. 1928 IV	R. 1929 V	W. 1948 IV
D. 1902 II	I. 1919 IV	N. 1929 V	S. 1931 VI	X. 1956 VI
E. 1904 IV	J. 1926 ?	O. 1929 V	T. 1932 V	Y. 1961 V

Figure 5—Historical earthquakes in Kansas, prior to 1977.

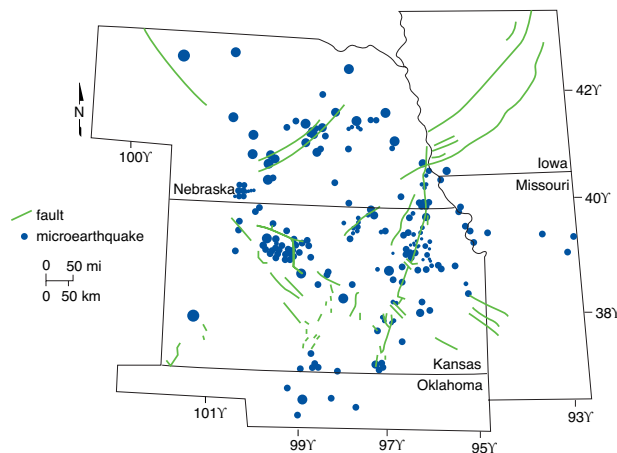


Figure 6—Microearthquakes recorded by the Kansas Geological Survey between August 1977 and August 1989 are size-coded by local magnitude. The largest event had a magnitude of 4.0 and the smallest had a magnitude of 0.8 on the Richter scale.

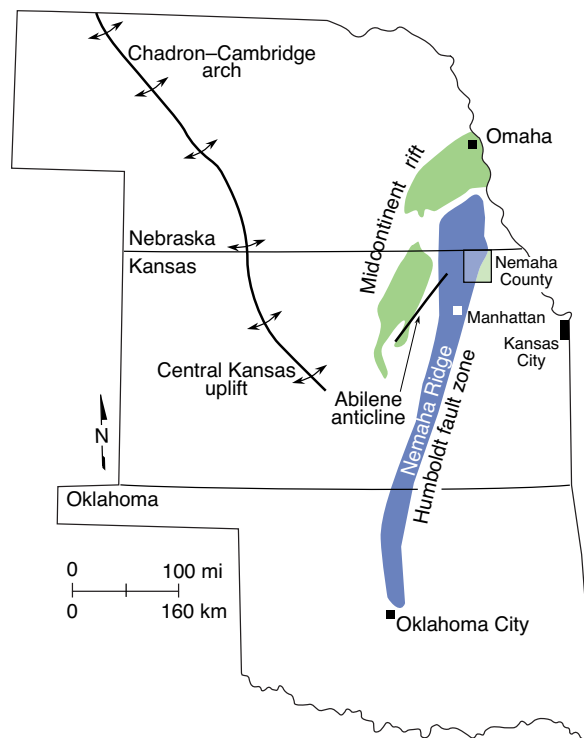


Figure 7—Major regional tectonic features that are apparently related to earthquake activity. Nemaha County is the locality where the Nemaha Ridge was discovered by drilling in the early 1900s (Kansas Geological Survey, 1989, Bulletin 226).

## Recording Kansas Earthquakes

To better understand earthquakes in Kansas, seismologists at the KGS maintained a network of seismometers throughout the state from December 1977 to June 1989 to monitor seismic activity. The network could pick up ground movements 1,000 times smaller than the thickness of a human hair. The recording stations could detect artillery firings at Fort Riley from 30 miles (50 km) away and also registered large earthquakes from locations as distant as Japan and South America.

During 12 years of recording, more than 200 small earthquakes in Kansas and Nebraska were registered (fig. 6). The largest measured about magnitude 4.0, and the smallest was magnitude 0.8. Seismograms from an earthquake that occurred southeast of Seneca, Kansas,

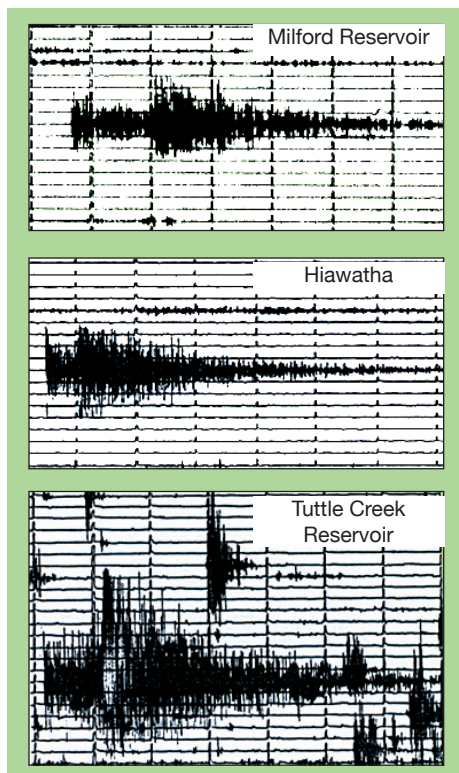


Figure 8—Seismograms from January 27, 1978, earthquake that occurred southeast of Seneca, Kansas.

on January 27, 1978, are shown in fig. 8. The record of the earthquake appears as a broad black area. These recordings were from stations at Milford Reservoir, Hiawatha, and Tuttle Creek Reservoir. The Tuttle Creek recording also shows some smaller blackened areas caused by artillery explosions at Fort Riley.

In the late 1980s, several small earthquakes were recorded in western Kansas northeast of Hays and near Palco, about 30 miles (50 km) northwest of Hays. These earthquakes occurred along faults associated with the Central Kansas Uplift (fig. 7). Many of the tremors had magnitudes of about 2.0. The largest was a magnitude 4.0 earthquake in June 1989 that measured IV on the Modified Mercalli Intensity scale at Palco and did minor damage.

The amount of earthquake activity observed in Kansas between 1977 and 1989 is consistent with the number and location of earthquakes experienced between 1867 and 1976, and Kansas will continue to have occasional, unpredictable, small-to-moderate earthquakes. By combining historical earthquake data with that obtained between 1977 and 1989, seismologists estimate that a magnitude 6.0 earthquake may occur in Kansas about every 2,000 years. Engineers and others use information collected during the KGS study when refining building codes, retrofitting dams, and constructing power plants. The data also were used to refine and update seismic hazard maps. Though the risk of a major earthquake in Kansas is slight, it is important to know the risk and build structures that will withstand any earthquakes that are likely to occur.

### Induced Seismicity

Beginning in 2013, Kansas saw an increase in seismic activity, particularly in the south-central part of the state. Several of those tremors were strong

### Related KGS Public Information Circulars

- *Induced Seismicity: The Potential for Triggered Earthquakes in Kansas* by Rex C. Buchanan, K. David Newell, Catherine S. Evans, and Richard D. Miller, KGS Public Information Circular 36, 2014, 6 p.
- *Seismology and Its Applications in Kansas* by Shelby L. Peterie, Richard D. Miller, and Julian Ivanov, KGS Public Information Circular 37, 2014, 6 p.

enough to be felt. Researchers are uncertain about the cause of the activity, though they are studying the possibility that it was triggered by human actions, such as the injection of saltwater—extracted during oil and gas production—into deep wastewater disposal wells. At the same time, there was a significant increase in seismic activity in Oklahoma, some of which has been linked to human activity. This is commonly referred to as **induced seismicity**. Several of the Oklahoma earthquakes were strong enough to be felt in much of Kansas. Located near disposal wells but also in areas historically prone to seismic activity, their causes are still under investigation.

### For Further Information

Additional information is available on the World Wide Web. We've listed only a few, but these will connect you to a wide range of up-to-date information on earthquakes.

**Earthquake information from the USGS**  
<http://earthquake.usgs.gov/>

**National Earthquake Information Center**  
<http://earthquake.usgs.gov/regional/neic/>

**Kansas Geological Survey**  
<http://www.kgs.ku.edu>

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The mission of the Kansas Geological Survey, operated by the University of Kansas in connection with its research and service program, is to conduct geological studies and research and to collect, correlate, preserve, and disseminate information leading to a better understanding of the geology of Kansas, with special emphasis on natural resources of economic value, water quality and quantity, and geologic hazards.

The Geology Extension program furthers the mission of the KGS by developing materials, projects, and services that communicate information about the geology of Kansas, the state's earth resources, and the products of the Kansas Geological Survey.

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