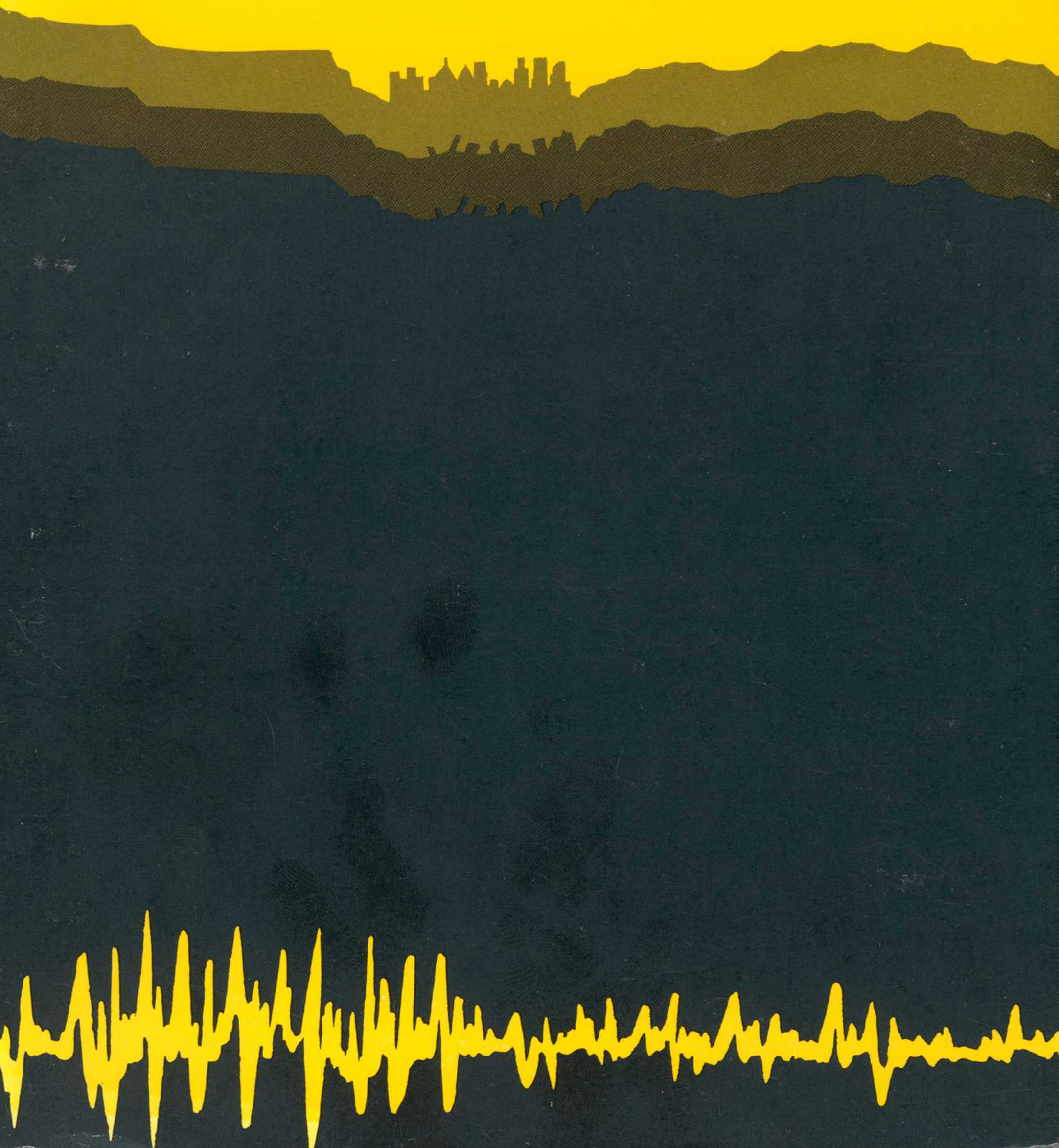
U.S. Department of the Interior / U.S. Geological Survey

Earthquakes



Earthquakes

by Louis C. Pakiser

This aerial view shows Turnagain Heights in Anchorage, Alaska, shortly after the March 27, 1964, earthquake.

One of the most frightening and destructive phenomena of nature that man experiences is a severe earthquake and its terrible aftereffects. Since long before man existed, probably for more than 4 billion years, the forces within the Earth that produce earthquakes have played an active role in shaping the Earth's surface. These unpredictable catastrophic movements of the Earth have caused a great number of human casualties and extensive property damage.

Today man is challenging the assumption that earthquakes must present an uncontrollable and unpredictable hazard to life and property. Scientists have begun to explore the means of predicting earthquakes. Sites of greatest hazard are being identified, and definite progress is being made in designing structures that will withstand the effects of earthquakes.

USGS scientist uses portable seismic recording equipment near Mount St. Helens, Washington.

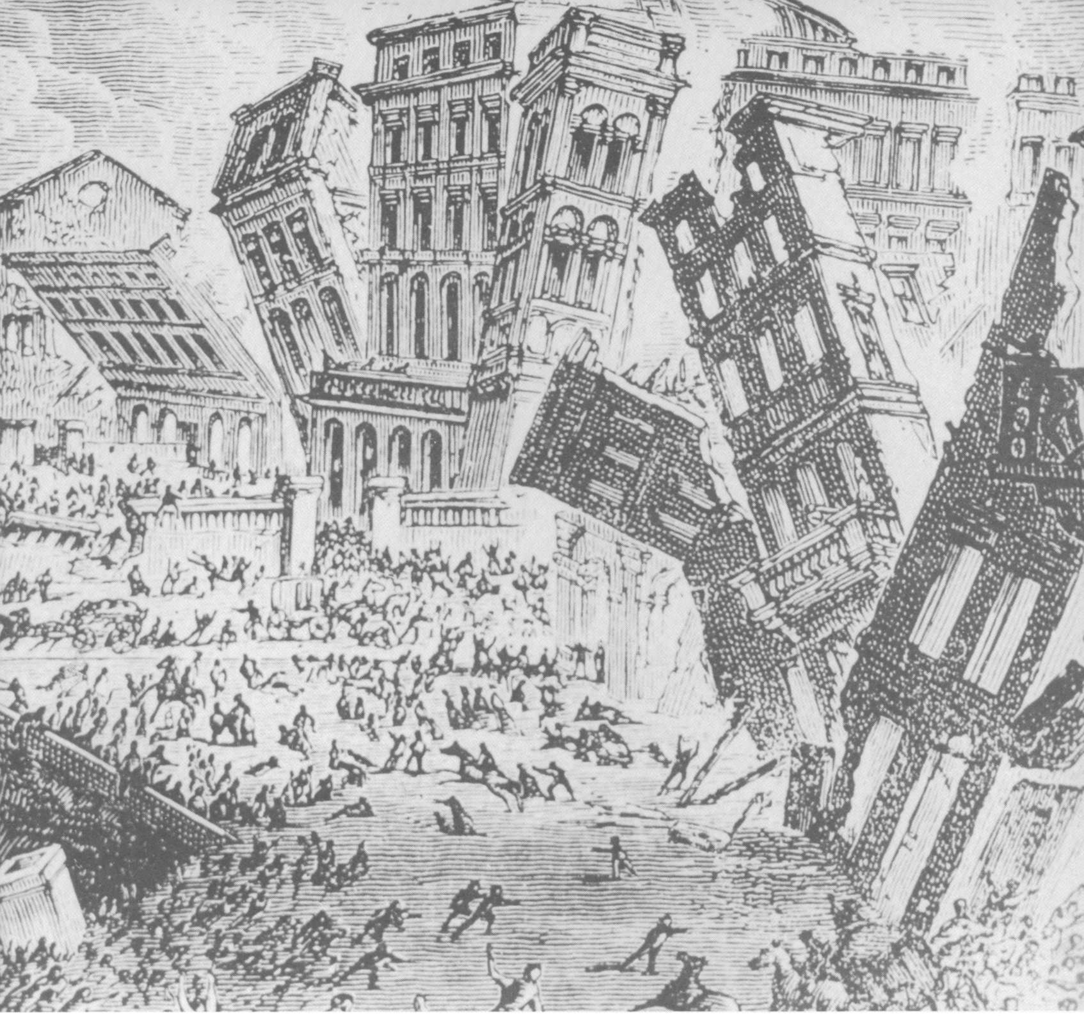
Earthquakes in History

The scientific study of earthquakes is comparatively new. Until the 18th century few factual descriptions of earthquakes were recorded, and the natural cause of earthquakes was little understood. Many people believed that an earthquake was a massive punishment and a warning to the unrepentant. A 16th century scholar, for example, suggested that statues of Mercury and Saturn be placed on each wall of buildings to protect against earthquakes. Those who did look for natural causes often reached fanciful conclusions; one popular theory was that earthquakes were caused by air rushing out of caverns deep in the Earth's interior.

An early earthquake for which we have detailed descriptive information occurred on November 1, 1755, in the vicinity of Lisbon, Portugal. Shocks from the quake were felt in many parts of the world. In some parts of the United States chandeliers rattled, and in Europe buildings trembled.

After the quake, Portuguese priests were asked to document their observations. Their records, still preserved, represent the first systematic attempt to investigate an earthquake and its effects. Since then, detailed records have been kept of almost every major earthquake.

The most widely felt earthquakes in the recorded history of North America were a series that occurred in 1811-12 near New



"The sea rose boiling in the harbour and broke up all the craft harboured there; the city burst into flames, and ashes covered the streets and squares; the houses came crashing down, roofs piling up on foundations, and even the foundations were smashed to pieces. Thirty thousand inhabitants of both sexes and all ages were crushed to death under the ruins."

—from *Candide;* Voltaire

Madrid, Mo. The shocks started December 16, 1811, and continued intermittently for 2 days. Large shocks followed on January 23, 1812, and again on February 7. The largest of these quakes was felt over an area of 2 million square miles—from Canada to the Gulf of Mexico and from the Rocky Mountains to the Atlantic Ocean. Because the most intense effects were in a sparsely populated region, the destruction of human life and property was slight. If this earthquake occurred in the same area today, it probably would cause severe damage to many cities in the central Mississippi Valley.

The San Francisco earthquake of 1906 was one of the most destructive in the recorded history of North America—the earthquake and the fire that followed killed nearly 700 people and left the city in ruins. The Alaska earthquake of March 27, 1964, however, was of greater magnitude than the San Francisco earthquake; it released perhaps twice as much energy and was felt over an area of almost 500,000 square miles. The ground motion near the epicenter was so violent that the tops of some trees were snapped off. One hundred and fourteen people (some as far away as California) died as a result of this earthquake, but loss of life and property would have been far greater had Alaska been more densely populated.

Earthquake movement during the San Francisco earthquake caused the tracks to buckle.

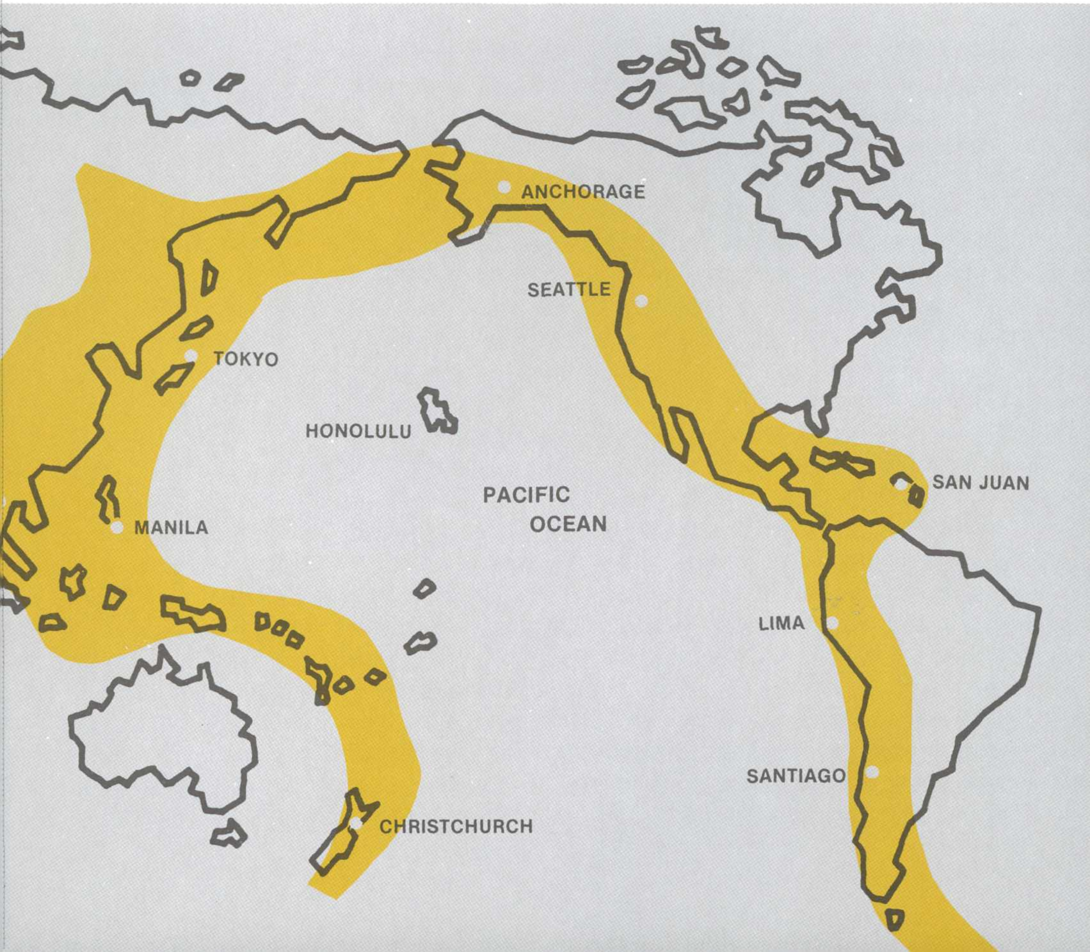
Locations of Earthquakes

Most earthquakes occur in areas bordering the Pacific Ocean. This circum-Pacific belt, called the "ring of fire," includes the Pacific coasts of North and South America, the Aleutians, Japan, Southeast Asia, and Australasia. Half a million people within this area have lost their lives because of earthquakes, and property valued in billions of dollars has been severely damaged or destroyed.

Earthquakes occur most frequently in those zones shown in yellow below.

The United States has experienced less destruction than other countries located in this ring of fire, but millions of Americans live in potential quake areas. Large parts of the Western United States are known to be particularly vulnerable. Nuclear reactors, great dams, schools, and high-rise apartments and other housing developments are being planned and built in places where the danger of major earthquakes is ever present. This has created an urgent need for more information on the nature, causes, and effects of earthquakes.

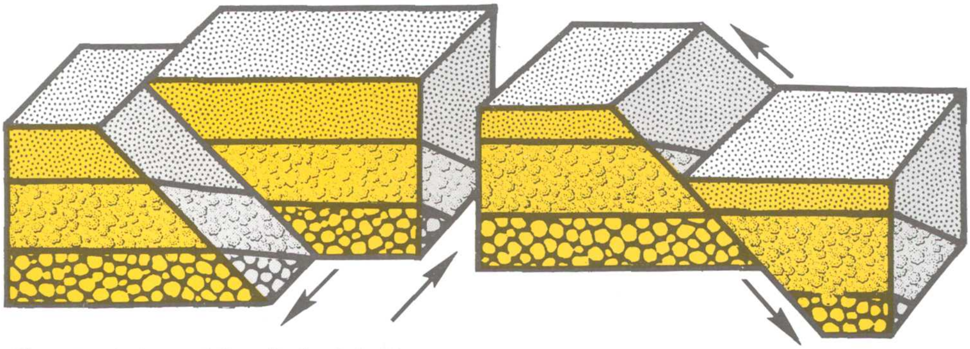
Scientists, including those of the U.S. Geological Survey's National Center for Earthquake Research in Menlo Park, Calif., are studying the causes of earthquakes in hopes of finding methods of prediction and of developing practices that will reduce the destructive effects of earthquakes.



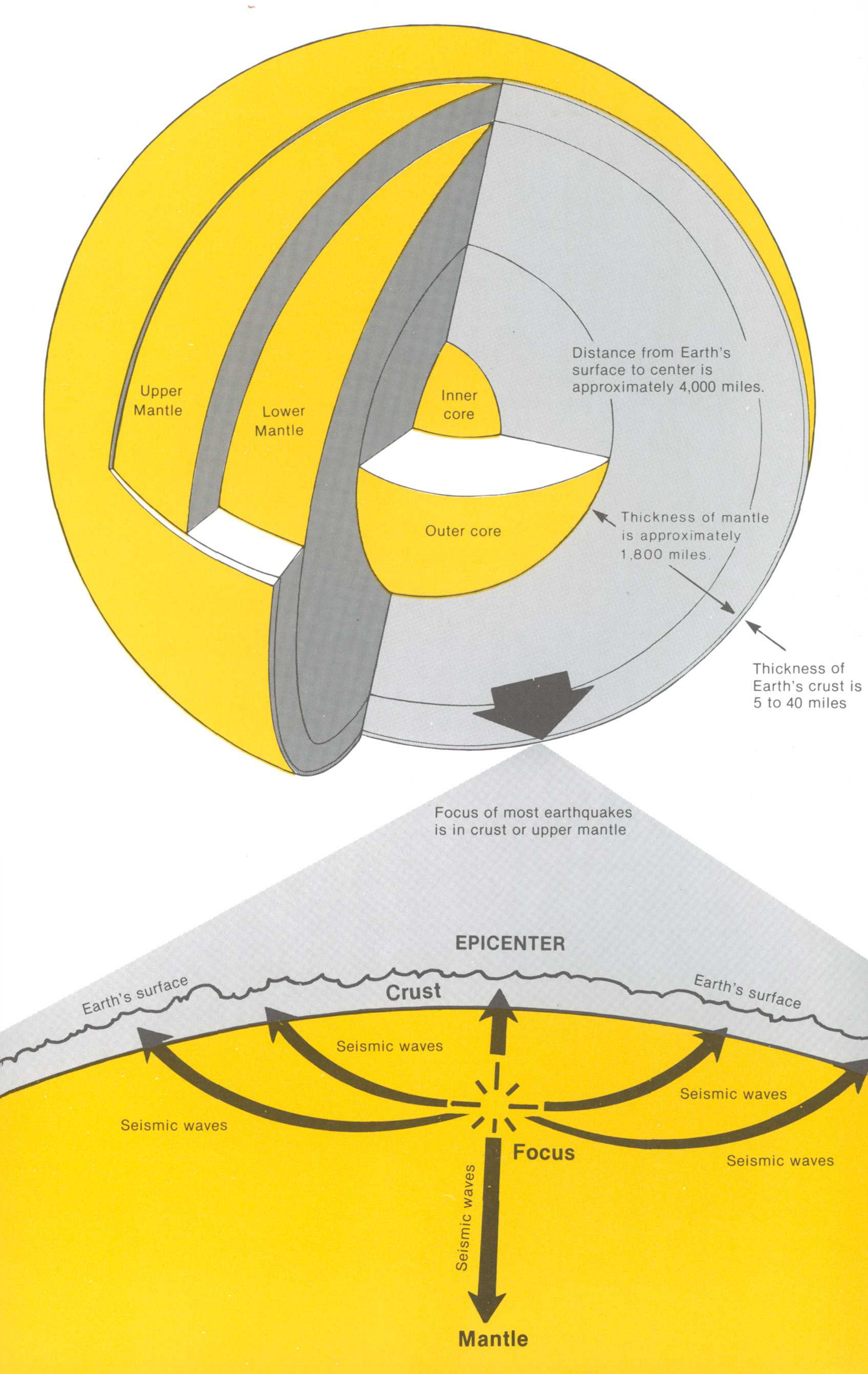
Nature of Earthquakes

An earthquake is the oscillatory, sometimes violent movement of the Earth's surface that follows a release of energy in the Earth's crust. This energy can be generated by a sudden dislocation of segments of the crust, by a volcanic eruption, or even by manmade explosions. Most of the destructive quakes, however, are caused by dislocations of the crust. When subjected to deep-seated forces (whose origins and natures are largely unknown) the crust may first bend and then, when the stress exceeds the strength of the rocks, break and "snap" to a new position. In the process of breaking, vibrations called "seismic waves" are generated. These waves travel from the source of the earthquake to more distant places along the surface and through the Earth at varying speeds depending on the medium through which they move. Some of the vibrations are of high enough frequency to be audible, while others are of very low frequency—actually many seconds or minutes between swings. These vibrations cause the entire planet to quiver or ring like a bell or a tuning fork.

A *fault* is a fracture in the Earth's crust along which two blocks of the crust have slipped with respect to each other. One crustal block may move horizontally in one direction while the block facing it moves in the opposite direction, or one block may move upward while the other moves downward. Faults are distinguished by the kinds of movements that characterize them. Movement along California's famous San Andreas Fault is predominantly horizontal, and the fault is called a *strike-slip* fault. A fault in which the movement is vertical is called a *dip-slip* fault. Along many faults, movement is both horizontal and vertical.



Movement along strike-slip fault (left).
Movement along dip-slip fault (right).



Upper Mantle
Lower Mantle
Inner core
Outer core
Distance from Earth's surface to center is approximately 4,000 miles.
Thickness of mantle is approximately 1,800 miles.
Thickness of Earth's crust is 5 to 40 miles
Focus of most earthquakes is in crust or upper mantle
EPICENTER
Earth's surface
Crust
Earth's surface
Seismic waves
Seismic waves
Seismic waves
Seismic waves
Focus
Seismic waves
Mantle

Geologists have found that earthquakes tend to reoccur along faults, which reflect zones of weakness in the Earth's crust. The fact that a fault zone has recently experienced an earthquake offers no assurance that enough stress has been relieved to prevent another quake.

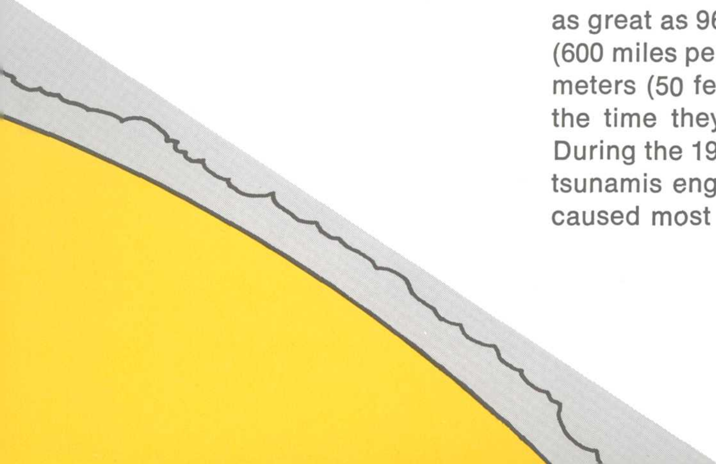
The *focal depth* of an earthquake is the depth from the Earth's surface to the region (*focus*) where an earthquake's energy originates. Earthquakes with focal depths from the surface to about 60 kilometers (38 miles) are classified as shallow. Earthquakes with focal depths from 60 to 300 kilometers (38 to 188 miles) are classified as intermediate. The focus of deep earthquakes may reach depths of 700 kilometers (440 miles).

The focuses of most earthquakes are concentrated in the crust and upper mantle. Compared to a depth of about 4,000 miles to the center of the Earth's core, earthquakes can be considered to originate in relatively shallow parts of the Earth's interior. Earthquakes in California along the San Andreas and associated faults have shallow focal depths; for most the depth is less than 10 miles. During the past 100 years, Earth movements have occurred along more than half the entire length of the San Andreas Fault and the rupture itself is visible at the land surface in many places.

Very shallow earthquakes are probably caused by fracturing of the brittle rock in the crust or by internal stresses that overcome the frictional resistance locking opposite sides of a fault. The immediate cause of intermediate and deep earthquakes is not yet fully understood.

The *epicenter* of an earthquake is the point on the Earth's surface directly above the focus. The location of an earthquake is commonly described by the geographic position of its epicenter and by its focal depth.

Earthquakes beneath the ocean floor sometimes generate immense sea waves or "tsunamis" (Japan's dread "huge wave"). These waves travel across the ocean at speeds as great as 960 kilometers per hour (600 miles per hour) and may be 15 meters (50 feet) high or higher by the time they reach the shore. During the 1964 Alaska earthquake, tsunamis engulfing coastal areas caused most of the destruction at



Kodiak, Cordova, and Seward and caused severe damage along the west coast of North America, particularly at Crescent City, Calif. Some waves raced across the ocean to the coasts of Japan.

Water levels in artesian wells fluctuate as seismic waves travel through the rock layers that hold the water. During passage of seismic waves from a large earthquake, water levels in some wells fluctuate wildly, not only in the immediate vicinity of the earthquake but also at great distances from it. The water level change may be long lasting or even permanent. The Alaska quake appears to have caused changes in wells in many areas, both local and remote. Water levels in wells in New Orleans, La., for example, rose and fell as a result of the quake.

Landslides triggered by earthquakes often cause more destruction than the earthquake shocks themselves. During the 1964 Alaska quake, shock-induced landslides devastated the Turnagain Heights residential development and many downtown areas in Anchorage. An observer gave a vivid report of the breakup of the unstable Earth materials in the Turnagain Heights region:

> *I got out of my car, ran northward toward my driveway, and then saw that the bluff had broken back approximately 300 feet southward from its original edge. Additional slumping of the bluff caused me to return to my car and back southward approximately 180 feet to the corner of McCollie and Turnagain Parkway. The bluff slowly broke until the corner of Turnagain Parkway and McCollie had slumped northward.*

Background: Fracture and pressure ridges developed in ice on a lake in northern Kenai Lowlands.

Seismic seawaves (tsunamis) damaged these railroad tracks.

The Turnagain Heights landslide shortly after the earthquake.


Shop Tape

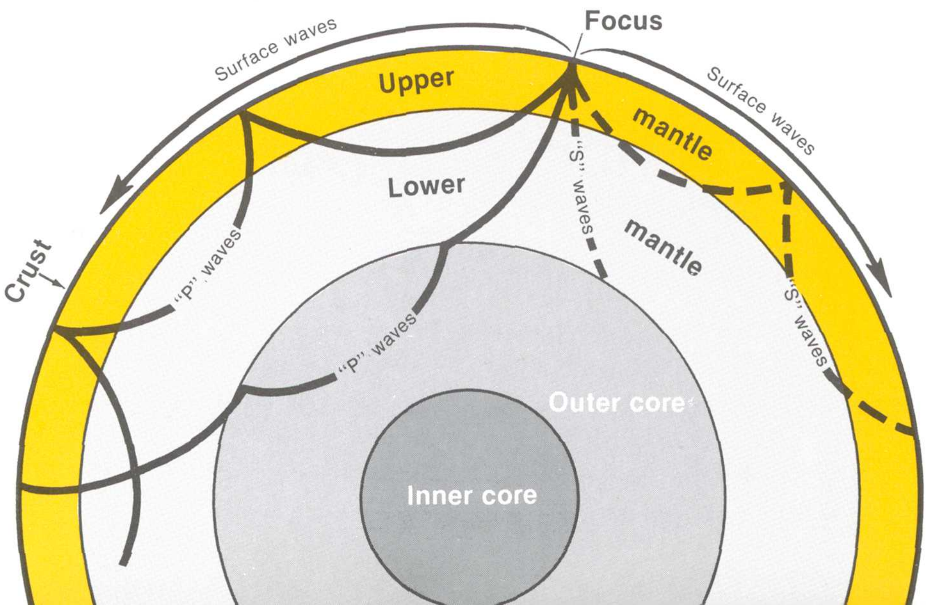
Measurement of Earthquakes

The vibrations produced by earthquakes are detected, recorded, and measured by instruments called seismographs. The zig-zag line made by a seismograph, called a "seismogram," reflects the varying amplitude of the vibrations by responding to the motion of the ground surface beneath the instrument. From the data expressed in seismograms, the time, the epicenter, and the focal depth of an earthquake can be determined, and estimates can be made of the amount of energy that was released.

The two general types of vibrations produced by earthquakes are *surface waves* which travel along the Earth's surface and *body waves* which travel through the Earth. Surface waves usually have the strongest vibrations and probably cause most of the damage done by earthquakes.

Body waves are of two types, *compressional* and *shear.* Both types of body waves pass through the Earth's interior from the focus of an earthquake to distant points on the surface, but only compressional waves travel through the Earth's molten core. Because compressional waves travel at great speeds and ordinarily reach the surface first, they are often called "primary waves" or simply "P" waves. P waves push tiny particles of Earth material directly ahead of them or displace the particles directly behind their line of travel.

Shear waves do not travel as rapidly through the Earth's crust and mantle as do compressional waves, and because they ordinarily reach the surface later they are called "secondary" or "S" waves. Instead of affecting material directly behind or ahead of their line of travel, shear waves displace



material at right angles to their path and are therefore sometimes called "transverse" waves.

The first indication of an earthquake will often be a sharp thud—signaling the arrival of compressional waves. This will be followed by the shear waves and then the "ground roll" caused by the surface waves. A geologist who was at Valdez, Alaska, during the 1964 earthquake described this phenomenon:

> *The first tremors were hard enough to stop a moving person and shock waves were immediately noticeable on the surface of the ground. These shock waves continued with a rather long frequency which gave the observer an impression of a rolling feeling rather than abrupt hard jolts. After about 1 minute the amplitude or strength of the shock waves increased in intensity and failures in buildings as well as the frozen ground surface began to occur . . . After about 3 1/2 minutes the severe shock waves ended and people began to react as could be expected.*

The times of arrival of compressional and shear waves at selected seismograph stations throughout the world indicate where and when the earthquake occurred and, sometimes, its focal depth. The recorded amplitudes of seismic waves indicate the amount of energy released by the quake.

The severity of an earthquake can be expressed in several ways. The *magnitude* of an earthquake, as expressed by the *Richter Scale,* is a measure of the amplitude of the seismic waves and is related to the amount of energy released—an amount that can be estimated from seismograph recordings. The *intensity,* as expressed by the *Modified Mercalli Scale,* is a subjective measure which describes how severe a shock was felt at a particular location. Damage or loss of life and property is another, and ultimately the most important, measure of an earthquake's severity.

The Richter Scale, named after Dr. Charles F. Richter of the California Institute of Technology, is the best known scale for measuring the magnitude of earthquakes. The scale is logarithmic so that a recording of 7, for example, indicates a disturbance with ground motion 10 times as large as a recording of 6. A quake of magnitude 2 is the smallest quake normally felt by humans. Earthquakes with a Richter value of 6 or more are commonly considered major in magnitude.

The Modified Mercalli Scale expresses the intensity of an earthquake's effects in a given locality in values ranging from I to XII. The most commonly used adaptation covers the range of intensity from the condition of "I—Not felt except by a very few under especially favorable conditions," to "XII—Damage total. Lines of sight and level are distorted. Objects thrown upward into the air." Evaluation of earthquake intensity can be made only after eyewitness reports and results of field investigations are studied and interpreted. The maximum intensity experienced in the Alaska earthquake of 1964 was X; the San Francisco earthquake of 1906 reached a maximum intensity of XI.

Earthquakes of large magnitude do not necessarily cause the most intense surface effects. The effect in a given region depends to a large degree on local surface and subsurface geologic conditions. An area underlain by unstable ground (sand, clay, or other unconsolidated materials), for example, is likely to experience much more noticeable effects than an area equally distant from an earthquake's epicenter but underlain by firm ground such as granite.

An earthquake's destructiveness depends on many factors. In addition to magnitude, these include the focal depth, the distance from the epicenter, local geologic conditions, and the design of buildings and other works of man. The extent of damage also depends on the density of population and construction in the area shaken by the quake.

The Alaska earthquake of 1964 demonstrated wide variations in its effects. The town of Whittier, built on firm granite, suffered little damage from the seismic waves despite the fact that it was close to the earthquake's epicenter. Whittier did experience great destruction and the loss of 13 lives from the enormous seawaves produced by submarine landslides, however. In Anchorage, much farther from the earthquake's epicenter, damage was selective; the greatest destruction occurred in areas where homes and other buildings were constructed near unstable slopes underlain by clay and other unconsolidated materials.


Government Hill Elementary School in Anchorage, Alaska, destroyed in the 1964 earthquake.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Prediction of Earthquakes

Reliable earthquake predictions improve disaster planning and preparedness activities, and thus help mitigate earthquakes. Predictions have the potential for greatly reducing casualties, personal property losses, and structural damage. The goal of earthquake prediction is to give warning of potentially damaging earthquakes at a time interval that allows appropriate immediate actions and with enough precision to avoid any sustained disruptive effects on society.

The U.S. Geological Survey conducts and supports research on the prediction of the time, place, and magnitude of earthquakes. This research includes field, laboratory, and theoretical investigations of earthquake mechanisms and fault zones. It is aimed at both long-term and short-term earthquake predictions.

Research on long-term earthquake prediction (earthquake potential) has proceded rapidly. Scientists have estimated dates of large prehistoric earthquakes from detailed studies of fault zones and have combined these results with seismic data to provide estimates of time intervals between earthquakes. More than a dozen large earthquakes have been sucessfully forecast since 1965 based on the recognition of seismic gaps, extended periods of earthquake quiescence.

Research on short-term prediction (within a few hours or days of the event) has proven more challenging. Difficulties in establishing magnitudes and timings of precursor events have limited the ability of scientists to provide reliable short-term warnings. Activities and events at Parkfield, California, however, may prove fruitful in research on short-term earthquake prediction.

The Parkfield Earthquake Prediction Experiment

The Parkfield section of the San Andreas fault has had remarkably consistent earthquake activity since at least 1857. Over the past 130 years, moderate-size earthquakes have recurred every 21 to 22 years on average. Other evidence, including seismograms of the last three moderate-size earthquakes, strongly suggest that these seismic events were very similar to each other.

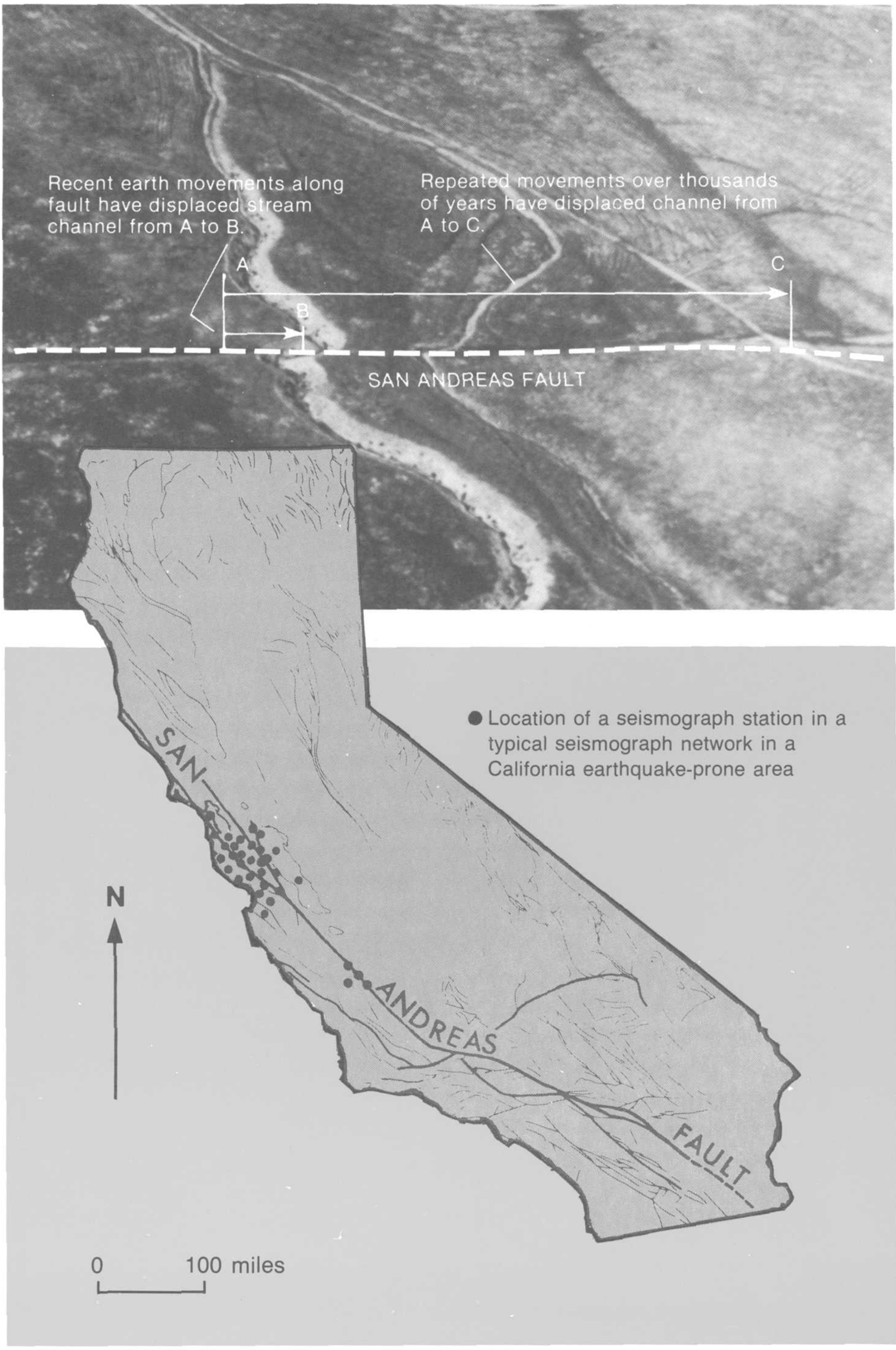
Based on this consistency and similarity, scientists at the USGS and the University of California at Berkeley have forecast that another moderate-size earthquake likely will occur at Parkfield in 1988 $\pm$ 5 years. The Parkfield prediction is the first to be endorsed by the National Earthquake Prediction Evaluation Council.

The anticipated Parkfield earthquake provides scientists with a unique opportunity to monitor and study an expected seismic event. An important goal of the experiment is to attempt a short-term (1- to 3-day) prediction of the moderate-size earthquake. This short-term warning will be based on precusor indicators, such as unusual increases in fault deformation and foreshock activity, which are being continuously measured and recorded by monitoring devices in the area.

Volcanoes and Earthquakes

Earthquakes on the island of Hawaii, the site of active volcanoes Kilauea and Mauna Loa, appear to be associated with volcanic activity. Abrupt increases in quake activity at times herald an eruption, and the location of swarms of tremors can indicate where lava may break out. Also, prior to an eruption, the volcano swells measurably in response to the upward movement of molten rock. Continuous seismic and tiltmeter (a device that measures ground tilting) records are maintained at the Geological Survey's Hawaiian Volcano Observatory, located on the rim of Kilauea Volcano, where study of these records enables specialists to make short-range predictions of volcanic eruptions.

The photograph on the top shows how Mauna Loa Volcano, 30 miles away, appears from a window at the Hawaiian Volcano Observatory. The observatory is shown below.


Recent earth movements along fault have displaced stream channel from A to B.
Repeated movements over thousands of years have displaced channel from A to C.
A
B
C
SAN ANDREAS FAULT
Location of a seismograph station in a typical seismograph network in a California earthquake-prone area
N
SAN ANDREAS FAULT
0 100 miles

Scientific understanding of earthquakes is of vital importance to the Nation. As the population increases, expanding urban development and construction works encroach upon areas susceptible to earthquakes. With a greater understanding of the cause and effects of earthquakes, man may be able to reduce damage and loss of life from this destructive phenomenon.

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A statue of Christ at Cemetery Hill overlooks the ruined town of Yungay, Peru. It and a few palm trees were all that remained standing after the May 31, 1970, earthquake.

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