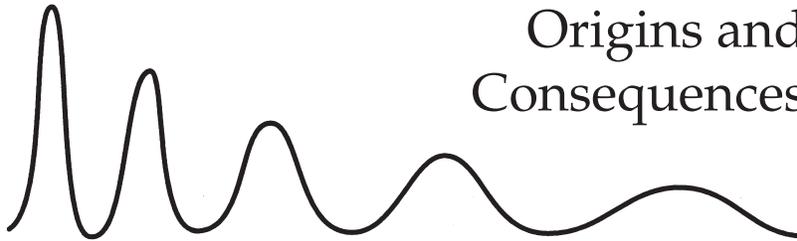


1 • Earthquakes: Origins and Consequences



A bad earthquake at once destroys our oldest associations: the earth, the very emblem of solidity, has moved beneath our feet like a thin crust over a fluid.

Charles Darwin, *The Voyage of the Beagle*

EARTHQUAKES ARE AMONG the most terrifying of natural phenomena. Striking without warning, and seemingly coming out of nowhere, they challenge our inherent assumptions about the stability of the very planet we live upon. Any shaking of the earth, whether lasting for minutes or only for seconds, seems eternal to those who experience it. A mild quake may inspire no more than passing interest, but a powerful quake can wreak awesome devastation. Figure 1-1 is an artist's interpretation of a quake that shook Naples, Italy, in 1805. A century later (in 1904) an American geologist, Clarence E. Dutton, published a seminal book about seismology (the study of earthquakes) in which he graphically described a strong temblor:

When the great earthquake comes, it comes quickly. . . . The first sensation is a confused murmuring sound of a strange and even weird character. Almost simultaneously loose objects begin to tremble and chatter. Sometimes, almost in an instant, sometimes more gradually, but always quickly, the sound becomes a roar, the chattering becomes a crashing. . . . The shaking increases in violence. . . . Through its din are heard loud,



FIGURE 1-1. Copper engraving of devastation in Naples, Italy, during an earthquake in 1805. (Private collection.)

deep, solemn booms that seem like the voice of the Eternal One, speaking out of the depths of the universe.¹

Dutton's figurative reference to an "Eternal One" alludes to an age-old belief that earthquakes are visited upon sinful mortals by divine wrath, either as punishment for sins committed or as a warning to those who might yield to temptation. In ancient Greece it was the god Poseidon "the earthshaker" (also the god of the sea) whose wrath was to be feared. The Bible contains many verses in both Old and New Testaments that equate earthquakes with God's anger. In contrast, many ancient myths attributed earthquakes to the stirring of giant creatures that supported the earth. In Japan it was a catfish, in China a frog. In the Philippine Islands it was thought to be a snake, and Native Americans believed the earth rested upon the back of a turtle.

The Greek philosopher Aristotle (384–322 BCE) developed a somewhat more rational, if still fanciful, explanation for

earthquakes. He believed that strong winds blew through caves and clefts inside the earth, creating “effects similar to those of the wind in our bodies whose force when it is pent up inside us can cause tremors and throbbings.”²

Among the early attempts at a scientific explanation of earthquakes was a book titled *Conjectures concerning the Cause, and Observations upon the Phaenomena of Earthquakes*, written in 1760 by John Michell (1724?–1793), a professor of geology at Cambridge University. From a study of the great Lisbon earthquake of 1755, Michell concluded that quakes were caused by shifting masses of rock many kilometers below the earth’s surface.

In 1793 Benjamin Franklin, among the leading scientists of his day, suggested a mechanism for Michell’s shifting masses:

I . . . imagined that the internal part [of the earth] might be a fluid more dense, and of greater specific gravity than any of the solids we are acquainted with; which therefore might swim in or upon that fluid. Thus the surface of the globe would be a shell, capable of being broken and disordered by any violent movements of the fluid on which it rested.³

Scientists had to wait more than a century before they could definitely establish a relationship between shifting masses of rock (Franklin’s broken “shell”) and earthquakes. Then in 1891 a powerful temblor shook the island of Honshu, in Japan. Known as the Mino-Owari earthquake, it left a zone of destruction marked by a fracture, or fault, that extended across the island from the Sea of Japan to the Pacific Ocean. In some places, vertical movement had created fault scarps several meters high (see figure 1-2). From that convincing evidence a Japanese scientist, Bunjiro Koto, concluded that the quake had been triggered by the fracturing of the earth’s crust, thus for the first time demonstrating a causal relationship between earthquakes and faulting.

Early in the twentieth century, by studying earthquake

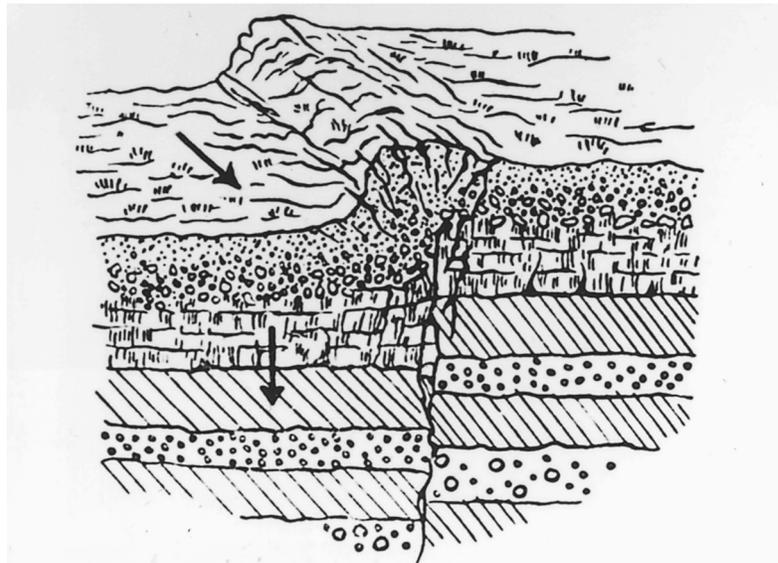


FIGURE 1-2. Drawing showing the 6-meter-high scarp created by rupturing along a fault across the island of Honshu, in Japan, in 1891, causing the Mino-Owari earthquake. In the photo, notice the offset of the road, indicating simultaneous horizontal and vertical movement. (From Montessus de Ballore, *Science Séismologique*, 414.)

waves and the time it takes for them to pass through the earth, scientists deduced that our planet has a dense, at least partly molten core at its center, and that the core is surrounded by a thick layer of less dense material, which they named the mantle. Above the mantle lies the thin, rocky crust (or “shell”) upon which we live. The crust can be several tens of kilometers thick where it comprises the continents, but it is only a few kilometers thick beneath the oceans. In some respects we might say that the earth resembles an apple. If an apple is sliced in two, the cross section reveals a small “core” (where the seeds are), a thick “mantle” (the edible flesh), and a “crust” (the skin). The relative proportions of those parts of an apple are not unlike the proportions of the main parts of the earth.

In the 1960s geologists began to understand that the outer part of the earth is made up of individual rigid plates, some very large, others small, as shown in figure 1-3 (and not entirely different from Benjamin Franklin’s speculation in 1793). The plates move very slowly over a ductile, or plastic, layer within the mantle. The movement of these tectonic (structural) plates, typically a few centimeters a year, is responsible for most earthquakes, as well as for volcanic activity. This is the theory of plate tectonics, which revolutionized the science of geology by providing a single, unifying concept that helps explain most geological processes and features. The block diagrams in figure 1-4 illustrate the kinds of faults that develop in the earth’s crust when plates collide, when they separate, and when they move past one another laterally.

The rigid tectonic plates are made up of rocky crustal material and a thin layer of the uppermost part of the mantle. Together they form what geologists call the *lithosphere* (from the Greek *lithos*, meaning “stone”). The ductile layer of mantle material over which the plates move is called the *asthenosphere* (from *asthenos*, meaning “weak”).

Tectonic plates are in motion presumably because of convection currents within the mantle. The currents are thought to be driven by heat from the earth’s core, much as convection

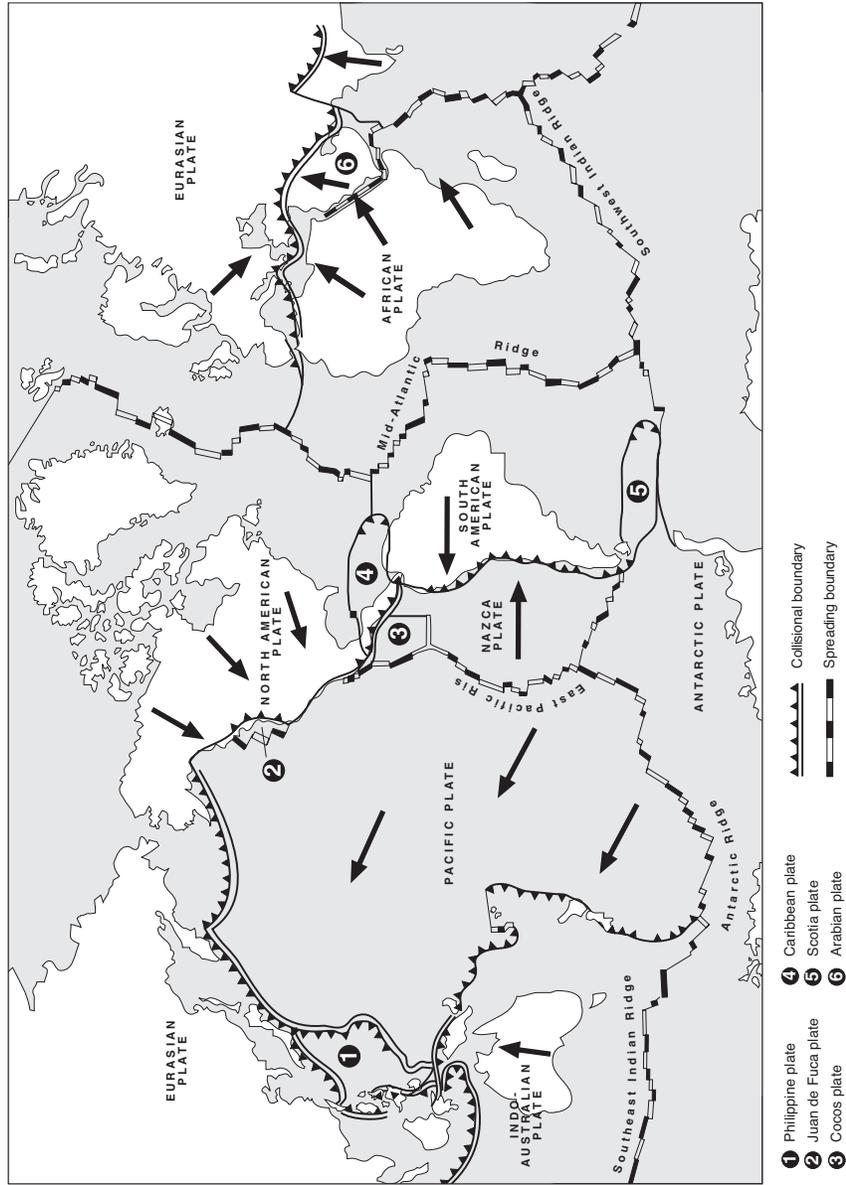


FIGURE 1-3. Configuration of the earth's tectonic plates, showing boundaries between colliding plates and between plates that are spreading apart. Arrows show the present directions of plate motion. Small black triangles at collisional boundaries indicate subduction zones.

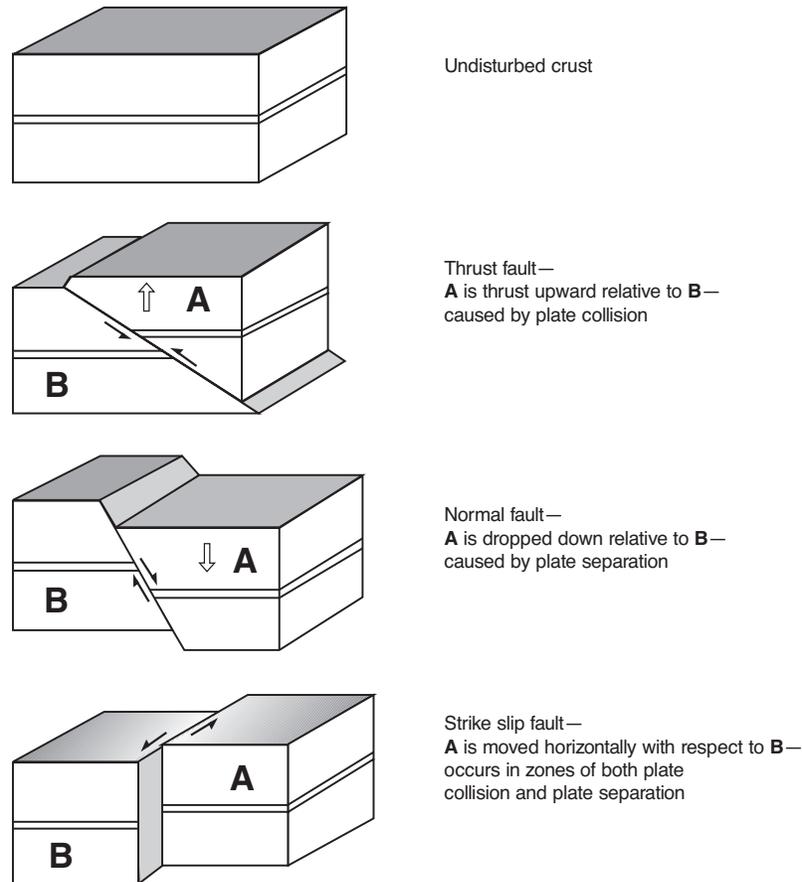


FIGURE 1-4. Block diagrams illustrating, from top, undisturbed rock layers in the earth's crust and the kinds of faults that develop in crustal rocks when plates collide, when they pull apart, and when they move past one another horizontally. Open arrows indicate crustal uplift and subsidence. The "strike" of a fault is the direction that would be taken by a horizontal line if it were drawn on a surface of the fault.

currents are created in a pot of water heated on a stove. Hot water, being less dense than cold water, rises to the surface, where it cools and becomes more dense. Therefore it returns to the bottom of the pot. A similar process is believed to be at work, albeit far more slowly, within the earth. Along their boundaries, tectonic plates may be separating from one an-

other, colliding with other plates, or grinding past one another laterally.

Plates spread apart along oceanic ridges, where molten rock, or magma, from the asthenosphere rises through the resulting fractures to create new crust on the bottom of the ocean. Oceanic crust is more dense, thus heavier, than continental crust.

Where oceanic and continental plates collide, the heavier oceanic plate ordinarily is thrust beneath the continental plate, an earthshaking process known as *subduction*. The Pacific plate, for example, is being subducted beneath the Aleutian Islands and the islands of Japan, and this movement is responsible for volcanism and frequent earthquakes in those areas. Where the collision is between two continental plates—as, for example, where the northward-moving Indian subcontinent is colliding with Eurasia—the result usually is the uplifting of mountain ranges such as the Himalayas of Tibet, Nepal, and northern India, again accompanied by frequent earthquakes.

The infamous San Andreas fault in California lies within a highly active tectonic zone that forms the boundary between the Pacific and North American plates. Both plates are moving laterally in a generally westerly direction, but the Pacific plate is moving slightly faster. Stresses therefore build up along the San Andreas and neighboring faults within the boundary zone until, from time to time, friction is overcome in one area or another and the sudden release of accumulated stress creates an earthquake.

The boundaries of tectonic plates are by far the most common sites of earthquakes, but plate interiors are not invulnerable. The same forces that created the plates can tear them apart, as today the Arabian platelet is being separated from the African plate along the axis of the Red Sea. Branching southward from the mouth of the Red Sea is the East African rift system, a zone of crustal weakness that includes the famous African rift valleys. That region is the site of volcanic activity and frequent earthquakes. Similarly (but without volca-

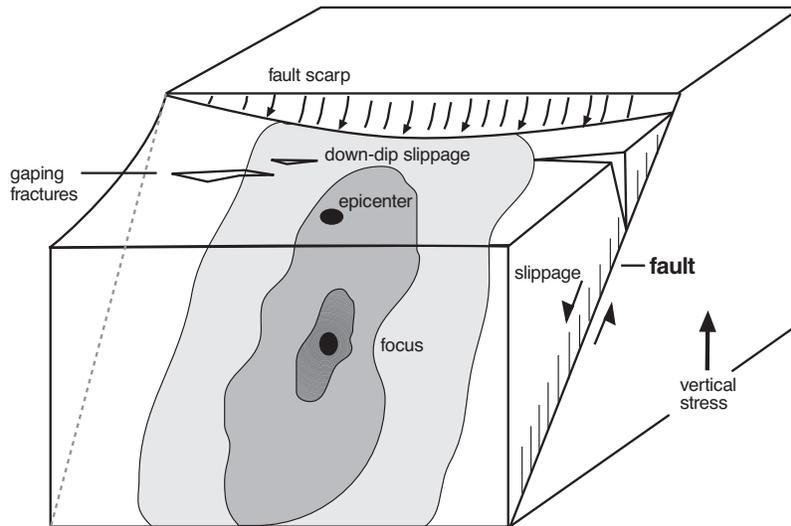


FIGURE 1-5. Block diagram showing the focus and epicenter of an earthquake caused by abrupt down-dip slippage along a fault produced by a vertical stress in the earth's crust. Such slippage often creates gaping fractures in the earth's surface, as depicted in figure 1-1. The *focus* is the place on the fault plane where rupturing originated. The *epicenter* is the location on the earth's surface directly above the focus. Rupturing expands outward along the fault in all directions from the focus, as shown by gradations in shading.

noes), the lower Mississippi Valley is underlain by an ancient rift. Presumably reactivated by the movement of the North American plate, old faults related to the rift gave way in 1811 and 1812, and the region was shaken by some of the most powerful earthquakes in American history.

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Earthquakes are caused by the sudden release of energy when slippage occurs where stresses created by tectonic movement have strained the earth's crust to the breaking point. The place on a fault where an earthquake originates is called the *focus*, or *hypocenter*. The place on the earth's surface directly above the focus is the *epicenter* (see figure 1-5). The waves of seismic en-

ergy released by the rupture—called body waves—are propagated through the crust either as push-pull (P) waves or as shear (S) waves. P waves move by successively compressing and dilating crustal material in the direction of propagation, while S waves shake particles of material in directions perpendicular to that direction. In typical midcrustal rocks, S waves travel at about 3 kilometers per second, whereas P waves move at about 5 kilometers per second. The faster P waves arrive at seismographs ahead of S waves, so P waves are also referred to as primary waves, and S waves as secondary waves.

When seismic waves reach the earth's surface they move along the surface in either of two forms, known as Rayleigh waves and Love waves. Rayleigh waves, named after the British physicist Baron Rayleigh (John William Strutt), cause particles in their path to move about in an elliptical fashion. Love waves, named for a British mathematician, A. H. Love, are surface shear waves. Particles in their path move in a horizontal plane at right angles to the direction of wave propagation. Both kinds of surface waves oscillate with lower frequencies, hence with larger amplitudes, than body waves and are largely responsible for earthquake damage.

Before the seismograph was invented in the late nineteenth century, the intensity of ground shaking during earthquakes was estimated by how and where the quakes were felt and by the amount of damage they caused. In 1902 an Italian seismologist, Giuseppe Mercalli, developed a scale with ten degrees of intensity, later modified to twelve as shown in table 1-1. Because the Mercalli scale is qualitative, its accuracy depends on subjective observation or, for past quakes, the accuracy of historical accounts.

In 1935 Charles Richter, a seismologist at the California Institute of Technology, developed a quantitative scale for measuring the *magnitude*, rather than the qualitative *intensity*, of earthquakes.* Magnitudes originally were calculated from

* A Japanese seismologist, Kiyoo Wadati, had developed a quantitative scale in 1931, but it was Richter's scale that became widely accepted for many years.

TABLE 1-1 The Modified Mercalli Scale of Earthquake Intensities

I	Rarely felt.
II	Felt by few people.
III	Felt mostly on upper floors of buildings.
IV	Felt indoors by many, outdoors by few.
V	Felt by most people. Some dishes and windows broken, plaster cracked.
VI	Felt by all. People run outdoors. Some furniture moved, chimneys damaged.
VII	Everyone runs outdoors. Much damage to poorly constructed buildings, slight damage to well-built structures. Chimneys broken.
VIII	Damage great to poorly constructed buildings, considerable to well-built structures. Chimneys, monuments, walls collapse. Sand and mud ejected from ground.
IX	Buildings moved from foundations, ground cracked, underground pipes broken.
X	Most masonry buildings and some wooden buildings destroyed. Ground badly cracked, rails bent, landslides on steep slopes, water splashed over riverbanks.
XI	Few masonry buildings remain standing. Bridges destroyed, broad cracks in ground, all underground pipelines out of service.
XII	Damage total. Waves in ground surface; objects thrown upward.

the deflection measured by a particular kind of seismograph corrected for the distance of the instrument from the epicenter of the quake. In time it became apparent that such calculations did not work well for the strongest earthquakes, and seismologists have developed other, more sophisticated magnitude scales, which are used today.

Table 1-2 indicates the relative amounts of seismic energy that are released by earthquakes of various Richter magnitudes. In the table, one “energy unit” represents an arbitrary value equal to the amount of energy that would be released by

TABLE 1-2 Relative Amounts of Energy Released by Earthquakes of Various Richter Magnitudes

Magnitude (M)	Duration, in seconds	Energy released, in arbitrary units*
1-2.9	short	less than M_4
3-3.9	short	less than M_4
4-4.9	1-5	$1 \times M_4$
5-5.9	2-15	$30 \times M_4$
6-6.9	10-30	$1,000 \times M_4$
7-7.9	20-50	$30,000 \times M_4$
8-8.9	30-90	$1,000,000 \times M_4$

*For the purposes of this table, one "energy unit" is given an arbitrary value equal to the amount of energy that would be released by a magnitude 4 (M_4) earthquake that lasted 1 to 5 seconds.

a magnitude 4 earthquake that lasted from one to five seconds. A magnitude of 4 generally is considered the threshold for causing significant damage. The amount of energy released by earthquakes increases greatly from one magnitude value to the next, as graphically illustrated in figure 1-6.

Some earthquakes are preceded by foreshocks if slippage along the responsible faults begins gradually. And many quakes are followed by aftershocks caused by continued, intermittent slippage along the responsible faults. Aftershocks have been known to continue for years.

Movement along some faults is more or less continuous, so that seismic energy is released gradually and there is no abrupt rupturing to cause any but minor earthquakes. Such faults are said to "creep." Typically, however, because of friction, faults remain "locked" for a time, in effect storing energy just as a compressed spring does—until enough stress has accumulated to overcome the friction, and the slippage occurs. In figure 1-7, erosion has exposed the surface of a fault that was polished smooth by the grinding of one block against the other.

On rare occasions, notably in California and Japan, emissions of bright white light have been reported along faults that have broken through to the earth's surface. Most likely the

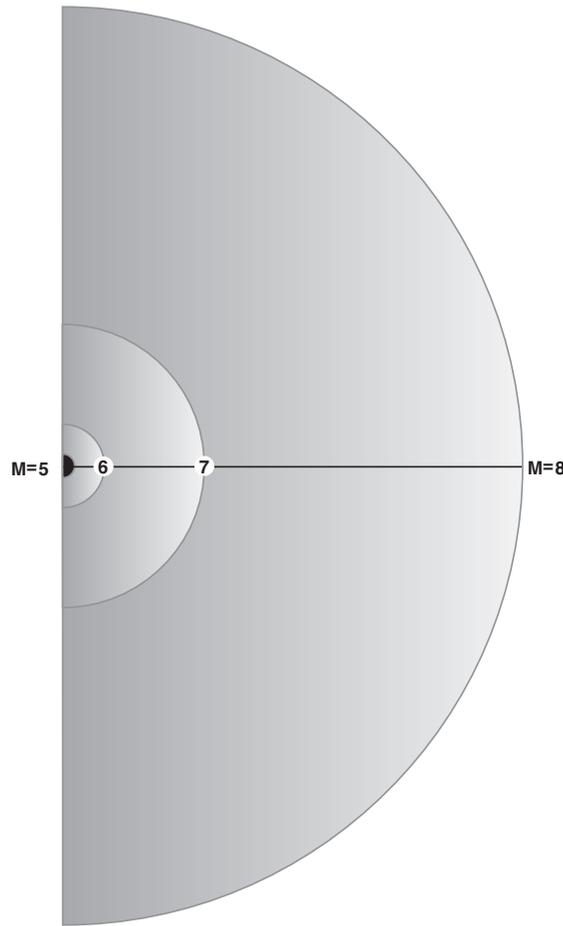


FIGURE 1-6. Schematic representation of relative amounts of energy (shown as cross sections of half spheres) released by earthquakes with magnitudes ranging from 5 to 8. Imagine each magnitude value as a three-dimensional spherical *volume*: the amount of energy released is 30 to 40 times greater from one magnitude to the next.

light is generated when electrons from the freshly ruptured rock collide with atoms in the air above the fault.

Because the earth's crust absorbs and scatters seismic waves, the intensity of ground shaking usually decreases rapidly with increasing distance from a quake's epicenter. The severity of an earthquake is also affected by local geological



FIGURE 1-7. A geologist slides down the polished surface of a fault, demonstrating the relative direction of movement of the block of crustal material that once lay above the fault. This type of fault is similar to that shown in figure 1-5.

conditions. Seismic waves in hard bedrock, for example, vibrate with higher frequencies and lower amplitudes than do waves in unconsolidated sediments. Conversely, seismic waves in unconsolidated material, such as marshes and filled land, tend to be amplified because ordinarily they vibrate with lower frequencies and higher amplitudes. For that reason buildings constructed on bedrock tend to survive earthquakes that would destroy structures built on less firm material such as reclaimed swamplands.

Major earthquakes usually are followed, in cities, by fires that result from broken gas mains, sparking electrical wires, and overturned stoves used for cooking or heating. Quake-related conflagrations often cause much more damage, and many more deaths, than the quakes themselves. Lisbon in 1755, San Francisco in 1906, and Tokyo and Yokohama in 1923 all suffered powerful earthquakes, but it was fire, not the quakes, that completed the destruction of the cities.

Faulting and displacement of the seafloor during earthquakes can produce the destructive ocean waves called *tsunamis*, a Japanese word meaning “harbor waves.” Tsunamis (often mislabeled “tidal waves,” though they are unrelated to tides) are fast-moving waves that can traverse entire oceans in hours. Approaching land, a tsunami can build to a great height in shoaling water and crash ashore with devastating results, especially in bays and harbors where its energy may be focused by a narrowing configuration of the shoreline.

In mountainous regions, earthquakes can produce ruinous landslides and mudflows. Damage can range from blocked roads, washed-out bridges, and disrupted irrigation systems to the destruction of entire towns and cities.

Other possible aftereffects of catastrophic earthquakes include famine, disease, economic disruption, and even political repercussions, as discussed in the following chapters.

• • •

About 75 percent of the earth's seismic energy is released along the boundaries of the Pacific plate. Another 23 percent comes from a zone of seismic activity that extends eastward from the Mediterranean area to Indonesia. The rest of the world accounts for only about 2 percent. Thus it is not difficult to predict, in general, where earthquakes are likely to happen. But any attempt to predict specifically where or when a quake may strike is fraught with difficulty.

Essential for the successful prediction of earthquakes is recognition of precursors such as geodetic changes (tilting of areas near faults) or the sudden lowering of water levels in wells. Changes in local magnetic, electric, or gravimetric fields, or unexplained changes in the velocity of seismic waves from quake activity elsewhere, all indicate local tectonic changes in the earth's crust. But none of these precursors, by themselves, are reliable predictors of seismic activity.

If part of a fault has remained inactive, or locked, for a considerable period while there has been seismic activity elsewhere along the fault, the locked segment is called a *seismic gap*. It seems obvious that such gaps are likely locations for future earthquakes—and the longer the period of quiescence, the greater the probability of recurring seismicity.

For the reasons outlined above, seismologists are loath to make specific earthquake predictions. An inaccurate prediction would not only discredit the scientists who made the prediction; it could have far-reaching social and economic consequences if towns or cities were needlessly evacuated, schools closed, and businesses shut down.

Efforts to find ways of predicting seismic activity will continue, of course, but in the meantime the most pragmatic approach to minimizing the danger of earthquakes is to assess known hazards. In her recent book *Earthshaking Science*, U.S. Geological Survey seismologist Susan Elizabeth Hough writes: "Faced with a growing awareness of the intractability of earthquake prediction and a stronger imperative to apply hard-won knowledge to matters of social concern, the seismo-

logical community has turned away from short-term earthquake prediction and toward long-term seismic hazard assessment.” Hough defines a hazard as involving not any one quake but “an evaluation of the average long-term hazard faced by a region as a result of all faults whose earthquakes stand to affect that region.” She goes on to point out:

Earth scientists are careful to differentiate “hazard,” which depends on the earthquake rate, from “risk,” which reflects the exposure of structures, lifelines, and populations to existing hazard. Risk is generally the purview of insurance companies; the evaluation of hazard is a matter of science.⁴

Once the earthquake hazard is understood for an area, much can be done to ameliorate the risk of damage in future quakes. Building codes can be made more rigorous, and existing structures can be strengthened. Certainly the cost will be great, and we might be willing to gamble that no devastating temblor will strike any time soon. But in an area of known hazard, such a gamble would be risky indeed.

In the following chapters we describe nine historic earthquakes or quake-prone regions, in each case emphasizing the long-lasting consequences—cultural, socioeconomic, and political—of only a few moments of seismic cataclysm.

INDUCED EARTHQUAKES

Not all earthquakes are natural events. Quakes have been caused by the weight of impounded water where large dams have been built, and they have occurred where large quantities of waste fluids have been pumped into deep wells.

In the early 1930s, after Hoover Dam was built on the Colorado River, tremors began to shake the area as Lake Mead filled. In 1940, five years after the dam was completed, a stronger earthquake shook nearby Las Vegas. With a magnitude of about 5, it caused minor damage.

There were similar earthquakes after the Aswan Dam was built in Egypt in 1970. More than 100 meters high and 3 kilometers wide, the dam impounded the Nile River to form Lake Nasser, which extends almost 350 kilometers upstream. Not unexpectedly, occasional tremors accompanied the rising water. Then on November 14, 1981, a more powerful earthquake, with a magnitude of 5.6, struck the region.

None of those quakes claimed any victims—but in 1967 an induced quake with a magnitude 6.4 killed several hundred people and injured some two thousand after the Koyna Dam was built near Bombay (now Mumbai), India.

Until the 1960s such activity puzzled seismologists. They considered it unlikely that the load created by filling a reservoir could strain the earth's crust enough to cause movement along faults. Some other mechanism had to be present. The answer to the puzzle came in 1965 near Denver, Colorado. On the grounds of the U.S. Army's Rocky Mountain Arsenal, engineers had drilled a hole more than 3 kilometers deep to dispose of liquefied nerve gas. They started pumping in March 1962. A month later tremors shook the Denver area, which had been free of seismicity for many years. The frequency of the quakes initially decreased from about thirty a month to only five in December. But starting in January 1963, the numbers increased rapidly. There were as many as forty temblors in late April alone, the strongest with a magnitude of 4.3. By that time, residents of the area had become alarmed.

David Evans, a consulting geologist in Denver, suggested that the quakes might be related to the pumping.¹ Government officials denied any connection, but in September 1963 the army agreed to stop pumping for a few months. Seismic activity continued, but the quakes were less frequent. The officials concluded that no connection existed, and pumping was resumed in September 1964. The number of quakes rose sharply, to more than eighty during July 1965. Seismographs installed by the U.S. Geological

Survey showed that virtually all the shocks had originated beneath the arsenal and were clustered around the drill hole. Pumping was discontinued, and seismic activity ceased. The connection was clear.

In a press conference, with the aid of a simple model, Evans explained what he believed was happening. He had drilled tiny holes in the bottom of an empty beer can. He placed the can on a board and tilted the board, but friction held the can in place. He then poured water into the can, which immediately slid downward. A similar phenomenon, he proposed, had taken place beneath the arsenal. The fluids pumped into the earth, under high pressure, had penetrated old fracture zones, reduced friction along inactive fault planes, and led to reactivation of the faults.

Subsequently some scientists suggested that active faults might be controlled by lubricating them so they would cause many low-magnitude tremors rather than stronger earthquakes at longer intervals. The problem, however, is in knowing just where to inject fluids into faults that might be hundreds of kilometers long and many kilometers deep. Even if optimal sites could be identified, it is unlikely that anyone would want to take legal responsibility for initiating an earthquake.

In the early 1990s some Russian nuclear scientists suggested researching the possibility of developing “tectonic bombs” that could be detonated in tunnels dug into fault zones to generate earthquakes, but fortunately nothing came of the idea. Indeed, the energy released by underground nuclear tests in the United States is known to have caused movement along faults. The notion of targeting specific faults with such devices, however, is best left to the realm of horror fiction.

MARK TWAIN'S EARTHQUAKE ALMANAC

Mark Twain happened to be in San Francisco on October 8, 1865, when the city was shaken (but not too seriously) by an earthquake. He thereupon took it upon himself to compile an "almanac" for the benefit of "several friends who feel a boding anxiety to know beforehand what sort of phenomena we may expect the elements to exhibit during the next month or two, and who have lost all confidence in the various patent medicine almanacs, because of the unaccountable reticence of those works concerning the extraordinary event of the 8th inst." Following are excerpts from Twain's "Earthquake Almanac":

Oct. 17.—Weather hazy; atmosphere murky and dense. An expression of profound melancholy will be observable upon most countenances.

Oct. 18.—Slight earthquake. Countenances grow more melancholy.

Oct. 19.—Look out for rain. It will be absurd to look in for it. The general depression of spirits increased.

Oct. 20.—More weather.

Oct. 21.—Same.

Oct. 22.—Light winds, perhaps. . . . Winds are uncertain—more especially when they blow from whence they cometh and whither they listeth. N. B.—Such is the nature of winds.

Oct. 23.—Mild, balmy earthquakes.

Oct. 24.—Shaky.

Oct. 25.—Occasional shakes, followed by light showers of bricks and plastering. N. B.—Stand from under.

Oct. 26.—Considerable phenomenal atmospheric foolishness. About this time expect more earthquakes, but do not look out for them, on account of the bricks.

Oct. 27.—Universal despondency, indicative of approaching disaster. Abstain from smiling, or indul-

gence in humorous conversation, or exasperating jokes.

Oct. 28.—Misery, dismal forebodings and despair. Beware of all discourse—a joke uttered at this time would produce a popular outbreak.

Oct. 29.—Beware!

Oct. 30.—Keep dark!

Oct. 31.—Go slow!

Nov. 1.—Terrific earthquake. This is the great earthquake month. More stars fall and more worlds are slathered around carelessly and destroyed in November than in any other month of the twelve.*

Nov. 2.—Spasmodic but exhilarating earthquakes, accompanied by occasional showers of rain, and churches and things.

Nov. 3.—Make your will.

Nov. 4.—Sell out.

Nov. 5.—Select your “last words.” . . .

Nov. 6.—Prepare to shed this mortal coil.

Nov. 7.—Shed.

Nov. 8.—The sun will rise as usual, perhaps; but if he does he will doubtless be staggered some to find nothing but a large round hole . . . where he saw this world serenely spinning the day before.¹

* On November 1, 1755, the city of Lisbon, Portugal, was destroyed by one of the most infamous earthquakes in history.