Appendix

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Earthquake Background

Earthquake Legends

Ancient peoples experienced the same natural disasters that can affect each of us. Among these were hurricanes, tornadoes, droughts, floods, volcanic eruptions, and earthquakes. Because they did not have scientific explanations for such catastrophes, ancient peoples invented folk narratives, or legends, to explain them. Such legends are part of the literature that we have inherited from many cultures. An examination of legends gives a small insight into the location and frequency of occurrence of major earthquakes.

Defining an Earthquake

Earthquakes are an especially noteworthy type of catastrophe because they strike suddenly, without clear warning, and can cause much panic and property damage in a matter of seconds.

An earthquake is a sudden, rapid shaking of the Earth caused by the release of energy stored in the Earth's crust. An earthquake occurs at a place, called the focus, which may be up to about 700 km deep in the Earth. The place on the Earth's surface that is directly above the focus is called the epicenter of the earthquake. It has long been known that earthquake epicenters often lie along narrow zones, or belts, of the Earth where mountain building and/or volcanic activity are also present. But earthquakes may also occur in seemingly "stable" areas like the central and eastern United States.

Plate Tectonic Theory and Earthquake Occurrence

According to the recently formulated (late 1960s) theory of plate tectonics, earthquakes occur because of the motion of the pieces of solid crust and upper mantle that form the 100 km-thick, outer rock shell of our planet. This shell, called the lithosphere, or rock sphere, is broken into major and minor pieces called plates.

There are seven to twelve major plates and a number of smaller ones. From a geophysical perspective the Earth is like a giant spherical jigsaw puzzle with its pieces in constant motion.

The reason for plate motion is unknown. Scientists speculate, however, that the internal heat of the Earth causes convection currents in the semimolten, mantle rock material beneath the plates. They suggest that this convective motion, driven by the Earth's internal heat, drives the plates. Such heat is believed to come from the decay of radioactive minerals in the mantle, which extends to a depth of 2,855 km below the Earth's surface.

Types of Plate Motion

The plates move, relative to one another, at between approximately 2 and 15 cm per year. Three types of plate motion are most important for understanding where and how earthquakes occur. Divergent plate motion occurs where the plates are moving apart. Such plate separation most often occurs along the mid-ocean ridges. As the plates separate, new ocean crust forms from mantle material by volcanic eruptions or fissure flows. Many shallow earthquakes result from separation of plates. Because these usually occur in the deep ocean, however, they are rarely of concern to humans.

Plates are moving toward each other in such places as around the Pacific Ocean basin, and the Mediterranean. This is called convergent plate motion. Where the leading edge of a plate is made of ocean crust and underlying mantle, the plate tends to sink under the edge of opposing plate. Such motion is called subduction.

An oceanic trench is a common feature at plate boundaries where subduction is occurring, such as along the Pacific side of the Japanese or Aleutian island areas and the Pacific side of South America. As the subducting plate sinks into the mantle, it begins to melt. The resulting molten rock materials gradually rise toward the Earth's surface to form volcanoes and fissure flows of lava. Subduction results in many earthquakes with foci from near the Earth's surface to about 700 km below the surface. Some of these earthquakes are extremely violent.

Where the opposing plates are both made of continental material, their collision tends to raise mountain chains. The convergent motion of the continental masses of India and Southeast Asia began millions of years ago and continues into the present. The result is the Himalayan Mountains, which are still rising slowly and are being subjected to frequent earthquakes as the mountain building process continues.

The conservation of the area of the lithosphere is one of the important concepts that relates to the divergent and convergent activity of plates. That is, a worldwide balance exists between the creation of new lithosphere at the mid-ocean ridges and the destruction of the lithosphere along subduction zones. This allows us to picture the Earth as remaining relatively constant in size. Earlier explanations of folded and thrust-faulted mountain ranges incorrectly required that the Earth shrink in size as it cooled. The mountains were thought to rise as the lithosphere buckled, something like the shriveling of the skin on an apple as it ages.

In the third major type of plate motion, the edges of the plates slip past each other. This is called lateral (or transform) plate motion. The line of contact between the plates is a fault. The stresses involved in lateral plate motion actually cause rupturing and movement on faults some distance from the area of contact between the plates. Therefore, it is proper to speak of a fault zone when discussing rock movement caused by lateral plate.

One of the lateral faults best known in to North Americans is the San Andreas fault of California. The San Andreas and its associated faults extend from the Gulf of California to the Pacific coast north of San Francisco. Earthquakes occur frequently in the San Andreas fault zone. Some of them have caused loss of life and extensive property damage.

Mid-Plate Earthquakes

Many earthquakes occur at places far from plate boundaries. Some of them, like the New Madrid earthquakes of 1811-1812 and the Charleston earthquake of 1886, have been major historical disasters. Explaining such mid-plate earthquakes has been a challenge to the theory of plate tectonics outlined above. Recent research has shown, however, that the zones of instability within plates can produce earthquakes along intraplate fault zones which may be hidden at the Earth's surface. Because of the location of these fault zones and their infrequent activity, it is still difficult to assess the hazards they may pose.

Plate Tectonics, Faulting, and Topography

From the previous discussion, the origin of major topographic elements of the ocean floor become more apparent. Among these are the world-circling, 60,000 km-long mid-ocean mountain ranges, or mid-ocean ridges, and the trenches, whose depth below the ocean floor exceeds any chasm found on land. Plate motion also causes the folding and faulting of continental rocks and their uplift into mountains. Thrust faulting may accompany such mountain building. A thrust fault is one in which the upper block of rock slides over a lower block which is separated from it by the fault. Earthquakes occur at and near the fault surface, as the blocks of rock move relative to one another.

Normal faults occur where rock units are pulled apart allowing movement vertically under the influence of gravity. The result of normal faulting, on a continental scale, is the creation of long, deep valleys or the lowering subsidence of large pieces of coastal topography. A normal fault is one in which the upper block moves downward relative to the lower block which is separated from it by the fault. As in thrust faulting, earthquakes occur at and near the fault surface as the blocks of rock move relative to one another.

Lateral faults occur where plates are sliding past each other. A lateral fault is one in which the blocks of rock move in a predominantly horizontal direction past each other with the vertical, or near-vertical, fault surface separating them. In the ideal case, lateral faults do not cause much change in the elevation of the opposing blocks of rock. Rather, they move the existing topography to different locations. Earthquakes occur at and near the fault surface as the blocks move relative to one another.

Detecting Earthquakes

When rock units move past each other along normal, thrust, or lateral fault surfaces, or zones, the result is often an earthquake. Vibrations arise at the earthquake focus and travel outward in all directions. The vibrations travel through the upper part of the lithosphere and also penetrate the deeper shells of the Earth’s structure. The waves that travel through the upper part of the lithosphere are called surface waves. Those that travel within the Earth are called body waves.

The two main varieties of surface waves are Love waves, which travel sideways in a snake-like motion, and Rayleigh waves, which have an up-and-down motion. Surface waves from a large earthquake travel for thousands to tens of thousands of square kilometers around the earthquake epicenter. They are primarily responsible for the shaking of the ground and damage to buildings that occur in large earthquakes.

Body waves are either P- (for Primary) waves or S- (for Secondary) waves. Regardless of the nature of the material through which they travel, P-waves are always faster than S-waves. The difference in the arrival times of the two types of body waves allows seismologists to locate the focus of an earthquake.

Instrumental Measurement of Earthquakes

One way to describe an earthquake is in terms of the amount of energy it releases. That energy is indicated by the strength of the surface and body waves that travel away from the earthquake focus. As simple as this principle may seem, it was not until the late 1800s that a machine (seismograph) to detect and record earthquake waves was invented by British scientists working in Japan. The most famous of these early seismographs was invented by John Milne, who returned to Great Britain to establish the field of seismology.

In modern observatories, seismograph instruments can measure the north-south, east-west, and vertical motion of the ground as the various types of seismic waves travel past. Each machine sends an electrical signal to a recorder which produces a highly amplified tracing of the ground motion on a large sheet of paper. This tracing is called a seismogram. Modern seismographs record data digitally, increasing the speed and accuracy of earthquake measurements.

The American seismologist Charles Richter used the amplitude of the body waves shown on seismograms to measure the amount of energy released by earthquakes. The scale which he created in 1935 is called the Richter Scale in his honor. It uses Arabic numerals to rate earthquake magnitudes. The scale is logarithmic and open-ended. That is, there is no lower or upper limit to the magnitude of an earthquake. However, the largest earthquake ever recorded had a Richter magnitude of 8.9. The Richter magnitude of an earthquake also can be measured from the amplitude of its surface waves.

In recent years seismologists developed a new magnitude scale called moment magnitude. The moment of an earthquake is a physical quantity (e.g., area of fault slip) which is related to the total energy released in the earthquake. Moment magnitude can be estimated in the field by looking at the geometry of the fault, or by looking at the record of the earthquake (seismogram). Moment magnitude is now preferred because it can be used to measure all earthquakes—no matter how large, small, close, or distant—at the same scale.

Intensity Measurement of Earthquakes

Even before seismographs came into common use, the effort to classify earthquakes by the damage they produce reached success through the work of the Italian seismologist Giuseppe Mercalli and other European scientists. The 1902 Mercalli scale was modified in 1931 by two American seismologists, H.O. Wood and Frank Neumann. In the Modified Mercalli scale, Roman numerals from I to XII are used to rate the damage, ground motion, and human impact resulting from an earthquake.

The intensity assigned to an earthquake is a relative measure. That is, the Modified Mercalli intensity at a given place depends on the distance from the earthquake epicenter as well as the geological structure of the area. For example, houses built on bedrock will receive less damage than similar houses built on sediment at the same distance from the earthquake epicenter. Poorly built structures will receive more damage than those reinforced to withstand earthquakes.

Earthquake Magnitude—The Size of an Earthquake

m_L	=	*Local magnitude*, devised by Richter and Gutenberg to describe local (Southern California) earthquakes. This is the *Richter magnitude* reported often in newspapers.
m_b	=	*P-wave* or *body* magnitude, determined using P-wave amplitude.
m_s	=	*Surface-wave* magnitude, calculated using Rayleigh wave amplitude having a period approximately 20 seconds. The m_s is commonly-reported magnitude, superseding that Of m_L.
m_w	=	*Seismic moment* magnitude. Determined by taking into account rupture area, displacement, and rock strength. These values are obtained by analysis of seismograms, including wave amplitudes; and field observations.

Location and Earthquake Risk

Earthquakes tend to occur where they have occurred before. There also appears to be some periodicity to the recurrence of earthquakes, that is, some more or less regular interval between major quakes. Unfortunately, human memory and written records do not go back far enough to allow us to predict earthquakes accurately along any known fault. Of course, some faults lie hidden beneath sediment or rock cover and have not been active in recorded time. When an earthquake occurs on such a fault, it may come as a surprise to everyone.

Scientists are developing and refining techniques, such as measuring the change in position of rock along a fault, that may eventually result in an ability to predict the magnitude and date of an earthquake on a known fault. Meanwhile, it is prudent to assume that an earthquake could occur on any fault at any time. Even if an earthquake occurs on a fault that is tens or hundreds of kilometers away, the resulting vibrations could inflict serious damage in your local area.

What Should Be Done To Prepare for an Earthquake?

Weaker structures are more prone to damage than structures built to resist earthquake shaking. Luckily modern houses built with wooden framing are fairly resistant to serious damage in small to medium earthquakes. Most modern commercial buildings are now designed to resist wind forces and earthquake shaking.

Since earthquake shaking is possible almost everywhere in the United States, earthquake safety should be practiced by everyone, whether at home, at school, at work, or on the road.

After personal safety in an earthquake has been attended to, it may be necessary to lead, or join, citizen action groups that are concerned with the safety of the community infrastructure during and after an earthquake. Will the “lifelines”—water, gas, electricity, phone and sewer lines—survive the anticipated earthquake? Will the hospital and other emergency services be operating and adequate to handle emergencies created by the earthquake? Even California, where individuals and governments are sensitive to these questions, the answer seems to be “not completely.” What is the status of earthquake preparedness where you live?