Earthquakes, Volcanoes, and Tsunamis

Resources for Environmental Literacy

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Environmental Literacy Council
National Science Teachers Association

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Contents

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Earthquake

"A strong earthquake occurred at 01:53:41 (UTC) on Sunday, March, 20, 2005. The magnitude 6.6 event was located in Kyushu, Japan."

USGS National Earthquake Information Center,
World Data Center for Seismology, Denver.

Volcano

"The Mount St Helens volcano has erupted in the United States, sending a cloud of ash and smoke nearly 12,000m (40,000ft) into the air."

BBC World News, Wednesday, 9 March, 2005

Tsunami

UN Responds to Tsunami Disaster "What happened on 26 December 2004 was an uprecedented, global catastrophe. It requires unprecedented, global response."

Secretary-General Kofi Annan Statement in Jakarta,
Indonesia, 6 January 2005

Preface

The primary responsibility of teachers of science is to teach science, not to inform their students on environmental issues—and certainly not to influence the stand students may take on those issues. Fostering student understanding of the scientific view of the natural world and how science goes about its work is the first order of business in the teaching of science.

Nevertheless, experienced science teachers—backed by research on learning—know that most students do better when they see how the science they are studying helps them to understand "practical" things that matter to them. Thus, it makes sense to organize science teaching contextually from time to time, that is, to treat the science content from a "real-world" perspective. Many such contexts exist, including inquiry, mathematics, health, sports, technology, history, biography, art, and other cross-cutting themes, such as scale, systems, constancy and change, and models. It is the contention of this project that the environment is another such context, and a particularly important one at that.

Environmental issues and concerns provide a particularly attractive context for teaching various scientific concepts and skills. That belief is what motivated the Environmental Literacy Council (ELC) and the National Science Teachers Association (NSTA) to join forces in developing this set of science/environment modules for teachers. From an educational perspective, science learning and environmental understanding effectively complement each other in two ways:

- The environmental context can improve science learning.
- Learning science can improve the ability of students to deal with environmental issues.

Another way of putting this is that studying science in the context of the environment is doubly productive. It shows how scientific knowledge and ways of thinking, coupled with the process of making decisions about our collective interaction with nature, can illuminate each other to the advantage of both.

—F. James Rutherford
Environmental Literacy Council

Introduction

When we think of natural hazards, earthquakes, volcanoes, and tsunamis quickly come to mind, although floods, hurricanes, typhoons, blizzards, and mud slides are also hugely destructive events. News stories that illustrate the risk associated with these high-profile and often dramatic events provide an exciting and relevant context for investigating important aspects of Earth science and risk assessment, both of which are included in science education standards.

But thinking of these powerful natural events only as "hazards" undervalues their importance in our lives. The surface of the Earth and our environment have been shaped substantially by the behavior of volcanoes, earthquakes, tsunamis, and the plate tectonic forces that foster them. Therefore, this module takes a look at these forces of nature, not only as hazards, but as players in the dynamic system that fashions the environment of the Earth's surface.

To help teachers tap the potential of using earthquakes and volcanic eruptions as a learning context and access the resources they need more readily, this module addresses six essential questions:

1. What are the components of the Earth's system?
2. Where are volcanoes located, what kinds of eruptions do they have, how are they related to earthquakes, and what effect do they have on the environment?
3. Where and how often do earthquakes occur, how is their magnitude expressed, how are they related to volcanoes, and what effect do they have on the environment?
4. What are tsunamis and lahars, and how are they generated?
5. What is the main idea of the theory of plate tectonics, how is it different from the notion of continental drift, what kinds of evidence led to its acceptance by the scientific community, and how does it help explain earthquakes and volcanoes?
6. What hazards do volcanoes and earthquakes present, and how can the risk associated with them be reduced?

The sequence of these essential questions is intentional—moving from the science that underlies the structure of the Earth to the hazards and risks associated with Earth's systems.

This topic provides an extraordinary opportunity for using a case study approach to instruction. Abundant information is readily available for many historically important volcanic eruptions, earthquakes, and tsunamis. Because the events (e.g., the eruption of Vesuvius in AD 79, the San Francisco earthquake in 1906, and the South Asia tsunami in 2004) are dramatic, students will be interested; however, desired learning will not follow if students focus primarily on the drama of earthquakes and volcanoes, bypassing the science involved. Teachers need to provide guidance to show that the main goal of these case studies is to use science information and scientific theory (including plate tectonics) to gain an understanding of fundamental Earth processes and risk analysis.

The next section of this module presents student learning goals. Good instruction usually begins with a clear picture of what "take-away" learning we want students to acquire—the understandings and ways of thinking that will remain with them long after the details of instruction have been forgotten. The learning goals for this module, which are selected from *Benchmarks for Science Literacy* (American Association for the Advancement of Science 1993) and *National Science Education Standards* (National Research Council 1996), assume student familiarity with the geosphere.

The learning goals are followed by the "Background Content for Teachers" section, which summarizes useful scientific and environmental information and is organized with reference to the essential questions. The "Teaching Approach" section includes an overview of the suggested student activity and supplementary exercises, suggestions regarding potential student misconceptions, commentary on assessing student learning, and some recommended resources.

The module concludes with a student activity, which is presented as an example and therefore may be replaced with another activity, as appropriate. The activity involves student handouts (instructions or readings), which are found in the "Student Materials" section.

About the Authors

The **Environmental Literacy Council** is a nonprofit organization dedicated to improving the knowledge base of K–12 teachers in environment-related sciences. Its membership—drawn from the life, physical, Earth, mathematical, and social sciences of prestigious institutions—reflects the cross-disciplinary nature of environmental concerns.

The **National Science Teachers Association** is the oldest national association of science educators in America and the largest organization in the world committed to promoting excellence and innovation in science teaching and learning for all.

This material is based upon work supported by the National Science Foundation under Grant No. ESI-0243521. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. Responsibility for the content and design rests with the Environmental Literacy Council and the National Science Teachers Association.

Disclaimer: The opinions, findings, conclusions, and recommendations expressed in *Resources for Environmental Literacy* are those of the Environmental Literacy Council and the National Science Teachers Association and may or may not conform to the individual viewpoints of each organization's members or staff on either current or historical events, or their impacts on the environment.

Dedication

This publication is dedicated to the memory of **Kathleen B. deBettencourt**. She was known for her dedication to the preservation of our environment through a better understanding of science, for being extraordinarily informed on the connections between science and responsible environmental stewardship, and as a leader in environmental education with a keen ability to collaborate effectively with others. As the founding executive director of the Environmental Literacy Council, Kathleen was innovative and tireless in advancing the Council's goals. To those of us fortunate to have worked with her, she was both an admired colleague and dear friend.

Student Learning Goals

In addition to the *content* goals that follow, case studies often call for students to improve their learning *skills*, including

- using the internet effectively,
- keeping accurate and useful notes,
- working well as part of a group, and
- communicating clearly.

Benchmarks for Science Literacy and *National Science Education Standards* describe core Earth science content appropriate for all students. They do not dictate instruction, but rather articulate some key ideas and skills students should be left with after their learning experiences. There is considerable overlap between science learning goals as expressed in the two documents; however, since some teachers choose to use one over the other, both are presented here. Only those that relate best to the expected learning outcomes of this module are included.

Note that in addition to goals having to do with geological processes, there are goals concerning the nature of systems, ideas associated with hazards and risks, and attributes of scientific inquiry (notably theory development).

From *Benchmarks for Science Literacy*

- The interior of the Earth is hot. Heat flow and movement of material within the Earth cause earthquakes and volcanic eruptions and create mountains and ocean basins. Gas and dust from large volcanoes can change the atmosphere. (p. 73)
- The slow movement of material within the Earth results from heat flowing out from the deep interior and the action of gravitational forces on regions of different density. (p. 74)
- The solid crust of the Earth—including both the continents and the ocean basins—consists of separate plates that ride on a denser, hot, gradually deformable layer of the Earth. The crust sections move very slowly, pressing against one another in some places, pulling apart in other places. Ocean-floor plates may slide under continental plates, sinking deep into the Earth. The surface layers of these plates may fold, forming mountain ranges. (p. 74)
- Earthquakes often occur along the boundaries between colliding plates, and molten rock from below creates pressure that is released by volcanic eruptions, helping to build up mountains. Under the ocean basins, molten rock may well up between separating plates to create new ocean floor. Volcanic activity along the ocean floor may form undersea mountains, which can thrust above the ocean's surface to become islands. (p. 74)
- Thinking about things as systems means looking for how every part relates to oth-

ers. The output from one part of a system (which can include material, energy, or information) can become the input to other parts. (p. 265)

- Any system is usually connected to other systems, both internally and externally. Thus a system may be thought of as containing subsystems and as being a subsystem of a larger system. (p. 265)
- The idea of continental drift was suggested by the matching shapes of the Atlantic coasts of Africa and South America, but rejected for lack of other evidence. It just seemed absurd that anything as massive as a continent could move around. (p. 248)
- Early in the 20th century, Alfred Wegener, a German scientist, reintroduced the idea of moving continents, adding such evidence as the underwater shapes of the continents, the similarity of life forms and land forms in corresponding parts of Africa and South America, and the increasing separation of Greenland and Europe. Still, very few contemporary scientists adopted this theory. (p. 248)
- The theory of plate tectonics was finally accepted by the scientific community in the 1960s when further evidence had accumulated in support of it. The theory was seen to provide an explanation for a diverse array of seemingly unrelated phenomena, and there was a scientifically sound physical explanation of how such movement could occur. (p. 248)
- From time to time, major shifts occur in the scientific view of how the world works. More often, however, the change that takes place in the body of scientific knowledge is in small modifications of prior knowledge. Changes and continuity are persistent features of science. (p. 8)
- In the short run, new ideas that do not mesh well with mainstream ideas in science often encounter vigorous criticism. In the long run, theories are judged by how they fit with other theories, the range of observations they explain, how well they explain observations, and how effective they are in predicting new findings. (p. 13)

From *National Science Education Standards*

- The solid Earth is layered with a lithosphere; hot, convecting mantle; and a dense metallic core. (p. 159)
- Lithospheric plates on the scale of continents move at the rate of centimeters per year in response to movements of the mantle. Major geological events, such as earthquakes, volcanic eruptions, and mountain building result from these plate motions. (p. 160)
- Land forms are the result of combinations of constructive and destructive forces. Constructive forces include crustal deformation, volcanic eruption, and deposition of sediment, while destructive forces include weathering and erosion. (p. 160)
- The outward transfer of Earth's internal heat drives convection circulation in the mantle that propels the plates comprising Earth's surface across the face of the globe. (p.189)
- Interactions among the solid Earth—the oceans, the atmosphere, and organisms—have resulted in the ongoing evolution of the Earth system. We can observe some changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take place over hundreds of millions of years. (p. 189)

- Normal adjustments of the Earth may be hazardous for humans. Humans live at the interface between the atmosphere driven by solar energy and the upper mantle where convection creates changes in the Earth's solid crust. As societies have grown, become stable, and come to value aspects of the environment, vulnerability to the natural process of change has increased. (p. 198)
- Internal and external processes of the Earth system cause natural hazards—events that change or destroy human and wildlife habitats, damage property, and harm or kill humans. Natural hazards include earthquakes, landslides, wildfires, volcanic eruptions, floods, storms, and even possible impacts of asteroids. (p. 168)
- Risk analysis considers the type of hazard and estimates the number of people that might be exposed and the number likely to suffer consequences. The results are used to determine the options for reducing or eliminating risk. (p. 169)
- Individuals can use a systematic approach to thinking critically about risks and benefits. Examples include applying probability estimates to risks and comparing them to estimated personal and social benefits. (p. 169)

References

American Association for the Advancement of Science. 1993. *Benchmarks for science literacy.* New York: Oxford University Press.

National Research Council. 1996. *National science education standards.* Washington, DC: National Academy Press.

Background Content for Teachers

Ideas and issues that can serve as background knowledge are summarized in this section for teachers. It is not intended to be comprehensive, but can easily be supplemented by reference books and websites listed under "Recommended Resources" in the "Teaching Approach" section of the module. Although this material is intended for teachers, some of the ideas presented might also be useful in the course of instruction for the students. It is highly recommended, however, that the student learning goals be emphasized when thinking about the core content that is most important for students to understand.

Essential Question 1:

What Are the Components of the Earth's System?

The Earth is a dynamic system, constantly changing as matter and energy are transferred among its different parts. It includes the following subsystems:

- the *geosphere*—the solid Earth including all the materials that comprise the crust, mantle, and core;
- the *hydrosphere*—all of the water of the Earth (oceans, rivers, lakes, groundwater, etc.), including glaciers and other frozen water;
- the *atmosphere*—the envelope of gases that surround the Earth (oxygen, nitrogen, carbon dioxide, etc.); and
- the *biosphere*—the sum of all living matter on the Earth.

The Earth, in turn, is but a subsystem of the solar system, the solar system a subsystem of the galaxy in which it is embedded, and that galaxy a subsystem of the universe. An advantage of systems thinking—whether of biological, mechanical, astronomical, or any other entity—is that one can isolate parts for study (or action) while keeping in mind that they are not entirely independent.

In the case of the geosphere, movement of rigid tectonic plates (also called lithospheric plates) at the Earth's surface atop a hotter and more ductile portion of the Earth's interior is a fundamental consequence of the slow release of the Earth's internal heat. At their margins, the interaction among these moving plates (which comprise the outer portion of the Earth including its surface) constantly changes and shapes the Earth. These changes are manifested in earthquakes and volcanoes that arise from such interaction.

The earthquakes and volcanic eruptions associated with the Earth's geosphere affect and even shape the environment (the hydrosphere, atmosphere, biosphere, and geosphere itself).

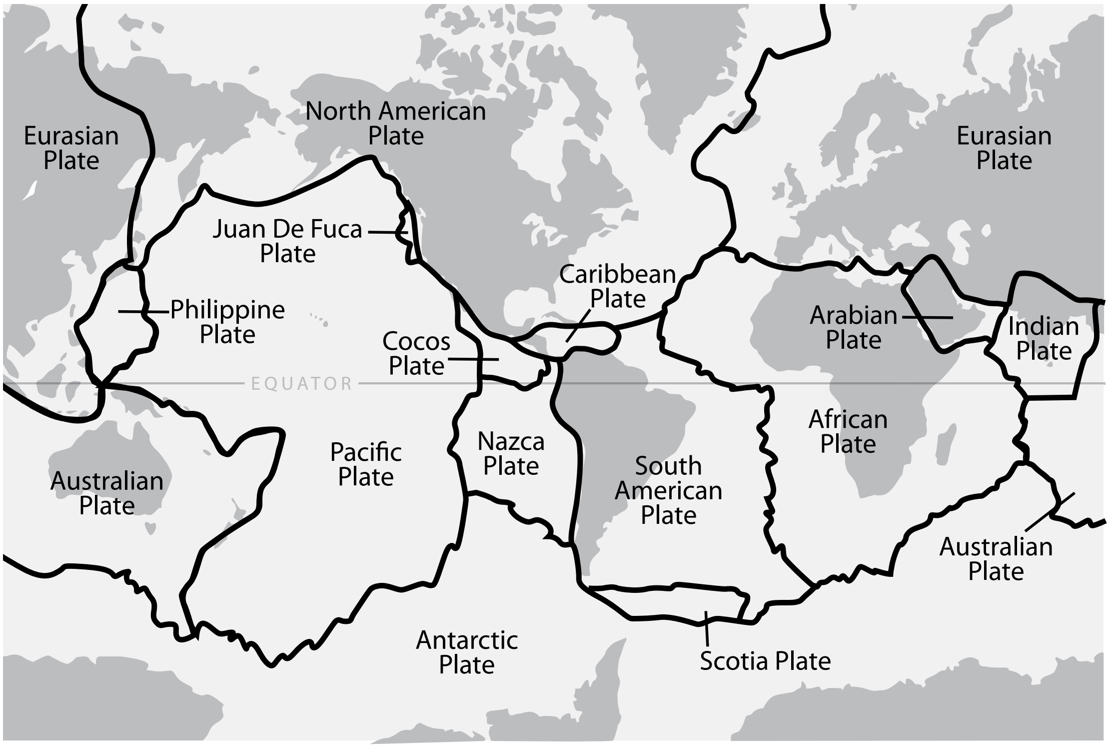


Figure 1. Location of Tectonic Plates

Source: Image by Jane Russell for the U.S. Geological Survey.

We are part of the Earth system's biosphere and thus are affected by these processes and events. Different aspects of the Earth system (subsystems within it) interact to create adverse and/or beneficial impacts on the environment. These interactions directly or indirectly cause natural hazards with risks for loss of lives and property.

Essential Question 2:

Where Are Volcanoes Located, What Kinds of Eruptions Do They Have, How Are They Related to Earthquakes, and What Effect Do They Have on the Environment?

Volcanoes occur because the Earth's crust is broken into 17 major tectonic plates that are rigid but float on a hotter, softer layer in the Earth's mantle (see Figure 1 for the location of these plates). Within the Earth's mantle, temperatures are hot enough to melt rock and form a thick, flowing substance called magma. Magma is lighter than the solid rock that surrounds it—buoyant like a cork in water—and, being buoyant, it rises. As the plates shift, they spread apart, collide, and/or slide past one another. Volcanoes grow because of repeated eruptions. Most occur near the edge of plates or along the edges of continents where one plate overlaps a second plate; this is called a subduction zone. Active volcanoes seen on land occur where plates collide; however, most of Earth's volcanoes are hidden from view, occurring on the ocean floor.

Volcanic eruptions occur only in certain places and do not occur randomly. Some tend to be explosive when they erupt, whereas others tend to be loosely flowing and nonexplosive.

Some volcanoes may exhibit only one characteristic type of eruption during an interval of activity; others may display an entire range of types (see *http://pubs.usgs.gov/gip/volc/eruptions.html*):

- *Strombolian:* Huge clots of molten lava burst from the summit crater to form arcs through the sky; lava clots combine to stream down the slopes of the volcano (see Figure 2).
- *Vulcanian:* A dense cloud of ash-laden gas explodes from the crater and rises high above the peak; steaming ash forms a whitish cloud near the upper level of the cone.
- *Vesuvian:* This type is named after the eruption of Mount Vesuvius in Italy in AD 79. Great quantities of ash-laden gas are violently discharged to form a cauliflower-shaped cloud high above the volcano.
- *Peléan:* Large quantities of gas, dust, ash, and incandescent lava fragments are blown out of a central crater, fall back, and form avalanches that move down the volcano at velocities as great as 100 mph.
- *Hawaiian:* This term is used for a fissure-type eruption where molten, incandescent lava spurts on the volcano's rift zone and feeds lava streams that flow down the volcano, or for a central-vent eruption where a fountain of fiery lava spurts to a height of several hundred feet or more.
- *Phreatic:* This type of eruption is driven by explosive expanding steam—a result of cold ground or surface water coming into contact with hot rock or magma. The distinguishing feature of phreatic eruptions is that they only blast out fragments of preexisting solid rock from the volcanic conduit; no new magma is erupted.
- *Plinian:* This is the most powerful type of eruption, involving the explosive ejection of relatively viscous lava that can send ash and volcanic gas tens of miles into the air.

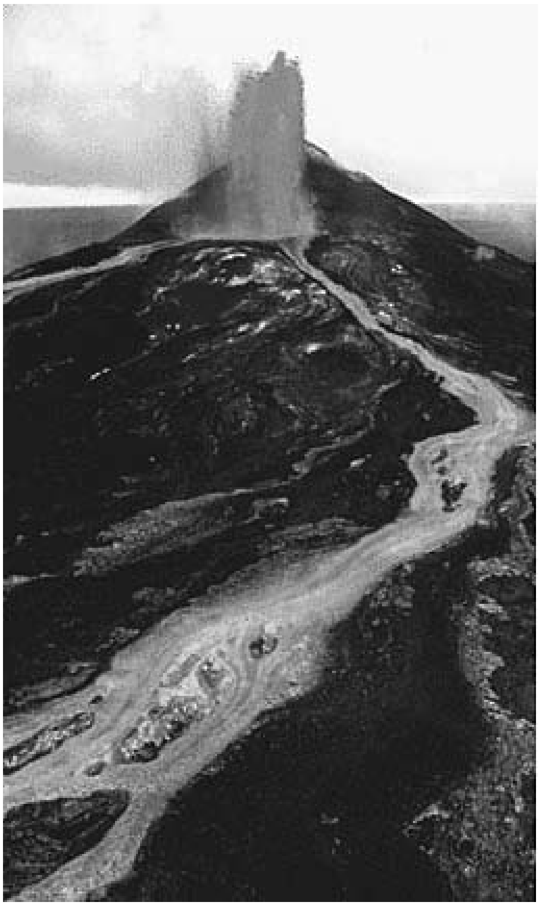


Figure 2. Strombolian Activity

Source: FEMA for Kids.

Explosive volcanic eruptions can be dangerous and deadly. The fiery clouds and hot lava that race down mountainsides destroy nearly everything in their path, including trees, plants, insects, and other wildlife. Ash erupting into the sky falls back onto the Earth, creating a blanket that can suffocate plants, crops, animals, and humans. They can also spark forest fires near the volcano.

Volcanic eruptions can also affect climate and weather patterns. Eruptions produce sulfuric acid aerosols that form a layer of haze in the stratosphere. This haze, which can remain in the atmosphere for years, reflects the Sun's radiation and reduces surface temperatures. On the other hand, volcanoes also provide many benefits to the environment. The gaseous emissions from volcanic vents over hundreds of millions of years formed the Earth's earliest oceans and atmosphere, supplying the ingredients vital to evolve and sustain life.

Essential Question 3:

Where and How Often Do Earthquakes Occur, How Is Their Magnitude Expressed, How Are They Related to Volcanoes, and What Effect Do They Have on the Environment?

An earthquake is a sudden movement of the Earth caused by the abrupt release of energy that has accumulated over a long time. Most earthquakes occur at the boundaries where the plates of the Earth's outer layer meet. In fact, the location of earthquakes and the kind of ruptures they produce help scientists define the plate boundaries. Most destructive quakes, however, are caused by dislocations of the crust. The crust may bend and then, when the stress exceeds the strength of the rocks, break and "snap" to a new position.

There are three types of plate boundaries: spreading zones, transform faults, and subduction zones. At *spreading zones,* molten rock rises pushing two plates apart and adding new material at their edges. Most spreading zones are found in oceans. *Transform faults* are found where plates slide past one another. Earthquakes at transform faults tend to occur at shallow depths and form fairly straight linear patterns. *Subduction zones* are found where one plate overrides, or subducts, another, pushing it downward into the mantle where it melts. Subduction zones are characterized by deep-ocean trenches, shallow to deep earthquakes, and mountain ranges containing active volcanoes.

Geologists have found that earthquakes tend to recur along faults, which reflect zones of weakness in the Earth's crust. If a fault zone experiences an earthquake, there is no guarantee that all of the stress will be relieved. Another earthquake can still occur.

Earthquakes may occur in an area before, during, and after a volcanic eruption, but they are not the cause or result of volcanic activity; rather they are the result of the active forces connected with the volcanic eruption.

The vibrations produced by earthquakes are detected, recorded, and measured by instruments called seismographs. The jagged line made by a seismograph—called a seismogram—reflects the changing intensity of the vibrations by responding to the motion of the ground surface beneath the instrument. From the data expressed in seismograms, scientists can determine the time, the epicenter, the focal depth, and the type of faulting of an earthquake and can also estimate how much energy was released.

The Richter scale is the best-known scale for measuring the magnitude of earthquakes. The scale is logarithmic, so 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 people. Earthquakes with a magnitude of 6 or more are considered major; great earthquakes have magnitudes of 8 or more.

Initial effects of an earthquake are violent ground motions which can produce cracks or fractures in the ground and liquefaction, where loose sandy soils with a high moisture content separate and give the surface a consistency much like that of

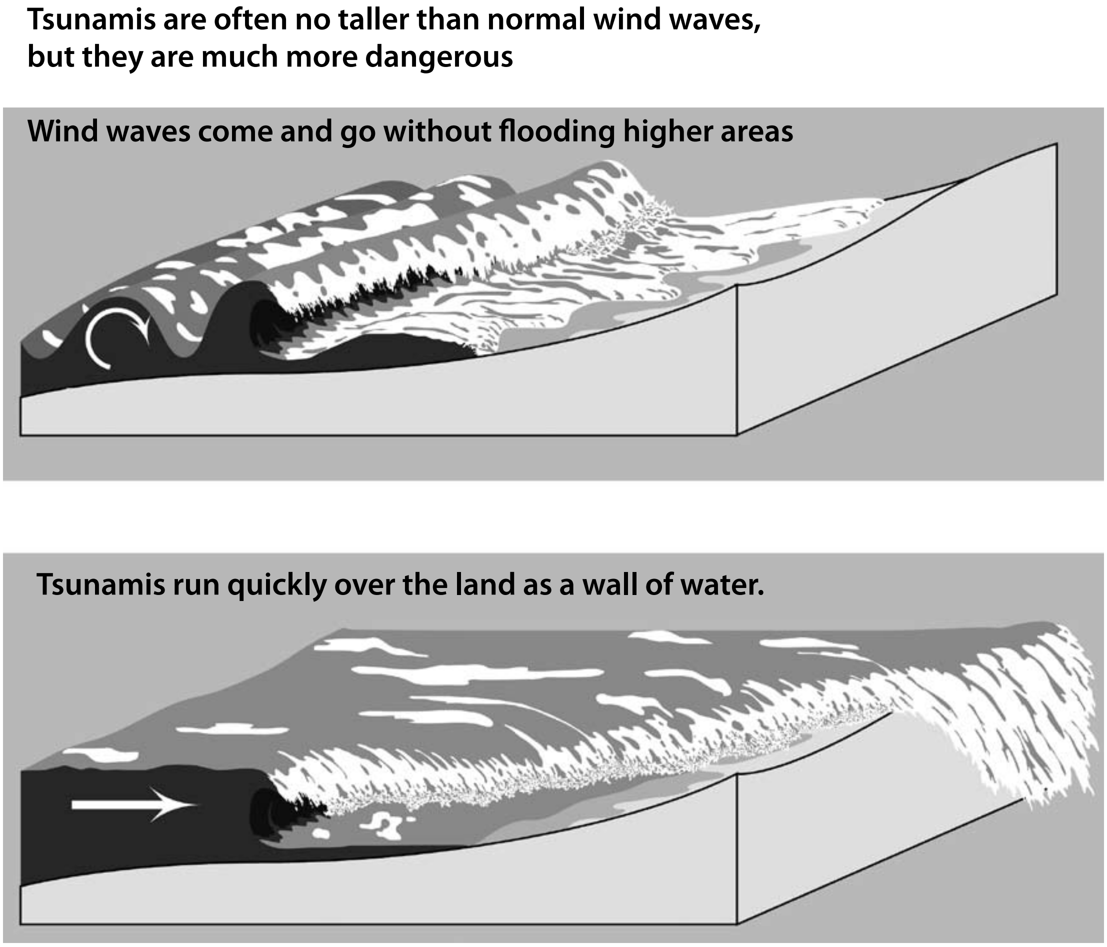


Figure 3. Difference Between Wind Waves and Tsunami Waves

Source: Image by B. Higman, University of Washington, Seattle.

quicksand. As destructive as earthquakes are, the resulting secondary effects such as landslides, tsunamis, fires, and floods can be even more devastating. Landslides are especially damaging and often account for the majority of lives lost. Tsunamis—large sea waves caused by an earthquake abruptly moving the ocean floor—can move at high speeds and cross thousands of miles before they run up on shore, wiping out everything in their path (see Figure 3). The risk of fire immediately after an earthquake is often high due to broken electrical lines and gas mains. Finally, subsoil disturbances can cause changes in groundwater flows, which in turn can cause abrupt changes in the level of the water table and a sudden drying up of surface springs.

Essential Question 4:

What Are Tsunamis and Lahars, and How Are They Generated?

A tsunami is a series of gigantic waves that occur in the ocean or in other large bodies of water. Formed when a large amount of water is rapidly displaced, tsunamis are often caused by an underwater disturbance such as an earthquake, a landslide, an erupting volcano, or even a meteorite impact. Moving outward from their initial source, the waves travel very fast—up to 600 mph. While traveling through deep water the waves may only reach a foot or two in height. The waves slow down as they reach shallow water, causing water to pile up into very high (and still very fast) waves as tall as 34 feet. Rapid changes in water levels are an indication of an approaching tsunami.

Tsunamis can be generated in all of the world's oceans, inland seas, and any other large body of water. Most tsunamis occur in the Pacific Ocean, which covers more than one-third of the Earth's surface. Between 1900 and 2001, 796 tsunamis were recorded in the Pacific Ocean (see "About Tsunamis" at *www.prh.noaa.gov/ptwc/abouttsunamis.htm*). In 2004, a tremendous tsunami caused terrible havoc across much of Asia and Indonesia and had impacts as far away as Africa and Alaska (Perkins 2005). Tsunamis can have negative effects on the natural environment when they cause damage to already fragile coral

Figure 4. Mount St. Helen's explosive eruption in 1982 sent pumice and ash 9 miles into the air and resulted in a lahar (the dark deposit on the snow) flowing from the crater into the valley.

Source: U.S. Geological Survey photograph by Tom Casadevall (March 21, 1982).

reefs and mangrove swamps, which are vital feeding and breeding grounds for fish. Destruction of these environments can leave coastlines vulnerable to erosion and local communities without a vital source of food.

Lahars are rapidly flowing mixtures of rock debris and water that originate on the slopes of a volcano. They are also referred to as volcanic mudflows or debris flows. Volcanic eruptions may directly trigger one or more lahars by quickly melting snow and ice on a volcano or ejecting water from a crater lake (see Figure 4). They form in a variety of other ways, including through intense rainfall on loose volcanic rock deposits and as a consequence of debris avalanches.

When moving, a lahar looks like a mass of wet concrete that carries rock debris ranging in size from clay particles to large boulders. As it rushes downstream, its size, speed, and the amount of water and rock debris it carries are constantly changing. Lahars have the strength to rip huge boulders, trees, and man-made structures from the ground, carrying them for great distances. They cover the surfaces they travel over with mud, particularly those of mountain and valley systems, and can destroy wildlife that exists on the Earth's surface and in its bodies of water.

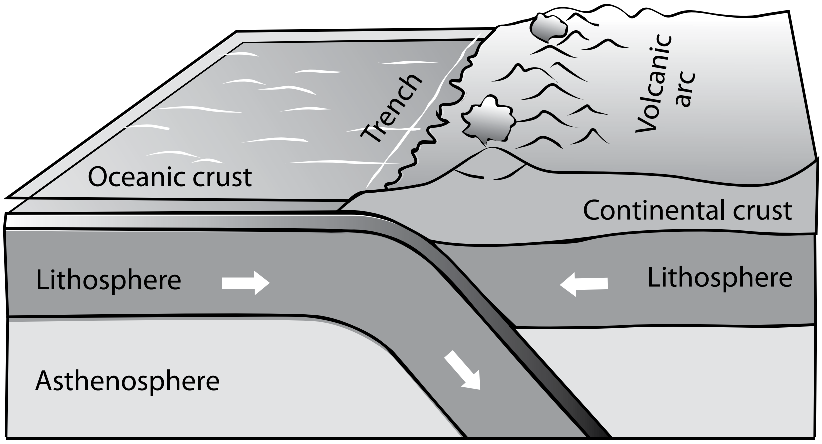
Essential Question 5:

What Is the Main Idea of the Theory of Plate Tectonics, How Is It Different From the Notion of Continental Drift, What Kinds of Evidence Led to Its Acceptance by the Scientific Community, and How Does It Help Explain Earthquakes and Volcanoes?

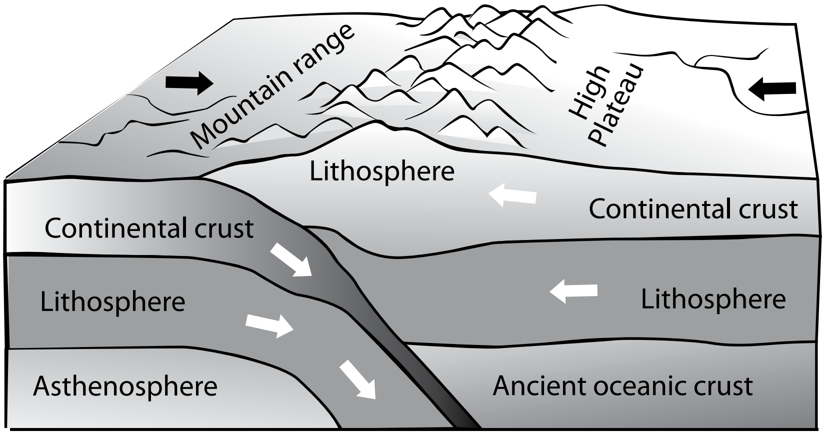
Plate tectonics is the field of study related to the causes and consequences of lithospheric motion, and plate tectonic theory describes a great number of phenomena that occur within the Earth system. A basic understanding of plate tectonics is a fundamental part of understanding each of the spheres that comprise the Earth system, from biosphere to atmosphere.

The theory of plate tectonics proposes that the surface of the Earth is broken into large plates that change both in size and position over time. Plate tectonics is a combination of the ideas of continental drift—the movement of continents over the Earth's surface—and sea-floor spreading—the creation of new oceanic crust. Evidence for this theory that has gained acceptance in the scientific community includes the fit of the continents, the distribution of identical fossils on various continents, and matching glacial striation and broad bands of rock across continents.

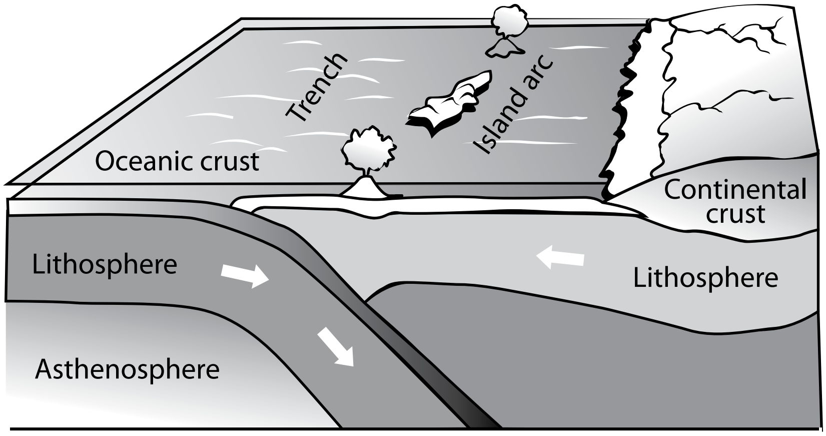
The outermost portion of the solid Earth, called the lithosphere, is composed of a series of discrete pieces, or plates. Each of the plates appears to be bounded by earthquake epicenters and, in some cases, volcanoes. Whereas some plates encompass both oceanic and continental regions on the Earth, others may be entirely located within an ocean basin. The rocks that make up the continental portions of plates are less dense than those that make up the ocean basins. In both cases, the rocks that make up the plates are less dense than the rocks that lie deeper in the Earth. In a sense the lighter, less dense rocks of the lithosphere can be said to "float" on the heavier, more dense rocks that underlie the continents and ocean basins. The high density of the oceanic rocks relative to the continental rocks makes them sink lower into the mantle below. This gives rise to the deep ocean basins.



Oceanic-continental convergence



Continental-continental convergence



Oceanic-oceanic convergence

Figure 5. Three Types of Convergence

Source: Kious, W. J., and R. I. Tilling. 1996. ***This Dynamic Earth: The Story of Plate Tectonics.*** U.S. Geological Survey.

Earthquakes and volcanoes are thought to result from the interactions that occur along the boundaries of two moving plates. The kinds of earthquakes and volcanoes produced depend on the kinds of lithosphere along the boundary (oceanic or continental) and whether the plates are coming together, moving apart, or sliding past one another (see Figure 5).

When at least one of two converging plates is oceanic at the point of contact, the oceanic lithosphere becomes consumed back into the Earth by a process known as subduction. This subduction gives rise to concentrated belts of volcanic activity. An example of this would be the volcanoes of the Cascades Range in the Northwest United States.

When the plates diverge from one another, volcanic activity creates new oceanic lithosphere to fill in the void that otherwise would appear between the diverging plates. It is in this manner that oceanic lithosphere is continually created and destroyed, a process that encompasses a transfer of energy and matter from the Earth's deep interior to the systems operating at or near its surface. These can both drive and be a consequence of the motion of the Earth's lithosphere.

The plane along which the rocks move is called a fault. Faults and the resulting earthquakes are caused by movements in the Earth's lithosphere where it is either compressed (pushed together) or rifted (pulled apart). During this process rocks may break as brittle material or be stretched like elastic until they finally break. In either case, when they break they release energy in the form of wave motion or vibrations, which form an earthquake. Faults may occur near the ground surface, where they can be observed, or very deep in the Earth's interior. Instrumentation and technology used to detect earthquakes can also locate exactly where faulting has occurred in the Earth's interior.

Essential Question 6:

What Hazards Do Volcanoes and Earthquakes Present, and How Can the Risk Associated With Them Be Reduced?

Some of the greatest impacts (and associated risks) from volcanic eruptions occur due to the interaction of volcanic material with the hydrosphere and atmosphere. Volcanically induced mudflows, for instance, occur when volcanic ash and debris interact with surface waters (or ice). When the Nevado del Ruiz volcano in Colombia erupted in 1985 under a cap of snow and ice, the resulting mudflows killed more than 23,000 people in a very short time (see *http://vulcan.wr.usgs.gov/Volcanoes/Colombia/Ruiz/description_eruption_lahar_1985.html*).

However, much of the damage associated with the 1991 eruption of Mount Pinatubo in the Philippines occurred months and even years after the eruption, as monsoonal rains mobilized the volcanic ash left behind on the flanks of the volcano (Wolfe and Hoblitt 1996). Atmospheric contributions from major volcanic eruptions can also have significant global impacts affecting climate and the geochemical cycling of various chemical elements. It is often the case that the indirect consequences of these events can have greater economic, meteorological, agricultural, and sociological impacts than the initial effects of the events.

Still, the worst earthquake in the world poses little risk if no one lives in or uses the region that is affected. The consequences of earthquake activity in December 2003 exemplify this point. On December 22 of that year, a magnitude 6.5 earthquake in central California killed two people and severely damaged 40 buildings (see *http://earthquake.usgs.gov/eqcenter/eqinthenews/2003/nc40148755*). Four days later, a magnitude 6.6 earthquake near Bam, Iran, killed

30,000 people, injured another 30,000 and damaged approximately 85% of all buildings and infrastructure (see *http://earthquake.usgs.gov/eqcenter/eqinthenews/2003/uscvad/index.php*). The next day a magnitude 7.3 earthquake occurred in the southwest Pacific Ocean; it went largely unreported (see *http://earthquake.usgs.gov/eqcenter/eqinthenews/2003/uscwbb/index.php*).

It is important to recognize that even with a natural disaster over which we have little control, our understanding and the choices we make can often have a greater effect on the risk that each of us experiences. Like other hazards, the risk associated with earthquakes and volcanoes is strongly dependent on the manner in which humans use and interact with the environment.

Now that significant hazards such as volcanoes and earthquakes are correlated with plate tectonics, allowing us to better locate areas subject to such hazards, is it possible that the timing of these potentially catastrophic events can be predicted? One question often posed is why volcanoes produce such heavy casualties. The answer probably lies in the fact that volcanoes can lie dormant for centuries between eruptions; hence, a lifetime view of a typical volcano shows constancy and little to no change. However, a view of hundreds or thousands of years can indicate an area characterized by catastrophic change. There are many cases—such as the eruptions of Vesuvius in AD 79, Krakatoa in 1883, and Mont Pelée in 1902—where humans were complacent regarding the risks associated with dormant volcanoes.

Geoscientists have had more success predicting volcanic eruptions than they have had with earthquake prediction. A common warning of an impending volcanic eruption is a series of earthquakes that increase in both magnitude and frequency. Volcanoes often give other clues indicating that an eruption may be near—changes in the shape of a volcano can be detected by satellites and sensitive surveying instruments, and monitoring the composition of gases emitted from active volcanoes might indicate an eruption is near. Still, a great many volcanoes are not well monitored, and there are volcanoes that do not give obvious visual signs that they are about to erupt. Therefore, making volcano predictions continues to be an inexact science.

Earthquake prediction has also not been very successful. Because large earthquakes associated with a particular fault are infrequent, geoscientists are forced to hypothesize earthquake precursors such as animal behavior, electrical field measurements, and foreshocks. However, none of these have resulted in total success. Other efforts to predict earthquakes rely on actively monitoring faults, but much of earthquake prediction today relies on looking for patterns of past earthquake behavior associated with a specific region or fault. Like other kinds of risk assessment, those patterns are then used to determine a probability that an earthquake of a certain magnitude will affect a particular region. Although short-term earthquake prediction is not very successful, longer-term earthquake forecasting can be a valuable tool for policy makers. This forecasting can identify both earthquake-prone areas and man-made structures that are especially vulnerable to damage from the effects of earthquakes. Based on this information, policy makers can develop increasingly sound and cost-effective building codes and emergency-response plans.

References

Perkins, S. 2005. Tsunami disaster: Scientists model the big quake and its consequences. *Science News* 167 (2): 19. Also available online at *www.sciencenews.org/articles/20050108/fob1.asp*.

Wolfe, E. W., and R. P. Hoblitt. 1996. Overview of the eruptions. In *Fire and mud: Eruptions and lahars of Mount Pinatubo, Philippines,* eds. C. G. Newhall and R. S. Punongbayan. Seattle: University of Washington Press. *http://pubs.usgs.gov/pinatubo/index.html.*

Teaching Approach

This section of the module provides an activity overview, a list of supplementary exercises, a discussion of possible student misconceptions, ideas for assessing student learning, and some recommended resources.

Activity Overview

Only one activity is described here, but it is an extensive one. Because information on earthquakes and volcanoes is abundant and easy to find (assuming internet access), the entire activity—including the presentations and assessment—can be carried out in less than two weeks. Although that is a large amount of instructional time, it is well worth it because it centers on geology's central concept and can contribute to student understanding of the nature of systems and of the way science works, as well as to the further development of communication skills.

The case studies in this activity will provide students with the opportunity to learn about tectonic-related hazards and the resulting interactions among the subsystems of the Earth's crust. Lahars and tsunamis can cause enormous destruction and are a direct consequence of interactions between the geosphere and the hydrosphere. The interaction of volcanic ash and aerosols with the atmosphere can affect climate globally and can have deadly consequences. Finally, humankind (as part of the biosphere) can also create hazards—and affect risk—in the way we use areas prone to earthquakes and volcanic activity.

Supplementary Exercises

For those teachers who feel their class could benefit from a bit more introduction to the theory of plate tectonics before the main lesson, try the following online resources:

- *(http://discoverourearth.org/student/tectonics/index.html)*: This website presents plate tectonics exercises for students with interactive simulations, 3-D graphics, and maps. The exercises teach students about the theories of continental drift and plate tectonics and include questions for students and teacher guides. Also see the related exercises on topography (*http://discoverourearth.org/student/topography/index.html*).
- (*www2.nature.nps.gov/geology/usgsnps/pltec/pltec1.html*): The U.S. Geological Survey (USGS) hosts this short online review of plate tectonic theory with easy-to-understand graphics showing the layers of the Earth and the different kinds of plate boundaries.
- Earth Like a Puzzle (*www.sio.ucsd.edu/voyager/earth_puzzle/index.html*): The Scripps Institution of Oceanography developed this online trip through the evi-

dence for the theories of continental drift and plate tectonics.

- Plate Movements (*www.divediscover.whoi.edu/tectonics/movements.html*): The Dive and Discover website of Woods Hole Oceanographic Institution includes a set of illustrations showing how plates slide, subduct, and collide.

Misconceptions

Student misconceptions may include the belief that earthquakes only happen in California, or that all mountains have the ability to become volcanically active. Many students know that Hawaii is volcanically active, but they may not know that there are many other active volcanoes within the United States. Also, they may not know that there is a close association between the occurrences of earthquakes and volcanic activity.

Assessing Student Learning

After the reports and the list of generalizations have been completed, the work of each student can be assessed by adding together three scores based on the following elements:

- *A team grade:* This grade can be applied to each team member. An evaluation should be made on the basis of the thoroughness and quality of both the written report and the presentation. If the students have not had prior experience in preparing reports and making presentations, guidance should be provided so students will know what is expected of them.
- *Student journals:* The journals should be collected and critiqued, and each student should receive feedback on the strengths and weaknesses of the journal.
- *A written examination:* The examination should be based on the essential questions and learning goals.

Recommended Resources

Books

De Boer, J. Z., and D. T. Sanders. 2004. *Volcanoes in human history: The far-reaching effects of major eruptions*. Princeton, NJ: Princeton University Press.

A clear and simply written book that joins history and natural science as the authors take a look at various major eruptions and their consequences.

Hough, S. E. 2004. *Earthshaking science: What we know (and don't know) about earthquakes*. Princeton, NJ: Princeton University Press.

An excellent summary integrating state-of-the-art research with explanations of earthquake phenomena, attempting to explain many of the current controversies.

Websites

Environmental Literacy Council: Plate Tectonics (*www.enviroliteracy.org/subcategory.php/200.html*)

This site breaks down the essentials of plate tectonic theory, describes the science of volcanoes and earthquakes, and offers links to interactive maps, lecture notes from scientists and professors, and online activities for students.

American Field Guide: Volcanoes: How Safe Are They? *(www.pbs.org/americanfieldguide/teachers/volcanoes/volcanoes_sum.html)*

The Public Broadcasting Service (PBS) maintains the American Field Guide site, which offers this classroom unit on volcanoes. Students learn about the location of, hazards associated with, and risks presented by the most dangerous volcanoes on Earth.

Natural Hazards Education and Research Cooperative (NHERC) (*www.naturalhazards.org*)

NHERC is an educational, scientific, and nonprofit organization committed to improving understanding of natural hazards.

Natural Hazards Center (*www.colorado.edu/hazards/resources/web/earthquakes.html*)

This center, part of the University of Colorado at Boulder, provides an extensive online list of resources on earthquakes.

This Dynamic Earth: The Story of Plate Tectonics (*http://pubs.usgs.gov/gip/dynamic/dynamic.html*)

This online USGS book, written by W. Jacquelyne Kious and Robert I. Tilling, provides a good lead-in for the exploration of the development of the theory of plate tectonics and further insight on the importance of these processes.

Earthquakes (*http://pubs.usgs.gov/gip/earthq1*)

This USGS resource, written by Kaye M. Shedlock and Louis C. Pakiser, contains information on the history, location, measurement and prediction of earthquakes. It also addresses why earthquakes occur, as well as their relationship to volcanic eruptions.

Volcano Hazards Program (*http://volcanoes.usgs.gov*)

The USGS offers information resources on the types and effects, locations, and history of volcanic eruptions. The site also provides resources for educators (*http://volcanoes.usgs.gov/educators.html*).

Student Activity

Earthquakes, Volcanoes, and Us

General case study instructions are included in the "Student Materials" section, but teachers may wish to add the time schedule, the form the team reports may take, how long the presentations can be, and suggestions for student data and note keeping.

Be sure that both volcano case studies and earthquake case studies are assigned in this activity. The "Student Materials" section includes two lists of internet sites that provide information on cases that vary by location, date, physical characteristics, and effects. This information will help teams start their investigations, but they are expected to find other useful sites on their own.

As student teams work on their case studies (mostly out of class, although 5–10 minutes could be allotted each day for team members to plan and check progress), teachers will want to focus class time on the following topics:

- The development of the theory of plate tectonics, with an emphasis on the evidence that finally led to its acceptance by most scientists; also, the nature of scientific theories.
- The concepts of hazard and risk; how to estimate risk; and how different risks compare (see the "Student Materials" section for a summary essay on risk; this essay will help students place their team's findings about the risk of earthquakes and volcanoes into a larger context).
- The concept of systems, with examples from anatomy, transportation, and astronomy.
- How to keep a useful scientific journal (unless it has been well covered previously).

This activity emphasizes the process of record keeping. If students are not experienced in using a journal, encouragement may be needed to get them started at placing thoughts onto paper. If students are not experienced in scientific inquiry, they may not see the value of keeping abundant notes—particularly early on in the activity. Help students to understand that keeping accurate and clear records of thoughts, observations, and conclusions is an important part of all scientific endeavors. Good journal keeping should be emphasized to assist in making entries meaningful, but at the same time encourage students to make entries regardless of how insignificant they might believe the entries seem at the time. By the conclusion of the activity, they may discover a trend among these seemingly "insignificant" details.

As student teams give their presentations, the entire class should work together to identify a list of generalizations about the nature of earthquakes and volcanoes: what causes them, what effects they have on the environment, and the hazards and risks associated with them. The essential questions listed in the previous sections of this module can provide a template for organization, and the results should be in accordance with the desired student learning goals.

Student Materials

Case Study Instructions for Students

You are a member of a team that is charged with investigating a past earthquake or volcanic eruption—or a series of such events. You will be provided with some internet references to get you started on your topic, but you will want to find other sources, both print and electronic. Each member of your team will keep a journal in which to record data, ideas, and questions. Drawing from these journals, your team will prepare a written report and make a presentation to the class. The report should describe the event(s)—where, when, magnitude, and what happened to people and to the environment—and should include answers to the following questions:

1. Which of the systems making up the Earth's surface—atmosphere, biosphere, geosphere, hydrosphere—were involved? How?
2. What was the source of the energy that made the event(s) possible?
3. How does the theory of plate tectonics explain what happened?
4. When is a similar event likely to occur in the same general area? What is the basis for making such predictions, and how trustworthy are they?
5. How can the event(s) be characterized using the concepts of hazard and risk? In this case, what was at risk? What steps could have been taken to reduce (mitigate) the risk to which people were exposed?
6. How does the risk associated with such events compare with that of other hazards, such as accidental poisoning, motorcycling, cigarette smoking, skin cancer, and air travel? On what basis?
7. What two or three sources would the team recommend to someone who wanted to learn about this event? Why?

As you begin your research, remember that you will need to approach each of your sources with a critical eye. Even the best resources will have a reason for presenting the information that you will review, and it is valuable to consider that as you do your research. The following sites can assist you in evaluating your sources:

- The University of California Berkeley Library offers a step-by-step guide for the evaluation of websites at *www.lib.berkeley.edu/TeachingLib/Guides/Internet/Evaluate.html.* Also see their one-page printable "Web Page Evaluation Checklist" at *www.lib.berkeley.edu/TeachingLib/Guides/Internet/EvalForm_General_Barker.pdf.*
- The Environmental Literacy Council provides website evaluation criteria at *www.enviroliteracy.org/article.php/528.html.*

Natural Hazards Case Studies: Earthquakes

Lisbon, Portugal 1755	http://nisee.berkeley.edu/lisbon http://geology.about.com/library/bl/bllisbon1755eq.htm www.olympus.net/personal/gofamily/quake/famous/lisbon.html www.science.soton.ac.uk/science_news/current_issue/index.php?link=article.php&article=13
New Madrid, Missouri 1811-12	http://hsv.com/genlintr/newmadrd http://quake.ualr.edu/public/nmfz.htm www.eas.slu.edu/Earthquake_Center/SEISMICITY/Street/rstreet.html http://quake.wr.usgs.gov/prepare/factsheets/NewMadrid
Charleston, South Carolina 1886	www.sfmuseum.org/1906.2/charleston.html www.muschealth.com/about_us/history/charlestonearthquake.htm http://neic.usgs.gov/neis/eq_depot/usa/1886_09_01.html
San Francisco, California 1906	www.sfmuseum.org/1906/06.html http://quake.wr.usgs.gov/info/1906 www.eas.slu.edu/Earthquake_Center/1906EQ www.exploratorium.edu/faultline/great/1906/index.html www.eyewitnesstohistory.com/sfeq.htm
Chile 1960	www.extremescience.com/GreatestEarthquake.htm http://neic.usgs.gov/neis/eq_depot/world/1960_05_22_tsunami.html www.drgeorgepc.com/Tsunami1960.html
Prince William Sound, Alaska 1964	http://neic.usgs.gov/neis/eq_depot/usa/1964_03_28.html www.aeic.alaska.edu/quakes/Alaska_1964_earthquake.html www.drgeorgepc.com/Tsunami1964GreatGulf.html www.intute.ac.uk/sciences/hazards/earthquake_2_report.html
Kobe, Japan 1995	www.seismo.unr.edu/ftp/pub/louie/class/100/effects-kobe.html www.hewett.norfolk.sch.uk/curric/NEWGEOG/Tectonic/Earth/Kobe.htm www.georesources.co.uk/kobelow.htm
Southeast Asia 2004	www.drgeorgepc.com/Tsunami2004Indonesia.html www.cbc.ca/news/background/asia_earthquake http://news.bbc.co.uk/2/hi/in_depth/world/2004/asia_quake_disaster www.cnn.com/SPECIALS/2004/tsunami.disaster

Natural Hazards Case Studies: Volcanic Eruptions

Hawaiian Islands	www.soest.hawaii.edu/GG/HCV/haw_formation.html http://hvo.wr.usgs.gov/volcanowatch www.volcano.si.edu/world/region.cfm?rnum=1302 www.solarviews.com/eng/hawaii.htm
Mt. Vesuvius 79	http://volcano.und.nodak.edu/vwdocs/volc_images/img_vesuvius.html www.cotf.edu/ete/modules/volcanoes/vmtvesuvius.html www.answers.com/topic/mount-vesuvius http://193.204.162.114/vesuvio/79_eruption.html www.dl.ket.org/latin3/historia/places/vesuvius/eruptions.htm
Mt. Tambora, Indonesia 1815	www.avonhistory.org/jean/tambora.htm www.physics.uoguelph.ca/summer/scor/articles/scor43.htm www.exn.ca/volcanoes/weather.cfm http://volcano.und.nodak.edu/vwdocs/volc_images/southeast_asia/indonesia/tambora.html
Mt. Pelée, Martinique 1902	http://volcano.und.nodak.edu/vwdocs/volc_images/img_mt_pelee.html http://vulcan.wr.usgs.gov/Volcanoes/WestIndies/Pelee/framework.html www.geology.sdsu.edu/how_volcanoes_work/Pelee.html
Mt. St. Helens, Washington 1980	http://vulcan.wr.usgs.gov/Volcanoes/MSH/May18/MSHThisWeek/intro.htm http://pubs.usgs.gov/fs/2000/fs036-00 www.ngdc.noaa.gov/seg/hazard/stratoguide/helenfact.html www.geology.sdsu.edu/how_volcanoes_work/Sthelens.html
Nevado del Ruiz, Colombia 1985	http://volcanoes.usgs.gov/Hazards/What/Lahars/RuizLahars.html www.ngdc.noaa.gov/seg/hazard/stratoguide/nevadofact.html www.geology.sdsu.edu/how_volcanoes_work/Nevado.html
Lake Nyos, Cameroon 1986	http://volcano.und.nodak.edu/vwdocs/volc_images/africa/nyos.html www.pbs.org/wnet/savageplanet/01volcano/01/indexmid.html http://www.geology.sdsu.edu/how_volcanoes_work/Nyos.html

The Nature of Risk

What is risk? How would you define it? Most people think of risk as a number, a statistical probability, the likelihood that something will happen, as in "the risk is one in a million."

But there is more to risk than just probability. Risk means that something bad, harmful, or negative could happen. If you were talking about winning the lottery you'd probably say "The chances of winning the lottery are one in a million." But if you were talking about being hit by lightning you'd say "The risk of being hit by lightning is one in a million." Risk implies a potentially negative outcome.

A hazard is simply some agent or circumstance out there—like a poison or pollution or an earthquake fault running under your house—known to cause an adverse effect under certain circumstances. It is the first factor that risk assessors investigate when studying a risk. Everything can post a hazard under the wrong circumstances.

Assessors of risk don't just study the agent to see what kind of hazard it could pose, they want to know the circumstances under which a hazardous substance poses a risk—i.e. what is the threshold? Does the risk increase at a constant rate? Is the risk big or small? At what levels? Severity of the consequences is also an important consideration. Think about the difference between germs that cause the common cold and being hit by lightning. Both are hazardous, but one has much more serious consequences.

Comparing the common cold to lightning helps to illustrate another factor involved in risk—exposure. If you are not exposed to the hazard, it's not a risk. Think about a poisonous snake in a display at a museum or zoo. It is hazardous, but safely inside its display it is not a risk to you because you are not actually exposed to it. But take the snake out and put it on the floor at your feet, and it is a risk, because now you have both hazard and exposure. You must have both for a risk to exist.

To fully understand exposure, risk assessors need to know not just whether we are exposed, but how much exposure to something (the dose) causes what kind of response and with what degree of likelihood. This is known as the dose-response relationship. Toxicology—the study of poisons—is one way to investigate the dose-response relationship. A toxicological study to see if a hazard (known or suspected) causes some specific negative outcome, like liver cancer, will provide different groups of test animals various doses of the suspected hazard and observe how many in each group get sick and at what doses. If a dose-response study gives a small dose of the hazard to a group of 100 mice and 20 show signs of the disease being investigated, the test indicates that there is a 1 in 5 chance—at that level of exposure—of mice developing that disease. If another group of 100 mice gets a larger dose and 50 get sick, the likelihood of illness at that level of exposure is 50%.

Now there are two ways to think about risk. We have a hazard—an agent known or suspected to cause harm—and a dose-response relationship showing what the likelihood is that the hazard will cause harm depending on the level of exposure. This gives us a richer way to think about risk since we can talk about whether the risk is bigger or smaller in terms of likelihood and based on the hazard and the severity of its consequences.

Going back to cold germs and lightning—in terms of likelihood, cold germs are a bigger risk since, even at modest levels, being exposed to them poses a pretty good likelihood of a negative outcome. The risk is high because the likelihood of it happening is high. However, in terms of hazard, being hit by lightning is a more serious hazard because, even though the likelihood of being exposed to a lethal dose is low, being killed is a more serious consequence than having the sniffles.

Risk is something that can be estimated but not measured. Estimating risk means predicting what we don't know based on what we do know, and we can't know everything about hazards or exposures. We can get a lot of good information from toxicology, but it has limitations. For example, studies often give test animals huge doses of the substance being investigated to make sure that it will trigger even the smallest possible response. Sometimes a huge dose can cause effects that simply wouldn't occur at lower doses. In other words, it is possible that the huge dose triggers some biological response in the animals that wouldn't happen at all if the dose were lower. Another way would be to give animals smaller doses, but if you want to make sure you catch any response that occurs at a likelihood of one in a million, you would need to dose more than a million animals to see if that response happens.

Also, what happens in rats or mice or other test animals may or may not happen in people. Our bodies and biochemical systems are similar, but not identical. So how much of a dose is safe for a rat may not give us a precise idea of how much is safe for humans.

Toxicological tests that use only one species of test animals may show that a substance is safe, but it is possible that the substance might still be dangerous to other species, including us. Tests on rats of a drug called thalidomide found it safe, but when pregnant humans took thalidomide they had babies with serious birth defects. So toxicologists went back and tried it on several other species of test animals until they tried rabbits, which showed the same results as people. This shows that they just hadn't tested thalidomide on the right species.

Still, since we cannot test potentially harmful substances on people—and, for financial and ethical reasons we can't use millions of test animals—toxicology provides important information about the dose-response relationship and the likelihood of a risk.

There is another important science that helps us understand risk—epidemiology, the study of patterns and causes of disease in human, other animal, and plant populations. An early demonstration of the power of epidemiology was by John Snow in England, who noticed in 1854 that an unusually large number of people in one small London neighborhood were getting cholera. He asked them what they ate, what they drank, where they worked, and where they traveled. After all his detective work, he discovered that the one thing they had in common was that they were all drinking from the same well. Officials turned off the well and nobody else got sick.

Epidemiology has helped identify some pretty well-known risks, including the risk of lung cancer from tobacco and the risk of heart disease from high cholesterol levels. But epidemiology also has its limits. Because it is subject to biases and confounding, epidemiologic studies can establish associations but rarely conclusions about causation.

Other sciences can help us understand risk too. For earthquakes, geology can tell what the probability is that we will be exposed to a tremor (within a pretty broad time span), and both engineering and physics can help to predict the various responses we will suffer (just the shaking of shelves or whole buildings collapsing) and from what doses (how severe the earthquake shaking was). Meteorology and hydrology can help us understand the dose-response relationships from floods—and likelihood of various severities of the hazard.

And now, new sciences—like genetics—are helping us understand risks. Tests can identify a mutation on a woman's DNA that may contribute to the likelihood she will develop breast cancer, and some genes may provide an indication of the likelihood of developing Alzheimer's disease. These genetic factors are part of how risk assessors gauge how much exposure to various external hazards will produce what likelihood of those diseases.

In addition to genetics, other powerful scientific procedures help to identify new hazards. Atmospheric chemistry helped recognize that chlorofluorocarbons (CFCs) destroy ozone molecules in the upper atmosphere, exposing us to more harmful ultraviolet radiation. And new techniques allow us to detect materials in our bloodstream at far lower levels that we could ever see before, shedding new light on potentially hazardous things to which we are being exposed.

Humans have faced serious threats for a long time and have conquered a lot of them, in part because of careful risk assessment. Yet, the industrial and technological age we live in creates new substances, products, and processes—like genetically modified food—that yield many benefits but can also introduce new risks. But while that risk race is being run, scientific advances are continually giving risk assessors better tools to figure out some of the most important questions we all face all the time: what are the risks, which ones are bigger or smaller, and how can we keep ourselves safe?