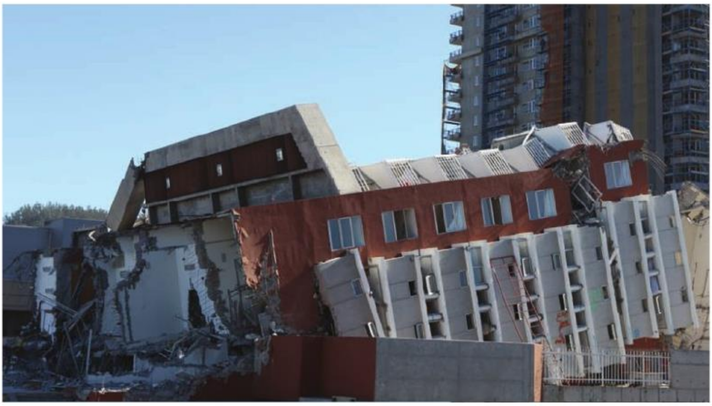
Lesson #1: Introducing Earthquakes



THIS APARTMENT BUILDING IN CONCEPCIÓN, CHILE, COLLAPSED AS A RESULT OF AN EARTHQUAKE IN FEBRUARY 2010.

PHOTO: U.S. Geological Survey/ photo by Walter D. Mooney, Ph.D.

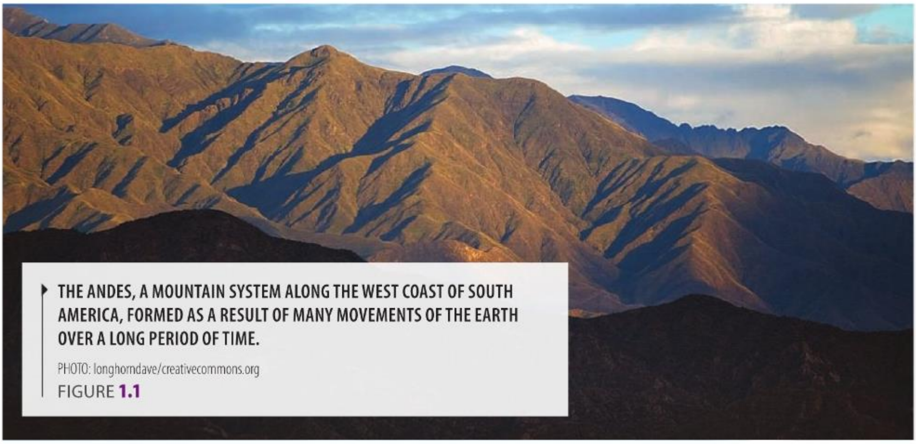
Introduction-

Did you know that during recorded history, more than 13 million people have died as a result of earthquakes and that about 1 million of those deaths occurred in the 20th century? In one earthquake alone in Turkey in 1999, more than 17,000 people were killed. And, when an earthquake generates a tsunami, the death toll can be even more disastrous. On December 26, 2004, nearly 300,000 people tragically lost their lives in the tsunami that was generated by the Great Sumatra-Andaman earthquake.

In this lesson, you will begin a series of inquiries on earthquakes. You will examine where earthquakes occur most often, and you will use this information to learn more about the earth and why earthquakes happen. What are the greatest risks that individuals face from earthquakes? How might scientists better predict earthquakes? What can society do to reduce the loss of life and property that results from earthquake damage. Let's find out.

RELIEF WORKERS IN HAITI SORT THROUGH RUBBLE AFTER THE 2010 EARTHQUAKE.

PHOTO: Kendra Helmer/U.S. Agency for International Development (USAID)



THE ANDES, A MOUNTAIN SYSTEM ALONG THE WEST COAST OF SOUTH AMERICA, FORMED AS A RESULT OF MANY MOVEMENTS OF THE EARTH OVER A LONG PERIOD OF TIME.

PHOTO: longhorndave/creativecommons.org

FIGURE **1.1**

What is an Earthquake?

Earthquakes are the shaking and vibrating of the earth. Large and sudden releases of energy cause earthquakes. The energy is released when movement occurs along large "cracks" called faults in the earth's outer layer. More than 90 percent of all recorded earthquakes happen this way. Melted rock on its way to the earth's surface can also cause earthquakes. This usually happens before a volcano erupts. Only about 5 percent of earthquakes are directly related to volcanic activity.

Earthquakes are beyond human control. People know they will happen, and some people are working to reduce the risks associated with them. Seismologists—scientists who study earthquakes—have made great progress in studying the events that come before an earthquake. They attempt to use these events to predict when the next earthquake might occur. The latest technologies use special satellites that monitor the movement of the earth's outer layer, and bore holes that monitor pressure on the rocks. These and other technologies are being used along the San Andreas Fault in California, in Alaska, and in parts of the Himalayas.

Myths About Earthquakes

Throughout the history, people have had imaginative and colorful explanations for why earthquakes happen. People in many cultures believed that the earth rested on the back of a massive creature whose movements caused the earth to shake. In Japan, the creature was thought to be a giant catfish; in Mongolia, a giant frog; in China, an ox and a giant tortoise; in India, elephants; and in parts of South America, a whale. The Algonquin Indians of North America thought the earth rested on an immense tortoise.

The people of Siberia, in northern Russia, thought a god called Tuli had a sled so big that it held the earth. They imagined that giant dogs pulled the sled. The dogs had fleas, and when they stopped to scratch, they shook the sled and its cargo—the earth.

IN INDIA, ELEPHANTS SUCH AS THIS ONE AT A TEMPLE, ARE CONSIDERED SACRED. HINDU MYTHOLOGY SAYS THAT THE EARTH WAS HELD UP BY EIGHT STRONG ELEPHANTS, WHO CAUSED EARTHQUAKES BY SHAKING THEIR HEADS.

PHOTO: McKay Savage/creativecommons.org

IN JAPAN, PEOPLE THOUGHT THE EARTH RESTED ON A GIANT CATFISH AND WOULD SHAKE EVERY TIME THE CATFISH MOVED.

IN 2010, AN EARTHQUAKE IN DICHATO, CHILE, CAUSED A SEA WAVE 10 METERS (33 FEET) HIGH TO WASH OVER PARTS OF THE CITY, LEAVING DESTRUCTION IN ITS WAKE.

PHOTO: U.S. Geological Survey/photo by Walter D. Mooney, Ph.D.

Famous writers and philosophers have sometimes tried to explain earthquakes. For example, the English playwright Shakespeare wrote, “The earth did shake when I was born” (*Henry IV, Part I*). The Greek philosopher Aristotle gave a natural explanation for earthquakes. He thought that atmospheric winds were drawn into the earth’s interior. These winds caused fires that swept through underground cavities trying to escape.

In the 1700s, many people believed that earthquakes were a punishment or a warning for those who were not sorry for wrongs they had done. This view was strongly reinforced by the great earthquake that occurred in Lisbon, Portugal, on November 1, 1755. It was All Saints’ Day, a holy day, when many people were attending church services. The earthquake was so strong that buildings shook all over Europe. Chandeliers rattled even in parts of the United States. Approximately 70,000 people were killed, mostly from aftershocks (earthquakes that happen after a main earthquake). Buildings collapsed, and a giant sea wave destroyed waterfront areas in Lisbon. Fires burned throughout the city.

Today, most people know that natural events within the earth cause earthquakes. Still, people all over the world fear and wonder about these vibrations. Folklore and legend helped explain these strange and frightful events to people of the past. Technology provides the scientific “stories” that help us understand earthquakes today.

Discussion Questions

1. *Why should we believe that scientific “stories” hold more truth than stories about a giant catfish shaking the earth?*
2. *Do you believe there will be more earthquakes in the world? Explain your reasoning.*

Lesson #2: When the Earth Shakes

WHEN A PEBBLE HITS THE WATER, WAVES MOVE OUTWARD IN ALL DIRECTIONS.

PHOTO: Phil Whitehouse/ creativecommons.org

Introduction-
An earthquake occurs when a piece of the earth's crust moves suddenly. This releases a huge amount of energy. The effect of this sudden release of energy is felt later as an earthquake at places hundreds or even thousands of miles away. How does the energy released by this sudden movement make the earth quake at places far away? In this lesson, you will investigate this question. You will also investigate how earthquakes can cause major damage to buildings and other structures, and read about how buildings can be made to withstand the destructive forces of earthquakes.

HOW WILL THE WATER DROP AFFECT THE WATER BELOW?

Earthquake Waves and The Transfer of Energy-
When a piece of the earth shifts suddenly, earthquake waves move out in all directions, just like sound moves out in all directions when a bell is rung. In fact, a P-wave is just like a sound wave. It pushes particles in the earth closer together and then stretches them apart. That is why we call it a "push-and-pull" wave. Another type of earthquake wave, an S-wave, moves particles in the earth's crust from side to side in a direction perpendicular to the direction of the wave energy. That is why we call it a "side-to-side" wave. In both cases, the energy released by the sudden movement of a piece of the earth's crust moves through the earth's particles, shaking them. But when the wave has passed, the particles come to rest back in their original positions, just as the pieces of tape returned to their original positions in your spring model. This happens because energy simply moves through matter, transferred by waves. We call this a transfer of energy. During an earthquake,

things on the earth's surface, such as fence posts, trees, and buildings move up and down or sway side to side. Once the earthquake waves have stopped, the fence posts, trees, ad buildings all come to rest in their original positions, unless they have been damaged by the energy in the waves.

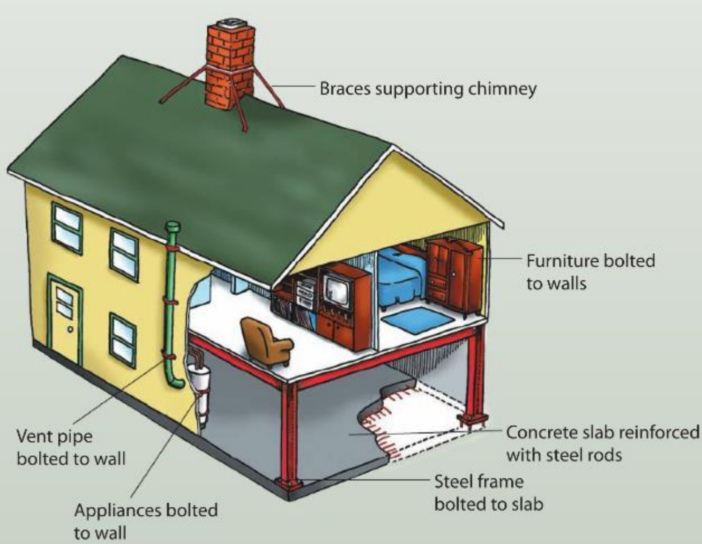
Designing EARTHQUAKE-RESISTANT Buildings

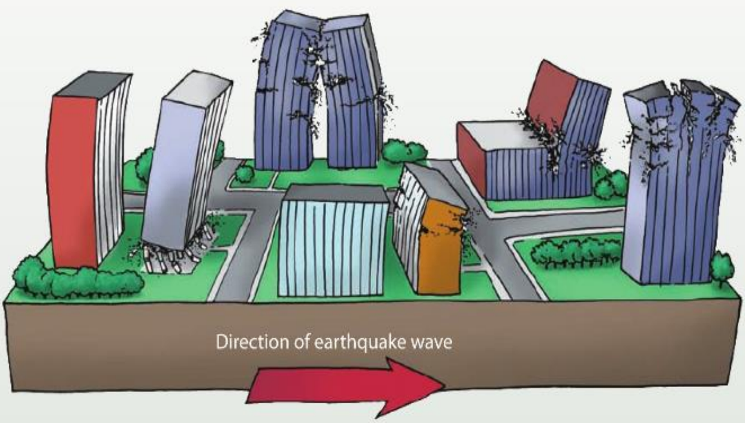
"Earthquakes don't kill people. Buildings do." Have you heard that saying? It's true that one of the greatest risks during an earthquake is personal injury from falling debris. What's more, the most populated regions of the world are also places where earthquakes occur most often.

This has happened mainly because many large cities were built long ago in coastal regions near waterways used for shipping. Not until the 1920s did scientists realize that some of these beautiful coastal areas are also the most prone to earthquakes.

People probably will not move away from coastal areas. But today, engineers have learned how to design buildings that are more resistant to earthquakes than those built more than a half-century ago. First, they design a foundation that is firmly connected to solid rock deep in the ground. Second, the building is "tied together." That means the beams and columns that support the structure are strapped together and to the ground with metal, and the floors and roofs are securely fastened to the walls. In California, the masonry walls of many houses at risk are sprayed with liquid concrete and reinforced with steel bracing.

THIS HOUSE SHOWS SOME OF THE THINGS A HOMEOWNER CAN DO TO REDUCE THE RISKS ASSOCIATED WITH GROUND MOVEMENT.





DESIGN MATTERS. THIS ILLUSTRATION SHOWS HOW GROUND MOVEMENT DURING AN EARTHQUAKE AFFECTS BUILDINGS WITH DIFFERENT SHAPES.

During an earthquake, a building will crack or collapse at places in the structure where there are weak connections. For this reason, in some older neighborhoods that are prone to earthquakes, steel frames are often added to existing structures to strength them. Bolting walls to foundations and adding reinforcement beams to the outside of an older home can also help improve its strength.

The size and shape of a building can also affect its resistance to earthquakes. Rectangular, box-shaped buildings are stronger than those of irregular size or shape. This is because different parts of an irregular-shaped building may sway at different rates during earthquake. This puts more stress on the building, which means it is more likely to collapse.

DURING AN EARTHQUAKE IN CALIFORNIA, THE LAYER OF SAND UNDERLYING THIS HIGHWAY BECAME LIQUEFIED, CAUSING THE ROAD SURFACE TO CRACK INTO RUBBLE.

PHOTO: U.S. Geological Survey/photo by S.D. Ellen

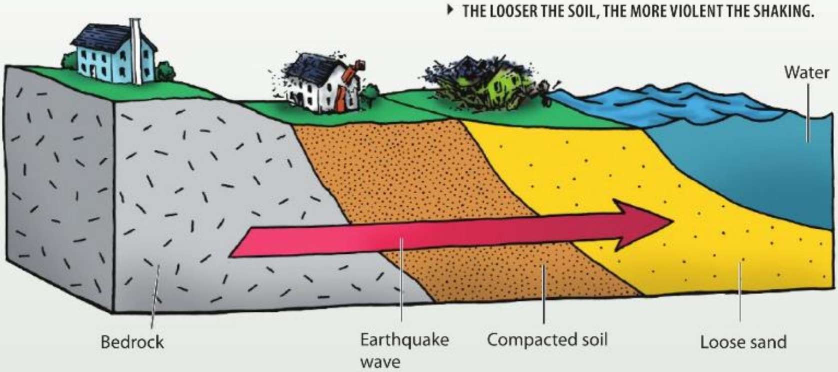
Buildings with open or unsupported first stories are most likely to be damaged during an earthquake. Tall buildings such as skyscrapers must be designed so that a certain amount of swaying or “flexing” can occur, but not so much that they could touch neighboring buildings. A tall building that does not sway slightly will crack and collapse. This is because the stress forces from the earthquakes get stronger as they move up the building.

For structures to withstand an earthquake, the ground itself must hold together. Many moist soils—especially those rich in clay—and loose soils, like sand, lose their compactness during an earthquake. When loose or wet soil shakes, parts of the soil rotate. The soil then acts like liquid or gelatin. A building standing on it can collapse as the foundation sinks. Buildings in earthquake-prone areas should stand on solid steel pilings driven deep through a loose or wet soil layer into solid rock deep in the ground.

Constructing earthquake-resistant buildings is cheaper than reinforcing older buildings to make them stronger. Reinforcing entire buildings with supporting frameworks is costly and complicated. Anchoring roofs to supporting masonry is being introduced in some developing countries, but progress is slow.

Even in developing countries, simple buildings made of adobe and similar materials can be made stronger. Techniques include putting bamboo reinforcing strips into the adobe, bracing doorframes and other weak points, and avoiding the use of heavy concrete roofs.

THE LOOSER THE SOIL, THE MORE VIOLENT THE SHAKING.



THE BUILDING IN THE FOREGROUND SUFFERED MORE DAMAGE THAN THE BUILDING IN THE BACKGROUND AFTER THE 2010 EARTHQUAKE IN HAITI. WHAT FACTORS COULD EXPLAIN THIS?

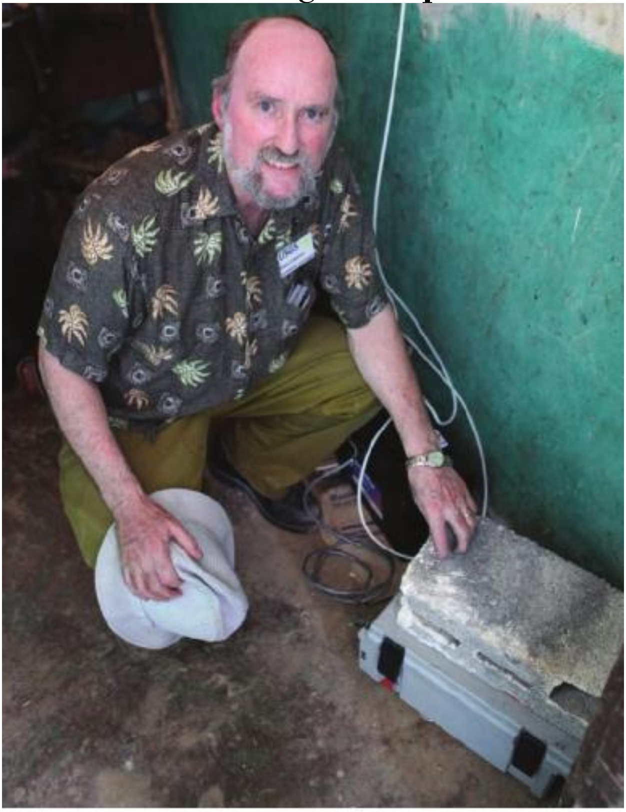
PHOTO: U.S. Air Force photo by Master Sgt. Jeremy Lock

THESE BUILDINGS IN CONCEPCIÓN, CHILE, ARE RAISED 10 METERS (33 FEET) OFF THE GROUND TO WITHSTAND SEA WAVES THAT COULD FOLLOW AN EARTHQUAKE.

Discussion Questions

1. *Which kind of building is more earthquake-resistant: a boxlike skyscraper or a museum built to look like a sculpture? Why?*
2. *If a house is partially sunken into the ground after an earthquake, what can you infer about the soil under the house?*

Lesson 3: Recording Earthquake Waves



SCIENTIST DR. WALTER MOONEY INSTALLS A SEISMOGRAPH IN A VILLAGE BUILDING TO KEEP TRACK OF AFTERSHOCKS FROM THE 2010 EARTHQUAKE IN HAITI.

Introduction-

How do scientists know where an earthquake occurred and how strong it was? They use seismographs. Seismographs are instruments that record the vibrations from an earthquake. In this lesson, you will use a model seismograph to record on paper the vibrations you create on a table or other surface. You will then examine a copy of a seismogram recorded during the Alaska earthquake of March 27, 1964. As you study the seismogram, you will discover how scientists record and interpret earthquake waves. Then you will use data recorded from three seismograph stations to model how scientists locate an earthquake's epicenter. This information will help you in Lesson 4, when you plot earthquakes on a world map.

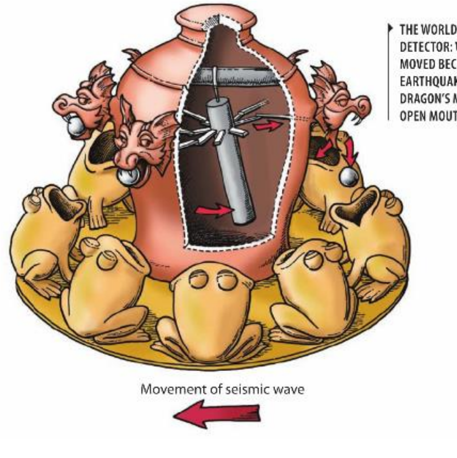
SEISMOMETERS, SENSORS THAT PROVIDE DATA TO A SEISMOGRAPH, WERE INSTALLED IN THE HOTEL MONTANA AFTER AN EARTHQUAKE HIT HAITI IN 2010. WHAT DO YOU THINK SCIENTISTS CAN LEARN BY USING THIS EQUIPMENT?

PHOTO: U.S. Geological Survey/photo by Sue Hough

<u>A Brief History of Earthquake Detection</u>-

Chinese scholar and astronomer Change Heng invented the first earthquake detector in about 132 A.D. This bronze vase was about 2 meters across, with a domed lid surrounded by eight dragons' heads. Each dragon held a bronze ball in its mouth. Eight bronze toads, with their mouths wide open, were at the base of the vase. The vase contained a heavy column that worked like a pendulum. When the earth shook, the pendulum pushed on a slider, or rod, which dislodged the ball from one of the dragons' mouths. The ball would then fall into one of the toads' open mouths.

As time went on, people invented other instruments to detect earthquakes. But it was not until 1880 that instruments could effectively record the vibrations from earthquakes. At that point, seismology, the study of earthquakes, became a true science. Siesmologists began to use mechanical seismographs to detect, record, and measure the vibrations produced by an earthquake. The record made by the seismograph, called a seismogram, was created on a rotating drum. Today, most seismographs are electronic, recording data directly into a computer.



THE WORLD'S FIRST EARTHQUAKE DETECTOR: WHEN THE VASE MOVED BECAUSE OF AN EARTHQUAKE, A BALL FROM A DRAGON'S MOUTH FELL INTO THE OPEN MOUTH OF A TOAD BELOW.

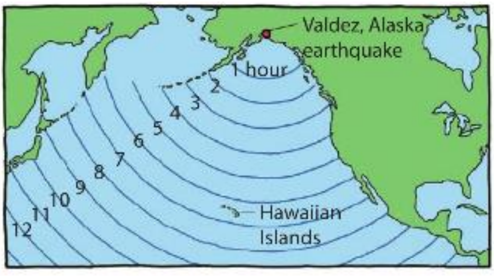
The Alaska Earthquake of 1964-

You now know that seismographs record the vibrations of earthquakes, and a seismogram is the record of those vibrations. The seismogram you will use in this inquiry was recorded in Bellingham, Washington, during the earthquake in Prince William Sound, near Valdez, Alaska, on March 27, 1964. This earthquake was one of the most violent ever recorded. The main shock (or earthquake) triggered 1000 aftershocks. These aftershocks occurred in a zone 1000 kilometers long. The ground near the southwestern end of Montague Island, off the coast of Alaska, rose almost 15 meters in the air. Many buildings were nearly split in half.

THIS SCHOOL SPLIT IN HALF WHEN SOME OF THE SOIL UNDER IT MOVED DOWNSLOPE DURING THE EARTHQUAKE IN PRINCE WILLIAM SOUND, ALASKA.

PHOTO: NOAA/National Geophysical Data Center

Landslides and tsunamis resulted from the earthquake. One tsunami caused flooding in basements in houses as far away as Hawaii. Tsunamis can be caused by earthquakes. A tsunami can travel for thousands of miles. More than six hours after the earthquake occurred near Valdez, Alaska, a huge tsunami reached Hawaii. Despite the great strength of the Alaska earthquake, only 122 people died, which is a relatively low number for such a large earthquake. Why? The area in which the earthquake occurred was not highly populated. The high was low, so the tsunami's effects were not as great. And schools and many businesses were closed because it was Good Friday, a religious holiday.



TSUNAMIS CAN BE CAUSED BY EARTHQUAKES. A TSUNAMI CAN TRAVEL FOR THOUSANDS OF MILES. MORE THAN SIX HOURS AFTER THE EARTHQUAKE OCCURRED NEAR VALDEZ, ALASKA, A HUGE TSUNAMI REACHED HAWAII.

Finding the Epicenter: The Tortoise and the Hare-

Seismographs are located all over the world. A seismograph station in Montana can pick up an earthquake occurring in California. If the earthquake is really strong, seismograph stations all over the world can also record this same earthquake. Why? Because earthquake waves that travel through the body of the earth move outward in all directions.

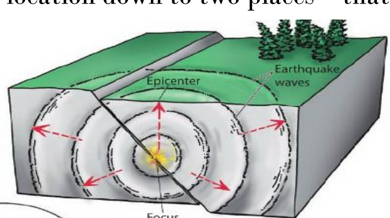
The point where the earthquake occurs is called the focus, and it can be shallow or deep in the earth. The point on the earth's surface directly above the focus is called the earthquake's epicenter. This is usually the lace that you read or hear about in the news when there has been an earthquake.

Damage from one earthquake can occur in many different places. Seismologists use special math calculations to pinpoint the exact location of the earthquake's epicenter. First, they use the arrival times of P- and S-waves, as shown on several seismograms. Then they plot those times on a special graph called a time-distance graph.

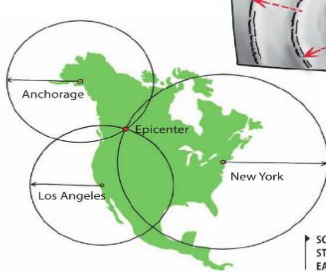
P-waves always travel at the same average speed. S-waves have a constant speed, too, only slower. Scientists can graph the speeds of both waves on a special graph. Like the tortoise in the story "The Tortoise and the Hare," an S-wave always travels more slowly than a P-wave. Although both animals in the story leave the starting line at the same time, the distance between the two becomes greater and greater the farther they are from the starting line (until the hare takes a break). By computer how many minutes apart the two animals are from each other at any one point in the race, you could calculate the distance they have traveled (how far they are from the starting line) using a time-distance graph.

In much the same way, by knowing when each wave arrives at the seismograph station and subtracting the difference, seismologists can determine how far away the earthquake's epicenter is from their station. The greater the difference in time between the P- and S-waves' arrival, the further the seismograph station is from the epicenter.

Is that enough information to pinpoint the exact location of the earthquake? No, because earthquake waves do not follow one path. They move outward in all directions in a circle around the epicenter. With data from a single station, the seismologist knows only that the earthquake could have happened anywhere in a circle around that station. With data from two seismograph stations, however, seismologists can narrow the epicenter location down to two places—that is, the two points at which the circles cross each other. But with data from three stations, they determine the exact point at which all three circles intersect, as shown on the map below. This point is the epicenter of the earthquake.



THE FOCUS OF AN EARTHQUAKE IS THE PLACE WHERE THE RUPTURE BEGINS AND ENERGY IS RELEASED. THE PLACE ON THE EARTH'S SURFACE DIRECTLY ABOVE THE FOCUS IS THE EPICENTER.



SCIENTISTS USE DATA FROM THREE SEISMOGRAPH STATIONS TO FIND THE EPICENTER OF AN EARTHQUAKE.

Canines to the Rescue

In 1985, a violent earthquake shook Mexico City and destroyed a factory. The people working inside were trapped under the debris. After rescuers searched for 10 days, the Mexican government was ready to give up trying to find missing workers. As a last resort, relatives of the trapped victims asked rescue expert Carolyn Hebard to search the factory ruins with her dogs. Hebard flew in from her home in New Jersey with her specially trained German shepherds to help with the rescue operation. Hebard and her dogs worked their way into the wreckage and found two survivors.

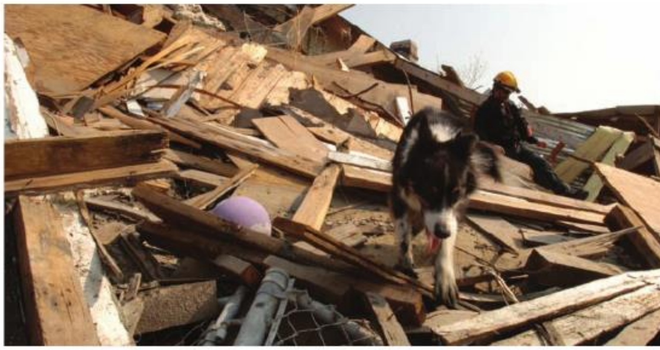
A RESCUE DOG IS TRANSPORTED WITH OTHER RESCUE WORKERS ON A BLACKHAWK HELICOPTER TO SEARCH FOR RESIDENTS TRAPPED BY HURRICANE KATRINA.

PHOTO: FEMA/Jocelyn Augustino

Hebard and Her Amazing Dogs: Hebard, a member of the National Association for Search and Rescue, is one of 1500 handlers of rescue dogs across the United States. She is one of the nation's respected experts on canine search and rescue. Hebard first learned search-and-rescue techniques as a hobby, because she loved dogs and the outdoors. She joined a search-and-rescue club. With the club members, she trained her dogs, Pasha and Aranka, in the woods.

The Nose Knows: Dogs are good at finding people stranded under rubble because they have an excellent sense of smell. Instead of tracking a scent by sniffing the ground, escue dogs are trained to sniff the air. The human body sheds tiny particles of dead skin that carry the human scent. These particles float on air currents where dogs' noses can easily detect them. By sniffing the air, dogs can search a much larger area than they could by just sniffing the ground.

Between search-and-rescue jobs, Hebard trains her dogs in the woods about once a week, just as athletes train between competitions. The dogs often practice by searching for one of Hebard's friends who has agreed to hide in the woods. As they sniff the air, the dogs catch a whiff of the person hiding. They know that they have a human scent and begin to zero in. Crouching low to the ground, they pace back and forth, smelling for the strongest scent.



THIS RESCUE DOG IS SEARCHING FOR PEOPLE TRAPPED BY HURRICANE KATRINA.

PHOTO: FEMA/Jocelyn Augustino

Following a scent is not always simple for dogs, says Hebard. The wind can confuse them. For instance, at an apartment building that collapsed after the 1995 earthquake in Kobe, Japan, three Swiss rescue dogs repeatedly sniffed and barked at the same two corners. Japanese rescue workers pried off a roof and moved other debris. After working for six hours, they found nothing. When they brought the dogs in again, the dogs indicated a different corner. The wind had been blowing from one direction in the morning and from a different direction in the afternoon.

THIS DOG IS SEARCHING FOR A VICTIM IN THE RED RIVER AFTER FLOODING IN NORTH DAKOTA IN 2009.

PHOTO: FEMA/Andrea Booher

A RESCUE DOG ALERTS A WORKER THAT HE HAS POTENTIALLY FOUND THE SCENT OF A POSSIBLE HUMAN AMONG THE DAMAGE FROM HURRICANE KATRINA.

PHOTO: FEMA/Marvin Nauman

A RESCUE WORKER AND RESCUE DOG SEARCH FOR SURVIVORS IN A PILE OF RUBBLE THAT RESULTED FROM A SERIES OF TORNADOES IN TENNESSEE IN FEBRUARY 2008.

PHOTO: FEMA/Jocelyn Augustino

Helping Out in Kobe: Hebard and her dogs also helped out during the earthquake in Kobe. She and her dogs searched the ruins of the city's train station. "The railroad tracks actually looked like a roller coaster," she said. "It was incredible the way they had bent. We had to crawl inside the station." They climbed over piles of broken glass and crushed filing cabinets. It took four hours to crawl through a structure that would have taken 10 minutes to walk through before the earthquake.

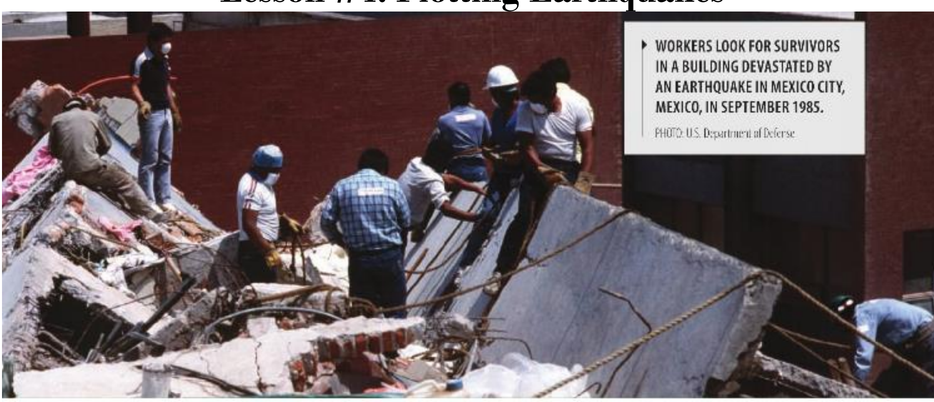
When a search-and-rescue mission is over, Hebard and her dogs return to a quiet life in New Jersey. Sometimes it takes the dogs a little time to adjust to having other family members around.

"You do become very close to the dog, and definitely after you've been on an extended search," said Hebard. "The bond between you and that dog becomes closer and closer."

Discussion Questions

1. *Suppose you were asked to build an automatic "sniffer" that could do the same job as a rescue dog. How would you design it?*
2. *While dogs are useful in search-and-rescue efforts, the work remains costly and dangerous. How could the need for such rescues after earthquakes and other natural disasters be reduced?*

Lesson #4: Plotting Earthquakes



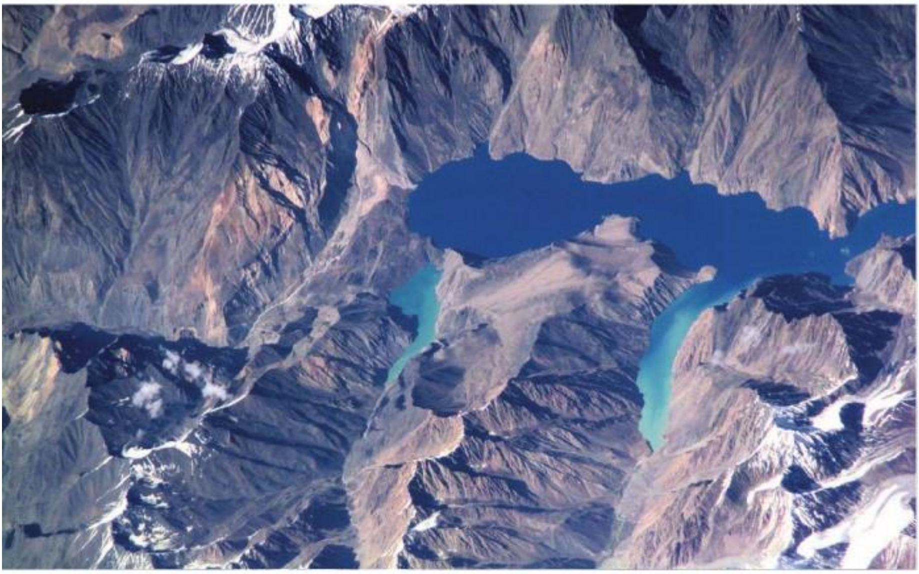
<u>Introduction</u>-

On September 19, 1985, a strong earthquake occurred in Mexico City. The quake killed more than 9000 people and destroyed thousands of buildings. Two months later, a powerful volcanic eruption occurred about 3200 kilometers south of Mexico City. Do you think there could be a relationship between where earthquakes and volcanoes occur?

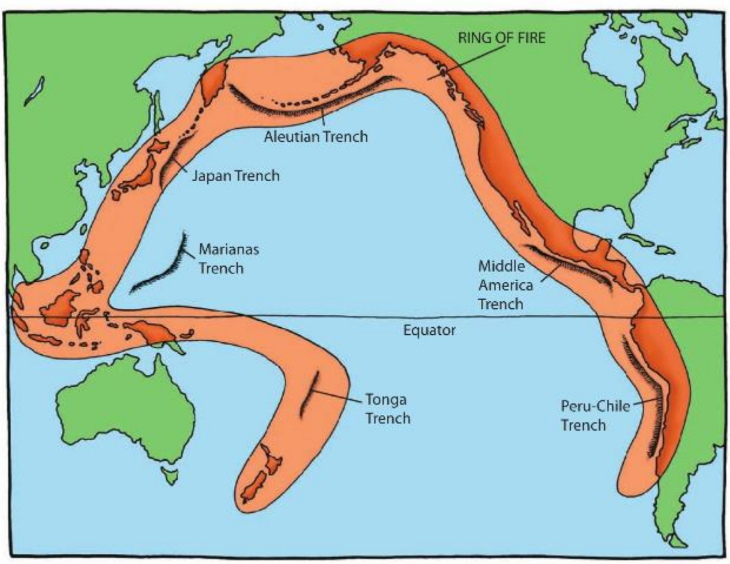
In this lesson and in Lesson 5, you will conduct inquiries that will help you begin to answer this question. In this lesson, you will plot on a world map a set of earthquakes that occurred in various parts of the world in the 1990s. You will then examine the map to determine whether you can see a pattern in the locations of the earthquake epicenters. Then, in Lesson 5, you will plot on the same map the locations of recent volcanic eruptions. Finally, you will analyze the locations of earthquakes and volcanoes. What do these powerful phenomena have in common? Let's find out.

LAKE SAREZ IN TAJIKISTAN WAS FORMED WHEN AN EARTHQUAKE TRIGGERED A MASSIVE LANDSLIDE NEARLY 100 YEARS AGO. THE LAND DAMMED UP THE MURGHOB RIVER, FORMING THE LAKE. SCIENTISTS MONITOR THE AREA BECAUSE THEY WORRY THAT THE FREQUENT SEISMIC ACTIVITY MAY ONE DAY CAUSE THE BANKS TO SLUMP INTO THE LAKE, CREATING A HUGE WAVE THAT COULD OVERTOP THE DAM AND FLOOD AREAS DOWNSTREAM.

PHOTO: NASA Goddard Flight Center



THE RING OF FIRE, OR CIRCUM-PACIFIC BELT, CONSISTS OF A CHAIN OF EARTHQUAKES AND VOLCANOES AROUND THE EDGES OF THE PACIFIC OCEAN. DEEP, NARROW DEPRESSIONS IN THE SEAFLOOR—CALLED DEEP-SEA TRENCHES—CIRCLE THE PACIFIC OCEAN ALONG THE RING OF FIRE.
FIGURE **4.1**



MAGNITUDE & INTENSITY

Geologists measure an earthquake in two ways—by its magnitude and by its intensity. Each method provides these scientists and others with important data about the earthquake and its effects. Geologists can use the data to assess the risks in earthquake-prone regions and prepare for future earthquakes.

IN FEBRUARY, 2010, AN EARTHQUAKE IN CONCEPCIÓN, CHILE, SEVERELY DAMAGED THIS BUILDING. THE EARTHQUAKE REGISTERED 8.8 ON THE RICHTER MAGNITUDE SCALE.
PHOTO: U.S. Geological Survey/photo by Walter D. Mooney, Ph.D.

Magnitude: "An earthquake with a magnitude of 6.8 on the Richter scale occurred today…" How many times have you heard a number like this being reported in the news?

In 1935, Charles Richter, a seismologist at the California Institute of Technology, developed the Richter Magnitude Scale. The Richer scale measures the magnitude, or total amount of energy, released at the source of an earthquake. The number that you normally hear on the news when an earthquake occurs is its magnitude. Richer scale ratings enable people to compare the strength of different earthquakes around the world.

The magnitude of an earthquake is determined by measuring the amplitude, or "swing," of the largest seismic wave on a seismogram. The Richer scale, shown in the table below, is open-ended; it has no maximum magnitude. As of the year 2010, the largest magnitude recorded on the Richter scale was 9.5. That earthquake occurred in Chile in 1960. The largest earthquake in the U.S. occurred in Alaska in 1964. It registered 9.2 on the Richter scale.

Each increase in a magnitude number on the Richter scale represents a tenfold increase in the amplitude seen on the seismogram. This means that a magnitude-6 earthquake has an amplitude 10 times greater than a magnitude-5 earthquake and 100 times greater than a magnitude-4 earthquake. This greater amplitude translates into longer and higher energy shaking of the ground. For example, an earthquake with a magnitude around 5.0 might only shake the ground for 30 seconds or so, while the 9.2 Alaska earthquake shook the ground for over nine minutes. And for every increase of magnitude of 1.0, there is an increase of 32 times the amount of energy released.

Descriptor	Magnitude	Average Number Each Year, Worldwide
Great	8 and higher	1
Major	7-7.9	18
Strong	6-6.9	120
Moderate	5-5.9	800
Light	4-4.9	6200 (estimated)
Minor	3-3.9	49,000 (estimated)
Very minor	Less than 3.0	Magnitude 2-3; about 1000 per day Magnitude 1-2; about 8000 per day.

Intensity: Scientists use the word "intensity" to describe the kind of damage done by an earthquake, as well as people's reaction to the damage. In other words, intensity is a measure of the earthquake's effect on people, structures, and the natural environment.

Many factors affect intensity. These include the distance an area is from the epicenter, the depth of the earthquake, the population density of the area affected by the earthquake, the local geology of the area, the type of building construction in the area, and the duration of the shaking. Magnitude also affects intensity, since an earthquake of a higher magnitude has a higher intensity than an earthquake of lower magnitude. But, an earthquake is a densely populated area that results in many deaths and considerable damage (high intensity) may have the same magnitude as an earthquake in a remote area that does no more than frighten the wildlife (low intensity).

The most common earthquake intensity scale used in the United States is shown in the table titled "Modified Mercalli Intensity Scale." This scale has intensity values ranging from I to XII. (Can you guess why it uses Roman numerals?)

Intensity Scale	Damage and Felt Observations
I	Not felt, except by a very few people under special circumstances.
II	Felt only by a few people at rest, especially on upper floors of buildings.
III	Felt only indoors, but many people did not recognize it as an earthquake. Stationary cars rocked slightly.
IV	Felt indoors by many, outdoors by few. At night some people were awakened by a sensation like a heavy truck hitting a building. Standing cars rocked noticeably.
V	Felt by nearly everyone. Many were awakened. Some dishes and windows were broken. Trees and other tall objects swayed.
VI	Felt by all. Many were frightened and ran outdoors. Heavy furniture moved. Plaster on walls and chimneys was damaged.

VII	Everyone ran outdoors. Slight to moderate damage to well-built structures. Considerable damage to poorly built structures. Some chimneys broken. Noticed by people driving cars.
VIII	Damage slight in well-designed structures, great in poorly built structures. Fallen chimneys, monuments, and walls. Heavy furniture was overturned. Sand and mud were ejected from the ground in small amounts.
IX	Damage was considerable in well-designed structures. Buildings shifted off foundations. Ground noticeably cracked. Underground pipes broken.
X	Well-built wooden structures destroyed. Ground badly cracked. Railroad tracks bent. Landslides considerable. Water splashed over riverbanks.
XI	Few, if any, masonry structures remained standing. Bridges were destroyed. Broad cracks formed in ground. Underground pipes completely out of service.
XII	Total damage. Waves seen on ground surfaces. Objects thrown upward into the air.

Discussion Questions

1. ***Look at the photo of earthquake damage in Sichuan, China. Where would you put this earthquake on the intensity scale?***
2. ***On average, there are about 8000 earthquakes of magnitude 1-2 per day, and only one earthquake of magnitude 8 or higher each year. Why are there so many minor earthquakes and so few major ones?***

A 2008 EARTHQUAKE IN SICHUAN, CHINA, CAUSED A SECTION OF THIS BUILDING TO COLLAPSE.

PHOTO: U.S. Geological Survey/photo by Sarah C. Behan

USING HISTORICAL EARTHQUAKE INTENSITY TO ESTIMATE FUTURE RISK

Since the mid-19th century, well before the Richter Magnitude Scale was developed, scientists have been using intensity as an approximation of the strength of an earthquake. The U.S. Geological Survey (USGS) collects data about historical earthquakes based on "felt observations" of citizens. People who think they have felt the impacts of an earthquake can go to the USGS website and fill out a questionnaire about where they were and what they experience. Compiling this data helps the USGS determine the intensity of earthquakes.

If records existed of the "felt observations" for all the earthquakes that have occurred on the earth, the maximum intensity of all earthquakes at a particular site would be a good estimate of earthquake risk for that rea. But scientists only have a small amount of data about the earthquakes that have occurred throughout history. Therefore, they make intelligent guesses about where and how often earthquakes occur, how large they will be, and how much shaking will occur. This information is then plotted on a map. People moving into an earthquake-prone city might use the map to get some idea of the risk of an earthquake occurring in that area. Earthquake maps are also used to determine building codes and insurance rates.

▸ THESE TWO PHOTOS SHOW DAMAGE FROM THE SAN FRANCISCO EARTHQUAKE OF 1906, WHICH REGISTERED 7.6 ON THE RICHTER MAGNITUDE SCALE. WHAT DO YOU THINK THE INTENSITY OF THIS EARTHQUAKE MIGHT HAVE BEEN?

PHOTO (right): Library of Congress, Prints & Photographs Division, LC-USZ62-17959
PHOTO (below): Library of Congress, Prints & Photographs Division, LC-USZ62-64748

Discussion Questions

1. *"Felt observations" have proven useful for understanding historical earthquakes. If you were guiding people today to keep a record of their felt observations, what information would you ask them to record, and in what form?*
2. *Besides a map showing felt observations, what other data could people use to get an idea of earthquake risks in a particular area?*

network Search

Using a Network for Seismic Monitoring

Do you use social networks through your computer, phone, or other device to keep in touch with your friends? Maybe you share information such as photos, or news about people you know. Scientists around the world who study earthquakes and volcanoes also use digital networks to keep in constant contact with each other, sharing scientific news, data, and ideas. The information they are sharing is about one of their favorite topics, seismic activity (frequency, intensity, and magnitude of earthquakes). Your conversations and the scientists' communications both rely on telecommunications networks, including satellites, sensor networks, and the Internet.

The Global Seismographic Network is a permanent set of more than 150 sensors that are placed around the world to monitor seismic activity. They are connected by a telecommunications network that allows data to flow from the sensors to scientists who can monitor it. The network was conceived in 1984 by a group of organizations, led by the U.S. Geological Survey (USGS), which were trying to coordinate the monitoring of seismic activity. While several organizations around the globe had been monitoring seismic activity, they had no easy way to share their information to produce timely, global analyses of Earth's crust in motion. With the Global Seismographic Network, not only did they succeed in connecting themselves in a network, they were able to get funding to set up more seismic monitoring stations. Today, sensors are in locations as diverse as a diary famr in Singapore, a snowy peninsula in Antarctica, and a remote island nation in the South Pacific called Tuvalu.

You may belong to some sort of club. As a member, you probably take part in regular club activities, like meetings or practices, and you agree to follow the club's rules or guidelines. Members of the Global Seismographic Network must agree to collect regular, standardized data on seismic activity. Each of the more than 100 members—universities, government agencies, and institute representing about sixty different countries—maintains one or more sophisticated sensors. In exchange for keeping their sensors in good, working order, the members get access to worldwide data on seismic activity. Just as your club president should make sure the activities of the club are running smoothly, the USGS helps many of the member countries maintain their sensors.

Collectively, the sensors of the Global Seismographic Network provide nearly uniform coverage of seismic events on the earth. Each sensor measures and records vibrations, and the sensors" clocks are set to be highly accurate, using global positioning satellites (GPS). It is important that scientists know exactly when seismic activity is taking place, so that they can see and study all the simultaneous activity around the world. The data collected by each sensor is sent to earthquake information and warning centers, using satellites and the Internet. Some of the seismic data is sent in real time, which means people receive it right away, while the events are happening. This can be extremely useful. Knowing the epicenter and magnitude of an earthquake immediately can help warning centers mobilize a rapid emergency response. Someday, as our technology improves, all of the monitoring stations' data will be available in real time.

WHY DO YOU THINK THE TINY ISLAND COUNTRY OF TUVALU WOULD AGREE TO MAINTAIN A SEISMIC SENSOR?

PHOTO: Stefan Lins/creativecommons.org

Even data that is not sent in real time can be used by researchers to better understand seismic events. Thanks to the Global Seismographic Network, within an hour of an earthquake anywhere on the globe, scientists know its location, depth, and magnitude. Using the data collected, scientists have been able to learn more about the earth's interior structure and what happens during an earthquake. They are looking at things such as the dep structure of spreading ridges. The more we can understand about the workings of the inner earth, the better chance we have of learning how to anticipate and prepare for earthquakes.

Data from the network also helps us understand the aftermath of earthquakes. High-frequency vibrations occur during an earthquake, but we now know they are followed by low-frequency vibrations that shake the earth for days or weeks. The giant Sumatra earthquake, which lasted about seven minutes, set the entire planet to vibrating within 21 minutes.

The Global Seismographic Network is also used for the military purpose of detecting underground nuclear explosions. In fact, the U.S. Department of Defense was one of the founding partners of the network, and some of the money to maintain it comes from the U.S. Air Force. AS early as the 1960s, scientists realized that nuclear explosions generated seismic waves: waves of energy that travel through the earth. The seismic waves produced by a nuclear explosion are large enough to be detected around the world. This means that countries can monitor each other to see who is testing nuclear weapons, sometimes in violation of international treaties. The U.S. Department of Defense operates a specialized center to scan data from the network for evidence of nuclear tests. It has documented a number of nuclear explosions, including the series of nuclear tests conducted by India and Pakistan in 1998.

SOLAR PANELS ARE USED TO POWER THIS SEISMIC MONITORING STATION IN THE BRAZILIAN AMAZON.

PHOTO: Earthquake Hazards Program/U.S. Geological Survey

SENSORS WILL RECORD ANY VIBRATIONS, INCLUDING THOSE NOT CAUSED BY EARTHQUAKES.

PHOTO: Kyle Nishioka, kylenishioka.com/creativecommons.org

You may wonder how scientists can tell the difference between a seismic wave generated by an earthquake and one generated by a nuclear weapons explosion. It turns out that while earthquakes produce strong waves along the earth's surface, the waves from nuclear explosions tend to be confined to deeper layers. Determining the kinds of waves produced by a seismic event allows for identification of its cause.

So, the Global Seismographic Network really serves three functions: earthquake monitoring, earthquake research, and nuclear test monitoring. The network does all three jobs best if the sensors are numerous, well-placed, reliable, and linked through strong communication networks. Both scientists and military strategists are working to improve the network and make it fully real-time, using state-of-the-art equipment. If we're lucky, the Global Seismographic Network's continuing work will mean that students in the future understand our shifting, elastic planet even better than top seismologists can today.

Discussion Questions

1. *Think about how your class might work on a large project: what are the advantages and disadvantages of working independently in small groups versus linking all groups' efforts together in a classroom effort?*
2. *What does this tell you about the advantages and disadvantages of linking individual monitoring networks into a global monitoring network?*

RING A BELL AND THEN STOP ABRUPTLY, AND YOU'LL UNDERSTAND WHY THE CONTINUED VIBRATIONS AFTER AN EARTHQUAKE ARE CALLED "RINGING" OF THE EARTH.

PHOTO: Steven Brener/ creativecommons.org

Lesson #5: Using Earthquakes to Study the Earth's Interior

THIS TECHNICIAN IS EXAMINING IMAGES OF A PATIENT'S HEAD DURING A CT SCAN.

PHOTO: National Cancer Institute/Linda Bartlett

<u>Introduction</u>-

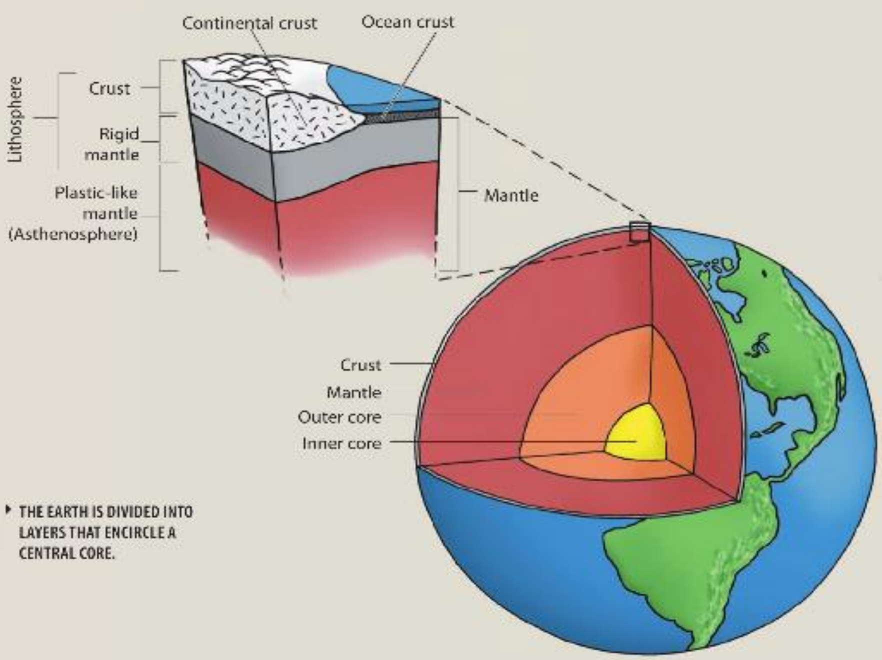
Doctors can study the inside of the human body using a technique called computed tomography (CT). The CT scanner passes X-rays through the patient from different directions and creates three-dimensional images of the interior of the human body. An examination of these images helps the physicians diagnose diseases, disorders, and other health-related occurrences.

In a similar way, scientists use earthquake waves to learn more about the inside of the earth. How can earthquake waves help scientists better understand the earth and its interior? In this lesson, you will investigate this question and view computer images of the earth's layers. You will also read about each layer of the earth's interior.

SHORT OF CUTTING IT OPEN, HOW COULD YOU DETERMINE THE INTERNAL STRUCTURE OF AN APPLE?

PHOTO: Scott Bauer, Agricultural Research Service/U.S. Department of Agriculture

The Earth's INTERIOR



THE EARTH IS DIVIDED INTO LAYERS THAT ENCIRCLE A CENTRAL CORE.

Ever since its formation—some 4.5 billion years ago—the earth has been losing heat. The deeper one goes inside the earth, the greater the temperature becomes. The pressure rises, too. The earth's outer layer, or crust, is the coolest and least dense of all the layers inside the earth. (You might compare the earth with a loaf of bread that is cooling on a shelf. The crust cools first; the soft inner part of the loaf remains warm much longer.)

There are two kinds of crust: oceanic and continental. The oceanic crust lies beneath the ocean. It is approximately 5 to 10 kilometers (3 to 6 miles) thick. The continental crust contains mostly land. It ranges from 15 to 70 kilometers (9 to 43 miles) thick and is thickest under high mountain areas. Both types of crust are made up of rock.

Directly under the crust is the mantle. Like the crust, the mantle is composed of rock; however, the rock in the mantle is much denser than that in the crust. The mantle is about 2900 kilometers (1800 miles) thick, and it makes up about 83 percent of the earth's interior. The top layer of the mantle is rigid. It is cooler than the lower part of the mantle. Geologists call this rigid part of the mantle, together with the crust, the lithosphere. The lithosphere is broken into pieces called "plates." (To visualize these plates, think about how an egg looks when its shell is cracked.)

The plates of the lithosphere "float" on the part of the mantle directly below it. This part of the mantle is called the asthenosphere. The consistency of the asthenosphere is like taffy. The asthenosphere is hot, and, like warm taffy, it can flow. The movement of the plates of the lithosphere on top of the slowly moving asthenosphere accounts for the formation of many mountains and volcanoes, as well as for earthquakes.

Beneath the mantle is the earth's innermost layer, the core. (Think of the center of an apple, which is also called the core.) The earth's core is divided into two parts: a liquid outer core, made of iron, and a solid inner core, made of iron and nickel.

Discussion Questions

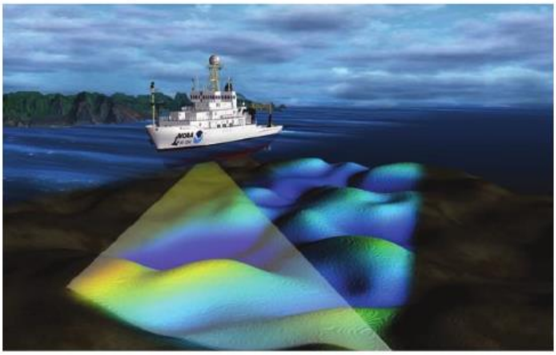
1. *Why is the crust the coolest layer of the earth?*
2. *How is rock in the earth's mantle different form rock in the earth's crust?*

Using Waves to Explore the Earth's Interior-

The deepest that scientists have drilled into the earth is 12 kilometers (7.5 miles). That's less than 0.2 percent of the distance from the surface of the earth to its center! So how do scientists know so much about the layers of earth's interior? How do they know, for example, that the lithosphere is rigid? Or that the asthenosphere is soft, like taffy? Or that the outer core is liquid?

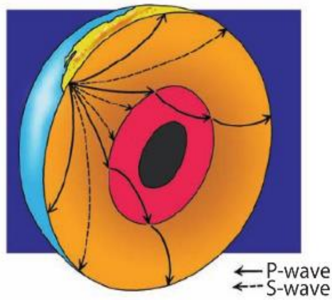
To understand how scientists study the earth's interior, think about how they study the deepest parts of the ocean floor, which, like the depths of the earth, have never been explored directly by humans. Scientists study the ocean floor and the inner earth using waves. To study the ocean, they analyze sound waves, using a technique called sonar. To study the inside of the earth, they analyze earthquake, or seismic, waves.

Sonar Waves: "Sonar" stands for Sound Navigation and Ranging. A sonar system consists of a transmitter and a receiver, just like a walkie-talkie, a phone, or any other two-way communication device. The sonar transmitter sends waves from a ship to the ocean floor. The waves bounce off the ocean floor, as shown in the illustration. A receiver detects the reflected waves. Oceanographers measure the time it takes for the second waves to complete a round trip. Because they know how far sound can travel in a certain amount of time, the scientists can then determine the depth of a specific area of the ocean. They can also combine information from many sound waves to create a profile that shows the shape of specific areas of the ocean floor.

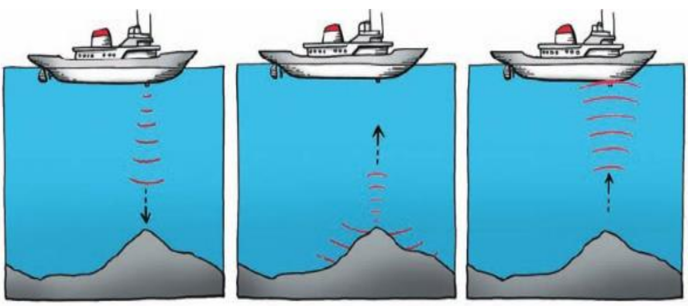


SOUND WAVES EMANATING FROM A SONAR SYSTEM ON A SHIP'S HULL COLLECT SONAR DATA IN A FAN-SHAPED AREA ON THE SEAFLOOR.

PHOTO: National Ocean Service/NOAA



THE PATHS OF P- AND S-WAVES PROVIDE SCIENTISTS WITH INFORMATION ABOUT THE EARTH'S INTERIOR STRUCTURE. FOR EXAMPLE, S-WAVES, UNLIKE P-WAVES, DO NOT TRAVEL THROUGH LIQUIDS.



SOUND WAVES BOUNCE OFF THE OCEAN FLOOR AND RETURN TO THE RECEIVER ABOVE.

OCEAN SCIENTISTS ABOARD A U.S. COAST GUARD SHIP LOWER SONAR EQUIPMENT INTO THE WATER FOR THEIR MAPPING OF THE SEAFLOOR NORTH OF ALASKA. THEY HOPE TO BETTER UNDERSTAND CURRENTS AND CLIMATE THROUGH THEIR RESEARCH.

PHOTO: National Ocean Service/NOAA

Earthquake Waves: Seismologists use earthquake waves to map the structure of the interior of the earth in much the same way oceanographers use sonar to map the ocean floor. As the earthquake waves move through the different layers of the earth, they change speed and direction. Sometimes they even stop. In other words, earthquake waves behave differently, depending on what substance they are traveling through. Because scientists know the average speed of P- and S-waves and also know how the waves travel, they can make educated guesses about the substances that make up the earth's interior. For example, they know that the outer core is liquid, because S-waves, which cannot travel through liquids, do not travel through the core. The more scientists learn about sound waves and seismic waves, the more they may discover about the earth's most hidden area—its interior.

Discussion Questions:

1. *Why do waves move at different speeds through different layers of the earth?*
2. *Why might S-waves travel more slowly than P-waves? Use internet or library resources to see if your hypothesis is correct.*

Lesson #6: Investigating Plate Movements

Introduction-

What does the word "model" mean to you? A model is often a smaller version of an object, such as a miniature airplane. In earth science, the shell of an egg can be used as a model of the earth's crust, which is too large and too complex to study firsthand in the classroom. In this lesson, you will use models to study how the earth's plates move and how the forces created by this movement result in earthquakes.

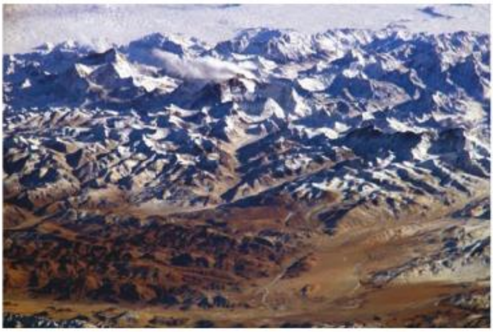
You will use two different styles of models in this lesson. One is quite simple, and the other is more complex. Using these models, you will investigate how the earth's lithospheric plates collide, separate, and slide past one another. You will use a relief globe to look for evidence of these interactions in landforms on the earth.

MOVING PLATES CAUSED THE ALPS MOUNTAIN RANGE THAT RUNS THROUGH EUROPE TO FORM. CAN YOU FIGURE OUT WHICH PLATES?

PHOTO: NASA Image courtesy Jeff Schmaltz, MODIS Rapid Response Team at NASA GSFC

COLLIDING, SLIDING, AND SEPARATING PLATES

The crust of the earth, along with the rigid uppermost part of the mantle, is called the lithosphere. The lithosphere is 18 to 120 kilometers thick. It covers the earth's interior and is broken into pieces called plates. The rocks that make up these plates grind, collide, move past one another, and separate as they float on a flowing, taffy-like, solid upper mantle called the asthenosphere. The place where plates meet is called a plate boundary. At some plate boundaries, the plates collide, and mountains, and trenches form, as shown in the photograph below. At other plate boundaries, the plates try to slide past one another. When this happens, energy builds up in the rock as it compresses or twists. When the force between the plates gets too great, the rock breaks, or ruptures, and an earthquake may occur.



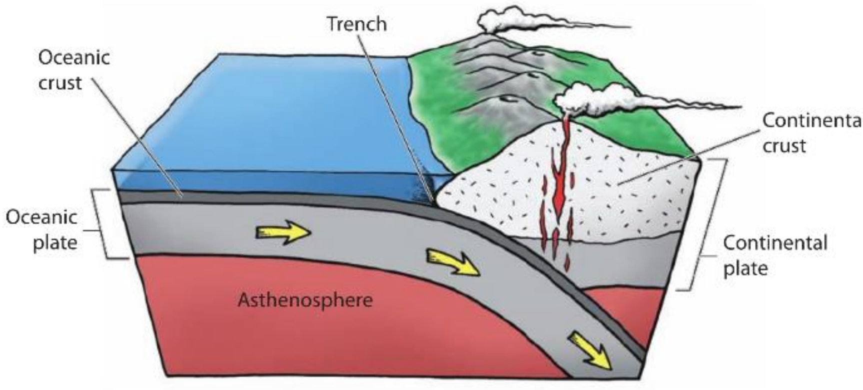
CAN YOU SEE EVIDENCE IN THIS PHOTO OF MT. EVEREST AND NEIGHBORING MOUNTAINS THAT PLATES HAVE COLLIDED?

PHOTO: Astronaut photograph ISS008-E-13304 taken from the International Space Station on January 28, 2004. Image provided by the Earth Observations Laboratory, Johnson Space Center.

Lithospheric plates can be either continental or oceanic. Continental plates contain the earth's continents. They are thick, but less dense than oceanic plates. Oceanic plates, which occur under the world's oceans, are thin and dense because of their composition.

More often, when two continental plates collide at what is called a convergent plate boundary, their edges crumple (imagine crumpling paper) and uplift to form mountains. This is what happened when the Indian-Australian Plate collided with the Eurasian Plate millions of years ago. Their collision formed (and is still forming) the Himalayas.

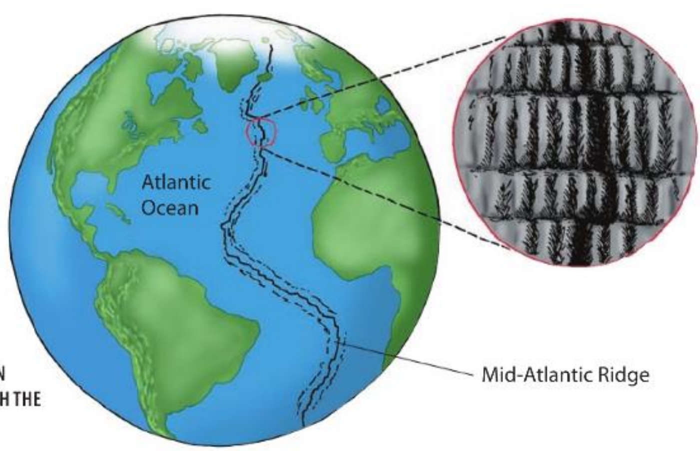
When a continental plate collides with an oceanic plate, it's a different story. The dense oceanic plate sinks and slides under the continental plate in a process called subduction, as shown in the top illustration at right. An older, colder oceanic plate can also slide under a younger, warmer oceanic plate, and the old plate moves deep into the earth. (This is because cold things are often denser than warm things.) When an oceanic plate moves under another plate, the bending of the sinking plate creates a trench, or deep valley, in the ocean floor. As the oceanic plate sinks deeper into the earth's hot interior at the trench, it is subjected to heat and pressure. As the temperature rises, part of the rock may melt. This molten, or melted, rock rises to the earth's surface and is the source of volcanoes.



WHEN OCEANIC AND CONTINENTAL PLATES COLLIDE, THE OCEANIC PLATE SLIDES UNDER THE LESS DENSE CONTINENTAL PLATE. THE ANDES MOUNTAINS IN SOUTH AMERICA FORMED THIS WAY.

Sometimes a new boundary can form under a continent. Hot rock flowing under a plate can cause the surface to thin and break. Then, the continent may split in two. The place where the plate splits is called a divergent plate boundary because the plates separate as melted rock flows to the surface. Like hot air that rises above cold air, melted rock inside the earth rises because it is less dense than the cooler, solid rock around it. The rising melted rock heats the crust and causes it to expand and bulge upward to form a ride, or mountain-like landform. If water from an ocean enters the place where the plate split, a mid-ocean ridge, as shown in the illustration below is formed.

Sometimes, at what is called a transform plate boundary, two plates slide past one another in such a way that it does not result in a new landform. You will learn more about these different types of plate boundaries in Lesson 7.



THE GROWING MID-OCEAN RIDGE CONTINUES TO PUSH THE CONTINENTS APART.

Earth's Moving Plates:

A Look Back

You've observed that Africa and South America seem to fit together like pieces of a puzzle. Scientists now believe that all the continents were once a single landmass. Earth's hot mantle separated those continents over time, and oceans formed between them. How did scientists long ago explain these changes? Let's take a look

Looking for Evidence: For centuries, some scholars hypothesized that continents move. For example, in 1620, Sir Francis Bacon, an English philosopher, noticed that continental margins looked as if they would fit together.

SIR FRANCIS BACON, ENGLISH STATESMAN AND PHILOSOPHER

PHOTO: Courtesy of Smithsonian Institution Libraries, Dibner Library of the History of Science and Technology, Washington, DC

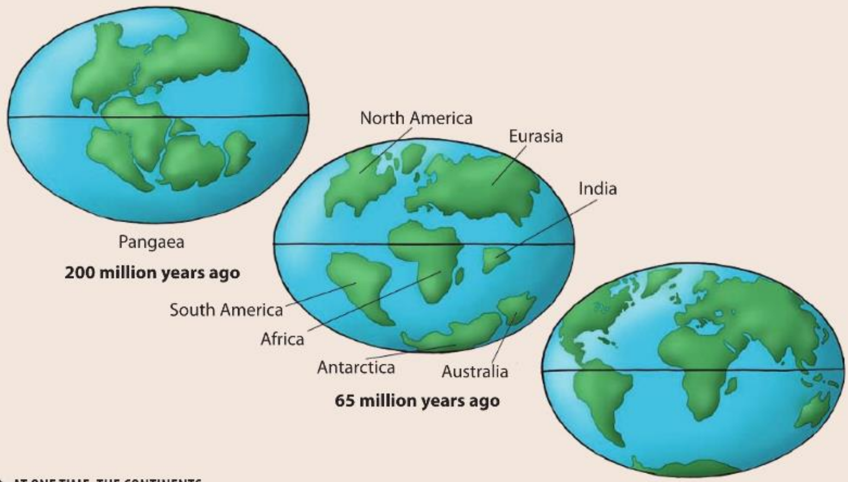
In the mid-1800s, Antonio Pellegrini, a geologist, noticed that identical fossils were found on continents separated by wide oceans. He thought a great flood caused these oceans to form, separating the continents and their fossils.

Edward Suess, an Austrian geologist in the mid to late 1800s, claimed that the scratches and gouges from glaciers line up along the boundaries of separated continents. He also noted similarities among plant fossils on different continents. He hypothesized that these fossil similarities were evidence that long land bridges had once connected the landmasses. He believed that the bridges later sank beneath the ocean.

In 1910, American geologist Frank B. Taylor explained that mountain ranges on distant continents line up. He theorized that large polar continents had broke apart, drifted toward the equator, and stayed there as a result of gigantic tidal forces. These forces, according to Taylor, were generated by the pull of gravity when the earth "captured" the moon.

The Breakup of a Supercontinent: After many scientists had gathered evidence, Alfred Wegener, a German meteorologist, proposed in 1912 the theory of continental drift. According to this theory, the continents were once united in one "supercontinent." Wegener named this continent Pangaea. He claimed that, over time, Pangaea had broken into pieces that drifted apart. South America and Africa had moved away from each other. North America and Europe had separated. His theory was supported by evidence from many different fields of science.

Wegener explained why the shorelines of different continents seem to match. He noted that mountain ranges of similar age and structure were now located on separated continents. Fossil animals, such as Mesosaurus (a freshwater reptile about 1 meter long), were found in countries on two different continents, Africa and South America. Because Mesosaurus lived only in fresh water, Wegener surmised that the continents at one time were connected. Finally, Wegener found evidence that continents currently in the Tropics were once covered with glaciers. This means the continents must have "drifted" or moved somehow.



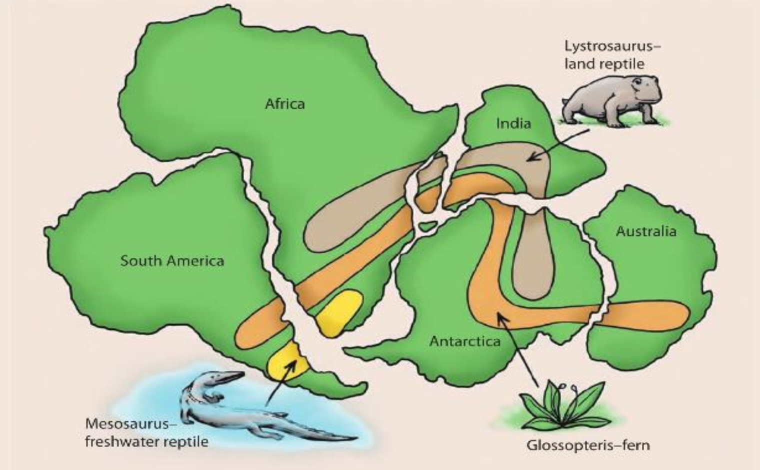
AT ONE TIME, THE CONTINENTS WERE ONE SUPERCONTINENT.

Wegener proved that continents appeared to move over time, but he could not prove why these events took place. What caused the continents to drift? Wegener thought he had answers. He argued that both gravitational tidal forces and the earth's rotation were responsible for continental drift. However, it was fairly easy for scientists to prove that these forces were much too weak. His explanations were not accepted.

Seafloor Spreading and the Drifting Continents: in the late 1950s and early 1960s, years after Wegener's death, new data about the seafloor emerged that enable geologists to suggest why continents appear to drift. Evidence from seafloor fossils and magnetic data suggested that younger parts of the floor were located closer to the mid-ocean ridge, while older parts of the seafloor were farther from the mid-ocean ridge, near the trenches. These data prompted the theory of seafloor spreading, which states that a force within the earth drives the ocean floor apart and allows new oceanic crust to form.

Plate Tectonics: In the late 1960s, scientists combined information on seafloor spreading and continental drift to propose the plate tectonics theory. This theory states that rigid plates move away from mid-ocean ridges, where new lithosphere is constantly being formed. It also proposed that old lithosphere moves away from these ridges and toward ocean trenches. At the trenches, old ocean lithosphere sinks into the earth. The plate tectonics theory also states that mountain chains of volcanic islands, such as Japan, form along trenches, where events such as earthquakes and volcanoes occur.

This theory was a major breakthrough for scientists. For many years, they had known that the earth's surface was slowly drifting, but they couldn't explain why. Today, they think they have found the answer. But there is still much to be learned about the earth's hidden interior and its effects on the planet's ever-changing surface.



WEGENER FOUND THAT EVIDENCE FROM FOSSILS, FOR EXAMPLE, SUPPORTED HIS THEORY THAT PLATES MOVE.

Discussion Questions:

1. *Why did it take so long for scientists to agree that continents move on the earth?*
2. *What evidence supports the theory of continental drift?*

Lesson #7: Investigating Faults

EVIDENCE OF THE HAYWARD FAULT IN CALIFORNIA

PHOTO: Naotake Murayama/creativecommons.org

<u>Introduction</u>-

In Lesson 6, you investigated how plates move over and under each other where they meet and how they can spread apart on the ocean floor. In this lesson, you will investigate in more depth what happens when continental plates slide past each other. What are the forces like when the plates slide and push against each other? What happens when the forces build up over time? You will use a model of a fault to investigate these questions and see how the forces created by plate movement cause rock to rupture and release vast amounts of energy in the form of an earthquake.

FOLDED GNEISS
FIGURE **7.1**

Earthquakes and Faults

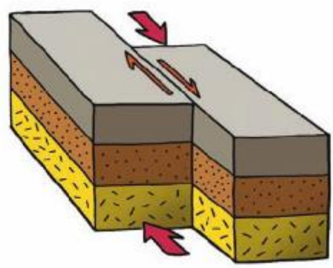
Push your hands together hard. If your palms are flat against each other, not much will happen. But if you push your hands together at an angle, they will slide past each other. The earth's plates work something like this. Most earthquakes are the result of huge pieces of rock in the earth that rub or press against each other as a result of changes inside the earth. As forces are applied to the rock, the rock slightly deforms. Energy builds up within and between pieces or rock. Suddenly, they slip past one another. Energy is released, and the ground ruptures and shakes. The longer the force is applied to the rock, the greater the amount of energy that will be stored in the rock, and the more severe the earthquake.

Plate boundaries occur along fractures or breaks in the earth's outer layer. A fault is a fracture along which blocks of rock on opposite sides of the fracture move. One type of fault is shown in the photo at right.

ALONG THE SAN ANDREAS FAULT, PLATES SLIDE PAST ONE ANOTHER. THE PATH OF WALLACE CREEK, WHICH FLOWS ACROSS THE FAULT, HAS CHANGED BECAUSE OF MOVEMENT ALONG THE FAULT. NOTICE THE RIDGES, WHICH HAVE BEEN FORMED BY HUNDREDS OF MOVEMENTS ALONG THE FAULT.

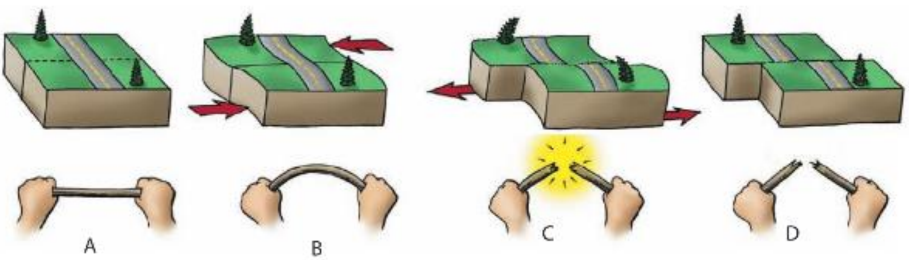
PHOTO: R.E. Wallace/USGS/NGDC/NOAA, Boulder, CO

Transform Faults: The San Andreas Fault in California, shown in the photo, is an example of a transform fault. The fault marks the line where the North American Plate and the Pacific Plate move horizontally past each other. No new landform is created along this boundary, but the rocks along the fault have jagged surfaces that hook and catch on each other, creating friction. The force behind each moving plate drags these hooked surface powerfully. I they are dragged strongly enough, the fault breaks, bending and fracturing the rock, and allowing the plates to slip past each other in opposite directions. On the surface, we experience this as a shallow earthquake. Fences, rivers, and other structures on the land along the fault that can change shape as a result of the forces created by the moving plates.



PLATES SLIDE PAST ONE ANOTHER ALONG THIS TRANSFORM FAULT.

One variable that affects the crust's behavior along a fault is the amount of friction between fault surfaces. Young faults have rough surfaces, but when a fault ruptures repeatedly, its rough surfaces, or protrusions, wear down and become smooth.



IF YOU APPLY FORCE TO A STICK, IT BENDS FIRST, THEN BREAKS. APPLY FORCE TO A ROCK, AND THE ROCK WILL STORE ENERGY. WHEN THE STRENGTH OF THE FORCE BECOMES GREATER THAN THE STRENGTH OF THE ROCK, THE ROCK WILL BREAK, AND AN EARTHQUAKE WILL OCCUR.

Subduction Faults: Another type of fault forms along a subduction zone. The earthquakes on these faults can be extremely large and destructive. The Alaska quake that you studied in Lesson 3 happened on a subduction fault. In this type of fault, seafloor slides beneath the continental plate and is melted in the intense heat below. Again, there is friction between the two plates, but the friction is generated between the surface of the lower plate and the edge and bottom of the top plate. The west coast of Washington and Oregon also experience subduction plate quakes. There, the Juan de Fuca Plate slides under the North American Plate. The beautiful, volcanic Cascade Mountain range developed as a result of the forces from this collision.

EVIDENCE OF THE SUBDUCTING DENALI FAULT IN ALASKA CAN BE FOUND IN THIS TRACE ALONG A GLACIER (NOTE HOW THE GROUND TO THE RIGHT OF THE TRACE IS HIGHER THAN THE GROUND TO THE LEFT).

PHOTO: U.S. Geological Survey

Spreading Faults: A third major type of fault happens along ocean bottoms where two plates pull apart and magma wells up into the chasm, causing seafloor spreading and the formation of new ocean floor.

AN EARTHQUAKE IN SAUDI ARABIA IN 2009 CAUSED THIS RUPTURE ON THE GROUND SURFACE FROM THE SPREADING OF THE PLATES BENEATH. NOTE THAT THE RUPTURE IS LARGER IN THE SOFT SEDIMENT (FOREGROUND) THAN IN THE ROCKY AREA (BACKGROUND).

PHOTO: U.S. Geological Survey/photo by John Pallister

Lesson #8: Convection in the Mantle

ARISTOTLE, A GREEK PHILOSOPHER WHO LIVED FROM 384 TO 322 BC

PHOTO: Courtesy of Smithsonian Institution Libraries, Dibner Library of the History of Science and Technology, Washington, DC

Introduction-

Like many people in his day, Aristotle, an ancient Greek philosopher, tried to explain why earthquakes and volcanoes occurred. He believed fire burned deep within the earth. He thought that when winds from the atmosphere were drawn underground, they mixed with the flames inside the earth and then exploded upward toward the surface. The results, according to Aristotle, were earthquakes and volcanic blasts. More than 1000 years later, Benjamin Franklin thought earthquakes came from a spark in the ground.

But why *does* the ground rattle and shake? Both Aristotle's and Franklin's theories had one thing in common—heat. And although theories since their times have changed, the earth's internal heat remains the explanation for why the earth's plates move.

In this lesson, you will investigate convection in the earth's mantle. You have seen convection many times in your life. Think of smoke rising from a campfire, or the air above the hot blacktop. Maybe you have felt cold air as you descended into a cave, or the draft under your front door in the winter. These convection currents happen when air at different temperatures mixes.

You will apply what you know about convection to better understand the earth's mantle. How do convection currents in the mantle cause the earth's plates to separate and ink back into the earth? What causes the continents to move over time? Using a special fluid that is very sensitive to heat, you will model convection currents in the mantle. By viewing computer images, you will be able to see what happens inside the earth. You will then relate convection cells to the movement of the earth's plates.

WHAT DO YOU KNOW ABOUT CONVECTION IN THE OCEAN?

PHOTO: Randolph Femmer/life.nbii.gov

Convection
Is the Answer

When Alfred Wegener introduced his theory of continental drift to the scientific world in 1912, even this most sympathetic listeners had a hard time taking him seriously. For one thing, he was telling them that the earth's land masses were rooted in the mantle, but drifted around the globe, gliding through the ocean floor like icebergs through the sea. He couldn't explain what caused the continents to move or how they managed their trips across the ocean floor.

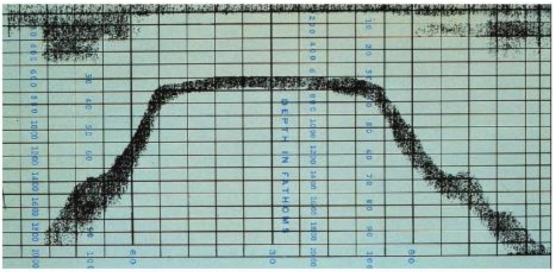
Geologists found his ideas completely implausible. Instead, they favored the idea that changes in the crust, like the eruption of mountain ranges, were caused by temperature fluctuations in the earth, which caused the earth to expand or shrink. Mountain ranges, under that hypothesis, were a sort of bunching up of the crust over shrinking earth. Adding to their skepticism towards Wegener and his theory was the fact that Wegener wasn't a geologist at all; he was a meteorologist. However, several scientists following Wegener provided theories and evidence that, after decades, brought the scientific community around to accepting continental drift.

First, a British geologist named Sir Arthur Holmes proposed that the shifting, semi-liquid mantle under the earth's crust flowed in a regular pattern. Heat, given off by decaying radioactive elements in the earth's core, drove the mantle's flow. And, he said, the slowly flowing mantle dragged continents with it. "Slowly" here meant quite slowly indeed; at most, a continent might move 15 cm (about 6 inches) over an entire year.

Holmes' theory relied on an understanding of thermal convection. As part of a fluid heats, it grows less dense and rises. Imagine a heated portion of the mantle moving upward, then cooling, becoming denser, and sinking downward again, creating a circular current. Like airport carousels that move luggage, said Holmes' theory, circulating parts of the mantle moved the continents.

Even though Holmes' theory provided a mechanism for continental drift, no one paid much attention, and people were still not convinced. It took the work of five other scientists to generate a consensus in favor of the theory within the scientific community.

Hard Data to the Rescue: Working in the 1950s and 1960s, Harry Hess and Robert Dietz studied the ocean floor and suggested that continental land masses weren't plowing through the seabed; instead, the seabeds were split at thin points along the crust, and magma came up through those splits, forcing parts of the ocean floor away from each other and forming new crust. In other words, Hess and Dietz figured that the continents weren't moving on their own; as chunks of seafloor slowly moved apart, they carried continents along with them. At the far edges of the crustal plates, the crust sank down into other rifts and melted back into the mantle. Hess and Dietz collected other data supporting the theory of mantle convection driving continental drift. For example, mid-oceanic ridges with volcanoes signaled that magma was welling up at plate boundaries.



GRAPH OF A GUYOT (AN UNDERSEA MOUNTAIN FORMED FROM AN EXTINCT VOLCANO) DISCOVERED BY HARRY HESS IN THE 1940S

PHOTO: NOAA Central Library

DR. ROBERT DIETZ EXPLAINING HIS FINDINGS ON THE INDIAN OCEAN SEVERAL YEARS AFTER HE PROPOSED THAT SEAFLOOR SPREADING OCCURS AT ACTIVE OCEAN RIDGES.

PHOTO: Archival Photography by Steve Nicklas, NOS, NGS/NOAA

Soon after Hess and Dietz presented their ideas, three other geologists—Fred Vine, Drummond Matthews, and Lawrence Morely—suggested that new discoveries about the magnetism of freshly formed rocks would support their theory of seafloor spreading. Their theory turned out to be correct, and it was crucial to the scientific community's acceptance of continental drift as reality.

The Work's Not Done: Today, we continue to seek information about the details of mantle convection and how exactly it contributes to continental drift. Where does convection occur, and what are the forces that generate and direct its flow? Keep in mind that the mantle's flow can be influenced by heating from the bottom, cooling at the top, and movement of crustal materials at plate boundaries. Because the forces of mantle convection are operating deep with the earth's interior, they are difficult to study. It is tricky to determine exactly how they contribute to the mantle's convection.

The "plume model" of the mantle convection assumes that magma wells up from deep in the mantle and generates the convection currents that move the continental plates. Imagine a simmering bowl of thick soup with crackers floating on the top. What do you think would happen to the crackers in the soup if you heated it to boiling? As the cooler soup sinks down and the hotter soup rises, currents are generated that move the crackers around. So, while the mantle is very active, the continental plates in this model are passive, reacting to the activity in the mantle. The plume model has frequently been used to diagram and explain mantle convection.

In recent years, however, evidence has accumulated for the "plate model" of mantle convection. This model gives the continental plates themselves an active role in generating the motion of the mantle below. According to this model, continental plates affect the mantle's convective flow by absorbing and reflecting heat, causing variations in mantle temperature. They also provide a continually changing surface boundary between mantle and crust. Crustal events, such as plates breaking up and slabs subducting, may change the flow of the mantle.

Geology in Space: If Earth turns out to be a much more active object than we previously thought, how active might other planets be? Looking around our solar system, it appears that Earth is the only planet that is seismically active. Some other planets, such as Mars and Venus, and the Moon, have features that reveal a seismic past: evidence of volcanic activity, for instance. But volcanoes on these planets have been extinct for as many as a billion years.

APOLLINARIS PATERA IS AN ANCIENT VOLCANO ON MARS WITH A CALDERA THAT IS 80 KILOMETERS (50 MILES) ACROSS!

PHOTO: NASA/JPL/Malin Space Science Systems

Some planetary moons also have features that suggest tectonic activity. Io, one of Jupiter's moons, has gas plumes rising high above its surface, and Ganymede, also orbiting Jupiter, has plate-like blocks alternating with trenches on its surface. Both features are reminiscent of place on Earth where shifting plates and the mantle below generate surface activity. More research will reveal whether and how convection is occurring on these moons. For example, if they have liquid interiors, it is more likely that they, too, are likely celestial bodies, with active interiors and surfaces in constant motion.

Discussion Questions:

1. *How does the work of Alfred Wegener continue to affect what scientists study today?*
2. *How might the study of tectonic features on other planets contribute to our understanding of Earth?*

Lesson #9: Introducing Volcanoes

<u>Introduction</u>-

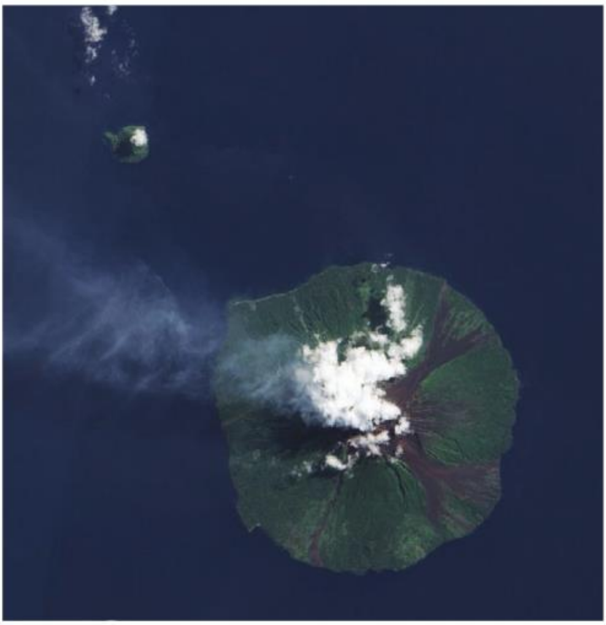
Earthquakes often occur with little warning. Volcanic eruptions, by contrast, can often be forecast well before they happen. Many different signs from the earth tell scientists that a volcano may be about to erupt. Earthquakes, which normally occur before a volcanic eruption, mean that molten rock within the earth is rising and putting pressure on rock. Usually these earthquakes are weak and cannot be detected without the aid of seismographs. An increase in the number of earthquakes may indicate to scientists that a volcano is getting ready to erupt.

WHAT DO YOU THINK THIS VOLCANOLOGIST IS DOING WITH THIS SEISMOGRAPH AT LAKE BUTTE IN YELLOWSTONE NATIONAL PARK?

PHOTO: NPS photo by Jim Peaco

Other signs of possible eruption include the presence of steam and ash, which can emerge during small explosions from a volcanic vent. The amount of sulfur in the air over a volcano might also increase as gas is released from the rising molten rock. The top and sides of the volcano may begin to bulge as the molten rock approaches the surface. Volcanologists use special tools to measure the changes that occur in a volcano. By monitoring these changes, scientists can attempt to forecast when the volcano might erupt. The right forecast can save lives and protect property.

What causes volcanoes? How are volcanoes destructive? Do volcanoes have any constructive, or good, effects? In this lesson, you will investigate questions such as these and discuss the relationships among volcanoes and other plate tectonics.



MANAM VOLCANO IS JUST OFF THE COAST OF MAINLAND PAPUA NEW GUINEA. IT STRETCHES 10 KILOMETERS (6 MILES) ACROSS AND IS ONE OF PAPUA NEW GUINEA'S MOST ACTIVE VOLCANOES.

PHOTO: NASA image created by Jesse Allen, using EO-1 ALI data provided courtesy of the NASA EO-1 Team

Volcanic eruptions can range from violent to mild. All kinds of eruptions have effects that can be both harmful and beneficial to people and the environment.

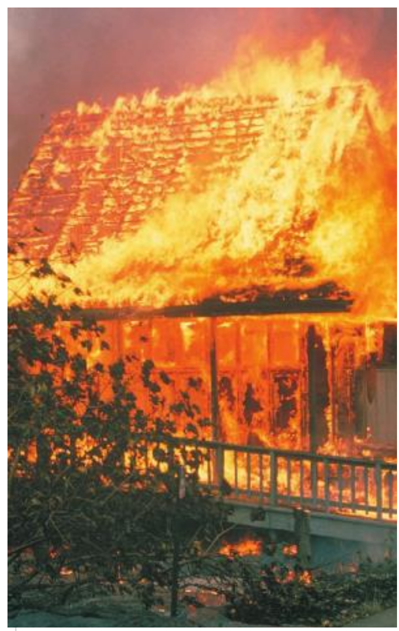
Volcanoes can be Destructive: When volcanoes erupt, they often spew molten rock and fragments of rock over the ground and into the air. Fine fragments of rock called ash, are usually ejected during very violent eruptions. Ash can affect people hundreds of kilometers away from an eruption. In 1980, in Spokane, Washington, it was dark at noon as a result of the ash cloud from the Mt. St. Helens' eruption more than 300 kilometers (186 miles) away.

FOR WEEKS, MT. ST. HELENS SPEWED VOLCANIC ASH OVER THE SURROUNDING LANDSCAPE AND FOR HUNDREDS OF KILOMETERS DOWNWIND TO THE EAST. NOTICEABLE AMOUNTS OF ASH FELL IN 11 STATES. ALTOGETHER, MT. ST. HELENS EXPELLED ENOUGH ASH TO COVER A FOOTBALL FIELD TO A DEPTH OF 240 KILOMETERS (149 MILES).

PHOTO: U.S. Geological Survey/Cascades Volcano Observatory/photo by Peter Lipman

Sometimes a volcano explodes sideways, shooting out ash and large pieces of rock that travel at very high speeds for several kilometers. These explosions can cause death by suffocation and knock down entire forests within seconds. Rivers of molten rock or hot fragments of rock from such eruptions can instantly ignite fires for great distances.

An erupting volcano can also be accompanied by earthquakes, flash floods, rockfalls, and mudflows. Floods occur when rivers are dammed by trees felled during an eruption or by molten rock moving across a river. Mudflows are powerful rivers of mud that form when debris from a volcanic eruption moves into a steam or river. Mudflows can move faster than people can run, and bridges in the path of these flows can be destroyed instantly. One kind of mudflow, called a lahar, happens when rain falls through clouds of ash or when rivers become chocked with falling volcanic debris. During the eruption of Mt. St. Helens in 1980, lahars destroyed more than 200 homes, more than 300 kilometers (186 miles) of roads, and 220 kilometers (137 miles) of river channel.



IN 1989, THE WAHAULA VISITOR CENTER IN HAWAII WAS ENGULFED BY A HOT LAVA FLOW AND BURST INTO FLAMES. ALL ATTEMPTS TO SAVE THE CENTER WERE USELESS.

PHOTO: U.S. Geological Survey/photo by J.D. Griggs

A volcanic eruption can also cause a tsunami. A tsunami is a series of sea wavs usually brought on by underwater earthquakes, but volcanoes can cause tsunamis, too. The collapse of an island during a volcanic eruption or the dumping of heavy loads of volcanic debris into the ocean can create massive waves. The 1883 eruption of Krakatoa, a volcanic island in Indonesia between Sumatra and Java, unleashed a tsunami that swept the coast of Sumatra and Java and drowned more than 36,000 people.

Severe-weather-related events often accompany volcanic activity. These include lightning, thunderstorms, and whirlwinds (including tornadoes). In addition, the heat caused by a volcanic eruption can melt snow and glaciers, which can lead to flooding and landslides. Ash clouds from an erupting volcano can temporarily affect the weather in cities that are hundreds or even thousands of kilometers away. For example, the 1883 eruption of Krakatoa released 20 cubic kilometers (4.8 cubic miles) of volcanic dust into the air. The dust rose so high that it reached the stratosphere. Within 13 days, it had encircled the globe and blocked sunlight from entering the atmosphere. For months, sunsets were strange-colored. Average daily temperatures around the world dropped an estimated 0.5°C (33°F) during 1884. It took five years for all of the volcanic dust to settle to the ground.

AFTER THE ERUPTION OF MT. ST. HELENS, THIS HOME WAS DAMAGED BY VOLCANIC MUDFLOW ALONG THE SOUTH FORK TOUTLE RIVER IN WASHINGTON STATE.

PHOTO: U.S. Geological Survey/Cascades Volcano Observatory/photo by Lyn Topinka

In 1815, a different Indonesian volcano, Tambora, erupted even more powerfully. It blasted about 150 cubic kilometers (36 cubic miles) of volcanic debris high into the atmosphere. The dust blocked so much sunlight that crops failed to grow around the world and 1816 became known as "the year without a summer." Again, it took several years before the effects of this eruption passed.

Volcanoes can be Constructive: Not all the materials that come out of volcanoes are harmful. Many volcanic areas have permanent hot springs that are beautiful to look at and provide recreation for residents and tourists. In addition, people can tap the geothermal energy of hot springs to heat their homes directly or to produce electricity. Islanders, for example, use geothermal energy to heat their homes, buildings, and swimming pools. Iceland has a very short growing season, but greenhouses heated by geothermal energy provide Icelanders with vegetables, tropical fruit, and flowers year-round. Some people living in Arctic regions also heat their homes and greenhouses with water from hot springs. The hot water flows through pipes in their houses, warming the air. Geothermal steam is used to generate electricity in places such as Italy, New Zealand, the United States, Mexico, Japan, and Russia.

Volcanoes provide a wealth of natural products. Basalt, which forms from cooled lava and makes up much of the seafloor, is a raw material for cleaning agents, and it has many chemical and industrial uses. Volcanic ash enriches the soil with mineral nutrients. Minerals in molten rock are a major world source of nickel, chromium, platinum, and several other important elements. Obsidian, or "volcanic glass," is an ideal material for fine stonework because it breaks with a typical curved fracture when struck with a sharp blow. Beautiful arrowheads of obsidian have been found in Ohio from the Hopewell culture, which flourished 1500 to 2300 years ago.

Volcanoes also create beautiful landscapes. Without volcanic activity, there would be none of the spectacular fissures that dot the Hawaiian landscape or the majestic peaks of the Cascade Range, such as Mt. Rainier.

Most people think of catastrophic events as violent natural hazards that create human and environmental risks. But as we have just seen, there is another side of the story. Catastrophic events can also be constructive forces on the earth. Volcanoes affect the composition of our oceans and atmosphere. Floods create sandy beaches along riverbanks. And earthquakes, as well as volcanoes, create and shape the mountains and islands that people enjoy.

MOST GEYSERS ARE HOT SPRINGS THAT ERUPT FOUNTAINS OF SCALDING WATER AND STEAM.

PHOTO: NPS photo by Frank Balthis

THIS OLD ENGRAVING SHOWS THE 1866 ERUPTION OF NEA KAMENI, SANTORINI, IN GREECE. A GIANT VOLCANIC EXPLOSION CAUSED THE SUDDEN SINKING OF THE ISLAND'S CENTER BENEATH.

PHOTO: P. Hedervari, National Geophysical Data Center/NOAA

Discussion Questions:

1. *The primary effect of a volcanic eruption is the spewing of lava, rocks, and/or ash. What are some secondary effects of a volcanic eruption?*
2. *What are two ways in which volcanoes are seen as beneficial?*

Earth's Waterworks

In the 1800s, fur trappers who ventured into the Rocky Mountains came back and told of "the place where hell bubbles up." No one believed them. One of the trappers, a Virginian named Jim Bridger, told people about finding a column of water as thick as his body that spouted 18 meters (about 60 feet). People called him a liar. But explorers later confirmed the trappers' stories. They had found the roaring geysers (springs that spout hot water and steam) and craters of boiling mud in the area that is now Yellowstone National Park. Today, several million people every year come to view these wonders at Yellowstone.

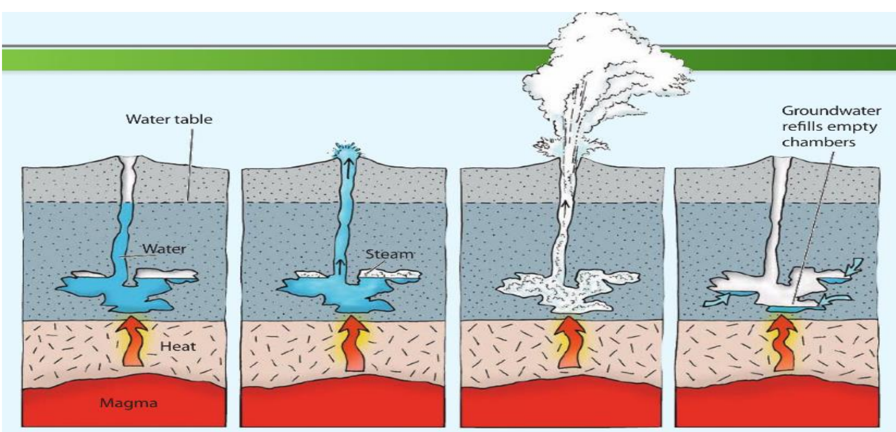
Yellowstone Park, located in Wyoming and Montana, is the hottest, most active geyser area in the world. It contains more than 500 geysers, or nearly three-fourths of all the world's geysers. In all, Yellowstone has 10,000 geothermal features ("geo" means "earth" and "thermal" means "heat"). Besides geysers, Yellowstone's geothermal features include hot springs and bubbling mud pots.

OLD FAITHFUL IS THE MOST FAMOUS GEYSER IN YELLOWSTONE NATIONAL PARK.

Why does Yellowstone have so many hot springs? Most of Yellowstone sits inside an ancient caldera. The volcano's last major eruption, which created the caldera, happened 600,000 years ago. Smaller lava flows from the volcano gradually filled up most of the caldera. Rock under the earth's surface can stay hot for thousands of years. Heat from molten rock a few kilometers below the surface heats the groundwater. The groundwater is held in a porous type of rock, and the heated water travels upward until its bursts through the earth's surface like a fountain.

Old Faithful, Yellowstone's most famous geyser, got its name because it normally erupts on a regular basis—on average, every 79 minutes. The eruptions are so regular because the water supply and the structure of the rock remain fairly constant over time. Yet Old Faithful isn't completely predictable. The time between eruptions actually varies between 45 and 105 minutes, depending on the amount of super-hot water left in the spongy rock when the geyser runs out of steam.

Recently, scientists lowered a video camera and other instruments into the vent of Old Faithful. They found that for the first 20 or 30 seconds of each eruption (which lasts for several minutes), steam and boiling water rocket through the narrowest underground cracks at the speed of sound!



A GEYSER FORMS WHEN MAGMA HEATS UP GROUNDWATER THAT IS UNDER PRESSURE.

What makes a Geyser go? Rainwater trickles through cracks into porous rock, where it collects like water in a sponge. Heat from magma a few kilometers beneath the earth's surface rises and heats the water in the porous rock. The porous rock layer is like a pressure cooker: it has lots of heat from the magma and lots of pressure from the weight of water and rock above it. The water in the porous rock can reach temperatures of 310°C (590°F) without boiling because of the tremendous pressure.

This super-hot water rises into pockets of groundwater that are also under pressure. Steam forms, more pressure builds, and bubbles rise. Steam keeps building until a spout of hot water and vapor explodes to the surface and shoots high into the air. More super-hot water then bursts into steam and blasts more groundwater out of the earth, erupting sometimes for up to several hours.

HOT SPRINGS ARE ONE OF THE GEOTHERMAL FEATURES FOUND AT YELLOWSTONE NATIONAL PARK.

PHOTO: NPS photo by J.R. Douglass

WHEN THE WATER FROM CASTLE GEYSER IN YELLOWSTONE NATIONAL PARK EVAPORATES, A MINERAL CALLED SILICA IS LEFT BEHIND. THIS MOUND OF SILICA IS CALLED A GEYSERITE.

PHOTO: NPS photo by George Marler

If the super-hot water mixes with cool groundwater that is not under pressure, it rises to the surface as a hot spring. When hot springs become chocked with pieces of weathered rock (sediment) that break off from the surrounding rock, bubbling mud pots are the result.

If the super-hot water rises to the surface with no resistance, it begins to boil and erupts at the surface as steam. This thermal feature, called a fumarole, is like a geyser, except that it is mostly steam.

When Geysers lost their Steam: Some old geysers lose their steam. The super-hot water carries minerals that, through time, accumulate on the walls of the underground channels and cracks. Like arteries, the cracks become clogged, and then steam and water can no longer escape.

For one Yellowstone geyser, named Porkchop, the pressure was too much. It spouted water and steam for years. Then one day it blew rocks the size of TV sets into the air and stopped gushing for good.

Discussion Questions:

1. *Why do geysers erupt? Why don't they remain as pools of hot underground water?*
2. *Imagine you are a scientist tasked with studying how geysers might serve as earthquake detectors. What sort of data could you gather?*

EARTHQUAKE PREDICTOR?

In 1990, a scientist from the Carnegie Institution in Washington, DC, worked with a person who owned property near a geyser in California to study patterns in the geyser's eruption cycle. The geyser didn't always erupt on schedule. For 15 years, the property owner had collected data on the geyser's eruptions. The scientist compared the data with records of thousands of earthquakes in California and found that major changes in the geyser's activity coincided with three large earthquakes that occurred within 248 kilometers (154 miles) of the geyser. In all cases, changes in the geyser happened one to three days before the earthquake. The scientist hypothesized that underground movements that caused the earthquakes may also have affected the geyser's water supply.

Earthquakes often hit the Yellowstone National Park area, shaking and moving the geysers' "plumbing system" and choking off the water supply. An earthquake in 1995 moved heat and water away from Steamboat Geyser and redirected it to Monarch Geyser, which had been dormant for 81 years. Suddenly, Monarch began blowing off steam. Could a geyser be an earthquake detector? It's possible, but more study needs to be done on this subject.

Lesson #10: Exploration Activity- Exploring Mitigation of Earthquakes and Volcanic Eruptions

Introduction-

On December 26, 2004, the fourth largest earthquake since 1900 rocked the region around Sumatra and triggered a tsunami that reached 14 countries. The landscape of Banda Aceh was permanently altered. The event killed 227,898 people, and 1.7 million people were displaced. The earthquake registered 9.1 on the Richter scale, and people in Banda Aceh experienced a Mercalli rating of IX. As tragic as this event was, valuable lessons were learned and headed. Was this disaster preventable? What technologies and designs have we developed as a result of tragedies like this one?

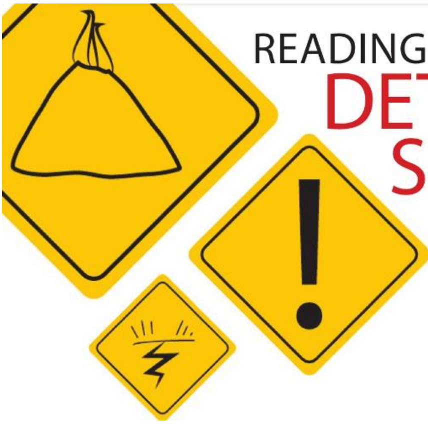
AN AERIAL VIEW OF THE DESTRUCTION IN BANDA ACEH, INDONESIA AFTER A 2004 TSUNAMI.

PHOTO: Patrick M. Bonafede/U.S. Agency for International Development (USAID)

In this activity, you will research an historic earthquake or volcanic eruption. Then you will relate the event to a specific technology, building design, or monitoring system that has been used to prevent the loss of lives in future earthquakes or volcanic eruptions. You will work with your group to give a historical perspective about the event, detail the event's impact on people's lives and their surroundings, and describe the technology used to monitor and predict these disasters. You will develop a detailed display summarizing your research and present it to the class.

AFTER A SERIES OF EARTHQUAKES IN 2006, ENGINEERS INSPECT A TRANSFORMER IN HAWAII TO MAKE SURE THAT IT REMAINS OPERATIONAL AT A SITE THAT TRANSMITS EMERGENCY MESSAGES.

PHOTO: FEMA/Adam Dubrowa



READING THE SIGNS: DETECTING SEISMIC EVENTS

The next time your mind is wandering during class, consider what you may be missing. In December of 2004, a ten-year-old British girl was able to save over a hundred people, including her family, thanks to what she'd learned from a video she'd seen in her geography class. The video showed a tsunami approaching shore; a tsunami is a series of enormous, fast-moving ocean waves generated by an undersea earthquake or volcanic eruption. They can be tremendously destructive. Although tsunami waves may not be tall waves in the open ocean, as they knock up against the rising seabed of the shore, they slow down, grow tens or hundreds of feet tall, and begin to pile up behind each other. As they gather for the crash on the shore, they may suck water back into the ocean, leaving people on the beach wondering why the tide's suddenly gone out so far.

Some time after Tilly Smith saw the tsunami video in class, her family took a winter seaside vacation in Thailand, on the Indian Ocean. While playing on the beach, Tilly noticed that the ocean was rising and becoming bubbly and frothy. The scene that unfolded before her eyes looked alarmingly like what she had seen in the video. In a panic, she screamed for her family to get off the beach. Luckily, her parents took her fright seriously, warned other vacationers and guards, and ran up the beach to their hotel. Other beachgoers followed. While they were sheltered on the third floor of the hotel, the beach was pummeled by the tsunami. It was one of the few beaches hit that day on which no one was killed.

The giant waves were caused by a powerful earthquake (magnitude-9) that had occurred in Sumatra, an island in another part of the Indian Ocean, earlier that day. Although Tilly's ability to read the signs of a tsunami got everyone off her hotel beach to safety, nearly 228,000 people in eleven countries were killed by the tidal waves from the Indian Ocean during the catastrophic event.

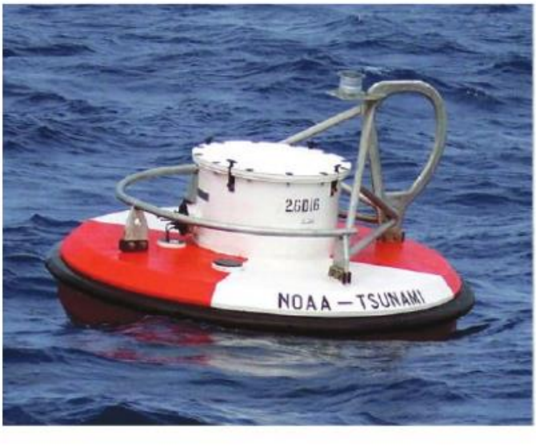
If a ten-year-old was able to see a tsunami coming and clear a beach, why couldn't more people have been saved that day? The answer lies partially in how difficult it can be to spot major catastrophes in time to warn authorities and have them get people to safety. Tsunamis are huge volumes of water pushed into motion by a catastrophic event undersea, but most of that rolling mass lies under the ocean's surface. In the open ocean, tsunami waves may look like normal waves, only a foot or so tall. The bulk of the enormous wave lies underneath. It's only when the mass is forced up and out of the ocean by rising shoreline that the size and force of the wave is apparent.

PEOPLE WERE STILL DIGGING THEIR BELONGINGS OUT OF RUINED HOUSES SEVERAL WEEKS AFTER THE 2004 TSUNAMI IN THE INDIAN OCEAN.

PHOTO: U.S. Navy photo by Photographer's Mate Airman Jordon R. Beesley

There are signs, though, that suck enormous waves are on the move under the ocean's surface. Water pressure may change suddenly undersea as the wave passes by. Being able to read this tsunami signal can help in setting up effective early warning systems. Many countries participate in a system designed to detect changes in ocean water pressure that signal an impending tsunami. In this four-part system, seafloor sensors constantly monitor water pressure and send signals to the surface buoys, which then relay the data to satellites, which send the data to tsunami warning stations.

Through its DART (Deep-ocean Assessment and Reporting of Tsunamis) program, the U.S. National Oceanic and Atmospheric Administration manages a set of sensors around the "ring of fire" in the Pacific, where plates collide. Its tsunami warning stations are staffed 24 hours a day, looking for signs of trouble. When a 2010 earthquake in Chile spawned tsunamis in the Pacific Ocean, DART buoys were able to detect them and warn people in Hawaii ten hours in advance. A loud siren blared from



BUOY THAT FORMS PART OF NOAA'S DART II SYSTEM

PHOTO: NOAA

the tsunami warning station, giving people time to evacuate coastal areas for higher ground. While the tidal waves that reached Hawaii during that event did not amount to much, the residents were better safe than sorry.

Such systems cost money to run and require trained, well-educated staff. In the absence of popular and governmental support, they may not be built. In 2004, there was no DART system in the Indian Ocean; the 2004 tsunamis, and the staggering loss of life in the coastal areas affected, gave the world a graphic demonstration of warning systems' importance. Governments around the region worked with the United Nations and other countries to install an Indian Ocean DART.

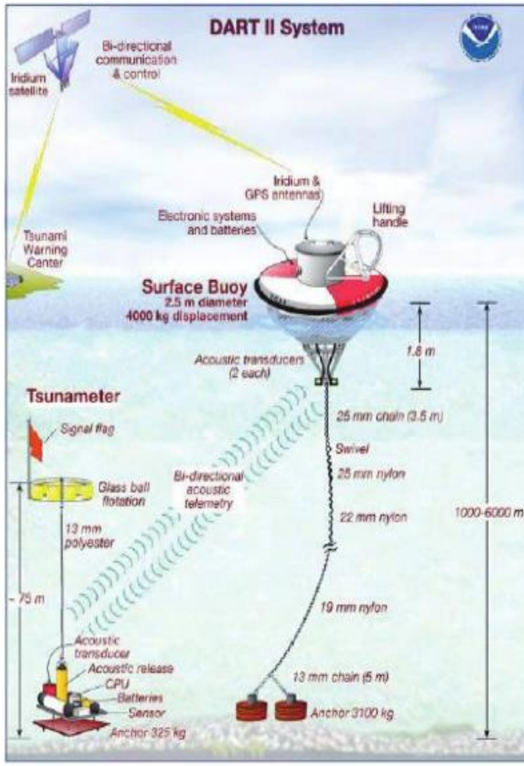


DIAGRAM SHOWING HOW THE DART SYSTEM TRANSMITS SIGNALS FROM THE OCEAN BOTTOM TO A TSUNAMI WARNING STATION

PHOTO: NOAA

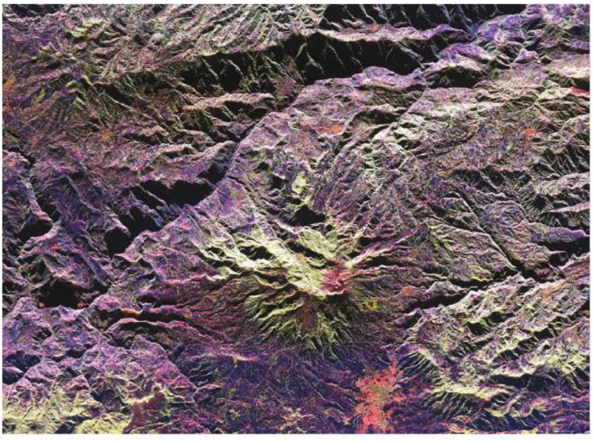
While early warning systems for tsunamis can be quite effective, what about warnings for other types of seismic events? There are a number of signs that can be monitored to determine whether a volcanic eruption is coming. For example, gases, particularly sulfur dioxide, are vented from volcanoes as magma shifts and rises to the surface. An eruption is often preceded by a marked changed in the amount and composition of gases from the volcanic cinder cone. The build-up of magma below the surface also causes a volcano to swell, a change that can be measured with a tiltmeter (an instrument that detects slight changes in slope). Movements of magma can cause shaking, or tremors, of parts of the volcano, which can be measured with the same sort of seismic equipment used for earthquakes.

Together, these signs—gases, tremors, and swelling—reveal that a volcano is becoming active. However, it's still not possible to predict with accuracy exactly when, or indeed whether, an eruption will occur; nor can we tell how severe the eruption might be. (Often, magma cools on the surface without erupting.) What volcanologists can do is tell us when an eruption is probable. The timing of an eruption depends on many conditions below the surface, such as temperature, structure of the rock overlaying the magma, and amount of pressure exerted by the magma.

AN ELECTRONIC TILTMETER ON THE POST IN THE FOREGROUND MONITORS CHANGES IN SLOPE ON MT. ST. HELENS IN WASHINGTON STATE.

PHOTO: U.S. Geological Survey

Consider the unfortunate events of 1993, when seven volcanologists were studying the active Galeras Volcano in Colombia, South America. They were collaborating to learn more about the early warning signs of eruption. Because the recent tremors and venting of gases had abated, the scientists thought it was safe to climb into the cone to take measurements. They were wrong. A massive explosion killed all but one of the scientists, Stanley Williams, who had to crawl out with broken legs and burned skin. It is thought that the Galeras Volcano had appeared to be "asleep" because magma had sealed up all the surface cracks, temporarily blocking the exit of gases and stilling the tremors. As magma continued to rise inside, the extreme pressure brought on by this situation literally burst the volcano open.



THE GALERAS VOLCANO (GREEN WITH REDDISH CONE) HAS ERUPTED MORE THAN 20 TIMES SINCE THE 1500S. IT IS ONE OF 15 VOLCANOES WORLDWIDE THAT ARE TARGETED FOR MONITORING BECAUSE THEY POSE HIGH RISK TO PEOPLE. NOTE THE CITY OF PASTO (ORANGE AT BOTTOM OF IMAGE) IS JUST 8 KILOMETERS (5 MILES) FROM THE VOLCANO.

Developing early warning systems for earthquakes has also proven to be difficult. For decades, scientists have been developing technology to monitor the seismic changes that accompany earthquakes. Earthquake monitoring stations now use specialized instruments to detect P-waves, the fast-moving waves that precede the arrival of the more damaging, slower waves.

Unfortunately, because the more destructive waves follow right on the heels of the P-waves, at best we can detect an earthquake less than a minute before its destructive impact. This falls short of what we need for an early warning system. Would you be able to put down what you are doing and evacuate to a safe place with less than a minute of warning? The good news is that in recent years, scientists have found that by positioning highly sensitive instruments as deep as a kilometer underground, they can measure subtle changes in stresses on rocks that might signal a quake.

With continued seismological research, we should be able to develop earlier warning systems for earthquakes as well as improve systems for volcanoes and tsunamis. Scientists continue to work on understanding the sometimes hard-to-read signs that a major seismic event is going to occur. As a professor at Arizona State University, the recovered Stanley Williams still climbs into volcano cones collecting data. The work that he and other scientists conduct may save a lot of lives by making it possible to forecast catastrophic events in a timely, accurate way.

Discussion Questions:

1. *The video Tilly watched in school helped her spot danger and warn her parents of the tsunami. What else could have helped people get off the beach to safety?*
2. *Scientific research is often expensive, and we cannot fund all the research we might like to fund. Suppose a friend said, "We're really far from being able to predict earthquakes. We should spend money on science that has a better chance of success." Do you agree or disagree? Why?*

Lesson #11: Volcanoes Change the Landscape

PILLOW LAVA ROCKS THAT FORMED OFF THE COAST OF HAWAII

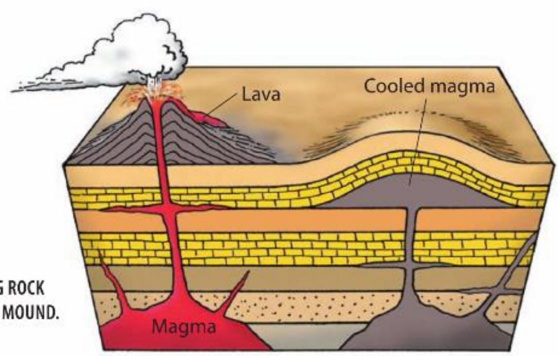
Introduction-

The hot molten rock that lies deep within the earth rises through fractures in the earth's crust. Sometimes it stays below the earth's surface, where it cools slowly and forms new rock. At other times, it spews out onto the land or the ocean floor. This is how volcanic mountains or islands form. If the molten rock flows into the ocean or emerges under the sea (such as along mid-ocean ridges), it cools as soon as it hits the water. In recent years, scientists have used remote-controlled cameras to observe how red-hot liquid rock emerging from the ocean floor cools and turns into a solid mound of lava in only a few seconds. Scientists call the resulting underwater balloon-shaped mounds of lava "pillows."

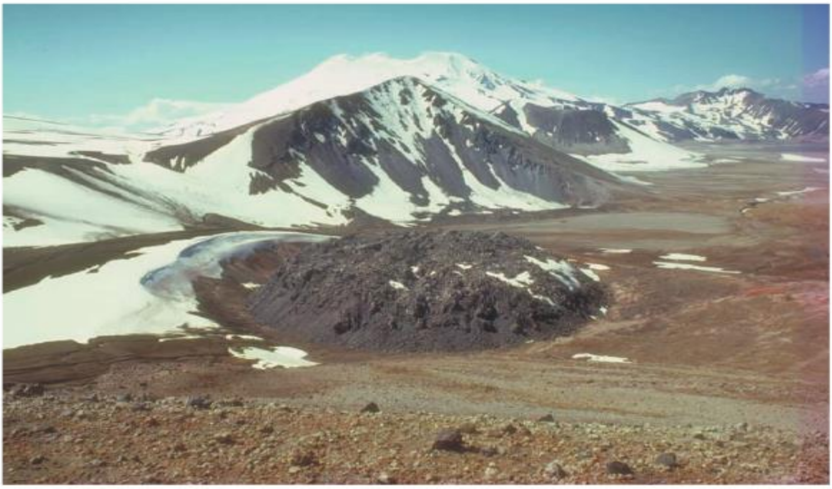
In this lesson, you will investigate land formation, which is one of the constructive effects of volcanoes. In the first inquiry, you will use a substance called Model Magma™ to stimulate how rising molten rock changes the shape of the land above it. In the second inquiry, you will use melted wax to model how cooled molten rock creates new landforms—both on land and under water. Through these investigations, you will see that volcanoes can change the landscape of the earth.

LAVA ERUPTS FROM A FISSURE BETWEEN PU`U `O`O CRATER AND NĀPAU CRATER IN HAWAII.

PHOTO: U.S. Geological Survey



MAGMA CAN PUSH UP THE OVERLYING ROCK AND SOIL, SHAPING THE LAND INTO A MOUND.
FIGURE **11.6**



THIS PHOTO SHOWS A LAVA DOME LOCATED AT THE TOP OF THE NOVARUPTA VENT IN THE VALLEY OF TEN THOUSAND SMOKES IN KATMAI NATIONAL PARK AND PRESERVE, ALASKA. THE BULBOUS, STEEP-SIDED DOME FORMED AT THE TOP OF THE VOLCANO WHEN THICK, RELATIVELY COLD MAGMA (THAT DID NOT FLOW EASILY) CAME OUT OF THE VOLCANIC OPENING. IN MOST CASES, A LAVA DOME WILL GROW AS SUCCESSIVE ERUPTIONS ADD TO ITS SHAPE.

FIGURE **11.7**

PHOTO: U.S. Geological Survey/photo by T. Miller

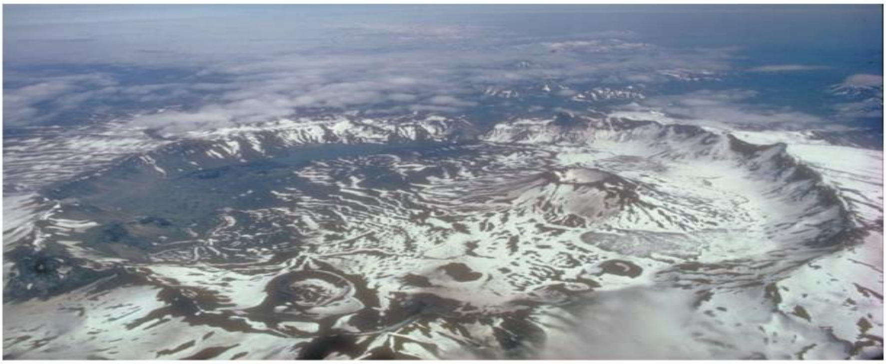
IF LAVA IS RUNNY, IT MAY FLOW QUICKLY OVER THE SURFACE OF THE EARTH AND COVER A WIDE AREA, AS SHOWN HERE. THIS IS CALLED A LAVA FLOW. LIKE THE FLOW OF A RIVER, LAVA FLOW FOLLOWS THE PATH OF LEAST RESISTANCE—FOR EXAMPLE, INTO GULLIES AND VALLEYS. THEREFORE, SCIENTISTS CAN PREDICT WHERE THE LAVA WILL TRAVEL. PREDICTING THE PATH OF A LAVA FLOW CAN HELP SAVE LIVES. THIS PICTURE OF A LAVA FLOW WAS TAKEN FROM THE PU'U 'O'O-KUPAIANAHA ERUPTION IN HAWAII.

FIGURE **11.8**

PHOTO: U.S. Geological Survey

OVER TIME, THE SURFACE OF A LAVA FLOW COOLS AND HARDENS INTO NEW ROCK. THE COOLED LAVA IN THIS PHOTO CRACKED WHEN HOT LAVA FLOWING BENEATH IT PUSHED UP ON ITS BRITTLE SURFACE.
FIGURE **11.9**

PHOTO: Pierre Guinoiseau/creativecommons.org

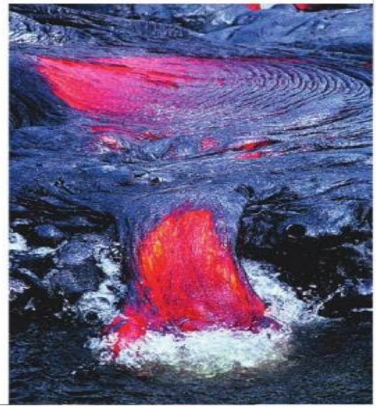


SOMETIMES MAGMA RETREATS OR ERUPTS FROM A SHALLOW, UNDERGROUND MAGMA CHAMBER. WITHOUT THE MAGMA TO SUPPORT THE GROUND ABOVE IT, THE OVERLYING ROCK COLLAPSES AND FORMS A LARGE, STEEP-SIDED, CIRCULAR OR OVAL VOLCANIC DEPRESSION, CALLED A CALDERA. (A CALDERA IS NOT A CRATER, WHICH IS SMALLER AND FORMS WHEN ROCK EXPLODES FROM THE VOLCANO DURING AN ERUPTION.)
FIGURE **11.10**

PHOTO: U.S. Geological Survey

SOME LAVA COOLS TO FORM A SKIN OR BLACK BASALT ROCK THAT IS WRINKLED BY THE HOT LAVA STILL FLOWING UNDER IT. IT HAS A SMOOTH, ROPY TEXTURE AND IS TYPICAL OF THE LAVA FLOW IN HAWAII.

PHOTO: U.S. Geological Survey/photo by J.D. Griggs
FIGURE **11.11**



SOMETIMES LAVA OOZES INTO THE OCEAN AND COOLS ON CONTACT WITH THE WATER. THIS IS ONE WAY THAT PILLOW LAVA FORMS.

PHOTO: U.S. Geological Survey/photo by J.D. Griggs

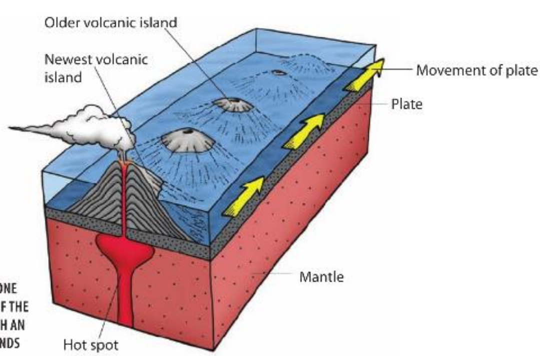
FIGURE **11.12**

AN ISLAND IS BORN

The explosion of an underwater volcano 32 kilometers (20 miles) south of Iceland in November 1963 gave scientists a rare chance to observe the formation of new land—the island of Surtsey. The first sign of island formation was smoke emerging from the North Atlantic. A fisherman thought this smoke was a ship in trouble, but it was actually the birth of an island.

Surtsey was formed by a volcano that erupted in relatively shallow water, about 130 meters (427 feet) deep. Like Iceland, Surtsey formed over an unusually hot region of the mantle, called a hot spot. A hot spot is a localized zone of melting in the mantle that is fixed in the mantle under the plate. Volcanoes form above the hot spot. The Hawaiian Islands also formed over a hot spot.

The hot spot below Surtsey is located in a region that happens to a coincide with the Mid-Atlantic Ridge. This is why a great volume of lava flows from the vents of Iceland. During the Surtsey eruption, hot magma shot upward into the ocean waters and outward in horizontal blasts, causing the island to grow out as well as up. The final eruptions were lava flows that were harder and more compact than earlier ash deposits. In just a few weeks, the lava flows had created a hard curst that protected the island from washing away immediately, and an island was born.



A HOT SPOT IS A LOCALIZED ZONE OF MELTING IN THE MANTLE. IF THE HOT SPOT IS LOCATED BENEATH AN OCEAN PLATE, VOLCANIC ISLANDS CAN FORM.

THE LAVA THAT FLOWED DURING THE SURTSEY ERUPTION BEGAN FROM A SHALLOW, UNDERWATER VOLCANO.

PHOTO: University of Colorado, Boulder, CO/National Geophysical Data Center/NOAA

WITHIN A FEW DAYS, THE NEW ISLAND OF SURTSEY HAD FORMED.

PHOTO: Photographer Howell Williams/National Geophysical Data Center/NOAA

Discussion Questions:

1. *Like Surtsey, the Hawaiian Islands are formed by a hot spot. As they drift away from the hot spot because of the movements of the Pacific Plate, what do you think happens then?*
2. *Other than from hot spot volcanoes, what are some other ways that islands can form? Use internet and library resources to gather additional information, if necessary.*

Volcanologists Talk About Their Work

A VOLCANOLOGIST COLLECTS SAMPLES FROM A STILL-MOLTEN LAVA FLOW.
PHOTO: U.S. Geological Survey

Q: What is it like to work on volcanoes?
A: Volcanoes are beautiful places where forces of nature combine to produce awesome events and spectacular landscapes. For most of us, they are also fun to work on! There's something moving about the idea of magma rising from deep inside our restless planet to flow gracefully onto its surface, as in Hawaii, or to explode violently onto its atmosphere, as at Mt. St. Helens. As one scientists put it, "I'm fascinated by the knowledge that some of the gases I breathe were once miles deep in the earth and arrived in my lungs by way of a volcano." Perhaps no spot on earth is untouched by the effects of volcanoes. In fact, more than half of the earth's surface is covered by volcanic flows, especially the seafloor. All forms of life on earth are linked in some way to volcanic activity. With this in mind, what could be more exciting or rewarding than to work on an active volcano?

Q: Are you scared when you work on an active volcano?
A: "Excited" is the first word that comes to mind when most of us think about our work at active volcanoes. Safety is always our primary concern, because volcanoes can be dangerous places. But we manage personal risk in the same way as police officers, astronauts, or those in any other hazardous professions. We try hard to understand the risk that is built into any situation. Then we train and equip ourselves with the right tools and support to be safe. Such training involves learning the past and current activity of the volcano, first aid, helicopter safety procedures, and wilderness survival techniques. Some of us, however, have experienced situations that we more than exciting. In the words of one scientist, "Scared? Oh sure. When a little steam explosion occurred from the dome at Mt. St. Helens in 1982, three of us were surveying the dome from less than 100 meters (328 feet) away. As soon as we saw the basketball size rocks streaming through the air, we ran for cover beneath a huge block of ice on the crater floor. Until the rocks stopped landing all around us, I was absolutely terrified."

VOLCANOLOGISTS REPAIRING EQUIPMENT AT A SEISMIC STATION ON REDOUBT VOLCANO, ALASKA

PHOTO: U.S. Geological Survey/Alaska Volcano Observatory/photo by Game McGimsey

Q: How about when the volcano is showing signs of activity and you have concluded the volcano is likely to erupt soon?
A: This is the most anxious time, because generally there is nothing more to be done than wait, watch, and hope that your team is right in its assessment of the situation. With modern monitoring instruments, an active volcano can seem almost overwhelming at this stage. Earthquakes can happen virtually nonstop for hours or days. Swelling or cracking of the ground occurs at rates that keep going up and up. And changes happen in the kinds and amounts of volcanic gases being released. Even so, there are always uncertainties, including the very real possibility that the process will simply stop before magma reaches the surface, and you will be asked to explain why there was so much fuss over a "failed eruption."

Q: What precautions do scientists take?
A: restless volcanoes can be very dangerous places, but it is possible to work safely around them if you are properly prepared. First and foremost, scientists protect themselves by working as a team to create a safety net in which all the important bases are covered. Like a professional driving team, a volcano-response team includes key staff who know the monitoring equipment extremely well. They include experts in several scientific disciplines who can interpret data from the field.

Q: What education do you need to become a volcanologist?
A: There are many paths to becoming a volcanologist. Most volcanologists have a college or graduate school education in a scientific or technical field, but the range of specialties is very large. Training in geology, geophysics, geochemistry, biology, biochemistry, mathematics, statistics, engineering, atmospheric science, remote sensing, and related fields can be applied to the study of volcanoes and the interactions between volcanoes and the environment. The key ingredients are a strong fascination and boundless curiosity about volcanoes and how they work. From there, the possibilities are endless.

IN OREGON, A SCIENTIST GENERATES ELECTRONIC DISTANCE MEASUREMENT (EDM) LINES WHILE THE HELICOPTER MEASURES AIR TEMPERATURE ALONG THOSE LINES TO MONITOR VOLCANOES FOR POTENTIAL ERUPTIVE ACTIVITY. THESE TECHNIQUES CAN DETECT MINOR SWELLING AND HEATING THAT OFTEN PRECEDE ERUPTIONS.

PHOTO: U.S. Geological Survey/Cascades Volcano Observatory/photo by Lyn Topinka

Discussion Questions:

1. *What qualities must a volcanologist have in order to be successful?*
2. *Do you think it is possible to work on the science of volcanoes without walking on active volcanoes? If so, how?*

Lesson #12: Viscosity and Volcano Types

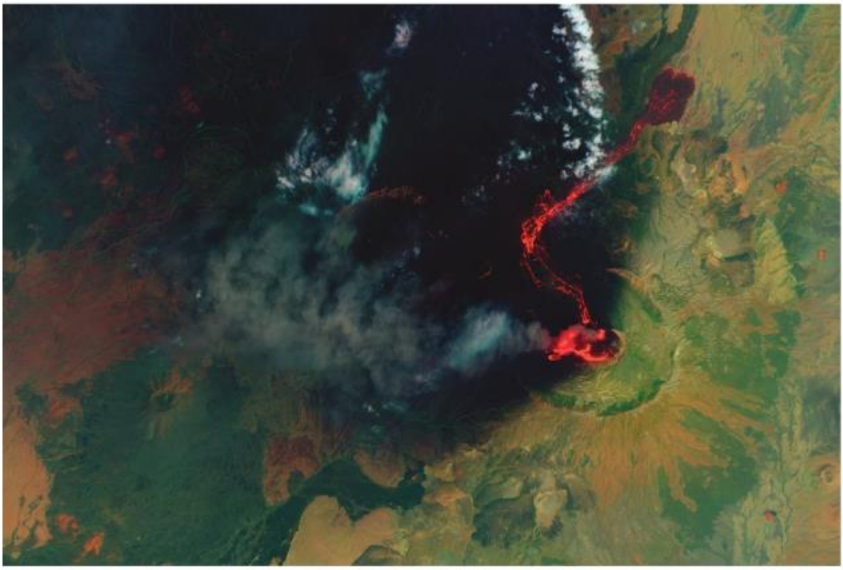
THIS PHOTO, TAKEN IN 1947 IN PARICUTÍN, MEXICO, SHOWS AN ERUPTION OF THE PARICUTÍN VOLCANO AT NIGHT. GLOWING HOT, BROKEN ROCKS OUTLINE THE SHAPE OF THE VOLCANO, CALLED A CINDER CONE.

PHOTO: U.S. Geological Survey

Introduction-

When a volcano erupts, a mixture of red-hot lava, rocks, and gases burst into the atmosphere. Some volcanoes spew runny lava onto the earth's surface; this lava flows freely over wide areas. Other volcanoes ooze sticky lava that flows only a short distance.

In Lesson 11, you learned that magma is melted rock beneath the earth's surface, and that when it reaches the earth's surface, it is called lava. The way in which magma and lava flow and whether fragments of lava and rock erupt from the volcano affect a volcano's shape and size. In this lesson, you will design an investigation to test how liquids flow and the conditions under which this flow changes. You will then relate your observations to lava flow and volcano type.



LAVA FLOWS FROM THE NABRO VOLCANO IN EAST AFRICA. THIS VISIBLE AND INFRARED LIGHT IMAGE SHOWS HOT LAVA AS ORANGE-RED AND COOLING LAVA FADING TO BLACK.

PHOTO: NASA Earth Observatory image by Robert Simmon, using EO-1 ALI data

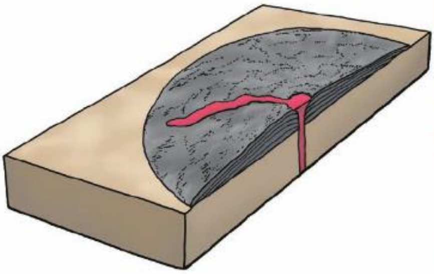
VOLCANO TYPES

Scientists classify volcanoes into three basic categories on the basis of shape and size. Let's take a closer look at these types of volcanoes.

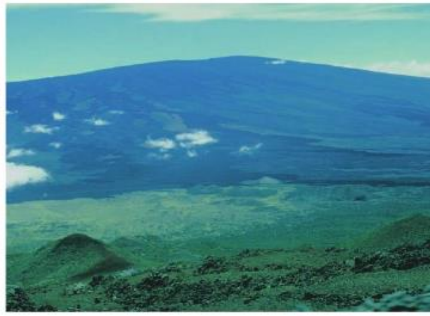
Shield Volcanoes: While many people think of volcanic eruptions as being explosive, many volcanic areas produce quiet, oozing lava. Fissures and hot spots are two examples. Fissures are long fractures in the earth's crust. Instead of erupting from one central vent, or opening, lava erupts gently like a fountain from the fissure in a long line. Fissures normally form in areas where two plates separate, such as along a mid-ocean ridge.

Like fissures, hot spots produce quiet eruptions. Most hot spots form under a plate instead of along its boundaries. Other hot spots coincide with mid-ocean ridges. Both fissures and hot spots produce runny lava that spreads out to form a wide, broadly sloping volcano. These volcanoes are called shield volcanoes because they resemble a warrior's shield. The slopes of a shield volcano are rarely steep; these volcanoes are wide and flat. Over thousands of years, shield volcanoes can reach massive size, for example, 9 kilometers (5.6 miles) high and 193 kilometers

(120 miles) wide. The Hawaiian Islands and Iceland are examples of shield volcanoes.



THIS CROSS-SECTION SHOWS HOW REPEATED LAYERS OF FLOWING LAVA FORM SHIELD VOLCANOES.



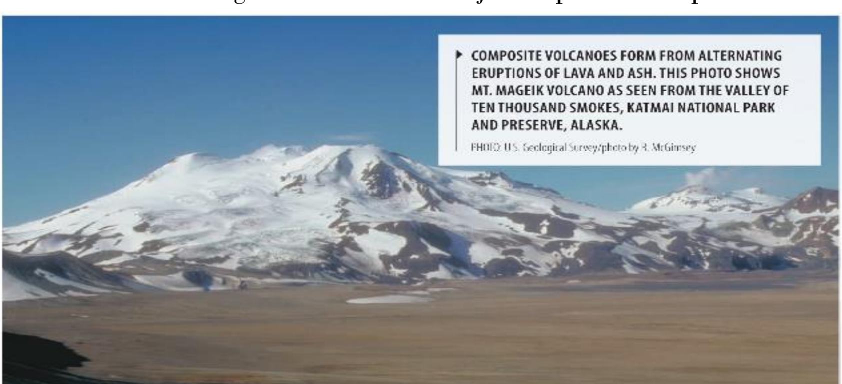
SHIELD VOLCANOES ARE FLAT ON TOP AND BROADLY SLOPING. THIS PHOTO SHOWS MAUNA LOA, A SHIELD VOLCANO IN HAWAII.

PHOTO: U.S. Geological Survey/photo by D. Little

Composite Volcanoes: Composite volcanoes are tall and pointed. They are some of the most picturesque volcanoes in the world because of their height and snow-capped summits. They form from alternating eruptions of lava and ash. A composite volcano is flat toward the base and steep toward the summit. The lava is sticky and does not flow before it solidifies.

These tall volcanoes usually form where two plates collide and one overrides the other. Thick magma and water from the sinking oceanic plate cause the volcano to be explosive. Water dissolves within the magma and travels upwards as small bubbles, like the bubbles in a carbonated soft drink. When the magma explodes from the volcano, it breaks the lava and rocks along the vent into pieces. Alternating layers of lava and fragmented rock pile up. Mt. St. Helens in Washington state and Mt. Fuji in Japan are composite volcanoes.

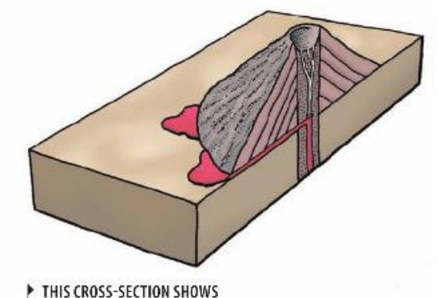
THIS CROSS-SECTION SHOWS HOW ALTERNATING LAYERS OF CINDERS AND LAVA FORM A COMPOSITE VOLCANO.



COMPOSITE VOLCANOES FORM FROM ALTERNATING ERUPTIONS OF LAVA AND ASH. THIS PHOTO SHOWS MT. MAGEIK VOLCANO AS SEEN FROM THE VALLEY OF TEN THOUSAND SMOKES, KATMAI NATIONAL PARK AND PRESERVE, ALASKA.

PHOTO: U.S. Geological Survey/photo by R. McGimsey

Cinder Cone Volcanoes: Cinder cone volcanoes are smaller than shield and composite volcanoes. If the eruption contains thick magma, the gas pressure shatters the rock within the volcano into small pieces. In other cases, the lava in the air may harden and fall as fragments. These small pieces are called cinders. These cinders accumulate around the opening, or vent, of the volcano. These volcanoes tend to be explosive, which is why the rock breaks into fragments. Cinder cones can also ooze lava at the base of the cone. Eldfell in Iceland and Sunset Crater are cinder cone volcanoes.



THIS CROSS-SECTION SHOWS HOW LAYERS OF CINDER FORM A CINDER CONE.

CAPULIN MOUNTAIN IN NEW MEXICO IS A HUGE CINDER CONE VOLCANO. ITS CONE IS MORE THAN 300 METERS (ABOUT 1000 FEET) ABOVE ITS BASE.

PHOTO: U.S. Geological Survey/photo by R.D. Miller

Discussion Questions:

1. *Why are composite volcanoes so tall?*
2. *What could make some lava more viscous than other lava?*

LAVA IN MOTION

What is 61 meters (200 feet) across, moves up to 64 kilometers (40 miles) per hour, and can destroy 14 villages?

LAVA!

On January 17, 2002, people living in the city of Goma in the Republic of Congo awoke to a startling reality. The sky was dark with falling ash, and three streams of red-hot lava were racing down the slopes of Mount Nyiragongo towards their homes. All the people could do was get out of their houses and run until they crossed the nearby Rwandan border. While the volcanic event lasted only two days, thousands of people returned to find their homes burned to the ground.

The Nyiragongo volcano is a stratovolcano (also called a composite volcano), the same type as Mt. St. Helens and Eyjafjallajökull. It's a steep-sided type of volcano that normally produces a viscous, slow-flowing lava, rich in silica. The Nyiragongo volcano, however, happens to have unusually thin, fast-flowing lava. At the top of Nyiragongo is a crater containing a lake of steaming lava; in the 2002 disaster, leaks in the side of the volcano widened into three fissures through which the pooled lava poured out.

The Nyiragongo volcano also erupted in 1977 and 1994. Given the timing of these events, what is your prediction for the date of the next eruption?

The Volcano Lovers

French geologists Maurice and Katia Krafft loved watching volcanoes erupt. They were so fascinated by these powerful forces of nature that watching volcanoes became their life's work. For over 20 years, they witnessed more than 140 eruptions—on every continent except Antarctica.

The Kraffts not only watched these eruptions, but they also took close-up pictures of them. They put themselves at great risk by getting close to volcanoes to understand them better. They knew the dangers of the fiery molten lava and scalding clouds of ash.

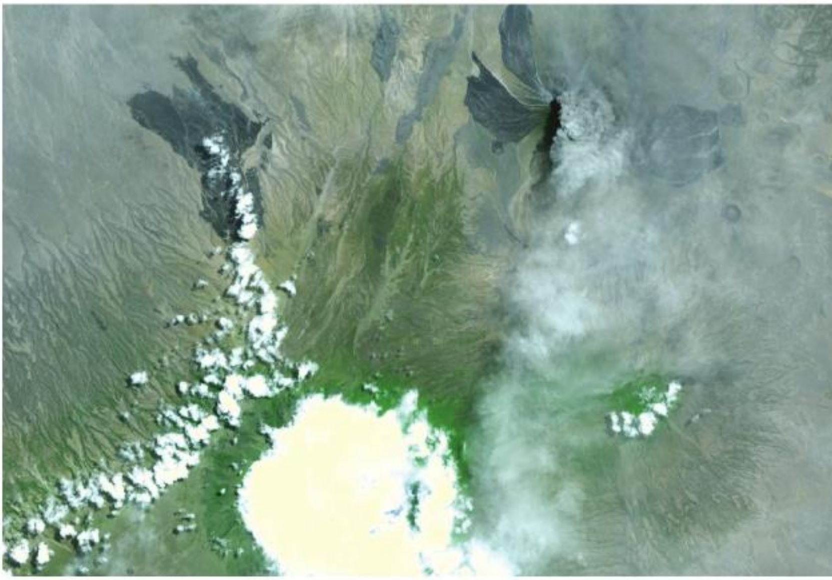
Maurice and Katia met during the 1960's while they were studying geology at the same university in France. Their passion for volcanoes brought them together. In 1968, after they were married, they founded a center for volcanology. ("Volcanology" is the study of volcanoes.) Their goal was to take measurements of molten lava, to analyze volcanic gases, and to record volcanic eruptions on film.

Through books and lectures, the Kraffts raised enough money to support their expeditions. As soon as they heard about an eruption anywhere in the world, they packed and boarded the next plane. In an average year, they visited about three big eruptions. In 1988, when volcanoes seemed to be erupting everywhere, the Kraffts circled the globe several times.

The films made by the Kraffts reveal the beauty and power of volcanic eruptions. The Kraffts picked up useful details that helped geologists understand volcanoes better. For example, they filmed molten lava that was black, instead of red, flowing from a volcano in the African country of Tanzania. No one knew about this kind of lava, which came from rock that melts at 500˚C (932˚F). The more common red lava comes from rock that melts at about 1000˚C (1832˚F).

Having witnessed hundreds of volcanic eruptions, the Kraffts were concerned about the danger of volcanoes when people living near them are not properly warned. For instance, when the Nevada del Ruiz volcano in Colombia, South America, started erupting volcanologist advised authorities of the danger to people living in nearby towns. Authorities did not believe that people living 47 kilometers (29 miles) away were in danger, and the scientists' warnings were not heeded. As a result, 22,000 people died in the mudflows caused by a later eruption. Had these people walked 20 meters (656 feet) to the nearest hill, Maurice said, they would have lived.

The Kraffts and others felt something had to be done to protect the 500 million people who live near the world's most active volcanoes, such as in Iceland. Maurice offered the best of his film footage, plus his knowledge of both volcanoes and cinematography, to make a video that would document the hazards of volcanoes.



OL DOINYO LENGAI IN TANZANIA IS THE ONLY KNOWN ACTIVE VOLCANO IN THE WORLD THAT SPEWS BLACK LAVA.

PHOTO: NASA image created by Jesse Allen, using data provided courtesy of NASA/GSFC/MET/ERSDAC/JAROS, and U.S./Japan ASTER Science Team. Image interpretation by Greg Vaughan, Jet Propulsion Laboratory

In June 1991, Maurice and Katia went to Unzen volcano in Japan. A deadly mix of hot gas, ash, and rock was surging down the volcano's upper slopes 35 times a day. It was the perfect chance for the Kraffts to film the flows and educate officials about the danger. Each time a chunk of lava near the summit broke away and began tumbling down, it shattered. The rock slide became a rock-and-ash stream that careened down the mountain at up to 100 kilometers (62 miles) per hour.

HOUSES ALONG THE MIZUNASHI RIVER WERE DESTROYED BY MUDFLOWS CAUSED BY UNZEN VOLCANO IN NORTHER KYUSHU.

PHOTO: U.S. Geological Survey/photo by T.J. Casadevall

THIS AERIAL VIEW OF UNZEN SHOWS THE PATH OF PYROCLASTIC FLOW EXPELLED BY THE VOLCANO. IT WIPED OUT OR FLOODED A LARGE SECTION OF SHIMABARA, A TOWN ON THE COAST BELOW.

PHOTO: U.S. Geological Survey/photo by T. Kobayashi, Univ. Kagoshima

At the point when the mountain was sending down medium-sized flows, Maurice and Katia were witnessing quite a show. Suddenly, a huge chunk of lava plunged toward them. They had not times to escape. The Kraffts, along with 49 other people, were killed.

Only two weeks later, because of the influence of the Kraffts' video, an evacuation saved an estimated 20,000 lives from a major eruption of Mt. Pinatubo, in the Philippine Islands. The work to which these two scientists devoted their lives continues to benefit people around the world. Through the films that the Kraffts made, the world can also share what they saw; the awesome beauty of a spectacular and deadly force of nature.

THE FIRST MAJOR ERUPTION OF MT. PINATUBO ON JUNE 12, 1991

PHOTO: U.S. Geological Survey/Cascades Volcano Observatory/photo by Richard P. Hoblitt

Discussion Questions:

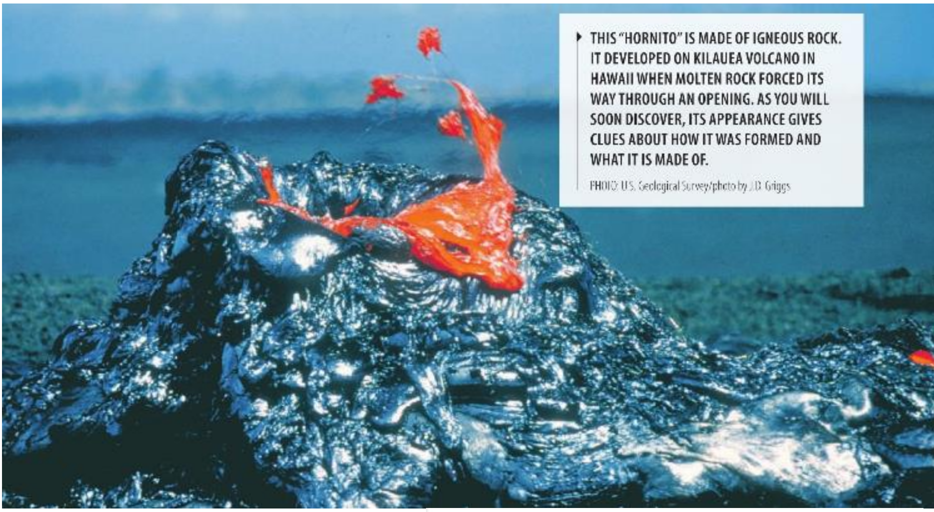
1. *Did you think it was wise for the Kraffts to have spent their lives documenting volcanoes, considering how dangerous it was?*
2. *Imagine you have been hired by the Japanese government to educate people about the dangers of area volcanoes. How will you do your job?*

Lesson #13: Igneous Rock

Introduction-

In some parts of the mantle, hot rock rises into the earth's crust and melts. When the melted rock eventually cools, either inside the earth or on the surface of the earth, it hardens. As it cools, its minerals form grains, which are called crystals. Rocks that form this way are called igneous, which comes from the Latin word for "fire."

In this lesson, you will examine five igneous rocks. You will analyze each rock's observable color, mineral composition, and texture (the size of its crystals). Your group will classify the rocks based on their properties.



THIS "HORNITO" IS MADE OF IGNEOUS ROCK. IT DEVELOPED ON KILAUEA VOLCANO IN HAWAII WHEN MOLTEN ROCK FORCED ITS WAY THROUGH AN OPENING. AS YOU WILL SOON DISCOVER, ITS APPEARANCE GIVES CLUES ABOUT HOW IT WAS FORMED AND WHAT IT IS MADE OF.

PHOTO: U.S. Geological Survey/photo by J.D. Griggs

THE GREEN ROCK YOU JUST OBSERVED IS MOSTLY MADE OF THE MINERAL OLIVINE, SHOWN HERE. OLIVINE HAS A CRYSTALLINE APPEARANCE, LIKE SALT. FOUR ELEMENTS—MAGNESIUM, IRON, SILICON, AND OXYGEN—CHEMICALLY COMBINE TO FORM OLIVINE. THE EARTH'S UPPER MANTLE CONTAINS A GREAT AMOUNT OF OLIVINE.

FIGURE **13.1**

PHOTO: NASA Ames Research Center, Tom Trower

MICA

FIGURE **13.3**

PHOTO: U.S. Geological Survey/Mineral Collection of Brigham Young University Department of Geology, Provo, Utah/photo by Andrew Silver

QUARTZ

FIGURE **13.4**

PHOTO: BobMacInnes/creativecommons.org

PINK FELDSPAR

FIGURE **13.5**

PHOTO: Wikimedia Commons

Igneous Rocks

Rocks formed by cooling magma or lava are called igneous rocks. Igneous rocks make up most of the ocean floor and continental crusts. These rocks are classified based on their texture, or crystal size, and their composition.

When rocks cool from magma, we call them intrusive igneous rocks. They're called "intrusive" because they form when magma forces its way, or intrudes, into layers of rock in the earth's crust. The rocks form by cooling slowly under the earth's crust. Because of the slow cooling time, large crystals have time to form, organizing layer over layer (consider how rock candy is able to grow large sugar crystals when a string is left in a sugar solution for days). These igneous rocks are also are also called plutonic rocks, after Pluto, the Roman god of the underworld.

Igneous rocks that cool from lava are called extrusive igneous rocks. A substance extrudes when it oozes out; for example toothpaste extrudes from the tube when you leave the cap off. When lava oozes out throughout the earth's crust, we say it "extrudes." Because it's exposed to the air, the lava cools relatively quickly, and the rocks formed from it have small crystals.

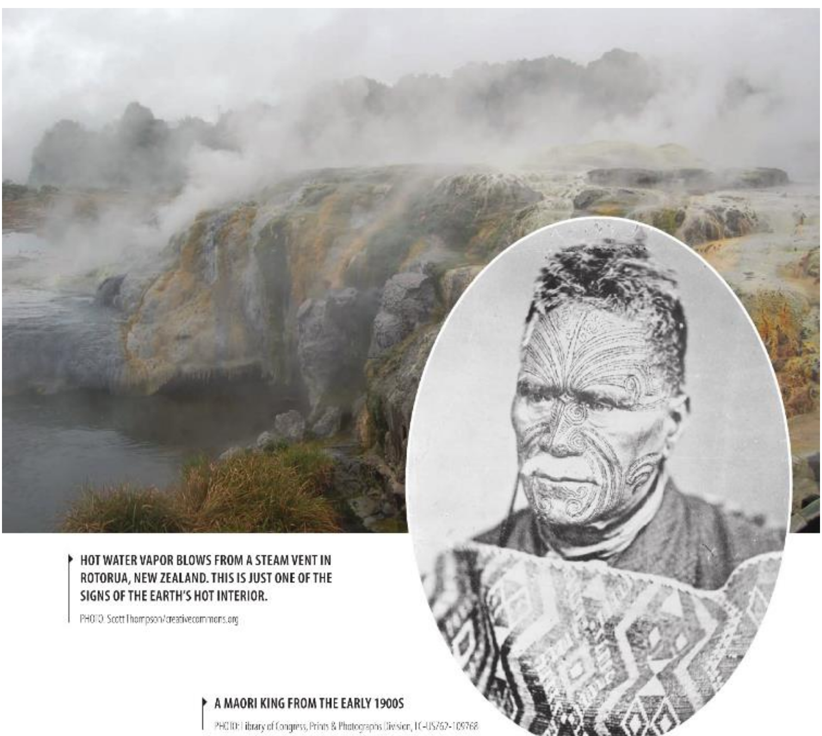
Igneous rocks are made of a mixture of naturally occurring minerals. Rocks can vary widely in their composition, but, like a baker's case of cookies and cakes, they all tend to be made from the same ingredients. In baked goods, the proportions of eggs, flour, butter, and so on vary from confection to confection; in different rocks, the proportions of various mineral differ. Some igneous rocks, for example, contain more iron and magnesium than others. These rocks tend to be dense and dark in color. Other igneous rocks contain more silica, the same material that glass if often made from. These rocks tend to be less dense and lighter in color.

The way these rocks form-quickly or slowly, under more or less pressure-and their composition determines their properties; hardness, brittleness, magnetic qualities, color, and so on. These qualities, in turn, determine how we can use the rocks. The composition of rocks also determines whether they will be part of the lower, denser ocean floor or the higher, less dense continental crust.

Under special conditions, rocks containing large amounts of copper, silver, and gold form. We call such rocks metal ores, or ore bodies. Under other conditions, veins containing diamonds and other gemstones crystallize. Conditions that form ore bodies and veins happen only inside the earth's crust. Obsidian, on the other hand, cools very quickly at the earth's surface, which allows no crystals to form. Before the invention of lasers, obsidian scalpels were used in eye surgery because their blades were shaper and harder than steel.

New Zealand, a large island country in the southwestern Pacific Ocean near Australia, is almost always blowing off steam. If volcanoes aren't exploding, then hot springs, geysers, and boiling lakes are fuming. When the British came to explore New Zealand, they found a people called Maori living there. The Maori like to tell stories. One Maori tale, "How Volcanoes Got Their Fire," tells how fire came to volcanoes in New Zealand. IN another tale, "Battle of the Giants," volcanoes act like giant people.

How Volcanoes Got Their Fire: A powerful medicine man named Ngatoro led his people from Hawaii to New Zealand in canoes. After they arrived, Ngatoro took his female slave, Auruhoe, and climbed the volcano Tongariro. He asked the rest of his people to stop eating until he and Auruhoe returned. He believed this would give him strength against the cold air high on the mountain. Ngatoro and his slave stayed longer than expected. His people got hungry and began eating again. When that happened, Ngatoro and Auruhoe felt the freezing cold. Ngatoro prayed to his sisters back in Hawaii to send fire to warm them. The sisters heard his cry for help and called up fire demons who began to swim under water toward New Zealand. When the fire demons came up at White Island to find out where they were, the earth burst into flames. The demons reached the mainland and continuedto travel underground toward Tongariro. Wherever the fire demons surfaced, hot water spewed from the earth and formed a hot spring or geyser. Finally, the fire demons burst out of the top of Tongariro. Their fire warmed Ngatoro and helped save his life, but Auruhoe was already dead from the cold. To remember the journey of Ngatoro and Auruhoe, the Maori called the mountain Ngauruhoe.



HOT WATER VAPOR BLOWS FROM A STEAM VENT IN ROTORUA, NEW ZEALAND. THIS IS JUST ONE OF THE SIGNS OF THE EARTH'S HOT INTERIOR.

PHOTO: Scott Thompson/creativecommons.org

A MAORI KING FROM THE EARLY 1900S

PHOTO: Library of Congress, Prints & Photographs Division, LC-USZ62-109768

ACCORDING TO THE LEGEND, MT. RUAPEHU GOT ITS BROKEN-UP TOP FROM THE STONES THAT WERE HURLED AT IT BY THE VOLCANO TARANAKI.

PHOTO: Felipe Skroski/creativecommons.org

MT. TONGARIRO IS LOCATED IN TONGARIRO NATIONAL PARK IN NEW ZEALAND.

Battle of the Giants: Three volcanoes-Taranaki, Ruapehu, and Tongariro-lived near each other. Taranaki and Ruapehu both fell in love with Tongariro, but she could not decide which one she preferred. Finally, they decided to fight for her. Tearing himself loose from the earth, Taranaki thrust himself at Ruapehu and tried to crush him. "I'll get you," fumed Ruapehu. He heated the waters in his crater lake until they were boiling. Then he sprayed scalding water over Taranaki and on the countryside around him. The scalding bath hurt Taranaki badly. Furious, he hurled a shower of stones at Ruapehu. He swallowed his broken cone, melted it, and spat it at Taranaki. The molten cone burned Taranaki badly, and he ran to the sea to cool his burns.

For a long time, when Tongariro erupted, the warlike tribes of the area saw it as a sign that they should act like the quarreling giants in the myth, and they made war with each other. Today, the Maori are still afraid that Taranaki will awaken and begin fighting again. They refuse to live or be buried anywhere on a line between Taranaki and the other two peaks. They may be right, Taranaki, 2400 meters (7874 feet) high and snow capped, last erupted only 300 years ago. In their stories, the Maori were probably describing events that they had seen. When a volcano erupts, the top of the mountain sometimes blows off or collapses into the crater. Such an event was probably the basis of the story about Ruapehu's broken cone. Scientists have also shown that the path of lava that flowed from Taranaki to the sea formed New Zealand's Wanganui River Valley.

Discussion Questions:

1. ***Why do people tell stories "How Volcanoes Got Their Fire?" Are non-scientific stories that explain catastrophic events useful?***
2. ***What sorts of volcanic events might people have been describing in the telling of "Battle of the Giants"?***

Lesson #14: Volcanic Ash

Introduction-

When magma forcefully erupts from a volcano, it can shatter into billions of fragments. These pieces can be as small as dust particles of as large as trucks. The fragmented materials include rocks, minerals, and broken pieces of volcanic glass. When the broken pieces are fine grained, the material is called volcanic ash.

Most people think of a volcanic eruption as fiery streams of red lava and glowing rock. Lava flows can pose great danger to people. They may cover the land and can even set buildings or trees on fire. Lava flows, however, are actually the least dangerous part of a volcanic eruption. Most lava flows do not move particularly fast. And because they are fluid, they tend to flow along low-lying areas. This means that predicting the path of the lava is fairly easy. Although property will be destroyed, areas likely to be affected by the lava can be evacuated.

Ash from violent eruption, in contrast, often poses great environmental and personal dangers. During an ash fall, the ash that has been ejected into the atmosphere settles back to the earth over a wide area. The ash may cover everything it falls on, smothering crops and coating people's lungs. Or it can erupt into the atmosphere, blocking sunlight, and making daylights turn to darkness. Ash can also move over the ground or close to it in clouds of ash and gas. These clouds, which move like raging rivers, sometimes move at more than 400 kilometers (249 miles) per hour. Melted glaciers, snow, and rain-soaked soils mix with the ash. These mudflows of ash flow down the mountainside, hugging the ground.

In this lesson, you will examine rock fragments that make up volcanic ash and model an ash fall. You will investigate how different-sized volcanic materials erupt into and settle out of the air. You will then discuss how an ash fall can affect the atmosphere, weather, the land, and people and animals.

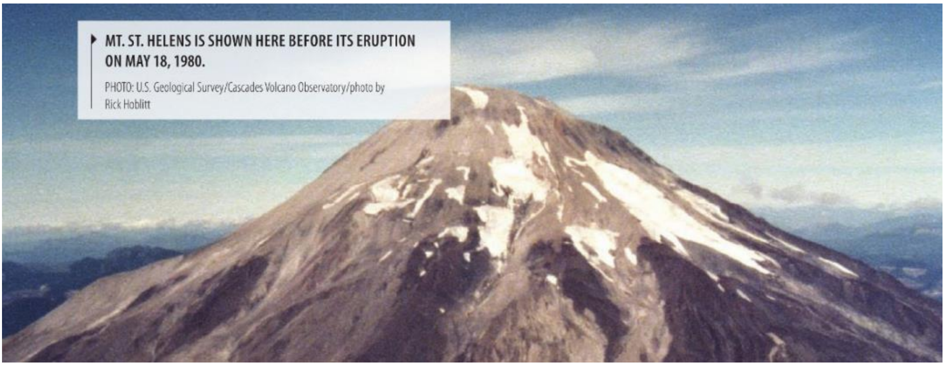
Mt. St. Helens Erupts

On May 18, 1980, a tremendous volcanic eruption occurred in Washington state. Mt. St. Helens, in the Cascade Range, “blew its top.”

Months before the eruption, scientists had observed many signs that the mountain was about to blow. A large bulge on the north face of the mountain kept growing, which was a sign that the magma was rising. On March 20, 1980, an earthquake shook the area. It measured 4.1 on the Richter scale. One week later, a series of explosions began that sent fragmented old volcanic rock and steam into the air. These earthquakes, together with periodic venting of rock and steam, continued for weeks. Sulfuric acid levels rose in local ponds and streams, and hydrogen sulfide odors increased dramatically.

On May 18, 1980, an earthquake that registered 5.0 on the Richter scale triggered the collapse of the bulging north side of the mountain, causing a volcanic landslide. The decrease in pressure on the magma chamber caused a violent release of steam and lava. As bubbling lava rose in the air, it solidified instantly. A fine ash cloud rose 19 kilometers (12miles) above the volcano, as shown in the photo.

Ash fell several meters deep in areas close to Mr. St. Helens, while prevailing winds drove the cloud to the east-northeast. Communities as far away as 800 kilometers (about 500 miles) were blanketed by ash. In Yakima, Washington, 130 kilometers (81 miles) to the east, the ash fall caused almost total darkness at midday. Nearly 1 billion tons of ash were deposited over a huge area. Acid droplets from the eruption remained suspended in the atmosphere for as long as two years.



MT. ST. HELENS IS SHOWN HERE BEFORE ITS ERUPTION ON MAY 18, 1980.

PHOTO: U.S. Geological Survey/Cascades Volcano Observatory/photo by Rick Hoblitt

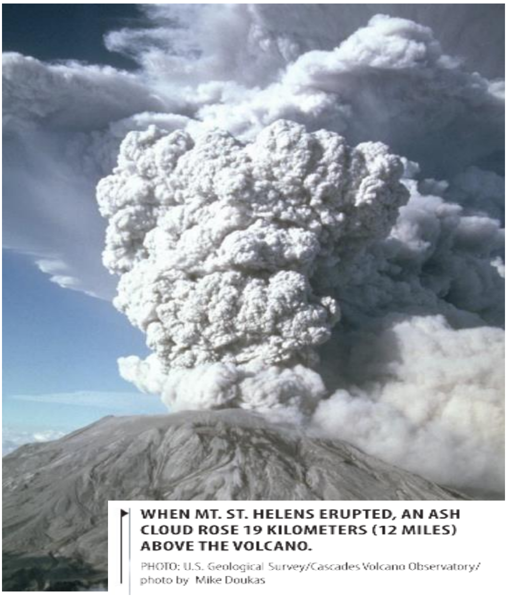
Flows of hot gases and volcanic ash more dense than air raced down the north side of the mountain. This heavy ash flow destroyed everything in its path. It caused steam explosions when it encountered bodies of water or moist ground. These explosions continued for weeks; one even occurred a year later.

Heat from eruption melted snow and glaciers, which mixed with ash on the upper slopes of the mountain and formed a thick volcanic mudflow. Like an avalanche, the mudflow displaced water in lakes and streams and caused flooding downstream.

The volcano’s warning signs had allowed scientists to warn government agencies which closed much of the area to tourists and restricted the activity of residents. Sadly, however, 63 people died as a result of the eruption, most of them because they ignored the evacuation advice.

The eruption of Mt. St. Helens left a large crater. Five more explosive eruptions occurred during 1980, and the volcano continued to erupt through 1986.

These successive eruptions created a lava dome on the floor of the crater. Today, eruptions appear to be over. But Mt. St. Helens is the most frequently active volcano in the Cascade Range, and scientists anticipate the volcano will erupt violently again.



WHEN MT. ST. HELENS ERUPTED, AN ASH CLOUD ROSE 19 KILOMETERS (12 MILES) ABOVE THE VOLCANO.

PHOTO: U.S. Geological Survey/Cascades Volcano Observatory/ photo by Mike Doukas

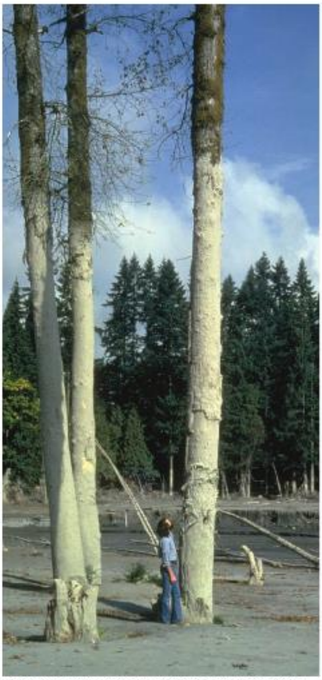
Monitoring the Volcano's Warning Signs: Scientists at the U. S. Geological Survey monitor Mt. St. Helens in order to predict future eruptions. In the photo on page 198, geologists use a steel tape to measure the distance across a crack in the volcano's crater floor. Widening cracks indicate that magma is rising, deforming the area, and leading to an eruption. These cracks usually extend outward from the lava dome, like the spokes of a wheel.

Geologists use a tiltmeter to electronically measure changes in the slope of the crater floor, which are caused by moving magma. Tiltmeters allow 24-hour monitoring. The information collected from these instruments is relayed to the volcano observatory.

Scientists also place seismographs at stations near the lava dome to monitor earthquake activity. And increase in the number of earthquake vibrations is often the first sign that a major eruption is approaching. Scientists also collect gas sample from the volcano. They place gas sensors around vents and near the lava dome and crater floor. Specially equipped airplanes measure sulfur dioxide gas, which usually increases 5- to 10-fold during an eruption.

PLUMES OF STEAM, GAS, AND ASH, WHICH ROSE 1000 METERS (ABOUT 3280 FEET) INTO THE AIR, ERUPTED FROM THE CRATER. SOME PLUMES WERE SEEN FROM PORTLAND, OREGON, 81 KILOMETERS (50 MILES) TO THE SOUTH.

PHOTO: U.S. Geological Survey/Cascades Volcano Observatory/photo by Lyn Topinka



NEARLY 220 KILOMETERS (137 MILES) OF RIVER CHANNELS SURROUNDING THE VOLCANO WERE AFFECTED BY MUDFLOWS. A MUD LINE ON THE TREES SHOWS THE DEPTH OF THE MUD.

[illegible]

Signs of Renewal: Plant and animal life returned to Mt. St. Helens. As early as the summer of 1980, new vegetation began to appear. Many small trees and plants, which had been protected during the eruption by packed snow, re-emerged after snowmelt. Seeds carried by the wind or by animals landed in the area and sprouted on the lava–covered ground. By 1985, new growth covered all the ridges surrounding the volcano. During the May 1980 eruption, many small animals-such as gophers, mice, frogs, fish, and insects-were protected from the blast because they were below ground or underwater. Many large animals, such as bear, elk, deer, and coyotes, were killed in the eruption, but with the return of a food supply, they have repopulated the region.

SCIENTISTS USE A STEEL TAPE TO MEASURE THE CHANGES IN THE CRACKS ON THE CRATER FLOOR.

PHOTO: U.S. Geological Survey/Cascades Volcano Observatory/photo by Lyn Topinka

Future Eruptions? Several other mountains in the Cascade Range (see map) pose a threat to populated area. Eruptions of Mr. Shasta in northern California would cause damage and perhaps fatalities to several nearby communities. Mt. Hood, in Oregon, lies less than 65 kilometers (40 miles away from the densely populated city of Portland. Probably the most dangerous eruption would be from Mt. Rainier, one of which completely covered an area that is now populated by 120,000 people. No one can predict when another mudflow from M. Rainier might take place or when any of these Cascade mountain volcanoes might "wake up." With continued monitoring and emergency evacuation plans in place, scientists and public officials hope everyone will be ready when the next volcano blows its top.

MAP OF THE CASCADE RANGE

GEOLOGISTS COLLECT GAS SAMPLES AROUND THE DOME OF THE VOLCANO.

PHOTO: U.S. Geological Survey/Cascades Volcano Observatory/photo by Thomas J. Casadevall

FIREWEED IS ONE SPECIES OF PLANT THAT RETURNED TO MT. ST. HELENS.

PHOTO: U.S. Geological Survey/Cascades Volcano Observatory/photo by Lyn Topinka

Discussion Questions:

1. ***What characteristics made the 1980 eruption of Mt.St. Helens particularly dangerous to people and wildlife?***
2. ***What allowed most people to escape its destructive effects?***

VOLCANO IN A CORNFIELD

In the mid-1900s, a farmer named Dionisio Pulido lived with his family in the small town of Paricutin, Mexico. Pulido's farm was a few miles outside the town. He had owned it for 31 years. There was nothing unusually about this farm, except for a small depression in the cornfield. Pulido and his wife had tried to fill the depression several times, but it always came back. In fact, one local resident recalled that, 50 years earlier as a small child, he had played near the "small hole." He remembered hearing underground noises like falling rocks near the hole and felt a pleasant warmth" coming from it.

The year 1943 started off as usual in Paricutin. There were reports of small earthquakes in the area, but no one was too concerned. Earthquakes were common in these parts. So, on February 20, Pulido mounted his horse and set off as usual to prepare his fields for spring planting. Then something very unusual happened.

"I heard a noise like thunders during a rainstorm, but I could not explain it, for the sky above was clear and the day was so peaceful," he recalled.

THE VOLCANO IN PULIDO'S FIELD WAS LATER NAMED PARICUTÍN. HERE IS THE VOLCANO SHORTLY AFTER IT FORMED IN 1943.

PHOTO: K. Segerstrom, U.S. Geological Survey/National Geophysical Data Center/NOAA

Pulido soon noticed something else in his field: along with the depression, a crevice had opened up on the side of a hill. “Here is something new and strange,” he remembered thinking.

THE VOLCANO PARICUTÍN GREW QUICKLY.

PHOTO: U.S. Geological Survey

A few minutes later, he heard thunder again, and he saw the trees tremble. “It was then I saw how, in the hole, the ground swelled and raised itself up 2 or 2.5 meters (6.6 or 8.2 feet) high, and a kind of fine dust-gray, like ashes-began to rise up in a portion of the crack. Immediately, more clouds of dust began to rise, with a hiss or whistle, loud and continuous. A smell of sulfur filled the air. I became greatly frightened.”

When sparks ignited pine trees 23 meters (75 feet) from the jagged rip in the ground, Pulido raced back to his home.

Throughout the night, the volcano continued to grow. By midnight, hug incandescent bombs were hurling into the air with a roar. Lightning flashes appeared in the heavy columns of ash. In the morning when Pulido returned to his cornfield, he saw an amazing sight. A cinder cone-almost 2 meters (6.6

ASH FROM PARICUTÍN COVERED THE TOWN AND SURROUNDING FIELDS.

PHOTO: U.S. Geological Survey

feet) high-had formed where the depression and crevice had been. The cone was spitting out fumes, clouds of ash, and rocks with great violence. By midday, the cone was nearly 10-meter (33 feet) high and still growing. That night, a neighbor described the scene: "Stones rose to a height of 500 meters (1640 feet). They flew through the air to fall 300 to 400 meter (984 to 1312 feet) from the vent… on the plowed fields where I used to watch the cattle of my grandfather."

On the night of February 22, Ezequiel Ordonez, a Mexican geologist, arrived on the scene and recorded it officially: 'I was witnessing a sight which few other humans had ever seen, the initial stages of the growth of a new volcano!"

On the second day, the hill had grown to 30 meters (98 feet), and by the third day, it had grown to 60 meters (198 feet). On the sixth day, it was 120 meters (394 feet). By the end of one month, the cinder cone was 148 meters (486 feet) high.

But the volcano's size was not the real problem. The problem was ash and lava that poured out of it.

A FLOW OF BLOCK LAVA FROM PARICUTÍN IN 1994, WITH ASH-COVERED FIELDS IN THE FOREGROUND

PHOTO: U.S. Geological Survey

Lava flows broke through the sides and base of the cone. They deposited a mass of black, jagged rocks about 1 meter (3.3 feet) deep all over Pulido's farm. Then the lava began to advance toward the town. By June, the situation became desperate. Ash soon covered the town of Paricutin and the surrounding farms. Thousands of cattle and hundreds of horsed died from breathing the ash. When the seasonal rains resumed in May, the ash turned to muddy rain. The farms were ruined. Government officials and geologists agreed that the town had to be evacuated. Some residents waited until the lava was at their back door before reluctantly leaving. Pulido and his family were among those who had to leave their farms.

By the end of September, the town of Paricutin had disappeared. The river of molten rock and ash had set fire to it. Today, the ruins of Paricutin and much of the nearby countryside still lie buried beneath lava rock.

Discussion Questions:

1. *Why do you think the farmers around Paricutin were so reluctant to leave the site of the eruption?*
2. *If you had to figure out where a new volcano is likely to form, what sorts of things would you look for?*

ASH GOES INTERNATIONAL

On April 14, 2010, mass confusion reigned at airports in London. Travelers managing luggage, business equipment, and children arrived at the airports only find guards and airline staff directing thousands of would-be passengers away from the gates, away from the planes. A newspaper headline explained: "ALL FLIGHTS CANCELLED DUE TO ASH CLOUD FROM EYJAFJALLAJÖKULL."

It sounded like a joke, but it wasn't funny to stranded travelers who wondered how they would find their ways back home. Eyjafjallajökull (pronounced EY-ya-fyat-lah-YOH-kuht, or, according to *The New York Times,* "Hey, ya fergot La Yogurt") was a fissure in Iceland. Even as the world struggled to pronounce its name, it was perfectly clear that grounded travelers were in trouble. Authorities repeated the message: There was no knowing how long the airports might be closed.

THE ERUPTION OF EYJAFJALLAJÖKULL

PHOTO: NASA image by Jeff Schmaltz, MODIS Rapid Response Team

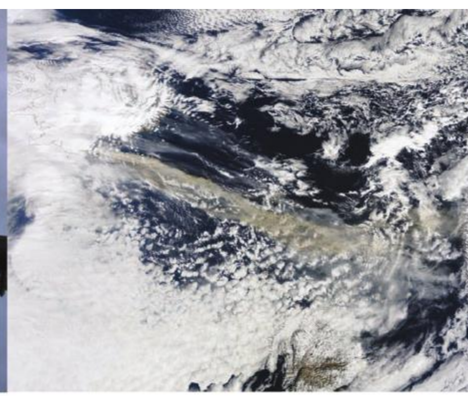
The eruption of Eyjafjallajökull actually began in March 2010, with fire fountains and lava flows, but not much ash. Then, with little warning, on April 14, new craters opened in the volcano and a giant ash plume of steam fine silica particles, and pulverized rock shot skyward. Carried by the jet stream, a fast moving current of air about 9000 meters (about 30,000 feet) above Earth's surface, the ash plume reached the airspace over mainland Europe within a day.

Airlines reacted quickly, cancelling all flights in and out of most European countries, including England, Scotland, Ireland, and France. While it was hard for scientists to determine how dangerous the material in the ash plume was, previous experience suggested that it might cripple airplanes engines. In 1989, a plane had lost power in its engines when it flew though a cloud from the eruption of Mr. Redoubt in Alaska. Engineers feared that particles of silica-a glasslike material found in sand, also known as silica dioxide-might be sucked into the hot engine, melt to form a glassy coating over engine parts and ventilation holes, and cause the engine to overhear or otherwise fail. The ash might also have damaged airplane windshields, making it tough for pilots to see out.

What made the volcano suddenly erupt so violently? The eruptive area lay beneath a glacier on Mt. Eyjafjallajökull, and the combination of the extremely hot magma and glacial ice proved explosive. Cold meltwater ran down into the volcanic vent and hit the magma whereupon the volcano erupted explosively, with steam shooting up and carrying liquid magma. But the glacial ice and meltwater also cooled the magma quickly, turning it into tiny, hard fragments. The eruption's heat also vaporized some ice, generating a powerful column of steam, which carried the ash (made of fragments of rock and silica) as high as 7300 meters (about 24,000 feet). The ash was then given a ride across the North Atlantic on the jet stream, which travels south and east from Iceland and over the European continent.

NATO PLANES LIKE THESE WERE USED TO DETERMINE THE EFFECTS OF THE ASH CLOUD ON AIRPLANE ENGINES.

PHOTO: DoD photo by Senior Airman Greg L. Davis, U.S. Air Force



A PLUME OF ASH FROM THE EYJAFJALLAJÖKULL ERUPTION MOVES SOUTHEAST OVER THE NORTH ATLANTIC OCEAN.

PHOTO: NASA image by Jeff Schmaltz, MODIS Rapid Response Team at NASA GSFC

As the ash spread over Europe, thousands of passengers were stranded. Ships, buses, and train filled up with people willing to pay extra to get home; they were missing important events, such as weddings, funerals, and the start of school. As no freight could travel, worries mounted about how to keep people supplied with food and medicines in Europe.

The North Atlantic Treaty Organization (NATO), an international military alliance, was asked to help. NATO sent some F-16 fighter jets through the ash cloud to see whether it might be possible for airlines to fly safely out. One of the plane's engines suffered glassy deposits from the fly-through, confirming that no commercial planes should fly until the ash cloud moved on.

But Europeans ad travelers were not the only victims of Eyjafjallajökull. Consider the Icelanders themselves. Many lived on farms near Eyjafjallajökull, which were suddenly flooded as meltwater poured off the volcano. Thanks to evacuations, no Icelanders were known to have died in the flooding, byt people returned to find their farms waterlogged and covered in ash.

Despite its powerful effects, the 2010 eruption of Eyjafjallajökull was mild compared to an eruption that occurred in Iceland a few centuries ago. On June 8, 1783, the crater of a fissure volcano called Laki burst open, freeing lakes of boiling lava. For nearly eight months lava spilled out, covering about 600 square kilometers (232 square miles) of countryside and killing about 10,000 people. A cloud of gases containing hydrofluoric acid and sulfur dioxide spewed out of the volcano and was carried over Iceland and to Europe on the winds. Unfortunately, sulfur dioxide reacts with water-even the water in human lung tissue-to form poisonous sulfuric acid. Tens of thousands of Europeans choked to death from inhaling the gases. A terrible winter followed, as Icelanders and their livestock died of sulfur and fluorine poisoning and famine. About a quarter of the population died. The winter was unusually hot; a lingering haze of ash and sulfur dioxide hung over Iceland and western Europe. Chroniclers of the time wrote that fresh-slaughtered meat had to be eaten immediately, because it would go bad by the next day.

Indeed, Iceland, sometimes called the land of fire and ice, is a highly volcanic place. It is part of the Mid-Atlantic Ridge (which you read about in Lesson 6), an area where magma is rising and plates are spreading. What is unusual about Iceland is that the ridge is above sea level, which means that violent eruptions are not buffered by the ocean.

There is concern that the 2010 eruption of Eyjafjalljökull forecasts a worse eruption of the nearby Katla volcano. Every time in history that Eyjafjallajökull has erupted, Katla has followed. Katla is larger, with a magma chamber ten times the size of Eyjafjallajökull's. And because Katla is beneath a huge glacier, an eruption could produce heaving flooding and an avalanche of giant chunks of ice. Scientists have been keeping a close eye on Katla for signs that it may erupt. Monitioring the effects of the Eyjafjallajökull eruption has allowed scientists to learn more about glaciovolcanoes (ice-covered volcanoes). While the volcanoes themselves are similar to other volcanoes, their interactions with the ice when they erupt make them unique.

Discussion Questions:

1. *Why did a volcanic eruption in Iceland close airports in Europe but not in North America?*
2. *Explain the statement "Every volcano is unique" and how this impacts our ability to predict and respond to volcanic eruptions.*

PASSERSBY HAVE USED LAVA ROCKS TO BUILD HUNDREDS OF "CAIRNS" (LANDMARKS MADE OF PILED ROCKS) ON A FARM IN ICELAND.

PHOTO: .mrMark:/creativecommons.org

Lesson #15: Exploring the Plate Tectonics Assessment

Introduction-

You have now finished your investigations of plate tectonics. During the next four periods, you will complete a two-part assessment. On the first day, you will review what you have learned in this unit. On the second day, you will complete Part A of the assessment. Your will design and carry out an investigation to test the effects of soils on building stability during an earthquake. Working individually, you will plan an investigation, record a plan, state the hypothesis, conduct the investigation, and record observations as they relate to the concepts and skills addressed in *Exploring Plate Tectonics*. On the third day, you will complete Part B, which is a set of multiple-choice and short-answer questions. On the fourth day, you will review the assessment and personally assess how well you have learned the concepts and skills in this unit.