Earthquakes

One of the most frightening and destructive phenomena of nature is a severe earthquake and the terrible after effects. An earthquake is a sudden movement of the Earth, caused by the sudden release of energy that has accumulated over a long period of time. For hundreds of millions of years, the forces of plate tectonics have shaped the Earth as the huge plates that form the Earth's surface slowly move over, under, and past each other. Sometimes the movement is gradual. At other times, the plates are locked together, unable to release the accumulating energy. When the accumulated energy grows strong enough, the plates break free. At this point, the plates are said to have reached their elastic limit. The **elastic limit** it the point just before the rocks break. If the earthquake occurs in a populated area, it may cause many deaths, injuries and extensive property damage.

Earthquakes in History

The scientific study of earthquakes is relatively new. Until the 18th century, few factual descriptions of earthquakes were recorded. The natural cause of earthquakes was little understood. Those who did look for natural causes often reached conclusions that seem fanciful today. One popular theory was that earthquakes were caused by air rushing out of caverns deep in the Earth's interior.

The most widely felt earthquakes in the recorded history of North America were a series that occurred in 1811-1812 near New Madrid, Missouri. A great earthquake, whose magnitude is estimated to be about 8 on the Richter Scale, occurred on the morning of December 16, 1811. Another earthquake occurred on January 23, 1812. A third earthquake, the strongest yet, occurred on February 7, 1812. Aftershocks were nearly continuous between these great earthquakes and continued for months afterwards. **Aftershocks** are vibrations in the Earth that occur while the rocks continue to shift and settle. The earthquakes were felt as far away as Boston and Denver. Because the most intense effects were in a sparsely populated region, the destruction of human life and property was slight. If just one of these enormous earthquakes occurred in the same area today, millions of people, buildings and other structures worth billions of dollars would be affected.

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

What Causes Earthquakes?

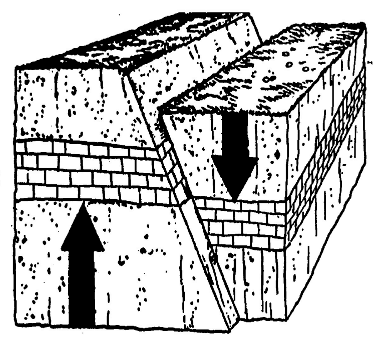
Geologists have discovered the cause of earthquakes. They also have found a way to predict where earthquakes are most likely to occur. Forces within Earth continually push, pull, and twist the rocks that make up the crust. When these forces become too great and the rocks have reached their elastic limit, the crust breaks or fractures.

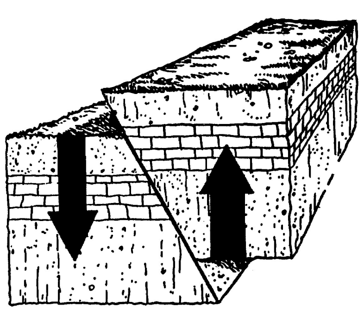
The crust may first bend and then, when the stress exceeds the strength of the rocks, break and "snap" to a new position becoming straight again. This movement of the Earth's crust is an **earthquake**. In the process of breaking, vibrations called "**seismic waves**" are generated. These waves travel outward from the source of the earthquake along the surface and through the Earth at varying speeds depending on the material through which they move. Some of the vibrations are of high enough frequency to be heard, while others are of very low frequency. These vibrations cause the entire planet to tremble.

A fracture in the Earth's crust along which sections of the crust slide past each other is called a **fault**. The movement of the rocks along a fault is called **slippage**. Slippage along a fault temporarily relieves stress in the crust. The rocks along the fault may then remain locked together until stress again builds up to the breaking point, causing another earthquake. Segments of an active fault that have been locked together for a long time are thus prime candidates for future earthquakes. Efforts to predict earthquakes are based largely on this idea.

Faults are divided into three main groups depending on how they move. **Normal** (vertical or dip-slip) **faults** occur in response to pulling or **tension**. Normal faults occur at **divergent boundaries**. The overlying block moves down the dip of the fault plane. An example of an area where normal faults take place is the **Sierra Nevada Mountains** in the Western United States.

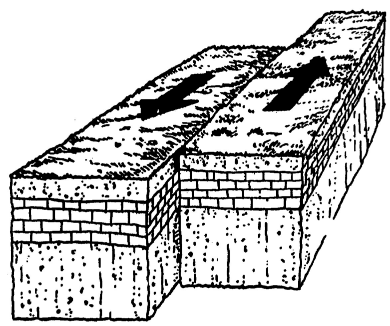
Normal fault





Reverse fault

Reverse (thrust) **faults** occur in response to squeezing or **compression**. Reverse faults occur at **convergent boundaries**. The overlying block moves up the dip of the fault plane. The building of the **Himalayas Mountains** is the results of reverse faults.



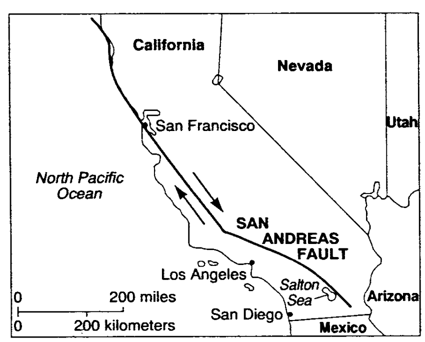
Strike-slip (horizontal) **faults** occur in response to **shear forces**. The blocks move horizontally past one another. Strike-slip faults occur at **transform fault boundaries**. The **San Andreas Fault** in California is a strike-slip fault. Most faulting along spreading zones is normal, along subduction zones is thrust, and along transform faults is strike-slip.

Most earthquakes occur along faults, although, some earthquakes are caused by erupting volcanoes. In addition, researchers intentionally create small earthquakes by setting off underground explosions or by dropping large weights on the ground. The explosions and the falling weights generate vibrations in the crust called seismic waves. Instruments on the surface record the seismic waves when they are reflected back upward by different rock layers. By studying these records, geologists can determine the structure of the crust. Scientists use this kind of information to locate oil, coal and natural gas deposits.

Earthquake Regions

Earthquakes can occur anywhere in the world. However, most earthquakes take place in regions called earthquake belts. One major earthquake belt lies around the Pacific Ocean. Eighty percent of the world's earthquakes occur around the Pacific Plate. Another major earthquake belt runs through the Mediterranean Sea, across southern Asia to Indonesia (Alpide belt). Many active volcanoes and young mountain ranges are located within these earthquake belts.

The states of Alaska and California lie in the Pacific earthquake belt. Both states have had and will continue to have strong earthquakes. Most of the earthquakes in the United States occur in the Western U.S. Movement of the Pacific seafloor causes the earthquakes in Alaska.



Most of California's earthquakes are caused by slippage of the crust along the San Andreas Fault. This major strike-slip fault extends for over 1000 kilometers (600 miles) through the state. Even though the southern part of California is slowly sliding northwest, it is not going to fall off into the Pacific Ocean. Southern California will act as an island as it slowly moves up the coast

Effects of Earthquakes

The crustal movements that occur during strong earthquakes can sometimes be observed on land. For example, the San Francisco earthquake of 1906 produced a tear in Earth's surface more than 400 km (235 miles) long. The displacement of fences and roads that crossed the San Andreas Fault showed that the crust had shifted horizontally by about 6 meters.

Earthquakes may also involve vertical crustal movements. During the Alaskan earthquake of 1964, large areas of land were uplifted or dropped down several meters. In fact, some sections of the seafloor along the coast were raised above sea level, becoming dry land.

Strong earthquakes can be deadly. Crustal movements in large quakes can destroy buildings and trigger landslides causing devastating loss of life. A single earthquake in China in 1976 is believed to have killed more than half a million people. Earthquake damage to buildings and other structures depends largely on the intensity (magnitude) of the earthquake, the location of the earthquake, the type of material on which the structures are built, the design of the buildings and structures, and disaster preparedness. A large magnitude earthquake, six or above on the Richter Scale, will do much more damage than an earthquake with the magnitude of four on the Richter Scale. Earthquakes located near populated areas will likely do more damage than equal magnitude earthquakes that occur in non-populated areas. Populated areas have more structures to damage resulting in more monetary damage and more likelihood of people dying.

Buildings and structures that are designed to withstand earthquakes will be more likely to survive an earthquake than those that are not reinforced and designed to withstand earthquakes. Most of the structures that collapsed in the North Ridge earthquake in California were not reinforced to withstand earthquakes or had a lot of open space between supports. A structure built on solid bedrock is less likely to be damaged by an earthquake than one built on loose sediments. This is because seismic waves are amplified as they pass through loose sediments causing the sediments to shake more violently than solid bedrock. Many of the structures that collapsed during the San Francisco earthquake of 1989, including the double-decked Nimitz Freeway, were built on loose sediments.

The final factor that determines earthquake damage is that of disaster preparedness. Cities that are prepared to deal with earthquakes will fair much better than those who are not. Baraboo, Wisconsin would suffer much more from an equal strength earthquake than San Francisco, California. People in San Francisco are prepared for earthquakes. People know they need to shut-off their natural gas, electricity and water as soon as possible. They know they should have a small amount of food and water stockpiled for an earthquake emergency. Their buildings and structures are designed to better withstand earthquakes. Baraboo residents do not plan for earthquakes because the likelihood of an earthquake is very small.

Earthquakes that occur on the seafloor may produce fast moving ocean waves called **tsunamis**. Tsunamis can be caused by underwater volcanic eruptions, landslides and earthquakes. A tsunami can cross an entire ocean, traveling at speeds of up to 960 km per hour (550 m.p.h.). On the open ocean, tsunamis are usually no higher than ordinary waves, so they often go unnoticed. However, when such waves reach shallow coastal waters, they pile up before striking the shore. Some tsunamis are more than 20 m high when they strike land. The largest of these waves on record was about 85 m high!

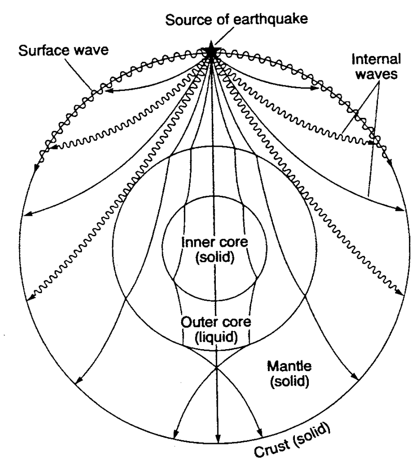
A tsunami is often more destructive than the geological event that produced it. In 1896, a tsunami nearly 30 m high hit the coast of Japan. Thousands of houses were swept away and more than 25,000 people were killed. In 1946, a tsunami that struck Hawaii tore railroad tracks from their beds, washed houses out to sea, and took 159 lives.

A tsunami usually gives warning before it strikes. Minutes before a large tsunami arrives the water near the shore suddenly drains seaward exposing parts of the beach that are normally submerged. Then, with a loud hissing sound, the wave rushes across the waterless beach and strikes the shore with a great roar. Following waves may pound the shore for several hours.

Liquefaction, which happens when loosely packed, water-logged sediments lose their strength in response to strong shaking, causes major damage during earthquakes. During the 1989 Loma Prieta earthquake, liquefaction of the soils and debris used to fill in a lagoon caused major sinking, fracturing, and horizontal sliding of the ground surface in the Marina district in San Francisco.

Earthquakes and the Earth's Interior

The Earth's crust vibrates when rocks fracture and slip along a fault. The vibrations travel through Earth as **seismic waves**. Some seismic waves travel along the surface. Others travel through Earth's interior. Both types of seismic waves move outward in all directions from the source of the earthquake.



The different types of seismic waves travel at different speeds. In addition, the speed of each wave type varies with the density of the material through which it travels. The more dense the material, the faster a seismic wave moves through it. The path that a seismic wave follows through the Earth depends on how rock layers of different densities are arranged within the Earth.

Geologists have gained their knowledge of Earth's internal structure and composition by studying how seismic waves travel through Earth's interior. As you have learned, these studies indicate that Earth has a solid inner core, a liquid outer core, a thick mantle of dense rock, and a thin crust of lighter rocks.

Seismic waves from earthquakes can be detected and recorded by using an instrument called a **seismograph**. The main part of a seismograph is a heavy, suspended weight, with a pen attached to it. The tip of the pen touches a chart wrapped around a drum that slowly rotates. The seismograph is firmly anchored to the bedrock. When an earthquake takes place, vibrations in the bedrock cause the drum to vibrate against the stationary pen. Thus, the pen traces a record of the earthquake movement. This trace is called a **seismogram**.

A seismograph can detect an earthquake that occurs thousands of kilometers away. The point where rocks first fracture is the source of seismic waves. This point, located underground, is called the **focus** of the earthquake. The point on Earth's surface directly above the focus is the **epicenter**.

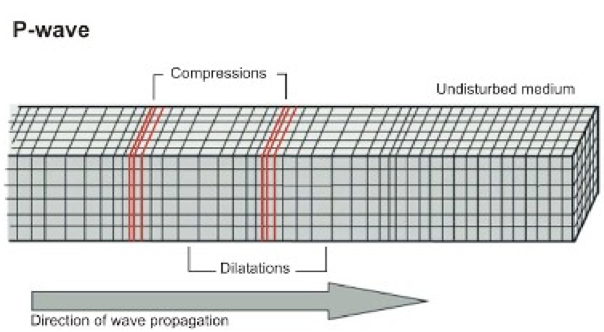
Because different types of seismic waves travel at different speeds, some waves from an earthquake reach a seismographic station before others do. **Seismologists** (scientists who study earthquakes) can use this fact to locate the earthquake's epicenter.

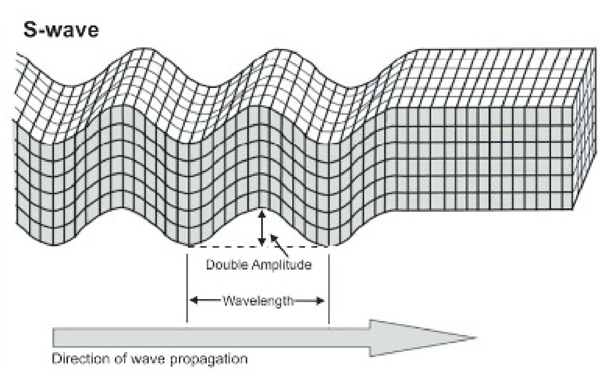
For example, by timing the arrivals of different seismic waves, seismologists in Chicago can determine the distance of an earthquake (but not its direction) from their recording station. This distance is then used as the radius of a circle drawn around the station on a map. The earthquake's epicenter lies somewhere on this circle. There are an infinite number of possibilities for the location of the earthquake along one radius using only one seismograph. Seismologists at recording stations in El Paso, Texas, and Phoenix, Arizona, can also calculate their distances from the earthquake and draw circles around their stations on a map. When two seismographs are used, the number of possible locations for the earthquake is narrowed down to two possible points where the two circle radii cross. When all three circles are combined on one map, the circles intersect at a single point. That point is the earthquake's epicenter. This method is called **triangulation**. The focus of an earthquake can be determined in a similar way. Most earthquakes occur within 50 km of Earth's surface. However, some deep earthquakes occur nearly 700 km underground.

Seismic waves

The two general types of vibrations produced by earthquakes are **body waves**, which travel through the Earth and **surface waves**, which travel along the Earth's surface. Surface waves usually have the strongest vibrations and probably cause most of the damage done by earthquakes. Surface waves are also the slowest of the waves. The surface waves do the most damage because they are in contact with the area for the greatest period of time and they have a vertical motion to lift and drop objects in the affected area.

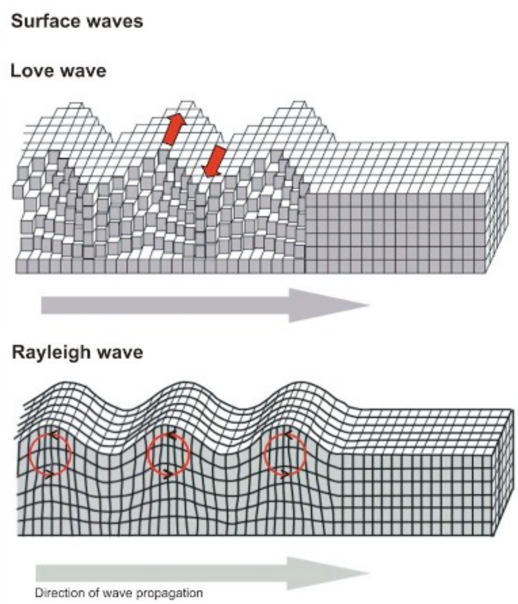
Compression (P waves) and **shear** (S waves) are the two types of body waves. Both body waves pass through the Earth's interior from the focus of an earthquake to distant points on the surface. Only compression waves travel through the Earth's molten outer core. Because compression waves travel at great speeds (5 m.p.s.) and ordinarily reach the surface first, they are often called "**primary waves**" or simply "**P waves**". P waves push tiny particles of Earth material directly ahead of them or displace the particles directly behind their line of travel. P waves are the fastest waves and warn of upcoming S, L and R waves. P waves do very little damage compared to the





other three.

Shear waves (S waves) do not travel as rapidly through the Earth's crust and mantle as do compression waves. Because they ordinarily reach the surface later, they are called "**secondary waves**" or "**S waves**". Instead of affecting material directly behind or ahead of their line of travel, shear waves displace material at right angles to their path. S waves do moderate damage and cannot travel through the Earth's liquid outer core.



Rayleigh (R waves) and **Love** (L waves) waves are the two types of surface waves. Rayleigh waves are generally the slower of the two surface waves and behave like water waves in that they move forward while the individual particles move in an circular path. The motion of a Love wave (L wave) is similar to that of an S wave, but the individual particles of the material only move back and forth in a horizontal plane perpendicular to the direction of the wave travel which is similar to the way a snake moves through the grass. The combination of Rayleigh and Love waves results in ground heave and swaying buildings. Surface waves cause the most devastating damage to buildings, bridges, and highways.

The severity of an earthquake can be expressed in several ways. The magnitude of an earthquake, usually expressed by the Richter Scale, is a measure of the amplitude of the seismic waves. The **magnitude** of an earthquake is a measure of the amount of energy released. It is estimated from seismograph readings. The **intensity**, as expressed by the Modified Mercalli Scale, is a subjective measure that describes how strong a shock was felt at a particular location.

The **Richter Scale**, named after Dr. Charles F. Richter of the California Institute of Technology, is the best known scale for measuring the magnitude of earthquakes. The scale is logarithmic so that a recording of 7, for example, indicates a disturbance with ground motion 10 times as large as a recording of 6. A quake of magnitude 2 is the smallest quake normally felt by people. Earthquakes with a Richter value of 6 or more are commonly considered major; great earthquakes have magnitude of 8 or more on the Richter scale.

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

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

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

The Loma Prieta earthquake of 1989 demonstrated a wide range of effects. The Santa Cruz Mountains suffered little damage from the seismic waves, even though they were close to the epicenter. The central core of the city of Santa Cruz, about 24 kilometers (15 miles) away from the epicenter, was almost completely destroyed. More than 80 kilometers (50 miles) away, the cities of San Francisco and Oakland suffered selective but severe damage, including the loss of more than 40 lives. The greatest destruction occurred in areas where roads and elevated structures were built on stable ground underlain by loose, unconsolidated soils.

Write all answers in your notebook!

Complete the Sentence:
Write the term that best completes each statement in your notebook.

1. When the buildup of stress in Earth's crust is so great that rocks reach their (elastic limit, tectonic force), an earthquake occurs.
2. A reverse fault is often located along a (divergent, convergent) plate boundary.
3. (Primary waves, Love waves) move through Earth by causing particles of rocks to move at right angles to the direction of the waves.
4. To locate an earthquake's (epicenter, elastic limit), scientists use information from three seismograph stations.
5. By noting the change in the speed and path of (seismic waves, Moho discontinuity), scientists have been able to determine the structure of Earth's interior.
6. Seismologists use the (seismograph, Richter Scale) to describe the magnitude of earthquakes.
7. One way to make your home seismic safe is to put heavy items on (upper, lower) shelves.
8. The San Andreas fault in California is an example of a (normal fault, strike-slip fault).
9. Most of the destruction during an earthquake is caused by (surface waves, body waves).
10. The radius of the circle seismologists draw on a map is equal to the distance from a station to an earthquake's (epicenter, focus).
11. Primary and secondary waves slow down when they hit the plastic-like (asthenosphere, lithosphere).
12. The slowest seismic waves are (body waves, surface waves).
13. Primary waves arrive at a seismograph station (first, second).
14. When rocks break because of stress, the energy released is in the form of a(n) (earthquake, tsunami).
15. The farther apart primary, secondary, and surface waves are, the (closer, farther away) the epicenter is.

Complete the sentence
Write the term that best completes each statement in your notebook.

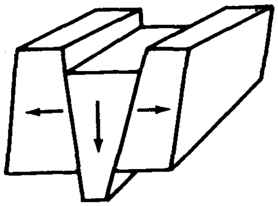
16. The breaking of rocks that causes vibrations in Earth are called ______.
17. Most earthquakes occur at the boundaries of _______.
18. ____ forces push on rocks from different, but not opposite, directions.
19. Tension pulls rocks apart and creates a ________.
20. At ________ boundaries, rocks are pushed from opposite directions.
21. At ________ boundaries, plates and the rocks that compose them are moving apart.
22. A bending and stretching rock will break when it reaches its ________.
23. Rocks on either side of a _________ move past each other without much upward or downward movement.
24. One of the most famous examples of a _________ is the San Andreas fault in California.
25. Rocks above a _____ are forced up and over rocks below the fault surface.
26. A ______ force creates a normal fault.

reverse fault	strike-slip fault	tectonic plates	normal fault
divergent plate	tension	earthquakes	shearing
convergent plate	transform fault	elastic limit	

Identification and Matching

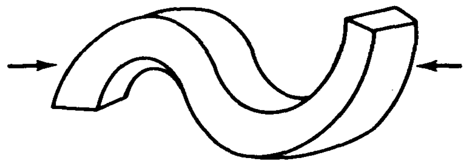
Identify each fault shown--normal fault, reverse fault, and strike-slip fault. Put your answers in your notebook. Then match each fault with its characteristics from the list. Each characteristic is used only once. Use only the blanks provided. Put your answers in your notebook.

27. __________
(Dip-Slip fault)



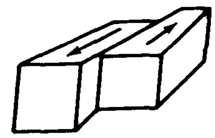
28. _____
29. _____
30. _____
31. _____

32. __________
(Thrust fault)



33. _____
34. _____
35. _____
36. _____

37. __________
(Horizontal fault)



38. _____
39. _____
40. _____
41. _____
42. _____

Characteristics

A. Tension pulls rocks apart.
B. Compression pushes rocks in.
C. Shearing forces push rocks from different, but not opposite, directions.
D. This kind of fault occurs at transform fault boundaries.
E. This kind of fault occurs at divergent plate boundaries.
F. This kind of fault occurs at convergent plate boundaries.
G. Rocks above the fault surface are forced up and over the rocks below the fault surface.
H. Rocks above the fault surface move downward in relation to rocks below the fault surface.
I. Rocks on either side of the fault boundary move past each other without much upward or downward movement.
J. Many of these faults occurred when the Sierra Nevadas were formed.
K. The Himalaya Mountains contain many of these faults.
L. The San Andreas fault is an example of this kind of fault.
M. Rocks become twisted and strained when they snag each other.

Short Answer
Answer the following questions in your notebook

43. What is the name for the study of earthquakes and the waves they create?
44. What is the name for scientists who study earthquakes?
45. List the three types of faults and give an example of each.
46. What is the point with-in the earth along the fault where an earthquake originates?
47. What is the point on the earth's surface directly above the point with-in the earth along the fault where an earthquake originates?
48. How do seismologists find the epicenter of an earthquake?
49. What is the name for sea waves that accompany some large earthquakes that occur under the ocean?
50. What does the scale developed in 1935 by Charles F. Richter measure?

Volcanoes

Few natural forces are as spectacular and threatening, or have played such a dominant role in shaping the face of the Earth, as erupting volcanoes. Vulcanism is the movement of **magma** through the crust or its emergence as **lava** onto the Earth's surface. An opening in the crust through which molten materials and rock particles reach the surface and pile up is called a **volcano**. A volcanic mountain, which is built up by successive deposits of volcanic materials, is also commonly called a volcano.

A volcano may be **active** (presently erupting), **dormant** (between eruptions), or **extinct** (no longer capable of erupting). Some extinct volcanoes are eroded down so the only remains are called volcanic necks. Devil's Tower is an example of a volcanic neck. A **volcanic neck** is the solidified magma from inside the extinct volcano. Examples of volcanic necks are Devil's Tower and Ship Rock, New Mexico. Most of the world's active volcanoes are found along the rim of the Pacific Ocean, which is also a major earthquake zone. This curving belt of active faults and volcanoes is often called the **Ring of Fire**. It is the largest plate boundary with the most plate interactions.

HISTORY

The United States ranks third, behind Indonesia and Japan, in the number of historically active volcanoes (that is, those for which we have written accounts of eruptions). In addition, about 10 percent of the more than 1,500 volcanoes that have erupted in the past 10,000 years are located in the United States. Most of these volcanoes are found in the Aleutian Islands, the Alaska Peninsula, the Hawaiian Islands, and the Cascade Range of the Pacific Northwest; the remainder are widely distributed in the western part of the Nation. A few U.S. volcanoes have produced some of the largest and most dangerous types of eruptions in this century, while several others have threatened to erupt.

VOLCANIC ERUPTIONS

At the top of a volcano there is a bowlshaped depression called a **crater**. Within the crater is an opening called a **vent.** The vent of a dormant volcano is usually blocked by a thin layer of solidified lava. When the molten lava inside the volcano builds up enough pressure, the molten rock breaks through the thin crust of hardened lava, and the volcano erupts.

There are different types of volcanic eruptions. During a quiet eruption, lava flows freely from the volcano's crater or from fissures in the volcano's sides. The lava may flow for many kilometers down the slopes of the volcano. In an explosive eruption, molten rock explodes forcefully from the volcano in billowing clouds of volcanic ash and cinders.

A volcanic eruption can be both spectacular and devastating. Lava flows and glowing clouds of ash and toxic gases from volcanoes have destroyed entire cities. In 1902, the eruption of Mount Pelee on the Caribbean island of

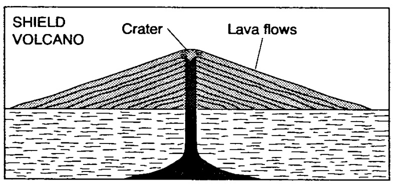
Martinique killed 30,000 people. In 1883, one of the most violent eruptions ever recorded took place on an Indonesian island called Krakatoa. The sound of this explosive eruption was heard more than 4800 km (2800 miles) away. Nearly two thirds of the island was blown away by the blast.

VOLCANIC MOUNTAINS

Vulcanism has produced some of the world's best-known mountains. Mount Etna in Sicily and Mount Kilimanjaro in Africa are volcanic mountains. The Hawaiian Islands are actually the tops of a chain of volcanic mountains that rise from the ocean floor.

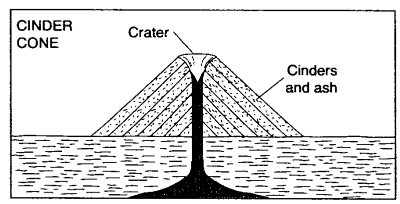
There are three types of volcanic mountains: shield volcanoes, cinder cones, and composite volcanoes. These volcanoes differ in size, shape, and the way they are formed.

Shield Volcanoes. Shield volcanoes occur at divergent boundaries and hotspots. When lava emerges from a volcanic vent or fissure in a quiet eruption, the freely flowing lava spreads out over Earth's surface until it cools and hardens into a layer of igneous rock. The lava is able to flow smoothly because it is basaltic lava. Basaltic lava is low in silica and high in iron and magnesium making it very fluid. Very little gas or water vapor is trapped in basaltic magma. In time, repeated lava flows build a broad, massive mountain with gentle slopes, called a shield volcano. Shield volcanoes are the largest type of volcanic mountain.



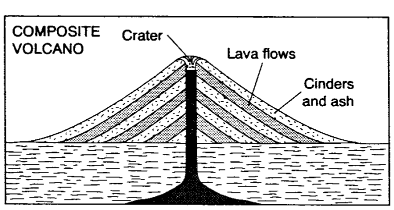
Mauna Loa and Mauna Kea are the largest of several huge shield volcanoes that make up the island of Hawaii. Both of these volcanoes rise almost 10 km (6 miles) from the ocean floor, reaching more than 4 km (2 miles) above sea level. Mauna Loa is the largest volcano on Earth. Iceland is another example of a series of shield volcanoes.

Cinder Cones. Cinder cone volcanoes generally occur at hotspots. In explosive eruptions, lava is hurled high into the air in a spray of droplets of various sizes. These droplets cool and harden into cinders and particles of ash before falling to the ground. The ashes and cinders pile up around the volcanic vent to form a steep, cone-shaped hill called a cinder cone. The eruptions are explosive because the lava is granitic. Granitic lava contains a lot of silica, gases and water vapor making it very thick and under extreme pressure.



Cinder cones are relatively small volcanoes, rarely rising more than 500 m high. Cinder cones may form quite rapidly. In February 1943, ashes and cinders began to spew from a fissure in a cornfield near the village of Paricutin, Mexico. In just six days, a cinder cone over 150 m high had replaced the cornfield. Seven months later, the cinder cone was about 450 m high, and the surrounding region was buried beneath a layer of ash nearly 1 m thick.

Composite Volcanoes. Composite volcanoes form at convergent boundaries that have subduction zones. The lava is composed primarily of rhyolitic and andesitic materials. These materials collect a lot of gases and water vapor making the eruptions quite explosive. A volcanic mountain built up by both lava flows and layers of ash and



cinders is called a composite volcano. Although not as big as shield volcanoes, composite volcanoes are generally much larger than cinder cones.

Many composite volcanoes are quite famous, either for their classic, cone-shaped peaks, or their powerful, explosive eruptions. Some well-known composite volcanoes are Mount Fuji in Japan, Mount Vesuvius in Italy, and Mount St. Helens in the United States.

DOME MOUNTAINS

Sometimes a large quantity of magma pushes up through the crust but fails to break through to the surface. Instead, the magma forces the overlying rock layers to arch upward, forming a large dome mountain. A dome mountain resembles a huge blister on Earth's surface. In time, the top layers of rock are worn away, exposing the solidified magma. The Henry Mountains of Utah and the Orange Mountains of New Jersey are dome mountains.

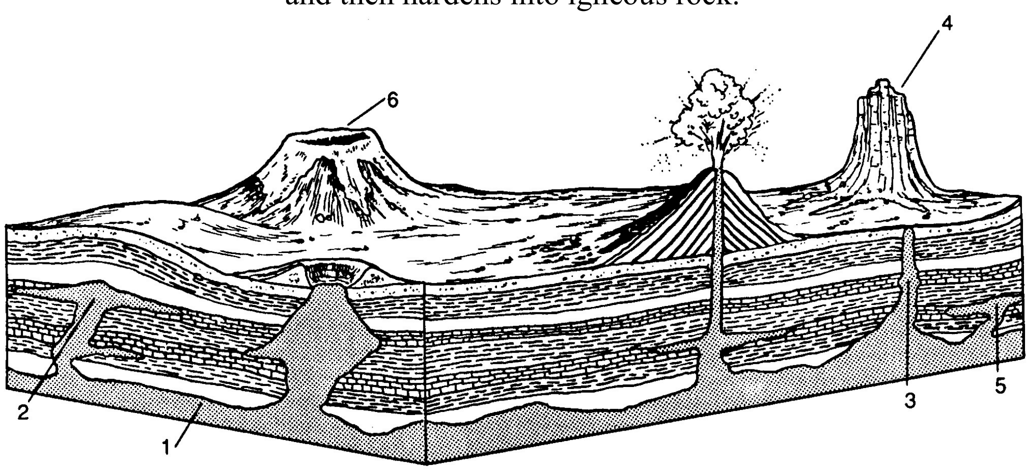
VULCANISM INSIDE THE CRUST

In addition to surface features like volcanoes and dome mountains, vulcanism also produces underground geologic features. Magma that remains deep within the crust eventually hardens into igneous rock, forming batholiths, sills, and dikes. These underground structures may be seen if they become exposed at the surface by uplift and erosion of the overlying rocks.

A **batholith** is a huge mass of coarse-grained, igneous rock that forms deep in the cores of mountain ranges. When exposed by uplift and erosion, a batholith may cover thousands of square kilometers. The largest batholith in North America, located in the Coast Ranges of western Canada, is about 2000 km (1200miles) long and 290 km (170 miles) wide. Other extensive batholiths underlie the Sierra Nevada in California and the Rocky Mountains in Idaho.

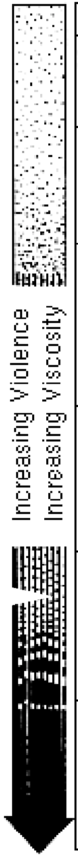
A **sill** is formed when magma flows between layers of sedimentary rock. The magma hardens into a sheet of igneous rock that is parallel to the adjacent rock layers. The Palisades-cliffs of diabase that line the west bank of the Hudson River, opposite New York City-are the exposed remnants of a sill. A **laccolith** forms when a sill pushes up on the rock layers above it creating a dome of rock.

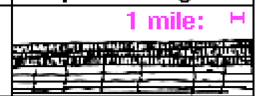
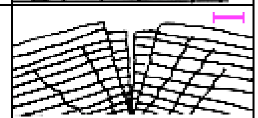
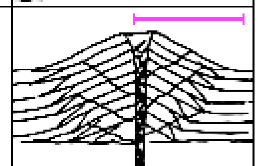
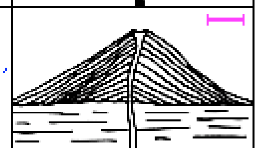
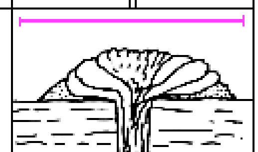
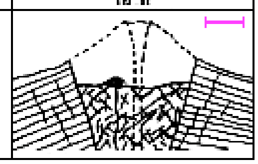
A **dike** forms when magma forces its way into a fracture that cuts across sedimentary rock layers and then hardens into igneous rock.



1. Batholith 2. Laccolith 3. Dike 4. Volcanic Neck 5. Sill 6. Caldera/Crater

Volcanic Landforms

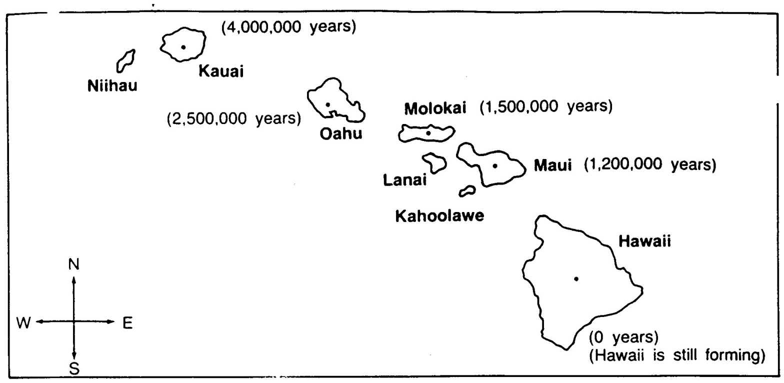


Volcano Type	Characteristics	Examples	Simplified Diagram
Flood or Plateau Basalt	Formed by widespread fluid lava flows emitted from fissures.	Columbia River Plateau	
Shield Volcano (Basaltic)	Created from fluid lava flows emitted from central vent or flank fissures; large; broad with slopes typically <10°.	Larch Mountain, Mount Sylvania, Highland Butte, Hawaiian volcanoes	
Cinder Cone (Basaltic to Andesitic)	Explosive liquid lava; small; emitted from a central vent; if continued long enough, may build up a shield volcano	Mount Tabor, Mount Zion, Chamberlain Hill, Pilot Butte, Lava Butte, Craters of the Moon	
Composite or Stratovolcano (Andesitic to Felsic)	More viscous lavas, much explosive (pyroclastic) debris; large, emitted from a central vent	Mount Baker, Mount Rainier, Mount St. Helens, Mount Hood, Mount Shasta	
Volcanic Dome (Felsic)	Form from gas-poor pasty viscous lava; relatively small; associated with composite volcanoes and calderas.	Novarupta, Mount St. Helens Lava Dome, Mount Lassen, Shastina, Mono Craters	
Caldera (Felsic)	Fromed by the cataclysmic eruption and collapse of a composite cone; frequently associated with plug domes and viscous magma.	Yellowstone, Los Alamos, Santorini, Crater Lake	

Hotspots: Thermal Plumes in the Mantle

In 1963, J. Tuzo Wilson, the Canadian geophysicist who discovered transform faults, came up with an ingenious idea that became known as the "hotspot" theory. Wilson noted that in certain locations around the world, such as Hawaii, volcanism has been active for very long periods of time. This could only happen, he reasoned, if relatively small, long-lasting, and exceptionally hot regions, called **hotspots**, existed below the plates that would provide localized sources of high heat energy (thermal plumes) to sustain volcanism. Specifically, Wilson hypothesized that the distinctive linear shape of the Hawaiian Island-Emperor Seamounts chain resulted from the Pacific Plate moving over a deep, stationary hotspot in the mantle, located beneath the present-day position of the Island of Hawaii. Heat from this hotspot produced a persistent source of magma by partly melting the overriding Pacific Plate. The magma, which is lighter than the surrounding solid rock, then rises through the mantle and crust to erupt onto the seafloor, forming an active seamount. Over time, countless eruptions cause the seamount to grow until it finally emerges above sea level to form an island volcano. Wilson suggested that continuing plate movement eventually carries the island beyond the hotspot, cutting it off from the magma source, and volcanism ceases. As one island volcano becomes extinct, another develops over the hotspot, and the cycle is repeated. This process of volcano growth and death, over many millions of years, has left a long trail of volcanic islands and seamounts across the Pacific Ocean floor.

According to Wilson's hotspot theory, the volcanoes of the Hawaiian chain should get progressively older and become more eroded the farther they travel beyond the hotspot. The oldest volcanic rocks on Kauai, the northwestern most inhabited Hawaiian island, are about 5.5 million years old and are deeply eroded. By comparison, on the "Big Island" of Hawaii, southeastern most in the chain and presumably still positioned over the hotspot, the oldest exposed rocks are less than 0.7 million years old and new volcanic rock is continually being formed.



Although Hawaii is perhaps the best-known hotspot, others are thought to exist beneath the oceans and continents. More than a hundred hotspots beneath the Earth's crust have been active during the past 10 million years. Most of these are located under plate interiors (for example, the African Plate), but some occur near diverging plate boundaries. Some are concentrated near the mid-oceanic ridge system, such as beneath Iceland, the Azores, and the Galapagos Islands.

A few hotspots are thought to exist below the North American Plate. Perhaps the best known is the hotspot presumed to exist under the continental crust in the region of Yellowstone National Park in northwestern Wyoming. The thermal energy of the presumed Yellowstone hotspot fuels more than 10,000 hot pools and springs, geysers (like Old Faithful), and bubbling mud pots (pools of boiling mud). A large body of magma, capped by a hydrothermal system (a zone of pressurized steam and hot water), still exists beneath the caldera.

Volcanoes and the Theory of Plate Tectonics

Volcanoes are not randomly distributed over the Earth's surface. Most are concentrated on the edges of continents, along island chains, or beneath the sea forming long mountain ranges. More than half of the world's active volcanoes above sea level encircle the Pacific Ocean to form the circum-Pacific "Ring of Fire." In the past 25 years, scientists have developed a theory--called plate tectonics--that explains the locations of volcanoes and their relationship to other large-scale geologic features.

According to this theory, the Earth's surface is made up of a patchwork of about a dozen large plates that move relative to one another at speeds from less than one centimeter to about ten centimeters per year (about the speed at which fingernails grow). These rigid plates, whose average thickness is about 80 kilometers, are spreading apart, sliding past each other, or colliding with each other in slow motion on top of the Earth's hot, pliable interior. Volcanoes tend to form where plates collide or spread apart, but they can also grow in the middle of a plate, as for example the Hawaiian volcanoes.

Write all answers in your notebook!

Sentence Completion:
Write the answers to the following questions in your notebook.

1. The Hawaiian Islands are examples of ______________ volcanoes.
2. Magma that flows out onto Earth's surface is known as _______________.
3. The opening at the top of a volcano's vent is known as a ________________.
4. Mt. Saint Helen's is an example of a _________________ volcano.
5. The state of volcanoes currently spewing smoke, ash, steam, cinders, and/or lava is ________.
6. The state of volcanoes not currently active is ___________.
7. Area around Pacific plate where earthquakes and volcanoes are common is known as the ________.
8. Openings in Earth's crust that allow magma to reach the surface are __________.
9. Type of boundary where plates separate is referred to as _________________.
10. Melted rock deep inside Earth is called _______________.
11. Type of boundary where one plate slides under another plate is a ________________.
12. A mountain formed from layers of lava and ash is called a _______________.
13. Area in Earth hot enough to melt rock into magma and create volcanoes is the ___________.
14. The type of magma containing a lot of silica and water vapor is __________.
15. Volcanic material thrown out during eruptions includes _________, _________, and ____________.
16. Substances that affect the explosiveness of volcanic eruptions are ___________, ____________ and ______________.
17. Steep-sided volcano found along convergent boundaries _______________.
18. Type of magma containing little silica is referred to as ______________.
19. The mineral that affects the thickness of magma is ______________.
20. A broad volcano made of flat layers of basaltic lava is a _________________.

Short Answer:
Write the answers to the following questions in your notebook.

21. What are the two important factors determine whether an eruption will be explosive or quiet?
22. What is the relationship between the amount of gases in magma and the explosiveness of a volcanic eruption?
23. What is the relationship between the silica content of magma and the explosiveness of a volcanic eruption?

24-29. Identify the three kinds of places where volcanoes can form. Give an example of a volcano found at each location. Put your answers into a chart form.

Volcano Type	Location where formed? (Write the best choice; divergent, convergent, hotspot)	Example of volcano: (Check your readings/notes for your answers).
Shield Volcano		
Composite Volcano		

Cinder Cone Volcano		

Volcanic Features

In your notebook, write the term or phrase that correctly completes each statement.

30. Masses of magma that cool underground and form the largest igneous rock bodies are called _______.
   a. batholiths b. laccoliths

31. Ship Rock in New Mexico is an example of a ___________.
   a. laccolith b. volcanic neck

32. Most igneous activity takes place ____________.
   a. underground b. above ground

33. Magma that squeezes into a horizontal crack and hardens forms a __________.
   a. dike b. sill

34. When the top of a volcano collapses into the vent, a __________ is formed.
   a. crater b. neck

35. A dome of rock pushed up by a magma sill is a ___________.
   a. batholith b. laccolith

36. Volcanic features that can sometimes be seen above ground are ___________.
   a. volcanic necks and laccoliths b. dikes and sills

37. Magma that squeezes into a vertical crack and hardens forms a ___________.
   a. dike b. sill

38. When erosion wears away the outside of a volcano, sometimes a solid magma core called a _________ is left exposed.
   a. cinder cone b. volcanic neck

39. The granite domes in Yosemite National Park in California are part of a
   a. batholith b. laccolith

40. Volcanoes are examples of igneous activity _____________.
   a. underground b. above ground

41. Magma that cools underground forms ___________.
   a. igneous rock b. sedimentary rock.

42. The difference between dikes and sills is the ___________ of their formation.
   a. direction b. size