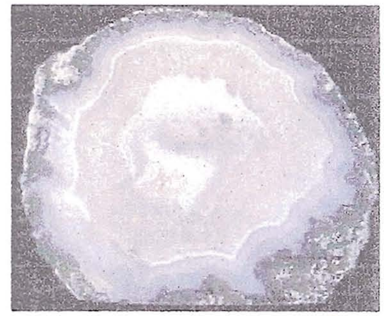
Module 4 - Earth Science
(Part I – Rocks and Minerals)

1. EARTH SCIENCE

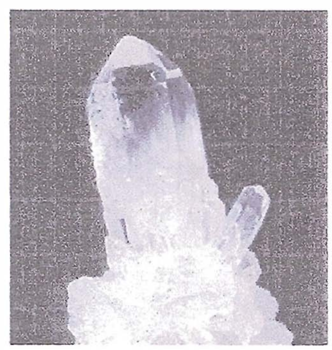
Earth science (also called geo-science) involves studying the origin, internal structure, and internal processes of the plant Earth. It also includes the formation of natural resources, and the evolution of its landscape.



2. MINERALS

Minerals are naturally occurring solid substances that are crystalline in nature and are formed as a result of certain geological process. These substances can be made up of a single element or a chemical compound. The study of minerals is called mineralogy. So far about 3,500 different minerals have been identified. Some of the commonly known minerals are diamond, quartz, topaz, calcite, gypsum, talc, fluorite, mica, and chromite. Figure 1 shows images of some the few minerals.

Talc



Quartz

Diamond

Gypsum

Figure 1: Images of few common minerals

2.1 Characteristics of Minerals

To be classified as a "true" mineral, a substance must:

i. be a naturally occurring solid,
ii. be made up of single element or compound.
iii. be inorganic (they are never formed by living or once-living things).
iv. have specific chemical compositions.
v. have a crystalline structure.

2.2 Grouping of Minerals

Each mineral possesses a unique set of identifying properties. Geologists use many different methods to classify minerals. It is quite common to classify a mineral by looking its **physical properties** such as crystal form, hardness, cleavage, luster, color, streak, specific gravity, and transparency.

Crystal form: The external shape or appearance that results from an orderly arrangement of atoms inside the crystal.
Hardness: It is the resistance of a mineral to scratching. The physical hardness of a mineral is usually measured according to the **Mohs scale**. This scale is relative and goes from 1 to 10. Minerals with a given Mohs hardness can scratch the surface of any mineral that has a lower hardness.

Cleavage: It is the property of a mineral to break along planes of its weakness.
Luster: It is the appearance of a mineral's surface in reflected light.
Color: Some minerals have a distinctive color in natural light. However, it is not a very reliable means of identification because the impurities in a particular mineral can affect the color of that mineral.
Streak: The color of a mineral in its powdered form. It is much more reliable than the color because the color may vary but the streak is always the same for a particular mineral.
Specific gravity: It is the comparison of mineral's density to the density of water.
Transparency: The property of mineral whether light can pass through it or not.

The grouping of minerals can also be based upon their chemical composition (i.e., which elements are present). Two simple tests that can be used to identify a mineral are (i) the **taste test**, and (ii) the **acid test** (or **fizz test**). The taste test is used to identify minerals such as salt (NaCl). The taste of salt is salty.

[Warning: You should never do this test on a mineral without a teacher's supervision as certain minerals can be poisonous.]

The acid test is used to identify carbonate minerals. When carbonate minerals make contact with dilute hydrochloric acid (HCL), the bubbles of carbon dioxide (CO_2) are produced.

3. ROCKS

Rocks are the materials of which mountains, cliffs and the surface of our planet Earth are made. Even sand, clay and soil are types of rock made from tiny particles. The processes that shape the rocks around us to form the landscape can take thousands or even millions of years.

Remember the minerals are the building blocks of rocks whereas the rocks are the building blocks of Earth's landscape.

Rocks are made of many different minerals. The largest group of rock-forming minerals is the silicates, all of which include the elements silicon (0.9%) and oxygen (93.8%). The minerals inside a rock usually form small crystal grains that are placed together to form a hard solid. **Minerals that form rocks fall into five main groups.** (i) **Silicates** – They make up nearly 95% of the Earth's crust. (ii) **Oxides** – The oxides are minerals that contain oxygen combined with one or more metals (such as iron, chromium, manganese, tin etc.). Oxides are generally called **ore minerals.** (iii) **Carbonate** – Two common carbonate minerals are calcite, and dolomite. These are the minerals found in the group of rocks called limestone. (iv) **Sulfides** and (v) **Sulfates** - Sulfur is the main element both in sulfides and sulfates. The most common sulfide mineral is pyrite whereas the most common sulfate mineral is gypsum.

3.1 Formation of Rocks

As discussed earlier the minerals are formed by crystallization. It is simply the growth of a solid from a material whose atoms combine together in specific chemical compositions and crystalline arrangements). Crystallization of minerals generally comes from two sources that are given below:

(i) Magma (molten rocks from the earth's interior): When it cools and solidifies it becomes minerals and rocks. The rocks formed from the magma are called **igneous rocks.**

(ii) Water solutions: When a water solutions containing minerals precipitate, it deposits these minerals that were dissolved in the water. These types of minerals are called **sedimentary rocks.**

3.2 Types of rocks

All rocks can be divided into three main groups - **igneous, sedimentary** and **metamorphic rocks** - according to the way in which they were formed as shown in Figure 2.

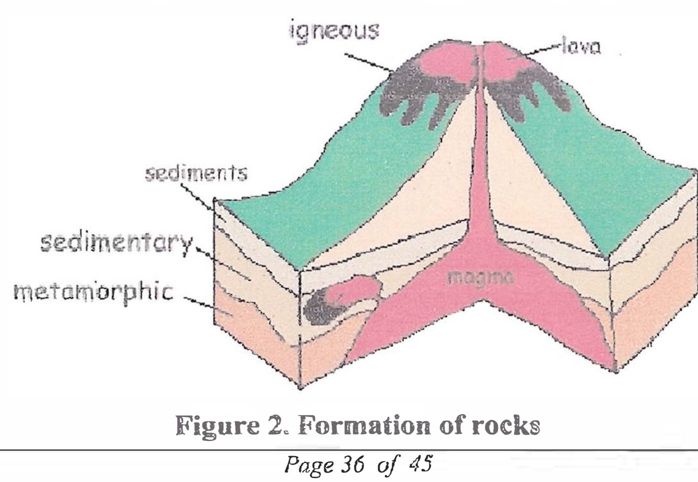


Figure 2. Formation of rocks

a) Igneous rocks: These rocks are formed from molten magma or lava. Molten, or hot, liquid *rock is called* ***magma*** *when it is still inside the earth, but once it comes out through a* **volcano** it is called **lava**. The word, igneous means "fire". All igneous rocks start deep in the earth as hot, molten magma. If the magma cools and hardens inside the earth it is called "**intrusive**" rock (see Figure 3). These rocks cool slowly and have large crystals. When the magma comes out of the earth's crust, it is called "**extrusive**". It cools off quickly, and the crystals that form are very small.

b) Sedimentary rocks: As mentioned earlier the sedimentary rocks are formed from deposited water solutions. Every minute of every day, rocks are being worn down by wind and rain. Tiny grains of dirt, sand, mud and clay are worn off and washed into streams, rivers, lakes and oceans. When these tiny bits of sand and dirt settle to the bottom of the water, they are called sediments. By each passing moment, more and more sediments pile on top of each other. After thousands and millions of years we end up with a really deep pile of sediment. Constant weight and pressure on top turns the sediment on the bottom into sedimentary rock. Sandstone and limestone are sedimentary rocks.

c) Metamorphic rocks: The word "metamorphic" means changed. When igneous, sedimentary or even metamorphic rocks get buried deep beneath the surface of the earth, over millions of years the heat and pressure inside the earth forces these rocks to realign into parallel planes as they re-crystallize and change into something else. For example limestone can be changed to marble and sandstone can be changed into quartzite. We may think of metamorphic rocks as recycled rocks. Figure 3 show how rocks are converted from one type to the other.

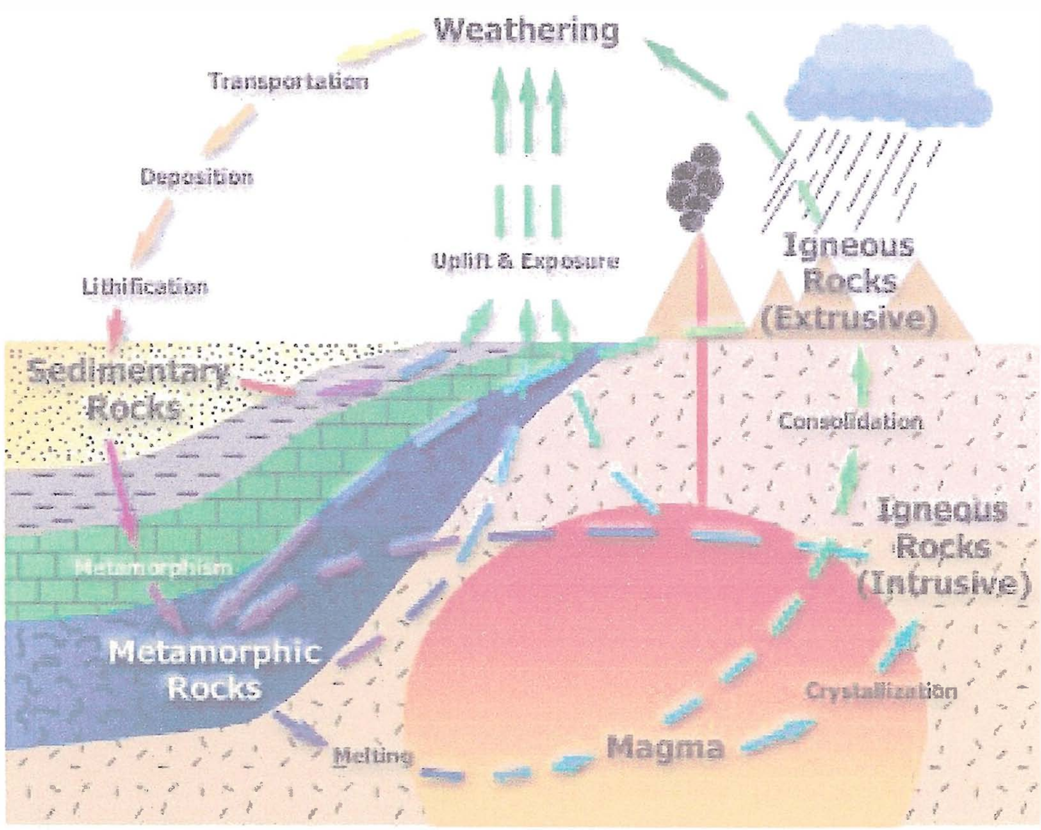


Figure 3. Rock conversion processes and rock cycle

Module 4 - Earth Science
(Part II – Volcanoes and Earth's Structure)

1. VOLCANOES

Volcanoes are one of Earth's most dramatic and violent incidents. It is a proof that the Earth is a planet that is continuously changing. Within minutes of an eruption, a volcano can change the physical landscape of the surrounding area up to several kilometers, potentially destroy hundreds and thousands of humans, and can affect global climate.

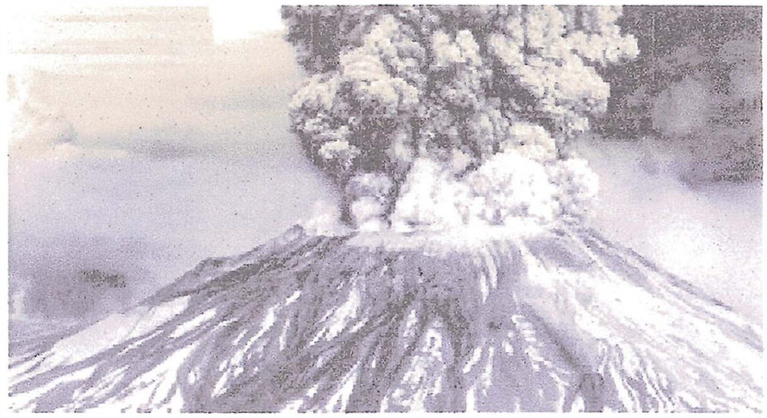


Figure 1. Volcanic eruption

Parts of volcano

Typically a volcano is a place on the Earth's surface where magma erupts through the earth's crust. It starts as a crack or hole (called **vent** as shown in Figure 2), through which hot molten rock (lava), gases, and fragments of volcanic ash and rock comes out of the Earth's surface.

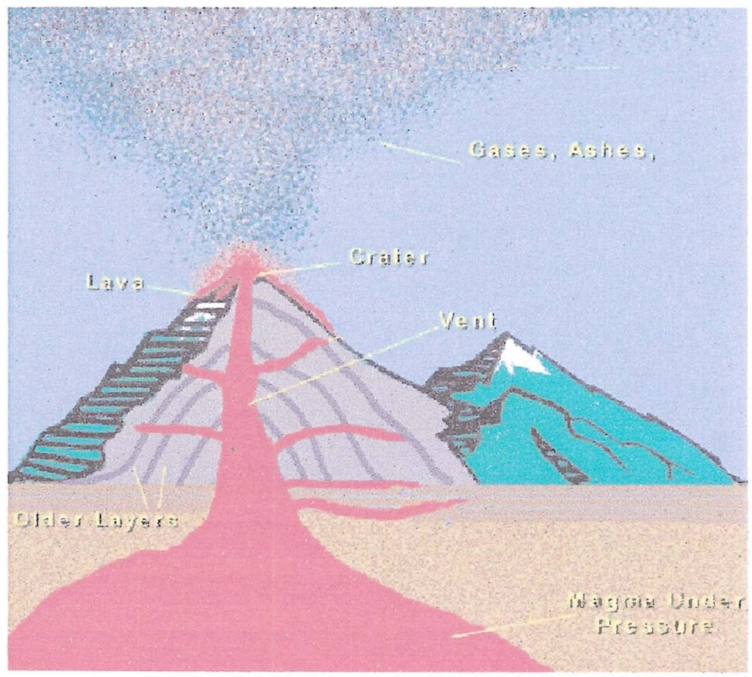


Figure 2. Parts of a typical volcano

What is magma?

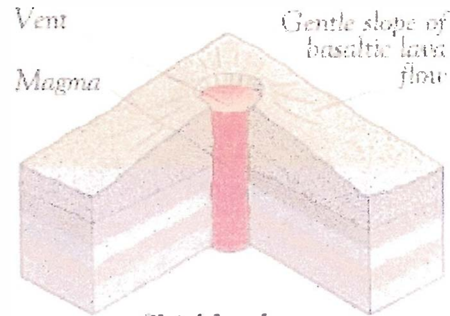
Magma consists of molten rock beneath the Earth's surface. When magma erupts from the Earth's surface through the vent, it is called lava. Magma typically consists of (1) a liquid portion (often referred to as the melt); (2) a solid portion made of minerals that crystallize directly from the melt; (3) solid rocks incorporated into the magma from along the vent and (4) dissolved gases.

1.1 Types of volcanoes

The type of a volcano is usually determined by the composition of magma and the characteristics of the erupting lava such as viscosity, size and the type of erupted products. Volcanoes can be divided into three main types.

a) **Shield cone volcano**

The volcanoes formed by a steady supply of easily flowing (low viscosity) basaltic lavas that leaves a gentle slope resembling a shield as shown in Figure 3.

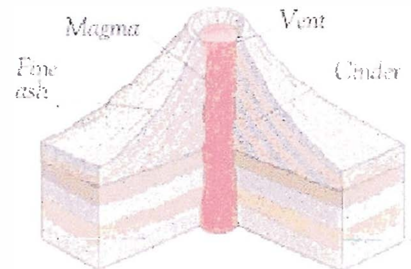


Shield volcano

Figure 3

b) **Cinder cone volcano**

Cinder cone volcano is formed by the accumulation of largely cinder-sized materials around the vent. The materials pile steeply (usually not taller than 300 meters) and are not well cemented together. This type of volcano is shown in Figure 4.

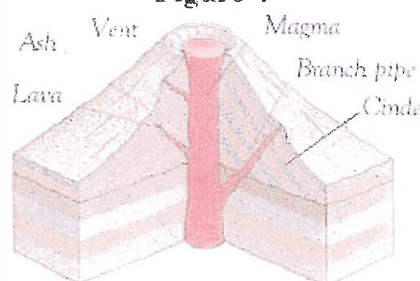


Cinder cone volcano

Figure 4

c) **Composite cone volcano**

Composite cone volcano is formed by the eruption of both lava and ash. The alternating layers of lava, ash, and mud p oduce a composite cone volcano as shown in Figure 5.



Composite volcano

Figure 5

There is no doubt that the volcanoes are highly dangerous; however, they do have some benefits as well. For example, they can improve land fertility, and can be a useful source of minerals and energy.

Volcanoes can also be classified on the basis of their activity. Three types of volcanoes based on this principle are as under:

1. **Active volcano:** The volcano that is continuously erupting is called an active volcano. Currently there are about 40-50 active volcanoes throughout our planet.
2. **Dormant volcano:** The volcano that is not erupting at present but has erupted sometime in the past and is most likely to erupt in the future is called dormant volcano. There are about 600 dormant volcanoes today.
3. **Extinct volcano:** The volcano that is neither erupting at present nor it likely to erupt in future is called extinct volcano.

2. EARTH'S STRUCTURE

The inner structure of Earth consists of four major layers that are commonly known as the **crust**, the **mantle**, the **outer core**, and the **inner core**. These layers are shown in Figure 6.

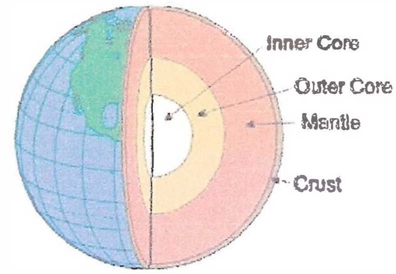


Figure 6. Four major layers of Erath

A cross-sectional view of the Earth is shown in Figure 7 that clearly shows these four layers along with their approximate thicknesses.

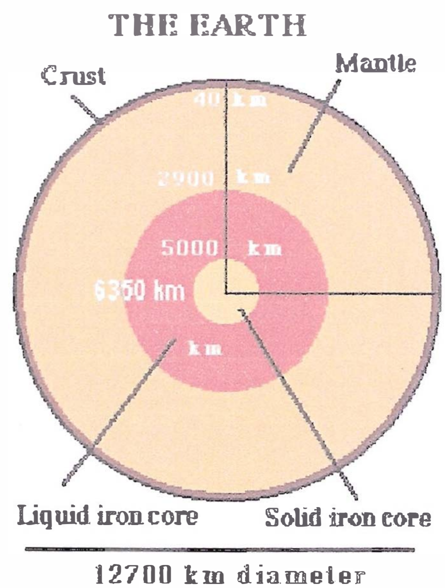


Figure 7. Cross-sectional view of Earth

The top part of the Earth is called crust. The crust is of two types; (i) **ocean floor crust**, and (ii) the **continental land crust**. These crusts are quite different from one another. We live on the continental crust. The oceanic crust is slightly thinner (10 km) than the continental crust (20-60km). The oceanic crust is made of dense basaltic rocks whereas the continental crust is made up of less dense material consisting of granite rocks.

The layer beneath the crust is called mantle which is rocky layer that is about 2900 km thick. This is composed of hot, iron rich silicate rocks.

The mantle is further sub-divided into the **asthenosphere** and **lithosphere**. Lithosphere is quite rigid whereas the asthenosphere behaves as a plastic. This means that asthenosphere is not rigid like solids but can flow with some ease. The asthenosphere gradually flows due to the convection currents that carry hot material upward and cold material downward. The constant flowing movement of asthenosphere can break lithosphere into many individual pieces which are known as **plates** (see Figure 8.). These plates continuously keep on moving as they slide on top of the asthenosphere.

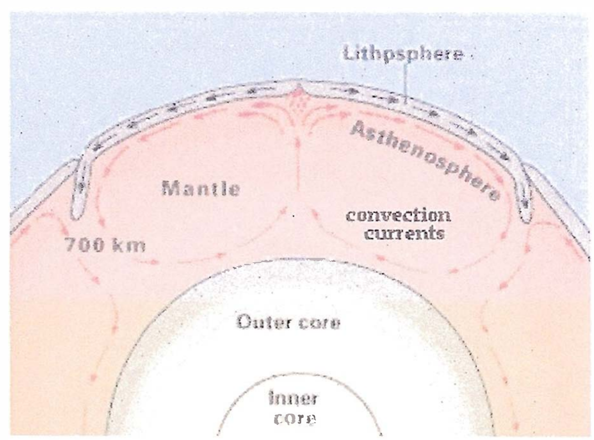


Figure 8. Convection currents cause the formation of plate

Below the mantle is the core. It consists of a dense material mostly made up of iron and nickel. The outer core is extremely hot and it is always in liquid form. The inner core - the centre of earth - is solid and has about 1350 km radius.

Module 4 - Earth Science
(Part III – Seismic Waves and Earthquake)

1. SEISMIC WAVES

A sudden breaking of rock or an explosion within the earth produces an earthquake and all earthquakes create waves that travel through the Earth's interior. These waves are called seismic waves. The ground movement is recorded on a machine called seismograph. Seismic waves are of different kinds. Two main types of seismic waves are:

1. **Body waves:** These waves travel through the earth's inner layers. Body waves are further divided in two types, **Primary wave (P-wave)** and **secondary wave (S-wave)**. P-wave is the fastest kind of seismic wave, and, consequently, the first to 'reach' at a seismograph. These waves **can move through solid rock and fluids**. The P-waves are **longitudinal** (like sound waves) which means that in P-wave the particles move in the "direction of wave propagation" as shown in the Figure 1. In both figures the particles are represented by cubes.

S-wave or secondary wave, which is the second wave you feel in an earthquake. These waves are slower than the P-waves and **can travel only through solid rock**. S-waves move rock particles up and down, or side-to-side--perpendicular to the direction of wave propagation as shown in Figure 2.

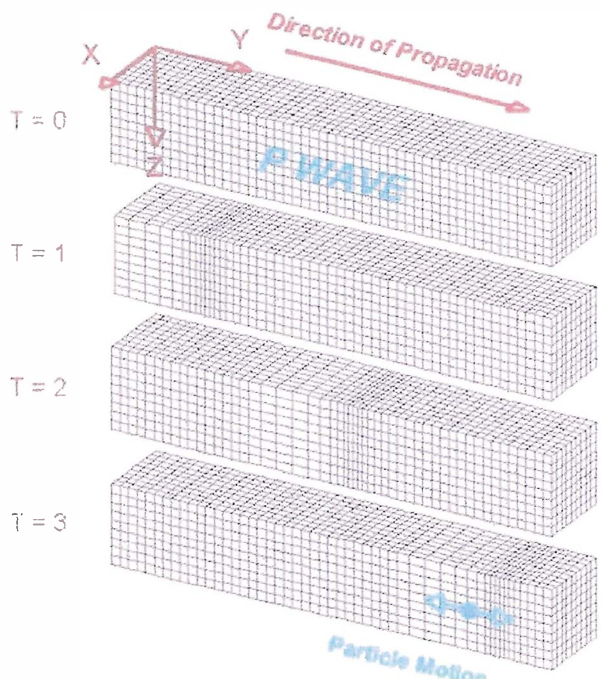


Figure 1: P-wave travels through a medium.

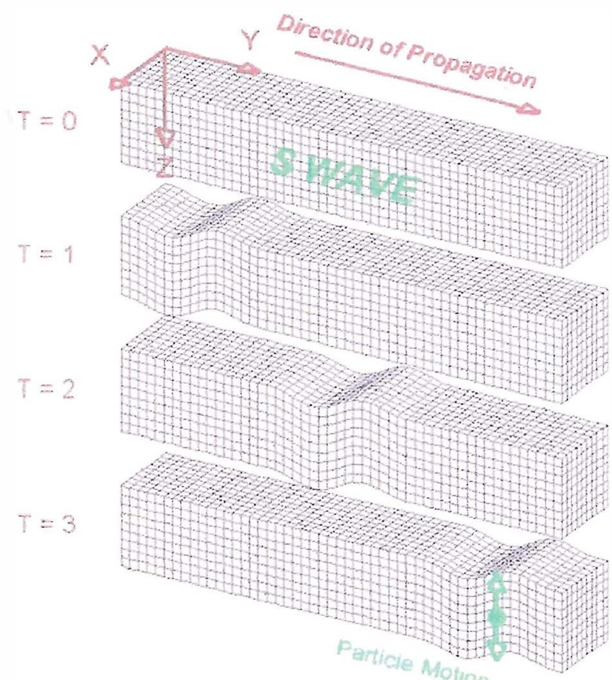


Figure 2: S-wave travels through a medium.

2. **Surface waves:** These waves can only travel on the earth's surface. Since they travel only through the crust, therefore, the surface waves can cause extensive damage and destruction. There are also two types of surface waves (i) **Rayleigh waves** and (ii) **love waves**. Rayleigh waves move the earth's surface in up and down motion. Most of the shaking felt from an earthquake is due to the Rayleigh wave, which can be much larger than the other waves. Love waves move the earth's surface from side-to-side.

2. FAULTS AND EARTHQUAKES

Fault and earthquake

We have already learnt how the earth plates are formed. Due to constant flowing movement of asthenosphere the plates are always under the influence of forces of compression or tension. When compressional forces are much stronger, than the rock breaks in two blocks or parts. The breaking of the rock under stress is called a **fault**. The faults may range in length from a few millimeters to thousands of kilometers. These faults allow the blocks to move relative to each other. This movement may occur rapidly and could result in the fo m of an **earthquake**.

California's San Andreas fault

Types of Faults

During an earthquake, the rock on one side of the fault suddenly slips with respect to the other. The plane (surface) of the fault may lie along the horizontal axis or vertical axis or at some arbitrary angle in between horizontal and vertical axis. The faults can be classified according to the angle of the fault (known as the dip) and the direction of slip along the fault. Faults that move along the direction of the dip plane are called **dip-slip faults** and described as either **normal** or **reverse**, depending on their motion. Both of these faults are shown in Figure 3 and 4.

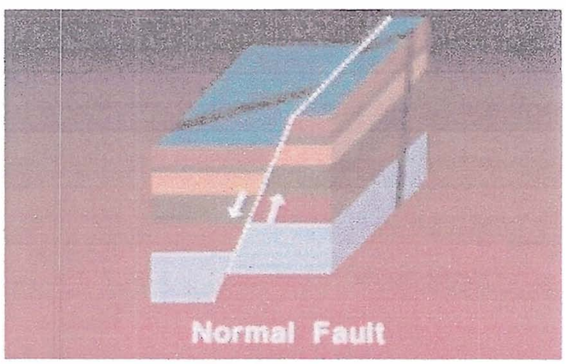


Figure 3

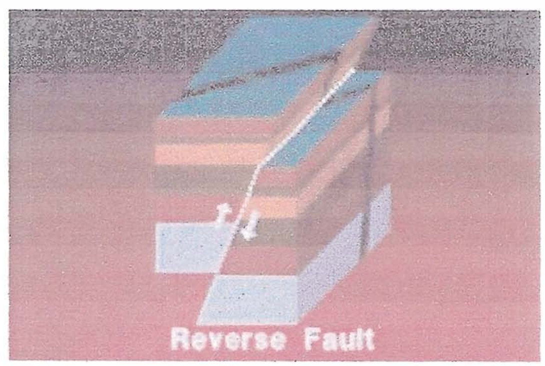


Figure 4

Figure 5

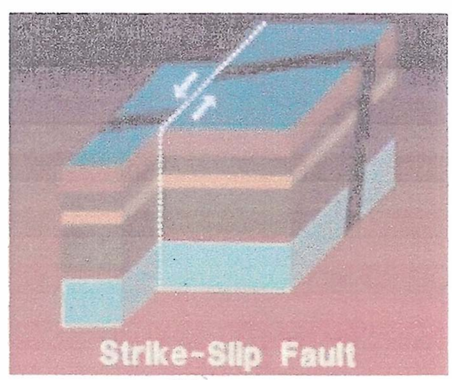


Figure 6

A **thrust fault** (see Figure 5) is also a dip-slip fault in which the upper block, above the fault plane, moves up and over the lower block. A **strike-slip fault** (see Figure 6) is a fault on which the two blocks slide past one another.

EARTHQUAKES MEASUREMENT

As described earlier a seismograph is machine that is used to detect and records an earthquake. A typical seismograph (Figure 7) consists of a very rigid frame fixed with the ground and contains a horizontal revolving cylinder on which a graph paper is rolled. A heavy weight with a pen at its bottom end hangs from the top over the revolving cylinder. When an earthquake occurs the weight and the pen remain fixed in air because of inertia. However, the frame and the cylinder paper move because of earth's vibration. The revolving paper cylinder moves back and forth and the hanging pen records the earthquakes waveform on the graph paper as shown in Figure 8.

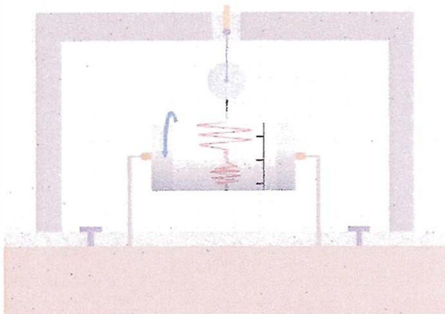


Figure 7: Seismograph

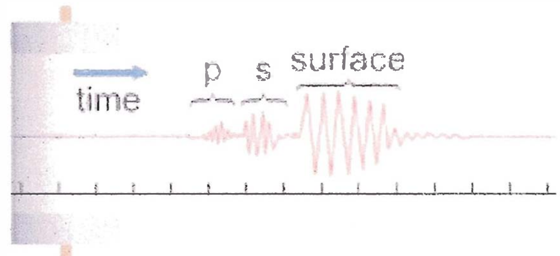


Figure 8: Earthquake waveform graph

Understanding Magnitude

Earthquakes release a tremendous amount of energy, which is why they can be so destructive. The magnitude of an earthquake, usually expressed by the **Richter scale**, is a measure of the amplitude of the seismic waves. This 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. Earthquakes with a Richter value of 6 or more or commonly considered major; great earthquakes have a magnitude of 8 or more on the Richter scale. The Table 1 below shows Richter scale values with the typical effects corresponding to that particular value.

Table 1

Richter scale value	Typical effects
< 3.4	Detected only by seismometers
3.5 - 4.8	Most people notice them, windows rattle.
4.9 - 5.4	Everyone notices them, dishes may break, open doors swing.
5.5 - 6.1	Slight damage to buildings, plaster cracks, bricks fall.
6.2 - 6.9	Much damage to buildings: chimneys fall, houses move on foundations.
7.0 - 7.3	Serious damage: bridges twist, walls fracture, and buildings may collapse.
7.4 - 7.9	Great damage, most buildings collapse.
> 8.0	Total damage, surface waves seen, objects thrown in the air.