Introduction

Earth is a very unique planet in the solar system. It is because of the presence of four dominant environmental segments. They are the Atmosphere, Hydrosphere, lithosphere, and biosphere. Lithosphere is the basic solid sphere of the planet earth. It is the sphere of hard rock masses and hot fluids, extending to more than 6000km inside, to the centre of the earth. The land we live in is on this lithosphere only. All other spheres are attached to this lithosphere due to earth's gravitational attraction. Study of the lithosphere is very essential to understand the lithology, structure, composition, internal processes that affect the external surface features, and the natural resources that are contained in various rock bodies. The interior of the earth can reveal the nature of lithosphere. A knowledge of earth's interior is essential for understanding plate tectonics. Hence, this lesson is about the interior of the Earth.

Objectives:

This lesson is aimed at understanding the following aspects:

1. The study of Earth's Interior
2. The Earth's Internal structure and composition.
3. The Lithospheric Plates .
4. The Earth's Internal processes.
5. The Magma and its emplacements.

The study of Earth's Interior

The study of the Earth's interior belongs to the discipline of earth science.
People know very little about the interior of the Earth.
Most of our present day information, have come from the use of seismological investigations.
The *seismic waves* are capable of reflecting the density variations in the vertical layers of the Earth. It was Isaac Newton, the English scientist who made the first and foremost investigation.

While studying the planets and their forces of gravity, he found that the average density of the Earth is twice that of surface rocks and the Earth's interior must be with materials of much denser composition. This was found about three centuries ago. Our knowledge of the Earth's interior has improved, immensely, since Newton's time.

The currently available information, comes from two sources. They are

a) The studies of the paths and characteristics of earthquake waves travelling through the Earth, and
b) the laboratory experiments conducted on the surface minerals and rocks at high pressure and temperature.

The other important data on the Earth's interior came from various geological observations such as:

a) the properties of surface rocks
b) Earth's motions in the Solar System,
c) Earth's gravity and magnetic fields, and
d) the flow of heat from inside the Earth.

The Earth's Internal Structure

During the course of earth's origin, the **earth's interior** has been sorted out by **Gravity**. The heavier elements like iron tend to sink toward the center of the earth. The lighter materials, the silicates, oxygen compounds and water have risen upward to become part of the surface mass. This action has created very distinct layers within the earth's interior. Based on these variations, the Earth's interior , is found to have three major solid layers. They are the outermost Crust, the middle Mantle and the central Core.

The Crust

The Crust is the outermost layer of the earth on which all living world exists.
This is a very thin layer. It is also a brittle layer. It is ranging from 5 km under the oceans to 100 km under the mountainous areas of continents. The crust is about 0.5 % of the earth's total mass. Usually, it's about 40 km thick under the flat continents.
The crust is made of many types of rocks and thousands of minerals.
These rocks and minerals are made from just 8 elements.
They are Oxygen (46.6%), Silicon (27.72%), Aluminum (8.13%), Iron (5.00%), Calcium(3.63%), Sodium (2.83%), Potassium (2.70%) and Magnesium (2.09%).

The rocks present in the earth's crust are solid, rigid and brittle in nature. They are also highly variable, including rocks of molten origin, rocks of sedimentary origin, and rocks that have undergone all sorts of structural and chemical alterations through metamorphism. The crust itself is divided into two sub-layers as continental crust and oceanic crust. The continental crust is much thicker than the oceanic crust.

Oceanic crust

The crustal mass existing under the oceans is about 10 km thick. It is generally made up of rocks rich in iron and magnesium. The oceanic crust is denser than continental crust. The reason is that this layer is dominated by relatively heavy, dark, dense rocks of "mafic" composition. Most of these mafic rocks are of volcanic in origin and are called "basalts." This dense, heavy mafic layer is sometimes called as "SiMa" denoting its chemistry as silica and magnesium

Continental crust (continental cratons)

This crustal mass make up the continental layer. The continental crust is about 30 to 50 km in thickness. It is made up of igneous, metamorphic, and sedimentary rocks. The continental crust is less dense than the oceanic crust. When the continental crust collides with oceanic crust, through plate movement, the continental crust rides over the top of the oceanic crust while the oceanic crust is pushed back down towards the mantle. This process is called as subduction.

The continental crust is made up of light colored rocks. These rocks are primarily composed of silicates, enriched in lighter elements, such as aluminum (Al), potassium (K), and sodium (Na). Hence, this layer is called as "SiAl" as it is dominated by silicate rocks with lighter elements mixed with aluminum. These rocks are granitic masses. Hence, this layer is normally called as a granitic layer. This is considerably thicker, around 40 km, than the oceanic crust containing the basaltic lower layer.

Zone of Transition

Below this crust, the earth's solid constituents have shown a zone of transition.
The density of the mass is very high and very rigid. Seismic soundings have identified a discontinuity between the crust and this layer. There seems to be a sharp increase in the velocity of seismic waves as they pass into this layer of differing density and rigidity. It was actually a discontinuity. The discontinuities are named based on the inventor who has identified it.

Mohorovicic discontinuity

Andrija Mohorovicic, first noticed this effect, in the year 1909. He found that some of the earthquake waves near the surface, moved slower than the earthquake waves that passed through the interior of the Earth. He also noticed that the P (primary, first and strongest) waves that passed through the interior of the Earth, did move in a straight line. These waves were bent or deflected by something different below. He decided that the outside layer of Crust was made of less dense material (Rock) and the layer existing below. This transition zone was named as Mohorovicic discontinuity. The layer of the earth's interior existing below the crust was named as the mantle. The Mantle was much denser. Waves of all other kinds move faster and straighter through this denser, more solid layer. Based on this observation, the nature of the mantle was identified, further.

The Earth's Mantle

Our knowledge of the mantle was derived mainly from analyses of earthquake waves , heat flow, magnetic, and gravity studies; and laboratory experiments on rocks and minerals. The mantle is the middle layer. This makes up the largest volume of the Earth's interior. It is almost 2900 kilometers in thickness. It is comprised of about 83% of the Earth's total volume. It is also divided into two distinct layers as upper mantle and lower mantle.

The Upper mantle

The upper mantle is about 670 kilometers in depth. It is a brittle and less dense mass. It is made up of peridotites. These are rocks made up of minerals like olivine and pyroxene. These are largely silicate minerals and the rocks are basic in character. These rocks are highly enriched with iron and magnesium, and hence they are called as "ultramafic" rocks. These ultramafic

rocks are dark in color due to the presence of iron and magnesium. These rocks are extremely heavy and dense compared with the typical surface rocks. The rocks in the upper mantle are more rigid and brittle because of cooler temperatures and lower pressures.
The upper mantle is also known as the **asthenosphere**, which flows as convection currents.

The Lower Mantle

The Lower Mantle is much thicker and denser. It is 670 to 2900 kilomteres below the Earth's surface. This layer is hot and plastic. The higher pressure existing in this layer causes the formation of minerals that are different from those of the upper mantle. The mantle varies in its state of matter. It is soft and in nearly liquid condition near its inner boundary.

The Earth's Core:

The core was the first internal structural element identified by the earlier workers. It was discovered in 1906 by R.D. Oldham, from his study of earthquake records. It also helped to explain the Newton's calculation of the Earth's average density. The outer core is presumed to be liquid in nature, because it does not transmit the shear (S) waves. The velocity of compressional (P) waves that pass through it is also found to be sharply reduced.

The inner core is considered to be solid because of the behavior of P and S waves passing through it.

Density of various layers

Mafic rocks contain denser minerals and therefore, oceanic crust is denser than continental crust. The average density of basalt is 3.0 g/cm^3 and granite is 2.7 g/cm^3.
Peridotite is more dense than crustal rocks, with an average density between 3.2 - 3.4 g/cm^3.
The inner core's density is estimated to be between 12.7 - 13.0 g/cm^3, using evidence from seismology.

This table shows the depth-wise variations of the earth's interior.
There is a continuous increase in the density of layers as crust, upper mantle, lower mantle, outer core and inner core. It ranges from 2.2 gm/cc to 13.1 gm/cc. The rock types also vary in these layers.

Table. Data on the Earth's Interior

	Thickness (km)	Density (g/cm^3)		Types of rocks and mineral concentrates found
		Top	Bottom	
Crust	30	2.2		Silicic rocks
			2.9	Andesite, basalt at base
Upper mantle	720	3.4		Peridotite, eclogite, olivine, spinel, garnet, pyroxene
			4.4	Perovskite, oxides
Lower mantle	2,171	4.4		Magnesium and silicon oxides
			5.6	

Outer core	2,259	9.9	12.2	Iron + oxygen, sulfur, nickel alloy
Inner core	1,221	12.8	13.1	Iron + oxygen, sulfur, nickel alloy
Total thickness	6,401			

(Robertson gives credit for most of the data to Anderson, Don L., Theory of the Earth: Boston, Blackwell Publications, 1989.)

Since the average density of surface material is only around 3000 kg/m^3, then we must understand that much denser materials are existing within the Earth's core.

Earth's Core is thought to be composed mainly of an iron and nickel alloy.
The core is the earth's ultimate source of internal heat because it contains radioactive materials. these radioactive materials release heat as they break down into more stable substances.

Gutenberg's discontinuity

Beno Gutenberg discovered the boundary as a discontinuity between the mantle and the outer core. This boundary was named after him, as Gutenberg discontinuity.
The outer core is at 2890-5150 km below the earth's surface.

Inner and Outer Core

The Earth's central Core contains two different layers as Outer Core and Inner Core. The Outer Core is a hot liquid layer and the Inner Core is a hot and solid layer. The outer core is about 2250 km thick. The outer core is known to exist in a liquid state because of the behavior of earthquake waves, particularly shear body waves or secondary waves. The temperature in the outer core is about 4000-5000^{0}C. The molten, liquid iron in the outer core is important because it helps to create the Earth's magnetic field. Liquid cannot respond to shear forces, so it can't transmit shear waves. As a result, there is a seismic shadow on the side of the earth antipodal to an earthquake's epicenter.

The Solid Inner Core

The inner core is 5150-6370 km below the earth's surface. It mainly consists of iron, nickel and some lighter elements , probably sulphur, carbon, oxygen, silicon and potassium. The temperature in the inner core is about 5000-6000^{0}C. Because of the high pressure, the inner core is solid. The solidity of the inner core is due to the presence of iron and nickel. The core is incredibly hot in the centre and the pressure is so great that the melting point of iron and nickel is elevated far beyond those high temperatures (6,500 K), leaving the nickel-iron as solid.

Earth's Magnetic Field

Eearths is like a bar magnet.
Earth's magnetic field is a dipole, (has both a North and South pole)

-Solar wind contains electromagnetic particles that are deflected by earth's field.

These particles distort the shape of earth's magnetic field in space.

-Van Allen belts – two belts in the inner magnetic field where high energy cosmic rays are trapped. Protects us from solar radiation.

The Lithospheric Plates

The lithosphere is broken up into various tectonic plates. There are currently seven or eight major and many minor plates existing on the earth. The lithospheric plates ride on the asthenosphere. These plates move in relation to one another. The movements happen at one of three types of plate boundaries. They are

a) convergent(or collisional)boundaries,
b) divergent boundaries(also called as spreading centers); and
c) conservative transform boundaries.

Dimensions of plates

The size of the tectonic Plates vary greatly. It may be from a few hundred to thousands of kilometers across. The Pacific and Antarctic Plates are among the largest plates on earth. The thickness of the Plates also vary widely. It ranges from less than 15 km for young oceanic lithosphere, to about 200 km or more, for ancient continental lithosphere. Tectonic plates probably got developed in the earlier period of the Earth's 4.6-billion-year old history.

Movement of Plates

The plates are not static bodies. They have been drifting on the surface, ever since-like slow-moving bumper cars repeatedly clustering together and then separating each other. The movement of plates has caused the formation and break-up of continents over time, including occasional formation of a supercontinent that contains most or all of the continents.

Magma and its Emplacements

Emplacement of magma from the earth's interior is another effect. Magma is a fully or partially molten rock mass of the earth's interior. It is usually consisting of silicate liquid. Magma migrates either at depth or to the Earth's surface, where it is ejected as a volcanic lava. A magma is characterized by the interactions of several physical and chemical properties.

These properties include:

a) chemical composition,
b) viscosity,
c) content of dissolved gases, and
d) temperature of the molten mass.

The properties of magma are:

1) Temperature

2) Density
3) Viscosity
4) Gas content
5) Abundance.
6) Chemical composition- major and minor elements.

Formation of Rocks

Magma gets solidified and form the igneous rocks. This process is called as crystallization process. Because oxygen and silicon are the two most abundant elements in magma, it is convenient to describe the different magma types in terms of their *silica* content ($SiO2$).

Types of Magma

There are three types of magma as recognized as:

1. Mafic Magma
2. Felsic Magma
3. Intermediate magma.

The mafic magma have relatively low silica and high Fe and Mg contents.
Mafic magma will cool and crystallize to produce the volcanic rocks like *basalt.*

The *felsic magma* are characterized by relatively high silica and low Fe and Mg contents. The felsic magma will crystallize to produce rocks like *dacite* and *rhyolite*. The Intermediate-composition magmas will crystallize to produce the rock *andesite*. Because the mafic rocks are enriched in Fe and Mg, they tend to be darker in color than the felsic rock types which are lighter in color.

If we look at the evolution of magma, there are two stages of development as
1) Primary melts and
2) Parental melts.

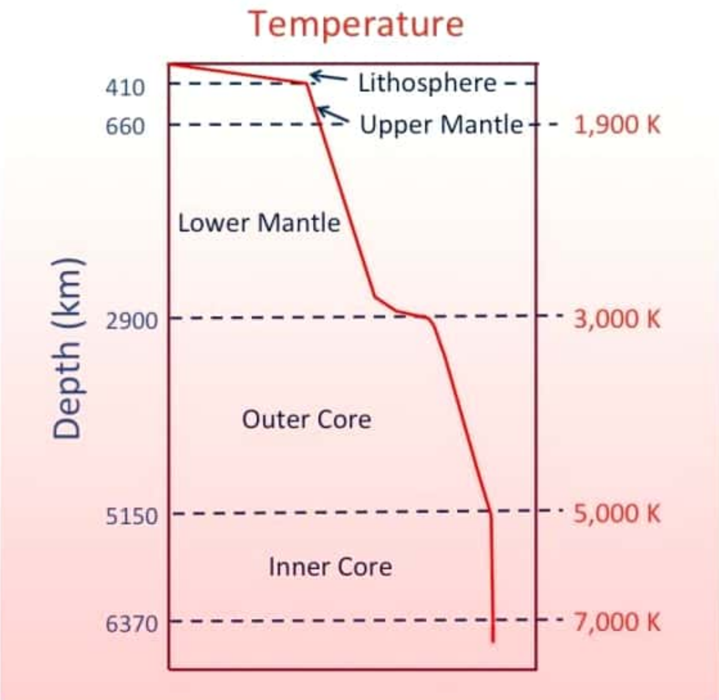
Primary melts are derived from the mantle. Others are derived from the bodies developed from primary melts. It is very difficult to fully understand the scientific mysteries behind many of these internal processes.

Volcanic Eruptions

Magma is the source of all igneous rocks. Emplacement of magma could be seen from the present day volcanic eruptions. A magma has enormous thermal and chemical energy. The magmatic melt is less dense than its source rock and hence it is propelled upward through the lithospheric layers. Not all the magma reaches the surface. Some may intrude and gets solidified well below the surface. On an average, 60 of the earth's 550 historically active volcanoes are in the eruption process every year.

Geothermal Gradient

This diagram shows the vertical variation of earth's temperaturefrom surface to the core.



The rate of increase in temperature of the earth's interior is knows as geothermal gradient. Geothermal gradient is the rate of increasing temperature with respect to increasing depth in the Earth's interior. It varies considerably from place to place. Away from tectonic plate boundaries, it is 25–30°C per km of depth. Away from active volcanic centres, the average gradient is nearly 30^{0}C per km. If this downward rate of increase continued uniformly, the temperature at which basaltic rocks would melt at 1050^{o}C at a depth of about 35 km. It is also controlled by the thermal conductivity of the rock masses.

Radioactive Elements

There is also a heat flow generated by the radioactive elements in various rock types. The major heat-producing isotopes in the Earth are potassium-40, uranium-238, uranium-235, and thorium-232. Heat flows constantly from its sources within the Earth to the surface. Heat from Earth's interior can be used as an energy source, known as geothermal energy.

Conclusion

The interior of the earth is a very unique condition which we have seen on the planet. Research still continues to unravel the truth behind the variations in the density, temperature and magnetic properties. There is also a danger related to the neo-tectonic movements which are generated from the earth's interior. Volcanic eruptions continue to threat the human life and surrounding environments. There is no place on earth which is free from earthquakes. The earth's interior is