CHAPTER 3

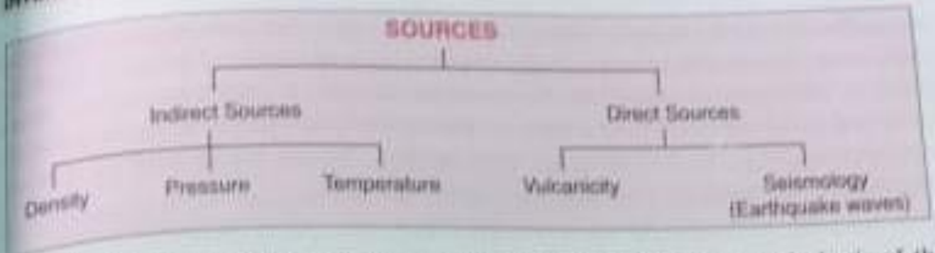
Interior of the Earth

Man's knowledge about earth's interior is very limited. Most of the information about earth's interior is gathered through indirect sources. The deepest mine of the world is Robinson Deep in South Africa from which gold is mined. This is just 4 km deep. In search of oil, man has drilled a hole only about 6 km deep. These depths are negligibly small as compared to the radius of the earth which is 6,370 km. Thus, only the upper part of the earth's crust just below the surface could be known more or less by direct observations. The lower part is beyond the reach of our direct observations and our knowledge about it is based upon indirect scientific observations.

Final conclusions have not yet been drawn regarding the thickness, density, temperature, pressure and the nature of materials found in different layers inside the earth.

However, the general consensus is that the earth's internal structure comprises of more or less concentric layers lying one above the other (Fig. 3.1). The outermost layer is known as ***crust***. Its average thickness is about 33 km. It is the solid layer of the earth which is composed of different types of rocks. Immediately below the crust is the **mantle** which extends upto a depth of 2900 km below the surface. Mantle is divided into two broad layers namely, the **upper mantle** and the **lower mantle**. Part of the **upper mantle** upto a depth of 400 km is known as ***asthenosphere*** and the part between 400 and 650 km is called **transitional zone**. Below the mantle *i.e.*, beyond the depth of 2900 km, there is core of the earth which extends right upto the centre of the earth. It is divided into **outer core** (liquid) and **inner core** (solid). These two layers of the core are separated from each other by a transition zone (liquid) which extends from depths of 4600 to 5151 km.

The sources which provide us knowledge about interior of the earth rare classified into two groups as per following chart :



Efforts have been made to collect information about earth's interior on the basis of the indirect sources. These sources are : (*i*) Density, (*ii*) Temperature, (*iii*) Pressure, and (*iv*) Earthquake waves.

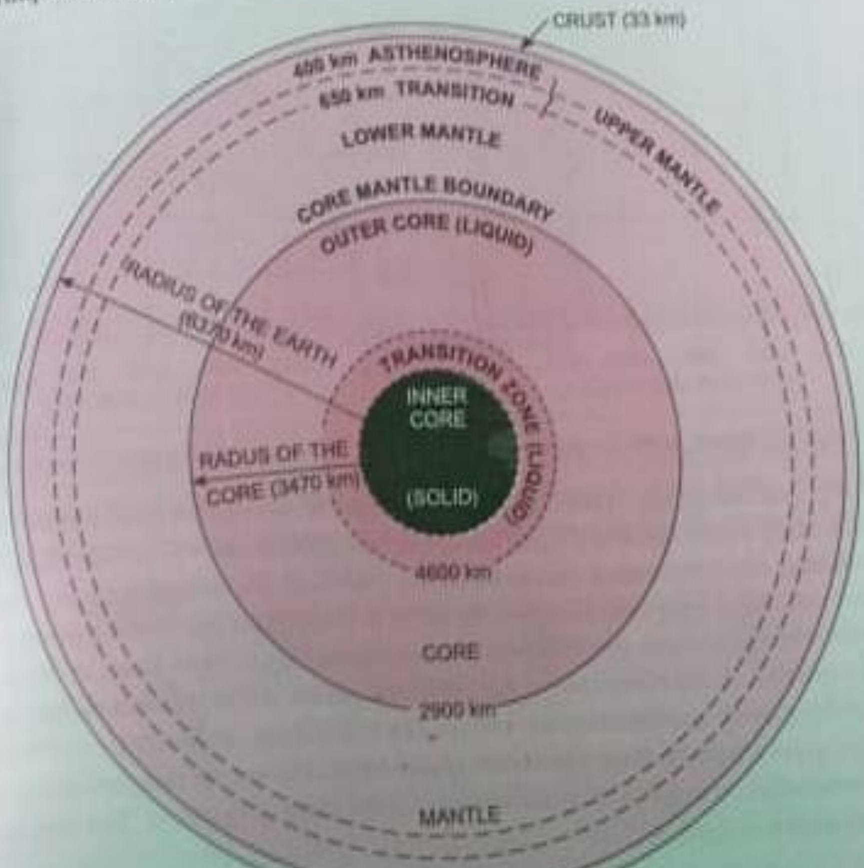


FIG. 3.1. Internal structure of the earth

1. Density. According to Newton's laws of gravity, earth's density as a whole is 5.5. The sedimentary rocks on the surface of the earth have an average density of 2.7. Beneath the sedimentary rocks, there are igneous rocks with average density varying from 3.0 to 3.5. This means that the density inside the earth must be much higher. It is estimated that the ... of the earth has a density of 11-12. It may rise to 13-14 at the centre of the earth (Fig. ... There are two opinions regarding the increased density of the interior of the ... According to first opinion, the increase in density with the increase in depth is due ... pressure of upper layers. According to second opinion, the core itself is made up of ... materials like nickel and ferrous (iron) which have high density.

2. **Temperature.** Digging of mines reveal that there is a gradual increase in temperature with the increase in depth inside the earth. The volcanic eruptions and hot springs further

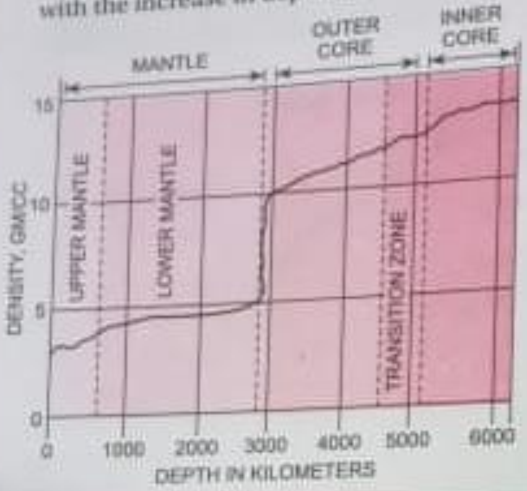


FIG. 3.2. Density inside the earth

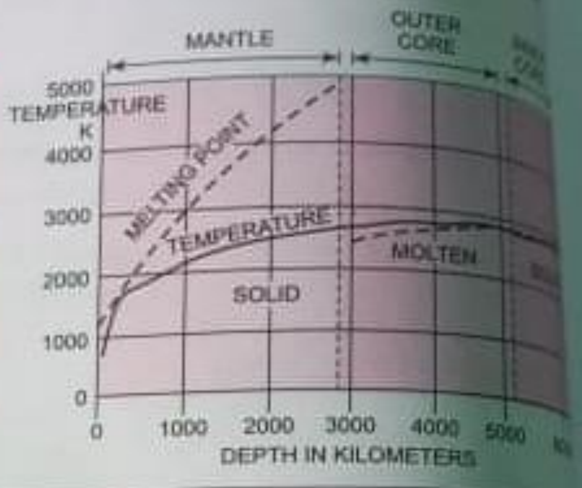


FIG. 3.3. Temperature inside the earth

confirm this fact. According to latest estimates, the rate of increase of temperature is 12°C per km at a depth of 100 km. It is 2°C per km in the next 300 km and 1°C per km below it. By this calculation, the temperature should be nearly 2900°C at the core of the earth. Fig. 3.3 shows that the actual temperature inside the earth is lower than the melting point upto a depth of 2900 km. Therefore, the materials behave like liquids or even gases in this part of the earth's interior. In the outer core of the earth, the actual temperature is slightly higher than the melting point and the materials behave like solids there. This may be due to higher density and pressure there. Near the centre of the earth, the actual temperature is again lower than the melting point. This is indicative of solid state of material. The core mainly consists of nickel and ferrous.

3. **Pressure.** Like density and temperature, pressure also increases with the increase in depth inside the earth. This may be due to the overlying layers or the presence of heavier materials at the core of the earth. It is estimated that the pressure at the centre of the earth is about 3500 kilobars (see Fig. 3.4). It is due to high pressure inside the earth that volcanic eruptions take place and tectonic forces are at work.

4. **Earthquake Waves.** The science of earthquakes is known as ***seismology*** and the

evidences based on earthquake waves are known as ***seismological evidences***. Earthquake waves have proved to be the most important source of information in the recent past. Mohorovicis used earthquake waves for the first time in 1909 to know about earth's interior. Following three types of earthquake waves are normally recorded by a seismograph :

(i) P-Waves. These are also known as ***Primary waves***. They are longitudinal waves like sound waves in which the movement of the particles is in the direction of the propagation of waves (Fig. 3.5). Their average velocity is 8 km per second which is higher than any other waves. **P-waves** can travel through all the mediums including solids, liquids, and gases.

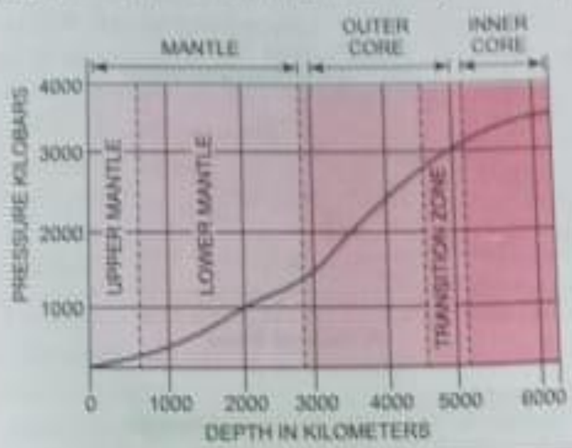


FIG. 3.4. Pressure inside the earth

(ii) S-Waves. These are known as ***Secondary waves*** and are transverse like light waves. The movement of the particles is at right angles to the direction of the waves. Their average velocity is 4 km per second. They can travel through solids only and disappear in liquids.

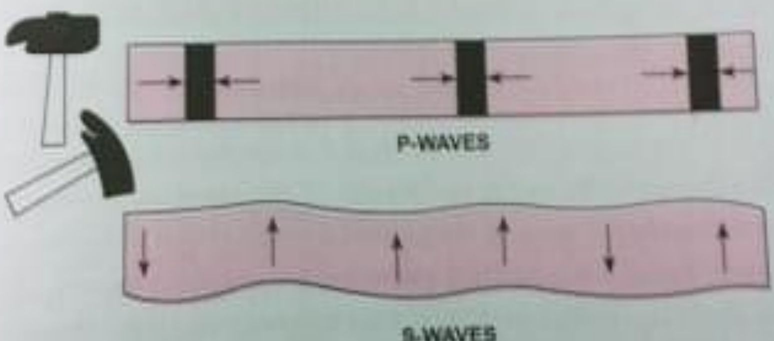
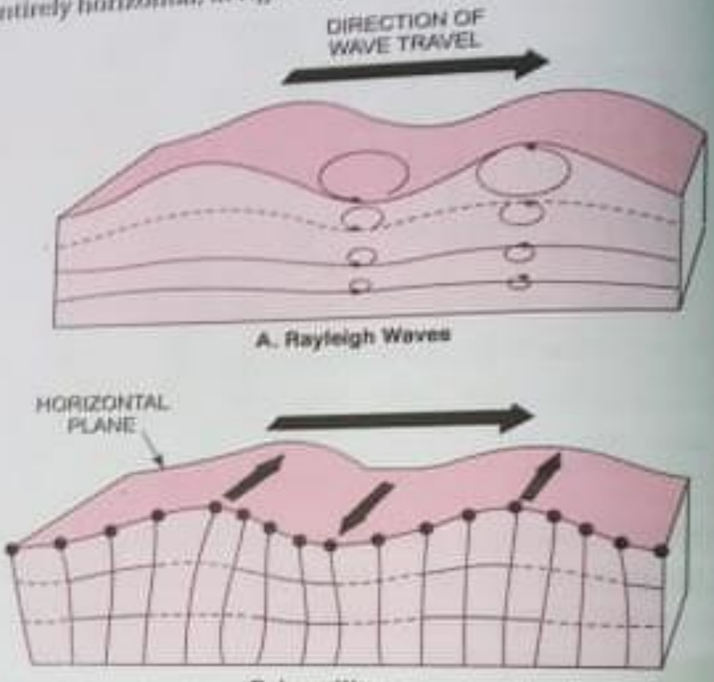


Fig. 3.5. P and S waves

(iii) L-Waves. These are also known as ***Long waves***. They travel along the surface of the earth and are often referred as **Surface waves**. **L-waves** can travel through all the mediums (solids, liquids and gases), but their average velocity is just 3 km per second.

P and *S*-**waves** are of a class called ***body waves*** because they travel through the body of the earth. Body waves are distinguished from **surface waves**, which move along the free upper crust of the earth. Surface waves are of two types ; they travel more or less together, but with different motions (Fig. 3.6). One type consists of **Rayleigh waves**, named after the English physicist, Lord Rayleigh. They can be visualised as water waves travelling across the surface of a still pond after a pebble has been tossed into the water. The second type of surface waves is the **Love wave**, named after the physicist A.E.H. Love. Motion in Love waves is entirely horizontal, at right angles to the direction of wave motion.



A. Rayleigh Waves

B. Love Waves

FIG. 3.6. Forms of surface seismic waves

5. Behaviour of the Earthquake Waves. Fig. 3.7 shows the behaviour of the earthquake waves. There is a change in the course and velocity of the waves on crossing the boundaries of different zones inside the earth. If the ground through which the waves travel is solid, they behave in one way. If it is liquid, the waves behave in a different way. Their velocity in both the cases differ. The earthquake waves suffer reflection and refraction when they travel through different media.

All the three **P, S** and **L-waves** are recorded near the focus of the earthquake. They follow a curved path in the interior of the earth which proves that the density increases inside the earth. **P** and **S-waves** are recorded along the surface upto a distance of 11,000 km from the focus of the earthquake. Their velocity also increases with the increase in depth.

But this process continues only upto a depth of 2,900 km. Beyond this depth, **S-waves** disappear and **P-waves** travel with reduced velocity. This process shows that the core of the earth behaves like liquids while mantle upto a depth of 2,900 km behaves like solids. On reaching the core, **S-waves** disappear and **P-waves** are refracted as a result of which there are no waves for a distance of 5,000 km beyond the 11,000 km mark. This area is known as ***Shadow Zone***. Normally, shadow zone is found between 103° and 143° distance from the focus of the earthquake.

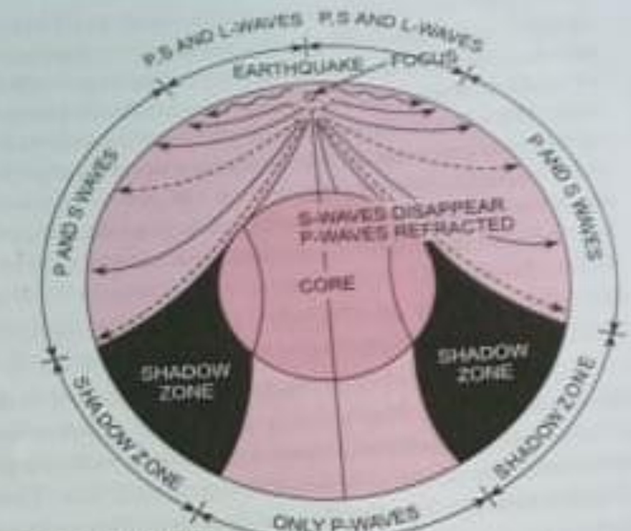


FIG. 3.7. Cross-section of the earth showing diagrammatically the paths of P, S and L-waves

The presence of shadow zone on the surface of the earth shows that earth's core is composed of heavy materials like **nickel** and **iron** whose density is 11-12.

Fig. 3.8 shows that the velocity of **P** and **S-waves** increases with the increase in depth upto 2,900 km *i.e.*, the core-mantle boundary. At this stage there is a sudden fall in the velocity of **P-waves** and the **S-waves** disappear altogether. The velocity of **P-waves** again rises till the centre of the earth is reached.

We are now in a position to discuss the interior of the earth in greater details after studying the behaviour of the earthquake waves. Based on the observations of the earthquake waves, the earth's interior has been divided into three main layers *viz.*, crust, mantle and core.

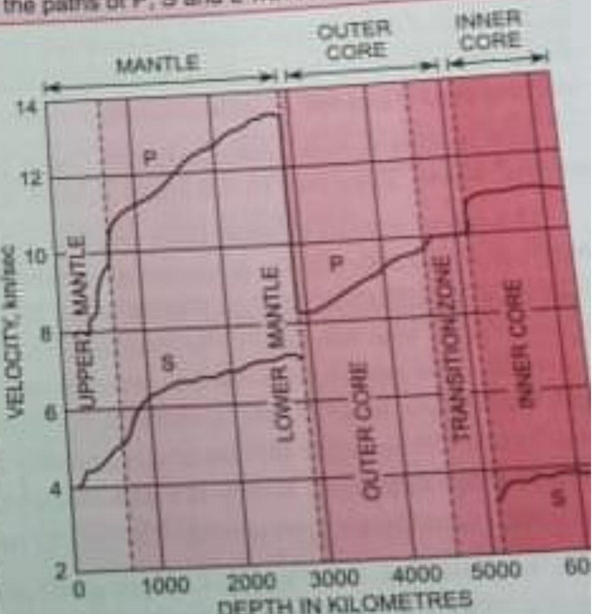


FIG. 3.8. Velocity of P and S-waves inside the e

1. **The Earth's Crust.** It is the outer-most layer of the earth which is very thin as compared to other layers. Its average thickness is only 33 km. It is thicker below mountains and thinner below the oceans. It is a solid layer of the earth which is composed of rocks. It is distinguished from the mantle by abrupt change in the velocity of the seismic rays. The change in velocity of the seismic rays corresponds to change in the rigidity of rocks from crust to mantle which is due to change in mineral composition or in physical state of rocks. **P-waves** travel at a velocity of about 6 km per second at the surface of the earth which increases to about 7 km per second at the base of the crust. The surface of sudden change in velocity separates the crust from the mantle and is known as ***Mohorovicic discontinuity***, also called ***Moho discontinuity*** or simply ***M. discontinuity***. This is named after the Yugoslav seismologist, Mohorovicic, who recognised this discontinuity after the study of earthquake waves of Kulpa valley in Croatia in the year 1909.

2. **The Earth's Mantle.** Below the Mohorovicic discontinuity, it is a very thick layer known as mantle. The velocity of both *P* and *S-waves* increases throughout the mantle layer. But the velocity of *P-waves* reduces drastically and *S-waves* terminate at the mantle-core boundary about 2,900 km below the surface. Thus, there is a plane of discontinuity or surface between the mantle and the core. This is known as ***Gutenberg discontinuity***. It is marked by the abrupt increase in density from 5.5 in the mantle to about 10.0 below the discontinuity (see Fig. 3.2). Velocity of *P-waves* is reduced from 13.8 km per second to 8.1 km per second (Fig. 3.8). The speed of the earthquake waves is so high at 2,900 km depth that only a very rigid and dense rock will withstand such shocks. Solid or rigid in this case means either crystalline or glassy. It also means that when subjected to the sudden twists and bends of earthquake waves the rock behaves as an elastic solid, that is, it changes shape when shear stresses are applied, but returns exactly to its former shape when those stresses are removed. Thus the mantle consists of solid rock.

The mantle is subdivided into two major parts depending upon the behaviour of the seismic waves. They are : (*i*) the upper mantle, and (*ii*) the lower mantle.

The *upper mantle* extends from crust to a depth of about 650 km. Its upper part upto a depth of about 300-400 km is known as ***asthenosphere***. Rocks in the asthenosphere behave as both a plastic solid and an elastic solid. It can be elastic and plastic at the same time depending on whether the forces that tend to deform it are applied and released suddenly or steadily. The presence of the soft layer or plastic layer in upper mantle was suspected by Beno Gutenberg in 1926. He noticed that the velocities of the earthquake waves slowed down below 150 km after first increasing rapidly from the surface to that depth. This zone is called low velocity zone. Below the asthenosphere from 400 to 650 km is the *transitional zone* which separates upper mantle from lower mantle.

3. **The Earth's Core.** Study of seismogram (a seismograph record) has confirmed that there is a spherical core at the earth's centre. If the earth were entirely solid, both *P* and *S-waves* would travel in all directions and the earthquake waves could be recorded directly opposite to its focus. However, it was observed that there is a region on the globe opposite

to the earthquake focus where *S-waves* are not received. This means that *S-waves* cannot pass the central part of the earth. It implies that the core of the earth is liquid because *S-waves* cannot pass through liquids. At the boundary of the core, *P*-waves are refracted and *S-waves* disappear. As such *P* and *S-waves* are not received between 103° and 143° distance from the focus of the earthquake and consequently it is known as ***shadow zone*** (Fig. 3.7). Only surface waves are received in the shadow zone. Beyond 143° only *P-waves* passing through the core and surface waves travelling along the surface are received. After studying the extent of the shadow zone, it has been calculated that the earth's core has a radius of 3,470 km. In other words, the radius of the core is a little more than half of the earth's total radius of 6,370 km.

Structure of Earth's Interior. The structure of earth's interior is therefore layered. The arrangement of layers is comparable to onion with its shells, one inside another. The inside of earth has a shallow crust as thin as an egg shell which can be compared with the size of a ball. Below the surface capped by sedimentary material, upper layer of the crust is mainly composed of crystalline igneous and metamorphic rocks, acid in nature. The lower layer of the crust has basaltic and ultra-basic rocks. The layer of heavier or inner silicates is not found beneath oceans. The oceans are mostly underlaid by dark coloured basalt. The famous Austrian geologist ***Suess*** has divided the earth into three main layers :

(i) Sial. The uppermost layer is mainly composed of Silicon (Si) and Aluminium (Al) and is known as Sial (Si + al). Continents are mostly composed of lighter silica having average density of 2.75 to 2.90. Its maximum depth is 100 km.

(ii) Sima. The second layer is mainly made up of Silica (Si) and Magnesium (Ma) and is known as Sima (Si + ma). This layer has average density of 2.90 to 4.75 and extends upto a depth of 2,900 km.

(iii) Nife. This extends from a depth of 2,900 km. to the centre of the earth. It is mainly composed to Nickel (Ni) and Ferrous (Fe) and is named Nife (Ni + fe). Its density is 11-12.

The following Table gives an idea of internal constitution of the earth.

TABLE 3.1

Name of the Layer	Chemical Composition	Average Thickness	Density	Physical Property
A. (i) Crust or outer part of litho-sphere immediately below the newer sedimentaries on surface.	SIAL (Sedimentary and the gra-nitic rocks) Or outer silicate layer	8 to 45 km (mainly under continents)	2.75 to 2.90	Solid.
(ii) Inner part of lithosphere or the substratum of greater strength.		45 to 100 km (partly under oceans)		Partly molten.
B. (i) Inner silicate layer.	SIMA (in part) (Basic rocks)	100 to 1,700 km. (mainly under oceans	3.1 to 4.75	Some properties of a solid and some like those of plastic materia close to melting point.

(ii) Transitional zone of mixed metals and silicates.	Wholly SIMA (ultra-basic rocks)	1,700 to 2,900 km.	4.75 to 5.00	
[B (i) and B (ii) together constitute the mantle]				
C. (i) Outer metallic core.	NIFE or Barysphere (Heavy metallic rocks)	2,900 to 4,980 km.	5.1 to 13.00	Liquid or in a plastic state. Solid and ... because of tremendous overlying pressure
(ii) Inner metallic core.		4,980 to 6,370 km.		

EXERCISES

I. VERY SHORT-ANSWER TYPE QUESTIONS

1. Name the three layers of the earth.
2. What is the average density of the earth ?
3. Which is the lightest layer of the earth ?
4. What is the most important source of information about the interior of the earth ?
5. Name three main earthquake waves.
6. Name two types of surface waves.
7. Which of the earthquake waves travel fastest ?
8. Name the waves that follow the circumference of the earth.
9. What is a seismogram ?
10. How do rocks of the earth's mantle behave when subjected to the earthquake waves ?
11. What do the curved path of the earthquake waves indicate ?
12. What is the average radius of the earth ?
13. What is the radius of the earth's core ?
14. Why uppermost layer of the earth has been called SIAL by Suess.
15. Name the two main materials of the earth's core.

Answers

1. The Crust, the Mantle and the Core.
2. 5.5.
3. Crust.
4. Earthquake waves.
5. P, S and L waves.
6. Rayleigh waves and Love waves.
7. P-waves.
8. L-waves.
9. A seismograph record.
10. As a solid elastic.
11. The curved path of the earthquake waves indicates that the density inside the earth increases.
12. 6,370 km.
13. 3,470 km.
14. Because it contains Silicon (Si) and Aluminium (Al).
15. Nickel and Ferrous.

II. SHORT-ANSWER TYPE QUESTIONS

1. How is it that our knowledge is based on indirect observations about the structure of the earth's interior ?

2. Into how many layers earth's interior can be divided. Describe briefly the crust of the earth.
3. What are the main evidences of the layered nature of earth's structure ?
4. What is significance of curved paths of earthquake waves in the interior of the earth ?
5. What do you mean by Shadow Zone ? What is its significance ?
6. Distinguish between the following :
   (i) P-waves and S-waves.
   (ii) Body waves and surface waves.
   (iii) Mohorovicic discontinuity and Gutenberg discontinuity.
   (iv) Core and mantle.
7. Write short notes on :
   (i) Density of the earth,
   (ii) Temperature within the earth,
   (iii) Pressure inside the earth,
   (iv) The earth's crust,
   (v) SIAL,
   (vi) SIMA,
   (vii) NIFE.

III. LONG-ANSWER TYPE QUESTIONS

1. What are the main sources of information regarding the interior of the earth. How do the earthquake waves help us in knowing about the interior of the earth ?
2. Discuss how do seismic waves suggest the layering of the earth's interior.
3. Discuss the structure of the earth, giving details about each of its layers or shells and arguments in support of your contention.