When we attempt to describe what lies in the interior of the earth, we are limited in our description because it would involve drilling a hole as deep as 6400 km to reach the centre of the earth. The truth is that hitherto, the deepest hole that has been drilled into the earth is only 16 km deep! Therefore, we cannot know what lies in the interior of the earth by direct methods; we have to rely on indirect methods to know about the structure of the earth’s interior. Although we claim to know much, geologists still believe that this is just the tip of the iceberg.

After having learnt this chapter, you should be able to

- Describe the processes that took place in the primitive earth
- Explain how these processes caused the differentiation of the earth
- Define seismic waves
- List four different kinds of seismic waves
- Point out six differences between P waves and S waves
- Explain how seismic waves are used to determine the thickness of various layers of the earth’s interior using appropriate diagrams
- Outline the methods which are used to find out the composition of the mantle
- Reproduce the theory which explains magnetism of the earth
- Extend this theory to explain magnetism of any other planet
- Summarize the thickness, state, temperature, density and composition of the layers of the earth’s interior using a table

If we examine the theories and hypothesis which attempt to explain the origin of the earth, we can conclude that all these theories have one thing in common – the primitive earth was in a molten state.

**Beginning with the assumption that the primitive earth** was in a molten state about 7 billion years ago, it would follow that the following processes should have happened simultaneously within this molten earth.

1. Lighter elements and minerals moved towards the
1. List the processes which took place in the primitive earth 7 billion years ago.
2. Explain how the earth was differentiated into the crust, mantle, core and the atmosphere.
3. Define ‘wave’ and explain how seismic waves are generated.
4. List four types of waves produced in an earthquake.

**How are seismic waves used to determine the thickness of the crust, mantle and core?**

Consequently, the heavier materials which sank towards the centre of the earth would form the core, the lighter materials which rose to the surface and eventually cooled and solidified would form the crust, the intervening part would form the mantle, and the gases would be confined near the surface of the earth to form the atmosphere and at a later stage, the hydrosphere.

It can therefore be concluded that the interior of the earth would consist of the crust, mantle and the core. How do we verify this?

Most of our knowledge about the interior of the earth comes from the study of the behaviour of seismic waves in the earth. Seismic waves are produced naturally during an earthquake but they can also be produced artificially through explosions.

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There are four kinds of Seismic waves – P or primary waves, S or secondary waves, Love waves (named after the British physicist Augustus Love) an Rayleigh waves (named after the British physicist John William Rayleigh). Out of these P and S waves provide maximum information about the earth’s interior.

The properties of P waves and S waves are summarised in the following table.

<table>
<thead>
<tr>
<th></th>
<th>P waves</th>
<th>S waves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave type</td>
<td>Compressional or Longitudinal</td>
<td>Shear or Transverse</td>
</tr>
<tr>
<td>Waves travel in the</td>
<td>Compressions and Rarefactions</td>
<td>Crests and troughs</td>
</tr>
<tr>
<td>form of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particle movement</td>
<td>Back and forth in the direction of wave propagation</td>
<td>Up and down perpendicular to the direction of wave propagation</td>
</tr>
<tr>
<td>Speed</td>
<td>Fast</td>
<td>Slow</td>
</tr>
<tr>
<td>Destruction caused</td>
<td>Less</td>
<td>Great</td>
</tr>
<tr>
<td>Medium of travel</td>
<td>Travel through all mediums</td>
<td>Do not travel through fluids</td>
</tr>
</tbody>
</table>

**Check your progress – 1**

1. List the processes which took place in the primitive earth 7 billion years ago.
2. Explain how the earth was differentiated into the crust, mantle, core and the atmosphere.
3. Define ‘wave’ and explain how seismic waves are generated.
4. List four types of waves produced in an earthquake.
5. Compare P waves and S waves on the basis of wave type, particle movement and medium of travel.

6. Which type of seismic waves would reach a seismic recording station earlier?

7. Which type of seismic waves cause more destruction? Justify your answer.

Consider the figure above. E is a point on the earth's surface where an artificial explosion is created. As a result of this, seismic P waves travel in all directions. One such P wave travels along the path EB. Upon reaching the crust-mantle boundary (the Mohorovocic Discontinuity, or simply, the Moho), it is partly refracted into the mantle and partly reflected back to the surface of the earth where it is recorded at a seismic recording station R.

Typical P wave velocities in the crust range from 5 km/s to 6.5 km/s. If we know the distance ER and the time that the P wave takes to cover the distance EBR, we can calculate the thickness of the crust \( t \) using the Pythagoras theorem.

Several such experiments indicate that the thickness of the continental crust is 70 to 80 km while the thickness of the oceanic crust is in the range of 10 to 20 km. On an average, the crust can be said to be about 60 km in thickness.

**THE CRUST** – [click here]

![Crust Diagram]

**THE MANTLE AND THE CORE**

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Consider the figure below. An explosion is created at point E on the earth’s surface due to which S waves travel in all directions. Most of them are refracted by the mantle and are received at points \( R_1, R_2, R_3 \) and \( R_4 \). Some of these S waves are blocked by the core, which suggests that it is in a liquid state. This is why no S waves reach the seismic recording station \( R_5 \).

The part of the Earth between the points \( R_3 \) and \( R_4 \) (including \( R_5 \)) is called the S wave shadow zone and the angle formed between these points at the centre of the earth (angle \( R_3CR_4 \)) is always equal to 150\(^\circ\).

Using some geometric principles, it is possible to calculate the radius of the core (CP or CQ), which is perpendicular to \( ER_4 \) (since \( ER_4 \) is a tangent to the circle which represents the core).

The result that we get using this method is that the radius of the core is...
3500 km. Since the radius of the Earth is 6400 km, the thickness of the mantle would be 2900 km.

A point to be noted here is that while S waves are blocked by the core (outer core), P waves are received at $R_5$ and all other stations in the shadow zone. P wave velocities are not uniform throughout the core, which indicates that there is a solid inner core (where the velocity of P waves increases).

Experiments conducted at various places on the earth indicate that the radius of the inner core is 1200 km.

**Check your progress – 2**

1. Briefly describe the method used to determine the thickness of the crust.
2. How are S waves useful in studying the interior of the earth?
3. Is the crust equally thick at all places? If no, state the thickness of the crust at different locations.

**What is the composition of the crust, mantle and core?**

**To watch multimedia click here**

**THE CRUST**
The most abundant rocks in the earth’s crust are granite and basalt. All other rocks within the crust are derivatives of these two basic rocks. Granite consists of silica and aluminium while basalt consists of silica and magnesium. Granite is present on the continental crust, which is why the upper crust is also called sial (from silica and magnesium). Basalt is present on the oceanic crust, which is why the lower crust is also called sima (from silica and magnesium).

**THE MANTLE**
The composition of the mantle cannot be determined directly. Therefore certain indirect methods are used to determine the composition of the mantle.

1. The thickness of the oceanic crust is in the range of 10 to 20 km. Therefore magma from the mantle can directly erupt through submarine volcanoes. A chemical analysis of this lava gives us the composition of the mantle.
2. The velocity of P waves in the mantle is about 8 km/s. Scientists passes P waves through several rocks present on the earth and found that the velocity of P waves equals to 8 km/s in only three rocks, viz. Peridotite, Dunite and Eclogite. It is interesting to note that these rocks are found mostly in the vicinity of submarine volcanoes.
3. It is believed that the primitive earth formed as a result of several meteoritic impacts. It is possible that the composition of the mantle is similar to the meteorites falling on the earth even today. A chemical analysis of meteorites gives results similar to the two methods discussed above.

**THE CORE**
The core of the earth is thought to be made up of mostly two elements – iron and nickel. It is believed that iron and nickel sank to the centre of the earth’s gravity form the molten mass of the primitive earth.

**Check your progress – 2**

1. Explain the terms ‘sial’ and ‘simu’.
2. Briefly discuss three ways in which the composition of the mantle can be determined.
The Earth’s Magnetism

In 1600, the English doctor and natural philosopher William Gilbert was the first to demonstrate the fact that the entire Earth behaves as an enormous magnet.

Although several explanations have been put forward to explain terrestrial magnetism, the dynamo theory is the most widely accepted. This theory suggests that convection currents consisting of positively charged ions of iron and nickel and free electrons within the liquid core behave like the individual wires in a dynamo, which, aided by the earth’s rotation, set up a gigantic magnetic field.

The magnetic poles of the Earth do not correspond with the geographic poles, which are the ends of its rotational axis. The north magnetic pole is presently located in the Canadian Northwest Territories, almost 1,090 km south of the geographic North Pole. The south magnetic pole is presently situated at the edge of the Antarctic continent. These magnetic poles are not constant. In fact, the earth’s magnetic field has changed polarity over geological time. At several periods during the earth’s geological history, these poles were also reversed. It is postulated that the solid inner core rotates more slowly than the outer core, thus accounting for the changing polarity of the earth’s magnetic field.

The properties of the earth’s interior are summarised in the following table.

<table>
<thead>
<tr>
<th></th>
<th>Crust</th>
<th>Mantle</th>
<th>Outer Core</th>
<th>Inner Core</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thickness</strong></td>
<td>60 km</td>
<td>2900 km</td>
<td>2300 km</td>
<td>1200 km (radius)</td>
</tr>
<tr>
<td><strong>Physical state</strong></td>
<td>Solid</td>
<td>Molten</td>
<td>Liquid</td>
<td>Solid</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>0-200 °C</td>
<td>2200 °C</td>
<td>3000 °C</td>
<td>5000 °C</td>
</tr>
<tr>
<td><strong>Density (gm / cm³)</strong></td>
<td>2.9</td>
<td>5.8</td>
<td>8.0</td>
<td>10.3</td>
</tr>
<tr>
<td><strong>Composition</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rocks</strong></td>
<td>Granite, Basalt</td>
<td>Peridoite, Dunite, Eclogite</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Minerals</strong></td>
<td>Quartz, Feldspar</td>
<td>Olivine, Pyroxene</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Elements</strong></td>
<td>O, Si, Al, Fe, Mg</td>
<td>Si, O, Mg, Fe</td>
<td>Fe, Ni</td>
<td>Fe, Ni</td>
</tr>
</tbody>
</table>
1. Describe a theory which satisfactorily explains magnetism in the earth.
2. Under what conditions would the earth’s magnetism cease to exist? Justify your answer using an actual instance of another planet.
3. Why is the inner core solid while the outer core liquid?
4. Using a table summarise the properties of the crust, mantle, the outer core and the inner core.

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Answers to ‘Check your Progress

1. The processes which took place in the primate earth 7 billion years ago are
   a. Lighter elements and minerals moved towards the surface of the primitive molten earth.
   b. Heavier elements and minerals sank down towards the centre of the Earth.
   c. The molten earth started cooling and solidifying from outside in.
   d. Gases began to escape.
2. The heavier materials which sank towards the centre of the earth would form the core, the lighter materials which rose to the surface and eventually cooled and solidified would form the crust, the intervening part would form the mantle, and the gases would be confined near the surface of the earth to form the atmosphere.
3. A wave is defined as a series of disturbances caused in the molecules of any medium due to the propagation of energy in that medium. Seismic waves are generated whenever there is an earthquake. Additionally, they may also be generated artificially by creating explosions.
4. P or Primary waves, S or Secondary waves, Love waves and Rayleigh waves.
5. | Particle movement | P waves | S waves |
<table>
<thead>
<tr>
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<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Back and forth in the direction of wave propagation</td>
<td>Up and down perpendicular to the direction of wave propagation</td>
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<td>Destruction caused</td>
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</tr>
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</table>
6. P waves are the fastest so they would reach seismic recording station earlier.
7. S waves cause the greatest amount of destruction. This is because in S waves, the particle movement is up and down. The molecules on the surface of the earth are free from the upper
side which is why they would vibrate with a greater intensity. In P waves, the molecules vibrate up and down but owing to the closely packed molecular structure of solids, particles vibrate with a lesser intensity.

8. When an explosion is created on the earth’s surface, there are two sets of P waves which arrive at a seismic recording station for a single explosion. The first set of P waves is the one which arrives directly to the recording station. The second set of P waves arrives later since the P waves are reflected from a denser surface (the mantle). Using some geometrical principles and time-distance calculations, it is possible to determine the thickness of the crust.

9. When S waves are made to pass through the centre of the Earth, they do not appear on the other side of the earth suggesting that the outer core must be in liquid state. Using some geometric principles, it is also possible to know the radius of the core.

10. No. The thickness of the continental crust is 70 to 80 km while the thickness of the oceanic crust is in the range of 10 to 20 km.

11. Sial: The upper layer of the continental crust comprising of granitic rocks rich in silicon and aluminum.
   Sima: The lower layer of the continental crust and the only layer of the oceanic crust comprising of basaltic rocks rich in silicon and magnesium.

12. Three ways in which the composition of the mantle can be determined are
   a. By studying the composition of meteorites
   b. By studying the composition of magma erupting from the mantle.
   c. By studying the composition of rocks in which the velocity of P waves is equal to that in the mantle.

13. The dynamo theory suggests that convection currents consisting of positively charged ions of iron and nickel and free electrons within the liquid core behave like the individual wires in a dynamo, which, aided by the earth’s rotation, set up a gigantic magnetic field.

14. If the core cooled down and solidified completely, the earth would lose its magnetism. This is because there would be no convectional currents, no electricity and hence no magnetism. The planet Mars is a classical instance where it has lost its magnetic field as its core has cooled down and solidified.

15. The inner core is solid because the high lithostatic pressure (5500 kms) it is subjected to suppresses the effect of high temperature while the outer core is liquid because the high temperature is not suppressed by the lithostatic pressure (2900 kms).

16. Refer the above mention table.