UNIT 1 ORIGIN AND FORMATION OF THE EARTH

Structure

1.0 INTRODUCTION

Our Universe which is almost 13.8 billion years old is an outcome of commonly accepted ***Big Bang theory***. The Universe broadly comprises galaxies and stars. Our Solar system is part of the galaxy ***'Milky Way'***. The Milky Way galaxy probably comprises tens of billions of other solar systems identical to ours!!! Our Solar system comprises Sun (the star at the centre) and its planets i.e. Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune which revolve around it. Pluto was earlier considered the ninth planet of the solar system but has been lately in the year 2006 deprived of the fame by the International Astronomical Union! The erstwhile ninth planet Pluto is no longer considered a planet. The eight planets are further divided into the inner set of planets and outer set of planets. The inner set of planets comprises the first four planets nearer to Sun i.e. Mercury, Venus, Earth and Mars. Our earth is one of the inner four planets. These inner planets are also known as terrestrial planets. The four planets Jupiter, Saturn, Uranus, and Neptune are designated as outer planets (Figure 1.1). Besides these planets the solar system has dwarf planets, asteroid belt, comets and other smaller celestial bodies.

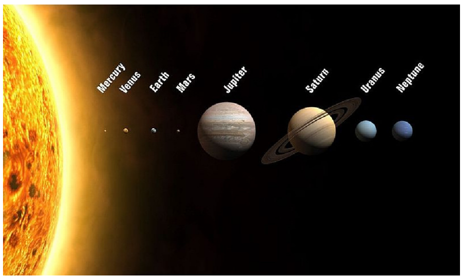

Figure 1.1 Solar system with sun and its planets.
(Source: commons.wikimedia.org)

1.1 OBJECTIVES

Recollect your school days when you were taught about the solar system. Our Solar System, minor part of Universe, consists of Sun and its planets. The Solar System started forming some 4.6 billion years ago. It is important to know about the solar system and how it came into being. It is also important to understand the formation of the planets. In this unit we will learn about the Solar System and its components. To be precise about earth and its attributes i.e. the structure and composition of earth, thermal, magnetic and gravitational fields of earth, atmosphere and hydrosphere of earth. We will also learn about the geological time scale which is scale devised to record the activities taking place on earth since its inception, i.e. approximately 4.6 billion years!

After reading this unit you will be able to:

- explain the formation of Solar system;
- describe the concept of inner and outer planets;
- explain the formation of Earth;
- discuss the internal structure of Earth; the atmosphere and hydrosphere of Earth;
- describe the gravitational, thermal and magnetic fields of Earth; and
- Outline the concept and significance of geological time scale.

1.2. SOLAR SYSTEM FORMATION AND PLANETARY DIFFERENTIATION

The ***nebulae hypothesis*** is the most commonly accepted hypothesis to explain the formation of our solar system. The nebulae (gaseous material) were composed predominantly of hydrogen and helium gases besides dust sized material chemically identical to materials found on earth. The nebula was supposedly rotating slowly under the influence of gravity. This slow rotation of the dispersed nebulae led to its contraction because of the influence of gravity. The contraction further led to faster rotation of the material and finally flattening of the nebulae into a disk shape. Gravity resulted in the accumulation of matter of the nebulae at the centre giving rise to a proto-Sun, the predecessor of present Sun. The matter in the proto-Sun condensed, and its temperature also rose higher to millions of degrees. This led to nuclear fusion where hydrogen atoms combined to form helium. Partial mass of the proto-Sun converted into energy released in the form of sunshine.

> In 1755, the German philosopher Immanuel Kant proposed **nebular hypothesis** for the origin of the solar system**.**

The proto-Sun concentrated most of the matter from the initial homogeneous nebulae. The subordinate, minor, leftover material from the nebulae formed ***solar nebula*** comprising a disk of gases and dust surrounding the proto-Sun. The solar nebula flattened into a disk with condensed, higher temperatures in the inner region and less dense outer regions. Gravitational attraction led to accretion of fine dust materials into ***planetesimals,*** i.e. few kms in size**.** The planetesimals collided and combined to form larger bodies i.e. the size of moon. This continued with more collisions under the effect of gravity, finally giving rise to the ***planets.*** The process of planet formation was completed approximately in a time span of 10 million years after the condensation of the nebula. The inner four planets are known as terrestrial planets owing to their being like earth. The volatile materials from these planets were boiled away because of their nearness to sun and also blown away by the solar winds far off from the sun forming the cold, gaseous outer planets. The inner planets comprise rock-forming silicates and metals like iron and nickel. The outer giant planets are probably formed of rocky (silica- and iron-rich cores) rimmed by liquid hydrogen and helium. Pluto after losing its glory as a planet is given the status of a ***dwarf planet*** composed of a frozen mixture of gases, ice, and rock. The solar system has an ***asteroid belt*** between Mars and Jupiter which hosts the planetesimals/asteroids. The asteroid belt has over 10,000 asteroids (size of the asteroids varies between > 10 km and dŠ 930 km). The largest asteroid is Ceres with a diameter of 930 km. The tiny broken pieces from asteroids strike earth and are called ***meteorites***. ***Comets*** are aggregates of dust and ice. There are probably many millions of comets present beyond the outer planets. At times, a comet enters the inner solar system identified as a bright object with a tail of gases.

1.3. FORMATION OF THE EARTH AND ITS INTERNAL STRUCTURE (CORE, MANTLE AND CRUST)

In this section we will learn about the birth of our planet 'Earth'. Earth is composed of three layers i.e. ***Core*** (inner most part); ***Mantle*** (the middle layer between the core and the crust); C*rust* (the outermost layer). Was earth from its inception at about 4.56 billion years, a differentiated body (comprising layers) or was homogenous. Did the structure of earth change with passaging time? When did the oceans and water bodies formed on the earth? How did the atmosphere on the earth formed or changed from the initial atmosphere, which became conducive to survival of various life forms. When did life originate on this blue planet? Are all the continents at the present time stationed at the same location during the past 4.5 billion years time span, or have they occupied different positions? We will try to understand the forces operational within earth which led to the differentiation of earth's internal structure. The internal and external geological processes will be briefly discussed which shaped the earth from its inception to the present state. We will try to answer the above questions.

> The oldest rocks (3.7-3.8 billion years) have been found in western Greenland. Rocks from southern Africa, western Australia, and the Great Lakes region of North America are also dated at 3.4-3.6 billion years. The oldest dated minerals viz. tiny zircons crystals at 4.0-4.2 billion years are found in sedimentary rocks in western Australia.

The earth no doubt probably formed by accretion of planetesimals and other materials from solar nebula. The earth was hot and molten at its time of inception/early stages. The ***gravitational differentiation*** (formation of different layers of earth) started around 4.4 billion years ago. The innermost layer is the ***Core,*** followed by the intermediate layer M*antle* and the outermost layer ***Crust*** (Figure 1.2). The three layers are different in terms of physical and chemical properties. The Earth's internal structure is proposed based on seismic waves which behave differently in different layers depending on the composition and physical nature of these layers. The two types of seismic waves i.e. P (compression) and S (shear) waves travel at different speeds and are also reflected and refracted from the boundaries marked between different layers through the Earth.

Iron-nickel segregated into the innermost core part, whereas the lighter material i.e. silicates formed in the uppermost layer of crust. The intermediate layer had both light and heavy materials which formed the mantle. The lighter material also dissipated heat from the interior to the surface, thus cooling the earth. This heat transferred from interior of earth to surface is also defined as primordial heat. This source of heat along with radiogenic heat is responsible for melting of mantle rocks and is identified as potential cause of plutonism and volcanism on earth till date. The differentiation process also led to formation of oceans and atmosphere. The internal and external geological processes were also set and the face of the earth formed and to date it is changing. All this make us believe that earth is a dynamic planet!

The earth's core is composed of iron and nickel predominantly. This part of earth is under extreme pressures up to 330-360 GPa. The core which is confined between 2890 Km to 6370 Km is further divided into inner core and outer core. It was possible to study the nature of the core with the help of seismic waves. The inner solid core extends from 5150 Km to 6370 Km, whereas the outer core which is molten extends from 2890 Km to 5150 Km. The mantle is the intermediate layer sandwiched between the core and the crust. This layer extends from the base of crust (which varies from the average depth of 60-80 Km in case of continental crust and 5-10 Km in case of oceanic crust to 2850 Km. The mantle is an important link between the core and crust. The heat from the interior of the earth is transferred by convection in the mantle to shallower depths. It comprises material intermediate in density between the materials of the core and crust. This all information has been possible through seismic wave data retrieved from different depths. Earth's crust is the top most layer, which is the least dense compared to the mantle and core. It is further divided into oceanic crust and continental crust. The oceanic crust is thinner (avg. 5-10 Km) and denser compared to continental crust which varies in thickness from 30-100 Km and is less dense (Figure 1.2).

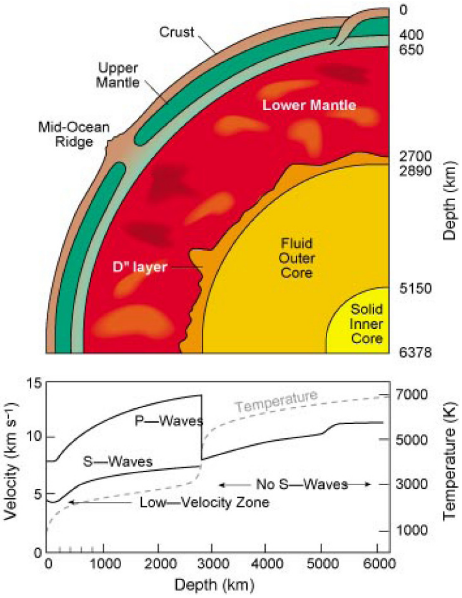

Figure 1.2: Structure of the Earth.
(Source: https://ase.tufts.edu/cosmos/print_images.asp)

Check Your Progress 1

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

Short question-answer

1. Name the different layers of earth.

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2. What is the average thickness of oceanic crust.

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Descriptive Question-Answer

3. Briefly discuss the formation of earth.

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4. Briefly discuss the components of solar system.

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1.4 COMPOSITION OF CRUST, MANTLE AND CORE

The enormous pressures and very high temperatures inside the earth make it impossible for us to venture inside earth even up to a few meters. The underground mining has at the most been carried out up to 10 km in rare cases. Thus, the nature of the lower crust, mantle and core materials is assessed by indirect geophysical data's. The nature of lower crust and upper mantle can be partially assessed by magmas which originate at these depths. It is through rocks like kimberlites and lamproites and some types of basalts (source magmas originate in mantle depths) which are enriched in xenoliths (from lower crust and upper mantle) that we have direct access to these deeper rocks. Otherwise to assess the physical nature (temperature, density etc) we have to rely on the indirect geophysical methods such as seismic wave data. The seismic wave data from different depths have been instrumental in deciphering the structure and composition of earth to a satisfactory level. Once information on the pressure, temperature, gravitational, magnetic fields and composition of the different layers are assessed, the same conditions are replicated in the high pressure-temperature laboratories where stability range of different minerals are assessed and thus we get a fair idea of what material the deeper earth is made up of. The velocities of P and S waves vary in different layers of earth depending on the density of the rocks which make up these layers. The P-wave velocities are higher for denser rocks (Table 1).

Table 1.1: Seismic wave velocities through different rock types

Rock type	Typical rocks of	Velocity of P waves	Density
Granite	Upper continental crust	6 Km/sec	2.6 g/cm^3
Gabbro	Oceanic crust	7 Km/sec	2.9 g/cm^3,
Peridotite	Upper mantle	8 Km/sec	3.3 g/cm^3

Since the P-wave velocities in upper continental crust matches well with granitic rocks, we conclude the continental crust comprises average granodiorite composition (member of granitic clan rock). The oceanic crust based on matches with P-wave velocity shows that it comprises basaltic/gabbroic material (through ocean floor dredging we also know that ocean floor has basalts!).

The seismic waves also helped in identification of ***Mohorovic¡ic´ discontinuity*** which is commonly addressed as ***Moho,*** which divides the crust and mantle. At the Moho the wave velocity is 8 Km/sec. This shows the rocks beneath i.e. mantle are denser compared to the crustal rocks. The mantle is 2850 km thick and extends from the base of the crust to 2890 Km. The P-wave velocity of 8 Km/sec shows that the **upper mantle** rocks are composed of peridotites (Table 1). The peridotites are ultra-mafic rocks (silica deficient and enriched in magnesium and iron).

The upper mantle comprises minerals such as olivine and pyroxene with Mg rich garnet pyrope. The upper mantle extends up to 410 km from the Moho. ***Lithosphere*** is the rigid, brittle layer and encompasses the upper 100 kms comprising the crust and upper part of mantle. The base of the lithosphere is marked by a ***low-velocity zone (LVZ).*** It is the zone where low percent partial melting takes place. This zone is identified based on S-waves which decrease in speed owing to melts present in this zone (S-waves cannot pass through liquids). The low-velocity zone also marks the beginning of ***Asthenosphere,*** which is a ductile layer. The LVZ extends up to 200 to 250 km below oceanic crust whereas it is poorly constrained beneath the stable continental cratons. From depth 410 km to 670 km, commonly known as ***transition zone***, mineral phases change to high pressure polymorphs because of continuous increase in pressure (**Note:** the phase change takes place in terms of structure and not composition). The mineral phases which forms are denser with more closely packed crystal structures. The ***lower mantle*** beyond 670 km (i.e. the transition zone) is relatively homogeneous up to 2890 Km. At the core-mantle boundary i.e. 2890 Km, a drastic change in the velocity of P waves is encountered i.e. a drop from 13 Km/sec to 8 Km/sec. The S-waves do not pass through the area beneath this boundary indicating it to be of liquid nature. Seismic wave data indicates that the outer core is liquid in contrast to the metallic solid inner core. The core of the earth is made up of iron and nickel making the inner core the densest part of the earth. The other two elements speculated to be the parts of core are oxygen and sulphur.

1.5 THERMAL FIELD, MAGNETIC FIELD AND GRAVITATIONAL FIELD OF EARTH

1.5.1. Thermal Field of Earth

The earth has an internal heat engine which is evident through volcanism at places on earth such as mid-oceanic ridges, along ring of fire etc, to name a few. Also at many places hot springs and geysers are as well surface manifestations of earth's internal heat. The two principal sources of heat responsible for earth's internal heat engine are: Primordial heat and heat generated through decay of radioactive elements such as U, Th, K etc. The most important source is the primordial heat, which is the heat given out since the inception and differentiation of earth. The other important source of internal heat is the heat given out by radioactive elements concentrated in the earth (especially in the crust). Convection is the most important process by which heat from the deep earth is convected to shallower depths. The heat transfer in lithosphere is by a process called conduction. It has been possible to measure temperatures at depths up to 10 km (inside mines and boreholes). The geothermal gradient is measurement of change in temperature/increase of temperature with depth inside earth. The geothermal gradient varies from place to place inside earth. The average geothermal gradient is 25-30^{o}C / km in the crust. The geothermal gradients at depth have been inferred through measurements made on lavas and rocks which solidified from these lavas. The figure 1.3 fairly indicates geothermal gradient inside earth. The geothermal gradient is very steep near Earth's surface. If we try to extrapolate the temperatures inside earth based on the geothermal gradient, it will lead to very high temperatures i.e. tens of thousands of degrees in the core which is actually not the case (Figure 1.3). The geothermal gradient can be as low as 10^{o}C/Km in subduction environments where cold oceanic crust is subducted. The geothermal gradients can be as high as 80^{o}-100^{o}C / km at mid ocean ridges where lavas are erupted continuously.

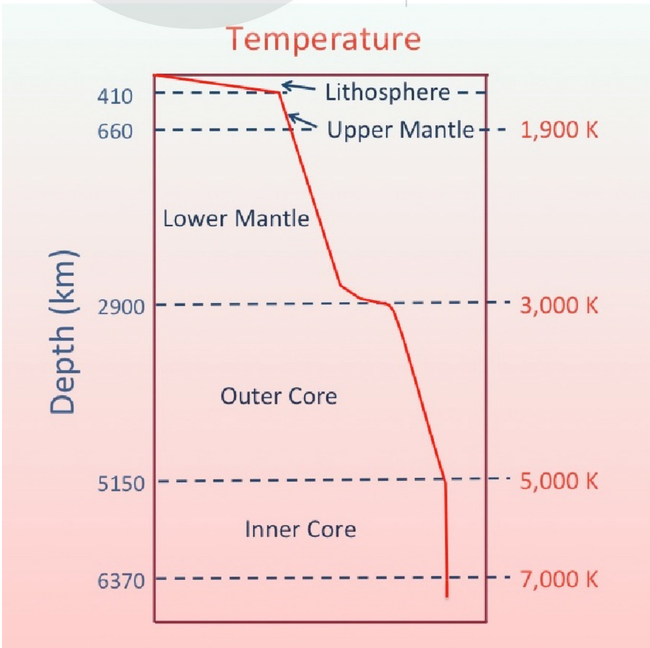

Figure 1.3: The geothermal gradient inside earth.
(Source: commons.wikimedia.org)

1.5.2. Magnetic Field of Earth

We learnt in the preceding section about the structure and composition of different layers of the Earth. The outer core is the molten layer of earth which comprises iron and nickel. The Earth's magnetic field is attributed to this molten outer core. The convective currents in the molten outer core which is composed of iron-nickel produces electric field and thus a large ***Geodynamo*** is created which produces a magnetic field which has its affect not only inside the earth or its surface but extends up to earth's atmosphere and also far into outer space. Around 400 years back it was believed that the Earth had a bar magnet at its centre inclined about 11° from this rotational axis responsible for the earth's magnetism. This contention was put to rest since earth's core has very high temperature and it has been proved through experiments that a permanent magnet will get destroyed at temperatures beyond 500^{o}C. Thus the earth's magnetism is being continuously produced and maintained by the electric field generated due to the convecting outer liquid core. Earth's magnetic field keeps changing and the same has been observed in the past (many magnetic reversals have been recorded in the ocean floor in the geologic past; Figure 1.4).

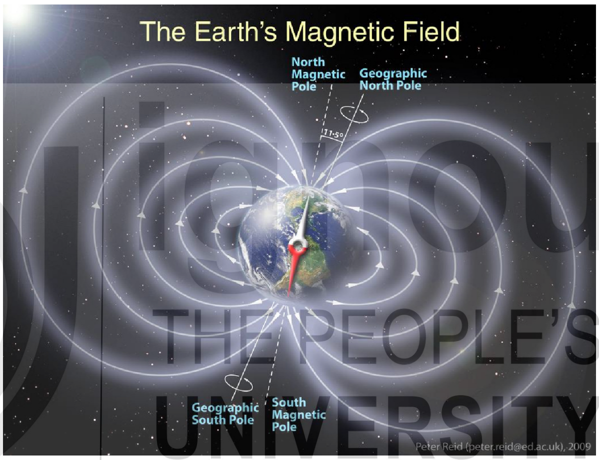

Figure 1.4: Schematic illustration of the invisible magnetic field lines generated by the Earth, represented as a dipole magnet field.
(Source: https://www.nasa.gov/mission_pages/sunearth/news/gallery/060410.html).

1.5.3. Gravitational Field of Earth

The gravitational field of earth can be said as a force between the object (with mass) and the centre of the earth. Earth's gravity is because of its mass. The gravity of Sun is responsible for keeping the planets of our Solar system in orbit.

The gravity of earth is responsible for the moon in its orbit. Earth's gravity is responsible for our atmosphere. Earth's gravity is responsible for our feet on earth! Earth's gravity is responsible for our existence on this blue planet! Let us also remind ourselves that it is not simple to define the gravitational field of earth as it sounds. It depends on many factors and is experienced differently at different locations on earth. For example an area on earth will have strong gravity if it has more mass in the subsurface compared to an area with less subsurface mass. The GRACE (Gravity Recovery And Climate Experiment) mission of NASA uses spacecrafts to measure the variation in earth's gravity.

Gravity is a natural force in which things with mass are brought towards each other. The more the mass an object possesses, the more the gravity it exerts on the surrounding objects. The reason everything is pulled towards the earth is the mass of the earth compared to the objects on it. Gravity was a major force in the evolution of the early Universe and its components. It was responsible for the formation of first stars, galaxies, planets, etc. It was the reason earth formed and differentiated into three layers viz: Crust, Mantle and Core.

Check Your Progress 2

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

Short question-answer

1. Give compositions of different layers of earth.

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2. What is a Geodynamo?

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Descriptive Question-Answer

3. Discuss the gravitational field of earth.

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4. Briefly discuss the geothermal gradient of earth.

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1.6 ATMOSPHERE AND HYDROSPHERE OF EARTH

The total water present on, above and under earth comprises the hydrosphere, whereas the atmosphere is defined as the outer gaseous layer of the earth held intact by gravity.

The atmosphere and hydrosphere are an integral part of earth and evolved with time since the birth of earth, i.e. around 4.56 billion years ago. The earth aggregated from smaller bodies like planetesimals which contained volatile components such as H_2O, carbon, carbon dioxide and nitrogen. Some minerals making up rocks had volatiles locked up in them. These volatiles got released during various geological processes which segregated earth into different layers. The volatiles were continuously released through volcanic activity/volcanism on earth's surface, which started since the inception of earth. The present volcanoes at the various plate margins emanate volatiles such as water, carbon dioxide, hydrogen, carbon monoxide and nitrogen. The water and other volatiles on earth would have also been added through extra terrestrial bodies that kept hitting the earth when it formed. The initial earth's atmosphere and oceans were impacted more by voluminous bombardment of extraterrestrial bodies with the early hot earth thus contributing to the various volatiles.

Earth's atmosphere is a consequence of Earth's gravity. The Earth's atmosphere is divided into five main layers: 1. the exosphere (farthest layer from earth's surface); 2. the thermosphere; 3. the mesosphere; 4. the stratosphere and 5. the troposphere (nearest layer to the earth's surface). It comprises gases enveloping the Earth. The two major components of the Earth's atmosphere comprise Nitrogen (78.1%) and Oxygen (20.9%). It has trace amounts of Argon (0.9%), Carbon Dioxide (~ 0.035%), Water Vapor, and other gases (neon, helium, methane, krypton and hydrogen). Atmosphere also has solid particulate matter viz. ash, dust, volcanic ash, etc. The Earth's atmosphere is a protective layer which absorbs harmful ultraviolet rays emitted from the Sun. The earth's atmosphere merges with outer space at an imaginary line known as Karman line at approximately 100 kms from the earth's surface. The **troposphere,** closest layer to the Earth's surface is 7 to 20 km thick and contains half of Earth's atmosphere. It contains almost all the water vapor and dust in the atmosphere. The clouds are formed in this layer. The **stratosphere** starts from where troposphere ends and is about 50 km above earth's surface. This layer with abundant ozone absorbs harmful radiation from the sun. The jet aircraft and weather balloons fly in this layer. The **mesosphere** begins at 50 km and extends up to 85 km. This layer is not well studied and according to scientists, meteors burn up in this layer. The **thermosphere** starts from about 85-90 km to between 500-1,000 km. The space shuttles fly in this zone and the International Space Station orbits Earth in this layer. The **exosphere**, the farthest layer from the earth's surface, is very thin with hydrogen and helium and it merges into outer space.

1.7 GEOLOGICAL TIME SCALE

The geological time scale has been devised to understand the geological evolution of earth regarding time. The International **Geological Time Scale** is prepared and regularly updated by the **International Commission on Stratigraphy (ICS) under the aegis of the International Union of Geological Sciences (IUGS).** The International **Geological Time Scale** starts at 4.56 billion years when the earth formed to the present time. It records the evolution of earth vis-à-vis geological events, life (which includes all life forms from cyanobacteria, unicellular organisms to the present-day humans), hydrosphere and atmosphere. The most important basis of formulation of this scale is rocks, fossil record and stratigraphic units. The International **Geological Time Scale** has been divided into Eons, Eras, Periods and Epochs. The broadest division of the Geological time scale is into four Eons viz: Hadean, Archean, Proterozoic and Phanerozoic (Figure 1.5).

Hadean, Archean and Proterozoic are together referred to as Precambrian i.e. time before the Cambrian which is the oldest Period of Phanerozoic Eon. The Precambrian encompasses the major part of the Geological time scale almost 4000 Ma. Hadean eon is the earliest Eon which started at ~4.6 Ga and ended at about 3.9 Ga ago. This was the time when earth was forming by cooling and records of felsic crust during Hadean can be ascertained based on zircon dates at 4.4 billion years. Archean eon began at 3.9 Ga and continued up to 2.5 Ga ago. Archean is further divided into Eo-archean, Paleo-archean, Meso-archean and Neo-archean eras. During Archean the continents came into existence and plate tectonic was an important geological phenomenon. First signs of life in the form of fossils of uni-celled microorganisms have been reported from Archean Era. Proterozoic eon began at 2.5 Ga and lasted until 0.542 Ga ago. The Proterozoic Eon is also further divided into Paleo-proterozoic, Meso-proterozoic and Neo-proterozoic eras. This Eon was marked by fully functional plate tectonics and well developed climate systems. During Proterozoic Eon the oxygen in Earth's atmosphere gradually increased. Phanerozoic Eon began at 0.542 Ga ago and is continuing to the present. The Phaanerozoic Eon has been further divided into three Eras viz: i. the oldest Paleozoic; ii. Mesozoic and iii. Cenozoic. The Paleozoic is further divided into six Periods namely, Cambrian (541-485 Ma), Ordovician (485-444 Ma), Silurian (444-419 Ma), Devonian (419-359 Ma), Carboniferous (359-299 Ma) and Permian (299-252 Ma). The Mesozoic Era has been divided into three Periods namely, Triassic (252-201 Ma), Jurassic (201-145 Ma) and Cretaceous (145-66 Ma). The Cenozoic Era has been divided into three Periods namely, Paleogene (66-23 Ma), Neogene (23-2.58 Ma) and Quaternary (2.58 Ma to the Present). Different life forms proliferated with the onset of the Phanerozoic eon. The Stage Meghalayan from India has been a recent addition to the Quaternary Period of the International Chronostartigraphic Scale, which started at 0.0042 Ma. So we are living in the Meghalayan age!

The boundaries between different time Periods were carefully marked based on stratigraphic and fossil break and appearance of index fossils. The Precambrian and Paleozoic boundary marks the first appearance of animals with the hard parts. The major boundaries also mark mass extinctions. The most significant mass extinctions which wiped about 95% of the living forms were recorded at the Paleozoic-Mesozoic boundary i.e. Permain-Triassic boundary also known as P-T boundary. The second significant mass extinction was recorded at Mesozoic-Cenozoic boundary i.e. Cretaceous-Paleogene boundary when 75% of the life forms thriving in the Cretaceous period perished.

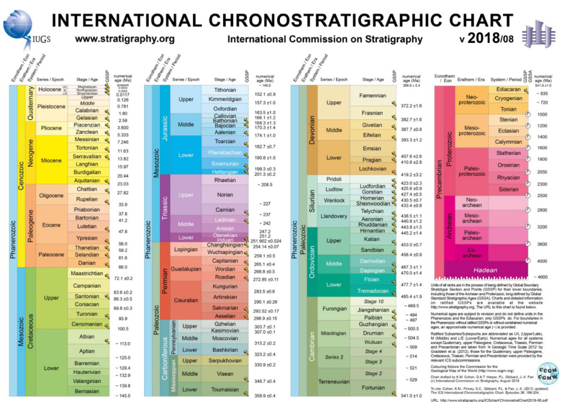

Figure 1.5: The International Geological Time Scale.
(Source: http://www.stratigraphy.org)

Check Your Progress 3

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

Short question-answer

1. Name the components of atmosphere.

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2. Why is hydrosphere important?

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Descriptive Question-Answer

3. Discuss the Proterozoic.

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4. Which major extinctions took place at different geological times?

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1.8 LET US SUM UP

The Unit on Origin and Formation of Earth deals with various aspects of earth since its inception from the gaseous state to its present form. Earth is the only habitable planet of Solar system. It is a planet which was born almost 4.6 billion years ago. The initial structure and composition differed from its present form and composition. The earth has been broadly divided into three prominent layers viz. Core, Mantle and Crust. The Crust which is the most explored layer of earth is divided into: Continental and Oceanic crust. The Continental crust differs from oceanic crust in terms of its thickness, composition, and nature. The earth's oceanic crust is capped by water. The hydrosphere of earth comprises the total of water present on, above and under earth's surface. Earth has its atmosphere which developed over the last 4600 billion years. Earth has a unique thermal, magnetic and gravitational field, put together these made earth a viable and unique planet for the sustenance of life! The geologists have recorded the events of evolution of rocks and life on earth devised in the form a Geological Time Scale which encompasses the journey of earth from its inception to the present time.

1.9 KEYWORDS

Eons	:	Eons are the largest intervals of geologic time and are hundreds of millions of years in duration.
Eras	:	Eons are divided into smaller time intervals known as eras. For example Cenozoic, Mesozoic and Paleozoic eras of Phanerozoic Eon.

1.10 REFERENCES AND SUGGESTED FURTHER READINGS

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1.11 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check Your Progress 1

Short question-answer

1. Crust, mantle and core

2. 5-10 Km

Descriptive Question-Answer

3. The solar nebula flattened into a disk with condensed, higher temperatures in the inner region and less dense outer regions. Gravitational attraction led to accretion of fine dust materials into ***planetesimals*** i.e. few kms in size**.** The planetesimals collided and combined to form larger bodies i.e. the size of moon. This continued with more collisions under the effect of gravity, finally giving rise to the ***planets.*** The process of planet formation was completed approximately in a time span of 10 million years after the condensation of the nebula. The inner four planets are known as terrestrial planets owing to their being like earth. The volatile materials from these planets were boiled away because of their nearness to sun and also blown away by the solar winds far off from the sun forming the cold, gaseous

outer planets. The inner planets comprise rock-forming silicates and metals like iron and nickel. The outer giant planets are probably formed of rocky (silica- and iron-rich cores) rimmed by liquid hydrogen and helium.

4. Briefly discuss the three layers of earth.

The earth's core is composed of iron and nickel predominantly. It is the part of earth is under extreme pressures up to 330-360 GPa. The core which is confined between 2890 Km to 6370 Km is further divided into inner core and outer core. It was possible to study the nature of the core with the help of seismic waves. The inner solid core extends from 5150 Km to 6370 Km, whereas the outer core which is molten extends from 2890 Km to 5150 Km. The mantle is the intermediate layer sandwiched between the core and the crust. This layer extends from the base of crust (which varies from the average depth of 60-80 Km in case of continental crust and 5-10 Km in case of oceanic crust to 2850 Km. The mantle is an important link between the core and crust. The heat from the interior of the earth is transferred by convection in the mantle to shallower depths. It comprises material intermediate in density between the materials of the core and crust. This all information has been possible through seismic wave data retrieved from different depths. Earth's crust is the top most layer which is the least dense compared to the mantle and core. It is further divided into oceanic crust and continental crust. The oceanic crust is thinner (avg. 5-10 Km) and denser compared to continental crust which varies in thickness from 30 to 100 Km and is less dense.

Answers to Check Your Progress 2

Short question-answer

1. The nature of the mantle and core materials is assessed by indirect geophysical data's.

2. The Earth's magnetic field is attributed to this molten outer core. The convective currents in the molten outer core which is composed of iron-nickel produces an electric field and thus a large ***Geodynamo*** is created which produces a magnetic field which has its affect not only inside the earth or its surface but extends up to earth's atmosphere and also far into outer space.

Descriptive Question-Answer

3. The gravitational field of earth can be said as a force between the object (with mass) and the centre of the earth. Earth's gravity is because of its mass. The gravity of Sun keeps the planets of our Solar system in orbit. The gravity of earth is responsible for the moon in its orbit. Earth's gravity is responsible for our atmosphere. Earth's gravity is responsible for our feet on earth. Earth's gravity is responsible for our existence on this blue planet. Let us also remind ourselves that it is not as simple to define gravitational field of earth as it sounds. It depends on many factors and is experienced differently at different locations on earth. For example an area on earth will have strong gravity if it has more mass in the subsurface compared to an area with less subsurface mass. The GRACE (Gravity Recovery And Climate Experiment) mission of NASA uses spacecrafts to measure the variation in earth's gravity.

Answers to Check Your Progress 3

Short question-answer

1. The Earth's atmosphere is divided into five main layers: 1. the exosphere (farthest layer from earth's surface); 2. the thermosphere; 3. the mesosphere; 4. the stratosphere and 5. the troposphere (nearest layer to the earth's surface). It comprises gases enveloping the Earth. The two major components of the Earth's atmosphere comprise Nitrogen (78.1%) and Oxygen (20.9%). It has trace amounts of Argon (0.9%), Carbon Dioxide (~ 0.035%), Water Vapor, and other gases (neon, helium, methane, krypton and hydrogen). Atmosphere also has solid particulate matter viz. ash, dust, volcanic ash, etc.

2. Proterozoic eon began at 2.5 Ga and lasted until 0.542 Ga ago. The Proterozoic Eon is also further divided into Paleo-proterozoic, Meso-proterozoic and Neo-proterozoic eras. This Eon was marked by fully functional plate tectonics and well developed climate systems. During Proterozoic Eon the oxygen in Earth's atmosphere gradually increased. Phanerozoic Eon began at 0.542 Ga ago and is continuing to the present.

Descriptive Question-Answer

3. The Phanerozoic Eon has been further divided into three Eras viz: i. the oldest Paleozoic; ii. Mesozoic and iii. Cenozoic. The Paleozoic is further divided into six Periods namely, Cambrian (541-485 Ma), Ordovician (485- 444 Ma), Silurian (444-419 Ma), Devonian (419-359 Ma), Carboniferous (359-299 Ma) and Permian (299-252 Ma). The Mesozoic Era has been divided into three Periods namely, Triassic (252-201 Ma), Jurassic (201-145 Ma) and Cretaceous (145-66 Ma). The Cenozoic Era has been divided into three Periods namely, Paleogene (66-23 Ma), Neogene (23-2.58 Ma) and Quaternary (2.58 Ma to the Present). Different life forms proliferated with the onset of the Phanerozoic eon (Figure 1.7). The Stage Meghalayan from India has been a recent addition to the Quaternary Period of the International Chronostartigraphic Scale which started at 0.0042 Ma. So we are living in the Meghalayan age!

4. The boundaries between different time Periods were carefully marked based on stratigraphic and fossil break and appearance of index fossils. The Precambrian and Paleozoic boundary marks the first appearance of animals with the hard parts. The major boundaries also mark mass extinctions. The most significant mass extinctions which wiped about 95% of the living forms were recorded at the Paleozoic-Mesozoic boundary i.e. Permain-Triassic boundary also known as P-T boundary. The second significant mass extinction was recorded at Mesozoic-Cenozoic boundary i.e. Cretaceous-Paleogene boundary when 75% of the life forms thriving in the Cretaceous period perished.