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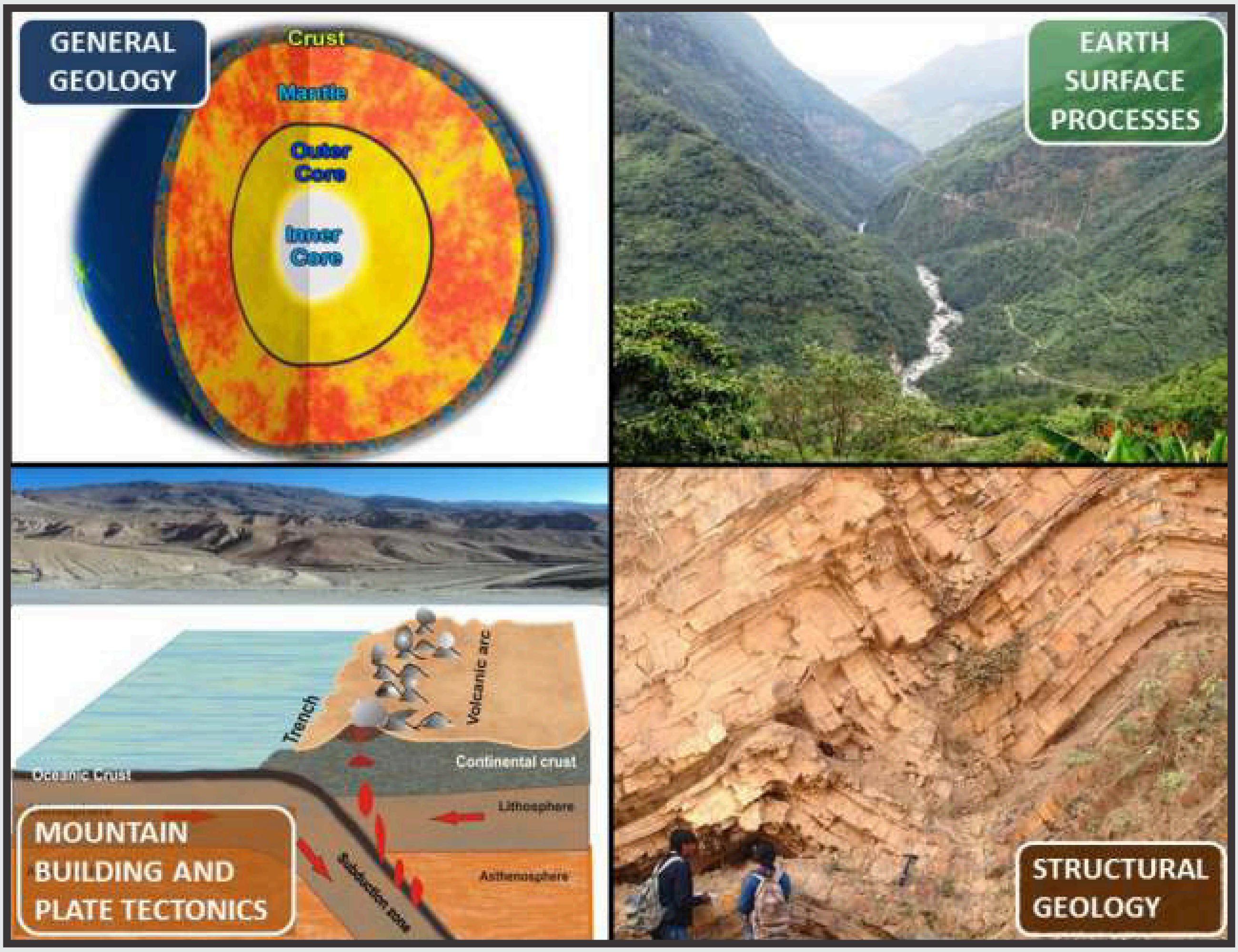
BGYCT – 131
PHYSICAL AND STRUCTURAL GEOLOGY



General Geology

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"शिक्षा मानव को बन्धनों से मुक्त करती है और आज के युग में तो यह लोकतंत्र की भावना का आधार भी है। जन्म तथा अन्य कारणों से उत्पन्न जाति एवं वर्गगत विषमताओं को दूर करते हुए मनुष्य को इन सबसे ऊपर उठाती है।"

– इन्दिरा गांधी

"Education is a liberating force, and in our age it is also a democratising force, cutting across the barriers of caste and class, smoothing out inequalities imposed by birth and other circumstances."

- Indira Gandhi

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PHYSICAL AND STRUCTURAL GEOLOGY

Block

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GENERAL GEOLOGY

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BGYCT-131: PHYSICAL AND STRUCTURAL GEOLOGY

List of audio / video materials related to this course

1. Earth System Science and Society -Part 1
   Link: https://www.youtube.com/watch?v=dVbjNn0ZHRg

2. Earth System Science and Society- Part 2
   Link : https://www.youtube.com/watch?v=0GMPIOrCdcE

3. Geoinformatics: An Introduction
   Link: https://youtu.be/vu7f5aFoox0

4. Applications of Geoinformatics
   Link: https://youtu.be/tfSDp2TO-Eg

5. Weathering, its types and Significance
   Link: https://www.youtube.com/watch?v=gBYijIPPVgc

6. Soil: Product of Weathering
   Link: https://www.youtube.com/watch?v=y-SENU4Abv8

7. Landslides: Its types and causes
   Link: https://www.youtu.be/cI73TU0hjQk

8. Landslides: Mitigation measures
   Link: https://www.youtu.be/BcUVeL43x7c

9. Deccan Volcanism-an Inside Story
   Link: https://www.youtube.com/watch?v=1a3glcg0oGs

10. Himalaya-an Overview
    Link: https://www.youtube.com/watch?v=vK5Cglisa1Y

11. Evolution of Himalaya
    Link: https://www.youtube.com/watch?v=gVGZKqrjVZY

Development of audio/video programmes is a continuous process. For recent materials pertaining to the course you may visit Youtube page of the School of Sciences, IGNOU.

Alternatively, you can visit eGyankosh website of IGNOU
Link : http://egyankosh.ac.in/handle/123456789/36575

PHYSICAL AND STRUCTURAL GEOLOGY

The Earth we live on is a unique and the only known planet conducive for sustaining life. It has fascinated the mankind since beginning of the civilisation providing us everything that we require for our livelihood and is therefore called "Mother Earth". Human beings have always been curious to enquire about its shape, size, extent and position in the space, internal structure, different kinds of features visible on its surface and the processes working on it. The branch of science dealing with the study of the Earth is known as **Geology**. In this course, we shall introduce Geology and its different aspects.

The course comprises four blocks. The first block **General Geology** provides an introduction to geology and Earth covering its origin, age and Solar system, internal structure and composition and internal geological processes: seismicity and volcanism.

The second block **Earth Surface Processes** contains four units. It first introduces you to the exogenic geological processes and then to the geological work of different geological agents such as river, wind, underground water, glaciers and oceans including the landforms developed by them.

The third block **Structural Geology** comprises five units. First unit introduces you to the basic concepts of structural geology and the next three units discuss different geological structures such as folds, faults, joints and unconformity, respectively. The fifth unit on field geology discusses about the fieldwork and related aspects.

The fourth block **Mountain Building and Plate Tectonics** comprises three units. The first two units provide an introduction to different theories of mountain building and the orogenic processes. Third unit introduces the concept of plate tectonics, a unifying theory for different geological phenomena.

Expected Learning Outcomes

After studying this course, you should be able to:

- define geology and discuss its significance to human society;
- describe important features of the Earth, its internal structure and composition, and different processes operating in it;
- explain geological works of agents such as river, wind, underground water, glaciers and oceans, and resulting landforms;
- define structural geology and describe different geological structures such as folds, faults, joints and unconformity; and
- introduce the concepts of mountain building, orogeny, continental drift, sea floor spreading and integrate these concepts with the theory of plate tectonics.

We hope that after studying this course you will develop basic understanding of the geology as a subject.

Wishing you success in this endeavour!!

BLOCK 1: GENERAL GEOLOGY

Geology is perhaps one of the oldest branches of science because man has been using natural resources of the Earth since times immemorial. The term **geology** (‘*Geo*’=the Earth, and ‘*logos*’ = knowledge of) means the ‘study of Earth’ or ‘science of Earth’. Today, geology is identified as a branch of Earth Science that studies all aspects of the planet. The Earth is a unique planet, which is delicately balanced by the conditions necessary for sustaining life. Man has always been curious to know more about this planet but unravelling its mysteries requires specific training. **Geologist,** the person who practices geology, is uniquely trained to understand both the destructive and constructive roles of mankind in the future of Earth’s environments and natural resources.

This block introduces you to the geology as a branch of science dealing with the study of the Earth and its aspects in four units.

Unit 1: Introduction to Geology introduces geology, its scope and subdisciplines. It also provides an idea about its relationship with other branches of science including Earth Science.

Unit 2: Earth and Solar System deals specifically with the Earth and the solar system. It begins with general features of the Earth and then discusses various theories regarding origin and age of the Earth.

In **Unit 3: Structure and Composition of the Earth**, you will learn about the internal structure and constitution of the Earth. It also covers aspects related to origin of hydrosphere, atmosphere and biosphere.

Unit 4: Earthquakes and Volcanoes deals with the phenomena of earthquakes and volcanoes originating from internal processes, their geological effects and relationship between earthquakes and volcanoes. It also covers a brief account of tsunami which is generally generated due to earthquakes.

Expected Learning Outcomes

After studying this block, you should be able to:

- define geology, discuss its importance, branches and relationship with other branches of science and Earth science;
- describe the important characteristics of the Earth;
- discuss various theories regarding origin and age of the Earth;
- explain internal structure of the Earth and its composition; and
- elaborate geological phenomena such as earthquake and volcano, and their impact.

We hope that after studying this block you will acquire basic knowledge about geology, important characteristics of the planet Earth including its structure and composition, and earthquake and volcano phenomena.

Wishing you success in this endeavour!

UNIT 1

INTRODUCTION TO GEOLOGY

Structure

1.1 INTRODUCTION

The Earth is a unique planet, home to millions. It is the only planet delicately balanced by the conditions necessary for sustaining life. The Earth we live on has fascinated the mankind since the beginning of the civilisation. You are aware that the Earth has provided us everything we require, think or imagine. It is therefore referred to as the “Mother Earth”. We have always been curious to know about this planet on which our forefathers lived. You recognise that since times immemorial man has been questioning about its shape, size, extent and position in the space besides different kinds of surface features of Earth and the processes working on it. Since the time of earlier philosophers to the present day scientists, we have acquired some knowledge about our planet. However, there is always a scope and need of new ideas and views as no knowledge is complete and final. One of the branches of science dealing with the study of Earth is Geology.

Now, do you think Geology is important to us and why?

Let us briefly learn about the Geology and its importance to human society. We will discuss about relation of geology to Earth science and different branches of geology in the unit. You will find that geology immensely serves the mankind and learning about geology is enjoyable. At the end, we will get acquainted with different kinds of career opportunities available in the field of geology. You may even develop an interest in Geology as a career!!

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ define geology and its relation to Earth science;
- ❖ discuss importance of geology to society;
- ❖ identify the branches of geology; and
- ❖ acquaint with the employment prospects in the field of geology.

1.2 GEOLOGY

The term **geology** has been derived from two Greek words **'Geo'** (*gagia* or *ge*, the ancestral Earth-goddess of Greek mythology) and *logy* (**'logos',** a suffix denoting 'knowledge of') meaning the Earth and discourse, respectively. Hence, in general, **geology** literally means 'study of Earth' or 'science of Earth.'

The study of the physical material of the Earth dates back at least to ancient Greece when Theophrastus (372-287 BC) wrote the book *Peri Lithon* (On Stones).

It is believed that the word geology was first used by Richard de Bury in 1473 and was taken into modern usage by Ulysis Aldrovandus in 1605. According to another view the word 'geology' was first used in 1778 in the work of Jean Andrea de Luc (a Swiss-born scientist) and at the same time in the work of Swiss Chemist, S.B. Saucer. As such geology is the oldest science because man has been using natural resources of the Earth since times immemorial. Today, geology is identified as a branch of Earth Science that studies all aspects of the planet. We will discuss about Earth science later in this section.

The person practicing geology is called a **Geologist.** Geologists are uniquely trained to understand the destructive and potentially beneficial role of mankind in the future of Earth's environments and natural resources. Fig. 1.1 shows geologists at work in the field. You will be acquainted with geologist's job, later in this unit.

Geology is an integrative science. To figure out how the Earth works, a geologist must integrate, or combine elements of chemistry, biology, physics and mathematics. Besides chemical, biological, physical and mathematical components, geology also integrates computational sciences. For example, while examining a piece of rock, a geologist must think of life, if any recorded, identify its minerals, analyse its chemistry and examine its material properties viz. physical, optical and engineering.

Fig. 1.1: A sketch showing geologists at work.

Let us look at Fig.1.2, which illustrates the relationship of geology to other basic branches of sciences viz. astronomy, physics, chemistry and biology. The interdisciplinary branches have become so vast and diversified that now they are regarded altogether as a separate discipline.

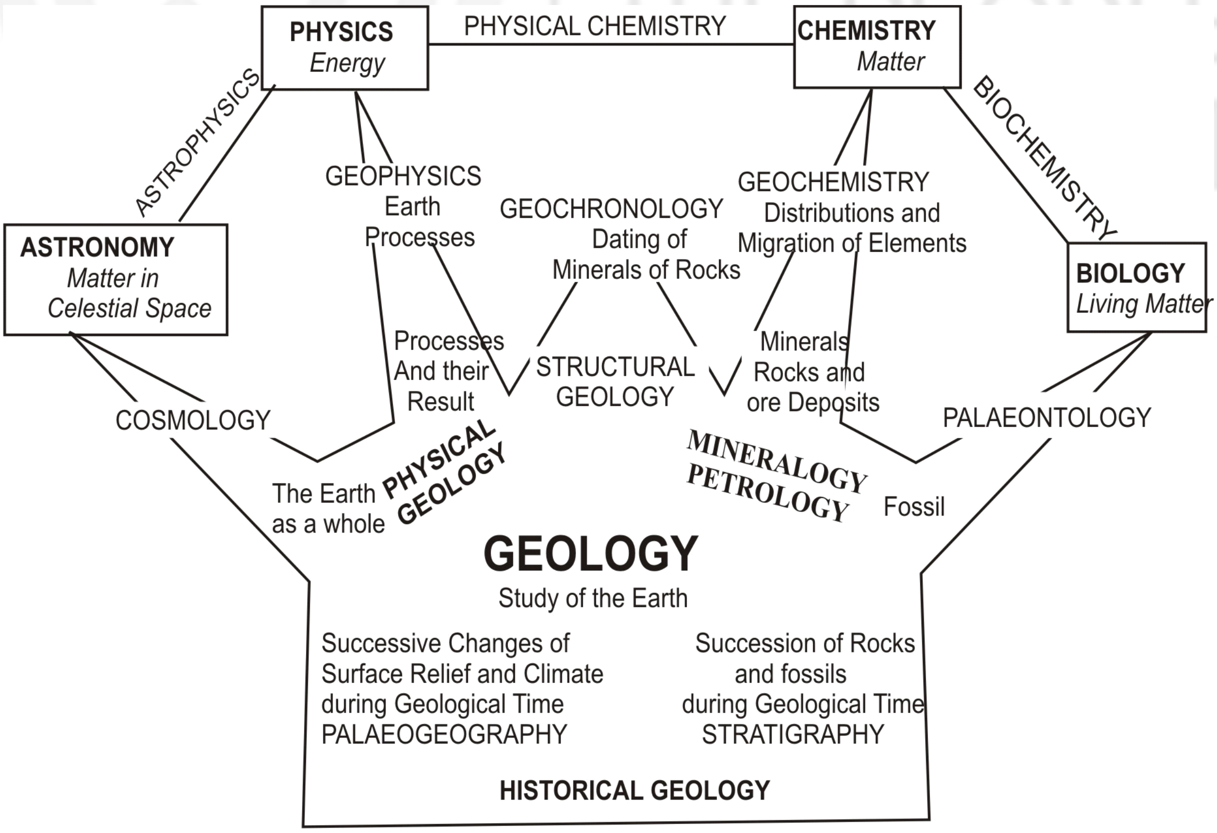

Fig.1.2: Interrelationship of Geology with other basic branches of sciences.
(Source: Arthur Holmes, 1981)

We will read about the different branches of geology in the following section.

1.2.1 Definition

Geology is a fascinating subject which observes pulse of the Earth. It studies the Earth as a whole, its origin, structure, composition and history (including life) and the nature of processes which have given rise to its present form.

Geology can be defined as the study of the history and evolution of the Earth and its inhabitants. It deals with the Earth, rocks of which it is composed and the changes it has undergone or is undergoing.'

According to Grotzinger and Jordan (2010) "Geology identifies the branch of Earth science that studies all aspects of the planet: its history, its composition, internal structure and its features."

1.2.2 How Does Geology Differ from Other Sciences?

Now let us discuss how geology differs from other sciences. Quite often you must have seen that scientists are portrayed as people who perform experiments wearing white labcoats. However, the subject of Geology differs from those sciences in following respects:

- Geology is an outdoor/field science with its own approach and standpoint.
- Field is its natural laboratory where one can observe the nature directly.
- Geologists try to probe Earth's long history by reading what has been "written on rocks".
- Geologists may have to work in the nook and corner irrespective of the remoteness and arduous nature of the terrain. They engage themselves in data collection. An incorrect perception/insight in the field and missing critical observation of evidence can abort discovery of a rich mineral deposit. It may also lead to failure of civil structures made by man such as dam.
- Almost all of the great discoveries were made in uncontrolled and natural field environment.
- Geological processes operate on much larger and longer scales.

Geology is fundamentally an observational field science and geological map is its main tool. Field is the natural laboratory for geology education. Hence, field component is the integral element of Geology curricula. However, in past few decades computer software have become available which can simulate field in laboratory to some extent.

1.2.3 How Do Geologists Study Earth?

You have read that geology is a field science and the field exists everywhere around us. Geologists must define the aim of the project before they start working on it. You must be thinking that what could be the aim for a geologist, e.g. it could be discovery of petroleum, mineral resource or location of an earthquake prone region. Let us discuss the following steps involved in geological studies:

- **Making observations**: Observation is collecting data using your five senses. Data is the information gathered during observation. For instance, observing that Sun rises in the east provides data about the Earth's orbit.
- **Building or modifying hypothesis or model**: A geoscientist proposes a hypothesis, based on careful observations over a long period and present it to the community for working evaluation and repeated testing. A hypothesis that is confirmed gains credibility.
- **Prediction**: It involves the use of hypothesis (or model) to predict the existence of other phenomena or to predict the results of new observations. This is done using **deductive reasoning**.
- **Conducting experiments to test predictions**: Testing a prediction involves collecting data or designing an experiment for accurate examination or careful testing of the hypothesis.
- **Drawing conclusions**: Geologists analyse the data obtained and draw conclusions they have collected to arrive at a conclusion.

Out of several principles being followed one of the fundamental is **'uniformitarianism'**. James Hutton in 1785 propounded the principle **'The present is the key to the past'.** It means that the ongoing processes on the Earth provide clues for unravelling its mysteries. Many such repeated observations attest the validity of the conclusion. It is thereafter the hypothesis becomes a **theory** or a **scientific law.**

1.2.4 Relationship of Geology with Earth Science

We have discussed about our obvious interest in the study of our 'Mother Earth'. The study of this constitutes Earth science. Earth scientists observe, classify and collect data about the Earth. They constantly strive to unravel secrets of the Earth. Earth Science integrates knowledge from traditional disciplines such as biology, chemistry, physics, mathematics, engineering and economics. **Earth Science** deals with the systematic study, including all the aspects of sciences related to the planet Earth: the atmosphere, hydrosphere and biosphere, as well as the solid Earth.

The broad areas of Earth science include the following:

- Geology
- Hydrology
- Oceanography
- Meteorology
- Astronomy

Of these we are concerned here and will concentrate on **geology**.

Hydrology is the study of the movement, distribution, and quality of water on the Earth's surface and other planets. **Oceanography,** also known as marine science is the branch of Earth science that studies all the aspects of the ocean. Earth's atmosphere, weather and climate form the subject matter of **Meteorology**. *Meteorologica* was the first Earth science book which was written by Aristotle and got published around 330 B.C. **Astronomy** deals with the study of outer space with respect to the Earth. It has fascinated the human beings since ancient times.

Earth Science also includes geography, in which we study the surface features of the Earth and its inhabitants without any reference to its genesis. You must study all of them to really understand how the Earth works.

Earth science presents the history of our planet, the processes modifying it and the projects of its future as well. The study of Earth science gives us a new perspective on why and how things happen around us. It also attempts to find solutions for real global environmental problems in relation to place and time.

- Watch these two videos to know about Earth System Science and its Societal impact:

1. Earth System Science and Society – Part 1
   Link : https://www.youtube.com/watch?v=dVbjNn0ZHRg
2. Earth System Science and Society – Part 2
   Link : https://www.youtube.com/watch?v=0GMPIOrCdcE

In this section, we have studied about the definition of geology, how it is related yet different from other sciences, how a geologist studies Earth and relationship of geology with Earth Science. In the next section, we will be discussing about different branches of geology but before going to the next section spend 5 minutes to check your progress.

SAQ 1

a) Define geology and state its relation with Earth science.

b) "Geology is an integrative science". Justify.

c) What are the major differences between geology and other sciences?

1.3 BRANCHES OF GEOLOGY

You have already learnt about the integration of basic sciences in geology. Now let us study about its various branches, also referred to as subdisciplines of geology and their scope.

1.3.1 General Geology

General geology includes:

a) **Planetary Geology**: Also known as **astrogeology,** which deals with Earth's environment in outer space. It is concerned with geology of the celestial bodies such as planets and their moons, asteroids and comets.

b) **Physical Geology**: Physical aspects, the internal and external agencies and processes that shape the Earth are dealt with in physical geology. It includes many sub-branches.

c) **Structural Geology**: It deals with the study of structures observed in the rocks. As a result of various physical forces structural changes occur on the external surface of the Earth. The study of these structures and forces involved constitutes structural geology.

d) **Geotectonics or Dynamic Geology**: It is related to the large-scale aspects of the Earth's crust. It concerns with the movements of the Earth's crust and the shape, structure, and arrangement of the rock masses resulting from deformation caused by movements. The study of these forces and changes forms the subject matter of geotectonics or dynamic geology.

e) **Geomorphology or Physiography**: It deals with the study of the surface features of the Earth which are produced as a result of various external agencies operating on the Earth's surface. Physiography describes only the external characteristics whereas in geomorphology we study their genesis also.

1.3.2 Mineralogy

Mineralogy is the branch of geology that deals with study of minerals related to their formation, composition, characteristics, properties (physical and optical), classification, mode of occurrence and origin as well as their geographical distribution and utilisation.

Descriptive Mineralogy deals with study of different characteristics of minerals. It is subdivided into the following:

a) **Physical Mineralogy** is the study of physical characteristics of the minerals.

b) **Optical Mineralogy** deals with optical characters of minerals.

c) **Chemical Mineralogy** accounts for the chemical makeup of the minerals.

d) **Crystallography** is a branch which deals with the study of crystals. This involves their external forms and internal atomic structure.

e) **Economic Mineralogy** deals with minerals of economic importance. It is the study of economically useful minerals and rocks of the Earth's crust like coal, petroleum, metallic and non-metallic ores.

1.3.3 Petrology

Petrology (Greek word *petra* meaning rock and *logos* meaning knowledge) is the branch of geology that deals with 'the study of rocks' including the origin, texture, structure, mineralogical composition, distribution, and history of rocks. There are three branches of petrology:

a) **Igneous petrology** deals with the study of all the aspects of igneous rocks which are crystallised on cooling and consolidation of hot molten material called magma.

b) **Sedimentary petrology** includes study of sediments or sedimentary rocks formed on mechanical disintegration or chemical decomposition of pre-existing rocks.

c) **Metamorphic petrology** deals with the study of rocks formed when a pre-existing rock undergoes changes in response to increased pressure and/or temperature in presence of chemically active fluid.

1.3.4 Historical Geology

It records the features and aspects of the history of Earth and comprises the following:

a) **Palaeontology**: The study of ancient remains of plants and animals that are found in the rocks of past geological periods is referred to as Palaeontology. The life of the past ages is preserved in the rocks in the form of fossils. **Fossils** are the remnants of plants or animals of the past geologic ages preserved in the rocks of Earth's crust by natural processes. Palaeontology can be further divided into vertebrate palaeontology, invertebrate palaeontology, micropalaeontology, palaeobotany and palynology. **Palaeobotany** deals with the study of ancient plant life whereas **Palynology** deals with the study of spores and pollens preserved in rocks.

b) **Stratigraphy**: The study and arrangement of rocks of the Earth in **chronological order** is the subject matter of stratigraphy. This branch of geology deals with the study of stratified and other rocks as a record of geological history. **Chronological order** is an arrangement of events in time or a record of events in the order of their formation/ occurrences.

We have read the definitions of core or general branches of geology, now we will discuss the applied and allied branches.

1.3.5 Applied and Allied Branches

a) **Mining geology**: It deals with the study of application of geology to mining engineering to select suitable sites for quarrying and mining.

b) **Engineering geology**: It deals with the geological studies related to problems that arise in civil engineering projects along with suitable treatments like construction of dams, tunnels, mountain roads, building stones and road materials.

c) **Hydrogeology or Geohydrology**: It is related with ground water and is the field between geology and hydrology.

d) **Rock Mechanics**: It is related with geology in dealing with the behaviour of rocks that is subjected to static and dynamic loads.

e) **Geophysics**: Interaction of geology and physics applied to survey and prospecting, is the branch known as geophysics. The constitution of the Earth and the nature of the physical forces operating on/within the Earth are its study materials.

f) **Geochemistry**: It concerns with the abundance, distribution and migration of various elements in the Earth.

g) **Biogeochemistry**: It deals with the study of geological, chemical, physical and biological processes and reactions that govern the composition of the natural environment. It involves atmosphere, biosphere, hydrosphere, lithosphere and pedosphere.

h) **Marine Geology** or **Geological Oceanography**: It involves geophysical, geochemical, sedimentological and palaeontological investigations within the ocean basins and at the coastal margins.

i) **Geoinformatics**: It develops and uses spatial data and informatics framework to address the problems of geology related to geomorphology, mineral exploration, structural geology, etc.

- Watch these two videos to understand about geoinformatics and its applications:

1. Geoinformatics: An Introduction
   Link : https://youtu.be/vu7f5aFoox0
2. Applications of Geoinformatics
   Link : https://youtu.be/tfSDp2TO-Eg

1.3.6 Emerging Areas of Geology

In similar manner, several emerging branches of geology are as follows:

a) **Medical Geology**: It deals with the relationship between natural geological materials and processes and their effects on human and animal health.

b) **Agriculture Geology**: It deals with nature and distribution of soil, occurrence of mineral fertilizers and underground water required for sustainable agriculture.

c) **Palaeoclimatology**: It is the branch of geology that studies past climate of the Earth.

d) **Gemology**: It is considered as a branch of mineralogy that deals with identification and evaluation of natural and artificial gems and gemstones.

e) **Forensic Geology**: It is the study of evidence(s) related to minerals, oil, petroleum and other materials found in the Earth that can be used in legal matters.

f) **Geomicrobiology**: It deals with the interaction between microorganisms and their metabolic processes with geological and geochemical materials and/or processes.

g) **Geotourism**: It deals with the tourism that sustains or enhances geographical character of a place – its environment, culture, aesthetics, heritage and the well being of its residents.

h) **Geoarchaeology**: It uses multidisciplinary techniques of geology, geography and other Earth sub-disciplines with archaeological study and thoughts, for example protection of building materials from weathering.

i) **Geostatistics**: It is the branch of statistics focussing on spatio-temporal datasets to investigate geological aspects.

These branches have become so vast and developed that they are often regarded as independent branches of science.

In this section, we have studied about various branches of geology. In the next section, we will be discussing about the importance of geology in our lives. Before going to the next section spend 5 minutes to check your progress.

SAQ 2

a) What is Planetary Geology?

b) What do you study in Petrology?

c) Distinguish between geomorphology and physiography.

d) List four emerging areas of geology.

1.4 GEOLOGY IN OUR LIVES

You must be curious by now with many questions in your mind. What do geologists do? How does geology affect our lives? What is the role of geologists in our society? How do geologists practice geology?

Let us find answers to these questions.

You have realised and read that our civilisation depends upon the natural resources (water, soil, fossil fuels, metals, mineral and others) of the Earth. It may be interesting to note that most of the ancient civilisations like Mohenjo-Daro and Harappa civilisations preferred river valleys for the simple reason of availability of water supply. A geologist is supposed to study the Earth, considering the short term and long term interests. In this regard, exploration and utilisation of earth materials is necessary to meet the present needs and also plan conservation for future.

Do you know that geology enters our lives many times a day and is relevant in day-to-day life? You would thus realise that geology is a highly utilitarian science. Knowledge of geology is absolutely necessary, in fact essential, for understanding the natural environment and planning for a more comfortable existence of man. Only through the knowledge of geology we can appreciate the fact that the supply of resources to mankind and energy, (fossil or nuclear) can be extracted from the Earth. Basic understanding of the Earth and its resources is a necessary for sustenance and improved agricultural productivity. Results succeed in feeding not only people of our country but also some of the less fortunate ones elsewhere.

Now we will read more about how geology is significant in our lives and in the service of man.

1.4.1 Natural Resources

We have discussed above that we get a variety of useful materials from the Earth's crust. Systematic geological studies are very important for their exploration and exploitation. Such materials are:

- **Building materials** like quartzite, sandstone, granite are used for construction of roads, buildings, etc. Mostly the locally occurring rocks are preferred as building materials because of their availability in the neighbourhood that reduces the transportation cost considerations.
- **Metals**: Metals like iron, aluminium, manganese, copper, lead, zinc, chromium, silver, gold, tin are important and have always been indispensable for our civilisation. These metals are extracted from the ores, for examples, copper is extracted from chalcopyrite; aluminium is extracted from bauxite ore.
- **Minerals**: Minerals like clays are used in cosmetic and ceramic industry. Mica is used as an insulator, sulphur bearing minerals are used in paint and pigment industry, diamond in abrasive industry. These are all extracted from rocks.
- **Fertilizers**: Rocks on weathering provide elements like phosphorus, potassium, nitrogen, and sulphur to the soil used as plant nutrients.
- **Gemstones**: We get precious and semiprecious stones like diamond, emerald, ruby, and moonstone, amethyst which are used by human beings for ornamental and decorative purposes.
- **Medicinal**: Various metallic ores are utilised for preparing *bhasmas* used in ayurvedic medicine.

1.4.2 Water Resources

You are well aware about the problem of water scarcity. The world today is facing acute water crises. You might wonder that if three-fourth of the world is covered with water which is a renewable resource, then how come problem has arisen? Water is the basic requirement of all living beings. It is most important requirement for human life for his personal needs, agriculture, etc. We get water in form of rain water, underground water, and mineral springs and above all from rivers and glacial melts. For proper planning, exploration, conservation and utilisation of water, geological studies are very important.

1.4.3 Power Resources

You must have observed in daily life that power generation is very important aspect for overall development. Power and energy supply to mankind is from biological, thermal or nuclear sources which come from the Earth. The natural resources as listed below provide power and energy. It is for geologists to explore and exploit them.

- **Coal** is required for domestic and industrial purposes. It is also used in thermal power plants for power generation. Several power houses in the country utilise coal for generation of electricity.
- **Petroleum** includes oil and natural gas apart from many other products. We hope you are familiar with the uses of petroleum products.

  Can you imagine your world without petrol or diesel?
- **Atomic minerals** bearing uranium and thorium are important fuel for nuclear power generation and development of the country.
- **Geothermal Energy** is the vast reservoir of heat energy in the Earth's interior, of which surface manifestations are the volcanoes, fumaroles, geysers, steaming grounds and hot springs. Currently, geothermal energy is being commercially exploited for the generation of electricity.

1.4.4 Engineering Projects

Knowledge of geology of the area is extremely useful and necessary before initiating, during and also in maintenance of any engineering projects including site selections such as in;

- **Dams**: The construction of dams and their site selection depends on the proper geological investigations.
- **Reservoir**: The reservoirs are constructed for storage of water for future use. The site of reservoir, the rocks and its base and surroundings are geologically investigated prior to its construction.
- **Tunnels**: Tunnels for roads, railway lines, underground canals, power houses are constructed and for their stability geological studies are necessary.
- **Railway lines**: For construction of railway lines especially in hilly terrains the knowledge of specific geological conditions is necessary.
- **Roads**: For construction of roads and highways definite geological investigations are required because they have to withstand heavy traffic. It becomes extremely important in the hilly terrains.
- **Bridges**: Proper geological studies, like study of catchment area, maximum volume of water expected to pass through the bridge, the foundation rocks are necessary for construction of bridges.

Now you can visualise that how geological studies are important for the construction of engineering projects. Without proper geological investigations it may not be even feasible to complete the project and even if it is completed it may not be stable.

1.4.5 Origin and Evolution of Life on the Earth

The only basis to know about origin and evolution of life is the records preserved in the rocks of the Earth's crust as fossils. With the help of fossils and other evidences we can understand about origin and evolution of life on the Earth. Fossils are useful in the study of evolution and migration of animals and plants through ages, ancient geography and climate of the region. This is studied in the branch of geology known as palaeontology, about which we have mentioned in subsection 1.3.4.

1.4.6 Natural Disaster Management

Geological studies can save the mankind from natural hazards. The acquaintance with the geology of the area can help managing the natural disasters and reducing the damage caused. For example:

- **Earthquakes**: We can identify the regions where the earthquakes may be expected. Therefore construction of huge structures can be avoided in such earthquake prone belts. Constructing earthquake proof buildings can also minimise the effects of earthquakes.
- **Floods**: Systematic geological investigations and taking effective measures can minimise the disaster in the flood prone regions.
- **Avalanches**: Avalanches of rocks/snow are masses which move downhill under the action of gravity. Precautions could be taken regarding any construction to minimise disaster in avalanche prone areas.
- **Sinking**: Quarrying, withdrawal of support, underground water, overloading of areas or earthquake can induce surface collapse. Such areas can be delineated and safety measures can be taken.
- **Landslides**: Landslides occur when slopes are destabilised anthropologically by construction activities, removal of forest cover, quarrying, river undercutting the base of adjacent rock or due to tectonic reason. Geologists can help in proper planning to avert the possible disasters.

1.4.7 Role of Geologist in Sustainable Agriculture

Geologists can play a significant role in educating the farmer or agriculturist and making him/her literate in respect of his/her land, rock underlying it; the structure and composition of soil. Geologist can enlighten the farmer with the concepts like water management, surface and groundwater resources and rainwater harvesting. Agriculture geology deals with this aspect.

We have discussed in this section about how geology plays a significant role in our lives; as a source of water, energy, food, minerals, metals and building materials, including construction of engineering projects and disaster management and also about the important role played by geologists in our society.

Eric Calais in Perkins (2011) mentions that in Geology, "There's room for those who love field work and there's room for those who don't". You have seen that **geology is for everyone as it works for everyone**. We are sure that having read this section you are fascinated about geology and might be intending to take up geology as your career option!

Now we will discuss about employment prospects in geology.

1.5 EMPLOYMENT PROSPECTS IN GEOLOGY

In recent years, exciting careers in geology has developed more interest amongst the youth to study this subject at undergraduate and postgraduate levels. The career of a geologist provides an opportunity to explore virgin terrains and provides satisfying adventurous feeling. People often imagine trekking to far-flung regions to hammer rocks when one talks of geology as a career. After reading the last section, you are now familiar with the challenging job as a geologist and role of a geologist.

Geology discipline offers a wide range of opportunities. The geologists play an important role in exploring and exploiting the mineral wealth and natural resources. The most important job of geologists is to assess natural disasters and their effects on environment, to discover the minerals of economic importance, underground water, and coal and petroleum resources. Geologists have to identify and suggest the suitable sites for construction of bridges, roads, buildings and laying railway lines. They are also responsible for exploration of the natural resources found in oceans. They determine the quality of soil by conducting geochemical and geophysical surveys.

Thus, the career in Geology is an exciting and interesting option as there are ample employment opportunities. Geologist can pursue a career as hydrogeologist, petrologist, palaeontologist, geophysicist and mining geologist, environmental geologist in Central and State government and also in semi governmental, private and multinational organisations. The Union Public Service Commission (UPSC) holds the competitive examination for employment as geologists in Geological Survey of India (GSI) and Central Ground Water Board (CGWB). You may get employed through competitive examinations in Coal India Limited (CIL), Oil & Natural Gas Corporation (ONGC), Oil Indian Limited (OIL), Indian Bureau of Mines (IBM), Steel Authority of India Ltd. (SAIL), National Hydro-electric Power Corporation (NPHC), Atomic Mineral Division (AMD), Mineral Exploration Corporation Limited (MECL) and Government of India undertakings, Central and State Ground Water Boards and State Mining Departments, infrastructure construction companies and many other organisations.

The defence and paramilitary forces also utilise the services of geologists as they provide valuable inputs for location of defence sites, terrain evaluation and navigation. It has been predicted that in the near future, rapid economic expansion in our country and rest of the developing world would further boost the demand for geoscience graduates globally. Geoscientists with specialised skills will be needed to help identify oil, gas and mineral resources, and also to recognise and manage natural and man-made environmental hazards (Perkins, 2011).

1.5.1 Prospects in Government Sector

In the previous subsection we have read that there are different kinds of jobs available to a geologist. Table 1.1 lists organisations and institutions where there are potential opportunities for geologists. Apart from the above list there are several Remote Sensing Agencies and Groundwater Board of State governments. In

Table 1.1: List of potential Institutes/Organisations employing geologists in India

Sl. No.	Institute/Organisation	Website	Year of Incep-tion	Location
1	Atomic Mineral Directorate For Exploration and Research (AMDER)	www.amd.gov.in	1948	Hyderabad & 6 regional headquarters
2.	Birbal Sahni Institute of Paleosciences (BSIP)	www.bsip.res.in	1946	Lucknow
3.	Central Ground Water Board (CGWB)	www.cgwb.gov.in	1972	17 regional divisions
4.	Central Mine Planning and Design Institute (CMPDI)	www.cmpdi.co.in	1973	Ranchi
5.	National Centre for Earth Science Studies (CESS), MoEF	www.cess.res.in www.ncess.gov.in	1978	Thiruvanthapuram
6.	Coal India Limited (CIL)	www.coalindia.in	1975	Kolkata
7.	Defence Research & Development Organisation (DRDO)	www.drdo.gov.in	1958	New Delhi (Several labs across India)
8.	Defence Terrain Research Laboratory (DTRL), DRDO	www.drdo.gov.in/drdo/labs/DTRL/english/indexnew.jsp?pg=hem/page.jsp	1988	New Delhi
9.	Department of Science & Technology (DST)	www.dst.gov.in	1971	New Delhi
10.	Geological Survey of India (GSI)	www.portal.gsi.gov.in	1851	Kolkata
11.	Hindustan Copper Limited (HCL)	www.hindustancopper.com	1967	Singhbhum (3 divisions)
12.	Hindustan Zinc Limited (HZL)	www.hzlindia.com	1966	Udaipur
13.	Indian Bureau of Mines (IBM)	www.ibm.nic.in	1948	14 regional divisions
14.	Indian National Centre for Ocean Information Services (INCOIS), MoES	www.incois.gov.in	2006	Hyderabad
15.	Indian Space Research Organisation (ISRO)	www.isro.org	1960	Bangalore (Several branches across India)
16.	Mineral Exploration Corporation Limited (MECL)	www.mecl.gov.in	1972	Nagpur
17.	Ministry of Earth Sciences (MOES)	http://moes.gov.in	2006	New Delhi
18.	National Bureau of Soil Survey & Land Use Planning (NBSS & LUP)	www.nbsslup.in	1956	Nagpur
19.	National Centre for Antarctic & Ocean Research (NCAOR), MoES	www.ncaor.nic.in	1998	Goa
20.	National Geophysical Research Institute (NGRI)	www.ngri.org.in	1961	Hyderabad
21.	National Institute of Oceanography (NIO), CSIR	www.nio.org	1966	Goa
22.	National Mineral Development Corporation (NMDC)	www.nmdc.co.in	1958	Hyderabad
23.	National Remote Sensing Centre (NRSC)	www.nrsc.gov.in	1973	Hyderabad

Sl. No.	Institute/Organisation	Website	Year of Incep-tion	Location
24.	Oil and Natural Gas Corporation (ONGC)	www.ongcindia.com	1956	Dehradun
25.	Physical Research Laboratory (PRL)	http://www.prl.res.in	1947	Ahemdabad
26.	Regional Remote Sensing Centres (RRSCs), ISRO	www.isro.gov.in	—	Kolkata, Nagpur, Jodhpur,, Bangalore Dehradun
27.	Space Applications Centre (SAC), ISRO	www.sac.gov.in	1972	Ahmedabad
28.	Steel Authority of India Ltd. (SAIL)	www.sail.co.in	1954	Bhilai (4 divisions)
29.	Wadia Institute of Himalayan Geology (WIHG)	www.wihg.res.in	1968	Dehradun
30.	Directorate of Geology and Mines (DGM) in states (e.g.)			
	● Andhra Pradesh	http://aponline.gov.in	1951	Hyderabad
	● Goa	http://goadmg.gov.in	2004	Goa
	● Gujarat	http://geomining.gujarat.gov.in	—	Gandhinagar
	● Himachal Pradesh	http://himachal.nic.in	—	Shimla
	● Jharkhand	http://jharkhand.gov.in	—	Ranchi
	● Karnataka	http://mines.kar.nic.in/	1894	Mysore
	● Kerala	http://dmg.kerala.gov.in	1946	Thiruvanthapuram
	● Madhya Pradesh	http://mineralresources.mp.gov.in	—	Bhopal (4 regional offices)
	● Meghalaya	http://meghalaya.nic.in	—	Shillong
	● Odisha	http://www.orissaminerals.gov.in	1955	Bhubaneswar
	● Rajasthan	http://dmg-raj.org/	—	Udaipur
	● Tamilnadu	http://www.tnmine.tn.nic.in	1957	Chennai
	● Uttar Pradesh	http://mineral.up.nic.in	1955	Lucknow
	● Chhattishgarh	http://chhattishgarhmines.gov.in	—	Atal Nagar

addition, geology and civil engineering departments in colleges and State and Central Universities offer teaching and research positions.

Employment prospectus for aspiring geoscientists at all career stages are on the rise. Many of today's senior geoscientists were trained as specialists in a specific area but in future, majority of the demand could be for researchers who have been trained to appreciate the interdisciplinary nature of the Earth sciences or job portals.

You may find more details regarding employment opportunities in the field of Geology in different websites listed in Table 1.1. You can also obtain information regarding vacancies from national newspapers or job portals.

1.5.2 Prospects in Industries

There are wide range of opportunities both in India and abroad in mining and related industries, civil engineering departments and geotechnical consultation companies, and several others. You can also find employment in cement, chemical, ceramic and mineral exploration industries. environment consultancy and petroleum industry utilises large number of geology graduates.

1.5.3 Geology Related Academic Programmes

According to the data compiled from the available sources, there are more than 145 institutions offering Bachelor level programmes in Geology and approximately 135 institutions offering Master level programmes in various universities/ colleges. The range and nomenclature of academic programmes pertaining to Geology in India are listed in Table 1.2. For more details you may search on their websites.

Table 1.2: List of Academic programmes in Geology offered by different institutions in India as in 2015

<table>
<tr><th>Sl. No.</th><th>Programmes Offered in Geology</th><th>Total No. of Institutions</th></tr>
<tr><td>1</td><td>M.Sc. (Geology)</td><td rowspan="9">135 Approx.</td></tr>
<tr><td>2</td><td>M.Sc. (Geological Sciences)</td></tr>
<tr><td>3</td><td>M.Sc. (Applied Geology)</td></tr>
<tr><td>4</td><td>M.Sc. (Applied Geology and Geoinformatics)</td></tr>
<tr><td>5</td><td>M.Sc. (Earth Science & Resource Management)</td></tr>
<tr><td>6</td><td>M.Sc. (Tech.) (Geology)</td></tr>
<tr><td>7</td><td>M.Tech. (Applied Geology)</td></tr>
<tr><td>8</td><td>M.Sc. (Petroleum Geology)</td></tr>
<tr><td>9</td><td>M.Tech. (Engineering Geology)</td></tr>
<tr><td>10</td><td>B.Sc. (Geology)</td><td rowspan="2">> 145</td></tr>
<tr><td>11</td><td>B.Sc. (Honours) (Geology)</td></tr>
</table>

After studying this section, you have now an idea about employment prospects in government and private institutes/organisations in the field of geology. You are now also aware about the kinds of academic programmes and number of institutes offering bachelors and masters programme.

1.6 SUMMARY

Let us summarise what we have learnt in this unit:

- Geology deals with all aspects of planet Earth: its history, its composition and internal structure and its features.
- Geology is a highly utilitarian science. Every aspect of geology is useful because whatever we see and or obtain from around is direct or indirect constituent of our Earth.
- Earth science is the systematic study of every physical aspect of the Earth and its surrounding which includes hydrology, oceanography, meteorology, astronomy and geology.

- There are several branches of geology that are widely related to other basic sciences with interdisciplinary and emerging branches.
- Geology is an exciting and interesting career option as this subject arouses interest in youth because of its adventurous nature, utilitarian aspects and employment prospects.

1.7 ACTIVITY

1. Go outdoor and observe our natural resources like the rocks, soils, water, etc. in your surroundings. Make a list of natural resources you have observed around you.
2. Make a list of materials around you. Do you think that these materials are related to geology? Visualise how these materials might have been directly or indirectly related or derived from the Earth.
3. Write down the usefulness of studying geology in your own perspective.

1.8 TERMINAL QUESTIONS

1. How do geologists study Earth?
2. Write an account of the usefulness of geology to our society.
3. Which kinds of employment options are available to a geologist?
4. Give an account of the government institutes and organisations where employment opportunities are available to geologists.

1.9 REFERENCES

- Holmes, A. (1981) Principles of Physical Geology, Thomas Nelson and Sons Ltd., 36, Park Street, London.
- Grotzinger, J. and Jordan, T. (2010) Understanding Earth, Sixth Edition. W.M. Freeman and Company, New York, 654p.
- Perkins, S. (2011) Geosciences: Earth works, Nature, Vol. 473, pp. 243-244. (www.nature.com/naturejobs/science/articles/10.1038/nj7346-243a, accessed on 06 October 2015).

1.10 FURTHER/SUGGESTED READINGS

- Dutta, A.K. (2010) (Reprinted), Introduction to Physical Geology, Kalyani Publishers, Ludhiana, 230p.
- Mahapatra, G.B. (2012) (Reprinted) A Textbook of Geology, CBS Publishers, New Delhi, 326p.
- Mathur, S.M. (2013) Physical Geology of India, 5th Edition, National Book Trust, Delhi, 222p.

1.11 ANSWERS

Self-Assessment Questions

1. a) Geology is the study of the history and evolution of the Earth and its inhabitants. It deals with the Earth, rocks of which it is composed and the changes it has undergone or is undergoing. According to Grotzinger and Jordan (2010) "Geology identifies the branch of Earth science that studies all aspects of the planet: its history, its composition, internal structure and its features."

   Geology is one of the branches of Earth science which include five branches namely Geology, Hydrology, Oceanography, Meteorology and Astronomy.

   b) Geology is an integrative science. Geologist must integrate, or combine elements of chemistry, biology, physics and mathematics. Besides chemical, biological, physical and mathematical components, geology also integrates computational sciences.

   c) Geology differs from other sciences in following respects:

   - Geology is an outdoor or field science having its own approach and standpoint.
   - Geological processes operate on much larger and longer scales.
   - Field is its natural laboratory where we can observe nature directly.
   - Geologists try to probe Earth's long history by reading what has been "written on rocks".
   - Geologists generally have to work in difficult terrain.
   - Almost all of the great geological discoveries were made in the uncontrolled and natural field environment.

2. a) Planetary Geology is also known as astrogeology deals with Earth's environment in outer space. It is concerned with geology of the celestial bodies such as planet and their moons, asteroids and comets.

   b) Petrology is the branch of geology that deals with 'the study of rocks' including the origin, texture, structure, mineralogical composition, distribution, and history of rocks.

   c) Geomorphology deals with the study of the surface features of the Earth which are produced as a result of various external agencies operating on the Earth's surface. Physiography describes only the external characteristics whereas in geomorphology we study their genesis also.

d) The emerging areas of geology are: Medical geology, Agriculture geology, Palaeoclimatology, Gemology, Forensic geology, Geomicrobiology, Geotourism, Geoarchaeology and Geostatistics.

Terminal Questions

1. Geology is a field science and the whole Earth is its laboratory. Geologists are uniquely trained to study the Earth. A geologist must first define the aim of the project. Your answer should also further include the steps involved in geological studies as given in subsection 1.2.3.

2. Geology is a highly utilitarian science hence knowledge of geology is essential for understanding natural environment and to plan for a more comfortable existence of man. Your answer should further include the points mentioned in section 1.4.

3. Career in geology is an exciting and interesting option and there are varieties of employment options available to geology students. Your answer should further include the points mentioned in section 1.5.

4. There are different kinds of government jobs available to geologists. You should refer to the subsection 1.5.1 to elaborate your answer.

UNIT 2

EARTH AND SOLAR SYSTEM

Structure

2.1 INTRODUCTION

In Unit 1 we have studied that the branch of science dealing with study of the Earth is Geology. We tried to comprehend what geology is, its various branches, its significance to the society and to our lives, and employment propects. Geology is one of the branches of Earth science dealing with the study of history and evolution of the Earth and also recording of evolution of life through geologic times.

The Earth is one of the planets of our Solar System, which is considered as a unique and privileged planet because of the conditions prevailing on it and making it habitable for different kinds of life forms. So, it is necessary to acquire knowledge of the Solar System.

Exploration of the Solar System through orbiting spacecrafts or flybys is one of the exciting adventures experienced by human. We have gained our current knowledge of the Earth by exploring not just the Earth itself but also other planetary bodies and that too in about last about five to six decades.

In this unit, we will get acquainted with the Solar System, its formation, its members and their characteristics. The planet Earth being our main concern of study, we shall discuss more about it including its origin and age. In succeeding Unit 3, you will study about the structure and composition of Earth with emphasis on its internal constitution.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ discuss about our Solar System and its constituents including planets, asteroids, comets and meteorites;
- ❖ elaborate the origin of the Solar System;
- ❖ discuss Earth's dimensional parameters and its position in Solar System;
- ❖ describe various theories put forward to explain origin of the Earth; and
- ❖ explain different methods of determining age of the Earth.

2.2 THE SOLAR SYSTEM: AN OVERVIEW

The universe is so vast that the Earth we live on appears to be just a speck of dust circling a small star in a remote corner of an obscure galaxy. We now know that the universe is about fifteen or twenty billion years old, while we, the human beings appeared around only two million years ago. This vast and ancient universe is populated with a variety of objects.

In your school, you have already learnt that the planet Earth, on which we live, is a member of the Solar System which in turn is the part of the galaxy known as **Milky Way** or **Akashganga**. It is one among the hundreds of millions of galaxies present in the Universe. The universe is considered as infinite in space and time.

In this section, we would briefly discuss about our Solar System and its members.

2.2.1 Our Solar System: A General Survey

Let us first take a general survey of the Solar System prior to discussing about its constituents.

The Milky Way galaxy contains about 100 billion stars which are not uniformly distributed. The congregation of stars and planets is known as **Solar System**. Solar System is a small part of the system of the stars known as **spiral nebula** or the **Galaxy**. One of the stars is the Sun, which is a part of our Solar System. There may be several such systems but our Solar System is the only planetary system somewhat known to us.

Our Solar System has disk like shape comprising eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune), their 172 known satellites, millions of smaller bodies like asteroids and comets and huge quantity of dust-grains and gases.

It has been observed that there is an orderly nature of the Solar System. Let us summarise here some of its major aspects:

- The Sun is at the centre of the Solar System.
- Visualised from top, all the eight planets are observed to move around the Sun counter-clockwise in an elliptical orbit.
- The plane in which the Earth orbits the Sun is called **ecliptic**. Viewing from side, except Mercury, all the planets would appear orbiting the Sun very close to ecliptic and thereby as in a thin disc.
- Most of the satellites have the orbital and spin directions similar to the planets.
- The first four planets closest to the Sun are composed of rocks and metals. They are also known as the **terrestrial** or **inner planets.**
- The next four planets which are away from the Sun are mainly composed of hydrogen and helium. They are also known as the **gas giants** or **outer planets.**
- Sizes of the outer planets and their orbits are about ten times larger than the sizes and orbits of the inner planets.
- There is a belt of asteroids between the inner and outer planets.

These provide a general survey of the Solar System. Let us go on a journey across our Solar System. We begin with the head of the family, the Sun.

2.2.2 The Sun

At night we can see many stars in the sky but during the day only Sun is visible because it is the star closest to us. The light of the other, more distant stars is too feeble to be seen during the day time. The Sun's apparent magnificence had led ancient civilisations to think of it as the 'Head' of the universe. Actually, it is only the 'Head' of its own family, the Solar System.

Sun is the only star of our Solar System and is positioned at its centre. It is a huge gaseous mass like other stars with its Solar System revolving around the centre of the Milky Way. All the planets and asteroids and some comets, revolve around the Sun in elliptical orbits in nearly the same plane. Physical characteristics of the Sun are tabulated in Table 2.1.

Table 2.1: Physical characteristics of the Sun

Sl. No.	Parameter	Data
1	Radius	13,91,104 km
2	Period of revolution	~ 224 x 10^6 years
3	Mass	2x10^{33} g (grams) (almost 99.87% of the mass of the entire Solar System) or 33,20,00 times than that of the Earth
4	Density (mean)	1.4 g/cm^3
5	Surface Temperature	6000 K
6	Temperature of the core	15 x 10^6 K
7	Composition (mass)	70% hydrogen, 28% helium and 2% all other elements
8	Distance from centre	30,000 light years of the Milky Way

The Sun is made up of several layers. The layer that forms the visible surface of the Sun is called the **photosphere.** The innermost layer of the Sun is its core where its energy is produced through nuclear fusion. The outermost layer of the Sun's atmosphere is called the **corona**. Normally, the corona cannot be seen due to the brilliance of the photosphere. However, it is seen during a total solar eclipse when it is visible in its full glory. The corona extends all the way upto the Earth's orbit and even beyond.

The Sun, like other stars has its own light and energy. The thermonuclear reactions wherein hydrogen nuclei combine under intense temperature and pressure to form helium nuclei release vast amount of energy. The Sun's nuclear fusion which continues today is similar to the reaction that occurs in hydrogen bomb.

Now, we shall discuss about planets of our solar system.

2.2.3 The Planets

You can see in Fig. 2.1 that planets are arranged according to their increasing distance from the Sun. The eight planets which go around the Sun are: Mercury **(Buddha),** Venus **(Shukra),** Earth **(Prithvi)**, Mars **(Mangal)**, Jupiter **(Brihaspati)**, Saturn **(Shani)**, Uranus **(Arun)** and Neptune **(Varun)**. Of the eight planets, Jupiter and Saturn are the most massive accounting for a majority of the mass of all planets. Except for Mercury and Venus, all the planets have big and small satellites going around them. There are also countless asteroids and comets in orbit around the Sun. Earth is one of the eight planets revolving around the Sun in our Solar System.

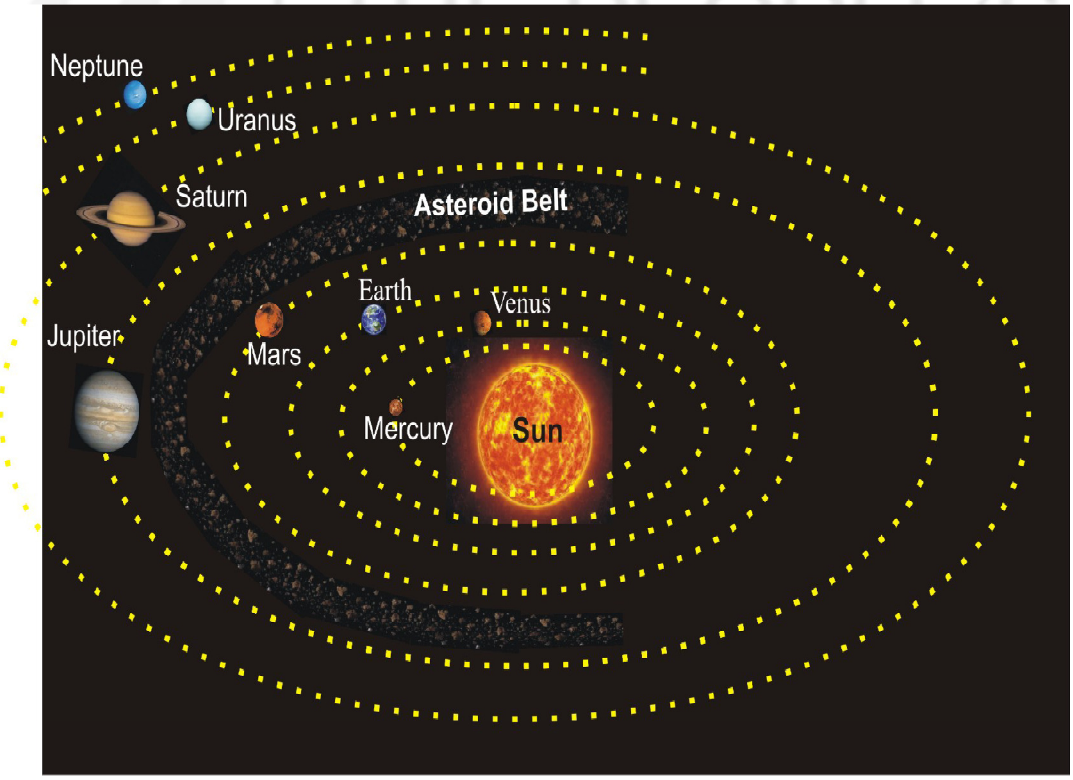

Fig. 2.1: Diagrammatic representation of our Solar System. There is asteroid belt between Mars and Jupiter. There is Kuiper belt farther from Neptune not shown in the figure. Sizes of the Sun and Planets are not to scale.

The eight planets can be grouped into following two groups:

- **The Inner planets** closest to the Sun consisting of Mercury, Venus, Earth and Mars, and lie between the Sun and the belt of asteroids.
- **The Giant Outer planets** comprise Jupiter, Saturn, Uranus and Neptune and lie beyond the belt of asteroids.

The inner planets are also known as the **terrestrial** ("Earth-like") planets. The inner planets are small and made up of rocks and metals. The planets grew close to the Sun in conditions which were so hot that volatile materials could not be retained. The radiation and matter streaming from the Sun blew away most of the hydrogen, helium, water and other light gases and liquids from these planets. The materials left behind were the dense metals such as iron and other heavy, rock forming substances.

Outer group of planets are also called **Jovian** (Jupiter-like) or **Gas Giant** planets. They are composed mostly of hydrogen and helium and the other light constituents of the original nebula and have rocky cores, like the Sun.

Before we discuss in detail about the Earth in the next section, we shall have a look into the planets in brief.

Mercury, the planet nearest to the Sun is very small. It is difficult to see the planet clearly because of the Sun's glare. It appears for a brief time as a morning object in the eastern sky, rising just before sunrise. Then it can be briefly seen as an evening object in the western sky, setting just after sunset. **Venus**, our nearest (at 40 millions km away) planetary neighbour is like Earth in both size and density. Its surface is dominated with volcanic features and is dotted with continent-like highlands and folded mountain belts. Studies suggest that although surface of the Venus has about 1000 relatively young craters, it does not have a heavily cratered terrain dominated by ancient impact structures like those of Moon, Mercury and Mars.

The **Earth**, also known as blue planet is a unique planet home to millions. It is the only planet delicately balanced by the conditions necessary for sustaining life. Seen from space it appears as a bluish sphere. Its surface is dominated by erosional and depositional features. We shall discuss more about general structure of the Earth in section 2.5.

Mars is the red planet having a diameter about half of the Earth is our closest neighbour after Venus. It appears Earth-like. There are ice caps at its poles, drifting white clouds and raging dust storms in its atmosphere. Seasonally changing patterns occur on its red surface. There are large dark areas on its surface called **maria** (meaning 'seas'). There are two major provinces on Mars which have contrasting surface characteristics. Southern hemisphere is heavily cratered whereas the northern hemisphere is relatively young and smooth where the impact craters were buried or destroyed by younger events. Recently, evidence of presence of water on Mars has been detected.

Jupiter is the largest planet of the Solar System. If Earth were placed on the face of Jupiter, it would look like a 50 paise coin on a dinner plate. It weighs more than twice as much as all the other eight planets put together. It also has a small rocky core which may contain iron, silicon and other heavy elements and seems more like the Sun in its composition than the other planets. The most outstanding feature on its surface is the Great Red Spot, a long oval area which is so huge that two Earths, side by side, could be dropped through it.

Saturn, the second largest planet, visible to the naked eye. It's three rings that girdle its equator are visible only through a telescope, make it the most striking and beautiful sight in the Solar System.

Uranus appears as a green disc with vague markings, even through the largest telescopes. Its colour is produced by the large amounts of methane and ammonia clouds in its outer atmosphere. Uranus is unique in the Solar System because its axis of rotation is tilted at an angle of 98° to the perpendicular and lies almost in the plane of its orbit around the Sun. Its one pole sometimes points directly towards the Sun.

Neptune was discovered in 1846 is so far away that from it the Sun would appear just as a bright point. It is orbited by Triton, one of the biggest satellites in the Solar System. Triton orbits Neptune in a clockwise direction, i.e. opposite to the planet's own rotation.

All planets, except Venus and Uranus, rotate on their axes in the anticlockwise direction. So, on all these planets, like on the Earth, the Sun rises in the east and sets in the west. Venus and Uranus rotate in a clockwise direction and as a result, on these two planets the Sun rises in the west and sets in the east! All planets except Uranus have their axes of rotations more or less perpendicular to the plane of orbits.

Let us read important physical characteristics of the planets of our Solar System and of their moons tabulated in Table 2.2.

Table 2.2: Physical characteristics of the planets of our Solar System
(compiled from www.windows2universe.org/our_solar_system/planets_table.html and other sources)

Parameters	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Diameter (with reference to the Earth=1)	0.382	0.949	1	0.532	11.273	9.459	4.007	3.883
Diameter (in km)	4,880	12,104	12,756	6,787	143,800	120,660	51,120	49,530
Mass (with reference to the Earth=1)	0.055	0.815	1	0.107	318	95	15	17
Mean distance from Sun (in AU)	0.39	0.72	1	1.52	5.20	9.54	19.18	30.06
Orbital period (in Earth years)	0.24	0.62	1	1.88	11.86	29.46	84.01	164.8
Mean orbital velocity (in km/sec)	47.89	35.03	29.79	24.13	13.06	9.64	6.81	5.43
Rotation period (in Earth days)	58.65	-243	1	1.03	0.41	0.44	-0.72	0.72
Mean temperature at surface (in C)	-180 to 430	465	-89 to 58	-82 to 0	-150	-170	-200	-210
Mean density (water=1) (in g/cm^3)	5.43	5.24	5.52	3.93	1.33	0.69	1.32	1.64
Surface composition	Silicate	Silicate	Silicate and Water	Silicate	-	-	-	-
Interior composition	Silicates Fe Core	Silicates Fe-Ni Core	Silicates Fe-Ni Core	Silicates Fe-Fes Core	H, He Rocky Core	H, He Rocky Core	H, He Rocky Core	H, He Rocky Core
Atmospheric composition	None	CO_2	$N_2 + O_2$	CO_2	H_2 + He	H_2 + He	H_2 + He	H_2 + He
Number of known Moons	0	0	1	2	67	62	27	13
Presence of rings	No	No	No	No	Yes	Yes	Yes	Yes
Magnetic field	Present	Present	Present	Weak	Strong	Present	Present	Nil

SAQ 1

a) Our Solar System is a part of ……………………….galaxy.

b) What is a galaxy?

c) What is a Solar System?

d) List the planets in our Solar System in the order of their increasing distance from the Sun.

2.2.4 Asteroids, Meteorites and Comets

You may be surprised to know that there is a gap of 547 million kilometres between the orbits of Mars and Jupiter. Located in this gap are thousands of irregularly shaped minor planetary bodies made of rock and metal, ranging in size from mere speck of dust to hundreds of kilometres. These bodies are believed to represent remains of original solar material which failed to bind together to form a planet. These bodies circle around the Sun, hitting each other and continually fragmenting into smaller dimensions. The larger bodies are called **asteroids** and the smaller pieces, when captured by the Earth are called **meteorites**. Asteroids circle the Sun and occupy a broadly disc-like environment known as the **asteroid belt**.

Thousands of fragments of asteroids enter the Earth's atmosphere every year, producing a streak of light across the sky. This streak of light shooting across the sky is called a **meteor** or a **shooting star**. The objects that enter the Earth's atmosphere, are of the size of a grain of sand or a pebble which are destroyed during flight. The objects that are large enough to survive during the flight and hit the Earth's surface are called **meteorites**. Meteorite is any solid matter, which falls on the Earth, Moon or any another celestial bodies from space. According to an estimate, there are more than 40,000 recorded finds of meteorites and about a thousand new meteorites are discovered every year.

Meteorites are composed of iron, nickel and rock forming minerals. Generally, they are classified into three broad groups based on the abundance of metallic and stony minerals they contain: **stony** (or stones), **iron** (or nickel-iron) and **stony-iron** (having both stone and iron components). Majority of the meteorites discovered so far are of the stony type.

Comets are of great interest to scientists because they are relics of the early history of the Solar System. **Comets** are made up mainly of 'ices' which represents a mixture of water ice with frozen gases such as methane, carbon dioxide and ammonia. They are mixed with specks of dust that make them look like dirty snowballs. Some comets reappear at predictable time intervals e.g. Halley's Comet. Its period of reappearance is 76 years. It was last visible in 1986.

Relevant important terms and their characteristics are given in Table 2.3.

Table 2.3: Summary of the characteristics of asteroid, meteorites and comets

Sl. No.	Terminology	Characteristics
1	Asteroid	A small rocky planet orbiting the Sun between the orbits of Mars and Jupiter
2	Meteors, meteoroids and meteorites	**Meteors, meteoroids and meteorites** are particles of dust and small rocks flying through space and have slightly different names, depending on exactly how they behave. The ones which are randomly wandering through space, are called **meteoroids**. When a meteoroid enters the Earth's atmosphere, it starts burning due to friction producing a streak of light with temporary luminous trail behind. They are known as **meteors**. When they strike the ground they are called **meteorites**.
3	Comet	An icy, rocky lump orbiting the Sun believed to have formed from the vast cloud of materials, which surrounds outer fringes of the Solar System.

Let us now understand how our Solar System and the Earth originated.

2.3 UNIVERSE AND SOLAR SYSTEM

We need to know how the universe came into existence and then how the Sun and the planets formed and evolved in order to understand origin of our Solar System and the Earth.

2.3.1 Origin of the Universe

The universe is so vast that majority of the cosmologists believe that it has no edge and hence no centre. Time and space were set at zero. It can be explained by Einstein' theory of relativity which says that the space and time are unalterably linked to form a space-time continuum meaning that there can be no time without space. Thus, when the universe began, all the matter and energy were compressed into an infinitely small high temperature and high density state in which both time and space were set at zero.

The **Big Bang** theory is the most accepted scientific explanation for origin and evolution of our Universe and its members. This theory explains evolution of the universe in which a dense and hot state was followed by expansion, cooling, and a less dense state. According to the theory, our universe began when a cosmic explosion took place around 14 billion years ago. All matter and energy were compacted into a single dense point at that time. This explosion was not a burst of matter into space but rather an explosion of space itself. Every particle of matter rushed away from every other particle, however, it is so far impossible to 'picture' the first moment of 'creation' of the universe. As the explosion continued, matter and energy rushed apart, the universe expanded and the temperature dropped, reaching 30 billion degrees centigrade after about one-tenth of a second. It is believed that at that moment the process began and still continues, the universe expanded and thinned out to form the galaxies and stars. Many thousands of years later, it became cool enough for electrons to join with nuclei to form clumps under the influence of gravity. These clumps ultimately condensed to form the galaxies and stars of the present-day universe, almost 5 billion years after the Big Bang. We as a geologist, focus on the past 4.5 billion years, during which our Solar System, lone star – the Sun and the planets revolving around it evolved.

Obvious question here is how we know that the Big Bang actually happened? There are two important phenomena that provided evidence that the Big Bang occurred: (1) expanding Earth, and (2) presence of background radiation. Hubble recognised through his studies that everywhere in the universe galaxies are moving away from each other meaning that the universe is expanding. The expanding universe suggests that the matter was packed much more densely in the early stages of the Universe. The background radiation, is a relic of the ancient past when the universe was in the initial phase of creation and is believed to be the fading afterglow of the Big Bang. In order to understand formation of the Earth, we need to know how the Solar System was formed.

2.3.2 Formation of the Solar System

We now move on to how and when our Solar System formed after the origin of the Universe.

Several ideas have been floated to it. Many of which have been modified and discarded. Any theory, formulated to explain the origin and evolution of the Solar System must take into account its various features and characteristics such as presence of (i) Sun, (ii) eight planets, (iii) one dwarf planet (Pluto), (iv) known number of satellites, (v) asteroid belt between the orbits of Mars and Jupiter, (vi) millions of comets and meteorites, and (vii) the interplanetary dust and gases.

The **Solar nebula theory** for the formation of the Solar System provides logical explanation for its evolutionary history and accounts for most of the characteristics of the planets and their moons, compositional differences between the inner and outer planets, and the presence of asteroid belt. Chemical composition of the universe also changed with time. Earlier, the universe was 100% hydrogen and helium whereas it later changed to 98% hydrogen and helium and 2% all other elements by weight. Information about the abundances of these heavier elements have been deduced from the study of meteorites.

We can explain change in composition of the universe by this way.

According to the idea (later addressed as **Nebular hypothesis**) was put forth by German philosopher. Kant states that origin of the Solar System could be traced to a rotating cloud of gas (hydrogen and helium) and fine dust called **nebulae**. The gases make up the Sun too, and the dust-sized particles are similar to the materials found on Earth in their chemical composition. Under the force of gravity, the diffused cloud that was rotating slowly contracted, leading to faster rotation of particles. We may compare this to the spin of ice skaters that increases when they pull in their arms.

As the expansion and cooling of the Universe continued, stars and galaxies began to form. The huge rotating cloud of gas contracted and flattened to form a disk of gas and dust as in the Milky Way Galaxy wherein the Sun later formed in the center and eddies gathered up material to form planets. The matter began drifting towards the centre, under the influence of gravitation pull. This drifting lead to accumulation of the matter towards the centre of the disc to form an object (the star to be) referred to as **proto-Sun** or **primitive Sun**, from which the present Sun has evolved. The proto-Sun became dense and hot with compression. With continued compression, internal temperature of the proto-Sun rose to millions of degrees due to contraction until it started generating its own energy, i.e. leading to beginning of nuclear fusion. This nuclear fusion is similar to the nuclear reaction in a hydrogen bomb.

The nebula, from which the Solar System is supposed to have been formed, started collapsing and core formation took place sometime around 5-5.6 billion years ago and the planets were formed about 4.6 billion years ago. The inner planets (Mercury, Venus, Earth, and Mars) are composed mostly of rocky and metallic material with only minor amount of gaseous material. The outer planets (Jupiter, Saturn, Uranus, and Neptune) have large size and low density in comparison to the inner planets. The outer planets are the primary products of the planet formation process and comprise almost all of the mass held in the planetary system.

As the planets formed, the ones in orbits close to the Sun and the others in orbits farther from the Sun developed in different ways. In other words, their composition changed with distance from the Sun. The inner planets emerged as dense, rocky masses and the outer planets with their rocky cores are composed mostly of hydrogen and helium and the other light constituents of the original nebula.

We have now discussed in brief about formation of the star and planets in the Solar System, let us now understand how the planet Earth has originated.

2.4 ORIGIN OF THE EARTH

You may have several questions in your mind about the Earth like how old is it and how did it form? Man has always been interested to find answers to these questions. Our present understanding about the origin of the Earth and its evolution has not come at a shot but in bits and pieces with continued research over a long period of time by different researchers and has matured with time. So, let us now study in this section how the Earth was formed and about the different hypotheses and theories which have been proposed by different researchers while trying to explain origin of the Earth.

We have discussed in the previous section that Earth along with other planets have a common origin that is described as solar nebula hypothesis. Majority of the scientists agree that Earth and the Solar System were formed by planetesimal accretion and gravitational contraction of a massive nebula. The cold primitive Earth became gradually heated due to compression by the increasing weight of accumulated matter and the decay of natural radioactive materials. When heat was produced quicker than it could escape, it resulted in melting of some constituents. Heavier matter were drawn towards the Earth's centre due to gravity and the core formed surrounded by a mantle of less dense material and an outer crust.

Many hypotheses and theories have been proposed to explain origin of the Earth and other related planets that can be broadly divided into the following two groups:

A) **Uniparental or Monistic Hypotheses:** This group of hypotheses is based on the assumption that the origin of the Earth is related to the systematic evolutionary process from one parent body. It has been favoured by Kant, Laplace, Lockyer, Hoyle, Carl Weizacker, Herald Yuri and Kuiper.

B) **Biparental or Dualistic Hypotheses:** This group of hypotheses is based on the assumption that two parent bodies were involved in the formation of the Earth. According to these hypotheses the Earth and other planets have been formed as a result of some explosion activity. It is supported by Buffon, Chamberlin and Moulton, James Jeans, Jeffrey, Russell, Lyttleton, Banerjee and others.

Let us now briefly discuss some of the popular hypotheses proposed to explain origin of the Earth:

1. **Nebular Hypothesis of Kant**: In 1755, the German philosopher Immanuel Kant suggested that the origin of the Solar System could be traced to a rotating cloud of gases and fine dust known as **nebula** and the idea was called **nebular hypothesis**. According to his hypothesis, the Solar System evolved from a single, large, flat, rotating nebula that extended beyond the position of the most distant planet. The rotating nebula, according to the law of universal gravitation, became more compressed and compact with an increase in the speed of rotation. As this nebula contracted the mass became concentrated towards the centre. This led to an increase in rate of rotation and a growth of centrifugal force. Particles of matter fell upon one another under mutual gravity attraction. It generated heat and imparted rotation to the parent mass. In this way the original cloud became a hot spinning mass of

gases called the **nebula**. He suggested that the eight planets including the Earth formed from the bulge at its equatorial plane.

2. **Nebular Hypothesis by Laplace**: In 1796 Laplace suggested that due to contraction and condensation of the gaseous nebula, velocity of the hot gases spinning nebula increased tremendously. Centrifugal force became more than the force of adhesion. Hence, a ring of gaseous matter was thrown up. This ring segregated to form one planet. Repetition of such event gave rise to other planets and the central part remained as the Sun.

3. **Planetesimal Hypothesis by Moulton and Chamberlin**: In 1905 According to this, as another star approached the Sun, huge tides or filaments of hot gases were pulled out from the Sun. As the star passed, these arms of gas were given a rotational motion. After the star was gone, the gaseous matter in these arms condensed into solid material and gradually drew together to form planets.

4. **Jeans Tidal Theory**: This theory was given by Jeans in 1919. Tidal effect was made on the Sun by a passing star. Cigar shaped projection came out of the Sun due to gravitational attraction of the passing star and this formed the parent body. From this cigar shaped filament, planets were formed on cooling and condensation.

5. **Jeffery Collision Hypothesis**: This hypothesis was proposed by Jeffery in 1929. According to him, there was collision between the Sun and a passing star. Passing star glazed surface of the Sun which resulted into solar matter coming out. He suggested that planets were formed by condensation of this solar matter.

6. **Binary Star Hypothesis by H. N. Russell**: Binary stars are also called **twin star** (Fig. 2.2). He considered two initial bodies called as components, the Sun and its companion. One of these revolves around the other. He hypothesised that intruding star approached the companion star due to which a filament was given out that later condensed to form planets.

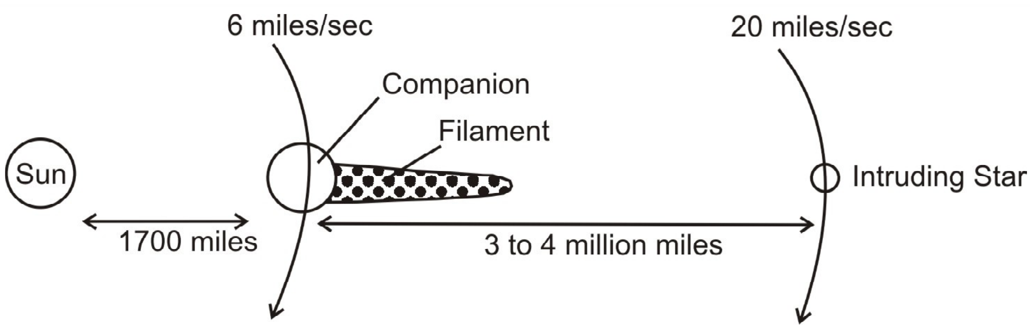

Fig. 2.2: Diagrammatic representation showing components of binary star and the intruding star.

7. **Modern Views**: Uniparental view of origin by evolutionary process has been much favoured by mathematicians, astronomers, physicists, chemists and geologists. The Carl Weizacker's view proposed in 1943

was modified by Herald Yuri in 1952 which was further revised by Kuiper in 1957.

Let us now briefly discuss these views:

a) **Hypothesis of Yuri-Kuiper**: According to this hypothesis, there was a big cloud of dust and gases in the space. It constituted a mixture of condensed water vapours, ammonia, methane like hydrocarbon gases and iron oxide dust. By the effect of light of stars, compression started in the components of this big cloud. This led the central part of the cloud to develop into **'ancestral Sun'** by the process of condensation (Fig. 2.3). In due course, the huge cloud of gas and dust rotating around the ancestral Sun, also divided into turbulent eddies of uneven sizes.

According to Kuiper, as the distance from the Sun increased, size of the eddies increased. They collided with one another and formed **'planetisimals'** (small planets) or **'protoplanets'** started by uniting and condensing. By collision and union of planetisimals larger planets were formed. One of these is our Earth. After melting, the differentiation started in the components of the Earth. After formation of the Earth various types of gases were ejected from its interior, and from these gases originated the atmosphere.

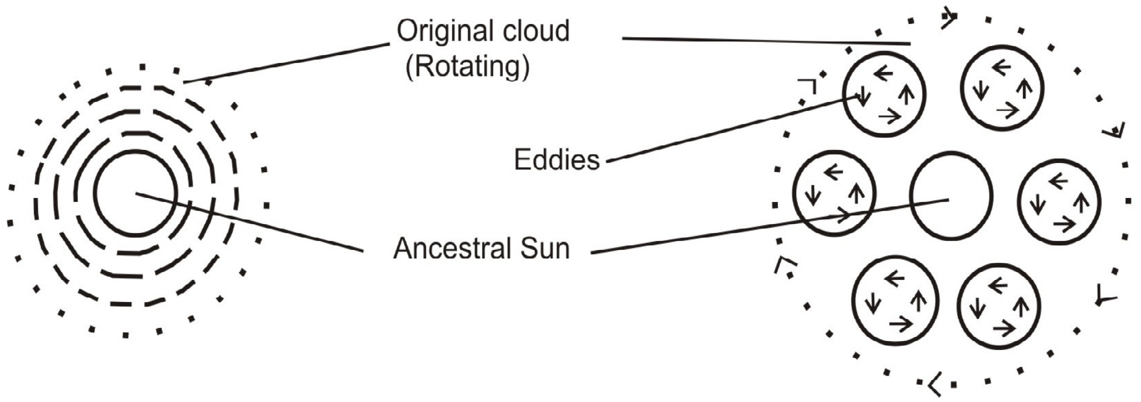

Fig. 2.3: Schematics showing process of condensation.

b) **Fred Hoyle's Magnetic Theory**: Fred Hoyle in 1958 propounded his hypothesis, according to which the protoplanetary cloud was created in the process of differentiation of the Sun from an original nebular matter that had been undergoing contraction. The differentiation of the nebular matter into Sun and the gaseous cloud was due to fast rotation of the nebular mass. The process of differentiation came to an end due to magnetic coupling between the Sun and the gaseous cloud and gave rise to planets.

Indian Physicist, Jayant Narlikar proposed a theory together with Fred Hoyle which is known as Hoyle-Narlikar's theory. It was motivated by their belief in the steady state model of the Universe.

c) **Big Bang Theory**: Currently, the Big-Bang theory is the best model proposed to explain origin of the Earth. It states that the universe emerged from a hot and dense state billion years ago. From this soup of elementary particles (electrons, protons, neutron, etc.), all the elements that we know today in the periodic table were formed. The Big Bang nucleosynthesis theory attempts to explain the related process. Big Bang nucleosynthesis occurred only in first three minutes. The universe has been expanding ever since the 'creation' which is called **Big Bang**. The theory was propounded first by George Gamow in 1940s and details were worked out by Fred Hoyle and William Fowler. The term **Big Bang** was coined by a famous English astronomer Fred Hoyle. There was of course no bang or explosion signalling the beginning of the Universe but it was certainly a violent event, since all the matter and energy in the Universe today was created at that point instantaneously. Astronomers believed that this event took place around 14 billion years ago. Big Bang theory has been remarkably successful in explaining several observations about the Universe.

Various planetesimals in our Solar System gathered enough material together to form Earth and other planets about 4.6 billion years ago. The Earth has been evolving and changing ever since its origin. It is believed that this early Earth was probably cool, composed mostly of silicates with compounds of silicates and oxygen, iron and magnesium oxides and some other elements in small amounts. It had generally uniform composition and density throughout. In the first tens of millions of years of the Earth's evolution, combinations of several factors such as (a) impact of small bodies like meteorites, (b) gravitational compression, (c) squeezing together of matter and (d) heat from radioactive decay increased temperature of the Earth. The temperature increased enough to cause some of its constituents to melt resulting into disappearance of homogeneous composition and replacement by a series of concentric layers of varying composition and density. This changed the Earth in a differentiated planet consisting of three concentric layers: core, mantle and crust. We shall discuss about these layers in this unit later in section 2.5 and further in Unit 3 Structure and Composition of the Earth.

In this section, we have discussed about the several hypotheses and theories proposed to explain origin of the Earth. Before discussing about age of the Earth, we will discuss about surface relief features of the Earth in the next section.

SAQ 2

a) What is Big Bang theory?

b) Explain Jeans Tidal theory of origin of Earth.

c) What is the difference between uniparental and biparental hypotheses?

d) What is binary star hypothesis?

We will now study in the next section about physical aspects of the planet we live on, i.e. the Earth.

2.5 SHAPE AND STRUCTURE OF THE EARTH

The Earth we live on has fascinated the mankind since the beginning of the civilisation. Its wealth of plants and animal life, snow covered peaks, blue oceans and white clouds make the Earth a beautiful planet. Human beings have extensively explored it. Yet, the first hand knowledge of the Earth is limited to a thin shell of rock and water extending to a few kilometres below the surface into the ocean, and to the atmosphere above. However, using indirect methods, such as the study of seismic waves generated during earthquakes, scientists have been able to picture the Earth's interior, without ever seeing or sampling it. We will now briefly discuss the current scientific knowledge about the Earth such as shape and size, surface features and its structure.

2.5.1 Physical Aspects

The Earth is nearly a spherical planet. More precise measurements show that Earth is not a perfect sphere. It is slightly flattened at the poles and bulged at the equator because of its daily rotation. The Earth rotates through 360° and revolves once around the Sun in a period of 365¼ days. The smooth curvature of Earth's surface is broken by mountains and valleys. This topographical variation is measured with respect to mean sea level (MSL). Parameters of the Earth relating to size, area, volume, density, mass and relief are given in Table 2.4.

Table 2.4: Parameters of the Earth relating to size, area, volume, density, mass and relief

A)	**The Size**	**Value**
1.	Equatorial diameter	12,757 km
2.	Polar diameter	12,714 km
3.	Equatorial circumference	40,077 km
4.	Polar circumference	40,000 km
5.	Earth's radius	6371 km
B)	**Area**	
1.	Area of sea floor (70.78%)	361 million km^2
2.	Area of lands (29.22%)	149 million km^2
3.	Total area of the Earth	510 million km^2
C)	**Volume, Density and Mass**	
1.	Volume	1.0817×10^{21} m^3
2.	Density	5.527 g/cm^3
3.	Mass	6×10^{21} tonnes

D)	Relief	
1.	Greatest height above sea level (Mt. Everest in Himalayas)	8848 meters
2.	Greatest depth below sea level (Challenger Deep in Mariana Trench off Japan and Philippines)	10,971 meters

2.5.2 Surface Relief Features

Surface relief or physical features of the Earth's crust can be broadly divided into following three main units:

a) **Continents**: They cover 29.2% of the Earth's surface. Nearly 75% of the land area is present in the north of equator. Continents have varied relief of plains, plateaus, mountain ranges, etc.

b) **Oceans**: They cover 70.8% of the Earth's surface area. Pacific Ocean, with average depth of about 4267 meters is the largest and covers almost half of the Earth. Ocean canyons, seamounts and trenches are met in different parts of oceans.

c) **Mid Oceanic Ridges**: These are raised hill type features formed under the sea water such as the Mid Atlantic Ridge. The ridge is centrally located between eastern and western margins of the Atlantic Ocean and is about 1610 km wide and rises about 4.2 km above the ocean floor. Islands are projections of oceanic ridges above the sea water.

There are numerous features on the Earth's surface of different elevations, which develop as a result of various internal and external processes operating inside and on its surface. We call it low relief when the earth surface is relatively flat and high relief when the surface is not flat and has high or low elevated features. So, when we speak of relief, it is the difference in elevation between two points.

We can broadly divide surface relief features of the Earth into five orders based on their extent, size and mode of formation:

a) **First order relief features**: First order relief features are the largest feature that can be recognised such as the continental platforms and ocean basins. These features are the tectonic plates and are the largest in their spatial extent. These plates referred to as **continental** and **oceanic** plates or transitional plates, are characterised by different rock and mineral composition. Continental plates are lighter in density whereas oceanic plates are denser. At the boundary between continental platform and ocean basins are the continental shelf.

b) **Second order relief features**: Examples of the second order relief features are the mountain ranges (such as the Himalaya, Mount Kilimanjaro, etc.) and valleys (such as Great Rift Valley of Africa, etc.) which form within the continental platforms and oceans. They are formed as a result of movements of these continental platforms and ocean basins.

c) **Third order relief features**: The relief features such as individual landform complexes of lesser extent and size than those of the second order are the third order relief features. These are formed by erosion and deposition of the surface and not as a result of movement of tectonic plates. Although, there is no upper or lower limit to the size of these third order relief features, we can distinguish between the second and third order relief features. If we can see the entire form of relief feature it is the third order feature. Typical examples of the third-order features are discrete mountain ranges, groups of hills and large river valleys.

d) **Fourth order relief features**: They are the sculptural details of the third order features. Individual landform features such as a mountain or a hill within the third-order features are the fourth order relief features.

e) **Fifth order relief features**: These consist of small individual features that may be part of the fourth-order relief such as a cliff, a waterfall or a sandbar.

2.5.3 Structure

We will now look into the Earth's structure in brief. Earth constitutes several layers but the three major layers are crust, mantle and core (Fig. 2.4).

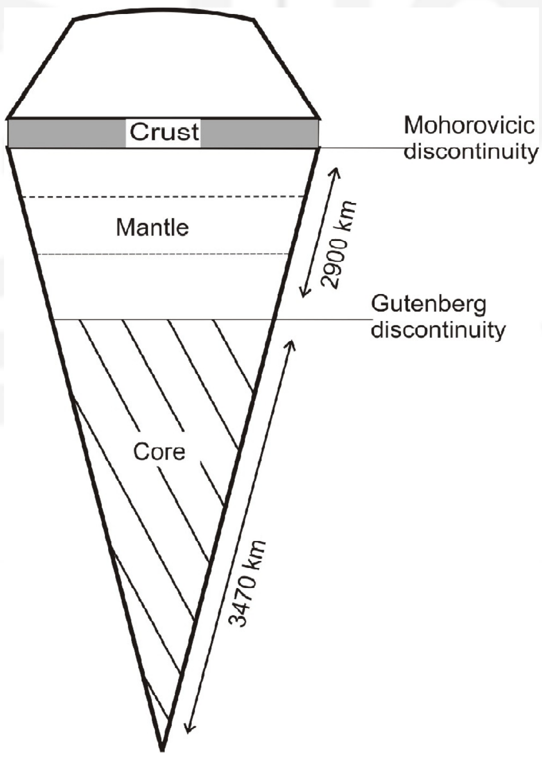

Fig. 2.4: Wedge of the Earth showing the crust, mantle and core with major boundaries.

The outermost solid layer on the surface of the Earth is the **crust**. It is about 10 km thick under the oceans and about 40 km thick under the continents. If you imagined the Earth to be apple sized, its crust would be as thick as the apple's skin.

Crust is the topmost part of a layer called **lithosphere**, the Earth's outer layer. The lithosphere has lumps which we see as mountains, and wrinkles in the form of trenches in the ocean. Beneath the crust, the bulk of the Earth's interior is hot and partially molten.

The innermost part of the Earth is the **core**. The intermediate layer between the core and the crust is known as **mantle.** It is about 2900 km thick and accounts for nearly 80% of Earth's total volume. Core is separated from the mantle by **Gutenberg discontinuity**. The imaginary line that separates the **lithosphere** from the mantle is known as 'Moho' or **Mohorovicic discontinuity**.

Before discussing about age of the Earth, spend few minutes to check your progress.

SAQ 3

a) List surface relief features of the Earth.

b) Mention the three layers of Earth.

c) Define lithosphere.

d) What is mantle?

2.6 AGE OF THE EARTH

It has been mentioned earlier that Earth has originated around 4.6 billion years ago but how did we come to this conclusion. You have heard about dinosaurs which existed 65 million years ago on the Earth's surface. Earth in its history has recorded how life evolved on it. How can we say with certainty that dinosaurs existed 66 million years ago? You may be wondering how we can tell, today, that a particular rock is a million years old, or a fossil is 65 million years old! We study about the age of the Earth under the subdiscipline **'Geochronology'.** Geochronology is defined as the science of Earth dating.

Now let us have an idea about the methods of estimation and calculation of age of the Earth.

2.6.1 Age Determination of Rocks

Various methods have been used for age determination of rocks and of the Earth which can be broadly classified into following two groups:

a) **Indirect methods**: These are geological methods used in relative dating of geological event (s).

   Relative age is the geologic age of a fossil, or a geologic event or feature expressed relative to other organisms, rocks, or features or events rather than in specific number in units of time.

b) **Direct methods**: Radioactive methods are used to determine absolute age.

   Absolute age or the actual age is the geologic age of a specimen such as a fossil or mineral or rock, or a geologic event or feature expressed in specific number in units of time.

   Absolute age can be determined by geological and radioactive methods.

   Some of the important methods are as follows:

A) **Geological Methods**

i) **Denudation or Sedimentation**: This method is based on the fact that deposition has been going on in the basins right from the origin of the Earth. It was proposed that if total thickness of the sediments could be known and the rate of deposition could be found out then the age can be calculated by the following formula:

$$\text{Age} = \frac{\text{Total thickness of sediments}}{\text{Sediments deposited in one year}}$$

The age 510 million years by this method has been calculated since the beginning of Cambrian sedimentation.

ii) **Salinity**: In this method, it is presumed that the first formed seas did not have saline water. All the salts of the seas today have been acquired from continuous weathering and erosion of rocks that constitutes the land. It was proposed that if the salt present in the seas and its addition per year could be worked out then the age can be calculated. By this method, age of the Earth was calculated to be 100 million years by Jolly using the following formula:

$$\text{Age} = \frac{\text{Total salt of oceans}}{\text{Salt added in one year}}$$

iii) **Glacial varves**: Glacial varves are deposits generated due to combined action of river(s) and glacier(s). In summers, coarse grained material is deposited and in winters the deposition of fine grained material takes place. Each pair of coarse and fine material is called a **varve** and represents one year. Geological time upto 10,000 years has been calculated by counting such varves. This method has been used for the lake deposits of the Karewa basin in the Kashmir valley.

iv) **Tree rings**: Trees have their annual growth rings. Secondary growth rings of trees can be counted. Each pair of such rings represents one year. Time up to few thousand years can be calculated on the basis of such rings.

v) **Palaeontological evidences**: Charles Lyell in 1867 estimated age of the Earth on the basis of evolution of animals and plants. He found twelve cycles of evolution, each corresponding to twenty million years. However, this method could help in reaching to rough estimation of age after origin of life.

B) **Radioactive Methods**

With the developing knowledge of radioactivity, more accurate dating of certain types of rocks has become possible. Radioactive substances can be easily detected using certain instruments. They have built-in clocks in the form of radioactive isotopes that change or decay at a constant rate into non-radioactive form. If this rate is known, age of the rock can be estimated by measuring the quantities of the radioactive isotopes and the non-radioactive ones into which they have changed in the rock. For example, uranium is transformed into certain isotopes of lead which are not radioactive. So, the age of uranium-containing rocks can be determined by comparison of the proportions of undecayed uranium and that of the corresponding lead isotopes present in the rock (Fig. 2.5).

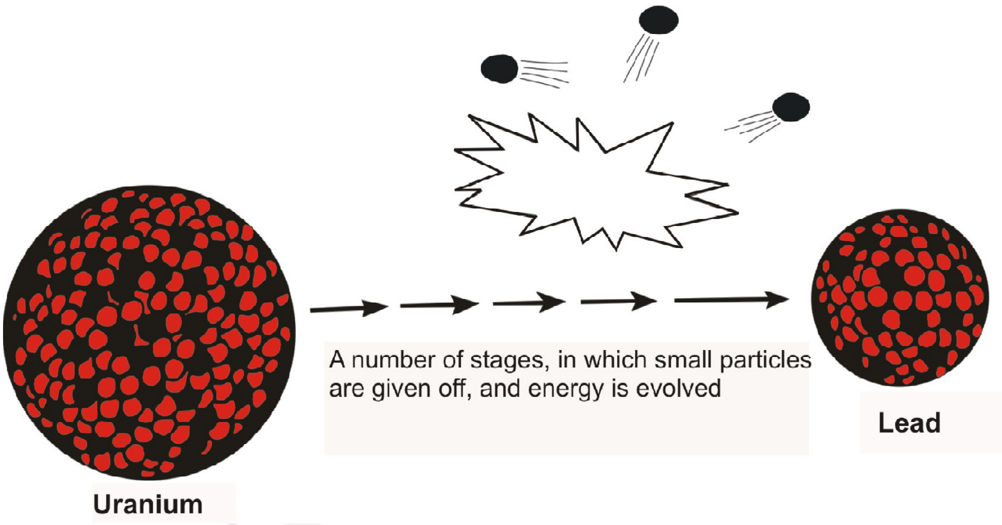

Fig. 2.5: Radioactive atoms have unstable nuclei. When these nuclei break down or decay, they emit characteristic particles or rays. The end result of this radioactive decay is formation of another kind of atom.

A radioactive parent element decays into a stable daughter element at a constant rate. Usually, the '**half life**' period is the time in which half of the material is consumed or disintegrated and half of the number of atoms remains out as original. This concept of half life is used to find out absolute age of the Earth. Radioactive elements like radium, uranium and thorium disintegrate into successively simpler elements of smaller atomic weight. This change takes place at a constant rate and continues till a stable substance is formed. This stable substance is called '**end product**' or '**daughter element**'. In the case of all the three elements (radium, uranium and thorium), the end product lead (Pb) is found in different isotopes. In this process of integration, three types of radiations are identified.

- α (Alpha) particle with Helium (He^{+}) atom.
- β (Beta) particle with Electron.
- Υ (Gamma) gaseous material which is X- ray.

Important advantages of radioactive methods over relative dating methods are as following:

- It provides absolute age of rocks.
- All rocks of the Earth's crust have small amount of radioactive elements.
- Radioactive age determination is based on the fact that radioactivity is not affected by temperature, pressure or chemical fluids.

In this process of radioactivity, it is assumed that after the origin, both lead and helium remain entrapped within the parent rock. Following five commonly used methods are available for finding out the age based on different radioactive series:

- U^{238}
- U^{235}
- Th^{232}
- Ar^{40} or K^{40}
- Sr^{87} or Rb^{87}

Main radioactive series along with their daughter elements and half life period are given in Table 2.5.

Table 2.5: Radioactive series, with mother element, daughter element and half life period of main radioisotopes

Radioactive series	Mother element	Daughter element	Half lifeperiod
1	U^{238}	Pb^{206} - 8 He^4	4.498 x 10^9 years
2	U^{235}	Pb^{207} - 7 He^4	0.0713 x 10^9 years
3	Th^{232}	Pb^{208} - 6 He^4	13.9 x 10^9 years
4	Rb^{87}	Sr^{87}	50 x 10^9 years
5	K^{40}	Ar^{40}, Ca^{40}	11.9 x 10^9 years
6	C^{14}	N^{14}	5730 years

Following are the commonly used methods for determining the age of the Earth:

a) **Uranium-Lead method**: Two isotopes U^{th232} and U^{pb235} of uranium can be used. Their half lives are 4498 million years and 713 million years, respectively.

b) **Thorium-Lead method**: Thorium Th^{232} yields lead Pb^{206} through radioactive decay and the half-life of thorium is 13,900 million years.

c) **Potassium-Argon method**: K-Ar dating depends on the decay of the naturally occurring K^{40} isotope to Ar^{40} and Ca^{40}. Potassium has three isotopes like K^{39}, K^{40} and K^{41} but only K^{40} is radioactive. Its half life is 11.9 x 10^9 years. About 90% of K^{40} decays to Ca^{40} and the remaining 10% decays to Ar^{40}. Assuming that no Ar^{40} was present when the rock was laid down (due to volatilisation), age of the rock can be calculated. We can determine age of a rock sample by measuring the amount of Ar^{40} and potassium in the rock. Some drawbacks of this method are the practical difficulties involved in measuring the small amount of argon in rock.

d) **Rubidium-Strontium method**: Rb^{87} yields Sr^{87} and its half-life period is about 50x10^9 years. This is useful for metamorphic rocks of Precambrian age. Rubidium-Strontium dating is based on the decay of naturally occurring Rb^{87} by β (Beta) emission. Both Rb^{87} and Sr^{87} can be measured in rock samples by mass spectroscopy.

e) **Radiocarbon Dating method**: Radiocarbon dating is the most commonly used method in which traces of radioactive isotope of carbon

C^{14} commonly known as carbon-14 is analysed to date materials which are less than 60,000 years old. C^{14} radioactively decays with a half life of 5730 years but because of the impact of cosmic rays some of the nitrogen in atmosphere is constantly being made into small quantities of C^{14}. Ordinary carbon C^{12} of which all the living organisms are made has radioactive isotope C^{14}, which is unstable. Some of the C^{14} in atmosphere combines with oxygen to form carbon dioxide. While most of the carbon dioxide in air is made up of normal carbon or C^{12}, there is some C^{14}. Since C^{14} is chemically the same as ordinary carbon, both are absorbed by plant and animal tissues in the same proportion as they are present in the atmosphere as carbon dioxide. Plants use this carbon dioxide in making their food which is then consumed by animals. Therefore, every plant or animal has some radioactive C^{14} in its body. The proportion of C^{14} in the tissues of plants and animals is the same as in the atmosphere, as long as the plant or animal is living. When an animal or plant dies, the metabolism stops and there is no further increase in amount of C^{14}. Following death, the C^{14} already present in the body, decays steadily into ordinary carbon. So the smaller the number of carbon-14 atoms remaining, the older is the fossil. By measuring the amount of C^{14} left in the piece of wood or bone, scientists can estimate when the organism died. The ratio of C^{14} to C^{12} decreases at a known rate. By finding out ratio between C^{14} and C^{12} and multiplying it by half life period, the age can be calculated.

This technique has been applied to materials of known age, and thus its accuracy was tested giving confidence in the age determinations of unknown samples. This method is applicable only to organic materials which still contain carbon. It cannot be used for fossils in which all organic matter has decayed. In that case, the age of the fossil can be estimated by determining the presence of other radioactive elements.

In 1949, American chemist Willard Libby discovered radiocarbon dating method to accurately date once living relics. This method is useful in dating the rocks up to Late Pleistocene but not the older ones.

2.6.2 Calculation of Age

Let us now understand how the age has been calculated and what the important findings are:

i) The age of the Earth has been obtained by Uranium-Lead ratio method and the age of the present day crust is estimated to be between 3500 and 5550 million years old.

ii) From meteorites by the measurement of Pb^{207} and Pb^{206}, If the amount of primordial Pb in the crust is taken as in the meteorites, the age of the Earth has come to be 4500 million years old.

iii) U-He and K-Ar dating of meteorites has given age of 4580 to 4520 million years. Sr^{87}/ Sr^{86} determinations also suggest the same age.

iv) It is concluded on the basis of radiometric dating that the Earth's crust must have been formed 4.6 billion years ago.

In India, there is a record of an oldest dated rock from Singhbhum craton, which is 3.77 million years old (Saha, 1994). The oldest reported age of 4.1-4.3 billion years for some zircon crystals from a metamorphic terrain in Australia (Compston et al. 1986) implied that there existed still older parts of the Earth's primordial or early crust from which the zircons were derived.

2.7 SUMMARY

Planet Earth is a part of our Solar System. Let us summarise about what we have learnt in this unit:

- Although several hypotheses have been proposed to explain origin of the Earth, the solar nebula theory is currently the most accepted one.
- The Earth originated from a rotating cloud of gas and dust. Their cooling and condensation formed the planets in outer ring and the remainder gave rise to the Sun.
- Earth is third planet from the Sun in our Solar System, having atmosphere and hydrosphere to support life. Broadly, it is composed of three layers: crust, mantle and core each separated by discontinuities.
- Although several methods of computing age of the Earth have been suggested, the radioactive methods are near perfect in determining the age of rocks and the Earth. There are evidences that suggest that Earth formed nearly 4.6 billion years ago.

2.8 ACTIVITY

1. Take a balloon and blow it up about half. Then mark it with some dots at different intervals. Now again blow it up to some extent. Do you see that the dots are going away from each other? Can you relate it with the expanding universe?
2. Take a cardboard and mark Sun and other planets at different intervals with their orbits. Place balls of relative sizes on the sites of the marks for Sun and planets. Does it help you to visualise our Solar System better?
3. Take a foam ball, cut it half and mark the three layers considering it as Earth.

2.9 TERMINAL QUESTIONS

1. Discuss the position of the planet Earth in the Solar System.
2. How did the universe form?

3. What are the different theories put forth to explain origin of the Earth? And which theory is considered as the best possible model?

4. What are the methods of determining age of the Earth and its rocks?

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2.11 FURTHER/SUGGESTED READINGS

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- Mahapatra, G.B. (2012) (Reprinted), A Textbook of Geology, CBS Publishers, New Delhi, 326p.

2.12 ANSWERS

Self-Assessment Questions

1. a) Milky Way.

   b) Galaxy is a collection of stars, dust clouds and gas. The Milky Way Galaxy is one among billions of galaxies in the Universe.

   c) Solar System is a small part of the system of the stars known as spiral nebula or the Galaxy. Congregation of stars and planets is known as Solar System.

   d) Members of our Solar System in the order of their increasing distance from the Sun are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune.

2. a) The term Big Bang was coined by an English astronomer, Fred Hoyle. The Big-Bang theory is currently the best model proposed to explain origin of the Earth. It states that a big violent event is responsible for creation of the universe around 14 billion years ago.

b) The Jeans Tidal theory was given by Jeans in 1919. According to this theory a cigar shaped projection came out of the Sun due to gravitational attraction of the passing star and this formed the parent body. From this cigar shaped filament, planets were formed on cooling and condensation.

c) The uniparental hypotheses are based on the assumption that the origin of the Earth is related to the systematic evolutionary process from one parent body whereas biparental hypotheses are based on the assumption that the origin of the Earth is related to the evolutionary process from two parent bodies and the Earth and other planets have been formed as a result of some explosion activity.

d) According to the Binary star hypothesis there were two initial bodies (twin stars), i.e. the Sun and its companion with one of them revolving around the other. When an intruding star approached the companion star, a filament was given out that later condensed to form planets.

3. a) The three main units of the surface relief features of the Earth are the continents, oceans and mid-oceanic ridges. However, based on their extent, size and mode of formation, surface relief features of the Earth can be broadly divided into five orders: first order-continental and ocean plates, second order-mountain ridges and valleys, third order-mountain ranges, fourth order-mountain or a hill, and fifth order-cliff or a sandbar.

b) The three layers of the Earth are the crust, mantle and the core.

c) Lithosphere is the upper layer of the Earth consisting of crust and upper part of the mantle.

d) The intermediate layer between crust and core is known as mantle. It is about 2900 km thick and accounts for nearly 80% of Earth's total volume.

Terminal Questions

1. Our planet Earth is located at the third position in distance from the Sun in our Solar System. You can further refer to subsection 2.2.3 to further discuss your answer.

2. It is believed that the universe was created around 14 billion years ago through a big violent event. All the matter and energy in the Universe today was created at that point instantaneously. As the expansion and cooling of the universe continued, stars and galaxies began to form. Most of the visible mass of the Universe, and almost all stars, are composed primarily of hydrogen and helium made during the Big Bang.

3. Many hypotheses and theories have been proposed to explain origin of the Earth that can be broadly divided into uniparental and biparental groups of hypotheses. Currently, the big bang theory is the widely

accepted theory. You can refer to section 2.4 to further discuss your answer.

4. There are various methods for age determination of rocks and of the Earth which can be broadly classified into two groups: (a) Geological methods used in relative dating of geological event(s) and (b) Radioactive methods to determine absolute age. You can refer to section 2.6 to further explain your answer.

UNIT 3

STRUCTURE AND COMPOSITION OF THE EARTH

Structure

3.1 INTRODUCTION

The Earth is a unique planet, home to millions. It is the only planet delicately balanced by the conditions necessary for sustaining life. Researchers have found that the size and composition of the Earth and its distance from the Sun are favourable for supporting its four spheres, i.e. atmosphere, hydrosphere, lithosphere and biosphere. Earth is at a distance from the Sun such that it allows existence of water in different forms. Had it been a little closer to the Sun, our oceans would not have existed; and if a little farther from the Sun, the oceans would have freezed. Gravitational field of the Earth is strong enough to hold an atmosphere. Considering the vastness of the Universe, we find that the Earth is a small place. We can compare the Earth to an oasis in space.

In this unit, we would discuss about constituents of the Earth, its internal structure and processes. We would also discuss in brief about origin of the atmosphere, hydrosphere and biosphere, Earth's internal temperature and magnetic field.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ discuss constituents of the Earth;
- ❖ write about the origin of atmosphere, hydrosphere and biosphere;
- ❖ explain Earth's interior, its different layers and composition;
- ❖ describe about Earth's internal temperature; and
- ❖ explain Earth's magnetic field and the geodynamo.

3.2 CONSTITUENTS OF THE EARTH

Let us begin with the discusion about the constituents of the Earth. The outer most part of the Earth is surrounded by layers of air, water, and living things. They are continually inter-reacting with each other. The outer part of the Earth consists of following four spheres:

1. Atmosphere
2. Hydrosphere
3. Lithosphere
4. Biosphere

We shall now discuss about characteristics and structure of these four spheres.

3.2.1 Atmosphere

Atmosphere consists of the gaseous matter which envelopes the solid Earth including the terrestrial land and oceanic water is termed as the atmosphere and it extends up to a considerable height. The atmosphere is not of the same density throughout and atmospheric pressure decreases with height. Its constituents are mainly nitrogen (78.03%), oxygen (20.99%) and the remaining gases (1%- argon 0.94%, CO_2 0.03%, varying amounts of water vapours and traces of hydrogen, ozone, methane, carbon monoxide and rare gases). It is a medium of climate and weather, winds, clouds, rain and snow.

Structure of Atmosphere: It is divided into several parts depending on composition and temperature as shown in Fig. 3.1. It comprises following five layers:

- **Troposphere** is the lower most and important layer of the atmosphere. Its average height is 16 km. At equator its thickness is 18 km and 8 km over the poles. The troposphere contains about three-fourths of the total mass of atmosphere, thus, it is densest of all layers. Here exists the air that we breathe.
- **Stratosphere** is the layer of atmosphere ranging from 16 to 50 km. Here air is at rest. It is free from cloud dust and water vapour. The upper part is rich in ozone. The ozone layer serves as a shield, protecting the troposphere and Earth's surface by absorbing most of the ultraviolet (UV) radiation found in the Sun's rays.

- **Mesosphere** it extends from 50 to 90 km over the Earth's surface. It lies above the stratosphere and is a cold region. A layer occurs within the mesosphere, called radio-waves absorbing layer.
- **Thermosphere** extends over mesosphere between 90 and 600 km. Ionosphere is a part of this layer. Radio waves transmitted from the Earth are reflected back by this layer making communication between places possible. Meteorites entering from the space burn up in this layer.
- **Exosphere** is the upper most layer of the atmosphere and has very thin air.

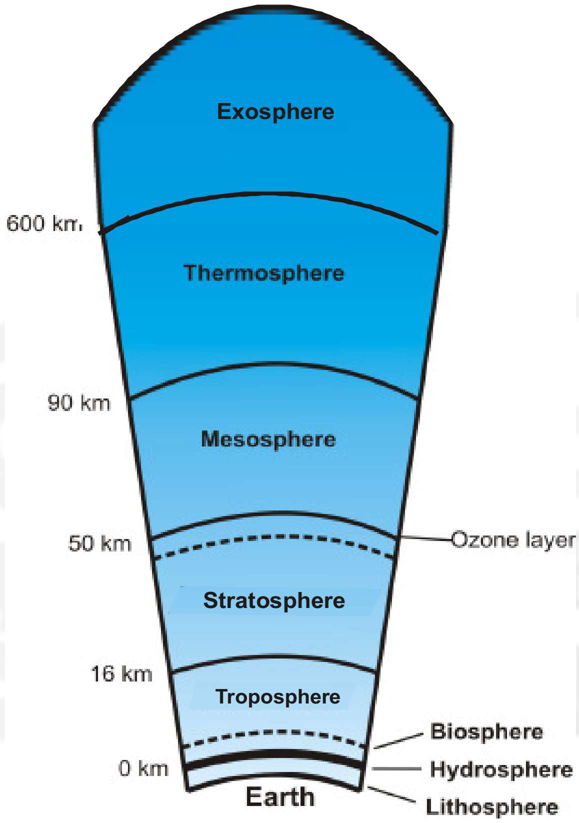


Fig. 3.1: Layers of atmosphere.

Temperature: In contrast to troposphere the temperature steadily rises in stratosphere to thermosphere. The temperature decreases from the surface to about 16 km in tropical regions and thereafter it starts increasing with height. As we go up in thermosphere, the temperature rise is very rapid.

3.2.2 Hydrosphere

Hydrosphere is the 'water sphere', embracing all the world's natural water resources: oceans, lakes, streams, rivers, underground water, and snow and ice including glaciers. Water is the only known substance which is present in Earth in its all three physical forms, i.e. liquid, solid and gas in its surface and atmosphere. The presence of water in its three forms and its conversion from one form to another are important for the maintenance of climatic conditions and sustenance of the Earth's ecosystems. The presence of freshwater is very important for sustaining life on Earth, hence it is the most precious but scarce natural resource. The availability of freshwater depends upon the transport of water vapour from the oceans through the atmosphere to land as rain and snow.

Most of the world's water is in the oceans but small fractions of water are present in its atmosphere and in freshwater lakes, rivers, ice caps (and glaciers) and groundwater as given in Table. 3.1. Water is circulated among the oceans, atmosphere, freshwater, groundwater and polar ice sheets, and this process is called **hydrologic cycle**.

Table 3.1: Distribution of world's water

Location of water	Volume of water (M^3)	Percentage of Total
Oceans	317,000,000	97.2
Ice caps and glaciers	7,000,000	2.15
Atmosphere	3,100	0.001
Surface waters (freshwater and saline lakes, rivers and inland seas)	110,300	0.017
Subsurface waters (soil moisture and ground water)	2,016,000	0.625

The world ocean covers about 70.8% of the global surface and its average depth is about 4267 m. The total volume of the world ocean is about 1.4 billion cubic km. The seawater is saline and comprises relatively similar proportions of salts like sodium, potassium and magnesium, over a considerable span of geological time. The dissolved salts or solutes are added to sea water from erosion of the rocks of the Earth's surface.

3.2.3 Lithosphere

Based on the physical properties, the outermost parts of the Earth can be divided into two parts i.e. the lithosphere and asthenosphere. Lithosphere is the rigid upper layer of the Earth and asthenosphere is the molten layer of the Earth under the lithosphere. The term lithosphere is used for the outer solid shell crust beneath the oceans and mountains consisting of the rocky crust and upper part of mantle. Lithosphere is about 100 km thick. Slow propagation of the seismic waves suggest that beneath the lithosphere lies the warm, molten and plastic asthenosphere layer extending up to a depth of about 300 kilometers on which the lithosphere moves. The term 'lithosphere' is derived from the Greek *lithos*, for "stone" and the word "asthenosphere" is derived from the Greek *asthenos*, meaning "without strength" or "devoid of force". We can compare the rocks in the asthenosphere to an open tube of toothpaste, which when applied slow pressure (strained), flows slowly. However, asthenosphere behaves like a solid when it is struck by an earthquake.

We can categorise the dominant rocks of the crust in the following two groups on the basis of their density as given in Fig. 3.2:

i) **SiAl**: They are light coloured silica rich (~70%) rocks such as granite forming the continental part with density ranging from 2.75 to 2.9 g/cm^3. Aluminium is the second most abundant constituent. Hence, it is called SiAl (Si-Silica and Al-Alumina).

ii) **SiMa**: They are below SiAl and form base of the oceans. They are dark coloured rocks like basalt with silica ranging from 40% to 50%. Magnesium takes the second place; hence it is called SiMa (Si-Silica and Ma-Magnesia). Their density ranges from 2.9 to 4.75 g/cm^3.

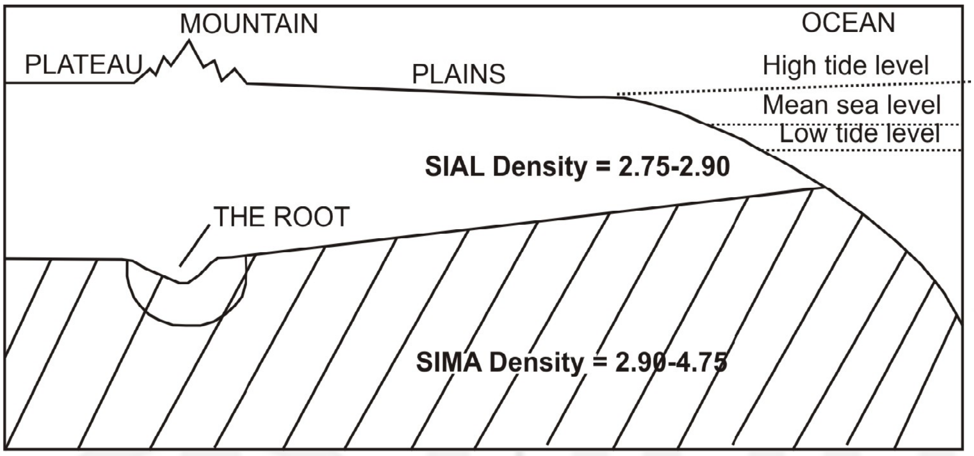


Fig. 3.2: Sketch showing SiAl and SiMa.

According to the estimation made by Clarke and Washington, the lithosphere consists of 95% igneous rocks, 5% sedimentary rocks (the metamorphic rocks being the altered equivalent of one or other of these rocks).

3.2.4 Biosphere

The biosphere is the biological component of Earth system, which interacts with and exchanges matter and energy with the other spheres hence it includes the atmosphere, hydrosphere and lithosphere. It is the part of the Earth which is inhabited by living organisms. As its name implies biosphere is 'life sphere' which includes all the Earth's living organisms and the dead organic matter produced by them. It includes forests, animals, insects, birds, bacteria, on land and in air and oceans. Biosphere ranges from about 10 km into atmosphere to deepest ocean floor ~11 km. The composition of the biosphere is distinctive and its chief constituents are compounds of carbon, hydrogen and oxygen. Biosphere is not separate from the non-living world because it has a complex relationship with rocks, soil, water and atmosphere.

3.2.5 Origin of Atmosphere, Hydrosphere and Biosphere

As discussed in Unit 2, we know that the Earth has originated from the cloud of gases and cosmic dust. Some believe that the protoplanetary cloud was hot while others believe that it was cool. Although, we do not have a very clear picture of how water and gases accumulated around the Earth, it is largely believed that Earth's atmosphere and hydrosphere have originated from the volcanic outgassing after its formation.

Origin of Atmosphere: Based on the origin of the Earth, residual atmosphere hypothesis and accumulated atmosphere hypothesis, two groups of hypotheses have been proposed to explain origin of the Earth's atmosphere and hydrosphere. The proponents of the residual atmosphere hypothesis believe that atmosphere and hydrosphere are residual materials from the primitive atmosphere that enveloped the Earth; however the hypotheses fail to explain the presence of very small amount of inert gases.

The proponents of the accumulated atmosphere hypothesis believe that atmosphere and hydrosphere have accumulated from degassing of the Earth's interior and through chemical reactions. The Sun's radiation had removed the gases from the Earth's surface, so the early Earth had no atmosphere. Earth's atmosphere was formed in its early history; when it was hot and mostly molten, the heavier elements such as iron and nickel migrated towards its centre, the lighter elements such as silicon and aluminium moved upward towards its surface and the lightest elements such as hydrogen, oxygen, methane, water vapour, etc. migrated further upward from its surface. Water vapour, carbon dioxide, methane and ammonia were released from the molten mass and volcanic eruption and they formed the initial atmosphere. Earth's gravitational field was able to hold its atmosphere in place. Helium and hydrogen being the lightest gaseous elements escaped from the Earth and were lost into space. Oxygen combined with ammonia and methane to form water, nitrogen, carbon dioxide and other compounds. Higher up three atoms of oxygen combined to form ozone molecules and so the ozone layer was formed at the same time.

By investigating the ancient rocks and the oxidation state of iron (Fe) in them, scientists have gathered information about the evolution of atmosphere with time. Presence of some minerals which can form only non-oxidising environments and the rocks which can form in deep water environment indicate different phases of evolution of the atmosphere. It suggests that percentage of oxygen has increased in the Earth's atmosphere with time. It was around 0.1% during 2.5 billion years ago and has increased after that to reach at the present level.

Origin of Hydrosphere: After formation of the atmosphere, wrinkled crust solidified on cooling Earth. The UV rays from the Sun broke up water into its constituents, hydrogen and oxygen. As the Earth cooled further, the water vapour present in the atmosphere condensed into liquid water and fell on Earth as rain giving rise to the Earth's water. The rain filled the huge craters on the Earth and formed water bodies.

Origin of Biosphere: We would learn in detail about evolution of life in the core course BGYCT-137 Stratigraphy and Palaeontology. Origin of life is one of the most difficult questions in science. Biosphere originated when the conditions were favourable after formation of the atmosphere and hydrosphere. We have discussed earlier that composition of the atmosphere was much different than at present. When the molten Earth surface was cooling down, volcanoes erupted massive amount of gases like CO_2, ammonia and methane. Gases condensed to form water which produced shallow seas. There was no oxygen at the time. Rock records of 3.8 billion years ago contain the evidence of early forms of life in the form of presence of bacteria (i.e. stromatolites) which may have existed in the shallow sea near to thermal vents as they would need a source of heat and minerals. Stromatolites are the early microbial communities which provide clues about the emergence of life on the Earth. Stromatolitic rocks were built by the trapping and building of sediment particles by the microbes.

It is believed that life originated on the Earth around 3.8 billion years ago at the beginning of the Archaean eon. Multicelled organisms have been found in the rocks of around 2.7 billion years ago. However, it is not clear how exactly life could have originated. Some scientists believe that life have originated in hot environment in outer space and then landed on Earth through meteorites. Some believe that life originated from a primordial soup through a series of chemical reactions in which inorganic compounds gradually transformed into organic compounds and then organic compounds into protocells (life) coinciding with oxygen accumulation.

Scientists believe that the common gases such as carbon dioxide, hydrogen, nitrogen, sulphur and phosphorous in the early (primitive) atmosphere combined to first form simple inorganic compounds such as methane, ammonia, water vapour and hydrogen cyanide. Then these inorganic compounds further interacted and combined to form simple organic compounds such as sugars, amino acids, purines and pyrimidines. And in the last phase, the simple organic compounds transformed into complex organic compounds like starch, protein, lipid and nucleic acids in the presence of oceanic water. It has been suggested that these complex organic compounds acquired some characters of the living organisms such as ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) and were able to absorb nutrients, to grow and reproduce. Life slowly and gradually transformed over the geological past from simple unicellular forms to the complex multicellular forms as existing today.

The concentration of the oxygen increased significantly at around 2.1 billion years, which also gave rise to the ozone layer. Ozone layer as we know filters out harmful ultraviolet rays. This filtration might have allowed evolution of new living organisms in shallow seas. The Precambrian fossils are very small and cannot be identified by naked eyes whereas the fossils found later (in Phanerozoic) have shells, bones or woods and are easily identifiable. First animal fossils (of trilobites) have been recorded from Cambrian rocks. Abundance of hard-shelled fossils and modern plants have been recorded from the Paleozoic rocks. However, large reptiles were reported from Mesozoic rocks. Then came the age of mammals when life forms diverged into a diverse groups of marine, terrestrial and flying animals. Evolution of birds and flowering plants have been witnessed in Cenozoic.

You have now learnt about constituents of the Earth i.e. the atmosphere, hydrosphere, lithosphere and biosphere. Before discussing about the Earth's interior spend few minutes to perform an exercise to check your progress.

SAQ 1

a) List the four spheres of the Earth.

b) What is stratosphere?

c) Define biosphere.

d) What are SiAl and SiMa?

3.3 EARTH'S INTERIOR: LAYERING AND COMPOSITION

Let us now discuss interior of the Earth. We have learnt earlier in Unit 2 that the Earth constitutes several layers. You must be wondering how we know that such layers exist. Man has burrowed up to about 4 km depth into the Earth in order to extract gold and other minerals and about 10 km in the search of petroleum. However, these efforts barely scratch the crust of our Earth. Most of our knowledge about interior of the Earth is largely based on direct and indirect observations and inferences.

Let us now explore 6400 km beneath our feet. You have already read that our Earth has a layered structure comprising:

- Crust
- Mantle, and
- Core

You can compare this layered structure of the Earth to that of a boiled egg. Like the shell of an egg, the Earth's crust is thin, brittle and can break easily. The mantle is hotter and denser because temperature and pressure inside the Earth increases with depth. You can compare the mantle and core with the white and yellow portions of boiled egg respectively . At the center of the Earth lies the core, which is nearly twice as dense as the mantle because of its composition. Unlike the yolk of an egg, however, the Earth's core is actually made up of liquid outer core and thick solid inner core. We hope that this analogy is helpful to you in visualising Earth's structure.

3.3.1 How Do We Study the Earth's Interior?

Radius of the Earth is about 6370 km. You cannot reach the centre of the Earth and make observations or collect samples. Under such conditions, you might be wondering, how geoscientists tell us about the structure and composition of Earth's interior. Most of our knowledge is largely based on the inferences drawn from direct and indirect observations.

Seismological data has logically proved that Earth comprises several layers, which are like onion shells resting one over the other. Before learning about how the **seismic waves** have been used to image structure of the Earth, let us know about some of the basic methods adapted to study Earth's interior:

1. **Earth's Internal Temperature**: The evidences of volcanic eruptions and hot springs indicate that high temperatures prevail in the interior of the Earth. A progressive rise in temperature with increasing depth is recorded in mines and deep wells all over the world. **Geothermal gradient** is the rate of increase of temperature in the Earth with depth. Geothermal gradient increases 20^{o} C to 30^{o} C per kilometer as we move downwards. Geologists study geothermal gradient in order to understand Earth's interior.

2. **Earth's Internal Pressure**: At the depth of 1.6 km the pressure is about 450 tonnes per square foot. It is estimated that at the core pressure may be about two million tonnes per square foot but because of decreasing gravity inside the pressure may be lower.

3. **Distribution of Densities**: The average rocks of the Earth's crust have density of only 2.6 to 3.0 g/cm^3. The Earth's average density is 5.52 g/ cm^3. Therefore, there must be some heavier materials inside e.g. the core being made up of iron and nickel.

4. **Gravity and Magnetic Survey**: Earth's gravitational and magnetic fields are influenced by the uneven distribution of mass of material within the Earth. These gravity and magnetic surveys also provide information about distribution of the mass of magnetic materials in the crust. **Gravity anomalies** give us information about the distribution of mass of the material in the crust.

5. **Evidences from Meteorites**: Meteorites are torn out pieces from other stars which fall on the surface of the Earth. Tens of thousands of tonnes of such wandering materials are received in a year by Earth. They consist of original solar material. The disintegrated materials from outer space-planets are termed **meteorites**. They can either be stony called **aerolites** or mostly metallic referred to as **siderite** or mixture of rock and metal called **siderolites**. Meteorite reflects the composition of the Earth with which we are presently concerned. **Meteorites** were created at the same time as the Earth, i.e. about 4.6 billion years ago, have been analysed at places e.g. Buldana lake in Maharashtra.

6. **Evidences from Volcanic Activity**: Volcanoes are windows through which you can look into Earth's interior. As and when the molten material is thrown on surface of the Earth, such as during volcanic eruption, it becomes available for analysis.

7. **Seismic Waves**: Much of the information about the structure and composition of Earth's interior comes from **seismology** (science that

deals with aspects of seismicity). The study of seismic waves provides a complete picture of the Earth's interior. **Seismic waves** are the vibration produced by an earthquake. Seismic waves or vibrations from large earthquakes pass through the Earth. These seismic waves differ from each other in respect of their propagation velocity, wavelength and path of travel and nature of vibration. Let us learn in detail about the types of seismic waves:

Seismic waves are basically of two types:

1. Body waves
2. Surface waves

1. Body Waves

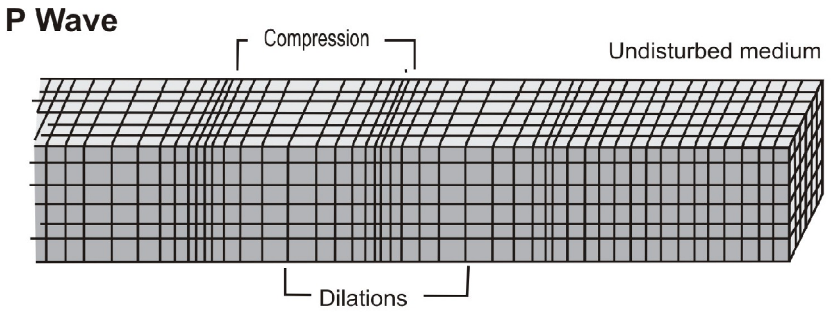
Body waves are generated due to the release of energy at the focus of the earthquake. These waves move in different directions in the Earth. The velocity of the waves increases with density of the material. Their direction also changes as they reflect or refract when cut across materials with different densities known as **seismic reflection** and **seismic refraction**, respectively. Body waves are of two types:

Primary waves or P-waves: The waves travel from the earthquake focus through Earth and the first wave to arrive is P-wave. They are similar to sound wave in air, except that P-waves travel through solid rock of the Earth's crust at about 6 km/s, which is about 20 times faster than sound waves travel through air. The velocity of sound wave is 330 m/s. P-waves are compression waves because they travel through solid, liquid or gaseous materials as a succession of compressions and expansions (Fig. 3.3a) and therefore, also referred as **longitudinal** or **compressional waves**. P-waves can be thought of as push pull waves: they push or pull particles of matter in the direction of their path of travel. Primary waves have short wavelength and high frequency.

Secondary waves or S-waves or Shear waves: S-wave travels through solid rock at a little more than half the velocity of P-waves. They are shear waves that displaces material at right angles to their path of travel. Shear waves do not travel through liquids and gasses. They are transverse or transitional waves (Fig. 3.3b). They travel at varying velocities through the solid parts, proportional to the density of the materials and have short wavelength and high frequency.

2. Surface Waves

The body waves interact with the surface rocks and generate new set of waves called **surface waves**. The direction of vibrations of S-waves is perpendicular to the wave direction in the vertical plane confined to the Earth's surface, like waves on the ocean. Their velocity is slightly less than that of S-waves. Surface waves are usually the most destructive waves in a large shallow focus earthquake especially in sedimentary basins. They have low velocity, low frequency and long wavelength. Surface waves are of two types:



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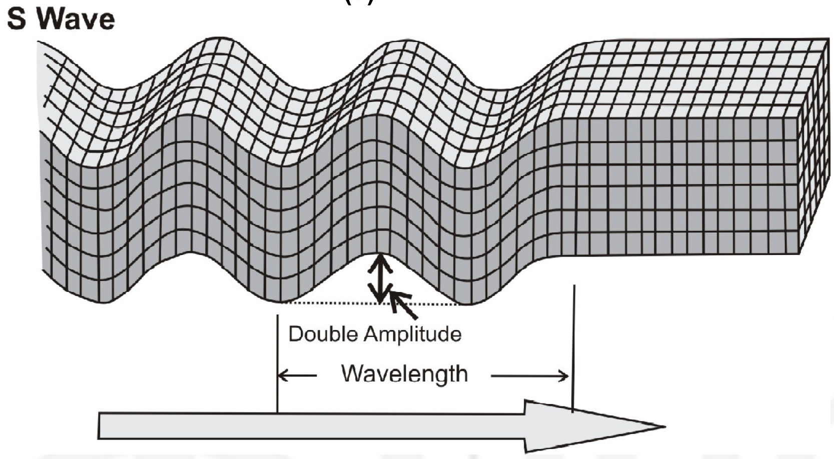
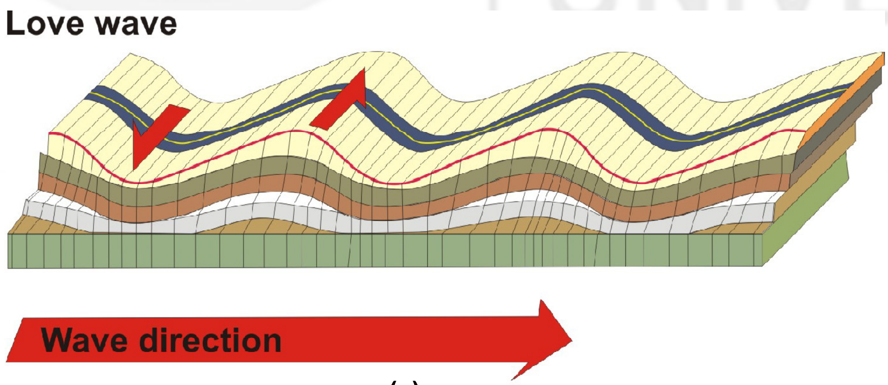


(b)

Fig. 3.3: Body waves move inside the Earth: a) Primary wave; and b) secondary wave.

Love wave: They are the surface waves wherein ground shakes horizontally from side to side in the propagation direction with no vertical motion (Fig. 3.4a).

Rayleigh wave: They are complex surface waves in which ground vibrates in a rolling, elliptical motion that diminishes as the depth increases partly in the direction of propagation and partly at right angles (Fig. 3.4b).



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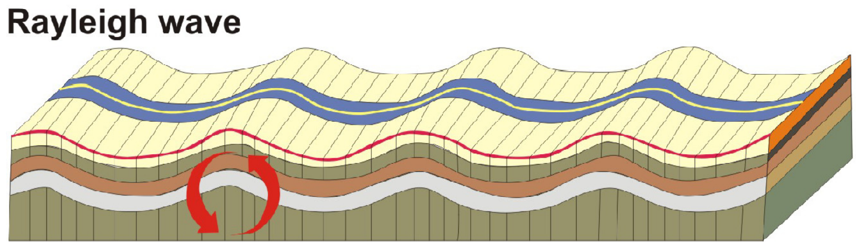

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Fig. 3.4: Diagram showing Surface waves moving on the Earth's surface: Love wave in top panel and Rayleigh wave in bottom panel.

P-wave and S-wave Shadow Zone

It was observed that seismographs located at any distance within 105° from the epicentre, recorded the arrival of both P and S-waves. However, seismograph located between 105°-142° from the epicentre record is receptive to only P-waves but do not record S-waves. This zone is identified as '**shadow zone**' (Fig. 3.5). Shadow zone is specific area on the opposite side of the Earth where the seismic waves are not received. The shadow zone of S-wave is much larger than that of the P-waves. You imagine a situation if the world was homogeneous, seismic waves would have a constant velocity. In reality, the Earth is heterogeneous and waves change their velocities. Due to heterogeneity of the Earths materials, the waves are reflected and/or refracted and/or absorbed by the various mediums within the planet.

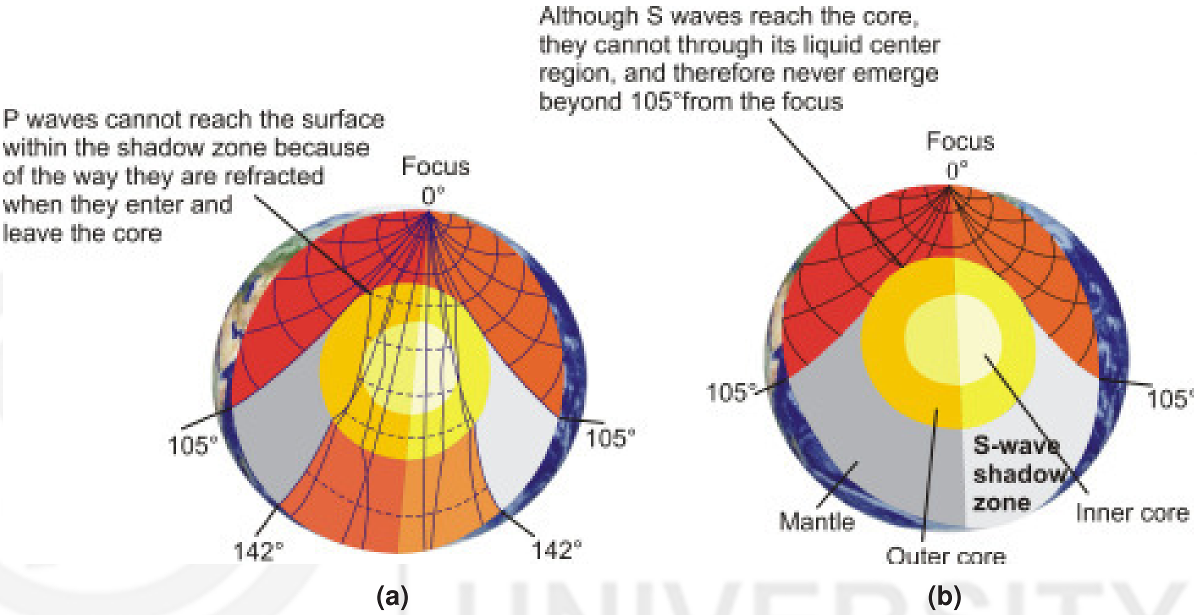


Fig. 3.5: Earth's core creates: a) P-wave; and b) S-wave shadow zones.

3.3.2 Layering and Composition

We have discussed earlier that Earth's interior has been identified as comprising three layers on the basis of seismic wave behaviour, physical and chemical properties. The three major layers of the Earth are crust, mantle and core (Fig. 3.6).

Crust is the outermost solid layer on the surface of the Earth. It is composed of brittle rock that fractures easily. It varies in thickness and chemical composition depending on whether it is oceanic or continental. They are formed by entirely different geological processes. The Earth's crust is in the form of a very thin layer of heterogeneous solidified rocks.

The crust is about 35 km thick and is composed of heterogeneous rocks (refer to Table 3.2). Earth's crust can be divided into oceanic and continental types (Fig. 3.7).

Seismic waves indicate that the crust is thinner and denser beneath the oceans than on the continents. Please go through Table 3.3 so that you are able to differentiate between characteristics of oceanic and continental crust.

Table 3.2: Layers of the Earth from crust to the core

Layer	Thickness (in km)
Lithosphere (consists of crust and upper mantle)	0 - 70 beneath oceanic areas 125 - 250 beneath continental areas
Crust	0 – 35
Upper Mantle	35 – 60
Mantle	35 – 2890
Asthenosphere	100 – 700
Outer Core	2890 – 5100
Inner Core	5100 – 6378

Table 3.3: Characteristics of oceanic and continental crust

S.No.	Attributes	Oceanic Crust	Continental Crust
1.	Average thickness	5-10 km	30 to 50 km 55-70 km in orogenic belts
2.	Seismic P-wave velocity	7 km/s	6 km/s (higher in lower crust)
3.	Density	3.0 g/cm^3	2.7 g/cm^3
4.	Probable composition	Basalt underlain by Gabbro	Granite, other plutonic rocks, schist, gneiss (with sedimentary cover)

Earth's crust is subdivided into two sublayers based on their composition as follows:

SiAl: It is also known as Upper continental crust and consists of all types of rocks exposed at the terrestrial surface. Its density is about 2.7 gm/cm^3. Sial comprises **felsic** rocks of granitic to granodioritic composition. **Felsic** refers to those igneous rocks having more than 65% of silica content. Silica (Si) is about 70%. This is followed by aluminum (Al) as second abundant constituent and hence named as SiAl.

SiMa: It is 22 km thick and is also known as Lower continental crust. It is a layer that envelopes the entire Earth. Basalt is its typical rock type. Its density is about 3 to 3.4 g/cm^3. Silica ranges from 40 to 50 % and magnesium takes the second place. Hence, it is called as SiMa (Si-Silica, Ma-Magnesium). On the basis of its composition, SiMa has been divided into:

- **Outer SiMa**: It extends upto the depth of 19 km and comprises rocks of **intermediate** composition. Intermediate refers to rocks between 55-65% silica.

- **Inner SiMa**: It is located at the depth beyond 19 km upto the depth of 33 km and comprises rocks of **mafic** to **ultramafic** composition. Mafic rocks have silica content between 44-55%. Ultramafic rocks contain less than 44% silica content.

Conrad Discontinuity is located at the depth of 11 km which separates the SiAl layer from underlying SiMa layer (Fig. 3.8).

Mantle lies between crust and core. Its upper surface is about 5 to 10 km below the oceanic crust and about 20 to 80 km below the continental crust. The imaginary line that separates the **lithosphere** from the mantle is known as '**Moho**' or **Mohorovicic discontinuity**.

There are two discontinuities namely, Mohorovicic and Gutenberg. **Mohorovicic** or **Moho discontinuity** forms outer limit of mantle. Gutenberg discontinuity forms the inner limit of mantle (Fig. 3.6 and 3.8). Mantle comprises 83% by volume of the Earth and 68% by mass. Its average thickness is about 2865 km and extends from 35 km to 2890 km. The mantle is also heterogeneous in nature, which is indicated by many discontinuities of lower order. It is the source region of most forces responsible for ocean floor spreading, continental drift, orogeny and major earthquakes. Higher seismic wave velocity (8 km/sec) of mantle versus crustal rocks is indicative of denser, ultramafic composition.

Crust and upper mantle together form the **lithosphere**, extending down to average depth of about 100 km, forming tectonic plates. It averages 70 km thickness beneath oceans and 125 to 250 km in thickness below the continents (Table 3.2). Beneath the lithosphere, the speed of seismic wave abruptly decreases in a plastic **low velocity zone** termed **asthenosphere**. **Asthenosphere** (derived from greek word asthenos meaning 'weak' is a weak ductile layer of rock that constitutes the lower part of the upper mantle over which the lithospheric plates slide.

Core is the innermost part of the Earth below the mantle. On the basis of the study of earthquake waves, the core has been further divided into outer and inner cores. Core is separated from the mantle by **Gutenberg discontinuity**.

The core extends from 2890 km to 6371 km (Table 3.2). Its upper boundary is marked by **Gutenberg discontinuity**. Astronomical data, laboratory experiments and seismology contribute to our understanding about core. The composition of the core probably is nickel and iron and hence, it is called as **NiFe** (Ni = Nickel, Fe = Ferrous i.e. Iron). Core composition is inferred from its calculated density, physical and electromagnetic properties, and composition of meteorites.

You already know from the behaviour of P waves that the inner core is solid. S waves which cannot penetrate through liquids indicate that the outer core upto its reach to the mantle, which make the shadow zone. **Outer core** is in liquid state and **Inner Core** is in solid state.

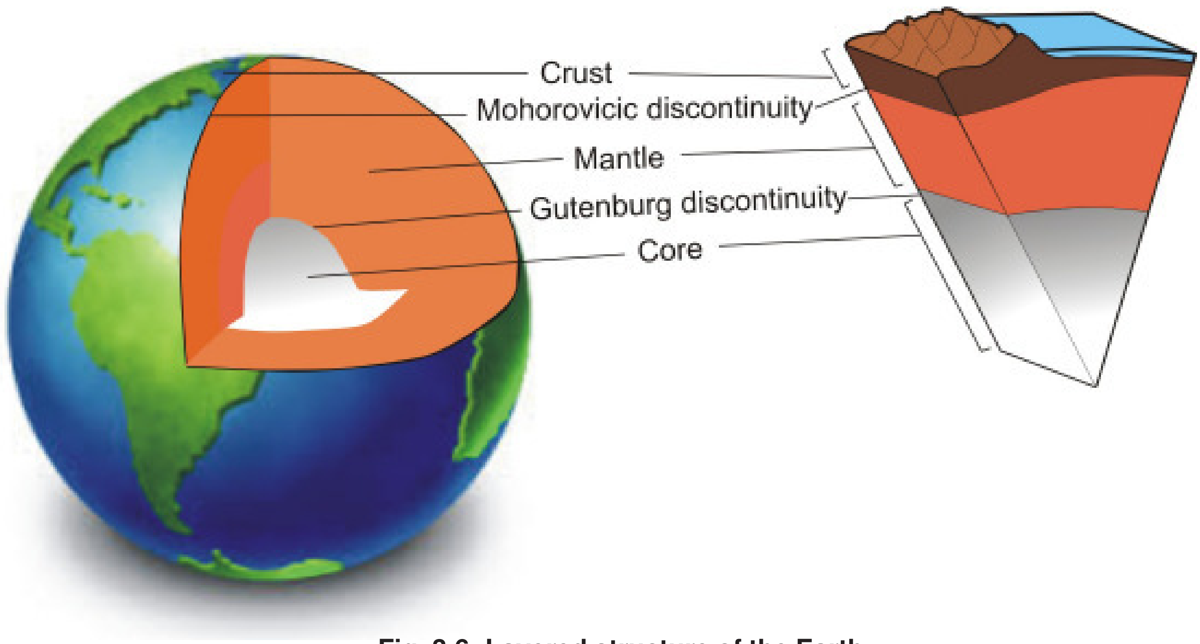


Fig. 3.6: Layered structure of the Earth.

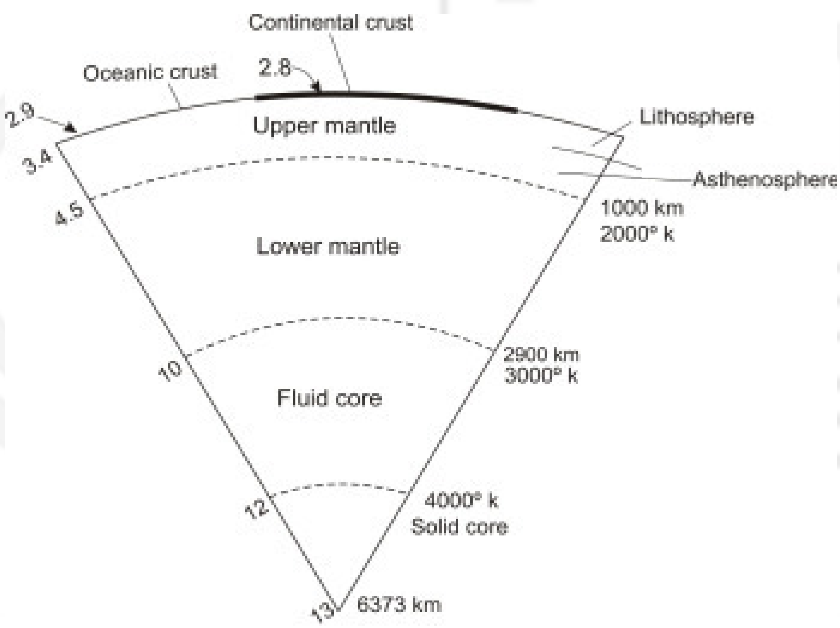


Fig. 3.7: Cross section of Earth showing the crust, mantle and core with major boundaries. Depths are in km from surface; temperature in degrees K; figures on left are mass density in 10^3 kg/m^3. (Source: After Bott, 1982)

Discontinuities: Analysis of deep and shallow earthquakes has shown that at certain depth there is an abrupt change or break in the velocity and other characteristics of earthquake waves, which indicates discontinuity (Fig. 3.8). They may be placed in two groups:

1. **Major discontinuities**: They are designated as first order discontinuities.

   a) **Mohorovicic** or simply, **Moho discontinuity** separates crust from the mantle. Its depth is variable and ranges from 2 to 10 km beneath the ocean to an average of 35 km beneath the continents. Note here that the Moho may reach up to 70 km beneath mountains, e.g. Tibetan plateau.

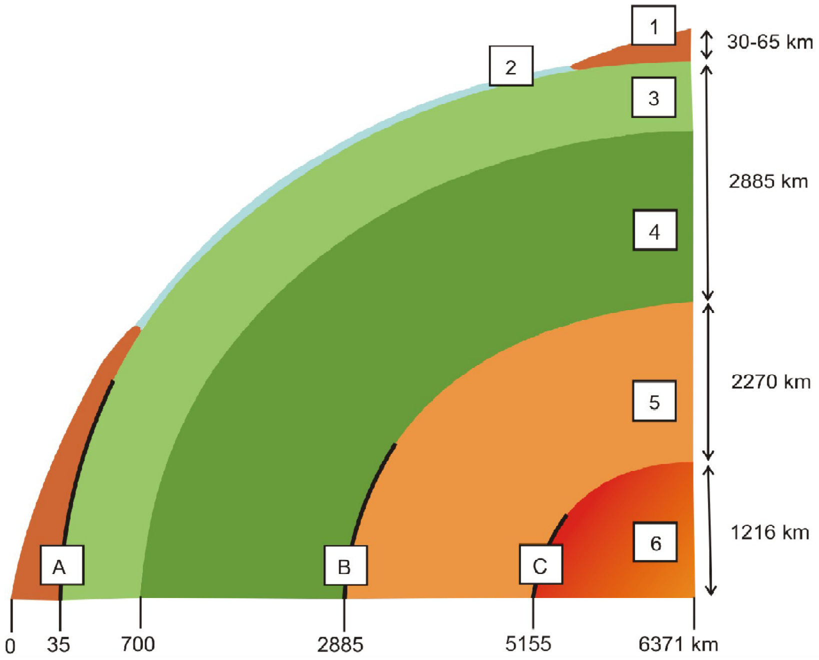


Fig. 3.8: Schematic section of the interior of the Earth: 1. continental crust, 2. oceanic crust, 3. upper mantle, 4. lower mantle, 5. outer core, 6. inner core. A: Mohorovicic discontinuity, B: Gutenberg Discontinuity, and C: Lehmann–Bullen discontinuity. Note that there is another discontinuity i.e. Conrad discontinuity, which is between upper and lower crust.

b) **Gutenberg discontinuity** separates mantle from the core.

2. **Minor discontinuities**: They are also known as second order discontinuities.

   a) **Lehmann-Bullen discontinuity** is between inner and outer core.

   b) **Conrad discontinuity** is between upper and lower crust which is among the eight such discontinuities.

3.4 EARTH'S INTERNAL TEMPERATURE

The evidence of Earth's internal heat is revealed through volcanoes, hot springs and the elevated temperatures measured in mines and boreholes. During the violent origin of the planet, energy was released by impacts with planetsimals which heated its outer regions. Further, gravitational energy released by differentiation of the core heated deep interior of the Earth. Besides, the decay of radioisotopes in Earth's interior continues to generate heat.

Heat flow refers to the gradual loss of heat through Earth's surface. Earth cools in two ways: through transport of heat by conduction and through the more rapid transport of heat by convection. Conduction dominates in the lithosphere, whereas convection is more dominant throughout most of Earth's interior.

3.4.1 Conduction through the Lithosphere

Do you know rocks conduct heat so poorly that a lava flow of 100m thickness takes about 300 years to cool from 1000°C to ground surface temperature (Grotzinger and Jordan, 2010). The conduction of heat through outer surface of lithosphere causes it to cool slowly overtime. As the lithosphere cools, its thickness increases just as the cold crust in a bowl of hot wax thickens with time. The Earth is divided into several plates which are continuously being created and destroyed at the plate boundaries. You will read about Plate Tectonics theory in Unit 16 of this course. The lithosphere rests on top of the hot molten asthenosphere. Heat that reaches from asthenosphere to the lithospheric plates through convection currents is lost by conduction.

3.4.2 Convection in Mantle and Core

The convection, transfers the heat more efficiently than conduction because the heated material itself moves. The asthenosphere below the rigid lithosphere is ductile material; it can flow like a very viscous fluid. In the upper part of the mantle convection currents are generated because of the high temperatures and pressure causing ductility.
Convection in the mantle is expressed at the surface through the movements of the tectonic plates as shown in Fig. 3.9. Further, deeper in the mantle, there is increase of intense pressure so that the lower part of the mantle flows readily than in the upper.

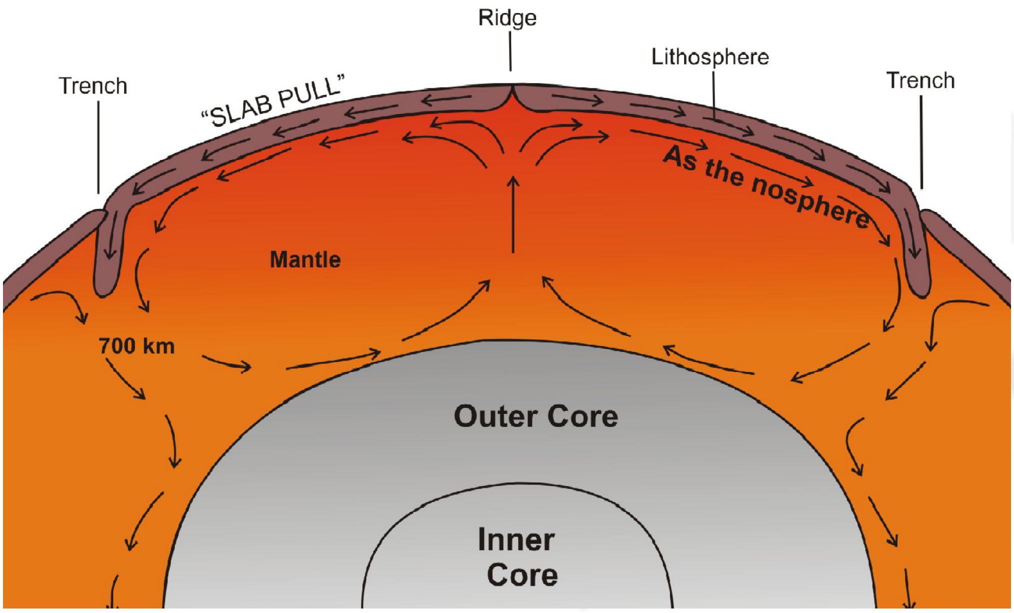


Fig. 3.9: Convection currents in the mantle.

We have learnt that the deepest layer (inner core) in the Earth's interior is a solid iron ball. Although it is very hot, the pressure is so high that iron cannot melt. Above the inner core is the outer core which is a shell of liquid iron. Although this layer is cooler but is still very hot probably 4000° to 5000° C. It has temperature ranging from 4400° C to 6100° C near the inner core. Thus, outer core is not under enough pressure to be solid, so it is liquid.

3.5 EARTH'S MAGNETIC FIELD AND GEODYNAMO

In the previous section, you have studied about Earth's internal temperature alongwith transport of heat by conduction and convection and its effect. In this section, let us see how the convection in the core and mantle affects the Earth's magnetic field. Geomagnetic field is magnetic field of the Earth that extends from its inner core to where it meets solar wind. Earth's magnetic field changes with time because it is generated by the movement of molten iron alloys in the Earth's outer core which is also called **'Geodynamo'**. The Geodynamo theory states that the molten iron and nickel in the Earth's outer core make up a conducting liquid. In this liquid core, convention currents are setup. As the Earth rotates, the liquid outer core spins, creating the Earth's magnetic field. These currents act like electrical current carrying wires and the whole system works like a gigantic dynamo. It is this dynamo which constantly regenerates the magnetic field of the Earth. This magnetic field extends outward from the Earth for several thousand kilometres and creates a protective cover around the Earth that deflects the Sun's solar wind. In the absence of this protective layer solar wind would have stripped Earth's atmosphere slowly and made it virtually lifeless.

SAQ 2

a) Mention the three layers of the Earth.

b) What are the primary waves?

c) What do you understand by Nife?

d) Write about the concept of geodynamo?

3.6 SUMMARY

Let us summarise about what we have learnt in this unit:

- The major constituents of the Earth are atmosphere, hydrosphere, lithosphere and the biosphere. Earth's biosphere has originated when the conditions were favourable after origin of atmosphere and hydrosphere.
- Based on the physical properties, the outermost parts of the Earth can be divided into two parts i.e. the lithosphere and asthenosphere.
- Most of our knowledge about the internal structure of the Earth is largely based on the inferences drawn from direct and indirect observations.
- Much of the information about the structure and composition of Earth's interior comes from **seismology**.
- The Earth consists of three layers: crust, mantle and core.
- Analysis of deep and shallow earthquakes has shown that at certain depth there is an abrupt change or break in the velocity and other characteristics of earthquake waves. This indicates presence of a discontinuity. Major discontinuities are the Mohorovicic and Gutenberg discontinuities.
- Earth cools in two ways: through transport of heat by conduction and through the more rapid transport of heat by convection. Conduction dominates in the lithosphere, whereas convection is more dominant throughout most of Earth's interior.

- Geomagnetic field is magnetic field of the Earth that extends from its inner core to where it meets solar wind. Earth's magnetic field changes with time because it is generated by the movement of molten iron alloys in the Earth's outer core which is also called '**Geodynamo**'.

3.7 TERMINAL QUESTIONS

1. How do we study the Earth's interior?
2. Explain the convection in mantle and core.
3. How did atmosphere originate on Earth?
4. Name the major discontinuities between crust and mantle, and mantle and core.

3.8 REFERENCES

- Bott, M.H.P. (1982) The Interior of Earth, 2nd Edition, Edward Arnold, London and Elevier, New York.
- Grotzinger, J. and Jordan, T. (2010) Understanding Earth, Sixth Edition. W.M. Freeman and Company, New York, 654p.
- Tarbuck, L. (1984) The Earth-Introduction to Physical Geology, Bell & Howell Co., Ohio.

3.9 FURTHER/SUGGESTED READINGS

- Dutta, A.K, (2010) (Reprinted), Introduction to Physical Geology, Kalyani Publishers, Ludhiana, 230p.
- Mahapatra, G.B., (2012) (Reprinted) A Textbook of Geology, CBS Publishers, New Delhi, 326p.

3.10 ANSWERS

Self-Assessment Questions

1. a) Atmosphere, hydrosphere, biosphere and lithosphere.

   b) Stratosphere is the atmospheric layer at 16 to 50 km from the surface of the Earth. The air here is at rest and is free from cloud dust and water vapour. The upper strata are rich in ozone, which serves as a shield, protecting the troposphere and Earth's surface by absorbing most of the ultraviolet radiation found in the Sun's rays.

   c) The biosphere is the biological component of Earth, which interacts with and exchanges matter and energy with the other spheres hence it includes the atmosphere, hydrosphere and lithosphere.

   d) Sial and Sima are the two groups of dominant rocks of the crust. **SiAl**

(Si-Silica and Al-Alumina) are the light coloured silica rich rocks with Aluminium being the second most abundant constituent. **SiMa** (Si-Silica and Ma-Magnesia) lies below the SiAl forming base of the oceans. They are dark coloured rocks like basalt with silica ranging from 40% to 50% and magnesium taking the second place.

2. a) Core, Mantle and Crust.

   b) Primary waves or P waves or longitudinal or compressional waves. P-waves can be thought of as push-pull waves: they push or pull particles of matter in the direction of their path of travel. Primary waves have short wavelength and high frequency. The waves travel from the earthquake focus through Earth and the first wave to arrive is P wave. They are similar to sound wave in air,

   c) Composition of the core probably is nickel and iron and hence, it is called as **NiFe** (Ni = Nickel, Fe = Ferrous i.e. Iron).

   d) Earth's magnetic field changes with time because it is generated by the movement of molten iron alloys in the Earth's outer core which is also called Geodynamo.

Terminal Questions

1. Your answer should include the points mentioned in subsection 3.3.1.
2. Your answer should include the points mentioned in subsection 3.4.2.
3. Your answer should include the points mentioned in subsection 3.2.5.
4. Mohorovicic and Gutenberg discontinuities.

UNIT 4

EARTHQUAKES AND VOLCANOES

Structure

4.1 INTRODUCTION

The configuration of Earth's surface is largely a product of the processes operating in interior of the Earth, ofcourse duly modified by exogenic processes. Both exogenic (external) as well as endogenic (internal) processes are constantly shaping the landscape. You have already learnt about the internal structure and constitution of the Earth in the previous unit including the origin of hydrosphere, atmosphere and biosphere. You will study about the geological agents (streams, wind, underground water, glaciers and the ocean) that are set in motion by energy external to the Earth i.e. radiant energy from the Sun. You will be introduced to the exogenic (external) processes in Block 2 Earth Surface Processes. Now, in this unit we shall study more about the endogenic processes operating from within the Earth. These endogenic processes are better realised when their effects are visible on the surface of Earth. We hope that this will enhance your comprehension about the internal processes operating on the surface of the Earth.

Expected Learning Outcomes

After reading this unit, you should be able to:

- define and list endogenic processes;
- describe the causes, types, recording and distribution of earthquakes;
- distinguish between magnitude and intensity of earthquake;
- identify the types, causes, landforms, effects and products of volcanism and distribution of volcanoes;
- discuss relationship between earthquake and volcanic belts in global perspective; and
- explain tsunami, its causes and effects.

4.2 ENDOGENIC PROCESSES

Before studying about the earthquakes and volcanoes, let us first understand what are the endogenic processes. The word endogenic is derived from two Greek words *endotha* meaning inside and *genus* meaning origin. The processes which originate within the Earth's crust are termed as **endogenic processes** that derive their energy from within the Earth from the following:

- Rotation of the Earth;
- Tidal friction;
- Radioactivity; and
- Primitive heat present since its origin.

Endogenic processes include the following:

- Earthquakes;
- Volcanic activity;
- Earth movements and mountain building;
- Convection currents leading to continental drift;
- Plate tectonics.

In this unit we shall discuss about the first two processes, i.e. earthquakes and volcanoes of the endogenic processes. Tsunami events, which is often generated due to undersea earthquakes is also discussed in the last section. We shall discuss the three processes, i.e. mountain building, continental drift and plate tectonics in Block 4 Mountain Building and Plate Tectonics.

4.3 EARTHQUAKES

You might have experienced doors and windows shaking and producing rattling sound. After realising the walls shaking, you might have got panicked and yelled to other occupants of the house, "it's an earthquake"! When due to various causes, stress accumulates in rocks locally until it exceeds strength of the rocks, it causes the rocks to fail and the rocks move along fractures. The movement of rocks is generally followed by a smaller rebound. The movement can produce shaking of ground because of the amount of energy involved. Any sudden movement of the Earth's crust due to a natural cause which produces shaking or trembling of ground is called **earthquake**. Study of earthquakes is called '**Seismology**'.

Before going further let us acquaint ourselves with the terminologies associated with earthquakes (Fig. 4.1).

i) **Focus or Hypocentre or Centrum**: It is the point, place or tract of origin of earthquakes. Thus, focus is the initial position of rupture within the Earth which generates **seismic waves**.

ii) **Epicentre or Epifocal**: Epicenter is a point directly above the focus of an earthquake on the Earth's surface.

iii) **Isoseismal Lines**: These lines join points of equal intensity on the surface where the earthquake occurs. These are closed circles around epicentre.

iv) **Homoseismal or coseismals lines**: These are the lines drawn through the points at which the earthquake is recorded at the same time.

v) **Pleistoseistic region**: Located around the epicentre is the region where maximum destruction occurs as a result of an earthquake.

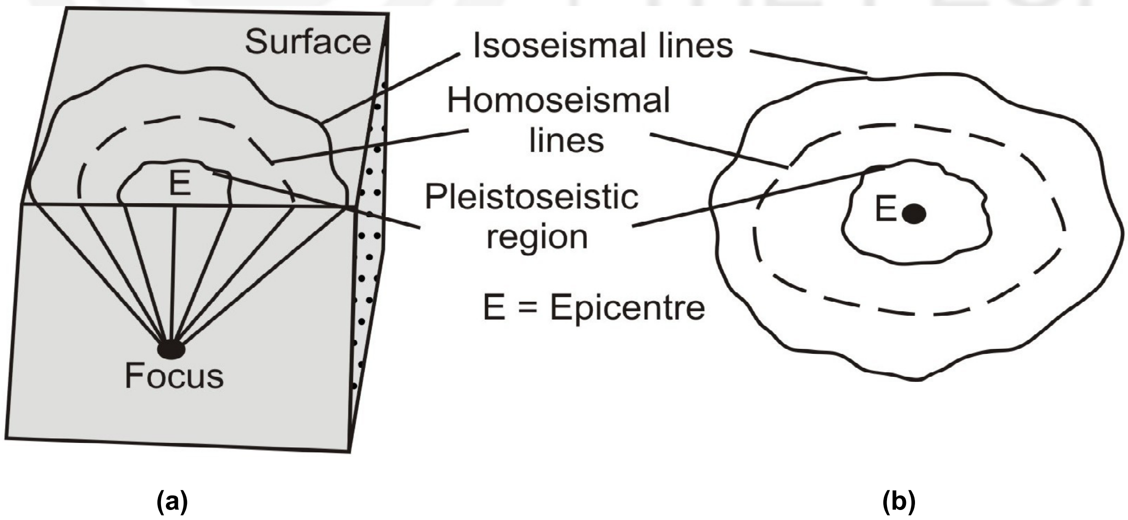


Fig. 4.1: General terminology used in mode of propagation of the earthquakes: a) cross sectional view; and b) top view.

4.3.1 Causes

Now you might be wondering why the Earth shakes and what causes the earthquakes?

Let us discuss the causes of earthquake. They can be placed into the following three groups:

1. **Surface Causes**: They produce earthquakes of minor intensity which are often insignificant and are caused due to:

   i) **Collapse of caves**: You will read in Unit 7 Geological Work of Wind and Underground Water of this course that caves and cavities are formed by the action of underground water in the rocks like limestone. The impact in the surrounding area may result in their collapse causing feeble earthquake.

   ii) **Landslides**: Massive landslide often causes shaking in the surrounding area.

   iii) **Blasting of rocks**: This can generate tremors in surrounding area which may produce cracks in the houses or induce landslides.

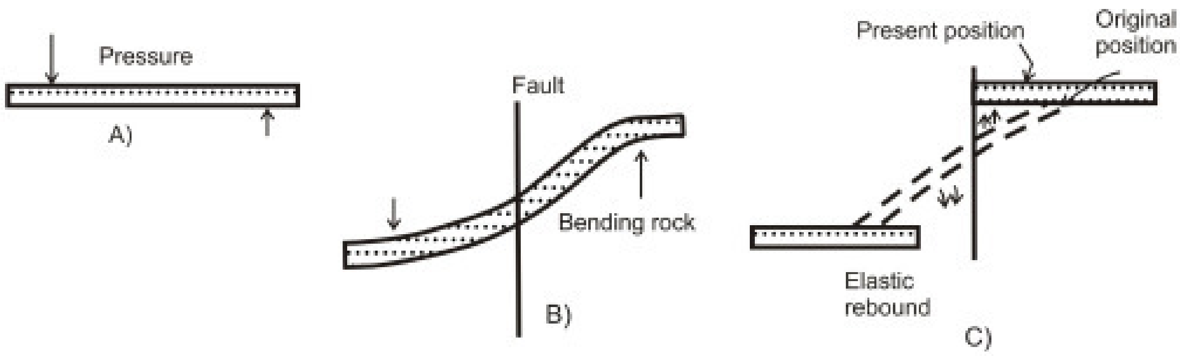
2. **Volcanic causes**: The earthquakes associated with volcanoes are more localised both in extent of damage and in wave intensity produced.

3. **Tectonic Causes**: They include most important causes for major earthquakes. Some of these are:

   i) **Plate Tectonics**: The crust of the Earth is divided into plates which may be continental, oceanic or combined. Movement of these plates produces earthquakes. In most of the cases, the earthquakes are disastrous.

   ii) **Movement along Fault planes**: Crustal displacements or structural disturbances cause sudden slipping of the Earth's crust along the faults. As a result of movement of the adjacent blocks of fault, major earthquakes are produced. You will read about fault planes in Unit 11 Faults of this course.

   iii) **Elastic Rebound Theory**: This describes the mechanism by which earthquakes are generated. Elastic Rebound theory was propounded by Harry Fielding Reid after studying 1906 San Francisco earthquake faultline. According to him the materials of the Earth, being elastic, can withstand a certain amount of stress without deforming permanently but if stress is continued for a long period of time or if it is increased in magnitude, the rocks will undergo permanent deformation or strain and eventually rupture. When the rupture occurs, rocks on either side of the fault tend to return to their original shape-position because of their elasticity and an elastic rebound occurs (Fig. 4.2a and b). In nutshell, you can learn that the Elastic-rebound theory is a concept that accounts for the earthquakes generated by the sudden slippage of rocks on either side of a fault plane. In this process, the rocks release the strain energy which has been gradually accumulated and attempts to return to an unstrained condition.



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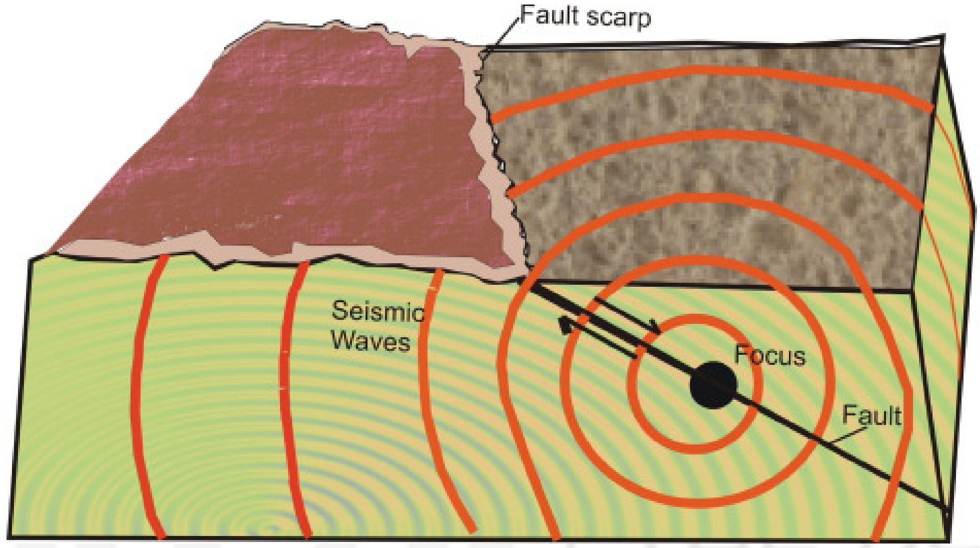

(b)

Fig. 4.2: a) Elastic rebound showing stages of rupture. A, B and C represent different stages of rupture; and b) Schematics showing generation of an earthquake. Earthquakes are usually associated with slippage along a fault.

4.3.2 Types

Earthquakes can vary in size, type and effect depending on factors like:

- Tectonic setting
- Bedrock
- Overlying unconsolidated material
- Building codes
- Presence or absence of groundwater

Now you will read about the types of earthquakes. Based on depth of their origin, earthquakes may be broadly classified into three types:

i) **Normal or shallow depth earthquakes** originate from within a depth of 50 km. Majority of the earthquakes in the past had been of this type.

ii) **Earthquakes of intermediate depth** originate at a depth of 50 to 240 km. These are rare in occurrence but their effects are felt over a large area.

iii) **Deep-focus earthquakes** originate at a depth of several hundred kilometres (240 to 725 km) and are very rare phenomena.

4.3.3 Earthquake Waves

Let us now discuss some of the properties of the seismic waves that are relevant to earthquakes.

The waves originate from focus and radiate in all directions in concentric circles (Fig. 4.3). According to the travel parameters they are of four types (Table 4.1).

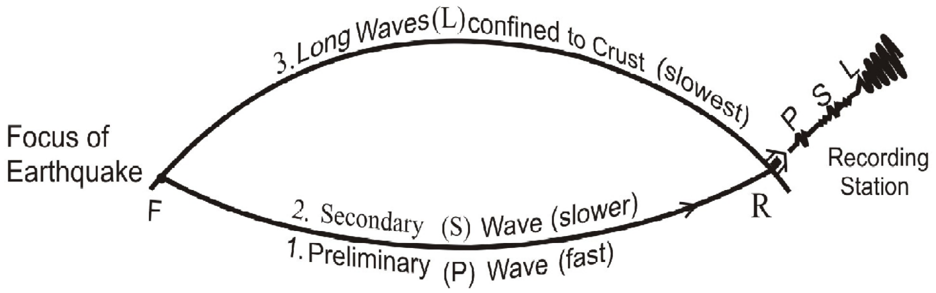

Fig. 4.3: Diagrammatic representation of earthquake waves – its origin, movement and the recording station.

Table 4.1: Properties of Seismic waves

Type	Relative Speed	Passes through	Type of Motion
Body waves			
P-wave (Push waves)	Fastest	Solid and liquid	Push and pull
S-wave (Shear waves)	Second fastest	Solid only	Side to side
Surface waves			
Rayleigh wave	Third fastest	Earth's surface	Up and down forward and back
Love wave	Slowest	Earth's surface	Side to side

4.3.4 Magnitude and Intensity

Whenever an earthquake shakes us you must have heard on radio/television, the scientists talking about magnitude and intensity of an earthquake. Let us read about magnitude and intensity.

The **magnitude** indicates the amount of energy released at the source or epicentre and it is measured by a 10 point **Richter scale**. It is the measure of earthquake strength as interpreted from the maximum wave amplitude recorded by a **seismograph**. The Richter scale is logarithmic. For each unit, the amplitude of ground motion increases by a factor of 10. The seismic waves increase even faster-by a factor of about 30. Richter scale was established by American geologist Charles Richter in 1935 in partnership with Beno Gutenberg from California Institute of Technology.

Intensity is used to define the extent of destruction an earthquake has caused and is dependent not only on the magnitude of the earthquake, but also soil type, building materials, population, and other human settlements.

Mercalli intensity scale is the 12-point scale that measures earthquake severity in terms of the damage inflicted. It is known as **Modified Mercalli scale** and is commonly used to measure the magnitude and intensities of earthquakes. It has 12 divisions from I to XII and mostly depend on effects of tremors (Table 4.2).

Table 4.2: The Modified Mercalli Intensity Scale

Magnitude	Intensity	Effects of Tremors
1.0-3.0	I	Instrumental – Detected only by seismographs
3.0-3.9	II	Very feeble – Noticed only by sensitive persons at rest, especially on upper floors
	III	Slight- Felt quite noticeably by persons indoors; standing car may rock slightly
4.0-4.9	IV	Moderate – Felt by people outdoors in motion; dishes, window, doors disturbed; walls make cracking sound; standing cars rocked noticeably
	V	Rather strong – Felt by nearly everyone; people are wakened, bells ring; unstable objects overturned; windows broken
5.0-5.9	VI	Strong – Slight damage; felt by all; many frightened; some heavy furniture moved
	VII	Very strong – Cracking of walls, damage negligible in buildings of good design and construction; slight to moderate in well-build ordinary structures; considerable damage in poorly build or designed structures
6.0-6.9	VIII	Destructive – Chimneys fall; considerable damage in ordinary substantial buildings with partial collapse; damage great in poorly built structures; fall of chimneys, factory stacks, columns, monuments, walls; heavy furniture overturned
	IX	Ruinous – Houses begin to fall; damage considerable in specially designed structures; well-designed structures thrown out; damage great in substantial buildings, with partial collapse; buildings shifted off foundations

Magnitude	Intensity	Effects of Tremors
7.0 and higher	X	Disastrous -Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; rails bent greatly
	XI	Very disastrous-Few structures left standing, ground fissured; bridges destroyed; rails bent greatly
	XII	Catastrophic- Total destruction, objects thrown into air, ground deformed; total damage; lines of sight and level are distorted; objects thrown into the air

4.3.5 Recording of Earthquake

Let us now understand how an earthquake is measured.

The study of measurement of earthquakes requires to record time, intensity and direction of each individual shock. The instrument is known as **Seismograph** (Fig. 4.4). The recording is done on photosensitised paper, which is so calibrated that there is co-ordination with time and date along with the rotation of the drum (Fig. 4.4). Seismograph records both the horizontal and vertical components. The records of seismic shocks prepared and presented by seismographs are known as **seismograms** (Fig. 4.5).

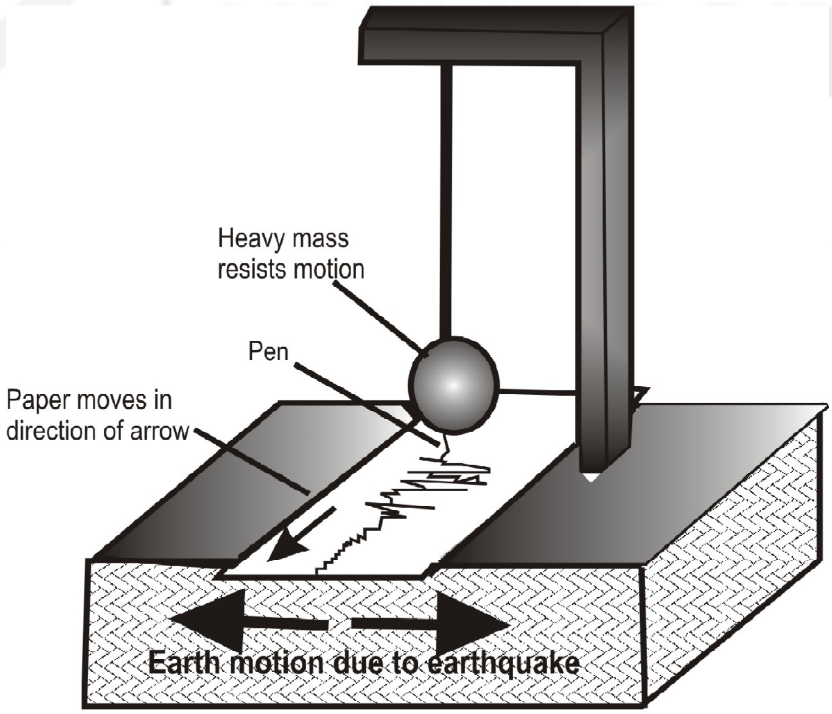

Fig. 4.4: A sketch of Seismograph, the instrument used to record earthquakes.

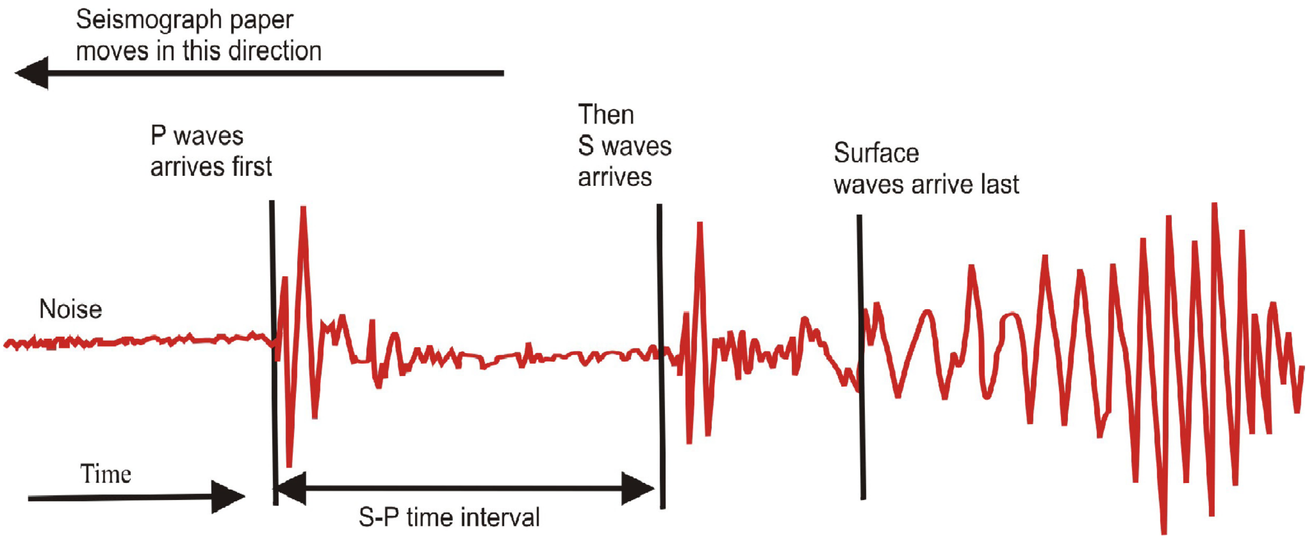

Fig. 4.5: A typical seismogram. The first wave to arrive at a seismometer is a P-wave, followed by the S-wave, and then by the surface waves.

4.3.6 Distribution of Seismic Belts

You might be wondering why certain areas in the world experience earthquakes more frequently? These areas are known as **Earthquake or Seismic Belts** (Fig. 4.6). They are:

i) **Pacific belt**: About 81% of world's largest earthquakes occur in the Circum-Pacific seismic belt. This belt includes the rim of Pacific plate and nearby plates and corresponds to the Pacific '**Ring of Fire**'. Eight out of ten largest earthquake since 1900 have occurred along this seismic belt.

ii) **Alpine or Mediterranean belt**: It extends from Java to Sumatra through Himalayas and Mediterranean and into Atlantic. This accounts for 17% of world's largest earthquakes, including some of the most destructive such as the Andaman-Sumatra earthquake in 2004.

iii) **Mid Atlantic belt**: It is the prominent earthquake belt and follows the submerged Mid Atlantic Ridge in Atlantic Ocean. This belt has not been particularly much destructive, as they occur far from populated areas.

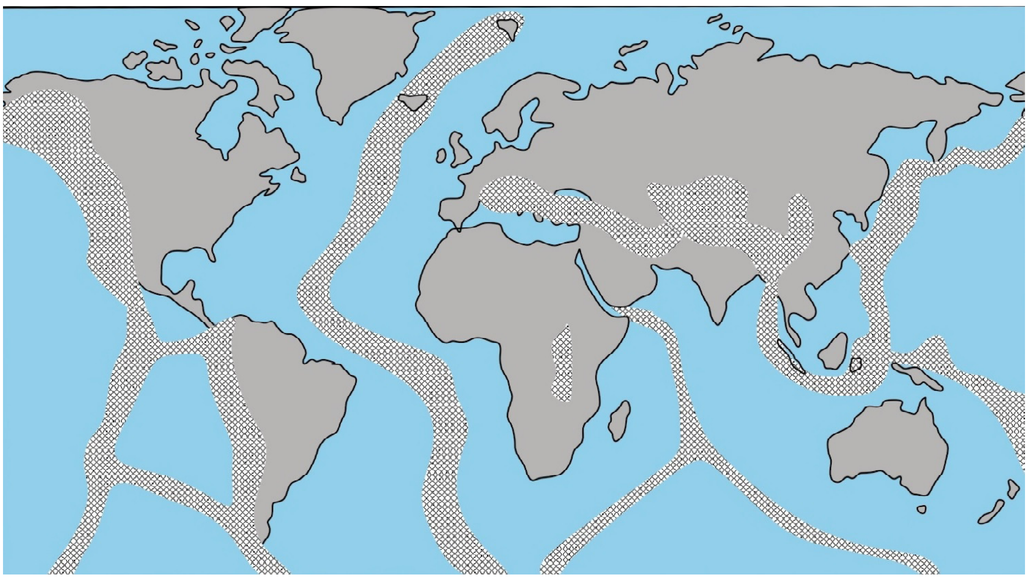

Fig. 4.6: Distribution of earthquakes: the shaded areas are the zones of active epicenters.

Major earthquake occurrences in India have been tabulated in Table 4.3.

Table 4.3: Major Earthquakes of Indian subcontinent

Date	Magnitude	Region	Remarks
16.06.1819	8.0	Kutch	About 2000 people killed
12.06.1897	8.7	Assam	One of greatest earthquakes of historical times. Shillong razed to ground causing 1572 deaths
04.04.1905	8.0	Kangra	20,000 lives lost
15.01.1934	8.3	India-Nepal Border	One of the most severe in Indian history with estimates of about 10,000 deaths
26.06.1941	8.1	Andaman Islands	Caused flooding in Port Blair
15,08.1950	8.5	Assam	532 people were killed
06.08.1988	5.8	Burma-India Border	3 killed, 11 injured
20.08.1988	6.5	Nepal-India Border	1000 killed, 1000 injured, extensive damage
19.10.1991	6.6	Uttarkashi	768 people were killed
30.09.1993	6.3	Latur	7601 people killed
22.05.1997	6.0	Jabalpur	38 people killed
29.03.1999	-	Uttar Pradesh	106 killed, 395 injured
26.01.2004	-	Gujarat	20717 animals lost, over 20000 people killed,1,50000 injured
08.10.2005	7.6	Pakistan and Kashmir	Over 87,000 killed in Pakistan and Kashmir
14.02.2006	5.3	Sikkim	Heavy landslide with 4 death
18.09.2011	6.9	Sikkim	Death>111
25.04.2015	7.8	Nepal, India	Death 8964 with injuries to 21952
26.10.2015	7.7	Afganistan, India, Pakistan	Death 399, injuries 2536
04.01.2016	6.7	India, Myanmar, Bangladesh	Death 11, injuries 200

What do you think whether earthquakes can be predicted?

In fact, this is a question which puzzles everybody. Work is being done to predict the earthquakes by scientists all over the world. In China and Japan, work has been done on animal behaviour but this has not been proved to be very reliable. It is hoped that in near future it may be feasible to evolve reliable criterion or certain methods to predict earthquakes.

4.3.7 Damages Caused by Earthquakes

Earthquakes can damage our environment in several ways. The immediate effect of earthquake is the shaking of the ground and loss to life and property. Some of the important effects of earthquakes are mentioned as follows:

i) **Faulting and Shaking**: The primary hazards of earthquakes are the ruptures in the ground surface that occur when faults break the surface. The permanent subsidence and uplift of the ground surface is caused by faulting and ground shaking inflicted by seismic waves radiated through earthquake. Ground shaking can be so hard that structures may collapse and cause loss to life and property.

ii) **Landslides**: Ground shaking and failure can cause mass movement of Earth materials.

iii) **Fire**: The secondary hazards of earthquake also include fire. This is ignited by ruptured gas lines or downed power lines.

iv) **Tsunamis**: The word '**Tsunami**' is of Japanese origin, meaning 'harbour wave'. A large earthquake that occurs beneath the ocean can generate destructive sea wave called Tsunami. It is generally associated with the world's largest earthquake and are the deadliest and most destructive hazard. These are large to very large sea waves generated by submarine earthquakes or volcanic eruptions or massive landslides. When tsunami waves strike coastal regions, severe destruction takes place. You may recall the destruction that took place on the east coast of India in early hours on 26th December 2004. We shall discuss about tsunami in the last section.

4.3.8 Seismic Zonation of India

Zoning refers to the parameter(/s) that characterise hazard having a constant value in each zone. Seismic zonation is the process of delineation of areas having different potentials for hazardous effects from future earthquakes. It can be done at any scale: national, regional or local. Seismic zonation maps are prepared to identify the regions in which earthquakes of various intensities may have occurred or may occur (Fig. 4.7). In a particular seismic zone, the rate of seismic activity remains fairly consistent. Earthquake hazard of India is being monitored mainly by Geological Survey of India (GSI) and the India Meteorological Department (IMD).

The first seismic zone map of India was published in 1962 by Bureau of Indian Standards (BIS) which classified the country into seven seismic zones based on the earthquake epicenters and the isoseismal map published by the GSI in 1935. The seven seismic zones were labelled from 0 (no damage) to VI (extensive damage).

Although map showing seismic zonation of India was prepared, it is frequently updated based on the data available. The 1970 map contained five seismic zones from I to V. Zone 0 was removed as it was considered that there is no region with zero possibility of earthquake shock and the zones V and VI were merged into one.

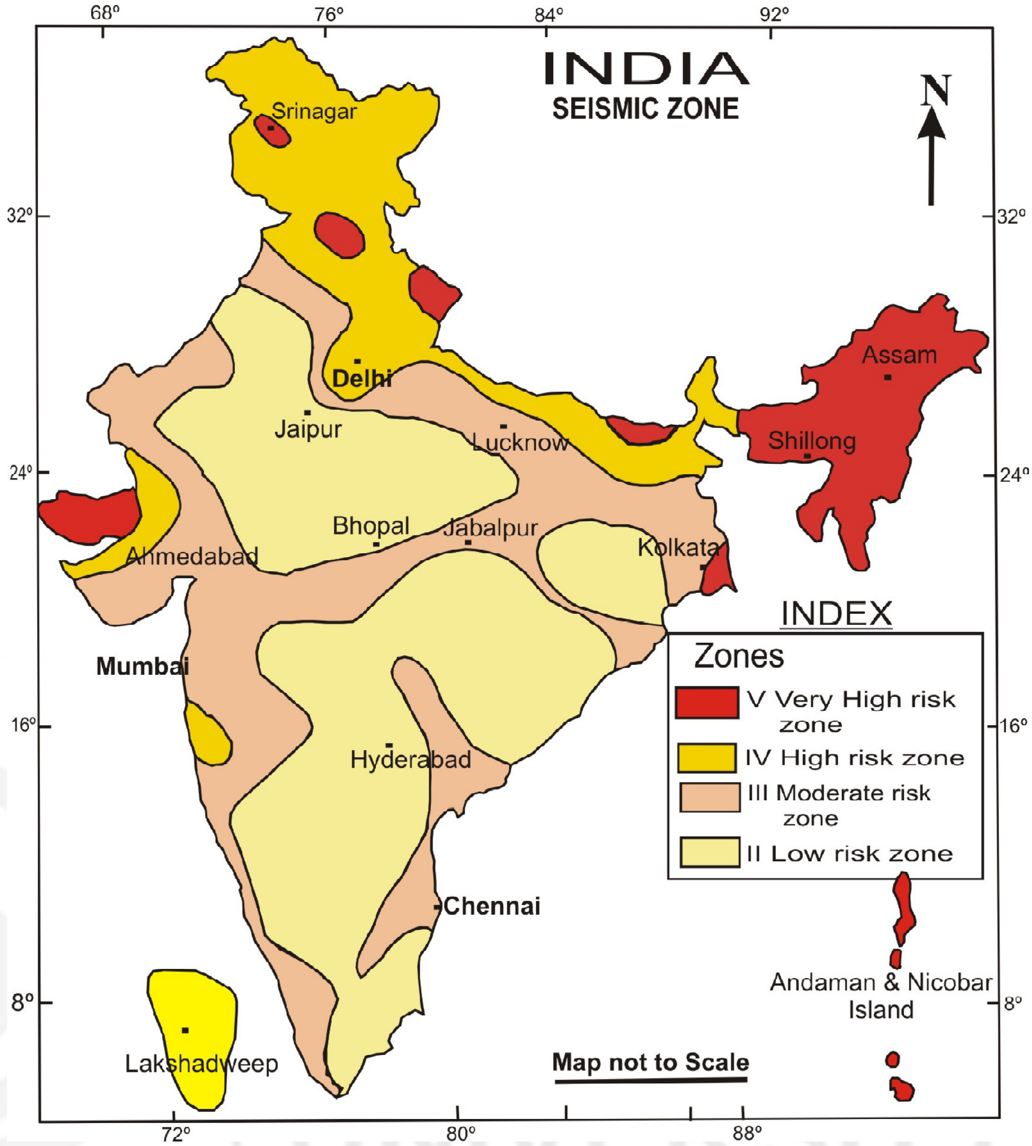

Fig. 4.7: The seismic zonation and intensity map of India.
(Source: BIS, 2002 and http://nidm.gov.in/safety_earthquake.asp)

The latest seismic zonation map on a national scale published in year 2002 is shown in Fig. 4.7. It is based on the available information such as intensity and frequency of earthquake occurrence, geology and tectonics of the country. It classified entire India into four seismic hazard zones i.e. from V to II, indicating intensity of damage or frequency of earthquake occurrences on a decreasing scale. The map contains only four seismic zones labelled from II to V because seismic zone I of the previous map is merged with those of seismic zone II. In this map (Fig. 4.7) 59% of the land mass of India has been classified as prone to earthquakes of which 11% is in very high risk zone V, 18% in high risk zone IV and 30% in moderate risk zone III. The capital cities of Guwahati and Srinagar are located in seismic zone V, while national capital of Delhi is in zone IV and Mumbai, Kolkata and Chennai are in zone III. 38 cities with population of half a million and above each and a combined population of million are located in these three regions. The seismic zonation map may be used to plan and reduce the loss of human life and economy caused by earthquakes by considering the relevant seismic coefficients while designing buildings.

In this section we have studied about earthquakes, their causes, effects, distribution, etc. Let us now spend about 5 minutes to check how you are progressing.

SAQ 1

a) What is an earthquake?

b) List the types of earthquakes depending upon the depth and origin.

c) Which seismic wave causes damage during the earthquake?

d) Name the instrument used for recording earthquake and also the data recorded.

4.4 VOLCANOES

You might have seen erupting **volcanoes** in movies, on television, and in newspapers and magazines. Despite this familiarity, have you ever questioned - how volcanoes occur?. Why do they erupt? Why are they located where they are? You will come to know answers to these questions in this section. You will learn that an important clue to a volcano's origin and eruptive processes is found in its shape and size.

The term **volcano** is derived from 'Vulcan', the Roman God of fire and metalwork. Volcano may be defined as any landform that releases lava, gas or ashes or has done so in the past (Fletcher, 2011). The geologic processes that give rise to volcanoes and volcanic rocks are collectively known as **volcanism**. Volcanism is the phenomenon of eruption of molten rock (magma) onto the surface of the Earth or a solid-surface planet or moon, where lava, pyroclastics and volcanic gases erupt through a break in the surface called a vent. Volcanoes occur not only on the Earth but on other planets too. About 1500 volcanoes are believed to be active on Earth's surface.

Magma, the molten rock is liquid; it is less dense than the rocks that produce it. Therefore, as magma accumulates and begins to float upward, finding a path to the surface by fracturing lithosphere along the zones of weakness. In some places, magma eventually reaches the surface and erupts as lava. Hot materials escape from an opening called **vent or fissure**. These vents and fissures are the volcanoes through which hot molten materials are ejected regularly (active) or intermittently (dormant). The passage through which the molten materials are ejected is the volcano. It may appear on the surface through some fissures called **fissure type** or through a single opening where it assumes shape of a cone called **cone or crater type**. If eruptions have ceased, it is extinct volcano, which was active in the past.

Scientists estimate that at least 500 million of the total world population is at risk from volcanoes. Millions of people are vulnerable to the effects of dangerous eruptions. Therefore, it is important to improve our understanding of the volcanoes and how they work. Study of volcanos is known as **Volcanology** and scientist studying volcanoes are called **volcanologist**.

Volcanology also improves our understanding of Earth's interior.

4.4.1 Causes

Let us now read about the causes of volcanism. Although the scientists are trying to investigate the ultimate causes, some of the basic probable causes are given as follows:

i) You have read that interior of the Earth is very hot. Water vapours and hot molten magma move towards the surface through low pressured weak planes. Release of high pressures, which build-up within magma chamber causes eruption of the volcanoes on Earth's surface.

ii) Accumulation of radioactive heat produces magma. This molten material ultimately comes out in form of volcanoes.

iii) Friction and fault movements at greater depths may cause melting and forcing of the molten material to the surface.

You will read in Unit 16 Plate Tectonics that the Earth's lithosphere is divided into several plates. These plates move in different directions. When these plates converge, one of the plates moves below the other. On the margin of the subsiding plate melting takes place and the molten material is thrown out forming chain of volcanoes parallel to plate boundary. For example, the Himalaya, at the boundary of the dynamic Indian plate that subducts below the relatively static Asian plate.

4.4.2 Types

Now you will read about the classification of volcanoes based on several features.

A) Based on their activity, volcanoes are classified into following three types:

- **Active Volcanoes**: A volcano is active when it is erupting intermittently or continuously.
- **Dormant Volcanoes**: These are the volcanoes which show eruptions with a lapse of considerable period.
- **Extinct Volcanoes**: These are those volcanoes which have not shown any volcanic activity within recorded period of history.

B) Based on the mode of eruption volcanoes are classified as:

- **Central Type**: In this the products escape through a single vent or pipe. The magma is more viscous in Central type volcanoes and tends to build a volcanic landform on the flanks of its central vent (as shown in Fig. 4.8a).
- **Fissure Type**: The lava comes out slowly through fissures. It flows to distances covering large areas being less viscous or more fluid (as shown in Fig. 4.8b). The lava flows of Deccan traps in central and southern India are of same type.

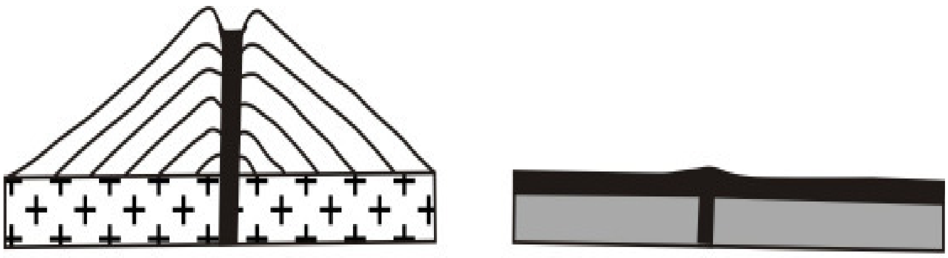

Fig. 4.8: Types of volcanoes: a) Central type; and b) Fissure type.

C) Based on nature of eruption, volcanoes may be of two types:

- **Explosive Type**: In this case, the lava is of acidic nature and because of their high degree of viscosity they produce explosive eruptions.
- **Quiet Type**: In this case, the lava is of basaltic composition, which is highly fluid and holds some gas. As a result the eruptions are quiet and the lava can travel long distances to spread as thin layers.

D) Besides the above, a number of other types of volcanoes have been identified according to their degree of explosive activity and nature of eruption (Fig. 4.9). They are tabulated in Table 4.4.

Table 4.4: Types of volcanism based on explosive activity and nature of eruption

Type	Hawaiian Type	Strombolian Type	Vulcanian Type	Vesuvian Type	Pelean Type	Plinian Type
Nature of Eruption	Mildest with no explosive activity	At times violent	Sometimes explosive	Highly explosive	Most Violent	Extremely violent
Type of material	Lava mobile and thin; spreads out. Little drops of lava form thread like masses blown up by wind called *Pele's hair.* Large quantities of gasses discharge quietly.	Lava is more viscous and the fragments of lavas are blown up into air forming bombs and scoriaceous fragments	Lava is very viscous, solidifies quickly. Huge quantity of rock fragments are blown during successive eruptions. Huge quantities of gases rise upwards vertically like cauliflower.	Magma explodes as a result of high gas content, which ascend in cauliflower like column of gases with much fragmental materials	Magma is highly viscous and forms hard cover in volcanic pipes. Escape of gases takes place through sides of volcanic cone as avalanche of molten rock material and gasses.	Many gases and volcanic ejecta rise in column to great heights like cauliflower. Huge fragmental products are produced with no discharge of lava
Examples	Hawaiian volcanoes	Volcano Stromboli in Sicily	Vulcano in Lipari, Sicily	Vesuvius near Naples	Mont Pelee, Martinique, West Indies	Pompeii, Rome

Pele's hair is the name given after **Pele** - the Hawaiian Goddess of Fire.

Stromboli is known as **lighthouse of Mediterranean** because the incandescent masses of gases are given off due to volcanic activity.

Plinian type is the name given after Pliny, the younger, who in his letters to Tactius, described a violent explosion of the Vesuvius that caused the destruction of cities of Pompeii and Herculaneum.

The **Volcanic Explosivity Index** (VEI) was devised by Chris Newhall of United States Geological Survey and Stephers Self at University of Hawaii. It is a relative study to measure explosivity of volcano.

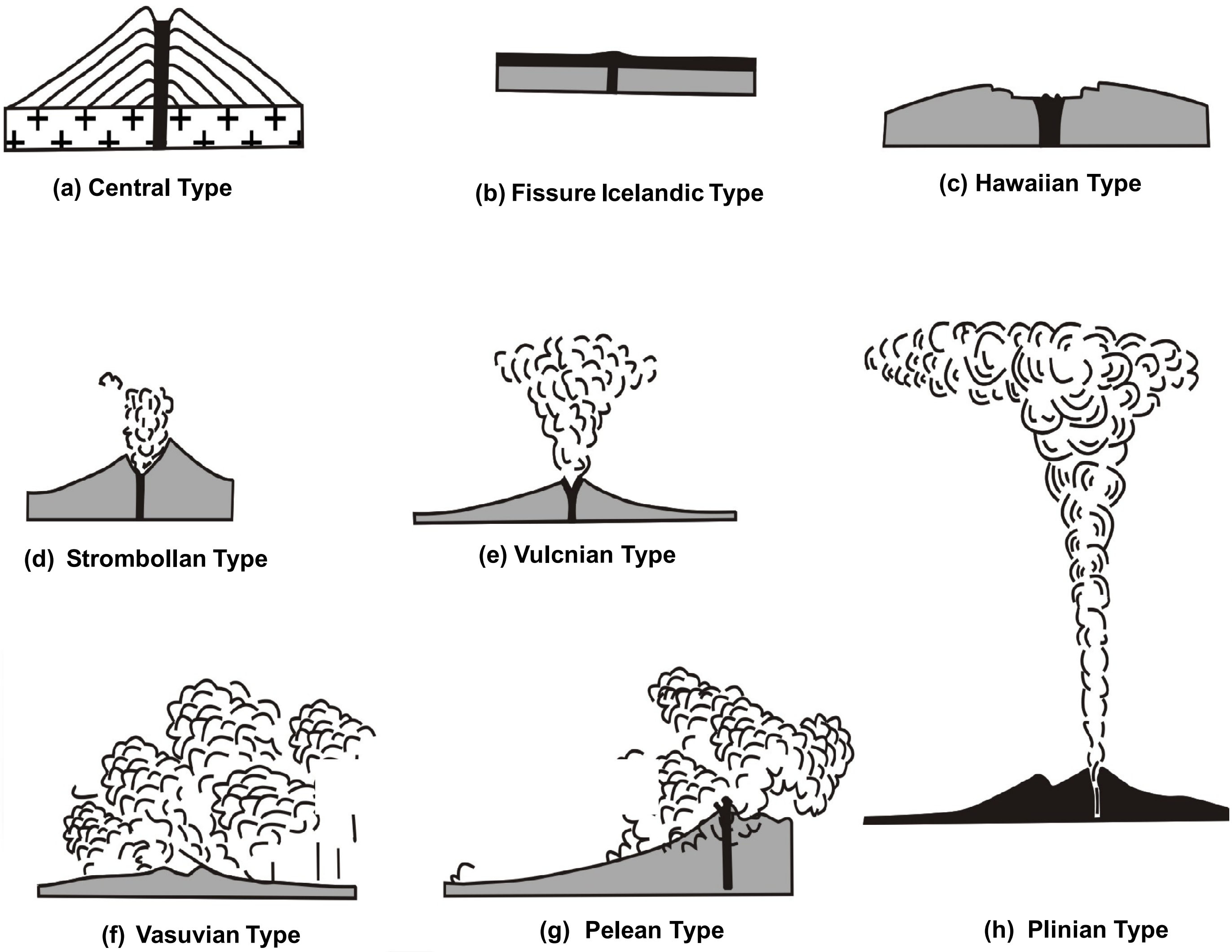

Fig. 4.9: Different types of volcanoes and their eruption style.

4.4.3 Volcanic Landforms

Volcanic landforms are controlled by the geological processes that form them and act on them after their formation. Volcanic landforms include both positive and negative relief features. The high or elevated relief features comprising of hills, mountains, cones, plateaus or upland plains are some of the examples of positive relief features. While the low lying features like craters, calderas, tectonic depression, etc. represent the negative relief features.

Before discussing volcanic landforms let us discuss the characters of a typical volcano. You might have quite often seen in newspapers and magazines or watched on television how a volcano looks like.

Volcanoes are generally conical in shape. Important features of a typical volcano have been shown in Fig. 4.10. **Crater** is a bowl-shaped pit, found at the summit of most volcanic mountains, surrounding the central vent. The formation of crater and volcanic cone is a result of accumulation of products of volcanic eruption. The crater of Mount Etna in Sicily is 300 m in diameter.

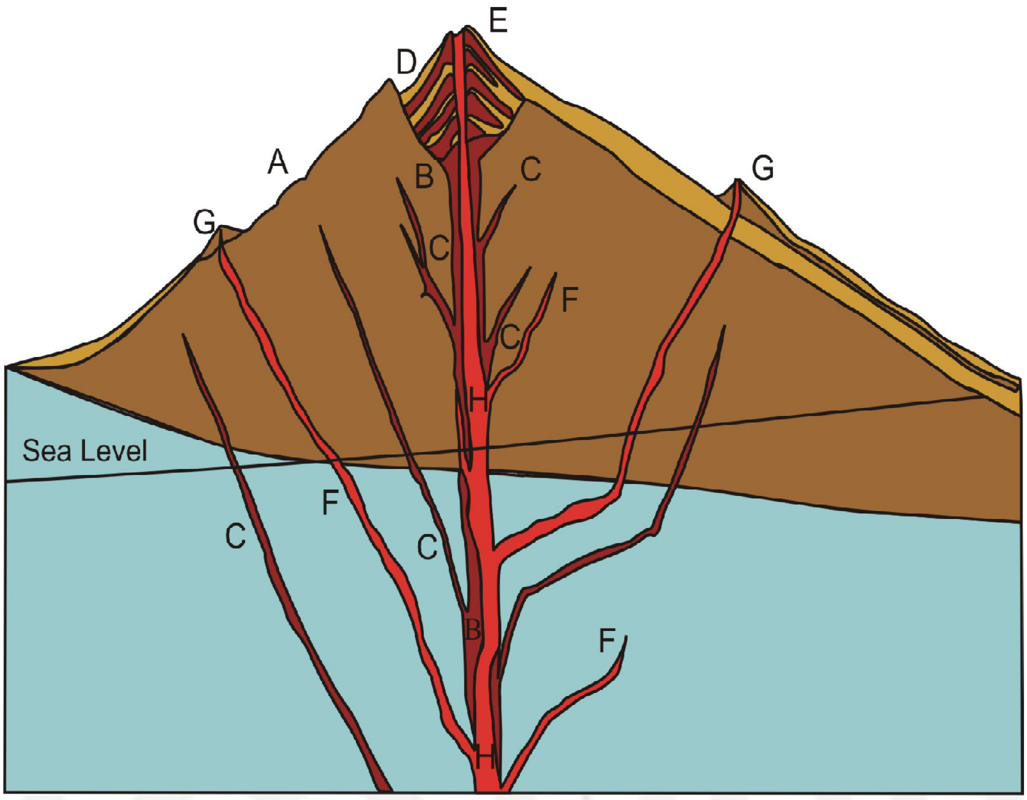

Fig. 4.10: A typical volcano: A) Main cone built by lavas and tuffs, B) The conduit, C) Dykes, D) Explosion crater, E) Eruptive cone, F) Later dykes, G) Parasitic cone, H) Main conduit. (Source: Holmes, 1981)

The positive and negative relief features are discussed below.

A) **Positive-relief features**: They are formed due to both quiet as well as explosive volcanic activity, some of which are as follows:

i) **Lava dome**: It is a bulbous, steep-side mass of rock. It looks as if lava has squeezed out like toothpaste, with very little lateral spreading (Fig. 4.11a).

ii) **Cinder cone**: These are volcanoes of central type eruption; steep sided with uniform slopes of 30° to 40°. When volcanic vents discharge pyroclasts, these solid fragments can build up to create cinder cones (Fig. 4.11b).

iii) **Composite cone**: These are made up of alternate lava flows and beds of pyroclastic material which build a concave-shaped composite volcano (Fig. 4.11c). Due to stratification, they are also known as 'strato-volcanoes'.

iv) **Lava cone**: These are built up of lava flows, due to heaping of lava during quiet type eruption, also known as 'plug-dome'.

v) **Shield volcano**: A lava cone is built by successive flows of lava from a central vent. Viscous lava may frequently form a plateau like structure aerially extending over several kilometers e.g. Deccan plateau.

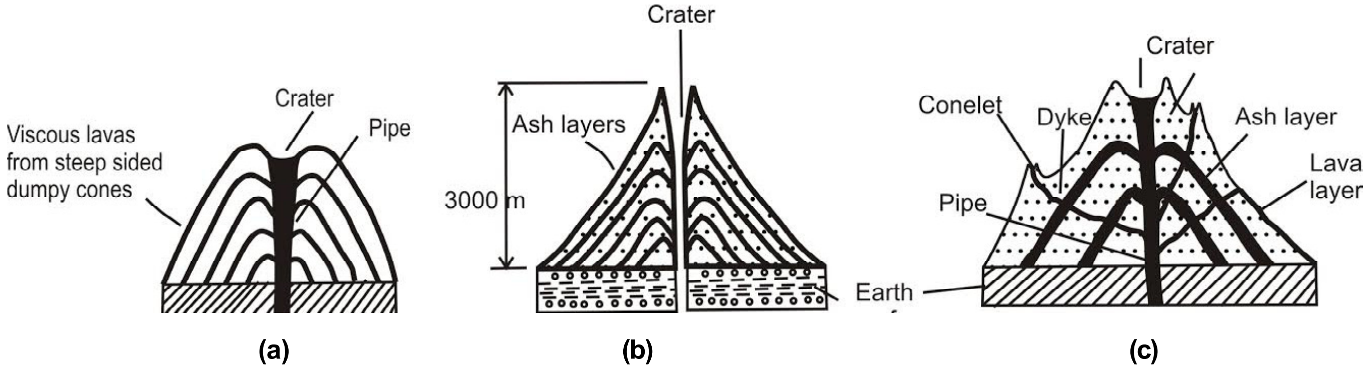

Fig. 4.11: Volcanic Cones: a) Lava dome; b) Ash and cinder cone; and c) Composite cone

B) **Negative-relief features**: Some of which are as follows:

i) **Crater**: You have already read about it.

ii) **Caldera**: When great volumes of magma are discharged rapidly from a large magma chamber, the chamber can no longer support its roof. In such cases, the overlying volcanic structure can collapse catastrophically, leaving a large, steep-walled, basin-shaped depression much larger than a crater, called a **caldera** (Fig. 4.12), e.g. Buldana lake. It is of two types:

- **Explosive type**: They are produced by explosive violence of volcanic activity (Fig. 4.12a). The top of the cone is blown up in the air producing the caldera.
- **Subsidence type**: It is produced due to submergence of the top because of the circular fractures produced as a result of erupting magma from below (Fig. 4.12b). When the volcanic activity ends water may be filled up in the calderas producing caldera lakes, e.g. Lake Toba of North Sumatra.

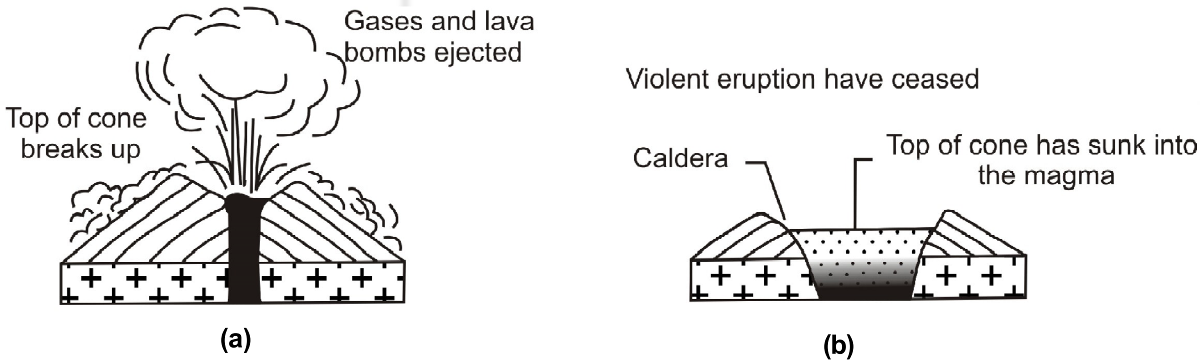

Fig. 4.12: Caldera formation and types: a) Explosive type; and b) Subsidence type.

iii) **Lava-tunnels**: The fluid lava drains through some weak spots lying at the periphery of the lava forming tunnel called lava tunnel.

4.4.4 Products of Volcanism

The volcano eruption consists of liquid, solid and gaseous materials. Let us learn about them:

Liquid: Magma is molten rock material consisting of mineral melt. It is most important product of volcanic eruption. On average the temperature of magma ranges between 1000° and 1200° C. The molten rock material below the surface is called '**magma**' and when it comes on the surface it is called **'Lava'.** Lava can be **felsic** (viscous) *or* **mafic** (less viscous or fluid). You will learn more about it in course BGYCT-135 Petrology.

Solid: The solid material of different sizes is ejected out of volcano during eruptions. They are called as '**pyroclastic material**'. These materials of varying sizes and grades are known differently as follows:

- **Volcanic bombs**: Its size is generally >32 mm. They come out as liquid masses from volcanoes and are thrown in air and solidified. They have smooth surface and may be rounded or oblong in shape (Fig. 4.13).
- **Lapilli or cinder**: They are also called as pumice stones. Their size ranges from 4 to 32 mm.
- **Volcanic Ash and volcanic dust**: They are fine grained and remain suspended in the atmosphere for a long time. They range in size between 0.25 and 4 mm.
- **Tuff**: Rocks made of ash and fine ash are known as tuff (Fig. 4.13).
- **Agglomerate**: They are pyroclastic rocks consisting mainly of fragments larger than 20 mm in diameter.

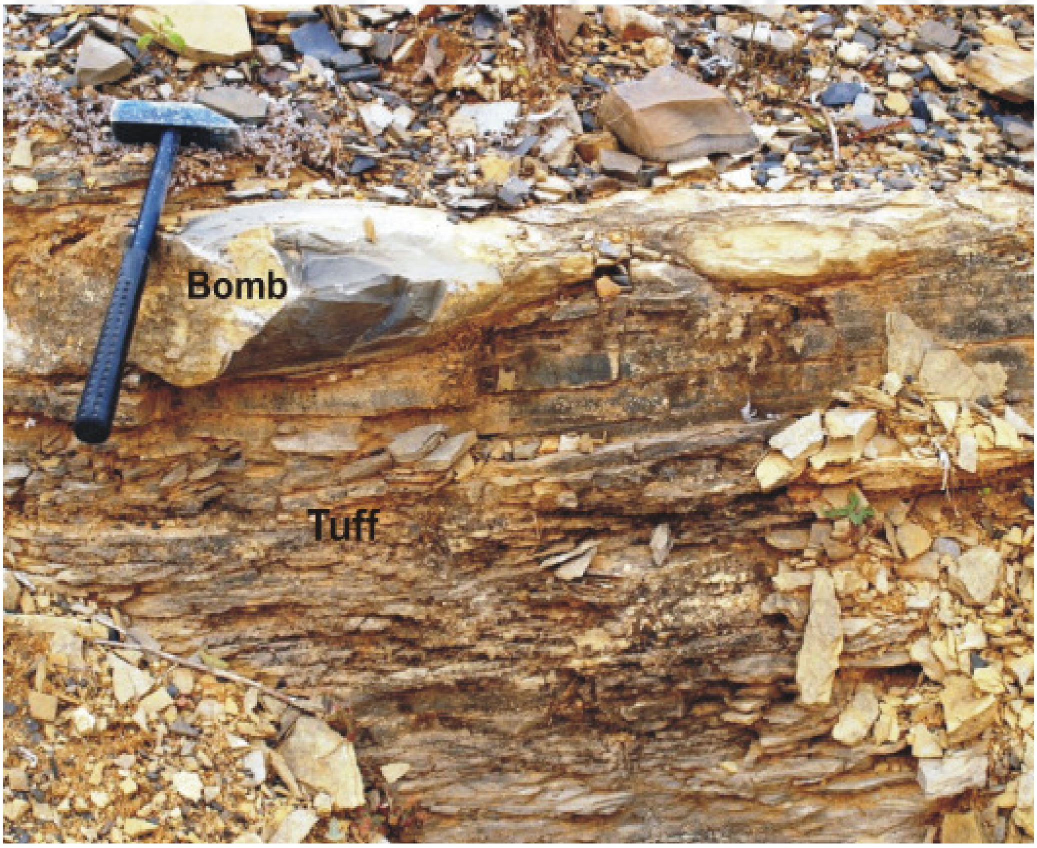

Fig. 4.13: Field photograph of elliptical volcanic bombs interbedded with tuff at Sidhi district, Madhya Pradesh. (Photo credit : Dr. Meenal Mishra)

Gases: Water vapours form one of the most important part constituting 90% of the total volcanic gases. These water vapours may come from the original magma or due to boiling of underground water in the volcanic area. Other gases include NH_3, CO_2, N_2, SO_2, Cl_2, HCl, H_2S, Hydrocarbon gases and arsenic vapours.

There are certain features associated with the decaying phases of volcanism viz. **fumaroles, hot springs, geysers, geyserites, calcareous tuffa,** etc.

4.4.5 Effects of Volcanism

We will briefly learn about the effects of volcanoes. They may be broadly divided into two groups, destructive and constructive, depending on their role in human life.

A) Destructive Effects

- Loss of life and property.
- Change in landscape.
- Towns are destroyed.
- Large areas are covered by lavas.
- Disaster due to acid rain.
- Rain water does not stay in the lavas because percolation is not possible except in some of the cavities. This makes life difficult to impossible in such areas.
- Often volcanism is accompanied by disastrous earthquakes. Soils and agricultural fields are destroyed.

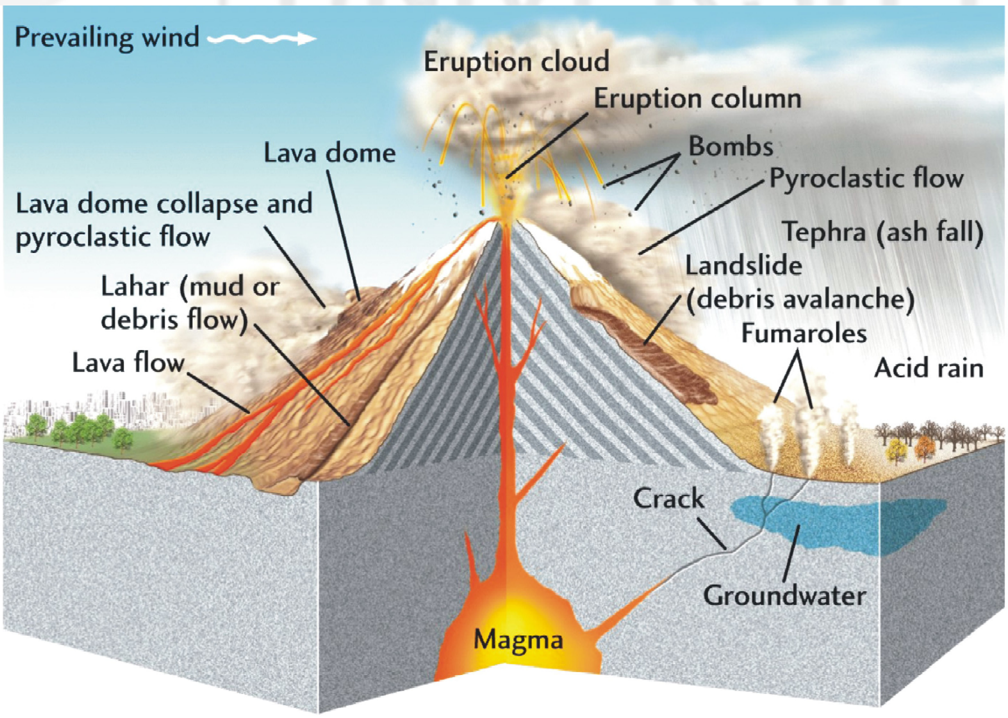

Fig. 4.14: Landforms and other effects associated with volcanism.

B) Constructive Effects

- The lavas produce fertile soil after weathering being derived from virgin materials, e.g. soils in Java and black soil in central and south India.
- Precious and semi-precious stones are found in volcanic rocks e.g. diamonds are found in South Africa.
- Ores and mineral deposits are extensively produced by volcanism and related processes.
- Crater lakes and caldera lakes are formed which provide source of fresh water to us, e.g. Buldana Lake in Maharashtra.

4.4.6 Distribution of Volcanic Belts

Almost all extinct and active volcanoes are concentrated in three major volcanic belts on the surface of the Earth. They are as follows (Fig. 4.15).

1. **Pacific belt**: It runs around Pacific Ocean and is also referred to as '**Ring of Fire**'.
2. **Atlantic belt**: It covers West Indies, East Atlantic, Iceland and St. Helena.
3. **Eurasian belt**: It covers Italy, East Mediterranean, Myanmar and Indonesia.

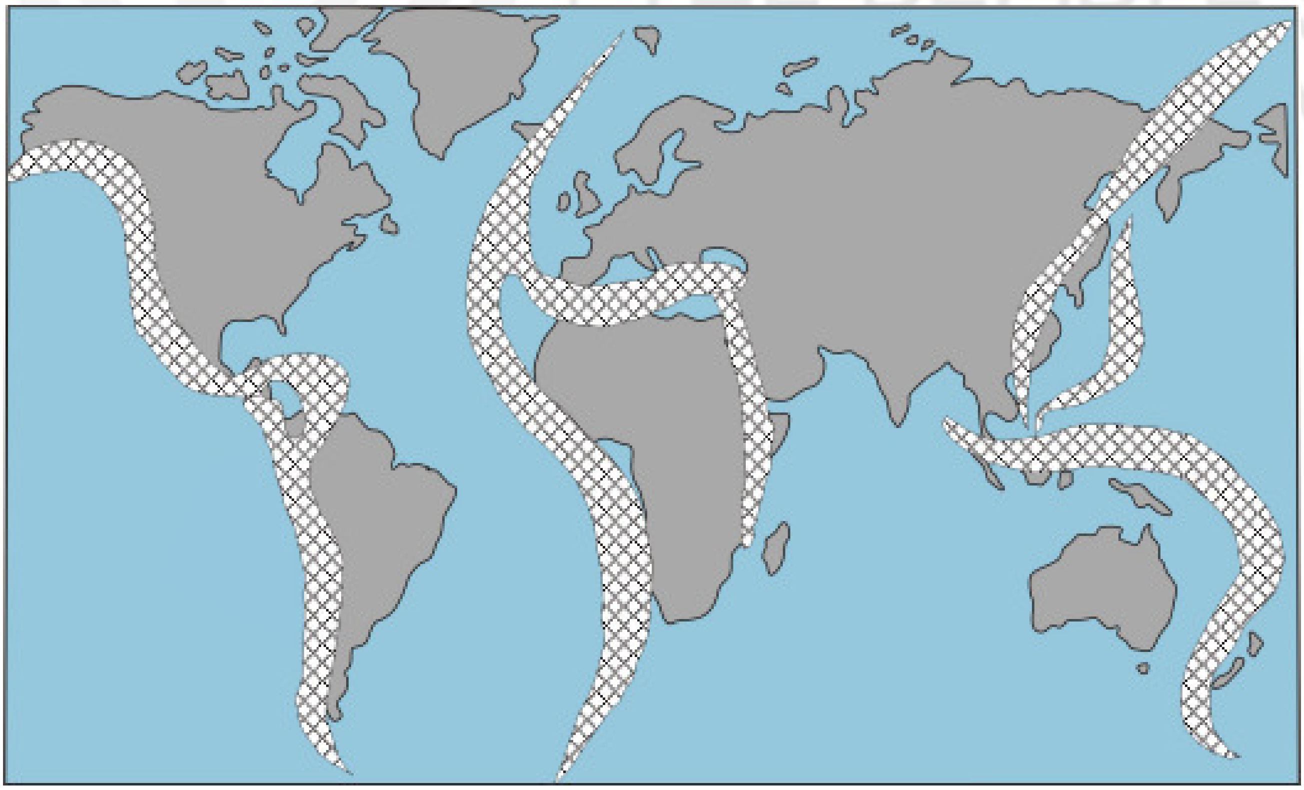

Fig. 4.15: Distribution of volcanic belts in world map.

In this section, we have studied about volcanoes, their causes, effects, distribution, etc. Let us now spend about 5 minutes to check how you are progressing.

SAQ 2

a) Define volcano.

b) Give example of volcanic activity in Indian subcontinent and the type of eruption.

c) Name the prominent volcanic belts of the world.

d) What is volcanism?

4.5 RELATIONSHIP BETWEEN EARTHQUAKES AND VOLCANIC BELTS

You have read in previous sections that the earthquakes and volcanoes are concentrated more along certain belts in the world map. If you observe carefully in Fig. 4.6 and Fig. 4.15, you will find that earthquake and volcanic belts almost coincide and overlap one another. In the Fig. 4.16, we may observe some relationship between above two figures and the plate boundaries.

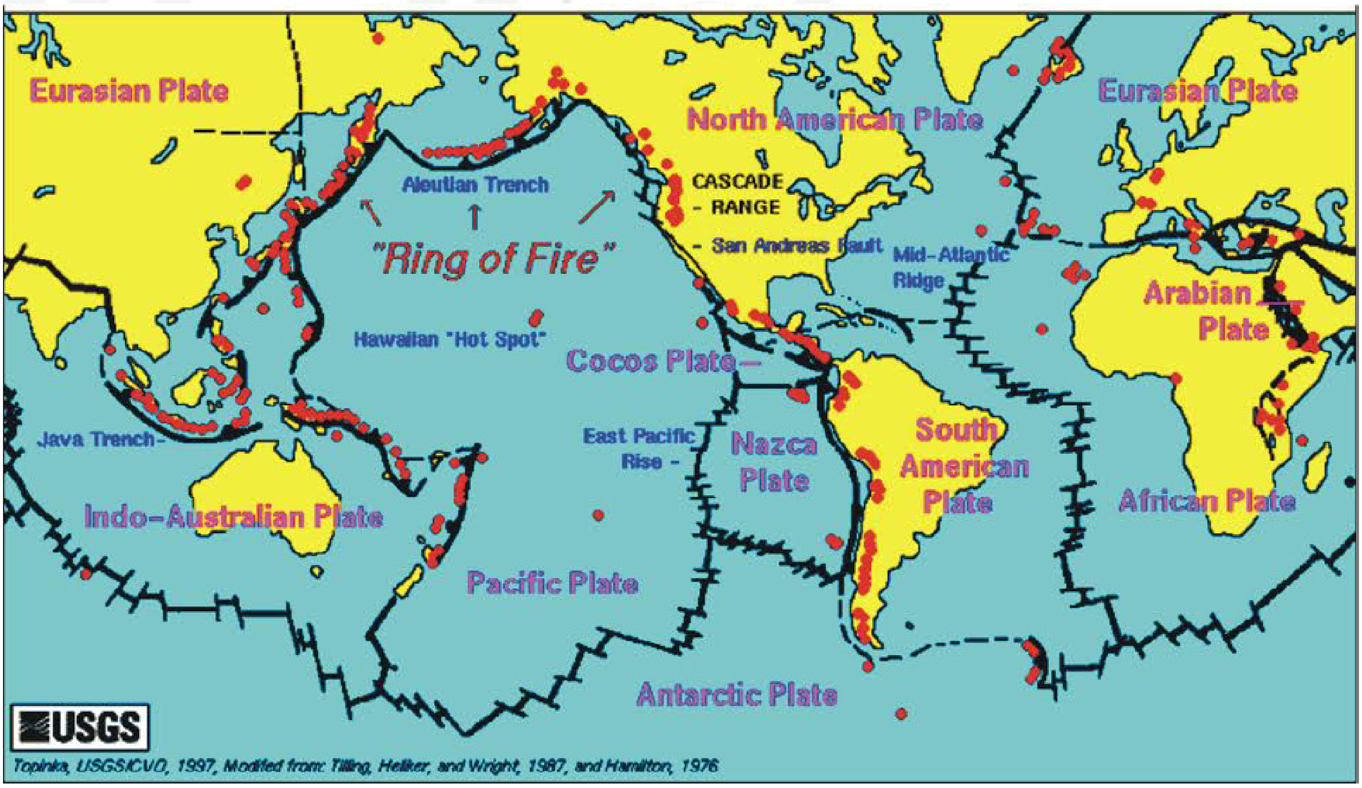

Fig. 4.16: Map showing the relationship between the earthquakes, volcanoes and the plate boundaries. Also indicated on the map is the Ring of Fire.
(Source: www.geology.isu.edu)

This indicates a relationship of earthquake and volcanic belts with the plate boundaries. You will read about plate boundaries in Unit 16 of this course. Earthquakes which do not fall along these belts are often produced due to movement in minor tectonic plates and other local factors. Even before the advent of Plate Tectonic Theory, geologists noted the concentration of volcanoes around the rim of Pacific Ocean and nicknamed it as ‘Ring of Fire’.

4.6 TSUNAMI

There are waves in the ocean surface which rise and fall normally caused by tides. However, due to some events ‘wave trains’ (i.e. repetition of waves) consisting of multiple waves are generated, the initial waves are larger than the normal and are followed by several much larger waves. These waves travel across the open ocean at great speeds and build into huge waves in the shallow water of a shoreline. Such huge waves are called **tsunami** or **harbour waves or seismic sea-waves**, which are very tall and have extreme power.

4.6.1 Causes

A tsunami is triggered when there is sudden movement of the ocean floor causing abrupt movement of water column. There could be several reasons for generation of a tsunami such as undersea earthquakes, landslide, large volcanic eruptions or even a meteorite impact in the ocean water. These events displace a large volume of water causing disturbance which gets transformed into a wave. This wave can travel across the ocean at the speed of 800 km per hour. Although, tsunamis are not easy to notice in mid-ocean where water is deep but when they approach shallow coastal area, the waves steepen and pile up. These waves may develop into a moving wall of water of even more than 20 m and become highly destructive. In the 1883 Indonesia tsunami the waves were found to have height of around 40 m.

Most tsunamis are caused by large earthquakes on the sea floor due to sudden movement of rock blocks past each other causing abrupt movement of the overlying water column. Resulting waves move away from source of the earthquake. Underwater landslides and even a landslide on land can cause a tsunami if slumps into the ocean. Although generation of tsunami by volcanic eruptions is not common, a volcanic eruption may cause landslides and result in generation of tsunami. Meteoritic impact may also trigger a tsunami.

After the 2004 tsunami, Indian National Centre for Ocean Information Services (INCOIS) coming under the Ministry of Earth Sciences (MoES) has developed an early warning system for tsunami for the Indian coasts.

4.6.2 Effects

Tsunamis were earlier known to the 22 countries surrounding the Pacific Ocean but the December 2004 tsunami wrecked havoc in Indian Ocean nations including India causing severe loss of life and property.

Although, small tsunamis occur almost every day with little or no adverse effect, large tsunamis have devastating effects to life, property and the landscape that are often irreversible. Severity of a tsunami’s effects depends on number of factors, such as (a) the magnitude of the tsunamigenic event, and (b) its distance from shore. According to an estimate, nearly 4.3 lakh people have lost their life since 1850 due to tsunamis. The tsunami of March 2011 in Japan caused death and/or missing of about 18,550 people.

Possible effects of a tsunami may be the following:

- massive loss of life, plants and natural resources
- damage to property, sewer drainage and water supply system, etc.
- change in soil salinity affecting crop-yield,
- change in landscape such as erosion of islands,
- severe flooding,
- disease caused by stagnant and contaminated water, solid waste, debris and contamination of soil and water by hazardous materials and toxic substances, etc., and
- environmental effects.

4.7 SUMMARY

The endogenic processes originate from within the Earth, which are also referred as land building processes. They are considered to be beneficial for sustaining life. In this unit we have leant about volcanoes earthquakes and Tsunami. Let us summarise what we have learnt in this unit:

- Most important causes of earthquakes are tectonic. Movement along plates during plate tectonics leads to disastrous earthquakes.
- Earthquake waves generate from focus. Primary waves are fast. Secondary waves are slower but Long waves are slowest and confined to the crust.
- Most common measure of earthquake is Richter scale which indicates magnitude of the earthquake. Seismograph records the earthquake and the record obtained with intensity, date and time is called seismogram.
- Earthquakes can cause damage in several ways *viz.* faulting and shaking, landslides, tsunamis and fire.
- The volcanoes may be defined as any landform that releases lava, gas or ashes or has done so in the past. They are centralised vents through which gases, hot liquid or solidified molten material is thrown out.
- Volcanoes may be active, dormant or extinct depending on time elapsed since last explosion. Calderas may be explosive or subsidence type.
- The liquids emanating from volcanoes are very hot and are called magma when below the surface and lava when they come on the surface. Products derived from volcanism may be gas, liquid and solid. Seven types of eruptions have been recognised based on different character and content of extrusion.
- Several causes of volcanism mostly appear to be related to plate tectonics in which subsiding plate melts and throws out molten material in form of volcanoes.

- Volcanoes too are found in belts like earthquakes. Both of these belts somewhat coincide and appear to be related to the lithospheric plate margins.
- Tsunamis are giant waves that are caused by undersea events such as earthquakes, landslides or volcanic eruptions or a meteoritic impact causing into loss of life, property and environment.

4.8 ACTIVITY

1. Visit geology laboratory in the nearby college/university or institute which has seismograph. There are many such labs in the country. Observe seismograph and its components. Ask for seismogram of previous day if it can be made available to you and study it. See the current one. It may have recorded your footsteps. Check timings and match it with your visit.
2. Find out the seismic zone in which your city is located.
3. Explore Bhuvan or Google Earth or any such package and find out where Barren island is located in India and what it is known for?
4. Explore Bhuvan or Google Earth or any such portal and check the recent image of Trinkat island in Andaman and Nicobar. Find out how the island looked like before December 2004. What are the changes you observe and what is the reason?
5. Check the Deccan Trap area and find out the states where it is distributed. And, prepare a map showing distribution of Deccan Trap volcanism.

4.9 TERMINAL QUESTIONS

1. What do you understand by magnitude and intensity of the earthquake?
2. List the types of damages caused by earthquakes.
3. Discuss the landforms developed as the result of volcanic activity.
4. Describe the harmful and useful effects of volcanism.

4.10 REFERENCES

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4.11 FURTHER/SUGGESTED READINGS

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4.12 ANSWERS

Self-Assessment Questions

1. a) An earthquake is a sudden and temporary shaking of ground caused by seismic waves due to sudden release of energy stored in rocks beneath the earth surface.

   b) Three types of earthquakes are recognised depending on depth of origin i.e. Deep, Intermediate and Shallow depth earthquakes.

   c) The long (L) waves are the slowest and they cause damage on the surface at the time of earthquake.

   d) The recording instrument is seismograph and record obtained is seismogram.

2. 1. Volcano is a hill or mountain formed due to accumulation of matter (solid, liquid and/or gaseous) erupted at the surface.
   2. It is known as Deccan Traps which occurred in south India. This was fissure eruption.
   3. Three volcanic belts are recognized: (i) Pacific belt (ii) Atlantic belt and (iii) Eurasian belt.
   4. Volcanism is a process that form volcanoes and includes rising of magma through crust, its emergence on earth surface as lava and solidification into volcanic rocks and landforms.

Terminal Questions

1. You should first define the intensity and magnitude of earthquakes and then give difference, if any. Refer to the subsection 4.3.4 to write answer.
2. Damages caused by earthquakes have been discussed in subsection 4.3.7. Refer to the subsection to write your response to this question.
3. Landforms generated due to volcanism has been described in the subsection 4.4.3. Refer to the subsection to write your response. Your answer should include both positive and negative relief features.
4. Your answer should include both the constructive and destructive effects associated with volcanism. Refer to the subsection 4.4.5 while writing your answer.

GLOSSARY

Absolute Age : It is the geologic age of a fossil, or a geologic event or feature expressed in specific number in units of time.

Basalt : It is a dark-coloured, fine-grained, igneous rock composed mainly of plagioclase and pyroxene minerals. It most commonly forms as an extrusive rock, such as a lava flow, but can also form in small intrusive bodies, such as an igneous dike or a thin sill.

Biogeochemistry : It deals with the study of geological, chemical, physical and biological processes and reactions that govern the composition of the natural environment. It involves atmosphere, biosphere, hydrosphere, lithosphere and pedosphere.

Crystal : They are minerals in a crystallised form. Crystals of different mineral have characteristic form or habit that is a reflection of its atomic structure.

Cryosphere : Cryosphere (Greek cryos meaning cold, frost or ice and sphaira meaning globe) is the part of the Earth's surface where water is in solid state which can be in the form of snow, ice and glacier.

Deductive Reasoning : It is the process of drawing logical inferences to develop hypothesis.

Experiment : It is a type of test that is designed which helps geologist to gather information under controlled conditions.

Feldspar : They comprise a group of minerals containing potassium, sodium, calcium and aluminium silicates. They are the most abundant minerals on Earth's crust and the most common rock-forming minerals.They are present in many of the igneous, metamorphic and sedimentary rocks.

Felsic rocks : It refers to the igneous rocks having more than 65% of silica content.

Fossil : A fossil is the remains of a plant or organism which are preserved in rocks either fully or in parts through some process.

Gabbro : It is a coarse grained intrusive igneous rock, similar in mineral composition to basalt but cools very slowly to produce large crystals. It is typically associated with large scale intrusive igneous bodies such as plutons and batholiths.

Gem : They are rare minerals which are formed under unusual geological conditions and are known for their preciousness.

Geothermal Energy : It is the vast reservoir of heat energy in the Earth's interior, of which surface manifestations are the volcanoes, fumaroles, geysers, steaming grounds and hot springs. Currently, geothermal energy is being commercially exploited for the generation of electricity.

Geothermal gradient : It is the rate of increase of temperature in the Earth with depth.

Granite : It is a coarse grained igneous rock comprising quartz, feldspar, and mica minerals. It corresponds to the average composition of the continental crust. It is formed at convergent (destructive) plate margins, typically in fold mountain (orogenic) belts.

Hypothesis : It is a testable educated guess that attempts to explain a phenomenon.

Intermediate rocks : It refers to the rocks which contain silica between 55-65%.

Mafic rocks : These rocks have silica content between 44-55%.

Marine Geology or geological oceanography : It involves geophysical, geochemical, sedimentological and palaeontological investigations within the ocean basins and at the coastal margins.

Mesosphere : It lies above the stratosphere and is a cold region extending from 50 to 90 km over the Earth's surface. Within the mesosphere, there occurs a layer called radio-waves absorbing layer.

Mean sea level (MSL) : It is the average level of sea over the period of 19 years, considering all stages of tide. The mean sea level conforms closely to the squashed spherical shape expected for rotating Earth. It is used as a reference level for measurement of elevations and depths.

Mid Oceanic Ridge : The junction between two oceanic plates along a divergent (constructive) plate margin. The ridge comprises a submarine mountain chain of basaltic volcanoes and is up to 1.5 km higher than the adjacent abyssal plain.

Milky Way Galaxy : It is one of the hundreds of millions of galaxies present in the Universe.

Mineral : A mineral is a naturally occurring inorganic solid crystalline substance having specific chemical composition.

Ocean Trench : An elongate depression of the ocean floor which runs parallel to a volcanic island arc or mountain belt. Oceanic trenches are the deepest part of the oceans and can be up to 11 km. They are located where oceanic lithosphere is being subducted into the asthenosphere, i.e Peru-Chile Trench which runs parallel to the west coast of South America.

Oceanic Crust : The crust that forms in the ocean basins. It is basaltic in composition, and comprises an upper layer of pillow lavas, a middle zone of vertical dolerite dykes and a lower layer of gabbro. The oldest oceanic crust is less than 200 million years old.

Paleomagnetism : The natural remnant magnetism in rock bodies. The permanent magnetisation acquired by rock that can be used to determine the location of the magnetic poles and the latitude of the rock at the time it became magnetised.

Physiography : It deals with the study of surface features of the Earth which are produced as a result of various external agencies operating on the Earth's surface.

Pluton : A medium sized igneous intrusion of up to 100 km^2 with a generally oval or circular shape in plan and steep or near vertical sides, e.g. Gangotri plutons in Higher Himalaya.

Polar wandering hypothesis : As the result of paleomagnetic studies in the 1950s, researchers proposed that either the magnetic poles migrated greatly through time or the continents gradually shifted their positions.

Quartz : After the feldspar, It is the second most abundant mineral in Earth's continental crust and is the important constituent of many rocks.

Relative Age : It is the geologic age of a fossil, or a geologic event or feature expressed relative to other organisms, rocks, or features or events rather than in specific number in units of time.

Rock : A rock (for example, basalt and granite) is composed of some combination of minerals which are the building blocks of rocks.

Sedimentary rock : Rock formed by the weathering of pre-existing rocks that have been transported, deposited and lithified.

Shallow-focus earthquake	An earthquake focus at a depth of less than 60 kilometers.
Stratosphere	It is the layer from 16 to 50 km. Here air is at rest. It is free from dust cloud and water vapour. The upper strata are rich in ozone.
Stromatolites	They are the early microbial communities whose fossils have been first reported from Archean rocks.
Theory	It is a hypothesis that has been aggressively tested and is generally accepted true. Example of successful theories includes theory of Plate Tectonics
Thermosphere	Part of the atmosphere which extends over mesosphere between 80 and 600 km.
Troposphere	It is the lower most but important layer of the atmosphere. Its average height is 16 km. Here exists the air that we breathe.
Tufa or tuff	An igneous rock formed near or on the surface of the Earth by compaction of detritus such as ash and small rock fragments (of less than 2 mm across in size) ejected from a volcano.
Ultramafic rocks	It refers to the rocks which contain less than 44% silica content.
Uniformitarianism	It is one of the most fundamental principle followed in geology. The principle 'The present is the key to the past' was given by James Hutton in 1785. The ongoing processes on the Earth provide clues for unravelling its mysteries.

NOTE

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