Indira Gandhi National
Open University
School of Sciences

BGGCT-131
PHYSICAL GEOGRAPHY

Block

2

LITHOSPHERE

Course Design Committee

Prof. Vijayshri
Former Director,
School of Sciences,
IGNOU, New Delhi

Prof. Milap Chand Sharma
Centre for the Study of
Regional Development,
Jawajarlal Nehru University,
New Delhi

Dr. Satya Raj
Discipline of Geography,
School of Sciences,
IGNOU, New Delhi

Prof. (Retd.) H. Ramachandran
Discipline of Geography,
University of Delhi
Delhi

Prof. Mahendra Singh Nathawat
Discipline of Geography,
School of Sciences,
IGNOU, New Delhi

Dr. Koppisetti Nageswara Rao
Discipline of Geography,
School of Sciences,
IGNOU, New Delhi

Prof. Sachidanand Sinha
Centre for the Study of
Regional Development,
Jawajarlal Nehru University,
New Delhi

Dr. Vijay Kumar Baraik
Discipline of Geography,
School of Sciences,
IGNOU, New Delhi

Dr. Vishal Warpa
Discipline of Geography,
School of Sciences,
IGNOU, New Delhi

Prof. N.R. Dash
Department of Geography,
The MS University,
Baroda

Dr. Subhakanta Mohapatra
Department of Geography,
School of Sciences,
IGNOU, New Delhi

Block Preparation Team

Prof. Biplab Biswas, (Unit 5 and 6)
Dept. of Geography,
The University of Burdwan,
Golapbag, Burdwan

Dr. Koppisetti Nageswara Rao (Unit 7, 8 and 9)
Assistant Professor
Discipline of Geography,
School of Sciences,
IGNOU, New Delhi

Prof. H.S. Sharma,(Editor)
Retd. Prof. Dept. Of Geography,
University of Rajasthan

Course Coordinators: **Prof. Mahendra Singh Nathawat and Dr. Satya Raj**

Block Production Team

Sh. Sunil Kumar
AR (P), IGNOU

Graphics Artists/Cartographers: Mr Ajit Kumar Mr. Sumit Mr Anil

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BLOCK 2: LITHOSPHERE

In the previous block of this course, you have learnt about earth as a living planet. So now you are aware of various theories and concepts related to the origin of earth. You have also studied about the interior of earth which still holds a lot of curiosity as interior of earth is the least explored part. You have also learnt about isostasy which is the stability between the upstanding features and low lying areas. In this block you will study about lithosphere. Lithosphere is the rocky outermost layer of earth consisting of the crust and the solid outermost layer of the upper mantle. This block is divided into 5 units.

In unit 5 you will learn about the materials of the earth's crust which includes different types of rocks and minerals.

In unit 6 you will learn that as lithosphere is broken into several rigid blocks or plates, there are plate movements which is responsible for the drift of continents and the formation of mountains etc. You will also get acquainted with different theories related to the continental drift and mountain building.

Unit 7 explains to you different endogenetic forces which are occurring beneath the surface of earth and constantly changing the earth topography through creation, destruction, recreation and maintenance of geo-materials.

Unit 8 and 9 discusses about exogenetic forces which occur on the earth's surface. You will get acquainted with the concept of cycle of erosion given by Davis and Penck and also study the landforms created by river, glacier, groundwater, sea waves, and wind.

So after studying this block, you should be able to:

- define lithosphere and identify various types of rocks;
- explain the process of drifting of continents and formation of mountains and plate movements;
- discuss endogenetic and exogenetic processes;
- describe the landforms created by river, glacier, groundwater, sea waves, and wind.

So we wish you good luck for studying this block.

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UNIT 5

MATERIALS OF THE EARTH'S CRUST: ROCKS AND MINERALS

Structure

5.1 INTRODUCTION

In the First Block of this course, you have learnt about geosphere. In this Unit 5 of Block 2, you will study the materials of the earth's crust i.e. rocks and minerals. You will be amazed to know that not only the landmass parts but oceanic base also forms a part of the earth's crust. Literally even as small as every centimetre portion of solid mass of planet earth is composed and covered by rock particles across the variety of physical landscapes. As you all know that rocks are very hard substance and soon after formation they may last for millions of year's altogether. You will be surprised to know that the oldest known rocks are around 3.6 billion years old which roughly corresponds with the age of planet earth itself. Such types of crust forming materials are called rocks and minerals. In this unit, you will study about rocks and minerals.

We would like to mention here that the study of rocks and minerals are not actually an essential or central part of 'Physical Geography'. It is the forte of a geologist. However, the rocks which lay exposed to various geomorphic agents like glacier, river, ocean, air or rainfall and wind etc. that helps to shape and develop different landform types are of particular interest in Physical Geography. The study of landforms is the central theme in physical geography and so it is useful to study the rocks and minerals. In this unit, we shall try to make an understanding of the basic ideas of the earth's crust, rocks and minerals as its constituents. Along with, we will also delve into the origin and classification of rocks, characteristics of the rocks and minerals and rock cycle spread over various sections and sub-sections of this unit.

Expected Learning Outcomes

After studying this unit, you should be able to:

- ❖ explain the fundamentals regarding the materials of the earth's crust;
- ❖ describe the origin and classification of different types of rocks and minerals; and
- ❖ analyse the rock cycle process which is continuous and repetitive in nature on the planet earth.

5.2 FUNDAMENTALS

You have already learnt in Unit 1 that earth's crust is the upper most part in the arrangement of layers or spheres spread over the earth's surface. It is a part of lithosphere which is made up of several rocks and minerals. Its average thickness is about 35-40 kilometres. In this section on fundamentals, you will learn about three concepts including concept of the earth's crust, continental crust and oceanic crust.

This will provide a basis for the proper understanding and appreciation of origin and classification of rocks as well as the process of rock cycle.

5.2.1 Basic Concept of the Earth's Crust

Do you have an idea about how the earth's crust has been formed? It was nearly thousands of years ago when the earth was in very hot state and everything was in its molten state. Slowly the temperature started reducing and a solid layer has formed in the outer part of Earth. It is known as 'Earth's crust', where the ambient conditions exist for the continuous thriving of higher forms of life including flora and fauna along with human beings.

The cooling of earth can be compared with the cooling of hot milk. As we find a relative hard or thick layer part that forms on top when hot milk after boiling is left for cooling

Earth's crust is the top most part which is relatively rigid part like the shell of an egg. The crust is formed by a combination of several rocks and minerals and there are several layers in it. All of these layers are together known as 'lithosphere'. Thickness of the crust may vary from few kilometres under the oceans to 75 kilometres under the mountainous regions like that of Himalayas.

The crust is separated from the lower layer called **Mantle**. The process of separation of different layers depends upon the chemical composition, density, temperature of the constituting rocks and minerals. The line that separates crust from the mantle is known as '***Moho Discontinuity***'. It was discovered in 1909 by A. Mohorovicic which marks the boundary between lower crust and upper mantle.

The earth's crust is further classified into two layers i.e. 'continental crust' and 'oceanic crust. Continental crust is that part of the earth's crust where human beings live and conduct all of their activities. This part is not continuous and is separated by very large water bodies including seas and oceans, rivers, streams and lakes etc. As opposed to this, oceanic crust is continuous and lies beneath the continental crust and extends up to mid-oceanic ridges. It is at this point i.e. mid-oceanic ridges, the earth's crust originates. These two layers are separated by a line of discontinuity known as '***Conrad Discontinuity***'. The Conrad discontinuity corresponds to the sub-horizontal boundary between Continental and Oceanic Crust. This boundary is observed in various continental regions at a depth of 15 to 20 kilometres. However, it is not found in Oceanic regions.

Mid-Oceanic Ridges are the volcanic mountain system under the oceans. Here magma is coming out to form oceanic crust and spreads towards the continents.

5.2.2 Concept of Continental Crust

It is observed that 7 billion cubic kilometres of continental crust lie above the **mean sea level**. It supports the life, settlement, agriculture and provide drinking water. We human beings are able to live here only because of the presence of continental crust. It is fragmented to form various major geographical features like continents, oceans and islands.

About 3.7 billion years ago, due to the volcanic activities over the very thin heavier oceanic crust, the **continental shields** started to form. The processes of formation of continental crust from volcanic activities are visible in different parts of the World till today. You will further study in this unit that it is because of volcanic activities that gave birth to **Igneous rocks** which subsequently after erosion gets transported and deposited to form **Sedimentary rocks**. All the above rocks later on under tremenadous heat and pressure gets modified to become **Metamorphic rocks**. It is a continuous and repetitive process known as rock cycle. So you can understand and say that the continental crust is made up of all the three types of rocks.

The continental crust is less dense than all the layers of the earth's interior. Its density is 2.7g/cm^3 whereas the density of the oceanic crust is 3.0 g/cm^3 and that of the earth's mantle is 3.3 g/cm^3. Main mineral composition of continental crust is Silica and Aluminium. This layer is also commonly known as ***Sial*** layer.

Do you have any idea that how coastal landforms are created? The continental crusts are drifting over the heavier oceanic crust and the collision between two continental crusts or continent and oceanic crust give rise to several landforms and associated features. The oceanic crust being heavier subducts back into mantle and melts down. It is the collision zone of two continents that gives rise to taller and heavier mountain chain systems like the Himalayas. Furthermore the greatest thickness of the continental crusts is also found there. Since the height of the mountain is always determined by the thickness of the continental crust.

On account of high temperature, pressure conditions and distortion leads to the modification of the continental crust to that of metamorphic rocks. You will be in a better position to examine the origin and destruction of the continental crust more aptly with the help of **Plate Tectonics theory** which you will study in the next unit of this block.

5.2.3 Concept of Oceanic Crust

You will be astonished to discover that about 70% of the earth's crust is covered by oceans. The oceanic crust originates from the **Mid-oceanic Ridges** and spreads towards the continents and then it goes down to magma again and it melts. This could be the reason that we always find the younger oceanic crust and it is not more than 200 million years old. All of the oceanic crusts are made up of basalt rock which is a volcanic rock. Some deposits of continental sediments near the continents and organic depositions in the deep sea zone are also found there. Oceanic crusts are heavier and its density is 3.0 g/cm^3. Primary wave (P) travels through this layer at a speed of 7 km/s. Mineral compositions of the rocks are mainly silica and magnesium. This layer is known as ***Sima***.

According to the **Plate Tectonic Theory**, the oceanic crust has its origin at the mid oceanic ridges and subducts at the **convergent boundaries** of two plates. Coastal features like Island arcs, volcanoes, oceanic trenches are formed at the subduction zone of two oceanic crusts. When an oceanic crust converges with a continental crust, it always subducts below the continental crust as the oceanic crust is more dense and heavy and it melts and gets subsumed into the mantle after subduction.

Before you proceed to next sub-section, it will be good to recapitulate few concepts and complete the given exercise below to make a better understanding.

Spend 5 mins

SAQ 1

a) Define earth's crust.

b) Why is continental crust known as sial?

5.3 COMPOSITION OF THE EARTH'S CRUST

You are well aware that the earth's crust is an integral part of the lithosphere. The word 'litho' means rocks. Rocks are made up of minerals which are composed by its elements. So the earth's crust is composed of minerals. You will be surprised to know that there are only **8 elements** in varying proportions which make up the crust of the earth's surface as shown in Table 5.1.

Oxygen is the most common chemical element of the crust accounting 46% of the rocks. Next important mineral is Silicon (28%). Aluminium, iron, calcium, sodium, potassium and magnesium constitute about 24% whereas others constitute 1% only. The minerals vary in their structure, shape, stability, solubility, hardness, crystal structure and colour. Minerals are seldom found in isolation but exist in stable compound form.

Table 5.1: Elements of the Earth's Crust

ELEMENT (symbol)	CRUST	
	Percent by mass	Percent by volume
Oxygen (O)	46.10	94.04
Silicon (Si)	28.20	0.88
Aluminum (AL)	8.23	0.48
Iron (Fe)	5.63	0.49
Calcium (Ca)	4.15	1.18
Sodium (Ma)	2.36	1.11
Magnesium (Mg)	2.33	0.33
Potassium (K)	2.09	1.42
Nitrogen (N)	Traces	Traces
Hydrogem (H)	Traces	Traces
Other	0.91	0.07

It is interesting to know that different ratio of mixing of mineral elements generates different rock types over the earth's crust. If you are keen to know about the multifarious properties of minerals then you can visit the website of following governmental institutions for further exploration like '***Geological Survey of India***' and '***Wadia Institute of Himalayan Geology***' etc.

5.4 ROCKS AND MINERALS: CRUST FORMING MATERIALS

Have you ever wondered about the ingredients which make up the earth's crust? Basically it is formed by different rock types and their constituent minerals. All rock types are formed with particular composition of different minerals. The size of the minerals may vary from microscope to few inches. You may be wondering that how it is possible to form rocks from such tiny mineral particles. The minerals are held together with particular strength and density and they determine the nature of any rock. The most common rock types found over the continental surface is:

- **Shale**: it is composed mainly by clay minerals and mixed with fine quartz grains,
- **Sandstone**: it is composed mainly by quartz sand and mixed with feldspars,
- **Granitic rocks**: these are composed together from quartz and potash feldspars mixed with amphibole or biotite mica,

- **Limestone and dolomite**: these two are composed mainly from calcite or dolomite,
- **Basaltic rocks**: it is composed of plagioclase feldspars, biotite mica, pyroxenes and olivine etc.

You have learnt that together these above-mentioned five rock types constitute about 92% of the total rocks found over the earth's surface. Let's attempt to recapitulate and memorize the key points studied so far before moving to the next section.

Spend 5 mins

SAQ 2

State the composition of the earth's crust.

5.5 ORIGIN AND CLASSIFICATION OF ROCKS

You may be wondering that how we can classify rocks into distinct types. Well rocks can be classified on the basis of several criteria. Such criteria includes chemical and physical properties, mineral content, mineral size grains, types of elements and origin of rocks etc. However, rocks are most commonly classified on the basis of their origin. Three major well known identified rock groups are **Igneous, Sedimentary** and **Metamorphic** rocks. You will now learn and explore more about these three major rock types along with their sub-types in the subsequent sections.

5.5.1 Igneous Rocks

Igneous rocks are originated in the initial stage of earth formation by the cooling of hot magma. Approximately, more than 80 per cent of earth's crust is made up of igneous rocks. The oldest known igneous rocks are thought to be as old as nearly 3.6 billion years. And the formation of youngest igneous rocks is still in progress as you are reading this unit since rock cycle is a continuous and repetitive natural process. Igneous rocks are also known as primary or parent rocks. All rock types are developed either directly or indirectly from the igneous rock. Magma is a very hot mixture of minerals and gases. Often, it comes out to the earth's surface through some weak points or some time gets stored under the surface. Classification of the igneous rocks depends on several factors. These factors encompass location of cooling of the hot magma, the mineral content, mineral size and acidity etc. The major characteristics are as follows:

- the rock forming elements are very compact which increases its hardness;
- the igneous rocks are very hard and heavy and therefore resistant to erosion;
- water cannot percolate through the rocks as there is no porosity;
- there is no layer as it is seen in sedimentary rocks;
- Igneous rocks do not contain any fossil but contains crystals and may be visible to the bare eyes.

You have studied that igneous rocks originate initially from the cooling of the magma inside the earth's crust or on the earth's surface. The cooling rate gives rise and helps to shape the chemical composition and mineral size etc. So the igneous rocks are classified primarily based on two parameters origin and chemical composition.

Now you will learn about the classification as well as variety of same rock type on the basis of a) place of origin and b) chemical composition.

a) Based on Place of Origin

When the rocks originate deep inside the earth's crust, it is known as intrusive igneous rocks. **Granite** is an example of intrusive rock. Intrusive rocks are characterized by larger mineral size and may be visible with bare eyes to a keen observer. Some igneous rocks originate in very deep portions of the crust and are having even larger minerals. This type of intrusive rock is called **plutonic** igneous rock. When it originates immediate below the earth's surface, it is known as **hypabyssal** igneous rock having smaller mineral size. The example is Porphyry.

Magma reaches the earth's surface through the weak points like joints, fractures and faults etc. Subsequently it cools very fast when it comes into contact with air and generates very finer microscopic minerals. This type of igneous rock is known as **extrusive** rock. **Basalt** is an example of extrusive rock. Magma may come out at the earth's surface from the mantle through volcanoes and generates lava rocks and the ash and other **Pyroclastic** rock. Tuff is an example of pyroclastic rock.

b) Based on Chemical Composition

Silica is a very important mineral of igneous rock and determines the pH or acidity of the rocks. Based on the acidic condition of the igneous rock, rocks can be classified into four categories.

i) **Acidic Igneous rock**: The content of silica is more than 65%. Granite is an acidic igneous rock.

ii) **Basic Igneous Rock**: Basalt is an example where the content of silica lies between 45-60%. Iron content of this rock is very high.

iii) **Intermediate Igneous Rock**: The pH of the rock is neutral and silica content is such that neither the rock falls in acidic nor in basic category. Diorite is an example of this type of rock.

iv) **Ultra-basic**: Igneous rock is peridotite. In this rock silica content is less than 45%.

Before you start reading the next section let us remember the crux of this section with the help of following activity in the form of check your progress.

SAQ 3

Classify igneous rocks based on their origin and chemical composition.

Spend 5 mins

5.5.2 Sedimentary Rocks

It will be interesting for you to know that nearly 70 per cent of landmass of the planet earth is covered under thin layers of sediments or debris. Such huge piles of sediments eventually gets settled on the beds of major and minor water bodies like oceans and seas, lakes and rivers etc. With the passage of time, rock materials becomes compacted over millions of years and thereafter erosion takes place and material is carried together with older rocks by agents of erosion such as water, ice, wind or wave etc. under the influence of gravity. Such kind of eroded and transported sediments/debris materials are known as sedimentary rocks. Later on the materials come to rest and gradually gets compacted, consolidated and cemented together. In this way you will notice that sand becomes sedimentary **sandstone** rock and similarly clay becomes sedimentary **shale** rock etc.

Although sedimentary rocks cover extensive areas but account only 8% of the total area of the earth's surface. Sedimentary rocks exist as layers of different rock beds. These are further separated by bedding planes. It is interesting to know that sedimentary rocks are very important source of coal, natural oil, drinking water and ores. Such types of natural resources play an important role in the spatial and economic activities.

In 1802, a farmer of Connecticut Valley of New England found a block of red sandstone in his field showing footprint of dinosaur of 200 million years ago. It was a Fossil! We can say that the remnants of plants, animals or their impressions may get converted as fossils.

The main characteristics of sedimentary rocks are as follows:

- sedimentary rocks are secondary formation and they have layers of beds separated by bedding plane;
- it is characterized by pore spaces and is lighter than the igneous rocks;
- it is the source of fossil fuels. They do not have any crystalline structure.

Now we will discuss the classification scheme on the basis of a) place of origin and b) chemical composition as discussed earlier in the case of igneous rocks.

a) Based on Place of Origin

Sedimentary rocks are secondary rocks as it originates from the primary igneous rocks. The weathered and eroded materials are transported by air, water, sea or glaciers. Such type of material gets deposited in different depositional environment like river bed, lakes or in seas. The sediment characteristics vary significantly on the basis of weathering processes, natural agents of erosion along with transportation. Furthermore, the characteristics also differ on account of the particle size, mixing and sorting of particles, chemical alteration, organic character, cementing and compaction etc.

When the parent rocks are broken up into small pieces, it starts accumulating and compacting to form new rocks known as clastic sedimentary rocks. Based on the depositional agency, environment and grain size, this group of sedimentary rocks can further be classified as **conglomerate, sandstone, loess** and **clay** etc.

b) Based on Chemical Composition

Rock particles may be chemically altered during the process of chemical weathering and gets deposited to make chemically formed sedimentary rocks.

This rock is commonly found in the arid and semi arid regions of the world. **Gypsum** is the best example of this type of rock.

Decomposition and disintegration of organic residue sometimes leads to the cementing and compaction of the rock particles to form a type of sedimentary rocks. Coal, dolomite and limestone are this type of rock. Most of the sedimentary rocks originate from the marine, sea, river or lake environment. They can be grouped into aqueous sedimentary rocks. Loess sedimentary rock originated mainly due to aeolian process .It is known as **aeolian sedimentary rock**. Another type like till and moraine types of sedimentary rocks originated mainly due to the glacial processes. They can be grouped into **glacial sedimentary rocks**.

You are required to recapitulate the main points through the exercise before reading the next section on metamorphic rocks.

SAQ 4

What are the major characteristics of sedimentary rocks?

Spend 5 mins

5.5.3 Metamorphic Rocks

The **primary igneous** and **secondary sedimentary** rocks may change their physical and chemical characteristics and form due to the huge pressure and heat. The transformed **tertiary rocks** are called **metamorphic rocks**. This word has its origin in the Greek word *metamorphosis*. *Metamorphism* makes the rocks to go through the process of re-crystallization which results into the transformation of the **Protolith** into harder and denser rock. Re-crystallization destroys bedding planes and joints systems. As a result, the **marble** or **quartz** may show no stratifications in the rocks. The metamorphic rocks cover a significant part of the earth's crust. It can be classified on the basis of types of transformed rocks, transforming agents and place of transformation.

The major characteristics of metamorphic rocks are as follows:

- metamorphic rocks are **denser** and **harder** than the original Protolith.
- the re-crystallization process makes **bigger crystals** which are prominent.
- the **ores are segregated** that makes it easy to mine. These rocks do not contain fossils.
- they may contain well developed **foliated** or **lineated structure**.

Metamorphism of the original igneous or sedimentary rocks may happen due to intense pressure and heat by agents of metamorphism in many places or localities. The original rocks may undergo intense pressure due to convergence of two plates and the rocks may get folded and transformed. The magma may come to the earth's surface and the heat may transform the rocks. Sometimes water penetrates deep into the crust and its heat, pressure and chemical reaction can alter the original rocks. In all the cases the effect of transformation may be very localized or regional. The metamorphism of rocks generates new texture, composition and foliation of rocks. These are classified based on the foliation and original rocks.

Foliated Metamorphic Rocks: Foliated Metamorphic rocks are very complex in its composition. The texture is layered, foliated, lineated, banded and the minerals are oriented. Slates and schist are examples of foliated metamorphic rocks.

Non-Foliated Metamorphic Rocks: These rocks are simple in its composition. The texture is granular and equi-dimensional and has no definite orientation of the minerals. Quartzite and Marble are non-foliated metamorphic rocks.

Metamorphic Rocks with an Igneous Protolith: Metamorphic rocks are considered to be derived from an original igneous protolith either because of the lithological characteristics (i.e. preservation of igneous textures and in some cases composition or mineralogy) or the lithological associations of the rock. Such rock types are classified as igneous metamorphic rocks. Pyroxene and hornblende are examples of this type of rocks.

Metamorphic Rocks with a Sedimentary Protolith: If the rocks are known to be derived from original sedimentary rock i.e. protolith, either because of the lithological characteristics or the lithological associations of the rock it is classified as metamorphic rocks with sedimentary protolith. Phyllite and quartzite come under this type of rocks.

Before going to the last section, you should carry out the following exercise just to ensure that you have memorized all the key points of this section well.

Spend 5 mins

SAQ 5

Describe the classification of the metamorphic rocks.

5.6 ROCK CYCLE

You are already familiar with and learnt about the rock cycle in Unit 3 of Block 1 of this course. You can refer back this section to learn about the same in detail. By now, you are already familiar that it is one of the several cycles continually happening over the earth's surface being driven by the Sun's energy as like all other systems on the planet earth. Just to let you understand one of the other parallel systems as like that of rock cycle is hydrological cycle. You will study about it in Unit 15 of same course. Some other prominent ones could be ecosystem, lithosphere, atmosphere, hydrosphere, cryosphere, biosphere etc. which you have already studied in Unit 1 of this course and further study in block 3 of same course.

To recapitulate, it refers to the constant cycling and recycling of rock particles over the planet earth's lithosphere. After doing so, you can see, notice and understand the intricate and complex relationship between one system to another as well as across all the systems through the seamless flow and exchange of energy and matter.

In other words, it means the change of one rock type into another rock type and vice-versa. The rock particles continuously alter its shape as well as structure under the conditions of pressure and heat. It is a gradual and long-term process which operates under the influence of natural agents. These include weathering and mass wasting processes, wind and water etc. In turn the rock cycle facilitates our understanding about the myriad inter-relationships that exists between different rock types on one hand as well as amongst different components of the planet earth as a system on the other hand. Besides it also helps to explore the genesis and interrelationships of three major rock types encompassing igneous, sedimentary and metamorphic.

5.7 SUMMARY

In this unit, you have learnt the following issues which characterize the materials of the earth's crust:

- Crust is the upper part of planet earth and is made up of many rocks and minerals.
- The crust is forming at the mid-oceanic ridges, in volcanoes and upliftments of sedimentary deposits through earth's movements.
- The crust is destroying at the converging plate margins.
- You have also learned that the earth's crust is having two parts- continental part and oceanic part.
- The crust is made up of different kinds of rocks including three major groups' being igneous, sedimentary and metamorphic rocks.
- The distinction and classification of the rocks are made by their constituent minerals and structure.
- Further, you have got the idea that each of the rocks is classified into diverse forms based on their nature of origin and mineral composition and other factors.
- And, you have also learnt that mostly all inter and intra -categories of rocks have distinct characteristics and rock cycle which happens to be a continuous and repetitive process on the planet earth.

5.8 TERMINAL QUESTIONS

1. Briefly describe the composition of the earth's crust.
2. Highlight the salient features regarding the origin and classification of igneous rocks.
3. Discuss in detail the chief characteristics of metamorphic rocks.

5.9 ANSWERS

Self-Assessment Questions

1. a) Surface layer of the earth is called earth's crust. Its average depth is about 35-40 kilometres. The crust is formed by several rocks and minerals and there are several layers in it. All these together are called lithosphere.

   b) Main composition of minerals of continental crust is Silica and Aluminium. That is why this layer is known as Sial layer.

2. Oxygen is the most common chemical elements of the crust accounting 46% followed by Sillicon (28%). Aluminium, iron, calcium, sodium, potasium and magnesium constitute about 24% whereas others constitute 1% only.

3. Based on origin- intrusive and extrusive

   Based on Chemical composition- acidic, basic, intermediate and ultra-basic.

4. Characteristics of sedimentary rocks are: (i) secondary formation and they have layers of beds separated by bedding plane; (ii) pore space and is lighter than the igneous rocks; (iii) source of fossil fuel; and (iv) do not have any crystallise structure.

5. Based on the foliation - folliated and non-folliated

   Based on original rocks - Metamorphic rocks with igneous protolith and metamorphic rocks with sedimentary protolith.

Terminal Questions

1. As you know that the earth's crust is composed of various rocks and their constituent minerals. Your answer should focus and cover on such rocks and minerals. For answering this question you can refer sub-section 5.3 in detail. Just try to make us understand that you have got it right by highlighting the salient features.
2. You have studied three major rock groups and their constituent minerals in detail. Your answer should highlight the salient features of rock forming materials. For answering this question you can refer section 5.5.1 in detail.
3. You know that metamorphic rocks are the third major rock types. Your answer should highlight importance of this rock type. For answering this question you can refer section no. 5.5.3 in detail.

5.10 REFERENCES/FURTHER READING

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UNIT 6

CONTINENTAL DRIFT, MOUNTAIN BUILDING AND PLATE TECTONICS

Structure

6.1 INTRODUCTION

You have studied materials of the Earth's crust in Unit 5 of this Block. In this unit you will learn about continental drift theory of Wegener, mountain building theories of Kober and Homes, and theory of plate tectonics. The continents are in motion relative to each other. After going through the Section 6.2, you will be able to define the 'Continental Drift' which is the movement of the Earth's continents relative to each other by appearing to drift across the ocean bed. This concept was independently and more precisely proposed by Alfred Wegener. The theories related to mountain building are propounded by various scientists explained in Section 6.3. Wegener's idea eventually helped to form the theory of plate tectonics. The theory of continental drift was supported by the theory of plate tectonics, which has been explained elaborately in Section 6.4. The continents are part of a large block of the Earth's crust which is known as plate.

Expected Learning Outcomes

After studying this unit, you should be able to:

- explain the basic idea of continental drift;
- explain the relationship between the theories of continental drift and plate tectonics;
- describe the origin and relationship of mountain building, Earthquake, volcanicity, tsunamis with plate tectonics.

6.2 CONTINENTAL DRIFT THEORY OF WEGENER

Density of the continental crust is lighter than all the layers of the Earth's interior and its density is 2.7g/cm3. Main composition of minerals of continental crust is Silica and Aluminum. That is why this layer is known as SIAL layer.

Oceanic crusts are heavier and its density is 3.0 g/cm3. The mineral compositions of the rocks are mainly Silica and Magnesium and so the layer is known as SIMA.

It is established fact that the Earth crust is made up of different parts, called plates, which move horizontally over the asthenosphere. This idea was later fully adopted and developed by Alfred Wegener in 1912 written in a book "The Origin of Continents and Oceans". This whole idea of the movements of continent crustal plates was termed as continental drift. The continents might have drifted which was first put forwarded by Abraham Ortelius in 1596. Let us now discuss about the continental drift theory. The 'Continental Drift Theory' of Alfred Wegener suggests that there might have been horizontal displacement of the continental masses on a global scale. Wegener assumed that there was only one super-continent named **Pangaea** meaning 'all lands'. It was surrounded by another super-ocean called **Panthalassa**. The northern part of Pangaea was called **Angaraland** and the southern part was called **Gondwanaland**. The northern and southern parts were separated by geosyncline, a long narrow shallow sea called **Tethys**, in which sediments were deposited. The minerals constituents silica and aluminum covering continental crust moved over the oceanic crust, which consists of silica and magnesium minerals. As you have already studied in Unit 5, there are two types of crusts i) continental crust also known as SIAL and ii) oceanic crust called as SIMA. The deep sea floor formed as the upper surface of SIMA is largely composed of basalt. During the Carboniferous period, the super continent Pangaea got broken and started drifting over SIMA.

Although, it was not well defined what may be the condition of the continents during pre-Carboniferous period but the postulation of a Carboniferous Pangaea does not mean that Wegner disbelieved in pre-Carboniferous drift. Major events before this time are known with much less certainty whereas the distribution of plants and animals can largely be explained by movements, which have taken place since the Carboniferous period (Steers, 1961). The Pangaea was disrupted during subsequent periods and broken landmasses drifted away from each other and thus the present position of the continents and ocean basins became possible.

6.2.1 Energy Responsible for Continental Drift

According to Wegener the continents after breaking away from the Pangaea moved in two directions: (i) Equator ward movement; and (ii) Westward movement. Refer to the Fig. 6.1 which explains how the present continents were once united in a single super continent as Pangaea.

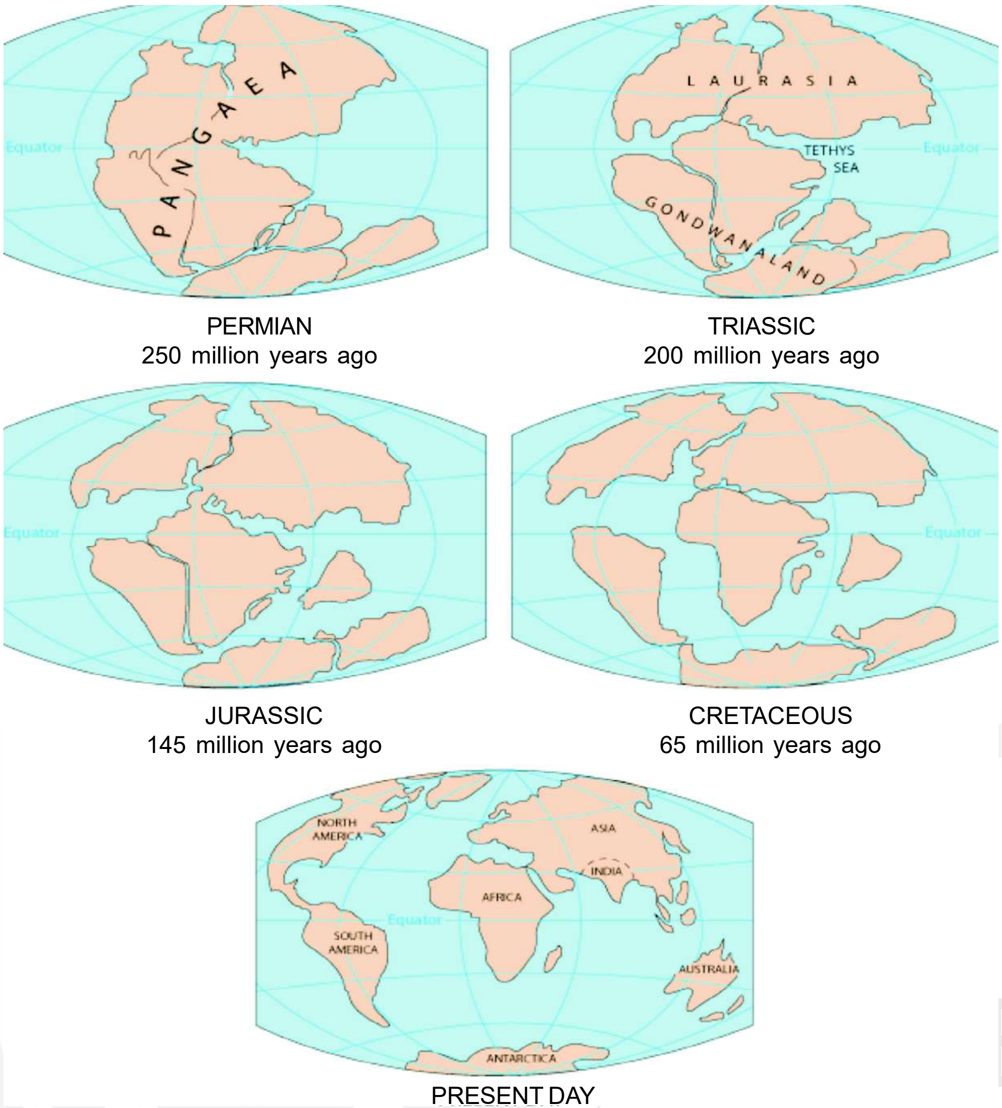

Fig. 6.1: Disruption of Pangaea and drifting of continents.
(*Source*: Illustration from USGS, 2012, URL: http:// pubs.usgs.gov)

The equator ward movement of southern part of broken Pangaea was mainly caused by gravitational differential force and force of buoyancy. The continental blocks are formed of lighter materials (SIAL) and are floating with friction on relatively denser oceanic crust (SIMA). Thus the equator ward movement of the continental blocks would depend on the relation of the centre of gravity and the centre of boundary of the floating continental mass. Generally, these two types of forces were operating on opposite directions. But because of the ellipsoidal form of the Earth, the resultant movements were directed toward the equator.

The westward movement of the continents was caused by the tidal force of the sun and the moon. According to Wegener, the maximum gravitational force of the sun and the moon was there when the moon was nearest to the Earth. The force dragged the SIAL over the interior of the Earth, SIMA towards the west.

This theory lacks the strength for explaining the potential force responsible for the movement of the continents. Such forces were extraordinarily small, but it is claimed that even these very small forces may be responsible to cause continental movement.

SAQ 1

What are Pangaea and Panthalassa?

Spend 5 mins

6.2.2 Mechanism of Continental Drift as Described by Holmes

It was Arthur Holmes, in 1919, who suggested the mechanism of continental drift in more scientific way. The theory says- (i) that the continents are drifting/ carried away by the **horizontal flow of hot magma** on which they sit, and (ii) the mantle is flowing because of its **convection current**. Holmes suggested that rocks in the interior of the Earth would buoyantly rise toward the surface from deep within the Earth when heated by radioactivity and then sink back down as they cool and become denser. He theorized that convection currents move through the mantle the same way heated air circulates through a room, and radically reshape the Earth's surface in the process. He proposed that upward convection might lift or even rupture the crust, that lateral movement could propel the crust sideways like a conveyor belt, and that is where convection turned downwards, the buoyant continents would crumple up and form mountains. Holmes also understood the importance of convection as a mechanism for loss of heat from the Earth and of cooling its deep interior. Not until after World War II, could scientists produce the hard evidence to support Holmes's fundamental concept. Holmes' theories have continued to be reinforced by new data from seismologists, mineral physicists and geochemists (Earth: Inside and out, 2000).

6.3 THEORIES OF MOUNTAIN BUILDING

Wegener also attempted to solve the problem of the origin of folded mountains of Tertiary period on the basis of his Continental Drift Theory. The frontal edges of westward drifting continental blocks of North and South America were crumpled and folded against the resistance of the rocks of the sea floor and thus the western cordilleras of the North and South America (Rockies, Andes and other mountains) were formed. Similarly, the Alpine ranges of Eurasia were folded due to equatorward movement of Eurasia and Africa together with Peninsular India. Here, Wegener postulated contradicting view points. According to Wegener, SIAL was floating upon SIMA without any friction and resistance but during the later part of his theory he pointed out that mountains were formed at the frontal edge of floating and drifting continental blocks due to friction and résistance offered by SIMA.

6.3.1 Geosynclinal Orogen Theory of Kober

Kober not only attempted to explain the origin of mountains on the basis of his Geosynclinal Theory but he also attempted to elaborate the various aspects of mountain building, e.g. formation of mountains, their geological history and evolution and development.

Kober's Geosynclinal Theory is based on the forces of the contraction produced by the cooling of the Earth. The force of contraction generated due to cooling of the rigid masses or forelands which squeeze buckle and fold the sediments into mountain ranges.

Base of the Theory

According to Kober, there were mobile zones of water in the places of present day mountains. He called those mobile zones of water as geosynclines or *Orogen*. The mobile zones of geocycline were surrounded by rigid masses which were termed by Kober as **'Kratogen'**. Kober identified six major periods of mountain building. Three mountain building periods, about which very little is known, are reported to have occurred during Pre-Cambrian period. Palaeozoic era saw two major mountain building periods-the Caledonian orogenesis was completed by the end of Silurian period and the Variscan orogeny was culminated in Permo-Carboniferous period. The last (6th) orogenic activity known as Alpine orogeny was completed during Tertiary epoch.

Mechanism of the Theory

According to him, the whole process of mountain building passes through three closely linked stages of ***lithogenesis, orogenesis*** and ***gliptogenesis***. The geosynclines are long and wide mobile zones of water which are bordered by rigid masses which have been named by Kober as ***forelands*** or ***kratogen***. These upstanding land masses or forelands are subjected to continuous erosion by fluvial processes and eroded materials are deposited in the geosynclines. This process of sediment deposition is called sedimentation. The ever-increasing weight of the deposited sediments due to gradual sedimentation put enormous pressure on the beds of geosynclines, resulting gradual subsidence of the beds of the geosynclines.

The second stage of mountain formation is called the stage of orogenesis. Both the forelands started moving towards each other because of horizontal movement cause by the force of contraction resulting from the cooling of the Earth. The compressive force generated by the movement of foreland causes contraction, squeezing and ultimately folding of sediments deposited in the geosyncline to form folded mountain ranges. If the compressive forces are normal and of the moderate intensity, only the marginal sediments of the

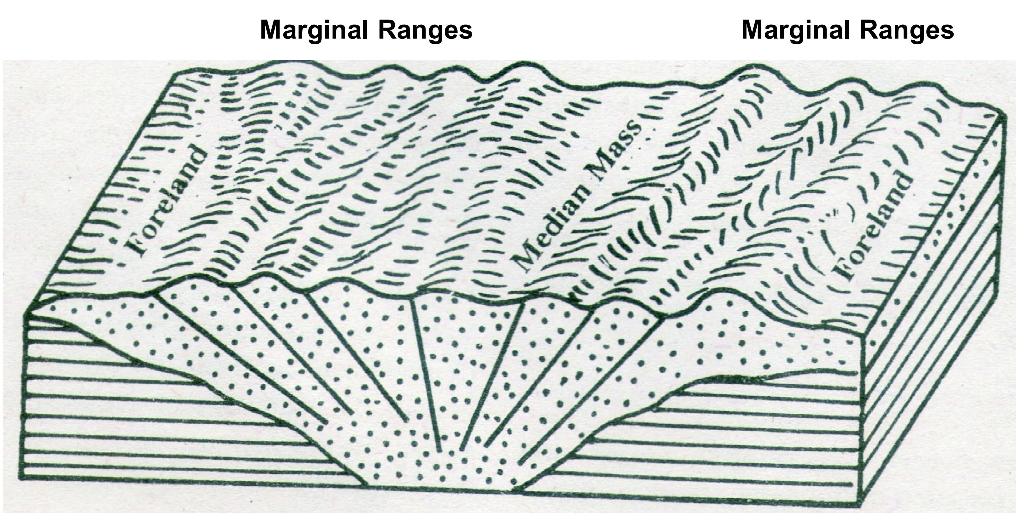

Fig. 6.2: Kober's Geosynclinal Theory of Mountain Building.
(*Source*: Savindra Singh, 2012, Physical Geography)

geosynclines are folded to form two marginal ranges and middle portion of the geosynclines remains unaffected by folding activity. This unfolded middle portion is called ***Zwischengebirge*** or median mass (Fig. 6.2). According to Kober, the Alpine mountain chain of Europe can be explained on the basis of median masses.

Third stage of mountain building is characterised by gradual rise of mountains and their denudation by fluvial and other processes. Continuous denudation result into gradually lowering of the height of mountains.

6.3.2 Convection Current Theory of Holmes

Arthur Holmes postulated his thermal convection current theory during 1928-29 to explain the intricate problems of the origin of major relief features of the Earth's surface. The driving force of mountain building implied by Arthur Holmes is provided by thermal convection current originating from deep within the Earth.

Base of the Theory

The origin of convective current within the Earth depends on the presence of radioactive elements in the rocks. The disintegration of radioactive elements generates huge heat which melts the rock as magma and thus causes convection current. According to Holmes, concentration of radioactive elements in the crust is also there but the generated temperature is not so high because there is gradual loss of heat through conduction and radiation from the upper surface at the rate of 60 calories per square centimeter per year. Though there is very low concentration of radioactive elements in the substratum but the gradual accumulation of heat produced by the radioactive elements cause convective currents. Ascending convective current originates under the crust near the equator because of greater thickness of crust, whereas descending convective currents are originated under the polar crust because of its shallow depth.

Mechanism of the Theory

The convective currents are divided into two major groups on the basis of their location i) convective currents of rising columns; and ii) convective currents of falling columns.

According to Holmes, the equatorial crust was stretched and ruptured due to divergence of rising convective currents which carried the ruptured crustal block towards the north and south and a syncline was created as Tethys Sea between two blocks. This phase is called **Opening of Tethys**. Again two sets of convergent or downward moving currents pull Laurasia and Gondowanaland towards each other and thus Tethys was compressed and folded into Alpine mountains including Himalyas. This phase is called **Closing of Tethys**. Geosynclines are formed due to subsidence of crustal blocks mainly continental slabs due to compressive force generated by convergent convective current moving laterally together under continental and oceanic crust. According to Holmes, the cyclic pattern of convective current and related mountain building pass through three phases or stages.

In the first stage, the rising convective current of two centers converge under the continental slabs and thus form geosynclines due to compression coming from the convergence of two sets of lateral currents. As the sediments are pressed downward into geosynclines, these go further downward and are intensely heated and metamorphosed. Metamorphism of sediment causes rise in their density which further cause downward movement of the metamorphosed materials. This stage is called **Lithogenesis**.

The second stage is marked by phenomenal increase in the velocity of convective currents. The main cause for this convective current is the downward movement of cold materials in the falling column and upward movement of hot materials in the rising columns of convective currents. The high velocity convergent convective current buckle geosyncline sediments and thus initiate the process of mountain building. This stage, thus, is called the stage of **Orogenesis** (Fig. 6.3).

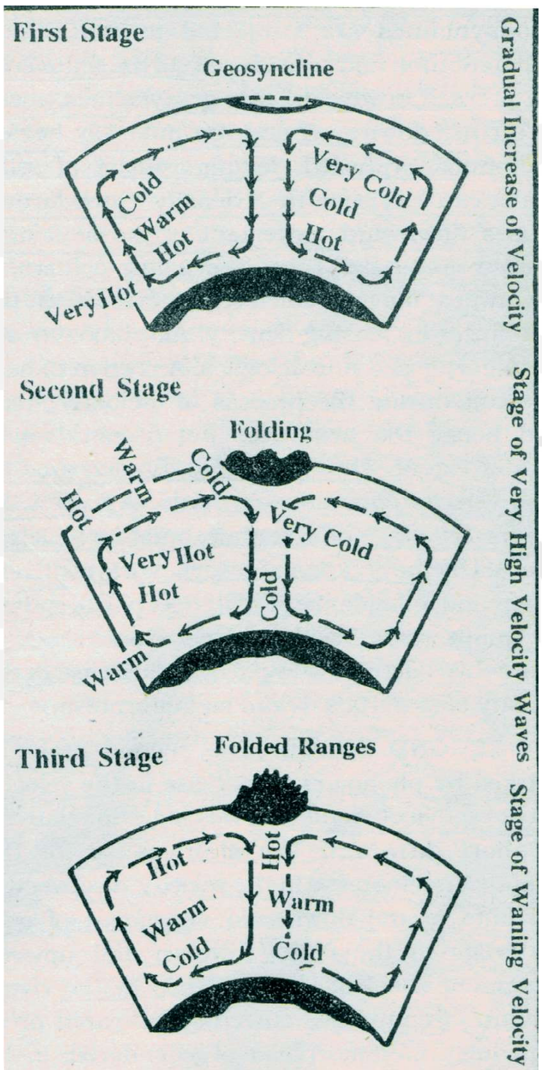

Fig. 6.3: Successive stage of Thermal Convective Currents under the Crust and Mountain Building.
(*Source*: Savindra Singh, Physical Geography)

The third stage is characterised by waning phase of thermal convective currents due to incoming hot materials in the falling column and upward movement of colder materials in the rising columns. The termination of the mechanism of convective current yields several results, e.g. (i) the materials of the falling columns start rising because of decrease in the pressure at the top of the falling column due to the end of deposition of materials. This mechanism causes further rise in the mountains. (ii) the metamorphosed rock (Eclogite) with increased density being heavier depressed downward and gets melted due to immense heat and thus it expands. This expansion in the volume of molten Eclogite causes further rise in the mountains. This stage is known as the stage of **Gliptogenesis**.

6.3.3 Plate Tectonic Theory and Mountain Building

Mountain building can be explained by the theory of Plate Tectonics. The theory tells that the result of plate convergence and its involvement in sedimentation, deformation, igneous activities, erosion and isostatic balance leads to formation of mountains. There are four different types of plate convergence (Fig 6.4):

1) Convergence of two oceanic plates,
2) Convergence of oceanic and continental plates,
3) Convergence of two continental plates and
4) Continent- Arc collision

Convergence of two Oceanic Plates and Mountain Building

Two oceanic plates may converge at the destructive plate boundary where one oceanic plate, which is heavier and denser compared to other oceanic plate, subducts in the trench beneath the lighter low density plate. The resultant compression leads to the formation of island festoons and Island-arcs. The best examples of this type are the Japanese Islands and Philippines Island. The ocean crust, along with its sediments, is thrust beneath and the rocks on the continental side of the trench are metamorphosed under high pressure condition. The molten magma rises up and forms a pile of volcanic rocks. The continuous pilling of volcanic rocks raises them above the ocean floor are finally exposes them above the sea level to form Island arcs.

Convergence of two Continental Plates and Mountain Building

When convergence and collision takes place, the continental plate having denser materials is subducted under the continental plate having relatively lighter materials. This brings about huge lateral compression in the sediment deposited in the geosyncline situated between two converging continental plates as well as the sediment laying on the margins of the continents. This compressional force is squeezed the fold and further deforms the sediments. Due to this, the folded mountains are formed.

The Alpine -Himalayan mountain system provides the best example in the formation of mountains by continent-continent collision. In the Mesozoic era there existed a long geosyncline, known as the Tethys Sea, between Lauratia in the north and Gondowana land in the south. After the Mesozoic era, Gondwanaland started breaking up and Deccan shield started moving northward at the approximate rate of 16 cm per year. The result of converge of these two land masses was that the Tethys sea became narrower and ultimately closed. The marine sediments and the crust of the Tethys seas suffered from compression

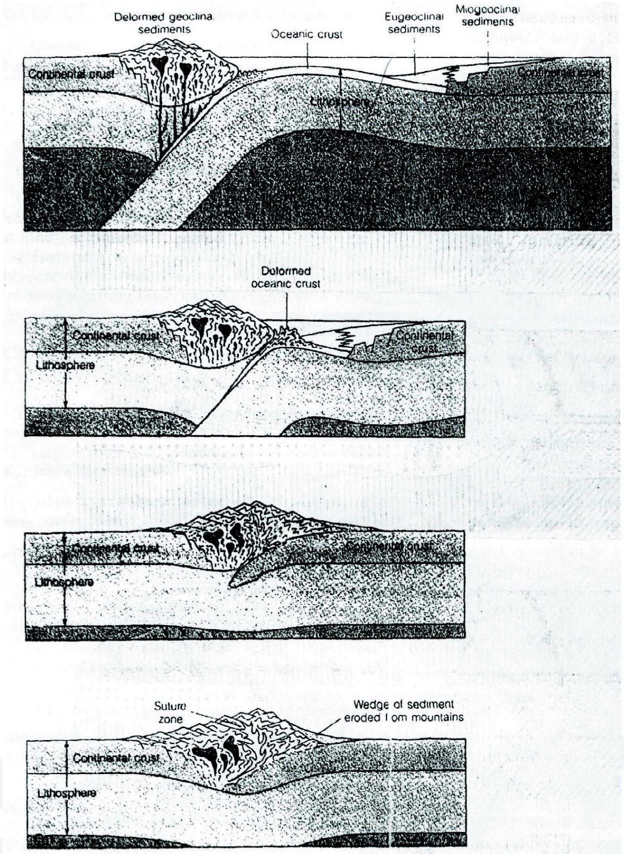

Fig. 6.4: Continent-Continent Collision and Complex Mountain Range.

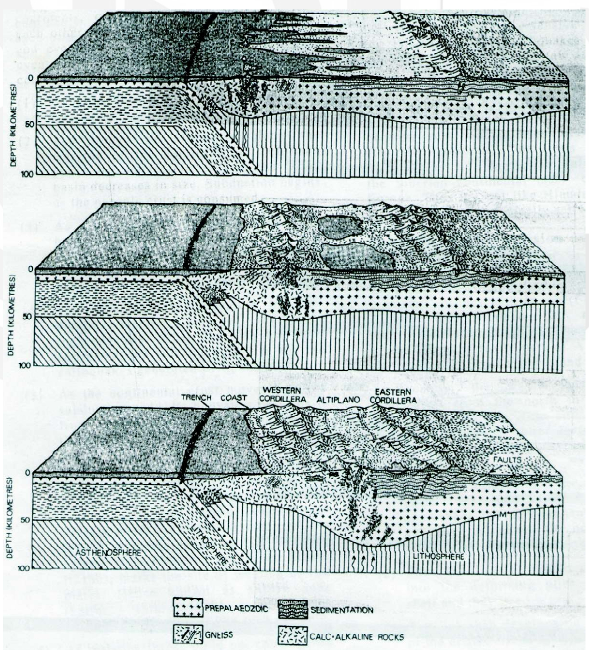

Fig. 6.5: Ocean-Continent and Mountain Building.

as a result of convergence of the two continental plates and these led to the folding of the rock strata and the Himalayas were born.

Convergence of Continental-Oceanic Plates and Mountain Building

Continent-ocean collision is the most prevalent of all the collisions as most of the mountains encircling the American coast of the Pacific Ocean formed by this type of collision. Convergence and collision generate intense compression force and the sediment deposited on the continental margin is squeezed and folded. The Rocky Mountains of western North America and the Andes of western South America are the best examples of mountain building by continent- ocean plate collision.

Continent - Arc collision

Continent-Arc collision occurs when a continental plate collides with an arc. This kind of situation exists in New Guinea where the mountains were formed about 20 million years ago due to convergence of the Islands arc lying to the north edge of Australia. As such, the northern part of the Island is an old Island arc while the southern part of the Island is a part of Australia.

Spend 5 mins

SAQ 2

What are major theories of mountain building?

6.4 PLATE TECTONIC THEORY

Let us now study the modern theory of **Plate Tectonics**. The concept of plate tectonics may be considered as a revival of the Continental Drift Theory. The Plate Tectonics theory tells that the Earth's outer layer consists of several rigid lithospheric plates consisting of continental (SIAL) as well as oceanic crust (SIMA) and the uppermost part of the mantle. Plates are defined as broad rigid segments of lithosphere consisting of continental and oceanic crust including the rigid upper part of upper mantle which floats on the underlying hot viscous asthenosphere. The rigid continental plates are 100-150 km thick where as the thickness of the oceanic crust ranges from 6 to 100 km. These plates are unable to deform except in response to very strong or prolonged forces. The plates are drifting or moving relative to each other and in the process huge pressure is generated along the margins or boundaries of the plates which are responsible for almost all the major geomorphic and tectonic features on the Earth's crust. The present shape and distribution of the continents and oceans can be described with seven major and over twenty minor lithospheric plates. The major plates are: African Plate, Pacific Plate, North American Plate, Antarctic Plate, Eurasian Plate, Indo-Australian Plate and South American Plate. The important other minor plates are: Cocos Plate, Filipino Plate, Juan de Fuca Plate, Caribbean Plate, Scotia Plate, Nazca Plate, Arabian Plate, etc. Refer to the figure 6.6, which shows the distribution of major and minor plates of the Earth.

You will understand that there are mainly three types of identified plate boundaries and margins: divergent or constructive plate boundaries, convergent or destructive plate boundaries, and transform or lateral plate boundaries. The divergent plate boundaries are mostly seen in the deep sea along the **mid oceanic ridges** and the process is known as "**sea floor spreading**". In this sea floor spreading process new oceanic crust is constructed.

i) **Divergent or constructive plate boundaries**: Two plates moving in opposite direction is called divergence. So, it is a zone of divergence characterized by continuous upwelling of mountain material resulting into the formation of new oceanic crust.

ii) **Convergent or destructive plate boundaries**: The boundary of two or more crustal blocks or plates is known as convergent plate boundary. Here the plates are dragged down through trenches along subduction zones into the mantle. The denser crustal plate goes down the lighter one and melts or gets destroyed into the mantle. The convergent plate boundaries can further be divided into three types:

a) Ocean - Ocean convergent plate boundary is marked by the formation of island arcs. Example of this type of plate boundary is seen along the Japan in the Pacific Ocean.

b) Ocean - Continent convergent plate boundary is seen all along the Pacific Ocean boundary. This is marked by the generation of volcanic arcs on the continents. Due to this volcanic activity, the Pacific Ocean boundary is named as 'Ring of Fire'.

c) Continent - Continent convergent plate boundary is seen between the Indian Plate (forming Indian sub-continent) and Eurasia Plate (forming Europe and Asia). The zone is marked by the development of huge mountain ranges, e.g., Himalaya.

iii) **Transform or lateral plate boundaries**: These are formed where two crustal plates slide past one another. In this case plates are neither created nor destroyed, but severe Earthquake is experienced.

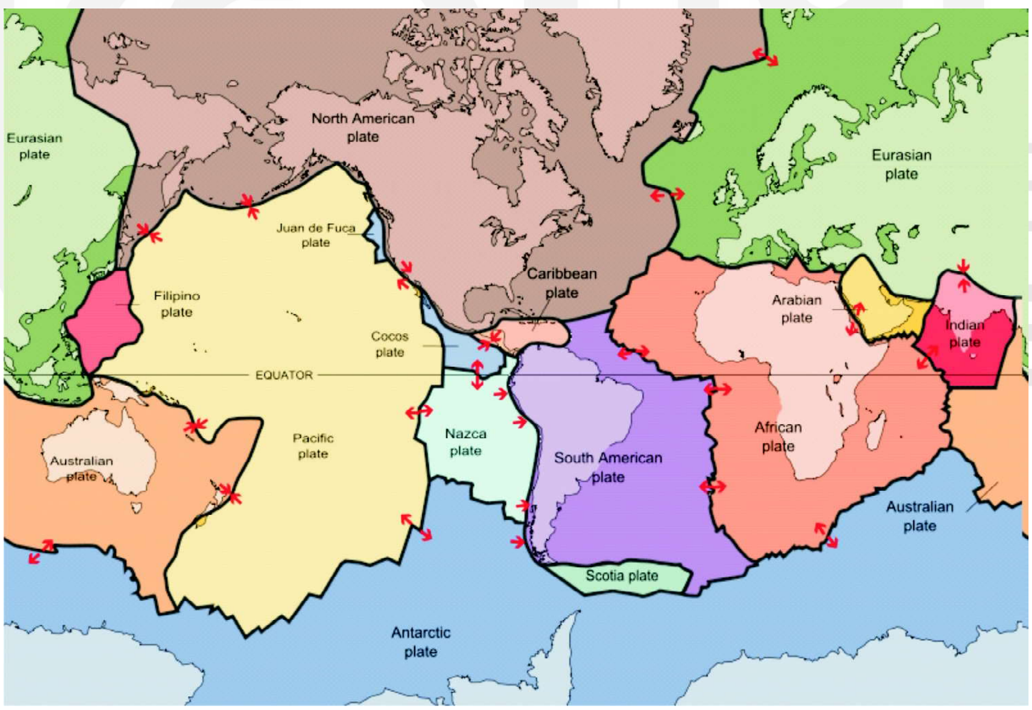

Fig. 6.6: Distribution of Plates of the Earth
(*Source*: http://www.indiana.edu/~g105lab/1425chap13.htm)

6.4.1 Mechanism of Plate Movement

There are various forces that act upon the plates to make them move. Three classes of possible mechanisms are namely convection current, slab pull, and ridge push. Now let us discuss about all three stages of mechanism in detail.

1. Convection Current

Convection current involves the whole mantle having large amount of radio activity which causes huge heat concentration in the mantle. As the current ascend from below, they diverge and spread laterally along the lower part of the plates. Convection current causes the lithosphere to split and the plate may move laterally along the direction of the convection current. The high heat flow along the mid-oceanic ridges provides evidence to this process. Convectional current is only found in Asthenosphere where the size of convection cells are said to be smaller. The other type of mantle convection involves jet like plumes are called mantle plume of low density materials from the core mantle boundary. As the plume reaches the lithosphere, it spreads out laterally doming surfacial zones of the Earth and moving them along in the direction of radial flow. Mantle plumes are thought to be responsible for the initial breaking of the Pangaea. Refer to Fig. 6.7, which illustrates the mechanism responsible for various plate movements.

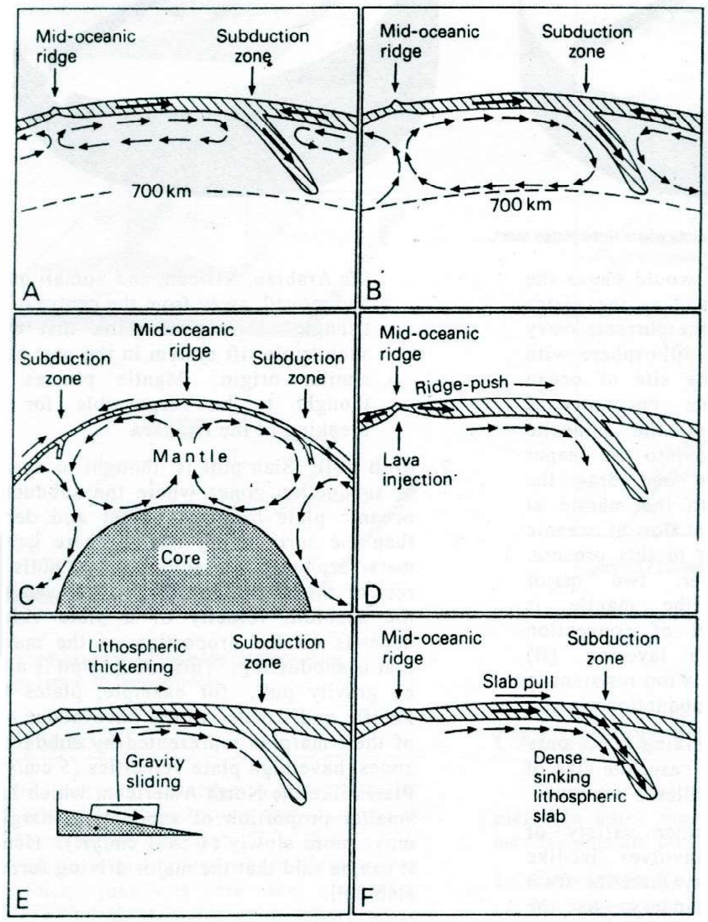

Fig 6.7: Mechanism of Plate Movements.

2. Slab Pull

In the convergent boundary, the denser plate slides down the lighter plate causing subduction. The subducted portion of the plate causes slab pull. This force accounts for most of the overall forces acting on plate tectonics. Besides this, the 'ridge push' force adds about 5 to 10 per cent of the overall force for plate movement.

3. Ridge Push

The magma coming out of the mid-oceanic ridges causes the 'Ridge Push'. Before the nineties, this force was considered to be the leading contributor for moving the plates around the Earth. There have been two main models of ridge push proposed by Earth scientists, namely gravity wedging and gravity sliding. We know that mid-oceanic ridges rise thousands of metres above the ocean floor. New sea floor or oceanic plate is created along the mid-oceanic ridges, it is very hot and thin as well as much higher in elevation than the abyssal plains and trenches. The newly created plate will effectively slide down the slope and try to move towards the subduction zone causing sea floor spreading. The oceanic plate gets thicker and denser as it progresses away from the spreading centre, the ridge push force increases towards the subduction zone (Fig 6.7).

With the advancement of the Plate Tectonic Theory, the Continental Drift Theory has got enormous improvement. Continental Drift Theory says that the continents are in motion while according to plate tectonics not only the continents but the sea floor are also spreading. The generation of new oceanic crust at mid-oceanic ridges seems to be compensated by the consumption of old oceanic crust along subduction zones. So, the crustal block is to move outward from the mid-oceanic ridges.

According to Plate Tectonic Theory, it is not SIAL that is in motion, floating over SIMA but the lithospheric block (Plate) over the asthenosphere. The Continental Drift Theory talked about the gravitational and tidal forces as the chief mechanism for the movement of the continents which were largely inadequate while Plate Tectonic Theory gave five different mechanisms for the movement of the continents. The theory explains almost every aspects on the geo-tectonic features of the Earth as well as the continental drift hypothesis. Therefore, we can infer that the Plate Tectonic Theory is the latest and modern concept of Continental Drift Theory.

SAQ 3

What are three classes of mechanism of plate movement?

Spend 5 mins

6.4.2 Plate Tectonic Theory: Mountain Building, Volcanism, Earthquake and Tsunamis

The theory of plate tectonics explains why different types of Earth movements, epirogenic and orogenic takes place which involves the processes of mountain building, Earthquake, volcanism and tsunamis, etc.

Plate Tectonics and Mountain Building

All the great mountain ranges of the world can be explained with the plate tectonic theory. Two plates result huge compression along their convergent plate boundary, which finally leads to formation of folded mountains. The Rockies, the Andes, the Alpine Himalayan belt, etc. are active folded mountains formed in Tertiary Period. Other mountains, namely Applachians in USA and Urals in Russia are zones where plate tectonics was active earlier and these mountains represent the zone of welding between two different plates.

Plate Tectonics and Volcanism

The worldwide distribution of volcanoes and their occurrence at specific place is related to different types of plate boundaries and their movements. Volcanic activity will take place when two plates converge as evident with the Pacific and the Eurasian plate; and the Nazca and the South American plates. The subduction of the plate is also resulted from the activity of melting and volcanism. It is proved with the portion of the molten Pacific and Nazca is thrown by the volcanoes of Mayon and Luzon in Philippines; Misti in Peru; Chimboroza and Cotopaxi in Andes, etc. whereas subducted African plate releases fire in Iran, Caucasus and Italy. Divergence leads to quite type of basaltic eruption which is seen along all the mid-oceanic ridges. There are two types of associations of volcanic activity with plate tectonics: plate margin volcanism and intra-plate volcanism.

> The 2004 Indian Ocean Earthquake and resultant Tsunami was due to an under-sea mega-thrust Earthquake that occurred at 00:58:53 UTC on Sunday, 26 December 2004, with an epicentre off the west coast of Sumatra, Indonesia. The Tsunami killed over 230,000 people in fourteen countries.

There are two types of plate boundaries where volcanic activities take place. i.e. constructive or divergent plate boundary and destructive margin or convergent plate boundary. Volcanism in central parts of plates beyond constructive and destructive margins is not common, but it can be explained as the surface expression of local thermal variation or hot spots in the mantle.

Plate Tectonics and Earthquake

Nature and movements of plate boundaries are responsible for the major Earthquakes. Frequent Earthquakes take place at the diverging as well as converging plate boundaries. Mid-oceanic ridges are common manifestation of the divergent plate margins. The oceanic ridges are offsets by many transform faults. Movement along this transform faults generate Earthquakes which have a shallow foci. Convergent plate boundaries are characterized by subduction of one plate under another and the zone is characterized by most widespread and intense Earthquake. Tensional Earthquake occurs on the oceanic side of the trench, where normal faulting occurs form tensional stresses generated by the initial bending of the plates. At intermediate depths, Earthquakes are caused by extension or compression, depending on the pacific characteristics of seduction zone.

Plate Tectonics and Tsunami

The movements of under-sea convergence or destructive plate margins are instigated to the creation of tsunamis. Tsunami occurs when there is rapid vertical movement in the oceanic crust that results in a displacement (rise or drop) in the overlying water. Due to this displacement in the ocean floor that can set off a tsunami. You may know that Earthquake is the result of plate tectonics. Tsunamis are the result of an Earthquake event which displaces sea water. Instead, most tsunamis tend to act like tide, with a rise in sea level that surges onto the coast with very strong currents. However, unlike a rising tide, there can be a rapid retreat of sea level prior to the huge surge i.e. tsunami (USGS, 2005). A tsunami is a series of ocean waves generated by sudden displacements in the sea floor, landslides, or volcanic activity. In the deep ocean, the tsunami wave may only be a few inches high. The tsunami wave may come gently ashore or may increase in height to become a fast moving wall of turbulent water several meters high (http://www.tsunami.noaa.gov).

SAQ 4

Spend 5 mins

Try to find relationship between volcanism and plate boundary?

6.4.3 Evidences of Continental Drift and Underlying Plate Tectonics

Evidences for continental drift and the underlying plate tectonics are as follows:

1. Most of the continents/shapes look like they were separated from a single great continent (Pangaea). They exist as pieces of a jig-saw puzzle. For example, have a look at the Figure 6.8, the shape of the east coast of North and South America matches with the shape of the west coast of Africa and Europe.

2. Geologically, both the coasts of Atlantic are also identical. The geological structure of the eastern coast of South America and western coast of Africa are more or less similar.

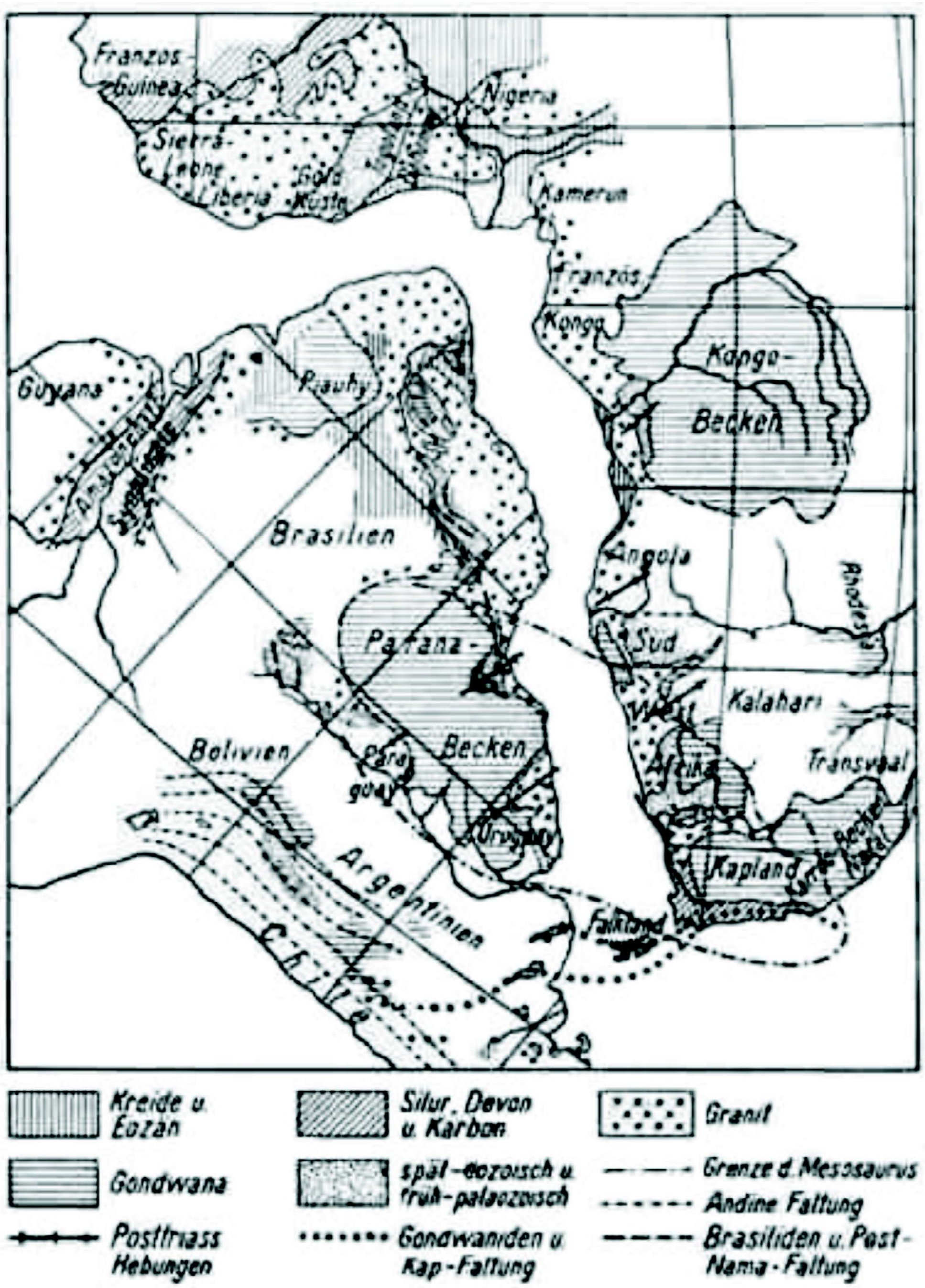

Fig. 6.8: Match of geology between eastern South America and western Africa
(*Source*: http://www.scientus.org/Wegener-Continental-Drift.html)

3. Many fossil comparisons along the edges of continents look like they fit together, which suggests species' similarities of that would only make sense, if the two continents were joined together at some point in the past.
4. There is a large amount of seismic, volcanic, and geothermal activities along the conjectured plate boundaries. The concentration is striking, and indeed this plot serves to define the plate boundaries extremely well.
5. There are ridges, such as the Mid-Atlantic Ridge where plates are separating that are produced by upwelling lava between the plates. Likewise, there are mountain ranges being formed where plates are pushing against each other (e.g., the Himalaya, which is still growing).
6. The upwelling of lava or magma in the mid-oceanic ridge forms a new crustal plate. So, it is certain that they are young in geological age. This has been scientifically proven.
7. Evidences for the disintegration of Pangaea in several crustal plates and their movement as continents are now extensive. Similar plant and animal fossils are found around different continental shores, suggesting that they are certainly joined together. The fossils of Mesosaurus, a freshwater reptile, found both in Brazil and South Africa are one of the important examples. Another is the discovery of fossils of the land reptile known as Lystrosaurus from rocks of the same age from locations in South America, Africa, and Antarctica (Fig. 6.9). There are also living evidences, may be the same animals being found on two continents. Some Earthworm families are also found in South America and Africa.

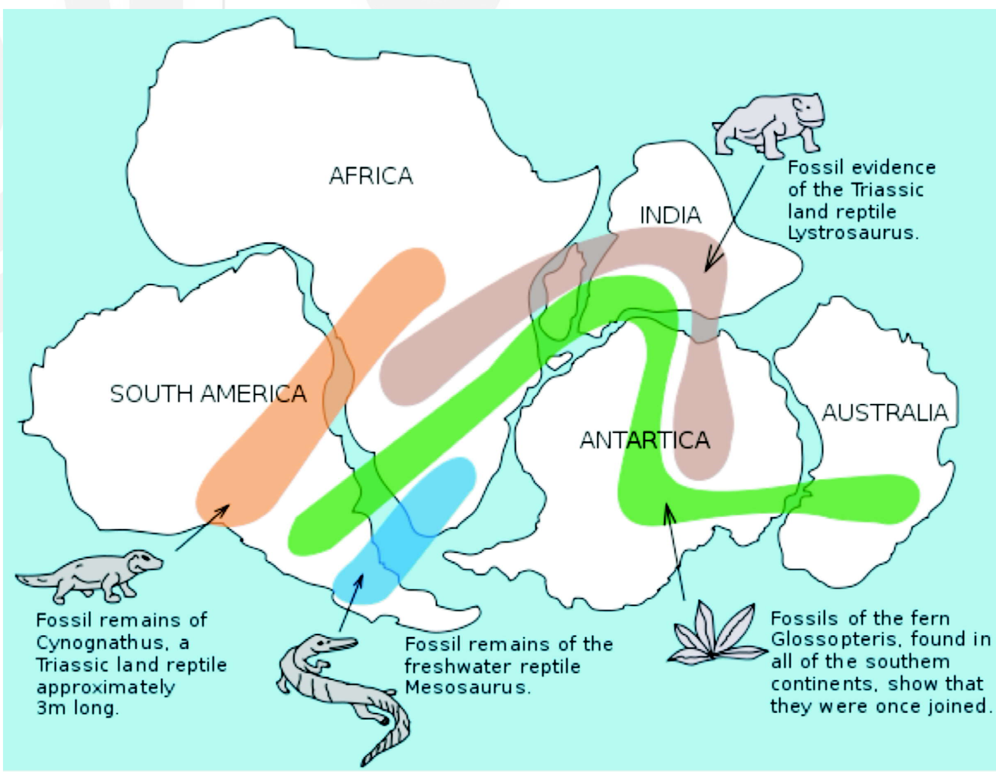

Fig. 6.9: Fossil Pattern Distribution of Fossil Pattern in Different Continents
Source: USGS (http://en.wikipedia.org).

6. 5 SUMMARY

Thus, in this unit, you have studied and learned the following key points and theories as follows:

- Wegener proposed the continental drift theory which suggests that the continental masses get displaced in horizontal manner on a global scale. He named Pangaea for the super-continent Panthalassa for the surrounded super-ocean. The Angaraland and Gondwanaland separated by a long narrow shallow sea which he called Tethys.
- There are two types of crusts i) continental crust (SIAL) and ii) oceanic crust (SIMA). The deep sea floor formed as the upper surface of SIMA. It was assumed that the super continent Pangaea got broken and started drifting over SIMA.
- According to the Wegener, the continents are moving by the action of tidal force of the sun and the moon. When the moon is nearest to the Earth then the maximum gravitational force occur between the sun and the moon. It results for moving of the SIAL over the interior of the Earth.This theory lacks the strength for explaining the potential force responsible for the movement of the continents.
- Plate tectonic theory explains that the crust is divided into various lithospheric plates which move in different directions on the Earth. There are three types of plate boundaries namely divergent (plates move in opposite direction), convergent (two plates come together) and transform (slide past one another). The mechanism involved in the plate tectonic theory is thought to be convection current, slab pull, and ridge push.
- You have learnt about the mountain building theories with detailed explanation of features of Geosyncline, convectional currents and plate movements. You have also learnt about the views of different geographers on mountain building like Kober's Geosyncline Theory and Convection Current Theory of Arthur Holms.

You will further study in detail about endogenetic and exogenetic forces. Endogenetic forces originated from beneath of the Earth and are responsible for creation of various topographical features. Whereas, exogenetic processes are responsible for landscape sculpture.

6.6 TERMINAL QUESTIONS

1. Explain elaborately theory of continental drift as defined by Wegner.
2. Briefly present the geosynclinal orogen Theory of Kober.
3. Explain the mountain building theory of Holmes.
4. Discuss the Plate Tectonic Theory and mountain building, earthquakes, volcanism and tsunamis.

6. 7 ANSWERS

Self-Assessment Questions

1. Wegner assumed that there was only one super-continent before the present form and shape of the continents that he called Pangaea whereas the super-continent Pangaea was surrounded by a super-ocean called Panthalassa.
2. The major theories of mountain building are:

   Mountain Building Theory based on Continental Drift Theory of Wegener;

Geosynclinal Orogen Theory of Kober; Convection Current Theory of Holmes; and Mountain Building according to Plate Tectonics Theory.

3. Three classes of mechanism of plate movements are:
   i) Convection Current
   ii) Slab Pull
   iii) Ridge Push
4. Plate boundary and volcanism are closely associated as the majority of volcanoes are situated mainly at plate boundaries

Terminal Questions

1. Refer to Sec. 6.2.
2. Kober attempted to explain the origin of the mountains on the basis of his Geosynclinal Theory and elaborated various aspects of mountain building e.g. formation of mountains, their geological history and evolution and development. Further refer to Sub-sec. 6.3.1.
3. Refer to Sec. 6.3.2
4. Refer to Sec. 6.4

6. 8 REFERENCES/FURTHER READING

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UNIT 7

ENDOGENETIC FORCES

Structure

7.1 INTRODUCTION

In Units 5 and 6 of this block, you have learnt about the lithosphere and materials of the Earth's crust. You now know the origin of continents and ocean basins, movement of plates, and also the composition of the Earth's crust. An important feature of the Earth's crust is that it is not static. The movement of different components of the Earth's crust is one of the causes for generating forces in the interior of the Earth. These forces are known as endogenetic forces. Although the endogenetic forces are active inside the Earth, some of its consequences are observed on the Earth's surface. For example, the relief and other topographical features of the Earth such as mountains, plateaus, cliffs, valleys and ravines are formed due to endogenetic forces. It is, therefore, important for you to learn about the endogenetic forces.

In Section 7.2 of this Unit, you will study how endogenetic forces are generated beneath the Earth's surface and cause to relative movements of various components of the Earth's crust. You will also study how different kinds of endogenetic forces are classified into two groups namely diastrophic forces and sudden forces. In Sec. 7.3, you will learn the concept of diastrophic forces which are generated deep within the crust but they cause long-term changes in the topography of the Earth such as formation of mountains and valleys. In Sec. 7.4 and 7.5, you will study the origin of sudden forces in the Earth's crust and its consequences. An important consequence of sudden forces is what we call volcanoes about which you will study in Sec. 7.4. In this section, you will also study the nature, types and distribution of volcanoes. In Sec. 7.5, you will learn about the other important consequence of sudden forces called Earthquakes. You will also learn about the origin of Earthquake, Earthquake waves, magnitude and intensity of an Earthquake. The Earth's relief and topography is caused by both endogenetic forces and exogenetic processes. Exogenetic processes originate in the Earth's atmosphere and continuously alter the major relief features created by endogenetic forces. You will study about exogenetic processes in the next Units of this Block.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define and classify endogenetic forces;
- describe how diastrophic forces includes epeirogenic and orogenic movements affect the crust;
- describe the nature and types of volcanoes and their distribution; and
- explain the origin, magnitude and intensity of an Earthquake.

7.2 ENDOGENETIC FORCES: BASICS AND CLASSIFICATION

We generally observe numerous topographical features such as mountains, valleys, plains etc., on the Earth's surface. Would you like to know how did they come into existence? Did these features exist when the planet Earth was formed or did they come into existence over a period of time? The topographic features of the Earth have evolved over time and have been mainly caused due to forces active in the Earth's crust. These forces are called endogenetic forces.

The endogenetic forces occurring beneath the surface of the Earth very often change the Earth's topography through the process of creation, destruction, recreation, and maintenance of geomaterials (materials in the Earth crust). These forces produce various types of vertical irregularities on the surface of the Earth in the form of mountains, ridges, plateaus, valleys, and plains, etc. In addition, volcanic activity and Earthquake events are also the expressions of endogenetic forces called sudden forces. As the name suggests, the sudden forces arise due to sudden movements of the interior components of the Earth. Although it is generally believed that the movement of the Earth's interior components is the major cause of endogenetic forces, the precise cause of endogenetic forces is not yet known. These forces are active in the interior of the Earth about which our knowledge is still limited. In fact, some Earth scientists assume that endogenetic forces are related to thermal conditions in the Earth's interior. The variation in temperature in different regions of the Earth's interior may cause contraction and expansion of rocks, and thereby generating endogenetic forces. In the present Unit, our major concern will be to discuss the effect of endogenetic forces on shaping the Earth's topography.

The endogenetic forces are classified into two types, namely diastrophic forces and sudden forces. Refer to Fig. 7.1, which depicts the classification of endogenetic forces as well as the consequences of these forces on the Earth's topography and relief features. The diastrophic forces can cause a component of the Earth's interior to move vertically or horizontally. The vertical movement is called epeirogenic movement and horizontal movement is called orogenic movement. Whereas sudden forces occur due to sudden and rapid movements that results a massive destruction in the interior of the Earth.

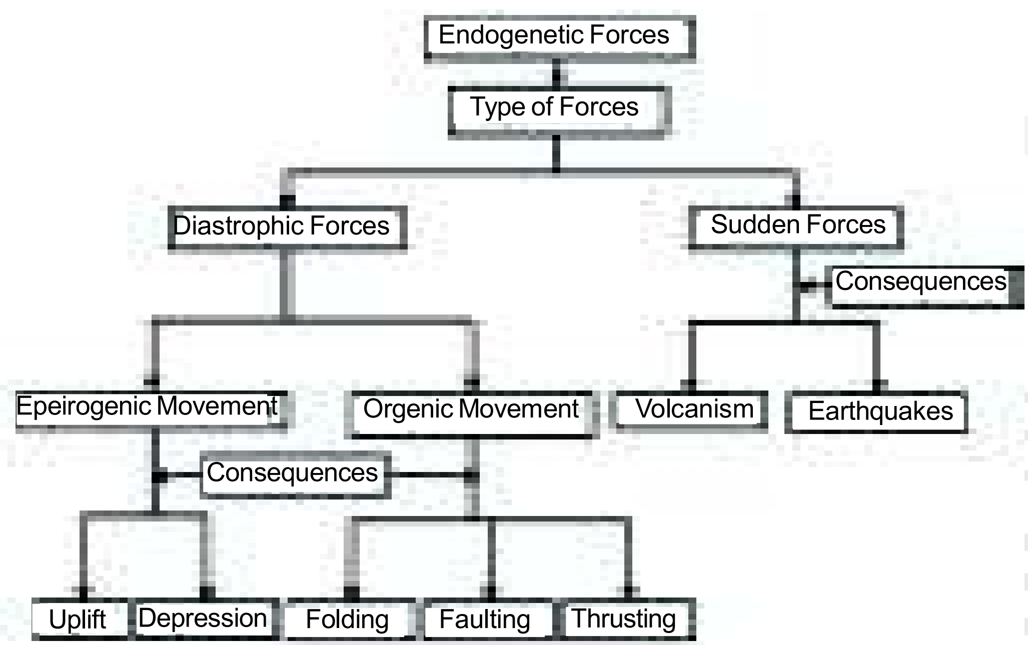

Fig. 7.1: Major types of endogenetic forces and their consequences in the Earth's crust.

Have you ever experienced the consequences caused by these endogenetic forces? If the answer is yes, then it might be the result of sudden forces; if it's no then it could be the effect of diastrophic forces. These are not even visible after thousands and millions of years. We all know that the change is the law of nature. Geologically, some changes are long period changes and are unable to recognize during our life time because they operate very slowly. On the other hand, short term changes can be identified within few seconds to hours, for example volcanic eruptions and Earthquakes. Probably, some of you might have directly experienced the consequences of volcanic and Earthquake activities or you must have read about these in news papers, or seen it on television or other sources. How do endogenetic forces affect the Earth's surface, and how do we identify the effects of these forces? To understand the importance and consequences of these endogenetic forces, you should study the following sections.

SAQ 1

Spend 5 mins

What are endogenetic forces and how are they caused?

7.3 DIASTROPHIC FORCES

You have already learnt that the diastrophic forces are a type of endogenetic forces and originate at some depth within the Earth's crust. Diastrophic forces include both vertical and horizontal movements. These are constructive forces, operate very slowly and are responsible for the formation of primary landforms such as mountain peaks, plateaus, valleys, plains, etc. Diastrophic forces can be classified into two types; (a) **epeirogenic movements** and (b) **orogenic movements**. Let us learn about the epeirogenic movements which are categorized under diastrophic forces.

7.3.1 Epeirogenic Movements

Epeirogeny means 'mainland'. The term introduced by Clarence Dutton, American Geologist in 1890 from the Greek 'epeiros'.

It is important for us to understand the properties of the crust since the movements mainly affect the Earth's crust. Crust is the very thin outermost layer of the Earth. It consists of oceanic crust and continental crust. The thickness of oceanic crust ranges between 5 and 7 kilometers which is substantially shallower than continental crust. The continental crust covers average distance of 35-40 kms, and in some places it extends upto 70 kms. Figure 7.2 represents the crust covered by the continents as well as oceans. The continental crust comprises of low-density silicate minerals such as aluminum and potassium, whereas, the oceanic crust is rich in iron; therefore it is denser than continental crust. The continental crust is thicker than oceanic crust but has a lower density. Because of this property, continents float on mantle just like icebergs that float on the ocean. The deepest and inaccessible zone of the Earth is called core which is surrounded by a shell silicate minerals-rich rock called as the mantle.

You may like to read Unit 5 for detailed information on lithosphere which consists of crust, mantle and core.

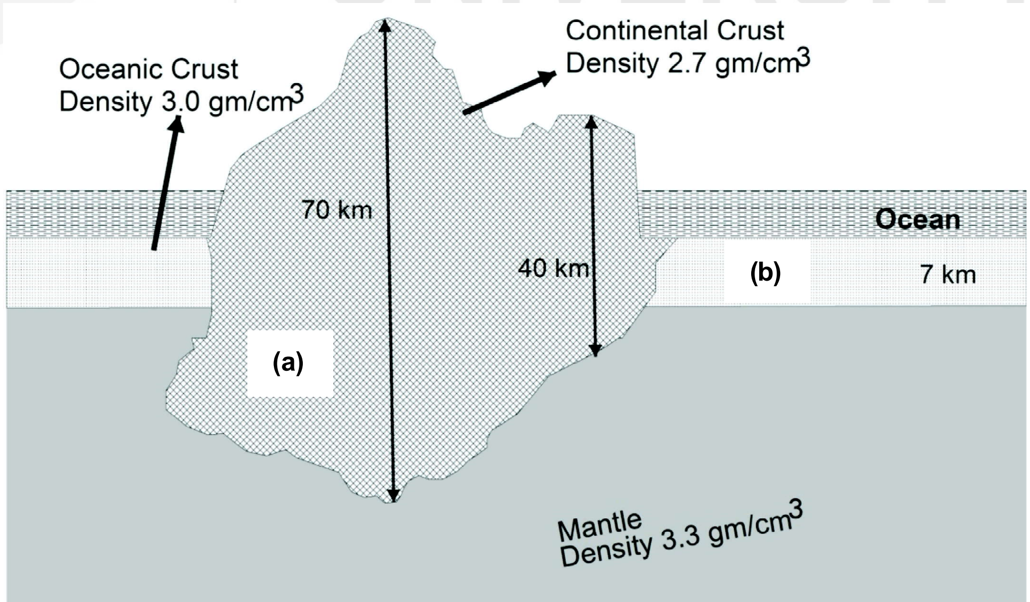

Fig. 7.2: Zones of the Earth's crust a) continents stand high due to continental crust which is thick and less in weight; b) oceans are low because oceanic crust is very thin and dense.

Let us now discuss about epeirogenic movements. These movements cause upliftment and subsidence of continental crust through upward and downward movements, respectively. Both upward and downward movements are in fact vertical movements caused by a set of forces acting along the Earth's radius. These affect the broad regions of the crust without causing significant folding or faulting. Epeirogenic movements are also known as continent building movements as these movements affect the large scale land masses.

You may like to read Unit 6 for the detailed information on plate tectonics and mountain building processes.

You may now understand that uplift is a part of vertical movement, and it causes the upliftment of whole continent or a part of it. Due to this activity, part of continents may rise (uplift) or sink (subsidence). The upliftment of a coastal land of the continents is called emergence. Some important examples of upliftment are Deccan Plateau, upliftment of submerged coastal Florida and West Coast Islands. Downward movement causes the subsidence of continental land area, and the land area near the coast submerged under the sea is called submergence. Due to the subsidence, Andaman and Nicobar islands are separated from Arakan Coast. Now we will discuss about orogenic movements.

7.3.2 Orogenic Movements

Do you know how the mountain belts are formed? You have to study the concept of plate tectonics and mountain building theories for better understanding of causes in the formation of mountains which has been explained in the previous units. According to plate tectonics theory, the uppermost mantle along with continental crust, also known as the lithosphere, is broken into seven major segments and perhaps a twenty smaller segments in different irregular dimensions and shapes. These segments are called lithospheric or tectonic plates, and are in constant motion with respect to one another. Due to this activity, major interactions take place along plate boundaries or margins which leads to the formation of mountain belts. Plates move in relation to each other in three different ways such as divergent (the plates move away from one another), convergent (plates move towards each other) and transform (the plates slide past one another). The mountain building activity takes place particularly in the convergent boundary between two plates.

Stress is a force that acts on a body unevenly in all directions referred to as differential stress. There are three types of differential stress including tensional, compressional and shear.

Orogenic movements occur mainly along the plate boundaries or plate margins that produce intense folding and faulting. The force is working on Earth's mantle in a horizontal manner cause to the orogenic movements. These horizontal forces act in three ways: towards each other, opposite one another and parallel to each other. The two forces operate face to face or towards each other are called **compressional forces or convergent forces**. You may be aware that the rocks are squeezed or crushed when compressional force applies on it. In the same way, compressional forces act at convergent plate boundaries that result in squeezing and crushing of the rocks. On the other hand, the forces act on the rock in opposite direction leading to rupturing of the rock. These forces are called **tensional forces or divergent forces**. Under **shearing forces**, the stresses act parallel to each other but in opposite directions like the motion of scissors. These forces can produce transform faults. Tensional and shearing forces create faults or fractures. If there is compression on one end, there may be tension on the other end. Hence, it is understood that folding and faulting often act together.

Folding

As you know that the Earth's crust comprises of different lithospheric plates and is constantly in motion. When two continents collide, the intervening sedimentary rocks of continental margins come under strong forces of compression. To understand the formation of folds refer to Figure 7.3, which explains you that the horizontal bedrock is bent or curved as a result of permanent deformation due to compression. The wavelike undulations imposed on the horizontal strata comprise of alternating archlike upfolds, called **anticlines** and troughlike downfolds, called **synclines**. A **monocline** is a single bend in or otherwise horizontal formation. The initial landform associated with an anticline is a rounded mountain ridge, and the landform associated with syncline is an elongated open valley. The size and shape of folds depend upon various factors such as the nature of rock, intensity, and direction of compressive forces, etc. Folds in some rock layers measured from few centimetres to kilometres, and are tight or broad, symmetrical or asymmetrical. Most of the mountain systems exhibit some degree of folding. We could find large scale folding structures in the mountains of Appalachian and Himalaya, etc.

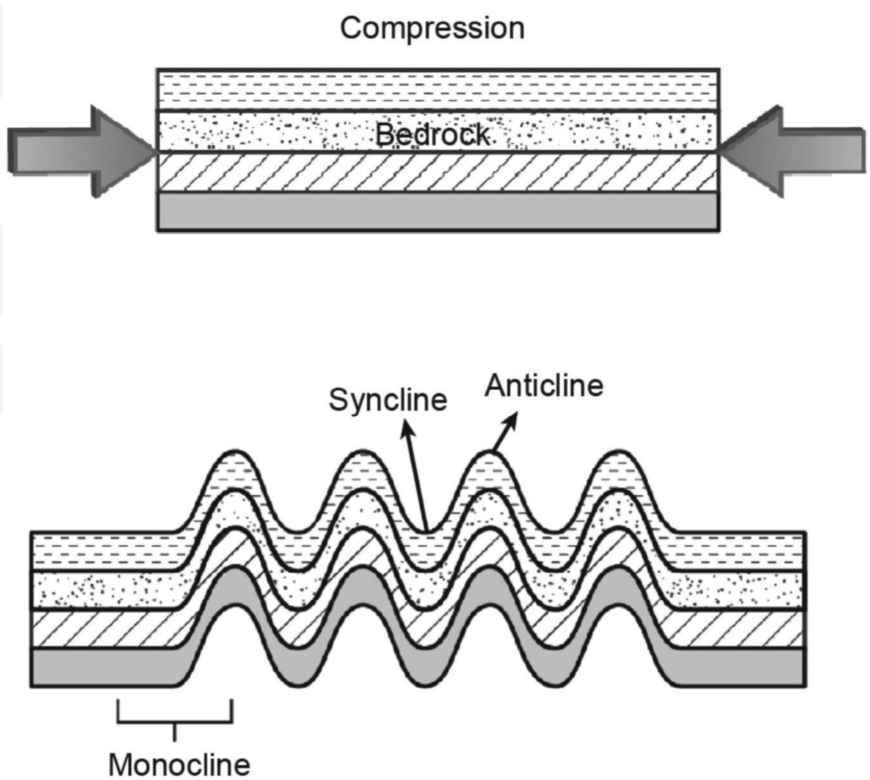

Fig. 7.3: Folds formed due to compressional forces.

Now you need to understand the terminologies which are associated with various components of folds. Take a look at the diagram in Figure 7.4. The two sides or flanks of folds are called limbs. The central line between the limbs, along the crest of anticline or trough of syncline is termed as the axis of fold. An imaginary plane drawn between the limbs, which divide the fold in half, is called the axial plane. If the axis is inclined from the horizontal, the fold is said to plunge. If the axial plane is vertical and the axis is horizontal, then the fold is termed as symmetrical whereas the axial plane is inclined, the fold is inclined. The important types of folds are illustrated in Figure 7.5. The compressive forces work regularly or more or less equal from both sides with moderate intensity known as ***symmetrical*** or ***simple*** or ***open folds***. These are very rarely found. Few examples of these folds are Jura Mountains of France and Switzerland. ***Asymmetrical folds*** are formed when both the limbs are unequal and irregular with different angles of inclination. One limb may be larger with moderate inclination and the other shorter with steep inclination.

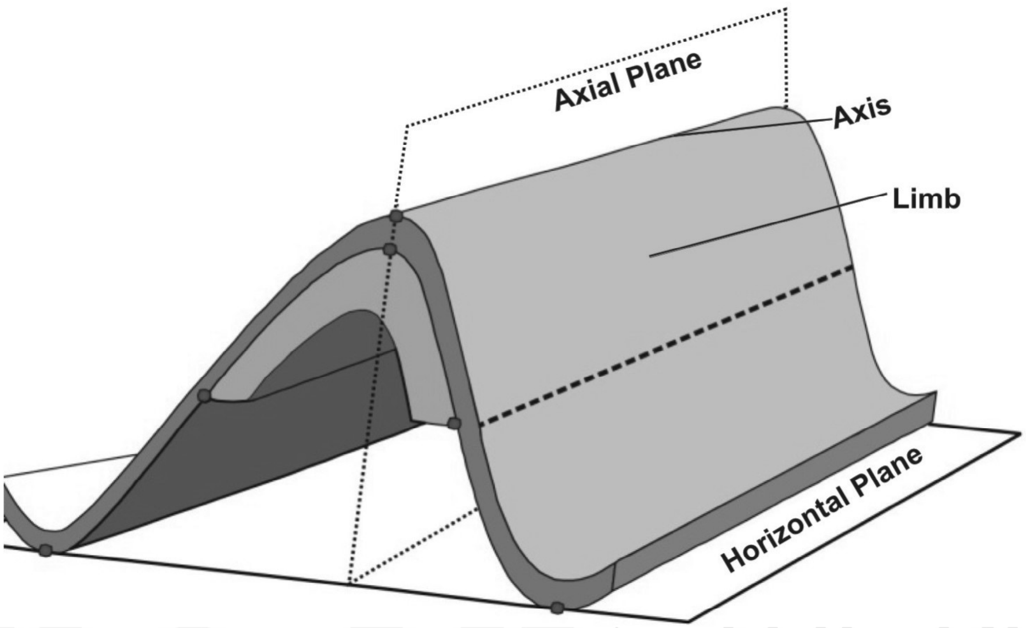

Fig. 7.4: Basic components of a fold.

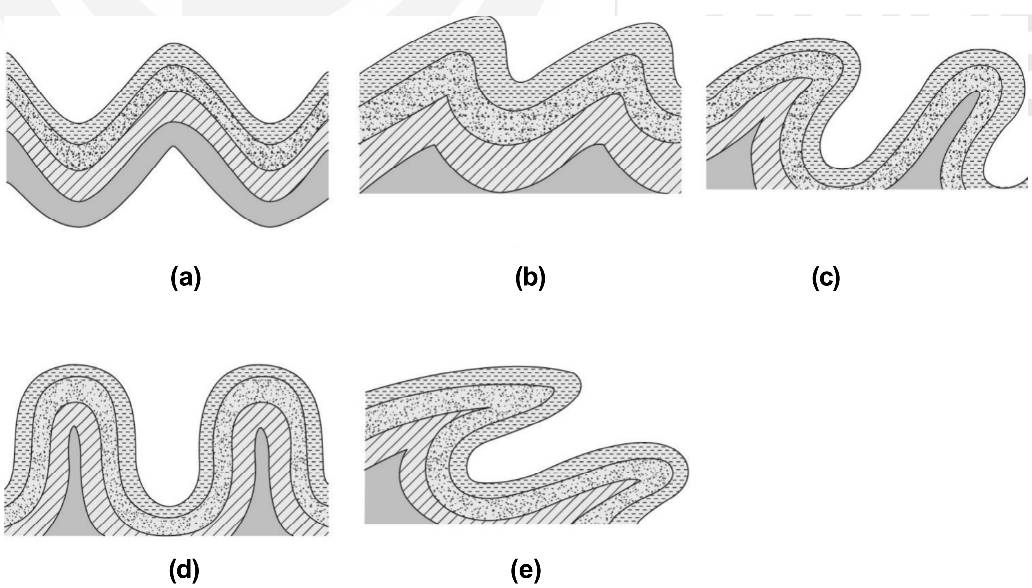

Fig. 7.5: Various types of folds formed due to compressive forces: a) simple; b) asymmetrical; c) overturned; d) isoclinals; and e) recumbent.

With the strong compressive forces both the limbs of fold become parallel called **Isoclinal folds**. In this type, both the limbs dip at equal angles in the same direction. **Recumbent folds** are formed when the intensity of compression over both the limbs of fold may be parallel as well as horizontal. With further increase in pressure, the recumbent folds may be sliced or sheared in which the slices of rock moves over the underlying rock on flat surfaces of low inclination is called as overthrust faults. The plane of shearing is a thrust plane and the structure is **Overthrust fold**. Individual rock slices or thrust sheets are carried horizontally for several tens of kilometers over the underlying rock strata. These kinds of thrust sheets are called nappes, meaning from the French word "cover sheet" or "table cloth". The example of nappes is European Alps. You will also find the distribution of major fold systems in the world at Fig.7.6.

Faulting and Thrusting

You have studied about the basic information on folds and their types. As you know folding is bending or wrinkling of rock layers which occur when compressional force acts on the pliable rocks. You now know that the fault or fractures can be formed due to the consequences of orogenic movements in the Earth's crust. **Fault** is a fracture in the crustal rock, which forms mainly due to tensional forces caused by the endogenetic forces. The plane along which the rock blocks are displaced is called fault plane. Faults are formed when rocks on both sides of the plane have moved relative to each other, or parallel to the plane. Due to tensional forces, rock layers can be dislocated. During the formation of fault, the vertical displacement of rock blocks may take place upto several hundred meters and horizontal displacement may extend upto several kilometers. When faults are of great horizontal extent, the surface trace or fault line can sometimes be followed along the ground for several kilometers.

You may like to read the information for identification of folds and faults at http://www.geosci.usyd.edu.au/users/prey/FieldTrips/BrokenHillOlary/Mapping.html

Detailed study of faults helps geoscientist to understand how the tectonic plates move relative to each other. The four basic types of faults are classified based on the angle of inclination and the direction of displacement of one wall relative to the other (Fig. 7.7). If the displacement is up or down along the fault plane, it is called a dip-slip fault; whereas a strike slip fault is formed when the displacement is parallel to the fault line; and the displacement that combine both strike and dip-slip are said to be oblique slip faults. The faces of the blocks on either side of the fault are termed as the walls. The surface is separating the walls in the fault plane is called fault scarp. The upper face is hanging wall and lower face is footwall.

Faults having primarily vertical movement are called as normal faults. A **normal fault** has a steep or nearly vertical dip. The direction of the movement is vertical and as a result one side is thus raised or upthrown relative to the other, that is downthrown. Normal faulting is an expression of the extension of faulted beds of the crust. In this type of fault, the lateral movement is in the opposite direction. Steep wall-like slope, escarpment or scarp, produced by a normal fault is called fault scarp. The height of fault scarp ranges from few meters to several hundred meters. Their length often attains 100 kms or more. Normal faults commonly occur as multiple and parallel series of faults.

The steep, high angle fault resulting from compressional forces is said to be a **reverse fault**. The opposite displacement leads to formation of a reverse fault

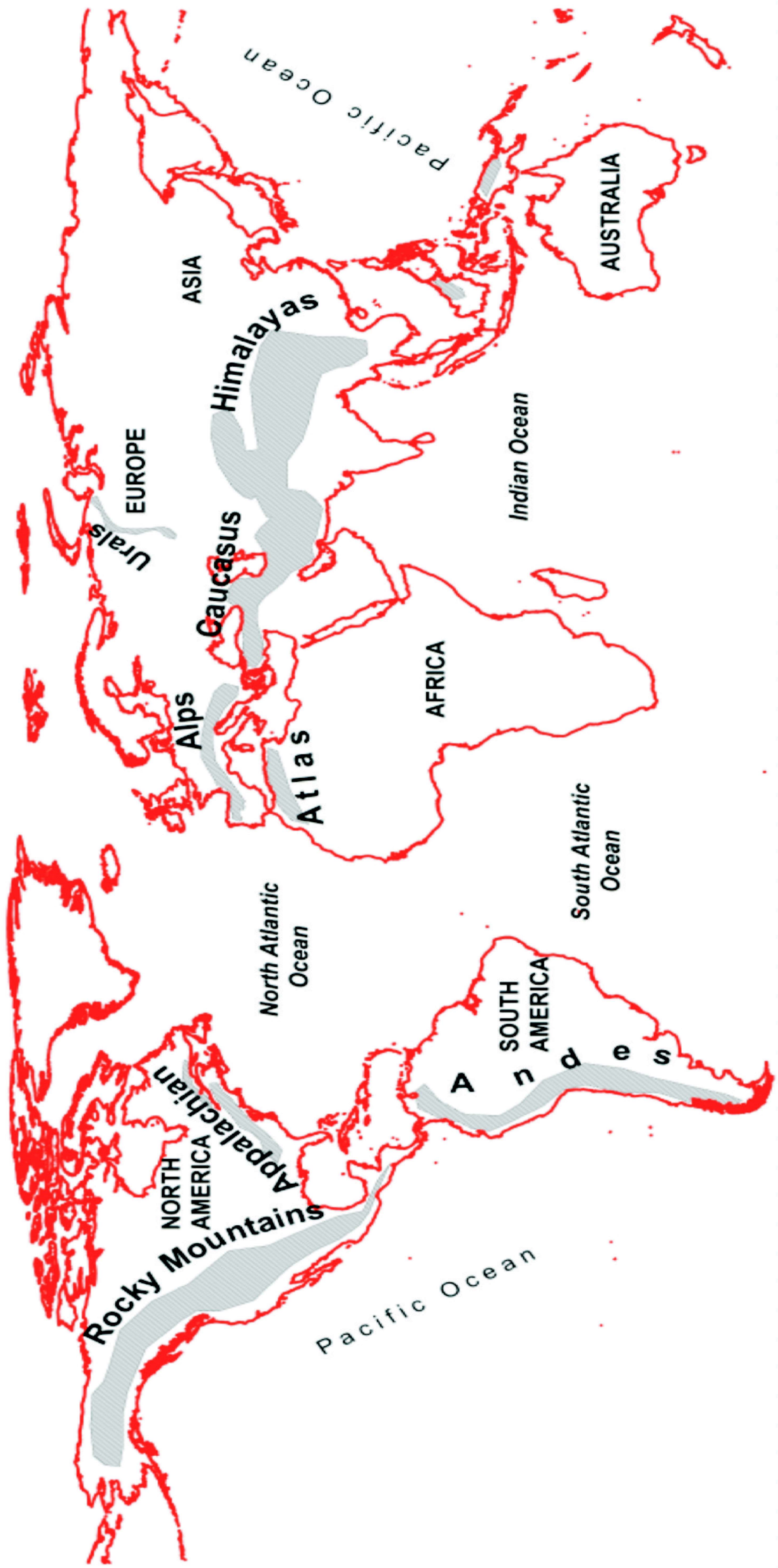

Fig. 7.6: Important folded mountain systems of the world.

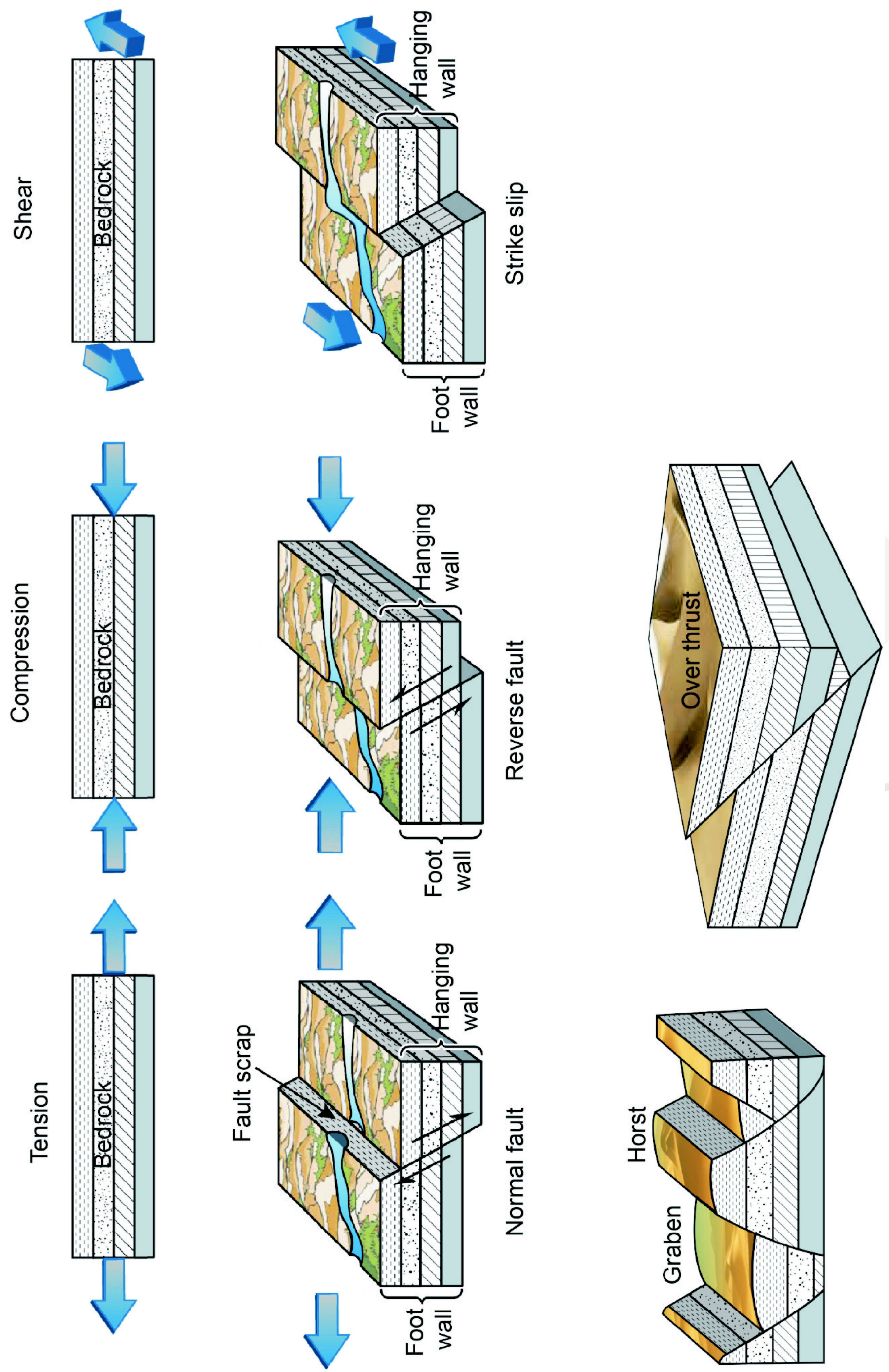

Fig.7.7: Faults formed mainly due to tensional forces.

in which the hanging wall moves up relative to the footwall. We shall remember that both normal and reverse faults form fault scarps at the margins of uplifted or down drifted blocks. The reverse fault causes shortening of the faulted area while normal faulting results in the extension of the faulted area. If a reverse fault is subjected to great compressional force, the upthrown block override the downthrown block at a relatively low angle, the resultant movement would be mainly horizontal. The rock slabs move laterally for tens of kilometres. Landslides often accompany reverse faulting.

When the rock blocks are displaced horizontally along the fault plane due to the horizontal movement wherein no fault scarps are produced, **lateral** or **strike-slip faults** are formed. These are highly complex faults. Only a thin fault line is traceable across the surface. These are also named as *shear faults, transcurrent faults, transform faults or wrench faults*. Some important examples are the Alpine Fault in New Zealand, the Great Glen Fault in Scotland and the Lorch-Alahama Fault or the Alhama de Murica Fault in Spain. Thrust and reverse faults are generally observed in subduction and continental zones.

A **graben** or **rift** forms where a block is displaced downward between two normal faults. A narrow fault block elevated between two normal faults is called a ***horst***. Topographically, horsts form block like plateaus or mountains with flat top, steep and straight sides. A graben is a valley or trench like structure bordered by steep and parallel walls. Best examples of the horst are Shillong Plateau in India, and the Rhine graben (East African Rift Valley System) which stretches for 600 kms in length and 70 kms in width.

Till now, in this section, you learnt two main forces which occur in the Earth's crust such as epeirogenic and orogenic movements caused by diastrophic forces. You may have understood about the upliftment and subsidence of the continents, which are explained briefly under epeirogenic movements. You also studied the formation of folds as well as tensional forces. Folds are formed due to compressional forces, whereas faults are formed due to tensional forces. In the following section and subsections, you will learn about sudden forces.

SAQ 2

Spend 5 mins

Mark the following statements as True or False:

a) Folds are formed due to compressive forces.

b) The consequences of epeirogenic movements are the formation of folds and faults.

c) Land subsidence occurs because of orogenic movements.

d) Strike-Slip fault is also called shear fault.

7.4 VOLCANISM

You have noted that the volcanism is one of the types of sudden force of endogenetic forces. Volcanism is one of the endogenetic processes capable of rendering sudden and massive changes in the surface features of the Earth. It represents processes and features related to the movement and solidification of magma both within the crust and on the surface. Surface processes include the formation of volcanoes. Volcanism can be observed mainly in the interiors of oceanic plates. The activity of molten magma is defined as extrusive volcanism whereas magma solidifying below the surface is called *intrusive volcanism or plutonic activity*.

Volcanic materials can be divided into two main groups:
(a) pyroclastic materials for example: ash, lapilli, tephra, pumice, scoria, etc.
(b) lava flow materials for example: lava, lava flow, pahoehoe and so on.

Let us now discuss about the nature and characteristics of a volcano. A volcano has a deep vent, or opening, usually circular or nearly circular in shape, through which heated materials consisting of gases, ash, water, liquid lava and molten rock are ejected from the Earth's interior to the surface of the Earth. You can study different types of features formed during the eruption of a volcano which are illustrated in Fig. 7.8. The ejection of the heated materials from a volcano through the vent is called eruption. Magma extruded onto the Earth's surface is referred to as lava. The magma commonly consists of molten rock, hot liquids, gases, water vapour and other materials that force towards the Earth's surface with high pressure. The erupted lava and other materials accumulate close to the vent leading to formation of a conical hill. The crater is created at the top of the cone as funnel-shaped depression. The base of the crater is connected with the interior part of the Earth by volcanic pipe through which the lava rises to the top. You have understood the nature and characteristics of a volcano. Let us now study the types of volcanoes based on their eruption and phases.

Volcanic activity is considered to be one of the most catastrophic phenomena. There are roughly 700 potential volcanoes identified, of which approximately 50 volcanoes erupt with major and minor risk. Some of known catastrophic historical eruptions were at Vesuviuos (79 AD), Tanbora (1815), Mount Pelee (1902), Mount St. Helens (1980), Nevado del Ruiz (1985) and Pinatubo (1991). Research shows that three fourths of all volcanic activity is underwater activity mainly at mid oceanic ridge spreading centres.

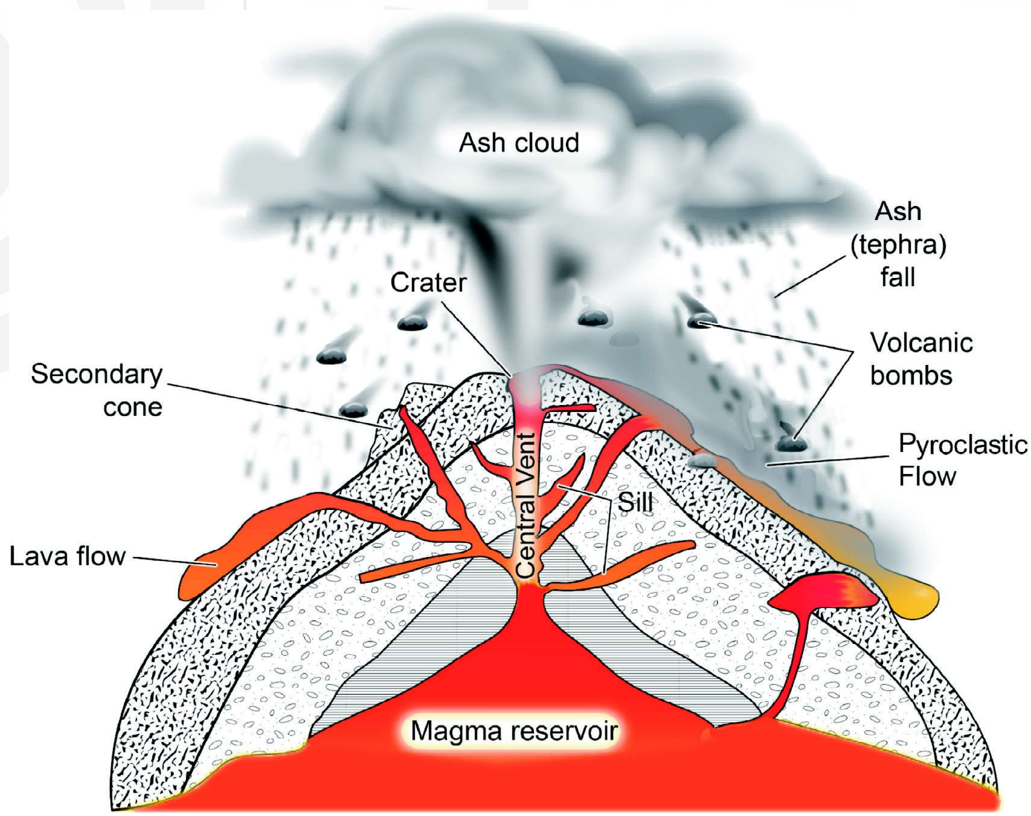

Fig. 7.8: Various features of volcano.

7.4.1 Types of Volcanoes

There is a wide range of variations in the form of volcanic eruptions and their periodicity. The nature of volcanic eruption whether explosive or quite, depends upon the type of magma. On the basis of mode of eruption, volcanoes are categorized into two principal classes such as **central** or **explosive eruption** and **fissure** or **quite eruption**. The explosive eruption of a volcano is an awesome spectacle. It erupts pyroclastic materials including lava and rock fragments that consist of solidified lava blobs, ashes and dust. We generally do not find any intensive explosion activity in the fissure volcanoes. Volcanoes are further classified into active, dormant and extinct based on the frequency or periodicity of the eruption.

Volcanoes of Central or Explosive Eruption

Central or explosive type of volcanoes erupt the liquid lava, rock fragments, ash and lapilli through pipe-like central vent or mouth. After the eruption, these materials accumulate around the volcanic vent, and form the cone and crater like structures. In central eruptions, the nature and intensity of the eruption can vary based on the ejected amount, pressure of gases and the viscosity of lava. Basic lava is also called mafic lava or basaltic lava which is less viscous and highly fluid in nature. If the lava is basic, it expresses low rate of eruption and absence of explosion. The lava flow is very quiet. Whereas the lava is acid in nature, therefore more viscous, the eruption will be highly explosive. Volcanoes of central eruption type may be subdivided into five major types such as Hawaiian, Strombolian, Vulcanian, Vesuvian and Pelean. The major types of central eruption volcanoes are shown in Fig. 7.9.

Krakatova
Krakatoa, a volcanic island in Indonesia, was quite for nearly 200 years and suddenly erupted in 1883 and continued for several months. Great seismic waves generated by this explosion which was causing loss of many thousands of people (approximately 36,000) living on low coastal areas of Sumatra and Java, and disappearance of the two-third of the island. You may imagine the strength of resultant materials of rock fragments and cloud of ash of volcanic eruption had raised nearly 80 kms and the sound of explosion was heard about 5000 kms away in Australia. The sunset in the different parts of the globe were colored by fine volcanic dust for many months afterward.

Hawaiian type of volcanoes

This type of volcanoes has less explosive activity and erupts quietly due to less viscosity of lava and non-violent nature of gases. Hawaiian eruptions are effusive eruptions that express the very simplest volcanic eruptions. They can also feed much larger lava flows through time. There is little or no tephra. Sometimes fountains of highly fluid basaltic spray rise up with the gases and when caught by strong wind, these lava pieces are stretched into long glassy threads known as "**Pele's Hair**'"(Pele is the goddess of fire in Hawaiian islands). These eruptions commonly occur in Hawaii islands and hence, named as Hawaiian type. Examples of these eruptions are Klauea Iki (1959) in Hawaii island and Krafla (1975-83) in Iceland.

Strombolian type of volcanoes

These are the most picturesque volcanic styles named after volcano formed the island of Stromboli, one of Lipri group of islands in the Mediterranean Sea. Strombolian is characterised by relatively mild explosion. It ejects liquid lava fragment materials like pumice, scoria, and bombs of hot materials as the bubble bursts. These eruptions are regular, rhythmic in intervals varying from few minutes to about an hour. Such volcanoes eject hundreds of meters to kilometres in height characterized by unusual lava flows. Strombolian eruption in the Mediterranean looks somewhat like an energetic Roman candle firework when viewed at night known to be the "**Lighthouse of the Mediterranean**".

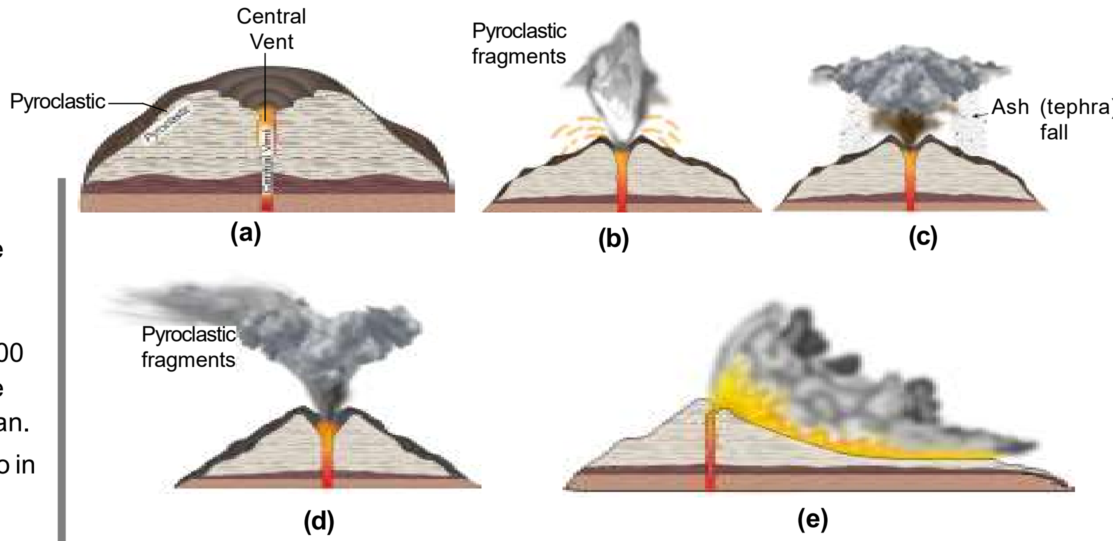

Fig. 7.9: Volcanoes of different types of eruptions a) Hawaian; b) Strombolian; c) Vulcanian; d) Vesuvian; and e) Pelean.

Interesting Facts

- Most volcanoes are 10,000 to 100,000 years old and expected that 10,000 more volcanoes are situated in the ocean.
- The biggest volcano in the world is Mauna Loa in Hawaii. The oldest volcano is Mt. Etna, Sicily, in Italy that is about 350,000 years old.
- Indonesia has more number of volcanoes in the world, and one of the volcanoes Merapi (means "mountain of fire") erupted recently in January 1994.
- Laki volcano in Iceland erupted in 1783 and lava flow was stretched about 65 kms.
- Stromboli has been known to be erupting for more than 2,000 years.
- Volcanoes emit gases such as water vapour, carbon dioxide, sulphur dioxide, hydrogen chloride, and hydrogen fluoride.
- Pumice, a volcanic material, is widely used for grinding and polishing stones, metals, and other materials.
- Weathered volcanic ash greatly improves soil fertility.

Vulcanian type of volcanoes

Vulcanian eruptions, named after eruptions on Volcano island of the Aeolian Islands in the Mediterranean, are more explosive. These eruptions are having more viscous magma where the resultant lava quickly solidifies and seals the mouth of the crater in between two eruptions. Due to this obstruction, the violent gases are difficult to escape from top of the volcano during the immediate next eruption. So the trapped gas in the underlying magma try to expand its space and subsequently, they force with high pressure and come out with explosion through the solidified vent. A much larger amount of ash and dust are emitted than their Strambolian counterparts. These can fill the atmosphere for many hundreds of square kilometres.

Vesuvian type of volcanoes

This type of volcanic eruption occurs with a very violent explosion considered as similar to Vulcanian and Strombolian. The lava mainly comes out with great forces from the lateral cracks, and intense gases keep on accumulating in the main vent. When build-up the high pressure, the explosion occurs rapidly and these ashes and gases form thick mushroom-like shaped clouds. These clouds can rise to greater heights in the sky. The Vesuvian eruption, also called Plinian type, was recorded by Pliny at Vesuvius in 79 A.D. These are the most spectacular eruption styles which can be seen on the Earth.

Pelean type of volcanoes

These eruptions are named after the explosive eruption of Mt. Pelee (1902) in Martinique Island in the Caribbean Sea. There was a terrific explosion of Mt. Pelee which engulfed the town of St. Pierre, destroying the city and killing all of its 30,000 inhabitants. It is considered as one of the worst volcanic events in the twentieth century. These are highly explosive and eject highly viscous lava. These volcanoes are characterised by hot glowing clouds (termed ***nuee ardente***, means glowing cloud). The emitted viscous lava forms a dome in the volcano's crater. The intensely hot glowing cloud travels rapidly down the flank of the volcanic cone searing everything in its path.

Volcanoes of Fissure or Quite Eruption

You have understood about the types and characteristics of central eruption type of volcanoes. You now know about the nature of fissure eruption type of volcanoes. In this type, vents form as linear features on the Earth's surface and the lava erupts out of faults or cracks without any explosive activity in the Earth's crust.

Fissure-fed eruptions often start as a sheet of magma which erupts along the fault. There is no pipe or central vent leading directly to the magma in the Earth's interior. So that it gets quickly localized to create a number of more discrete vents along the fissure. As you know, low viscous lava i.e. basaltic lava comes out from the lateral cracks along the hillslope, which leads to the formation of small hillocks and cinder cones. For instance, in between June 1783 and February 1784, a series of fissure-fed eruptions occurred in an area near the mountain Laki in Iceland. A huge volume of lava ejected about 14 km^3 of magma from a 28 kilomters long fissure. This type of eruption also took place in Travera, Newzealand in 1886. It was little explosive covered a length of 15 kms long fissure.

Active Volcanoes:

Mona Loa (Hawaii Islands), Etna (Sicily), Vesuvius (Italy), Pinatubo & Mayon (Phillippines). Cotopaxi Volcano in Ecuador is the world's highest active volcano (19,600 ft high).

Dormant Volcanoes:

Fujiyama (Japan) and Krakatoa (Indonesia)

Extinct Volcanoes:

Pope Mountains (Mynmar), Mt. Kilimanjari (Africa) and also found in Mauritius, and Malagassy.

Frequency of Eruption Type Volcanoes

You have studied about the volcanoes classified based on the nature and intensity of eruption. You will now know that the frequency of eruption type of volcanoes, which are divided into three types, namely active, dormant and extinct. Active volcanoes remain in continuous process that erupting periodically volcanic lava, gases, ash, and other materials. The volcanoes remain quiet after their eruptions for some time, but there is a possibility of eruption in future, are named as dormant volcanoes. When the eruption is completely stopped with no indications of future eruption, such kinds of volcanoes are categorized as the extinct volcanoes. In extinct type, the crater is covered with water and lakes are formed. Although we must remember that many of these are considered dormant may become active any day as no one knows what is happening below the ground surface.

You may like to read about volcanoes at http://volcanoes.usgs.gov/index.php

SAQ 3

Spend 5 mins

Match the following?

a)	Volcanic material	i)	Central eruption
b)	More explosive	ii)	Hawaiian
c)	Strombolian	iii)	Vulcanian
d)	Mild explosion with liquid lava	iv)	Pumice

7.4.2 Distribution of Volcanoes

Do you know the volcanoes are the indicators for identifying plate boundaries? At present more than 1500 active volcanoes are distributed over the globe. It has been observed that volcanic activity is strictly confined to certain limited sectors of the crust. These are mostly found on the marginal parts of the continents, and in the littoral zones of oceans and seas. This information can be utilized to locate the edges of plates. Volcanic activity is mainly associated with plate boundaries.

You may like to read about volcanoes at http://volcanoes.usgs.gov/index.php

Volcanoes are mainly distributed as long belts to circle the Earth. It is apparent from the Fig. 7.10 that the most notable area of volcanism in the world is around the margin of the Pacific Ocean known as the *Pacific Ring of Fire*. The line of volcanoes that circles most of the Pacific Ocean is also known as ***Ring of Fire*** or ***Circum-Pacific Belt***. This zone is known to be the site of frequent volcanic eruptions where more than seventy five percent of the active and inactive volcanoes are located. The important volcanic belts are grouped into five classes such as volcanic ridges, volcanic arcs, volcanic chains, volcanic clusters and volcanic lines. Volcanic ridges and their associated volcanic activity concentrated mainly in the Mid-Atlantic Ridge system, the East-Pacific Rise, the Carlsberg Ridge, and the ridges encircling the Antarctica Continent. Arc volcanism includes the Aleutian Islands, Kamchatka, the Kurile Islands, Japan, Philippines, Celebes, New Guinea, Solomon Islands, New Hebrides, New Zealand, and the Indian Ocean belt. It may represent early stages of subduction zones. Volcanoes like Cotopaxi, Katmai, Fujiyama, etc. are located in this belt. Volcanic chains are straight line of volcanoes extended through the Andes of South America, Central America, Mexico, the Cascade Mountains of western U.S.A. Volcanic clusters are found in oceans and on continents, for example, the Galapagos, Canary Islands, Azores in the Atlantic, Mauritius in the Indian Ocean, and East African Rift Valley, etc. Extinct volcanoes and seamounts are arranged as volcanic lines, which include Hawaiian-Emperor-Seamount chain, Austral-Marshall-Gilbert chain, etc.

7.5 EARTHQUAKES

As we know, number of Earthquakes occurs every year across the world. Some of them have more destructive effects on human life, property and environment. Hence, it is essential to have an idea about the Earthquake. Earthquakes may last only a few seconds or may continue upto several minutes. They can occur at any time of the day or night, and at any time of the year. Simply, the Earthquake is the passage of vibrations that occur in the Earth's interior due to the sudden disturbance or movement of rocks through the Earth's crust. According to Strahler and Strahler, an Earthquake is a motion of the ground surface, ranging from a faint tremor to a wild motion capable of shaking buildings apart and causing gapping cracks to open up in the ground. It is a form of energy of wave motion transmitted through the surface layer of the Earth in widening circles from a particular point. This point is called focus which is the source for releasing the sudden energy. We now study the origin of Earthquakes, and then go on to the Earthquake measurement and destructive effects on the landscape, and their distribution.

7.5.1 How Earthquakes Occur?

Earthquakes are caused by volcanic explosions or by sudden displacements of rocks in fault systems. Earthquakes may be distinguished into two types-volcanic and tectonic. Volcanic Earthquakes are caused due to volcanic

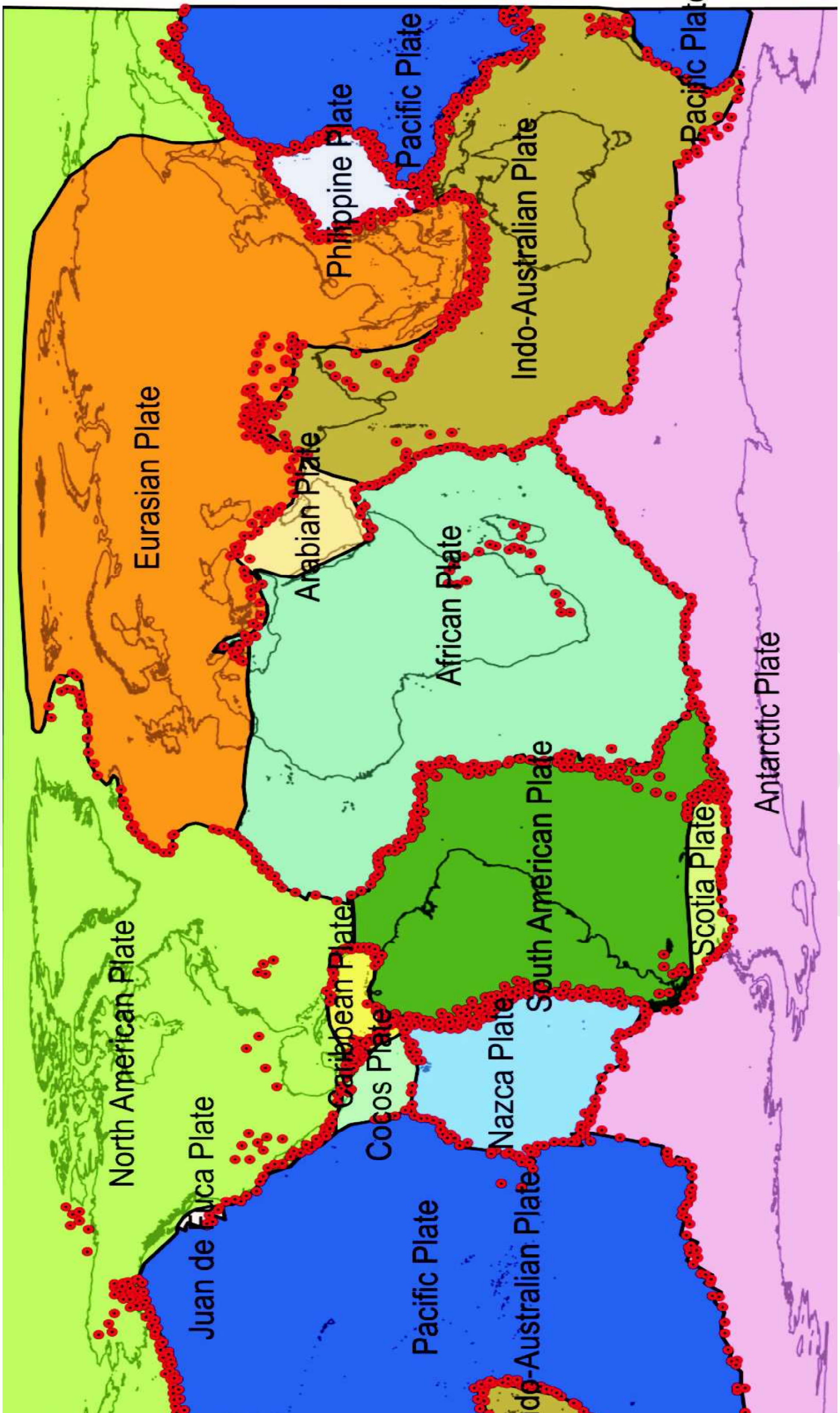

Fig. 7.10: Majority of volcanoes and earthquakes distributed along the plate boundaries on the planet earth.

eruptions of explosive and fissure types. When the magma released from the volcanic system in the Earth's interior due to the changes of pressure under the volcano, an empty space is left to be filled. The vibrations are generated by the movement of magma or other fluids within the volcano. It results in collapse of surrounding rocks to fill the void, creating Earthquake. Generally, volcanic eruption is followed by Earthquakes and many of severe Earthquakes cause volcanic eruptions. The explosive gases coming upward and push the crustal surface from below with great force, due to which intensity may be little high near the volcano but their area of disturbance is relatively low. Whenever the gases try to come out from the weak crustal surface with violent explosion, it causes the sudden disequilibrium in the crustal surface, which generates severe tremors. These Earthquakes are an indication of magmatic activity and may be a precursor to a volcanic eruption. Tectonic Earthquakes are triggered when the crust is subjected to strain which eventually ruptures and moves during the faulting activity. These may possibly originate from few kilometers depth to over 700 kms. The major Earthquakes originate along the faults that form the boundary between down going and overriding tectonic plates. They typically form linear networks or systems, with branches leading from a main fault. The best example of this system is the San Andreas Fault system of western California, North America. The main fault line of this system connects the Pacific and North American Plates. Deep intraplate Earthquakes (originate at >300 kms depth) usually are caused by normal faulting, and reliably have very few aftershocks.

7.5.2 Earthquake Waves

How do the seismic waves travel that occur during an Earthquake?

We will do a small experiment to know the travelling of *seismic waves*. Take a pebble and throw it into a quite pond. You can find ripples in the pond. If you focus on the ripples you can observe how they are moving out in radial pattern. They will travel outward in all directions gradually losing energy from the point of the origin where pebble is dropped. *Seismic waves* also travel in the same manner with intense energy from the focus point and gradually losing energy with distance.

Generally Earthquake originates from several kilometres deep below the Earth's surface. In order to understand an Earthquake, you must refer Fig. 7.11 which shows two main terms: **focus** and **epicentre**. The rock rupture or sudden breakage of rocks deep within the crust at a point or place is known as *focus* or *hypocenter*, and the point on the Earth's surface located vertically above the focus is termed as *epicentre*. The depth of focus from the epicentre, called as **focal depth**, is an important parameter in determining the potential damage of an Earthquake. The vibrations or seismic waves radiate from this point of rupture or focus, and are propagated up to the Earth's surface. The location of these two points is determined by measuring the seismic waves received at seismic stations, and calculating back to the waves' point of origin. You know that the seismic waves are generated during an Earthquake. For recording an Earthquake, an instrument called ***Seismograph*** is generally used. There are two types of waves: body waves and surface waves released during an Earthquake. These waves travel outward in widening circles, like the ripples produced when a rock is thrown into a lake, gradually decrease with increasing distance from the focus of an Earthquake.

Body waves, *primary (P)* and *secondary (S)* waves, and *surface* or *long (L)* waves are generated by an Earthquake. Body waves can travel through the interior of the Earth, but surface waves only move along the surface of the Earth like ripples on water. P wave is the fastest kind of seismic wave and first

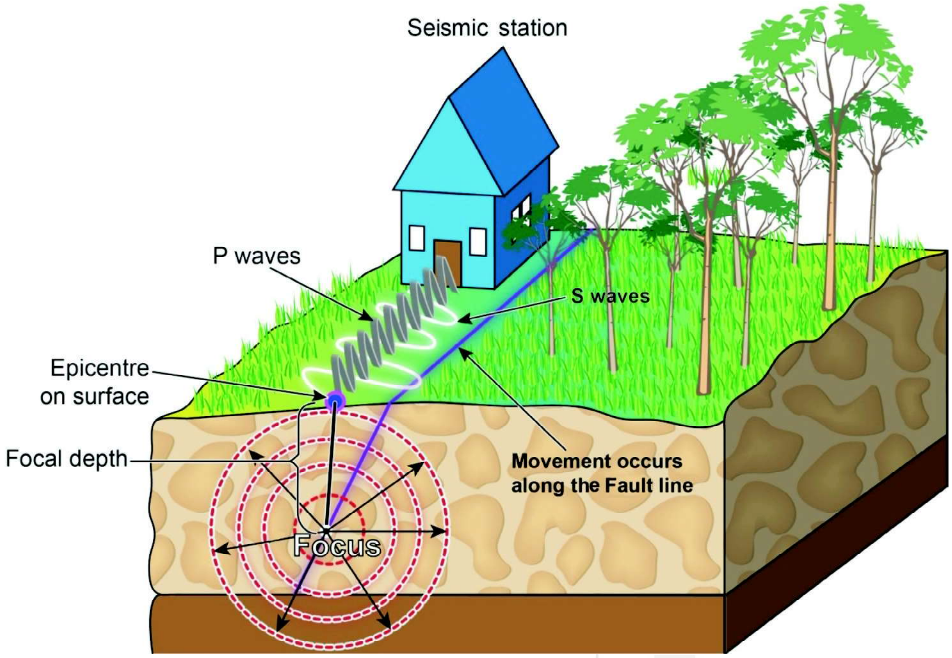

Fig.7.11: Block diagram of an earthquake.

to arrive at a seismic station that can be recorded on the Seismograph. This can move through solid rock, liquids and gases. P waves are "push and pull" waves like sound waves, which pushes and pulls the air in each particle vibrating to and fro in the direction of propagation. These are also known as compressional or longitudinal waves. The second type of body waves is the S wave or secondary wave which appears only after the P waves have arrived. These are transverse or shear waves, in which the motion of each particle is at right angle to the direction of propagation. S waves can pass only through solid rock and move rock particles up and down, or side-to-side-perpendicular to the direction of the wave travels. Both P and S waves travel through the body of the Earth hence, they are called as body waves.

Surface waves are two types: love waves and rayleigh waves. love wave is the fastest surface wave and moves the ground from side-to-side in horizontal motion. Rayleigh waves are much larger than the other waves move the ground up and down, and side-to-side in the same direction of wave. It rolls along the ground just like a wave rolls across the ocean or lake.

Surface waves or L waves are of lower frequency than body waves that travels through the crust. They arrive after body waves because of the complexity of their paths through crustal layers, and it can pass through both land and water. These waves are responsible for the damage and destruction associated with Earthquakes. The speed of the surface waves and the related damages gets reduced in case of deeper Earthquakes.

How do Earthquakes affect the people?

You know, thousands of Earthquakes occur around the globe each year, most are too small to affect us. Earthquakes of larger magnitude and high intensity release great energy, which causes disturbances in natural and man-made environments with respect to the loss of life and property. Because of intense ground shaking the landslides, surface faulting, avalanches, tsunamis, flashfloods, etc., may occur that directly influence the amount of damage. Other damages among these hazards are damage of roads, bridges, railways, ports, airports, and water, wastewater, electric power, telecommunication-lines, natural gas and liquid fuels, etc.

7.5.3 Magnitude and Intensity of Earthquake

Now we know that the seismic waves reach the epicentre first, and the areas closest to the epicentre experience maximum intensity. Therefore, it is important to study how to measure the size and destructiveness of an Earthquake. The magnitude of an Earthquake indicates the quantity of energy that is released by Earthquake at the source point. Charles F. Richter (1900-1985), a leading seismologist, devised a rating scale of Earthquake magnitude in 1935. Today, we popularly know it as **Richter Scale**. This scale is based on the amplitude of seismic waves - the stronger the Earthquake, the stronger the seismic vibrations it causes. It consists of numbers that ranges from less than 0 (negative numbers) to more than 8.5. Table 7.1 explains various magnitudes on Richter scale and their effects during an Earthquake. Richter magnitude is determined from the logarithm to the base 10 of the amplitude recorded by a seismograph, which states that an increase of one in magnitude corresponds to a factor of 10 increases in the amplitude of ground motion. For example, a magnitude of 6.0 Earthquake causes 10 times larger shaking than that of a magnitude of 5.0 Earthquake. The Richter scale has no lower or upper limit. However, the highest magnitude Earthquakes so far measured have been rated as 8.9 on the Richter scale. You may notice in Table 7.1 that magnitudes 8 or above are coded as great Earthquakes. Magnitude ranging between 8 and 8.9 Earthquake occurs once in a year on an average for the whole planet.

The US Geological survey is a responsible institution for measuring and assessing the Earthquakes across the world.

You may like to read about earthquakes at http://earthquake.usgs.gov/earthquakes/

Now you might understood the scale of magnitude of an Earthquake but it may not be provided enough the destructive effect on the landscape. The Earthquake intensity is a qualitative measure of the actual shaking at a particular location during an Earthquake, which can be determined from the reported effects of the tremor on human beings, furniture, buildings, and geological structures, etc. Intensity varies from place to place within the disturbed region. If it is highly populated area, it can inflict more causalities and huge potential damages whereas it can affect the remote areas insignificantly with the same magnitude of Earthquake shocks.

In order to study the intensity of an Earthquake, the scale was developed by the Italian seismologist Mercalli in 1902. Later on it was modified by Harry Wood and Frank Newmann in 1931. The modified **Mercalli Scale** consists of 12 increasing levels of intensity, from Roman numeral I to XII, illustrates the distribution of intensities that are ranging from imperceptible shaking to catastrophic destruction (Table 7.2). The occurrence of a great Earthquake in the ocean may not possible of damaging cities, dams, and highways because the energy level gets decreased over long travel distance into a built environment. On the other hand, the magnitude of 6.5 or 7.0 has shallow focus directly below a populated area, the destructive potential is very high. You now understand that the measuring of destructive power of an Earthquake is termed as Earthquake intensity.

Distribution of Earthquakes and Plate Tectonics

Plate tectonic theory is accepted by the Scientific Community as the most possible explanation of causes of Earthquakes. You have studied about the theory of plate tectonics in Unit 5. As you know the Earth's crust consists of seven major plates and twenty minor plates. These plates are constantly

Table 7.1: Magnitude of an Earthquake on Richter Scale and its Effects

Magnitude	Description	Earthquake effects	Frequency of occurrence (estimated)
Less than 2.0	Micro	Micro Earthquakes, not felt, or felt rarely by sensitive people; detected by seismographs.	Continual/several million per year
2.0-2.9	Minor	Felt by some people but no damage to buildings.	Over one million per year
3.0-3.9	Minor	Often felt by people, but very rarely cause damage; shaking of indoor objects can be noticeable.	Over 100,000 per year
4.0-4.9	Light	Some landscape but no loss of life.	10,000-15,000 per year
5.0-5.9	Moderate	Felt by everyone; moderate landscape damage but no loss of life.	1,000-1,500 per year
6.0-6.9	Strong	Damage to a moderate number of well-built structures in populated areas; Earthquake-resistant structures survive with slight to moderate damage; poorly designed structures receive moderate to severe damage; felt in wider areas; strong to violent shaking in epicentral area.	100-150 per year
7.0-7.9	Major	Major landscape damage with high loss of life in populated areas; well-designed structures receive damage; felt across great distances.	10-20 per year
8.0-8.9	Great	Massive to total landscape destruction and heavy loss of life; moderate to heavy damage to sturdy or Earthquake-resistant buildings; felt in extremely large regions.	One per year
9.0+	Great	Total landscape destruction and massive loss of life; permanent changes in ground topography.	One per 10-50 years

(*Source*: Earthquake facts and statistics, United States Geological Survey. http://earthquake.usgs.gov/learn/topics/)

Table 7.2: Description of the Levels of Modified Mercalli Intensity

Intensity	Shaking	Description/damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Weak	Felt quite noticeably indoors, especially on upper floors of buildings but many people do not recognize it as an Earthquake; standing motor cars may rock slightly; vibrations similar to the passing of a truck.
IV	Light	During the day felt indoors by many, outdoors by few; at night, some awakened; dishes, windows, doors disturbed; walls make cracking sound; sensation like heavy truck striking building; standing motor cars rocks noticeably.
V	Moderate	Felt by nearly everyone; many awakened; some dishes, windows broken; unstable objects overturned; pendulum clocks may stop.
VI	Strong	Felt by all, many frightened; some heavy furniture moves; few instances of fallen plaster; slight damage.
VII	Very strong	Everybody runs outdoor; damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Slight damage in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse; great damage in poorly built structures; fall of chimneys, factory stacks, columns, monuments, walls; heavy furniture overturns.
IX	Violent	Considerable damage in specially designed structures; well-designed frame structures thrown out of plumb; buildings shifted off foundations; ground cracks conspicuously.
X	Extreme	Some well-built wooden structures gets destroyed; most masonry and frame structures destroys with foundations; damage to transportation network.
XI	Extreme	Few structures remain standing; bridges destroys, fractures in ground; underground pipe lines disturbed; Earth slumps and land slips; great damage of transportation network.
XII	Extreme	Total damage; waves seen on ground surfaces; lines of sight and level distorted; objects thrown upward into the air.

(*Source*: Earthquake facts and statistics, United States Geological Survey. http://earthquake.usgs.gov/learn/topics/)

moving in relation to each other and this relative movement of plates is the fundamental cause of Earthquakes. Nearly all seismic, volcanic and tectonic activities take place along the boundaries of these moving plates. Therefore, the boundaries between different plates have an important significance. You may know that these are recognized as convergent or destructive plate boundaries, transform or conservative plate boundaries, and spreading or divergent plate boundaries. Most of the Earthquakes like shallow, intermediate and deep are found to occur along the convergent plate boundaries where oceanic plates are undergoing subduction. Strong pressures build up at downslanting contact of the two plates, and are relieved by sudden fault slippages results in high magnitude Earthquakes. The best examples of such great plate boundary Earthquakes are experienced in Japan, Alaska, Chile and other narrow zones close to oceanic trenches and volcanic arcs of the Circum-Pacific Zone.

> You may find recent information on world Earthquakes at http://www.earthquakes.bgs.ac.uk/earthquakes/recent_world_events.html

Transform boundaries are those where two plates just glide past each other without any collision. This mechanism happens along the transform faults. For example, the San Andreas Fault forms the transform boundary between the American plate and the Pacific plate in California. Moderate to strong Earthquakes are found to be occurring along this zone. Spreading boundaries are identified at the mid-oceanic ridge and its branches where new lithosphere is created and spreading on either side of the ridge. The mid-oceanic ridges and the African rift system zone stretch out mostly along mid-oceanic ridges and transform faults, and contains with shallow Earthquakes. Earthquakes also occur at scattered locations over the continental plate's far away from active plate boundaries. These are related to the Mediterranean and Trans-Asiatic Earthquake Belt extending along Alpine Mountain System of Europe and North America, through Asia Minor and Himalayan System including Tibet and China.

SAQ 4

What is an earthquake?

Spend 5 mins

7.6 SUMMARY

Thus, in this Unit, you have studied and understood the following important aspects:

- As you know many of the features found on the Earth's surface are not stable or changeless. Changes will continuously occur both on the surface and beneath the surface.
- The relief of the Earth's surface is created by the interaction of both endogenetic and exogenetic processes. The forces coming from within the Earth known as endogenetic forces which give rise to land upliftment and subsidence, folding, faulting, earthquakes, and volcanism, etc.
- You have learnt that endogenetic forces are responsible for the creation of major relief features of the earth's surface such as mountains, plateaus, plains and valleys, etc.

- There are two types of Earth movements namely diastrophic and sudden movements which may occur as a result of the work of endogenetic forces.
- Diastrophic movements comprising both vertical (epeirogenic) and horizontal (orogenic) movements operate very slowly, and their effects become perceptible after thousands and millions of years.
- Sudden movements result into sudden and rapid events such as Earthquakes and volcanic eruptions which produce volcanic mountains and lava plateaus.

You will learn about exogenetic processes in detail in the next Units 8 and 9 of this Block.

7.7 TERMINAL QUESTIONS

1. What are diastrophic forces? Explain these with suitable illustrations?
2. Explain various types of volcanoes?

7.8 ANSWERS

Self-Assessment Questions

1. The forces coming from beneath the Earth's surface and causing horizontal and vertical movements are called as endogenetic forces. These movements are leading to land upliftment, subsidence, folding, faulting, volcanism, and Earthquakes etc. Endogenitic forces are responsible for giving birth to major relief features such as mountains, plains, valleys, etc.
2. a) True; b) False; c) False; d) True
3. a) -iv), b) -iii), c) -i), d) -ii)
4. An Earthquake is a vibration or shaking of the ground caused by rocks breaking under sudden forces and movement of large sections of the Earth's crust.

Terminal Questions

1 Diastrophic forces are one of the types of endogenetic forces and they operate from beneath the Earth's crust. These forces are actively involved in the formation of primary landforms such as mountains, valleys, plains etc. Diastrophic forces can be divided into two groups such as epeirogenic and orogenic movements. Epeirogenic movements are vertical movements caused by a set of forces acting along the Earth radius. Orogenic movements are affected by tangential forces that come into action on Earth's mantle in a horizontal direction. For complete details refer to Sec. 7.3.

2 Volcanoes classified based on mode of eruption are central and fissure types. On the other hand, volcanoes are also categorized as active, dormant and extinct related to the frequency of eruption type. For complete details refer to Sub-sec. 7.4.2.

7.9 REFERENCES/FURTHER READING

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UNIT 8

EXOGENETIC PROCESSES-I

Structure

8.1 INTRODUCTION

In Unit 7 of this block, you have studied about endogenetic forces that operate within the Earth's crust and are responsible for land upliftment and subsidence, folding, faulting, Earthquakes, volcanic eruptions, etc. In this unit, you will learn the subject of exogenetic processes or forces originated from the Earth's atmosphere, and are continuously engaged in the destruction of major relief features created by endogenetic forces. Exogenetic processes are active and visible on the Earth's surface. There are three basic types of exogenetic processes namely weathering, mass wasting and erosion occurs on the Earth's surface.

In Sec. 8.2, you will learn the origin and consequences of weathering and mass wasting processes on the Earth's surface. Weathering simply refers to disintegration and decomposition of rocks in-situ by weather phenomena i.e. temperature, precipitation, freezing and thawing, etc. Mass wasting or mass movement is a process by which the weathered material moves downslope under the force of gravity.

While studying Sec. 8.3, you will learn about the concept of cycle of erosion. You will also study about the theories of landform development propounded by

William Morris Davis (American Geographer and Geomorphologist) and Walther Penck (German Geomorphologist). Erosion is the movement of weathered material, which is primarily performed by the various geomorphic agents. The work of river, glacier, groundwater, sea waves and winds under various external processes are explained broadly in Unit 9. Now you will study the process of weathering and mass wasting, and the concept of cycle of erosion in this unit.

Expected Learning Outcomes

After studying this unit, you should be able to:

- ❖ explain the process and types of weathering;
- ❖ define and classify the mass wasting;
- ❖ elucidate the processes involved in the formation of various landforms by geomorphic agents; and
- ❖ describe the concept of cycle of erosion explained by W.M. Davis and W. Penck.

8.2 WEATHERING AND MASS WASTING

Have you ever observed the local topographical features of your surroundings? For example, physical features like mountains, valleys, plains, rivers, deserts coasts, etc., may appear with little change over a long period of time. Is it true that these features are not changing since the Earth has evolved? In fact, centuries back people thought that mountains, deserts and lakes, etc., cannot alter their form and are permanent features on Earth's surface. Advanced scientific experiments discovered that the Earth has been evolved 4.6 billion years ago, and the Earth's features are continually succumbing to the exogenic processes of weathering, mass wasting and erosion along with the affect of climate change.

Exogenetic forces are also called land wearing forces.

As we observe, the processes lead to alter the topography are mostly working slow and ongoing. But, some processes reveal change with sudden effect for example events like Earthquake, flood, landslides, etc. We can understand that Earth is a dynamic planet, and the behaviour of the external processes on the Earth's surface is more predictable.

You now know that the epeirogenic and orogenic forces elevate the land, while opposing exogenetic processes continually wear it down. **Exogenetic/ exogenic/epirogene** forces are also called as denudational or destructional processes originated within Earth's atmosphere. These are operated largely by the force of gravity. Various geomorphic agents such as running water, groundwater, glaciers, wind and waves remove the disintegrated rock materials from one part of the Earth's crust, and transport as well as deposit them elsewhere. These processes are continuously engaged in the rock wastage, land destruction or land sculpture that may collectively be defined as denudation or degradation. In this section we will focus on the process of weathering and mass wasting. Let us now discuss about the process of weathering.

Weathering is a static process. It continuously engages in the process of disintegration or decomposition of rock in-situ, that means, it does not involve in the process of removing rock materials by a transporting agency. The products of weathering, e.g. sand, clay, and rock fragments etc., tend to accumulate on the spot as soft surface layer called regolith, which covers the bed rock. Scientific definition of weathering involves mechanical fracturing or chemical decomposition of rocks by natural agents at surface of the Earth. Weathering process is of mainly two types- (i) **physical** or **mechanical weathering** (ii) **chemical weathering**. Before discussing about the types of weathering, you shall know the important factors that affect the weathering process.

Controlling Factors of Weathering

Weathering plays a major role in denudation process. The nature and intensity of weathering vary from place to place and from region to region. There are mainly four variable factors namely rock structure, climate, topography and vegetation, which influence the type and rate of weathering. The physical structure of the rock includes rock massiveness, porosity, permeability, joint patterns, bedding planes, faults, fractures, etc., and mineral composition of the rock involves chemical composition, grain size, crystallinity etc., largely affect the nature and intensity of weathering. The minerals forming the rock determine whether rock is more susceptible to chemical or physical weathering. Rocks have high percentage of carbonates, which consist of more soluble minerals those can easily be affected by the chemical weathering. Rocks with numerous joints allow the entry of water, air, and roots of the trees, etc. and are more subjected to mechanical disintegration. Horizontal bedded rocks are affected by the mechanism of disintegration and decomposition, whereas vertical strata is broken down due to frost action and ice.

The major climatic factors include temperature and humidity that play an important role in determining the rate of weathering. Topographical factors include elevation, slope and aspect that also influence the rock exposure responsible for weathering. The nature of weathering is largely determined by natural vegetation cover and its type in a particular region. Vegetation covers and protects the rock outcrops from the direct impact of sunrays but at the same time the roots penetration breaks down the rocks which leads to the disintegration of rocks. We now know that the weathering takes place in two types of processes i.e. physical weathering and chemical weathering. Physical weathering is more effective in warm and wet environments, whereas chemical weathering is apparently more effective in cold and dry environments. Usually, in most places both physical and chemical weathering processes operate considerably at a time and are difficult to separate them for ascertaining the work that has been carried out individually. We will now study about the physical weathering in the following section.

8.2.1 Physical or Mechanical Weathering

Physical or ***mechanical weathering*** is the breakdown of massive bedrock into smaller fragments ranging in size from large blocks or boulders to fine sand and silt by various physical stresses. It involves mechanical disintegration of rocks without any change in its chemical composition through several ways, namely frost action, salt-crystal growth, thermal expansion and contraction and the mechanical action of plants and animals. We can understand it is a simple process involved in the disintegration of rocks over time as illustrated in Fig. 8.1. It begins with the formation of cracks in bedrock. When cracks widen and deepen, the rock becomes susceptible to disintegration. Those cracks are called joint lines that may extend from ten to hundreds of meters into the bedrock.

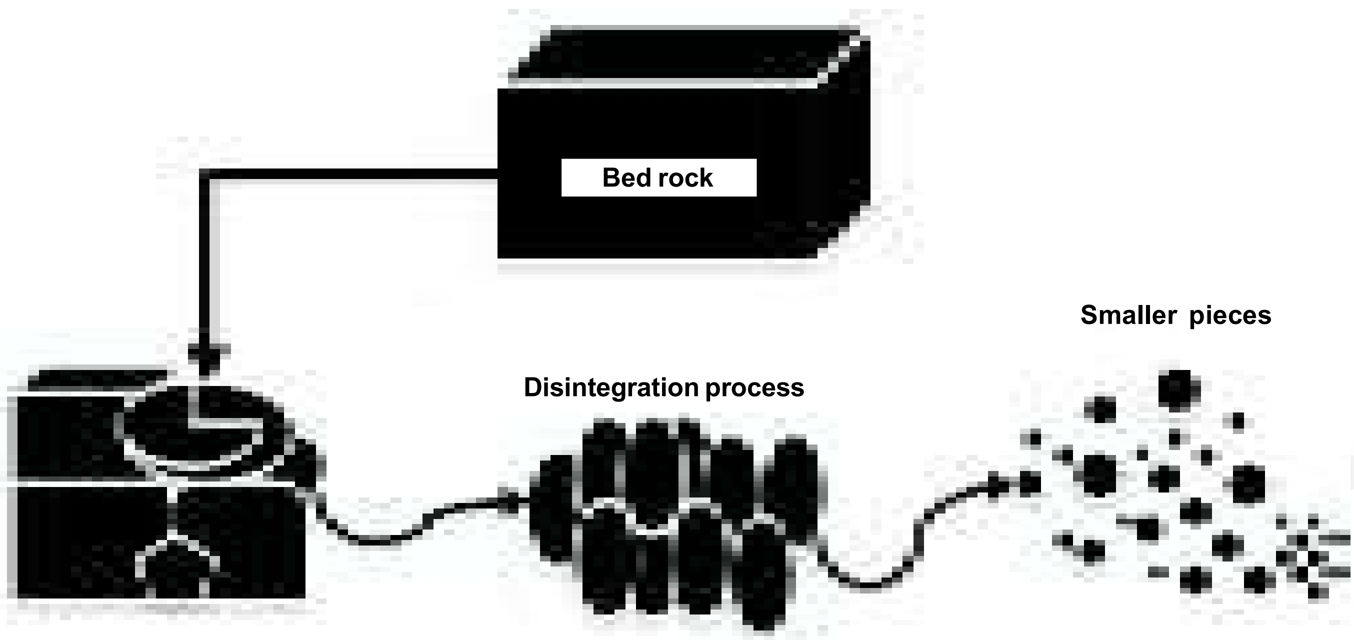

Fig. 8.1: Mechanical disintegration of rocks; intersecting joint lines leading to the formation of blocks; and smaller particles that are subsequently eroded away.

Frost action *or* ***ice wedging*** is one of the most effective types of mechanical weathering. Water in the rock periodically freezes and thaws during night and day. The water entered into the joints freezes and forms ice, which causes the joints deepening and widening. When the ice thaws, the water flows further deep into the rock. Generally, when water freezes, it increases about nine percent in volume. This repeated expansion activity of water can cause pressure in rock pores, cracks and crevices leading to the disintegration of rocks. This process is found to be most effective in well-bedded or jointed rocks, and very common in cold climatic regions (–5° to –15°C). Frost action is responsible for the rock debris that accumulates at the base of mountain slope which is called *talus slope*. See Fig. 8.2, which shows the effect of frost action on the rock. This process can be commonly observed in the polar and high mountain landscapes.

Salt crystal growth is caused by the crystallization of salts from evaporating water. In arid regions, dry weather draws moisture to surface through rock openings by capillary action of water, which may contain salts. As the water evaporates, the salts are left behind as tiny crystals. These crystals expand as

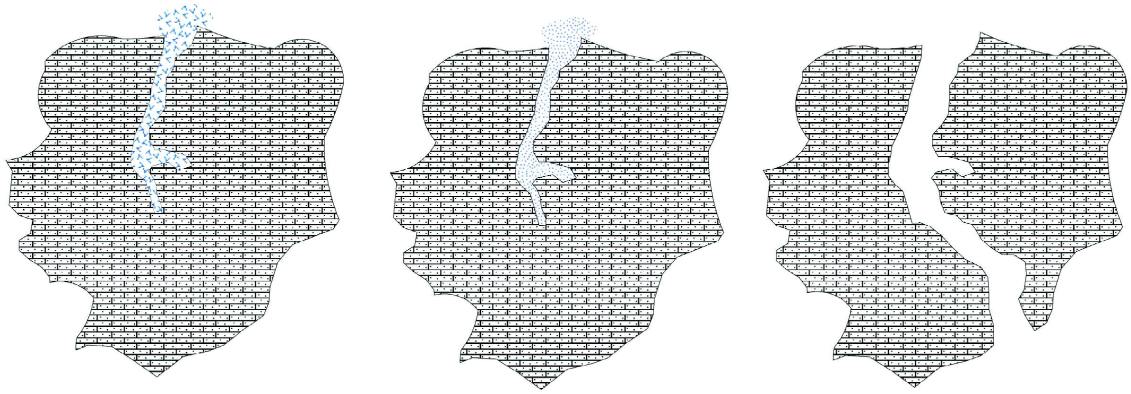

Fig. 8.2: **Frost action: a) water seeps into cracks; b) water freezes to ice; and c) breaks the rock.**

they heat up or dry, and exert a force or enough pressure towards breaking up the rocks. ***Thermal stress*** weathering results from the expansion and contraction of bedrock which is caused by rapid temperature changes. This type of weathering is mostly found in desert regions where there is very hot in the day and cold in the night. Some rocks such as shales and sandstones are less affected by temperature changes because the particles between the rock layers are separated by the silica. Whereas crystalline rocks like granites in which particles are closely associated with each other so that they gets affected by expansion and contraction due to temperature variations. In the hot desert areas, the outer layers of the rock expand from heat in the day, and contract from rapid cooling during the night. Differential expansion and contraction due to diurnal range of temperature causes the tension and stresses leading to the formation of parallel joints in the rocks. This process is termed as ***exfoliation***. Physical weathering along with the chemical weathering processes further weaken the joints, the layers thereby start peeling off in sheets or slabs of rock rather than eroding grain by grain (Fig. 8.3a). Expansion process can also be observed in rock quarrying where rock explodes and breaks after blasting operations.

Plants and animals are also direct contributors to the mechanical weathering. The penetration of plant roots into cracks exert expansive force that widens joints and other fractures (Fig. 8.3b). This can lead to the eventual disintegration of an entire rock mass. Furthermore, the activities of dead organism also significant factor in rock disintegration where they promote chemical weathering processes.

8.2.2 Chemical Weathering

Chemical weathering is the breakdown of rocks by the alteration of rock-forming minerals. Chemical alteration of minerals involves many types of reactions between the atmospheric and biotic agents. Some minerals (e.g. olivine and augite occur in basalt) are far more alterable than others like quartz. Quartz is extremely resistant to chemical change and slightly soluble in water and more in saline water. It is known that many minerals soluble in rainwater are usually acidic in nature and leach rocks quite actively. Chemical weathering is most effective in warm and humid climates compared to cold

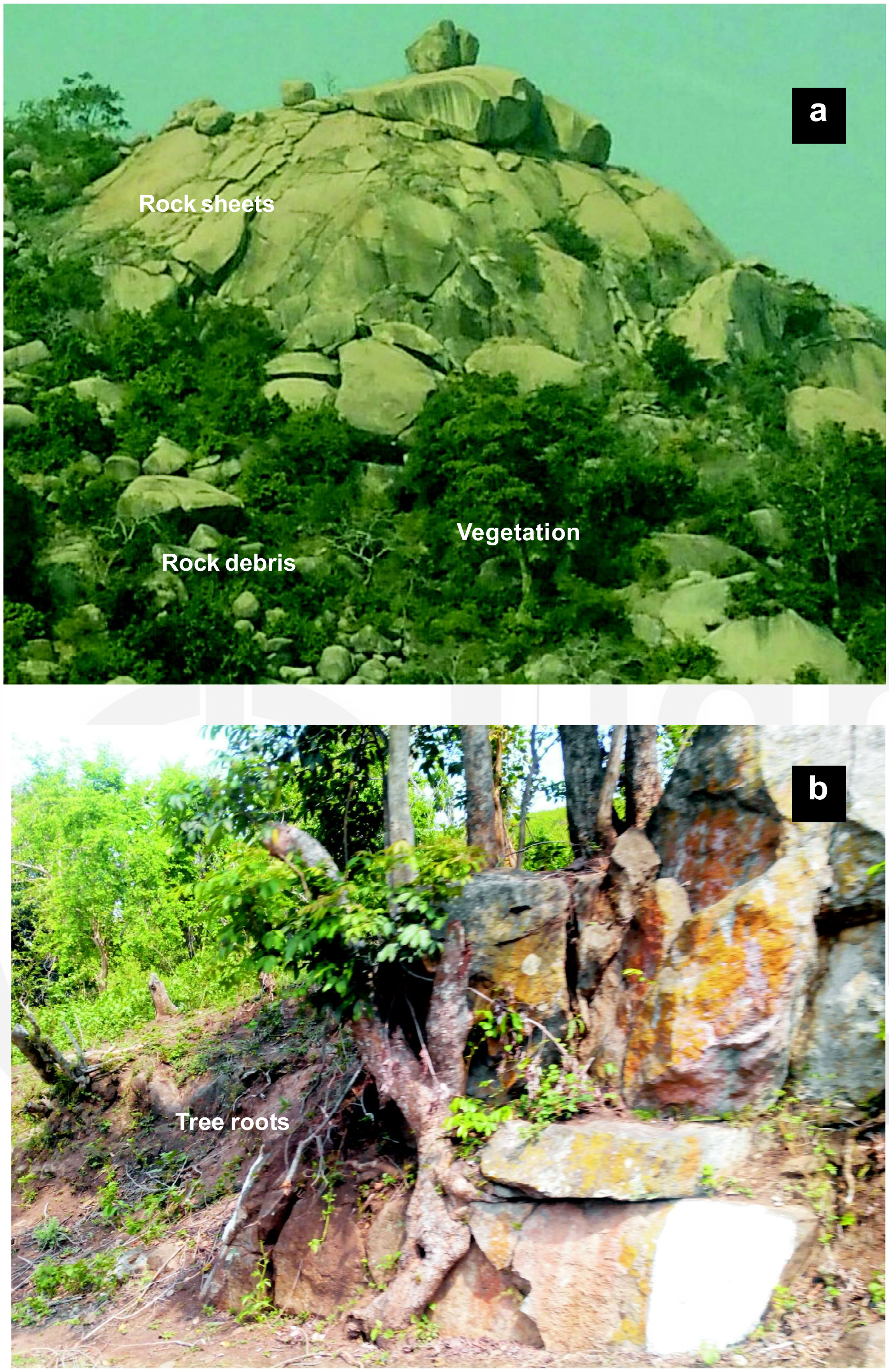

Fig. 8.3: a) Rock exfoliation; b) roots grow into rock cracks leading to formation of fractures.

and dry regions, where heat and moisture are in abundance. Chemical weathering involves a number of processes, all associated with moisture, disintegrate the minerals in rock. Most significant among the processes of chemical weathering are ***carbonation, hydrolysis,*** and ***oxidation***.

Carbonation starts in the atmosphere, which involves the condensed vapor in the cloud and carbon dioxide. You may know that carbon dioxide (CO_2) in the atmosphere combines with rainwater forms a weak carbonic acid (H_2CO_3). When rainwater infiltrates into the ground, it takes on more carbonic acid. For instance, carbonate rocks such as limestone and dolomite are altered by the dissolving action of H_2CO_3. From this reaction, a very soluble product i.e. calcium bicarbonate is produced that can be easily removed by runoff or groundwater. In other words, the seepage of acidic water in the limestone region leads to the rock corrosion and leaching. This is more prominent in karst topography regions. Karst landforms are developed by various chemical weathering processes where underground water widens the cracks of limestone rock through carbonation.

When water-carrying acids penetrate into the contacts of rock crystals they are able to absorb certain minerals. In this *hydration* process, no chemical change occurs but various chemical reactions may take place leading to alteration of mineral content. One set of these reactions is **hydrolysis –** a process involving chemical combination of water and a mineral. The process involves active participation of water in chemical reactions to produce a new mineral compound. The significant result of hydrolysis is that it produce a weaker or soft mineral, which results to disruption of the rock. For example, silicate minerals like potassium feldspar present in many igneous rocks are weathered and a clay mineral, Kaolinite, is formed that is susceptible to disintegration. Most of the minerals, except highly resistant mineral like quartz, are very susceptible to chemical change when exposed to atmospheric and biotic agents. Hydrolysis is mostly observable in weathering of granite and igneous rocks that alters the minerals irreversibly.

You may observe many of the rusting metals in your locality. What do you think of the causes behind it? You can also find rusting of iron in water supply pipes, which can be commonly seen in several dwelling houses. You might have also observed the rusting in old blades or iron knife/forks, etc. These are very common examples around us. This is a work of oxidation process commonly occurring in the natural environment. ***Oxidation*** is a process, in which the dissolved oxygen in water comes into contact with certain rock minerals, especially iron, to form oxides. Oxidation generally accompanies hydrolysis and is the most apparent in rocks containing iron. When oxygen combines with iron, the reddish iron blisters are formed which is probably the most common oxidation effect in the lithosphere. This process is known as rusting, and is responsible for an initial indication of chemical weathering in many rocks due to their discolouration as brownish-red to red. When the iron is oxidized, it forms ferric iron, which in turn is transformed into limonite. Limonite is a mineral that resembles with rust. We can see colourful stains on rock faces where groundwater is supposed to seeps from rock faces mixing with iron and other oxides. You can observe the rusting on iron pipe in domestic water supply (Fig. 8.4).

Spend 5 mins

SAQ 1

Describe the weathering process and note the principle chemical weathering processes.

Fig. 8.4: Process of rusting on iron tap.

8.2.3 Mass Wasting

You have got knowledge in understanding the process of weathering in which the massive bedrock breaks up in a place, and is made available for movement. The weathered material is moved relatively for a short distance down the slopes under the influence of gravity with or without the assistance of running water called ***mass wasting*** or ***mass movement***. There are several factors favoring mass wasting such as structure (closely spaced joints, faults, etc.), composition and permeability of rocks, topography (steep slopes and cliffs), climatic factors (large variations in temperature, heavy rainfall, etc.), vegetation cover, and also the role of slope gradient is another more important factor of mass wasting. Do you know the huge amount of debris may involve in the mass movement that can be sometimes able to bury a town or village? Rugged young mountains are the sources where rapid mass wasting events can be observed. Generally, young mountains are eroded by rivers and glaciers into regions characterized by very steep and unstable slopes that result in sudden destructive slides and falls. When pores in the sediment are filled with water, they cause the materials slide past one another due to loss of bonding among the sediment particles. Normally water adds considerable weight to a mass of materials. When heavy rainfall occurs, the added weight sometimes may cause the material to slide or flow down slope. You might have observed in some places, particularly in hilly regions that the forest or vegetative cover is often removed for various purposes like timber, farming, mining or development resulting in large scale destruction finally leading to surface materials to move down slope. We know that the trees protect against erosion and contribute to slope stabilization due to their root system, which holds the soils and regolith. It is well known fact that the removal of plant cover triggers mass wasting. Due to an Earthquake and its aftershocks particularly faulting and jointed bed rocks can dislodge enormous volume of rock materials.

Gravity is a natural force which attracts every object towards the center of the Earth.

Isaac Newton, renowned physicist, first proposed universal gravitation law in 1920 says that any object in the universe attracts every other object with a gravitational force, which lies between the centre of the two objects.

If the material lies on flat Earth's surface, it will not move further due to gravitational force, the reason is that the gravity acts downward parallel to ground. Where there is an availability of steep slopes, the material will move down slopes under the force of gravity.

We now discuss briefly about types of mass wasting. There are mainly three basic classes of mass movement such as falls, slides and flows. See Fig. 8.5, which depicts the processes involved in the formation of falls, slides and flows. Falls involve the process of falling rocks down the slope. The sliding occurs where the velocity at the base is similar to that at the top, so the material

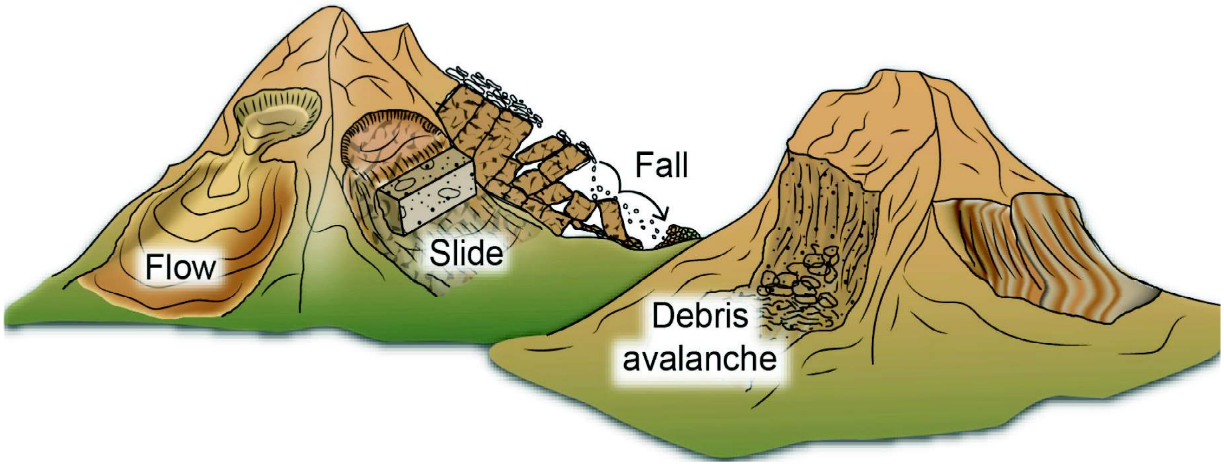

Fig. 8.5: Types of mass movement.

behaves as a rigid solid that detaches along a basal surface e.g. slumps and landslides. In flowage, the material behaves as a fluid because the velocity of flow is maximum at the surface for example soil creep, Earthflows and mudflows.

Falls: Falls refer to the free falling of pieces of rock over any steep slope. In this process, the rock blocks or fragments are dislodged from a cliff or steep slope, and fall, roll or bounce down to the cliff foot. These falls mostly occur in the mountainous region due to frost action and other weathering processes. The resultant broken rock material accumulates at the foot slope forming steep ramp-like incline and are collectively referred to as *talus* or *scree*.

Slides: Slides occur when the large masses of rock as a unit or block moves downslope abruptly. This type of mass wasting where in a mass of rock or soil material slips downhill over a slippage surface is called failure plane. Landslides are the most significant type of mass wasting, which is an instantaneous collapse of a slope sometimes happens without water lubricant or clay. Do you think that landslides occur in a sudden movement of slope displacement in a fraction of time? The answer may be yes, but it commonly occurs in a series of minor displacements over days and more, or even a long period of time. In slides, the displacement can be of one meter to several meters or more downslope.

Flows: Plastic nature of materials that may have liquid or non liquid stability are in flowing motion termed as flows. The most common slower flow type of mass movement is creep or soil creep. The slowest and imperceptible downhill movement of debris and soil is described as creep. The mechanism involves freeze/thaw and wet/dry conditions contributing to soil creep by progressively moving soil particles down the hill. The rate of creep is very slow. We may observe the evidence of this process in the field through downward curvature of trees and gravestone, the tilt of fencing posts, electric and telephone poles, and inclined structures on creeping slopes, etc. Vegetation cover can help to reduce the rate of soil creep.

Some flows are characteristically rapid movement, and occur when the soil mass is being saturated with the water. The most common type of flow movements are Earthflow and mudflow. The rapid movement of water-laden soil material flowing down on low-angle terraces or hill sides is known as

Earthflow. This can happen on any steep slopes when the underlying rocks are in saturated condition during or after rainfall. At the top of the area, a steep scarp is developed where the moving debris is pulled away from the upper slope. The flow effect is very clear in the lower portion; where a toe of material pushes out over the valley floor. On the other hand, a ***mudflow*** is a mass of saturated rock particles of all sizes soaked with sudden heavy rainfall and/or shallow groundwater. The runoff waters carry the soil and rock debris from a large slope area, and wash them to a valley or canyon. Then the water and debris move down the mouth of the canyon and spread out on the gentle slopes below. Mudflows are very common in the arid and semi-arid regions. They often begin as slides or slumps, emerging from failure mass, and moving long distances downslope.

SAQ 2

Spend 5 mins

a) Link falls and slides.

b) Mark the following statements as True or False?

i) Gravity is the controlling force of mass wasting.

ii) Landslide is one of the types of mass wasting.

iii) Rapid mass wasting events always occur only in heavy rains.

iv) Rivers and mass wasting combine to modify and sculpture the Earth's surface.

Till now, in this section, you have learnt two basic external processes which occur on the surface of the Earth, namely weathering and mass wasting. You might have understood how weathering occurs and also the types of weathering processes such as physical and chemical weathering. You also studied briefly about mass wasting and its types. Mass wasting is the down slope movement of rock and soil under the direct influence of gravity. In the following section, you will learn about the concept of cycle of erosion, and Davis and Penck's views on the cycle of erosion process.

8.3 CONCEPT OF CYCLE OF EROSION

You now know the endogenetic forces that create various types of relief features in different dimensions on the Earth's surface. Whereas the exogenetic processes are operating on the relief and trying to eliminate the differences made by the endogenetic forces, and bringing the surface to the sea level or base level. Erosion is a process in which various erosive agents obtain and remove rock debris from the Earth's crust, and transport them for a long distance. In the process of erosion, if new relief feature is formed then the same process sets renewed again till the feature is converted into featureless plain called *peneplain*. The destruction of these relief features levelled upto sea level due to the process of erosion, which is defined as ***cycle of erosion***.

The concept of the cycle of erosion or geographic cycle of erosion is initially proposed by William Morris Davis, American Geomorphologist and Professor of Physical Geography at Harward University, in 1899, which was key idea in the history of geomorphology. The main concept of Davis was to arrange landforms into a cycle of development. There are mainly five theories proposed about the development of surface relief or landform in the history of geomorphology such as W.M. Davis (1899), W. Penck (1924), K.K. Markov (1948), L.C. King (1962), I.P. Gerasimov and J.A. Mecerjakov (1970). In the following subsections, we will focus on the process of cycle of erosion proposed by Davis and Penck.

8.3.1 Davis Model

The geographical cycle theory of W.M. Davis was the first modern theory of continental erosion and landscape evolution. He postulated his concept of geographical cycle is a period of time during which an uplifted landmass undergoes its transformation by the process of land sculpture ending into low featureless plain or peneplane. He assumed that the initial form of landmass got uplifted from beneath the sea by Earth movements. According to Davis, the landscape is a function of structure, process, and stage. All of these three play a dominant role in the origin and development of landforms in a particular place. Structure deals with the nature of rock (whether hard or soft) as well as its structural characteristics (folds, faults, etc.). In the soft rock, the cycle is completed in short duration compared to the hard rocks. Process is concerned with internal and external forces that shape the landscape. Stage means the length of time during which the processes are at work. Land sculpture varies in different stages. When landmass is uplifted, the erosional agents start working on it to convert featureless surface. Davis envisioned a continuous sequence of terrain evolution which is linked to the life cycle of organism defining as youth, mature, and old stages. Fig. 8.6 explains the three basic stages of erosion.

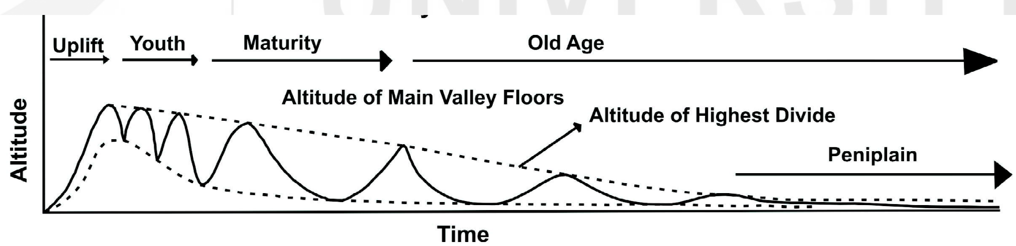

Fig. 8.6: Diagrammatic representation of Davisian cycle of erosion.

Youthful Stage

The process of denudation is initiated by the upliftment of landmass above sea level. In humid climatic environment, because of sufficient rain, a system of streams normally develops on the emerged landmass. The top surfaces or summits of stream divides are not affected significantly by the erosion. The stream divides are separated by small rivers and tributaries that are engaged in headward erosion. These streams with incise deep, steep sided, narrow, v-shaped valleys, flow rapidly, and have irregular gradients marked by waterfalls and rapids. In this stage, shallow lakes and swamps can be found due to the incomplete drainage system. By the end of the middle youth stage the valley side slopes experience retreat, and as tributaries start to extend their valleys into the interfluve area by headward erosion. This is the reason, as Davis described, the area is in a younger and juvenile stage of development.

Maturity

The early stage of maturity indicates lateral erosion and the well integrated drainage system. The falls and rapids are worn away and thus the area would develop smooth profiles. The main river and its tributaries are graded to the base level of erosion. The stream will consume less amount of energy to move its load that results in the reduction of valley deepening due to the substantial decrease in channel gradient and flow velocity. Because of the lateral erosion, V-shaped valleys of youthful stage are transformed into broad U shapes, and sometimes produce floodplains. By the end of mature stage, relief is reduced rapidly and valley floors exceed slowly by the nature of graded streams.

Old Stage

This stage is characterized by the gradual reduction of river gradients and associated decline of stream energy, absence of valley incision, and sharp decrease of relief, etc. The area is dominated by extensive flood plains over which a few major streams meander broadly and slowly (Fig. 8.7). By the end of old stage, the whole surface approaches closer and closer to the base level, termed by Davis a *peneplain* meaning near plain. Above the peneplain a few erosional remnants are described as *monadnocks* after Mount Monadnock in New Hampshire, USA. Millions of years after the cycle began, the land is subject to renewed uplift which includes a new cycle of erosion, a process which Davis termed as rejuvenation.

This theory was very popular among the educators and researchers in the first half of the twentieth century, because of its easiness in understanding landscape development in evolutionary terms. The geographical cycle' sequential stages such as youth, mature and old could appear in many areas in the nature. However, there are some imperfections observed in his assumptions and raised doubts about his conclusions by the scientific community. For example, most interfluves appear to grow narrower with parallel retreat of valley slopes but as Davis described interfluves grows lower as the cycle advances. A more important difficulty with Davisian model is that the land upliftment does not take place until the cycle is completed. Another example, the peneplain surfaces are recognized in some areas but not everywhere. The scientific evidences also show that isostasy takes place more or less continuously as denudation advances.

> **Peneplain**
> It means almost a plain. *Paene* is a Latin word meaning '*almost*'.

8.3.2 Penck Model

Walther Penck, German geomorphologist, proposed many observations in the 1920's with respect to Davisian Cycle of Erosion. According to him, the landscape characterized in a specified area is related to the tectonic activity of that region. Davis imagined that the landscape is a function of structure, process and time, in which upliftment and denudation process begins to work

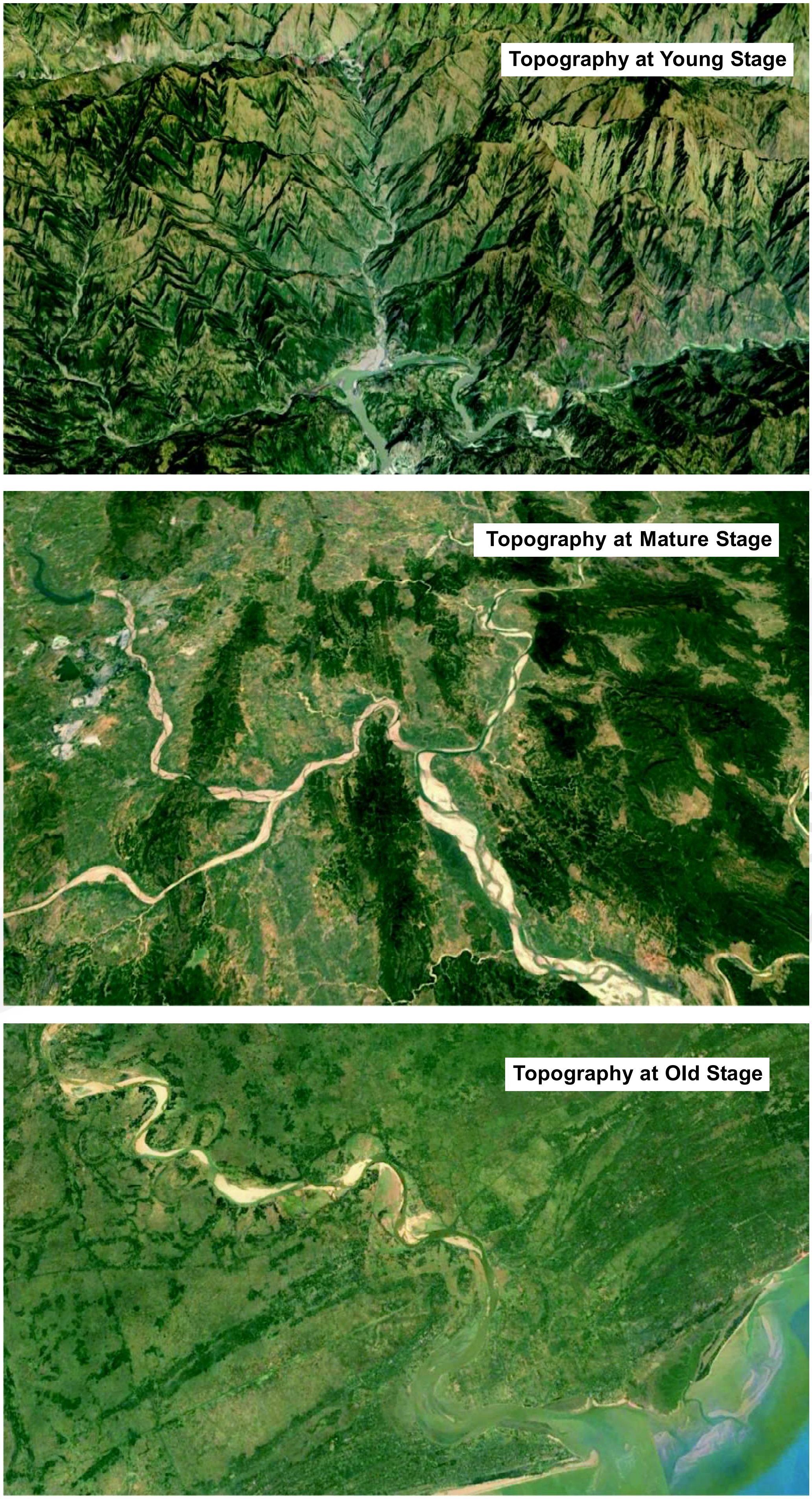

Fig. 8.7: Davisian idea of geographical cycle depicts various stages of cycle of erosion.

alternatively. Penck's forward thinking is that the landforms are an expression of the phase, and rate of landscape upliftment in relation to rate of erosion, where both upliftment and erosion are in continuous process. According to Davisan model, erosional process starts to work when the landscape is completely uplifted and further the landmass is slowly eroded to endforms of low relief. Penck agreed with the concept of Davisian eroded landforms of low relief but he opposed the rapid upliftment and repeated cycle of endforms erosion. According to Penck, upliftment of the land area and denudation process starts at the same time. He used the term *Entwickelung* meaning thereby development in the place of 'stage'. For the youth, maturity, and old stages he proposed the terms ***Aufsteigende Entwickelung*** (waxing or accelerated rate of development), ***Gleichformige Entwickelung*** (uniform rate of development), and ***Absteigende Entwickelung*** (wanning or decelerating rate of development). Fig. 8.8 explains three basic phases of landscape development as proposed by Penck.

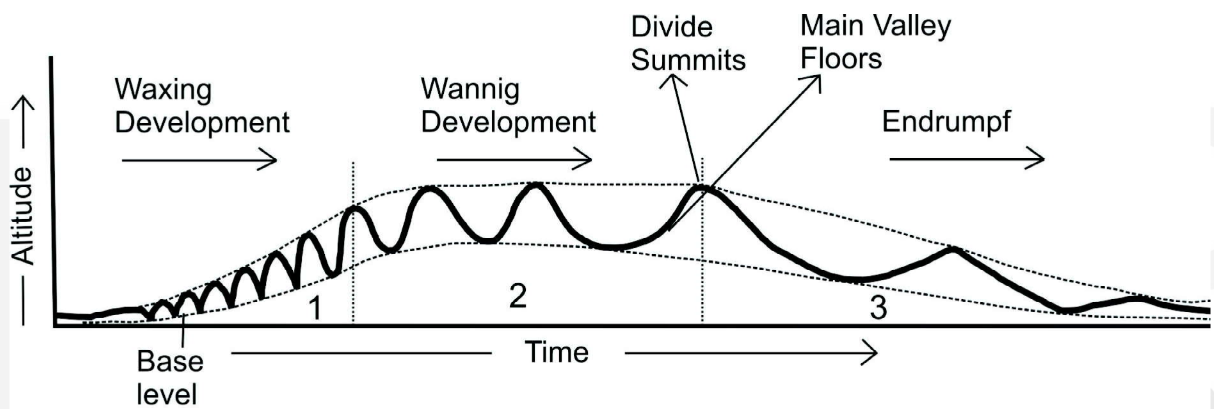

Fig. 8.8: Penck's concept of the landscape development.

In the first phase of development, land surface rises slowly and reaches to the summit level at maximum. The landscape development begins with the upliftment of *Primarumpf* (initial landscape with low height and relief) representing an initial featureless broad land surface. The rivers with accelerated rate of down cutting due to steep gradient and velocity form narrow V-shaped valleys. In this stage, rate of upliftment is high where there is no significant effect of erosion. Since the upliftment of landmass far exceeds the valley deepening, the absolute height goes on increasing. Straight slopes can be observed on valley sides due to lower rate of valley deepening and divide summits. When upliftment rate exceeds the denudation, the convex slopes are formed resulting from waxing or accelerated rate of development called *Aufsteigende Entwicklung*.

Second phase is uniform development of the landscape. Upliftment and denudation match one another that form straight slopes resulting from steady-state development are called *Gleichformige Entwicklung*. Initially, it is characterized by the continuance of accelerated rate of upliftment and attains maximum altitude (absolute relief), but relative relief remains constant. In a subsequent sub-phase, the altitude, and relative relief are unchanged due to the rate of erosion of divide summits that matches the valley deepening. At the end of this second phase, upliftment of the land stops completely. Altitudes of summit divides start decreasing and relative relief remains constant because of the rate of lowering of divide summits which equals the rate of valley deepening.

The final phase of landforms development leads to waning development termed as *Absteignede Entwicklung,* where upliftment is less than the denudation and concave slopes are formed. The progress of upliftment remains constant and erosion process of summit divides gets decreased. It means that the erosional process is dominant, and both the absolute and relative reliefs show declining trend. We can observe in this final phase of landscape development that upliftment is almost absent and valley deepening slows down. The valley side slopes of upper part have steep slopes called gravity slopes while the lower part is called wash slope, which consists of low inclined talus material. Further, ridges of the summit divides are reduced to steep side of conical residuals and their heights get decreased which are called inselbergs. This inselberg landscape is observed by a series of concave wash slopes termed as *Endrumpf*.

SAQ 3

Spend 5 mins

How many stages are identified in the Davisian model of landscape development?

8.4 SUMMARY

So far in this Unit, you have thoroughly studied and understood the following key points:

- As you know land surfaces are constantly undergoing modifications through diverse processes. These processes are categorized as endogenetic and exogenetic.
- You came to know that exogenetic processes originate from the Earth's atmosphere. They involve mainly weathering, mass wasting, and different types of erosional processes.
- You have learnt about two important models propounded by prominent Earth scientists namely Davis and Penck.
- The genetic classification of geographical cycle of erosion was initially proposed by Davis that explains three stages of landscape development namely young, mature and old.
- Penck's view on the denudation processes is that the landmass changes are interrelated with the tectonic activity.
- In nutshell, you have studied the processes related to weathering and mass wasting, and the cycle of erosion. This information will definitely help you to understand the processes carried out by various geomorphic agents in the landform development.

- You will learn elaborately the processes of running water, groundwater, glacier, sea waves and wind in the next Unit 9 of this Block.

8.5 TERMINAL QUESTIONS

1. Explain the chief weathering processes with suitable illustrations?
2. Describe Davis and Penck's views on landscape evolution process?

8.6 ANSWERS

Self-Assessment Questions

1. Weathering is breakdown of the rock by mechanical disintegration and chemical decomposition. Carbonation, hydrolysis and oxidation are three basic types of chemical weathering processes.
2. a) Falls are the downward movement of rock or soil through air, whereas slides occur as large blocks of rock moves downhill abruptly.

   b) (a) True (b) True (c) False (d) True
3. Three stages: youthful, mature and old.

Terminal Questions

1. There are mainly two types of weathering processes such as physical and chemical weathering. Physical weathering is breaking of rocks by various mechanical processes, whereas the rock material is altered into another substance by chemical reactions is known as chemical weathering. You can refer to Sub-sec. 8.2.1 and 8.2.2.
2. The concept of cycle of erosion explains the relationship between the stream erosion and landscape development. In Davis's opinion, the landscape is a function of structure, process and stage. Penck's hypothesis mainly envisages that the landform evolution of a particular region is dependent on the tectonic activity of the region concerned. You can refer to Sec. 8.3.

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UNIT 9

EXOGENETIC PROCESSES-II

Structure

9.1 INTRODUCTION

In the previous Unit 8 of this block, you have studied the processes related to weathering, mass wasting, and erosion. As you know, exogenetic processes originated from the Earth's atmosphere are involved in changing the Earth's relief features by denudation. Geomorphic agents include river, glacier, groundwater, sea wave and wind that do the work of denudation. You may be knowing that running water is more forceful than other geomorphic agents because running water is nearly ubiquitous, which exists everywhere except in Antarctica. Sec. 9.2 begins with the study of erosional and depositional processes with the work of running water. Glaciers are masses of ice formed from the accumulation and compression of snow. Though, they are slowly moving but capable of transporting and depositing the eroded materials of the land under them. You will study glaciation and related processes in Sec. 9.3.

Underground water has the ability to dissolve and erode certain types of bedrock giving rise to a complex terrain, which you will study in Sec. 9.4. Sec. 9.5 explains you the wave activity along the seashore that results in creation of various forms and processes. We can see rhythmic rise and fall of tides, and low and gentle waves in the sea. It is known that the shoreline is constantly being modified by waves. In the desert region wind establishes spectacular sand and dust storms, and is continuously carved out the terrain. You will learn about the work of wind in Sec. 9.6. Overall, this unit briefly explains you the work of principal mobile agents on denudation process, and also various geomorphic features which are created by them.

Expected Learning Outcomes

After studying this unit, you should be able to:

- describe the work of river, glacier and groundwater;
- explain the work of sea waves and wind; and
- elucidate the processes involved in the formation of various landforms by geomorphic agents.

9.2 WORK OF RIVER

You may know that the principal erosional agents such as running water, glaciers, groundwater, sea waves and wind are responsible for the erosion, transportation and deposition of materials. The work of river or running water is one of the most important among all the exogenetic processes because rivers remove the materials from the land area and transport to the oceans. The work of river consists of three closely interrelated activities namely erosion, transportation and deposition. Rivers or streams are of mainly two types: perennial and ephemeral. Perennial rivers hold water flow throughout the year which is permanent and are found in humid regions. Many of the major streams and most tributaries carry water occasionally during the wet season or during or after rainfall. These impermanent flows are called ephemeral streams, which are mostly found in arid climates.

The work of running water begins with the effect of precipitation. Rivers receive water primarily from rainfall, snow, hail or sleet, and the same water reaches finally to the sea after undergoing several processes. Due to gravitational force, the water flows downstream, and at the same time some forces, called frictional forces also resist the downstream flow. Water flow depends mainly on these two basic forces of gravitation and friction. Stream erosion is actively engaged in removing materials from its floor or bed, and sides of the channel. The capacity of eroding material generally depends on its energy. Fig. 9.1 illustrates various processes such as hydraulic action, corrosion, abrasion, and attrition of running water.

The river erodes both vertical and lateral. The force of the flowing water sometimes can break the rocks of valley sides and erodes poorly consolidated alluvial materials such as sand, silt, clay and gravel due to the impact of currents of a channel. This erosion process may be called ***hydraulic action***. It is the mechanical erosion, which helps to loosen and remove the materials of rocks by water alone. While removing the materials, the stream channel undergoes some type of chemical process of solution or acid reactions, which dissolute the soluble materials. This process is known as **corrosion**. For example, the river flowing in limestone region dissolves the rocks along the joints and forms cavities in them.

The pebbles and rock fragments strike against the rocks along the river bed and walls that results in weakening the rock to break down. The broken material moves down with the flowing water. In this type of **abrasion** process, the river makes its course deeper and wider. A cylindrical hole carved by the

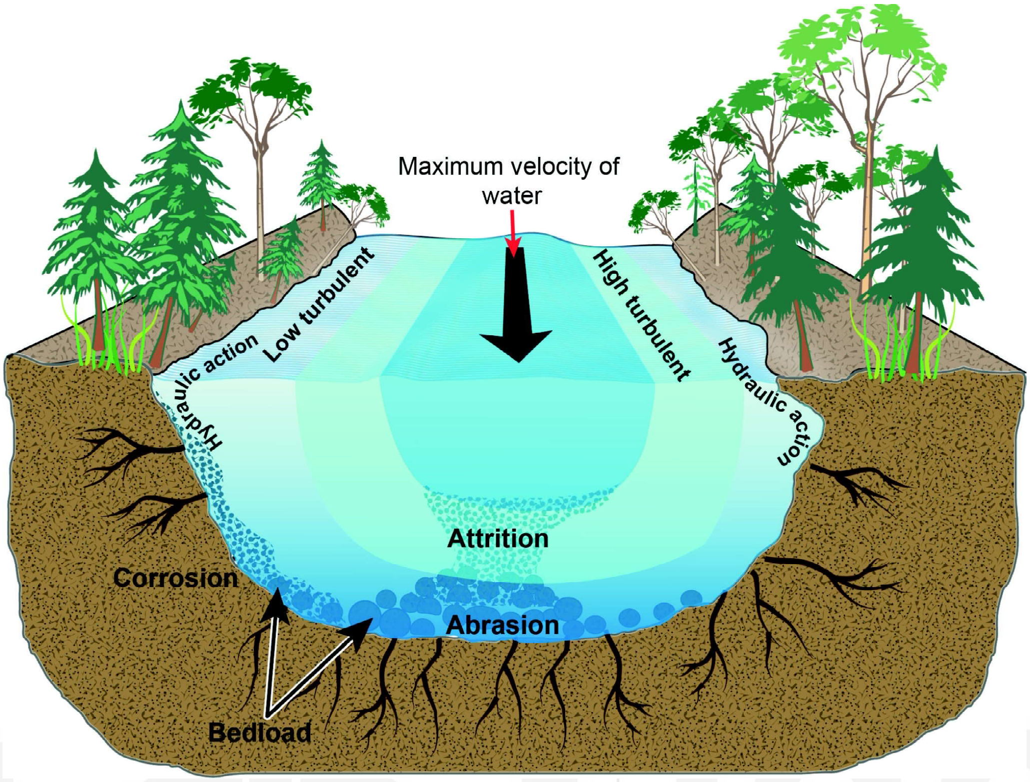

Fig. 9.1: Processes involved in the river erosion.

action of the swiftly moving river, termed as a pothole, is produced by the stream abrasion. Some other important features of abrasion are plunge pools, chutes and troughs. The rock fragments like boulders and cobbles collide against each other while moving with the water and are disintegrated into smaller grains of sand and silt. This process is termed as **attrition**. Because of the erosion, channel widening generally occurs where weathering and hill slope processes contribute to overall widening of the valley. See Unit 8 for understanding the cycle of erosion that explains a V-shaped valley which is the result of youth stage, whereas a broad flat-bottomed valley can be found during the mature or old stages of the river system.

As you have studied that the river carries or transports the rock fragments, sand and silt etc. through its course of flow for long distances. During the transportation, the rock fragments roll down along the bed of the stream in the direction of water flow. In this process, the rolling and bouncing of larger particles (boulders, cobbles, gravel and sand) can strike against one another, and they become smaller, rounded and polished. These materials dragged along the bed are referred as bed load. Some minerals are dissolved in water and carried in solution as the dissolved load. Dissolved particles of clay and silt floats in the river water and carries it in turbulent suspension. If the water is stagnant, these particles are settled down at the bottom. This type of suspended load carried by a stream completely depends on the volume and velocity of a river, and varies based on the size and quantity of the rock. Suspended and dissolved loads are carried in the water column much faster than bed load.

The subject of geomorphology deals with the study of landforms in a scientific way, and those who specialize in this subject are called geomorphologists.

Geomorphologists in their landforms study put their effort into knowing the relationship between river water flow, processes and resultant geomorphic features. You just take a drainage map or toposheet for observing a river. How it is visible on the map? Whether it is bent or straight or curved? It may be of straight, braided, meander or curvy nature. We can find a straight river or stream very rarely. Rills and gullies are hillside channels formed by the action of running water. Rills are tiny channels with a few centimetres wide and deep that are cut by small rivulets. They lead to the formation of long and narrow, continuous and discontinuous, and incised stream beds which are called gullies. They are also named locally as dongas, luvakas, ramps and vocarocas. Stream valley contributes the water to the channel from its surrounding terrain that includes valley bottom or floor and sloping walls. The resistant rock forms nearly vertical walls leading to the creation of narrow V shaped valleys. Rapids and waterfalls are resultant features of V-shaped valleys. More resistant beds create rapids by down streams stepping of gradient below nick point. During the course of time, the erosion eliminates the resistant rock. Waterfalls are formed due to abrupt vertical drop of streams.

Alluvial channels are composed of loosely consolidated sediments (alluvium) which demonstrate the stream ability in the transportation of material. These are categorised into two types i.e. meandering channels and braided channels. Meandering channels are deep and smooth channels, and they transport generally mud that consists of silt and clay. Braided channels are shallow in depth and wide, and transport their load which consists of sand and gravel through water flow. Meanders are sinuous bends of a highly characteristic form.

Fluvial erosional landforms: rill, gullies, rapids, waterfalls, valleys, alluvial channels, etc.
Fluvial depositional landforms: flood plains, alluvial fans, bajadas, terraces, deltas, and so on.

Have you ever observed the flood activity of a river? Majority of the people generally experience, or see or read in the news channels and papers, etc. The effects of flood are particularly experienced by those who are living along the river course. In floods, higher is the velocity of the river, higher is the carrying capacity of load. We may notice that the flooded channels have erratic flow regimes with fluctuations in volume of flow. When the intensity of forces of erosion decreases, then the load of rock fragments, sand, and silt are deposited at near or away from the place of flow. Floodplain is the best example of depositional form wherein coarse material deposits as levees near the channel, and bars mainly at outside of the river meander bends. The fine sediments of silt and clay cover the flood plain. Some of other features like oxbow lakes, sloughs, ridge and swale topography, backswamp, etc., are the result of flood plains. Some of flood plain features are given in Fig. 9.2. The river originates from the mountains and reaches nearly levelled surface, a large scale of rock fragments deposited resulting in the formation of alluvial fans and cones. Maximum scale of deposition occurs near the river's mouth leading to the formation of deltas.

SAQ 1

Spend 5 mins

Name a few erosional and depositional landforms under fluvial processes?

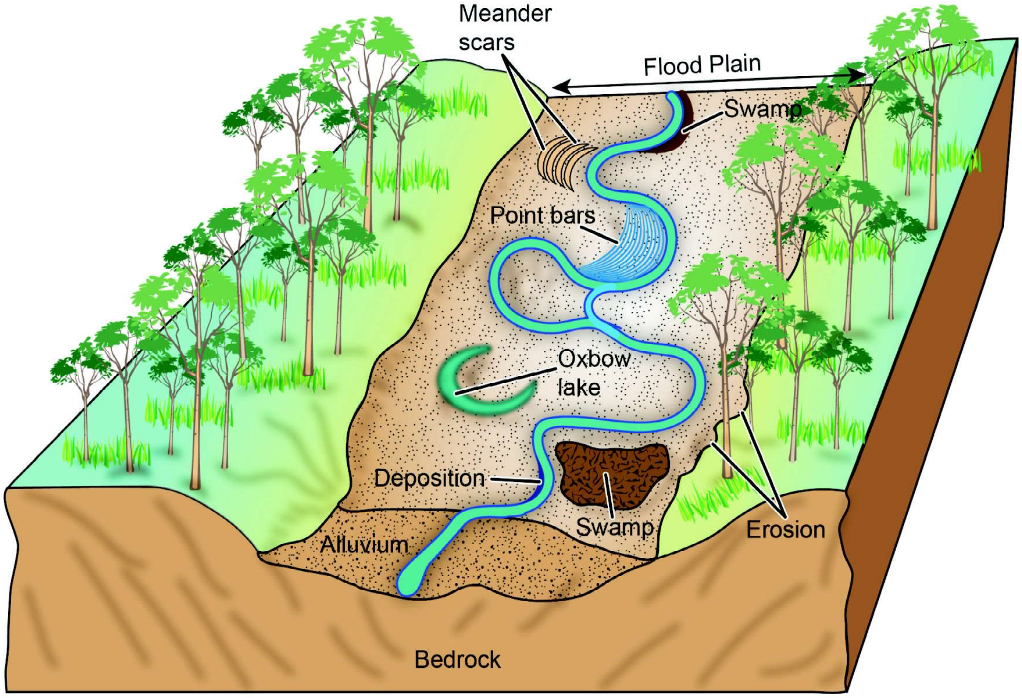

Fig. 9.2. Typical landforms formed by the work of river.

9.3 WORK OF GLACIERS

The subject of glaciology deals with the behaviour of glacial ice. Glacier is formed due to the accumulation of huge volume of ice above snow line, which is the zone between permanent and seasonal snow, under extreme cold climatic conditions. There are two types of glaciers namely **valley glaciers** (mountain or Alpine glaciers) and **continental glaciers**. Valley glaciers can be long or short, narrow or wide, single or multiple branches of tributaries like rivers. Their width is small compared to their length that varies from a fraction of kilometer to few kilometers. Each glacier is a stream of ice that flows down the valley from snow accumulation center near its head. On the other hand, continental glaciers exist in the form of large scale ice sheets in non-mountainous areas of the continents. These enormous ice masses flow out in all directions from one or more accumulation centers. The poles receive very low total annual solar energy which results in the large scale accumulation of ice. Example of this category is Greenland in the Northern Hemisphere and Antarctica in the Southern Hemisphere.

Glaciers can reshape the landscape through erosion, transportation, and deposition of rock materials. Glacial erosion results from the movement of ice over rock floor and accomplishes with the help of rock fragments, which are embedded in the ice by partial melting and refreezing. ***Abrasion*** is a type of erosion, which acts at the ice-rock interface that helps to detach small parts of solid bedrock without its movement. Constant abrasion produces glacial smoothing and polishing. This abrasive process is known as scouring. Scouring creates various types of features. In the scouring process, melt water penetrates into the cracks and joints of rock floor of the glacier and freezes. As the water freezes, it expands and exerts tremendous leverage leading rock to loosen. When rock fragments embedded in the ice at the

Glaciers

- Occupy about 10% of world's land surface.
- Major part of ice-sheets is covered by Greenland and Antarctica.
- The relationship of annual ablation (melting) and accumulation (addition of ice) provide the glacier mass budget.

bottom of a glacier, scratches and grooves called glacial striations which may be gouged into the bedrock. These linear scratches provide clues to the general direction of ice movement. Where strong, sharp-pointed piece of rock held by basal ice and dragged over the rock surface that produces larger curved striations fitted together is known as grooves. Grooves are generally gouged out by groups of boulders packed and frozen together. These furrows are of variable dimensions generally measuring over meter in length.

Ice Age
The most recent ice age in geological epoch named as Pleistocene began about 2.5 million years ago and ended about 10,000 years ago.

Another important mechanism of glacial erosion is ***plucking***. Glacial plucking accomplishes erosion in the same way as abrasion, but it removes larger fragments of the bedrock. Plucking process is the most effective on the lee side of rock mounds. Rock mounds are smoothly polished on the stoss side of ice advancement and show a striated and grooved surface due to abrasion, whereas the other side or lee side may be steep and has an irregular and striated surface. This unique asymmetrical feature is named as a *Roche moutonnee* (French word for *sheep rock)*. These are aligned hills often occurring as groups. We can observe from the Fig. 9.3 on the lee side of the rock is well jointed and is favourable for plucking. On the other hand, the rock surface is moulded due to abrasion on stoss side which is apparently less jointed. Large moutonnes generally ranging more than a kilometer long are called flyggbergs.

Formation of a glacier takes over hundreds or thousands of years of time. This thick ice mass generally appears to be motionless but it moves very slowly perhaps only a few centimetres per day.

The largest island on the Earth is Greenland covering ice sheet of about 1.7 million square kilometres with an average 5000 feet thickness. Antarctic ice sheet occupies 13.9 million sq kms with maximum thickness of about 14000 ft covering the entire continent. At present, these two continental glaciers combinedly represent almost 10% of the Earth's land area.

Glacial valleys and cirques are some of the important forms of glacial erosion. U shape of glaciated valley is formed due to the erosion of base of the glacier having steep walls and flatter floors. In glacial valleys, channelized ice masses

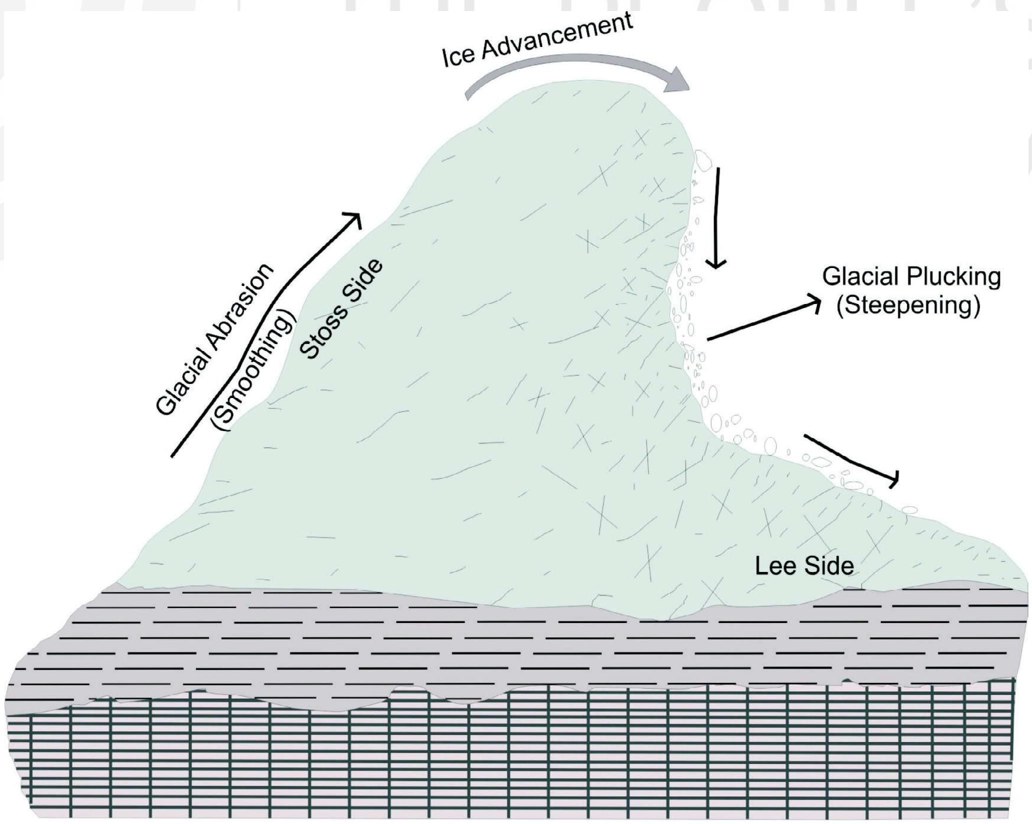

Fig. 9.3: Formation of roche moutonnee; this feature is produced by both mountain glaciers and continental ice sheets.

excavate troughs ranging from less than kilometer to a few kilometers. The small tributaries joining the main glacier valley lead to the formation of hanging valleys. Hanging valleys are the remnants of tributary glaciers that are less effective in bedrock erosion compared to the principle glacial valley, so that the tributary valley is cut off sharply from the steep wall of the main valley. This postglacial topography often involves in the creation of waterfalls, for example, the Yosemite valley in USA and Lauter brunnen valley in Switzerland. Some parts of valleys over deepened by the glacier are known to be glaciated rock basins, which contain lakes or inlets of the sea. These are called fjords which can be found in Norway, New Zealand, and Scotland. The flatter floor of the glaciated valley is positioned above the sea level. On the other hand, a fjord floor is glaciated valley which is drowned by the sea. This floor lies below the sea level.

Where an ice field scours the side of a mountain for a long time resulting into formation of a small basin is called cirque. Cirques characteristically have steep and perpendicular slopes. They can vary from tens of meters to kilometers in width. For example, Walcott Cirque in Antarctica occupies 16 km width and their walls are nearly 3000 m high. Many large cirques apparently owe their development through the repeated episodes of glaciation. When cirques no longer contain a glacial ice and their bottoms depression like small lakes are formed to hold water termed as *tarns*. Where large glaciated mountain summits have steep-sided and/or pyramid-shaped peaks involved in expansive quarrying of the headwalls of the mountain are called a *horn*. Several separated glaciers develop on different sides of a glaciated highland, which are generally separated by narrow or sharp ridges and are termed as arêtes (Fig. 9.4).

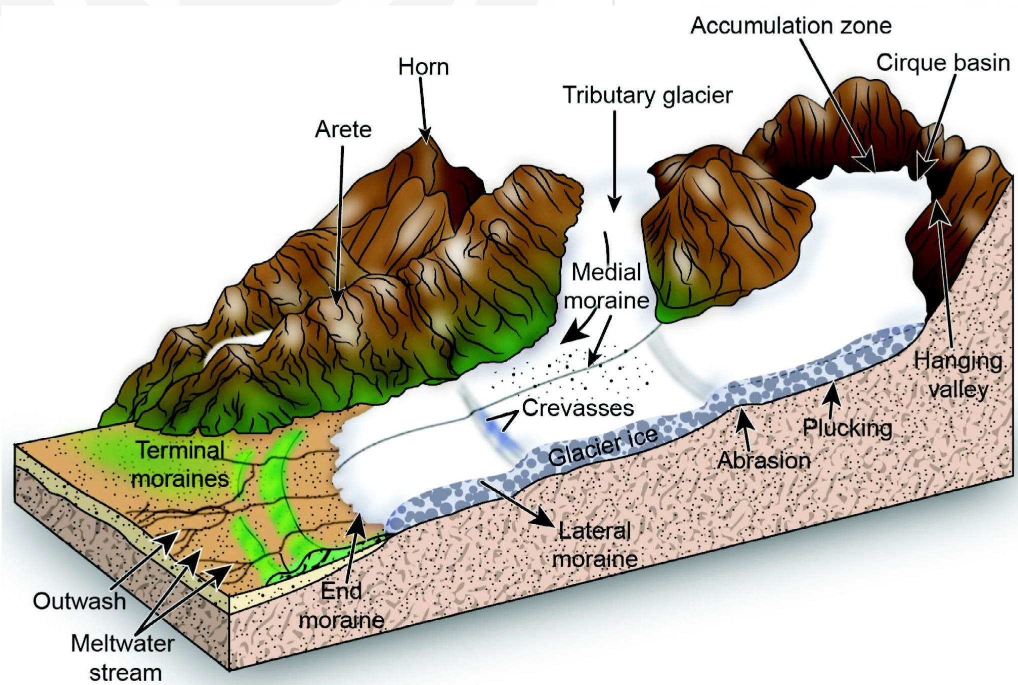

Fig. 9.4: Various landforms formed by glacial action.

Glaciers are capable of carrying a huge amount of rock debris over considerable distances. Glacial deposition is mainly of two types: deposition directly from the ice after melting; and by melt water flowing from a glacier. The material deposited from the ice is known as till, and the landforms created by such deposits are called *moraines*. Till is a glacial deposit composed of various sizes of boulders or stones in combination of smooth mixture of clay, silt or sand. The large bulk of this unsorted debris eroded by glacial melt water streams are redeposited at the low layers of ice in the form of moraines. The transportational work of glaciers generally involves when rock debris are transported on its surface are called as supraglacial or along its bed known as subglacial or somewhere in between the two are termed as englacial. The glacier carries frost shattered material from the valley walls and once it is fallen onto the ice surface forming a long ridge of material at the sides of the glacier are called *lateral moraines*. *Medial moraines* are formed by the merger of two lateral moraines where two valley glaciers flow together. The rock fragments also accumulate as thin layer of sediments on the surface through upward shearing of the ice and by down wasting which releases the englacial materials. Englacial debris is found in the main body of the glacier and is covered from subsequent snow fall. Some of the supraglacial material may fall into crevasses and become englacial. Overtime some materials moves downward through the ice due to ice melting and is also buried by overriding ice. Much of the materials deposited beneath the glacier is termed as *ground moraines*.

Erosional glacial landforms:

glacial trough, U-shape valley, fjords, hanging valley, domes, whaleback, striation, grooves, cirque, tarn, paternoster lakes, roches moutonne, flyggberg, arêtes, col, horn, nunatak, etc.

Depositional glacial landforms: Lateral, medial and terminal moraines; drumlins, till, erratics, eskers, kames, outwash plain, kettle hole, pitted plains and so on.

Drumlins are egg shaped features composed of till that are formed in the shape of streamlined asymmetrical hills. They form parallel to the direction of the ice movement. Eskers are long narrow ridges composed largely of sand and gravel deposited by stream flowing tunnels within or beneath the ice tunnels. Kames are steep mounds and conical hills commonly formed with eskers. These are individual mounds or hills composed of stratified drift. They may represent former crevasse filling, which comprises of stratified debris that enters crevasses though supraglacial streams. At the end of the glaciation on land, the vast quantity of sediment is deposited as flat alluvial aprons, that leads the stream channel to become braided. This type of broad accumulation of stratified material is said to be outwash plains. Kettels form as a block of stagnant ice, which is decayed and buried. These water filled irregular depression or pits are called kettel lakes.

Spend 5 mins

SAQ 2

Describe glacial abrasion process?

9.4 WORK OF GROUNDWATER

Our ancestors knew about the fresh groundwater and used it for thousands of years. But the velocity and patterns of groundwater movement demonstrated by Henri Darcy (French Engineer) during 19th century only through the measurement of the inclination of groundwater body, and the hydro-conductivity of the soil or rock material. Now, with our advanced knowledge we can be able to assess its origin and depth, and one can also recognize whether it moves or not. Do you know nearly half of the world's underground water is found within 8000 meters of the surface? This water is located beneath the Earth's surface in pore spaces and cracks of rocks. The more porous material contains large space so that it can hold more water. The materials with high permeability are able to transmit underground water through their interconnected openings.

The work of groundwater involves chemical processes of rock weathering at the surface or below the surface by the movement of groundwater. The **corrosion** or **solution** process is one of the most effective ways of erosion process in the erosional work of groundwater. Dissolution is a process by which rock or water combines with a solution or a group of solutes. Solubility depends on the mineral content of rock, for example halite is more soluble compared to gibbsite. Most of the rocks are soluble to some extent in water. The work of groundwater particularly in limestone, dolomite, and chalk areas produces distinctive assemblage of landforms at the surface which is termed as karst topography. Limestone is composed of calcium carbonate which reacts strongly with carbonic acid solution to produce calcium bicarbonate. This calcium bicarbonate compound tends to be dissolved in water. As we know that rainwater is mainly the basic source for groundwater. Carbon dioxide (CO_2) gas is present in the atmosphere, and is dissolved on rainwater, lakes and oceans. The rainwater mixed with carbon dioxide becomes an active solvent. When this solvent percolates into the rocks, it dissolves and disintegrates the rock particles by solution. CO_2 when dissolved in water forms weak carbonic acid ($H_2O + CO_2 \rightarrow H_2CO_3$). Carbonic acid is the main solvent in karst landscape.

Coarse grained soils: (sand and gravel) in which interparticle spaces are large so that the gravity water can move rapidly. Those materials have high permeability or hydraulic conductivity. On the other hand, fine texture soils (clay or tightly cemented soil or rocks) have less permeability.

Dolomite rock is calcium magnesium carbonate rock that seems to be slightly less soluble than limestone under normal conditions, but characteristically behaves as limestone in natural waters. Solution along joints and cracks in limestone beneath the surface are slowly widened which results into the formation of underground gullies and caverns (Fig. 9.5). These are formed

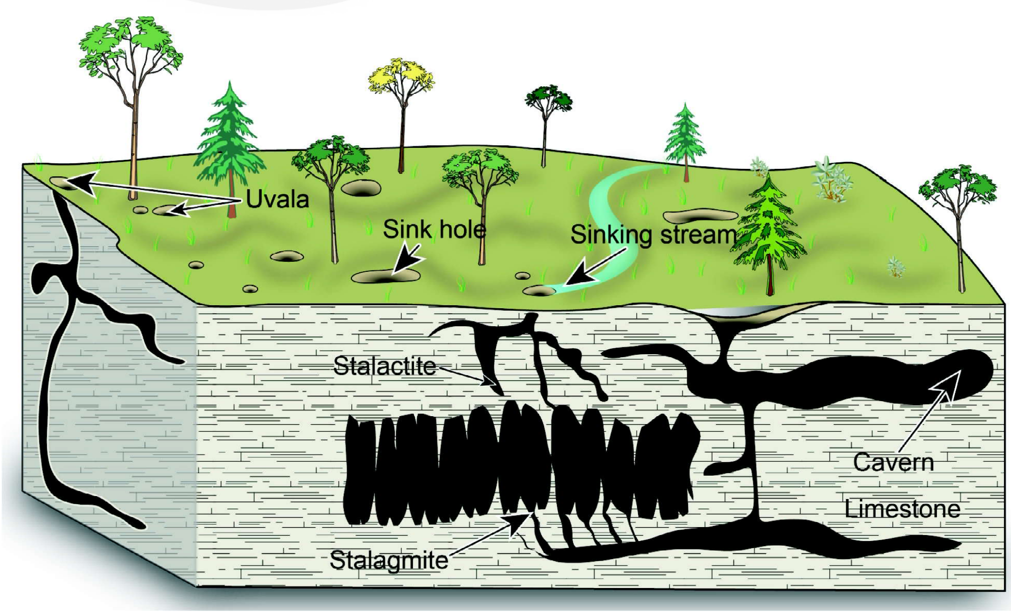

Fig. 9.5: Process of underground water forming various features.

both horizontally and vertically. Caves are excellent traps for sediments, and they allow the water flowing from a sink or percolation point to a spring or a seepage point. Calcite precipitation produces fashionable and decorative landforms inside caves are called *speleothems*. Speleothems are mainly made up of carbonate deposits and are formed by water through dripping and/ or flow. When water and CO_2 leaves from the solution, the calcite compound is deposited. Much of the deposition occurs on the sides of the cavern, and also from the roof and the floor. Stalagmites and stalactites are the most common types of speleothems. Stalagmites grow from the floor by the water flow towards the sides and the roof, whereas stalactites form from the water which drips from the ceilings. The largest cave system in the world is Mammoth Cave, USA that occupies more than 560 kms of known passages and particularly one passage at vertical depth of 110 m.

The word *Karst* is the German form of the Indo-European word *Kar* which means rock and also originated from the word *Kras*, the name of the West Slovenia, where the vegetation mearly appeared on limestone surface. Jovan Cvijiv (1893) known to be the first researcher in modern history extensively worked and published in German about *Karst topography*.

The term **karst** denotes both a set of processes and an assemblage of landforms. A variety of small scale solutional features and sculptures like grooves or holes are found on limestone and dolomite surfaces on the ground or in caves known as karren. These are also called lapies in French and lapiaz in Spanish. These features widely occur in groups and are called karren fields. Karren is resulted from the surface dissolution of limestone and is notably not developed on chalk because of its high porous nature. The most common surface features of karst landscapes are sinkholes or dolines. These are simply closed depressions formed in circular or ellipsoidal in shape. These range from less than a meter to several hundred meters diameter and from a few meters to over a hundred meters of depth. The combination of processes namely dissolution of surface carbonate rocks, cave collapse, subsidence, and piping are involved in creating several types of sinkholes. Uvalas are formed by the connection of more than one sinkhole, and consist of flat floors. They are generally larger than small dolines. Due to the decalcification of impure limestone, there is an accumulation of material inside sinkholes called Terra Rossa. A polje is a large closed depression with flattened floors that is predominantly observed in temperate regions. The word polje in Slavic language means a cultivable field. These are also named as campo or piano in Italy, plans in France, hojos in Cuba, pla in Spain and wangs in Malaysia. More porous material contains large space due to which it can hold more water. The high permeability materials are able to transmit underground water through these interconnected openings.

Rivers flowing through karst landscape involved in erosion process leads to the formation of various types of valleys. They particularly form gorges more frequently by the cavern collapse. The river flow gradually decreases its water at a particular point leading to the creation of a blind valley, where the river's total load flows into the interior of the karst mass. Dry valleys are more or less like normal river valleys that lack fluvial channels in their beds and are found mainly at the head waters of the channel system. They are common in karst landscapes and characteristically have steep slopes and flat floors in limestone regions.

SAQ 3

Match the following:

i) Karren	a) stalagmites and stalactites
ii) Speleothems	b) carbonate rock
iii) Dolomite	c) lapies
iv) Polje	d) hojos

Spend 5 mins

9.5 WORK OF SEA WAVES

Many of us know that more than seventy percent of our blue planet is covered with ocean waters. Waves and currents of oceans create a special and spectacular landscape in coastal terrain. Let us understand the process of moving water by waves and ocean currents. In specific terms, waves are agents of erosion and currents are responsible for transportation and deposition. Waves are important agents involved in the activity of shoreline changes and it is to remember that waves are formed by wind blowing over a water surface. The wind action near the surface is comparatively high than the deep water. Wind waves operate on all shorelines, from small ponds, lakes, to the larger ocean basins. Waves are formed in water in orbital motion that decreases towards bottom called as wave of oscillation (Fig. 9.6). Movement of the water in this process is very weak at a depth approximately equal to half of their wavelength (L/2). As the wave passes, the water moves upward and downward called wave crest and wave trough. The horizontal distance from trough to trough or from crest to crest is called wavelength (L), which is proportional to the wind velocity. The vertical distance from crest to trough is known as wave height. Water moves faster on the crest than in the trough. Sea waves move through the sea in the direction of the wind, and its height depends on wind speed, wind duration and distance of the wind. When the wave reaches to shallow water, it will tilt forward then the wave breaks abruptly. After breaking of the wave, the force of the wave translates up the

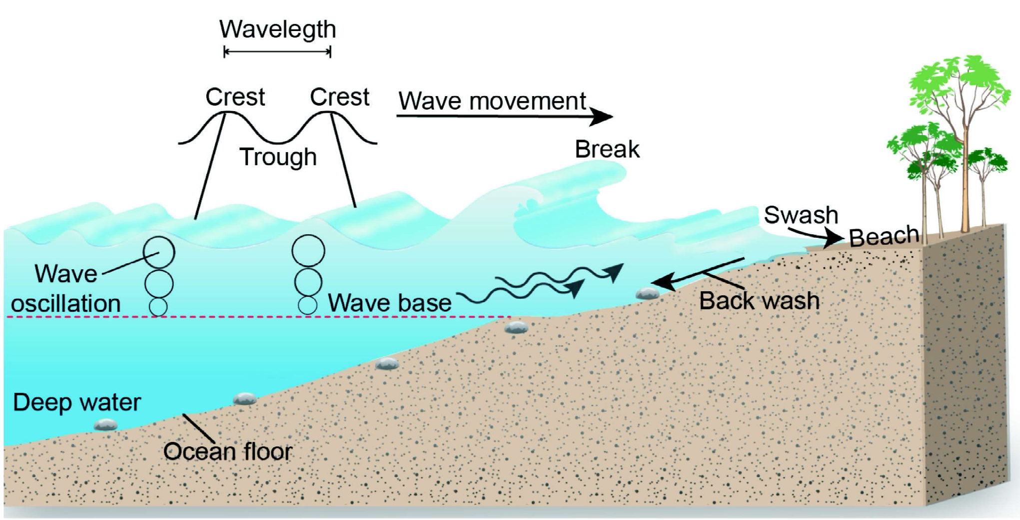

Fig. 9.6: Wave action in deep and shallow water.

beach and creates a swash. The resultant wave return flow forms backwash, which creates a rip-current. This rip current is a localized current which causes unexpected danger for bath takers. In shallow water, inshore part of a wave crest moves more slowly than the offshore parts. When a wave approaches the coast, its crest tends to run parallel to the topographic contours of the seafloor. This process is called wave refraction.

About 70% of the Earth's surface is occupied by the oceans. According to UN, nearly 66% of world's total population lives within a few kilometres of the coast.

Another important action of ocean water is called *tide,* which has a regular and predictable pattern. The tides rise and fall in a cycle that produces two high tides and two low tides in a day. Tides are movements of the ocean water formed due to the gravitational attraction of the Sun and the Moon. They bring changes in water levels along the coasts. Almost all coasts experience rising tide and falling tides. They are two types a) high spring tides are higher than normal high tides that occur when the Earth, the Moon and the Sun are in the same alignment, b) low neap tides, alternate with spring tides, occur when the Moon and the Sun are perpendicular to one another with respect to the Earth. Tides control the vertical ranges of wave action. A large tidal range is able to produce a broad shore zone whereas a small tidal range may create small wave energy at constant level. Ocean currents also play an important role in the circulation of sediment supply. Ocean currents may be described as mass movement of water circulated by wind in the open sea. You may refer Block 4 of this course to understand about the ocean currents and tides, and other related oceanic information.

Waves are responsible for erosion along the coastline. Because of **corrosion**, the soluble rocks to some extent gets dissolved in sea water by wave action. But this process is less significant in the work of waves as solution is slow due to high calcium carbonate distribution in the ocean water. **Abrasion** plays an important part in shoreline processes. Waves mobilize the smooth rounded stones, sand, pebbles, and small boulders to hit against rocky cliffs and shore that lead to the intense erosion. The resultant debris is broken, smoothened, and made smaller by further wave action, and most of it is transported towards the sea due to artillery force of the waves. An enormous amount of pressure is mounted on rock joints and cracks of the coastal rocks leading to the formation of cleavages. Unlike corrosion or abrasion, the rock materials are disintegrated into finer or very small fragments, and are easily transported by under-tow and rip-currents towards the sea. This process is called **attrition**. Due to hydraulic action of the waves, coastal rocks are disintegrated as waves strike against coastal rocks with huge force. The rock comprises of holes or cracks filled with the air, when water enters into those holes, the compressed air break down the rock into smaller pieces. It is estimated that approximately 36 tonnes per square meter area pressure is released by water waves during a storm event on the coast. In the storm, the intense wave speed coupled with the sheer mass of water involved in such hydraulic pounding is responsible for severe coastal erosion. When the sea water is deep, the sea waves act with limited force, whereas shallow water coast is much affected by waves with an enormous force causing to greater erosion. The breaking waves produce tremendous pressure on coastal rocks but the intensity generally depends on the distance between rocks and breaking waves.

Tsunamis are generally produced by sudden landslides or slumping on a seafloor in which Earthquakes are associated with faulting of the seafloor, and also less commonly by imparting asteroids and comets. Tsunami is a Japanese word that means Harbour Wave. The tragic Tsunami in the world's history occurred on 26 December 2004 in the Indian Ocean that was generated by an Earthquake of an intensity of 9.4 on Richter Scale in Sumatra region, Indonesia. It killed nearly 2.3 lakhs people in total including 1.67 lakhs in Indonesia, 35000 in Srilanka, 1800 in India and 8000 in Thailand. Tsunamis strike the coast sometimes from 100 to 150 kms long with the velocity of 400 to 500 kms per hour. The height of the wave may be 1 to 2 ft in the open sea but it can reach upto 40 m when it reaches to the coast. Though tsunami waves are very rare to happen but it may create a large scale destruction and erosion of the coast.

Waves form a variety of landscape features. Steep slope or vertical wall of the rock or sediment formed in the shore of the sea due to the undercutting process of the waves is called a *cliff*. The steepness of the cliff generally depends on bedrock lithology and geological structure, and weathering process. Cliffs are considered to be the transition zone between the continent and the sea. Along the joints and bedding planes, the waves put pressure and actively cut at the base of the cliff which leads to the formation of a concave shape. This type of concave cut is termed as *notch* or *nip*. Due to further under cutting, the upper part of the cliff looks hanging and it may collapse at some point of time. *Wave cut platform* or *terraces* are formed during the cliff recession process at cliff's face. When softer part of the platform gets slow erosion, while the harder part remains uneroded, the feature is known as rock reef.

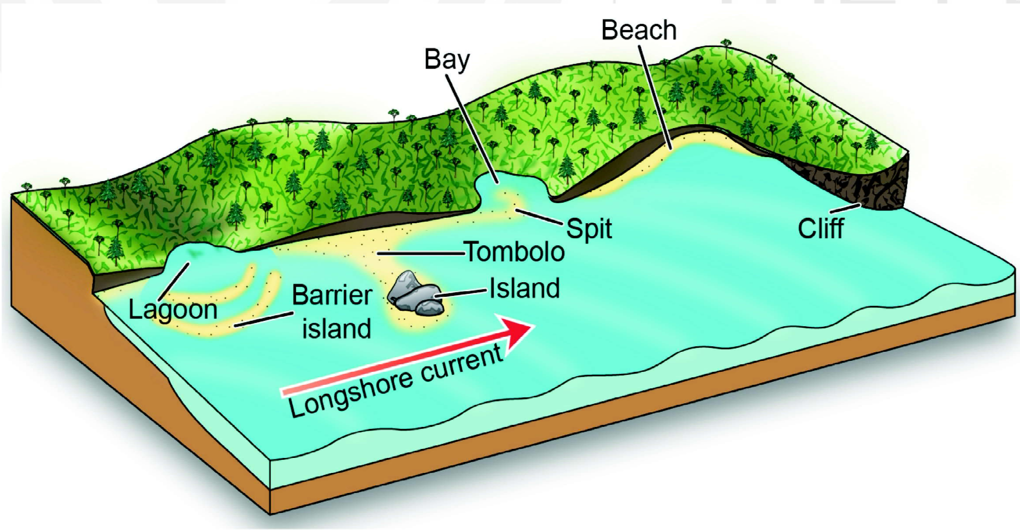

Fig. 9.7: Various coastal landforms.

Gorge, sea cave, sea arch, sea stack, bay, bar, spits, etc. are commonly formed due to the intense erosion occurring at the structural weakness of the rocks. *Gorge* is one type of erosional feature formed by the wave action along weak fault lines or joints in rock with a low dip. Gorges are also called as geos or yawns in Scotland and zawns in South-West England. When waves forcefully strike against the closely spaced jointed rocks, the soft rock part gets cut down and eroded away, which results in the formation of *sea caves*. *Sea archs* form when two caves on opposite sides of top portion are united. When the arch falls in and the remnant part remains standing on wave cut platform, the resultant feature is called *sea stack*. When the material is eroded easily than the surrounding composed material of the coast, *bay* is formed. *Bars* are formed in inter-tidal and sub-tidal zones. They are in various shapes like linear, sinuous or crescent, and are generally parallel or oblique to the coast. When sand and/or gravel gets accumulated by waves, tides and wind action, a *barrier* is formed. *Spits* are sub-aerial outcrops of sediments consisting of sand and gravel which are deposited as a result of longshore drift currents. Barrier spits are formed at the mouths of estuaries. A strand of beach sand that connects islands to islands or islands to the mainland forms a *tombolo*.

Coastal erosional landforms:

shore platforms, cliffs, notches, ramps, potholes, caves, archs, stacks, sea tunnels, etc.

Coastal depostional landforms:

beaches, spits, bars, barriers, tombolo, coastal dunes, estuaries, tidal flats, salt marshes, coral reefs, atolls, and so on.

Sediment is accumulated along the landward margins of the ocean is known as a *beach*. Beaches are generally composed of various locally available abundant materials and also by the sediment derived from cliffs and mountains and rivers. Some beaches are pebble beaches commonly observed in the middle and high latitudes, and some are sandy in nature occurring along tropical coasts. The materials are transported from one place to another due to wave action on the coast. During storms, the force of the wave is higher which causes to dismantling of rocks and widening of the fractures. In the beach, accumulation and loss of sand depend mainly on the level of wave activity. Low energetic waves can move the sand towards the beach face because of reducing backwash. Due to high energetic waves, beaches tend to affect erosion because of the movement of sand towards open water by strong backwash. If you observe the beach constantly, you will see wide sandy beaches in the summer period and narrow beaches in winter. It happens because of the varying intensity of wave activity during summer and winter. The winter period is largely affected by storms. *Coastal dunes* are formed by the sediment deposited at the edge of seas through the action of waves, currents and wind. They are similar to desert dunes and are mainly composed of medium to fine size quartz grains. *Estuaries* are long and narrow tidal inlets and are partially enclosed but connected to the open sea.

Spend 5 mins

SAQ 4

What do you understand by wave action?

9.6 WORK OF WIND

Wind is a geomorphic agent in all terrestrial environments. Work of wind causes aeolian processes including erosion, transportation, and deposition. Wind erodes and moves a variety of materials and further deposits them at a greater distance from their source area. The ability of erosion and transportation by wind mainly depends on particles weight, size and shape. The flat shaped particles move very slowly compared to the rounded grains. Aeolian particles are generally round in shape than those of glacial and fluvial environments. Wind transports sand-sized particles and silt that can travel as dust storms over distances of thousands of kilometres. Turbulent winds are supposed to lift large quantities of fine dust into the air forming a dense high cloud called a dust storm. Standing within the dust cloud, one seems to be shrouded in deep gloom or even total darkness.

In arid regions, the action of wind is very important because of presence of less vegetation, bare rock and soil surfaces which make the aeolian processes happen. Arid regions are mainly characterized by mechanical weathering, which includes the process of disintegration of rocks due to the diurnal range of temperature and the frost action. The disintegrated rock particles are transported by the wind they not only strike against the rocks standing on their way but also collide against each other. The gradual reduction in the size of rock particles by mutual friction and forceful contact they break down further into small particles, finer sand and dust. This process is called **attrition**. We can also observe wind action along sandy coasts over barren areas and in alluvial plains where the areas are marginal to glaciers and ice sheets. In all other environments except arid, wind activity is very low due to protective vegetation cover and moisture containing soils.

Aeolian:

The Greek God of the windy. Aeolian processes are said to be wind action processes.

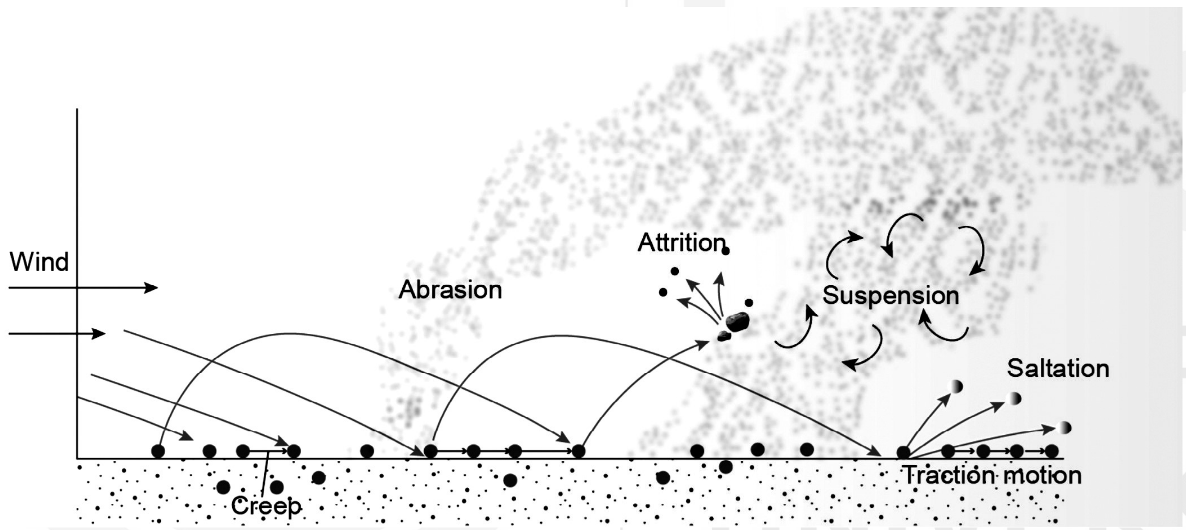

Fig. 9.8: Wind transports tiny dust particles in suspension; sand and other larger particles move by saltation and traction processes.

Wind performs deflation and abrasion types of erosional work. The process of removing, lifting and blowing away the unconsolidated sand and dust particles by wind is called ***deflation***. Deflation is accomplished mainly by air currents. The lifting of large scale loose particles from a place leads to the formation of depressions or hollows, which are known as blowouts or deflation hollows. *Blowouts* are formed with a few meters to more than a kilometre diameter generally in plain regions of dry climate. Sometimes the depression is filled up with rainwater and a type of shallow pond or lake is created. Deflation is responsible for the formation of pedestal rocks, which consists of residual masses of weak rock capped with harder rock. It is active in semi desert and desert regions. Deflation is also a factor in the formation of a reg surface. Thin veneers of gravel or coarse material lay as protective blanket that shields the underlying finer materials from wind known as *lag deposits*. These can also be observed in mountainous and periglacial environments in addition to desert areas. These coarse materials of lag deposits are also called gibber

Nearly 42 million square kilometres consisting of 30% of total land is occupied by dry regions.

(Australia), desert armour (North America), hammada, serir, and reg (Arab region). Stone pavements formed by large scale lag deposits are assembled with continuous and flat stone cover. These have some other names in different regions like desert pavements in USA, gibber plains in Australia, gobi in Central Asia.

Wind carries the enormous quantity of sand and small angular rock fragments as tools of erosion, and these particles attack rocks and soil surfaces in the form of sand blasting. As a result, the rock surfaces are smoothened and polished. This process is called aeolian ***abrasion***. Wind abrasion is most effective within a meter of Earth's surface because normal wind cannot lift and carry normal size of particles beyond the height of 180 cm. When the wind is obstructed by large boulders, then its speed gets reduced leading to the deposition of the material, for example, sand and clay accumulation.

Wind transports particles mainly in different ways namely creep, reptation, saltation, traction, and suspension. Turning and pushing of coarse particles on the surface by wind action is known as ***creeping***. Estimation of the quantity of material moved by creeping is difficult because creeping and reptation process occur simultaneously. The ***reptation*** is a type of movement where particle move in small jumps caused by the impact of high-energy grains. ***Saltation*** involves the upliftment of fine particles that travel some distance, and then falls and hits the surface. The impact of energy lifts the other grains. Small particles with high velocity generally travel long distances. Saltation heights can reach upto 3 m but average is 0.2 m. The saltation is higher over a rocky surface or pebble surface than over a bed of loose sand. Larger particles more than the size of sand grains move by traction, being rolled or pushed along the ground at low angle by the wind. In a turbulent airflow, the very fine particles stays at considerable heights for many days and are finally deposited as dust. This process is termed as **suspension**. The grains remain airborne for long period of time called as long term suspension, while grains falling quickly on the surface are called short term suspension.

There are two climatic types categorized for water deficient regions i.e. desert or arid, and steppe or semi arid. The major desertification of the Sahara covers parts of ten countries with East-West expanse of more than 4800 kms and North-South extent ranges from 500 to 800 kms. The United Nations General Assembly announced the year 2006 as the International Year of Deserts and Desertification.

Ventifacts are smooth surface blocks of rock outcrops or boulders that are polished or faceted by the impact of wind transported particles. These are generally associated with pits, flutes, grooves, etchings and helicoidal forms found in resistant rock. The ventifacts and their associated forms provide a clue in determining the wind direction and circulation. *Yardangs* are composed of flat tops and lack a keel that seems like the hall of a cap-sized ship. The windward face is wider and higher than the leeward side. These are formed due to abrasion and deflation processes. Several forms of yardangs can be found in southern part of Tibesti Masiff (central-eastern Sahara), deserts of Egypt, Iran, Arabia, Central Asia, Namibia, Peru and the Southern Andes. A *sand dune* is hill of loose sand shaped by the wind. Deposition of sand with huge accumulations in the form of dunes found as aeolian sand deposits is known as *sand seas* or *ergs*. Ergs always migrate in the direction of the predominant wind. These landforms occur at the end of regional-scale sand transport pathways. This reflects the resultant direction of sand transporting winds and topographic factors. For instance, in the Sahara Desert, enormous reddish dune sand originates from sandstone made up of great sand sea. Erg is also called edeyen in Libya, koum or kum and pesky in Central Asia, nafud in Arabia and qoz in the Sahara. A desert pavement of pebbles on top of vast flat-surfaced sheets of sand anywhere is called a *reg*.

Sand and dust particles moved by the wind action are eventually deposited when wind lies down. Under simple conditions of uni-directional wind patterns, simple dunes are formed with stoss and lee slopes. Several types of dunes are formed by wind action (Fig. 9.9). *Transverse dunes* are characterized with a gentle slope on the windward side and a steep leeward slope. There are deep depressions between the dune ridges. These are composed of strips that are fundamentally perpendicular to the wind. *Barchan* is of Turkish origin, and is isolated an half-moon (crescent) shaped dune having an asymmetrical profile. These are developed on flat and pebble-covered ground surface or pediment. They commonly occur on the margins of ergs, and are small in size and their height is normally one tenth of their width.

Fig. 9.9: Work of wind forming various features.

Star dunes remain fixed in a particular place and are almost permanent features of the desert landscape. These are characteristically large sand hills with dune crests radiating away from the centre and are not migrated. Star dunes, cones, sand mountains and ghourds are categorized under pyramidal dunes. These have numerous slip faces that develop as a consequence of multiple wind directions. *Seif* is an Arabic word that means a 'curved sword' which is applied to linear or longitudinal dunes with sinuous crests. These are formed where two dominant wind directions are present at approximately right angles to each other. Crests can be straight or can occupy high elevation point that may be separated from the edge at the top of the leeward face. A linear dune seif is also named as sif or silk. The corridors between sand ridges are known as gassi or goud. Wind-formed ripples are commonly present on the surface of sand dunes. Wind can blow sand inland that helps the formation of dune along the coasts of oceans or lakes. Some types of dunes are controlled by vegetation, topographical and local sediments.

Vegetation anchored dunes developed from the stabilization of aeolian sand around plants called a nebkha or shrub, shadow and hummock dunes. These are covered in large areas of lowlands in semiarid and coastal areas. *Loess* is a fine grained sedimentary deposit which consists of grains of quartz, feldspar, carbonate and clay minerals transported by wind from arid areas and deposited elsewhere. Czech and Slovak Republics and central China are known for thick loess deposits called Loess Plateau.

SAQ 5

Spend 5 mins

How do sand dunes form?

9.7 SUMMARY

- As you know land surfaces are constantly undergoing modifications through diverse processes. These processes are categorized as endogenetic and exogenetic processes.
- Exogenetic processes originate from the Earth's atmosphere. They involve mainly weathering and mass wasting, and also different types of processes such as erosion, transportation and deposition by water, ice, sea waves and wind.
- The process of erosion includes solution, hydraulic action, abrasion, and attrition. All these are mostly involved in the work of river, underground water, ice, sea waves and wind at various stages.
- The eroded material will then transported by different processes i.e. suspension, traction, and saltation etc., and deposit at some other places. Particularly these processes create landforms over a period of time.
- Study of the evolution of landforms is another interesting specialized subject known as geomorphology.
- In this unit, we have discussed the processes and forms related to running water, underground water, glacier, sea waves, and wind. You can further elaborately study about the landforms formation and processes by various erosional agents through the given references in this Unit.

9.8 TERMINAL QUESTIONS

1. Does the river work contributes in changing the land's surface? Explain.
2. Describe the important erosional and transportation processes of the wind?

9.9 ANSWERS

Self-Assessment Questions

1. Erosional landforms: rills, waterfalls, rapids, V shaped Valley's etc., depositional landforms: alluvial plain, levees, delta etc.
2. Glacial abrasion is a part of erosion process that disintegrate or separate small pieces of bed rocks.
3. i) c ii) a iii) b iv) d

4. Waves are formed by wind. The oscillated waves create crest and trough.

5. Sand dunes are formed by wind action in desert environment. They are of several types such as transverse dunes, star dunes, linear dunes etc.

Terminal Questions

1. The work of river starts with the water flow. The running water disintegrates rock materials along valley sides and erodes materials, then transports, and some of it deposits along its course. Further, you can refer to Sec. 9.2.

2. Attrition, deflation and abrasion are three types of wind erosion processes and they operate particularly in arid regions. For more information, you can refer to Sec. 9.6.

9.10 REFERENCES/FURTHER READING

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GLOSSARY

Bedding Plane	:	The Plane or line of separation of two sedimentary beds is known as Bedding plane.
Conrad Discontinuity	:	The line of separation between the oceanic and continental crust is known as Conrad discontinuity.
Deformation	:	refers to changes in the shape and/or volume of a rock body. It depends on the environmental conditions, the composition and texture of the rock and the stress.
Earth's crust	:	The surface layer of the Earth is called Earth'crust. Its average depth is about 24-32 kilometres.
Extrusive Igneous Rock	:	When the cooling of the magma takes place on the Earth's surface, it generates Extrusive Igneous rock.
Endogentic forces	:	Forces coming from the Earth's beneath cause to topographical changes of Earth.
Epeirogenic movements	:	Forces affect the Earth's crust under vertical movement causing landmass upliftment and subsidence.
Earthquake	:	It occurs within the Earth's crust along fault line from which tremendous amount of energy can be released with sudden force.
Erosion	:	The physical removal of material by geomorphic agents namely water, ice, wind or waves.
Exogenitic processes	:	Weathering, mass wasting and erosion occur at or near the Earth's surface which are collectively called exogenitic processes.
Fossil	:	Solidification, cementing of the part or whole of any living organism or their impression in the sedimentary rocks is known as Fossil.
Fold	:	It is occurred due to rock deformation. Two types of folds mainly observed are anticlines and synclines. Upfolds are anticlines and downfolds are synclines.
Fault	:	It is a fracture in the crust along which displacement can occur.
Geosyncline	:	A long narrow shallow sea called Geosyncline.
Glacial plucking	:	Process of glacial erosion which involves in removing larger fragments of the bedrock.
Igneous Rock	:	Cooling and solidification of the magma generates Igneous rock.
Intrusive Igneous Rock	:	Sometimes the cooling of the magma takes place within the Earth's crust and generates Intrusive Igneous

rock.

Mass wasting : Because of gravity, the rock or soils move down slopes.

Metamorphic Rock : Intense pressure and temperature may modify the basic characteristics of the Igneous and Sedimentary rocks to develop Metamorphic rocks.

Mid-oceanic Ridge : The zone of the oceanic crust where magma up wells to form new oceanic crust is known as Mid-oceanic ridge.

Mohorovicik Discontinuity : The plane of separation of the Earth's crust from its lower part Mantle is known as Mohorovicik Discontinuity or Moho Discontinuity.

Orogenic movements : Forces affect the Earth's crust under horizontal movement causing plates move towards each other, opposite one another or slide past each other.

Pangaea : Wegner assumed that there was only one super-continent named Pangaea.

Panthalasa : The Pangaea was surrounded by a super-ocean called Panthalasa.

Plates : Plates are defined as broad rigid segments of lithosphere consisting of continental and oceanic crust including the rigid upper part of mantle which floats on the underlying hot viscous asthenosphere.

ProtBolith : The original rock which is disintegrated and decomposed to form loose materials is called Protolith.

Re-crystallization : It is the process of metamorphism of rocks.

Sedimentary Rock : The compaction, consolidation and cementing of eroded materials generates sedimentary rocks.

Seismic wave : is generated when rock within the Earth's crust breaks and releases a high amount of energy which moves out in all directions as waves.

Seismograph : The instrument measures the seismic wave's intensity during an event of Earthquake.

Sial : Main composition of minerals of continental crust is Silica and Aluminum. This layer is also known as Sial layer.

Sima : Main composition of minerals of Oceanic crust is Silica and Magnesium. This layer is also known as Sima layer.

Tsunami : A tsunami is a series of ocean waves generated by sudden displacements in the sea floor, landslides, or volcanic activity. In the deep ocean, the tsunami wave may only be a few inches high. The tsunami wave may come gently ashore or may increase in height to become a fast moving wall of turbulent water several meters high.

Volcanic eruption : It occurs when hot materials viz. molten rock, ash, and steam are thrown through vent from the Earth's interior.

Weathering : The disintegration and decomposition of rock at or near the surface.

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