



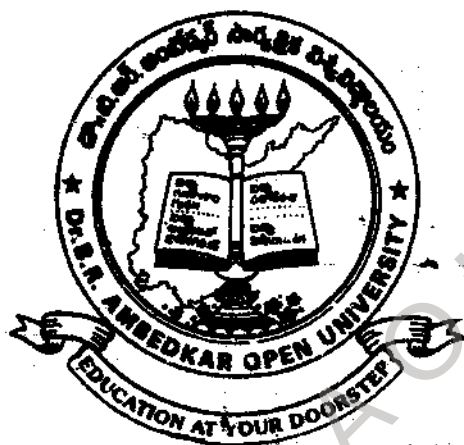
BS2

GEOLOGY

Geology - I & II

COURSE - I

**General Geology, Crystallography,
Mineralogy and Palaeontology**



*"We may forgo material benefits of civilization, but we
cannot forgo our right and opportunity to reap the benefits
of the highest education to the fullest extent..."*

- Dr. B.R. Ambedkar

**Dr. B.R. AMBEDKAR OPEN UNIVERSITY
HYDERABAD
2002**

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PREFACE

This book deals with the topics in Geology included in the syllabus for the Second Year of the B.Sc., course offered by Dr. B.R. Ambedkar Open University. These topics generally cover the "core" area of the subject to be studied in the Second Year of the Three Year Degree Course in Science. The syllabus for the sake of convenience is divided into 6 blocks, each of which comprises 4 units. Each block generally covers a specified area of the subject. The units are prepared by specialists in accordance with a format so designed as to enable the student to read and understand them without much difficulty. Each unit begins with contents followed by the objectives of the lesson and has at its end model questions intended to test the student's comprehension of its subject matter. Technical terms with which the student may not generally be familiar are given at the end of each unit under the head "Glossary".

The objective of this book is to explain, the general geology, crystallography, mineralogy and palaeontology. The first two blocks are allocated to general geology to explain about earth's characters, the internal processes like volcanoes, mountains, earthquakes and external processes such as the geological work of weathering, groundwater, rivers, glaciers, seas, lakes and wind. The 3rd block is exclusively allocated to crystallography to describe crystals, their properties and the normal classes of six crystal systems. The 4th block mainly explains about minerals, their physical properties, silicate structures and important rock forming minerals under mineralogy. The 5th and 6th blocks are allotted to palaeontology, to explain about fossils, fossilisation and important groups of fossils with their morphological characters.

The University hopes that this course material will help the student to get acquainted with the concepts and principles of General Geology, Crystallography, Mineralogy and Palaeontology.

BRAOU

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BRAOU

BLOCK - I

GENERAL GEOLOGY

BRAOU

UNIT - 1 : SCOPE AND DEVELOPMENT OF GEOLOGY

Contents

- 1.0 Objectives
- 1.1 Introduction
- 1.2 Scope of Geology
- 1.3 Branches of Geology
- 1.4 Applications of Geology
- 1.5 Development of Geology
- 1.6 Relationship with other Sciences
- 1.7 Summary
- 1.8 Check Your Progress - Model Answers
- 1.9 Model Examination Questions
- 1.10 Glossary

1.0 OBJECTIVES

After completion of this unit, you should be able to:

- define the science of geology
- explain branches or sub divisions of geology
- explain scope, application and development of geology
- describe the relationship with other branches of science.

1.1 INTRODUCTION

Geology is defined as the science of the Earth (Geo: Earth; Logos; Discourse of Science) that deals with our Planet Earth in all aspects viz., its shape and size, origin and age, the materials that compose it and also such natural phenomena associated with it as the Volcanoes, Earthquakes, Mountain Chains, Great Lakes and Seas, Glaciers and Rivers.

Geology examines the origin and development of the solid earth, its constitution as well as its composition and various processes that operate upon its surface and beneath the surface. In many instances it requires significant consideration of the Hydrosphere and the Atmosphere.

1.2 SCOPE OF GEOLOGY

Modern Geology aims at tracing the whole evolution and development of the earth and its inhabitants right from its origin and inception to the present day. It attempts at an intelligent and crucial appreciation of the products resulting from natural processes acting upon and within

the earth. It is to give answers to some of the fundamental questions that have started in the face of mankind from the beginning of history, Questions like - When and where did life originate? Since how long life has existed on our Earth? What are Volcanoes and Earthquakes? What forces have created such long and mighty mountain ranges like the Himalayas with many a lofty peak.

Geology uses all the available knowledge and techniques provided by the sister sciences in a continuing effort to understand the many secrets the earth still holds from us. The basic aim of the geological study is not just to gather information and assemble facts but to work out the basic principles that govern these facts; not just to know how things happen but also why they happen. As in other sciences, the Geologist proceeds from the known to the unknown. Familiarising himself with the present, he tries to reconstruct the past history of the earth, the sequence of the events and the various forms of life that inhabited on our Earth. For this interpretation is required through knowledge of the materials that constitute the earth and its structure as well as a clear conception of the agencies and processes that have been relentlessly at work. Since many of these agencies involve tremendous physical and chemical changes, the science of Geology enlists the aid of the both Physical and Natural Sciences such as Physics, Chemistry, Botany and Zoology. Therefore sometimes its field of work and study overlaps those of other sciences.

A critical study of the earth opens up vast opportunities and scope of enterprise, especially in the economic field as most of man's basic resources are from the Earth and its atmosphere, the soils which provide man's sustenances through agriculture, natural fuels like coal, petroleum and gas, all mineral products so essential in our daily life in domestic and industrial fields. To locate and utilise those natural resources there is the need for the best skills and hence the need for geologists who make practical use of the knowledge gained from a systematic study of the earth science. Every nation worth mentioning has on its staff a band of geologists to prospect and locate the natural resources. In our country the Geological Survey of India was established in 1853 and later after Independence several sister organisations like the Oil and Natural Gas Corporation, Bureau of Mines, Mineral Exploration Corporation, Central Ground Water Board, National Geophysical Research Institute, National Mineral Development Corporation, Hindustan Zinc Limited., have come into existence and they have been of immense help in locating and developing valuable mineral deposits from several parts of our country.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. What is the science of geology ?

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1.3 BRANCHES OF GEOLOGY

The science of Geology is traditionally divided into two broad areas - Physical and Historical.

Physical geology, also called General geology, examines the materials composing the earth and seeks to understand many processes that operate on its surface and below the surface. The aim of the Historical geology on the other hand is to understand the origin of the Earth and its development through time. Thus, it strives to establish an orderly chronological arrangement of the multitude of physical and biological changes that have occurred in the bygone ages.

As a broad and comprehensive science, geology has quite a good number of branches or sub divisions, each of which underscores certain important aspects of the study of the Earth.

Physical Geology : This branch concerns itself mainly with the physical aspects of the earth like the shape, size and constitution of the earth; as also the processes and the agencies that are always at work; the dynamic forces and movements that have brought significant changes on and inside the surface of the Earth. Thus, the geological action of the blowing wind; flowing river and underground water, moving ice in the form of glaciers, the work of the seas and lakes as well as the activities of the living organisms form the subject matter of physical geology.

Mineralogy : It is the science of minerals which are inorganic substances that make up rocks and minerals that compose the solid rocky frame work of the earth's crust. It deals mainly with the physical, optical and chemical properties of minerals including their crystalline form and structure, their mode of occurrence and their mutual association. It also gives the description of individual minerals with an emphasis on the chief and distinguishing characteristics of the mineral species.

Crystallography is the study of crystal shapes and habits. Crystal is a homogeneous, anisotropic solid and is characterised by definite chemical composition and orderly arrangement of atoms. Various shapes of crystals are existing in different minerals.

Palaeontology : This is the science of fossils which concerns itself with the mode and nature of preservation of fossils within the strata and their utilisation in the correlation of different rock formations. It helps in the reconstruction of the history of the earth based on the evolution of life on earth and it is of great importance in our search for such natural resources as Coal and Petroleum.

Petrology : The science of rocks - it deals with the several varieties of rocks, their nature, chemical and mineralogical composition, mode of occurrence, characteristic forms, structure and textures and their origin and classification.

Stratigraphy and Historical Geology : This is an important branch of geology which attempts at unravelling past history of the earth based on the information recorded in the strata or layers of rocks. It traces the evolution of the earth through geological ages with the help of remnants or remains of animals and plants preserved in rocks as fossils.

Structural Geology : It deals with the methods of study and interpretation of the structures and interrelation ship of rock formations in the crust of solid earth or lithosphere which has been some-what mobile. There are continuous movements of smaller magnitude along with major and forceful movements which result in the formation of mountains. Structural geology

concerns itself mainly with the interpretation of such structural features as folds, faults and joints in the strata and their mode of formation. It is of immense value and use in the successful location of economic mineral deposits.

Economic Geology : This is the most useful and important branch of geology since it deals with economic minerals and rocks, their mode of occurrence, processes of formation of mineral deposits, their origin and finally exploration and exploitation.

Engineering Geology : This branch deals mainly with the applied aspects of geology in engineering practices like the construction of dams and bridges across rivers, selection of sites for rail or road tunnels, railcuts, etc., It also deals with construction materials and ground water.

Mineral Exploration : This branch deals with the different methods of exploration for mineral resources.

Mineral Economics : This branch of geology deals with the mineral policies.

Other important branches include X-ray Crystallography, Micropalaeontology, Petroleum geology, Hydrogeology, Sedimentology, Remote Sensing for geological purposes, Ore Mineragraphy, Mining geology etc. The study of the applied aspects of geology is usually referred to as Applied geology.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. Name the important branches of geology ?

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1.4 APPLICATIONS OF GEOLOGY

Geological knowledge finds application in many fields of human activity. A majority of our industries depend heavily upon the natural resources of the earth - minerals, fuels and ground water. Apart from the industrial needs of these resources, man requires some of them for his ordinary activities like building construction and road laying. Supply of water for drinking, agricultural and industrial purposes is of great concern. Prospecting for all these resources, their exploration and exploitation requires a thorough knowledge of the subject of geology.

The engineering applications of geology are many. The location of satisfactory sites for dams and buildings, flood control and water supply, tunnel construction, determination of the best locations for roads, bridges and pipelines require a thorough knowledge of the geology of the areas concerned.

As minerals are concentrated in relatively few places in the crust no nation can be self-sufficient in all minerals. As every country depend on imports of atleast some minerals, problems involving international policies arise. As mineral resources are not replenishable, utmost care has to be taken in their exploitation, use and trading.

1.5 DEVELOPMENT OF GEOLOGY

We are aware that the earth is one of the nine planets that orbit the Sun which is a star. Sun is a member of a much larger family of perhaps 1,00,000 million stars that compose Milky Way. This is but one of the thousands of millions of galaxies in an incredibly and incomprehensively large universe. But this modern view of the earth's position in space is vastly different from that held by our ancestors a few hundred years ago when the earth was considered to occupy a privileged position. Ancient Greeks thought that the earth is at the centre of the universe. This is called geocentric view of the universe. They believed that the earth was spherical, motionless body at the centre of the universe and it was surrounded by a transparent hollow celestial sphere on which the stars were hung and carried on a daily trip around the earth.

The Famous Greek philosopher **Aristotle** (384 - 322 B.C.) concluded that the earth was spherical since it always shows a curved shadow when it eclipsed the moon. But the first Greek to profess a Sun - centred or Heliocentric universe was **Aristarchus** (312 - 230 B.C.) who used simple geometric relations to calculate the relative distances from the earth to the sun and the moon. However, Aristotle's view was presented in finest form by **Elaudius Ptolemy** in the second century A.D. For almost thirteen centuries their views were held in great esteem - and it was Polish Atronomer **Nikolus Copernicus** (1473 - 1543) who established that the earth was a planet and was a part of the solar system with the sun at the centre and the planets like Mercury, Venus, Earth, Mars, Jupiter and Saturn orbiting it. Later **Kepler**, **Galilelo** and **Newton** by their studies brought about a new orientation in the ways of Astronomy. Thus in about 500 years perception of the earth has changed from the earth being the centre of the universe to its being a small planet orbiting an average star (Sun) in one of the hundred thousand million galaxies.

The early Greeks were the first observers of the geological phenomena and they drew logical conclusions from their observations. But many of their observations were lost during the dark and the middle ages. It was only during the renaissance that people began to observe facts as the early Greeks did. During this period **Dante St. Francis** of Assisi and **Marcopolo** were the leaders of thought and observation. They tried to discover the world around them and this was the age of **Columbus** and **Magellam**.

The later part of eighteenth century is generally regarded as the begining of modern geology. During this period **James Hutton**, a Scottist scientist, putforth a principle that came to be known as the doctrine of **Uniformitarianism**. This is a basic concept in modern geology. It simply states that the Physical, Chemical and Biological laws that operate today have also operated in the geological past. In other words it may be stated that the forces and processes that are presently shaping our planet have worked much in the same way in the past also. This idea is popularly known as "**the present is the key to the past**".

To say that geologic processes in the past were the same as those occuring today is not to suggest that they operated at precisely the same rate. Although the processes have remained essentially the same, their rates have undoutedly varied during geologic time. The acceptance

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. The average specific gravity of the Earth is

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2.3 CONSTITUTION OF THE EARTH

The dominant rocks constituting the crust fall into two well contrasted groups.

- a) A light upper layer of such rocks like granite and related types having an average sp. gr. of 2.7. Chemically these rocks are rich in Silica while Alumina is the abundant element of the remaining constituents. Such rocks are, on the whole collectively known **Sial**.
- b) A dark and heavy lower layer of such rocks as basalt and related types with sp. gr. 2.9 to 3.3. In these rocks the Silica (40 -50%) is the dominant constituent though much less abundant than in Granite. The Magnesia takes the second place in these heavy rocks and the whole groups is referred to as **Sima**.

The Sial is the dominant material of the continental portions of the Earth's crust down to a depth of several kms while the Sima forms the foundations of the ocean floor and extends beneath the continents.

The solid Earth is divided into four principal units 1) the inner core, the innermost solid zone having a radius of about 800 miles or 1300 kilometers 2) the outer core, a molten layer of some 1360 miles or 2200 kilometers. 3) the Mantle, the solid, less dense layer having a thickness of 1800 miles or 2900 kms. and 4) the Crust, the relatively thin outer shell of the Earth.

A very important zone exists within the mantle and it deserves special mention. This zone called **Asthenosphere** is located between depths of 70 and 700 kms (45 and 400 miles). The asthenosphere is a hot, weak zone that is capable of gradual flow. Situated above the asthenosphere lies a zone called the Lithosphere (sphere of rock) which includes the crust and the uppermost mantle. In contrast to the hot and plastic asthenosphere, the lithosphere may be considered to be cool and rigid.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

4. The branch which combines the knowledge of geology and physics is called

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1.7 SUMMARY

Geology deals with our planet earth in all aspects namely size, shape, origin and age, composition of minerals; rocks, fossils and also the natural phenomena like volcanoes, earthquakes, mountain building activities, erosion, transportation and deposition of sediments by wind, rivers, glaciers, lakes, seas etc.

Geology aims at tracing the whole evolution and development of earth and its inhabitants right from its origin and inception to the present day. A critical study of the earth opens up vast opportunities and scope for enterprise in the economic field as most of man's basic resources originate from the Earth.

Important branches of geology include physical geology, mineralogy, crystallography, palaeontology, petrology, stratigraphy, structural geology, economic geology, mineral exploration, mineral economics etc. Physical geology deals with the physical aspects of earth. Mineralogy is the study of minerals. Crystallography covers the science of crystals. Study of rocks is called petrology. Palaeontology deals with fossils, while stratigraphy explains about the past history of earth. Structural geology aims at explaining the different structures of earth. The study of formation of economic minerals comes under economic geology. Mineral exploration deals with the various exploration and prospecting methods of mineral resources. Mineral economics is the study of mineral policies. Geological knowledge finds application in many fields of human activity. Majority of industries depend heavily on natural resources like minerals, fuels and groundwater. Engineering applications like location of sites for dams, buildings, bridges etc., required the knowledge of geology. The development of geology starts with the fundamental theories of origin of earth. Basic concept of modern geology starts with the James Huttons theory of uniformitarianism. It simply states that the physical, chemical and biological processes which operate today have also operated in the geologic past.

The other basic sciences like physics, chemistry , biology are directly or indirectly related to the science of geology.

1.8 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Geology is one of the branches of science which deals with different aspects of Earth like size, shape, age, origin, internal composition and natural processes with in and outside the earth.

2. Important branches of geology include physical geology, mineralogy, crystallography, palaeontology, petrology, structural geology, stratigraphy, economic geology, mineral exploration, mineral economics etc.
3. Present is the key to the past explains the principle of uniformitarianism.
4. The branch that combines the knowledge of geology and physics is called geophysics.

1.9 MODEL EXAMINATION QUESTIONS

I. Answer in about 30 lines

- a) Give a brief account of the various branches of geology.
- b) Explain the scope and development of geology.

II. Answer in about 10 lines.

- a) Mention briefly about the applications of geology.
- b) What is the relation of geology with other basic sciences ?

1.10 GLOSSARY

Fossil	: Remnants or remains of animals and plants - organic remains - permanently preserved in rocks.
Geocentric	: The theory by which the earth is believed to be at the centre of the universe.
Geochemistry	: The study of the composition of the earth and the chemical processes that are responsible for the formation of the earth.
Heliocentric	: The theory in which the sun is believed to be at the centre of the universe.
Hydrosphere	: Watery envelope of the earth
Lithosphere	: Rock formation in the outer cover or crust of the earth.
Sidereal year	: The time required for the earth to return to a given point in its orbit with reference to the fixed stars in the sky.
Oceanography	: Physical science of the oceans.
Sub-stratum	: Portion just beneath a rock formation.

UNIT - 2 : EARTH - SHAPE, SIZE, CONSTITUTION AND PROCESSES

Contents

- 2.0 Objectives
 - 2.1 Introduction
 - 2.2 Shape and size of the Earth
 - 2.3 Constitution of the Earth
 - 2.4 Continental Masses and Ocean Basins
 - 2.5 Geological Processes
 - 2.6 Summary
 - 2.7 Check Your Progress - Model Answers
 - 2.8 Model Examination Questions
-

2.0 OBJECTIVES

After completion of this unit, you should be able to

- explain position of the Earth in solar system
 - describe shape and size of the Earth
 - explain constitution of Earth
 - define geological processes
-

2.1 INTRODUCTION

You are already aware that our Earth is member of the solar system. The origin of solar system, the universe, galaxies, internal composition of Earth namely crust, mantle and core and also about the physical environments namely atmosphere, hydrosphere and lithosphere were clearly explained in the 1st year Science and Technology course, unit no. 15. Before starting this unit, you are advised to go through the unit 15 in Science and Technology course.

Solar system consists Sun at the centre around which nine Planets including the Planet Earth revolve in nearly circular orbits with definite period of revolution. The nine planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto. Each one of the planets of the solar system moves in a sort of an elliptical path around the Sun (S) which is situated at one focus of the ellipse.

The solar system is a huge rotating system of which the bulb is the Sun. It consists of nine planets, their Moons or satellites and numerous small interesting bodies including asteroids, comets and meteoroids. About 99.85 percent of the mass of the solar system is contained within the Sun while the planets collectively make up most the remaining 0.15

percent. Under the control of Sun's gravitational force, each planet maintains an elliptical orbit and travels in a counter clockwise direction. The planets except for Venus and Uranus, also rotatable counter clockwise about their axis. In compliance with Kepler's law, the nearest planet to the Sun, Mercury has the fastest orbital motion of 48 Km/sec and the shortest period of revolution of 88 days. And the farthest planet Pluto has an orbital velocity of 5 Km/sec and requires 248 years to complete one revolution. (See Table 2.1).

Planet	Number of Satellites or Moons	Mean distance from Sun (Millions of Miles)	Period of revolution (in days)	Period of rotation (in days)	Diameter (in miles)	Density (gm/cm)
Mercury	-	36	88	59	3,015	5.1
Venus	-	67	225	243	7,526	5.3
Earth	1	93	365.25	23Hr.56m.0.4s	7,920	5.52
Mars	2	142	687	24Hr.37m.23s	4,216	3.94
Jupiter	15	483	12 years	9Hr. 50m	88,700	1.34
Saturn	15	886	29.5 years	10Hr. 25m	75,000	0.70
Uranus	5	1,780	84 years	10Hr. 25m	29,000	1.55
Neptune	2	2,790	165 years	18 Hr.,	28,000	2.27
Pluto	1	3,670	248 years	6.4 days	1,500	1.52

Table 2.1 Description of Solar System

Upon examining the above table we observe that the planets fall nicely into two groups; the **Terrestrial** (Earth like) planets of Mercury, Venus, Earth and Mars; and extra terrestrial or **Jovian** (Jupiter like) Planets of Jupiter, Saturn, Uranus and Neptune. Pluto the outer most planet because of its great distance and small size is still mysterious in its nature. The largest terrestrial planet has the diameter only 1/4 as great as the diameter of the smallest Jovian planet Neptune and its mass is only 1/17 as great. Hence the Jovian planets are often called giants.

The densities of the terrestrial planets average about 5 times the density of water and the jovian planets average about 1.5 times. The terrestrial planets are composed of dust, rock and metallic material. The Jovian planets contain with varying amounts of frozen ammonia and methane which account for the low densities.

Moon : Planet Earth has only one natural satellite the Moon, which accompanies it on its annual flight around the Sun. The planet satellite system is unique in the solar system because Moon is unusually large when compared with its parent planet. The distance from the Sun to the Moon is about 348,000 kilometers or 2,40,000 miles. The diameter of the Moon is about 2,160 miles or 3,475 Kms and its density is computed to be 3.3 times that of water. This is comparable to that of the crustal rocks of the Earth, the gravitational attraction of the Moon is about 1/6 of that experienced on the Earth's surface.

Like the Earth, the Moon rotates on its axis but does so at a much slower rate than the Earth. It also revolves around the Earth with a period of about a month. The latter motion

causes the relative position of the Sun, Earth and Moon to change producing the phases of the Moon and the eclipses of the Sun and the Moon. Since the period of rotation of the Moon being nearly equal to 24 hrs which is equal to the Earth's period of rotation, we observe always the same side of face of the Moon throughout. It is part of general knowledge that the Sun and Moon produce tides or the periodic rise and fall of the ocean level and these tides have a profound influence on the geological action of the rivers and seas.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. List out the nine planets in order of the distance from the Sun.

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2.2 SHAPE AND SIZE OF THE EARTH

That the shape of the Earth is spherical needs no special emphasis since the age old explanations are part of general knowledge like the gradual disappearance of a receding ship from the beach. Shape is the shape of the shadow of the Earth as seen against the face of the Moon during a full lunar eclipse is also spherical. It can be demonstrated geometrically that a sphere is the only body that will always cast a circular shadow upon another sphere.

But careful observations by several eminent geographers have led to the conclusion that the shape of the Earth is not a perfect sphere but an oblate spheroid, that is, it is flattened at the poles. A cross section of the Earth through the poles gives an ellipse while the equator remains a circle. The Earth's oblateness is attributed to the centrifugal force of the Earth's rotation which deforms the somewhat plastic Earth into a form in equilibrium with respective forces of gravity and rotation.

But with recent advances in Geodesy it is now established that the Earth's figure is not even a spheroid but a Geoid. Its surface is the sea-level surface of the oceans extended in an imaginary way under the continents to form a continuous figure.

The Earth's equatorial diameter is 12,756 kms where as the length of the polar diameter is 12,714 kms. Relative to the size of the Earth this difference is small and insignificant. None of the other departures from this sphericity like ocean depths and mountain peaks is as great as the polar flattening since the highest mountain is only about 5.5 miles above sea level and the greatest depth of the ocean is less than 7 miles. The mass of the Earth is computed to be in the order of 7×10^{21} tons, and the average specific gravity of the Earth is about 5.5.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. The average specific gravity of the Earth is

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2.3 CONSTITUTION OF THE EARTH

The dominant rocks constituting the crust fall into two well contrasted groups.

- a) A light upper layer of such rocks like granite and related types having an average sp. gr. of 2.7. Chemically these rocks are rich in Silica while Alumina is the abundant element of the remaining constituents. Such rocks are, on the whole collectively known **Sial**.
- b) A dark and heavy lower layer of such rocks as basalt and related types with sp. gr. 2.9 to 3.3. In these rocks the Silica (40 -50%) is the dominant constituent though much less abundant than in Granite. The Magnesia takes the second place in these heavy rocks and the whole groups is referred to as **Sima**.

The Sial is the dominant material of the continental portions of the Earth's crust down to a depth of several kms while the Sima forms the foundations of the ocean floor and extends beneath the continents.

The solid Earth is divided into four principal units 1) the inner core, the innermost solid zone having a radius of about 800 miles or 1300 kilometers 2) the outer core, a molten layer of some 1360 miles or 2200 kilometers. 3) the Mantle, the solid, less dense layer having a thickness of 1800 miles or 2900 kms. and 4) the Crust, the relatively thin outer shell of the Earth.

A very important zone exists within the mantle and it deserves special mention. This zone called **Asthenosphere** is located between depths of 70 and 700 kms (45 and 400 miles). The asthenosphere is a hot, weak zone that is capable of gradual flow. Situated above the asthenosphere lies a zone called the Lithosphere (sphere of rock) which includes the crust and the uppermost mantle. In contrast to the hot and plastic asthenosphere, the lithosphere may be considered to be cool and rigid.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. The Earth's principal layers are
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2.4 CONTINENTAL MASSES AND OCEAN BASINS

Of the nearly 197 million square miles that make up the surface of the Earth, nearly 70% is covered by the interconnecting bodies of sea water, the Pacific Ocean alone covering fully a third of the globe with an average depth of 14,000 ft. The continents of Europe, Asia, Africa, North America, South America, Australia and Antarctica are the parts of the continental masses that rise above sea-level. The high stand of the continents above the sea floors is accidental. They are mainly made up of the sialic matter which is generally less dense than the simatic ocean floors and the continents stand higher, like the ice-burys in sea water, than the denser material beneath and around them. The surface of the crust reaches different levels in different places. The area of land and sea floor between successive levels have been estimated and quite interesting results are obtained. Accordingly it is known that there are two dominant levels 1) the continental platform and 2) the deep-sea platform with a gentle slope called the continental slope connecting both of them. The continental platform includes the submerged outer border known as continental shelf which extends beyond the shore zone to an average depth of about 100 fathoms (or 200 meters). The real ocean basins must be regarded as commencing at the edge of the continental shelf. The basins are more than full and the overflow sea water inundates about 11 million square kms. of the continental platform. The North sea, Baltic sea etc., are examples of the shallow seas (shelf seas) which lie on the continental shelf.

The continents themselves have a varied relief of plains, plateaus and mountain ranges, the last reaching its high pinnacle in Mount Everest in the mighty Himalayas (29, 140 ft). The ocean floors are less vigorously diversified than the continents, but island areas and submarine ridges rise from their normally monotonous surfaces; and basins and trenches sink to more than average depths. The deepest sounding of the oceans so far made is 34,340 ft. (Swire deep off the Philippines).

2.5 GEOLOGICAL PROCESSES

Through out the life time of the Earth changes of all kinds have been going on in the Earth's crust and on its surface, in its materials, their structures, distribution of land and sea, mountains and plains and even climate and weather. The processes responsible for these changes are called geological processes. They can be divided broadly as follows.

1. **External processes** or processes of external origin, which include weathering, erosion and deposition.
2. **Internal processes** or processes of internal origin, which include diastrophism and igneous activity.

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3.2 VOLCANOES

The term Volcano is derived from the name **Vulcan**, the Roman God, applied to Mt. Etna in Sicily and to some of the volcanoes of the Lipai Islands north of Sicily. The term **Vulcanism** is used to embrace all aspects of volcanic activity. The name volcano is generally applied to the surface form which develops around a central vent which may be an orifice or a fissure through which hot incandescent magmatic materials are continuously or intermittently ejected. It is often symmetrical in shape. A volcanic mountain differs structurally and genetically from the majority of the world's mountains. As the solid materials accumulate around the vent of conduit they build up a cone which increases in size until a huge volcanic mountain is formed. A cone so constructed is called a volcano.

Volcanoes may vary in size from small conical hills to some of the loftiest mountains on the earth's surface. Some of the highest peaks like Cotapaxi in Ecuador has the distinction of being the highest volcano 6380 mtrs. high. Mount Kilimanjaro, Mount Fuji and Mount Mayon are examples of such perfect conical shape. The Hawaiian Islands are volcanoes that reach a height of more than 4200 mtrs. above sea-level and they are built on the ocean floor of the Pacific where the depth is more than 4200 to 5400 mtrs. Not all Volcanoes are active at present and some of them have become extinct like the Mt. Shasta, Mt. Rainier, Mt. Hood, Mt. Baker in the Cascade ranges of western U.S. Mt. Etna in Sicily is a high mountain built as a volcano that is still active. Every well-developed volcanic cone has near its top **volcano crater** a kind of funnel-shaped depression out of which volcanic material are thrown out, up during explosive eruptions. In some volcanoes lavas emerge through the crater, in others they break through the sides of the cone or emerge from the fissures beyond the base. It should be noted that the magma is not merely molten rock but it differs essentially from the latter in being charged with gases and volcanic constituents just as aerated waters differ from ordinary water. While the magma is confined under high pressure its gaseous constituents remain dissolved, but as it comes on to the surface the overhead pressure is reduced and the gases begin to get liberated either freely or explosively according to local circumstances. The molten matter erupted at the surface is thus relatively impoverished in gases and volatiles and then is called lava to distinguish it from the original magma. In a volcanic eruption not only the eruption of hot gases and molten lavas, but also vast quantities of fragmental materials often produced by the explosion of rapidly liberated gases. Such materials are collectively known as **pyroclastics** and they contain from the finest particles to masses of scoria and volcanic bombs of considerable size. The popular belief that volcanoes are burning mountains arises from the fact that the volcanic pyroclastic materials including hot gas often may be luminous because they are incandescent.

3.2.1 Volcanic Products

The products of volcanic eruption consist of gases, rock fragments of different sizes and finally the lavas of different composition. Steam is the commonest of the volcanic gases. It is discharged by active volcanoes in immense quantity as indicated by the great height and enormous volume of the clouds that accompany many eruptions. These clouds consist of the dust and ash by the up rushing column of steam and other gases. Due to friction between ash particles and also to the atmospheric disturbance, the volcanic eruptions and the rains that ensue are accompanied by electrical manifestations which culminate in spectacular lightning discharges. Other gases of volcanic origin in order of abundance are CO_2 and smaller proportions of H_2 , CO , S and Cl .

The pyroclastic materials that are blown into the air by the explosive activity of volcanoes and shower down at various distances from the cone, vary very much in size from fine volcanic dust and ash to big volcanic bombs. These materials are classified in the following manner 1) Pieces larger than 32mm in diameter are called **blocks** if ejected as solid and angular fragments. 2) **Bombs** if ejected as clots of molten lava and hence somewhat roundish or ellipsoidal. 3) **Lapilli** or **cinders** which are between 32mm and 4mm. 4) **ash** which are between 4 mm and 1/4mm and still finer material is called **volcanic dust**.

The volcanic ejectments in part are composed of solid rock and in part of a spongy, cellular or vesicular character. This vesicular condition is due to the fact that while most of the gas is escaping into the air and carrying fragments with it, a minor part is expanding within the particles of the liquid lava puffing them up into cellular forms.

The bombs, lapilli or cinders and most of the ash fall near the volcanic vent and thus help build an edifice round it called the **volcanic cone**. The dust is carried for long distances and spread over an immensely large area. Microscopic volcanic dust from the great catastrophic eruption of the Krakatao volcano in 1883 encircled the whole world and its dispersion through the atmosphere was reasonable for the vividly coloured and quite spectacular sunsets that were seen during the following months. The projectile power of the volcanoes is simply astounding. Thirty-ton blocks of rocks were blown out by the Stromboli in 1930 to a distance of about 3 kms. Even more astonishing are the huge blocks up to several hundred tons carried forward for miles by the pelean clouds of Mont Pelie during the great eruption in 1929.

Lavas: In volcanoes the liquid rock materials that comes out of the vent is called lava. As the magma issues out a lava it cools on the surface, darkens and crusts over. It is very viscous and its under part may still be moving while the upper part crusts over and breaks up into rough angular jagged blocks which are borne as a tumbling lava flow. Its surface consist of a chaotic blocks with sharp points. Such lavas are called **block lavas**. In Hawaiian Islands it is called **aa**. They are difficult to cross on foot.

In marked contrast to the block lava other lava flows harden with smooth surfaces which have curious ropy or curved or corroded forms. They are called **Ropy lavas** in Hawaiian Island. Ropy lavas begin to crystallize at a higher temperature, minute bubbles of gas escape quietly and the flow congeals with a smooth skin which wrinkles into ropy and corroded forms like those assumed by flowing pitch or coal tar.

When a lava of the ropy type flows over the sea floor or otherwise beneath the chilling cover of water, it consolidates with a structure like that of a jumbled heap of pillows appropriately called **pillow lava**. By the time each emerging tongue of lava has swollen to the size of a pillow the rapidly congealed skin prevents its further growth. This type of pillow lava is common in the submarine lavas associated with geosynclinal sediments of former geological periods.

The mobility of a molten lava depends upon its composition. Silica rich lavas are usually stiff and viscous and congeal as thick tongue before they have travelled far. The appearance and character of a lava stream depend upon several factors. The chemical composition of the magma determines the nature of the resulting rock whether it is light coloured lava (rhyolite) or a **black basalt** or of intermediate character as **andesite**.

Check Your Progress

Note a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. Classify the pyroclastic materials.

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3.2.2 Volcanic Eruption and Cones

The eruption of a volcano is often preceded by earthquake and by loud rumblings like thunder which may continue on gigantic scale during the course of eruption. The loud rumblings are probably due to the movement of gases and molten rock that are held in under great pressures. During one of the greatest volcanic eruptions like that of Tambora on Sumbawa Island of Indonesia in 1815, the land rumblings were heard over an area of 1,000 kms radius.

The nature of a volcanic eruption is largely determined by the type of materials ejected from the volcanic vent. These products are gases, molten rock or solid fragments. A given volcano may emit all the three types of products but in some regions a certain product predominates. Thus the Hawaiian volcanoes generally discharge very hot and highly fluid lava from which the enclosed gases escape very rapidly. Such eruptions are non-explosive. On the other hand, some volcanoes erupt with great explosive violence. Mt. Pelic on the island of Martinique in the West Indies is a typical example of explosive type. In May, 1902 it began to erupt in a series of violent explosions but discharged almost no lavas. Intermediate between these two extreme types is the one exemplified by Stromboli in the Mediterranean sea which erupts mildly every 15 minutes hurling small masses of partially solidified lava into the air. Steam also issues from the openings and forms a cloud, which reflects the light from the incandescent lava.

Volcanic eruptions are broadly categorised into two types (1) **central eruptions** and (2) **fissure eruptions**.

Majority of the present day volcanoes belong to the central type but during certain periods of geological time the fissure type eruptions have poured out lava and which covers the surrounding country as sheets of greater size than the limited flows of central types of eruptions.

When eruptions take place through a vertical chimney the orifice is widened into a crater with flaring sides by outward explosion and inward lumping. But with the accumulation of volcanic products around the vent a conical or dome shaped mountain is gradually built up. Volcanoes with the familiar cone and crater structure are said to be of the central type, because the volcanic activity is centralised around a pipe-like conduit. The top of a volcano generally is marked by a pit or crater. The crater may be widened to great size due to repeated eruptions.

3.2.3 Types of Volcanoes

Successive eruptions from a single vent build the mountainous accumulation of material known as volcanoes. Three types of volcanoes are generally recognised. a) shield volcano b) cinder cones and c) composite cones or strato volcanoes. Each has a characteristic style of eruption and consequently characteristic form.

Shield Volcano: When highly fluid lava is extruded, the volcano takes the shape of a broad slightly domed structure called a shield volcano. Shield volcanoes are built primarily of basaltic lava flows and contain only a small percentage of pyroclastic material. They have a slope of a few degrees at their flanks and not more than 10 degrees near summit. Typical example of a shield volcano is the Mouna Loa in the Hawaiian Islands which is one of the largest volcanoes in the world.

Cinder Cones: As the name suggests cinders are built up of ejected rock fragments. Because unconsolidated pyroclastic material has a high angle of repose (between 30 and 40 degrees) these volcanoes have the steepest slopes. Cinder cones are built of chiefly of cinder and ash and are generally circular in ground plan and have the form of truncated cone with a crater at its top. They are quite numerous in the Hawaiian Islands.

Composite cones or Strato Volcanoes: These volcanoes consist of alternating layers of lava flows and pyroclastic materials. They have structures that are intermediate in form between the steep cinder cones and the flat domes of shield volcanoes. This composite construction shows that a volcano thus built was at times violently explosive in activity and at other times quite, swelling up streams of lava. The deposits of successive eruptions form layers, some of coarser and some of finer materials. Thus a crude layering or stratification is produced, the layers sloping down and out from the conduit of the volcano. The layering is further accumulated by the sheets of lava which are intercalated between the beds of fragmental ejects. Mt Mayon in the Philippines is the most active volcano of this type. Other examples include that sacred mountain of Japan, the magnificent Fujiyama towering 2700 meters above the surrounding country.

Calderas : Some volcanoes have usually large craters, with huge circular pit resulting from an explosive eruption or collapse of a former volcanic cone, they are called **calderas**. A name given after **La Caldera** of the Canary Islands. Most calderas are of great size and many of them are very wide as compared with their depth. Two splendid examples of depressions of this type are the calderas at the summits of Kilonea and Mouna Loa in **Hawaii**. Both these are formed by the collapses into the partially emptied magma chamber below. Such collapse is the result of the withdrawal of the lava column from below the shield-shaped cone either by eruptions on to the surface or by movements of magma within the crust. The impression is ample proof of the downward movement of the summits of the cones. Further the steep inner walls of many calderas are marked by concentric and interweaving fissures marking the slips and faults caused by the down-dragging cone. Here the magma is injected into the concentric fissures and dykes are formed.

Fissure Eruptions : Even though volcanic eruptions from a central vent are the most familiar, by far the largest amounts of volcanic materials are extruded from cracks in the earth's crust called, **fissures**. Rather than building cone, those long narrow cracks distribute volcanic materials over a wide area. An extensive area in western India was formed in this manner, and the numerous fissures extruded very fluidal basaltic lava. It is popularly called Deccan traps. Another famous example of such fissure eruption is the Columbia river

altitude. On the basis of their mode of origin mountains are grouped as Relict type of mountains, Tectonic mountains and Accumulation mountains. Relict type of mountains are formed due to differential erosion. Tectonic mountains are also called as deformation mountains with subgroups as fold mountain and fault mountains. Accumulation mountains are formed due to the accumulation of sediments and with upliftment and subsidence. Volcanic mountains are formed due to the accumulation of volcanic products.

In India we are having Aravali, Satpura, and Vindhyan mountains. The eastern ghats, western ghats and Himalayan mountain ranges are the other. In India we have mighty Himalayas in the North, Eastern ghats and Western ghats in the South. There are also Aravalis, Satpura and Vindhyan mountains. Mountain building activity follows processes connected with mantle which produce geosynclines and geanticlines. Complex fold mountains are formed due to deformation of crustal movements.

3.5 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The pyroclastic material are classified based on their sizes.
 - a) Blocks - larger than 32 mm
 - b) Bombs - ejected as clots and some what rounded
 - c) Lapilli or Cinders - the size between 32 mm to 4 mm
 - d) Ash : The size between 4 mm to 1/4 mm.
 - e) Fine ash or volcanic dust : smaller than 1/4 mm.
2. Strato volcanoes
3. Hawaiian, Strombolian, Volcanian, Vesuvian, Plinian and Pelean types of volcanic activity.
4. The mountains are classified on the basis of their origin. The different types of mountains are (i) Relict type (ii) Tectonic type or Deformation type (iii) Accumulation type.
5. The three physiographic parts of India are (i) Peninsular India (ii) Extra Peninsular India and (iii) Indo-gangetic alluvial plain.

3.6 MODEL EXAMINATION QUESTIONS

- I. Answer the following questions in 30 lines each.
 1. Describe the types of volcanic cones and explain how they are built up.
 2. Give an account of the products of volcanic eruptions.
 3. Mention briefly about different phases of volcanic activity.
 4. What are the main mountain types. Explain.
- II. Answer the following questions in 10 lines.
 1. Give brief account of the types of volcanic eruptions.
 2. Write down the mountain ranges of India.
 3. Describe How fold mountains are formed.

It has been continuously active since the dawn of history, its eruptions being as a rule very much rhythmic consisting of mild explosions. A Volcano is said to be in the **Strombolian phase** when it ejects clots of incandescent lava and the magma in its crater and does not crust over between consecutive explosions.

Vulcanian Type : This is the phase of activity exemplified by Vulcano in Lipari Islands. Its lava is more viscous and pasty and quickly crusts over solidly between successive eruptions. Gases accumulate and gather sufficient strength beneath the congealed cover and below off at longer intervals shattering the crust formed after an earlier eruption, hurling angular fragments of rocks with great explosive violence. The resulting volcanic clouds are dark and dense and characteristically assume convoluted or "**Cauliflower**" shape as the gases and dust ascend high and expand. They are not incandescent even in nights. The major eruptions of several volcanoes begin with a vulcanian phase. Vulcanian is the term often used for eruptions in which only cold material is blown out. Activity of this type is mostly likely to occur during the cleaning out of a volcanic vent after the volcano has been dormant for quite sometime.

Vesuvian Type : This is the paroxysmal extension of strombolian and vulcanian types, the new and characteristic feature being the extremely violent explosion of a magma which has become highly charged with gases during a long interval of mild activity. In consequence of the preliminary removal of the contents of volcanic pipe, down to a considerable depth, often as a result of escape of the lava through lateral fissures and vents, the overhead pressure on the underlying magma is relieved. The magma then bursts into explosive forth and expels itself as vast luminous and incandescent clouds of cauliflower form. These clouds ascend to very great heights and from them showers of ashes are widely distributed.

Plinian Type : The most violent vesuvian type of eruptions sometimes culminate in a stupendous blast of up rushing gas which rises to a height of several miles and then spreads out into an expanding cloud of globular masses of gas and vapour. This phase was first observed in pliny during the catastrophic eruption of vesuvius.

Pelean Type : The Pelean phase is the most violently explosive of all its eruption clouds are denser than even those of Vulcanian. In this type the limit of high viscosity and explosiveness is reached. Upward escape is prevented by the growth of an obstructive dome above the conduit. Intermittent spurts of tightly compressed magma force their passage through the lateral cracks and each of these sweeps down the slopes as in intensively hot avalanche of self explosive fragments of lava lubricated by constantly expanding gases and vapours. These downward rolling explosive blasts, one of which nearly wiped out St. Pierre in 1902, are generally known as Nue'es ardents. But as a matter of fact, they do not glow as the French term suggests but are ink black in colour and hence it is best to describe them as pelean clouds.

The extraordinary feature of a pelean clouds are that is ejected horizontally from beneath the lava plug in the summit of the volcano instead of blasting the plug out vertically upward. It is extremely hot and it travels at great speed carrying with it an enormous quantity of rock fragments including blocks many meters in diameter. This phase of activity derives its name from the volcano of Mount Pele situated on the Island of Martinique in the West Indies.

Submarine Volcanoes : Violent submarine volcanic eruptions have been observed in the volcanic belt of **Aleutian Islands** and in the south central Pacific ocean area. Cones may be

built few hundred meters above sea level but when volcanic activity declined the small volcanic Islands are soon destroyed by the waves. Panteller a small Island near Sicily, is such a submarine volcanic island.

Mud Volcanoes : Gases issuing out at the surface may carry with them particles of sand and clay which are deposited at the vent and as the process continues a small cone is built up. Water present, the sand and clay form mud which dries up and hardens the surface of the mount. Gases accumulate below the hardened surface until the pressure is sufficient to blow off the top of the cone in the miniature scale of a volcano. Therefore they are called mud volcanoes and are found mostly in areas where petroleum and natural gas bearing strata occur below, as is the case in the bank region of Russia. They are also found in the regions of volcanic origin in Burma.

Features Associated with decadent Vulcanism : Many volcanoes give off steam and other gases during the dormant intervals between eruption. Even long after the volcanoes have ceased to be active, these emanations may continue to issue from the craters or their flanks. Also large bodies of magma that have ascended to the higher levels of the crust without reaching the surface on solidifying give off their dissolved gases which escape through fissures to the surface. These emanations issue at the surface either as gases when they are called fumaroles or as hot waters when they are called hot spring or geysers.

3.2.5 Causes of Vulcanism

1. Release of high-pressures, which build-up within magma chambers below the ground surface.
2. Accumulation of radio-active heat produces magma. Ofcourse other factors like frictional heat and the increase of heat with depth cause the formation of magma and their eruption on to the earth's surface causes volcanism.

3.2.6 Distribution of Volcanoes

1. They are concentrated in a narrow-belt called Circum-Pacific Ring of Fire, where the volcanoes are located on the high, young folded mountains.
2. Other volcanic areas include the scattered areas in the Pacific, particularly the Hawaiian Island, a belt that includes Arabia, Madagascar and the rift valleys of Africa, the Mediterranean belt, the volcanoes of West-Indies and those of Iceland.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. Classify the phases of Volcanic Activity.

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3.3 MOUNTAINS

A mountain is a conspicuous highland with small summit area. In the study of mountains, we come across certain terms such as cordillera, system, range, group, chain etc. A high land composed of a large number of mountains without definite arrangement, is known as mountain group. A mountain range consists of mountains arranged in a long narrow belt. Such mountains are closely associated in age and origin. A mountain system consists of many ranges and groups, all of which are related in age and mode of origin. Where mountain systems independent in age and origin, occur in more or less parallel rows they may be called mountain chain. A cordillera is a combination of chains, systems and ranges in one general portion of a continent.

In exceptional cases, single isolated mountains may be found. Usually they are the result of extensive erosion of a region or of volcanic activity.

There are quite a good number of mountain chains in the world. No two mountains are alike. Every mountain range presents a challenge to a person who wants to study the history of its formation.

Studies of historical geology show clearly that mountains have been formed during every era and probably in every period of earth's history. The spectacular heights of many of the deformation mountain chains have been attained slowly and gradually in several stages. The mountain building activity is known as **orogeny**. The areas where these activities take place are known as orogenic belts. Orogenic movements are essentially tangential to the crust. Great mountain building activity starts in the region where there was earlier a geo-syncline. Geo-syncline provides site for the deposition of material. The deposited material slowly gets uplifted due to tangential movements. In India the lofty Himalayas are the products of uplift of sediments deposited in the then existing Tethy's sea.

3.3.1 Classification

Mountains are classified on the basis of their origin broadly into three types. They are (i) Relict type (ii) Tectonic type or Deformation type and (iii) Accumulation type.

The agencies involved in mountain making process are volcanic activity, differential erosion and crustal movements.

i) Relict type of Mountains : Relict Type of mountains are formed due to differential erosion. Relict type of mountains are also known as **circum denuded** type of mountains. Most of the mountains in Peninsular India like 'Eastern Ghats' and 'Western Ghats' are classified as Relict type of mountains. Relict type of mountains are formed when an area undergo different degrees of erosion. Surrounding part gets more eroded leaving the central portion to escape the erosion.

ii) Deformation type of Mountains or Tectonic type of mountains : These can be divided again into fault type and fold type of mountains.

Fault type of mountains are produced due to the displacement or dislocation of rock blocks on either side along a plane of weakness. Fault type of mountains are also known as **Block Mountains** which result due to displacement of blocks of rocks either from a ridge or a low land. The raised part of ridge is called **Horst**, depressed area is called **Graben**.

Fold type of mountains: Another very important tectonic type of mountain is the fold type. In this type several stages are noticed. They are (a) Accumulation of Sediments in subsiding geo-syncline. (b) These sediments are subjected to lateral pressure due to tangential movements. (c) Upliftment of these sediments to form folded mountains.

iii) Accumulation type of mountains : When volcanic eruption takes place, solid and liquid lava is given out. These volcanic products heap up to form volcanic mountains or what are known as accumulation Mountains.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

4. Give the basis for the classification of mountains into different types.

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3.3.2 Mountain Ranges of India

India is broadly divided into 3 physiographic divisions namely Peninsular India, Extra peninsular India and Indo-Gangetic alluvial plain.

The mountains belonging to the Peninsular India are different from the mountains of extra Peninsular India. In Peninsular India we have the oldest mountain range known as Aravali mountains. This mountain range divides Rajasthan into two parts. The present length and height of this range is only a poor remnant of mighty Aravali mountain chain. Satpura and Vindhyan mountains are in central India. Eastern Ghats and Western Ghats are on the east and west coast of Peninsular India. All these mountains are of relict type. In the extra Peninsular India we have the highest mountain chains of the world known as Himalayas. Himalayas extend from Indus bend in the north west to Brahmaputra bend in north east. The Himalayan mountain chains fall under the category of deformation type or tectonic type. Because they are of Tectonic type, they exhibit faulted and folded structures.

3.3.3 Mountain Building and Magmatic Intrusion

In every case mountain building follows a general trend of events. Processes connected with mantle produce geosynclines and geanticlines. Erosion of geanticlines produces sediments for geosynclines resulting in the subsidence of geosyncline and rise of geanticlines. Metamorphism and granitic intrusion takes place with subsidence. Geosynclinal folding takes place giving rise to mountain building activity involving thrusting of older masses over younger strata. The origin of orogeny may be explained according to the theories of 'convection currents', 'plate tectonics' etc.

Formation of complex fold mountains due to deformation of crustal movement is generally associated with intrusion of magma. The magmatic intrusion may be due to the

increase of pressure and upliftment of sediments. Granite batholiths are generally associated with complex folded mountains as magmatic intrusions.

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.
5. Name the three parts of mountain ranges in India.

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3.4 SUMMARY

The internal geologic processes are acting internally within the Earth. These processes are mainly diastrophism and igneous activity. These activities are causing volcanic eruptions, mountain building processes and earthquakes. In this unit the volcanoes and mountains were discussed.

Volcanoes are the conical or dome shaped structures built by the emission of lava and it contained gases from a restricted vent in the earth's surface. Volcanoes may vary in size from small conical hills to some of the lofty mountains on the Earth surface. The molten rock material, if it is within the earth crust is called magma, if it comes out through volcanic vent it is called lava. The products of volcanic eruption consists of gases, rock fragments and lava. The gases are mainly CO_2 , H, CO, S and Cl. The rock fragments are classified based on their size as volcanic bombs, cinders or lapilli, ash, fine ash, tuff and volcanic dust. The lavas are called block lavas. Volcanic eruptions are divided into two types central eruptions and fissure eruptions. Majority of the present day ones are of central type. Deccan basalts are best example for fissure eruptions. The important volcanic types are shield volcano, cindercones, composite cones, calderas, fissure eruptions. When highly viscous lavas are extruded, the volcano takes the shape of a dome and is called shield volcano. Cinder cones are built of cinder and ash and generally have the form of truncated cone with a crater at its top. Intermediate in form between the steep cinder cones and flat domes of shield volcanoes are the composite cones. Calderas are usually large craters with huge circular pit due to the explosive eruption of former volcano. If the volcanic material are extruded from the cracks of the earth crust, it is called fissure type.

Based on the degree of explosive activity and nature of eruption volcanic activity is classified as Hawaiian type, strombolian type, vulcanian type, vesuvian type, plinian type and pelean type.

The cause for volcanism are the release of pressure from the magma chamber under the ground surface, radioactive heat in the magma, frictional heat in the magma and increase of heat with depth.

A mountain is a conspicuous high land mass elevated appreciably above the average

altitude. On the basis of their mode of origin mountains are grouped as Relict type of mountains, Tectonic mountains and Accumulation mountains. Relict type of mountains are formed due to differential erosion. Tectonic mountains are also called as deformation mountains with subgroups as fold mountain and fault mountains. Accumulation mountains are formed due to the accumulation of sediments and with upliftment and subsidence. Volcanic mountains are formed due to the accumulation of volcanic products.

In India we are having Aravali, Satpura, and Vindhyan mountains. The eastern ghats, western ghats and Himalayan mountain ranges are the other. In India we have mighty Himalayas in the North, Eastern ghats and Western ghats in the South. There are also Aravalis, Satpura and Vindhyan mountains. Mountain building activity follows processes connected with mantle which produce geosynclines and geanticlines. Complex fold mountains are formed due to deformation of crustal movements.

3.5 CHECK YOUR PROGRESS - MODEL ANSWERS

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 - a) Blocks - larger than 32 mm
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2. Strato volcanoes
3. Hawaiian, Strombolian, Volcanian, Vesuvian, Plinian and Pelean types of volcanic activity.
4. The mountains are classified on the basis of their origin. The different types of mountains are (i) Relict type (ii) Tectonic type or Deformation type (iii) Accumulation type.
5. The three physiographic parts of India are (i) Peninsular India (ii) Extra Peninsular India and (iii) Indo-gangetic alluvial plain.

3.6 MODEL EXAMINATION QUESTIONS

I. Answer the following questions in 30 lines each.

1. Describe the types of volcanic cones and explain how they are built up.
2. Give an account of the products of volcanic eruptions.
3. Mention briefly about different phases of volcanic activity.
4. What are the main mountain types. Explain.

II. Answer the following questions in 10 lines.

1. Give brief account of the types of volcanic eruptions.
2. Write down the mountain ranges of India.
3. Describe How fold mountains are formed.

UNIT - 4 : INTERNAL GEOLOGICAL PROCESSES - EARTHQUAKES

Contents

- 4.0 Objectives
- 4.1 Introduction
- 4.2 Recording of Earthquakes
- 4.3 Earthquake Waves
- 4.4 Intensity of Earthquakes
- 4.5 Classification of Earthquakes
- 4.6 Causes of Earthquakes
- 4.7 Distribution of Earthquakes
- 4.8 Summary
- 4.9 Check Your Progress - Model Answers
- 4.10 Model Examination Questions

4.0 OBJECTIVES

After completion of this unit, you should be able to

- define earthquakes
- classify earthquakes
- describe the causes of earthquakes
- explain the distribution of earthquakes

4.1 INTRODUCTION

In the earlier unit the internal geologic processes namely Volcanoes and Mountains were discussed. Here the remaining processes, namely earthquakes is discussed. Numerous physical forces are continuously at work within the body of the earth and upto its surface. The agents working on the surface are constantly changing the shape and size of the features that give its variety and beauty. Likewise, the physical forces beneath the surface are rearranging rock materials by shifting magmas and altering the structure of solid rocks. The adjustment beneath the surface, involve various crustal movements. Some movements are slow and radial where as some others are sudden and tangential.

The sudden and tangential movements inside the earth surface produce tremors in the rocks. Such sudden movements beneath the earth's surface are known as **earthquakes**. No other demonstration of the mighty forces at work within the earth surface is so terrifying to man as are earthquakes. They occur suddenly and swiftly, cover vast areas and leaves everything in shambles. Mountain making is an evidence of tremendous forces that act upon the surface of the earth, but the growth of mountains is so slow that man's life span is too

short to enable him detect the movements that takes place. It is very different with earthquakes. The solid land shakes, surface objects are destroyed in few seconds. Earthquakes come without warning. In spite of great advancement, science has failed to safeguard man against earthquakes in devising methods of detecting them in advance. **Herodotus, Plin** and many other philosophers and historians mentioned earthquake occurrences and destructiveness. The earliest recording of earthquakes dates back as early as 2500 years ago.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. What are Earthquakes ?

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4.2 RECORDING OF EARTHQUAKES

The first instrument made was able to record only the fact that there had been an earthquake and did not furnish information regarding its magnitude or velocity. This instrument called **Siesmoscope**, was invented in 136 A.D. Chinese.

In principle a seismograph consists of a heavy mass suspended like a horizontal pendulum, pivoted against a massive support which is firmly attached to the ground so that it shakes with the vibration of the ground. Because of its inertia the weight tends to remain stationary. It is the relative movement between the weight and the rest of the instrument that is recorded, after being suitably magnified. A small mirror attached to the weight reflects a beam of light on to a sheet of photographic paper wrapped around a cylindrical drum which rotates on a long screw. While rotating, the drum carries the paper along at right angles to the beam of light. The vibrations is thus recorded continuously.

A seismograph record is called **Seismogram**. The exact time of the beginning and ending of the shock, and the intensity of the shock can be deduced from this record.

The science of determining the size and character of earthquakes is called "**Seismology**". The detailed record of an earthquake is made on an instrument called **seismograph** which was invented and first used in Italy in 1841. The record of an earthquake shock is called **seismogram**.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. The science which deals with earth quake is ---

4.3 EARTHQUAKE WAVES

When earthquakes occur, there is a release of energy in the form of plastic waves. These waves generated during sudden crustal disturbances beneath the earth surface are called **seismic waves**. These are of 4 types. They are (i) Longitudinal waves (ii) Shear waves (iii) Ray Leigh waves (iv) Love waves.

Longitudinal waves consist of alternating pulses of compression and refraction acting along the direction in which the waves travel. They are like sound waves. Longitudinal waves are commonly known as 'P' waves.

Shear waves create oscillations at right angles to the direction of wave travel. They are similar to light waves. Shear waves are also known as 'S' waves.

By Ray Leigh waves the particles are set into motion in circles lying in vertical planes. Love waves make particles oscillate along the lines in horizontal plane at right angles to the direction of wave travel. These two types of waves are together known as surface waves or L-waves.

'P' waves travel with greater velocity than the 'S' waves. 'P' waves and 'S' waves are together known as body waves where as 'L' waves are called surface waves. Among 'P', 'S', 'L' waves, 'P' waves are the fastest and then come the 'S' waves and the 'L' waves last of all.

'P' waves can travel through solids and liquids where as 'S' waves can travel only through solids but are obstructed by liquids.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. Write about the earthquake waves ?

4.4 INTENSITY OF EARTHQUAKES

To know the strength and severity of the earthquakes, we need a scale of reference to measure its intensity. The intensity is measured by the effect of an earthquake on a seismograph or by the sensation of people, and by the damage it has caused to the life and property. The first seismograph to be introduced is that by Italian seismologists Rossi and Forrel. And therefore the intensity scale is known as Rossi Forrel Scale. Rossi Forrel Scale consists of ten (10) divisions. The higher the number in the intensity scale, greater will be the effect of the earthquake.

Mercalli, another Italian seismologist, put forth another scale with 12 divisions. In this scale the measure of the intensity depends upon the acceleration produced by the seismic waves.

The latest scale used to measure the intensity of the earthquake was given by Richter and it is known as Richter scale. All the recent earthquakes recorded have been measured on Richter scale. It is the one that is normally followed now.

A line drawn through all places having the same intensity of earthquakes, is known as **isoseismal line**. By comparing the intensities at the epicenters along the isoseismal line we can calculate the depth of the focus of an earthquake.

4.5 CLASSIFICATION OF EARTHQUAKES

The Earthquakes are classified on the basis of the depth of the focus. **Focus** of the earthquake means the exact place of disturbance beneath the earth's surface. The vertical projection of focus point on to the surface of the earth is called **epicentre**. No earthquake has been recorded whose focus is deeper than 700 kms. All earthquakes which originate at a depths of more than 300 kms. or whose focus is deeper than 300 kms. are called deep focus earthquakes. About 3% of the recorded earthquakes are of deep focus type. All those earthquakes which have their focus between 70 and 300 kms. depth are termed as Intermediate focus earthquakes. Intermediate focus earthquakes have been recorded in south Western Asia and Mediterranean lands. Earthquakes with focus at a depth of less than 70 kms. are known as shallow focus earthquakes. Majority of the earthquakes fall in this category.

Some of the famous earthquakes of India and adjacent areas are Assam earthquake of 1897, Assam earthquake of 1950, North Bihar earthquake of 1934, Koyana earthquake of 1967 and Quetta earthquake of 1935. Latur earthquake of 1993, Bhoj earthquake of 2001.

The study of these earthquakes shows that in the Himalaya region, where younger rocks come into contact with older rocks, earthquakes are frequent. These areas are very unstable and dislocations are often caused to relieve the strain.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

4. Point out the basis for the classifications of the earthquakes ?
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-
-
-

4.6 CAUSES OF EARTHQUAKES

Earthquakes originate due to various causes. These are in the order of importance: faulting, volcanism, landslides and collapse of cavern roof etc. Landslides and collapse of cavern roofs may not be the cause of the earthquakes but they may be the effects of the earthquakes. Vast majority of earthquakes originate within 16 kilometers of the surface, and may be due to causes acting at much greater depths. Earthquakes are directly associated with earth movements along faults. It is this movement associated with faulting which sets up elastic waves that produce an earthquake.

The movement along fault is influenced by many factors, the main one being the amount of strain that has accumulated in the rocks. It also depends upon the character of the fault whether it is old one or a new one.

Prof. H.F. Reid, after careful study of the 1906 San Francisco earthquake along San Andreas fault has proposed a new idea for the origin of earthquakes which is known as **Elastic rebound theory**. According to this theory the sudden shifting of rock along a fault, which is the normal cause of earthquakes, is the result of quick relief of elastic stress which accumulates by slow shifting of adjacent portion of the earth's crust in opposite direction until the rocks can no longer withstand the strain.

Therefore, it is believed that most of the earthquakes are due to structural disturbances which are termed as tectonic earthquakes. Tectonic earthquakes are the results of tectonic movements.

Earthquakes are also caused by volcanoes. The movement of magmas and gases within the earth's crust may result in earth tremors. It has long been known that earthquakes accompany the volcanic eruptions. Earthquake shocks may occur before an eruption, which is a warning for volcanic activity, but greater number of shocks follow the volcanic eruption indicating the readjustment taking place between the magmas and the surrounding rocks below the surface. Earthquake shocks which accompany volcanic eruption are less severe and less destructive than those caused due to faulting.

Submarine Earthquakes : Earthquakes which occur under the sea water are called submarine earthquakes. They cannot spread very far in sea water. They can be recorded by seismograph and felt by passing ships. The effects of submarine earthquakes on sea waves are considerable and produce vertical dislocation on the sea bottom and cause huge sea waves which are known as **tsunamis**.

5.2.3 Influence of climate on weathering

Weather is not uniform all over the world, its nature and extent being largely controlled by climatic conditions may be recognized and considered. i) The hot, most moist climate of the equatorial belt, ii) The hot and dry desert climate, iii) The cool and moist climate of the temperate zones and iv) The cool and dry Arctic regions. In each of these climatic regions rock weathering is going on continually but each region presents peculiarities of its own.

In the equatorial regions owing to high temperature and excessive rainfall, chemical weathering is very active and dominant but the thick vegetation hinders transport the product of weathering. Here the organic agencies are much pronounced and chemical reactions are more rapid and vigorous than in cooler latitudes and therefore the decomposition of silicates is almost complete and much of silica is removed in solution. The characteristic end product of chemical weathering is the **Laterite** which consists largely of red hydrated oxides of iron and alumina.

In desert regions peculiar conditions prevail, characterized by a dry climate and consequent lack of vegetation and hence the character of weathering differs a great deal from what is found elsewhere. The daily range of temperature is so very great that the effects of alternate expansion and contraction have full play. Rainfall is sparse in deserts and so the solution by downward percolating water is of minor importance. Since the air is very dry and the sun very hot the capillary water is drawn towards the surface where evaporation results in the concentration of salts that are in solution. The warm concentrated solutions react with the constituent of rocks and tend to decompose them. Crystallisation of new compounds takes place between the mineral grains and this may cause splitting of solid rocks in much the same manner as the freezing water. Since the waters are constantly rising up towards the surface by capillary action and depositing their dissolved contents, the surface materials become cemented resulting in the formation of '**Hard-Pan**' and irregular concretionary mass in the mantle rock. A very common phenomenon in desert regions is the occurrence of a brown black shiny crust on the rocks known as "**desert varnish**" which consists mainly of oxides of iron and manganese. In temperate regions the weathering is a sort of combination of all other processes since there are marked seasonal variations. In winter frost action is dominant, whereas in summer water plays a more conspicuous part. In general solution and chemical decomposition are the dominant types of weathering in these temperate lands.

In the Arctic regions where a large part of the surface is covered with snow during most of the year, the underlying rocks are saturated with melt water which is repeatedly frozen and thawed. In such an environment **frost action** and the wedge work of ice are the dominant agents of mechanical weathering. This results in the formation of strikingly sharp ridges and peaks so characteristic of the mountains of high altitudes above the snow line. Under such climatic conditions disintegrations is the dominant process which leads to the accumulation of great masses of fresh rock materials.

5.2.4 Products of weathering - soils

An examination of a freshly cut cliff as in a new highway or quarry wall will often reveal a succession of layers of different earth materials. Starting at the base of the exposure there may be solid rock usually called the **bed rock** which is still in its original place and

focus is more than 300 kms. are called deep focus earthquakes. If the depth of the focus is in between 70 and 300 kms. then they are called intermediate focus earthquakes. Earthquakes with focus at a depth of less than 70 kms. are known as shallow focus earthquakes.

Earth quakes are caused due to the earth movements along faults. H.F. Reid proposed elastic rebound theory for earthquakes. It states that the sudden shifting of rock along a fault results in release of elastic stress. Therefore most of the earthquakes are due to structural disturbances. Earthquakes are also caused by volcanoes. The submarine earthquakes on sea bottom cause huge sea waves called Tsunamis.

Earthquakes are distributed along two major belts namely Circum-Pacific ring of fire and second chain extends over Indonesia, Andaman-Nicobar Islands and Burma. Now a days earthquakes are occurring everywhere due to human activities.

4.9 CHECK YOUR PROGRESS-MODEL ANSWERS

1. The sudden and tangential movements within the earth surface are known as Earthquakes.
2. The science of Earthquakes is called Seismology.
3. There are four types of earthquake waves namely Longitudinal waves, Shear waves, Ray-Leigh waves and Love waves.
4. Based on the depth of the Focus earthquakes are divided into deep focus, intermediate focus, and shallow focus earthquakes.
5. H.F. Reid proposed elastic rebound theory.

4.10 MODEL EXAMINATION QUESTIONS

I. Answer the following questions in 30 lines each

- i) What are the causes and effects of earthquakes ?
- ii) Give a brief account of classification of earthquakes.
- iii) What are the methods used for detecting and recording of earthquakes ?

II. Answer the following questions 10 lines each

- i) Write notes on epicentre and focus.
- ii) Write notes on earthquake belts.

BRAOU

BLOCK - II

EXTERNAL PROCESSES

BRAOU

UNIT - 5 : ROCK WEATHERING AND GROUNDWATER

Contents

- 5.0 Objectives
- 5.1 Introduction
- 5.2 Rock weathering
 - 5.2.1 Mechanical weathering
 - 5.2.2 Chemical weathering
 - 5.2.3 Influence of climate on weathering
 - 5.2.4 Products of weathering - soils
 - 5.2.5 Mass wasting
- 5.3 Groundwater
 - 5.3.1 Distribution
 - 5.3.2 Porosity and Permeability
 - 5.3.3 Aquifers and Aquicludes
 - 5.3.4 Springs and Wells
 - 5.3.5 Geological work of groundwater
 - 5.3.6 Uses of groundwater
- 5.4 Summary
- 5.5 Check Your Progress-Model Answers
- 5.6 Model Examination Questions

5.0 OBJECTIVES

After completion of this unit, you should be able to

- explain physical & chemical weathering processes and
- describe the products of weathering
- define groundwater
- explain the geologic work of groundwater

5.1 INTRODUCTION

The external processes are those which derive their energy from external sources and ultimately from Sun. These processes are also called as exogeneous processes. These processes are mainly caused by geological agents like weathering, groundwater, wind action, running water through rivers, glaciers, lakes, seas, oceans etc. The configuration of the land surface are the out come of the joint actions of some geological agents having both

constructive as well as destructive effects on the existing surficial features. Since these agents originate upon the Earth's surface they are known as epigene-geological processes. Already the internal geological processes, also called as hypogene processes were discussed in the earlier units with the topics of volcanoes, mountains and earthquakes.

5.2 ROCK WEATHERING

Weathering may be defined as the total effect of various subaerial processes that bring about the disintegration and decay of rocks exposed on the surface of the earth. It is the process of alteration of rock materials, during long exposure to air, moisture and organic matter. The prime elements of weather are temperature, pressure and moisture. Warmth and moisture favour chemical action which brings about decomposition of the earlier complex minerals into altered minerals of simple composition, the changes of temperature and pressure either due to seasonal variation bring about physical or mechanical disintegration of rocks. Thus weathering is related to the surface of the lithosphere where rocks, air and water come together. Water or moisture soaks into the cracks and joints of rocks, dissolves and alters minerals, expands by freezing and enlarges joints and fractures. This process begins in cracks or fractures and ultimately the entire rock is effected.

The geological work accomplished by weathering is of two kinds.

- 1) **Physical or Mechanical** changes in which the materials are disintegrated by temperature changes, frost action and organisms and
- 2) **Chemical** changes in which the minerals are decomposed, dissolved and loosened by water, oxygen, carbon-di-oxide of the atmosphere and by organisms and products of their decay. The physical, chemical and biological agents actively co-operate with one another.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. What is meant by weathering ?

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5.2.1 Mechanical Weathering

When a rock undergoes mechanical weathering it is broken up into smaller fragments each containing the characteristics of the original matter. This mechanical breaking up of rocks exposes additional fresh surfaces to water and air. Therefore disintegration aids decomposition of the chemical alteration of rock materials. On the other hand some chemical changes are directly responsible for mechanical disruption on a large-scale. Normally both phases of weathering go on at the same time. In nature four

important factors of physical processes lead to fragmentation of rocks, these are frost action, temperature effects, mechanical effects of animals and plants and gravity.

Factors effecting mechanical weathering

1. Frost action or wedge work of ice

Water entering the cracks and other original planes like joints and bedding planes freezes and thaws. As freezing continues size increases, ice exerts pressure on the surrounding rocks and causes damage. On mountain tops in day time the temperature may reach 120°F degrees or more and the rocks may become distinctly warm or even hot but at night the temperature may drop to below freezing point. Under such circumstances disintegration is most effective. The frost shivered fragments fall to lower levels and accumulate there as screes of angular debris.

2. Effects of changing temperatures

In deserts, semi-arid regions and monsoon lands with a marked dry season the rocks are heated by the scorching Sun in the midday to a very high temperature and cooled to a very low temperature during nights. Since the rocks are poor conductors of heat, only the outer layers of the rocks are effected due to alternate heating and cooling and so in course of time they get detached from the main mass of the rocks. These thin outer layers of rocks peel off as curved shells. This separation of successive thin shells during weathering from massive rocks such as granite or basalt is known as **Exfoliation**.

This type of weathering is conspicuous only where mechanical disintegration is somewhat aided by chemical decomposition due to the presence of appreciable moisture contact.

The process of exfoliation results in the formation of rounded masses of rocks. Such a sort of weathering is called **Spheroidal Weathering**, and the rounded masses of rocks are called residual boulders. The attack starts from the edges and the corners and they are gradually worn down sharp corners and edges are the first to fall away with the development of rounded outlines and as a consequence the hills become more or less dome shaped. On convex slopes successive shells may be seen overlapping like the tiles on a roof, each ready to fall away as soon as it is liberated by the formation of radial cracks. This effect is well observed in the Inselbergs (isolated island mounts) of Mozambique and other parts of Africa. Another famous example is afforded by the sugar loaf Hill in Rio Janeiro, Brazil.

3. Mechanical work of plants and animals

The growing rootlets of plants and trees exert an almost incredible pressure as they work down into cracks and crevices. Cracks are widened by expansion during growth and wedges of rocks are forcible rendered apart. Burrowing, animals large and small (Earthworms, Rodents) play an important part in preparing material for removal by rain wash and wind. They bring large quantities of partly decayed rock fragments to the surface where they are exposed more effectively to chemical decomposition. It is estimated that worms bringing particles to the surface at the rate of more than 10 tons per acre on average every year.

Plants of all kinds like Fungi and Lichens contribute to chemical weathering since they abstract certain elements from rock materials. Water containing bacteria attack the

minerals of rocks and soils very much vigorously and the remains of dead organisms decay in the soil largely as a result of the petrefying action of the soil bacteria and fungi. The chief organic product of this kind of action is a sort of complex of brown jelly like substance collectively called **Humus**. It is the a chief characteristic organic constituent of soils and water, it can dissolve small amounts of such substances like limonite.

4. Action of Gravity

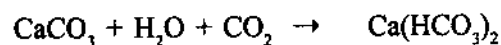
Gravity helps in the removal of products of weathering, thereby exposing fresh surfaces of rocks for further weathering. It removes by slow downward movement of the loosened rock-debris. In steep mountain valleys wheathered products tend to fall down by gravity and accumulate at the base of the mountain. Such accumulations of the rock fragments dislodged from cliffs by weathering and deposited below are known as **Talus**. The slope of Talus is generally about 25 to 30 degrees.

5.2.2 Chemical Weathering

The Chemical Weathering involves the complex processes that alters the internal structures of minerals by removing or adding elements. During this transformation, the original rock decomposes into new substance which is balanced with the surface environments. Consequently, the products of chemical weathering will remain unchanged as along as they remain in their new environment. Water is the most importnt agent of chemical weathering. The major process by which water decomposes rocks are **solution, oxidation and hydrolysis**. They act as carrier of dissolved oxygen and carbon-di-oxide together with various acids and organic produts derived from the soil. The degree of decay or decomposition depends upon the composition and concentration of solutions so formed, on the temperature, on the pressure of bacteria and on the substances taken into solution from the decomposed products. The chief changes that ocur in chemical weathering are **solution, oxidation, hydration and the carbonation**. Only a few common minerals resist decomposition, quartz and muscovite being the notable examples, while others like calcite (carbonates) are removed entirely by solution. Most silicate minerals break down into insoluble residues such as clay minerals, with liberation of soluble substances which are removed in solution.

Chief processes of chemical weathering

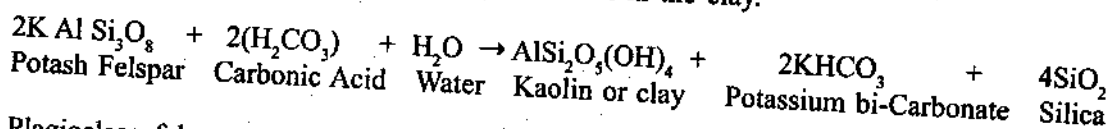
(1) **Solution** : Carbon-di-oxide (CO_2) dissolved in water forms Carbonic acid (H_2CO_3). Rain water with dissolved Carbon-di-oxide percolates into the cracks and crevices of rocks and attacks them in several ways. Limestones are readily attacked, the carbonate being converted into bicarbonate which is readily soluble and can be carried away in solution. For example.



In many limestone regions the effects of solution are more spectacular as evidenced in the **Pennines** particularly around **Ingleborough** where many limestone pavements are found with deeply grooved and furrowed surfaces. When limestones contain impurities such as quartz and clay they remain undissolved and so accumulate to form the mineral basis of soils. The read earth known as **Terra Rossa** of the true Karst or the **clay with flints** of Chalk-lands are example of such residual deposits.

(2) **Oxidation** : In this process water with dissolved oxygen acts as an agent of decomposition of rocks. Iron minerals in rocks are easily attacked. The iron silicates such as pyroxenes, amphiboles and the ferrous Iron is converted to ferric Iron (as in Hematite) or to various other hydroxides (Limonite or Goethite etc.), with accompanying colour changes from green black to yellow, red or brown. Hence many soils in warm moist climates are coloured red, yellow or brown.

(3) **Hydration** : This process involves chemical addition of water to certain minerals of rock to form new minerals chiefly hydrous oxides and hydrous silicates. Thus orthoclase an abundant felspar in the most widespread continental rock granite is decomposed and converted largely to Kaolin, the principal mineral in the clay.



Plagioclase felspar are likewise decomposed and most of the alumina is used up in the formation of kaolin. Other hydrous silicates formed by hydration include serpentine talc, chlorite, zeolite etc.

(4) **Carbonation** : Another process of decomposition is carbonation by which CO_2 is added to certain bases particularly to oxides of calcium, magnesium, sodium and potassium to form either carbonates or bicarbonates of these metals. All surface water contain dissolved CO_2 derived from the atmosphere. Carbonated water dissolves many substances much more readily than pure water and consequently is an active agent of chemical weathering.

When Al_2O_3 and Fe_2O_3 are also present in minerals as biotite, augite, hornblende, clay, chlorite minerals and limonite remain as residual products. In the presence of oxygen limonite is also precipitated from solutions containing $\text{Fe}(\text{HCO}_3)_2$. For this very reason weathered rock surfaces are commonly stained a rusty brown colour.

Chemical weathering, therefore, either breaks down minerals into soluble compounds which can be removed in solution or so weakens the rocks that they can be attacked more readily by other agents of weathering. It contributes to the disintegration of rocks i) by the general weakening of adhesion between minerals, so that the rocks can readily be attacked by physical agents. ii) by the formation of solutions which are washed out by rain so that rock becomes porous and ready to crumble e.g. the liberation of grains of a sandstone by solution of the cementing medium. iii) by formation of alteration products with a greater volume than the original material so that the outer shell, as in exfoliation, swells and pulls away from the fresh rock within.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. What is exfoliation ?

5.2.3 Influence of climate on weathering

Weather is not uniform all over the world, its nature and extent being largely controlled by climatic conditions may be recognized and considered. i) The hot, most moist climate of the equatorial belt, ii) The hot and dry desert climate, iii) The cool and moist climate of the temperate zones and iv) The cool and dry Arctic regions. In each of these climatic regions rock weathering is going on continually but each region presents peculiarities of its own.

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In desert regions peculiar conditions prevail, characterized by a dry climate and consequent lack of vegetation and hence the character of weathering differs a great deal from what is found elsewhere. The daily range of temperature is so very great that the effects of alternate expansion and contraction have full play. Rainfall is sparse in deserts and so the solution by downward percolating water is of minor importance. Since the air is very dry and the sun very hot the capillary water is drawn towards the surface where evaporation results in the concentration of salts that are in solution. The warm concentrated solutions react with the constituent of rocks and tend to decompose them. Crystallisation of new compounds takes place between the mineral grains and this may cause splitting of solid rocks in much the same manner as the freezing water. Since the waters are constantly rising up towards the surface by capillary action and depositing their dissolved contents, the surface materials become cemented resulting in the formation of '**Hard-Pan**' and irregular concretionary mass in the mantle rock. A very common phenomenon in desert regions is the occurrence of a brown black shiny crust on the rocks known as "**desert varnish**" which consists mainly of oxides of Iron and manganese. In temperate regions the weathering is a sort of combination of all other processes since there are marked seasonal variations. In winter frost action is dominant, whereas in summer water plays a more conspicuous part. In general solution and chemical decomposition are the dominant types of weathering in these temperate lands.

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5.2.4 Products of weathering - soils

An examination of a freshly cut cliff as in a new highway or quarry wall will often reveal a succession of layers of different earth materials. Starting at the base of the exposure there may be solid rock usually called the **bed rock** which is still in its original place and

relatively unchanged. Lying above the bed rock may be a layer of soft mineral matter, the **regolith** which may be formed in place by decomposition and disintegration of the bedrock that lies directly beneath it. Within this regolith individual mineral grains or small groups of mineral particles are easily separated from one another. In some places the regolith has been stripped away exposing the bed rock which then appears at the surface as **Outcrop**.

In many places the soil grades down through subsoil composed of partially weathered material into the original fresh bed rock beneath. Soils are the most useful products of weathering and they are a complex mixture of inorganic mineral matter and decomposed organic residues. They differ greatly from area to area, not only in quantity but in quality as well.

The chief factors in the soil formation are i) parent rock material ii) climate iii) action of living organisms iv) slope of the land surface v) time. Hence the character of the ultimate soil derived from a given rock will to a great extent depend upon other factors of soil formation.

Soils which rest upon the bed rock from which they are derived are called **residual soils**. They show a gradual transition downward into subsoil and in turn to solid bed rock. Transported soils are those which are derived from mantle rocks that have been carried to their present position from their original places. They owe their present location and position to agents of transportation like wind, running water, moving ice or simply gravity. Since these agents accomplish different degrees of sorting transported soils naturally vary in texture from fine silts to coarse gravel. They also vary in chemical composition.

Types of Soils

The mature soils are grouped into classes or types determined by the prevailing climate and associated vegetation of the concerned areas. They are described in the following.

1. Lateritic - soils : These are developed by intense weathering in hot, humid climate regions under the rain forests. The material, high in iron and aluminium oxides and hydroxides; is red, yellow or brown in colour and very often is leached of bases and silica. Basalts, Granites and Gneisses generally give rise to lateritic soils under peculiar tropical monsoon climates. This type has little agricultural value because it lacks important salts and humus.

2. Black Soil or "Chernogem" : As the very name indicates it is black in colour and granular in texture. It is a type of clayey soil which is generally formed from the decomposition of basalts and other types of basic rocks. They contain high percentage of oxides of aluminium, calcium and magnesium and rather variable percentage of humus. The iron and the humus content determine the black colour of the soil. It swells up when wet and has a high water-retaining capacity. This is a highly fertile soil and so very suitable for cotton cultivation, that is often referred to as the Black cotton soil. These are generally formed in temperate, sub-humid climates typically associated with tall grass vegetation.

3. Podsol : This type of soil is generally developed in subarctic to cool moist climates under a cover of coniferous forests. The colour of the soil is ash grey, organic matter low, acid often leached and it is almost always underlain by a secondary clayey subsoil. It is generally sandy and not very much fertile.

7. Write any two uses of groundwater ?

5.4 SUMMARY

External processes or exogeneous processes are mainly caused by the geological agents like weathering, groundwater, wind action, rivers, glaciers, lakes, seas, oceans etc. The topics of rock weathering and groundwater are discussed in this unit.

Weathering may be defined as the total effect of various subaerial processes that brings about disintegration and decomposition of the rocks. The disintegration occurs with physical processes and hence called as physical or mechanical weathering. The decomposition of rocks occurs with chemical processes. The factors effecting mechanical weathering are frost action, temperature, plants and animals, gravity etc.

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Chemical weathering involves complex processes that alters the internal structures of minerals by removing or adding elements. Solution, oxidation, hydration and carbonation are the processes in chemical weathering. Chemical weathering breaks down minerals into soluble compounds which can be removed in solution or weaken the rock.

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The water that is found in the pore spaces of rocks below the ground surface is called groundwater. The ultimate source of groundwater is rainfall. Surface water, after infiltration, becomes a part of the groundwater. The groundwater occupies the saturation zone, above it is the zone of aeration. The upper surface of the zone of the saturation is water table. The level of water table is important in predicting the behaviour of wells.

A body of permeable sediment or rock through which groundwater moves is called an aquifer. Impermeable layers of rocks or sediment are called aquicludes. A spring may be the natural outlet on the surface through which groundwater flows. A geyser is a special

country's freshwater requirements. In addition, it is of great significance as an equalizer of stream flow and as an agent of erosion. The erosional work of groundwater is responsible for the creation of caves and caverns and other related features.

Sources of Groundwater : The chief source of all but a meagre quantity of groundwater is the annual rainfall or snowfall or simply the meteoric water from the atmosphere. Of the water that is precipitated nearly half is returned to the atmosphere by evaporation or transpiration. About one fourth of it flows as run off in streams and rivers and is carried into the lakes and seas or oceans. The remaining find its way into the crustal rocks through pores, cracks, fissures and other openings in bedrock. Some of the factors that favour the descent of water into the earth's crust are humid climate, dense vegetation which interferes with the run off and a relatively high degree of porosity and permeability and fissuring of the bed rocks.

5.3.1 Distribution

The water that descends into the crustal rocks is known as groundwater. Perhaps a large amount of it, returns to the surface through natural seepages and springs, a large amount moves to the surface by capillary action in loose rock materials and then evaporates, some amount is drawn up to the leaves by transpiration and eventually evaporated and a considerable amount is removed through wells for domestic consumption and industrial uses while, a small amount of water enters into chemical combination with various minerals and rocks to be held there often for ages.

Another source of groundwater is that which occupied the spaces between grains of sand and silt and other materials as the sediments accumulated, on the floors of the lakes or seas ultimately to become sedimentary rocks. Such water trapped in the sediments is called the **connate water** and is commonly found along with oil in many oil fields.

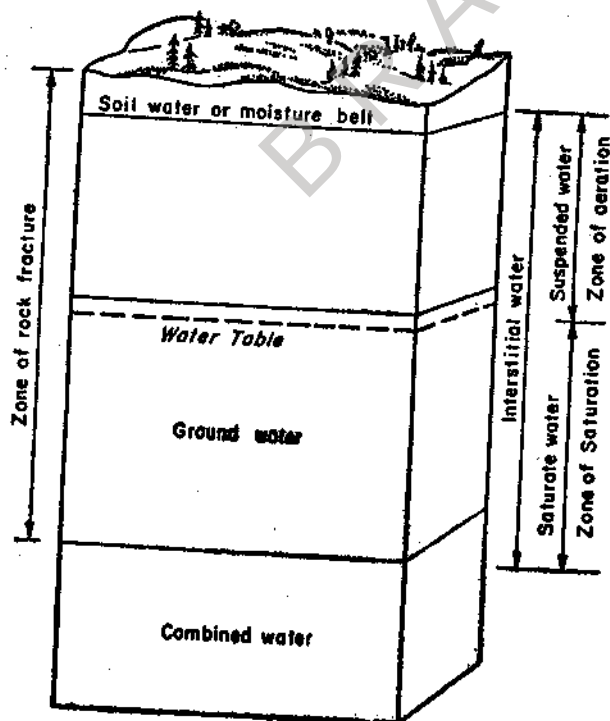


Fig. 5.1 Distribution of Groundwater

5.3.3 Aquifers and Aquicludes

A lithological unit that is capable of containing and transmitting water through it is called an **Aquifer** (water-carrier). Bodies of gravel and coarse sand are very good aquifers. Many sandstones are good aquifers. Some limestones are also aquifers since due to solution the fractures and bedding planes in limestones are enlarged into open passage ways. Igneous and metamorphic rocks and some shales which have extremely small spaces between their grains should be normally impermeable and therefore not aquifers. But they may be rendered permeable by the presence of cracks, fissures, spaces between layers and other openings that are too large to be controlled by molecular attraction.

On the other hand, impermeable layers composed of materials such as clay that hinder or prevent water movement are called **Aquicludes**. The smaller the pore spaces, the slower the water moves. If the spaces between the particles are very small the films of water clinging to the particles will come into contact or overlap. As a result, the force of molecular attraction which binds the water to the particles extends across the opening and the water is held firmly in place. Clay is an eminent example of such an aquiclude.

The depth to which the surface water penetrates varies with the character of the rocks in that area. In some places they reach a depth of several thousands meters whereas in other places very little water is collected at more than a few hundred meters.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

5. What is an aquifer?

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5.3.4 Springs and Wells

A spring is defined as a natural outlet on the ground surface from a flow of undergroundwater. Groundwater moves down either to the first impervious layer or to the water table. If the groundwater comes out at the ground surface of the ground and flows either continually or intermittently, it is called a **spring**.

Springs usually issue upon a hill side or in a valley. An ordinary hill side spring is formed where aquifer formations like gravels and sandstones rest upon impervious strata. Where the water comes out to the surface along an escarpment, it comes out in the form of several small seepage springs.

An aquifer spring issues out on the hill side or in a valley when an aquiferous formation interbedded with impervious strata is exposed on the surface.

Check Your Progress

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4. What is groundwater?

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5.3.2 Porosity and permeability

The **Porosity** of a rock is determined by the percentage of the total volume of pore space available in the total volume of the water bearing rock. Apart from mineral particles, rock contains interstices, pores or voids and since water moves through these openings or interstices, their nature and volume become important in the movement of undergroundwater. Porosity varies with the nature of the material. Weathered or stratified rocks are usually more favourable for containing of water than massive igneous rocks. The range of porosity in earth materials is extremely great.

Sediments are usually quite porous and open spaces may occupy from 10 to 60 percent of the volume. The amount of pore space depends upon the size and shape of the grains as well as packing, degree of sorting etc. Clay, for example, has a high porosity of nearly 50% while in many sands and gravels voids make up only up to 20 percent. Most igneous and metamorphic rocks are composed of tightly interlocking crystals. The amount of open space between the grains may be negligible. Therefore, if these rocks are to have greater porosity, fissures and joints must provide a significant proportions of the open space. Porosity alone is not a satisfactory measure of a materials ability or capacity to yield groundwater. Although clay has a high percentage of porosity and can hold water in a large quantity, its pore spaces are so small in size that water is unable to move. Such rocks or materials are called impervious. The rock or sediment may be porous and still do not allow water to move through it.

The **permeability** of a material is the capacity or ability to transmit a fluid. It is a measure of the velocity of percolation and may be said to be the rate at which the rock formation will allow water to flow through it under a given amount of pressure. Groundwater moves, through small openings. Coarse grained sands and gravels without fine grained particles in the spaces between grains are more permeable and allow water to move readily through them.

Although, a rock may posses high porosity, it is not necessarily to be permeable. For example clay has high porosity than sand but since the particles that make up clay are minute flakes, the interstices between them are small and, therefore, water will not pass easily through the clay beacuse fine grained material gets swollen closing the interstices and also because of the molecular attraction. In contrast, water is free to move through sand because the passage ways are relatively large.

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The most common device used by man for tapping undergroundwater is the well - an opening dug or drilled into the zone of saturation. Well serves as a reservoir into which groundwater moves and stored from which water can be drawn from the surface. Discharging water from the wells lowers the waterlevel and so creates a cone of depression. Large scale withdrawal of water may cause cone of depression more wide and deep resulting in the lowering of the water table in the vicinity.

Most of the wells are simply dug down in loose rock material to a few meters below the water table. The depth seldom exceeds 15 meters in humid-regions. Wells are bored in loose materials with large augers, rotated by power-developing machine to a depth of 100 feet or more. In hard rock formations wells are drilled by rigs using rotary methods. Drilling deep wells for irrigation and industrial purposes is quite helpful and also helps in gaining knowledge of the underground rocks.

Artesian springs and wells : A certain arrangement and disposition of inclined rock formations makes it possible for special pattern of circulation of groundwater. In a series of inclined rock layers which include permeable layer like a sandstone and an impermeable layer like shale or clay above and below, groundwater can percolate through the sandstone which is an aquifer. In the shale the water is held immobile. In the area of water intake where the sandstone is cut by the surface of the ground, Meteoric waters enter the aquifer and percolate down. Percolation is confined within the aquifer because it is confined in between impervious formations. The aquifer acts like a broad, flat sandfilled conduit holding the groundwater under hydrostatic pressure of the column of water extending up to the water table at its upper end. Wells piercing the root layer and penetrating the aquifer releases water which rises in each well to the level of the water table. Such wells are known as **artesian wells**, which may be defined as wells whose waters rise above the aquifer. The name artesian is derived from the French province of Artois in which near Calais, the first well of this kind in Europe was bored. Conditions favourable for the formation of artesian wells exist in New Jersey, New York and other areas of the Atlantic Coastal Plain of the U.S.A. The largest artesian system in North America is based on the Dakota sandstones.

In India the well-known Cuddalore sandstones in South Arcot District of Tamilnadu form an excellent artesian system and are very good sources of groundwater supply in the state. Artesian to semi-artesian conditions exist in the Rajahmundry sandstones in east and west Godavari districts of Andhra Pradesh and places such as Sattupally in Khammam district.

Artesian contains are not confined to wells. They operate also where the confined water has a natural outlet usually through a fissure or fault plane in the rocks. The result is a natural artesian spring. Hot or thermal springs bring warm or hot water to the surface and they are called hot water springs. Usually an excess of 15 to 20°F over mean temperature is regarded as characterising of a thermal spring. Most of the thermal springs derive their heat from masses of magma that is pushed into the crust nearly to the surface and are now cooling. The water may pass through masses of volcanic rocks of recent geological age which have not yet cooled to the normal temperatures of the earth's crust. Yellow stone National Park in the U.S.A, contains thousands of such hot water springs (many of them boiling) where in recent times successive out pourings of lava covered a wide area. Another source of heat of thermal springs is the special conditions of the groundwater circulation that carry it in to a depth sufficient to warm it by the normal increase in the earth's crust and then rise to the surface under hydrostatic pressure. It is known that the temperature of the earth's interior rises downward at 1°F for every 50 to 75 feet. Water

7. Write any two uses of groundwater ?

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5.4 SUMMARY

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enlarges them into caves. The materials that is dissolved by the groundwater is carried away and discharged into streams.

The features that arose the curiosity of visitors to these caves are the stone formation that often exhibit quite bizarre patterns and given some caverns, a wonderland appearance. These features are created by the seemingly endless dripping of water from the ceiling of the caves of great spans of time. The calcite that is left behind produces kind of limestone we call **travertine**. These cave deposits are broadly called **Drip-Stones**, an obvious reference to their mode of origin.

Although cavern formation takes place in the zone of saturation the deposition of dripstone is not possible until caverns are above the water table in the zone of aeration. This commonly occurs as nearly by streams cut their valleys deeper causing the water table to drop as the elevation of the river drops. As soon as the cave chamber is filled with air, the stage is set for the decoration phase of caves building to begin.

The various dripstone features found in caverns are collectively called **speleothems**, no two of which appear alike. Perhaps the most familiar speleothems are **Stalacities**. These ice like pendants hang from the ceiling of the cavern and form where the water seep through the cracks above. When the water reaches the air in the cave, a little amount of evaporation takes place. Thus some of the CO_2 in solution escapes and a residue of calcium carbonate is deposited. Deposition occurs as a ring around the edge of the water drop. As drop after drop follows, each leaves an infinitesimal trace of calcite, behind, and a hollow limestone tube is created, and water then, moves through the tube, remains, suspended momentarily at the end, contributes a tiny ring of calcite, and falls to the cavern floor. The stalactite just described is appropriately called a soda straw. Often the hollow tube of soda straw becomes plugged or its supply of water increases. In either case, the water is forced to flow, and hence to deposit along the outside of the tube. As deposition continues, the stalactite takes on the more common conical shape.

Speleothems that form on the floor of the cave and reach upward to the ceiling are called **Stalagmites**. The water supplying the calcite for stalagmite growth from the ceiling spreads over the surface. As a result, stalagmites do not have a central tube and are usually more massive in appearance and rounded on their upper ends. When the downward growing, stalacmites and upward growing stalagmites join, they form pillar like structures.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

6. The vertical hanging of CaCO_3 from roofs of caves is known as :-

The cave shapes mass formed on the floor of the cave is -

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In the State of Andhra Pradesh there are several caves in the limestone country of which mention may be made of the Borra Caves near Anantagiri of Visakhapatnam district and Kona Rameswaram near Rayalacheruvu of Anantapur district. In Borra caves stalactites and stalagmites are seen in the process of formation.

Sinkholes : The solution of those rocks is so rapid that caves and cavern usually collapse from the weight of the overlying strata before erosion can open them to the surface. Such an opening that connects a cave with the surface is called a **Sink hole**. It may be formed by the solvent action of the surface water which finds its way into the cave.

A natural bridge may be formed by the collapse of all but one portion of the roof of a cave. A famous example is natural bridge off Virginia State in the U.S.A. Natural bridges are also formed by other ways. For examples the natural bridge that forms during the process of erosion of a region when a stream perforates the neck of one of this rather deeply intrenched meanders as in the case of rainbow bridge, Noah (U.S.A.). One natural bridge can be found on Tirumala hills.

Karst topography : Many areas of the world that have been landscaped have been shaped to a large extent by the dissolving power of groundwater. Such areas are known to exhibit Karst-topography. The term is derived from a plateau region located along the north eastern shore of the Adriatic sea in the border area between Yugoslavia and Italy where such topography is strikingly developed. Generally arid and semi-arid areas do not develop karst topography. When solution features exist in such regions, they are more likely to be remnants of a time, when more humid conditions prevailed.

Karst areas characteristically exhibit an irregular terrain punctured with many depressions. These depressions are called sinkholes or sinks, about which mention has been made already. In the limestone areas of Kentucky and Southern India there are literally tens of thousands of these depressions varying in depth from a few meters to a maximum of 30 mtrs. Karst regions show a striking lack of surface drainage. Following a rainfall the runoff is generally funnelled below ground through caverns until it finally reaches the water table. When small streams do occur at the surface, their paths are usually short.

Deposition by Groundwater : The chief ingredients carried in solution by groundwater are the bicarbonates of calcium, magnesium and iron and colloidal silica. The iron and silica are derived as the water passes through the soils down of the water table. Some of the bicarbonates of calcium are acquired in the soil zone and more may be added as it passes through limestones and dolomites. These materials are available for deposition in the zone of saturation between grains which are cemented firmly together. Calcite, silica and iron compounds are the chief cementing media. The loose sediments are thus cemented to form compact rocks.

Replacement and substitution may also take place during the percolation of groundwater. Replacement is the process by which groundwater dissolves such matter as already present and at the same time deposits from solution an equal volume of a different substance. Such replacement is well exemplified by parts of certain limestone formations in which calcite has been replaced by dolomite or even silica. The change often takes place, particle by particle so that the original structure are perfectly retained. Calcareous fossil shells may thus be transformed to any of the materials mentioned. Petrified wood is a common example. The famous petrified forests of Arizona in USA owe their origin to this process of replacement. Equally eminent examples of such petrified wood are found near Sattanur in Tamilnadu.

Another kind of groundwater deposition consists of nodules and concretions common in certain sedimentary rocks. Under certain circumstances chemical precipitation takes place around some nucleus such as a small leaf or animal remain or even a small pebble. Deposition, once started, seem to lead to further precipitation on the same surface and concentric layers of mineral matter are deposited. Rounded irregular bodies called concretions are formed in this manner. Many coal seams contain concretionary masses of iron sulphide in the form of marcasite. Other concretions are made up of calcite, gypsum, barytes, quartz and calcium phosphate.

Cavities in rocks may become lined with crystals formed by precipitation from groundwater. Those which are round or egg-shaped are called **geodes**. In semi-arid regions capillary action draws lime bearing waters to the surface where by evaporation a lime rich deposit called **Kankar** is formed. **Flint Nodules** in chalk deposits and **cherts** in limestones are some of the well-known examples of concretions.

When underground water highly charged with mineral matter reaches the surface in the form of a spring there is a deposition of part or whole of the mineral content it carried. Reduction of pressure, lowering of temperature and escape of CO_2 are among the principal factors which cause deposition by springs. Deposits of calcium carbonate are not uncommonly found around springs of even relatively cool waters. **Travertine** is the general name given to spring deposits of calcium carbonate. Porous mass of calcium carbonate deposited by spring is often referred to as **Calcareous Tuff**. Large hot springs yield extensive deposits in their immediate vicinities, like the great quantities of travertine deposited around mammoth hot springs of Yellow Stone National Park. In the same region from many of the hot springs and geysers, alkaline waters carry silica in solution which is similarly deposited around the basin as siliceous **sinter** or simply **geyserite**.

5.3.6 Uses of groundwater

In most of the countries majority of the population depends upon the groundwater for their domestic consumption. For several cities and towns much water is drawn from the groundwater sources either for public supply or for industry. Much of the groundwater in rural areas is used up for irrigation. In refreshing contrast to the non-replenishable natural resources like petroleum, coal, iron and maganese, groundwater formally is a renewable natural resoruce. There is constant recharging of the undergroundwater reservoirs as water seeps in or percolates into the ground from the surface.

Recognising the need for increased supply of groundwater, government agencies in several countries including our own, have undertaken numerous studies of subsurface geology in certain critical areas like dry and perched tracts far removed from any known perennial source of water like rivers and lakes. The location of a new aquifer or a successful tube well is mostly based upon a detailed examination of the geological conditions, porosity and permeability of rocks, and other features like joints, fissures and other openings. Every state government now has a department of Hydrogeology for the purpose of locating sites for new sources of groundwater.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

7. Write any two uses of groundwater ?

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type of thermal spring which intermittently ejects large quantities of hot water with considerable force.

The primary erosional work carried on by groundwater is that of dissolving soluble rock materials, especially lime stones, which results in the creation of caverns and caves. Stalactites and stalagmites are the depositional features of groundwater in lime stones. Karst topography is another feature of groundwater. Karst areas exhibit an irregular terrain punctuated with many depressions, which are called sinkholes. The depositional features of groundwater are the geods, kankar, travertine etc. The groundwater is useful for domestic, industrial and agricultural purposes.

5.5 CHECK YOUR PROGRESS-MODEL ANSWERS

1. The physical disintegration and chemical decomposition of rocks exposed to climate is called weathering
2. The process by which concentric curved shells or plates, are successively stripped from a massive rocks is known as Exfoliation. It is due to rapid temperature changes which cause expansion and shrinkage of the constituent mineral particles of the rock or the exposed surface.
3. The important types of soils are the lateritic soils, black soils, pod soils and loamy soils.
4. The water that is found in the pore spaces of rocks below the ground surface is called groundwater.
5. A body of permeable sediment or rock through which groundwater moves freely or stored is an aquifer.
6. Stalactites and stalagmites
7. The uses of groundwater are domestic industrial and agricultural.

5.6 MODEL EXAMINATIONS QUESTIONS

I Answer the following questions in 30 lines

1. Describe the processes responsible for weathering ?
2. Describe the geological work of groundwater ?

II Answer the following questions in 10 lines

1. What is chemical weathering ?
2. What are the different types of soils ?
3. What are the sources of groundwater ?
4. Distinguish between porosity and permeability.
5. What are the uses of groundwater ?

UNIT - 6 : RIVERS

Contents

- 6.0 Objectives
- 6.1 Introduction
- 6.2 Running Water
- 6.3 Geological Features of Rivers
- 6.5 Drainage Systems
- 6.6 Valley Developments
- 6.7 River Erosion
- 6.8 Types of Streams
- 6.9 River Capture or Piracy
- 6.10 Associated Landscapes
- 6.11 Summary
- 6.12 Check Your Progress-Model Answers
- 6.13 Model Examination Questions

6.0 OBJECTIVES

After completion of this unit, you should be able to

- explain geological work of rivers
- describe the geological features of rivers
- define drainage systems
- explain types of streams
- describe the associated land scapes.

6.1 INTRODUCTION

Water falls upon the earth mainly as rain, sleet, hail and snow. This process is called precipitation. Some of this water is evaporated, some penetrates or percolates into the rocks below to become groundwater and some is retained on the surface for longer or shorter periods and is carried off as streams ultimately to find its way into the seas and oceans. It is established that about 22% of the total precipitation on the land area of the earth is carried off by streams and constitutes the run-off by streams which is the chief degrading agent on the land surface and therefore, the most important factor in the process of denudation. The area which receives the rainfall is called the **catchment area** and it has a direct bearing on the rate at which erosion takes place. The distribution of rainfall is influenced by the winds which carry water vapour from places where it is evaporated to regions where the temperature favours its condensation and precipitation.

Of all the geological agents running water may have the greatest impact on the people. We depend upon rivers for energy, travel, irrigation and their fertile flood plains have fostered human progress since the dawn of civilization. It is the eminent agent of landscape alteration and has shaped much of our physical environment.

6.2 RUNNING WATER

The work of the running water begins with the rain drop. On smooth slopes the running water or run off takes the form of a thick film of water which moves downhill more or less uniformly as sheet flow. On uneven slopes the run off seeks out and follows the initial depressions and thus collects into rills. These rills then modify the original slopes by enlarging their runways into miniature valleys called Gullies. Several gullies join to form streams which later unite to form a river system. A **stream** can be defined as body of water carrying rock particles and flowing down a slope along a channel which may be a mighty river like the Ganges or the Godavari. In any given part of its course, a stream is a quantity of water flowing down a slope at a certain average velocity. The slope is measured along the stream and is often referred to as the **gradient** of the stream. The average velocity is often expressed in metres per second or kms. per hour. Every stream possess a definite amount of energy depending up on its volume and velocity. The energy of a stream is partly utilised by friction and partly by the transport of solid rock materials in suspension.

Streams attempt to maintain a balance behaviour between all the factors which control their flow. An Import contral over stream flow is the **base level**. It is the lowest point to which a stream can erode its channel. Two general types or general base level exit. Sea level is considered the **ultimate base level** since it represents the lowest level to which stream erodin could lover the land. **Temporary or local base levels** include lakes, resistant rock and main streams which act as base levels for their tributaries. All have the capacity to limit a stream at a certain level. Any change will cause a corresponding readjuctment of stream activities.

The observation that streams adjust their profile for changes in base level led to the concept of a graded stream. A **Graded Stream** has the correct slope and other channel characteristic necessary to maintain just the velocity required to transport the material supplied to it. On the average a graded stream is not eroding or depositing material but is simply transporting it. Once a stream has reached this state of equilibrium it becomes a self-regulting system in which a change in one characteristic causes an adjustment in the others to counter act the effect.

6.3 GEOLOGICAL WORK OF RIVERS

The geological activities of a River can be divided into three processes 1) Erosion
2) Transportation and 3) Deposition

Erosion

The erosion work is accomplished by a number of sub-processes which act in co-operation with each other. Erosion of a stream involves hydraulic action, abrasion, solution and removal of material. These activities go on simultaneously in all stream channels. They are described here individually.

Hydraulic Action : It is lifting and moving of loose rock particles by the force inherent in the flow of water. It is the quarrying effect of the impact of water itself thrown against loose debris into cavities and crevasses of cracks, joints etc. The rock materials is churned up and removed or washed away.

Corrosion or Abrasion : It is the mechanical wear of rock, due to the impact and friction of silt, sand, gravel and boulders carried by the streams on the bed and the sides of the stream channel. Rubbing, scraping, bumping and crushing are involved. This is also called **attrition**. In most streams bed material and load decreases in average diameter from head to the mouth of the stream. This results partly from abrasion and partly from gradual sorting out and deposition of coarse particles as gradient, channel and other factors gradually change from point to point along the stream.

The corrosive power of river water varies as the square of the velocity of the stream. If the velocity of the current is doubled, it will hurl twice as many sand grains as before in the same period and it will erode the rock surface four times as fast as it was before the velocity was doubled. If the channel is composed of bed rock most of the erosion is accomplished by the abrasive action of water loaded with sediment, a process analogous to sand blasting. Pebbles caught in eddies serve as cutting tools and bore circular holes into the channel floor which are called **pot holes**.

Solution : It occurs as the water of the stream dissolves matter from the minerals that constitute the bed rock in the channel and the rock particles in transport. Only a small proportion of the matter in solution in stream water gets dissolved by the streams themselves. Most of it is contributed by the groundwater beneath the slopes tributary, to the streams and percolated into the streams.

Transportation

The materials carried by a stream are called its **load**. This load is derived from a number of sources. A large part of it is supplied by weathering and removal of rock from the slopes of its tributaries, streams transport their loads carried mechanically as sediments or carried in solution as dissolved load. They move the loads a) by pushing and dragging many of the angular pieces on the floor of the channel. b) by rolling the subangular and rounded pebbles along the floor. c) by carrying in suspension the finer grains of sand, clay; and silt d) by dissolving and carrying in solution the more soluble compounds.

Boulders, pebbles and large rock particles slide or roll along the bed, sand gains are lifted above the bed by eddies and jump to new position of rest. This jumping movement of rock particles in a stream of water or air is often referred to as **saltation**. Sliding, rolling and saltation are transitional into the movement of the suspended particles.

Deposition

Whenever a stream's velocity is reduced due to several causes, its competence is also lowered. Consequently, some of the suspended particles begin to settle out. Materials deposited in this manner gradually is called **Alluvium**. Although some material settles in the channel temporarily, it tries to reach its final destination, viz. the ocean or sea ultimately.

Many streams rise in flood seasonally because of the distribution of rainfall in time over the streams or the river system. During the floods, the stream is able to transport an

increased aggregated load. A common flood time occurrence in many streams is nearly ten fold increase in discharge. Part of the increased load that usually accompanies augmented discharge and velocity in a stream is supplied by its tributaries. Another part of it is picked up by the stream from its own channel. Therefore, streams much of the geological work is accomplished during regular seasonal floods than during intervals of low water.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. Define the term "base level" ?

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6.4 GEOLOGICAL FEATURES OF RIVERS

Water Falls

Some streams particularly in mountain head water areas, have steep slopes and channels consisting of bedrock. Turbulence resulting from steep downstream slope sets up frictional forces capable of moving, rock particles of very large dimensions. The stream erodes its bed by hydraulic plucking, the lifting out by turbulent water of blocks bounded by joints and other surface of weakness. Under special conditions like a stream falling over a rock hedge of cliff as at water falls, the increased velocity of the falling water sets up strong turbulence at the base of the falls where both hydraulic plucking and abrasion deepen the stream bed quite exceptionally. The cliff is gradually undermined and the waterfalls tend to retreat upstream. In arid regions, narrow valleys often have nearly vertical walls, while in humid regions the effect of mass wasting and slope erosion caused by heavy rainfall produce the typical V-shaped valleys. A narrow V-Shaped valley indicates that the primary work of the stream has been down cutting towards base level. On the other hand streams with broad valley floors have been widened by lateral (side to side) erosion. The most prominent features of a narrow valley are **rapids** and **waterfalls**. Both occur where the stream profile drops rapidly a situation which is usually caused by variation in the erodibility of the bed rock into which the stream channel is cutting. Waterfalls are places where the stream profile makes a vertical drop.

Once a stream has cut its channel closer to base-level it begins to reach a graded condition and downward erosion becomes less dominant. At this point, energy is directed from side to side. Due to this lateral erosion the valley of the stream is widened and ultimately a flat valley floor called **flood plain** is produced.

Oxbow lake

The outstanding and striking features of broad valley is the presence of meanders and point bars. **Meanders** are loop like bends in a stream channel. They occur in very small

streams as well as in large rivers like the Mississippi and Ganges or Godavari. Meanders can form in a stream whether or not the stream is carrying a load. A meandering pattern appears to represent a condition of stability or near equilibrium. Though load is not necessary for the development of meanders, many meandering streams carry abundant loads and deposit sediments according to a definite pattern. These sediments are generally laid down on the convex bank of the channel building up crescent shaped bars which are known as **point bars**. Whether it meanders or not, a stream in a valley floor with alluvium accomplishes much erosion by bank caving. Meanders continually change position by moving sideways and slightly downstream. The sideways movement occurs because the maximum velocity of the stream shifts towards the outside of the bend, causing erosion of the outer bank. At the same time the reduced current at the inside of the meander results in the deposition of coarse sediment, especially gravel sand. Thus by eroding its outer bank and depositing material along its inner bank a stream moves sideways and slightly down stream without changing its channel size. On certain occasions one meander moved down stream faster than another and finally erodes the neck of the land between them. When this happens, the meander is said to be **cut-off**. This may be defined as the intersection of meander bend by the bend next upstream, causing the stream to bypass the loop between the bends. The usual results of such a neck cut off is called an **Ox-bow lake** which is a curved lake occupying a cut off meander loop that becomes blocked with alluvium at both ends.

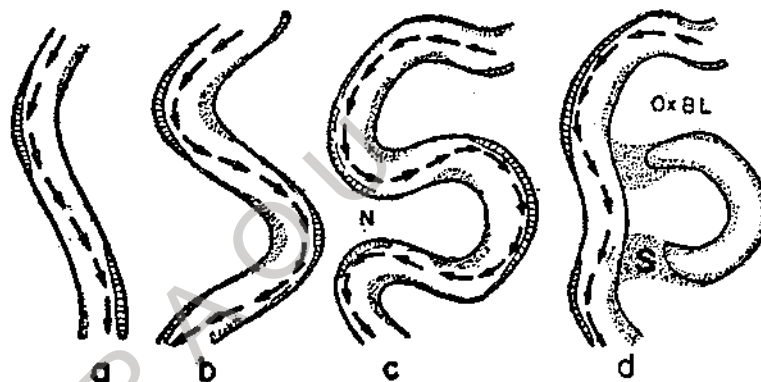


Fig. 6.1 Ox-bow lake

N = Neck Ox BL = Oxbow lake S = Silt of clay

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. What is a meander ?

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3. Explain Ox-bow lakes.

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Another characteristic feature associated with broad valley of a stream is the **flood plain** which is that part of a stream valley inundated during floods. The channels of many meandering streams are bordered by **natural levees**. These are broad low ridges of fine alluvium along both sides of stream channel. Natural levees are built up and are added to only during floods so that the flood is converted essentially into a lake deep enough to submerge the levees.

Not all streams meander placidly on their flood plains. Those that have more load than their channels can handle tend to become logged, causing the stream to break into many intertwining channels. Because such a stream had a braided appearance it is appropriately called a **braided stream**. A braided stream may be defined as one that flows into three or more inter connected channels around islands of alluvium. Such streams are especially found in dry regions or in those regions where streams emerge from glacial sources.

Alluvial fans

When a stream flows down through a steep highland valley and comes out suddenly on to a wide and nearly level valley floor, the abrupt decrease of slope reduces the stream energy and also its ability to transport the load. The resulting deposit of alluvium is concentrated at the foot of the steep slope in the form of a **fan**. It may be defined as a fan shaped body of alluvium built at the base of a steep slope. The surface of the fan slopes outward through a wide area from an apex at the mouth of the steep valley. On most fans the stream channel pattern is braided. Unless special circumstances preserve it, a fan will be destroyed piece-meal by continued erosion. A fan therefore is likely to be a temporary deposit representing a stream's quick attainment of near equilibrium at a place where equilibrium on the original slope is impossible.

Deltas

A delta is a body of sediment deposited by a river flowing into standing waters of the sea. The flow of the stream is checked by frictions as the water diffuses into the waters of a lake or sea. The stream loses its energy and deposits its load in the form of a delta. There are several kinds of deltas. A delta differs from a fan in two ways. 1) Loss of stream energy is gradual rather than abrupt. The sediments are deposited more slowly and with an orderly arrangement 2) The level surface of the lake or sea sets an approximate limit to up building of the deposit, the top of which is flatter than the profile of an alluvial fan.

The particles in the bed load are deposited first in the order of decreasing weight. Far beyond the suspended particles drop out. A layer deposited at any one time is sorted grading from coarse at the mouth of the stream to fine offshore. The deposition of many successive layers create an embankment that grows outward. This coarse, thick, steeply

sloping part of each layer in delta is called **Foreset bed**. Traced seaward each bed becomes rapidly thinner and finer, covering the bottom over a wide area.

This gently sloping fine and thin part of each layer in a delta is called bottom set bed. The topset beds are deposited above the already deposited forest beds. The stream gradually extends seaward over the growing delta, erodes the top of the foreset beds during floods, and at other times deposits part of its bed load in its channel. The channel deposits from the **topset beds**, of the delta which are stream channel sediments that overlie the foreset beds. During floods the stream spills out of its channel and forms distributary channels through which the water enters the sea independently multiplying the topset beds. These radiating distributary channels give the delta its somewhat triangular shape resembling the Greek letter from which the deposit derives its name.

6.5 DRAINAGE SYSTEMS

A stream is a small component in a much large river system. Each system consists of a **drainage basin**, the land area that contributes water to the stream. The drainage basin of one stream is separated from another by an imaginary line called **drainage divide** or **interfluvium** as already mentioned. Such divides range in size from a small ridge separating two small gullies to **continental divides** which split continents into enormous drainage basins. For example the western ghats in peninsular portion of India, is a large divide that runs North-South, and separates the drainage basins of the East flowing rivers Godavari, Krishna and Kavery and other rivers that flow West into the Arabian Sea.

Although divide separate the drainage of two streams, if they are tributaries of the same river, they form both part of the larger drainage system. All drainage systems are made up of interconnected network of streams which form particular patterns depending upon the material over which they flow. In regions where the surface material is relatively uniform, a branching tree, like arrangement develops and is referred to as the **dendritic pattern**. Where bands of alternatively resistant and less resistant rocks are exposed at the surface a **Trellis Pattern** forms. Here, the main stream is able to cut across the resistant ridges, while tributaries occupy valleys cut into soft rocks. Where an elevated structure such as a dome or a volcano exists, the drainage takes the forms of **radial pattern** (Fig. 6.2)

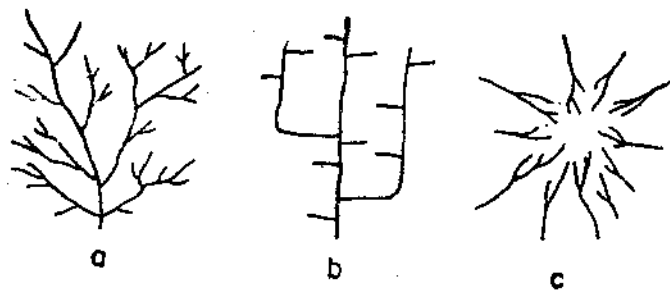


Fig. 6.2 a = Dendritic Pattern, b = Trellis Pattern c = Radial Pattern

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.
4. What are the different types of drainage patterns ?

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6.6 VALLEY DEVELOPMENTS

A major portion of the rain water runs off the surface in thin sheets over smooth sloping land surfaces. However, on the slightly irregular running water flows in tiny rills. These rills unit to form gullies and then into streams or river which cut out deep and deeper channels. These streams later join to form a river or a river system.

The deepening of a valley accompanies its growth in length. During each successive down pour the gully acquires more surface water and washed out deeper. Side gullies develop and grow into tributaries. The tributaries also acquires side gullies and the surface water of a large area is directed through the single main channel. It follows that the erosion of the main channel increased for increased volume means increased velocity with its greater eroding power. Streams that flows only during rainy season or during a downpour of rain are called **intermittent streams**. As a valley is deepened the floor of the channel approaches the level of the groundwater table. The pore spaces of rocks are saturated with water, and after the bottom of the valley penetrates this level, its reserve of water is sufficiently increased so that it supports the stream even during the dry seasons. Seasons that have their valleys cut to the groundwater table level are known as **permanent streams**.

In regions where the ground slopes are steep the down-cutting by the streams will proceed much more rapidly than, where the slopes are gentle, such that there is approximately a balance between the amount a stream erodes and the amount it aggrades, such a stream is said to be as a **graded stream**. The depth limit of a valley is determined by the level of the body of water into which its river flows. In general the level of the sea or ocean or some times a lake is approximately the depth limit of the valley. Only the lower end of the valley ever attains this limit, since the stream bed must have a gradient or else the stream will not flow. The lowest possible level of which a stream can erode its drainage basin by mechanical wear is the **base level** of stream erosion.

The widening of a valley or lateral erosion goes on in conjunction with its deeping. In some regions conditions for down cutting are more favourable than for lateral erosion as in the case of colorado river or certain, tributaries of Himalayan rivers whose walls are thousands of meters high and with a few hundred meters wide. Most valleys are much wider than the strems though the character of the rock over which the stream flows may produce local variation in width. A **narrow valley** will be formed where the stream cuts across hard resistant rock.

Valley widening is accomplished in many ways, the most important of which are. 1) by creeping and slumping 2) by rain wash 3) by the activities of animals and plants 4) by glacial erosion 5) by under cutting and 6) by tributaries. The course of a stream is rarely straight and at each curve, it tends to cut more on one bank than on the other. This is due to the fact that the water tends to pile up on the bend and the outside of the curve receives a greater volume of water. In this way the velocity is increased and the bank is undermined and moved back. Thus by this process of meandering the valley is gradually widened.

Stages of River development

A newly uplifted or elevated land marks the starting point in the history of a drainage system which consists of a main river with its family of tributaries. The topography produced by stream erosion will change as erosion continues and advances. Changes are determined in part by the altitude of the uplifted areas and the nature of the rocks and the structural features associated with them. By the process of stream erosion the land is sculptured into a series of hills and valleys.

The first effect of erosion is to roughen the surface of the area by excavating gullies and valleys and by leaving ridges and hills as divides. Ultimately the divides are lowered and the result is a comparatively level surface or a plain. Hence, erosion tends to produce plains. The sequence of forms, essentially hills and valleys through which landmass is thought to evolve from the time it begins to be eroded till it reaches the base level is generally known as the **cycle of erosion**. In the first part of the evolution, the surface is generally irregular and the stream gradients are steep and erosion rapid so that the valley is being actively deepened and makes sharp cuts into the land. Because of the vigorous growth of the valleys a land surface in this state is called **youthful stage** or simply *in youth*. In this stage streams flow rapidly in V-shaped valleys or canyons or gorges with steep sides. The slopes are steep because sufficient time has not elapsed for the valleys to be widened. If the area is recently elevated the streams are numerous and have few tributaries. Since they have not had time to erode extensively, they still have rapids and waterfalls along their course. The grand Canyon of the Colorado which is a youthful valley, is an eminent example.

In the later part of the evolution, the surface has become more stable. As erosion continues the topography changes until the features characteristic of youths are classified into different forms and the sharp straight lines of the landscape give place to valleys with flaring sides and gently rounded upper slopes. The divides are narrowed and the region becomes thoroughly dissected by a complex network of valleys resulting in very rugged topography. The number of tributaries to the main stream is to some extent determined by the amount of rainfall. Tributaries and streams are more numerous in semi-arid regions. As the tributaries are deepened the lakes and swamps are drained or filled and the escarpments that produced waterfalls and rapids are lowered so that the rivers attain gradients which are gentle and the river erodes more slowly. Towards the close of this stage the lower courses of streams become graded. A landscape in this condition is described as **mature**.

In the next stage, the stable mature surface is lowered to the base level with the rate of erosion becoming increasingly slow. A stream with a surface in a late phase of erosion lying close to the base level is believed to have attained **old age**. In this stage, the deep channels are transformed into broad valleys with gentle slopes and low divides. The streams lose their vigour and deposit their load rather than erode. The valleys become shallower owing to deposition and the sluggish streams swing from side to side in long loop plains

a land surface thus worn down by streams and mass wasting to very low relief, nearly a plain with very gentle slopes of old age topography is called as **peneplain**. Frequently isolated residual hills of more resistant rock formations rise above the general level of the peneplanation. These features are called **Monadnocks**, named after the Mt. Monmadanock in New Hampshire.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

5. The end product of river erosion is ____

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6. Define the three major stages of stream evolution ?

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6.7 RIVER EROSION

As the drainage basin of a river system passes through the successive stages of normal cycle of erosion, it may be interrupted at any stage by various geological processes. Among the causes of interruption, the following are the most important, namely (1) Glaciation and other interferences by gradational agents (2) Volcanic action and (3) Diastrophism.

A glacier may fill a stream valley with ice or cover its basin with a snow field that protect the surface from weathering and stream erosion. During the great ice age many areas in Northern Hemisphere which were in mature stage of topography, were subjected to continental glaciation. As the glaciers receded enormous amounts of glacial debris were deposited irregularly in several forms over the pre-glacial topography with the result that youthful features again were developed and superimposed on large area which had been eroded for beyond the youthful stage. This is especially true of the region to the South and East of the Great Lakes in North America.

Due to volcanic action lavas may flow down the slopes of a valley and completely fill its stream channel. In such cases the erosion cycle is interrupted and starts a new cycle of erosion only locally and temporarily or they may cause the streams to start their geological work a new. Changes in the level produced by depression or elevation are generally called diastrophism.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

7. List out the various geological processes that interrupts the Cycles of erosion.

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Subsidence or Drowning : Depression of the land or rise of sea level hastens the development of old age by bringing the depressed area nearer the base level and by decreasing the material the streams must remove before a featureless plain is produced. When such a rise in sea level occurs along the coast line, the sea occupies the lower ends of the valleys and converts them into **bays** and **estuaries**. The valleys then are **drowned**. Thus the River Hudson in North America is drowned, as far north as Albany and the St. Lawrence River appears as an arm of the sea as far inland as Montreal. The tributaries of the main stream after submergence become dismembered and are forced to enter tide waters by separate courses.

Rejuvenation : The most common and significant cause of interruption of the normal cycle of erosion is the rise or uplift of the land in any stage of its erosional history prior to peneplanation, say in maturity or old age. This uplift will result in a notable increase in velocities of the streams. If a peneplanned area is elevated the gradients of the streams are increased and they set to work by cutting gorges and canyons in the bottoms of their old valleys with the result that the region takes new typical characteristics of the youth. Such a region is said to be rejuvenated and the streams infused with new vigour through increased gradients become **rejuvenated** or revived streams. They start a new cycle of erosion. The effect is most pronounced on the valley floors of the streams which are graded or nearly so but in time the whole region is distinctly affected by the revival of erosive action.

If the old stream had meandering course before rejuvenation, the revived stream proceeds to cut a youthful valley in the old valley floor without changing course. Such streams which are able to hold their courses notwithstanding the change of level are called **antecedent** i.e., they antedate the diastrophic events that influenced the present topography. Such deeply cut meanders in a rejuvenated region are called **entrenched** or **incised** meanders. There are several excellent examples of entrenched meanders, among which are the most celebrated San Juan River of South eastern Utah in U.S.A. We have the excellent example of Krishna river with incised meanders in the rejuvenated region of Srisailem, where the Krishna river is being harnessed for power generation. Some of the *natural bridges of Utah* owe their origin to the perforation of necks between entrenched meanders. The famous rainbow bridge carved out of sandstone has a height of 90 meters and span of 80 meters long across neck between old meanders.

Rejuvenation may be by uniform uplift of an old eroded surface in which case the altitude is increased but the attitude or slope is not very much changed, or the rejuvenation may be by tilting accompanying uplift of an old eroded surface. An excellent example is

the south western part of the Colorado plateau which is an old peneplained surface uprised hundreds of meters with a southward slope and deeply trenched by the Colorado river.

Stream terraces are another example of interruption, that caused increased erosion. A **Stream terrace** is a bench along the side of a valley, the upper surface of which was formerly the alluvial floor of an old valley. In a stream flowing on a broad valley floor cut from bedrock, sudden increase in the rate of erosion results in the cutting of a new valley within the floor of the older one. The floor of the older valley is left as a pair of stream terraces, which will in time be entirely destroyed by erosion.

6.8 TYPES OF STREAMS

On the basis of their characteristics and patterns, streams are classified into a number of groups each of which implies something of the origin and history of stream. They are described below.

Consequent Streams : On any newly uplifted land surface the first streams will have their own characters determined by the original slope and natural irregularities of the surface. Such streams are, therefore, *consequent* of the original relief features. They may not only lengthen by head erosion and deepen and widen their valleys but also they may have tributaries developed as a direct consequence of the initial topography. All such streams whose pattern is determined solely by the direction of the slope of the land or consequent on the initial topography, are called **Consequent streams**. These occur generally in massive and flatlying rocks and commonly have dendritic patterns.

Subsequent Streams : These are streams that occupy a belt of weak rocks and these pattern is determined by the nature of the weak rocks. They originate independently of the original topography and are determined and regulated by erosion proceeding differently upon bed rock according to differences in hardness, structure and resistance to erosion. Since they originate and develop independently and subsequent to the original relief of the land they are appropriately called **Subsequent streams** in contradiction with the streams that are more commonly the tributaries of the main consequent streams. Usually subsequent tributaries develop at nearly right angles to a consequent main stream. This angular pattern of stream courses is known as trellis patterns. Streams in which no adjustment of rock structure takes place since they develop in a large area of massive rock formation as granite, never have subsequent tributaries. This is because the adjustment is complete from the beginning. This insequent stream pattern is often tree like and hence designated as **dendritic**.

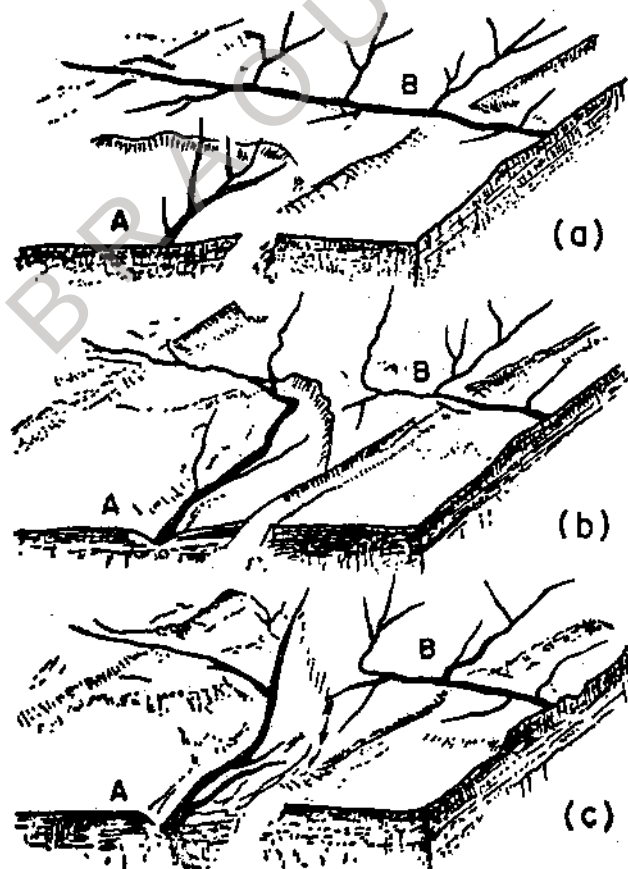
Obsequent Streams : A subsequent stream that develops as a tributary at about right angles to the main consequent stream may, in turn have tributaries which often flow in the opposite direction to the original course, of consequent stream and hence called **Obsequent streams**. Condition particularly favourable for the development of obsequeunt streams are to be found in regions of tilted strata where escarpments such as cuestas form the land surface which is worn down by erosion.

Antecedent Streams : These are streams that have maintained their courses across a local uplift of the crust that rose by folding or faulting in their paths. The name **antecedent** stream arises due to the fact that the stream is antecedent to or older than the uplift.

Super imposed Streams : A Super imposed stream is one that was let down or superposed from overlying strata on to a buried surface underneath them. The stream's path was not controlled in any way by the surface on which it is now flowing. Most superposed streams began as consequents of the surface of the covering rocks.

6.9 RIVER CAPTURE OR PIRICY

During the growth of a drainage system by stream erosion, it often happens that certain streams steal or capture parts (or all) of other streams by a process known as stream piracy or capture. When one of two streams flowing in opposite directions from a single divide (a line separating the two drainage systems) has a steeper gradient than the other, it can extend its valley headward shifting the divide against the weaker stream. In this way it reverses the weaker stream little by little and can capture a long tributary by intercutting it at its mouth. This process of stream capture, the diversion of a stream by the headward growth of another stream, is illustrated in Fig 6.3. A stream whose upper water have been captured by another is said to be **headed**. Through the process of stream capture there is a strong tendency for many streams to leave the harder and more resistant rocks and envelop softer or less resistant rocks. In other words they tend to adjust their courses to the characters and structure of the various rock formations of a region. This is known as structural adjustment of streams. Capture of drainage on a still largest scale becomes possible when the major river equires vigorous subsequent tributaries each working along feebly resistant formations and each pushing back the secondary divide at its head. (Fig. 6.4) Endowed with a relatively low local base level, a deeply entrenched subsequent S cuts back



Fig, 6.3 Stream Capture or Piracy

Check Your Progress

b) Compare your answer with the one given at the end of this unit.

6.10 ASSOCIATED LANDSCAPES

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or cliffs usually situated in arid regions that are usually more favourable than others because weathering agents which cause valley widening are less effective under such dry climatic condition. The grand canyon of Colorado river in Arizona state is the greatest of all canyons. Many of the Himalayan rivers like the Sind and Ganges and their tributaries which are too numerous to be cited here have also cut deep gorges in their courses.

Narrows and Gaps : River narrows and water gaps are only special types of gorges. If a stream cuts across a belt of hard and resistant rocks, the valley carved out by the stream is less wide in hard and resistant rocks than in weaker rocks. Such local contractions of river valleys formed under the conditions just described are called the narrows and if they are very short they are called watergaps.

A watergap abandoned by its stream becomes Windgap because of the tendency for wind to blow with unusual force through them. Windgaps are formed as a result of stream capture or piracy about which has already been explained.

River terraces : Along the sides of a river valley there may be benches or nearly that surface with steep fronts facing the river in the valley and too high to be covered by flood waters. Two or more of such bench like terraces may be arranged one above another in a step like form in both sides of the valley. Such benches when formed by the action of the river are called River Terraces.

One mode of origin of these river terraces is due to the process of rejuvenation of the rivers which have attained late maturity or early old age. A river on approaching grade in its down-cutting process begins to widen its valley floor notably by meandering back and forth from one side of the valley to the other. A flood-plain of such a river may be covered with more or less stream deposited soil called fluvial alluvium, uplift of this region at that time causes the river to be revived and make it cut young and steep-sided inner valley (or Gorge) into the old flood plain. The remnants of the old valley flat consisting the bedrock covered with alluvium constitute the rock-terraces.

Rock towers and Pillars : During the process of denudation of the lands by erosion it very commonly happens that certain local portions are not cut down as fast as other portions of the area and hence are left standing out more prominently above the general level of the country. Among such remnants of erosion are the Rock towers, Pinnacles or pillars. These, as their name indicate, consist of harder isolated masses of resistant rocks and are variously shaped.

Ridges : Where erosion proceeds upon a region of highly inclined or folded strata which consists of alternately of hard and soft beds, the hard beds stand out bold in relief in the form of ridges because erosion cuts down the weaker and softer beds much more rapidly developing the valleys in them.

Hog Backs : A Hogback is an erosional ridge with a long, relatively gentle slope on one side and a short and Precipice steep slope on the other side. Such a ridge develops where rock formations are moderately tilted with a hard layer lying between two soft layers. The long gentle slope is caused by the removal of the weak rock from the top of the hard layer and the tendency of the weak underlying rock to erode or weather faster than the hard tilted layer just above it.

Cuesta : A Cuesta is a sort of a ridge of resistant rock formation with the slope on one side being very steep forming an escarpment and its dip slope.

Mesas and Buttes : A mesa is a waste land capped by resistant bed and having steep side all around. An excellent example, is the Table Mountain behind Cap Town in South Africa produce by long continued wearing back on all sides. A mesa dwindles into an isolated flat - topped hill. Such a hill is called Butte a name widely used in America, but in South Africa similar residual landforms many of which are capped by isolated relics (outliers) of one continuous dolerite sills are called **Kopjes**.

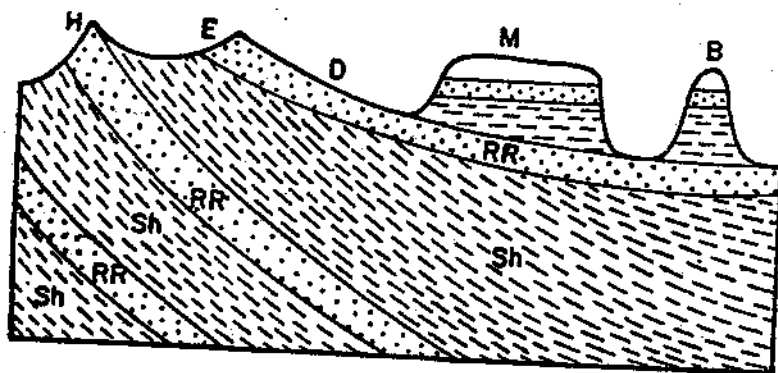


Fig 6.5 Illustrating the relation of various erosional land forms to the structure and dip of the strata

Sh-Shale, RR = Resistant Rock, H = Hog back, E = Escarpment,
D = Dipslope, M = Mesa, B = Butte

6.11 SUMMARY

Rivers are acting as geological agents. Water reaches earth due to rainfall. After reaching earth some of this water is evaporated, some Penetrate or Percolates into the earth and the remaining carried as streams and rivers.

The work of running water begins with raindrop. On uneven slopes rain drops make rills. These rills then modify and form gullies. Several gullies join to form streams which later unite to form river system. A stream can be defined as a body of water moving down slope. It may carry some rock particles as well.

The geological activities of rivers include erosion, transportation and deposition. The processes of erosion involves hydraulic action, abrasion, solution and removal of materials. These materials are carried by pushing and rolling on the floor of the river, carried by suspension and solution. When ever stream velocity reduces the materials are deposited as alluvium.

The geological features of rivers are water falls, ox-bow lakes, alluvial fans, deltas etc. Water falls are formed along the mountain head water areas where slopes are steep and channels consisting bed rock. Along the broad valleys meanders are common. On certain occasions one meanders moved down stream faster than another and erodes the neck of the land, which results in the formation of ox-bow lakes. When river suddenly enters on to a wide and nearly leveled valley, alluvial fans are formed. Whenever river joins standing waters of seas, deltas are formed.

A stream is a small component of a larger river system. Each system consists of drainage system. All drainage systems are made up of inter connected net work of streams. Drainage patterns are grouped as dendritic, trellis and radial patterns. There are three stages in valley development and river system development. The three stages are youth, mature and old age. In youth stage stream flows rapidly in v-shaped valleys or canyons or gorges with steep slopes. Streams may have rapids and water falls in youth stage. In mature stage the topography becomes rugged and streams become graded. In the next old stage a stable mature surface is lowered to the base level. The stream loses vigour and deposits the sediments.

River erosion may be interrupted by glaciation, volcanic action and diastrophism. Depression of the land or rise of sea level hastens the development of old age of river system. Sometimes in the mature or old age due to upliftment, the stream gradients may be increased and work by cutting gorges, and canyons and shows typical characteristics of youth, this is called rejuvenation.

On the basis of stream characteristics and patterns, streams are classified as consequent, subsequent, obsequent, antecedent and super imposed streams. River capture or piracy is a process which occurs in youth stage of river. Here, one river reaches the course of another and diverts the course because of greater gradient of first river.

The associated landscapes with river system development are the canyons & gorges, Narrows & gaps, River terraces, Rock towers & Pillars, Ridges, Hogbacks, Cuesta, Measa Buttes etc.

6.12 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Base level is the level below which a stream can not erode.
2. The meander is one of the curves of regular freely developing curves, bends, loops turn or windings in the course of a stream. The meander cut off is formed when a stream cuts through a meander neck.
3. The crescent shaped body of standing water situated by a side of a stream in the channel of a meander after the meander cut off, is called ox-bow lake.
4. The different types of drainage patterns are 1) dendritic 2) Trellis 3) Radial
5. Peneplain
6. Youth, mature and old age.
7. Glaciation, volcanism and diastrophism interrupts river erosion.
8. River capture or River piracy is the process that occurs in the youth stage. In this process one river enters into second river and diverts its course.

6.13 MODEL EXAMINATION QUESTIONS

I. Answer the following Questions in 30 lines

1. Describe the geological work of rivers.
2. Describe the stages in valley development.
3. Give an account of different drainage patterns.
4. Write briefly about the classification of streams.

II. Answer the following questions in 10 lines

1. What is meant by base level of erosion ?
2. Describe the structure of deltas.
3. What are meanders ?
4. How are Ox-bow lakes formed ?
5. What is meant by river rejuvenation ?
6. What is meant by river capture ?

BRAOU

UNIT - 7 : GLACIERS

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 - 7.8.1 Heat Distribution Hypothesis
 - 7.8.2 Solar Radiation Hypothesis
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- 7.9 Summary
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- 7.11 Model Examination Questions

7.0 OBJECTIVES

After completion of this unit, you should be able to

- explain glacier formation and classification
- describe geological work of glaciers
- explain the existing glaciers
- describe the causes of glaciation

7.1 INTRODUCTION

Snow fall is common in places and regions of high altitudes especially during the colder seasons. In such regions where the mean annual temperature is near the freezing point of water, much of the snow remains unmelted from one year to the next and consequently accumulates to great depths forming the snow fields. The elevation or the level of lower limit of such perennial accumulation of snow is called snow line. It rises from

almost see level in the polar regions to altitudes of as much as 6000 mts. in tropical mountains.

The snow is commonly flaky and dry but as it accumulates in the snow fields, it is compact, partially melted and in refreezing it acquires a granular texture, when it is called **Neve** or **firn**. As the snow crystals are buried and compact the air between them is expelled out and the water from the melting snow seeps in and freezes and thus the deep layers are transformed into compact but still porous ice.

With successive snowfalls over a long period a snow field grows in size and depth until the pressure on the ice which is formed in depth is sufficient to start its outward flow as a glacier, ice is a weak solid and if a body of ice is as much as 60 to 90 mts. thick, its own weight is enough to overcome its slight rigidity and it begins to be deformed, flowing outward and downward in a manner as a shift fluid flows but nevertheless remaining as solid. As soon as a body of ice becomes thick enough to flow in this way, it becomes a glacier.

A glacier may be defined as a body of ice consisting mainly of recrystallized snow, flowing on the land surface in a manner similar to that of a river.

Glaciers originating in valley heads creep slowly downwards as tongue like streams of ice, flowage being maintained by the yearly replenishment of the neve fields. Ultimately glaciers dwindle away by melting, their front movements of ice is just balanced by the wastage. The glaciers vary in size from short but wide tongues of ice or snow on the narrow beaches of a cliff to tongues of ice extending down the valleys from the mountains like those of Alps, Himalayas etc. Because these glaciers are very viscous and therefore move extremely slowly, the glacier has to be enormously greater than that of a corresponding river. When the glaciers overflow the land and terminate in sea water sufficiently deep to allow the ice to float huge masses break away from the front and become ice bergs.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. Define the term glacier ?

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7.2 CLASSIFICATION OF GLACIERS

On the basis of their form, we can readily distinguish four kinds of glaciers (i) Cirque glacier (ii) Valley glacier (iii) Piedmont glacier (iv) Ice Sheet.

Cirque glacier : It is a small glacier occupying a cirque or resting against the head wall of a cirque.

Valley glacier : It is a glacier that flow downward through a valley. In many respects they behave like a stream of water. It is otherwise known as alpine glacier because of their typical development in the region of Alps mountains.

Piedmont glacier : It is a glacier on a low land at the base of the mountain, fed by one or more valley glacier. Example Malaspin glacier in Alaska.

Ice Sheet or Continental glaciers : It is a broad glacier of irregular shape generally blanketing a large land surface. Example - Antartica and Green land is covered by ice sheets.

7.3 GLACIAL MOVEMENT

The average rate of movement of glaciers is far less than that of a river. It is not more than a few feet per day. Alpine glaciers move a meter or less per day. However a few ice tongues in Greenland have been recorded with a rate of even 3 meters or a fraction. The movement of the glacial ice is called a flow. The movement of a glacier resembles that of a river in many ways. The centre move more rapidly than the margins where it meets resistance along the walls of the valley. The surface moves more rapidly than the deeper portions of the ice. At curves in its course the convex portion moves more rapidly than the concave. Since some parts of the ice moves faster than other parts, the movement of a glacier is spoken off as **differential movement**.

The way ice flows is complex but is believed to be of two basic types. One mechanism involves internal movement within the ice. Ice behaves as a little solid until the load upon it is equivalent to the weight of about 50 to 60 meters of ice. Once the load is surpassed the ice will behave as a plastic material and flow continously. Another mechanism of glacial movement consists of the whole ice mass slipping along the ground. The lower portions of most glaciers are thought to move by the sliding process. Glaciers move down slope under the influence of gravity. The main causes of glacial motion lie within the ice of the glacier itself as it reacts to the changing conditions under which it exists. Melting of ice at the points of great compressional stress and its refreezing after a forward movement is an important factor. As glacial ice moves it recrystallize to that of a schist. When it refreezes it expands and the surrounding ice mass is subjected to the thrust of its expansive force. As the temperature rises it expands giving a forward thrust to the glacier. The sum of all these factors perhaps may be the cause of glacier motion.

Glaciers are constantly raining and loosing ice. As we learned earlier, snow accumulation and ice formation occur above the snowline. Here the additions of snow thicken the glacier and promotes movement. Below the snowline, snow from the previous winter as well as some of the glacier ice melts into the sea. Whether the margin of a glacier is advancing, retreating or remaining stationary depends upon the economy of the glacier that is it depends upon the balance or lack of balance between accumulation on one hand and the wastage on the other. If ice accumulation exceeds wastage the glacier front advances until the two factors balance. At this point the terminus of the glacier is stationary. At a later time when wastage exceeds accumulation the ice front will retreat until a balance again is reached.

7.4 FEATURES OF GLACIERS

The head or upper end of a valley glacier is generally marked by one or more large gaping cracks or crevasses known as **Bergs-chrund**. Where the glacial ice passes through a construction in a valley it thick and the rigid crust is thrown into wave-like pressure ridges. On the other hand where the valley opens out, the ice is stretched and cracked into a series of deep crevasses. Transverse crevasses develop across a glacier where there is a marked steepening of the slope of the valley floor. Longitudinal crevasses roughly parallel to the direction of flowage are formed where the ice is obliged to spread out. The marginal crevasses point up the valley at about 45 degrees due to the more rapid movement of the central portion of the glacier.

If the valley is deep, the mountain sides are undermined by the moving glacial ice and heaps of rock fragments or immense blocks of rocks gather on the ice at the sides of the valley forming lateral moraines and when two tributary glaciers meet a medial moraine results by the union of two lateral moraines. The debris carried to the terminus of the glacier is deposited about its end as the ice melts and at many places forms a crescent shaped ridge known as the terminal moraine.

In the zone below the snowline a good deal of water is usually evident atleast during summer. This is the melt water resulting from the melting of glacial ice. It is seen as small pools and streams on the surface of the glacier. Some of the melt water follows englacial channels for a time and may issue from the sides of the glacier as springs. The general tendency is for the melt water to accumulate in the form of a stream at the bottom of the glacier and to issue at or near the terminus from a tunnel. The water from such a channel is often very turbid and whitish because it is charged with finely grounded particles of fresh and unweathered rocks. Two notable features associated with melting and partial draining of melt water are the glacier tables and moulins. This slabs of rocks or patches of debris on the surface of a glacier may be sufficiently heated by the sun to melt the underlying ice. But large blocks act as a protection from the sun's rays and as the surrounding ice melts away they are left as glacier tables perched on a column of thick glacial ice. The superficial small pools and rills gather into streams which mostly tumble and fall into crevasses and are lost in the depths of the ice. The water carries with it the mud, sand and boulders from the surface moraines. These erode the crevasses and produce vertical shafts that are often referred to as moulins or glacier mills.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. Glacier developed cracks within the flowing ice known as -

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3. What is Bergschrund?

7.5 GEOLOGICAL WORK OF GLACIERS

The geological work of glaciers is expressed in the process of glaciation which is the alteration of the land surface by glacial ice passing over it. Glaciation includes erosion, transportation and deposition. As most glaciers are at present shrinking the eroded bedrock surfaces as they are uncovered from year to year can be seen and watched as also the making of glacial deposits at the glacier margins. Similar things were observed early in the 19th century by various European naturalists. Chief among such European observers was Louis Agassiz who convinced the scientific world with a wealth of irresistible evidence that the landscapes of vast areas of Europe bear the unmistakable hallmark of a widespread glaciation. By examining such glaciated districts from which glaciers have melted away and retreated, it can be seen that the glacial erosion takes place mostly well back beneath the glacier and that deposition occurs mostly at or near the outer margin, glaciers are capable of carrying on great amount of erosional work.

7.5.1 Erosion

Glaciers erode the land primarily in two ways. Glacial erosion, like stream erosion, includes abrasion and plucking and is generally preceded by weathering in the form of frost wedging.

First, as a glacier flows over a fractured bedrock surface, it loosens and lifts blocks of rock, incorporates them into the ice and carries them off. Indeed as a transporter of sediment, ice has no equal since the rock debris once is acquired by the ice will not settle out as the enload carried by a stream or the wind. Consequently glaciers can carry huge blocks that no other erosional agent could possibly do. This process of lifting out and removal of pieces of bedrock by a glacier is called, **quarrying or plucking**. It occurs when melt water penetrates the cracks and joints along the rock floor of the glacier and refreezes. As the water expands, it exerts tremendous coverage that pries the rock loose. In this manner sediments of all sizes, ranging from fine particles as rock flour to big blocks, become part of the glacier's load.

The second major erosional process is abrasion. As the ice and its load of rock fragments move along, it acts as giant file the surface below as the rocks within the ice. The pulverized rock produced by the glacier is appropriately called **rock flour**. When the embedded material consists of large fragments, long scratches and grooves called glacial striations may be seen. These linear scratches on the bedrock surface provide clues to the direction of glacial movement. On the other hand, not all abrasive action produces striations. When the sediment consists of fine silt sized particles, the rock surfaces over which the glaciers move may become highly polished. A striation or groove does not show as a rule the direction of a glacier. The direction of a flow of the glacier can be determined by rock

hills and small knobs that are not symmetrical. Usually the upstream side of a rock hill is predominantly abraded, striated and gently sloping, whereas the downstream side is predominantly plucked and therefore has a steeper slope. Such features of resistant hummocks of bedrock moulded by glacial erosion are called **Roches moutonnées** since they resemble sheep lying down or sheepskin wigs placed "face" downward.

Crag and Tail : Another important evidence of glacial erosion is the Crag and Tail. These are features developed when highly resistant obstructions such as old volcanic plugs that lay in the path of the glacial ice like the protruding knots in a plank of wood. The crag boldly faces the direction from which they came while the Tail (bedrock with a thin veneer of boulder clay) is a gentle slope on the sheltered side where the softer sediments were protected by the obstruction from the full impact of glacial erosion. An excellent example of crag and tail is afforded by the famous castle rock of Edinburgh.

Cirques : This is a prominent and notable characteristic feature of alpine glaciation. A cirque is a steep walled recess, shaped like a half bowl and excavated mainly by frost wedging. A cirque begins to form beneath a snow field or snow bank just above the snow line, on summer days water from the melting snow infiltrate drops and the water freezes and expands, prying out rock fragments. The smaller rock particles are carried away down slope by melt water during thaws. This activity creates a depression in the bedrock and enlarges it.

If the snowbank grows to be a glacier plucking helps to enlarge the cirque still more but frost wedging continues as water descends the rock wall of the cirque and freezes there. Many cirques have rock basins in their floors usually containing small lakes. After the glacier has melted away, the cirque basin is usually occupied by a lake often called cirque lake.

Characteristics of a Glaciated Valley - The glaciated valleys differ in several ways from the ordinary stream valleys. They show innumerable evidences of glaciation. They are described as follows :

- (1) A valley which has been vigorously glaciated has a broad bottom and very steep vertical sides that is, it has a U-shaped cross-section or profile instead of the very characteristic V-shaped cross profile of a stream valley. This is because a glacier not only erodes the bottom of its valley but also its sides. Thus the valley is made much broader at the bottom with its sides very much steepened.
- (2) Many glaciated valleys or canyons in mountains are much straighter and more open for long distances than stream eroded valleys. This is because a glacier has a much stronger tendency to take a straight course than river and so the lower ends of the ridges or spurs which project down into the valley alternatively from opposite sides are truncated by glacial erosion.
- (3) In glaciated valleys the tributary valleys show typically a discordance of position. They join the main valley much above its bottom and therefore are called hanging valleys. Hanging valleys often produce spectacular cascading waterfalls, such as those in National Park, California.
- (4) Another striking feature of a glaciated valley in mountainous regions is the presence of cirques at the head of glaciated valleys. Two cirque walls may be cut back towards

each other from opposite sides of a mountain mass until only a very sharp divide known as knife-edge ridge is left between the cirques. Such a jagged knife-edge ridge is called as **Arete**.

A **col** or a gap in a mountain crest forms at a place where the head walls of two cirques intersect each other. A **matterhorn** is a bare shaped peak left standing where cirques have eaten into it from three or more sides. The most famous example of such horns is the Matterhorn the highest peak in the Alps Mountains in Switzerland.

- (5) A less common but nevertheless important feature of glaciated valleys is that large glaciers entering the sea may erode their valleys moving below the sea-level. This is because the moving ice is able to displace the water until its depth becomes so great that the ice is beyond up and broken.

The deep bay-like narrow arms of the sea with high steep walls knows as **Fjords** along th coasts of Norway, Sweden, Alaska and Chile are glaciated valleys partly submerged.

Check Your Progress

Note : a) Space given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

4. What is a cirque ?

7.5.2 Transportation

Unlike streams, a glacier carries its load of rock particles all in a jostling mass without any sorting so that the deposits made directly from a glacier are not sorted and are not stratified. The glacier carries its load in its side and on its top and the load is concentrated on the floor and sides because this is where glacier and bedrock are in contact and where abrasion and plucking are most effective. Most of the rock debris on the surface of a valley glacier has accumulated there by land sliding and slump consists of very fine particles such as fine sand and silt. Most of these particles are fresh and unweathered. They have usually angular and jagged surfaces and are unmistakably the products of crushing and grinding. Fine sand and silt produced that way in a glacier is known as rock flour. Fresh rock flour evidently a product of rapid erosion of bedrock by glaciers.

7.5.3 Deposition

Glacial deposition takes place mainly in the down stream parts of glaciers where melting and evaporation release rock fragments from the ice. The sediments may deposited directly from the ice. The sediments deposited directly by glaciers or indirectly in glacial streams, lakes and the sea, together constitute **glacial drift**. Glacial deposits are of two types.

(1) Those that are directly deposited by a glacier are called glacial deposit, glacial till and (2) those by glacial streams are called **Glacio-fluvial deposits** or **outwash**. Glacial tills deposited as glacial ice melts and drops its load of rock fragments. Deposits of till are characteristically unsorted, a mixture of many different sizes of sediment. When big boulders are found in glacial till they are called glacial erratics, indicating that they are derived from a source outside the area where they are found. In many areas erratic boulders may be seen dotting pasture and farm land.

Outwash is sorted according to the size and weight of the fragments. Since ice is not capable of such sorting activity, these sediments are not deposited directly by the glacier as till but rather reflect the sorting action of the glacial melt water. Accumulations of outwash often consist largely of sand and gravel that is bed load material.

Perhaps the most widespread features created by glacial deposition are **moraines**, which are simply layers of ridges of glacial till. A **ground moraine** may be described as a sheet of heterogenous unstratified rock debris which is deposited underneath a glacier which is melting and receding. When it consists of very fine material with pebbles or boulders scattered through its mass it is very often called boulder clay. The pebbles and boulders are often characteristically striated as a result of abrasion against the bed rock. Ground moraines have a levelling effect, filling in low spots and clogging old stream channels, often leading to a disruption of normal drainage.

Terminal or End Moraines : As the name implies terminal or end moraines form at the terminus or the end of a glacier. Here while the ice front is stagnant the glacier continues to carry and deposit large quantities of rock debris, creating a ridge of till tens to hundreds of metres high. A terminal moraine is usually crescent or horse-shoe shaped in outline with their concave side towards the head of a valley-valley glaciers often leave loop like terminal moraine ridges across the valleys or at their mouths.

The sides of an Alpine glacier accumulate large quantities of debris from the valley walls. When the glacier melts away, these materials are left as ridges or **lateral moraines** along the sides of a valley. In most glaciated valleys these lateral moraines are more conspicuous than the terminal moraines or ground moraines. If, after a glacier has retreated a considerable distance, its terminus again remains relatively stationary for sometime another terminal will accumulate around it. Such a precessional moraine develops during every considerable pause in the recession of a glacier. A very typical example of such recessional moraines is displayed by the great succession of curving ridges south of the lakes Michigan and Erie.

Drumlins : These are unstratified glacial deposits of special and unusual interest. In many areas the glacial drift is moulded by a streamline flow of ice into nearly parallel smooth ridges and troughs that range up to many miles in individual length. These forms resemble the streamline bodies of racing automobiles, offering minimum frictional resistance to the ice flowing over them. They are typically low, rounded mounds or hills of glacial till with elliptical bases, with long axes parallel to the general direction of movement of a glacier. They have steeper sides. They are 1/2 to 1 km long. The example of drumlins is in the region between Syracuse and Rochester, New York where thousands of them rise conspicuously above the level of the Ontario Plain. They are also abundant in Wisconsin and Ireland.

Erratic Boulder Trains : These are boulders of glacial origin left strewn irregularly all over the country during the wasting of a glacier. They vary in sizes ranging from pebbles to

7.8.3 Solar Topography Hypothesis

This is due to professor R.F. Flint, an eminent American geologist, who recognised the topographic theory with variations in solar radiations. Briefly this theory states that only during periods of high continents, the variations in solar radiation produce continental glaciation. It recognises an intimate connection with high lands and glaciers. If the radiation minimum is coincident with low temperatures of high and extensive continents, then glaciers advance. A wastage of glacial ice would occur with a radiation maximum. This theory seems to answer most of the objections raised in regard to other hypothesis. Still, it is based partly on the facile assumption that modern, small scale fluctuations of solar radiations were much greater, in the past.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

6. What are the causes of glaciation ?

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7.9 SUMMARY

A body of ice consisting mainly recrystallised snow, flowing on the land surface in a manner similar to that of a river is called glaciers. Glaciers originate in valley heads and move down like ice streams. Glaciers vary in size.

Glaciers are classified on the basis of their form as cirque glaciers, valley glaciers, piedmont glaciers and ice sheet. The glaciers move very slowly and is not more than a few feet per day. The movement of glaciers resembles to that of rivers. The centre moves more rapidly than margins.

The head or upper end of a valley glacier is marked by one or more large gaping cracks or crevasses known as Bergs-Chrund. Transverse and longitudinal crevasses are the other features of glaciers.

The geological work of glaciers includes erosion, transportation and deposition. Glacier erosion includes abrasion and plucking and is generally proceeded by weathering in the form of frost wedging. The features of erosion are the crag and tail, cirques etc. The glaciated valleys differ in many ways than that of stream Valley. Presence of cirques at the head of the glaciated valley is the striking feature of glaciated valley.

Glaciers carry rock particles without sorting and deposits made by glaciers are not stratified. Usually glaciers carries rock debris on its sides because this is where glacier and bed rock are incontact and where abrasion and plucking are more effective.

Glacial Lake sediments : The cold waters of marginal glacial lakes have a higher density than the water at moderate temperatures. For this reason the settling of silts and clays is much retarded and so the fine sediments in suspension become diffused throughout the lake water and are deposited over the floor of the entire lake basin. The fine-grained sediments are laid down in plainly separated annual layers called **varves**. Glacial varves commonly consist of alternate laminae, one of which was laid down during the summer and the other during the winter. The summer band consists of light coloured coarse silt where as the winter band is darker in colour and fine grained and thinner. Each varve represents a year. By careful study and analysis it has been possible to estimate the rate of recession of a continental ice sheet on glaciers.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

5. Name any five glacial deposits -

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7.6 EFFECTS OF GLACIATION ON RELIEF AND DRAINAGE

Valley glaciers have brought about considerable topographic changes by straightening, deepening, widening and steepening the sides of their valleys and modified the divides into cirque basins, aretes and matterhorns. The continental ice sheets of the great ice age have not profoundly altered the relief of the country over which they moved and though many hills and low mountains were somewhat scoured and rounded off and many valleys were deepened and widened, the major relief features were almost left unaffected by ice erosion during the passage of ice sheets. The vast continental glaciers left the country somewhat less rugged than it was before glaciation. The movements of the ice of continental ice sheets caused the mantle of soils to be removed from their place of origin, mixed up and transported often for long distances. Over the eastern and central Canada ice erosion predominated over deposition while farther south and southwest glacial deposition, predominated. This explains why eastern parts of Canada are generally characterized by bare rock ledges or thin soils, where as deep glacial soils generally prevail over New England, the upper Mississippi valley etc.

The effects of glaciation upon drainage are very profound. Many pre-glacial valleys were more or less completely filled with glacial debris, causing new streams to follow courses very much different from those of the predecessor of pre-glacial valleys. In other cases streams were crowded out of their valleys by the ice itself and forced to erode new channels elsewhere. Many such new channels have been held to since the disappearance of the ice. Immediately prior to the great Ice age, the combined Allegheny and Monongahela

Rivers flowed north-wide into the Erie lake basin instead of through the Ohio Valley as at present. Accumulation of much glacial debris across the northwestern Pennsylvania caused the change. In many such cases where streams were forced to find new channels this have carved out pictureque gorges usually containing waterfalls, The famous Niagara Gorge and Niagara falls are excellent examples.

Most of the several thousands of lakes in northern parts of north America are the direct results of the glaciation of the Pleistocene Ice age. Even the great lakes were not in existence before the Ice age. Some of these lakes occupy the rock basins scoured out by glacial erosion but most of them fill basins, which were formed by glacial drift deposits blockading valleys causing the streams in them to be locally ponded.

7.7 EXISTING GLACIERS

Greatest of the present day glaciers are the vast ice sheets or continental glaciers occupying much of the Greenland, Iceland and Antarctica. The lesser ones are the ice caps that occur in the Arctic Islands of the Spitz bergen Scandinavia and Iceland. Of the valley glaciers that exist now a days the Alpine type are the most abundant. They are best known in the Alps mountains where there are atleast 2,000 of them. The most prominent among them is the Great Aletsch Glacier which is over 14 kms long.

The great Himalayan mountains support a magnificent system of very large high altitude valley glacier. The largest of these is the Fed chenکو which is 60 kms long. Kedarnath and Kanchanajunga found in Kumaon and Nepal Himalayas support many valley glaciers. The Andes in south America support many valley glaciers. Several of them flow into tide water where they break off to form ice-bergs. Southern Alaska of U.S.A. is verily a wonderland of lofty mountains, vast fields of perpetual snow and numerous valley glaciers of large size.

The Great Ice Age : An early as 1821 European scientist Louis Agassiz was the first to recognise features characteristic of glaciation in places at considerable distances from any of the existing glaciers. He naturally inferred that the glaciers must once have covered wide areas that are now free from ice. Gradually through the work of many scientists information on the character and extent of former glaciation, was added to the growing body of knowledge until today we have a fairly good and comprehensive picture of the former glacial epochs.

During the last period of geological time in the Cenozoic era known as the Pleistocene period most of the North America and Eurpoe was covered by vast and thick ice sheets. This ranks as one of the most interesting and remarkable occurrences of geological time. The total area overwhelmed by thick ice masses approached nearly eight million square miles. Half of this was in North America where the ice radiated from three main centres, namely Labrador, the Keewatin district bordering the Hudson Bay and Cordilleran ranges of the West America. Much of Europe upto Urals and beyond was under ice. A subsidiary ice cap radiated from the Alps and the Himalayas and other mountain ranges of Asia were similarly glaciated. In the Southern Hemisphere New South Wales and Tasmania were glaciated. Newzealand was largely shrouded in ice and so were the extensive tracts of Patagonia and Southern Chili. The Antarctica sheet, like that of Greenland, was thicker and more massive and extensive than it is today.

The climatic change evidently led to a general lowering of the snow line and were clearly world wide in their effects. Detailed studies of the glacial drift have shown that glaciation was not confined to the effects of a single great advance and retreat of ice. In many places around the Alps, four successive sets of boulder clays, moraines and outwash gravels were preserved showing that glaciation was repeated four times during the Pleistocene period. The intervals between the major glacial epochs are known as the interglacial epochs which are represented by ancient soils and locally by lake and river deposits sandwiched between old and younger bed of glacial or glacio fluvial drift. Some of the interglacial beds contain plant remains and, therefore, provide valuable information as to the climatic conditions at the times when they were deposited.

7.8 CAUSES OF GLACIATION

Through the course of glacial and interglacial epochs, world temperatures have fluctuated rather considerably, the change from a non-glacial climate to glacial climate in middle latitudes requiring an average reduction of about 6 degrees centigrade. For the causes of this fluctuations of temperatures, many hypotheses have been advanced, brief summaries of which are given below.

7.8.1 Heat Distribution Hypothesis

Changes in the bodily movements of the Earth such as the eccentricity of the Earth's orbit and the inclination of its axis to the ecliptic have been thought to be the probable causes of glaciation. These are real periodic changes accompanied by corresponding changes in the climate. If the variations reached extremes sufficient to account for the glaciation of the pleistocene, there thought to have been several such or similar ice ages throughout the reckoned geological time. Actually there was only one another similarly great ice age at the close of the carboniferous period.

7.8.2 Solar Radiation Hypothesis

This is yet another hypothesis based on astronomical data. It relies upon the observed variations in the solar constant or the quality of heat reaching the outer surface of the earth's atmosphere. At present this is just less than 2 calories per square minute and it has varied as much as 3 percent since continuous measurements were began by the Smithsonian Institution of Washington of U.S.A. in 1918. Sir George Simpson bases a theory on the large scale changes in the solar constant in the geological past. He assumed that increased solar radiations would raise temperatures increasing planetary circulation of the atmosphere, precipitation and cloudiness. The cloudiness and precipitation in low latitudes would produce a pulvial climate. In high latitudes cloudiness would decrease the melting of increased snowfall. As a result, glaciers would begin to expand in both polar hemispheres and an ice age would begin. Continued rise of heat at the earth's surface, however, would eventually destroy these glaciers and an interglacial epoch would set in. As the radiation diminished, the process would reverse. Glaciers would form once again and a second glaciation would begin ending only when radiation had decreased to a point where precipitation was inadequate to support the glaciers. They would waste and the second glacial period would end. This is an unique theory in that it calls for glaciation with rise of temperature and two glaciations per cycle. If we assumed that two large fluctuations of temperature took place, then the radiation curve would produce four glaciations which is the case in the Pleistocene Ice age.

7.8.3 Solar Topography Hypothesis

This is due to professor R.F. Flint, an eminent American geologist, who recognised the topographic theory with variations in solar radiations. Briefly this theory states that only during periods of high continents, the variations in solar radiation produce continental glaciation. It recognises an intimate connection with high lands and glaciers. If the radiation minimum is coincident with low temperatures of high and extensive continents, then glaciers advance. A wastage of glacial ice would occur with a radiation maximum. This theory seems to answer most of the objections raised in regard to other hypothesis. Still, it is based partly on the facile assumption that modern, small scale fluctuations of solar radiations were much greater, in the past.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

6. What are the causes of glaciation ?

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7.9 SUMMARY

A body of ice consisting mainly recrystallised snow, flowing on the land surface in a manner similar to that of a river is called glaciers. Glaciers originate in valley heads and move down like ice streams. Glaciers vary in size.

Glaciers are classified on the basis of their form as cirque glaciers, valley glaciers, piedmont glaciers and ice sheet. The glaciers move very slowly and is not more than a few feet per day. The movement of glaciers resembles to that of rivers. The centre moves more rapidly than margins.

The head or upper end of a valley glacier is marked by one or more large gaping cracks or crevasses known as Bergs-Chrund. Transverse and longitudinal crevasses are the other features of glaciers.

The geological work of glaciers includes erosion, transportation and deposition. Glacier erosion includes abrasion and plucking and is generally proceeded by weathering in the form of frost wedging. The features of erosion are the crag and tail, cirques etc. The glaciated valleys differ in many ways than that of stream Valley. Presence of cirques at the head of the glaciated valley is the striking feature of glaciated valley.

Glaciers carry rock particles without sorting and deposits made by glaciers are not stratified. Usually glaciers carries rock debris on its sides because this is where glacier and bed rock are incontact and where abrasion and plucking are more effective.

The sediments deposited directly by glaciers constitute glacial drift. Glacial deposits are of two types namely, directly deposited by glaciers or glacial till and by glacial streams, (glacio-fluvial or out wash). Glacial till deposits are unsorted and the depositional features are the moraines which are simply layers of till. Glacio-fluvial deposits are well sorted due to glacial melt water. The terminal or end moraines are formed at the end of the glaciers. Drumlines, erratic boulder trains, out wash plains, kettle holes, kames, eskers, glacial lakes etc are the depositional features of glaciers.

Glaciation affects the relief and drainage. Valley glaciers brought about considerable topographic changes by straightening, deepening, widening and steepening of the sides of the valley. Many pre-glacial valleys were more or less filled with glacial debris and will effect drainage.

Greatest of present day glaciers are occupying Greenland, Iceland and Antarctica. The causes of glaciation are the heat distribution, solar radiation and solar topography.

7.10 CHECK YOUR PROGRESS-MODEL ANSWERS

- 1) Glacier may be defined as a large mass of ice consisting mainly of recrystallised snow, moving slowly on a land mass.
- 2) Crevasses.
- 3) The gap between the head of the glaciated valley and the mass of glacier ice is known as Bergs-Chrund.
- 4) Cirques are the circular depressions formed by plucking and grinding on the upper parts of mountain slopes.
- 5) Moraines, drumlines, erratic boulder trains, outwash plains, kettle holes, kames, eskers etc are the features of glacial deposits.
- 6) The causes of glaciation are the heat distribution, solar radiation, solar topography etc.

7.11 MODEL EXAMINATION QUESTIONS

I. Answer the following questions in 30 lines.

1. Describe the erosional activity of glacier and resulting forms.
2. Describe the deposits formed by glacial action.

II. Answer the following questions in 10 lines.

1. Give an account of the types of glaciers.
2. What are the characteristics of a glaciated valley ?
3. Write briefly about the great ice age.
4. What are the causes of glaciation.

UNIT - 8 : LAKES, SEAS AND WIND

Contents

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- 8.2 Lakes
 - 8.2.1 Geological work
 - 8.2.2 Swamps
 - 8.2.3 Lake Origin
 - 8.2.4 Destruction of Lakes
 - 8.2.5 Types of Lakes
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- 8.3 Seas
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 - 8.3.3 Geological Work of Seas
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 - 8.4.1 Geological Work of Wind
 - 8.4.2 Deserts - Geological Process
- 8.5 Summary
- 8.6 Check Your Progress - Model Answers
- 8.7 Model Examination Questions

8.0 OBJECTIVES

After completion of this unit, you should be able to

- explain the lakes, and their geological work
- describe seas and their geological work
- explain wind as a geological agent.

8.1 INTRODUCTION

Lakes, seas and wind are acting as agents of external geological processes. Lakes feed freshwater to the rivers and serves as settling basins in the drainage system. The deep seas or oceans supply moisture to the atmosphere. Seas are the depository sites for all the debris derived from land and carried by the rivers. The geological work of wind is very active in arid and semi-arid regions. Wind not only erodes, transport and deposit rock

the Halite, Gypsum, Glauber salt, Epsom salt, Magnesium Chloride and Calcite. During the desiccation of a salt lake dissolved substances are deposited in the order of their insolubility. The entry of flood waters during the rainy season may dilute the waters enough to check precipitation of mineral matter from solution and the land-derived sediments will accumulate on the lake-floor. It is therefore recognised why alternately layers of clay and sand and one or more beds of salts are often found in old lake deposits. Extensive deposits of soda and borax mark the sites of former lakes as in parts of the Death Valley, California.

8.2.2. Swamps

A marsh or Swamp is an area of wet, saggy and saturated ground usually filled with decaying vegetable matter. They are closely related in their development to the level of the water table. In such areas the run-off or infiltration of surface water is delayed or even prevented. Many swamps occupy basins that represent a phase intermediate between lakes and dry land. Indeed many basins fluctuate between swamps and lakes. Swamps are often the successions to lakes and sluggish streams. Other swamps occupy flat areas in which growth of vegetation alone prevents surface water from creating channels and forming streams. Roots and stems spread the water effectively and keep it dispersed. A marsh or swamp is very much likely to occur wherever there is a wide expanse of relatively flat and poorly-drained land with an abundant supply of water. Such conditions are to be found on the till plains of recent glaciation with poor drainage along the flood plains, deltas of major rivers and also along the coastal regions adjacent to the broad but shallow continental shelf. Excellent examples of swamps or marshes are found in north central United States and adjacent parts of Canada and also in eastern parts of Russia.

Sediments that accumulate in swamps contain a large proportion of organic matter such as peat (partly decomposed plant matter formed in swamps). Aquatic vegetations such as, water weeds and rushes grown in shallow water close to the shore. Dead plants are attached and decomposed by bacteria beneath the water surface. The bacteria exert certain waste products that are toxic in nature. When these toxic products reach a certain concentration the bacteria cannot any longer thrive and get killed and the partly decomposed plant substance is preserved, when dry peat is combustible in some regions it is used as a fuel and indeed it is the first step in the transformation of vegetable matter into coal. Swamps also accumulate inorganic sediments mostly clay and silt. A complete gradation exists from mineral sediments to peat and this gradation is reflected in the occurrence of impure clayey coal representing deposits in ancient swamps into which streams were bringing mineral particles.

Many natural products useful to mankind are won from lake water or from the deposits that accumulate in lakes and swamps. Saline lakes have exclusive deposits of Calcium Carbonate in the form of white Chalky marl. This is useful for agriculture and also to some extent in the manufacture of cement. The diatoms that lived in certain lakes contributed to beds of diatomaceous earth useful as an abrasive and refractory. In many parts of Europe extensive deposits of peat are used as sources of domestic fuel. Several reclaimed marshlands and swamps have yielded very large tracts of rich high humous soil, a fertile belt for agriculture. This is so several places in Hotland, Eastern parts of U.S.A.

8.2.3 Lakes Origin

Lakes may have originated in many ways. Most lake basins are the result of gradational processes but some are due to volcanic activity. The important types of lake basins are briefly described below.

Basins formed by glaciation : Lakes are generally numerous in areas recently covered by glacial ice. Glacial lakes are either due to erosion or deposition or both. Of these the most numerous by far have resulted from the deposition of glacial debris in such a manner, so to obstruct the drainage of valleys. Many thousand lakes of Minnesota, Wisconsin, Newyork and New England belong to this category. Numerous lakes of different sizes in Tibet are considered to have been formed by the obstruction caused by glacial moraines in river valleys.

Glaciers may blockade valleys and thus cause ponding of waters. Lakes of this type occur in the Alps, Greenland and Alaska. The great lakes of North America constitute the most remarkable group of big lakes in the world. Lake superior, the largest fresh water lake in the world, is 1,180 feet deep. The Great lakes cover a very large area of about 95,000 Square miles. These immense basins were primarily gouged out by ice along the sites of broad preglacial valleys.

Quite a good number of glacial lakes have been eroded or excavated by the direct action of flowing ice example the cirque lakes in Sierra Nevada, Cascade and Rocky Mountains, the Alps and the Himalayas. Finland alone has more than 60,000 glacial lakes. A preglacial valley partially blocked by deposition of drift may give rise to a chain of lakes.

Basins formed by streams : Lake basins are formed both by degradational and aggradational work of streams. At certain places the two processes have been active in the formation of a lake basin. Many shallow lakes are formed upon flood plains by streams that wander in meandering loops over the valley flats. Where the streams cutoff the neck of a meander, the abandoned part of the channel remains a crescent - shaped Ox-bow lake. Similarly further down the river valley on the delta surface, the water in the main channel breaks, through the levels and forms branching channels or tributaries. As a result of uneven deposition of sediments by the network of tributaries on a delta, certain shallow basins are completely surrounded by the deposits and so converted into the delta lakes. The delta of the Nile, Danube and Mississippi rivers show such basins.

Basins formed by the action of groundwater : When the roofs of the caves and caverns in limestone country collapse resulting in the formation of sink holes, they are filled with groundwater forming small lakes. A number of lake basins in Florida were formed in this way and other examples are found in the Karst topography of Kentucky and Tennessee.

Lake basins are also formed by waves and shore currents, due to wind activity, by mass movement, with diastropism and by volcanic activity.

8.2.4 Destruction of Lakes

In course of time lakes may slowly disappear due to the following reasons.

1. By filling with sediments : Streams flowing into lakes carry sediments, most of which accumulates on the floors of lakes. By this process lakes may become completely filled and thus get destroyed.

2. By filling with organic remains : In humid, temperate climate regions, plants grow profusely in the shallow border portions of lakes. As the plants die their remains accumulate to form bogs which encroach from all sides and the lakes become completely filled. Thus accumulation of vegetable matter and also shells of animal lead to lake-filling.

3. **By cutting down outlets :** The dams of lakes, especially those formed of glacial debris usually consist of loose, incoherent materials which can be easily cut into by outlet streams. By this process, a lake surface may be reduced gradually until the lowest level of the lake basin is reaching, thus causing the destruction of the lake.

4. **By removal of ice dams :** Where a lake is formed due to blocking of a tributary valley by a glacier and consequent ponding of water, the shifting of the glacier may allow escape of the water. Similarly melting of the glacier may also lead to destruction of lakes.

5. **By evaporation :** In arid regions evaporation may exceed intake to such an extent that the lake basins become dry.

6. **By diastrophism :** Small lakes may be drained through fissures formed during earthquake disturbances. Large lakes may be destroyed by the down-faulting of their outlet areas.

8.2.5 Types of Lakes

The important types are salt or saline lakes, alkaline lakes, and playa lakes.

Salt or Saline Lakes : Salt or saline lakes may be formed in either of the following two ways viz., (i) by accumulation of saline matter in lakes with no outlets and (ii) by cutting off arms of the sea either by diastrophism or deposition of sediments particularly in the form of a delta. To the second category belong some of the salt lakes like the Caspian sea which is the largest body of inland saltwater known.

The salton sea occupies the lowest part of a great desert depression extending from Southern California to the head of the Gulf of California. The Colorado River has built an extensive alluvial fan deposit across the depression, thus separating the salton sea from the Gulf of California.

Salt lakes are less numerous than the fresh water lakes. They do not have outlets and invariably occur in arid regions particularly in those of interior drainage like the Great basin area of western U.S.A. In such regions the precipitation and inflow are not sufficient to cause the lakes to overflow the lowest points of their basins to form outlets. Increased evaporation in the dry and desiccated climate leads to the concentration of mineral salts in the water and thus a fresh water lake in the beginning may eventually become a salt lake since there is no outlet and the mineral matter gets steadily increased. The Great Salt lake in Utah is the most renowned example of a salt lake.

The Dead Sea of Palestine (now part of Israel and Jordan) lies in the lowest position of the Jordan river valley which was formed by sinking of a long narrow block of earth's crust between two nearly vertical parallel faults. It covers an area of nearly 500 Sq. miles. Its great depth is about 1300 feet and its surface lies about 1300 feet below general sea level, making it the lowest lake in the world.

Alkaline Lakes : Lakes containing excessive amounts of alkaline carbonates are commonly referred to as alkaline lakes. They occur at many places in Egypt, Hungary, Venezuela etc. They are special types of saline lakes and found also along the western part of the Great basin in USA. Mono lake in east central California is an excellent example of this nature being rich in salt and soda. There are a good number of alkaline lakes called dands in sind province of Pakistan.

Playa Lakes : Shallow, flat-bottomed depressions are formed by weathering and wind action in many desert areas. During the wet seasons they are flooded by waters from intermittent streams and when the water supply ceases, they shrink and finally disappear by evaporation, leaving in their beds, deposits of alkali salts that are often as much whitish as freshly fallen snow. Such lakes are characteristic features in the deserts of the Great basin. Similar lakes exist in the desert of Arizona and New Mexico.

8.2.6 Indian Lakes

Lakes are few and far between in a large country as the Indian subcontinent. There are only a few lakes in the Peninsular region. A few lakes have also been formed along the coast by bars and deltas. Along the Western coast of Kayals these are separated from the Arabian Sea by narrow bars. On the East Coast of the Peninsula the notable are the Pulicat Lake in Andhra Pradesh, situated just a few tens of kms north of Madras. The Chilka Lake is situated on east coast of Orissa.

Kolleru Lake : The Kolleru lake is a large fresh water lake in the coastal district of Krishna in Andhra Pradesh. It is formed probably due to the outward and lateral growth of two big deltas of the mighty rivers of Krishna and Godavari. It is very shallow and elliptical in shape and covers an area of about 150 kms and it is being gradually silted up by small streams that flow into it of which Budameru is well-known.

Sambhar Lake : This lake is of unique nature. It lies on the border of Jodhpur and Jaipur, about 64 kms west of Jaipur city in Rajasthan. It is situated at an elevation 1200 ft above mean sea level, with an area of nearly 120 kms. It is generally dry in summer leaving a marshy patch. It is filled with saline muds and has been worked as a source of common salt for centuries.

Lonar Lake : This is an unusual circular depression in the deccan traps in the Buldana district of Maharashtra. It is about a mile in diameter and nearly 300 ft. below the level of the surrounding country. It is occupied by shallow water during the monsoon but becomes dry in hot weather showing encrustations of sodium carbonate locally called Urdo and Sodium chloride. This lake is surmised to be a crater lake probably of volcanic origin associated with deccan trap activity in the distant geological past.

The Nal : This is a large saline lake of nearly 80 square kms in area situated about 75 kms south west of Ahmedabad. The waters are blackish when the lake is full and become markedly saline in the hot summer. It may be an arm of the sea cut off between Saurashtra and Gujarat.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. Name some Indian lakes.

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8.3 SEAS

In common the the terms sea and ocean are used synonymously to refer to large continuous bodies of salt water covering large parts of the earth's surface. But in scientific terminology the oceans are larger bodies of salt waters occupying huge basins between the continents like the Pacific, Atlantic and Indian oceans. The lesser bodies of salt water are called the seas like the North Sea, Yellow Sea and the Arabian sea etc. These are called **epicontinental seas** which occupy the narrow platforms (continental shelves) that border the lands nearly everywhere. They are also known as **shelf seas** as they are landward extensions of the open and broad oceans. Other bodies of shallow water lying within the continental regions and having less open connections with the ocean are called **Epeiric seas**. The Baltic sea and the Hudson Bay are good examples of such epeiric seas. A Mediterranean sea is special type of epeiric sea with a depth of several thousands of feet. The Mediterranean and Caribbean sea are examples of this category.

8.3.1 Relief Features

The surface of the sea or ocean is the datum or reference plane for all topographic and geologic survey. All level surfaces are theoretically paralalled to the mean sea-level, which is assumed to be constant.

The topography of the sea floor, contrary to the belief of people of few generations ago, is by no means smooth but the profile is as much rugged and diversified as the land surface. Long mountain chains, isolated hills and mountains including volcanic cones, broad mountainous featureless plains, trenches and canyons mark the ocean floor in as much the same way as they mark the land surface.

The ocean basins occupy about 2/3 of the earth's surface but there is an excess of water and so the basins are more than full. Its waters, therefore, spread out over the low borders of the continental masses covering them to depths that vary from zero to hundreds of meters but with average about 70 fathoms at the outer edge. In places this submerged continental fringe is more than 160 Kms. wide. Here, some of the important topographic features of the ocean bottom are described below.

Continental Shelf : This is the nearly flat submerged border of a continental mass, mostly less than 100 fathoms below mean sea level it varies in width up to 320 Kms. but with an average of about 64 Kms. This continental shelf slopes seaward about 2 mts. per Km. from the shoreline to about 70 fathoms where the sea bottom begins to descend more abruptly into the abyssal depths. In many places the bottom material is mostly solid rock but sand, mud or even gravel may exist. Sinking of the coast line or rise of the coast line brought about by diastrophism or gradation may profoundly change the configuration of the shore lines.

Continental Slope : Beyond the 70 fathoms line the slope of the ocean bottom generally becomes more abrupt. Its lower edge grades imperceptibly into the main floor of the deep sea. The continental slope varies in width upward from a few tens of Kms. but it is nearly every where a feature of the border of the ocean basin. Its area is a little more than twice that of the continental shelves. The continental slopes are thought to be margins of the continental masses composed of relatively higher rocks that grade seaward into heavy rocks underlying the ocean basins proper.

Deep Sea Floor : It lies seaward of the base of the continental slope and it is not a featureless plain but seems to possess a great variety of irregular features like ridges both broad and narrow, submerged mountain chains, and flat topped peaks. One of such most outstanding features is the mid-atlantic ridge, that extends from Iceland nearly to Antarctica, mostly lying under about 2700 meters of water and about 1800 meters above the deeper portions on either side. The Hawaiian Islands stand on one such great submarine ridge that is more than 3,200 Kms. long in the Mid-Pacific area.

Submarine Canyons : At many places the continental slopes and outer parts of continental shelves are characterized by deep V-shaped, steep walled valleys called submarine canyons. Some of them have tributaries with a dendritic pattern like that made by stream erosion on land. Some canyons lie off the mouths of rivers such as the Indus, Hudson or Columbia. Their lower reaches extend to depths of as much as 1,800 to 2,700 metres below sea level. Their walls in places are rocky.

Sea Mounts and Guyots : A remarkable feature of the ocean bottom is the presence of a series of submarine mountains aptly referred to as sea mounts that are more than 900 meters high on the deep sea floor. Most sea mounts have conical tops, but some have flat tops and they are called guyots now submerged to depths of about 1 to 2 thousand meters may represent volcanic peaks which were truncated by wave erosion in the geological past or capped with broad coral reefs and subsequently were drowned by subsidence of the ocean floor or by rise of the sea level.

Trenches and Deepes : These are long narrow deep basins in the ocean floor. They are most conspicuous in the Pacific ocean, several of them being curiously close to its coasts, at the foot of the continental slopes of the west coasts of South America or along the front of island areas as illustrated by the Aleutian trench. Other notable trenches are the Kurile trench, Japan trench, Mindanao or Philippine trench, Marianas trench, the Java trough in the Indian Ocean and Puerto Rico trough in Atlantic.

The deepest sounding have been obtained in these trenches like 10,332 meters in Philippine trough and 10,692 meters in the Marianas trough. The origin of these deep sea troughs and trenches is little known but it is well-known that they lie along active and mobile belts of the earth's crust as is indicated by the fact that numerous earthquakes originate beneath or near these troughs and trenches.

Mid Ocean Ridges : These are found in all of the major oceans and represent more than 20 percent of the earth's surface. They are certainly the most prominent topographic features in the ocean. They form an almost continuous mountain range, varying in width from 500 to 5,000 kilometers which extends for some 64,000 kilometers. The crests of the ridges are marked by deep cliffs or rifts and are flanked by ridges and lines of peaks that extend outward for hundreds of kilometers. The axes of the ridges are marked by frequent earthquakes and are characterized by a much higher heat flow through the crust. The rifts at the centre of the ridge known as median valleys are the sites where new magma wells up from the asthenosphere below, continually creating new oceanic crust.

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.

4. What are seas ?

5. Name any three relief features of seas ?

8.3.2 General Features

The general features of seas includes the nature of sea water, temperature, density and pressure, forms of life in the sea.

The nature of sea water : The sea water contains about half of the elements known to man, of which the chlorides predominate and these give the sea water its saline nature or saltiness. The mineral matter accounts for 3.44% by weight of sea water. For a cubic mile of sea water this percentage amounts to 152 million tons and this gives us the idea of the immensely large may, fantastic amounts of mineral matter present in the oceans of today.

Through millions of years of geological time the rivers and streams the world over have been slowly adding dissolved substances to the oceans. Some of these such as Iron, Silica and Calcium are used up in the life processes by animals and plants that live in the ocean and in effect removed from sea water. The most abundant salt by far in solution is the common salt which is nearly 78% of the dissolved matter. The other principal constituents in solution are chloride and sulphate of magnesium, the sulphates of calcium and potassium. Murray estimated that if all the dissolved matter in sea water be precipitated, it would form a layer about 50 meters thick over the entire ocean floor. In addition to the salts in solution, there are gases dissolved in sea water supplied by the living organisms and submarine volcanoes. The principal gases are nitrogen, oxygen and carbon-di-oxide.

Temperature, Density and Pressure : The temperature of the ocean depends entirely upon the solar radiation. It varies greatly from the equator to the poles. At the equator the surface temperature averages about 80 degrees F. where as in the polar regions it is 28 degree F. near the freezing point of the sea water. The temperature of the sea water generally changes from the surface to the 600 fathom line, where it is about 39 to 40 degrees F. Nearly two-thirds of the ocean water is cold and the heavy cold waters that originate in polar and sub-

polar regions creeping towards the equator, dominate the circulation of the modern oceans and influence the general climate of the bordering lands. The normal specific gravity of sea water is about 1.025 slightly higher than the pure fresh water. In cold polar seas it increases to 1.028, whereas in warm tropical seas it may decrease to 1.022. Changes in the density with changes in temperature, pressure, dilution and concentration are responsible for certain currents in the ocean. The pressure increases with depth in accordance with well known hydrostatic laws. One cubic foot of sea water at the surface weights about 64 pounds. Accordingly at a depth of 330 meters the pressure naturally is 64,000 pounds per square foot. At a depth of 12,000 meters it will be more than 1,100 tones per square foot.

Forms of life in the sea : Both animals and plants live in various forms and countless numbers in the sea. The animals range in size from ultramicroscopic unicellular forms to the giant sized whales. Lower orders of animals are much more common and numerous than the highly evolved ones. Among the higher forms of animals are whales, seals, walruses, sea turtles and several kinds of fishes. The plant forms are mostly simple sea weed which range in size from the minute diatoms to those of tens of meters long.

The whole of the surface waters of the many seas are crowded with teeming millions and billions of microscopic algae which are busy, with the help of sunlight and chlorophyll, converting the inorganic substances in sea water into organic compounds which in turn supply not only the food for the majority of marine animals which live on the surface and intermediate depths of the sea but also at the myriads of creatures living near and on the sea floor, the level to which the sun rays can hardly penetrate. The marine environment has been conveniently divided into several life zones, each characterized by certain forms of fauna and flora.

Littoral Zone : This zone includes the area exposed between the high and low sides. In this zone the ebbing tide lays bare the sea bottom and the high tide covers it with tide waters. It is always within the influence of strong waves. Due to this, living conditions are somewhat difficult and organisms must either be firmly attached to the bottom or burrow into the mud. Some forms find refuge in tidal pools. Certain varieties of sea urchins (echinoderms) occupy holes that they make in solid rock.

Neritic Zone : This extends from the low tide mark to the edge of the continental shelf. Since the water is less than 130 meters deep, the sun's rays can light up the whole area, food is abundant and vast numbers of different species of organisms thrive on each other and on the materials in solution in sea water. It is established that a greater abundance of life per unit area flourishes in this zone than in any other place on earth.

Bathyal Zone : This zone extends from 70 fathoms line to 1,000 fathom line. The higher parts of the area receive a little amount of sunlight but even there the plant life is very much restricted. The floor of the sea in this zone has a prolific animal life despite the fact that the plant life is limited. Since the rate of deposition of sediments is slow, bottom dwelling scavengers destroy much of the organic matter. The calcareous sediments consist largely planktonic shells and the siliceous deposits are mainly diatoms and sponge spicules.

Pelagic Zone : This zone includes the waters of the wide expansive sea that lie beyond the littoral zone. The life of this zone includes the floating planktonic forms as well as the free-swimming forms of the ocean. Algae and diatoms are the most common plants and many varieties of animals inhabit this realm. Their resistant inorganic skeletal remains contribute abundantly to the formation of several sedimentary rocks.

Abyssal Zone : The abyssal or deep sea zone includes all the portions of the sea below 1,000 fathom line. It receives no sunlight, its temperature is near freezing at all times and the pressure is greater than 1 ton per square inch. Since the plants that require sunlight cannot thrive in this environment, the animals that depends upon plant food must live on those that which settle from the surface waters. The shells and bones of animals that live on abyssal bottoms indicate that only highly specilized creatures are able to survive at such depths.

It is usually beleaved that life on earth first appeared in the sea or in the brackish waters of the coastal swamps. With its introduction, biochemical activity ensured which profoundly influenced the conditions in the marine environment. Many and varied organisms that live in the sea have hard parts made up of calcium carbonate or of silica and these later contributed to the formation of limestones and siliceous deposits. It is largely through the living organisms and their ability to precipitate calcium carbonate or amorphous silica that the cementing materials for other sediments are obtained. Thus life in the sea is a rock builder and hence a geological factor of great importance.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

6. The marine environment is divided into several life zones. Name them.

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8.3.3 Geological Work of Seas

Erosion : Most of the geological work of the seas is accomplished by the surf, shoreward of the line of breakers, when a wave dashes against a rocky shorecliff, water is forced into many cracks and crevices causing a hydraulic pressure which tends to disrupt blocks in the face of the cliff. Also many fissures and cracks are filled suddenly with compressed air which on retreat of the waver has its pressure released quickly thus produce an explosive recoil which dislodges sometimes even large masses of rock. The very impact of a wave against a shore consisting of loose materials is sufficient to force off rock materials from the cliffs. The erosion by impact and quarrying is comprehensively called **hydrauliking**.

Waves also erode by abrasion as the rock fragments quarried out by the waves or rolled down into the water are hurled back by the waves against the shore. Rock fragments are thus effective tools in cutting the shore line under-cutting the promontories. The overhanging rock then topples into the sea and more tools are worn by corrosion and undergo reduction in size or attrition as they are carried back and forth as on a wash board. Shells and rocky materials are reduced by grinding between coarse pieces. They are worn down to finer and finer sizes as they are dragged and rolled to and fro on the beach by the moving water. A minor factor in the removal of rock material by waves is the solvent action

of sea water. This is particularly true of calcareous rocks where organisms increase the activity of the water and hence its solvent action. Currents scour the bottom in shallow water and thereby assist in coastal shore erosion. The shallow surf zone with a vertical thickness of not more than 10 metres may therefore be described as an erosional knife-edge or saw cutting horizontally into the land, and beyond the surf zone fine rock particles are moved and loose sediments are redistributed but little erosion of bedrock takes place.

Results of Wave Erosion : Where waves are at work ceaselessly cutting into a shore of at least a moderately high land, a steep front facing the sea soon develops. This is called **sea-cliff**. At first the waves may attack the whole face of the cliff but after a time the cliff becomes so high that the waves attack only its lower portion where a horizontal notch or nip at the base is formed as a result of sawing action of the waves.

On rocky coasts the continued advance of the sea by erosion and retreat of the sea cliff produces bevelled rock bench, the Wave Cut terrace partly exposed at low tide. A multitude of such features as groves, furrows, testify to abrasion of its surface in the turbulent surface. Unusually resistant rocks may be left standing as reefs called **Rock reefs**. In places where turning water from the spray and splash of storm waves rotate the water and sediments caught in small rock basin grinding the holes deeper and producing the familiar tidal pools. They are much common on many sea coasts.

In rocks which are highly jointed wave erosion may quarry out sea caves. If erosion breaks through the roof of top of the cave, it forms a blow hole called Gloop in England or Spouting Horn. Since most rocks are closely jointed, caves may be expected along any rocky shore line subjected to vigorous attack by waves. If part of the roof of such a sea cave collapses or if two sea caves on opposite sides of a sharp headland or promontory unite, a natural bridge or sea arch results. The waves will continue to batter the arch until it collapses. In such cases the seaward rock mass becomes an island or sea stack sometimes called **chimney rock** or **skerry**. A famous example of such sea stacks is the Old Man of Hoy in the Orkney Islands. It is an isolated jointed column of coloured sandstone 180 meters high.

Due to differences in the resistance of rocks occurring on the sea shore, waves easily erode them differentially. Rock with joints are eroded easily to form coves while the more resistant rocks stand out to form headlands. In detail a shoreline of coves and headlands become quite irregular or crenulate. In unconsolidated rocks such as gravel sand and clay, a cliffed shore line may remain almost straight.

A wave cut terrace on subsequent uplift becomes a plain of marine erosion. The surface of newly raised plain of marine erosion is usually smoother than that of a peneplain of river erosion with which it has a close resemblance, but the erosion remnants left by the waves are more steep-sided than those on a peneplain formed by stream erosion. A conspicuous marine terrace with an average altitude of 30 metres faces the sea at many places along the coast of southern California. Another remarkable example of the long plain or erosion with steep-sided isolated masses of rock (former Islands) rising above its surface occurs on the east coast of India.

Deposition

Marine deposits : Viewed in a broad way there are two important classes of marine deposits, (i) those laid down in shallow water-comparatively near the borders of the land on

the continental shelf and the continental slope and (ii) the deep sea deposits laid down on the floor of the deep oceans.

Shore deposits : Storm waves commonly toss up coarse material far high on the shore out of reach of the ordinary waves or long shore currents also leads to deposition.

Beach Deposits : The term beach is used broadly to indicate the entire area along the sea extending from the line reached along the sea by high tide to the low tide mark. The loose material ranging in size from very fine rock particles or sand to large boulders which is shifted and ground up by the action of waves, under low and shore currents is called a beach ridge or embankment. But along rocky cliffs much of the beach may be nearly barren of deposits, where as along sandy coast a sandy beach may be nearly continuous. Local accumulation of gravel or sand in bays are bayhead beaches. Where most of the beach cobbles and pebbles are flattened disc shaped ones produced by gliding wave motion, they may overlap to form a single beach. By far the greater number of beaches are made mainly of quartzose sand. Local concentration of native Gold, magnetite (in the form of black sand), Zircon, Rutile, Monazite may occur in deposits called beach places. Wind-blown sands derived from beaches commonly pile up on shore as coastal deposits.

Barrier Beaches : On a number of gently sloping sandy shores the waves and currents have built up ridges of sand to form strips of land some distance off shore. Such ridges are known as **Barrier Beaches**. Offshore islands or island bars. The area behind the barrier beach is more or less completely shut off from the open sea as a **lagoon**. The origin of these barrier beaches is not very clearly understood. One possible explanation is that these were begun as relatively beaches on a nearly flat sea bottom during the recent ice age when the sea level was much lower than it is at present. As sea level was slowly restored to its original position the waves gradually might have driven the beach ridges upwards and landward to their present positions. It is not worthy that the valleys behind the lagoons are drawn by the post-glacial rise of the sea-level. Barrier beaches are very common along the atlantic coast from New Jersey Southward and along the Gulf coast of Texas.

Spits and Bars : A long shore current shifts sediments parallel to the coastline, but owing to the tendency of current to continue in a straight line it fails to follow and indentation that may be produced by a narrow bay of any origin. Where the long shore current passes from a shallow to deeper water at the entrance to such bays, deposition of sediment is certain to take place. A ridge which becomes a land projection or spit is thus built up. When a spit is built almost or entirely across the entrance to the bay it becomes a **baymouth bar**.

Bars are cut off indentations and tend to simplify the form of the coastline. Islands become connected with the mainland or with each other in a similar manner. Such islands are said to be tied and the bars acting as the line of connections are called **Tombolos**. They are numerous along the New England coast of United States.

If the free end of a spit is beaten by violent storm waves or by those seasonal and the terminal materials thus turned back may be deposited as curved spit or **hook**. By prolonged deposition the curved end of the hook may be extended until it reaches the main land and forms a **loop**.

Where sediment-laden shore currents are deflected seaward on both sides of a point of land, a projecting spit with curved or cusped sides is built up as cusped spit or a large scale cusped foreland. Cape Canaveral Florida and Cape Fear, North Carolina in U.S.A., are outstanding examples of such cusped forelands.

Wave-Built Terrace : Where a cliff and wave-cut bench are being eroded by wave action, the eroded materials are ground up and may be gradually shifted over the bottom to the deeper water at the seaward edge of the wave-cut bench and there get deposited. A very considerable wave built terrace, may be formed by this process in course of time. The continental shelf in such cases may be a combination of wave-cut benches and wave built terrace.

Shallow water features such as sea-cliffs, wave-cut benches, beach, barrier beach, spit may often be preserved for sometime after elevation of the shallow sea bottom into land. On the other hand various features formed by waves and currents are subject to change from season to season and from year to year. Therefore a beach spit or bar may show different outlines within a short span of time of a decade or so. Thus shorelines may have changed in their outline very considerably during certain periods of geological time.

Marine Deposits : The regions or environments of marine deposition or sedimentation include the shallow epi-continental seas, the continental slopes and the deep sea floor sediments of this nature and cover quite a large portions of the earth's land surface at present as sedimentary rocks. Such sedimentary rocks are now being laid down in the modern ocean basins.

According to their location on the sea floor marine deposits are classified as follows : 1) **Littoral deposits** formed between high and low tides 2) **Neritic** or shallow water deposits that collect on the continental shelf and at similar depths elsewhere between low tide and 100 fathoms line 3) **Deep sea deposits** consisting predominantly muds and oozes. The muds are deposited on the continental slope generally referred to as the **Bathyl zone** while the oozes belong to the much deeper portions of the sea bottom called **Abyssal zone**.

Littoral Deposits : Where the continents and oceans meet are accumulated certain sediments derived from the land as well as from the sea and therefore a mixture of both. These sediments accumulate along the shore zone and also in the lagoons and estuaries. In this **Littoral zone** conditions of deposition are not everywhere the same. Some consists of bare rock platform, others are nearly vertical sea cliffs, and still others are composed of gravel, sands, muds - shells and shell fragments. The sediments of the littoral or shore zone are derived mainly from the shore by the wave action. The waters are aided by frost action, by undercutting and by the wind. The work of the wind is more important in generating waves and currents that carry sediments to the beaches. The beach deposits vary with either boulders of large cobbles or both. Where the supply of finer materials is extensive even on exposed coasts the materials may be pebbles or even sand. The grinding action is caused by surf rolling up and down the beach dragging the boulders and cobbles and pebbles back and forth over each other and over the rock bottom. As agitation causes and the sediments are finally deposited they are graded in the order of size from the shore onward into the sea.

Neritic or Shallow Sea Deposits : Neritic zone is that portion of the ocean basin extending from the low tide level to an average depth 70-100 fathoms. It includes the major portions of the continental shelf together with the epicontinental seas (as the Baltic Sea, Hudson Bay). It covers about 11 million square miles. in tracts varying in width from a few miles to several hundreds of miles as in the North Sea.

The shoreward portion of the shallow sea bottom lies within the range of wave and current action. When such currents are generated the sediments are sorted out in such a manner that the coarser rock materials are deposited near the shore and they grade into finer

deposits seaward. In general rock bottom and coarse sediments occur off rocky points or sea-cliffs on shore. Wherever strong current effect the bottom such coarse sediments occur in places like between islands and narrow straits. Sand prevail on the continental shelf off sandy coasts or in areas of moderate currents. Muds are deposited off large river mouths, in sheltered areas near the shore and in depressions on the continental shelf.

The greater bulk of the shallow sea deposits is made up of debris derived from land by way of streams, glaciers, dust, sand stroms, shore erosion and explosive volcanoes. Part is contributed by corals, calcareous algae, shelly fish and chemical precipitation, where the supply of land ditritus is small, the sediments may consist chiefly of the remains of oranisms and chemical precipitates.

The structural fetures of the off shore marine sediments are variable. Deposits near the shore are usually lenticular in shape with much crossbedding and a great variation in size of particle. Ripple marks and current bedding are characteristic features of shallow water deposition. Where the sea floor has steep slopes the sediments may slump and develop crumpled and irregular bedding places. In deeper waters the strata are more or less uniformly thick and the chemical sediments may show well defined seasonal laminations.

Terrigenous Sediments : Beyond the continental shelf the ocean bottom descends rather abruptly to the deep sea floor with an average depth of 4 kms below the surfac. This is the continental slope which begins at an average distance of about 6 kms from the shore. It is in general covered by fine sediments of terrigenous materials which remain in suspension for a long period. These are called the **blue mud** and owe their colour to the presence of organic matter and to the deoxidized condition of the iron. They grade landward into shallow water deposits and on seaward side they pass into the oozes and the **red mud** of the abyssal depths.

The blue muds cover an extensive area of about 15 million sqaure miles. and they have been encountered at distances as great as 200 miles off shore and out from the mouths of great rivers such as the Amazon, they extend to a distance of 1000 miles. Volcanic mud, scarite and pieces of pumice may be strewn over to the sea botton at places even at a distances of several hundreds of miles from the land. This organic matter contributes to the deoxidizing agents of the blue mud zone but probably little is preserved in fossil form.

Pelagic Deposits : These are made up of organic oozes and red clay of the abyssal zone. The oozes are largely composed of the remains of marine organisms belonging to a group called plankton. This includes the uni-cellular marine plants called diatoms and animals like foraminifera and radiolarians and certain floating molluscs known as pteropods. These plankton predominantly made up of diatoms are present in such large number that they turn the surface of the sea into a kind of a vegetable soup called Plankton soup. Form this prolific overhead source the sea floor received a slow and steady rain of plankton shells which have escaped destruction by being eaten or by being dissolved in the sea water. In the bathyal zone they make a large contribution to form blue and green muds. Both of which are characterically calcareous deposits. In the abyssal zone the plankton shells, accumulate with little contamination from other source to form the deep sea oozes which together with red clay constitute the pelagic deposits. These deposits are named according to the most abundant organic remains composing them. Thus these are the globigerina oozes, pteropod oozes, the diatom oozes and the radiolarian oozes.

The composition and distribution of the deep sea oozes depend upon the temperature of the surface waters and the depth of the underlying ocean floor. Diatoms thrive well in

cold Arctic seas which are evidently unfavourable for other forms, Radiolarians, on the other hand, are especially abundant in warm, tropical waters. Foraminifera of which Globigerina are common found in both tropical and temperate regions.

The Globigerina and other calcareous foraminiferal shells dissolve more rapidly than the radiolarian and other siliceous forms as they sink to the bottom where the solvent power of the sea water increase with depth. Only a few large varieties succeed in reaching the depths of about 3,000 fathoms. The siliceous remains persist to greater depths, some of them down to even 5,000 fathoms.

Radiolarian Oozes : It is essentially a variety of red clay that is notably rich in the remains of radiolarians. Diatoms and sponge spicules are also commonly present. It occurs in the tropical beds of the Indian and Pacific Oceans.

At greater depths of the ocean the bottom is covered by a very fine red clay (usually almost chocolate brown) which is composed of terrigenous clay, insoluble portions of the plankton shells and other organic matter. Volcanic ash and meteoric dust from the skies are also included. Secondary products found in the red clay include black nodules of manganese dioxides and crystals of various silicate and other minerals. The Red clay occupies about 40 million square miles. of the ocean bottom and most of it in the Pacific Ocean.

8.4 WIND

The earth's atmosphere is mostly made of air and the wind is nothing but air in motion. Winds are regarded as current of air moving more or less parallel to the surface but their flow is often turbulent moving upward, and downward, twisting and turning even within the atmosphere itself. The primary cause of such movement is the differences in air pressure created by differences in heating by the sun. Heated air expands and rises, cooler air descends or flows in along the ground to take its place. Winds are, therefore, essentially currents carrying load of moisture and dust from high pressure to low pressure regions. They distribute not only moisture as water vapour to fall as rain in favourable conditions but also carry, fine-grained rock particles such as dust and sand on the earth's surface. Since these materials are land derived, the geological action of wind is more important over the land than over the sea.

8.4.1 Geological work of wind

Wind, is an important geological agent of erosion, transportation and deposition of rock material though, it is much less effective than running water. The velocity of the wind increases rapidly with height above the ground surface just as the velocity of the stream increase upward from the channel floor. In the zone a few feet above the ground surface the average velocity of upward motion in an air eddy is approximately one fifth the average forward velocity of the wind. This velocity of upward movement is of great significance in the transportation of smaller particles by the wind. The materials moved by the wind can be divided into two sizes namely sand and dust. Wind-driven sand averages between 0.15 mm and 0.30 mm and is seldom finer than 0.06 mm. Wind erosion is mostly of two types- **deflation** and **corrosion**. Both accomplish removal and transportation of rock material but the first is done without the aid of tools where as the second namely corrosion requires the assistance of grinding materials.

Wind erosion : Already loosened particles of rock such as dust and fine sand are picked up and carried from one place to another. This activity is very strikingly conspicuous in regions where vegetation is either sparse or lacking. In such regions the impact of wind itself is sufficient to remove large quantities of earthy matter by the process of **deflation** (Latin deflare-Flow away). Eddies, whirl winds and updrafts which help the wind to lift and remove its load in this way. Thus many exposed lands are swept free of loose material which is carried away as fast as weathering produces it. A more spectacular method of wind erosion is that of corrosion and abrasion whereby the wind employ its load of sand as a cutting tool as a natural sand blast. By this process rock surfaces in the way of such wind are scored and grooved. In arid region such grooves are very conspicuous and where the winds have a slight variation of direction, the grooves show a parallel alignment and their sides are forms often strongly fluted. Many odd-shaped land forms are the result. These are undercut hills with caves, mushroom rocks, table rocks and pedestal rocks (fig. 8.1). A familiar example of wind abrasion is the "frosting" and ultimate destruction of plate glass of windows of the houses which are directly exposed to hard winds. Wind-driven sand has its greatest erosive power somewhat relatively close to the ground because the lower and heavy fragments not being lifted high. They accomplish the greatest work. Telegraph poles in desert regions are often cut down by wind erosion and hence must be heavily protected at the bases. Pebbles and boulders on deserts some times have more or less angular faces carved upon them by wind erosion. Such levelled stones are called **Einkanter** or simply **Ventifacts Dreikanter** (meaning one or three edged). A ventifact is defined as a stone that is shaped and polished by wind.

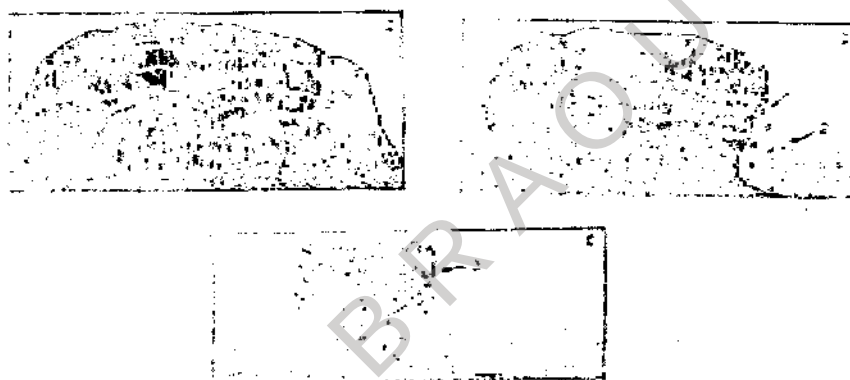


Fig. 8.1 Pedestal Rocks

Einkanter are apparently formed by the cutting of pebbles under conditions of a constant direction of the wind while dreikanter are formed when the pebbles were over turned as a result of undermining so that several facets are developed in succession. It may be pointed out here that corrosive action of the wind is much less generally effective in cutting and sculpturing of rocks than was formerly thought of by geologists.

Stream erosion even in desert regions seems to accomplish more than wind erosion because though rainfall is scanty, it rains very heavily when it does as "Cloudburst". In desert regions of high relief torrential streams rush down the stream courses carrying heavy loads of rock derived from the abundant weathered rock material lying almost unprotected by vegetation.

The greatest geological work accomplished by the wind seems to be deflation, the picking up and transportation of really large quantities of finer materials which were either laid down through the agency of running water or were produced by weathering.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

7. What are the process involved in wind erosion ?

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Wind Transportation : The method by which rock particles are carried by wind varies according to size, shape and specific gravity of the particles and with the blowing of the wind. In general, dust particles are carried in **suspension** and sand particles by **traction**, chiefly by rolling or creep. A gentle breeze can carry dust in suspension and roll fine sand, whereas a strong breeze with a velocity of 25 miles.ph can move sand grains a millimeter indiameter, and gales and hurricanes can carry sand in suspension to heights of a few hundres of feet and can roll along the ground pebbless 5 to 6 inches in diameter.

A **Whrilwind** or devil wind, is a strong upward moving current of air that may lift fine particles very high above the surface and may drift some distance from the place of origin. A **tornado** is a much violent whirling mass of air with much greater lifting power but of slight gradational effect. It originates as a column of whirling air in the strom clouds. Tornadoes are known to lift heavy objects and to transport them several miles.

Under the motive power of the wind loose grains of sand may be picked up from surface, carried for some distance forward and dropped again in a series of bouncing moments known as **saltation**. This impulse together with the drag of the wind on the surface over which it is blowing causes a forward motion or creep of the loose sand. Saltation and creep are the most important factors producing the movement of the drifting sand.

The sources of wind load are very much varied. The Chief source is the rock waste formed by weathering and corrosion. Flood-plain and sand bar deposits of dried up lakes, beach sands and glacial moraines commonly serve as intermediate source. Violent Volcanic explosions supply tremendous quantities of very light angular rock dust. The wind power of transportation by suspension is notably different from its capacity for rolling, so that a separation of rock particles occur depending upon the method of transportation. Generally, the seperation removes clay, dust and silt from the larger and heavier particles of sands. Just like winnowing of grain, this is done by the wind.

Wind deposition : Whenever and wherever the wind loses its ability to transport material, deposition of sand and dust from the air occurs much as in streams of water. The saltating sand grains close to the ground move relatively slowly and are deposited early, whereas the suspended particles travel faster and farther before dropping to the ground. Wind deposits

show a progressive decrease in the diameter of the particles with increasing distance from the sources. Generally there is also a difference in topography between sand deposits which occur in heaps and mounds near the source and the deposits consisting chiefly of clay and silt which occurs as a general blanket over the ground farther from the source.

Sand Deposit : Deposits of sand tend to assume certain characteristic and recognizable shapes. The particles are large and are usually sorted. Winds heap sand deposits into mounds and ridges called **sand dunes**. They are common along sandy shores of lakes and the flood plains of the streams flowing through sandy areas. In fact, wherever loose sand is available in abundance on land, dunes are likely to be formed especially if there is persistent wind direction.

A dune begins to develop where there is a slight irregularity of surface or some obstacle, such as a boulder, causing a local check in the velocity of the wind with the resultant, deposition of some of the load it carries. Once the piling up of the sand has started, its growth is accelerated, by its own shape and size. In its early stage a dune is an oval sand pile with the wind flowing swiftly and freely over it. But sooner a lag in the wind velocity develops on the *leeward* side because of air swirls and funnel winds set up in the wind shadow or the protected zone. As the height of the sand increases the summit of the pile advances faster than the leeward foot, a crest is formed and a steep slope or **slip face** develops down which sand grains slide or roll. The lateral margins of the developing dune also may be dragged forward with the wind to produce wing-like extensions or horns in the direction. On the windward side of a typical dune the mid-profile normally shows a long gently slope about 10 to 15 degrees from the horizontal and on the leeward side, a steeper slope or slip face with an angle of 20 to 30 degrees.

Since, most of this moving sand, sliding down the slip face previously was taken from the front margin of the windward side, swept up the slope and dropped at the crest, the continual transfer produces a slow migration of the dune in the direction of the wind movement. The rate of migration of sand dunes is of course determined by several factors. Usually, it does not exceed a few mts per year but in few cases may be as much as 30 or more meters/year. As dunes migrate, they gradually lose part of their sand and thus shrink in size. During their growth and forward migration these sand dunes may cover valuable farmlands and forests. Dunes seldom attain heights greater than a few hundred meters although some dunes in the great Sahara desert of Africa are said to be more than 30 meters high.

If the wind has a constant or prevailing direction, the dunes assume the normal plan and profile. But variable winds tend to produce the characteristic profile with each change in wind direction and so the typical form is lost in the confused sand pile that results. In regions, such as deserts and semi deserts where the dunes are best developed on a grand scale, normally two types are recognised. They are transverse dune or barchan and longitudinal dune or Seif.

Barchans : A Barchan is a crescent shaped sand dune with a gentle slope on the windward side on the outer curve and having the wings or horns of the crescent drawn out with the wind on the leeward side. It is a streamlined dune produced by wind blowing from one direction only and any variation in wind direction tends to destroy its typical form.

These dunes are formed, where supplies of sand are limited and the surface is relatively flat, hard and lacking vegetation.

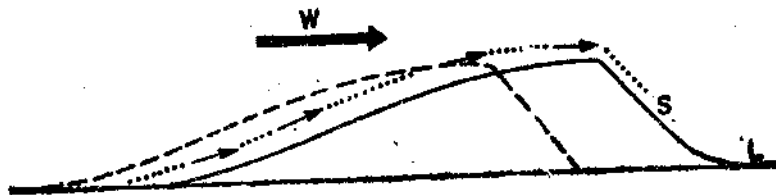


Fig. 8.2 Barchans

Seifs or Langitudinal dunes : This is a sand dune resembling in plan the outline of an Arabian sword. It is developed by several winds having set but in somewhat different directions. It may be considered as a sort of modification of the typical type of barchan dunes. Seifs are well-developed in Arabia, Libya and the Fresh Sahara and the deserts of Australia.

Transverse dunes : In regions where vegetation is sparse or absent and sand is very plentiful, the dunes form a series of long ridges that are separated by troughs and oriented at right angles to the prevailing wind. Because of this orientation, they are formed as transverse dunes. Typically many coastal dunes are of this type. In addition they are common in many arid regions.

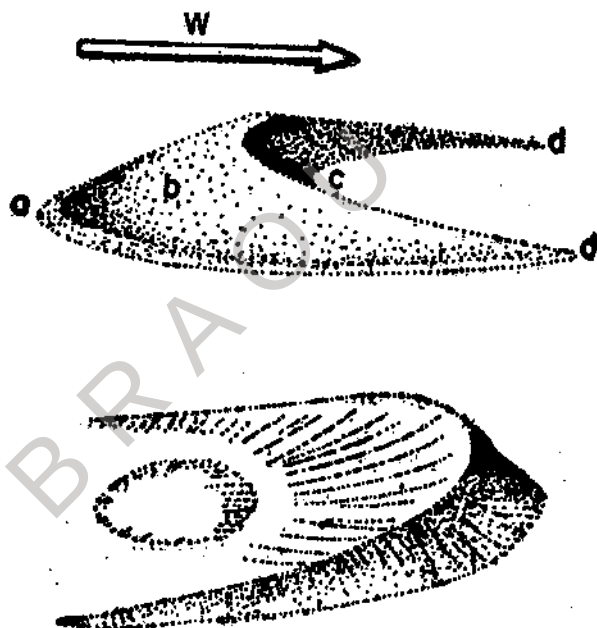


Fig. 8.3 Barchans

a	=	Wind ward margin	b	=	Crest
ab	=	Wind ward slope	bc	=	Slip face
d	=	horn or wing	w	=	Wind direction

Dune Structure : An ideal section of a dune shows the bedding of the gentle windward side cutting shortly across the steeper beds of the slip face. As the dune is sheared off again in the process of migration or by variable winds and the sand redeposited the complexity of the cross-bedded internal structure may be much increased. Beds of rounded grains of more or less uniform size usually quartz, and the truncation of layers with many change in the bedding inclination are the typical characteristics of sand dunes of all ages.

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.

8. What is a Dune ?

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Ripple Marks are common on sand dunes and on sand surfaces associates with them. They are formed by friction at the inter-face of wind and sand under the sorting action of surface creep, the coarsest grains collecting at the crests and the finest in the troughs.

Dust and Clay Deposits : Slackening of the wind allows is suspended load to settle slowly out of the air. Rain and snow are even more effective in rapidly clearing the air. The occurrence of mud-rains and dust-coloured snowfalls are well-known. Dust deposits in general are widespread and without special forms and hence escape much of our attention but their total bulk is undoubtedly large. Wind-blown deposits are generally called *Aeolian* deposits. Some of the wind-laid dust deposits are of such magnitude as to deserve a special mention. Dust that is of volcanic composition and origin is called volcanic ash. It is derived from volcanic explosions and eruptions and many of its particles are often glassy, and sharp. Surface dust originating chiefly from desiccated glacial outwash or from desert areas have given rise to deposits called loess.

Loess : It is non-stratified yellowish or buff-coloured silt, intermediate in texture between clay and sand. It is composed of small angular mineral fragments of quartz, feldspar, hornblende, calcite and others, all of them slightly weathered. In thickness, the loess may range from a few meters to 10 metres or more metres in the Central United States. In China loess deposits reach few hundred metres in thickness. When exposed in banks of gullies or excavations, the loess reveals a remarkable property of standing in vertical cliffs even though the material is not cemented together. This is probably due to the fact that the grains are sufficiently angular to interlock rather than roll or slide over each other as most sand grains tend to do.

On account of its texture and freshness of its minerals, loess makes fertile soils as in the mid western states of the U.S.A., like Iowa, Illinois or Missouri or the Rhine basin in Europe. There are many evidences to show that loess is a wind deposit. The very fine size of the particles is highly indicative of its aeolian origin. The loess material blankets the divides, hill slopes indiscriminately as if it had settled from the air. Most of the deposits are generally considered to be aeolian deposits closely related to the pleistocene glaciation of large parts of North America, Europe and Asia. Many exposures of loess show that, they are intimately associated with glacial till and outwash deposits. The loess deposits of China are known to reach an enormous thickness of 1000 ft. in shensi and adjoining provinces. This loess is believed to have accumulated from silt blown in from the deserts of central Asia by the prevailing westerly winds. It is so easily eroded by wind and rain wash that certain

roadways laid in it, through the wear of centuries of travel have become depressed into deep narrow canyon like profiles.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

9. What is loess ?

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8.4.2 Deserts-geological processes

In arid and dry regions wind is the dominant gradational agent. Often wind is seasonal and may blow for days on end from a single direction only. In such areas called desert regions the sky is generally clear, the atmosphere persistently dry and the diurnal variation in temperature. There is little or no soil and naturally the vegetation is sparse and sometimes totally lacking since the average annual rainfall is very meagre. When it rains, it is generally in the form of cloud bursts and the torrents dash down the slopes with great amount of erosion of the surfaces. Many of the deserts are closed drainage basins. The run-off from each gully is heavily loaded and spreads over the gentle surface of the central basin and drops its load of sediment in apron-like fans. The turbulent waters and their journey in the temporary **playa lakes** at the foot of the slopes where desiccation takes place. The dry revines called **wadies**, become channels through which the wind is tunneled and their walls are worn and polished by the wind-driven sand. Sand may be blown into dunes but the fine rock particles and dust from the dry playas are caught by the wind and blown beyond the confines of the basin leaving behind only larger fragments like coarse sand and pebbles called **Lag-stones**. Accumulating over a long period of time, the entire surface is covered with these rock fragments to form a *desert pavement*. Lag-stone may often show a shining black or brown iron and manganese crust known as **desert-varnish**.

The relative intensities of various geological processes in the desert regions vary very much from their intensities in moist regions. As a result, the land in a desert region lack the soil and sediments show distinctive characteristics.

In desert regions the weathering mainly mechanical and necessarily the regolith is thinner, less continuous and often coarse-grained. Since mechanical weathering is controlled by joints in the parent bed rock, rock fragments tend to break off along joints, leaving steep, rugged cliffs. Hills cut by erosion from flat lying layers of rock with cliff slopes are the **buttes** and **mesas** which are quite common in such dry regions.

In many valleys of the desert regions streams in flood effectively undercut the side slopes of the valleys causing them very often to cave in, as the flood subsides, the load is deposited rapidly creating a flat floor of alluvium. The result is a steep sided flat-bottomed **Box-canyon** very characteristic of many dry regions.

8.5 SUMMARY

Lakes, seas and wind are acting as agents of external geological processes. Lakes feed freshwater to the rivers. A lake may be defined as a natural inland depression or basin containing appreciable amount of water. The water in lakes may vary in chemical composition from, soft, fresh and hard. Lakes are widely distributed over the earth's surface. Lakes serve as settling basins in the drainage system. The sediments brought in by the inflowing streams are sorted and gradually deposited on the lake bottom. The erosion work of lakes is like seas and the erosional features includes cutterraces, cliffs, caves, stacks, arches etc. The depositional features of lakes are beaches, barriers, bars, deltas, wave built terraces etc.

A swamp is an area of wet, saggy and saturated ground usually filled with decaying vegetable matter. Lakes may have originated in many ways. The important types of lake basin are basins formed by glaciation, basins formed by streams, basins formed by the action of groundwater, basins formed by wave actions & shore currents, basins formed by wind action; basins formed by diastropism, basins formed by volcanic activity and basins of unusual origin. The destruction of lakes occurs with filling of sediments, organic remains, by cutting down outlets, by removal of ice dams, by evaporation and by diastropism. The important lake types are salt lakes, alkaline lakes and playa lakes. The most prominent indian lakes are kolleru lake, sumbhar lake, lonar lake, The nal lake etc.

Seas or oceans are the large continuous bodies of salt water covering large parts of the earth's surface. Oceans are occupying large basins between the continents where as seas occupies the narrow platforms that border the lands. The relief features of seas are the continental shelf, continental slope, deep sea floor, submarine canyons, sea mounts and guyots, trenches and deeps, mid oceanic ridges etc. The general features of sea are nature of sea water, temperature and density, life in the seas. The marine environment has several life zones namely littoral zone, nerotic zone, Bathyal zone, pelagic zone and abyssal zone. The depositional features of seas are the Barrier beaches, spits and bars, wave built terrace etc.

Wind is nothing but air in motion. Wind is an important geological agent of erosion, transportation and deposition. The materials moved by the wind can be divided into two sizes namely sand and dust. Wind erosion is mostly of two types namely deflation and corrosion. Because of wind erosion many features like undercut hills with caves, mushroom rocks, table rocks, pedestal rocks are getting formed. Einkanter and drierkanter are formed by the cutting of pebbles with wind. Wind erosion is effective in desert regions. Rock particles are carried by blowing wind. The source material for wind transportation is generated with weathering and corrosion. Where ever wind loses its ability to transport, the particles will get deposited. Sand is deposited in the form of sand dunes. Barchans and seifs are sand dunes. Barchans are crescent shaped sand dunes. Ripple marks, dust and clay deposits, loess are the other deposits of wind.

8.6 CHECK YOUR PROGRESS-MODEL ANSWERS

1. A lake may be defined as a natural inland depression or basin containing appreciable amount of water.

2. The causes of origin of lakes are glaciation, streams, action of groundwater, wave action and shore currents, wind action, mass movement, diastropism, volcanic activity, unusual origin etc.
3. Kolleru lake, Sambhar Lake, Lonar lake, The nal lake etc.
4. Large continuous bodies of salt water covering large parts of the earth surface are called seas.
5. Continental shelf, continental slope, submarine canyons, trenches etc.
6. Littoral zone, Neritic zone, Bathyal zone, Pelagic zone, Abyssal zone etc.
7. The processes involved in wind erosion are deflation and abrasion.
8. A dune is a mound or ridge of sand deposited by wind.
9. Loess is a silt, usually accompanied by some clay and some fine sand. It is non-stratified.

8.7 MODEL EXAMINATION QUESTIONS.

I Answer the following questions in 30 lines each.

1. Discuss the geological functions of lakes.
2. Describe the geological work of seas.
3. Describe the deposits formed by wind.

II Answer the following questions in 10 lines each.

1. Describe origin of lakes
2. What are lake deposits
3. Describe topography of seafloor
4. What are marine deposits
5. Explain processes of wind erosion
6. How are sand dunes formed ?

BLOCK - III

CRYSTALLOGRAPHY

BRAOU

UNIT - 9: FUNDAMENTALS OF CRYSTALLOGRAPHY

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9.0 OBJECTIVES

After completion of this unit, you should be able to

- define crystallography,

- explain parts of crystals,
- describe crystal symmetry, and
- define crystal forms and crystal intergrowths.

9.1 INTRODUCTION

The ancient Greek philosophers observed a solid (now known as a variety of glaciers) in the Alpine mountains of Europe. This substance was bounded by smooth planar surfaces. It was transparent. That is, objects on the other side of it could be seen clearly through it. Its luster was vitreous and splendid. That is it looked like glass and sunlight falling on its surface reflect with brilliancy, giving clear images. Those Greek philosophers thought that this solid was originally water, supercooled to ice naturally and lost the property of melting back to water, because of being kept under intense cooling for a very long time.

It was subsequently realised that ice cannot loose the property of melting back to water under any circumstances and the solid described was no way related to ice. The term crystal has slowly been extended to refer to any naturally formed solid bounded by smooth planar surfaces, called faces. The term crystalline has been used as the adjective form of the term crystal and the term, crystallinity is used as an abstract noun of the term crystalline. People have been fascinated at the beauty and mystery associated with crystals. They cut these crystals into gems. The study of gems has been called as gemmology and has been developed hundreds of years ago in several countries, including India. Gems have been used as jewels and have a very high value. Gems have been believed to have superhuman properties in curing certain diseases and in bringing good or bad to their owner

9.2 CRYSTALLOGRAPHY

The Scientific study of crystals is known as **crystallography**. The scientists engaged in the study of crystals are called crystallographers. Crystallography has developed as a science since 17th century by the efforts of Steno (1638-1686) of Holland. Guglielmini(1655-1710) of Italy, Delisle (1736-1790) Haüy(1743-1822) and Bravais(1811-1863) of France, Weiss(1780-1856), Naumann(1797-1873) and Neumann(1798-1895) of Germany, Wollaston(1766-1828), Miller(1801-1880) and Barker (1881-1931) of England, Fedorov (1853-1919) and Wulff(1863-1925) of Russia and several others.

9.2.1 States of Matter

Anything that occupies space is called matter. Matter is otherwise called substance. Matter occurs in gaseous, liquid and solid states. Gases have no definite size or shape. The size and shape of a gas of a given weight is determined by the size and shape of the container in which it is found

Liquids have definite size, but do not have any definite shape. The size of a liquid of a given weight is constant at a given temperature and pressure. Its size is not dependent upon the container in which it is kept. Its shape however depends upon the container.

Solids have definite size and shape. The size of a solid of a given weight is constant at a given temperature and pressure. Its size and shape are not dependent upon the container in which it is kept. It is rigid. Only when sufficient pressure is applied on the solid, its shape can be altered and it can be broken into pieces.

9.2.2 Crystalline Substances

A solid substance is said to be crystalline, if it is bounded by naturally-formed faces. Such solids are said to be macrocrystalline, as their crystalline nature could be established from their faces and other megascopic features seen with the naked eye. The study of the surface features of such crystals is called morphological crystallography or geometrical crystallography. This branch is somewhat related to solid geometry. The application of various branches of mathematics to study the geometrical relationship of the planar surface of crystals comes under the purview of mathematical crystallography.

When crystals do not show faces, their crystalline nature could only be established by examining thin sections or grain mounts of crystals under a special type of microscope, called polarising microscope. Such solids are said to be microcrystalline. The branch of science that studies the optical properties of crystals is called optical crystallography. Optical studies on certain viscous liquids revealed that they exhibit properties peculiar to crystals in certain directions. Such liquids are called liquid crystals. Ammonium oleate is an example of a liquid crystal.

Some crystals are so small that even microscopic methods fail to establish their crystalline nature. In such cases, the crystalline nature could be established by the use of x-ray diffraction methods. Such solids are said to be cryptocrystalline. The science that studies internal arrangement of atoms in crystals using X-ray diffraction methods is called X-ray crystallography or structural crystallography. Electron microscope can also be used to establish the crystalline nature of such solids.

If the crystalline nature of a solid cannot be established by any known methods, the solid substance is then called amorphous substance. Very few minerals like opal and man-made substances like glass are amorphous substances. As almost all solids are now established to be crystalline, solid state is now used as a synonym for crystalline state. Amorphous substances like glass are considered to be super cooled liquids.

9.2.3 Amorphous Substances

The atoms in amorphous substances are arranged in a random manner. These substances usually possess isotropic properties that is properties do not change with direction. The interatomic distance in amorphous is more or less same in all directions. Light travels with same velocity in all the directions.

9.2.4 Crystal

A crystal is a homogenous anisotropic solid and is characterised by definite chemical composition and orderly arrangement of atoms. A substance is said to be a solid, if it is rigid and has a definite size and shape. It is said to be homogeneous, if the properties of any minute portion of the solid are same as that of the whole solid. A solid is said to be anisotropic if any or all of its properties show changes in their values with change in direction within the solid.

Because a crystal has definite chemical composition, it should be possible to express its composition by means of a definite chemical formula. For example, the composition of quartz crystal can be expressed by the chemical formula, SiO_2 . The chemical composition of some crystals can be expressed as a solid solution of two or more members. Such crystals are said to show **isomorphism**. In such cases, the chemical composition of the crystal cannot be expressed by a definite chemical formula. The chemical composition of the end members can, however, be expressed by chemical formula, while the chemical composition of the crystal can be expressed by giving the relative proportions of the end members. For example, plagioclase crystal is a solid solution of albite and anorthite. The chemical composition of albite is $\text{NaSi}_3\text{AlO}_8$ and of anorthite is $\text{CaSi}_2\text{Al}_2\text{O}_7$. A particular plagioclase crystal may have 75 percent albite and 25 percent anorthite. Such a plagioclase is called oligoclase.

Crystals having same chemical composition may possess different properties because of difference in the arrangement of atoms within them. Such crystals are said to show **polymorphism**, for example, crystals of diamond and graphite contain only carbon atoms, but differ in their atomic arrangement. It is known that diamond is the hardest mineral, while graphite is one of the softest minerals. As such, it becomes necessary to consider both chemical composition and internal arrangement of atoms to define a crystal. Thus, crystals having same chemical composition and same internal arrangement of atoms are said to belong to the same species. The branch of science that studies the chemical composition of crystals and the geometry of arrangement of atoms within the crystals is called **crystal chemistry** or **chemical crystallography**.

The orderly arrangement of atoms in a crystal imparts symmetry to the crystal. Under favourable conditions, the internal symmetry is exhibited outwardly by symmetrical development of naturally-formed faces.

According to the definition of a crystal as given here, it is not necessary for a crystal to show naturally formed face. But, according to the traditional definition of a crystal, it should show naturally formed faces.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. Define the term "Crystal".

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The process by which crystals are formed is called **crystallisation**. Crystals are formed from solution by precipitation or evaporation, from melts by freezing, from gases by condensation and from other crystals by transformation. Calcium carbonate precipitates as calcite or aragonite from sea water. Complete evaporation of sea water cut off from the sea leads to the formation of gypsum and finally halite. Cooling of water to a temperature of

0°C results in the freezing of water into ice. Cooling of rock melt results in the fractional crystallisation of crystals. Condensation of sulphur vapour leads to the crystallisation of sulphur. On heating quartz crystals to a temperature of more than 870°C at atmospheric pressure, quartz undergoes transformation to tridymite. On change of temperature and pressure, as assemblage of crystals transforms to a new assemblage of crystals by a process called metamorphism. Crystals formed by natural processes are called natural crystals. Crystals grown in the laboratory or industry are called synthetic crystals. No difference can be noted between the natural and synthetic crystals of the same species. They are together called as real crystals.

9.3 PARTS OF CRYSTAL

The important parts of crystals are faces, edges, corners, centre, axes, zones, planes, interfacial angles etc.

9.3.1 Faces of a Crystal

A Crystal is polyhedron and extends in three dimensions. It is bounded on its surface, edges and corners. A face is a plane and extends in two dimensions. It is a polygon bounded by three or more sides. A crystal has four or more faces. All the faces in a crystal with same size and shape belong to one crystal form. A crystal may have one or more forms. The number of forms and the number of faces in each form can be known by simple counting.

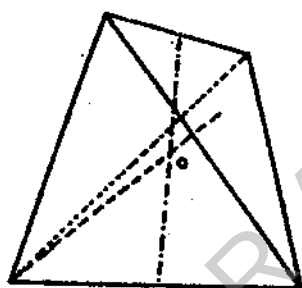


Fig. 9.1 A crystal showing a 4-faced form, where each face is an equilateral triangle. A vertical nonpolar axis and an inclined polar axis are also shown. O is centre.

Fig. 9.1 depicts a crystal having only one form has 4 faces and each face has the shape of an equilateral triangle Fig. 9.2 depicts a crystal having a total of 12 faces belong to 2 forms. The first form has 4 faces and each face has the shape of rectangle. The second form has 8 faces has the shape of an isosceles triangle.

9.3.2 Edges of a Crystal

The sides of a face are also called edges. An edge is a straight line and extends in one dimension. It is formed by the intersection of two faces belonging to one or more forms. The total number of edges (E) in a crystal is obtained by the equation.

$$E = \frac{1}{2} (f_1 s_1 + f_2 s_2 + \dots + f_n s_n) \dots \dots \dots 1$$

where f_1 = number of faces in the first form

f_2 = number of faces in the second form

f_n = number of faces in the nth form

s_1 = number of sides of a face of f_1 form

s_2 = number of sides of a face of f_2 form

s_n = number of sides of a face of f_n form

In figure 9.1, there is only one form with $f_1=4$ and $s_1=3$. Then $E=\frac{1}{2}(4 \times 3)=6$ In figure 9.2, there are forms with

$f_1=4, s_1=4, f_2=8$ and $s_2=3$. Then $E=\frac{1}{2}(4 \times 4 + 8 \times 3)=20$

The edges of a crystal belong to one or more sets. Edges having same length belong to one set and are formed by the intersection of faces belonging to one or two forms. All the 6 edges in the crystal shown in figure 9.1 are formed by faces belonging to one form and constitute one set. In figure 9.2, the 4 edges of same length formed by the intersection of faces of the 4-faced form belong to one set. The 8 edges of same length formed by the intersection of the 8-faced form belong to the second set. The remaining 8 edges formed by the intersection of a face of one form and a face of the other form belong to a third set.

9.3.3 Corners of a Crystal

A corner is a point without any dimension. It is also called solid angle. It is formed by the intersection of three or more faces or three or more edges. The number of corners (C) of a crystal is obtained by the equation.

$$C=E+2-F$$

Where F=total number of faces belonging to all forms

In the crystal shown in figure 9.3

$$C=20+2-12=10$$

The corners of a crystal belong to one or more sets. Corners formed by same number and same types of faces and edges belong to one set. Each of the 4 corners in the crystal shown in figure 9.1 is formed by the intersection of 3 faces belonging to the same form. As such, all these corners belong to one set. Each of the 2 corners of the crystal shown in figure 9.2 is formed by the intersection of 4 faces of one form and constitute another set.

9.3.4 Centre of a Crystal

Centre of a crystal is a point centrally situated within the crystal. This point coincides with the centre of gravity of the crystal. Point 'O' in the crystal shown in figure 9.2 represents the centre of these crystals.

9.3.5 Axes of a Crystal

Axis is a straight line passing through the centre of a crystal. The plural form of axis is axes. It cuts the surface of the crystal at two points called terminals. These terminals are diametrically opposite to each other. Terminals at centre of faces, midpoints of edges and corners alone are important.

An axis may be polar or non-polar. The two terminals of a polar axis are not interchangeable, as they belong to two different sets. The two terminals of a non-polar axis are interchangeable, as they belong to the same set.

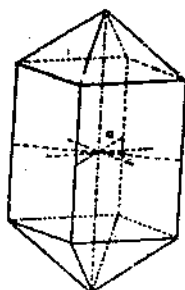


fig: 9.2 A crystal showing a 4-faced form and an 8-faced form.
A vertical axis and 4 horizontal axes are also shown.

All axes in a crystal whose terminals belong to a single set constitute one set of nonpolar axes. All axes in a crystal whose terminals belong to two sets constitute one set of polar axes. In figure 9.1 the axes passing through the midpoints of edges constitute a set of 3 nonpolar axes. The axes passing through corners and centres of faces constitute another set of polar axes. Only one polar axis and one nonpolar axis are shown in the figure.

If a set contains only one axis, it is called singular axis. No other axis in the crystal is identical to that singular axis. In figure 9.2, the axis passing through the two corners, constituting one set, is singular non-polar axis. In addition to this singular axis, there are two more sets of axes, with each set consisting of two axes. Some crystals have no single axes at all, while others have one, three or many single axes. All axes in some crystals are singular axes.

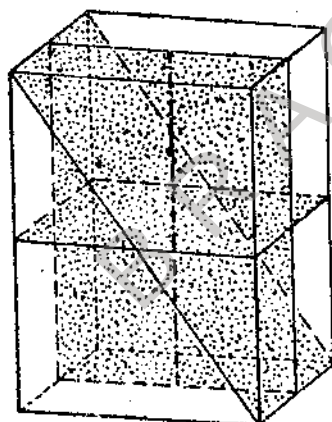


Fig: 9.3 A crystal showing three 2-faced forms. A vertical axis a horizontal plane and an inclined plane are also shown.

A crystal is oriented by holding it in such a way that an important axis is made vertical axis. Its top terminal is held by the index finger and the bottom terminal by the thumb of the left hand. The axes normal to the vertical axis are called horizontal axes. The axes inclined to a vertical axis are called diagonal axes. There can be only one vertical axis, but many horizontal and inclined axes. In figure 9.1, one vertical axis and one diagonal axis are shown. In figure 9.2, one vertical axis and four horizontal axes are shown.

9.3.6 Planes of a Crystal

A plane of crystal passes through the centre of a crystal. It cuts the surface of the crystal along a polygonal outline. It is convenient to treat a plane to lie either normal to or parallel to an axis. As only one axis can lie normal to a plane, the number of planes in a set can be known from the number of axes that lie normal to them.

When a crystal is oriented about an important vertical axis, the plane normal to it is called horizontal plane. The planes passing through the terminals of vertical axis are called diagonal planes. There can be only one horizontal plane and several vertical and inclined planes.

The crystal shown in figure 9.3 shows a vertical axis, a horizontal plane, a vertical plane and an inclined plane.

9.3.7 Zones of a Crystal

All the faces in a crystal whose mutual intersections are all parallel to one another belong to one zone. The axis passing through the centre of the crystal and lying parallel to these intersections are all parallel to one another belong to one zone. The axis passing through the centre of the crystal and lying parallel to these intersections is called its zone axis. A zone usually contains faces belonging to several forms. All the faces of a form need not belong to the same zone. Any two faces of a crystal must belong to one zone. A face can belong to more than one zone.

According to the law of zone, the faces of any crystal fall in a small number of zones with each zone containing three or more faces. For example, faces of crystals shown in figure 9.2 and 9.3 fall in three zones.

9.3.8 Interfacial Angles of a Crystal

The angle any two face normals make at the centre of a crystal is the interfacial angle of the two faces. This angle is the supplementary angle of the angle between the two faces. Figure 9.4 represents a cross section of ABCD of a crystal passing through its centre, O. OF and OG are normals drawn for faces CD and CB. Angle $\angle FOG$ is interfacial angle of faces CD and CB. It is supplement to the angle $\angle DCB$ and equals to the angle $\angle FCE$.

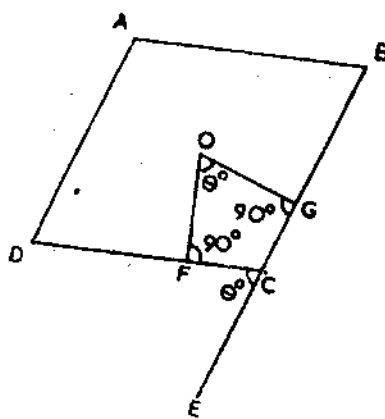


Fig 9.4. A cross-section of a crystal showing interfacial angle.

9.4 CRYSTAL SYMMETRY

An ideal crystal shows an external symmetry due to orderly arrangement of faces of every form of the crystal. A form is repeated on the surface of the crystal a number of times due to symmetry of operations. The symmetry operations are

1. Rotation about an axis passing through the centre of the crystal through an angle.
2. Reflection about a plane passing through the centre of the crystal.
3. Inversion about the centre of the crystal.
4. A combination of rotation about an axis and inversion about centre, and
5. A combination of rotation about an axis and reflection about a plane normal to the axis.

In order to understand symmetry operations, three mutually perpendicular axes $+a$, $+b$ and $+c$, meeting at one point are visualised as in figure 9.5. On rotation about one of the axis through an angle 180° no change of sign of axis takes place about that axis, but the other two axes show changes of sign. On reflection about a plane parallel to two axes, no sign change takes place about those axes, but the third axis shows change of sign. On inversion about the centre, sign change takes place for all the three axes. From figure 9.5, it is seen that the effect of inversion is obtained by the combined effect of rotation about an axis through an angle 180° and reflection about the plane normal to the axis. This observation indicates that symmetry operation are interrelated.

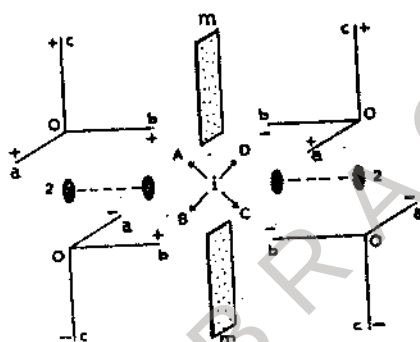


Fig: 9.5 Symmetry operations of rotation (2), reflection (m) inversion (i) and their combinations.

The various symmetry elements that produce symmetry in crystals are now discussed.

9.4.1 Axes of Symmetry

When a crystal is held about a vertical axis, it shows a particular orientation. When the crystal is rotated about the vertical axis through an angle it may show again an identical orientation. The crystal is then said to have attained a congruent position. The axis is called an axis of rotary symmetry or an axis of symmetry. The number of congruent positions attained by crystal in one complete rotation of 360° is called its symmetry symbol. Axis of symmetry is symbolised as X , which may be 1, 2, 3, 4, or 6. This number is repeated on the surface of the crystal a number of times due to symmetry of operations. The symmetry operations are obtained by dividing 360° by X . The axes of symmetry are shown in table 9.1.

Table 9.1 : Axes of Symmetry

Angle of rotation	Symmetry symbol	Name of axis of symmetry	Description of Symmetry
360°	1	Monad (i.e. axis of 1-fold symmetry)	Monogonal
180°	2	Diad (i.e. axis of 2-fold symmetry)	Diagonal
120°	3	Triad (i.e. axis of 3-fold symmetry)	Trigonal
90°	4	Tetrad (i.e. axis of 4-fold symmetry)	Tetragonal
60°	6	Hexad (i.e. axis of 6-fold symmetry)	Hexagonal

Unlike solid geometry, crystals do not show an axis of 5-fold symmetry or an axis of symmetry of order more than 6. Any crystal should attain a congruent position in one complete rotation of 360°. A crystal has infinite number of such monad axes. When a crystal is devoid of all symmetry elements, all its axes are normal axes.

When one axis in a set shows a particular type of symmetry, the other axes in the same set should also show the same type of symmetry. By knowing the number of axes in a set and by finding out the symmetry about one axis in the set, it is taken for granted that all the axes in the set shown the same type of symmetry.

9.4.2 Planes of Symmetry

A crystal can be cut about a plane passing through the centre of the crystal into two halves. If one half is the mirror image of the other, the plane is said to show reflection symmetry or plane of symmetry. The plane of symmetry cuts the surface of the crystal along a polygonal outline. This outline passes through edges and corners and cuts faces and edges in a symmetry manner. This outline divides a face into two halves, one the mirror image of the other. The mirror of any edge that meets this outline is seen on the other side of the outline. Some faces and edges may lie parallel to this outline. In order to establish plane of symmetry about a plane, the polygonal outline of the plane is studied to establish that every edge that it is contact with the outline has mirror image.

A plane of symmetry is symbolised as "m". If one plane in a set symmetry plane all the planes in that set should also be symmetry planes. It is convenient to deal a plane of symmetry to lie normal to an axis of symmetry. A symmetry plane normal to the vertical axis is called horizontal symmetry plane. A symmetry plane parallel to the vertical axis is called vertical symmetry plane. A symmetry plane inclined to the vertical axis is called inclined symmetry plane. There can be only one horizontal plane.

9.4.3 Centre of Symmetry

A crystal is said to show inversion symmetry or centre of symmetry, if its faces, edges and corners are arranged symmetrically about its centre. In such a crystal, every face

has a parallel edge of same length belonging to the same set. Corners of the same set occur as diametrically opposite points. Every axis has congruent terminals. No axis is polar. Fig 9.2 depicts a crystal having centre of symmetry. A presence or absence of centre of symmetry is determined by the presence or absence of other symmetry elements in the crystal. Modern crystallographers do not treat centre of symmetry as an independent symmetry element. Centre of symmetry is symbolised as "I".

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.

2. What is symmetry of a crystal ?

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9.5 CRYSTAL FORMS

All the faces of same size and same shape in a crystal belong to a single crystal form. A form is characterised by a fixed number of equivalent faces. Any face of a form can be brought to the position of any other face of the same form by symmetry operation, reflection and inversion. Equivalent faces include congruent and enantiomorphic faces. Any two faces of a form are called congruent, if one face can be brought into the position of another by rotation. Any two faces of a form are called enantiomorphic, if one face can be brought into the position of another by reflection or inversion.

The number of faces in a form is determined by the symmetry elements of the crystal in which it is found and by the orientation of the faces of a form with reference to symmetry axes and symmetry planes. For example, a crystal having only a tetrad axis will have one-faced forms and four-faced forms, the face of the one-faced form is normal to the tetrad axis and is at the top terminal and/or bottom terminal of the tetrad axis. The faces of the four-faced form lie either parallel to or inclined to the tetrad axis (Figure 9.6)

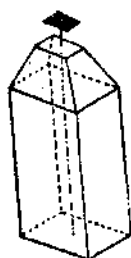


Fig. 9.6 A crystal showing tetrad symmetry with pedion, tetragonal prism and pyramid

If a symmetry plane is introduced normal to the tetrad axis, there will be no change in the faces of the form lying parallel to the tetrad axis. But, the number of faces in the other forms gets doubled. There are in total 48 forms. Of these forms, 33 forms occur in non-isometric systems only, while 15 forms occur in the isometric system only. Forms may be

open or closed. A closed form encloses space without the presence of any other form. An open form cannot enclose space without presence of one or more additional forms.

The main types of forms were discussed thoroughly in practical manual.

Open Forms and Closed Forms: Crystal forms are either open or closed. An open form cannot occur alone in a crystal, as it cannot enclose space without the help of one or more other forms, a closed form can occur alone in a crystal as it can enclose space without the help of other forms. An open form has 1,2,3,4,6,8 or 12 faces, where a closed form has 4,6,8,12,16,24 or 48 faces.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. What are open and closed forms ?

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9.6 CRYSTAL INTERGROWTHS

A crystal intergrowth consists of two or more single crystals of the same species intergrowth in a symmetrical manner. The following three types of intergrowths are recognised.

1. Parallel intergrowths
2. Fibrous intergrowths
3. Twinned intergrowths

9.6.1 Parallel Intergrowths

In a parallel intergrowth, faces of one single crystal lie parallel to similar faces of another single crystal. Crystals of alum, hematite, ice and copper show parallel intergrowths. Figure 9.7 shows an alum crystal where parallel intergrowth of two octahedral forms is noted.

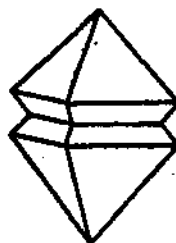


Fig. 9.7 Intergrowth of two octahedrons

9.6.2 Fibrous intergrowths

In a fibrous intergrowth, each fibre represents a single crystal and innumerable such fibres parallel to one another. All these fibres are parallel to a crystallographic axis. Asbestos represents a group of minerals showing this type of intergrowth.

9.6.3 Twinned Intergrowths

In a twinned intergrowth, some faces of one single crystal lie parallel to similar faces of another single crystal of the same species, while the other faces do not show such a parallelism.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

4. What are the 3 types of intergrowths ?

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9.7 SUMMARY

The study of crystals is known as crystallography. Anything that occupies space is matter or otherwise called as substance. Matter occurs in gaseous, liquid and solid state. If solid substance is bounded by naturally formed faces, it is called crystalline. If the crystalline nature of a solid can not be established by any known methods, the solid substance then is called amorphous.

A crystal is a homogenous, anisotropic solid and is characterised by definite chemical composition. The process by which crystals are formed is called crystallisation. Crystals formed by natural processes are called natural crystals and crystals formed in the laboratory are called synthetic crystals. They are together called as real crystals.

The important parts of the crystal are faces of the crystal, edges of the crystal, corners of the crystal, centre of the crystal, axes of the crystal, planes of the crystal, zones of the crystal and interfacial angles of the crystal.

Crystal must show the external symmetry due to orderly arrangement of faces, corners and edges. The three main elements of symmetry are planes of symmetry, axes of symmetry and centre of symmetry. A plane of symmetry divides a crystal into two similar halves (mirror image). A crystal has an axis of symmetry, when it comes to occupy the same position in space more than once in a complete rotation of 360° . A crystal has a centre of symmetry, when its like faces, edges, corners, are arranged in pairs and at regular positions on opposite sides of a central point.

All the faces of same size and shape in a crystal belong to a single crystal form. A form is characterised by a fixed number of equivalent faces. There are open forms and closed forms. An open form can not occur alone. A closed form can occur alone in a crystal.

If two or more single crystals of the same species intergrown in a symmetrical manner, then such character is called as intergrowths. There are three intergrowths in crystals namely parallel intergrowth, fibrous intergrowth and twinned intergrowths.

9.8 CHECK YOUR PROGRESS - MODEL ANSWERS

1. A crystal is a homogeneous an isotropic solid with definite chemical composition and orderly arrangement of atoms.
2. The symmetry of a crystal is the orderly arrangement of faces, edges, corners etc. of every form of the crystal.
3. Open form can not occur alone in a crystal where as closed forms can occur alone in a crystal.
4. There are three types of intergrowths in crystal namely parallel intergrowths, fibrous intergrowths and twinned intergrowths.

9.9 MODEL EXAMINATION QUESTIONS.

I. Answer the following questions in about 30 lines each

1. What are the different parts of a crystal ?
2. What is crystal symmetry ? Explain the symmetry elements.

II. Explain the following in about 10 lines each.

1. Crystal
2. Crystallography
3. Crystal Intergrowths
4. Crystalline substance.

UNIT - 10 : CLASSIFICATION OF CRYSTALS

Contents

- 10.0 Objectives
- 10.1 Introduction
- 10.2 Law of Rational Indices
- 10.3 Crystallographic Axes
- 10.4 Classification
 - 10.4.1 Isometric System
 - 10.4.2 Tetragonal System
 - 10.4.3 Orthorhombic System
 - 10.4.4 Monoclinic System
 - 10.4.5 Triclinic System
 - 10.4.6 Hexagonal System
- 10.5 Crystallographic Notation
 - 10.5.1 Weiss Notation
 - 10.5.2 Miller Notation
- 10.6 Summary
- 10.7 Check Your Progress - Model Answers
- 10.8 Model Examination Questions

10.0 OBJECTIVES

After completion of this unit, you should be able to

- explain law of rational indices,
- describe classification of crystals, and
- define crystallographic notation.

10.1 INTRODUCTION

In the earlier unit, the basic fundamentals of crystallography were discussed. In this unit based on the crystallographic axes of the crystals, how crystals were classified is explained. Based on this, crystals were classified as Isometric, Tetragonal, Orthorhombic, Monoclinic, Triclinic and Hexagonal systems. These systems of crystals are explained in detail in the units 11 and 12. Crystallographic notation, which is a simple method of expressing the position of a crystal face with reference to the crystallographic axes is also discussed.

10.2 LAW OF RATIONAL INDICES

In order to study crystal faces, it is necessary to evolve a method to indicate their position in space. The position of any plane in space is determined in coordinate geometry with the help of three reference axes, which are normal to each other. The intercepts made by any plane on these three axes define the plane. A similar method can be used to indicate the position of crystal faces. It is found that the intercepts obtained for faces of crystals would be represented by rational numbers in crystals devoid of singular axes, but would be represented by irrational numbers in all other crystals. Representation of intercepts by irrational numbers is rather cumbersome.

The best way to indicate the position of crystal faces is to choose three of four reference axes, which lie parallel to the principal edges of the crystal. In crystals devoid of singular axes, the three axes that constitute a single set are chosen as the reference axes. In crystals having only one singular axis, that axis is chosen as one of the reference axes. Two or three axes that constitute another set and lying normal to the singular axis are chosen as the other reference axes. In crystals having only three singular axes, all these three axes are chosen as the reference axes. In crystals having a singular axis lying normal to the first axis and parallel to the principal edges of the crystal are similar, three singular axes lying parallel to three principal edges, which are not in one plane, are chosen as the reference axes.

In crystals having three reference axes, a prominent face that intersects all the reference axes is chosen as the unit face. In crystals having four reference axes, a prominent face intersecting the singular axis and two of the horizontal axes and lying parallel to the other horizontal axis is chosen as the unit face. The ratio of the intercepts made by the unit face on the three reference axes are called parameters. The intercepts made by any other face on these three reference axes bear a specific relationship with the parameters of the unit face. That is, the ratio of each intercept of a face on an axis and the parameter of the unit face on the same axis is a rational number. This law is known as the law of rational indices and was stated first by Haüy of France in 1784.

Fig.10.1 shows the clinographic projection of the a,b and c reference axes, intersecting at point O. The front-to-back axis is the a-axis, the side-to-side axis is the b-axis and the top-to-bottom axis is the c-axis. The front terminal of the a-axis, the left-hand side terminal of the b-axis and the top terminal of the c-axis are positive. The back terminal of the a-axis, the left hand side terminal of the b-axis and the bottom of the c-axis are negative.

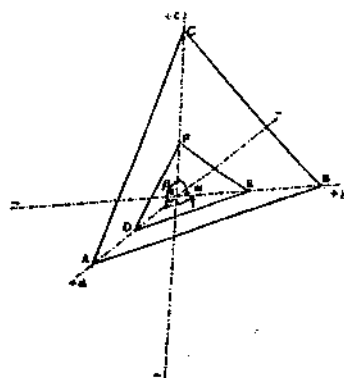


Fig.10.1 Axial Cross showing a,b and c reference axes passing through 'O' and making angles of α , β , γ . ABC is a unit face and DEF is another face.

The angle between the (+) b-axis and the (+) c-axis is alpha (α), angle between the (+) c-axis and the (+) a-axis is beta (β) and angle between the (+) a-axis and the (+) c-axis is gamma (γ).

The unit face, ABC intersects the (+) a, (+) b and (+) c axes at distance of OA, OB and OC. The parameters of the unit face are the ratio of the lengths OA, OB and OC. Another face DEF, intersects the a, b and c axes at distances of OD, OE and OF. It is noted that the ratios of OA/OD, OB/OE and OC/OF are rational numbers. This is true with any other face. But, if a face lie parallel to a reference axis, its intercepts is said to be infinity (∞).

10.3 CRYSTALLOGRAPHIC AXES

The reference axes in crystals, used to indicate the position of crystal faces, are known as crystallographic axes. They are called together as axial cross. The plane containing two or three crystallographic axes is called plane. The manner in which the crystallographic axes is chosen in different crystals is given in the previous section. Figure 10.1 depicts the axial cross of the crystallographic axes of a crystal having three axes. The ratio of the lengths of these crystallographic axes is called axial ratio. The angles between different pairs of crystallographic axes are known as axial angles. The axial ratio and axial angles of a crystal species are together called axial elements. The axial elements change from one crystal species to another except for those species of crystals devoid of singular axes.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. What is a crystallographic axis ?

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10.4 CLASSIFICATION

The different crystals available are classified based on the number of crystallographic axes and their axial elements. A crystal system is otherwise called system of crystallisation. There are a total seven systems. Out of which six systems are important for Under Graduate students.

10.4.1 Isometric or Cubic System

All the three crystallographic axes are equal in length and make an angles of 90° with each other. That is, $a = b = c$, $\alpha = \beta = \gamma = 90^\circ$. As the a, b and c are equal in length, they are otherwise called the a_1 , a_2 and a_3 (Figure 10.2). All these three axes are interchange-

This system has five crystal classes, as listed below:

1. Ditesseral inversion class
2. Tesseral inversion class
3. Ditesseral polar class
4. Tesseral holoaxial class
5. Tesseral polar class

Ditesseral Inversion Class or Normal Class or Galena Type

This class is otherwise called normal, holosymmetric or holohedral class. It is also called $4/m\bar{3}2/m$ class. As hexoctahedron is the general form in this class, this class is otherwise called hexoctahedron class. As galena is the principal mineral belonging to this class, this class is also called galena type.

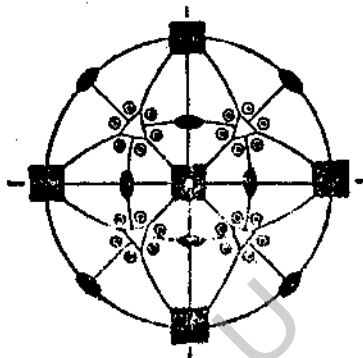


Fig. 11.1 Symmetry diagram of ditesseral inversion class.

The symmetry elements in this class are as follows:

Axes	III	tetrad axes, each normal to a symmetry plane,
	IV	inversion triad axes,
	VI	diad axes, each normal to a symmetry plane, and
Planes	3	axial
	6	diagonal
Centre	1	

In short, the symmetry elements are III $4/m$, IV 3, VI $2/m$, i. The Hermann-Mauguin symbol is $4/m\bar{3}2/m$. Figure 11.1 shows the symmetry diagram of this class.

The forms in this class are described below:

1. **Cube** has 6 faces (fig. 11.2). It is otherwise called hexahedron. When it occurs alone in a crystal, faces are square shaped. The miller symbol of the form is $\{100\}$. The three axes passing through the centres of the faces of the form are called cubic axes. These axes coincide with the crystallographic axes and show tetrad symmetry. The symmetry planes normal to these axes are called axial planes symmetry.

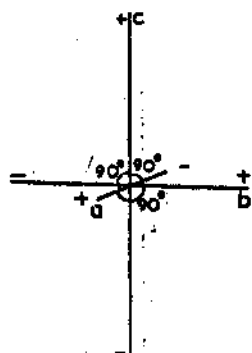


Fig. 10.4 Axial cross of orthorhombic system

10.4.4 Monoclinic System

All the three crystallographic axes have different lengths. The b axis lies normal to a and c axes. That is, $a \neq b \neq c$, $\alpha = \gamma = 90^\circ \neq \beta$. The position of the b axis is fixed and it coincides with the singular axis that lies normal to the a - c axial plane, containing innumerable singular axes. The a and c axes are made to lie parallel to two principal edges (Figure 10.5). For knowing fully about axial elements, it is sufficient if a/b and c/b ratios and angle β are known.

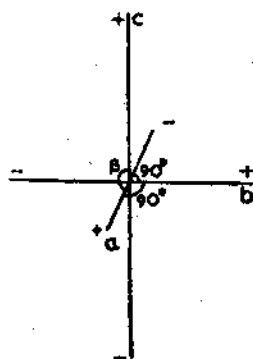


Fig. 10.5 Axial cross of Monoclinic system

10.4.5 Triclinic System

All the three crystallographic axes have different lengths and axial angles have different values, other than 90° . That is, $a \neq b \neq c$, $\alpha \neq \beta \neq \gamma \neq 90^\circ$ (Figure 10.6). As all the axes in the crystal are singular axes, three axes are lying parallel to three principal edges, which are not in one plane, are chosen as the a , b and c axes. For knowing fully about axial elements, it is necessary to know a/b and c/b ratios and values of α , β and γ angles.

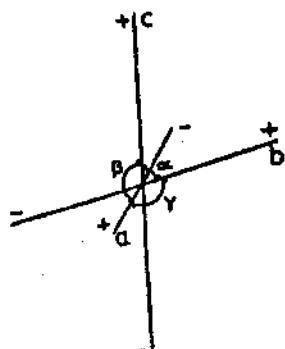


Fig. 10.6 Axial cross of triclinic system

10.4.6 Crystals having Four Crystallographic Axes

Hexagonal System : Three out of the four crystallographic axes are in the horizontal plane and are equal in length. They are called a_1 , a_2 and a_3 axes and make angles of 60° or 120° with one another (Figure 10.7). The fourth axis is singular and vertical and lies normal to the plane containing the a_1 , a_2 and a_3 axes. It is called the c-axis (Figure 10.8).

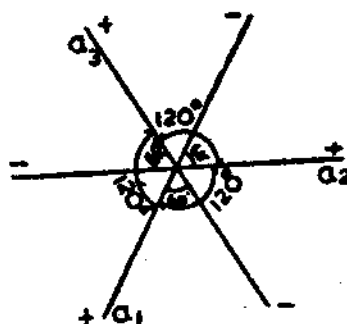


Fig. 10.7 Horizontal axes in hexagonal system

As there are two sets of horizontal axes with three axes in each set, the a_1 , a_2 and a_3 axes coincide with either of the two sets. The a_2 -axis is the side-to-side axis. The a_1 and a_3 axes are the front-to-back axes, with the a_1 -axis slanted towards left of the observer and the a_3 -axis slanted towards right of the observer. The positive terminals of the a_1 -axis is towards front, the a_2 -axis is towards right-hand side, the a_3 -axis is towards back and the c-axis is towards top.

The crystals belonging to the trigonal system are dealt more conveniently by considering them as to contain four crystallographic axes, like in the Hexagonal system. In a rhombohedral form, there are 6 rhomb shaped faces, 12 edges and 8 corners. The 8 corners belong to two sets, with one set containing 2 corners and other set containing 6 corners. The 12 edges belonging to two sets, with each set containing 6 edges.

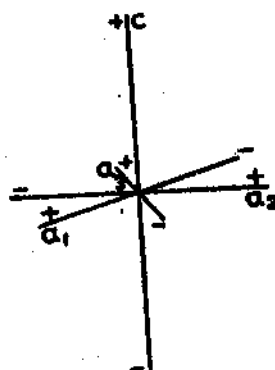


Fig. 10.8 Axial cross of hexagonal system

The axis passing through the two corners is a singular axis and is called the vertical axis or the c-axis. The mid-points of the edges arranged in a zigzag fashion constitute the 3 horizontal axes and are called a_1 , a_2 and a_3 axes (Figure 10.9). Some crystallographers do not consider trigonal system as an independent system and recognise only 6 crystal systems. They recognise hexagonal and trigonal divisions within the hexagonal system.

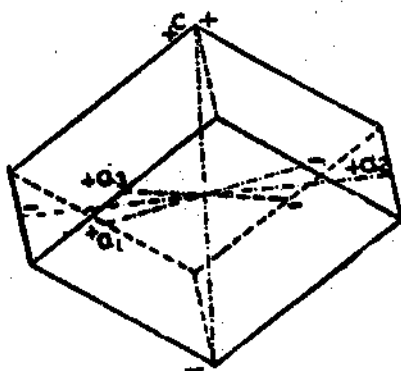


Fig. 10.9 Hexagonal axial cross in Rhombohedron

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. How many crystal systems are there ?

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10.5 CRYSTALLOGRAPHIC NOTATION

Crystallographic notation is a simple method of expressing the position of a crystal face with reference to the crystallographic axes. The parameter system of Weiss and the index system of Miller are the two systems available for crystallographic notation.

10.5.1 Weiss Notation

The parameters of a unit face on the reference axes (that is, crystallographic axes) are considered as $1a$, $1b$ and $1c$, where a , b and c are the relative lengths of the 3 crystallographic axes. The intercepts of any other face can be pa , qb and rc , where p , q and r are rational numbers. That means, the face cuts the a -axis at a distance of p units, the b -axis at a distance of q units and the c -axis at a distance of r units. In the parameter system of Weiss, the position of any face is indicated by pa , qb , rc . If any face intersects the negative terminal of a crystallographic axis, the sign of infinity is placed before the corresponding axial letter. Thus, if a face cuts the a -axis at a distance of one unit (that is the same distance at which the unit face cuts), cuts the negative side of the b -axis at a distance of 2 units and lies parallel to the c -axis, its Weiss symbol is $a, 2b, \infty$.

10.5.2 Miller Notation

The index system of Miller is obtained from the parameter system of Weiss by taking the reciprocals of the parameters. The reciprocals of parameters are called indices.

Thus, pa, qb, rc is written as $1/p \ 1/q \ 1/r$ or hkl , where $h = 1/p, k = 1/q, l = 1/r$. The indices are written in the axial order a, b and c and no mention of the axes is made. The reciprocal of infinity is zero. The indices are written as whole numbers and punctuation marks are not put in between the numbers. Thus, if $2a, 3b, 6c$, is the Weiss symbol, its Miller symbol is

$$1/2 \ 1/3 \ 1/6 \text{ or } 321$$

When Miller symbol is given within parenthesis, it indicates face symbol. When given in flower brackets, it indicates form symbol. When given in square brackets, it indicates zone symbol, thus, (321) indicates face symbol, $\{321\}$ indicates form symbol and $[321]$ indicates zone symbol.

If an index is negative, it is indicated by marking a bar on the number. Thus (100) is Miller symbol of a face which is normal to the negative terminal of the a -axis and lies parallel to the b and c axes.

For crystals belonging to the hexagonal and trigonal systems, Miller symbol consists of four indices, written in the axial order a_1, a_2, a_3 and c . The general Miller symbol of a face of a hexagonal crystal can be written as $(hkil)$, where $h+k+i = 0$. That is, the sum of the first three indices is zero. If any two of the first three indices are known, the third index can be known from the above relationship. Thus, if 2 and 1 are the first two indices, the third index should be 3.

Dots are put in between one index and other of a Miller symbol, if there is ambiguity without such dots. For Miller symbols, such as $(3.2.1.0)$ or $(h.h.2h.l)$, it is necessary to put dots in between one index and the other of a Miller symbol to avoid any ambiguity. Miller symbol is represented by whole number of small magnitude, such as 0, 1, 2 and 3.

Crystal System and Singular Axes : The system to which a crystal belongs is best known from its number of singular axes. Complete absence of singular axis indicates isometric system. Presence of only one singular axis indicates tetragonal, hexagonal or trigonal systems. Presence of only 3 singular axes indicates orthorhombic system. Presence of one singular axis with innumerable singular axes normal to it indicates monoclinic system. Presence of all axes as singular axes indicates triclinic system.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. What is crystallographic notation ?

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10.6 SUMMARY

Law of rational indices explains us about the crystals position in space. The best way to indicate the position of crystal faces is to choose three of four reference axes, which lie parallel to the principal edges of the crystal. In crystals having four reference axes, a prominent face intersecting the singular axis and two of the horizontal axis is chosen as the unit face. The ratio of the intercepts made by the unit face on these three reference axes are called parameters. The intercepts made by any other face on these three reference axes bear a specific relationship with the parameters of the unit face. That is the ratio of each intercepts of a face on an axis and the parameter of unit face on the same axis is a rational number. And this law is known as law of rational indices. The reference axis in crystal, used to indicate the position of crystal faces are known as crystallographic axis. The plane containing two or more crystallographic axis is called axial plane. Based on the crystallographic axes and axial elements, all the available crystals were classified into 7 systems; of these isometric, tetragonal, orthorhombic, monoclinic and triclinic are important for U.G. student.

In isometric system, all the three crystallographic axes are equal in length and make an angle of 90° with each other. In tetragonal system, two out of the three crystallographic axes are equal in length and the third axis differs in length. However they make an angle of 90° with each other. In orthorhombic system all the three crystallographic axes differ in length but make an angle 90° with each other. In monoclinic system all the three crystallographic axes differ in length and α and γ are equal to 90° but β is not equal to 90° . In triclinic system the three crystallographic axes differ in lengths and the three angles α , β and γ are also not equal to 90° . In hexagonal system, crystals are having four crystallographic axes. Three are equal in size and horizontal, where as the fourth axis is a vertical and differ in length from other three.

Crystallographic notation is a simple method of expressing the position of a crystal face with reference to the crystallographic axes. There are two systems for this namely Weiss and Miller notation.

10.7 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The crystallographic axis is the reference axis in crystals used to indicate the position of crystal faces.
2. There are seven crystal systems, namely Isometric, tetragonal, orthorhombic, monoclinic, triclinic, hexagonal and trigonal. First 6 are important.
3. Crystallographic notation is a simple method of expressing the position of a crystal face with reference to crystallographic axes.

10.8 MODEL EXAMINATION QUESTIONS

- I. Answer the following questions in about 30 lines each.
 - 1) Describe the Law of Rational Indices ?

- 2) Classify the crystals into systems.
- 3) Explain briefly about various crystal systems.

II. Answer the following questions in about 10 lines each.

- 1) What is crystallographic axis ?
- 2) Explain Weiss Notation
- 3) Explain Miller Notation

BRAOU

UNIT-11 : ISOMETRIC, TETRAGONAL AND ORTHORHOMBIC SYSTEMS

Contents

- 11.0 Objectives
 - 11.1 Introduction
 - 11.2 Isometric System
 - 11.3 Tetragonal System
 - 11.4 Orthorhombic System
 - 11.5 Summary
 - 11.6 Check Your Progress - Model Answers
 - 11.7 Model Examination Questions
-

11.0 OBJECTIVES

After completion of this unit, you should be able to

- describe the crystal forms of isometric system,
 - explain the tetragonal crystal system, and
 - describe the crystals of orthorhombic system.
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11.1 INTRODUCTION

In the earlier unit, how crystals are classified into 6 systems were discussed. In this unit an attempt is made to explain the normal class of Isometric, Tetragonal and Orthorhombic systems. In Isometric system all the 3 crystallographic axes are of equal length and make an angle of 90° with each other. In tetragonal system two out of the three crystallographic axes are equal and the third differs in length, but they make an angle of 90° with each other. In orthorhombic system all the three crystallographic axes differ in length but make an angle of 90° with each other.

11.2 ISOMETRIC SYSTEM

The system is otherwise called cubic system. Crystals in this system are devoid of singular axes. They have three crystallographic axes of equal lengths and make angles of 90° with each other. The axes are named as a_1 , a_2 and a_3 axes, the front-to-back axis is a_1 -axis. The side-to-side axis is a_2 -axis. The vertical axis is a_3 -axis. The front terminal of a_1 -axis, the right-hand side terminal are negative. The three axes are interchangeable. These axes show tetrad, inversion tetrad or diad symmetry. The planes normal to these axes are called axial planes. These crystals have invariably four triad axes, showing triad or inversion triad symmetry. This symmetry is called tesseral symmetry. All the crystal forms in this system are closed forms and are not found in non-isometric systems.

This system has five crystal classes, as listed below:

1. Ditesseral inversion class
2. Tesseral inversion class
3. Ditesseral polar class
4. Tesseral holoaxial class
5. Tesseral polar class

Ditesseral Inversion Class or Normal Class or Galena Type

This class is otherwise called normal, holosymmetric or holohedral class. It is also called $4/m \cdot \bar{3}2/m$ class. As hexoctahedron is the general form in this class, this class is otherwise called hexoctahedron class. As galena is the principal mineral belonging to this class, this class is also called galena type.

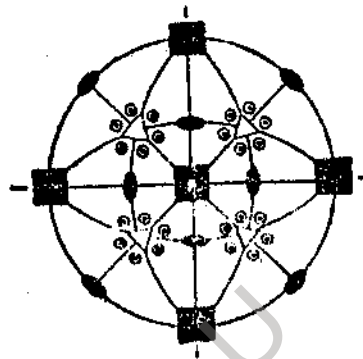


Fig. 11.1 Symmetry diagram of ditesseral inversion class.

The symmetry elements in this class are as follows:

Axes	III	tetrad axes, each normal to a symmetry plane,
	IV	inversion triad axes,
	VI	diad axes, each normal to a symmetry plane, and
Planes	3	axial
	6	diagonal
Centre	1	

In short, the symmetry elements are III $4/m$, IV 3 , VI $2/m$, i. The Hermann-Mauguin symbol is $4/m \cdot \bar{3}2/m$. Figure 11.1 shows the symmetry diagram of this class.

The forms in this class are described below:

1. **Cube** has 6 faces (fig. 11.2). It is otherwise called hexahedron. When it occurs alone in a crystal, faces are square shaped. The miller symbol of the form is $\{100\}$. The three axes passing through the centres of the faces of the form are called cubic axes. These axes coincide with the crystallographic axes and show tetrad symmetry. The symmetry planes normal to these axes are called axial planes symmetry.

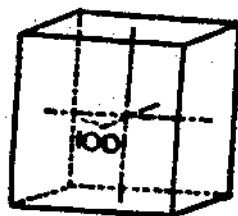


Fig. 11.2 Cube

2. **Octahedron** has 8 faces (Fig. 11.3), when it occurs alone in a crystal, faces have the shape of equilateral triangles. The miller symbol of the form is $\{111\}$. The four axes passing through the centres of the faces of the form are called octahedral axes. These axes show inversion triad symmetry.

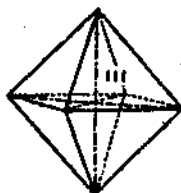


Fig. 11.3 Octahedron

3. **Dodecahedron** has 12 faces (Fig. 11.4). It is otherwise called rhombic dodecahedron. When it occurs alone in a crystal, faces are rhombshaped. The miller symbol of the form is $\{110\}$. The six axes passing through the centre of the faces of this form are called dodecahedral axes.



Fig. 11.4 Dodecahedron

4. **Tetrahexahedron** has 24 faces (Fig 11.5). When it occurs alone in a crystal, faces have the shape of isosceles triangles. The form looks as if four faces are arranged on each of the six cubic faces. The miller symbol of the form is $\{hko\}$ where $h > k$. $\{210\}$ is one such form. The faces of this form lie in the zone containing cubic and dodecahedral faces.

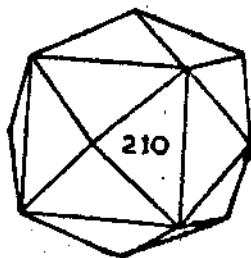


Fig. 11.5 Tetrahexahedron

5. **Trisoctahedron** has 24 faces (Fig. 11.6). It is also called trigonal trisoctahedron. When it occurs alone in a crystal, faces have the shape of isosceles triangles. The form looks

as if three faces are arranged on each of the eight octahedral faces. The Miller symbol of the form is $\{hhl\}$, where $h > 1$, $\{221\}$ is one such form. The faces of this form lie in the zone containing octahedron and dodecahedron.

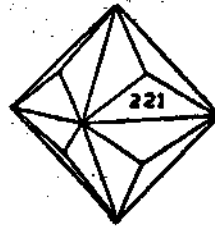


Fig. 11.6 Trisoctahedron

6. **Icositetrahedron** has 24 faces (Fig. 11.7). It is otherwise called tetragonal trisoctahedron or trapezohedron. When it occurs alone in a crystal, faces have the shape of quadrilaterals. The miller symbol of the form is $\{h11\}$, where $h > 1$. $\{211\}$ is one such form. The faces of this form lie in the zone containing cube and octahedron.

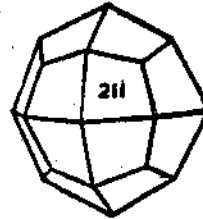


Fig. 11.7 Icositetrahedron

7. **Hexaoctahedron** has 48 faces (Fig. 11.8). When it occurs alone in a crystal, faces have the shape of scalene triangles. The miller symbol of the form is $\{hkl\}$, where $h > k > 1$. $\{321\}$ is one such form.

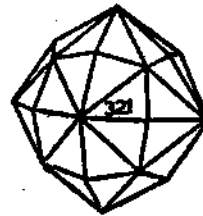


Fig. 11.8 Hexoctahedron

The minerals crystallising in this class are listed below:

1. Galena, PbS
2. Halite, $NaCl$
3. Periclase, MgO
4. Alabandite, MnS
5. Fluorite, CaF_2
6. Spinel, $MgAl_2O_4$
7. Magnetite, $Fe^{+2}Fe_2^{+3}O_4$
8. Chromite, $Fe^{+2}Cr_2O_4$
9. Analcite, $NaSi_2Al_6H_2O$

10. Sodalite, $3\text{NaSiAl}_3\text{O}_8\cdot\text{NaCl}$
11. Almandine, $\text{Fe}^{3+}_2\text{Al}_2\text{Si}_2\text{O}_{12}$ and other garnets
12. Diamond, C
13. Gold, Au
14. Copper, Cu

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. Name at least five minerals crystallising in Isometric system.

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11.3 TETRAGONAL SYSTEM

Crystals in this system are characterised by having only one singular axis, which shows tetrad or inversion tetrad symmetry. The singular axis coincides with vertical crystallographic axis or c-axis. The a_1 and a_2 axes are horizontal crystallographic axes, which are perpendicular to c-axis. The a_1 and a_2 axes lie in a horizontal plane and make angles of 90° to each other. The a_1 -axis is the front-to-back axis and a_2 -axis is the side-to-side axis. The front terminal of a_1 -axis, the right-hand side terminal of a_2 -axis and the top terminal of c-axis are positive terminals. The other terminals are negative. The two horizontal axes are interchangeable. These axes may diad symmetry and may lie normal to symmetry planes.

There are 7 crystal classes in the system, which are listed below:

1. Ditetragonal equatorial class
2. Tetragonal equatorial class
3. Ditetragonal polar class
4. Tetragonal holoaxial class
5. Tetragonal polar class
6. Ditetragonal inversion class
7. Tetragonal inversion class

Ditetragonal Equatorial Class Or Normal Class or Zircon Type

This class is otherwise called normal, holosymmetric or holohedral class of the tetragonal system. As ditetragonal bipyramid is the general form of this class, this class is otherwise called ditetragonal bipyramid class. As zircon is the principal mineral belonging to this class, this class is also called Zircon type.

Symmetry elements

Planes 3 axial and
2 diagonal --- 5

Axes I tetrad axis normal to symmetry plane,
II diad axes, each normal to a symmetry plane
II diad axes, each normal to a symmetry plane

5

Centre 1

In short, the symmetry elements are I $4/m$, II $2/m$, II $2/m$, i. The Hermann-Mauguin symbol is $4/m2/m2/m$. Figure 11.9 shows the symmetry diagram of this class.

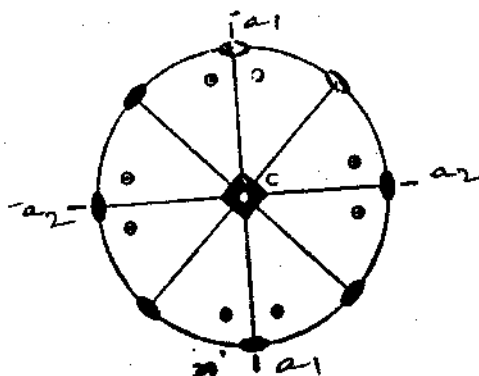


Fig. 11.9 Symmetry diagram of Ditetragonal equatorial class

The vertical crystallographic axis should coincide with the tetrad axis. The horizontal crystallographic axes may coincide with one or other of the two sets of diad axes.

The forms in this class are described below.

1. **Basal pinacoid** has 2 faces. It is an open form. Its miller symbol is (001) . The axis normal to the faces is the c-axis.
2. **Tetragonal prism I order** has 4 faces. It is an open form. The zone axis coincides with the c-axis. The miller symbol of the form is $[110]$. The faces cut the horizontal axes at unit distances.
3. **Tetragonal prism II order** has 4 faces. It is an open form. All the faces of the form lie in one zone. The zone axis coincides with c-axis.

The miller symbol of the form is (100) . Each of these faces lies parallel to one horizontal axis and normal to the other horizontal axis.

Depending upon the choices of the horizontal crystallographic axes, I order prism becomes II order prism and vice versa.

4. **Ditetragonal prism** has 8 faces. It is an open form. All the faces of the form lie in one zone. The zone axis coincides with the c-axis. The miller symbol of the form is (hko) , where $h > k$. (210) is the miller symbol of the one of these forms.

5. **Tetragonal bipyramid I** order has 8 faces. It is a closed form. The faces have the shape of isosceles triangles. The miller symbol is (hhl), where h and l have no specific relationship. (111) is the miller symbol of the one of these forms.
6. **Tetragonal bipyramid II** order has 8 faces. It is a closed form. The faces have the shape of isosceles triangles. The miller symbol is (hol), where h and l have no specific relationship. (101) is the miller symbol of one of these forms. One of the horizontal crystallographic axes lies parallel to the faces of the form.

Depending upon the choice of the horizontal crystallographic axes. I order bipyramid becomes I order bipyramid and vice versa.
7. **Ditetragonal bipyramid** has 16 faces. It is a closed form. The faces of the form have the shape of isosceles triangles. The miller symbol is (hkl), where $h > k$ and l can have any value. (211) is the miller symbol of one these forms.

The minerals crystallising in this class are listed below.

1. Rutile, TiO_2
2. Anatase, TiO_2
3. Cassiterite, SnO_2
4. Pyrolusite, MnO
5. Hausmannite, $\text{Mn}^{+4}\text{NO}_2^{+2}\text{O}_4$
6. Calomel, HgCl
7. Zircon, ZrSiO_4
8. Vesuvianite (or idocrase), $\text{Ca}_{10}\text{Al}_4(\text{Mg, Fe})_2\text{Si}_9\text{O}_{34}(\text{OH})_4$

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. Ditetragonal bipyramid is having number of faces.

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11.4 ORTHORHOMBIC SYSTEM

Crystals in this system are characterised by having three singular axes, which may show diad symmetry and have planes of symmetry normal to them. The front-to-back axis is called a-axis, the side-to-side axis is called b-axis and the vertical axis is called c-axis. In prismatic crystals, c-axis lies parallel to the prismatic axis. In tabular crystals, c-axis lies normal to pinacoid faces producing tabular habit. It is a convention to choose the shorter of

the other two axes as brachy axis or a-axis and the longer of the two axes as macro axis or b-axis. Although the lengths of these three axes different, they make angles of 90° .

In this system, 3 crystal classes are recognised. They :

1. Didigonal equatorial class
2. Digonal holoaxial class
3. Didigonal polar class

Didigonal Equatorial Class or Normal Class or Barytes Type

This class is otherwise called normal, holosymmetric or holohedral class of the orthorhombic system. It is also called $2/m2/m2/m$ class. As rhombic bipyramid is the general form of this class, this class is also called rhombic bipyramidal class. As barytes is the principal mineral belonging to this class, this class is otherwise called barytes type.

The symmetry elements of this class are as follows.

Planes -----	3 axial
Axes -----	I diad axis normal to a symmetry plane, }
	I diad axis normal to a symmetry plane, } ---- 3
	I diad axis normal to a symmetry plane, }
Centre -----	1

In short, the symmetry elements are $I 2/m, I 2/m, I 2/m, i$. The Hermann-Mauguin symbol is $2/m2/m2/m$. Figure 11.10 shows the symmetry diagram of this class.

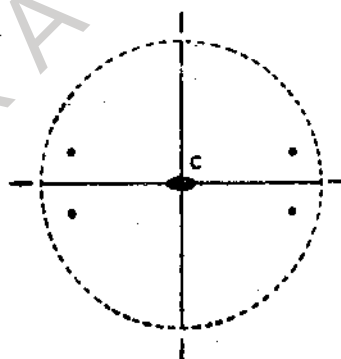


Fig. 11.10 Symmetry diagram of Diagonal Equatorial class

The forms of this class are described below.

1. **Basal pinacoid** or c-pinacoid has 2 parallel faces. It is an open form. The miller symbol of the of this form is $\{001\}$. The faces of this form lie normal to c-axis and parallel to a and b axes.
2. **Side pinacoid** or b-pinacoid has 2 parallel faces. It is open form. The miller symbol of the form is $\{010\}$. The faces of the form lie normal to b-axis and parallel to other axes. As the faces are parallel to the brachy axis, this form is also called **brachy pinacoid**.

3. **Front pinacoid** or a-pinacoid has 2 parallel faces. It is open form. The miller symbol of the form is (100). The faces of the form lie normal to a-axis and parallel to other axes. As the faces are parallel to the macro axis, this form is also called **macro pinacoid**.
4. **Rhombic prism I order** has 4 faces. It is an open form. All the faces lie in one zone. The zone axis coincides with a-axis. The faces cut the other two axes. The miller symbol of the form is {okl}, where k and l have no specific relationship. {011} is the miller symbol of one such form. As the zone axis of this form coincides with the brachy axis, this form is also called **brachy dome**.
5. **Rhombic prism II order** has 4 faces. It is an open form. All the faces lie in one zone. The zone axis coincides with b-axis. The faces cut the other two axes. The miller symbol of the form is {hol}, where h and l have no specific relationship. {101} is the miller symbol of one such form. As the zone axis of this form coincides with the macro axis, this form is also called **macro dome**.
6. **Rhombic prism II order** has 4 faces. It is an open form. All the faces lie in one zone. The zone axis coincides with c-axis. The faces cut the other two axes. The miller symbol of the form is {hko}, where h and k have no specific relationship. {110} is the miller symbol of one such form.
7. **Rhombic bipyramid** has 8 faces. It is closed form. The faces have the shape of scalene triangles. The faces cut all the three axes. The miller symbol of the form is {hkl}, where h, k and l can have any value. {111} is the miller symbol of one such form.

The Minerals crystallising in this class are listed below.

1. Sulphur, S
2. Marcasite, FeS_2
3. Chalcocite, Cu_2S
4. Stibnite, Sb_2S_3
5. Brookite, TiO_2
6. Barytes, BaSO_4
7. Anhydrite, CaSO_4
8. Olivine, $(\text{Mg, Fe})_2\text{SiO}_4$
9. Silliminite, $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$
10. Andalusite, $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$
11. Zoisite, $\text{Ca}_2\text{Al}_2\text{Si}_2\text{O}_{10}(\text{OH})_2$
12. Hypersthene, $(\text{Mg, Fe})\text{SiO}_3$
13. Staurolite, $\text{FeAl}_4\text{O}_9\text{Si}_2\text{O}_7(\text{OH})_2$
14. Topaz, $\text{Al}_2(\text{F, OH})_2\text{SiO}_4$
15. Cordierite, $(\text{Mg, Fe})_2\text{Al}_2\text{Si}_2\text{O}_{10}$
16. Aragonite, CaCO_3

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. List out at least five minerals crystallising in orthorhombic system.

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11.5 SUMMARY

The three crystal systems namely, Isometric, Tetragonal and Orthorhombic systems were explained. The isometric system is also called as cubic system. In this all the three crystallographic axes are equal in length and make angles 90° with each other. The three axes are interchangeable and show tetrad, inversion tetrad and diad symmetry. All the crystal forms are closed forms. The crystals of this system are divided into 5 classes namely Ditesseral inversion class, Tesseral inversion class, Ditesseral polar class, Tesseral holoaxial class and Tesseral polar class. Among these the first one the Ditesseral inversion class or normal class or galena type was discussed. In this normal class the symmetry elements are 13 axes, 9 planes and a centre. There are seven forms namely cube, octahedron, dodecahedron, trisoctahedron, trapezohedron, tetrahexahedron and hexa octahedron and are explained. Cube has 6 faces, octahedron has 8 faces, dodecahedron has 12 faces, the trisoctahedron, trapezohedron and tetrahexahedron are having 24 faces each. The hexaoctahedron is unique and is having 48 faces.

In tetragonal system one of the three crystallographic axis differs in length and makes an angle 90° with each other. The crystals of this system were divided into 7 classes namely Ditetragonal equatorial class, tetragonal equatorial class, Ditetragonal polar class, Tetragonal holoaxial class, Tetragonal polar class, Ditetragonal inversion class and tetragonal inversion class. The ditetragonal equatorial class or normal class or zircon type is also called as holosymmetric or holohedral class of tetragonal system. In this the symmetry elements are 5 planes, 5 axes and a centre. The forms are Basal pinacoid (2 faces), tetragonal prism Ist order (4 faces), tetragonal prism IInd order (4 faces), Ditetragonal prism (8 faces), tetragonal pyramid of Ist order (8 faces), tetragonal pyramid IInd order (8 faces), ditetragonal bipyramid (16 faces) are existing.

In Orthorhombic system all the three crystallographic axes differs in length but make an angle of 90° to each other. The crystals of this system are grouped under 3 classes; namely didigonal equatorial class, digonal holoaxial class, and didigonal polar class. The didigonal equatorial class or normal class or Baryte type may also be called as holosymmetric or holohedral class of orthorhombic system. The symmetry elements of this class are 3 planes, 3 axes and a centre. The names of the crystal forms in this system are basal pinacoid (2 faces), side pinacoid (2 faces), front pinacoid (2 faces), rhombic prism of Ist order (4 faces), rhombic pyramid of IInd order (4 faces) and rhombic bipyramid (8 faces).

11.6 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Galena, Halite, Periclase, Albandite, Flourite, Spinel, Magnetite, Chromite, Analcite, Sodalite, Almandine, Diamond, Gold, Copper etc are the minerals crystallising in isometric or cubic system.
2. Ditetragonal bipyramid of tetragonal system normal class is having 16 faces.
3. Sulphur, Marcasite, Chalcosite, Stibnite, Brookite, Barytes, Anhydrite, Olivine, Silliminite, Andalusite, Zoesite, Hyperthene, Staurolite, Topaz, Cordierite, Aragonite etc minerals are crystallising in orthorhombic system.

11.7 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines each.

- 1) Describe the normal class of Isometric or cubic system.
- 2) Explain the symmetry elements, crystal forms in normal class of tetragonal system.
- 3) Define the symmetry elements and crystal forms of barytes of orthorhombic system.

II. Explain the following in about 10 lines each.

- 1) Hexaoctahedran
- 2) Cube
- 3) Tropezohedran
- 4) Different crystal classes of tetragonal system
- 5) Ditetragonal bipyramid
- 6) Names of crystal forms in orthorhombic system

UNIT - 12 : MONOCLINIC, TRICLINIC AND HEXAGONAL SYSTEMS

Contents

- 12.0 Objectives
- 12.1 Introduction
- 12.2 Monoclinic System
- 12.3 Triclinic System
- 12.4 Hexagonal System
- 12.5 Summary
- 12.6 Check Your Progress - Model Answers
- 12.7 Model Examination Questions

12.0 OBJECTIVES

After completion of this unit, you shall be able to

- explain the crystals of monoclinic system,
- describe the triclinic crystal system, and
- explain the crystal forms of hexagonal system.

12.1 INTRODUCTION

In the earlier unit you were explained about isometric, tetragonal and orthorhombic crystal systems. In this unit the remaining crystal systems namely monoclinic, triclinic and hexagonal systems are described.

In monoclinic system all the three crystallographic axes differ in length. The angles between b and c axes, or between b and a axes is 90° . The angle between c and a axes is not equal to 90° . In triclinic system all the three crystallographic axes are of unequal lengths and make angles other than 90° . In hexagonal system there are all together 4 crystallographic axes, three are in equal size one differs from others.

12.2 MONOCLINIC SYSTEM

Crystals in this class have innumerable singular axes. All the axes confined to one single plane and the axis normal to that plane are singular axis. The singular axis perpendicular to that plane is called b crystallographic axis. The a and c crystallographic axes lie in the plane perpendicular to the b-axis. The angle between b and c axis or between b and a axes is 90° . The angle between c and a axes is not equal to 90° and is designated as beta (figure 12.1). The front-to-back axis is a-axis. The side-to-side axis is b-axis. The vertical axis is c-axis. As a-axis is inclined to the vertical axis, it is called clino axis. As

b-axis makes an angle of 90° to vertical axis, it is called ortho axis. The front terminal of a-axis are positive terminals. The other terminals are negative. Although the position of b-axis is fixed; the choice of a and c is arbitrary.

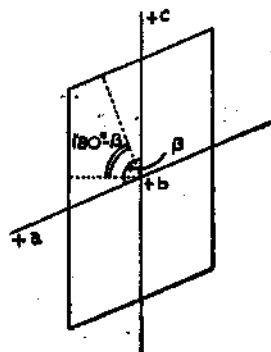


Fig. 12.1 Monoclinic System

The b-axis alone shows symmetry by being a diad axis and or by having a symmetry plane normal to it.

This system has three crystal classes, as listed below.

- 1) Digonal equatorial class
- 2) Digonal polar class
- 3) Monogonal equatorial class

Digonal Equatorial Class or Normal Class or Gypsum Type

The class is otherwise called normal, holosymmetrical or holohedral class of the monoclinic system. It is also called rhombic prismatic class, as gypsum is the principle mineral belonging to this class, this class is also called gypsum type.

The symmetry elements are

Planes	1
Axis	1 diad axis normal to asymmetry plane,
Centre	1

In short, the symmetry elements are $I, 2/m, i$. The Hermann-Mauguin symbol is $2/m$. Figure 12.2 shows the symmetry diagram of this class.

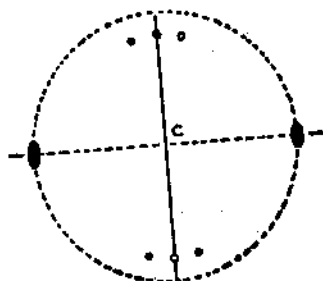


Fig. 12.2 Diagram showing Digonal Equatorial class

The forms in this class are described below.

1. **Basal Pinacoid** or **c-pinacoid** has 2 parallel faces. It is an open form. The faces are parallel to each other and to the plane containing a and b axes. The miller symbol of the form is $[001]$.
2. **Side pinacoid** or **b-pinacoid** has 2 parallel faces. It is an open form. The faces are parallel to each other and to the plane containing a and c axes and perpendicular to b-axis. The miller symbol of the form is $[010]$. As the faces are parallel to the clino-axis, the form is also called **clino-pinacoid**.
3. **Front pinacoid** or **a-pinacoid** has 2 parallel faces. It is an open form. The faces are parallel to each other and to the plane containing b and c axes. The miller symbol of the form is $[100]$. As the faces are parallel to the ortho-axis, the form is also called **ortho-pinacoid**.
4. **Rhombic prism III order** has 4 faces. All the faces lie in one zone. The zone axis coincides with c-axis. The miller symbol of the form is $\{hko\}$, where there is no specific relationship between h and k $\{110\}$ is one such form.
5. **Rhombic prism I order** has 4 faces. All the faces lie in one zone. The zone axis coincides with a-axis. The miller symbol of the form is $\{okl\}$, where there is no specific relationship between h and k $\{011\}$ is one such form. As the zone axis coincides with the clino-axis, the form is otherwise called **clino-dome**.
6. **Rhombic prism II order** has 2 parallel faces. It is an open form. The faces lie parallel to the b-axis and cut the other axis. The miller symbol of the form is $[hol]$, where there is no specific relationship between h and l. $[101]$ is one such form. This form contains $[101]$ and 101 faces. 101 is example of another form. This form contains $[101]$ and 101 . As the faces of the form is parallel to the ortho-axis it can be called ortho-dome. As it has one half of the faces of an orthodome, it is called **hemiorthodome**.
7. **Rhombic prism IV order** has 4 faces. It is an open form. All the faces of the form lie in one zone. The faces cut all the 3 crystallographic axes. The miller symbol of the form is $\{hkl\}$. $\{111\}$ is one such form. This form contains (111) , $(\bar{1}\bar{1}1)$, $(1\bar{1}\bar{1})$ and $(\bar{1}11)$ faces another such form contains $(\bar{1}11)$, $(1\bar{1}\bar{1})$, $(\bar{1}\bar{1}1)$ and (111) . The miller symbols are such that this form may be called bipyramid. As it has one half the faces of a rhombic bipyramid, it is called **hemibipyramid**.

The minerals belonging to this class are listed below.

1. Realgar, As_2S_2
2. Orpiment, As_2S_3
3. Cryolite, Na_3AlF_6
4. Borax, $Na B_4O_7 \cdot 10H_2O$
5. Malachite, $Cu_2(OH)_2CO_3$
6. Gypsum, $CaSO_4 \cdot 2H_2O$
7. Monazite, $(Ca, La, Y, Eh) PO_4$
8. Clinozoisite, $Ca_2Al_3SiO_{12}(OH)$

9. Sphene (or Titanite), CaTiOSiO_4
10. Diopside, $\text{CaMgSi}_2\text{O}_6$
11. Tremolite, $\text{Ca}_2\text{Mg}_5\text{Si}_3\text{O}_{22}(\text{OH})_2$
12. Muscovite, $\text{KAl}_2\text{Si}_3\text{AlO}_{10}(\text{OH})_2$
13. Orthoclase, KAlSi_3O_8

Check Your Progress

- Note :
- a) Space is given below for writing your answer.
 - b) Compare your answer with the one given at the end of this unit.

1. Name the crystal classes of monoclinic system.

12.3 TRICLINIC SYSTEM

Crystals in this system possess only singular axes. They have three crystallographic axes of unequal lengths and make angles other than 90° . The vertical crystallographic axis is c-axis. Between the other two axes, the side-to-side axis is chosen as bigger than the front-to-back axis. The side-to-side axis is called b-axis or macro-axis. The front-to-back axis is called a-axis or brachy axis.

The angle between a and b axes is called gamma (γ), that between b and c axes alpha (α) and that between c and a axes beta (β). The front terminal of a-axis, the right-hand side terminal of b-axis and the top terminal of c-axis, are called positive terminals. The other terminals are negative. Crystals in this system are devoid of axes of symmetry and planes of symmetry, the only symmetry that can be present in this system is centre of symmetry.

This system has two crystal classes, as listed below.

1. Monogonal inversion class
2. Monogonal polar class

Monogonal Inversion Class or Normal Class or Axinite Type

The class is otherwise called normal, holosymmetric or holohedral class. It is also called I class. As pinacoid is the general form in this class, this class is otherwise called pinacoidal class. As axinite is the principal mineral belonging to this class, this class is also called axinite type. The symmetry diagram of this class is shown in figure 12.3.

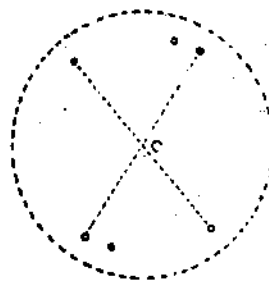


Fig. 12.3 Diagram showing Monogonal inversion class.

Centre of symmetry is the only symmetry present in this class.

The forms present in this class are listed below.

1. **Front pinacoid** or **a-pinacoid** has two parallel faces. The faces are parallel to the plane containing b and c axes. As faces are parallel to macro-axes, this form is also called **macro-pinacoid**. The miller symbol of the form is $\{100\}$.
2. **Side pinacoid** or **b-pinacoid** has two parallel faces. The faces are parallel to the plane containing a and c axes. As these faces are parallel to brachy-axis, this form is also called **brachy-pinacoid**. The miller symbol of the form is $\{010\}$.
3. **Basal pinacoid** or **c-pinacoid** has two parallel faces. The faces are parallel to the plane containing a and b axes. The miller symbol of the form is $\{001\}$.
4. **Pinacoid I order** has two parallel faces. The faces are parallel to a-axis and cut the other axes. As the faces are parallel to the brachy axis, the form can be called **brachydome**. As the form has one half of the faces of the brachydome, it is called **hemi-brachydome**. The miller symbol of the form is $\{0kl\}$. $\{011\}$ is one such form.
5. **Pinacoid II order** has two parallel faces. The faces are parallel to b-axis and cut the other axes. As the faces are parallel to the macro axis, the form can be called **macrodome**. As the form has one half of the faces of the macrodome, it is called **hemi-macrodome**. The miller symbol of the form is $\{h0l\}$.
6. **Pinacoid III order** has two parallel faces. The faces are parallel to a-axis and cut the other axes. As the faces are parallel to the vertical axis, the form can be called as a **rhombic prism** or **prism**. As the form has one half of the faces of a prism, it is called **hemi-prism**. The miller symbol of the form is $\{hk0\}$. $\{110\}$ is one such form.
7. **Pinacoid IV order** has two parallel faces. The faces cut all the three axes like bipyramid. As the form has one fourth the number of faces of a bipyramid, it is called a **quarter-bipyramid**.

The minirals belonging to this class are given below.

1. Plagioclase series like Albite, $\text{NaAlSi}_3\text{O}_8$
2. Kyanite, $\text{Al}_2\text{O}_3\cdot\text{SiO}_2$
3. Rhodonite, MnSiO_3
4. Amblygonite, LiAlFPO_4

5. Axinite, $(\text{Ca, Mn, Fe})_3\text{Al}_2\text{BO}_3\text{Si}_4\text{O}_{12}(\text{OH})$

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.
2. List out the minerals crystallised in Triclinic system.

12.4 HEXAGONAL SYSTEM

Crystals in this system are characterised by having only one singular axis, which shows hexad, inversion hexad, triad or inversion triad symmetry. This singular axis coincides with the vertical crystallographic axis or c-axis. The a_1 , a_2 and a_3 axes are horizontal crystallographic axes, which lie perpendicular to c-axis. The a_1 , a_2 and a_3 axes lie in a horizontal plane and make angles of 60° or 120° with each other. The a_1 -axis is the front-to-back axis slanting towards left, the a_2 -axis is the side-to-side axis. The front terminal of a_1 axis, the right-hand side terminal of a_2 axis, the back terminal of a_3 axis and the top terminal of c-axis are positive terminals. The other terminals are negative. The three horizontal axes are interchangeable. The axes may show diad symmetry and may lie normal to symmetry planes.

This system is divided into hexagonal and trigonal divisions and into 13 crystal classes, as shown below.

Hexagonal Division

1. Dihexagonal equatorial class
2. Hexagonal equatorial class
3. Dihexagonal polar class
4. Hexagonal polar class
5. Hexagonal holoaxial class
6. Dihexagonal inversion class
7. Hexagonal polar class
8. Hexagonal inversion class

Trigonal Division

9. Ditrigonal inversion class
10. Trigonal inversion class

11. Ditrigonal polar class
12. Trigonal holoaxial class
13. Trigonal polar class

Some crystallographers consider hexagonal division as hexagonal system and include classes under trigonal division under trigonal system.

Hexagonal Division

Dihexagonal Equatorial Class or Normal Class or Beryl Type

This class is otherwise called normal, holosymmetric or holohedral class. It is also called as $6/m2/m2/m$ class. As dihexagonal bipyramid is the general form of this class, this class is also called dihexagonal bipyramid class. As beryl is the principal mineral belonging to this class, this class is also called beryl type.

The symmetry elements in this class are as follow:

Planes	4 axial + 3 diagonal = 7
Axes	I hexad axis normal to a symmetry plane, }
	III diad axes, each normal to a symmetry plane, } = 7
	III diad axes, each normal to a symmetry plane. }
Centre	1

In short, the symmetry elements are I $6/m$, III $2/m$, III $2/m$, i. The Hermann-Mauguin symbol is $6/m2/m2/m$. Figure 12.3 shows the symmetry diagram of this class.

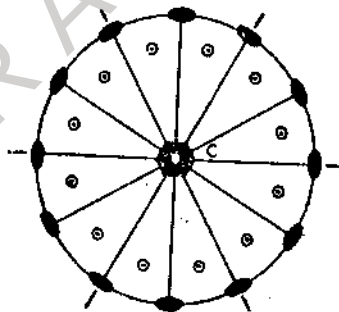


Fig. 12.3 Symmetry diagram of dihexagonal equatorial class

The vertical crystallographic axes should coincide with the hexad axis. The horizontal crystallographic axes may coincide with one or other of the two sets of diad axes.

The forms in this class are described below.

1. **Basal pinacoid** has 2 faces. It is an open form. Its miller symbol is $\{0001\}$. The axis normal to the faces is the c-axis.
2. **Hexagonal prism I order** has 6 faces. It is an open form. All the faces of the form lie in one zone. The zone axis coincides with the c-axis. The miller symbol of the form is $\{1010\}$. One of the horizontal diad axis lies parallel to the prismatic faces.

3. **Hexagonal prism II order** has 6 faces. It is an open form. All the faces of the form lie in one zone. The zone axis coincides with the c-axis. The miller symbol of the form is $\{1120\}$.

Depending upon the choice of the horizontal crystallographic axes, I order prism may become II order and vice versa.

4. **Dihexagonal prism** has 12 faces. It is an open form. All the faces of the form lie in one zone. The zone axis coincides with the c-axis. The miller symbol of the form is $\{hkio\}$, where $h+k=i$ and $h>k$. $\{2130\}$ is the miller symbol of these forms.

5. **Hexagonal bipyramid I order** has 12 faces. It is a closed form. The faces have the shape of isosceles triangles. The miller symbol of the form is $\{hohl\}$, where h and l have no specific relationship. $\{1011\}$ is the miller symbol of one of these forms. One of the horizontal crystallographic axes lies parallel to the faces of the form.

6. **Hexagonal bipyramid II order** has 12 faces. It is a closed form. The faces have the shape of isosceles triangles. The miller symbol of the form is $\{h.h.2h..l\}$, where h and l can have any value. $\{1121\}$ is the miller symbol of one of these forms.

Depending upon the choice of the horizontal crystallographic axes, I order bipyramid may become II order bipyramid and vice versa.

7. **Dihexagonal bipyramid** has 24 faces. It is a closed form. The faces have the shape of isosceles triangles. The miller symbol of the form is $\{hkil\}$, where $h>k$, $h+k+i=0$ and l can have any value. $\{2131\}$ is the miller symbol of these forms.

The best example of a mineral crystallising in this class is beryl, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$.

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.
3. Explain the symmetry of Beryl type.

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12.5 SUMMARY

The crystals belonging to monoclinic, triclinic and hexagonal systems are discussed.

The crystals of monoclinic system have innumerable singular axes. The singular axis perpendicular to that plane is called 'b' crystallographic axes. The a and c crystallographic axes lie in the plane perpendicular to the b-axis. This system has 3 crystal classes namely Digonal equatorial class, Digonal polar class and monogonal equatorial class. The digonal

equatorial class or normal class or gypsum type is also called as holosymmetrical or holohedral class of monoclinic system. The symmetry elements are one plane, one axis and a centre. The forms present in this crystal class are Basal Pinacoid (2 faces), side Pinacoid (2 faces) Front Pinacoid (2 faces) Rhombic prism of IIIrd order (4 faces), Rhombic Prism of Ist order (4 faces), Pinacoid of IInd order (2 faces) and Rhombic Prism of IIIrd order (4 faces).

The crystals of Triclinic system have three crystallographic axes of unequal lengths and make angles other than 90°. Crystals in this system are devoid of axes and planes of symmetry. The only symmetry present is a centre of symmetry. This system has two classes namely monogonal inversion class and monogonal polar class. The monogonal inversion class or normal class or Axinite type is also termed as holosymmetrical or holohedral class of triclinic system. The forms in this system are Basal Pinacoid (2 faces), side Pinacoid (2 faces) Front Pinacoid (2 faces) Pinacoid of Ist order (2 faces) Pinacoid of IInd order (2 faces), Pinacoid of IIIrd order (2 faces) and Pinacoid of IVth order (2 faces).

Crystals in hexagonal system are unique, and are having four crystallographic axes. Three axes are same in length and differ with fourth. The a_1 , a_2 and a_3 are horizontal axes, and the 'c' axis is vertical. The a_1 , a_2 and a_3 make angles 60° or 120° with each other. Hexagonal system is divided into 13 crystal classes. The dihexagonal equatorial class or normal class or Beryl class is also called as holosymmetrical or holohedral class of hexagonal system. The symmetry elements are 7 planes, 7 axes and a centre. The forms in this class are Basal pinacoid (2 faces), Hexagonal prism of Ist order (6 faces), Dihexagonal prism (12 faces), Hexagonal bipyramid Ist order (12 faces), Hexagonal bipyramid IInd order (12 faces) and Dihexagonal bipyramid (24 faces).

12.6 CHECK YOUR PROGRESS - MODEL ANSWERS

1. In monochromic system there are three classes namely Digonal Equatorial Class, Digonal Polar Class and Monogonal Equatorial Class.
2. Minerals belonging to Triclinic system are Plagioclase, Kyanite, Rhodonite, Amblygonite, Axinite etc.
3. The symmetry elements of beryl type are 7 planes, 7 axes and a centre.

12.7 MODEL EXAMINATION QUESTIONS

- I. Answer the following questions in about 30 lines each.
 - 1) Describe the symmetry and crystal forms of monoclinic system.
 - 2) Explain the crystal forms of Axinite type.
 - 3) Describe the Hexagonal system, normal class.
- II. Answer the following questions in about 10 lines each.
 - 1) Write down the names of minerals crystallising in monoclinic system.
 - 2) Explain the symmetry elements of Triclinic system.
 - 3) Write down various crystal classes in hexagonal system.

BLOCK - IV

MINERALOGY

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UNIT - 13 : MINERALOGY - SILICATE STRUCTURES

Contents

- 13.0 Objectives
- 13.1 Introduction
- 13.2 Classification
- 13.3 Silicate Structures
 - 13.3.1 Independent Tetrahedral Groups
 - 13.3.2 Double Tetrahedral Groups
 - 13.3.3 Ring Structure
 - 13.3.4 Chain Structure
 - 13.3.5 Sheet Structure
 - 13.3.6 Framework Structure
- 13.4 Summary
- 13.5 Check Your Progress - Model Answers
- 13.6 Model Examination Questions

13.0 OBJECTIVES

After completion of this unit, you should be able to:

- define a mineral,
- explain about mineralogy, and
- describe the silicate structures.

13.1 INTRODUCTION

In the earlier units, you have studied about crystallography and crystal systems. In this block, there are four units and these deal exclusively with mineralogy. You will know about different groups of minerals and properties. Mineralogy course of Geology has two aims. One is to prepare the student their to identify minerals. The second one is to provide him with an understanding of the physics-chemistry, and the genesis of minerals so that he can apply his mind to find out the bearing of this data on the interpretation of earth's history. This block acts as a guide for such a course. Here stress is given to general principles and to the importance of mineralogical data in interpreting geological phenomena, particularly in the areas of economic geology and petrology.

Mineralogy is the science of minerals or is the scientific study of minerals which make up the solid parts of the universe. They constitute the rocks of the earth's crust and hence the subject that deals with the minerals i.e., mineralogy is a branch of geology.

Minerals are chemical compounds. Therefore Mineralogy and chemistry have got close affinity. A **mineral** can be defined as a homogeneous solid body occurring naturally. It is inorganically formed and has a definite chemical composition with an orderly atomic arrangement. The origin of mineralogy dates back to prehistoric days. Early human beings used natural pigments prepared from red hematite and black manganese oxide in cave paintings. During stone age man used flint tools. The mining and extraction of metals from their respective ores probably started 4,000 years ago, though written records are not available for its verification.

The first written work on minerals is of Aristotle (384-322 B.C.) and then of Theophrastus (372-287 B.C.). During the first century A.D., Pliny described several minerals including some gem stones. Mineralogy emerges as a science through the publication of Georgius Agricola (1556) a German physician known as the 'Father of modern mineralogy'; in which details of mining and metallurgy were incorporated. Subsequent studies about regular bodies were made by Nicholas Steno (1669) which contributed to the growth of crystallography. Slow but steady progress was recorded during eighteenth century. Many new minerals were recognised and attempts were made to classify them.

The pioneering work on classification is of A.G. Werner (1770-1817). He succeeded in standardizing the terms by the external appearance of minerals. In 1828 William Nicol used the microscope for the identification of minerals and even today the polarizing microscope is powerful determinative tool in the study of minerals.

Subsequently during nineteenth century Fedorow, Carlow and Shownflies advanced theories for internal symmetry of crystals which form basis for X-ray crystallography. In 1912 Max Von Laue of the University of Munich demonstrated the X-ray diffraction by crystals and explained how the diffraction patterns can be interpreted to give actual position of the atoms in crystals. Thus it was proved for the first time that there is an orderly arrangement of atoms in the crystals. In 1914 W.H. Bragg and W.L. Bragg, British scientists, published their work on crystal structure determinations. In addition, improvements were made in technique and the electron microprobe provided a very powerful tool for the study of chemistry of mineral.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. What are mineral and mineralogy ?

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13.2 CLASSIFICATION

Minerals are classified into two groups. 1. rock forming 2. economic.

Rock forming minerals are very important constituents of rocks such as orthoclase, augite, biotite, hornblende etc. Economic minerals are important and are very useful to the society. Ex: Hematite, bauxite, galena etc., metals can be extracted from the economic minerals.

Minerals can also be classified as :

a) Primary and b) Secondary. **Primary** minerals are formed as products of magmatic consolidation. **Secondary** minerals are formed due to the operation of certain processes, on the early formed magmatic bodies. Quartz is of primary origin and malachite (an ore of copper) is of secondary origin.

From petrological angle minerals can be classified into a) Essential and b) Accessory. **Essential** minerals are those which are dominant and also decided the name of the rock. Accessory minerals are of least proportion and are significant in the naming of the rock. Potashfeldspar is an essential mineral and biotite is an accessory mineral in granite (a rock). However the most important and scientific classification of minerals is based on their chemical composition. According to J.D. Dana, a great American mineralogist, the following subdivisions were made :

1. Native elements like gold, copper, manganese etc.,
2. Sulphides like galena, Pyrite
3. Sulpho-salts
4. Haloid like rocksalt
5. Oxide like quartz
6. Oxygen salts like feldspars, pyroxenes, amphiboles, calcite etc.
7. Organic salts and
8. Hydrocarbon compounds

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. Minerals are classified into two groups they are (i)
(ii).....

Various minerals have been grouped into certain families based on their structural affinities and similarities in certain other aspects. They are as follows:

1. Silica group
2. Feldspar group
3. Feldspathoid group
4. Zeolite group
5. Pyroxene group
6. Amphibole group
7. Garnet group
8. Epidote group
9. Mica group

Minerals of the above groups are dealt in detail independently with reference to their physical (in hand specimen) and optical (under the polarising microscope) properties, chemical composition, mode of occurrence and their uses. In addition to the above groups a miscellaneous group of minerals is also dealt in this book.

Many of the properties of minerals mostly depend up on their chemical composition. One should have clear idea about their structure and chemistry to understand the minerals.

It is desirable to study the chemistry of the earth's crust even before the study of mineral chemistry and structure. Geophysical investigations reveal that there are three divisions in the earth which are crust, mantle and core (figure 13.1).

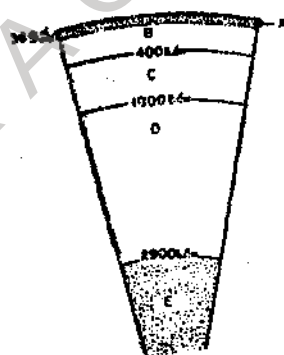


Fig 13.1 The Internal Structures of the Earth

Crust is the Uppermost shell of the earth with a thickness of 30-36km under the continents and 10-13 km under the oceans. However the crust is only an insignificant part of the earth and is a thin layer like the skin of an apple.

The mineralogy of the earth's crust depends on the chemical elements that it contains. Determination of the elements in the crust is difficult if not impossible due to its non uniform nature and the sample studies can be made either at the surface or at shallow depths. According to Clarke and Washington (1924) the upper 10 miles consist of igneous rock (or their metamorphic equivalents) to an extent of 95% followed by 4% of shale, 0.75% sandstone and 0.25% limestone. The composition of crust therefore would be more

or less the same as that of average composition of igneous rocks. The oceanic crust is made up of heavier and darker rocks known as basalts in contrast to the light coloured granitic rocks contained by continental crust.

Several rock samples from various geographical horizons of the crust have been analysed chemically and the average composition is given in Table 13.1. from which it is obvious that only eight elements O, Si, Al, Fe, Ca, Na, K and Mg - nearly make up 99% of the earth's crust (Table 13.2). Ti, H, P and Mn range in amounts between 0.1% and 1%. All the remaining put together make up less than 0.5% of the crust and many of these are of economic importance. The earth's crust which is made up of over 80 elements (excluding certain radioactive elements) contains nearly 2000 minerals out of which many are of very rare occurrence. The mineralogy of the crust is simple. The mineralogical variations in the crust have bearing on the geological environments. Three major types of environment may be recognised - magmatic, sedimentary and metamorphic. It is therefore convenient to consider the occurrence of minerals within the limitations of these three major rock groups.

Table-13.1 : The average amounts of the elements in crystal rocks in grams per ton or parts per million.

Element	•ppm	Element	•ppm
O	466,000	Dy	5
Si	277,200	Sn	3
Al	81,300	B	3
Fe	50,000	YB	3
Ca	36,300	Er	3
Na	28,300	Br	3
K	25,900	Ge	2
Mg	20,900	Be	2
Ti	4,400	As	2
H	1,400	H	2
P	1,180	Ta	2
Mn	1,000	W	1
F	700	Mo	1
S	520	Cs	1
Sr	450	Ho	1
Ba	400	Eu	1
C	320	Ti	1
Cl	200	Tb	0.9
Cr.	200	u	0.8
Zr.	160	Hg	0.5
Rb	120	I	0.3
V	110	Sb	0.2
Ni	80	Bi	0.2
Zn	65	Tm	0.2
N	46	Cd	0.2
Ce	46	Ag	0.1
Cu	45	In	0.1
Y	40	Se	0.09
Li	30	A	0.04

Nd	24	Pd	0.24
Nb	24	Pt	0.005
Co	23	Au	0.005
La	18	He	0.003
Pb	16	Te	0.002
Ga	15	Rh	0.001
Th	7	R	0.001
Sm	7	Ir	0.001
Gd	6	Os	0.001
Pr	6	Ru	0.001
Sc	5		
Hf	5		

Table - 13.2 : The major chemical elements in the earth's crust.

	Weight Percent	Atom percent (Weight percent divided atomic weight)	Ionic Radius (Å) ^o	Volume Percent
O	46.60	62.55	1.40	93.77
Si	27.72	21.22	0.42	0.86
Al	8.13	6.47	0.51	0.47
Fe	5.00	1.92	0.74	0.43
Mg	2.09	1.84	0.66	0.29
Ca	3.63	1.94	0.99	1.03
Na	2.83	2.64	0.97	1.32
K	20.59	1.42	1.33	1.83

13.3 SILICATE STRUCTURES

The crust consists of 95% of silicate minerals of which 60% is feldspar and 12% quartz. Quartz and the great group of silicates are the most important rock forming minerals. The silicates were formerly considered as salts of silicic acids but now their classification is made on the basis of the crystal structures of compounds. In the silicate structures the atoms of silicon are in four fold coordination with oxygen i.e., silicon atom is situated at the centre of a tetrahedron whose corners are occupied by atoms of oxygen (Figure 13.2).

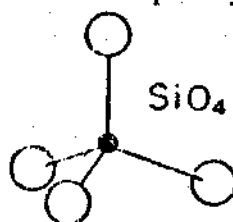


Fig. 13.2 Silicate Structure, Independent tetrahedra.

The distance between the centres of two adjacent oxygens is twice the radius of oxygen. Different silicate types arise from the different ways in which Silicon-Oxygen tetrahedra (SiO_4) occur, either as distinct units or a linkage.

They are as follows:

13.3.1 Independent Tetrahedral Groups

Independent tetrahedral groups: As shown in figure 13.2, the silican oxygen tetrahedra are present as separate units and thus the composition would be SiO_4 . Ex: Forsterite, Mg_2SiO_4 . This group of silicates is known as the **nesosilicates** (Greek 'neso' meaning 'island').

13.3.2 Double Tetrahedral Structures

In certain structures the Silicon Oxygen tetrahedra (SiO_4) may occur in pairs which are linked by the sharing of one oxygen between them by which the composition would be Si_2O_7 (Figure 13.3). Ex. Hemimorphite, $\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})_2\text{H}_2\text{O}$. These silicates are known **soro-silicates** (Greek Soro meaning group).

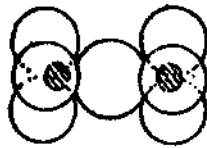


Fig. 13.3 Soro Silicate

13.3.3 Ring Structures

In such structures two of the oxygens with adjacent tetrahedra and linkage takes place each SiO_4 tetrahedra shares in such a way so as to form rings and the resulting composition is Si_3O_9 or Si_6O_{18} with six (Figure 13.4) tetrahedra. Ex: Benitoite ($\text{BaTiSi}_3\text{O}_9$) with three tetrahedra and Beryl ($\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$) with six tetrahedra. These silicates are also known as the **cyclosilicates** (Greek 'Cyclo' meaning 'ring').

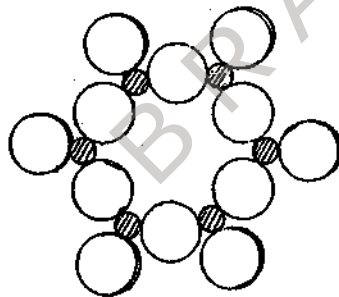


Fig. 13.4 Cyclo Silicates

13.3.4 Chain Structures

There are two chain structures a) single chain b) double chain. Single chain structures are found in pyroxenes and the double structures in amphiboles. Tetrahedra are linked together to produce chains of indefinite extent. In single chains Si:O is 1:3 (figure 13.5a) and in double chains Si:O is 4:11. In double chain structures two single chains are present side by side with the apexes of tetrahedra oriented in the same direction and are joined by sharing oxygen atoms, at regular intervals (Figure 13.5b). This group silicates is known as **inosilicates** (Greek 'ino' meaning chain).

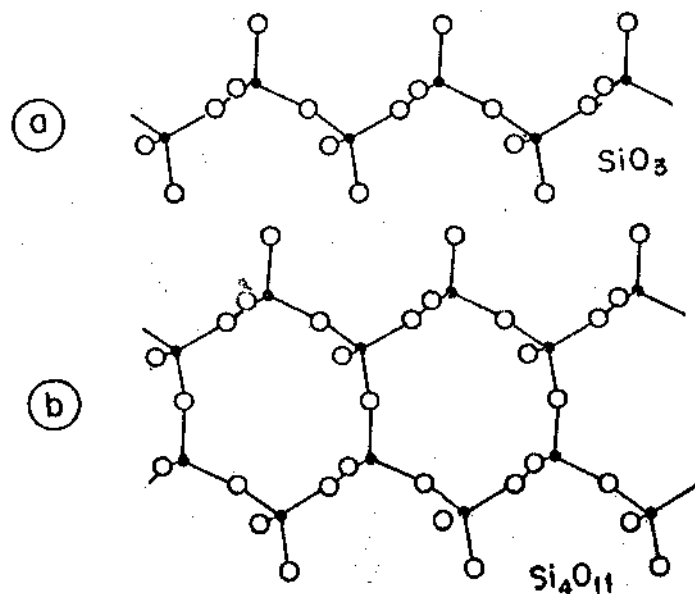


Fig. 13.5 Silicate Structures : Open Circle and dots represents the Oxygen and Silicon atoms respectively (a) single chain (b) double chain

13.3.5 Sheet Structures

In this type a sheet structure is formed when the SiO_4 - tetrahedra are linked by three of their corners with three oxygens of each tetrahedron sheet. In this Si:O ratio is 2:5 (Figure 13.6) and this is found in all flaky minerals such as micas and chlorite. The sheets form hexagonal network which is responsible for the pseudo-hexagonal form and cleavage being parallel to plane of sheet in micas. This division is known as **phyllosilicates** (Greek 'phylon' meaning 'leaf' or 'sheet').

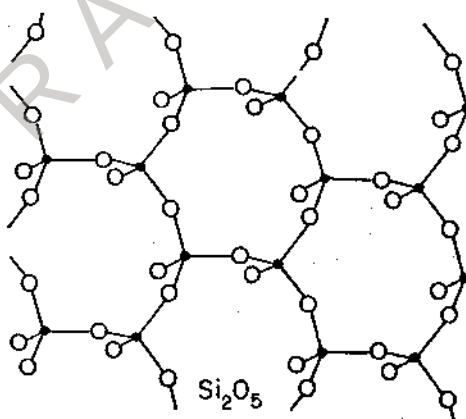


Fig. 13.6 Linkage a sheet structure. Silicon - Oxygen tetrahedron. Open Circle and dots stand for oxygen and silicon atom respectively.

13.3.6 Frame Work Structures or Three Dimensional Net Works

In such structures each silicon-oxygen tetrahedron shares all its corners with adjacent tetrahedra giving a three dimensional network (Figure 13.7). The silicon:oxygen ratio is 1:2, Feldspars and quartz have this structure. This division is known as **tectosilicates** (Greek, 'tecto' meaning 'frame').

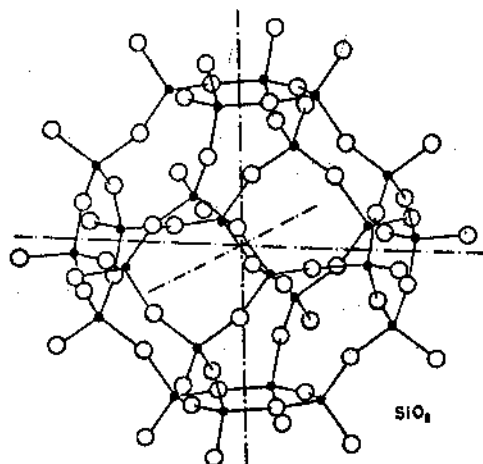


Fig. 13.7 Tecto Silicate Structure -Three dimensional network open circle represents Oxygen atoms, Silicon atoms are shown by dots.

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.
3. Classify silicate structures.

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13.4 SUMMARY

A mineral is a homogeneous solid body occurring naturally and should be inorganically formed and has a definite chemical composition with an orderly atomic arrangement. The study of minerals is the mineralogy. The study includes physical and optical properties, chemical composition, mode of occurrence and uses. Mineralogy is one of the branches of geology. The various groups of minerals are classified based on the structural affinities and similarities in certain other aspects. They are silica group, feldspar group, feldspathoid group, zeolite group, pyroxene group, amphibole group, garnet group, epidote group, mica group and other miscellaneous minerals.

From the chemical analysis of various rocks from different geographical locations, it was found that only eight elements namely O, Si, Al, Fe, Ca, Na, K and Mg nearly make up 99% of the earth crust. The earth crust is made up of over 80 elements and contains nearly 2,000 minerals. Out of these many are of rare occurrence.

Crust consists of 95% of silicate minerals of which 60% is feldspar and 12% quartz. Silicates are the most important rock forming minerals. These silicates were classified based on the crystal structure into six groups; namely independent tetrahedral groups, double tetrahedral groups, ring structures, chain structures, sheet structures and frame work structures.

Independent tetrahedral group is also called as neso silicates, consists of SiO_4 composition. Garnet and olivine families are examples.

Double tetrahedral group is called sorosilicates and consists of Si_2O_7 composition. Ex. Epidote.

Ring structure silicates are called cyclosilicates and consist of Si_3O_9 or Si_2O_6 composition. Ex: Pyroxenes, Amphiboles, etc.

Sheet structure silicates are called phyllosilicates and consist of Si_4O_{10} composition. Ex: Mica family.

Frame work structure silicates are called tecto silicates and consist of SiO_2 composition. Ex: Feldspars, Zeolites, etc.

13.5 CHECK YOUR PROGRESS - MODEL ANSWERS

1. A mineral is a homogeneous, inorganic material with definite chemical composition. The study of minerals is called mineralogy.
2. Minerals are classified in three ways as (1) Primary and Secondary (2) Rock Forming and Economic and (3) Essential and Accessories.
3. Silicate structures are classified into six groups namely independent tetrahedral groups, double tetrahedral groups, ring structures, chain structures, sheet structures and frame work structures.

13.6 MODEL EXAMINATION QUESTIONS

- I. Answer the following questions in about 30 lines each.
 - 1) What is a mineral ? Write about the development of Mineralogy.
 - 2) Write an essay about silicate structures.
- II. Explain the following questions in about 10 lines each.
 - 1) Classification of Minerals.
 - 2) Major chemical elements in earth crust.
 - 3) Chain silicate structure.
 - 4) Framework silicate structure.

UNIT - 14 : PHYSICAL PROPERTIES OF MINERALS

Contents

- 14.0 Objectives
- 14.1 Introduction
- 14.2 Common Properties
 - 14.2.1 Colour
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 - 14.2.6 Fracture
 - 14.2.7 Tenacity
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 - 14.2.9 Specific Gravity
- 14.3 Rare Properties
 - 14.3.1 Phosphorescence
 - 14.3.2 Fluorescence
 - 14.3.3 Fusibility
 - 14.3.4 Magnetism
 - 14.3.5 Electricity
- 14.4 Summary
- 14.5 Check Your Progress - Model Answers
- 14.6 Model Questions

14.0 OBJECTIVES

After completion of this unit, you should be able to:

- explain the physical properties of minerals,
- describe the rare properties, and
- define specific gravity of minerals.

14.1 INTRODUCTION

It is observed that each mineral has a set of outward signs or physical properties. Some of those are very characteristic and differentiate the mineral from each others. These properties can be determined either by inspection or simple tests. Because they are

determined in hand specimens they are very important in the identification of minerals. These properties are of great practical significance as they can be readily determined for the identification of minerals. These properties are quickly and easily observed than the chemical composition or crystal structure. Other physical properties of minerals which depend on their behaviour towards light and are known as optical properties are not considered here and are treated separately in course II. Yet other physical properties such as those determined by X-rays are beyond the scope here. The physical properties are grouped as common properties and rare properties for easy understanding.

14.2 COMMON PROPERTIES

These are the general properties, one can observe in all the minerals. These include colour, streak, lustre, hardness, cleavage and parting, fracture, tenacity, form and structure and specific gravity.

14.2.1 Colour

Minerals exhibit great variety of colours. The colour of a mineral is usually not a dependable or distinguishing character. It is produced either due to reflection or transmission of light and its selective absorption within the body of a material or on its surface as the case may be. The causes of colours in minerals are varied. In some it is a fundamental property, directly related to the chemical composition of the mineral. In some it is related to composition but depends on crystal structure. In others it is due to impurities. Minerals which exhibit constant and characteristic colour are known as **idiochromatic**. Those with variable colour are termed **allochromatic**. Metallic minerals generally exhibit consistency in colours than the non-metallic minerals.

Due to the interferences of light either at the surface or in the interior of mineral a series of colours are produced on turning about in light. On rotation colours change in rapid succession. Ex: Diamond.

Some minerals show rainbow colour either internally or on the surface. The internal phenomena, can be caused by light refracted and reflected from fractures, cleavage planes etc. Some specimens of labradorite show colours ranging from the blue to green or yellow when angle of incidence light changes. Surface phenomenon is due to interference of light when it is reflected from the surface. Generally metallic minerals such as hematite show this property.

In some minerals the surface is rather dull and its colour is different from the true colour. In bornite the true colour is shown by freshly broken surface, it is bronze coloured but it is quickly turned into purple-violet due to oxidation on exposure.

14.2.2 Streak

It is the colour of finely powdered mineral. Generally it can be observed by scratching the mineral upon the surface of a white unglazed porcelain streak plate. The hardness of this plate is about 7. So, this cannot be used with minerals of greater hardness. Streak is more reliable diagnostic property than the colour, as it is more constant. Streak of transparent and translucent minerals is white. The streak of dark coloured minerals with a non-metallic lustre is lighter than the colour, but minerals which exhibit metallic lustre have

streak darker than their colour. In spite of identical appearance magnetite and chromite can be differentiated by their streak, which is black for magnetite and light brown for chromite.

14.2.3 Lustre

It is nature and amount of shine that any mineral can offer by the reflected light on its surface. It varies with the composition and the reflecting capacity of the mineral surface. Fundamentally lustre is of two types, metallic and non-metallic. Metallic lustre is the brilliant appearance of a metal, such as golden, silvery. The native metals and most of the sulfides belong to this type. Ex: Pyrite. Minerals with non-metallic lustre are generally light coloured and their streak may either be colour-less or light coloured. Several varieties of non-metallic lustre are recognised.

Vitreous:- The lustre of glass. Nearly all the silicates exhibit this lustre.

Adamantine:- A brilliant lustre like that of a diamond. This lustre is characteristic of minerals with refractive indices between 1.9 and 2.6. Example: Zircon, diamond and rutile.

In the above range of refractive indices and by the combination of a yellow or brown colour a resinous lustre is produced. It is the lustre like that of resin.

Pearly:- It is the shine of pearls. This is generally observed on mineral surfaces that are parallel to cleavage planes. Ex: Cleavage surface of talc.

Silky:- The reflection like that of silk, Ex:- Asbestos, gypsum.

Greasy:- Look as though covered with a thin layer of oil. Ex: Nepheline and massive quartz.

Earthy:- Appearance of dry earth. Ex: Kaolin.

The other terms of lustre used in decreasing order of reflection are: Splendent, shining, glistening, glimmering and dull.

14.2.4 Hardness

It is generally defined as the resistance of a mineral to scratching or abrasion on its surface. Hardness is used as diagnostic property in the identification of minerals since the beginning of the systematic mineralogy. Diamond is the hardest of all minerals as it can scratch all others. Talc is the softest as any other mineral can scratch upon its surface. F. Mohs an Australian mineralogist proposed a scale of hardness in 1824.

1. Talc	2. Gypsum	3. Calcite
4. Fluorite	5. Apatite	6. Orthoclase
7. Quartz	8. Topaz	9. Corundum
10. Diamond		

Any mineral of this scale can only scratch those lower in the scale and will be scratched by the higher in the scale. Hardness may vary with crystallographic direction.

The tools that are used in finding out the hardness of a mineral are the simplest.

Mineral of hardness 1. have greasy feel, the thumb nail is slightly harder than gypsum of, 2; a soft pin can scratch calcite of 3; but cannot make an impression on fluorite of 4; Whereas soft iron will scratch fluorite. A good knife will scratch apatite. (5) but with difficulty it may scratch feldspar (6) Common glass lies between orthoclase (6) and quartz (7). Hence, quartz can scratch glass.

Minerals of equal hardness may scratch each other. Hardness must be determined only from fresh surface of the mineral but not from an altered or weathered surface as they lose their original hardness.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. Arrange the following minerals in Moh's Scale of hardness.

- 1) Diamond 2) Gypsum 3) Fluorite 4) Corundum
5) Topaz 6) Quartz 7) Orthoclase 8) Talc
9) Calcite 10) Apatite

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14.2.5 Cleavage and Parting

a) Cleavage

It is a very useful diagnostic property. Cleavage is defined as the tendency of a mineral to cleave or break or split along certain planes or directions of weakness. The splitting may take place with varying degrees of ease and perfection. Hence, cleavage planes are maximum cohesion in a mineral. Such directions along which such breakage takes place in some minerals may be one while others may have two or three. Cleavage is said to be perfect as in the micas. Cleavage has bearing on crystal structure and it is breaking of a mineral between atomic planes. It is a directional property. Cleavage is described with reference to its quality and crystallographic direction. The direction is expressed by the face of a crystal to which cleavage planes are parallel.

Ex: Cubic (001) Octahedron (III) prismatic (110) (Figure 14.1) only crystalline substances possess this property where as amorphous (see below) substances lack cleavage totally.

Other terms that are used for cleavages with less perfection are distinct, indistinct, interrupted etc.

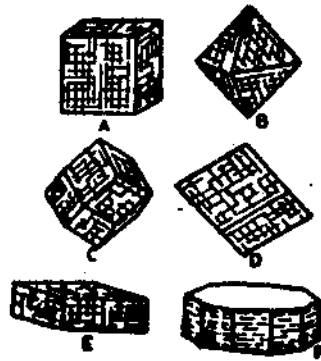


Fig. 14.1 Cleavage

b) Parting

This feature is very similar to cleavage. Parting results due to the weakness produced by pressure or twinning. It can be considered as false cleavage. Parting is not exhibited by all substances but only by those who are twinned or subjected to the proper pressure.

Parting results from stresses in operation either during or after formation. Ex. Basal parting of pyroxene (Figure 14.2).

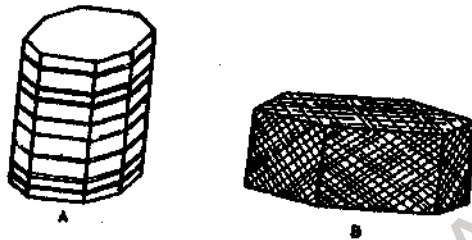


Fig. 14.2. Parting

14.2.6 Fracture

Fracture means breaking in a direction other than that of the cleavage plane. It differs from cleavage in being irregular, curved or uneven and that too not confined to any crystallographic direction.

Common types of fractures are:

- (i) **Even** : If the nature of the broken surface is flat and smooth it is called Even fracture. Ex. Chert.
- (ii) **Uneven** : If the surface is entirely irregular and rough, many of the minerals exhibit uneven fractures. Ex. Quartz.
- (iii) **Splintery** : If breakage takes place into minute threads or needle like form called splintery cleavage. Ex. tremolite.
- (iv) **Hackly** : Fracture is hackly when the highly irregular broken surface develops needle like projections or sharp points. Ex. native copper.

- (v) **Conchoidal** : Conchoidal fracture is produced when minerals like quartz are broken. The fractured surface has a number of curvatures both concave and convex in a concentric form as is the case with a broken glass. The fracture is also known as shell like. If such features are not very distinct the term sub-conchoidal may be used.
- (vi) **Earthy** : When the broken surface is very smooth and soft. Ex. Chalk.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. List out the different type of fractures with examples.

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14.2.7 Tenacity

The force or strength which keeps the particular mineral to resist, crushing, bending, breaking or tearing is called its tenacity. Various terms used to describe the tenacity of a mineral are as follows:

- (i) **Brittle** : A mineral which breaks easily to grains or powder.
- (ii) **Ductile** : A mineral which shows a smooth surface when cut by a knife Ex. Kaolin, talc.
- (iii) **Flexible** : A mineral that yields to bending stress and remain bent is flexible. Ex. Asbestos.
- (iv) **Elastic** : When a mineral yields to stress and regains its original shape on the release of pressure. Ex. A plate of white mica.
- (v) **Malleable** : If a mineral is flattened or deformed without any breakage under hammer then it is called malleable. Ex. Native Gold.

14.2.8 Form and Structure

- (a) **Forms** : The external geometrical shape is the reflection of the internal arrangement of the atoms. Such shape is also called 'Form'. Forms are of three types.
- (i) **Crystallised** : If a mineral develops well defined shape and occurs like a perfect crystal.
- (ii) **Crystalline** : If a mineral does not bear a regular shape but indications of crystallization are visible by the presence of small grains where in fact each grain is small crystal by itself.

- (iii) **Amorphous** : If a mineral lacks regular shape as well as internal atomic structure. This means its formation has not undergone the process of crystallization.

Quartz occurs as perfect crystals (crystallized) or in the crystalline state. While ordinary glass or opal occur as amorphous bodies.

- (b) **Structure** : Many a times minerals exhibits a definite shape externally which is termed as 'Structure'. Structures are very characteristic in some minerals. Minerals may occur individually being independent of themselves or in groups or aggregation. The following are the important types of structures of minerals.

- i) **Acicular** : When a mineral is made up of very sharp and slender needles. Ex. Natrolite.
- ii) **Capillary** : If mineral is hair like ex. Millerite
- iii) **Bladed** : When aggregate of thin blade like parts are seen. ex. Kyanite.
- iv) **Reticulated** : If groups of slender crystals are in Lattice shape ex. Rutile needles in some micas.
- v) **Radiated or divergent** : When fibres or Needleless diverge from a central point. ex. celestites.
- vi) **Dendrite** : It occurs somewhat plant like or tree like ex. Manganese oxide.
- vii) **Drusy** : When a surface is covered with a layer of mixture of crystals. ex. Quartz.
- viii) **Columnar** : For an aggregate of thin or stout parallel columns. ex. Tourmaline.
- ix) **Lamellar or tabular** : When a mineral is made up of an aggregate of plates one over the other. The plates are separable. ex. Chlorite.
- x) **Fibrous** : When a mineral is made up of an aggregate of fibres, which may be parallel or radiating ex. Asbestos, gypsum.
- xi) **Granular** : If a mineral is composed of large number of grains of more or less same size ex. Chromite.
- xii) **Foliated** : If a mineral is made up of leaves that can be easily separated. ex. Mica.
- xiii) **Mamillary** : The mineral is composed of large rounded masses. ex. Malachite.
- xiv) **Globular** : When there are spherical or hemispherical over-lapping projections in a mineral. ex. Hematite.
- xv) **Batryoidal** : The word is derived from Greek and implies a 'bunch of grapes'. So that structure is an aggregate of spherical masses of the size of peas. ex. Psilomalene.
- xvi) **Oolitic** : When the aggregate is of small spheres (fish roe) ex. Siliceous oolite.
- xvii) **Reniform** : When the aggregate is in the shape of kidney. ex. Hematite.
- xviii) **Banded** : If the mineral bears bands of various colour and differing texture. ex. Banded hematite.

- xix) **Amygdaloidal:** When a rock contains almond shaped nodules. ex. Zeolites as infillings in cavities of lavas.
- xx) **Stellate:** When fibres are arranged in a radial fashion from a common centre resulting in starlike forms. ex. Wavellite.
- xxi) **Wiry:** As in a rope when the slender wires are twisted . ex. in copper.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. Mention the forms or structures of the following minerals ?

(i) Kyanite

(ii) Natrolite

(iii) Quartz

(iv) Mica

(v) Asbestos

Pseudomorphism

It is a phenomenon by virtue of which a mineral can assume a false form. Externally it assumes a form, of different mineral but differs totally in chemical composition. This is due to replacement of one mineral by another without disturbing the outward shape. Such replacements are called pseudomorphs. They are formed (a) by gradual change of chemical composition by alteration (b) by replacement of original particles by those of altogether different mineral (c) a new mineral occupying the Cavities. (d) by deposition of one mineral on the other.

Polymorphism

This is a phenomenon by virtue of which a body with a definite chemical composition may appear in a different form. Each form may exhibit different physical properties. This may crystallise in different crystal systems. The two forms of the substance CaCO_3 are calcite crystallising in hexagonal system and aragonite crystallising in orthorhombic system. So this chemical body is dimorphic. Likewise there are three forms of the substance TiO_2 rutile, octahedrite and brookite and the substance is known as trimorphic.

Isomorphism

It is derived from the Greek 'Isos' meaning same and 'morphe' for shape or form. This term was introduced in 1819 by Mitcherlich. Isomorphism, is the feature by virtue of which substances with analogous or allied chemical composition can crystallise in closely related crystalline form. Calcite, dolomite and magnesite are isomorphous. Similarly, albite and anorthite are isomorphous and their solid solutions will give rise to plagioclase series the members of which crystalline in triclinic system. In such series one element replaces another or one atom by another with a similar atomic radius.

14.2.9 Specific Gravity

Specific gravity of a mineral is the ratio of its weight to that of an equal volume of water at 4°C which is taken as unit. That is to say that a mineral having a specific gravity of 3 weighs three times that of same volume of water. When a body is weighed in water it loses part of its weight. The loss of weight is equal to the weight of equal volume of water. Let the weight of mineral in air be presumed as w_1 and that in water as w_2 and the loss of weight is $w_1 - w_2$. Then the specific gravity of the mineral is $\frac{w_1}{w_1 - w_2}$. This is heavy for a mineral consisting of heavier and closely spaced atoms and vice-versa. The specific gravity of most of the rock forming minerals is between 2.5-3.00 except for pyroxenes which is slightly more than 3.00. For most of the iron ores it ranges between 4.00 and 5.00 and for tungsten ores it is still more i.e., more than 7.00. Several methods, most of which are simple, are in practice for the determination of specific gravity of a body.

Of these the most important are by using (a) Jolly's spring balance for small samples (b) Walker's steelyard for larger specimens (c) heavy liquids and (d) Chemical balance.

Jolly's Spring Balance

The method employing this balance is based on Archimedes principle as shown in (Fig:14.3), it consists of a vertical stand with an adjustable base and attached with a graduated scale and a mirror. A spring in vertical suspension against the scale is also provided from top screw at the lower end of which there are two scale pans in vertical fashion one below the other, to find out the specific gravity. A fragment of the given mineral is first placed in upper pan and the elongation of the spring with reference to its bottom point is measured on the graduated scale, which is proportional to the weight of the mineral in air (w_A). Then the mineral is transferred to the lower pan and fully immersed in water in a beaker placed on a movable stand. The reading now obtained on the scale is proportional to the weight of the mineral in water (w_B).

$$\text{Then specific gravity (G) of the body} = \frac{w_A}{w_A - w_B}$$



Fig. 14.3. Jolly's spring balance

Walker's Steelyard

This balance is used to find out the specific gravity of bigger specimens. As shown in fig (14.4) the instrument consists of a beam which is graduated. A heavy weight is suspended to the short arm of the beam. The beam is pivoted on a support which is vertical. The beam is balanced or brought into horizontal position by adjusting the position of the weight on the short arm. Let a mineral specimen of which specific gravity is to be determined is tied with a thread to the main arm and be suspended. Due to this balance is tilted. The specimen is moved along with beam till such time the balance is restored. Let this position be noted as 'm'. Now the specimen is full immersed in water in a beaker by which the balance is again disturbed. The specimen in full immersion is moved with beaker along the arm and the reading is noted as 'n' where it is balanced. The instrument works on the principle of levers and hence 'm' and 'n' are inversely proportional to the body weights in air and in water respectively.

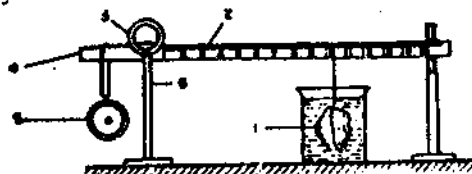


Fig. 14.4. Walker Steel Yard

So, the body weight in air is proportion to $1/m$ and the body weight in water is proportional to $1/n$.

$$\text{Specific gravity} = \frac{1/m}{1/m - 1/n} = \frac{n}{n - m}$$

Pycnometer

This is used to find out the specific gravity of a small piece of a mineral or of liquids. It is a small glass bottle with a ground glass stopper. There is a very fine opening through the stopper (Fig 14.5). Now let the weight of the bottle under dry and empty conditions be W_1 . The weight of pycnometer with the fragments is noted as W_2 . Then the bottle is partly filled with pure water and boiled for sometime to drive out the air bubbles if any through the capillary opening in the stopper. Some more water is added to the bottle to the top of the opening when it gets cooled and then the weight is noted as W_3 . Then the bottle is emptied and filled up only with water again to the same mark and let this weight be W_4 . The amount of water in the last stage is naturally more. This excess of water of final stage is equal in volume to that of mineral fragments.



Fig. 14.5. Pycnometer

$$\text{Specific gravity (G)} = \frac{W_2 - W_1}{W_4 + C(W_2 - W_1) - W_3}$$

Where $(W_2 - W_1)$ is the weight of the sample

W_3 is for pycnometer with sample fragments and water

$W_4 + (W_2 - W_1)W_3$ stands for the weight of the displaced sample.

Care must be taken to drive out the entire air, otherwise it would result in a serious error. However, it is not desirable to use this bottle for determination of specific gravity unless other technique is not available.

But for friable fine grained clays there is no other go but to use pycnometer.

Heavy Liquids

This method is very simple with heavy liquids. The two liquids which are generally used are methylene iodide and bromoform, which are visible with acetone. When a mineral grain is introduced into a known liquid if it floats the conclusion is that the mineral has got less specific gravity than the liquid. On the contrary if the substance sinks it is concluded that the liquid is lighter in density. If the grains sink, the liquid is made more dense by adding a miscible solution of higher density so that they may neither sink nor float. Likewise if the mineral grains float the liquid should be diluted with such a miscible solution of lower density till such time the grains neither sink nor float. At this stage the specific gravity of liquid and solid are the same.

However, the specific gravity of such liquids in which the grains neither sink nor float can be found out by either pycnometer or by Westpahal balance. In this a graduated arm is provided on which riders can be adjusted. A sinker is introduced into the liquid and the arm is balanced by the adjustment of riders, and the reading is noted which directly gives the specific gravity of the liquid.

14.3 RARE PROPERTIES

These properties are not seen in all the available minerals. These are specific to some particular minerals. Here also all the properties can not be observed in minerals. Certain properties are limited to a variety of minerals. These include Phosphorescence, Fluorescence, Fusibility, Magnetism, Electricity etc.

14.3.1 Phosphorescence

Some substances emit light when they undergo heating, rubbing. Even on exposure to electric radiation certain minerals exhibit this property. Diamond, fluorite display phosphorescence under varied conditions. Diamond, on exposure to sun become phosphorescent.

14.3.2 Fluorescence

As this is very well displayed by the mineral fluorspar this phenomenon is known as fluorescence. By virtue of this on exposure to electrical radiation a mineral emits light.

14.3.3 Fusibility

On heating various minerals behave in different ways. Some are fused very easily even in candle flame. Ex. Stibnite, whereas Quartz is infusible. Vonkobell has suggested fusibility scale which is as follows.

1. Stibnite	2. Chalcopyrite	3. Almandine
4. Actinolite	5. Orthoclase	6. Enstatite

A mineral which is a good conductor is fused with more difficulty in a blowpipe flame than a poor conductor with the same melting point, as the former transfers the heat rapidly to other parts and reaches the melting temperature very late in relation to the other.

14.3.4 Magnetism

Minerals like Magnetite are highly magnetic. Generally minerals containing iron are more magnetic but monazite which lacks iron is also magnetic, but weakly. Quartz, feldspars are non-magnetic.

14.3.5 Electricity

In some minerals, electric charge may be induced by heating and yet in other minerals the same is possible only on application of pressure on them. Tourmaline and quartz belong to first type where they are known as pyroelectric and the latter as piezoelectric which was first detected in quartz in 1881 by Pierre and Jacques Curie. It was known by the close of first world war that sound waves that are produced by a submarine can be detected by the piezoelectric current by employing quartz.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

4. Name the rare properties
-
-
-
-

14.4 SUMMARY

Mineralogy is the study of physical and optical properties of minerals. Each mineral will show a set of properties. If the properties are seen physically, they are called physical properties. Others, which are observed with the help of light and polarising microscope are called optical properties. The physical properties are grouped into two namely common or general properties and rare properties. The general properties are common and are seen in all minerals whereas the rare properties are seen in some specific minerals only.

The general physical properties are colour, streak, luster, hardness, cleavage and parting, fracture, tenacity, form and structure and specific gravity. The colour is produced either by reflection or by transmission of light. The causes of colour in mineral are varied. Streak is the colour of the powder of the mineral which can be observed by rubbing the mineral on a streak plate. Luster is the appearance of the surface of the mineral under reflected light. Hardness of a mineral is generally defined as the resistance of a mineral to scratching or abrasion on its surface. Cleavage is defined as a tendency of a mineral to break or split along certain planes or directions of weakness. False cleavage is parting. The observation on the broken surface is called fracture. The force or strength which keeps the particular mineral to resist, crushing, bending, breaking or tearing is called as tenacity. Form, structure and habit are synonymous and is due to the internal arrangement of atoms.

Pseudomorphism is a phenomenon by virtue of which mineral can assume false form. Polymorphism is by the virtue of which a body with a definite chemical composition may appear in a different form. Isomorphism is the feature by virtue of which substances with analogous or allied chemical composition can crystallise in closely related crystal form. Specific gravity of a mineral is the ratio of its weight to that of an equal volume of water at 4°C. Jolly's spring balance, Walker's steelyard, pycnometer can be used to know specific gravity.

The rare properties are specific and are not uniform to all minerals. These includes Phosphorescence, Fluorescence, Fusibility, Magnetism, Electricity etc.

14.5 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Talc-1, Gypsum-2, Calcite-3, Fluorite-4, Apatite-5, Orthoclase-6, Quartz-7, Topaz-8, Corundum-9, Diamond-10.
2. Even-chert, Uneven-Quartz, Splintery-Tremolite, Hackly-Native Copper, Conchoidal-Quartz, and Earthy-Chalk.
3. (i) Kyanite - bladed (ii) Natrolite - Acicular (iii) Quartz - Drusy (iv) Asbestos - Fibrous (v) Mica - Foliated.

14.6 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines each.

- 1) Explain the physical properties of minerals.
- 2) How do you identify minerals physically.

II. Answer the following in about 10 lines each.

- 1) Explain the terms Isomorphism, Polymorphism and Pseudomorphism.
- 2) What is specific gravity of minerals?
- 3) What is hardness of minerals?
- 4) Describe forms of minerals?
- 5) Explain phosphorescence and Fluorescence?

UNIT - 15 : NESO, SORO, CYCLO AND INO SILICATES

Contents

- 15.0 Objectives
- 15.1 Introduction
- 15.2 Nesosilicates
 - 15.2.1 Olivine group
 - 15.2.2 Garnet group
- 15.3 Sorosilicates - Epidote group
- 15.4 Cyclosilicates - Tourmalene group
- 15.5 Inosilicates
 - 15.5.1 Pyroxene family
 - 15.5.2 Amphiboles family
 - 15.5.3 Differences between pyroxenes and amphiboles
- 15.6 Summary
- 15.7 Check Your Progress - Model Answers
- 15.8 Model Examination Questions

15.0 OBJECTIVES

After completion of this unit, you should be able to -

- explain the minerals of nesosilicates
- describe the minerals of sorosilicates
- define cyclo silicates
- describe pyroxene and amphibole families

15.1 INTRODUCTION

In the 13th unit, all the rock forming silicate minerals were grouped into six separate groups based on the silicate structure. They are nesosilicates, sorosilicates, cyclosilicates, inosilicates, phyllosilicates, and tectosilicates. The olivine and garnet groups were explained under nesosilicates, sorosilicates like epidote group was discussed. Tourmalene as cyclosilicate was explained. The pyroxene family and the Amphibole family were discussed under inosilicates. The individual minerals were explained in the practical manual.

15.2 NESOSILICATES

This group of minerals are consisting of independent tetrahedra of SiO_4 and are stacked together in a regular manner throughout a crystal structure and are linked together

only through the medium of other cations which lie between them. Mineral olivine and garnet comes under this category.

15.2.1 Olivine group

The minerals of olivine group all possess orthorhombic symmetry and a structure consisting of independent (SiO_4) tetrahedra linked by divalent atoms in octahedral coordination. This family consists of an isomorphous series of nesosilicates with the general formula $\text{R}^{2+}_2(\text{SiO}_4)_2$ in which R = magnesium or Iron. The colour of olivine mineral shows shades of green, pale-green, olive-green, greyish-green etc. The streak is colourless, lustre is vitreous, fracture conchoidal, hardness is 6 to 7. Olivine is the essential minerals of igneous rocks known as peridotites, dunite and also occurs in basic igneous rocks like olivine-gabbros, basalts and dolerites. The variety forsterite is formed by metamorphism. The magnesium end member is forsterite Mg_2SiO_4 , and the iron end member is fayalite Fe_2SiO_4 , in between is olivine $(\text{MgFe})_2\text{SiO}_4$.

15.2.2 Garnet group

The origin of the word 'Garnet' is from Latin 'granatus' which means 'like a grain'. In ancient times garnets were the first to be used as precious stones or ornamental stones due to their pleasing and beautiful shades of colour lustre. Though they are very characteristic of metamorphic rocks they are also found in some igneous rocks and in sediments as detrital grains. They are called isometric cubic silicates. In chemical composition they bear a general formula $\text{X}_3\text{Y}_2(\text{SiO}_4)_3$, where 'X' stands for Ca, Mg, Fe^{+2} , or Mn^{+2} and 'Y' for Fe^{+3} , Al, Cr^{+2} or Ti.

The following are the important members of this group.

Species	Formula
Almandite	$\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$
Pyrope	$\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$
Spessartite	$\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$
Grossularite	$\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$
Andradite	$\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$
Uvarovite	$\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$

Very rarely does any natural garnet approach the formulae mentioned above. This is due to large scale atomic substitution. So the name of any species goes by the component that is present in greatest amount. Limited substitution takes place between andradite and grossularite and also between pyrope, spessartite and Almandite.

Garnets crystallise in cubic system. They are fairly hard but as they are brittle they may be broken into small cubic grains. Alteration effect on garnets is least. Specific gravity is fairly high. Their fracture is either uneven or subconchoidal. Under microscope they are all isotropic. They are seen as rounded or subrounded crystals with characteristic cracks but lacking cleavage. Garnets are used as abrasives and gem stones.

Check Your Progress

Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.

1. Name the different species of Garnet group.

15.3 SOROSILICATES - EPIDOTE GROUP

Sorosilicates were represented by epidote group of minerals. The epidote group includes several members which are complex silicates. Their general formula is $X_2Y_3Si_3O_{12}(OH)$, where X stands for calcium and iron, Y for aluminium, manganese, iron and cerium. Calcium aluminium silicate may occur as dimorphous with zoisite of orthorhombic system and clinozoisite of monoclinic system. Other members crystallise in monoclinic system. The members of this group are isostructural, a mixed type having SiO_4 and Si_2O_7 both.

Most of the minerals occur in metamorphic rocks. Allanite is found in igneous rocks such as granites and pegmatites. Zoisite and clinozoisite are peculiarly identical in chemical composition with anorthite, a feldspar which is less stable under conditions of medium grade of metamorphism. They exhibit different colours. Their hardness is 6-7 and specific gravity is 2.7-4.0. Cleavage is markedly present in some members parallel to basal plane (001). Their lustre is vitreous.

The common species are as given below

1. Zoisite :	$Ca_3Al_2(SiO_4)_3OH$
2. Clinozoisite :	$Ca_3Al_2(SiO_4)_3OH$
3. Epidote :	$Ca_2(AlFe)_3(SiO_4)_3OH$
4. Allanite :	$(CaFe)_2(AlFeCe)_3(SiO_4)_3OH$

Check Your Progress

Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.

2. The members of Epidote group Crystallise in

15.4 CYCLOSILICATES - TOURMALENE

Cyclosilicates were represented by Tourmalene minerals. These are prismatic crystals of hexagonal system, often exhibit distinct hemimorphism. They are also seen as massive or radiating groups of acicular or columnar crystals. These minerals show subconchoidal to uneven fracture, hardness is 7.5, generally black, dark blue, yellow, green, reddish or pink in colour, streak appears colourless, luster, is vitreous. the chemical composition is variable because of substitutions but the structure does not change.

In thin section it is brown, brownish yellow, yellow or green and is strongly pleochroic. It is seen as subhedral grains or as triangular or hexagonal cross-sections. It's relief is high and birefringence moderate to strong. Alteration to micas or chlorite is noticed in some cases. Optically negative. Colour, striations, absence of cleavage and typical cross sections are very characteristic. Straight extinction, strong pleochroism, (maximum absorption when it is at right angles to the vibration plane of polariser) high relief are also diagnostic features. Distinguished from apatite by higher hardness. Differs with beryl by its sharp striations and hemimorphism. Different varieties fuse differently forming greenish glass. Insoluble even in HF.

It occurs as an accessory mineral in igneous (schrol) and metamorphic rocks such as granite, syenites, gneisses and schists. It also occurs in pegmatites. Brown magnesium rich variety (Dravite) occurs in marbles. In sediments it occurs as rounded grains.

It is used in industries due to its piezoelectric property in the construction of pressure gauge. Certain varieties occurring in Brazil, USA, England are used as precious or gem stones.

Varieties

1. Schrol	iron rich black tourmalene
2. Dravite	magnesium rich brownish variety
3. Rubellite	a colourless red or pink variety of tourmalene which is used as precious stone
4. Achroite	a blue variety
5. Elbaite	Colourless, green, blue or yellow variety.
6. Indicolite	Indigo blue variety
7. Brazilian emerald	is green variety
8. Brazilian Sapphire	is Berlin-blue type.

Chemical composition of Tourmalene = $\text{Na, (MgFe)}_3\text{Al}_6(\text{OH})_4(\text{BO}_3)_3\text{Si}_6\text{O}_{18}$

15.5 INOSILICATES

Inosilicates are called chain silicates. In this there are two groups namely single chain and double chain. The single chain silicates are represented by pyroxenes and the double chain silicates are represented by Amphiboles.

15.5.1 Pyroxene family

There is an intimate relationship between the member of pyroxenes group with reference to their physical properties, chemical composition and also structure. They crystallise in the orthorhombic and monoclinic systems. They are essentially metasilicates and their chemical composition may be expressed by the general formula $(XYZ)_2W_2O_6$ where X, Y, Z, W stand for elements with identical ionic radii. In the structure they can also replace each other. However, "X" stands for Ca, Na, 'Y' stands for Mg, Fe^{+2} , Mn^{+2} , Li, 'Z' for Al, Fe^{+3} , Ti and 'W' is usually for Si which can be replaced partially by Al.

Pyroxenes are typically characterised by prismatic cleavage and in some parting is also noticed. Twinning is common. They range in hardness from 5-7 and specific gravity from 2.8-3.7 usually they are dark coloured but may also be white, blue or yellow. They alter readily to chlorite or amphibole. They are essential constituents of many igneous rocks. They also occur in metamorphic rocks both contact and regional but are rarely present in sedimentary rocks.

Augite and pigeonite are the commonest minerals of the pyroxene group. The soda pyroxenes are jadeite and aegirine. Following is the list of principal species.

Orthorhombic Pyroxenes

1.	Enstatite	$MgSiO_3$
2.	Hypersthene	$(MgFe)SiO_3$

Monoclinic Pyroxenes

3.	Diopside	$CaMg(Si_2O_6)$
4.	Hedenbergite	$CaFe(Si_2O_6)$
5.	Augite	$(CaMgFeAl)_2(AlSi_2)_2O_6$
6.	Pigeonite	$MgSiO_3$
7.	Jadeite	$NaAl(Si_2O_6)$
8.	Aegirine	$NaFeSi_2O_6$
9.	Spodumene	$LiAlSi_2O_6$

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. Mention at least two members with chemical composition from each of the following.

(1) Orthorhombic pyroxenes

(2) Monoclinic pyroxenes

.....
.....

Enstatite : Orthorhombic, Prismatic or massive form, hardness 5 to 6, white, grey, pale green or yellow in colour, streak white, vitreous luster, uneven fracture, chemical composition MgSiO_3 . In thin sections it shows nonpleochroic, parallel extinction, occurs in intermediate and basic igneous rocks.

Hypersthene : Orthorhombic, well formed crystals are rare, perfect cleavage (010), Hardness 5.5 to 6, Brownish green, dark brown to black in colour, greyish streak, vitreous luster, uneven fracture, chemical composition is $(\text{MgFe})\text{SiO}_3$. In thin sections it is pleochroic (greenish to pale reddish), straight extinction, occurs in basic igneous rocks.

Diopside : Monoclinic, Prismatic or massive or granular form, Hardness 5 to 6, colourless or light greenish, streak white or grey, vitreous luster, uneven fracture, perfect cleavage (110), chemical composition is $\text{CaMgSi}_2\text{O}_6$. In thin sections distinct cleavage, parallel extinction occurs in igneous rocks like granites and pegmatites.

Augite : Monoclinic, granular or lamellar or massive form, hardness 5 to 6, greenish to brownish black in colour. Colourless streak, uneven to conchoidal fracture, vitreous to resinous luster, chemical composition is $(\text{CaMgFeAl})_2(\text{AlSi})_2\text{O}_6$. In thin sections zoning can be seen, straight or symmetrical extinction. occurs in gabbros, basalts, andesites, diorite etc. rocks.

15.5.2 Amphibole family

There is an intimate relationship between amphiboles and pyroxenes with reference to their crystallography, chemical composition and physical properties. It is difficult to distinguish members of one group from those of the other megascopically. In spite of such marked similarity the corresponding members of pyroxenes and amphiboles are not dimorphic, though originally they were considered to be so.

Like pyroxenes they are mostly metasilicates. The structure of amphiboles is based on double Si_4O_{11} chains parallel to C-axis, instead of the metasilicate ratio of Si_4O_{12} . The chemical composition of the various members of this group can be expressed by a general formula $(\text{X}, \text{Y}, \text{Z})_{7-8}(\text{Si}_4\text{O}_{12})(\text{OH})_2$ where 'X' stands for Ca and Na, 'Y' for Mg, Fe^{+2} (Mn at times) and 'Z' for Fe^{+3} , Ti and Al. Hydroxyl group is always present in the structure. The ratio between Si and O is 4:11 in amphiboles but where as in pyroxenes it is 1:3. Al may replace Si. [OH] may be replaced by F. K may be present in small amount along with Ca, Na, Mg. Fe^{+2} and Mn^{+2} are interchangeable. There is a limited substitution between Al and Fe^{+3} .

Based on the chemical composition and crystal system the various species are grouped into the following series :

I. ORTHORHOMBIC AMPHIBOLES

1. Anthophyllite $(\text{MgFe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$

II MONOCLINIC AMPHIBOLES

2. Cummingtonite series
 - a. Cummingtonite $(\text{MgFe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$
 - b. Grunerite $(\text{MgFe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$
3. Tremolite series
 - a. Tremolite $\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2$
 - b. Actinolite $\text{Ca}_2(\text{MgFe})_3\text{Si}_8\text{O}_{22}(\text{OH})_2$
4. Hornblende series $(\text{Ca, Na, Mg, Fe, Al})_{7-8}(\text{AlSi})_8\text{O}_{22}(\text{OH})_2$
5. Sodium amphibole series
 - a. Glaucophane $\text{Na}_2(\text{MgFe})_3(\text{AlFe})_2\text{Si}_8\text{O}_{22}(\text{OH})_2$
 - b. Riebeckite $\text{Na}_2\text{Fe}^{2+}_3\text{Fe}^{3+}_2\text{Si}_8\text{O}_{22}(\text{OH})_2$
 - c. Arfvedsonite $\text{Na}_3\text{Mg}_4\text{AlSi}_8\text{O}_{22}(\text{OH})_2$

III. TRICLINIC AMPHIBOLE

Cossyrite

Silicate of iron titanium sodium and aluminium

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

4. What is the general formula for the chemical composition of Amphiboles.

Anthophyllite : Orthorhombic, massive or fibrous form, perfect cleavage hardness 6, white or grey or brown or green in colour, streak white, vitreous luster, chemical composition is $(\text{MgFe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$. In thin sections colourless to Pale yellow or green in colour, straight extinction. Occurs in metamorphic rocks.

Tremolite : Monoclinic, prismatic or columnar form, perfect cleavage, uneven fracture, hardness 5 to 6, colour white, streak white, vitreous luster, chemical composition is $\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2$. In thin sections colourless, oblique extinction. Occurs with metamorphosed lime stone, basic and ultra basic igneous rocks like green stones and serpentine.

Actinolite : Monoclinic, Prismatic crystals, perfect cleavage, uneven fracture, Hardness 5 to 6, colour green, streak colourless, vitreous luster, chemical composition is $\text{Ca}_2(\text{MgFe})_3\text{Si}_8\text{O}_{22}(\text{OH})_2$. In thin sections greenish colour, pleochroic, oblique extinction, occurs in low and medium grade metamorphic rocks.

Hornblend : Monoclinic, prismatic crystals, perfect cleavage (110), uneven fracture, hardness 5 to 6, black, dark brown and dark green colour, colourless streak, vitreous luster,

chemical composition $(\text{CaNaMgFeAl})_{7-8}(\text{AlSi})_8\text{O}_{22}(\text{OH})$. In thin sections green or brown colour, pleochroic, oblique extinction. Occurs in igneous and metamorphic rocks. Sometimes in detrital sediments also.

15.5.3 Differences between Pyroxenes and Amphiboles

The most important features by which amphiboles can be distinguished from pyroxenes are listed below.

1. Pyroxenes appear as short and stout (stubby) crystals, whereas amphiboles have a tendency to develop into long prismatic, fibrous or acicular forms.
2. Pyroxenes are dominant in blackish basaltic or diabasic rocks, while amphiboles are most abundant in metamorphosed limestones near igneous contacts and in light coloured more acidic rocks with potashfeldspar, quartz, and muscovite.
3. The cleavage which reflects the internal chain geometry is very prominent in the members of both the groups as prismatic parallel to C-axis. The cleavages intersect at 87° to 93° in pyroxenes whereas in amphiboles at 124° and 56° .
4. In thin sections pyroxenes are generally non-pleochroic whereas amphiboles are pleochroic.
5. Basal sections of pyroxenes are eight sided but in amphiboles they are six sided.
6. Massive varieties of these two groups differ in form. They are platy or granular in pyroxenes, while they are either columnar or fibrous in amphiboles.
7. The lustre of amphiboles is more brilliant than that of pyroxenes.
8. In pyroxenes orthopinacoid is present but the same is absent in amphiboles.
9. On the clino-pinacoid both show oblique extinction but the angle is about 16° in amphiboles whereas in pyroxenes it is around 48° .
10. Amphiboles yield water in a closed tube on heating, but not pyroxenes.

Tourmaline differs with amphiboles by lack of cleavage. Epidote, though has basal cleavage differs from amphiboles by its yellowish and oily green colour.

15.6 SUMMARY

All the rock forming silicate minerals are divided into six types. In this unit the neso, soro, cyclo and inosilicate are discussed. The nesosilicates are consisting of independent tetrahedra of SiO_4 and are represented by olivine and garnet group of minerals. The mineral olivine possesses orthorhombic symmetry and consists of an isomorphous series of nesosilicates with general formula $\text{R}^{2+}_2(\text{SiO}_4)$. Olivine appears light green, pale green or olive green by colour. This is an essential mineral in igneous rocks. Magnesium rich olivine is called forsterite and iron rich olivine is called fayalite, in between is olivine. Garnet minerals are called isometric cubic silicates. The general formula is $\text{x}_3\text{y}_2(\text{SiO}_4)_3$. These are fairly hard, specific gravity is high. These are the characteristic minerals of metamorphic rocks and also found in igneous and sedimentary rocks. These are used as abrasives and gem stones.

The sorosilicates are represented by epidote group of minerals. The general formula is $x_3y_3 Si_3O_{12}(OH)$. These minerals crystallised in both orthorhombic and monoclinic systems. Most of the minerals occur in metamorphic rocks. Cyclosilicates are represented by tourmalene mineral. Tourmalene crystallised in hexagonal system. Strong pleochroism and high relief are the important features. It occurs in igneous and metamorphic rocks.

Inosilicates are called chain silicates. These are again divided into single chain and double chain silicates. Single chain silicates are pyroxenes, double chain silicates are amphiboles. Pyroxenes are crystallised in orthorhombic and monoclinic systems. These are metasilicates with the general formula $(XYZ)_2W_2O_6$. These are essential constituents of igneous rocks also occur in metamorphic and sedimentary rocks, twinning is common. Amphiboles are also metasilicates with the general formula $(XYZ)_{7-8}(Si_4O_{12})(OH)_2$. Amphiboles are crystallised in orthorhombic, monoclinic and triclinic systems.

15.7 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The names of species in garnet group are almandite, pyrope, spessartite, grossularite, almandite and uvarovite.
2. Orthorhombic and monoclinic systems
3. Orthorhombic pyroxenes are enstatite, hypersthene, monoclinic pyroxenes are diopside, hedenbergite, augite, pagonite, jadite, agirine, and spodumene.
4. The general formula for the chemical composition of Amphiboles is $(XYZ)_{7-8}(Si_4O_{12})(OH)_2$.

15.8 MODEL EXAMINATION QUESTIONS

I Answer the following in about 30 lines each

1. Write an essay on nesosilicates.
2. Describe Pyroxene minerals.
3. Explain the Amphibole family.

II Write about the following in about 10 lines each.

1. Olivine
2. Garnet
3. Tourmalene
4. Epidote.

UNIT - 16 : PHYLLO, TECTO SILICATES AND MISCELLANEOUS MINERALS

Contents

- 16.0 Objectives
- 16.1 Introduction
- 16.2 Phyllosilicates - Mica Family
- 16.3 Tectosilicates
 - 16.3.1 Feldspar Family
 - 16.3.2 Feldspathoids Family
 - 16.3.3 Silica Minerals
- 16.4 Miscellaneous Minerals
- 16.5 Summary
- 16.6 Check Your Progress - Model Answers
- 16.7 Model Examination Questions

16.0 OBJECTIVES

After completion of this unit, you should be able to -

- explain mica minerals
- describe feldspar group of minerals
- define silica minerals
- explain the various miscellaneous minerals

16.1 INTRODUCTION

In the earlier unit the four silicate groups neso, soro, cyclo and ino silicates were discussed. In continuation, in this unit the remaining silicate groups of minerals such as phyllo, tecto silicates and various other miscellaneous individual minerals are discussed. The phyllo silicates are represented by mica group of minerals. The tectosilicates includes feldspars, feldspathoids and silica minerals. The miscellaneous such as Natrolite, Beryl, Zircon, Sphene, Kyanite, Sillimanite, Calcite, Barytes, Chlorite, Staurolite, Serpentine, Talc, Apatite are explained.

16.2 PHYLLOSILICATES - MICA FAMILY

The term 'Mica' was probably derived from the latin 'Micare'. Meaning to shine. Minerals of the mica group are characterised by their platy morphology and highly perfect basal cleavage. This is due to the fact that they bear Si_4O_{10} layered atomic structure, or sheet structure. They constitute a group of hydrous silicates of aluminium together with alkalis,

ferrous iron and magnesium. Some varieties may contain lithium and titanium. All of them crystallise in monoclinic system. As the front to back or a-axis is very less tilted with reference to the vertical crystallographic or c-axis (B being close to 90) i.e., the angle between these two axes being almost 90°, the monoclinic symmetry is not distinctly seen. So their forms may be very intimate to those of hexagonal system. Micas can be termed pseudo-hexagonal monoclinic. The following is the list of members of mica group.

1.	Muscovite	Potassium mica and also very commonly known as white mica.
2.	Biotite	Magnesium - iron mica and also known as brown mica.
3.	Phlogopite	Magnesium mica
4.	Lepidolite	Lithium-potassium mica
5.	Paragonite	Sodium mica
6.	Zinnwaldite	Lithium-iron mica (very rare)

Of the above members, muscovite and biotite are very commonly seen in the rocks.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. The Silicon, Oxygen ratio in mica group is

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Muscovite : Monoclinic system, tabular form, in one direction perfect cleavage, chemical composition is $KAl_2(AlSi_3O_{10})(OH)_2$. In thin section it is transparent. Parallel extinction, occurs in acid igneous rocks such as granites, pegmatites. It is called white mica and is useful in electrical industry in condensers as material of insulation, used for lamp chimneys, used as roofing material and also used in the manufacture of rubber tyres and lubricants.

Biotite : Monoclinic system, tabular form, cleavage perfect in one direction, chemical composition is $K(FeMg)_3(AlSi_3O_{10})(OH)_2$. In thin section it is translucent, brownish colour. Strongly pleochroic. It occurs in acid to intermediate igneous rock. It is also called brown mica. No economic importance.

16.3 TECTOSILICATES

Tectosilicates are also called as framework silicates with SiO_2 structure. The feldspars, feldspathoids, silica minerals are included in this tectosilicates.

16.3.1 Feldspar Family

Feldspars are the most abundant of all minerals. They are also very important rock-forming minerals. The members of this group are closely related in chemical composition, physical properties and crystal structure. They are aluminosilicates of potassium, sodium, calcium and barium. They are further classified into three sub-groups:

1. Potash feldspars
2. Barium feldspars and
3. Soda-lime feldspars or plagioclase feldspars which form an isomorphous series.

The structure of the feldspars is a three dimensional net work of SiO_4 and AlO_4 tetrahedra. Their composition can be represented by a formula XY_4O_8 , where 'X' stands for K, Na, Ca or Ba and 'Y' for Si and Al. Si and Al have a ration ranging from 3:1 to 1:1. The barium feldspars are of rare occurrence. Barium feldspars with more than 90% of $\text{BaAl}_2\text{Si}_2\text{O}_8$ molecule is known as Celsian but those with less than 30% of $\text{BaAl}_2\text{Si}_2\text{O}_8$ molecule are hyalophane. The members of the family considered here are

I. Potash feldspars		
1.	Orthoclase	Monoclinic
2.	Microcline	Triclinic
II Barium feldspar		
3.	Celsian	Monoclinic
4.	Hyalophane	Monoclinic
III Plagioclase (Soda-lime) feldspars		
5.	Albite	Triclinic
6.	Oligoclase	Triclinic
7.	Andesine	Triclinic
8.	Labradorite	Triclinic
9.	Bytownite	Triclinic
10.	Anorthite	Triclinic

Feldspars crystallise in monoclinic and triclinic systems. Their colour is white, grey or pink, range in hardness from 6 - 6.5 and specific gravity 2.5-3.0. Twinning is noticed, either simple or repeated. Cleavage present in two directional.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. Give the classification of members of feldspar group.

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Orthoclase : Monoclinic, massive form, perfect cleavage (001), hardness - 6, concoidal to uneven fracture, fleshred colour, white streak, vitreous luster, chemical composition is

KAlSi_3O_8 . In thin sections grey polarisation colour, oblique extinction. It occurs in granites, granodiorites, syenites and their volcanic equivalents. Also occurs in metamorphic and sedimentary rocks. Used as mild abrasive, and in the manufacture of sanitary ware, Porcelain and Pottery.

Microcline : Triclinic, massive or granular form, perfect cleavage (001), uneven fracture, hardness 6, colour pink, white or grey, white streak, vitreous luster, chemical composition is KAlSi_3O_8 . In thin sections colourless, grey polarisation colours, oblique extinction, cross-hatched twinning is seen. Occurs in all important igneous rocks and also in sedimentary and metamorphic rocks.

Plagioclase : Triclinic, massive form, distinct cleavage, uneven fracture, hardness 6, greyish white colour, colourless streak, chemical composition is $(\text{NaCa})\text{Al}(\text{AlSi})\text{Si}_2\text{O}_8$. In thin sections colourless, grey polarisation colour, oblique extinction, lamellar twinning, occurs in igneous, metamorphic and sedimentary rocks. Useful in the manufacture of porcelain and potteries.

16.3.2 Feldspathoid Family

There is a lot of similarity between feldspathoids and feldspars as far as their chemical composition is concerned. They are formed in place of feldspars when a magma lacks in silica and proportionately rich in alkalies. Hence they can be described as feldspars deficient in silica. They never occur with free quartz that would result in reaction with the latter to form feldspars. Their association with feldspars also is very rare. Leucite and nepheline of this group differ from orthoclase and albite of feldspar group respectively only in being deficient in the amount of SiO_2 .

They are all tectosilicates but the structural bondage between the species is relatively less in relation to that of feldspars. Various members of the group are as follows.

Leucite	Potassium aluminium silicate
Nepheline	Sodium aluminium silicate
Cancrinite	Hydrated silicate of sodium and aluminium with calcium carbonate
Sodalite	Sodium aluminium silicate with sodium sulphide
Lazurite	Sodium aluminium silicate with sodium sulphide
Hauyne	Sodium aluminium silicate with calcium sulphate
Nosean	Sodium aluminium silicate with sodium sulphate

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. Name atleast two sodium feldspathoids ?

Leucite : Cubic system, usually tropezohedral crystals, imperfect cleavage, hardness 5.5 to 6, colourless to white colour, clourless streak, vitreous luster, brittle to conchoidal fracture, chemical composition $K Al Si_2 O_6$. In thin sections euhedral, inclusions are seen; isotropic, occurs abundantly in recent lavas as phenocrysts but rarely in plutonic igneous rocks. Used for the manufacture of alum and potash fertiliser.

Nephelene : Hexagonal, small prismatic or large grains, hardness 6, colourless or white or yellowish or reddish, colourless streak, vitreous luster, chemical composition is $Na Al SiO_4$. In thin sections subhedral, parallel extenction, grey polarisation colour. Occurs in sodarich igneous rocks such as nephelene syenite and some basaltic rocks, useful in glass industry.

Sodalite : Cubic system, granular form, poor cleavage, Hardness 5.5 to 6, colour may be white, blue, green, grey or pink, colourless streak, vitreous to greasy luster, uneven fracture chemical composition is $3 (Na Al SiO_4) Na Cl$. In thin sections it appears blue and isotropic. Occurs in nephelene syenite. Used as ornamental stone.

16.3.3 Silica Minerals

All species which have their chemical composition as SiO_2 are included under this group. They occur in various forms. They are quartz, tridymite, cristobalite, jasper, flint, chalcedony, opal. Out of all, quartz which is a crystalline form is the most abundant mineral occuring as an essential constituent of many rocks of igneous, sedimentary and metamorphic origin. The word quartz, seems to originate from the Saxonword 'Querkluffertz' meaning, cross-vein-ore which during course of time became 'querertz' tending ultimately to 'quartz'. The other crystalline forms namely tridymite and cristobalite are of wide occurrence in volcanic rocks. Among the cryptocrystalline and amorphous forms, opal alone is common but others are rare.

The temperature ranges of stability of various polymorphs of SiO_2 vary from species to species. Such variationis found even within the species. The silicon-oxygen atoms change their positions according to temperature - pressure conditions α -quartz is stable upto $573^\circ C$ - $1470^\circ C$ and β -quartz is stable 573° and $870^\circ C$. Tridymite is stable between $870^\circ C$ - $1470^\circ C$ and cristobalite from $1470^\circ C$ to 1728° (melting-point) and above that temperature till the boiling point the liquid silica is stable. Pressure also influences the inversion temperature. Tridymite and cristobalite are not stable beyond 3000 kg/cm^2 and 5000 kg/cm^2 respectively which means the absence of these two minerals in plutonic rocks which are formed under great pressure. The transformation between the three crystalline forms is sluggish due to which the high temperature tridymite and cristobalite can exist even below their inversion temperature. These three members have a low and high temperature modifications known as α and β respectively.

The classification of forms of silica is as follows :

1. Crystalline forms	Quartz, Tridymite, Cristobalite
2. Cryptocrystalline form	(without water molecules);

a. Fibrous

Chalcedony,

b. Granular

Flint, Jasper, Chert

3. Cryptocrystalline hydrous forms Opal, Chalcedony

The only amorphous form which is of very rare occurrence is lechatelierite.

Quartz : Hexagonal, prismatic, granular or massive form, cleavage absent, Hardness 7, colourless to white, coloured with impurities, colourless streak, vitreous luster, conchoidal fracture. The chemical composition is SiO_2 . In thin sections colourless, anhedral grains, straight or wavy extinction occurs in igneous sedimentary and metamorphic rocks. Used in glass industry, abrasives, building stones, pottery etc. The varieties of quartz are rock crystal, milky quartz, smoky quartz, amethyst, rose quartz, aventurine, cat's eye, tiger eye etc.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

4. Quartz Crystallises in _____ Crystal System.

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16.4 MISCELLANEOUS MINERALS

Apart from the silicate minerals explained earlier, there are certain individual minerals important to study because these minerals are also acting as rock forming minerals. The minerals included here are the Natrolite, Beryl, Zircon, Sphene, Kyanite, Sillimanite, Calcite, Corundum, Barytes, Chlorite, Staurolite, Serpentine, Talc, Apatite.

Natrolite : Orthorhombic, prismatic or fibrous or massive form, perfect cleavage (110), uneven fracture, hardness 5 to 5.5, white or yellow in colour, colourless or white streak; vitreous luster, the chemical composition is $\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10} \cdot 2\text{H}_2\text{O}$. In thin sections euhedral, straight extinction occurs in cavities of basalt.

Beryl : hexagonal, prismatic form, imperfect cleavage, hardness 7-8, conchoidal or uneven fracture, greenish yellow, emerald green, blue, pink or white colour, vitreous luster, chemical composition is $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$. In thin sections colourless, straight or parallel extinction, occurs in granite pegmatites. The varieties are Aquamarine, morganite, emerald, used as a gem stone.

Zircon : Tetragonal, Prismatic form, conchoidal fracture, hardness 7.5, commonly brown or reddish brown colour, colourless streak, vitreous to adamantine luster, chemical composition is ZrSiO_4 . In thin sections colourless, low pleochroic, straight extinction occurs as accessory mineral in plutonic igneous rocks. Jargoon and Hycinth are the gem varieties.

Sphene : Monoclinic, euhedral form, distinct cleavage (110), Hardness 5 to 6, generally brown, also green, yellow in colour, white streak, adamantine luster, chemical composition is Ca Ti O_5 . In thin sections colourless or pinkish or brownish or yellowish, pleochroic, symmetrical extinction, occurs as accessory mineral in acid and intermediate igneous rocks and in schists or gneisses.

Kyanite : Triclinic, bladed form, hardness 4 in one direction 7 in other direction; blue, grey or green in colour, white streak, vitreous or pearly luster, chemical composition is Al_2SiO_5 . In thin sections tubular, straight extinction. Typical mineral of regional metamorphism. Used as gem and in the manufacture of refractories, glasses, spark plugs etc.

Sillimanite : Orthorhombic, large slender crystals, cleavage present (010), uneven fracture, hardness 6.5 to 7, white or brownish or yellowish colour, colourless streak, vitreous luster, chemical composition is Al_2SiO_5 . In thin sections prismatic form, parallel extinction occurs in schists, gneisses, eclogites and slates. Used in the manufacture of Porcelain and refractories.

Calcite : Hexagonal, rhombohedral or granular or massive, pisolitic, fibrous, nodular and stalactitic forms, cleavage 3 sets present, hardness 3, colourless or white, white streak, vitreous or earthy luster, chemical composition is Ca CO_3 . In thin sections colourless, twinkling is seen. Symmetrical extinction occurs as important constituent of sedimentary limestone. Used in fertiliser, cement industries and in the manufacture of bleaching powder, glass, soap, paper and paints. Marble is used in buildings, limestone is used as road material, also used as flux and ornamental material.

Corundum : Hexagonal, barrel shaped crystals, uneven fracture, cleavage absent, hardness 9, light brown colour, sub vitreous luster. Chemical composition is Al_2O_3 . In thin sections usually clear and if coloured, the colour is often patchy, the refractive index is very high. It is an original constituent of alumina rich igneous rocks such as syenites, nepheline syenites and anorthosites. It is mainly used as abrasive and some varieties of corundum like ruby, sapphire and emerald are used as gemstones.

Barytes : Orthorhombic, tabular, prismatic or massive form, cleavage present, uneven fracture, hardness 2.5 to 3.5, colourless, streak white, vitreous to resinous luster, chemical composition is Ba SO_4 . In thin sections colourless, subhedral, straight extinction. It is an important vein mineral occurs in association with calcite, quartz, galena, magnetite etc. used in the manufacture of paper and paints. Used by oil companies for making drilling mud, and also used as flux in the smelting of iron and manganese.

Chlorite : Monoclinic, scaly aggregate or tabular form, perfect (001) cleavage, uneven fracture, hardness 2 to 2.5, green colour, streak white to light green, vitreous luster, chemical composition is $(\text{Mg Fe Al})_6 (\text{Al Si})_4 \text{O}_{10} (\text{OH})_8$. In thin sections, colourless or green, if it is green pleochroic, ultra blue polarisation colours, occurs in all types of rocks as alteration product of biotite, hornblende, pyroxene, olivine etc.

Staurolite : Orthorhombic, prismatic crystals, perfect (001) cleavage, uneven fracture, hardness 7 to 7.5, colour green, streak white or light green, luster vitreous, chemical composition is $\text{Fe Al}_4\text{Si}_2\text{O}_{10}(\text{OH})_2$. In thin sections it is yellowish in colour, pleochroic, extinction is straight and also symmetrical, occurs in metamorphic rocks.

Serpentine : Monoclinic, fibrous or foliaceous or massive form, conchoidal fracture, hardness 2.5 to 5, green, red, reddish brown, yellow or white in colour, streak white,

chemical composition is $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$. In thin sections greenish yellow, parallel extinction occurs as an alteration product of pyroxenes, Amphiboles etc.

Talc : Monoclinic, hardness 1, Apple green to white in colour, streak white, pearly luster, chemical composition is $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$. In thin sections it is colourless, parallel to straight extinction. It results from the alteration of magnesium rich rocks and minerals. It is an important constituent of Talc schist and steatite.

Apatite : Hexagonal, massive or granular form, conchoidal to uneven fracture, Hardness 5, bluish green, green blue, violet, brown or yellow in colour, streak white, vitreous luster, chemical composition is $\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{ClOH})$. In thin sections colourless, straight extinction basal sections are isotropic, occurs as accessory constituent of igneous rocks. Used in the manufacture of fertilisers.

16.5 SUMMARY

In this unit the phyllosilicates, tectosilicates and other important rock forming minerals were explained. Mica family represented for the phyllosilicates. Minerals of mica family are characterised by platy morphology, it is due to Si_4O_{10} layered structure. They constitute a group of hydrous silicates of aluminium together with alkalis, ferrous iron and magnesium. All are crystallised in monoclinic system. The important varieties are muscovite, biotite, phlogopite, lepidolite, paragonite, zinnwaldite etc.

The tectosilicates were represented by feldspar family, feldspathoid family and silica minerals. Feldspars are most abundant of all minerals. Feldspars are aluminosilicates of potassium, sodium, calcium and barium. The structure is a three dimensional net work of SiO_4 and AlO_4 tetrahedra. The potash feldspars are orthoclase and microcline, barium feldspars are celsian and hyalophane, the soda-lime feldspars are the plagioclase series. Feldspars crystallised in monoclinic and triclinic systems.

Feldspars deficient in silica are the feldspathoids. They never occur with free quartz. They are similar to feldspars but their association with feldspars is rare. They are formed in place of feldspars when the magma lacks silica and rich in alkalis. The important varieties are leucite, nepheline, concrinite, sodalite, lazurite, hauyne, nosean etc.

The silica minerals have their chemical composition SiO_2 . They occur in various forms. These are the essential constituents of igneous, sedimentary and metamorphic rocks. The important mineral is quartz. The silica minerals are divided into three types namely crystalline, cryptocrystalline and cryptocrystalline hydrous minerals. The crystalline varieties are quartz, tridymite, cristobolite, the cryptocrystalline varieties are chalcedony, flint, zasper, chert. The cryptocrystalline hydrous minerals are opal and chalcedony.

The other important rock forming minerals such as Natrolite, Beryl, Zircon, Sphene, Kyanite, Sillimanite, Calcite, Corundum, Barytes, Chlorite, Staurolite, Serpentine, Talc, Apatite were also explained.

16.6 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The silicon and oxygen ratio in mica group is 4 : 10

2. Potash feldspars are orthoclase and microcline, Barium feldspars are celsian and hyalophane, the soda-lime feldspars are plagioclase series such as albite, oligoclase, andesine, labradorite, bytownite, and anorthite.
3. Sodalite, Nosean, Nephelene, lazurite, hauyne are the sodium feldspathoids.
4. Hexagonal system.

16.7 MODEL EXAMINATIONS QUESTIONS

I. Answer the following in about 30 lines each

1. Explain mica family of minerals
2. Describe the feldspar family
3. Write an essay on feldspathoid minerals

II. Write about the following in about 10 lines each

1. Silica minerals
2. Calcite
3. Berytes
4. Chlorite
5. Beryl
6. Sphene

BRAOU

BLOCK - V

PALAEONTOLOGY

BRAOU

UNIT - 17 : SCOPE AND APPLICATIONS OF PALAEOLOGY

Contents

- 17.0 Objectives
- 17.1 Introduction
- 17.2 Fossils
- 17.3 Scope of Palaeontology
- 17.4 Applications of Palaeontology
- 17.5 Summary
- 17.6 Check Your Progress - Model Answers
- 17.7 Model Examination Questions
- 17.8 Glossary

17.0 OBJECTIVES

In this unit we have discussed about fossils, palaeontology and the importance of fossils. After completion of this course, you should be able to -

- explain the term fossil
- describe the branch palaeontology
- explain the importance of palaeontology

17.1 INTRODUCTION

The remains of animals and plants of past age preserved in the rocks by natural processes of sedimentation and erosion are known as fossils. Marine animals are much more abundant as fossils than those which inhabited the continental lands.

Although life originated on earth more than 3000 million years ago fossils are abundant and of various kinds only from the Early cambrian. Precambrian fossil record is scanty.

Fossils are used extensively in stratigraphic and palaeoecological studies. They provide evidence in support of the theory of organic evolution.

The present-day marine environments and their respective faunal association are used as a general model for interpretation of ancient sediments and funas in relation to ecology. Fossils are an important tool in interpretation of the past ecosystems, palaeogeography and palaeoclimate.

Biostratigraphy is an important branch of stratigraphy. This branch deals with the spatial distribution and temporal relations of fossils and fossil bearing rocks. The different

biozone based on stratigraphic ranges of species and genera are used in local, regional and intercontinental correlation of rock formations. The stratigraphic systems, from Cambrian through Quaternary, were established on the basis of fossil content.

Fossils provided the most important evidence in support of several aspects of organic evolution. Dynasty after dynasty organisms appear as simple, adaptable, and easily modified forms. They spread into the many natural environments where they successfully reach a zenith of abundance and complexity. Under optimum conditions, they pass into old age with loss of racial vitality and ease of adaptability, finally disappearing from the scene. Senile races never take the backward trail to simplicity and renewed strength, rather they march on to inevitable extinction. This is the panorama of organic development that the palaeontologist visualises from his study of the fossil record left in the rocks by former organisms.

17.2 FOSSILS

The word fossil was introduced by the Romans for a peculiar object dug out of the earth. Later the term has been used to refer to organic relics preserved in the rocks.

The term fossil has been variously defined :

The remains of animals and plants of past ages preserved in the rocks are known as fossils. (Words, 1946). "Fossils are the remains or traces of any recognizable organic structure preserved since pre-historic time". (Stirton, 1959). A fossil is the remains of a plant or animal, or the record of its presence, Preserved in the earth". (Shimer, 1933). "Fossils are the remains or traces of animals or plants which have been preserved by natural cause in the earth's crust", (More, Lalicker and Fischer, 1952). "Any dead organism that is vulnerable to the natural processes of sedimentation and erosion may be called a fossil, irrespective of the way it is preserved or of how recently it died." (Brasier, 1980).

Whatever way a fossil is defined, it should possess the following characteristics :

1. It must have some evidence of the existence of an animal or plant that once lived.
2. It must furnish some idea of the size, shape, form, structure, ornamentation etc., or part or all of the organism.
3. A fossil must have age. The organism must have lived prior to the beginning of recorded human history. Accordingly, remains of life from Pleistocene (Ice Age) or older rocks are definitely fossil. But the modern definition appears to discard the concept of time.
4. Fossils must have been preserved in the materials of the earth's crust by natural agencies and processes.
5. Fossils, as such, do not necessarily represent extinct species. Some species of rodents in Europe and Australia were first found as fossils and later were discovered living on those continents.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. Define the term fossil.

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17.3 SCOPE OF PALAEOLOGY

Palaepontology is the study of ancient life through its fossil remains or the traces of its activity as recorded by ancient sediments. It is important because life on this planet has not always been as it is now. By studying the fossils in progressively older rocks, scientists attempt to establish an account of how all animal and plants which make up the modern biosphere evolved from their earliest beginnings. The geological training inclines the scientists towards using fossils to correlate rocks and establish the relative ages of rock units, their biological background inclines to working out how these animals and plants actually lived.

The incompleteness of the fossil record may be sufficient to mask many of the finer gradations in the evolution of life or perhaps the rock types under study do not contain the vital fossils needed for relative dating. The story of palaepontology is the story of how these and other obstacles have been and are being, overcome. Literally palaepontology means a 'discourse on ancient beings', but it has developed into a complex and exciting field which takes as its subject the biology, not just of one movement in geological time, but of the 3500 million years or so during which life has flourished on earth.

Palaepontology establishes the evolutionary development of life. By doing so, it helps the geologist to study rocks in order. It seeks to account for not only the regular minor extinction of individual species, but also the periodic mass extinctions which have, in the past, wiped out whole sections of the living world. By combining with the interpretations of the sedimentologists, it re-creates the environments in which fossil organisms once lived, and by applying engineering principles and the laws of reasons behind the design of mysterious skeletal features. Palaepontology is simply the history of nature, and the natural scientific answer to the question 'where do we come from?' with advances in our understanding many subdivisions have arisen and these are explained in the forthcoming unit no. 18.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. Define the branch Palaepontology ?

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17.4 APPLICATIONS OF PALAEOLOGY

To discover the changes, which have taken place on the earth in past geological times, the evidence furnished by fossils is of primary importance. Each great group of stratified rocks, known as a system is characterised by a particular assemblage of genera and species, some of which are confined to it and enable us to identify the system. In addition the knowledge of palaeontology is useful in arranging the different rock formations in a chronological order.

The nature of climate of past ages may be judged to some extent by the characters of fossils, the evidence furnished by land plants is particularly valuable, since their distribution is determined largely by temperature and is better marked than in the case of marine animals.

Study of fossil animals and plants is of highest importance, not only because they include the ancestors of modern species, but also because among fossil forms we find many groups which are all together extinct and which often throw light on the relationship of existing animals and plants. Another important application is in the subject of evolution; it is only by a study of the stratigraphical succession of fossil forms that the race-history or phylogeny of animals and plants can be traced with certainty.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. Describe any one application with Palaeontology ?

17.5 SUMMARY

The remains of animals and plants of past ages preserved in the rocks by natural process of sedimentation and erosion are known as fossils.

Fossil record shows that life of various organisms started from early cambrian, are precambrian fossil record is scanty.

The word fossil was introduced by Romans for any peculiar object dug out of the

earth. The term fossil is defined in many ways, but fossils must have certain characters: Those are fossils must show evidence of existence of the organisms, size, shape, form, structure, ornamentation etc. The organism must have lived prior to the beginning of recorded human history, fossils must have been preserved in rocks by natural processes and do not necessarily represent extinct species.

Palaeontology is the study of fossils. It is important to study fossils to know about the past, because life on this planet has not always been as it is now. By studying fossils the scientist can arrange the rock systems according to their ages in chronological order and also correlate with other rocks of same ages.

The evidence furnished by fossils is useful to know changes occurred on the earth surface in past geological times. The nature of climate of past ages may be judged using the characters of fossils. The study of Palaeontology has highest importance in the subject of organic evolution and also to know the ancestors of modern plants and animals.

17.6 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The term fossil has been defined variously. The remains of animals and plants of past ages preserved in the rocks are known as fossils.
2. Palaeontology is a branch of geology and is defined as the study of pre-historic life known as fossils.
3. The knowledge of Palaeontology is useful in arranging rock systems in chronological order, useful to know organic evolution, and to know the climatic changes in the past geological ages.

17.7 MODEL EXAMINATION QUESTIONS

I. Answer the following questions in about 30 lines each.

1. What is Palaeontology ? Explain its applications.
2. What is a fossil ? Explain how these are useful in organic evolution.

II. Answer the following questions in about 10 lines each.

1. Write down the scope of Palaeontology.
2. Briefly describe the character of fossil.

17.8 GLOSSARY

Fossil : Remnants of pre-historic life preserved in rocks.

Palaeontology : Study of fossils.

Biozone : Rocks deposited during the total time range of a species, as evidenced by the presence of fossils of the species.

UNIT - 18 : BRANCHES OF PALAEOONTOLOGY

Contents

- 18.0 Objectives
- 18.1 Introduction
- 18.2 Palaeoecology
 - 18.2.1 Basic Ecological Concepts
 - 18.2.2 The Marine Ecosystem
 - 18.2.3 Biologic activity and Ichonology
- 18.3 Organic Evolution with Fossil Record
- 18.4 Biostratigraphy
 - 18.4.1 Biozone
 - 18.4.2 Correlation of strata with fossils
 - 18.4.3 Stratigraphic range and zone fossils
 - 18.4.4 Kinds of biozones
- 18.5 Summary
- 18.5 Check Your Progress - Model Answers
- 18.6 Model Examination Questions

18.0 OBJECTIVES

In this unit, we expose you to different branches of Palaeontology. After completion, you should be able to

- explain the Palaeoecology
- define Organic evolution
- describe the Biostratigraphy

18.1 INTRODUCTION

The study of fossils is known as palaeontology. With advances in our understanding of Palaeontology, many sub divisions have arisen within palaeontology. The study of fossil plants is known as Palaeobotany and the study of fossil animals is known as palaeozoology. But the generally used term is palaeobiology to refer to the more interpretative biological aspects of the science. Study of the relation of plants and animals to their environment in the geological part is palaeoecology. The study of small fossils is known as micropalaeontology. This science has a special botanical branch, concerned with fossil spores and pollen called polynology.

The bases for the theory of organic evolution are fossils. So organic evolution is discussed here as a special topic. Biostratigraphy is concerned with the spacial distribution and temporal relations of fossils and fossil bearing rocks.

Palaeoecology, Organic evolution with fossil record and Biostratigraphy are discussed here.

18.2 PALAEO ECOLOGY

Ecology is the study of interrelationships between organisms and their environment and Palaeoecology is the same kind of study for ancient organisms. Ecological information is not preserved as such in rocks. What is now known is only the post-mortem history of organic remains (taphomy) and the burial process (biostratinomy) Yet palaeoecology can provide us with good knowledge about the history of life on earth.

18.2.1 Basic ecological concepts

The environment is the physical and biological surroundings in which organism lives.

The ecosystem consists of a chosen portion of physical environment plus all of the organisms contained in it. The habitat is the environment in which an organisms lives (for example, tidal flat and rocky shore). There may be more than one habitat in an ecosystem. Most habitats are occupied by several species, each with its own ecologic niche, ecological life and the role it plays in the ecosystem. Normally each species is represented by two or more individuals, which constitute a population. Populations of two or more species occupying a habitat compose a community.

In an ecosystem communities consist of producers which synthesize organic compounds from the environment in the form of photosynthetic plants, herbivores which consume these plants; carnivores which devour herbivores; parasites which feed upon living organisms without necessarily killing them-scavengers which feed on dead organisms; decomposers (bacteria) which break down the dead organic materials; transformers (mostly bacteria) which chemically alter the decomposition products and make them utilizable once again by producers. The sequence of species from producers through top level carnivores in any ecosystem is termed as food chain or food web. It is not easy to reconstruct a realistic food web of the palaeoecosystems but it is possible to assign fossil animals to their correct feeding type.

18.2.2 The Marine Ecosystem

To study the present day marine sediments and faunas palaeontologist developed a model. Several depth related zones are delineated in modern oceans as shown in fig 18.1 and defined below.

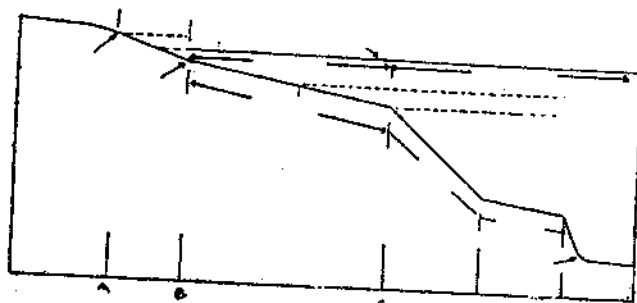


Fig. 18.1 Schematic diagram of environmental zones
A = Land, A-B = Inter tidal zone, B-C=Continental shelf, C-D=Continental slope,
D-E=Abyssal plane, E=Trench.

Littoral : Inter tidal zone,

Sublittoral : low tide to - 180m; continental shelf and shallow epicontinental sea,

Bathyal : continental slope and continental rise from 180m to about 4 km.

Abyssal : Abyssal plains from 4 km. to 5 km.

Hadal : Trenches below - 5 km.

Organisms living in marine ecosystem are commonly classified as shown below:

Benthos (benthonic) are bottom dwellers. They include epifaunal types living on the sea floor or seaweeds and infaunal types living buried within the sediment. Benthonic forms capable of locomotion are called vagile and immobile forms, sessile.

Pelagic organisms are those that live in the water above the bottom. Nektonic forms are swimmers. Planktonic forms are transported primarily by waves and currents. Phytoplankton are microscopic plants and zooplankton, microscopic animals.

Benthonic organisms are also classified into four groups, according to their feeding habit. **Carnivores** which feed mainly upon other animals, whether living or as carrion; **suspension feeders** which feed by selecting from the surrounding water the suspended micro-organisms and detritus; **deposit feeders** which feed upon the detritus deposited on the bottom, together with its associated micro-organisms; **grazers** which feed by selectively removing organic surface films (chiefly algal coatings) from the substratum.

The main controls which effect the distribution of recent and fossil animals are the nature of the substrata temperature, salinity, depth of water and water turbulence. Based on the studies of fossils, it is possible to interpret these factors relating to any environment as also the palaeoclimatic and palaeogeographic features of any particular geological period.

Most palaeoclimatic studies that have used fossil data have mainly dealt with faunas and floras of the Cretaceous and Cenozoic periods. Fossil plants are excellent climatic indicators. Coral reefs grow only in areas where the temperature seldom falls below 18°C. Nearly all living reefs lie within about 30° Latitude of the equator. The fossil coral reefs have thus been used as palaeoclimatic indicators of former tropical, or near-tropical climates. The fossil plants from the Cenozoic strata of Spitzbergen in the Arctic Ocean, the great profusion of corals in the "Silurian" of island of Gotland in the Baltic Sea, and the fossil ferns and primitive sponges found on Antarctic all prove that these areas had a much warmer climate than the climate that prevails there today.

18.2.3 Biologic activity and ichnology

Ichnology is the study of behaviour of once living animals by examination of the tracks, trails, borings, and workings, which they made during their life-period. These are called trace fossils or ichno fossils.

Even without represented skeletal parts, many organisms have left fossil evidence of their presence and way of life in the form of trace fossils. Thick triassic redbed sequence of the Connecticut valley (USA) was deposited in swampy lowland areas. No bones of the dinosaurs that lived at that time were preserved because of the unfavourable warm humid

climate of the region. But tracks on bedding surface reveal the presence of several dinosaur species. Many sedimentary rocks barren of fossils show evidence of abundant benthonic life through the presence of trace fossils. A sequence lacking in trace fossils may be interpreted as having been deposited in an anoxic environment. Trace fossils have been of immense value in understanding the explosion of life at the Precambrian - Cambrian boundary because trace fossils have never been used directly in analysing the life habit and locomotion of trilobites and other Arthropods.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. Name the depth zones in modern oceans.

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18.3 ORGANIC EVOLUTION WITH FOSSIL RECORD

The modern theory of organic evolution is a result of the collective efforts made by palaeontologists, geneticists, morphologists, and systematic neontologists. Evolution is an extremely complex process and only a few salient features are stated here.

With the passage of time, as generation of individuals of a species of plant or animal are reproduced, the average set of physical characteristics of the population of individuals undergoes change. This change is termed organ evolution. Some changes produced are described as acquired characteristics which cannot be passed on to another generation. Other changes can be inherited that is, transmitted from one generation to the next.

Genes which are the units of genetic material contained in the reproductive cells of the organism provide a mechanism of transmission of changes from one generation to another. Each gene is responsible for the replication of a particular characteristic of the organism. No adult individual of a species is identical in all respects to either parent, to any sibling (except identical twins) or to any offspring. This is because genes of two individuals are exchanges in the process of sexual reproduction. This process of production of individual differences (variation) is known as recombination.

A second mechanism of inherited change is known as mutation, which is sudden change, in a gene, or a group (gene pool). Mutations may arise by random fixation of new chromosomal combinations in sexual reproduction, as gene mutations which apparently involve a change in the composition of the chemical unit that makes up the gene, or by a loss of one quater of the parental genes, as in small population in genetic drift. Mutations are thought to have been caused by exposure to X-ray radiation and radio-active radiation, or to certain substances, by temperature changes. The mutations, however, are slight in comparison with the more persistent characters in the race that are inherited from the parents and their immediate ancestor.

Gene mutations, new chromosomal combinations in sexual reproduction, and loss of one fourth of parental genes in small Populations, then, are thought to produce the variability we see in interbreeding populations or in the individuals etc. In every population some individuals produce more offspring than others. Greater fecundity (number of offspring produced), sexual activity, and other factors succeeding populations will result in greater number with these qualities. As a result, natural selection progressing towards adaptive features will favour those that contribute most to the gene pool of the interbreeding population. Thus the fittest are not necessarily the ones that appear to be the most physically fit. They may possess other qualities that make them more suited to survive in all extremes of their environment. This differs from the Darwinian concept.

While the environment changes, as it does almost continuously to a lesser or greater degree, those individuals with the hereditary potential to cope best with these changes will tend to survive in greater number and to invade and sustain themselves in other ecological niches, for various reasons not available to their predecessors. In this way the environment is the directive force in evolution, though the environment does not directly change the genetics of the organisms.

Contribution of fossil record to our understanding of evolution : The fossil record contributes little to our understanding of the basic mechanism of evolution, but is our sole source of documentation for the large-scale evolution of life. Without the fossil record, large-scale organic evolution would remain a hypothesis instead of being an accepted fact.

Fossil record has contributed five principal types of information to our understanding of evolution in relation to phylogenetic relationships among major taxonomic groups, time of appearance of major adaptations, and rates, trends and patterns of evolution.

Extinction : Extinction is a dominant feature of life history and has a strong influence on evolutionary patterns. When an environment becomes unfavourable, the choice left for a population living in it is to become adapted to the changed environment, migrate to a more favourable area or die out. When a population of a species cannot adapt one of the first two mechanisms, it becomes extinct, leading to termination of lineage. A species may also become extinct when phyletic changes have so accumulated that the organism is judged to be a new species. This type of extinction is called phyletic extinction.

Relict groups : Certain taxa persist in limited regions long after their counterparts have died out elsewhere. This has become possible because of the geographic isolation of the regions where they are protected against higher predators. Examples: 1. The persistence of blastoids in the eastern hemisphere during the late Palaeozoic; 2. Many articulate brachiopod taxa, Nautilus, marsupials, and the primitive bivalve Neotrigona persist in the Australia - New Zealand region. In both marine and terrestrial realms, this region has apparently maintained some degree of biogeographic isolation for many millions of years.

Mass extinction : Instances are numerous in the fossil record that show groups of higher categories faced mass extinction within relatively limited spans of time. Mass extinction occurred at the ends of Cambrian, Ordovician, Devonian, Permian, and Triassic periods, and also during the late Cretaceous and the Pleistocene times. The late Permian and the late Cretaceous mass extinctions represent the greatest faunal crisis unparalleled in the long history of the organic world. The former led to the extinction of fusulinid foraminifera, Productoid brachiopods, and many bryozoan and ammonoid taxa. The later crisis eliminated the dinosaurs, and the previously existing ammonites and several gastropod and bivalve taxa.

Major extinctions have always coincided with widespread volcanic and organic activity, accompanied by changes in atmospheric and oceanic temperatures; widespread emergence of continental shields and mountain belts, at times sharply reducing the areas of shallow seas, which have caused drastic environmental changes.

Rapid extinctions of large groups of organisms lead to vacant environment, and these are rapidly filled by adaptive radiation of other groups of organism. Fossil record amply demonstrates that major episodes of extinction and subsequent rapid evolutionary radiation mark the transition from one geologic era to the next.

Phylogenetic relationship : Phylogenetic relationships among taxonomic groups are determined from both biologic information and the fossil record.

Taxonomic relationships of the extinct groups are determined by establishing affinities with phyla that have living representatives. For example the graptolites were established as hemichordates because of their resemblance to living Pterobranchs. On the other hand, certain extinct groups, such as the archaeocyathids of the Cambrian system defy classification with recognized living groups. Such groups are commonly termed "problematica".

There are certain living taxonomic groups whose affinities are understood largely through study of the fossil record. For example the subungulate mammals include modern-day colonies (small rodent - like forms), elephants, and sea cows. The fossil record shows that these strikingly different groups have basic similarities among their primitive Tertiary ancestors on the continent of Africa, where they apparently shared a common ancestry.

The fossil record occasionally provides a missing link in a species that represents a transitional stage between higher taxa. Example: The reptile-like bird Archaeopteryx, of the Middle Jurassic, possessed both reptilian and avian characters, providing the transition link between the two taxa.

In general, it is much easier to establish phylogenies for major vertebrate groups than for major invertebrate and plant groups because all recognized classes and orders of the vertebrates have originated since the cambrian. Invertebrate animals fall into several phyla whose late precambrian and cambrian origins are undocumented by the known fossil record. Although all higher vascular plants taxa have apparently originated since the early palaeozoic, the fossil record of plants is less complete.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. What is Archaeopteryx ?

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18.4 BIOSTRATIGRAPHY

Stratigraphy is concerned with the study of stratified rocks, their classification into ordered units and their historical interpretation. It bears not only upon past geological events but also upon the history of life. The three main branches of stratigraphy are litho-, bio- and chronostratigraphy. Lithostratigraphy is based on the rock characters and is only of real value within a relatively small region. In the stratigraphic column based on lithostratigraphy the basic rock unit is the formation. Formations may be clubbed together into higher rank units called groups, or divided into lower rank units called members and beds. Chronostratigraphy organises the sequence of rocks on a global scale into chronostratigraphic units which are referred to a single standard geological time scale. The conventional chronostratigraphic units used are system, series and stage. Erathem, a unit larger than system and chronozone, a unit smaller than stage are also used by some.

18.4.1 Biozone

Biostratigraphy is broadly concerned with all spatial distribution and temporal relations of fossils and fossil-bearing rocks. In biostratigraphy the stratigraphic record is subdivided into biostratigraphic units based on fossil occurrences. The fundamental biostratigraphic unit is known as a biozone (the term zone is used with reference to local sections), which represents all rocks throughout the world that were deposited during the time interval in which a species lived. No species is present in all rocks of its biozone, and the reasons for this situation are many.

1. A new species arising from a preexisting one can spread throughout areas of the earth's surface if there were no effective barriers. Oceans are barriers to terrestrial animals and land masses to marine animals. However, species spread aided by such agents as floating logs, bird and strong winds across major barriers. Land corridors (for example, the isthmus of Panama) facilitated migration. Planktonic larvae of many shallow water benthonic species were transported across the deep oceans by major currents.

2. Even within their geographic ranges, species can generally inhabit only certain types of local environment. As a result, many fossil species are restricted to certain rock types. Such fossils may be known as 'facies fossils'.

3. Sharp temperature changes and abrupt physiographic barriers restrict group of species to certain regions, which are called faunal or biogeographic provinces. Species confined to any province are termed endemic. The main faunal provinces of the present continental shelves are tropical shelf, warm temperature, cold temperature and polar regions whose limits are defined by latitude but also by the warmer or colder water marine currents, that flow from one regions to another. Today's faunal provinces have existed throughout most of the cenozoic.

18.4.2 Correlation of strata with fossils

Correlation is the matching of strata of formation from outcrop to outcrop (or from well to well underground) to determine synchrony of biologic and geologic events as recorded in the different rock formations. Correlation may be local, regional or intercontinental. Correlation with the help of fossils is based on two criteria: 1. In a given line of descent the less specialised forms occur in the older rocks and the more advanced in younger

formations; 2. When a species becomes extinct it never appears again. This the principle of the irreversibility of evolution. If animals had not evolved, correlation of rocks with fossils within a sedimentary basin would be difficult, and correlation between basins almost impossible.

18.4.3 Stratigraphic range and zone fossils

Most stratigraphic work is based on studies of vertical fossil distribution in local stratigraphic sections. First, a stratigraphic column is erected based on lithology. Secondly, levels of appearance and disappearance of fossil species are recorded. Stratigraphic interval bounded by its lowest most and upper most occurrences is the stratigraphic range of the fossil species. The stratigraphic ranges of one or more specified kinds of fossil delimit a biozone and such fossils are called zone fossils. Ideally, zone fossils should possess the following characters:

- 1) a wide horizontal distribution, preferable intercontinental;
- 2) a short vertical range so that they could be used to define very precise part of the geological column;
- 3) enough morphological characters to enable them to be identified and distinguished easily.
- 4) strong hard shells to enable them to be commonly preserved,
- 5) independence of facies - normally free-swimming animals fulfil this condition.

A biozone fossil assemblage is sometimes contaminated by what are known as reworked and leaked fossils. Reworked fossils are derived from reworking of older rocks and can be differentiated from indigenous fossils. Leaked fossils are the organic remains leaked from younger sources. For example, Eocene fossils in saline series of salt range are believed by some to be leaked fossils.

18.4.4 Kinds of biozones

Four main kinds of biozones are in use:

Assemblage Zone : An Assemblage zone is the body of strata with a certain natural assemblage of fossils without regard to their ranges. Example: Meekoceras assemblage zone of spiti (Triassic of Himalayas). The assemblage zone, being controlled by the environment, is of use only in local correlation.

Characteristic fossils of an assemblage zone are termed guide fossils or index fossils. Example: Meekoceras lilangense, M. Varadha, Xenodiscus radians and Aspidites spitiensis are the index fossils of Meekoceras assemblage zone. Planktonic and nektonic species are generally the best marine index fossils. Many ordovician and silurian graptolite taxa and mesozoic ammonite taxa have provided good index fossils. Benthonic species, such as cambrian trilobites and late palaeozoic fusulinid Foraminifera are good index fossils. Sudden morphologic changes within species and genera can also be used for correlation, especially of rocks of caenozoic era. Shell coiling reversal in Globorotalia menardii (a planktonic foraminifera) has been used for recognition of the Pliocene-Pleistocene boundary in deep sea sediment cores.

Range Zone : A Range Zone is the body of strata representing the total horizontal and vertical range of occurrence of one particular species, genus or other taxon. Examples : *Miscellanea miscella* range zone, *lystrosaurus* range zone; *Psiloceras planorbis* (ammonite) Range Zone defined that lowest zone of the Jurassic of Europe. Each range zone is always named after a particular species which occurs within it. Range Zones are perhaps of more general application.

Where there are a number of zonally useful species or where the ranges of individual species are long, a more precise definition may be given by the use of overlapping stratigraphical ranges. Such zones are called concurrent range zones.

Acme or Peak Zone : An Acme Zone (epibole) is a body of strata representing the maximum abundance of a particular species, genus or other taxon (but not necessarily its total range). The zone takes its name from the taxon whose zone of maximum development it delimits. Example: *Glossopteris* Acme zone in the flora from Raniganj formation of middle to upper Permian. Acme zones may be narrow but are often useful as marker horizons in geological mapping. Acme zones are useful locally.

Interval Zone : An interval zone represents an interval between two distinct biostratigraphical horizons. It may not have any distinct fossils, or may be barren of fossils. It is simply a convenient way of referring to a group of strata bracketed between two named biostratigraphically defined zones.

Biostratigraphic systems, from Cambrian through Quaternary, were established on the basis of fossil content. The system boundaries were fixed at major faunal and floral breaks. Some boundaries representing distinct evolutionary changes or extinctions that occurred during short time intervals on a world-wide scale.

Systems have been subdivided into series, and series into stages, also on the basis of fossils. The units systems, series and stages are called time-rock units, implying that they are isochronous units. The bounding surfaces of isochronous units are everywhere the same age. Thus, systems, series and stages are all recognized primarily on the basis of biostratigraphic equivalence. Many workers now desire that geologic systems be redefined in places other than the original type areas, using boundaries recognizable within fossiliferous rocks, rather than the rock units themselves. Accordingly, a system could have its lower boundary defined in one place and its upper boundary defined elsewhere. The type section for each boundary could be so selected that the boundary would be defined by good index fossils contained within rocks formed by nearly continuous deposition.

Radiometric age determinations have provided an absolute geologic time scale although it is not without defects. But such age determinations are of little value in local correlations, especially for rocks well back in the stratigraphic record.

Fossils give a relative chronology which continues to be the primary basis of chronostratigraphy. The relative sequence given by the fossils is only supplemented and enhanced by absolute dates. It is most unlikely that radiometric dating will replace the fossil data as a tool for correlation.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. What is meant by Acme ?

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18.5 SUMMARY

Palaeontology is the study of fossils. There are many divisions in palaeontology. Palaeobotany deals with plant fossils, where as palaeozoology is the study of animal fossils. In general many scientist are using the term palaeobiology for the combination of both plant and animal fossils. Palaeoecology is the term used for the study of fossil communities. The study of microfossils are known as micropalaeontology. Orgnic evlution is one of the topics of palaeontology. Biostratigraphy is concerned to spacial distribution and temporal relations of fossils and host rocks.

There are so many branches but only the important ones like Palaeoecology, Organic evolution and Biostratigraphy are discussed in this unit.

Ecology is the study of interrelationship between organisms and their environment. Palaeoecology is also the same kind of study mainly concerning about ancient organisms and the then climatic conditions. Palaeoecology can provide us a good knowledge about the history of life on earth. The ecosystem consists of physical and biological environments with the all organisms. The food chain or food web squence is useful in palaeoecology to assign fossil animals to their correct feeding type. In order to know the past ages marine ecosystem scientists developed a model based on present marine system. In this depth zones were marked for different depths from shoreline as littoral, sublittoral, bathyal, abyssal, and hadal zones. The Benthos are bottom dwellers, most palaeoclimatic studies that have used fossil data have mainly dealt with faunas and floras of the cretaceous and caenozoic periods.

The modern theory of organic evolution is result of the collective efforts of palaeontologists, morphologists, genetecists and systematic neontologists. The fossil record contributes five principle types of information to our understanding of evolution in relation to phylogenetic relationships among major taxonomic groups, time of appearance of major adoptations and rates, trends and pattern of evolution. Phylogenetic information among taxonomic groups are determined from both biologic and fossil informations. Taxonomic relationships of the extinct groups are determined by establishing affiniteis with phyla that have living representations.

Stratigraphy is concerned with the study of stratified rocks, their classification into ordered units and their historical interpretation. Biostratigraphy is broadly concerned with the spacial distribution and temporal relations of fossils and fossil bearing rocks. Correlation

is the matching of strata of information from out crop to out crop to determine synchrony of biologic and geologic events. Four kinds of biozones are in use namely assemblage zone, range zone, acme or peak zone, and interval zone. Radiometric age determinations are little value in local correlations, where as fossil record is much useful in chronostratigraphy.

18.6 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The depth zones in modern oceans are littoral, sub littoral, bathyal, abyssal and hadal.
2. The reptile-like bird with teeth, of middle Jurrassic period is the Archaeopteryx.
3. An Acme zone is a body of strata representing the maximum abundance of a perticular species, genus or other taxon.

18.7 MODEL EXAMINATION QUESTIONS

I Answer the following questions in about 30 lines each

1. Explain how the fossil record is helpful in palaeocological studies.
2. Explain the role of fossils in stratigraphic studies.
3. What are the specific evidences the fossil record has provided in support of the theory of organic evolution?

II Explain the following in about 10 lines each

1. Palaeoecology
2. Biozone
3. Kinds of Biozones
4. Correlation

UNIT - 19 : CONDITIONS AND KINDS OF FOSSILISATION

Contents

- 19.0 Objectives
- 19.1 Introduction
- 19.2 Conditions of Fossilisation
- 19.3 Kinds of Fossilisation
 - 19.3.1 Unaltered remains
 - 19.3.2 Altered remains
 - 19.3.3 Objects indicating the presence of organisms
- 19.4 Pseudofossils
- 19.5 Fossil Record and its Imperfections
- 19.6 Uses of Fossils
- 19.7 Summary
- 19.8 Check Your Progress - Model Answers
- 19.9 Model Examination Questions

19.0 OBJECTIVES

In this unit, an attempt is made to present the conditions and kinds of fossilisation. After completion, you should be able to

- describe the conditions of fossilisation
- explain the kinds of fossilisation
- define Pseudofossils
- describe the uses of fossils

19.1 INTRODUCTION

The soft, fleshy tissues of an organism may be preserved in certain exceptional circumstances, but the possession of hard parts vastly increases an animal or plant's chances of being successfully fossilised. For any organic life, some conditions are necessary to become fossil. Fossilisation is the process of transformation of organic life of prehistoric ages into fossils. This involves several kinds of preservation.

19.2 CONDITIONS OF FOSSILISATION

Fossilization is the sum of the process involving the burial of a plant or animal in sediment and eventually preserving in full, part, or a trace of it. For an animal or plant to become fossilized two conditions are generally necessary :

1. It must possess a hard skeleton of some kind or other, since the soft parts are rapidly decomposed. Soft-bodied animals, such as Jelly fishes leave no trace of their existence.

2. The organism must be quickly buried in a protective medium, such as soft mud or volcanic ash, or else it soon is decayed and decomposed by bacteria, and crumble to pieces. On continental lands a greater number of terrestrial animals after death will be exposed and will soon be entirely decomposed. The exceptional places of fossilisation on the land surface are : peat-bogs, dust and ashes thrown out by volcanoes, sand and sand-dunes, landslides, deposits of travertine thrown down by calcareous springs, and stalagmites formed on the floor of limestone caves. Animals and plant remains of land origin may be transported by rivers and ultimately buried in a river bed, or lake, or sea.

Since preservation by a protective covering is a first condition for fossilisation, animals and plants which live in the aquatic sites (especially the seas) have a much better chance of becoming fossils than terrestrial organisms. For this reason, marine animals are much more common as fossils than those which lived on land.

3. The structure and composition of the hard parts (skeleton) play an important role in fossilisation.

- a. If the shell is thin, it is easily broken up during preservation. Because their skeleton is very strong and not easily destroyed many molluscs and corals occur abundantly in fossil form.
- b. The hard parts may consist of a horny substance known as chitin (as in insects), of silica (as in diatoms, radiolarians and sponges), of carbonate of lime (as in many animals and some plants), and of woody or corky tissue (as in most plants). During fossilisation and preservation chitin is dissolved with difficulty and silica is readily removed by the action of percolating water. Calcite being more stable than aragonite, shells of calcite are preserved better than argonitic shells.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. What are the two main conditions for fossilisation ?

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19.3 KINDS OF FOSSILISATION

Ancient organisms are preserved in the following kinds.

- I. Unaltered remains : i. The entire organism preserved.
- ii. The skeleton preserved almost unchanged.

- II. Altered remains : i. Petrification ;
ii. carbonisation (distillation).

III. Objects indicating the former presence of organism :

- i. moulds, casts and impressions ;
ii. Tooth marks ;
iii. Coprolites;
iv. Gastroliths ;
v. Trace fossils (ichnofossils).

19.3.1 Unaltered remains

1. The entire organism preserved. In certain conditions, animals may be preserved as such with no change from the original state. Extinct woolly rhinoceros and mammoths have been preserved in cold storage in the frozen tundra of northern Siberia for over 25,000 years. The preservation is so perfect that the eyes, skin, blood, flesh, and even partly digested vegetation in the stomach remain much as they were when the animal died. Insects encased in fossil resin, known as amber, are found in the oligocene beds on the Baltic shores but their soft parts are not preserved.

2. The skeleton preserved almost unchanged. Thousands of mammalian bones and many molluscan shells from Tertiary strata in different parts of the world, and the countless branchiopod shells in the Upper Cambrian strata have suffered little alteration since burial.

19.3.2 Altered remains

1. **Petrification.** Petrification literally means "transformation into stone." This may occur by gradual addition of a chemically precipitated substance into pore spaces (premineralization) or by a molecular exchange of substances that were once part of the organism, with other substances carried in by percolating water solutions (replacement). The majority of fossils have undergone more or less alteration since their burial.

The common petrifying or replacing substances and how they change the original remains are described below :

Silica. The best replacement agent is silica. The fossil logs in the petrified forest of Arizona (USA) are one of the best examples. Silicified trees, logs and wood are found in cretaceous formations of Tiruchirappalli district, Tamil Nadu. Much of the original woody material was dissolved and replaced by molecules of silica. When sectioned and polished, the cell structure of the fossil wood can be observed under the microscope. Most fossil wood is preserved in this way. The process is sometimes referred to as histometabasis.

Collophane. Nearly all fossil bone tissue is petrified by collophane or calcite. Little is silicified. Collophane is an amorphous, hydrous, calcium-carbonate phosphate mineral residue of organic bone tissue and phosphorite rock. After the animal matter in the bone disappears percolating solution in the sediments deposit collophane.

Calcite. Calcium carbonate is carried in solution in underground water and may be added to the original porous structure of bone or shell. Once hard parts are well premineralized in this way they appear to be turned to stone. Without chemical analysis it is impossible to

differentiate between collophane and calcium carbonate methods of preservation.

Iron oxides. Sometimes fossils are infiltrated by certain iron compounds, such as hematite, limonite, or vivianite.

Iron sulphide. Calcareous bones in some fossils are replaced with pyrite which is probably formed from the interaction of iron in the sediments and sulfur derived from decaying organic matter. Unfortunately, it is not a satisfactory method of preservation, since oxidation of the pyrite causes the specimens to disintegrate.

In rare cases there are other replacing minerals, such as sulphate of lime, barytes, galena, malachite, and spathic iron.

2. Carbonisation (Distillation)

When animals with chitinous skeletons, such as graptolites, or plants are buried quickly in fine-grained sediments the volatile organic materials are distilled out, leaving a residue of carbon.

This carbonfilm shown an outline of the soft parts that usually lost in fossils. The marine reptile ichthyosaurs is preserved by the carbon-film method in the dark shales of Bavaria, Germany. The coal deposits (fossil fuel) are preserved by this method.

19.3.3 objects indicating the presence of organisms

1. Moulds, casts and impressions : When a fossil shell or bone is buried in fine-grained sediments, the surrounding silt settles tightly around it. When the shell material is progressively removed by leaching a void is left in the rock. The surface features of the original shell are left impressed on the wall of the void. This is called the external mould. If the cavity on the inside of the shell, such as a bivalve shell, is filled with sediment and if that filling is preserved, it become internal mould. External and internal moulds, then, are negative of the original. Sometimes though setting of the strata the external mould comes into contact with the internal, and the external ornamentation thus becomes impressed upon the internal ornamentation and thus becomes impressed upon the interior markings, as in many brachiopod and pelecypod shells from the palaeozoic period. When the hollow or void between the external and internal molds is filled with mineral matter a cast is formed. Such a cast will bear an exact surface likeness to the original shell, but will lack entirely its internal structure. In museums plaster of Paris casts are made of fossil specimens for detailed studies.

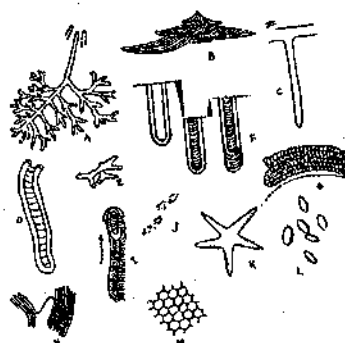


Fig. 19.1 Common types of trace fossils (Modified from Clarkson 1979)

A=Chondrites, B=Zoophycus, B=Skolithos, D=Rhizacorallium E=Thalessinoides, F=Diplocraterion, G=Nereites, H=Helminthoids, I=Crusina, j=Vertebrate footprints, K=Asteriacites, L=Pelecypodichnus, M=Net-like structures of certain origin.

There are other impressions which are without thickness. The impressions of leaves are preserved in shales and limestones. When a leaf falls upon soft mud, it will impress there its form and surface markings, later the leaf will be blown away by the wind. If this impression or mould be covered by sediment, the imprint is preserved without the leaf itself being enclosed. The venation, the outline, and other diagnostic features are clearly preserved. The oldest Jurassic bird *Archaeopteryx* is preserved this way.

2. **Tooth Marks :** Rodents frequently grow on flesh bones before these bones are buried. Later these bones, clearly showing the tooth marks, are preserved as fossils. Many fossil bones from cave deposits show tooth marks.

3. **Coprolites :** Fossil dung or excrete of many ancient animals, especially of fish and reptiles, are known as coprolites. They may be in the form of straplike markings, nodules and pellets. They are phosphatic in composition. They often contain such indigestible remnants of the animals food as fragments of scales, bones, teeth, or shells. Recent deposit, known as guano, are largely due to the excrement of sea birds and of such marine mammals such as seals.

4. **Gastroliths :** Highly polished stomach stones from the gizzards of birds or the stomachs of reptiles are also fossils. Such stones have been found within or near the rib baskets of dinosaurs, and no other stones like them were found in the formations where the skeletons were preserved.

5. **Trace fossils :** Certain sedimentary structures, such as tracks, trails, burrows, etc. which are related to organic activity are described as trace fossils or ichnofossils or (Fig. 19.1) These fossils may be often be the only evidence of life in a sediment if body fossils were not preserved.

19.4 PSEUDOFOSILS

An inorganic form very often mistaken for true organic remains is the dendrite. Dendrites are crystalline structures of branching form resulting from a colloidal solution. These branching incrustations, formed usually of manganese dioxide, are common, either enclosed, as in moss agate, or merely as surface markings.

Fossil objects due to inorganic agencies

Many objects due to inorganic agencies are often called fossils. Ripple marks, mud cracks and rain-drop imprints preserved in sedimentary strata are included in this category.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. What are pseudofossils ?

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19.5 FOSSIL RECORD AND ITS IMPERFECTIONS

Fossils of invertebrates and other animals, and of plants preserved in rocks of the earth's crust are extraordinarily numerous and highly diversified. They constitute the fossil record. But the known fossil record is, as a guide to the evolution of ancient life, unquestionably limited, patchy and imperfect for various reasons.

1. At present the oldest known fossils are recorded from Green land. Yeast-like microfossils are about 3800 million years old. Our present knowledge of the fossil record of the Precambrian sediments older than 570 million years is very meager. Fossils of invertebrate animals in considerable numbers occur only from early Cambrian onwards. Over two million species of animals and one third of a million of plants are known to be living today. New species of plants are being discovered at the rate of 4,750 per year and new species of animals at the rate of 10,000 per year. By contrast, only about 130,000 fossil species have been described and named. This figure is woefully too low for the fossil record that spans hundreds of million years while the fauna and flora represent only an instant of geologic time. Extinct animals which have successively appeared and disappeared since life originated on the earth must be a staggering figure, estimates of which range from 50 million to 4 billion species. But only a very small fraction of the animals and plants of this multitude has been preserved and often in an imperfect manner.
2. Some animals without hard parts are not preserved while others, particularly land animals, have limited chances of entombment in sediment.
3. Most of the Precambrian organisms are microscopic and submicroscopic in size and await discovery.
4. The remains of animals which are originally present in the rocks have been dissolved by underground waters. Some fossils, preserved in rocks, especially limestones, have been obliterated, and even destroyed when the rocks were metamorphosed.
5. Denudation has removed large thicknesses of fossil-bearing rocks, causing breaks in the succession of strata. Breaks are also caused by a temporary absence of sediment deposition.
6. The modern ocean basins are very young geologically, the oldest sediments known there being of Triassic age. Even these sediments are approaching a subduction zone and will be consumed there without trace. Contrary to the earlier belief, the ocean basin sediments do not provide clues to the life more ancient than Triassic.

19.6 USE OF FOSSILS

Fossils are of great value

- 1) as stratigraphic indicators, for correlation of deposits containing them and for determination of relative geologic age;
- 2) as record of past forms of life, showing the course of evolutionary modifications of animals and plants during geologic time, and

- 3) as evidence of changing environments and geographic patterns during geologic history.

Some details of how palaeontological data have been utilised in the areas of stratigraphy, palaeoecology and organic evolution, are described in unit no. 18.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. State the uses of fossil

19.7 SUMMARY

Fossilisation is the process of burial of any plant or animal in sediment and preserving all, part or a trace of it. Two conditions are important for fossilisation. One is the organism must possess a hard skeleton and the second one is quick burial in a protective medium such as soft mud, volcanic ash. The important locations for fossilisation are peat-bags, dust and ashes of volcanoes, sand of sand dunes, deposits of travertine thrown by calcarious springs and stalagmites.

Ancient organisms are preserved mainly in three kinds. Unaltered remains, altered remains and objects indicating the former presence of organism. In certain conditions extinct woolly rhinoceros and mammoths have been preserved in cold storage in total as entire organism. Many skeletons and shells have suffered very little alterations.

Petrification and carbonation are the two methods in altered remains kind. Petrification means transformation into stone. The material may be silica, collophane, calcite, iron oxides, iron sulphides etc. Carbonation is other method where distillation process occurs and carbon material fossil will appear. The important objects indicating the presence of organisms are moulds, casts, impressions, tooth marks, coprolites, gastrolites and trace fossils.

An inorganic form very often mistaken for true organic remains is called pseudofossil. Ripple marks, raindrop imprints, mudcracks and dendrite are pseudofossils.

The fossil record is a guide to the evolution of life, but this record is limited, patchy and imperfect for various reasons. An important imperfection is about the figure of extinct animals. There may be more. Only hard parts are preserved as fossil but there is no record of soft bodied and extinct. Most of the precambrian period organisms are sub microscopic and await discovery.

Fossils are mainly useful in stratigraphic correlation and determination of geologic age of rock formations. They are also useful as indicators of evolution of plants and animals

and are also showing evidence of changing environments and geographic patterns during geological ages.

19.8 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Hard skeleton and quick burial in the protective medium.
2. Inorganic forms like dendrite appear as fossils, but actually they are not fossils and therefore they are called pseudofossils.
3. Fossils are useful as indicators of evolution, palaeoecological condition and stratigraphic correlation of geologic rock formations.

19.9 MODEL EXAMINATION QUESTIONS

- I. Answer the following questions in about 30 lines each.
 1. What are fossils ? Write down the conditions of fossilisation.
 2. What are the kinds of fossilisation ? Explain the uses of fossils.
- II. Explain the following in about 10 lines each.
 1. Pseudofossils
 2. Moulds, casts and impressions
 3. Uses of fossils
 4. Fossil record and imperfections.

UNIT - 20 : CLASSIFICATION OF ORGANISMS

Contents

20.0	Objectives
20.1	Introduction
20.2	The cell
20.3	Kingdoms of life
20.4	Major phyla
20.5	Summary
20.6	Check Your Progress - Model Answers
20.7	Model Examination Questions
20.8	Glossary.

20.0 OBJECTIVES

In this Unit, we have attempted to make understand the classification of Organisms. After reading this Unit, you will able to

- describe the cell-unicellular and multicellular organisms.
- classify the kingdoms of life.
- list out the major phyla
- explain the morphology.

20.1 INTRODUCTION

Matter on the earth is either organic or inorganic. Organic matter comprises living animals and plants having various organs for eating, breathing, and reproduction. The animals and plants together form the 'biosphere' or the living world. The rest of the matter such as that in air, earth, and water is called inorganic. The basis of the living matter is the protoplasm which has two important properties : (1) Chemically it always contains proteins or albumins and (2) Physiologically it has the power of waste and repair, of growth and of reproduction. These two properties distinguished the protoplasm (the living matter) from the inorganic matter.

20.2 THE CELL

The fundamental unit of an organism is cell. A unit cell is usually provided with an outer cell membrane. The membrane protects the softer cell material within, called the protoplasm (or cytoplasm). Vacuoles (small bubbles within the protoplasm) are filled with food products or water. They serve to nourish the cell or to regulate the salt and water balance. A darker, membrane-bound by, the nucleus, helps to control both vegetative and sexual division of the cell and the manufacture of the proteins. Other small bodies

concerned with vital functions such as locomotion within the cell are the organelles. Other organelle that can occur in abundance are the chloroplasts (chloroplasts). These contain chlorophyll or similar pigments for the process of photosynthesis.

There are unicellular and multicellular organisms. Unicellular organisms are of two kind (1) Prokaryotic organisms which lack a nucleus cell vacuoles and organelles in the cell. Proper sexual reproduction is unknown. (2) Eucaryotic organisms which are nucleate with division and sexual reproduction. All multicellular organisms are eucaryotic.

Nutrition : An organism can build up its body by two basic ways : By heterotrophy or by autotrophy. In heterotrophy the organism captures and consumes living or dead organic matter. In autotrophy the organism synthesises organic matter from inorganic matter by the process of photosynthesis. Quite a number of groups of organisms employ these two methods together. They are therefore known as mixotrophic.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. What are autotrophy and heterotrophy

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20.3 THE KINGDOMS OF LIFE

Living individuals all belong to naturally isolated units called species. Species may be defined as groups whose members will interbreed and (except for sex difference) are more like one another than any members of another similar group. The individuals which are the ultimate items of classification can thus be grouped into species the species combines into genera (singular genus), the genera into families, the families into orders, orders into classes, the classes into phyla (singular, phylum), and the phyla into kingdoms. The highest category (or division or taxon) is the kingdom or superkingdom. The taxon, phylum in animals is defined on the basis of major structure differences. The corresponding taxon in plants is the 'division' and is defined largely on structure life history and photosynthetic pigments. In this scheme (the hierarchical classification of Carolus Linnaeus, the Swedish Naturalists), the smaller the category, the more similar are its members (Table 20.1). The name of the species consists of two parts (binomial nomenclature), the generic name and the trivial name. For example, the scientific name for a dog is *canis familiaris*.

KINGDOM	ANIMALIA	ANIMALIA	ANIMALIA
PHYLUM	ARTHROPODS	CHORDATA	CHORDATA
Class	Crustacea	Mammalia	Mammalia
Order	Decapoda	Carnivora	Primatida
Family	Nephrosidae	Canidae	Homonidae

Genus	Homarus	Canis	Homo
Species	Homarus americanus	Canis familiaris	Homo sapiens
Individual	a common lobster	a pet dog	Rama, Sita

Table 20.1 Hierarchy of Taxonomic Groups

Organisms are traditionally divided into two kingdoms of the plants and animals. The former are autotrophs and the latter heterotrophs. Many groups of unicellular organisms collectively known as protista which abound in the aqueous environments appear to straddle the plant/animals boundary. These organisms are both heterotrophic and autotrophic. To create some order in the extraordinary diversity of unicellular organisms their predominantly autotrophic representatives were assigned to the plant kingdom as protophytes or phytoflagellates and placed in various algal phyla. The predominantly heterotrophic unicellular organisms, on the other hand, remained at the base of the animal kingdom as protozoans. However, this division ran into problems with both the heterotrophic fungi, which had previously been treated as plants, and a group of unicellular organisms without nuclei. These unicellular organisms (prokaryotes) are distinct from all other organisms whose cells do have nuclei, i.e. the eukaryotes. The classification of Whittaker (1969) overcomes these anomalies recognising two superkingdoms and five kingdoms. The classification of Whittaker as presented by Lehmann and Hillmer (1980) is shown below :

- I **Superkingdom : Prokaryota (unicellular organisms without nuclei)**
 1. Kingdom : Monera
 1. Subkingdom Bacteria
 2. Subkingdom Cyanophyta (blue-green algae)
- II **Superkingdom : Eukaryota (having cells with nuclei)**
 2. Kingdom. Protista (unicellular organisms with nuclei)
 1. Subkingdom protophyta (prominently autotrophic unicellular organisms, 'lower algae')
 2. Subkingdom protozoa (predominantly heterotrophic unicellular organisms)
 3. Kingdom : Fungi
 4. Kingdom: plantae
 5. Kingdom : Animalia

The Monera are single celled but they lack a nucleus, cell vacuoles and organelles. This primitive prokaryotic condition, in which proper sexual reproduction is unknown, is characteristic of the division Cyanophyta (blue-green algae) and the division Schizomycophyta (bacteria). The other four kingdoms are eukaryotic. Their cells are nucleate with vacuoles and organelles, and are capable of properly coordinated cell division and sexual reproduction.

The protista are mobile unicellular organisms with rather varied body plans. Some, like the dinoflagellates (division pyrrophyta), have whiplike flagella for locomotion, and photosynthetic pigments. Hence they resemble the true plantae and are probably close to the ancestral line of that group. The foraminifera and the radiolarians (Phylum Sarcodina) engulf their food with the aid of mobile pseudopodia, whilst the tintinnids (phylum Ciliophora) have a coat of bristle like cilica and ingest their food through a mouth.

surrounded by tentacles. These heterotrophic protists are therefore more akin to animals than to plants.

The multicellular and largely non-mobile algae and the higher land plants both belong to the Kingdom plantae. Their remains are, for the most part, the concern of palaeobotany.

The Fungi are heterotrophic, feeding by absorption of pre-formed organic material.

The kingdom animalia comprises multicellular invertebrate animals and vertebrate animals that feed by ingestion of pre-formed organic matter, either alive or dead. Zoologists recognize approximately 20 phyla in the animal kingdom. The exact number is variable because certain small groups are allocated to the major phyla by some or treated as separate phyla by others. The division of animal kingdom into various phyla is based on several characteristics, degree of organization, type of symmetry, presence and kinds of spaces within the body, absence or presence of an anus, division of body into segments. Possession of limbs of one sort or another, nature of excretory, respiratory, and skeletal systems, and pattern of development of these features of organization.

The simplest animals are included in the phylum porifera. The structure of soft parts as well as hard skeletons becomes more and more complex from the porifera through the Chordata. Thus, the birds, reptiles and mammals which have the most complex body structure in all respects are included in the phylum chordata. Although, in the present book, we are mainly concerned with the fossil record left by invertebrate animals, a brief description of the different phyla is also given in order to enable the student appreciate the evolutionary trends in the animal kingdom through the long geologic time. In addition, in view of their great importance and application in several kinds of geological studies, a lesson is devoted to a study of Foraminifera which belong to the kingdom protista.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. What is the sequential order of classification.

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20.4 MAJOR PHYLA

Major phyla of the kingdom animalia are as follows :

1. Phylum porifera
2. Phylum Coelenterata (cnidaria)
3. Phylum Ctenophora

4. Phylum platyhelminthes
5. Phylum Nematohelminthes
6. Phylum Trochelmintehs
7. Phylum phoronida
8. Phylum Bryozoa
9. Phylum Brachiopoda
10. Phylum Mollusca
11. Phylum Annelida
12. Phylum Arthropoda
13. Phylum Echinodermata
14. Phylum Hemichordata
15. Phylum chordata

Phylum Porifera (Latin, porous : pore, ferre: to bear)

This phylum includes the sponges, the simplest of the multicellular animals. Cells show incipient organization into tissues; lack organs. They possess radially symmetrical sac-like body, open at the top and with the wall perforated by numerous canals. Water is taken in through many small openings, bringing in food and expelling waste materials through a single large opening. Reproduction is by asexually budding or of organic fibres, sponging.

There are approximately 3,000 recent species.

The porifera are usually colonial in habit and occur primarily attached to rocky bottoms in warm, shallow marine waters. The flexible skeletons of bath sponges with the living protoplasm removed are of considerable economic value.

Geological time - Cambrian to Recent

Phylum Coelenterata (Greek, Kilos: hollow, enteron: inside cavity)

This phylum includes such soft-bodied animals as the hydroids, jellyfish and sea animals which are rarely preserved as fossils, and the corals. There are approximately 10,000 recent species.

The Coelenterata show an advance over the sponges in several ways. Tissues well developed and include three layers of cells, but organs only slightly developed. Middle cell layer develops largely from external layer. Large central body cavity with single opening, the mouth. Mouth encircled by tentacles, bear 'stinging' cells. Some have skeletons of CaCO_3 . Radial or biradial or biradial symmetry; a few with bilateral symmetry, some colonial.

The phylum Coelenterata is one of the best represented in the fossil record. The Coelenterata fossils (corals) are of great stratigraphic importance.

Geological time - Cambrian to Recent

Phylum Ctenophora

The ctenophora are small, free-swimming, jellyfish like marine animals. No skeleton. Lack 'stinging' cells. Tentacles do not encircle mouth. Bear plates of cilia for swimming. Biradial symmetry, None colonial, Medial cell layer (mesoderm) developed from internal cell layer. The Ctenophors are not known in the fossil record.

Phylum Platyhelminthes (Greek, platy: flat, helminthes: worm)

The planarians, flukes, tapeworms, and ribbon worms are included in this phylum. Tapeworms and flukes are dreaded parasites in man and other animals. Over 6000 recent species are recorded.

Tissues developed; some organs differentiated, bilateral symmetry; flattened, head slightly differentiated. There is no positive fossil record of flat worms. Some of trails and burrows found in pre-Cambrian rocks are believed to have been made by these animals.

Phylum Nematohelminthes (Greek. nemotos: thread, helminthos: worm)

The Nematohelminths are also called roundworms. Most are parasites. Ascaris, the largest of the intestinal worms, hookworms, pin-worms and trichina, are some of the commonest kinds. The plant parasites of this phylum cause enormous damage to agricultural plants, usually by attacking the roots. The group is not known in the fossil state. The long, slender, 'horsehair worms, Gordiacea and the parasites spiny headed worms, Acanthocephala are usually included in one phylum with the roundworms. The Gordiaceans are frequent in freshwater pools and streams.

Phylum Trochelminthes (Greek. trochos: wheel, helminthos : worm)

Rotifers are microscope organisms living in slow-flowing streams, ponds, and pools. Some live in brackish and salt waters. Others are parasitic. The movement of the cilia around the mouth is suggestive of a rotating wheel. No fossils of this group are known.

Phylum Phoronida

The two living phoronid genera Phoronis and Phoronopsis are distributed worldwide and live in dense colonies on muddy or sandy substances. They are microscopic living in branched colonies on muddy or sandy substrates. They also bore system of closed vessels. Secrete a chitinous envelope. It is likely that this phylum has existed since the mesozoic.

Phylum Bryozoa (Greek, bryon: moss, zoon: animal)

The Bryozoa are microscopic animals living in branched colonies attached to different objects. They form carpet-like or thin films as incrustations over rocks, shells, or other kinds of life in marine waters. Only a few kinds live in fresh waters. The structure of the lophophore (circular or horseshoe-shaped ridge around mouth which bears a circle of tentacles) is suggestive of relationships with the branchiopods. The body structure is more advanced than in coelenterates. There are approximately 3000 living species.

Bilaterally symmetrical, not segmented, body cavity between wall of gut and body wall, cavity formed within medial cell layer and is lined completely by cells from this layer. Gut looped to bring anus near mouth. Circle or horseshoe of ciliated tentacles around mouth.

No respiratory organs, hermaphroditic, eggs fertilised in body cavity, colonies developed by asexual budding, skeleton of CaCO_3 .

Geological time - Ordovician to Recent.

Phylum Brachiopoda (Greek, brachios, arm, pods : foot)

The brachiopods provide very important fossil record in the Palaeozoic. Superficially, they show a marked resemblance to bivalve molluscs (pelecypoda), but structurally they are much closer to some of the less advanced phyla. A majority of them live in marine waters. Some live in brackish and estuarine waters. About 120 recent species are known.

Bilaterally symmetrical, body elongate, usually divided into segments may bear pairs of appendages. Well developed nervous, excretory, circulatory and respiratory systems. Head not strongly differentiated. Internal body cavity relatively large. Separate sexes with trochophore larvae, united sexes or asexual reproduction by budding.

Geological time - Proterozoic to Recent

Phylum Mollusca (Latin, mollis : soft)

The molluscs are another very important group of invertebrates because so many are preserved in the fossil record. They have become widely adapted to life in marine waters, in streams and lakes, and even on land. There are approximately 70,000 living species.

Soft, unsegmented, bilaterally symmetrical bodies, without lophophore, muscular foot or locomotion. Head differentiated, well developed circulatory, nervous, respiratory and excretory systems. Spaces of internal body cavity reduced in size. Circular system includes spacious cavities about organs. Differentiated dorsal skin the mantle. Sexes usually separate, fertilization external or internal, mostly oviparous. Most have calcareous shell of one or more pieces.

Geological time - Cambrian to Recent

Phylum Annelida (Latin, annelus: little ring)

The phylum Annelida includes the earth worm, the leeches, and the marine worms, Polychaetes. Annelids were well diversified by middle Cambrian time. Trails and burrows are also indicative of their presence as early as the Proterozoic. Chitinous, horny, or siliceous jaws are the hard parts usually preserved as fossils. About 7000 recent species are known.

Bilaterally symmetrical, body elongated, usually divided into segments may bear pairs of appendages. Well developed nervous excretory, circulatory and respiratory systems. Head not strongly differentiated. Internal body cavity relatively large. Separate sexes with trochophore larvae, united sexes or asexual reproduction by budding.

Geological time - Proterozoic to Recent.

Phylum Arthropoda (Greek, arthro : joint, pods : foot)

This phylum includes the onychophorids, crustaceans, trilobites, spiders, centipeds, millipedes, and insects. The arthropodes are by far the most successful animal phylum inhabiting all environments at all suited for life, in the sea, on land, and in the air. Insects are the only invertebrate animals capable of flight in the air. With over one million recent species they alone represent 75% of all known present day species. Ninety percent of present - day arthropod species belong to the class insecta. The arthropods were already in existence at the beginning of the cambrian with highly evolved forms.

Bilaterally symmetrical, body usually segmented and jointed into head, thorax, and abdomen, paired, jointed appendages. External skeleton of chitin, the skeleton in some is impregnated with CaCO_3 . Circulatory system includes large spaces around organs. Internal body cavity reduced in size. Sexes usually separate, fertilization nearly always internal, oviparous egg - laying or ovoviviparous (eggs hatched in body), one to several larval stages.

Geological time - Cambrian to Recent

Phylum Echinodermata (Greek. echinos : hedgehog, derma: skin)

This phylum includes such sessile groups as the cystoids, blastoids (sea bus), crinoids (sea lillies and feather stars), and such free moving animals as the sea cucumbers, starfish 'sea urchins, heart urchins, and sand dollars. Echinoderms were abundant in the palaeozoic, only the crinoids are still living. Approximately 5000 species are known.

Primitive bilateral symmetry masked by secondary radial, typically pentamerous, symmetry. Torsion of viscera in development changes position of mouth and anus. System of radial canals and associated structures called water vascular system. Skeleton of calcareous plates and spines developed in medial cell layer just below skin. Sexes separate, ova fertilized in sea.

Geological time - Cambrian to Recent.

Phylum Hemichordata

This phylum includes acorn worms, tunicates, lanceletes and the extinct graptolites. The phylum is of great phylogenetic significance for two reasons and secondly it includes the extinct graptolites which provide by far the most important and accurate guide fossils for the Ordovician and Silurian.

Bilateral symmetry. Some have traces of axial supporting rod, the notochord. No water vascular system. Gill slits between anterior gut and external surface. Nervous, excretory, circulatory systems moderately well developed. Some colonial. Chitinous skeleton in some. Anus terminal.

Geological time - Cambrian to Recent.

Phylum Chordata (Greek. chorda : string)

This phylum includes all the higher vertebrate animals (lampreys, fish, amphibians, reptiles, birds and mammals). Chordates live in almost every environment in water, on land, and in the air. About 65,000 species are recorded.

Notochord and gill slits well developed, at least in embryo. Nervous, excretory, circulatory, and respiratory systems well developed and segmented. Most have internal skeleton of bone and / or cartilage. Anus subterminal.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. From which group number of fossils occur ?

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20.5 SUMMARY

Matter on the earth has been divided into organic and inorganic. All the living things such as plants and animals are organic, and the minerals, rocks etc are inorganic. The basis of living organism is protoplasm, which is useful for metabolic activities. The fundamental unit of any organism is the cell. An organism can build up its body either by heterotrophy or by autotrophy. In autotrophy mainly the plants synthesise by photosynthesis, where as in heterotrophy mainly the animals capture and consume living or dead organic matter. All the living organisms are classified in the order of kingdom, phylum, class, order, family, genus and species. Many groups of unicellular organisms are collectively called as protista, and these are both autotrophic and heterotrophic. The multicellular and largely non-mobile algae and the higher land plants come under the kingdom of plantae. The kingdom animalia comprises multicellular vertebrate and invertebrate animals.

There are about 20 major phyla in general but about 15 are important in palaeontology. They are porifera, coelenterate, ctenophora, platyhelminthes, trochophorinthes, phoronida, bryozoa, brachiopoda, mollusca, annelida, arthropoda, echinodermata, hemichordata, chordata.

Phylum Porifera includes mainly sponges and are approximately about 3000 recent species. The geological age is from cambrian to recent. Phylum coelenterata comprises of soft bodied jelly fish like sea animals and are about 10,000 species. The geologic age is cambrian to recent. The phylum ctenophora includes small, swimming, Jelly fish like sea animals and all are extinct. Phylum platyhelminthes comprises of planarians, flukes, tape worms and ribbon worms and are 6,000 species. Their geological age precambrian. Some furrows of cambrian ages are believed to have been made by these worms.

Phylum nematohelminthes consists of parasitic roundworms. No fossils were identified. Phylum trochelminthis consists of rotifers and has no fossil record. Phylum phoronida includes microscopic organism living in branched colonies on muddy and sandy substances and are existed since the mesozoic. Phylum bryozoa consists of microscopic organisms living in branched colonies and are approximately 3,000 living species. Their

geological age spread over ordovision to recent periods. Phylum branchiopoda provides very important fossil record and are bivalved shell animals of proterozoic to recent period. Phylum mollusca consists of 70,000 living species and so many are preserved as fossils from cambrian to recent. Phylum annelida includes earthworms, beeches etc. Phylum arthropoda consists of onychophoroids, crustaceans, trilobites, spiders, centipedes, millipedes and insects and their geological period is from cambrian to recent. Phylum hemichordata includes mainly extinct graptolites. Phylum chordata includes all the higher vertebrate animals from ordovision to recent periods.

20.6 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Autotrophy comprises of plants and will generate food from photosynthesis, where as heterotrophy group consists of animals and these will depend on other organism for food.
2. Kingdom, Phylum, class, order, family, genus, species is the sequential order of classification.
3. Molluscans are many, which are fossilised.

20.7 MODEL EXAMINATION QUESTIONS

I. Answer the following questions in about 30 lines each.

1. Explain the Phyla Animal Kingdom.
2. List the creteria used in modern classification of organism.

II. Answer the following questions in about 10 lines each.

1. How does organic difer from inorganic matter?
2. Describe the cell
3. What are procaryotic and eucaryotic cells?

20.8 GLOSSARY

- Autotroph** : An organism utilisation inorganic materials as food.
- Cilia** : Numerous short, hair-like processes on surface of cell. Occur in many animals.
- Cytoplasm** : Semi-fluid, living portion of cell surrounding the nucleus.
- Dinoflagellate** : Single-celled microscopic organism with both 'plant, and animal' characteristics. Place in Division pyrthophyta, kingdom protista.
- Flagellum** : Long, slender, whip-like process extending from cell (plura, flagella).
- Hermaphrodite**: An animal or plant having both the male and female organs of generation.

- Heterotroph** : An organism capable of utilizing only organic materials as a source of food (pre-formed food).
- Lophophore** : Circular or horseshoe - shaped ridge around mouth which bears a circlet of tentacles.
- Notochord** : A rod-like cord of cells that forms the chief axial supporting structure of the lower chordates.
- Nucleus** : Dense body suspended in interior of living cell. Bears Place in most of hereditary material and controls most of cellular activity.
- Oviparous** : Producing eggs that mature and hatch after being expelled from the body.
- Ovoviviparous** : Producing eggs that are hatched within the body, so that the young are born alive but without placental attachment.
- Pseudopodia** : Lobate or thread-like extensions of cell periphery that change in shape, character, and position with activity of cell (singular, pseudopod).
- Sessile** : Attached by the base, or without any distinct projecting support.
- Tintinnid** : A microscopic unicellular organism covered with numerous cilia. Placed in phylum Ciliophora of kingdom protista.
- Tentacle** : Slender arc like extension of cell periphery of variable length and shape like a pseudopod but of fixed position.
- Valve** : One of the two convey (rarely flat or concave) calcareous plates that lie on either side of soft body. The two valves are articulated along a dorsal hinge line.
- Viscera** : The organs in the cavities of the body, especially those in the abdominal cavity.

BRAOU

BLOCK - IV

FOSSILS - MORPHOLOGY

BRAOU

UNIT - 21 : FORAMINIFERA AND CORALS

Contents

- 21.0 Objectives
- 21.1 Introduction - Foraminifera
 - 21.1.1 Test Morphology
 - 21.1.2 Classification
 - 21.1.3 Geological History
 - 21.1.4 Use of Foraminifera
- 21.2 Corals
 - 21.2.1 Class Anthozoa
 - 21.2.2 Living conditions of corals
- 21.3 Summary
- 21.4 Check Your Progress - Model Answers
- 21.5 Model Examination Questions
- 21.6 Glossary

21.0 OBJECTIVES

In this Unit, we have discussed about foraminifera and corals. After reading this Unit, you will be able to

- describe the morphology of Foraminifera
- explain the classification of Foraminifera
- describe the class Anthozoa (Corals)
- define the living conditions of corals

21.1 INTRODUCTION - FORAMINIFERA

Kingdom :	Protista
Phylum :	Sarcodina
Class :	Rhizophoda
Order :	Foraminifera

The Foraminifera are an order of single-celled protists. They live on the sea floor and also in the surface water layers of oceans. Those that live on the bottom are known as benthic foraminifera and those that live in the surface waters as planktonic foraminifera. The protoplasm of the cell is enclosed within a shell (test). The test is composed of tectin (organic matter), and mineral substances (calcite, aragonite or silica) secreted by the animal or of

agglutinated particles gathered from the substrate. The chambers are interconnected by an opening (foramen) or several openings (foramina). This group Foraminifera takes its name from their foramina. They are mostly microscopic organisms less than 1mm in size. As microfossils they are next to none in importance:

Geological age : Cambrian to Recent:

21.1.1 Test Morphology

The foraminiferid is composed of one or more chambers. When more than one chamber is present, the initial one proloculus is generally the smallest. The chambers are separated by septa whose intersection with the test will form a line of contact called suture. The primary orifice through which the protoplasm leaves and enters the test is called the aperture.

Shape and chamber arrangement: Unilocular (single chambered) tests are sac-shaped, globose, radiate, tubular, branched tubular, planispiral, irregular, hemispherical. The arrangement of chambers in multilocular (many chambered) tests may be uniserial, biserial, triserial, biserial-uniserial, triserial - biserial - uniserial, annular, quinqueloculine (Fig. 21.1)

Coiling : The coiling in foraminiferid tests may be involute, evolute, trochospiral.

Aperture : The aperture is the principal orifice in the wall of the final chamber. The aperture may be single or multiple. In shape, the aperture may be circular, radiating, slit-shaped, chevron shaped, loop shaped, hooded, sieve-like (cribrate), arcuate, crescentic etc. In position, the aperture may be terminal, peripheral, sutural, umbilical, extra-umbilical (Fig. 21.2)

Ornamentation calcareous tests exhibit a varied superficial sculpture consisting of spines, keels, rugae, fine striae, costae, granules. Agglutinated forms rarely exhibit ornamentation (Fig. 21.3).

Chamber wall : The composition and structure of the chamber wall are of great importance in the classification of foraminifera. The test wall may have chitinous, agglutinated, calcareous or siliceous composition. Chitinous walls appear to be the most primitive. Fossil examples are not well known. Agglutinated walls are commonly composed of a layer of chitinous material covered by a cap of cemented material particles. All agglutinated foraminifera are benthic. Calcareous walls are composed of aragonite or calcite crystals. Siliceous walls are rare.

There are different types of calcareous wall structure; 1. microgranular walls, 2. poecelaneous walls, 3. radial hyaline walls, 4. finely granular hyaline walls, 5. monocrystalline walls, and 6. spicular walls.

Chamber Development : In multilocular tests, chambers are added one after another. Where there is no overlap of previous chamber walls by the new wall, the arrangement is termed non-laminar. If overlap occurs, layers of successive walls are formed and this is a multilaminar condition. Each lamina may also be composed of two distinct lamellae, the arrangement being known as bilamellar. Where the lamellar structure is only visible with electron microscope, the wall may be called cryptolamellar. Different types of lamellar walls have been used in classification of the Foraminifera.

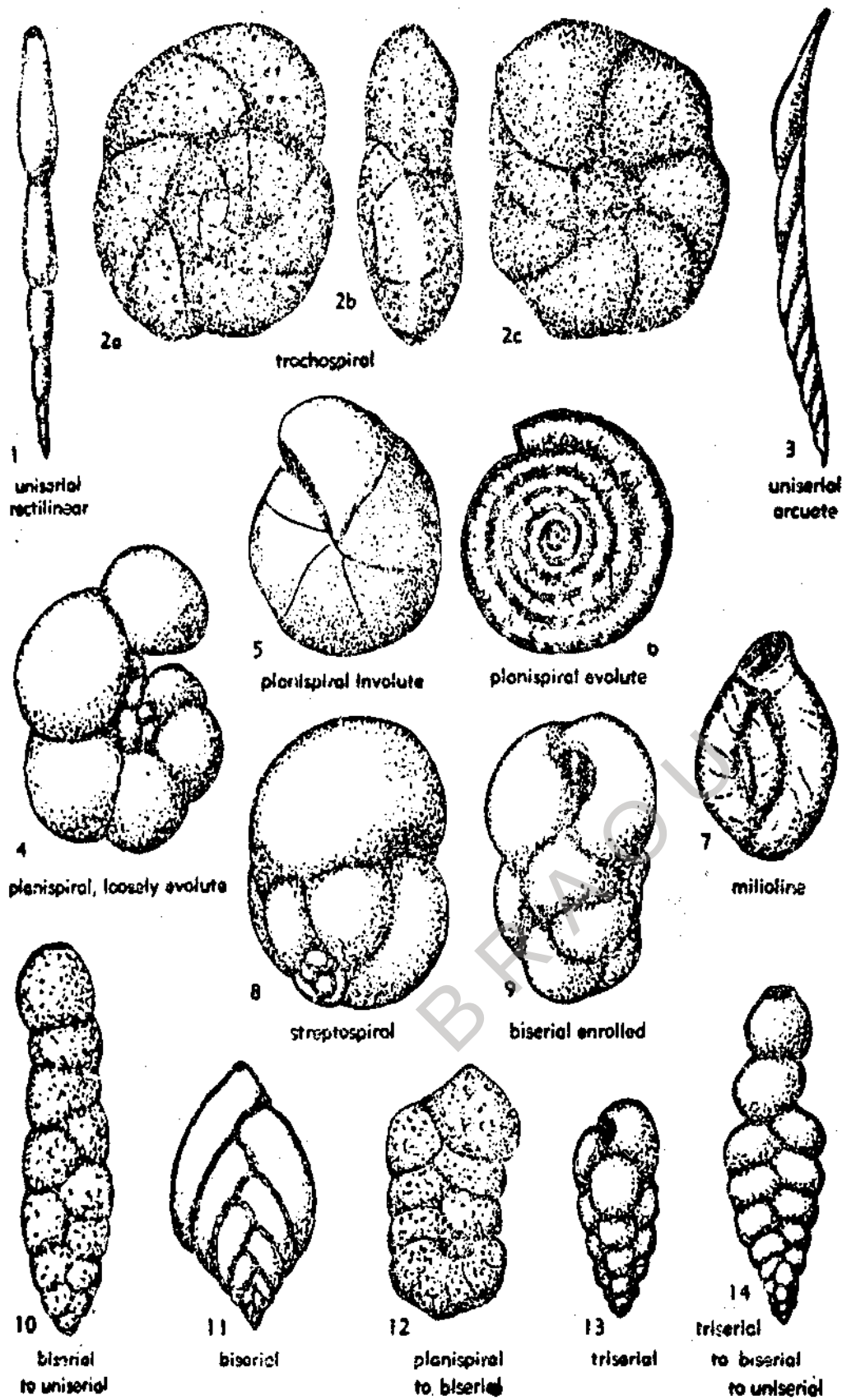


Fig. 21.1 Arrangement of chambers in foraminiferal test.

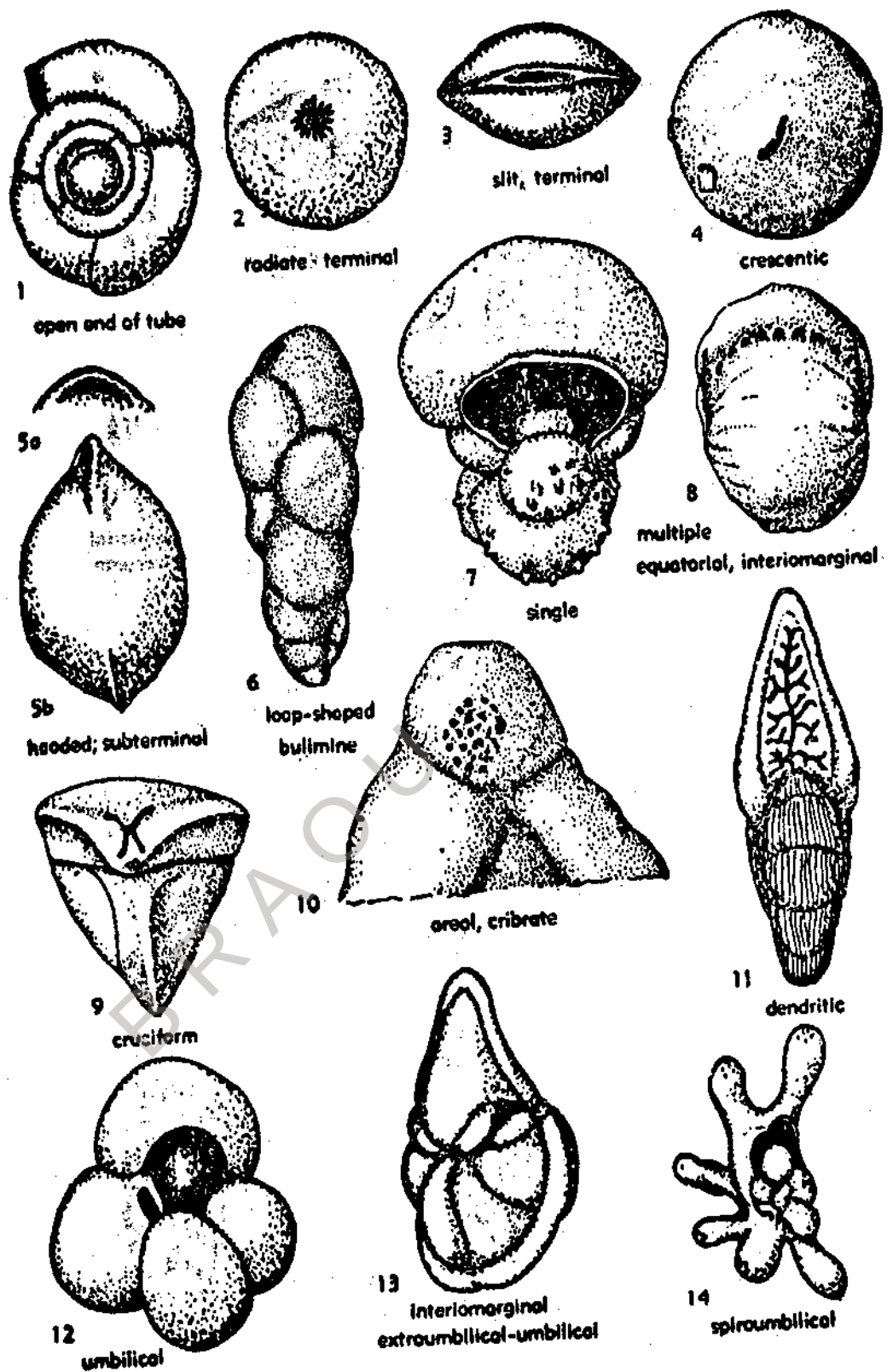


Fig. 21.2 Location form of primary apertures in foraminiferal test.

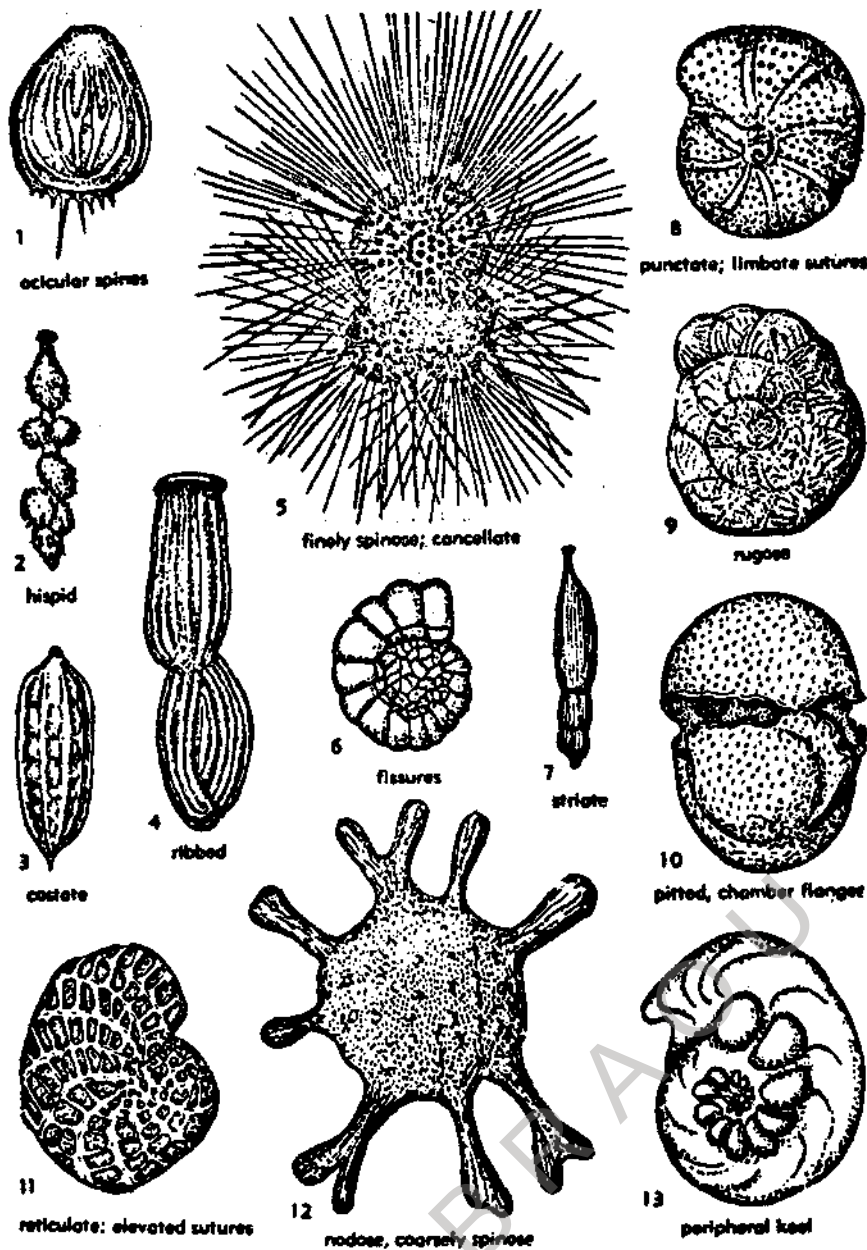


Fig. 21.3 Ornamentation of oraminiferal of test

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. What are the different shapes of test in Foraminefera ?

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21.1.2 Classification

On the basis of wall composition and structure, chamber shape and arrangement, aperture, and ornamentation, the order Foraminifera is subdivided into 5 suborders and 19 superfamilies (Table 21.1). The order Foraminifera is also divided into three artificial groups which are in common use : 1. Larger (benthic) foraminifera, 2. Smaller (benthic) foraminifera, and 3. Planktonic foraminifera is applied to groups which include large individuals (more than 1 mm diameter), with complex endoskeleton structures. The families shown below constitute the large foraminifera group:

Table 21.1 Classification of Foraminifera

Suborder	Superfamily	Wall composition	Wall structure
Allogromina and	Lagynacea	Tectinous	Non-laminar, mostly imperforate
	Ammodiscacea	Agglutinated	Non-laminar, imperforate
Textularina	Lituolace		perforate
	Parathuramminacea		
	Endothyracea	Calcareous	Microgranular, non-laminar
	Fusulinacea		Non-laminar
Miliolina	Miliolacea	Calcareous	porcelaneous imperforate
	Spirillinacea		
	Nodosariacea		
	Bilininacea		
	Duostominacea		
	Robertinacea		
	Discorbacea	Calcareous	
Rotalina	Globigerinacea		Multilaminar, hyaline perforate
	Rotaliacea		
	Orbitoidacea		
	Casidulinacea		
	Nonionacea		
	Carteinacea		

Superfamily : Fusulinacea (extinct)

Superfamily : Miliolacea

Family : Soritidae

Family : Alveolinidae

Superfamily : Orbitoidacea

Family : Discocyclinidae (extinct)

Family : Lepidocyclinidae (extinct)

Superfamily : Rotaliacea

Family : Miogypsinidae (extinct)

Family : Nummulitidae

Smaller benthic foraminifera comprise the majority of individuals and species.

Planktonic species live in the surface water layers of the ocean. They lack self-locomotion and are transported horizontally by the oceanic current system. The planktonic forms accumulate and form the deposit known as Globigerina ooze on the deep ocean floors. The superfamily Globigerinacea include all the planktonic species.

Characters of important sub-orders and super families are described.

Sub-order Allogramina

These foraminifera have an entirely organic test with only one chamber. They are rarely preserved as fossils and are geologically insignificant.

Sub-order Textularina

The Textularina are characterised by elongated and biserial test. They have non-laminar wall with a tectinous inner and an agglutinated out layer. Aperture round simple and terminal, often absent. Two superfamilies are included: the Ammodiscacea, which are mostly unilocular and the Lituolacea, which are multilocular.

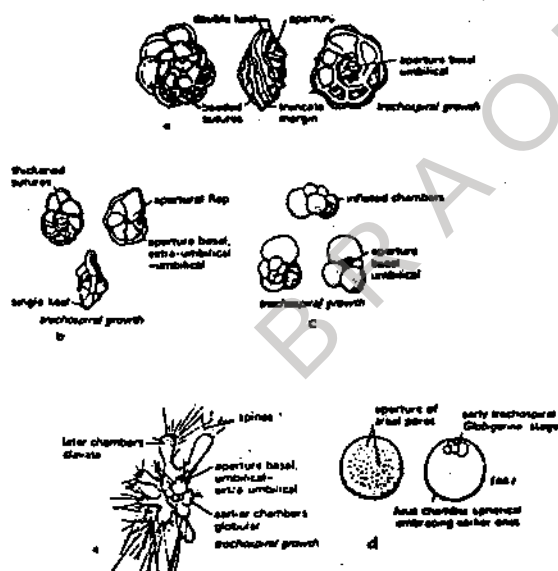


Fig. 21.4 Superfamily Globigerinacea (a) Globotruncana (b) Globorotalia (c) globigernia (d) Orbolina (e) Hestigerinella

Sub-order Fusulinina

The foraminifera of this suborder have non-laminar, calcareous, microgranular walls. The group was largely Palaeozoic in age, becoming extinct in the Triassic.

Superfamily Fusulinacea : The fusulines are extinct larger forms. They have microgranular perforate test, but with chambers arranged planispirally in a discoidal to fusiform plan. Two kinds of wall structure are found. The ancestral, fusulinid wall is primarily two-layered with a dark, partly organic outer tectum and an inner, clear diaphanotheca. Secondary deposition of a dark epitheca within the chamber may give the inner walls a four layered appearance.

Superfamily Globigerinacea : The planktonic Globigerinacea typically have trochospirally coiled tests with inflated, coarsely perforate chambers bearing fine spines during life. the wall is composed of optically radial and bilamellar low magnesium calcite. The primary aperture is also found. The planktonic species Globotruncana, Globorotalia and Orbulina are widely used for correlation (Fig. 21.4)

Superfamily Rotaliacea : Wall is built of optically radial bilamellar calcite. Generally growth is planispiral or trochospiral, with a biconvex, lenticular test profile. Nummulites are rotaliacean larger foraminifera widely used in correlating Eocene rocks from around the Tethys Ocean. (Fig. 21.5) Miogypsinids are also larger foraminifera (Middle oligocene to Lower Miocene).

21.1.3 Geological History of Foraminifera

There are no convincing fossils of foraminifera from Precambrian rocks. Ammodiscacean fossils have been reported from early Cambrian rocks. Pre-Ordovician records of calcareous foraminifera are not definitely established.

Foraminifera with hard tests were certainly rare until the Devonian. The Fusulinia began to flourish from Devonian, the fusulinids reaching acme of their development in late Carboniferous and Permian times. The suborder became extinct at the end of the Palaeozoic.

The Mesozoic Era Witnessed a great development of the foraminifera. The Rotalina appeared and radiated largely from endothyracean ancestors. Miliolina and complex textularina, followed by the first planktonic foraminifera appeared in the Jurassic. Larger miliolines and rotalines dominated the cretaceous tropical regions while the planktonic foraminifera were very abundant in the Cretaceous chalk seas. The planktonic Globotruncanidae which dominated at this time became extinct at the end of the Cretaceous.

The planktonic Globigerinidea and Globorotalidae appeared in the Palaeocene. Nummulites, soritids and orbitoids appeared and attained worldwide distribution in the Eocene. However, orbitoids dies out in the Miocene. After the Miocene times, the larger foraminiferal stocks have progressively dwindled in distribution and diversity, mostly because of the adverse climatic conditions. Planktonics have also diminished in diversity since late Cretaceous times. However, there were planktonic booms in the Eocene and Miocene associated with warmer climatic phases of the period.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. What is the geological age of globigerinidae ?

21.1.4 Uses of Foraminifera

Foraminifera constitute one of the most important microfossil groups. As they are small in size and numerically abundant, small samples (such as well cutting and cores) are enough for laboratory analysis. It is easy to remove the foraminifera from the sediment.

Because of their extensive variability, rapid evolution and abundance, foraminifera are excellent biostratigraphic indicators (index fossils) for mafic rocks. Planktonic foraminifera are excellently suited to intercontinental correlation of Mesozoic (especially Upper Cretaceous) and Cainozoic rocks. Benthic foraminifera can be used for local correlations.

Environmental interpretations based on fossil foraminifera are reliable. For example, changes in depth salinity and climate can be traced in late glacial and postglacial raised beaches and beach deposits.

The depth ranges of Recent genera and species have been used as indicators of the depth of deposition in ancient sedimentary basins. Using this knowledge, benthic depth-related assemblage are recognised in Cretaceous sediments. The ratio between planktonic and benthic individuals increases from shallow to deep waters. This criterion is also used in recognising the depth of deposition.

The narrow temperature ranges of recent planktonic species have become useful tools in palaeoecology, especially of Quaternary sediments.

Living planktonic species may be used as markers of circulation and of distinct water masses. Cretaceous current patterns can be reconstructed from the distribution of fossil planktonic foraminifera.

21.2 CORALS

Kingdom : Animalia

Phylum : Coelenterata

Classes

1. Scyphozoa

2. Hydrozoa

3. Anthozoa (Corals)

Subclasses

1. Cerianthipatharia

2. Octocorellia (Alcyonaria)

3. Zoantharia (Madreporaria, stony corals)

Orders

1. Antipatharia

2. Ceriantharia

1. Pterocorallia

2. Cyclocorallia

3. Heterocorallia

4. Tabulata

21.2.1 Class Anthozoa (Corals)

The anthozoans are sessile and are exclusively marine coelenterates that include the corals and sea anemones. They exist only as polyps occur as solitary forms or in colonies. Over 6000 species are known to exist in the seas today, most of which occur in the Indo-Pacific coral reefs. Fossil anthozoans are found from the Ordovician onwards.

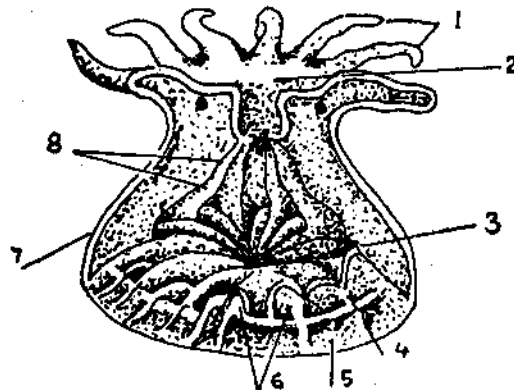


Fig. 21.5 Body plan of an hexacoral polyp with an ectoskeleton.

The polyp is a hollow cylinder, closed below by the basal disc, above the oral disc through which the mouth opens (Fig. 21.5). The oral disc bears one or more circles of long, tapering tentacles. A tube (stomodaeum) leading from the mouth to the gastral cavity is a characteristic feature. The cavity is divided into compartments by radial, vertical mesenteries (sarcosepta). The mesenteries are arranged in couples. Each radial chamber is in contact with one of the hollow retractile tentacles. The mesenteries are usually attached to the stomodaeum. The polyp wall consists of an external layer (ectoderm), an intermediate layer (mesogloea) and an internal layer (endoderm). The reproductive cells are situated in the endoderm. The zygotes give rise to free-swimming planula larvae which later settle down to the bottom of the water and become attached. The sedentary polyp begins to secrete calcium carbonate between the base of the animal and the rock surface to which it is attached, gradually forming a CaCO_3 base called the basal plate. The ectoderm of the lower part of the body secrete a calcareous, horny or chitinous skeleton. Some polyps secrete no hard parts at all. The skeleton of a single polyp is called a corallite (cup), while the skeleton of an entire colony is a corallum. In a solitary coral, the corallite and the corallum are identical.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. Corals belongs to which class of Phylum coelenterata ?

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Subclass : Cerianthipatharia : Of the three anthozoan subclasses, the Cerianthipatharia are least important as fossil. They have only existed since the Miocene. Some of them (the Anthipatharia) are sedentary forms with a black chitinous axial skeleton and their colonies grow several metres high. Others (the Ceriantharia) are solitary corals which grow up to 50 cm tall. They live in tubes which were not fossilised.

Subclass : Octocorallia (Alcyonaria) : The Octocorallia are exclusively colonial. They are distinguished by the possession of eight mesenteries and eight tentacles. The skeleton consists of calcareous spicules of different shapes, developed in great quantities in the mesogloea and remaining detached, as in Alcyonium. In some forms the spicules are firmly cemented together forming tubes, as in Tubipora, or a branching axis, as in Corallium.

Fossil octocorals are relatively rare and not found in rocks older than the Cretaceous. Six recent orders are known with about 2500 species. Some of them with solid skeletons are important recent coral reef builders.

Tubipora (organ-pipe coral), Corallium (precious red coral), Alcyonium (dead men's fingers), Gorgonis (sea fan), Pennatula (sea pen), and Heliopora (blue coral) and the recent Octocorallia forms. Isiss and Moltkia are the fossil forms of the Upper Cretaceous.

Subclass : Zoantharia : The Zoantharia include the greatest number of recent and fossil anthozoans. Eight hundred and thirty one fossils genera are recorded. All the Zoantharia have calcareous skeletons. They are important components of modern fossil coral reefs.

The corallite is bounded by an outer calcareous wall (theca). In many corals, the theca is surrounded by another calcareous layer, the epitheca, with ring-like wrinkles. The whole space enclosed by the outer wall is the visceral chamber. The visceral chamber is divided up by various skeletal elements Which can be classified in the following manner :

1. radial skeletal elements : septa, costae and pali;
2. horizontal skeletal elements : tabulae, dissepiments and syntapticulae;
3. central skeletal elements; columella and aulose.

The septa are radiating vertical plates extending from the margin towards the centre, and alternating the position with the mesenteries. They are of different size, some reaching the centre, others being shorter. They frequently occur in distinguishable series or cycles, the largest being the primary, the others are the secondary, tertiary, etc. The septal faces are usually granulated, the septal edges are wavy, serrated, rippled or smooth. On the external wall of the corallite continuations of the septa are visible as costae (ribs). In some corals the septa are poorly developed. In some forms the partial or complete absence of one of the principal caused the formation of a groove, the fossula. The septal layout is of importance in the classification of corals.

The pali (singular, palus) are the vertical radiating plates attached to the columella and placed opposite the inner ends of some of the shorter septa.

Inside the cup, those septal ends which are bowed sideways may fuse and create an internal tube, the aulos. In certain Pocorallia, the aulos separates the inner and out parts of the tabulae (see below). The columella is vertical rod in the centre of the corallite, projecting up into calice (see glossary) from the base of the chamber. It is formed from the fusion of

inner ends of the larger septa. It is said to be styliform when it is solid and ends in a knob or point in the calyx (see glossary), and pseudocolumella when it is formed by the twisting together of processes given off from the inner edges of the septa.

Bars or rods, known as synapticulae, are often found joining one septum to another. Similarly, adjacent septa are often connected by thin plates, called the dissepiments. These may be horizontal or oblique, usually curved. They are characteristic in certain Pterocorallia genera and are usually restricted to the peripheral portion of the interseptal areas. Tabulae are horizontal plates (transverse partitions) crossing the septa. They are either flat or convex upward and arranged one above another. They occupy the central part of the visceral chamber, dividing it into horizontal compartments. The tabulae is subject to much variation in distance from each other, and the total structure gives to the corallite a vesicular character.

Growth of a corallite : Soon after the polyp settles down to the bottom and secretes a basal plate of calcium carbonate, the basal portion of the animal develops four or six folds (primary mesenteries). An equal number of radial ridges are secreted on the basal plate between the folds. These are the primary septa of the skeleton. The wall (theca) next appears at the edge of the septa. It is formed either by the thickened ends of the septa, or as an independent secretion between the ends of the septa. At the edge of the basal plate an upgrowth may occur forming the epitheca outside the wall. This complete structure is roughly conical or cup-shaped. For sometime the polyp extends down to the base of the cup. But as the skeleton is built upward the lower part of the visceral chamber becomes completely cut off by the developments or tabulae which are secreted by the basal part of the polyp. No soft parts of the polyp occurs below the tabulae and dissepiments. As growth further proceeds more of these partitions are formed, and eventually a large part of the corallite ceases to have any direct connection with the polyp. The depression in the upper and larger part of the corallite which houses the polyp is known as the calyx (cup).

Development of coral colony : Some corals remain simple (i.e. consist of a single individual) throughout life. Others become compound and form colonies by giving off buds. In lateral budding, new individuals may arise from the part of the polyp below the circle of tentacles, forming a branching colony, as in *Dendrophyllia*. In calicular budding, buds arise on the upper surface of the polyp and then the young corallites are found inside the calyx of the parent; in basal budding which is common in the *Octocorallia*, the buds spring from creeping prolongations, which are given off from the base of the coral.

Corallum Shapes : When the individual corallites in a compound coral are free and diverge from one another, the corallum is termed dendroid when they are nearly parallel to one another it is fasciculate the corallites are in contact and, owing to growth-polygonal in outline, the corallum is massive.

Order : Pterocorallia (Rugosa, Tetracorallia)

This order is characterised by feather-like arrangement of the septa (Pterocorallia), the horizontal wrinkles (rugae) on the external wall (Rugosa), or the arrangement of the septa into quadrants (Tetracorallia). The forms in this group are predominantly solitary occasionally colonial. The Pterocorallia are characterised by a special type of septal layout and also by the abundance of the tabulae and the development of an epitheca.

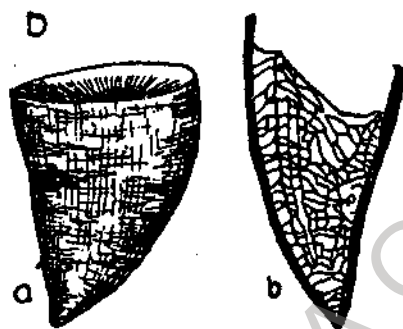
In the Pterocorallia the development of the septa follows a different course from the other zoantharians. Instead of the six primary septa appearing simultaneously, two septa,

one on each side, are first formed and meet in the centre of the coral, representing the cardinal and counter septa. In the early growth stages these two together form a single septum located in the plane of symmetry and represent the initial septum of the corallite. Next, two more septa appear, one on each side of the cardinal septum, and as growth proceeds they become more widely separated from the cardinal system, and eventually form the lateral septa of the adult. The cardinal, counter and lateral (alar) septa divided the cavity of the corallite into four quadrants of somewhat unequal size (hence Tetracorallia). Subsequent septa (metasepta) are formed only in these four quadrants. Short minor septa may be inserted at a later stage in the gaps between the countersepta and the counter-lateral septa, which remains free of metasepta.

Occurrence : Ordovician to Permian.

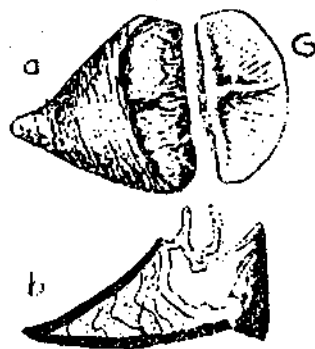
Zaphrentis (Fig. 21.6): Solitary, turbinate, conical, or cylindrical often curved, calyx deep, theca thick. Septa moderately numerous, the larger reaching very nearly the centre, the smaller usually short; Tubulae domed and well developed, narrow area of dissepiments, columella absent.

Occurrence : Devonian.



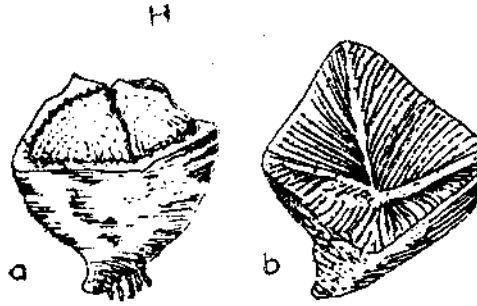
Pterocorals (Fig. 21.6) Zaphrentis

Calceola (Fig. 21.7) : Solitary, conical or slipper-shaped coral; one side is flat, the other hemispherical; calyx very deep; short septa and tabulae; dissepiments more or less bladder-shaped, Occurrence : Lower to Middle Devonian.



Pterocorals (Fig. 21.7) Calceola

Goniophyllum (Fig. 21.8) : Similar to Calceola, but quadrangular; operculum consists of four plates forming a pyramid over calyx. Visceral chamber filled with vesicular tissue; thick leaf-shaped septa; numerous more or less thickened tabulae. Occurrence : Silurian.



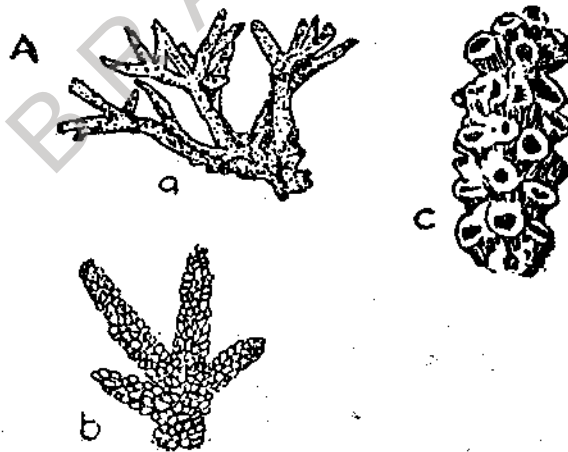
Pterocorals (Fig. 21.8) Goniophyllum

Order Cyclocorallia : Most cyclocorallia are active reef-formers. Cyclic insertion septa is a characteristic feature of this order. Between the six protosepta, six further, second-order septa are formed. Between these and the protosepta, 12 third-order septa are formed, than 24 fourth-order septa, etc. The basic unit of six is thus maintained, while the cyclical arrangement is usually expressed in the length of the septa. The septal insertion in this order differs from that in the Pterocorallia in which the addition of new septa is restricted to only four of the original protoseptal space.

Occurrence : Triassic to Recent.

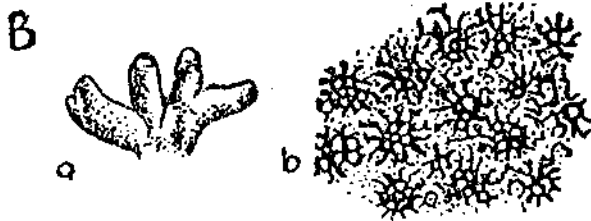
Some important present day reef-forming Cyclocorallia are described :

Acropora (Fig. 21.9) : Important reef-former; 200 Recent species (40% of the living Cyclocorallia); skeleton very light and porous, branched; calices usually large at the end of branches and smaller laterally; no columella. Occurrence : Eocene to Recent.



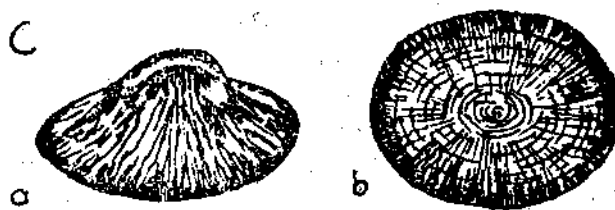
Cyclocorallia (Fig. 21.9) Acropora

Porites (Fig. 21.10) : Colonial; massive and sometimes furnished with blunt lateral branches or encrusting, the calices are usually close together. Trabecular columella with a ring of pali; distributed worldwide; important reef-formers with about 100 Recent species. Occurrence: Jurassic to Recent.



Cyclocorallia (Fig. 21.10) Porities

Cyclolites (Fig. 21.11) : Solitary, disc-shaped, unattached; coral lum domes at the top and flat at the bottom with wrinkled epitheca; septa thin and perforate. Occurrence : Cretaceous to Eocene.



Cyclocorallia (Fig 21.11) Cyclolites

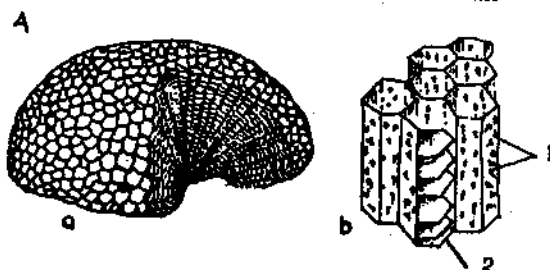
Order Heterocorallia

The order Heterocorallia is restricted to the Lower Carboniferous. The four protosepta form a simple axial cross; the other septa are formed by peripheral division of the protosepta.

Order Tabulata : The tabulata skeleton consists of a simple tube partitioned by horizontal tabulae. Septa are rudimentary end, in many genera, absent. They are exclusively colonial, the individual tubes being fused or connected by short tubules. The walls are perforated by numerous rows of pores. Occurrence : Middle Ordovician to Permian.

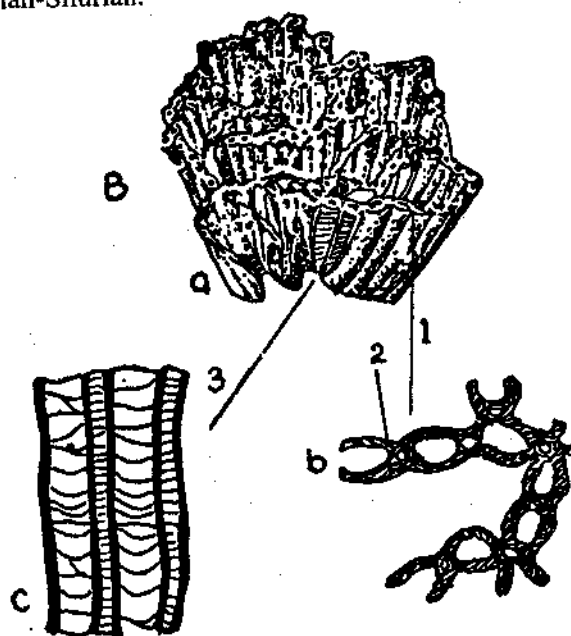
Favosites (Fig 21.12) : The Favosites include most of the so-called "honeycomb corals" Mainly massive colonies with more or less pronounced polygonal corallites. Septa either absent entirely or poorly developed as ridges or thorns; Walls perforated by small pores, which constitute the distinctive feature of the Favosites. The tabulae are generally very numerous and close together.

Occurrence : Upper Ordovician to Middle Devonian



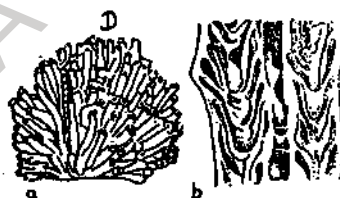
Tabulate Corals (Fig 21.12) Favosites 1. spines and pores 2. tubulae

Halysites (Fig. 21.13) : The Halysites are the so-called "chain corals". Corallum composed of long cylindrical corallites which are fused along their narrow edge. Tabulae numerous and range from horizontal to concave upward. Septa absent or very poorly developed. Occurrence : Ordovician-Silurian.



Tabulate Corals (Fig. 21.13) Halysites
1. Cor. 2. M.Cor. 3.Tab

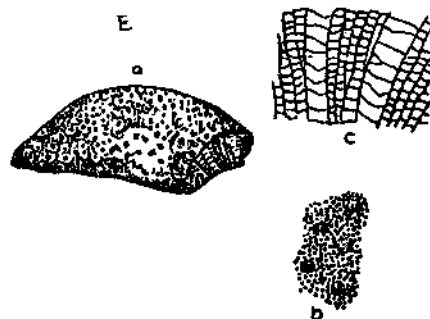
Syringopora (Fig. 21.14) : Colonies consists of thin cylindrical, slightly curved corallites which are linked by stolons. Tabulae quite numerous and close together, Septa, if present, inconspicuous. Occurrence : Silurian to Upper carboniferous.



Tabulate Corals (Fig. 21.14) Syringopora

Heliolites (Fig. 21.15) : Massive hemispherical colonie. The corallites have 12 septa which are sometimes present as thorns.

Occurrence : Upper Silurian to Middle Devonian.



Tabulate Corals (Fig. 21.15) Heliolites

21.2.2 Living conditions of corals

Corals are exclusive marine organisms which predominantly inhabit warm shallow sea areas where waters are clear, water temperature is in the range from 25° to 30°C and water salinity from 35-40‰. Most of the present-day reef-building corals live at depths not exceeding 80-90 metres. They are occasionally reported down to depths of 6000 m. The modern coral reefs are restricted to latitudes between 30°N and 30°S.

The Great Barrier Reef off the east coast of Australia is the largest Recent reef. It is about 3000 km long and in some places 100-300 km wide. Fossil coral, reefs are the sites of oil accumulation.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

4. What is the geologic age of Zaphrentis ?

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21.3 SUMMARY

In this unit both phylum foraminifera and corals are explained. Foraminifera is an order of single celled protista. They live both on the sea floor as benthos and on the surface of water as planktonic animals. They are mostly microscopic organisms with less than 1 mm in size.

The Foraminifera test consists of one or more chambers. The test is sac-shaped, globose, radiate, tabular, branched tabular, planispiral, irregular, hemispherical etc. The coiling may involute, evolute, trochospiral. The test chamber walls may be chitinous, agglutinated, calcareous or silicious in composition.

Foraminifera is classified into 5 sub orders and 19 families. The suborders are allogromina, textularina, miliolina and rotolina.

There are no convincing fossils of foraminifera from precambrian rocks. Ammodiscacean fossils have been reported from early Cambrian rocks. Fusilina began to flourish from devonian and extinct by the end of palaeozoic. The rotolina, miliolina and textularina abundant in mesozoic era. Globo-truncanidal become extinct by the end of cretaceous. The planktonic globigerinidal appeared in the palaeocene. Nummulites, solitids and orbitoids attained worldwide distribution in the eocene. However orbitoids were extinct during miocene.

Foraminifera are excellent biostratigraphic indication for mafic rocks because of variability, rapid evolution and abundance. Benthonic foraminifera is useful for local

correlations. These are also useful in environmental interpretations and depth zone identification of sedimentary rocks.

Corals belong to class Anthozoa of phylum Coelenterata. The Anthozoans are sessile and are exclusively marine. Over 6000 species are known to exist in the seas of today. Fossil anthozoans are found from the Ordovician onwards. Anthozoa includes three sub-classes namely Cerianthipatharia, Octocorallia and Zoantharia. The Cerianthipatharia are least important as fossils. The Octocorallia are exclusively colonial. Fossil octocorals are relatively rare and not found in rocks older than Cretaceous. The Zoantharia includes the greatest number of recent fossil anthozoans. These are important components of modern fossil coral reefs. The main organisms are Zaphrentis, Calceola, Goniophyllum, Acropora, Porites, Cyclolites, Favosites, Halysites, Syringopora, Heliolites etc. The geological age of Zaphrentis is Devonian, Calceola occurs from lower of middle Devonian, Goniophyllum is available as fossil from Silurian formations. The geological ages of Acropora, Porites, Cyclolites are from Eocene to recent, Jurassic to recent and Cretaceous to Eocene respectively. Favosites are common during upper Ordovician to middle Devonian. Halysites occurs from Ordovician to Silurian. The geological period of Syringopora is from upper Silurian to upper Carboniferous. Heliolites are abundant during upper Silurian to middle Devonian.

21.4 CHECK YOUR PROGRESS-MODEL ANSWERS

1. The shape of the test in Foraminifera may be sac, globose, radiate, tabular, branched tabular, planispiral, irregular, hemispherical, uniserial, by serial, triserial, angular etc.
2. The geological age of Globorinae is Palaeocene.
3. Corals belong to class Anthozoa of phylum Coelenterata.
4. The geological age of Zaphrentis is Devonian.

21.5 MODEL EXAMINATION QUESTIONS

I. Answer the following questions in about 30 lines each.

1. Describe the morphology of Foraminifera
2. Explain in detail the various corals.

II. Answer the following questions in about 10 lines each

1. Write down the geological history of Foraminifera
2. What are uses of Foraminifera
3. Write about Zaphrentis and Calceola
4. Favosites & Halysites.

21.6 GLOSSARY

Agglutinated : Test composed of grains of foreign materials and, sponge spicules, etc. cemented together.

Apertural face	:	Flattened surface of chamber adjacent to aperture.
Biserial	:	Test with two rows of chambers. Chambers alternate on their either side of the plane between the rows.
Chamber	:	The space within the test as well as the enclosing walls. Test may be divided into several chambers separated by partitions (septa).
Costae	:	Ridges on external surface of test.
Foramina	:	Opening connecting adjacent chambers in test. Typically formed as aperture and enclosed by development of additional chambers.
Fusiform	:	Spindle - shaped.
Involute	:	Coiled test in which inner portion of last whorl extends to cover part of the adjacent inner whorl.
Keel	:	Keel-like ring along outer margin of the test.
Megalospheric	:	Test with relatively large initial chamber. Constructed by individual formed asexual division of parent.
Microspheric	:	Test with relatively small initial chamber. Constructed by individual formed from sexual union of two cells.
Perforate	:	Test with many small openings in chamber walls.
Planispiral	:	Coiled test with whorls of coils in single plane.
Proloculum	:	Initial chamber of test.
Pseudopod	:	Lobate or thread-like extension of cell periphery that changes in shape character, and position with activity of cell.
Septa	:	Portion between chambers of test.
Spiral suture	:	Line of contact between whorls in coiled test.
Suture	:	Line of contact between adjacent chambers of test.
Test	:	Skeleton of foraminifera (Protozoan)
Trochoid	:	Coiled test in which whorls form a spiral on the surface of a cone.
Uniserial	:	Test in which chambers form a single linear or curved series.
Umbilicus	:	Depression in axis of coiled test.
Basal disc	:	Fleshy wall closing off lower (aboral) end of the polyp.

Basal Plate	: Skeletal plate formed initially beneath basal disc of polyp. The septa and walls extend up and out from the basal plate.
Calice	: Upper (oral) end or corallite on which basal disc of polyp rests. Typically bowl-shaped.
Coenosarc	: Layer soft tissue connecting polyps in a colonial coral.
Columella	: Longitudinal rod in the centre of corallite, formed by inner end of septa and typically projecting up into calice.
Corallite	: Skeleton formed by individual polyp and consisting of walls, septa, and accessory structures such as tabulae and dissepiments.
Corallum	: Skeleton of colony or solitary polyp. In the latter, the corallum and corallite are identical.
Dissepiment	: Small curved plate forming a vesicle. Typically occur between septa near periphery of corallite with convex surface facing inward and upward.
Epitheca	: Sheath of skeleton material that form the wall of the corallite.
Medusoid	: Type of coelenterate of free-living, jellyfish form. Inverted bowl-like form with mouth and tentacles downward.
Mesentery	: One of several radial sheets of soft tissue that partition the internal body cavity.
Mural Pore	: Circular or oval hole in wall between corallites.
Oral disc	: Fleishy wall closing off upper end of the cylindrical column that forms the polyp's sides.
Polyp	: Type of coelenterate of hydra-like form. Columnar body with base attached to bottom and with tentacle and mouth directed upward.
Septum	: One of several longitudinal plates arranged radially between axis and wall of corallite.
Tabulae	: Transverse partitions in corallites. Either flat or convex upward. May extend from axis to wall or be limited to area near axis.
Tabularium	: Axial portion of corallite in which tabulae occur.
Tentacles	: Arm-like extensions around mouth that serve primarily for food getting.
Theca	: Skeletal deposit enclosing corallite and, presumably, sides of polyp.

- Trabeculae** : Rod of radiating calcite fibres that forms an element of the coral skelton.
- Turbinate** : Corallite with angle of about 70° between sides expending from apex.
- Zygote** : Cell formed by union of egg and sperm cells.

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UNIT - 22 : GASTEROPODA AND CEPHALOPODA

Contents

- 22.0 Objectives
- 22.1 Introduction - Gasteropoda
 - 22.1.1 Soft Parts
 - 22.1.2 Morphology
 - 22.1.3 Classification
 - 22.1.4 Distribution
- 22.2 Cephalopods
 - 22.2.1 Morphology
 - 22.2.2 Classification
 - 22.2.3 Distribution
- 22.3 Summary
- 22.4 Check Your Progress - Model Answers
- 22.5 Model Examination Questions
- 22.6 Glossary

22.0 OBJECTIVES

In this Unit, we have presented two important fossil groups Gasteropoda and Cephalopoda

After completion of this unit, you should be able to

- describe the morphology of Gasteropods.
- explain the classification and distribution of Gasteropods.
- describe the morphology of Cephalopods
- explain the classification and distribution of Cephalopods.

22.1 INTRODUCTION - GASTEROPODS

Gasteropod is one of the main divisions of phylum Mollusca. Gasteropods include animals which are having coiled and uncoiled calcareous shells. Originally they were exclusively marine but especially during mesozoic and canozoic time, large number of them became adapted to life in fresh water and in the air, enabling them to invade dry land.

However, large number of Gasteropods are still have adaptation to marine environment. Taking together living as well as fossil representatives of the gasteropods, we find them out numbering all other molluscans together. The common representative of gsteropod presently living is snail. Snails are vary slow moving. The average size of these snails is nearly 1 inch in length or diameter. But fully grown adults of different kinds range in size from 0.5 mm to nearly 60 cms. Gasteropods live on shallow sea bottom. Gasteropods which can live on land are the only molluscans, which have acquired lungs and thus have been able to move out of water bodies. They can climb trees and climb down mountains. On the whole, gasteropods are most inactive, sluggish and gregarious. Gasteropods are the source of food with high nutrition value. Some of the shells are suppose to be of great value possessing occult powers. Few shells are also used in the preparation of paints.

22.1.1 Soft parts of gasteropods

Palaeontological study of the Gasteropods first requieres examination of most significant anatomical features. The soft parts of the gasteropods are divisible into three main parts such as head, mantle and foot. (Fig. 22.1)

The head is mobile anterior part of the body containing mouth, eyes and one or two pairs of sensory tentacles.

The visceral mass comprise parts of digestive tract behind the mouth cavity, relatively large liver, kidney, heart, reproductive organs and nervous system. The placement of the main nerve cords has bearing on the classification of gasteropods.

The foot is fleshy, highly muscular part of the body which is broad flat sole on which it crawls. The mantle comprises the portion of the body covering which secretes the shell.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. The soft parts of the gasteropods are divisible into three parts. Name them (1) _____
(2) _____ (3) _____

.....
.....
.....
.....

22.1.2 Morphology

Shells of gasteropods may be broadly divided into two groups. Those which exhibit little or no signs of coiling and those which are partly or distinctly coiled. But such a division only facilitates the description and not usable as a basis of division of gasteropods.

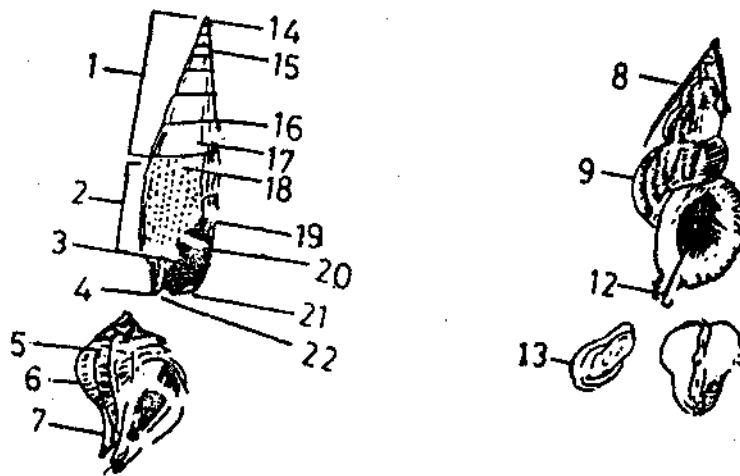


Fig. 22.1

Non-coiled Gastropods : The most common sort of non-coiled gastropods shell has the form of a asymmetrical cone, elliptical or sub-circular at the base and generally more sloping on one side than the other. The apex is more or les paralel to the rounded lower margin of the shell, by concentric folds or wrinkles, by radial ridges and grooves. A majority of non-coiled shells are classes zoologically with coiled shells because the earliest formed parts are found to show coiling.

Generally the delicate, very minutte initial part of the shell is lost before the adult growth stage is reached. The terms used in describing the morphological features of non-coiled gastropods remains the same as in the case of coiled gastropods.

Coiled Gastropods : Gastropods generally posses coiled shells and in most, the plan of coiling gives rise to or is associated with pronounced symmetry of the body. This is shown by the torsion of soft parts in which the anus and gills have become shifted from their initial position.

The shell of a coiled gastropod consists of a single piece and hence it is called univalve. It is made up of a long tube, open at one end tapering to a point to the other. The tube is coiled like a screw. Such type of coiling is called spiral coiling. Some times it is coiled in one plane then it is called plano spiral. Thus we have two types of coiling in gastropods (Fig. 22.2)

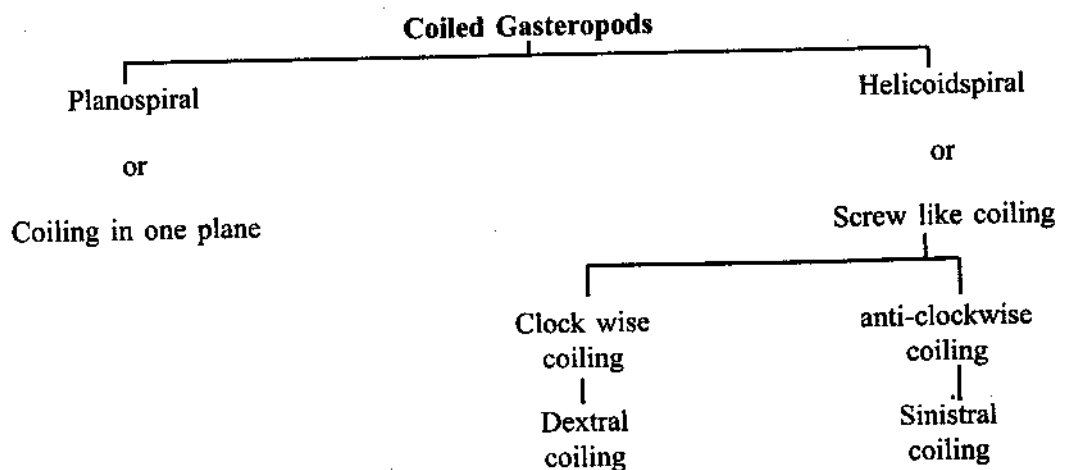




Fig. 22.2
a&b Planispiral shells

Each coil is called whorl. The line between the whorls is called suture. The diameter of the whorl increases towards the base and decreases towards the top to a point, known as the apex of the gastropod. The biggest whorl will be towards the base and has an aperture. The whorl having aperture is also known as last whorl. Except the last whorl, all other whorls together is known as spire of the gastropods.

The shape and size of the spire varies from one gastropod to another. Sometimes the number of whorls may be more, sometime few, therefore the length may be long or short. When a gastropod shell is held in the hand, such that the apex is away from the observer, then, aperture of the gastropod may be towards the right or left of the observer. If the aperture is to the right of the observer, when the apex is away from him, then the coiling is known as Dextral. If the aperture is to the left of the observer, when the apex is away from him then coiling is known as Sinistral. Dextrally coiled gastropods are very common where as sinistrally coiled gastropods are very rare.

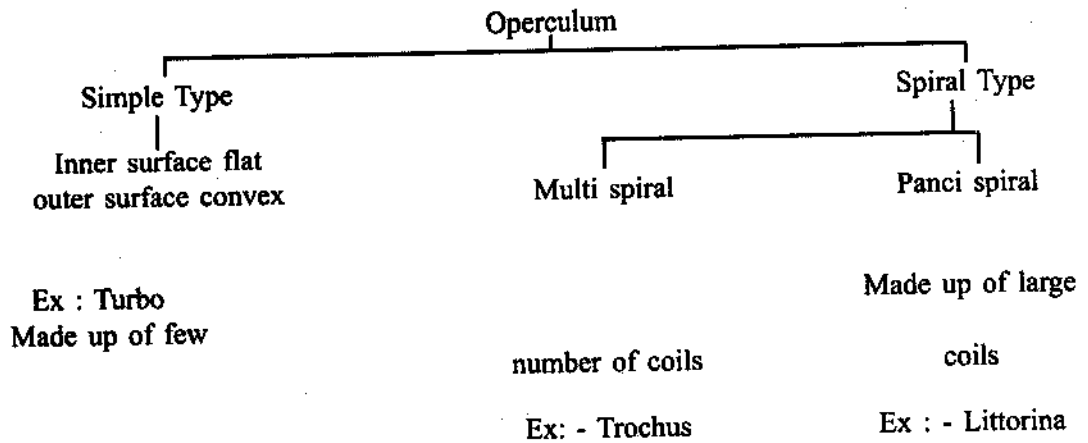
Inside the gastropod shell, whether it is Dextral or Sinistral we find a pillar like structure running from Apex to the base. This pillar like structure is called Axial pillar or Columella. The Axial pillar is formed inside because of fusion of the innerparts of the whorls. Some gastropods do not have axial pillar or columella, instead there will be a tube like space, which is known as umbillicus. Thus we have two types of coiled gastropods, one with columella and another with umbillicus. Those gastropods having columella are called imperforate; and those having umbillicus are called perforate.

The opening in the last whorl of the gastropod is called aperture. Aperture varies in its form. No two gastropods have identical type of aperture. The nature of the aperture is of great importance in the classification of gastropods. Aperture may be circular, oval, elongage or oblong in shape. The margin of the aperture is called Peristome, the aperture has outer and inner parts. The outer part is called outer lip and the inner part is called inner lip. The outer lip may be twisted outside or inside. If it is twisted outside, then it is called Reflected type. If it is twisted inside is called Inflected type. The margin of the aperture which is called peristome may be without break, that it known as Holostomatus.

If the margin of the aperture runs with a break and creates a notch in between then it is called siphonostomatus.

Aperture of the gasteropod shell serves as entrance to the animal to get into the shell and come out of the shell. There is calcareous disc attached to the aperture, which closes the aperture, when the animal withdraws into the shell; the calcareous disc meant for closing the aperture is called operculum.

Operculum being soft is not found in fossil specimens. Operculum is attached to the dorsal part of the posterior end of the foot. The form of the gasteropod varies from gasteropod to gasteropod. Operculum are of two types.



All coiled gasteropods do not have same appearance, they show marked difference in their form. Depending upon the factor like (i) type of coiling (ii) length of the spire and (iii) size and shape of the last whorl.

We can classify the coiled gasteropods into eight (8) different forms. They are :

1. Discoidal form	:	Ex : Planorbis
2. Conial or trochi form	:	Ex : Trochus or conus
3. Turbinate form	:	Ex : Turbo
4. Turretted form	:	Ex : Turritella
5. Fusiform	:	Ex : Fusinus
6. Cylindrical form	:	Ex : Pupilla
7. Globular form	:	Ex : Natica
8. Convolute form	:	Ex : Cypraea

The surface of the gasteropod shell is frequently ornamented with delicate line, which may be parallel to the whorls then they are called spiral ornamentation. Some times the delicate lines cut across the whorls then they are called transverse ornamentation. In addition to this, we can also observe rounded elevated positions known as knobs; thron like prolongation on the surface is also not uncommon then it is termed as spines. Spines, knobs and delicate lines both spiral type and transverse type can be seen in a single gasteropod shell as in the case of Murex.

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.
2. Which type of coiling is rare in gastropods.
-
-
-
-

22.1.3 classification of gastropods

The class gastropoda of phylum mollusca is sub-divided into three orders. See table 22.1

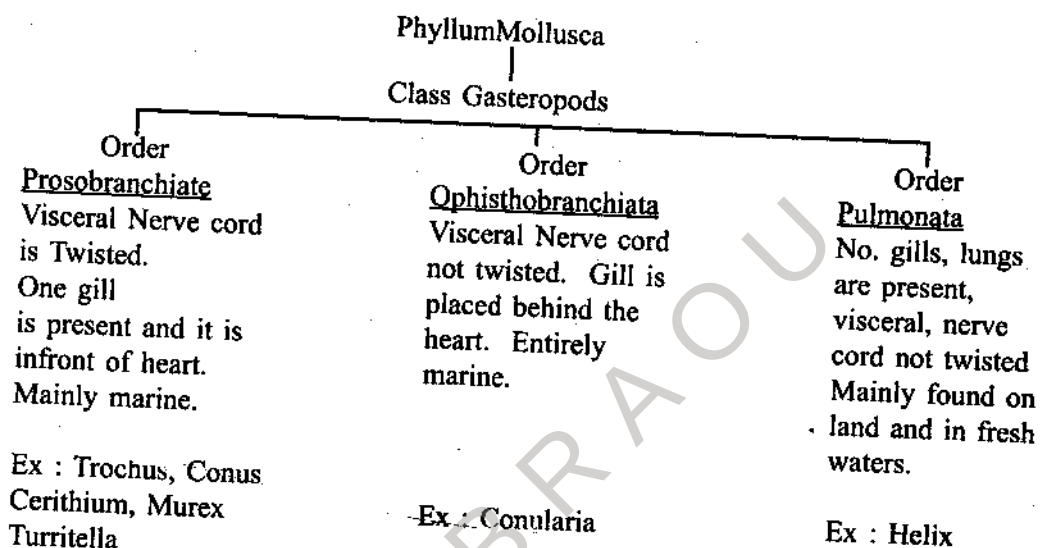


Table 22.1 classification

22.1.4 Distribution

Some of the gastropods live on land, other in fresh waters but majority of them are marine. They are found in all parts of the sea in the world but they are abundant in shallow waters of the sea specially in warm regions.

In the palaeozoic and mesozoic formation, the gastropods were less abundant but they exceed in number than other molluscs during tertiary and present. The earliest representative is from cambrian period. Throughout Palaeozoic period Holostomatus, Prosobranchiates were dominated. Ophisthobranchiates started appearing during carboniferous period.

Marine forms of Pulmonata group appeared first in Devonian period. Non-marine forms in carboniferous but were rare during mesozoic because abundant in tertiary deposits.

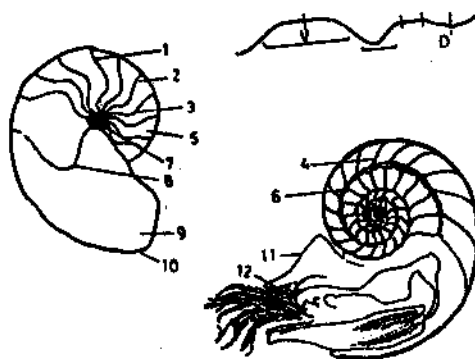
The important gasteropods are *Voluta*, *Murex*, *Cerethium*, *Chrysodomus*, *Turritella*, *Natica*, *Trochus*, *Bellerophon*, *Canularia*, *Tentaculites*, *Planorbis*, *Helix* etc.

22.2 CEPHALOPODS

Fossil representative of cephalopods are common in sedimentary rocks of all geological ages. Cephalopods are marine. They are fast moving among the molluscan group unlike gasteropods. Presently, the cephalopods are represented by cuttle fish, squid, loligo and pearly Nautilus. The Belemnites, Ammonites, Goniatites which are extinct also belong to this class of cephalopods. The existing forms of cephalopods exhibit bilateral symmetry. It has well developed digestive system, nervous system and reproductive system. Cephalopods have distinct well marked head. The body parts are enclosed in a calcareous shell secreted by mantle, usually the shell forms a protective covering surrounding the body. Cephalopods are most highly developed invertebrates attaining a length of nearly 54 feet in some cases. Like fishes, the cephalopods are equipped with highly developed eyes and other sense organs. They have an efficient methods of locomotion. Cephalopods have prehensile tentacles with sucker discs which emit clouds of inky fluids, when it is surrounding by enemies, inky fluids released from the ink sacks and make the surrounding water dark, in such dark waters of the sea it escapes from the clutches of the enemies. The cephalopods also possess the ability of changing the colour of the body according to their psychological state. Because of these characters, the octopus which also come under cephalopods have earned the names as devil fish. Cephalopods which has mantle cavity, contain, pair of gills and also furnishes the chief means of locomotion. The intake of water is through a slit, having one way valve, which closes automatically and water is ejected through a nozzle located at the ventral margin. The expulsion of water may be very powerful and forceful making a jet which serves to propel the animal rapidly backward from the hyponome aperture. The direction of the movement is controlled by moving the hyponome into different positions. The effectiveness of this method of locomotion is attested by the fact that one of the squids, a relative of loligo may reach sufficient speed to leap from water into boats. These loligos is geologically significant because its structures and habits clearly resembles true cephalopods. Many living cephalopods give evidence of rapid evolution and their shells are widely distributed over the globe. The group called ammonoids are particularly good index fossil having wide geographic distribution and limited geological time range. They are of great use for stratigraphical geologist.

22.2.1 Morphology

The shell of the cephalopod belonging to Nautiloidean and Ammonidean groups is coiled in a single plane. Hence, it is planospiral coilings. (Fig. 22.3)



The shell comprises of number of coils or whorls. The outer coil cover the inner coils. Each whorl has a horse-shoe shaped cross section. The planospirally coiled shell of a cephalopod has been divided into number of chambers with the help of transverse partitions known as septa. The first formed chamber is located in the centre. The size of the chambers gradually increase. The last formed chamber is seen outside, which is the biggest of all the chambers. It is in this chamber, the organism dwelled before its death. Therefore, the last chamber is also known as body chamber or living chamber. Except the body chamber, all other chambers in cephalopods are filled up with gas to allow the shell to float on water. From the centre of the shell, there runs a long prolongation known as siphuncle. The position of the siphuncle varies. The siphuncle is found like a tube running from the initial chamber to the body chamber. The siphon extends through this opening or tube. The intersection of siphuncle with the septum produces a funnel shaped neck like projection known as septal neck. The siphuncle is found running only through the chambers which are filled up with gas. The septal necks may be directed backwards towards the initial chambers or it may be directed towards the body chamber. If it is directed backwards, then it is called Reterosiphonate condition. If it is directed forward towards the body chamber, then, it is termed as Prosiphonate condition. In Nautiloidea, the septal necks are Retrosiphonate, where as in Ammonoidea the septal necks are Prosiphonate. The line where the edge of the septum units with the outer or tubular part of the shell is known as suture line.

There are two types of suture lines found in the tetrabranchiates. They are simple suture lines in Nautiloidea and complicated suture lines in Ammonoidea. A simple suture line is usually straight or slightly undulating.

The Ammonoidea are the extinct group which includes Ammonites, goniatites and ceratites. They as a rule show complicated suture lines. The siphuncle is found at the outer margin of the shell and not in the centres as in the case of Nautiloidea. The septal necks are directed forward of what is termed as prosiphonate. The form of suture lines varies considerably in different genera and is of great importance of systematic studies in geology. The central part of each septum is flattened or slightly undulose but the edges become folded or even filled giving rise to very complex suture lines; by this means greater support is afforded to the outer tubular parts of the shell than in the case in the Nautiloids where the suture lines are simple. Different parts of the complicated suture lines are given different names. The portion of the suture lines which are convex towards the mouth are called saddles and the in between concave portions are termed as Lobes. The lobes and saddles are almost similar on the two sides of the shells. Commonly at the external margin, the lobe is called external lobe, then the superior and inferior lobes on the side of the whorls near the inner margin the lobes are known as auxillary lobes. The saddles are also arranged in a similar manner and they are named as external saddle, superior saddle, inferior saddle and auxillary saddle etc.

In the early Ammonoids the suture lines were comparatively simple. Form carboniferous period the complexity in suture line started attaining maximum complex suture lobes in Ammonoids belonging to triassic period.

In the body chamber of some ammonites, goniatites, bacullites, and scaphites, a pair of calcareous plates known as Aptychus are occasionally found. Probably Aptychus served as a closing lid for the aperture in the body chamber of Ammonoids. Aptychus resembles in function to that of operculum of gasteropods.

Not all cephalopods have planospiral coiling. In some ammonoids the shell is a straight cone Ex : Lobobacterites. In some it is coiled in helicoid spiral Ex : Turrilites.

In some cephalopods belonging to Ammonoidean group, there is a tendency to get uncoiled. It starts uncoiling in such a way that the body chamber is quite free then it is called Scaphitoid coiling. Some times the uncoiling takes place giving a shape of a crozier hook, then it is refereed as Hamitoid coiling. Extreme uncoiling is found in Baculites in which major part is found straight leaving only a small remaining part coiled.

The surface of the shell may be smooth or ornamented with striation, ribs, tubercles or spines.

Important Tetrabranchiates :

Orthoceras	Goniatites	Ceratites
Phylloceras	Pinacoceras	Baculites
Turrilites	Scaphites	Macroscaphites

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. Cephalopods are coiled in a _____

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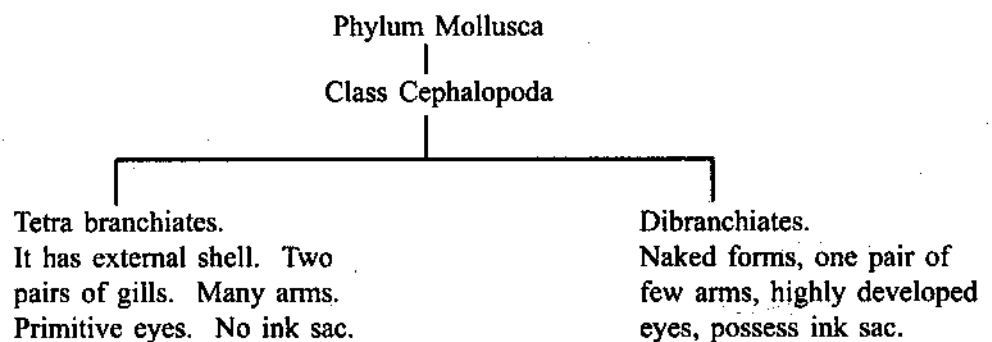
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22.2.2 Classification

Although cephalopods have been much studied and are represented by some of the best documented evolutionary sequences known, the classification of this group is yet not satisfactory. Cephalopods fall into two orders, such as Tetrabranchiates and Dibranchiates



In Tetrabranchiates we get two groups namely Nautiloidea and Ammoniodea, where as Dibranchiates have only dibranchia group. The embryonic stage of cephalopod shell is called protoconch.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

4. Name the two orders of class cephalopods ?

.....

.....

.....

.....

22.2.3 Distribution

Nautiloides are represented at present by four species. Nautiloides appears much earlier in the geological series than Ammonoids and Dibranchates. Nautiloidea are found in cambrian, and attained maximum during carboniferous and permian.

Ammonoids have a shorter geological range than the Nautiloides. The earliest representative found in lower devonian. Belmenites is a dibranchia and found during mesozoic.

22.3 SUMMARY

The two important fossil groups of phylum mollusca namely gastropods and cephalopods are discussed in this unit.

gastropods include animals, which are having coiled and uncoiled calcareous shells. Large number of gastropods still have adaptation to marine environment and very few are adapted to fresh water and land environment.

The common representative of gastropods presently living is snail. These are very slow moving and are most inactive and sluggish. The soft parts of gastropods are divisible into head, mantle and foot. The shells of gastropods are divisible into two types one is shell without coiling and another shell with coiling. The non-coiled gastropod shell has the form of a asymmetrical cone. The shell of coiled gastropod consists of a single piece and hence it is called univalve. In majority cases the shell is a cone coiled into a helicoid spiral, open at one end and tapering to a point at the other. Each one of the individual coils is described as whorl. All the whorls except the last together form the spere. The tapering end is called the apex. The whorls are separated by a line called suture. The coiling of the shell is generally clock-wise and called dextral, but in few cases it is anti clock-wise and are called sinistral. The last body whorl ends in an opening called aperture. The calcareous plate that closes the aperture is called operculum. The coiled gastropods are classified into 8 types. They are discoidal form, conial, turbinate, turreted, fusiform, cylindrical, globular and convolute forms.

The class gastropoda animals are subdivided into 3 orders, namely prosobranchiata, ophistrobranchiata and pulmonata. In the palaeozoic and mesozoic, gastropods are less in

number, but they exceed the other molluscans during tertiary and present periods. The earliest representative is from cambrian.

The second group are cephalopods and all are marine. They are fast moving. The body parts are enclosed in a calcareous shell. Many cephalopods give evidence of rapid evolution and their shells are widely distributed over the globe. The Ammonoids are good index fossils.

The shell of cephalopods is coiled in a single plane and consists of number of coils or whorls. The shell is divided into number of chambers. The first formed chamber lies at the centre. The last formed chamber is seen outside which is the biggest and is called bodychamber. Two types of suture lines found in tetrabranchiata simple in nautiloidea and complicated in ammonoidea. The Ammonoidea are the extinct group which includes Ammonites, goniatites and ceratites. The surface of the shell may be smooth or ornamented with striations, ribs, tubercles or spines. The class cephalopods is divided into tetrabranchiates and dibranchiates.

Among cephalopods the nautiloids are said to be the most ancient forms and occur in rocks of lower cambrian, and attained maximum development during carboniferous and permian periods. The ammonoids were found during devonian period. The dibranchia represented by belemnites appeared during mesozoic period.

22.4 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The three parts are head, mantle and foot.
2. Sinistral type of coiling is rare and dextral is frequent.
3. Planospiral type.
4. Tetrabranchiates and dibranchiates.

22.5 MODEL EXAMINATION QUESTIONS

I Answer the following questions in about 30 lines each

1. Describe the morphology of gastropod shell
2. Write about the morphology of cephalopod shells

II Answer the following questions in about 10 lines each

1. Give the classification of gastropods
2. Give the classification of cephalopods
3. Write about distribution of gastropods
4. Describe ammonoid shell

22.6 GLOSSARY

Aperture	:	Opening of the shell
Body whorl	:	Last formed whorl
Peristome	:	Margin of the aperture
Septum	:	Portion inside the shell
Siphuncle	:	Tube leading from living chamber to protochouch
Spire	:	Shell exclusive of the body whorl
Suture	:	Junction between two continuous whorls

BRAOU

UNIT - 23 : PELECYPODS AND BRACHIOPODS

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23.0 OBJECTIVES

In this unit we discuss about Pelecypods and Brachiopods. After completion you should be able to

- explain the shell morphology of pelecypods
- describe the important genera of pelecypods
- explain the shell morphology of Brachiopods
- define the various orders in Brachiopoda

23.1 INTRODUCTION - PELECYPODS

The pelecypods are a division of molluscs. They bear a shell that consists of two calcareous valves as in brachiopods. Other shell bearing molluscs are all generally

univalved. They are called pelecypods because the shape of their foot resembles a hatchet (Gr. *pelekus*; a hatchet; *podos*; food). This group is also known as lamellebranches, referring to the sheet like or lamellar form of the gills (Latin, *lamella*; a plate; *branchiae*; gills). This group was originally named Bivalvia by Linnaeus in 1758. The pelecypods are also known by the name clams. Many fresh water and a few marine clans (for example, *Mytilus*) are called mussels. Some of the pelecypods (oysters and clams) are important sources of sea food. A few are pearl-producers. The shells of some are used in the manufacture of buttons and ornaments. Certain pelecypods, *Bankia*, *Teredo* and *Martesia* known as shipworms are the notorious wood borers. They cause enormous damage to the wooden structures built in marine waters and to ships.

23.1.1 Shell Morphology

Pelecypod shell consists of two convex calcareous valves that articulate along a dorsal hinge line. As they are attached to the right and left sides of the body, the two valves are called right and left respectively. The larval shell, *prodissoconch*, is equivalve and bilaterally symmetrical, in the majority of pelecypod adult shells, the two valves on either side of the *commissure* are virtually mirror images of each other (except for teeth and sockets along the hinge line). Thus they are equivalves but may be asymmetrical in outline. Many others have dissimilar valve because of adaption to different modes of life. A few pelecypods attach one valve to some object on the bottom and use the other as a lid or operculum. As a result of such attachment the two valves become different. In the extinct *Exogyra* and *Gryphea* the upper valve is much smaller than the lower one.

The earliest part of each valve is the pointed beak. The rounded and elevated part of each valve directly adjacent to the beak is the *umbo*.

Shape of Shell : Most Pelecypod shells tend to be laterally compressed, and somewhat elongated longitudinally. The shells are of different shapes; rhomboidal, orbicular, quadrate, mytiliform, trigonal, rostrate, truncate, alate, etc.

Measurement of Shell : The height is measure along a line in the plane of symetry from umbo to the ventral margin the length is the greatest distance between the anterior and posterior margins measured in the plane of symmetry; the thickness is the greatest distance between valves (when shell is closed) measured at right angles to the plane of symmetry. Although minute forms are less then 3 mm long, most pelecypods are 2.5-5.0 cm in length and width. Upper Cretaceous fossil form *Haploscapa* has a shell nearly 1 metre wide and 1.5 metre long. The largest modern clam, *Tridacna*, of the South Pacific and Indian Oceans reaches a metre in length.

Orientation of pelecypod shell :

1. Place the shell so that the beaks are uppermost and pointing forward or away from the observer.
2. The valve on the right is the right valve; that on the left, the left valve.
3. The front of the shell is anterior; the back part of the shell, always having the pallial sinus, is posterior.
4. If a single adductor scar is present, it will be in the posterior part of the shell.

5. The posterior portion of the shell is usually more developed.
6. The upper or hinge line part of the shell is dorsal, the lower, the ventral.
7. The foot is always in a ventral portion.

Composition and structure of shell material : The typical pelecypod shell is composed of three distinct layers.

1. an outer *periostracum* which forms thin outermost layer made of dark-coloured proteinaceous substance, *conchiolion*. This layer is distinct in modern shells but rarely preserved in fossils.
2. the middle prismatic, layer, the *ostracum*. Where this layer is thick, as in some Cretaceous clams, like *Inoceramus*, it may have a fibrous appearance.
3. an inner lamellar layer. When very thin uniform argonitic lamellae of this layer are crumpled, refraction of light rays causes iridescence. For this reason the inner layer is termed the *mother of pearl layer*. When the laminae of the inner layer are thick and not crumpled, the inner surface of the valve has a porcalaneous appearance.

Underlying the areas of muscle attachment there is a specialised region of calcite deposition which is not secreted by the mantle. It is distinct from the lamellar layer and termed the *hypostracum*.

The shell layers under the periostracum consist of two intermixed phases: a) a organic matrix, and b) crystalline calcium carbonate in the form of calcite or aragonite. Some pelecypod shells such as those of oysters exhibit purely calcitic platelet structure (example - *Cardium*) have a purely aragonitic cross-lamellar structure; the majority (example *Mytilus*) have different layers composed of calcite and aragonite.

The two phases tend to be formed in pelecypods in a number of incurrent patterns, occuring in discrete shell layers. Six primary types have been differentiated.

- i) Single Prismatic structure with columnar polygonal calcite or aragonite prisms.
- ii) Calcareous prismatic structure with tiny radiating acicular crystals.
- iii) Calcareous structure in which tabular sheets of argonite are found resembling a brick wall when cut in section. This structure seems to be phylogenetically the oldest; it is also the strongest.
- iv) Foliated structure of lam-like calcitic crystallites arranged in sheets.
- v) Crossed-lamellar structure which is normally aragonitic. Here the shell is made of closely spaced lamellae within each of which are found thin stacked plates of aragonite, those of adjacent lamellae being inclined in opposition to one another.
- vi) Homogeneous structure with small granualr anhedral crystals.

Shell structure and mineralogy are very useful in taxonomy. But they are rarely preserved in older fossils. Tertiary fossils many retain their original aragonite, but there are no known molluscs with aragonite older than the Carboniferous.

Surface ornamentation (sculpture): The first formed embryonic shell, prodissoconch, can be distinguished at the tip of the beak of many pelecypods. Growth lines formed on the surface as the shell grows are arranged concentrically and parallel of the margins of the prodissoconch. Radial elements are arranged radially from the breaks and consist of fine grooves and ridges (costelle), coarser, rounded and angular ridges termed costae, prominent ribs, and rows of protuberances and spines. Cancellate sculpture is present on those shells having both concentric and radial elements about equally developed.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. How many valves are present in pelecypod shell ?

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23.1.2 Hinge line structures

Hinge line : The valves of most pelecypods interlock dorsally by means of teeth and sockets that lie along a straight or curved hinge line. Teeth and sockets occur in both the valves, teeth in one valve fitting into corresponding sockets in the other. shells which do not possess such locking devices are called edentulous.

Cardinal area : The flat or slightly curved area on each valve between the beak and hinge line is known as the cardinal area. This area has sculpture different from that of the rest of the shell. In some specialised species the cardinal area is separated into two distinct parts : an anterior heart-shaped area, the lunule and a posterior elongated, shallow depression, the escutcheon (Fig. 23.1) The shells in which the beaks directed towards each other are orthogyral; those in which the beaks are directed anteriorly or forward, as in *Venus*, are prosogyrae, and the shells in which the beaks are directed backward, as in *Nucula*, *Trigonia*, *Donax* are opisthogyral.

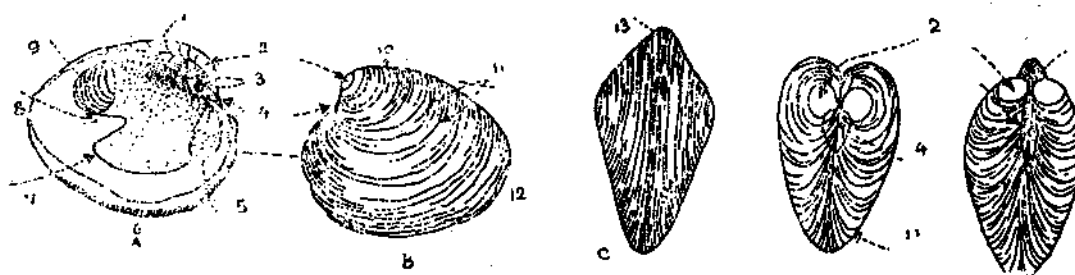


Fig. 23.1 External morphological features of pelecypod shells

A= Left Interior B=Left Exterior C=Ventral Margin D=Dorsal View F=Posterior View

1) Ligemental groove 2) Umbo 3) Sockets 4) Lunule

5) Anterior adductor 6) Left interior 7) Pallial line 8) Pallial sinus 9) Posterior adductor 10) Dorsal 11) Growth lines 12) Posterior 13) Marginal crenulation.

Ligament and resilium : Most pelecypods have specialised structures along the hinge line that cause the shell to open when the adductor muscles are relaxed. The ligament is an elastic band, rod, or hemicylinder of conchiolin passing from one valve to the other above the hinge line. It is bent or stretched when the shell is closed. Its lateral edges are inserted into grooves, ligamental grooves, situated in the cardinal area of each valve.

The resilium is a triangular pad composed of fibrous conchiolin impregnated with calcareous spicules and is an organ to compression. It is situated in a central pit, the *resilifer* along and below the hinge line (23.2). The two pits, one in each valve, that receive the resilium together constitute the *resilifers*. In shells with very thin valve (as in *Mya*), one valve may develop a resilifer and the other a spoon-like projection from inside the beak to oppose it. Such a process for lodging the resilium is known as the *clavicle*. Other structures beneath the beaks are the *myophores* for the attachment of muscles, and *buttresses* for strengthening the shell.

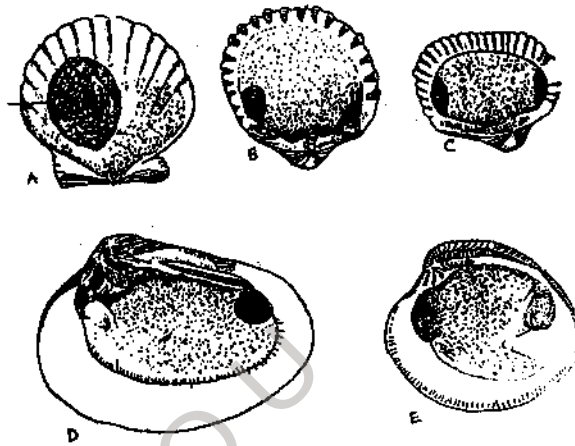


Fig. 23.2 Interior view of right valves, showing the different types of dentition and differences in the muscle scars.

A=Taxodont B=Cyclodont C=Isodont D=Schizodont E=Teledont

Definition : The dorsal, or carinal margin of the valves of denticulate pelecypods is generally thickened and bears numerous tubercles and corresponding pits, ridges and troughs, or teeth and sockets. In some species the cardinal margin is reinforced by a thick vertical plate, known as the *hinge plate* which carries the teeth and sockets. (Fig. 23.2) The valves are locked along the hinge, line, the teeth on one valve fitting into the sockets on the other. This interlocking apparatus constitutes the hinge of the shell, and the term dentition applies collectively to the number, nature, and arrangement of teeth and sockets and other irregularities. The teeth are divided into three groups: in the first kind, there are one or more teeth, the cardinal teeth, situated immediately beneath the umbos. Two other groups of teeth, the *lateral teeth*, are placed on either side of the cardinal teeth.

23.1.3 Hinge Types

The most important types of hinge are :

1. **Taxodont :** numerous subequal parallel teeth, oblique or vertical with respect to the edge of the hinge, fit it to sockets in the opposing valve.
 - a) Ctenodont, pseudoctenodont (teeth converging towards the side;)

- b) Actinodont (teeth converging towards the outside).
2. **Dysodont** : Very small weak teeth or rather fine fluting of the periphery.
 3. **Heterodont** : In each valve, a small number of different -shaped teeth and the corresponding sockets. The hinge, or cardinal, teeth lie under the umbo, the lateral teeth laterally more or less in parallel with the hinge line.
 4. **Preheterodont** (diagenodont) : a few ridges covering towards the umbo (*Lysodesmo*).
 5. **Isodont** : two teeth and two sockets respectively, symmetrically placed either side of the ligament pit (*Spondylus*).
 6. **Schizodont** : a triangular hinge teeth of the left valve fits into a socket between usually divergent and sometimes fluted teeth of the right valve (*Trigonia*).
 7. **Desmodont** : hinge teeth absent; the ligament is sometimes carried by inwardly projecting processes (*chondrophords*).
 8. **Pachyodont** : one to three unsymmetrical peg-shaped projections fit into corresponding sockets in the opposing valve (*rudistids*).

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.

2. How many hinge types are present ?

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23.1.4 Classification

The features listed below are most used for classification of Pelecypoda :

1. character of gills and associated soft parts;
2. character of dentition, ligament and ligament grooves, and resilium and resilifer;
3. nature and position of the muscle scars, pallial line, and pallial sines;
4. shape, size, and ornamentation of the valves which may be used with utmost caution.

Neuzoological classifications of Pelecypods are based on the form and structure of the gills. But most palaeontologists prefer a classification based mainly on the nature of the dentition. The present classification (Table 23.1) is based on the in the Treatise, in which six subclasse are defined.

Table 23.1 Classification of CLASS PELECYPODA

Subclass	Order
1. Palaeotaxodonta	Nuculoida
2. Cryptodonta	1. Solemyoida
	2. Praecardoida
3. Pteriomorphia	1. Arcoida
	2. Mytiloida
	3. Pterioda
4. Palaeoheterodonta	1. Modiomorphoida
	2. Unionoida
	3. Trigonoida
5. Heterodonta	1. Veneroida
	2. Mytoida
	3. Hippuritoida
6. Anomalodesmata	Pholadomyoida

23.1.5 Ecology

All pelecypods are exclusively aquatic, dwelling on bottom. Some live in fresh water, but the majority are marine forms live in the littoral zone and over the continental shelves and slopes. Deep sea species occur to a depth of 10,450 m. Some pelecypods move freely over sediments, ploughing through soft mud and sands by means of the foot, some burrow into soft bottoms; some bore holes into rocks on the bottom or into wooden structures rising from the bottom, others attach themselves permanently by cementation of one of the valves, a few adults are swimmers. Palecypods are typically gregarious and in many localities, are enormously abundant over large area. The oyster beds of many sea bottoms are an example. In general, an abundance of species and individuals of fossil marine pelecypods implies shallow water species possess thicker, more robust, ornamented and coloured shells. Pelecypods are dispersed chiefly by currents that transport the free-swimming larva.

23.1.6 Geological History

The oldest identifiable fossil pelecypod seems to be *Fordillatroyensis* from the Lower Cambrian. The most important genera and species appeared during the course of the Ordavician period. Some Devonian species lived in fresh water. Brackishwater forms appeared in great numbers in later Palaeozoic rocks.

The pelecypods underwent great change at the close of Palaeozoic. During the Triassic many ancient genera became extinct but many new genera made their debut. Since the Triassic Palecypods of the world have become increasingly modern.

Most pre-Carboniferous pelecypod shells are not generally preserved probably because their shells of aragonite, being composed of a relatively unstable form of calcium carbonate, were easily destroyed by solution. Pelecypod shells of this period only consist

of impressions and fillings of their interior. In contrast, Carboniferous and later shells are well preserved. Many genera were locally abundant during the mesozoic and built bioherms. *Gryphea*, *Exogyra*, and *Inoceramus* were such genera in the Jurassic and Cretaceous. *Ostrea* has been an important contributor of shells from the cretaceous to the present time.

In general, pelecypods are not among the best index fossils, especially in strata older than the Carboniferous and latter rocks, many useful index fossils have been described, including, *Myalina*, *Aviculolpecten*, *Pernopecten*, *Exogyra*, *Gryphaea*, *Inoceramus*, *Rhipurites*, *Protocardium*, *Radiolites*, *Venercaidia*, and *Glycymeris*.

23.1.7 Morphological Charectes of Genera

Subclass : Palaeotaxodonta The Palaeotaxodonta are bivalves with a simple taxodont (ctenodont) hinge and protobranch gills. They represent an isolated group without descendants.

Examples: Ctenodonta (Fig. 23.3.1) : Shell oval to elongated, surface smooth or with fine concentric lines, curved row of teeth; teeth bent or straight, integripalliate, ligament external. Ordovician to Carboniferous.

Nucula (Fig. 23.3.2) Oval to triangular, posterior end truncated, surface with concentric ribs, opisthogyal, inner ligament on a resilifer. The teeth are slightly curved. Upper Cretaceous to Recent.

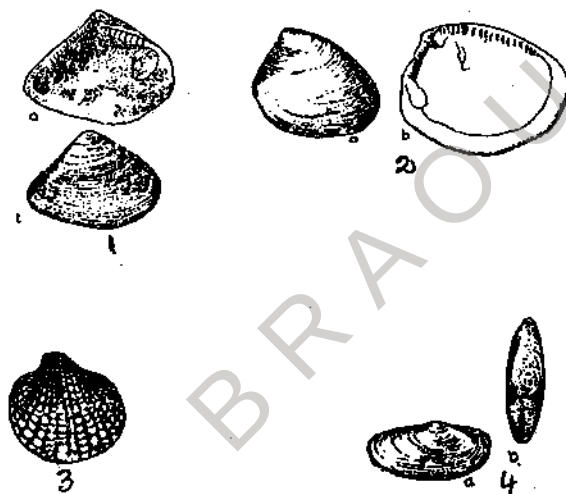


Fig. 23.3 Examples of pelecypod genera.
1. Ctenodonta 2. Nucula 3. Cardiola 4. Solemya

Subclass Pteriomorphia

This subclass includes the orders Arcoida (=Pseudectenodonta).

Pterioida (=Monomyaria) and **Mytiloida**(=Anisomyaria). Many of its members live attached by means of byssus threads throughout their lives, a few bore into hard substrate.

Examples of the *Order Arcoida* (taxodont hinge, but filibranch gills):

Arca (Fig. 23.4.1) : Large, thick-walled, trapezoid shell with concentric and radial ornamentation, straight hinge line, ligament external and amphidetic, integripalliate; isomyaria. (Triassic) Jurassic-Recent. Modern Arca species mostly live in warm seas.

Eurydesma (Fig. 23.4.2): Shell smooth and thick, oval with deep lunule. Index fossil for the marine beds of the lower Permian of the continental Gondwana.

Idocramus (Fig. 23.4.3): Shell egg-shaped to rounded, inequilateral, with concentric ribbing, numerous small ligament pits along the hinge line. Prismatic layer very thick, often disintegrated, in Upper Cretaceous representative. *Inoceramus* is an important guide fossil for the Upper Cretaceous. Jurassic - Cretaceous.

Pecten (scallop) (Fig. 23.4.4): Equilateral shell, but inequivalve, right valve convex, left valve flattened, monomyarian, integripalliate, hinge isodont, ligament in a central pit. Shallow byssal notch. Pronounced radiating ribs. Cretaceous-Recent.

Spondylus (Fig. 23.4.5): Thick shell, inequivalve, equilateral, integripalliate, hinge isodont, ligament in central pit, radial ribs furnished with spines. Attached by the larger (right) valve which has a prominent area. Jurassic-Recent.

The following four genera, which are also monomyarian, are 'oysters' in the wider sense, they are attached by their left usually more convex valve. The ligament is lodged in a triangular pit, no hinge teeth, only one adductor muscle scar placed centrally.

Ostrea (oyster) (Fig. 23.4.6): right valve flattened, shell with lamellar structure. Cretaceous-Recent.

Lopha (= Alectryonia) (Fig. 23.4.7): Shell similar to that of *Ostrea* but folded radially in a zig-zag fashion. Upper Triassic-Recent.

Gryphaea (Fig. 23.4.8): Shell strongly inequivalve, with strongly convex and incurved left valve which is fixed in the juvenile stage only. The right valve forms a flat lid. Lower Jurassic-Recent.

Exogyra (Fig. 23.4.10): Small to fairly large shells with peripheral spiral umbo. Middle Jurassic-Recent. This genus provides a number of Cretaceous guide fossils.

Examples of the Order Mytiloida (=Auisomyaria) which are characterised by the presence of a weak anterior muscle scar and a more or less toothless hinge line:

Mytilus (Fig. 23.4.9): it is a common mussel. Very inequilateral, the umbo is shifted almost completely to the front, hinge line toothless or slightly indented, long narrow opisthodontic ligament, small anterior adductor scar, attached by byssus threads. Triassic to Recent.

Subclass : Palaeoheterodonta

Bivalves with an actinodont hinge consisting of a few cardinal teeth and undifferentiated lateral teeth which are not distinctly separate from the cardinals. This subclass includes the oldest known bivalves, the Actinodonta, Unionidae and Trigonidae.

Examples

Trigonia : Triangular, thick-walled, strongly sculptured shell with opisthogyral anterior umboes. The hinge teeth are crenulated, the triangular tooth of the left valve deeply indented. The adductor scars are backed up by ridges, genus - Triassic to Cretaceous - Family, Triassic to Recent.



Fig. 23.4 Examples of pelecypod genera

1. Arca 2. Eurydesma 3. Inoceramus 4. Pecten 5. Spondylus
6. Ostrea 7. Alectryonia 8. gryphaea 9. Mytilus 10. exogyra

Subclass : Heterodonta

This subclass includes bivalves with heterodont hinges which are predominantly free-living. They have eulamellibranch gills. At present, they are the most dominant group.

Examples of the Order Veneroida which are adapted to a whole range of different biotopes:

Cardtia : Large thick - walled shell with radial ribs, strongly convex, prosogyral umboes moved well to the anterior, external ligament, two hinge teeth left three right, reduced laterals. Anterior adductor scar on a platform, inner margin crenulated. Genus, Palaeocene-Recent, Family, Devoion-Recent. *Venericardia* differs from *Cardita* by the possession of a small lateral tooth at the front and rear of the right valve. Palaeocene-recent.

Cardium (cockle): Equivalve and often equilateral shell, rounded, usually with radiating ribs, external ligament, opisthodontic, hinge with two opposite conical cardinal teeth and a lateral tooth to the front and the rear, two at the front in the right valve. Genus, Miocene-Recent, Superfamily, Triassic - Recent.

Mya : Large, oval, almost toothless (desmodont) bivalves with deep pallial sinus, internal ligament on a chondrophore in the left valve with a corresponding pit in the right valve, lives deeply buried. Nowadays this genus is found mainly in muddy areas and in the estuaries of cold seas, Genus, Oligocene-Recent.

Megalodon : Shell strongly convex rounded, triangular, thick, equivalve, wide hinge plate with two cardinal teeth on each side, posterior adductor scar on a projecting ridge, anterior one small and well sunken. Devonian-Triassic.

Examples of the Order Hippuritoida : The hippuritids are inequivalve and fixed by the right or left valve, they are rarely free-living. The hinge of the unattached valve has two teeth and a socket that of the attached valve one tooth and two sockets with the exception of *Diceras* which is fixed by its right valve and always has two teeth in the right valve. The two adductor scars are either on the shell wall or on special myophores.

Hippurites : Right valve fixed, large, with longitudinal ribs, tall conical with three vertical grooves, left valve lid-like, porous, with central umbo, two openings, inner layer (hypostracum) of the right valve forms three folds. Upper Cretaceous.

Radiolites : Inequivalve, right valve fixed, conical, left valve without folds, outer shell layer (ostracum) blister-cellular. Upper Cretaceous.

Subclass : Anomalodesmata

This small group of eulamellibranch or septibranch bivalves more or less isomyarian with thickened or incurved hinge line and no teeth. It includes some of the so-called desmodonta. Its representatives are mostly burrowing forms.

23.2 BRACHIOPODA

The brachiopod animal lives inside a shell which consists of two pieces. One valve is placed on the dorsal surface and the other is placed on the ventral surface of the body. The

valves can be opened and closed. Generally the main part of the body occupies only the posterior portion of the shell.

In brachiopod fossils, the shells are nearly always closed. The reason is that death of brachiopod animal results in the relaxation of the muscles which keep the shell closed. In contrast, in the lamellibranch fossils, the shells are found generally with the two valves separated. This condition prevails because the mechanics of the hinge structure are such that the lamellibranch valves are forced apart on death of the animal.

23.2.1 Shell morphology

The brachiopod shell consists of two plates : a convex ventral plate, the ventral or pedicle valve, attached to the ventral or abdominal part of the animal, and a convex dorsal plate, the dorsal or brachial valve, attached to the dorsal side of the animal. In the embryonic shell, the protogulum a third plate, known as the prodeltidium, is present attached to the dorsal side of the animal and this plate ultimately fuses to the ventral plate completely to surround the pedicle.

The valves of a brachiopod are equilateral but are of different sizes and shapes. The ventral valve is generally larger than the dorsal, and its pointed apex, the beak usually projects over the rounded beak of the dorsal valve.

The shell is bilaterally symmetrical, with the plane of symmetry passing through the apices of the valves and the middle of the anterior margin (Fig. 23.5). The length of the shell is measured along the plane of symmetry, the width at right angles to this plane where the shell is widest, and the thickness in the plane roughly at right angles to the valves.

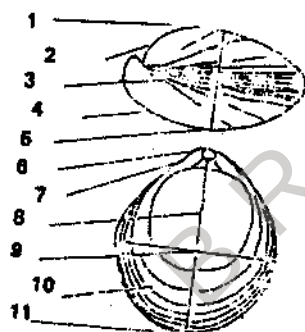


Fig. 23.5 Morphological features of articulate brachiopod shells

1. dorsal 2. brachial valve 3. thickness 4. pedicle valve 5. Ventral 6. posterior
7. foramen 8. length 9. width 10. growth line 11. anterior

The part of the brachiopod shell adjacent to the pedicle and containing the viscera is designated posterior, that part containing the brachia, anterior.

Shape and size of the shell : The ultimate shape of the brachiopod shell depends on the way additions of shell material are made to the more or less triangular valves of the protogulum, and the size depends upon the species and stage of growth. In most shells the ventral valve is convex, but the dorsal varies considerably. The shell may be circular (as in *Atrypa*), ovate (as in *Lingula*), elongate (as in *Discina*), semicircular (as in *Crania*), triangular (as in *Spirifer*), or pyramidal. The brachiopod shells vary in size. Adult shells range from a few millimetres to as much as 12 cm wide or long *productus gigantus*, from the Carboniferous, reached 300 mm in width and 2.25 mm in length.

Composition of shell material : In the Inarticulata, the shell is composed of chitinous-phosphatic material or of calcite secreted by the mantle epithelium. Thin layers of inorganic material often alternate between layers of organic material. Calcium phosphate is the main constituent.

The shells of the Articulata are composed of calcite material. In these the shell matter is arranged in three layers :

- 1) On the outside is a thin 'horny' organic layer, known as the periostracum, which is rarely preserved in fossils.
- 2) Lying next to the periostracum, is the primary layer (laminated layer). This consists of thin, parallel laminae of fibrous calcite crystals. The primary layer forms the exterior of fossil forms.
- 3) Below the primary layer occurs the secondary layer (prismatic layer). In this layer, the calcite fibres are oblique with respect to the primary layer. All internal structures are formed the secondary layer.

- 1) **Impunctate :** the shell has no perforations; this is the most primitive shell structure.
- 2) **Pseudopunctate :** the shell is not perforated. It is penetrated by rod-shaped units and tends to weather more easily in those areas, giving rise to pore-like depression. In the unweathered state, these units are represented by superficial tubercles on the inside of shell.
- 3) **Punctate :** the valves are penetrated by canal running at right angles to the surface. The canals are in contact with the mantle and widen into trumpet-shaped cavities towards the outside.

The structure of the shell is of taxonomic importance.

Surface features of shell : The shells of most primitive brachiopods are smooth on the exterior except for the concentric growth lines. Shells of young individuals of all species also tend to be smooth, but in the adults there is nearly always some development of ornamentation. The rounded or pointed posterior extremity of the valves is called the beak. It is usually more conspicuous on the ventral valve, and situated in the middle of the cardinal margin except in certain Acrotretida. The rounded posterior portion of each valve adjacent to the beak is termed the umbo. Growth lines tend to develop concentrically about the beaks. Striations are minute ridges on the shell radiating from the beaks. In some of the advanced brachiopods, crenulations or wrinkles of the mantle along the anterior margin are reflected on the exterior of the shell in the form of coarse radial ridges separated by prominent troughs. Such ridges are known as plications or costae. Spines may also develop along the hinge line or the cardinal margin. A few of the more highly developed brachiopods exhibit a large fold or plica along the plane of symmetry in one valve and a corresponding depression, the sinus or sulcus, on the other valve (Fig. 23.6).

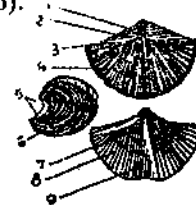


Fig. 23.6 Surface features of articulate brachiopod shells
1. beak ridge 2. Interarea 3. cardinal extremity 4. fold 5. beak
6. commissure 7. umbo 8. plication 9. sulcus.

Structures on the cardinal margin: The line along which the valves join posteriorly and also along which they turn is called the hinge line. It is an imaginary line in the inarticulate, but consists of two teeth in the pedicle valve and corresponding sockets in the brachial valve, in the articulate.

The areas between the umbo and the hinge line in one or both valves is often curved towards the opposed valve, this area is known as the palintrope which often has longitudinal or transverse striations. If the sculpture on the surface of the palintrope differs from that of the valve, palintrope is called the area, interrarea, or cardinal area. The area on the ventral valve is wider than that on the dorsal and is often conspicuously triangular in shape. Probably the cardinal area is device for keeping the beaks apart so that the shell might be opened more widely.

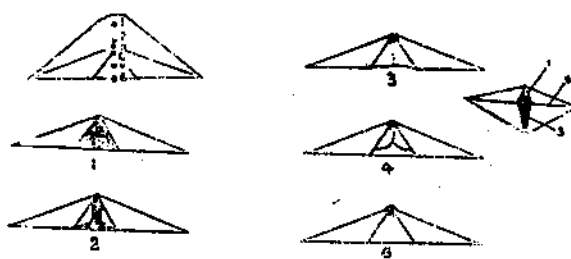
The pedicle foramen : The opening through which the pedicle or stalk merges is the pedicle foramen or pedicle opening. It may be a large gap between the valves, or a restricted opening shared by both valves, or an opening confined to the ventral valve. In discina the foramen is often near the centre of the valve so that the pedicle protrudes at right angles to the plane of the valves.

In certain articulate forms, as in *Orthis*, pedicle opening is in the form of a triangular cavity, under the umbo of the pedicle valve, known as the delthyrium. The corresponding cavity in the brachial valve is known as the notothyrium (Fig 23.7a)

In the Rhynchonellida, Spiriferia and Terebratulida (the teletrematous brachiopods), a delthyrium is found in young individuals' but subsequently becomes partly closed by two plates which grow from the side of the delthyrium. These plates are designated deltidial plates, and together form the deltidium (deltarium) (Fig. 23.7b). The corresponding structure in the notothyrium is called the chilidium.

The deltidial plates may ultimately meet and fuse at the hinge line along the median line of the delthyrium to appear as a single plate, when it is called a pseudodeltidium or deltarium. This is a characteristic feature in the Orthida, Pentamirida and Strophomenida (the protrematous brachiopods).

The pedicle foramen and its protective plates are also of taxonomic significance. The terms used for the description of the pedicle and the surrounding area are given in (Fig. 23.7c).



A= Pedicle foramen 1. notothyrium 2. hinge line 3. delthyrium.

B=Various degrees of development of the brachiopod deltidium (diagrammatic representation): 1. no deltidium, open delthyrium, 2 deltidial plates (deltarium, so-called deltidium discretum), 3. United deltidial plates (syndeltarium), 4. henidium, 5. xenidium.

C=The position of the brachiopod pedicle foramen (schematic representation):
1. epithyridid 2. permesothyridid, 3. mesothyridid, 4. submesothyridid 5. hypothyridid
6. amphithyridid.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. What are the different shapes of brachiopoda shells ?

23.2.2 Internal Skeletal Structures

Brachial supports : These are calcareous supports for the fleshy parts. Brachial supports are of two parts, the brachiphore which bound the dental sockets, and the brachiphore processes, which are elongated extensions of the brachiphore. The calcified brachial support is called the brachidium in the telotrematous shells. The simplest brachidium consists of two small rod like processes or small plates, the crura. Crura which extend anteriorly for some distance and then join form a loop. In the most highly specialized Telotremata the crura are produced anteriorly to form a variety of spirally enrolled processes, known as spires or spiralia. The two spiralia of a brachidium usually united.

Pallial markings : The mantle is often folded in such a way as to produce tabular extension (pallial sinuses). Such sinuses often level pallial markings on the interior surfaces of the valves. These markings usually have a dendritic appearance. They are of considerable importance in the identification of certain families.

Muscle Scars : The places of attachment of the various muscles are marked by pits, elevated areas, or by areas on platforms of various kinds. These muscle scars and structures for attachment are of considerable importance in classification.

In the inarticulate brachiopods complex sets of muscles are present which leave a system of scars on the internal surface of the valves.

Articulate brachiopod shells possess a relatively simple muscular system. The adductor muscles leave two scars on the valve and four on the dorsal. The diductors leave two main scars on the ventral valve and two on the cardinal processes. The adjustor muscles may leave small scars on both valves, and secondary diductors leave impressions which are seldom preserved in fossil shells (Fig. 23.8).

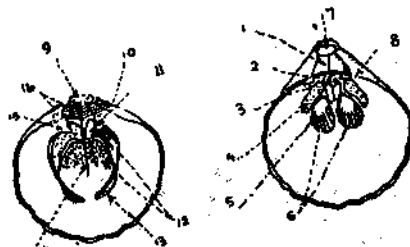


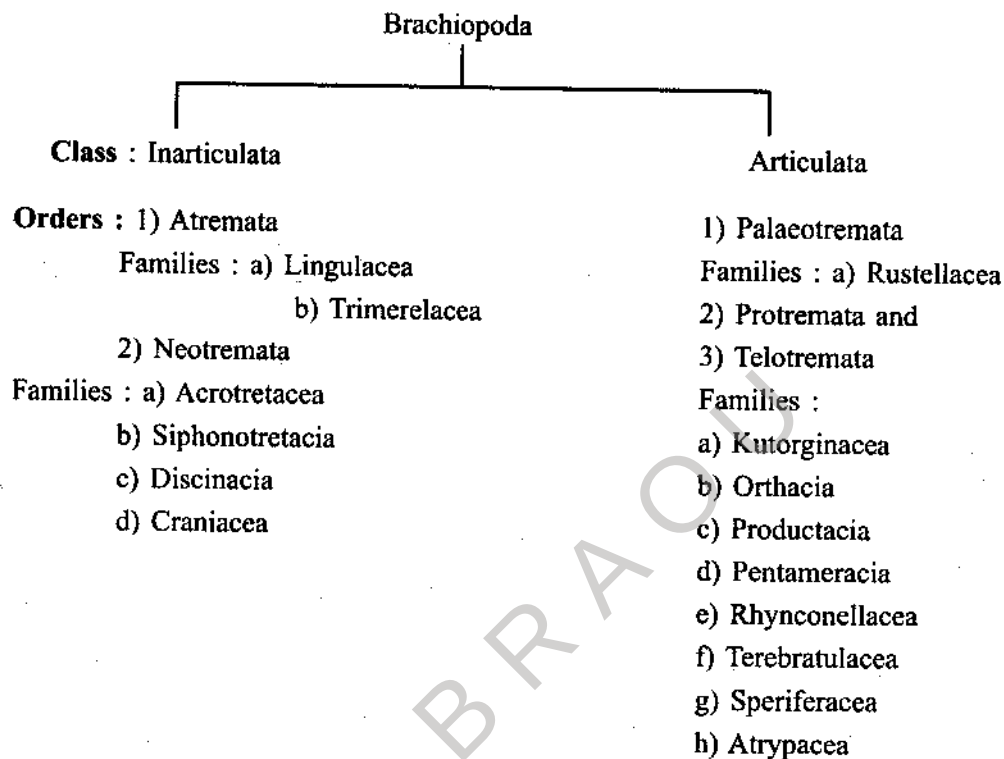
Fig. 23.8 Internal structures of brachiopod shells.

1. Deltidial plates 2. Protractor scars 3. Divaricator scars 4. Adjustor scars 5. Adductor scars 6. Diductor scars 7. pedicle opening 8. hinge tooth 9. Cardinal process 10. Tooth-socket 11. Crural process 12. Adductor scars 13. Loop 14. Septum 15. Crura 16. Hinge plate.

In many atrematous brachiopods each valve has an elevated area, known as the platform, to which muscles are attached. This structure may be solid or may be a plate supported by a median septum. The ventral valve of many protrematous and telotrematous forms has a structure, known as spondylium. This is cuplike or spoon-shaped platform, lying immediately anterior to the delthyrium and often supported by a median septum.

23.2.3 Classification

The two valves of a brachiopod are joined together by means of a hinge and in somecases they are held together by muscles. Based on this Brachiopods are classified into two classes. The organisms in which the two valves of the shell are joined by muscles are grouped under class Inarticulata and the remaining in which the valves are joined by hinges are grouped as articulata.



Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

4. What is the difference between articulata and inarticulata.

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23.2.4 Ecology

Brachiopods are dominantly marine sessile benthos. They inhabit shallow-water environments. Many forms occur more abundantly where the sea-bottom is rocky, or formed of corals. Brachiopods also thrive on substrata covered by mud to free of mud. On favourable bottoms at various times during the past they lived in unbelievable profusion, resulting in the formation of Coquinas which are common in silurian strata in many parts of the world. Living forms have world-wide distribution. Over 70 percent of the existing species are found between the intertidal zone along the shore line and a depth of 200 metres. A few forms occur in deep water to a depth of 6000 metres and are characterized by their thin shells. However, the brachiopods are much less numerous in the modern seas than in former period of the earth's history.

23.2.5 Geological History

Brachiopods have a long geological history extending from the Cambrian to Recent. They attained their greatest importance in the palaeozoic and reached the climax of their long career in the Ordovician and Silurian. Only about 70 Recent genera are known as against about 1700 fossil genera.

All orders except the teletrematous were represented in the lower Cambrian. The inarticulate brachiopods had a leading position in the Lower Cambrian. Although these forms have persisted to the Recent they were at no time important and rarely abundant since then.

By the close of Upper Cambrian the protrematous brachiopods became dominant and maintained their dominant position during the Ordovician and Silurian. They had a second expansion in the Carboniferus with a host of new spine-bearing genera represented by myriads of individuals. They became completely extinct during the Permian.

The telotrematous brachiopods first appeared in the Ordovician and gradually rose in importance and were more abundant than the proteremmatous forms in the Upper Devonian. They were however, related to a subordinate position during the Carboniferous, but regained the leading position in the Permian and retained it to the present. The spire bearing telotremata almost vanished in the permian although a few stragglers survived to the Jurassic. Since the Jurassic the loop-bearing and crura bearing forms have been dominant.

A number of articulate brachiopods are important guide fossils.

23.2.6 Homeomorphy

Among brachiopods, the condition known as homeomorphy is common. External resemblance in shape and patterns of ornamentation between shells belonging to different genera is so pronounced that, without careful study, one may be mistaken for the other. But they differ radically in the internal structure. Punctuate shells belonging to the order Terebratulida contain at least five independent developments of the same character. Thus, without close examination of the internal structure, one may confuse species belonging to different genera and families. Two categories of homeomorphy are recognized:

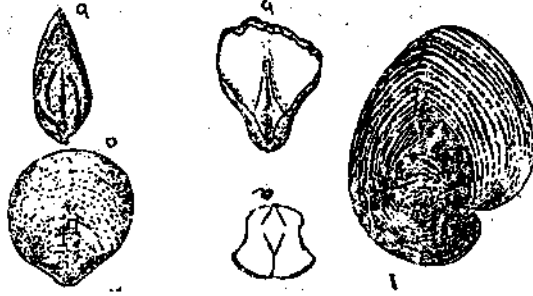
a) isochronous homeomorphy in which shells, having contemporaneous or near contemporaneous occurrence are closely similar but unrelated. Isochronous homeomorphs are common among the Jurassic brachiopods.

Conchidium (Ordovician - Devonian), and *Pentamerus* (Silurian) :

The important genera are :

1. *Conchidium*, a) transverse section of the umbonal region, b) brachial valve with a spondylium 2. *Pentamerus*.

Fig. 23.12 Order Pentamerida

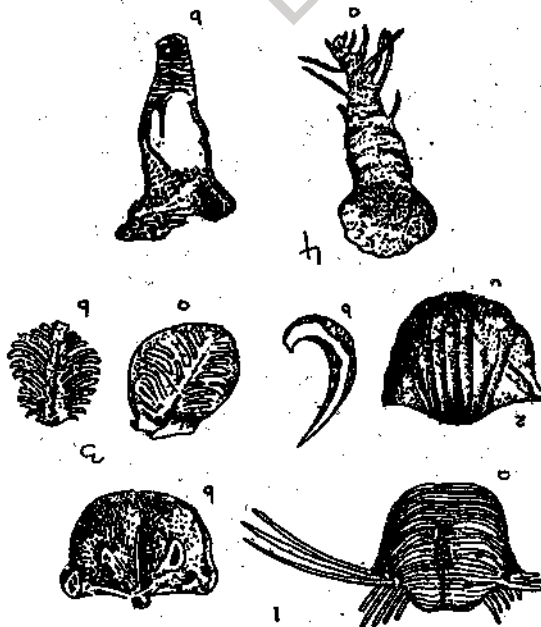


The Pentamerida have shells which are impunctate, large and strongly biconvex, often a smooth, thickly rounded, and elongate. They have a short hinge line and an open delthyrium. Spondylium is well developed in the pedicle valve. Brachial skeleton is represented by crura. Ordovician - Permian.

Order : Pentamerida (Fig. 23.12)

Important genera are : *Strophomena* (Ordovician), *Leptaena* (Ordovician - Carboniferous), *Chonetes* (Middle Silurian - Middle Permian), *Productus* (Carboniferous - Permian), *Gigantoproductus* (the largest known brachiopod from the Lower Carboniferous, with a 35 cm long hinge line), *Oldhamia* (Carboniferous - Permian), and *Richthofenia* (index fossil for the marine Permian).

Fig. 23.11 Order Strophomenida
1. *Productus* 2. *Gigantoproductus* 3. *Oldhamia* 4. *Richthofenia*



b) Heterochronous homeomorphy in which two or more shells of difference geological age simulate one another.

23.2.7 Important Orders

Order : Lingulacea (Atremata)

The lingulacea have small elongated valves. The long flexible pedicle passes out between the umbones, the opening is being shared by both valves. Lower Cambrian - Recent.

Lingula : *Lingula* lives in tubes with in burrows in the sediment on the sea floor, and is attached to the tube by means of the pedicle. It survives when left uncovered by the sea during low tide for several hours, and can live in places of oxygen-poor waters. When buried by a rapid deposit of sediment *Lingula* survives by tunnelling to the surface.

Lingula has the distinction of being probably the oldest known genus in the animal kingdom. Species of this genus are found today in the Pacific and Indian oceans. The shells of living *Lingula* are similar to those of fossil *Lingula* rocks of Ordovician period. *Lingula* is an example of 'living fossil'.

Order : Orthis (Fig. 23.9) The Orthis are characterised by biconvex valves, long straight hinge lines, pronounced interaces and an open delthyrium. Cambrian-Permian. Two suborders are distinguished according to the shell structure: (1) the Orthis (impunctate), (b) the Dalmatellacea (punctate). *Orthis* and *Platystrophia* are the representative genera of the Orthis. Both are common in the Lower Palaeozoic of the northern continents. *Dalmanella* is the representative genus of the Dalmatellacea. This genus was distributed worldwide from the Ordovician to Devonian.



Fig 23.9 Class Articulata (Order Orthis)
1. Platystrophia 2. Orthis 3. Dalmanella

Order : Strophomenida (Fig 23.10 & 23.11)

The Strophomenida are pseudopunctate and usually have one concave and one convex valve with fine radial ornamentations. Spondylium is absent. Pseudodeltidium nearly always is present throughout life. Cardinal processes are well developed. Pedical opening is small, at the apex of the umbo, but closed in fixed forms. Ordovician-Jurassic.



Fig. 23.10 Order Strophomenida
1. Strophomena 2. Leptaena 3. Rafinesquina 4. Chonetes

Order : Rhynchonellida (Fig. 23.13) The Rhynchonellida have shells which are impunctate and fibrous, and triangular to rounded in outline. The hinge is short. A sulcus and a fold as well as a short protruding beak mark the pedicle valve. Brachial skeleton is represented by crura only, but sometime absent. The delthyrium is narrowed from the sides by deltidial plates, but a opening usually remains under the umbo for the pedicle. Since the members of this order are all externally similar, the septa and brachidia, which are very variable, have great taxonomic importance. Middle Ordovician - Recent, they are especially diverse in the Mesozoic.



Fig. 23.13 Order Rhynchonellida : *Rhynchonella loxiae*
a) brachial valve, b) view from the front, c) view from the side.

The representative genera are : Rhynchonella. In the narrowest sense this generic name applies to approximately triangular forms with pronounced ribs, a sulcus and a fold, dental supports a dorsal median septum, which are widespread in the European Upper Jurassic. The Family Rhynchonellidae existed from the Triassic to the Cretaceous.

Order : Spiriferida (Fig. 23.14 & 23.15) This is a large and important group with predominantly a impunctate shells, although a few genera also have punctate shells. The radially ribbed or folded shells are strongly biconvex. The spiral (helicopegmate) brachidium is characteristic. There is usually well developed interarea in the pedicle valve but not in the brachial valve. The delthyrium of the pedicle valve is open or narrowed by deltidial plates. The order is common from the Middle Ordovician to the Upper Permian, with only a few forms surviving to the Lower Jurassic. The important genera with impunctate shell structure are :

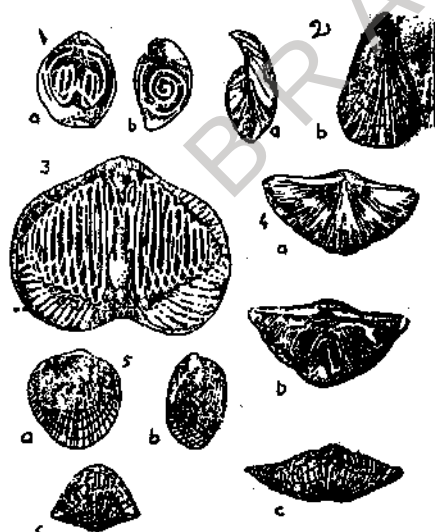


Fig. 23.14 Order Spiriferida :
1. *Dayia* 2. *Uncites* 3. *Athyris*, brachial valve 4. *Spirifer* 5. *Atrypa*.

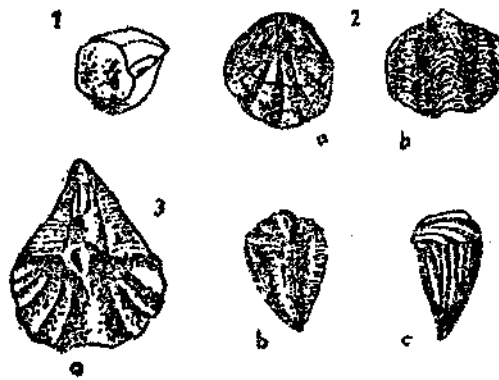


Fig. 23.15 Order Speriferida.

1. *Cyrtia* 2. *Speriferina* a. brachial valve b. from margin, 3. *Cyrtina*, a. interior of the pedicle valve, b. view from behind, c. view from the side.

Atrypa : The brachidium consists of two simple spiral bands which initially bend outwards from the crura and then form a hollow cone with their tips towards the middle of the brachial valve. Silurian - Devonian.

Athyris : In this genus the two valves are equally curved with lamellar and sometimes spiny sculpturing. The tips of the brachial spirals are directed outwards. The genus is distributed worldwide from the Devonian to the Permian (? Triassic) with the largest number of species in the Middle and Upper Devonian.

Spirifer : The long straight hinge line is characteristic. The interarea of the pedicle valve is well developed, and the delthyrium is usually open. The pedicle valve has a pronounced sulcus and strongly diverging dental supports. Spiriferids form a very diverse and stratigraphically important group which is widely distributed in the Devonian and Carboniferous.

Order : Terebratulida : The Terebratulida are punctate brachiopods, usually smooth, occasionally with marginally folded valves. Short hinge line and looplike brachidium (ancylopegment). Round foramen in the area. The order has been in existence since the Upper Silurian, they were particularly diverse in the Cretaceous.

Some of the important genera are :

Stringocephalus : Large biconvex forms, usually with smooth rounded valves. The umbo of the pedical valve protrudes like a beak. There is a tall median ridge (septum) ventrally and a very long robust cardinal process dorsally. The genus is distributed worldwide in the Middle Devonian. *Stringocephalus burtini* is an index fossil for the Upper Middle Devonian.

Terebratula : (Fig. 23.16 & 23.17) Smooth, rounded to elongate oval valves with round pedicle foramen, rarely ribbed. On the frontal margin of the brachial valve there is an indentation bounded by two folds. The loop-like brachidium is short and has no median ridge. The Genus *Terebratula* in the narrower sense is restricted to the Miocene to Pliocene a median plate, brachidium is supported by a median septum. The genus is relatively common in the Triassic.

Terebratella Shell smooth or with radiating ribs, with sulcus and fold as well as a low Inter area. The loop-like brachidium is long and attached to the median septum by means of a transverse bring. The genus has existed since the Oligocene.

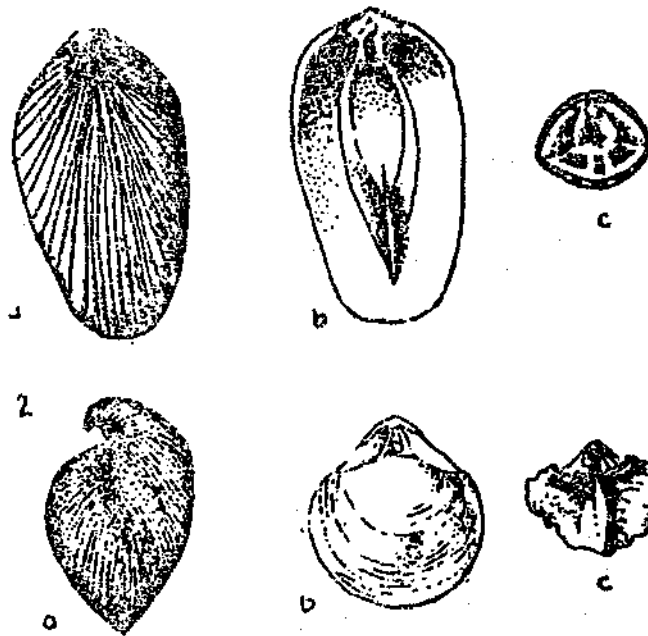


Fig. 23.16 Order Terebratulida

1. Rensselaeria, (a) & (b) brachial valve (c) hinge region from the inside 2. Stringocephalus (a) lateral view (b) brachial valve (c) hinge region from the inside.

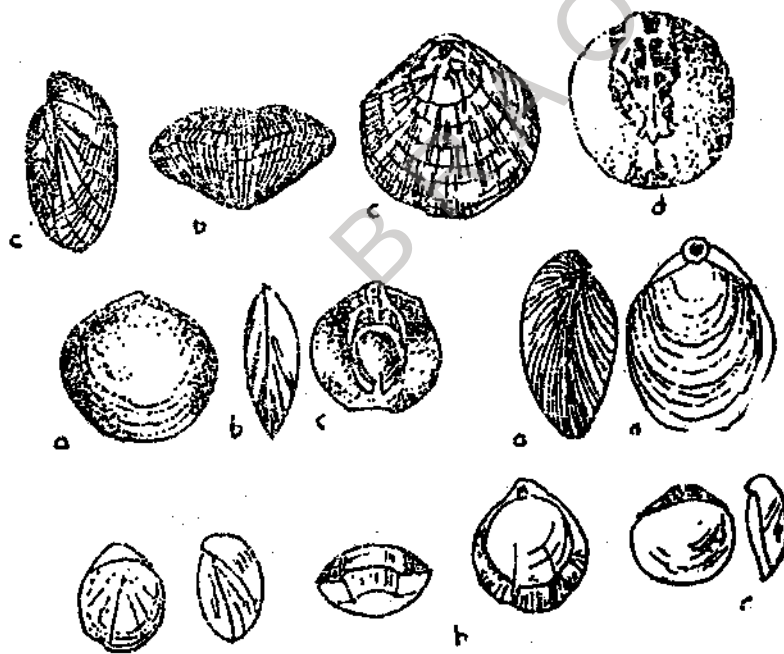


Fig. 23.17 Order Terebratulida

1. a, b, c, d = Terebratella 2. a, b, c = Cincta. 3. a, b=Terebratula, 4. a, b, c = Coenothyris.

23.3 SUMMARY

Both Pelecypods and Brachiopods are discussed in this unit.

Both these two groups consist of shell that consists of two calcareous valves. But they differ radically in several other aspects. The shells of pelecypods are characterised by inequilateral valves, equivalved, valves are at right and left. The plane of symmetry lies in between valves and umbo. Pedicle or opening is absent. Both teeth and sockets are seen in some animals and are present in both of the valves. The valves are opened at hinge line. The shell is three layered growth lines can be observed as surface ornamentation. There are eight types of hinges seen in pelecypods. Pelecypoda group are again classified into 6 sub classes namely Palaeotoxodonta, Cryptodonta, Pteriomorphio, Palaeoheterodonta, Heterodonta and Anamalodesmata.

Pelecypods are exclusively aquatic, bottom dwelling animals and are abundant over large area. The oyster beds of many sea bottoms are best locations for the occurrence.

The geological history of pelecypods reveals, that these animals started existence from lower cambrian and some are available in recent times also. In general pelecypods are not among the best index fossils.

The valves of brachiopods are equilateral but of different sizes and shapes. The shell is bilaterally symmetrical, with a plane of symmetry. In most of the shells the valves are dorsal and ventral. The shell material may be phosphatic or calcitic in composition. Growthlines can be seen on the shells. Pedicle opening is present. Teeth lie in one valves and sockets in the other. Valves are opened and closed by muscles. The shell is of three layered.

Brachiopods are classified as articulata and inarticulata classes based on joining of valves. Brachiopods are dominantly marine sessile organisms and inhabit shallow water environment. However these animals are much less in the modern seas than in past geological period.

Brachiopods are having long geological period extending from cambrian to recent. They attained greatest importance in palaeozoic period and reached climax during ordovician and devonian.

23.4 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Pelecypod shell consists of two inequilateral shell valves.
2. Eight different hinge types are present namely, taxodont, dysodont, heterodont, preheterodont, Isodont, schizodont, desmodont and Pachyodont.
3. The shapes of brachiopod shells are circular, ovate, elongate, semicircular, triangular, or pyramidal.
4. In Articulata class the valves of the shell are joined together by hinges, where as in the other class called inarticulata, the shells are joined with muscles.

23.5 MODEL EXAMINATION QUESTIONS

I Answer the following in 30 lines each.

1. Explain the shell morphology and geological history of pelecypods.
2. Describe the shell characters and geological history of Brachiopods.

II Answer the following in 10 lines each

1. Compare the pelecypod shell with Brachiopod shell.
2. Classify Pelecypods.
3. Classify Brachipods.
4. Describe the pelecypod hinge types.

BRAOU

UNIT - 24 : ECHINODERMATA, TRILOBITA AND GRAPTOLITES

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- 24.0 Objectives
- 24.1 Introduction
- 24.2 Echinodermata
 - 24.2.1 Classification
 - 24.2.2 Distribution in space and time
- 24.3 Trilobites
 - 24.3.1 Classification and morphology
 - 24.3.2 Distribution in space and time
- 24.4 Graptolites
 - 24.4.1 Morphological characters
 - 24.4.2 Geological history
- 24.5 Summary
- 24.6 Check Your Progress - Model Answers
- 24.7 Model Examination Questions

24.0 OBJECTIVES

After completion of this unit, you should be able to -

- explain the classification and distribution of Echinodermata.
- describe the classification and distribution of trilobita.
- explain the morphology and geological history of graptolites.

24.1 INTRODUCTION

In this unit the three important groups of fossils namely echinodermata, trilobita and graptolites are explained. Echinoderms are marine and spiny skinned animals. Trilobites are distinguished by segmented organisation of body. In graptolites skeleton consists of a series of cuplike chitinous chambers.

24.2 ECHINODERMATA

Highly organised, exclusively marine, spiny skinned animals are called echinoderms. Their body plan and structural organisation is very different from that of any other invertebrate group. Living representatives of Echinodermata include starfish or sea stars

(Asteroids), brittle stars (ophiuroids), sand dollars and other sea urchins (echinoids), sea cucumbers (holothroids); sea lillies (stalked crinoids) and feather stars (free crinoids). All Echinoderms are characterised by the possession of skeletal elements formed of calcite built up in crystalline form. The body structure of echinoderms is much advanced over that of coelenterates and other radially symmetrical invertebrates. Surrounding the digestive tube there is a body cavity. Within the body cavity, we get, nervous system, reproductive parts and highly organised water circulatory system. No heart is present. The water circulatory system of ancient types of Echinoderms does not serve for the purpose of locomotion but for respiration, sensation and for gathering food particles.

Echinoderms are divisible into two groups

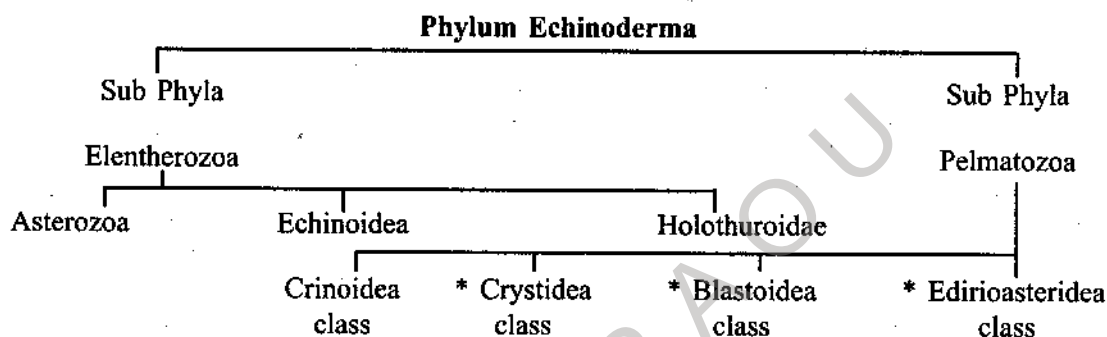
(i) Pelmatozoa

(ii) Eleutherozoa

Pelmatozoa : They are stem bearing animals, which are more or less permanently fixed in mode of growth.

Eleutherozoa : They are free moving animal and those which are not attached to the sea bottom.

24.2.1 Classification



Extinct groups are indicated by asterisk (*). The classification chart above indicates that majority of the pelmatozoans are now extinct. Among sub-phyla Eleutherozoa, Echinoidea class are highly represented in the marine environment even today. Not only they have good present day representation but also very good fossil record in the geological history.

Class Echinoids : Echinoids are globular, discoidal, heart shaped animals, which are armoured by a subcutaneous box like skeleton composed of many plates. This skeleton or test encloses the vital organs and on outside with movable spines. The classes namely Regular Echinoidea and irregular Echinoidea.

In regular Echinoidea the anus is located opposite the mouth within a circle of plates termed the apical system and in irregular Echinoidea the anus is acentral. Regular Echinoids exhibit with few exceptions perfect radial symmetry whereas in irregular echinoids there is bilateral symmetry and regular echinoids both anus and mouth are central being placed at opposite poles of the test. In irregular Echinoids the anus is always and the mouth often excentric.

Parts of Echinoids : In the test we may distinguish clearly 3 parts they are (i) apical disc (ii) corona (iii) peristome. The *Apical disc* in the echinoid test is found at the top or at the summit, surrounding the anus and it is known as apical system also. The central part of the echinoid test is called *corona* and the parts between the mouth and the lower margin of the corona, known as *peristome*.

Apical disc consists of anus surrounded by patch of plates known as periproct. The periproct is in turn surrounded by a ring formed of ten plates. Among these 10 plates, 5 are big and more or less of hexagonal shape known as *genital plates* or *Basal plates*; alternative to these genital plates are 5 small more or less of triangular shape known as *ocular plates* or *Radial plates*. The genital plates are provided with a perforation which serves as the opening for the genital plate which is highly perforated and is known as *Madreoporic plate*. In the ocular plates also we find perforation through which the terminal tentacle of the radial water-vessel projects.

In regular Echinoids the apical disc is large, particularly in some regular Echinoids like *cidaris*. When all the 5 genital plates and all the 5 ocular plates form a single row and touch the periproct, then it is known as *Insert Condition*. On the other hand some time in some Echinoids, we find only genital plates touching the periproct, where as the ocular plates form the outer ring, then the condition is known as *Exsert*.

In the irregular Echinoids, the apical disc is small and it does not enclose periproct. The growth of the madreoporic plate is also irregular, such that it extends to the centre of the disc and sometimes even cuts across the periproct.

CORONA : It is one of the most important parts of the Echinoid test which is situated in between apical disc at the top and peristome at the base. The corona of typical Echinoid consists of twenty (20) columns of plates extending from apical disc to peristome. There are 5 double columns of ambulacral, separated by 5 double columns of interambulacral. Each double column of plates start alternately from genital and ocular plates. The double column of plates starting from ocular plates are called *Interambulacral plates*, *Ambulacral area*, where as the triangular area occupied by interambulacral plates is called *interambulacral area*. The plates in ambulacral as well as interambulacral areas are alternatively arranged such that where one ends the other starts. By this type of arrangements, if we join the inner ends of the plates, we get a zig-zag line. Thus, we have 2 columns of plates in each ambulacral and interambulacral areas.

In the ambulacral areas, the ambulacral plates are smaller in size and numerous in number than the interambulacral plates of interambulacral areas. Each ambulacral plate we find at the outer margin two small circular holes known as *pair of pores*. Each pair of pores corresponds to a single tube foot, since each tube foot divides as it base into two canals. Very frequently the pair of pores is surrounded by an oval raised fun known as *Peripodium*. The pair of pores are some times horizontal and seen in one plane but usually they are inclines such that innerpore is lower than the outer pore. Each ambulacral plate is called a *primary plate*. Some times, these primary plates may get fused together to form a *compound plate*. The compound plates can be differentiated by a primary plates very easily by the fact that each primary plate has a pair of pore and a notch. If number of primary plates are fused together to form a compound plate, then we can count the pair of pores and notches present in a compound plate and indicate the number of primary plates involved in fusion to form a compound plate.

In each compound plate we may get some times small plates known as Demiplates, and *included* plates.

The position of the pair of pores in ambulacral plate may vary. Sometimes, the pair of pores are placed one above the other forming a single row of pair of pores, then such arrangement is termed as unigerminal pair of pores or uniserial pair of pores. In some cases the pair of pores may be alternately nearer to and farther away from the margin of the plates, to form two rows of pair of pores, then it is termed as biserial or bigerminal pair of pores. Sometimes we may get the arrangement such a way that it forms 3 rows, then it is termed as *Polygerminal* or polyserial pair of pore arrangement. In all such arrangements, formation of one row, two rows and three rows, the number of pairs of pores remains the same but only their placement in each ambulacral plate differs.

In some echinoids, the arrangement of pair of pores are so arranged that it gives the appearance of rose petal, then such arrangement of pair of pores is known as Petaloid or Sub-petaloid depending upon its perfection. If it is perfectly of petal shape as in the case of 'sentella' then it is called petaloid. If it is slightly unperfet resembling petal shape, then it is called sub-petaloid as in the case of 'Micraster'.

The development of compound plates was first found in triassoic Echinoids. By these compound plates, we get larger number of tube feet in each vertical row. The Bigerminal and Polygerminal pair of pores causes the tube feet to be shaped over a larger area and so increase their mechanical efficiency. The petaloid pair of pore arrangement is particularly well developed in flattened or cake like echinoids and in such echinoid, the tube feet have for the most part lost their locomotory function and have become respiratory organs.

With very few exception the echinoids of mesozoic and tertiary periods, had twenty columns of plate in corona. In paleozoic echinoid more than twenty columns of plates are found.

The plates of both the ambulacral and interambulacral areas are often provided with rounded elevations known as *Tubercles*, larger tubercles are called Primary and Smaller one are called secondary. The tubercle are attached with thorn like prolongation known as *Spines* or *Radioles*.

PERISTOME : On the lower surface of the Echinoid test is the peristome, in the centre of which there is mouth. Peristomes are made up of plates. Some of them perforated and some of them are not perforated. The shape of the peristome changes depending upon the position of the mouth. Peristome may be circular, pentagonal or Decagonal in outline if the mouth is in the centre, the outline of the peristome will be oval. In the regular Echinoid, the size of the peristome is large, where as in irregular echinoid, the peristome is small.

There is conical or pyramidical structure for mastication. It is called *Aristotle's lantern*. This is found in Regular Echinoids. The structure of the lantern is composed of 40 calcareous pieces and 5 teeth, they project from the mouth and help in mastication of food.

24.2.2 Distribution in space and time

The important echinodermata organisms are the micraster, scutella, cidaris, holaster and hemiaster.

Echinoids are marine invertebrates. Some echinoids live at great depths in the ocean. About 12 species found below 2000 fathoms and end species is even found below 2900 fathoms. By far the large number, they are characteristic of shallow waters of the sea. About 201 species out of 297 species which are existing are found below 150 fathoms of the sea. Another characteristic feature of Echinoids is the nature of the ocean bottom. Echinoids are abundant in sea whose bottom is rocky, sandy or calcareous, where they are rare in muddy or clayey ocean bottom. Echinoids are rare in palaeozoic formation especially in precambrian age. The earliest representative is from ordovician. In mesozoic and tertiary formation, we get echinoids representations in the form of fossils.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

1. The hard part of the echinoid is called _____

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.....

.....

.....

24.3 TRILOBITES

Animals called Arthropods (arthro=Joint; Pods=Foot) are invertebrates of highly varied forms, distinguished primarily by a segmented organisation of the body and possession of a hardened external covering. The arthropods belongs to 5 main types namely insecta, Chelicerata, Myriapods, Onychopora and Crustacea.

Crustacea containing Lobsters, Crabs, Shrimps, Cray fishes, ostracodes and important extinct invertebrates called Trilobites. Roughly, three fourths of all known kinds of animals-invertebrate and vertebrate-belong to the Arthropods which include at least 700,000 species. Arthropods have well developed digestive system, circulatory system and nervous systems with sense organs. Arthropods are found in an extremely wide range of environments. From palaeontological view point, it is appropriate to focus attention almost wholly on the aquatic forms, because most fossils occur in sediments of marine or fresh waters, important groups such as the trilobites seems to have been exclusively marine.

Trilobites are an extinct group of Arthropods which occupy a dominant role in the early part of the palaeontological record. They are marine organisms. The name of Trilobites date back at least to the first scientific publication on these fossils by Lhwyd (1698) in England. The name refers to the division of the body into three longitudinal segments or lobes which are very distinct in many specimens. The size of the adult Trilobites ranges from 6mm (Agnostus) to 75 cms long (Paradoxides). Most Trilobites are however 2 to 7 cms in length and 1 to 3 in width.

24.3.1 Classification and morphology

Phylum Arthropods

Class Crustacea

Sub-Class Trilobita

Trilobites have three (three) main skeletal divisions : (a) Cephalon (b) Thorax (c) Pygidium. (Fig. 24.1 & 24.2)

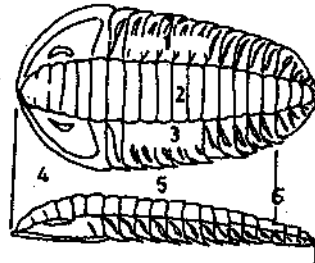


Fig. 24.1 A Trilobite

1-Pleural lobe 2-axis 3-Pleural lobe 4-Cephalon 5-Thorax 6-Pygidium

Cephalon : It is also known as head or head shield or cephalic shield. It is one of the most important part of the trilobites. Cephalon is usually semicircular or triangular in shape. The central part of the cephalon is more convex and is known as Glabella. Adjacent to glabella on either side in cephalon we have triangular areas known as Cheeks. Glabella and Cheeks are separated by means of axial furrow. The form and size of the glabella varies in different trilobites. Cephalon has two borders namely posterior border and the lateral border. Glabella, the most prominent part of the cephalon is divided into number of chambers with the help of furrows known as glabel furrows and the chambers are called glabel chambers. The two borders posterior and lateral meet together and describe an angle known as genal angle. Some times the meeting of the two borders is very acute, such that they get extended to form spine like structure known as genal spines. The cheeks

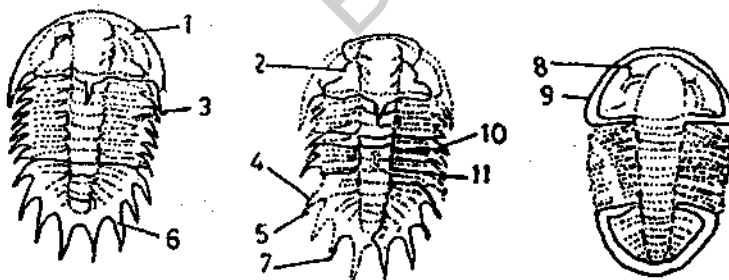


Fig. 24.2 Trilobite structure

1-Cephalon 2-Cranidium 3-Thorax 4-Pleural spine 5-Pleural furrow 6-Pygidium
7-Marginal spine 8-Ocular ridge 9-Border 10-Thoracic segment 11-Pleuron

on either side of the glabella intumescence is divided into 2 parts with the help of a line known as facial suture. The two parts thus obtained are termed as fixed cheek and free cheek. The part of the cheek adjacent to the glabella on either side is called fixed cheek. The size of the fixed cheek and free cheek varies in different trilobites and the size of the free cheek and

fixed cheek depends mainly upon course of facial suture. The running direction of the facial suture also varies, some times it starts from the posterior border and runs towards lateral border, some times, it starts from the lower end of the lateral border, runs towards the lateral border near the glabella. If the facial suture starts from the posterior border, then the genal angle lies in the free cheek area, then such trilobites are referred as Ophisthoptarian type, on the other hand, if the facial suture starts at the lower end of lateral border, then the genal angle lies in the fixed cheek area, such trilobites are referred as Proparian type. The area occupied by fixed cheek and glabella in the cephalon is termed as Cranidium.

Eyes in trilobites are considered to be one of the highly developed visual organs. Trilobites usually have compound structured eyes with number of lenses. Each lens is spherical in shape. Eye is found entirely on free cheek which rests on lobe situated in fixed cheek. There are trilobites having one or two or three lenses, then they are said to have simple eye. There are in Harpes each eye is made up of 3 lenses. In Trinucleus, it is made up of only one lens. Some trilobites, like Agnostus, Microdiscus, Phacops, the eyes are absent, which do not mean that they did not have eyes since beginning, but they lost their vision because of disuse. In Phacops the eyes are well developed. In Remopleurides, there are as many as 15000 lenses in each eye. In cyclopyge, the eyes are very large so much so that it covers a large area of the free cheek. The eyes are semicircular in Olenellus.

In the compound type of eyes again, there are two types namely Holochroal type and Schizochroal type. In Helochroal type of compound eye, there is single common transparent coating of cornea, whereas in the schizochroal type of compound eye each lens is given a common transparent coating of cornea independently.

Thorax : It is the central and most important part of trilobites. Thorax is made up of number of segments. These segments are known as thoracic segments. The thoracic segments vary in number with a maximum of 42 and minimum of 2. The segments are movable, so that when the body is in motion, the segments slide one over the other given wavy motion. Each segment, consists of 3 parts, the central part known as median part and two lateral or side parts. The division of segments into three parts is due to the development of two furrows. The longitudinal central part of the cephalon, thorax and pygidium is called the axis. The lateral or side parts of the segments are called Pleura.

The thoracic segments are short and wide. The pleura may be blunt or rounded or drawn into thorn like prolongation known as pleural spine. The Central part of the each thoracic segment is the axial segment and the lateral parts of the segment are called the pleural segments. The transverse grooves between axial segments of thorax are the articulating furrows; and those between any two adjoining pleura are called the interpleural grooves.

Pygidium : The Pygidium is the posterior part of the trilobite body, where as the cephalon is the anterior part. It is usually triangular or semicircular in shape and outline. The segments are fused unlike thoracic segments. Hence the segments are immovable. Very similar to thoracic segments, the segments in pygidium also is divided into 3 parts namely the central or axial segments and 2 lateral or pleural segments. The margin of the pygidium may be smooth or wavy. Some times, the pleural segments develop spines known as pleural spines. The anus is situated on the ventral side of the last germinal segment of the pygidium.

In primitive trilobites, all segments belonging to thorax and pygidium were unfused, so movable. Later, the segments in pygidium were found fused making a clear distinction

between thoracic segments and pygidium segments. Hence, it is believed that pygidium is derived part of thorax. Trilobites having smaller thorax will have bigger pygidia, trilobites having bigger thorax shall have smaller pygidia.

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.

2. The important parts of the body of trilobites are

(i) _____ (ii) _____

(iii) _____

.....

.....

.....

.....

24.3.2 Distribution in space and time

The important trilobites are the calymene, paradoxides, phacops, olenellus, agnastus, microdiscus, redlichia, griffithides, trinucleus.

Trilobites are marine organisms. It is an extinct group. Trilobites are found in abundance during cambrian rocks of Palaeozoic era. Trilobites form important faunal group of lower palaeozoic era. i.e. Cambrian, Ordovician, and Silurian periods.

It is not only first representative from cambrian period, but also maximum development and maximum number of trilobites were found during cambrian period. In silurian, they were still abundant but during Ordovician they were on decline. The end of Palaeozoic era marked the end of trilobites.

24.4 GRAPTOLITES

These are vertebrate animals of primitive characters. These animals belongs to phylum hemichordata.

KINGDOM : ANIMALIA

PHYLUM : HEMICHORODATA

Classes

1. Enteropneusta (acron worms)
2. Pterobranchia
3. Graptolithina
(graptolities)

Orders

1. Dendroidea
2. Tuboidea
3. Camaroidea

4. Stolonoidea
5. Crustoidea
6. Graptoloidea

24.4.1 Morphological Characteristics

The graptolite skeleton consists of a series of cuplike chitinous chambers, the *thecae* (=hydrothecae, singular, *theca*) arranged in series along a branch the *stipe*. The stipes may be solitary or form a branching net, constituting the colony, the *rhabdosome* (Fig. 24.3). The entire colony is surrounded by a chitinous covering, the *periderm*. The earliest stage in the development of the graptolite colony is the *sicula* (Fig. 24.4). It is a conical or dagger-shaped chamber built by the initial polyp (zooid) of sexual origin. The sicula is open at the base, and consists of two parts: the apical end with a thin wall and the apertural part with a thick wall marked with lines of growth. The sicula terminates in a long apical thread-like *nema* (also known as *virgula*). The rhabdosome hangs from one end of the nema. A spinelike projection is sometimes found at the apertural end of the sicula, but has no connection with the virgula. In some species, the virgula projects beyond the distal end of the common canal.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

3. The entire skeleton of graptolites known as _____

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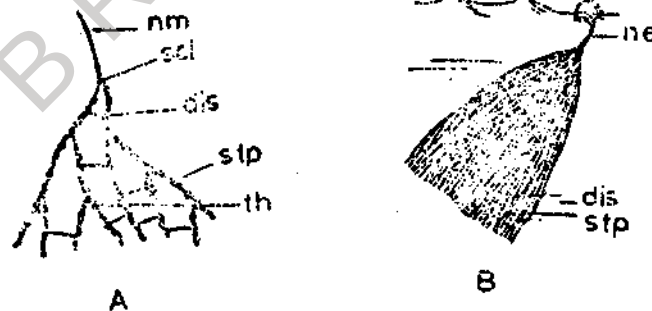


Fig. 24.3 A. Dendroid graptolite B. Reconstruction of colony of Dictyonema
dis. dissepiment, nm, nema, scl, sicula, stp, stipe, th, theca

In the growth of the stipe, a single individual, the *budding zooid*, gave rise to three zooids (Fig. 24.5). One of these was a new budding zooid. It built a slender tube, the *stolotheca*. Because this, in turn, gives rise to another set of zooids, stolothecae form the axis of the stipe. The other two zooids construct thecae that open laterally from the stipe. One of them (the female zooid?) formed a larger theca, the *autotheca* while the other zooid (the male zooid?) a smaller theca, the *bitheca*. The thecae are connected internally by a

delicate tubule, the *stolon*. which extends through the stolothea and divides into three branches, one to each theca of the next generation. The wall of the theca consists of two layers. The inner is composed of half rings that dovetail to form zigzag longitudinal sutures. The outer layer consists of thin concentric sheets deposited on top of one another. The stolothea which contained and extended the stolon did not actually appear as a theca on the fully developed rhabdosome. With the transition to a planktonic lifestyle the biothecae were reduced so that only the autothecae remained visible.

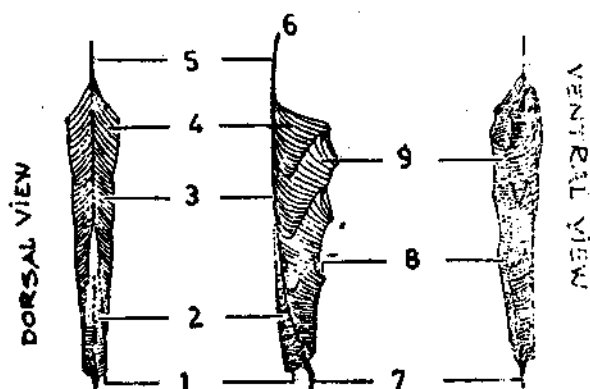


Fig. 24.4 Structure of the sicula in Monograptus

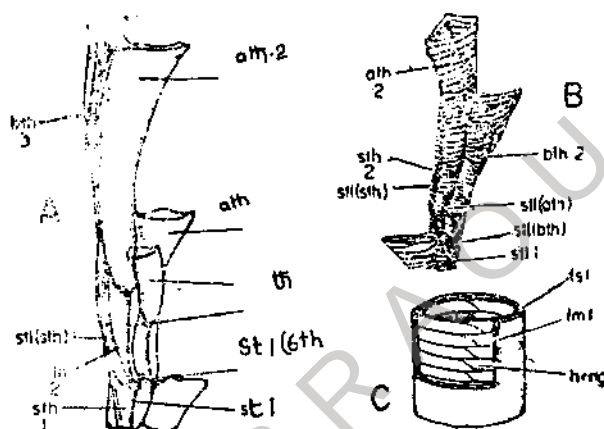


Fig. 24.5 Detailed Morphology of the Dendroid Graptolites.

A) Lateral view of portion of stipe. Three buds arise from stolothea 1 (sth.1). One of these forms stolothea 2 (sth.2), one forms bitheca 2 (bth 2) and one forms autothea 2 (ath 2). A chitinoid tube, the stolon (stl.) extends along the stolothea and gives off side branches for the bitheca [stl.(bth)], and to the autothea [stl.(ath)]. B) Lateral view of the portion of stipe showing tusellor half rings that form part of skeleton. Labeling of thecae correspond to that in A. C) Detailed of skeleton showing inner and outer layers. Based on Kozłowski, 1947. Abbreviations: ath, autothea, bth, bitheca, fs.1, fusellor layer, h.rng.hol, ring (of fusellor layer: 1m, 1, lamellar layer, sth, stolothea, stl, stolon-abbreviations in parenthesis indicate which branch. (After Kozłowski.)

As thecae were added a bladelike graptolite colony developed. When there are several (radiating branches stipes) their proximal parts are sometimes enclosed in a horny sheat, the *central disc*. (Fig. 24.6) A dendritic or bushlike framework results when the bladelike rhabdosomes are held together by supporting cross bars, the *dissepiments*.

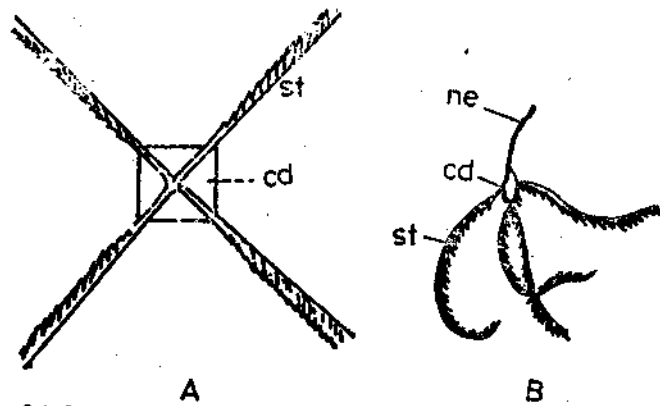


Fig. 24.6 A,B. Tetragraptus cd=central disc ne=nema st=stipe

The thecae arranged in a continuous series along one row (uniserial) as in *Monograptus* (Fig. 24.7) two rows (biserial) as in *Diplograptus*.

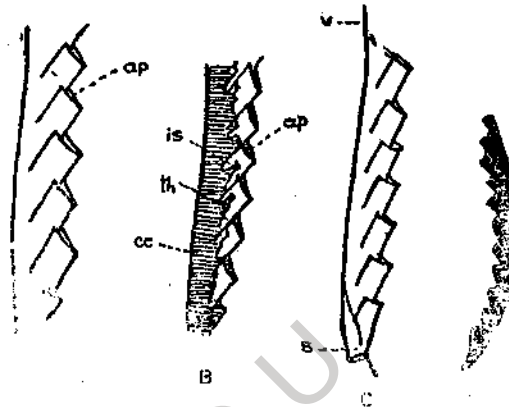


Fig. 24.7 A,B,C,D. Enlarged figures to show the structure of *Monograptus*

ap=aperture of hydrotheca cc=common coral the theca is intertheca septum sicular v=virgula

(Fig. 24.8), or four rows (quadriserial). The thecae usually similar in form, but diminish in size towards the proximal end of the rhabdosome. They may resemble the sicular in shape, or they may be tubular, prismatic.

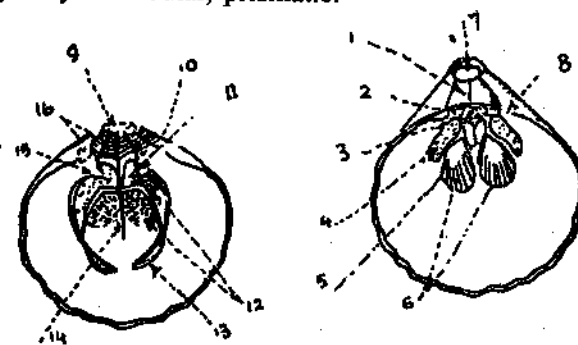


Fig. 24.8. A,B Diplograptus, C-Reconstruction of colony of *Diplograptus*.

A=Enlarged figure to show the structure of *Diplograptus* s, sicular, se=median septum, v=virgula

Conical, straight or coiled. They may be in contact throughout their entire length as in *Phyllograptus*, at their bases only as in *Nemagraptus* (Fig. 24.9) or, in a few cases entirely separate as in *Rastrites* (Fig. 24.10). The thecae communicate freely with the common canal.

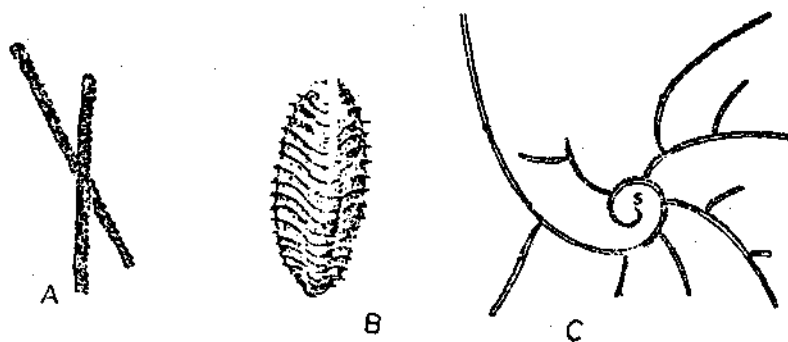


Fig. 24.9 Graptolites. A=*Didymograptus* B=*Phyllograptus* C=*Cyrtograptus*

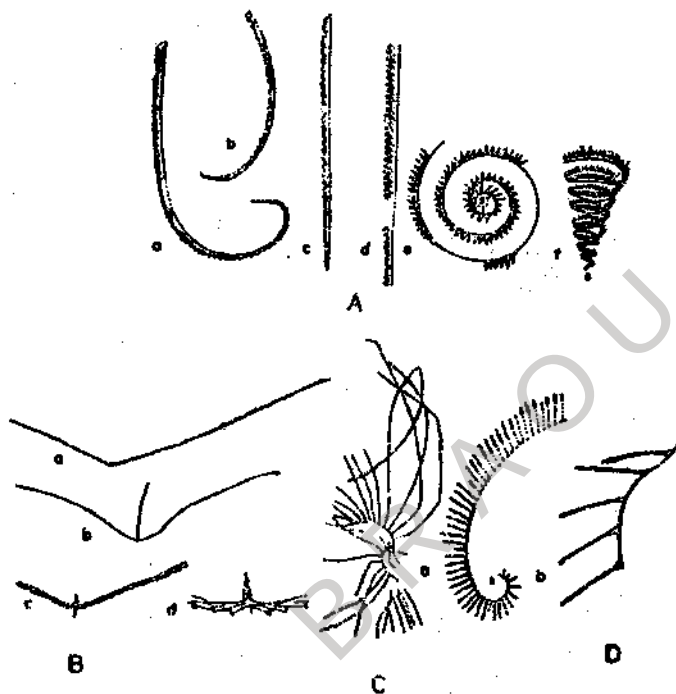


Fig. 24.10 Graptolites

- A. various species of *Monograptus* B. various species of *Leptograptus*
C. *Nemagraptus* D. Different species of *Rastrites*

Order Gryptoloidea

Members of this order were exclusively planktonic or hemiplanktonic. Following the reduction in the number of stipes from more than four to two, various forms appeared with pendant or horizontal stipes (with respect to the sicula) or with stipes raised to varying degrees (reclined, erect). In some cases the stipes actually fused over the sicula so that forms arose with biserial thecae. They are characteristic of the Upper Ordovician. At the Ordovician, Silurian boundary some forms reduced the thecae on one side, beginning at the proximal end, so that uniserial forms arose. The latter make up the graptolite fauna of the Silurian and Lower Devonian.

The graptoloids are divided into two groups based on the configuration of the stipes.

1. **Axonolipa** Both stipes remain free, so that the rhabdosome is bilateral and uniserial. The nema which emanates from the sicula also remain free.
2. **Axonophora** The stipes are erect fused back to back with the nema (also known as virgula in this configuration) in between. The rhabdosome is thus biserial or secondarily uniserial.

Axonolipa graptoloids

Dichograptus : Rhabdosome bilaterally symmetrical, with a maximum of eight long uniserial main stipes produced dichotomously. Thecae sample tube-like, usually strongly overlapping. A central disc is frequently present. Lower Ordovician.

Tetragraptus (Fig. 24.6) : Four stipes which rise from the bifurcation of two short branches coming off from opposite sides of the sicula, thecae simple, notched. A central disc may not be present. Lower Ordovician.

Didymograptus (Fig. 24.9) : Only two stipes, thecae usually simple, straight. Lower to Middle Ordovician.

Leptograptus (Fig. 24.10) : Two simple, slender uniserial stipes given off in opposite directions from the sicula at angles greater than 180° . Thecae are long tubes with slight sigmoid curvature, in contact for about half their length (resembling a pipe-bowl). Middle to Upper Ordovician.

Nemagraptus (Fig. 24.10) : Biserial, thecae subprismatic or subcylindrical tubes, overlapping and placed obliquely. virgula prolonged beyond the distal extremity of the rhabdosome. Middle Ordovician-Lower Silurian.

Monograptus : Rhabdosome unbranched, uniserial, straight, curved or spiral. Thecae vary variable, those at the proximal end some times differing from those at the distal end. Silurian - Lower Devonian.

24.4.2. Geological History.

Graptolites began as simple dendroid forms in the Upper Cambrian. They attained their main acme of development in the Ordovician and had a second minor acme during the Silurian. Nearly all the species in the two periods are different, the biserial axonophore rhabdosome characterising the Ordovician and the uniserial axonophore Monograptus rhabdosome the Silurian. However, a few stragglers persisted through the Devonian and possibly into the early Carboniferous. Their disappearance at the close of the Silurian and the beginning of the Devonian may perhaps be corrected with the advent of the fishes, which appeared in great numbers at that time.

24.5 SUMMARY

The three important groups of fossils namely echinodermata, trilobita and graptolites were explained in this unit.

Echinoderms are marine and spiny skinned animals. Their body structure is different from other invertebrates. Water circulatory system is the special character. These animals are divisible into two groups namely Pluteozoa and Echinozoa. Majority of Pluteozoans are extinct. Class Echinoidea of Echinozoa are highly represented in the marine environment even today. The important body parts of echinoids are apical disc, corona and peristome. Echinoids are rare in palaeozoic formations of precambrian age. The earliest is from orthovisian. In mesozoic and tertiary periods we get good echinoid fossil record. Micraster, hemiaster, holaster, scutella, cidaris are the good examples for fossils.

Trilobites are an extinct group of arthropods, which are dominant in the early part of palaeontological record. They are marine. The body is divisible into three parts namely cephalon, thorax and pygidium. The important trilobites are the Calymene, Paradoxides, Phacops, Olenellus, Agnostus, Microdiscus, Redlichia etc. These animals are found in abundance during Cambrian period.

As a whole these are the important group of extinct faunal animals of Cambrian, Ordovician and Silurian periods.

Graptolites are the primitive vertebrate animals. The graptolite skeleton consists of a series of couple-like chitinous chambers arranged in a series along a branch the stipe. Graptolites are divided into two groups called Axonolipsa and Axonophora. These groups of animals are also extinct and are dominant during Ordovician period and very few in Silurian and Devonian.

24.6 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Shell
2. Cephalon, thorax and pygidium.
3. Rhabdosome

24.7 MODEL EXAMINATION QUESTIONS

I Answer the following questions in 30 lines each

1. Explain various parts of echinoid test
2. Describe the morphology of a typical trilobites ?
3. Write an essay about graptolites

II Answer the following questions in about 10 lines each

1. Describe the corona of echinoid
2. Differentiate between uniserial and biserial pores in echinoids
3. Describe the evolution of graptolites
4. Explain how graptolites differ from corals

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Faculty of Science

Second Year (3 year Degree Course)

MODEL QUESTION PAPER

GEOLOGY

Course - I

General Geology, Crystallography, Mineralogy, Palaeontology

Time : 3 hours

Max. Marks : 70

Section - A

Note : a) Answer any three questions in about 30 lines each.

b) Each question carries 15 marks.

1. What is geology ? Explain various divisions.
2. What is weathering ? Write down various kinds of weathering.
3. Write down the classification of crystals into various systems.
4. Write down the physical properties of minerals.
5. What is fossil ? What are the conditions for fossilisation.
6. Explain the morphological features of Trilobites.

Section - B

Note : a) Answer any five questions in about 10 lines each.

b) Each question carries 5 marks.

7. Explain the internal composition of Earth.
8. What are the products of volcanoes ?
9. What is meandering ?
10. Explain sand dunes.
11. What is symmetry in crystals ?
12. What is lustre of minerals ?
13. Explain about Feldspars.
14. What are the uses of fossils ?
15. Classify the gasteropod fossils.
16. Compare the pelecypod shell with brachiopod shell.

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Second Year (3 year Degree Course)

GEOLOGY

Course - I

General Geology, Crystallography, Mineralogy, Palaeontology

ASSIGNMENT - I

I. Answer the following questions in about 30 lines each.

1. What are Earthquakes ? Explain the classification of Earthquakes.
2. Explain the crystal forms of normal class of Isometric system.
3. Write down the morphology of gasteropods.

II. Answer the following questions in about 10 lines each.

1. Explain about physical properties of pyroxene minerals.
2. What is River capture ?
3. What are the kinds of fossilisation ?

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GEOLOGY

Course - I

General Geology, Crystallography, Mineralogy, Palaeontology

ASSIGNMENT - II

I. Answer the following questions in about 30 lines each.

1. Explain the geological actions of Rivers.
2. Write an essay about Amphibole family.
3. Writedown the morphological characters of Pelecypods.

II. Answer the following questions in about 10 lines each.

1. Explain Spheroidal weathering.
2. Define a crystal.
3. Write the Geological history of graptolites.

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GEOLOGY

Course - I

General Geology, Crystallography, Mineralogy, Palaeontology

ASSIGNMENT - III

I. Answer the following questions in about 30 lines each.

1. Write about the deposits formed by glaciers.
2. What is silicate structure ? Explain the various types.
3. Write about the morphological characters of Brachiopods.

II. Answer the following questions in about 10 lines each.

1. What are Aquifers?
2. Explain Symmetry elements.
3. Compare Olivine and Garnet minerals.

BRAOU



BS2 - G2

GEOLOGY *Geology II*

OPTICAL MINERALOGY & PETROLOGY

BRAOU

BRAOU

GEOLOGY

COURSE - II

OPTICAL MINERALOGY & PETROLOGY



"We may forgo material benefits of civilization, but we cannot forgo our right and opportunity to reap the benefits of the highest education to the fullest extent..."

- Dr. B.R. Ambedkar

Dr. B.R. AMBEDKAR OPEN UNIVERSITY
HYDERABAD
- 2002

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PREFACE

This book deals with the topics in Geology included in the syllabus for the Second Year of the B.Sc. course offered by the Dr. B.R. Ambedkar Open University. The topics generally cover the 'core' areas of the subject to be studied in the Second year of the Three Year Degree Course in Science. The syllabus for the sake of convenience is divided into blocks, each of which comprises a number of Units. Each block generally covers a specified area of the subject. The Units are prepared by specialists in accordance with a format so designed as to enable the student to read and understand them without much difficulty. Each Unit begins with a statement of its objectives, and assignments at the end of the course material intended to test the student's comprehension of subject. Technical terms with which the student may not generally be familiar with are given appropriately under the head, 'Glossary'.

The University hopes that this course material will help the student to get acquainted with the concepts and principles of optical mineralogy and petrology.

The main aim of this course is to explain the two main divisions of Geology, namely, Optical Mineralogy and Petrology. Block - I consists of Optical Mineralogy, here the important aspects related to the microscopic observations of the minerals are explained in four units. Petrology is explained in 20 units from Block 2 to 6. Block 2 and 3 are earmarked to igneous Petrology, Block 4 deals with Sedimentary Petrology, Block 5 and 6 discuss the Metamorphic Petrology. Here we have tried to discuss about the textures, structures, formations and classifications of the these rock groups. The university expects the students will be able to know about Optical Mineralogy and Petrology by studying this course.

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BLOCK - I OPTICAL MINERALOGY

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UNIT : 1 SCOPE AND DEVELOPMENT OF OPTICAL MINERALOGY

Contents

- 1.0 Objectives
- 1.1 Introduction
- 1.2 Optical Mineralogy
- 1.3 Nature of Light
 - 1.3.1 Corpuscular Theory
 - 1.3.2 Hygen's Theory
 - 1.3.3 Electo Magnetic Theory
 - 13.4 Ordinary Light - Polarised Light
- 1.4 Reflection
- 1.5 Index of Refraction
- 1.6 Critical Angle and Total Internal Reflection
- 1.7 Becke Line
- 1.8 Double Refraction
- 1.9 Summary
- 1.10 Check Your Progress - Model Answers
- 1.11 Model Examination Questions
- 1.12 Glossary

1.0 OBJECTIVES

After completion of this unit you should be able to

- * explain the definition of mineral
- * describe the nature of light
- * define reflection and refraction
- * explain Critical angle, becke line and double refraction

1.1 INTRODUCTION

In the identification of minerals a detailed study of their optical properties is very essential. These properties can be studied under polarising or petrological microscope. Rocks which are aggregates of minerals can also be studied and identified with the help of microscope. Optical Mineralogy deals with mineral investigation in thin sections under polarized light. To understand the optical behaviour of minerals it is all the more essential to understad the nature of light, and certain terms like wave motion, reflection, refraction, refractive index, total reflection, critical angle, double refraction and polarisation.

1.2. OPTICAL MINERALOGY

Optical mineralogy is the study of the optical properties of the minerals.

In determinative mineralogy both physical and chemical properties are to be checked. The Science of crystallography began as a subdivision of physical mineralogy. A mineral always exhibit the same crystal form, this was not known for a long period, but the early crystallographers suspected that definite internal arrangement of the constituent units were responsible. 1784 R.J. Hawy a french mineralogist-cum-crystallographer proposed the idea that crystalline matter consist of minute units of definite shapes which are so stacked as to be produced the characteristic external form. He called these as integral molecules. Later Max von Lave on the basis of the experimental work of Krippings & Fredrich was able to show that ordered internal arrangements of the constituent units were present in all crystalline matter and that what R.J. Havy had guessed was essentially correct. So thus a branch of X-ray crystallography and crystallography was born. Because all solid matter is crystalline the Science of crystallography is no longer just a sub-division of mineralogy. It has become, a very important in various phases of chemistry, physics, metallurgy, biology and its importance is increasing day by day now it has evolved into a separate branch. Optical mineralogy is also a branch of mineralogy and is concerned with optical properties of minerals. Optical Mineralogy is the method of studying of minerals by observing the behaviour of light, when it passes through a mineral or a crystal or substance. Normally an ordinary beam of light is behaved in many ways depending up on the internal structure of a mineral. The different ways in which the light behaves can be measured interms of certain constents and these constents are called as optical properties. The common optical properties useful in the recognition are refractive index, birefrengence, pleochroism, optic axial angle, extinction angle, optic sign, etc. The minerals in optical mineralogy is observed in two ways. If the minerals are transparent they were studied under 'transmitted' or refracted 'light'. If the minerals are opaque in nature they are studied under reflected light by using microscope or reflecting microscope or metallurgical microscope. It is experimentally proved that there is a definite relationship between optical properties and physical properties on one hand and chemical compositions on the other hand. It means by observing the optical properties of a mineral one can have an idea about its physical properties and also its chemical composition. Optical mineralogy is mainly concerned with the phenomena of light. Hence an elementary knowledge of optics is very essential for the student of optical mineralogy.

1.3 NATURE OF LIGHT

Light is a kind of energy that transmitted through a medium called ether, which spread throughout in space and the source of light is sun or luminous body. The sensation of light is felt when light rays effect the optic nerves of human eye. Several theories have been proposed to explain the nature of light.

1.3.1 Corpuscular Theory

This is the first theory and was supported by Sir Issac Newton. According to this theory the light is transmitted from a luminous body and consist of minute particles. These particles traversed at high velocity in straight lines, that are known as 'corposcules' when these particles reach the eye, the sensation of vision is felt.

The various colours seen in the light are due to the different sizes of the corpuscles.

1.3.2 Hygen's Theory : (Wave Theory)

In 1680 another theory was proposed by Hygen's and it was called as 'Wave theory' of Hygen's. According to this theory, light travels in the form of waves in a medium called ether, and penetrate all into the space. When the waves of light reach the eye then they produced the sensation of vision.

The different colours in the light are due to the difference in wave lengths of the light rays.

The distance between two successive crests or troughs is called as 'Wave Length'. Always the wave length symbols in greek letter called ' λ '. ' λ ' is expressed in millimicrons (m. μ). The violet colour is having the smallest wave length is 0.00039 mm and Red light is having the greatest wave length 0.00076 mm.

1.3.3 Electro Magnetic Theory

According to this theory light is propagated in the form of waves and these waves are containing different magnetic fields which are at right angles to each other and to the direction of propagation of light.

Hertz succeeded in producing rays similar to light rays with the help of electricity and the electromagnetic theory was accepted for some time.

Only the wave theory could explain satisfactory the phenomena of light, such as reflection, refraction, Interference, polarisation. White light consists of seven components which are

Violet	-	410 m μ	-	0.00041 m.m
Indigo	-	440 m μ	-	0.00044 m.m
Blue	-	470 m μ	-	0.00047 m.m
Green	-	515 m μ	-	0.000515 m.m
Yellow	-	560 m μ	-	0.00056 m.m
Orange	-	620 m μ	-	0.00062 m.m
Red	-	759 m μ	-	0.000759 m.m

All these are monochromatic lights. Monochromatics light is the light of single wave length. However in practical tests light with very narrow range of wave length is also used on monochromatic light.

1.3.4 Ordinary Light - Polarised Light

In ordinary light the vibration take place in all directions in a plane at right angle to the ray as shown in fig. 1.1



fig. 1.1 Ordinary light

But in polarised light the rays are vibrating in only one direction Fig. 1.2

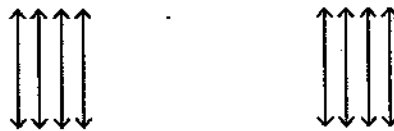


fig. 1.2 Polarised Light

Polarisation of light will occur by two processes of phenomena of light viz. reflection and refraction. Refracted light is used in petrological microscope. This microscope is useful to observe transparent minerals in thin sections. Reflected light is used in metallurgical microscope. This is to identify the opaque minerals.

1.4 REFLECTION

When a ray of light strikes upon a surface separating one medium from another. It is usually in part 'reflected' or bent back in to the original medium. (Fig. 1.3)

The reflection depends on two phenomenae.

- a) Smoothness of the surface
- b) Angle of the surface

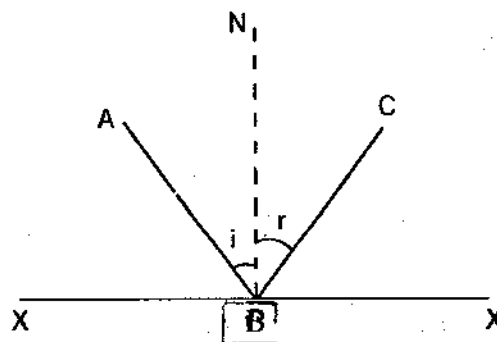


Fig. 1.3 Reflection

Let 'XX' represents a surface separating one medium from the other. AB represent a ray of incident light, that strikes the surface at 'B'. BC represent the reflected light.

The reflected light obeys two laws.

1. The angle of incidence (i) is equal to the angle of reflection (r)
2. The incident and reflected rays lie in the same plane Normal to the surface between the two media at the point of reflection.

AB = Incident ray

BC = Reflected ray

BN - Normal drawn which separate equal angle of incident and reflected rays.

1.5 INDEX OF REFRACTION

It is true that light travels in a straight line as long as the medium of passage is not changed, refraction results due to difference in the velocity of light in two media. The index of refraction which for any medium is defined as the ratio between the velocity of light in a vacuum and that in the medium. The precise relationship between angle of incidence (i) and the angle of refraction (r) is given by Snell's law (after Snell in 1621). According to this law for the same two media $\sin i / \sin r$ is a constant (n) and this constant is called refractive index. The refractive index of a vacuum is unity and that of air is slightly more than 1 i.e., 1.000274 but for all practical purposes it can be considered as 1 only. When a light ray passes through the medium, then the velocity of light in air be (v) and that in a medium be V. So, the ratio between two velocities which is a constant is the refractive index of that medium which is v/V or $1/V$ or is equal to the reciprocal of the velocity. Refractive index is also inversely proportional to the wave length of the light.

If indices of refraction of two different media are n_1 and n_2 then $\frac{n_1}{n_2} = \frac{v_2}{v_1}$ i.e.

i.e., the refractive indices of two media are inversely proportional to the velocities of light in them.

Refractive indices of Water is 1.33; Crown glass 1.53; Canadabalsam; 1.54, Diamond: 2.42.

It may be observed under the petrological microscope that the relief or the distinctness of the boundary of a mineral depends on the difference of index of refraction between mineral and the mount. The mineral that has higher refractive index than that of a mount (Canadabalsam) that exhibits well marked boundary otherwise it is invisible. Like wise the refractive indices of two minerals in contrast can also be compared

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.

1. Define the term "Index of refraction"

.....
.....

1.6 CRITICAL ANGLE AND TOTAL INTERNAL REFLECTION

When the incident ray strikes the boundary surface at right angles that is angle of incidence being zero, $\sin i = 0$ and r also must be zero. So when a ray enters a denser medium from a rarer medium it is not refracted but suffers only the loss of velocity.

It was observed that when light passes from a rarer medium into a higher refractive index medium it is refracted towards the normal but if the passage of light is in reverse direction then the light is refracted away from the normal. As shown in the figure 1.4, light rays ABCDEF are the angle of refraction is 90° that is the ray just grazes the surfaces between two media. The angle of incidence at which this phenomenon takes place is known as **critical angle**, and if the angle of incidence exceeds the critical angle then it is not the refraction that takes place but **total internal reflection** takes place.

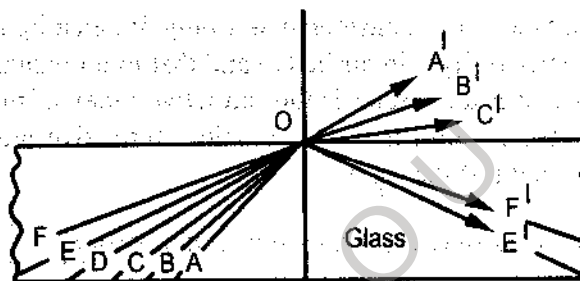


Fig. 1.4 Critical angle

1.8 BECKE LINE

The study of Becke effect (after F. Becke 1893) facilitates the determination of relative refractive indices of two minerals in contact. As shown in the figure 1.5 two minerals with different refractive indices are in contact. When the rays are thrown on the contact some are refracted and some are

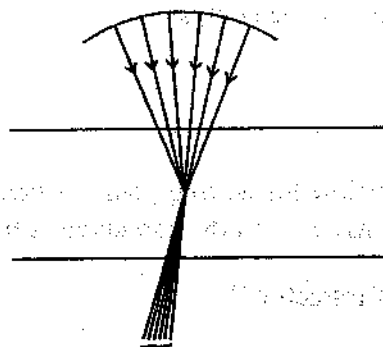


Fig. 1.5 The Becke effect

reflected but anyway the concentration of rays takes place in a medium of higher refractive index and when observed through eyepiece of microscope a bright line **Beckeline** was noticed. On raising the objective this line appears moving into the medium of higher refractive index and on lowering the line moves into the field of lower refractive index medium. Becke line can be obtained by using high power objective (100 X or 120 X) and by restricting the light by means of the diaphragm below the stage.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

2. What is Becke test.

1.8 DOUBLE REFRACTION

It is the property of minerals with an exception of those of cubic system, by virtue of which when the light passes through them it is broken into two rays-ordinary and extra-ordinary. All such minerals are known doubly refracting, and minerals crystallising in cubic system are singly refracting. It is therefore clear that this property has bearing on atomic structure of crystals. Ordinary and extra-ordinary rays travel through the same medium with different velocities and the mineral has two refractive indices corresponding to one incident ray. This property of double refraction is very well exhibited by Iceland spar, which is a colourless transparent variety of calcite. If a calcite rhomb is placed over a dot on the paper it is clearly observed that there are two images of the dot. By rotating the rhomb one image moves round the other which is stationary. The one which moves round is formed by extra-ordinary and is known as extra-ordinary image while the stationary one is formed by ordinary ray and is called ordinary image.

As shown in the figure 1.6 when normal incidence of a ray of light takes places on the bottom plane of the rhomb it is broken into ordinary rays. The extra-ordinary ray is refracted in the medium and when comes out from the opposite side will

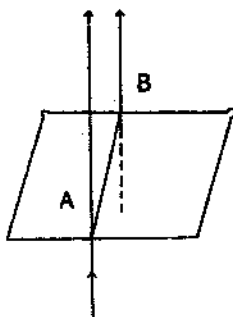


Fig 1.6 Paths of Ordinary and Extraordinary rays

in the medium and when comes out from the opposite side will follow the original path, but there will not be any bending in ordinary ray because of which the ordinary image is stationary. Either these rays i.e., ordinary and extra-ordinary rays is polarised along mutually perpendicular planes. Birefringence is the difference in greater and least indices of refraction mineral. Minerals exhibiting the property of double refraction are anisotropic and which do not show are isotropic minerals.

1.9 SUMMARY

Optical Mineralogy deals with the optical properties of minerals. These properties can be observed with the help of microscope with thin sections of minerals under polarised light. Light is a kind of energy and can be explained with corpuscular theory, wave theory and electromagnetic theory. In ordinary light vibrations can takes place in all directions where as in polarised light, light rays can vibrate in only one direction.

If any light when passing from one medium to other, gets reflected, the property is called reflection. This reflection mainly depends on two laws. The index of refraction for any medium is defined as the ratio of velocity of light in vaccume and in the medium. The relief under petrological microscope depends on the difference of index of refraction between mineral and mount.

When light passes from rarer medium to high refractive index medium, then the light refracted away from the normal. If the angle of refraction is 90° and passes through the surface between two media then it is called critical angle. If the angle of incidence exceeds critical angle there it is total internal reflection. The study of Becke effect is useful in the determination of relative refractive indices of two minerals in contact. When light passes through some minerals it may separated into ordinary ray and extra-ordinary ray. This property is called double refraction. All the minerals of cublic systems show refraction and minerals of all other crystal systems show double refraction.

1.10 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The incidence of refraction is ratio between the velocity of light in vaccume and that in the medium.
2. Becke test is useful to know the relative refractive indices of two minerals in contact.

1.11 MODEL EXAMINATION QUESTIONS

I Explain the following in 30 lines each

1. What is double refraction ?
2. Write about nature of light.

II. Explain the following in 10 lines each

1. Define Critical Angle and Becke line
2. What are Refraction, Index of refraction

1.12 GLOSSARY

1. Crystallographer	:	A man who studies details of crystals
2. Mineralogist	:	A man who studies about minerals
3. Petrological microscope	:	An instrument used for study of optical properties of minerals by using polarised light.

UNIT : 2 DESCRIPTION OF A POLARISING MICROSCOPE

Contents

- 2.0 Objectives
- 2.1 Introduction
- 2.2 Nicol Prism
- 2.3 Petrological Microscope
 - 2.3.1 Mechanical Parts
 - 2.3.2 Optical Parts
- 2.4 Summary
- 2.5 Check Your Progress - Model Answer
- 2.6 Model Examination Questions.

2.0 OBJECTIVES

After completion of this unit, you should be able to

- * describe Nicol prism
- * explain the parts of Petrological microscope

2.1 INTRODUCTION

It is a type of microscope, used in the study of thin section of minerals and rocks. It differs essentially from an ordinary biological microscope in having a revolving and graduated stage and two nicol prisms, one below the stage and the other above it. Nicol prisms serve the purpose of converting ordinary light into polarized light, suitable for the determination of optical properties of minerals. A petrological microscope is therefore called a polarizing microscope. There are several makes of petrological microscope.

2.2 NICOL PRISM

For the identification of minerals under the microscope it is very essential that the polarised light is available and the appliance that produces such light is known as 'Nicol Prism'. It is a very important part of the petrological microscope. The first polarising prism was invented in 1828 by William Nicol, a lecturer in natural philosophy at Edinburgh. It is William Nicol who contributed to geology the basic tools modern petrography. Nicol prism is also called nicol which depends upon the principles of double refraction for its action. A long cleavage rhombohedron of Iceland spar (variety of calcite) is used in the construction of a nicol prism. The rhomb is chosen in such a way that its length is three times its thickness. The ends of the specimen are ground down such that the rhomb is cut into two halves. The two parts are cemented together by canada balsam of which refractive index is 1.54 (Fig 2.1). When a ray of light enters the prism it is resolved into two rays-ordinary and extra-ordinary.

The cementing material which is the canada balsam is place in such a position between two halves that the angle of incidence of the ordinary ray always exceeds the critical angle so that total internal reflection of the same ray may take place, and it may not pass through the prism.

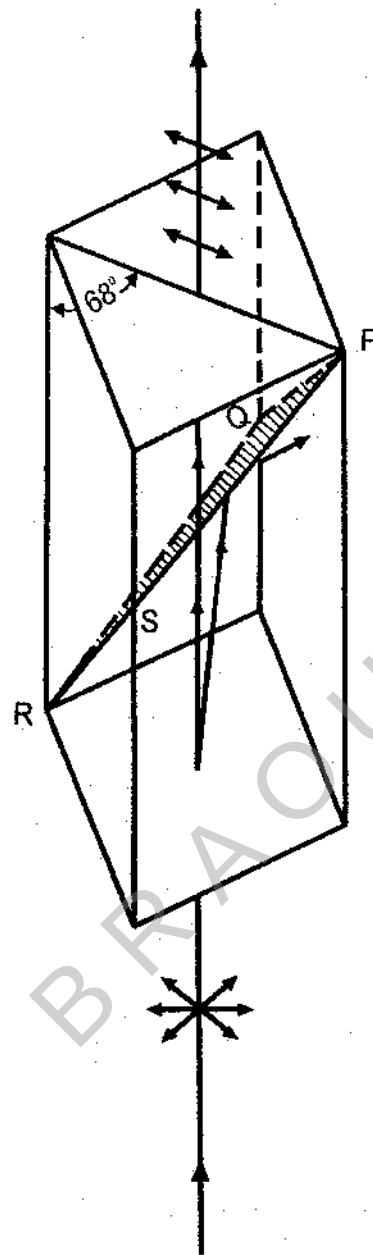


Fig. 2.1 Construction of a Nicol Prism
PQRS - Plane

The extra-ordinary ray with smaller refractive index than that of ordinary ray and which is also close to that of canada balsam proceeds of the prism, undeviated and forms the polarised light. As the extra-ordinary ray in calcite (Iceland spar) vibrates parallel to the shorter diagonal of the nicol, the polarised light is ultimately transmitted out has plane of polarisation lying parallel to the shorter diagonal.

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this unit.

1. What is Nicol prism ?

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.....

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.....

2.3 THE POLARISING OR PETROLOGICAL OR PETROGRAPHIC MICROSCOPE

The identification of common minerals is very easily accomplished with the help of polarised light under the petrological or polarising microscope. This microscope is extensively used to examine transparent minerals. Other types of microscope used for mineral identifications are : a) reflecting or ore microscope, and b) binocular microscope. The reflecting microscope is used for the identification of polished sections of metallic ores. The petrological or petrographic microscope is quite different from a binocular microscope as the latter is devoid of most important appliances known as nicol prism.

However the primary function of any microscope is to give an enlarged image of an object placed on its stage. The magnification is produced by two parts of the microscope a) the objective, and b) the eyepiece. For mineral identification three objectives are used depending upon the necessity, which are low (2X), medium (10X) and high (50X) power. The image of an object is magnified to 20 times (20X) or 100X or 1200X. An objective 10X with an eyepiece 5X gives a total magnification of 50X i.e., 50 times linear.

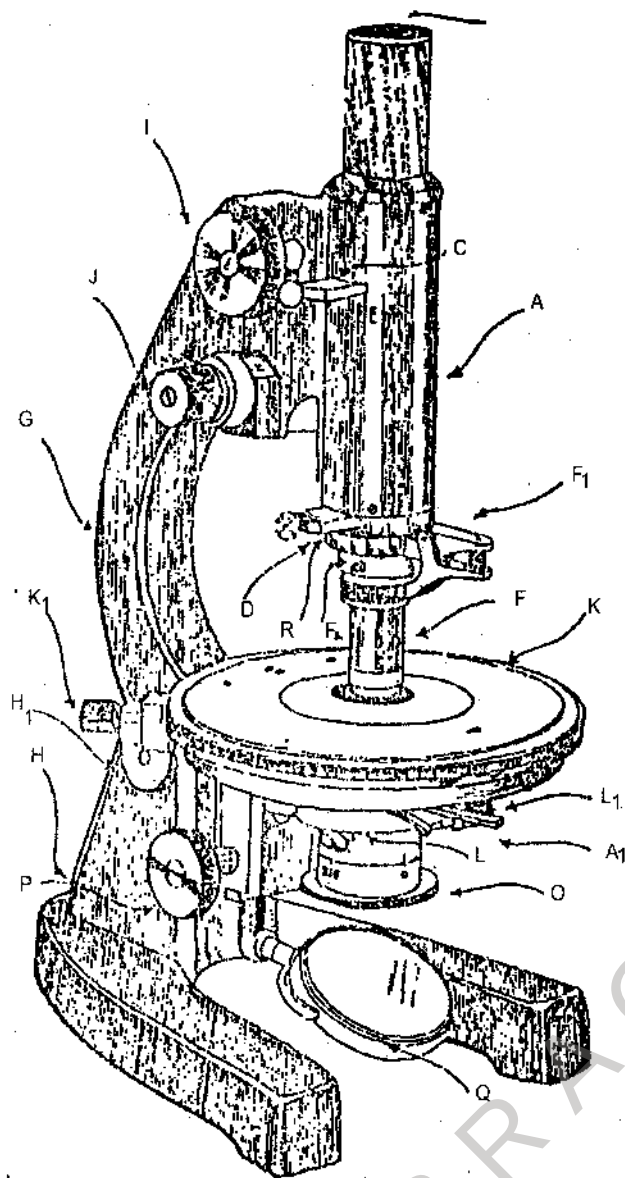
2.3.1 Mechanical parts of the Microscope

1. Stage

It is a circular table with an opening on which thin section of the mineral or the rock is placed for examination. It is rotatable and the amount of rotation can be measured by means of its graduated margin. The section is held on the stage by spring clips. Stage can be clamped with the help of a screw (K_1).

2. Tube

It is hollow and cylindrical (A). It is generally straight and attached to this are several optical parts such as eye-piece(B), objective (F), analyser(D), Bertrand lens(C), and accessory plates like quartz wedge or a mica plate or a gypsum plate.



- A. Micro Scope Tube
- B. Eye Piece
- C. Bertrand Lens
- D. Analyses
- E. Tube
- F. Objective
- F1. Clutch
- F2. Centering Screws
- G. AKM
- H. Foot
- I. Course adjustment Screw
- J. Fine Adjustment Screw
- K. Rotating Stage
- K1. Vernier Screw
- L. Lower Condensing Lens
- L1. Upper Condensing Lens
- M. Iris Diaphragm
- O. Polariser
- P. Sub Stage Screw
- Q. Mirror
- R. Accessory Slot

Fig. 2.2 Petrological microscope

3. Objective Holders

Most of the modern manufactures are providing with clutches (F1) to hold the objective. Clutches consist of steel tongues which are screwed to tube.

4. Centering Screws :

If the object exactly under the cross hairs does not remain central on rotation of the stage centering is needed. For this purpose centering screws (F2) are provided.

5. Adjustment Device

Either by raising or lowering the tube with the help focussing screw (I) the clarity of the field is obtained and the fine microscopes adjustment of the stage with a screw (P) would also bring in the focussing.

6. Sub-Stage :

This carries the polariser (O) and the permanent condensing lens (L) an auxiliary condensing lens and an iris diaphragm (M)

2.3.2 The Optical Parts

The illumination system is attached to sub-stage and consists of a mirror, diaphragm and a condenser,

1. Mirror :

Mirror(Q) is fixed below the stage and is issued to reflect the light through the source to the object. Both the sides (Plane and concave) of this can be used and can be rotated in any direction.

2. Diaphragm :

It is used to facilitate the change from parallel to convergent light.

Check Your Progress

- Note : a) Space is given below for writing you answer.
b) Compare your answer with the one given at the end of this unit.

2. List out the different mechanical parts of petrological microscope.

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A thin section of mineral which is to be examined under the microscope has three parts : a) A thin glass slide (3" X 1"). The mineral grain, of which the thickness is 0.035 mm (by grinding) and c) a very thin over the grain the transparent cover slip is placed so that the grain may be in a fixed position. Such sections are placed on the opening provided in the stage so that the reflected light from the mirror may pass through the polariser or the lower nicol to transmit polarised light which in turn enters through the eye-piece with two cross hairs at right angles. The polariser, analyser, bertrand lens, condenser and the diaphragm may be pushed in or convergent light into a well defined image. The polariser or lower nicol as already noted transmits plane polarised light vibrating in a N - S (front-back) direction. The analyser which is above the stage and fitted in the tube transmits light vibrating in a E-

W direction. When both nicols are in diagonal of one is at 90 to the shorter diagonal of the other. When a ray of light enters the polariser it is the extra-ordinary ray that comes out which vibrates parallel to it's shorter diagonal. Such extra-ordinary ray would directly enter the analyser through the objective in the absence of a mineral section on the stage and vibrates parallel to its logner diagonal as the nicols are crossed and the ray is internally reflected back as that is the eye-piece and a dark field results. Exactly the same happens when an isotropic mineral section (minerals of cubic system) is placed on the stage and the nicols are crossed. This is because the extraordinary ray that comes out of the polariser enters the isotropic medium which is singly refracting and in which in any direction the ray travels with same velocity, passes through unchanged and when that ray enters the upper nicol it vibrates parallel to longer diagonal of the analyser (crossed nicols) and is reflected back resulting in producing the dark field. Through out the rotation of the stage, the isotropic minerals remain dark under crossed nicols. With anisotropic media on the stage the phenomenon differs, as they are doubly refracting and the velocities of rays change as per the direction. The plane polarised ray of monochromatic (one wave length) light that leaves the lower nicol when enters the section of anisotropic minerals is resolved into two rays-one fast and the other slow and vibrating at right angles. Such two rays when enter the analyser are further resolved into two each (Fig 2.3) out of that two rays would vibrate parallel to longer diagonal to be thrown aside and the other two which are extra-ordinary rays which vibrate parallel to its shorter diagonal will be transmitted out but difference in phase. Due to this phase difference two rays interfere.

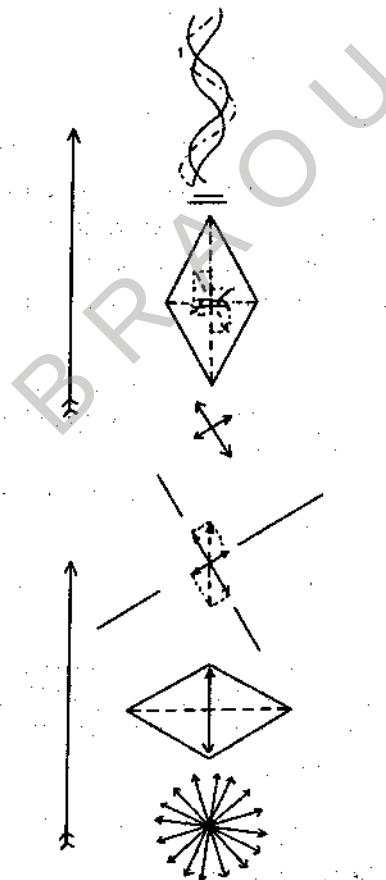


Fig 2.3 Diagram representing the Happening in a mineral plate viewed between crossed Nicols

If the phase difference is any number of whole wave-lengths when the rays oppose each other resulting in dark field through out the rotation of stage. On the contrary, if the phase difference in two extra-ordinary rays in any number of odd half wave lengths i.e., $1/2$, $3/2$, $5/2$ the vibrations help each other except in four positions in complete rotation of the stage where vibration directions of nicols and the vibration directions of the mineral coincide. In these four positions the effect of interfering rays is neutralised and darkness results and between any two such positions the colour is bright.

2.4 SUMMARY

Polarising Microscope is also called as Petrological microscope. This is essentially used for the observation of optical properties of minerals and rocks. It is fitted with a special device called Nicol Prism. This Prism converts ordinary light into polarised light. This mainly depends upon the property of double refraction. The petrological microscope is used to observe the transparent mineral sections.

The main components of polarising microscope is divided into two groups. Those are mechanical parts and optical parts. The main mechanical parts are the stage, tube, objective holders, centering screws, adjustment device, sub stage etc. The stage is useful for placing the mineral specimen in thin section. By rotating this stage one has to observe the properties. In tube there are eye-piece, objective, analyser, bertrand lens and accessory plates are available. Objective holders are useful to hold objective, centering screws are useful to keep the exact mineral grain at the centre. Sub stage carries the polariser and the lens.

The important optical parts includes mirror and diaphragm. The thin section of the mineral consists of 3 parts, a thin glass slide, mineral grain and the thin cover slip. Such sections are placed on the opening provided in the stage so that the reflected light from the mirror may pass through the polariser, which in turns enter through the eye-piece with two cross-hairs at right angles. Through out the rotation of the stage, the isotropic minerals remain dark under crossed nicols, where as in the case of anisotropic minerals due to double refraction, at four positions darkness appears and in between the colour is bright.

2.5 CHECK YOUR PROGRESS - MODEL ANSWERS

1. In a polarizing microscope the polarizing light is available and the appliance that produces such light is known as 'Nicol prism'.
2. Mechanical parts - stage, tube, objective holders, centering screws, adjustment device and sub-stage.

2.6 MODEL EXAMINATION QUESTIONS

I. Answer the following in 30 lines each.

1. Explain the various components of petrological microscope.

II. Answer the following in 10 lines each.

1. Briefly describe "Nicol prism".

* * *

UNIT : 3 OPTICAL PROPERTIES OF MINERALS

Contents

- 3.0. Objectives
- 3.1. Introduction
- 3.2. Ordinary Light
 - 3.2.1. Colour
 - 3.2.2. Form
 - 3.2.3. Inclusions
 - 3.2.4. Cleavage
 - 3.2.5. Refractive Index
- 3.3. Plane Polarised light
 - 3.3.1. Pleochroism and Pleochroic haloes
 - 3.3.2. Twinkling
- 3.4. Crossed Nicols
 - 3.4.1. Isotropic or Anisotropic
 - 3.4.2. Extinction
 - 3.4.3. Interference colours
 - 3.4.4. Alteration
 - 3.4.5. Twinning
- 3.5. Summary
- 3.6. Check Your Progress - Model Answers
- 3.7. Model Examination Questions
- 3.8. Glossary

3.0 OBJECTIVES

After completion of this unit, you should be able to

- * describe the properties under ordinary light
- * explain the properties under polarised light
- * describe the properties under crossed nicols.

3.1 INTRODUCTION

To study the optical properties of minerals under the Perological Microscope thin sections (of 0.35 mm thickness) are to be prepared. When they are placed on the stage and viewed through eyepiece of the microscope various properties as mentioned below under various conditions may be observed. These properties vary from mineral to mineral. Of the many optical properties some are very characteristic of minerals by which they can be very easily identified. Study of optical properties is carried out by using 1) ordinary light (without any nicol) 2) plane polarised light using only polariser 3) crossed nicols i.e., by introducing both polariser and analyzer into the field and 4) convergent polarised light between crossed nicols.

Surface of the grain is very rough, of relief very high and outline bold if the mineral has a higher refractive index than that of its surroundings. If the case is reverse then the boundary of the mineral is very faint and relief much lower and surface very smooth.

Determination of relative refractive indices is made by conducting Becke test.

Out line may be	--	weak / moderate / strong / very strong
Surface may be	--	smooth / moderate / rough / very rough
Relief may be	--	low / moderate high / very high

Therefore refractive index may be - low / moderate / high / very high.

It is low (1.5-1.56) in quartz, nepheline, muscovite and some feldspars. It is moderate (1.56-1.60) in basic plagioclase, chlorite. Refractive index is high (1.6-1.7) in amphiboles, biotite, olivine, apatite and some pyroxenes. It is very high (above 1.7) in most pyroxenes, kyanite, garnet, sphene, etc.

Check Your Progress

- Note : a) Write the answer in the space given below.
b) Compare your answer with the one given at the end of the Unit.

2. List out the properties which you observe under ordinary light in microscope

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3.3 PLANE POLARISED LIGHT

3.3.1. Pleochroism and pleochroic haloes

Pleochroism is due to differential absorption of light by the mineral in different directions. If the section that is placed on the stage, on rotation shows any change in the shades of the colour then the mineral is said to be pleochroic. Ex : Hypersthene is pleochroic from light pink to light green and biotite is straw yellow to reddish brown.

Some times the mineral may be non-pleochroic but the spots in it may be pleochroic. Such are known as pleochroic haloes. They are due to some disintegration product of radioactive inclusions.

3.3.2. Twinkling

It is observed in calcite. It is because calcite shows doubly refraction and a few grains of the granular mosaic transmit ordinary ray while others extraordinary ray. As there is a difference in refractive indices of ordinary and extraordinary rays the distinctness of the boundaries of the corresponding grains varies. On rotation of the stage therefore the effect of twinkling is to be observed.

3.2 ORDINARY LIGHT

3.2.1 Colour

Minerals may be colourless or may exhibit distinct colours. Sometimes same mineral may exhibit different colours or shades of same colour. Ex. Quartz is colour less and Biotite is brown, Hornblende is green, Magnetite is black .

3.2.2 Form

It varies from grain to grain of the same mineral. However some outlines are very characteristic. Ex. Sphene-lozenge shape, Nepheline-hexagonal (if cross section). If a grain is completely irregular without any regular shape then the form is described as **anhedral**. The term **euhedral** used when the grain is very regular in outline. The intermediate shape i.e., when the shape is neither anhedral nor euhedral the term **sub hedral** is used. Quartz grains invariably are anhedral, apatite and sphene, and garnet generally are euhedral and biotite is subhedral.

3.2.3. Inclusions

Air bubbles or foreign material is caught up as inclusion in certain minerals. Such inclusions at time are very characteristic of certain minerals Ex. : In leucite inclusions are in a radial fashion.

3.2.4. Cleavage

Cleavage cracks are seen as a set of parallel lines. Sometimes there may be more than one set also. To observe the property incident light should be made dim by using the aperture.

Number of sets of cleavage also depends upon the direction in which the section is cut. Hornblende in a basal section has two sets of cleavage but in a longitudinal section, only one set.

One set of cleavage	:	Micas
Two sets of cleavage	:	Feldspars, Pyroxenes, Amphiboles, etc.
Three sets of cleavage	:	Calcite, Dolomite etc.
Four sets of cleavage	:	Fluorite
Six sets of cleavage	:	A rarity as in sphalerite

3.2.5 Refractive Index

It is defined with reference to the nature of outline, the nature of surface and its relief.

Surface of the grain is very rough, of relief very high and outline bold if the mineral has a higher refractive index than that of its surroundings. If the case is reverse then the boundary of the mineral is very faint and relief much lower and surface very smooth.

Determination of relative refractive indices is made by conducting Becke test.

Outline may be	--	weak / moderate / strong / very strong
Surface may be	--	smooth / moderate / rough / very rough
Relief may be	--	low / moderate high / very high

Therefore refractive index may be - low / moderate / high / very high.

It is low (1.5-1.56) in quartz, nepheline, muscovite and some feldspars. It is moderate (1.56-1.60) in basic plagioclase, chlorite. Refractive index is high (1.6-1.7) in amphiboles, biotite, olivine, apatite and some pyroxenes. It is very high (above 1.7) in most pyroxenes, kyanite, garnet, sphene, etc.

Check Your Progress

- Note : a) Write the answer in the space given below.
b) Compare your answer with the one given at the end of the Unit.

2. List out the properties which you observe under ordinary light in microscope

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3.3 PLANE POLARISED LIGHT

3.3.1. Pleochroism and pleochroic haloes

Pleochroism is due to differential absorption of light by the mineral in different directions. If the section that is placed on the stage, on rotation shows any change in the shades of the colour then the mineral is said to be pleochroic. Ex : Hypersthene is pleochroic from light pink to light green and biotite is straw yellow to reddish brown.

Some times the mineral may be non-pleochroic but the spots in it may be pleochroic. Such are known as pleochroic haloes. They are due to some disintegration product of radioactive inclusions.

3.3.2. Twinkling

It is observed in calcite. It is because calcite shows doubly refraction and a few grains of the granular mosaic transmit ordinary ray while others extraordinary ray. As there is a difference in refractive indices of ordinary and extraordinary rays the distinctness of the boundaries of the corresponding grains varies. On rotation of the stage therefore the effect of twinkling is to be observed.

3.4. CROSSED NICOLS

3.4.1. Isotropic or Anisotropic

If the thin section of a mineral remains constantly dark throughout the rotation of the stage between crossed nicols, then it is called '**Isotropic**' substance. If it changes its colours from position to position then the substance is called '**Anisotropic**'. For anisotropic substances the following properties are to be observed.

3.4.2 Extinction

Extinction means darkness. Anisotropic substances become dark four times in a complete rotation of 360° of the stage. This happens when vibration directions of the two adjoining positions of extinctions of darkness is 90° . Extinction angle is the angle between a vibration plane and a crystallographic direction in a mineral section. To note the angle of extinction it is desirable to rotate the stage till the cross-wire of the eyepiece is parallel either with cleavage present in the grain or the crystal edge which is regular. There are three types of extinction. Straight or parallel extinction : When a mineral becomes extinct in a position where cleavage or crystal edge is parallel with the cross-wire.

Oblique Extinction : When the mineral becomes extinct at a position where the crystallographic direction marks angle with cross-wire.

Symmetrical Extinction : If the mineral becomes extinct when cross-wire dissects the angle between cleavages or edges of a crystal, it is called symmetrical extinction.

3.4.3. Interference or Polarisation Colours

These colours are shown by the mineral in intermediate positions between the positions of extinction. They are due to the phase difference between the light rays passing through a section. They may be bright or dim depending upon the thickness of the section, the direction in which the section is cut and the birefringence. If the thickness is more, the birefringence will be more and high order interference colours are obtained.

Ex : Quartz - Green, Yellow, Blue interference colours

Augite - Green, Blue, yellow, Red

Olivine - Green, Blue, Yellow, Red

3.4.4. Alteration

This property can also be observed under ordinary light but still it can very clearly be noticed only between crossed nicols. Generally the alteration takes place along cracks or cleavages and resultant products may be cloudy or turbid in appearance. Minerals which are altered will show aggregate polarisation.

Ex : Feldspar alter to sericite.

3.4.5. Twinning

This property is best observed in thin sections between crossed nicols. If a mineral grain shows two parts joined along a straight line and if the two parts become extinct one after the other during rotation then the grain is twinned and the twinning is of simple type.

In plagioclase feldspars alternate bands become dark and bright between crossed nicols on rotation due to lamellar twinning. Here twinning takes place on the same law repeatedly.

Ex : Microcline - Cross hatched twinning.

Check Your Progress

Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

3). What is extinction ?

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3.5 SUMMARY

Petrological or polarising microscope is useful for the study of mineral or rock thin sections under microscope. With this instrument one has to observe the optical properties of minerals. Optical properties of any mineral should be observed under four different conditions. Those are under ordinary light, plane polarised light, crossed nicols and convergent light.

The properties under ordinary light are mainly colour, form, inclusions, cleavage and refractive Index.

Under plane polarised light to get polarisation nicol prism is to be used. The properties like Pleochroism, Pleochroic haloes and twinkling should be observed under plane polarised light.

Properties such as extinction, interference colours, alteration, twinning must be observed under crossed Nicols. By using convergent light, properties like uniaxial or biaxial, optic sign, dispersion, 2V should be observed.

The property colour can be observed with the eye. The forms of minerals are grouped into three types namely euhedral, subhedral and anhedral, air bubbles or impurities are seen as inclusions. The cleavage is similar to physical property and may be explained as one set, two sets, three sets, four sets or six sets. Refractive index can be noticed by observing the relief.

Under plane polarised light, with the rotation of stage, if colour changes then the mineral is pleochroic, other wise non pleochroic. Twinkling property is visible in only calcite mineral. In some mineral grains, fine particles only changes colours, such property is called plerochroic haloes.

Under crossed nicols, if we observe complete darkness with rotation, then it is isotropic otherwise if we get darkness at four positions and in between bright colour, the property is anisotropic and the bright colours are interference colours. Twinning can also observe under crossed nicols. The properties with convergent light are not important for U.G. Student.

3.6 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The mineral thickness in thinsection is always should be 0.35 mm.
2. (i) Colour (ii) Form (iii) Inclusion (vi) Cleavage and (v) Refractive index
3. Extinction means darkness. Anisotropic substances become dark four times in complete rotation of 360° of the stage.

3.7 MODEL EXAMINATION QUESTIONS

I. Answer the following questions in about 30 lines each

1. What are the optical properties of minerals ?
2. Mention the properties of a mineral that are observed under the petrological microscope under plane polarised light.

II. Answer the following questions in about 10 lines each

1. What is meant by 'crossed nicols'. Explain the terms 'Extinction', 'Twinning', and Interference colours.

3.8 GLOSSARY

Analyser	:	This lies above the petrological microscope stage.
Anisotropic	:	Substances in which light is transmitted with different velocity in different directions.
Anisotropism	:	The property by virtue of which the substance becomes anisotropic is called anisotropism.
Biaxial Crystals	:	Crystals which are having two axes.
Birefringence	:	The difference between two refractive indices is called birefringence.
Crossed nicols	:	The nicols are said to be crossed when vibration direction of the analyser is at right angles to the vibration direction of the polariser.
Dispersion	:	When white light breaks up into colours of the spectrum on entering a medium it is called dispersion.
Extraordinary ray	:	This ray is produced and refracted, even with normal incidence, when light passes through an anisotropic mineral.
Extinction	:	Extinction means darkness.
Iceland spar	:	A transparent variety of calcite.
Inclusion	:	A portion of one substance enclosed within another.
Isotropic	:	Substances in which light is transmitted with same velocity in

Isotropism	: all directions.
Optical mineralogy	: The property by virtue of which the substance becomes isotropic is called Isotropism.
Optic axis	: It is the part of mineralogy which deals with optical behaviour of minerals.
Ordinary ray	: Optic axis is the direction along which no double refraction takes place.
Oremicroscope	: The ray which passes through anisotropic minerals as it would pass through anisotropic substance.
Petrography	: It is the microscope used to study the optical and textural aspects of the ore.
Pleochroic haloes	: Systematic description of rock, in hand specimen and thin section.
Polarisation colours	: Some spots or patches which are highly pleochroic contrary to the host minerals, are called pleochroic haloes.
Polarising or petrological microscope	: Colours produced by the anisotropic mineral under crossed nicols. These colours are seen in between the positions of extinction of mineral.
Plane polarised light	: It is the microscope used to study minerals and textural aspect in the rock.
Uniaxial crystals	: In ordinary light, the vibrations take place in all directions in a plane at right angles to the ray is called plane polarised light.
2V	: Crystals which are having one optic axis.
	: The angle between two optic axes in the biaxial minerals.

* * *

UNIT : 4 ISOTROPIC AND ANISOTROPIC SUBSTANCES, UNIAXIAL AND BIAXIAL MINERALS

Contents

- 4.0 Objectives
- 4.1 Isotropism and Isotropic substance
- 4.2 Anisotropism and Anisotropic substances
- 4.3 Uniaxial Crystals
- 4.4 Biaxial Crystals
- 4.5 Summary
- 4.6 Check Your Progress - Model Answers
- 4.7 Model Examination Questions

4.0 OBJECTIVES

After completion of this unit you should be able to

- * describe isotropism and isotropic substances
- * explain anisotropism and anisotropic substances
- * explain uniaxial crystals
- * describe biaxial crystals.

4.1 ISOTROPISM AND ISOTROPIC SUBSTANCES

All the transparent substances can be divided into isotropic and anisotropic, from optical point of view. Non-crystalline substances like gases, liquids and glass and among crystals all those which crystallise in cubic or isometric system are known as isotropic substances. The property by virtue of which the substance become isotropic is called isotropism. Isotropic is derived from 'iso' for equal and 'tropic' for rotate or turn. It means that an isotropic medium shows uniform physical properties in any direction it observed. Light travels with same velocity through such media along any direction. Due to this the wave front is a sphere and the wave surface a circle. These substances do not break light ray that passes through plane but are singly refracting. Isotropic substance have a single refractive index. These fragments remain dark between crossed nicols in all positions. Isotropic substances have no birefringence as they have single refractive index. So, birefringence which is the difference in maximum and minimum refractive indices is zero.

4.2 ANISOTROPISM AND ANISOTROPIC SUBSTANCES

The property by virtue of which the substance becomes anisotropic is known as anisotropism. 'Anisotropic' substances are just the reverse of isotropic substances with reference to their optical behaviour. All the minerals crystallising in systems other than isometric or cubic are anisotropic. Light does not travel with the same velocity in all directions. A ray of light that enters this media is doubly refracted into ordinary and extra-ordinary rays which travel with

different velocities and vibrate at right angles to each other. They are also known as slow and fast rays. For a given orientation each anisotropic substance has two refractive indices. As the velocity differs in different directions in this media the wave front can't be a sphere but could generally be an ellipsoid and the wave surface also is not a circle but an ellipse. As anisotropic media are doubly refracting they can't remain dark throughout the rotation of the stage but become extinct or dark in four positions where the vibration directions of the substance are parallel. In intermediate positions the substance becomes bright. Anisotropic substances are classified into uniaxial and biaxial.

Check your progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

- 1). What is isotropism ?

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4.3 UNIAXIAL CRYSTALS

Careful observation reveals that in calcite prism there is one and only one direction which is vertical crystallographic axis (c) along which there is no double refraction. Along this direction it behaves as singly refracting substance. Along this one dot that is marked on paper is seen as only one dot but two images of dot i.e., ordinary image and extraordinary image. For this reason C-axis is known as optic axis and since there is only one such direction crystal like calcite are said to be **Uniaxial**. Through this media light ray is double refracted into ordinary and extraordinary rays in any direction except along C-axis. By experimentation it was observed that while extraordinary and ordinary rays travel maximum difference in velocities. In wave front of the ordinary ray, ray has greater velocity. Cross section of the ray velocity surfaced wave front is a sphere and the wave surface a circle. For extra - ordinary ray the wave front is an ellipsoid and the wave surface an ellipse. Minerals with the higher velocity of extra-ordinary ray are negative. Ex : Calcite. In uniaxial crystals principal optic section is parallel to C-axis. Optic signs of minerals are determined with the accessory plates such as mica plate, gypsum plate and quartz wedge.

4.4 BIAXIAL MINERALS

Crystals of orthorhombic, monoclinic and triclinic systems are known as optically biaxial. They have got two directions along which there is no double refraction i.e., light travels with zero birefringence. Biaxial minerals have three principal vibration directions X-fastest, Y-Intermediate and Z-slowest lines which bisect the angles between optic axes are called bisectrices. If it bisects acute angle it is acute bisectrix while that bisecting the obtuse angle it is obtuse bisectrix. Biaxial crystals are positive when the acute bisectrix coincides with the vibration

direction of slow ray (Z) and are negative when its coincidence takes place with the vibration direction of fast ray (X). The angle between two optic axes is optic axial angle ($2V$).

In uniaxial minerals, either the N_e value is greater than the N_o value or vice versa. Those uniaxial minerals, in which N_e value is greater than the N_o value, are called uniaxial positive ($N_e > N_o$), as in Quartz -- ($N_e = 1.553 : N_o = 1.544$), and those in which N_o value is greater than N_e value ($N_o > N_e$) are called uniaxial negative, as in calcite ($N_o = 1.658 : N_e = 1.486$). In Biaxial minerals, N_m value is nearer to N_p value or to N_g value. Those biaxial minerals, in which the N value is nearer to the N value, as in Augite ($N_p = 1.712 : N_m = 1.717 : N_g = 1.737$), are called biaxial positive; those in which the N value is nearer to N_g value, as in hornblend ($N_p = 1.614, N_m = 1.628, N_g = 1.633$), are called biaxial negative. Anisotropic minerals exhibit, under crossed nicols, four positions of extinction (darkness), at intervals of 90° , throughout the rotation of the microscope stage, alternated by four positions of maximum illumination with interference colours, at intervals of 90° (Anisotropism).

Check your progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

- 2). In calcite mineral along the direction of vertical crystallographic axis (C) there is no

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- 3). Name the mineral, which shows biaxial negative property.

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4.5 SUMMARY

All the transparent substances can be divided into isotropic and anisotropic. All the gases, liquids and the minerals crystallised in cubic system are called isotropic substances. Light travels with same velocity in isotropic substances in all directions and shows uniform properties in all directions. These substances will have single refractive index and appears dark under crossed nicols.

The opposite to isotropic is anisotropic. The minerals crystallised in Hexagonal, Tetragonal, Orthorhombic, Monoclinic and Triclinic shows anisotropism. Light travels with different

speed in different directions. These materials may not remain dark through out the rotation of the stage but become extinct or dark in four positions, in between appears bright with interference colours. Anisotropic substances are again grouped as uniaxial and biaxial.

The minerals of Hexagonal and Tetragonal are uniaxial crystals. In uniaxial crystals principal optic section is parallel to 'C'-axis. The minerals of Orthorhombic, Monocline and Triclinic systems show biaxial property. Here the light passes into three directions with different velocities. Biaxial crystals are again divided into positive biaxial and negative biaxial. The angle between two optic axes is optic axial angle ($2V$).

4.6 CHECK YOUR PROGRESS - MODEL ANSWERS

1. If light travels in equal speed and in all directions, it is isotropism
2. Double Refraction
3. Hornblend

4.7 MODEL EXAMINATION QUESTIONS

I. Answer the following in 30 lines.

1. Explain about the isotropic and anisotropic property of minerals

II. Answer the following in 10 lines.

1. Differentiate uniaxial from biaxial minerals.

* * *

BLOCK - II PETROLOGY - IGNEOUS ROCKS

BRAOU

UNIT : 5 PETROLOGY - CLASSIFICATION OF ROCKS

Contents

- 5.0 Objectives
- 5.1 Petrology - Introduction
- 5.2 Rocks and Minerals
- 5.3 Three Major Group of Rocks - Classification
 - 5.3.1 Igneous rocks
 - 5.3.2 Sedimentary Rocks
 - 5.3.3 Metamorphic Rocks
- 5.4 Characteristics of Rocks
- 5.5 Rock Forming Minerals
- 5.6 Summary
- 5.7 Check Your Progress-Model Answers
- 5.8 Model Examination Questions
- 5.9 Glossary

5.0 OBJECTIVES

The unit aims to review briefly about petrology-rocks and minerals

At the end of this unit you will be able to

- * define petrology and its branches
- * define the origin of three major group of rocks
- * describe the characteristics of three major group of rocks
- * define the rock forming minerals.

5.1 PETROLOGY - INTRODUCTION

The Earth is made up of with different types of Rocks. The study of these rocks is known as **petrology**. Petrology not only deals with the rocks of the Earth but also with the rocks of the moon. The characters of the rocks situated at greater depths can be known with the help of meteorites. In general, petrology deals with the rocks of the Earth's outer layer - the rocks available upto 50 kilometers depth of the Earth. This course explains us the characters of the different crustal rock out crops, their occurrence, composition and origin. Rock can be studied in two ways; as physical units possessing specific characters or as units of the earth's crust and therefore as tools for interpierring earth's history. The study of rocks as physical units involves the study of their chemical, mineralogical and textural characters in other words, it is a descriptive study, and is designated as **petrography**. The study of the origin of rocks as part of the earth processes in termed as **petrogenesis**. Petrology is therefore a broader term which refers to the study of all aspects of rocks and includes both petrography and petrogenesis. Petrogenesis is mostly interpretative in nature and this interpretation is essentially based on the petrographic characters.

The term **lithology**, the study of stones is almost synonymous with petrology, but is restricted to study of stones in engineering, architecture and in other fields of applied geology.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

1. What is Petrology ?

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2. What is Petrography ?

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5.2 ROCKS AND MINERALS

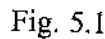
As mentioned already, rocks are aggregates of minerals. They are made up of definite assemblages of minerals. Although around 2000 minerals are known, about 50 or so of these are rock forming minerals and of these again only some 30 are common in rocks. It is probable that these few minerals make up 99.9 percent of the earth's crust.

In comparison with a mineral, which is homogeneous, a rock is heterogeneous because it is an assemblage of minerals. There are of course, rocks which contain only one mineral, but these are few and rare.

The term 'rock' is normally understood to mean a hard, solid object. But in petrology, however, it is often used without references to hardness and cohesion of the material. Beds of loose sand and volcanic ash are as much units of the earth's crust as are sandstone, tuff and granite.

5.3 THREE MAJOR GROUPS OF ROCKS

Geologists are interested in rocks mainly because they provide clues for understanding the geological environment prevailing at the time the minerals aggregated into rocks. Based on the mode of formation as understood from field observations, earth's rocks are classified into three major groups : Igneous, Sedimentary and Metamorphic. The inter relation between these three rock groups is shown in the following Fig - 5.1



Igneous rocks (Ignis = fire) are formed from a hot molten rock material called magma or lava which on cooling crystallised and solidified into rocks. Some of the rocks are formed at some distance below the surface due to solidification of lava flows. Rocks formed below the surface are exposed at some places because the over lying rocks which covered them during their formation have been removed by erosion.

Sedimentary rocks (L-sedimentum, setting) are formed from the accumulation of sediments which become hard and compact in course of time. The sediments consists of materials derived from weathering of preexisting rocks. Rock fragments of various sizes, unaltered minerals, products of chemical action or remains of organisms (fossils) or mixtures of these materials constitute the sediments. The loose mineral grains and rock particles are transported by water, wind and ice to basins where they are deposited as layers or strata. The soluble substances are deposited by chemical means or through the agency of organisms. These processes have been going on throughout the geological time and therefore it is possible that some of the sedimentary particles have gone through many cycles of change and sedimentation.

Metamorphic rocks (Gr. Meta + morphe, change of form) are those that have formed under the influence of heat, pressure and chemical conditions present at depths in the crust. These three factors bring about changes in the minerals and structures of originally igneous or sedimentary rocks, when they are carried to depths. In other words, the original rocks are transformed into new types beneath the surface of the earth.

The original crust of the earth must have been entirely igneous, because it formed from a hot molten liquid material. This was subjected to the relentless action of water, wind and ice, which resulted in the formation of sedimentary rock. These two groups of rocks when carried to depths or when subjected to the action of hot magmas or lavas would have been transformed into metamorphic rocks. Under extreme conditions of metamorphism rocks may be melted and a new type of magma may be generated. This new magma may solidify and give rise to

a new generation of igneous rocks, which in course of time go through the changes mentioned above. This cycle of changes leading to the formation of the three groups of rocks from each other is referred to as the 'petrogenetic cycle or rock cycle'.

Check Your Progress

Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

3). What is rock cycle ?

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5.4 CHARACTERISTICS OF ROCKS

The three groups of rocks can be distinguished from each other based on their textural or structural characters and characteristic mineral assemblages.

The igneous rocks are usually massive, unstratified and unfossiliferous. They often, occupy fissures breaking across other rocks. They show interlocking grains of minerals and some times glass. They show signs of cooling from a high temperature.

The sedimentary rocks on the other hand are composed of broken fragments mineral or rocks, precipitated materials and some times material of organic characters or origin. They may be loose and unconsolidated or may have been made compact by pressure or cementing substance. They are characterised by stratification and some times contain fossils. Indeed, these are the rocks which are suitable for the preservation of fossils.

The metamorphic rocks as mentioned earlier are formed under the influence of great heat and pressure. These factors cause recrystallization and hence like igneous rocks, they often show inter locking crystals. Pressure causes the development of folia or banding. As these rocks are formed either from igneous or from sedimentary rocks, they may often retain traces or relics of the original structures.

Some typical examples for these three groups of rocks are :

Igneous : Granite, Syenite, Gabbro, Rhyolite, Trachyte, Dolerite, Basalt.

Sedimentary : Sandstone, Limestone, Shale, Conglomerate, Breccia.

Metamorphic : Slate, Schist, Gneiss, Marble, Quartzite.

Minerals characteristic of rocks belonging to these three groups are given in the table below:

Igneous	Sedimentary	Metamorphic
Orthoclase	Mostly Quartz	Staurolite
Microcline	Mostly Calcite	Kyanite
Plagioclase	Mostly Clay minerals	Andalusite
Quartz	Minerals of chemical or	Sillimanite
Leucite	Organic precipitates	Cordierite
Nepheline	Halite	Garnet
Augite	Gypsum	Wollastonite
Hornblende	Anhydrite	Tremolite
Muscovite	Glaucinite	Chlorite
Biotite	Chert	Graphite
Olivine etc	Carbonates etc	Talc etc.

According to the calculation of E.W. Clarke and H.S. Washington, the earth's crust to a depth of 16 kms is composed of 95 % igneous rocks and 5 percent sedimentary rocks (shale 4%, sandstone 0.75% and limestone 0.25%). The metamorphic rocks are regarded as belonging to their original types-igneous and sedimentary, and therefore not given separately. From these calculations it is clear that the total amount of sedimentary rocks and other materials is insignificant in comparison to the amount of igneous rocks, and that the average composition of the crust is almost the same as the average composition of the igneous rocks. Based on an exhaustive study of the available data on existing analysis of rock and careful computation of these analysis the average chemical composition of the earth's crust, to depth of 16 Kms is calculated. Details are given in the table below. Column 1 in the table show percentages of different chemical elements and column 2 shows the composition as recast into the form of oxides.

1		2	
Element	% by weight	Oxide	% by weight
Oxygen	46.71	SiO ₂	59.07
Silicon	27.69	Al ₂ O ₃	15.22
Aluminium	8.07	Fe ₂ O ₃	3.10
Iron	5.05	FeO	3.71
Calcium	3.65	MgO	3.45
Sodium	2.75	CaO	5.10
Potassium	2.58	Na ₂ O	3.71
Magnesium	2.08	K ₂ O	3.11
Titanium	0.62	H ₂ O	1.30
Hydrogen	0.14	TiO ₂	1.03
Phosphorous	0.13	P ₂ O ₅	0.30
Manganese	0.09	MnO	0.11
Other elements	0.44	Other oxides	0.79
100.00		100.00	

From the above table, it can be seen that oxygen is the most abundant element and that just a dozen elements make up nearly 99.5 per cent of the total. The earth's crust consists almost entirely of oxygen compounds, mainly silicates of aluminium, sodium, potassium, calcium, magnesium and iron. If the volume of the atoms of different elements in the crust is calculated, oxygen alone makes up more than 90 % of the total volume.

5.5 ROCK-FORMING MINERALS

As mentioned already around 30 minerals account for 99.9 per cent of the earth's crust. These are the most important among the rock forming minerals. Silicates are the commonly occurring group of minerals. Of these again feldspars are the most abundant. The chief members are orthoclase, microcline and plagioclases. Another important silicate is quartz, come next. Allied to the feldspars but with less silica content are the feldspathoids, of which nepheline and leucite are important. Among the micas, muscovite and biotites are the chief members. Chlorite occurs as an alteration product of biotite and other ferromagnesian minerals. Among the ferro-magnesian minerals, three groups are important i.e., pyroxenes, amphiboles and olivines. Enstatite, hypersthene and augite are the common pyroxenes. Among the amphiboles, hornblende, actinolite and tremolite are of common occurrence. The olivines contain less silica in comparison to the pyroxenes. Other important silicates include garnets, epidote, andalusite, kyanite, sillimanite, cordierite and staurolite, the last five being characteristic of metamorphic rocks. Among oxides mention is to be made of magnetite, hematite limonite and ilmenite. Calcite and dolomite among carbonates and apatite, a phosphate are the other important minerals.

5.6 SUMMARY

Rocks are mineral aggregates, occurs naturally in the Earth. Study of rocks is known as Petrology. The observation of rocks gives us clues to know the conditions of formation. The study is useful to separate the economically useful minerals. Rocks are three types. Those are Igneous rocks, Sedimentary rocks, and Metamorphic rocks. Igneous rocks are formed due to the solidification of early magma. Sedimentary rocks are formed from the accumulation of sediments, separated from the rock out crops due to weathering. Metamorphic rocks are formed under the influence of heat, pressure and chemical conditions at depths in the crust.

The absence of fossils is the main character of igneous rocks. These rocks will occupy the cracks, and other empty places as intrusives. These are formed from great temperatures due to cooling and solidification. Sedimentary rocks are formed from the loose sediments and are characterised with the presence of fossils. Metamorphic rocks are formed due to recrystallisation of pre-existing rocks and are characterised by bands and schists. The important minerals with in the igneous rocks are the different types of feldspars, pyroxenes, amphiboles, micas, olivines etc. The quartz is the main mineral in sedimentary rocks along with calcite, halite, gypsum, anhydride, chert etc. Metamorphic rocks consist of staurolite, kyanite, andalusite, sillimanite, garnet type of minerals oxygen is the major element in rocks. A total of only 12 elements composes 99.5 percent in rocks. 99.9 percent of the earth crust consists of only 30 minerals.

5.7 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The study of rocks is petrology
2. The study of rock sections under petrological microscope is called petrography.
3. The inter relation ship between three rock types is rock cycle.

5.8 MODEL EXAMINATION QUESTIONS

I Answer the following in 30 lines each

1. Explain the Scope and Aims of petrology.
2. What are rocks? How they are classified ?
3. What are the main differences in the three major groups of rocks ?

II Answer the following in 10 lines each

1. Igneous rocks
2. Sedimentary rocks
3. Metamorphic rocks
4. Rock cycle

5.9 GLOSSARY

Petrology	:	Science of rocks
Petrography	:	Descriptive study of rocks
Petrogenesis	:	Origin of rocks
Rocks	:	Aggregates of minerals and units of earth's crust
Lithology	:	Science of stones
Igneous rocks	:	Rocks formed from hot molten material called magma or lava
Metamorphic rocks	:	Rocks formed due to action of great heat, pressure and chemically active fluids at depth on pre existing rocks.

* * *

UNIT : 6 FORMS AND STRUCTURES OF IGNEOUS ROCKS

Contents

- 6.0 Objectives
- 6.1 Forms of Igneous Rocks
 - 6.1.1 Forms of Extrusive rocks
 - 6.1.2 Forms of Intrusive rocks
- 6.2 Structures of igneous rocks
 - 6.2.1 Vesicular and Amygdaloidal Structure
 - 6.2.2 Block and Ropy Structure
 - 6.2.3 Pillow or Ellipsoidal Structure
 - 6.2.4 Flow Structure
 - 6.2.5 Jointing
 - 6.2.6 Columnar or Prismatic Jointing
- 6.3 Summary
- 6.4 Check Your Progress-Model Answers
- 6.5 Model Examination Question
- 6.6 Glossary

6.0 OBJECTIVES

The purpose of this unit is to acquaint you with the forms and structures of igneous rocks. At the end of this unit you will be able to :

- * describe different forms of igneous rocks
- * describe different structures of igneous rocks
- * differentiate extrusive from intrusive rocks

6.1 FORMS OF IGNEOUS ROCKS

The igneous rocks are formed from a hot molten rock material called **magma**. Magmas are generated by the melting of rocks locally within the crust due to heat produced by radioactivity, removal of pressure or crystal deformation.

Molten magma like any material which is under pressure tend to move to the area of least pressure and thus the direction of movement is usually upward. In its upward movement, magma may be erupted on the surface through fissures or volcanic vents giving rise to lava flows. Lavas are extrusive forms of magma. For each eruption on the surface there must have been a great amount of sub-surface activity. Magmas before reaching the surface are injected into rocks in crust. On solidification these injection masses give rise to intrusive rocks. It is not necessary that all magmas erupt to the surface some of them may completely solidify with in the crust only.

Thus igneous rocks can be broadly divided into 1) extrusive igneous rocks formed due to solidification of lavas erupted to the surface and 2) Intrusive igneous rocks formed due to

solidification of magma intruded into the crystal rocks. The latter group of rocks may be exposed at the surface through subsequent denudation or earth movements. The extrusive igneous rocks are distinguished by their fine grain and presence of glass which indicate rapid cooling and also by their form and characteristic structures such as vesicularity. The intrusive igneous rocks on the other hand are much coarser in grain and do not show glass. They assume typical form which are easily recognisable in the field. While extrusive rocks produce contact effects on the rocks underlying them, intrusive rocks affect the adjacent rocks on all sides.

The typical forms and structures exhibited by extrusive and intrusive rocks are described below.

Check Your Progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this Unit.

I. Extrusive igneous rocks are characterised by.....
.....
.....
.....

6.1.1 Forms of Extrusive Igneous rocks

Lavas are erupted to the surface either from fissures in the ground (fissure eruption) or from individual volcanoes (volcanic eruption). They flow on the ground and solidify as tabular bodies of wide areal extent in proportion to their thickness, elongated in the main direction of the flow. The form of a lava flow depends on the fluidity of the magma which in turn depends on its composition and temperature of eruption. Basic lavas like basalt are highly mobile and flow for great distances. Whereas acid lavas like rhyolite are slow in their flow and therefore remain heaped up around the orifice of eruption.

In India, the Deccan plateau is a typical example for solidified lava flows. It is built up lava flows erupted to the surface through fissures, the eruption having taken place many times.

In all eruptions, along with lava, large quantities of fragmental rock materials and gases are also ejected. While the gases escape, the fragmental materials consisting of volcanic blocks lapilli, dust, tuff etc., accumulate giving rise to pyroclastic deposits which are found associated with the lava flow.

6.1.2 Intrusive Forms

The forms assumed by intrusive igneous rocks depend on the geological structure of the rocks which they penetrate, and their relation to this geological structure. The magma may be injected along the structural planes like bedding planes, cleavage planes etc of the intruded rock giving rise to concordant igneous bodies or it may break across the structural planes giving rise to discordant igneous bodies. The concordant bodies while spreading along the bedding planes may have had to lift the overlying cover of rock, exerting force in an

approximately vertical direction, to make place for themselves. The discordant bodies occupy fissures present in the rocks and in doing so may widen them exerting force in an approximately horizontal direction.

The intrusive igneous bodies may also be distinguished as minor and major intrusions depending on the size and the depth of formation, the former being relatively smaller and formed at lesser depths and latter larger and formed at greater depths.

The term 'Pluton' is also used for a body of igneous rock that has formed beneath the surface of the earth by consolidation from magma.

Check Your Progress

Note : a) Space is given below for writing your answer.

b). Compare your answer with the one given at end of this unit.

2. Bring out difference between concordant and discordant igneous bodies.....

.....

.....

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.....

A list of the common intrusive bodies is given below and they are described briefly in this unit.

Minor Intrusives

Concordant

Sill
Laccolith
Phacolith
Lopolith

Major Intrusives

Discordant

Dyke
Ring dykes and cone sheet
Volcanic necks

Batholith

Stock
Boss

Sills :- A sill is a tabular sheet of magma injected along the principle structural plane. (Fig. 6.1) The thickness may be from a few centimeters to a hundred meters or even more. The upper and lower surfaces are nearly parallel, but at distance it becomes flatly lenticular. Depending on the force of injection of the magma, its temperature, fluidity and weight of the overlying strata, the sill may spread any distance. In Andhra Pradesh Dolerite sills are found intrusive into limestones belonging to the Cuddapah period, similar sills are also found in the Gondwana strata in our country. The Great sill in the north of England covers an area of about 4,000 square kilometers. In the Karoo region of South Africa dolerite intrusion of sill character is estimated to penetrate the rocks over an area of about 5,63,000 square kilometers.

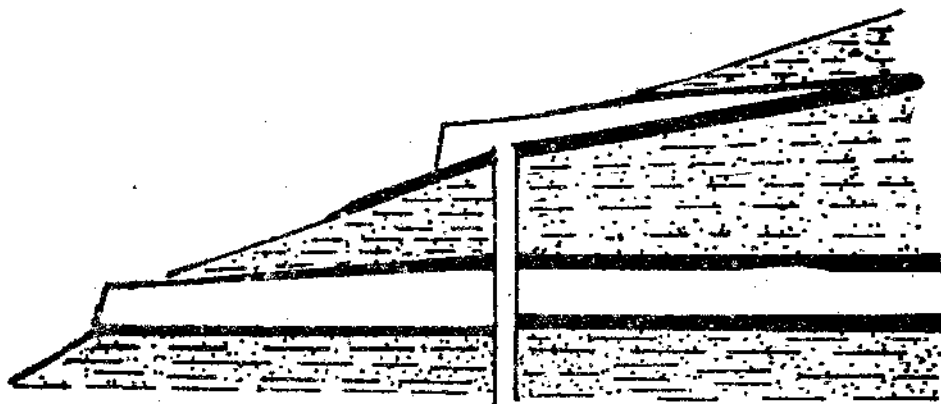


Fig. 6.1 Sill

Laccoliths :- Every sill, as described above is more or less like an extremely flat lens. When the convexity of the lens is greater than normal, particularly on the top, a plano-convex form is produced. Such a form is called a **laccolith**. Fig 6.2 It has a domed top and a flat base. A laccolith forms when the supply of the magma from below is more than that can be accommodated by spreading side ways. Many laccoliths are less than a few kilometers in diameter and are circular or elliptical in ground plan.

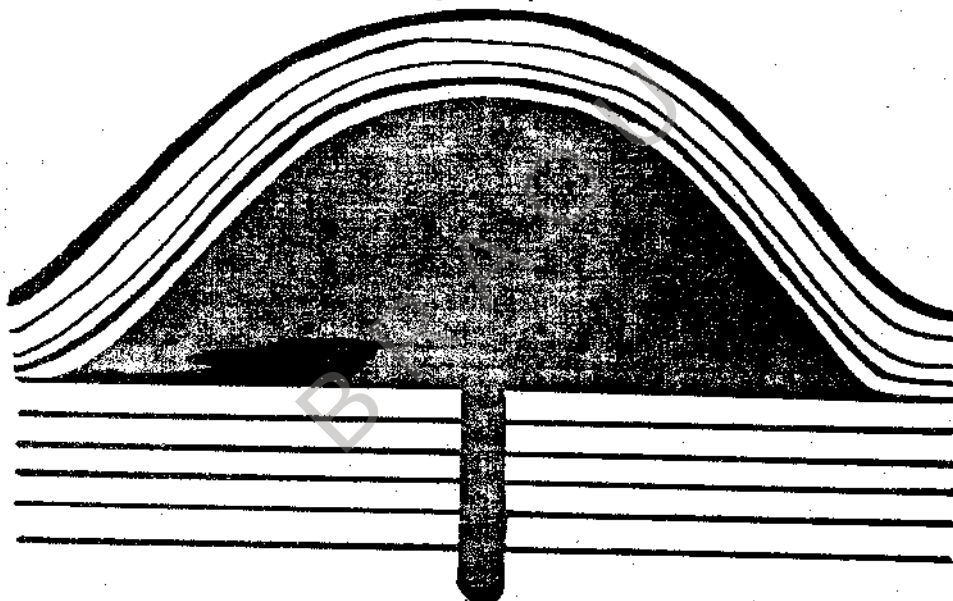


Fig. 6.2 Laccolith

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this Unit.

3. The magma of considerable viscosity injected heaps up to form a bun shaped igneous body known as.....

along steeply inclined arcuate fractures.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

6. Dykes which tend to occur as systems and are parallel to one direction on the radial to a centre is also known as

.....
.....
.....

Volcanic necks :- These are masses of igneous material which close up the vent of ancient volcanoes. They may occupy the cylindrical pipe and may be intrusive into the volcanic debris which partly fills the pipe.

Batholiths :- A batholith is a gigantic intrusive body with steeply inclined sides and without any visible floor. The upper surface alone is visible when exposed and field observations are restricted to this surface. (Fig.6.6) The origin of batholiths is debated. Some batholiths are considered to be igneous, while others are metamorphic and still others are partly igneous and partly metamorphic. Opinion is also divided as to whether they are concordant or discordant intrusions. They may be considered as solidified forms of large magmatic bodies which in their upward movement invade and digest parts of the country rock. Some times they contain inclusions of undigested rock.

Batholiths are mostly located in mountain making zones and their intrusion usually follows the mountain-building movement.

The Alaska-British Columbia granite batholith is about 2000 kms long and its maximum width is 80kms. In India batholiths are exposed in the Himalayan region.

The term **Stock** is used for an irregular mass of batholithic habit, but of smaller dimensions. The out crop is usually less than 100 square kilometers.

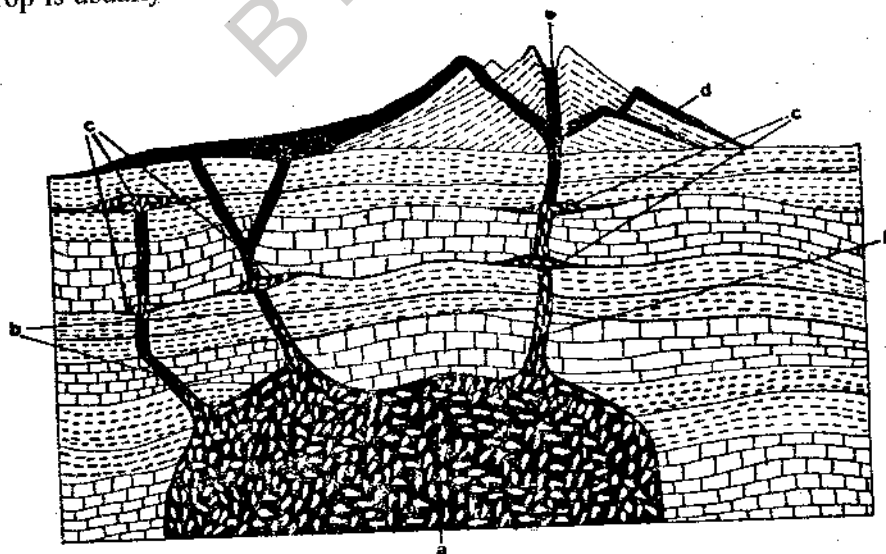


Fig. 6.6 Forms

a) Batholith b) Dykes c) Laccoliths d) Lavaflows e) Volcanic neck

The term **Boss** is applied to stock which has an approximately circular outcrop. Stocks and Bosses are usually found as off shots of larger batholiths.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this Unit.

7. Batholiths are always associated with

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.....

.....

.....

Multiple and Composite intrusions

Sometimes a single magma may be injected along a single channel in two or more successive pulses. This gives rise to a multiple intrusion.

On the other hand if magmas of different compositions are injected along the same channel usually with sufficiently long intervals of time, the result is a composite intrusion.

Sills and Dykes may be sometimes multiple or composite.

6.2 STRUCTURES OF IGNEOUS ROCKS

The terms '**Texture**' and '**Structure**' are used to indicate certain physical features of rocks and rock masses. Although there is one general agreement. It is generally understood that '**Texture**' refers to small scale features like the mutual relations of the mineral constituents in the rock, while '**Structure**' include large scale features that are observed in the field like jointing, flow banding etc. Some petrologists use these two terms synonymously.

The structures commonly exhibited by igneous rocks are described below.

6.2.1 Vesicular and Amygdaloidal structures

When lavas erupt on the surface, the gases present in them escape due to diminution of pressure. The escape of gases produces in the lava flows, cavities, bubbles or vesicles of different shape and sizes, elliptical, cylindrical or irregular. They may be large or small. Most lava flows are characterised by vesicular structure. When the vesicles are filled with secondary minerals usually calcite, form of silica or zeolites they are called **Amygdales** and the lavas are said to have **Amygdaloidal** structure.

6.2.2 Block and Ropy structures

The surface of some lavas is covered with a mass of rough, angular block of all dimensions which during the flow of the lavas are borne along as a tumbling mass. Such lavas are called

block lavas on the other hand some lavas, which are usually very mobile, solidify with surfaces exhibiting wrinkled or ropy forms. The surfaces are somewhat smooth and often highly glazed. These are called **Ropy** lavas.

In Block lavas, the vesicles are large and irregular in shape while in Ropy lavas they are smaller regular in shape usually spherical, and much more numerous.

6.2.3 Pillow or Ellipsoidal structures

Some lavas exhibit the appearance of a pile of small masses comparable to pillows, sacks or cushions. The pillows have a vesicular crust. They are often elongated and parallelly arranged and may be connected with each other by short tubes or necks or along their sides. The structure is supposed to be due to rapid cooling, particularly due to contact with water.

6.2.4 Flow structure

By the time a lava is erupted on the surface, it is no more homogeneous. It shows layers and patches of differences in composition, gas content and degree of crystallization. Due to the flow of the lava, these patches are drawn into parallel bands or streaks showing differences in colour, texture and composition such a structure resulting from the flow of lava is called **flow structure**.

6.2.5 Jointing

Joints are divisional planes or fractures found in igneous rocks. These are produced by contraction due to cooling, joints usually occur in sets, the joints in a set being parallel to each other. In granites three sets of joints are commonly seen, one of them nearly horizontal and the other two vertical and perpendicular to each other, if the joints in these sets are equally spaced, they give rise to a structure of cuboidal blocks.

If horizontal joints are closely spaced, **sheet structure** is produced.

6.2.6 Columnar or Prismatic structure

When a homogeneous magma cools and contracts uniformly the joints produced commonly two or three sets of vertical joints, take on a regular geometrical pattern, enclosing between them four, five or six-sided columns or made prisms (Fig. 6.7). The whole mass of rock appears as if it is of vertical columns. This structure is exhibited mainly by basaltic rocks.

Columnar structure is seen in the Deccan Lava flows in the Salsette Island near Bombay and near Hoshangabad.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this Unit.

8. Columnar joints are characteristically found in

.....

.....

.....

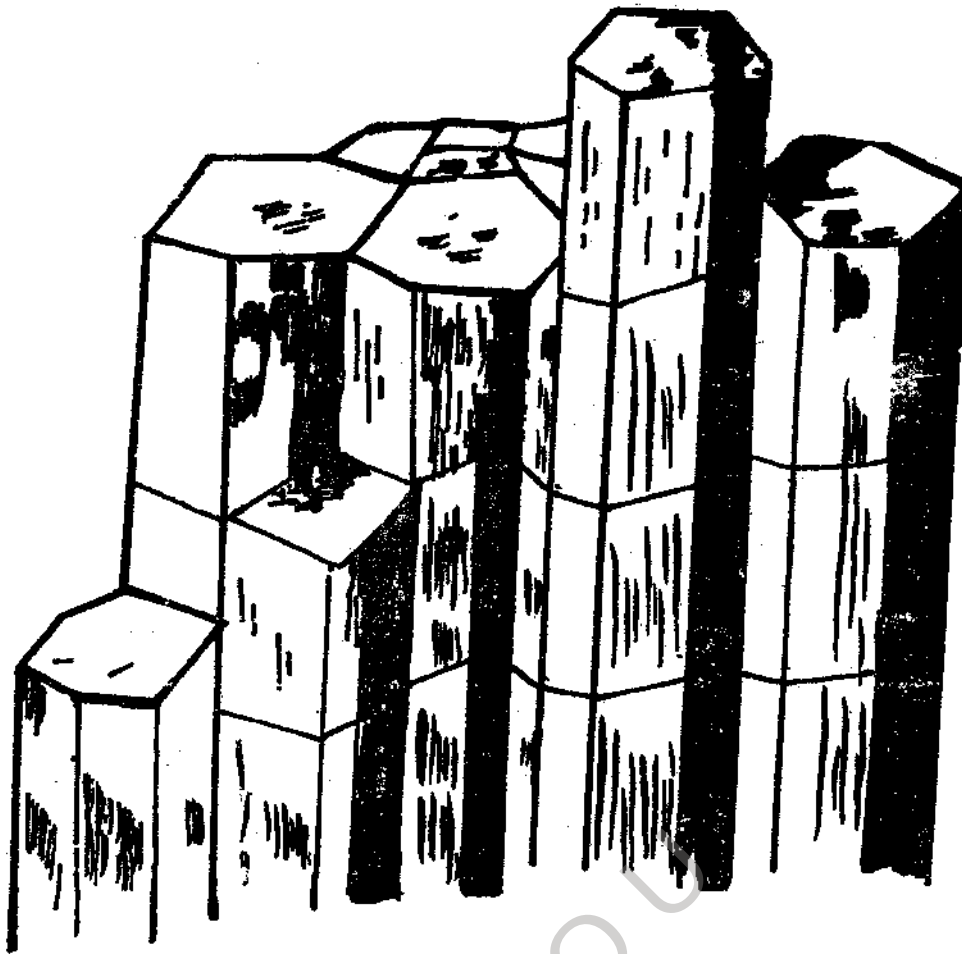


Fig. 6.7 Columnar Structure

6.3 SUMMARY

Igneous rocks formed from early magma are available in different forms and structures. When a lava erupted on the surface through fissures or volcanic vents, they are called as Extrusive rocks. Some times magma before reaching the surface are injected into rocks in the crust, and after solidification are called Intrusive rocks. The forms shown by extrusive rocks are called Extrusive forms and the forms shown by intrusive rocks are called Intrusive forms.

Extrusive forms are formed due to the eruption of lava on to the surface and flow on the ground and solidify as tabular bodies of wide areal extent in proportion to their thickness, elongated in the main direction of flow. In India, Deccan Plateau is a typical example.

Intrusive forms are formed due to the penetration of magma into the rocks. These are divided into two types one is concordant, second one is discordant. Concordant forms are formed with the magma injection along the structural planes like bedding planes, cleavage planes etc. If the magma breaks the structural planes then such forms are called Discordant forms. The important Concordant forms are sill, lacolith, lopolith, facolith etc. The main Discordant forms are dyke, ring dyke, cone sheet and volcanic neck. The other important forms are

batholith, stock, boss etc. When we are observing rock formations, we may encounter certain morphological features in the formation, such features are called structures. The important igneous structures are Vesicular, Amygdaloidal structures, Block and Ropy structures, Pillow and Ellipsoidal structures, Flow structures, Jointing structures, Columnar or Prismatic structures. These structures help us to know the history of crystallisation.

6.4 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Rapid cooling and fine grained
2. In the concordant bodies the magma is injected along the cleavage planes, bedding planes etc without cutting across the structure or bedding plane ex : sill, lapolith. In the discordant form the magma is injected across the structural planes such as cleavage planes and bedding planes example dyke.
3. Laccolith
4. Phacolith
5. Size, form and pronounced sagging
6. Swarms
7. Orogenic belt
8. Basalts.

6.5 MODEL EXAMINATION QUESTIONS

- I. Answer the following questions in 10 lines each.
 1. Explain the different forms of Igneous rocks with neat diagrams.
 2. What are concordant and discordant intrusive? Give examples.
 3. What is a batholith? How does it differ from other forms of intrusion?
 4. Give brief accounts of the structures shown by igneous rocks.
- II Answer the following questions in 10 lines each.
 1. Differentiate forms and structures
 2. Concordant forms
 3. Multiple Intrusions
 4. Explain Stock and Boss forms.

6.6 GLOSSARY

Amygdales	:	Vesicles filled with secondary minerals
Amygdaloidal structure	:	Structure of lavas produced due to amygdales
Batholith	:	A deep seated gigantic intrusive body with steeply inclined sides and without any visible floor

Block structures	: Structure of lavas showing a mass of rough angular blocks
Boss	: A stock with an approximately circular outcrop
Columnar structure	: A structure produced due to the injection of magmas of different compositions along coaxial cone shaped fractures and having arcuate out crops
Concordant forms	: Intrusive bodies formed along the structural planes of the invaded rock
Discordant forms	: Intrusive bodies cutting across the structural planes of the invaded rock
Dyke	: A discordant intrusion looking like a narrow parallel sided wall of igneous rock
Ellipsoidal structure	: Structure of lavas appearing as pile of small masses
Extrusive surface	: Igneous rocks formed due to the solidification of lava erupted to the surface igneous rock
Intrusive igneous rocks:	Igneous rocks formed due to the solidification of magma injected or irrputed into rocks below the surface of the earth
Joints	: Divisional planes or fracture in igneous rocks
Laccolith	: A concordant intrusion which has domed top and flat base
Lava	: Hot molten rock material erupted on the surface. It is the extrusive form of magma
Lopolith	: A massive concordant intrusion with a lenticular shape, sunk centrally like a basin or saucer
Magma	: Hot molten rock material occurring below the surface of the earth
Intrusion	: An intrusion big in size and formed at a great depths
Minor intrusions	: An intrusion formed due to the injections of single magma along a single channel in two or more pulses
Phacolith	: A concordant crescent shaped intrusions occupying the crest or trough region in folded rocks
Pillow structure	: Same as ellipsoidal structure
Pluton	: Any body of igneous rock formed beneath the surface of the earth

BRAOU

UNIT : 7 TEXTURES AND MICROSTRUCTURES OF IGNEOUS ROCKS

Contents

- 7.0 Objectives
- 7.1 Introduction
- 7.2 Textures
 - 7.2.1 Degree of Crystallisation
 - 7.2.2 Grain Size
 - 7.2.3 Shape of Crystals
 - 7.2.4 Mutual Relations of Crystals
- 7.3 Microstructures
 - 7.3.1 Reaction Rim
 - 7.3.2 Myrmekite
 - 7.3.3 Xenolithic Structure
 - 7.3.4 Orbicular Structure
 - 7.3.5 Spherulitic Structure
 - 7.3.6 Fracture Forms
- 7.4 Summary
- 7.5 Check Your Progress-Model Answers
- 7.6 Model Examination Questions
- 7.7 Glossary

7.0 OBJECTIVES

The purpose of this unit is to give an over all view of textures and micro structures of igneous rocks

By the end of this unit, you will be able to

- * define textures
- * describe the different factors that affect textures of igneous rocks
- * describe the microstructure and its different types

7.1 INTRODUCTION

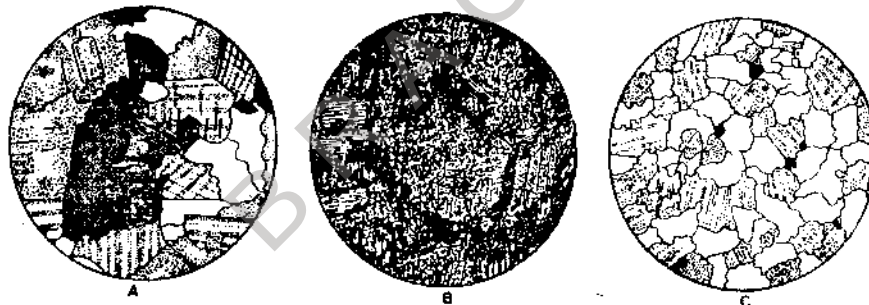
Igneous rocks are made up of mineral crystals or grains, formed due to the crystallisation of magmas. As magmas move upward, minerals start crystallising from them due to cooling. If the solidification is complete within the earth the rock will be composed of all crystals. But when these magmas are erupted at the surface, along with the crystals already formed inside the earth they cool somewhat rapidly and some times very rapidly under such condition formation of crystals is not favoured. As a result, the remaining liquid solidifies into a mass which is not crystalline. This non crystalline igneous material is called **glass**. Therefore igneous rocks may be composed entirely of crystals sometimes of both crystals and glass and rarely entirely of glass.

developed when their growth is hindered by factors such as disturbing environment, reaction with magma and juxta position of other crystals. They have to take shapes of what ever open spaces were available between already formed crystals. Crystals shaped can also be described with reference to their relative dimensions. Crystals may be equal or equidimensional when they are more or less equally developed in all directions , as for example, Garnet, Leucite and Augite. Inequant crystals may be described as tabular, platy or flaky if they are more developed in two directions than in the third as micas or some feldspars. Crystals better developed in one direction than in the other two, are said to be prismatic and they occur as prisms, rods and needles. Hornblende, Sillimanite and Tourmaline are common examples. Other forms such as shreds rugged patches veins etc., may be described as irregular.

7.2.4. Mutual Relations of Crystals

The over all pattern of arrangement of the crystals or crystals and glass in a rock is an important factor of its texture. This arrangement may not be regular or orderly, the point of interest is how the grains are placed in relations to each other. Different terms are used to describe the patterns. They are explained below.

Equigranular textures : Equigranular textures are those in which the crystals or grains are all of approximately the same size giving the rock in evenly granular appearance. Equigranular textures are further designated as **panidiomorphic** (Fig 7. A) when most of the crystals are Euhedral (Ex : lamprophyre) **Hypidiomorphic**, (Fig 7.B) when most of the crystals are Subhedral (Ex : Granite) and **Allotriomorphic** (Fig 7.C) when majority of the crystals are Anhedral (Ex : Aplite).



A = Panidiomorphic texture
B = Hypidiomorphic texture
C = Allotriomorphic texture

Fig : 7.1. Equigranular

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answers with the one given at the end of this Unit.

5. Holocrystalline texture is characteristic of

6. When the majority of the constituent crystals are Euhedral then the feature is known as _____ give example.

Inequigranular textures : Inequigranular textures are those in which the differences in the sizes of the constituent grains of an igneous rock are very conspicuous both in hand specimen and under the microscope. Further, when the sizes vary gradually from the smallest to the largest, the texture is said to be **seriate**. Usually there will be two dominating sizes, crystals of intermediate sizes being very few or even absent. Among the inequigranular textures, **Porphyritic** and **Poikilitic** textures are two important types. In porphyritic textures, large crystals, usually well shaped, called phenocrysts belonging to one or more minerals are set in a base termed groundmass which may be fine-grained, microcrystalline, merocrystalline or glass (Fig 7.2). If the phenocrysts are gathered in clusters, the texture is called **Glomeroporphyritic**. The pairs of terms **megaporphyritic** and **magaphenocrysts**, **microporphyritic** and **microphenocrysts** are used depending respectively on whether the texture is distinguishable with the naked eye or only under the microscope.

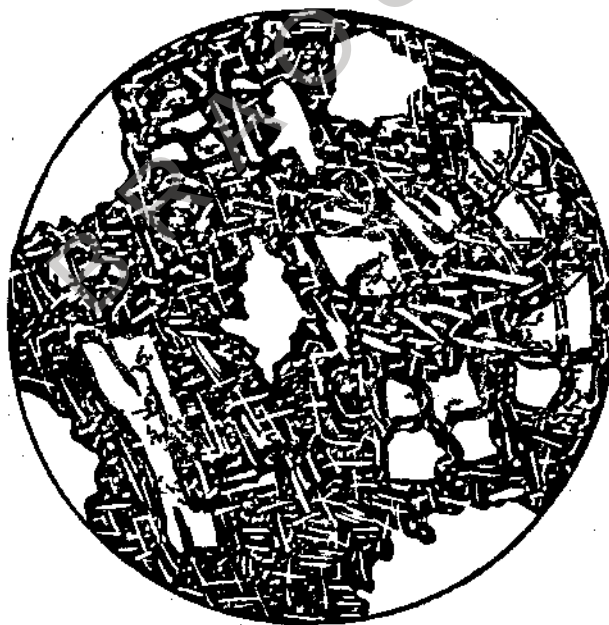


Fig. 7.2. Porphyritic texture

Check your progress

- Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this Unit.

7. When large crystals are enveloped in a ground mass, then the texture is named as

.....
.....
.....
.....

The porphyritic texture is a result of crystallisation in two stages during which the conditions of solidification of the magma were changed, by intrusion or extrusion. The phenocrysts originated at depth under conditions of slow cooling and belong to the early stage of crystallisations when the magma was hot and thin. The groundmass composed of fine grains some times even of glass, may have formed because of rapid cooling due to sudden transfer from a depth to a higher level in the crust or due to extrusion at the surface. This is the reason for many extrusive rocks, dykes and minor intrusions showing porphyritic textures. Some granites are also porphyritic. In this case the differences in grain size are supposed to be due to differences in the molecular concentrations of the minerals concerned.

In poikilitic texture smaller crystals are enclosed in the larger ones without common orientation. (Fig 7.3). In other words, this texture is the converse of porphyritic texture. The inclusions must be large enough in number so as to produce a distinct pattern. Some authors coined the terms 'oikocryst' for the enclosing crystal and the enclosed crystals respectively.

Coming to the origin of this texture, the smaller crystals must have formed earlier than the larger ones which enclose them, which means that cooling should have been slow till the end of crystallisation. The difference in grain size in this case is explained based on relative molecular concentrations of the minerals. Minerals present as smaller crystals as larger crystals were in much higher proportion and formed towards the end, while the rate of cooling remained slow throughout.



Fig. 7.3. Poikilitic texture

Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this Unit.

8. Poikilitic texture is converse of

.....
.....
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Ophitic texture is a special type of poikilitic texture in which plates of augite enclose numerous thin laths of plagioclase. (Fig. 7.4). This texture is characteristic of dolerites. The term '**subophitic**' is used when the plagioclase grains are of approximately the same size as pyroxene grains and their enclosure is only partial



Fig. 7.4 Ophitic texture

Two other inequigranular textures, commonly found in basalts, are to be mentioned, these are intergranular and intersertal textures. In basalts, the texture is determined by a framework of plagioclase laths so arranged that triangular or polygonal interspaces are left between them. When these interspaces are filled with granules of augite, olivine and iron oxides, the texture is said to be **intergranular**. If the infilling substances are glassy cryptocrystalline or fine grained chloritic or serpentinous material, the term **intersertal** is used.

Directive textures :- These are produced by flow in magmas during their crystallisation. Due to the flows of the magma crystals may be brought in parallel lines or bands, which follow the stream lines of the magma. The stream-lines may be contorted if the magma is very viscous. In lavas such as Trachytes, Andesites etc., which are rich in felspar, the felspar laths are arranged in parallel rows by the flow. This texture is known as **Trachytic texture** (Fig 7.5).

UNIT : 8 CLASSIFICATION OF IGNEOUS ROCKS

Contents

- 8.0 Objectives
- 8.1 Introduction
- 8.2 Classification
 - 8.2.1 Chemical and Quasi-chemical Classification
 - 8.2.2 Mineralogical Classification
 - 8.2.3 Classification based on Geological Occurrence and Texture
 - 8.2.4 Other Classification
- 8.3 Summary
- 8.4 Check Your Progress-Model Answers
- 8.5 Model Examination Questions
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8.0 OBJECTIVES

In this unit, our main focus has been laid on the classification of igneous rocks. By the end of this unit, you will be able to

- * describe the bases for classification of igneous rocks
- * describe the different classifications of igneous rocks
- * classify the igneous rocks

8.1 INTRODUCTION

Igneous rocks, as already mentioned constitute about 95 percent of the crustal rocks. They show great variations in their chemical, mineralogical and textural characters and as such their classification is a delicate task. A general scheme of classification useful for all purposes and acceptable to all does not seem to be available. Various classifications have been suggested since 1866, each having its own objective. Each has merits and demerits as well, and none can fully combine the advantages of all. Some are useful in the field and some are in the laboratory work.

8.2 CLASSIFICATIONS

The research work regarding igneous rocks begins with field observations, continues with microscopic study and ends with the crucible. As it is not possible to use any one classification in these three stages, different petrologists proposed different classifications. Broadly there are three main bases of classification.

1. Chemical composition of the rocks
2. Mineral assemblage of the rocks
3. Geological occurrence and texture.

Some important classifications are explained below.

Hayninte	Cordierite
Noselite	Garnet
Cancrinite	Sphene
Micas	
Muscovite	Topaz Biotite
Tourmaline	Phlogopite
Zircon	
Other Minerals	
Apatite	Gold
Cassiterite	Hematite
Chromite	Magnetite
Crysoberyl	Ilmenite
Columbite	Monazite
Corundum	Pyrite
Fluorite	Rutile

Of the above minerals again only a few are found to occur more frequently in igneous rocks. An estimate of the average mineral composition of igneous rocks prepared by T.F.W. Barth is given below.

Mineral	Percentage in Igneous Rocks
Silicates	
Quartz	12.4
Alkali felspar (Or, Ab)	31.0
Plagioclase	29.2
Pyroxene	12.0
Hornblende	1.7
Biotite	3.8
Muscovite	1.4
Olivine	2.6
Nepheline	0.3
Sphene	0.3
Chlorite, Serpentine	0.6
Other minerals	
Magnetite, Ilmenite,	
Hematite	4.1
Apatite	0.6
	100

It can be seen from the above table that twelve silicate minerals make up 95.3 percent of the average mineral content of igneous rocks. Of these, chlorite and serpentine are not pyrogenetic minerals, they are formed due to the alteration of iron-magnesium silicates.

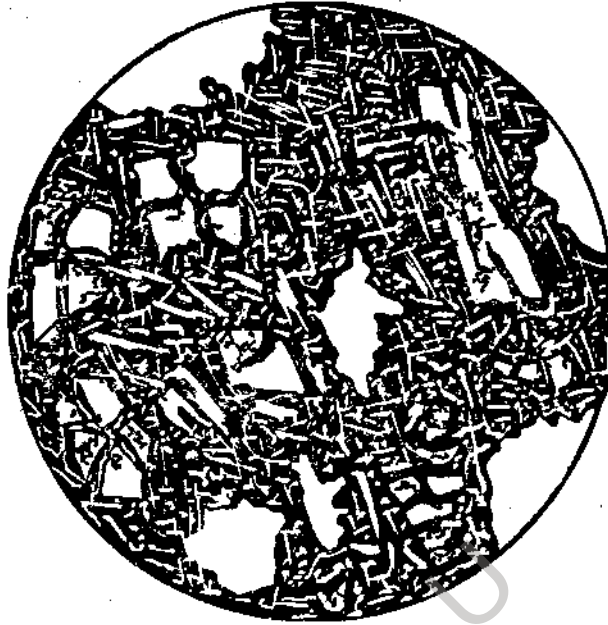
7.2 TEXTURES

The term 'texture' refers to certain small-scale physical features of rocks. It deals with the mutual relations of the mineral crystals or crystals and glass, when present, in a rock. Certain textural aggregates are of very small dimensions and are referred to as 'microstructures'.

Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this Unit.

Check your progress

Fig. 7.2. Porphyritic texture



Inequigranular textures : Inequigranular textures are those in which the differences in the sizes of the constituent grains of an igneous rock are very conspicuous both in hand specimen and under the microscope. Further, when the sizes vary gradually from the smallest to the largest, the texture is said to be *seriate*. Usually there will be two dominating sizes, crystals of intermediate sizes being very few or even absent. Among the inequigranular textures, Porphyritic and Poikilitic textures are two important types. In porphyritic textures, large crystals, usually well shaped, called phenocrysts belonging to one or more minerals are set in a base termed groundmass which may be fine-grained, microcrystalline, microcrystalline or glass (Fig 7.2). If the phenocrysts are gathered in clusters, the texture is called Glomeroporphyritic. The pairs of terms megaporphyritic and magaphenocrysts, microporphyritic and microphenocrysts are used depending respectively on whether the texture is distinguishable with the naked eye or only under the microscope.

6. When the majority of the constituent crystals are Euhedral then the feature is known as _____ give example.

7.2.2. Grain size

The size of crystals in igneous rocks may vary widely. It may range from submicroscopic dimensions to giant crystals measurable in meters like quartz and feldspar in pegmatites. Two terms are used to describe the sizes of crystals **phaneric** and **aphanitic**. If the crystals are visible to the naked eye or visible with the aid of a hand lens, the rock is said to be **phaneric** or phanocrystalline. On the other hand, if the individual crystals cannot be recognised in this way, the rock is said to be **aphanitic**. Aphanitic rocks may be microcrystalline, merocrystalline, cryptocrystalline or glassy.

Phaneric rocks are further distinguished as **coarse grained** when the average diameter of the crystals is more than 5mm, **medium grained** when it is between 1mm and 5mm and **fine grained** when it is less than 1 mm.

Like crystallinity, grain size also depends on the rate of cooling and viscosity of the magma. Slow cooling and lesser viscosity favour formation of larger crystals while rapid cooling and high viscosity produce smaller crystals. An additional factor which controls the grain size is the molecular concentration of the crystallising substance in the magma.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this Unit.

4. Crystals are visible to the naked eye or with the aid of pocket lens then the rock is said to be

7.2.3. Shapes of crystals

The shapes of mineral grains are described with reference to the development of their crystal faces and thus their crystal form. If the crystal is bounded by well developed faces it is said to be **euhedral**, on the other hand, if the crystal faces are absent, it is said to be **anhedral**. An intermediate stage of development of faces is indicated by the term **subhedral**. The crystal forms indicate the environment in which the crystals are developed. Euhedral crystals are formed under conditions of slow cooling and crystallisation in a thin liquid medium with comparative freedom from interference by neighbouring crystals. Anhedral crystal are

developed when their growth is hindered by factors such as disturbing environment, reaction with magma and juxta position of other crystals. They have to take shapes of what ever open spaces were available between already formed crystals. Crystals shaped can also be described with reference to their relative dimensions. Crystals may be equal or equidimensional when they are more or less equally developed in all directions , as for example, Garnet, Leucite and Augite. Inequant crystals may be described as tabular, platy or flaky if they are more developed in two directions than in the third as micas or some feldspars. Crystals better developed in one direction than in the other two, are said to be prismatic and they occur as prisms, rods and needles. Hornblende, Sillimanite and Tourmaline are common examples. Other forms such as shreds rugged patches veins etc., may be described as irregular.

7.2.4. Mutual Relations of Crystals

The over all pattern of arrangement of the crystals or crystals and glass in a rock is an important factor of its texture. This arrangement may not be regular or orderly, the point of interest is how the grains are placed in relations to each other. Different terms are used to describe the patterns. They are explained below.

Equigranular textures : Equigranular textures are those in which the crystals or grains are all of approximately the same size giving the rock in evenly granular appearance. Equigranular textures are further designated as **panidiomorphic** (Fig 7. A) when most of the crystals are Euhedral (Ex : lamprophyre) **Hypidiomorphic**, (Fig 7.B) when most of the crystals are Subhedral (Ex : Granite) and **Allotriomorphic** (Fig 7.C) when majority of the crystals are Anhedral (Ex : Aplite).



A = Panidiomorphic texture
B = Hypidiomorphic texture
C = Allotriomorphic texture

Fig : 7.1. Equigranular

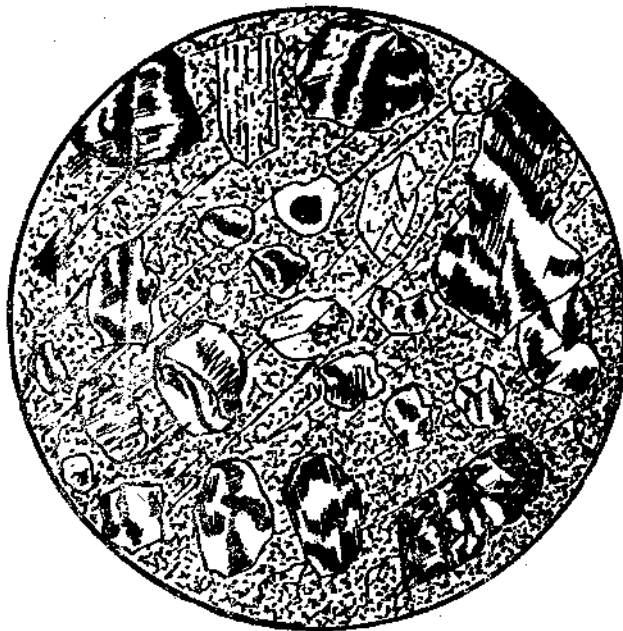
Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answers with the one given at the end of this Unit.

5. Holocrystalline texture is characteristic of

Fig. 7.3. Poikilitic texture



In poikilitic texture smaller crystals are enclosed in the larger ones without common orientation. (Fig 7.3). In other words, this texture is the converse of porphyritic texture. The inclusions must be large enough in number so as to produce a distinct pattern. Some authors coined the terms 'oikocryst' for the enclosing crystal and the enclosed crystals respectively. Coming to the origin of this texture, the smaller crystals must have formed earlier than the larger ones which enclose them, which means that cooling should have been slow till the end of crystallisation. The difference in grain size in this case is explained based on relative molecular concentrations of the minerals. Minerals present as smaller crystals as larger crystals were in much higher proportion and formed towards the end, while the rate of cooling remained slow throughout.

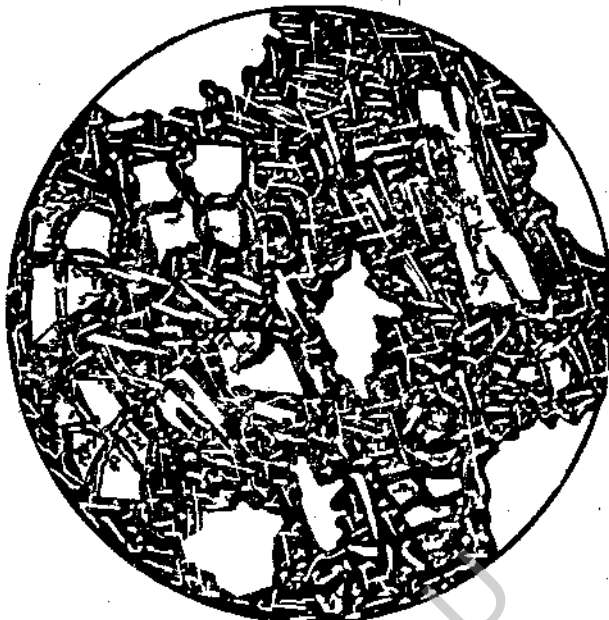
The porphyritic texture is a result of crystallisation in two stages during which the conditions of solidification of the magma were changed, by intrusion or extrusion. The phenocrysts originated at depth under conditions of slow cooling and belong to the early stage of crystallisations when the magma was hot and thin. The groundmass composed of fine grains some times even of glass, may have formed because of rapid cooling due to sudden transfer from a depth to a higher level in the crust or due to extrusion at the surface. This is the reason for many extrusive rocks, dykes and minor intrusions showing porphyritic textures. Some granites are also porphyritic. In this case the differences in grain size are supposed to be due to differences in the molecular concentrations of the minerals concerned.

7. When large crystals are enveloped in a ground mass, then the texture is named as

Note : a) Space is given below for writing your answer.
b) Compare your answer with the one given at the end of this Unit.

Check your progress

Fig. 7.2. Porphyritic texture



Inequigranular textures : Inequigranular textures are those in which the differences in the sizes of the constituent grains of an igneous rock are very conspicuous both in hand specimen and under the microscope. Further, when the sizes vary gradually from the smallest to the largest, the texture is said to be *seriate*. Usually there will be two dominating sizes, crystals of intermediate sizes being very few or even absent. Among the inequigranular textures, Porphyritic and Poikilitic textures are two important types. In porphyritic textures, large crystals, usually well shaped, called phenocrysts belonging to one or more minerals are set in a base termed groundmass which may be fine-grained, microcrystalline, merocrystalline or glass (Fig 7.2). If the phenocrysts are gathered in clusters, the texture is called Glomeroporphyritic. The pairs of terms megaporphyritic and magaphenocrysts, microporphyritic and microphenocrysts are used depending respectively on whether the texture is distinguishable with the naked eye or only under the microscope.

6. When the majority of the constituent crystals are Euhedral then the feature is known as _____ give example.

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this Unit.

8. Poikilitic texture is converse of

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Ophitic texture is a special type of poikilitic texture in which plates of augite enclose numerous thin laths of plagioclase. (Fig. 7.4). This texture is characteristic of dolerites. The term '**subophitic**' is used when the plagioclase grains are of approximately the same size as pyroxene grains and their enclosure is only partial

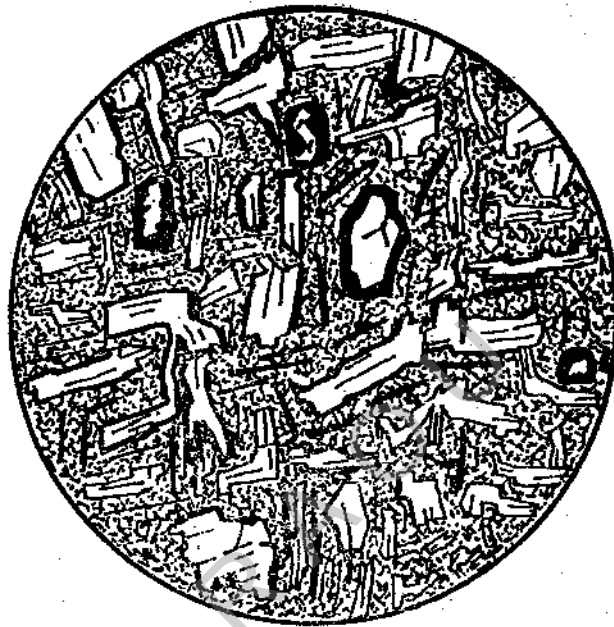


Fig. 7.4 Ophitic texture

Two other Inequigranular textures, commonly found in basalts, are to be mentioned, these are intergranular and intersertal textures. In basalts, the texture is determined by a frame work of plagioclase laths so arranged that triangular or polygonal interspaces are left between them. When these interspaces are filled with granules of augite, olivine and iron oxides, the texture is said to be **intergranular**. If the infilling substances are glassy cryptocrystalline or fine grained chloritic or serpentinous material, the term **intersertal** is used.

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Fig. 7.5 Directive texture (Trachytic texture)

Intergrowth texture :- These textures are produced by the intergrowth of two minerals. The mineral present in smaller proportion is embedded in the other as disconnected patches possessing the same optical orientation over a considerable area. Intergrowth textures are produced due to simultaneous crystallisation of the two constituents or due to the phenomenon of exsolution.

The most common type of intergrowth is between quartz and felspar the latter comprising orthoclase, microcline and feldspars the latter comprising orthoclase, microcline and sodic plagioclase and is known as **Graphic texture** (Fig 7.6) In this texture large grains of felspar, most commonly orthoclase, enclose many small grains of quartz and the pattern resembles ancient writing or script and hence the term Graphic. This texture is commonly seen in Pegmatites. When this intergrowth is reduced to microscopic dimensions it is said to be Micrographic and the material is called Micropegmatite. The term **Granophyric** is used when the intergrowth of quartz and felspar is irregular, unlike is graphic texture in which it is regular. The intergrowth of orthoclase (or microcline) and albite is called **Perthite** which, when microscopic in size is called Microperthite. The inter growth of plagioclase and vermicular quartz is called **Myrmekite** the plagioclase having generally replaced orthoclase.

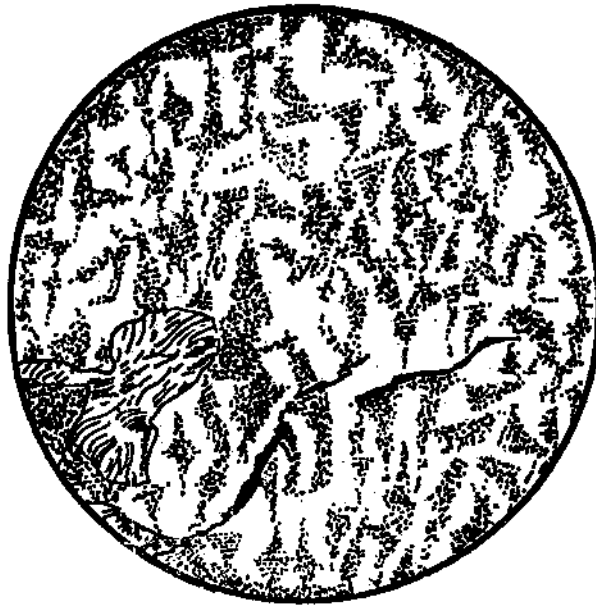


Fig. 7.6 Graphic texture

Intergrowth is also observed between Orthorhombic and Monocline Pyroxenes, Quartz and Tourmaline, Nepheline and Felspar and Magnetite and Felspar.

7.3 MICROSTRUCTURES

As already mentioned, microstructures are textural aggregates which can be studied only under the Microscope. The common Microstructures are described below.

7.3.1 Reaction Rim Structures

It will be seen in a following unit that reaction often takes place between early formed minerals and the magma surrounding them. Due to this reaction, it is possible that the entire mineral may disappear and a new mineral may come in its place. But when the reaction is incomplete the corroded crystals are found surrounded by the products of reaction. Reaction may also take place when a foreign mineral (called Xenocryst) is introduced into magma. The zone of reaction product is known as a **Reaction rim** (fig 7.7) If the Reaction rims are produced by primary magmatic reaction they are termed as **coronas** and if they are produced by secondary magmatic reaction or reactions such as those operating in metamorphism, they are termed as kelyphitic borders. The term zoning is used for concentric rims or zones found in crystals which exhibit the property of solid solutions.

In coronas a nucleus of an early formed mineral is often found. This will be surrounded by one or more rims of reaction minerals. Olivine surrounded by rim of pyroxene which in turn is surrounded by a rim containing hornblende is often seen in basic igneous rocks. These rims may be granular or fibrous in structure.

7.3.2 Myrmekite

It is an intergrowth of Quartz and Plagioclase, is found to occur on the borders of orthoclase crystals, and is supposed to be due to replacement of Orthoclase by Plagioclase. The reaction liberates silica which appears as Quartz and potash which goes to form Biotite often found associated with myrmekite.

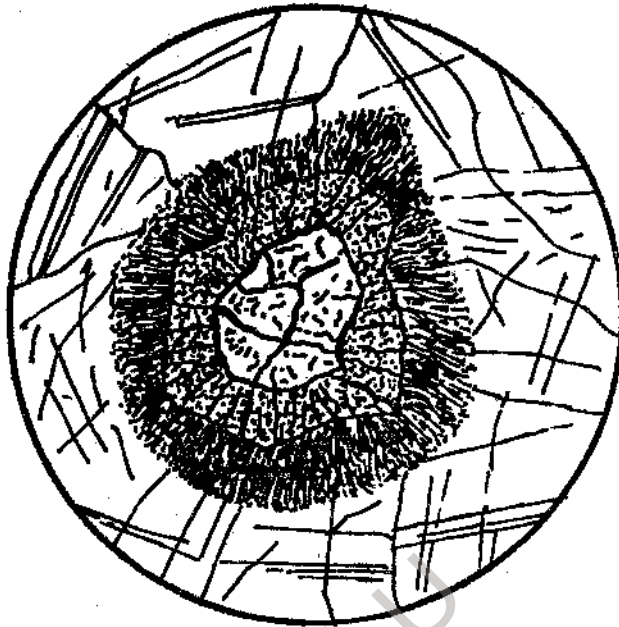


Fig.7.7 Reaction rim

7.3.3 Xenolithic structure

During the upward movement of magmas, fragments of rocks fall into them giving rise to Xenoliths (Gr. Strange or foreign rocks) or enclaves (Fr inclusion) which may be of varying in sizes, from blocks many meters in length to fragments of microscopic dimension. These inclusions may consist of any kind of rock and may be partly or completely digested by the magma. Because of the sharp differences in composition between them and the magma by which they are enclosed, the Xenoliths can be easily recognized in outcrops. Their outlines become indistinct because of reaction between the xenolith and the magma and the altered minerals are disposed throughout the magma.

The term **schlieren** is used for the hazy ill-defined dark streaks found in granite rocks. These may have resulted from the incomplete mixing of assimilated fragments of foreign origin or may be due to segregation and late movement of the magma.

Xenoliths are classified as cognate and accidental. **Cognate xenoliths** are those which are genetically related to the enclosing rocks and most often during an early stage of crystallisation. **Accidental xenoliths** are fragments of country rock which may be igneous, sedimentary or metamorphic and which may have been included within the igneous rock due to its intrusion or extrusion.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this unit.

9. If the inclusions of foreign rock fragments are genetically related to the enclosing rocks then it is called

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7.3.4 Orbicular structure

A few igneous rocks, commonly those formed deep inside the crust, contain ball like segregations consisting of concentric shells of different mineral composition and texture, which may or may not be built up around a xenolithic kernel. These ball-like segregation are called **orbicles** and rock contain orbicles is said to have an **orbicular structure**. Although the nature of orbicles formation is uncertain, most of them are supposed to be due to reaction with accident at xenoliths.

7.3.5 Spherulitic structure

Some volcanic rocks show spherical bodies which are built up of fibrous crystals with radiate arrangement about a common centre. These bodies are called **Spherulites**. The

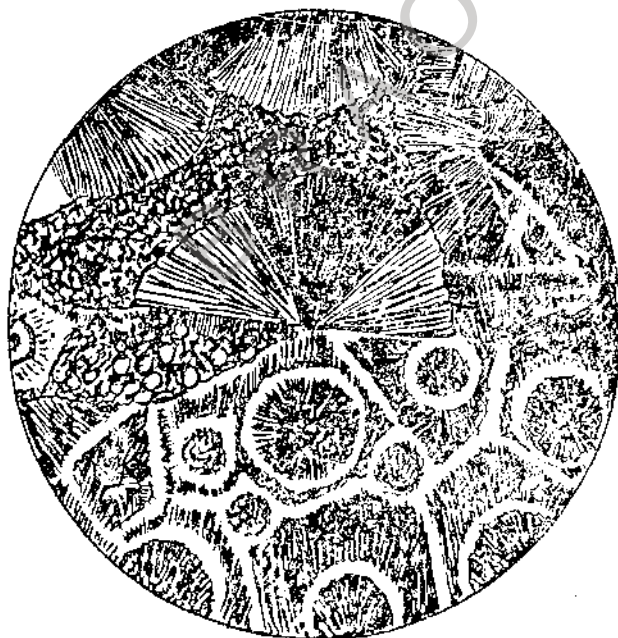


Fig. 7.8 Spherulitic Structures

growth may be completely spherical or it may be only a small part of a sphere. (Fig 7.8). Spherulites may vary in size. They are usually small and visible under a hand lens or

microscope. But giant compounds of 3 meters or more in diameter are reported from Rhyolites of Colorado in U.S.A.

Spherulites represent rapid growths in a quickly cooling lava that has come to rest, facilitating the growth of fibrous crystals and their radial arrangement. Spherulites are common in acid volcanic rocks and consist of radiating intergrowth of Quartz and Felspar fibres or needles.

7.3.6 Fracture forms

Most glassy rocks show minute, curved, sometimes partially concentric lines of fractures formed due to shrinkage of the cooling glass. These are often so well developed that the rock appears as an aggregate of small nodules consisting of a number of onion like shells. As these small spheres of glass look like pearls, the term **Perlitic structure** is used for this appearance (Fig 7.9)



Fig. 7.9 Fracture forms

A = Perlitic Structure, B = Expansion forms

Sometimes irregularly radiating fractures are produced in minerals adjacent to altered olivine crystals in Gabbros or Norites. When Olivine alters to Serpentine there is an increase in volume and the stress so produced cause fracturing of the surrounding minerals. (Fig 7.9).

7.4 SUMMARY

Igneous Rocks are formed due to cooling and crystallisation of magma. If the solidification completes within the earth, the rocks will be composed of full of crystals. If the solidification occurs on the ground, glass will appear due to rapid cooling. Igneous rocks may be composed entirely of crystals, some times both crystals and glass, rarely entirely of glass. Minerals formed directly from magma are called **Pyrogenetic minerals**. Silicates are

more abundant in Pyrogenetic minerals. Studies of the crystal structures of silicates revealed that tetrahedra with a silicon atom at the centre and four oxygen at the four corners. Based on the crystal structure, silicates are classified as Sorosilicates, Cyclosilicates, Inosilicates, Phyllosilicates, Tectosilicates. In general igneous rocks compose of silicates 12.4%, alkali feldspars 31% Plagioclase 29.2%, Pyroxenes 12%, Hornblend 17%, Biotite 3.8%, Muscovite 1.4%, Olivine 2.6%, Nepheline 0.3%, Sphene 0.3%, Magnetite, Haematite, Ilmenite together 4.1%, Chlorite, Serpentine 0.6%, Apatite 0.6%

There are certain small scale physical features in rocks. These are called textures and structures. These characters are useful to know the valuable information about the nature of cooling and solidification of igneous rocks. The term structure is used for large scale physical features. The term texture is used to know the grain size, shape and mutual relationship of grains. Very small features are called Micro structures, which are visible only under microscope.

Texture of any igneous rocks is described with reference to degree of crystallisation, grain size, shape of crystals and mutual relationship of crystals and glass. Based on the degree of crystallisation, textures are classified as Holocrystalline, Mesocrystalline and Holohyaline. The rate of cooling and viscosity of the magma are the main factors which determine degree of crystallinity.

Two terms are used to describe the sizes of crystals one is Phaneric and other one is Aphanitic. If the crystals are visible to naked eye then it is Phaneric. If the crystals are visible with microscope only, then the texture is Aphanitic. Phaneric rocks are further divided into coarse, medium and fine grained.

With regard to shape of crystals, textures are divided into euhedral, subhedral and anhedral.

The other textures with mutual relationship of crystals and glass are Equigranular and In-equigranular. Poikilitic, Porphyritic, Directive, Graphic textures are the other textures in igneous rocks.

The small scale features are the microstructures. The common microstructures are Reaction structures, Myrmekite structure, Xenolithic structure, Orbicular structure, Spherulitic structure and Fracture forms.

7.5 CHECK YOUR PROGRESS : MODEL ANSWERS

- 1) Minerals formed from magma are called Pyrogenetic minerals.
- 2) (i) Degree of crystallisation (ii) Grain size or granularity (iii) Shape of crystals (iv) Mutual relationship of crystals and glass
- 3) (i) Holocrystalline (entirely of crystals) (ii) Microcrystalline (Both crystals & glass) (iii). Holohyaline (entirely of glass)
- 4) Phanerocrystalline or phaneric
- 5) Plutonic rocks
- 6) Panidiomorphic & Lamprophyre
- 7) Porphyritic texture
- 8) Porphyritic texture
- 9) Cognate xenolith

7.6 MODEL EXAMINATION QUESTIONS

I. Answer the following question in 30 lines each.

1. Give an account of the average mineral composition of igneous rocks
2. Explain the texture in relation to igneous rocks. Describe the different types.
3. Explain the various micro structures of Igneous rocks.

II. Answer the following questions in 10 lines each.

1. Bring out the difference between Porphyritic and Poikilitic textures.
2. Describe the common intergrowth textures ?
3. What is a 'micro structure'?
4. Explain how reaction rims are produced.
5. What are xenoliths ?

7.7 GLOSSARY

Accidental xenoliths	:	Xenoliths having no genetic relationship with the enclosing rock
Allotriomorphic texture	:	Equigranular texture with anhedral crystals
Anhedral	:	Crystal faces absent
Aphanitic	:	Grains not visible to the naked eye or even with a hand lens
Coarse grained	:	Average diameter of crystals more than 5mm.
Cognate xenoliths	:	Xenoliths having genetic relationship with the enclosing rock
Corona	:	Reaction rims produced by flow in magmas
Equigranular texture	:	Texture in which all grains are of approximately the same size
Euhedral	:	Crystal faces well developed
Fabric	:	Combined nature of shapes of crystals and their mutual relations
Fine grained	:	Average diameter of crystals less than 1 mm
Glass	:	Non-crystalline igneous material
Granophyric texture	:	Irregular intergrowth of quartz and felspar
Granularity	:	Size of grains
Graphic texture	:	Regular intergrowth of quartz and felspar
Holocrystalline	:	Composed entirely of crystals
Holohyaline	:	Composed entirely of glass
Hypidiomorphic texture	:	Equigranular texture with subhedral crystals
Inequigranular texture	:	Texture produced due to the filling of interspaces
Intergrowth texture	:	Texture produced due to intergrowth of two minerals

Intersertal texture	:	Texture produced due to the filling of interspaces between plagioclase laths in basalts by glassy cryptocrystalline or fine grained material.
Kelyphitic borders	:	Reaction rims produced by secondary magmatic reactions or metamorphic reaction
Medium grained	:	Average diameter of crystals between 1 mm and 5 mm.
Merocrystalline	:	Composed partly of crystals and partly of glass
Microstructure	:	Textural aggregate of microscopic dimensions
Myrmekite	:	Intergrowth of plagioclase and vermicular quartz
Ophitic texture	:	Special type of poikilitic texture in which numerous laths of plagioclase are enclosed in plates of augite.
Orbicular structure	:	Structure produce to ball-like segregations
Panidiomorphic texture	:	Equigranular texture with euhedral crystals
Perlitic structure	:	Structure produced by curved and concentric fractures in glasses
Perthite	:	Intergrowth of orthoclase or microcline and albite
Phaneric or		
Phanerocrystalline	:	Grains visible to the naked eye or with a handlens
Phenocrysts	:	Large crystals in porphyritic texture
Poikilitic texture	:	Inequigranular texture in which smaller crystals without any common orientation are enclosed in large ones of another mineral.
Porphyritic texture	:	Inequigranular texture in which large crystals are set in a fine grained, cryptocrystals like, merocrystalline or glassy groundmass.
Reaction rims	:	Zones of reaction product around a mineral
Schlieren	:	Hazy ill-defined dark streaks found in granitic rocks
Spherulite	:	Spherical bodies built of fibrous crystal with radiate arrangement
Subhedral	:	Crystal faces paritally developed
Trachytic texture	:	Directive texture produced due to arrangement of felspar laths in parallel rows, characteristic of trachytic lavas
Xenolith	:	Foreign rock fragment found in igneous bodies
Zoning	:	Concentric reaction rims found in minerals exhibiting the property of solid solutions.

* * *

UNIT : 8 CLASSIFICATION OF IGNEOUS ROCKS

Contents

- 8.0 Objectives
- 8.1 Introduction
- 8.2 Classification
 - 8.2.1 Chemical and Quasi-chemical Classification
 - 8.2.2 Mineralogical Classification
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- 8.3 Summary
- 8.4 Check Your Progress-Model Answers
- 8.5 Model Examination Questions
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8.0 OBJECTIVES

In this unit, our main focus has been laid on the classification of igneous rocks. By the end of this unit, you will be able to

- * describe the bases for classification of igneous rocks
- * describe the different classifications of igneous rocks
- * classify the igneous rocks

8.1 INTRODUCTION

Igneous rocks, as already mentioned constitute about 95 percent of the crustal rocks. They show great variations in their chemical, mineralogical and textural characters and as such their classification is a delicate task. A general scheme of classification useful for all purposes and acceptable to all does not seem to be available. Various classifications have been suggested since 1866, each having its own objective. Each has merits and demerits as well, and none can fully combine the advantages of all. Some are useful in the field and some are in the laboratory work.

8.2 CLASSIFICATIONS

The research work regarding igneous rocks begins with field observations, continues with microscopic study and ends with the crucible. As it is not possible to use any one classification in these three stages, different petrologists proposed different classifications. Broadly there are three main bases of classification.

1. Chemical composition of the rocks
2. Mineral assemblage of the rocks
3. Geological occurrence and texture.

Some important classifications are explained below.

8.2.1 Chemical and quasi-chemical classifications

The chemical classifications are based on the chemical composition of the rocks. These are of great value in comparing rock series using chemical data and in discussing about the magma types. Chemical analysis of rocks, of course, indicate nothing about the mineral content and textural features; that means chemical classifications do not take into consideration, the conditions of magmatic crystallisation. It has been found that magmas of identical compositions may give rise to rocks of entirely different mineral contents and texture under different conditions of cooling. Also, these classifications cannot be used for immediate determination, classification of rocks.

Chemical compositions of rocks determined by chemical analysis are expressed in terms of oxides. Of these, the most important is a basis for igneous rock classification. It is one of the earliest methods of classification, and is still in wide use. According to this basis, igneous rocks are classified as **Acidic or silicic** in which silicic is more than 66 percent, **Intermediate** in which silica ranges between 52 and 66 per cent; and **Ultrabasic or Ultramafic** with silica less than 52 per cent. These terms were proposed in 1897 by Franz J. Loewinson-Lessing and are still in general use. The terms 'Acid' and 'Basic' are not used here as in chemistry to indicate hydrogen-ion concentration.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this Unit.

1. Based on silica percentage the igneous rocks are classified into explain

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The important influence of the silica content of a magma on the mineral assemblage of the rock formed from it is emphasised in the classification proposed by S.J. Shand. His classification is based on the saturation principle. The minerals which are capable of existing in igneous rocks in the presence of free silica of magmatic origin are said to be **Saturated**. These are the minerals of high silication and Shand includes Felspars, Pyroxenes, Amphiboles, Micas, Magnetite, Ilmenite, Tourmaline, Sphene, Zircon, Apatite and Topaz in this class. On the other hand, minerals which are very rarely found in associated with free silica of magmatic origin are said to be **Unsaturated**. These are the minerals of low silication and include Felspathoids, Analcite, Olivine, Corundum, Calcite and Spinel. Based on the presence of these classes of minerals, igneous rocks are classified as follows :

1. Oversaturated rocks containing saturated minerals and free silica of magmatic origin.
2. Saturated rocks containing only saturated minerals.
3. Under saturated rocks containing unsaturated minerals.

After silica, alumina is the next important oxide in igneous rocks. Shand proposed further classification based on the relationship between Al_2O_3 and Na_2O , K_2O and CaO .

Check your progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this Unit.

2. The classification based on the saturation principle was proposed by

-----and further classified into (i)-----

----- (ii)-----

(iii)-----

Another important classification based on chemical composition was advanced by Cross, Iddings, Pirson and Washington in the year 1903 and this is popularly known as CIPW classification. The chemical analysis of rocks are first calculated into a set of standard minerals called the **Norm** by following rules which are based on the known principles of crystallisation of minerals in magmas. The norm is divided into two groups, the **salic** and the **femic**, the most important constituents of which are given below :

Salic minerals

Quartz
Orthoclase
Albite
Anorthite
Leucite
Nepheline
Corundum
Zircon

Femic minerals

Diopside
Hypersthene
Olivine
Acmite
Magnetite
Ilmenite
Hematite
Apatite

The relative proportions of salic and femic minerals taken groupwise or with reference to two or three minerals at a time form the basis for division of rocks into classes, orders etc., classification is very elaborate and hence cannot be given here.

Check Your Progress

Note : a) Space is given below for writing your answer.

b) Compare your answer with the one given at the end of this Unit.

3. Standard minerals or the Norm in CIPW classification are divided into two groups such as----- Define the two groups

In view of the fact, that the hypabyssal rocks are related to plutonic or volcanic **bodies**. Petrologists prefer to call the rocks formed at sufficient depth beneath the surface of the earth as **plutonic** and all others, that is those formed at or near the surface as **volcanic rocks**.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

5. Under plutonic conditions, crystallisations take place with

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8.2.4 Other Classifications

Some Petrologists used the factor of association in their classification. Rocks are divided into broad categories or kindreds based on their constant and serial chemical and mineral characters, their association in geographical distribution and their connection with tectonic processes. This basis, however did not gain much popularity.

G.W. Tyrell in his book "The Principles of Petrology" adopted a classification termed as the tabular classification which takes into consideration mainly the factors of mineral assemblage and geological occurrence. The factor of chemical composition is included in part. This classification can be used for the immediate determination of rock types and as such is very useful for geologists and students.

The plan of this classification which is given in the accompanying tables is outlined here. Since felsic minerals constitute about 75% of the average igneous rocks, occurring in it as the essential minerals, the main vertical subdivisions are based on relations between the three felsic mineral groups - quartz, feldspars and feldspathoids. As quartz does not occur along with feldspathoids five divisions characterised respectively by the predominance of quartz, quartz and feldspar, feldspars only, feldspars and feldspathoids and feldspathoids only, are included. Another division is added for predominantly mafic rocks, which are almost devoid of felsic minerals. These six divisions are regrouped into oversaturated, saturated and understaruated classes. This arrangement also agree fairly with the silica percentage classification. Horizontal divisions are made into Plutonic, Hypabyssal and Volcanic groups. The plutonic group is further subdivided based on whether the rocks consist largely of felsic minerals or of mafic minerals or have nearly equal amounts of both. Important rock types have been shown in the Table 8.1 in their proper places.

It is to be borne in mind that the mineralogical classification included in this scheme is applicable strictly only to the plutonic rocks. The volcanic rocks are placed in the table as per their crystallised minerals, and as these rocks usually contain some cryptocrystalline or glassy material, they may not be quite equivalent to the plutonic rocks which are shown above them in the Table. For example, when the standard mineral composition of Andesite is worked out, it is found to contain 15 per cent excess silica which must be occuring hidden in

be known only from a study of their surface representatives, namely lavas and the rocks produced from them (magmas and lavas) due to solidification. However, volatile constituents which form an important part of magmas escape to considerable extent during solidification inside or when they are erupted at the surface, therefore the chemical composition of igneous rock obtained by their chemical analysis does not fairly represent the composition of magmas.

Practically all the known chemical elements are found to occur igneous rocks. Of these only nine elements-Oxygen, Silicon, Aluminum, Iron, Calcium, Sodium, Potassium, Magnesium, and Titanium-make up about 99.25 percent of the bulk composition of igneous rocks. All the other elements accounts for the remaining of 0.75 percent.

Clerk and Washigton computed the average composition of igneous rocks based on over 5000 analyses. The percentages by weight of different elements and in terms of their oxides are given respectively in column 1 and 2 of the following table. The average composition of magmas can be taken to be nearer to this.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

1. Define the term "Magma"?

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Chemical Composition of magmas :

Element	1	2	Percentage
	Percentage	Oxide	
Oxygen	46.59	SiO ₂	59.1
Silicon	27.72	Al ₂ O ₃	15.34
Aluminium	8.13	Fe ₂ O ₃	3.08
Iron	5.01	FeO	3.80
Calcium	3.63	MgO	3.49
Sodium	2.85	CaO	5.08
Potassium	2.60	Na ₂ O	3.84
Magnesium	2.09	K ₂ O	3.13
Titanium	0.63	H ₂ O	1.15
Phosphorous	0.13	CO ₂	0.102
Hydrogen	0.13	TiO ₂	1.050
Manganese	0.10	ZrO ₂	0.039
Sulphur	0.052	P ₂ O ₅	0.299
Barium	0.050	Cl	0.048

Table : 8.1 TABULAR CLASSIFICATION OF IGNEOUS ROCKS

	OVERSATURATED			SATURATED			UNDERSATURATED			
	Quartz + Felspars			Felspars			Felspars+ Felspathoids	Felspathoids	Mafic Minerals Predominant	
	Quartz	Predominant Orthoclase	Predominant Plagioclase	Predominant Alk Felspar (Or., Ab)	Predominant Sodalime Plagioclase	Predominant lime Plagioclase				
Felsic Mafelsic Mafic	Igneous Quartz Veins	Granite	Granodiorite (Tonallite)	Syenite	Diorite	Anorthosite Gabbro	Nepheline Syenite		Dunite Periodotite Picrite	
		Granopyre Felsite		Aplites Porphyries Lamprophyres		Dolerite Tachyryte				
		Rhyolite	Dacite	Trachyte	Andesite	Basalt Tachyryte	Phonolite	Nepheline Basalt Leucite Basalt	Olivine rich Basalts	
		Obsidian	Pitchstone							
Average Silica Percentage	90	72	66	59	5	48	54.5	43	41	

TABLE 8.1

8.4 CHECK YOUR PROGRESS - MODEL ANSWERS

- 1). Based on silica percentage the igneous rocks are classified into (i) Acidic (silica percentage is more than 66%) (ii) Intermediate (silica percentage is from 52-66%) (iii) Basic (silica percentage ranges from 45-52%) (iv) Ultra basic (silica percentage is less than 45%)
2. S.J. Shand (i). Oversaturated (ii) Saturated and (iii) Undersaturated
3. (i) Salic (ii) Famic. The salic minerals are light colour minerals and the Femic minerals are dark colour minerals.
4. Colour index. The Leucocratic rocks (less than 30% of mafic minerals). The Melenocratic rock (ranging 60-90%) of mafic minerals.
5. Rapid cooling, greater pressure.
6. The basis for tabular classification or (i) mineral assemblage (ii) biological occurrences.

8.5 MODEL EXAMINATION QUESTIONS

I. Answer the following questions in 30 lines each

1. Mention the basis of classification of igneous rocks and give their merits and demerits.
2. Explain how igneous rocks are classified based on the principle of saturation.
3. Give a brief account of the CIPW classification.
4. What are essential and accessory minerals, felsic and mafic minerals? How are they used in the classification of igneous rocks.

II. Answer the following questions in 10 lines each

5. How are igneous rocks classified based on geological occurrence ?
6. Explain briefly the tabular classification of Tyrrell.

8.6 GLOSSARY

Accessory minerals	: Minerals present in small quantities in an igneous rock
Acid Igneous rocks	: Igneous rocks with silica more than 66 percent.
Basic igneous rocks	: Igneous rocks with silica between 45 and 52 percent.
CIPW classification	: A chemical classification of igneous rocks put forward by Cross, Iddings, Pirson and Washington. (CIPW)
Colour Index	: Percentage of dark minerals presents in an igneous rock.
Effusive rocks	: Igneous rocks formed on the surface of the earth.
Essential minerals	: Minerals which occur in a large proportion in an igneous rocks and are diagnostic of that rock
Felsic minerals	: Minerals belonging to feldspar and felspathoids families and quartz and therefore rich in silicon and aluminium.

Felsic rocks	: Igneous rocks with colour index between 10 and 40
Femic minerals	: Minerals rich in iron and magnesium
Holofelsic rocks	: Igneous rocks with colour index less than 10
Hypabyssal rocks	: Igneous rocks formed at shallow depth or near the surface.
Hypermelanic rocks	: Igneous rocks with silica between 52 and 66 percent
Leucocratic rocks	: Light coloured rocks or rocks with less than 30 percent mafics
Mafelsic rocks	: Igneous rocks with colour index between 40 and 70
Mafic igneous rocks	: Same as basic igneous rocks.
Mafic minerals	: Ferro-magnesium minerals.
Mafic rocks	: Igneous rocks with colour index more than 70
Melanocratic rocks	: Dark coloured rocks, or rocks with 60 percent to 90 percent mafics
Mesocratic rocks	: Igneous rocks with 30-60 percent mafics
Norm	: A set of standard minerals used in CIPW classification
Oversaturated Igneous rocks	: Igneous rocks containing saturated minerals and free silica of magmatic origin
Plutonic rocks	: Igneous rocks formed under deep seated conditions.
Primary minerals	: Original minerals of igneous rocks
Silica minerals	: Minerals rich in silicon and aluminium
Saturated igneous rocks	: Igneous rocks containing only saturated minerals.
Saturated minerals	: Pyrogenetic minerals which are capable of existing in the presence of free silica of magmatic origin
Secondary minerals	: Minerals formed by weathering or metamorphism or circulating solutions.
Silicic igneous rocks	: Same as acid igneous rocks.
Ultrabasic igneous rocks	: Igneous rocks with silica less than 45%
Ultramafic igneous rocks	: Same as ultra igneous rocks
Undersaturated igneous rocks	: Igneous rocks containing unsaturated minerals
Unsaturated minerals	: Pyrogenetic minerals which are very rarely found in association with free silica of magmatic origin.
Volcanic rocks	: Same as effusive rocks.

BRAOU

BLOCK - III IGNEOUS PROCESSES

BRAOU

UNIT : 9 MAGMAS - THEIR BEHAVIOR

Contents

- 9.0 Objectives
- 9.1 Introduction
- 9.2 Chemical composition of Magmas
- 9.3 Physico-Chemical Nature of Magmas
- 9.4 Temperature of Magmas
- 9.5 Movement of Magmas
- 9.6 Primary Magmas - Chemical Composition
- 9.7 Origin of Magmas
- 9.8 Summary
- 9.9 Check Your Progress - Model Answers
- 9.10 Model Examination Questions

9.0 OBJECTIVES

In this unit, our main focus is to describe magmas - chemical composition, physico-chemical nature of magmas, temperature of magmas, primary magma and origin of magmas.

At the end of this unit you will be able to

- * define the term magma and its chemical composition
- * describe the physico chemical nature, temperatures of magmas
- * describe the primary magmas
- * describe the origin of magmas.

9.1 INTRODUCTION

It is difficult to define the term 'magma'. In a way acceptable to all petrologists. Defined very simply, magma is hot molten rock matter. It is the parent material of igneous rock. But magma has many other characters. The study of molten lavas, which are magmas poured out on the surface of the earth through volcanic vents, yields much information about the physical and chemical nature of magmas. The definition given by F.F. Grout which is cited below, gives a more complete picture of the magmas.

"Magma is defined as a natural fluid, generally very hot made up largely of a mutual solution of silicates, with some oxides, sulphides and water, held in solution by pressure, the matter may reduce the viscosity of the fluid, but heat is the main factor in its fluidity. The term magma may properly include fluids in which crystals may be residual from melting or in the process of growth, so long as the amount of solid matter does not give the aggregate notable rigidity".

9.2 CHEMICAL COMPOSITION OF MAGMAS

As it is not possible to study magmas directly, their physical and chemical nature can

be known only from a study of their surface representatives, namely lavas and the rocks produced from them (magmas and lavas) due to solidification. However, volatile constituents which form an important part of magmas escape to considerable extent during solidification inside or when they are erupted at the surface, therefore the chemical composition of igneous rock obtained by their chemical analysis does not fairly represent the composition of magmas.

Practically all the known chemical elements are found to occur igneous rocks. Of these only nine elements-Oxygen, Silicon, Aluminum, Iron, Calcium, Sodium, Potassium, Magnesium, and Titanium-make up about 99.25 percent of the bulk composition of igneous rocks. All the other elements accounts for the remaining of 0.75 percent.

Clerk and Washigton computed the average composition of igneous rocks based on over 5000 analyses. The percentages by weight of different elements and in terms of their oxides are given respectively in column 1 and 2 of the following table. The average composition of magmas can be taken to be nearer to this.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

1. Define the term "Magma"?

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Chemical Composition of magmas :

Element	1	2	Percentage
	Percentage	Oxide	
Oxygen	46.59	SiO ₂	59.1
Silicon	27.72	Al ₂ O ₃	15.34
Aluminium	8.13	Fe ₂ O ₃	3.08
Iron	5.01	FeO	3.80
Calcium	3.63	MgO	3.49
Sodium	2.85	CaO	5.08
Potassium	2.60	Na ₂ O	3.84
Magnesium	2.09	K ₂ O	3.13
Titanium	0.63	H ₂ O	1.15
Phosphorous	0.13	CO ₂	0.102
Hydrogen	0.13	TiO ₂	1.050
Manganese	0.10	ZrO ₂	0.039
Sulphur	0.052	P ₂ O ₅	0.299
Barium	0.050	Cl	0.048

Chlorine	0.048	F	0.030
Chromium	0.037	S	0.052
Carbon	0.032	(Ce, Y) ₂ O ₃	0.020
Fluorine	0.030	Cr ₂ O ₃	0.055
Zirconium	0.026	V ₂ O ₅	0.025
Nickel	0.020	MnO	0.124
Strontium	0.091	NiO	0.025
Vanadium	0.017	BaO	0.055
Cerium & Yttrium	0.015	SrO	0.022
Copper	0.010	Others	0.023
Other elements	0.034		
100.100		100.100	

9.3 PHYSICO - CHEMICAL NATURE OF MAGMAS

Looking from the point of view of their physico-chemical state, magmas may be considered as multicomponent systems. In this system there will be a liquid phase, and number of solid phases consisting of crystals of different minerals. In addition, there may be a gaseous phase also. The liquid phase may be considered as a solution of different components. As silicates are the most abundant minerals in igneous rocks, a large part of this liquid should consist of substances having the same chemical composition as silicates. We do not have definite knowledge regarding the physical constitution of silicates present in this liquid. It is probable that coherent structures composed of (SiO₄) and (AlO₄) groups in silicates minerals might be present in this liquid also. Free cation of Na⁺, Ca⁺, K⁺, Mg⁺, Fe⁺ etc. are also present in addition to these groups. The (SiO₄, AlO₄) groups may be linked together in suitable manner and compound groups like (SiO₂), (AlSi₂), (AlSi₃O₃) etc. may be formed. These compound groups bonded with suitable cations produce different silicates. All these reactions required for the formation of the compound groups depend upon the composition and temperature of the magma.

9.4 TEMPERATURE OF THE MAGMAS

It is possible to measure temperatures of lava flows, but temperatures of magmas cannot be measured directly. They are to be estimated from the melting points of minerals or rocks formed from the magmas. As magmas solidify at depth where pressure is high, minerals crystallise at temperatures much lower than their actual freezing points. Similarly under high pressure minerals melt at temperature much lower than their melting points. Hence this difficult to experimentally determine the freezing points or melting points of minerals formed at depth.

The temperatures of lava flows is estimated to be in the range of 900°C - 1100°C. Temperature will be higher for lavas containing large quantities of gases. Lavas of this type in Hawaii were observed to have temperature from 1153°C - to 1350°C.

But under the influence of high pressure at depth, magmas may exist in the liquid state at temperatures much lower than the temperatures of lavas. Based on the investigations made on certain minerals occurring in plutonic rocks, petrologists assume that the temperatures of

magmas in the crust may be ranging from 700°C to 1100°C

Check Your Progress

- Note :** a). Space is given below for writing your answer
b). Compare your answer with one given at the end of this unit.

2. What are the temperature ranges for magma and lava.

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9.5 MOBILITY OF MAGMA

Batholiths were formed in the earth crust due to crystallisation of magma at source, where as sill, dyke, lapolith etc, intrusive forms were formed after moving the magma to other rocks. This shows crystallisation of magma took place at source and also after movements to some other place. It indicates mobility to magma the main reasons for this novelty of magma are :

- i). The impact of gravitational pressure of crystal rocks on the magma reservoir.
- ii). Lateral thrusting and tecktonic movements.
- iii). The changes in the volume of magma due to addition or deletion of gases, partial crystallisation, changes in pressure and temperatures.
- iv). Assimilation of country rocks adjacent to magma reservoir.

9.6 PRIMARY MAGMAS

From the definition of term 'igneous rock', we know that all igneous rocks are formed due to the consolidation of magmas. In view of the fact, that igneous rock including a great variety of types which differ widely in the composition, one is tempted to assume one magma for each type of igneous rock. Petrologists do not consider the existence of so many magmas possible. Field and laboratory studies indicates that all types of igneous rocks could have formed from a limited number of magmas, may be two or even one. These are called **Primary magmas**. Washlstrom considers the primary magma as an uncontaminated and extensive mass of magma which existed at the beginning of a petrogenetic cycle. Petrologists have explained how most types of igneous rocks, in spite of their variations in compositions can be derived from these primary magmas through the operation of two processes known as **Differentiation** and **Assimilation**. These processes are explained in a later Unit.

The processes of differentiation and assimilation may lead to the production of many subsidiary magmas through the modification of the primary magmas. The magmas so produced are called **Derivative magmas**.

It is generally assumed that there are two primary magmas. This assumption is based mainly on the frequency with which different types of igneous rocks occur in the crust. It is commonly observed that granites and granodiorites and rocks of related composition from the greatest

batholiths, while basalts from enormous plateaus covering area of hundreds of thousands of square kilometers. Statistical data collected by Daly pertaining to the areas covered by these two categories of rocks in North America also prove their predominance. Based on these and similar observations two primary magmas-Granitic and Basaltic are considered to be responsible for the formation of the igneous rocks.

In 1851, Bunsen presumed the existence of two primary magmas Acid and Basic, and argued that different types of igneous rocks can be produced by the mixing of these two magmas in different proportions. Holmes and Harwood agreed with his view based on the studies carried out on Tholeiitic dykes, north of England.

Buddington argued that many primary magmas of different composition could exist. His view was based on the studies of meteorites and stratiform igneous rocks.

Based on geophysical observations, it is known that two layers Granitic and Basaltic exist in the earth's crust. One view is that these layers may produce granitic and basaltic magmas locally by remelting.

Some petrologists believe that only one primary magma, a magma of basaltic composition, exists and not two and that majority of the igneous rocks could form from this single primary magma. Bowen and his associates, after conducting experiments on silicate melts, proved that almost all types of igneous rocks can be derived from a magma of Basaltic composition.

At present, many petrologists believe in the existence of two primary magmas. Although it is theoretically possible to derive all types of igneous rocks from a single Basaltic magma, they argue that in view of the enormous quantities of granitic rocks a separate magma for them is to be presumed.

Composition of Primary Magma :

The approximate composition of these two magmas can be known from the average composition of Granodiorite and Plateau Basalt, given in the table below.

Oxides	Granodiorite	Plateau Basalt
SiO ₂	65.01	48.80
Al ₂ O ₃	15.94	13.98
Fe ₂ O ₃	1.74	3.59
FeO	2.65	9.79
MgO	1.91	6.70
CaO	4.42	9.38
Na ₂ O	3.70	2.59
K ₂ O	2.75	0.69
H ₂ O	1.04	1.80
TiO ₂	0.57	2.19
MnO	0.07	0.17
P ₂ O ₅	0.20	0.33
	100.00	100.00

It can be seen from the table that the Granite or Acid magma whose composition is considered to be nearer to that of Granodiorite contains in composition to the basaltic or basic magma, higher proportion of SiO_2 , Al_2O_3 , Na_2O and K_2O and lower proportion of Fe_2O_3 , MgO , CaO and TiO_2 . In other words granitic magma is rich in silica, aluminium and alkalies where as basaltic magma is relatively poor in these but rich in the oxides of Iron, Magnesium, Calcium and Titanium.

9.7 ORIGIN OF MAGMAS

There are two different views regarding the origin of primary magmas. It is generally believed that the earth was in a liquid state before it became a solid body by cooling and consolidation. Parts of this origin liquid which remained uncooled are considered of to be the primary magmas. This is one view. The other view is that primary magmas are produced by the local melting of rocks which may be caused by radioactive energy friction release of pressured transfer of rocks into hot interior of the earth and the upward movement of hot fluids.

9.8 SUMMARY

Magma is a hot, molten rock matter. It is the parent material to igneous rocks. If the molten rock matter lies in the earth crust it is called as **magma**, if the molten matter comes out to the surface, then it is termed as **lava**. The physical observations on magma is not possible. But their physical and chemical nature can be known only from lavas and rocks. The chemical composition of igneous rocks may represent to certain extent with the chemical composition of magma. All the known chemical elements are found in igneous rocks. But only nine elements namely Oxygen, Silicon, Aluminium, Iron, Calcium, Sodium, Potassium, Magnesium and Titanium constitutes about 99.25 percent of the bulk composition, the remaining all other elements accounts only 0.75 percent.

Magmas may be considered as multi component systems. As silicates are the most abundant minerals in igneous rocks, magmas might be the same chemical composition.

Temperatures of the magmas cannot be measured directly. They are to be estimated from the melting point of minerals and rocks formed from the magma. The temperature of lava flows is estimated to be in the range of 900°C - 1100°C . Many Petrologists assume that the temperatures of magmas in the crust may be in the range of 700°C - 1100°C .

All the igneous rocks are formed at different locations due to mobility of magma. The main reasons for the mobility are gravitational pressure, lateral thrusting and tectonic movements, changes in the volume of magma and Assimilation.

Primary magma is the original molten rock material. There are different opinions about this magma. Some petrologists are saying there is altogether only one primary magma. Some are told that there are two primary magmas. Ultimately, it indicates that the primary magmas are very few. In igneous rocks granite group of rocks and basalt group of rocks are dominated the other rocks. So majority petrologists are believing that there are two primary magmas. Some are saying primary magma is one that is basaltic in nature. Bowen, a noted petrologist and his associates after conducting experiments on melts, proved that almost all types of igneous rocks can be derived from a magma of Basaltic composition.

There are two different views, regarding the origin of magma. First one is the magma after crystallisation formed as rocks. Second thought is rocks due to radioactivity, pressure and temperature melted and formed the magma.

00 CHECK YOUR PROGRESS - MODEL ANSWERS

- 1). The molten rock material beneath the surface of the earth is known as magma. It is a parent material to all igneous rocks.
- 2). The usual range of temperatures for magma is 700°C - 1100°C and lava is 900°C - 1100°C .

9.10. MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines each.

- 1). What is magma ? Explain its physical and chemical characters.
- 2). Describe the chemical nature of primary magma.

II. Answer the following in about 10 lines each.

1. Explain the terms 'Primary Magma' and 'Derived magma'.
2. Explain the origin of Primary magma.

UNIT : 10 CRYSTALLISATION OF MAGMAS

Contents

- 10.0 Objectives
- 10.1 Introduction
- 10.2 Crystallisation of Unicomponent Magma
- 10.3 Crystallisation of Binary Magmas
- 10.4 Crystallisation of a Binary Magma or Binary System with Solid Solutions
- 10.5 Summary
- 10.6 Check Your Progress - Model Answers
- 10.7 Model Examination Questions
- 10.8 Glossary

10.0 OBJECTIVES

In this unit, we have presented the process of crystallisation of magmas - Unicomponent magma, Binary magmas and Binary system with solid solutions.

At the end of this unit you will be able to

- * describe the crystallisation of unicomponent magma
- * describe the crystallisation of binary magmas
- * describe the crystallisation of binary magmas with solid solutions.

10.1 INTRODUCTION

Magmas become igneous rocks by crystallisation or by solidification without crystallisation (formation of glass) with the loss of much of their volatile constituents. The essential difference between crystalline and glassy matter is that in a crystal the molecules or atomic groups are arranged in a definite manner and nearly packed, whereas in a glass they settled down without any recognizable pattern. A glass is an amorphous solid. The density of a glass is less than the density of the corresponding crystalline substance, because unit volume of glass contains lesser number of molecules than unit volume of crystalline matter due to lack of neat and close arrangement.

Our knowledge about the crystallisation of magmas is entirely based on Laboratory investigations of phase relationship in various silicate systems under controlled conditions. Most magmas are multi-component consisting of three, four or five principal constituents with a number of minor ones. Magmas with two or one principal components are also known, but uncommon. Experimental observations related to the crystallisation of two simple types of magmas a unicomponent magma and binary magma are discussed.

10.2 CRYSTALLISATION OF UNICOMPONENT MAGMA

A magma containing only one constituent is called a **Unicomponent magma**. The rock formed from it is called Monomineralic rock. Dunite, Pyroxenite, and Anorthosite are

examples for such rocks and they contain Olivine, Pyroxene and Plagioclase (labradorite) respectively.

The consideration of the crystallisation of a Unicomponent magma is practically the same thing as the consideration of the crystallisation of a single pure mineral from a melt of its own composition. A rock forming mineral which has been investigated is Augite. The crystallisation of Augite melt is studied with reference of two factors - the temperature and the power of spontaneous crystallisation, which is measured by the number of crystals initiated in unit volume of the magma in unit time. Crystallisation begins at the freezing point, but the rate is extremely slow till a temperature of 37°C below the freezing point is reached. Between 37°C and 55°C below the freezing point, the number of centres of crystallisation increases greatly reaching the maximum at 55°C . Afterwards, the number decreases rapidly until crystallisation ceases at 120°C below the freezing point. This phenomenon of crystallisation taking place not at the freezing point but at some temperature below it is called **Supercooling** or **Supersaturation**. The temperature ranges in which the generation of crystal is slow called the **Metastable region** and the temperature range in which it is rapid is called the **Labile region**.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

1). Power of spontaneous crystallisation means

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2). The temperature region which the generation of crystals are slow is called.....

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Grain Size of Igneous Rocks :- From the above observations, it is possible to explain the variation in grain size of igneous rocks. If the cooling of a magma is slow, it spends more time in the metastable region of crystallisation, in which only a few centres of crystallisation are initiated and these crystals grow to a large size. Sometimes, because of this slow cooling crystallisation of the magma may be completed in the metastable region itself and the resulting rock contains fewer, but larger crystals. Hence, slow cooling produces coarse grained textures. On the other hand, if the cooling is rapid, the magma crosses the metastable region in which a large number of crystals are initiated and the resulting rock is therefore fine grained.

Under conditions of very rapid cooling of a magma might pass through both the metastable and labile regions almost without crystallisation. As the possibility of crystallisation ceases at some temperature below the freezing point 1200°C in the case of augite as described above, the magma solidifies as glass. However, glasses being greatly supercooled liquids in which the molecules or atomic groups are not arranged in any definite order as in crystals, they are unstable. They are slowly transformed into crystalline matter under the influence of heat, pressure and circulating solutions due to igneous intrusions. This process of transformation of glass to crystalline matter is called **Devitrification**.

It is to be remembered that rate of cooling is not the only factor that controls the grain size of igneous rocks. It is of course the chief factor. Other factors include the number of constituents in the magma, the concentrations of the constituents present and viscosity of the magma.

The magmas composed of several constituents, the rate of crystallisation of one constituent is increased by the presence of the other and hence other things being equal, a multicomponent magma gives rise to a rock of finer grain while a magma with one of two constituents gives a coarse grained aggregate. For example, between Gabbro and Anorthosite, the former is relatively fine grained as it is multicomponent while the later composed of only one mineral is coarse-grained.

Coming to the factor of molecular concentration of the constituents present, other factors being equal constituents in the very small amounts, like the molecules of Apatite, Zircon etc., produce smaller crystals because the material available for their growth is very limited. On the other hand, constituents present in large amounts, produce large crystals.

The growth of crystals in a magma requires diffusion of molecules towards their respective centres of crystallisation. High viscosity of magmas hinders this diffusion and hence the growth of crystals and as a consequence the rock produced fine grained. Rhyolitic magmas are much more viscous than basaltic magmas and therefore rhyolites are more fine grained than basalts.

The presence of water and other fluids in magmas greatly reduce its viscosity and hence magmas rich in these constituents produce larger crystals.

Check Your Progress

Note : a). Space is given below for writing your answer.

b). Compare your answer with the one given at the end of this Unit.

3). Devitrification is a process which gets speeded up at temperature and pressure.

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10.3 CRYSTALLIZATION OF BINARY MAGMAS OR BINARY SYSTEM

The crystallisation of a Binary magma or a Bi-component magma consisting of two independent constituents may be illustrated by using the Temperature-Composition Diagram. In this diagram the abscissa represents composition and the ordinate temperature.

Let us assume that a binary magma consists of two components A and B. Because A and B can be mixed in any proportion, many binary magmas of A and B can exist, like for example, a magma with 90 per cent. A and 10 per cent B (represented A 90, B 10), a magma with 80 percent A and 20 per cent B (A 80, B20) and so on. All possible binary magmas of A and B are represented on the abscissa in the (Fig. 10.1)

Let the freezing point of A be T that is, a magma consisting entirely of A (A100 B0) would crystallize at T (represent by M on the diagram). Similarly let the freezing of B be T which means that a magma composed entirely of B (A0 B100) would crystallise at T (represented by N on the diagrams).

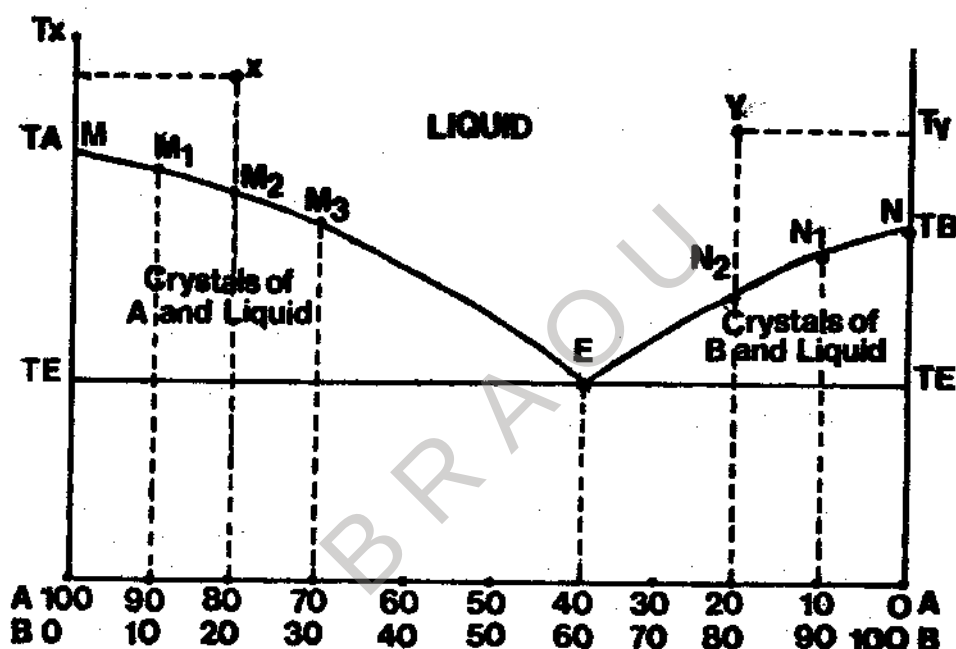


Fig 10.1 Binary System

While discussing about the crystallisation of any binary magma the fundamental principle to be kept in mind is that the specific properties of each constituent are modified in the presence of the other. Most important is that the freezing points are lowered. In the present case, the freezing point of A magma is taken as T (point M). The addition of 10% of B to the A magma, producing the binary magma of composition A 90 B 10 causes a certain lowering of the freezing point which is now represented by M1. The addition of 20 percent of B causes a further lowering of freezing point to M2 and so on. A similar lowering of freezing point is produced in B magma by the addition of A and it is represented by the point N1, N2 etc., When these points are joined we get the curves ME and NE meeting at E. These curves represented the freezing points of all possible mixture of A and B. The curves ME and NE are called **freezing point curves** or **saturation curves** of liquids.

Any point on the diagram indicates the temperature and the composition of the magma. For example, the point 'X' indicates the magma A80 B 20 at a temperature of T_x . Any change in the composition, temperature of both is indicated by movement of the point. Thus horizontal movement means a change of composition at constant temperature vertical movement indicates change in temperature at constant composition and diagonal movement means change in both temperature and composition. Another point to be noted in this context is that magmas indicated by points above the curves ME and NE are unsaturated Magmas represented by points on the curve NE are saturated with B and ME are saturated with A while those indicated is by points on the curve. The point E indicates a magma which is saturated with both A and B when crystallisation beings crystals of the constituents with which the magma is saturated at any particular temperature, separate out first.

With the help of the diagram, let us now understand the crystallisation A80 B 20 at the temperature of T^0_x . This is represented by the point 'X' on the diagram. As the temperature falls without change of composition the point X moves vertically downwards until the point M2 is reached. At M2 the magma is saturated with A and therefore A beings to crystallise. As crystallises, the magma becomes poorer in A component and relatively enriched in B component, with a consequent fall in the freezing point along the curve ME. Hence the point moves down the curve until the point E is reached, the diagonal movement indicating both the lowering of temperature and the change in composition. At this magma becomes saturated with B also and both A and B crystallise together at constant temperature until the magma is exhausted. This occurs when the temperature is T_x and the magmatic composition is A40 B 60. Similiarly we can trace the crystallisation of the magma A 20 B 80 at a temperature of T^0_y (represented by the Y^0). As the temperature falls the point moves vertically down and touches the point N_2 on the curve NE. At this point the magma is saturated with B and so B starts crystallising with the consequent enrichment of A in the magma and lowering of the freezing point. The point moves down the curve NE, till the point E is reached when A also starts crystallizing.

From the above two examples, we can see that the crystallisation of a binary magma takes place in three stages : 1) Cooling of magma prior crystallisation 2). Crystallisation of one component which is in excess of certain standard proportion (A40 B60 in the above case) with falling temperature and 3). Simultaneous crystallisation of both components at constant temperature.

The point E in the diagram is called the **Eutectic**. The standard proportion of the two constituents and the temperature favouring their simultaneous crystallisation are respectively called the Eutectic composition and the Eutectic temperature. A binary magma with Eutectic composition crystallises only in two stages unlike the other binary magmas which crystallise in three stages. The two stages are : 1). Cooling of magma prior to crystallisation and 2) Simultaneous crystallisation of both constituents at constant temperature.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

4). Define Eutectic point ?

10.4 CRYSTALLISATION OF A BINARY MAGMA OR BINARY SYSTEM WITH SOLID SOLUTIONS.

In the above discussion of the crystallisation of a binary magma, it has been assumed that the constituents are of unchanging composition and independent of each other. But most of the pyrogenetic minerals are not of this character. They consist of two or more members, which are isomorphous and miscible in all proportion in the solid state producing, homogenous crystals, such crystals are called **mix crystals or solid solutions**. Plagioclase feldspars are a good example for this and their formation from magmas follows a course, totally differ from that of independent constituents.

To understand and the formation of mix crystals, we may consider briefly the crystallisation of plagioclase feldspars, from a binary magma composed of the isomorphous Albite and Anorthite. The crystallisation can be represented, as in the earlier case, by means of a temperature composition diagram Fig. 10.2.

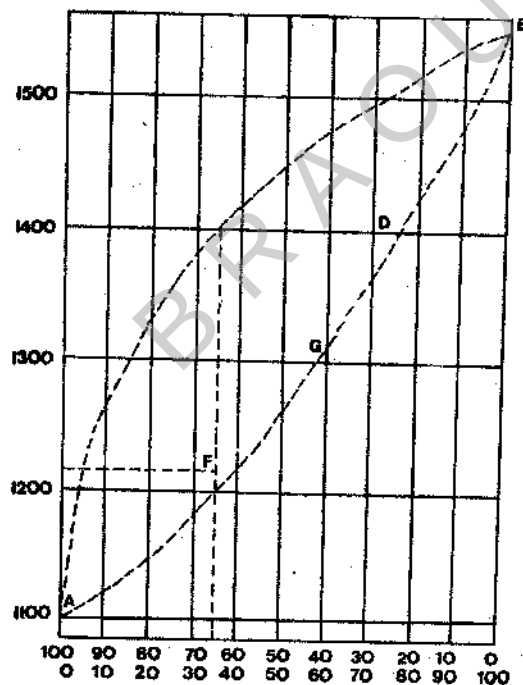


Fig. 10.2 Crystallisation of plagioclase feldspars

In mix crystals there is only one freezing point curve instead of two present in the case of non-mixing constituents and this is called the Liquids. In this, a melting point curve called

the **solidus** and this does not coincide with the freezing point curve at any given temperature crystals of a certain composition. The compositions of the crystals and the liquid which are in equilibrium with each other at a given temperature can be known from the solidus and the liquidus respectively. For example, at 1400° C, the composition of the liquid is indicated by 'C' and composition of the crystals is indicated by 'D'. As the temperature falls, the composition of the crystals changes appropriately by reactions with the liquid so to maintain the equilibrium, at the lower temperature. Thus there is a continuous change in the composition of the crystals with fall in temperature. When crystallisation ultimately comes to an end. The crystals formed have the same composition as the original liquid.

Under conditions of rapid cooling the early formed crystals may not change over as quickly as the temperature falls and as a result zones are formed around a Kernel, each zone having a composition appropriate to the temperature of its formation.

Investigations were carried out on the crystallisation of many binary systems comprising different silicates, the discussion of which is not wanted here. These investigations have helped petrologists in understanding the modes of formation of different types of igneous rocks.

10.5 SUMMARY

Magmas become igneous rocks by crystallisation. Solidification of magma with crystallisation gives rise to crystals. Solidification without crystallisation is formation of glass. Crystallisation may be complete or incomplete. If crystallisation is complete crystals appear completely, otherwise glass material may appear.

A magma containing only one constituent is called a Unicomponent magma. The rock formed from this is called Monomineralic rock. Most magmas are multi component consisting of three, four or five constituents, and gives more number of rock types.

The crystallisation of a single mineral from a melt of its own composition comes under crystallisation of unicomponent magma. In this, the temperature and power of spontaneous crystallisation play a vital role. Crystallisation starts at freezing point and this process is called super cooling. The grain size in igneous rocks depends on rate of cooling. If the rate of cooling is slow larger crystals will form, if it is faster glassy matter will be formed. This glass matter some times changes into crystals. This process of transformation of glass to crystals is called **Devitrification**. The other factors that controls the grain size in igneous rocks are number of constituents of the magma, the concentrations of the constituents present and the viscosity of the magma.

The crystallisation of binary magma takes place in three stages (1). Cooling of magma prior the crystalliation (2). Crystallisation one component, which is in excess than other (3). Simultaneous crystallisation of both components at constant temperature. If the Bi component magma consists of two or more numbers which are isomorphous and miscible in all proportion in the solid state, then the magma produces homogeneous crystals. Such crystals are called mixed crystals or solid solutions. This can be clearly seen in the crystallisation of the plagioclase feldspar, from a binary magma composed of the isomorphous Albite and Anorthite. In the silicates there are many binary component crystallisations.

10.6 CHECK YOUR PROGRESS - MODEL ANSWERS

- 1) Number of crystals generated in unit volume in unit time.
- 2) Metastable region
- 3) Increase
- 4) The constant proportion in which the two constituents simultaneously crystallise is called Eutectic point.

10.7 MODEL EXAMINATION QUESTIONS

A. Answer the following questions in 30 lines

1. Explain the crystallisation of Unicomponent magma ?
2. Explain how the rate of cooling of magma influences the grain size of igneous rock. What are the other factors which control the grain size?
3. Give an account of the crystallisation of a binary magma with two independent constituents?
4. Explain how the course of crystallisation of a binary system with two independent constituents?

B. Answer the following questions in 10 lines

1. What are the differences between crystal and glass?
2. Explain the following terms.
 - i). Devetrification
 - ii). Eutectic
 - iii). Liquidus and Solidus

10.8 GLOSSARY

Binary magma	:	Magma containing two constituents.
Devetrification	:	Process of transformation of glass to crystalline matter.
Eutectic	:	The standard proportions of the two constituents present in a binary magma and the temperature favouring their simultaneous crystallisation.
Labile region	:	Temperature range in which generation of crystals is rapid.
Liquidus	:	Freezing point curve or saturation curve
Metastable region	:	Temperature range in which generation of crystals is slow.

- Mix crystals : Homogeneous crystals produced by the mixing in the solid state of two or more isomorphous constituents.
- Solid solutions : Same as mix crystals.
- Solidus : Melting point curve
- Super cooling : Crystallisation of magma taking place not at the freezing point but at some temperature below it.
- Unicomponent Magma : Magma containing only one constituent.

* * *

UNIT : 11 ORIGIN OF IGNEOUS ROCKS

Contents

- 11.0 Objectives
- 11.1 Introduction
- 11.2 Reaction Principles
- 11.3 Variations in Igneous Rocks
- 11.4 Differentiation
 - 11.4.1 Practical Crystallization
 - 11.4.2 Liquid Immiscibility
 - 11.4.3 Gaseous Transfer
- 11.5 Assimilation
- 11.6 Summary
- 11.7 Check Your Progress - Model Answers
- 11.8 Model Examination Questions
- 11.9 Glossary

11.0 OBJECTIVES

This unit discusses about the origin of igneous rocks the processes and sub processes.

At the end of this unit, you will be able to

- * describe the reaction principles or series
- * describe the variation igneous rocks.
- * describe the process differentiation and assimilation.

11.1 INTRODUCTION

In the previous units it has been mentioned that the origin of different types of igneous rocks could be traced to two primary magmas. We shall examine in this Unit the basic principles behind the processes responsible for the evolution of the diverse types of rocks from these primary magmas.

11.2 REACTION PRINCIPLES

Investigations carried out on the modes of crystallisation of magmas of varying number of components reveals that two basic reactions in magmas are responsible for the formation of pyrogenetic minerals.

Minerals formed as parts of Eutectic systems in magmas are independent of each other and their composition do not change. The process of mix-crystal series are in reaction with the liquid from which they are forming and their composition are continuously modified with falling temperature. Bowen called such reactions as continuous reactions and the minerals related to each other through continuous reaction constitute a **continuous reaction series**. Plagioclase feldspars are an example for this.

Reactions, relations of another type also exists in magmas in this, early formed minerals react with the liquid only at certain temperature to produce minerals of different composition and crystal structure. Olivine, for example may be transformed into Pyroxenes or Pyroxene into Amphibole at certain suitable temperature. Such abrupt changes constitute what Bowen called a Discontinuous reaction and the minerals formed by such reactions, when arranged in the proper order of succession give rise to **discontinuous reaction series**. Two minerals related by this type of reaction are called **Reaction pair**. These minerals do not have a definite melting point; on heating they break up into some other minerals plus liquid. This phenomenon is known as **Incognuent melting**. Orthoclase on heating breaks up into Leucite plus liquid and clinoenstatite breaks up into olivine plus liquid. It is possible that a mineral of Discontinuous reaction series may itself be a number of a Continuous reaction series and both types of reaction series may occur together in the same magma.

Bowen distinguished the commonly occurring Pyrogonetic minerals as belonging to Continuous reaction series and Discontinuous reaction series and represented them in the following scheme, which is called **Bowen's reaction series, Reaction principle or Reaction relation**. In this arrangement each minerals supposed to react with the magmatic liquid and produce the mineral placed beneath it.

Discontinuous Series	Continuous Series
Olivine	Calcic plagioclase
Mg-Pyroxene	Clac-alkali plagioclase
Ca-Pyroxene	Alkali-calc plagioclase
Amphibole	Alkali-calc plagioclase
Biotite	Alkali-plagioclase
	Potash felspar
	Muscovite
	Quartz

Fig. : 11.1 Bowen's Reaction Principle

The minerals placed on the left-hand side constitute a Discontinuous reaction series and those on the right-hand side a Continuous reaction series.

Beginning at the upper end of the series in the more basic magmas, at first two distinct reaction series, the continuous series of the plagioclases and the discontinuous series Olivine-Pyroxenes-Amphiboles are seen to occur. In the later stages, they become less distinct and a certain amount of interlocking begins and they finally merge into a single series. This is shown diagrammatically by a convergence of the two series.

It is to be noted that the minerals given at the end after the convergence of the two series are on a different footing from the others. It cannot be said that Biotite and Alkali Plagioclase react with any liquid to produce potash felspar. On the other hand these last minerals are formed from the liquid which is left over the final stage, and it is to be understood that they are placed in this scheme simply in the order of their formation. Bowen's reaction principle is of great significance in the discussion about the origin of igneous rocks.

As crystallisation of magma proceeds, the number of crystals increases and they form of down. Separation of crystals in this manner is called **Gravitational differentiation**.

Several observers have noted the sinking of crystals in lavas. The sinking or rising of crystals in a magma depends on the specific gravity and viscosity of the magma. All crystals whose specific gravity is higher than that of the magma sink to the bottom. Minerals like olivine and pyroxene which form in the early stages have higher specific gravity and therefore sink

1. by gravitational sinking of earlier crystals and
2. by filtration of the liquid by earth pressure

Apart from localisation of crystals explained above, differentiation in magmas may also take place due to localised accumulation of crystals, and such accumulation of crystals and their separation from magma may take place in two ways.

The most important process in magmatic differentiation is the fractionation of magma due to crystallisation. The process where by magmas yield contrasted fractions by separation of crystals from the liquid while cooling is called **Fractional crystallisation or Crystallisation Differentiation**. In a way beginning of crystallisation in a cooling magma is indeed the beginning of differentiation. Crystallisation may be localised due to diffusion and convection of molecules. In the magmas, crystallisation usually starts near the margin because the temperature is less. Molecules of the minerals crystallising first from a magma diffuse towards the margins from all parts of the magma. Thus minerals crystallising early may be concentrated near the margins and those crystallising late may be concentrated inside. As mafic minerals form earlier than felsic minerals, igneous masses may show concentration of mafic minerals around a central part consisting of felsic minerals, thus showing evidence of differentiation.

11.4.1 Fractional Crystallisation

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3. Define the Differentiation process.

Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

Check Your Progress

1. Fractional Crystallisation
2. Liquid immiscibility
3. Gaseous transfer

Magmatic differentiation is believed to take place in many ways, important of which are

Differentiation takes place normally in two stages. In the first stage contrasted parts such as crystals, sub-magmas or immiscible liquids are formed due to physico-chemical processes operating during the solidification of magmas. In the second stages these parts are separated from each other and segregated in different regions of the magma chamber or as distinct masses.

Magmatic differentiation is the process whereby a broadly homogeneous magma breaks up into unlike fractions which ultimately form rocks of different compositions. These rocks may form separate bodies.

11.4 MAGMATIC DIFFERENTIATION

An important task of petrologists has been to explain these variations in igneous rocks. It was mentioned in the previous unit that two primary magmas are supposed to exist and that different types of igneous rocks could be derived from these two magmas. Petrologists describe the origin of different rock types from a single magma or two magmas and the variations found in single masses due to two causes Differentiation and Assimilation.

Field and Laboratory studies on igneous rocks show that their composition varies widely. These variations may be seen in a number of related but separate intrusions or extrusions or they may be seen within a single rock mass. Some igneous masses are uniform in composition and texture; in other significant distribution of contrasted parts with regard to the margins is noticed. These contrasted parts may be arranged symmetrically or asymmetrically with regard to the margins of rocks.

11.3 VARIATIONS IN IGNEOUS ROCKS

2. When a mineral on heating, breaks up into some other mineral and liquid, then the melting is known as

1. What is a Discontinuous reaction series?

Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

Check Your Progress

loose mesh or framework with residual liquid in the interstices. If this whole mass is deformed at this stage due to simple downward pressure or lateral earth pressure, the crystal mesh will be slowly crushed down and the interstitial liquid is squeezed out. The liquid tends to move towards the region of low pressure and may form bands in the least affected portion of the mesh or may form a separate intrusive body. This process is called **Filteration differentiation**.

If we imagine the above processes to be operating in a magma which is crystallising, it is possible to explain based on Bowen's reactions relation, how different rocks types can be produced from this magma. For example, if the primary basaltic magma crystallises inside the earth without undergoing differentiation, it may produce a gabbro having olivine, pyroxene and calcic plagioclase. On the other hand the same magma may give rise to such varied rock types as Dunite, Gabbro, Diorite, Tonalite, Granodiorite or even Granite, if minerals crystallising from the magma separate from it at different stages, for example separation of olivine crystals before they change over to pyroxene produces Dunite. Similarly separation of pyroxene crystals produces Pyroxenite and Calcic plagioclase crystals Anorthosite. Separation of Olivine and Magnesium pyroxene together, leads to the formation of the Periodotite, addition of plagioclase to these at a later stage produce Gabbro. At the end the residual liquid consisting of alkali-felspar and Quartz with a little biotite may produce a granite.

11.4.2 Liquid immiscibility

It is observed that mixture of aniline and water which is perfectly homogeneous above 166° C, separates into fractions of aniline as mixed with some water and water admixed with some aniline, below that temperature, Petrologists believe that, in a similar way with fall in temperature, separation may take place in magmas, producing immiscible liquid fractions.

11.4.3 Gaseous Transfer

Fenner proved that volatile substance present in magmas play an important role in magmatic differentiation. Gases react with magmas, take some substances into solution and precipitate some other substances. These reactions depend on the temperature. Volatile substances present in the magma reservoir travel upwards from the bottom of the reservoir. A part of these volatile escapes through volcanoes, while another part enters into the rocks surrounding the reservoir. These volatiles carry a number of substances in a dissolved state from one place to another, thus causing Differentiation of the magmas.

11.5 ASSIMILATION

Assimilation is another factor which brings about diversity in igneous rocks. Assimilation is defined as the process whereby foreign rock material, either in liquid or in solid form is incorporated in a magma. Rocks produced through assimilation are called **Hybrid rocks**.

Some petrologists believe that the mixing of the two primary magmas in different proportion gave rise to so many types of igneous rocks.

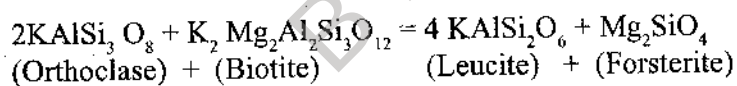
Reaction between magma and the wall rock is a normal features of igneous intrusions. In the course of such reactions certain minerals in the wall rock become partially or completely digested by the magma thus producing a change in its composition. The end product of the crystallisation of such a magma is contaminated igneous rock which is made up of material

contributed partly by the original magma and partly by the wall rock.

Bowen suggested that reactions between the magma and the wall rock referred to above, depend on the pressure, temperature and composition of the magma as also the composition of the wall rock. A magma can digest a rock only under certain conditions. It has been mentioned in the previous Unit that the component with which a magma is saturated at a particular temperature starts crystallising from that magma at that temperature. When a mineral in the reaction series is crystallising from a magma, it is to be understood that the magma is oversaturated with the minerals in the series and is unsaturated with those placed below it. At such a stage the magma will not be able to assimilate minerals or a rock containing minerals with which it is oversaturated. For example, a granitic magma from which biotite is crystallising, cannot assimilate olivine, pyroxene or amphibole or rocks containing these minerals, but it can react with them and produce biotite.

Petrologists explained the origin of some important rock types based on the changes produced in the composition of magmas by assimilation of foreign rocks. For example, we may consider the origin of alkaline rocks. These rocks contain minerals of low silication, like Leucite and Nepheline. Based on the small proportion of these rocks in the crust it is not possible to assume a separate alkaline magma to be existing. Daly after studying the mineralogical and chemical composition of these rocks and their mode of occurrence, came to the conclusion that these are formed due to the interaction of a basaltic magma with calcareous sediments.

While concluding this discussion on the origin of igneous rocks, it is to be mentioned that a magma of a certain composition may give rise to two different sets of minerals under different conditions of temperature and pressure as well. For example, a magma of suitable composition may give rise to Orthoclase and Biotite under high pressure and low temperature and to Leucite and Forsterite under low pressure and high temperature. The former combination of minerals is formed deep inside the earth and the latter combination on the surface. The total compositions of orthoclase plus biotite and leucite plus forsterite, the minerals in both cases have been taken in a fixed molecular ratio are the same as shown below :

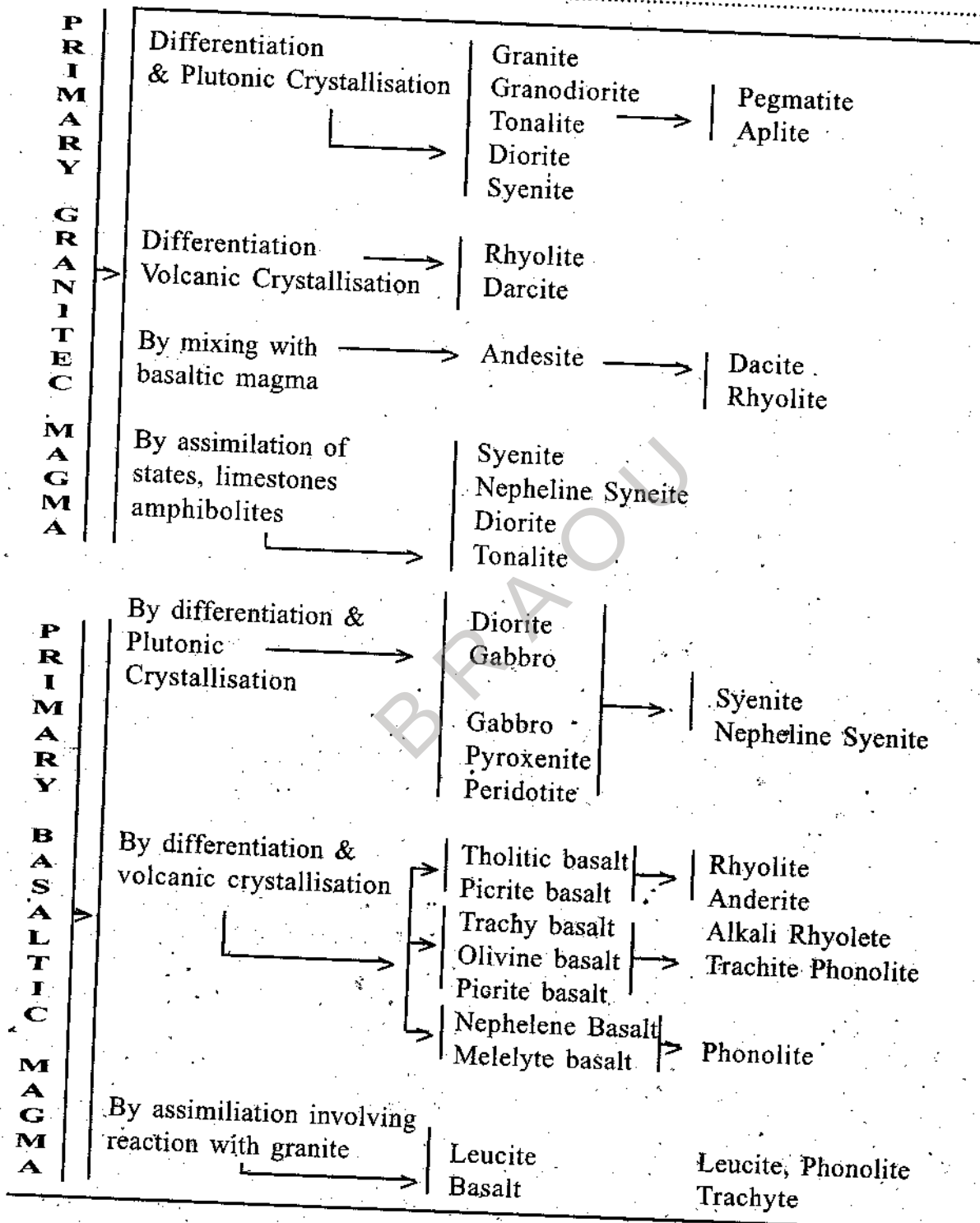


The minerals on the left hand side produce mica syenite, a plutonic rock while those on the right hand side produce Leucite basalt, a volcanic rock.

In the foregoing discussion the broad principles based on which the origin of diverse igneous rocks from one or two primary magmas can be explained, have been considered. As discussion about the genesis of individual rock types is not in the scope of the present Unit, an outline of the probable courses of evolution of some important igneous rock types from the primary Granitic and Basaltic magmas is given at the end of this Unit. This outline, is a simplified version of the one given in *Igneous and Metamorphic petrology* written by F.J. Turner and J Verhoogen, and prepared on the basis of data collected from the studies of the chemical, mineralogical and textural characters and modes of occurrence of igneous rocks, the result of the experiments conducted on silicate melts and a series of Geophysical and Geochemical investigations.

Check Your Progress

- Note : a). Space is given below for writing your answer.
 b). Compare your answer with the one given at the end of this Unit.
 4). What is Assimilation ?



11.6 SUMMARY

Reaction principle, differentiation, assimilation are the three main processes involved in the formation of igneous rocks from the magma. 'Bowen' a noted petrologist proposed the 'Reaction principle'.

A mineral of a mix-crystal series is in continuous reaction with the liquid from which it has crystallised, and its composition is continually being modified with falling temperature. Bowen called such reactions as continuous reactions and the minerals related through this process are continuous reaction series. The another type of reaction relation also occurs in the magmas in which the early formed minerals react with the liquid at a certain temperature to form a mineral of different chemical composition. The two minerals thus related are called Reaction pair. The process is called Discontinuous reactions and the minerals related this process are called Discontinuous reaction series.

In the basic magmas, the continuous reaction series of plagioclase and the discontinuous series, Olivine - Pyroxenes - Amphiboles are seen to occur. In the later stages, they finally merge and gives micas and quartz. Bowen's reaction principle has great significance in the origin of igneous rocks.

Field and Laboratory studies on igneous rocks show that their composition varies widely. These variations are mainly due to differentiation and assimilation.

The process of breaking of homogeneous magma into unlike fractions which ultimately forms rocks is called **Magmatic Differentiation**. This process takes place in two stages, Magmatic Differentiation is believed to take place through Fractional crystallisation, Liquid immiscibility, and Gaseous transfer.

The process where by magmas yield contrasted fractions by separation of crystals from the liquid while cooling is called Fractional Crystallisation. The minerals crystallising early may be concentrated near the margins and those crystallising late may be concentrated inside. Due to this, mafic minerals formed certain encircles felsic minerals at the centre. The other methods are gravitational sinking of early formed minerals and filtration differentiation. Liquid immiscibility is the other process in which the early formed minerals may be separated in magmas due to fall of temperature. In gaseous transfer mechanism, the gases react with magma and take some substances into solution and precipitates some other substances.

Assimilation is another mechanism which brings diversity in igneous rocks. In this, the foreign rock material either the liquid or solid form is incorporated in the magma rocks thus produced are called Hybrid rocks. Some petrologists believe that the mixing of the two primary magmas in different proportions gave rise to so many types of igneous rocks. Petrologists explained the origin of some important rock types based on the changes produced in the composition of magma by assimilation of foreign rocks.

11.7 CHECK YOUR PROGRESS - MODEL ANSWERS

- 1). Minerals formed by reaction when arranged in a proper order give rise to a discontinuous series.

- 2). Incongruent melting
- 3). Differentiation is the process where by a homogenous magma splits into heterogeneous compounds which on consolidation give rise to different types of igneous rocks. The process take place by three sub processes. (i). Fractional crystallisation. (ii). Liquid immiscibility. (iii). Gaseous transfer
- 4). Assimilation is defined as the process where by foreign rock material either in liquid or in solid form is incorporated in a magma.

11.8 MODEL EXAMINATION QUESTIONS

A. Answer the following questions in 30 lines.

1. Explain the nature of Continuous and Discontinuous reactions in magmas.
2. Give a detailed account of the Reaction principle.
3. What is Magmatic Differentiation ? How does it takes place ?
4. What is Assimilation ? Explain the conditions under which foreign rock fragments can be assimilated by a magma.

11.9 GLOSSARY

Assimilation	:	A process whereby foreign rock material, either in liquid or in solid form, is incorporated in a magma.
Bowen's Reaction Series	:	A scheme showing the arrangements, in the order of their formation, of common rock-forming pyrogenetic minerals produced by Continuous and Discontinuous reactions in magmas. This was put forward by N.L. Bowen.
Continuous reaction	:	Reaction between an early formed mineral and the magma taking place continuously with fall in temperature and leading to continuous modification in the composition of the mineral, but without any change in its structure.
Continuous Reaction Series	:	Minerals related through continuous reaction.
Crystallisation differentiation	:	Process whereby magmas yield contrasted fractions by separation of crystals from liquid, while cooling.
Discontinuous reaction series	:	Minerals related through discontinuous reaction.
Filtration differentiation	:	Process involving the squeezing out of the interstitial liquid from a mesh of crystals, thus leading to differentiation.

Gravitational differentiation	: Process involving the sinking to the bottom in a magma of crystals with higher specific gravity, thus leading to separation of crystals from the liquid.
Hybrid rocks	: Rocks produced through assimilation.
Incongruent melting	: The phenomenon of a mineral, which has no definite melting point, breaking up on heating, into some other mineral plus liquid.
Liquid immiscibility	: A process of magmatic differentiation involving the separation of the magma into two or more immiscible liquid phases at a lower temperature.
Magmatic differentiation	: Process whereby a broadly homogeneous magma breaks up in to unlike fractions.
Reaction Pair	: Two minerals related to discontinuous reaction.
Reaction Principle	: Same as Bowen's reaction series.
Reaction Relation	: Same as Bowen's reaction series.

* * *

UNIT : 12 DESCRIPTION OF IGNEOUS ROCKS

Contents

- 12.0 Objectives
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- 12.2 Plutonic rocks
 - 12.2.1 Granite, Granodiorite and Diorite
 - 12.2.2 Syenite, Nephelene syenite and Related Alkaline rocks
 - 12.2.3 Gabbro, Anorthosite, Pyroxenite, Peridotite and Dunite
- 12.3 Hypabyssal Rocks
 - 12.3.1 Aplite, Pegmatite, Dolerite and Lamprophyre
- 12.4 Volcanic rocks
 - 12.4.1 Rhyolite and Dacite
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12.0 OBJECTIVES

In this unit, we attempted to describe the different types of igneous rocks-Plutonic, Hypabyssal and Volcanic rocks

After having completed this unit, you will be able to

- * describe the different types of igneous rocks
- * list the essential minerals of rocks
- * describe the petrogenesis of important igneous rocks

12.1 INTRODUCTION

A large number of rock types have been recognised among the igneous rocks. Only a few of these are common and abundant in the earth's crust. The great majority comprise of rock types that differ from the common ones only in a relatively minor way with regard to their mineralogical composition and textural characters. There are some rock types which are very restricted in their occurrence and therefore of only academic interest to specialists in systematic Petrography.

The commonly occurring standard types of igneous rocks are described in this unit. Rock types which show some resemblances in composition and texture and from a natural association are grouped together to indicate their probable genetic relationship.

12.2 PLUTONIC ROCKS

Plutonic rocks were formed at greater depth in the earth's crust. In this group the rocks were crystallised at slow rate of cooling. So crystallisation may be completed, and these crystals are well developed and bigger in size.

12.2.1 Granite, Granodiorite and Diorite

These three rock types are characterised by the presence of Quartz, Orthoclase, Plagioclase and number of accessory minerals. They show gradual variations in the amounts of felspar minerals.

Granite contains abundant quartz (10 to 40%) and felspars. Both Potash felspar and Sodic plagioclase are usually present, the potash felspar always dominating. From Granite, Granodiorite to Diorite the proportional amounts of quartz and potash felspar decrease, while that of sodic plagioclase increases. In Granodiorite, while quartz is still abundant as in Granite, but in lesser quantity, sodic plagioclase predominates over potash felspars. When these two felspars occur in approximately equal amounts the name **Damellite** is given. Granodiorite in which plagioclase is greatly in excess of orthoclase are called **Tonalites**. With the gradual decreases of quartz and orthoclase to practical disappearance, Tonalite passes over to Diorite, with accessory Quartz it is called **Quartzdiorite**. It is to be noted that from Granite to Diorite, the plagioclase becomes less sodic, more calcic. In Granite, the plagioclase is usually Albite or Oligoclase, in Granodiorite it is lime oligoclase or Andesine and in Diorite it is usually Andesine.

Coming to the accessory minerals they are most often Biotite and Hornblende, Biotite occurring most at the Granite and Hornblends at the Diorite end. Pyroxenes are comparatively rare. Magnetite, Aplites, Zircon, Ilmenite etc. may occur as minor accessories. The collective proportion of mafic minerals increases from Granite to Diorite. These rocks are mostly coarse grained and Hypidiomorphic, Graphic and Porphyritic texture are seen in some Granites.

Granite, Granodiorite, Tonalite and Diorite from a natural association and occur extensively in the batholiths of eroded fold mountain ranges and in continental shield regions of the earth's crust. They may occur as stock and bosses or as minor intrusions like laccoliths and ring dykes. While granite and granodiorite form the main part of the batholiths, quartz diorites and diorites tend to occur as their marginal facies.

Among the rocks of this series, the Granites are unique because they are the most abundant of all plutonic rocks. Beside the essential mentioned above, granites may contain many characteristic minerals depending upon their chemical composition. Among these Biotite, Muscovite, and Lithium, Mica, are most common and Hornblende Sodic amphiboles like Riebeckite may be found in alkalic granites. Pyroxene is rare in normal Granite, but Enstatite and Hypersthene are present in some potassic granites. All these occur as the major accessories. In addition to these, many minerals are found to occur as major accessories. These include Zircon, Sphene, Aplites, Tourmaline, Magnetite, Epidote, Zoisite and sometimes Almandine.

The varieties of granites are named according to the characteristic or major accessory mineral present, as Muscovite granite, Hornblende Granite etc. Some granites are named according to the typical texture they show, as graphic granite, etc.

In view of the abundance, the variations shown in their textural and structural characters and differences in mode of occurrence of Granites, the origin of these rocks has been extensively debated. While some petrologists believe that granities are formed due to the recrystallisation and transformation of certain preexisting rocks through metasomatic processes. The later processes are collectively referred to as 'Granitization'. Granitization includes all processes whereby solid rocks are changed into rocks of granitic composition and texture without passing through a magmatic stage.

There are evidences for both modes or origin Wahlstrom suggested that those formed directly from magmas may be called the '**Granites**' proper, while those formed through granitization may be referred to as '**Granitic rocks**'.

In India Granites and Granitic rocks are found extensively in Karnataka, Rajasthan, Tamilnadu, Andhra Pradesh, Orissa, West Bengal, Bihar, Assam and Himalayan Region. Mount Abu in Rajasthan is formed of a granitic batholith. In Andhra Pradesh these rocks are found mainly around Hyderabad and in Khammam, Guntur, Nellore and Prakasam districts.

Granodiorities and Diorites are found to occur as marginal facies of granites in Bihar and Karnataka.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

1). The essential minerals of

- (i) Granite.....
(ii) Granodiorite.....
(iii) Diorite.....

2. The collective proportion of the mafic minerals from Granite to Diorite
.....
.....

12.2.2 Syenite, Nepheline Syenite and Related Alkaline Rocks

These rocks are characterised by the predominance of alkali-felspar. In Syenite alkali-felspar is the essential mineral. The felspar may be Orthoclase, Microcline or Perthite. Small amounts of Plagioclase and Quartz may be present. One or more mafic minerals, like Hornblende, Biotite or Augite, occur as the major accessories. Syenite in which alkalic felspar and Plagioclase occur in nearly equal amounts is called **Monzonite**.

Rocks containing sodium and or potassium in excess of the amount needed to form felspar with the available silica are called alkalic or **alkaline rocks**. Such rocks contain feldspathoid minerals such as Nepheline, Sodalite, Analcite or Leucite and are characterised by the predominance of alkali felspar, usually Albite, with one of these minerals, more commonly Nepheline. Nepheline syenites are typical examples of alkaline rocks. The mafic minerals which occurs characteristic accessories may include Biotite, Soda-Pyroxenes and Soda-Amphiboles. Iron oxides, Corundum, Zircon, Apatite and Sphene may occur as minor accessories.

We may consider Granite, Syenite and Nepheline syenite as belonging to a series. The Silica content decreases from Granite to Syenite to Nepheline-syenite. In Granite, quartz is an essential mineral, in Syenite it may occur as an accessory and in Nepheline-syenite it is never found as the later rock is an undersaturated rock.

The textures of these rocks are variable. Some are Hypidiomorphic, while others Allotrimorphic. Some show the Propyritic texture. The grain size is coarse to medium.

The rocks of this group belong to the Plutonic type and occur as relatively small intrusives like small stocks, volcanic rocks or plugs, sills and dykes related usually to granitic batholiths.

In India rocks of this group occur in Tamilnadu, Andhra Pradesh, Orissa and Rajasthan. In Andhra Pradesh, Nepheline, Zircon, and Corundam Syenites are found near Palavanha in Khammam district.

Check Your Progress

Note : a). Space is given below for writing your answer.

b). Compare your answers with the one given at the end of this Unit.

3. In syenite when alkali felspars and plagioclase occur in equal amounts then the rock is said to be

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4. In Nepheline syenite Quartz is totally absent. Why ?

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12.2.3 Gabbro, Anorthosite, Pyroxenite, Periodotite and Dunite

These rocks form a very important and abundant set of plutonic rocks.

The Gabbros are mafelsic rocks. They are composed chiefly of calcic plagioclase (Labradorite) and Augite or Diallage. Sometimes Hypersthene and Olivine may be present. Biotite, Hornblende, Ilmenite and Magnesite may be present as accessories. Gabbros in which Hypersthene predominates over clinopyroxene are called Norites. Accessory Quartz produces Quartz Gabbro. By reduction of all mafic minerals, Gabbros pass into Anorthosites, which are of felsic composition, Labradorite is their one and only constituent and therefore it is a monomineralic rock. Pyroxenite and Dunite are the other important monomineralic rocks, characterised by the presence of pyroxene and olivine respectively. Periodotite is one olivine rich rock which usually containing other mafic minerals such as Pyroxenes, Amphiboles and Micas. These three rocks types are ultramafic.

Serpentinites consist almost entirely minerals of the serpentine group, all of which are considered to have formed due to late or post magmatic hydrothermal alteration of pyroxenes and olivine present in Pyroxenites, Dunites and Periodotites.

The rocks of this group are coarse grained and Hypidiomorphic. Gabbros, Norites and Anorthosites occur as thick sills, great dykes and large stocks. They are sometimes found as huge bodies of batholithic dimensions, Pyroxenites, Periodotites and Dunites are found to occur into the lower parts of thick sills and lopoliths in which they grade upward into mafic rocks.

In India Gabbros and the related rocks mentioned above are found in Tamilnadu, Orissa, West Benal, Rajasthan, Himalayan region and in Andaman and Nicobar islands. In Andhra Pradesh Anorthosites are reported to be occurring near Kondapalli in Krishna district.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

5. List out Monomineralic rocks with essential minerals.

12.3 HYPABYSSAL ROCKS - DYKE ROCKS

Hypabyssal rocks were formed at intermediate depth i.e. shallow depth in the earth crust. In this rock, the texture shows mesocrystalline or mesohyaline. Here crystals were formed after moving the magma and after loosing some temperature.

12.3.1 Aplite, Pegmatite, Dolerite and Lamprophyre

These rocks, although of varied mineral composition, have a common mode of occurrence normally as dykes or veins cutting across granitic plutons or other rock formations.

Aplites are light coloured rocks consisting of Quartz and alkali-felspars with occasionally small amount of Muscovite, Fluorite, Tourmaline, Topaz etc. They are fine grained and allotriomorphic in texture. These occur as veins of dykes within plutonic bodies.

Pegmatites, on the other hand, vary greatly in grain size, composition and occurrence. Among the pegmatites, some are fine grained like Aplites; but most of them are extremely coarse grained with crystals measuring a few meters in length. Some times they show marked intergrowth structures. Pegmatites are found to occur as veins or dykes, ranging upto hundreds of meters in length and width, mainly outside a plutonic mass to which their mineral composition has a general correspondence. Pegmatites are mostly related to Granites and Syenites and rarely to other plutonic types.

The granite pegmatites are mainly composed of alkali-felspar and Quartz, but they may also be rich in many other minerals. Based on the mineralogical composition, pegmatites are classified as :

1. Simple Pegmatites : The mineral assemblage is essentially simple, composed chiefly of Quartz, Alkali-felspar and Micas (muscovite and biotite). Some rare minerals are either absent or present as accessories.

2. Complex Pegmatites : In addition to Quartz, Felspars and Micas, a variety of rare minerals occur in considerable abundance. These rare minerals include Tourmaline, Topaz, Corundum, Apatite, Garnet, Fluorite, Lithium micas, Beryl, Spodumine, Cryolite, Chrysoberyl, Cassiterite, Molybdenite, Wolframite, and Amblygonite, Columbite, Tantalite, Aresenopyrite, and Uraninite. When some of these minerals which are economic importance occur in large quantities, the pegmatites constitute valuable mineral deposits.

Both Aplites and Pegmatites are developed during the residual magmatic stage of the plutonic rocks with which they are associated. The fine and even grain of aplites indicates comparatively small amounts of volatiles, while the textural characters of pegmatites indicate large quantities of volatiles in the magmatic residues from which they formed.

Dolerite (called Diabase in U.S.) is the hypabyssal form of gabbroic magmas. It is composed of Labradorite, Augite and Iron oxides, it is fine to medium grained and is characterised by Ophitic texture. If Olivine or Hypersthene is present it is called as Olivine dolerite or Hypersthene dolerite. Accessory quartz produces quartz dolerite. In Great Britain, altered dolerites are known as **Diabases**. Dolerites occur very commonly as shallow intrusive dykes and sills, among which these are the most predominating.

The term 'lamprophyre' is applied to a group of dark dyke rocks which are holofelsic or mafelsic and are characterised by an abundance of euhedral crystals producing **panidiomorphic or porphyritic textures**. Dark minerals occur both as phenocrysts and in the ground mass, whereas light minerals occur only in the ground mass. The essential constituents of lamprophyres are Biotite, Hornblende or Pyroxenes or combinations of the

these and felspar or feldspathoids. They are variously named depending on the minerals present. Apatite, Opaque, oxides and quartz are common accessories. They range in composition from syenitic to gabbroic and are usually rich in alkalis, especially potassium. They occur as member of dyke swarms associated with intrusions of granite or granodiorite or as minor members of olivine basalt flows.

In India dykes and veins of Aplites, Pegmatites, Dolerites and Lamprophyres are found in many places.

Aplite veins are found in the granite masses in Bihar, Rajasthan, Andhra Pradesh.

Pegmatites containing workable mica deposits are found to occur in Bihar (Koderma mica belt) Andhra Pradesh (Nellore mica belt) and Rajasthan (Bhilwara Mica belt) Minor veins of pegmatites occur associated with mass of the granitic bodies. In Andhra Pradesh, pegmatites are found to occur in Viskhapatnam, Krishna, West Godavari and Khammam districts.

Dolerite dykes are of very common occurrence. In Andhra Pradesh Dolerites dykes and sills are seen in the formations of the cuddpah basin and Dolerite dykes in the Granites and Granitic rocks in and around Hyderabad. Dolerite dykes are also formed in the granitic rocks in Karnataka, Madhya Pradesh, Bihar, Rajasthan and Assam. Dykes and sills of Dolerite are common in the coalfields of different states.

Lamprophyres are found to occur in the coalfields of West Bengal, Rajasthan, Tamilnadu, Karnataka and near Chelama in Kurnool dist of Andhra Pradesh.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

6. Characteristic texture exhibited by Dolerite is

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12.4 VOLCANIC ROCKS

Volcanic rocks were formed after coming out of magma on to the surface as lava. In this process due to rapid cooling rate and deletion of gases, the rocks will show holohyaline texture. Crystals are in minute sizes.

12.4.1 Rhyolite and Dacite

Rhyolite is the volcanic equivalent of Granite. It shows the same minerals as Granite. The textures is usually fine grained, but some times Porphyritic. The phenocrysts of quartz and

felspar may be found embedded in an abundant cryptocrystalline or glassy groundmass which frequently shows flow banding. The extreme glassy modification of Rhyolite is a pure black glass known as **Absidian**. Glassy rhyolites with a resinous or pitch-like lustre than a glassy lustre are called **Pitchstones**.

Rhyolites in which the plagioclase considerably exceeds the Orthoclase are called **Dacites**. They correspond to granodiorites, tonalites and quartz diorites in composition. Dacites may approximate to another volcanic rock, andesine in composition and texture, but are distinguished from it by the abundance of quartz. The rock intermediate between Rhyolite and Dacite is called **Rhyodacite**.

In India Rhyolites are found in Rajasthan and Kashmir and as differentiated forms in the Deccan traps in Maharashtra and Gujarat. Glasses are also found in these traps. Dacites are found in Kashmir.

12.4.2 Trachyte and Phonolite

Trachyte is the volcanic equivalent of Syenite, while **Phonolite** is the volcanic equivalent of Nepheline syenite or Leucite syenite. These are fine grained or porphyritic in trachytes orthoclase (Sanidine) or other alkali felspar occurs as phenocrysts in a groundmass consisting largely of flow oriented laths of alkali felspar (trachytic textures). Trachytes are named according to the predominating mafic mineral as Biotite-Trachyte etc. Trachyandesite is the volcanic equivalent of Monzonite.

In India Trachytes are found to occur in Kashmir and as differentiated forms in Deccan lavas. Minor occurrences of phonolites are reported from Rajasthan.

12.4.3. Andesite and Basalt

Andesites and Basalts form very important groups because Basalts are the most abundant and Andesites are next most abundant among lavas.

In Andesites felsic minerals are predominant. Plagioclase (andesine) is the predominating constituent. Alkali felspars may occur in a subordinate amount. Quartz is not usually visible but may be present in the groundmass which may be cryptocrystalline or glassy. The mafic minerals may be Biotite, Hornblende, Augite, Enstatite or Hypersthene, giving rise to the varieties like Biotite, Andesite etc. Andesites are usually porphyritic with felspars and mafic minerals occurring as phenocrysts. The groundmass may show Trachytic textures. Glassy rocks of andesitic composition are called **Vitro-andesites** or **Hyalo-andesites**.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

7. Give the Plutonic equivalents of

- 1). Rhyolite.....
- 2). Trachyte.....

3). Basalt.....

Basalts are volcanic equivalents of Gabbros and Dolerites and contain felsic mafic minerals in almost equal amounts. These are lavas in which calcic Plagioclase is the chief minerals constituent along with a number of mafic minerals. The mafic mineral comprise Augite, Olivine and Iron oxides. Hornblend, Biotite and Hypersthene occur only in exceptional cases. In the undersaturated types Leucite and Nephiline may be found. Two groups of Basalts are commonly distinguished-olivine-bearing basalts and olivines-free basalts. The former are called Picrite basalts and the latter Theolites. Theolitic basalts often contain quartz.

Basalts are fine grained or porphyritic, with phenocrysts of olivine Augite or Plagioclase. They show vesicles, usually with crystals of Zeolites or cryptocrystalline and amorphous forms of silica. Glasses of Basaltic composition are called Tachylite.

In India andesites are found mainly in Bihar in the Rajmahal area and in Kashmir. They also occur among the Deccan lava as their differentiated types.

Deccan lava are typical examples for basalts. Basalts rocks are also seen Kashmir, Assam and Bihar.

The commonly occurring plutonic and volcanic rocks described above may be tabulated as shown (Table 12.1) in indicating the approximate correspondence in their chemical and mineralogical composition.

Plutonic Rocks	Volcanic Rocks
Granite	Rhyolite
Ademallite	Rhyodacite
Granodiorite	Dacite
Tonalite	
Doprote	Andesite
Syenite Trachyte	
Nepheline-syenite or	Phonolite
Leucite-syenite	
Gabbro	Basalt

Table 12.1

12.5 SUMMARY

So far a large number of igneous rocks were recognised, but very few of these are common and abundant in the earth's crust. Some types are very rare. The commonly occurring igneous rocks are separated into three groups based on their origin. Those are Plutonic rocks, Hypabyssal rocks and Volcanic rocks.

Plutonic rocks were formed at greater depth in earth's crust. The important rock types are Granite, Granodiorite, Diorite, Syenite, Nepheline syenite, Gabro, Anorthosite, Pyroxinite, Peridotite, Dunite.

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12.7 MODEL EXAMINATION QUESTIONS

I. Answer the following question in 30 lines

1. Write detailed petrographic notes on the following rock types under the heads: Essential minerals, Accessory minerals and Texture. Mention about their modes of occurrence.
Granite, Grandiorite, Diorite, Syenite, Gabbro, Peridotite, Aplite, Dolerite, Lamprophyre, Rhyolite, Dacite, Trachyte, Andesite and Basalt.
2. Comment about the mineralogical nature of the following types of igneous rocks :
Tonalites Monzonite, Nepheline Syenite, Norite, Serpentinite, Rhyodacite, Phonolite, Trachyandecite.

II. Answer the following question in 10 lines.

1. What is 'Granitization' ?
2. Write notes on :
 - (a). Monomineralic rocks.
 - (b). Volcanic glasses
3. Give brief accounts of the distribution in India of the following rock types Granites, Gabbro, Pegmatites, Dolerite, Basalt.

12.8 GLOSSORY

Adamellite	:	Igneous rock having equal amounts of potash felspar and sodic plagioclase.
Alkali or Alkaline rocks	:	Igneous rocks containing sodium and/or potassium in excess of the amount needed to form felspar with the available silica.
Andesite	:	Felsic lava with predominating plagioclase (Andesine) nearly equivalent to Diorite or Quartz-diorite in composition.
Anorthosite	:	A monomineralic rock composed of Labradorite
Aplite	:	Light coloured and fine grained rock containing quartz and alkali felspar and occurring as veins or dykes within plutonic bodies
Basalt	:	Volcanic equivalent of Gabbro and Dolerite; most abundant type among volcanic rocks.
Dacite	:	Rhyolite with plagioclase in excess of orthoclase; corresponds

in composition to granodiorite.

Diabase	:	In US-Dolerite. In Great Britain - altered dolerite.
Diorite	:	Plutonic igneous composed essentially of the plagioclase andesine.
Dolerite	:	Hypabyssal form of gabbroic magma.
Dunite	:	Monomineralic rock composed of olivine.
Gabbro	:	A mafelsic plutonic igneous rock containing chiefly calcic plagioclase and augite.
Granite	:	A plutonic igneous rock with quartz and potash felspar, sometimes plagioclase also, as essential minerals; most abundant type among plutonic rocks.
Granodiorite	:	Similar to granite but with less quartz, less potash and more sodic plagioclase.
Granitic rocks	:	Rocks formed through granitization.
Hyalandesite	:	Glassy rock of andesite composition.
Lamprophyre	:	Glassy rock of andesitic dyke rock dark in colour with many euhedral crystals and pandiomorphic or porphyritic texture.
Monomineralic rock	:	A rock consisting essentially of one mineral.
Obsidian	:	Extreme glassy modification of rhyolite; shows vitreous lustre.
Pegmatite	:	Extremely coarse grained rock occurring as veins or dykes outside plutonic bodies and containing chiefly quartz, alkali feldspars and micas (simple pegmatites) and sometimes many other minerals in addition to the above (complete pegmatites)
Peridotite	:	Olivine - rich igneous rock with Pyroxene, Amphibole or Mica.
Picrite basalt	:	Olivine bearing basalt.
Pitchstone	:	Glassy rhyolite with resinous or pitch like lustre.
Phonolite	:	Volcanic equivalent of Nepheline-syenite or leucite syenite.
Pyroxenite	:	A monomineralic rock composed of pyroxene.
Rhyodacite	:	Volcanic rock intermediate between Rhyolite and Dacite;

equivalent of Admellite.

Rhyolite	:	Volcanic equivalent of Granite.
Serpentine	:	Rock consisting entirely of minerals of serpentine group formed due to late or Post magmatic hydrothermal alteration of pyroxenes and olivine.
Syenite	:	Plutonic igneous rock characterised by the predominance of alkali felspar.
Tachylite	:	Glass of basaltic composition.
Theolite	:	Olivine-free basalt.
Tonalite	:	Granodiorite with plagioclase greatly in excess of orthoclase.
Trachyandesite	:	Volcanic equivalent of Monzonite
Trachyte	:	Volcanic equivalent of Syenite.

12.9 REFERENCES

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BLOCK - IV SEDIMENTARY ROCKS

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UNIT : 13 FORMATION OF SEDIMENTARY ROCKS

Contents

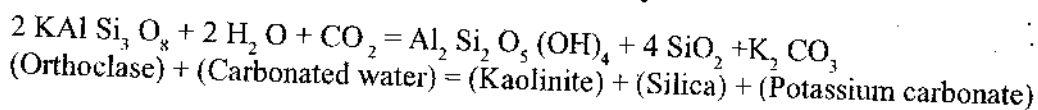
- 13.0 Objectives
- 13.1 Introduction
- 13.2 Weathering
 - 13.2.1 Mechanical Weathering
 - 13.2.2 Chemical Weathering

Thermal action or Temperature changes : The alteration of extreme temperatures day and night helps to shatter rocks. The rocks are not good conductors of heat, hence the exposed rocks expand during the day time due to high temperature and contract when temperature falls during night times. Thus the rock disintegrates into flakes or layers (exfoliation) due to alternative expansion and contraction.

13.2.2 Chemical Weathering

It is a process of alteration of rocks by chemical decomposition brought about by a different agents. Chemical weathering is accomplished by the action of carbon-dioxide, water and oxygen upon the unstable constituents of rocks. The chemical weathering includes many chemical processes like Solution, Oxidation and Reduction, Hydration and Carbonation. The rate of Chemical weathering varies greatly from region to region. Moderate temperatures and abundant moisture accelerate chemical reaction. Therefore the process is more rapid and important in warm regions than in cold or very hot regions, although some chemical weathering occurs every where on the earth's surface.

Carbonation : Chemical reaction involving CO_2 are among the most important in nature (Reaction of carbonates, bicarbonates with minerals). The Carbonation involves Biological action and with the help of Hydration, promotes the weathering rapidly. Mainly the feldspar and ferromagnesian minerals, upon carbonation produce carbonates of the alkali and alkaline earth metals. They are soluble and easily removed leaving behind a clay mineral the following equation represents the change in the orthoclase feldspar which is the most common mineral of many igneous rocks, especially Granites and Syenites.



Similarly Sodium carbonate and calcium bicarbonate may be removed from the plagioclase feldspars, ferromagnesian silicate also suffer similar changes. By this process as the silicates change into soft minerals and thus the strength of the rock is greatly reduced which promotes decomposition and disintegration.

Hydration : This is the process by which minerals take up water and expand, thereby causing stresses within the rock, thus reducing its durability. It is a complex process that acts on silicates (feldspars and ferromagnesian minerals) and produces a variety of clay. Depending upon the nature of silicate minerals different clays are produced.

Oxidation and Reduction : This is a common process of chemical weathering involving the reaction of minerals, specially iron bearing minerals, with oxygen. Iron is the chief constituent of many minerals and rocks. These iron bearing constituents are susceptible to chemical weathering through the processes of oxidation and reduction. The effects of oxidation and reduction are easily distinguished by colour change. The ferrous is changed into ferric state to give an orange or reddish brown crust which crumbles easily.

13.2.3 Biological Weathering

Plants and animals may contribute to the weathering process. The biological action may be

13.2 WEATHERING

Weathering is the loosening and breaking down of the rocky material of the earth's crust into finer and finer particles under the influence of certain physical and chemical agents. This results in the formation of a covering of rock waste which is called **Regolith**. This involves in two processes, i.e., **Mechanical weathering** and **Chemical weathering**. Commonly the process operate together but depending upon local conditions and circumstances, either of two may predominate. The third type of weathering is known as **Biological weathering** where both the mechanical and chemical aspects are involved.

13.2.1 Mechanical Weathering

In high mountains, desert regions, ice covered areas, mechanical weathering is dominant. The disintegration is the mode of breaking of rocks. The most common agents of mechanical weathering are Abrasion, Frost action, Temperature etc.

The most generally effective agent of Mechanical weathering is the Abrasive action of grains carried by the agent which are capable of wearing away the hardest rock. Abrasion also affects the grains themselves, due to the mutual collisions. The effectiveness of abrasion depends upon the following factors.

- (i). Hardness and cohesiveness of the rock being weathered
- (ii). Hardness, size and abundance of the sediment being carried
- (iii). the velocity of the transportation.
- (iv). the medium of transportation.

The resistance of the rocks to abrasion does not depend simply on the hardness and toughness of the minerals, but also on the compaction of grains. For ex: the porous sandstone containing resistance quartz is more easily eroded than non-porous limestone which contains much softer mineral calcite, because in limestone the calcite grains are closely compacted or interlocked.

The effectiveness of abrasion depends upon the tools (moving grains) available. The water without sediments flowing on rock is in-effective, where as water carrying hard and large sedimentary particles is a very efficient agent of weathering, as the particles wear away the bed rock more rapidly. The energy required for disintegration depends upon the movement of the agent that transport sediments. The three major agents or media of transportation are Air, Water and Ice.

Frost Action : The freezing of water in fissures tends to disrupt the rocks into angular fragments. The weathering by frost action is more common on mountains or at high altitudes. This process is capable for disintegration of rocks. All three major groups of rocks provide avenues, such as bedding planes in sedimentary rocks, Schistosity or planes of shearing in Metamorphic rocks and fractures in Igneous rocks, for the entrance of water. The water after entering these fractures will increase in the volume due to being which causes widening of the fissures and disintegration of the rocks. This process takes place only in areas subject to freezing temperatures.

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Wind is the most effective agent of transportation. It breaks the fragments into finer particles and rounds off the sharp edges of the fragments. The grains transported by wind show perfectly spherical forms, indicating long transportation, homogeneity and uniformity.

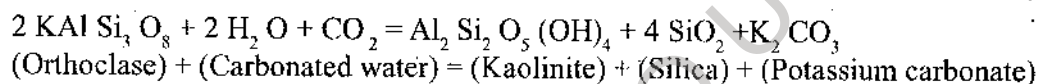
Dust and more rarely fine sand are carried in suspension upward much high into atmospheric layers by the rapidly rising air currents or due to volcanic explosions.

Thermal action or Temperature changes : The alteration of extreme temperatures day and night helps to shatter rocks. The rocks are not good conductors of heat, hence the exposed rocks expand during the day time due to high temperature and contract when temperature falls during night times. Thus the rock disintegrates into flakes or layers (exfoliation) due to alternative expansion and contraction.

13.2.2 Chemical Weathering

It is a process of alteration of rocks by chemical decomposition brought about by different agents. Chemical weathering is accomplished by the action of carbon-dioxide, water and oxygen upon the unstable constituents of rocks. The chemical weathering includes many chemical processes like Solution, Oxidation and Reduction, Hydration and Carbonation. The rate of Chemical weathering varies greatly from region to region. Moderate temperatures and abundant moisture accelerate chemical reaction. Therefore the process is more rapid and important in warm regions than in cold or very hot regions, although some chemical weathering occurs every where on the earth's surface.

Carbonation : Chemical reaction involving CO_2 are among the most important in nature (Reaction of carbonates, bicarbonates with minerals). The Carbonation involves Biological action and with the help of Hydration, promotes the weathering rapidly. Mainly the feldspar and ferromagnesian minerals, upon carbonation produce carbonates of the alkali and alkaline earth metals. They are soluble and easily removed leaving behind a clay mineral the following equation represents the change in the orthoclase feldspar which is the most common mineral of many igneous rocks, especially Granites and Syenites.



Similarly Sodium carbonate and calcium bicarbonate may be removed from the plagioclase feldspars, ferromagnesian silicate also suffer similar changes. By this process as the silicates change into soft minerals and thus the strength of the rock is greatly reduced which promotes decomposition and disintegration.

Hydration : This is the process by which minerals take up water and expand, thereby causing stresses within the rock, thus reducing its durability. It is a complex process that acts on silicates (feldspars and ferromagnesian minerals) and produces a variety of clay. Depending upon the nature of silicate minerals different clays are produced.

Oxidation and Reduction : This is a common process of chemical weathering involving the reaction of minerals, specially iron bearing minerals, with oxygen. Iron is the chief constituent of many minerals and rocks. These iron bearing constituents are susceptible to chemical weathering through the processes of oxidation and reduction. The effects of oxidation and reduction are easily distinguished by colour change. The ferrous is changed into ferric state to give an orange or reddish brown crust which crumbles easily.

13.2.3 Biological Weathering

Plants and animals may contribute to the weathering process. The biological action may be of either physical or chemical nature. The burrowing animals and growing roots exert pressure by which rocks get weakened and break up. Due to the remarkable penetrating and expanding

power of roots, rocks are disintegrated. They also provide openings which allow air and water to enter. The animal excretions provide acids which promote decay. The activities of micro-organisms are significant in this weathering. They are principally concerned with the formation of soil which is the end product of weathering.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answers with the one given at the end of this Unit.

1. What is weathering ?

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13.3 TRANSPORTATION

The soluble or insoluble materials supplied by weathering is transported to varied distances ranging from negligibly small to very great distances.

The movement is determined by the interplay of gravity and one or other of the three agents-air, water and ice. Gravity causes materials to settle to a lower level, but moving median deflects settling from a straight downward course and it may completely overcome the force of gravity for longer or shorter intervals of time and thus result in transportation. The transportation of material depends upon the density, viscosity and velocity of the agent. Material carried in solution is not controlled by gravity. It may be transported and may remain in solution indefinitely. Rivers may carry material either as bed load or in suspension or in solution. The material carried in bed load may pass into bottom by currents and carried forward. Due to this disintegration takes place before they are deposited and thus a part of load passes into suspension. The finer materials in suspension like sand ultimately find its way into the streams and seas and is finally deposited when the velocity of the agent is checked. The coarse material which the agent is unable to lift rolls along the bed, and finally it is deposited.

Wind is the most effective agent of transportation. The wind breaks up the transported material into finer particles and rounds off the sharp edges of the fragments. The grains transported by wind show perfectly spherical forms, indicating long transportation, homogeneity and uniformity.

Dust and more rarely fine sand are carried in suspension upward much high into atmospheric layers or for longer distances by turbulently rising air currents or due to volcanic explosions. Some dust is so fine that it remains suspended until it is washed out by the rain.

Glaciers are masses of ice that flow higher to lower levels and are capable of transporting large amounts of sediments. Because of its high viscosity and lack of turbulence the movement is slow, when compared to the water. The glacier acquire their load mainly from the surface on which they flow. They pick up the loose material and in turn break up the bed rock during their journey, Thus much finer sediments are produced.

Depending upon the velocity and mobility of the agent, the sorting of the sediments takes place. In the initial stage the agents deposit larger and heavier particles and carried finer and lighter ones to greater distances. Thus beds of comparatively pure sand and clay are deposited separately.

13.4 DEPOSITION

The ultimate destination of transported materials is deposition. Deposition takes place when the velocity of the transporting agent is checked, or when a change in physical or chemical conditions occurs. The nature of variation in the mineralogical composition of any sedimentary deposits depends upon the following factors.

1. the composition of the source rock subjected to weathering
2. the degree and mode of weathering.
3. the modification of sedimentary material that occurs during transportation.
4. the speed of the agent.
5. the nature and amount of sedimentary load and its distribution.

The depositional environments are difficult to classify in detail, because they are influenced by so many other complex factors. The most obvious differentiation is between marine and non-marine or continental environments based on the site of deposition.

Material carried in suspension or in other ways by agents is deposited mechanically due to the check in the velocity. Such deposits are known as **Clastic rocks** or **Detrital rocks**.

Material carried in solution may be deposited either on land or in water directly by Physico-Chemical processes such as Precipitation and Evaporation or by organisms. Such deposits are known as **Non-clastic rocks** or **Non Detrital rocks**.

The material carried in suspension is deposited layer after layer. Each layer, called a bed has its characteristic features like Colour, Texture and Hardness. Cohesion and Composition disposed approximately parallel to each other. Thus different beds are formed. The plane separating between one bed from the other is called **Bedding plane**. If the bed is very thin or paper like or less than 1 cm thick, it is known as a **Lamina**. If it is more than 1 cm thick, the bed is known as a **Stratum**.

If the deposition is in still water, the material is deposited in a graded manner from coarser at the bottom to finer at the top. A regular stratification is according to the size from bottom (coarse material) to top (finer material) will be produced as shown in the fig. 13.1.

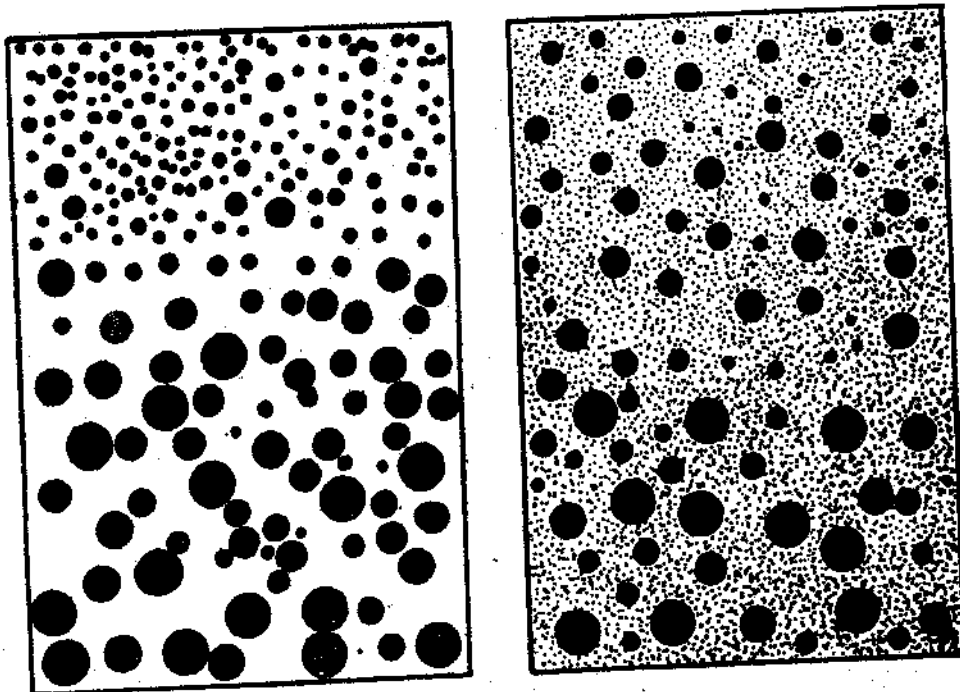


Fig. 13.1 Graded form

If the deposition takes place in running water horizontal or lateral gradation takes place. The coarse materials deposited first, then successively finer and finer sediments until the finest clay is dropped. Thus a horizontal or lateral gradation is produced. Thus the process is repeated to produce **stratification**.

The material deposited will be loose and unconsolidated. As the layers pile up one over the other, pressure increases on the underlying unconsolidated sediments and the water occupying the interspaces of the grains gets squeezed out and the grains become interlocked due to mutual molecular contact. This is known as **Binding or Cementation**. These binding substances are commonly supplied by percolating water. The most common of such materials are carbonates of calcium or magnesium, oxides of iron, silicon and clay.

The processes of welding and cementation generally act together in the hardening and consolidation of a sediment to form a sedimentary rock. Thus sand is changed to sandstone, mud to mudstone and clay to shale.

However the most common minerals which occur in sedimentary rocks are Quartz, Clay minerals, Feldspars, Gypsum, Anhydrite, Calcite, Muscovite, Garnet and Epidote. Eg. Sandstone mostly contains Quartz and Limestone is made up of Calcite.

Minerals of sedimentary rocks are of two types. (a). **Allogenic** (originated elsewhere) and (b). **Authigenic** (formed in place or on the spot). The allogenic minerals have originated elsewhere and transported to the place of deposition. The authigenic minerals are formed at the site of deposition only.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answers with the one given at the end of this Unit.

2. Describe the different types of Sedimentary minerals.

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3. Very fine Paper like thin beds are known as

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13.5 SUMMARY

The sedimentary rocks are formed by three processes namely Weathering, Transportation and Deposition. Sedimentary rocks comprised of sediments broken from pre-existing rocks by the action of weathering agents such as frost action, Temperature, Gravity, and Transporting agents such as Wind, Water and Glaciers. The sediments carried in suspension are deposited, when the velocity of the transporting agent is checked or with the change of physical conditions. Weathering, Transportation and Deposition are the three processes involved in the formation of sedimentary rocks.

The Physical disintegration and chemical decomposition of rocks into small fragments is called Weathering. The physical disintegration is mainly due to physical process and hence it is called Physical weathering or Mechanical weathering. The agents for this physical disintegration are Frost action, Temperature, Gravity etc. The freezing of water in fissures tends to disrupt the rocks into angular fragments and this process is Frost action. The extreme temperatures day and night helps to shatter the rocks. Due to this, rocks expands and contracts. This alternate expansion and contraction damages the rocks and loose fragments may be separated. Along the mountain regions due to steepness and gravity loose particles will be separated.

The process of chemical decomposition brought by chemical reaction with different agents is called Chemical weathering. Chemical reaction involving CO_2 is called Carbonation. If minerals react with water it is hydration. The reactions of iron bearing minerals with oxygen are termed as Oxidation and Reduction.

Plants and animals may also contribute weathering process called Biological weathering. In

this the burrowing animals and growing roots exert pressure by which rocks gets weakened and break up.

The broken fragments of weathering may travel to varied distances from negligibly small to very great distances with the aid of wind, water and ice. the rock fragments during transportation expose to Saltation, Abrasion and Explosion.

Deposition takes place, when the velocity of transporting agent is checked or there may be a change in physical or chemical conditions. The depositional environments are marine or non-marine based on the site of deposition, materials carried in suspension is deposited mechanically due to check in velocities, and such deposits are called Clastic or Detrital rocks. Material in solution deposited by physico-chemical processes are termed as Non-Clastic or Non-Detrital rocks. The material deposited will be loose and unconsolidated. Due to compaction, water will get squeezed out binding and cementation takes place. This process may cause hardening and consolidation of sediment to form a sedimentary rock.

13.6 CHECK YOUR PROGRESS - MODEL ANSWERS

- 1). The process of physical disintegration and chemical decomposition of rocks is known as weathering.
- 2). The sedimentary minerals broadly classified into two types (i). Allogenic
(ii). Authigenic.
(i). Allogenic minerals. The minerals which have been formed else where, and have brought to the site of deposition are formed as Allogenic minerals.
(ii). Authigenic minerals - The minerals which have been formed with in the site of deposition are termed as Authigenic minerals.
- 3). Lamina.

13.7 MODEL EXAMINATION QUESTIONS.

I. Answer the following questions in 30 lines.

1. Explain briefly the factors which bring about disintegration of rocks ?
2. What are the conditions under which rocks are decomposed ?

II. Answer the following questions in 10 lines.

1. Explain the factors which cause deposition of transported materials ?
2. What are clastic and non-clastic rocks?

13.8 GLOSSARY

Abrasion	:	Reduction in size of rock particles by rubbing of two particles together.
Allogenic	:	The term applied to the derived portion of sediment when

originated away and transported to the site of deposition.

Authigenic

: The term applied to the derived portion of a sediment which originated at the place of deposition.

Exfoliation

: A processes of weathering in which thin sheets to rocks split off owing to differential expansion and contraction during heating and cooling.

Ferromagnesian

: Minerals that are rich in iron and/or Magnesium and usually dark in colour, for example, Olivines, Pyroxenes, Amphiboles and Biotite.

Kaolinite

: It is a clay mineral produced during weathering and hydrothermal alteration of feldspars and feldspathoids under acidic condition.

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BRAOU

UNIT : 14 SEDIMENTARY ROCKS - PROPERTIES

Contents

- 14.0 Objectives
- 14.1 Introduction
- 14.2 Mineral Composition
- 14.3 Textures
 - 14.3.1 Clastic Textures
 - 14.3.2 Non-clastic Textures
- 14.4 Structures
 - 14.4.1 Physical Structures
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 - 14.4.3 Organic Structures
- 14.5 Summary
- 14.6 Check Your Progress - Model Answers
- 14.7 Model Examination Questions
- 14.8 Glossary

14.0 OBJECTIVES

In this unit, we have presented the textures and structures of sedimentary rocks.

At the end of this unit, you will be able to

- * describe the term 'Textures'
- * describe the different types of Textures-Clastic and Non-clastic textures.
- * describe the Sedimentary Structures - Physical, Chemical and Organic structures.

14.1 INTRODUCTION

Sedimentary rocks are those formed by the deposition of the solid materials carried in the suspension by the agents to transport. Their properties mainly mineralogical, textural and structural characters are discussed in this unit. These characters give us information regarding conditions of deposition, the extent of denudation, mode of transport, climate and other palaeogeographical features of the period to which the rocks belong.

14.2 MINERAL COMPOSITION

The minerals of sedimentary rocks fall into two groups 1. the insoluble residues of rock decomposition and 2. the comparatively durable minerals derived from pre-existing rocks. Amongst the former are the groups of clay minerals (Kaolinite, Halloysite etc), the Micaceous minerals including the Hydro micas and Chlorites, the Aluminium hydroxides (Bauxite, Gibbsite etc.) and the ferric oxides and hydroxides. Minerals of ferro-magnesian group, such as Serpentine and Talc are rarely found.

A large number of mineral species are found in the second class. Quartz is always the most abundant, certain accessory minerals such as Zircon, Rutile, Tourmaline, Garnet, Kyanite,

Magnesite etc are frequently present in sediments. Certain rock-forming minerals susceptible to decomposition may also be seen in sedimentary rocks. Thus Olivine may occasionally be found in the shore sands, Feldspars are also seen in sedimentary rocks.

The mineral composition of a sediment is affected by many factors. The insoluble residues of rock decomposition usually form the chief constituents of clay, whereas sands consist of quartz and feldspars. The grain size of this quartz and feldspars are similar to sands of source rocks. These are relatively durable and hence most abundant in sediment.

The mineral composition also depends on the nature of the rocks forming the gathering ground of the material. If the country rock consists mainly of some mineralogically uniform rock such as Quartzite, or a Granite, poor in ferromagnesian minerals and accessory minerals, the composition of the sediment resulting from its denudation will be simpler than that resulting from the waste of a lithologically or mineralogically heterogeneous region.

The duration and nature of the transport is also a factor in determining the mineral composition. Long and continued drifting to and fro by wind or by water tends to effect a separation of particles according to mass and surface area, and therefore according to composition. Wind is particularly efficient sorter of sand grains. In deserts, sands are shifted and redistributed until there is an approach to mineral uniformity. Long continued transport in rivers or along the shores may be almost equally effective in producing clean, graded and uniform deposits.

The panning or washing for gold or other heavy constituents from sand or gravel is an illustration of the effectiveness of these modes of sorting. The streaks and patches of sands rich in garnet or magnetite found in some beaches are examples of natural panning.

The transport tends to destroy the softer, more cleavable, and brittle mineral grains and thus to produce greater mineral uniformity in the final material. The feldspars are more altered and softer, and are consequently more easily broken down to silt and clay grade than is the hard and intractable quartz. The waves of the sea are more effective in eliminating the feldspars from sands, other minerals may be similarly eliminated from sands in proportion to their softness, susceptibility to alteration and cleavability.

14.3 TEXTURES

Textures refer to grain to grain relationship of a rock. In sedimentary rocks textures may broadly be divided as Clastic and Non-clastic. **Clastic textures** are those which are characteristic of mechanically deposited while **Non-clastic** are those which are characteristic of rocks deposited chemically or by the activity of organism.

14.3.1 Clastic Textures.

The term Clastic is applied to the textures of any rock whose original fragmental character is clearly visible. Textures of sedimentary rock includes mainly the grain size and shape of grains.

Grain Size : The grain size of sedimentary rocks depends on the mode of weathering, the texture and composition of the preexisting rock and kind and amount of transport.

If the mode of weathering is chiefly decomposition, the material produced is of flour-like fineness. On the other hand, disintegration produces coarser grains because it operates along cleavages, around the margin or coarser grain in rocks or along the joints and fissures in fine grained rocks. Therefore the material produced has the same grain size as the original rock or larger grain size depending on spacing of joints or fissures; coarse grained rocks yield a mass of broken grains of nearly the same size as the original rock but fine grained and dense rocks will break along fracture planes and therefore give larger fragments.

The grain size also depends on the amount of transport, continued transport reduces the grain size. The medium of transport is also an important factor. Grains transported by wind are subjected to more wear and tear than those transported by water and hence wind borne deposits are more fine grained.

The size of the detrital grains expressed in terms of the average diameter. The overall fabric of the rock grains are differently described as boulder, cobble, pebble etc. depending on their sizes. Details are given in the following table.

Grade	Range of Size of Fragments	Main Groups
Boulder	Greater than 200 mm	Rudites
Cobbles	Between 200 mm and 50 mm	
Pebbles	-do- 50 mm and 10 mm	
Gravel	-do- 10 mm and 2 mm	Gravel
Very coarse sand	-do- 2 mm and 1 mm	
Coarse sand	-do- 1 mm and .5 mm	
Medium sand	-do- .5 mm and .1 mm	Sand
Fine Sand	-do- .25 mm and .1 mm	
Silt Sand	-do- .1 mm and .01 mm	Silt

Shape and Rounding of Grains : The shapes of clastic grains depend on the original shapes of the material supplied by weathering and on the kind of transport. The quartz fragments derived from Granites will be sharply angular or irregular, the feldspar grains will be parallel cleavage fractures and Micas will be as irregular flakes and so on. Fine grained rocks normally give rise to angular fragments because they are determined by fissures in the rocks.



Fig. 14.1 Shape of the Grains

The kind and extent of transport have an important influence on the shape of grains. The grains which are initially angular become smooth and rounded by continued transport. Roundness of clastic grains is an expression of the angularity or otherwise of its edges and corners. According to the degree of roundness, grains may be described as Angular, Sub-

angular, Sub-rounded, Rounded and Well rounded. Grains transported for larger distances become more smooth and rounded than those transported for shorter distances.

For a given distance of transport, grains carried by wind are the most rounded while those carried by ice are the least rounded. Grains transported by water occupy an intermediate position. Other factors which have an effect on the degree of rounding and the size, weight and hardness of the grains.

Sorting : Another important aspects of clastic sediments is their sorting. Most agents of transport tend to sort the grains according to their size, shape and density. Sediments showing a number of grain sizes are said to be unassorted or ill-assorted or graded. Glaciers produce ill-assorted sediments. On the other hand, wind and water produce well-sorted sediments, those transported by wind being the best sorted.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answers with the one given at the end of this Unit.

1). Well sorted Sediments are the product of

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2. Roundness of the Sediments is.....

- a). Inversely proportional to the distance of transport
b). Directly proportional to the distance of transport
c). Both a and b

14.3.2 Non-Clastic textures

The factors considered under clastic textures do not straight away apply to Non-clastic textures. Roundness in the case of the clastic grains means the wear and tear to which they are subjected during transportation. Non-clastic materials were transported in solution and precipitated subsequently, and hence the term 'Roundness' has no application here. The non-clastic textures are produced by one or more of the following processes. (1) Direct crystallisation of inorganic reaction among dissolved salts (2) Crystals growth, (3) Replacement during Silication or Dolomitisation.

A typical Non-clastic textures consist of interlocking crystals with no intergranular spaces. Such texture is said to be **crystalline granular**. In most of the chemical sediments recrystallisation takes place atleast partially due to deep burial and consequent increase in temperature and pressure. These textures may be referred to as **crystalloblastic textures**.

Non-clastic crystalline textures usually consist of grains which are visible to the naked eye. They may be divided into **coarse grained**, greater than (5 mm) **medium grained** (1 to 5 mm)

and **fine grained** (less than 1 mm). Some important textures shown by non-clastic sedimentary rocks are given below.

- (1) **Amorphous** : Particles commonly of clay size or colloid size.
- (2) **Oolitic** : Composed of small spheres or ellipsoidal aggregates (0.25 to 2.0 mm) diameter. The oolites show concentric or radial structure internally.
- (3) **Pisolitic** : Similar to oolitic but diameter more than 2 mm.
- (4) **Spherulitic** : Spheres with radiating internal structure.
- (5) **Saccharoidal** : Fine, equigranular.
- (6) **Porphyroblastic** : Larger crystals embedded in a fine grained matrix.

Cohesion : All sedimentary rocks are initially loose and soft but they become hard and compact in course of time. This happens mainly due to two processes (1). Welding or Induration and (2). Cementation. Welding involves the influence of pressure due to the weight of superincumbent material or earth movements. That is, the rock becomes compacted under pressure. In cementation, the grain or particles are bound together by cementing substance which may be Siliceous, Calcareous, Ferruginous or Argillaceous.

14.4 STRUCTURES

The structures of sedimentary rocks may be broadly divided into (i) Physical structures (ii) Chemical structures and (iii) Organic structures.

14.4.1 Physical Structures.

Bedding : The most important primary structure of sedimentary rocks is Layering. The layers are called as Strata or Lamina and the resulting structure is Bedding or Stratification or Lamination. A **Stratum** is an individual layer of rock with more than 1 cm. thickness. A **Lamina** is similar to Stratum but with less than 1 cm. thickness. The Stratum or Lamina appear distinctly different due to change in the chemical composition, textures, etc. The surface which separates two layers is called the **Bedding plane**.

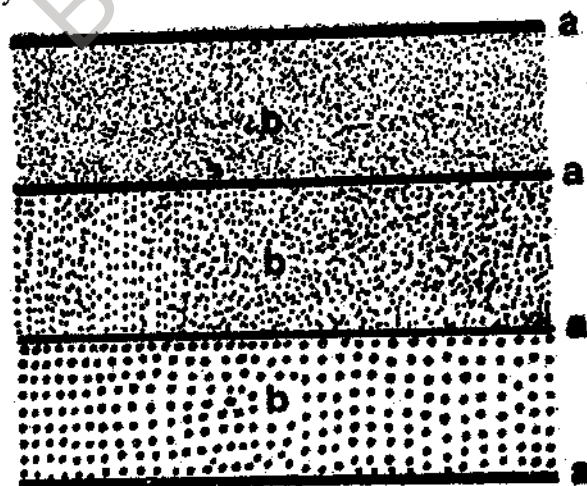


Fig. 14.2 Bedding -
a) Bedding Plane b) Beds

Some Sedimentary rocks or deposits are non-bedded such as Glacial Till and Loess and fine bedded deposits may get destroyed due to latter effects. The sedimentary rocks where they lack bedding may give rise to massive sedimentary rocks of homogeneous in nature.

The different structures related to Bedding are Cross bedding or Current bedding and Torrential bedding.

Graded bedding : Graded bedding is a term used to describe the textural sequence in individual beds which grade from coarse at the bottom to finer at the top.

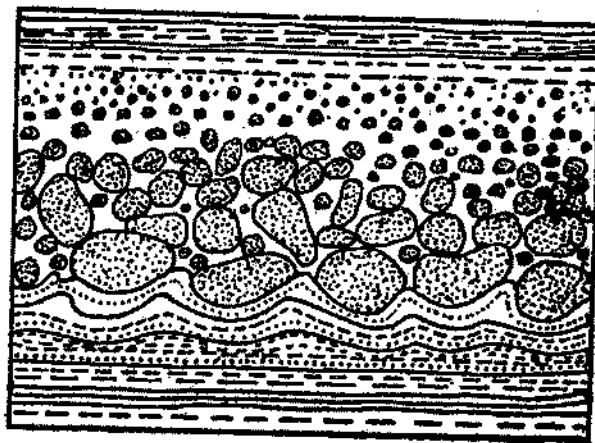


Fig. 14.3 Graded Bedding

The most perfect graded beds resulted from the deposition of suspended particles of grains in the bodies of standing water. In such types the coarse particles settle down to the base and finer and finer particles to the top. This type of structure indicates a quiet and deep water environment.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answers with the one given at the end of this Unit.

3). The term "Stratum" is used for the layers

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4). Describe Graded bedding.

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Cross bedding : It is most commonly well known feature of many structures. Changes in velocity and direction of the currents of transporting agent result in an irregular type of

bedding known as **Cross bedding**. The minor bedding planes indicate the condition or changes in velocity and direction of current.

- (i) **Tabular** : In which commonly the major bedding planes are parallel with subsidiary bedding planes running in different directions (Fig. 14.4A)
- (ii) **Lenticular**: In which the layes show extreme irregularities in shape and deposition. The major bedding planes may intersect with each other at different angles (Fig. 14.4B)
- (iii) **Wedge shaped** : This structure is more complex and its origin is still subjected to controversy. In this Bedding planes of different sets dip in different directions and at different angles (Fig. i4.4C)

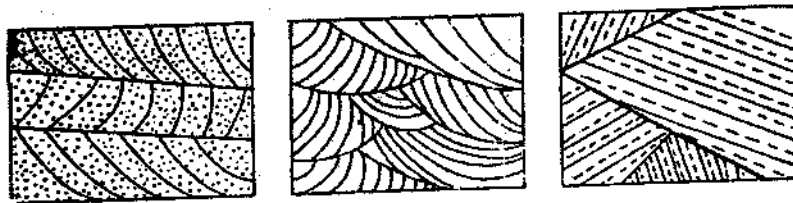


Fig. 14.4 Current Bedding.

The origin and significance of current bedded materials are products of bottom currents and they indicate shallow water environment or deposition by air.

Torrential bedding : Torrential bedding is the succession of graded beds i.e., alternate layers of the coarse & fine grains (Fig. 14.5) bedding show an alternation of coarse current bedded material and fine horizontal laminae. It is found in alluvial fans built in semi-arid regions due to the (i) Seasonal alternation of condition (ii) Alternation of longer periods (iii) Repeated storms that produced quantities of new land derived sediment and (iv) Successive submarine landslides and possibly other causes.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

5). Torrential bedding shows as alternately of

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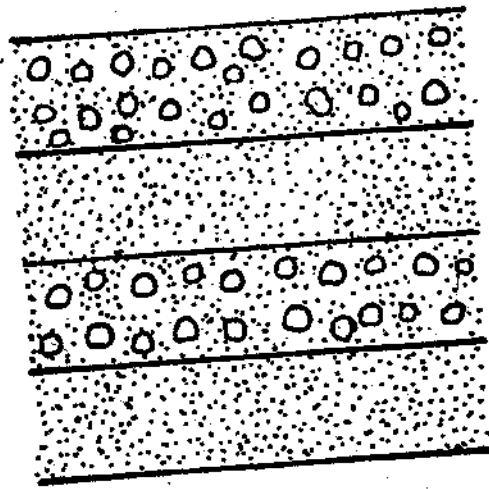


Fig. 14.5 Torrential Bedding

Bedding Plane Irregularities and Markings : The bedding planes of some sediments are characterized by some minor structures such as Ripple marks, Striations and Grooves.

Ripple marks : The various ripple patterns are developed in sediments as a result of Water waves, Water currents or Wind currents (Fig. 14.6). They indicate Paleo current directions. The Ripple marks are more commonly seen in sandstone than in Argillaceous rock. When the currents flowing over a bed of sand reaches a certain velocity by which the sand particles tend to give rise to wavy appearance on the surface of the sandstone. These wavy surfaces are known as **Ripple marks**.

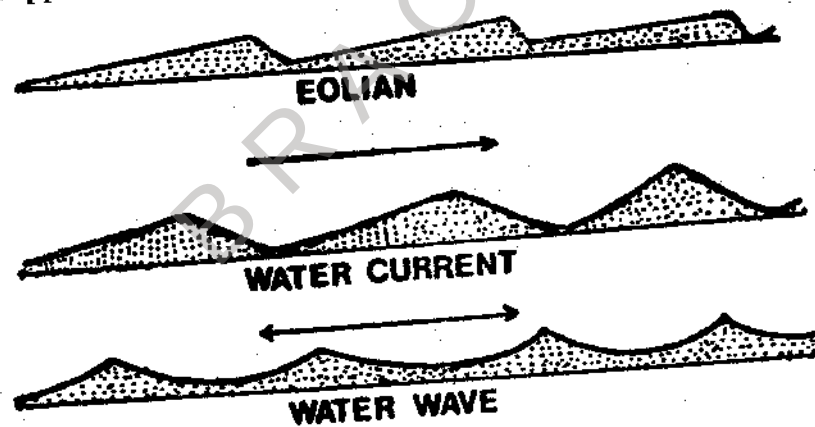


Fig. 14.6 Ripple Marks.

Broadly ripple marks are of two types (i) Symmetrical Ripple marks produced by wind action and (ii) Asymmetrical Ripple marks produced by water action.

Ripple marks formation can be distinguished from the Ripple Index and by the concentration of coarse grain at crest or trough.

The Ripple marks formed by wind consists of coarse particles or grains at the crest and

whereas the Ripple marks formed by the action of water consist of coarser particles at the crest.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

6). List out the applications of Ripple marks in Sedimentary Petrology.

Mud Cracks : These are peculiar features in sedimentary rocks exhibited by the Argillaceous type. All colloidal sediments shrink or drying closer to each other due to the evaporation of water due to sun's heat. Thus cracks of polygonal shape are developed in soft sediments which are known as **Mud cracks or Sun Cracks**.

The formation of Mud cracks depends upon the (a) original porosity or water content of the mud (b) the amount and kind of clay minerals present and (c) the thickness and homogeneity of the mud.

Other Markings : The markings other than those produced by currents are seen in the sedimentary strata. These markings are (i) Tracks and trails of animals (ii) Rain drop and Hail prints (iii) Impressions of salt or ice crystals (iv) Minor erosion features. Tracks and trails are markings produced by various organisms usually in soft sediments. They usually contain footprints of Amphibians, Reptiles which may be curve of long radius or straight.

The Rain drop and Hail impressions are small circular to elliptical pits formed in wet muds.

The conditions for required preservation of markings are (i) fine grained rocks of Argillaceous type (ii) the sediments must be damp but generally saturated with water.

14.4.2 Chemical Structures

Chemical action on sedimentary rocks is responsible for various sedimentary structures. These structures are Concretions, Secretions and Geodes.

Concretions : The term concretions is used loosely for a variety of more or less rounded bodies. Chiefly of inorganic origin occurring in all sedimentary rocks. Concretions are masses of different chemical and mineralogical composition than their enclosing rock. They are generally spherical, spheroidal or disc shaped (They are not pebbles and fragments of other rocks but they are closely related in their origin to the surrounding sediments). They are concentric around a nucleus. The nucleus may be a fossil or inorganic fragment (They are externally smooth and compact and they are internally fissured)

They vary in size from small pellets like objects to great spheroidal bodies of many feet in diameter. They are homogeneous in composition and generally consists of more or less impure silica, calcite, siderite and iron. Chemically they represent the minor constituent of the enclosing rock. eg.: In limestone the concretions are of silicon or flint.

Secretions : These are formed within the empty cavities in rocks by percolating solutions. The cavity may be completely or partially filled by mineral matter, usually in the form of crystals. Empty space left after deposition is known as **Wing**.

A **Druse** is cavity lines with the minerals identical with those of the enclosing rock. Some times the secreted material is readily separated as **Geode**.

The significant features of Geode are :

(i) their sub-spherical shape (ii) the hallow interior (iii) the outer chalcedonic layer. (iv). the inner lining of inward projecting crystals (v) the evidence of growth by expansion. They vary in size from an inch or two to a foot or more in diameter.

4.4.3 Organic Structures

These are manily formed in sedimentary rocks with the activites of organisms. There are two important structures in this, those are 'Bioherms' and 'Biostromes'. The dome shaped or bioconvex like structures are termed as 'Bioherm', Coral reefs are examples for 'Bioherms' Bedding strata like structures formed by the organisms are called 'Biostromes'. These Biostromes are formed with corals or Algae activity.

Coral reefs are very common. There are three important types in this, those are **Fringing reefs**, **Barrier reefs** and **Atolls**.

14.5 SUMMARY

The sediments separated from the earlier rocks will be deposited as sedimentary rocks. These rocks may show some properties of its own. The important properties discussed here are mineral composition, texture and structures. These characters are useful in knowing the depositional climate and environment, denudation and other palaeo geographical features.

The minerals in sedimentary rocks are separated into insoluble residues as detrital and durable minerals as non-detrital. The minerals formed due to the decomposition of basic rocks are called Detrital minerals and minerals formed due to disintegration are called Non-detrital minerals. In Detrital rocks, the essential minerals are Kaolinite, Halloysite, Bauxite, Gibbsite, Ferric oxides and accessory minerals are Serpentine and Talc. Quartz and feldspars are essential minerals in Non-detrital rocks and Zircon, Rutile, Garnet, Kyanite, Tourmaline etc. will appear as accessory minerals.

Like igneous, here also, the mutual relationship of mineral grains are called textures. Textures in sedimentary rocks are classified as Clastic and Non-clastic textures. Clastic textures are shown by the sedimentary rocks originated due to physical disintegration. Non-clastic textures are shown by the sedimentary rocks originated with chemical decomposition.

The term clastic is applied to the textures of any rock whose original fragmental character is clearly visible. In clastic textures the grain size and shape are important characters. Depending upon the average radius of mineral grains, these are classified as Boulders, Cobbles, pebbles, Gravel, very coarse sand, coarse sand, medium sand, fine sand and silt sand. The shape of the grains depend on the transport media and the distance of transportation. The grains which are angular at the beginning will become rounded after transportation. According to the degree of roundness grains may be described as Angular, Sub-angular, Sub-rounded, Rounded. The grains will be arranged according to their size, shape and density by transporting agents and this is called Sorting. Materials transported by wind shows best sorting.

The term roundness has no application in non-clastic rocks. The non-clastic textures are produced by one or more of the following processes i.e., direct crystallisation, crystals growth, and replacement. If recrystallisation takes place with increase of pressure and temperature then the texture is called as **crystalloblastic**. Important non-clastic textures are Amorphous, Oolitic, Pisolitic, Spherulitic, Saccharoidal and Porphyroblastic.

The large scale features of sedimentary rocks are called 'Structures'. These are mainly physical, chemical and organic. The important physical structures are Bedding, Graded bedding, Cross bedding, Torrential bedding, Ripple marks, Mud cracks etc. The important chemical structures are Concretions, Secretions, Geods etc. The organic structures are formed due to the activities of organisms and these are Fringing reefs, Barrier reefs, Atolls etc.

14.6 CHECK YOUR PROGRESS - MODEL ANSWERS

- 1). Wind
- 2). Directly proportional to the distance of the transport.
- 3). greater than 1 cm in the thickness.
- 4). Graded bedding is one in which beds display a vertical gradation. Normally the grading is formed large grains at the base of bed and smaller ones at the top
- 5). coarse graded material and fine horizontal bed
- 6). (i). Stratigraphic order (ii) Paleo current and flow analysis (iii) Regional Paleogeography.

14.7 MODEL EXAMINATION QUESTIONS

I Answer the following questions in 30 lines.

1. Bring out the difference between clastic and non-clastic textures ?
2. Bring out the factors effecting the clastic textures ?
3. What are different types of physical structures and briefly explain them ?

II. Answer the following questions in 10 lines.

1. Write short notes on :
 - a. Concretions
 - b. Secretions
 - c. Oolitic
 - d. Pisolitic

14.8 GLOSSARY

Algae	: A group of primitive and largely agatic plants that have no flowers, leaves or vascular system.
Brachiopods	: A phylum of invertebrate animals having a body enclosed by two valves of a calcareous materials.
Chert	: A very fine silica which may be of organic or inorganic origin. It occurs as bands or layers of nodules in sedimentary rocks.
Coccoliths	: Microscopic calcareous plates secreted by certain unicellular organisms variously as signed to the Algae, Protozoa
Corals	: A group of animals belonging to the phylum ceolenterata. They secrete a hard calcareous sekeleton and are important geological in stratigraphy because of their reef building activities.
Crinoidea	: Fixed or free living marine echinodermata, that contains the sea lilies. They are typically snsible benthonic marine animals consisting of a stem and a calyx or cups of calcite.
Crptocrystalline	: The term used for the material that is no fine grained that individual crystals cannot be identified even under microscope.
Dendudation	: The weathering and transportation process with result in general lowering of the land surface.
Diatoms	: Microscopic marine of fresh plants classified as a sub-division of the algae.
Flint :	: A nodular variety of chalcedony (silica mineral)
Foraminifera	: The forminifera are mainly marine benthonic forms in which there is considerable morphological variation, ranging from a single, non-chambered flask shaped animals to the complex chambered animals.
Lamellibranches	: A group of marine or fresh water molluscas having bivalve calcareous shell which is secreted by a bivalve mantle.
Permeability	: The ability of a rock to allow pore fluids and gases to pass through it.
Porosity	: Ther term porosity is the percentage of void space that a rock contains.
Radiolaria	: An order of phylum protozoa whose member have a external skeleton composed of silica
Stalactites	: A pendant accumulation of calcium projecting downwards from the roofs of limestone caverns.
Stalagmites	: A pendant accumulation of calcium carbonate of upward projections from the floors of the limestone caverns.
Texture	: In sedimentary rocks the term texture is used to indicate the size and shape of the grains.

* * *

UNIT : 15 CLASSIFICATION OF SEDIMENTARY ROCKS - CLASTIC ROCKS

Contents

- 15.0 Objectives
- 15.1 Introduction
- 15.2 Rudaceous rocks
 - 15.2.1 Conglomerates
 - 15.2.2 Breccia
- 15.3 Arenaceous rocks
 - 15.3.1 Sandstones
 - 15.3.2 Arkoses
 - 15.3.3 Greywackes
- 15.4 Silt rocks
- 15.5 Argillaceous rocks
 - 15.5.1 Shale
 - 15.5.2 Clay
- 15.6 Summary
- 15.7 Check Your Progress - Model Answers
- 15.8 Model Examination Questions

15.0 OBJECTIVES

The purpose of this unit is to give you overall view of classification of sedimentary rocks.

By the end of this unit, you will be able to

- * classify the sedimentary rocks.
- * describe the different types of sedimentary clastic rocks.

15.1 INTRODUCTION

Sedimentary rocks have been variously classified on the basis of mineralogical composition, environment of deposition, mode of formation and textural or structural features. No classification is entirely satisfactory; but broadly speaking, the sedimentary rocks are classified into two groups or divisions (i) Clastic or Detrital rocks or Mechanical rocks and (ii) Non-clastic or Chemical or Organic rocks. Clastic rocks are sub-divided based on the grain size and Non-clastic rocks are subdivided based on the nature of source material. (Fig. 15.1)

These are rocks which are made-up of fragments of minerals or rock matter produced by mechanical action of the agents of denudation like wind, water, glacier etc., This group is commonly sub-divided on the basis of grain size into Rudaceous rocks or Rudites, Arenaceous rocks or Arenites and Argillaceous rocks or lutites.

CLASSIFICATION OF SEDIMENTARY ROCKS

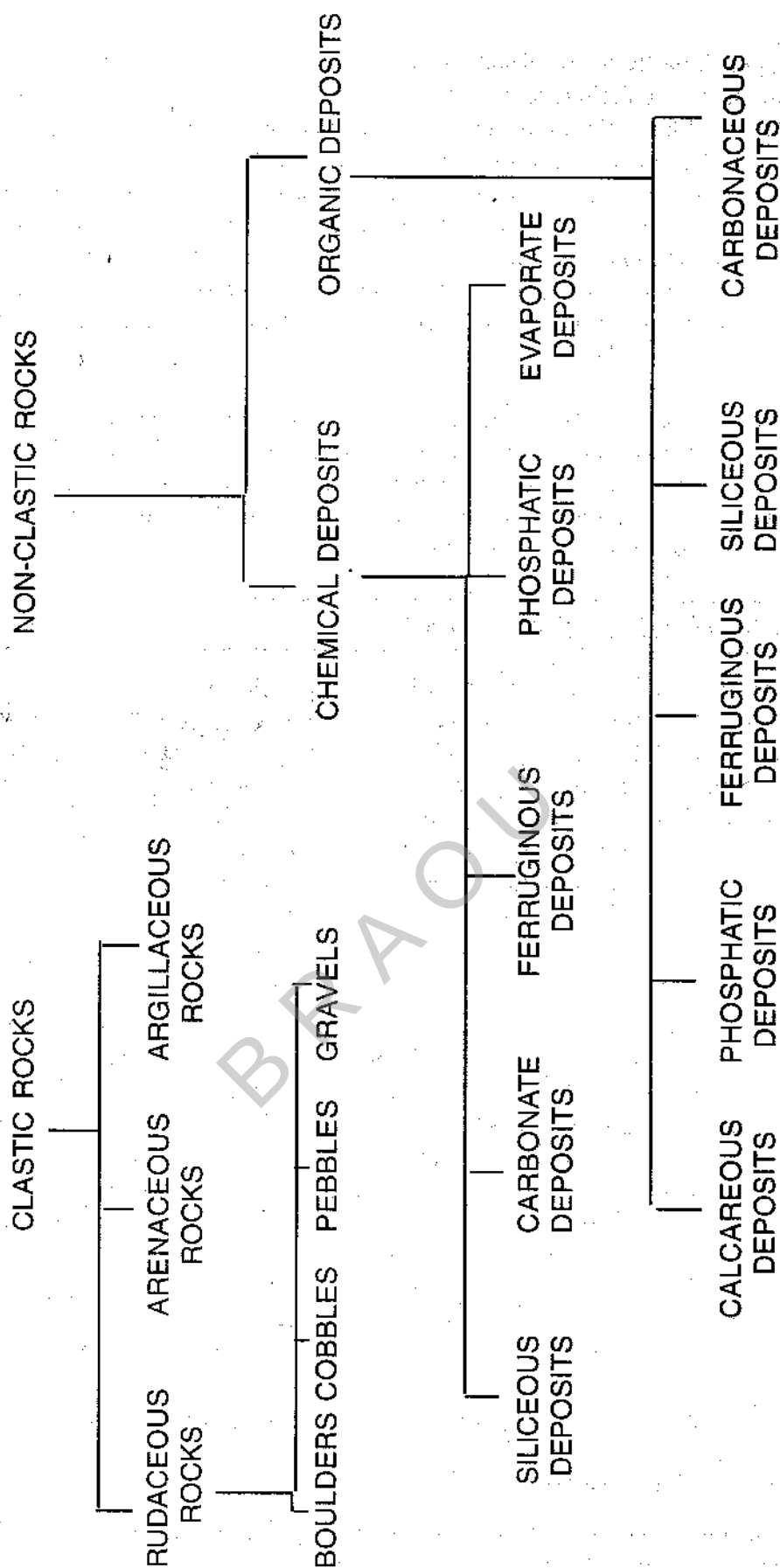


Fig. 15.1 Classification of Sedimentary Rocks.

This grouping is partly chemical and mineralogical from the Rudaceous to the Argillaceous rocks and increasing definiteness of chemical and mineral composition can be traced. The pebble and boulder rocks form the most heterogeneous group from the point of view of composition. The arenaceous rocks, however, composed mostly of Quartz, with subordinate Felspar are necessary, highly siliceous. The Argillaceous rocks, which comprise the finest products of rock decay, and especially of decomposition, are consequently made up of chiefly hydrous aluminium silicates. Silt rocks are intermediate in composition, between the arenaceous and argillaceous groups nevertheless, the composition may vary between wide limits. Even in the argillaceous group rocks devoid of hydrous silicates may occur as example Detrital limestone and Mud.

Another mode of grouping of sedimentary rocks is according to the agent most prominent in producing their present characters as Aqueous (water formed), Aeolian (wind-formed), Glacial (ice-formed), still another mode is according to the location of deposition as marine, continental, fluviatile, estuarine, lacustrine etc. Both these rocks of grouping are also applicable to the other classes of sedimentary rocks.

15.2 RUDACEOUS ROCKS

In these rocks 50% or more of the rock fragments are fairly large and size is always more than 2 m.m. The grains in this group are classified into (1). Boulder (size above 200 m.m.) 2). Cobbles (size 200-50 m.m.) 3) Pebbles (size 50-10 m.m.) 4). Gravels (size 10-2 m.m.). When the grains are cemented they form Conglomerate and Breccia. If the grains are rounded the rock is called Conglomerate, if angular, then the rock is Breccia. A fundamental distinction between angular and rounded fragments depending on the amount of transport the material has suffered. In Breccia, materials suffered less or no transport, but in Conglomerate more transport.

15.2.1 Breccia

The huge accumulation of Talus or Scree occur at the bases of slopes. The material in breccia looks fresh and sharply angular. These are often grooved, scratched and shattered. In sub tropical regions, deserts, polar regions, the weathering occurs mainly due to physical disintegration. Here the changes of material are nil, so they become compact and formed as Breccia rock. While Breccias are mainly formed under subaerial conditions, they may infrequently be of marine origin. A volcanic Breccia is called Agglomerate. It is composed chiefly of the igneous materials, but may contain non-volcanic fragments. These will be brought up from the basement of the volcano, or torn from the sides of the volcano.

Breccia may also be formed along the planes of movements in the crust. These are called Fault Breccia or Crush breccia. This will represent the first stage of 'Mylonisation'. The other type is intraformational Breccia made by the cracking and breaking up of clay or silt under sun's heat or by drying and the incorporation of the angular fragments in a succeeding bed of sand.

15.2.2 Conglomerate

Conglomerates consist only of the more durable fragments which, by reason of their hardness and toughness have been enabled to survive the vicissitudes of transport, and in doing so

have been worn down and rounded. Loose rounded deposits with rounded fragments are described as Gravel, Pebble-beds or Shingle. Gravel consists of more or less rounded fragments of diameters between 2 to 10 m.m., Pebble beds and Shingle consists of larger fragments ranging upto 50 m.m. or 2 inches in diameter.

Cobble and boulder-beds are formed by torrential action, where large rivers debouch from mountain valleys on to an adjacent low land.

They are built up as Alluvial fans at the mouth of each valley, and in course of time may become confluent one with another along a mountain front. In this way formations many hundreds of even thousands of feet thick or now being produced along the margins of greater mountain ranges. Owing to the inability of sea waves and currents to shift coarse material at more than shallow depths, marine pebble beds are limited to less than 30 meters of thickness. Thick and coarse pebble and boulder beds are, therefore most probably fluvial origin. Undoubted marine conglomerates are usually found as thin beds succeeding and unconformity and are due to the gradual re-advance of the sea during a subsidence. The principal types of conglomerates are of marine, fluvial, estuarine, lacustrine or glacial origin. Of these, the fluvial conglomerates are by far, the most abundant and important. These conglomerates composed of rounded fragments, always indicate long continued transport, mostly in water.

In general the fragments in conglomerates are derived from quartzites or granites. Sometimes limestone fragments can also be available. Fossil record is very poor. These fragments may be united with the help of matrix and this matrix may be argillaceous, calcareous or ferruginous.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

1). Classify the clastic rocks.

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.....
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2). What are the shapes of fragments in Breccia and Conglomerate rocks ?

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15.3 ARENACEOUS ROCKS OR ARENITES

These include sedimentary rocks in which the grain size ranges between 2 m.m. to 1/256 m.m. These rocks chiefly consist of sand grade material. When consolidated they form Sandstone, Arkose and Grewacke. These are of three principal families.

15.3.1 Sandstone

These are mechanically formed clastic sedimentary rocks which result from compaction and consolidation of sand particles. The sandstones are medium grained with wide variation in colour, shape, size and compaction. They show a variety of colours like grey, red, brown, white depending upon the nature of cementing material. The grains may be rounded or irregular, fine or coarse and loosely or densely packed. The shape, size and packing of the grains are responsible for the properties like porosity and permeability. Quartz is the common constituent of sandstone. The other minerals present in considerable amount are Feldspars, Garnet, Magnetite and Mica. Depending upon the composition of cementing material, the Sandstone are classified into (i) Siliceous sandstone (ii) Calcareous sandstone (iii) Argillaceous sandstone and (iv) Ferruginous sandstone.

15.3.2 Arkose

These rocks are principally composed of Quartz, Feldspar and some Granite fragments and occur as thin blankets covering Granite. It is a Sandstone, generally with coarse and angular grains, moderately well sorted rocks containing Quartz, Feldspars and rock fragments. Of these the liable constituents, namely feldspars and rock fragments, make up 25% of rock. Between these two, feldspars constitute half or even more. If the liable particles are less than 5% it is known as Sub-arkose derived from granite or gneisses. It may be mistaken for Granite, if it has been subjected by mild metamorphism. It is always pink to reddish in colour.

15.3.3 Greywacke

The name is derived from German term. Grwacke (grey sandstone) and is applied to sandstones which contain poorly sorted angular to sub-angular fragments of Quartz, Feldspar and small fragments of silicious slate and Phyllite bounded together in Argillaceous matrix which imparts great toughness and hardness. It is dark in colour.

Tyrrell recognised greywacke which include the components of igneous, sedimentary and metamorphic origin. In general, the average Greywacke consists mainly of Quartz, Feldspars and some materials of sedimentary and metamorphic origin. These rocks are divided into two sub-groups depending upon the dominances of feldspar and rock fragments. If feldspars are dominant, it is known as **Feldspathic greywacke** and if rock fragments are significant it is known as **lithic greywackes**.

15.4 SILT ROCKS

Silts are of finer grain than sandstones, but coarser than mud or clay. They often exhibit very perfect lamination and are earthy in texture lacking the plasticity of clay and rough feel of sandstones. As an example of wind formed silt, the loess, a fine calcareous sediment of yellowish colour, which forms thick, uniform, unstratified subjects in central Europe, Asia and the United States of America may be cited.

The mechanical compaction of silt results as silt rocks. Compacted silts are quite common in the sediments of post geological ages and may be called as **Silt stones**. These rocks are wide spread in many Palaeozoic formations, which they have been described as gritty slates, finegrained sandstones, greywackes, quartzites, slaty greywackes, etc.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

3. Rocks having particles of gravel size is known as

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4. A sandstone with abundant feldspar usually derived from disintegration of granite is known as

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15.5 ARGILLACEOUS ROCKS

These are fine grained clastic rocks, where the grain size is less than $1/256$ m.m. They are largely composed of fine silica particles and clay minerals. These minerals when consolidated they form sedimentary rocks. The common rocks of this type are clay stone, shale, and mud stone.

Clay is defined as a natural plastic earth material composed of hydrous aluminium silicates. The intruded clay is a clay stone, which is nothing but shale. However some writers have used the term claystone for a rock less indurated than a shale.

15.5.1 Shale

The grain size in these rocks is less than 0.01 m.m. When loose and dry these material forms dust, with varying amount of moisture it forms mud and clay. When welded into a compact rock is called Shale and these are well bedded and splits easily along the bedding plane. If it lacks fissibility they are called **mud stones**.

Fine grained texture, thin layered structure and lamination are the main characters of a shale. The identification of minerals in these rocks is difficult because of their extremely fine state. In majority of shales Quartz, Clay minerals and other minerals are available in three equal proportions. The minerals in Argillaceous rocks are of three types : 1. Clay minerals produced by the decomposition of rocks mainly hydrated silicates of Aluminium, Hydrated iron oxides etc. 2. Fresh mineral fragments produced by rock disintegration mainly 'rock-flour'. 3. Calcareous and Carbonaceous matter, Iron sulphide, Pyrite. In general their chemical and mineral composition may vary enormously according to their percentage and according to

their relative percentage of main groups of constituents. A common chemical character is relatively high porportion of alumina, resulting from the concentration of hydrated aluminium silicates and finely divided mica. Further clays often shows dominance of potash over soda, due to potassic salts are more readily adsorbed by the colloidal matter in clays than the sodic salts.

Most clays but not all possess the characteristic property of plasticity when wet. Kaolin the purest type of clay is not plastic. On the other hand, the slime produced by the fine crushing of gold quartz is very plastic. The cause of plasticity is not known. It depends neither on composition nor on grain size. It probably has some connection with the presence of colloidal matter in clays, and its property of retaining moisture and adsorbable substances.

Dusts, muds, and clays may be classified according to their modes of origin as marine fluvial, lacustrine, glacial, aeolian or volcanic. Dusts are formed on dry land due to wind or volcanic clays of glacial origin almost always requires the co-operation of water for their deposition. The glacially produced silts and muds form large contribution to lacustrine deposits.

The boulder clays is the most typical Argillaceous rock of glacial origin. Material of clay grade is more in glacial deposit, and this is mingled with materials of all other grades especially pebbles, cobbles and boulder of all sizes. This boulder clay can be seen only in regions of low relief. Towards mountains the boulder clay loses much of its clay base and becomes loam and sometimes as glacial drift. Boulder clay is frequently associated with finely laminated fluvio glacial sediments, with alternating bands usually of silt or clay, each pair of which is supposed to represent seasonal deposits of a year. By the study of these varves one can estimate the length of time taken for their formation. After compaction, the boulder clay becomes Tillite.

Muds and clays of fluvial origin with silt, form the alluvium found along the lower courses, and on the flood-plains of large rivers. They vary greatly in composition and usually carry a large quantity of organic matter of vegetable nature. Many deltas and lacustrine deposits are of essentially similar character. Lakes act as settling tanks for rivers, and lacustrine silts and muds, which are spread slowly and evenly over the whole floor of the lake, have tendency to very fine than lamination.

The sea is the best centre of deposition for Argillaceous rocks. Marine muds are chiefly deposited between the 100 - 2500 fathom contour line. At greater depths only abyssal ooze are found. There are five types of marine muds namely blue mud, red mud, green mud, coral mud and volcanic mud. Among these, blue mud is the most abundant and important, areal spreading is also more. The blue colour is due to finely divided organic matter and sulphide of iron. Red mud is confined to mouths of great rivers Amazon and Hoang - Ho. Red colour is due to presence of ferric oxide. Green muds colour is with Glauconite mineral. Green mud is usually more calcareous in composition than others. Coral muds and Volcanic muds are formed in the oceanic areas around coral islands and volcanic islands respectively.

Different types of clays, upon compaction becomes shale. Red Shale, Ferruginous shale, Green shale are the various terms used for the description of Shales. The Black shales are formed in shallow depth seas with reducing. The description of shales not only depends on

colour but also on the presence of minerals. Based on mineral composition Green shale is called as Glauconite shale, Black pyrite shale etc. Some shales are called with the fossils they are having. Based on the characteristic minerals shales are divided into 4 types

- 1). **Silicious Shale** :- In this, silica appears in the form of Quartz. Quartz grains resembles clay grains and are round in shape. In general silica percent in any shale is 58%, however in silicious shale the silica percent is above 85%. The other elements are ferrous iron carbonates, glauconite, organic matter etc.
- 2). **Arkose Shale** :- The feldspar percentage is more than 10. Quartz grains may be rounded or angular.
- 3). **Micaceous Shale** :- Mica flakes are abundant along the laminae. The texture is in between sand and clay.
- 4). **Chloritic Shale** :- Chlorite is very abundant in the total mass. This is composed with different silt minerals. Feldspar is more than Quartz.

15.5.2 Clay

Clays and mud stones are consolidated dusts and muds. Clays may retain as much as 15 percent of water, but in mudstones the process of weldings into a firm rock has driven out much of the original moisture. These are classified as marine, fluviatile rocks. Their constituents are the same as in dusts and muds, with the addition of some Authigenous minerals. The process of induration seems to develop finally divided impure white mica, chloritic substances and also minute needles of rutile. The important varieties of clays are China clay, Pottery clay and Fire clay.

The china clay or Kaoline is a white non-plastic material consisting the mineral kaolinite (pure hydrated silicate of alumina) mingled with fragments of quartz, feldspar, mica, etc. the residual minerals of granite. Kaoline is formed due to the action of Boric and Hydrofluoric acids on feldspars of granite. Granite after Kaolinisation will become China stone. In this quartz, kaolinised-feldspar or Topaz and feldspars are more in composition. These minerals will act as flourine in Hydrothermal process. Some times China clay may be transported and deposited as sedimentary beds. High quality Kaoline is formed from Singhbhum granites of Bihar and also Idar granites of Rajasthan, China clay deposits in Neyudi (Tamil Nadu) are best examples for sedimentary beds.

Pottery clays are very plastic and highly aluminous clays without iron. Brick clays are more abundant varieties of clays containing fluxes, especially compounds of iron and magnesium, which promotes marginal fusion of particles when they are burnt, thus finding the particles firmly together.

Fire clays can be exposed to high temperature without melting. They are used for making certain kinds of refractory bricks. In general, these are formed from sediments. Some deposits are also available as residues. Fire clays often occur beneath coals, and probably represent the soils. For using this as refractories, the clay must contain practically negligible quantities of alkalis, iron and magnesium and free silica must be present in small quantities.

Marl is a clay rock which contain a considerable proportion of lime and magnesia. By an increase in the proportions of calcareous matter, marlstone passes over to argillaceous limestone.

Check Your Progress

Note : a). Space is given below for writing your answer.
b). Compare your answers with the one given at the end of this Unit.

5). What are the different types of Shales ?

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6). Name the three clays.

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15.6 SUMMARY

Sedimentary rocks are classified on the basis of mineral composition, environment of deposition, mode of formation and textural and structural features. These rocks are classified as clastic or detrital rocks and non-clastic or non-detrital rocks or chemical or organic rocks. Clastic rocks are discussed here in this unit.

Clastic rocks are those which are formed by physical desintegration of rocks with frost action, temperture, gravity etc. These are the products of mechanical or physical weathering. Clastic rocks are classified based on their grain size as Rudacious rocks. Are, naceous rocks, Silt rocks and Argillaceous rocks. The grain size in Rudaceous rocks is more than 2 m.m. radius. The grains may be coarser. The important rocks are Breccia and Conglomerate. In Breccia, the grains appear in angular shape and in Conglomerate rounded shape. Rudacious rocks with loosely packed rounded grains are called Gravel, Pebble and Shingle.

The grain size range in aenaceous rocks is in between 2 m.m. and $1/256$ m.m. Generally sand seized grains are seen. The main rock types are Sand stones, Arkose and Greywackes. Sand stones are formed with compaction and consolidation of sand particles. Quartz is the impartant mineral in sand stone. Arkose rocks are composed of the angular fragments of Quartz, Feldspar and Granite, Greywackes composed of angular or sub-angular grains of quartz, feldspar, siliceous slate bounded in argillaceous matrix.

In silt rocks the grain size is in between sand and clay. Due to compaction of silt, Silt stones or silt rocks are formed.

The grain size in argillaceous rocks is less than 1/256 m.m. These are mainly composed of clay and sand particles. Shale and clay are the important types. Different types of clays up on compaction will become shale. Shales are classified based on mineral composition as Siliceous shale, Arkose shale, Micaceous shale and Chloritic shale. After compaction of dust and mud, clay may be formed. Different types of clays are China-clay, Pottery-clay and Fire-clay.

15.7 CHECK YOUR PROGRESS - MODEL ANSWERS

- 1). Clastic rocks are classified on the basis of grain size as rudaceous rocks
Arenaceous rocks, Silt rocks and Argillaceous rocks.
- 2). The fragments in Breccia appear as angular and in conglomerate as rounded.
- 3). Arenaceous rocks.
- 4). Arkose Rocks.
- 5). Siliceous shale, Arkose Shale, Micaceous shale and Chloritic shale.
- 6). China-clay, Pottery-clay, and Fire-clay.

15.8 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30-lines each

1. Classify sedimentary rocks.
2. Write down the classification of clastic rocks.

II. Answer the following in about 10 lines each.

1. Arenaceous rocks.
2. Rudaceous rocks.
3. Argillaceous rocks.
4. Silt rocks.

* * *

UNIT : 16 CLASSIFICATION OF SEDIMENTARY ROCKS - NON - CLASTIC ROCKS

Contents

- 16.0 Objectives
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16.0 OBJECTIVES

After studying this unit you should be able to

- * describe the Non-clastic rocks
- * explain the Chemical deposits
- * classify the Organic deposits

16.1 INTRODUCTION

This is the second major class of sedimentary rocks which include the chemical and organic sediments. These rocks represent those products of weathering, which are carried in the natural solutions and deposited through precipitation or evaporation or by the action of organisms. These rocks are generally homogeneous in character with interlocking crystalline grains.

This group of rocks is further sub-divided into two main classes, 1. Chemical deposits or Precipitates 2. Organic deposits.

16.2 CHEMICAL DEPOSITS

The rocks explained here represent those products of rock weathering, which are carried

away in aqueous solution, and deposited directly by physico-chemical processes such as Evaporation and Precipitation. In general precipitation from solution produces a very finely divided crystalline or amorphous powder, which shows very fine texture. On the other hand, the evaporation of solutions may, under favourable circumstances promote the growth of large crystals as in many salt and gypsum deposits. The recrystallisation of fine grained chemical deposits favours the same development. The oolitic and pisolitic structures also produce an effect of coarse grain.

Crystallisation may start from a centre and proceed radially, as in some Stalactites and Concretions; or it may take place intermittently around a nucleus, producing concentric arrangement of crystals as in orbits and pesolites or there may result a layered rock owing to interrupted deposition upon a surface or with in a cavity as in Stalagmites, Onyx, Agate.

Concretions are masses of differing chemical and mineralogical nature to the enclosing rock. These are mainly formed with silica, calcite and some other minerals of inorganic matter. They are generally rounded or nodular, and sizes may vary from diameters of less than one inch to many but concretions are stronger than enclosed rocks and hence they resist rock weathering. Septarian structures are a type of concretions with shale composition. These are identified with the internal tension joints, which are arranged haphazardly. These joints are mainly due to dehydration of material in colloidal state. Concretions are usually externally smooth and compact but often they are internally fissured, and the cracks healed again with another mineral which is frequently calcite.

Secretions are formed of substances deposited with in empty cavities in any rock. The space may be completely or only partially filled with mineral matter carried in by percolating solutions, which is often deposited in bands parallel to the wall of the cavities. Amygdales and Agates are secretory structures found in igneous rocks. A **Druse** is a cavity lined with minerals identical with those of the enclosing rock. Sometimes these hallow secretions are readily separable, and are then called **Geodes**. **Dendrites** are secretory forms of iron and manganese oxides, which are found has delicate plumose and arborescent growths resembling moss or branches. They coat the faces of fissures and parting planes in the faces of fissures and parting planes in finely grained limestone. In polished sections these dendrites stimulate lines of trees, like a ten country landscape, producing the well known landscape marble.

Stylolite is another structure seen in chemical deposits of sedimentary rocks. These are irregular suture-like boundaries developed in some lime stones and dolomites, which are generally independent of bedding planes. **Stylolites** are formed by some kind of pressure controlled solutions followed by immediate local redeposition. Insoluble clay material appears as a thin layer along Stylolite plane.

Depending upon the composition and process of formation this group is further subdivided into five classes as given below:

i. Silicious deposits	silica is the main constituent.
ii. Carbonate deposits	Carbonates of calcium & magnesium are the main constituents.
iii. Ferruginous deposits	Oxides and hydroxes of the iron are the main constituents.

- iv. Phosphatic deposits
- v. Evaporite deposits

Phosphate is the main constituent. Evaporation is the process involved in the formation of these deposits. Salts are the chief constituents.

16.2.1 Siliceous deposits

The commonly known deposits of this type are Chert and Flint. Chert and Flint are practically synonymous terms. Flint is formed from cryptocrystalline silica with glassy or waxy appearance and breaks with conchoidal fracture. The chert also forms in the same way as flint but shows some shades of grey and flat or uneven fractures. They are commonly associated with limestones. Chert and Flint are very resistant to weathering. The shapes, sizes, colour, textures and weathering characteristics of chert and flint may be different in different formations or zones.

16.2.2 Carbonate Deposits

This sub-group include sedimentary rocks in which the main constituents are carbonates or bicarbonates of calcium and magnesium. Though depositions of calcium carbonates mainly takes place due to the work of organisms. Some times deposition occurs chemically due to change in physical-chemical conditions. The loss of carbondioxide, evaporation of water from the roofs and floors of limestone caves leads to the formation of Stalactites and Stalagmites respectively.

Limestone : The term limestone is used for those rocks in which the carbonate fraction i.e. calcite exceeds the other constituents. The constituent of limestone is mainly calcite, which contains CaO and CO_2 with minor amounts of MgO . Rock intermediate in composition between limestone and dolomitic limestone have been variously named. If the Mg content is between 1 to 2% the limestone is called as **Magnesian limestone**. In a limestone, if more than 50% calcite is replaced by dolomite by alteration process then it is known as **dolomitic limestone**. In some cases the limestone contains spherical or ellipsoidal grains of calcium carbonate which resembles fish roe. Such grains are known as **ooliths**. The rocks containing ooliths are called **oolitic limestone**.

16.2.3 Ferruginous Deposits

These include the rocks which are rich in iron compounds and are of chemical origin. The group is commonly and often referred to as Iron formation or **Ironstone**. A precise definition of these deposits is difficult to give because different deposits have different modes of formation. Broadly it can be restricted to the rocks on which the iron content exceeds the other constituents. The main iron minerals present are i. Sulphides (Pyrite), ii. Silicates (Glauconite) and iii. Oxides (Hematite and Magnetite).

Iron is present in natural solution commonly as bicarbonates. The loss of carbondioxide from solutions converts bicarbonates into ferrous carbonate which oxides in contact with air and water or form rusty films or Iron hydroxides. If the precipitation occurs under reduction conditions the ferrous carbonate is directly deposited.

16.2.4 Phosphatic Deposits

This group includes rocks, which contain mainly phosphatic substances. They are formed from sea water rich in phosphoric acid. The term 'Phosphate' is vaguely used in sedimentary petrology. It has been used for those rocks which composed mainly of Apatite and it is also used for rocks which are rich in Phosphates of calcium apart from Apatite. If the Phosphate occurs as a minor constituent, the term phosphate is used as prefix. Eg. Phosphatic limestone or Phosphatic shale. The components of these rocks are difficult to study because of their crystals are sub-microscopic and are mixed with fine grained impurities.

16.2.5 Evaporite Deposits

Evaporite deposits are rocks which are formed by the process of evaporation from concentrated solutions or brines. These include some of the very important deposits of economic value like Rock sulphur, Rock salt, Gypsum, Anhydrite, Calcium carbonate and Nitrate.

16.2.6 Other deposits

These are called as Residual deposits. These are insoluble products of rock weathering which have escaped distribution by transporting agents.

1. Terra Rossa: limestone country in arid regions is often covered with a reddish clayey soil, the terra rossa, which is the insoluble residue of clay and other mineral matter left behind after solution of the limestone. In regions of larger rainfall the terra rossa is washed into depressions, swallow-holes and caves, soon after formation leaving bare limestone on the uplands.

2. Terra cotta-clay : This is also a residue formed after rock desintegration. Felsphethic gneiss and Felspathic sandstones are source materials for this Terra cotta-clay. In India these are available along the Eastern and Western coasts.

3. Clay with Flints : It is a reddish clay mingled with unworn and broken flints, and with a few rounded Quartz grains. Flint fragments are harder and looks like abrasives. All these constituents are probably derived from the desintegration of chalk. The residues like clay, flint and quartz grains unite and formed the clay with flints.

4. Laterite, Bauxite : Laterite is a reddish, porous concretionary material. This is available in many parts of our country. South Bihar, Madhya pradesh, Maharastra, Orissa, Jammu, East coast, Malabar areas are prominent for the occurrence of Laterite. If Laterite exposes to atmosphere, it will become harder. Based on this property, Laterites are using in the manufacture of bricks. When Aluminium content predominates, the colour become light and the rock becomes earthy and clay like, then it is called Bauxite.

5. Kankar : This is available as lumps, and nodules and irregular in shape. It is composed of impure calcareous substances. These deposits are available in India in the Archaen gneissic complex and along the Indo-Gangetic alluvial plains.

6. Soils : These are the superficial layers usually less than a foot in thickness, of desintegrated

and decomposed rock material. Soils are formed as thin layered strata parallel to earth's surface. The upper layer is called A, followed by B,C,D down wards. A layer is composed of vegetable cover, B layer is with clay and other minerals, C layer consists of partial weathered rock material and D layer is made up of bed rock.

A and B layers together are called 'Solum'. C layer is subsoil. Solum and sub soil together called as Regolith. In general the soils formed after transportation have no relation with bed rocks.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

1. What are the major groups of Non-clastic rocks

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2. Rocks carried in aqueous solution and deposited with evaporation and precepitation are called

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3. What are the different groups in chemical deposits ?

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16.3 ORGANIC DEPOSITS

These are deposits which are formed due to direct and indirect activities of animals and plants. Organic deposits are absent in polar and desert regions. The organic deposits can be of two categories. i. Bio-chemical and ii. Bio-Mechanical deposits. Biochemical deposits are formed due to the vital activities of organisms which accelerate the reaction and favour precipitation. The rocks are usually fine grained.

Bio-mechanical deposits are formed due to the fragmentation of hard parts of organisms like skeletons, shells etc., and their accumulation. The grain size depends upon the size of organisms or fragments into which their hard parts break. To differentiate between bio-chemical and bio-mechanical, it is very difficult, because the line of demarcation is very hazy and they grade into each other.

The organic deposits are classified into 5 types depending upon the chemical composition. They are :-

1. Calcareous deposits or Carbonate deposits	Ex. Fossiliferous limestone precipitated along with the shells of animals
2. Phosphatic deposits	Ex. Phosphorities formed due to excretion of animals or birds (guano)
3. Ferruginous deposits	Ex. Bacterial Iron are precipitated due to bacteria.
4. Siliceous deposits	Radiolarium ooze rich in silica
5. Carbonaceous deposits	Ex. Coal & Peat formed due to oxidation and decomposition of plant material.

16.3.1 Carbonate or Calcareous Deposits

The rocks are formed due to gradual accumulation of shells or skeletons of sea animals, like corals, crinoids etc. Eg. Fossiliferous limestone or Dolomite.

Limestone and Dolomitic limestone : The organic limestone is deposited mainly due to bio-mechanical process. The bio-mechanical limestones are frequently heterogeneous in composition consists of chiefly Calcite (CaCO_3) and hard parts of organisms such as shells and calcareous skeletons or their broken fragments. These are known as fossiliferous limestones. These limestones are further named depending upon the organisms involved. Eg. Shelly limestone, Coral limestone, Algal limestone, Crinoid limestone etc.

The **Shelly limestone** is a rock in which fossil shells such as Brachiopods and Lamellibranchs form a large part of it.

The corals are marine animals of very simple structure with radial symmetry, often living in colonies which build reefs in warm condition. If the limestone contains the remains of corals, it is known as **coral limestone**.

Algae are aquatic plants, which secrete lime and their remains may build up large masses of limestone. Such limestone is known as **algal limestone**.

Crinoidal limestone is due to the breaking up of crinoidal detritus, which may consolidate with varying quantities of fragment and mineral grains. Crinoids have a calcareous casing

supported on a stem made up of innumerable small discs. When the animal dies the discs disintegrate to form calcareous deposits known as Crinoidal limestones. These are especially prominent in palaeozoic formations.

Chalk : It is a soft white limestone made of finely divided calcium carbonate with minute plates of 1 or 2 microns diameter. These plates are derived from external skeletons of calcareous organisms and they are known as **coccoliths**. The chalk also contains Foraminifera, Radiolaria and other fossils which differ in kind and abundance in different places. The Foraminifera are very minute and primitive jelly like organisms (Protozoa) with a hard globular covering of lime or carbonates. They float on the surface when living and sink to accumulate on the floor. The Radiolaria are similar to Foraminifera with complicated and beautiful siliceous frame works.

Limestones which contain a noticeable amount of other substances like siliceous, argillaceous, ferruginous etc. are named after those substances as Siliceous limestone, Argillaceous limestone, Ferruginous limestone etc.

16.3.2 Phosphatic Deposits

The main source of the phosphates is the mineral Apatite, which is a common accessory minerals of many igneous rocks. This mineral is broken up (mechanically) and slowly passes into solution by carbonated water. The solutions ultimately pass into river and later into the sea. The calcium phosphate which is present in the water is utilised by the fish and other animals. The remains of these animals accumulate to form **phosphate deposits**.

Guano is another phosphatic deposit of organic formed due to the accumulation of excrement of fish-eating sea birds, which live in great flocks on islands (eg. in the West-indies). Rain falling on these accumulation leaches out the phosphates from them and percolates down into the underlying rocks, where replacement occurs in limestone with the formation of calcium phosphate. In this way beds of phosphorite or layers of phosphatic nodules consisting of calcium phosphate are formed. The phosphates are important for fertilizer and chemical industries.

16.3.3 Ferruginous deposits

These include some iron deposits precipitated by the activity of the organisms. The ferruginous deposits associated with coal measures are known as **Clay-Iron stone**. These iron ores are economical to smelt on account of their coal content. The impure limonitic deposits formed to the action of Bacteria or Algae is known as **Bog-Iron ore**. Eg: Finland and Sweden deposits. In some cases iron is present as Hematite, Limonite and Magnetite in Fossiliferous limestones or Shelly limestones. Eg: The Lake Superior deposits are the greatest Hematite deposits of the world.

16.3.4 Siliceous deposits

These deposits include rocks in which silica is the chief constituent and are deposited by the aid of organisms like Radiolaria and diatoms. The deposits are homogeneous, porous and friable, with an earthy lustre. They are composed of the Oolitic tests of Diatoms and the skeletal framework of Radiolaria. They are usually white or cream coloured and rarely buff,

red or brown. The silicious framework of the shells can sink to greater depths where they mingle with red clay and the non-organic substances to form ooze. If the accumulation of the particular organisms is more than 20%, the deposits are named after the organisms concerned. Eg: Radiolarian ooze. Radiolarian deposits also forms in shallow waters as Radiolarian chert.

16.3.5 Carbonaceous deposits

This group includes rocks rich in carbon, and formed by the burial of ancient plants. Eg: Coal, Peat, Lignite or Brown coal, Bituminous coal and Anthracite are the different ranks of coal depending upon the degree of coalification.

The coal seams are formed in extensive peat-bogs from dense vegetation, which is covered by silts and mud. Peat is formed as the first stage in the formation of coal. It consists of high ash content and burns with a smoky flame.

Lignite coal : It is more compact than Peat, and less compact than coal. It has less moisture and oxygen and high carbon content than Peat. It commonly retains the structures of the original wood.

Bituminous coal : It includes the ordinary household varieties. It contains the high percentage of carbon and less water. It burns readily and does not disintegrate so easily on exposure and has a typical banded structure, with alternating bright and dull layers. The three major kinds of material which are recognized by their Microscopic features are (i) Fusain, a soft black powdery substance, which readily soils the fingers and occurs as thin bands (ii) Vitrain, bands of bright black coal with a fraction of inch or more thickness and (iii) Durain, bands of dull hard coal containing resins.

Anthracite is a hard variety of coal with a semi or sub-metallic lusture and conchoidal fracture. It contains 90-95% of carbon, with low oxygen and hydrogen. This type of coal has been formed when coal bearings beds were subjected to pressure and increased temperatures. It burns with short flame and less smoke more heat.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answers with the one given at the end of this Unit.

4. Classify Organic deposits.

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5. What is Guana ?

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6. List out different types of Coal.

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16.4 SUMMARY

The non-clastic rocks represent those products of weathering, which are carried in natural solutions by the action of organisms. Non-clastic rocks are divided into Chemical deposits and Organic deposits.

The Chemical deposits are classified into six groups based on mineral composition and depositional environment. Those are Siliceous, carbonate, Ferrugeneous, Phosphatic, Evaporite and other deposits.

Silica is the main component in Siliceous deposits. Chert and Flint are the type rocks. Chert shows conchoidal fracture, where as Flint shows even or uneven fracture. Both these rocks resist weathering.

Carbonate deposits consists of Calcium, Magnesium carbonates and Bicarbonates. Dolomite and Limestone are the type rocks. The loss of CO_2 with evaporation of water from the roofs and floors of Limestone caves leads to the formation of Stalactites and Stalagmite.

Rocks rich in iron compounds are called ferrugeneous deposits. Pyrite, Siderite, Glauconite, Haematite, Magnetite are the deposits in this group.

Phosphatic deposits contain mainly phosphate substances. Apatite is the main mineral in this group. The crystals are submicroscopic and are mixed with fine grained impurities.

Evaporite deposits are rocks formed by the processes of evaporation from concentrated solutions or brines.

The insoluble residues of clay and other mineral matter left behind after solution of limestone are called Terra rossa. Terra rossa appears as reddish clay. The residue formed after the desintegration of felspathic gneiss and felsphethic sand stone is called Terra cotta - clay. Reddish clay mingled with unworn, broken flint is called Clay with flint. Laterite is a reddish, porous, concretionary material. Kankar is available as lumps and nodules in irregular shape. The superficial layer of the earth's surface formed by the desintegrated and decomposed material is called Soil.

The deposits formed by the direct or indirect actions of animals and plants are called Organic deposits. The rocks formed due to gradual accumulation of shells, skeletons, corals, crinoids will become carbonate deposits. Shelly limestone is a type rock. Based on the matrix these rocks are called as Siliceous limestones, Argilloceous limestones, Ferrugeneous limestones etc.

Due to mechanical braking the Apatite mineral passes into solution and reaches into sea.

These waters rich in phosphate are utilised by certain fishes and animals; Upon death this will give phosphate deposits. Guanó is a type of phosphate deposit formed from the accumulation of excrement of fish eating birds.

Iron deposits precipitated by the activity of the organism are called Ferruginous deposits. The ore formed in this way with the actions of Algae and Bacteria is called Bog-Iron ore.

In Siliceous deposits, Silica is the main component. This Silica is derived from the Radiolarian and Diatom like organisms.

Carbonaceous deposits of organic origin is due to the burial of ancient plants. Coal is main type. Peat, Lignite, Bituminous coal and Anthracite are the four main varieties of coal.

16.5 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Non-clastic rocks are grouped into chemical deposits and organic deposits.
2. Chemical deposits
3. Chemical deposits are classified as Siliceous, Carbonate, Ferruginous, Phosphatic, Evaporite and other group of rocks.
4. Organic deposits are classified as Calcareous, Phosphatic, Ferruginous, Siliceous and Carbonaceous deposits.
5. 'Guano' is a Phosphatic deposit formed from the excreta of fish eating birds.
6. Peat, Lignite, Bituminous coal and Anthracite are the four coal varieties.

16.6 MODEL EXAMINATION QUESTIONS

I. Answer the following questions in about 30 lines each.

1. Classify non-clastic rocks.
2. How do you classify chemical deposits.
3. What are different types of Organic deposits

II. Answer the following questions in about 10 lines each.

1. Limestone
2. Phosphatic deposits
3. Siliceous chemical deposits
4. Different varieties of coal.

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BRAOU

BLOCK - V METAMORPHIC ROCKS

BRAOU

UNIT : 17 METAMORPHISM - AGENTS AND KINDS

Contents

- 17.0 Objectives
- 17.1 Introduction
- 17.2 Agents of Metamorphism
- 17.3 Kinds of Metamorphism
 - 17.3.1 Heat Predominant
 - 17.3.2 Directed Pressure Predominant
 - 17.3.3 Directed Pressure and Heat Predominant
 - 17.3.4 Uniform Pressure and Heat Predominant
 - 17.3.5 Role of Chemical Active Fluids
- 17.4 Zones, Grades and Facies of Metamorphism
- 17.5 Summary
- 17.6 Check Your Progress-Model Answers
- 17.7 Model Examination Questions

17.0 OBJECTIVES

This unit discusses about the metamorphism, Agents and Kinds of metamorphism. By the end of this unit, you will be able to

- * define metamorphism
- * describe the agents of metamorphism and their role in metamorphism
- * describe the different types of metamorphism
- * describe the zones, grades and facies of metamorphism

17.1 INTRODUCTION

Igneous rocks are formed at high temperatures at about 650°C to 1200°C and at pressures of one atmosphere to 10,000 atmosphere from a predominantly silicate melt. On the other hand, sedimentary rocks are deposited on the earth's surface at low temperature and pressure. These two groups of rocks represent the extreme ranges of temperature and pressure involved in the processes of rock formation. During the vast geological time, these rocks were subjected to different temperature and pressure conditions, under the influence of which they were transformed into new types of rocks. These rocks have new mineral assemblages, which are in equilibrium under the changed conditions of temperature and pressure and therefore also exhibit new structures and textures. This transformation takes place in an essentially solid medium, usually aided by a little amount of chemically active pore fluid, either solutions or percolating gases, present in the pores of rocks. This process of transformation of pre-existing rocks into new types due to pronounced changes of temperature, pressure and chemical environment is termed as "**Metamorphism**". The term was first introduced by Lyell in 1932 and is restricted to all such changes which takes place below the shells of weathering and cementation. The products of metamorphism are called the "Metamorphic" rocks. Under

normal conditions, there is no change in the bulk composition of the rock and the pore fluids merely facilitate mineralogical changes. But there are however cases of rock alternation involving addition or removal of substances through the medium of the fluids present.

17.2 AGENTS OF METAMORPHISM

Heat, pressure and chemically active liquids or gases are the three factors responsible for metamorphism.

It is a well known fact that temperature increases with depth in the earth. At a depth of a few miles, the temperature is so high that rocks which are stable at the surface may be subjected to great changes because of the heat. This is geothermal energy. Heat is also supplied by, magmatic bodies in regions of igneous activity. In addition, heat is generated by friction as rock masses are thrust over one another. The heat so generated may be significant role, but it can cause **Low grade Metamorphism**. The main effect of heat is to bring about recrystallisation and therefore that is more important in determining the assemblage of minerals in metamorphic rocks.

The pressure is due to the superincumbent load and rocks which are deeply buried in the crust or due to low angle thrust in the upper part of the earth's crust. In general the pressure at any point may be resolved into two kinds, namely, Uniform pressure or Hydrostatic pressure and or Non-uniform pressure or Directed pressure or Confining pressure which operates equally in all directions.

While Uniform pressure may act on both liquids and solids, Directed pressure exists only in solids. Uniform pressure leads to a change in volume which directed pressure leads to a change of surface.

Chemically active fluids play an important role in metamorphism. Water is the main fluid aided by Carbon dioxide, Hydrochloric, Hydrofluoric and Boric acids and other emanations from magmatic bodies. They act as catalysts or solvents and facilitate chemical reaction and mechanical adjustment. The water involved in metamorphism may be derived from three sources. i) Juvenile water rising from igneous bodies, ii) Meteoric water or Carbonate water in the pore space of sediments and iii) water combined in hydrous minerals.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answers with the one given at the end of this Unit.

1. What is Metamorphism ?

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2. What are the agents of metamorphism?

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17.3 KINDS OF METAMORPHISM

The three factors mentioned above operate together in producing metamorphism. The chemically active fluids work practically in every case while Heat, Uniform Pressure and Directed pressure may dominate simply or in combination. The different kinds of metamorphism are thus due to various combinations of Heat, Directed pressure, Uniform pressure and Chemically active fluids, the last however being necessary for most kinds of mineral change in metamorphic rocks.

The types of metamorphism are named based on the agent or agents which play predominating role in bringing about the changes. They are given below :

17.3.1 Heat Predominant

The term '**Thermal metamorphism**' is used for all types of transformations in which heat is the dominating factor. The factor of pressure also comes into play, though in a subordinate manner, through the crowding aside of the country rock, volume expansion due to heating and the weight of the superincumbant mass of rock.

The term '**Pyrometamorphism**' is used for intense local changes at very high temperature. These changes usually takes place along the immediate contacts of large magmatic bodies with country rock and in Xenoliths immersed in Basaltic lavas. The term '**Contact metamorphism**' is used for changes which take place in aureoles surrounding intrusive rocks at lower temperature in contrast to the very high temperature of **Pyrometamorphism**. Contact metamorphism is also of local extent only. The contact zone is rarely more than several metres wide.

17.3.2 Directed Pressure Predominant

Directed pressure or Shearing stress operates in the upper parts of the earth's crust, especially in organic belts, causing low angle faults or over thrusts. Its action leads to the mechanical breaking-down of rocks with no new mineral formation, except when heat produced by friction is involved granulation, flowage, distortion, and rupture of mineral grains are some of the effects of the dominant action of stress. The metamorphism which is due to the dominant action of stress is called '**Cataclastic or Kinetic metamorphism**'.

17.3.3 Directed Pressure and Heat - Both Predominant

The changes produced by the combination of directed pressure and heat which operate at some depth in the crust are the most important among metamorphic changes. These involve more or less complete recrystallisation of rocks combined with the production of new structures. This kind of metamorphism may be called '**Dynamothermal metamorphism**'.

17.3.4 Uniform pressure and Heat - Both predominant :

The combination of Uniform pressure and Heat dominants at depths where directed pressure diminishes and finally ceases to operate because of the increasing plasticity of rocks. Mineralogical changes are more prominent and complete while new structures are rarely seen. Because of the factors of great depth, uniform pressure and great heat involved the term '**Plutonic metamorphism**' is used for this type of metamorphism.

Some geologists made a distinction between 'Local metamorphism' and Regional metamorphism. **Local metamorphism** is of local extent only and is connected with the intrusions of magmas. The contact zone is of limited extent and the temperature decreases away from the contact of the intrusive and the country rock. Contact metamorphism comes under this category. **Regional metamorphism**, on the other hand, is developed over a regional scale covering many thousands of square kilometers in precambrian shields and folded mountain ranges involving the action of heat and pressure. The heat may be of mechanical, geothermal or magmatic origin and the pressure may be powerful Directed pressure or Hydrostatic pressure. In general the metamorphism occurs with increasing pressure and temperature, and this process is called **Progressive metamorphism**. But sometimes the low grade minerals metamorphosed with lowering of pressure and temperature, and this process is termed as **Retrogressive metamorphism**.

17.3.5 Role of Chemically Active Fluids

As already mentioned pore fluids facilitate metamorphic changes. In normal metamorphism there is a little or no change in the bulk composition of the rock. But in some cases, the role of magmatic emanations is so evident that the composition of the country rock is considerably altered either by the addition or removal of material. Metamorphism involving substantial addition or by the removal of material is generally termed as '**metasomatism**'. When the introduction or removal of material is through the media of aqueous or hydrothermal solutions it is called '**Hydrothermal metamorphism**' or **Pneumatolytic metamorphism** or simply **Pneumatolysis**'.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

3. The different kinds of metamorphism are classified based on the agents : Name them.

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4. What is Retrogressive metamorphism ?

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pressure. In Dynamothermal metamorphism Heat and Directed pressure dominate equally. In Plutonic metamorphism Heat and Uniform pressure are predominant. 'Local Metamorphism' involves changes which are confined to a small area. Contact metamorphism falls in this category. 'Regional metamorphism' is developed over a large area and may include Dynamothermal metamorphism and Plutonic metamorphism.

Normally, metamorphism does not involve any change in the bulk composition of the rocks. But there are cases where material is either added or removed significantly through the agency of chemically active fluids-such changes are referred to as 'Metamorphism'. Depending on the variations in pressure and temperature and as a consequence in the conditions of metamorphism, with increasing depth in the crust, three depth zones are recognised. Grubenmann called them Epizone, Mesozone and Katazone. Epizone nearer the surface and Kata zone at great depths, Mesozone being intermediate between the two.

Eskola proposed the concept of the metamorphic facies in which the compositional aspects of the rocks is included. A metamorphic facies includes rocks of varying chemical composition, characterised by a definite set of minerals which are at equilibrium under P-T conditions. Metamorphic grade indicates the stage or degree of the metamorphism of the rocks. Barrow demarkated zones of increasing metamorphic grade in the scottish highlands, each zone characterised by the occurrence of certain index mineral.

17.6 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The process of transformation of pre-existing rocks into new types with the influence of heat, pressure and chemically active fluids and gases is called Metamorphism.
2. i) Temperature or Heat ii) Pressure - stress and uniform pressure
iii) Chemically active fluids.
3. i. Thermal metamorphism (Temperature or Heat)
ii. Cataclastic metamorphism (Stress)
iii. Dynamothermal metamorphism (Stress)
iv. Plutonic metamorphism (Uniform pressure and heat)
4. The metamorphosis of low grade minerals with lowering of levels is called Retrogressive metamorphism.
5. i) Epizone ii) Mesozone iii) Katazone

17.7 MODEL EXAMINATION QUESTIONS

- I. Answer the following questions in 30 lines
1. Explain the term 'Metamorphism' and give an account of the agents of metamorphism?
2. Give brief account of the Kinds of metamorphism?

II. Answer the following questions in 10 lines.

1. Explain the following terms.
 - a) Local metamorphism
 - b) Regional metamorphism
 - c) Metasomatism
 - d) Metamorphic facies
 - e) Grade of metamorphism
2. Give and account of the depth zones of metamorphism.

* * *

BRAOU

UNIT : 18 MINERALOGICAL CHARACTERS OF METAMORPHIC ROCKS

Contents

- 18.0 Objectives
- 18.1 Introduction
- 18.2 Composition of Original Rocks
 - 18.2.1 Argillaceous Rocks
 - 18.2.2 Arenaceous Rocks and Acid Igneous Rocks
 - 18.2.3 Limestone and Carbonate Rocks
 - 18.2.4 Intermediate and Basic Igneous Rocks
- 18.3 Influence of Heat
- 18.4 Influence of Uniform pressure
- 18.5 Influence of Stress
- 18.6 Minerals of Metamorphic rocks
- 18.7 Summary
- 18.8 Check Your Progress-Model Answers
- 18.9 Model Examination Questions

18.0 OBJECTIVES

In this unit, we have presented the overall view of mineralogical characters of metamorphic rocks.

At the end of this Unit, you will be able to

- * describe the effects of metamorphism on original rocks
- * describe the influence of heat, uniform pressure, stress
- * describe the minerals of metamorphic rocks.

18.1 INTRODUCTION

The metamorphic rocks are derived from the pre-existing rocks-igneous or sedimentary-due to the action of one kind of metamorphism or the other. The mineralogical and the textural or structural changes which take place during metamorphism depend on the composition of the original rocks and the type of metamorphism to which they are subjected or, in other words, the agents involved in bringing about the changes. The influence of these factors in the formation of new mineral assemblages is briefly outlined below.

18.2 COMPOSITION OF THE ORIGINAL ROCKS

The nature of minerals produced during metamorphism primarily depends on the chemical composition of the original rock. Usually there is no essential change in the chemical composition of the rock during metamorphism, unless material is added from outside. There

may however be a partial loss of water and carbon dioxide which is not significant. As an example, we may consider the changes produced in a Shale consisting of Quartz, Muscovite, Chlorite, Clay minerals and Iron oxide. This rock when subjected to contact metamorphism gives rise to a Hornfels consisting of Quartz, and Andalusite, Cordierite, Biotite and Felspar. The same shale under dynamothermal metamorphism gives rise to a Garnetiferous mica schist consisting of Quartz, Muscovite, Biotite and Garnet. Between these two rocks, the bulk composition is almost the same. As the minerals present in the shale are unstable under metamorphic conditions, they interact with each other and produce minerals which are in equilibrium under new conditions of temperature and pressure. These changes are facilitated by the interstitial rock moisture.

In order to consider the metamorphic changes produced, we may classify the original rocks broadly into the following four groups based on their initial composition.

1. Argillaceous rocks
2. Arenaceous rocks and acid igneous rocks (Quartz felsphatic rocks)
3. Limestones and other carbonate rocks
4. Intermediate and basic igneous rocks

18.2.1 Argillaceous rocks

These are composed mainly of finest product of weathering which include clay minerals, iron oxides, silica and undecomposed rock powder containing particles of Quartz, Felspar and Mica. These constituents are in approximate equilibrium under surface conditions of low temperature and pressure, and particularly susceptible to recrystallisation. During metamorphism, as temperature and pressure rise, reactions take place in a succession and even manner, in these rocks. The rocks show an orderly series of change and are therefore most suitable for establishing successive zones of Progressive metamorphism.

18.2.2 Arenaceous rocks and Acid igneous rocks

Although these two groups of rocks are of diverse origin, they possess nearly the same chemical and mineral composition. These are composed mainly of Quartz and Felspar which are stable over a wide range of temperature and pressure conditions and hence show significant changes only when subjected to High grade metamorphism.

18.2.3 Limestones and other Carbonate rocks

Rocks containing pure Calcium carbonate are stable under metamorphic conditions. They do not show much change except re-crystallisation. Dolomite gives rise to Calcite and some Magnesium minerals. Impure Limestones both Calcareous and Dolomitic, however, are unstable and give rise to new mineral assemblages under changing temperature and pressure conditions. Temperature produces mineralogical changes releasing carbon dioxides which facilitates further changes.

18.2.4 Intermediate and basic igneous rocks

These rocks are composed chiefly of lime-soda, Plagioclase, Pyroxene, Olivine and Iron oxides and like the argillaceous rocks, they are fairly susceptible to metamorphic changes producing typical mineral combinations.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

1. How many groups of original rocks identified to study metamorphic changes.

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.....

18.3 INFLUENCE OF HEAT

As mentioned earlier, metamorphic changes take place in a solid state. The rocks are not melted or dissolved totally, but only a small portion is in solution at any given time. It is to be noted that heat does not melt the rocks, that is but only leads to molecular adjustment between minerals or recrystallisation. The minerals formed are those which develop with absorption of heat. Heat promotes the expulsion of gases and also leads to an increase in volume. The nature of minerals formed depends on the pressure factor as explained below.

18.4 INFLUENCE OF UNIFORM PRESSURE

Uniform pressure 'operation equally in all directions, favours the formation of minerals of small specific volume and high density. These develop as nearly equidimensional crystals which are not stable or favoured under conditions of stress. Hence, these minerals are called **Antistress** minerals and include Anorthite, Potash felspar, Augite, Hypersthene, Olivine, and Andalusite, Sillimanite, Cordierite, and Spinel. Since Uniform pressure is dominant at great depths, that is in the Katazone, metamorphic rocks formed in the deeper are denser than those developed at shallow depths in the crust.

18.5 INFLUENCE OF STRESS

Directed pressure or Stress is the dominating factor in the Epi and Meso-zones and it decreases with increasing temperature, or, in other words, with increasing depth in the crust. At shallow depths stress produces crushing and granulation in hard brittle rocks and shearing in all rocks in general. At greater depths, with increasing temperature, rocks are subjected to recrystallisation and flow of fractureless deformation. Directed pressure is considered to be an important factor in recrystallisation because it lowers the melting point of minerals and increases their solubility.

The formation of minerals is based on Ricke's principle that solution takes place at points of greatest pressure in a crystal with concurrent precipitation at the area of least pressure.

Because Stress act in a particular direction and Pressure is less in other directions, crystals grow in a direction perpendicular to that of greatest pressure producing elongated forms oriented parallel to the direction of least pressure. In other words, stress favours the formation of Prismatic, Rod-like (one dimension more), Flaky or Tabular (two dimensions more)

minerals. Such minerals are called **Stress minerals**, and include minerals of the Mica group, Chlorite, Albite, Epidote, Zoisite, Amphiboles, Kyanite, Staurolite, Talc etc.

The unidirectional nature of stress also promotes mechanical movements in rocks, by the rotation of prismatic or platy crystals or by plastic flow or deformation in a direction perpendicular to that of greatest pressure. Thus stress is mainly responsible for the parallel structures of metamorphic rocks.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

2. What are the reasons for the formation of Stress minerals and Antistress minerals.

18.6 MINERALS OF METAMORPHIC ROCKS

Minerals like Quartz, Felspar, Biotite, Muscovite and Hornblende which are abundant in igneous rocks are also abundant in metamorphic rocks. However, as the nature of minerals formed during metamorphism is controlled by the varying Pressure - Temperature conditions, minerals characteristic of the relevant Pressure - Temperature conditions are formed in the corresponding metamorphic rocks. Minerals which are common and typical of rocks formed under different metamorphic conditions are given below depth and zone wise. Some minerals like Sericite, Chlorite, Talc, Garnet, Staurolite, Kyanite, Andalusite, Sillimanite and Cordierite are typical of metamorphic rocks only.

EPIZONE : Sericite, Chlorite, Chloritoid, Talc, Brucite, Actinolite, Epidote, Zoisite, Albite, Glaucofan, Mg-garnet, Calcite, Dolomite, Magnesite.

MESOZONE : Biotite, Muscovite, Staurolite, Kyanite, Anthophyllite, Epidote, Zoisite, Na-plagioclase, Hornblende, Cumingtonite, Granerite, Actinolite, Almandine, Calcite, Brucite. Some Epizone minerals along with some katazone minerals.

KATAZONE : Biotite, K-felspar, Sillimanite, Andalusite, Enstatite, Hypersthene, Olivine, Diopside, Herdenbergite, Omphacite, Hornblende, Augite, Jadeite, Cordierite, Garnet, Ca-plagioclase, Scapolite, Calcite and Brucite.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

3. What are the minerals especially seen in Metamorphic rocks than Igneous rocks
-
-
-

18.7 SUMMARY

Metamorphic rocks are formed from pre-existing rocks namely igneous and sedimentary by the processes of metamorphism. The mineralogical changes which take place during metamorphism depend on the composition of the original rock, and the type of metamorphism. Some times Water and CO_2 may be added or deleted in the metamorphic process.

In order to study the metamorphic changes during the original rocks are classified based on their initial mineral composition into four groups. Those are Argillaceous, Arenaceous, Limestones and other Carbonates and Intermediate and Basic igneous rocks.

Argillaceous rocks are easily susceptible to recrystallisation. During metamorphism, as temperature and pressure rises reactions take place in succession and even manner. These rocks are best suitable for establishing successive zones of Progressive metamorphism.

Lime stones and other Carbonate rocks are stable under metamorphic conditions and show recrystallisation. At low temperatures these rocks releases CO_2 out.

Intermediate and basic igneous rocks are fairly susceptible to metamorphic changes and may yield typical mineral combinations.

During metamorphism heat does not melt the rocks, but leads to molecular adjustment of minerals and recrystallisation. Heat promotes the expulsion of gases and also increases the volume.

In the process of metamorphism, Uniform pressure favours the formation of minerals of specific volume and high density. Stress will not act, so the minerals formed are Anti stress minerals. On the other hand, Directed pressure is the dominating factor and produce crushing and granulation. Here, stress will act, and hence, the minerals are stress minerals.

Minerals which are abundant in igneous rocks namely Quartz, Felspar, Biotite, Muscovite, Hornblend, etc are also prominent in Metamorphic rocks. Apart from this Diopside, Graphite, Tourmalene, Garnet etc are seen in Metamorphic rocks. Similarly the Accessory minerals of igneous rocks Apatite, Zircon, Sphene, Magnetite, Ilmenite etc are also seen in metamorphic rocks. The typical minerals of metamorphic rocks are Sericite, Chlorite, Tale, Garnet, Staurolite, Kyanite, Andalusite, Silliminite and Cordierite.

18.8 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Four groups are identified and those are
 - a. Argillaceous rocks
 - b. Arenaceous and Acid rocks

- c. Limestones and other carbonates
 - d. Intermediate and Basic rocks.
2. Anti stress minerals are formed due to Uniform pressure and Stress minerals are formed with Directed pressure.
3. Sericite, Chlorite, Talc, Garnet, Staurolite, Kyanite, Andalusite, Sillimanite, Cardiorite etc are seen in Metamorphic rocks only

18.9 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines each

- 1. Explain the impact of metamorphism on the original rocks.
- 2. Explain the role of Heat and Pressure on metamorphic minerals.

II. Answer the following in about 10 lines each

- 1. Mineral composition in metamorphic rocks
- 2. Stress and Anti stress minerals

* * *

UNIT : 19 TEXTURES, STRUCTURES AND CLASSIFICATION OF METAMORPHIC ROCKS

Contents

- 19.0 Objectives
- 19.1 Introduction
- 19.2 Textures
 - 19.2.1 Crystal Shapes
 - 19.2.2 Crystal Growth and Mutual Relations
- 19.3 Structures
 - 19.3.1 Cataclastic Structure
 - 19.3.2 Hornfelsic Structure
 - 19.3.3 Granulose Structure
 - 19.3.4 Foliated Structure
- 19.4 Classification of Metamorphic Rocks
- 19.5 Summary
- 19.6 Check Your Progress - Model Answers
- 19.7 Model Examination Questions

19.0 OBJECTIVES

In this Unit we have discussed above Textures, Structures and Classification. After completion of this unit, you should be able to

- * explain the textures
- * describe the structures
- * classify the metamorphic rocks

19.1 INTRODUCTION

The distinction between Texture and Structure remains same as in igneous rocks. But it is harder to distinguish between the two in the case of metamorphic rocks, as different textures may be closely interwoven and relic textures of the original rocks may be preserved in the midst of textures due to recrystallisation.

Metamorphic rocks are classified based on Texture, Mineral composition, Chemical elements, Grades of metamorphism and Metamorphic facies.

19.2 TEXTURES

The textures of metamorphic rocks depend on the shapes of the mineral crystals, on the mode of growth and on mutual relation, their structures depend on the inter-relations of various textures within the same rock unit and are frequently dominated by the directive forces due to unequal pressure.

19.2.1 Crystal shapes

Many minerals have a natural elongated or flattened habit of growth, and possess one or more good cleavages parallel to the dimensional directions. Some of these minerals such as Mica, Chlorite, Talc, and Hornblende are favoured by metamorphic processes. **Leith** and **Mead** have attempted to show that there is a marked tendency for rocks rich in these minerals to be developed by metamorphism from several types of sedimentary and igneous rock. There is in fact an actual change of composition, with a tendency to the elimination of such constituents as are not necessary for the formation of typical metamorphic minerals. The flaky and rod like mineral forms are those best adapted to the physical environment produced under metamorphism.

The Micas along with Chlorite and Talc, are flaky or lamellar in their crystal habits, being well developed in two dimensions and but poorly in the third. The ratio between the length and thickness is called index of elongation, and it provides a rough index to the intensity of recrystallisation. The Biotites of granites show index of elongation averages 1.5 in Gneissose granite 2.5 and in Contact metamorphic Biotite schist 5 and in dynamically metamorphosed mica schist 6 to 7. The crystals generally lie in the dimension perpendicular to the direction of greatest pressure and as their cleavage-planes are parallel to this surface. An abundance of micaceous minerals causes the development of a Schistose structure and Planes of easy splitting will occur in the same direction. Micas and related minerals give rise to a tabular, lamellar or plane type of schistosity.

Hornblendes, on the other hand, are prismatic, rod-like, or columnar crystals with a strong development in but one dimension. The index of elongation for hornblende in igneous rocks is about 2.5; in Hornblende-schist it is about 5. The prisms are generally arranged parallel to the direction of least pressure, like a bundle of pencils. In sections perpendicular to the direction of elongation, a Hornblende schist will show an evenly-granular texture; in other directions the texture will be rod-like or linear. The abundant presence of Hornblende or other columnar minerals thus gives rise to a linear type of Schistosity.

Most other minerals occurring in metamorphic rocks, such as Quartz, Felspars, Garnets, Pyroxenes, and Calcite, have, in general, an equidimensional habit. They tend, however, to be somewhat elongated in schists of dynamothermal origin, the elongation being due to plastic flow or to recrystallisation according to Rieke's principle. Hence, in this case a gneissose structure is produced which is due to the parallelism of flattened and lenticular minerals. On the other hand, these minerals remain equidimensional during Contact or Plutonic metamorphism, and a Granulose texture will be produced on metamorphism in rocks mainly composed of them.

19.2.2 Crystal growth and Mutual relations

As the growth of crystals in metamorphic rocks takes place in a practically solid medium, the textural characters are strongly contrasted with those resulting from crystallisation in the comparative freedom of a magmatic melt. The syllable **Blasto** (from Gr. blastos, a sprout) has therefore been used by Becke, either as a suffix or prefix, in the nomenclature of metamorphic textures and structures, to distinguish them from outwardly similar igneous textures. In many metamorphic rocks, the growth of all the minerals takes place almost simultaneously, there is consequently no real order of crystallisation, and the individual

minerals tend to enclose each other quite indifferently. Mix crystals and zoning of crystals are rarely found in metamorphic rocks.

19.3 STRUCTURES

The term **Structure** is used in a broad sense to include both small scale and large scale features seen in metamorphic rocks. Structures of metamorphic rocks develop in a solid medium by growth of crystals which recrystallise simultaneously. Since the order of crystallisation of minerals in igneous rocks as indicated in the reaction series has no application in relation to metamorphic rocks, the metamorphic structures differ completely in significance from the textures of Igneous rocks although there may be some superficial resemblance between some of their textural or structural patterns.

Becke proposed the term 'blastic' (Gr. blastos, sprouting) to be used as a prefix or suffix in naming the metamorphic structures to distinguish them from superficially similar igneous fabrics. Structures which are mainly due to recrystallisation with development of crystal form are described as 'Crystalloblastic'. If the metamorphic minerals have a granular habit, the term 'Granoblastic' is used. Crystal faces are usually poorly developed in metamorphic minerals and such minerals are described as 'Xenoblastic'. A few minerals however can develop their crystals form inspite of the resistance of a solid medium and these are termed 'Idioblastic'.

Becke established the following sequence of perfection of idioblastic order.

Usually	:	Magnetite, Sphene, Rutile,
Idioblastic		garnet, Kyanite, Staurolite, Andalusite
		Epidote, Zoisite
		Pyroxenes, Amphiboles,
		Micas
		Calcite
		Scapolite, Cordierite
Rarely Idioblastic	:	Quartz, Plagioclase
		Orthoclase, Microcline

This sequence although not universally valid, is consistent enough to give evidence as to whether certain rocks are Igneous or Metamorphic. A rock containing Plagioclase for example, is metamorphic, if the Plagioclase crystals are Xenoblastic because well shaped grains of plagioclase are never seen in rocks of metamorphic origin. On the other hand, Euhedral crystals of Plagioclase are common in rocks of igneous origin.

Some metamorphic rocks have an even grained aspect, but others are characterised by large Idioblastic crystals such as a Garnet, Cordierite, Staurolite etc., which are known as 'Porphyroblasts' and the structure is 'Porphyroblastic'. The term Augen (G. Auge, eye) refers to eye-or lens-shaped porphyroblasts, usually of felspar to mixtures of felspar and quartz found in sheared, granulated rocks. The term 'Poikiloblastic' structure denotes a Porphyroblast containing inclusions of other minerals. If original Porphyritic or Ophitic textures are recognisable even as remnants, they are respectively called as 'Blastoporphyratic' and 'Blastophytic'. That is the term 'Blasto'-is used as a suffix for all structures produced by recrystallisation and as a prefix for structure of original rocks which still form an integral part of the recrystallised rocks the term Palimpsest structures is used for such relief structures.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

1. Crystals developed during recrystallisation without proper crystallographic faces are described as.....crystals.

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.....

2. The texture produced by recrystallisation the term 'Blast' is used as

.....

.....

.....

The structures of metamorphic rocks may be broadly categorised as Nonfoliated and Foliated, the former lacking in and the later possessing directional arrangement of the mineral grains. The nonfoliated structures include Cataclastic, Hornfelsic and Granulose structures and the Foliated structures include Slaty cleavage, Schistose and Gneissose structures. These are briefly described below.

19.3.1 Cataclastic structure

Cataclastic structures are those of broken and fragmented rocks developed by mechanical deformation of hard brittle rocks due to Catalastic metamorphism. There is almost no new mineral formation. In the initial stages of deformation, simple crushing of rocks takes place producing structureless aggregates, continued intense movement under stress results in the rolling of grains and finally the rock becomes a more or less streaky, pulverised rock.

19.3.2 Hornfelsic structure

Hornfelsic structure also known as **Maculose structure**. It is one in which porphyroblasts of strong minerals like Andalusite, Cordierite, Chloritoid Biotite etc., are well developed. Spots appear as a result of the incipient crystallisation of these minerals. These spots on continued crystallisation, develop into Granoblastic structure. After showing an incipient banding or foliaform this stage there exit transitions to Granulose, Schistose and Gneissose structures. Hornfelsic structure is typically developed in Argillaceous rocks under Contact or Thermal metamorphism.

19.3.3 Granular structure

This structure is developed largely in rocks with Granoblastic and equidimensional minerals like Quartz, Felspar, Pyroxene, Granet, Calcite, Dolomite etc. Flaky or platy and linear minerals are either absent or present only in small quantities. Some times parallel, banded or streaky structures may be present due to alternation of patches differing in mineral composition or

granularity. Granulose structures are common in products of Thermal and Plutonic metamorphism.

19.3.4 Foliated structure

Foliated structures are by far the most common and important among metamorphic structures. The term Foliation or Schistosity is applied to cleavage or facility due to parallelism of platy or linear minerals in metamorphic rocks. Foliation may be subdivided according to the degree of perfection of the parallel surfaces as **Slaty cleavage** (most perfect) Schistosity and Gneissic structures (least perfect).

Foliation results from the parallel or subparallel arrangement of tabular, flaky and linear minerals. Under the influence of the directed pressure, micaceous minerals and prismatic crystals such as Amphiboles, Tourmaline or Epidote tend to be oriented with their greater dimensions or subparallel to the plane of foliation. If the structure is dominated by prismatic minerals the term lepidoblastic is used. The folia may be plane underlying or lenticular where **pnemotoblastic** is used and if it is dominated by tabular minerals the term **lepidoblastic** is used. The Folia may be plane, underlying or lenticular where they bend around porphyroblasts. Within the plane of foliation there may develop what is known as **lineation** resulting from the parallel alignment of linear minerals such as Hornblendes, Sillimanite and Tourmaline.

The least perfect foliation which is more common in quartzo-felspathic rocks is described as Gneissose or Granulose structure. Gneissose structure is basically a composite structure with alternation of foliate (schistose) and non-foliate (granulose) bands and lenticles. The foliation of gneissose structure is truly planar but crumbled, dragfolded and contorted. The structure is coarse and foliation may be often interrupted. Although a gneissic rocks may split along the plane of foliation, the fracture surface is much rough than in a schist.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

3. List out the metamorphic structures with examples.

19.4 CLASSIFICATION OF METAMORPHIC ROCKS

Metamorphic rocks may be classified in many ways. The simplest and the most practical method is to divide them into foliated and nonfoliated rocks as was done by Pirson and A. Knopf. Another way is to divide them into lithologic types as Marbles, Quartzites, Hornfelses, Slates, Phyllites, Schists and Genisses. These two classifications are useful for descriptive purposes. There are other classifications based on structural and mienralogical characters,

chemical composition, grade of metamorphism and the concept of metamorphic facies. Turner suggested four criteria for classification of metamorphic rocks. 1. Field association 2. Mineral composition 3. Structure and 4. Chemical composition. A study of these factors helps in correlating the rocks with the type of metamorphism as also the nature of the original rocks.

Field studies of rock associations through light on this ultimate cause of metamorphic rocks, as for example, the association of thermally metamorphosed rocks with igneous intrusion, or the occurrence of rocks deformed by cataclastic metamorphism in zones of intense shearing. The gradation of metamorphic rocks into a sediment or igneous rocks is good evidence to know the original rock.

The mineral assemblage is the best criterion for knowing the temperature and pressure. They also give an indication of the nature of the parent rock. For example, staurolite is found typically in Schists derived from Argillaceous rocks. Graphite is mostly derived from sediment. Minerals are also helpful estimating the Grade of metamorphism.

The structure is important in understanding the intensity and kind of deformation involved in metamorphism.

Chemical analysis of a rock gives the most exact data from which the nature of the parent rock and the extent to which it has been affected by metamorphism can be deduced.

The ideal basis of classification and the one commonly used is the concept of metamorphic facies put forward by **Eskola**. In this classification, the mineral assemblages produced by metamorphism are taken into account. Many consistent in their paragenetic associations. The nature of these assemblages of metamorphic minerals is determined by the physical conditions of metamorphism, bulk composition of the metamorphic rock. The regularity in occurrence of mineral assemblages facilitates a simple classification of metamorphic rocks on the basis of chemical and mineralogical composition and also the P-T conditions.

An outline of the metamorphic facies is advanced by Eskola and his followers arranged according to the inferred relationship to P-T conditions.

The metamorphic rocks produced from pre-existing rocks under different kinds of metamorphism and the processes involved are explained in the units to follow.

19.5 SUMMARY

The terms textures and structures are same as in igneous rocks. Texture is the mutual relationship between crystals, the systematic arrangement of crystals naturally gives us structures. It is very difficult to separate one from other in metamorphic rocks. The textures mainly depend on crystal shapes, growth and mutual relations. Mineral grains have a natural elongated or flattened habit of growth and are parallel to dimensional directions. The flaky or rod like minerals are those best adapted to the physical environment. The Micas, along with Chlorite and Talc are flaky or lamellar and being well developed in two dimensions and poorly in third direction. Hornblendes are prismatic, rod-like or columnar in shape and development is in a single direction. The other minerals such as Quartz, Felspars, Garnets, Pyroxenes and Calcite have an equidimensional habit. In many metamorphic rocks the growth

of all the minerals take place simultaneously so it is not possible to know the order of recrystallisation.

The term structure is used in a broad sense to include both small scale and large scale features in metamorphic rocks. Becke a noted petrologist proposed to use the term 'blastic' as a prefix or suffix in naming the metamorphic structures to distinguish them from igneous fabrics.

Structure developed due to recrystallisation of crystals is called Crystalloblastic. If the rock shows granular habit then the structure is Granuloblastic. If crystal faces are poorly developed, such structures are called Xenoblastic. If the faces developed completely then those structures are termed as Idioblastic. Again these structures are categorised as foliated and non-foliated. The foliated includes slaty cleavage, schistose and Gneissose structures. The non-foliated includes Cataclastic, Hornfelsic and Granulose structures.

Cataclastic structures are those of broken fragments of rocks developed by mechanical deformation. Hornfelsic structures consists of spots as a result of incipient crystallisation. Some parallel, banded or streaky features are common in granulose structures. The foliated structures are divided into three types based on the degree of perfection of the parallel surfaces as Schistose, Gneissose and Slaty cleavage.

Metamorphic rocks may be classified in many ways. The simplest is to divide them into foliated and non-foliated. The other type is, rocks are divided into Marbles, Quartzites, Hornfels, Slates, Phyllites, Schists and Gneisses. Turner a noted petrologist suggested four criteria namely field association, mineral composition, structure and chemical composition for classification. But the ideal basis of classification is concept of metamorphic facies put forward by 'Eskola'. In this the mineral assemblages are considered as a facies.

19.6 CHECK YOUR PROGRESS-MODEL ANSWERS

- 1) Xenoblastic crystals
- 2) Suffix
- 3) (i) Cataclastic (ii) Hornfelsic (iii) Granular
(iv) Foliated structure (Slate) (v) Maculose (Marble) (vi) (Schists & Gneisses)

19.7 MODEL EXAMINATION QUESTIONS

I. Answer the following in about 30 lines each

1. Describe the textures and structures of metamorphic rocks.
2. Explain in detail about the classification of metamorphic rocks.

II. Answer the following in about 10 lines each

1. Foliated structures
2. Explain the terms Foliation and Lineation
3. What criteria Turner described for classification of metamorphic rocks.

* * *

UNIT : 20 MAGMAS AND METAMORPHISM

Contents

- 20.0 Objectives
- 20.1 Introduction
- 20.2 Metasomatism
- 20.3 Pneumatolysis
- 20.4 Injection metamorphism, Granitization, Anatexis and Palingenesis
- 20.5 Petrogenetic Cycle
- 20.6 Summary
- 20.7 Check Your Progress-Model Answers.
- 20.8 Model Examination Questions

20.0 OBJECTIVES

In this unit, we have briefly explained magmas and metamorphism

At the end of this unit, you will be able to

- * define magmas
- * describe the process-metasomatism
- * describe the process-pneumatolysis
- * describe the injection metamorphism, grantization anatexis and palingenesis.

20.1 INTRODUCTION

The effects of Heat, Directed pressure and Uniform pressures on pre-existing rocks have been discussed in the next block. These three agents of metamorphism are factors dependent essentially on depth in the crust. It has been mentioned that metamorphism is a process which takes place essentially in the solid state, facilitated by magmatic fluids. The magmatic emanations play a very important role in all kinds of metamorphism not only because they facilitate the changes but also because they contribute sometimes new materials to the rock or remove material from them. While at lesser depths the magmatic emanations play a prominent role, at greater depths residual magmas or primary magmas themselves may attack the country rocks and bring about significant changes in them.

The large scale magmatic activities are characteristic of the Katazone. Magmatic intrusions apart from being a major source of heat during metamorphism, contribute the medium for metamorphic changes. Magmatic emanations-both liquids and gases-as also residual magmas, play an important role in bringing about changes in pre-existing rocks. Some of the processes which involves the action of these magmatic fluids are briefly explained below.

20.2 METASOMATISM

The process of mineral or rock alteration by agency of solutions is termed as **metasomatism**. The process of alteration involves the enrichment of the rock by new substance brought in from outside and this enrichment takes place by definite chemical reactions between the minerals and the enriching substances. This means that the alterations and replacements are produced by solutions of external origin which bring in new substances. There is thus addition or removal of material. Some geologists, however, consider metasomatism as due to any kind of solution generated within or outside the rock and it need not necessarily include addition of material from outside.

Metasomatic processes are classified based on the kind of rocks they affect as : 1. Metasomatism of carbonate rocks, 2. Metasomatism of silicate rocks and silica. 3. Metasomatism of salt deposits and 4. Metasomatism of sulphide deposits. Of these, the first two are common.

Eskola further simplified and also considered the depositional environment of metasomatism. He classified metasomatism into 5 groups 1. Alkali metasomatism 2. Lime metasomatism 3. Iron-magnetite - silicate metasomatism 4. Metasomatism with the introduction of Si, Sn, B, Li, F, D and S and 5. Carbondioxide metasomatism.

The metasomatism of silicate rocks which is more common is further classified on the basis of the material added whether metallic compounds are added or non-metals and their compounds are added. The first group involves addition of alkalies, magnesia, lime, iron and nickel. The second group involves the action of halogens, sulphur, phosphorous, silica, water and carbondioxide.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

1. Describe the process 'Metasomatism'.

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20.3 PNEUMATOLYSIS

Pneumatolysis or Pneumatolytic metamorphism is defined as the alteration in rocks due to the combined effects of Heat and Magmatic emanations largely consisting of Halogen elements, water, compounds of boron, phosphorous and alkali metals. This process is effected by these agents mainly in the gaseous state and at high temperature. The alteration may effect the igneous rock itself as well as the country rock. The minerals formed include Muscovite, Lithium mica, Fluorite, Topaz, Tourmaline and Apatite.

Pneumatolysis is more common in connection with the intrusion of Granitic magma than with Basic magma. Three main types of pneumatolysis are observed related to granite

intrusions and these are due to the action of water or steam, Boron and Fluorine which are concentrated in the residual liquids towards the end of crystallisation of Granite. Water, Boron and Fluorine together attack the solidified parts of the igneous mass and as a result feldspars are partially replaced by Tourmaline. This process is called **Tourmalisation**. In case of intense activity the feldspars are completely replaced by tourmaline and a rock composed of Quartz and Tourmaline known as **Schorl rock** is formed.

Due to the action of superheated steam and fluorine, the Feldspars in Granites are converted into white mica (Muscovite) which often contains Lithium. The resulting rock is an aggregate of Muscovite and this is called **Greisen** and the process of alteration is called **Greisening**. Topaz is a common constituent of Greisen and it may sometimes be so abundant as to constitute a Topaz rock.

When the Feldspars of Granite attacked by superheated steam aided by a little fluorine and Boron, the mineral Kaolinite is formed. This process is known as **Kaolinisation**.

Intrusion of basic igneous rocks produces less common pneumatolytic effects. In these cases action of Chlorine, Phosphorous, Titanium and their compounds and water is involved. Minerals like Apatite, Rutile and Scapolite are formed.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

2. Name the metamorphic process due to the continued action of Heat and Magmatic emanations.

20.4 INJECTION METAMORPHISM, GRANITIZATION, ANATEXIS AND PALINGENESIS

The effects of residual magmas which form towards the end of the process of crystallisation of primary magma and which are still mobile will now be considered. The residual magmas are rich in water, alkalies, aluminium and silica, that is, in the components of Feldspar and Quartz. The forceful injection of these residual magmas or other undifferentiated granitic magmas into country rocks produces significant mineralogical changes, particularly addition of feldspars or feldspathoids. These changes are referred to as **Injection metamorphism**. The injection of these magmas along the bedding or schistosity of country rock results in the production of banded gneiss or lit-par-lit-gneiss. In those rocks, bands or folia of granitic material alternate with bands of country rock which is more or less altered due to reaction with the magmatic emanations.

Numerous field evidences which indicate large scale invasion of country rock by granitic magmas have been recorded. During these invasions country rock is more or less thoroughly assimilated and complete admixture of material between the country rock and magma takes place.

The resulting pasty mass is rendered gneissose partly due to magmatic flow and partly due to pressure at great depths. This gives rise to what is called the **composite gneiss** or **Migmatite**. In a later stage the gneissic texture may be obliterated and a rock having the characters of granite is produced. These processes whereby solid rocks are changed into rocks of granitic composition and texture without passing through a magmatic stage is referred to as **granitisation**. This regional **granitisation** with the production of a pasty viscous mass possessing some magmatic characters and capable of movement has been called **Anatexis** by Sederholm. It has been visualised by many petrologists that at great depths apart from regional **granitisation**, there are possibilities even for the melting or fusion of metamorphosed country rocks due to the heat from large scale magmatic intrusions. This process of formation of a new magma by the melting or fusion of country rocks with heat from another magma, with or without the addition of granitic material is called '**Palingenesis**' by Sederholm.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answers with the one given at the end of this Unit.

3. Anatexis is the

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4. The process of complete melting of rock is known as

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20.5 PETROGENETIC CYCLE

To summarise the processes involved in the evolution of three major groups of rocks in the crust, we may say that at first the entire crust was igneous and fresh material is being added with every new eruption of magma. Due to the action of external geological forces, these rocks have been changed over into different types of sedimentary rocks. Due to metamorphism these two groups of rocks have been more or less completely reconstituted with new minerals and textures. With the regional melting of the metamorphosed rocks at great depths in the crust, magma is regenerated and the rock cycle starts a new.

20.6 SUMMARY

Along with Temperature, Directed pressure and Uniform pressure, the magmatic fluids are also play an important role in the process of metamorphism. Metamorphism generally takes place in solid state. The magmatic emanations contribute sometimes new material to the rock or remove material from them. The magmatic intrusions contribute the medium for metamorphic changes. Magmatic emanations-both liquids and gases-as also residual magmas play an important role in bringing about changes in pre-existing rocks.

The rock alterations by the influences of solutions is called Metasomatism. The enrichment of the rock by substances brought in from outside occurs in this process. Metasomatic processes are classified initially as four groups but later Eskola classified into 5 groups.

Pneumatolysis is defined as the alteration in rocks due to the combined effects of heat at magmatic emanations largely consisting of halogen elements, Water, compounds of Boron, Phosphorus and Alkali metals. The process occurs in gaseous include Muscovite, Lithium mica, Fluorite, Topaz, Tourmalene and Apatite.

The magmatic fluids involves in Metasomatism, and magmatic gases play a vital role in Pneumatolysis, like wise residual magmas are key in the process of Injection metamorphism. The residual magmas are rich in water, Alkalies, Aluminium and Silica and components of Felspars and Quartz. The forceful injection of residual magmas into country rocks adds Felspars and Felspathoids to them. These changes are called Injection metamorphism.

The field evidences indicate large scale invasion of country rock by granite magmas with this country rock is more or less assimilated. The resulting pasty mass is rendered gneissose partly due to magmatic flow and partly due to pressure at great depths. This results the formation of Migmatites. In a later stage Gneissic texture changes to granitic composition and texture as this transformation is called Granitisation. The processes of formation of pasty viscous mass of magmatic character with regional granitisation is called 'Anatexis'. The process of formation of new magma by melting or fusion of country rocks with heat from another magma without addition of granitic material is called Palingenesis.

20.7 CHECK YOUR PROGRESS - MODEL ANSWERS

1. The metamorphic process by the agency of circulations fluids or solution is termed as metasomatism
2. Pneumatolysis
3. Partial melting of rock
4. Palingenesis

20.8 MODEL EXAMINATION QUESTIONS

I. Answers the following in about 10 lines each.

1. Metasomatism
2. Pneumatolysis
3. Granitization
4. Tourmalinisation
5. Anatexis
6. Palingenesis
7. Schorl rock
8. Lit-par-lit-gneiss
9. Migmatite

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UNIT : 21 CATACLASTIC AND THERMAL METAMORPHISM

Contents

- 21.0 Objectives
- 21.1 Introduction
- 21.2 Cataclastic Metamorphism
 - 21.2.1 Crush Breccia
 - 21.2.2 Cataclasite
 - 21.2.3 Flaser Rocks
 - 21.2.4 Mylonite
- 21.3 Thermal Metamorphism
 - 21.3.1 Hornfels
 - 21.3.2 Quartzites
 - 21.3.3 Marbles
 - 21.3.4 Skarns and Tactites
- 21.4 Summary
- 21.5 Check Your Progress - Model Answers
- 21.6 Model Examination Questions

21.0 OBJECTIVES

The purpose of this unit is to acquaint you with the process of Cataclastic and Thermal metamorphism

After completion of this unit, you should be able to

- * explain the process and products of cataclastic metamorphism.
- * describe the process and products of thermal metamorphism.

21.1 INTRODUCTION

The process of metamorphism occurs in different ways depending upon the dominance of the various agents like temperature, direct pressure, Uniform pressure and Chemically active liquids. Here in this unit the processes of Cataclastic metamorphism and Thermal metamorphism are discussed. Cataclastic metamorphism occurs with directed pressure and Thermal metamorphism takes place with the dominating action of heat.

21.2 CATACLASTIC METAMORPHISM

Cataclastic metamorphism is due to the dominating action of Directed pressure or Stress, of Orogenic or other origin causing folding, faulting, flowage and granulation. The minerals and rocks are subjected to crushing and granulation (cataclastic). As temperature is very low, no new minerals are formed. However, when heat is generated locally due to considerable lateral movement, minerals characteristic of low temperature may be produced.

Fine grained rocks as a whole are subjected to Cataclasis. In coarse grained rocks individual mineral grains are subjected to the effects of crushing. Simple crushing and granulation leads to the formation of a structureless aggregate. But when strong lateral movement takes place as along planes of thrust faults, the broken mineral and rock fragments are rolled out and pulverised and as a result parallel, lenticular and banded structure are produced.

Rocks and minerals show varying degrees of resistance to pressure and susceptibility to fracture and crushing. Harder and more brittle materials are deformed by fracture and crushing whereas softer, less brittle and more soluble materials undergo plastic deformation and even recrystallisation. Therefore hard, brittle and resistant rocks like granites and sandstones show the effects of cataclasis prominently whereas softer and more chemically susceptible rocks such as clay rocks, carbonate rocks and basic igneous rocks do not show significant changes. They may however be deformed by cleavage flow and recrystallisation to some extent.

Crush breccia, Cataclasite, Flaser rocks and Mylonites are the chief products of Cataclastic metamorphism. Slate is also sometimes included in this category. But as slate shows the influence of heat to some degree as revealed by the formation of new minerals, it is described under Dynamothermal metamorphism.

21.2.1 Crush Breccia

This rock, also known as Friction breccia, is characterised by the presence of angular fragments of varying sizes set in a matrix, which is normally subordinate and made up of smaller mineral and rock fragments. Crush breccia is usually coarse grained. Those which are fine grained are called "Microbreccias".

Crush breccia is formed when rocks are merely shattered and pulverised. There is no evidence of lateral thrusting or shearing. Fine grained rocks are affected as a whole while in coarse grained rocks, individual grains may show effects of crushing. The rock is fissured in all directions dividing into angular fragments which are separated from each other by pulverised material.

Crush breccias are derived from hard and brittle rocks like plutonic igneous rocks, Limestones, Marbles and Gneisses. If the fragments are some what rounded by shearing, the term 'Crush Conglomerate' is used.

21.2.2 Cataclasite

Cataclasites are the products of the final stages of cataclasis, while friction breccias belong to the earlier stages. Under the influence of Directed pressure, larger mineral fragments of rocks show optical anomalies or bedding or gliding along cleavage planes in the initial stages. In the next stage, as stress exceeds the elastic limits of the mineral grains, they are flattened, elongated and subjected to peripheral granulation.

21.2.3 Flaser rocks

Unlike crush breccias and Cataclasites, Flaser rocks show evidences of considerable differential movement during crushing. They exhibit parallel structures. Quartz occurring in the original rocks is more easily breakdown than felspar as it is more resistant to granulation. Larger crystals of quartz become enveloped in a mantle of finely crushed material Felspar

crystals are early flattened and fractured. They occur more commonly as porphyroclasts which have been crushed and rolled into lenticular eye-like forms producing 'Augen' structure. These lenticular forms are enveloped by streaks of finely crushed rock in which a considerable amount of recrystallisation may have taken place. However the rocks are not totally transformed. These rocks in which lenticles of relatively unaltered material are preserved in a finely crushed and partially recrystallised matrix are called **Flaser rocks** (Germ Flaser streaks, lenticles). Depending on the original rocks varieties are named as Flaser-granite, Flaser-gabbro etc. These are also called as Augen gneisses because of the banded nature of the rocks.

There may be derived from any type of source rock igneous rocks of Plutonic, Hypabyssal and Volcanic occurrences, Sandstones or Limestones.

21.2.4 Mylonite

Rocks which have been completely pulverised and rolled out by extreme differential movement during cataclastic metamorphism are called Mylonites. These are formed along major fault zones under strong directed pressure. They are chemically stable and do not show evidences of appreciable recrystallisation. They are largely fine grained although some scatterlenses of uncrushed source rock may be seen here and there, aligned with flow or laminated structure in the direction of movement. In spite of their pulverised condition, they are compact and hard. Most Mylonites show laminations with individual bands marked by differences in color, granularity and composition. The amount of recrystallisation varies with the kind of rock acted upon. Quartz whereas Basic igneous rocks are sheared into Chlorite schists showing the dominance of crystallisation over cataclasis.

Along zones of intense and rapid movement, the amount of frictional heat developed is so great that mineral particles may be fused locally and the rock vitrified. The resulting rock materials is a dark glassy material which forms disconnected lenses in some Mylonites. These are called Ultra Mylonites.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.
- 1). Name the products of Cataclastic metamorphism

21.3 THERMAL METAMORPHISM

Thermal metamorphism is due to the dominating action of heat. It includes Contact Metamorphism, Pyrometamorphism, Optalic metamorphism and also Pneumatolytic metamorphism. It is not possible to mark off these types sharply as they pass one into the other gradually. Contact metamorphism takes place at lower temperatures and mineralogical

changes are facilitated by rock moisture and magmatic emanations. Pyrometamorphism is due to the highest degree of heat under relatively dry conditions without actual fusion of rocks. Optallic metamorphism involves the underrating and burning effects produced by lavas or small dykes on rocks with which they come into contact. In Pneumatolytic metamorphism changes are produced with positive additions of material from magmatic sources.

The nature and extent of changes produced by thermal metamorphism depend on a number of factors related to the intrusive mass. These factors are 1. size of the intrusive mass 2. initial temperature 3. rate of cooling 4. depth of the intrusion and 5. chemical composition.

In general, larger intrusive masses produce a greater degree of metamorphism ones. Therefore the contact aureoles around large batholiths may be several miles wide while the contact effects in the case of smaller intrusives like sills and dykes may be limited to a few feet or inches near the contacts. Higher initial temperature and slower rate of cooling produce greater metamorphic effort. The rate of cooling of magmatic body depends to a large extent on its depth in the crust. Intrusive which are deep-seated cool slowly over a long period of time producing greater changes while lavas erupted to the surface cool rapidly, producing feeble effects. The chemical nature of the intrusive is also important. Other things being equal, granites are found to produce greater metamorphic effects than other intrusive bodies. This is because acid magmas are changed with larger quantities of chemically active fluids than other magmas and these fluids greatly facilitate metamorphic changes.

The nature and extent of changes produced also depend on the composition and textural characters of the rocks subjected to metamorphism. Some rocks react quickly to temperature changes while others may not react at all, or may show only in significant changes. For example, Argillaceous rocks, impure limestones and basic igneous rocks are very susceptible to thermal metamorphism and show interesting mineralogical change whereas pure Limestones or Sandstones are stable under metamorphic conditions. These latter rocks are merely recrystallised into granoblastic aggregates.

Rocks which have a porous or open texture are more suitable for metamorphic changes than rocks with close, dense or compact textures because porous rocks permit diffusion of magmatic fluids which play an important role in metamorphism.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

2). Name the factors which control the Thermal metamorphism.

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A group of interesting and commonly occurring rock types are produced by Thermal metamorphism. These include Hornfelses, Quartzites and Marbles. These are described below.

21.3.1 Hornfelses

Hornfelses are formed due to the Contact metamorphism of Argillaceous and similar rocks. They are commonly found in contact aureoles surrounding bodies of plutonic rocks, particularly Granites, Granodiorites and Quartz diorites.

Hornfelses are light to dark coloured, fine grained and usually massive. They show unoriented mineral grains and their texture is said to be Hornfelsic. They are composed mainly of Quartz, Felspar, Biotite, Muscovite, Pyroxenes, Garnet and Calcite. Minerals like Andalusite, Cordierite, Garnet and Vesuvianite commonly occur as large porphyroblasts containing numerous small inclusions. Therefore many Hornfelses show a combination of Prophyroblastic and Granoblastic fabrics. The matrix usually consists of fine-grained Felspar, Quartz, Micas, Magnetite and Graphite. Hornfelses of lower grade commonly show relief textures.

Hornfelses include the following varieties : Pelitic hornfelses are formed from Argillaceous or Pelitic sediments. These are dark, massive and fine grained containing Andalusite (Chistolite variety is more common), or Cordierite or both. These minerals occur as porphyroblasts containing abundant inclusions. Garnet, Biotite and Muscovite may also occur as porphyroblasts. Micas, Felspar and Quartz occur as matrix.

Arenaceous hornfelses are derived from Felspathic sandstones, Arkoses of acid volcanic rocks such as Rhyolites and Dacites. These are usually light coloured, fine grained and unfoliated. They commonly show Granoblastic structure with Prophyroblasts of Quartz, Biotite, Muscovite and Felspars.

Calc-silicate hornfelses are derived from Argilloceous limestones or Dolomites. These are usually light coloured and show a combination of Granoblastic and Prophyroblastic textures. These are composed essentially of lime-bearing silicates such as Calcium plagioclase, Calcite, Vesuvianite, Wollastonite, Scapolite and minerals of Epidote group. Hypersthene, Diopside and Hedenbergite are the common Pyroxenes found in these rocks. Among the Garnets, Andradite and Grossularite are found to occur. Quartz, Graphite and Phlogopite may occur in small quantities.

Mafic hornfelses are formed due to high temperature contact metamorphism of Basalt and Andesite. These are dense, dark coloured and granoblastic aggregates of Calcium-plagioclase, Hypersthene, Diopside and sometimes Olivine, Biotite or Hornblende.

21.3.2 Quartzites

Quartzites are formed by the Contact or Regional metamorphism of Arenaceous rocks such as Sandstones, Felspathic sandstones, Argillaceous sandstones or Calcareous sandstones.

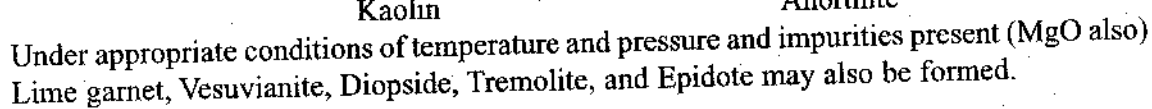
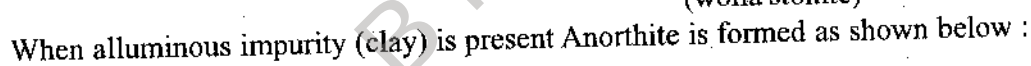
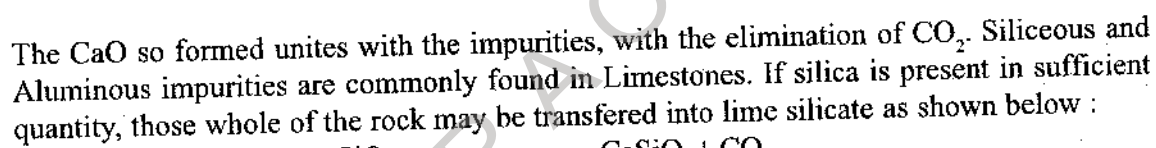
Quartzites are usually Granoblastic showing interlocking grains. They may be banded, thin or thick bedded or laminated. Primary bedding, Crossbedding, Lamination and Ripple marks are commonly preserved in quartzites.

Quartzites consist essentially of Quartz. Pure Quartzite is white. The colour of impure varieties is variable depending on the kind and amount of foreign material, especially iron oxide. Most quartzites contain some grains of Felspar, Magnetite and Chlorite. Sillimanite formed from clay minerals present in the parent rocks may be sometimes seen. Garnet, Apatite,

Varieties of Quartzites are named based on the prominent or characteristic minerals as Micaceous quartzite, Felspathic quartzite, Garnetiferous quartzite, Ferruginous quartzite etc. They also named based on the structural characters, as Banded quartzite, Cross-bedded quartzite etc.,

Marbles are formed due to the Contact or Regional metamorphism of carbonate rocks.

Marbles are composed chiefly of carbonate minerals, particularly calcite. However many other minerals—commonly silicates—may be present depending on the impurities of silica or clay minerals occurring in the original rocks. When pure calcium carbonate rocks (limestones) are subjected to thermal metamorphism, they merely recrystallise giving rise to Crystalline limestone and Marble. But when impurities are present, which is the usual case, calcium carbonate is dissociated as shown below :


$$\text{Ca Mg}(\text{CO}_3)_2 \xrightarrow{\quad\quad\quad} \underset{\text{Dolomite}}{\text{CaCO}_3} + \underset{\text{Calcite}}{\text{MgO}} \cdot \underset{\text{Periclase}}{\text{CO}_2}$$

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Brucite-marbles.

Check Your Progress

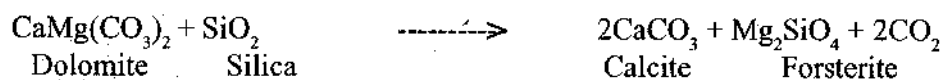
- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

3). Define the term Dedolomitisation.

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The presence of silica and clay impurities facilitates Dedolomitisation. The MgO produced unites with the impurities to form a number of new minerals. With silica as the impurity, Tremolite or Diopside may be formed depending on the amount of Silica present, and the reactions may be represented as follows :

1. With small amount of SiO_2



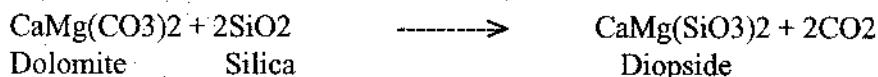
The final product is a forsterite marble. Forsterite on hydration gives rise to Serpentine and the rock is then called Serpentine marble or Opicalcite, which usually shows streaks of beautiful colours.

2. With intermediate amount of SiO_2 :



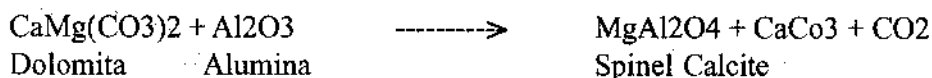
The result is a Tremolite-marble.

3. With large amount of SiO_2 :



The entire rock may be converted to Diopside or a Diopside - marble may be formed.

When Al_2O_3 is present as impurity spinel may be formed.



When both SiO_2 and Al_2O_3 are present, forsterite may be produced along with spinel.

coarse grained iron silicate masses and shows Granoblastic or Porphyroblastic structures, where as Tactites composed of ore minerals and silicates and shows Xenoblastic structure.

21.3.4 Skarns and Tactites

Skarns and Tactites are products related to the Thermal metamorphism of carbonate rocks. The term skarn was originally used to indicate the coarse-grained iron silicate masses occurring as well defined zones at the contact between marbles and plutonic rocks, but now it is used for lime-silicate zones in general. Skarns are lime silicate rocks very rich in iron silicates. They are formed due to Pyrometasomatism.

They may be Granoblastic or even Porphyroblastic. Mineralogically, they are simple, sometimes containing. One mineral-Hedenbergite, Actinolite, Grossularite, Diopside or Wollastonite. Minerals commonly present include Foesterite, Tremolite, Grossularite, Andradite, Epidote, Sphene and Vesuvianite. Calcite may abundant or may be even be totally absent.

'Tactites' are rocks composed of ore minerals and silicates. These are formed by the Thermal metamorphism of carbonate rocks. These rocks are xenoblastic and coarse-grained or crudely foliated, when prismatic and bladed minerals are present. The minerals commonly present include Sphalerite, Galena, Scheelite, Molybdenite, Bornite, Pyrrhite, Pyrotite, Chalcopyrite and Magnetite. The silicates include Tourmaline, Grossularite, Zoisite, Vesuvianite, Chondrorite and Foresterite.

21.4 SUMMARY

The agents of metamorphism are Heat, Pressure and Chemically active fluids and Gases. Directed pressure or Stress is the main agent for Cataclastic metamorphism. Here the minerals are rocks which are subjected to crushing and granulation. Temperature is very low, fine grained rocks are completely subjected to cataclasis and coarse grained rocks only individual grains are effected with crushing. Rocks and minerals show varying degree of resistance to fracture and crushing. Granites and sandstones show the effects of cataclasis prominently. Clay rocks, carbonate rocks and Basic igneous rocks do not show significant changes. The products of Cataclastic metamorphism are crush Breccia, Calacласite, Flaser rocks and Mylonites.

Crush Breccia is characterised by the presence of angular fragments of various sizes set in matrix of small...

UNIT : 22 DYNAMOTHERMAL METAMORPHISM

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22.2 Products

22.2.1 Slates

22.2.2 Phyllites

22.2.3 Schists

22.2.4 Gneisses

22.2.5 Amphibolites

22.3 Summary

22.4 Check Your Progress - Model Answers

22.5 Model Examination Questions

22.0 OBJECTIVES

In this unit, we have presented the process and products of Dynamothermal metamorphism.

Thermal metamorphism is due to the dominating action of heat. It includes Contact metamorphism, Pyrometamorphism, Optalitic metamorphism and also Pneumatolytic metamorphism. Contact metamorphism takes place at lower temperatures, Pyrometamorphism is due to high temperature, Optalitic metamorphism is with the burning effects of lavas and dykes on rocks, and in Pneumatolytic metamorphism positive additions from magmatic sources may take place. The products of thermal metamorphism are Hornfels, Quartzites, Marbles and Skarns and Tactites.

Hornfels are formed due to Contact metamorphism of argillaceous rocks. They are commonly found in contact aureoles surrounding plutonic rocks. The important varieties are pelitic Hornfels, calc-silicate Hornfels, mafic Hornfels and Aenaceous hornfels.

Quartzites are formed by the Contact or Regional metamorphism of arenaceous rocks. These will show Granoblastic texture. Quartzites are composed of essentially of quartz and is available in different colours. The main types are Micaceous quartzites, Felsphatic quartzites, Garnetiferous quartzites and Ferruginous quartzites. Marbles are formed due to Contact or Regional metamorphism of carbonate rocks. These will show Granoblastic structure. The different colours are mainly due to the substances of original source rocks.

Skarns and Tactites are product of thermal metamorphism of Carbonate rocks. Skarns are coarse grained iron silicate masses and shows Granoblastic or Porphyroblastic structures, where as Tactites composed of ore minerals and silicates and shows Xenoblastic structure.

21.5 CHECK YOUR PROGRESS - MODEL ANSWERS

1. a. Crush breccia b. Flaser rocks c. Mylonite
2. Depends on size of intrusive mass, temperature, rate of cooling, depth of intrusion and chemical composition.
3. The destruction of Dolomite and reconstitution of calcite is called Dedolomitisation.

21.6 MODEL EXAMINATION QUESTIONS

I. Answer the following in 30 lines each

1. Explain the process and products of Cataclastic metamorphism
2. What is Thermal metamorphism and what are the products?

II. Answer the following in about 10 lines each

1. Explain the rocks
Hornfels, Quartzite, Marble, Skarn and Tactite
2. Differentiate the following
 - a. Crush breccia - Cataclasite
 - b. Flaser rocks - Mylonites
3. What is Ultra mylonite ?
4. What is crush conglomerate ?

* * *

UNIT : 22 DYNAMOTHERMAL METAMORPHISM

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- 22.0 Objectives
- 22.1 Introduction
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- 22.4 Check Your Progress - Model Answers
- 22.5 Model Examination Questions

22.0 OBJECTIVES

In this unit, we have presented the process and products of Dynamothermal metamorphism.

At the end of this unit, you will be able to

- * describe the process of dynamothermal metamorphism
- * describe the products of dynamothermal metamorphism

22.1 INTRODUCTION

Dynamothermal metamorphism is due to the combined action of Directed pressure and Heat or sometimes referred to as Regional metamorphism. The Heat factor brings about recrystallisation, while Directed pressure results in the deformation of rocks and production of new structures. The new structures are characterised by foliation, with minerals oriented perpendicular to the direction of greatest stress and parallel to the direction of least stress. The deformation involves the interaction of three processes which are termed as Clastic, Plastic and Blastic processes.

In the Clastic process, the minerals present in the rocks are fractured ruptured and rolled out. During Plastic deformation, the rocks and minerals, under powerful confining pressure, stretch and flow by movement along cleavage and gliding planes without any rupture. This is called **Fractureless deformation**. Under suitable conditions of pressure and temperature even minerals like Calcite and Quartz can be flattened and pressed out into ribbons.

Blastic deformation is due to the processes of recrystallisation. The original minerals are

elongated perpendicular to the direction of the greatest pressure and new minerals which are suited to the stress conditions are formed, in other words, stress minerals are developed.

It is probable that the three processes referred to above may be operation simultaneously during dynamothermal metamorphism. However, all minerals are not equally susceptible to the operation of these processes. Some are fractured or ruptured while others are elongated by flow and recrystallisation. The ultimate products are more or less completely recrystallised rocks with partially changed or altogether new textures and structures.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

- 1). The deformation involves the interaction of three processes, name them

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22.2 PRODUCTS

The most commonly occurring and very interesting group of metamorphic rocks are produced by dynamothermal metamorphism. These include Slates, Phyllites, a large variety of Schists and Gneisses and Amphibolites.

22.2.1 Slates

Slates are fine grained rocks with a highly developed planar Shistosity, also called as **Slaty cleavage**, because of which they split readily smooth, flat, closely spaced parallel surfaces. The Slaty cleavage which is due to the dominant orientation of flaky minerals is always at an angle to the relict bedding. Lineation may also be present. They do not show any segregation banding. The mineral components are too small to be identified with the naked eye, except for a few porphyroblasts that may occur in some slates. Even under the microscope some of the materials remains unidentified.

The main mineral components are Quartz, Felspar, Chlorite, Sericite, Biotite, Magnetite, Hematite, Pyrite, Calcite, Dolomite and Organic materials. X-ray studies of the cryptocrystalline matrix reveal that it consists chiefly of minerals of the Chlorite type and of some Clay minerals.

Slates show different colours-grey, black, purple or red and sometimes shades of green. Slates are formed by Lowgrade Regional metamorphism of argillaceous rocks like Shales, Mudstones and Clay stones.

22.2.2 Phyllites

Phyllites are formed from slates due to increasing temperature or greater activity of fluids in slightly higher grade of metamorphism. These are fine grained and micaceous, occasionally with segregation banding. Due to the presence of minerals such as Micas, particularly Sericite, and Chlorite, Phyllites show a satiny lusture along the surface of schistosity. In grain size and mineral composition Phyllites lie between Slates and Schists. A high degree of mineral orientation is characteristic of Phyllites.

Phyllites are composed chiefly of fine grained Sericite or Muscovite, Chlorite, Quartz and minor amounts of Magnetite, Hematite, Graphite, Pyrite and Tourmaline. In calcareous types Calcites and Epidote may be present. Mineralogically Phyllities fall into three types as Sercite-phyllites, Chlorite-phyllites and Sericite-chlorite-phyllites.

Phyllites are formed due to Low-grade Regional metamorphism of argillaceous rocks and tuffaceous sediments.

22.2.3 Schists

The schists are so named because of their characteristic Schistosity or foliation which is due to the mineral orientation. Segregation layering showing alternation of Micaceous and Quartz-felspathic streaks is usually well developed. The mineral grains are coarse enough to be identified in a hand specimen.

Schists show great variations in mienrals and structures. Schists may be Monomineralic or Polymineralic. Chlorite schists, Actinolite schists, Muscovite schists and Talc schists are examples for Monomineralic schists, most schists however, contain two or more minerals as in Calcite-sericite schists, Sericite-albite schists, Sillimenite-garnet-quartz-felspar schists etc. Some Calcite schists are ideally schistose as in Biotite schist or Actinolite. Others like Hornblende schist and Tourmaline schist are well-lineated. Still others show porphyroblasts of Garnet, Staurolite, Kyanite and K-felspar.

Depending on the conditions of temperature and pressure at the time of formation, schists may be broadly divided into two categories, namely Low-grade schists and High grade schists.

The Low-grade schists are characterised by the presence of low temperature minerals like Albite, Muscovite, Chlorite, Actinolite and Talc. They are product of Low grade metamorphism and mostly confined to the outer and upper zones of areas affected by Regional metamorphism.

Muscovite schists, Muscovite-biotite schists and Biotite schists are derived from argillaceous rocks. Quartzo felspathic schists are derived from Arenaceous rocks. Calc-schistose marbles containing chiefly Calcite and small amounts of Quartz, Felspar, Muscovite, Chlorite, Epidote etc., that are derived from impure carbonate rocks, Chlorite, and Actinolite schists are derived from mafic and ultramafic igneous rocks.

The High grade schists are characterised by the presence of high temperature minerals like Garnet, Biotite, Sillimanite, Staurolite, Cordierite, Andalusite and Kyanite. Quartz, K-felspar and Plagioclase occur abundantly in siliceous derivatives. They are markedly foliated and

porphyroblastic. The High-grade schists are formed due to Regional metamorphism at greater depths in the earth's crust.

Highgrade schists derived from argillaceous rocks are characterised by the occurrence of Aluminium silicates such as Staurolite, Kyanite, Cordeirite Sillimanite and are named based on the mineral, present as Staurolite schists, Kyanite schists, Staurolite-kyanite schists etc. Quartz, K-felspar Na-plagioclase, Garnet, Micas, Graphite, Iron ores may be present in some varieties depending on the original composition of the sediments.

Calc-schists or Schistose marbles containing Calcite and other minerals like Diopside, Zoisite, Biotite, Phlogopite, Grossularite and Ca-plagioclase are derived from calcareous rocks. Quartz and Felspar rich varieties derived from siliceous igneous rocks and from impure arenaceous rocks. Hornblende schists are derived from Basic igneous rocks.

22.2.4 Gneisses

The term 'Gneiss' is used to include all coarse grained quartzo-felspathic rocks of diverse origin characterized by gneissic structure. Like Schists, Gneisses occur in great variety and are named variously. The terms Granite-gneisses, etc., refer to the composition of original rocks while the terms Augen gneisses, Banded gneisses and Injection gneisses refer to the conspicuous structures and the terms Biotite gneiss, Kyanite gneiss, Staurolite gneiss refer to the mineral composition.

Gneisses show well-defined planar orientation. The structure is formed by alternating concentrations of dark and light minerals or by variations in grain size or by concentration of pink and white feldspars in different layers. With disappearance of Gneissic banding, Gneisses may pass gradually into the Granitoid igneous rocks.

Quartzo-felspathic gneisses contain Quartz and Felspar, mainly Orthoclase, Microcline and Perthite. These are formed by the deep-seated High grade metamorphism of acid igneous rocks and arenaceous rocks.

Pelitic gneisses are formed by Regional metamorphism of argillaceous rocks. They are characterised by minerals like Sillimanite, Kyanite, Andalusite, Cordierite and Staurolite.

Calc-gneisses result from Regional metamorphism of Limestones containing large amounts of sand and clay. They contain Calc-silicate minerals like Diopside, Tremolite, and Scapolite and Carbonates. Grossularite and Wollastonite may be found in some varieties.

Hornblende gneisses are essentially Hornblende-felspar-quartz rocks and are derived from mafic igneous rocks.

The term 'Para-gneisses' and 'Ortho-gneisses' are used to indicate gneisses derived respectively from sedimentary rocks and igneous rocks.

22.2.5 Amphibolites

Amphibolites are metamorphic rocks composed essentially of Hornblende and Plagioclase.

Garnet and Mica may present in some varieties. The foliation is found in varieties containing Mica and is mainly due to the alignment of Hornblende and Biotite. Amphibolite may be coarse grained or fine grained, they may be homogeneous or show segregation of dark minerals.

Amphibolites are formed by Regional metamorphism of moderate to high grade. These are formed from certain rocks of igneous and sedimentary origin, but more commonly from mafic to ultra-mafic igneous rocks. Amphibolites are usually metamorphosed gabbros.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

- 2). List out the products of Dynamothermal metamorphism.

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22.3 SUMMARY

Dynamothermal metamorphism is due to the combined action of Directed pressure and Heat. Sometimes this process is also called as Regional metamorphism. The heat factor brings about recrystallisation while the Directed pressure involves deformation. The Deformation will occur as Clastic, Plastic and Blastic processes. In the Clastic processes the minerals present in rocks are fractured, ruptured and rolled out. During plastic deformation the rocks and minerals under confining pressure, stretch and flow by movement along cleavage and gliding planes without any rupture. Blastic deformation is due to the process of recrystallisation and new minerals are formed, which are suited to the stress conditions. The ultimate products are more or less completely crystallised rocks with partially changed or altogether new structures and textures. The Products of Dynamothermal metamorphism are Slates, Phyllites, Schists, Gneisses and Amphibolites.

Slates are fine grained rocks with highly developed Schistosity, because of which they split parallel to the surfaces. The important minerals are Quartz, Felspar, Chlorite, Sericite, Biotite, Haematite, Magnetite, Pyrite, Calcite, Dolomite and Organic matter. Slates are formed by lowgrade regional metamorphism of argillaceous rocks like Shales, Mudstones and Claystones.

Phyllites are formed from slates due to increasing temperature. Here also source rocks are the argillaceous rocks. The minerals include are Micas particularly Sericite, Chlorite etc. These are fine grained rocks. Calcite and Epidote may also present. These are again grouped as Sericite phyllites, Chlorite phyllites and sericite. Chlorite and phyllites, sericite-Chlorite-Phyllites, schists are characterised by schistosity or foliation. Segregation bands are common.

Schists may be Monomineralic or Polymineralic. Depending upon the conditions of pressure and temperatures at the time of formation, Schists are grouped as Low-grade schists or High grade schists. Schists are derived mainly from argillaceous rocks, sometimes from carbonates and mafic rocks.

The coarse-grained quartz-felspathic rocks are called Gneisses and are characterised by Gneissic structures. These are formed by the deep seated High grade metamorphism of acid igneous rocks and amaceous rocks. Pelitic gneisses are formed by Regional metamorphism of argillaceous rocks. Calc-gneisses are due to Regional metamorphism of Limestones. Hornblend gneisses are formed from mafic igneous rocks.

Amphibolites and metamorphic rocks mainly composed of Hornblend and Plagioclase. The texture is Granoblastic. These are formed by Regional metamorphism of low to high grade and are formed from mafic to ultra-mafic igneous rocks. Amphibolites are usually metamorphosed Gabbros.

22.4 CHECK YOUR PROGRESS - MODEL ANSWERS

1. i) Clastic ii) Plastic iii) Blastic processes
2. i) Slate, ii) Phyllites iii) Schists iv) Gneisses v) Amphibolites.

22.5 MODEL EXAMINATION QUESTIONS

- I. Answer the following questions in 10 lines each
1. Explain the following terms :
 - a. Clastic deformation
 - b. Plastic deformation
 - c. Blastic deformation
2. Write petrographic notes on the following :
 - a) Slate b) Phyllite c) Schist d) Gneiss e) Amphibolite
3. Name some common varieties of Schists and Gneisses and comment about their origin.

UNIT : 23 PLUTONIC METAMORPHISM

Contents

- 23.0 Objectives
- 23.1 Introduction
- 23.2 Products
 - 23.2.1 Granulites
 - 23.2.2 Charnockites
 - 23.2.3 Eclogites
- 23.3 Summary
- 23.4 Check Your Progress - Model Answers
- 23.5 Model Examination Questions

23.0 OBJECTIVES

In this unit, we have presented the process and products of Plutonic metamorphism

At the end of this unit, you will be able to

- * describe the process of plutonic metamorphism
- * explain the products of plutonic metamorphism

23.1 INTRODUCTION

At great depths in the earth's crust, that is in the Katazone, Temperature is very high and Directed pressure becomes negligible while Uniform pressure becomes a dominating factor. Changes produced in rocks due to the combined action of Heat and Uniform pressure at great depths are included under the term Plutonic metamorphism. At these depths large scale magmatic intrusions, especially those of Granitic magma, are a characteristic feature and the phenomena connected with the injection of large quantities of magma and magmatic emanations deserve special consideration. In other words both Plutonic metamorphism and action of magmas and magmatic emanations are characteristic of the Katazone. The effects of Plutonic metamorphism are discussed in this Unit.

The influence of Directed pressure being practically absent, parallel structures which are characteristic of Dynamothermal metamorphism are not conspicuous in the products of Plutonic metamorphism. These rocks, on the other hand, exhibit even-grained and granular structures which lack the directional element. The formation of antistress minerals of high density but lesser specific volume is favoured under conditions of plutonic metamorphism. Quartz, Felspar, Garnet, Pyroxene, Corderite and Sillimanite are the common constituents of the rocks resulting from Plutonic metamorphism. As recrystallisation without any marked directional features is the main features of these rocks, they sometimes bear close resemblances to the products of extreme thermal metamorphism.

Another point to be noted here is that both plutonic igneous rocks and the products of plutonic metamorphism are formed at great depths in the earth's crust under almost similar

conditions and has such it becomes sometimes difficult to distinguish between these two groups unless characterised by specific mineral assemblages or textures.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

- 1). The Plutonic metamorphism takes place in which zone

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23.2 PRODUCTS

Pyroxene bearing rocks are abundant among the product of Plutonic metamorphism. Granulites, Charnockites and Eclogites are the important types.

23.2.1 Granulites

The term Granulites normally refers to a rock with Granulose or Granoblastic fabric. In mineral composition Granulites may be Quartz-felspathic or Pyroxene-bearing.

The typical Granulites are light coloured rocks consisting of Xenoblastic feldspar and Quartz, frequently with abundant Pyroxene and Garnet. Sillimanite, Kyanite, Spinel etc., may be present occasionally in small quantities. The typical texture is that of a Granulose gneiss. Foliation determined by the alternation of coarse elongated Quartz grains with layers containing fine grains of other minerals is characteristic of these rocks. These are mostly derived from igneous rocks and arkoses or felspathic sand-stones.

Leptite is a term now extensively used to indicate fine-grained granulose metamorphic rocks, which are composed chiefly of Quartz and Feldspars, with subordinate mafic minerals, including Biotite, Hornblende, and occasionally Garnet. They have a wide range of composition from almost pure Quartzite to Amphibolite, and undoubtedly represent a great variety of original rock types. Eskola distinguishes blastoporphyritic leptites which have been derived from porphyritic acid igneous rocks and even-grained leptites probably of sedimentary or tuffaceous origin. A cordierite-leptite has the composition of an argillaceous sediment.

Leptitic rocks clearly derived from granite porphyry and Aplite occur in Benguela (Portuguese West Africa), where they are intrusive into an Archaean basement, and have been immersed, as have the Finnish examples, in immense granite batholiths. In both regions, as also in Peninsular India, rocks of this character are associated with Scapolite and Cordierite-bearing granulites, and with members of the Charnockite series.

PYROXENE-GNEISS, PYROXENE-GRANULITE : Pyroxene-bearing rocks are abundant under conditions of Plutonic metamorphism. Associated with the common types of the Saxon

granulites there are dark varieties which are rich in pyroxenes (Augite and Hypersthene) and Plagioclase. Alkali-felspar may sometimes occur, Garnet is often an important accessory, and there are Quartz-rich, Quartz-poor, and Quartz-free varieties. Most of these rocks have a typical Granulose structure (Pyroxene-gneiss). The Pyroxene-granulites of Saxony seem to have been basic igneous rocks which have acquired their present mineral composition and texture by slow recrystallisation under conditions of great uniform pressure and heat. The gneissose structure of some varieties may have been impressed by load metamorphism.

Pyroxene-gneisses and Granulites have been described from many parts of the world, but almost exclusively from Archaean Basement complexes. Thus from the Lewisian Gneiss of the North-west of Scotland, Garnetiferous hypersthene-augite-plagioclase-granulites have been described, in which, as in the Saxon rocks, and in the charnockite series, all the minerals are xenoblastic and extraordinary freshness. Some varieties of pyroxene-granulites and gneisses in this locality contain Quartz. They are believed to be all of Plutonic igneous origin.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

2). What are the products of Plutonic metamorphism ?

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23.2.2 Charnockites

The charnockites series of India and other localities, although usually ranked as igneous rocks, may also be considered in this connection. Charnockite itself is a granular Hypersthene granite; the Charnockite series comprises a group ranging from Charnockite, through intermediate and basic rocks (Quartz-norite and Norite), to pyroxenites, all characterised by the abundance of Pyroxenes, especially Hypersthene. They are unquestionably of plutonic igneous origin, and are most often of Archaean age. The evidence for metamorphic recrystallisation is found in their well marked xenoblastic texture, like that of a coarse Hornfels; the ideal freshness of the minerals; the occasional presence of Gneissose banding; and the appearance of myrmekitic Quartz-felspar growths or Quartz de corrosion. The occasional abundance of garnet without signs of concomitant dynamic metamorphism, and of sporadic round quartz grains enclosed in feldspars and mafic minerals alike, may also be regarded as signs of metamorphism. This constituent possibly represents silica set free during recrystallisation, like the round quartz grains of an Amphibolite.

The peculiar characters of rocks of the Charnockite series may be explained in two ways : they are either of primary igneous crystallisation under conditions of high temperature and great uniform pressure; or they represent plutonic igneous rocks of the usual characters which have undergone slow recrystallisation in the solid state on being subjected to conditions of plutonic metamorphism. In this connection it may be noted that the analysis of the

Charnockite series; and it is therefore conceivable that the Charnockite series represents these rocks transformed by recrystallisation without notable chemical change.

In India these rocks are formed as layers along the gently folded Archean formations. Later these are exposed to Regional metamorphism. Charnockite series is seen mainly as an associated rocks of Hypersthene granites, because these are always available with Pyroxene granulites and Sillimanite gneisses. Sir Thomas Holland named these rocks as Charnockites in memory of Job Charnock, the first mayor of Calcutta city.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

- 3). How does Charnockite get that name ?

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23.2.3 Eclogites

Eclogite is a coarse grained granulose rock consisting of Garnet and Pyroxene Rutile, iron ores, and Apatite, may occur as subordinate constituents; and various other minerals, such as Quartz, Kyanite, Sillimanite, Felspars, Bronzite, and Olivine, may replace Pyroxene to such an extent that the rock passes over to the group of Garnet-amphibolite. Most frequently, Eclogites and the associated Garnet-amphibolites occur in Archaean formations. Their mode of occurrence and chemical composition suggest derivation from basic igneous rocks, especially Dolerite and Gabbro. Under conditions of Plutonic metamorphism, Lime-soda-plagioclase is unstable; the Anorthite molecule reacts with original Olivine or Augite so as to form Garnet; and the Albite molecule enters into the Pyroxene to form Omphacite. Jadeite itself appears in many Alpine eclogites. Any alumina remaining after the above reactions are completed may unite with silica to form Kyanite or Sillimanite. Eclogites may also be of primary igneous origin, being due to the direct crystallisation of a basic magma under conditions of great hydrostatic pressure. These eclogites as a whole are poor in alkalies and rich in chromium oxide.

Eskola believes that this variety of eclogite represents the dark segregations common in Granites, which have been recrystallised, along with the surrounding granite-gneiss, under conditions of Plutonic metamorphism.

23.3 SUMMARY

At greater depths that is in Katazone, Temperature is very high and Directed pressure become negligible, while Uniform pressure becomes a dominating factor and the changes produced under such conditions are included under Plutonic metamorphism. The rocks so produced

exhibits even-grained and granular structures. Quartz, Felspar, Garnet, Pyroxene, Cordierite and Sillimanite are the common constituents of these rocks. Recrystallisation without any marked directional features is the main character in Plutonic metamorphism. Both Plutonic igneous rocks and products of Plutonic metamorphism are formed at great depths under almost similar conditions and become difficult to separate. Pyroxene bearing rocks are abundant. The main products of plutonic metamorphism are Granulites, Leptites, Pyroxene - granulites, Charnockites and Eclogites.

Granulites normally refers to rocks with granulose or granoblastic fabric. In mineral composition, these rocks may be Quartz - feldspathic or Pyroxene bearing. Along with Quartz and Felspars, the rocks are also having pyroxene and garnet. These are mostly derived from igneous rocks and arkoses or feldspathic sandstones.

Leptite rocks are fine grained, granulose metamorphic rocks. These rocks consists of Quartz and Felspar with subordinate mafic minerals. These are derived from porphyritic igneous rocks and tuffaceous sediments.

Pyroxene granulites are the other types, and these are showing Xenoblastic fabric. Most of the rocks are showing typical granulose texture, with the mixing of Pyroxene and Granulites. They are believed to be all of Plutonic igneous origin.

Hypersthene bearing granites are called Charnockites. The rocks which are showing the presence of Hypersthene are called Charnockitic series. In otherwords, the Hypersthene-quartz-felspar rocks are called Charnockites. They are either of primary igneous crystallisation under conditions of high temperature and great uniform pressure or they represent plutonic igneous rocks of usual characters.

Eclogite is coarse grained granulose rock, consisting of Garnet and Pyroxene. The word Eclogite can be used from Pyroxene-garnets to Plagioclase - Amphibole - Kyanite rocks. Eclogites represents the dark segregations common in Granites.

23.4 CHECK YOUR PROGRESS - MODEL ANSWERS

1. Katazone
2. Graunulites, Charnockites and Eclogites
3. Holland a noted Petrologist named the Hypersthene granites as Charnockites in memory of the founder, Mayer of Calcutta Job Charnock.

23.5 MODEL EXAMINATION QUESTIONS

- I. Answer the following questions in about 30 lines
 1. Explain the processes and products of Plutonic metamorphism.
 2. Describe the rock series of Charnockites and Granulites.
- II. Answer the following questions in about 10 lines
 1. Granulites
 2. Pyroxene-gneiss
 3. Eclogite rocks.

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UNIT : 24 TYPICAL INDIAN ROCKS

Contents

- 24.0 Objectives
- 24.1 Introduction
- 24.2 Indian Rocks
 - 24.2.1 Charnockites
 - 24.2.2 Khondalites
 - 24.2.3 Gondites
 - 24.2.4 * Kodurites
 - 24.2.5 Deccan traps
- 24.3 Summary
- 24.4 Check Your Progress - Model Answers
- 24.5 Model Examination Questions

24.0 OBJECTIVES

In this unit, we have presented the description of typical Indian rocks.

At the end of this unit, you will be able to

- * describe the important Indian rocks.
- * explain the occurrence of Indian rocks.

24.1 INTRODUCTION

Almost all known types of Igneous, Sedimentary and Metamorphic rocks are found to occur in the Indian sub-continent. These types were studied and described in research papers, reports and other publications connected with geological investigations. It is not possible to give an account of all these types as they are numerous. Certain rock types, however, of typical Indian occurrence are considered to be very peculiar in their characters and are given. Under this category some of the rocks known as Charnockites, Khondalites, Kodurites and rocks of the Deccan traps are described below.

24.2 INDIAN ROCKS

24.2.1 Charnockites

Sir. T.H. Holland was the first to discover the occurrence of a Hypersthene-granite composed of Hypersthene, Microcline, Quartz and accessory Iron ores at Pallavaram near Madras. He found that this rock formed large masses associated with granulitic rocks, having the mineral composition of Norite. He named this rock 'Charnockite' in honour of Job Charnock, the founder of Calcutta, whose tombstone was found to have been made of this rock.

According to Holland, the Charnockite is not a single type of rock but includes a number of lithological types genetically related to it. To all these types, he gave the name the Charnockite

series. All these types are characterised by the presence of Enstatite and a high proportion of dark ferro-magnesian minerals which impart to the rock its dark colour.

Holland divided the Charnockite series into four divisions which are not sharply marked off from each other. These are called the Acid, Intermediate, Basic and Ultrabasic divisions.

The Acid charnockites to which the name 'Charnockites' was restricted by Holland - are Hypersthene granites and are typically developed in the central position of Magazine Hill near St. Thomas Mount in the suburbs of Madras city. They are coarse-grained and composed of greenish grey Microcline, blue Quartz, Plagioclase and Hypersthene. Garnet is reported in some varieties.

The intermediate Charnockites are most abundant. The Shevroy hills near Salem are typical exposure. These rocks are characterised by a composite structure and all the minerals found in the acid and basic divisions are frequently found in the same specimen. The Basic and Acid portions are arranged in parallel bands or distributed in irregular patches.

The Basic Charnockites are equivalent to Norite and are composed of Hypersthene, Augite plagioclase and Iron ores, often with Hornblende. Typical rocks are found in the flanks of the hill near St. Thomas Mount. These rocks are **granulitic** in texture.

The Ultrabasic varieties are Pyroxenites and occur as schlieren or as veins and dykes in the Norites mainly in the low hills near Pallavaram. They are dark, medium-grained rocks consisting almost entirely of dark Hypersthene (Bronzite).

The origin of Charnockites some consider them to be plutonic igneous rocks. Their field relations possession of features which are regarded as evidences of magmatic segregation and differentiation. Intrusion of dykes into surrounding rocks and well defined contact effect at junction with other rocks are the evidences cited for their igneous origin. Others consider them to be products of Plutonic metamorphism of some igneous and some sedimentary rocks at high temperature and pressure at great depths in the crust (Katazone). Yet others consider them to be Hybrid rocks.

In India, the Charnokite series is mainly confined to South India. The chief occurrences are found in the Nilgiris, Palanis, Annamalai and Shevroy Hills in Tamilnadu and the Eastern ghats in Visakhapatnam and Krishna Districts in Andhra Pradesh. Minor occurrences are found in Karnataka, Madhya Pradesh and West Bengal.

Check Your Progress

- Note :** a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

- 1). Hypersthene granite is other wise known as

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24.2.2 Khondalites

Khondalites occur as a common associate of Charanockites in the Eastern part of India, particularly in the Eastern ghats. The name was proposed by T.L. Walker after the hill tribe called Khonds, who inhabited the hills in Orissa.

Khondalites are foliated rocks comprising of Quartz, Garnet, Sillimanite and Graphite. They are grey to red in colour and show numerous small red Garnets. These are called as Garnet-graphite schists or gneisses. These rocks are mined for graphite in Andhra Pradesh.

Khondalites are considered to be para-schists and para-gneisses having formed, due to the metamorphism of Alumina rich clay rocks.

Khondalites are found chiefly in Orissa, Andhra Pradesh, Madhya Pradesh and Tamilnadu.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

- 2). Name the minerals present in Khondalites.

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24.2.3 Gondites

The names 'Gondites' was coined by L.L. Fernor, after the Gonds of Madhya Pradesh to designate certain metamorphic rocks rich in Manganese silicates. The Gondites are composed largely of Quartz, Spessartite, Rhodonite, and other Manganese silicates. The rocks are either massive or banded. These are formed due to the Regional metamorphism of Manganiferous sediments.

The Gondites occur in Madhya Pradesh, Maharashtra and Orissa where Manganese ore deposits are found to occur associated with them. These ore deposits are considered to have formed due to chemical alteration of the Manganese minerals in Gondite.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

- 3). Gondites are host rocks for metallic mineral. Name it.

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24.2.4 Kodurites

Kodurites are so named after the village Kodur in Visakhapatnam district in Andhra Pradesh by L.L. Fermor. These are found to occur in association with the Khondalites in the Eastern ghats and are considered to be Hybrid rocks. They consist of Quartz, Felspar, Spessartite, Rhodonite and Apatite in various proportions. Altered portions of these rocks have given rise to manganese ores in Kodur, Garbham and other places in Visakhapatnam district in Andhra Pradesh and in Ganjam district in Orissa.

Kodurites are formed due to the metamorphism of mixtures of varying proportion of a manganiferous sediment and igneous rocks of acid to intermediate composition.

24.2.5 The Deccan Traps.

The Deccan traps are lava flows of basaltic composition occurring an about 5,16,000 square kilometers covering parts of Gujarat, Maharastra, Madhya Pradesh and Andhra Pradesh. These are called traps because of the flows produce step like topogrophy (traps: Swedish term meaning 'stairs' or steps). They are sometimes referred to as plateau basalts because they form plateau-like land forms. The lavas are essentially horizontal and are considered to have formed due to the accumulations of a number of flows which erupted at intervals through several fissures in the earth's crust. The individual flows vary in thickness and the average thickness is about 16 mts. The maximum thickness of the Deccan traps is more than 180 mts near Bombay.

The chief rock type of deccan traps is Basalts. In a few places in Western India the traps show a variety of differentiated types such as Rhyolite, Obsidian, Trachyte, Andesite, Olivine-gabbro etc. The Deccan trap basalts are black or dark grey, fine grained, hard and compact rocks, showing remarkable uniformity in texture and composition. Non-porphyritic types are more common than porphyritic types. Amygdaloidal structure with infillings of various forms of Silica, Zeolites and Calcite are very commonly seen. Columnar structures seen in some areas as near Hoshangabad in Narmada valley and in the Sills of Satpura hills. Beds of volcanic ash associated with flows are common. Spheroidal weathering is characteristic. The traps, on weathering, give rise to black soil. In place with tropical climate, Laterite is formed from them.

Check Your Progress

- Note : a). Space is given below for writing your answer.
b). Compare your answer with the one given at the end of this Unit.

- 4). Kodurite is a typical example of

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24.3. SUMMARY

Sofar from 1 to 23 units, you are learned about various types of Igneous, Sedimentary and Metamorphic rocks. Now we have given in this unit about some important and peculiar rocks identified in India Only. It is not possible to explain in detail of all these types, as they are numerous. However, certain important rocks such Charnockites, Khondalites, Kodurites, Gondites, and Deccan Trap rocks are described below.

Holland, a noted Petrologist named Charnockites for the Hypersthene-granite rocks occurred at Pallavaram near Madras. He coined Charnockite term in honour of Job Charnock, the founder of Calcutta. Charnockite is not a single rock but includes many. All these types are termed as Charnockite series. These are of four groups namely Acid, Intermediate, Basic and Ultra basic groups. Regarding its origin some considered as Plutonic igneous rocks and other as the products of Plutonic metamorphism. The chief occurrences are found in Nilagiris, Palanis, Annapalem and Shevroy hills in Tamilnadu and Eastern ghats of Andhra Pradesh, and minor occurrences are found in Karnataka, Madhya Pradesh and West Bengal.

Khondalite occurs as a common associate of Charnockites particularly in the Eastern ghats. The name was coined by T.L. Walker after the hill tribe of Orissa called Khonds. Quartz, Garnet, Sillimanite and Graphite are the essential minerals. These rocks occur in Orissa, Andhra Pradesh, Madhya Pradesh and Tamilnadu.

The manganese silicate rich metamorphic rock is called Gondites after the Gonds tribe of Madhya Pradesh. These rocks consist of Quartz, Spessartite, Rhodonite and other Manganese silicates. These are formed due to Regional metamorphism of manganeseiferous sediments. The Gondites occur in Madhya Pradesh, Maharashtra and Orissa.

Kodurites are so named after the village Kodur in Visakhapatnam district of Andhra Pradesh. These are found to occur as associate of Khondalites. They consist of Quartz, Felspar, Spessartite, Rhodonite and Apatite. These are famous in Visakhapatnam district of Andhra Pradesh and Ganjam District in Orissa.

The other important rocks of India are Deccan trap rocks. The Deccan trap rocks are of basaltic composition. Basalts are the chief rock type and are black or dark grey in colour. These are fine-grained, hard and compact rocks. Spheroidal weathering is the characteristic indication. These rocks on weathering give rise to black soil. Laterite is formed from this Basalts in the areas of tropical climate. These rocks spread over the parts of Gujarat, Maharashtra, Madhya Pradesh and Andhra Pradesh.

24.4 CHECK YOUR PROGRESS - MODEL ANSWERS

- 1). Charnockite
- 2). Quartz, Garnet, Sillimanite and Graphite
- 3). Manganese
- 4). Hybrid rocks.

24.5 MODEL EXAMINATION QUESTIONS

I. Answer the following questions in about 30 lines.

1. Write notes on 'Charnockite Series'.
2. Describe the Deccan traps with reference to their distribution, mode of occurrence and petrographic characters. Comment about their mode of formation.

II. Answer the following questions in about 10 lines each.

- 1). Charnockites
- 2). Khondalites
- 3). Gondites
- 4). Kodurites

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SYLLABUS

BLOCK - I : OPTICAL MINERALOGY

- Unit - 1 : Scope and Development of Optical Mineralogy
- Unit - 2 : Description of a Polarising Microscope
- Unit - 3 : Optical properties of Minerals
- Unit - 4 : Isotropic and Anisotropic substances, Uniaxial and Biaxial Minerals

BLOCK - II : PETROLOGY - IGNEOUS ROCKS

- Unit - 5 : Petrology - Classification of Rocks
- Unit - 6 : Forms and Structures of Igneous Rocks
- Unit - 7 : Textures and Microstructures of Igneous Rocks
- Unit - 8 : Classification of Igneous Rocks

BLOCK - III : IGNEOUS PROCESSES

- Unit - 9 : Magmas - Their behaviour
- Unit - 10 : Crystallisation of Magmas
- Unit - 11 : Origin of Igneous Rocks
- Unit - 12 : Description of Igneous Rocks

BLOCK - IV : SEDIMENTARY ROCKS

- Unit - 13 : Formation of Sedimentary Rocks
- Unit - 14 : Sedimentary Rocks - Properties
- Unit - 15 : Classification of Sedimentary rocks - Clastic rocks
- Unit - 16 : Classification of Sedimentary rocks - Non-Clastic rocks

BLOCK - V : METAMORPHIC ROCKS

- Unit - 17 : Metamorphism - Agents and Kinds
- Unit - 18 : Mineralogical characters of Metamorphic rocks
- Unit - 19 : Textures, Structures and Classification of Metamorphic rocks
- Unit - 20 : Magmas and Metamorphism

BLOCK - VI : KINDS OF METAMORPHISM

- Unit - 21 : Cataclastic and Thermal Metamorphism
- Unit - 22 : Dynamo thermal Metamorphism
- Unit - 23 : Plutonic Metamorphism
- Unit - 24 : Typical Indian Rocks

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FACULTY OF SCIENCE
SECOND YEAR (3 YEAR DEGREE COURSE) EXAMINATION
MODEL QUESTION PAPER
GEOLOGY

Course - II Optical Mineralogy & Petrology

Time : 3 Hours

Max. Marks : 70

Section : A

Note: A) Answer any three questions in about 30 lines each.
B) Each question carries 15 marks.

1. Explain the Petrological (Polarising) microscope.
2. Describe the classification of igneous rocks.
3. Briefly explain the origin of igneous rocks.
4. Describe, how sedimentary rocks are forming.
5. What is metamorphism ? Explain the agents and types of metamorphism.
6. Explain in detail about Plutonic Metamorphism.

Section : B

Note: A) Answer any five questions in about 10 lines each.
B) Each question carries 5 marks.

7. Briefly explain Nicol Prism.
8. Explain the terms Isotropic and Anisotropic.
9. What are the differences between igneous forms and structures.
10. What is Xenolith.
11. What is Devitrification.
12. What are elastic rocks.
13. Explain about Amacious rocks.
14. What are the various zones of metamorphism.
15. Explain the structures of metamorphic rocks.
16. What are the products of Thermal metamorphism.

FACULTY OF SCIENCE
SECOND YEAR (3 YEAR DEGREE COURSE) EXAMINATION

Assignment - I

GEOLOGY

Course - II Optical Mineralogy & Petrology

I. Answer the following questions in about 30 lines each.

1. Explain the textures of igneous rocks.
2. Describe the classification of sedimentary rocks.
3. Explain the structures of metamorphic rocks.

II. Answer the following questions in about 10 lines each.

1. What is twinning.
2. What are the rock forming minerals.
3. What are the agents of metamorphism.

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FACULTY OF SCIENCE
SECOND YEAR (3 YEAR DEGREE COURSE) EXAMINATION

Assignment - II

GEOLOGY

Course - II Optical Mineralogy & Petrology

I. Answer the following questions in about 30 lines each.

1. Explain the forms of igneous rocks with neat sketches.
2. Write down the classification of clastic rocks.
3. Explain the cataclastic metamorphism.

II. Answer the following questions in about 10 lines each.

1. What is pleochroism in minerals.
2. What are felsic and mafic minerals.
3. Explain the term 'metasomatism'.

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BRAOU

BRAOU

FACULTY OF SCIENCE
SECOND YEAR (3 YEAR DEGREE COURSE) EXAMINATION

Assignment - III

GEOLOGY

Course - II Optical Mineralogy & Petrology

I. Answer the following questions in about 30 lines each.

1. Write about the Crystallisation of unicomponent magma.
2. Write down the structures of sedimentary rocks.
3. Explain the Thermal metamorphism.

II. Answer the following questions in about 10 lines each.

1. Mematic differentiation.
2. Rudaceous rocks.
3. Zones of metamorphism.

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