BUREAU'S
HIGHER SECONDARY (+2)
GEOLOGY
(PART-I)

(Approved by The Council of Higher Secondary Education, Odisha, Bhubaneswar)

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FOREWORD

The Odisha State Bureau of Textbook Preparation and Production has made a pioneering effort in publishing this textbook in Geology which is expected to meet the requirement of students in the subject. The Bureau has utilised the best talents available within the State in preparation of this Text.

The book is meant for the first year students of the +2 course. The first edition of the book was authored by Prof. Sadasiba Panda, Mr. Anil Kumar Paul, Mr. Premananda Ray, Prof. Hrushikesh Sahoo, Dr. Rabindra Nath Hota and reviewed by Prof. Satyananda Acharya. The book has been rewritten by Dr. Ghanashyam Lenka, Prof. Hrushikesh Sahoo, Prof. Rabindra Nath Hota, Prof. Shreerup Goswami, Dr. Sudhir Kumar Dash, Dr. Naba Kishore Sahoo and Dr. Manoj Kumar Pattanaik according to the latest revised syllabus of the Council of Higher Secondary Education, Odisha and gives a complete coverage of the subject matter.

I have every hope that the teachers and the students of Geology will find this book useful and fruitful. Constructive suggestions for the improvement of this book shall be highly appreciated.

Geetika Patnaik
Director
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Pustak Bhavan, Bhubaneswar

PREFACE TO SECOND EDITION

Consequent upon changes in Higher Secondary syllabus, the course contents of the Bureau's Higher Secondary (+2) Geology Part – I has been modified with addition of Zone, Laws of Crystallography, Classification of Minerals and Trilobite in Crystallography, Mineralogy and Palaeontology sections respectively. In addition, the existing course contents of some sections have been elaborated for better understanding by the students.

The Board of Writers hope that the Book of the Second Edition will cater to the need of the students of Geology of Odisha in general and Higher Secondary students in particular. Suggestions for further modification are invited from the readers for betterment of the Book.

BOARD OF WRITERS

PREFACE TO FIRST EDITION

Geology is the science of the earth. It includes different aspects of the earth like its origin, age, and study of its materials. Study of the subject teaches us as to why earthquakes occur or why and how mountains form, what are fossils and economic minerals. Research in different directions takes the workers to enunciate the laws of the nature from its evolution up to the present stage.

It is, thus, a fascinating study and takes the students outside the class rooms to examine a river or spring, a bending of rock (folds) or its displacement resulting in a fault. It evolves as a natural science and a good part of the subject is learnt outside the four-walls; this is known as fieldwork. It has its laboratory wing as well.

The present textbook has been written by a group of teacher-geologists who are very experienced and are selected by the Bureau of Text Book Preparation and Production, Odisha based on the courses of studies for, Higher Secondary (+2) classes. Being a natural science, the subject is vast and they were almost forced to concisely write the parts given to them. Attempts have been made to bring the style of the language uniform and simple. Line diagrams are drawn and photographs are also added. More photographs will be planned for the reprint.

Sometimes a student may feel that more than the approved course materials have been pushed into the book. This has been done to improve their concept on those topics.

Inspite of honest efforts, the authors might have failed at places and experts will please point them for a better reprint. These innovative feedbacks are needed for the quality betterment of the book which is desirable as it leads to a similar improvement of our students.

The Odisha State Bureau of Text Book Preparation and Production has conceived to print the book and constant support for completion of the book has been made. The authors are thankful to the members of the staff of the Bureau for their full co-operation.

We hope thisc book will attract students to choose geology as their professional subject in future. Study of this subject is fascinating and invigorating.

Prof. S. Acharya
Reviewer

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CHAPTER – 1
GENERAL GEOLOGY

1.1. GEOLOGY- A FASCINATING DISCIPLINE OF NATURAL SCIENCE

Our home planet "The Earth" is a member of the solar system. Also known as the 'Blue Planet', it is the only heavenly body of revolution that has a delicate balance of physico-chemical conditions, which support sustenance of life that is unique and special.

Geology is a natural scientific discipline and is a term derived from the summation of two 'Greek' words such as 'Ge or Geo' meaning the earth and 'Logos' meaning science or discourse. It pertains to the study of the earth as a whole or part thereof. In a broader sense, geology could be reframed as 'Earth Science' which considers the whole earth as closed system, which is ever dynamic and a mosaic of four interactive parts that are ever changeable both among and within them. These four parts are called four reservoirs of materials of the earth (Fig.1.1) which also represent the four open systems such as (i) *THE ATMOSPHERE* which surrounds the – earth's surface as a continuous canopy (layer) composed of a gaseous mixture of nitrogen (N), oxygen (O), hydrogen (H), carbon

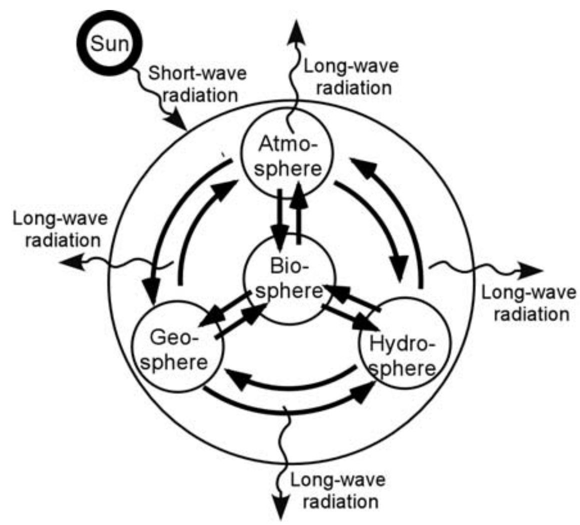

Fig.1.1: Reservoirs of earth materials and transfer of energy

dioxide (CO_2) and water vapour ($H_2O\uparrow$). (ii) *THE HYDROSPHERE* which forms the storehouse of earth's total water regime comprising the oceanic and sea water, stream (river) water, lake water, surface run-offs, frozen water in form of snow and ice, and underground water (iii) *THE GEOSPHERE,* which is the solid earth composed of soils, regolith (loosely cemented rock particles), solid rocks, layers of rock-metal association and metallic alloys (Fe-Ni), as is observed and interpreted from the top towards the centre of the earth. (iv) *THE BIOSPHERE* which forms the earth's organic world comprises of the living beings and the undecomposed organic matters. This sphere persists through all the aforesaid spheres. Biosphere is considered as an informal sphere as against the former three, which are the formal ones.

Geology, as a word was first used by the Swiss natural scientist named Jean - Andre Deluc in 1778 and was later introduced as a formal and fixed scientific term by Horace - Benedict de Saussure.

The term 'Geology' or the 'Earth Science' in a nutshell pertains to the scientific study of the earth, its composition, structure, physico-chemical attributes, developmental history and above all the natural processes, which shape it. The earth is essentially a closed system or very close to it in which the energy reaches the earth from the sun and eventually returns to the space as long wave radiations (Fig. 1.1).

1.2. SCOPE OF GEOLOGY

The scope of geology covers a rather wide spectrum in conjunction with other fundamental and applied scientific disciplines such as Physics, Chemistry, Botany, Zoology, Geography and Planetary and Atmospheric sciences. With time, new frontiers of advanced subjects like Geophysics, Geochemistry, Geobotany, Bio-geology, Environmental geology, Astro-geology have also come up. Even with a subject like political science, it has a link forming an interdisciplinary subject called 'Geo-politics'. In anthropological and archaeological disciplines, geology enters as a subject to deal with the socio-physical aspects of human race and the stone and metallic implements used during different lithic (Paleolithic, Mesolithic, Neolithic) and later ages. This subject also enters to the remote discipline of ancient history. An important sub-discipline of geology is 'Economic Geology' - an applied branch which is directly linked with the study of the vast kingdom of metallic and nonmetallic economic minerals including the industrial minerals and rocks. Economic geology plays a vital role in boosting the developmental growth and industrial strength of the nations and their people.

1.3. SUBDIVISIONS (BRANCHES) OF GEOLOGY

The domain of geology abounding its widened scope is further divisible into a seemingly great number of subdivisions termed as the branches for the sake and convenience of systematic study. The main and allied branches of geology may be named as follows:

	Main (Principal) Branches		**Allied Branches**
(i)	General geology	(x)	Engineering geology
(ii)	Physical geology (Geomorphology)	(xi)	Marine geology
(iii)	Geotectonics	(xii)	Geophysics
(iv)	Mineralogy (Crystallography inclusive)	(xiii)	Geochemistry
(v)	Petrology (Igneous, Sedimentary and Metamorphic)	(xiv)	Geo-hydrology / Hydrogeology
(vi)	Structural geology	(xv)	Environmental geology
(vii)	Historical geology or Stratigraphy		
(viii)	Palaeontology		
(ix)	Economic geology		

The cardinal themes of the main branches are briefed as follows:

1.3.1. General Geology: It is the formal branch of geology that deals with the broad features / aspects of the earth in particular and the other members of solar family with the Sun as the kingpin and sole controller. It also deals with certain principal aspects of the cosmos - the ordered universe. The features of the earth include its origin, age, constitution, internal structure and the depth zones of the marine (oceanic) realms.

1.3.2. Physical Geology: It serves as a tool to understand the physical process, which moulds the earth surface. The terms, synonymous with this branch, are ‘geomorphology’ and ‘dynamic geology’. This branch deals with (i) the geometry (ii) origin and developmental history of landform features of mountains, plateaus, valleys, rivers, lakes, glaciers, deserts, oceans and ground water (iii) geological work of the exogenetic (external) geological agents mentioned above, in constantly transforming the features of the earth’s surface and (iv) aspects of natural geologic phenomena such as denudation, weathering, erosion, mass wasting, landsides, soil creep, avalanches and soil erosion.

1.3.3. Geotectonics: This branch deals with the major and very large sized structures of the earth’s lithosphere (the crust and its lower part) and their changes produced by crustal deformation brought about by the interplay of the earth’s endogenetic (internal) forces. It describes and explains the geometry and mode of formation of the mega (very large scale) crustal features and their causative processes. These features are lofty fold mountains, block mountains, rift valleys, mid-oceanic ridges, geosynclines, and island arcs etc. It also deals with the global concepts of isostasy, eustasy (sea level changes), continental drift, convection cells, seismicity, ocean-floor-spreading and the plate-tectonics. In a simple sense, this sub-discipline deals with the movements of various crustal parts and the formation of resultant large scale crustal and infra-crustal features.

1.3.4. Mineralogy: It. is a formal branch that deals with the atomic structure, physico-chemical and optical properties of the minerals present in the earth's lithosphere and the crust in particular. Crystallography is an important sub-branch which describes the internal atomic structure in a three dimensional perspective and the external geometric forms of the crystalline minerals. The mode of occurrence, genesis and uses of minerals are also studied in this branch.

1.3.5. Petrology: It is the branch that studies the mode of occurrence, textures, structures, mineralogical and chemical compositions, classification and genesis of the rocks of *igneous*, *sedimentary* and *metamorphic* classes, present in the crust and below it. Each major rock class is further divisible into sub-branches such as plutonic, hypabyssal and volcanic types in case of igneous rocks; residual, mechanical, chemical and organic types in case of sedimentary rocks and into contact (thermal), dynamo-thermal, plutonic and cataclastic types of metamorphic rocks. All the three major classes of igneous, sedimentary and metamorphic rocks are, thus, further divisible into relatively smaller sub-types.

1.3.6. Structural Geology (or Structure): Under the influence of tectonic forces, crustal deformations take place in plastic, elastic and brittle stages of the rocks to produce a great variety of geological structures such as folds, faults, joints, rock cleavages, foliations and lineations. The total aspects of these structural elements in respect of their geometry, attitude, classification, mode of formation and causes constitute the bulk of structural geology.

1.3.7. Stratigraphy or Historical Geology: Broadly stratigraphy deals with the succession of geologic events and / or rock layers from the beginning of the crustal formation up to the present time. It aims at establishing and describing the correct order of superposition of rock-units on the earth's surface. Thus, it actually establishes the correct succession of rock formations / layers. It thereby unfolds the history of geological events on the earth from the geologic past to the present time and hence it is also referred to as historical geology as a synonym.

1.3.8. Palaeontology: It deals with the morphologic characteristics, modes of preservation, taxonomic classification, geological history of the ancient lives - both invertebrates, vertebrates and of plants. Thus, it consists of many sub-branches namely, Invertebrate Palaeontology, Vertebrate Palaeontology, Palaeobotany, Palynology, Micropalaeontology, Ichnology etc. Fossils are remains of geologically very old and ancient lives in form of entire body or hard parts, which are calcified, and / or silicified (petrified) in form of moulds and casts or as traces of remains / relics, which are preserved in various modes within sedimentary strata. Fossilisation is a natural process. Fossils have important uses in the fields of bio-stratigraphic correlation, palaeoclimatic interpretation, top and bottom criteria for correct stratigraphic interpretation and palaeogeographic reconstruction. It helps in the field of economic geology in general and in petroleum exploration in particular. It also helps in knowing organic classification and its evolution. Palaeobiodiversity, palaeoenvironment, palaeoecology, palaeobiogeography, palaeovegetation can also be revealed from this fossil science.

1.3.9. Economic Geology: It is the branch that deals with various geologic and geo-economic aspects of the vast array of metallic, non-metallic, industrial minerals and some specific rocks and the fuel minerals such as petroleum, natural gas, coal, radioactive minerals and geothermal sources. This branch describes the useful minerals (ore and nonmetallic minerals) in respect of their commercial value (metal contents) mode of occurrence, classification, grades, uses and origin.

Applied aspects of this important branch include geological exploration, value assessment of economic deposits, mining, beneficiation, reserve estimation and different aspects of mineral economics. The applied aspects of this branch have great bearing on the formulation of conservation measures that leads to a National Mineral Policy for the country. A brief description of the applied aspects of the allied branches is submitted as follows. These are more or less applied branches which utilise the application of the cardinal/main branches in close conjunction with scientific disciplines other than geology viz; chemistry, physics, geography, botany, zoology and anthropology. Also geoscience is amalgamated in some respect with humanities disciplines like History (as Ancient History and Archeology). The formal list of applied branches having direct relation with the main branches described above is as follows:

1.3.10. Engineering Geology: This applies the geologic basics to the field of engineering structures such as dams, reservoirs, tunnels, bridges and embankments, in which concepts of geology and civil engineering are given nearly equal weightage to construct engineering structures in the most suitable and safe geologic sites recommended by geological studies. Geologist recommends a few favourable site choices and one of them is finally selected paying equal weightage to geo-safety and engineering feasibility of total cost factors after a methodical cost-benefit analysis.

1.3.11. Marine Geology: This allied branch deals with the application of geological knowledge in evaluating the favourable locales in the littoral, offshore and shelf regions to explore into the realm of marine sedimentary sites to describe the coastal geomorphologic characteristics, the presence of offshore oil and gas reservoirs, manganese nodules and vast mineral wealth of black sand beach placers.

1.3.12. Geophysics: It relates to the study of physical properties like gravity, density, magnetism, elasticity (seismic wave behaviour), electrical and electromagnetic behaviour and radioactivity response of the rock and mineral deposits underneath. Geophysical methods take the advantage of the deviation of the properties from normal ground behaviour i.e. deviation from the normal values termed as “anomalies”. These methods are quickly and easily completed on the surface over large areas, which can be explored economically and efficiently. Exploration geophysics otherwise termed as geophysical prospecting methods are helpful in knowing the subsurface geological structure to help in discovering variety of metallic minerals, radioactive deposits and petroleum traps. Resistivity methods in particular, aid in assessing the potentials of ground (underground) water of a region.

1.3.13. Geochemistry: This branch is of relatively recent application in which chemistry of earth's constituents are studied and as such it relates to the study of the occurrence, distribution, abundance, mobility etc. of different elements present in the crustal apron. In this method, geochemical anomalies detected in the ore body and its surroundings are used to locate the variety of metallic and non-metallic economic deposits.

1.3.14. Hydro-geology: Also termed as geohydrology, it deals with mode of occurrence, movements, qualitative and quantitative nature of ground water present in the zone of saturation below the surface. The characteristics of water-bearing and conducting strata (the aquifers) are studied to assess the ground water potential in terms of quantity and quality.

1.3.15. Environmental Geology: This is the branch that relates geology to the human activity. It describes the reciprocal relation between the environment and the modern mankind. The modern society and its detrimental effects on our ecosystem through mining, urban development and other anthropogenic activities those affect the global environmental balance through pollution of air, water, land and biota are studied. Restoration of the environment through geological endeavours is of prime interest to the modern society. Geology plays a positive role in Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP). These aspects constitute the cardinal themes of this emerging branch.

1.4. THE EARTH AS A PLANET

1.4.1. Earth-The space ship: Artificial spaceships are man-made satellites, space-stations and sky-labs which are launched into the space, where they whirl around the earth. But the earth itself is the natural spaceship like the countless number of celestial bodies, which rotate about in the limitless space. There are more than three thousand artificial satellites orbiting the earth in the outer-space. So also there are about millions / billions of heavenly bodies like galaxies, stars, planets with their natural satellites etc., which revolve in definite orbits in the boundless space- the universe. The earth is one of them, which along with its satellite i.e. our moon and the co-planets orbit the sun since eternity guided by Newtonian universal law of gravitation. While the artificial space crafts, (the man made satellites) sail through the vast ocean of space around the earth in remote controlled orbits, the natural spaceship, the Earth does so in natural and definite orbit around the sun. Hence, the earth can be called a natural spaceship.

1.4.2. Earth’s place in space: The lovely planet, we inhabit, is more or less a huge spherical body of revolution, which is a tiny speck in the vast universe. The following analogy may be cited to give an idea about the size of the earth in relation to the universe. If all the seashores of this globe represent the universe, any sea-shore singularly will be a galaxy, a handful of sands of a seashore will show the size of the solar system and the earth in it will be represented by a tiny sand particle.

1.4.3. The Universe (The Cosmos) and its birth: Universe means the unimaginably vast space which is unbounded with its dots of bodies around. By definition, the universe includes everything that abounds in space. This space is filled with matter which varies from the tiniest and invisible cosmic particle to the gigantic galaxies. The universe is known to be composed of many types of comparatively small and large dense bodies e.g., the galaxies, the constellations (star groups), the stars, the planets and other heavenly bodies. The totality of the heavenly bodies from grand galaxies down to the smallest cosmic dust filling the endless space describes the Universe whose dimension is beyond our comprehension. Astrophysicists are of the opinion that the universe is ever expanding and hence growing rapidly. There are two divergent theories on the mode of origin of the universe. These are the Big Bang and the Steady State theories. According to 'Big Bang' theory the universe has a finite beginning, through a tremendous explosive expansion of superdense and very condensed matter. The 'steady state' theory states that the universe expands through a process of continuous creation of matter which (the process) remains unchanged through eternity.

1.4.4. Galaxy: A galaxy is a rotating stellar system (star system) consisting of a swarm of stars, which are held together by mutual gravitational attraction. In other words, a galaxy is an enormously large cluster of stars. Our galaxy to which the sun along with its planet families belong is an aggregate of about one hundred billion stars. Ours is called "Milky Way" galaxy which looks like a discus (a disc-shaped metal used in discus throw) when viewed through powerful optical telescope. It is a pancake shaped whirling body, which is gigantic in size. A part of the "Milky way" is clearly seen with naked eye as a faint luminous broad band across the sky during a clear autumn night. It takes about 100,000 years for the light to go from one end of our galaxy to the other end. There are billions of galaxies in the universe. The nearest galaxy comparable to our Milky Way in size is the Andromeda galaxy.

1.4.5. Stars and Planets: A star is a self-luminous and incandescent globe of hot gases. Stars produce their own light and are seen twinkling in the sky. The stars vary in size, temperature and constituent materials. Many stars occur in pairs (twins). They may even occur in triplets or quadruplets. Most of the stars have their own systems of planets and satellites revolving round them. In such cases, a star constitutes a star system. Our sun is a star having its own planetary and satellite system called the "solar system". Planets and satellites are non-luminous heavenly bodies, which shine only because of reflection of star (sun) light from their surface. The planets whirl round their stars in definite orbits.

1.4.6. The earth in the solar system

(i) The Solar system: Our sun is a star and hence has its star system known as the solar system. Everything within the sun's gravitational control constitutes what is called our solar system. This sun-centered system (Fig. 1.2) comprises of the sun, eight planets (our Earth included), dwarf planets (Pluto), sixty one natural satellites called the Moons, about thousands of asteroids (also referred to as planetoids), scores of comets and uncounted millions of meteors, all of which revolve round the sun.

(ii) The Sun: The sun is just a member among the 136 billion stars of the Milky Way galaxy. Our sun is a relatively small star. Epsilon Aurigie, the largest star known so far in our galaxy is about 27×10^7 times as big as the Sun.

Our sun is a huge sphere of hot gaseous mass. The elements present are in form of burning gases and vapours. The major elements, which make up the bulk

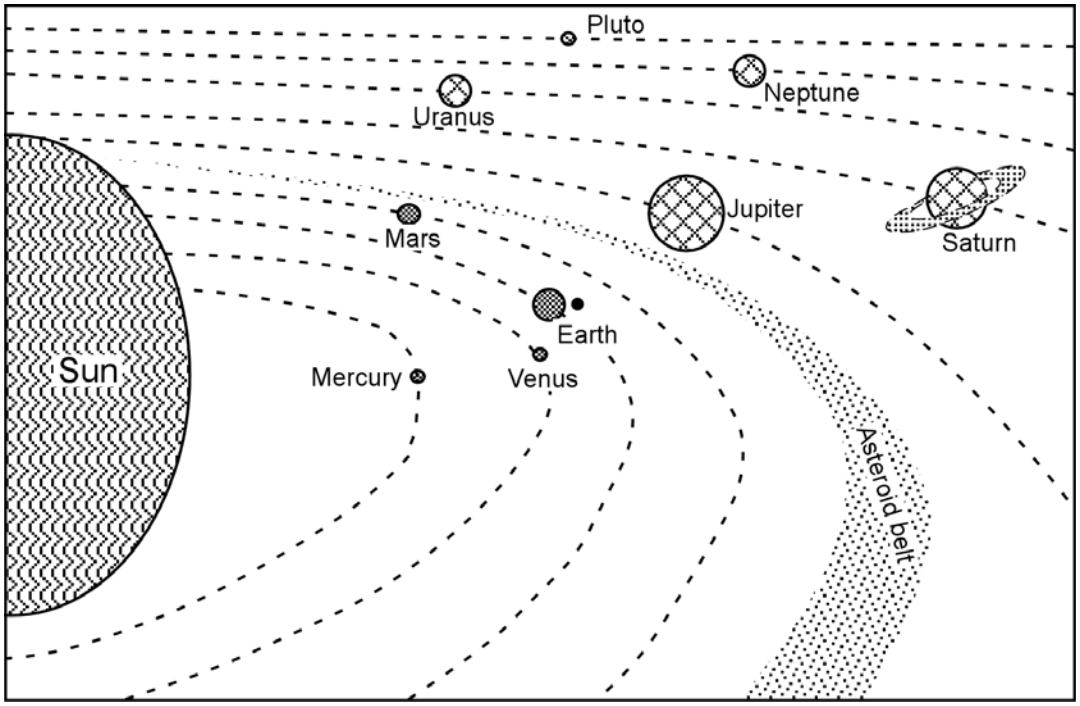

Fig.1.2: Solar system

of the Sun are hydrogen and helium. It emits radiant energy in the form of heat and light and this energy is generated within it by conversion of hydrogen to helium through nuclear reaction. The temperatures at the surface and at the centre of the sun are 6000° C and 20,000,000° C (20 million degree Celsius) respectively. Its diameter is about 190 times greater than the earth's diameter.

(iii) The Planets: The name planet evolved from the Greek word "Planets" meaning wandering. Planets are, thus, heavenly bodies, which appear to wander or move about the sky, whereas the stars are seemingly fixed in their relative positions in the sky. The sun has eight planets, which revolve round it in elliptical orbits and also rotate about their own axes. The eight planets and the dwarf planet Pluto as arranged in the order of their increasing distances from the Sun are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto (Fig. 1.2). The nine planets fall into the following two groups, which vary so much in size, density and composition.

(i) The inner group of planets which include Mercury, Venus, Earth and Mars.

(ii) The outer group of planets which include Jupiter, Saturn, Uranus, Neptune and Pluto.

The inner planets are small in size, fairly dense (higher average density), hotter in comparison with the outer planets, which are larger in size (except Pluto which is a tiny dwarf planet), lighter with low average density and cooler. The outer group contains much of light gases of hydrogen and helium, whereas the planets of the inner groups are almost devoid of light gases. The inner planets, being hotter and of weak gravitational field, lack in lighter gases. In general, the planetary motions show systematic uniformity. The orbits of all planets, except Pluto and Mercury lie in one plane. All planets revolve round the sun in elliptical orbits and in the same direction from west to east except, Uranus which rotates east to west. Mercury is the tiniest planet and Jupiter is the largest. In respect of size, the Earth ranks fifth. The order of the planets based on their increasing sizes would be Pluto, Mercury, Mars, Venus, Earth, Uranus, Neptune, Saturn and Jupiter (Fig. 1.2). The Earth is the densest planet of the solar system and Saturn is the lightest planet having the lowest density.

Three of the inner planets i.e. Earth, Venus and Mars are known to have definite atmosphere in some form. The astrophysicists are of the opinion that life may possibly exist on Mars that shows markings of dried river channels etc.

Among the outer planets, Jupiter and Saturn are known to have cold and dense atmosphere, which is rich in methane and ammonia gases. The two planets commonly seen in the sky in naked eyes are Venus and Mars. Venus is the brightest of all planets and clearly visible during sunrise and sunset. Mars looks reddish in colour. The numerical data of the planets of solar system are given in Table 1.1.

Table 1.1: Numerical data of planets of the Solar system

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Diameter (Km)	4,880	12,104	12,756	6,787	1,42,800	1,20,000	51,800	49,500	4,880
Size relative to Earth (Diameter of Earth=1)	0.38	0.95	1 = 12,756 Km	0.53	11.21	9.14	4	3.9	0.18
Mass (Earth=1)	0.055	0.815	1	0.108	317.8	95.2	14.4	17.2	0.003
Mass in Kg	$3.3X10^{23}$	$4.87X10^{24}$	$5.98X10^{24}$	$6.42X10^{23}$	$1.9X10^{27}$	$5.69X10^{26}$	$8.68X10^{25}$	$1.02X10^{26}$	$1.29X10^{22}$
Volume (Earth=1)	0.06	0.86	1	0.15	1321	764	63	58	0.006
Density (Water=1 gm/cc)	5.42	5.25	5.52	3.94	1.31	0.69	1.29	1.64	2.0
Number of moons	0	0	1	2	16	18	15	8	1
Length of day in Earth hours	1416	5832	24	24.6	9.8	10.2	17.2	16.1	154
Period of revolution around Sun in Earth years	0.24	0.62	1.0	1.88	11.86	29.5	84.0	164.9	247.7
Average distance from Sun in million Km	58	105	150	228	778	1427	2877	4497	5900
Equatorial surface gravity in m/s^2	3.7	8.87	9,766	3,693	20.87	7,207	8.43	10.71	0.81
Gravity (if Earth=1)	0.38	0.91	1.0	0.38	2.36	0.92	0.89	1.12	0.07
Equatorial surface gravity (1 Kg on Earth)	0.38	0.91	1.0	0.38	2.14	0.74	0.86	1.10	0.08
Escape velocity(m/s)	4,300	10,400	11,200	5,000	59,500	35,600	21,300	23,300	1,100
Obliquity (tilt of axis)	0	178	23.4	25	3.08	26.7	97.9	29.6	122.5
Orbit inclination (in degree)	7	3.39	0	1.85	1.3	2.49	0.77	1.77	17.15
Orbit eccentricity (deviation from circular)	0.206	0.007	0.017	0.093	0.048	0.056	0.047	0.009	0.248
Rings	Nil	Nil	Nil	Nil	Faint ring comprising rock fragments	Four main ring groups separated from three faint ring groups	Faint narrow rings consisting of rocky and carbonaceous materials	Narrow rings	Nil

The Sun is 1.6 million km in diameter, 13 times larger than Jupiter, the largest planet.

(iv) Asteroids: Also known as planetoids, these are a group of smaller bodies of the system found in between the inner and the outer planets (between Mars and Jupiter). These are thought to be remnants of a planet, which broke into pieces by collision with another bigger heavenly body. The asteroids vary in size (diameter) from 2 km to over 800 km. There are about 1500 asteroid bodies.

(v) Comets: Comets are wandering members of the solar-system. They move around the sun in highly eccentric orbits. Comet derives its name from the Greek word 'Kometes' meaning long-haired. Comets are objects that go around the sun with regular periodicity. Some comets are known to reappear to our vision at predictable intervals. The famous "Halley's comet" appears after every 76 years. It appeared last in 1986 and shall reappear again in 2062.

(vi) Meteors: Meteors are heavenly objects, which move about in space within the solar system in definite courses. They greatly vary in size, shape and composition. During their flight in space, the meteors may come within the earth's gravitational field. As they fall through the earth's atmosphere, they get burnt up by frictional heat produced and emit flash of light. Many of them may burn away in ionosphere (an electrically charged layer of the atmosphere) to yield ashes and dusts, while some of them may survive total burning and fall on the earth's surface in the form of solid bodies called "Meteorites". The world's largest meteorite that fell on southwest Africa weighs 70 tonnes. Meteorites vary in composition.

It is surmised that the meteorites represent either broken parts of comets or pieces of asteroids. Meteorites provide us with information about the composition of the earth's interior.

(vii) Satellites: Satellites (otherwise called the moons) are heavenly bodies, which revolve round the planets. Like the planets, the satellites do not themselves produce light but get lighted by the Sun's rays reflecting from their surface. There are in total sixty one (61) satellites belonging to the planetary domains of our solar system. Two planets e.g., Mercury and Venus do not possess moon. Saturn has the highest number of 18 satellites, followed by Jupiter (16).

The earth has one satellite (i.e. our moon) only. Some satellites of the outer planets are quite large in size and somewhat larger than Mercury. Titan, the largest satellite of Saturn is the only satellite known to have an atmosphere composed mainly of nitrogen.

1.5. OUR PLANET "THE EARTH"

The most important planet to us is the Earth that distinguishes itself from other heavenly bodies of the solar system in respect of the following facts.

(i) It is the largest of the minor or inner group of planets.

(ii) The earth, with a radius of about 6400 km and large circumstance of about 40,000 km, might seem to be large enough but in fact, this whirling planet is but a tiny speck in the astoundingly vast Universe.

(iii) It is the only planet of the solar system and the only member of the myriads of systems in the universe, which presents an intermingling condition of air, water and land. Thus, it is unique among the planets in having abundant water, an atmosphere and surface temperature conditions that has supported life.

(iv) It is the only planet known till date, where living being including intelligent creatures like man exists. The other planet, where probability of life is surmised is the Mars.

(v) Unlike other planets, the Earth has a strong magnetic field of its own.

(vi) It is the densest planet. It shows evidences of erosion of its surface (change of landforms by actions of air, water etc.), which is completely lacking in other planets.

(vii) While in other planets and satellites there are innumerable meteoritic craters (depressions made by impact of meteorites), the Earth's surface shows much less evidence of such craters, which are very much modified by erosion.

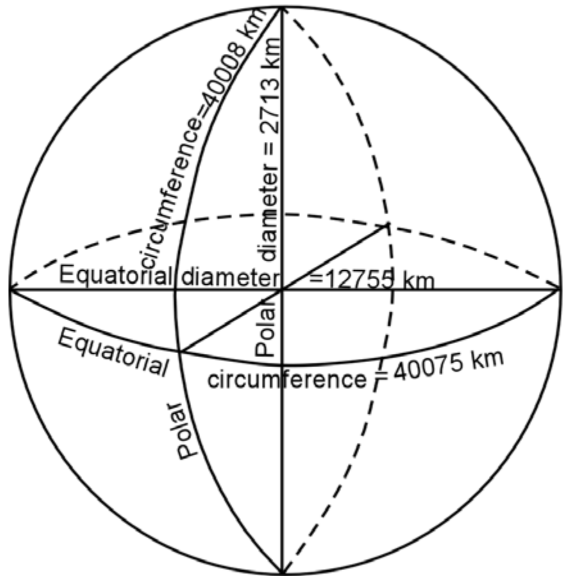

Fig.1.3: Flattened (oblate) spherical shape of the Earth

1.5.1. Physical Aspects of Earth: The following physical aspects of the Earth are noteworthy.

(i) Shape: The figure of the earth corresponds to an imperfect sphere which is slightly flattened (oblate spheroid).

The idea of earth's shape as an oblate sphere with slight flattening at the poles and bulging at the equator was propounded by Newton in 17^{th} century. According to Newton; the earth being a rotating sphere would be subjected to centrifugal flattening in the Polar Regions. Thus, the earth departed from perfect sphere and would be roughly orange-shaped. This is attested by the fact that the equatorial diameter of the earth is about 42 km greater than the polar diameter (Fig. l.3).

The idea of Pear-shaped earth was first proclaimed by Sir James Jeans by the beginning of 20th century. The latest measurements by artificial satellites confirm the idea of Jeans and indicate the shape to be a slightly flattened sphere with some irregularities at the north and south poles. Thus, the shape of the earth as per the latest computations is more nearly PEAR - shaped than orange-shaped.

(ii) Size: Earth is an average-sized planet in the solar system. Latest data based on geodesic survey (Geodesy deals with the study of measurement of dimensions of the Earth) and satellite observation, speak of the following measurements relating to the dimension (size) of the Earth.

Equatorial diameter	:	12,755 km
Polar diameter	:	12,713 km
Mean diameter	:	12,742 km
Equatorial circumference	:	40,075 km
Polar circumference	:	40,008 km
Area	:	510 million square kms
Volume	:	1.08×10^{27} cc
Mass	:	5.976×10^{27}gm

The difference between equatorial and polar diameters of the earth (12,755 - 12713 = 42 km) indicates the bulging and flattering of the earth at the equator and poles respectively (Fig. 1.3).

1.5.2. Internal Temperature:

The following estimates of temperature within the earth's various zones are made,

(i) Crust: From near surface temperature to about 1000° C at the base.

(ii) Mantle: From 1000° C to 3500° C at the base of lower mantle.

(iii) Core: 3500° C to nearly 6000° C at the centre of the earth.

Along with temperature, pressure also increases with depth and at the centre, the prevailing pressure would be 3.75 million times as high as the pressure at the earth's surface (i.e. 3.75 million atmospheric pressure).

1.6. ORIGIN OF THE EARTH

The origin of the earth not deals with the creation of the matter of which the planets are composed, rather the very appearance of this cosmic matter as a single whole body of conceivable state and form having individual existence. The birth of the planet earth must have been due to some unique phenomenon which occurred in the universe in the remote past in which the earth saw the first glimpse of its existence. Because of their similarities in motions and composition, the earth, along with its co-planets and satellites, forms a part and parcel of the solar system, and as such all of them including the Sun must have been formed simultaneously. Thus, the origin of the earth is intimately related to that of the solar system and the birth of the sun and its member planets, satellites etc. The Earth in particular must have been born due to some unique celestial phenomenon that occurred in very remote past, about 4,500 million years ago.

Subsequently many hypotheses were put forward from time to time. Few of them appeared easily convincing and were taken as most satisfactory for some years but are now regarded as only historically important. An acceptable theory must explain the fundamental regularities of the solar system. The most imperative fundamental regularities are:

(i) **Orbital regularities:** It has been observed that orbits of all the planets are almost circular, lie in one plane and the revolution is in one and in same direction.

(ii) Distance regularities: The various members of the solar system are distributed at varying distances from the sun is a proved fact.

(iii) Differentiation of planets: Interior of all the planets can be divided into inner and outer with characteristic difference in density

(iv) Distribution of angular momentum: Angular momentum (M) is defined as the mass of the body (m) multiplied by its velocity (v) and by the radius of the orbit (R). A body rotating around a central object must have angular momentum. In case of solar system the distribution of angular momentum is such that the sun accounts for less than 2 percent of momentum in spite of the fact that it possesses more than 99 percent of the mass of the solar system.

Many hypotheses have been put forth relating to the origin of the earth. There seems to be two basic premises on which the hypotheses are based.

(i) A hot ball of fire origin attesting the planet's birth in a hot state (Hot ball of fire stage).

(ii) A cold origin speaking of the birth of our planet from a cold and dust cloud state.

In another way, the hypotheses advanced so far, may be put into two major groups such as *condensation* hypotheses and *fragmentation* hypotheses. The two groups postulate diametrically opposite mode of origin of our planet and hence of the solar system. Both the groups of hypotheses have merits and demerits.

It is beyond the scope to present here an account of all the hypotheses. Only some important hypotheses which enjoy scientific acceptance and popularity during some period or the other are discussed below. It may be mentioned here that more than one hypothesis put forth by individual scientists carry the same or nearly same idea in some modified ways and as such the related hypotheses are treated in a combined form in the following description. Some of them belong to "Condensation (evolutionary hypotheses)" school and the others to

"Fragmentation (Catastrophic or Tidal hypotheses)" school.

1.6.1. Condensation/ Evolutionary Hypotheses: Hypotheses under this group postulate the birth of the planets through the process of condensation of diffused gas and particles. In other words, condensation hypotheses speak of the formation of the planets and the solar system by gathering together or coagulation of diffused matter scattered in .space. The earliest theory for the origin of earth was put forwarded by Kant and Laplace.

(i) Nebular Hypotheses: These were propounded by Kant (1755), Laplace (1796) and Helmond later on. Kant's original idea was largely modified by Laplace. The solar system originated through condensation of matter from a rotating, hot and gaseous body of diffused nature called the nebula. The nebula cooled down through radiation of heat energy. As it cooled down, it contracted. More and more contraction caused increase of the speed of rotation of the nebula. As the speed had become very high in course of time, bulging of the equatorial zone of the nebula took place under increased centrifugal forces. It then flattened into a disk. As a result of this, a gaseous ring of diffused matter was separated and then thrown off into the space. This thrown-off-ring gradually condensed to form a sphere which revolved round the nebula and also rotated around its own axis. Thus, the planet was formed (Fig. 1.4). In succession, more rings were thrown off

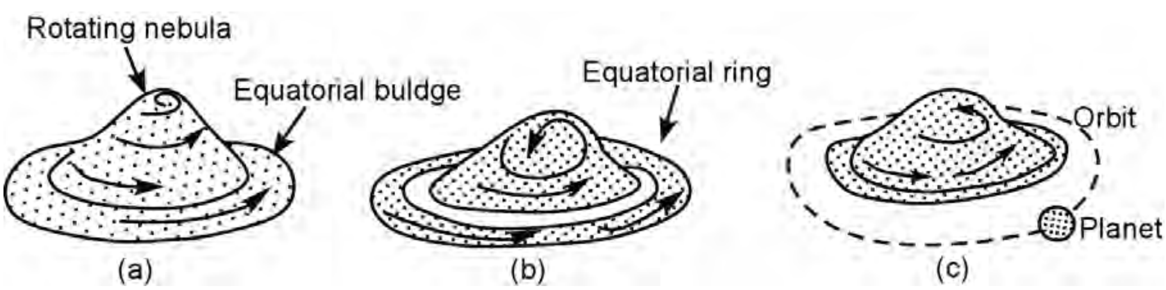

Fig.1.4: Stages of Nebular hypothesis

to form other planets. The satellites formed around the planets before their solidification in the same way as the planets evolved. The remainder of the nebula formed the sun. This mode of origin of the earth was very popular during 18th and 19th centuries but thereafter the idea got gradually weakened. Kant and Laplace only differed in the mode and time of separation of the rings. While Kant advocated formation of nine separate rings, from the nebula, Laplace advocated for one primary ring first from which other rings were thrown in rotating secondary rings to form planets etc.

(ii) Meteoric Cloud Hypotheses: A meteoric cloud origin of the earth and the solar system was advocated by Darwin and Lockyer (mid 20th century), who thought of the existence of cloudy matter in form of bodies varying in size. These were called meteoroids which constantly collided with each other to unite together under gravitational pull. This process continued to form lager unions, which became the centres of condensations to form planets and satellites.

According to Otto Schmidt (1943) in his meteoric hypothesis (also known as Interstellar Dust hypothesis) all planets including the earth were derived from some foggy matter occurring in the central part of our galaxy. As the sun-a star moved very close to this centre of the galaxy, it attracted the foggy matter which was detached *I* thrown off in form of particles called meteoroids, which revolved round the sun. The meteoroids ultimately got together (united) to form bigger bodies which gave rise to planets and satellites. He postulated a cold origin of earth.

(iii) Dust Cloud Hypotheses: Propounded by Weizacker in 1944, Kuiper in 1951 and Urey in mid 20th century the ideas were laid down under the general head of Dust-cloud hypotheses. The solar system coagulated from a vast cloud of dust forming the inter-stellar matter. This cloud consisted of dust and diffused gas from which one portion condensed to form the Sun and the others rotating round the Sun eventually formed the planets etc. The original cloud of dust formed an intricate pattern of turbulent motion. The whole thing was like a spiral nebula which was nothing but a rotating disc .of cloudy matter. The nucleus of this disc formed the sun around which there existed a gas-dust envelope. As this envelope revolved around the nucleus (the sun); concentric cells / whirls were formed. In these cells, there were eddies consisting of gas and dust. In course of time, the dusts of each eddy coagulated to form bigger particles and formed what are known as proto-planets. The gases present in proto-planets were driven away by the pressure of sun's light. After the complete removal of the gases, the proto-planets gave rise to planets and satellites through contraction of dusts. The bigger concentrations gave birth to the planets and the smaller ones to the satellites.

This group of hypotheses had acceptance and rejection in close succession.

(iv) Planetesimal hypothesis: According to Moulton (1901) and Chamberlin (1901) the solar system originated from matter, which was in form of tiny dust grains called “Planetesimals”. The planets evolved from a cloud of planetesimals, which revolved around the sun. The planetesimals, the tiny cosmic fragments collided with each other and united together to form larger bodies, which became planets and satellites revolving around the sun. This idea was that of a solid origin of the earth and the other planet and satellites to start with.

1.6.2. Fragmentation / Catastrophic Hypotheses: Fragmentation concept believes in the birth of the planets and satellite in form of fragments of hot and gaseous bodies thrown off single or larger bodies of stars. These fragments were formed by breaking up of the sun and / or similar stars, under gravitational explosion of matter. The earth was formed directly in one piece of filament thrown out of the sun or similar companion star.

(i) Gaseous tidal hypotheses: These postulate a hot ball of fire origin of the Earth and other planets. Planets and satellites were formed by gradual cooling and solidification of originally hot and gaseous fragments, which were detached from the sun and/or another star under mutual gravitational attractions. According to Buffon (1749), the planets evolved from hot gaseous bodies, which were detached from the sun as a result of its collision with another star of our galaxy. Jean (1919) and Jeffrey (1925) postulated tidal hypotheses which are otherwise known as "Hit and Run" hypotheses. A big star during its course of wandering in the space approached the sun and caused violent tidal distortion in the sun by its very strong gravitational pull (Fig. 1.5). As it came very close to the sun, parts of the sun affected by strong tide were pulled away in the form of a spindle shaped filament

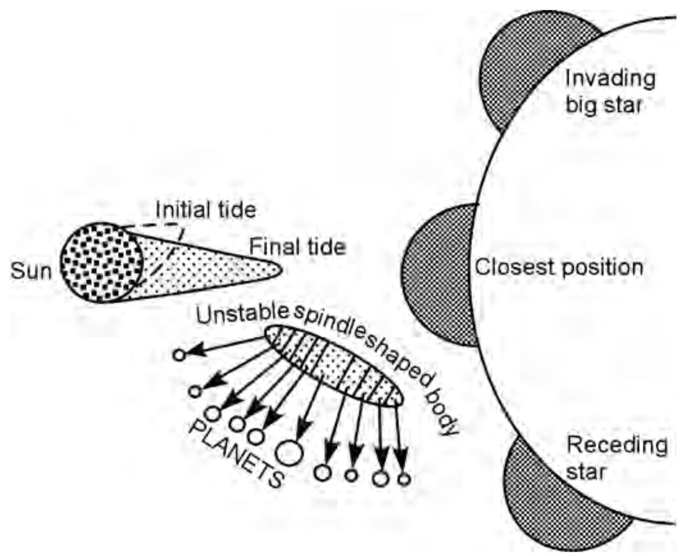

Fig.1.5: Tidal hypothesis

which was in unstable state. Then, as the big star receded away, this unstable filament broke away into pieces of hot and gaseous masses. Few of them were carried away along with the receding star; while major bulk of them fell into the gravitational field of the Sun. They formed globular masses orbiting the sun. The bigger masses gradually cooled down and concentrated to planets. The smaller masses solidified into the satellites. One of the planets further broke away into pieces called asteroids / planetoids. The plus points of this hypothesis are (i) it explains the ordering of the planets sizes (cigar shaped) shown in Fig.1.6 and arrangement of satellites. Failure of this concept is its lack of facts to explain the difference in elemental composition between the parent sun, which contain light He and H elements and the planets, which are composed of heavier elements of Si, AI, Fe and Mg.

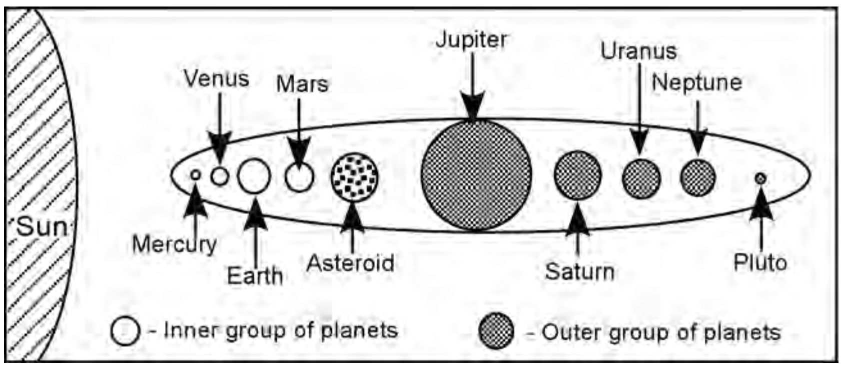

Fig.1.6: Cigar-shaped arrangement of the planets showing their relative sizes

(ii) Binary or Double star hypothesis: The "Binary" hypothesis was put forth by Russell (1937), who believed in the existence of many stars as pairs in the universe. Our solar system was born from one of these star pairs, which consisted of the sun and another smaller star known as the companion star.

A huge-sized third star came into the region of these paired stars and caused tidal explosion in the companion star, which was completely disrupted. When the third star came close to the companion star, some parts of the companion star, were carried away along with the third star which eventually receded away. The rest fell into the sun's gravitational control. These parts retained by the sun revolved round it and gradually cooled down to form the planets.

The double star hypothesis of the solar system was propounded by Lyttleton (1938), who also believed the birth of the earth and other planets and satellites of the solar system in nearly the same way as Russell explained. According to him, the companion star of the sun was at same distance as equal to the distance of the planets Saturn or Uranus from the sun.

(iii) Supernova Hypothesis: This hypothesis was put forth by Fred Hoyle in 1946. The sun had once a companion star as its former twin, which exploded due to nuclear reactions resulting in transformation of lighter elements into heavier ones. This explosion in the companion star produced a cloud of incandescent gases and this stage is named by him as the “Supernova stage”. This gaseous cloud was retained by the sun’s gravitational force and the remainder of the star as the nucleus receded away far off. In the supernova stage, the gaseous cloud contained particles of iron and other terrestrial elements. These particles aggregated to form the earth and other planets and satellites. As they were within the sun's gravitational field, they revolved round the sun and gradually cooled down to the solid form in which the planets and the satellites exist at present. This hypothesis explains (i) the great distance between the sun and its planets (ii) problem of angular momentum of the planets (iii) compositional differences in elements of the sun and the planets. However, it fails to account for the cigar shaped arrangements of the planets.

1.6.3. Big-Bang Theory: According to the Big-Bang theory, the universe and obviously the solar system are the result of an explosion within the nebula and is getting wide acceptance from various quarters. In other words, large scale explosion in the nebula has given rise to the planets and the sun. When the Big Bang occurred, matter was spattered radically in all directions. Recent studies confirm that the expansion of the universe occurred in a radial manner, when the bang took place. This theory is a cosmological model for the universe from the earliest known periods through its subsequent large-scale evolution. The model accounts for the fact that the universe expanded from a very high density and high temperature state and offers a comprehensive explanation for a broad range of phenomena, including the abundance of light elements, the cosmic microwave background, large scale structure and Hubble's Law. After the initial expansion, the universe cooled sufficiently to allow the formation of subatomic particles, and later simple atoms. Giant clouds of these primordial elements later coalesced through gravity to form stars and galaxies. In 1965, the cosmic microwave background radiation was discovered, which is one of the imperative evidences in favour of this theory.

1.6.4. Origin not yet fully known: Of the many hypotheses so far postulated, some had gained acceptance for a time and then were discarded on the advent of new ones which earned followers to meet the same fate. Notwithstanding the fact that there has been astounding development in the fields of astronomy and astrophysics, the origin of the solar system in general and of the earth, in particular is not as yet definitely known. There seems to be a great deal to know and theorise. The general consensus among the astronomers is that the earth like other planets and satellites had its birth as a gaseous and hot ball of fire. It cooled down from a primary gaseous state to its present solid form.

1.7. AGE OF THE EARTH

The planet Earth was not born instantaneously. It evolved from some previously existing hot and gaseous state, which eventually condensed to its solid state, via a liquid state. This change over was a period of very slow process of transition, which prolonged for a good length of time. Thus, the age we seek, does never mean the time of its birth in gaseous or liquid state. Rather it means the time of the evolution of the planet as a solidified mass. As such, our planet's birth or so to say, the age of the Earth, in fact relates to its time of solidification leading to the formation of its stable crust. Thus, the age of the Earth, we seek, is no precise time in terms of second / minute / hour / day / year or even centuries. It is an overwhelming number expressed in terms of millions of years. Since the 18th century, attempts have been made to estimate this age. The estimates made by naturalists like Buffon and Lightfort in 18th century based on non-scientific notions were frantically low and untenable figures. The earliest astrological calculation relating to the date of birth of our planet was made by the 'Archbishop Usher of Iceland' in 1664 and accordingly, the Earth was said to have been born at 9am on 26th October in 4004 BC - a figure to amuse only and never to rely upon.

Unfortunately, the age cannot be computed directly from material that is solely from the Earth. There is evidence that energy from the Earth's accumulation caused the surface to be molten. Further, the processes of erosion and crustal recycling have apparently destroyed all of the earliest surfaces. The oldest rocks which have been found so far (on the Earth) date to about 3.8 to 3.9 billion years ago (by several radiometric dating methods). Some of these rocks are sedimentary, and include minerals, which are themselves as old as 4.1 to 4.2 billion years. Rocks of this age are relatively rare, however rocks that are at least 3.5 billion years in age have been found on North America, Greenland, Australia, Africa, and Asia. While these values do not compute an age for the Earth, they do establish a lower limit (the Earth must be at least as old as any formation on it). This lower limit is at least concordant with the independently derived figure of 4.55 billion years for the Earth's actual age.

Since the mid 19th century, various methods based on the teachings of astronomy, astrophysics, physics, biology, geology and nuclear chemistry have been meaningfully tried with. These methods have given multitude of estimates pertaining to the age of the Earth, which vary within wide limits. Various modern methods of estimating the age of the Earth are classified and listed below. Each method may be otherwise described as a clock.

1.7.1. Extrinsic clocks: These methods are based on external parameters comprising apparent and relative methods, which give widely variable age figures. These clocks are discussed briefly hereunder.

(i) Biological evolution clock: This method is based on the theory of organic evolution of lives from simple unicellular to multi-cellular series of organisms and then from a series of animals and plants to the most evolved creature, the man. The beginning of this time from the appearance of very first life on the Earth is traced back by radiocarbon analysis of the most primitive fossil finds going back to the root of the evolution, reconstructed by the biologists. Age of the oldest fossil gives the minimum age of the Earth. This method provides rather a very low age figure which is of the order of 1000 million years (my) as deduced by Darwin and Poulton during mid of late 19th century. This low age figure is due to the fact that it represents only a fraction of the actual age as the very first life (probably not fossilized) appeared on the planet much later than the time of the Earth's solidification.

(ii) Moon’s retreat clock: It is broadly related to the tidal force of the Earth's moon. It is primarily based on the concept of lunar separation from the Earth. Moon was very close to the Earth to start with and it has drifted away from the Earth to its present position. This distance divided by the moon's retreat or shift from the Earth gives the age of the Earth. The rate of shift of the moon is calculated from the value of tidal energy in the shallow seas at different geologic times. At the beginning the rate of shift was faster with larger tides. Consequent upon the increase of distance, the tides became smaller in magnitude effecting slower rate of retreat. Based on this premise and the present distance of the moon from the Earth as 0.38 lakh km, Jeffrey and Badwin estimated the age of the Earth to be about 4000 my.

(iii) Sedimentation clock: Ever since the formation of hydrosphere, the surface rocks of the Earth were relentlessly eroded and deposited in the oceans during different geologic times. If the entire and aggregate thickness of the sedimentary column on the globe ranging from very inception to the present is geo-scientifically deduced and the average rate of sedimentation per annum is considered, the time of beginning' of the deposition could easily be traced back. According to Murray, the rivers of the world carry a sedimentary load of about 16 km^3 to the sea annually. The total thickness being known, the time of the start of the sedimentary deposition could be calculated. In this method the age of the Earth has been calculated to be 400 my. This method has a number of drawbacks as the global sedimentation throughout the geologic periods was neither continuous nor of uniform rate. There have been major breaks in sedimentation due to large unconformities and non-deposition. These imperfections greatly affect the reconstruction of an ideal and optimum global sedimentary column.

(iv) Salinity clock: This clock is based on the rate of salinity of oceanic water. The sea / oceanic water is assumed to have been fresh at the beginning and it gradually became saline by the addition of salts (chlorides, sulphates etc) of Na, Ca and Mg supplied to the oceans through rivers annually. From the total mass of Na^+ ions in the present day seas and oceans divided by the annual addition of Na^+ per year the age of the oceans and hence that of the Earth calculated by Jolly, Clarke and Solas varies between 99 to 250 my. This clock has a number of demerits and gives low age figures.

(v) Rate of cooling of the Earth: The Earth cooled to its present state from an initially hot ball of fire of initial surface temperature of about 3900° C. By rationally assuming an average rate of cooling, the age of the Earth could be estimated. It was first used by Kelvin in 1862 and then tried by Helmholtz in the late 19th century. The estimates have been variable from 20 to 400 my as advocated from time to time. The low estimate figure is due to the fact that these estimates did not consider the influence of radiogenic heat produced in Earth's crust. Further this method has many other drawbacks arising out of assumptions considered in the estimates.

1.7.2. Intrinsic clocks: The radiometric method is the only intrinsic clock which is considered the most modern and reliable method of estimating the age of the Earth in some absolute sense. This method is primarily based on the principle of radioactivity, a process of spontaneous disintegration of certain unstable natural isotope elements such as U, Th, K, Rb etc with emission of α, β and γ rays. This process is completely free from the influence of external parameters such as temperature, pressure and chemical reactions. Radioactivity was discovered by Becquerel in 1896 and application of this principle to the subject of age dating of rocks was first attempted by Boltwood in 1910. The basic principle is to find out the age of the oldest rocks and crust of the Earth by measuring the radioactive decay of the long-lived radioactive isotope series. Various long-lived radioactive series are characterized by their specific half-life times (T) and corresponding disintegration constants (λ), which are related by the formula $T = 0.693/ \lambda$. These two factors being known, the time (t) of the formation and hence the age of the parent mineral and rock can be computed with certainty. The factor ‘t’, the age can be found out from the following formula

$$t = 3.323T \times \log_{10}(1+\frac{N_d}{N_p})$$

where

t = time of formation of the mineral / rock in million years

T = half-life period,

N_d = amount of the stable daughter element (say Pb^{207})

N_p = amount of parent element (say U^{235})

The values of N_d and N_p could be determined by sophisticated devices and t (age of the rock) could be calculated. The age of the oldest rock in the crust is the minimum age of the Earth.

Important and useful radiometric clocks with their half-life periods and nature of decay are given in Table 1.2 and the radiometric ages derived from different meteorites are given in Table 1.3.

Table 1.2: Different radiometric clocks with their half-life periods

Series	Parent - End	Half life (T)
Uranium - Radon series	U^{238} - Pb^{206} (α - decay) clock	4.5×10^8 years
Uranium - Actinium series	U^{235} - Pb^{207} (α - decay) clock	7.1×10^8 years
Thorium series	Th^{232} - Pb^{208} (α - decay) clock	1.4×10^8 years
Rubidium - Strontium series	Rb^{87} - Sr^{87} (β - decay) clock	4.7×10^8 years
Potassium - Argon series	K^{40} - A^{40} (β - decay) clock	1.3×10^8 years

By application of the above one or combination clocks, the oldest rocks on the Earth, the extraterrestrial meteorites and primordial crust of the Earth could be dated and the minimum age of the Earth be estimated with certainty. Some pertinent radiometrically computed ages of the oldest rocks of the Earth are listed in Table 1.4.

Table 1.3: Radiometric ages of different meteorites

Meteorite	C	Age (billions of years)
Chondrites (CM, CV, H, L, LL, E)	Sm-Nd	4.21 ± 0.76
Carbonaceous chondrites	Rb-Sr	4.37 ± 0.34
Chondrites (undisturbed H, LL, E)	Rb-Sr	4.50 ± 0.02
Chondrites (H, L, LL, E)	Rb-Sr	4.43 ±- 0.04
H Chondrites (undisturbed)	Rb-Sr	4.52 ± 0.04
H Chondrites	Rb-Sr	4.59 ± 0.06
L Chondrites (relatively undisturbed)	Rb-Sr	4.44 ± 0.12
L Chondrites	Rb-Sr	4.38 ± 0.12
LL Chondrites (undisturbed)	Rb-Sr	4.49 ± 0.02
LL Chondrites	Rb-Sr	4.46 ± 0.06
E Chondrites (undisturbed)	Rb-Sr	4.51 ± 0.04
E Chondrites	Rb-Sr	4.44 ± 0.13
Eucrites (polymict)	Rb-Sr	4.53 ± 0.19
Eucrites	Rb-Sr	4.44 ± 0.30
Eucrites	Lu-Hf	4.57 ± 0.19
Diogenites	Rb-Sr	4.45 ± 0.18
Iron (plus iron from St. Severin)	Re-Os	4.57 ± 0.21

The age of the oldest rock would indicate the age of the Earth at the minimum. The maximum age of the Earth i.e. time of formation of the first crust (solidified Earth) must be much earlier than the oldest dated rock of the crust so far dated. Because of the complex geological and erosional processes operating on

Table 1.4: Ages of some old rocks

Rock	Locality	Age
Granite gneiss (Morton gneiss)	Minnesota (USA)	3,700 my
Granite	Kola peninsula, Russia	4,100 my
Anorthosite and Granite gneiss	West Greenland	3,900 my
Older Metamorphic Group	Champua (Odisha, India)	3,800 my

the Earth's surface ever since its solidification, it is indeed very difficult to discover and date the oldest rock. The oldest rock of the moon, which has not undergone erosion / denudation has been dated to be 4500 my. Earth's daughter (moon) cannot be older than the Earth. Thus in all logistic estimation, the age of the Earth may safely be put at 4500 my, which is also the figure reiterated by the age of the meteorite.

1.8. INTERNAL CONSTITUTION OF THE EARTH

The internal constitution of the earth primarily relates to the structural and compositional aspects of the layered earth. The internal structure of the earth deals primarily with concentric layering of the earth based on their physical / seismologic characteristics, which distinctively vary in their densities and seismic (earthquake) wave characteristics. On the other hand, the compositional layerings of the earth are characterized by their totality of the nature of the bulk chemistry, analogy with the composition of meteorites, smelter differentiated products and three distinctive established compositional layers.

1.8.1. Earth's internal structure: Man can hardly peep into the earth down to a depth of about 12 km through very deep underground mining and deep drilling. The Kola Superdeep Borehole was drilled by Soviet Union in the Pechengsky

District of the Kola Peninsula of Russia. Drilling began on 24 May 1970 using the *Uralmash-4E*, and later the*Uralmash-15000* series drilling rigs. A number of boreholes were drilled by branching from a central hole. The deepest, SG-3, reached 12,262 metre long in 1989 and in terms of true depth, it is the deepest borehole in the world. For two decades it was also the world's longest borehole, in terms of measured depth along the well bore, until surpassed in 2008 by the 12,289 metre long Al Shaheen oil well in Qatar and in 2011 by 12,345 metre long Sakhalin-I well in the offshore of the Russian island Sakhalin. This 12 km. depth, however, represents a minute fraction (less than 0.15%) of the earth's radius (6371 km). Direct observation of the interior of the earth is not possible due to the fact that the interior becomes hotter with depth, which is convincingly indicated by the volcanic eruptions. Besides, since direct observation of the interior of the earth cannot be made conveniently, all the important sources of data on the structure of the earth are indirect and are logically derived and inferred from other evidences. These are seismological studies, analysis of meteorites, tomographical studies and studies of geochemical differentiation of earth. Among them the seismological studies is the most important one.

The layers of the earth's interior are distinguished by their physical and chemical properties, particularly in their thickness, depth, density, temperature, metallic content etc. Now-a-days much information about the interior of the earth has been obtained from the study of the propagation of the earthquake waves through the earth. It has been identified that three types of waves carry energy away from place of origin of the earthquake. These waves are:

(i) **Longitudinal, Primary or P-waves:** They are similar to sound waves in which the particles move to and fro in the direction. These waves travel in solid, liquid and gaseous media. They have short wave length, high velocity and high frequency.

(ii) **Transverse, Secondary, S-waves or Sheer waves:** These waves are like the waves which run along a string that is fastened at one end, stretched fairly tight and shaken at right angles to the path of the wave. These waves travel only in solid medium. In comparison to the Primary waves, they are slow in motion. They also have short wavelength, high velocity and high frequency.

(iii) **Surface-waves, Rayleigh or L-waves:** These are transverse waves and are confined to the outer skin of the crust and are responsible for most of the destructive force of earthquakes. They have low frequency, long wavelength and low velocity.

(iv) P and S waves travel from the focus of an earthquake through interior of the earth to the recording stations

(v) P waves travel 1.7 times faster than S waves

(vi) L waves travel from the epicenter along the earth's surface to the recording station.

(vii) An L wave is the last to arrive because they travel at a slower speed and over a longer route.

Difference between P and S wave is enumerated in Table 1.5.

The seismic body waves such as P (primary-compressional) and S (secondary-shear) waves are recorded in seismograms (seismic records) from which the velocities of P- and S-waves could be numerically and graphically plotted against the distance along the radius of the earth. From these, the density, rigidity and bulk modulus factors against depth could be calculated to throw light on the nature of variation of these factors vis-a-vis depth (radius) of the earth. This is known as velocity - depth graph, which shows a number of breaks/ discontinuities at certain depth (radius). These discontinuities within the earth's interior are found because of changes in chemical composition, density, state and physical properties of the materials. These are physically expressed in terms of -

Table 1.5: Difference between P and S wave

P wave/ Push-pull wave	S wave
(i) Compressional wave	(i) Shear wave
(ii) Longitudinal wave	(ii) Transverse wave
(iii) Registered first (Primary wave)	(iii) Registered second (Secondary wave)
(iv) Average Velocity:6-8 km/s	(iv) Average Velocity:3-5 km/s
(v) P waves are characterized by propagation caused by longitudinal vibration (parallel to the direction of the propagation) of the particles of the travelling medium.	(v) S waves have an elastic shear mechanism of transmission that promotes propagation of the waves in the direction perpendicular to the direction of vibration of excited particles.
(vi) Shorter wave length	(vi) Short wave length
(vii) Higher velocity (1.7 times higher than that of S wave)	(vii) High velocity
(viii) Higher frequency	(viii) High frequency
(ix) Travel in all medium	(ix) Travel in solid medium only
(x) Velocity of P wave: $\sqrt{(K+4/3\ \mu)/p}$	(x) Velocity of S wave = $\sqrt{\mu/p}$
Where k = Incompressibility; p = Density and μ = Rigidity	Where k = Incompressibility; p = Density and μ = Rigidity
(xi) Average velocity of P wave in sial is 6.1 km/s Average velocity of P wave in sima is 6.8 km/s Average velocity of P wave in mantle is 8.1 km/s	(xi) Average velocity of S wave in sial is 3.4 km/s Average velocity of S wave in sima is 4.4 km/s Average velocity of S wave in mantle is 4.5 km/s

sharp rise or fall indicating 1st order discontinuities at definite depths. These discontinuities / breaks rationally corroborate to interpret the following aspects of the earth's internal structure.

(i) The earth is a spheroid of revolution.

(ii) Its interior is concentrically divisible into a number of onion like layers or shells (Fig. 1.7) of varying density and elastic properties in which the interlayer /zone boundaries are qualified by either 1st order or 2nd order discontinuities.

(iii) The internal structural layers are concentrically more or less homogeneous but radially somewhat heterogeneous.

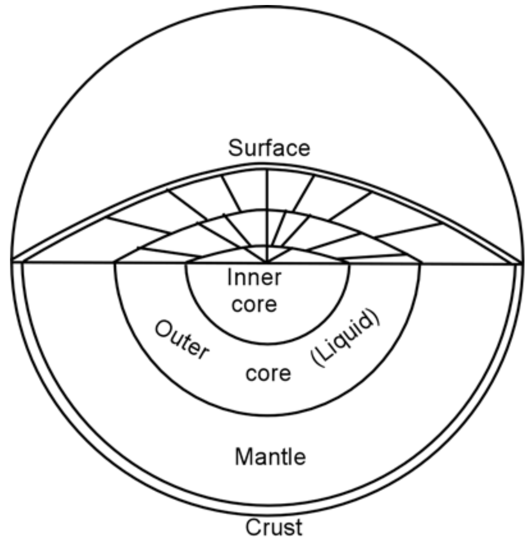

Fig.1.7: Concentric onion shell like structure of the Earth

(iv) Its interior is denoted by spherically symmetrical distribution of elastic and density properties.

(v) The nature and values of P- and S-wave velocities indicate the state of materials i.e. whether rigid, solid, soft solid, liquid or viscously flowing.

(vi) The density increases from about 2.6 g/cc near to surface to about 13 g/cc in the centre of the earth. The average density of the earth is 5.52 g/cc as determined by Cavendish in 1798.

Based on the above geophysical premise, various types of zonal models have been advocated by a large number of pioneer workers. The earliest was a simple three-fold zonal model of crust-mantle-core, by Oldham (1906). A four-fold zonal model with further division of the core (inner and outer) was interpreted by Lehman (1936). The present knowledge of the earth's interior is based on the discovery of a number of 1st and 2nd order discontinuities there by dividing the interior into a multi-zoned concentric layers characterized by distinctive seismic-physical attributes. After 1950, the more improved concentric models have been proposed by Gutenberg, Wadati, Wiechert, Geiger, Jeffrey, Bullen and Bullen-Hadon and others. The historical aspects relating to discovery of Earth's interior is presented in Table 1.5. It is just not possible here to deal with such models. However, a comprehensive but simplistic structural model is presented in Fig.1.8.

1.8.2. Compositional models of the Earth's interior: These models present various layering / shells characterized by their (a) similarity with meteorite composition (b) the concept of primary geochemical differentiation of elements in primordial molten stage of earth's evolution (c) mineral and rock assemblages of the interior and (d) laboratory experiments based on theoretical and hypothetical deductions. Of the various models, two compositional models are briefly presented below.

(i) Goldschmidt's (1922) compositional model based on the analogy with copper smelter products comprising three density differentiated products of top slag, intermediate sulphide-oxide matte and the bottom most metal alloy of Fe and Ni. The model is presented in Fig. 1.9.

(ii) Compositional model of the earth's interior based on similarities with types of meteorites - the shooting stars. The layered model is presented in Fig.1.10 after Buddington (1943).

(i) Crust (0-33km):

(a) Sial (0-11km)

(b) Sima (11-33km): Outer Sima (11-19km) and Inner Sima (19-33 km)

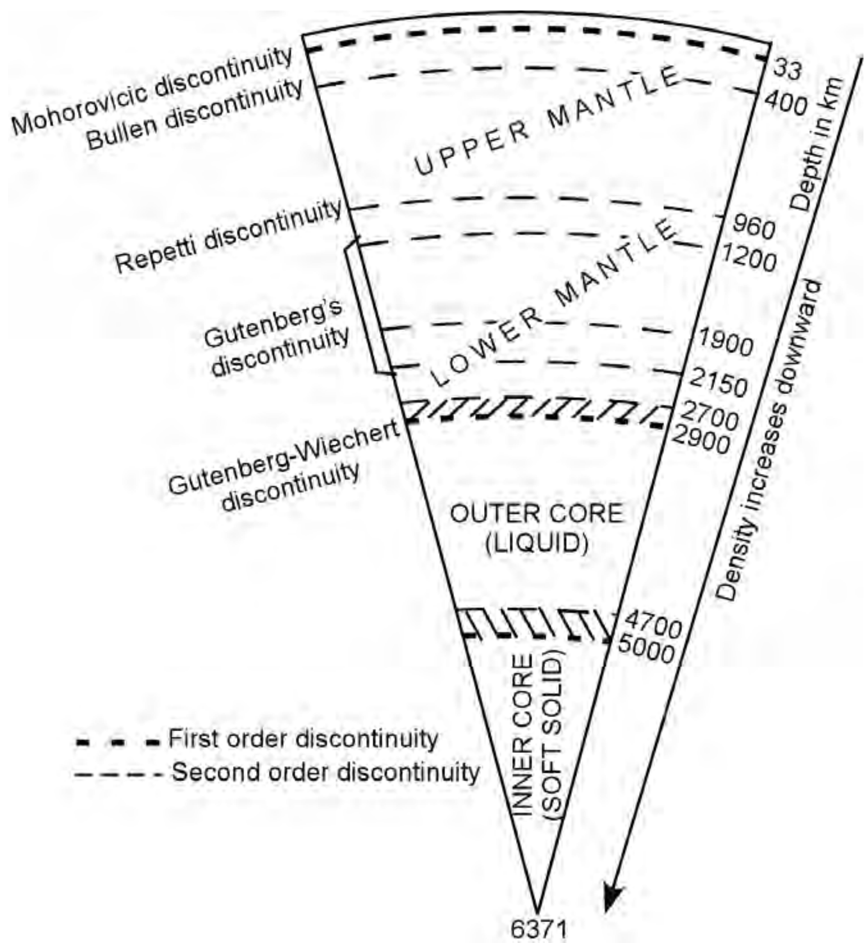

Fig.1.8: Schematic and comprehensive model of the interior of the Earth (Note: The discontinuity between Sial (Upper crust) and Sima (Lower crust) is known as Conrad discontinuity, which is a slanting boundary)

(ii) Mantle (33-2900km):

(a) Upper Mantle (33-1000km): Guttenberg layer (33-410km),
Golitsyn's layer (410-1000km)

(b) Lower Mantle (1000-2900) Upper part (1000-2700km)
Lower part (2700-2900 km)

Table.1.6: Historical aspects regarding interior of the earth

1906 :	Richard Oldham discovered core while studying 1897 Assam earthquake
1909 :	While studying propagation of seismic waves of the earthquake occurred in the Kulpa valley of Croatia on 8th October, 1909; A. Mohorovicic estimated the thickness of the crust to be 54 km.
1910 :	A Shadow zone was discovered while measuring how P and S waves travel through the earth and out the other side
1912 :	Guttenberg estimated the thickness of Mantle as 2867 km by the help of Physicist Weichert's equation.
1923 :	Conard studied the Tauern-earthquake (November 28, 1923) and interpreted a 'P*' wave, which he attributed to be an effect of a transition zone within the crust. Accordingly in 1927, he divided crust into SIAL and SIMA.
1926 :	Jeffreys opined the absence of S wave in the outer core and stated that outer core is liquid. Jeffreys studied the Jersey and Hereford earthquake (UK) and introduced the terms Pg and Sg for waves travelling within the granitic crust.
1928 :	Stoneley detected differences between continental and oceanic crust based on the dispersion of Love waves.
1936 :	Inje Lehmann divided core into outer core and inner core and stated many imperative issues regarding centre of the earth.
1937 :	Jeffreys officially coined the terms 'Pg', 'P*', 'Pn' and 'Sg', 'S*', 'Sn'
1938:	Guttenberg and Richter supported views of Inje Lehemann on the Core of the earth.
1970:	Inner core is solid

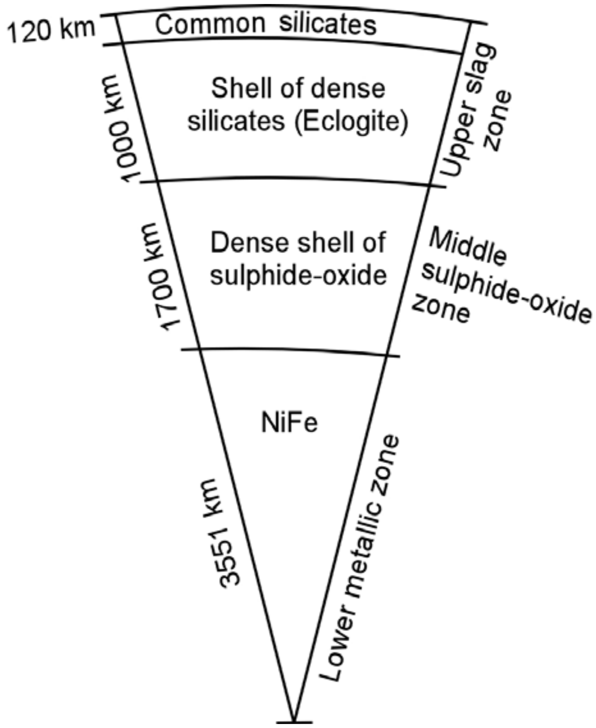

Fig.1.9: Goldschmidt's compositional model

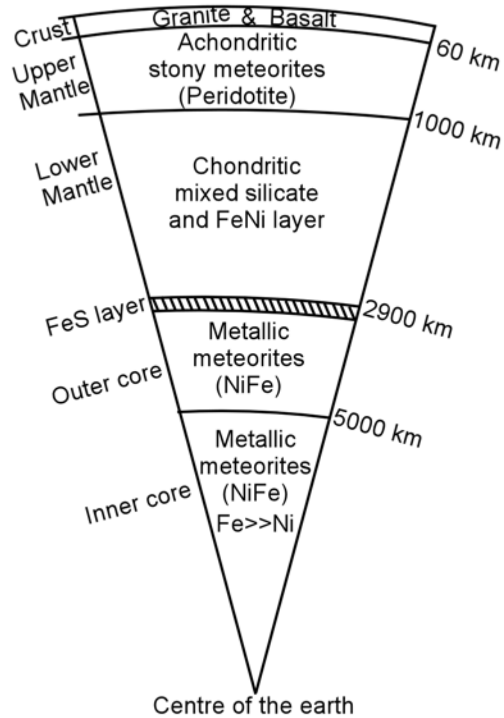

Fig.1.10: Buddington's meteriotic model

(iii) Core (2900-6371km):

(a) Outer Core (2900-4982km)

(b) Middle Core (4982-5121 km)

(c) Inner Core (5121-6371km)

1.8.3. Crust: It is the uppermost concentric layer of the earth. It is chiefly characterised by:

(i) Variable thickness that ranges from 33 km (average) on the continents down to about 5 km in the oceanic sector.

(ii) Its maximum thickness on land is about 60-70 km in the, areas of fold mountain belts.

(iii) It is broadly divisible into two sub-layers such as upper sialic crust (Sial) and lower simatic crust (Sima) by a somewhat inclined separating surface termed as Conrad discontinuity.

(iv) Sial stands for upper sub-layer, which is rich in silicon (Si) and aluminium (Al).

(v) Sima stands for silicon (Si), magnesium (Mg) and iron (Fe).

(vi) Sial is composed of igneous and metamorphic rocks such as granite and granitic gneisses with or without a thin veneer of sediments. The average density of sial is about 2.6 gm/cm^3.

(vii) Sima forms the bulk of oceanic part comprising mostly basaltic rocks having density between 3 - 3.2 gm/cm^3.

(viii) Simatic crust is much thinner in comparison to sialic one.

(ix) The base of the crust is characterized by a pronounced first-order discontinuity termed as Mohorovicic discontinuity below which rock layer shows an abrupt increase of seismic velocities of P- and S-waves and also density.

(x) The internal temperature at the base of the crust is about 1000°C.

(xi) In general, the crust forms uppermost concentric layer of the earth's interior, which is solid, strong and rigid.

(xii) It accounts for about 3% of the volume and 1% of the mass of the earth's interior.

1.8.4. Mantle: It is the second major concentric layer from the top that underlies the crust. Principal characteristics of the mantle are:

(i) This layer is about 2867 km thick.

(ii) It accounts for about 80% of the volume and 67% of the mass of the earth's interior.

(iii) This concentric zone is bounded in between the Mohorovicic discontinuity at 33 km depth at the top and the Gutenberg Wiechert discontinuity at about 2900 km radial depth at the bottom.

(iv) It is divisible into two major sub-zones called the upper mantle and the lower mantle respectively above and below the pronounced second order discontinuity termed as Repetti discontinuity at 960 km depth.

(v) Lower mantle is about two times thicker than the upper mantle.

(vi) There is an about 150 km thick viscous low velocity zone in the lowermost part of the mantle.

(vii) There are about nine second order discontinuities within the mantle.

(viii) The densities in the mantle increases with depth and varies from 3.5 to 4.4 gm/cm^3 in the upper mantle and in the base of the lower mantle, the density goes up to 5.6 gm/cm^3.

(ix) Mantle is the major storehouse for the earth's internal energy and forces, which support ocean-floor spreading and continental drifting.

(x) Upper mantle is composed of a mixture of ultrabasic-basic rocks called pyrolite.

(xi) Lower mantle is composed of heavy silicates mixed with Fe and Ni.

(xii) The crust and upper part of the Gutenberg layer together constitute what is known as lithosphere. The lithosphere is underlain by ‘asthenosphere’, which is a layer of virtually of no strength to resist deformation and it is the low seismic velocity layer. The asthenosphere is situated somewhat 70 to 220 km depth. To be more precise, the lithosphere is separated from the rest of the mantle by the asthenosphere.

1.8.5. Core: Core forms the lowermost concentric zone of the earth's interior. Thus, it forms the lowermost composite zone lying below the mantle from which it is demarcated by a first-order discontinuity called Gutenberg - Wiechert discontinuity at a depth of 2900 km. It is also known as ‘Centrosphere’. Its radial thickness is about 3471 km. It is principally composed of Fe and Ni and hence, in general, referred to as 'NiFe'. Density of the core varies from 9.8 gm/cm^3 at the top to about 13 gm/cm^3 at the very centre of the earth. It accounts for about 17% of the volume and 32% of the mass of the earth's interior.

Later findings reveal a major two-fold division of the core into (i) outer core and (ii) inner core, which are separated from one another by inner-outer core boundary, which is a pronounced discontinuity placed at a depth of 5000 km. Between the two cores, lies a 300 km wide transition zone. The outer core (2100 km thick) is thicker than the inner core (1370 km). Densities in the outer core vary from 9.8 gm/cm^3 to 10.7 gm/cm^3. Outer core does not transmit S-waves and hence said to be in liquid/semi-solid state. It controls the earth's magnetic field. Another school stated three fold divisions of core (Outer Core-2900-4982km: a state of homogenous fluid; Middle Core-4982-5121 km: fluid to semi fluid sate, Inner Core-5121-6371km: solid). Inner core is said to be in soft-solid condition as it distinctly transmits P-wave and very feebly weak S-wave. The outer core is said to be composed of Fe, Ni and a little sulphur. Thus it is otherwise known as NiFe. Inner core is composed of solid Fe and Ni alloy and has a high density varying from about 11 to 13 gm/cm^3 at the very centre. The study of meteorites demonstrates that the earth is having a nickel-iron core. It is presumed that when all the oxygen and sulphur had been consumed in reaction with the active metals, excess iron and nickel would separate in the form of droplets. Because of their comparatively high density and high pressure in the core, these drops of iron would sink through the molten or viscous silicates towards the center of the planet, eventually concentrating there in to a central metallic mass, the core of the earth. Several of the rarer metals which are not chemically very active such as gold, platinum etc would react to only a moderate extent with oxygen and sulphur. They are also found in the core.

1.8.6. Discontinuities

Discontinuities within the earth's interior are found because of changes in chemical composition, density, state and physical properties of the materials. Discontinuities are classified into two types: first order discontinuity and second order discontinuity.

First order discontinuities are those discontinuities, which divide the earth's interior into three major divisions (crust, mantle and core). They are Mohorovicic discontinuity found at the depth of 33 km and Guttenberg-Weichert discontinuity found at 2900 km depth. All other discontinuities found in the interior of the earth are known as second order discontinuities. Other three second order discontinuities are conard (11km depth), Repettii (1000km depth), Lehmann discontinuities (5000 km depth) separating sial and sima; upper mantle and lower mantle and outer core and inner core respectively. Besides, other discontinuities are enumerated hereunder:

- **(i)** **Density break:** At a depth of 80km, density changes from 3.36 to 3.87 gm/cm^3.
- **(ii)** **Gravity break:** At a depth of 150km, gravity changes from $984 cm/sec^2$ to $974 cm/sec^2$ till it reaches a depth of 1200km.
- **(iii)** **Olivine-β spinel discontinuity at 410km depth; β spinel-γ spinel discontinuity at 520 km depth and γ spinel-garnet discontinuity at 660 km depth:** The mantle consists of olivine-pyroxene complex, which exists in a solid state. It is believed that the upper mantle has a mix of 3 parts of ultramafic rocks and one part of basalt known as pyrolite. Olivine is predominant mineral in the mantle showing polymorphism. Olivine, β spinel, γ spinel and garnet have same chemical composition with different atomic structures. At the depth of 410 km, olivine is transformed to β spinel; at 520 km depth β spinel is transformed to γ spinel and at 660 km

depth γ spinel is transformed to garnet. These are three imperative seismic discontinuities found at 410, 520 and 660 km depths in the earth's interior.

(iv) **Elastic-strain discontinuity:** At 700km depth the capability of the materials in storing the elastic-strain energy changes. However, up to 700km the capability is more.

(v) **Repetti discontinuity:** At 950 to 1000km depth there is a rapid rise in the velocity of seismic waves representing Repetti discontinuity.

(vi) **Gravity break:** At 1200km depth, gravity attains its minimum value i.e. 974cm/sec^2, thereafter it rises up to 1068cm/sec^2 at the core boundary.

(vii) **Seismic discontinuity:** At a depth of 2700km, the seismic velocity reaches its maximum i.e., 13.7km/sec and gradually it decreases.

1.8.7. Shadow Zone: A seismic shadow zone is an area of the Earth's surface where seismographs cannot detect an earthquake after its seismic waves have passed through the Earth. When an earthquake occurs, seismic waves radiate out spherically from the earthquake's focus. The primary seismic waves are refracted by the liquid outer core of the Earth and are not detected between 104° and 140°. The secondary seismic waves cannot pass through the liquid outer core and are not detected more than 104°. This is because—P-wave velocity is equal to $\sqrt{(K+4/3\ \mu)/p}$, whereas S-wave velocity is equal to $\sqrt{\mu/p}$ (Incompressibility: k, Density: p, Rigidity: μ). S-wave velocity is entirely dependent on the rigidity of the material. When S wave travels through liquid, liquid having zero rigidity, hence always making the S-wave velocity overall zero and as such S-waves lose all velocity when travelling through a liquid. P-waves, however, are only partially dependent on rigidity and as such still maintain some velocity (if greatly reduced) when travelling through a liquid.

1.9. DEPTH ZONES OF THE OCEANS

1.9.1. Introduction: Oceans represent a lion's share of our hydrosphere of the earth's surface. The ocean is a sea in expanded form. There are four such oceanic realms such as the Pacific (49%), the Atlantic (26%), the Indian (21 %), the Arctic (4%) in order of their decreasing sizes. The oceanic areas inclusive of the seas, bays and gulfs cover about 510 million km^2 of the earth's surface. The marine areal coverage is more in the southern hemisphere than the northern counterpart. The highest point of the earth's surface is the peak of Mount Everest of the Himalayan range, which is 8.848 km high above the mean sea level (MSL). The deepest part of the ocean is the Challenger Deep in the Mariana Trench located in the Western Pacific ocean with a depth of 10.994 km below the mean sea level.

1.9.2. The oceanic subdivisions based on depth: The oceanic realms of the earth can be classified into a number of schemes basing on various criteria of which the depth of ocean is considered as the most widely used and the fundamental parameter. The subdivisions (Fig. 1.11) made singularly on this depth basis are as follows.

(i) Littoral (Foreshore) zone
(ii) Sub-littoral or continental shelf zone (Neritic zone)
(iii) Bathyal (Continental slope) zone
(iv) Continental rise zone
(v) Abyssal (Deep sea platform) zone
(vi) Hadal (Restricted oceanic trench) zone

The major features / characteristics of these depth zones are comprehensively described below.

(i) Littoral zone: It is the depth zone that lies between the levels of high tide and low tide. It is otherwise also known as foreshore zone or beach zone, which gets regularly and alternately covered and uncovered by rise and fall of sea tide respectively. This zone enjoys the tidal wave dominated transition environment. It is characterized by beach sands, bar sands shore lines and tidal flats. The average width of this zone is 3 to 4 km sea-ward from the coast line.

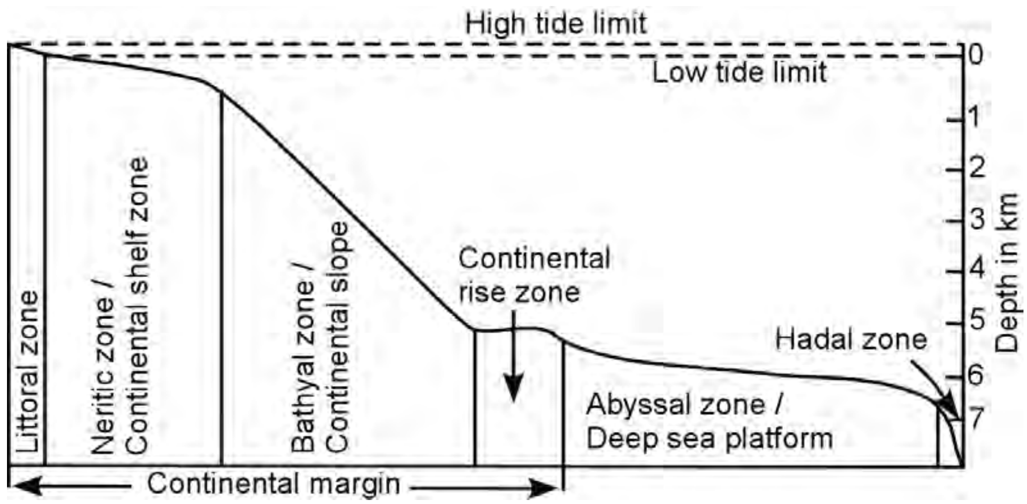

Fig.1.11: A schematic section of oceanic depth zones

(ii) Sub-littoral or continental shelf zone: It is the next shallow water depth zone. It is also termed as Neritic depth zone. It is the part of the continental margin that lies between the littoral zone and the continental slope zone. It is the outer border of the continental platform that extends from the low tide line to the depth, where shallow ocean floor (bottom), shows a marked increase in its slope. In other words, shelf is the undersea water borderland that is marked by a very gentle slope like that of a low terrace towards the oceanic end. The important characteristics of this shelf zone are as follows.

(a) It is the shallow marine water zone that runs parallel to the sea coast.

(b) Shelves of the world constitute about 18% of the earth's total land area and about 7.5% of the total oceanic realm.

(c) The maximum depth of the shelf is 200 metres (l00 fathoms). Its average depth is taken as 133 m, below mean sea level.

(d) The width of the shelf varies appreciably from a few tens of km to 1500 km, the average being 78 km.

(e) The floor of the shelf is a gently sloping surface that shows very low gradient. Its slope angle is averagely less than 0.1°.

(f) Within shallow depths (45-60 m), the shelf floor is filled with coral reefs in form of ridges, barriers and islands in tropical and warm conditions.

(g) It bears submarine canyons those deeply cut through the shelf floor.

(h) The shelf areas, in general, are built up of thick sedimentary strata which increase in thickness from near the shore line towards the oceanic part.

(i) The sedimentary strata of the shelf area comprise of :

i) Well sorted clastic and terrigenous (land derived) sediments which are sands, silts and muds from near the shore towards the oceanic depth.

ii) Chemogenic sediments such as limestone and evaporites.

iii) Organogenic sediments such as phosphorites, coralline-algal limestone and variety of shell-limestones, composed of dead shells of benthic fauna such as corals, mollusks and brachiopods.

(j) Based on width, the continental shelves are of two principal types such as (a) Pacific type with narrow shelves and (b) Atlantic type with wide shelves.

(k) Economic potentiality of the shelves comprises of (a) offshore oil and gas (b) monazite and limonite rich beach placers (c) phosphorites (d) store house of sea food.

(iii) Bathyal or continental slope zone: Continental slope depth zone, otherwise termed as bathyal depth zone is a part of the continental margin that lies between the continental shelf and the ocean-ward continental rise. The oceanic depth zone from 200 metres to 4,000 metres (4 km) into the open ocean constitutes this .zone of continental slope. The marine water of this zone is mostly dark except the uppermost thin layer, which is penetrated by the sunlight. The following are the principal characteristics of this depth zone.

(a) It is dimly to very dimly lighted up to about 1000 m (1 km).

(b) Beyond above mentioned distance, this depth zone is dark, quiet and cold.

(c) The temperature of this zone is as low as 10° C and the hydrostatic pressure is high.

(d) Width of this zone varies from 16 km to more than 160 km.

(e) The average slope of this zone is in between 3° - 6°.

(f) The depth of this zone ranges from 200 to more than 3000 m.

(g) This zone is devoid of wave actions and sea currents. However, it is frequently witnessed by density (turbidity) currents.

(h) The floor of this zone is frequently witnessed by turbidity (density) currents.

(i) The sloping floor is somewhat irregular by deeply cut channels forming submarine canyons.

(j) The nature of slope of the bottom surface may be straight or concave.

(k) The sediments of the slope zone are texturally fine grained in general. However, compositionally the slope sediments are heterogeneous comprising of variously coloured clastic muds, silts, fine sands, greywacke, volcanic muds, coralline and foraminifera silts and a variety of organic oozes (shells of micro-organisms).

(l) Economic importance:

(i) Deepwater oil and gas fields

(ii) Phosphorite deposits

(iii) Varieties of sea food and source of dissolved salts.

(iv) Continental rise zone: It is the part of the continental margin that lies between the continental slope zone and the abyssal depth zone. It is also termed as continental apron zone. It is characterized by a gentle incline that shows a comparatively smooth topography which may be with or without subdued submarine canyons. The sedimentary apron and the organic deposits here are more or less akin to bathyal depth zone.

(v) Abyssal depth zone: It is the depth zone that forms an extensively flat oceanic floor which is intervened by complex submarine topographic features and relief aspects of the ocean bottom. These features are (a) oceanic fore-deeps or trenches (b) mid-oceanic ridges (c) deep submarine fans (d) sea mounts (submerged conical submarine hillocks / peaks fully immersed under sea water) (e) sea guyots (rows of flat topped sea mounts). Other important features of this depth zone are as follows:

(a) The average oceanic depths of this zone go down to more than 4 km. The foredeep or trench parts show more than 10 km depth below mean sea level.
(b) The oceanic water of this zone is cold recording very low temperature (<4°C).
(c) This is an absolutely dark depth zone, which is under very high hydrostatic pressure.
(d) The sediments of this depth zone are thin and condensed. It has very slow rate of sedimentation.
(e) The depth zone shows variably thick / thin covers of sediments.
(f) The sediments of this depth zone comprise of very fine-grained and rather thin veneers of (a) red muds / clays (b) turbidites (c) Ferro-manganese (Ni,

Co, Pb, Zn rich) nodules (d) varieties of deep sea pelagic muds comprising varieties of calcareous and siliceous oozes.

(g) This zone is inhabited by very few marine organisms such as anaerobic bacteria, which thrive in reducing environment.

(vi) Hadal depth zone: It forms the deepest depth zone of the oceanic floor that exists beyond the limit of abyssal zone. It is indeed a deep trench zone where the depth of the floor is more than 6.5 km (6500 m) below the mean sea level. This depth bears the very deep part of the oceanic trenches. The deepest oceanic trough / trench is that of the Mariana Trench located near the island of Quam in the Western Pacific ocean at a depth of 11.035 km (11035 m) below mean sea level. This depth is more than 2 km as compared to the height of the Mount Everest (8848 m) which is the highest point on the land. The hadal depth zone has the shortest areal coverage amongst the various depth zones. It is the darkest zone that hardly supports any marine organism.

1.10. CERTAIN INFORMAL TERMS DESCRIBED

1.10.1. Continental Margin: It includes the zones / provinces which lie between the shoreline and the abyssal zone (plain). It includes the depth zones of continental shelf (sub-littoral or neritic depth zone), continental slope zone and continental rise zone.

1.10.2. Continental Border Land: This forms a part of continental margin between the shore line and continental slope and not the continental rise zone. Thus, it is the continental margin minus continental rise.

1.11. SAMPLE QUESTIONS

1.11.1. Long answer type questions

(i) Describe the internal structure of the Earth giving the most acceptable model.

(ii) Bring out the distinction between earth's internal structure and co~stitution. Briefly describe the earth's constitutional models.

(iii) List the various important hypotheses propounded on the origin of the earth. Briefly describe the salient features of any three hypotheses.

(iv) (What are Geology and its scope? Give a short account of the subdivisions of the ‘geology’.

(v) What are the various methods of estimating the age of the earth? Briefly discuss their merits and drawbacks.

(vi) What is an intrinsic clock? Briefly describe it in relation to earth’'s age dating.

(vii) What is meant by 'depth zone' of the oceans? Briefly describe the depth zones giving a schematic diagram.

1.11.2. Write short notes in 3 - 5 sentences

(i) Milky Way (ii) Nebulae (iii) Meteorites (iv) Comets

(v) Biosphere (vi) Scope of geology (vii) Earth System Science

(viii) Shape and figure of the Earth

(ix) How is the Earth related to the Sun?

(x) Mohorovicic discontinuity

(xi) Applied branches of geology

(xii) How are the stars different from planets?

(xiii) How is the earth unique and different from the co-planets of our solar system?

(xiv) What is Universe and how it is different from Cosmos

1.11.3. Distinguish between the following pairs.

(i) Big bang and steady state theories; (ii) Meteors and meteorites

(iii) Natural and artificial satellites; (iv) Inner core and outer core

(v) Mantle and core; (vi) Crust and mantle; (vii) Upper and lower mantles

(viii) Inner group and outer group of planets; (ix) Sial and Sima

(x) First and second order discontinuities; (xi) P-wave and S-wave

(xii) Seismograph and seismogram

1.11.4. Fill in the blanks with appropriate word (s) given in the bracket.

(i) A leap year consists of _______days. (364, 365, 365.5, 366)

(ii) The Sun is the ________sized star in the universe. (very large, large, the average, tiny)

(iii) The inclination of the Earth's rotational axis to its orbital planet is . (90°, 66.5°, 45°, 22.5°)

(iv) The difference between the equatorial and polar diameters of the Earth is ______km. (22, 32, 42, 52)

(v) A substance weighted at equator will be __________at the pole. (exactly same, nearly same, more, less)

(vi) The planet in which the Sun rises in the west and sets in the east is (exactly. (Mercury, Venus, Mars, Uranus)

(vii) Planetoids lie in between Mars and _______(Earth, asteroids, Jupiter, Saturn)

(viii) _is termed as search light of the space. (Comet, Meteor, Quasar, Pulsar)

(ix) The Moon's reflected light takes __________to reach the Earth's surface.

(8 minutes, 8 seconds, 1.3 minutes, 1.3 seconds)

(x) Earth’s magnetism originates in ___________. (lower mantle, outer core, inner core, centre of the Earth)

(xi) During __________month the Milky Way across the sky is best seen. (January, April, August, October)

(xii) Acceleration due to gravity (g) in the Earth is highest at _______(Equator, 45° N, 45° S, pole)

(xiii) Deepest depth zone of the ocean is known as __________zone. (Bathyal, Abyssal, Hadal, rise)

(xiv) Offshore oil fields are mostly located in ________(shelf, slope, Bathyal, Abyssal)

(xv) Mariana trench, the deepest locale in the oceanic realm is in the ______ocean. (Indian, Atlantic, Pacific, Arctic) zone.

Answers:

(i) 366 (ii) average (iii) 22.5 (iv) 42 (v) less (vi) Uranus (vii) Jupiter (viii) Quasar

(ix) 1.3 seconds (x) Outer core (xi) October (xii) pole (xiii) Hadal (xiv) shelf

(xv) Pacific

1.11.5. Answer in one or two words

(i) Which planet of the solar system has highest number of natural satellites?

(ii) Name the smallest planet of the solar system.

(iii) Name the planet that has no ‘moon’.

(iv) Name the densest planet of the solar system.

(v) Which member of the solar system is called as 'Bad Omens'?

(vi) What is the age of the solar system?

(vii) How old is our home planet ‘Earth’?

(viii) What is the diameter of the Earth?

(ix) Which is known as the sister planet of the Earth?

(x) Which is the largest natural satellite (moon) of the solar system?

(xi) Which is known as the red planet?

(xii) Which planet is termed as the blue planet?

(xiii) Who discovered galaxy?

(xiv) Who discovered solar system?

(xv) What are the average and highest density values of the Earth?

(xvi) Name the galaxy to which our Earth belongs?

(xvii) Name the seismic waves which aid to understand the Earth's internal structure?

Answers

(i)Saturn (ii) Pluto (iii) Venus and Mercury (iv) Earth (v) Comet (vi) 5 by (vii) 4.5 b.y. (4500 my) (viii) 6371 km (ix) Venus (x) Titan of Saturn (xi) Mars (xii) Earth (xiii) Harold Sappti (xiv) Copernicus (xv) 5.5 and 13 (xvi) The Milky Way (xvii) P, S and L

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CHAPTER – 2

GEOMORPHOLOGY

2.1. INTRODUCTION

The term geomorphology is derived from three Greek words: geo (earth), morph (forms) and logus (science). It is, thus, the science of earth forms or land forms. It is also defined as the interpretative description of the relief features of the earth's surface. The word physiography was thought to be synonymous of geomorphology and, in the early days, was included both in geology and geography courses. Geographers study this branch as a discussion of the land forms with respect to man's environment, i.e. how'much they are useful to man. Moreover, they do not give much importance on the origin of the land forms. Gradually, there has been a decline of interest among geographers in this branch. As a result, geomorphology becomes primarily a part of geology in which the origin of the land forms are given due cognizance.

2.1.1. History and background of geomorphology: The science of land forms is too old and dates back to Herodotus (485? - 425 B.C.), the father of history. The history of modern geomorphology dates back to James Hutton (1726 - 1797), who propounded the doctrine of *'Uniformitarianism'* i.e., the present is the key to the past'. Hutton has nicely described the fact that the rivers, glaciers, seas had been doing the same work since their inception, as they are doing it today, may be at different rates at different times. John Playfair (a great friend of Hutton, 1748-1819) elaborated and expounded Hutton's principle in form of scientific writings, Lyeril (1797- 1875) is also a great exponent of the theory of *'Uniformitarianism'*. Major Powell (1834 - 1902) contributed a lot to geomorphology on his study in the

Colorado Plateau and the Grand Canyon of the Colorado river during his expedition. It is W.M. Davis (1850 - 1934), the great definer, analyst and systemizer, who gave new concepts to modern geomorphology by his genetic methods of the description of the land forms.

Till recent times, geomorphology was a much neglected branch. Its importance increased only after the applications of geomprphic studies to other branches of geology. Practical applications of geomorphic principles to hydrology, pedology, engineering geology, petroleum geology, economic mineral deposits, mining and such other fields increased the importance of this branch of science. In recent years, branches like regional, quantitative and experimental geomorphology have gained much importance. The importance of geomorphology has increased manifold after the development of aerial and satellite remote sensing. All kinds of remote sensing studies and their applications are incomplete without the study of geomorphology.

2.1.2. Land forms: As geomorphology means the science of earth forms and features, a knowledge of the relief features becomes essential. The relief features of the earth are broadly divided into three orders. The *first order* relief features are the *Continental platforms* and the *ocean basins.* There are *mountains, plateaus* and *plains* on the continental platform and the ocean basins; these are the *second order* relief features. All the minor landforms on the mountains, plateaus and the plains, to name a few - hills, mesa, buttes, mounds, dunes, valleys, flood plains, deltas, kames, eskers, drumlins, terraces, pediment, bajada, beach, coast etc, are the *third order* relief features.

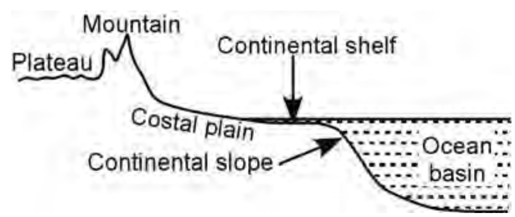


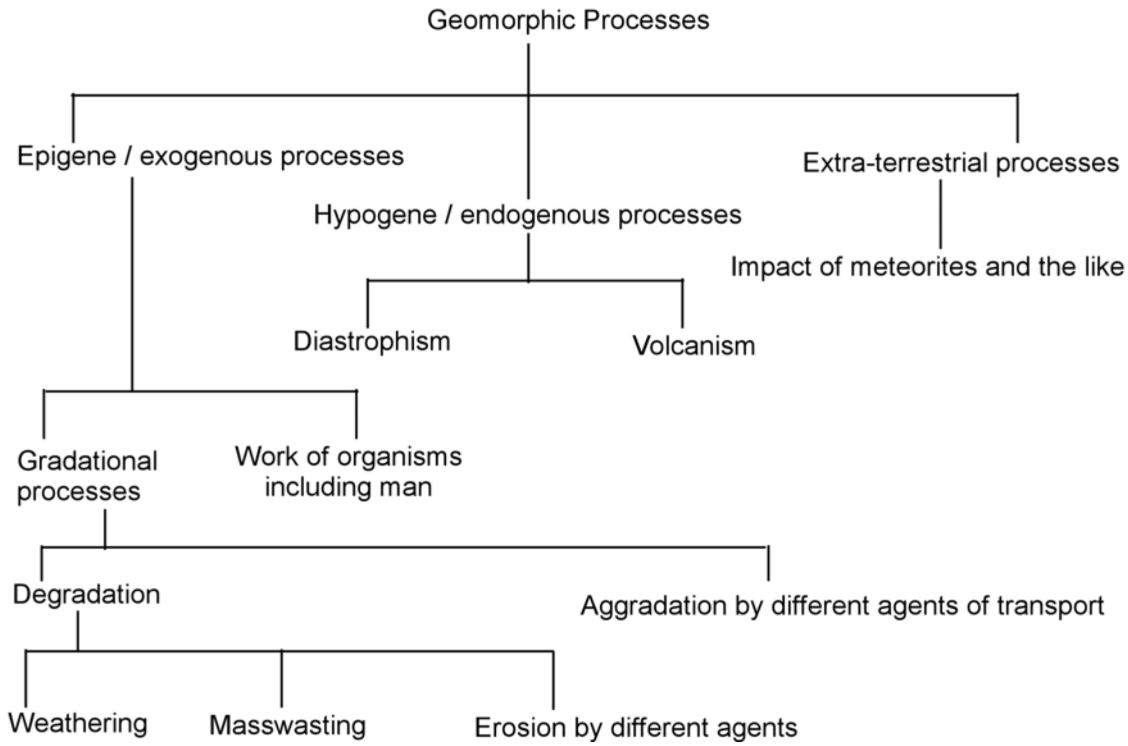
Fig.2.1: Relief features of the earth

2.1.3. Geomorphic Precesses and Agents: All those physical and chemical processes that modify the earth's surface forms are termed as geomorphic processes. A geomorphic *agent* is any natural medium that is capable of scouring and transporting earth material. Thus, running water, underground water, glaciers, wind, waves, currents, tides and tsunamis are the geomorphic agents. They are also called as geologic agents or mobile agents. These agents originate outside the earth's crust and the work performed by them act at or near the earth's surface. For this reason, they are termed as *exogenetic* or *epigene* processes. They tend to bring the earth's surface to a common level, that is, they degrade the highlands and aggrade the low lands. For this, they are also termed as gradational agents. The processes are gradational processes. Earth's surface is also modified by *weathering* and *masswasting* processes. All these processes are *exogenetic* or *epigene* processes. Other geomorphic processes, such as diastrophism and volcanism originate within the earth's interior and modify the earth's surface. These are *endogenetic* or *hypogene* processes. Earth's surface is also affected by the impact of meteorites. This is an *extra-terrestrial* process. The different geomorphic processes are outlined in Table 2.1.

2.2. WEATHERING

2.2.1. Weathering: Weathering is the disintegration and or decomposition of rocks in situ or in place. This includes a group of processes that act collectively at and near the earth's surface. They fragment the solid rocks and convert them into clastic state. The portion of the earth's crust which is exposed to the weathering processes in known as the zone of weathering. Rock weathering is broadly divided into three types **-** (i) Physical weathering (ii) Chemical weathering and (iii) Biological weathering.

Table - 2.1



2.2.2. Physical Weathering Processes: These are otherwise called as mechanical weathering processes. They take place in three different ways- (i) Expansion due to unloading, (ii) Thermal expansion and (iii) Growth of crystal.

(i) Expansion due to unloading: Igneous rocks are formed at great depths. This leads to the formation of large scale fractures roughly parallel to the earth's surface. These fractures give an impression of foliation on the overlying rocks known as *exfoliation. Sheet structures* of most granitoid rocks are formed by this process.

(ii)Thermal expansion: Rocks are composed of different minerals which have different co-efficients of expansion. Repeated differenti'al thermal expansion and contraction of different minerals help in disintegration of rocks. This leads to *mass exfoliation* or *granular exfoliation.*

(iii) Growth of crystals: Freezing water in cracks and fractures form ice crystals. They exert tremendous pressure and disintegrate solid rocks. It is known as *frost-wedging.* A very similar process is *frost - heaving* where due to freezing of water, expansion results, rocks disintegrate and on an inclined slopes are acted upon by gravity. Alternate freezing and thawing is much more effective in disintergation of solid rocks. In arid and semiarid regions, formation of salt crystals has also the similar effect.

Another possible process of physical weathering is termed as *colloid plucking* by Reiche. He advocates the weathering of rocks after soil and mantle is removed by erosion just like gelatine removes portions of glass kept over it.

2.2.3. Chemical Weathering Processes: The different chemical weathering processes are (i) Hydration, (ii) Hydrolysis, (iii) Oxidation (iv) Carbonation and (v) Solution.

(i) Hydration: The process of *hydration* involves adsorption of water molecule such as the conversion of haematite to limonite. *Hydration* is a process in which water is involved in the new mineral.

$2Fe_2O_3 + 3H_2O = 2Fe_2O_3{\cdot}3H_2O$

(ii) Hydrolysis: It involves the formation of hydroxyl is by chemical reaction. Alteration of feldspars and olivine are good examples.

$KAlSi_3O_8 + H_2O = HAlSi_3O_8 + KOH$

Orthoclase + Water = Orthosilic acid + Potassium hydroxide

$MgFeSiO_4 + H_2O = Mg(OH) + H_2SiO_3 + FeO$

Olivine + Water = Magnesium hydroxide + Orthosilic acid + Ferrous oxide

(iii) Oxidation: Ferrous oxide in the above reaction reacts with water and oxygen and is oxidised to form limonite. It also involves hydration.

$4FeO + 3H_2O + O_2 = 2Fe_2O_3 \cdot 3H_2O$

Ferrous oxide + Water + Oxygen = Limonite

(iv) Carbonation: The formation of potash carbonate by reaction of potassium hydroxide with water and carbon dioxide is an example of carbonation.

$2KOH + H_2O + CO_2 = K_2CO_3 + 2H_2O$

Potassium Hydroxide + Water + Carobon dioxide = Potassium carbonate + Water

(v) Solution: Calcium carbonate is dissolved in presence of water and carbon dioxide to form calcium bicarbonate which is soluble and is removed by solution.

$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2$

Calcium Carbonate + Water + Carbon dioxide = Calcium bicarbonate

By this process limestone, dolomite, chalk, marble are decomposed.

2.2.4. Biological Processes: The work of organisms including that of man aid in disintegration and decomposition of rocks. Growth of plant roots and stems expand the joints and fractures in rocks. More important is the decay of plants that produce humic acid which help in chemical weathering. Burrowing animals bring fresh rock material from the earth's surface and help in weathering. Termites bring soil and build mounds or ant-hills. Prairie dogs and bears do the same work. The chemical and mechanical work of earthworms is note worthy. Human activity is equally important through mining and engineering constructions.

2.2.5. Significance of Weathering: Weathering helps in the formation of soils which is essential for humanity. It aids in mass wasting and prepares the land for erosion. Topographic surfaces are lowered down by weathering. It creates certain land forms like mantle rock (regolith), mounds, huddo rocks etc and modify them.

2.3. EROSION

Erosion includes all such processes by which the mobile agencies acquire and remove rock materials. Commonly, transportation is considered as an integral part of erosion. Erosion takes place in many ways.

The mechanism by which loose materials are acquired by the river and swept away is the *hydraulic action.* That is the sweeping away of loose materials. Corresponding mechanism by the wind is *deflation* and when performed by the glacier it is termed as *scouring.* Two other mechanisms by which the glaciers acquire the materials are *plucking* and *sapping. Plucking* means the acquisition of parts of the bedrock by a glacier when *frosting* and *heaving* disintegrate the bed rock. *Sapping,* on the other hand, is undermining of the bed rock.

Processes by which the agents erode the earth materials while in transit, are *corrasion (or abrasion)* and *corrosion. Corrasion* is the mechanical abrasion of the rocks on the river bed and the sides. The running water carries boulders, rock fragments, which dash against the bed rock and the sides resulting in the erosion of the river bed and the sides. *Corrosion* means the chemical erosion by water, especially, when it is charged with alkalies, carbonates, acids etc. Similarly, *corrasion* is affected by the wind action and glaciers. (Glaciers also erode the earth materials by *gouging,* i.e. the local basining of the softer bed rock, which is also a process of *corrasion).*

During transit, the rock fragments are eroded by wear and tear through mutual rubbing, grinding, knocking, scrapping etc. This mechanism is known as *attrition*, performed by the river, the glaciers and the wind.

2.4. TRANSPORTATION

Transportation of the rock debris takes place by *traction, saltation, suspension, floatation* and *solution. Traction* is partial support of material by the *buoyancy* of water or wind. This takes place by rolling, pushing and dragging. When the movement takes place in intermittent leaps and bounds by running water and wind, it is termed as *saltation.* Temporary support of rock particles by moving water or air is *suspension.* Materials are carried by the glaciers in a similar manner. Though suspension is not the correct term, yet this type of transportation by the glaciers is termed as suspension. Besides, running water transports materials by two more ways **-** *flotation* and *solution.* Certain materials like pumice and organic materials float on water and are carried down stream. Some eroded materials, especially those which are decomposed by chemical weathering and by corrosion are transported by water in solution.

Weathering disintegrates and decomposes the solid rocks and helps in erosion. The agencies acquire the loose material and tranpsort them to the places of accumulation and aggradation.

2.5. RIVERS

2.5.1. Introduction: Precipitation takes place in form of rainfall, snowfall and mist or fog. Part of the rainfall goes underground by *percolation* and is stored as ground water; another part goes back to the atmosphere by *evaporation* and *evapotranspiration.* Rest of the rainfall flows down the surface in form of *run off.* This is the major source of running water. Besides, the melting of snow and ice gives rise to running water. Other sources are the seepage of undergound water in form of springs; overflows from the lakes. Sheet wash and run off concentrate to form rills, gullies and ravines. These converge to form streamlets, which unite to form streams. Further streams combine to form rivulet, those give rise to rivers. Thus, a complex branching tree type drainage develops. Some rivers are perennial in which water flows throughout the year like the Ganges. A few are intermittent in which case; the source of water fails periodically. These are typical of semideserts. The third type is *ephemeral,* where streams flow only in response to precipitation. Most of the rivers of South India including Odisha belong to this category.

The streams which develop consequent to the rise of land mass are termed as *consequent* streams (Fig.2.2). Subsequently, few tributary streams flowing almost parallel to the strike of the beds join the consequent streams. They are termed as *subsequent* streams (Fig.2.2). Some tributary streams join the subsequent streams. Some of them flow along the *dipslope* or *resequent* slope, these are termed as *resequent* streams (Fig.2.2). Some others flow along the slope opposite to dip slope, known as *obsequent* streams. (Fig.2.2).

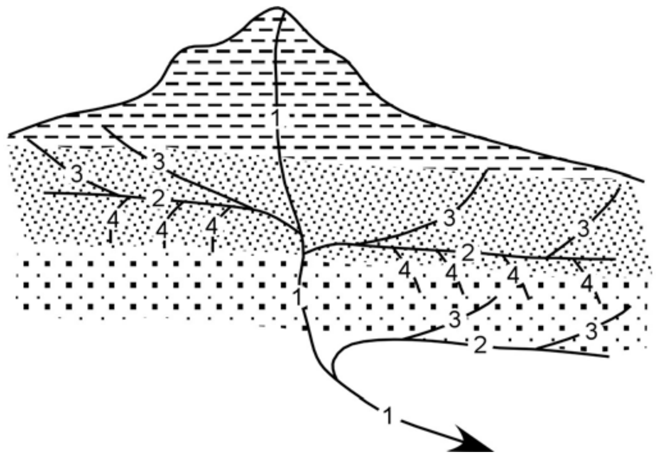


Fig.2.2: Types of streams: 1 - Consequent, 2-Subsequent, 3 - Resequent, 4 - Obsequent

Some streams are not controlled by geologic structure. These have zig-zag orientation and are termed as *insequent* streams (Fig. 2.3).

Fig.2.3: Insequent stream

Few streams existed before the imposed surface relief and maintain their course by cutting the newly rising land mass. Rivers like the Indus, the Sutlej, the Brahmaputra existed before the rise of the Himalayas. Such streams are called *antecedent* streams. Some rivers join and debouch their load to longer rivers. These are *tributary* rivers of the major ones; like the lira, the Ong, the Ib, the Tel which are tributaries of the river Mahanadi. Similarly, larger rivers before debouching to the sea or ocean may be bifurcated or divided into many channels. These are called the distributaries like the Kathjori, the Devi, the Kuakhai, the Birupa, the Luna etc. which originate from the river Mahanadi.

Each river creates its own valley, though a few rivers flow in pre-existing valleys. Valley development takes place by valley deepening, vaHey widening and valley lengthening. The development of a river system can be compared with that of human life. Commonly, the rivers originate from the mountains and the highlands. In the initial stage, gutters combine to form streamlets and streams. In this region, gradient is high and valley deepening by downward cutting is prominent. The rate of erosion is high and the eroded materials are transported easily. Numerous tributary streams join the trunk stream and the river system is developed. Valleys lengthen their course by headward erosion. The initial stage passes to the youth stage and the river system or drainage system is re-established.

Fig. 2.4: V - shaped valley

Headward erosion and downward cutting continues. At this stage, the river valley is 'V' - shaped (Fig. 2.4). In this hilly terrain rapids and water falls are formed. Potholes develop by whirling action and grinding. The river with higher gradient captures some rivers by headward erosion. This is known as *river capture* or *river piracy* (Fig 2.5). The river, which is captured is khown as captured river and the rest of it downstream is a *misfit* river (Fig 2.5), The point at which capturing takes place is know as *elbow of capture* and the gap is known as *wind gap.* Some tributary valleys are at higher relief than the trunk valley found mostly in preglaciated regions. Gradually, lateral

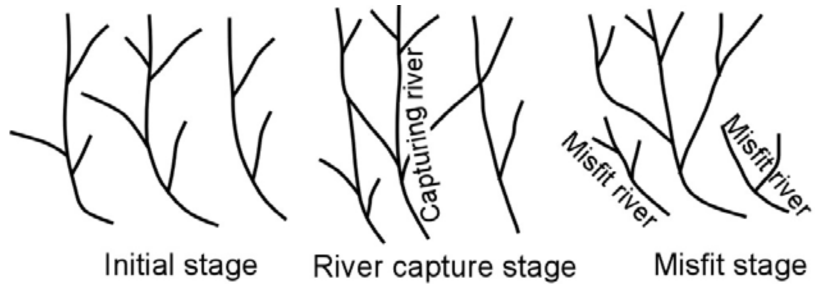


Fig. 2.5 : River piracy

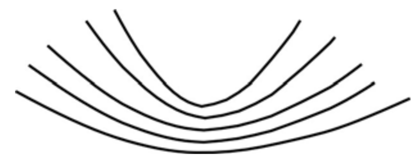


Fig.2.6: Flat valley of river

cutting dominates over downward cutting and valley widening takes place. By this time, the river almost enters the plain and this marks the begining of mature stage. The river valley becomes more flat (Fig. 2.6). The gradient and velocity decrease, as a result of which, transporting power decreases and the load is deposited. Due to reduced velocity and obstruction in its path, the river course is deflected and it flows in a curving fashion known as *river meandering.* In meanders, the velocity of water is more in the down stream or outerside and is less in the inner or upstream side. Lateral cutting is more in the down stream side and during flood, the river takes a short-cut course forming *oxbow* or *horse-shoe lakes.* The stages of formation of the ox-bow lake are shown in (Fig. 2.7).

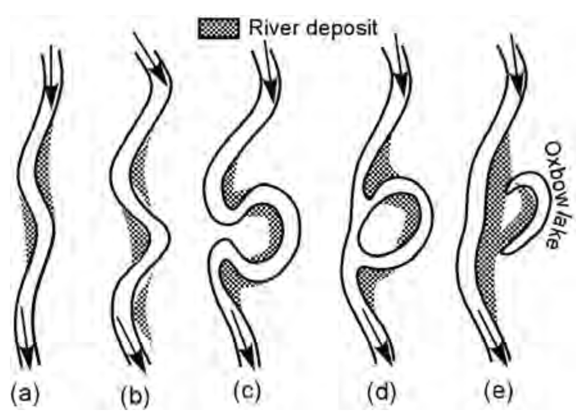
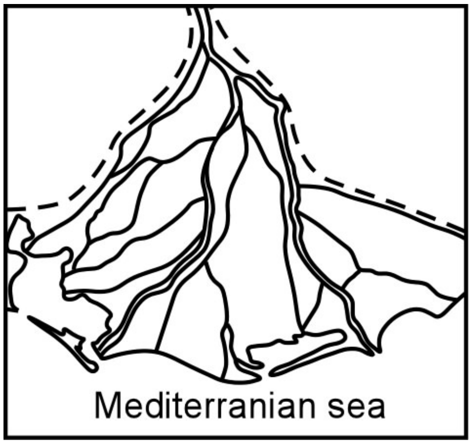


Fig.2.7: Stages of formation of ox-bow lake

During maturity, no land is left out undrained and any lake or swamp existed in the youthful stage, disappear. Rapids and waterfalls almost vanish from this region.

Towards the old stage, the river flows almost at the *base-level* of erosion, that is the sea level. Downward cutting is almost negligible. However, lateral cutting coutinues, though at a slower rate. The river flows almost in a flat valley. Width of the river increases. Gradient is much reduced, hence the velocity is slow. During high floods, the water overflows the valley and forms flood plains and a part of the load is deposited on them. On both sides of the river, deposition takes place at a greater rate forming low ridges that parallel the river course. They vary in width and are known as *natural levees.* Meandering continues, but the valley width is many times that of the meander width. At the last statge, the river meets the sea or lake. That is known as the mouth of the river which is commonly very wide and is termed as *estuary.* Rarely, the river terminates in a marsh or uesert. Still rarely, it disapeears in some limestone or chalk terraines. These are loosing streams. Some rivers form a *delta* (the Greek letter '∆') by its own deposition which obstructs the flow and the river is branched and repeatedly with *braided islands.* The delta once formed grows larger and larger like that of the Sunderban delta or the Mahanadi delta. The line drawing of Nile delta and landsat view of the Mahanadi delta are shown in (Figs. 2.8a and 2.8b) respectively.

2.5.2. Geological Work: Rivers are gradational agents. They degrade the high lands and aggrade the low lands. They tend to bring the earth's surface to a common level nearer to the sea level. By downward cutting and lateral cutting, the rivers erode the high lands. However, there is a limit to the vertical erosion. This is the sea level and is termed as the *base level of erosion.* The extent of vertical erosion is confined at certain elevation (base level of erosion) which commonly matches with the sea level. River erosion takes place by *hydraulic action, abrasion, corrosion* and *attrtion.*



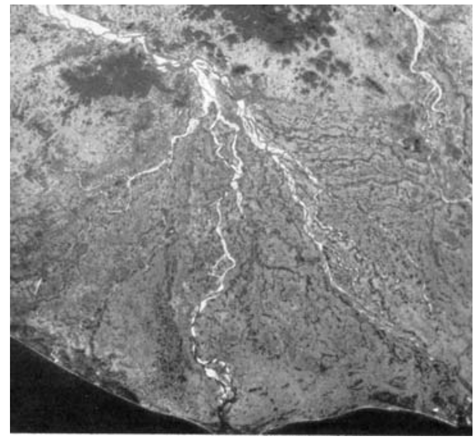


Fig.2.8a: Delta of river Nile Fig.2.8a: Landsat view of Mahanadi delta

Transporation by the river takes place through *traction, saltation, suspension, floatation* and *solution.* Higher the gradient, higher is the velocity of the running water. The transporting power increases with increasing velocity. Commonly, if the velocity is doubled, the transporting power is its cube capacity. Thus, with increasing velocity, the eroded materials along with the materials from mass wasting are transported down stream by the river. Also a part of the load is carried in solution.

In the plains, the gradient is less, hence the velocity goes down. Besides, any obstruction in the river path by irregularities, hard rocks, vegetation, damming, curves of meanders - all contribute to the reduction of velocity. When the river meets the sea or lake, the velocity is minimum. For all these reasons, the transporting power of the river is greatly reduced and the load carried by it is gradully deposited as a sedimentary unit.

2.5.3. Importat Fluvial Land Forms

(i) Youthful Topography

(a) 'V'- Shaped valley: These are formed by vertical erosion or down ward cutting the sign of hecticactivity (youthful) (Fig. 2.4)

(b) Water falls, Rapids, Cascades: When a river flowing over a hard resistant rock flows over a soft less resistant rock by some reason, a scarp face is formed after erosion and it gives rise to *water fall* (Fig. 2.9a). In hilly *terraines,* when streams flow down along vertical escarpments, water falls are formed. Also, in case of pre-glaciated terraines, streams flowing over hanging valleys give rise to water falls. If the steepness of the cliff is less; it forms *rapids* and when water flows along step - like structures, *cascades* (Fig. 2.9b) are formed. Mostly, water falls, rapids and cascades are formed due to differential erosion. Niagara fall and Victoria fall are good examples of falls. In India, Gersoppa fall of the Saraswati river is nearly 350 meters. In Odisha, Khandadhar (820 feet) water fall is the best example. Bareipani on Budhabalang has a height above 600 meters.

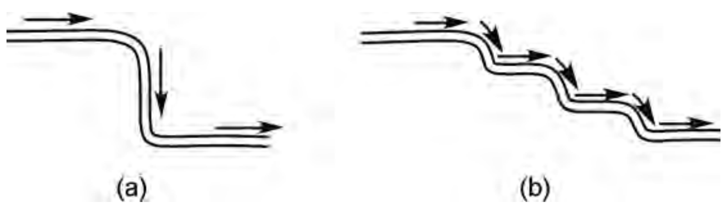


Fig. 2.9: (a) Water fall; (b) Cascade

(c) Canyon and Gorge: When the valley walls are steep and high in comparison to the width of the channel, the feature is known as *gorge.* The steep walls are commonly hard and resistant rocks with high *flow* dips. In some cases, faults or major joints help in down cutting. *Gorges* with rapids are known as *canyons.* Good examples are the Grand Canyon of the Colorado river, (a tourist site) the Gilgit Gorge of the Indus river is neady 7,000 meters deep. The Satkoshia Gorge of the Mahanadi river is famous in Odisha and is about 21 km. long. A canyon section is shown in (Fig. 2.10).

(d) Potholes: Commonly, at the foot of falls and rapids, boulders and pebbles, grind the hard rock bed by whirling action of the water generating holes of different diameter and depth. These are *pot holes* filled with sand and / or heavy materials of the bed.

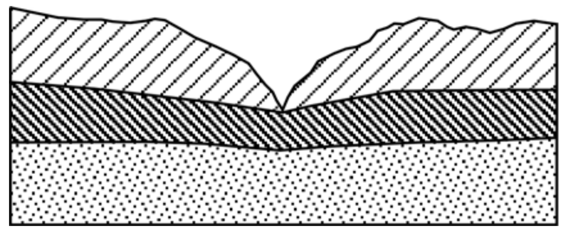


Fig. 2.10: A section of the river course showing canyon section

(e) Cliffs / Scarps: Cliffs, scarps are formed due to differential erosion aided by mass wasting and weathering of alternate hard and soft rocks.

(ii) Mature Topography: As the fluvial geomorphic cycle proceeds, the ‘V’shaped valleys gradually form flat river valleys; water divides become narrower, hills and ridges become sharper with maximum possible relief.

(a) Outlier and Inlier: In case of homogenous or low folded regions, erosion leaves portions of younger rocks surrounded by older rocks - the land form is outlier (Fig 2.11a). Where a part of the older rock is exposed due to erosion surrounded by younger rocks, the land form is an inlier (Fig. 2.11b).

(b) Mesa and Butte: As erosion proceeds, isolated table land with nearly flat or very gentle slope, survive due to hard resistant cap rocks. This is termed as *mesa* (Fig. 2.12a). *Butte* is similar erosional remnants with smaller flat summit area (Fig. 2.12b). They have steep sided cliffs. In Koraput district of Odisha *mesas* and *buttes* are numerous - Panchapatmali, Bafalimali, Sasubohumali etc. are famous mesas which contain bauxite deposits.

(c) Cuesta and Hog back: As erosion proceeds in areas underlain by low dipping

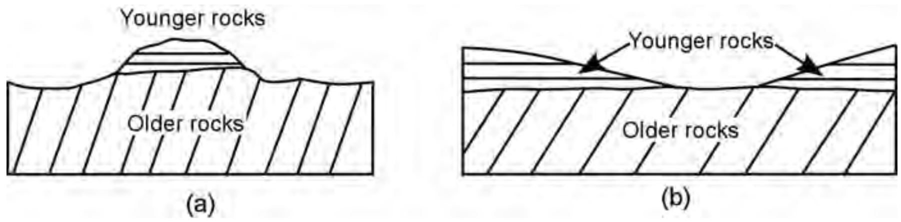


Fig. 2.11: (a) Outlier and (b) Inlier

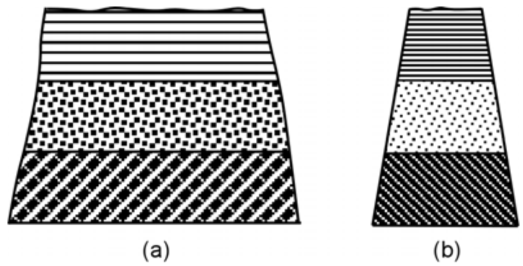


Fig. 2.12: (a) Mesa and (b) Butte

rocks, the dip slope or resequent slope becomes lower than the slope opposite to dipslope (obsequent slope). The resulting land forms are termed as *cuesta* (Fig. 2.13a). In areas with high dips, resequent slope becomes almost equal to obsequent slope. This type of land form is termed as *hogback* (Fig.2.13b).

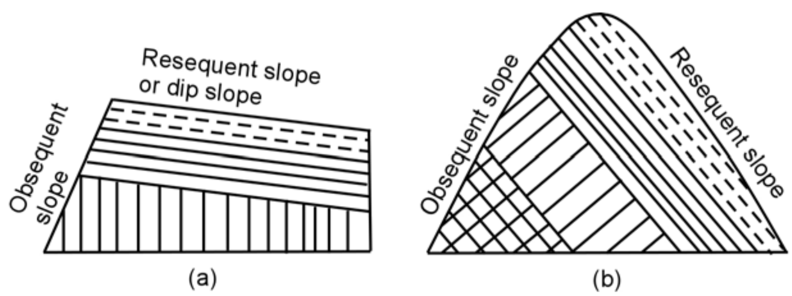


Fig.2.13: (a) Cuesta and (b) Hohback

(d) Homoclinal ridge: In moderately dipping areas, ridges intermediate between cuesta and hogback are formed, which are termed as *homoclinal ridges.*

(iii) Old Topography: As geomorphic cycle proceeds the entire landscape is subdued and is converted to a gently rolling or almost flat topography with a low mean sea level.

(a) Peneplain: As defined by Davis, it is almost a plain formed towards the penultimate stage of a fluvial cycle. It represents a large land area of low relief with minor irregularities here and there.

(b) Monadnocks: In the rolling peneplain the irregularities are in form of minor hillocks studded here and there. These isolated hillocks which have survived the extensive erosion are termed as *monadnocks.* Paresnath hill is one such hillock in Bihar and Dhauli off Bhubaneswar should be considered that way.

(c) Flood plain: Flood plain is the area on both sides of the river formed by deposits during flood. It is almost a plain land. Within the flood plain, the gently sloping raised features on both sides of the river bed are known as *natural levees.*

(d) River terrace: The river terraces are remnants of older flood plains or valley floors. Due to rejuvenation, the older valleys are uplifted and the rivers carve their own valleys once again giving rise to *terraces.* These are marked on both sides of the river or occasionally on one side only. When they occur on both sides the terraces are termed as *paired* or *cyclic.*

(e) Deltaic plain: The large plain formed by the coalescence of the flood plains of the braided channels or the distributaries within the *delta* is termed as *deltaic plain.* Swamps and marshes may exist within the deltaic plain.

(f) Estuary: Very often the river meets the sea with a widened mouth through which sea water enters the river and goes back to the sea during high tide and low tide respectively. This portion of the river mouth is the *estuary.*

2.5.4. Indian Rivers: The major extraperinsular rivers are the Indus, Ganges (Ganga River) and the Brahmaputra and their tributaries. These rivers are perennial as they are fed by glaciers from the Himalayas. The major peninsular rivers are westerly flowing (Narmada and the Tapti) and southeasterly flowing

(Mahanadi, Godavari, Krishna and Cauvery).

The Mahanadi is the longest river of Odisha followed by the Brahmani, Baitarani, Subarnarekha, Bansdhara and the Rushikulya etc. The Tel river is a large tributary of Mahanadi; similarly, the Indravati is a large tributary of Godavari.

The Satkoshia gorge is typical of its kind in the Mahanadi river. The river Mahanadi forms a large delta with numerous, branching distributaries like Kathjori, Kuakhai, Daya, Bhargabi, Kushabhadra, Devi, Luna, Chittrotpala, Birupa etc. This, delta looks like a bird's foot (this name is brought from B.F.D. of U.S.A.) from the aerial view. Naraj is at the head of the Mahanadi delta (Fig.2.8b), east of which the alluvial plain extends upto the Bay of Bengal. The deltas of the Mahanadi, Brahmani and the Baitarani join and coalesce to form one delta, although, in detail, they are three and can be termed as tri-delta.

2.6. GLACIERS

A glacier is a mass of snow and ice that moves slowly over the land away from its place of accumulation. Avalanches are masses of ice formed on cirques that flows down hill with a great velocity.

2.6.1. Formation of Glaciers: Glaciers originate from the snow field which may form on plains, plateaus or mountains. Three conditions are necessary for the formation of a snow field: (i) abundant snow fall; (ii) cold climate and (iii) low rate of summer melting and evaporation. In cold regions, precipitation takes place in form of snow fall or ice. Snow consists of delicate thin tabular hexagonal crystals in form of tiny flakes like foam or cotton. When it falls on the ground, it is in form of granules and is called as *neve.* Successive falls press these granular ices into a flaky structure, air is squeezed out and the mass assumes a granular structure. This form is known as *firn.* This change is brought about by partial melting and subsequent freezing known as *regelation.* Firn is intermediate between snow and compact ice. Gradual accummlation of snow, neve and compact ice give rise to snow field. The lower or outer edge of a snow field above which all the snow does not melt during summer is known as *snowline.* Snow line occurs at any altitude at high latitudes and at high altitude at low latitudes. Thus, snow line occurs at about 5,500 to 6,000 meters in the equatorial belt, around 4,000 meters in the Himalayas, while almost at sea level in Antarctica and the Arctic regions. On the surface of glacial ice, cracks are developed due to various reasons. These cracks are termed as *crevasses.* When the glacier bends over an inclined surface, the cracks parallel to the rocky wall are known as *bergschrund.* Creavasses may be longitudinal, transverse or marginal.

2.6.2. Movement of Glaciers: The lay man's concept is that the glaciers are streams or rivers of ice. Actually, the repeated processes of melting and freezing with fracture, shear and gravity are responsible for the movement of glaciers. Presence of shear planes, thrusts and bands in the lower parts of the glaciers act as slippage planes. The rate of motion varies from glacier to glacier. Long and large glaciers move faster than the smaller ones. Generally the larger glaciers move faster than smaller ones but during summer all the glaciers move faster in comparison to winter season. Even within the body of glacier there is differential velocity i.e. the top and central part of the glaciers move faster than that of the bottom and sides which are obstructed by friction of walls. The movement varies from a fraction of a centimeter to nearly 30 meters per day. In the Himalayas, most of the glaciers move from a few centimeters to a meter per day. Fedechenkow glacier in the Pamir Himalayas moves more than 10 meters per day.

2.6.3. Types of Glaciers: Broadly, the glaciers are divided into two major types:

(i) Continental glaciers including ice caps and ice sheets

(ii) Mountain glaciers **-** these are valley glaciers and piedmont glaciers.

Continental glaciers are large bodies of snow found in Antarctica and Greenland. Larger bodies of continental glaciers are also called as ice sheets, while ice caps are small continental glaciers mainly found in Iceland. In some cases the continental glaciers occur on the top of mountain from which valley and piedmont glaciers move away in different directions. Valley glaciers rise in ice caps or snow fields and occupy mountain valleys. Two or more valley glaciers combine to give rise to piedmont glaciers on plains or intermontane valleys. Glaciers loose their mass by melting, evaporation and sublimation. Wastage by all these processes is termed as *ablation.* Ice fronts retreat by *back wasting* and *down wasting.* Glaciers also thin out through *ablation.* Before ablation, some glaciers meet the sea and large blocks of ice floats on sea water, known as *ice-bergs.*

2.6.4. Geological Work of Glaciers: Like other mobile agents glaciers are gradational agents. They erode, transport and ultimately deposit materials. In its domain, it is the most powerful agent.

(i) Erosion: Glacial.erosion takes place by *abrasion, gouging, plucking* and *sapping.* Ice, itself, does not do much abrasion; but as the ice moves, it gathers boulders, rock fragments, sand, soil which become its cutting tools. As it moves over the land, glaciers erode all loose material on its way and degrade almost all projections of the solid rocks, just like bulldozer works. Valley glaciers smooth their floors and walls, thus, reshape the 'V'-shaped valleys to 'U' shaped ones. At the foot of steep slopes, they *gouge* the bed rock and form depressious in form of *troughs,* which after melting of glaciers give rise to *trough lakes.* Continental glaciers modify the whole topography and smoothen the surface by abrasion. In case of valley glaciers, rain water or melt water enters the joints, cracks, fractures and crevasses present in glacial mass and freezes resulting in expansion. This expansion and fragmentation of glacier loose boulders and are plucked up by the glaciers by the process of *sapping*. In this way, .the valley glaciers make headward erosion giving rise to great *amphitheatre* like basins at the head of the glaciers.

(ii) Transportation: The transporting power of a glacier is equally high. It can carry any material from loose debris to large boulders as big as a house. Eroded materials from the gound, sides and plucked up materials from the bed rock are all carried away. Some debris is caught up and is carried within the glacial ice. Most of the rock debris drifted by the glacier on its upper surface is known as *glacial drift*. The big boulders which are carried away are known as *erratics*. Glacier transports the material by *traction*, *suspension* and *floatation*. Actually, no material is suspended within the solid mass, but the materials carried within the glacial ice are said to be in suspension. Similarly, no material floats over the glacier; but the drift carried by the glacier are said to be floating on it.

(iii) Depostion: Once the glacial ice melts, all the load carried by glacier are deposited which are unassorted and unstratified mixture of boulder and fine debris. These are called ‘'till’ and the rock formed by consolidation of till is known as tillite. While moving, glaciers deposit the excess load on the sides and at the ground. These are moraines (Fig.2.14). The deposits made on the ground or bed rock are ground moraine and along the sides are lateral moraine. The moraine formed at the junction of two glaciers is known as medial moraine. At the end, when the glacial ice melts the transported load is finally deposited forming *terminal moraine* or *end moraine*. *Recessional moraine* marks a series of end moraines formed by pulses of successive retreat of the glacier.

2.6.5. Landforms Produced by Glaciers: Glaciers modify earth surface by degradation and aggradation. Typical landforms are produced by glacial erosion and deposition. After the glacial ice melts, streams are formed and certain landforms are produced by the combined action of both river and glacier which are termed as *pro-glacial* or f*luvio-glacial* landforms.

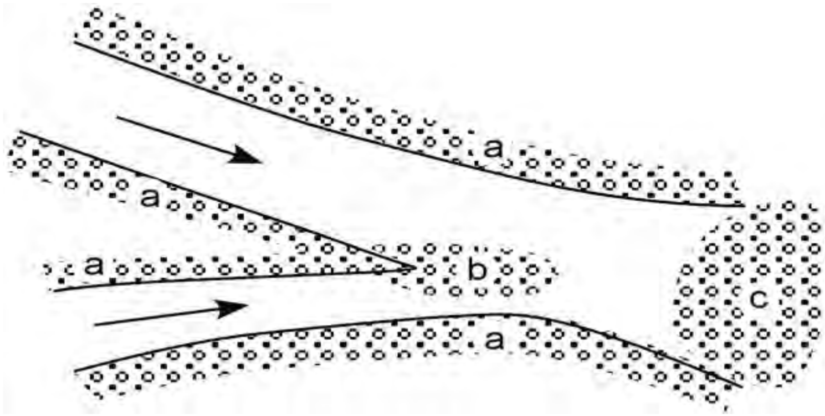


Fig. 2.14: Different types of moraines – (a) Lateral moraine, (b) Medil moraine and (c) Terminal moraine

(i) Erosional Landforms:

(a) Glacial valley: In contrast to river valleys, the glacial valleys are broad with relatively smooth and steep sided walls - forming 'U' shaped vallyes.

(b) Hanging valley: The base of the tributary glaciers generally lie at a higher level than the trunk glaciers because of lower eroding capacity. After snow melts away, the valley floor of the tributaries exist much above the floor of the trunk valley. This gives rise to *hanging valleys* with steep cliffs which in many instances form water falls.

(c) Cirque: One of the most typical features of all mountain glaciers is the development of amphitheatre like depressions at the head of the glaciers with that of the snow field due to head ward erosion. These depressions are cirques, corries or CWM (Fig. 2.15).

The valley floor of glacier is smooth and polished with nearly vertical walls. Similar basins are also formed in sub-polar regions, but they lack steep head walls. Cirque may be individual, compound or complex. Due to retreat of glaciers, it gives rise to lake.

Fig. 2.15: Cirque

(d) Glacial trough: Less resistant rocks are easily eroded by the glacier forming broad elongated basins. These commonly head at the edge of the cirques. After glaciers melt, they commonly give rise to *trough lakes.*

(e) Horns: Head-ward erosion at the cirque walls and in case of compound cirques, high, sharp and steep sided peaks are left out in form of *horns.*

(f) Aretes: In mountainous terraines at the head of cirques glacial erosion, frost action and gravity collectively play their role to form serrated or saw-toothed ridges which are known as aretes.

(g) Nunataks: These are peaks of resistant rocks that stand out in the snow field and are not covered by ice.

(h) Fjords / Fiords: These are long straight or broadly curveJ valleys filled with sea water. These are formed by glacial erosion beyond the sea level now covered with sea-water. They occur extensively in Scandinavia, Greenland, Alaska, Newzealand and other regions. Norway is called the land of five 'F's out of which one is fiord. During Pleistocene the glaciers carved their valleys much deeper than the sea level before melting. After the retreat of glacial ice the sea water covered the vaIreys forming *fjords* or *fiords.*

(i) Roches moutonnee: The bed rocks are smoothened and striated due to glacial erosion. Hard and resistant rocks often survive glacial erosion, where as -

surrounding weaker rocks are easily eroded, as a result of which the remnants of erosion are left out as small elongated hills, the upstream sides or stoss sides of which have

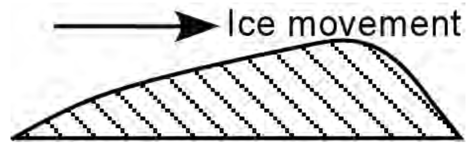


Fig 2.16: Roches moutonnee

gentle slopes and (Fig 2.16) the leeward side or downward side is relatively steeper. These are called as *roches moutonnee* and occur profusely resembling herds of sheep. They are prominent features of continental glaciated regions.

(j) Ice-scoured plain: In continental glaciated regions almost a low land is formed with basins, lakes, knobs etc. due to effective glacial erosion. This low land is termed as *ice-scoured plain.* These are common in Canadian Shield, Scandinavia and Russia.

(ii) Depositional Landforms: As mentioned earlier, glacial depsists consist of a mixutre of dirt, rock flour and sub angular rock boulders which are often striated, unstratified and unassorted. The deposits are moraines.

(a) Drumlin: A tytical ground moraine is termed as *drumlin* which is an elongate4, oval shaped hill (Fig 2.17). The hill ranges in height from a few meters up to 50 meters and in length from half a kilometer to 3 kilometers.

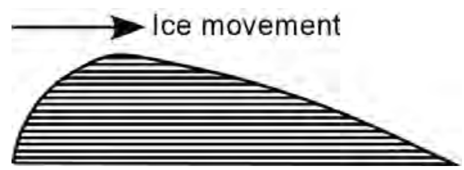


Fig 2.17: Drumlin

The shape is that of inverted spoon or egg. The longer axis is parallel to the direction of glacial movement.The tapering end points towards the direction of flow, that is, opposite to that of roches moutonnee which are erosional in contrast to depositional nature of *drumlins.* The down hill side of the drumlin is smooth and gently sloping. The drumlins generally occur in swarms or groups. The topography is often termed as *basket of eggs* topography.

(b) Knob and Basin, Kame and Kettle: These are featuers associated with moraines. In the first type, the *knobs* or *hummocks* consist of unstratified drift and in the second type, the larger *kames* or *knobs* consist of stratified sand and gravel. The basins are depressions within the interspaces between the knobs. *Kettles* filled in with water form *kettle lakes.*

2.6.6. Fluvio-Glacial Land Forms: Melting of glacial ice releases large volume of water that flows down the slope. A number of land forms are produced due to the combined action of glacial ice and melt water. These are termed as *Glacio-fluvial forms.*

(i) Out-wash Plain: The rock debris carried by the glaciers are transported by the streams and are immediately deposited forming fans and deltaic land. This plain land is termed as *out wash plain.* At times, the deposits occuring on the valley floors extend downward and are termed as *valley trains.* In some cases, blocks of ice are buried beneath the out wash plain and after melting of ice, depressions are formed. These are termed as *kettles.* Out wash plains pitted with depressions are known as *pitted out wash plains.*

(ii) Kames, Kame Terraces: Kames are small mounds composed of poorly stratified sediments formed by ice melt water. Kame terraces are fillings of glacial troughs and deposits between a glacier and the side wall. These are poorly sorted.

(iii) Eskers: These are long, narrow and smooth surfaced ridges of low height composed of stratified sand and gravel similar to lateral moraines. Commonly, this landform is produced when the ice is stagnant and hence eskers are commonly formed in areas where ice stands for a considerable time and, thus, are common in continental glaciated regions.

(iv) Glacio-lacustrine plain: Lakes are common in glaciated areas. They are formed in many ways; by glacial erosion, melting of ice and by other processes. These are temporary features of the earth's crust and are quickly filled in with sediments forming lacustrine plains in glacial regions. The coarse silt is quickly deposited in the lakes, while the fine sediments like mud settles afterwards. These altern.lte depositon of coarse silt and mud gives rise to varves and the rock, thus formed, is varvite. One set of course and fine material forms usually in one year.

2.6.7. Pleistocene Glaciation: The knowledge on glaciers and glacial landforms would be incomplete without a little idea on the Pleistocene Glacial Epoch. It is believed that more than one fifth of the land surface of the globe was covered with snow and ice during this period. During this great Ice Age, four major advances and four retreats of the continental giaciers have been recognized. The glacial epoch began nearly one million years ago with alternation of glacial and interglacial periods. The recent period, whether interglacial or post-glacial is a great question. The retreat of the last glaciation is estimated to be nearly 25,000 years ago. Most of the present day landscapes, especially those in the northen humisphere are the products of this Great Ice Age. During this period, the sea level fluctuated appreciably as evidenced by the occurrences of marine fossils, coral reefs and marine strandlines. Little of the earth's topography is older than Tertiary and most of it not older than Pleistocene, is a general concept of geomorphology. Most of the well glaciated regions show youth topography.

2.6.8. Glaciation in India: Glacial climate is evidenced in South India during the Precambrian times. During Late Carboniferous - Early Permian icesheets covered central part of India as evidenced by glaciation and glacial deposits in the form of Talchir Boulder Bed, shales and sandstones.

Pleistocene Glacial Epoch is marked by the ice-caps through out the extrapeninsular region and numerous valley glaciers descended down from the Himalayas almost up to the plains. The proglacial and postglacial land forms are well developed throughout this region. There were four glacial and three interglacial periods. During the warm interglacial periods lacustrine deposits were formed of which Karewa bed is an example. Numerous glacial lakes were formed during this period. The Pleistocene glacial period is evidenced by mass extinction of the great Siwalik mammals and other fauna leaving the fossils in glacial deposits.

A number of hypotheses have been proposed to explain the cause of the Ice Age out of which long continued variation of the solar radiation seems to be most appropriate.

2.7. WIND

2.7.1. Introduction: In general, the regions having precipitation less than 25 cm per annum are termed as deserts and between 25 cm to 50 cm are termed as semideserts. Running water plays the same role in the semideserts as it does in humid regions. However, some typical semi-arid landforms are produced in the semi-deserts. In arid or desert regions, streams are subdued and wind gets increasing importance as a geologic agent. Permanent streams are rare in deserts. Streams may originate elsewhere and pass through deserts like the Nile. However, intermittent and ephemeral streams do occur in deserts.

Wind does its work everywhere on the earth’s surface, even on the seas and glacial regions: However, its effect is more pronounced in the deserts, and semi deserts, on barren coasts, stream valleys and lands. In arid and semi arid regions, typical landforms are produced by the combined action of weathering, masswasting, running water and the wind.

2.7.2. Geological work of Wind: Wind does the same geological work like rivers and glaciers. It erodes the land, transports the eroded material and ultimately deposits them.

(i) Erosion: Wind acquires the lossened material by sweeping action which is termed as *deflation.* This blowing out of sand, dirt and soil may create depressions on the gound. In deserts, this excavation forms *blow-out.* The cutting tools for wind abrasion are the sand particles, which strike against the bed rocks and obstructions that become spotted, grooved and polished. Wind *abrasion* becomes more effective when the tools are hard, velocity is high and the bed rock is soft. Rocks with hard and soft minerals are affected differentially forming honey comb structure. Attrition by the wind takes place when the blown particles collide against each other. Greater the velocity of the wind and greater the length of transit, greater is the effect of attrition. In the process, the sand particles become finer and spherical.

(ii) Transportation: Transportation by the wind takes place through *traction, saltation* and *suspension.* The fine and light dust particles are picked up and carried away by suspension for hundreds of kilometers. It is believed that the dust particles forming loess of China have been derived from the deserts of central Asia situated thousands of kilometers away. In case of some volcanic explosions, dust has almost travelled throughout the globe. One such example of volcanic dust from the Krakatoa volcano of East Indies in 1883, in which case the dust remained in suspension in the atmoshphere for nearly three years. Relatively larger sand grains are transported by traction and saltation.

(iii) Deposition: When the wind encounters any obstruction, the velocity is naturally reduced resulting in deposition of transported sands. Once sand accumulation takes place, they themselves obstruct the wind movement and the load is deposited. These are aeolian deposits, especially sand mounds. At times, this deposition is temporary. One important feature of these deposits is that the sand particles are arranged according to their size and weight. The finer dust particles are carried away for long distances and are ultimately deposited elsewhere.

(i) Erosional Landforms: By the processes of erosion, wind forms a number of landforms typical of deserts and semideserts. Some of the important landforms are given below.

(a) Blowouts: Blowouts are small scale depressions produced by deflation of weathered materials. They are more common in areas of sand accummulation. The intermontaine depressions within sand hills are similar features.

(b) Pedestal rock: These are pillar like rock masses with narrow base and wide rock caps (Fig.2.18). *Pinnacles* are similar features with less prominent cap rock. These are produced by the combined action of weathering, gravity and wind abrasion. However, it is the wind abrasion which is mainly responsible for the formation of this pillar like structure.

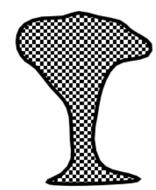


Fig.2.18: Pedestal rock

(c) Ventifacts: These are faceted and angular rock fragments, also known as *dreikanter.* Wind blowing in a particular direction, produces smooth and flat surfaces.

(d) Windows and arches: These are features formed by the combined action of weathering, gravity, wind, ground water and running water. The surface forms are like arches which act as natural bridges.

(e) Bowls and caves: These are commonly seen in areas of calcareous sandstones, where calcium carbonate is dissolved by chemical weathering; sand grains are disintegrated and are blown out by wind, forming bowl and cave like features.

(f) Desert pavement: In deserts and semi-deserts, the dust and finer particles of the weathered rocks are blown out by the wind, and heavier pebbles and rock fragments are left out. After long exposure to wind, the fragments and pebbles become finely polished. This type of land surface is termed as *desert pavement* which is like a sea broken rocks. They are *lag deposits.* The areas with large sized rock fragments are termed as *hammadas.*

(ii) Depositional Land Forms: The transported materials by wind are ultimately deposited when the velocity of the wind decreases. There are two distinct types of deposits; accumulation of sand forming sand hills and that of dust and silt particles known as loess. Besides the deserts and semideserts; the wind deposits are also formed along sea coast, stream courses and in glacial outwash plains.

(a) Sand Hills: Different types of sand hills are formed due to accumulation of sand grains. Sand shadows and sand drifts occur on the lee side of the obstructions.

Sand dunes are typical hills formed by sand accumulation. Commonly, they occur in groups. They are termed as *dune colonies* or *dune complexes.* They vary in shape, size and height: There are different types of dunes. *Transverse dunes* (Fig 2.19a) extend transverse to the direction of wind, where as *longitudinal dunes* (Fig. 2.19b) extend parallel to the wind direction. *Parabolic dunes* (Fig. 2.19c) commonly occur along shore lines with the end points tapering towards wind ward direction. *Barchans* (Fig. 2.19d) are the typical sand dunes characteristic of deserts and semi deserts. They are *crescent* shaped. The two tapering ends point along the direction of wind. All types of dunes are prone to migration along the direction of wind, unless they are held by obstructions.

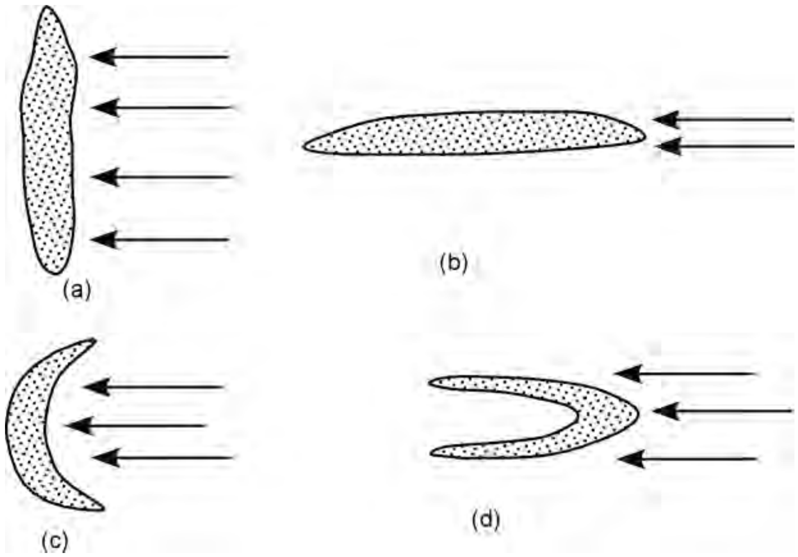


Fig 2.19: (a) Transverse dune, (b) Longitudinal dune,
(c) Barchan and (d) Parabolic dune

(b) Loess: The fine dust and clay particles carried by wind are ultimately deposited at a great distance from the place of the origin. The deposits are called *loess.* Unweathered loess is grey. But, commonly, the loess is buff coloured. The fine dust and clay consist of angular to sub-angular particles of quartz, feldspar, calcite, dolomite and other minerals. Generally, they are calcareous, permeable and stand out in form of vertical walls. At times, the dust and clay particles are derived from glacial outwash plains and fluvial deposits.

In northen China, the great loess deposits almost cover an area of about 4,00,000 km^2 with a thickness of more than 60 to 70 meters. In India, loess is seen in the foot hills of the western Himalays, in Himachal Pradesh and western U .P.

Besides the landforms described above which are aeolian in origin, a large number of landforms are found in deserts and semi-deserts due to combined action of wind and running water.

In India, the desert land forms are seen in the Thar desert west of the Aravallies.

2.8. DIASTROPHISM

The endogenetic processes originate within the earth's interior and modify the earth's surface. The processes are (a) *diastrophism* and (b) *volcanism. Diastrophism* includes all crustal movements in the earth. It may either be (i) a slow process with relatively large movements or (ii) fast process with relatively less movement. *Orogeny* and *epeirogeny* belong to former category while earthquake is a process of later category. Volcanism is the movement of the magma on to the earth's surface.

The slow and relatively large movements within the earth belong to two types (a) orogeny and (b) epeirogeny.

2.8.1. Orogeny means mountain building activities commonly accompanied with deformation almost on a horizontal scale. It deforms the rock strata in form of folds, faults with tilting and displacments. It involves tangential forces with resulting compression or tension of rock strata. Plate tectonics is mainly responsible for orogenic activities. The Himalayas and the Aravallies are formed due to orogenic activities.

2.8.2. Epeirogeny on the other hand is continent making or regional uplift of the landmass without much horizontal deformation. Commonly, it is acted upon by vertical forces from beneath the earth surface. Such movements affect the sea-level which is either raised or lowered. The continents, individually, have been subjected to great earth movements. Some coastal plains are underlain by marine sediments that show that, they were beneath the sea in geologic past. Their present position above water indicates a broad regional uplift of the land.

2.9. EARTHQUAKE

Earthquake is a vibration or oscillation of the earth's surface. Just as waves are generated on the water surface of a pond when a stone strikes it, similarly, the earth's crust which has considerable elasticity, is set into tremors by a sudden blow from internal or external sources. At times, the shocks are highly disastrous to human life and property. General destruction takes place in a few seconds. Earthquakes may be natural or artificial.

2.9.1. Causes of Earthquakes

The causes of earthquakes may be divided into three groups (i) surface causes, (ii) volcanic causes and (iii) tectonic causes.

(i) Surface causes: Great explosions, landslides, slips on steep coasts, dashing of sea waves, avalanches, railway trains, heavy trucks, some large engineering projects cause minor tremors. Some of them are man made, others are natural.

(ii) Volcanic causes: Vocanic eruptions produce earthquakes. Earthquakes may precede, accompany and frequently follow volcanic eruptions. They are caused by sudden violent displacments of lava within or beneath the conduit of the valcano.

(iii) Tectonic causes: Structural disturbances resulting in the relative displacements of the parts of the lithosphere is the main cause of this type of earthquake. Most of the disastrous earthquakes belong to this category and occur in areas of great faults and fractures. Sudden yielding to strain produced on the rocks of accumulating stress causes displacements especially along old fault zones known as great transform faults.

Reid proposed the idea of *elastic rebound* hypothesis. Stresses accumulate on the two sides of the fault plane and produce strain. The rock deforms, bends and when the stress crosses the elastic limit, sudden displacement of the two sides of the fault plane takes place (Fig.2.20). This results in a strong blow to the rocks and produces tremors.

Earthquakes often occur on the ocean floor. This produces large sea waves known as *tsunamis* that produce devastating effects on the sea coasts. The tsunami produced by the earthquake near the Sumatra coast affected far of places like Srilanka and South India and even African coast.Tectonic earthquakes are classified according to their depth of origin into:

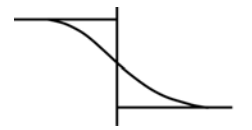


Fig. 2.20: Elastic rebound

(i) Normal: When the depth of origin is less than 50 km.

(ii) Intermediate: When the depth is in between 50 to 400 km and

(iii) Deep seated: When the depth is more than 400 km.

2.9.2. Propagation of Earthquake:

The place of origin from which earthquake starts is known as *focus, origin, hypocentre* or *centrum* (Fig.2.21). Commonly, *focus* is not a point, rather a lengthy tract.

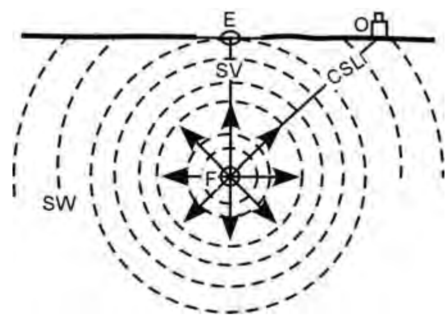


Fig.2.21: Earthquake parameters and propagation. F: Focus, E: Epicentre, SV: Seismic vertical, CSL: Coseismalline, O: Observatory, SW: Earthquake waves

The area on the surface vertically over the *focus* is termed as *epicentre, epifocus* or *epifocal area.* The vertical line passing through the *centre* and *epicentre* is *seismic vertical.* The area of disturbance is known as seismic area. Line joing the places where the shock arrives at the same time is known as *homoseismal* or *co-seismal* and the line joining the places of equal intensity of the quake is known as *isoseismal.* If the *focus* is a point, then the *coseismals* are circles, but generally, they are elliptical as the focus is commonly a line. The *epicentre* is determined from the study of distribution of *co-seismals and* iso-seismals.

The energy released by an earthquake propagates by waves. These are of three types (Fig.2.22). The *primary, push* or *P-waves* which are longitudinal and compressional and the *secondary, shake, shear* or S-*waves* which are transverse and distortional in nature. The third waves are called *long, Raleigh or L-waves*. These waves are responsible for all the destruction and damage. The P- and S-waves obey the laws of reflection and refraction. The P-waves are transmitted through solids and fluids, but the S-waves are obstructed by fluids. P-waves travel outward in straight lines in all directions from the focus. S-waves vibrate at right angles to the direction of propagation and is more destructive than the P-waves. The L–waves follow a circumferential path unlike P- ans S-waves, which proceed towards the centre. These L-waves are thought to be produced by P- and S-waves and cause greatest damage on the surface. The P-waves are fastest and L-waves are slowest. After the main waves die down, after shocks are felt. The Pwaves are the fastest and the L-waves are the slowest.

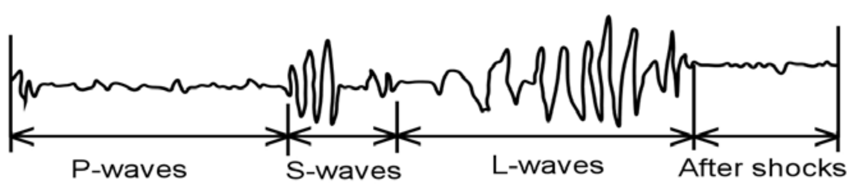


Fig. 2.22: Different types of earthquake waves

2.9.3. Intensity of the Earthquake: The intensity of the earthquake is measured by the damage done to the ground and humanity. The intensity is measured by an instrument known as *seismograph,* where the shocks are recorded. *Seismometers* record local shocks only. The instrument consists of a steel pillar attached firmly to the floor of the building of the observatory. The pillar is connected by a wire to a cylindrical rod with a sharp point at its upper end and with a long pointer hanging a pencil point at the other end. The pencil point touches a rotating drum and records the oscillatory movement on the paper fixed on the drum. A chronograph records the time of the arrival of the shock. The record on the sensitized paper is known as *seismogram.*

Rossi and Forel proposed a scale with ten divisions of the different intensities of the shocks. They are (1) Microseismic (2) Extremely feeble, (3) Very feeble, (4) Feeble, (5) Moderate, (6) Fairly strong, (7) Strong, (8) Very strong, (9) Extermely strong and (10) Shock of extreme intensity. Microseismic shocks are recorded by delicate instruments only, whereas in case of shock of extreme intensity, general destruction of the buildings and ground takes place and produces land slides in hilly terraines.

Mercalli, an Italian scientist, put forward another scale. It has twelve divisions given in Table 2.2.

Charles Richter proposed another scale to measure the intensity of the earthquakes based on the magnitude which is known as Richter's scale. In case of the earthquakes, the potential energy is transformed into kinetic energy in the form of elastic seismic wave. Magnitude is a measure of the energy released during the earthquake. It is defined as the logarithm of the maximum amplitude recorded by a standard Wood Anderson seismometer kept at a distance of 100 km from the epicentre. This scale is valid upto 600 km epicentral radius. The magnitude of the waves is divided from 0 to 9 in this scale. In this scale, the higher step-represents an earthquake record ten times the previous step. That is an earthquake of magnitude 8 is ten times larger than that of magnitude 7 and one *hundred* times larger than that of magnitude 6. The quakes of magnitude less than 5 do not cause much damage. The *strongest* earthquake so far measured is 8.9 in the Richter’s scale.

Table. 2.2: Mercalli Scale

(i)	Instrumental	: Recorded by Seismographs
(ii)	Very feeble	: Perceived only by sensitive persons.
(iii)	Feeble	: Perceived by persons at rest
(iv)	Moderate	: Perceived by persons in motion
(v)	Fairly strong	: Wakes persons, rings bells
(vi)	Strong	: Slight damage to building
(vii)	Very strong	: Produces cracks in walls
(viii)	Destructive	: Throws chimneys
(ix)	Ruinous	: Over throws buildings
(x)	Disastrous	: General destruction of the buildings
(xi)	Vey disastrous	: Few buildings are left, fissures are produced on the ground
(xii)	Catastrophic	: Total destruction of the buildings and ground

2.9.4. Effects of earthquakes: Instrumental to moderate earthquakes in the Mercalli scale do not have much effect. Typical.effects of destructive earthquakes can be of the following types:

(i) Panic: Vibratory waves accompanying the earthquake cause panic among the animals and humans. More damage is caused by panic.

(ii) Physical damage: This includes collapse of buildings, cracks in ground, roads bridges, walls, water tanks, rivers and dams.

(iii) Public health: This includes danger of diseases on account of pollution of water bodies, breakdown of sewage and sanitary pipes, heart failures and other conditions leading to epidemics.

(iv) Civic services and conveyances: Civic services like water pipes, sewers, electric connections, roads etc are disrupted. Transmission towers and transformers also collapse.

(v) Disruption of economic activities: On account of widespread damage and destruction, economic activities of the people like farming, business, tread and services are severely affected. It affects the people to large extent.

(vi) Fire: Collapse and breakdown of small and big containers containing inflammable substances like gas, petrol, kerosene, chemicals pose the dangers of major fire. Fire is also caused due to short circuit of electric line.

2.9.5. Earthquake belts or Seismic belts: Earthquakes occur in some well defined zones on the earth. These zones are termed as *earthquake belts* or *seismic belts* (Fig. 2.23). Most of the earthquakes occur along the circumference of the

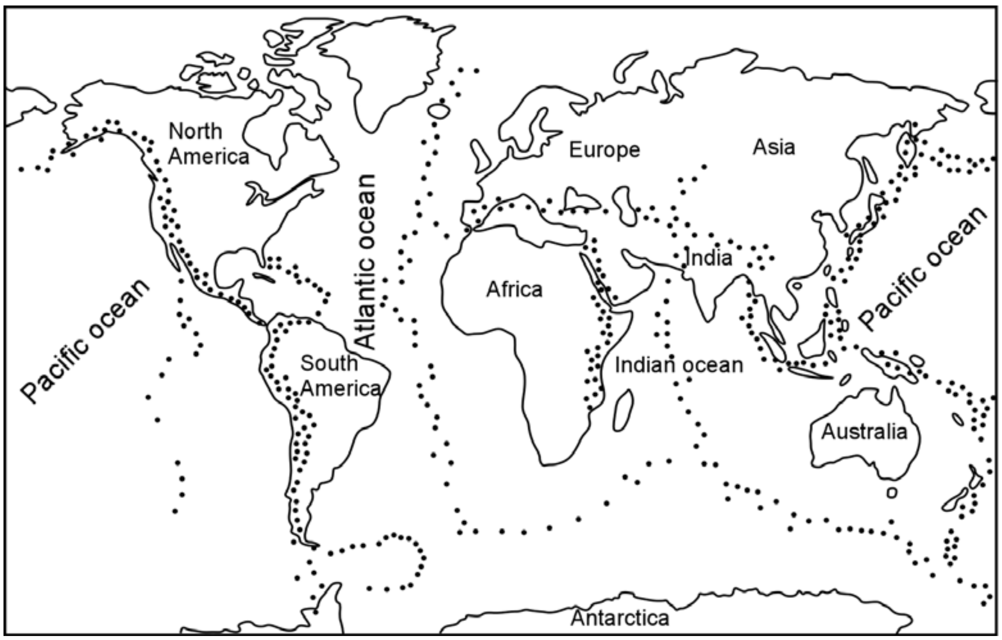


Fig. 2.23: Earthquake belts of the world

Pacific ocean. This is known as Circum-Pacific Belt. Another belt starts from the East Indies, passes through the Himalayas, Asia Minor and goes to the Mediterranean region and the Alps. This is known as Himalayan - Mediterranean belt. Nearly 68% of the quakes occur in the first belt and 21% in the second belt. Remaining 11 % occur in other areas. Rift valley region of East Central Africa is a minor belt. Besides these, earthquakes occur sporadically.

2.9.6. Some Major Earthquakes: Some major earthquakes recorded world over are mentioned below:

(i)	1737	:	Kolkata Earthquake
(ii)	1906	:	San Fransisco Earthquake
(iii)	1920	:	China Earthquake
(iv)	1923	:	Japan Earthquake
(v)	1976	:	China Earthquake
(vi)	2008	:	China Earthquake

Some major earthquakes of India are:

(i)	1819, 2001	:	Cutch Earthquake
(ii)	1897, 1950 and 1988	:	Assam Earthquake
(iii)	1987	:	Kangra Earthquake
(iv)	1934 and 1988	:	Bihar Earthquake
(v)	1967	:	Koyna Earthquake

2.9.7. Forecast of earthquakes: Earthquakes occur suddenly without warning. Their forecast can minimize the destruction. However, till today no completely satisfactory way has emerged to predict the occurrence of earthquake. Some of the observations, which can be correlated with earthquake occurrences, are as follows:

(i) In many instances the earthquakes occur in periodic cycles. However, periodicities in time and space for major earthquakes have not been widely detected or accepted.

(ii) Another approach to the statistical occurrence of earthquakes involves the postulation of trigger forces that initiate the rupture. Such forces have been attributed, for example, to severe weather conditions, volcanic activity, and tidal forces. Usually correlations are made between the physical phenomena assumed to provide the trigger and the repetitjon of earthquakes.

(iii) For prediction of the time of earthquake occurrence, a proposal is that precursory changes in a region will cause the velocity of seismic waves through the region to change. Thus, if appropriate travel-time residuals are plotted as a function of time, fluctuations will provide a forewarning.

(iv) For many years prediction research has been influenced by the basic argument that strain accumulates in the rock masses in the vicinity of a fault and results in crustal deformation. Deformations have been measured in the horizontal direction along active faults (by trilateration and triangulation) and in the vertical direction by precise leveling and tilt-meters. Some investigators believe that changes in groundwater level-occur prior to earthquakes. It should be noted that water levels in wells respond to a complex array of factors such as rainfall; thus, if changes in water level are to be studied in relation to earthquakes, such factors need to be removed.

(v) Strain buildup in the focal region may have significant effects on other observable properties, including electrical conductivity and gas concentratipn. Because the electrical conductivity of rocks depends largely on interconnected water channels within the rocks, resistivity may increase before the cracks become saturated. As pore fluid is expelled from the closing cracks, the local water table would rise and concentrations of gases such as radioactive radon would increase.

(vi) Less well-grounded precursory phenomena, particularly earthquake lights and animal behaviour, sometimes draw more public attention. Many reports of unusual lights in the sky and abnormal animal behaviour preceding earthquakes are known to seismologists. Both these phenomena are usually explained in terms of a release of gases prior to earthquakes and electric and acoustic stimuli of various types. At present there is no definitive experimental evidence to support claims that animals sometimes sense the coming of an earthquake.

2.10. VOLCANOES

Magma once formed inside the earth tends to move upward. When it intrudes into the crust, it forms intrusive igneous rocks. When it extrudes or erupts or ejects to the surface of the earth it gives rise to volcanoes. A valcano is a conical hill with a nearly circular opening known as vent, through which hot gases, vapour, molten liquid - the lava and rock fragments are ejected from beneath the earth. The vent is connected to the magma chamber by a pipe or conduit. This type of valcano is called central type. In another case known as fissure eruption, the lava is erupted through long fissures with absence of large amounts of gases and rock fragments. *Geysers, fumaroles* and some *hot springs* are distinctly phenomena of volcanism. However, they are related to ground water only.

2.10.1. Description of a volcano: Typically a valcano is generally conical, commonly with gentle slope in all directions (Fig. 2.24). At the top of the cone is a circular pit known as *crator* which varies in diameter from a few meters to even few kilometers. Crators are formed due to unequal accumulation of rock fragments and lava. This *cone* and *crator* structure is typical of central type of valcanic eruption. In this case, there is a pipe or conduit through which eruptions take place. Lava moving upward, at times cuts through the country rocks forming dykes. When these dykes come to the surface they form *secondary* or *parasitic cones* and *crators.* In some cases, sills are formed. In some

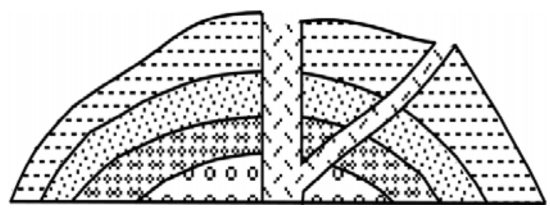


Fig. 2.24: Volcano

valcanoes, large nearly circular pits are formed, either due to violent explosions blowing up at the summit, or due to subsidence along circular fractures. These pits are termed as *calderas.* The first one is called as *explosion caldera* and the second type is *subsidence caldera.* Lava cones are conical structures, gently sloping, cover wide area, formed mainly by quiet type of volcanoes. *Cinder cones* are formed around the volcanic pipe by accumulation of loose fragmentary materials known as cinders. *Composite* or *mixed cones* are intermediate between cinder cones and lava cones, consist of layers of pyroclastic materials with intercalations of lava flows. They are also called as *strato - volcanoes. Shield valcano* resembles warrior's shield, covers large areas with very gentle slopes.

In case of fissure eruptions, lavas are piled up flow after flow over extremely large areas resulting in enormous thickness giving rise to volcanic plateau. The Deccan plateau is an example of fissure eruption.

Fumaroles are fissures or vents through which gases come out. *Hot springs* are abundant in volcanic regions. *Geysers* are smimilar to hot springs through which hot gases and hot water are ejected intermittently in regular periodic intervals. They are abundant in Iceland and Newzealand. Yellow stone National Park at California is one of the best examples. *Meteor crators* are features very similar to volcanic crators, but are formed due to impact of meteorites. They often form lakes, known as *crator lakes. Mud volcanoes* look like volcanoes, but are made up of mud and are found in oil-field regions. Some of the volcanic plateaus are so much flat that, they give rise to plains, known as *lava plains.* Similarly, ash showers form plains known as *ash plains.*

2.10.2. Volcanic products: Hot gases, molten lava and rock fragments are ejected through volcanoes.

(i) Hot gases: Gaseous products always accompany volcanism. Water vapour is the chief constituent and it constitutes more than 90% of the volcanic gases. When ejected, it forms clouds. Other gases are carbon dioxide, nitrogen, sulphur dioxide, hydrogen sulplide, hydrogen, sulphur, chlorine, ammonia, carbon monoxide, boron, fluorine, hydrochloric acid, phosphorous, arsenic and many others.

(ii) Liquid products: The hot molten liquid ejected through a volcano is known as lava. Lavas vary greatly in chemical composition, which is mainly responsible for their viscosity. There are mainly two types of lavas - acid lava and basic lava. Acid lavas are rhyolitic or dacitic. Basic lava is basaltic. Trachytic and andesitic lavas are intermediate in composition. Lava erupted through fissures are basaltic in nature. Lava on solidification produces different types of forms like *block lava*, *ropy lava* and *pillow lava*. The surface of the lava flow in many instances contains numerous vesicles formed due to escape of volatiles forming *vescicular* structure. Often, the vescicles are filled in by secondary minerals known as *amygdules* also amygdales and the resulting structure is *amygdaloidal*.

(iii) Solid products: Lava moving upward often explodes the solidified rocks of the crust. These are knwon as *pyroclasts* or *pyroclastic* materials. The rock formed after solidification is known as *pyroclasitc rock*. The pyroclasts vary in shape and size. The larger angular fragments are known as *volcanic blocks* while *volcanic bombs* are somewhat rounded. Smaller fragments are called *lapilli* or *cinders*. Still smaller fragments are volcanic sand, dust and ash respectively. Dust and ash on consolidation form a rock known as *tuff*. Some pyroclasts are spongy due to escape of gases and the resultant mass becomes spongy. Extreme stage of vesciculation produces a rock termed as *pumice* that floats on water.

2.10.3. Classification of volcanoes: Volcanoes have been classified into *central type* and *fissure type* according to the nature of pipe and volcanic erruptions.

Depending upon the activity, the volcanoes are classified as *active, dormant* and *dead* or *extinct.* Volcanoes which erupt very often like the Vesuvius are classed as *active* volcanoes. *Dormant* volcanoes erupt intermittently with lapse of considerable period of time between successive eruptions. Other volcanoes which have not shown any eruption within recorded period of history are said to be *dead* or *extinct.* An extinct volcano might still be in a dormant stage.

The volcanoes are also classified according to their nature of eruptions into: (i) *explosive*, (ii) *intermediate* (iii) *quiet type.* In the first case, gases escape with violent explosion with consequent blowing up of the upper part of the neck of the volcano with formation of huge quantities of pyroclasts. In the intermediate type, explosion takes place in the begining with the formation of pyroclasts and at a later period lava is erupted quietly. In the last type, lava is erupted quietly without much explosion.

Volcanoes are also classified depending upon the nature of activity of particular type of eruption. They are:

(i) Hawaiian type: Typical of the volcanoes of the Hawaiian islands, in which case, more fluid lava is ejected without much explosion and without ejection of gases or pyroclasts.

(ii) Strombolian type: It is typical of the Stromboli volcano in the Mediterranean. Less fluid basic lava is ejected, at times with violent explosions. Pyroclasts are dust, bomb etc.

(iii) Vulcanian type: Named after the vulcano in the Mediterranean near Stromboli. Viscous lavas are ejected, form a crust over the volcano, so that, when next eruption takes place, the earlier formed crust is broken with violent explosion. Large amount of pyroclasts are thrown up from this type at volcano. Composition of lava in successive eruptions vary appreciably. Lava compostion varies from volcano to volcano of this type.

(iv) Pelean type: It is most violent type of volcano that expels gases and dusts in enormous quantities.

(v) Vesuvian type: It is named after the volcano, the Visuvius, near Naples in the Mediterranean. It is highly explosive. Ascending gases, dusts and ashes form cauliflower like forms.

(vi) Plinian type: Most violent type of the Vesuvian eruption is termed as Plinian type after Pliny, the younger. The gaseous clouds of cauliflower like columns rise vertically to great heights. Large quantities of pyroclasts are ejected with little or no outpouring of lava.

The above eruptions belong to central type of volcanism. The fissure eruptions are seen in Iceland in the present day, hence, they are termed as Icelandic type.

2.10.4. Distribution of volcanoes: At present there are abount 500 active volcanoes world over. Might be, there are a number of active submarine volacnoes. The number of extinct and dormant volcanoes is too great.

Volcanoes, like earthquakes, occur in some typical belts. Volcanoes occur on steep continental borders near great ocean deeps and in or near youthful mountains. This indicates their occurrence within the zones of weakness of the crust. Volcanoes occur largely in and around the Pacific Ocean region. Here, the active valcanoes occur in form of a ring round the Pacific and is known as *Ring of Fire*. Another belt starts from the East Indies, passes through the Himalayas, the Asia Minor, the Mediterranean and continues up to the West Indies. Besides these two belts, volcanoes also occur sporadically. Volcanic belts nearly coincide with that of earthquake belts (Fig. 2.23).

In India, volcanoes are rare. One active volcano in the Barren Island of Bay of Bengal erupted in 1795, 1803 and 2003. It emits sulphurous vapours. The volcano in the Narcondum Island is dormant at present. India had witnessed great fissure eruption in Cretaceous - Eocene times in form of the Deccan volcanics which covered vast areas. At present, it covers an area of more than 3.5 lakhs of square kilometers with an average thickness of nearly 2000 meters. In Precambrian time dykes have traversed the Singhbhum granite and parts of Keonjhar district shows lava spread west of Keonjhargarh upto Brahmani river.

2.10.5. Causes of volcanism: In the interior of the earth, temperature and pressure rise with increase of depth. Heat tends to melt the crustal and subcrustal rocks, but high pressure keeps the rocks in the solid state. At greater depths, the rocks are in a viscous state. Release of pressure during diastrophism and plate movement forms pockets of magma. Rise of temperature due to radiogenic heat, internal heat or any other source at a particular level also forms pockets of magmas. Once formed, magma tends to move towards the upper part of the crust. Diastrophism is also responsible for faults, joints, fractures, fissures in the crustal rocks which act as avenues for the upward movement of magma. Magma finds its way through these weaker planes and is ejected to the surface and gives rise to volcanism.

2.11. GEOLOGICAL WORK OF UNDERGROUND WATER

Underground water becomes a dominant agent in areas covered by limestone, which are prone to solution activities. Dolomite and chalk behave similarly, though to a lesser degree. Erosion is done through corrosion (chemical action) in case of ground water. Carbonates are dissolved and are transported by solution to be precipitated elsewhere. Surface water passing through joints, fractures and weaker planes tends to dissolve carbonates. Thus, descending water dissolves calcium carbonates and forms surface and near-surface solution and leaves a residue of red clayey soil known as *terra rossa*. Locally, in high relief areas, an etched, pitted, grooved and rugged surface known as *lapies* is formed by the solution activities. The depressions formed by this process are known as *sinkholes.* In most cases, they are formed by solution activities which are termed as *dolines*; whereas, a few are formed by collapse of the roof over solutional openings and are termed as *collapse sinks.* Through these holes and through weaker planes, gradually, the surface water passes to ground water and some surface streams are lost. These streams are called as *loosing streams.* The whole region becomes a plain pitted with numerous sinkholes with minor erosional remnants known as *hums* or *haystack hills* or pepino hills with loosing streams. This type of plain is termed as *Karst plain* and the topography as *Karst* topography (also Carso).

In most cases, the surface water is diverted along joints, fractures, weaker planes or sinkholes to an underground route forming *natural tunnels.* Collapse of a part of the roof of a tunoel gives rise to *natural bridge* or *karst bridge.* The descending ground water along joints, fractures, bedding planes forms *caves* or *cavems.* These may be simple or complex, may extend horizontally or vertically, may or may not be occupied by streams presently. Dry caves usually have two or more levels or stages. Commonly, the caves show a number of depositional features.

In limestone terraines, the descending ground water becomes saturated with dissolved carbonates. Once it is over saturated, the carbonates are precipitated and deposition takes place. A number of depositional features are encountered in caves. They are *cave travertine*, *drip stones. Travertine* includes a number of forms and *drip stone* includes forms developed by water dripping from the cavern ceilings. *Stalactites* are developed by downward extending forms from the ceilings and *stalagmites* are the upward growing forms, besides *pillars* and *columns.* These add to the scenic beauty of the limestone caves. In the lower reaches, the ground water exposed in form of springs of variable sizes and volumes. Commonly, it is aesian in nature.

In India, karst topography is marked in Maharastra, in Vindyan limestone as of M.P. and Rajasthan. In Odisha, it is marked north of Bargarh and in Koraput (Gupteswar Caves) near the border of Odisha and Chattishgarh states in the Vindhyan Supergroup of rocks along Kolab river. Stromatolitic limestone has also developed in these sequences.

2.12. GEOLOGICAL WORK OF WAVES, CURRENTS, TIDES AND TSUNAMIS

Lakes and oceans are bodies of standing water, where movement of water goes on instantaneously. This movement of water is due to waves, currents, tides and tsunamis, which carry on gradational work like other agents along the coast and the shore.

Shore line is the line of demarcation between land and water which fluctuates from moment to moment. Coast is a zone of indeterminate width that extends landward from the shore. This is commonly a gently sloping plane and generally characterised by different types of topography.

Waves are produced by wind action. Slope of the shoreline into the sea is a controlling factor. Larger waves (wave-heights) are formed by higher wind velocity, duration of wind and by the extent of water over which wind blows. This last factor is known as *fetch.* Wave heights so far recorded are about 16 meters. Waves dash forward on to the shore as *swash* and the water which goes back along the sea-ward slope is *back-wash. Tsunamis* are waves produced by submarine earthquakes, volcanism and slumping or landslides along coasts. Tsunamis have attained heights of 30 to 40 meters. These cause greater erosion along the shoreline during a brief period than that of waves. Ocean currents are formed by several ways, where, there is continuous and progressive forward movement of water. Wind and temperature difference and earth’s rotation are major factors for ocean currents. Geomorphically, however, longshore or littoral currents, rip-currents, underflow currents are significant. *Tides* are almost insignificant in case of lakes. But, in case of oceans and especially in funnel-shaped bays and estuaries, tidal currents are significant to transport considerable debris and even carry on scouring action.

These marine agents perform the same work of erosion, transportation and deposition like other agents. The processes of erosion, transportation are similar to that of running water. Moreover, shock pressure of breaking waves and wave impact exert great pressure. Waves and tsunamis are significant for marine erosion in form of corrasion, corrosion, hydraulic action and attrition. Currents with minor local exceptions are unimportant erosional agents, but are important as far as transportation in concerned.

Sea cliffs, wave-cut benches, marine terraces, bays, sea-arches or *caves, stacks, islands* and a number of other features are produced by marine erosion. Eroded sand and gravel grains are transported by currents and are ultimately deposited.

A number of typical features are formed by marine deposition. Among these, *beaches* are unique. Beach is a temporary feature of the shoreline which is restricted to the temporary veneer of rock debris that accumulates along and on a wave-cut bench. Beaches may extend for tens or hundreds of kilometers along a shore (Puri beach, Gopalpur beach; Chandipur beach are examples in Odisha. Marina beach of Chennai, Goa beach are equally famous). Along rugged shorelines, beaches are limited to strips (Vizag beach, Rameswaram beach). Beach materials are deposited by streams, landslides, weathering of sea-cliff, marine erosion of sea-cliffs, slope-wash etc. Some materials come from the sea by waves. *Bars* are various submerged or emergent embankments of sand and gravel on the sea floor by waves and currents. A nearly 60 km long bar separates the Chilika lake from the sea excepting at Gahirmatha mouth which is open to the sea. *Spits* are bars that are attached to the sea at one end and open to the sea at the other. Commonly, spits are parallel to coasts. In some cases, they are hook-shaped. When two such spits converge off shore or when recurving of a single or compound spit becomes attached to the shore at both ends, it produces *cuspate spits.* Spits commonly form by long shore currents. *Barrier beaches* or *offshore bars* are formed by waves and currents. At times, offshore bars or cuspate spits are attached to the shore on both ends to form lagoons (Chilka, Pulicut). Some coasts are characterized by the growth of *coral reefs.*

Most parts of the present day coasts are affected by the fluctuations of the sea level during the Pleistocene Glacial Epoch and largely by post glacial rise of the sea-level, they leave geological impression on the shoreline which, therefore, should be properly studied and understood.

2.13. SAMPLE QUESTIONS

2.13.1. Long type questions

(i) What is weathering? Describe different processes of physical (and or Chemical) weathering.

(ii) What is erosion? Describe different processes of erosion performed by river / glacier / wind.

(iii) Briefly describe the geological action of rivers.

(iv) Describe the geological action of glaciers.

(v) Describe the geological action of wind.

(vi) Describe the causes and effects of earthquakes.

(vii) What is volcanism? Describe different types of volcanism.

(viii) Write an easy on the different products of volcanism. Add a note on the occurrence of volcanoes.

2.13.2. Distinguish between the following pairs within 3 to 5 sentences

(i) Orogeny and epeirogeny

(ii) Weathering and Erosion

(iii) Seismograph and Seismogram

(iv) River terrace and Kame terrace

(v) Inselberg and monadnock

(vi) Hydration and hydrolysis

(vii) Crator and caldera

(viii) Ice sheet and ice cap

(ix) ‘U’ - shaped and ‘V’ - shaped valley

2.13.3. Write short notes within 3 to 5 sentences

(i) Barachan

(ii) Delta

(iii) Orogeny

(iv) Epeirogeny

(v) Drumlin

(vi) Sand dune

(vii) Roches moutonnee

(viii) Cirque

(ix) Esker

(x) Kames

(xi) Moraine

(xii) Pedestal rock

(xiii) Glacial valley

(xiv) Loess

(xv) Ring of fire

(xvi) River meandering

(xvii) River piracy

(xviii) Epicentre

(xix) Canyon and gorge

(xx) Hanging valley

(xxi) Ventifact

2.13.4. Answer the following within one short sentence:

(i) Name the geologic agent that produces kames.

(ii) Name the geologic agent that produces monad nocks.

(iii) Name the crescent shaped sand dune.

(iv) Define the focus of the earthquake.

(v) What is orogeny?

(vi) With which geological process pedestal rock is associated?

(vii) What is Reichter scale?

(viii) Define volcanic crator.

(ix) Mention the processes of chemical weathering.

(x) Mention two processes of wind erosion.

2.13.5. Correct the sentences if they are incorrect without changing the word/s underlined.

(i) Drumlin is produced by wind deposition.

(ii) Hydrolysis involves adsorption of water.

(iii) Deccan trap is a good example of cone and crator type of volcanic erruption.

(iv) Tsunamis is formed commonly due to volcanism.

(v) During earthquake, maximum damage is caused by the S-waves.

(vi) Cirques are features associated with fluvial action.

(vii) U-shaped valley is formed by river erosion.

(viii) Canyons and gorges are formed during old stage of river cycle.

(ix) Roches moutonnee are formed by glacial deposition.

(x) Loess is formed due to river deposition.

Answers

(i)	glacial deposition	(ii)	Hydration
(iii)	fissure type of volcanic eruption	(iv)	due to submarine earthquakes
(v)	L - waves (or Raleigh waves)	(vi)	glacial action
(vii)	glacial erosion	(viii)	youthful stage of river cycle

(ix) glacial erosion (x) wind (aeolian) deposition

2.13.6. Fill in the blanks with appropriate word / words.

(i) The point or tract where earthquake originates is known as _________ .

(ii) Ring of fire is the volcanic belt along the coast of ___________ocean .

(iii) Deccan volcanics is type of ______________eruption.

(iv) In the recent days, volcanism occurs at ____________ in India.

(v) Crescent shaped sand dunes are known as ____________ .

(vi) Basket of egg topography is formed due to numerous ______________ .

(vii) Lakes formed due to cut off meanders are known as _____________lakes.

(viii) The triangular area formed by the distributaries of a river near the sea is known as _____________ .

(ix) 'V' - shaped valley is the characteristic feature of the _________satage of the fluvial cycle.

(x) The transported soil deposited by the rivers is known as ____________ .

(xi) Loess in formed due to wind _____________ .

(xii) Solution is a process of ________________weathering.

Answers

(i)	focus	(ii)	Pacific
(iii)	fissure	(iv)	Barren islands
(v)	barchans	(vi)	drumlins
(vii)	ox-bow lakes	(viii)	delta
(ix)	youthful	(x)	alluvium

(xi) deposition (xi) chemical

2.13.4. Choose the correct answer from the choices given in the following:

(i) The branch of geology that deals with forms of the earth''s surface is

(a) Petrology (c) Geomorphology

(b) Structural geology (d) General geology

(ii) The First order relief features of the earth are

(a) Mountains, plateaus and plains (c) Valleys, Inselbergs, Mouad Rocks

(b) Continental platform (d) None of the above

(iii) Sand dunes are produced by the action of

(a) River (c) Wind

(b) Glacier (d) Underground water

(iv) Corrosion is the erosion by:

(a) Running water (c) Wind

(b) Glacier (d) None of the above

(v) Deflation in the process of transportation by:

(a) River (c) Wind

(b) Glacier (d) None of the above

(vi) Drumlins are formed by:

(a) River erosion (c) Wind erosion

(b) Glacial deposition (d) Wind deposition

(vii) Out of the following which is not a process of chemical weathering

(a) Hydration (c) Solution

(b) Hydrolysis (d) Thermal expansion

(viii) Eskers are formed by

(a) River erosion (c) Solution

(b) River deposition (d) Wind deposition

(ix) The liquid material erupted from a volcano is know as:

(a) Cinder (c) Valcanic ash

(b) Lapilli (d) Lava

(ix) The lava flow occupying large areas in western and central India is known as:

(a) Rajmahal trap (c) Deccan trap

(b) Rajahmundry trap (d) Sylhit trap

(x) The area vertically above the focus of the .earthquake is known as:

(a) Cetnre (c) Hypocentre

(b) Epicentre (d) None of the above

(xi) The tunnel shaped depression through which lava is erupted is known as

(a) Caldera (c) Meteor crater

(b) Crator (d) None of the above

(xii) The earthquake wave which is transmitted through solid as well as liquid is known as:

(a) P-wave (c) L-wave

(b) S-wave (d) Ground wave

(xiii) Effusive basaltic lava with much fluid is errupted in case of

(a) Hawaiian type (c) Vulcanian type

(b)	Strompalian type	(d)	Pelean type

(xiv) 'U' - shaped valleys are formed by the action of

(a)	River	(c)	Waves
(b)	Glacier	(d)	Weathering

Answers

(i)	Geomorphology	(ii)	Mountains, plateaus and plains
(iii)	Wind	(iv)	Running water
(v)	Wind	(vi)	Glacial deposition
(vii)	Thermal expansion	(viii)	Glacial deposition
(ix)	Lava	(x)	Epicentre
(xi)	Crator	(xii)	P-wave
(xiii)	Hawaiian type	(xiv)	River

****

CHAPTER – 3

CRYSTALLOGRAPHY

Crystallography is the branch of science that deals with the study of crystals. It includes the classification of crystals into different systems and classes, their descriptions, study of mathematical relationships existing between different faces in addition to imperfections of crystal growth and crystalline aggregates.

The term *crystal* has been derived from the Greek word *krustallos*, which means clear ice. The name was given to transparent quartz crystal with well-developed flat surfaces.

3.1. CRYSTALLINE AND AMORPHOUS SUBSTANCES

A crystal is a regular polyhedral form characterised by flat surfaces known as faces. The development of faces is the manifestation of the internal ordered arrangement of the atoms and depends on the physicochemical conditions prevailing at the time of formation of the mineral by solidification of gas or liquid or precipitation from solution. The process of formation of crystals is known as crystallisation. Thus, a crystal is a special form of a mineral. Common salt (NaCl) is prepared from seawater in coastal parts of Odisha, mostly in Ganjam district. The seawater is allowed to stand in rectangular fields and allowed to evaporate by sunrays. The end product of evaporation is solid common salt, which appears in different shapes, predominantly in rectangular forms. Close examination confirms the cubic shape of most of the solids. In fact, one NaCl molecule is formed by combination of one Na^+ and one Cl^-. A number of NaCl molecules join together to form a NaCl crystal. One such crystal is shown in Fig.3.1. The solid circles are Na^+ and Cl^- ions, which occur at the corners of small cubes. Nine such small cubes make a three-dimensional form, which is also a cube. The crystal grows by successive addition of ions in all directions. It is to be noted that the seawater is collected during high tide time and is allowed to stand for about 15 days, during which the water evaporates; reactions and stacking of NaCl cubes are completed. Crystallisation of $CuSO_4$ from solution is a common experiment that is carried out in chemical laboratories. The experiment is to be performed within a stipulated time of about two hours. $CuSO_4$ crystals are formed by cooling of the solution. It is seen that big crystals are formed if the rate of cooling is slow. On the other hand, small sugar-grain like crystals are formed if the rate of cooling is rapid. Examination of these small crystals by high magnification or by X-ray methods confirms the existence of miniature crystals. No crystal is formed if instantaneous cooling is achieved by addition of ice-cold water. In this case, crystals are not formed, rather a noncrystalline mass of $CuSO_4$ remains. If any foreign chemical substance is added during cooling, crystal formation is affected and distorted crystals are formed. From the above observations it can be concluded that suitable physicochemical conditions are necessary for formation of good crystals. The crystals have two characteristics i.e. internal atomic structure and outer form. Since the natural conditions in which the minerals are formed vary appreciably, the minerals show different degree of crystal growth. In ideal conditions, both the internal atomic structure and the corresponding outer form develop. In this case the mineral is said to be *crystallized*. Common examples are rock crystal (transparent variety of quartz with well developed faces), calcite, staurolite, beryl etc. In case of some minerals, development of well-defined faces may be absent even though internal

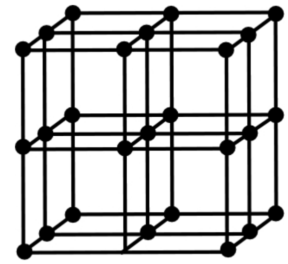


Fig. 3.1: Atomic structure of NaCl

atomic structure are present. In these cases, the minerals are said to be *crystalline*. Crystalline substances may also occur in such a fine-grained state that their crystalline character can be ascertained only with the aid of a microscope. In such case, the material is said to be *microcrystalline*. If the crystal formation is so imperfect that crystallinity cannot be detected with microscope, but can be determined by X-ray analysis, the material is referred to as *cryptocrystalline*. Statistical study has shown that more than 98% of the minerals show definite crystalline structure.

When both the internal atomic structure and the outer form are absent, the substance is said to be *amorphous*. The fundamental difference between a crystalline body and an amorphous substance is the presence and absence of definite internal ordered arrangement of the atoms in space respectively. In amorphous substance, the atoms exhibit a haphazard and random disposition. The difference between arrangement of atoms or ions in crystalline and amorphous substances is analogous to the difference between disciplined soldiers and chaotic mob. Opal and lechatelierite, two varieties of silica and limonite, a variety of hydrated iron oxide are examples of amorphous minerals. Many people use dazzling stones in their rings, most of which are amorphous glasses artificially cut with flat surfaces. These colourful glasses should not be confused as natural crystals. The natural glasses are formed when superheated lava cools instantaneously coming in contact with water. The cooling is so rapid that the atoms do not get time to arrange themselves in any ordered manner. The disordered state of atoms results in the formation of natural glass.

3.2. MORPHOLOGY OF CRYSTALS

3.2.1. Face: The most important attribute of a crystal is the presence of flat surfaces known as faces and their arrangement in a distinctive pattern. These are the external expression of the internal atomic structure. The common faces are normally parallel to net-planes containing maximum number of lattice points (ions/atoms). The faces are of two types, *like* and *unlike*. Like faces have equal properties i.e. they are similar in shape, size and orientation. NaCl commonly crystallizes in the form of cube. One such cube is shown in Fig.3.2, which is bounded by six square faces of equal size and shape. ABCD, BCFG and CDEF are three like faces of the cube. Unlike or dissimilar faces are characterized by different properties i.e. they are unequal in size and shape. A crystal shown in Fig.3.3 has two types of faces, square (PQRS, RWXY, QUVW) and equilateral triangular (PQU, PTS, QRW, SRY). The square faces are bigger in size than the triangular faces.

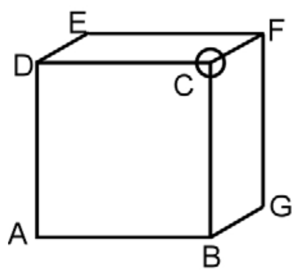


Fig. 3.2: Like faces of a simple form with solid angle at C

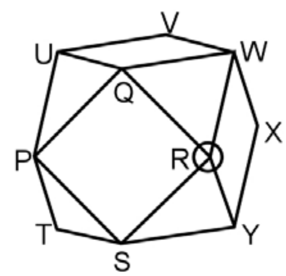


Fig. 3.3: Unlike faces of a combination form with solid angle at R

3.2.2. Form: The forms of crystals can be of different types depending on the nature and number of faces. Due to paucity of naturally occurring crystals, models made up of wood, plastic or glass are generally used in practical classes.

(i) Simple form: A crystal bounded entirely by like (similar) faces is termed as a simple form. The crystal shown in Fig.3.2 is a simple form because it is made up of six square faces, which are all alike.

(ii) Combination form: A crystal having two or more types of faces is called combination form. The crystal shown in Fig.3.3 is a combination form because it is made up of two types of faces i.e. square and equilateral triangular. In naturally occurring combination forms two or more sets of faces may be present

(iii) Closed form: A crystal may be termed as a closed form (solid) when it encloses some space. It can occur independently.

(iv) Open form: An open form does not enclose any space. Since the crystals are three-dimensional solids, an open form cannot occur independently. It occurs in association with other form(s), giving rise to a combination form.

(v) Holohedral form: The form having maximum number of faces as per the demand of highest degree of symmetry possible in a system is known as holohedral form. Octahedron of isometric system with eight faces is an example.

(vi) Hemihedral form: This is the form with half of the number of faces present in a holohedral form. The number of faces decreases consequent upon decline of the symmetry in comparison to holohedral form. The faces are evenly distributed throughout the crystal. Tetrahedron with four faces is the hemihedral form of octahedron of isometric system.

(vii) Hemimorphic form: This is the form with half of the number of faces present in a holohedral form. The faces are present at one extremity of the vertical crystallographic axis. Hemimorphic forms do not possess centre of symmetry.

(viii) Tetartoidal form: These forms have a quarter of the number of faces corresponding to the holohedral form. They lack both the plane and centre of symmetry.

(ix) Enantiomorphic form: These are the forms with half of the number of faces of a holohedral form. They lack both plane and centre of symmetry. They occur in two positions, which are mirror images of each other but not superposable i.e. one cannot be converted to other by any rotation. Because they are related to each other as hands of human being, they are commonly designated as right- and left-handed.

(x) Common forms: A closed or open crystal form having a set of like faces is designated by a name. Some common forms are cube, tetrahedron, prism etc. Common forms occurring in a crystal class are indicated by different names. Their definition and description are given in later part of this chapter.

3.2.3. Edge: An edge is formed by the intersection of two adjacent faces. Therefore, it is parallel with the rows of atoms occurring at the intersection of net-planes. BC edge in Fig.3.2 is formed by the intersection of ABCD and BCFG faces. Similarly, in Fig.3.3, PQ edge is formed by the intersection of square face PQRS and triangular face PQU.

3.2.4. Solid angle: A solid angle is formed by the intersection of three or more faces. In Fig.2 the circle at C indicates a solid angle formed by the intersection of three faces ABCD, CDEF and BCFG faces. Similarly, in Fig.3.3, the circle at R indicates a solid angle formed by the intersection of four faces PQRS, QRW, WRYX and SRY.

3.2.5. Interfacial angle: The angle between two faces of a crystal is termed as interfacial angle. In reality it is the angle between the perpendiculars drawn onto the concerned faces. The angle A as shown in Fig.3.4 is the interfacial angle between crystal faces 1 and 2. This angle is used for projection of crystal faces. The interfacial angle is measured by goniometer. Two types of goniometers are available; these are contact-goniometer and optical-goniometer. The contact-goniometer consists of one graduated protractor and a straight-edged arm movable on a pivot (Fig.3.5). The base of the protractor and the arm are brought accurately in contact with adjacent faces of the crystal between which the interfacial angle is to be measured (Fig.3.5). PO and QO are perpendiculars onto the crystal faces 1 and 2. $\angle A + \angle B = 180° = \angle B + \angle C \Rightarrow \angle A = \angle C$. In the present case the interfacial angle ($\angle A$) between the crystal faces 1 and 2 is 70°.

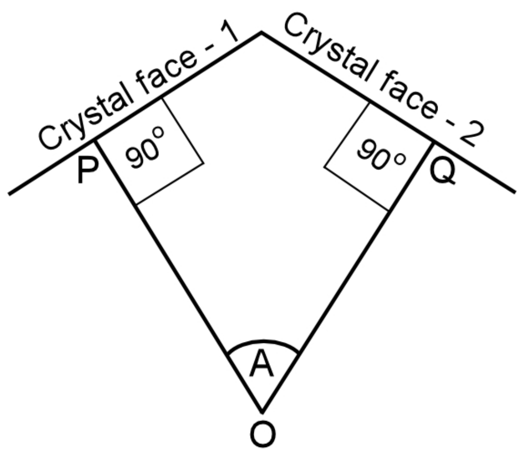


Fig.3.4: Interfacial angle between two faces of a crystal

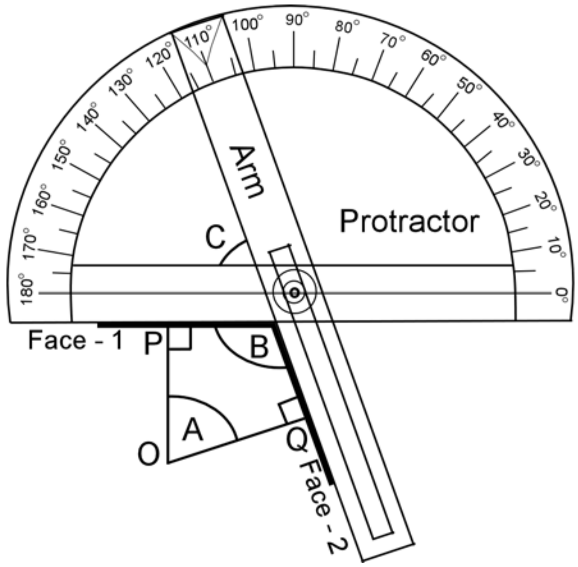


Fig.3.5: Contact-goniometer showing the interfacial angle between two crystal faces

Optical goniometer, also known as reflecting-goniometer is a sophisticated instrument used for small crystals possessing smooth, flawless and brilliant reflecting faces. It consists of a vertical graduated scale capable of rotation and a fixed horizontal arm perpendicular to the plane of the circle. A mirror is fixed on the horizontal arm. The crystal is placed at the centre of the graduated circle with an edge parallel to the horizontal arm. The image of a distant signal is observed by reflection from the mirror and also by reflection from the crystal face. By rotation of the graduated circle with the crystal, two images are made to lie in the same straight line. The circle is then rotated until an image is obtained from the adjacent face by reflection. The amount of rotation is the angle between the perpendiculars onto the crystal faces and thus, the interfacial angle. The principle is shown in Fig.3.6. The light reflected from the face PQ, when the crystal is in PQRS position is seen. In the next instance, the crystal is rotated to PQ′R′S′ position and the light reflected from QS′ is seen again. The crystal has been rotated through the angle SPS′, which is the supplementary of the internal angle between faces PQ and PS, and thus is the interfacial angle between faces PQ and PS.

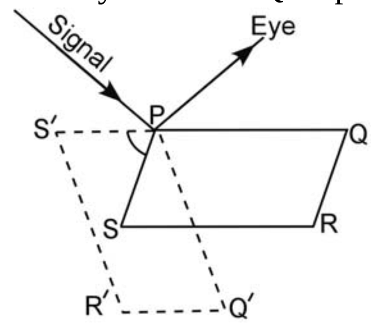


Fig.3.6: Principle of optical-goniometer

3.3. SYMMETRY ELEMENTS OF CRYSTALS

Examination of a crystal indicates the existence of regularity in the arrangement of like faces, edges, solid angles etc. This regularity constitutes the symmetry of the crystal and depends on the internal atomic structure of the mineral. The symmetry can be defined with reference to three criteria *viz.* plane of symmetry, axis of symmetry and centre of symmetry generated by reflection, rotation and inversion operations respectively.

3.3.1. Plane of symmetry: A *plane of symmetry* is an imaginary plane that passes through the centre and divides a figure or a crystal into two similar and similarly placed halves, which are mirror images of each other. It appears as if one half of the figure or the crystal is generated by reflection of the other half on a plane mirror surface. The plane of symmetry is also known as *mirror plane* or *mirror* and is denoted by the letter ‘*m*’ (some authors denote it by ‘P’). The presence of the plane of symmetry can be well visualized from different two-dimensional figures shown in Fig.3.7a-g. The dashed lines represent planes of symmetry.

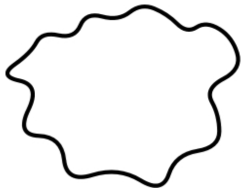


Fig.3.7a: No plane of symmetry in an irregular figure

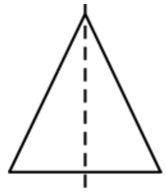


Fig.3.7b: One plane of symmetry in isosceles triangle

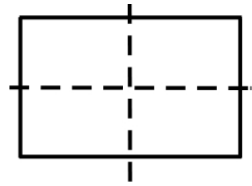


Fig.3.7c: Two planes of symmetry in rectangle

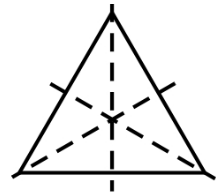


Fig.3.7d: Three planes of symmetry in equilateral triangle

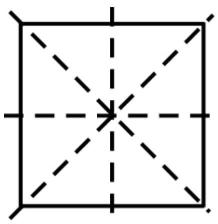


Fig.3.7e: Four planes of symmetry in square

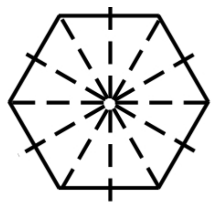


Fig.3.7f: Six planes of symmetry in regular hexagon

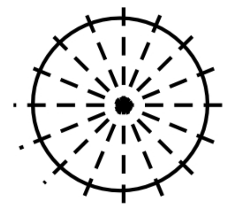
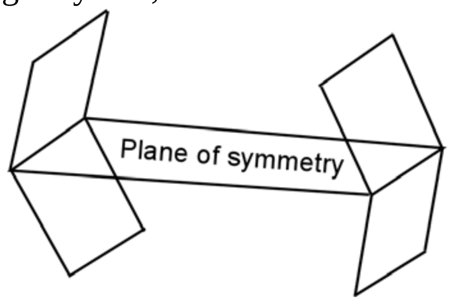


Fig.3.7g: Infinite number of planes of symmetry in circle (a few are shown)

In Fig. 3.7(a) an irregular figure is shown which is not symmetrical with respect to any plane and thus, lacks a plane of symmetry. The isosceles triangle, rectangle, equilateral triangle, square and hexagon shown in Figs. 3.7(b), (c), (d), (e) and (f) have 1, 2, 3, 4 and 6 number of planes of symmetry respectively. The circle (Fig.3.7g) has infinite number of planes of symmetry (only a few are shown) each coincident with a diameter of the circle. Two three-dimensional crystal forms, a prism and a cube are shown in Figs.3.8 and 3.9 respectively. The upper two faces of the prism are related with the lower two faces by a horizontal plane of symmetry. Similarly, a cube has nine planes of symmetry indicated by numbers 1 to 9. A sphere has infinite number of planes of symmetry.

3.3.2. Axis of symmetry: Symmetry operations like rotation and rotation combined with inversion give rise to axes of symmetry. An axis of symmetry is an imaginary line, which



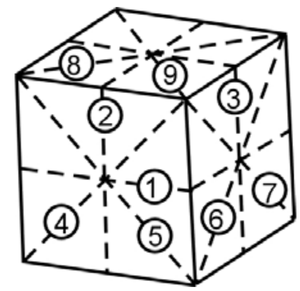
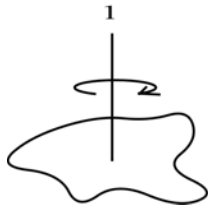
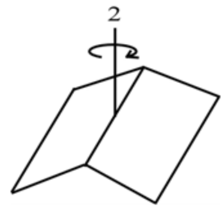


Fig. 3.8: Plane of symmetry in a prism **3.9: Nine symmetry planes in cube**

passes through the centre of the crystal. The rotational axis, commonly known as *axis of symmetry*, involves rotation of the crystal about the concerned axis by certain angle as a result of which the crystal occupies the immediately next similar position in space. The angle between two consecutive similar positions in space is known as the *elementary angle of rotation*. The axes of symmetry are one-fold, two-fold, three-fold, four-fold and six-fold with elementary angles of rotation 360°, 180°, 120°, 90° and 60° respectively. These are represented by numbers 1, 2, 3, 4 and 6 respectively (Figs.3.10a-e). The axes of 2-fold, 3-fold, 4-fold and 6-fold are also known as diad, triad, tetrad and hexad axes respectively. The degree of the axis indicates the number of times the crystal occupies the same position in space in a complete rotation of 360° about the concerned axis. Axis of one-fold rotation (1) is universally present in all the objects whatever the shape may be. Hence, it is not regarded as a symmetry element by many authors. However, in the true sense, it indicates the lack of symmetry and is used in classification of crystals into 32 symmetry classes. A pinacoid is shown in Fig.3.10b. It consists of two faces, which interchange their positions twice in a complete rotation of 360°. In Figs.3.10c-e the trigonal, tetragonal and hexagonal pyramids possess rotational axes of 3-, 4- and 6-fold respectively.

(a)




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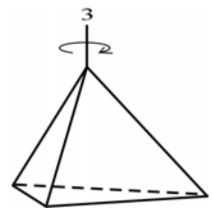

(c)

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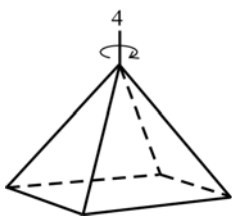


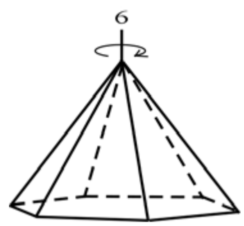
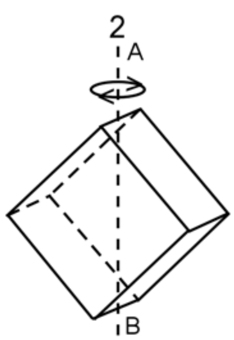
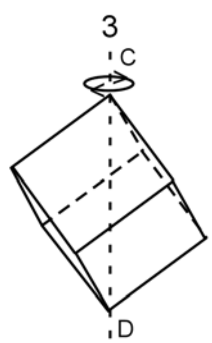
(e)


Fig.3.10a-e: Axes of symmetry

Even, a single form may have axes of different degrees. For example, a cube has six axes of 2-fold symmetry, which join the mid points of opposite edges (Fig.3.11a), four axes of 3-fold symmetry, which pass through the opposite corners (solid angles) (Fig.3.11b) and three axes of 4-fold symmetry, which emerge at the mid points of opposite faces (Fig.3.11c).

(a)


(b)


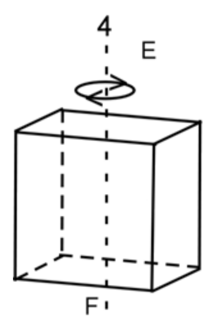
(c)


Fig.3.11a-c: Axes of symmetry in cube

Axis of 5-fold symmetry is not possible in crystallography. It can be proved both by experiment and mathematical deduction. According to the rule, there should not be any empty space in crystal structure of stable compounds i.e. the available space should be completely filled in. Any amount of two-dimensional empty space can be completely filled in by suitable size paper-cuttings of rectangular, equilateral triangular, square and regular hexagonal shapes, which are the two-dimensional horizontal cross sections of three-dimensional solid objects having 2-, 3-, 4- and 6-fold axes of symmetry respectively. The horizontal cross-section of a three-dimensional object having an axis of 5-fold symmetry is a regular pentagon, whose sides are equal and subtend 72° at the centre. If attempt is made to fill in any specified space by small paper cuttings of regular pentagons, small empty spaces (holes) will remain. Existence of empty spaces (holes) is not permitted within stable and ordered crystal structure. This leads to the impossibility of existence of axis of 5-fold symmetry. Similar arguments are also true for 7-fold and other higher degree symmetry axes. The mathematical treatment of this problem will be addressed in higher classes.

The *rotoinversion axes* involve rotation by the elementary angle of rotation followed by inversion through a point. Corresponding to five elementary angles stated above, there are five rotoinversion axes designated as $\bar{1}$, $\bar{2}$, $\bar{3}$, $\bar{4}$ and $\bar{6}$. These are read as bar one, bar two etc. $\bar{1}$ is equivalent to a centre of symmetry (or centre of inversion, i), $\bar{2}$ is equivalent to a mirror plane (m), $\bar{3}$ is equivalent to a 3-fold rotation axis plus centre of symmetry (3+i), $\bar{4}$ is unique and $\bar{6}$ is equivalent to a 3-fold rotation axis with a perpendicular mirror plane (3/m). These will be discussed at length in higher classes.

3.3.3. Centre of symmetry: A crystal is said to have a *centre of symmetry* if like faces, edges, solid angles etc. are arranged in pairs in corresponding positions on opposite sides of a central point. The centre of symmetry is an imaginary point located at the centre of the crystal. If a straight line is drawn through it, similar faces, edges and solid angles are encountered on either side of the point at equal distances. It is observed that when a crystal having centre of symmetry is made to stand on a certain face, an identical face remains to the top of the crystal. A crystal having an axis of even-fold perpendicular to a mirror plane generally possesses a centre of symmetry.

3.4. CRYSTALLOGRAPHIC AXES

In solid geometry (geometry of three dimension) the position of lines and planes are expressed with respect to three mutually intersecting perpendicular axes. Since the crystals are also three-dimensional bodies bounded by flat faces, reference axes similar to those of solid geometry are also taken into consideration to designate different planes (faces) and lines (edges, zone axes etc) of crystals. Unlike the axes of solid geometry, which are mutually perpendicular and extend indefinitely in all the three directions, the crystallographic axes are of finite length and not always perpendicular to each other. The crystals are classified into six systems each of which is characterised by a set of crystallographic axes having unique characters. The six systems are isometric, tetragonal, hexagonal, orthorhombic, monoclinic and triclinic. The axes are generally designated as lower case alphabets ‘a’, ‘b’ and ‘c’. The c-axis is always vertical in position where as b-axis is perpendicular to c-axis (except triclinic system) and lies in horizontal plane. The a-axis may or may not lie in horizontal plane containing b-axis. The angles between b- and c-axes, c- and a-axes and a- and b-axes are designated by ‘α’, ‘β’ and ‘γ’ respectively. The ratio of lengths of crystallographic axes is known as *axial ratio*.

3.4.1. Axes of isometric system: In case of isometric system, all the three crystallographic axes are equal in length and they are mutually perpendicular to each other, i.e. $a = b = c$ and $\alpha = \beta = \gamma = 90°$.

3.4.2. Axes of tetragonal system: In case of tetragonal system, the horizontal (a and b) crystallographic axes are equal in length, vertical axis (c) is either shorter or longer than the horizontal axes. All the three axes are mutually perpendicular to each other, i.e. $a = b \neq c$ and $\alpha = \beta = \gamma = 90°$.

3.4.3. Axes of hexagonal system: The hexagonal system is characterized by three horizontal crystallographic axes of equal length, which are inclined to each other at 120°. The vertical axis is either shorter or longer than the horizontal axes and perpendicular to the horizontal crystallographic axes at the point of their intersection.

3.4.4. Axes of orthorhombic system: The orthorhombic system has three crystallographic axes, which are unequal in length but perpendicular to each other i.e. $a \neq b \neq c$ and $\alpha = \beta = \gamma = 90°$. The a- and b-axes lie in the horizontal plane and were designated as brachy- and macro-axes respectively in old convention.

3.4.5. Axes of monoclinic system: Three crystallographic axes of unequal length characterize this system. The c-axis is vertical, b-axis (ortho) is horizontal in position and perpendicular to the c-axis while a-axis (clino) is inclined to the vertical plane containing the b-c axes and slopes down towards the observer. In this case $a \neq b \neq c$, $\alpha = \gamma = 90°$ and $\beta \neq 90°$.

3.4.6. Axes of triclinic system: In case of triclinic system, all the three crystallographic axes are unequal in length and inclined to each other i.e. $a \neq b \neq c$ and $\alpha \neq \beta \neq \gamma \neq 90°$. The c-axis is vertical, a-axis slopes to the front and right of the observer and b-axis is inclined to the right of the observer. In old convention, a and b axes were designated as brachy- and macro-axes respectively.

3.5. REPRESENTATION OF CRYSTAL FACE

Most of the crystals are three-dimensional polyhedral forms having a number of faces. The positions of the faces with respect to crystallographic axes are expressed in a manner almost similar to that of solid geometry. The character and nature of the faces are expressed by intercepts, parameters and indices.

3.5.1. Intercepts: Intercepts are the distances between the point of intersection of the crystallographic axes and the points of intersection of the face under consideration and crystallographic axes. In Fig.3.12, OX, OY and OZ crystallographic axes are denoted by conventional symbols ‘a’, ‘b’ and ‘c’ respectively. ABC and PQR are two crystal faces. The intercepts of the face ABC on a, b and c axes are OA, OB and OC respectively. Similarly the intercepts of the face PQR on a, b and c axes are OP, OQ and OR respectively.

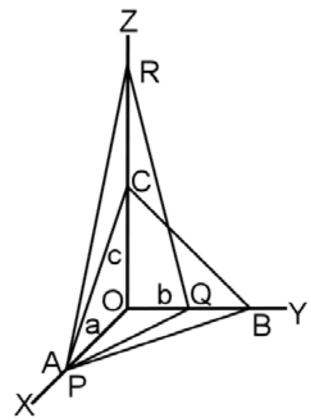


Fig. 3.12: Crystallographic axes with two faces ABC and PQR

3.5.2. Parameters: Parameters are the ratios of the intercepts i.e. the intercepts of the face in consideration are compared with those of a unit form. If ABC is a face of the unit form then OA, OB and OC are unit distances in a, b and c axis directions respectively. Parameters of the face PQR are OP/OA, OQ/OB and OR/OC on a, b and c axes respectively.

This is expressed as 1a, ½ b and 2c [Since OP=OA, OQ=½ OB and OR=2OC]

This type of representation of parameters is known as *Weiss parameter*. The symbols 1a, ½ b and 2c indicate that the face under consideration (PQR) intersects the a-axis at unit distance, b-axis at half of the unit distance and c-axis at twice of the unit distance.

3.5.3. Indices: The indices are obtained from the Weiss parameters by taking the reciprocals and clearing the fractions. The indices are written in axial order i.e. a, b and c and hence the alphabets a, b and c associated with the parameters are omitted. The indices of the face PQR are 1/1, 1/½, 1/2 ⇒ 1, 2, ½ ⇒ 241

This system of representation of indices is known as *Miller indices*. For a face that intersects the a-axis at unit distance, b-axis at twice of the unit distance and remains parallel with the c-axis, the Weiss parameters are 1a, 2b, ∝c (it is assumed that the face intersects the c-axis at infinite distance). The miller indices are 1/1, 1/2, 1/∝ or 210 (read as two, one, naught but not as two one zero or two hundred ten). A face may cut all the three axes at unequal lengths. In such cases, the symbols may be 123, 321, 234 or any other numerical depending on the lengths of the intercepts. If the lengths of intercepts cannot be determined precisely the general symbol ‘hkl’ may be used. The intercepts and indices are inversely related i.e. the highest intercept corresponds to the lowest index and vice versa. The Miller indices of a face are also known as the symbol of the corresponding face.

3.5.4. Symbol of a crystal: A simple form consists of a set of fixed number of faces which possess similar characteristics i.e. shape, size and crystallographic orientation. For example, a cube (Fig.2) consists of six square faces each of which intersects one crystallographic axis and remains parallel with other two axes.

The Weiss parameters of the face towards the observer that intersects the a_1-axis and remains parallel with other two axes are 1a ∝b ∝c and the corresponding Miller indices are 100, which is the symbol of the corresponding face. The symbols of faces to the right and top, which intersect only a_2 and a_3-axes are 010 and 001 respectively. The symbols of remaining three faces, which intersect the axes on the negative sides are $\bar{1}00$, $0\bar{1}0$ and $00\bar{1}$. Out of these six symbols one is to be used to represent the form i.e. the cube. There is disagreement among various authors regarding representation of face and form symbols. Dana and Ford as well as Read indicate the face symbol without bracket and form symbol within '( )' bracket. Hurlbut and Klein on the other hand, prefer to keep face symbol within '( )' bracket and form symbol within '{ }' bracket. Generally the symbol of one of the faces of a crystal is taken to represent the form symbol. There is also lack of unanimity regarding selection of the form symbol. Dana and Ford as well as Read prefer to follow the convention $h>k>l$ i.e. the first digit of the symbol is the greatest and last digit of the symbol is the least. Thus, the cube is represented by the symbol (100). Hurlbut and Klein and others follow the convention $h<k<l$ i.e. the first digit of the symbol is the least and last digit of the symbol is the greatest. According to them the symbol {001} represents the cube. In both the cases the form symbol does not indicate the number of faces of the crystal. Thus, two or more forms, which bear similar relationship with the crystallographic axes, even though they have dissimilar number of faces are represented by the same symbol. To avoid these confusions, in this book, the general symbol of the form that intersects all the three crystallographic axes is represented by the symbol '$(hkl)_n$' where $h<k<l$ and 'n' is the number of faces. Thus, the cube is represented by the symbol $(001)_6$, which indicates that it is a form having six faces all of which intersect one crystallographic axis at unit distance remaining parallel with other two axes. Hence, it is a unique symbol that differs from the form symbols of pinacoid $(001)_2$ and pedion $(001)_1$, which have dissimilar number of faces but similar crystallographic relationship.

3.6. ZONE

A zone comprises a set of faces whose mutual intersections are parallel with each other and with a common line drawn through the centre of the crystal. The common line is known as the zone axis and the faces belonging to the same zone are known as tautozonal faces.

3.6.1. Zonal equation: Zonal equation refers to the mathematical relationship that exists between the faces in a zone and is commonly expressed by symbol [uvw]. If 'hkl' and 'pqr' are two faces belonging to the zone [uvw], then

u = kr – ql, v = lp – rh and w = hq – pk.

It is pictorially expressed in Fig.3.13.

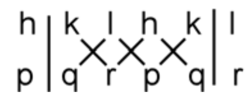


Fig. 3.13

Example: The four faces of the cube lying to the left, back, right and front belong to a zone as their intersections (edges) are mutually parallel with each other and with the a_3 crystallographic axis passing through the centre of the crystal.

The symbols of faces to the front and right of the cube are 100 and 010 respectively, and both of them belong to a zone. In this case, h = 1, k = 0, l = 0; p = 0, q = 1, r = 0; u = kr – ql = (0×0) – (1×0) = 0; v = lp – rh = (0×0) – (0×1) = 0 and w = hq – pk = (1×1) – (0×0) = 1; thus, [uvw] = [001], which is the a_3 axis

3.6.2. If the indices of two faces lying in a zone are added, the sum is the indices of the face lying between them.

Example: If the two faces of the cube in the above example are added (100 + 010) the sum becomes '110', which is a dodecahedron face laying to the front-right of the observer in a combination form of cube and dodecahedron (Fig.3.23)

3.6.3. If a face with indices 'hkl' lies in the zone [uvw], the zonal equation uh + vk + wl = 0, is satisfied.

Example: In the above example the face symbol (hkl) is 100 and the zone symbol [uvw] is [001]. The zonal equation uh + vk + wl = (0×1) + (0×0) + (1×0) = 0.

3.6.4. If [uvw] and [efg] are two intersecting zones, the intersection is a possible crystal face. If the indices of the face are hkl, then the zonal equations 'uh + vk + wl = 0' and 'eh + fk + gl = 0' should be simultaneously satisfied. The values of h, k and l are calculated as: h = vg – fw, k = we – gu and l = uf – ev as shown in Fig.3.14.

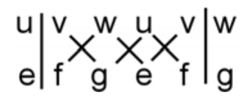


Fig. 3.14

Example: In cube, 'a_2' and 'a_3' with symbol [010] and [001] are two zones, where u = 0, v = 1, w = 0, e = 0, f = 0 and g = 1; if 'hkl' is the indices of the face lying in both the zones, then h = vg – fw = (1×1) – (0×0) = 1, k = w×e – g×u = (0×0) – (1×0) = 0 and l = u×f – e×v = (0×0) – (0×1) = 0 i.e. the face 100 towards the observer is the face common to both the zones.

3.7. LAWS OF CRYSTALLOGRAPHY

The developments of external forms and angular relationships between crystal faces suggest the prevalence of some fundamental laws. These are (i) Law of constancy of interfacial angle, (ii) Law of rational indices, (iii) Law of axial ratio, (iv) law of crystallographic axes and (v) Law of constancy of symmetry. These are explained below:

3.7.1. Law of constancy of interfacial angle: Law of constancy of interfacial angle states that "the interfacial angle between two faces of a crystal at a particular temperature remains constant regardless the size and shape of the crystal". The external form of a crystal is the manifestation of its internal atomic structure, which is fixed at a particular temperature. The size of the crystal is controlled by the amount of material available and the prevailing physicochemical conditions.

The crystal faces are parallel to the net-planes containing maximum number of ions. Since the positions of net-planes are fixed, so also the faces of the crystal and the angle between them, which determine the amount of interfacial angle.

3.7.2. Law of rational indices: The study of crystals has established the law of rational indices, which states that "the intercepts that any crystal face makes on the crystallographic axes are either infinite or small rational multiples of the intercepts made by the unit form". These ratios may be 1:2, 2:1, 2:3, 1:∝ etc, but never like $1:\sqrt{2}$, $1:\sqrt{3}$ etc. Hence the values of 'hkl' in Millar indices must always be either whole numbers or zero. This is due to the fact that the crystals are formed due to regular stacking of whole number unit cells in three dimensions not by their fractions.

3.7.3. Law of axial ratio: The ratio between the crystallographic axes (a:b:c) is known as the axial ratio. It is commonly expressed by making either 'a' or 'b' as unity. The law of axial ratio states that "the ratio between the lengths of the axes of a given crystal is always constant". In case of all isometric crystals it is 1:1:1. The a:c values of zircon and octahedrite, which crystallize in tetragonal system are 1:0.901 and 1:1.777 respectively. The a:c values of hexagonal minerals beryl and quartz are 1: 0.996 and 1:1.1 respectively. The axial ratios (a:b:c) for sillimanite and barite, which crystallize in orthorhombic system are 0.98:1:0.75 and 0.815:1:1.31 respectively. For gypsum and orthoclase, which crystallize in monoclinic system, the axial ratios (a:b:c) are 0.372:1:0.412 and 0.658:1:0.553 respectively. The axial ratio of triclinic crystal axinite is 0.972:1:0.778.

3.7.4. Law of crystallographic axes: The positions of the crystallographic axes are mostly fixed by the symmetry elements of the crystals. These are either coincident with the axes of symmetry, perpendicular to planes of symmetry or intersect each other at the centre of symmetry. The law states that "crystals of a given mineral are referred to the same set of crystallographic axes".

3.7.5. Law of constancy of symmetry: The X-ray analysis of crystal structure has revealed the law of constancy of symmetry which states that "the symmetry in all crystals of a particular mineral is constant, though they may not be similar in form". For example, the mineral garnet commonly crystallizes in the form dodecahedron or trapezohedron or a combination of both. In a few cases, it also takes the hexoctahedron habit. All these forms belong to the hexoctahedral class of isometric system, which is characterized by three axes of four-fold, four axes of three-fold and six axes of two-fold symmetry axes, nine planes of symmetry and a centre of symmetry.

3.8. DESCRIPTION OF NORMAL CLASSES

On the basis of axial relationship, the crystals have been grouped under six systems. Each system constitutes a number of classes out of which one has the maximum number of symmetry elements and all the forms are holohedral. Such a class is known as the *normal class* of that system. Thus, a normal class of a system is defined as the class that shows maximum symmetry and consists of only holohedral forms belonging to that system. Description of axial relationship, symmetry elements and forms present in different normal classes are given in following pages.

3.8.1. Normal class of isometric system (Hermann-Mauguin symbol: $4/m\bar{3}2/m$)

(i) Axial relationship: Crystals belonging to isometric or cubic system are referred to three crystallographic axes, which are equal in length and perpendicular to each other (Fig.3.15). Since these axes are mutually interchangeable, they are all designated by letter 'a'. However, to distinguish them from each other and for proper orientation, they are designated as a_1, a_2 and a_3. In proper orientation, a_1 axis runs from front to back, positive on observer side and negative on the other side; a_2 axis runs from right to left, positive on the right hand side and negative on left hand side and a_3 axis is vertical, positive at the top and negative at the bottom. Axes a_1 and a_2 axes lie in the horizontal plane and a_3 is vertical and perpendicular to the plane containing the a_1 and a_2 axes. Since all the crystallographic axes are equal in length the axial ratio (a:b:c) in case of isometric system is equal to 1:1:1.

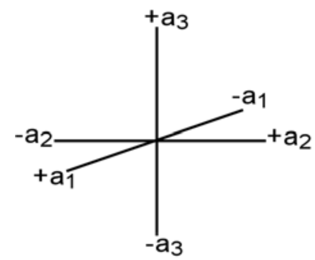


Fig. 3.15: Crystallographic axes of isometric system

Five classes are grouped under this system. These are hexoctahedral ($4/m\bar{3}2/m$), hextetrahedral ($\bar{4}3m$), diploidal ($2/m\bar{3}$), gyroidal (432) and tetartoidal (23). The *hexoctahedral class* (*$4/m\bar{3}2/m$*) is the *normal class of isometric system* as it shows maximum symmetry among all the classes and also as *galena type* after the characteristic mineral galena that crystallizes in this class.

(ii) Symmetry elements: Crystals belonging to this class are characterised by three axes of 4-fold symmetry, which are coincident with the crystallographic axes. There are four axes of 3-fold symmetry, which emerge in the middle of each of the octants formed by intersection of crystallographic axes. In addition, there are six axes of 2-fold rotation, each of which bisects one of the angles between two crystallographic axes (Fig. 3.11). There are nine mirror planes, three axial i.e. each contains two of the crystallographic axes and six diagonal each of which bisects the angle between a pair of the axial planes. Centre of symmetry is also present.

(iii) Forms: The forms occurring in this class are listed in Table 3.1.

Table 3.1: Forms of the normal class of isometric system

Sl. No.	Name of the form	Number of faces	Form symbol	Shape of faces in simple form
1.	Cube or Hexahedron	6	$(001)_6$	Square
2.	Octahedron	8	$(111)_8$	Equilateral triangle
3.	Dodecahedron	12	$(011)_{12}$	Rhombus
4.	Tetrahexahedron	24	$(0kl)_{24}$	Isosceles triangle
5.	Trisoctahedron	24	$(hll)_{24}$	Isosceles triangle
6.	Trapezohedron	24	$(hhl)_{24}$	Trapezium
7.	Hexoctahedron	48	$(hkl)_{48}$	Scalene triangle

(a) Cube or Hexahedron $(001)_6$: The cube (Fig.3.16) is a solid bounded by six square faces and the adjacent faces make 90° angles with each other. Each face intersects one crystallographic axis and remains parallel with other two. The symbols of the faces towards the observer, to the right and in the top of the crystal are 100, 010 and 001 respectively. The symbols of the faces on the opposite side of these faces intersecting the a_1, a_2 and a_3 axes on the negative sides are $\bar{1}00$, $0\bar{1}0$ and $00\bar{1}$ respectively. The form symbol is $(001)_6$.

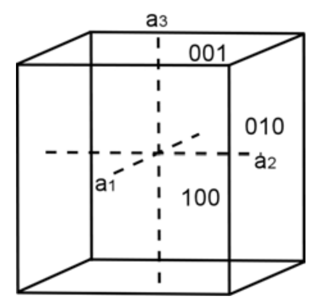


Fig.3.16: Cube

(b) Octahedron $(111)_8$: The octahedron (Fig.3.17) is a closed form bounded by eight equilateral triangular faces, each of which intersects all the three crystallographic axes at equal distances. The symbols of eight faces are $111, \bar{1}11, \bar{1}\bar{1}1, 1\bar{1}1, 11\bar{1}, \bar{1}1\bar{1}$, $\bar{1}\bar{1}\bar{1}$ and $1\bar{1}\bar{1}$. The form symbol is $(111)_8$.

(c) Dodecahedron $(011)_{12}$: The dodecahedron (Fig.3.18) is a solid bounded by 12 rhomb-shaped faces, each of which intersects two of the crystallographic axes at equal distances and remains parallel with the third. Due to the rhombus shape of the faces, it is commonly known as rhomb-dodecahedron. The symbols of twelve faces are $110, \bar{1}10, \bar{1}\bar{1}0, 1\bar{1}0, 101, \bar{1}01, \bar{1}0\bar{1}, 10\bar{1}, 011, 0\bar{1}1, 0\bar{1}\bar{1}$ and $01\bar{1}$. The form symbol is $(011)_{12}$.

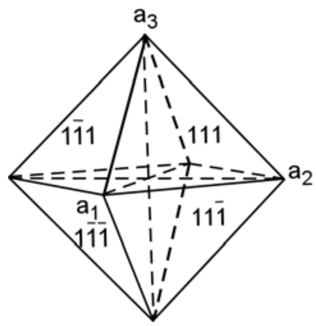


Fig.3.17: Octahedron

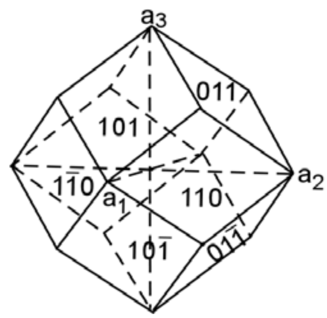


Fig.3.18: Dodecahedron

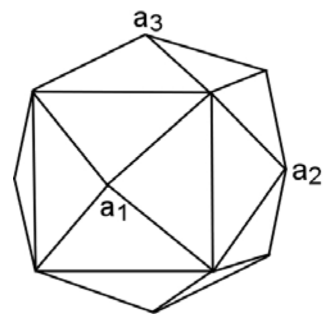


Fig.3.19: Tetrahexahedron

(d) Tetrahexahedron $(0kl)_{24}$: The tetrahexahedron (Fig.3.19) is a solid bounded by 24 isosceles triangular faces, each of which intersects two of the crystallographic axes at unequal lengths and remains parallel with the third. Hence the form symbol is $(0kl)_{24.}$ Four faces of the tetrahexahedron occupy one face of hexahedron (cube) making a small pyramid, hence the name. There can be many tetrahexahedrons depending on the values of k and l. The most common form is $(012)_{24}$, though forms like $(013)_{24}$, $(014)_{24}$, $(023)_{24}$ etc also occur. Thus, the tetrahexahedron is said to be a variable form. If either k or l becomes zero, the faces become parallel with two crystallographic axes and the form becomes a cube. If k is equal to l, intercept on two crystallographic axes become equal and the form becomes a dodecahedron.

Thus, the cube and the dodecahedron are said to be the *limiting forms* of the tetrahexahedron.

(e) Trisoctahedron (hll)$_{24}$: The trisoctahedron (Fig.3.20) is a solid having 24 isosceles triangular faces, each of which intersects two of the crystallographic axes at equal lengths and the third at a greater distance. Thus, the form symbol is (hll)$_{24}$. The most common form is (122)$_{24}$ though forms like (133)$_{24}$ and (233)$_{24}$ also occur. It has the appearance of being formed by a three-faced pyramid grown on each face of octahedron. It is also known as trigonal trisoctahedron as each face has three edges and three of the faces occupy one face of the octahedron. The limiting forms of trisoctahedron are octahedron and dodecahedron.

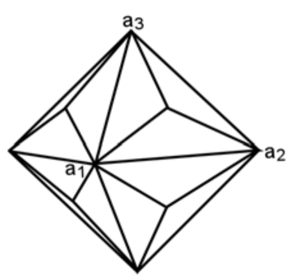


Fig.3.20: Trisoctahedron

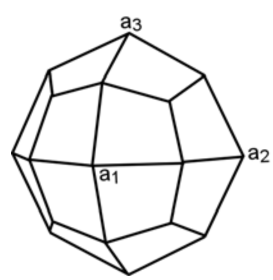


Fig.3.21: Trapezohedron

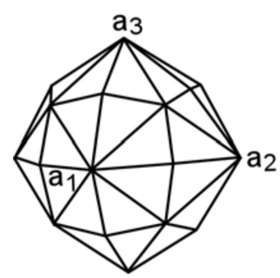


Fig.3.22: Hexoctahedron

(f) Trapezohedron (hhl)$_{24}$: The trapezohedron (Fig.3.21) is a solid bounded by 24 trapezoid faces, each of which intersects two of the crystallographic axes at equal lengths and the third at a smaller distance. Thus, the form symbol is (hhl)$_{24}$. Depending on the values of h and l, there are various trapezohedrons like (112)$_{24}$, (113)$_{24}$, (114)$_{24}$, (223)$_{24}$, but the form with symbol (112)$_{24}$ is most common. Since four faces of this form each having four edges occupy one face of the octahedron this form is also known as tetragonal trisoctahedron. The limiting forms of trapezohedron are cube and octahedron.

(g) Hexoctahedron $(hkl)_{48}$: The hexoctahedron (Fig.3.22) is a solid having 48 scalene triangular faces, each of which intersects all the three crystallographic axes at different lengths. Thus, the general form symbol is $(hkl)_{48.}$ Depending on the values of h, k and l, different hexoctahedrons exist, but the most common form is $(123)_{48}$. Six faces of the hexoctahedron occupy one face of the octahedron, hence the name. By varying the relations between the intercepts made by the faces of the hexoctahedron, all other forms of hexoctahedral class can be obtained. Therefore, the hexoctahedron is known as the *general form* of the hexoctahedral class. The six other forms described above are known as *special forms*.

Various forms of hexoctahedral class also occur in combinations with each other. In such cases, the shapes of the faces of the simple forms get obliterated but the crystallographic character like intercept relationship of each form remains intact. Some common combination forms are cube and dodecahedron (Fig.3.23) and cube, octahedron and dodecahedron (Fig.3.24).

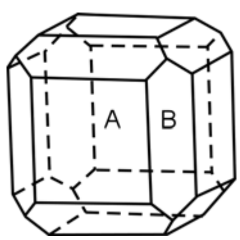


Fig.3.23: Combination of cube and dodecahedron

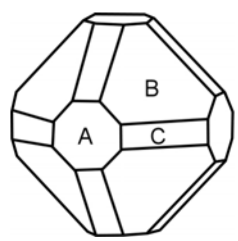


Fig.3.24: Combination of cube, octahedron and dodecahedron

Minerals crystallizing in this class are diamond, native platinum, gold, silver and copper, argentite, cerargyrite, cuprite, chromite, fluorite, galena, garnet, halite, magnetite, pentlandite, sylvite, uraninite, etc.

3.8.2. Normal class of tetragonal system (Hermann-Mauguin symbol: 4/m 2/m 2/m)

(i) Axial relationship: Crystals belonging to tetragonal system are referred to three crystallographic axes, which are perpendicular to each other (Fig.3.25). Out of the three axes, two are horizontal, lie in the horizontal plane, equal in length and thus, are mutually interchangeable. They are designated as a_1 and a_2. Axis a_1 runs from front to back, positive on observer side and negative in the back; a_2 axis runs from right to left, positive on right hand side and negative on the left hand side. The third axis is vertical; perpendicular to the plane containing a_1 and a_2 axes and is different in length, either shorter as in case of zircon or longer as in case of octahedrite. It is designated as 'c'. The a:c values in case of zircon and octahedrite are 1:0.901 and 1:1.777 respectively.

Seven classes are grouped under this system. These are ditetragonal dipyramidal (4/m 2/m 2/m), tetragonal scalenohedral ($\bar{4}$2m), ditetragonal pyramidal (4mm), tetragonal trapezohedral (422), tetragonal dipyramidal (4/m), tetragonal disphenoidal ($\bar{4}$) and tetragonal pyramidal (4). The *ditetragonal dipyramidal class* (*4/m 2/m 2/m*) is known as the *normal class of tetragonal system* as it shows the maximum symmetry among all the classes belonging to tetragonal system and *zircon type* after the characteristic mineral zircon that crystallizes in this class.

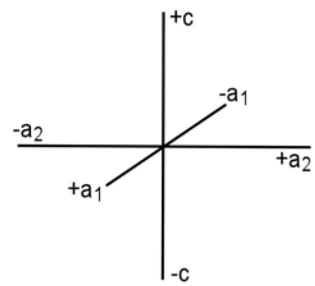


Fig.3.25: Crystallographic axes of tetragonal system

(ii) Symmetry elements: The vertical crystallographic axis 'c' is the axis of 4-fold symmetry. In addition, there are four axes of 2-fold symmetry, two of which are coincident with the horizontal crystallographic axes and other two are diagonal and bisect the angles between the horizontal crystallographic axes. There are five planes of symmetry, three are axial (one horizontal and two vertical) each containing two of the crystallographic axes and other two are vertically diagonal bisecting the angles between the vertical axial planes mentioned above. Centre of symmetry is present.

(iii) Forms: Different forms belonging to this class are basal pinacoid, three types of prisms and corresponding three types of pyramids. These are given in Table 3.2.

Table 3.2. Forms of normal class of tetragonal system

Sl. No.	Name of the form	Number of faces	Form symbol	Shape of faces in simple form
1.	Basal pinacoid	2	$(001)_2$	Square
2.	Tetragonal prism of first order	4	$(110)_4$	Rectangular
3.	Tetragonal prism of second order	4	$(100)_4$	Rectangular
4.	Ditetragonal prism	8	$(hk0)_8$	Rectangular
5.	Tetragonal dipyramid of first order	8	$(hhl)_8$	Isosceles triangle
6.	Tetragonal dipyramid of second order	8	$(0kl)_8$	Isosceles triangle
7.	Ditetragonal dipyramid	16	$(hkl)_{16}$	Scalene triangle

(a) Basal pinacoid $(001)_2$: The basal pinacoid (Fig.3.26) is an open form composed of two horizontal faces, which remain parallel with the horizontal axes and intersect the vertical crystallographic axis at equal lengths from the centre of the crystal. The form symbol is $(001)_2$ and the symbols of two faces two faces occurring at top and bottom are 001 and $00\bar{1}$ respectively. Since it forms the base of the crystal, it is known as basal pinacoid.

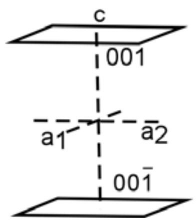


Fig.3.26: Basal pinacoid of tetragonal system

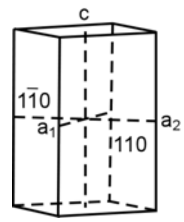


Fig.3.27: Tetragonal prism of first order

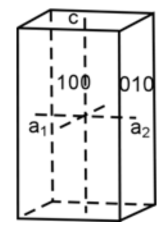


Fig.3.28: Tetragonal prism of second order

(b) Tetragonal prism of first order $(110)_4$: It is an open form that consists of four rectangular faces, each of which intersects the horizontal crystallographic axes at equal lengths and remains parallel with the vertical crystallographic axis (Fig.3.27). The form symbol is $(110)_4$ and the four faces are 110, $\bar{1}10$, $\bar{1}\bar{1}0$ and $1\bar{1}0$.

(c) Tetragonal prism of second order $(100)_4$: It is an open form that consists of four rectangular faces, each of which intersects one horizontal crystallographic axis and remains parallel with the other two crystallographic axes (Fig.3.28). The form symbol is $(100)_4$ and the four faces are 100, 010, $\bar{1}00$ and $0\bar{1}0$.

(d) Ditetragonal prism $(hk0)_8$: The ditetragonal prism (Fig.3.29) is an open form that consists of eight rectangular faces, each of which intersects both the horizontal crystallographic axes at different lengths. The form symbol is $(hk0)_8$. This prism can be thought of as derived from the tetragonal prism of first order by development of two faces on each face of the tetragonal prism of first order. Depending upon the different intercepts made on the horizontal crystallographic axes a number of ditetragonal prisms exist but the most common one is $(120)_8$.

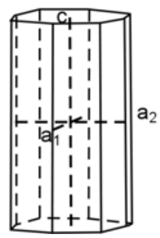


Fig.3.29: Ditragonal prism

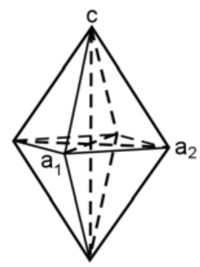


Fig.3.30: Tetragonal dipyramid of first order

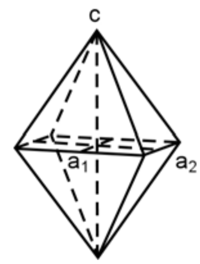


Fig.3.31: Tetragonal dipyramid of second order

(e) Tetragonal dipyramid of first order (hhl)$_8$: It is a closed form having eight isosceles triangular faces, each of which intersects both the horizontal crystallographic axes at equal lengths and the vertical crystallographic axis at a different length (Fig.3.30). The form symbol is (hhl)$_8$. If a face of this dipyramid cuts the horizontal and the vertical crystallographic axes in the same ratio as the axial ratio i.e. h:l = a:c, the form is called *unit* or *fundamental* form and the symbol becomes (111)$_8$. Though the unit dipyramid is most common, dipyramids with symbols (221)$_8$, (331)$_8$, (112)$_8$, (113)$_8$ etc also exist.

(f) Tetragonal dipyramid of second order (0kl)$_8$: It is a closed form having eight isosceles triangular faces, each of which intersects the vertical crystallographic axis and one of the horizontal crystallographic axis at different lengths remaining parallel with the other horizontal crystallographic axis (Fig.3.31). The form symbol is (0kl)$_8$. The unit dipyramid (011)$_8$ is most common, but dipyramids with symbols (021)$_8$, (031)$_8$, (012)$_8$, (013)$_8$ etc also exist.

(g) Ditetragonal dipyramid (hkl)$_{16}$: The ditetragonal dipyramid (Fig.3.32) is a solid bounded by sixteen scalene triangular faces each of which intersects all the three crystallographic axes at unequal lengths. The form symbol is (hkl)$_{16}$. There are various ditetragonal dipyramids depending upon the different intersections on the crystallographic axes.

Fig.3.32: Ditragonal dipyramid

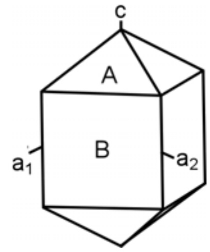


Fig.3.33: Combination of tetragonal dipyramid of first order (A) and tetragonal prism of first order (B)

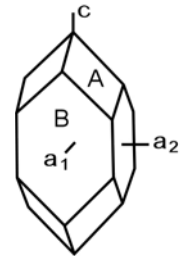


Fig.3.34: Combination of tetragonal dipyramid of first order (A) and tetragonal prism of second order (B)

Different forms of the normal class of tetragonal system also occur in combinations with each other. Combination forms of tetragonal dipyramid of first order and tetragonal prism of first order as well as tetragonal dipyramid of first order and tetragonal prism of second order are shown in Figs.3.33 and 3.34 respectively.

Important minerals crystallizing in this class are anatase, apophyllite, autunite, cassiterite, idocrase, octahedrite, pyrolusite, rutile, zircon etc.

3.8.3. Normal class of hexagonal system (Hermann-Mauguin symbol: 6/m 2/m 2/m)

(i) Axial relationship: Crystals belonging to the hexagonal system are referred to four crystallographic axes. Three of them lie in the horizontal plane, are equal in length with angles of 120° between their positive ends (Fig.3.35). These axes are mutually interchangeable and are designated as a_1, a_2 and a_3. The fourth axis, c, is vertical and is different in length. When properly oriented, one horizontal crystallographic axis (a_2) is left to right, positive on right hand side and negative on left hand side. The other two horizontal axes make 120° angles on either side of a_2. The positive end of a_1 axis is to the front and left while negative end of the a_3 axis is to front and right of observer. The proper orientation of the crystallographic axes and the method of their notation are shown in Fig.30. The a:c values in case of beryl and quartz are 1: 0.996 and 1:1.1 respectively.

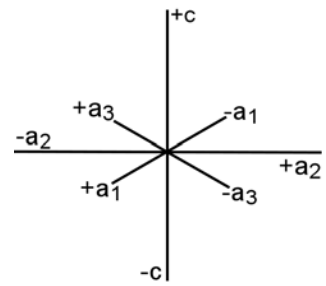


Fig.3.35: Crystallographic axes of hexagonal system

Twelve classes grouped under this system. These are dihexagonal dipyramidal (6/m 2/m 2/m), ditrigonal dipyramidal ($\bar{6}$m2), dihexagonal pyramidal (6mm), hexagonal trapezohedral (622), hexagonal dipyramidal (6/m), trigonal dipyramidal ($\bar{6}$), hexagonal pyramidal (6), hexagonal scalenohedral ($\bar{3}$2/m), ditrigonal pyramidal (3m), trigonal trapezohedral (32), rhombohedral ($\bar{3}$) and trigonal pyramidal (3). The *dihexagonal dipyramidal* (*6/m 2/m 2/m*) *class* is known as the *normal class of hexagonal system* as it shows the maximum symmetry among all the classes belonging to hexagonal system and *beryl type* after the characteristic mineral beryl that crystallizes in this class.

(ii) Symmetry elements: The vertical crystallographic axis is the axis of 6-fold symmetry. There are six horizontal axes of 2-fold symmetry, three of them are coincident with the horizontal crystallographic axes and other three bisect the angles between horizontal axes. There are seven mirror planes, one horizontal that contains all the three horizontal crystallographic axes and six vertical, three of which are vertical and axial each containing one of the horizontal crystallographic axis and the vertical crystallographic axis and other three bisect the angles between the vertical axial planes. Centre of symmetry is present.

(iii) Forms: Different forms belonging to this class are basal pinacoid, three types of prisms and corresponding three types of pyramids. These are given in Table 3.3.

Table 3.3: Forms of normal class of hexagonal system

Sl. No.	Name of the form	Number of faces	Form symbol	Shape of faces in simple form
1.	Basal pinacoid	2	$(0001)_2$	Hexagonal
2.	Hexagonal prism of first order	6	$(10\bar{1}0)_6$	Rectangular
3.	Hexagonal prism of second order	6	$(11\bar{2}0)_6$	Rectangular
4.	Dihexagonal prism	12	$(hk\bar{i}0)_{12}$	Rectangular
5.	Hexagonal dipyramid of first order	12	$(h0\bar{h}l)_{12}$	Isosceles triangle
6.	Hexagonal dipyramid of second order	12	$(hh\overline{2h}l)_{12}$	Isosceles triangle
7.	Dihexagonal dipyramid	24	$(hk\bar{i}l)_{24}$	Scalene triangle

(a) Basal pinacoid $(001)_2$: The basal pinacoid (Fig.3.36) is an open form having two horizontal faces, which remain parallel with the horizontal axes and intersect the vertical crystallographic axis at equal intercepts. The form symbol is $(0001)_2$ and the symbols of two faces occurring at top and bottom are 0001 and $000\bar{1}$ respectively. As it forms the base of the crystal, it is known as basal pinacoid.

(b) Hexagonal prism of first order $(10\bar{1}0)_6$: It is an open form consisting of six rectangular faces, each of which intersects two of the horizontal crystallographic axes at equal lengths and remains parallel with third horizontal and vertical crystallographic axes (Fig.3.37). The form symbol is $(10\bar{1}0)_6$. Six faces are $10\bar{1}0$, $01\bar{1}0$, $\bar{1}100$, $\bar{1}010$, $0\bar{1}10$, and $1\bar{1}00$.

(c) Hexagonal prism of second order $(11\bar{2}0)_6$: It is an open form consisting of six rectangular faces, each of which intersects two of the horizontal crystallographic axes at equal distances and the intermediate horizontal axis at one-half of this length remaining parallel with the vertical crystallographic axis (Fig.3.38). The form symbol is $(11\bar{2}0)_6$. Six faces are $11\bar{2}0$, $\bar{1}2\bar{1}0$, $\bar{2}110$, $\bar{1}\bar{1}20$, $1\bar{2}10$ and $2\bar{1}\bar{1}0$.

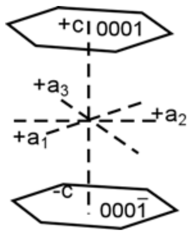


Fig.3.36: Basal pinacoid of hexagonal system

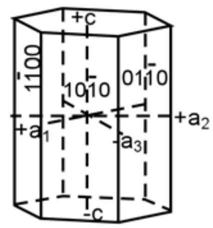


Fig.3.37: Hexagonal prism of first order

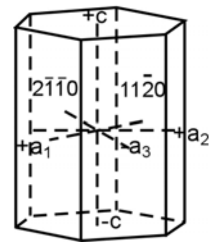


Fig.3.38: Hexagonal prism of second order

(d) Dihexagonal prism $(hk\bar{i}0)_{12}$: The dihexagonal prism (Fig.3.39) is an open form that consists of twelve rectangular faces, each of which intersects all the three horizontal crystallographic axes at different lengths. The form symbol is $(hk\bar{i}0)_{12}$. This prism can be thought of as derived from the hexagonal prism of first order by development of two faces on each face of the hexagonal prism of first order. Depending upon the intercepts made on the horizontal crystallographic axes, a number of dihexagonal prisms exist but the most common one is $(12\bar{3}0)_{12}$.

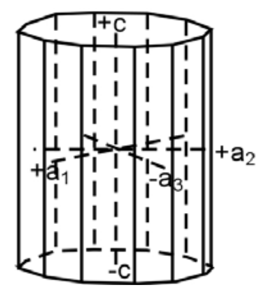


Fig.3.39: Dihexagonal prism

(e) Hexagonal dipyramid of first order $(h0\bar{h}l)_{12}$: It is a closed form having twelve isosceles triangular faces, each of which intersects two horizontal crystallographic axes at equal lengths and the vertical crystallographic axis at a different length remaining parallel to the third horizontal crystallographic axis (Fig.3.40). The form symbol is $(h0\bar{h}l)_{12}$. If a face of this dipyramid cuts the horizontal and the vertical crystallographic axes in the ratio equal to axial ratio, as in case of tetragonal system, the form is called *unit* or *fundamental* form and the symbol becomes $(10\bar{1}1)_{12}$.

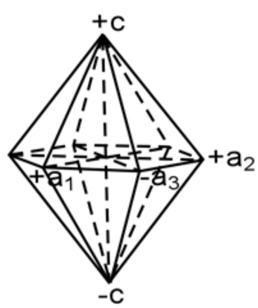


Fig.3.40: Hexagonal dipyramid of first order

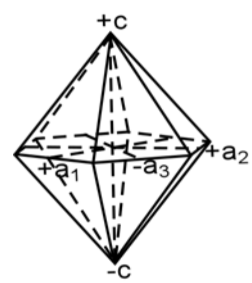


Fig.3.41: Hexagonal dipyramid of second order

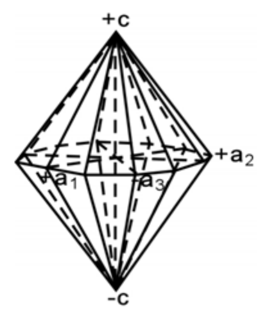


Fig.3.42: Dihexagonal dipyramid

(f) Hexagonal dipyramid of second order $(hh\overline{2h}l)_{12}$**:** It is a closed form having twelve isosceles triangular faces, each of which intersects two of the horizontal axes at equal lengths and the third (the intermediate horizontal axis) at half of this distance and the vertical crystallographic axis at different length (Fig.3.41). The form symbol is $(hh\overline{2h}l)_{12}$. The unit dipyramid $(11\bar{2}1)_{12}$ is most common.

(g) Dihexagonal dipyramid $(hk\bar{i}l)_{24}$**:** The dihexagonal dipyramid (Fig.3.42) is a solid bounded by twenty four scalene triangular faces each of which intersects all the four crystallographic axes at unequal lengths. The form symbol is $(hk\bar{i}l)_{24}$. There are various dihexagonal dipyramids depending upon the different intersections on the crystallographic axes but the form $(21\bar{3}1)_{24}$ is most common.

Various forms of the normal class of hexagonal system also occur in combinations with each other. Combination form of hexagonal prism of first order and hexagonal dipyramid of first order is shown in Fig.3.43.

Important minerals crystallizing in this class are beryl, covellite, molybdenite, nicolite, β-tridymite, etc.

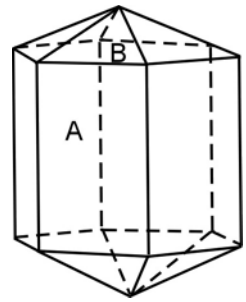


Fig.3.43: Combination of hexagonal prism of first order (A) and hexagonal dipyramid of first order (B)

3.8.4. Normal class of orthorhombic system (Hermann-Mauguin symbol: 2/m 2/m 2/m)

(i) Axial relationship: Crystals belonging to the orthorhombic system are referred to three crystallographic axes, which are unequal in length and perpendicular to each other. They are designated as a, b and c (Fig.3.44). In proper orientation, the c-axis is vertical, positive at top and negative at bottom; b-axis runs from left to right, positive on the right hand side and negative on the left hand side and the a-axis is front to back, positive on the observer side and negative on the other side. The proper orientation of the crystallographic axes and the method of their notation are shown in Fig.3.44.

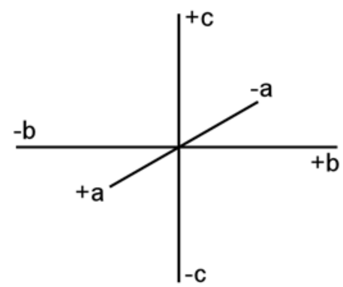


Fig.3.44: Crystallographic axes of orthorhombic system

Formerly the a-axis was called the brachy (short)-axis and the b-axis the macro (long)-axis.

Three classes belong to this system. These are rhombic dipyramidal (2/m 2/m 2/m), rhombic pyramidal (mm2) and rhombic disphenoidal (222). The *rhombic dipyramidal class* (*2/m 2/m 2/m*) is known as the *normal class of orthorhombic system* as it shows maximum symmetry among all the classes belonging to this system and *barite type* after the characteristic mineral barite that crystallizes in this class.

(ii) Symmetry elements: Three crystallographic axes are the axes of 2-fold symmetry. There are three axial planes of symmetry each containing two of the crystallographic axes. Centre of symmetry is present.

8.4.3. Forms: Pinacoids, prisms and dipyramid are the characteristic forms of this class. These are given in Table 3.4.

Table 3.4: Forms of normal class of orthorhombic system

Sl. No.	Name of the form	Number of faces	Form symbol	Shape of faces in simple form
1.	Front or a-pinacoid	2	$(100)_2$	Rectangular
2.	Side or b-pinacoid	2	$(010)_2$	Rectangular
3.	Basal or c-pinacoid	2	$(001)_2$	Rectangular
4.	First-order prism	4	$(0kl)_4$	Rectangular
5.	Second-order prism	4	$(h0l)_4$	Rectangular
6.	Third-order prism	4	$(hk0)_4$	Rectangular
7.	Rhombic dipyramid	8	$(hkl)_8$	Scalene triangle

(a) Front or a-pinacoid $(100)_2$: It is an open form having two rectangular faces each of which intersects a-crystallographic axis remaining parallel with the other two crystallographic axes (Fig.3.45). The form symbol is $(100)_2$ and two faces are 100 and $\bar{1}00$. Its old name is macropinacoid, as both the faces are parallel with macro- (b) axis. It is also known as front-pinacoid as one of the face remains in front of the crystal.

(b) Side or b-pinacoid $(010)_2$: It is an open form having two rectangular faces each of which intersects b-crystallographic axis remaining parallel with the other two crystallographic axes (Fig.3.45). The form symbol is $(010)_2$ and two faces are 010 and $0\bar{1}0$. Its old name is brachypinacoid, as both the faces are parallel with brachy- (a) axis. It is also known as side-pinacoid as both the faces remain to the side of the crystal.

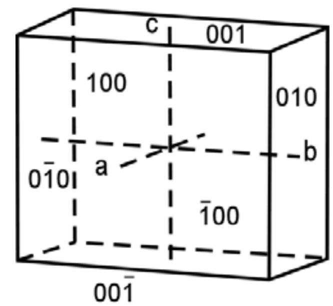


Fig.3.45: Combination of a-, b- and c-pinacoids of orthorhombic system

(c) Basal or c-pinacoid $(001)_2$: It is an open form having two rectangular faces each of which intersects c-crystallographic axis remaining parallel with the other two crystallographic axes (Fig.3.45). The form symbol is $(001)_2$ and two faces are 001 and $00\bar{1}$. It is also known as basal pinacoid as one of the face forms base of the crystal.

(d) First-order prism $(0kl)_4$: It is an open form having four rectangular faces each of which remains parallel with a-crystallographic axis and intersects b- and c-crystallographic axes at unequal lengths. The form symbol is $(0kl)_4$ and the unit form symbol is $(011)_4$. The first order prism is shown in Fig.3.46. Its old name is brachydome, as all the four faces are parallel with brachy (a) axis.

(e) Second-order prism $(h0l)_4$: It is an open form having four rectangular faces each of which remains parallel with b-crystallographic axis and intersects a- and c-crystallographic axes at unequal lengths. The form symbol is $(h0l)_4$ and unit form symbol is $(101)_4$. The second order prism is shown in Fig.3.47. Its old name is macrodome because all the four faces are parallel with macro (b) axis.

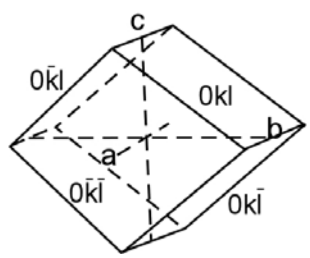


Fig.3.46: Combination of a-pinacoid and first order prism of orthorhombic system

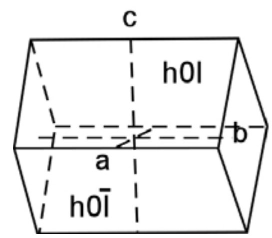


Fig.3.47: Combination of b-pinacoid and second order prism of orthorhombic system

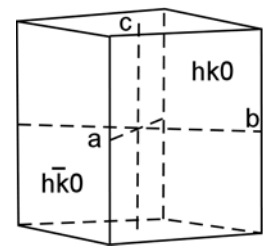


Fig.3.48: Combination of c-pinacoid and third order prism of orthorhombic system

(f) Third-order prism $(hk0)_4$: It is an open form having four rectangular faces each of which remains parallel with c-crystallographic axis and intersects a- and b-crystallographic axes at unequal lengths. The form symbol is $(hk0)_4$. The third order prism is shown in Fig.3.48.

(g) Rhombic dipyramid $(hkl)_8$: It is a solid bounded by eight scalene triangular faces each of which intersects all the three crystallographic axes at unequal lengths. The form symbol is $(hkl)_8$. The rhombic dipyramid is shown in Fig.3.49.

Various forms of the normal class of orthorhombic system also occur in combinations with each other. Combination forms of basal pinacoid, first- and second-order prisms; a-pinacoid, b-pinacoid, first-order prism and second-order prism as well as basal pinacoid, first-, second- and third-order prisms are shown in Figs.3.50, 3.51 and 3.52 respectively.

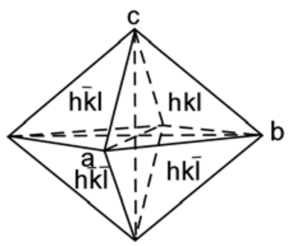


Fig.3.49: Rhombic dipyramid of orthorhombic system

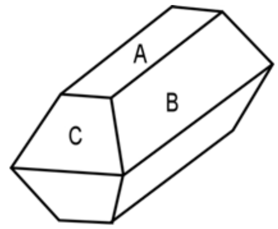


Fig.3.50: Combination of basal pinacoid (A), first- (B) and second-order (C) prisms of orthorhombic system

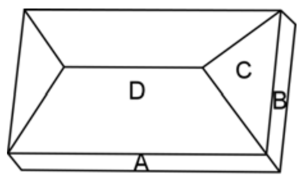


Fig.3.51: Combination of a-pinacoid (A), b-pinacoid (B), first- (C) and second-order (D) prisms of orthorhombic system

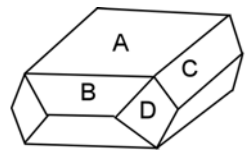


Fig.3.52: Combination of basal pinacoid (A), first- (B), second- (C) and third-order (D) prisms of orthorhombic system

Minerals crystallizing in this class are aragonite, andalusite, anglesite, anhydrite, anthophyllite, aragonite, barite, brookite, celestite, cerussite chrysoberyl, columbite, cordierite, enstatite, goethite, lawsonite, marcasite, olivine, sillimanite, stibnite, sulphur, topaz etc.

3.8.5. Normal class of monoclinic system (Hermann-Mauguin symbol: 2/m)

(i) Axial relationship: Crystals belonging to monoclinic system are referred to three axes of unequal length which are designated as a, b and c as in case of orthorhombic system. However, the a-axis is inclined to the plane containing the b and c axes. The a and b axes as well as b and c axes are perpendicular (i.e. $\alpha = \gamma = 90^\circ$), where as a and c axes are inclined to each other (i.e. $\beta \neq 90^\circ$). In proper orientation b and c-axes are perpendicular to each other, c is vertical, positive at top and negative at bottom while b axis runs from right to left, positive on the right hand side and negative on the left hand side. The a crystallographic axis is inclined to the vertical plane containing b and c axes and slopes down towards the observer (Fig.3.53). Formerly the a-axis was called the clino- (inclined) axis and the b-axis the ortho- (perpendicular) axis. In case of gypsum, a:b:c = 0.372:1:0.412, β = 113° 50′ and in case of orthoclase a:b:c = 0.658:1:0.553, β = 116° 01′.

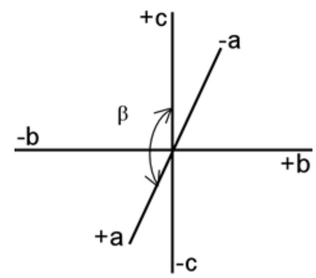


Fig.3.53: Crystallographic axes of monoclinic system

Three classes are grouped under this system. These are prismatic (2/m), domatic (m) and sphenoidal (2). The *prismatic class* (*2/m*) is known as the *normal class of monoclinic system* as it shows maximum symmetry among all the classes belonging to this system and *gypsum type* after the characteristic mineral gypsum that crystallizes in this class.

(ii) Symmetry elements: The b-crystallographic axis is the only axis of 2-fold symmetry, a-c axial plane is the only plane of symmetry and centre of symmetry is present.

(iii) Forms: Pinacoids and prisms are the characteristic forms of this class. These are given in Table 3.5.

(a) Front or a-pinacoid $(100)_2$: It is an open form having two faces each of which intersects a-crystallographic axis remaining parallel with the other two crystallographic axes. The form symbol is $(100)_2$ and two faces are 100 and $\bar{1}00$ (Fig.3.54). Its old name is orthopinacoid, as the faces are parallel with ortho- (b) axis.

Table 3.5: Forms of normal class of monoclinic system

Sl. No.	Name of the form	Number of faces	Form symbol	Shape of faces in simple form
1.	Front or a-pinacoid	2	$(100)_2$	Rectangular
2.	Side or b-pinacoid	2	$(010)_2$	Rectangular
3.	Basal or c-pinacoid	2	$(001)_2$	Rectangular
4.	Second-order pinacoid	2	$(h0l)_2$ and $(\bar{h}0l)_2$	Rectangular
5.	First-order prism	4	$(0kl)_4$	Rectangular
6.	Third-order prism	4	$(hk0)_4$	Rectangular
7.	Fourth-order prism	4	$(hkl)_4$ and $(\bar{h}kl)_4$	Rectangular

(b) Side or b-pinacoid $(010)_2$: It is an open form having two faces each of which intersects b-crystallographic axis remaining parallel with the other two crystallographic axes. The form symbol is $(010)_2$ and two faces are 010 and $0\bar{1}0$ (Fig.3.54). Its old name is clinopinacoid, as the faces are parallel with clino- (a) axis.

(c) Basal or c-pinacoid $(001)_2$: It is an open form having two faces each of which intersects c-crystallographic axis remaining parallel with other two crystallographic axes (Fig.3.54). The form symbol is $(001)_2$ and two faces are 001 and $00\bar{1}$.

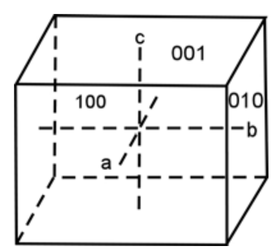


Fig.3.54: Combination of a-, b- and c-pinacoids of monoclinic system

(d) Second-order pinacoid: Since the opposite ends of the a-crystallographic axis are not interchangeable the second-order prism does not exist. Instead, two similar faces remain in the obtuse angle side of the a-c intersection, which intersect the a- and c-crystallographic axes at unequal lengths. The symbols of these two faces are h0l, and $\bar{h}0\bar{l}$. The form symbol is $(h0l)_2$. It is designated as positive second-order pinacoid. Similarly, in the acute angle side of the a-c intersection, two similar faces ($\bar{h}0l, h0\bar{l}$) occur with the form symbol $(\bar{h}0l)_2$, which constitute the negative second-order pinacoid. These two forms are independent of each other, and the presence of one does not necessitate the presence of another. The combination form of second-order pinacoids and b-pinacoid is shown in Fig.3.55. The old name of second-order pinacoid is hemiorthodome, as the faces are parallel with ortho- (b) axis and possess half of the number of faces of a dome.

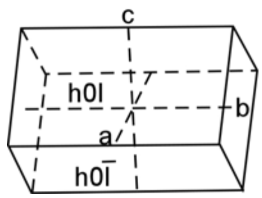


Fig.3.55: Combination of b- and second order pinacoids of monoclinic system

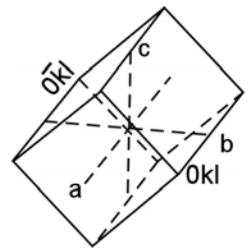


Fig.3.56: Combination of a-pinacoid and first order prism of monoclinic system

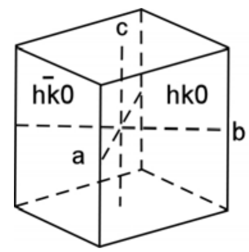


Fig.3.57: Combination of c-pinacoid and third order prism of monoclinic system

(e) First-order prism $(0kl)_4$: It is an open form having four faces each of which remains parallel with a-crystallographic axis and intersects b- and c-crystallographic axes at unequal lengths. The form symbol is $(0kl)_4$. The first-order prism with a-pinacoid is shown in Fig.3.56. Its old name is clinodome, as the faces are parallel with clino- (a) axis.

(f) Third-order prism $(hk0)_4$: It is an open form having four faces each of which remains parallel with c-crystallographic axis and intersects a- and b-crystallographic axes at unequal lengths. The form symbol is $(hk0)_4$. The third-order prism in combination with basal pinacoid is shown in Fig.3.57.

(g) Fourth-order prism: It is an open form having four faces each of which intersects all three crystallographic axes at different lengths. There are two independent forms designated as positive with form symbol $(hkl)_4$ and negative with form symbol $(\bar{h}kl)_4$. These prisms in association of other forms are shown in Fig.3.58.

All the forms of the normal class of monoclinic system are open forms. So they generally occur in combinations with each other (Figs.3.55 – 3.58).

Many minerals crystallize in this class. Some common minerals are azurite, chlorite, diopside, epidote, gypsum, kaolinite, malachite, monazite, muscovite, orpiment, orthoclase, realgar, sphene, talc, tremolite, wolframite etc.

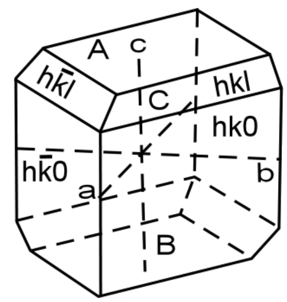


Fig.3.58: Combination of c-pinacoid, third order prism and positive fourth order prism of monoclinic system

3.8.6. Normal class of triclinic system (Hermann-Mauguin symbol: $\bar{1}$)

(i) Axial relationship: In case of triclinic system all the crystallographic axes are unequal in length and inclined to each other i.e. a ≠ b ≠ c and α ≠ β ≠ γ ≠ 90°. The axial ratio (a:b:c) in case of axinite is 0.972:1:0.778; α = 102°41′, β = 98° 09′ and γ = 88° 08′. Three rules are followed in determining the position of the crystallographic axes and orienting a triclinic crystal. These are (i) c-axis is the zone axis and the most pronounced zone is vertical. (ii) the face intersecting the a-axis in positive side should slope forward to the right and (iii) a- and b-axis directions are

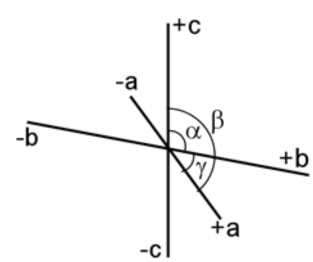


Fig.3.59: Crystallographic axes of triclinic system

determined by the intersections of the faces 010 and 100 with 001 respectively. In old convention, a and b axes were designated as brachy- and macro-axes respectively. The proper orientation of the crystallographic axes and the method of their notation are shown in Fig.3.59.

Two classes viz. pinacoidal ($\bar{1}$) and pedial (1) belong to this system. The *pinacoidal class* ($\bar{1}$) is known as the *normal class of triclinic system* as it shows maximum symmetry among all the classes belonging to this system and *axinite type* after the characteristic mineral axinite that crystallizes in this class.

(ii) Symmetry elements: Centre of symmetry is the only symmetry element of this class. Axis and plane of symmetry are absent.

(iii) Forms: Pinacoids are the characteristic forms of this class. These are given in Table 3.6.

Table 3.6: Forms of normal class of triclinic system

Sl. No.	Name of the form	Number of faces	Form symbol	Shape of faces in simple form
1.	Front or a-pinacoid	2	$(100)_2$	Rectangular
2.	Side or b-pinacoid	2	$(010)_2$	Rectangular
3.	Basal or c-pinacoid	2	$(001)_2$	Rectangular
4.	First-order pinacoid	2	$(0kl)_2$ and $(0\bar{k}l)_2$	Rectangular
5.	Second-order pinacoid	2	$(h0l)_2$ and $(\bar{h}0l)_2$	Rectangular
6.	Third-order pinacoid	2	$(hk0)_4$ and $(h\bar{k}0)_2$	Rectangular
7.	Fourth-order pinacoid	2	$(hkl)_2$, $(h\bar{k}l)_2$, $(\bar{h}kl)_2$ and $(\bar{h}\bar{k}l)_2$	Rectangular

(a) Front or a-pinacoid $(100)_2$: It is an open form having two faces each of which intersects a-crystallographic axis remaining parallel with other two crystallographic axes. The form symbol is $(100)_2$ and two faces are 100 and $\bar{1}00$

(Fig.3.60). Its old name is macropinacoid as the faces are parallel with macro (b) axis.

(b) Side or b-pinacoid $(010)_2$: It is an open form having two faces each of which intersects b-crystallographic axis remaining parallel with other two crystallographic axes. The form symbol is $(010)_2$ and two faces are 010 and $0\bar{1}0$ (Fig.3.60). Since the faces are parallel with brachy (a) axis it is also known as brachypinacoid.

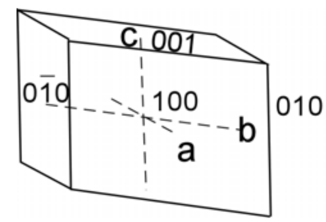


Fig.3.60: Combination of a-, b- and c-pinacoids of triclinic system

(c) Basal or c-pinacoid $(001)_2$: It is an open form having two faces each of which intersects c-crystallographic axis remaining parallel with other two crystallographic axes. The form symbol is $(001)_2$ and two faces are 001 and $00\bar{1}$ (Fig.3.60).

(d) First-order pinacoid: It is an open form consisting of two faces each of which intersects b- and c-crystallographic axes at unequal lengths remaining parallel with a-crystallographic axis. There are two first-order pinacoids, positive with form symbol $(0kl)_2$ and negative with form symbol $(0\bar{k}l)_2$. The first-order pinacoids are shown in Fig.3.61. Its old name is hemibrachydome as the two faces are parallel with brachy- (a) axis.

(e) Second-order pinacoid: It is an open form consisting of two faces each of which intersects a- and c-crystallographic axes at unequal lengths remaining parallel with b-crystallographic axis. There are two second-order pinacoids, positive with form symbol $(h0l)_2$ and negative with form symbol $(\bar{h}0l)_2$. The second-order pinacoids are shown in Fig.3.62. The old name is hemimacrodome as the two faces are parallel with macro- (a) axis.

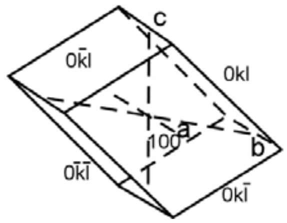


Fig.3.61: Combination of a-pinacoid and first order pinacoid of triclinic system

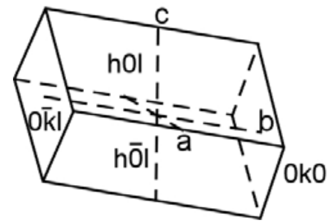


Fig.3.62: Combination of b- and second order pinacoids of triclinic system

(f) Third-order pinacoid: It is an open form consisting of two faces each of which intersects a- and b-crystallographic axes at unequal lengths remaining parallel with c-crystallographic axis. There are two first-order pinacoids, positive with form symbol $(hk0)_2$ and negative with form symbol $(h\bar{k}0)_2$. The third-order pinacoids are shown in Fig.3.63.

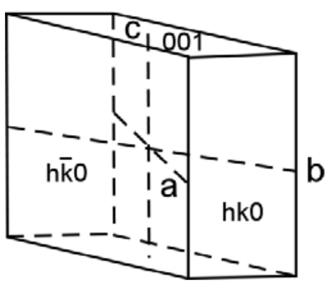


Fig.3.63: Combination of c- and third order pinacoid of triclinic system

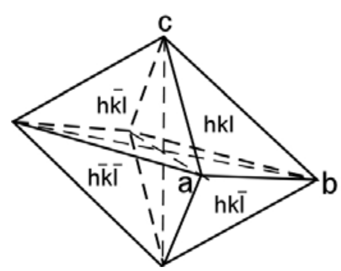


Fig.3.64: Fourth order pinacoids of triclinic system

(g) Fourth-order pinacoid: It is an open form consisting of two faces each of which intersects all the three crystallographic axes at unequal lengths. There are four fourth-order pinacoids, positive right $(hkl)_2$, positive left $(h\bar{k}l)_2$, negative right $(\bar{h}kl)_2$ and negative left $(\bar{h}\bar{k}l)_2$. These two-faced forms can exist independent of each other. The combination of fourth-order pinacoids is shown in Fig.3.64.

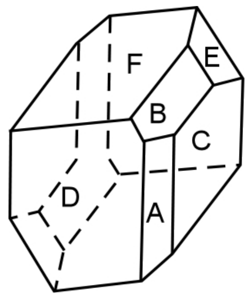


Fig.3.65: Combination of a-pinacoid (A), positive second-order pinacoid (B), positive (C) and negative (D) third-order pinacoids and fourth order positive right (E) and left (F) pinacoids of triclinic system.

All the forms of the normal class of triclinic system are open forms. So they cannot occur independently. The combination form of a-, second-, third- and fourth-order pinacoids is shown in Fig.3.65. Axinite, amblygonite, kaolinite, kyanite, microcline, pectolite, plagioclase feldspars, polyhalite, rhodonite, turquoise, ulexite and wollastonite are some of the important minerals crystallizing in this class.

3.9. SAMPLE QUESTIONS (CRYSTALLOGRAPHY)

.3.9.1. Long answer type questions

(i) Describe the axial relationship, symmetry elements and forms present in the normal class of isometric system. Name five minerals crystallizing in this class.

(ii) Describe the axial relationship, symmetry elements and forms present in the normal class of tetragonal system. Name five minerals crystallizing in this class.

(iii) Describe the axial relationship, symmetry elements and forms present in the normal class of hexagonal system. Name five minerals crystallizing in this class.

(iv) Describe the axial relationship, symmetry elements and forms present in the normal class of orthorhombic. Name five minerals crystallizing in this class.

(v) Describe the axial relationship, symmetry elements and forms present in the normal class of monoclinic system. Name five minerals crystallizing in this class.

(vi) Describe the axial relationship, symmetry elements and forms present in the normal class of triclinic system. Name five minerals crystallizing in this class.

3.9.2. Write short notes in 3 – 5 sentences

(i) Crystal
(ii) Axis of symmetry
(iii) Plane of symmetry
(iv) Centre of symmetry
(v) Edge of crystal
(vi) Solid angle of crystal
(vii) Intercepts
(viii) Octahedron
(ix) Dodecahedron
(x) Pinacoid of second order
(xi) Interfacial angle
(xii) Zone
(xiii) Law of rational indices
(xiv) Law of constancy of symmetry

3.9.3. Answer in one sentences

(i) Define crystallography
(ii) Define a crystal
(iii) What is microcrystalline substance?
(iv) Prism
(v) Pinacoid
(vi) Hexahedron

3.9.4. Distinguish between the following pairs

(i) Crystalline and amorphous substances
(ii) Crystallized and crystalline substances
(iii) Like and unlike faces
(iv) Simple form and combination form
(v) Closed form and open form
(vi) Holohedral form and hemihedral form
(vii) Hemimorphic form and tetartoidal form

(viii) Index and parameter

(ix) Prism and pinacoid

(x) $(001)_6$ and $(001)_2$

3.9.5. Fill in the blanks with appropriate word/ words

(i) The term crystal has been derived from Greek word __________ .

(ii) Generally common salt is prepared from ______________.

(iii) Big crystals are formed if the rate of cooling is ______________ .

(iv) Total number of plane of symmetry in normal class of monoclinic system is ___ .

(v) __________ is the general symbol of tetrahexahedron.

(vi) Enantiomorphic forms are mirror images of each other but ____________ .

(vii) The angle between two successive similar positions of crystal in space is known as _______

(viii) The rotoinversion axes involve ___________ followed by ____________ .

(ix) $\bar{3}$ is equivalent to a ___________ plus ______________________ .

(x) $\bar{6}$ is equivalent to a ________________ .

(xi) A cube has ____________ planes of symmetry

(xii) The ratio of lengths of crystallographic axes is known as ____________.

(xiii) The angles between c- and a-axes is designated by ___________ .

(xiv) Parameters are ______________ of the intercepts

(xv) The class having maximum symmetry is ________________ .

Answers

(i)	Krustallos	(vi)	Superposable	(xi)	9
(ii)	Seawater	(vii)	Elementary angle of rotation	(xii)	Axial ratio
(iii)	Slow	(viii)	Rotation, inversion	(xiii)	β

(iv)	1	(ix)	3 plus i	(xiv)	Ratios
(v)	$(0kl)_{24}$	(x)	3/m	(xv)	Hexhedral

3.9.6. Choose the correct answer

(i) The branch of Geology dealing with the study of crystals is:

(a) Crystallography (c) Mineralogy

(b) Petrology (d) Stratigraphy

(ii) The district of Odisha in which maximum amount of common salt is prepared is:

(a) Keonjhar (c) Koraput

(b) Ganjam (d) Cuttack

(iii) The general symbol of dodecahedron is:

(a) $(hkl)_{24}$ (c) $(100)_6$

(b) $(011)_{12}$ (d) $(hkl)_8$

(iv) The total number of planes of symmetry in the normal class of isometric system is:

(a) 7 (c) 9

(b) 8 (d) 10

(v) The number of planes of symmetry of sphere is:

(a) 1 (c) 100

(b) 2 (d) $\propto$

(vi) The number of crystallographic axes of hexagonal system is:

(a) 1 (c) 3

(b) 2 (d) 4

(vii) In the monoclinic system the amount of β is:

(a) 90° (c) Less than 90°

(b) More than 90° (d) 180°

(viii) The axes of isometric system are designated by alphabet:

(a) a

(b) b

(c) c

(d) i

(ix) The form symbol of octahedron is:

(a) $(001)_2$

(b) $(111)_8$

(c) $(010)_{12}$

(d) $(111)_{16}$

(x) The crystallographic name of cube is:

(a) Hexahedron

(b) Parallelepiped

(c) Pyramid

(d) Hexoctahedron

(xi) If the symbols of a pair of tautozonal faces are 120 and 100, the zone symbol is:

(a) $[0\bar{1}0]$

(b) $[00\bar{2}]$

(c) $[10\bar{1}]$

(d) $[\bar{1}10]$

(xii) The symbols of a pair of intersecting zones are [010] and [101]. The symbol of the face at intersection is:

(a) $10\bar{1}$

(b) 100

(c) $10\bar{1}$

(d) 111

Answers

(i)	Crystallography	(v)	$\propto$	(ix)	$(111)_8$
(ii)	Ganjam	(vi)	4	(x)	Hexahedron
(iii)	$(011)_{12}$	(vii)	More than 90°	(xi)	$[00\bar{2}]$
(iv)	9	(viii)	a	(xii)	$10\bar{1}$

****

CHAPTER – 4

MINERALOGY

The branch of science dealing with the study of minerals is known as mineralogy.

4.1. DEFINITION OF MINERAL

Mineral is a naturally occurring homogeneous substance with a definite (sometimes variable within certain limits) chemical composition and is commonly characterised by the presence of a typical internal atomic structure with or without the development of external crystalline form. These are usually formed by the inorganic natural processes.

For example, quartz, the common mineral of the earth crust, is generally formed by consolidation of magma and has a fixed chemical composition (SiO_2). It is characterized by its own internal atomic structure, which is expressed by development of hexagonal/trigonal crystalline form. Thus, it is a mineral. For similar reasons, corundum, haematite, magnetite, chromite, bauxite, graphite, calcite, magnesite, orthoclase, microcline, plagioclases, biotite, muscovite, olivine, topaz, talc, granet, beryl, hornblende, augite, sillimanite, kyanite pyrite, chalcopyrite, gypsum, apatite, fluorite etc. are all minerals.

4.2. PHYSICAL PROPERTIES OF MINERALS

Each mineral has its own set of physical properties by which it can be identified and distinguished from other minerals. These are form, colour, lustre, streak, hardness, cleavage, fracture, specific gravity including special properties like taste, order, feel, tenacity, diaphaneity as well as electrical, magnetic, radioactive properties and reaction with acids.

4.2.1 Form

Mineral with a definite internal atomic structure without the development of well-defined faces is said to be *crystalline*. Under favourable physico-chemical conditions, the outer form with well developed crystal faces develops. In this case the mineral is said to be *crystallised*. Rock crystal, garnet, staurolite etc. frequently show crystallized forms. A mineral is said to be *cryptocrystalline* when the degree of crystallization is noticeable under high power microscope. The term *amorphous* is used to describe complete lack of crystallinity. When the mineral lacks the outer geometric form, the term *massive* is used. Depending on the development of outward form and structure, certain terms are used, which have their usual meaning. These terms are explained in Table 4.1.

Table 4.1. Forms of minerals

Sl. No.	Terminology	Description	Example
(i)	Acicular	: Fine needle like crystals	: Sillimanite
(ii)	Amygdaloidal	: Almond shaped	: Zeolites
(iii)	Bladed	: Lath shaped	: Kyanite
(iv)	Botryoidal	: Resembling a bunch of grapes	: Psilomelane
(v)	Capillary	: Exhibiting a fine hair like form	: Pyrite
(vi)	Columnar	: Form of slender column	: Beryl
(vii)	Colloform	: Combination of botryoidal, globular, mamillary and reniform	: Limonite
(viii)	Concentric	: Onion shaped banding	: Hematite
(ix)	Concretionary	: Spherical or ellipsoidal or tuberose forms on the surface	: Goethite
(x)	Dendritic	: Branching tree or moss like form	: Copper

(xi)	Equidimensional	:	Equally developed in all directions	:	Garnet
(xii)	Fibrous	:	Consisting of fine thread like strands	:	Asbestos
(xiii)	Foliaceous/flaky	:	Thin lamellae or leaves	:	Micas
(xiv)	Granular	:	Coarse or fine grain like	:	Marble
(xv)	Lamellar	:	Separable plates or leaves like	:	Gypsum
(xvi)	Lenticular	:	Flattened ball or pellet like	:	Azurite
(xvii)	Mammillary	:	Large mutually interfering spheroidal surfaces	:	Malachite
(xviii)	Massive	:	Compact aggregate without form	:	Kaolin
(xix)	Oolitic	:	Aggregation of small spheres	:	Hematite
(xx)	Pisolitic	:	Aggregation of small rounded masses	:	Bauxite
(xxi)	Radiating	:	Crystals or fibers arranged around a central point	:	Stibnite
(xxii)	Reniform	:	Kidney shaped	:	Hematite
(xxiii)	Reticulate	:	Form of cross meshes like a net	:	Rutile
(xxiv)	Scaly	:	Small plate like	:	Tridymite
(xxv)	Stalactitic	:	Cylindrical or conical form	:	Calcite
(xxvi)	Stellate	:	Fibers radiating from a center to give rise to star-like forms	:	Wavellite
(xxvii)	Tabular	:	Like broad flat surface	:	Wollastonite
(xxviii)	Tuberose	:	Irregular rounded surfaces	:	Aragonite
(xxix)	Wiry (filiform)	:	Resembling thin wires twisted like the strands of a rope	:	Silver

4. 2.2. Colour

Colour is a physical property that attracts the first attention. The colour of a mineral is determined by looking at a fresh surface in reflected light. It depends on the combined effect of its composition, internal atomic structure and nature of impurities present. These characters affect the colour absorption and reflection properties of a mineral. A mineral is blue when it absorbs all the colours of the visible spectrum except blue. Black colour is due to absorption of all the colours while white colour is indicative of lack of absorption. Many minerals are identified by their characteristic colours. The colour of a mineral may differ from its true colour by certain extent due to the presence of impurities, play of colours caused by thin coating on the surface and by inconsistent reflection and refraction of light caused by stained surfaces and cleavage cracks. A mineral is said to be colourless, when it is clear and transparent as in case of rock crystal, a variety of quartz. In some instances a mineral shows different colours. The mineral quartz, which is an oxide of silica, is commonly colourless or white, but it is also found in pink, green, brown and even in black colours. The corundum, which is an oxide of aluminium shows pale brown, deep red and dark blue colours. Generally minerals containing Al, Na, K, Ba and Mg as their main elements are colourless or light coloured while those with Fe, Cr, Mn, Co, Ni, Ti, V and Cu are dark coloured. The elements, which control the colour of a mineral, are known as *chromophores*. The colour of a mineral is controlled by the presence of a little amount of these elements. The mineral is called *idiochromatic* or self-colouring when the elements controlling the selective reflection of certain wavelengths are major constituents of the mineral. Sphalerite is an example of idiochromatic mineral. Its colour changes from white - yellow - brown - black as its composition changes from pure ZnS to a mixture of ZnS and FeS. Ruby and sapphire are examples of *allochromatic* varieties of corundum. Ruby is deep red due to the presence of small amount of Cr where as Fe and Ti give sapphire deep blue colour. Presence of minor quantity of Cr imparts green colour to emerald (a variety of beryl). Structural defect is also responsible for variable colour of certain minerals. Purple, smoky and black colours of quartz are due to damage of the crystal structure by radiation to different extents. Oxidation or reduction of certain element like iron and the presence of minute inclusions of other minerals also control the colour of minerals to certain extent. The diagnostic colours of some of the minerals are given in Table 4.2.

Table 4.2. Diagnostic colours of some minerals

Mineral	Diagnostic colour	Mineral	Diagnostic colour
Azurite	Deep blue	Malachite	Green
Biotite	Brown	Orthoclase	Flesh (buff) colured
Chalcopyrite	Golden yellow	Pyrite	Brass yellow
Galena	Lead gray	Sulphur	Yellow
Hematite	Steel gray	Tourmaline	Black

When viewed from different angles, some minerals show a series of colours, which is known as *play of colours*. It is shown by diamond and is due to dispersion of white light to its constituent colours. Some varieties of feldspars, when rotated, show a series of colours over broader surfaces. This phenomenon is known as *change of colours*. *Opalescence* is milky appearance exhibited by opal and moonstone (a variety of K-feldspar). *Iridescence* is a display of colours produced due to interference of light rays from minute cracks and fractures. Minerals like quartz, calcite and mica at times show this effect. Some minerals show the iridescent colours due to the effect of stain on their surfaces by chemical reaction. Copper pyrites (peacock ore) is a good example showing this effect.

4.2.3. Lustre

Lustre can be defined as the nature and amount of shine offered by a mineral due to reflection of light on its clean surface. There are three main varieties of lustre viz. metallic, sub-metallic and nonmetallic (Table 4.3).

Table 4.3. Lustres of minerals

Sl. No.	Lustre		Description/ Example
(i)	Metallic	:	A mineral having a brilliant appearance of a metal is said to have metallic lustre. Such minerals are opaque to light. Galena, chalcopyrite, hematite are common minerals showing metallic lustre.
Sl. No.	Lustre		Description/ Example
(ii)	Sub-metallic	:	The imperfect metallic lustre is known as sub-metallic lustre. Chromite, psilomelane, wolframite etc. show sub-metallic lustre.
(iii)	Non-metallic	:	Minerals with non-metallic lustre are generally light coloured and transmit light through thin edges. The following terms are used to describe the lustre of nonmetallic minerals.
(a)	Adamantine	:	It is the brilliant lustre shown by minerals of high refractive index. Examples are diamond, cerussite, sphalerite, anglesite etc.
(b)	Vitreous	:	The lustre of broken glass, e.g. quartz, tourmaline etc.

(c)	Sub-vitreous	:	Imperfect vitreous lustre is termed as sub-vitreous, e.g. lustre of feldspar, calcite etc.
(d)	Pearly	:	The lustre of pearl, e.g. talc, muscovite etc.
(e)	Resinous	:	The lustre of resin, e.g. sphalerite etc.
(f)	Greasy	:	The lustre of oily glass, e.g. nepheline, opal etc.
(g)	Silky	:	The lustre of silk, e.g. gypsum, asbestos etc.
(h)	Earthy	:	The lustre of clay, e.g. kaolinite
(i)	Dull	:	When no lustre is discernible, it is described as dull, e.g. kaoline
(j)	Splendent	:	The surface of the mineral is sufficiently brilliant to reflect objects distinctly like those from a mirror e.g. Galena.
(k)	Shining	:	When the surface is less brilliant and objects are reflected indistinctly, the lustre is said to be as shining e.g. pyrite, hematite etc.
(l)	Glistening	:	When the mineral surface is less brilliant and is incapable of giving any image
(m)	Glimmering	:	Lustre feebler than glistening.

4. 2.4. Streak

The colour of the powder of a mineral is known as its streak. It may be completely different from the colour of the mineral. It is considered as a very important factor in mineral identification. The streak of a mineral is obtained by rubbing the mineral on a white unglazed porcelain plate known as *streak plate*. The hardness of the streak plate is about 6.5; as such it can be used for minerals having hardness less than 6.5. When a mineral of hardness equal to or greater than 7 is rubbed against the streak plate, white colour of the streak plate is produced with a scar on the plate surface. This is to be taken into consideration while determining the streak. In such cases, the streak is determined by observing the colour of the mineral powder obtained by crushing the mineral against white background. The streak of some minerals is given in Table 4.4.

Table 4.4. Characteristic streak of a few minerals

Mineral	Colour	Streak	Mineral	Colour	Streak
Arsenopyrite	White	Black	Orthoclase	Flesh colured	White
Chalcopyrite	Golden yellow	Greenish black	Pyrite	Brass yellow	Brownish black
Covelite	Indigo blue	Black	Realgar	Red	Orange yellow
Hematite	Steel gray	Cherry red	Rutile	Dark brown	Colourless

4.2.5. Hardness

The hardness is a significant property for identification of minerals in hand specimens. It is a measure of the resistance to scratch. Normally the hardness of a mineral is compared with the minerals of a standard scale known as Mohs scale of hardness, which is given in Table 4.5.

Table 4.5. Mohs scale of hardness

Hardness	Standard mineral	Hardness	Standard mineral
1	Talc	6	Orthoclase
2	Gypsum	7	Quartz
3	Calcite	8	Topaz
4	Fluorite	9	Corundum
5	Apatite	10	Diamond

The hardness test is made by scratching the mineral under examination with the standard minerals given in the Mohs scale of hardness. For example, if the mineral whose hardness is to be determined scratches orthoclase, then its hardness is greater than 6 but if it is scratched by quartz, then its hardness is less than 7. In such case it may be presumed that the hardness of the mineral under examination is about 6.5. Hardness may also be tested by means of fingernail, brass plate (copper coin), iron plate, glass plate and streak plate whose hardness values are 2.5, 3.5, 4.5, 5.5 and 6.5 respectively. Some precautions are to be observed while testing the hardness of a mineral. While rubbing against each other a definite scratch must be produced on the softer mineral. The hardness of a mineral is related to its atomic structure. It increases with the density of packing of ions in crystal structure. Since the atomic structure varies in different directions, the hardness values also vary in different directions. Kyanite shows two strikingly different hardness values, 5 along the length of crystal and 7 in the direction perpendicular to the length of crystal. Similarly the hardness of calcite on basal pinacoid is 2 where as on all other faces the hardness is 3.

4.2.6. Cleavage

Many of the crystallized minerals have a tendency to break along certain planes parallel to each other. These planes are called cleavage planes and this property of the mineral is called *cleavage*. This property is related to the internal atomic structure of the mineral. In minerals possessing cleavage, the directions of the cleavage planes are parallel to certain faces. In the plane of cleavage, the constituent atoms are more closely packed together and the binding force is greater in this direction than the direction perpendicular to it. The cleavage plane is a plane of least cohesion, as a result of which, splitting occurs along it. Some minerals like quartz lack cleavage, where as others show several sets of cleavages.

Depending on the degree of their development, the cleavages are described as perfect, good, distinct, poor, indistinct (imperfect) etc. The cleavage planes commonly occur in sets. Minerals like biotite and muscovite show one set of cleavage; feldspars show two sets of perfect cleavages; calcite and galena have three sets of cleavages; fluorite is characterised by four sets of cleavages and sphalerite has six sets of cleavages. Due to the presence of perfect cleavages, the micas separate in form of thin sheets.

4.2.7. Fracture

Fracture is the nature of the broken surface in any direction other than the cleavage plane. It is not related to the crystalline structure of the minerals. Different types of fractures are given in Table 4.6.

Table 4.6. Different types of fractures seen in minerals

Sl. No.	Fracture		Description
(i)	Conchoidal	:	In this case the mineral breaks with a curved concave or convex surface as in case of quartz, opal, flint etc. The term subconchoidal is used to describe less developed conchoidal fracture.
(ii)	Even	:	The fracture surface is flat as in case of chert.
(iii)	Uneven	:	The fracture surface is rough due to minute elevations and depressions as in case of feldspars etc. It is the most common variety of fracture seen in case of majority of the minerals.
(iv)	Hackly	:	The fracture surface is studded with sharp elevations as in case of sillimanite.

4.2.8. Specific gravity

The specific gravity of a mineral is the ratio of the weight of the mineral to that of an equal volume of water. In selecting a mineral for determination of its specific gravity the sample should be pure and free from alteration products and inclusions. The specific gravity of minerals depends on the atomic weight of the constituent elements and the manner in which the atoms are packed in the crystal structure. For example with similar crystal structure celestine ($SrSO_4$), barite ($BaSO_4$) and anglesite ($PbSO_4$) have specific gravity values of 2.9, 4.5 and 6.3 respectively. The influence of the manner of packing on the specific gravity is discernible in case of carbon minerals like graphite and diamond. Graphite with loose packing has specific gravity 2.3 while diamond with close packing has specific gravity of 2.54. Generally the non-metallic minerals have specific gravity of about 2.6 – 2.8 where as the metallic minerals have specific gravity about 5 or more. However, there are some exceptions. The specific gravity of the minerals can be accurately determined by chemical balance, Walker's steelyard balance, Jolly's spring balance, pycnometer or specific gravity bottle and by heavy liquids. The specific gravity of a mineral can also be expressed in a relative sense by using words like low, moderately low, high and very high with specific gravity values of less than 2.5, 2.5 – 3.5, 3.5 – 7 and more than 7 respectively.

4.2.9. Special properties

Special properties of the minerals are taste, odour, feel, tenacity, diaphaneity and properties based on magnetism, electricity, radioactivity and acid reaction.

(i) Taste: The water-soluble minerals have some characteristic tastes. The tastes given in Table 4.7 are noteworthy.

(ii) Odour: Some minerals have characteristic odour that comes out when the mineral is blown with mouth, rubbed or heated. These are given in Table 4.8.

(iii) Feel: Some minerals have characteristic feel as given in Table 4.9.

Table 4.7. Taste of certain minerals and substances

Taste		Substance	Taste		Substance
Saline	:	Halite, Common salt	Alkaline	:	Potash and soda salts
Cooling	:	Potassium chlorate, Nitre	Astringent	:	Green vitriol
Sweet astringent	:	Alum	Bitter	:	Epsom salt, sylvite

Table 4.8. Odour of certain minerals

Odour		Mineral
Earthy	:	Kaolin, bauxite when blown by mouth
Sulphurous	:	Sulphur, pyrites when struck, sulphides when heated
Garlic/ alliaceous	:	Arsenic minerals when heated
Foetid (rotten egg smell)	:	Limestone and some quartz when heated or rubbed

Table 4.9. Characteristic feel of certain minerals

Feel		Mineral	Feel		Mineral
Greasy	:	Graphite	Smooth	:	Galena
Soapy	:	Talc, chlorite	Rough	:	Bauxite

Some minerals like graphite and psilomelane mark the paper and blacken fingers.

(iv) Tenacity: Some minerals have definite properties dependent upon their tenacity. These are given in Table 4.10.

(v) Diaphaneity: Diaphaneity refers to the amount of light transmitted through the minerals. Depending on the amount of light transmitted, the following terms given in Table 4.11 are used.

Table 4.10. Tenacity property of certain minerals

Property		Mineral
Sectile	:	The mineral can be cut by a knife; e.g. graphite, gypsum, steatite
Malleable	:	The mineral flattens under hammer; e.g. native gold, silver and copper
Flexible	:	The mineral can be bent; e.g. talc, selenite
Elastic	:	The mineral restores its original position after bent; e.g. mica flakes
Brittle	:	The mineral when struck yields powder in stead of slice

Table 4.11. Degree of diaphaneity of minerals

Term		Description
Transparent	:	In this case the outline of an object is clearly seen through the mineral as in case of rock crystal.
Subtransparent/ Semitransparent	:	The objects are seen but the outlines are not distinct.
Translucent	:	Light is transmitted through the mineral but objects are not seen

Subtranslucent	:	Light is transmitted through the thin edges of the mineral and the objects are not seen
Opaque	:	No light is transmitted, even on the thin edges of small splinters.

(vi) Magnetism: On the basis of magnetic strength the minerals can be grouped under four groups as given in Table 4.12. The degree of magnetism is determined by an electro-magnet of variable magnetic intensity.

Table 4.12. Magnetic property of certain minerals

Degree of magnetism		Mineral
Highly magnetic	:	Magnetite, pyrrhotite
Moderately magnetic	:	Siderite, chromite, ilmenite, hematite
Weakly magnetic	:	Monazite, spinels, tourmaline
Non-magnetic	:	Quartz, feldspar, calcite and a number of rock-forming minerals

(vii) Electrical properties

Native metals like gold, silver and copper conduct electricity. Graphite, though a non-metal, is a good conductor of electricity. Some minerals like tourmaline develop electric charge in different parts when heated up. Such minerals are known as pyroelectric. When heated up, the crystal becomes negatively charged at its sharp end and positively charged at its blunt end. When subjected to pressure, some minerals like quartz become electrically charged. This effect is known as piezoelectricity.

(viii) Radioactivity

Minerals containing elements of high atomic weight such as uranium, thorium, radium etc are radioactive. They emit α-, β- and γ-rays in different quantities. Minerals like uraninite and monazite are radioactive minerals.

(ix) Reaction with acids

Some carbonate minerals like calcite, aragonite, galena, sphalerite and dolomite (when finely powdered) react with HCl. Such minerals are readily identified in the laboratory by their reactive property. Some of the minerals like sylvite, halite are soluble in HNO_3. A few other minerals are also soluble in H_2SO_4 or HF.

4.3. CLASSIFICATION OF MINERALS

The minerals have been classified into different divisions, classes and groups on the basis of chemical composition and crystal structure. All the naturally formed minerals are divided into two big and independent groups. These are:

(i) Inorganic minerals which include all the natural compounds including native elements except organic compounds.

(ii) Organic minerals comprising diverse compounds of carbon excluding carbonates and carbides.

The inorganic minerals are divided into divisions on the basis of their chemistry and bonding between their structural units. Naturally occurring native elements, especially metals with metallic bonds between their atoms are given a special position. Intermetallic compounds are included within this group. Organic compounds differ from inorganic compounds in chemical properties, crystal structure and type of bonding between their structural units. Previously, the naturally occurring substances like peat, lignite, coal, resin and petroleum were regarded as independent minerals. Recent investigations have established that these substances are heterogeneous mixtures of a number of organic minerals.

From economic view point, the minerals are classified as ore-forming, from which one or more metals can be extracted and rock-forming, which form the rocks constituting the crust of the earth. Hematite, chalcopyrite, galena and sphalerite are ore-forming minerals from which Fe, Cu, Pb and Zn are extracted respectively. Quartz and orthoclase are rock-forming minerals. The rock-forming minerals are further classified into essential and accessory. The essential minerals form bulk of the rock volume and presence or absence of these minerals affects the nomenclature of the rock. The accessory minerals, on the other hand, are present in minor amounts. A rock composed of quartz, potash-feldspar and plagioclase as essential minerals and biotite and amphibole as accessory minerals is named as granite. In the absence of quartz, the rock may be named as syenite if amount of potash-feldspar is more than plagioclase or diorite, if amount of potash-feldspar is less than plagioclase. The rock will remain as granite even if both biotite and amphibole are absent or tourmaline takes their place.

A simplified classification scheme of minerals on the basis of chemical composition is given in Table 4. 13.

Table 4.13. Chemical classification of minerals

Native elements	Gold (Au), Silver (Ag), Platinum (Pt), Copper (Cu), Iron (Fe) etc
Semimetals	Arsenic (As), Bismuth (Bi), Diamond (C), Graphite (C), Sulphur (S)
Sulphides and	Antimonite (Sb_2S_3), Argentite (Ag_2S), Arsenopyrite (FeAsS), Bismuthinite (Bi_2S_3), Bornite (Cu_5FeS_4), Chalcocite (Cu_2S),

sulphosalts	Chalcopyrite ($CuFeS_2$), Cinnabar (HgS), Cobaltite (CoAsS), Covellite (CuS), Cubanite ($CuFe_2S_3$), Enargite (Cu_3AsS_4), Galena (PbS), Greenockite (CdS), Lollingite ($FeAs_2$), Marcasite (FeS_2), Millerite (NiS), Molybdenite (MoS_2), Niccolite (NiAs), Orpiment (As_2S_3), Pentlandite $(Fe,Ni)_9S_8$, Proustite (Ag_3AsS_3), Pyrargyrite (Ag_3SbS_3), Pyrite (FeS_2), Pyrrhotite ($Fe_{1-x}S$), Realgar (AsS), Smaltite ($CoAs_{3-x}$), Sperrylite ($PtAs_2$), Sphalerite (ZnS), Stannite (Cu_2FeSnS_4), Stephanite (Ag_5SbS_4), Wurtzite (ZnS) etc
Fluorides	Cryolite (Na_3AlF_6), Fluorite (CaF_2)
Chlorides	Cerargyrite (AgCl), Halite (NaCl), Sylvite (KCl) etc
Oxides	Anatase (TiO_2), Braunite (Mn_2O_3), Cassiterite (SnO_2), Chromite ($FeCr_2O_4$), Chrysoberyl ($BeAl_2O_4$), Columbite $(Fe,Mn)Nb_2O_6$, Corundum (Al_2O_3), Cristobalite (SiO_2), Cuprite (Cu_2O), Franklinite ($ZnFe_2O_4$), Hausmannite (Mn_3O_4), Hematite (Fe_2O_3), Ice (H_2O), Ilmenite ($FeTiO_3$), Magnetite (Fe_3O_4), Opal ($SiO_2{\cdot}nH_2O$), Perovskite ($CaTiO_3$), Pyrolusite (MnO_2), Quartz (SiO_2), Rutile (TiO_2), Brookite (TiO_2), Spinel ($MgAl_2O_4$), Tenorite (CuO), Trydimite (SiO_2), Uraninite (UO_2), Zincite (ZnO) etc
Hydroxides and hydroxyl-containing oxides	Boehmite (AlOOH), Brucite [$(Mg(OH)_2$], Diaspore ($HAlO_2$), Goethite ($HFeO_2$), Hydrargillite [$Al(OH)_3$], Lepidocrocite (FeOOH), Limonite ($HFeO_2{\cdot}nH_2O$), Manganite [$MnO_2{\cdot}Mn(OH)_2$], Psilomelane ($mMnO{\cdot}MnO_2{\cdot}nH_2O$), Sassolite [$B(OH)_3$] etc
Nitrates	Potassium nitrate (KNO_3), Soda nitre ($NaNO_3$)

Carbonates	Aragonite ($CaCO_3$), Azurite [$2Cu(CO_3)\cdot Cu(OH)_2$], Calcite ($CaCO_3$), Cerussite ($PbCO_3$), Dolomite [$CaMg(CO_3)_2$], Magnesite ($MgCO_3$), Malachite [$CuCO_3\cdot Cu(OH)_2$], Rhodochrosite ($MnCO_3$), Siderite ($FeCO_3$), Smithsonite ($ZnCO_3$), Strontianite ($SrCO_3$), Witherite ($BaCO_3$) etc
Sulphates	Barite ($BaSO_4$), Celestite ($SrSO_4$), Anglesite ($PbSO_4$), Anhydrite ($CaSO_4$), Gypsum [$CaSO_4\cdot 2H_2O$] etc
Chromates	Crocoite ($PbCrO_4$)
Molybdates	Powellite ($CaMoO_4$), Wulfenite ($PbMoO_4$)
Tungstates	Scheelite ($CaWO_4$), Wolframite $(Mn, Fe)WO_4$
Phosphates	Chlorapatite [$Ca_5(PO_4)_3Cl$], Fluor-apatite [$Ca_5(PO_4)_3F$], Monazite $(Ce,La)PO_4$, Pyromorphite [$Pb_5(PO_4)_3Cl$], Xenotime (YPO_4), Vanadinite [$Pb_5(VO_4)_3Cl$], Vivianite [$Fe_2(PO_4)_2\cdot 8H_2O$]
Arsenates	Annabergite [$Ni_3(AsO_4)_2\cdot 8H_2O$], Erythrite [$Co_3(AsO_4)_2\cdot 8H_2O$], Scorodite [$Fe(AsO_4)\cdot 2H_2O$]
Vanadates	Carnotite [$K(UO_2)_2(VO_4)_2\cdot 3H_2O$], Tyuyamunite [$Ca(UO_2)_2(VO_4)_2\cdot 8H_2O$]
Borates	Ascharite ($MgHBO_3$), Boracite ($Mg_3B_7O_{13}Cl$), Borax ($Na_2B_4O_7\cdot 10H_2O$) etc
Silicates	Actinolite [$Ca_2(Mg,Fe)_5(Si_4O_{11})_2(OH)_2$], Aegirine [$NaFe(Si_2O_6$], Albite ($NaAlSi_3O_8$), Almandite [$Fe_3Al_2(SiO_4)_3$], Andalusite ($Al_2SiO_5$), Andradite [$Ca_3Fe_2(SiO_4)_3$], Anorthite ($CaAl_2Si_2O_8$), Anorthoclase [$(Na,K)AlSi_3O_8$], Augite [$Ca(Mg,Fe,Al)(Si,Al)_2O_6$], Axinite [$Ca_2(Mn,Fe)Al_2BSi_4O_{15}(OH)$], Beryl [$Be_3Al_2(Si_3O_{18})$], Biotite [$K(Mg,Fe)_3(Si_3AlO_{10})(OH,F)_2$], Calamine

	$[Zn_4(Si_2O_7)(OH)_2 \cdot H_2O]$, Cancrinite $[Na_3Ca(AlSiO_4)_3(CO_3,SO_4)]$, Celsian $(BaAl_2Si_2O_8)$, Chloritoid $[FeAl_2(Al_2Si_2O_{10})(OH)_4]$, Chrysocolla $(CuSiO_3 \cdot nH_2O)$, Cordierite $[Al_3(Mg,Fe)_2(Si_5AlO_{18})]$, Diopside $[CaMg(Si_2O_6]$, Enstatite $[Mg_2(Si_2O_6]$, Epidote $[Ca_2(Al,Fe)_3(Si_2O_7)(SiO_4)O(OH)]$, Fayalite (Fe_2SiO_4), Forsterite (Mg_2SiO_4), Grossularite $[Ca_3Al_2(SiO_4)_3]$, Hedenbergite $[CaFe(Si_2O_6]$, Helvite $[(Mn,Fe,Zn)_8(BeSiO_4)_6S_2]$, Heulandite $[(Ca,Na_2)(AlSi_3O_8)_2 \cdot 5H_2O]$, Hornblende $[Ca_2Na(Mg,Fe)_4(Al,Fe)(Si,Al)_4O_{11})_2(OH)_2]$, Hypersthene $[Mg,Fe)_2(Si_2O_6]$, Jadeite $[NaAl(Si_2O_6]$, Kaolinite $[Al_4(Si_4O_{10})(OH)_8]$, Kyanite (Al_2SiO_5), Lazurite $[Na_8(AlSiO_4)_6(SO_4)]$, Leucite $(KAlSi_2O_6)$, Margarite $[CaAl_2(Al_2Si_2O_{10})(OH)_2]$, Marialite $[3(NaAlSi_3O_8) \cdot NaCl]$, Microcline $(KAlSi_3O_8)$, Montmorillonite $[Al_4Si_8O_{20}(OH)_4 \cdot nH_2O]$, Muscovite $[KAl_2(AlSi_3O_{10}(OH)_2]$, Nacrite $[Al_4(Si_4O_{10})(OH)_8]$, Natrolite $[Na_2(Al_2Si_3O_{10}) \cdot 2H_2O]$, Nepheline $(NaAlSiO_4)$, Nontronite $[(Fe,Al)_2(Si_4O_{10})(OH)_2 \cdot nH_2O]$, Olivine $(Mg,Fe)_2SiO_4$, Orthoclase $(KAlSi_3O_8)$, Penninite $[(Mg,Fe)_5Al(AlSi_3O_{10})(OH)_8]$, Phenacite (Be_2SiO_4), Phlogopite $[KMg_3(Si_3AlO_{10})(OH)_2]$, Pyrope $[Mg_3Al_2(SiO_4)_3]$, Pyrophyllite $[Al_2(Si_4O_{10})(OH)_2]$, Rhodonite $[(Mn,Ca)SiO_3]$, Sanidine $(KAlSi_3O_8)$, Serpentine $[Mg_6(Si_4O_{10})(OH)_8]$, Sillimanite (Al_2SiO_5), Sodalite $[Na_8(AlSiO_4)_6Cl_2]$, Spessartite $[Mn_3Al_2(SiO_4)_3]$, Sphene $(CaTiSiO_5)$, Spondumen $[LiAl(Si_2O_6]$, Staurolite $[Fe_2Al_9Si_4O_{23}(OH)]$, Talc $[Mg_3(Si_4O_{10})(OH)_2]$, Thorite $(ThSiO_4)$,

	Topaz [$Al_2(SiO_4)(F,OH)$], Tourmaline [$(Na,Ca)(Mg,Al)_6(B_3Al_3Si_6(O,OH)_{30}$], Tremolite [$Ca_2Mg_5(Si_4O_{11})_2(OH)_2$], Uvarovite [$Ca_3Cr_2(SiO_4)_3$], Vermiculite [$(Mg,Fe^{+2},Fe^{+3})_3(Si,Al)_4O_{10}(OH)_2\cdot 4H_2O$], Vesuvianite [$Ca_3Al_2(SiO_4)_2(OH)_4$], Willemite ($Zn_2SiO_4$), Wollastonite ($CaSiO_3$), Zinnwaldite [$KLiFe^{+2}Al(Si_3AlO_{10})(F,OH)_2$], Zircon ($ZrSiO_4$), Zoisite [$Ca_2Al_3(Si_2O_7)(SiO_4)O(OH)$] etc

4.4. PHYSICAL PROPERTIES OF SOME MINERALS

The physical properties of quartz, corundum, haematite, magnetite, chromite, bauxite, graphite, calcite, magnesite, orthoclase, microcline, plagioclase, biotite, muscovite, olivine, topaz, talc, granet, beryl, hornblende, augite, sillimanite, kyanite, pyrite, chalcopyrite, gypsum, apatite and fluorite are described below

4.4.1. Quartz

(i) Chemical composition

Quartz is composed of silica and oxygen. In the purest form it is silicon dioxide (SiO_2; Si = 30.5% and O = 69.5%)) and colourless (rock crystal) or white in colour. Substitution of Al^{+3} for Si^{+4} results in introduction of Li^{+1}, Na^{+1}, Ti^{+2} etc, which impart different colours to quartz. This substitution, however, takes place in very minor quantities (0.0001 – 0.0216 %).

(ii) Physical properties

(a) Form: Massive and crystalline are common forms. Rock crystal (transparent variety of quartz) is crystallized with well-developed crystal faces. Chalcedony is fibrous and microcrystalline.

(b) Colour: Pure quartz is colourless. Different varieties of quartz are differently coloured. Rock crystal is transparent, citrine is yellow, amethyst is purple, rose quartz is pink, smoky quartz is yellow-brown to black, morion is black, milky quartz is milky white, carnelian is red, sard is brown, chrysoprase is apple green, agate is banded or variegated, onyx is white with gray bands, jasper is brown, chert is light gray, flint is dark coloured.

(c) Lustre: Vitreous to sub-vitreous.

(d) Streak: White.

(e) Hardness: 7.

(f) Cleavage: Absent.

(g) Fracture: Commonly conchoidal, even in case of chert.

(h) Specific gravity: 2.65.

(i) Diaphaneity: Transparent (rock crystal) to translucent.

(j) Special property: Piezoelectric.

(iii) Use: Quartz is used in building industry (sand), glass making, abrasive (in soap and toothpaste industry), pottery, in preparation of silica bricks (refractory) and manufacture of ferro-silicon. It is also used as a flux, as lining of tube-mills (grinding of ores and minerals) and as a filler. Due to its piezoelectric property, quartz is extensively used in short wave radio apparatus and radio circuits. Thin quartz plates, which function as oscillators and mechanically vibrate at a constant rate, are used in electronic circuit in the watch. This circuit counts the crystal frequency and provides digital time display of the watch. It is also used in manufacture of quartz-wedge, used in petrological microscopes.

4.4.2. Corundum

(i) Chemical composition: Corundum is composed of aluminium and oxygen. In the purest form it is aluminium oxide (Al_2O_3; Al = 52.9% and O = 47.1%). However, minor amounts of Cr, Ti, Fe^{+2}, Ca, Mg, Ni, Si and Mn replace Al.

(ii) Physical properties

(a) Form: Massive, coarse or fine granular crystalline; crystallized varieties are barrel shaped pyramidal.

(b) Colour: Common varieties are colourless, white, gray, greenish or reddish. Gem varieties: ruby (with trace amount of Cr) is red, sapphire (with trace amounts of Ti, Fe^{+2}) is blue, oriental amethyst is purple, oriental emerald is green, oriental topaz is yellow.

(c) Lustre: Adamantine to vitreous; crystal faces are usually dull.

(d) Streak: White.

(e) Hardness: 9.

(f) Cleavage: Absent but rectangular partings are common.

(g) Fracture: Conchoidal or uneven.

(h) Specific gravity: 3.9 – 4.1.

(i) Diaphaneity: Transparent to translucent.

(iii) Use: Corundum is used as an abrasive commonly known as emery, which is either ground from the pure or impure massive mineral. Gem varieties of corundum are ruby, sapphire, oriental amethyst, oriental emerald and oriental topaz coloured as red, blue, purple, green and yellow respectively.

4.4.3. Hematite

(i) Chemical composition: Hematite is composed of iron and oxygen. In the purest form it is ferric oxide (Fe_2O_3; Fe = 70% and O = 30%). However, minor amounts of Ti, Fe^{+2}, Al and Mn replace Fe^{+3}.

(ii) Physical properties

(a) Form: Tabular, micaceous (specularite), foliaceous aggregates, reniform, granular, amorphous (ocher), pseudo-octahedral (martite). Crystallized varieties are rhombohedral.

(b) Colour: Steel gray to iron black; earthy forms (ocher) are red.

(c) Lustre: Crystallised varieties (specularite) are metallic and highly splendent, fibrous varieties are silky and amorphous varieties (ocher) are dull and earthy.

(d) Streak: Cherry red.

(e) Hardness: 5 – 7.

(f) Cleavage: Absent.

(g) Fracture: Subconchoidal.

(h) Specific gravity: 4.9 – 5.3.

(j) Diaphaneity: Opaque

(i) Magnetic property: Moderately magnetic

(iii) Use: Used in steiel industry for extraction of iron metal and in ferroalloy industries. Red ochre is used as pigment and polishing powder

4.4.4. Magnetite

(i) Chemical composition: Magnetite is composed of iron and oxygen. In the purest form it is ferrosoferric oxide (Fe_3O_4; Fe = 72.4% and O = 27.6%). Sometimes iron is replaced by minor amounts of Ti and Mg.

(ii) Physical properties

(a) Form: Massive, granular, coarse to fine grained; crystallized varieties are octahedral or combination of octahedron and rhombohedron forms.

(b) Colour: Iron black.

(c) Lustre: Metallic or submetallic.

(d) Streak: Black.

(e) Hardness: 6.

(f) Cleavage: Absent; some varieties exhibit octahedral parting.

(g) Fracture: Subconchoidal.

(h) Specific gravity: 5.18.

(k) Diaphaneity: Opaque

(i) Magnetic property: Highly magnetic

(iii) Use: Magnetite is used for extraction of iron metal and in ferroalloy industries.

4.4.5. Chromite

(i) Chemical composition: Chromite is composed of iron, chromium and oxygen. In the purest form it is $FeCr_2O_4$ (Fe = 25% Cr = 46% and O = 29%). Sometimes chromium is replaced by minor amounts of Mg, Al and Zn.

(ii) Physical properties

(a) Form: Massive, granular coarse to fine grained; crystallized varieties are octahedral.

(b) Colour: Iron black to brownish black.

(c) Lustre: Submetallic.

(d) Streak: Brown.

(e) Hardness: 5 – 6.

(f) Cleavage: Absent.

(g) Fracture: Conchoidal.

(h) Specific gravity: 4.5 – 4.8.

(l) Diaphaneity: Opaque

(i) Magnetic property: Moderately magnetic.

(iii) Use: Chromite is used for extraction of chromium metal, preparation of stainless steel, refractory bricks and pigments.

4.4.6. Bauxite

(i) Chemical composition: Bauxite is a mixture of three aluminium hydroxide mineral phases viz. diaspore ($HAlO_2$), gibbsite [$Al(OH)_3$] and bohemite [AlO(OH)] in different amounts. Common impurities are Fe_2O_3, TiO_2 and phosphorus compounds.

(ii) Physical properties

(a) Form: Amorphous, earthy granular or pisolitic masses.

(b) Colour: Dirty white, grayish, brown, yellow or reddish brown.

(c) Lustre: Earthy.

(d) Streak: Dirty white to brown.

(e) Hardness: 2 -3.

(f) Cleavage: Absent.

(g) Fracture: Conchoidal.

(h) Specific gravity: 3 – 5.

(m) Diaphaneity: Opaque

(iii) Use: Bauxite is used for extraction of aluminium metal, preparation of refractory bricks and manufacture of Al_2O_3, which is used as abrasive.

4.4.7. Graphite

(i) Chemical composition: Graphite is composed of pure carbon. Common impurities are SiO_2, FeO and clay minerals.

(ii) Physical properties

(a) Form: Foliated, scaly, lamellar, columnar, radiating or granular aggregates. Crystalised form is hexagonal tablet.

(b) Colour: Iron gray to deep steel gray.

(c) Lustre: Metallic.

(d) Streak: Shining black.

(e) Hardness: 1 – 2 (marks paper).

(f) Cleavage: One set perfect basal.

(g) Fracture: Conchoidal to uneven.

(h) Specific gravity: 2 – 2.3.

(n) Diaphaneity: Opaque

(i) Feel: Greasy

(j) Tenacity: Sectile, flexible

(k) Electric property: Good conductor of electricity.

(iii) Use: Graphite is used in manufacture of refractory crucibles, batteries, paint, and lead of pencil. It is also used as electrodes in electric furnaces and as generator brush, lubricant and in electro-plating.

4.4.8. Calcite

(i) Chemical composition: $CaCO_3$, with 56% CaO and 44% CO_2. Fe^{+2}, Mg^{+2} and Mn^{+2} replace Ca^{+2} to certain extent.

(ii) Physical properties

(a) Form: Commonly crystallised in form of rhombohedron; also occurs in fibrous, lamellar, stalactitic, nodular, granular and compact forms.

(b) Colour: Colourless or white; sometimes with gray, yellow, blue, red, brown or black tints

(c) Lustre: Vitreous to earthy.

(d) Streak: White.

(e) Hardness: 3.

(f) Cleavage: Perfect 3 sets.

(g) Fracture: Uneven.

(h) Specific gravity: 2.71.

(o) Diaphaneity: Transparent to translucent.

(iii) Use: Iceland spar, a transparent variety of calcite is used in the construction of Nicol prism, which is used to produce polarized light in petrological microscopes. Calcite is used as flux in extraction of iron metal from iron ores, in manufacture of quicklime, cement, bleaching powder, calcium carbide, glass, soap, paper, paint etc. It is also used as building and ornamental stones.

4.4.9. Magnesite

(i) Chemical composition: $MgCO_3$, with 56% MgO and 44% CO_2. Fe^{+2}, and Mn^{+2} replace Mg^{+2} to certain extent.

(ii) Physical properties

(a) Form: Usually massive, granular, fibrous or earthy. Crystals are rare.

(b) Colour: White, gray, yellow or brown.

(c) Lustre: Vitreous.

(d) Streak: White.

(e) Hardness: 3 – 5.

(f) Cleavage: Perfect 3 sets in crystals.
(g) Fracture: Conchoidal.
(h) Specific gravity: 2.8 – 3.2.
(i) Diaphaneity: Transparent to translucent.

(iii) Use: Magnesite is used for production of CO_2, Mg, Mg-salts, manufacture of refractory bricks, crucibles, special cements. It is also used in paper, sugar and chemical industries.

4.4.10. Orthoclase

(i) Chemical composition: $KAlSi_3O_8$, (K_2O = 16.9%, Al_2O_3 = 18.4% and SiO_2 = 64.7%); in some varieties Na replaces K to certain extent.

(ii) Physical properties

(a) Form: Commonly prismatic, elongate or flat. It also occurs in massive, lamellar and granular forms.
(b) Colour: White, gray and flesh-red.
(c) Lustre: Vitreous to pearly.
(d) Streak: White.
(e) Hardness: 6.
(f) Cleavage: Perfect 2 sets aligned at 90°.
(g) Fracture: Conchoidal to uneven.
(h) Specific gravity: 2.56.
(i) Diaphaneity: Transparent to translucent.

(iii) Use: Orthoclase is used in the manufacture of porcelain and pottery, for the production of glazes on earthenware, sanitary ware, enameled brick etc. It is also used in manufacture of opalescent glass, as a binder for abrasives. Moonstone, an opalescent and colourless variety of orthoclase is used as gemstone.

4.4.11. Microcline

(i) Chemical composition: $KAlSi_3O_8$, (K_2O = 16.9%, Al_2O_3 = 18.4% and SiO_2 64.7%) in some varieties Na replaces K to certain extent.

(ii) Physical properties

(a) Form: Commonly prismatic, stubby to elongate crystals are common. It also occurs in massive, lamellar and granular forms.

(b) Colour: White, gray, pale yellow and bright green (Amazonstone).

(c) Lustre: Vitreous to pearly.

(d) Streak: White.

(e) Hardness: 6.

(f) Cleavage: Perfect 2 sets.

(g) Fracture: Conchoidal to uneven.

(h) Specific gravity: 2.56.

(ix) Diaphaneity: Transparent to translucent.

(iii) Use: Microcline is used in the manufacture of porcelain and pottery, for the production of glazes on earthenware, sanitary ware enameled brick etc. It is also used in manufacture of opalescent glass, as a binder for abrasives and in facing of artificial building material. Amazonstone is used as an ornamental material.

4.4.12. Plagioclase

(i) Chemical composition: Plagioclase feldspars form a complete solid solution series from pure albite ($NaAlSi_3O_8$) to pure anorthite ($CaAl_2Si_2O_8$). The composition of different members is given in Table 4.14.

(ii) Physical properties

(a) Form: Cleavable masses or irregular grains, lamellar and granular forms.

(b) Colour: Colourless, white and gray; less commonly greenish, flesh-red.

(c) Lustre: Vitreous to pearly.

(d) Streak: White.

(e) Hardness: 6.

(f) Cleavage: Perfect 2 sets.

(g) Fracture: Conchoidal to uneven.

(h) Specific gravity: 2.605 – 2.765.

(ix) Diaphaneity: Transparent to translucent.

Table 4.14. Composition of plagioclase feldspars

Sl. No.	Name of the plagioclase feldspar	Composition
1.	Albite	$Ab_{100}\,An_0$ to $Ab_{90}\,An_{10}$
2.	Oligoclase	$Ab_{90}\,An_{10}$ to $Ab_{70}\,An_{30}$
3.	Andesine	$Ab_{70}\,An_{30}$ to $Ab_{50}\,An_{50}$
4.	Labradorite	$Ab_{50}\,An_{50}$ to $Ab_{30}\,An_{70}$
5.	Bytownite	$Ab_{30}\,An_{70}$ to $Ab_{10}\,An_{90}$
6.	Anorthite	$Ab_{10}\,An_{90}$ to $Ab_0\,An_{100}$

Where: Ab = Albite ($NaAlSi_3O_8$) and An = anorthite ($CaAl_2Si_2O_8$). Figures as subscript indicate the composition in percent. For example $Ab_{70}\,An_{30}$ is equal to albite 70% and anorthite 30%. From the above table it is evident that the composition of each member of the plagioclase feldspar is variable within certain limits.

(iii) Use: Plagioclase feldspars are used in the manufacture of porcelain and pottery, for the production of glazes on earthenware, sanitary ware enameled brick etc. It is also used in manufacture of opalescent glass, as a binder for abrasives and in facing of artificial building material.

4.4.13. Biotite

(i) Chemical composition: $K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$. There is considerable substitution of Fe^{+2}, Fe^{+3} and Al for Mg, Al for Si and Na, Ca, Ba, Rb and Cs for K. F may replace some OH.

(ii) Physical properties

(a) Form: Foliated books of pseudo-hexagonal crystals and also disseminated as irregular grains or flakes or foliated masses.

(b) Colour: Black, greenish black and brownish black.

(c) Lustre: Vitreous to splendent; pearly on cleavage planes.

(d) Streak: White.

(e) Hardness: 2 - 3.

(f) Cleavage: Perfect 1 set basal.

(g) Fracture: Uneven.

(h) Specific gravity: 2.7 – 3.2.

(ix) Diaphaneity: Transparent to translucent.

(i) Tenacity: Flexible and elastic.

(iii) Use: Biotite is used as insulator in electrical industry, manufacture of lubricants, wall-finishes, artificial stone, rubber tyres, pharmaceutical industry and to give gloss to wallpaper.

4.4.14. Muscovite

(i) Chemical composition: $KAl_2(AlSi_3O_{10})(OH)_2$. Minor substitution of Na, Rb and Cs for K, of Fe^{+2}, Fe^{+3}, Li, Mn, Ti, Cr for Al and of F for OH are common.

(ii) Physical properties

(a) Form: Foliated books of pseudo-hexagonal crystals, massive or disseminated scales and as irregular grains or flakes or foliated masses.

(b) Colour: Colourless and transparent in thin sheets. Thicker blocks are translucent with light shades of yellow, brown, green and red.

(c) Lustre: Vitreous; pearly on cleavage planes.

(d) Streak: White.

(e) Hardness: 2 - 3.

(f) Cleavage: Perfect 1 set basal.

(g) Fracture: Uneven, ragged.

(h) Specific gravity: 2.76 – 3.

(ix) Diaphaneity: Transparent to translucent.

(i) Tenacity: Flexible and elastic

(iii) Use: Muscovite is used to cover lanterns, lamp chimneys and oil stoves. It is used as insulator in electrical industry, manufacture of lubricants, wall-finishes, artificial stone, rubber tyres, pharmaceutical industry and to give gloss to wallpaper. Powdered muscovite is used to give the *frost* effect on Christmas cards and Christmas trees. It is also used in manufacture of mica (glimmer) plate, used in petrological microscopes.

4.4.15. Olivine (Peridot)

(i) Chemical composition: Olivine includes a group of related minerals, which form a complete solid solution series from pure forsterite (Mg_2SiO_4) to pure fayalite (Fe_2SiO_4). The composition of different members is given in Table 4.15.

(ii) Physical properties

(a) Form: Crystallised varieties are prismatic in habit. Massive and compact grains are common.

(b) Colour: Forsterite is colourless, white or green and Fayalite is green to yellow. Other members are green, pale green, olive-green, grayish-green, brownish.

(c) Lustre: Vitreous.

(d) Streak: White.

(e) Hardness: 6 - 7.

(f) Cleavage: Poor.

(g) Fracture: Conchoidal.

(h) Specific gravity: 3.2 – 4.3.

(ix) Diaphaneity: Transparent to translucent.

Table 4.15. Composition of olivine group of minerals

Sl. No.	Name of the olivine	Composition
1.	Forsterite	$Fo_{100}\,Fa_{0}$ to $Fo_{90}\,Fa_{10}$
2.	Chryosolite	$Fo_{90}\,Fa_{10}$ to $Fo_{70}\,Fa_{30}$
3.	Hyalosiderite	$Fo_{70}\,Fa_{30}$ to $Fo_{50}\,Fa_{50}$
4.	Hortonolite	$Fo_{50}\,Fa_{50}$ to $Fo_{30}\,Fa_{70}$
5.	Ferro-hortonolite	$Fo_{30}\,Fa_{70}$ to $Fo_{10}\,Fa_{90}$
6.	Fayalite	$Fo_{10}\,Fa_{90}$ to $Fo_{0}\,Fa_{100}$

Where: Fo = forsterite (Mg_2SiO_4) and Fa = fayalite (Fe_2SiO_4). Figures as subscript indicate the composition in percent. For example $Fo_{30}\,Fa_{70}$ is equal to forsterite 30% and fayalite 70%. From the above table it is evident that the composition of each member of the olivine group is variable within certain limits.

(iii) Use: Olivine is used as refractory material for the casting industry. Peridot, the transparent green variety of olivine is used as gemstone.

4.4.16. Topaz

(i) Chemical composition: $Al_2SiO_4)(F,OH)_2$. Al_2O_3 = 56.6%, SiO_2 = 33.4% and H_2O = 10%.

(ii) Physical properties

(a) Form: Prismatic, columnar and granular.

(b) Colour: Colourless, wine-yellow, straw-yellow, white, grayish, blue or pink.

(c) Lustre: Vitreous.

(d) Streak: White.

(e) Hardness: 8.

(f) Cleavage: Perfect 1 set.

(g) Fracture: Subconchoidal to uneven.

(h) Specific gravity: 3.5 – 3.6.

(ix) Diaphaneity: Transparent to translucent.

(iii) Use: Topaz is used as abrasive and the transparent varieties are used as gemstone.

4.4.17. Talc

(i) Chemical composition: $Mg_3Si_4O_{10}(OH)_2$. Ti, Ni, Fe and Mn may substitute for Mg.

(ii) Physical properties

(a) Form: Tabular, fine-grained massive with foliaceous structure or massive granular

(b) Colour: White, gray, apple-green.

(c) Lustre: Resinous, pearly, greasy.

(d) Streak: White.

(e) Hardness: 1, marks on a cloth.

(f) Cleavage: Perfect 1 set.

(g) Fracture: Subconchoidal to uneven.

(h) Specific gravity: 2.7 – 2.8.

(ix) Diaphaneity: Transparent to translucent.

(i) Feel: Greasy, soapy.

(j) Tenacity: Sectile

(iii) Use: The most common use is in talcum powder. Talc is also used as slabs on laboratory tabletops in switchboards, paint, ceramic, rubber, insecticide, roofing, paper and foundry facings.

4.4.18. Garnet

(i) Chemical composition: The general formula of garnet group of minerals is $R^{+2}_3R^{+3}_2[SiO_4]_3$, where R^{+2} is Ca, Mg, Fe^{+2} or Mn and R^{+3} is Fe^{+3}, Cr or Ti. The group consists of 2 series viz. Pyralspite and Ugrandite. The compositions of minerals belonging to these two series are given in Table 4.16.

Table 4.16. Composition of garnet group minerals

Series	Mineral	Composition	Series	Mineral	Composition
Pyralspite	Pyrope	$Mg_3Al_2Si_3O_{12}$	Ugrandite	Grossular	$Ca_3Al_2Si_3O_{12}$
	Almandine	$Fe_3Al_2Si_3O_{12}$		Andradite	$Ca_3Fe_2Si_3O_{12}$
	Spessartite	$Mn_3Al_2Si_3O_{12}$		Uvarovite	$Ca_3Cr_2Si_3O_{12}$

(ii) Physical properties

(a) Form: Generally granular and crystallized in the form of rhomb-dodecahedron and trapezohedron of isometric system.

(b) Colour: The members are differently coloured as given in Table 4.17.

(c) Lustre: Vitreous to resinous.

(d) Streak: White.

(e) Hardness: 6 – 8.

Table 4.17. Colours of different garnets

Mineral	Colour	Mineral	Colour
Pyrope	Red, deep crimson, mulberry, occasionally black	Grossular	Pink, brown, yellow, green, white
Almandine	Deep red, occasionally transparent (in gem variety)	Andradite	Brown, yellow, green
Spessartite	Pink, violet, brownish-red.	Uvarovite	Emerald green

(f) Cleavage: Absent; cracks are often present.

(g) Fracture: Conchoidal to uneven.

(h) Specific gravity: 3.5 – 4.3.

(ix) Diaphaneity: Transparent to translucent.

(iii) Use: All varieties are used as abrasive and transparent varieties of almandine, andradite and pyrope are used as gemstones.

4.4.19. Beryl

(i) Chemical composition: $Be_3Al_2Si_6O_{18}$; small amount of Na, Rb and Li may substitute for Be; H_2O and CO_2 may occur within rings.

(ii) Physical properties

(a) Form: Hexagonal prism or columnar aggregates.

(b) Colour: Colourless, bluish-green, emerald-green, golden-yellow, pink, white.

(c) Lustre: Vitreous.

(d) Streak: White.

(e) Hardness: 7 – 8.

(f) Cleavage: Indistinct.

(g) Fracture: Conchoidal to uneven.

(h) Specific gravity: 2.7 – 2.9.

(ix) Diaphaneity: Transparent to translucent.

(iii) Use: Beryl is the major source of beryllium, which is made alloy with copper resulting in increase of hardness, tensile strength and fatigue resistance of copper. Emerald, transparent and emerald-green (pale green) and aquamarine, transparent pale blue varieties of beryl are used as gemstones.

4.4.20. Hornblende

(i) Chemical composition: Hornblende is a member of the amphibole family. Its atomic structure is similar to other amphiboles, except that there is a large vacant site, which is occupied by K or Na. Hornblende is a silicate of aluminium, calcium, magnesium and iron with sodium. The composition is variable and represented by the formula $(K,Na)_{0-1}(Ca,Na,Fe,Mg)_2(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH)_2$. Many end members have names as given in Table 4.18.

(ii) Physical properties

(a) Form: Massive, bladed, columnar, fibrous. Crystallised varieties are prismatic.

(b) Colour: Black, dark green or greenish black.

(c) Lustre: Vitreous, fibrous varieties are silky.

(d) Streak: White.

(e) Hardness: 5 - 6.

(f) Cleavage: Perfect two sets.

(g) Fracture: Uneven.

(h) Specific gravity: 2.7 – 2.9.

(ix) Diaphaneity: Transparent to translucent.

(iii) Use: Building stone, mosaic flooring.

Table 4.18. Chemical composition of hornblende end members

Sl No.	End member	Chemical composition
1.	Edenite	$Ca_2NaMg_5(AlSi_7)O_{22}(OH)_2$
2.	Ferro-edenite	$Ca_2NaFe_5(AlSi_7)O_{22}(OH)_2$
3.	Paragasite	$Ca_2NaMg_4Al(Al_2Si_6)O_{22}(OH)_2$
4.	Ferro-paragasite	$Ca_2NaFe_4Al(Al_2Si_6)O_{22}(OH)_2$
5.	Tschermakite	$Ca_2Mg_3Al_2(Al_2Si_6)O_{22}(OH)_2$
6.	Ferro-tschermakite	$Ca_2Fe_3Al_2(Al_2Si_6)O_{22}(OH)_2$
7.	Tremolite	$Ca_2(MgFe_5)Si_8O_{22}(OH)_2$
8.	Ferro-actinolite	$Ca_2(FeMg_5)Si_8O_{22}(OH)_2$
9.	Glaucophane	$Na_2Mg_3Al_2Si_8O_{22}(OH)_2$
10.	Kaersutite	$Ca_2Na(Mg,Fe)_4Ti(Al_2Si_6)O_{22}(OH)_2$

In addition to the above, in case of some hornblende varieties, F^- or O^{-2} substitute for (OH) and Fe^{+3} substitute for Fe^{+2}.

4.4.21. Augite

(i) Chemical composition: Augite is a member of the pyroxene family. Its chemical structure is similar to other pyroxenes, complex and variable and represented by the formula $(Ca,Mg,Fe,Na,)(Mg,Fe,Al)(Si,Al)_2O_6$. Ti, Li, Mn and other elements may also be present in the crystal lattice in small amounts.

(ii) Physical properties

(i) Form: Commonly crystalline, also occurs as massive, lamellar, granular and prismatic forms.

(ii) Colour: Black and dark green.

(iii) Lustre: Vitreous.

(iv) Streak: White.

(v) Hardness: 5 - 6.
(vi) Cleavage: Perfect two sets.
(vii) Fracture: Uneven.
(viii) Specific gravity: 3.2 – 3.5.
(ix) Diaphaneity: Transparent to translucent.

(iii) Use: Building stone, mosaic flooring.

4.4.22. Sillimanite

(i) Chemical composition: Al_2SiO_5. Small amount of Fe may be present.

(ii) Physical properties

(a) Form: Long slender prismatic, needle-shaped and fibrous.
(b) Colour: White, brown, gray and pale green.
(c) Lustre: Vitreous.
(d) Streak: White.
(e) Hardness: 6 - 7.
(f) Cleavage: Perfect but rarely seen.
(g) Fracture: Uneven.
(h) Specific gravity: 3.23.
(ix) Diaphaneity: Transparent to translucent.

(iii) Use: Manufacture of refractory bricks.

4.4.23. Kyanite

(i) Chemical composition: Al_2SiO_5. Minor amounts of Fe, Mn, Cr may be present.

(ii) Physical properties

(a) Form: Long blade-shaped, sometimes form parallel or radiating aggregates.

(b) Colour: Blue, darker towards center of crystal, occasionally white, gray or green.
(c) Lustre: Vitreous to pearly.
(d) Streak: White.
(e) Hardness: 5 parallel to length of crystal and 7 perpendicular to length.
(f) Cleavage: Perfect two sets.
(g) Fracture: Uneven.
(h) Specific gravity: 3.6 – 3.7.
(ix) Diaphaneity: Transparent to translucent.

(iii) Use: Manufacture of spark plugs and refractory porcelains.

4.4.24. Pyrite

(i) Chemical composition: FeS_2. Ni and Co replace Fe; in addition, Cu, V, Mo, Cr, W, Au and Ti may be present in the crystal lattice.

(ii) Physical properties

(a) Form: Commonly occurs as cubes (often striated), pyritohedra or octahedra. Also occurs as massive, granular, reniform, globular and stalactitic.
(b) Colour: Blue, Bronze-yellow to brass-yellow.
(c) Lustre: Metallic to splendent.
(d) Streak: Greenish or brownish-black.
(e) Hardness: 6 – 7.
(f) Cleavage: Imperfect.
(g) Fracture: Conchoidal to uneven.
(h) Specific gravity: 4.8 – 5.1.
(ix) Diaphaneity: Opaque.

(iii) Use: Pyrite is mined for the gold and copper associated with it. It is the source of iron metal in countries where oxide ores are not available. It is also the chief source of sulphur from which H_2SO_4 and copperas ($FeSO_4$) are manufactured. Copperas is used in dyeing, manufacture of inks, as preservative of wood and as a disinfectant.

4.4.25. Chalcopyrite

(i) Chemical composition: $CuFeS_2$, small amount of Ag, Au and Zn may be present in the crystal lattice.

(ii) Physical properties

(a) Form: Crystalline and massive aggregates.

(b) Colour: Brass-yellow

(c) Lustre: Metallic.

(d) Streak: Greenish black.

(e) Hardness: 3 – 4.

(f) Cleavage: Imperfect.

(g) Fracture: Conchoidal to uneven.

(h) Specific gravity: 4.1 – 4.3.

(i) Diaphaneity: Opaque.

(iii) Use: Chief ore of copper.

4.4.26. Gypsum

(i) Chemical composition: $CaSO_4 \cdot 2H_2O$. Minor amounts of Fe, Mn, Cr may be present.

(ii) Physical properties

(a) Form: Crystalline, laminated, granular, fibrous (Satin spar) and fine-grained massive (Alabaster).

(b) Colour: Colourless (Selenite), white, gray, various shades of yellow, red and brown.

(c) Lustre: Vitreous, pearly and silky.

(d) Streak: White.

(e) Hardness: 2, can be scratched by finger nail.

(f) Cleavage: Perfect one set.

(g) Fracture: Conchoidal.

(h) Specific gravity: 2.32.

(ix) Diaphaneity: Transparent to translucent.

(i) Tenacity: Sectile

(iii) Use: Production of plaster of Paris and making of adamant plaster for interior use. Gypsum serves as a soil conditioner and land plaster for fertilizer. Uncalcined gypsum is used as a retarder in Portland cement. Satin spar and alabaster are cut and polished for ornamental purposes. It is also used in manufacture of gypsum plate used in petrological microscopes.

4.4.27. Apatite

(i) Chemical composition: $Ca_5(PO_4)_3(OH,F,Cl)$, Flourapatite is most common. Mn and Sr may replace Ca to some extent.

(ii) Physical properties

(a) Form: Prismatic crystals, colloform, massive, mammillated, concretionary and granular.

(b) Colour: Usually in shades of green or brown; also blue, violet and colourless.

(c) Lustre: Subresinous to vitreous.
(d) Streak: White.
(e) Hardness: 5.
(f) Cleavage: One set poorly developed.
(g) Fracture: Conchoidal to uneven.
(h) Specific gravity: 3.15 – 3.2.
(ix) Diaphaneity: Transparent to translucent.

(iii) Use: Serves as a source of phosphate for fertilizer and production of phosphorus chemicals. Transparent varieties are used as gemstones.

4.4.28. Fluorite (Fluorspar)

(i) Chemical composition: CaF_2, Minor amount of Y, Ce and other rare-earth elements may substitute for Ca. Na, Ba, Sr and Cl may be present in small amounts.

(ii) Physical properties

(a) Form: Commonly crystallized (cube), also occurs in massive and granular forms.
(b) Colour: Colourless to light green, bluish green, yellow, purple, white, brown and pink.
(c) Lustre: Vitreous.
(d) Streak: White.
(e) Hardness: 4.
(f) Cleavage: Perfect octahedral.
(g) Fracture: Conchoidal to uneven.
(h) Specific gravity: 3 – 3.25.
(ix) Diaphaneity: Transparent to translucent.

(iii) Use: Fluorite is used as flux in steel making, manufacture of opalescent glass, in enameling cooking utensils and for preparation of HF. Transparent fluorite is used for the construction of lenses.

4.5. SAMPLE QUESTIONS

.4.5.1. Long answer type questions

1. Give an account of the physical properties of minerals.

4.5.2. Describe the following minerals with reference to their chemical composition and physical properties

(i)	Quartz	(viii)	Magnesite	(xv)	Talc	(xxii)	Pyrite
(ii)	Corundum	(ix)	Orthoclase	(xvi)	Garnet	(xxiii)	Chalcoprite
(iii)	Hematite	(x)	Microcline	(xvii)	Beryl	(xxiv)	Gypsum
(iv)	Magnetite	(xi)	Plagioclase	(xviii)	Hornblende	(xxv)	Apatite
(v)	Chromite	(xii)	Biotite	(xix)	Augite	(xxvi	Fluorite
(vi)	Bauxite	(xiii)	Muscovite	(xx)	Sillimanite	(xxvii)	Topaz
(vii)	Graphite	(xiv)	Olivine	(xxi)	Kyanite	(xxviii)	Calcite

4.5.3. Distinguish between the following pairs

(i)	Cleavage and fracture	(iv)	Lamellar and lenticular
(ii)	Colour and streak	(v)	Stalactitic and stellate
(iii)	Fibrous and foliaceous	(vi)	Transparent and translucent

4.5.4. Fill in the blanks with appropriate word/ words

(i) Sillimanite shows __________ form.

(ii) The hardness of apatite is _______________ .

(iii) Calcite has ____ set of cleavages.

(iv) The hardest mineral in Moh's scale is ________________ .

(v) Chromite shows ____________ habit.

(vi) Quartz has _________ set of cleavages

(vii) The mineral having golden yellow colour and greenish black streak is __________ .

(viii) Mineral used in digital clock is __________ .

(ix) Hardest mineral in hardness box is _________________ .

(x) Mineral used in preparation of face powder is ___________________ .

Answer

(i)	Acicular	(iii)	3	(v)	Octahedral	(vii)	Chalcopyrite	(ix)	Topaz
(ii)	5	(iv)	Diamond	(vi)	0	(viii)	Quartz	(x)	Talc

4.5.6. Choose the correct answer

(i) The form of asbestos is:

(a) Fibrous (c) Acicular

(b) Foliaceous (d) Columnar

(ii) The streak of hematite is:

(a) Brown (c) Black

(b) Cherry red (d) Green

(iii) The mineral that conducts electricity is:

(a) Graphite (c) Muscovite

(b) Hematite (d) Quartz

(iv) Highly magnetic mineral is:

(a) Hematite (c) Magnetite

(b) Chalcoprite (d) Graphite

(v) The mineral having two different hardness values is:

(a) Fluorite (c) Orthoclase

(b) Kyanite (d) Topaz

(vi) The system in which magnetite crystallizes is:

(a) Isometric (c) Hexagonal

(b) Tetragonal (d) Orthorhombic

(vii) The mineral used in the manufacture of Plaster of Paris is:

(a) Quartz (c) Apatite

(b) Gypsum (d) Plagioclase

(viii) Which of the following mineral is used in manufacture of cement:

(a) Calcite (c) Beryl

(b) Plagioclase (d) Talc

(ix) Which of the following mineral crystallizes in hexagonal system:

(a) Orthoclase (c) Beryl

(b) Gypsum (d) Talc

(x) The mineral showing earthy lustre from which a metal is extracted is:

(a) Bauxite (c) Magnetite

(b) Chalcopyrite (d) Hematite

Answer

(i)	Fibrous	(iii)	Graphite	(v)	Kyanite	(vii)	Gypsum	(ix)	Beryl
(ii)	Cherry red	(iv)	Magnetite	(vi)	Isometric	(viii)	Calcite	(x)	Bauxite

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CHAPTER – 5

PALAEONTOLOGY

5.1. INTRODUCTION

The branch of science that deals with the living world is known as biology. The animal biology, which deals with the science of animals, is termed as zoology, while the plant biology is studied under the heading botany**.** The study of ancient plants and animals together is grouped under the heading palaeontology, which is an important branch of geology. For the systematic study of ancient plants and animals the branch paleontology is divided into palaeobotany that deals with the study of plant fossils, and palaeozoology, which is devoted to the study of remains of ancient animals.

A number of hypotheses have been proposed for the origin of the earth. It is postulated that at the start of the event, a huge mass of hot gases accumulated in the outer space, which gradually concentrated and solidified to give rise to the present solar family, with sun at the center, encircled by all the planets including our mother earth. In due course of time, as the geological clock advanced, the earth from its hot gaseous state become a solid structure through a hot liquid phase and slowly cooled down to a stage when the temperature become congenial for the atmosphere to be separated into different layers along with the formation and accumulation of water. As the environment became amiable for the sustenance of life on the earth, the living world (both plant and animal) initially originated in the small and large water bodies, and gradually spread over and migrated to land and air space available on this earth.

A statistical account indicate that there are more than 350,000 types of plants and a little above 1,120,000 types of animals, presently live on the surface of the earth, though quite a good number of them have perished forever during the past geological periods. As we brood over, questions come to our mind as to how the living world originated? Whether all the types were created at one go? And when and how they come to live on this earth? To answer these questions, scientists through ages are engaged in the search for the truth.

According to the available scientific information, the living world originated long after the creation of the earth and only after the environment became congenial for them to live, some two to three thousand million years ago. At the beginning, the living bodies were very simple, primitive and unicellular in nature. Gradually they differentiated into plants and animals and became more and more complicated and adapted to different ways of living. The number of different species gradually increased until they reached the enormous diversity of today.

5.2. FOSSIL

The earth is made up of different type of rocks namely igneous, sedimentary and metamorphic. The sedimentary rocks often contain certain remains and markings, which resemble the present day organisms which live upon the surface of the earth. On further examination they are found to be either parts or impressions of ancient plants or animals which are preserved by nature in the sedimentary rock. These naturally preserved parts or impressions of ancient animals and plants are known as fossils. The 'Salagrams' described in various Hindu mythology are nothing but sedimentary rock pebbles rolled down from the Himalayas by the rivers, which are associated with fossils.

The term fossil, which has been derived from an ancient European ward (fodar = to dig up) has been defined as, 'remains of geologically ancient plants and animals that resembles the parts of the present day animals and plants which have been preserved in the rocks of the earth's crust by natural processes and agencies' . It may be mentioned here that the remains of organisms must be geologically old.

5.2.1. Development of modern living world and fossils: We must take the help of fossils for the study of ancient living world. But before that one must acquire detail knowledge about the present day animal and plant kingdom. The fossils are nonliving bodies and are certain hard parts like bones, outer shells of ancient animals, leaves, spores and trunks of ancient plants or their casts and impressions Hence, before studying the ancient living world with the help of fossils one should be well versed with the present day animals and plants.

While going through the available fossil records, we wander how the modern animals and plants have slowly evolved from their ancient ancestors. This is clearly evident when we compare the modern elephants and horses with their available fossils.

The organic world consists of two kingdoms. Animal kingdom and Plant kingdom. The animal kingdom consists of twelve phyla with their modern representatives. Each main division is termed as Phylum and includes animals built on the same fundamental plan and believed to have descended from one ancestral stock. They are (i) Protozoa (Amoeba, euglena, radiolarian, foraminifera); (ii) Porifera (sponges); (iii) Canidaria (Sea anemones, corals hydra, jelly fishes); (iv) Helminthes (Hook worm, round worm, flat worm); (v) Annelida (leeches, earth worms); (vi)Arthropoda (insects, shrimps, iobsters, spiders, centripeds); (vii) Bryozoa (moss animals); (viii) Brachiopoda (lamp shells); (ix) Molluscs (calms, snails, nautilids, octpus); (x) Echinodermata (star fishes, sea urchins sea cucumbers); (xi) Protochordata (acronworm, amphioxus) and (xii)

Chordota (sea squirts, fishes, amphibians, reptiles, birds and mammals). Each phylum is divided and subdived in to smaller groups, known as Classes, Orders, Families, Genera and Species. Similarly the Plant kingdom consists of two divisions namely Cryptogamia and Phanerogamia, Cryptogamia includes (i) Thallophyta; (ii) Bryophyta; (iii) Pteridophyta and Phanerogamia includes (i) Gymnospermae and (ii) Angiospermae.

A brief classification of animals and plants which are presently living under various conditions of land and water, on the surface of the earth is given below and illustrated in Figs 5.1 and 5.2.

Sl. No.	Group	Species	Sl. No.	Group	Species
(i) Animals					
1.	Arthropods	9, 00,000	4.	Protozoans	30,000
2.	Molluscs	45,000	5.	Worms	38,000
3.	Chordates	45,000	6.	Other invertebrates	21,000
(ii) Plants					
1.	Flowering plants	2, 59,000	3.	Mosses etc.	23,000
2.	Ferns and conifers	10,000	4.	Algae and fungi	21,000

Certain ancient plants and animals are known to us only through their fossils because, they have been extinct since long from the surface of the earth, while a few other animals and plants still continue to be in the primitive stage since their origin.

Changes are the unchanged truth of nature. The environment on the surface of the earth changes from time to time. Those animals and plants which adjust themselves with the changed environment progress and survive for a long period while those which are unsuccessful in adjusting themselves to the changed environment become extinct. Further, each distinct environment such as a desert, a river or a pond, a snow caped mountain each support a more or less a unique type of animal and plant community. The fleshy stems of a cactus which adapts and survives in desert conditions or the streamlined shape of a fish along with its fins and tail are adaptations to live in water are a few examples only.

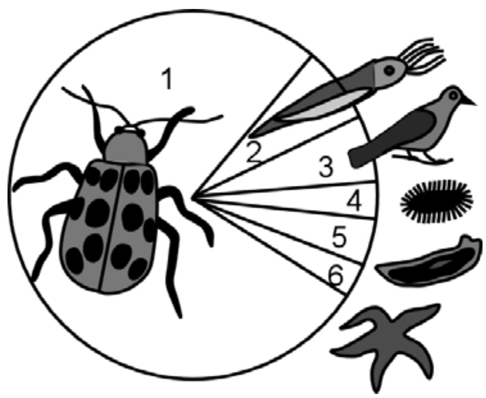


Fig. 5.1: Pi-diagram showing distribution of animals

Fig. 5.2: Pi-diagram showing distribution of plants

Sedimentary rocks are often rich in fossils. On examination they indicate that along with geomorphological evolution of the earth, the contemporaneous living world has also gradually evolved. Long after the creation of the earth and with the formation of the atmosphere rain fall must have started. The rain water coming down the high lands and hill tops through small nalas and gullies gradually increase their width as they reach the valley area forming small and big rivers and ultimately discharged the water into shallow regions which gave rise to modern seas and oceans. The running water on its way denuded the surface of the earth by braking down the rock formation into smaller and smaller size and transported and deposited in the lakes and oceans.

Simultaneously birth and death continued in the living world. After the death, some of the dead bodies of animals and plants must have been carried away by the running water and it is natural that they might have been buried under sand and mud deposited in the lakes and oceans. In due course of time the rock debris deposited under the sea water converted into sedimentary rocks as various geological processes acted upon them. Along with the consolidation of the sediments into sedimentary rocks, the dead bodies of animals and plants or their impressions were also preserved within these sedimentary rocks in selective areas. These animals and plants or their impressions, which are preserved within the sedimentary rocks formed millions of years back, are known as fossils.

The process of formation of sedimentary rocks continued unabated, one above the other and buried the dead bodies of animals and plants which were gradually evolving from simpler to complicated ones. The processes of formation of the sedimentary rocks indicate that different sedimentary beds have been formed during a particular geological period. Hence, each sedimentary layer has its own age. Thus, if they are not disturbed by different geological forces, the oldest or the first formed rock strata of a geological formation remain at the bottom while the newer layers are deposited above the older ones. Sedimentation and formation of sedimentary rocks is continuing in the present day lakes and oceans burring the dead animals and plants and preserving them for the formation of fossils in the future

Quite a good number of animals and plants which were flourishing on the surface of the earth at one time or other, starting from the origin of life, do not exist today as they are dead and gone. Very often, we take the help of their available fossils to understand them. Unfortunately, the fossil record is very often found to be incomplete. Further, the early formed organisms were soft bodied having neither internal nor external hard parts. As most of the sedimentary rocks are formed inside water, the land plants and animals do not get adequate chance to be fossilised. However, the geological disturbances are mainly responsible for the hindrances in the process of fossilisation.

It is said that the earth itself is the book of history of the earth, the sedimentary rock layers being its pages, while the fossils and such other imprints and impressions are the letters, which can give us a complete picture of the geological past of our mother earth. As has been mentioned earlier, quite good number pages along with the descriptive writings have been completely destroyed or not available for our perusal. Whatever lost is lost, but if we can systematically arrange and study the available fossils, we will be able to get a picture of the past history of the ancient living world, animals and plants. By reconstructing the ancient living world with the help of their traces and broken parts preserved as fossils in the light of the present day representatives, it is possible to have a better understanding of the extinct animals and plants (Fig. 5.3).

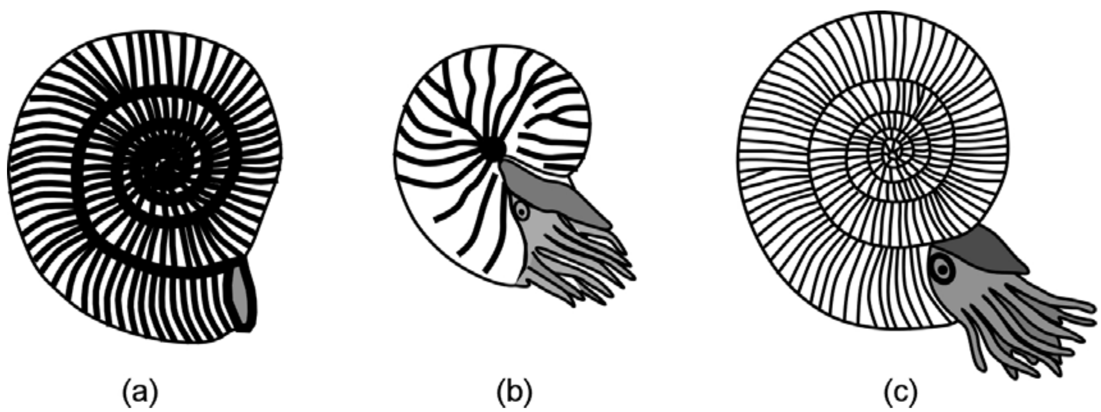


Fig.5.3: Extinct (a) and living (b and c) cephalopods

5.2.2. Conditions favorable for fossilisation: The animals and plants require certain favorable conditions to be preserved as fossils. After death, their soft parts are decomposed due to bacterial action. Hence, possession of hard parts like exoskeleton, bones, nails and tooth etc. are favorable condition for fossilization. Leaves and flowers are rarely fossilized while trunks of big trees, bones and exoskeletons are commonly preserved as fossils. After the death of the organisms it must be immediately buried so that it does not get destroyed. The dead bodies, if, left on the surface of the earth they are easily destroyed but if they are immediately buried under sediments or natural ice sheets, the possibility of preservation of hard parts, their impressions or at times the whole body with hard and soft parts are more. The availability of finer rather than coarser sediments and undisturbed conditions of sedimentation for a longer period are some of the favorable conditions. Commonly the hard parts are composed of calcareous substances. Once they are buried under the sediments, they come in contact with the ground water, which contains dissolved minerals and salts. Very often, the original substances of the hard parts are replaced by the minerals present in the ground water. Hence, the presence of highly mineralized ground water favors the chance of fossilization. This indicates that, the geologic conditions favourable for preservation of remains of plants and animals are

(i) The organisms should have some hard parts, and

(ii) Their remains should be entombed quickly under a thick cover of sediments.

Both these conditions are equally important but fulfillment of these two conditions may not always be sufficient for conversion of remains of organisms into well formed fossils.

5.3. MODES OF PRESERVATION OR TYPES OF FOSSIL RECORDS

Various types of fossils are observed to have been preserved within the sedimentary formations. The type of fossil records depends mostly upon the nature and composition of the original part and different conditions of fossilization. From the point of view of their mode of preservation, several distinct types of fossils have been recognised. Some of the important modes of preservation of animals and plants are given below.

5.3.1. Preservation of the whole organism, including its soft parts: Dead bodies with soft parts, though very rarely, found to have preserved under most favorable conditions. The woolly mammoth with unaltered hard and soft parts preserved under continental ice sheets unearthed from Siberia, the whole body of rhinoceros preserved in natural asphaltic oil pool in California, various insects preserved in amber (Fig. 5.4) (fossilized resin) are some of the examples. Besides, quite a good number of impressions of soft parts are found to have been preserved as fossils.

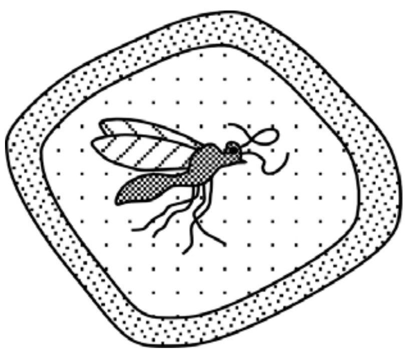


Fig. 5.4: Preservation in amber

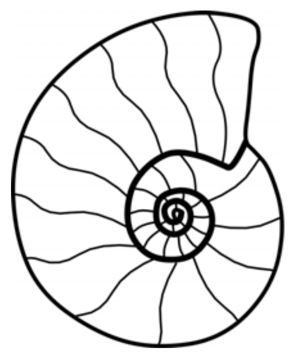


Fig. 5.5: Unaltered hard part

5.3.2. Preservation of unaltered hard parts: The hard parts of various organisms are composed of minerals like calcite, aragonite, silica and chitin. The original content of the hard parts are commonly destroyed and replaced by secondary mineral matter dissolved in the ground water. But under certain selective conditions, exoskeletons of arthropods and shells of brachiopoda, mollusca and bones and teeth of vertebrates are found preserved unaltered at times in their original colour and luster (Fig. 5.5).

5.3.3. Carbonisation: In selective cases, the soft and semi hard parts like leaf and wood of some plants undergo decomposition and lose nitrogen and oxygen while its residual carbon is preserved providing a clear impression of the original plant body (Fig. 5.6). Conversion of vegetable matter into coal takes place in this process.

5.3.4. Petrification: In this process the original organic substances are completely replaced by inorganic substances in such a way that the original internal and external structures are well preserved. This replacement takes molecule by molecule; one molecule of the organic substance is taken away by the ground water and substituted by an inorganic molecule while keeping the original external and internal structure intact even in the microscopic dimension. This is a very slow process in which large tree trunks are fossilised (Fig. 5.7). It involves removal, in solution, of each individual molecule of the material constituting the hard parts (of plants and animals) and simultaneous precipitation of an equivalent quantity of the replacing mineral.

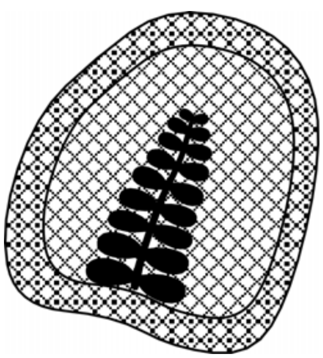


Fig. 5.6: Carbonisation

Fig. 5.7: Petrified wood

5.3.5. Moulds and casts: In majority cases, the original substance present in the hard parts buried under the sediments are totally removed in solution. In the process a hallow space is created within the rock layer which is a replica of the original hard part. The wall of this cavity with the ornamentations of the original hard part is known as external mould. At times the inside space of the hard part is totally filled with sediments before its final dissolution and preserved as internal mould, which may bear its internal ornamentation. When the space between the internal and external mold is filled in with very fine sediments and preserved they are called casts. Fig. 5.8 depicts different stages of formation of moulds and casts.

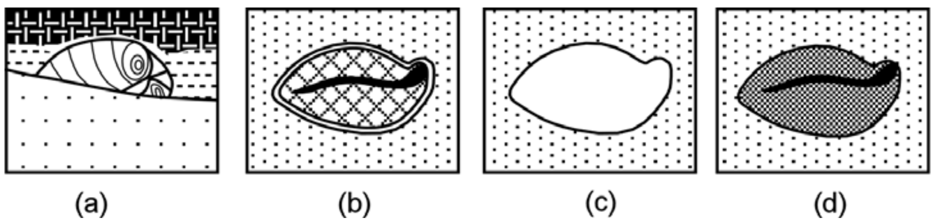


Fig. 5.8: Different stages of formation of moulds and casts

5.3.6. Other types of fossilisation: In selective cases, the foot prints (Fig. 5.9) and trails of animals, burrows and borings of worms and mollusks are preserved as mould and casts. Gastroliths are smooth rounded pebbles found in the rib cages of dinosaurs and crocodiles which probably aided in their digestion, the fossil excreta providing clue to diet as well as the intestinal structure of the of the ancient animals are preserved as fossils, which are known as coprolites.

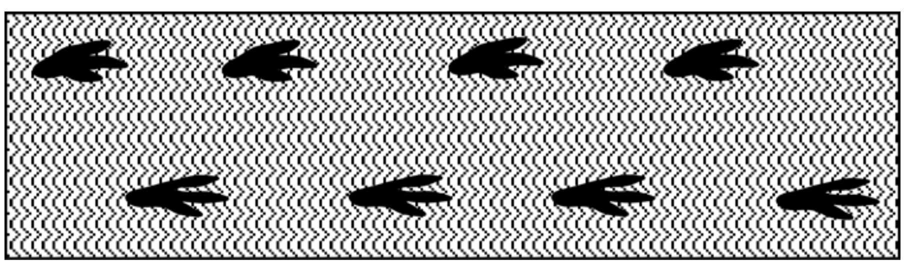


Fig. 5.9: Foot print

5.4. USES OF FOSSILS

As has been mentioned earlier, fossils are considered as alphabets of the book of history of earth which provide very interesting information about the early history.

5.4.1. Fossils provide evidence of evolution and migration: The fossils of most primitive animals and plants are preserved in the rocks, which were formed during the early part of the geological period of the earth while sedimentary rocks which were formed during later geological periods contain remains of more and more advanced forms of plants and animals indicating that more and more completed and advanced animals and plants evolved from earlier ones. A verity of organisms, though have been extinct since long from a particular region, newer and more developed types have flourished during subsequent periods in some other region indicating that along with their evolution the animals and plants have migrated from place to place on the surface of the globe. The geological history of present day horses and their primitive ancestors may be taken as examples. The primitive horses originated in North America and in course of their evolution they migrated to India, through Central Asia. This type of scientific conclusion is possible because of systemic research on the available fossil records.

5.4.2. Fossils help in establishing the geological age and order of superposition of a sedimentary formation along with their correlation with the formations of one area with the other: Due to their gradual evolution, the fossils of different organisms are found preserved within rock beds formed contemporaneously with the organisms. The fossil assemblage of a rock bed is different from the bed above and below it .The rock-beds formed during different geological periods should contain fossil remains of those organisms which were flourishing during that particular geological period. Hence, it is possible to establish the geological age of a particular bed and the chronological order of the sedimentary formation and correlate the same with other sedimentary formation formed elsewhere on the surface of the earth with the help of fossils (Fig. 5.10).

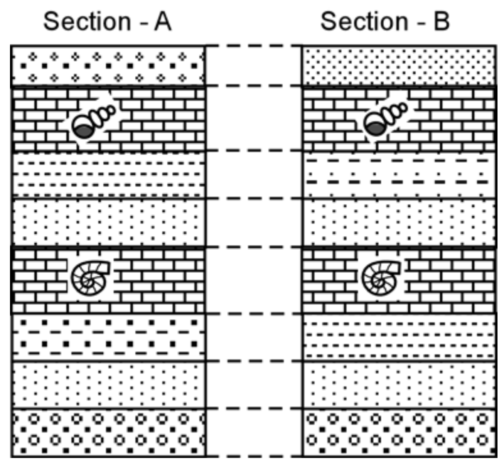


Fig. 5.10: Correlation with the help of fossils

5.4.3. Study of ancient geography: Distinct differences are found among aquatic and land animals and plants. Shallow and deep water organisms differ from each other in many respects. The ancient organic world can be visualized in the light of their present day representatives. By examining the fossils and the rocks in which they are preserved, the rock beds formed under different climatic conditions and environments can be differentiated from each other. Fossils of marine animals are found to be preserved in the rocks of the Himalayas indicating the presence of a sea in the region where the Himalayas is found today. Hence, by systematic study of the fossils the distribution of land and sea, changes in climatic conditions and such other ancient geographical features on the surface of the earth can be well established.

5.4.4. The search for new deposits of coal and petroleum: The fossil fuel deposits are always associated with the ancient organic world. Most of the large deposits of coal are associated with the sedimentary rocks deposited in lake-basins during Permian period. On the other hand, petroleum deposits are commonly formed within marine sediments of Tertiary period. Amber with ancient insects is used as jewellery. Hence, with the help of fossils, a geologist while establishing the age of the rocks of the area can locate fresh deposits of coal, petroleum and other useful rocks and minerals.

Apart from the above, the fossils are helpful in finding missing links of the animal and plant kingdom, which became extinct since long and in establishing a full picture of the organic evolution, fixing their geological age and working out a correct classification of the organic world and a standard geological time-scale.

5.5. INDEX FOSSILS

Fossils of certain animals and plants which are characteristic of certain geological horizons, beds or strata of rocks are called index fossils. They have limited geological range or vertical distribution with a very wide geographical distribution indicating that they were short lived but had worldwide distribution. The index fossils are useful in correlating the rock beds located miles away from each other in which they are preserved. A few examples along with their stratigraphic ages are given in Table 5.1.

5.6. GEOLOGICAL TIME

Among various methods employed for determining the age of the earth, the help of fossils preserved in sedimentary rocks is very important. The simple observation that younger layers formed on top of older ones became the first key

Table 5.1: Examples of index fossils

Sl. No.	Fossil	Major group	Phylum/ Class	Geological age
1.	*Phacops*	Invertebrate	Trilobite	Middle Devonian
2.	*Productus*	Invertebrate	Brachiopoda	Lower Carboniferous
3.	*Glossopteris*	Plant fossil	Pteridosperma	Lower to Middle Permian
4.	*Gangamopteris*	Plant fossil	Pteridosperma	Lower to Middle Permian
5.	*Ptilophyllum*	Plant fossil	Cycad	Jurassic
6.	*Trigonia*	Invertebrate	Pelecypoda	Lower Cretaceous.
7.	*Physa*	Invertebrate	Gastropoda	Upper Creteceous
8.	*Cardita*	Invertebrate	Pelecypoda	Upper Creteceous
9.	*Turritella*	Invertebrate	Gastropoda	Lower Eocene
10.	*Ostrea*	Invertebrate	Pelecypoda	Lower Miocene

to the long geological time scale. Considering the time taken for the formation of the present day sedimentary rocks as 'standard time', the age of first formed sedimentary formations, which were formed during a period when neither any animal or plants were leaving on the surface of the earth, named as 'Archaean' formation is fixed at 3000 to 4500 million years. The rock layers formed before the Archaean formation might have been eroded but most of the layered rocks formed afterwards are fossilferous. The total time taken for the formation of whole of the sedimentary rock formation from the Archaean till the present day is represented as 'The Geological Time Scale'. The Geological Time Scale begins with the formation of the earth's independent existence as a planet which coincides with 4600 million years before present. Then onwards, the earth's history has been divided into units having different intervals that are mostly on the basis of their fossil contents and other characterstics. The detail of the geological time scale has been described in startigraphy. The entire period has been divided into five /four (Azoic and Proterozoic taken together as Precambrian) time blocks known as era.

5.6.1. Azoic and Proterozoic era: Out of four time blocks mentioned above, the rocks formed during the first part of the earliest era does not preserve any fossil indicating that during that period of time life was not existing on the surface of the earth though rocks formed during the later period are found to contain fossils. The first part is known as Azoic, while the later part is known as Proterozoic, which is sometimes called as Precambrian era. The combined age of Azoic and Proterozoic is 3000 to 4000 my (million years).

5.6.2. Paleozoic era: This is the second time block. It has been divided into five periods.

(i) Cambrian: The rocks formed during this period were studied around Wales and named after its Latin name Cambria. A variety of marine invertebrate fossils dominated by trilobites are preserved in the rocks formed during this period that experienced a temperate climate. The duration of this period is about 100 my.

(ii) Ordovician: This period is named after a tribal community of Europe. During this period transgression of sea took place. There was an expansion in the verity of marine invertebrates which includes brachiopods, trilobites, gastropods, corals, echinoids, foraminifer and sponges. The cephalopods and many types of mosses and algae flourished during this time period. This period continued for about 60 my.

(iii) Silurian: This period has been named after an ancient tribe of Welsh. During this period volcanic activity occurred in many parts of the globe. Dry climate prevailed, with the development of deserts. The end of this period witnessed mountain building activities. Abundance of bony fish, coral, trilobite, mollusca, marine moss and algae are observed during this period. The time span of this period is 250 to 230 my BP (before present).

(iv) Devonian: This period commenced about 405 my ago and lasted for 60 my. This period witnessed expansion of fishes, land plants, emergence of first land animals and primitive amphibians. Great forests of seed ferns and appearance of land plants marked the Late Devonian period.

(v) Lower Carboniferous: This period started some 345 my ago and lasted for about 35 my. It was a period of shallow warm seas with the abundance of corals, brachiopods and crinoids while on land amphibians continued to develop with the forests covered by land plants.

(vi) Upper Carboniferous: This period lasted for about 30 my and witnessed large scale sea transgression, landslides, development of lowlands and great swamps. The land area was covered with thick forests crowded with very high plants. The giant ‘dragonflies’, many types amphibians and primitive reptiles roamed the forests while foraminifera, coral, brachiopod, mollusca and a few trilobites are among the marine invertebrates found during this period.

(vii) Permian: This period is named after a state in Soviet Russia. During the early part of this period, large scale natural calamity and devastation took place throughout the surface of the earth. Volcanic and mountain building activities were wide spread accompanied with change in the course of rivers and shrinking of seas. Large reptiles were dominating the land as well small and big water bodies. The ferns of the earlier period were replaced by pine type plants. The sea was crowded with giant cephalopods along with other invertebrates. The Palaeozoic era ended at the end of this period.

5.6.3. Mesozoic era: The animals and plants of this era were much more evolved than those of earlier times and hence the name Mesozoic. Because of domination of reptiles, some name it as ‘era of reptiles’. This era has been divided into three periods viz. Triassic, Jurassic and Cretaceous

(i) Triassic: During this period, major part of the earth surface experienced dry climate while active volcanoes poured out hot lava in many places. Many types of new plants and animals appeared on the land and water. Reptiles, in particular, developed and established their mastery with the incoming of flying reptiles for the first time. This period began some 230 million years ago and lasted for about 49 my.

(ii) Jurassic: Named after the Jura Mountains, this period, began 180 million years ago and lasted for about 46 my. Dinosaurs dominated land and swamps while flying reptiles were seen gliding through the air. Large ammonites together with gastropods, pelecypods and squids crowded the shallow seas. The oldest known bird and mammals were seen for the first time during this period.

(iii) Cretaceous: This period began about 135 my ago and lasted for 70 my. It witnessed wide spread sea transgression and experienced cold and dry climate. With the appearance and spread of flowering plants, abundant food was available for the growth of mammal, bird and reptile population though dinosaurs were still dominating the surface of the earth. However, the later part of this period witnessed large scale devastation due to which most of the dinosaurs and the gigantic ammonoids faced death.

5.6.4. Kainozoic (Cenozoic) era: The last 62 my of the geological time scale has conveniently grouped under (i) Tertiary - 61 my and (ii) Quaternary - last and recent 1 my.

(i) Tertiary (sub-era): This sub-era has been divided into five periods. The lower Tertiary includes Paleocene, Eocene and Oligocene periods. During these periods, regression of sea was very prominent, though; transgression of sea took place in a few other regions. The globe was dotted with active volcanoes. Most of the ancestors of modern mammals like elephant, horse, camel, rhinoceros, pig, cow and buffalo were roaming in the forests crowded with both flowering and non-flowering plants. The upper Tertiary includes Miocene and Pliocene periods marked by the continued rise of modern mammals. Continental uplift produced drier climates over wide areas and converted low swamps into grassy land, which helped the ancestors of the present day mammals with grazing habits to flourish along with small carnivores like dogs and saber-toothed tigers. Ape-like creatures were quite common and many of the older type mammals became extinct. Towards the close of Pliocene times, which witnessed continued earth movements with the rise of mountain ranges like Alps and Himalayas and appearance of most primitive ancestors of man .

(ii) Quaternary (sub-era): This sub-era, includes Pleistocene and Recent periods. During Pleistocene period, which began about one million year ago, most part of the earth surface was covered with continental ice sheets of thousands of feet in thickness due to at least four glacial advances with intermittent inter-glacial periods. Man emerged sometimes in this frozen world and witnessed the rise of the modern mountain ranges like Himalayas. With the repeated changes in climatic conditions, there were large scale migration of the flora and fauna. Many large mammals like wooly mammoths, sabre-toothed tigers became extinct at the end of the Pleistocene. The globe experienced the last of the glacial retreat about 11,000 years ago and entered into the Recent period of the Geological time scale, in which we are living today. On one hand, this Recent period is likely to be an inter-glacial period with fast approaching ice-age while on the hand, the modern man's boost for the technical development and scientific achievements and thinking of escaping the calamity by making the 'outer space' inhabitable.(?)

Animals without back-bone include a vast assemblage of animals ranging in size, structural diversity, phylogenetic relationship and adaptation to different modes of existence. They had evolved during the late Precambrian but were not abundant until approximately 600 million years ago. From that time, millions of species of invertebrates have evolved and died, leaving a fantastic record of evolution. Some important phyla are described below.

5.7. TRILOBITE

Trilobites belong to phylum Arthropoda, class Crustacea and subclass Trilobita. The trilobites derive their name from the fact that the body is longitudinally divided into three parts by means of two furrows, which extend from the anterior to posterior (Fig.5.11). The central segment is known as axial lobe while the other two on either side are known as pleural lobes.

5.7.1. Morphology: The body is oval in outline and flattened from above downwards. The body is transversely divided in to three parts, the cephalon (head), thorax (body) and pygidium (tail). The segments of the head and pygidium are fused together, but those of the thorax remain free. The dorsal surface of the body is protected by a strong calcareous exoskeleton known as carapace which covers part or sometimes the whole of the body.

(i) Cephalon: The part which covers the head is known as the head shield or cephalic shield. The cephalon is semicircular at the anterior side and almost flat at the posterior side. The cephalon is made up of six fused segments. The median part of the cephalon is inflated and is termed as glabella and the laterals are -

cheeks. The glabella is marked off from the cheeks by means of furrows on each side, known as axial furrows. The form and relative size of the glabella vary in different genera, in some it extends quite to the anterior margin of the head-shield, in others it extends only a part. Sometimes it is wider behind than in front, in other cases it widens anteriorly, or it may be of uniform width throughout. The glabella is composed of three glabellar lobes which are separated from each other by transverse or oblique

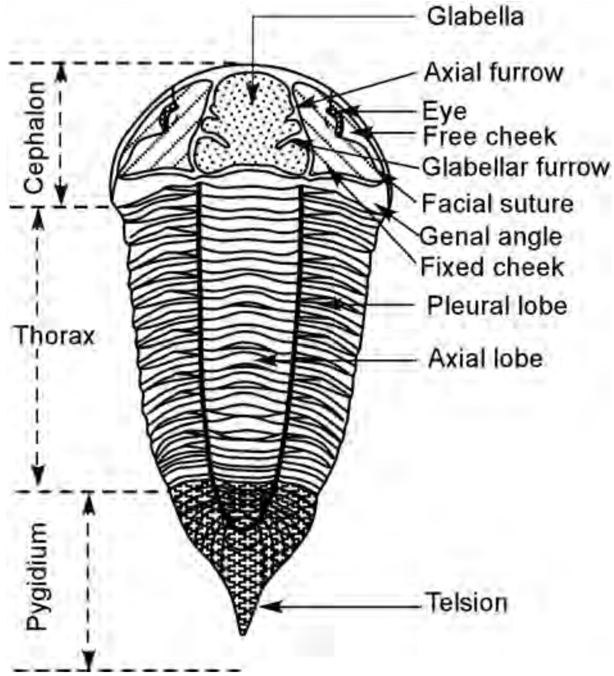


Fig. 5.11: Trilobite

glabellar furrows. On the posterior part of the glabella, there is another furrow which extends continuously. This is known as neck-furrow and the segment of the glabella behind it is the neck-ring. The cheeks are more or less triangular in shape and usually less convex than the glabella. The posterior angles of the cheeks are genal angles, which may be rounded or produced in to spines, called genal spine. Each cheek is usually divided in to two portions by a suture known as facial suture. The inner part that lies between facial suture and glabella is termed as fixed cheek and the outer part is free cheek which is slightly movable on fixed cheek. The course of facial suture varies in different genera; it may commence from posterior border, inside the genal angle or at or near the genal angle, or on the lateral border in front of the genal angle. It passes inward to the eye, then bends forward and may continue up to the anterior margin. The shapes of the facial sutures vary in different forms. They are of following types:

Protoparian: The sutures are marginal with cephalic shield. Free cheek and fixed cheeks are not divided and eyes are present.

Hypoparian: The sutures are similar to protoparian type but eyes are absent.

Opisthoparian: The sutures commence from the posterior margins inside the genal angles and are present on the dorsal side of the cephalic shield.

Proparian: The sutures start from the posterior or lateral sides and terminate at the anterior or lateral margins.

Gonatoparian: This type is intermediate between opisthorian and proparian types. The facial sutures start from the genal angles and continue till the anterior or lateral margins.

Some of the trilobites are blind and in others the eyes are compound comprising a number of lenses, conical to elliptical in shape and are located one on each free cheek at the angles made by the suture lines. Though the eyes are located on the free cheek they rest on a buttress or lobe on adjacent part of the fixed cheek. Each eye may be covered by a transparent chitinous layer called cornea.

(ii) Thorax: Thorax is the middle portion of the transverse lobe which occurs at the posterior of the cephalon. It consists of a series of segments which vary in number from two to fortytwo and are not fused together rather movable upon one another. Each segment is divided in to three lobes by two axial furrows. The central or median lobe is called axial lobe and the lateral lobes, lying on either side of the axial lobe are known as the pleurae. Each pleuron at some distance from the axis is curved downward and directed posteriorly. This point in each pleuron is called fulcrum. Sometimes, the outer part of each pleuron overlaps the anterior of the succeeding one and then the front part of the pleura may be smooth and flattened to form articulate surface of the facet. In some cases, the terminal parts of the pleura are rounded and in some cases are produced in to spines.

(iii) Pygidum: The third and posterior part of the body is called pygidium. The pygidum is commonly triangular or semi circular in shape and composed of three to six segments which are fused together and immovable. Like thorax, the pygidum is also divisible in to axial and pleural portions. The margin of the pygidum is either entire or may be provided with a posterior spine or a number of lateral spines. The axial spine of the pygidum is called telson.

5.7.2. Some important fossils

(i) Paradoxides (Fig. 5.12)

Phylum - Arthropoda, Class - Trilobita,

Order – Redlichiina, Genus – Paradoxides

Body large, elongated, narrowed posteriorly; head-shield broad, semicircular with a border and long genal spine. Glabella broad in front with 2 - 4 furrows on each side; facial sutures extend from posterior to anterior border, eyes large and arched. Thorax long with 16-20 segments, pleura grooved and produced into spines. Pygidum very small, plate like with 2 - 8 segments. Age: Middle Cambrian.

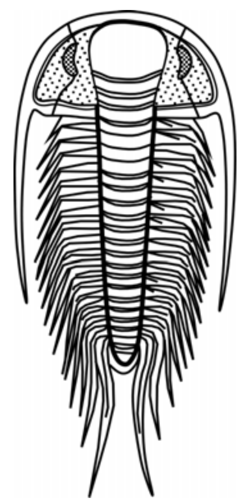


Fig. 5.12: Paradoxides

(ii) Calymene (Fig. 5.13)

Phylum - Arthropoda, Class - Trilobita,

Order – Phacopida, Genus – Calymene

Head-shield semicircular and large, genal angles rounded, glabella inflated, broadest behind, eyes small, prominent facial sutures extending from the genal angles to the anterior border. Thorax consists of 13 segments axis prominent; pygidium with 6 - 11 segments; margin entire. Age: Ordovician to Silurian.

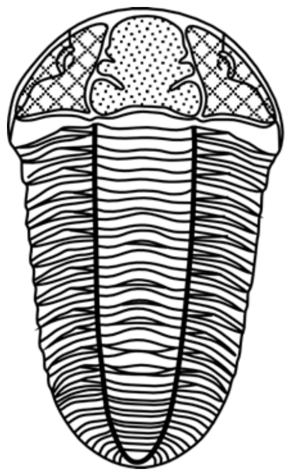


Fig. 5.13: Calymene

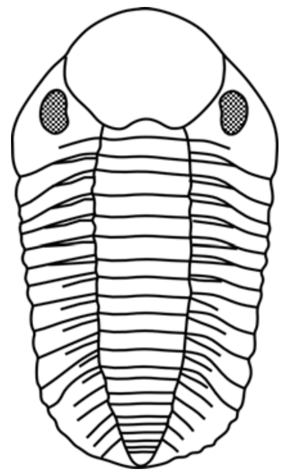


Fig. 5.14: Phacops

(iii) Phacops (Fig. 5.14)

Phylum - Arthropoda, Class - Trilobita,

Order – Phacopida, Genus – Phacops

Large head-shield, nearly semicircular, glabella prominent, broadest in front, with 3 - 4 furrows. Facial sutures start from lateral border of the cheeks in front of the genal angle, continuous in front of glabella. Eyes large, thorax with 11 segments, pleurae grooved; pygidium prominent. Age: Ordovician to Devonian.

5.8. BRACHIOPODA

The name Brachiopoda has been derived from two Greek wards: Brachion = arm + podos = foot. The muscular lophophore of the animal is used both as foot for locomotion and arm for collecting food. The cilia help in collection of food. The Brachiopods are one of the most important marine invertebrates. They are sessile in habit and live in shallow seas attached mainly to the substratum, though, they begin life as free-swimming larvae, which accounts for their wide geographical distribution.

5.8.1. Morphology: The soft parts in the living organism include the muscular pedicle, circulatory and digestive systems, genital glands and the arm like pair of ciliated lophophore. The lophophore (also known as brachia) are used to gather food.

The soft parts of the animal are enclosed within a hard exoskeleton known as shell, which is secreted by a thin skin like mantle membrane. In fact, the soft parts are enclosed in a cavity formed by the mantle, known as mantle cavity. The shell is divided into two unequal parts known as valves (Fig. 5.15). The valves are equilateral and are placed in dorso-ventral position in the animal. The ventral valve is comparatively larger and more convex then the dorsal valve. Both the valves are drawn posteriorly and produced into a beak like structure known as umbo (umbones). In the posterior part of the animal the valves are joined with each other along a line below their umbones, called hinge line. The valves open along the anterior margin. The hinge line may be straight or curved. The valves are held together either by teeth and socket present along their hinge line or by muscles. The forms with teeth and socket are grouped as Articulate and those with muscles are known as Inarticulate. In case of articulate brachiopods the hinge consists of two small curved processes or teeth on the ventral valve, which fit into

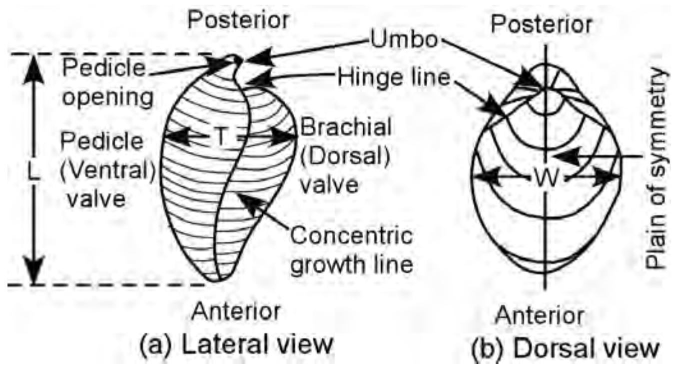


Fig. 5.15: Brachiopod

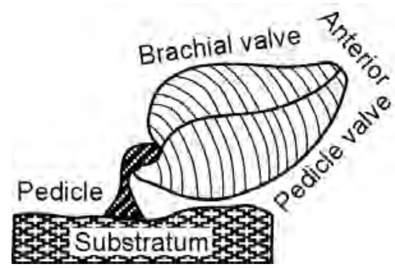


Fig. 5.16: Brachiopod with pedicle

the corresponding sockets on the dorsal valve. In a few cases, the dental systems on the ventral valve are supported by small calcareous plates known as dental plates. In some shells a triangular area is found in between hinge line and umbo, known as cardinal area or hinge area. The area may be in both the valves or in onevalve only. In majority cases a small circular opening is found on the umbo of the ventral valve. This opening is called pedicle opening. In a few cases this opening is found shared by both the valves. In the living brachiopods, a stout fibrous muscular structure known as pedicel comes out through the pedicel opening with the help of which the animal attaches itself to the substratum (Fig. 5.16). Because of the presence of the pedicle opening, the ventral valve is called as pedicle valve. Since the brachia are attached to the dorsal valve, it is also known as brachial valve.

The valves are opened and closed by two sets of muscles known as divaricator and adductor muscles which connect the valves at their interior surface. The scars of these muscles in fossils are described as muscular impressions. The brachia are attached to the brachial valve or the dorsal valve by means of brachial skeleton. The brachial skeleton may be in the form of two curved hooks, known as crura. Other forms of brachial skeleton may be looped ribbon or spirally coiled shaped. The shape and size of the shells vary widely. It may be biconvex, plano-convex or concavo-convex in shape. The shells vary in length from less than 3 cm to a length of 30 – 40 cm. A line joining the middle point of the anterior and posterior margins divides the valves into two equal halves making the valves equilateral (Fig. 5.15b). The length of the shell is measured from the umbo to the anterior margin and width from lateral to lateral margin while the thickness from the centre of one valve to the centre of the other on their outer surface (Fig. 5.15a)

The external surface the shells are sculptured with various types of ornamentation like concentric and radial growth lines (or rings), radiating ribs, tubercles, spines as well as small elevations (or ridges) and depressions. In some cases the lateral margin on both the sides of the hinge line are drawn into ear like structure while in others the anterior margin of both valves are crenulated or dentate providing a better grip when the valves are closed.

Brachiopods constitute an important group of fossilised animals in terms of their utility. These are marine invertebrates and live in shallow seas between shore line and 200 m depth. They had worldwide distribution and their fossils are preserved in abundance both in Palaeozoic and Mesozoic rocks. Presently more than 200 types of both articulate and inarticulate are found living in different parts of the earth. These are mostly sessile benthos living at the bottom of the sea attached to the underwater rocks. A few types, however, are found floating on the surface of the water.

The study of Brachiopoda fossils preserved in different geological formations indicates that they came to live on the surface of the earth during the early part of the Palaeozoic era. More than 30,000 types of Brachiopoda fossils are found preserved in the sedimentary rocks deposited from Cambrian period till the recent times. Those living during Cambrian period were mostly inarticulates. With the advance of geological time, the number of articulates increased with a spectacular decrease in the number of inarticulates. Gradually their number increased during Ordovician and Silurian, reaching a climax during Devonian. Most of the Brachiopods perished leaving only a few families during the Mesozoic era, most of which are living even today. From the fossil records it is evident that the animals belonging to the phylum Brachiopoda are a successful group with a geological age ranging from early Palaeozoic to Recent.

5.8.2. Description of some important fossils

(i) Productus (Fig.5.17)

Phylum - Brachiopoda, Class - Articulata, Order – Protremata, Genus – Productus

Shell is broad with dorsal valve concave, ventral valve convex, straight hinge line with ears, ornamented with concentric growth lines, radiating lines and spines, ventral valve with two hubs on either side of a central sulcus (depression) that runs from the umbo to anterior margin. Age - Carboniferous to Permian.

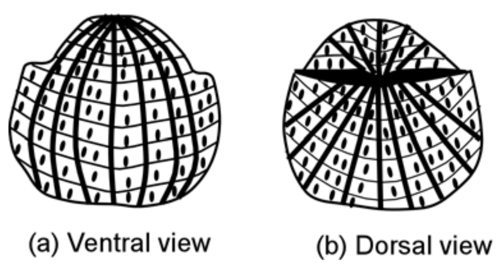


Fig. 5.17: Productus

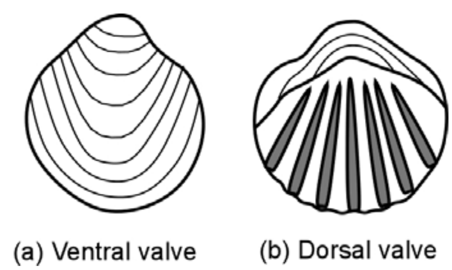


Fig. 5.18: Spirifer

(ii) Spirifer (Fig.5.18)

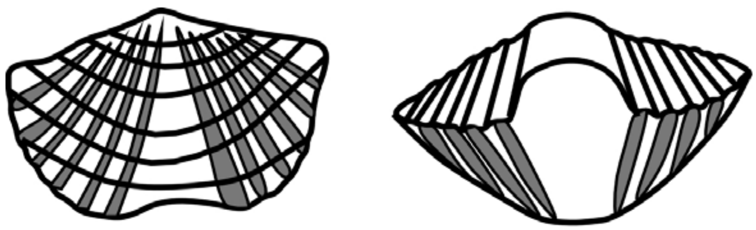
Phylum - Brachiopoda, Class - Articulata, Order – Telotremata, Genus – Spirifer

Shell is broad, triangular, biconvex with straight and long hinge line with ears and cardinal area. The surface is ornamented with radial ribs, anterior margin dentate, dorsal valve with ridge and ventral valve with sulcus. Age - Silurian to Permian.

(iii) Rhynchonella (Fig.5.19)

Phylum - Brachiopoda, Class - Articulata, Order – Telotremata, Genus – Spirifer

Shell triangular, hinge line curved, umbo small and curved, anterior margin produced into a tongue like projection, surface ornamented with strong ribs. Age - Upper Jurassic.



(a) Ventral view (b) Anterior view

Fig.5.19: Rhynchonella

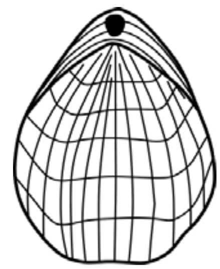


Fig. 5.20: Terebratula

(iv) Terebratula (Fig. 5.20)

Phylum-Brachiopoda, Class - Articulata, Order - Telotremata, Genus - Terebratula

Shell biconvex, elongated, egg shaped, large ventral umbo with big circular pedicle opening, curved hinge line, anterior margin of both the valves with two folds, ornamented with fine concentric growth lines. Age - Late Mesozoic to Late Tertiary.

5.9. LAMELLIBRANCHIA

Molluscs include five classes of invertebrate animals. They live in marine, freshwater as well as on land. A few aquatic forms are free swimming but majorities are bottom dwellers. Out of the five classes mentioned above, lamellibranches (pelecypods) and gastropods are two forms living in abundant number while cephalopods are represented by nautilus, octopus, and squid.

The term lamellibranchia has been derived two words lamella = leaf + branchia = gills i.e. they have leaf like gills. Due to the presence of plough shaped foot (pelecy = plough + poda = foot), they are also known as pelecypoda. They started their life during Cambrian and many of them continue till present day. Most of them are bottom dwellers, either as borers or crawlers, some of them cement themselves to fixed objects while a few of them are free swimmers. Majority of them are marine and live in different depths of sea from shore line to a depth of about 6000 m. Some of them live in fresh water ponds, rivers and brackish water lakes.

5.9.1: Morphology: The living body, which includes soft parts like mouth, digestive, circulatory, urinary, reproductive, respiratory organs and the locomotary system is enclosed in a bivalved shell which is compressed laterally. The respiratory system consists of a pair of leaf like gills and the locomotary system is a plough shaped foot. The shell opens to expose the foot interiorly for its movement and the siphons posteriorly to take food and oxygen from water.

The calcareous shell made up of two equal valves placed on the right and left sides of the body (Fig. 5.21). The height of the valve is measured from the ventral to dorsal margin; the length from anterior to posterior margin, while the thickness from the centre of the right to the centre of the left valve (Fig. 5.21). The anterior and posterior sides of the valve must be ascertained to differentiate the left and the right valves. Certain characteristics features are:-

(i) The umbones are directed towards the anterior side.

(ii) The valves are posteriorly elongated.

(iii) Lunule is present at the anterior while escutcheon at the posterior side of the umbo.

(iv) Pallial sinus is posteriorly placed.

(v) Out of two adductor impression the larger one is posteriorly placed.

(vi)Where only one adductor impression is present it is always posteriorly placed.

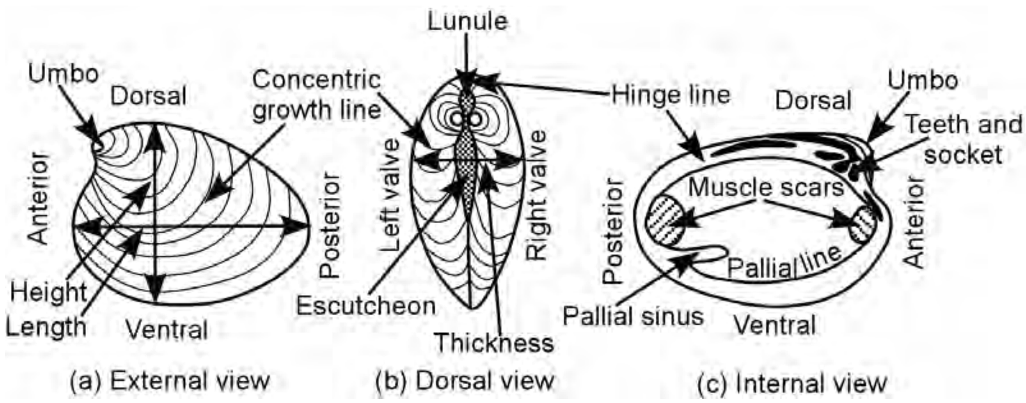


Fig. 5.21: Different views of Pelecypod

Once the anterior and posterior sides of the valves are known, it can easily be placed on the side of the shell, to which it belongs. The valves are joined together in the dorsal margin along the hinge line and open at their ventral margin. Dorsal side of each valve above the hinge line are drawn into a beak like structure, known as umbo (plural - umbones), which are commonly directed interiorly though in a few cases, the umbones are posteriorly directed. The valves are held together by means of teeth and sockets present on the hinge line of each valve, which forma a 'dental system'. The hinge line may be straight or curved and the number and nature of both teeth and socket are varable in different forms. The teeth and socket of one valve fit into corresponding sockets and teeth of other valve. In a few cases, a hinge area is found between the umbo and hinge line on both the valves. The hinge area of both the valves together form a small heart-shaped depression in front of the umbones, on the anterior side of the shell, known as lunule while the other part the hinge area lies posterior to the umbones is bit elongated and is named as escutcheon. The equivalved shell is inequilateral, as a line drawn from umbo to the central point of the ventral margin divides the valve into two unequal parts. Generally the valves are posteriorly elongated. The inner sides of both the valves are glossy to feel because of an enamel coating. The valves are closed by means of one or two adductor muscles which run from interior of one valve to that of the other and the impressions of these muscles on the inner side of the valves are known as adductor impressions. In valves with two adductor impressions, the posterior adductor impression is generally larger than the anterior one. Sometimes both the adductor impressions are almost equal in size. In a few cases, there is only one adductor impression, which is commonly placed at the center of the valve. The opening of the valves is controlled by a 'C' - shaped spring like ligament, found externally at the hinge margin above the escutcheon. The adductor impressions on each valve are connected with each other by a line known as pallial line caused due to the attachment of the mantle membrane. The pallial line may be simple or entire. In a few cases the pallial line may have a fold like sharp bend near the posterior adductor impression, known as pallial sinus. The number, nature and placement of teeth are variable. Different types of dentition are:-

(i) Taxodont - Hinge line straight with numerous small similar sized teeth and socket.
(ii) Heterodont - Few teeth of different shape and size.
(iii) Isodont - Two or three strong and equal sized teeth present in each valve
(iv) Schizodont - Very few, thick, grooved and strong teeth appear to diverge from below the umbones.

(v) Dysodont - Teeth numerous, small and similar in shape and size, radiate from below the umbones.

(vi) Desmodont - True teeth and socket are absent.

The shell is decorated externally with different colours which are seldom preserved in fossils. However, the pearly layer is sometimes preserved on the inner surface of the valves. The shells are ornamented with both coarse and fine radiating ribs and concentric rings. Tubercles and spines are present in some forms. In some cases, the shell exhibits wing-like projections on either side of the umbones, which are commonly described as 'ears'. The ventral margin of the valve may be smooth or it may be crenulated and dentate.

Sometimes it becomes difficult to differentiate the brachiopod and pelecypod shells from each other. The salient features of shells of both the groups are given in Table 5.2.

Table 5.2: Distinction between brachiopoda and pelecypoda

	Brachiopoda	Pelecypoda
(i)	Shell inequivalved	Shell equivalved
(ii)	Valves equilateral	Valves inequilateral
(iii)	Valves dorsal and ventral	Valves left and right
(iv)	Pedicel opening present	Pedicel opening absent
(v)	Teeth on the ventral and socket on the dorsal valve	Teeth and socket on both the valves
(vi)	Ligament absent	Ligament present
(vii)	Lunule and escutcheon absent	Lunule and escutcheon present

Lamellibranchia is a group of invertebrate animals having wide geographical distribution and geological range. The earlier fossils are found preserved in rocks formed during Middle Cambrian period and continued to grow in number during the entire Paleozoic era. The Palaeozoic forms became extinct at the end of the era. New forms appeared and multiplied during Mesozoic era, a few of which are still living today.

5.9.2: Description of some important fossils

(i) Pecten (Fig. 5.22)

Phylum - Mollusca,

Class - Lamellibranchia,

Order – Anisomyaria, Genus – Pecten

Shell slightly convex and triangular in shape, equivalved with equilateral valves, hinge line straight, ears present on either side of the umbo, but are not similar in size. Valves have one large adductor impression. Shell is ornamented with radiating ribs.

Fig. 5.22: Pecten

Geological age - Carboniferous to Recent.

(ii) Arca (Fig. 5.23)

Phylum - Mollusca,

Class - Lamellibranchia,

Order – Anisomyaria, Genus – Arca

Prominent umbo interiorly pointed, distinct cardinal area, hinge line straight taxodont dentition, ventral margin dentate, radiating and concentric lines present. Geological age - Jurassic to Recent.

Fig. 5.23: Arca

5.10. GASTROPODA

Gastropoda constitute an important group of invertebrates among the mollusca. The term gastropoda has been coined from two Greek words, gastros (stomach) + podos (foot), which refer to the presence of foot on the ventral part of the animal. It is remarkable to observe that the gastropods have been constantly growing from Cambrian to present day with negligible history of extinction. These are mostly marine animals living in shallow seas, though some are terrestrial and a few others live in fresh water environments.

5.10.1. Morphology: The animal with its soft parts lives inside a cone shaped shell which in a majority of cases is spirally coiled. The soft parts include the broad flattened muscular foot, a distinct head with one or two pairs of tentacles, a pair of eyes, mouth along with teeth like structures and radula (file-like tongue), digestive, circulatory, respiratory, nervous, urinary and genital systems. The soft parts are enclosed in a bag formed by the mantle which in turn secretes the outermost univalved shell.

The Gastropod shell is a long tubular cone like structure, which is generally coiled (Fig.5.24). The coiling may be helicoidal like a screw or may be planispiral. Each coil of 360 degrees is known as a whorl. The number of whorls varies widely in different forms. In a majority of cases the whorls are in contact with each other while in a few cases they are separated from each other. The line of contact of the whorls is termed as suture line. In the embryonic stage the shell of the animal starts as a small pointed structure known as protoconch. As the animal grows older, the whorls increase in size as well as in number by addition of calcareous substances secreted by the mantle.

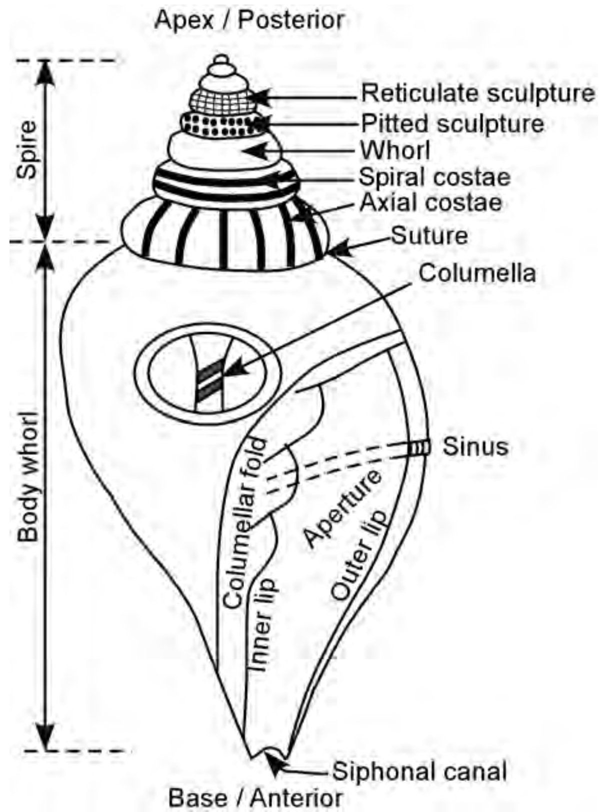


Fig. 5.24: Gastropod

All the whorls together from below the protoconch, except the last whorl, constitute the spire of the shell. The last whorl in which the animal lives is generally larger than rest of the whorls and is known as the body whorl. The pointed part of the shell is known as apex and the part of the shell opposite and farthest to that of the apex is termed as base. Basing on the number and size of the whorls, the nature of the spire in different forms varies widely. It may be long, short, horizontal (flat) or depressed. The angle produced by drawing two tangents on either side of the shell from the apex to the base is known as spiral angle. The spiral angle in different forms varies depending upon the shape of the shell. The opening of the shell is known as aperture. In clockwise or dextral coiling, the aperture comes to the right hand side of the observer if the shell is held in upright position while in anticlockwise or sinistral coiling the aperture comes to the left hand side. The inner part of the whorls fuse together to form a pillar like structure extending from the apex to the base is called the columella and the shell with a columella is known as imperforate. In other forms, the inner part of the whorls instead of fused together are left as a tube like hollow space, which extends from the apex and opens at the base of the shell is called as umbilicus. A shell with an umbilicus is known as perforate.

The gastropod shell is a single chambered conical tube like structure closed near the apex and opens near its base. In exceptional case it may be multichambered. The shape and size of the aperture vary in different forms and the operculum, a horny plate which closes the aperture varies accordingly. The operculum is attached to the dorsal part of the foot and closes the aperture when the animal withdraws into its shell. It is rarely preserved as fossil. The margin of the aperture is named as peristome. The inner side of the peristomal margin is known as inner lip while the outer side is called as outer lip. The outer lip may be rolled outwardly or inwardly and accordingly termed either as reflected or inflected. The peristomal margin may be provided with two notches, one at the anterior end and the other at the posterior end. These are known as anterior or siphonal canal and posterior or anal canal respectively. Such forms are known as siphonostomatous. Shells without any break in the peristomal margin are known as holostomatous.

The shells of the gastropod are ornamented with different ornamental elements like axial and spiral coastae, smooth, pitted and reticulate sculptures, needles and spine. These ornamental features are arranged either parallel or transverse to the suture line. .Many gastropod shells are decorated with shades of different colours, which are seldom preserved in fossils.

Depending upon raised or depressed spire, number and shape of the whorls, nature of the spiral angle and size of the last whorl, a variety of forms of gastropod shells have been observed. Some of them are given below.

(i)	Discoidal	-	Planispirally coiled. All the whorls are in one plane.
(ii)	Turbinate	-	Spire angle acute, spire sharp, base flat.
(iii)	Trochiform	-	Spire acute, body whorl is globular with convex base.
(iv)	Turreted	-	Spire long with numerous whorls, sharp and acute apex, body whorl is small compared to the long spire.
(v)	Conical	-	Body whorl large with the aperture as long as the body whorl, spire is short.
(vi)	Fusiform	-	Shell spindle-shaped, body whorl widest at the middle of the shell and tapers anteriorly with long siphonal canal.
(vii)	Cylindrical	-	Convex apexes. After the first few whorls, the diameter of rest of the whorls remain same.
(viii)	Globular	-	Spire sharp and short. Body whorl is globular and large.
(ix)	Convolute	-	Spire concealed by the last whorl. Aperture is as long as the shell and with crenulated lips.
(x)	Patelliform	-	Shell cap-like with sharp and acute apex.

The Gastropods are a successful group of invertebrates with wide geographical distribution and long geological range. Hence, their fossils are found preserved in most of the rocks deposited beginning from Cambrian to the Recent period.

5.10.2. Description of some important fossils

(i) Conus (Fig. 5.25)

Phylum - Mollusca, Class - Gastropoda, Order – Neogastropoda, Genus – Conus

Spire short, sometimes flat with obtuse spiral angle. Shell conical with long body whorl and elongated aperture. Lips parallel. Age - Cretaceous to Recent.

Fig. 5.25: Conus

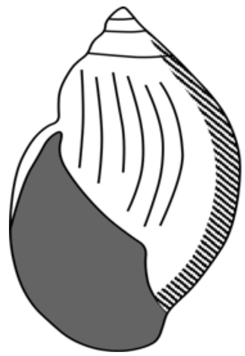


Fig. 5.26: Physa

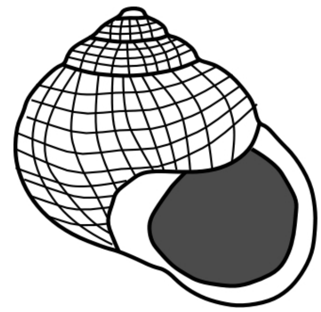


Fig. 5.27: Natica

(ii) Physa (Fig. 5. 26)

Phylum - Mollusca, Class - Gastropoda, Order - Basommatophora, Genus - Physa

Short spire with globular body whorl and sinistral coiling. Age – Cretaceous to Recent.

(iii) Natica (Fig. 5. 27)

Phylum - Mollusca, Class - Gastropoda, Order - Mesogastropoda, Genus - Physa

Shell globular, spire short, large body whorl, aperture circular to semicircular with umbilicus. Age - Eocene to Recent.

5.11. CEPHALOPODA

The name cephalopoda has been derived from Greek words cephalon = head + podos = foot. They are more evolved than pelecypods and gastropods.

These exclusively marine invertebrates are represented by the living natilus, octopus and squid. The living forms have a bilaterally symmetrical body with well developed head encircled by arm like processes near its mouth out of which two are longer than the others and are used for locomotion and catching of food, eyes, mouth with jaws, radula, digestive and circulatory systems, gills for respiration and nerve rings

Based on the presence or absence of a shell and its nature, the cephalopods are divided into subclasses Nautiloidea, Ammonoidea and Dibranchia. The Nautiloids and Ammonoids have external shells while the Dibranchia (or Coleoids) have either an internal shell or no shell at all.

5.11.1. Morphology: The Nautiloidea shell is a conical tube like structure (Fig. 5.28). The shell is closed at the pointed posterior end and opens at the wider anterior end. The ventral part is marked by the presence of a depression known as hyponomic sinus along the margin of the aperture and the surface opposite to it is dorsal part. The shell may be straight or coiled or may be partially coiled and partially straight or even slightly curved. The coiling is commonly in a horizontal plane but in some forms the coiling is helicoidal. Each coil of 360º is known as a whorl. In a coiled shell, the whorls may be in touch with each other or the last whorl completely embraces the earlier whorls while in others each whorl may remain separate from the other whorls.

The interior of the shell is divided into a number of chambers by means of transverse partitions known as septa. The septa are generally concave towards the aperture of the shell, however, there are exceptions. The outer shell starts with the embryonic protoconch and grows with addition of septa as the animal grows in age. After the formation of septa, the animal comes to live in the last chamber, which is known as the body chamber. The body chamber is always larger than the earlier chambers and is nearer to the aperture. This process goes on and shell thus grows in size and becomes multi-chambered. All the chambers except the body chamber are filled with air. These chambers are known as air chamber. The air in the chambers helps the animal to maintain equilibrium while floating and diving in water.

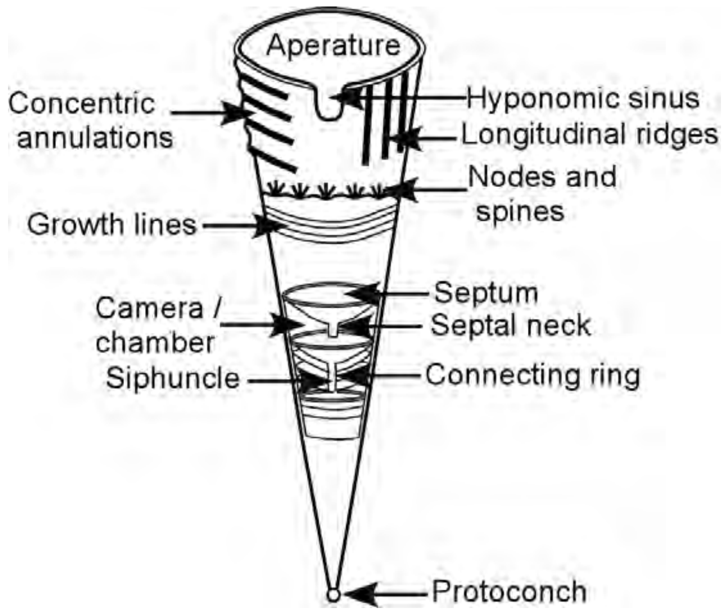


Fig. 5.28: Cephalopod

All the chambers are traversed by a slender cord like siphuncle consisting of the septal neck and connecting ring. The siphuncle starts from the body chamber passing through the centre or periphery of the septa and extend up to the first formed chamber. At the point where the umbilicus pierces the septa, a short tube like structure is produced on the septa called septal neck .The septal neck in some forms found directed towards the aperture of the shell while in others it may be directed towards the preceding chamber. In Nautiloids the siphuncle passes through the central part of the successive septa, the septal neck being directed backwards facing the protoconch, where as in ammonoids, it is found near the outer margin of the shell with the septal neck pointing towards the aperture. When isolated, each septum appears like a 'glass funnel' and the stem of the funnel forming the septal neck. A number of funnels are arranged according to their size from smaller to larger, the siphuncle passing through their stems appear like a chain of funnels inside a conical outer shell. The outer margin of the septa may be simple or may be systematically folded and crenulated. The line along which the septa are joined with the inner side of the tubular shell is described as suture line. The nature of suture line differs in different groups of cephalopods. In Nautiloidea the suture line may be simple or slightly undulating, while in Ammonoidea it is generally complex depending on the nature of the margin of the septa. In the complex type of suture line, the convex portion facing towards the aperture is known as saddle while the concave portion in between two saddles is known lobe. Due to further crenulations the primary saddles and lobes may develop secondary, superior, inferior, auxiliary and inner saddles and lobes starting from the outer margin to the inner margin of the whorl. Basing on their complexity four types of suture line are recognised (Fig. 5.29). These are:

(i) Straight or slightly undulating suture line is known as Nautiloid type (Fig. 5.29a).

(ii) Suture line with rounded saddles and angular lobes is known as Goniatite type (Fig. 5.29b).

(iii) Suture line with rounded saddles and finely crenulated lobes is known as Ceratite type (Fig. 5.29c).

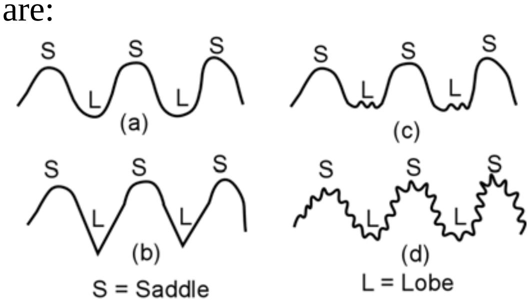


Fig. 5.29: Suture lines of cephalopod

(iv) Suture line with complex saddles and lobes is known as Ammonoid type (Fig. 5.29d).

As mentioned earlier the Coleoidea or Dibranchia subclass of cephalopods possesses an internal shell though in most cases a shell is absent. Belemnites, an extinct coleoidea and a fossilised representative of this group, possesses an internal shell consisting of three parts known as (i) guard or rostrum (ii) phragmocone and (iii) pro-ostracum. The guard is commonly preserved as fossil. It is the solid conical part the shell found at its apex. The phragmocone is found inside a conical hollow space in the guard and is divided into chambers traversed by the siphuncle. The calcareous plate, either oval or elongated in shape projected from above the phragmocone is known as pro-ostracum. The phragmocone and the pro-ostracum are seldom preserved as fossil.

The surface of the shell may be smooth or ornamented with transverse ribs, which may be bifurcating, trifurcating or multiplicating. Spine and tubercles also constitute some of the ornamental features of the surface of the shell.

The Cephalopods are exclusively marine animals largely adapted to warmer seas. Except Ammonoidea, representatives of all other subclasses of Cephalopods are found living today. Some of them live in bottom of the sea while others found swimming in warm and shallow sea water.

The fossil record indicates Nautiloids to be the most ancient form which came to live on this earth much before the Ammonoids. Nautiloid fossils are found preserved in rocks formed from Early Paleozoic times till the present day and with the passage of time they have progressively evolved though they attained their culmination during Silurian. During Late Paleozoic the earlier Nautiloids lost their importance though during Mesozoic Nautilus type of nautiloids appeared which attained worldwide distribution during Cretaceous time and are found to occur in the modern seas as well.

The Ammonoids, however, appeared during late Paleozoic times though the Mesozoic era witnessed their culmination and subsequent extinction. Some of the Cretaceous ammonoids were extremely large in size. They were totally extinct at the end of Cretaceous period and do not occur as fossils within the rocks formed during later periods.

The Coleoidea subclass appeared during early Mesozoic era with the Belemnites attaining their abundance during Jurassic and Cretaceous periods. This subclass became less important during Tertiary and represented today by octopuses, squids and cattle-fishes.

5.11.2. Description of some important fossils

(i) Nautilus (Fig. 5.30)

Phylum - Mollusca, Class - Cephalopoda, Order - Nautiloidea, Genus - Nautilus

Shell globular, the last whorl covers all earlier whorls, large body chamber simple nautiloid suture line. Age - Devonian - Recent.

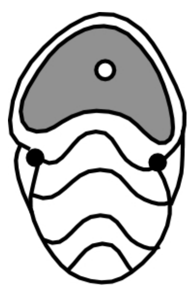


Fig. 5.30: Nautilus

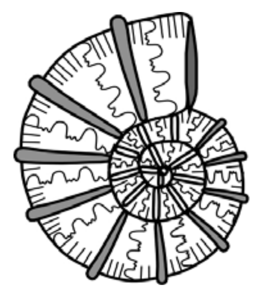


Fig. 5.31: Ceratite

(ii) Ceratites (Fig. 5.31)

Phylum - Mollusca, Class - Cephalopoda, Order - Ceratida, Genus - Nautilus

Shell discoidal, planispiral, ceratitic suture, fine ribs present. Age - Triassic.

5.12. PALAEOBOTANY

Study of the ancient plant life constitutes the subject matter of palaeobotany. It has been mentioned earlier that along with the evolution of the animal kingdom, the plant world also evolved simultaneously. Evidences are quite ample to state that the plants appeared first followed by the animals. Systematic examination and study of the plant fossils preserved within the ancient rock formations conclusively establish the fact that the ancient plants were in many ways different from their modern representatives. The earliest plants were exclusively aquatic and in due course of evolution gradually migrated towards land. With the change of habitats various changes took place in morphology as well as in anatomy of the land plants.

The fundamental difference between the plants and animals is primarily in their food habits. The plants prepare their own food with the help of chlorophyll present in them in the presence of sunlight from minerals collected from water and carbon dioxide from air where as the animals directly or indirectly depend on the plants for their food. Furtherer, animals move about freely while plants remain stationary. Because of their immobility, they are regarded as good indicators of palaeoclimate.

5.12.1. Classification of Plant Kingdom: Keeping the organic evolution in view, the plant kingdom has been divided into four broad groups viz. Thallophyta, Bryophyta, Pteridophyta, and Spermatophyta. Generally the Thallophytes constitute the most primitive members while most modern plants are placed under the Spermatophyta group.

(i) Thallophyta: These are mostly microscopic, unicellular and most primitive plants without differentiation of root, stem, leaf etc. Algae, fungi, bacteria and diatoms are included in this group. These are rarely fossilised; though, their hard outer cover sometimes accumulate to form rocks.

(ii) Bryophyta: The plants belonging to this group are mostly land plants. Most of them prefer marshy and swampy areas. Plants like liverworts and mosses belong to this group. The mosses develop leaves, stems, trunks and hair-like roots, though, the liverwort are considered primitive because of their thallus-like body without any differentiation. Rhynia is a rare example of a fossilised bryophyta.

(iii) Pteridophyta: These are fern-like plants with distinct roots, stems, branches and leaves. They suck water along with minerals from the soil by its roots and transport it up to their leaves where food is prepared in the presence of chlorophyll with the help of sunlight and carbon dioxide from air. After the food is prepared, it is transported back to all parts of its body. For this purpose these plants specially develop vascular system. Though flowers, fruits and seeds are not developed, they generally propagate by means of 'spores'. Four distinct types of pteridophytes have been recognised and they are ferns, equisetales, lycopodiales and sphenophyllales.

(a) Fern: These are plants with compound leaves and spores. In size, they range from small shrubs to large trees. These were wide spread during Mesozoic era and are preserved in Gondwana rocks.

(b) Equisetales: The trunk of these plants are with nodes and internodes. Leaves are small and develop at the nodes while internodes are marked with vertical striations. They appeared during Mesozoic era and many are found preserved in Gondwana rocks.

(c) Lycopodiales: These are creepers with branches and spirally arranged moss like leaves. The plants of this type originated during Devonian period and are preserved abundantly in the Gondwana rocks of Carboniferous age.

(d) Sphenophyllales: These are herbaceous climbers. Stem jointed with nodes and internodes, leaves arranged in whorls around the nodes. These plants became extinct at the end of the Palaeozoic era. Fossils of these types of plants are found in the rocks of Lower Gondwana period.

(iv) Spermatophyta:- These are most modern plants with distinct root, trunk, branch, leaf, flower, fruit and seed. They propagate through seeds. Sub-phylum Gymnosperms and Angiosperms are included in this phylum.

(A) Gymnosperms: Small evergreen pine like trees with unprotected or naked seeds are included in this category. This sub-phylum includes six classes viz. Cycadophylicales, Cycadales, Cordaitales, Ginkgoales, Coniferales and Gentales.

(a) Cycadophylicales: Though the plants of this group look like ferns, these are with true but naked seeds. The plants of this class form the major bulk of the Gondwana coal deposits. *Glossopteris, Gangamopteris* and *Verebraria* are a few plant fossils found in the Lower Gondwana rocks.

(b) Cycadales: Plants with stout trunks marked by leaf scars. *Ptilophyllum* and *Nilsonia* are a few fossilised cycadales preserved in Upper Gondwana rocks. These types of plants came to exist during the Permian period and are found to live even today.

(c) Cordaitales: Tall trees with large trunk branching at the tip. Leaves with parallel venation and look like swords. This type of plants appeared during end of the Paleozoic era and became extinct before the advent of the Mesozoic era.

(d) Ginkgoales: Plants resembling conifers in appearance with fan like leaves range in age from Permian to Recent. Ginkgoales with worldwide distribution are represented by only one species the *Ginkgo*.

(e) Coniferales: Evergreen trees with needle-like leaves. They range in age from Permian to Recent. At present they are represented today by the pines.

(f) Gentales: These are small trees with a few living representative adopted to desert environment so far not found to occur as fossils.

(B) Angiosperms: These are most modern flowering plants propagating by seeds. The monocotyledon seed germinate with a single leaflet with parallel venation. They are characterized by cylindrical stem and fibrous roots. The palm and grass type of trees are examples of the monocots. The dicotyledon seeds, on the other hand, germinate with two leaflets, generally with reticulate venation. They range from small shrubs to very large evergreen trees of the rain forests.

5.12.2. Evolution and geological distribution of plant kingdom

It is considered that the plants appeared on this earth some times during the beginning of the Palaeozoic era or even a little earlier. This is evidenced from the occurrence of fossils of a few primitive plants in the sedimentary rocks formed at the start of Cambrian period.

The early ancestors of land plants came to live on this planet during Devonian and Silurian periods. The evolutionary process during this period was comparatively slow, hence very few fossils are preserved in the rocks formed during this period.

At the start of the Carboniferous period the plant world evolved rapidly and towards Permian period they attained worldwide distribution. A major part of the land mass was covered with thick forests. The coal deposits and associated plant fossils stand evidence to the above fact.

In India, Glossopteris type plant fossils occur in abundance in the Lower Gondwana rock formations deposited during this periods. *Glossopteris*, *Gangamopteris*, *Gondwanidium*, *Schzoneura* are a few examples of Pteridophytes which were predominating the Indian forests of Lower Gondwana period while during the Upper Gondwana period the dominant plant life was cycadophylicales, which include *Ptilophyllum*, *Williamsonia*, *Otozamites* type of plants. These are a few examples of plant fossils preserved in Gondwana rock formations.

Gradually the gymnosperms became extinct during the Cretaceous period and were replaced by more evolved angiosperms which spread worldwide and dominate the present day landscape.

5.12.3. Description of some important plant fossils

(i) *Glossopteris* (Fig. 5.32)

Phylum- Spermatophyta, Sub-phylum – Gymnosperm
Class - Cycadofilicales, Genus – *Glossopteris*

The frond or leaf is generally large and lenticular in shape with smooth margin and acute apex. In length the leaf grow up to 30 to 40 cm with reticulated venation and prominent mid rib. It is associated with *Vertebraria* type rhizome.

Geological age - Upper Carboniferous to Lower Triassic. Fossils are reported from Lower Gondwana formations.

Fig. 5.32: *Glossopteris*

(ii) *Gangamopteris* (Fig. 5.33)

Phylum-Spermatophyta, Sub-phylum – Gymnosperm,

Class - Cycadofilicales,

Genus - *Gangamopteri*s

The leaf is similar to that of *Glossopteris* in size, but with parallel venation and without a distinct mid rib. It occurs in association with *Glossopteris* and *Verebraria* type rhizome in Lower Gondwana formations.

Geological age - Upper Carboniferous to Lower Triassic.

Fig. 5.33: *Gangamopteris*

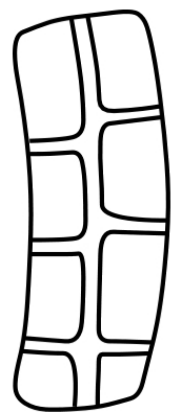


Fig. 5.34: *Verebraria*

(iii) *Verebraria* (Fig. 5.34)

Phylum - Spermatophyta, Sub-phylum – Gymnosperm,

Class - Cycadofilicales, Genus – *Veretbraria*

It is the root associated with both *Glossopteris* and *Gangamopteris* type of leaves. Its body appears to have made up of two rows of bricks giving a look of vertebral column. *Verebraria* fossils are reported from Lower Gondwana formations.

Geological age - Upper Carboniferous to Lower Triassic.

(iv) *Ptilophyllum* (Fig. 5.35)

Phylum – Spermatophyta,

Sub-phylum - Gymnosperm

Class – Cycadales, Genus – *Ptilophyllum*

The compound leaf of this cycad bears small pinnules with entire margin, acute apex and prominent mid rib from where veins are given off. The pinnules overlap on each other and their leaf bases are fully attached to the main rachis. In India, it is reported from all the Upper Gondwana formations.

Fig. 5.35: *Ptilophyllum*

Geological age - Jurassic to Cretaceous.

5.13. SAMPLE QUESTIONS

5.13. 1. Long answer type questions

(i) Give an account of the uses of fossils.

(ii) Describe different modes of fossilization with examples.

(iii) Give an account of the development of modern living world.

(iv) With neat sketches describe the morphology of trilobites.

(v) With neat sketches describe the morphology of brachiopods.

(vi) With neat sketches describe the morphology of lamellibranches.

(vii) With neat sketches describe the morphology of gastropods.

(viii) With neat sketches describe the morphology of cephalopods.

(ix) Give an account of the plant kingdom.

(x) Give a concise account of the geological time scale.

5.13. 2. Write short notes in 3 – 5 sentences

(i)	Fossil	(ii)	Petrification	(iii)	Index fossil
(iv)	Cephalon	(v)	Umbo	(vi)	*Productus*

(vii)	*Spirifer*	(viii)	*Rhynchonella*	(ix)	*Terebratula*
(x)	*Pecten*	(xi)	*Arca*	(xii)	*Conus*
(xiii)	*Physa*	(xiv)	*Natica*	(xv)	Siphuncle
(xvi)	Collumella	(xvii)	*Nautilus*	(xviii)	*Ceratites*
(xix)	*Glossopteris*	(xx)	*Gangamopteris*	(xxi)	*Verebraria*
(xxii)	*Ptilophyllum*	(xxiii)	*Paradoxides*	(xiv)	*Calymene*

(xv) Dentition of Pelecypods (xvi) Suture of Cephalopods

(xvii) Coiling of Gastropods (xviii) Favourable conditions of fossilisation

5.13. 3. Distinguish between the following pairs

(i) Moulds and casts

(ii) Carbonisation and petrification

(iii) Sinistral coiling and dextral coiling

(iv) Thallophyta and bryophyta

(v) Gymnosperms and angiosperms

(vi) Monocotyledon and dicotyledon

(vii) *Glossopteris* and *Gangamopteris*

5.13. 4. Fill in the blanks with appropriate word/ words

(i) Pseudomidrib is characteristic of __________.

(ii) Vegetable matter is converted to coal by _______________ process.

(iii) The hollow space created by complete removal of a fossil is known as __________.

(iv) Fossil excreta are known as ______________.

(v) An index fossil has ______ vertical distribution and _____ geographical distribution.

(vi) __________ is known as geologist's clock.

(vii) Dragonflies are characteristic of ___________________ period.

(viii) ______________ is known as the era of reptiles.

(ix) The Himalayas was formed during _______________ sub era.

(x) Productus is characterized by ______________ valves.

(xi) Pallial sinus is seen in ______________.

(xii) Wing-like projections on either side of the umbones of *Pecten* are known as _____.

(xiii) Each coil of gastropod is known as a____________.

(xiv) The type of coiling in which all the whorls are present in one plane is known as _________.

(xv) Cephalopods with internal shell belong to the subclass ____________.

Answers

(i)	*Gangamopteris*	(vi)	Fossil	(xi)	Lamellibranches
(ii)	Carbonisation	(vii)	Upper Carboniferous	(xii)	Ears
(iii)	Mould	(viii)	Mesozoic	(xiii)	whorl
(iv)	Coprolites	(ix)	Tertiary	(xiv)	Discoidal
(v)	Limited, wide	(x)	Concavo-convex	(xv)	Dibranchia (or Coleoids)

5.13. 5. Answer in one sentences

(i) Define fossil

(ii) In which class of fossils lunule and escutcheon are present.

(iii) Name the phylum and class of *Arca*.

(iv) In which condition the whole organism including the soft parts is preserved?

(v) What is index fossil?

(vi) Name the era when there was no life in the earth.

(vii) What are the functions of lophophore in Brachiopods?

(viii) Name the phylum with largest number of species.

(ix) Name the organ by which a brachiopod attaches itself to the substratum.

(x) Name the organ by which the interior of the Cephalopod is divided into a number of chambers.

5.13. 6. Choose the correct answer

(i) The branch of Geology dealing with the study of ancient organisms is:

(a) Palaeontology (c) Mineralogy

(b) Petrology (d) Stratigraphy

(ii) The type of rock in which fossils are generally preserved is:

(a) Igneous (c) Metamorphic

(b) Sedimentary (d) Lava flows

(iii) The process of conversion of plants into coal is:

(a) Lithification (c) Carbonisation

(b) Petrification (d) Sedimentation

(iv) The number of sub-classes of class Cephalopoda is:

(a) 2 (c) 4

(b) 3 (d) 5

(v) Smooth rounded pebbles found in the rib cages of dinosaurs and crocodiles are:

(a) Boulders (c) Gastrolith*s*

(b) Coprolites (d) Cocoliths

(vi) Biostratigraphic correlation of rocks is done with the help of:

(a) Fossils (c) Radioactivity

(b) Rocks (d) None of the above

(vii) Mesozoic is known as the era of :

(a) Birds (c) Fishes

(b) Reptiles (d) Mammals

(viii) The duration of Cambrian period is about:

(a) 400 my (c) 200 my

(b) 300 my (d) 100 my

(ix) Productus is characterized by the presence of:

(a) Straight hinge line and ears (c) Straight hinge line and without ears

(b) Curved hinge line and ears (d) Curved hinge line and without ears

(x) Glossopteris has:

(a) Parallel venation (c) Both parallel and reticulate venations

(b) Reticulate venation (d) No venation

Answers

(i)	Palaeontology	(vi)	Fossils
(ii)	Sedimentary	(vii)	Reptiles
(iii)	Carbonisation	(viii)	100 my
(iv)	3	(ix)	Straight hinge line and ears
(v)	Gastroliths	(x)	Reticulate venation

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