THE EARTH MATTERS

GEOLOGY

STD ELEVEN

The Constitution of India

Chapter IV A

Fundamental Duties

ARTICLE 51A

Fundamental Duties- It shall be the duty of every citizen of India–

(a) to abide by the Constitution and respect its ideals and institutions, the National Flag and the National Anthem;

(b) to cherish and follow the noble ideals which inspired our national struggle for freedom;

(c) to uphold and protect the sovereignty, unity and integrity of India;

(d) to defend the country and render national service when called upon to do so;

(e) to promote harmony and the spirit of common brotherhood amongst all the people of India transcending religious, linguistic and regional or sectional diversities, to renounce practices derogatory to the dignity of women;

(f) to value and preserve the rich heritage of our composite culture;

(g) to protect and improve the natural environment including forests, lakes, rivers and wild life and to have compassion for living creatures;

(h) to develop the scientific temper, humanism and the spirit of inquiry and reform;

(i) to safeguard public property and to abjure violence;

(j) to strive towards excellence in all spheres of individual and collective activity so that the nation constantly rises to higher levels of endeavour and achievement;

(k) who is a parent or guardian to provide opportunities for education to his child or, as the case may be, ward between the age of six and fourteen years.

The Coordination Committee formed by GR No. Abhyas - 2116/(Pra.Kra.43/16) SD - 4 Dated 25.4.2016 has given approval to prescribe this textbook in its meeting held on 20.06.2019 and it has been decided to implement it from academic year 2019-20.

GEOLOGY

Standard XI

2019

Maharashtra State Bureau of Textbook Production and Curriculum Research, Pune.

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The Constitution of India

Preamble

WE, THE PEOPLE OF INDIA, having solemnly resolved to constitute India into a SOVEREIGN SOCIALIST SECULAR DEMOCRATIC REPUBLIC and to secure to all its citizens:

JUSTICE, social, economic and political;

LIBERTY of thought, expression, belief, faith and worship;

EQUALITY of status and of opportunity; and to promote among them all

FRATERNITY assuring the dignity of the individual and the unity and integrity of the Nation;

IN OUR CONSTITUENT ASSEMBLY this twenty-sixth day of November, 1949, do HEREBY ADOPT, ENACT AND GIVE TO OURSELVES THIS CONSTITUTION.

NATIONAL ANTHEM

Jana-gana-mana-adhināyaka jaya hē
Bhārata-bhāgya-vidhātā,

Panjāba-Sindhu-Gujarāta-Marāthā
Drāvida-Utkala-Banga

Vindhya-Himāchala-Yamunā-Gangā
uchchala-jaladhi-taranga

Tava subha nāmē jāgē, tava subha āsisa māgē,
gāhē tava jaya-gāthā,

Jana-gana-mangala-dāyaka jaya hē
Bhārata-bhāgya-vidhātā,

Jaya hē, Jaya hē, Jaya hē,
Jaya jaya jaya, jaya hē.

PLEDGE

India is my country. All Indians are my brothers and sisters.

I love my country, and I am proud of its rich and varied heritage. I shall always strive to be worthy of it.

I shall give my parents, teachers and all elders respect, and treat everyone with courtesy.

To my country and my people, I pledge my devotion. In their well-being and prosperity alone lies my happiness.

Preface

Dear Students,

Welcome to Standard Eleven!

So far you have learnt Geology as part of Geography. This book presents an extended view to the magnificent world of geology dealing with formation of Solar system, evolution of our planet and the way in which variety of rocks, minerals and landforms are created. It gives me immense pleasure to place this new edition of class XI text book in your hands.

This book is an accessible and comprehensive guide to the important topics in geology, richly illustrated with examples from India in general and the state of Maharashtra in particular. It also includes numerous embedded exercises and activities, designed to encourage the students so as to engage with the concepts presented.

Geologists are scientists who study the structure and dynamics of the Earth and its natural resources. They also review human intervention on the Earth's resources, like metals, oil and gas so that they can be exploited for commercial purposes without much damage to the environment. They are also involved in the conservation of environment and study of climate change. They help analyse natural disasters and ensure safety, suitability and sustainability of sites chosen for mining, construction of roads, tunnels, bridges, dams etc.

The teaching in geology is expected to inculcate analytical skills through observation and understanding of the processes operating on the Earth. Use QR Code / link given in the textbook. The students will find this book interesting and useful for selecting geology as a career option.

(Dr. Sunil Magar)
Director
Maharashtra State Bureau of
Textbook Production and
Curriculum Research, Pune

Pune
Date : 20 June 2019
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Learning Outcomes

- The goal of this book is to introduce students with fundamental knowledge of diverse fields in geology like mineralogy, stratigraphy, geomorphology etc and understand the scope of the subject.
- In addition, it is imperative that the students :
- Learn to think scientifically, analytically and apply scientific methods in their practical work.
- Understand the concept on origin of the Earth and planetary system.
- Know the processes involved in the formation of various types of common surface features.
- Identify the common rock forming minerals and the underlying processes.
- Communicate the geological information, both in classical and common man's language.
- Collect, illustrate and analyse basic geological information from the field.
- Interpret geological maps and construct cross sections.
- Develop and aptitude for detailed understanding of rocks and minerals.
- Communicate observations and interpretation in a geological report.

- For Teachers -

As we know, the subject of geology is highly interdisciplinary and hence teaching geology is a challenging task that needs integration of both theoretical and practical aspects. After the edition published in 2011, there have been tremendous developments in the subject vis-a-vis improvement in methodology of teaching, demanding an update of standard XI geology textbook. The geology teacher therefore, essentially needs to be updated with the latest developments. In this context, following guidelines should be followed to improve the overall teaching of the subject.

- Please refer to Science and Geography textbooks from standard V to standard X before using this textbook.
- To begin with, get familiar with the textbook yourself and enhance the subject by referencing and cross referencing the concepts, adding case studies and updating new information.
- Plan carefully and independently for the teaching of the content and supervising activities in each chapter.
- The present book has been prepared for constructive and activity-based teaching.
- The teaching learning interactions, processes and participation of all students is very necessary and so is your active guidance.
- Use geological aids for appropriate understanding of the concepts.
- Some chapters may be difficult to follow and therefore you are expected to utilize the allotted number of periods fully. Do not finish the chapter in short.
- Major concepts of geology are not easy to understand and have a scientific base. Hence, encourage group work putting in collective efforts. This will help the students to assimilate the content without feeling the 'burden of learning'.
- Facilitate peer learning as much as possible by frequently reorganizing the class structure.
- Please do not teach the lessons in the book by just reading them aloud.
- Follow the order of the chapters as given in the content as the concepts have been introduced in a sequence to facilitate knowledge building.
- Do not use the boxes titled 'Do you know?' for evaluation.
- Use QR Code given in the textbook. Some weblinks have been given at the end of the book.
- Teacher as well as students are expected to use these references. These references will surely help to explore knowledge beyond the textbook.
- The book contains an exercise based on the back cover. Teachers are requested to instruct the students to remove the cover in order to study this page and solve the exercise.
- Please bear in mind that extra reading is always helpful for in depth understanding of the subject.
- Use thought-provoking, activity-oriented, open-ended, multiple choice questions for evaluation. Some examples are given at the end of every chapter.

Contents

Front Page : This page gives the gist of the entire book. Hexagons represent pictures unique to the Deccan traps specific to Maharashtra.

Back Page : Philatelly is the science of study and collection of stamps of minerals. This page represents philatellic mineralogy and mineral nomenclature.

Acknowledgement : Geological Survey of India for maps
A.V.Vartak, SudhaVaddadi, C.Rajeshekhar and Rohit. A.Vartak for Back Cover.

Chapter - 1 Introduction to Geology

Highlights :

- Introduction to geology, its scope, relationship to other branches of science and career prospects.
- Earth as a component of Universe, Milky Way galaxy and our Solar system.
- Major components of the Earth's surface.

Introduction :

The Earth has been observed and interpreted by humans since long. Therefore, the knowledge about the Earth has been gathered through observations and surveys even before any written script. Geology, the science of the Earth, therefore evolved from observations about the Earth. Commonality of such observations and its interpretation laid the foundation of the subject. Knowledge of rocks was implemented since the stone age about 3.3 million years ago (Ma), to select suitable rock type (such as quartzite) for making stone tools. This was followed by human attraction for metals leading to different metal based ages (Bronze age ~ 3000 to 1200 BCE and Iron age ~ 1200 to 1 BCE), while the attraction for gold and silver is everlasting. Hunt for these metals and making of alloys like bronze needed detailed knowledge of rocks and minerals, their occurrences and composition. The modern age of industrialisation further increased the demand for metals as well as fuels like coal, crude oil (petroleum) and nuclear minerals. Ultimately, the demand for professional knowledge of geology led to the development of this subject as a special branch of natural science.

1.1 Definition, importance and branches of geology :

Exploration for the natural resources (as stated above), necessitated the knowledge of rock forming processes. The study of rocks (petrology) and minerals (mineralogy) and their mapping were some of the chief objectives of a geologist. Mining and extraction of metals from minerals required the knowledge of engineering and chemistry, which further led to the development of specialised branches like geochemistry, mining geology and economic geology.

Knowledge of rocks, their distribution and ages evolved the science into many specialised branches like igneous petrology, metamorphic petrology and sedimentary petrology. Spatial and temporal arrangement of rocks and associated fossils (if any) are studied in Stratigraphy. Life being one of the most exclusive components of the Earth system, the study and evolution of life in the form of fossils has interested a large community of observers, biologists, philosophers and scientists, developing the branch of Palaeontology. The study of fossils and their systematic arrangement provided a framework for the geological time scale (Table 1.1). Several well established laws, concepts and methods of physics and mathematics were used time and again resulting into new branches like geophysics. Apart from the most fundamental branches, many applications and specialisations have resulted in applied branches, evolving our professional knowledge on the subject (Table 1.2). Living on the Earth, we all are interested to gain more knowledge about its origin and future.

1.2 Origin of the Universe and formation of the Earth :

In order to understand the origin of the Earth, we need to have some basic knowledge of cosmology (the science of Universe). The Earth is part of our Solar system which itself is located on one arm of the huge Milky Way galaxy (one amongst the billions of galaxies in the Universe). Therefore, however brief, it is necessary to begin with evolution of the Universe to understand the evolution of the Earth. The Universe is all of space and time and its contents, including

Table : 1.1 Geological time scale

Eon	Era	Period		Epoch	Boundary Dates (Ma)
Phanerozoic	Cenozoic	Quaternary		Holocene	0.0117
				Pleistocene	2.58
		Neogene		Pliocene	5.33
				Miocene	23.0
		Paleogene		Oligocene	33.9
				Eocene	56
				Paleocene	66
	Mesozoic	Cretaceous			145
		Jurassic			201
		Triassic			252
	Paleozoic	Permian			299
		Carboniferous	Pennsylvanian		323
			Mississippian		359
			Devonian		419
			Silurian		444
			Ordovician		485
			Cambrian		541
PRECAMBRIAN – Proterozoic	Neo-				1000
	Meso-				1600
	Paleo-				2500
PRECAMBRIAN – Archean	Neo-				2800
	Meso-				3200
	Paleo-				3600
	Eo-				4000
PRECAMBRIAN – Hadean					~ 4600

Note : #1 : Vertical timeline of boundary dates is not drawn with a uniform scale.

Note : #2 : Boundary dates from the International Commission on Stratigraphy 2018 Geologic Time Scale

Table : 1.2

Branches of Geology

Physical geology	Mineralogy	Petrology	Historical geology	Structural geology	Geotectonics	Economic geology	Hydro-geology	Engineering geology	Interdisciplinary geosciences
Geo-morphology and Remote sensing	Rock forming minerals	Igneous petrology	Palaeontology and Micro-palaeontology	Structural geology - (general)	Global tectonics	Ore forming processes	Groundwater geology	Geotechnology	Environmental geology
Neo-tectonics	Ore minerals	Sedimentary petrology	Stratigraphy	Structural geology - (Experimental)	Regional tectonics	Mining geology	Hydro-geochemistry	Engineering seismology	Geophysics
Disaster management	Crystallography	Metamorphic petrology	Paleogeography		Geodynamics	Mineral economics	Watershed development and management	Surveying	Geochemistry
Pedology	Analytical geochemistry	Petrogenesis	Quaternary geology		GPS geodesy	Coal geology		Geotextile engineering	Geotourism
Planetary geology	Industrial mineralogy		Paleoclimatology		Seismo-tectonics	Petroleum geology			Geoinformatics
			Geochronology		Active tectonics	Nuclear geology			Oceanography
			Palynology			Ore dressing			Medical geology
			Paleobotany			Industrial mineralogy			Geostatistics
			Paleoecology						Isotope geology
									Climate change
									Remote sensing and GIS
									Geoarchaeology
									Planetary geology
									Gemology
									Paleoecology
									Palaeobotany

galaxies, planets, stars and every other form of matter and energy. Our Universe is the oldest (13.7 billion years), biggest and is expanding farther and faster. The Universe is filled with dark energy and dark matter apart from the visible matter.

Do you know?

Dark energy is a theoretical form of energy postulated to act in opposition to gravity and to occupy the entire Universe, accounting for most of the energy in it and causing its expansion to accelerate.

Dark matter is a postulated form of matter that is thought to account for approximately 85% of the matter in the Universe, and about a quarter of its total energy density.

In 1927, Belgian Catholic priest, Georges Lemaître proposed the expanding model for the Universe to explain the observed Red Shifts and based upon the Hubble law. Hubble's law (Hubble–Lemaître law) is the observation in physical cosmology which proposed that the objects observed in deep space are moving away from the Earth.

Do you know?

Red Shift : If the source of an electromagnetic wave such as light is moving away from the observer, it undergoes increase in wavelength equivalent to decrease in wave frequency and the phenomenon is called 'Red Shift'. Red Shift is an example of the Doppler effect (shift) named after the Austrian Physicist Christian Doppler, who described the phenomenon in 1942.

Objects in space move apart and is defined as cosmological Red Shift supporting the expanding nature of Universe. Backtracking or reversing this expansion finds the basis for Big Bang theory.

The Red Shift (Doppler Shift/Doppler effect) measured the velocities of various galaxies receding away from the Earth as approximately proportional to their distance from the Earth. In 1929, Edwin Hubble provided a comprehensive observational basis for Lemaître's theory. Hubble's observations revealed that relative to the Earth, galaxies are receding in every direction at velocities directly proportional to their distances from the Earth and each other, thus approving the expanding Universe and the Big Bang theory.

The Big Bang model is presently the most widely accepted and attested theory explaining origin and evolution of the Universe. It states that the Universe began as an immensely hot (>10^{32} degree Kelvin), dense point roughly 13.7 billion years (13.7 × 10^9 years) ago. After an initial accelerated expansion at around 10^{-32} seconds, separation of the four known fundamental forces took place : i) Gravitation – the weakest but infinite force, ii) Weak Nuclear Force – next weakest but short range, iii) Electromagnetic Force – stronger with infinite range and iv) Strong Nuclear Force – strongest but short range. The Universe gradually cooled and continued to expand, allowing the first sub-atomic particles and simple atoms to form. Dark matter gathered under the influence of gravity. Giant clouds of hydrogen and helium were gradually drawn to the places where dark matter was most dense, forming the foundations for first galaxies, stars and solar system.

The Big Bang theory is thus a scientific theory which considers the Universe to begin as very hot, small and dense super-force (the mix of the four fundamental forces) in an entity called 'singularity'.

Do you know?

The step by step evolution of the Universe according to Big Bang theory can be reconstructed as timescale for Universe (refer to page no. 12) similar to Geological time scale (table 1.1).

In geological context, one of the most important processes of the universal evolution is the Nucleosynthesis that explains the build-up of periodic table, as foundation to Earth matter, minerals and rocks. Nucleosynthesis is the process of creating new atomic nuclei from pre-existing nucleons (primarily protons and neutrons). Minerals are the natural compounds of elements from the periodic table. Heavier nuclei were created subsequently by several processes during star formation, known as Stellar Nucleosynthesis. Fusion processes created many of the lighter elements up to iron and nickel. Supernova Nucleosynthesis occurred within exploding stars (called supernova explosion) by fusion and is responsible for subsequent formation of elements between Mg (atomic number 12) and Ni (atomic number 28).

Do you know?

Supernova explosion is an event that occurs upon the death of certain types of stars. Supernova may expel much of the matter away from star at velocities up to 30,000 km/s. This creates shock waves into the surrounding interstellar medium, sweeping up an expanding shell of gas and dust which is observed as a supernova remnant.

The synthesis of heavier elements absorbed energy (endothermic process) from the energy produced during the supernova explosion. Some of the heavier elements were created due to the absorption of multiple neutrons in few seconds during the explosion. The elements formed in supernovas include the heaviest elements such as uranium (U) and thorium(Th).

Do you know?

Heavy elements and heavy metals : A heavy element is an element with atomic number greater than 92. The first heavy element is Neptunium (Np), with atomic number 93. Heavy metals are generally defined as metals with relatively high densities, atomic weights or atomic numbers. In metallurgy, a heavy metal may be defined on the basis of density, whereas in physics the distinguishing criterion might be atomic number, and a chemist is more concerned with their characteristic chemical behaviour.

The origin of the Solar system is explained by most widely accepted theory of planetary formation, the 'Nebular Hypothesis' proposed by Immanuel Kant in 1755 and modified by Pierre Laplace in 1796. It states that the Solar System formed 4.6 billion years ago from gravitational collapse of a Nebula. A stepwise evolution of our solar system is given below:

1) After the collapse of nebular cloud, the mass compressed in the centre and heated due to collision of particles. This happened in less than 100,000 years.
2) The central part then developed into a protostar while rest of the gas flowed in rotatory motion, around the centre. The centrifugal force helped to form an 'accretion disc' in an ecliptic plane and further cooled.
3) The star/protostar further compressed under its own gravity.
4) The accretionary disc continued to cool and formed metals, rocks and ice by the process of condensation.
5) The dust particles collided with each other to form larger and larger particles until they achieved sizes of small asteroids.
6) Some of these particles became big enough to have a representative gravity. They continued to consume the solid matter within their own orbit achieving the status of planetsimals which later became planets.
7) The Sun generated strong solar winds, which swept all the gas left in protoplanetary nebula. However, a large protoplanet like Jupiter pulled-in some nebular gas due to its gravity, while rest of the planets remained rocky or icy.
8) The Solar System was finally complete and composed of planets and asteroids in stable orbits, creating their own system (Fig. 1.1).

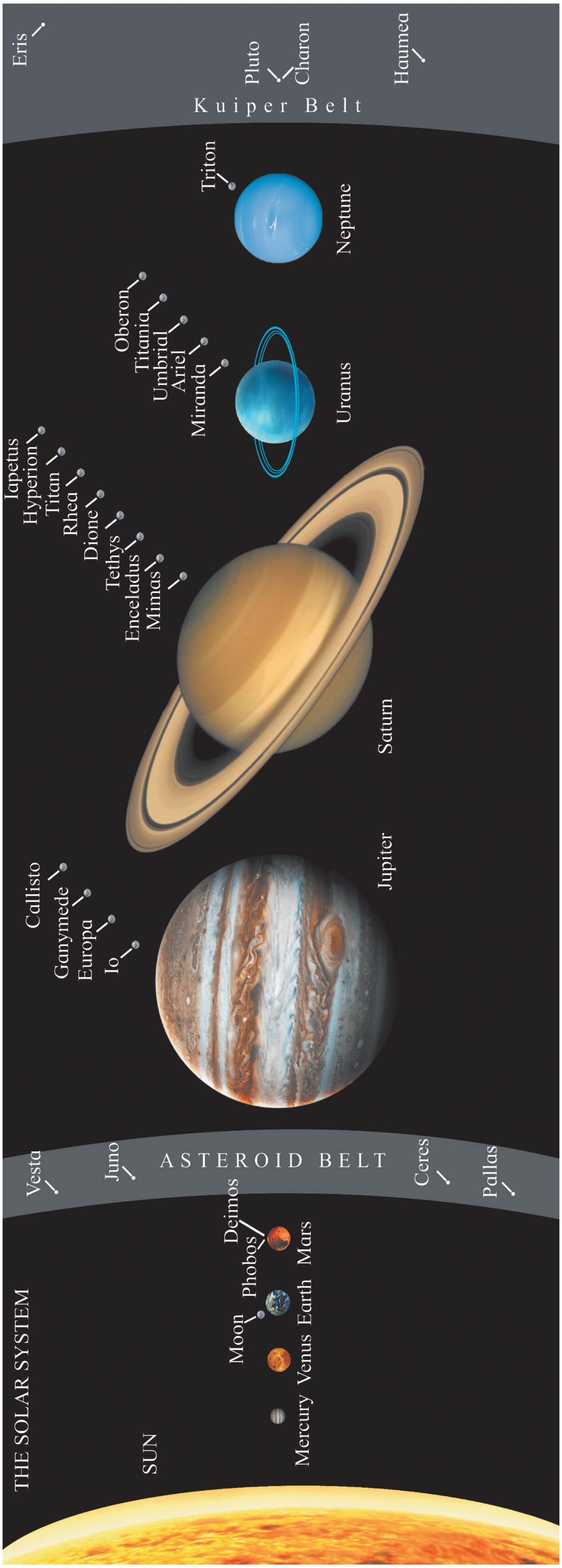


Fig. 1.1 : Details of our solar system

Amongst the planets of our solar system, Earth is unique due to the following characteristics (after Condie 2011) :

1) Earth is the largest and most massive of the four terrestrial planets.
2) Earth is third in distance from the Sun; and along with Mars it ideally falls in the 'habitable zone' of the Solar system.
3) It has a moderately dense atmosphere, about 100 times denser than that of Mars.
4) Earth's atmosphere is the only one having a significant (21%) proportion of molecular oxygen.
5) It is only planet with liquid water on its surface.
6) To the best of our knowledge, it is the only planet in the solar system, that supports living organisms.
7) The only terrestrial planet having a moderately strong magnetic field.
8) The only terrestrial planet having a large satellite, the moon; and without the Moon, the Earth's spin axis would wobble too much to support life.
9) Earth's near-circular orbit results in more or less constant amount of heat from the Sun. If the orbits were more elliptical, the Earth would freeze over in the winter and roast in the summer. In such a case, higher forms of life would not survive.
10) The massive asteroid impact on the Earth in 65 Ma led to the extinction of dinosaurs that probably cleared the way for the evolution and diversification of mammals and the eventual appearance of humans.
11) Without the huge gravity field of Jupiter, the Earth would be bombarded with meteorites and comets and higher life forms would not survive on the planet.
12) In case the Earth was much larger, the force of gravity would be too strong for higher life forms to exist.

13) If the Earth was much smaller, water and oxygen would escape from the atmosphere and higher life forms would not survive.

14) Suppose, the Earth was only 5% closer to the Sun, the oceans would evaporate and greenhouse gases would cause the surface temperature to rise too high for any life to exist (like on Venus today).

15) If the Earth was only 5% farther from the Sun, the oceans would freeze over and photosynthesis would be greatly reduced, leading to a decrease in atmospheric oxygen. Again, higher life forms would not be able to exist.

16) In case the Earth did not have a magnetic field of just the right strength, lethal cosmic rays would kill most or all life forms (including humans) on the planet.

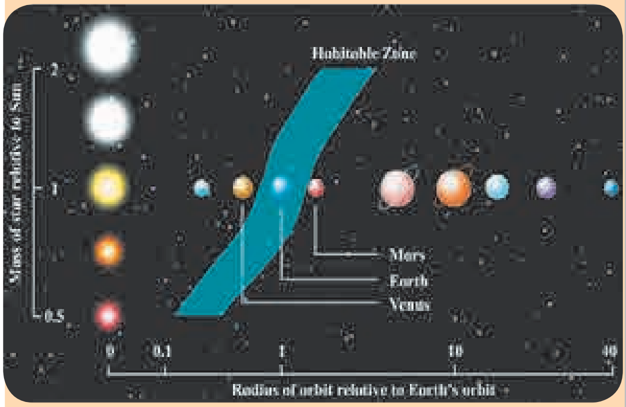
17) If the Earth did not have an ozone layer in the atmosphere to filter out harmful ultraviolet radiation from the Sun, higher life forms would not exist.

18) If the Earth's axial tilt (23° 30') was much greater or smaller, surface temperature differences would be too extreme to support life.

Do you know?

The Habitable Zone : The theory of Habitable Zone also called the Goldilocks Zone or Circumstellar Habitable Zone (CHZ) was developed in 1964 by Stephen H. Dole in his book Habitable Planets for Man. He discussed the concept of CHZ as well as various other determinants of planetary habitability, eventually guessing the number of habitable planets in the Milky Way galaxy. It broadly refers to the area around a star where liquid water could exist on a sufficiently large body.

If we consider the Sun as the only source of energy, this zone looks like a ring around the Sun. Rocky planets with an orbit within this ring may have liquid water to support life. The zone shifts as the Sun changes and evolves. A long time ago, Mars probably belonged to the Habitable Zone since the Sun was brighter during its early age. As the Sun ages its luminosity will grow again and this zone will shift outwards. The Habitable Zone around a single star looks similar to the one in our Solar System. The only difference is the size of the ring. If the star is bigger than the Sun it has a wider zone, if the star is smaller it has a narrower zone.



Depiction of Habitable Zone

If we observe the Earth from the space, the surface of the Earth would be noticed first. The processes operating on the Earth's surface, carving its beautiful landforms and the oceans, would be overwhelming.

1.3 Earth's surface : The Crust

Internally the Earth is layered into Core, Mantle and Crust. Crust being the outermost layer, is observed as the Earth's surface. Major features of the Earth's surface include land (~29.22%) that lies above sea level and the oceans (~70.78%) lying below sea level. When we look at this distribution compositionally, the surface can also be visualised as the crust which can be divided into continental and oceanic crust. The continental crust being lighter (average density 2.7 gm/cm^3) remains above sea level. The oceanic crust being heavier (~3 gm/cm^3) remains below sea level. The density of these two crustal types is the function of their composition. It can be broadly divided into granitic (continental crust) and basaltic (oceanic crust). With this criterion the continental crust comprising ~34.7% includes land, continental shelves and continental regions covered by shallow seas. The oceanic crust is ~ 65.3% comprising of the ocean floor. Both, the continental crust and oceanic crust show a bimodal distribution (Fig. 1.2) with large part of the continental crust lying below ~ 500m upto sea level (= 0m) and a large part of the ocean floor lying ~ 4km below sea level.

The landforms on the Earth's surface explain the processes by which they are formed. The characteristic landform features over the surface of the Earth can be divided into oceanic and continental crusts as given below:

Oceanic crust : Major features

a) **Ocean ridges :** Ocean ridges also called Mid Oceanic Ridges (MOR) are widespread linear rift systems in the oceanic crust, where new lithosphere is formed as the oceanic plates drive away from each other (fig. 1.3). A medial rift valley generally occurs near their crests in which new oceanic crust is produced by intrusion and extrusion of basaltic magmas. The worldwide ocean-ridge system is interconnected from ocean to ocean measuring more than 70,000 km in length.

Do you know?

Iceland is the only place where the Mid-Oceanic Ridge is exposed on the surface, all the others occur below sea level.

b) **Ocean basins :** Ocean basins comprise 38% of the Earth's surface which is more than any other crustal type. They are tectonically stable and are characterized by a thin sediment cover (approximately 0.3 km thick) e.g., Indian Ocean basin.

c) **Volcanic islands :** Volcanic islands occur in ocean basins (such as the Hawaiian Islands). They are large volcanoes on the seafloor whose tops have emerged above sea level (if they are below sea level, they are called seamounts).

d) **Trenches :** Oceanic trenches (Fig. 1.3) mark the beginning of subduction zones and are associated with intense earthquake activity. Trenches run parallel to the island arc systems and range in depth from 5 to 8 km, representing the deepest parts of the oceans e.g. Java - Sumatra trench, Mariana trench.

Do you know?

The deepest part of the Earth's surface is ~11 km below sea level at Mariana trench in the west Pacific Ocean and deepest point is known as Challenger Deep.

Continental crust : Major features

a) **Precambrian shields :** Precambrian shields are stable parts of the continents composed of Precambrian rocks (older than ~540 Ma, Table 1.1), with little or no sediment cover. Shield areas, in general, exhibit little relief and have remained tectonically stable over

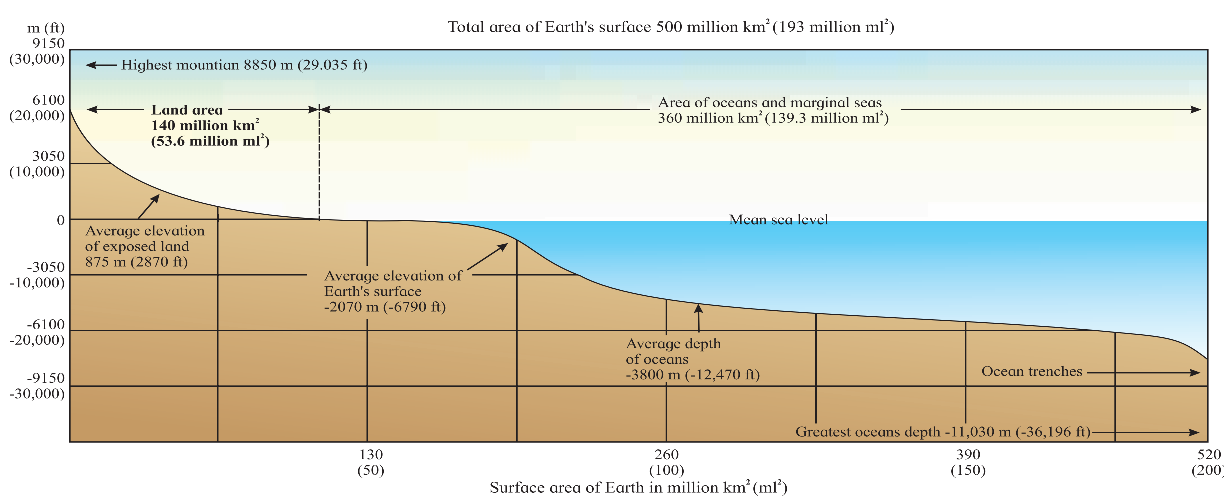


Fig. 1.2 : Hypsometric curve showing bimodal distribution of continents and ocean basins

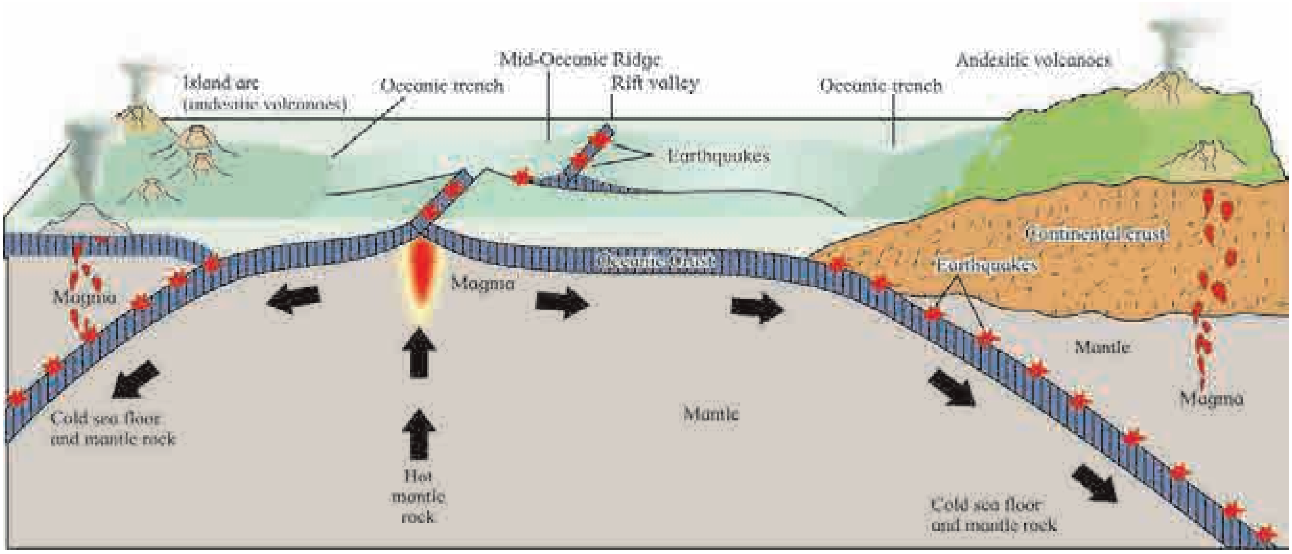


Fig. 1.3 : Important components of the oceanic and continental crust

long periods. They comprise about 11% of the total crustal volume, with the largest shield areas occurring in Africa, Canada, Antarctica and India. Peninsular India comprises a major Precambrian shield.

b) **Platforms :** Platforms are stable parts of the crust with little relief. They are composed of Precambrian basement similar to that in shields overlain by 1 to 3 km of relatively undeformed sedimentary rocks. Shields and the Precambrian basement of platforms are collectively called cratons. Platforms comprise 35% the crustal volume.

c) **Cratons :** Craton is an isostatically positive portion of the continent that is tectonically stable relative to adjacent orogens. Cratons are composed of uplifted, eroded ancient orogens and stable platforms. Dharwar craton of Karnataka is an important example.

d) **Collisional orogens :** Collisional orogens are long, curvilinear belts of compressive deformation produced by the collision of two continents. Collisional orogens range from several thousands (e.g., Himalaya) to tens of thousands of kilometers in length and are composed of a variety of rock types. They are expressed at the Earth's surface as mountain ranges with varying degrees of relief depending on their age.

These are the first order features of landforms and ocean floor. Further the processes like erosion and deposition alter the shape of these primary features of the Earth. These are dealt with in detail in the chapters ahead.

1.4 Scope of geology :

From the historical perspective of a geologist, merely as a mineral explorer, the scope during modern times has greatly increased in several fields like natural disaster assessment and mitigation, exploration and management of: groundwater, petroleum, coal, coal bed methane, gas hydrate, rare Earth and gemstones; geotechnical services for infrastructure developments like dams and tunneling, remote sensing applications, environmental impact assessment, climate change investigation and remediation, geoarchaeology, watershed management studies etc.

The subject of geology is highly interdisciplinary and practical, with imagination for several possibilities in nature. A basic degree in geology develops unique acumen in reporting, managing and solving problems in nature at various scales with experience. Geologists therefore, have a great role to play as an explorer, planner, protector and executor in majority of the Earth works. There is a legacy of great geologists in India like Thomas Oldham (1816-1878), H. B. Medlicott (1829-1905), G. E. Pilgrim (1875 to 1943), E. H. Pascoe (1878-

1949), J. B. Auden (1903-1991), Gansser (1910-2012). In independent India, late D. N. Wadia, M. S. Krishnan, W. D. West and B. P. Radhakrishna had longlasting influence as architects of Geosicence development. There are over dozens of government agencies, many of which are operating under the Ministry of Mines, Ministry of Earth Sciences, Ministry of Water Resources, Department of Science and Technology and CSIR. Several public/private sector companies like ONGC and Coal India Ltd. are operating in the country. A detailed account of these agencies and their scope is given in Table 1.3 and Table 1.2 gives applied as well as fundamental branches of geology.

Do you know?

Eminent Indian geologists :

Prof. D. N. Wadia (1883-1969)

Darashaw Nosherwan Wadia, Fellow of Royal

Society (FRS) was a pioneering geologist in India and among the first Indian scientists to work in the Geological Survey of India (GSI). Wadia obtained BSc degree in 1903 in botany and zoology and another BSc degree in 1905 in botany and geology from Baroda. In 1905 he graduated with M.A. in biology and geology and began to teach undergraduates. He became Professor of Geology at the Prince of Wales College at Jammu at the age of 23. His 'Textbook of Geology' (1919) was the first such updated work for the students of geology in India. In 1928, Wadia became paleontologist at the GSI and after retiring took up an offer from the Government of Ceylon (Sri Lanka) for the post of mineralogist. He was instrumental in the foundation of the Atomic Minerals Division (AMD) for exploring and prospecting raw material for India's atomic energy program. He contributed greatly to the academic and research development of geology in India. He is remembered for his work and ideas on the Himalayan Syntaxis, an important geological concept and structure in the Himalaya. Pro D. N. Wadia was awarded with 'Padma Bhushan'. He is popularly known as 'Father of Indian geology'.

Prof. M. S. Krishnan (1898-1970)

Maharajapuram Seetharaman Krishnan was

the first Indian to serve as Director of the GSI. M. S. Krishnan undertook higher studies availing Associateship of Royal College of Science and Scholarship at Imperial College, London in 1921. He was awarded the Ph.D degree from London University. He was appointed as Assistant Superintendent (geologist) in the GSI, promoted as Superintending Geologist and was posted as Director for the newly formed Indian Bureau of Mines (IBM). He left the post in 1951 to become permanent Director of GSI. After four years, he was transferred to New Delhi as Mineral Adviser and Ex-Officio Joint Secretary to the Government of India (Ministry of Scientific Research) in 1955. In April 1957, he was transferred to Indian School of Mines (ISM) as its first Director to organize the expanded courses in mining and newly started course in Applied Geophysics and Petroleum Technology. Krishnan also served as Head of the Geology and Geophysics Department, Andhra University, Waltair from 1958 to 1960, and was instrumental in the foundation of the National Geophysical Research Institute (NGRI), Hyderabad, of which he was the Director between 1961 and 1963. He published the book 'Geology of India and Burma', a widely used reference book. He was awarded 'Padma Bhushan'.

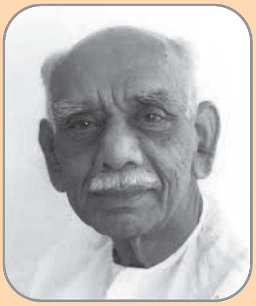
Prof W. D. West (1901-1994)

William Dixon West obtained a first class

degree in Natural Sciences from St. John's College, Cambridge, winning the prestigious Winchester Prize in 1922. In 1923, he joined the GSI and became its Director from

1946 to 1951. At GSI, he created a separate wing for geophysical investigation, exploratory mining and drilling and also for petroleum exploration and Rare Earth minerals. The later wings gave rise to some separate organisations like the Oil and Natural Gas Commision (ONGC) and Atomic Mineral Division (AMD) of the Department of Atomic Energy. He joined the University of Saugar (now Dr. Harisingh Gour Univerisity) as Professor and Head of Department of Applied Geology in 1955. He remained there till the end of his days as a great inspiration for academic and research development of geosciences in India.

B. P. Radhakrishna (1918-2012)



Bangalore Puttaiya Radhakrishna, was a leading geologist of India during modern times. BPR graduated from the Central College, Bangalore in 1937 obtaining BSc (Hons) degree in geology with gold medal and soon after graduation, he joined the Mysore Geological Department as a field assistant at the age of 19 and served as Director for 37 years till retirement in 1974. He was instrumental in great expansion of activities in mineral resource development and the utilisation of groundwater resources. He was the founder member of the Geological Society of India, formed in 1958 for geological research, by providing a forum for free exchange of ideas and media for quick publication of results and wide dissemination of knowledge. He served as the first Secretary for fifteen years and later as the Editor from 1974 to 1992. He contributed towards a series of publications, memoirs, lecture notes, field guide books, mineral resource series and text books of geology. Many symposia, group discussions and field workshops were organised during his tenure as an Editor and President of the Society. He was honoured as Fellow of the Geological Society of London, Fellow of the Geological Society of America and Doctor of Science by the Indian School of Mines (ISM). His work received many distinguished awards including National Mineral Award, Fellow of Indian National Science Academy, National Mineral Award for excellence and 'Padma Shree' by the President of India. He created immense interest in research amongst young geologists.

Activity :

1) Visit a geology department in your area and collect the information on its functions.
2) In a group discussion lead the following topics :

a) Pros and Cons of mining.
b) Role of geology in the economic development of India.
c) Inputs of geology in Civil Engineering, Environmental Science and Geography.
e) Role of geologist in solving the water scarcity problem in India.
f) Alternative theories to Big Bang and Nebular hypothesis.

Summary :

- Geology is one of the oldest branch gathering information about the Earth and has greatly evolved by its integration with other branches of science.
- The subject is deeply rooted in cosmology and begins with the origin of solar system.
- The topography and composition of the Earth's surface is the reflection of ongoing and past geological processes that are further elaborated in the following chapters.
- Geology as a profession has a large scope in many organisations, institutes and industries.

Do you know? **Universe time scale**

Epoch	Time	Radiation temperature	Description
Planck epoch	$<10^{-43}$ s	$>10^{32}$ K	The Planck epoch is dominated by quantum effects of gravity.
Grand unification epoch	$<10^{-36}$ s	$>10^{29}$ K	The fundamental forces are unified described by a Grand unification theory.
Inflationary epoch or Electroweak epoch	$<10^{-32}$ s	10^{28} K ~ 10^{22} K	Cosmic inflation expands the space within ~10^{-33} seconds. The Universe is super-cooled from about 10^{27} down to 10^{22} degree kelvins. The Strong interaction becomes distinct from the Electroweak interaction.
Quark epoch	10^{-12} s ~ 10^{-6} s	$>10^{12}$ K	The forces of the Standard Model separated, but energies were too high for quarks to coalesce into hadrons (these are the highest energies directly observable in experiment in the Large Hadron Collider).
Hadron epoch	10^{-6} s ~ 1 s	$>10^{10}$ K	Quarks are bound into hadrons. A slight matter-antimatter-asymmetry results elimination of anti-hadrons.
Neutrino decoupling	1 s	10^{10} K	Neutrinos cease interacting with baryonic matter. The observable sphere of Universe is approximately 10 light-years in radius at this time.
Lepton epoch	1 s ~ 10 s	10^{10} K ~ 10^{9} K	Leptons and anti-leptons remain in thermal equilibrium.
Big Bang Nucleosynthesis	10 s ~ 10^{3} s	10^{9} K ~ 10^{7} K	Protons and neutrons are bound into primordial atomic nuclei (hydrogen and helium-4). Small amounts of deuterium, helium-3, and lithium-7 are also synthesized. At the end of this epoch, the spherical volume of space as observable Universe is about 300 light-years in radius, baryonic matter density is about 4 grams per m^3 (about 0.3% of the air density at sea level). Most of the energy is in electromagnetic radiation.
Photon epoch	10 s ~ $1.2{\cdot}10^{13}$s (380 ka)	10^{9} K ~ 4000 K	The Universe consists of plasma of nuclei, electrons and photons; temperatures remain too high for the binding of electrons to nuclei.
Recombination	380 ka	4000 K	Electrons and atomic nuclei first become bound to form neutral atoms. Photons are no longer in thermal equilibrium with matter and the Universe first becomes transparent. Recombination lasts for about 100 ka, during which Universe is becoming more and more transparent to photons. The photons of the cosmic microwave background radiation originate at this time.
Dark Ages	380 ka ~ 150 Ma	4000 K ~ 60 K	The time between recombination and the formation of the first stars. The only source of photons was hydrogen emitting radio waves at hydrogen line.
Reionization	150 Ma ~ 1 Ga	60 K ~ 19 K	The earliest modern Population III type stars are formed.
Galaxy formation and evolution	1 Ga ~ 10 Ga	19 K ~ 4 K	Galaxies form 'proto-clusters'. Galaxy clusters beginning at 3 Ga, and into superclusters from about 5 Ga.
Present time	13.8 Ga	2.7 K	Farthest observable photons are the CMB photons. They arrive from a sphere with the radius of 46 billion light-years. The spherical volume inside it is commonly referred to as Observable Universe.

(Ref : Compiled from various data, available literature and Internet resources. K is temperature in degree kelvin, s = seconds, ka = 1000 Years, Ga = Giga years = 10^{9} years also called billion years.)

Table 1.3 : Important geological organizations, public sectors, institutes and industries in India where degrees in geology (B.Sc./M.Sc./Ph.D) is required.

No.	Name of Organization	Major Function
Government Organizations		
1	Geological Survey of India, Kolkata (GSI)	Detailed survey and production of geological maps, mineral exploration.
2	Central Ground Water Board, Faridabad (CGWB)	Groundwater exploration, conservation and development.
3	Indian Bureau of Mines, Nagpur (IBM)	Mining regulation, survey, certification, licensing and methods development.
4	Atomic Mineral Division, Hyderabad (AMD)	Atomic minerals exploration and development.
5	Department of Geology and Mining (various states) (DGM)	Mining exploration, development and licensing.
6	Groundwater Survey and Development Agency, Pune. (GSDA)	Groundwater survey and development.
7	Survey of India, Dehradun. (SOI)	Topographic mapping and production of maps.
8	National Thematic Mapping Organisation, Kolkata. (NATMO)	Thematic map development.
9	Indian Institute of Seismology, New Delhi	Earthquake monitoring and research.
10	Maharashtra Remote Sensing Application Centre, Nagpur. (MRSAC)	Land use planning.
11	National Bureau of Soil Survey and Land Use Planning, Nagpur (NBSS and LUP).	Soil survey and land use planning.
12	Disaster Management Institute, New Delhi (various other places).	Disaster monitoring and mitigation.
13	Defence Terrain Research Lab, Delhi (DTRL)	Defense related terrain research.
14	Central Mine Planning and Design Institute, Ranchi (CMPDI)	Mine plan design, development and regulation.
15	Directorate General of Hydrocarbons, New Delhi (DGH)	Planning and regulation of hydrocarbon exploration.
Public/Private Sector Organisations		
1	Oil and Natural Gas Commission Ltd., Dehradun (ONGC).	Oil exploration and development.
2	Coal India Ltd., and its subsidiaries, New Delhi (CIL).	Coal exploration and mining.
3	Mineral Exploration Corporation Ltd., Nagpur (MECL).	Mineral exploration.
4	Oil India Ltd., Duliajan, Assam (OIL).	Oil exploration and development.
5	Gas Authority of India Ltd., New Delhi (GAIL).	Natural Gas exploration and development.
6	Minerals and Metals Trading Corporation, New Delhi.	Mineral trading.
7	National Mineral Development Corporation, Hyderabad (NMDC).	Mineral exploration and development.
8	Indian Rare Earths Ltd., Mumbai (IRE).	Rare Earth element mineral exploration and development.
9	Manganese Ore India Ltd., Nagpur (MOIL).	Manganese ore exploration and development.
10	Hindustan Zinc Ltd., Udaipur (HZL).	Zinc ore exploration and development.
11	Bharat Gold Mines Ltd., Mysore (BGML).	Gold exploration and development.
12	Hindustan Copper Ltd., Kolkata (HCL).	Copper ore exploration and development.
13	National Aluminum Company Ltd., Bhubaneshwar (NALCO).	Aluminum ore exploration and development.

14	Hindustan Aluminum Company Ltd., Mumbai (HINDALCO).	Aluminum ore exploration and development.
15	National Thermal Power Corporation, New Delhi (NTPC).	Thermal power using coal.
16	Steel Authority of India, Bhilai (SAIL).	Manufacture of steel using iron ore.
17	Neyveli Lignites Ltd., Neyveli.	Lignite coal exploration and development.
	Institutes	
1	CSIR-National Institute of Oceanography, Goa (NIO).	Oceanography Research.
2	Wadia Institute of Himalayan Geology, Dehradun (WIHG)	Research in Himalayan Geology.
3	Indian Space Research Organization, Bengaluru (ISRO).	Earth observation and research.
4	Indian Institute of Science, Bengaluru (IISc).	Geoscience research.
5	National Centre for Polar Ocean Research, Goa (NCPOR).	Antarctic geological research.
6	IIT (Indian School of Mines), Dhanbad (ISM).	Academic and research institute.
7	Indian Institute of Scientific and Educational Research (Various states) (IISER).	Advanced geoscientific research.
8	Indian Institute of Geomagnetism, Mumbai (IIG).	Advanced geoscientific research.
9	Physical Research Institute, Ahmedabad (PRL).	Geoscience academics and research.
10	Indian Institute of Technology (IITs), Various places.	Geoscience research.
11	Birbal Sahni Institute of Paleoscience, Lucknow (BSIP).	Geoscience and paleoclimate research.
12	National Centre for Earth Science studies (NCESS), Trivandrum.	Earth science research and development.
13	Agharkar Research Institute, Pune (ARI).	Natural science research.
14	Geological Society of India, Bengaluru.	Publication and promotion of geoscience research
15	National Institute of Rock Mechanics, Bengaluru.	Rock mechanics and geotechnology research and consultancy.
16	Gondwana Geological Society, Nagpur.	Publication and promotion of geoscience research.
17	Gemological Institute of India, Mumbai.	Gemology training and research.
18	Jawaharlal Nehru Aluminum Research Institute, Nagpur.	Aluminum research and development.
	Industries	
1	Vedanta Group	Mining and Petroleum
2	Reliance Group	Petroleum
3	Tata Group	Mining
4	Oil Field Instrumentation	Petroleum
5	Schlumberger	Petroleum
6	Halliburton	Petroleum
7	L & T Group	Cement and Petroleum
8	Weatherford	Petroleum
9	Associate Cement Co. Ltd	Cement production
10	Adani Group	Mining
11	Birla Group	Cement production
12	Singhania Group	Cement production
13	Dalmia Group	Cement production
14	Jindal Group	Mining and Petroleum
15	Ambuja Group	Cement production
16	Essar Group	Petroleum

EXERCISE

Q. 1. Fill In the blanks :

1) Framework for geological time scale is provided by.................
   a) Study of fossils
   b) Systematic arrangement of fossils
   c) Study of fossils and their systematic arrangement
   d) Stratigraphy and age of fossils.

2) The Metal age is represented by................. :
   a) ~ 3000 to 1200 BCE
   b) ~ 1200 to 1 BCE
   c) ~ 3000 to 1 BCE
   d) ~ 2500 to 100 BCE

Q. 2. Choose the correct alternative :

1) Four fundamental forces that separated after Big Bang are :
   a) Gravitation, weak nuclear force, Electromagnetism and strong nuclear force
   b) Magnetism, Atomic force, Plasma and Dark energy
   c) Cosmic microwave force, Nuclear force, Gravitation and Electromagnetism
   d) Nuclear force, Magnetism, Centrifugal force, Gravitation

2) Choose the correct statement :
   a) Universe gradually cooled and continued to expand
   b) Universe suddenly cooled, expanded and became stable
   c) Universe gradually warmed and continued to expand
   d) Universe gradually cooled and continued to contract

3) Choose the statement that is not true about heavy elements :
   a) An element with atomic number greater than 92
   b) First heavy element discovered is Neptunium
   c) These metals have high density
   d) These metals are alkaline in nature

Q. 3. Arrange the following in correct order :

1) Sequence of events occurring at the time of origin and formation of the Solar system according to Nebular hypothesis.
   i. Planetesimals formed
   ii. Strong solar wind episode
   iii. Cloud collapse
   iv. Protostar formation
   v. Accretionary disc cooled
   a) ii - iii - v - iv - i   b) ii - iii - iv - v - i
   c) iii - iv - v - i - ii   d) i - ii - iii - iv – v

Q. 4. Match the correct pair of periods in the geological time scale and their corresponding span.

A) Paleozoic	i) 3000 Ma
B) Mesozoic	ii) 400 Ma
C) Precambrian	iii) 60 Ma
D) Cenozoic	iv) 150 Ma

a) C - i, A - ii, D - iii, B - iv
b) A - i, B - ii, C - iii, D - iv
c) A - ii, B - iii, C - iv, D - i
d) A - i, B - iii, C - ii, D - iv

Q. 5. Find the odd one out :

i) Outer core   ii) Basins   iii) Mantle   iv) Crust
A) i,   B) ii,   C) iii,   D) iv

Q. 6. Answer in brief :

1) Discuss with scientific attestation the concept of 'Expanding Universe'.
2) Discuss the role of Nucleosynthesis in understanding the Periodic table in general.
3) Give a stepwise account of the Nebular hypothesis.

4) Write at least five characteristics of the Earth that makes it unique amongst other planets.
5) Give reasons why the planet Jupiter was formed as the giant gaseous planet.
6) Discuss the effects of the strong Solar wind during early stages of the planetary formation.
7) What would happen if the Earth's moon is removed from the planetary system?
8) Discuss, why continents lie above sea level whereas the ocean floor is below sea level.
9) Discuss why continental crust is lighter than oceanic crust.
10) What will happen if the Earth's present magnetic field is decreased by about half.
11) What will happen if the Earth's present axial tilt is increased/decreased.
12) What would have happened, if the planet Jupiter with its present mass and gravity did not exist.
13) Discuss the effect of a giant meteorite impact to the life on Earth, with reference to the 65 Ma event.
14) Write a note on interdisciplinary branches of Geology.
15) Elaborate the scope of geology amongst private sectors.

Q. 7. Read the following passage and answer the questions :

Kepler's three laws are purely empirical, derived from accurate observations. In fact they are expressions of more fundamental physical laws. The elliptical shapes of planetary orbits described by the first law are a consequence of the conservation of energy of a planet orbiting the Sun under the effect of a central attraction that varies as the inverse square of distance. The second law describing the rate of motion of the planet around its orbit follows directly from the conservation of angular momentum of the planet. The third law results from the balance between the force of gravitation attracting the planet towards the Sun and the centrifugal force away from the Sun due to its orbital speed. The third law is easily proved for circular orbits. Kepler's laws were developed for the solar system but are applicable to any closed planetary system. They govern the motion of any natural or artificial satellite about a parent body. Kepler's third law relates the period (T) and the semi-major axis (a) of the orbit of the satellite to the mass (M) of the parent body. This relationship was extremely important for determining the masses of those planets that have natural satellites. It can now be applied to determine the masses of planets using the orbits of artificial satellites.

(Source : *Lowrie, Fundamentals of Geophysics 2007*)

1) State whether Kepler's laws can be applied to any other Solar system in the Universe, explain with reasoning.
2) How can the masses of planets having natural satellites be determined?
3) How are the elliptical shapes of planetary orbits explained?
4) Use of Kepler's laws in any modern application of Physics.

❖❖❖

Chapter - 2 Earth's Surface: Processes

Highlights :

- Physical and chemical processes are constantly acting on the surface of the Earth resulting into various landforms.
- Soil is a product of weathering and various factors are responsible for soil formation.

Introduction :

Weathering is a natural process of *in-situ* mechanical disintegration and/or chemical decomposition of rocks and minerals of the Earth's crust. These processes are carried out by certain physical and chemical agencies and are included under the term Geomorphic Processes. The weathered product may remain *in-situ* or get transported.

2.1 Agents of weathering :

The agencies involved in the process of weathering are atmosphere, water and organisms.

2.2 Types of weathering :

There are several processes by which rocks and minerals undergo weathering. These may be classified into two main types, viz. mechanical or physical weathering and chemical weathering.

2.2.1 Mechanical (Physical) weathering :

This is one of the most common geological processes of *in-situ* disintegration of rocks and minerals into smaller fragments without any change in chemical composition. Mechanical weathering is achieved by a number of processes and its nature depends upon the climatic conditions. These processes mainly depend on the predominance of effective agents like temperature changes (frost wedging and exfoliation), and animal/plant activity. The agents of physical weathering are described below.

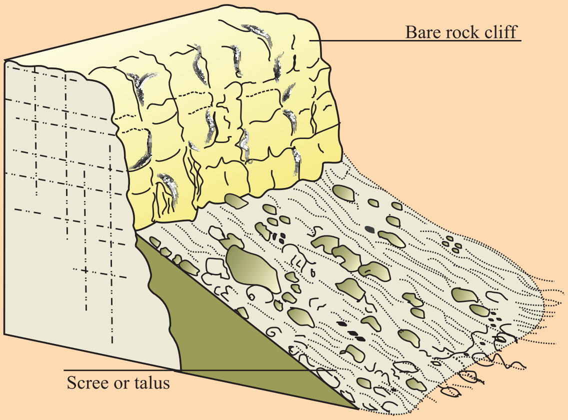
i) **Frost wedging :** The process of freezing of water and thawing of ice due to temperature changes and its effect on rocks is known as frost action. It is confined to regions in higher latitudes and altitudes.

The pores, cracks, fractures and cavities are widened due to subsequent cycles of freezing and thawing, leading to gradual disintegration of rocks. Thus, the affected rocks in such a climate become weak and get fractured.

Do you know?

When water in a fracture freezes, it exerts tremendous pressure on the walls of the fracture or joints due to increase in volume. It is estimated to be about 30,000 pounds per square inch (2109 Kg/cm^2) at 8^{o}C below freezing point.

It is observed that in mountainous region, along steep mountain slopes, such jointed blocks are dislodged from the rock body. As blocks after blocks are dislodged from the slope, they fall and accumulate at the base to form a huge deposit of angular rock fragments. Such deposits are known as scree or talus.



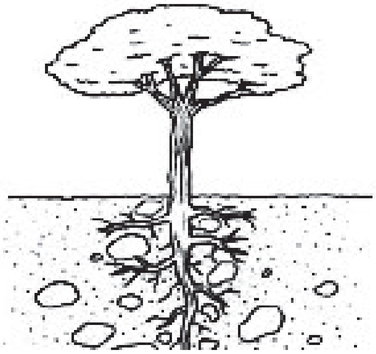
ii) **Thermal effects :** Thermal effect is more common in arid, semi-arid and desert regions where diurnal temperatures in summer and winter vary considerably. Rocks, like many other solids, expand on heating and contract on cooling.

Such repeated variations in temperature gradually break the rocks into smaller pieces, especially the top layers. Tensile stresses developed by alternate expansion and contraction are also responsible for the disintegration of the exposed rocks.

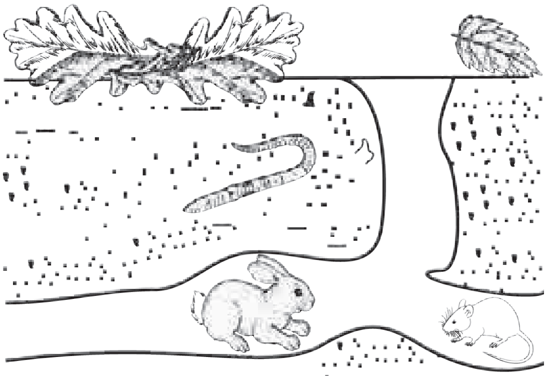
iii) Exfoliation : Exfoliation is the process by which layers peel away from the outer surface of the exposed rock. Rocks which are subjected to such a process, assume a characteristic dome shape. This dome appears like a bald central part surrounded by a number of exfoliated sheets. Exfoliation is mainly observed in plutonic rocks such as granites. When these rocks are exposed on the surface, pressure decreases due to removal of overburden resulting in expansion. This expansion causes fractures, which are generally parallel to the surface of the exposed rock and are at right angles to the direction of expansion (Fig. 2.1).

Fig. 2.1 : Exfoliation

iv) Plants and animals : Plants and various organisms also play a considerable role in rock disintegration directly or indirectly. When plant roots enter rock fractures, they exert pressure. This results in wedging apart of the rock blocks. Lichens and moss open tiny cracks in the rock and loosen the mineral grains. Man is also directly or indirectly responsible for disintegration by various activities such as quarrying and mining. Burrowing animals like earthworms and rodents engage in transferring the soil material to the surface.(Fig. 2.2 A and B).



A) Activity of plants



B) Activity of animals

Fig. 2.2 : Weathering by plants and animals

2.2.2 Chemical Weathering :

It is the process of alteration of rocks by chemical decomposition brought about by atmospheric gases and moisture. Various important chemical processes leading to decomposition of rocks are dissolution, hydration, hydrolysis, carbonation, oxidation and reduction.

Fig. 2.3 : Chemical weathering in limestone

i) **Dissolution :** Water is a universal solvent and number of minerals get dissolved in it. On saturation, precipitation of salts occurs at favourable places. The removal of soluble matter from bed rock by water is termed as leaching and residue is termed as leachates.

e. g. $CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2(HCO_3)^-$

Calcite Carbonic acid Calcium ion Bicarbonate ion

Solution is commonly the first stage in chemical weathering and it removes the most readily soluble minerals. The process depends on pH. SiO_2 is more soluble at pH > 9 while Al_2O_3 is soluble only below pH-4 and above pH-9. Limestones are insoluble in pure water but in presence of dissolved CO_2, calcium carbonate is replaced by calcium bicarbonate which is soluble in water. Calcite in limestones is among the most soluble of common rocks (Fig. 2.3)

e.g. $CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$

Calcite Calcium Bicarbonate

ii) **Hydration :** It is the process whereby certain minerals absorb water into the crystal lattice, e.g. iron oxides absorb water and turn to hydrated iron oxides.

$2Fe_2O_3 + 3H_2O \rightarrow 2Fe_2O_3.3H_2O$

Hematite $\rightarrow$ Limonite

iii) **Hydrolysis :** It is a chemical reaction between the minerals and water. The H^+ and OH^- ions of water react with the ions of the mineral. In hydrolysis, water is a reactant and not merely a solvent.

e.g. The feldspars in coarse grained granite, under hydrolysis, form clay minerals. This process also involves volume expansion .

$2KAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2K^+$

Orthoclase Water Kaolinite Silicic acid

iv) **Carbonation :** This process can occur readily because bicarbonate is nearly always present in sub-surface waters and is also a major component of stream waters. Bicarbonate ion is derived from the photosynthetic fixation of CO_2 and its subsequent respiration by plant roots and bacterial degradation of plant debris.

e.g. $H_2O + CO_2 \rightarrow H_2CO_3$

$H_2CO_3 \rightarrow H^+ + HCO_3^-$

v) **Oxidation :** It is the process of reaction with Oxygen e.g. Ferrous (reduced state) to Ferric (oxidised state).

$4FeO + O_2 \rightarrow 2Fe_2O_3$

It is the process whereby the minerals lose one or more ions or atoms in the presence of oxygen. Oxidation takes place when rock comes in contact with oxygen from air or from water i.e. oxic conditions. Ferrous iron (Fe^{2+}) of the minerals is oxidised to ferric iron (Fe^{3+}) on exposure to moist air (Fig. 2.4).

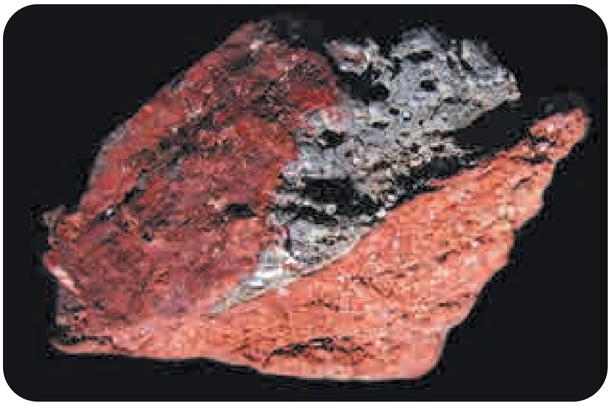


Fig. 2.4 : Oxidation in basalt

vi) **Reduction :** It is the reverse process of oxidation and usually occurs in waterlogged (anaerobic) conditions in the absence of free oxygen (anoxic conditions).

e.g. The reduction of iron to ferrous state makes it more soluble and mobile, hence water from bogs is stained brown by oxides. These oxides are further reduced in the presence of anaerobic bacteria and then converted back to ferric state as the water is aerated and the ferric oxide precipitates as Hematite (Fe_2O_3).

Table 2.1 : Chemical weathering of common minerals and their products.

Olivine $(Mg,Fe)_2SiO_4$	Magnesium dissolves as bicarbonate, iron is oxidized to hematite, silica leached away.
Augite $(Ca,Na,Mg,Fe,Mn,Ti,Al)_2(Al,Si)_2O_6$	Magnesium and calcium dissolve as bicarbonate, alumina and silica form clay on hydrolysis. Under extreme oxidizing conditions, silica is leached away and alumina changes to aluminium hydroxide.
Hornblende $(Ca,Na)_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_2$	
Biotite $K(Mg,Fe)_3AlSi_3O_{10}(OH,F)_2$	Potassium dissolves as bicarbonate, alumina and silica form clay on hydrolysis.
Orthoclase $KAlSi_3O_8$	Potassium dissolves as bicarbonate, alumina and silica form clay on hydrolysis, but under extreme oxidising conditions, silica is leached away and alumina changes to aluminum hydroxide and soluble silica.
Muscovite $KAl_2(AlSi_3O_{10})(F,OH)_2$	Potassium dissolves as bicarbonate, alumina and silica form clay on hydrolysis, but under extreme oxidizing condition, silica is leached away and alumina changes to aluminum hydroxide and soluble silica. It is also a highly resistant mineral and generally does not decompose (Fig.2.5)
Quartz SiO_2	Chemically, it is highly resistant and under normal conditions of weathering, remains unchanged. Under special conditions, quartz may be dissolved by alkaline waters.

2.3 Susceptibility of minerals to chemical weathering :

Minerals within rocks, exhibit varying degrees of resistance to chemical weathering. All minerals in the rock do not decompose with the same degree. Some are more susceptible, while others are resistant to chemical weathering. Apart from carbonate minerals, those minerals which crystallise from magma at higher temperature are more susceptible to decomposition. Susceptibility decreases in minerals which crystallise at lower temperatures. This leads to a regular order of susceptibility of minerals with respect to chemical weathering. Common rock forming minerals are arranged according to their resistance to chemical weathering, as shown in Goldich stability series (Fig.2.5).

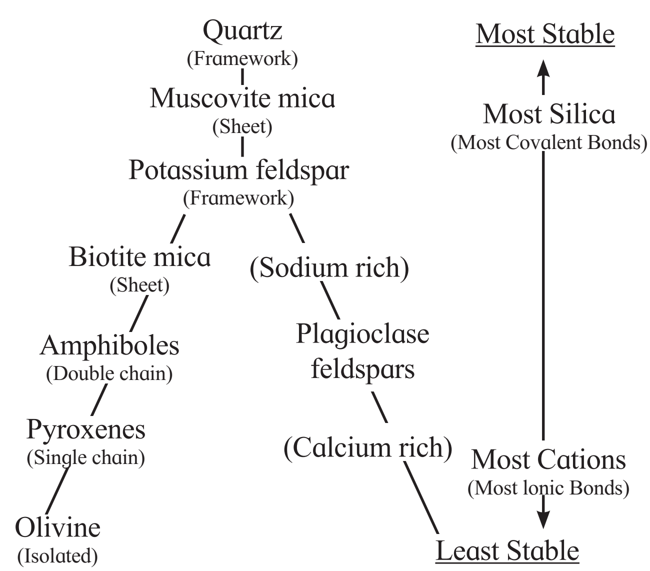


Fig. 2.5 : Goldich stability series

2.4 Factors affecting chemical weathering :

Weathering is affected by variations in factors like nature of rocks, climate, slope and surface area with time.

i) Nature of rocks : Under similar conditions of weathering, different rocks respond differently, e.g., if granite and sandstone are exposed to similar weathering conditions, granite will be more resistant to weathering than sandstone. This is because gases and moisture find easy pathways into the rock mass through the pores in sandstone. Some minerals in the rocks have different weathering susceptibility according to the Goldich stability series.

ii) Climate : The process of weathering is intimately related to the climatic conditions prevailing in an area. Same type of rocks, if exposed to different climatic conditions, show different trends and degrees of weathering. Cold and humid conditions favour both chemical and mechanical weathering, while totally dry and cold climates neither favour chemical nor mechanical weathering. In hot and humid climates, chemical weathering processes predominate, while in hot and arid climate, mechanical weathering is pronounced.

iii) Slope : Steep slope facilitates removal of broken rocks and loose material under the influence of gravity. Rocks on mountain slopes devoid of vegetation are more susceptible to weathering.

iv) Surface area : Greater the surface area, faster will be the decomposition. A non-fractured massive rock will naturally decompose rather slowly.

2.5 Spheroidal weathering :

A common feature observed along many road cuts (specially in Deccan basalt region) is the occurrence of a number of spheroidal or ellipsoidal rock boulders, surrounded by a number of concentric rings of weathered rock material (Fig. 2.6). In many cases, the central boulders present are hard and compact and show very less alteration.

Spheroidal weathering is typically shown by basaltic rocks, where three sets of joints are mutually perpendicular to each other. Such joints divide the entire outcrop of rocks into a number of cuboidal blocks of various sizes. Percolating groundwater surrounds each block and chemical decomposition starts from all sides of the block. The rate of decomposition is not the same everywhere. Along the corners of such blocks, water attacks from three sides. Along the edges, weathering occurs from two sides and along the surface only from one side. As a result, decomposition is relatively fast along the corners and slow along the surfaces. Therefore the shell of the decomposed rock is thickest along the corners and thinnest along the surface. The products of decomposition swell with increase in volume and in due course, the outer decomposed layer detaches itself from the inner undecomposed rock. The inner rock is now subjected to the same process. Repetition of this process develops a number of rings and the size of the inner undecomposed rock becomes smaller and smaller and at the same time it becomes more and more spheroidal. This unaltered rock at the centre is known as residual boulder or core stone. The entire process is known as spheroidal weathering. The iron oxides released by decomposition give a reddish or yellowish tinge to the outer decomposed shell.

Fig. 2.6 : Spheroidal weathering in basalt

2.6 Genesis of soil :

The final product of weathering is formation of soil. Soil is an important natural component of the Earth and its ecosystem. It is an admixture of organic matter, minerals, gases, liquids and organisms that together support life. Study of soil is called as 'Pedology' and the layer of soil on the surface of the Earth is known as 'Pedosphere'.

Geologists define soil as a naturally occurring material which is in the form of layers or horizons of varying thicknesses. These layers have evolved from the surface weathering of the Earth's crustal material. A typical soil consists of 50% solids (45% mineral and 5% organic matter), and ~50% voids (or pores) which are occupied by water and air.

2.6.1Soil Profile :

Given sufficient time, an undifferentiated soil will evolve as a soil profile. It consists of several layers, referred to as soil horizons. The vertical exposure of soil horizons is referred to as a 'Soil Profile'. These horizons differ in their texture, structure, density, porosity, consistency, colour and reactivity. The horizons show variable thickness and generally lack sharp boundaries. The biological influences on soil properties are strongest near the surface. The chemical influences decrease with depth. Mature soil profiles typically include three basic horizons: A, B, and C. The living component of the soil is largely confined to the O, A and B horizons (Fig. 2.7).

2.6.2 Soil Horizons :

O Horizon : It consists of thin organic layers of decaying plants, animal tissues and is saturated by water. It is the top layer in places covered by vegetation.

A Horizon : It is the top soil and consists of mostly minerals from parent material with organic matter. It is also called as mineral horizon. This is generally the most productive layer of the soil. Conservation efforts are focussed here.

B Horizon : It is rich in minerals that have leached from horizons 'O' and 'A'. The horizon is usually lighter in colour, dense and low in organic matter. It is the zone of accumulation of clays and colloids.

C Horizon : It is the zone of soil consisting of partly decomposed bedrock underlying the B horizon. It grades downwards into fresh, unweathered bedrock.

D or R Horizon : Below the C horizon, the unweathered rock basement is present. This is the bedrock horizon.

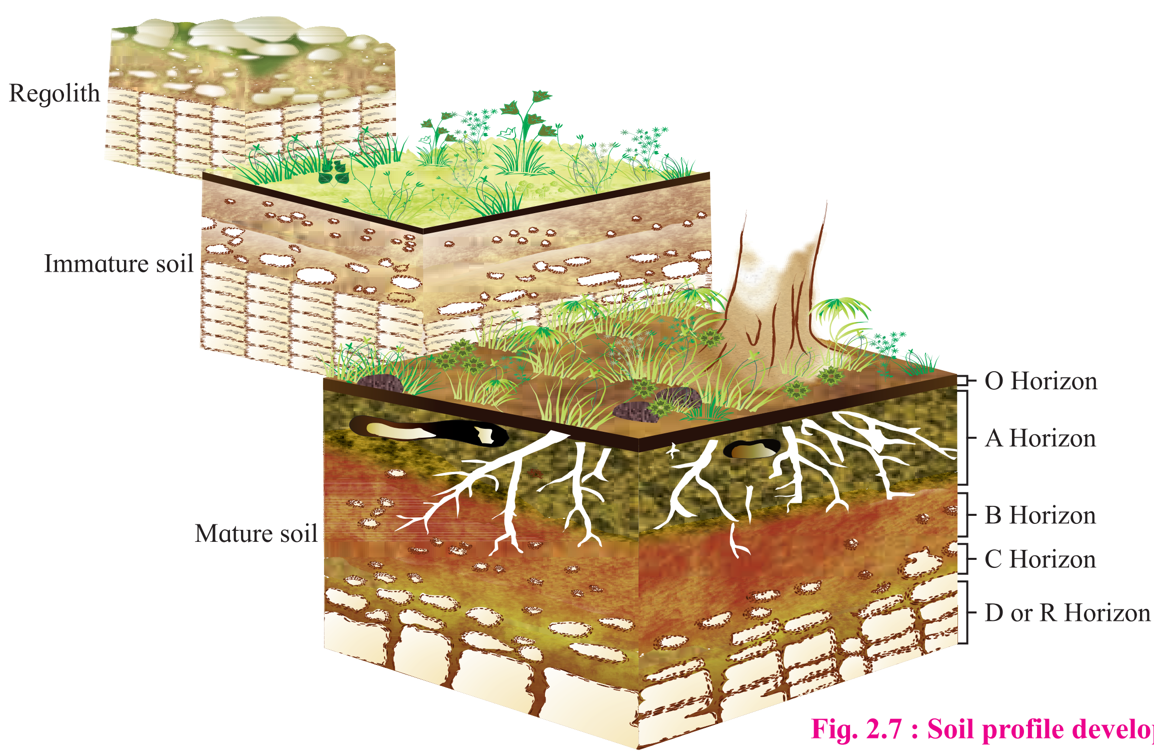


Fig. 2.7 : Soil profile development

2.6.3 Factors affecting soil formation :

Soil formation is influenced by five main factors that are intertwined in the evolution of a soil. They are: climate, organisms, topography (relief), parent material and time.

i) **Climate :** The principal climatic variables influencing soil formation are effective precipitation and temperature. Both affect the rates of chemical, physical, and biological processes. In humid tropical climates, rate of weathering and erosion is rapid.

ii) **Organisms :** Plant and animal activity produces humic acids that are powerful weathering agents.

Plants can physically as well as chemically break down the rocks. Plants stabilize soil profiles. Animal and human activites tend to increase soil erosion, by disturbing the soil profile.

iii) **Topography :** The topography or relief is characterized by the slope, elevation and orientation of the terrain. Steep slopes encourage rapid soil loss. Therefore, soils on steep terrain are shallow, poorly developed as compared to soils on gentle or flat terrain.

iv) **Parent material :** The mineral material from which a soil forms is called parent material. As the parent material is chemically and physically weathered, transported, deposited and precipitated, it is transformed into a soil.

v) **Time :** Typical reaction rates are slow, the longer a rock unit has been exposed, the more it is likely to be weathered.

2.7 Soil erosion and conservation :

Soil erosion is the displacement of the upper layer of soil. This layer is most fertile because it contains most organic and nutrient rich materials. Soil erosion takes place due to factors such as water, wind and tillage of farmland.

Soil conservation is the prevention of soil loss by erosion or reduced fertility caused by over-usage, acidification, salinisation or other chemical soil contamination processes. Slash-and-burn and other unsustainable methods of subsistence farming are practiced in some lesser developed areas. A sequel to the deforestation is typically large scale erosion, loss of soil nutrients and sometimes total desertification.

Soil conservation is the name given to a handful of techniques aimed at preserving soil. Soil loss and loss of soil fertility re-mediated by methods of conservation like reforestation, crop rotation, contour ploughing and building terraces.

Do you know?

Black soils of Maharashtra : The soils of Maharashtra are residual, derived from the underlying basalt. These are generally called as black cotton soil (regur) which is clayey, rich in iron and moisture retentive, but poor in nitrogen and organic matter. Black soils of upland are of low fertility but they are darker, deeper, and richer in valleys. Due to their high fertility and retentivity of moisture, black soils are widely used for producing several important crops.

Activity :

1) Take a photograph of a soil profile along a road cutting pit or excavation and draw the vertical soil profile digram and describe.
2) Visit nearby soil testing lab and gather information about various properties of soils.

Summary :

- The exogenic and endogenic processes govern the Earth's surface. These processes are continuously operating as rock cycle (described in chapter 4).
- Study of soil helps to understand the composition of parent rocks and the long term climates experienced by it.

EXERCISE

Q. 1. Fill in the blanks :

1) The process of freezing and thawing of water due to temperature changes and its effect on rocks is known as................. .

2) Vertical exposure of soil horizons is referred to as a................. .

Q. 2. Fill in the blanks using the correct options :

1) Development of spheroidal weathering is independent of ....

   a) rock type

   b) chemical decomposition

   c) percolating water

   d) joints mutually perpendicular to each other.

2) Mechanical weathering is more pronounced in .... climate.

   a) hot and humid   b) hot and arid

   c) cold and humid   d) wet and humid

3) The most common type of mechanical weathering is...............

   a) sheeting

   b) thermal expansion and contraction

   c) oxidation

   d) action of burrowing organisms

4) The mineral calcite in limestone is transported in water during............. process.

   a) oxidation   b) reduction

   c) dissolution   d) frost action

Q. 3. Choose the correct alternative :

1) Statement that is true regarding chemical weathering.

   i) All the minerals in the rock decompose with the same intensity/rate

   ii) Minerals crystallizing at lower temperature are more susceptible to decomposition.

   iii) Minerals crystallizing at higher temperature are more susceptible to decomposition.

   iv) Minerals in the rock offer same degree of resistance to chemical weathering

2) Which of the following statement is incorrect?

   i) Plants stabilize soil profiles.

   ii) Animals tend to increase erosion.

   iii) Steep slopes encourage rapid soil loss.

   iv) Study of soil is called 'Pedosphere'.

Q. 4. Find the odd one out :

1) i) The weathered product may remain *in-situ* or get transported.

   ii) Process of freezing and thawing of water gives rise to frost wedging.

   iii) Thermal effect is more common in arid, semi-arid and desert regions.

   iv) Soil is a naturally occurring material which is in the form of layers .

   a) i   b) ii   c) iii   d) iv

2) i) Temperature, wind, basalt, glaciers, organisms.

   ii) Dissolution, hydration, hydrolysis, carbonation, erosion.

   iii) O Horizon, A Horizon, B Horizon, C Horizon.

   iv) Cracks, fractures, cavities, joints.

   a) i   b) ii   c) iii   d) iv

Q. 5. Give geological terms for the following :

1) Parent material from which soil is formed.

2) Mechanical weathering of rocks due to freezing and thawing of water within fissures or cracks.

3) The process by which layers peel away from the outer surface of the exposed rock.

4) Type of weathering resulting in the formation

of concentric rings of weathered rock material surrounding a central boulder.

Q. 6. Answer in brief :

1) Discuss the role of topography in soil formation.
2) How are processes of mechanical weathering and chemical weathering complementary to each other?

Q. 7. Answer in detail :

1) Explain the process of oxidation and reduction in chemical weathering.
2) Describe the factors affecting weathering.

Q. 8. Read the following passage and answer the questions :

Panchgani is well-known for its impressive tableland, string of mesas and is a popular getaway for tourists from Mumbai and Pune. The flat-topped hills are the result of differential erosion The mesas and the tableland are built of flat-lying caprocks and are scarp-bound on all sides. The ferricrete duricrusts (or laterites) act as the caprock. The mesa tops are featureless. There is evidence of pseudo-karstic activity and mechanical disintegration of the crust rim. The broadly accordant heights of the mesas suggest that they were formed due to the breaching and fragmentation of an extensive lateritised surface and subsequent back-wearing of the cliffs The formation of mesas appears to be a three stage process: formation of lateritised surface, breaching and fragmentation of the lateritised surface by stream incision, and slope retreat and circum-denudation of isolated patches.

(Source : *Kale V. S, 2014 in Kale (edited).*)

1) Describe the process by which flat- topped hills and tableland have been created in Panchgani area.
2) What is the role of stream incision in creating a typical landscape of the Panchgani and similar such areas of Maharashtra?
3) Why does the author consider the formation of mesas as a three stage process.

Chapter - 3 Earth's Surface : Landforms

Highlights :

- The processess that create and shape the various landforms visible on the surface of the Earth and the characteristics of such landforms are studied.
- Landforms created due to erosional and depositional processes by water, wind and ice are explained.

Introduction :

Amongst all the known planets of the Solar system, Earth is unique. It is probably the only planet whose surface is being continuously renewed. When compared to the Moon, the Earth's surface is much younger, though the two formed around the same time. This chapter lists and explores a few of the important forces that continually reshape Earth's surface, leading to the formation of varied surface landforms, many of them unique to our planet.

You have studied and understood the two key processes weathering and erosion, responsible for reshaping the Earth's surface. Most weathering processes involve running water. Wind, glaciers and biological agents also play a significant role. Weathering as a process does not give rise to magnificent landforms, it helps the process of erosion. Water, wind and ice work relentlessly to erode i.e. carve and flatten our planetary surface, resulting in erosional landforms. It was as early as 1546 when Agricola, a German physician, recognized the importance of water as the most powerful erosive agent. Water along with wind and ice also transports material to places of deposition giving rise to spectacular depositional landforms.

Do you know?

Air and water differ from ice in that they are both fluids. Viscosity is a measure of a fluid's resistance to flow. Wind has a low viscosity; while water has greater viscosity than wind. Ice "flows" but only by melting and refreezing as it moves over a surface.

Activity :

Try moving the open palm of your hand through air and then through water in a bucket. You will note the effect of density difference on your hand. Blow air on a sheet of paper several times. You can tell that the faster the air blows, more is the force exerted on the paper. Now direct a stream of water against the paper with the same velocity as the air. The force striking the paper would be 800 times as great because water is 800 times denser than air.

3.1 Erosional and depositional landforms :

Water and wind are the most important agents of erosion and deposition. The processes that shape the landscape in areas where there is little or no rain differ from those at work in moist regions. Dry landscapes, where there is rarely a covering of soil or the action of rivers to smoothen the contours, consist of mainly bare rock, sharp cliffs, and dry valleys. The most active agent of erosion as well as deposition in a dry arid environment is therefore wind.

The wind patterns of our planet are determined by :

i) **Variations in solar radiation :** The amount of solar radiation received on Earth, varies with respect to latitude because of the angle at which solar radiation strikes different latitudes. When the Sun's rays strike the Earth's surface near the equator, the incoming solar radiation is more direct i.e. it makes an almost perpendicular angle with the surface at the equator. At higher latitudes, the radiation makes a smaller angle with the surface of the Earth. This results in cooler average surface temperature at regions away from the equator and warmer average surface temperatures near the equator.

ii) **Coriolis effect :** The coriolis effect is an apparent deflection of the path of an object that moves within rotating co-ordinate system. On Earth, any object (wind, water) that moves along a north-south path (or longitudinally) will get deflected to the right in the Northern hemisphere and to the left in the Southern hemisphere. This happens because :

1) The Earth rotates eastward
2) The tangential velocity at a point on the Earth is a function of latitude.

Gravity : It is one of the most important force in transportation and deposition of the sediments. During transport it can further erode landform as seen significantly in glacial and fluvial processes.

3.2 Fluvial (Riverine) landforms :

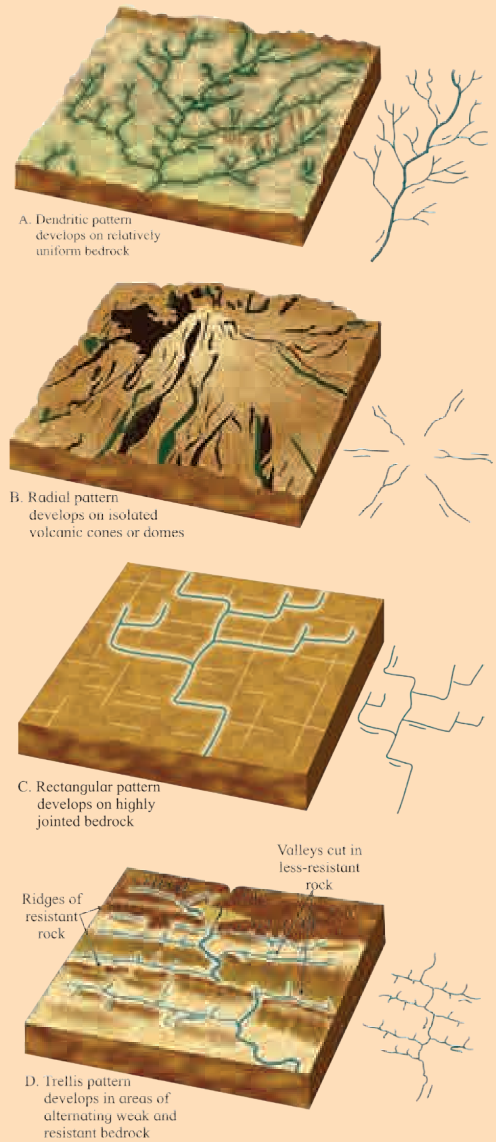
Fluvial landforms are controlled by river systems. A river system is a network of connecting channels through which water precipitated on the surface is collected and transported back to the ocean. At any given time, about 1300 cubic km of water flows in the world's rivers. Rivers are one of the most powerful agents of erosion on our planet. They also transport and deposit enormous amounts of alluvium. A river system is made up of a main channel and all of the tributaries that flow into it, and can be further divided into three subsystems :

1) **Collecting system :** It consists of the network of tributaries in the catchment area that collect water and carry it along with sediments to the main stream. The tributaries usually form a dendritic or tree like drainage pattern, with numerous branches that extend upslope.

2) **Transporting system :** It is the main trunk stream which functions as a channel through which water and sediments flow from the catchment area towards the ocean. The major process operating in this region is transportation, but deposition also takes place when the channel meanders and the river overflows its banks.

3) **Dispersing system :** It consists of a network of distributaries at the mouth of the river which disperse the sediments and water in the ocean, lake, or a dry basin.

Do you know? Drainage patterns



Drainage patterns of rivers

Do you know?

Bramhaputra and Sindhu (Indus) rivers are actually longer than Ganga, but the distances they cover in India are lesser than that of Ganga. Hence, Ganga is the longest river of our country. It is also the third largest river of the world by discharge.

3.2.1 Fluvial erosional landforms :

Erosion of land is one of the major processes associated with fluvial systems. It has occurred on this planet throughout the geological time and will continue to operate as long as the river system exists and the land is exposed above the sea level. The evidence of erosion is ubiquitous and varied. It can be observed in the thick layers of sedimentary rocks that cover a large part of continents and bear witness to the extensive erosion and deposition that took place over the ages. Erosion by rivers can be accomplished by three basic processes :

A) Removal and transport of regolith : Loose rock debris or regolith is washed downslope into the drainage system and is transported as sediment load in streams and rivers.

B) Downcutting of stream channel : It is a fundamental process of erosion in all stream channels, accomplished by the abrasion of channel floor by sand and gravel, as the channel is eroded downstream by flowing water.

C) Headward erosion : The tendency of rivers to erode headward (upslope) and to increase the lengths of their valley until they reach the divide.

The above processes give rise to the following fluvial erosional landforms :

1) Valley : A valley is a low area between hills or mountains, often with a river flowing through it (Fig.3.1). Valleys are gradually carved out by rivers with the aid of weathering and mass movement of debris (erosion).

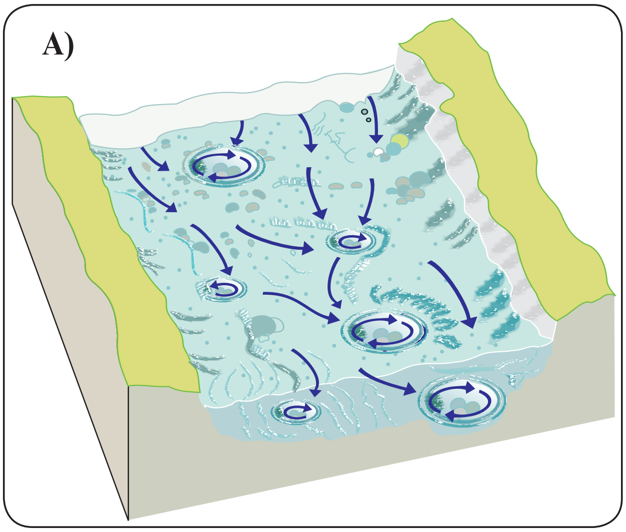
Fig. 3.1 : Zanskar valley, Jammu and Kashmir

2) Gorge : A gorge is a narrow, deep valley with steep, rocky walls (Fig. 3.2). It is formed due to down cutting action of the river over a long period of time.

Fig. 3.2 : River Penna gorge, Gandikota, Cuddapah district, Andhra Pradesh

3) Waterfall : A waterfall is a feature characterised by a sudden drop in the channel profile of a stream or river. A waterfall is commonly found in areas where differential erosion of soft and hard rock has resulted in a step like feature where water flows down the step with great force.

4) Potholes : Potholes are deep holes (Fig. 3.3 A, B) created by drilling action of sand, gravel, pebbles and boulders trapped in a depression and swirled around by currents. It is an effective and interesting type of abrasion. As the pebbles and cobbles are worn away, new ones replace them and continue drilling the bedrock of the river channel, thus deepening the potholes.



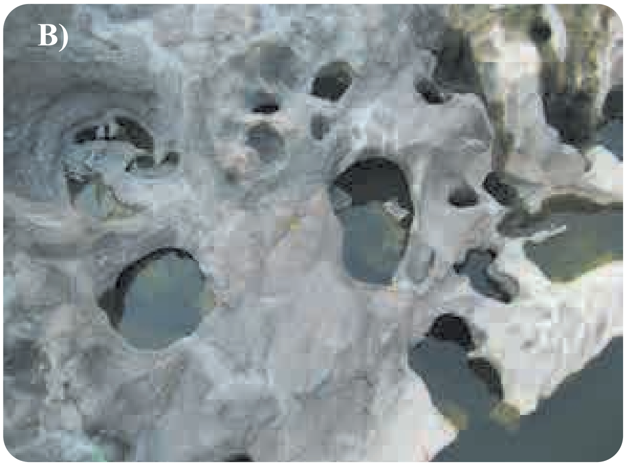


Fig. 3.3 : A) Process of pothole formation, B) potholes at Nighoj, Kukadi River, Maharashtra

5) **Meandering river channel :** All rivers have a tendency to flow in a sinuous pattern, owing to the bends in the river channel. The irregularities in the river channel deflect the flow of water to the opposite bank, where the sheer force of flowing water causes erosion and undercutting of the bedrock.(Fig. 3.4 A). With time, the bend grows larger and is accentuated, eventually growing into a large meander. Erosion takes place on the outside bend of the meander where velocity is greatest (Fig. 3.4 B, C), whereas deposition takes place on the inside of the meander, where velocity is low.

Activity : Visit a sandy sea shore during low tide. Observe how the sea water drains out of the beach sand. You will see miniature drainage channels and features like tiny meanders, braiding of stream channels etc. developing in a short duration of time. (NOTE : This activity is to be carried out under teacher/parental supervision).

6) **Oxbow lake :** As a meander bend becomes accentuated, it develops an almost complete circle. Eventually the river channel completely abandons the old meander loop, which remains as a crescent shaped lake known as an Oxbow lake (Fig. 3.4 C, D).

3.2.2 Fluvial depositional landforms :

In lower parts of a river system (i.e. the transporting and dispersing systems) the gradient of the river becomes very low, due to which the stream velocity reduces and the river deposits its sediments. Most large rivers are always muddy. In some cases, the weight of the sediment exceeds the weight of water present in the river. Deposition of sediments in the lower transporting and dispersal segments of the river

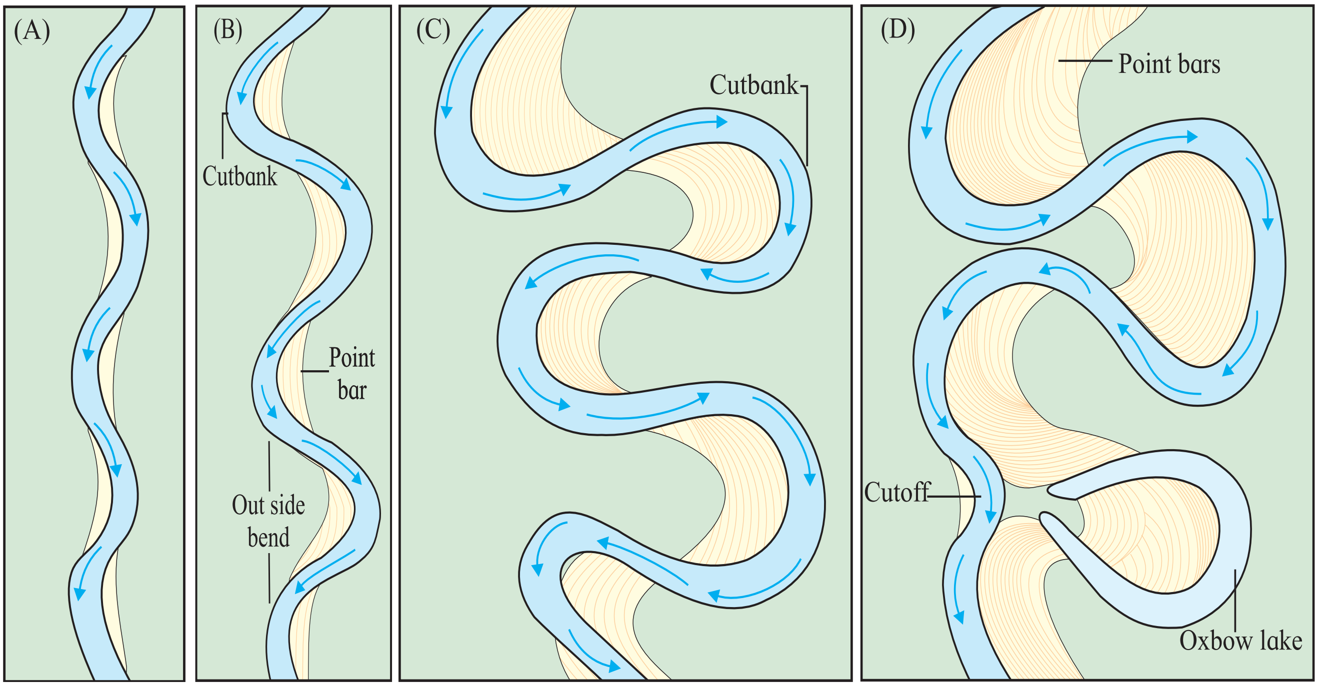


Fig. 3.4 : A, B, C, D Stages of development of meandering river and the formation of oxbow lake

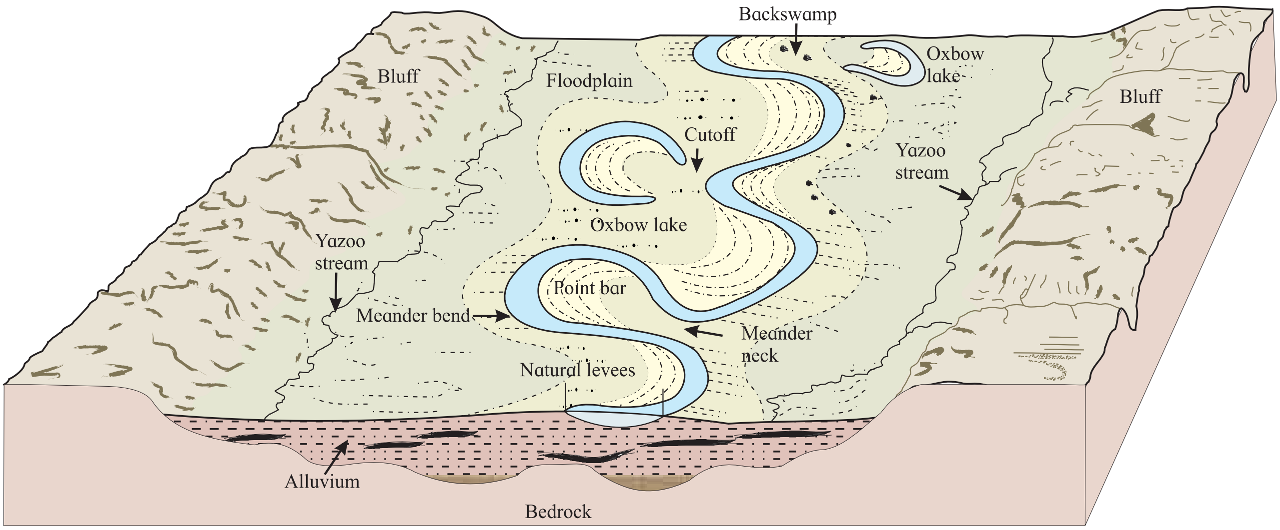


Fig. 3.5 : Major features of a floodplain

creates prominent and distinctive landforms. (Fig. 3.5). If a river carrying silt, sand and gravel loses energy, it slows down on a gentler gradient. The coarser fragments i.e. gravel will get deposited first, followed by sand and silt. The following fluvial depositional landforms are observed in nature :

1) **Floodplain :** It is a flat surface, formed due to extensive sediment deposition, over which a stream flows. The base of a floodplain can be a gently sloping surface which is covered with large quantities of sediment. During high floods, a floodplain may be completely covered with water.

2) **Natural levees :** They are high embankments on either side of a river. They form when a river overflows its banks during flood stage and the water is no longer confined to a channel, but flows over the flood plain. This unchanneled flow reduces the flow velocity significantly, and some of the suspended sediment settles down. The coarsest material deposits first, i.e. closest to the channel, followed by finer particles.

3) **Point bar :** It forms on the inside bend of the meander where deposition takes place. On the inside of the meander, the velocity is at a minimum and some of the sediment is deposited on the point of the meander inner bend.

4) **Alluvial fans :** An alluvial fan is a fan-shaped fluvial deposit, found in dry lands, which consists of coarse detrital sediment. It is usually found in areas where a steeper slope passes abruptly into a gentle slope, for example, a mountain front. The river dumps its sediments at the point where the gradient changes from steep to gentle and the sediments spread out forming a fan-shape, hence called alluvial fans (Fig. 3.6).

Fig. 3.6 : Alluvial fan

5) **Delta :** Delta is a triangular fluvial deposit formed when the river enters a lake or the sea. As the river enters the sea, it slows down and its sediment carrying capacity decreases. This leads to the river dumping its sediments in the sea, forming a huge fan of alluvial deposits. There are three types of deltas : (Fig. 3.7 A, B, C), arcuate, cuspate and bird-foot.

Fig.3.7 **A) Arcuate delta :** These deltas have an arc shaped coastline. e.g. Ganga delta, India.

Fig.3.7 **B) Cuspate delta :** These deltas have a kite like appearance because the material is deposited evenly on either side of the main channel. e.g. Ebro delta, Spain.

Fig.3.7 **C) Bird-foot delta :** These deltas have a ragged coastline due to which they have a bird foot like appearance. e.g. Mississippi delta, USA.

3.3 Coastal landforms :

Coastal landforms are formed due to movement of water by wind generated waves, tides, tsunamis and a variety of density currents. Water in oceans and lakes is in constant motion, as it moves, it constantly modifies the shores of all the continents and islands of the world. Coastline processes can change in intensity from day to day, and from season to season, but they never cease to operate. Nearly all of the world's present shorelines were profoundly affected by the rise in sea level caused by the melting of the glaciers during late Pleistocene.

Coastal systems are complex open systems wherein the principal sources of energy are a) wind generated waves, which is the driving force behind erosion, transportation and deposition and b) gravity, as its influence is felt in tides and near shore currents.

A number of processes are responsible for shaping up coastal landforms :

Wave refraction : Concentrates energy on headlands and disperses it in the bay (Fig. 3.8).

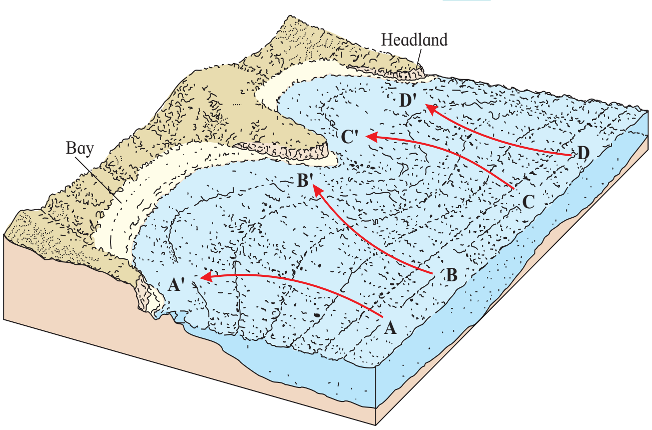


Fig. 3.8 : Wave refraction

Longshore drift : is generated when waves strike the shore obliquely. The sediments present in water move up the beach slope diagonally, but the backwash of the waves carries the particles back down on the beach-face at right angle to the shoreline. This movement results in a net transport parallel to the shore. Therefore an enormous amount of sediment constantly moves parallel to the shore (Fig. 3.9).

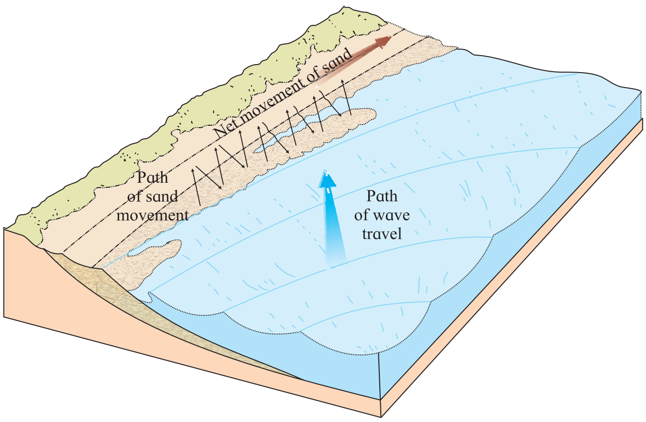


Fig. 3.9 : Longshore drift

Do you know?

Influence of longshore drift on human activities in Ratnagiri, Maharashtra :

Ratnagiri is a picturesque coastal town along the coast of Maharashtra and is the district headquarters of Ratnagiri. It is an ancient sea-port. The port being open to wave attack and sand accumulation due to the longshore drift from the Arabian sea, it was decided to construct a breakwater parallel to the coastline at some distance from the existing jetty. This was intended to help the docking of fishing boats even during rough weather and prevent the port area from clogging up with sand. This jetty is used for extensive fishing activity based near the port. The breakwater unfortunately did not serve its purpose. Today, there is continuous and extensive accumulation of sand in the Ratnagiri (Mirya Bandar) port. This is dredged out to keep this ancient port in working order, ready to berth large fishing trawlers.

3.3.1 Coastal erosional landforms :

Coastal erosion has been altering world's shorelines since the oceans were first formed. With every surging action of the waves, the movement of longshore currents, tides and pounding storms, the coastline erodes and evolves. Added to that, the sea level constantly fluctuates, which facilitates the process of reshaping the morphology of a coast. The rate at which coastlines are eroded is extremely variable. It depends on the configuration of the coast, size and strength of waves, and physical properties of the bedrock.

Coastal erosional landforms are sculpted in a variety of forms majorly due to wave action. When a wave breaks against a sea cliff, the sheer impact of water can exert a pressure exceeding 100 kg/m^2. Water enters every crack and crevice of the rock and compresses the air present within. The compressed air then acts as a wedge and widens the cracks, which in turn loosens the block.

The most effective process of erosion along the coast is abrasive action of sand and gravel moved by wave action. These tools of erosion operate by cutting the bedrock horizontally, forming wave-cut cliffs and wave cut platforms.

i) **Sea cliff** : When steeply sloping land descends beneath the water, waves act like a horizontal saw, cutting a notch into the bedrock at sea level. This undercutting produces an overhanging sea cliff or wave cut platform (Fig. 3.10).

ii) **Wave cut platform** : The fallen debris of collapsed sea cliffs is broken up and removed by wave action, and this process is repeated on the fresh surface of the new cliff face. As the sea cliff retreats, a wave cut platform is produced at it's base (Fig. 3.10).

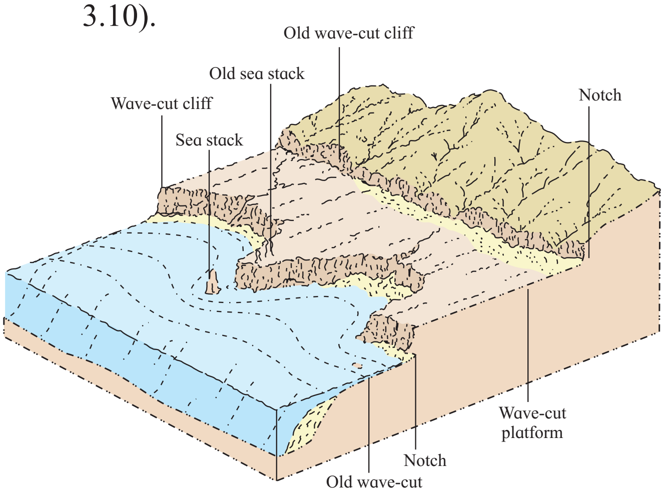


Fig. 3.10 : Wave cut platform and sea cliff

iii) **Sea cave** : Sea caves are formed when erosion takes place at a zone of weakness (for example, a joint) that extends throughout the outcrop. If a joint extends across a headland, wave action can hollow out a sea cave (Fig 3.11 A, 3.12).

iv) **Sea arch** : Sea arches form as a result of different rates of erosion of a rock which arises due to the varied resistance of bedrock. The arches may have an arcuate or rectangular shape (Fig 3.11 B).

v) **Sea stack** : Sea stack is an isolated pinnacle formed when a sea arch collapses. A new arch can develop from the remaining headland (Fig 3.11 C).

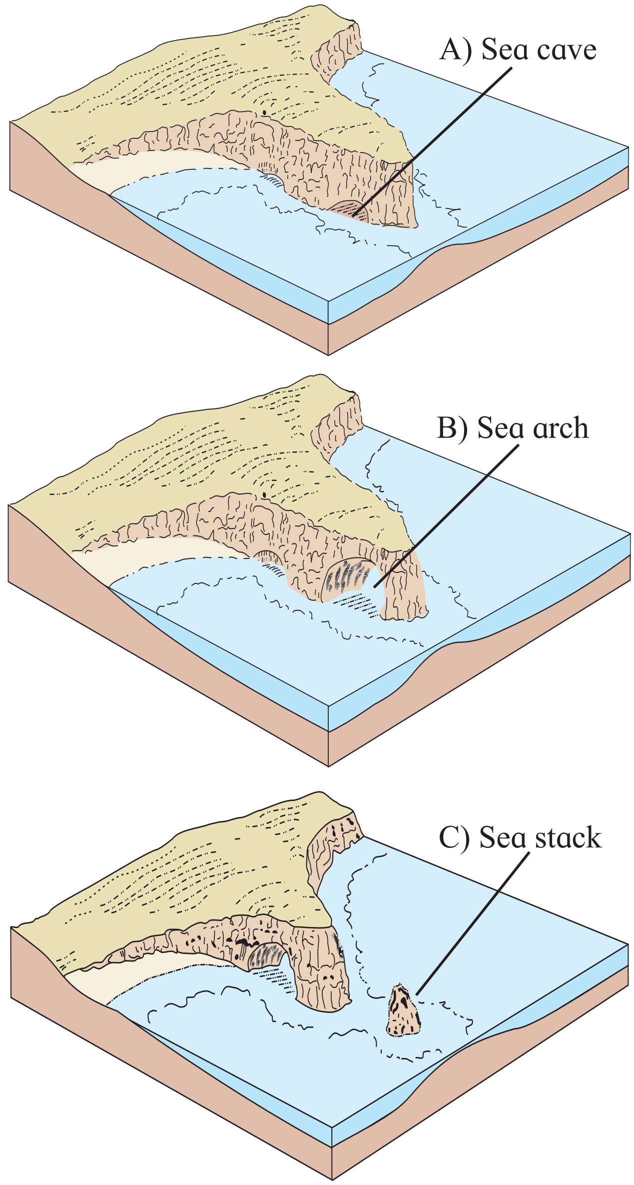


Fig. 3.11 : Sequence of development A) Sea cave, B) Sea arch, 3) Sea stack

Fig. 3.12 : Sea cave at Sarjekot, Malvan, Maharashtra

3.3.2 Coastal depositional landforms :

Coastlines receive sediment input from various sources, but majority of the sediments are derived from land and fed to the sea by rivers. The sediments are then transported by waves and currents and deposited in areas having low energy environments. The deposited sediments build a variety of landforms depending upon the geochemical environment and energy conditions present at the site of deposition.

i) **Beaches :** A beach is a shore built of unconsolidated sediments, mostly sand. Some beaches are composed of cobbles and boulders while there are others composed of fine silt and clay. The physical characteristics of a beach i.e. slope, composition and shape depend largely on the wave energy. The supply and size of available sediments also plays a huge role in formation of a beach.

ii) **Spits :** Generally, in areas where straight shorelines are indented by bays, longshore currents can extend the beach from the mainland to form a spit. A spit or sand spit is a deposition of sand or shingle, extending or jutting out into the sea from the mainland. A spit can grow far out across the bay as material is deposited at its end (Fig. 3.13).

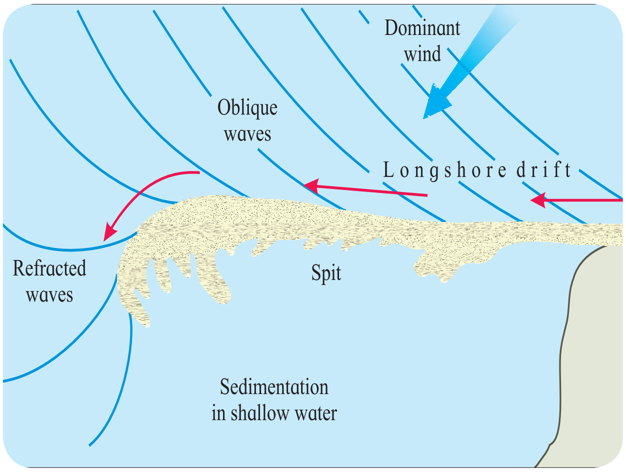


Fig. 3.13 : Formation of a Spit

iii) **Tombolos :** Tomobolos are formed when beach deposits grow outward and connect the shore with an offshore island. It forms because the island creates a wave shadow zone of extremely low energy conditions, along the coast, in which longshore drift cannot occur (Fig. 314).

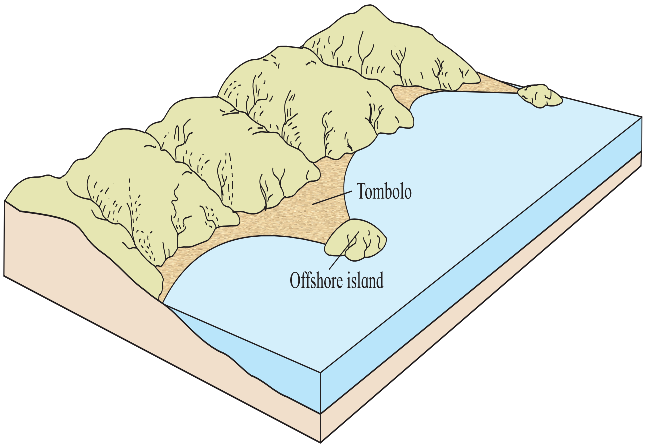


Fig. 3.14 : Tombolo

iv) **Reefs :** Reefs form a unique depositional feature as they are biological in origin. Reefs are built by coral polyps (invertebrate colonial organisms). The polyps get attached to hard substrates in shallow marine environments and secrete layers of calcium carbonate in order to form colonies to reside in. Reefs are extremely sensitive and can flourish only under specific temperature, salinity and water depth, therefore they are important indicators of past climatic, geologic and tectonic conditions.

There are three major types of reefs.They are as follows :

a) **Fringing reefs :** Fringing reefs generally range from 0.5 to 1 km in width and are attached to shores of volcanic islands or continents. The corals grow seaward in order to get food supply (Fig. 3.15 A).

b) **Barrier reefs :** Barrier reefs are roughly parallel to the shore and are separated from the mainland by a lagoon. They can be more than 20 km wide (Fig. 3.15 B).

c) **Atolls :** Atolls are roughly circular reefs that enclose a shallow lagoon in which there are no exposed central landmasses. The outer margin of an atoll is evidently the most vigorous site of coral growth

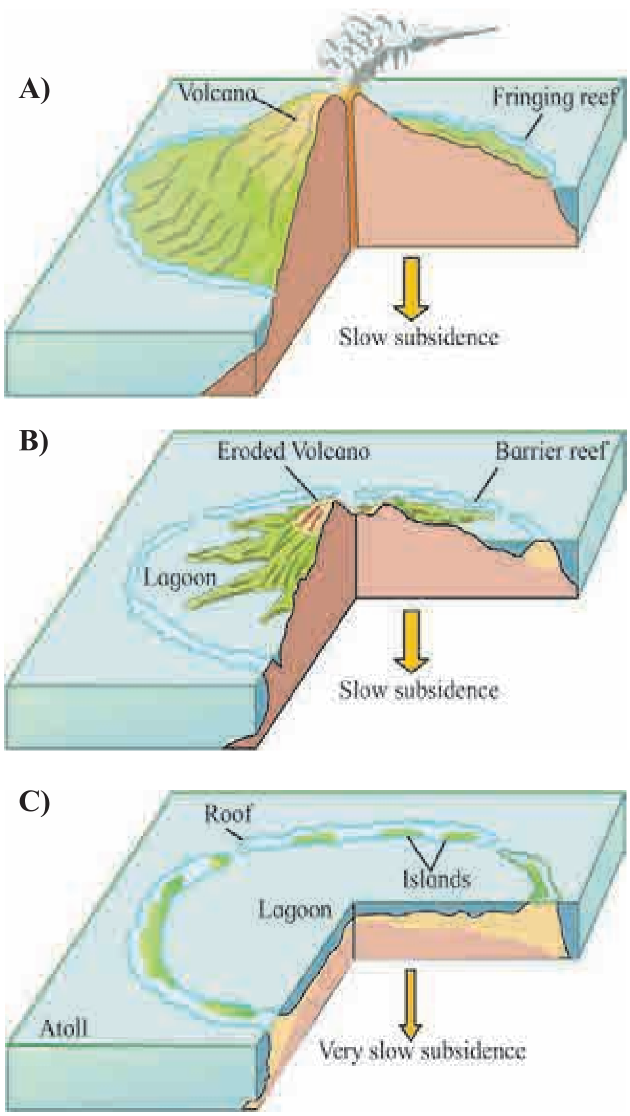


Fig. 3.15 : Formation of A) Fringing reef, B) Barrier reefs, C) Atolls

3.4 Aeolian landforms

Aeolian landforms are formed in deserts of the world where the effects of wind are most prominent. The aeolian system is a dynamic open system driven primarily by heat from the Sun, which is radiated to the Earth's surface. The uneven heating of Earth's surface makes the atmosphere a vast convecting fluid that envelop the entire planet.

A desert is a dry region usually having sandy or rocky soil and little or no vegetation. Water lost in evapo-transpiration in a desert exceeds the amount of precipitation in that region. Most deserts receive less than 25 cm annual rainfall. Vegetation cover is absent or sparse, which results in the ground surface being exposed to wind action.

3.4.1 Aeolian erosional landforms

Wind can do little to erode solid rock exposed at the surface, but it has tremendous capacity of carrying loose weathered material from one place to the other. For wind to operate as an effective agent of erosion, there are two prerequisites; presence of disintegrated rock fragments produced by chemical and mechanical weathering, and a dry climate. Dry climate is necessary because it ensures absence of vegetation, which usually covers the surface and holds the loose particles together. The major processes that operate during wind erosion are;

A) **Corrasion or abrasion :** It is the natural sandblast action of windblown sand. It is essentially the same process as artificial sandblasting used to clean building stone. Wind carries sand grains along with it, which impact rock surfaces and knock off smaller particles from the rock.

B) **Deflation :** It is the lifting and removal of loose material from Earth's surface. The grains are lifted up because of turbulent nature of wind. Deflation occurs where vegetation is absent or sparse.

C) **Attrition :** It is the wear and tear of sand particles due to mutual impact and friction as they are carried along by wind.

The above processes give rise to a number of aeolian erosional landforms.

1) **Deflation basins :** Deflation basins or hollows, as the name suggests, are broad shallow depressions formed due to deflation action of wind. They range in size from small depressions to large basins several kilometrs in diameter. These basins can also develop in areas where sand grains in sandstone are held together by calcium carbonate cement. During rainy periods, water collected in these depressions will dissolve the calcerous cement present in the sandstone. Now, since the calcareous material holding the sandstone together is no longer present, the sand grains begin to fall apart. These fallen, loose sand grains are picked up by strong winds during dry periods and transported. This process results in formation of a large depression.

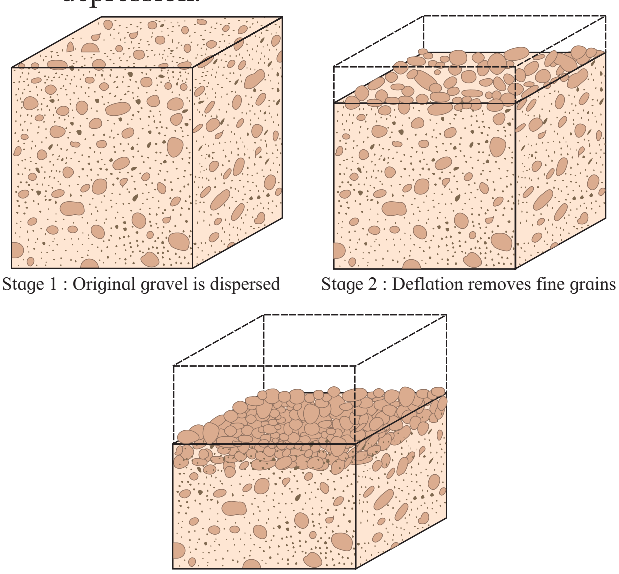


Fig. 3.16 : Formation of desert pavement / lag deposit

2) **Desert pavements :** Wind can only erode sand and dust size particles, so anything coarser than sand remains figuratively untouched by wind. Desert pavements or lag deposits are formed when wind selectively removes fine sediment and leaves behind coarser fragments (Fig. 3.16 a, b, c).

3) **Ventifact :** Ventifacts are exposed, soft, poorly consolidated rocks, shaped and polished by wind. These rocks are distinguished by two or more flat faces that meet at sharp edges and are generally well polished. The striations on ventifacts show the prevelant direction of wind during erosion (Fig. 3.17 A, B, C, D).

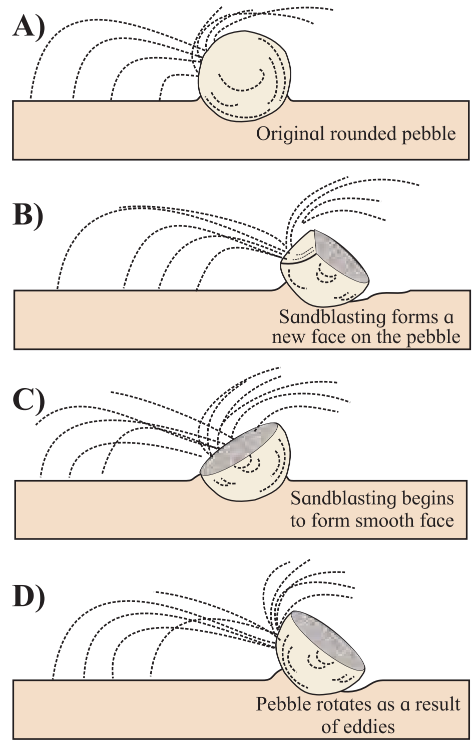


Fig. 3.17 : Formation of a typical ventifact

4) **Yardang :** Yardangs are distinctive linear ridges, generally large landforms produced by abrasion action of wind. The name is derived from the Turkistani word 'Yar', which means ridge or bank. They typically occur in clusters oriented parallel to the prevailing wind direction that formed them. (Fig. 3.18).

Fig. 3.18 : Yardang

Theoretically, they can form in any rock type, but they are best developed in soft, fine grained sediment or volcanic ash that can be easily pliable but cohesive enough to retain steep slope.

5) **Mushroom rocks / Rock pedestals :** Mushroom rock, as the name suggests, resembles a mushroom in shape. It is typically formed due to differential erosion of rock, especially at the bottom portion of the rock. (Fig. 3.19). This happens because at an average height of ~ 1m, the material carrying capacity of the wind and the speed is maximum, therefore, abrasion is maximum here. As the wind moves further up, its material carrying capacity decreases, which leaves the upper portion of the rock fairly untouched (uneroded). In some cases, mushroom rocks are also formed due to presence of soft rock layers at the base of hard rock layers.

Fig. 3.19 : Mushroom rock

6) **Mesa :** A mesa is an isolated, flat topped, steep sided desert mountain. It is formed by weathering and erosion of horizontally layered rocks (Fig. 3.20). Some rocks are more prone to weathering and erosion than others, hence they get weathered at a faster rate. This process is called differential erosion. The more resistant layers form cliffs, while the less resistant layers form the gentle slopes. Cliffs retreat and are eventually cut off from the main plateau.

7) **Butte :** A butte is an isolated hill, with a relatively flat top. Buttes are smaller landforms than mesas (Fig. 3.20). In distinguishing mesas from buttes, the rule of thumb is that a mesa has a top that is wider than its height.

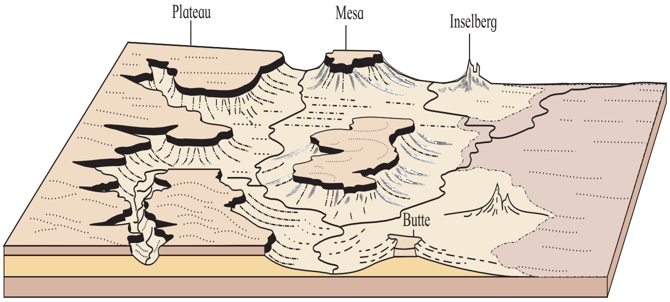


Fig. 3.20 : Mesa and butte

8) **Inselberg / Monadnock :** An inselberg or monadnock is an isolated hill, pinnacle, ridge or small mountain that rises abruptly from a relatively plain surrounding (Fig. 3.21). The word inselberg has a German origin, it literally means 'Island Mountain'. Inselbergs are mostly erosional remnants, they are composed of more resistant material.

Fig. 3.21 : Inselberg

Mesas, buttes and inselbergs are landforms which can also form due to other erosional processes, e.g. the mesas and buttes seen in deccan traps.

3.4.2 Aeolion depositional landforms :

When wind velocity decreases, it does not have enough energy to sustain the weight of the suspended sediment, as a result it gets deposited. Wind blown sand accumulates, upon deposition, to give rise to sand sheets, ripples and dunes. The structure formed will be a function of sand supply, wind direction and velocity. About 40%

of wind deposits are gently undulating, almost flat sand sheets. The following landforms are formed due to aeolian deposition :

Dune :

Dune is a hill of loose sand built by deposition of aeolian and fluvial sediments, but they occur more widely in aeolian environments. Dunes migrate downwind and modify the landscape rapidly, damaging or obliterating almost anything that comes in their path. Forests have been entombed by advancing dunes, streams diverted, and villages completely covered. Dunes march on, leaving behind devastated countrysides and damaged properties.

Formation of dunes : Many dunes originate where an obstacle such as a large rock outcrop, vegetation or any human made structure, essentially anything that creates a zone of quieter, calmer air behind it. As wind blows up or around the obstruction, its velocity is reduced and deposition occurs (Fig. 3.22). Once a small dune is formed, it itself acts as a barrier, disrupting the flow of air and causing continuous deposition downwind. Dunes range in size from 30 cm to 500 m high and about a kilometer wide.

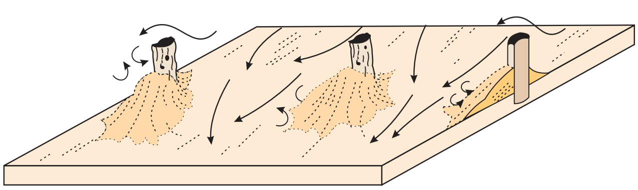


Fig. 3.22 : Formation of sand dunes

Migration of dunes : A sand dune is typically asymmetrical with a gently inclined windward slope and a steeper downwind slope i.e. lee side or slip face. The lee or slip face of a dune shows direction of prevailing wind. The wind picks up sand particles from the windward slope and drops it beyond the crest of the dune, this accumulates on the slip face. When the sand grains exceed the 'angle of repose', they spill down the slip face causing small landslides or 'avalanches' (Fig. 3.23 A, B).

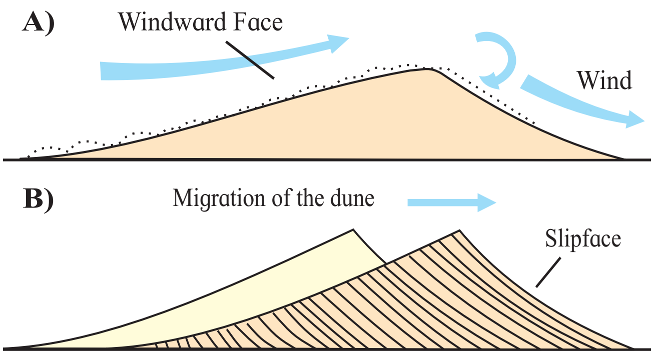


Fig. 3.23 : Migration of dunes

Types of dunes :

1) **Transverse dunes :** Transverse dunes typically develop where there is high supply of sand and constant wind direction. These dunes develop wavelike forms, with sinuous ridges and troughs perpendicular to the prevailing wind direction (Fig. 3.24). Transverse dunes generally form in deserts where exposed ancient sandstone formations provide ample supply of sand.

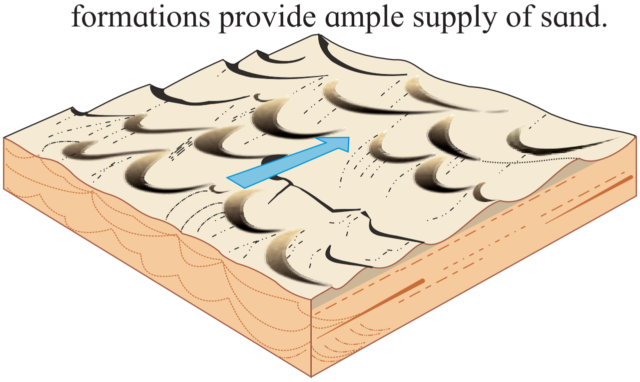


Fig. 3.24 : Transverse dunes

2) **Barchan dunes :** Barchan dunes form in areas with limited supply of sand, and where wind blows at moderate velocity in a constant direction. Barchan dunes are crescent shaped, small and isolated. The tip of a barchan dune points downwind (Fig. 3.25). Constant wind direction gives rise to beautiful symmetric barchan dunes.

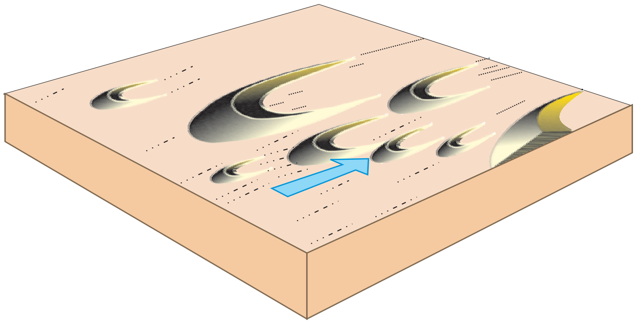


Fig. 3.25 : Barchan dunes

3) **Linear or Seif dunes :** 'Seif' (Arabic word for sword) dunes are long, parallel ridges of sand, elongate in a direction parallel to the vector resulting from two slightly different wind directions. These develop when strong prevailing winds converge and blow in constant direction over an area with limited sand supply (Fig. 3.26). These dunes do not attain great heights but they can extend downwind for several kilometers.

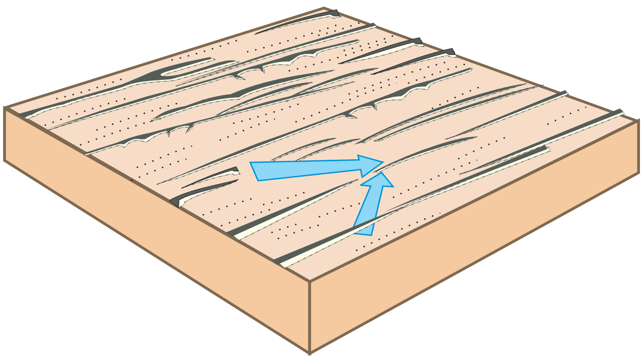


Fig. 3.26 : Linear or Seif dunes

4) **Star dunes :** Star dunes are mounds of sand with a high central point from which three or four arms radiate. The internal structure of star dunes suggests that they are formed due to winds blowing in three or more directions (Fig. 3.27).

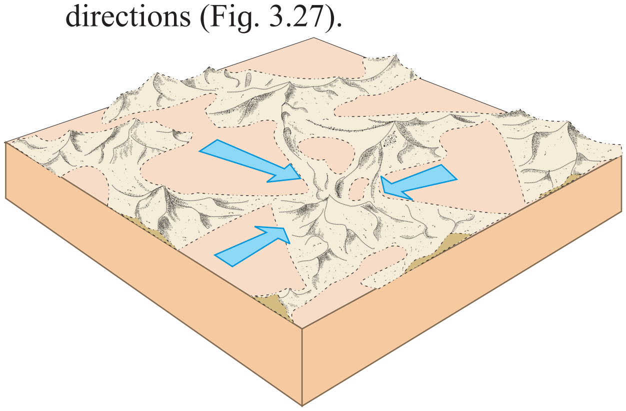


Fig. 3.27 : Star dunes

5) **Parabolic dunes :** Parabolic dunes develop along coastlines where vegetation partly covers a ridge of wind- blown sand, which is transported landward from the beach. In map view, a parabolic dune is similar to a barchan, but the tips of a parabolic dune point upwind and are fixed in place by vegetation (Fig. 3.28). Such dunes are also present in Thar desert.

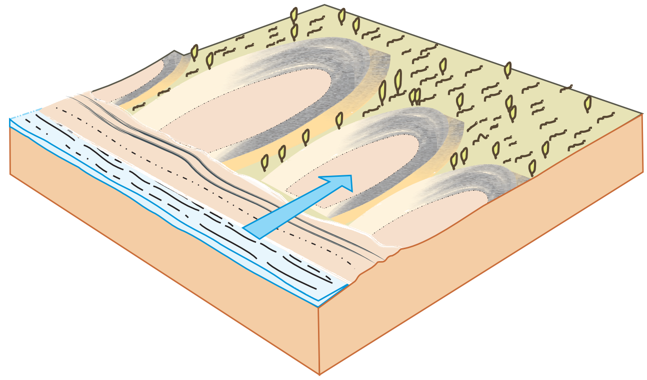


Fig. 3.28 : Parabolic dunes

3.5. Glaciated landforms :

Glaciers constitute an important part of the cryosphere, the portion on our Earth where the temperatures are so low that water is in a frozen state. Snow, perennially frozen ground, and sea, lake and river ice are other components of the cryosphere.

A glacier is a permanent body of ice, consisting largely of recrystallized snow, that moves downslope due to gravitational pull. The process of modification of land surface by the action of glacier ice, is called glaciation and it involves erosion, transport, and deposition of sediment.

3.5.1 Glacial erosion :

A glacier changes the land surface over which it moves. A glacier acts as :

1) an abrasive 'file' – whereby it rubs or rasps away hard rock.
2) a plow – it scrapes up weathered rock and soil and plucks out blocks of bedrock.
3) a sled – it carries away the load of sediment acquired by plowing and filing.

Small-scale erosional features :

a) Glacial striations : These are long sub parallel scratches engraved on bedrock. Due to the ploughing action of rock fragments which are studded along the base of a glacier that is slowly but steadily moving down a valley (Fig. 3.29).

Fig.3.29 : Glacial Striations (the deep grooves on the surface almost perpendicular to the strata)

Do you know?

Principal types of glaciers, classified according to form.

Glacier type	Characteristics
Cirque type	Occupies bowl shaped depression on the side of a mountain.
Valley glacier	Flows from cirques on to and along floor of valley.
Fjord glacier	Occupies submerged coastal valley and base lies below sea level.
Piedmont glacier	Terminates on open slopes beyond confining mountain valleys and is fed by one or more large valley glaciers.
Ice cap	Dome shaped body of ice and snow that covers mountain highland, or lower-lying lands at high latitudes and displays generally radial outward flow.
Ice field	Extensive area of ice in a mountainous region that consists of many interconnected Alpine glaciers. Lacks domal shape of ice cap. Its flow is strongly controlled by underlying topography.
Ice sheet	Continent size masses of ice that overwhelm nearly all land within their margins.
Ice shelf	Thick glacier ice that floats on sea and commonly is located on coastal embayments.

b) Glacial chatter marks : They are rows of small crescent-shaped cracks, similar to the marks made when a chisel slips across a wood or stone surface. The horns of the crescent point in the direction of ice movement. The stick-slip motion of stones across the glacier bed gives rise to sets of small curved fractures on brittle rock surfaces (Fig. 3.30).

Fig. 3.30 : Glacial chatter marks

Landforms of glaciated mountains :

a) Cirques : They are bowl-shaped hollows on a mountainside, open downstream and bounded upstream by a steep slope (Fig. 3.31). Cirques are excavated mainly by frost wedging, glacial plucking and abrasion. The floors of many cirques are rock basins, which may contain small lakes, called tarns, ponded behind a bedrock threshold at the edge of the cirque. Headward growth of cirques on opposite sides of a mountain crest can produce a narrow serrated ridge called an arête (French for 'fishbone,' 'ridge,' or 'sharp edge') (Fig. 3.32).

b) Horn : Where three or more cirques have sculpted a mountain mass, the result can be a high sharp-pointed peak or horn, the classic example of which is the peak – Ama Dablam in the Himalayas.

Do you know?

Ama Dablam 6,812 m (22,349 ft) is a popular Himalayan peak for climbing expeditions and is a prominent peak that is frequently visible on the trek up to Everest Base Camp. Ama Dablam means 'Mothers

Necklace' in Nepali and is in reference to the hanging glaciers that fall off the peak's, icy ledges. It has also been referred to as a 'Matterhorn' of the Himalayas.

c) Col : A col (from the Latin collum, 'neck'),or pass, is when two cirques erode headward into a ridge from opposite sides. When their headwalls meet, they cut a sharp-edged gap in the ridge (Fig. 3.33 B).

Fig. 3.31 : Glacial cirque and horn, Rohtang pass, Himachal Pradesh, India

d) Glacial valleys : Instead of fashioning their own valleys, glaciers probably follow the course of preexisting valleys, modifying them in a variety of ways. The chief characteristic of a glacial valley includes a cross profile that is trough like (U-shaped) and a floor that lies below the floors of smaller tributary valleys. From such hanging valleys, streams often descend as waterfalls. Because the tongue of an advancing glacier is relatively broad, it tends to broaden and deepen the V-shaped stream valleys into broad U-shaped troughs (Fig 3.33 A, B).

e) Truncated spurs : As a moving river of ice has difficulty in negotiating the curves of a stream valley, it tends to straighten and simplify its course. In this process of straightening, the ice cuts or shears-off any spurs of land that come across its flow. The cliffs thus formed, are shaped like large triangles or flatirons, with their apex upwards and are called truncated spurs (Fig 3.33 A, B).

f) Fjords : A segment of a deep glaciated valley, partly filled by an arm of the sea is called a fjord. Fjords are common features along the mountainous west facing coast of Norway.

Fig. 3.32 : Arête bordering a glacier in Karakoram range, Ladakh, India

3.5.2 Glacial deposits and resulting landforms

As a glacier moves, it plucks, collects and encompasses a host of Earth materials within its ice. As and when this ice melts, the material is deposited on the glacial valley floor. The general term 'drift' is applied to all deposits that are laid down directly by glaciers or that, as a result of glacial activity, are laid down in lakes, oceans, or streams. Drift can be divided into two general categories: unstratified and stratified.

i) Unstratified Drift : As the term conveys, is the material deposited from a melting glacier without any sorting and is called 'till'. It is composed of rock fragments ranging in size from boulders weighing several tonnes to tiny clay and colloid particles. The type of till varies from one glacier to another. If clay size particles predominate, it is called clay till. If larger size

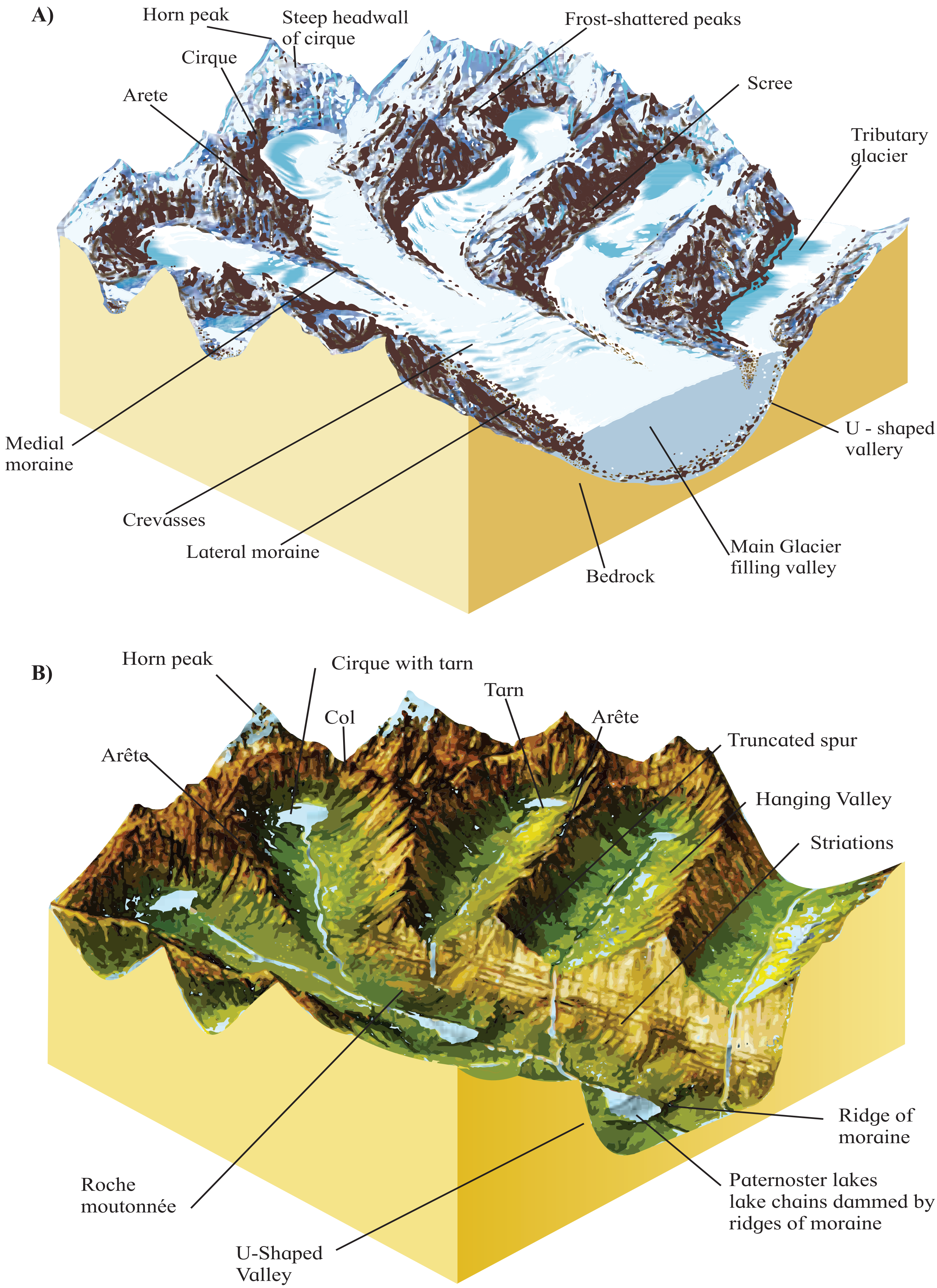


Fig. 3.33 : Glaciated terrain A) with glaciers, B) post glacier melting

rock fragments and boulders predominate, then the deposits are called as boulder tills or stony tills.

Unstratified drift or till is further named based on the topographic form, and location, it is deposited at with respect to the flow channel of the glacier, and includes moraines, drumlins, erratics, and boulder trains.

a) **Moraine :** Moraine is a general term used to describe many of the glacial deposits composed largely of till (Fig. 3.34).

A terminal moraine, or end moraine, is a ridge of till that marks the utmost limit of a glacier's advance. A terminal moraine can vary in size from hundreds of meters to very low, interrupted walls of debris. It forms when a glacier reaches the critical point of equilibrium the point where the glacier melt rate is matched by the rate of ice nourishment. So, as the ice melts in the zone of wastage, the debris is released and the terminal moraine grows.

Behind the terminal moraine, and at varying distances from it, a series of smaller ridges known as recessional moraines may build up. These ridges mark the position where the glacier front was stabilised temporarily during the retreat of the glacier.

'Till' is laid down across the length and width of a glacial valley. It forms gently rolling plains across the valley floor, appearing at times as a thin veneer or may be tens of meters thick and is called ground moraine.

Valley glaciers also produce two special types of moraine :

- **Lateral moraine :** Seen as a ridge along each side of the valley. It is formed due to rubble that kept tumbling down from the valley walls and collected along the side of the glacier. When the glacier melts, this debris is stranded as a ridge (Fig. 3.34).
- **Medial moraine :** Created when two valley glaciers join to form a single stream of ice. The material formerly carried along the edges of the separate glaciers is combined in a single moraine near the centre of the enlarged glacier (Fig. 3.33 A).

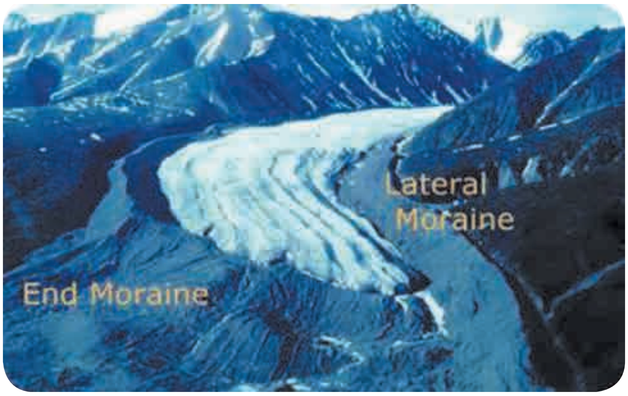


Fig. 3.34 : Glacial moraines

b) **Drumlins :** Drumilns are formed of till. They are elongated features that can reach a kilometer or more in length, 500m or so in width and over 50m in height. One end is quite steep, whilst the other end tapers away to ground level. The stoss end is the steeper of the two ends and faces the ice flow (Fig. 3.35).

The lee slope is the more gentle slope and becomes lower as you move away from the source of the ice. This means that the highest point will always be at the stoss end of the drumlin and the lowest point will be the end of the lee slope. It is common to find several drumlins grouped together. The collection of drumlins is called a 'swarm'. Areas with swarms of drumlins are sometimes referred to as 'basket of eggs' topography because of the rounded bumps that remind people of a box containing eggs.

There is still some debate about how drumlins are formed, but the most widely accepted idea is that they were formed when the ice became overloaded with sediment. When the competence of the glacier was reduced, material was deposited in the same way that a river overloaded with sediment deposits the excess material. The glacier may have experienced a reduction in its competence for several reasons, including melting of the ice and changes in velocity. If there is a small obstacle on the ground, it may act as a trigger point and 'till' will build up around it.

Fig. 3.35 : Drumlin field, Northern Ireland

Do you know?

It is difficult to understand how the material could have been directly deposited in the characteristic shape of a drumlin unless the ice was still moving at the time, but it may also have been reshaped by further ice movements after it was deposited.

c) **Erratics and boulder trains :** A stone or a boulder that has been carried from its place of origin by a glacier and left stranded on bedrock of different composition is called an erratic. The term is used whether the stone is embedded in a till deposit or rests directly on the bedrock. An erratic can weigh several tonnes (Fig. 3.36). Some could have travelled a limited distance of a few hundred meters or also hundreds of kilometers. Boulder trains consist of a series of erratics that have come from the same source and appear as a line of erratics stretching down-valley from their source or in a fan shaped pattern with the apex near the place of origin. They are good indicators of the direction of flow of the glacier.

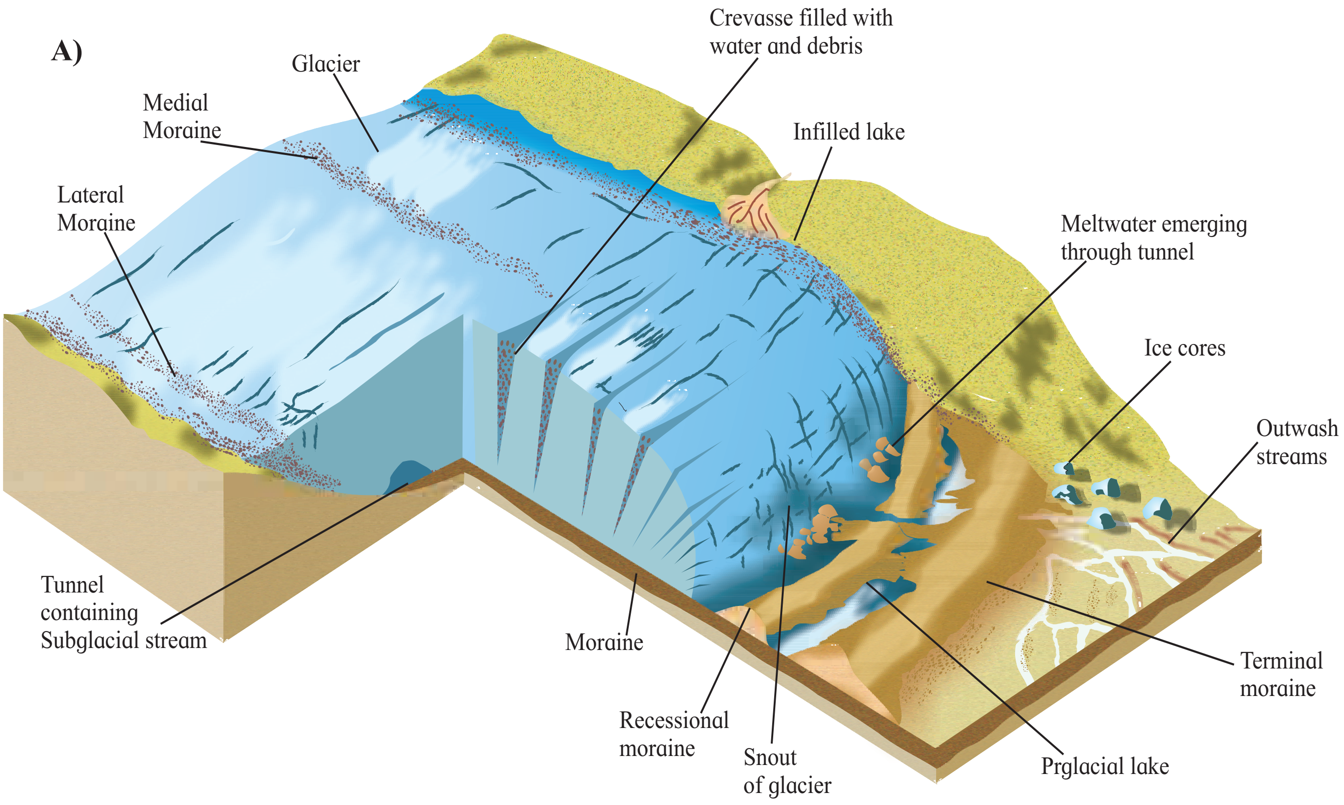
Fig. 3.36: Glacial erratics

ii) Stratified drift : It is ice-transported sediment that has been washed and sorted by glacial meltwaters according to particle size. Since water is a much more selective sorting agent than ice, deposits of stratified drift are laid down in recognisable layers, unlike the random arrangement of particles typical of till. Stratified drift occurs in outwash plains, kettles, eskers, kames and varves.

a) **Outwash sand and gravel :** The sand and gravel that are carried outward by meltwater from the front of a glacier are referred to as outwash. When continental ice sheets melt, the outwash deposits stretch for kilometers, forming what is called an outwash plain or 'Sandar' (Fig. 3.37 A).

b) **Kettles or Kettle holes :** These are small depressions in glacial debris. When an ice sheet retreats it may leave behind small 'lenses' of ice that get buried in glacial till or outwash before it finally melts. When these lenses finally melt, they leave behind a small pit or depression or kettle in the drift. These depressions range from a few meters to several hundred meters in diameter and a few meters to over 30 m in depth. Many outwash plains are pockmarked with kettles and are referred to as pitted outwash plains (Fig. 3.37 B).

A)



B)

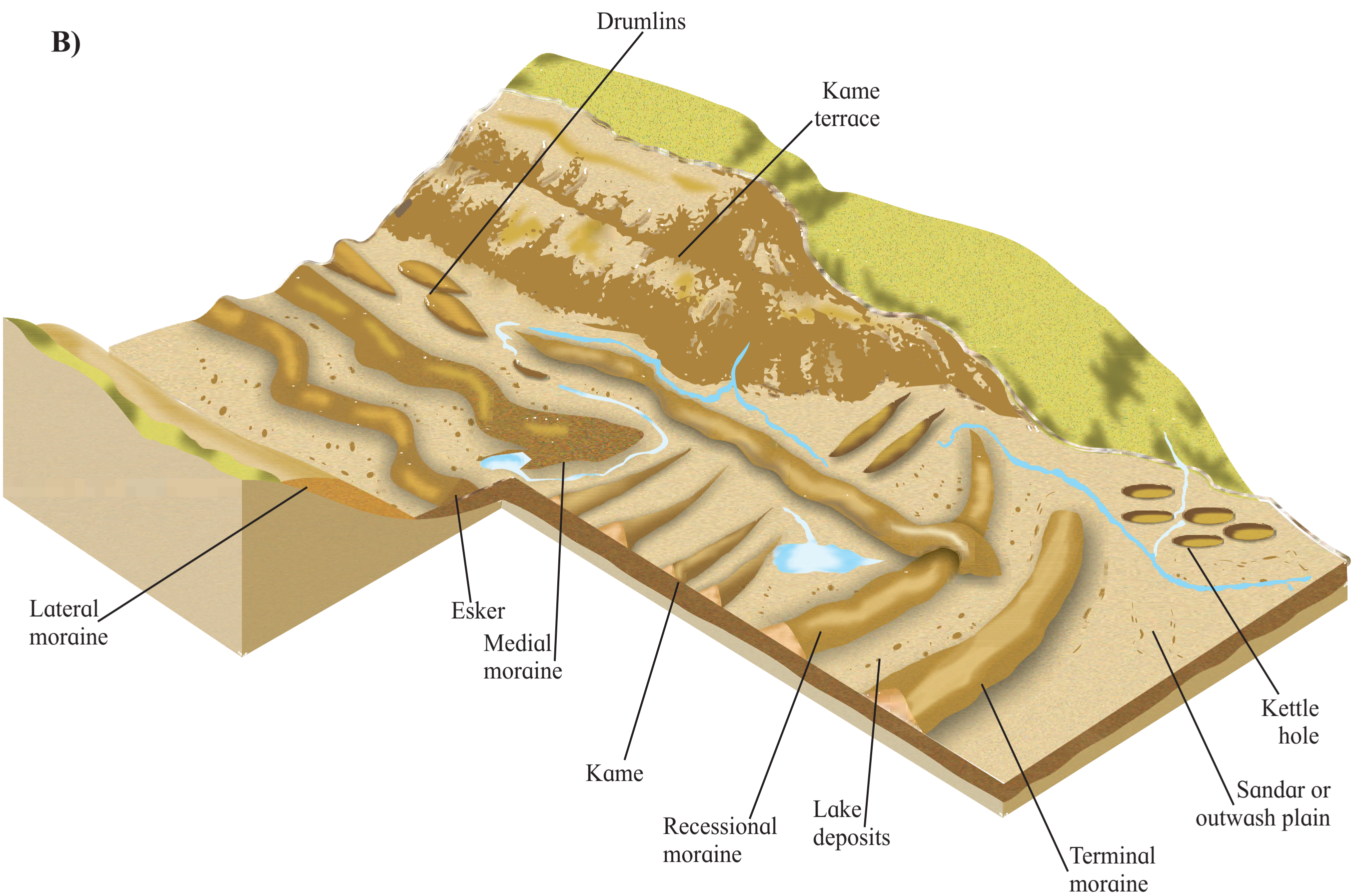


Fig. 3.37: Glacial valley A) During glaciation, B) After glaciation

c) **Eskers and crevasse fillings :** Winding or snaking, steep walled ridges of stratified sand and gravel, sometimes branching and often discontinuous are called eskers. They are now believed to be deposits left by englacial streams of water flowing beneath the ice (Fig. 3.37 B).

Crevasse fillings or Kames are similar to eskers in height, but they form crescentic ridges. They are formed from the material that was caught-up in cracks and crevasses on the glacier surface, and later the material gets deposited as the glacier melts.

A kame terrace on the other hand is a deposit of stratified sand and gravel that has been laid down between a wasting glacier and an adjacent valley wall. When the glacier melts, the deposit stands as a terrace along the side of the valley (Fig. 3.37 B).

d) **Varves :** A varve is a pair of thin sedimentary beds, one of coarse and the other fine sediment. This couplet of beds is usually interpreted as representing the deposits of a single year and is thought to be formed as a result of the alternate freezing and thawing of glacial lakes. During thaw, large amount of coarse particles settle to the bottom of lakes (giving rise to the thin coarse bed). During the following winter, when the water freezes, and the waters of lakes are not disturbed by winds, then the finer clay and silt sink to the bottom and form a thin layer of fine sediment. Varve pairs are used for counting the freeze-thaw cycles and hence dating specific glacial events.

3.5.3 Glacial mass budget :

Glaciers grow by accumulation the building up and compaction of new snow. At the same time ice is lost by ablation that is, melting and evaporation. The difference between accumulation and ablation is the glacial mass budget. If the budget is positive (accumulation exceeds ablation) the glacier advances. If it is negative (ablation exceeds accumulation) the glacier retreats. Usually, glaciers have a negative budget at the foot (the ablation zone) and a positive budget at the top (the accumulation zone).

3.6 Connecting to life/Job skills

Understanding the processes of landform formation gives an insight into the material properties and the internal structure of the said landforms. Constructing roads, buildings, dams, canals, ports, jetties and other man-made structures need an understanding of the landforms. Portions of our Konkan railway periodically experience landslides. If a house is constructed on a wrong spot, say on a sea cliff, it may slide into the sea due to wave attack at the base of the cliff. It is important, then, to study and research the landform on which a railway track, or your house and all valuable infrastructure is to be constructed, or you plan to purchase. No location can be certified as completely safe, but a little research on understanding the landform can help prove some sites to be relatively safer.

Activity :

Prepare a list of all the landforms mentioned in this chapter.

i) Classify them based on their mode of formation.

a) Erosional b) depositional.

ii) Classify them based on location giving Indian examples.

Summary :

- The Earth's surface is unique because of the methodical and constant sculpting by 'erosive agents', viz. water, wind and ice. The heat from the sun and the activity of organisms on the surface materials also plays an important role in development and evolution of various landforms.

- The combined effects of the erosive power of water, wind and ice along with the variations in climate through the Earth's past have resulted in a unique set of landforms. A systematic study of these landforms helps a geologist interpret the processes that could have created them. Hill, valley, plateau and beach are colloquial terms which are used to depict landforms, but when these very common and simple appearing features are studied in detail, the intrinsic differences in various kinds of each of these features is evident.
- Topographic differences are further accentuated or enhanced by the underlying differences in geological structure and rock type. The systematic study of landforms is what a Geomorphologist does and hence contributes to a better understanding of our planet.

EXERCISE

Q. 1. Choose the right alternative :

1) Barchan dunes are formed under .... conditions
   a) High wind velocity and higher supply of sand.
   b) Winds blowing in multiple directions.
   c) High wind high moisture content.
   d) Limited supply of sand and moderate wind velocity.
2) The most active agent of erosion and deposition in dry and arid environment is ....
   a) Temperature   b) Wind
   c) Heat   d) Water
3) Earth experinces higher average temperature at the equator because
   a) Suns rays strike perpendicular at the equator
   b) Suns rays strike oblique at the equator
   c) Equatorial area is closer to the sun
   d) Magma is generated along the equator.

Q. 2. Choose the correct sequence of development of desert pavement :

a) Finer fraction removal - deflation - gravel dispersal
b) Dispersed gravels - finer fraction removed - lag gravels
c) Lag gravels - dispersal of gravels - removal of gravels
d) Lag gravels - dispersal of gravels - filling up of finer material

Q. 3. Find odd one out :

1) i) Ventifact   ii) Yardang
iii) Oxbow lake   iv) Mesa
a) i   b) ii   c) iii   d) iv

2) i) Sea cave   ii) Sea horse
iii) Sea arch   iv) Sea stack
a) i   b) ii   c) iii   d) iv

Q. 4. Sort out the following into erosional and depositional landforms :

i) Desert pavement
ii) Potholes
iii) Star dunes
iv) River meander
v) Cirque
vi) Moraines

a) Erosional : i - iii - vi
   Depositonal : ii - iv, v
b) Erosional : i - ii - iv - v
   Depositonal : iii - vi

c) Erosional : i - iii - ii
Depositonal : iv - v - vi

d) Erosional : iv - v - vi
Depositonal : i - ii - iii

Q. 5. In case of sea level rise which of the following landforms would submerge first :

a) Sea cliff b) Drumlins

c) Tombolos d) Eskers

Q. 6. Answer in brief :

1) What makes the surface of the Earth and that of the Moon to differ?
2) What are the forces and agents that drive the material on the surface of the Earth?
3) State the relationship between variation in solar radiation with latitudes
4) Distinguish between an alluvial fan and delta
5) State the use of glacial mass balance and budget
6) What kind of landforms changes can occur as a result of glacial melting due to global warming

Q. 7. Read the following passage and answer the questions :

The 250–800 m high Siwalik Ranges form the southern front of the Himalaya. These are made up of sediments deposited by ancient Himalayan rivers in their channels and floodplains in the last 16 to 1.5 Ma. The rugged Siwalik ranges are commonly broken by south-facing scarps, while on their steepened northern slopes, rush down streams through unending cascades and waterfalls as can be seen in the central sector. Then, there are long flat stretches within the otherwise rugged Siwalik terrain called the duns. The duns represent gravelly deposits within depressions or fillings of now vanished lakes that were formed in the synclinal valleys owing to ponding of rivers and streams or to slackening of current velocity as a result of decrease in gradient following tilting of the ground.

Ref: K. S. Valdiya, The Making of India., (2016).

1) When did the sediments deposited by rivers and flood plains on the southern front of Himalaya stop?
2) Differentiate between northern and southern slopes of the Siwalik hills.
3) What kind of -sedimentation is represented by the duns as compared to the Siwaliks?
4) Explain why lakes within the valleys to disappear?

Chapter - 4 Rock Forming Processes

Highlights :

- The two basic sources of energy called exogenic (driven by Sun) and endogenic (driven by geothermal energy within the Earth) are explained.
- Classification of rocks based on the mode of formation into three basic types (igneous, sedimentary and metamorphic) are elaborated.

Introduction :

As a terrestrial planet, Earth's interior is divided into the core, the mantle and the crust. The crust and upper mantle are collectively known as the lithosphere, from where the tectonic plates originate and plays an important role in governing the rock cycle which results in the formation of rocks.

The Earth has two basic sources of energy. The energy that reaches the Earth from the Sun (solar energy) is exogenic meaning from an external source. Solar energy is converted into heat and absorbed by the atmosphere, hydrosphere and lithosphere. This heat drives the water cycle which further controls the exogenic processes. The other source of energy arising within the Earth as geothermal energy is called endogenic. Large amount of heat is trapped within the Earth. This energy is responsible for endogenic processes like tectonic activity.

It is in the lithosphere where the rocks are formed, recycled and re-formed. The nature of these rocks differ depending on the processes by which they are formed. The origin of any rock can be determined by its texture and composition which in turn forms the basis of rock identification and classification. Study of rocks in terms of its composition, texture, structure, origin, occurrence, alteration and association with other rocks is called as Petrology. The word petrology is derived from the Greek word 'Petros' meaning rock and 'Logos' meaning science.

Rocks are naturally occurring aggregates of minerals. Based on their mode of formation, the rock forming processes are classified as :

i) Igneous processes that involve melting, cooling and crystallisation of magma or lava.

ii) Sedimentary processes involve weathering, erosion, deposition, and lithification of fragments of pre-existing rocks.

iii) Metamorphic processes involve changes in texture, structure and / or mineral composition under different temperatures and / or pressure conditions generally in presence of chemically active fluids.

Over geological time, rocks are gradually transformed from one type to another and the process is described as 'Rock Cycle'.

The rock cycle is a model that describes the formation, breakdown, and reformation of a rock as a result of sedimentary, igneous, and metamorphic rock forming processes.

4.1 Exogenic and endogenic processes :

The dictionary meaning of the term exogenic is the process originating at or near the surface of the Earth, such as weathering and denudation. The sedimentary rocks, ore deposits and landforms are commonly formed by the exogenic processes. Endogenic processes originate within the Earth giving rise to the rocks, ore deposits and landforms that form due to tectonism, diastrophism, volcanism and metamorphism.

4.2 Extraterrestrial processes :

These include landforms formed by extraterrestrial activity such as impact of meteorites, e.g. the Lonar lake (Buldhana district, Maharashtra).

4.3 Genesis, classification and characteristics of rocks :

The early Earth was like a ball of fire with everything in molten state. While cooling, the outermost solid surface (crust) was first formed and this rock is called as an igneous ('Ignis' meaning fire) rock. Thus, all the rocks formed due to rapid or slow cooling of magma (within the subsurface) and lava (on the surface of the Earth) are called igneous rocks. A large variety of igneous rocks are therefore classified on the basis of rate of cooling of magma / lava and depth of formation.

In due course of time, the Earth experienced rainfall initiating the hydrological cycle (water cycle). This in turn initiated the phenomenon of weathering and denudation resulting in erosion and transportation of pre-existing rocks and their deposition in basins. Consolidation of the deposited material formed sedimentary rocks ('sedimentum' meaning settling). Several geological processes can result in rise in temperature and pressure causing the recrystallization of minerals of pre-existing rocks. These newly developed rocks are called as metamorphic (meta meaning 'After', morphic meaning 'Change in form') rocks.

The different approaches to the study of rocks are petrography, petrology, petrogenesis and lithology.

Petrology is a branch of geology that deals with description and systematic classification of rocks. The study of rocks as thin sections under microscope is called petrography.

Petrogenesis is a branch of petrology that deals with the origin and formation of rocks.

Lithology is a general terminology for description of rocks in hand specimen/or in the field, using characteristics like colour, texture and mineral composition.

4.3.1 Genesis, classification and characteristics of igneous rocks :

Igneous rocks are formed by cooling and consolidation of hot, molten rock material.

Magma :

Magma is a hot molten material formed at great depth. The temperature of the magma is around 800° to 1400° C. It is a hot melt of rocks or minerals. It is under great pressure at depth. Any factor which reduces the pressure will cause the eruption of the magma. Magma consists of volatile (gaseous) substances such as, water vapour, carbon dioxide, sulphur dioxide, etc. and non-volatile substances like oxides of silicon, aluminium, iron, calcium, sodium, potassium, magnesium, etc. When the same hot molten rock material erupts on the surface, it is known as lava.

Formation of igneous rocks :

When the magma present at great depth moves upward into the Earth's crust, both pressure and temperature decreases. Decrease in pressure within the crust will cause the intrusion of the magma onto the surface, as lava. Reduction of pressure allows the gases to escape into the surrounding rocks of the crust. The magma cools slowly and the whole mass of different minerals gives rise to igneous rocks. Types of igneous rocks thus formed, depends upon the original composition of the magma and its rate of cooling. Under slow rate of cooling, there is sufficient time and space for igneous rocks to form larger crystals (e.g. gabbro) whereas if the rate of cooling is rapid, fine grained rocks are formed. If the cooling is very fast, the rock melt does not develop minerals and forms a glassy rock, e.g. pitchstone, obsidian.

The igneous rocks, which are formed inside the Earth by injection of magma are known as intrusive or hypabyssal igneous rocks. These rocks are formed under a slow rate of cooling, are relatively medium grained. e.g. dolerite.

The rocks which are formed on the surface by the eruption of volcanoes are known as extrusive or volcanic igneous rocks. These rocks are formed under conditions of rapid rate of cooling and are fine grained. e.g. basalt.

Classification of igneous rocks :

Igneous rocks are classified on the basis of genesis, chemical and mineralogical composition, petrographic characters and occurrences.

A simple classification is suggested based on chemical, mineral and textural characters. The chemical classification considers magmatic composition in which the percentage of felsic minerals (silica and aluminum bearing) and mafic minerals (iron and magnesium bearing) are present. Accordingly, the rocks having SiO_2 % > 66% are termed as acidic, those containing SiO_2% : 65% - 55% are called intermediate, rocks containing SiO_2% : 54% - 44% are basic while rocks with SiO_2% < 44% are termed ultrabasic (Table 4.1).

Quartz is a mineral entirely comprising of SiO_2, whereas SiO_2 can also occur in rocks as silicate compounds with other elements.

Classification based on mineral composition considers essential and accessory minerals, such as felsic and mafic rocks. Felsic rocks are light in color consisting of feldspars and quartz. Mafic rocks are dark colored, consisting of olivine, pyroxenes and amphiboles.

The general classification suggested for beginners is based on :

1) Mode of occurence or depth of formation.
2) Percentage of quartz or silica
3) Presence of feldspars.

On this basis igneous rocks are classified as plutonic, hypabyssal and volcanic.

Plutonic igneous rocks :

Plutonic ('Pluto' meaning god of underworld) describes the igneous rock material whose origin is deep seated. Rate of cooling at this depth is slow. As a result, large and almost equal sized crystals are formed. Texture thus formed is called equigranular. The matrix of such rocks is completely composed of crystals which can be recognized by unaided eye. Such rocks are termed as holocrystalline ('holo' meaning complete) e.g. granite, syenite, gabbro.

Volcanic igneous rocks :

Magma generated within a magmatic chamber is suddenly and rapidly pushed upwards to the surface due to tectonic activity. As the magma moves upwards, fine grained minerals are formed due to rapid cooling. Before and during this movement, the earlier formed minerals grow larger in size. The admixture of fine and coarse grained minerals thus formed is described as porphyritic texture. Very rapid cooling does not permit crystallization, resulting into glassy (holohyalline) rock e.g. rhyolite, trachyte and basalt.

Table 4.1 : Tabular classification of igneous rocks

Silica %	Mode of occurence or depth of formation		
	Plutonic	**Hypabyssal**	**Volcanic**
Acidic (> 66%)	Granite	Pegmatite	Rhyolite
Intermediate (65 - 55%)	Syenite		
Basic (54 - 44%)	Gabbro	Dolerite	Basalt
Ultrabasic (< 44%)	Dunite		

Hypabyssal igneous rocks :

The term hypabyssal is used for intrusive igneous rocks that crystallize at intermediate depths i.e., between plutonic and volcanic conditions. Some hypabyssal rocks contain coarse as well as fine grained minerals showing porphyritic relationship (e.g., pegmatite, dolerite).

Characteristics of igneous rocks :

1) These are first formed rocks by the cooling of magma or lava, hence are also called as primary rocks.
2) They are massive and unstratified.
3) They are non-fossiliferous.
4) They often occur as veins and fissures intruding into country rocks.
5) They exhibit baking or alteration effects along their contacts with country rocks.
6) They display an interlocking texture consisting of minerals, glass or both.
7) Lava flows may show gas cavities or amygdales.
8) They are composed of pyrogenetic minerals formed at high temperature.
9) They exhibit equigranular / porphyritic / glassy texture.

4.3.2 Genesis, classification and characteristics of sedimentary rocks :

Sedimentary rocks are formed by weathering and erosion of the pre-existing rocks. The process of weathering and erosion is carried out by agents like sunlight, river, wind, glaciers, and oceans. The eroded products are transported and later deposited. These loose sediments on consolidation give rise to sedimentary rocks.

Genesis :

Sedimentary rocks are formed by lithification of weathered rock fragments that are physically transported and deposited. During transportation the fragments are abraded resulting in reduction in size. Such fragments are called clasts and the rock is referred to as clastic e.g., conglomerate and sandstone. Some of these rocks are formed from chemical precipitation and crystallisation. Such rocks are termed as non-clastic e.g., limestone. Few sedimentary rocks are also formed by lithification of organic matter like shell fragments and are called as bioclastic e.g., fossiliferous limestone.

The process of deposition of loose fragments or clasts or rock debris is termed as sedimentation. It also includes material precipitated from solutions or water.

Classification :

Sedimentary rocks can be classified based on type of weathering, transportation and grain size (Table 4.2)

During transportation, water reacts with minerals and may form solutions. Under appropriate conditions precipitation takes place leading to formation of two types of deposits :

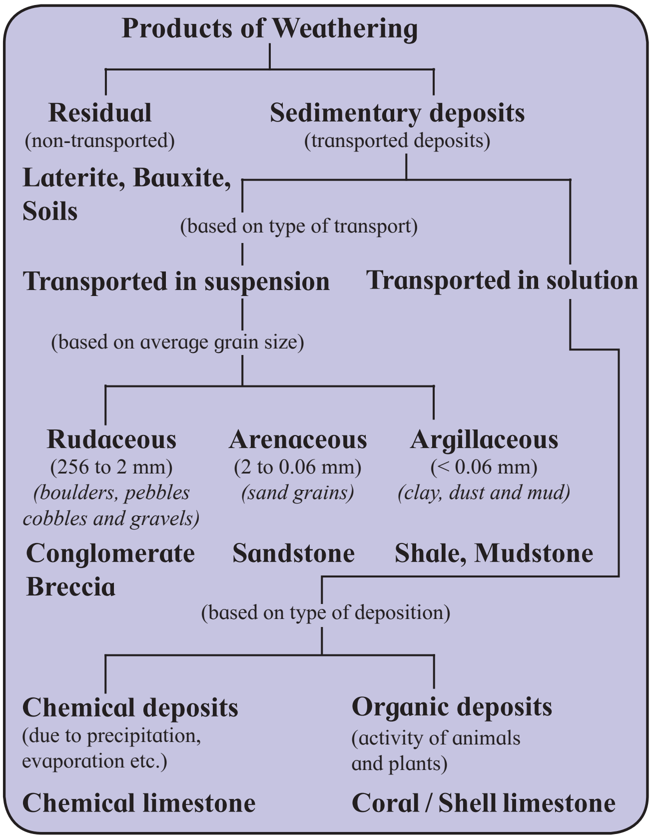
1) Chemical deposits : These deposits are formed by evaporation and precipitation e.g., limestone.
2) Organic deposits : Fragments of shells of animals and parts of plants are deposited and cemented to form fossiliferous and shell limestone.

During weathering, a rock may undergo *in-situ* chemical changes giving rise to residual deposits e.g., laterite, bauxite and soil.

Characteristics of sedimentary rocks :

1) They are derived from mechanical and / or chemical breakdown of pre-existing rocks.
2) Most of these rocks are layered or stratified.
3) These rocks show clastic textures with different cementing materials like silica, calcium carbonate, iron oxide, carbon or clay.
4) These rocks may contain fossils.
5) They may show primary structures like current bedding, ripple marks and mud cracks.
6) They may contain tracks, trails, burrows and imprints.

Table : 4.2 Classification of sedimentary rocks



4.3.3 Genesis, classification and characteristics of metamorphic rocks :

Rocks may undergo transformation due to change in temperature, pressure and presence of chemically active fluids.

Almost all pre-existing rocks are subjected to heat and pressure below the surface of the Earth. This brings about change in mineral composition and texture of original rock by recrystallisation. This results in the formation of new rock termed as metamorphic rock. Thus, the resulting rock shows change in mineral composition, texture and structure.

Genesis :

Metamorphism results from the change in physical and chemical environment of the original rock. These changes are because of different factors known as agents of metamorphism which are : temperature, pressure and chemically active fluids and gases.

1) **Temperature :** This is the most important agent of metamorphism. A rock begins to change chemically at temperatures above 200°C. Temperature increases with increasing depth (due to geothermal gradient), intrusion of magma, plate tectonics and radioactive decay.

2) **Pressure :** Pressure increases with depth and due to tectonic movements. Rocks can be subjected to pressures of two kinds:

   a) Directional pressure

   b) Uniform or hydrostatic pressure.

   Directional pressure is dominant within tectonically active zones. It is also termed as non-uniform pressure or stress. The effect of stress reduces the melting point of minerals and increases their solubility. As depth increases the directional pressure gradually changes into confining or uniform pressure.

3) **Chemically active fluids and gases :** These are derived from magma and are called as hydrothermal solutions. These fluids may contain carbon-dioxide, hydrofluoric acid, bromine, fluorine and water vapour in supersaturated state.

Classification of metamorphic rocks :

Metamorphic rocks are classified into three categories based on agents of metamorphism.

1) **Cataclastic metamorphism :** In this type the directional pressure plays an important role. There is no significant change in temperature. Since, directional pressure is the only operating agent, it mechanically breaks down the rock by crushing, fracturing and granulation. In this process no new mineral is formed e.g., slate.

2) **Thermal metamorphism :** In this kind of metamorphism there is increase in temperature, which is the dominant factor. The main source of heat is intrusion of magma. Along the contact between magma and host rock, recrystallization takes place (e.g., sandstone metamorphosed to quartzite and limestone metamorphosed to marble).

Table 4.3 : Genesis of metamorphic rocks

Original Rock	Types of Metamorphism (agent of metamorphism)	Product of Metamorphism	Structure
Argillaceous	Cataclastic (directed pressure or stress)	Slate	Slaty cleavage
Sandstone / Limestone	Thermal (temperature)	Quartzite/Marble	Granulose
Argillaceous (shale, mudstone) Basic igneous rock (basalt, gabbro)	Dynamothermal (directed pressure and temperature dominant)	Mica-garnet schist, Biotite schist, Biotite gneiss. Hornblende schist, Hornblende gneiss.	Schistose and Gneissose

3) **Dynamothermal metamorphism :** This metamorphism is also called regional metamorphism. Here heat and directional pressure are dominant. The rise in temperature and directional pressure is due to tectonic activity or magmatic intrusion. The temperature recrystallises the pre-existing minerals and directional pressure aligns the minerals perpendicular to direction of maximum pressure, thereby orienting the minerals to form schists and gneisses, e.g., hornblende gneiss, mica-garnet schist.

Characteristics of metamorphic rocks :

1) Metamorphic rocks are derived by the physical and chemical transformation of pre-existing (igneous, sedimentary or metamorphic) rocks.
2) They are formed in response to pronounced changes in the temperature, pressure and chemical environment.
3) Mineral transformation takes place in the solid state.
4) These rocks exhibit recrystallisation.
5) Metamorphic rocks show interlocking arrangement of minerals.
6) They exhibit granularity, schistosity and gneissosity.
7) Staurolite, kyanite, sillimanite, garnet are characteristic metamorphic minerals.
8) Metamorphic rocks are devoid of fossils but are favoured to form economic ores and gemstones.

4.4 The rock cycle :

The rock cycle explains the evolution and transfer of igneous, sedimentary and metamorphic rocks. Rock components of the crust, slowly but consistently, are being changed due to different processes operating on the Earth.

The rock cycle is driven by two forces :

1) Earth's internal heat responsible for the endogenic processes.
2) The hydrological and other cycles on the Earth's surface powered by the sun (exogenic processes).

Due to internal forces generated within the Earth the intrusive rocks are uplifted and exposed to the surface. On their exposure to the atmosphere, these rocks get weathered, both physically and chemically. The weathered material after erosion gets transported by different agents and finally gets deposited as unconsolidated sediments along rivers, lakes and the ocean. With further addition of sediments, the weight (overburden) increases and the layers begin to subside. Eventually, with depth, the sediments are heated and partially melted to get mixed with the mantle material. This mixed mantle material may once again erupt as igneous rocks. Pre-existing rocks can be subjected to temperature and pressure and change to form metamorphic rocks. Thus, in nature, there appears to be a cyclic production, destruction and reproduction of all the three types of rocks. This appears to be a continuous process, ever since the process of weathering and erosion started. This phenomenon is called the Rock cycle (Fig. 4.1)

Activity :

Collect various types of rocks from your area of residence and also from rock polishing shops. Identify their mineral contents and sort the rock samples into igneous, sedimentary and metamorphic rocks.

Summary :

The rocks are transformed from one type to another in response to the endogenic and exogenic processes by altering their mineralogy, texture and other physico-chemical properties.

Rocks are classified into three basic types and their intermediate forms are explained by the rock forming processes.

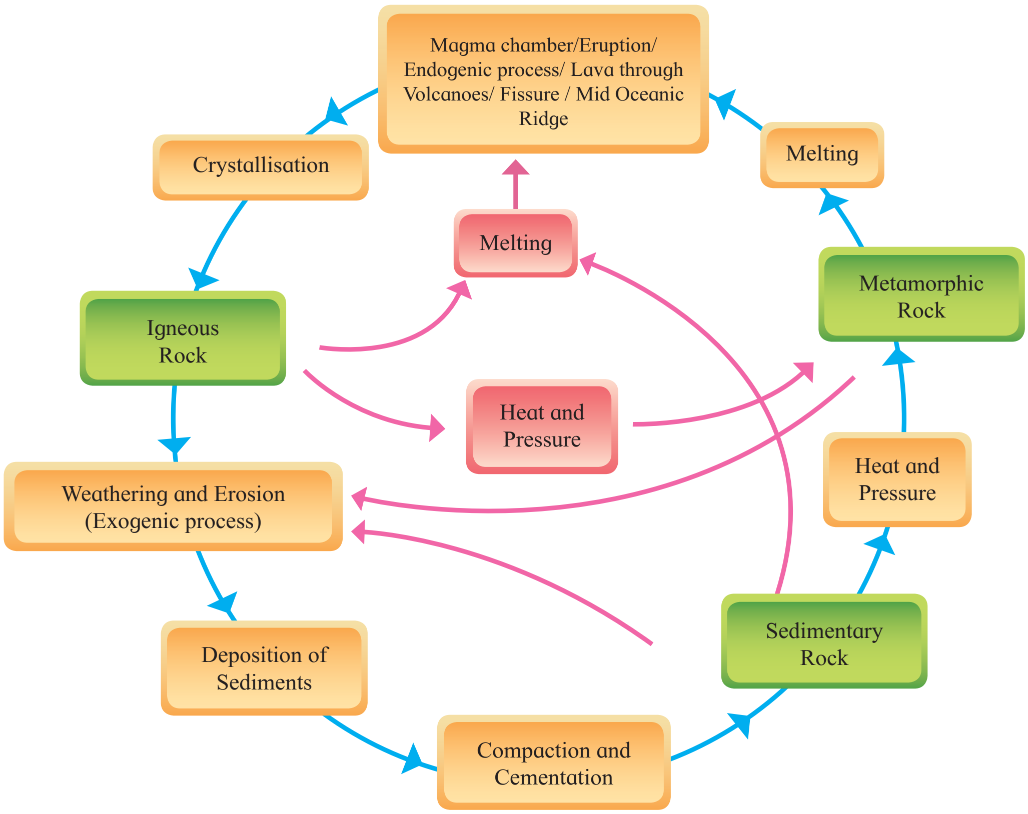


Fig. 4.1 : Rock cycle

EXERCISE

Q. 1. Fill in the blanks :

1) Metamorphic rocks characteristically show .... of material.
2) Cycle driven by exogenous and endogenous processes is known as ....

Q. 2. Multiple choice questions :

1) Sedimentary rocks are mainly formed by........... processes.
   a) endogenous b) exogenous
   c) extra terrestrial
   d) both exogenous and exogenous
2) If no crystallization takes place .... rock is developed.
   a) holocrystalline b) glassy
   c) plutonic d) Hypabyssal

Q. 3. Give geological terms :

1) Rocks that are classified on the basis of grain size are ....

2) The class of igneous rocks which exhibit equigranular texture are ....

Q. 4. Match the pairs :

1) Process / **Product**

Process	**Product**
A) Cataclastic	i) Granite
B) Thermal	ii) Slate
C) Dynamothermal	iii) Quartzite
D) Plutonic	iv) Mica schist

1) A-ii, B-iii, C-iv, D- i
2) A-iii, B-ii, C-i, D-iv
3) A-iv, B-i, C-iii, D-ii
4) A-ii, B-iv, C- iii, D- i

2) Types / **Rocks**

Types	**Rocks**
a) Rudaceous	i) Shell limestone
b) Organic deposits	ii) Conglomerate
c) Argillaceous	iii) Limestone
d) Chemical deposits	iv) Mudstone

1) a-iv, b-iii, c-i, d-ii
2) a-i, b-ii, c-iii, d-iv
3) a-iii, b-iv, c-ii, d-i
4) a-ii, b-i, c-iv, d-iii

Q. 5. Strike the odd one out :

1) Plutonic, Hypabyssal, Volcanic, Organic deposits.
2) Rudaceous, Arenaceous, Argillaceous, Hypabyssal
3) Cataclastic, Thermal, Dynamothermal, Volcanic.

Q. 6. Eliminate the incorrect statement :

1) The crystallisation of magma is not governed by the ....
   a) Temperature and pressure
   b) Composition of magma
   c) Visco sity of magma
   d) Geographic position of the magma on the Earth's surface
2) Plutonic igneous rocks are ....
   a) Deep seated and have moderate temperature pressure conditions.
   b) Near the Earth's surface and possess high temperature pressure conditions.
   c) Deep seated with high temperature pressure and fast cooling conditions.
   d) Deep seated with high temperature pressure and slow cooling conditions.

Q. 7. Distinguish between :

1) Igneous and Metamorphic rocks.
2) Volcanic Igneous and Plutonic Igneous rocks.
3) Rudaceous and Arenaceous Sedimentary rocks.
4) Cataclastic and Thermal metamorphism.

Q. 8. State whether True or False and justify in either case :

1) Hypabyssal rocks contain coarse and fine grained minerals.
2) Sedimentary rocks are layered or stratified
3) Metamorphic rocks exhibit recrystallization.

Q. 9. Write short notes on :

1) Characteristics of igneous rocks.
2) Classification of sedimentary rock.
3) Genesis of sedimentary rocks.
4) Genesis of metamorphic rocks.

Q. 10. Give geological reasons :

1) Plutonic igneous rocks usually exhibit coarse grained texture.
2) Volcanic rocks exhibit fine grained texture.
3) No new minerals are formed in cataclastic metamorphism.
4) Some minerals are formed in dynamothermal metamorphism.

Q. 11. Answer in detail :

1) Explain the process of transformation of igneous and metamorphic rocks into sedimentary rocks.
2) Explain the role of endogenic and exogenic processes in conversion of one rock type into another.
3) Explain how metamorphic rocks can be converted to sedimentary rocks.

Chapter - 5 Mineralogy

Highlights :

- Nomenclature and classification of minerals.
- Characteristic features of minerals.
- Physical properties for mineral identification.

Introduction :

Rocks are fundamental units of the Earth's crust and study of Earth begins with the study of rocks. A close examination of rocks reveals that they are made up of smaller units known as minerals. Minerals may vary in colour, hardness, density, crystal form, crystal size, transparency, composition, occurrence and abundance.

Some minerals are radioactive (Uraninite) while others are magnetic (Magnetite) (Fig. 5.1).

Fig. 5.1 : Uraninite   Magnetite

Minerals such as fluorite glow with a vibrant luminescence after exposure to ultraviolet light. Feldspar and quartz are most abundant minerals found in the Earth's crust. Mankind has a desire for many minerals and gemstones due to their strikingly beautiful colors. Some specimens of opal exhibit rainbow-like colors while some specimens of the gemstone, tourmaline show progressions of watermelon like green to pink colours (Fig. 5.2).

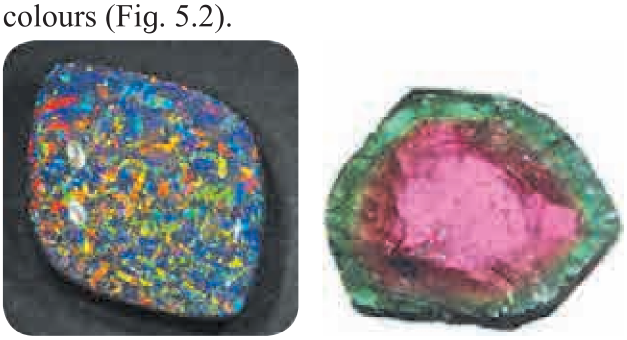


Fig. 5.2 : Opal   Tourmaline

Few minerals are deceiving and many amateur prospectors have been tricked into thinking that they have found gold but have instead found pyrite (Iron disulphide) otherwise known as "Fools Gold" (Fig. 5.3 A) due to its uncanny resemblance to the precious metal.

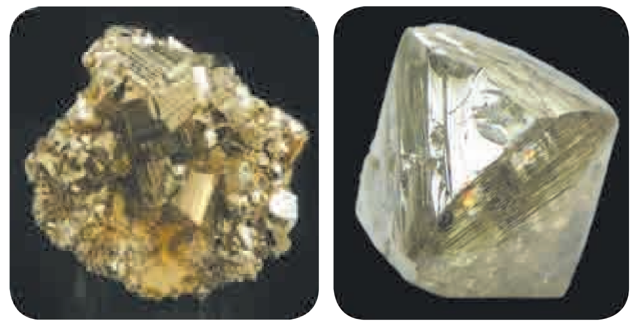


Fig. 5.3 : A) Pyrite (fool's gold)   B) Diamond

Diamond, the hardest natural substance found on Earth, has long been priced as the most desirable of all minerals due to its spectacular interaction with light. Majority of diamonds are impure and not suitable as gemstones. They, however, can be used in the industry as cutting tools (Fig. 5.3 B).

5.1 Mineral nomenclature :

Name of any mineral is its identity. The names of many minerals are derived from antiquity. Most of the earlier mineral names were based on their physical properties like colour, density, etc. Later with the discovery of new elements, many new minerals were named. A set of guidelines formulated by the Commission on New Minerals and Mineral Names (CNMMN) under the International Mineralogical Association (IMA) are followed in naming minerals. The master list of minerals prepared by CNMMN in November 2018 has 5,389 minerals.

Many minerals are named after famous personalities or scientists who discovered or analysed them. Moreover, there are names of minerals that convey information about the region where they have been found. Some are quite specific about the location. Some mineral names convey useful information about the mineral itself and are based on the chemical composition, colour, crystal form, hardness, lustre or other properties. Majority of mineral names end in 'ite' which is derived from the Greek word lithos (from its adjective form-ites) meaning rock or stone.

5.1.1 Minerals named after person :

The first mineral which was named after a person is Prehnite. It was named after Col. von Prehn in 1790. Since then, the naming of minerals after people became a common practice. Few other commonly occurring minerals which have been named after persons are Biotite (French mineralogist Jean-Baptise Biot), Dolomite (French mineralogist, D.de Dolomieu), Heulandite (German mineral collector and dealer John Henry Heuland).

People who have two minerals named after them :

1) **Marie Sklodowska Curie :**
   a) Sklodowskite
   b) Curite (named after Marie and her French physicist husband Pierre).

2) **Neil Alden Armstrong :** American, astronaut, first human being to land on the moon's surface.
   a) Armstrongite
   b) Armalcolite (named after Neil Armstrong and other Apollo 11 crew members Aldrin and Collins).

Minerals named after persons of Indian origin :

1) **Radhakrishnaite :** Named after Bangalore Puttaiya Radhakrishnan (1918 - 2012) Indian Mineralogist, who was Director Mysore Geological Department.
   A mineral found in Kolar Gold field, Karnataka.

2) **Rustumite :** Named after Rustum Roy (1924 - 2010) B.Sc and M.Sc in Chemistry from Patna University and Ph.D in ceramic science and Professor at Pennsylvania University, specialist in crystal chemistry of minerals and synthetic materials.

5.1.2 Minerals named after a place :

Common minerals named after the place from where they were first reported from or are abundantly found are Amazonite (named after area near the Amazon River), Labradorite (named after Labrador province, Canada) and Muscovite (named after the Russian province Muscovy).

5.1.3 Minerals named after their chemical composition :

Common mineral names derived from their chemical composition are Calcite (derived from the Greek word 'Chalx' which means burnt lime), Cavansite (named after its elemental contents of Calcium, Vanadium and Silicon), Halite (Greek word 'hals' which means salt).

5.1.4 Minerals named after physical properties :

1) **Colour :** Some of the common minerals named after their color are Beryl (Greek word 'beryllos' which means a green stone), Hematite (after Greek word haimetites, meaning blood-like), Kyanite (Greek word 'kyanos' meaning blue).

2) **Lustre :** Stilbite-Named after German word 'stilbein' which means 'to shine' because of its brilliant lustre. It is a member of the zeolite group of minerals, commonly found as a secondary mineral in basalt.

3) **Cleavage :** Orthoclase-Named after the Greek words 'ortho' and 'klao' meaning 'straight' and 'cleave'. It breaks due to two cleavages meeting at right angles.

4) **Hardness :** Diamond-Named after the Greek word 'adamas' which means 'invincible' because of its hardness.

5) **Sp. gravity :** Barite-Named after the Greek word 'barys' which means 'heavy' because of its high specific gravity. It is also known as heavy spar.

6) **Magnetism :** Magnetite-Named for its strong magnetic property. It is an important ore of Iron.

5.1.5 Minerals named after Sanskrit word :

1) **Corundum :** Named after the Sanskrit word 'Kuruvind' which means 'ruby'.

2) **Opal :** Named after Sanskrit word 'Upala' which means 'gem'.

5.1.6 Mineral names from antiquity :

Many mineral names have been in existence from antiquity like Quartz, Galena, Gypsum etc.

5.2 History of Mineralogy :

The history of mineralogy goes back to Aristotle the Greek philosopher (384 - 322 BCE) who was one of the first to write about minerals and their properties in the western tradition.

Theophrastus, the Greek philosopher (372 - 287 BCE) is known for the first written work on minerals. He wrote a book on mineralogy called 'Conerning Stones'. Pliny the Elder, Roman naturalist (23 - 79 CE) recorded the mineralogical ideas of his time. He wrote an encyclopaedic work 'Natural History'. Agricola Georgius, a German scholar and scientist (1494-1555) was a town physician and considered as the 'Father of Mineralogy'. His book 'De re metallica' published in 1556, is about the mining practices and metallurgy techniques of his time.

5.3 Mineralogy - Salient points :

1) Elements are the building blocks of minerals while minerals are the building blocks of rocks.
2) There are more than 5000 mineral species approved by the International Mineralogical Association (IMA)
3) Silicate minerals compose over 95% of the Earth's crust. Silicon (27.7%) and Oxygen (46.6%) constitute approximately 75% of the Earth's crust.
4) Eight elements account for most of the key components of minerals due to their abundance in the crust. These eight elements constitute more than 98% of the crust by weight. These eight elements in decreasing order of abundance are Oxygen, Silicon, Aluminium, Iron, Magnesium, Calcium, Sodium and Potassium.
5) Differences in crystal structure and chemistry greatly influence the physical properties of minerals. The carbon allotropes diamond and graphite have vastly different properties.

5.4 Mineral characteristics :

Five criteria essential for classifying a substance as a mineral are as follows :

1) **A mineral has to occur naturally :** Substances produced artificially by humans are not considered as minerals. With the help of modern technology, many compounds can be produced in the laboratory by artificially simulating the conditions under which they are formed in nature, e.g. precious and semi-precious stones such as topaz, corundum and even diamond can be produced synthetically. Cubic Zirconia also known as American diamond is a synthetic gem variety and does not qualify as a mineral.

2) **A mineral has to be formed by inorganic processes :** Substances originating from plants (amber, rudraksha etc) or animal (ivory, pearls, corals etc) cannot be termed as minerals. Calcite or aragonite which is formed inorganically due to the processes of evaporation or crystallization are minerals, but the same substances deposited by the activity of organisms (mollusk shells) do not qualify as minerals.

3) **A mineral has to be in a solid state :** Accordingly, water which is in liquid form is not a mineral while ice which is in solid form, is termed as a mineral. Therefore mercury, petroleum etc. also cannot be considered as minerals.

Do you know?

Natural oil (Petroleum) although occurs naturally, is liquid in nature and is formed by organic processes, is dealt with separately and not in mineralogy.

4) **A mineral must have a definite chemical composition or a definite range of chemical composition :** Quartz crystals collected from any part of the Earth will always have the same chemical composition i.e SiO_2. Many minerals may exhibit a range of chemical composition, for e.g. plagioclase feldspars form a wide

range of minerals from Na rich (albite) to Ca rich (anorthite) varieties.

5) **A mineral must possess an ordered internal atomic structure :** Definite physical and chemical characters will be exhibited by a substance if its atoms are orderly arranged in a geometric pattern. Such substances qualify as minerals. For example natural glass which is formed by faster cooling of lava is not a mineral because it lacks an ordered internal atomic structure.

Activity :

Using the above significant characteristics of minerals, derive a holistic definition for a mineral.

5.5 Physical properties of minerals :

The physical properties vary from mineral to mineral depending on their chemical composition and crystal structure. Minerals possess widely different physical properties such as form, colour, streak, lustre, fracture, cleavage, hardness, specific gravity etc. The study of these physical properties is the first step in identification of minerals. Some properties like radioactivity, specific gravity, magnetism, electrical and thermal properties may need instruments for measurement.

Some of the original properties of the minerals may be partly or completely altered due to their exposure to air and water which causes corrosion or rusting. Hence, whenever geological studies are to be carried out, it is important to obtain fresh, *in-situ* sample.

5.5.1 Characters depending upon light :

1) Colour : Colour is the first property one notices in a mineral. It is also one of the reasons that attracts people to minerals, especially to gem stones. However, colour is not a very reliable property to be used in the identification of minerals. It usually confuses an inexperienced collector into making an incorrect identification. It is important to know what causes colour in minerals in order to understand this mineral property.

Colour is determined by its wavelength. When pure white light (containing all wavelengths of visible light) enters a mineral, some of the wavelengths might be absorbed while other wavelengths are emitted. If this happens, then the light that is transmitted through the mineral will no longer be white but will have some colour. Colour in minerals is caused by the absorption or lack of absorption of various wavelengths of light.

Colourless minerals (transparent and translucent) like quartz, calcite, fluorite can exhibit certain colours due to the presence of transition elements. These transition elements cause a mineral to exhibit a certain colour if they are part of the chemistry of the mineral. The most common chromophoric (colour causing) transition elements with unfilled electron shells are Ti, V, Cr, Mn, Fe, Co, Ni, Cu. However, if there is just a trace of these elements, they still can strongly influence the colour of the mineral. Copper usually produces green and blue colours. Iron is known for the red and yellow colours that it typically produces. However, almost any element can be responsible for a characteristic colour. Thus, minerals of same composition can exhibit different colours e.g. quartz (Fig. 5.4), calcite (Fig. 5.5), fluorite (Fig. 5.6) etc. Minerals of different compositions can also exhibit the same colour e.g. calcite (Fig. 5.7 A), natrolite, (Fig. 5.7 B) and milky quartz (Fig. 5.7 C) all exhibit white colour. Hence, colour cannot be considered as the most diagnostic property for identifying minerals.

Quartz varies widely in colour, due to minor (parts per billion) impurities and even defects in its crystalline structure. Pure quartz has no colour. Varieties of quartz, shown in figure 5.4 include : amethyst (purple), smoky quartz (brown to black), citrine (yellow), rosy quartz (pink), rock crystal (clear).

Amethyst

Smoky quartz

Citrine

Rosy quartz

Rock crystal

Fig. 5.4 : Varieties of quartz showing different colours due to presence of chromophoric elements

Fig. 5.5 : Variety of colours exhibited by Calcite

Fig. 5.6 :Variety of colours exhibited by Fluorite (CaF_2)

A) Calcite ($CaCO_3$)

B) Natrolite ($Na_2Al_2Si_3O_{10}\cdot 2H_2O$)

C) Milky quartz (SiO_2)

Fig. 5.7 : Minerals with different chemical composition showing white colour

Do you know?

V^{+3} in grossular garnet (variety of garnet) causes the green colour.

Cr^{+3} causes green colour in emerald (variety of beryl)

Mn^{+3} causes red colour in muscovite mica

Cu^{+2} usually produces blue and green colours in minerals such as azurite and malachite.

2) Streak : Streak refers to the colour of a mineral's powder left behind after it is rubbed across a porcelain streak plate. This property is studied only for coloured (not white) minerals. Minerals with hardness less than 6.5 are tested with the help of the porcelain plate, while those with higher hardness are checked with other streak plates, e.g corundum plate. Streak of a mineral may be different from the colour of the mineral e.g. pyrite, which shows golden colour has a pencil lead grey streak (Fig. 5.8).

Fig. 5.8 : The streak of golden coloured mineral pyrite is pencil lead grey

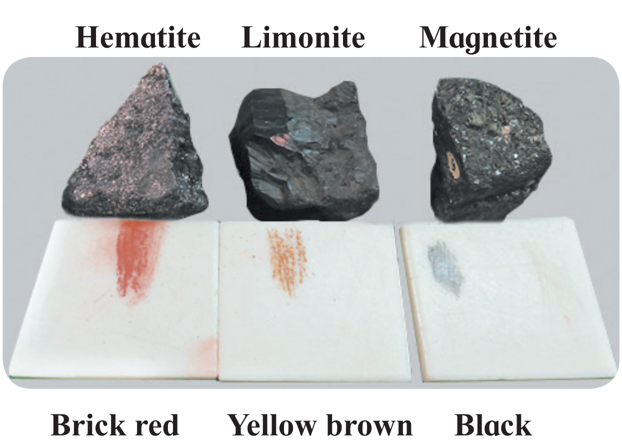


Fig. 5.9 : Streak of different dark coloured Fe-bearing minerals appears brick red, yellowish brown and black

Streak of the mineral is a more reliable identification characteristic than the colour of the mineral.

Do you know?

Application of streak in identifying gold

Kasauti stone/touch stone is a small piece of fine grained black stone which is used by goldsmiths for testing the purity of gold.

A piece of gold to be tested is scratched on the 'Kasauti' stone, which leaves a streak on it. This is compared with the streak obtained from piece of gold of known purity.

3) Lustre : Lustre describes the appearance of a mineral when light is reflected from its surface. It is the degree of reflected light and directly related to optical properties (mainly refractive index) and surface conditions.

Lustre of minerals is mainly classified as Metallic and Non-metallic :

i) Metallic lustre : Strictly belongs to opaque minerals, where light is completely reflected from the surface. Most ore minerals having high content of metals exhibit metallic lustre, e.g., galena, magnetite, pyrite (Fig. 5.10), etc.

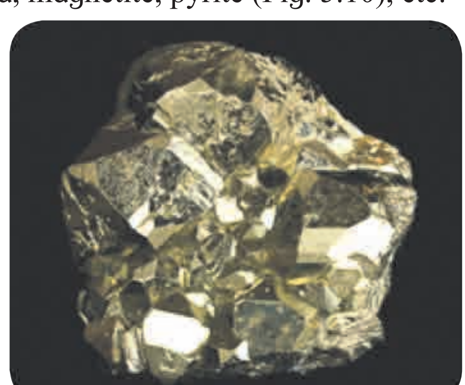


Fig. 5.10 : Metallic lustre in pyrite

Submetallic lustre : Some minerals have lustre similar to that of a metal, but are dull and less reflective. Submetallic lustre often occurs in near-opaque minerals with very high refractive indices, such as hematite, chromite (Fig. 5.11) etc.

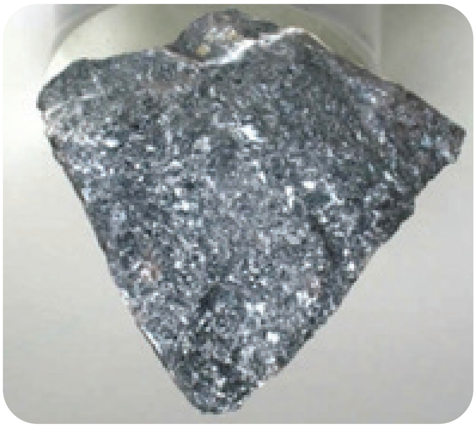


Fig. 5.11 : Sub-metallic lustre in Chromite

ii) Non-metallic lustres : Other lustre types are collectively known as non-metallic lustres. They may be brilliant or faint where reflection is poor due to scattering of light from the mineral surface. The different types of non-metallic lustres are:

a) Adamantine lustre : An exceptionally brilliant lustre exhibited by minerals having very high refractive index, e.g. diamond (Fig. 5.12), zircon, corundum (ruby, sapphire). These minerals are used as precious gem stones.

Fig. 5.12 Adamantine lustre in Diamond

b) Dull / Earthy lustre : Dull lustre is also known as 'earthy' and is used to describe minerals that have poor reflectivity. The surface of minerals with dull lustre is coarse and porous, e.g., kaolinite (Fig. 5.13), limonite, bauxite.

Fig. 5.13 : Dull / Earthy lustre in Kaolinite

c) Greasy / Waxy / Oily lustre : It results from light scattered by a microscopically rough surface, e.g. chalcedony (Fig. 5.14), opal etc.

Fig. 5.14 : Waxy lustre in Chalcedony

d) Pearly lustre : It results due to reflection from successive layers, such as cleavage surfaces, e.g. talc (Fig. 5.15), muscovite, gypsum.

Fig. 5.15 : Pearly lustre in Talc

e) Resinous lustre : Minerals have the appearance of resin, chewing gum or (smooth-surfaced) plastic, eg., amber (Fig. 5.16) which is a form of fossilised resin.

Fig. 5.16 : Resinous lustre in Amber

f) Silky lustre : It is due to the reflection from minerals having parallel arrangement of extremely fine fibres, e.g. gypsum (satin spar) (Fig. 5.17), asbestos, malachite.

Fig. 5.17 : Silky lustre in Gypsum (Satin spar)

g) Vitreous lustre : It is generally shown by broken glass. This type of lustre is one of the most commonly observed lustres and occurs in transparent or translucent minerals with relatively low refractive indices. Common examples include quartz (Fig. 5.18), fluorite etc.

Fig. 5.18 : Vitreous lustre in Quartz

Subvitreous lustre : When the minerals exhibit feebly developed vitreous lustre, they are said to show subvitreous lustre, e.g milky quartz, calcite (Fig. 5.19), etc.

Fig. 5.19 : Subvitreous lustre in Calcite

5.5.2 Characters depending upon crystal aggregate habits :

4) Form : Most minerals are formed within the spaces in between other minerals and may grow into shapeless masses. However, if they are formed freely in a hole or a cavity within a rock, the mineral takes the form of a crystal. These crystal-lined cavities are called geodes, vugs or pockets.

Form is the natural mode of occurrence of a mineral or the common geometric morphology of the mineral. Various forms are identified as follows :

Degree of crystallisation :

i) **Crystallised :** The minerals occur in the form of well developed crystals, e.g. quartz (Fig. 5.20).

Fig. 5.20 : Crystallised form in Quartz

ii) **Crystalline :** The minerals occur in the form of aggregates of imperfectly developed crystals, e.g. quartz (Fig. 5.21).

Fig. 5.21 : Crystalline form in Quartz

iii) **Cryptocrystalline :** The minerals occur as partly crystalline and partly amorphous and lack a perfect shape, e.g. agate, chalcedony (Fig. 5.22).

Fig. 5.22 : Cryptocrystalline form in Chalcedony

iv) **Amorphous :** The minerals are formed in nature as solids without development of internal atomic structure, e.g. opal (Fig. 5.23)

Fig. 5.23 : Amorphous form in Opal

Growth dominantly in one direction :

Minerals of this category exhibit slender forms and are described as :

i) **Acicular :** The minerals are needle-like and may occur individually or in aggregates, e.g. actinolite (Fig. 5.24).

Fig. 5.24 : Acicular form in green coloured needles of Actinolite

ii) **Columnar :** Such minerals occur as columns of varying sizes e.g., beryl (Fig. 5.25).

Fig. 5.25 : Columnar form in Beryl (Aquamarine)

iii) **Fibrous :** Minerals are made up of thin hair-like separable fibres or crystals, e.g. asbestos (Fig. 5.26).

Fig. 5.26 : Fibrous form in Asbestos (Serpentine)

iv) **Radiating or Divergent :** The minerals appear as diverging needles from central nucleus e.g. natrolite (Fig. 5.27).

Fig. 5.27 : Radiating form in Natrolite

v) **Wiry :** Some minerals occur in nature in the form of thin wires, which may be twisted or stretched in different directions, e.g. native copper or native silver (Fig. 5.28).

Fig. 5.28 : Wiry form in Native Silver

Growth in two dimensions :

Minerals of this category are described as :

i) **Bladed :** The mineral appears like a flat blade of a knife, e.g. kyanite (Fig. 5.29).

Fig. 5.29 : Bladed form in Kyanite

ii) **Foliated :** Mineral occurs as flakes or plates which are separable and can split into sheets or lamellae, e.g., muscovite and biotite (Fig. 5.30).

Fig. 5.30 : Foliated form in Biotite

iii) **Tabular :** Mineral occurs in the form of a flattened rectangular shape, resembling a table, e.g. barite (Fig. 5.31), plagioclase etc.

Fig. 5.31 : Tabular form in Barite

Growth in three dimensions :

i) **Equidimensional :** Minerals grow equally in three dimensions and appear as stubby crystals, e.g. garnet, pyrite (Fig. 5.32).

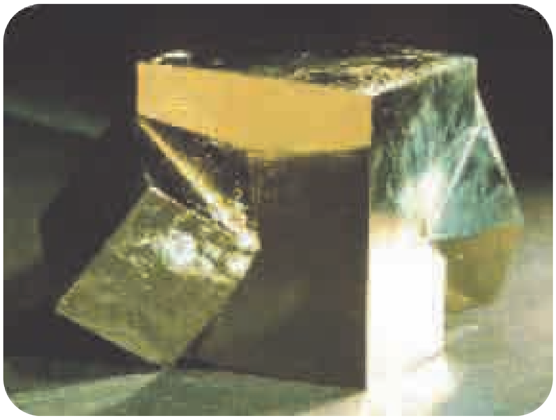


Fig. 5.32 : Equidimensional form in Pyrite

Growth with curved surfaces :

i) **Botryoidal :** Crystals occur in spheroid aggregates resembling a bunch of grapes, e.g., chalcedony, agate (Fig. 5.33).

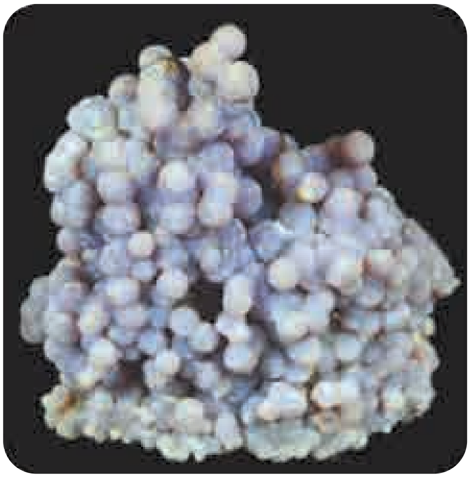


Fig. 5.33 : Botryoidal form in Agate

ii) **Granular :** Mineral occurs as distinct grains resembling a lump of sugar, e.g., olivine (Fig. 5.34).

Fig. 5.34 : Granular form in Olivine

iii) **Oolitic :** These minerals appear like small spherical growths, resembling eggs of fish, e.g. bauxite (Fig. 5.35).

Fig. 5.35 : Oolitic form in Bauxite

iv) **Pisolitic :** Mineral grains resemble pea-sized spheroids, coarser than oolites, e.g., bauxite (Fig. 5.36).

Fig. 5.36 : Pisolitic Bauxite

v) **Reniform :** Mineral is circular or roughly circular, resembling the shape of a kidney, e.g., hematite (Fig.5.37), psilomelane etc.

Fig. 5.37 : Reniform form in Hematite

Growth in miscellaneous manner :

i) **Dendritic :** Minerals show branch-like growth in different directions, e.g. native copper (Fig. 5.38).

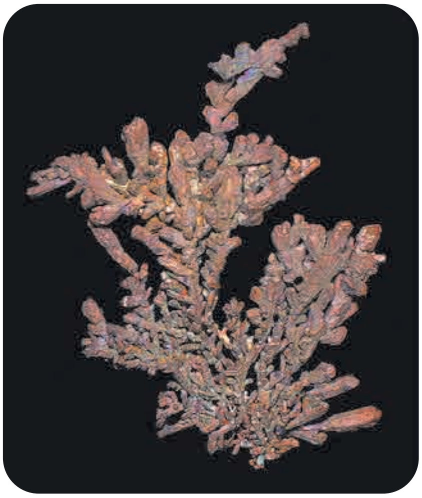


Fig. 5.38 : Dendritic form in Native Copper

ii) Massive / Compact : The minerals cannot be individually identified with the naked eye as they form a compact mass exhibiting an irregular shape, e.g. rosy quartz (Fig. 5.39).

Fig. 5.39 : Massive form in Rosy Quartz

5.5.3 Characters depending upon cohesion and elasticity :

Cohesion : It is the force of attraction existing between molecules. It shows resistance to any external influence that tends to separate them, Cohesion force is related to bonding force.

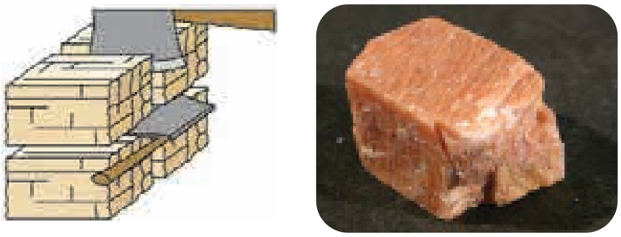
Elasticity : It is the force that tends to restore the molecules of a body into their original position from which they have been disturbed.

The result of cohesion and elasticity in a mineral appears as cleavage, fracture and hardness.

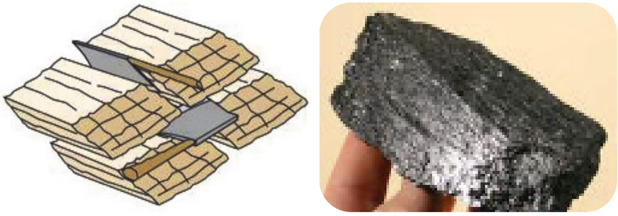
5) Cleavage : The manner in which a mineral breaks is determined by the arrangement of its atoms and the strength of the chemical bonds holding them together. As this property is unique to the mineral, careful observation can aid in mineral identification (Fig. 5.40).

The word cleavage is derived from 'cleave' meaning to break or split. Cleavage is therefore, a plane of weakness along which mineral splits easily. Only crystalline minerals can show cleavage, though every crystalline mineral may not possess cleavage (e.g. quartz). Amorphous minerals (limonite, opal etc.) do not show cleavage. Cleavage, if present, occurs as numerous parallel planes along which the mineral is equally weak. Hence, all such weaker planes along a single direction are referred to as 'sets of cleavage'. Depending upon their atomic structure, crystalline minerals will exhibit one set of cleavage (e.g. mica, Fig. 5.40 A), two sets of cleavage (e.g. feldspars Fig. 5.40 B, amphiboles Fig. 5.40 C), three sets of cleavage (e.g. galena Fig. 5.40 D, calcite, Fig. 5.40 E) or four sets of cleavage (e.g. fluorite, Fig. 5.40 F).

A) Biotite and muscovite micas exhibit one set of cleavage.

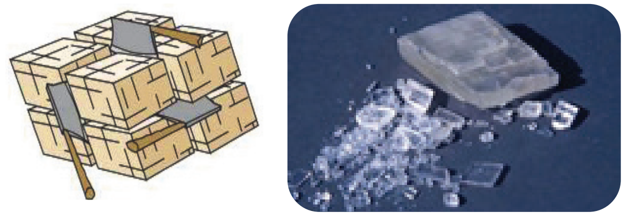


B) Orthoclase and plagioclase fedspars exhibit two sets of cleavage at approximetely 90° from each other.

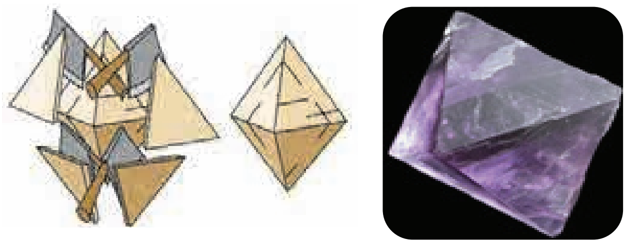


C) Hornblende (an amphibole) has two sets of cleavage at 124°. from each other.

D) Galena has three sets of cleavage that form two 90° angles (cubic cleavage)



E) Calcite has three sets of cleavage - 105° in one plane and 75° in another



F) Fluorite has four sets of cleavage (octahedral cleavage)

Fig. 5.40 : Minerals and their cleavages

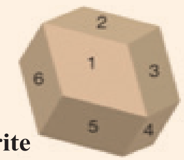
Quality of cleavage can be categorised into :

- **Perfect :** Minerals with perfect cleavage split without leaving any rough surface. A full, smooth plane is formed where the crystal breaks, e.g. calcite.
- **Good :** Minerals with good cleavage also leave smooth surfaces, but often leave minor residual rough surfaces e.g. feldspars.
- **Poor :** Smooth crystal edge is not visible in minerals with poor cleavage, since the rough surface is dominant, e.g. barite and apatite.
- **Indistinct :** If a mineral exhibits cleavage, but it is so poor that it can hardly be distinguished, it is indistinct cleavage e.g. beryl.
- **None :** Some minerals never exhibit any cleavage. Thus, broken surfaces are fractured and are rough, e.g. quartz.

Do you know?

Six cleavage planes can give a 12-sided form e.g., sphalerite.

Number of cleavages and their directions	Name and description of how the mineral breaks
6 cleavages intersect at 60° and 120°	**Dodecahedral cleavage** Shapes made of dodecahedrons and parts of dodecahedrons

Shape of broken pieces (cleavage directions are numbered)	Illustration of cleavage directions
 **Sphalerite**	

6) Fracture : The appearance of broken surface of the mineral is expressed by the term fracture. It is the irregular breaking of a mineral along a surface which is not parallel to the cleavage or to the parting planes. The fracture planes are not related to the atomic structure of the mineral. These are simply ruptures which are devoid of any systematic and regular placement of planes. The different types of fractures are described as follows :

i) Conchoidal : Broken surface shows concentric rings or concavities which may be deep in character, e.g., obsidian (Fig. 5.41 A). When the broken surface shows faint concentric rings, it is subconchoidal fracture. e.g. rock crystal, flint (Fig. 5.41 B)

A)

B)

Fig. 5.41 : A) Conchoidal, B) Subconchoidal fracture

ii) **Earthy :** Fractured surface is soft and smooth resembling the broken surface of chalk, e.g. bauxite, limonite (Fig. 5.42).

Fig. 5.42 : Earthy fracture in Limonite

iii) **Hackly :** Broken surface is highly irregular and exhibits sharp, pinching projections. e.g. asbestos, native copper (Fig. 5.43).

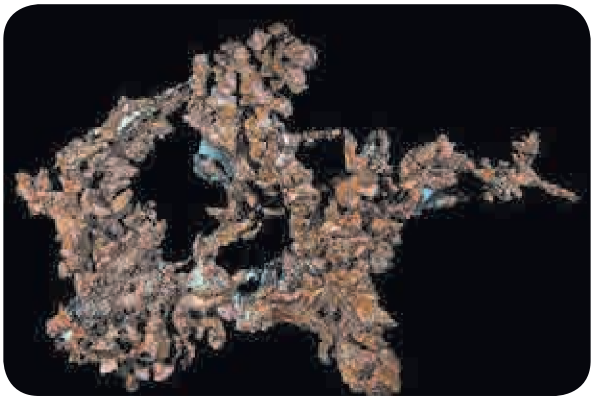


Fig. 5.43 : Hackly fracture in Native Copper

iv) **Splintery :** The mineral breaks with a rough woody fracture, e.g. kyanite, serpentine (Fig. 5.44).

Fig. 5.44 : Splintery fracture in Serpentine

v) **Uneven :** Broken surface is rough and irregular with a rugged appearance, e.g., orthoclase, magnetite (Fig. 5.45).

Fig. 5.45 : Uneven fracture in Magnetite

7) Hardness : Hardness of mineral is a measure of its resistance to abrasion or scratching.

The degree of hardness is determined by observing the comparative ease or difficulty with which one mineral is scratched by another. Hardness of a mineral depends upon its atomic structure, hence it is considered to be a reliable property in mineral identification.

In 1822, an Austrian mineralogist Friedrich Mohs devised a hardness scale, (Table 5.1) based on one mineral's ability to scratch another mineral. He placed 10 minerals in order, from softest to hardest, giving a relative hardness value of 1 to the softest mineral i.e. talc and 10 to the hardest i.e. diamond. Each mineral on the scale scratches the one below it (the lower number), but not the one above it (the higher number). This is known as Mohs' scale of hardness, and is one of the best practical methods of estimating a mineral's hardness :

Note : It must be noted that Mohs' scale is arbitrary and non-linear (Fig. 5.46), i.e. the steps between relative hardness values are not necessarily equal. Rather, it is a method of gauging the relative hardness of minerals. If a mineral cannot be scratched by a knife blade but can be scratched by quartz then its hardness is between 5 and 7 (stated as 5-7) on Mohs' scale. A relative hardness value of 6.5 means, that the mineral could scratch orthoclase (feldspar) but not quartz.

Table 5.1 : Mohs' hardness scale with objects of equivalent hardness			
	Mineral Name	**Scale Number**	**Common Object**
Increasing Hardness	Diamond	10	
	Corundum	9	
	Topaz	8	Masonry Drill Bit (8.5)
	Quartz	7	
	Orthoclase	6	Steel Nail (6.5)
	Apatite	5	Knife/Glass Plate (5.5)
	Fluorite	4	
	Calcite	3	Copper Penny (3.5)
	Gypsum	2	Finger nail (2.5)
	Talc	1	

Test : Using moderate pressure, drag a sharp edge over the smooth surface of a mineral. If the surface of the mineral is scratched, then it is softer than the material used to scratch it, if not then it is harder.

Terminology :

Soft : can be scratched by a fingernail (1-2 Mohs').

Medium : can be scratched by a knife or nail (3-5 Mohs').

Hard : cannot be scratched by a knife, but it can scratch glass (6-9 Mohs').

Diamond is the hardest known mineral (10 Mohs').

Do you know?

Hardness is measure of the strength of the structure of the mineral relative to the strength of its chemical bonds. It is not the same as brittleness, which is another measure of strength that is purely related to the structure of the mineral. Minerals with small atoms, packed tightly together with strong covalent bonds throughout, tend to be hardest minerals. The soft minerals have metallic bonds or even weaker Van der Waals bonds as important components of their structure. Hardness is generally consistent with the chemistry of minerals.

Minerals exhibiting hardness more than 7 can be cut and polished as gemstones, e.g. crystalline varieties of quartz, corundum, beryl, etc. Any mineral with hardness less than 7 cannot be used as a gemstone, but can be used in making sculptures or artifacts, e.g. jade, chalcedony, malachite, turquoise, etc.

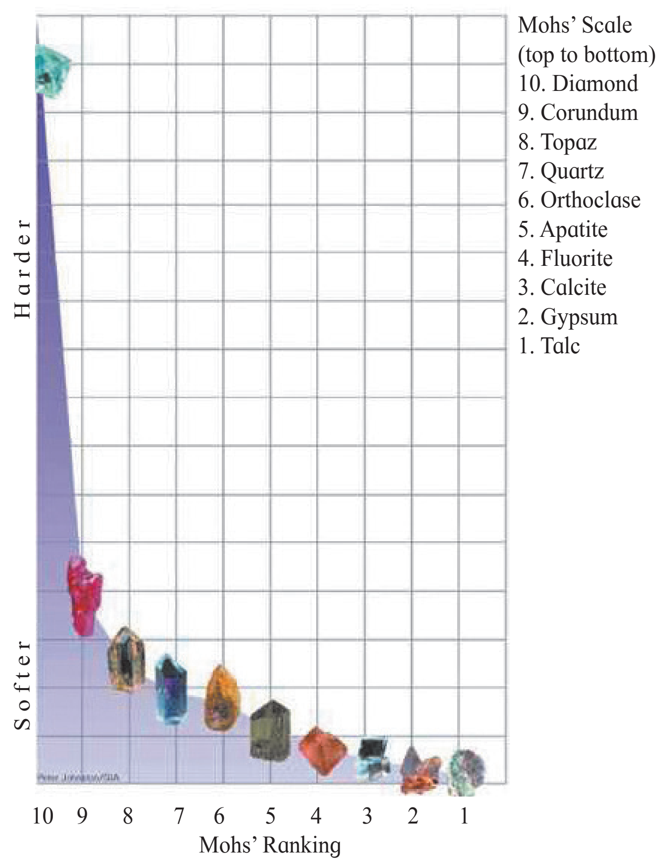


Fig. 5.46 : Non-linear relationship between Mohs' scale and hardness of minerals

8) Specific Gravity : Specific gravity of a mineral is defined as a number that expresses the ratio of the weight of the mineral in air to the weight of an equal volume of water displaced by it at normal temperature and pressure (NTP) conditions. The specific gravity of a mineral depends upon the atomic arrangement, crystal structure, chemical composition. It varies with temperature and pressure. For a mineral of variable composition crystallising in specific structure, the variation in specific gravity will depend on the atomic weight of the individual atoms, e.g., in olivine, specific gravity varies from 3.2 for pure forsterite (Mg_2SiO_4) to 4.4 for pure fayalite (Fe_2SiO_4). The atomic weight of Mg is 24.3 and Fe is 55.8.

The common rock forming minerals have specific gravity that ranges between 2.5 and 3.5 while the average specific gravity for metallic minerals is about 5.0. Ore minerals have specific gravity around 3.0.

The specific gravity of minerals can be determined in the laboratory by two methods i.e. Walker's steelyard balance and Jolly's spring balance.

Do you know?

Minerals like galena (7.5), barite (4.25) and hematite (5.26) having high specific gravity are commonly used to increase the weight of drilling muds for oil- well drilling especially to avoid blow-out. Gravity separation technique depends on the difference in specific gravity of minerals. This method is environment friendly and used for the separation of high specific gravity minerals and metallurgical waste.

Classification of Minerals :

On the basis of chemical composition and internal structure, minerals are classified as follows :

Oxides : Oxides are minerals that consist of metal cations (atoms with a positive charge) bonded to oxygen anions. An anion is an atomic structure that has a net negative charge, e.g. haematite (Fe_2O_3) and magnetite (Fe_3O_4).

Sulphides : Sulphides consist of metal cations bonded to a sulphide anion, e.g. pyrite (FeS_2) and galena (PbS).

Sulphates : Sulphates are minerals that consist of metal cations bonded to a sulphate (SO_4^{-2}) anion. e.g. gypsum ($CaSO_4.2H_2O$).

Halides : Halides are minerals that consist of metal cations bonded to halide anions. Halide refers to the elements chlorine, fluorine, iodine, e.g. fluorite (CaF_2).

Carbonates : Carbonates are minerals that contain metal cations bonded to the carbonate (CO_3^{-2}) anion, e.g. calcite ($CaCO_3$).

Native Elements : Minerals that consist of one single element belong to this group, e.g. copper, gold and silver.

Silicates : Silicates make up over 95% of the Earth's crust and about 97% of the mantle. They are the most common minerals on Earth. Silicates are minerals that contain the fundamental silicon tetrahedra (SiO_4) (Fig. 5.47). A tetrahedra is a geometric shape similar to a four-sided pyramid. The silica tetrahedra is composed of one silicon atom (Si^{+4}) surrounded by four oxygen atoms (O^{-2}).

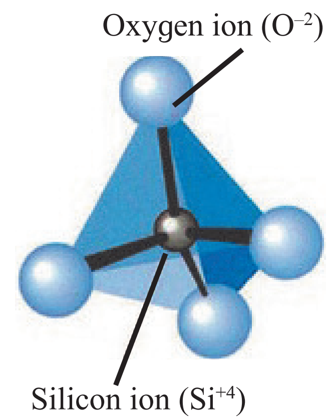


Fig. 5.47 : Silicon tetrahedra

Classification based on structure of silicates :

SiO_4 tetrahedra is the fundamental unit of all silicate minerals. This unit can either occur alone or in different combinations (along with other cations) in the mineral structure. Different groups of silicate structures of rock forming minerals are as follows :

i) **Nesosilicates :** In this group, SiO_4 tetrahedra occur as independent units, (Fig. 5.48) e.g., olivine, garnet, kyanite etc.

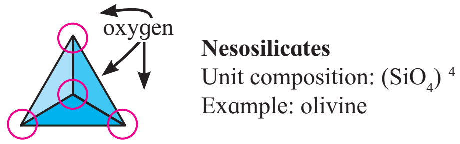


Fig. 5.48 : Nesosilicates

ii) **Sorosilicates :** SiO_4 tetrahedra occur in pairs, (Fig. 5.49) e.g., epidote etc.

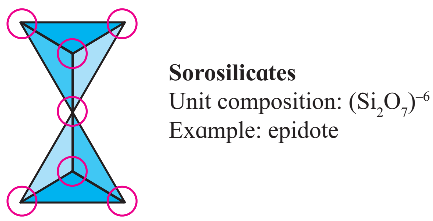


Fig. 5.49 : Sorosilicates

iii) **Inosilicates :** These are also called as 'chain silicates'. In this group of minerals SiO_4 teterahedra occur as chains resulting in preferential growth of mineral along one direction. Two varieties of Inosilicates occur in nature. They are single chain silicates (Fig. 5.50 A) e.g. pyroxenes and double chain silicates (Fig. 5.50 B) e.g. amphiboles.

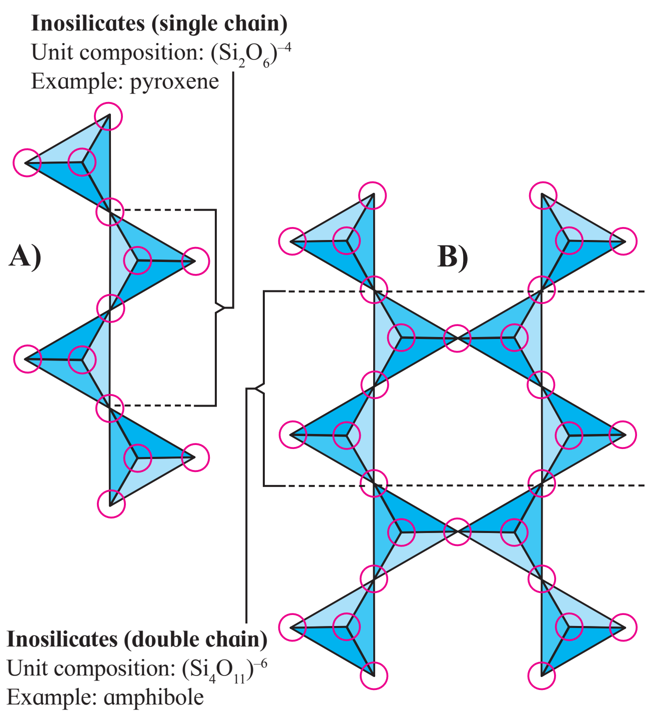


Fig. 5.50 : Inosilicates

iv) **Cyclosilicates :** These are known as 'ring silicates'. In this group of minerals, 3 or 4 or 6 SiO_4 teterahedra occur in the form of a ring (Fig.5.51) e.g., beryl, tourmaline.

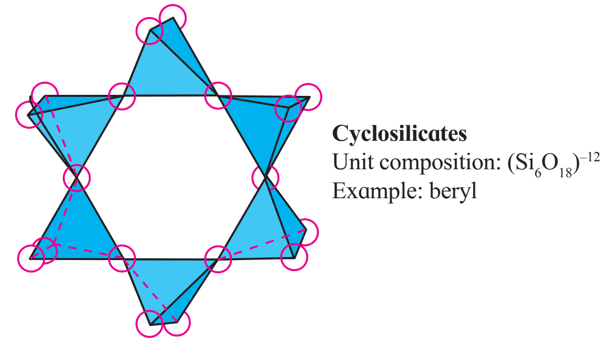


Fig. 5.51 : Cyclosilicates

v) **Phyllosilicates :** These are 'sheet silicates'. In this group, SiO_4 teterahedra occur as sheets, resulting in preferred growth along two directions of a mineral (Fig. 5.52) e.g., micas, talc, serpentine.

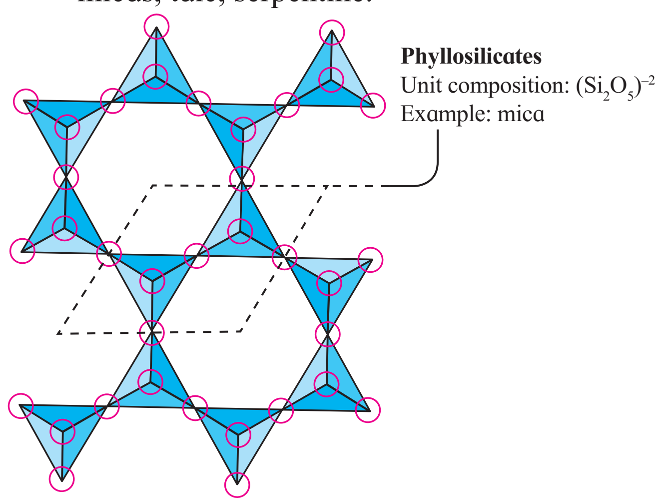


Fig. 5.52 : Cyclosilicates

vi) **Tectosilicates :** In this group, SiO_4 tetrahedra occur in a three-dimensional framework resulting in equidimensional growth of minerals (Fig. 5.53) e.g., quartz, feldspars, zeolites.

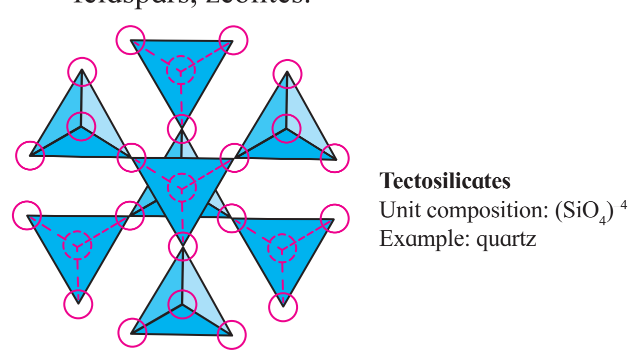


Fig. 5.53 : Tectosilicates

Rock forming mineral groups :

Rocks are composed of minerals. Only a few of the minerals are rock forming. Most rocks however, are a combination of commonly occurring minerals such as feldspars, quartz, micas, olivine, pyroxene and amphiboles.

Feldspar group :

Feldspar is one of the most abundant mineral found in the continental crust. This group constitutes over 50% of the Earth's crust.

The name feldspar is derived from the German word 'Feldspat'. 'Feld' meaning field and 'Spat' meaning a rock (that does not contain ore).

Silicate structure : All feldspars are tectosilicates. Ca, Na, K cations also occur in tectosilicates.

Chemical composition : It is expressed as X(Al SiO)$_4$O$_8$,where X is Ca, Na, K and Ba.

Varieties : This group is sub-divided on the basis of chemical composition and isomorphism into :

i) Alkali feldspars ii) Calc-alkali feldspars

i) Alkali feldspars or Potassium Sodium feldspars. e.g. orthoclase and microcline.

Albite ($NaAlSi_3O_8$) to Orthoclase ($KAlSi_3O_8$) isomorphous minerals. It is a substitution of sodium by potassium.

Orthoclase : Name has its origin in the Greek words- 'Orthos' meaning right, 'Clase' meaning to cleave (cleavages are at right angles) (Fig. 5.54).

Fig. 5.54 : Orthoclase

Microcline : 'Micro' meaning small or little, 'Cline' meaning to incline or to lean (Fig. 5.55).

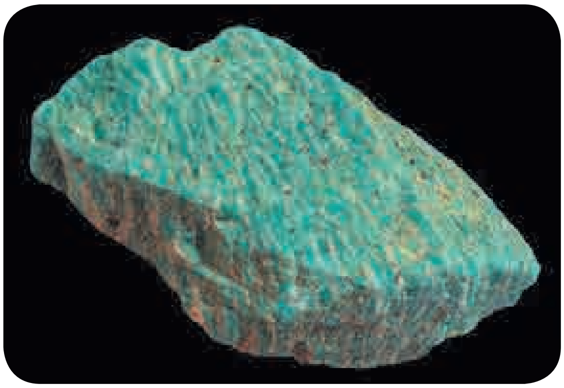


Fig. 5.55 : Microcline

Table 5.2 : Varieties of feldspar group of minerals can be given as follows:

Alkali feldspar

Potash feldspar ($KAlSi_3O_8$) | Barium feldspar ($BaAl_2Si_2O_6$)

Orthoclase .... Hyalophane .... Celsian.

Microcline

Soda Orthoclase

Soda Microcline

Albite ----- Oligoclase --- Andesine --- Labradorite --- Bytownite --- Anorthite.

($NaAlSi_3O_8$) Soda feldspar | ($CaAl_2Si_2O_8$) Lime feldspar

Plagioclase or Lime soda feldspar

ii) Calc-alkali feldspars - Plagioclase series of feldspars or lime soda feldspars, e.g. plagioclase (Fig. 5.56) and labradorite (Fig. 5.57).

Fig. 5.56 : Plagioclase

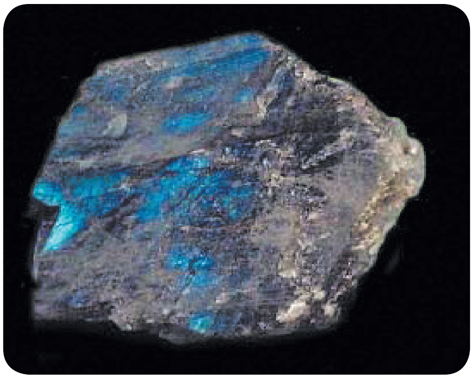


Fig. 5.57 : Labradorite

Plagioclase feldspars : Plagioclase series of feldspar minerals are a homogeneous mixture of albite and anorthite. In this series Na-Si is replaced by Ca-Al. The minerals so formed are called isomorphs. The two boundary minerals albite and anorthite are called end members.

Albite (Ab) $\rightleftharpoons$ Anorthite (An).

Table 5.3 : Plagioclase minerals and their composition :

Names	Ab content (%)	An content (%)
1. Albite	100-90	0-10
2. Oligoclase	90-70	10-30
3. Andesine	70-50	30-50
4. Labradorite	50-30	50-70
5. Bytownite	30-10	70-90
6. Anorthite	10-0	90-100

Physical properties of feldspar group :

Colour : Blue, orange, pink, white, green and gray.

Streak : White or pale shade of body colour.

Lustre : Vitreous to subvitreous

Form : Tabular

Cleavage : Two sets, at right angles

Fracture : Conchoidal to uneven

Hardness : 6 - 6.5

Specific gravity : 2.55 - 2.76

Occurrence : Feldspars are found in igneous rocks (e.g., granite, syenite, pegmatite), sedimentary rocks (e.g., arkose a variety of sandstone containing atleast 25% feldspar) and metamorphic rocks (e.g., gneiss).

Uses : Feldspars are used in the manufacture of glass, porcelain, sanitary ware and as filler in paints, plastic, rubber and adhesive industries. Feldspars are also used as gemstones e.g., orthoclase as moonstone, labradorite as sunstone and microcline as amazonite.

Silica group :

Quartz or 'Gargoti' was used during the stone age. The word quartz is derived from the German word 'Quarz' which came from the Polish dialect term 'Kwardy', corresponding to the Czech term 'Tvrdy' meaning hard. Quartz is the second most abundant mineral in the Earth's crust.

Silica group constitutes 12% to 15% of all rock forming minerals. This group includes crystalline, cryptocrystalline and amorphous minerals.

Silicate structure : Silica minerals are tectosilicates.

Chemical composition : The minerals of this group are characterised by same chemical composition i.e. SiO_2. Crystalline quartz is most abundant.

The composition varies from crystalline to cryptocrystalline silica, i.e. from SiO_2 to $SiO_2 \cdot nH_2O$. Varieties of cryptocrystalline silica are mixtures of cryptocrystalline silica (chalcedony) and hydrous silica (opal).

Varieties : Several varieties of silica can be recognised on the basis of their forms :

1) Crystalline silica (SiO_2) :

Well defined crystals are absent, but a marked tendency towards crystallisation is exhibited.

Rock crystal : Colourless and transparent (Fig. 5.58).

Fig. 5.58 : Rock crystal

Amethyst : Violet or purple coloured (Fig. 5.59), colour resulting from trace amounts of Fe impurity.

Fig. 5.59 : Amethyst

Rosy quartz : Pink colour (Fig. 5.60), resulting from traces of Ti impurity.

Fig. 5.60 : Rosy quartz

Milky quartz : Milky white coloured (Fig. 5.61), colour due to numerous air cavities.

Fig. 5.61 : Milky quartz

2) Cryptocrystalline silica (SiO_2+SiO_2nH_2O) :

Crystals are partially developed. Some faces of the crystals are developed and remaining faces are not (amorphous).

Chalcedony : A fibrous variety of quartz, (Fig. 5.62), white, brown or gray in colour, shows waxy lustre and is found as cavity fillings. Name derived from the town of 'Chalcedon', a district in Istanbul, Turkey.

Fig. 5.62 : Chalcedony

Agate : A variety of chalcedony, exhibits alternate curving layers of different colours (Fig. 5.63). Name is derived from the occurrence of the stone along the shoreline of river Achates (now called Dirillo), in south western Sicily.

Fig. 5.63 : Agate

Onyx : Also a variety of chalcedony, exhibits alternate, parallel white and black or dark brown layers (Fig. 5.64).

Fig. 5.64 : Onyx

Jasper : An impure, opaque variety, red, brown, (Fig. 5.65) or yellow in colour. Name has its origin in the Latin word 'Gasper' from the Biblical Hebrew word 'Gizbar' meaning treasurer.

Fig. 5.65 : Jasper

Flint : Usually black or in shades of gray, found as nodules and breaks with sharp edges (Fig. 5.66). Name has been derived from Proto-Indo-European word 'Splind' meaning to split or cleave.

Fig. 5.66 : Flint

3) Amorphous silica (SiO_2nH_2O) :

There is total absence of crystallanity, not a single crystal face developed.

Opal : An amorphous variety of silica. Name derived from Sanskrit word 'Upala' meaning precious stone (Fig. 5.67).

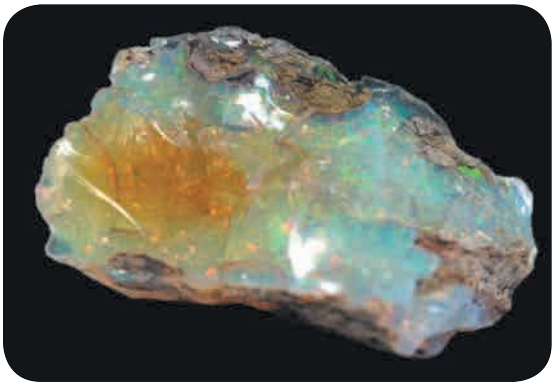


Fig. 5.67 : Opal

Physical properties of silica group :

Colour : Colourless or white, also shows variety of colours.

Streak : White.

Lustre : Vitreous, subvitreous, waxy.

Form : Prismatic, botryoidal , massive.

Cleavage : Absent.

Fracture : Conchoidal to subconchoidal, uneven.

Hardness : 5.5 - 7 (variable depending upon silica variety)

Specific gravity : about 2.65

Occurrence : It occurs in igneous rocks like granite, pegmatite; as secondary mineral within cavities of basalts; in sedimentary rocks such as sandstone and in metamorphic rocks like quartzite, schist and gneiss.

Uses : In glass, ceramics, abrasive and refractory industries, piezoelectric crystal plates used in quartz watches and also used as decorative and semi-precious stone.

Flint was used in the manufacture of tools as it has the property of splitting into thin, sharp splinters when struck by another hard object.

Amphibole group :

The name 'Amphibole' is derived from Greek word 'Amphibolus' meaning ambiguous.

Amphibole is an important group of rock forming minerals which are basically dark coloured (mafic).

Silicate structure : Amphiboles are double-chain inosilicates.

Chemical composition : These minerals are complex silicates of Mg, Fe, Ca and Al with a hydroxyl group (OH radical) present.

Varieties : Amphiboles include hornblende, tremolite and actinolite.

Hornblende : Hornblende is the most common mineral. Name is derived from German terms 'Horn' referring to its colour and 'Blende' meaning to deceive, owing to its similarity in appearance to metal-bearing ore minerals (Fig. 5.68).

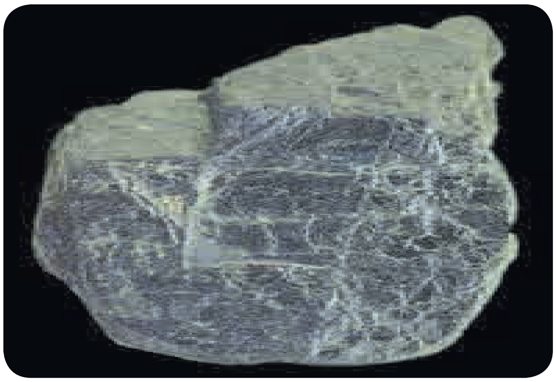


Fig. 5.68 : Hornblende

Tremolite : Name has been derived from Tremola Valley, Switzerland (Fig. 5.69).

Fig. 5.69 : Tremolite

Actinolite : Name has been derived from the Greek words 'Aktim' for ray and 'Lithos' for stone, meaning fibrous in nature (Fig. 5.70).

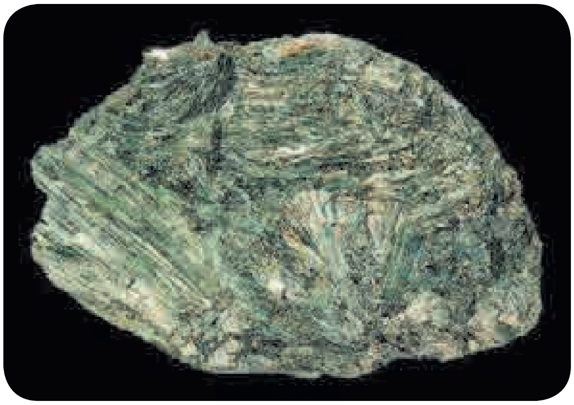


Fig. 5.70 : Actinolite

Physical properties of amphibole group :

Colour : Black, dark green, dark brown

Streak : White, colourless.

Lustre : Vitreous, silky, dull.

Form : Prismatic, acicular, fibrous, bladed, columnar and massive

Cleavage : 2 sets, prismatic, at 124^0 and 56^0.

Fracture : Uneven.

Hardness : 5 - 6

Specific gravity : 2.9 - 3.4

Occurrence : Hornblende is an important constituent of many igneous rocks such as granite, syenite, diorite and andesite. Amphiboles are common in metamorphic rocks e.g. schist and gneiss.

Uses : 'Nephrite', a variety of amphibole is fibrous aggregate of actinolite and tremolite. It is used as a gemstone, in sculptures, jewellery, tools, etc.

Pyroxene group :

The name 'Pyroxene' has its origin in the Greek words- 'Pyro' meaning fire and 'Xenox' meaning stranger.

Pyroxene is an important rock forming mineral group, which is similar to amphibole group, except for different atomic structure and the absence of hydroxyl group (OH radical).

Silicate structure : All pyroxenes are single chain inosilicates.

Chemical composition : Pyroxenes are complex silicates of Mg, Fe, Ca and Al.

Varieties : Pyroxenes are a group of allied minerals. The common members of this group are augite and hypersthene.

Augite : $(Ca, Na, Mg, Fe, Mn, Ti, Al)_2(Al, Si)_2O_6$ is a common brownish black variety.

Name has been derived from the Greek word 'Auge' meaning shine or lustre, in allusion to the appearance of its cleavage surface (Fig. 5.71).

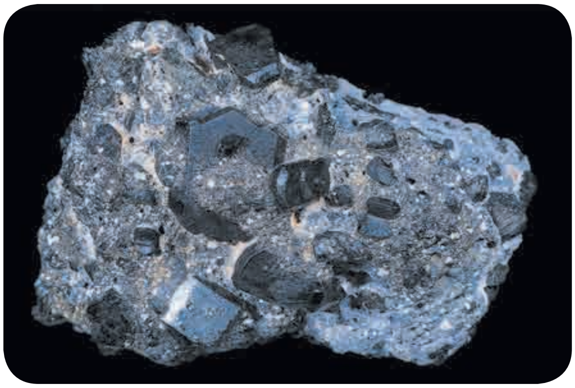


Fig. 5.71 : Augite

Hypersthene : $(Mg,Fe)SiO_3$

It is gray or greenish black in colour with metallic lustre.

Name has its origin from the Greek words 'Hyper' meaning exceeding, 'Sthenos' meaning strength (Fig. 5.72).

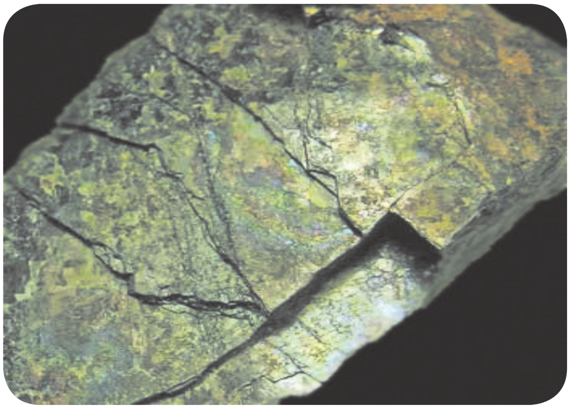


Fig. 5.72 : Hypersthene

Physical properties of pyroxene group :

Colour : Gray, greenish brown, brownish black.

Streak : White or pale body colour

Lustre : Vitreous, subvitreous.

Form : Prismatic, granular, massive.

Cleavage : Two sets, at nearly 90^0.

Fracture : Uneven

Hardness : 5 - 6

Specific gravity : 3.22 - 3.56 (increases with Fe content)

Occurrence : Pyroxenes are found in basic and ultrabasic igneous rocks like gabbro, dolerite, basalt and peridotite.

Augite is found in metamorphic rocks like schist and gneiss and hypersthene is found in charnockites and granulites.

Uses : Used in ceramics. Jadeite is used as a gemstone.

Do you know?

Nephrite (an amphibole) and Jadeite (a pyroxene) are two different minerals which together form mineral Jade.

Mica group :

Micas are important rock forming minerals. They can be cleaved into thin elastic plates.

Name Mica has its origin in the Latin word 'Micare' meaning to flash or glisten.

Silicate structure : All micas are phyllosilicates.

Chemical composition : Micas are silicates of Al and K with Mg or Fe. Some varieties contain Na, Li or Ti. Hydroxyl group is present in micas and is partially replaced by fluorine.

Varieties :

Muscovite : Hydrated silicate of Aluminium and Potassium with Fluorine, silvery white in colour. Name Muscovite originated from 'Muscovy glass' because it came from Muscovy province of Russia (Fig. 5.73).

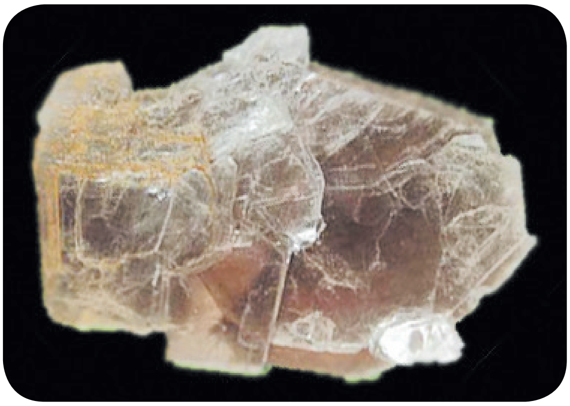


Fig. 5.73 : Muscovite

Biotite : Hydrated silicate of Mg, Fe, Al, and K with F, black to brown in colour (Fig. 5.74).

Fig. 5.74 : Biotite

Physical properties of mica group :

Colour : Colourless, silvery white, dark green, brown, black.

Streak : White, colourless.

Lustre : Pearly, silky.

Form : Foliated, flaky, lamellar

Cleavage : One set, perfect

Fracture : Uneven.

Hardness : 2 - 3

Specific gravity : 2.76 - 3.1

Occurrence : In igneous rocks, it occurs in pegmatite and granite; in sedimentary rocks such as sandstone and in metamorphic rocks like schist and gneiss.

Uses : As insulator in electrical industries, as filler in rubber, in lubricants and paints, has wide applications in ayurvedic medicines.

Do you know?

Mica is a good electrical insulator that can withstand extremely high temperatures. It is commonly used in equipments like toasters, electric irons and hair dryers where the heating elements are sandwiched between mica sheets.

Olivine group :

Like amphiboles and pyroxenes, olivines are also mafic i.e., dark coloured minerals.

Silicate structure : Olivines are nesosilicates.

Chemical composition : Olivine is chemically $(Mg,Fe)_2SiO_4$ with two end members, forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4).

Varieties : The olivine group consists of an isomorphous series between forsterite and fayalite.

Forsterite : It is green, yellow, yellowish green, white.

Fayalite : It is greenish yellow, yellowish brown or brown.

Olivine : It has been named after its typical olive green colour (Fig. 5.75).

Fig. 5.75 : Olivine

Physical properties of olivine group :

Colour : Usually olive green.

Streak : White.

Lustre : Vitreous, but often shows dull lustre due to alteration by weathering.

Form : Granular, massive.

Cleavage : Absent

Fracture : Conchoidal to uneven.

Hardness : 6.5 - 7

Specific gravity : 3.2 - 4.3 (depending on Fe content)

Occurrence : It occurs in monomineralic ultrabasic igneous rocks like dunite. It also occurs in rocks like peridotite (olivine and pyroxene), basalt, dolerite and gabbro.

Uses : Olivine is used in the manufacture of refractory bricks and its variety Peridot is used as a gemstone.

Zeolite group :

The term 'Zeolite' was originally coined by Swedish mineralogist Axel Fredrick Cronstedt, who observed that rapid heating of the mineral produced large amounts of steam from water that had been adsorbed by the mineral. Based on this, he named the mineral as Zeolite, from the Greek word 'Zein' meaning to boil.

Silicate structure : Zeolites are tectosilicates.

Chemical composition : Zeolites are aluminosilicates of alkali and alkaline earth metals.

Do you know?

Zeolites belong to the family of solids known as 'molecular sieves'. Molecular sieves are crystalline metal aluminosilicates having a three dimensional interconnecting network of silica and alumina tetrahedra. Natural water of hydration is removed from this network by heating, to produce uniform cavities which selectively adsorb molecules of a specific size.

Varieties :

Heulandite : Named after John Henry Heuland, a British mineral collector and dealer (1778-1856). It shows tabular form and vitreous to pearly lustre (Fig. 5.76).

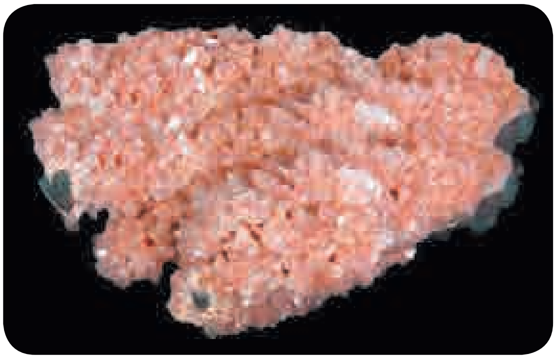


Fig. 5.76 : Heulandite

Stilbite : Originated from the Greek word 'Stilbein' meaning to glitter or shine or 'Stilbe' a mirror, alluding to its pearly or vitreous lustre. It shows unique 'bowtie' form (Fig. 5.77).

Fig. 5.77 : Stilbite

Scolecite : Named from the Greek word 'Skolex' which means worm, with reference to the mineral's reaction to a blowpipe flame. Crystals radiate out from a centre without producing stellar forms (Fig. 5.78).

Fig. 5.78 : Scolecite

Mesolite : Originated from the Greek word 'Meso' meaning middle and 'Lithos' meaning stone, due to its chemical composition being in between that of Natrolite and Scolecite. It shows cotton-ball cluster of acicular white crystals (Fig. 5.79).

Fig. 5.79 : Mesolite

Physical properties of zeolite group :

Colour : White, red, pink, yellow, brown.

Streak : White

Lustre : Pearly to vitreous.

Form : Crystals are usually thin and delicate, acicular or may occur as sheaf-like aggregates.

Cleavage : Perfect, one or two sets.

Fracture : Subconchoidal to uneven.

Hardness : 3.5 - 5.0

Specific gravity : 2.1 - 2.4

Occurrence : They usually occur in cavities and veins of volcanic basic rocks such as basalts (Deccan trap), also in acid igneous rocks like rhyolite. Few zeolite minerals occur in tuffaceous sediments.

Uses : Zeolites are mainly used in domestic and commercial water softening and purification.

5.8 : Rock forming minerals :

Apophyllite :

Apophyllite, according to recent studies, is the name of a group of minerals and is not a specific mineral title.

It is generally found along with zeolites and has very high water content.

The name apophyllite has been derived from Greek words 'Apo' meaning away from and 'Phyll' meaning leaf, referring to its tendency to exfoliate (i.e. flake apart like a leaf) when heated due to loss of water.

Silicate structure : Apophyllite is a phyllosilicate.

Chemical composition :
$(K,Na)Ca_4Si_8O_{20}(F,OH).8H_2O$

Varieties : On the basis of variable ratio of fluorine and hydroxyl group, apophyllites can be differentiated into the following mineral species :

i) **Fluorapophyllite :** White, colourless, yellow, green, (F > OH); (Fig. 5.80).

Fig. 5.80 : Fluorapophyllite

ii) **Hydroxyapophyllite :** White, colourless, (OH > F); (Fig. 5.81).

Fig. 5.81 : Hydroxyapophyllite

iii) **Natroapophyllite :** Brown, yellow, colourless, (K replaced by Na) (Fig. 5.82).

Fig. 5.82 : Natroapophyllite

Physical properties of apophyllite :

Colour : Usually white, green, yellow, also blue, brown, pink, violet.

Streak : White

Lustre : Vitreous, pearly

Form : Prismatic, tabular, massive

Cleavage : Perfect, one set.

Fracture : Uneven

Hardness : 4.5 - 5

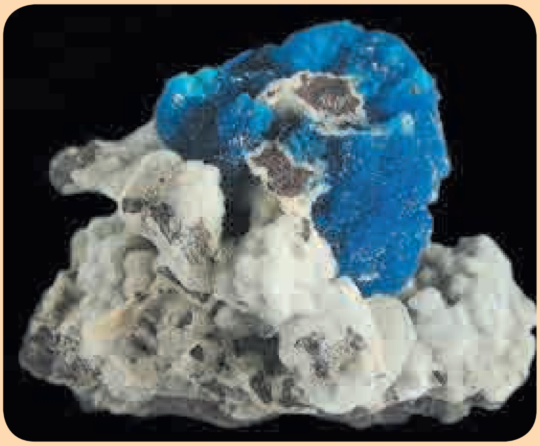
Specific gravity : 2.3 - 2.4

Occurrence : Apophyllite is a secondary mineral which occurs as cavity fillings in vesicles of volcanic igneous rocks like basalt.

Uses : As a decorative mineral and as an ornamental stone.

Do you know?

Cavansite is also found along with zeolites and apophyllite. It is found in many regions of the world, but it is generally accepted that the ones from Wagholi Dist, Pune, Maharashtra excel in quality and quantity to those found in other countries.



A cluster of cavansite mineral crystals shown on a bed of microcrystalline stilbite, quarried in Wagholi, Pune, Maharashtra.

Talc :

Mineral talc (Fig. 5.83) is a soft, non-metallic mineral.

The name has been derived from Arabic word 'Talq', due to the pure colour of its powder.

Silicate structure : Talc is a phyllosilicate.

Chemical composition : Talc is hydrated magnesium silicate, $Mg_3Si_4O_{10}(OH)_2$.

Varieties :

i) **Soapstone or Steatite (Talc schist) :** It is a metamorphic rock composed predominantly of talc which has a soft texture and soapy feel.

ii) **Pot stone :** It is impure Steatite, hard, grey or black coloured, used especially in prehistoric times to make cooking vessels.

iii) **French chalk :** It is a kind of Steatite used for marking cloth and removing grease, also used in powder form as a dry lubricant.

Fig. 5.83 : Talc

Physical properties of talc :

Colour : White, pale green, brown, gray, yellowish white, brownish white.

Streak : White

Lustre : Vitreous, pearly, greasy, waxy.

Form : Foliated, fibrous.

Cleavage : One set, perfect.

Fracture : Uneven

Hardness : 1 (Mohs' scale), very soft and easily scratched by finger nail.

Specific gravity : 2.7 - 2.8

Occurrence : Talc commonly occurs in metamorphic rocks like talc schists.

Uses : Talc is used in paint, paper, ceramics, plastics, cosmetics and talcum powders. Soapstone is used to make ornamental objects, sculptures, bowls, countertops, sinks, etc.

Do you know?

During Stone age, the people of Scandinavia used soapstone carved moulds to cast metal objects such as knife blades and spear heads.

Seals of Mohenjodaro and Harappan civilization were made from soapstone (steatite).

Gypsum :

Name 'Gypsum' originated from the Greek word 'Gypsos' meaning plaster. Mineral gypsum found in abundance near Paris is called Plaster of Paris.

Gypsum is the most common sulphate mineral found on the Earth's crust, extracted, processed and used by man in construction or decoration in the form of plaster and alabaster since 9000 BCE.

It is an indefinitely recyclable raw material which can be reused because the chemical composition of the raw material in the final product remains unchanged.

Silicate structure : Gypsum is a non-silicate mineral belonging to sulphate group i.e. it lacks silicon.

Chemical composition : Hydrated calcium sulphate, ($CaSO_4 2H_2O$).

Varieties :

i) **Alabaster gypsum :** Fine grained and off white coloured (Fig. 5.84).

Fig. 5.84 : Alabaster gypsum

ii) **Selenite gypsum :** Transparent and bladed (Fig. 5.85).

Fig. 5.85 : Selenite gypsum

iii) **Satinspar gypsum :** Pearly and fibrous (Fig. 5.86).

Fig. 5.86 : Satinspar gypsum

Physical properties of gypsum :

Colour : Colourless, milky white, grayish, yellowish, red or brown

Streak : White

Lustre : Vitreous, pearly, silky.

Form : Elongated and generally as prismatic crystals, granular, lamellar, fibrous.

Cleavage : Perfect, 2 sets.

Fracture : Hackly, brittle.

Hardness : 2 (Mohs' scale)

Specific gravity : 2.31 - 2.33

Occurrence : As an evaporite mineral and as a hydration product of anhydrite, in bedded deposits associated with limestones, shales and salt deposits, also formed by precipitation from natural waters.

Uses : In the manufacture of plaster of paris, blackboard chalk, wallboard, in cement industry to control the setting or hardening time of cement, as a fertilizer for plant growth in soils with deficiency of Ca and S.

Calcite :

Calcite is one of the most common minerals on the surface of the Earth. It is the crystalline form of $CaCO_3$, occuring as chalk, limestone and marble (Fig. 5.87).

Silicate structure : It is a non-silicate mineral belonging to the carbonate group.

Chemical composition : Calcite is calcium carbonate ($CaCO_3$).

Varieties : Iceland spar : Pure, transparent and colourless showing double refraction (Fig. 5.88).

Fig. 5.87 : Calcite

Fig. 5.88 : Iceland spar

Physical properties of calcite :

Colour : Colourless, white, gray, black, brown, yellow, red, blue, green

Streak : White.

Lustre : Vitreous, pearly, resinous, dull.

Form : Crystalline (rhombohedral), massive

Cleavage : Perfect, 3 sets.

Fracture : Uneven, conchoidal (rarely observed due to perfect cleavage).

Hardness : 3 (Mohs' scale)

Specific gravity : 2.71 - 2.94

Occurrence : Calcite occurs in sedimentary rocks like limestone and metamorphic rocks such as marble, as vein and cavity fillings in igneous rocks like basalt and as deposits in limestone caves.

Uses : The pure variety of calcite i.e. Iceland spar is used in the manufacture of optical lenses, optical instruments and Nicol's prism. Calcite is used in cement industry, in manufacture of soap, paints, paper, abrasive, in soil treatment as a conditioner and also in medicines (Fig. 5.88).

Do you know?

We can differentiate between the minerals Gypsum and Calcite with an acid test. Calcite ($CaCO_3$) gives effervescence of CO_2 even when cold weak acids such as vinegar are placed on the specimen, whereas Gypsum ($CaSO_4.2H_2O$) shows no reaction.

$$CaCO_3 + 2H^{(+1)} \rightarrow Ca^{(+2)} + H_2O + CO_2 \uparrow$$

Fluorite :

The name Fluorite (Fig. 5.89) was derived from Latin word 'Fluere' meaning to flow. In the mining industry, it is often called Fluorspar.

Silicate structure : Fluorite is a non-silicate mineral belonging to halide group.

Chemical composition : Calcium fluoride (CaF_2)

Fig. 5.89 : Fluorite

Physical properties of fluorite :

Colour : Colourless, deeply coloured due to impurities.

Streak : White

Lustre : Vitreous, dull

Form : Crystalline (octahedral), massive

Cleavage : Four sets, often cleaves into perfect octahedrons.

Fracture : Subconchoidal, uneven.

Hardness : 4 (Mohs' scale)

Specific gravity : 3.18 - 3.56

Occurrence : It is a very common rock forming mineral. It often occurs as a gangue mineral associated with metallic ores deposited in veins by hydrothermal processes. It is also found in fractures and cavities of some sedimentary rocks such as limestones and dolomites.

Uses : Fluorite is an important industrial mineral used in chemical, metallurgical and ceramic industries. It is also used as a gemstone and ornamental stone.

Do you know?

The Smithsonian National Museum of Natural History is the world's largest museum and research complex located in Washington D.C. It opened in 1910 and today houses about 3,75,000 mineral specimens from around the world. It is one of the largest collections of its kind with great value to the scientific community. The purpose of the collection is to support scientific research.

Summary :

- Minerals are identified and described by observation and analytical methods There are about 5,389 mineral species recognised.
- Minerals derive their names after their founders, localities where they were found irst or from their chemical composition and physical properties.
- Depending upon chemical composition and atomic structure, minerals exhibit different physical properties like colour, streak, lustre, form, cleavage, fracture, hardness and specific gravity. These are readily used to identify and differentiate minerals.
- Based on chemical composition, minerals are classified as oxides, sulphates, halides, carbonates and silicates. Silicates are most abundant and are classified according to their structures as nesosilicates, sorosilicates, cyclosilicates, phyllosilicates and tectosilicates.
- Rocks are aggregates of minerals which give us clues to the rock forming processes.

EXERCISE

Q.1. Fill in the blanks :

1) Silicates make up over .... % of the Earth's crust.
2) Mohs' scale is .... and ....

Q. 2. Match the correct pairs :

1)

Minerals	Characters
a) Amethyst	i) Numerous air cavities
b) Rose Quartz	ii) Fe impurity
c) Milky Quartz	iii) Ti impurity
d) Onyx	iv) Alternate, parallel white and black layers

1) a-ii, b-iii, c-i, d-iv
2) a-iii, b-iv, c-ii, d-i
3) a-i b-ii, c-iv, d-iii
4) a-iv b-i, c-iii, d-ii

2)

Silicate structure	Mineral
a) Nesosilicates	i) Olivine
b) Sorosilicates	ii) Beryl
c) Cyclosilicates	iii) Mica
d) Phyllosilicates	iv) Epidote

1) a-ii, b-iii, c-iv, d-i
2) a-i, b-iv, c-ii, d-iii
3) a-iv, b-i, c-iii, d-ii
4) a-iii, b-ii, c-i, d-iv

Q. 3. Complete the series :

1) Complete the plagioclase series:-
   Albite, ..., ..., ..., ..., ...
   a) Albite, Oligoclase, Andesine, Labradorite, Bytownite, Anorthite
   b) Albite, Anorthite, Bytownite, Andesine, Labradorite, Oligoclase
   c) Albite, Andesine, Anorthite, Bytownite, Labradorite, Oligoclase
   d) Albite, Oligoclase, Labradorite, Bytownite, Anorthite, Andesine

2) Write the Hardness scale in the ascending order.
   Talc, ..., ..., ..., ..., ...
   a) gypsum, corundum, diamond, fluorite, quartz
   b) corundum, gypsum, fluorite, diamond, quartz
   c) diamond, quartz, corundum, gypsum, fluorite
   d) gypsum, fluorite, quartz, corundum, diamond

Q. 4. Identify the odd one out :

1) Agate, onyx, jasper, flint, opal
2) Heulandite, stilbite, mesolite, scolecite, forsterite
3) Sorosilicate, cyclosilicate, inosilicate, nesosilicate, phyllosilicate

Q. 5. Give geological terms :

1) Flat blade-like form exhibited by mineral kyanite.
2) Exceptionally brilliant lustre exhibited by minerals having very high refractive index.
3) Highly irregular broken surface with sharp projections.

Q. 6. Choose the correct alternative :

1) Minerals which glow after being exposed to ultraviolet light are said to be ....
   a) Fluorescent b) Radioactive
   c) Iridescent d) Opalescent

2) Amphiboles are .... silicates.
   a) Hydrous ferromagnesian
   b) Ferromagnesian
   c) Potassium - aluminium
   d) Hydrated alumino

Q.7. Distinguish between :

1) Mica and Apophyllite.
2) Calcite and Fluorite.

Q. 8. State whether the statement is True or False and correct the False statement :

1) Fluorite and calcite are silicates in composition.
2) Cubic zirconia is considered as a mineral.

Q. 9. Give geological reasons :

1) Minerals of the same composition exhibit different colours.
2) Opal is classified as an amorphous silicate.

Q. 10. Explain the concept :

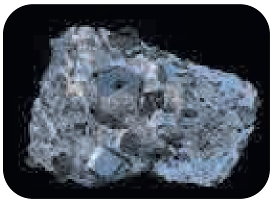
1) Lustre and hardness.
2) Degree of cooling and crystallization in silica.
3) Streak and hardness.

Q. 11. Long answer questions :

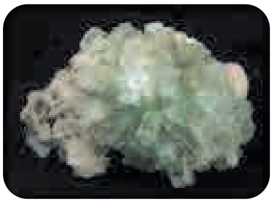
1) Discuss in detail the criteria for classifying a substance as a mineral.
2) Give the interdependence of cleavage, hardness and lustre citing suitable examples.
3) Enumerate and describe the forms dependant on the degree of crystallization. Give suitable examples.
4) Describe with examples, forms independent of the degree of crystallization.

Activity no. 1 : Observe the photographs, identify and distinguish between the following pairs :

A)

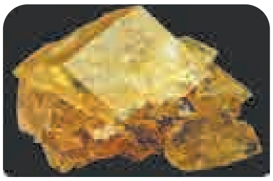


B)



C)

D)



Activity no. 2 : Crossword

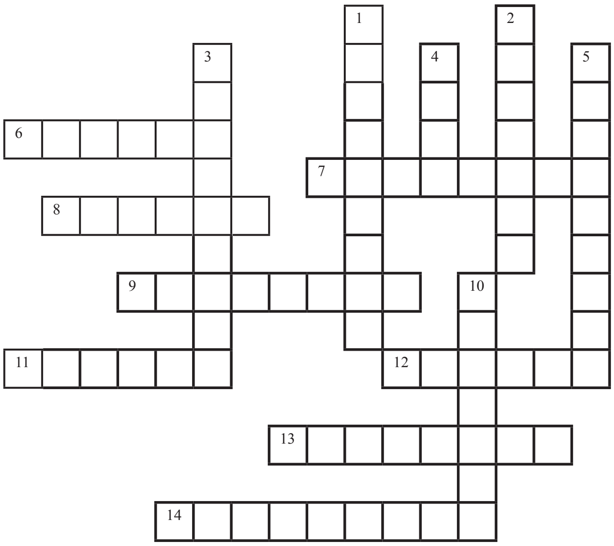
Name the common minerals, using the given information.

DOWN :

1) a naturally magnetic mineral
2) a bright blue copper carbonate
3) metamorphic quartz sandstone
4) a silicate mineral known for its perfect cleavage resulting in thin sheets
5) strontium sulphate its name means celestial
10) a common carbonate mineral often a replacement mineral in fossils

ACROSS :

6) the main source of lead
7) an iron ore, sometimes used in jewellery
8) sometimes called fool's gold
9) sulphide mineral, long metallic slender bladed crystals
11) a very heavy sulphate mineral
12) rock salt
13) calcium fluoride
14) a bright green copper carbonate



Activity no. 3 : Observe the back cover of your text book and answer the following questions :

1) Name the 'Father of Mineralogy'.
2) Classify the stamps into their mineral classes.
3) List the minerals found within the state of Maharashtra.
4) Ice is considered as a mineral - Justify.
5) Identify and name the native elements depicted in the stamps.
6) Sort the minerals containing (OH) group in their chemical composition.
7) Categorise the minerals having 'Water of Crystallisation' in their chemical composition.
8) Find and name all the minerals with 'Ca' in their chemical composition.
9) List all the minerals which are oxides.
10) Enumerate all the carbonate minerals.

Activity no. 4 : Collect the information on minerals museums in the state of Maharashtra/India.

Chapter - 6 Geology of Maharashtra

Highlights :

- An account of physiography and stratigraphy of Maharashtra
- Geographic and geological distribution of economic mineral deposits of Maharashtra.

Introduction :

After gaining sufficient knowledge on the fundamental aspects of geology, it is necessary to understand the geology of our own state. Geology of Maharashtra occupies special status globally due to Deccan volcanism and the Lonar meteorite crater. The state is also gifted with economic minerals and hydrocarbons. Maharashtra is the third largest state in area after Rajasthan and Madhya Pradesh. Maharashtra covers a large part of west-central India between North latitudes 15°45' and 22°00', and East longitudes 73°00' and 80°59'. The total area of Maharashtra is 3,07,713 sq. km. exposing a wide range of geological features and mineral resources. Rock formations from Archaean to Holocene age are exposed in Maharashtra.

6.1 Physiographic subdivisions of Maharashtra :

Maharashtra can be divided into three physiographic regions (Fig. 6.1), namely-

1) Maharashtra Plateau
2) Western Ghats (Sahyadri)
3) Coastal Region (Konkan)

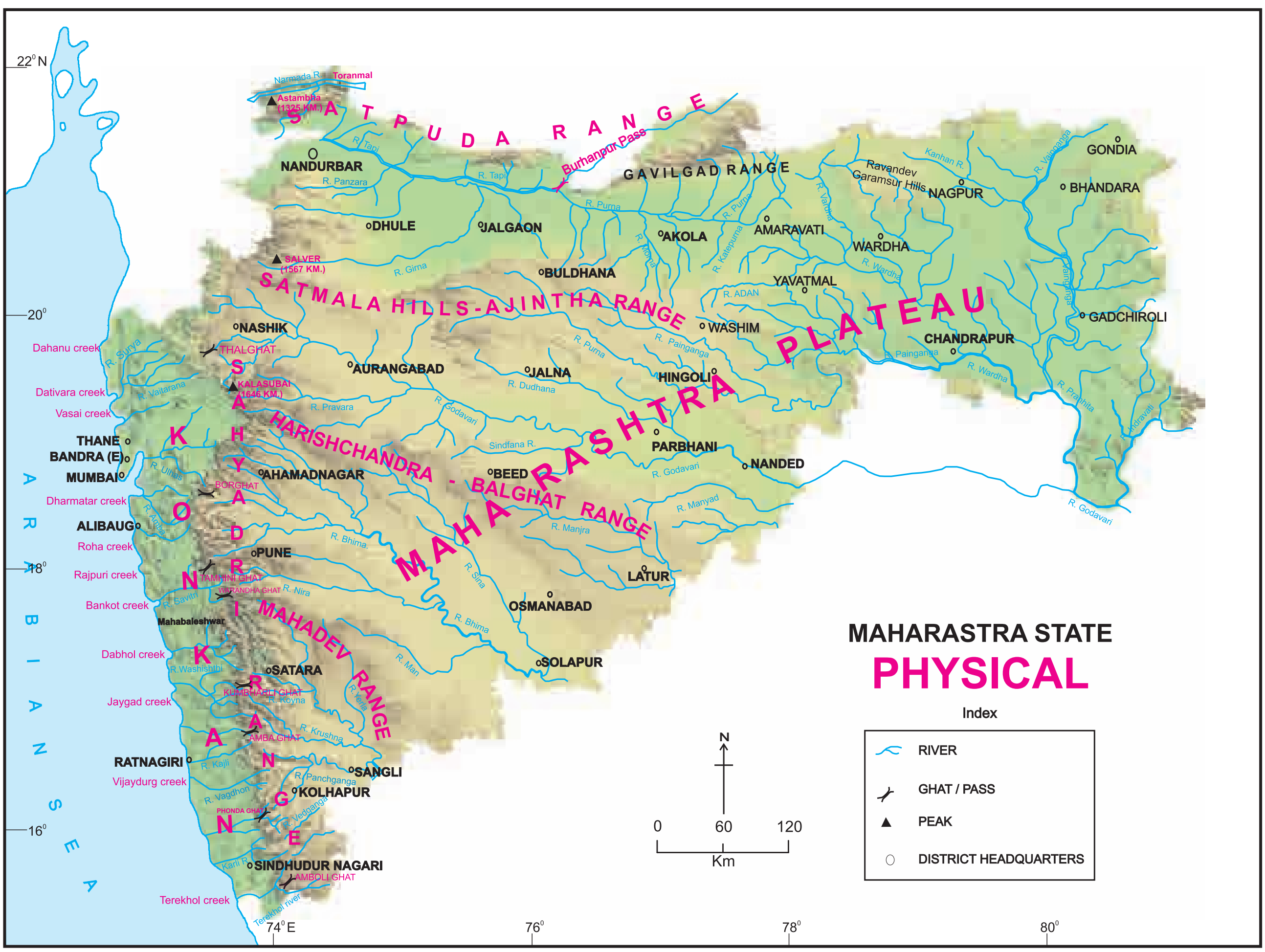


Fig. 6.1 : Map showing the physiographic features of the state of Maharashtra.

1) **Maharashtra plateau :** Maharashtra Plateau is a major part of Deccan plateau of Peninsular region of India. It is formed by basaltic lava erupted through fissures. These basaltic lava flows are horizontal to sub-horizontal and are found to spread practically all over the state. The landscape is more or less uniform with flat-topped hill ranges. They occupy about 81% area of the state and mainly covers Vidarbha, Khandesh, Marathwada and some Western Maharashtra divisions. The region is traversed by eastwest and northwest to southeast trending river valleys, and hill ranges with more or less similar trends. The altitude of Maharashtra Plateau varies from 400 to 600 msl with gentle eastward gradient. It has been exposed to denudation for several millions years.

   The Satmala, Ajantha, Harishchandra-Balaghat range and Mahadev hills stretch across the Maharashtra plateau. Their altitude ranges between 600m and 900m above msl. Melghat range which is a branch of Satpura hill trends east-west, almost parallel to northern border of the State. Satmala-Ajantha hills trend in east-west direction and separate Tapi basin from Godavari basin. Harishchandra-Balaghat hills trending northwest-southeast separate Godavari basin and Bhima basin. Mahadev hills run northwest-southeast, dividing Bhima and Krishna basins.

2) **Western Ghats :** The Western Ghats are also known as Sahyadris. They are situated to the west of Maharashtra Plateau and extends north-south. They are parallel to the west coast of India. The average elevation is between 1000 and 1300 msl and decreases from south to north. Many hills are places of pilgrimage, hill stations and forts.

   The topography is formed by differential weathering and erosion of rock masses. The rock masses are composed of series of near horizontal lava flows of basalt. The thickness of the lava flows varies from less than a meter to more than 35m. Due to differential weathering and erosion, harder lava flows form steep scarps whereas the softer lava flows form gentler slopes, resulting in a step-like topography. Because of this step-like or terraced appearance the hills are called 'Traps'. These hills are generally flat-topped or table-topped. The Sahyadris have a gentler slope towards the Deccan plateau and steep slope towards west. Major rivers in Maharashtra flow in an easterly to southeasterly direction with their sources in Sahyadri, whereas some of their tributaries originate in the east-west trending ranges. The major easterly flowing rivers are Godavari and Krishna which originate at Trimbakeshwar and Mahabaleshwar respectively, in the Western Ghats. Godavari basin is the largest basin of the Indian Peninsular region next to Ganga basin. Wardha, Penganga, Wainganga, Manjra, Pranhita, Indravati and Shabari are the main tributaries of Godavari. Koyna and Bhima are the major tributaries of Krishna. The major westerly flowing rivers are Narmada and Tapi. The Narmada river originates at Amarkantak in Madhya Pradesh and flows along the northern boundary of Maharashtra. Where as the Tapi river originates near Multai in Betul district of Madhya Pradesh and flows nearly parallel to the Narmada river before meeting the Arabian sea.

Do you know?

The highest peak in the Sahyadris is Kalsubai at 1646m (5400ft) which is located in the Harishchandragad-Kalsubai sanctuary. Kalsubai is also known as the Everest of Maharashtra.

3) **Coastal region :** A narrow coastal plain between Western Ghat and Arabian Sea is known as Konkan coast. In Maharashtra

state, the coastal lowland is called 'Konkan' and the vast plateau region east of the Ghats is known as 'Desh'. The Konkan coastal belt is about 720 km long and its width varies from about 50 - 105 km. The formation of coastal lowland mainly depends on the length of rivers, volume of water (perennial or seasonal) flowing through rivers, the alluvium brought by rivers, extent of catchment areas and slope of land.

The Konkan belt consists of number of east-west trending ridges. There are some small and narrow plateaus. The average height of these plateaus is about 60 to 100m above msl. These plateaus are covered by laterite in South Konkan. Several short and swift rivers originate in Sahyadri and flow westwards finally to enter the Arabian Sea. Due to limited length and heavy rainfall, the velocity of water flow is high. Many of the coastal streams carry out severe erosion in their source region and have caused diversion of some of the plateau rivers, towards west. This has resulted in development of waterfalls all along the western slope of Sahyadri. The major rivers are Ulhas, Vashishthi, Shastri, Vaitarna, Savitri, Patalganga, Kundalika and Terekhol.

6.2 Stratigraphy :

Various rock formations are exposed in the state of Maharashtra along with their varied lithology. The distribution of different rock formations is shown in (Fig. 6.2) and their stratigraphic succession is given in Table 6.1.

i) **Paleo-archean (3600 - 3200 Ma) :** The oldest rocks exposed in the state are biotite gneisses belonging to Amgaon gneissic complex, Tirodi gneisses and Peninsular gneisses, that formed the basement.

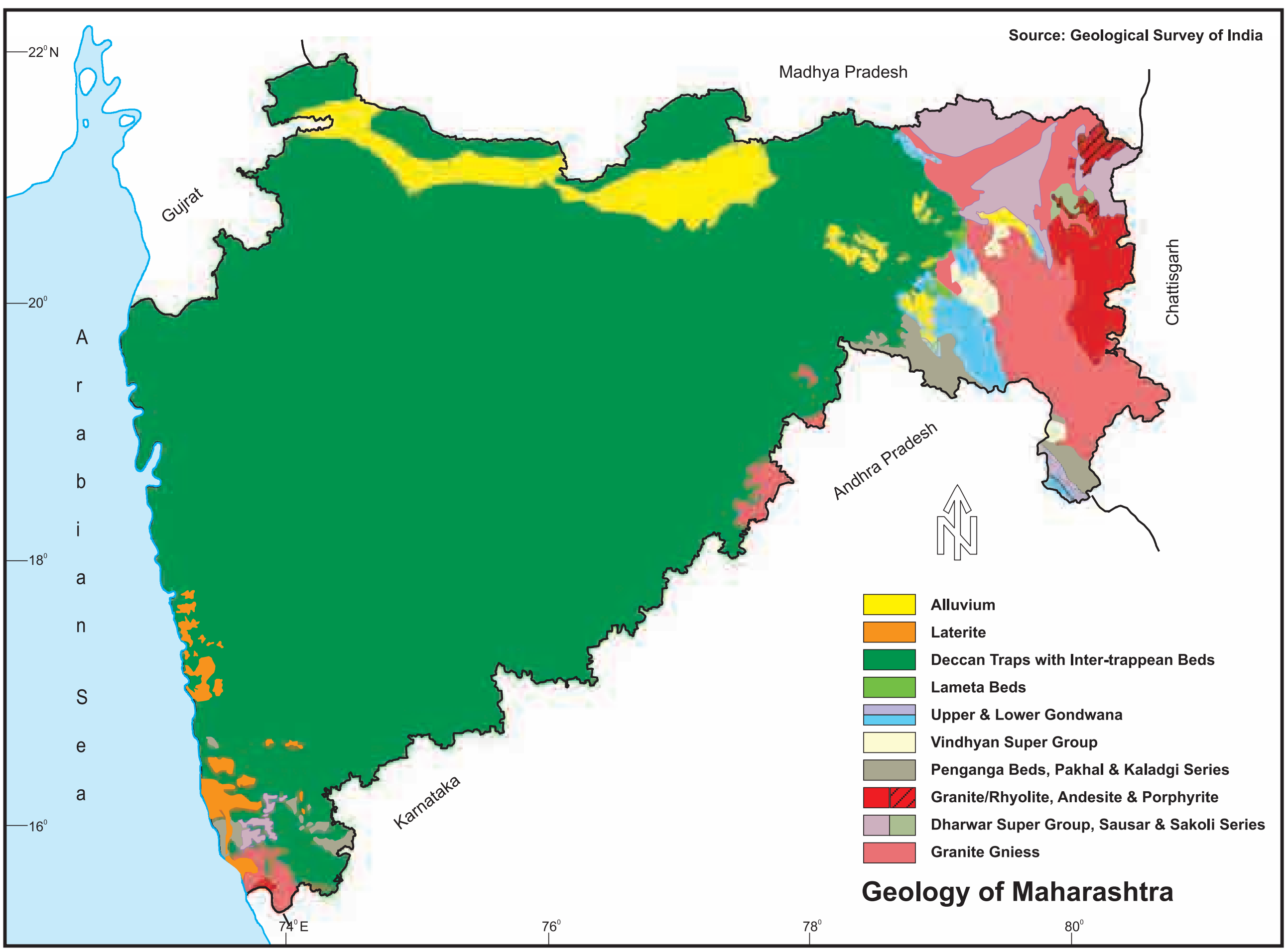


Fig. 6.2 : The generalized Geological map of Maharashtra

ii) **Neo-archean (2800 - 2500 Ma) :** The basement gneisses are overlain by volcanics and metasediments belonging to Amgaon, Sakoli and Dongargarh groups. They are represented by different types of schists, gneisses, quartzites, marbles, amphibolites, hornblende schists with intercalated bands of iron and manganese ores. These rocks were involved in several orogenic cycles and hence are intensely deformed and mixed up. They are intruded by Dongargarh granite, a batholith in Gondia and Gadchiroli districts.

iii) **Paleo-to-Meso proterozoic (2500 - 1000 Ma) :** After the intrusive activity there was a long period of non-deposition during which these rocks were subjected to weathering. This resulted in the development of Eparchaean unconformity. Bhandara, Nagpur and Gondia regions are represented by Khairagarh and Sausar groups. The Sausar group hosts one of the richest manganese ore deposits.

iv) **Neo-proterozoic (1000 - 541 Ma) :** Denuded topography formed during Eparchean unconformity became the sites of deposotion for the Neo-proterozoic sedimentation. They are represented by sediments of Kaladgi Group in the Ratnagiri district and sediments of Pakhal Group, Vindhyan Supergroup and Penganga Group in the Gadchiroli, Chandrapur and Yavatmal districts.

During the period between Cambrian and Upper Carboniferous there is no lithological record in Maharashtra. During this period India was part of Gondwanaland and was covered by thick sheet of ice.

v) **Upper Carboniferous (323 - 299 Ma) :** During Carboniferous period glacial to fluvio-glacial sediments were deposited in the linear rift basins, that are exposed in Nagpur, Chandrapur and Yavatmal districts represented by 'Boulder Bed' or tillites at the base (Talchir Formation).

vi) **Permian (299 - 252 Ma) :** Talchirs are followed upward by deposition of fluvial sediments during warmer period now represented by coal-bearing sandstones and shales of Barakar and Kamthi formations.

vii) **Triassic (252 - 201 Ma) :**The sedimentary sequence viz., Mangli, Pachmari and Maleri. formations are represented by sandstone and shale.

viii) **Jurassic (201 - 145 Ma) :** This period is represented by the Kota and Chikiala formations comprising of limestone.

Do you know?

The strata ranging in age from Upper Carboniferous to Jurassic is called as Gondwana Supergroup.

ix) **Upper Cretaceous (100 - 66 Ma) :** After the cessation of sedimentation in the Gondwana basin around 100 Ma, there was a marine incursion marked by deposition of Bagh beds in Dhule district and contemporaneous fluvial and lacustrine Lameta beds were deposited in parts of Nagpur, Chandrapur, Amravati and Yavatmal districts.

x) **Upper Cretaceous to Lower Paleocene (~ 69 - 61 Ma):** This time is represented by voluminous outpouring of lava through extensive fissures resulting in the formation of Deccan basalt, which is one of the well-known flood basalt provinces of the world. The Deccan traps cover an area > 500,000 sq. km. The eruption was mostly non explosive and the lava spread over extensive areas in the form of nearly horizontal flows of varying thickness (Fig. 6.3). Number of such flows are found piled one above the other and some individual flows can be traced for several hundred kilometers. The flows occupy almost the entire area of Maharashtra except some parts of Nagpur, Bhandara, Gondia, Chandrapur, Gadchiroli and Yavatmal districts in Vidarbha region and Ratnagiri and Sindhudurg districts in coastal Konkan. Two types of lava flows are recognized. They are the pahoehoe or ropy lava and the 'aa' or blocky lava. Pahoehoe lava flows predominate in Dhule, Aurangabad, Pune and Nasik districts, whereas in rest of Maharashtra, 'aa' lava flows are dominantly exposed. In Maharashtra between some flows intertrappean beds of lacustrine origin are found. Red bole beds commonly occur in between two lava flows. The flows are intruded by number of dolerite dykes trending nearly N-S, parallel to the west coast. East-west trending dykes are commonly exposed in northern part of Maharashtra around Nandurbar, Dhule and Jalgaon districts.

Fig. 6.3 : Stratigraphic exposures of lava flows in Malshej Ghat area of Maharashtra

Do you know?

The term 'Deccan trap' was first coined by W. W. Sykes in 1833 after the Swedish word 'trapp / trappa' meaning stair to describe the step-like or terrace-like topography peculiar to Deccan trap terrain. The name Deccan is an anglicised form of the Prakrit word 'Dakkhini', itself derived from the Sankrit word 'Dakhina' meaning south.

Deccan basalts have uniform mineralogical and chemical characters. It is essentially composed of plagioclase and augite with accessory amount of biotite and hornblende. Olivine may or may not be present. It shows compact, vesicular, amygdaloidal, pipe amygdaloidal, pillow and columnar structure. The cavities in vesicular basalts are filled with secondary minerals like heulandite stilbite, apophyllite, quartz, amethyst, chalcedony, agate, jasper, opal, calcite etc. Ropy lava structure, columnar joints are commonly observed in basalts (Fig.6.4 and 6.5).

Fig. 6.4 : Ropy Lava

Fig. 6.5 : Columnar joints, Tumzai Hills, Panhala

Do you know?

The rock cut caves of Ajanta, Ellora and Elephanta are the UNESCO world heritage sites.

The Ajanta caves located in Aurangabad are 30 rock cut Buddhist cave monuments in Deccan Basalt.

The Kailash Temple or cave 16 as it is known at Ellora is a huge monolithic temple dedicated to Lord Shiva.

Table 6.2 : Lithostratigraphy of Deccan traps
(M1 - M4 are marker horizons)

Super Group	Group	Sub Group	Formation
DECCAN TRAPS	SAHYADRI	Mahabaleshwar	Mahabaleshwar
			M4
		Diveghat	Purandargad
			Diveghat
			Elephanta
		Lonavala	Karla
			Indrayani
		Kalsubai	M3
			Upper Ratangad
			M2
			Lower Ratangad
			M1
			Salher

xi) **Paleocene-Oligocene (66 - 23 Ma) :** This period is mainly represented by lateritization in western Maharashtra.

xii) **Miocene-Pliocene (23 - 2.58 Ma) :** This period represents episodes of sedimentation and lateritization.

xiii) **Pleistocene-Recent (<2.58 Ma) :** This period is represented by Quaternary alluvium, soils and laterites. Important archaeological sites and the Toba volcanic ash occurrence are unique to the Quaternary sequence of Maharashtra.

6.3 Distribution of major economic minerals of Maharashtra :

Though most of the mineral deposits of Maharashtra state are concentrated in eastern Maharashtra, the major mineral deposits of bauxite occurs in western Maharashtra. The minerals which are being economically exploited are manganese ore, iron ore, coal, bauxite, limestone, sillimanite, kyanite and clays. Deposits of copper, gold, tungsten, barite, magnetite, ilmenite and chromite are also worth mentioning. Other minerals like andalusite, antimony, asbestos, lead and zinc, platinum, silver, diamond, corundum and radioactive minerals are occurrences that have not been proved to be economically viable so far.

6.3.1 Manganese ore :

Manganese ore deposits of Maharashtra are the part of world famous manganese ore producing Nagpur-Bhandara-Balaghat belt of India. Manganese is mainly used in the manufacture of steel. It is also used in the manufacture of ferro-alloys, dry batteries, manganese chemicals and paints.

6.3.2 Iron ore :

Iron ore deposits of Maharashtra occur in Chandrapur, Gadchiroli, Gondia and Sindhudurg districts. They are mostly concentrated in the Vidarbha region. The iron ore minerals are hematite and magnetite.

6.3.3 Coal :

Coal is a compact, stratified rock formed by accumulation and preservation of plant matter. It is combustible and considered a fossil fuel. Plants when buried in marshy land get decayed and carbonization process gives rise to coal. These coal bearing areas are present only in the Vidarbha region. Coal is being mined from several underground and opencast mines in Nagpur, Chandrapur and Yavatmal districts. Major portion of coal produced is used for power generation, while part of coal produced is utilized in cement plants, textile mills, paper mills, brick and lime kilns and railways. Coal deposits in Vidarbha have the potential of meeting the requirements of increasing thermal power generation and other industries in western Maharashtra.

Lignite (low rank brown coal) also occurs in association with Tertiary sediments in Ratnagiri and Sindhudurg districts of Maharashtra. It is brown in colour and contains abundant non-combustible matter.

6.3.4 Bauxite :

Bauxite is a mixture of various minerals of aluminium hydroxide. It is a porous clay-like rock sometimes having pisolitic structure, and different colours depending upon its composition. The colours generally vary between earthy white to brownish yellow. Bauxite occurs as blanket deposits, lenses and pockets and intercalated beds within sedimentary strata or as detrital deposits. It also occurs as a layer below laterite cap developed on basalts of Sahyadri. Bauxite is principally used as a source of aluminium, but it is also used in refractory, chemical, abrasive, iron and steel, cement and other industries.

Bauxite deposits in Maharashtra are reported from Kolhapur, Raigad, Satara, Sangli, Sindhudurg, Ratnagiri and Thane districts.

6.3.5 Limestone and dolomite :

Limestone is a fine grained sedimentary rock predominantly composed of calcium carbonate. In Maharashtra limestone occurs in rock formations of different ages, which includes, Kaladgi, Pakhal, Vindhyan, Penganga, Gondwana, Lameta, Bagh beds and intertrappean beds. However, economically important limestones occur in Neoproterozoic Vindhyan Supergroup and Penganga Group of Yavatmal and Chandrapur districts. In these districts, considerable reserves of cement and flux grade limestones are available. A good quality limestone is mainly used in cement industry. It is also used in paper, sugar, rubber, metallurgical and other industries.

Extensive deposits of dolomite associated with metamorphic rocks of Sausar Group occur in Nagpur district. Dolomite is also associated with limestones of Penganga Group in Chandrapur and Yavatmal districts.

6.3.6 Kyanite and sillimanite :

These are aluminium silicate minerals commonly found in metamorphic rocks like gneisses and schists. In Maharashtra kyanite and sillimanite are used as refractory material in refractory industries because of their high degree of melting point and alumina content. They are also used for the manufacture of porcelain used in spark plugs. Kyanite and sillimanite deposits in Maharashtra are present in Bhandara and Gadchiroli districts.

6.3.7 Fluorite :

Occurrence of fluorite is reported mostly from Dongargaon area of Chandrapur district. Fluorite along with barite occur as cavity filling deposits. It is being economically exploited by Maharashtra State Mining Corporation. It is use in metallurgy, glass and ceramic industries.

6.3.8 Barite :

Significant occurrences of barite have been reported from Mul area of Chandrapur district. Some minor occurrences are also noticed in Gadchiroli, Yavatmal and Sindhudurg districts. Barite occurs as cavity filling mineral in quartz veins in granite gneiss. It is used in drilling mud, filler in paper and rubber industries.

6.3.9 Chromite :

Chromite is the ore of chromium. In Maharashtra, chromite occurs in Bhandara, Chandrapur, Nagpur and Sindhudurg districts. Chromite occurs as pockets, veins, lenses and as discontinuous bodies. It is used in steel, refractory and metallurgical industries.

6.3.10 Copper :

Copper mineralisation occurs in shear zones traversing the Sakoli Group of rocks from Nagpur, Bhandara, Chandrapur and Gadchiroli districts. The deposits in Chandrapur, Gadchiroli and Nagpur districts are of economic importance.

6.3.11 Tungsten :

Tungsten in the form of wolframite and sheelite mineralization occurs in Nagpur district. Minor occurrences are reported from other parts of Nagpur and Bhandara districts.

6.3.12 Silica sand :

Silica sand is available from the sandstones and decomposed quartzites belonging to Kaladgi Supergroup occur in south Konkan. The sand deposits mainly occur in Sindhudurg, Ratnagiri and Kolhapur districts at number of places. These reserves are used in foundry, chemical and glass industries.

6.3.13 Secondary minerals :

Zeolites and associated secondary minerals including varieties of silica, occur as cavity filling minerals in Deccan Trap. They include heulandite, stilbite, apophyllite, natrolite, mesolite, cavanzite, chabazite, prehnite etc. Silica minerals include rock crystal, amethyst, agate, opal etc.

6.3.14 Oil and natural gas :

The off-shore area along the west coast of Maharashtra has assumed importance because of the occurrence of oil and natural gas. The off-shore area includes the giant Bombay High Field which is surrounded by several small fields. The Bombay High, which is the largest known oil field in India, is located about 160 km west-north-west of Mumbai in the Arabian Sea. In Maharashtra, potential areas for Coal Bed Methane (CBM) have been identified in Wardha Valley coal field areas.

Summary :

- Physiographically Maharashtra state is divided into three regions :

  a) Maharashtra Plateau, b) Western Ghats and c) Coastal region.

- Rock formations from Archean to Holocene age are exposed in Maharashtra.
- Archean rocks belonging to Amgaon gneissic complex, Tirodi gneisses, peninsular gneisses form the basement. Basement gneisses are overlain by volcanics and meta-sediments. These formations have been later intruded by dolerite dykes at many places. After the Eparchaean unconformity, rocks of Neoproterozoic period were deposited. These are overlain by basaltic rocks which erupted during Cretaceous period and cover about 81% of the state.
- Coal deposits are found in Vidharbha region. Commercial deposits of non-metallic minerals like limestone and dolomite, kyanite, sillimanite, fluorite, barite, etc. are found in southern and eastern regions of Maharashtra. Off shore areas of Maharashtra state have the commercial deposits of oil and natural gas. These are being exploited from 'Bombay High'.

Table 6.1 : Stratigraphic sequence in Maharashtra state.

Stratigraphic Sequence	Age in Million Yrs.	Representative Rock Formations	Geographic Distribution
xiii) Holocene-Pleistocene (Quaternary)	< 2.58	Alluvium, laterite, sand, soils, volcanic ashe	Younger and older alluvium in Nagpur, Bhandara, Gondia, Chandrapur, Wardha, Yavatmal, Akola, Amravati, Jalgaon, Dhule and Nandurbar districts. Laterite in Kolhapur, Satara, Sangli, Raigad, Ratnagiri, Sindhudurg and Thane districts. River terraces of Wainganga, Wardha and Penganga rivers; raised beaches along west coast
xii) Miocene-Pliocene	2.58 - 23.0	Sediments, lignite, shales and laterites	Ratnagiri and Sindhudurg districts
xi) Paleocene-Miocene	< 66	Laterites, saprolites, ferricretes, bauxites, lateritic soils	Laterites occur in majority of coastal stretches. Few occurrences are their in central eastern Maharashtra
x) Palaeocene-Upper Cretaceous	~ 69 - 61	Deccan Trap basalt flows with intertrappean beds	Basalt flows cover most of the state from west of Nagpur and Chandrapur, up to the Arabian sea coast excepting in the eastern parts of Nagpur, Bhandara, Gondia, Chandrapur, Gadchiroli and Ratnagiri districts. Intertrappeans occur in Nagpur, Yavatmal, Chandrapur districts and Mumbai.
ix) Upper Cretaceous	100 - 66	Infratrappeans (Lameta and Bagh beds)	Lameta Formation in Nagpur, Chandrapur and Yavatmal districts. Bagh Beds in Dhule district.
viii) Jurassic	201 - 145	Limestone of Chikiala and Kota formations	Gadchiroli district
vii) Triassic	252 - 201	Clays and sandstone of Maleri and Pachmari formations	Sironcha Tahsil of Gadchiroli district and Achalpur Tahsil of Amravati district
vi) Permian	299 - 252	Sandstone and shale (Mangli Formation) Sandstone and shale (Kamthi Formation) Sandstone, shale and coal (Barakar Formation)	Nagpur, Chandrapur, Yavatmal and Gadchiroli districts
v) Upper Carboniferous	323 - 299	Talchir Formation	Nagpur, Chandrapur and Yavatmal districts
iv) Neo-proterozoic	1000 - 541	Limestone, shale and sandstone (Vindhyan Supergroup) Limestone and shale (Penganga Formation)	Nagpur, Chandrapur and Yavatmal districts
		Limestone and shale (Pakhal Group)	Chandrapur district
		Conglomerate, sandstone and shale (Kaladgi Group)	Ratnagiri and Sindhudurg districts
iii) Palaeo - Meso-proterozoic	2500 - 1000	Khairagarh Group, Sausar Group	Nagpur, Bhandara and Gondia districts
ii) Neo-archean	2800 - 2500	Dongargarh Granite, Nandgaon Group, Sakoli Group, Bailadila Group, Amgaon Group	Nagpur, Bhandara, Gondia, Chandrapur and Gadchiroli districts
i) Paleo-archean	3600 - 3200	Tirodi and Amgaon Gneissic Complex, Peninsular Gneissic Complex	Nagpur, Bhandara, Chandrapur, Gadchiroli, Ratnagiri and Sindhudurg districts.

EXERCISE

Q. 1. Fill in the blanks :

1) Bagh beds occur in .... districts.
   a) Dhule b) Ratnagiri
   c) Satara d) Hingoli

2) Lameta beds occur in parts of .... districts.
   a) Yavatmal b) Kolhapur
   c) Solapur d) Raigad

Q. 2. True or false :

1) During the period between Cambrian and Upper Carboniferous there is no lithological record in Maharashtra.
2) A narrow coastal plain between Western Ghat and Arabian Sea is known as Konkan coast.
3) Sahyadris are also known as Western Ghat.

Q. 3. Choose the correct alternative :

1) The pahoe-hoe lava flows predominate in
   a) Dhule - Aurangabad- Pune- Nasik
   b) Osmanabad- Sangli- Satara- Latur
   c) Nagpur - Buldhana- Amravati- Akola
   d) Parbhani - Beed- Nanded- Akola

Q. 4. Match the following :

River	Origin
a) Narmada	i) Betul
b) Godavari	ii) Amarkantak
c) Krishna	iii) Trimbakeshwar
d) Tapi	iv) Mahabaleshwar

1) a-ii,	b-iii,	c- iv,	d-i
2) a-iii,	b-ii,	c-i,	d- iv
3) a- iv,	b-i,	c-ii,	d-iii
4) a-i,	b- iv,	c-iii,	d-ii

Q.5. Arrange the following Geological formations of Maharashtra in the correct stratigraphic sequence (oldest to youngest) :

a) Lameta beds - Talchir formation - Kaladgi group
b) Talchir formation- Kaladgi group- Lameta beds
c) Kaladgi group - Talchir formation- Lameta beds
d) Lameta beds -Kaladgi group - Talchir formation

Q. 6. Give geological reasons :

a) Iron mining is economically suitable in Maharashtra.
b) Bauxite mining is feasible in Maharashtra.
c) Secondary minerals like zeolite occur in Deccan traps.
d) Thermal power plants in Maharashtra have their coal source in Vidarbha region.

Q. 7. Write Short notes on :

1) Building stones of Maharashtra.
2) Energy resources in Maharashtra.
3) Secondary minerals found in Deccan Traps.
4) Uses of kyanite and sillimanite.
5) Occurrence of following economic deposit.
   a) Manganese b) Iron one c) Coal
   d) Bauxite e) Chromite f) Copper

Q. 8. Answer in detail :

1) Describe lithostratigraphy of the Deccan traps.
2) Give the genesis of Laterite and Bauxite.
3) Explain why thickness of Basalt is variable in the Deccan Volcanic Province .
4) Give an account of major economic minerals of Maharashtra.
5) Describe general succession of stratigraphy of Maharashtra.

Q. 9. Read the following passage and answer the questions :

The Singhbhum Shear Zone hosts mineral deposits of great economic value. The sulphide deposits were formed in this shear zone before the third-phase deformation. The original copper mineralization is attributed to hydrothermal activity. The passage of hydrothermal fluids was controlled by faults of the rift zone. Along the shear zone, the deposits of chalcopyrite, pyrite and pyrrhotite are syngenetic with respect to volcano - sedimentary phase, predating the main tectonothermal event. The total reserve in the Singhbhum Shear Zone is of the order of 217 million tonnes with 1.36 % Cu. In the Gangpur Basin, the lead and copper deposits of the Sargipali belt are estimated to be 206 million tonnes with 6.73 % Pb and 0.33 % Cu.

Ref : K S Valdiya, The making of India 2016.

1) What kind of deposit is characteristic of the Singhbhum Shear Zone?
2) How is the copper mineralization associated in the shear zone?
3) Calculate the total estimated Cu and Pb content in the Singhbhum Shear Zone.
4) If the Sargipali deposits are dated 1660 Ma, find the period referring to the geological time scale.

◈◈◈

Calendar of Important Earth Events

Sr. No.	Important Earth Events	Day
1)	World Wetlands Day	February 2
2)	World Water Day	March 22
3)	World Meteorological Day	March 23
4)	International Geologists Day	First Sunday of April
5)	International Day for Mine Awareness	April 5
6)	World Heritage Day	April 18
7)	Earth Day	April 22
8)	Coal Miners Day	May 4
9)	International Museum Day	May 18
10)	World Environment Day	June 5
11)	World Ocean Day	June 8
12)	Indian Geologist Day (Birth Anniversary of M. S. Krishnan)	August 24
13)	World Ozone Day	September 14
14)	International Day for Preservation	September 16
15)	World Tourism Day	September 27
16)	World River Day	Last Saturday of September
17)	UN International Day for Natural Disaster Reduction.	October 13
18)	Earth Science Week.	October 14 to 20
19)	World Tsunami Day	November 5
20)	National Pollution control	December 2
21)	World Soil Day	December 5
22)	International Mountain Day	December 11
23)	World Energy Conservation Day	December 14

Activity : Celebrate the event with some relevant activities.

PRACTICAL EXERCISES

Practical No.	Name of the Exercise
1	**Study of physical properties of minerals:** a) Colour b) Streak c) Lustre
2	**Study of physical properties of minerals:** d) Forms
3	**Study of physical properties of minerals:** e) Fracture f) Cleavage g) Hardness
4	**Determination of specific gravity of minerals.**
5	**Study of silica group of minerals.**
6	**Study of feldspar, amphibole and pyroxene groups of minerals.**
7	**Study of mica, olivine and zeolite groups of minerals.**
8	**Study of apophyllite, talc, gypsum, calcite and fluorite minerals.**
9	**Identify and describe the minerals in the given igneous rocks and classify them :** Granite and its varieties, pegmatite, syenite, syenite porphyry, diorite porphyry, gabbro, dolerite, basalt and its varieties, dunite, rhyolite.
10	**Identify and describe the minerals in the given sedimentary rocks and classify them :** Conglomerate, breccia, sandstone and its varieties, limestone and its varieties.
11	**Identify and describe the minerals in the given metamorphic rocks and classify them :** Marble, quartzite, muscovite schist, biotite schist, hornblende schist, mica garnet schist, tremolite schist, actinolite schist, granite gneiss, hornblende gneiss, augen gneiss.
12	**Study of topomaps.**
13	**Study of contour maps -** To draw profile of the maps and describe map nos. 1 to 10.
14	**Study of District Resource Map / (DRM).**
15	**Study of mineral resources of Maharashtra state.**
16	**Study of some important geological heritage sites of Maharashtra state:** i) Lonar meteor crater ii) Nighoj potholes iii) Honeycomb structure (Harihareshwar) iv) Natural bridge (Gulunchwadi) v) Columnar joints (Kolhapur, Naldurg and Gilbert hill) vi) Panchgani tableland vii) Sandan valley viii) Hot springs.
17	**Sketch and neatly label the landforms depicted in the given photographs:** a) River : erosional and depositional features b) Sea : erosional and depositional features c) Wind : erosional and depositional features d) Glacier: erosional and depositional features.
18	**Field work - Visit to nearby sites of geological interest and prepare report:** i) River meanders ii) Potholes iii) Columnar joints iv) Waterfalls v) Road cuttings vi) Spheroidal weathering vii) Red boles viii) Tableland/ Mesa/ Butte ix) Coastal erosional features

- **General Instructions for teachers :**

1 Mineral specimens which show the required physical properties clearly should be used.

2 Rock specimens should clearly show mineral characteristics.

3 Topomaps of your area of interest (area around your district where the college is located) should be downloaded from the Survey of India map portal : www.soinakshe.gov.in. The sample questions have been provided at the end of practical. Teachers can frame more questions based on available topomaps.

4 For section drawing use map nos. 1 to 10 from this textbook.

5 DRM of Nagpur district has been provided as a sample in textbook. Use DRM of your district for your practical which is available with Geological Survey of India, publication division, Central region, Nagpur : www.gsi.gov.in. Sample questions are provided at the end of practical. Teachers can frame more questions based on available DRM.

6 Use the given outline map of Maharashtra for marking mineral resources and geological heritage sites.

7 For drawing and labelling of landforms, alter the figures from textbook as per your requirement.

8 Teachers should strictly follow the rules for 'educational visit' given by concerned authority and institution.

- **General Instructions for students :**

1 Make the best use of time available for performing experiments.

2 Come prepared with subject knowledge.

3 Bring geometrical instruments, a notebook and a journal.

4 Handle the specimens carefully. Do not write on or mark the specimens.

5 Draw accurate, labelled diagrams, wherever necessary in the journal.

6 For practical nos. 1 to 8, observe each specimen carefully and write down the description referring to chapter 5 and for practical nos. 9 to 11 refer to chapters 4 and 5. Observe the properties in clear day light.

7 Observe the topomaps, write the description and get it checked by the teacher.

8 Complete the journal on the same day of the practical.

- **Following procedures are to be followed by a student while writing the journal :**

1 Write date and year in which the experiment is performed, name and roll number, title and exercise no. clearly.

2 Write the description of the specimen/map, area and avoid overwriting.

- **Practical No. 1**

Study of physical properties of minerals :

a) Colour b) Streak c) Lustre

- **Practical No. 2**

Study of physical properties of minerals :

d) Forms

- **Practical No. 3**

Study of physical properties of minerals :

e) Fracture f) Cleavage g) Hardness

- **Practical No. 4**

Determination of Specific Gravity of minerals :

Specific Gravity of a mineral is the ratio of the weight of the mineral in air to that of an equal volume of water displaced by it at Normal Temperature and Pressure (NTP).

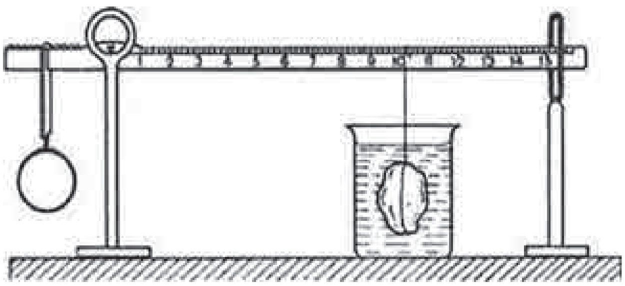
The specific gravity of a mineral can

be determined with the help of Jolly's spring balance and Walker's steel yard balance.

Walker's steel yard balance :

This instrument has a long graduated beam, which is pivoted on a pillar near one end. The beam is counterbalanced by heavy weight suspended to short arm near pivot.

The specimen tied to a thread is suspended on the long graduated steel beam and moved along the beam until it counterbalances the constant weight. The levelling of a beam is facilitated by a pointer on a vertical stand and a mark on the beam.



The reading 'Wa' is recorded by the position of sample in air, on the beam. The specimen is then immersed in water in beaker and is moved along the beam, until the constant weight is again counterbalanced and second reading 'Ww' is obtained. The reading 'Wa' and 'Ww' are inversely proportional to the actual weight of the body in air and water respectively.

If, Wa = Weight of mineral in air

Ww = Weight of mineral in water

Wa-Ww = Loss in weight

$$\therefore \text{ Sp.gr} = \frac{Wa}{Wa - Ww}$$

Readings and Calculations :

Mineral	Readings	1st	2nd	3rd	Average	(Wa-Ww)
Quartz	Wa					
	Ww					
Calcite	Wa					
	Ww					
Barite	Wa					
	Ww					

- **Practical No. 5**

Study of silica group of minerals

- **Practical No. 6**

Study of feldspar, amphibole and pyroxene groups of minerals

- **Practical No. 7**

Study of mica, olivine and zeolite groups of minerals.

- **Practical No. 8**

Study of apophyllite, talc, gypsum, calcite and fluorite minerals.

- **Practical No. 9**

Identify and describe the minerals in the given igneous rocks and classify them : Granite and its varities, pegmatite, syenite, syenite porphyry, diorite porphyry, gabbro, dolerite, basalt and its varieties, dunite, rhyolite.

- **Practical No. 10**

Identify and describe the minerals in the given sedimentary rocks and classify them : Conglomerate, breccia, sandstone and its varieties, limestone and its varieties..

- **Practical No. 11**

Identify and describe the minerals in the given metamorphic rocks and classify them : Marble, quartzite, muscovite schist, biotite schist, hornblende schist, mica garnet schist, tremolite schist, actinolite schist, granite gneiss, hornblende gneiss, augen gneiss.

- **Practical No. 12**

Study of Topomaps

A topomap is characterised by large scale detailed and quantitative representation of relief, usually using contour lines, physical structures and symbols. These maps are classified on the basis of scale. They show important natural and man-made features, such as relief, vegetation, water bodies, cultivated land, settlements, transportation networks, etc. The Survey of India with Head Quarters at Dehradun, prepares and publishes the topomaps in India for the entire country. The topomaps are drawn in the form of series of maps at different scales. Hence, in the given series, all maps employ the same reference point, scale, projection, conventional signs, symbols and colours.

The Survey of India prepares topomaps of India on 1:10,00,000, 1:250,000, 1:1,25,000, 1:50,000 and 1:25,000 scales providing a latitudinal and longitudinal coverage of 4° × 4°, 1° × 1°, 30' × 30' and 15' × 15' respectively. Each topomap has a numbering system.

Reading of topomaps : The study of topographical maps is simple. It requires the reader to get acquainted with the legend, conventional signs, symbols and the colour shown on the maps.

The first thing one can notice on a topomap is the name of the state, which is found at the top centre of the map. On the top left corner map number is printed. The map is divided into grids. These grids represent longitudes and latitudes. These can be read in the form of degree (°), minutes (') and seconds ("). This will help to pinpoint any location on the map with accuracy.

Latitude is angular distance measured North and South of the Equator. The Equator is 0°. As one goes North of the Equator, latitude increases upto 90° at the North pole. If one goes South of the Equator, the latitude increases upto 90° at the South pole.

Longitude is angular distance measured East and West of the Prime Meridian. The Prime Meridian is 0° longitude. As one goes East from the Prime Meridian, the longitude increases to 180°. This Meridian is known as the International Date Line. In the Eastern hemisphere, the longitude is given in degrees East and in the Western hemisphere, it is given in degrees West.

Horizontal lines on the map are latitudes and vertical lines are longitudes. On 1:50,000 scale map, latitudes and longitudes have 05' difference. Our nation India is North of the Equator and to the East of the Prime Meridian. The latitude is written as 19° 30' 15" North, while longitude is written as 75° 45' 10" East.

Map scale represents the relationship between distance on the map and the corresponding distance on the ground. The scale on the topomap is found at the bottom centre of the map.

Scale is represented in two different ways on a topomap. The first one is a ratio scale and second one is called linear / bar / graphic scale. 1 : 50,000 indicates 1cm on the topomap equals 50,000 cm (i.e.1/2 km) on ground. Below the ratio scale is a graphic scale representing distance in kilometres. The graphic or bar scale is a means of visually showing scale of the map and is used to make fast estimates of distances on the topomap. For. e.g. a map of 1 : 50,000 ratio scale will show a bar indicating that 2 cm on the map equals to 1 km. on the ground.

At the bottom left and bottom right corner of the map, conventional signs and symbols are shown. With the use of these symbols one can 'read' the topomap easily.

Contour lines are represented by brown lines in the map. With the help of contour lines, one can visualise three dimensional layout of the map. A contour line is an imaginary line that connects points of equal elevation above Mean Sea Level (MSL).

Branched dark brown lines on the map indicate drainage. Various patterns of drainage can be studied. One can identify important rivers and their tributaries on the map.

Interpretation of topomaps :

Understanding of map language and sense of direction are essential in reading and interpreting topomaps. A thorough knowledge of the legend/ key given in the map showing various natural and manmade features is essential. Every Survey of India topomap contains a table showing conventional signs and symbols at the base of the map. Conventional signs and symbols are internationally accepted. A topomap is usually interpreted under the following heads :

a) Marginal information
b) Relief and drainage
c) Land use
d) Means of transport and communication
e) Human settlements

a) Marginal information : It includes the topomap no., its location, grid references, its extent in degrees and minutes of latitude and longitude, scale, districts covered etc.

b) Relief and drainage : Relief is the difference between the highest and lowest elevation in an area. A relief map shows the topography of the area, which includes the identification of the plains, plateaus, hill or mountains along with peaks, ridges, and the general direction of the slope. These features can be studied as follows :

- Hill : Map with circular contours, increasing in contour value towards centre represents a hill. It may exhibit steep or gentle slopes.
- Plateau : Contours at centre are absent indicating elevated flat land with respect to surrounding lowland.
- Plain : Absence of contours indicates plains.
- Ridge : A chain of hills with elongated or oval shaped contours.
- Depression : Circular contours with decreasing contour value towards the centre.
- Valleys : Sharp drop in contour values between two adjoining hillocks.
- Drainage of the area : Important rivers, their tributaries, type and extent of valleys formed by them and types of drainage pattern, e.g. dendritic, radial, trellis, etc. are studied.

c) Land use : It includes the use of land under different categories like :

- Natural vegetation and forest - dense or thin, reserved, protected, classified / unclassified.
- Agricultural, orchard, wasteland, industrial, etc.
- Facilities and services such as schools, colleges, hospitals, parks, airports, electric substations, post offices, police stations etc.

d) Means of transport and communication : Means of transportation include national or state highways, district roads, cart tracks, camel tracks, footpaths, railways, waterways, major communication lines, post offices, etc.

e) Human settlements : Settlements can be specified as follows:

- Rural settlements : Types and patterns of rural settlements e.g. compact, semi-compact, dispersed, linear etc.
- Urban settlements : Types of urban settlements and their functions e.g. capital cities, administrative towns, religious towns, port towns, hill stations etc.

Activity :

Download topomap of your area from Survey of India map portal : www.soinakshe.gov.in

Sample questions

Q. 1. Answer the following :

1) What are topomaps?
2) Name the organisation which prepares the topomaps for India.

3) Which are the commonly used scales for mapping in our country (used by the Survey of India)?
4) What are contours?
5) What does the spacing of contours indicate?
6) What are conventional signs?

Q. 2. Draw the conventional signs and symbols of the following features :

1) International boundary 2) Villages
3) Footpath with bridges 4) Bench Mark
5) Places of worship 6) Railway lines
7) Metalled road

• Practical No. 13

Study of Contour Maps

Any real world location or objects on the Earth's surface which can be represented two dimensionally (on a paper, a computer monitor etc.) is called as a map. Many maps only show the two-dimensional location of an object without taking into consideration its elevation. Topomaps, on the other hand, deal with the third dimension by using contour lines to show elevational changes on the surface of the Earth (or below the surface of the ocean).

A topomap is a representation of three-dimensional surface on a flat piece of paper.

Relief of the land surface can be represented with the help of 'contour lines' or 'contours'. Contouring (drawing contours) is the standard method of representing relief on topomaps. Contour lines are defined as lines joining points of equal elevation. If we randomly measure elevations on the hill surface and join those elevation points having equal values, contours are generated. Following are the characteristics of contours :

1) Each contour has its value represented in the form of elevation in meters or feet.
2) All the elevations measured are with reference to the Mean Sea Level (MSL). The elevation of MSL is globally considered to be is 'Zero'.
3) Contours are continuous brown coloured lines on the topomaps published by Survey of India (SoI).
4) Every point on a contour line represents the same elevation.
5) Shifting from one contour line to another always indicates a change in elevation.
6) The difference in values between two adjacent contours is called Contour Interval (C.I.). It is uniform for all contours present in a particular map and it will not change. On Survey of India map, contour interval is usually 20 m and the scale is 1 : 50,000.
7) If the contour values go on increasing in a certain direction, it means you are moving uphill and if values are in decreasing order, you are moving downhill.
8) Contour lines never intersect one another.
9) Absence of contours indicate flat ground.
10) In any map, index contours are thicker than other contours. They carry a number which represents its elevation. Index contours help in finding values of adjoining contours.

Thus, with the help of contours one can see the broad features and relative heights of highlands and lowlands such as hills (symmetrical and asymmetrical), valleys, ridges, plateaus, spurs etc. Contours have different shapes and spacing. With the help of the shape of contours we can determine the feature and spacing suggests the type of slope.

1) Evenly spaced contours represent a uniform slope, e.g. symmetrical hill (Fig. 1a.).
2) Contours that are widely spaced indicate a gentle slope, contours that are closely spaced indicate a steep slope, e.g. asymmetrical hill (Fig. 1b.).

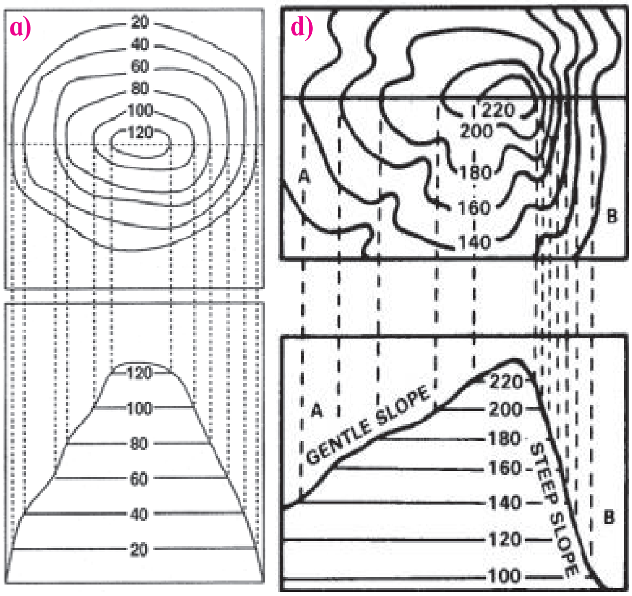


Fig. 1 : a) Symmetrical hill, b) Asymmetrical hill

Interpretation of contour patterns :

Shape of contours indicates the type of physical features present on the map. Compare the topomap with the landscape perspective from Fig. 2 a and b.

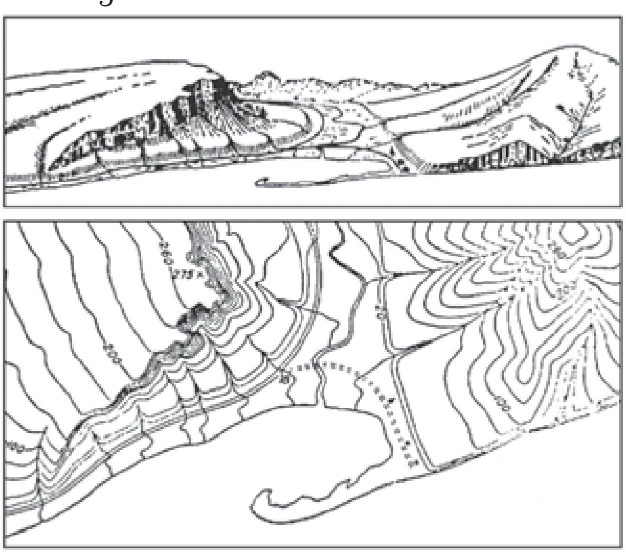


Fig. 2 : a) Landscape, b) A contour map derived from above landscape perspective. Contour lines are far apart for level land and closely spaced for steep slopes.

Different physical features represented by contours are as follows :

1) Hill : Hill appears as a set of closed and more or less circular shaped contour lines. Values of contours increase towards the centre. There are two types of hills : a) symmetrical hill and b) asymmetrical hill.

a) Symmetrical hill : A hill having uniform slope on all its sides. It is represented by evenly or regularly spaced circular contours with increasing elevations towards the centre (Fig. 1 a.).

b) Asymmetrical hill : A hill having steep slope on one side and gentle slope on the other. It is represented by closely spaced contours (steep slope) on one side and widely spaced contours (gentle slope) on the other side (Fig. 1 b.).

2) Ridges and saddles : A chain of hills is described as a ridge. A ridgeline can be drawn by joining tops of hills along a range. Water flows in opposite directions on either side of a ridgeline (Fig. 3).

Saddles are low points on the ridges. They are often important to map users, as they represent the lowest point for crossing the ridge. (Fig. 3).

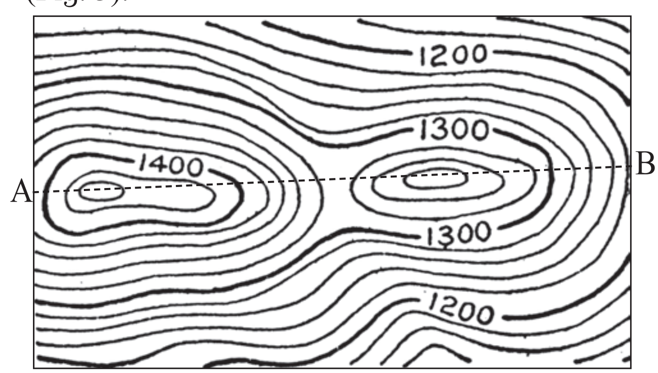


Fig. 3 : Ridge and saddle (AB is the ridge line)

3) Depression : Depression is represented by circular or semi-circular contours where the contour values decrease towards the centre (Fig. 4).

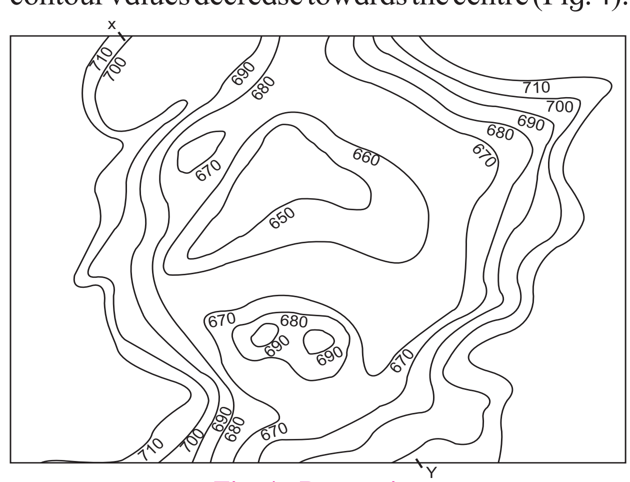


Fig. 4 : Depression

4) Valley : Valley is formed due to the channelling of running water in the form of streams over a long period of time. Water forms stream channels which have a lower elevation than the surrounding land. In contour maps the valley is depicted as a "V" shaped contour whose apex points upstream or towards higher elevation. As the stream flows downhill it will cross a number of contour lines, making a "V" on each. So valleys and stream channels appear on contour maps as a series of V's. If the stream has cut a narrow or deep channel, the V associated with it on the contour map will be narrow, if the stream channel is wider, the V will be wider (Fig. 5).

If the valley is formed due to a glacier, it is "U" shaped in cross section. The valley has a flat base, the sides of which are steeper than the valleys occupied by streams.

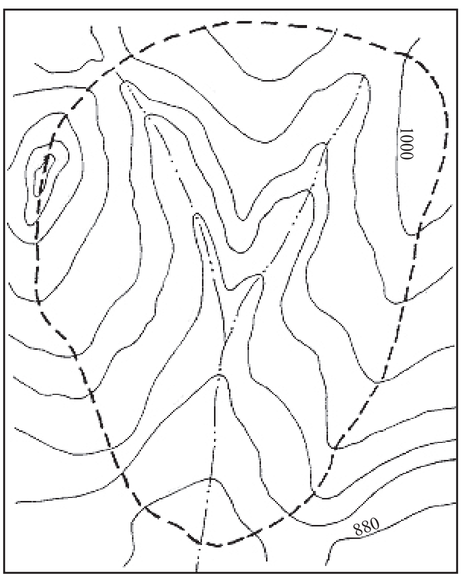


Fig. 5 : "V" Shaped Valley

5) Plateau : Plateau and tableland is a large elevated land. Plateau is fairly levelled. On a map it appears as a flat area. (with few contour lines) surrounded by sloping land (with a number of contours) (Fig. 6).

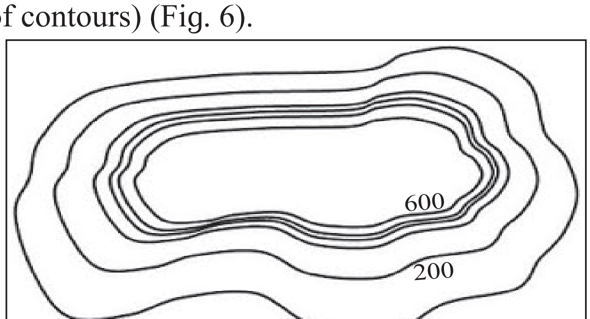


Fig. 6 : Plateau

6) Spur : Spur is represented by "V" shaped contours with its apex towards lowland which is reverse of "V" shaped valleys (Fig. 7).

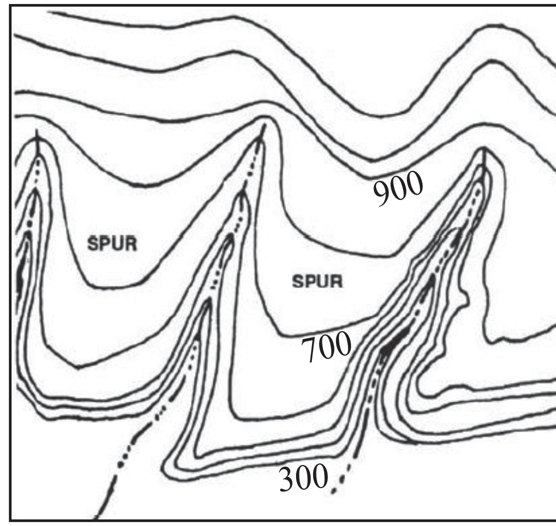


Fig. 7 : Spur

Creating topographic profile :

Topographic profile is a cross-sectional view along a line drawn through a portion of a topomap. Topographic profile is useful in understanding topomaps as well as it is very useful for geologists in analysing numerous problems. There are two types of topographic maps – 1) Contour maps (as described above) and 2) Geological maps. In the geological map, bedding planes are introduced between or on the contours.

Procedure for drawing topographic section along X-Y line :

1) Join X-Y point by straight line. Keep a blank paper strip along X-Y line on the map. Mark both X and Y points, by keeping point X on left side of the paper strip and point Y at right side of the paper strip (Fig. 8).

2) Mark the point of intersection between the X-Y line and contour line as tick marks on the paper strip. Write the elevation of the index contours below their respective marks on your paper strip.

3) Once all the markings are done, remove your paper strip from the map. On the blank paper draw a line (base line) at least as long

as X-Y section line. Place your paper strip with the tick marks along the base line and mark the start (X) and end (Y) points of your section line.

4) Transfer all tick marks on the base line with their appropriate elevations. Remove the paper strip. Draw vertical lines above your start (X) and end (Y) points. These will be the boundaries of your profile.

5) Look at the scale give on the map e.g. 1 cm = 100m.

6) Plot all the points with respect to their elevations and scale, perpendicular to the tick marks on the base line. For example, if a tick mark shows elevation 1200m, the point should be plotted at a height of 12cm perpendicular from the tick mark on the base line (Fig. 9).

7) Join all the points with freehand and smooth line (Fig.10). This is the topographic profile of the map along X-Y line.

Description of Map :

Topographic map is described on the basis of following points :

Topography of the area : Interpret the contour patterns with the help of their shape and spacing and identify the types of physical features present in the given map. Each map is provided with geographical North mark. Write the location of each feature with respect to its direction. For example an asymmetrical hill is located at north east side of the map having height 600m with its steep slope directed towards northeast and gentle slope towards southwest. The description of physical features can be written along following points :

a) Hill : It may be either symmetrical or asymmetrical. If symmetrical hill is present, write its location on the map and its height. For asymmetrical hill add a direction of its steep and gentle slopes.

b) Depression : Write its location and depth.

c) Valley : Describe the direction of flow, e.g. A "V" shaped valley is flowing towards the western side of the map.

d) Plateau : Write its location and height.

e) Ridge : Draw a ridge line and mark the saddle on the map and write its orientation in the description, e.g. Ridge line is oriented in Northwest – southeast direction. Describe the number of hills it contains with their locations and heights.

f) Spur : Write its location and slope direction.

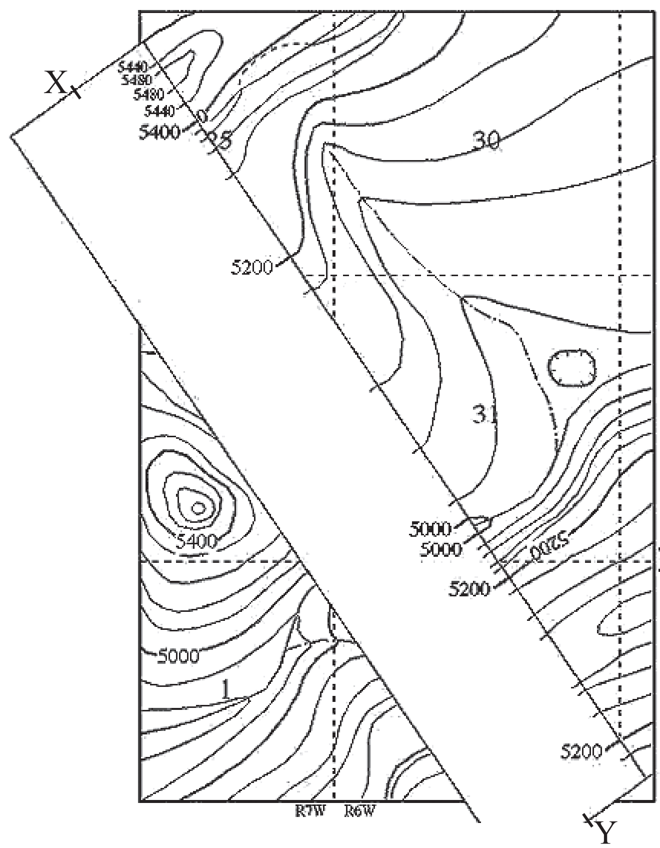


Fig. 8 : Marking the ticks wherever the contours cross the X-Y line

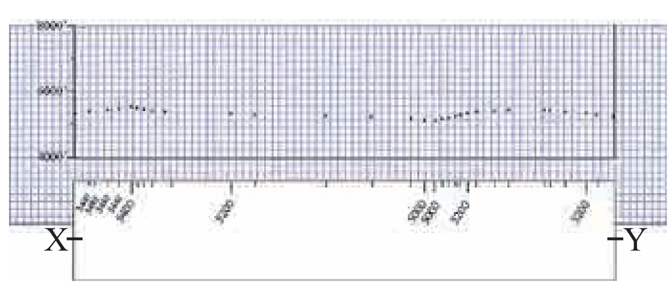
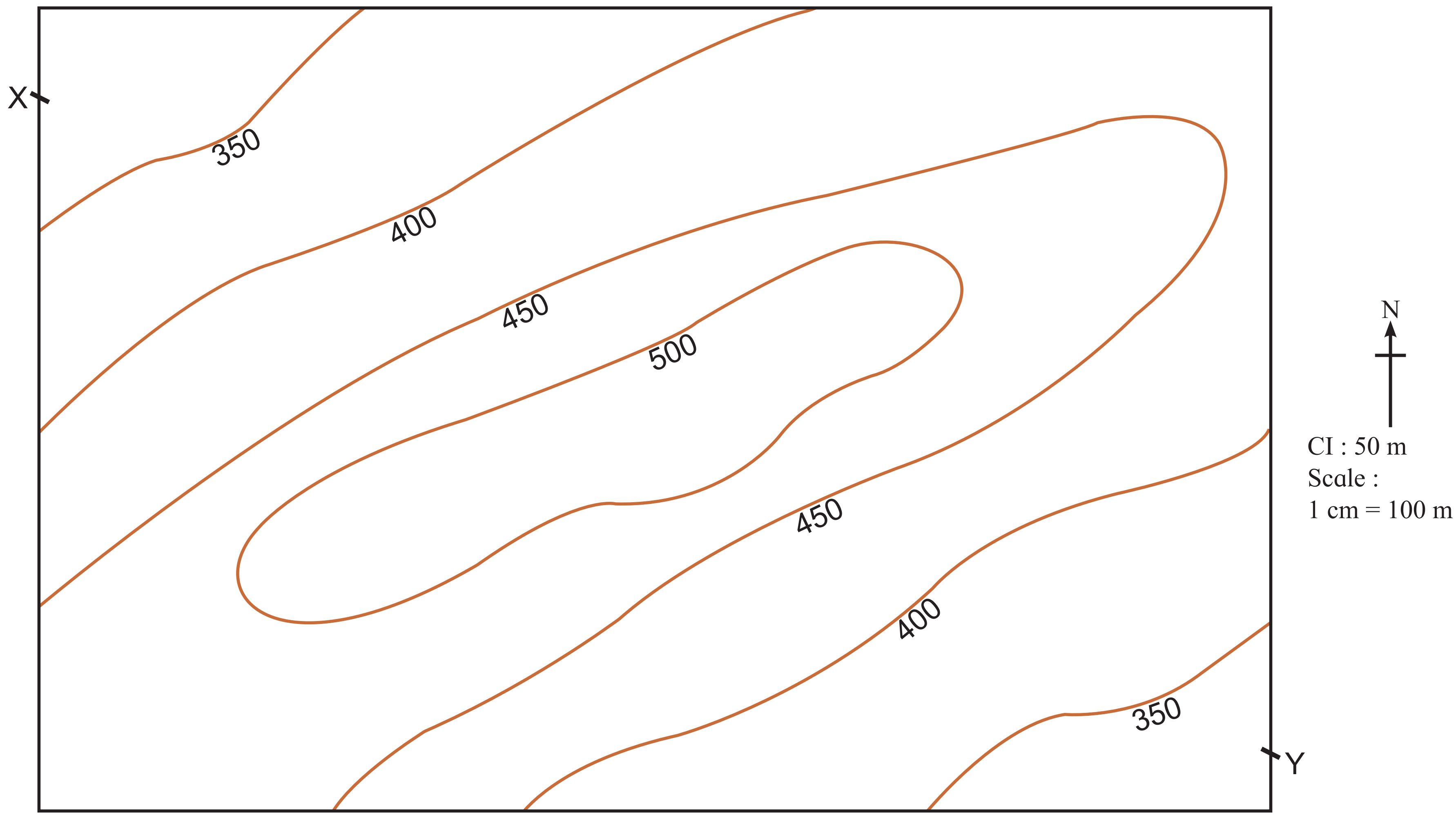
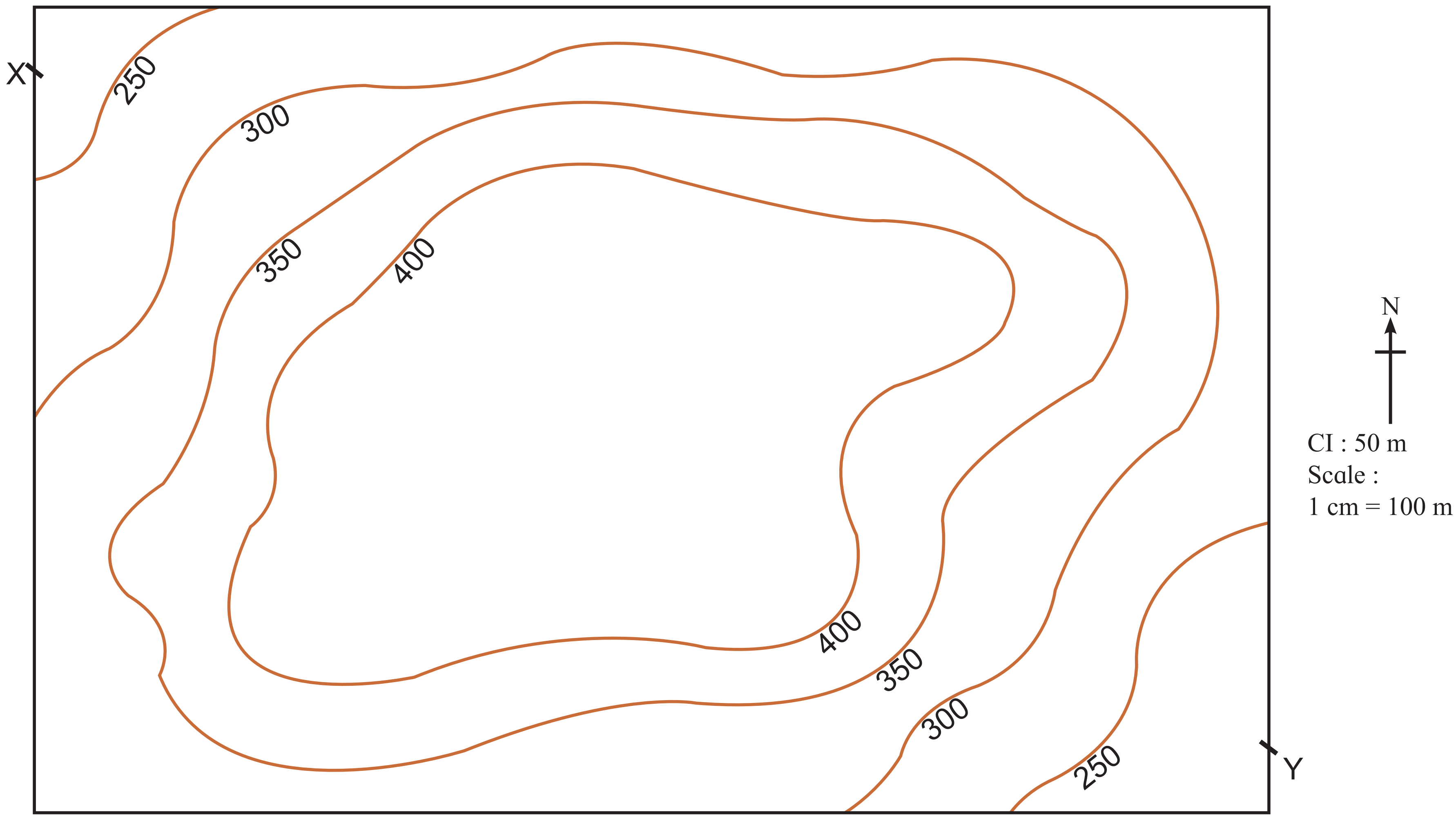


Fig. 9 : Marking elevations with the help of paper strip

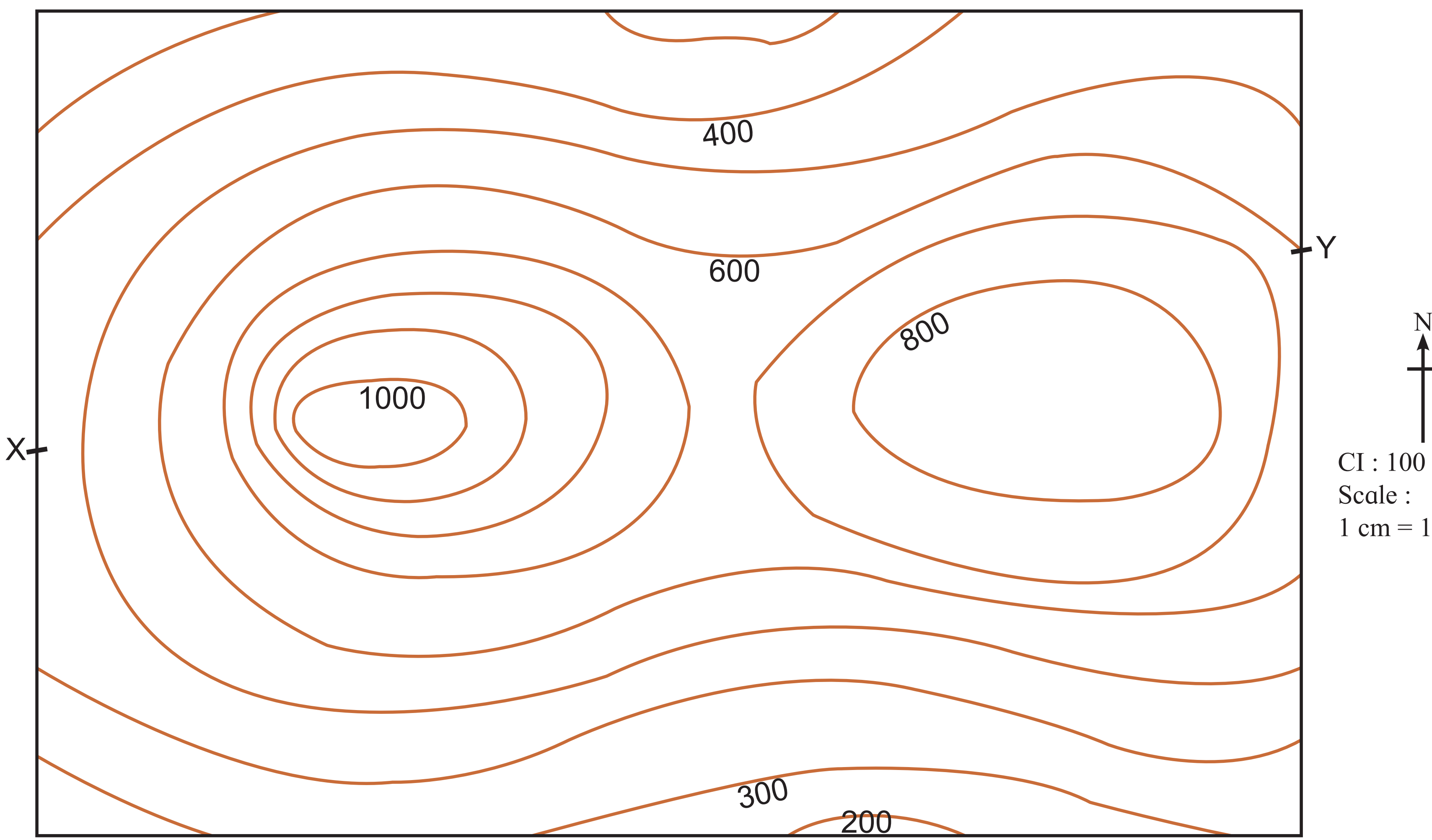
Map no. 1



Map no. 2

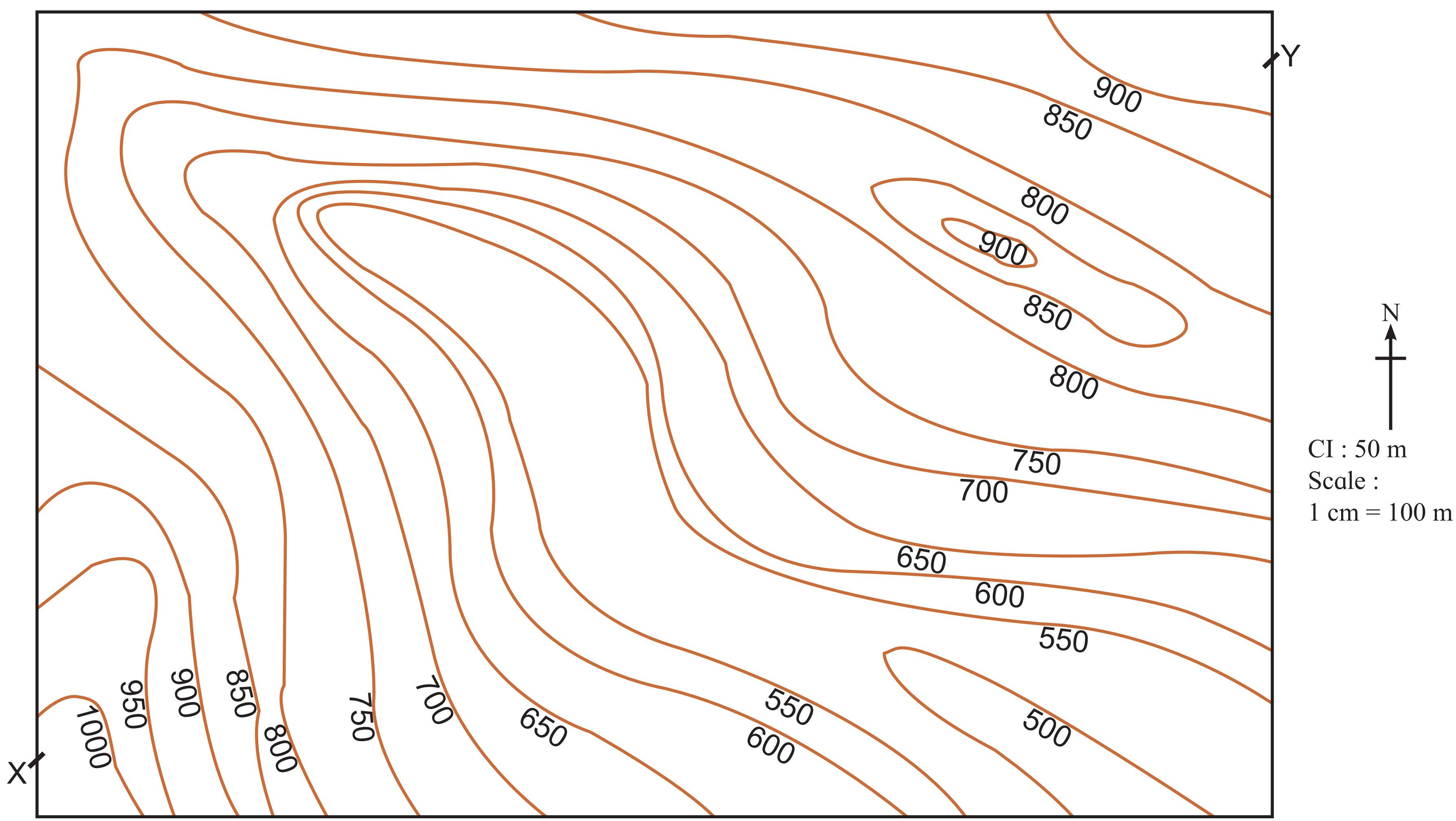


Map no. 3



CI : 100 m
Scale :
1 cm = 100 m

Map no. 4


Y
X
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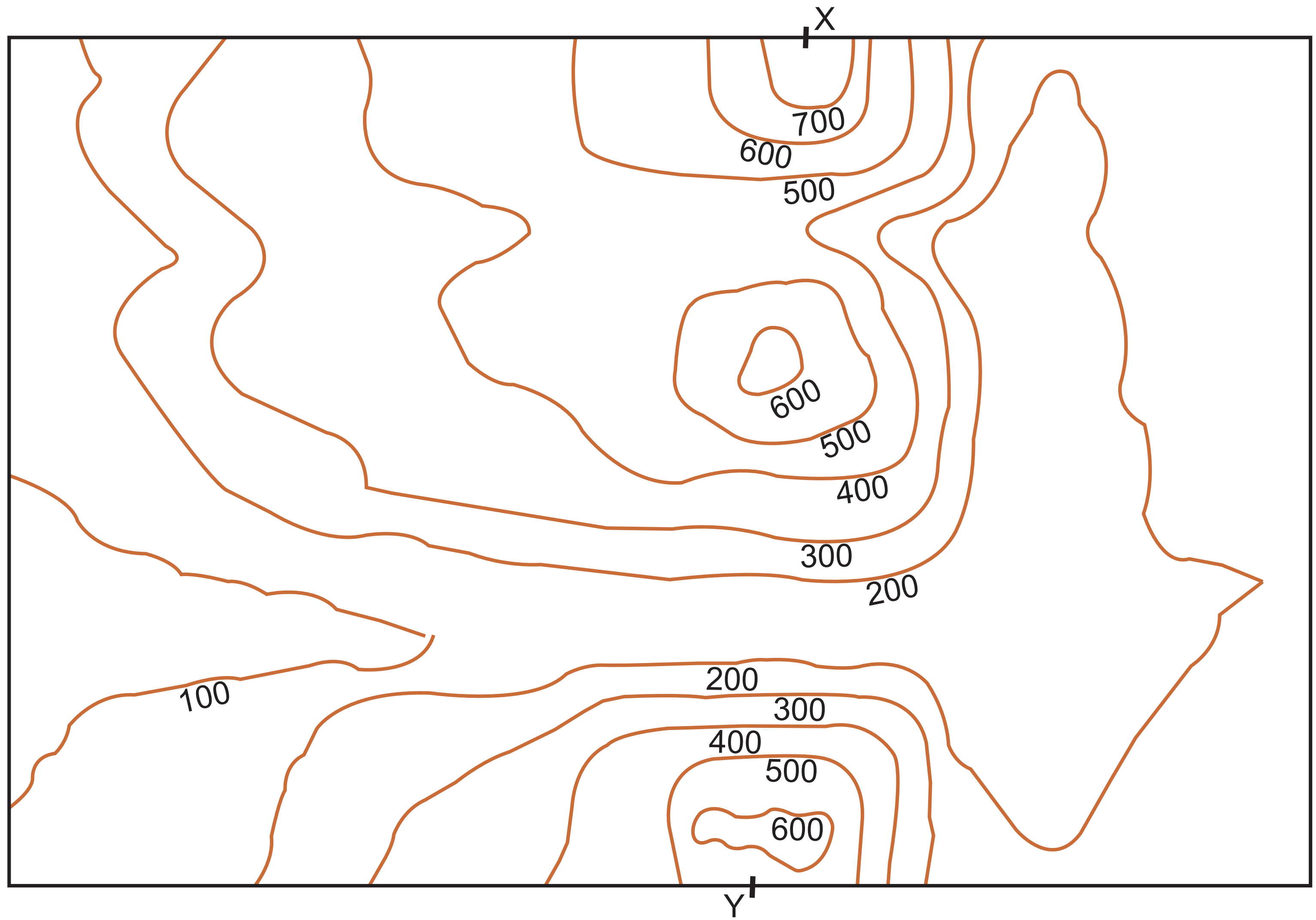
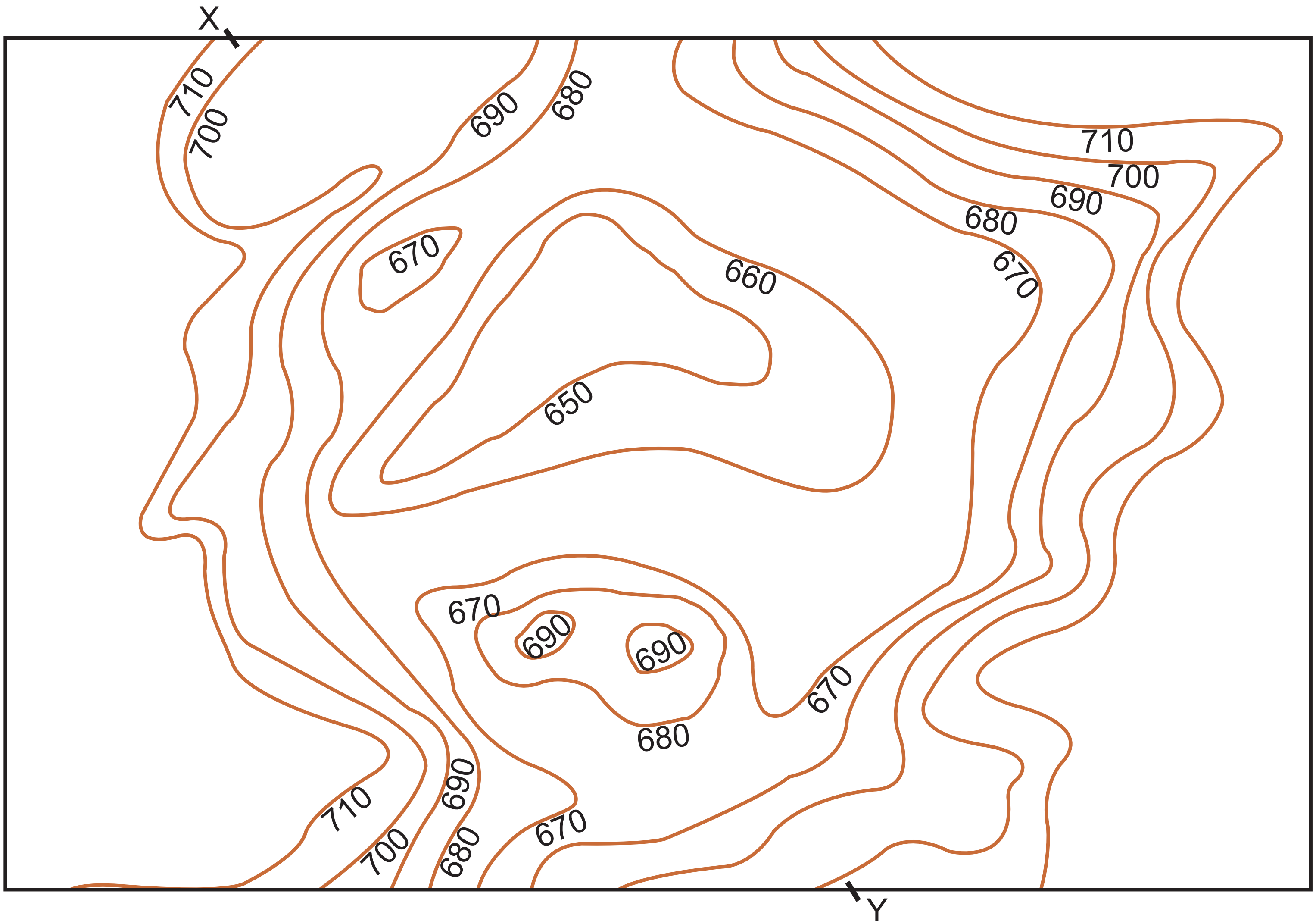
CI : 50 m
Scale :
1 cm = 100 m

Map no. 5



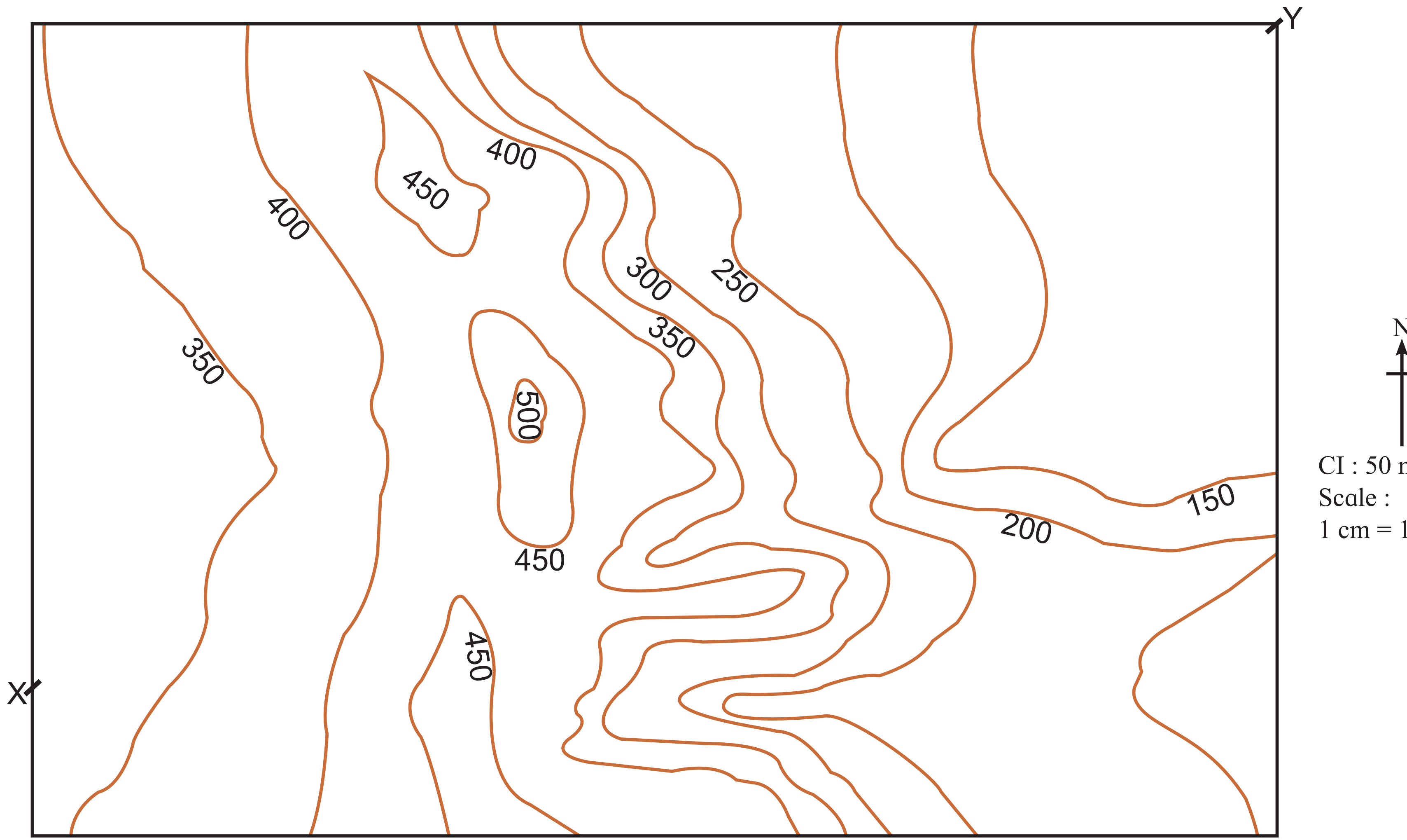
CI : 100 m
Scale :
1 cm = 100 m

Map no. 6



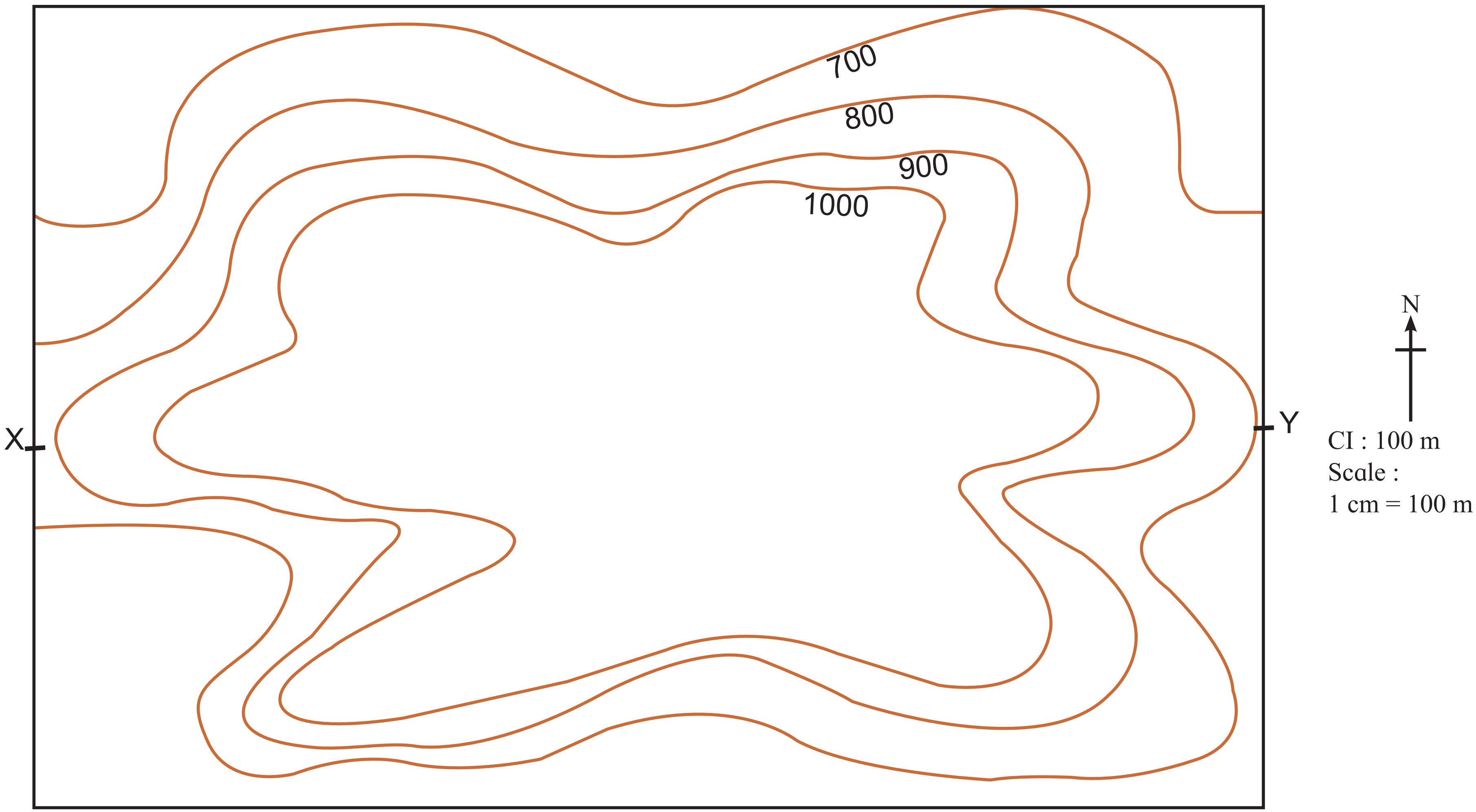
CI : 10 m
Scale :
1 cm = 100 m

Map no. 7

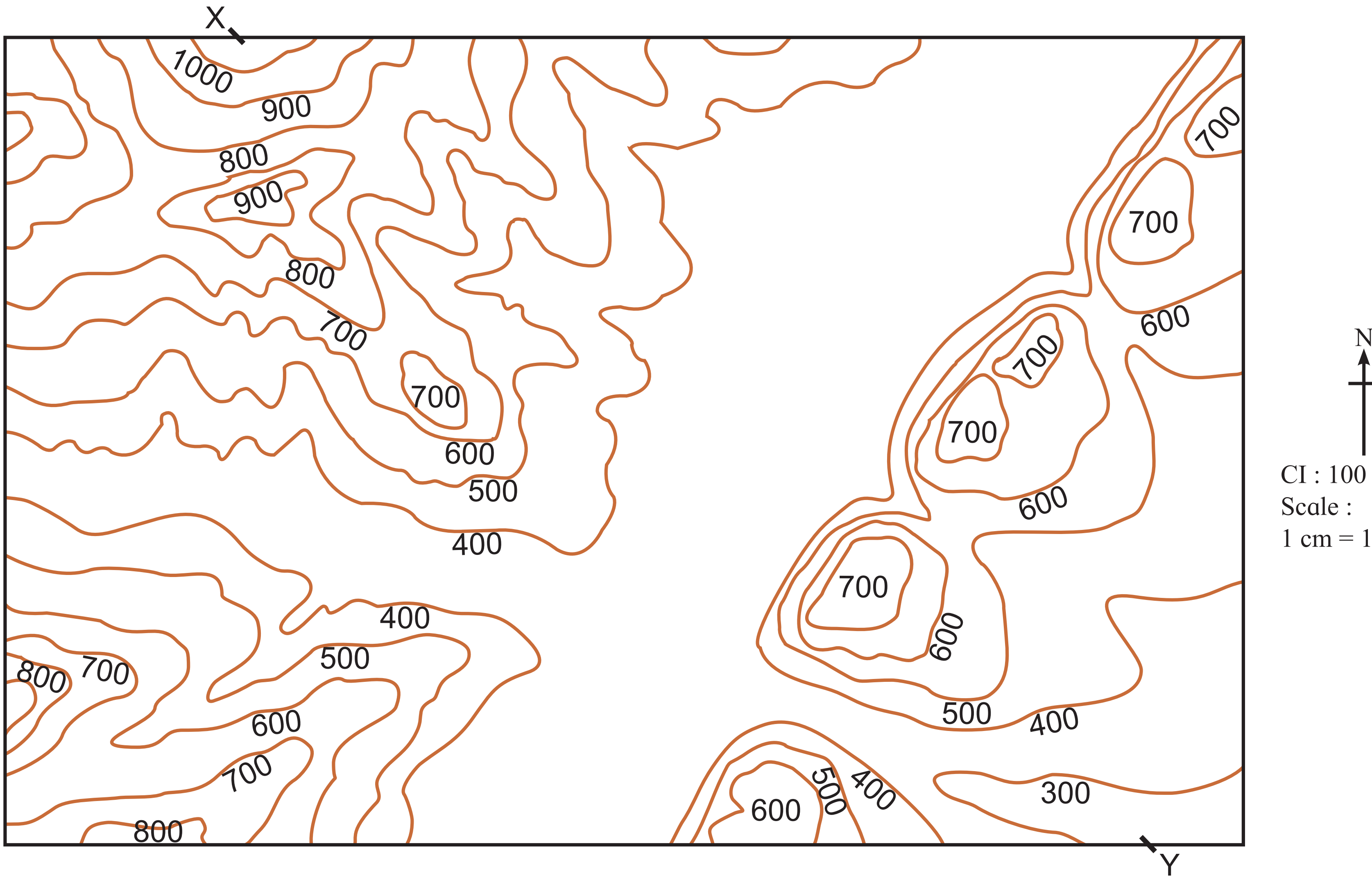


CI : 50 m
Scale :
1 cm = 100 m

Map no. 8

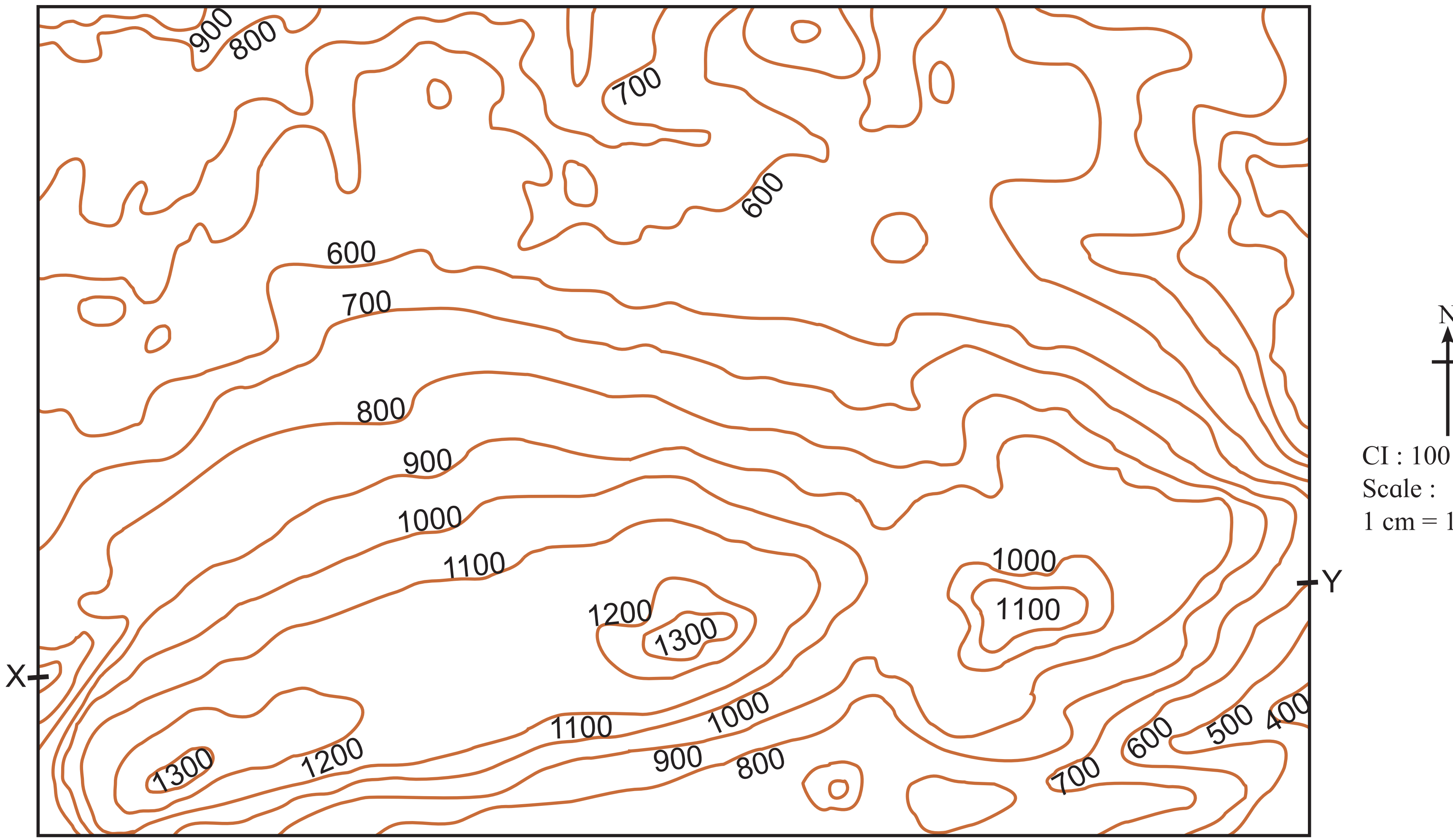


Map no. 9



CI : 100 m
Scale :
1 cm = 100 m

Map no. 10



CI : 100 m
Scale :
1 cm = 100 m

• Practical No. 14

Study of District Resource Map (DRM) for Nagpur District. (Note : Use your own DRM)

Nagpur district is situated in the eastern part of Maharashtra and renowned for its citrus orchards and manganese deposits. It falls in Survey of India degree sheet nos. 55K, L, O, P between latitudes 20°35':21°44'N and longitudes 78°15':79°40'E. It covers an area of 9892 sq. km and is bounded by Chhindwara, Seoni and Balaghat districts of Madhya Pradesh in the north; Bhandara, Chandrapur, Wardha and Amravati districts of Maharashtra in the east, southeast, south and southwest and northwest respectively. Nagpur is the district headquarters and Katol, Narkher, Kondhali, Jalalkheda, Savner, Mohpa, Kalmeshwar, Ramtek, Kantni, Mauda, Kuhi and Umrer are some of the major towns. Nagpur is well connected with other metropolitan cities by Southeastern Railway, Central Railway and National Highways Nos. 6 and 7. Nagbhir-Nagpur and Nagpur-Chhindwara extension lines (0.76m guage) of Southeastern Railway pass through the southeastern and northwestern part of the district. All important places within the district and adjacent districts are well connected by a network of state highways and all weather roads.

Nagpur district lies along the southern fringes of the Satpura range. It is hilly in the northeast and west where the elevation varies from 350m to 583m msl. The southern and eastern parts have a vast pediplain with gentle slopes towards east. The average elevation of the pediplain surface is about 300m msl. Pench and Kanhan are the main tributaries of Wainganga river flowing from northwest to southeast in the northern part.

Rock formations ranging in age from Archaean to Recent are exposed in the district. Tirodi Gneissic Complex of Archaean to Palaeo Proterozoic age (>2500-2200 m.y.) comprising migmatite, orthogneiss and granulite occupies the eastern and northeastern part. An outcrop of granulite is marked at 14 km northeast of Mauda. Amgaon Gneissic Complex of Archaean-Palaeo Proterozoic age occupies the southeastern part and comprises granitic gneisses and migmatitic gneisses with calc-silicate, quartzite, ultramafic and amphibolite. Sakoli Group of Meso Proterozoic age (2000-1600 m.y.) occupies the southern part and comprises mica schist, phyllite, carbonaceous phyllite, metabasalt with associated tuff, metarhyolite and felsic volcanics with associated tuff. Sausar Group of Meso Proterozoic age occupies the northern part and comprises quartz-muscovite schist, feldspar-muscovite schist and intercalated quartzite (Sitasawangi Formation); calc-gneiss and manganiferous marble with pockets of manganese ore (Lohangi Formation); muscovite-biotite shcist with manganese ore (Mansar Formation); quartzite and quartz-muscovite schist (Chorbaoli Formation); muscovite-biotite schist and quartz-biotite granite (Junewani Formation) and crystalline limestone and dolomite (Bichua Formation) which are repeatedly tight folded. The Sausar Group is a ***store house of manganese ore*** deposits. Talchir Formation of Carboniferous to Permian age (345-230 m.y.) and Kamthi Formation of Permian to Triassic age (280-195 m.y.) of Gondwana Supergroup are exposed around Umrer, Savner and Kamthi. Former comprises of boulder bed, sandstone and shale and latter comprises of sandstone and ferruginous sandstone. Coal seams occur in Barakar Formation underlying the Kamthi Formation. Lameta Group of Cretaceous age (136-65 m.y.) is exposed between northwest of Nagpur and south of Umrer as disconnected patches. Almost half of the district in its western and southern parts is occupied by the Deccan Trap comprising 60m thick pile of basaltic flows of Cretaceous to Palaeogene age (60-62 m.y.). At places, Intertrappean (sedimentary) beds separate the individual flows. Isolated laterite cappings are found around Kondhali. Alluvial deposits of Pleistocene to Recent age are found along Kanhan, Jam, Wunna and Sur rivers.

Nagpur district is well known for its economic mineral deposits, particularly manganese ore. About 55 manganese ore deposits have been explored. Some of the important deposits are located at Gumgaon, Ramdongri, Kodegaon, Kandri, Satak, Mansar, Lohdongri, Kachurwahi, Waregaon, Bhandarbodi, Manegaon, Mandekasa and Hiwra. The other mineral deposits found are copper at Pular and Parsori in Umrer tehsil and tungsten at Agargaon in Umrer tahsil. Important coalfields are located in Kamthi and Umrer areas. Clay deposits associated with rocks of Kamthi Formation are located at 25 km east of Nagpur and 21 km northeast of Savner. Limestone, calcitic marble and dolomitic marble deposits are found at Katta, Hiwara, Kadbikhera, Sarkaritola, Pauni, Chorbaoli, Deolapar, Mansar, Chargaon, Kachurwahi, Junewani, Kardi and Dahoda.

Other economic minerals reported are antimony (Kolari), chromite (Taka), gold (Pular-Parsori, Mokhabardi and Kolari in Bhiwapur tehsil), lead-zinc (Anjani, Tambekhani, Kolari, Bhaori), kyanite (10 km southeast of Kuhi) and mica (Koradi).

EXPLANATION

LITHOLOGY	STRATIGRAPHIC STATUS		AGE	NATURE AND CHARACTERISTICS
Alluvium			QUATERNARY	Loamy consisting of sand, silt and clay with pebbles and gravels at places, soft, unconsolidated
Laterite			CAINOZOIC	Yellow to reddish brown, porous, exhibits pisolitic structure
18 simple flows of basalt	Karanja Fm.	SAHYADRI GROUP (DECCAN TRAP)	CRETACEOUS-PALAEOGENE	Dark grey, sparsely to moderately porphyritic, massive rock
6 flows of basalt (3 simple & 3 compound)	Chikhli Fm.			Dark grey, sparsely to moderately porphyritic, massive rock
Intertrappean beds				Red and grey clay, limestone and sandstone
Undifferentiated basalt				Dark grey, fine grained with compact and massive clinkery surface
Conglomerate, sandstone, shale, limestone		LAMETA GROUP	CRETACEOUS	Green and red, medium grained, calcareous, friable, arkosic and arenaceous rock
Sandstone and ferruginous Sandstone	Kamthi Fm.	GONDWANA SUPERGROUP	PERMIAN-TRIASSIC	Reddish yellow, buff, dark brown, medium to coarse grained, hard and compact rock
Boulder bed, sandstone, shale	Talchir Fm.		CARBONIFEROUS-PERMIAN	Greenish, fine grained, compact sandstone with interbedded greenish shale
Granite, pegmatite			MESO PROTEROZOIC	Medium to coarse grained and composed of feldspar, biotite and muscovite
Crystalline limestone, dolomite	Bichua Fm.	SAUSAR GROUP		Pale, buff to creamy white, medium grained rock
Muscovite-biotite schist, quartz-biotite and granulite	Junewani Fm.			Light grey, buff to brown, very fine grained, massive rock
Quartzite and quartz-muscovite schist	Chorbaoli Fm.			Light buff, grey to reddish, massive rock
Muscovite-biotite schist with manganese ore	Mansar Fm.			Light grey to pale brown, silvery white, coarse grained, laminated and fissile rock
Calc-gneiss and manganiferous marble with manganese ore pockets	Lohangi Fm.			Greenish to brown, black, fine to coarse grained rock
Quartz-muscovite schist, feldspar-muscovite schist and interculated quartzite	Sitasaongi Fm.			White, grey to pink, fine to medium grained rock
Silicified zone, quartz reef				White, angular to subangular fragments in quartzose matrix
Metarhyolite, tuff, felsic volcanics and associated tuff		SAKOLI GROUP		Light grey to black, very fine grained, porphyritic, tuffaceous and massive rock
Mica schist				Silvery sheen, greyish to greenish grey, medium to coarse grained and well foliated
Phyllite, carbonaceous phyllite				Grey, light greenish, brown, soft, well foliated and crenulated
Tourmalinite, corticale				Black, closely associated with felsic rock
Metabasalt with associated tuff				Earthy green, fine grained, porphyritic, vesicular and amygdular, hard rock
Amphibolite	AMGAON GNEISSIC COMPLEX		ARCHAEAN PALAEO PROTEROZOIC	Dark green, medium to coarse grained, massive, hard and at places shows spheroidal weathering
Ultramafic rock				Greyish white to light green, foliated and crenulated at places
Quartzite (± Kyanite, Sillimanite)				Pink, white, grey and at places black due to presence of magnetite
Calc-silicate rock				Greenish to brown, medium to coarse grained rock
Granite gneiss with migmatitic gneiss	Granitic gneisses with migmatite/granite	TIRODI GNEISSIC COMPLEX		**Migmatite :** coarse to medium grained, mesocratic, distinctly gneissose and often prophyroblastic **Gneiss :** light to dark grey, medium to coarse grained and distinctly banded **Granite :** light grey, medium to coarse grained and massive
	Granulite			Pale brownish, medium to coarse grained having greasy appearance.

STRUCTURAL INDEX

- Confirmed litho-contact
- Inferred litho-contact
- Central Indian Shear zone (CIS)
- Attitude of bedding : inclined/vertical
- Attitude of foliation : inclined/vertical
- Attitude of joint : inclined/vertical
- Overturned anticline
- Anticline showing plunge
- Thrust
- Fault
- Lineament
- Boundary for data base gap

MINERAL INDEX

- Antimony
- Chromite
- Clay
- Copper
- Coal
- Gold
- Lead
- Zinc
- Kyanite
- Limestone
- Dolomite
- Manganese
- Mica
- Tungsten

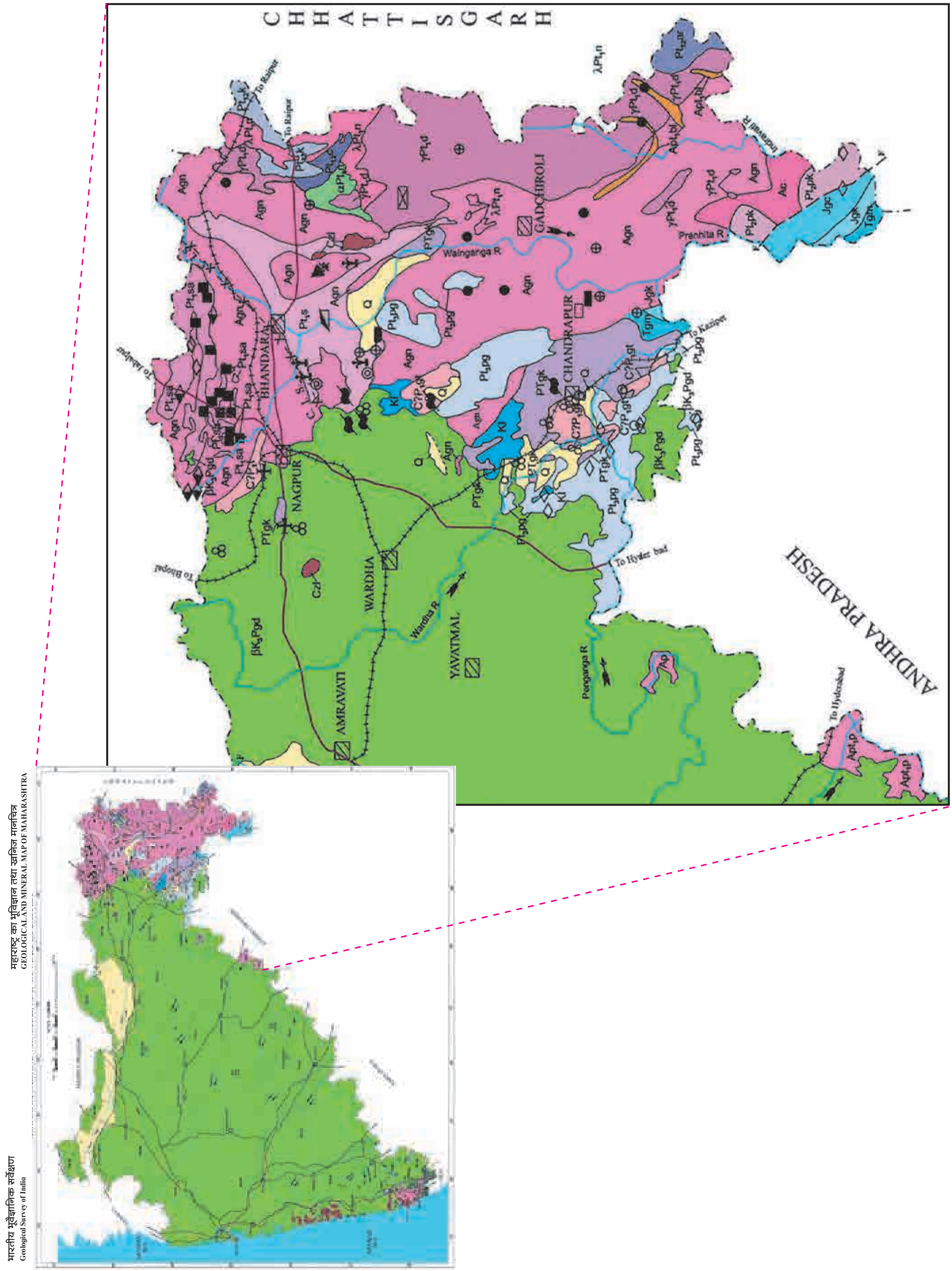
GENERAL INDEX

- District boundary
- State boundary
- Height of triangulation station in m
- Railway line
- Road
- Settlement
- Drainage with direction of flow
- Reservoir

Practical No. 15

Study of Mineral Resources of Maharashtra state.

(For Practical Numbers : 15 refer to chapter number 6)



L E G E N D

Q	Alluvium			Quaternary
Czl	Laterite			Cainozoic
Kl				
βK_2Pgd	Deccan Trap			Upper Cretaceous to Palaeogene
Jgc	Lameta Group	Sandstone, chert limestone and clay	Gondwana	Upper Carboniferous to Lower Cretaceous
Jgk	Chikiala Formation	Ferrugenous sandstone and conglomerate	Gondwana	Upper Carboniferous to Lower Cretaceous
Tgm	Kota Formation	Sandstone, grit, red clay and limestone	Gondwana	Upper Carboniferous to Lower Cretaceous
PTgk	Maleri Formation	Ferrugenous calcareous sandstone and shale	Gondwana	Upper Carboniferous to Lower Cretaceous
$C?P_1t$	Kamthi Formation	Ferrugenous sandstone	Gondwana	Upper Carboniferous to Lower Cretaceous
	Talchir Formation	Shale, siltstone, sandstone, conglomerate and tillite	Gondwana	Upper Carboniferous to Lower Cretaceous
Pt_3pg / Pt_3bm	Penganga Group/ Badami Group (Kaladgi Basin)	Limestone, shale, chert, sandstone/ Shale, sandstone, quartzite		Neo Proterozoic
Pt_2pk	Pakhal Supergroup	Dolomite, limestone, shale, sandstone, quartzite		Meso Proterpzoic
$Pt_{12}ar$ / $Pt_{12}k$	Abujhmar Group/ Khairagarh Group	Basalt, shale, sandstone and conglomerate/ Alternating sequence of Sandstone, siltstone,grit and metabasalt		Palaeo-Meso- Proterozoic
Pt_1sa	Sausar Group	Calc.-gneiss, marble, biotite granulite schist, quartzite and schistose grit		Palaeo Proterozoic
Pt_1s	Sakoli Group	Metabasalt, metapellites (phylite, mica schist), quartzite, BIF, banded chert and tuff		Palaeo Proterozoic
λPt_1d	Dongargarh Granite (Granite)			Palaeo Proterozoic
λPt_1n / αPt_1n	Bijli Rhyolite /Pitepani volcanics	Rhyolite, acid tuff and rhyolitic conglomerate/ Green tuff, metabasalt and gabbro	Nandgaon Group	Palaeo Proterozoic
APt_1p	Peninsular Gneissic Complex (Younger phase)	Granite gneiss and granite		Archaean-Palaeo Proterozoic
Apt_1bl	Bailadila Group	(Meta-ultramafite/gabbro, meta-basalts, quartzite, mica-schist, phylite,BHQ)	Dharwar Supergroup	Archaean-Palaeo Proterozoic
Apt_1dc	Chitradurga Group	(BIF, phyllite, schist, amphibolite,quartzite	Dharwar Supergroup	Archaean-Palaeo Proterozoic
βApt_1dc	Chitradurga Group	(Metabasalt)	Dharwar Supergroup	Archaean-Palaeo Proterozoic
Ac	Bhopalpatnam granulite	Pyroxene granulite, charnockitic gneiss, charnockite		Archaean
Ap	Peninsular Gneissic Complex (Older Phase)	Granite gneiss and migmatite with enclaves of amphibolite, quartz mica schist, BMQ, quartzite and meta ultramafics		Archaean
Agn	Gneissic Complex (Amgaon/Bastar?Tirodi Gneiss)	(Granite gneiss and migmatite with enclaves of amphibolite, quartz mica schist, BMQ, quartzite and meta ultramafics)		Archaean

INDEX TO MINERALS

Clay	Ilmenite	Barytes	Tungsten Ore
Bauxite	Manganese	Gold	Ochre
Dolomite	Copper Ore	Pyrophyllite	Glass sand
Limestone	Chromite	Zinc Ore	Sillimanite
Iron Ore	Coal	Kyanite	Dimensional stone

INDEX TO GEOLOGICAL STRUCTURES

F F Fault

C. I. S. Central India Shear Zone

Lonar Crater

- **Practical No. 16**

Study of some important geological heritage sites of Maharashtra state.

1) **Geoheritage sites :** Geoheritage sites are geologically important sites found either locally or globally. These sites are a result of natural processes and not formed by human intervention.

- These are tourist destinations and provide local and regional economic benefits.
- Geoheritage sites can be small, but scientifically significant, such as a road cut etc. They can also be extensive areas with international recognition.
- These geoheritage sites are vulnerable to urbanization, infrastructure development, agriculture, over-use and erosion.
- Conservation strategies, appropriate to the type of site are important for protection of geoheritage sites from loss, in order to maintain them for long-term public interest.

2) **Geodiversity :** Geodiversity is the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, processes) and soil features. It includes their assemblages, relationships, properties and interpretations.

3) **Geoconservation :** It includes actions and measures taken to preserve geodiversity and geoheritage for the future.

4) **Geotourism :** It is the tourism with a strong focus on natural wonders (including geological and geomorphic features).

Some important geological heritage sites of Maharashtra state :

1) **Lonar meteorite crater (Lonar, Buldhana district (19.9756°N, 76.5092°E, 610-msl) :** Lonar crater is a unique crater found in Deccan basalt and has been created due to an impact of a meteorite. The crater's age has been estimated to be around 52,000 years (Pleistocene). This remarkably circular crater is nearly 150 m. deep. The average diameter of the impact crater is ~1.8 km. The monsoon runoff flows into lake via multiple streams. As the water evaporates gradually during the dry season, the dissolved salts are left behind. The concentration of salts steadily increases and the lake water becomes brackish and then saline (Fig.1).

It was earlier thought of as a volcanic crater but the presence of high pressure/ high temperature mineral - Maskelynite has confirmed that the crater originated due to a hyper velocity meteorite impact.

Fig. 1 : Meteorite crater at Lonar

2) **Nighoj potholes (Nighoj, Ahmednagar district. (18.9319°N, 74.2627°E, 575-msl) :** This site shows magnificent potholes in basalt flows within the rocky channel of the Kukadi River. The narrow inner channel (~300m long and >15m. deep), exhibits intricately undulating walls with remnants of multiple potholes of various sizes (~1 - 5m) and shapes (Fig. 2).

Fig. 2 : Potholes at Nighoj

3) **Honeycomb structure (Harihareshwar, Raigad district. (17.9912°N, 73.0183°E, 5-msl) :** The sea cliff at Harihareshwar has a well developed honeycomb structure within basalts. It displays a great variety of micro-features and patterns such as circular solution depressions, potholes, honeycomb structure etc. They are formed due to chemical weathering caused by sea water (Fig. 3).

Fig. 3 : Honeycomb structure at Harihareshwar

4) **Natural Bridge (Gulunchwadi, Ane ghat, Pune district. (19.1512°N, 74.2169°E, 755-msl) :** Gulunchwadi village on Ahmednagar – Kalyan highway has a natural bridge in Aradara nala. The nala passes under this rock bridge, which is about 2 - 7 m. high and has a span of 10 - 13 m. The basaltic bedrock has been incised by Aaradara nala, along a winding course in this stretch. (Fig. 4).

Fig. 4 : Natural bridge at Gulunchwadi

5) **Columnar joints :** Columnar joints in basalt develop due to contraction induced by conductive cooling. Tension from the contraction gives rise to polygonal fracture system (pentagonal or hexagonal). Spectacular columnar joints in basalt have been reported from following sites in Maharashtra :

a) Panhala hill (Panhala fort area, Kolhapur district (16.4822°N, 74.0627°E, 907-msl)

b) Jyotiba hill (Jyotiba hill, Wadi Ratnagiri village, Kolhapur district (16.4730°N, 74.1038°E, 910-msl)

c) Tumzai hill (Tumzai, Jadavwadi village, Kolhapur district (16.4028°N, 74.0324°E, 889-msl)

d) Bandivade village (Bandivade village area, Kolhapur district (16.4913°N, 74.0020°E, 875-msl)

e) Naldurg (Naldurg fort area, Naldurg village, Osmanabad district (17.8171°N, 76.2896°E, 566-msl),)

f) Gilbert hill (Gilbert hill,, Andheri Mumbai (19.1206°N, 72.8402°E, 10-msl)(Fig. 5)

Fig. 5 : Columnar joints, Tumzai Hills, Panhala

6) **Tableland, Panchgani (Mahabaleshwar) (Panchgani, Satara district (17.9221°N, 73.6725°E, 1386-msl) :** Panchgani is a plateau in the Deccan flood basalt terrain and is capped by thick laterite. The basalt sequence here has many horizontally placed lava flows, sometime separated by red boles. Panchgani is known for its impressive laterite-capped tableland and string of mesas (Fig. 6).

Fig. 6 : Tableland at Panchgani

7) **Sandhan valley (Samrad, Ahmednagar district (19.5129°N, 73.6863°E, 740-msl) :** Sandhan is a classic example of a slot canyon in the Deccan traps. Canyons (valleys) which are significantly deeper than their widths are termed as slot canyons. The Sandhan canyon is upto 100 m deep and 2 - 30 m. wide. Canyons are primarily formed by the process of scouring by flood waters rushing through narrow openings in rocks along fractures and lineaments (Fig. 7).

Fig. 7 : Sandhan valley at Samrad

8) **Hot springs :** Chot spring is spring produced by the emergence of geothermally heated groundwater onto the surface. This hot water can have temperatures upto 100°C. Hot springs can result a) in a region which has suffered recent volcanic activity or in which magmatic activity still continues at greater depth or b) when the rock structure is favourable, the groundwater may travel to greater depths and get heated due to increase in temperature. When this hot water emerges on the surface, it gives rise to hot springs.

Hot springs from Maharashtra are formed due to favourable rock structure type. Some of the localities of hot springs in Maharashtra are given below.

Konkan region :

a) Vajreshwari (19.4870° N, 73.0280° E) : Thane district

b) Pali (18.5380°N, 73.2207° E) : Raigad district

c) Aravali (17.29725°N, 73.5°E) : Sangameshwar, Ratnagiri district

d) Unhale (16.3750° N, 73.2222° E) : Rajapur, Ratnagiri district

e) Tural (17.2554° N, 73.5300° E) : Ratnagiri district (Fig. 8)

Marathwada region :

f) Unkeshwar (19.34° N, 78.22° E) : Nanded district

North Maharashtra region :

g) Unapdev (20.16°N, 75.29°E) : Jalgaon district

Fig. 8 : Hot springs at Tural

- **Practical No. 17**

Draw sketch and label the various landforms seen in the photographs :

a) River : erosional and depositional features

b) Sea : erosional and depositional features

c) Wind : erosional and depositional features

d) Glacier : erosional and depositional features

(For Practical no. : 17 refer to chapter number 3)

- **Practical No. 18**

Fieldwork

Geology is a natural science. Nature is the best 'guide to study geology'. It mainly requires the study and understanding of basic phenomena in the classroom followed by fieldwork. The observations made in the field are useful in understanding basic concepts in geology and it is a good practice to be one with nature.

Preparation for fieldwork :

Before going for field studies, you should plan your programme. Know the topography of the area, rock types (lithology) of the area, accessibility, areas to be covered in given time and possible obstacles and problems likely to occur during fieldwork. Prepare a check list of all the geological instruments and accessories required during fieldwork.

Before you start fieldwork, study and read the topomap in detail. Mark the areas to visit. With the help of contours delineate hilly, undulating or plain lands in the area. Mark the villages and the cities falling in the area for immediate help, during problems in the field. Locate the roads to reach the proposed study area.

With the help of geological map of the area, plan your route in the area that will cover observation and study of maximum number of rock types and structures. Care should be taken while planning the route. If you are planning to take a traverse across the hill, the other side of the hill should have a road for easy accessibility. Estimate the time required for your planned route. Starting the fieldwork early in the morning and ending before sunset is the best. Generally, fieldwork is arranged in winter and bright sunny days of summer.

A topomap is a must during fieldwork to check whether everything is going on according to plan. Clinometer similar to Magnetic compass is useful to orient yourself with respect to north direction. During fieldwork, a geological hammer is required to collect rock and mineral samples. A notebook is essential to note down the points and draw figures of the structures found in the study area. Carry lunch box and water bottle for keeping your self energetic and fresh. Field shoes, helmet, safety jackets and sample bags are essential during fieldwork. These are essential accessories. Other items like medicines, first aid kit, ropes, measuring tape, camera etc. can be put in your haversack.

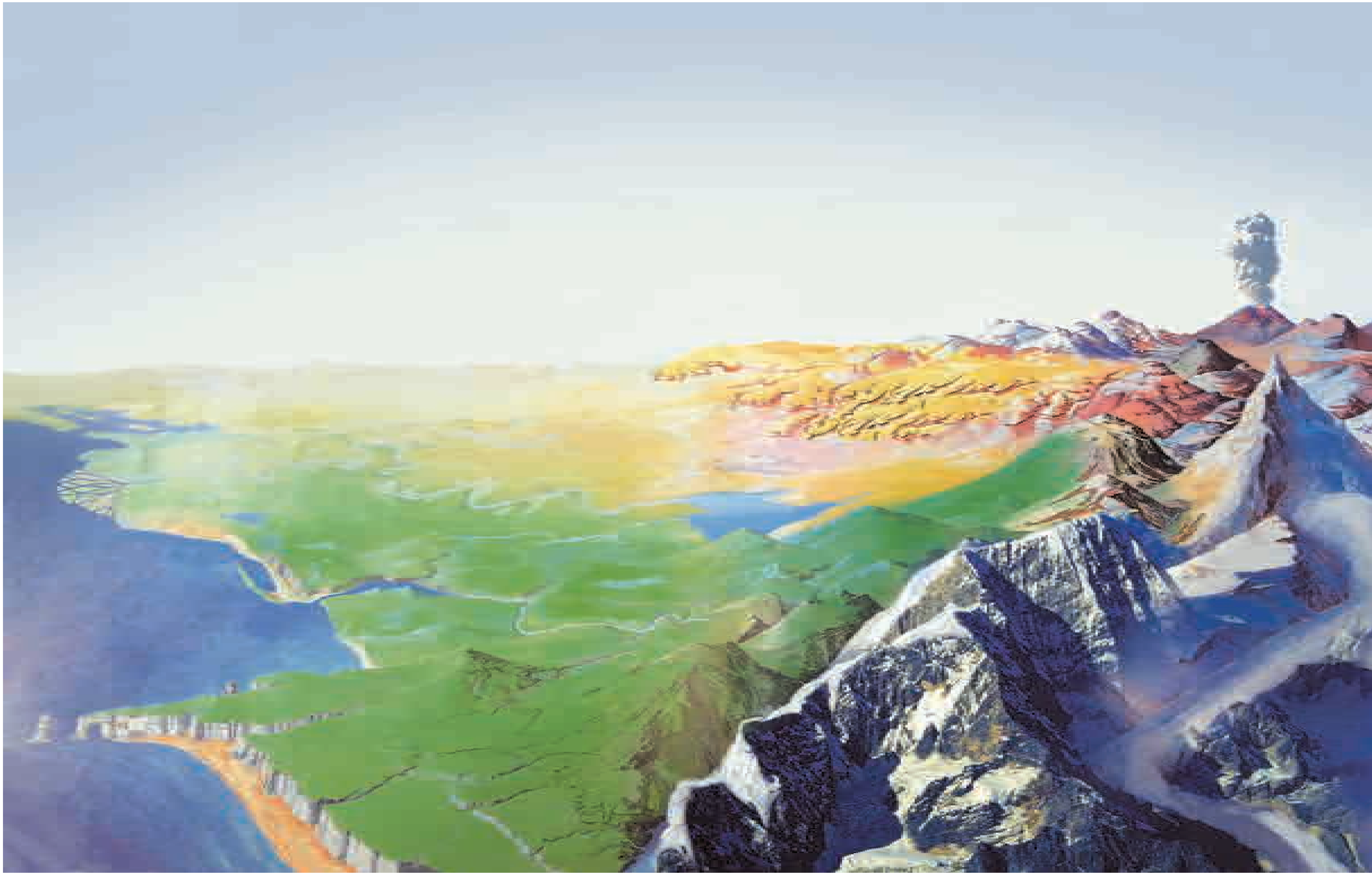
During fieldwork :

Discipline should be maintained during fieldwork. Your activities should not disturb local people and natural habitats. Taking observations and noting them in the notebook is essential. Click photographs of the features/ rocks etc. by placing a suitable scale (hammer, pencil, coin, etc.)

Fieldwork : Visit to nearby site of geological interest and report writing :

1) River meanders
2) Potholes
3) Columnar joints
4) Waterfalls
5) Road cuttings
6) Spheroidal weathering
7) Tableland / Mesa / Butte
8) Coastal erosional features etc.
9) Geologically important sites

Observe the following picture carefully. Identify the landforms formed by different agents of erosion. Number them with pencil here and write their names in the sequence in your notebook.



GLOSSARY

- **Aa lava flow :** (A Hawaiin term) A lava flow with a surface covered by angular, jagged blocks. also called blocky lava.
- **Abrasion :** The mechanical wearing away of a rock by friction, rubbing, scraping or grinding.
- **Accretion disc :** A disc of interstellar material gathered into orbit by gravitational field of a star or black hole and gradually spiralling into the object.
- **Aeolian :** Pertaining to wind.
- **Aeolian environment :** The sedimentary environment of deserts, where sediment is transported and deposited primarily by wind.
- **Amphibole :** An important rock-forming mineral group of ferromagnesian silicates. Amphibole crystals are constructed from double chains of silicon-oxygen tetrahedra Example: Hornblende.
- **Amphibolites :** A granular metamorphic rock consisting of mainly hornblende (Amphibole mineral) and plagioclase with little or no quartz and mud, washed out from the glacier.
- **Angle of repose :** It is a stable or critical angle at which a sloping surface composed of loose material is stable.
- **Aphanitic texture :** A rock texture in which individual crystals are too small to be identified without the help of a microscope. In hand specimens, aphanite rocks appear dense and structure less.
- **Asthenosphere :** The zone of Earth directly below the lithosphere, from 70 km to 200 km below the surface. Seismic velocities are distinctly lower in the asthenosphere than in adjacent parts of Earth's interior. The material in the asthenosphere is therefore believed to be soft and plastic in nature.
- **Avalanche :** A large amount of ice snow, dirt or rock or mixture of these material falling or sliding or flowing suddenly or quickly down the side of a mountain.
- **Backwash :** The return sheet flow down a beach after a wave is spent.
- **Bar :** An offshore, submerged, elongated ridge of sand or gravel built on the seafloor by waves and currents.
- **Basalt :** A dark-coloured, aphanitic (fine-grained) igneous rock composed of Plagioclase (over 50 percent) and Pyroxene. Olivine may or may not be present. Basalt and Andesite represent 98 percent of all volcanic rocks.
- **Batholith :** A large discordant plutonic rock with more than 100 square kilometre surface exposure, a large intrusive mostly of granite.
- **Bay :** It is a body of water partially surrounded by land along the shore line.
- **Baymouth bar :** A narrow, usually submerged ridge of sand or gravel deposited across the mouth of a bay by longshore drift. Baymouth bars commonly are formed by extension of spits along embayed coasts.
- **Beach :** A deposit of wave-washed sediments along a coast between the landward limit of wave action and the outermost breakers.
- **Bed :** A layer of sediment 1 cm or more in thickness.
- **Bedding plane :** A surface separating consecutive layers of sedimentary rock.
- **Bedload :** Material transported by currents along the bottom of a stream or river by

rolling or sliding, in contrast to material carried in suspension or in solution.

- **Bedrock :** The continuous solid rock that underlies the regolith everywhere and is exposed locally at the surface. An exposure of bedrock is called an outcrop.
- **Big Bang Theory :** This theory explains how the Universe began with a small singularity then inflated over the period of 13.8 billion years to the cosmos.
- **Biosphere :** The totality of life on or near Earth's surface.
- **Biotite :** "Black mica." An important rock-forming ferromagnesian silicate with silicon-oxygen tetrahedral arranged in sheets.
- **Bog :** An area of wet muddy ground that is formed due to accumulation of dead plant material.
- **Bole beds/ Red bole :** It is reddened clay rich horizon between basalt flows.
- **Boulder :** A rock fragment with a diameter of more than 256 mm (about the size of a volleyball). A boulder is one size larger than a cobble.
- **Braided stream :** A stream with a complex system of converging and diverging channels separated by bars or islands.
- **Carbonaceous :** Containing carbon.
- **Carbonate mineral :** A mineral formed by the bonding of carbonate ions $(CO_3)_2$ with positive ions. For example: Calcite ($CaCO_3$), Dolomite ($CaMg(CO_3)_2$).
- **Carbonate rock :** A rock composed mostly of carbonate minerals. Examples: Limestone, Dolomite.
- **Cave :** A naturally formed subterranean open area, chamber, or series of chambers, commonly produced in Limestone by solution activity.
- **Cement :** Minerals precipitated from groundwater in the pore spaces of a sedimentary rock and binding the rock particles together.
- **Chert :** A Sedimentary rock composed of granular cryptocrystalline silica.
- **Clastic texture :** The texture of sedimentary rocks consisting of fragmentary particles of minerals, rocks or organic skeletal bound by some cementing material.
- **Clastic :** 1. pertaining to fragments (such as mud, sand, and gravel) produced by the mechanical breakdown of rocks. 2. A sedimentary rock composed chiefly of consolidated clastic material.
- **Clay minerals :** A group of fine-grained crystalline hydrous silicates formed by weathering of minerals, such as, Feldspar, Pyroxene or Amphibole.
- **Clay :** Sedimentary material composed of fragments with a diameter of less than 1/256 mm. Clay particles are smaller than silt particles.
- **Conglomerate :** A coarse-grained sedimentary rock composed of rounded fragments of pebbles, cobbles or boulders.
- **Continent :** A large landmass, from 20 km to 60 km thick, composed mostly of granitic rock. Continents rise abruptly above the deep-ocean floor and include the marginal area submerged beneath sea level. Examples: the African continent, the South American continent.
- **Core :** The central part of Earth below a depth of 2900 Km.
- **Country rock :** A general term for rock surrounding an igneous intrusion.
- **Crater :** An abrupt circular depression formed by extrusion of volcanic material, by collapse or by the impact of a meteorite.
- **Creep :** The imperceptibly slow downslope movement of material.

- **Crevasse :** 1. (glacial geology) a deep crack in the upper surface of a glacier. 2. (Natural levee) A break in a natural levee.
- **Cross-bedding :** Stratification inclined to the original horizontal surface upon which the sediment accumulated. It is produced by deposition on the slope of a dune or sand wave.
- **Crust :** (Planetary structure) the outermost layer or shell of Earth (or any other differentiated planet). Earth's crust is generally defined as the part of Earth above the Mohorovicic discontinuity. It represents less than 1 percent of Earth's total volume. See also continental crust, oceanic crust.
- **Cryosphere :** It is a permanent frozen water part of the Earth system.
- **Crystal form :** The geometric, symmetrical network of atoms within a crystal.
- **Crystal lattice :** A symmetrical three dimensional arrangement of atoms inside the crystal.
- **Crystal :** A solid, polyhedral form bound by naturally formed plane surfaces resulting from growth of a crystal lattice.
- **Crystalline texture :** The orderly arrangement of atoms in a crystal.
- **Cuesta :** An elongate ridge formed on the tilted and eroded edges of gently dipping strata.
- **Debris flow :** The rapid downslope movement of debris (rock, soil and mud).
- **Decomposition :** Weathering by chemical process. Synonymous with chemical weathering.
- **Denudation :** The combined action of all of the various processes that cause the wearing away and lowering of the land, including weathering, mass wasting, stream action, and groundwater activity.
- **Depression :** 1. (structural geology) A circular or elliptical downward. After erosion, the youngest beds are exposed in the central part of the structure. 2. (Topography) a depression into which the surrounding area drains.
- **Detrital :** 1. pertaining to detritus. 2. A rock formed from detritus.
- **Detritus :** A general term for loose rock fragments, produced by mechanical weathering.
- **Diastrophism :** It is large scale deformation at Earth's crust by natural process leading to formation of continuous and oceans through tectonic stresses. It is also called as tectonism.
- **Differential erosion :** Variation in the rate of erosion on different rock masses. As a result of differential erosion, resistant rocks form steep cliffs, whereas non-resistant rocks form gentle slopes.
- **Diorite :** Aphanitic intrusive igneous rock consisting mostly of Plagioclase, Feldspar and Pyroxene, with some Amphibole and Biotite.
- **Discharge :** Rate of flow; the volume of water moving through a given cross section of a stream in a given unit of time.
- **Disintegration :** Weathering by mechanical process. Synonymous with mechanical weathering.
- **Dissolved load :** The part of a stream's load that is carried in solution.
- **Divide :** A ridge or other topographic feature which separates adjacent drainage basins dividing water to flow in opposite directions.
- **Dolomite:** 1. A mineral composed of Ca Mg $(CO_3)^2$. 2. A sedimentary rock composed primarily of the mineral Dolomite.
- **Dolostone :** A sedimentary rock composed mostly of the mineral Dolomite. Sometimes referred to simply as Dolomite.

- **Double refraction :** Optical phenomena exhibited by same minerals especially calcite where light ray enters the crystal and splits up into separate rays.
- **Drainage basin :** The total area that contributes water to a single drainage system.
- **Drainage system :** An integrated system of tributaries and a trunk stream, which collect and funnel surface water to the sea, a lake, or some other body of water.
- **Dyke :** A tabular or sheet like discordant igneous body that cuts vertically or steeply inclined across host rock.
- **Earthquake :** A series of elastic waves propagated in Earth, initiated where stress along a fault exceeds the elastic limit of the rock so that sudden movement occurs along the fault.
- **Ecliptic plane :** An imaginary plane containing the Earth's orbit around the sun.
- **Ecology :** The study of relationships between organisms and their environments.
- **Entrenched meander :** A meander cut into the underlying rock as a result of regional uplift or lowering of the regional base level.
- **Epicentre :** The area on Earth's surface that lies directly above the focus of an Earthquake.
- **Equigranular :** It is a rock characterised by crystal/ mineral at nearly same size.
- **Erosion :** It is the action of surface processes (such as water, wind or ice flow) that removes and transports soil, rock or dissolved material from one location to another on the Earth's surface.
- **Escarpment :** A narrow cliff, with a very steep slope.
- **Esker :** A long, narrow, sinuous ridge of stratified glacial drift deposited by a stream flowing beneath a glacier in a tunnel or in a subglacial streambed.
- **Estuary :** A bay at the mouth of a river, formed by subsidence of the sand or by a rise in sea level. Fresh water from the river mixes with and dilutes seawater in an estuary.
- **Evaporite :** A rock composed of minerals derived from evaporation of minerals, derived from evaporation of mineralized water. Examples: Rock salt, Gypsum.
- **Exposure :** Bedrock not covered with soil or regolith; outcrop.
- **Extrusion :** It is the movement of relatively viscous lava onto the Earth's surface through volcanic activity.
- **Extrusive rock :** A rock formed from a mass of lava that flows out on the surface of Earth. Example: Basalt.
- **Fan :** A fan-shaped deposit of sediment. See also alluvial fan, deep sea fan.
- **Fault block :** A rock mass bounded by faults on at least two sides.
- **Fault scarp :** A cliff produced by faulting.
- **Fault :** A surface along which a rock body has broken and been displaced.
- **Felsic :** Of rocks consisting chiefly of feldspars, felspathoids and quartz having light colour.
- **Ferromagnesian minerals :** A variety of silicate minerals, containing abundant iron and magnesium. Examples: Olivine, Pyroxene, Amphibole.
- **Fissure eruption :** Extrusion of lava along a fissure.
- **Fissures :** It is long narrow opening, cracks, fissures in surrounding rock.
- **Flood Basalt Province :** Flood basalt province is largest eruption of lava on Earth exceeding 2000 cubic volume. It is one type

of large igneous province that characterise the Earth surface formed in geological past.

- **Flood basalt :** An extensive flow of basalt erupted chiefly along fissure. Synonymous with plateau basalt.
- **Floodplain :** The flat, occasionally flooded area bordering a stream.
- **Fluvial Environment :**The sedimentary environment of river systems.
- **Fluvial :** Pertaining to a river or rivers.
- **Focus :** The area within Earth where an Earthquake originates.
- **Foliation :** A planar feature in metamorphic rocks, produced by the secondary growth of minerals. Three major types are recognized: slaty cleavage, schistosity and gneissic layering.
- **Formation :** A distinctive body of rock that serves as a convenient unit for study and mapping.
- **Fossil Fuel :** Fossil fuels (oil, natural gas and coal) are sources of energy that have developed within the Earth over millions of years from plant or animal remains.
- **Fossil :** Naturally preserved remains or evidence of past life, such as; bones, shells, casts, impressions and trails.
- **Gabbro :** A dark-coloured, coarse grained rock composed of Ca-plagioclase, Pyroxene and possibly Olivine, but no Quartz.
- **Gangue :** It is commercially worthless material that surrounds or mixed with a wanted mineral in an ore deposit.
- **Geology :** The Scientific study of origin of Earth rocks, minerals, landforms and life forms and the processes that have affected them over the course of Earth's history.
- **Geomorphic Processes :** A process of physical and chemical changes which affect modification of Earth's landform and natural forces acting upon it to produce landform.
- **Geothermal energy :** It is the thermal energy or heat generated and stored in the Earth.
- **Geothermal Gradient :** It is increase in temperature with increase in depth due to outward heat flow from hot interior.
- **Glass :** 1. a state of matter in which a substance displays many properties of solid but lacks crystal structure. 2. An amorphous igneous rock formed from a rapidly cooling magma.
- **Glassy rock :** It is a rock formed by rapid cooling of lava or magma in which crystallisation does not take place.
- **Glassy texture :** The texture of igneous rocks in which the material is in the form of natural glass rather than crystal.
- **Gneiss :** A coarse-grained metamorphic rock with a characteristic type of foliation (gneissic layering), resulting from alternating layers of light-coloured and dark-coloured minerals. Its composition is generally similar to that of granite.
- **Gneissic Complex :** It is the primordial sialic basement crust along cratonic zones as undergone repeated period of folding and deformation, episode of metamorphism and emplacement of granite.
- **Gondwana land :** An ancient supercontinent of southern hemisphere comprising of landmass like South America, Antarctica, Africa, India and Australia, formed 200Ma
- **Graded bedding :** A type of bedding in which each layer is characterized by a progressive decrease in grain size from the bottom of the bed to the top.
- **Gradient :** (stream) the slope of a stream channel, measured along the course of the stream.

- **Grain :** A particle of a mineral or rock, generally lacking well-developed crystal faces.
- **Granite :** A coarse-grained igneous rock, composed of K-Feldspar and Quartz, with small amounts of ferromagnesian minerals and Plagioclase.
- **Granulation :** It is crushing of mineral and rock by low stress at low temperature along a plane of movement.
- **Groundwater :** Water below Earth's surface. It generally occurs in pore spaces of rocks and soils.
- **Headland :** An extension of land seaward from the general trend of the coast; a promontory, cape or peninsula.
- **Headward erosion :** Extension of a stream headward, up the regional slope of erosion.
- **Horizon :** 1. (geologic) a plane of stratification assumed to have been originally horizontal. 2. (Soil) a layer of soil distinguished by characteristic physical properties, soil horizons generally are designated by letters (for example, a horizon, B. horizon, C. horizon)
- **Hydrosphere :** The waters of Earth, as distinguished from the rocks (lithosphere), the air (atmosphere), and living things, (biosphere).
- **Hydrothermal Deposits :** Concentration of metallic minerals formed by precipitation of soil from hot mineral- laden water by magma (Hydrothermal solutions)
- **Hydrothermal solutions :** a hot water solution originating within the Earth carrying dissolved mineral substances.
- **Ice sheet :** A thick, extensive body of glacial ice that is not confined to valleys. Localized ice sheets are sometimes called ice caps.
- **Ice wedging :** A type of mechanical weathering in which rocks are broken by the expansion of water as it freezes in joints, pores or bedding planes. Synonymous with frost wedging.
- **Igneous rock :** Rock formed by cooling and solidification of molten silicate minerals (magma). Igneous rocks include volcanic hypabyssal and plutonic rocks.
- **Index contour :** A contour line shown on a map in a distinctive manner for ease of identification, being printed more prominently than other contour lines, generally labelled with value along its course.
- **Intermittent stream :** A stream through which water flows only part of the year.
- **Internal drainage :** A drainage system that does not extend to the ocean.
- **Intrusion :** 1. Injection of a magma into a pre-existing rock. 2. A body of rock resulting from the process of intrusion.
- **Intrusive rock :** Igneous rock which, while it was fluid, penetrated into or between other rocks and solidified. It can later be exposed at Earth's surface after erosion of the overlying rock.
- **Isomorph :** Existence of two or more substance in the same crystal form, structure and composition.
- **Island arc :** Long, curved chain of oceanic islands associated with intense volcanic and seismic activity and orogenic processes.
- **Isostasy :** It is the equilibrium (balance) that exists between parts of the Earth's crust like lithosphere floating above Asthenosphere on underlying mantle.
- **Lacustrine :** A sedimentary deposit formed in the base of ancient lakes.
- **Lagoon :** A shallow body of seawater separated from the open ocean by a barrier island or reef.
- **Lava :** Magma that reaches Earth's surface.

- **Levee (natural) :** A broad, low embankment of a river channel during floods.
- **Lithification :** The processes by which sediment is converted into sedimentary rock. These processes include cementation and compaction.
- **Lithosphere :** The relatively rigid outer zone of Earth, which includes the continental crust, the oceanic crust and the part of the mantle lying above the softer asthenosphere.
- **Load :** The total amount of sediment carried at a given time by a stream, glacier or wind.
- **Loess :** Unconsolidated, wind-deposited silt and dust.
- **Longitudinal profile :** The profile of a stream or valley drawn along its length, from source to mouth.
- **Longshore current :** A current in the surf zone moving parallel to the shore. Longshore currents occur where waves strike the shore at an angle. The waves push water and sediment obliquely up the beach, and the backwash returns straight down the beach face, so the water and sediment follow a zigzag pattern, with net movement parallel to the shore.
- **Mafic :** Relating or containing group of dark coloured silicate minerals
- **Magma :** A mobile silicate melt, which can contain suspended crystals and dissolved gases as well as liquid.
- **Magmatic differentiation :** A general term for the various processes by which early-formed crystals or early-formed liquids are separated and removed from a magma to produce a rock with composition different from that of the original magma. Early crystallized ferromagnesian minerals commonly are separated by gravitational settling, so that the parent magma is left enriched in silica, sodium and potassium.
- **Mantle :** The zone of Earth's interior between the base of the crust (the Moho discontinuity) and the core.
- **Marble :** A metamorphic rock consisting mostly of metamorphosed Limestone or Dolomite.
- **Mass movement :** The transfer of rock and soil downslope by direct action of gravity without a flowing medium (such as a river or glacial ice). Synonymous with mass wasting.
- **Matrix :** The relatively fine-grained rock material occupying the space between larger particles in a rock. See also groundmass.
- **Metamorphism :** Alteration of the minerals and textures of a rock by changes in temperature and pressure and by a gain or loss of chemical components.
- **Mineral :** A naturally occurring inorganic solid having a definite internal structure and a definite chemical composition that varies only within strict limits. Chemical composition and internal structure determine its physical properties, including the tendency to assume a particular geometric form (Crystal form).
- **Mohorovicic discontinuity :** The first global seismic discontinuity below the surface of Earth. It lies at a depth varying from about 5 Km to 10 Km beneath the ocean floor to about 35 Km beneath the continents. Commonly referred to as the Moho.
- **Mudflow :** A flowing mixture of mud and water.
- **Natural arch :** An arch-shaped landform produced by weathering and differential erosion.
- **Nebula :** It is a giant interstellar cloud of faintly luminous diffused cloud of dust and gas in space.
- **Neutrons :** It is neutral subatomic particle, which is a constituent of atomic nucleus except hydrogen. It has no electric charge.

- **Nucleons :** It is a collective name for two important subatomic particles, neutrons and protons which are located in the nucleus of atoms.
- **Obsidian :** A glassy igneous rock with a composition equivalent to that of granite.
- **Ocean basin :** A low part of the lithosphere lying between continental masses. The rocks of an ocean basin are mostly basalt with a veneer of oceanic sediment.
- **Orogen :** A belt of the Earth's crust involved in the formation of mountains.
- **Orogenic :** It is a process of mountain formation especially by folding and faulting of the Earth crust.
- **Outcrop :** An exposure of bedrock.
- **Outwash plain :** The area beyond the margins of a glacier where melt water deposits sand, gravel,
- **Outwash :** Stratified sediment washed out from a glacier by melt water streams and deposited in front of the end moraine.
- **Oxidation :** Chemical combination of oxygen with another substance.
- **Pa hoe hoe lava flow :** A type of lava flow whose surface is glassy, smooth, undulating and ropy. (A Hawaiian term), also called ropy lava.
- **Pebble :** A rock fragment with a diameter between 2 mm (about the size of a match head) and 64 mm (about the size of a tennis ball).
- **Pediment :** A gently sloping erosion surface formed at the base of a receding mountain front or cliff. It cuts across bedrock and can be covered with a veneer of sediment. Pediments characteristically form in arid and semiarid climates.
- **Peninsula :** An elongate body of land extending into a body of water.
- **Peridotite :** A dark-coloured igneous rock of coarse-grained texture, composed of olivine, pyroxene and some other ferromagnesian minerals, but with essentially no feldspar and no quartz.
- **Permafrost :** Permanently frozen ground.
- **Physiographic map :** A map showing surface features of Earth.
- **Physiographic :** The study of the surface features and landforms of Earth
- **Plate tectonics :** It deals with the dynamic of Earth's lithosphere to understand mountain building process, volcanoes, Earthquakes, evolution of Earth surface and reconstruction of past continents and oceans.
- **Pleistocene :** An epoch of Quaternary period representing the time between 2.6myto 11700 years ago.
- **Plucking (glacial geology) :** The process of glacial erosion by which large rock fragments are loosened by ice wedging, become frozen to the bottom surface of the glacier, and are torn out of the bedrock and transported by the glacier as it moves. The process involves the freezing of subglacial meltwater that seeps into fractures and bedding planes in the rock.
- **Point bar :** A crescent-shaped accumulation of sand and gravel deposited on the inside of a meander bend.
- **Pore space :** The spaces within a rock body that are unoccupied by any matter.
- **Porosity :** The percentage of the total volume of a rock or sediment that consists of pore space.
- **Pothole :** A hole formed in a stream bed by sand and gravel swirled around in one spot by eddies.
- **Protons :** It is a subatomic particle found in the nucleolus of an atom. It has positive electrical charge equal and opposite to that of electron. Number of protons is called atomic number.

- **Protostar :** An early stage in the evolution of a star after the beginning of the collapse of gas cloud but before contraction.
- **Pumice :** A rock consisting of frothy natural glass.
- **Pyrogenetic Minerals :** Mineral which are crystallised from a completely or almost completely unhydrous magma.
- **Radiogenic heat :** Heat generated by radioactivity.
- **Radiometric dating :** Determination of the age in years of a rock or mineral by measuring the proportions of an original radioactive material and its decay product. Synonymous with radioactive dating.
- **Recessional moraine :** A ridge of till deposited at the margin of a glacier during a period of temporary / stability in its general recession.
- **Recrystallisation :** Reorganization of elements of the original minerals in a rock resulting from changes in temperature and pressure and from the activity of pore fluids.
- **Red bole beds :** Interbasaltic clay occuring in the volcanic terrain.
- **Regolith :** The blanket of soil and loose rock fragments overlying the bedrock.
- **Rejuvenated stream :** A stream that has had its erosive power renewed by uplift or lowering of the base level or by climatic changes.
- **Relief :** The difference in altitude between the high and the low parts of an area.
- **Rhyolite :** A fine-grained volcanic rock composed of Quartz, K-Feldspar, and small amount of Plagioclase. It is the extrusive equivalent of Granite.
- **Rift valley :** 1. a valley of regional extent formed by block faulting in which tensional stresses tend to pull the crust apart. Synonymous with graben. 2. The down dropped block along divergent plate margins.
- **Ripple marks :** Small waves produced on a surface of sand or mud by the drag of wind or water moving over it.
- **River system :** A river with all of its tributaries.
- **Roche moutonnée :** An abraded knob of bedrock formed by an overriding glacier. It typically is striated and has a gentle slope facing the upstream direction of ice movement.
- **Saltation :** The transportation of particles in a current of wind or water by a series of bouncing movements.
- **Sand :** Sedimentary material composed of fragments ranging in diameter from 0.0625 mm to 2 mm. Sand particle is larger than silt particle but smaller than gravel. Much sand is composed of quartz grains, because quartz is abundant and resists chemical and mechanical disintegration, but other materials, such as, shell fragments and rock fragments can also form sand.
- **Sandstone :** A sedimentary rock composed mostly of sand-size particles, usually cemented by calcite, silica, or iron oxide.
- **Scarp :** A cliff produced by faulting or erosion.
- **Shingle :** A mass of small rounded pebbles, specially on a sea shore.
- **Schist :** A medium-grained or coarse grained metamorphic rock with strong foliation
- **Schistosity :** The type of foliation that characterizes schist, resulting from the parallel arrangement of coarse-grained platy minerals, such as, Mica, Chlorite and Talc.
- **Shore :** The zone between the water line at high tide and the waterline at low tide. A narrow strip of land immediately bordering a body of water, especially a lake or an ocean.

- **Sill :** A tabular body of intrusive rock injected between layers of the enclosing rock.
- **Sinkhole :** A depression formed by the collapse of a cavern roof.
- **Snowline :** An altitude of a given area above which the land is permanently covered by snow.
- **Solumn :** Upper part of soil profile which is influenced by plant root, A- horizon, B- horizon.
- **Sorting :** The separation of particles according to size, shape, or weight. It occurs during transportation by running water or wind.
- **Spit :** A sandy bar projecting from the mainland into open water. Spits are formed by deposition of sediment moved by longshore drift.
- **Splay :** A small deltaic, deposit formed on a floodplain where water and sediment are diverted from the main stream through a crevasse in a levee.
- **Spring :** A place where groundwater flows or seeps naturally to the surface.
- **Stellar :** Relating to stars or star-like.
- **Stream load :** The total amount of sediment carried by a stream at a given time.
- **Striation :** A scratch or groove produced on the surface of a rock by a geologic agent, such as a glacier or stream.
- **Subaerial :** Occurring beneath the atmosphere or in the open air, with reference to conditions or processes (such as erosion) that occur on the land. Contrast with submarine and subterranean.
- **Subduction zone :** A geologic process in which one edge of one crustal plate is forced below the edge of another.
- **Suspended load :** The part of a stream's load that is carried in suspension for a considerable period of time without contact with the stream bed. It consists mainly of mud, silt and sand. Contrast with bedload and dissolved load.
- **Swash :** The rush of water up onto a beach after a wave breaks.
- **Talus :** Rock fragments that accumulate in a pile at the base of a ridge or cliff.
- **Terrace :** A nearly level surface bordering a steeper slope, such as, a stream terrace or wave-cut terrace.
- **Texture :** The size, shape, and arrangement of the particles that make up a rock.
- **Tidal flat :** A large, nearly horizontal area of land covered with water at high tide and exposed to the air at low tide. Tidal flats consist of fine-grained sediment (mostly mud, silt and sand).
- **Till :** Unsorted and unstratified glacial deposit.
- **Tillite :** A rock formed by lithification of glacial till (unsorted, unstratified glacial sediment).
- **Turbulent flow :** A type of flow in which the path of motion is very irregular, with eddies and swirls.
- **Unconformity :** A structure between successive rocks representing a missing interval in geologic record, produce by interruption in deposition or erosion.
- **Veins :** An epigenetic filling of minerals in fault, fracture, cracks, features in surrounding rocks.
- **Vesicle :** A small hole formed in a volcanic rock by a gas bubble that became trapped as the lava solidified.
- **Volatile :** 1. Capable of being readily vaporized. 2. A substance that can readily be vaporized, such as; water or carbon dioxide.

◈◈◈

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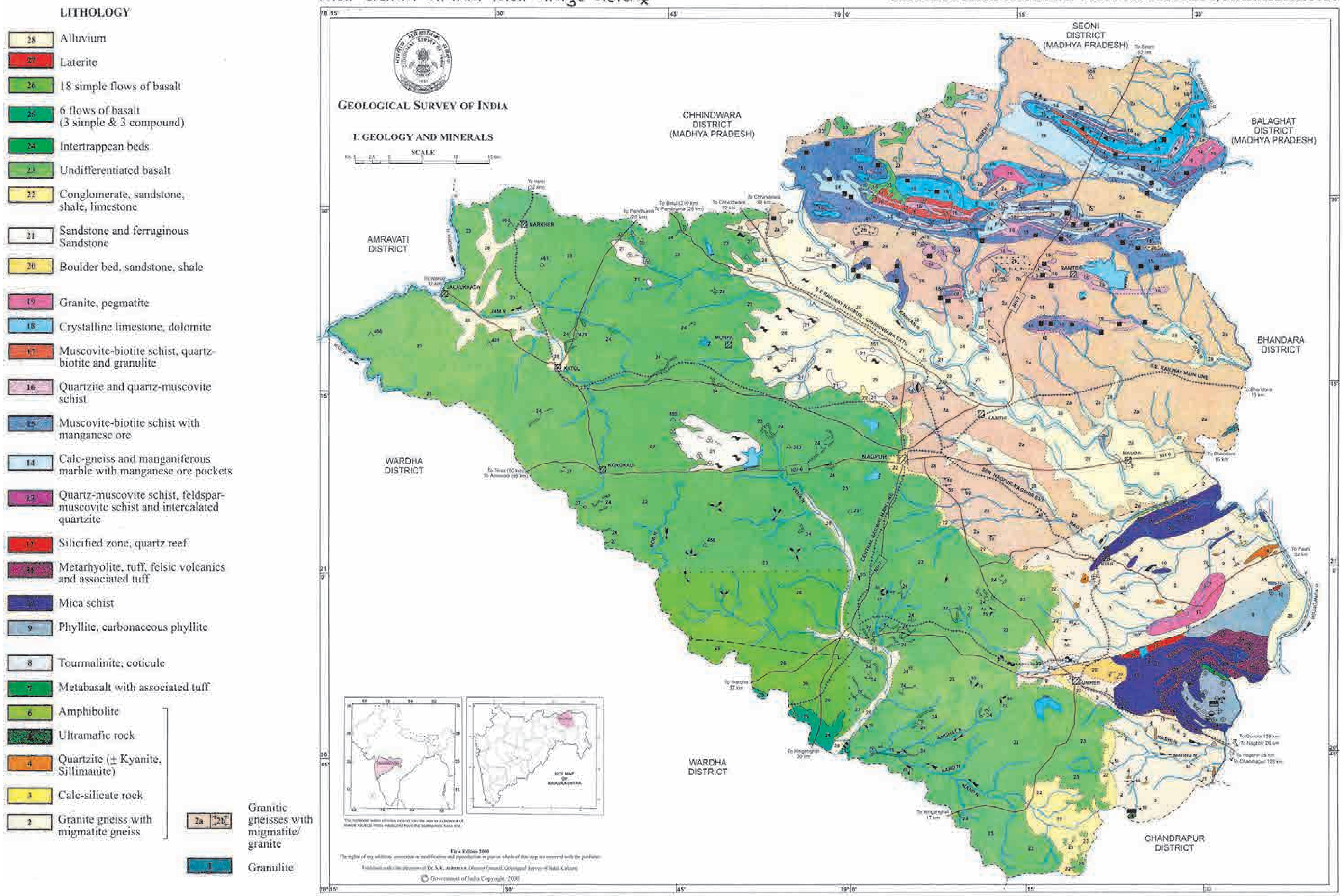
NOTES

जिला संसाधन मानचित्र–जिला नागपुर महाराष्ट्र

DISTRICT RESOURCE MAP NAGPUR DISTRICT, MAHARASHTRA



DRM based practicals :

Answer the following questions :

Geomorphology (map II) :

1) Name two localities of valley filled deposits.
2) Name the locality situated in highly dissected area near a dam-site.
3) Name the main river along with it's tributaries.
4) Identify the flow directions of river.
5) Name two towns located near palaeo-channels.
6) Mention the number of dam sites. Name the nearest village/town near the dam sites.

Geohydrology (map III) :

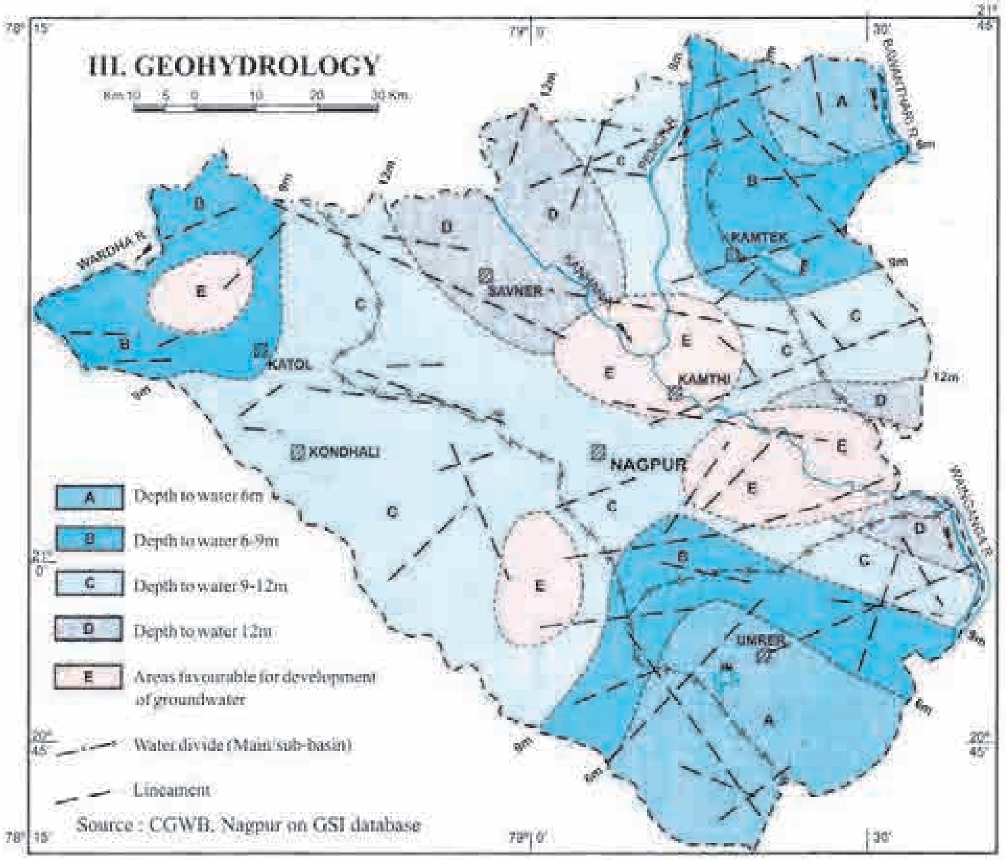
1) Identify and mark the water-divides.
2) Name the town most favourable for groundwater development.
3) At what depths can groundwater be encountered in following towns:
   a) Nagpur b) Umrer c) Savner d) Ramtek
4) Identify the towns with shallower groundwater.
   a) Nagpur and Savner b) Katol and Nagpur
   c) Savner and Ramtek d) Kondhali and Umrer
5) Identify and describe whether the river flow is controlled structurally.

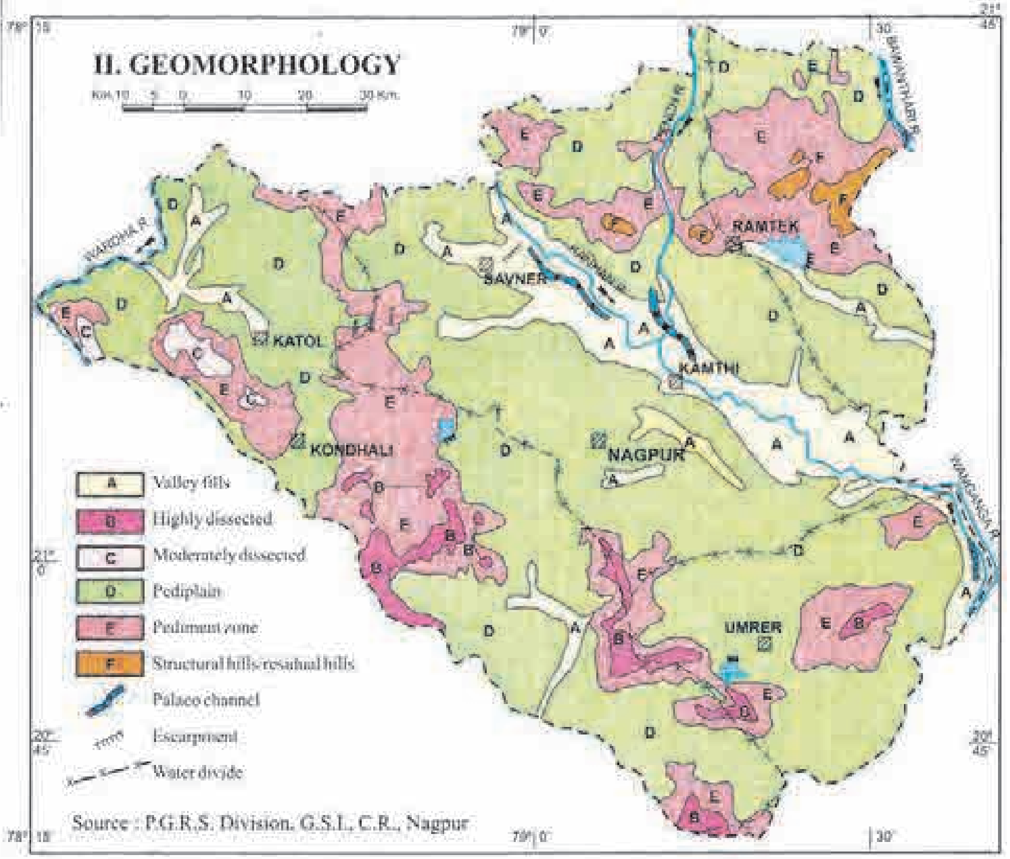
Geotechnical and natural hazards (map IV) :

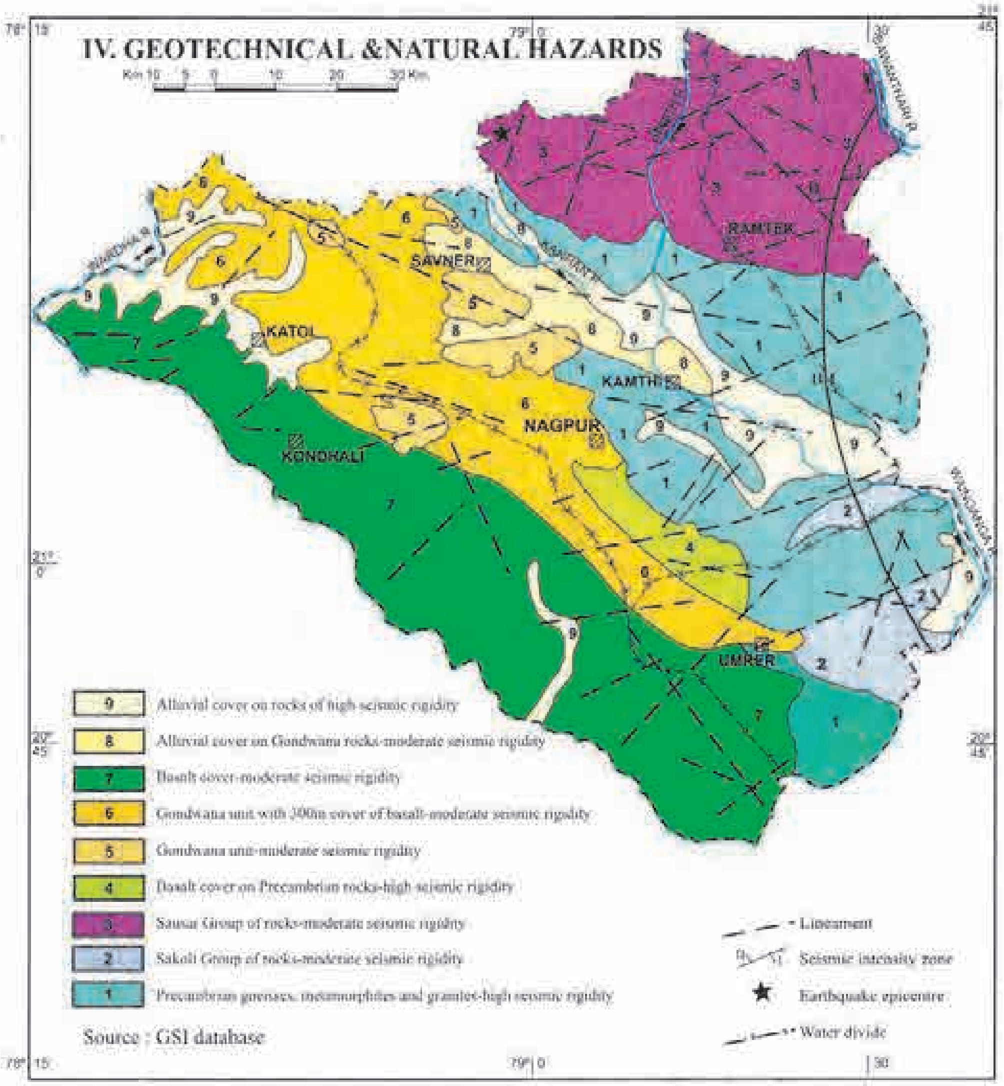
1) What is the average trend of lineaments?
2) For which towns will you recommend anti-seismic civil engineering structures?
3) Identify the town located in a dangerous zone with reference to earthquakes from the following pairs :
   a) Ramtek and Nagpur b) Kamthi and Kondhali
   c) Ramtek and Kamthi d) Savner and Kamthi
4) In which direction and at what distance is an earthquake epicentre located from Savner and Ramtek

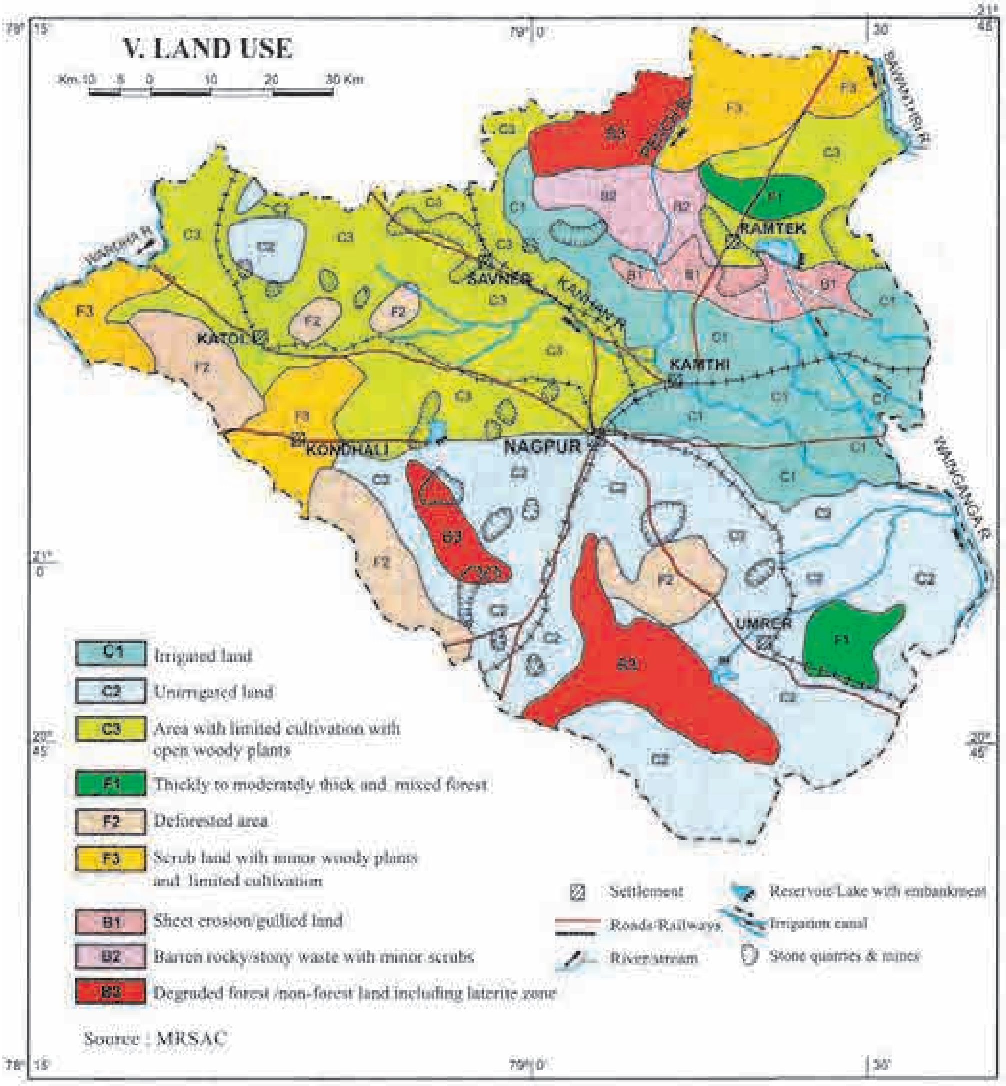
Land-use (map V) :

1) Name the towns which have mixed forest cover near Ramtek and Umrer
2) Identify the land use pattern around the following towns;
   Kamthi :
   Nagpur :
   Katol :
   Kondhali :
   Savner/Ramtek :
3) Give the location of sheet erosion and gullied land.









Philatellic mineralogy and mineral nomenclature

Agricola Georgius (1494-1555), a German scholar and scientist is considered as the 'Father of Mineralogy'.

The first stamp on a mineral was issued by Newfoundland in 1897, which features mineral Ice.

Colombia issued this stamp on Gold in 1932

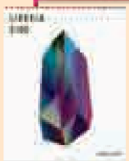
Named after Person

Prehnite
$Ca_2Al_2Si_3O_{12}(OH)_2$

Dolomite
$CaMg(CO_3)_2$

Smithsonite
$ZnCO_3$

Named after Place



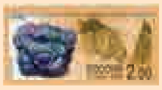
Tanzanite
$Ca_2Al_3(Si_2O_7)(SiO_4)\ O(OH)_2$

Copper Cu

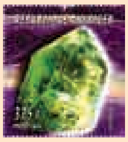
Muscovite
$KAl_2(AlSi_3O_{10})(F,OH)_2$

Named after Colour

Rhodochrosite
$MnCO_3$

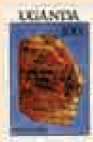


Hematite
Fe_2O_3



Olivine
$(Mg,Fe)_2SiO_4$

Named after Form



Monazite
$(Ce, La, Nd, Th)(PO_4SiO_4)$

Anatase - TiO_2

Epidote
$Ca_2(Fe^{+3}Al_2)(Si_2O_7)(SiO_4)O(OH)$

Named after Chemical Composition

Mesolite
$Na_2Ca_2Si_9Al_6O_{30}.8H_2O$

Cavansite
$Ca(VO)Si_4O_{10}.4H_2O$

Calcite
$CaCO_3$

Named after Cleavage

Dioptase
$CuSiO_3.H_2O$

Orthoclase
$KAlSi_3O_8$

Euclase
$BeAl(SiO_4)(OH)$

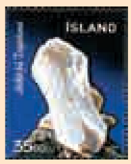
Named after Other Physical Properties

Diamond
C
(Hardness)

Analcime
$Na_2(Al_2Si_4O_{12}).2H_2O$
(Electricity)

Barite
$BaSO_4$
(Sp. gravity)

Magnetite
Fe_3O_4
(Magnetism)



Stilbite
$(Na,Ca)_4(Si,Al)_{18}O_{36}.12H_2O$
(Lustre)

Named after Sanskrit Words

Corundum
Al_2O_3

Opal
$SiO_2.nH_2O$

Maharashtra State Bureau of Textbook Production and Curriculum Research, Pune.

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