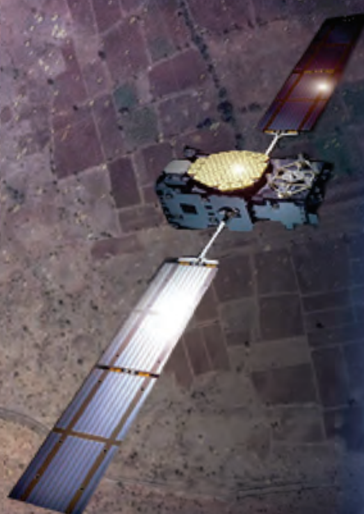
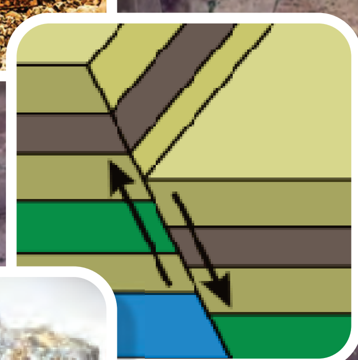
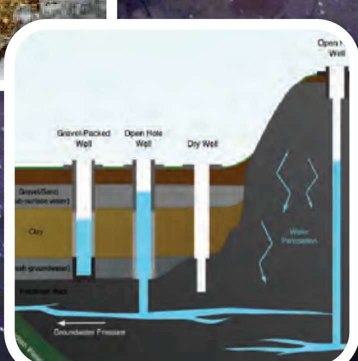
EARTH'S DYNAMICS







GEOLOGY

STANDARD TWELVE

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 30.1.2020 and it has been decided to implement it from academic year 2020-21.

GEOLOGY

STANDARD TWELVE

N8P5X4

Download DIKSHA App on your smartphone. If you scan the Q.R. Code on this page of your textbook, you will be able to access full text and the audio-visual study material relevant to each lesson provided as teaching and learning aids.

2020

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

First Edition : 2020

Third Reprint : 2022

Geology Subject Committee :

Dr. N. J. Pawar (Chairperson), Pune

Dr. Satish Jagdeo Sangode, Pune

Mrs. Suneeti J. Malik, Pune

Dr. Sudhakar Janardan Pandit, Pune

Shri Ajit Vaman Vartak, Pune

Shri Abhijit Jaysingrao Patil, Kolhapur

Shri R. J. Jadhav, Member-Secretary

Geology Study Group :

Dr. Hrishikesh Samant, Mumbai

Dr. Ashwini Supekar Ganjave, Pune

Dr. Dipak Panaskar, Nanded

Mr. Arun Keshav Khadilkar, Solapur

Dr. Vinay Madhusudan Dikshit, Solapur

Illustrations : Bhatu Bagale

Cover : Ganesh S. Dhavale

Typesetting : DTP Section, Textbook Bureau, Pune

Paper : 70 GSM Creamwove

Print Order : N/PB/2022-23/1,000

Printer : RUNA GRAPHICS, PUNE

Production

Shri Sachchitanand Aphale
Chief Production Officer

Shri Prasant Harne
Production Officer

Publisher

Shri Vivek Uttam Gosavi
Controller
Maharashtra State Textbook Bureau, Prabhadevi, Mumbai - 400 025

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,

Heartfelt congratulations and welcome to standard XII !

Your study of the geology so far, has enriched you with knowledge about the fascinating world of minerals, formed on and within our planet earth, the processes that lead to their formation and to the creation and evolution of the magnificent landforms from the lofty Himalayas to the deep ocean trenches. In your previous studies of the subject, as a part of geography during your school years and as a separate subject of geology in your XI standard, you have been introduced to the basic ideas about the various geological processes.

This new edition of the book presents an extended view of the subject from an earth and planetary sciences point of view. The various applied aspects of the subject of geology have been presented to interesting and thought provoking writings on hydrogeology, economic mineral deposits and geohazards. The science of data collection and interpretation of satellite data has also been introduced. It gives me immense satisfaction and pleasure to present this new edition of class XII text book.

Just like the XI standard text book, this book too is an accessible and comprehensive guide to the important topics in geology, more so from an applied science point of view. The topics are illustrated with examples and case studies from India in general and the state of Maharashtra in particular. The book also includes numerous thought provoking activities and questions.

Studying and understanding the dynamics of our planet, its resources, even the play of internal forces and surface atmospheric phenomena which sometimes cause loss of human lives and property, will surely lead to the formation of an aware and sensitive citizen, who is equipped to work towards the betterment of the planet. You are encouraged to use the QR code and links given within the text for achieving a better understanding the various topics. This book is sure to cause many students to take up earth science as a lifelong career.

(Vivek Gosavi)
Director
Maharashtra State Bureau of Textbook
Production and Curriculum Research, Pune

Pune
Date: 21 February 2020
Bhartiya Saur : 2 Phalguna 1941

STD. XII Geology

Learning Outcomes

- The goal of this book is to introduce students with fundamental knowledge of diverse applied fields in geology like hydrogeology, palaeontology, stratigraphy, petrology, geohazards and structural geology and remote sensing.
- In addition, the analytical exercises incorporated within the text will imbibe the habit of scientific and analytical thinking in the learner.
- Understand the origin and classification of the common rocks found on the earth's surface.
- Know the processes involved in the formation of various surface landforms due to the interaction of the earths internal forces with the crustal layers.
- Identify the common rocks and their underlying processes of formation.
- Understand the science of palaeontology and fossil formation.
- 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 structures.
- Communicate observations and interpretation in a geological report.

- For Teachers -

You have been teaching Earth sciences in general and geology specifically, and as experienced mentors, we all know that the subject of Geology is interdisciplinary and hence teaching Geology is a challenging task that needs integration of both theoretical and practical aspects. As the field of Earth sciences has seen a continuous evolution in the accepted theories and due to the improved technologies, leading to better understanding of natural phenomena, the need to update and upgrade the first edition of the book published in 2012 was felt necessary. In this context, following guidelines should be strictly adhered to, 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.
- It is expected that the teacher and student is well versed with the topics and subject matter dealt with in the new edition of the Std. XI textbook, published in 2019.
- 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 a hurry.
- Major concepts of geology are complex and need deep understanding. 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.
- USE the highlighted boxed in texts titled 'Do you know?' for adding value and joy to the process of understanding the subject.
- The contents of 'DO You Know?' are NOT to be used 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.
- 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 : A mosaic depicting various chapters as well as the dynamic nature of our planet Earth.

Back Page : Calcite (nail head spar) on fine quartz crystals. Location Chandivli quarries, Mumbai, Maharashtra
Dimensions : 6.5cm × 2.5cm × 4.0cm,
Green Apophyllite - Location: Pashan quarries, Pune, Maharashtra, India.
Dimensions: 2.5cm × 2.0cm × 1.5cm

Acknowledgement : Back page photos by Mr. Arnav Samant

1 The Dynamic Earth

Introduction :

Away from the bustling noise of crowded cities or man-made activities; the Earth appears like a stable, calm and peaceful planet in tranquillity of nature. It is however a highly dynamic planet similar to all other planets in the Solar system; and is orbiting around the Sun at ~30 km/s. It is also internally dynamic, as evident from the phenomena of plate tectonics operating through geological ages. The Earth on its surface is undergoing many dynamic processes as expressed by the activity of oceans, rivers, glaciers, winds and atmospheric circulation. We can distinguish the Earth's dynamism into: a) the orbital or planetary dynamics; b) the surface dynamics or Earth surface processes; and c) the internal dynamics as part of the evolution of the Earth. This chapter describes the internal dynamics of the Earth. It is therefore, necessary to learn about the internal structure/interior of the Earth in order to understand its expression on the surface by the processes such as plate tectonics.

The Interior of the Earth :

The Earth evolved as a planet from Solar nebula at about 4.56 Ga, and gradually shaped into a spherical body (fig.1.1). With the ongoing cooling, the outermost layer called the crust was formed. The temperature of the universe is of the order of -270 °C, and the Earth's interior is at >4000 °C. Presently the average surface temperature of the Earth is 14°C - 15°C, and the temperature at the core of the Earth is 6000 °C. This results in temperature gradient with the Earth's interior. This temperature gradient of the Earth is however not linear and shows several kinks that are influenced by the compositional layering (fig. 1.2). The heat loss occurs by processes such as conduction, convection and advection. Whereas, the heat generated is mainly in the form of the primordial heat accrued during the formation of the planet. Convection and advection being physical processes, the Earth material in the form of magma is simultaneously undergoing differentiation and mixing to cause depletion of original magma that was available during the early part of planetary evolution. Convection plays a major role in driving the plates, (fig. 1.2, 1.3) while advection gives rise to formation of ocean floor and other events like lava eruption on the surface.

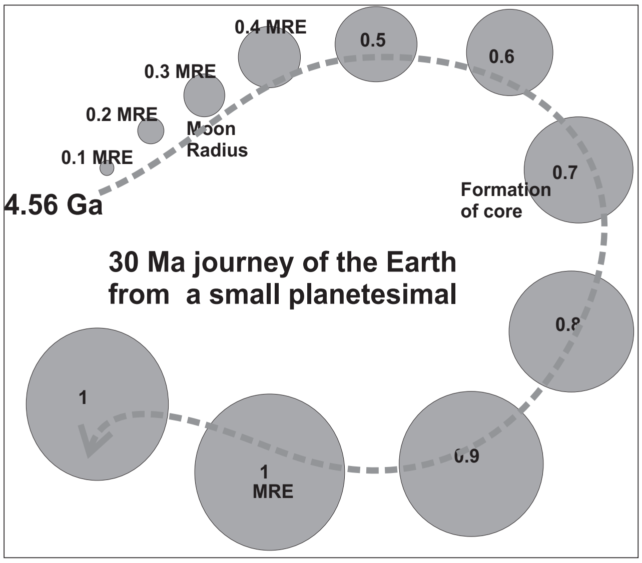


Fig. 1.1 : Evolution of the Earth from a planetismal state

Formation of the Earth from an asteroid like body to a spherically layered Earth system at ~4.53 Ga is one of the most dynamic internal process the Earth has experienced in its early stage of evolution. Note the step-wise differentiation particularly at 0.3 MRE (mean radius of the Earth), initiation of magma oceans at ~0.5 MRE and segregation of the core at 0.7 MRE (fig 1.1). The overall size of the planet is increased because of addition of mass as the Earth cleared its own orbit.

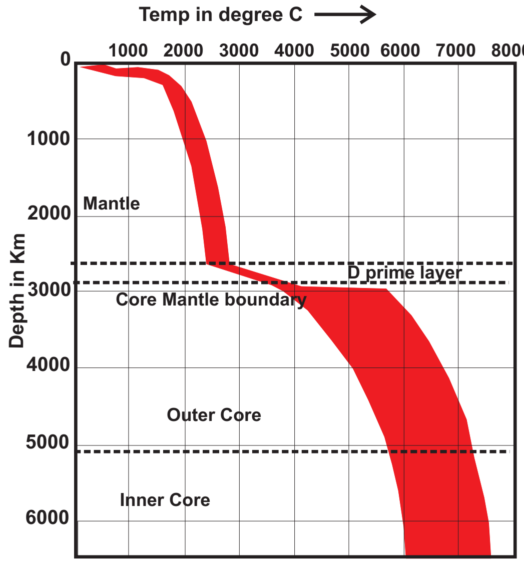


Fig. 1.2 : Internal layering of the Earth

Earth comprises mainly of silicate compounds (minerals) having definite crystal structures and compositions that remain stable at particular pressure (P) and temperature (T) conditions of the molten magma to solid rocks. Molten magma is dynamic and experiences changing Pressure - Temperature (P-T) conditions due to its upward/downward movement (convection and advection). Change in temperature with depth is influenced by the convection current that governs physical movement of the magma.

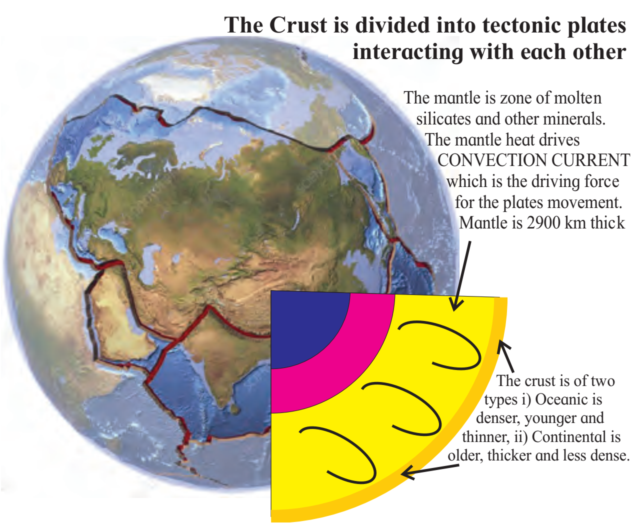


Fig. 1.3 : Convection current governing the surface dynamics of the Earth

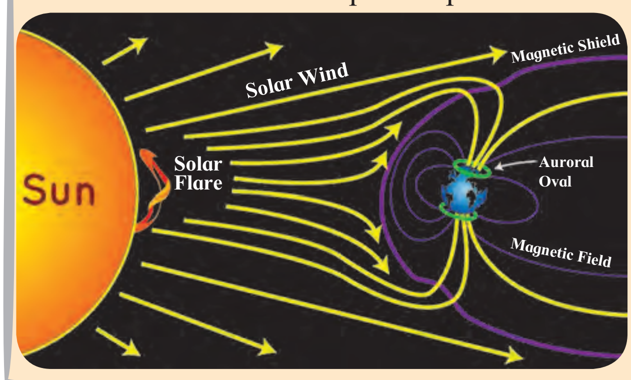
Convection also facilitates differentiation of magma compounds, where heavier melt (compounds) sink deeper into the Earth. This process facilitates layering of the Earth where compositional and temperature stabilities are achieved. These processes were more dynamic during the initial phase of evolution of the Earth. Heavier elements like Fe and Ni sank towards the center of gravity of the Earth forming the inner core.

A) The Core:

Core is divided into inner and outer core as a result of P-T stability conditions of Fe-Ni compounds wherein P increases the melting point of Fe-Ni compounds making the inner core to remain solid. Lowering of the Pressure at about 5100 km results in melting of Fe-Ni matter to produce the liquid outer core. The outer core being liquid, is therefore more dynamic and the convection currents created are supposed to generate the Earth's magnetic field.Information about the core is obtained indirectly from seismology.

Do you know?

The magnetic field generated by the Earth's core, protects it's surface from the solar winds that are high energy electromagnetic radiations, of potentially harmfully charged particles. Without the magnetic field, the Earth would be an inhospitable planet.



Inner Core :

The temperature at the centre of the Earth reaches upto ~ 6,000°C and is largely considered to be the heat left over after the planet's creation (primordial heat), apart from other sources like heat generated by radioactive decay. Inner core is ~1,200 km thick, and is about the same size as the Earth's moon. Due to the tremendous pressure, material in the core does not melt and hence it remains solid.

The Outer Core :

The outer core is ~2,200 km thick. Density of the outer core is about 10 -12 gm/cc. The temperature in the outer core ranges from 2,200°C to 4,900°C. The molten material comprises mostly of iron with little nickel. About 10% of it is made up of other elements, most likely oxygen and sulphur.

Discontinuities are layered boundaries in the interior of the Earth discovered through seismic studies.

Boundary between inner core and outer core is named as Lehmann discontinuity after its discovery by the Danish seismologist Inge Lehmann (fig. 1.4).

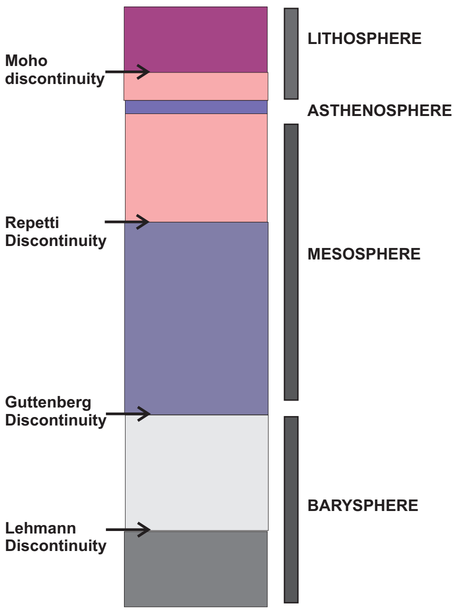


Fig. 1.4 : Discontinuities in the interior of the Earth

B) The Mantle :

Earth's Mantle has a thickness of about 2900 kms. It is the most important layer governing the geodynamic processes of the Earth. Mantle is divided into upper (~640 kms) and lower mantle (~2200 kms).

Lower mantle : It is more viscous than the upper mantle and it convects slowly. It is known to have temperatures as high as 2,200°C. Lower mantle compositionally contains magnesium, silicon and oxygen with small amounts of iron, calcium, and aluminium to forms a typical mineral known as perovskite ($MgSiO_3$).

Upper mantle : The upper mantle consists of two different types of layers, namely lithosphere and the asthenosphere. The rigid lithosphere is composed of a rocky crust that is ~40 kms to 280 km thick and floats on top of the asthenosphere. Asthenosphere is ~180 km thick with temperature as high as ~1,450°C. Asthenosphere is less rigid than the lithosphere and behaves plastically. Lithosphere mainly represents the rock composition known as peridotites, which contains the mineral olivine and pyroxene. Peridotites are heavier than most of the crustal rocks and therefore they tend to sink into the upper mantle.

The Crust :

The Crust is brittle and most fragile outermost layer of the Earth and is the main source of earthquakes. It represents mountains, ocean floor and all the landforms and is part of lithosphere. Crust under the oceans is thin, measuring 5 to 10 km and under land is between 20 and 70 km. It is therefore, divided into two types: oceanic crust and continental crust.

The oceanic crust found beneath the oceans is composed of basalt, while the continental crust is largely made up of granites. However, a large part of the continental crust is eroded and transferred to the ocean basins in the form of sediments which can later be recycled along with the oceanic crust. Rocks as old as 3.8 Ga can be found on the continental crusts; and are the source of information for the geodynamic history of the Earth. Continents are therefore a rich source of knowledge about the evolution of the Earth.

Earliest impressions of the dynamics of the Earth were philosophically routed and several hypothesis were proposed. It was during the early 17th century that the dynamics of the Earth were understood from geological records. As discussed and hypothesized by many philosophers and geologists during the 17th century, continents are floating over the asthenosphere making the continental/ lithospheric plates. The most acceptable explanation of these observations has been offered by the theory of 'Continental Drift'.

The Continental Drift Theory:

Internal dynamics of the Earth is expressed by changes on its surface i.e., the crust. For over a long time, humans were unable to explain the origin of various surface features of the Earth, and it was during early 17^{th} Century when the geological idea of continental drift evolved as a hypothesis and a school of thought. It faced many criticisms due to imagination and limitations to explain the driving forces. This was also due to the state of knowledge of science and technology until the advent of geophysics (particularly seismology and magnetism) during the nineteenth century. However, the continental drift is the basic theory which evolved the concept of plate tectonics, a revolution in geology. It is therefore necessary to learn both these aspects in detail which are pivotal to understand many of different subjects within the scope of Geology.

Do you know?

The theories of continental drift and plate tectonics are evolved over four centuries as accounted in the time line below :

1620 Francis Bacon noted 'conformable instances' along the opposite sides of the mapped Atlantic coastlines.

1858 Antonio Snider-Pellegrini suggested that 'the continents were linked during Carboniferous Period'. He observed that plant fossils in coal-bearing strata of that age were similar in both Europe and North America.

1885 The famous Austrian geologist Edward Seuss identified similarities between plant fossils from South America, India, Australia, Africa and Antarctica to suggest the name 'Gondwana' (after the indigenous homeland of the Gond people of India). He defined it as an ancient supercontinent 'Gondwana Land' surrounded by the ancient ocean named 'Tethys'.

1910 American physicist and glaciologist Frank Bursley Taylor proposed the concept of 'continental drift' to explain the apparent geological continuity of the American Appalachian mountain belt (extending from Alabama to Newfoundland) with the Caledonian Mountains of NW Europe (Scotland and Scandinavia), occurring on two opposite sides of the Atlantic Ocean.

1912 Alfred Wegener, the German meteorologist who spent his entire life to gather evidences re-proposed the theory of continental drift. He compiled a considerable amount of data, and suggested that during the late Permian, all the continents were once assembled into a supercontinent named 'Pangaea', meaning all Earth. Pangaea began to break apart after the beginning of the Mesozoic Era, about 200 Ma ago, and continents then slowly drifted into their current positions.

1937 South African geologist Alexander du Toit supported to the theory by drawing maps illustrating a northern supercontinent called Laurasia (i.e. the assembled land mass of North America, Greenland, Europe and Asia) as explanation for distribution of coal-forming plants, and widely scattered coal deposits in the Northern Hemisphere.

1944 Wegener's theory was also consistently promoted by an eminent British geologist and geomorphologist Arthur Holmes in 1930s and 1940s, through his renowned book 'Principles of Physical Geology'.

1940–1960 The ocean floor topography was discovered through improvements in geophysical surveying after World War II. Harry Hess (captain in the US Navy, later professor at Princeton), proposed 'Seafloor Spreading', a pivotal concept to continental drift and plate tectonics

1961 The American geologists Robert Dietz, Bruce Heezen and Harry Hess proposed that the linear volcanic chains called mid-ocean ridges in the ocean basins are the sites of ocean floor spreading.

1963 Two British geologists, Fred Vine and Drummond Matthews, finally proposed a hypothesis that convincingly explained magnetic reversal stripes onto the ocean floor. They suggested that the new oceanic crust formed in the process of ocean floor spreading acquired its magnetisation in the prevailing global magnetic field. By linking these observations to Hess's sea-floor spreading model, they laid the most convincing foundation and proof for modern plate tectonics.

1965 Canadian Professor J. Tuzo Wilson offered a fundamental reinterpretation of Wegener's continental drift theory and became the first person to use the term 'plates' to describe the division and pattern of relative movement between different regions of the Earth's surface (i.e. plate tectonics).

1960s - Present day. There was an increasingly wide acceptance of the theory of plate tectonics gaining a better understanding of the boundaries and structure of the lithospheric plates, with several modern tools of approach.

Continental Drift Theory :

Alfred Wegener proposed this theory in 1915 published in a book entitled 'The Origin of Continents and Oceans'. He proposed the existence of Supercontinent called Pangaea that began breaking apart about 200 million years ago (fig. 1.5).

Fig. 1.5 : Reconstruction of the supercontinent Pangea

He further gathered various evidences to prove that the Continents were drifted to present positions. The evidences used in support of continental drift hypothesis are shown in (fig. 1.6): A) Fit of the continents, B) Fossil similarities across continents, C) Matching of mountain ranges on different continents, D) Rock types, structural similarities and E) Paleoclimate evidences.

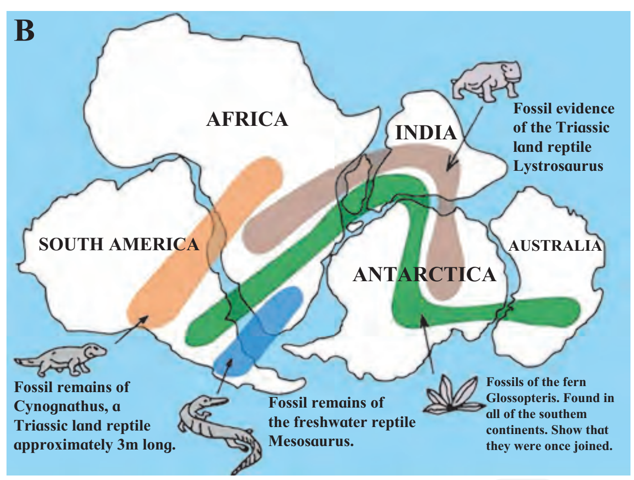


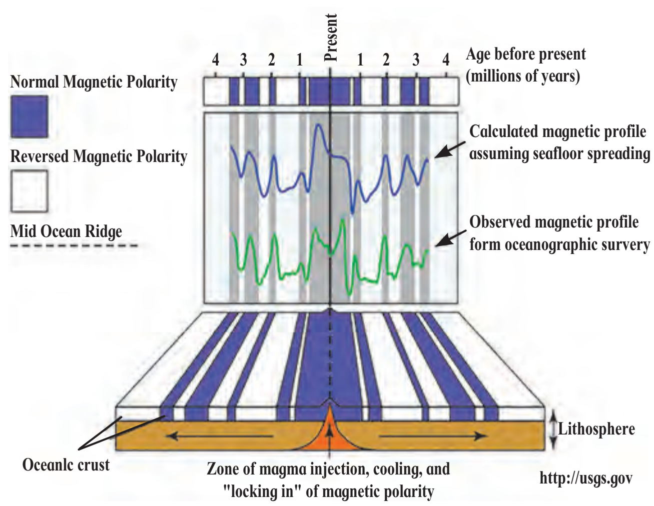
Fig 1.6 : (A-E). Various evidences as foundation to the theory of continental drift

Major objection against the theory of continental drift was its inability to provide a mechanism capable of moving continents across the globe. Wegener drift theory suggests that, continents broke through the ocean crust, much like ice breakers cut through ice was not convincing. The renewed interest in continental drift was supported by the ocean floor magnetic anomalies and the apparent polar wandering. Records from ocean floor also explained the driving mechanism and forces. This encompassed the foundation to another great theory called Plate tectonics.

Plate Tectonics :

During the 1950's and 1960's new technology permitted extensive mapping of the ocean floor which mainly benefited the geoscience community to refine the continental drift with scientific evidences. In 1963, Fred Vine and D. Matthews linked the discovery of magnetic stripes in the ocean crust near ridges to Hess's concept of seafloor spreading. They revealed that the ridges were spreading and creating new crusts (fig. 1.7); and if dated they can find the rate of sea floor spreading. These rates of seafloor spreading are accurate to the drifting of adjoining continents.

FORMATION OF MAGNETIC ANOMALIES AT A MID-OCEAN RIDGE



Enduring Resources for Earth Science Education - http://earthref.org/ERESE
http://earthref.org/cgi-bin/erda.cgi?n=212

Fig. 1.7 : Symmetry of anomaly pattern with respect to ridge depicting the centre of spreading in opposite direction

Plates are well defined by belts of seismicity e.g. linear pattern of earthquake. Earthquakes are generated as the plates interact. Thus all the plates on the globe are interacting with each other (fig. 1.8)

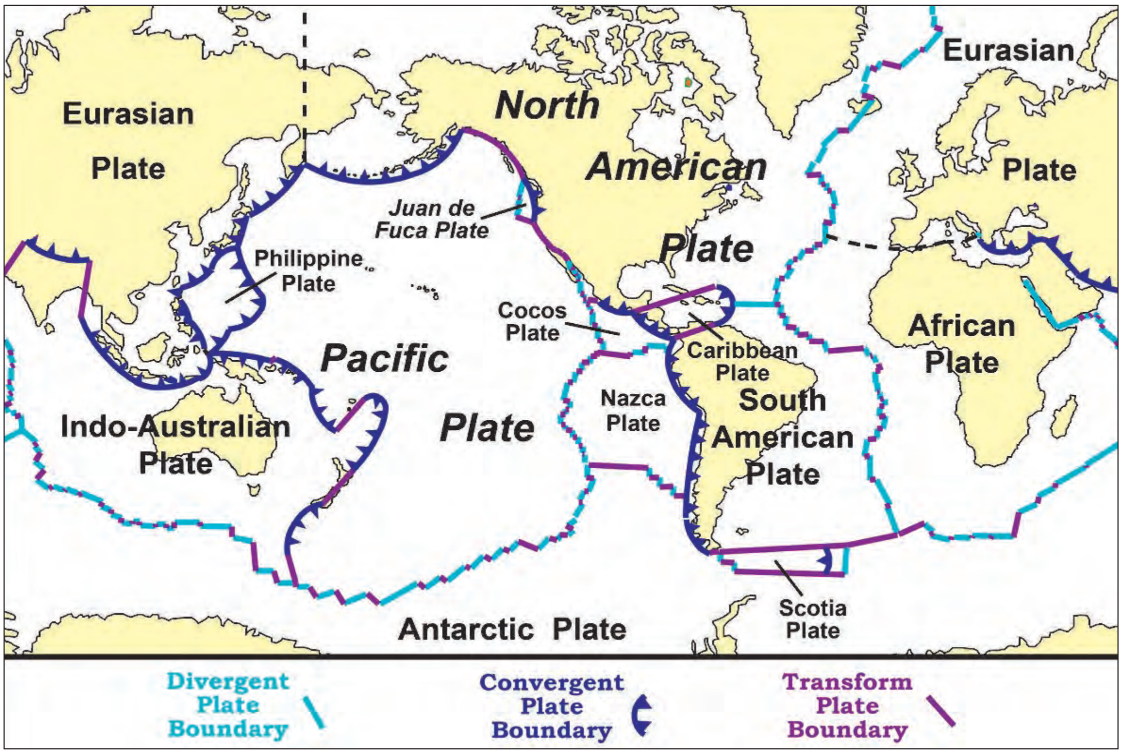


Fig. 1.8 : Major Lithospheric plates on the globe

Plate boundaries :

All major interactions among individual plates occur along their boundaries that are classified into different types : (1) Divergent plate boundaries (also called constructive margins); (2) Convergent plate boundaries (destructive margins) and (3) Transform fault boundaries (conservative margins). Each plate is bounded by a combination of the three types of boundaries and new plate boundaries can be created.

1) Divergent plate boundaries :

These boundaries are located along the oceanic ridges where the ocean floor is spreading and are called as constructive plate margins as they form new plate material (fig. 1.9). Along well-developed divergent plate boundaries, the seafloor is elevated forming the oceanic ridges.

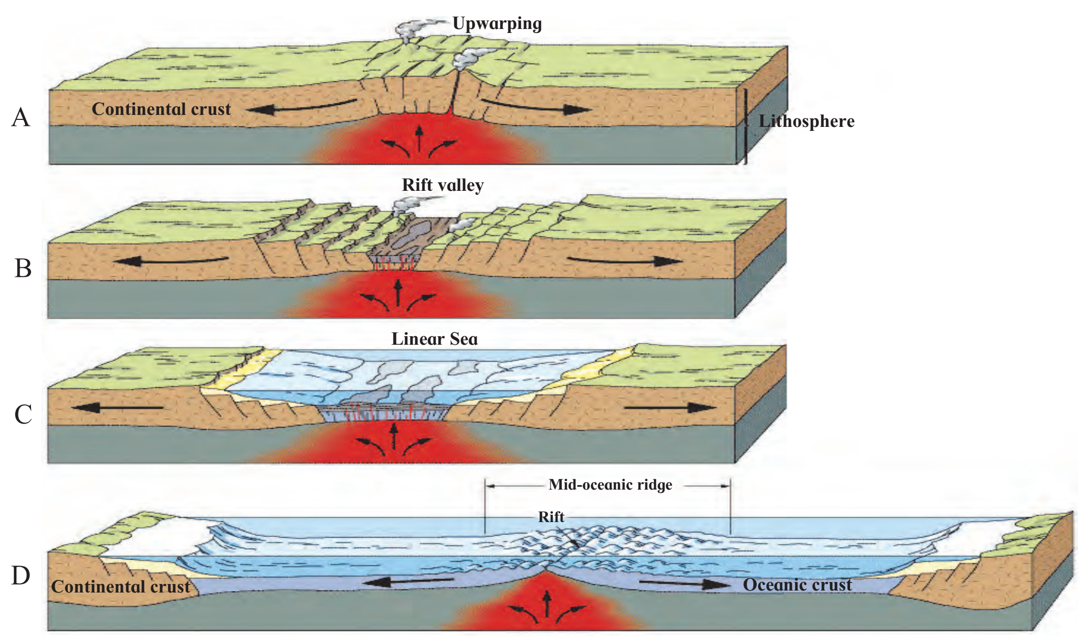


Fig. 1.9 : Development of Midoceanic Ridge in the ocean

Continental rifts are a kind of divergent plate boundaries where the landmass is split into two or more smaller segments. The best example for such a boundary can be seen in East African rifts valleys (fig. 1.10) and the Rhine Valley in northern Europe.

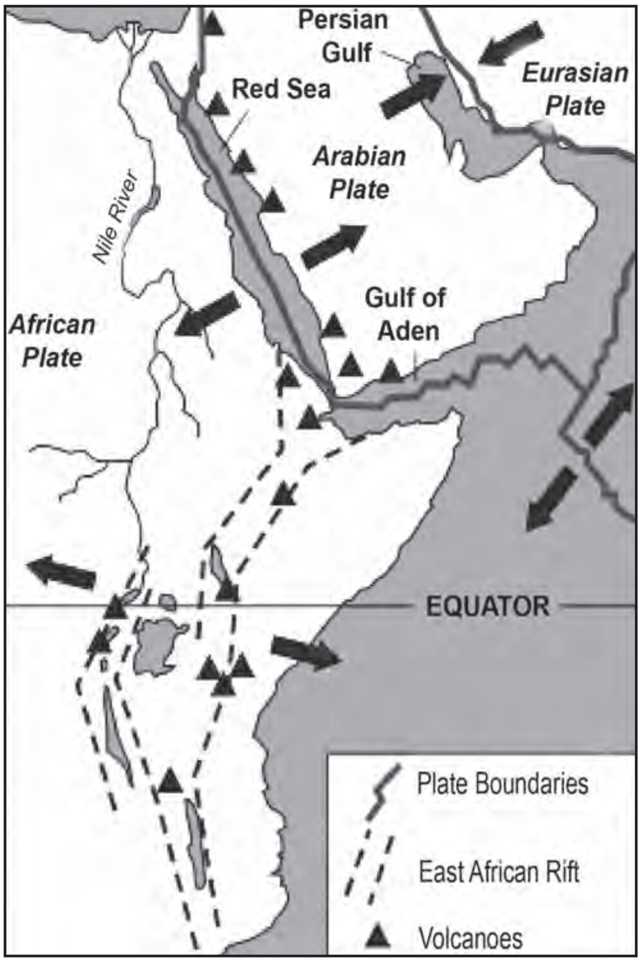


Fig. 1.10 : East African Rift valley as an example of divergent continental margin

2) Convergent plate boundaries :

Older portions of oceanic plates are returned to the mantle along the destructive plate margins. The descending plate forms an ocean trench called subduction zones (fig. 1.11). The plate dips at an average angle of 45° where it descends into the mantle. There are three types of convergent plate boundaries.

A) Ocean – continent convergence

B) Ocean – ocean convergence

C) Continent – continent convergence

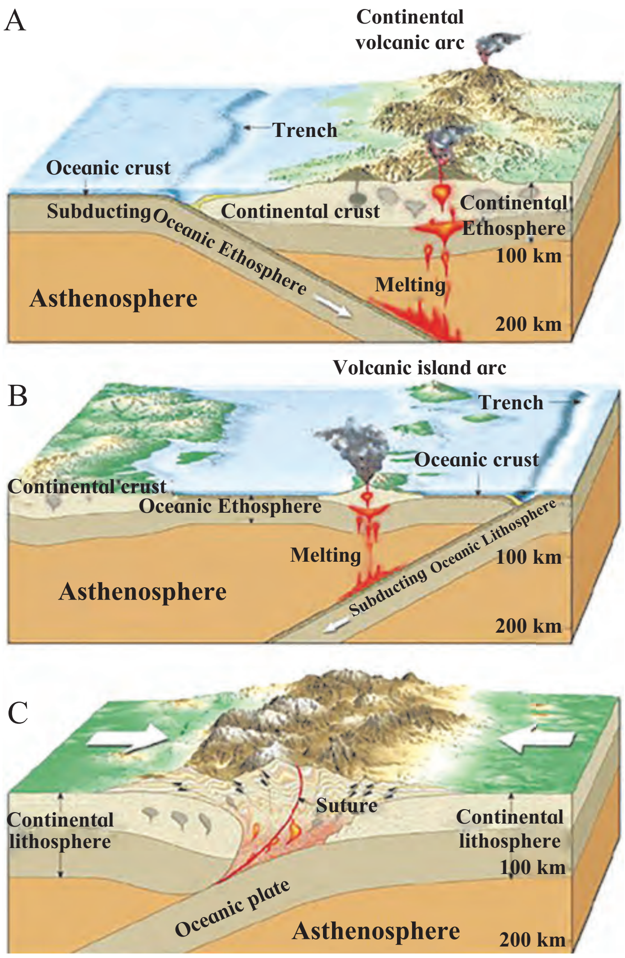


Fig. 1.11 : Types of convergent plate boundaries

3) Transform fault boundaries :

Plates slide past one another without creating/destroying any new lithosphere as transform faults (fig. 1.12). Most of the transform faults join two segments of a mid-ocean ridge as parts of prominent linear breaks in the oceanic crust known as fracture zones. Some interesting examples of Transform fault are the San Andreas fault (USA) (fig. 1.13) and the Alpine fault of New Zealand cutting through continental crust.

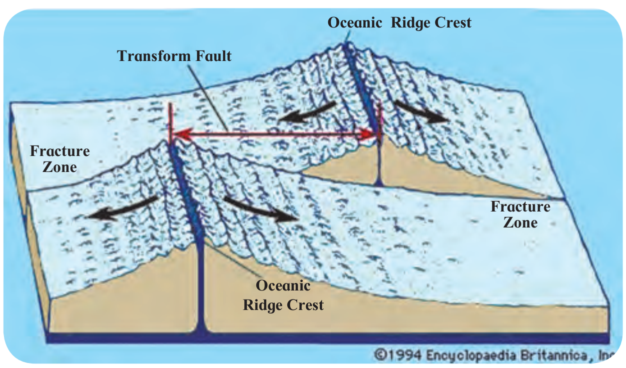


Fig. 1.12 : Concept of transform fault

Fig. 1.13 : San Andreas Transform Faults

Types of Mountains :

Mountains express the dynamics of the interior of the Earth and hence are very significant in understanding plate tectonics. They are positive relief structures or landforms rising above the surrounding land. Mountain building involves a combination of movements and processes such as upliftment, folding, deformation, faulting, metamorphism, igneous activity, erosion and sedimentation. The younger mountains achieve highest elevation as the rate of uplift exceeds the rate of erosion e.g., Mount Everest (8848 m). Different mechanisms of mountain building process evolve into various types of mountains.

There are four main types of mountains: i) fold mountains, ii) fault-block mountains, iii) volcanic mountains, and iv) relict mountain.

Fold Mountains are formed when two plates collide or a compressive force is developed within a plate. Many of the world's great mountain ranges are fold mountains including the Andes, Himalayas, and the Rockies.

Fault-block Mountains are formed along fault lines and either side of the fault are called fault blocks. Some of the fault blocks are pushed up, while others are pushed down resulting in the difference in elevation. Satpuras and Vindhyans are considered as fault-block mountains.

Volcanic Mountains are caused by volcanic activity when magma erupts all the way to the surface of the Earth. The hot magma will cool and harden forming a mountain. Examples of the volcanic mountains include Mount Fuji in Japan and Barren island in the Bay of Bengal, the only active volcano in India.

Relict type of mountains are formed by differential erosion e.g. Sahyadris.

Do you know?

Mountain ranges of India : India is a unique country representing almost all kinds of mountain types of the world. Below is the summary of information on some of the important mountain ranges of India. Students may search a map of India from reliable web resources to locate the mountains listed in the table as an activity.

Mountains	Salient Features
Karakoram Range	A sub range of the Hindu Kush Himalaya, K2, the second highest peak in the world is located here Famous Glaciers : Siachen Glacier, Biafo Glacier.
Ladakh Range	Southeastern extension of the Karakoram Range. from the mouth of the Shyok River in Ladakh to the border with Tibet
Zanskar Range	Boundary line between Ladakh region of Kashmir & remaining two regions of the state i.e. Jammu and Kashmir Highest peak : Kamet. Coldest place in India: Dras (The Gateway to Ladakh) Famous Passes : Shipki, Lipu Lekh (Lipulieke), and Mana Pass

Pirpanjal Range	Separates Jammu Hills to the south from the Kashmir (Kashmir Valley), beyond which lie the Great Himalayas Highest Point : Indrasan. India's longest rail tunnel known as Pir Panjal Railway Tunnel, Banihal road tunnel Famous Passes : Pir Panjal Pass, Banihal Pass, Rohtang pass
Dhauladhar Range (White Range)	Spread in J & K and Himachal, with home to major hill stations like Kullu, Manali & Shimla Highest peak : Hanuman ji Ka Tiba, or 'White Mountain'
Shivalik Range	Southernmost & Outer Himalayas also known as Manak Parbat in ancient times. About 2,400 km long from Indus till Brahmaputra.
Aravali Range	Means 'line of peaks', runs across Gujarat, Rajasthan, Haryana & Delhi, and Mewar hills Highest Peak : Gurushikhar, Mt Abu. Famous passes : Pipli Ghat, Haldi Ghat.
Kaimur Range	Eastern portion of the Vindhya Range in MP, UP & Bihar, Parallel to river Son
Mahadeo Range	Forms the central part of the Satpura Range, located in MP. Highest peak : Dhoopgarh
Ajanta Range	Maharashtra, south of river Tapi, sheltering caves of world famous paintings of Gupta period
Rajmahal Hills	In Jharkhand, made up of basaltic rocks, Point of Ganges bifurcation,
Garo Khasi Jaintia Hills, Mikir Hills	Continuous mountain range in Meghalaya a group of hills located to the south of the Kaziranga National Park (Assam), a part of the Karbi Anglong Plateau
Abor Hills	Hills of Arunachal Pradesh , near the border with China, bordered by Mishmi and Miri Hills
Mishmi Hills	In Arunachal Pradesh with its northern & eastern parts touching China. Situated at the junction of North Eastern Himalaya and Indo-Burma ranges
Patkai Range	Also known as Purvanchal Range, consist of three major hills. The Patkai-Bum, the Garo-Khasi-Jaintia and Lushai Hills situated on India's north-eastern border with Burma
Vindhya Range	A complex, discontinuous chain of mountain ridges, hill ranges, highlands & plateaus running through Madhya Pradesh, Gujarat, Uttar Pradesh and Bihar Highest peak – Sadbhawna Shikhar.
Satpura Range	A range of hills in central India. Passes through Madhya Pradesh, Gujrat, Maharashtra, Chhattisgarh Highest peak : Dhupgarh
Dalma Hills	Located in Jamshedpur, famous for Dalma national park & minerals like iron ore & manganese
Girnar Hills	Gujarat
Harishchandra	At Pune, acts as a water divide between Godavari & Krishna, hills made up of Deccan basaltic lava
Balaghat range	Between MP & Maharashtra, famous for manganese deposits.
Nilgiri Hills	Referred as Blue mountains, a range of mountains in the westernmost part of Tamil Nadu at the junction of Karnataka and Kerala Hills are separated from the Karnataka plateau to the north by the Moyar River and from the Anaimalai Hills & Palni Hills to the south by the Palghat Gap

Palani Hills	Eastward extension of the Western Ghats ranges,adjoin the high Anamalai range on the west, and extend east into the plains of Tamil Nadu
Anamalai Hills	Also known as Elephant Hill. A range of mountains in the Western Ghats in Tamil Nadu and Kerala with highest peak Anamudi
Cardmom Hills	Part of the southern, Western Ghats located in southeast Kerala and southwest Tamil Nadu
Pachamalai Hills	Also known as the Pachais, Eastern Ghats in Tamil Nadu

Summary :

- Surface of the Earth is an expression of the dynamic processes that are occurring in the interior of the Earth.
- The Earth's interior is divided into several compositional and thermal layers interacting with each other by conduction, convection or advection resulting into many dynamic activities such as plate tectonics.
- Plate tectonics is one of the most important phenomenon which explains several important processes occurring on the surface.
- Mountain ranges are the locations where the signatures of the Earth's internal dynamics since geological past are evident and can be studied readily by geologists.

EXERCISE

Q. 1. Choose the correct alternative :

1) The difference between the temperature of Universe and the interior of the Earth is of the order of

   a) 2000° C　　b) 10000° C

   c) 600° C　　d) 6000° C

2) The lower boundary of mantle convection is set at about …… Km from the surface of the Earth.

   a) 5000 km　　b) 2000 km

   c) 2900 km　　d) 300 km

3) Although the inner core and outer core are of approximately the same composition (Fe-Ni), the inner core remains solid due to

   a) Increase in melting point of the compound due to increase in Pressure.

   b) Decrease in melting point of the compound due to increase in Pressure

   c) Increase in melting point of the compound due to decrease in Pressure

   d) The source of heat is in the outer core.

4) When two plates collide, they are likely to form

   a) Fault-block mountains

   b) Volcanic mountains

   c) Domal mountains

   d) Fold mountains

Q. 2. Very short answer :

1) How do the convection currents maintain the temperature of the mantle?
2) What controls the temperature gradient of the Earth?
3) What is the main driving force for plate motion?
4) Why has the radius of the Earth increased from its very early stage of formation?

Q. 3. Short answer :

1) Write down any two major points describing the difference between Continental crust and Oceanic crust.
2) The Himalaya and Sahayadri are two different types of mountains, justify this sentence.
3) Mention any two most important properties of asthenosphere.
4) Give any two examples of the continental landmasses that broke up as a result of break-up of the supercontinent PANGEA.

Q. 4. Short answer :

1) Give any three evidences that indicate the continents have drifted.
2) Describe how magnetic strips on the ocean floor explain the Plate tectonics.
3) Give an example of the divergent continental margin.
4) Describe how relict type of mountains are formed.

Q. 5. Long answer :

1) Describe what tectonic activity is undergoing at the western margin of South American plate.
2) Describe what are the limitations of Continental drift theory and how the theory of Plate tectonics resolved them.
3) Describe different types of plate boundaries and exemplify then with the Indian-Australian plate.
4) Write a short note on the San Andreas Transform fault of North America.
5) Give an account on the internal layering of the Earth.

Q. 6. Assessing Unseen para :

"To find out whether these changes are due to changes of composition, temperature or other parameters, we turn to density, which is the most useful quantity that can be determined with reasonable precision. Density is deduced by combining information from seismology with knowledge of the mass of the Earth, deduced from its gravitational attraction, and its moment of inertia, determined from the movement, or precession, of its axis of rotation. The resulting density variation with depth inside the Earth is not uniquely determined, but it is known within fairly close limits at most depths, so that next we can ask what material will match the density at any specified depth".

Quoted from : The Inaccessible Earth: An integrated view to its structure and composition By Brown and Musset p.2

1) What does the authors wants to indicate by saying "reasonable precision when determination of the density".
2) How is the density of such a large body like the Earth's is determined?
3) How the composition of the material at great depths in the interior of the Earth is determined?
4) What is the interrelation of density, mass, temperature and pressure?

Q. 7. Unseen para :

"A theory of mantle convection is a dynamical theory of geology, in that it describes the forces that give rise to the motions apparent in the deformation of the Earth's crust and in earthquakes and to the magmatism and metamorphism that has repeatedly affected the crust. Such a dynamical theory is a more fundamental one than plate tectonics, which is a kinematic theory it describes the motions of plates but not the forces that move them. Also plate tectonics does not encompass mantle plumes, which comprise a distinct mode of mantle convection".

Quoted from : Dynamic Earth: Plates, Plumes and Mantle Convection - GEOFFREY F. DAVIES p.4

1) In what way the author emphasizes that the Earth's crust is linked to the mantle?
2) Distinguish between some of the kinematic and dynamic aspects of the Earth.
3) How the author emphasize mantle plume to explain both dynamic and kinematic changes of the Earth.

2 Petrology

Introduction :

Petrology is the branch of geology, which deals with the study of rocks. The term petrology is derived from the Greek word 'petros' meaning rocks and 'logos' meaning study. Petrology, therefore, includes the mineralogical, textural and chemical description of rocks along with their geological origin, mode of occurrence and their relation to the physico-chemical environment of the Earth. Petrological studies are carried out under two major heads as follows, viz,

a) **Petrography :** Description and systematic classification of rocks

b) **Petrogenesis :** Studies of the origin / genesis of the rocks

Rock is an aggregate of minerals. Most rocks are composed of two or more minerals (e.g. granite). However, a few are composed of a single mineral (e.g., dunite). Some rocks may also contain fossil remains of plants and animals (fossiliferous limestone) or they may be formed by recrystallization of pre-existing rocks (e.g. marble).

IGNEOUS PETROLOGY

The first formed rocks on the Earth are igneous/ primary rocks. The term igneous, is derived from the Latin word 'igneus' meaning fire. They are formed through cooling and solidification of magma or lava. These rocks may form with or without crystallization either below the surface, as intrusive (plutonic) rocks or on the surface as extrusive (volcanic) rocks. Magma, may be derived from melting of pre-existing rocks either in the mantle or in crust. One or more processes such as increase in temperature, decrease in pressure, or change in composition cause melting.

Minerals of the igneous rock are broadly classified into two groups viz. i) Primary and ii) Secondary. Primary minerals are the minerals which have developed as a result of crystallization from magma or lava (i.e., pyrogenetic minerals), while secondary minerals are those which are formed after the solidification of the rock either by alteration of the primary minerals or by precipitation from solution, in voids or vesicles of rocks.

Primary minerals can be grouped into two, viz., 1) essential and 2) accessory.

Essential minerals are necessary for the classification, identification or nomenclature of the rock. Accessory minerals are present in small amounts and are therefore, not important in the nomenclature e.g., in granite, quartz and feldspar are essential minerals, while biotite and / or hornblende are accessory minerals. Presence or absence of accessory minerals does not make any difference in nomenclature of rocks.

Secondary minerals are those which are formed from secondary solutions in cavities of igneous rocks, most commonly found in volcanic igneous rocks, e.g., calcite, zeolites etc.

The minerals may be felsic or mafic. The felsic minerals are light in colour, with low specific gravity, e.g., minerals from silica and feldspar groups. Mafic minerals are dark coloured, with higher specific gravity, e.g., minerals belonging to pyroxene, amphibole, mica, olivine groups and iron ores.

Rocks are described as a) phaneric or phanero-crystalline, if their minerals can be distinguished separately with the naked eye, e.g. a coarse grained rock like granite. b) rocks, in which the mineral grains cannot be distinguished by the naked eye, are described as aphanitic, e.g. a fine grained rock like basalt or rhyolite. (fig. 2.1)

Classification of Igneous rocks :

1) Based on mode of occurrence : Igneous rocks formed at great depths inside the Earth are called plutonic rocks. The name is derived from Greek God of underworld – Pluto. They have a slow rate of cooling and are characterized by a coarse grained, equigranular texture. Granite is a typical plutonic rock.

Rocks, which solidify on the Earth's surface from lava, are described as volcanic rocks. The lavas may have erupted either from a volcano or through fissures. A very rapid rate of cooling of the lava makes these rocks fine grained or even glassy. They show characteristic features such as vesicles, amygdales and flow structure. Volcanic rocks may show inequigranular textures under the microscope, e.g., basalt.

The hypabyssal rocks consolidate at a depth in between volcanic and plutonic depths. They show characters which are intermediate between plutonic and the volcanic rocks, e.g., dolerite.

2) Based on SiO_2 percentage : The percentage of SiO_2 in a rock decides the nomenclature of the igneous rock as :

a) Acidic with SiO_2 greater than 65% e.g. granite;

b) Intermediate with SiO_2 - 55 - 65%; e.g. syenite

c) Basic with SiO_2 - 45 - 55% e.g. basalt and

d) Ultrabasic with less than 45% SiO_2 e.g. peridotite

3) Based on colour index :

a) Rocks rich in felsic minerals are often light coloured and are termed as leucocratic i.e., acidic rocks which contain essentially quartz and alkali feldspar (e.g., granite).

b) Intermediate igneous rocks have a colour index between acidic and basic rocks and are called mesocratic (e.g., syenite).

c) Rocks rich in mafic minerals are dark coloured and are called melanocratic, such as, basic rocks which are rich in augite, hornblende and olivine (e.g., basalt).

d) Ultrabasic rocks are very dark in colour and hence, are classified as hyper-melanocratic (e.g. peridotite).

a) Phaneric

b) Aphanitic

Fig 2.1 : Degree of crystallinity

Textures of Igneous rocks :

Texture describes the mutual relationship of the minerals and /or glass, contained in a rock. It takes into account relative amounts of crystalline and glassy matter, as well as the size, shape and the arrangement of minerals.

a) Equigranular texture : If rock consists of mineral grains of almost equal size, it is said to possess an equigranular texture. As this texture is characteristically exhibited by granite it is also known as Granitic texture (fig. 2.2).

b) Inequigranular texture : If the rock possesses mineral grains and other constituents like glass having different sizes, it is said to exhibit inequigranular texture e.g. porphyritic texture, where large crystals called phenocrysts are embedded in a matrix of finer grains or glassy groundmass.

Porphyritic texture is typically shown by some volcanic rocks like basalt (fig. 2.3).

Fig. 2.2 : Equigranular

Fig. 2.3 : Inequigranular (Porphyritic)

Tabular Classification of Igneous rocks :

Depth of occurrence	Acidic	Interme-diate	Basic	Ultra-basic
	Silica> 65%	Silica 55 - 65 %	Silica 45 -55 %	Silica <45%
Plutonic	Granite	Syenite	Gabbro	Dunite
Hypa-byssal	Pegma-tite		Dolerite	
Volcanic	Rhyolite	Trachyte	Basalt	
Mineral content	Ess- Quartz, Feld-spar. Acc-Bi-otite, Horn-blende	Ess- Feld-spar. Acc- Quartz	Ess- Feldspar, Augite Acc-Ol-ivine Quartz absent	Olivine
Colour Index	Leuco-cratic	Meso-cratic	Melano-cratic	Hyper melano-cratic

Texture becomes finer ↓

[Ess - essential, Acc - Accessory]

Quartz content reduces as Silica % decreases →

Structures of Igneous Rocks :

They are large and easily recognizable features to the naked eye. Structures provide information about genesis of the rock.

Some of the common igneous structures are as follows :

i) **Vesicular structure :** Magma erupts on the surface in the form of lava . When lava is rich in gaseous content i.e., volatiles it erupts and gases escape into the atmosphere leaving behind the cavities of various shapes and sizes. These cavities are called vesicles and the resulting structure is called vesicular structure e.g. vesicular basalt. Vesicles can also be pipe shaped.

ii) **Amygdaloidal structure :** Vesicles can subsequently get filled by secondary minerals such as calcite, zeolites and varieties of silica. Such filled vesicles are called amygdales. The rock is then said to exhibit amygdaloidal structure e.g. Amygdaloidal basalt (fig. 2.4)

Fig. 2.4 : Amygdaloidal basalt

iii) **Ropy structure :** Lavas of basic composition are mobile, due to low viscosity and can flow greater distances. During this process, their upper surface gets wrinkled resembling ropes. This structure is termed as ropy structure.

iv) **Columnar structure :** During rapid cooling of basic lava, number of cooling centres are developed. Lava tries to aggregate around these centres. It is the result of contraction of lava during cooling. Due to this, tensile stress is developed. At right angles to the stress direction, vertical joints or cracks are formed. Such joints results in the formation of hexagonal or polygonal columns, giving rise to columnar structure e.g. Columnar basalt.

v) **Pillow structure :** This structure is most commonly observed when hot lava erupts under water. In this structure, the volcanic igneous body appears as pile of numerous overlapping pillows or sacks stacked one above the other.

As the lava flows, its upper surface gets solidified immediately due to contact with water, hence crust of a pillow shows glassy texture.

Types of Igneous bodies :

The magma rising from mantle may or may not reach the surface of the Earth forming extrusive or intrusive igneous bodies respectively (fig. 2.5)

A) Extrusive bodies :

When lava travelling through fissures and volcanoes cools rapidly at the Earth's surface it forms Extrusive igneous bodies.

Lava flows :

The only extrusive form of igneous bodies is lava flows. Their thicknesses may range from few centimetres to hundreds of meters and cover an area from a few meters to many square kilometers. The Deccan plateau of western India is the example of lava flows.

B) Intrusive bodies :

The forms of Intrusive bodies are dependent upon viscosity of magma and the structure of the rocks they intrude. Igneous intrusive bodies are classified as concordant and discordant depending on their structural relation with the host rock. Concordant bodies are more or less parallel to the structure of the host rocks and discordant bodies cut across the host rocks.

1) Concordant igneous bodies :

a) **Sill :** Sill means shelf or slab of stone. It is a tabular sheet of igneous rock intruded between and parallel to the existing strata. They are thin tabular sheets of magma which have been intruded along the bedding planes or foliations. They show nearly parallel upper and lower margins and pinch out with distance. Their thickness may vary from a few meters to hundreds of meters and may extend laterally for few kilometres. On the basis of their origin, sills are differentiated into simple, multiple and composite types. Simple sill is formed by a single intrusion. Multiple sills are formed by two or more intrusions. Composite sills consist of more than one rock type, formed

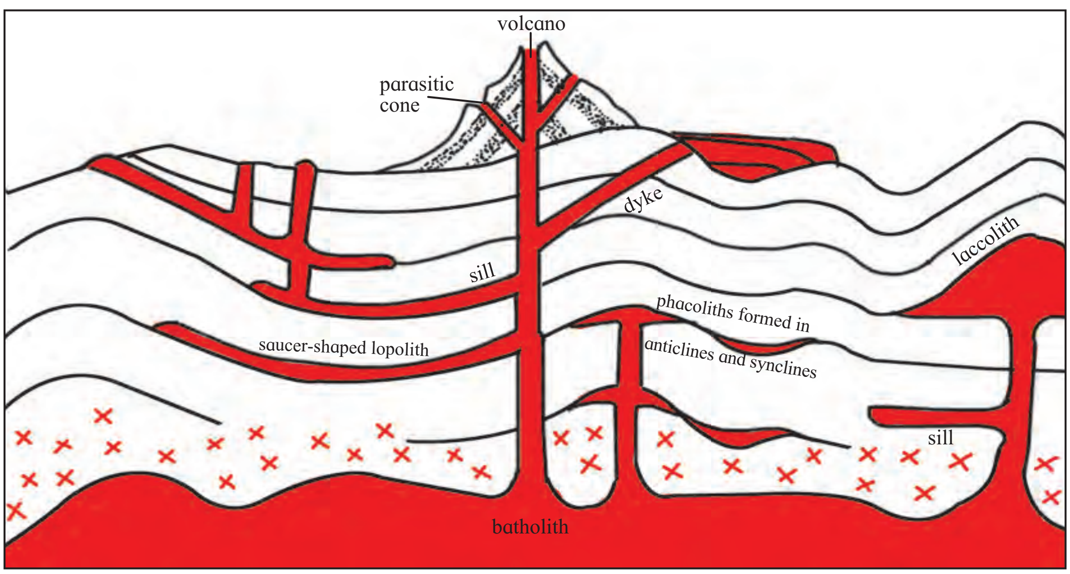


Fig. 2.5 : Concordant and discordant Igneous bodies

by more than one intrusive episode.

b) **Laccolith :** The term laccolith is derived from the Greek word 'lakkos' meaning a cistern and 'litho' meaning stone. It is a bun shaped structure having a flat base and domed top and does not spread very far, tends to heaps itself up around the orifice of the eruption. The strata above it are generally lifted up in the form of an inverted bowl. Laccolith may be a few Kilometers in diameter and about thousands of meters thick.

c) **Lopolith :** Lenticular, centrally sunken saucer or basin-like concordant igneous bodies are called as lopoliths. In Greek 'lopos' mean basin. Generally, their thickness varies by $1/10^{th}$ to $1/20^{th}$ of their width, and diameters range from tens to hundreds of kilometers. The characteristic shape is the result of sagging caused by the weight of intruding magma.

d) **Phacolith :** The Greek word 'phaco' meaning lens. These are crescent shaped structures found in highly folded regions. They are formed at the crests and troughs of folds which are regions of weakness and tension. They exhibit doubly convex lens-like form.

2) Discordant igneous bodies :

Discordant igneous bodies show cross cutting relationship with the structures of the host rocks. They are described as follows :

a) **Dyke :** The word Dyke is derived from the Scottish term 'dike' meaning a wall of stone. Dyke is a vertical or near vertical wall-like body of igneous rock intruded into the older rocks. They cut across the foliation or bedding of the country rocks. It is a narrow, elongated, parallel sided wall of igneous rock. Its thickness varies from a few centimetres to many meters. Similarly its length can vary from a few meters to several kilometres.

Dykes are frequently more resistant to erosion than the enclosing rocks and tend to project as 'walls' above the surface. However, dykes can also be excavated out to form a 'trench' due to weathering and erosion. Many a times dykes bake and harden the adjacent country rock on either side. They may occur as isolated bodies or as 'swarms'. Dykes may be vertical, inclined, ring shaped, radiating or arcuate in nature. Outwardly dipping dykes from a common centre are called as 'cone sheet'.

b) **Batholith :** The term Batholith is derived from Greek word 'bathos' meaning depth. Batholiths are large scale igneous intrusions. They have extremely large dimensions, with steeply dipping walls. They extend on the surface up to thousands of kilometres with irregular outline. They are generally granitic in composition. Stock and boss are offshoots of batholiths where stock is irregular in shape and boss is more or less circular and both are less than 100 sq. kms in aerial extent. A roof pendant is a pendant shaped body of country rock hanging from the roof of the batholith. Xenoliths are fragments of country rocks found within the batholiths.

SEDIMENTARY PETROLOGY

Sedimentary rocks are one of the three main rock groups, along with igneous and metamorphic rocks. They are formed as a result of :

1) Deposition of the weathered remains of other rocks.
2) Biogenic activity and.
3) Precipitation from solution.

Formation of Sedimentary Rocks :

Formation of sedimentary rocks is a slow process that may require millions of years. Sedimentary rock formation begins when the pre-existing rocks are exposed to weathering processes.

The formation of sedimentary rocks involves five different processes as shown in fig. 2.6 :

1) **Weathering :** The first step is transforming solid rock into smaller fragments or dissolved ions by physical and chemical weathering.

2) **Erosion :** Erosion begins with the transportation of the weathered products from their original location. This can take place by gravity, running water, wind, or moving ice.

3) **Transportation :** Sediment can be transported by sliding down slopes, being picked up by the wind, or carried by running water. Longer transportation of sediments results into finer sediments.

4) **Deposition :** Sediments are deposited when the energy of the transporting medium drops resulting in their settling. The final sediment thus reflects the energy of the transporting medium.

5) **Lithification and cementation :** Lithification is the process that converts sediments into sedimentary rock. The processes of compaction and cementation are involved in this change. Increased load of overlying sediments results in reduction of pore spaces and water within them. The dissolved minerals get precipitated in these pore spaces to act as cement binding the minerals.

Classification of sedimentary rocks :

By considering the manner in which the detritus (particles of sediment) is distributed, transported and deposited, a simple, tabular classification for sedimentary rocks, based on the products of weathering is depicted in table 2.1.

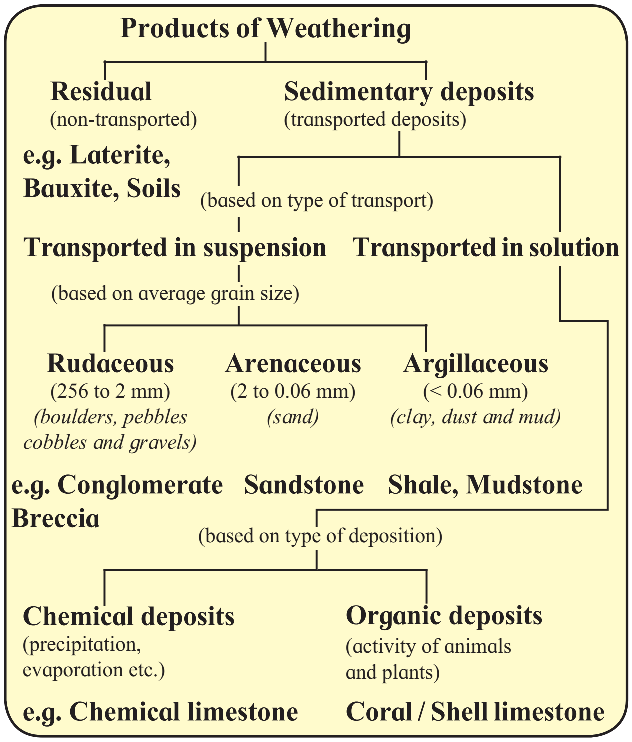


Table 2.1: Products of Weathering

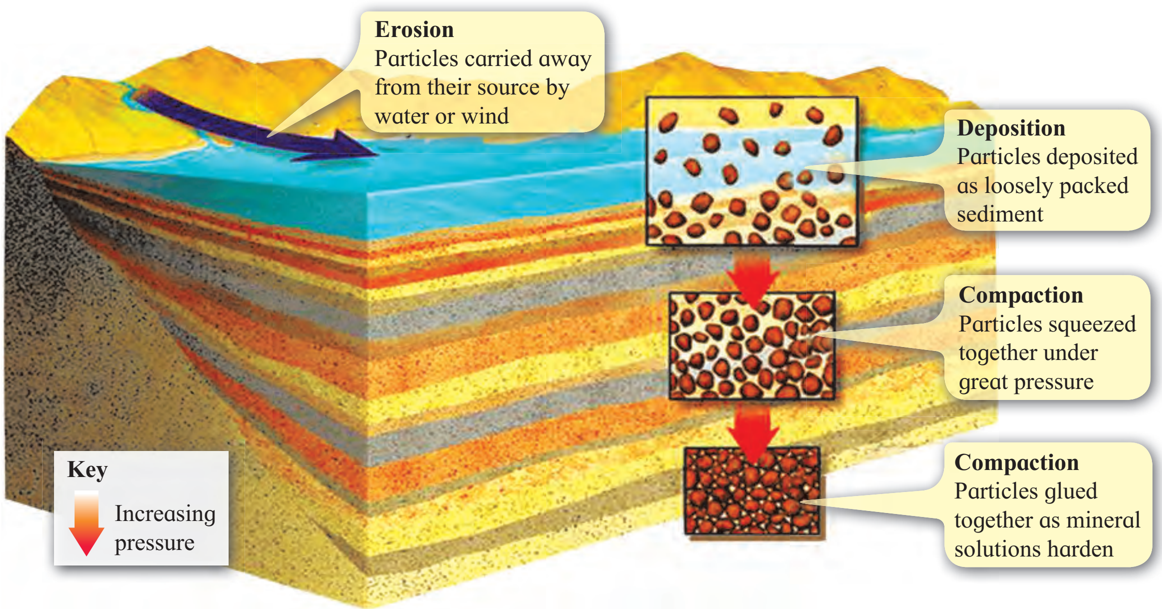


Fig. 2.6 Processes involved in formation of sedimentary rocks

1) Non-transported (Residual deposits)

2) Transported deposits

1) Non-transported (Residual deposits) : These are also known as sedentary deposits formed due to accumulation and consolidation of the materials which were left behind as residue. These are the insoluble products of rock weathering. e.g. Laterite and bauxite (fig. 2.7. a and b).

a) Laterite

b) Bauxite

Fig. 2.7 : a and b : Examples of residual deposits

2) Transported deposits : They are formed from the materials that have been transported mechanically by saltation, traction and suspension or chemically in solution. Besides, some organic processes also play an active role in the formation of transported deposits. These are classified into two groups :

A) Clastic rocks B) Non-clastic rocks

A) Clastic rocks : These detrital rock fragments are carried and deposited by mechanical means and later cemented. On the basis of grain size, the clastic rocks are further classified as :

(i) Rudaceous rocks (Rudites) : Very coarse grained rocks with grain size more than 2 mm in diameter. Boulders, cobbles, pebbles and gravel are transported by traction i.e. by rolling or creeping. e.g. Conglomerates- in which constituent grains are rounded, (fig. 2.8 a) and breccia in which constituent grains are angular (fig. 2.8 b).

a) Conglomerate

b) Breccia

Fig. 2.8 : a and b : Examples of Rudaceous rocks

(ii) Arenaceous rocks (Arenites) : These rocks consist of sand-sized grains. They are transported by either saltation or suspension. Grain size ranges between 2 mm and 1/16 mm. e.g. siliceous sandstone and (b) ferruginous sandstone (fig. 2.9. a and b)

a) Siliceous sandstone

b) Ferruginous sandstone

Fig. 2.9 : a and b: Examples of arenaceous rocks

Do you know?

Wentworth's scheme of classification of grain size.

Size range (mm)	Name of particle	Group	Consolidated Rocks
>256	Boulder	Rudaceous	Conglomerate, Breccia
>64	Cobble		
>4	Pebble		
>2	Gravel		
>1	Very coarse sand		Sandstone, Arkose, Grit
>1/2	Coarse sand		
>1/4	Medium sand	Arenaceous	
>1/8	Fine sand		
>1/16	Very fine sand		
>1/32	Coarse silt	Argillaceous	Siltstone
>1/64	Medium silt		
>1/128	Fine silt		
>1/256	Very fine silt		
<1/256	Clay		Claystone

(iii) Argillaceous rocks (Argillite) :

(a) Siltstone : Constituent particles in siltstone are finer than sand and coarser than clay. These grains are transported by suspension. (fig. 2.10).

Fig. 2.10 : Siltstone

(b) Shale : It is made up of clay particles, usually transported in suspension e.g. Claystone, Mudstone, Shale etc. Their grain size is finer than Silt rocks i.e., less than 1/16 mm. Shales normally exhibit laminations (fig. 2.11).

Fig. 2.11 : Shale

B) Non-clastic rocks : These are the rocks formed due to chemical precipitation as well as due to the activity of biological agents. They are of two types :

i) Chemical deposits   ii) Organic deposits

i) Chemical deposits : They may be formed a) Due to evaporation of saturated solutions, giving rise to deposits of Salt and Gypsum (fig. 2.12)

a) Salt

b) Gypsum

Fig. 2.12. a and b : Examples of chemical deposits

b) As a result of reaction between the components carried in solution e.g. siliceous (chert fig. 2.13 and flint), ferruginous and carbonate (limestone fig. 2.13 and dolomite) deposits.

Fig. 2.13 : a) Chert

Fig. 2.13 : b) Limestone

ii) Organic deposits : These are products of accumulation of organic matter preserved under suitable conditions. The deposition may be bio- chemical or bio-mechanical. Organic deposits are of five types :

a) Siliceous : Radiolarian ooze; diatomites.

b) Calcareous : These deposits are formed as a result of biomechanical as well as biochemical processes eg. Fossiliferous Limestone (fig. 2.14), Chalk, Marl etc.

c) Phosphatic : Calcium Phosphate is utilized by certain organisms, especially fish and brachiopod which are consumed by birds and bats. The bird and bats droppings accumulate in heaps and later get transformed into 'Guano'.

d) Ferruginous : These deposits are formed by biochemical oxidation of Fe carried in solution in bogs and deposited as bog-iron ore.

e) Carbonaceous : Coal is a product of deposition and burial of plant matter (fig. 2.15).

Fig. 2.14 : Fossiliferous Limestones

Fig. 2.15 : Coal

Texture and structures of sedimentary rocks :

1) Clastic texture :

Loose detrital fragments derived from weathering of pre-existing rocks undergo erosion and transportation. They are finally deposited and are bound together by fine grained particles known as the matrix. This arrangement of grains and the matrix after compaction gives rise to clastic texture (fig. 2.16).

Fig 2.16 : Conglomerate showing clastic texture

2) Sedimentary Structures :

The process of deposition usually imparts variations in layering, bed forms or other structures that give clues to the depositional environment.

I) Stratification and bedding :

a) Stratification : It is layering formed during deposition. Stratification results by changes in depositional conditions with time. (fig. 2.17)

Fig. 2.17 : Bedding in sedimentary rocks

b) Bedding : The beds in sedimentary rocks are evident because of differences in mineralogy, clast size and degree of sorting or colour of the different layers (fig. 2.17).

i) Planar bedding : It is the simplest sedimentary structure formed generally in all sedimentary environments and also under a variety of depositional conditions (fig. 2.18).

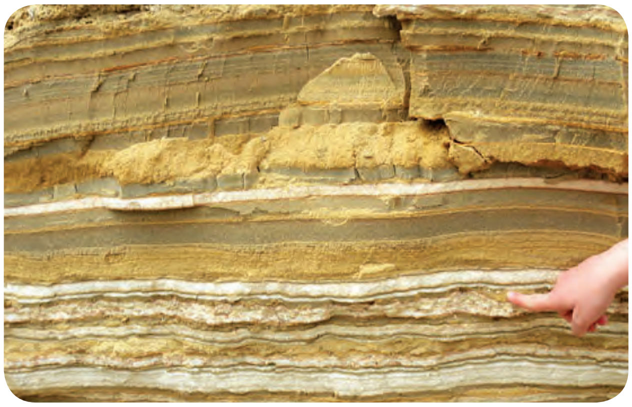


Fig. 2.18 : Planar bedding

ii) Cross Bedding : It consists of sets of beds that are inclined relative to each other. The beds are inclined in the direction of movement of the wind or water. Boundaries between sets of cross beds usually represent an erosional surface. It is very common in beach deposits, sand dunes and river deposits. Individual beds within cross-bedded strata are useful indicators of current direction and tops and bottoms of the beds (fig. 2.19).

Fig. 2.19 : Cross bedding

iii) Graded Bedding : As current velocity decreases, the larger or heavier particles are deposited first, followed by finer particles (fig. 2.20 a and b). This results in bedding showing a decrease in grain size from the bottom of the bed to the top of the bed. This helps in determining top and bottom of beds.

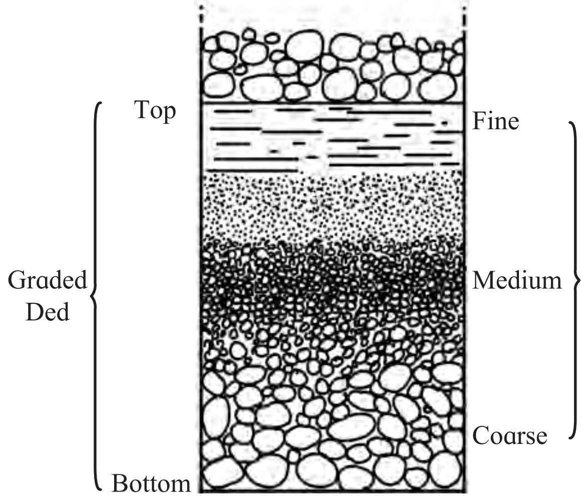


Fig. 2.20 : a) - Graded bedding

Fig. 2.20 : b) Graded bedding in sedimentary rocks

iv) Ripple marks : It is the wavy pattern seen on mud or sand deposits. Ripple marks are produced by wave action when the sand is moved up and down in an oscillatory motion by wind or water. Ripples can be symmetrical or asymmetrical (fig. 2.21).

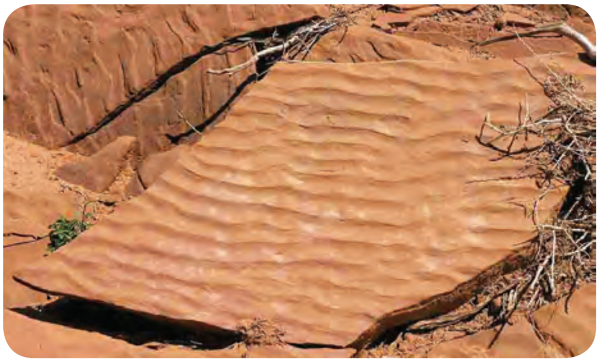


Fig. 2.21 : Ripple marks in Sedimentary rocks

METAMORPHIC PETROLOGY :

Metamorphic, (Meta=other; morph=form) rocks are formed when pre-existing rocks are transformed into new rocks by heat, pressure and chemically active fluids below the Earth's surface or along the boundary of tectonic plates. In general, metamorphism means a partial or complete re-crystallisation of minerals in the pre-existing rocks and the production of new structures. Therefore, metamorphic rocks result when the pre-existing rocks lose their stability due to the pronounced changes of temperature, pressure and chemical environments, below the shell of weathering and have re-established stability by adjusting to the new environment.

Thus, metamorphism is 'response of solid rocks to the pronounced changes in temperature, pressure and chemically active fluids'.

Agents of metamorphism :

Metamorphism results because of the changes in the physical and chemical environment of the original or pre-existing rock. The agents responsible for metamorphic changes are :

(a) Temperature, (b) Pressure and (c) Presence of chemically active fluids.

Temperature plays a major role in the chemical processes of metamorphism such as dehydration and melting of the earlier minerals.

a) Geothermal gradient, proximity of magma or emplaced igneous rocks and the ascending gases and get solutions from the Earth's interior are responsible for the rise in tempature.

b) During metamorphism, pressure may act in two ways viz. i) confining or uniform pressure and ii) Directed pressure or stress.

i) Confining pressure is a non-directional and uniform pressure resulting from the waight of the overlying rocks. Confining pressure increases with depth.

ii) Directed pressure, is most effective in techonically active zones of the lithosphere. Reduction in melting point of minerals, thereby increasing ther solubility, is the effect of directed pressure.

c) Accelaration of metamorphic reactions by heating the rocks in contact is possible due to the high temperature chemically active fluids rising from the magma chember.

Types of metamorphism :

The predominant agent of metamorphism defines the kind of metamorphism. Thus, the major kinds of metamorphism are :
(a) Cataclastic, (b) Thermal or contact and (c) Dynamo-thermal metamorphism.

(a) Cataclastic metamorphism : It is a metamorphism in which directed pressure (or stress) plays the major role. The directed pressure mechanically breaks down the pre-existing rocks giving rise to crushing and fracturing, but without the formation of any new mineral in the affected rock. This causes the lamination of the argillaceous rocks to get deformed with the development of slaty cleavages (e.g. shale metamorphoses into slate).

(b) Thermal or contact metamorphism : Rocks are thermally metamorphosed when they are intruded by magma and the high temperature of the magma heats the country rocks. The pressure (either directed or uniform) effects are almost negligible and recrystallization occurs due to thermal metamorphism. Hence, the calcareous rocks like limestone and arenaceous rocks like sandstone develop a granulose structure when thermally metamorphosed. Limestone forms Marble and Sandstone forms Quartzite.

(c) Dynamothermal metamorphism : Dynamothermal metamorphism involves both high temperature and high pressure effects at a high level. The pre-existing rocks are therefore, subjected to more or less complete recrystallisation and result in the development of new structures. Foliation is a characteristic feature and the typical rocks are schists and gneisses.

Intensity of dynamothermal metamorphism increases with depth. Hence, in the initial stages of metamorphism, the argillaceous rocks like shales are altered to Phyllites and with further increase in temperature and pressure, schists are developed. At much higher temperature and pressure gneisses are formed.

Structures of metamorphic rocks :

The structures of metamorphic rocks are formed by the deformation and recrystallisation of the minerals in the preexisting rocks. The different metamorphic structures are 1) slaty cleavage, 2) granulose, 3) schistose and 4) gneissose.

1) **Slaty cleavage :** The slaty cleavage results from the flattening and rotation of mineral fragments under the action of directed pressure (fig. 2.22). When the argillaceous rocks are subjected to cataclastic metamorphism it results in the formation of slates, which are generally rich in micaceous minerals.

Fig. 2.22 : Slate exhibiting slaty cleavage

2) **Granulose structure :** This structure is developed by thermal metamorphism in which original rock undergoes only re-crystallisation. As there is no action of directed pressure, the sedimentary rocks like limestones and sandstones simply recrystallize to give marble (fig. 2.23 a) and quartzite (fig. 2.23 b) respectively.

Fig. 2.23 : a) Marble exhibiting Granulose structure

They show interlocking grains of calcite and quartz respectivelyof almost equal size with polygonal shapes.

Fig 2.23 : b) Quartzite exhibiting Granulose structure

3) **Schistose structure :** This structure is marked by the linear or parallel arrangement of minerals in a direction perpendicular to the maximum stress (fig. 2.24)

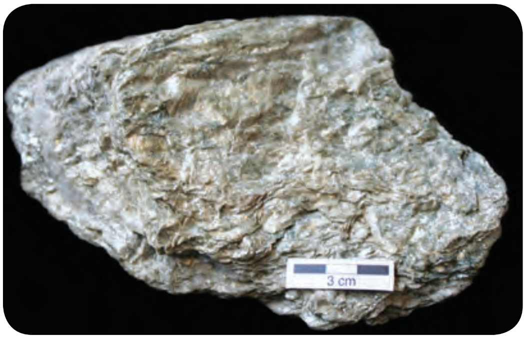


Fig. 2.24 : Muscovite exhibiting Schistose structure

The schistose structure is developed due to the unidirectional alignment of the minerals such as biotite, muscovite, chlorite and talc, which are flaky and hornblende which is prismatic with a columnar or rod-like appearance. These structures are developed with high temperatures and with strong directed pressures or stress. Because of directed pressure, the minerals form layers or folia arranged in parallel layers or bands. This parallel alignment of the flaky or the platy minerals characteristically gives rise to foliation in metamorphic rocks, which is also called as schistose structure.

4) **Gneissose Structure :** This structure is developed when the original rock possesses both flaky minerals and quartz. The flaky minerals like mica give rise to a schistose band while the hard and resistant minerals like quartz and feldspar recrystallize to form a granulose band.

When both, granulose and schistose bands alternate with each other, they give rise to gneissose structure which is a composite structure (fig. 2.25)

Fig. 2.25 : Gneissose structure
Alternate bands of Biotic and Quartz exhibiting Gneissose structure

This structure develops due to the effect of high temperature and directed pressure on the pre- existing rock.

4) Importance of petrology in civil engineering :

In engineering geology, knowledge of rock properties is important for the construction of large structures. Rocks, which are competent, durable and free from weak planes, are suitable for foundation (e.g. granite, syenite, gabbro, Quartzite sandstone). For flooring purpose, they should be resistant to abrasion. i.e. able to withstand wear and tear. e.g. limestone and marble. Rocks durable to weathering are appropriate for roofing e.g. slate, limestone. Owing to its attractive colour and softness, marble is used for decorative purpose and for sculpture or face work of buildings. Laterites are suitable for small-scale constructions. Neatly dressed sandstone can be suitable for walls. For superstructure construction, rock should be easily workable and available in plenty. Thus, different rocks are suitable for different purposes, by virtue of their special physical properties which are inherent and characteristic to them.

Building stones :

For construction of large civil structures like dams, highways, bridges, tunnels etc, an engineer must know the engineering properties of rocks, such as strength, durability, colour, appearance, workability etc. These properties are very important because different rocks are suitable for specific purposes and no rock is ideal or best suited for all kinds of constructions. According to the need of construction a building stone is cut and shaped. All tests are performed in the geotechnical lab in accordance with the Bureau of Indian Standards Code (BIS).

For selection of good qualities of building stones, following properties are important. 1) Crushing strength, 2) Transverse strength, 3) Porosity, 4) Density, 5) Abrasive resistance, 6) Frost and fire resistance, 7) Durability and 8) Appearance.

1) **Crushing strength / Compressive strength :** It is the maximum load per unit area which a rock can withstand without undergoing failure/fracturing. Crushing strength should be greater than $100 N/mm^2$.

2) **Transverse strength :** It is the capacity of a stone to withstand bending loads. Shear strength is determined when the stone is used as a column.

3) **Porosity :** It is the ratio between the total volume of pore spaces and total volume of rock sample.

4) **Density :** Density of a rock is the weight per unit volume. Bulk density refers to weight per unit volume of a rock with natural moisture content.

5) **Abrasive resistance :** It is the resistance offered by a rock to mechanical wear and tear i.e. abrasive resistance refers to hardness of rocks.

6) **Frost and Fire resistance :** The freezing of water in cracks may break rock into angular fragments known as frost action. Fire resistance of rocks becomes necessary when they are used near furnaces.

7) **Durability :** It refers to the life of a structure. Durability of a building stone is also susceptibility or resistance to the weathering.

8) **Appearance :** Rocks which are to be used for face work should be decent, uniform in colour, capable of retaining polish and free from clay, cavities, spots of other colour, bands etc. Light colours are pleasing.

Summary :

The study of rocks provide us with important information about the nature of the Earth's crust and mantle. In addition, it enables us to gain a sense of the Earth's history, including tectonic processes that occurred over the long course of geological time. Petrology relies heavily on the principles and methods of mineralogy because most rocks consist of minerals and are formed under the same conditions. It can be studied under the branches of igneous, metamorphic, and sedimentary petrology.

- Igneous petrology focuses on the composition, forms of igneous bodies and texture of igneous rocks. Igneous rocks include volcanic and plutonic rocks.
- Sedimentary petrology highlights the composition and texture of sedimentary rocks. They are classified as sandstone, siltstone and shale based on the grain size and are bound together in a matrix of finer material. These rocks are further classified based on the products of weathering into residual and transported deposits.
- Metamorphic petrology deals with the composition and texture of metamorphic rocks which have undergone chemical, mineralogical or textural changes due to change of pressure, temperature or both.

EXERCISE

Q. 1. Select and write the correct answer :

1) An example of a discordant igneous intrusion is ....

   a) Sill b) Lopolith
   c) Laccolith d) Batholith

2) The hypabyssal equivalent of basalt is ....

   a) Gabbro b) Dolerite
   c) Pegmatite d) Dunite

3) A sedimentary rock in which the constituent grains are rounded is ....

   a) Breccia b) Sandstone
   c) Conglomerate d) Laterite

4) One of the structures exhibited by sedimentary rocks is ....

   a) granitic b) schistose
   c) clastic d) cross bedding

5) Thermal metamorphism of sandstone results in the formation of ....

   a) Marble b) Slate
   c) Quartzite d) Mica schist

6) Foliation in rocks is a characteristic feature resulting from ....

   a) cataclastic metamorphism
   b) dynamothermal metamorphism
   c) thermal metamorphism
   d) plutonic metamorphism

7) a) Examples of concordant bodies are sill, dyke, laccolith, lopolith.

   b) Examples of concordant bodies are sill, laccolith, lopolith, batholith.

   c) Examples of concordant bodies are sill, laccolith, lopolith.

   d) Examples of concordant bodies are sill, dyke, laccolith, lopolith, batholith.

8) a) The wavy pattern seen on beach sands is called ripple marks.

b) The wavy pattern seen on beach sands is called graded bedding.

c) The wavy pattern seen on beach sands is called cross bedding.

d) The wavy pattern seen on beach sands is called stratification.

9) a) Syenite — i) Hypabyssal acidic rock.

b) Rhyolite — ii) Plutonic acidic rock.

c) Granite — iii) Plutonic intermediate rock.

d) Pegmatite — iv) Volcanic acidic rock.

A) a) – iv); b) – i); c) – iii); d) – ii).
B) a) – ii); b) – iii); c) – i); d) – iv).
C) a) – iii); b) – iv); c) – ii); d) – i).
D) a) – i); b) – ii); c) – iv); d) – iii).

10) a) Residual rock — i) Shale

b) Chemical deposit — ii) Phosphorite

c) Argillaceous rock — iii) Limestone

d) Organic deposit — iv) Bauxite

A) a) – i); b) – iv); c) – ii); d) – iii).
B) a) – iii); b) – ii); c) – iv); d) – i).
C) a) – ii); b) – i); c) – iii); d) – iv).
D) a) – iv); b) – iii); c) – i); d) – ii).

11) a) Slaty cleavage — i) alternate light and dark coloured bands.

b) Gneissose structure — ii) cataclastic metamorphism.

c) Schistose structure — iii) thermal metamorphism.

d) Granulose structure — iv) parallel arrangement of minerals.

A) a) – iv); b) – iii); c) – ii); d) – i).
B) a) – ii); b) – i); c) – iv); d) – iii).
C) a) – iii); b) – ii); c) – i); d) – iv).
D) a) – i); b) – iv); c) – iii); d) – ii).

Q. 2. Answer the following :

1) What is a rock?
2) What is meant by the term ‘textures of rocks’?
3) Name the texture of igneous rocks which exhibits a large variation in grain sizes and shapes.
4) Give two examples of evaporites.
5) What is stratification?
6) What is graded bedding?
7) What is meant by metamorphism of rocks?
8) Describe confining pressure ?
9) Describe directed pressure ?

Q. 3. Answer in brief :

1) How are extrusive igneous rocks formed? Give an example.
2) What are sills? Describe with neatly labelled diagram.
3) Write a short note on clastic texture with example.
4) What are organic deposits? Give examples.
5) Describe slaty cleavage.
6) What is meant by thermal/ contact metamorphism?
7) Mention the factors responsible for rise in temperature.
8) Explain the role of fluids in metamorphism.

Q. 4. Write short notes :

1) How is equigranular texture formed in igneous rocks? Explain with diagram.
2) What is a laccolith? Describe its characteristics with the help of a neatly labelled diagram.
3) What is meant by cross bedding? Explain in brief with the help of a diagram.
4) What are residual deposits? Describe with examples.
5) Which are the major agents of metamorphism? Describe their role in brief.
6) What is meant by cataclastic metamorphism?

Q. 5. Describe the following :

1) Classify igneous rocks on the basis of mode of occurrence/ depth of formation. Give examples.
2) How are vesicular and amygdaloidal structures formed? Describe with diagrams.
3) Describe in brief, the processes involved in the formation of sedimentary rocks.
4) Classify sedimentary rocks according to their grain size, giving examples of each.
5) Explain schistose and gneissose structures with the help of labelled diagrams.

3 Palaeontology and Stratigraphy

Introduction :

Palaeontology is the study of ancient life that is preserved in the form of fossils. 'Palaeo' means ancient, 'Ontos' means life and 'Logos' is study. Initially, the term fossil was applied to any object dug up from the ground.

Today the word fossil is used to refer only to objects associated with prehistoric life forms older tha 11,000 years. The term fossil was coined by the German mineralogist Georgius Agricola (1494 -1555). Generally fossils are found in sedimentary rocks. The term fossil is further extended to any recognizable structure in sedimentary rocks that indicates some sort of life. Life on Earth in its primitive form probably came into existence about 3500 to 3600 million years ago. Currently, we are in geological time interval known as the Holocene epoch, which began about 11,000 years ago. Therefore, any remains or evidence of ancient life forms before the Holocene Epoch i.e. before 11,000 years ago definitely counts as a fossil. Fossils can range in size. Macrofossils can be held in the hand and examined with good hand lens. They can be several meters long and weigh several tons like logs of petrified wood and dinosaur bones. Microfossils are very small and require a microscope to study them. Their size can be in micrometres, e.g. fossilised pollen and spores.

Palaeontological studies deals with taxonomy, morphology of hard parts, their nature, inter - relationship, environmental implications, distribution, age and evolution of ancient life.

Two major branches of palaeontology are recognized, viz. Palaeozoology and Palaeobotany. Palaeobotany deals with study of plant fossils and palaeozoology with vertebrate and invertebrate animal fossils. Micropalaeontology is a specialized branch that deals with the study of microfossils. Paleoichnology comprises the study of Ichnofossils and/or Trace fossils. Palynology or Palaeopalynology is yet another branch, which deals with the study of organic walled microfossils like pollen, spores, seeds, seed coats etc.

Do you know?

1) Aristotle, the Greek philosopher was one of the first to classify living things into either plants or animals.
2) Leonardo da Vinci (1452-1519) stressed that fossils were organic in nature and natural in origin.
3) William Smith (1789-1839) a British engineer was the first to note that there is an intimate relation between the fossils and sedimentary rocks containing them. He realized the importance of fossils and further, described and defined sedimentary rock units on the basis of fossils contained in them. William Smith's observation was the beginning of a new era as integrated approach was significant in the study of palaeontology and stratigraphy.

Prerequisites of fossilisation :

When an organism is buried quickly, there is less decay and a better chance for it to be preserved as it does not come in contact with oxygen. Hard parts of organisms, such as bones, shells and teeth have a better chance of being fossilised. Number of prehistoric organisms living in geologic past exceeds many billions. It has been estimated that only one out of every

10,000 organisms leaves behind fossil record. So far only about 91,000 species of fossils are known.

If an organism is to be preserved in the form of a fossil there are a set of certain prerequisites like :

1) It is necessary that the organism possesses a skeleton of hard parts that can withstand decomposition.
2) Composition and structure of its hard parts should be suitable for preservation.
3) Further, it should be covered or buried quickly by some sediment (deposits), so that dispersal and disintegration of hard parts of skeleton is prevented.

Possession of a skeleton or hard parts and quick burial are the two most important prerequisites for preservation that are most commonly fulfilled in case of aquatic organisms. After the death of an aquatic organism, its body sinks to bottom of the water body. Later, it is quickly buried by sediment, preventing destruction and dispersal. Chances of burial and preservation of terrestrial or land animals are higher when they die on the banks of lakes or rivers. Rarely land animals may be covered by volcanic ash and instantaneously preserved. The probability of an animal being preserved as a fossil is further governed by the composition and structure of its hard parts. If the skeleton consists of thin fragile shell, it can easily broken and chances of preservation diminish; whereas tough and strong skeletons are more likely to be preserved. It is not only the nature of skeleton, but its composition which determines the degree of fossilization. If the skeleton is composed of siliceous matter, and calcium carbonate (invertebrates), chances of fossilization are high whereas, phosphatic vertebrate skeletons and chitinous skeletons of insects have maximum chances of preservation, as they dissolve with difficulties.

Modes of preservation of organisms for fossilisation :

1) **Entire organism preserved :** Rarely, the organisms are preserved in a virtually unaltered state. Ice, amber, and tar can preserve entire organisms e.g. Woolly mammoth preserved in ice from Siberia, insects preserved in amber from Baltic countries (fig. 3.1), Dominican Republic, fossils from tar pits of Rancho La Brea, California, USA.

Fig. 3.1: Insect preserved in amber

2) **Entire skeleton preserved :** Most of the vertebrate skeletons are entirely preserved due to differential solubility. Such skeletons and shells once buried remain unaltered e.g. entire skeletons of the giant reptiles of the Mesozoic era such as Mesosaurus braziliansis (fig. 3.2).

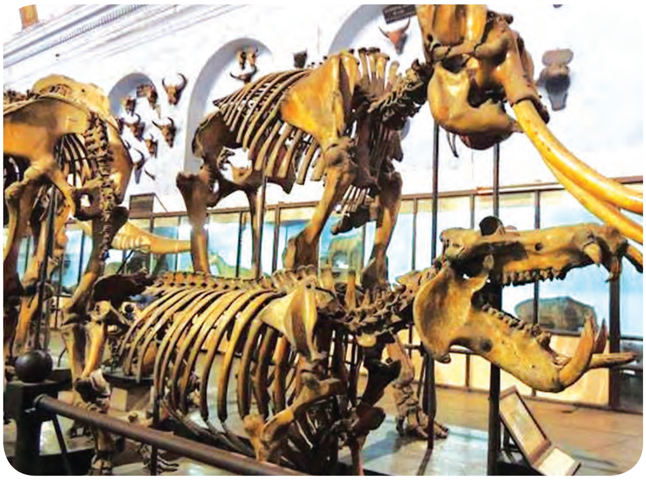


Fig. 3.2 : Entire skeleton of Mesosaurus braziliansis

3) **Petrification :** The process of removal and replacement of organic matter by inorganic minerals thereby converting the material

into rock is known as petrification. In this process, the replacement takes place molecule by molecule. Such fossils show internal and external details permitting the study of anatomy and morphology in detail. A variety of minerals are known to cause petrification. The most common replacing material is silica, calcite, dolomite, pyrite and accordingly, petrification may be a result of silicification, calcification, pyritization. e.g. Petrified wood fossils from Akal wood fossil park, Rajasthan, National fossil wood park, Thiruvakkarai T.N., National fossil wood park, Sathanur, T.N, and petrified woods near Chandrapur, Maharashtra (fig. 3.3).

Fig. 3.3 : Petrified wood

4) **Carbonization :** Process of carbonisation forms carbonized fossils. It is a process of incomplete chemical decomposition of organic matter, reducing it to a carbon residue or a thin film. Parts of plants are usually preserved with this mode. Buried broken parts of stems, leaves etc., undergo dehydration and decomposition loosing nitrogen, oxygen and hydrogen. Carbon contained within the remains of a soft-bodied animal or plant forms a stamp-like impression on the sediment Organisms like graptolites and plant fossils from Gondwana are preserved as carbonized fossils (fig. 3.4).

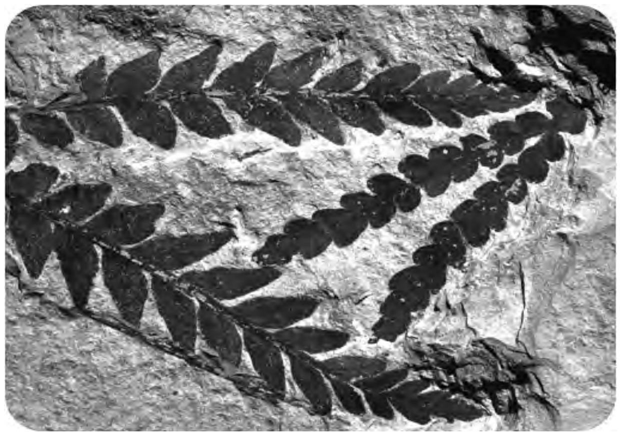


Fig. 3.4 : impression of carbonised plant fossils

5) **Imprints :** Imprint as a mode of preservation is more common in case of soft bodied organisms like jelly fish (fig. 3.5). They leave behind their impression on the surface of fine grained sediments. These preserved impression are indicative of many morphological features.

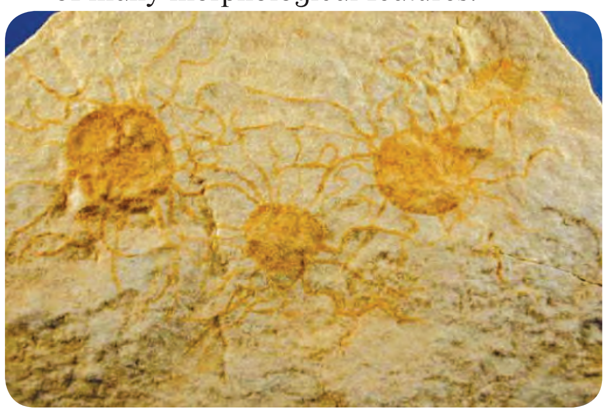


Fig. 3.5 : Imprint of jelly fish

6) **Cast and Mould :** Sometimes, open pores in the rock let water and air reach the organism or part of it, causing it to decay or dissolve, leaving behind a cavity in the sediment. This empty cavity is called a mould. A mould shows the original shape and the external morphology of the organism. Later, sand or mud may fill the mould and harden, forming a cast of the original organism. A cast is a replica of the original organism. This is the most common mode of preservation of invertebrate fossils e.g. shells from Cretaceous of Tiruchirappalli (TN), Bagh Beds (MP) and Jurassic of Kutch (Gujarat) (fig. 3.6)

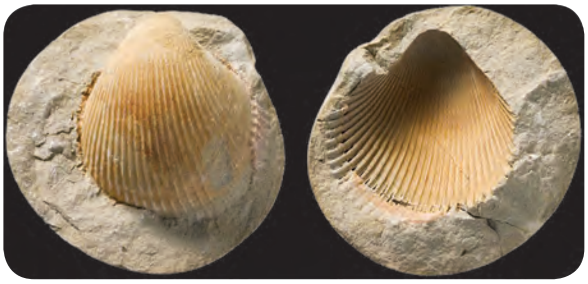


Fig 3.6: Cast and Mould of bivalve

Types of fossils :

Broadly speaking, paleontologists divide fossils into two main groups :

1) Body fossils 2) Trace fossils

1) **Body fossils :** Body fossils are remains of body parts of ancient animals, plants and other life forms. They may be preserved intact or fragmented (fig. 3.7a).

Fig. 3.7. a) Body fossil

2) **Trace fossils :** Trace fossils (sometimes also called ichnofossils) provide evidence about the movements and/or activities of ancient organisms, but not necessarily about their appearance. Tracks, trails, burrows, footprints, nests, worm burrows, gizzard stones, and coprolites are considered to be trace fossils. They range in size from worm burrows to dinosaur footprints (fig. 3.7 b).

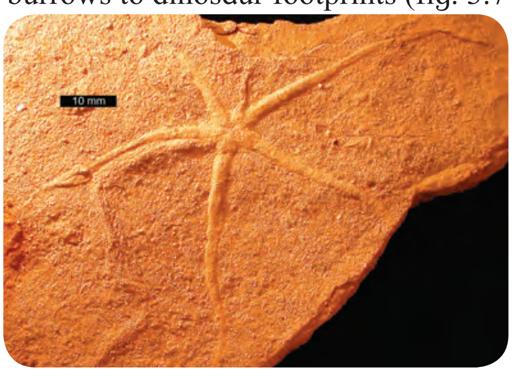


Fig. 3.7. b) Trace fossil

Do you know?

Various kinds of trace fossils : Track : an impression made by a single foot.

Trackway : a number of tracks made during a single trip.

Trail : an impression made by an animal without legs.

Burrows : a hole dug by a life form in loose sediment (like mud).

Borings : a hole dug by a life form into a hard substrate (like wood or rock).

Coprolites : animal faecal pellets that have fossilized.

Uses of fossils :

Fossil records have facilitated palaeontologists, stratigraphers and biologists to unravel the geological events. Many uses of fossils are known. Some important uses are as follows :

1) **Determination of the geological age of strata :** Geological age of the fossils is the geological age of the rocks they are contained in.

2) **Information of Palaeo- environment and history of deposition :** Characters of animals and plants from different environments vary. Presence of vertebrate fossils and plant fossils indicate terrestrial environments like lakes, ponds, rivers, flood plains, etc. Marine environments are indicated by th exclusive presence of fossils of corals, trilobites, brachiopods, ammonoids, nautiloids etc.

3) **Determination of palaeo-climate :** Terrestrial plants thrive in specific climatic conditions. The occurrence of fossils of such plants is evidence of the existence of climatic conditions in the geologic past. For example occurrence of palm fossils indicate tropical climate.

4) **Correlation of widely separated strata :** Fossils are frequently used to determine relative or comparative ages of sedimentary rocks. Similarity of fossils in widely separated rocks indicates equality in their age. So by associating similar fossils among such rocks, they can be correlated.

5) **Reconstruction organic evolution :** Fossil record is invaluable for reconstruction of organic evolution because change in characters of animals and plants is gradual. This change is recorded in the fossils found in successively younger strata. For example, the earliest horse of Eocene age was the size of a dog with five toes. It was succeeded by forms with lesser number of toes and increased height. Finally, modern day horse has evolved. This is the evidence of the evolution of modern day horse.

6) **Exploration of Petroleum and Coal Reserves :** Some microfossils like Foraminifera and Ostracoda are very sensitive to the environment. Therefore, they are indicators of environments. Marine reducing environment with rapid deposition, good compaction ratio, low current index and ideal temperature condition are essential for the generation of hydrocarbons. All these factors can be inferred with the help or microfossils. For exploration of petroleum, deep drilling is required. Such drilling must have stratigraphic control. For this purpose, accurate correlation of subsurface rocks is essential. Such correlation can be established by using microfossils, especially Foraminifers and Ostracods. Plant fossils are useful in the study of coal deposits.

Do you know?

Geo Parks aim to protect geodiversity (rocks, minerals, landforms and fossils) and promote geological heritage within the general public as well as support sustainable economic development of the area, primarily through the development of geological tourism.

It is interesting to know that the first stamp on fossils was issued by India. This stamp was issued to commemorate the Centenary of Geological Survey of India in 1951. The stamp features a fossil elephant: Stegodon ganesa", which was the probable direct ancestor of our modern day elephant. Such fossils were reported from Siwalik Hills of Himalayas.

Terminologies used in palaeontology :

1) **Index fossil :** These are fossils which are easily recognisable, distinctive, widely distributed and abundant. They existed for a limited life span. (e.g Ammonites from Mesozoic, trilobites from Palaeozoic). Index fossils are used as stratigraphic markers.

2) **Chemical fossils :** When some organisms decompose they leave a characteristic chemical signature. Such chemical traces provide indirect evidence for the existence of past life.

3) **Pseudo fossils :** These are visual patterns in rocks that are produced by naturally occurring geological processes rather than biologic processes. They can easily be mistaken for real fossils, for e.g. dendritic markings formed by filling of fissures in a rock by manganese oxide, which are tree like.

4) **Living fossils :** Living fossils are present day forms which also exists as fossils. (e.g.

cyanobacteria, horseshoe crabs, ginkgo biloba, cycads).

5) **Reworked fossil :** Reworking can happen to any fossil. It simply means that the fossil may have been removed from its original sedimentary layer and redeposited in a younger layer. A reworked fossil can mislead a geologists about age of the rock in which it was found

Do you know?

Lagerstatten Unique windows into the past

These spectacular fossil deposits represent an amazing 'snapshot' in time. These extraordinary fossil deposits, where organisms are so well preserved that even their soft parts remain as carbon films, are referred to as Lagerstätten, a German word meaning 'deposit places'.

Do you know?

Fossil parks in India

The Geological Survey of India (GSI) currently maintains the following fossil parks:

- Siwalik Fossil Park, near Saketi, Himachal Pradesh is notable for its life-size models of the vertebrates that might have roamed the Sivalik Hills 1.5-2.5 million years ago.
- Mandla Plant Fossils National Park, near Dindori, Madhya Pradesh is a park that attempts to preserve the fossil remains of a primordial forest that covered the region 40—150 million years ago.
- National Fossil Wood Park, Tiruvakkarai in Tamil Nadu.
- National Fossil Wood Park, Sathanur, in Tamil Nadu.

Other fossil parks in India include :

- Indroda Dinosaur and Fossil Park, Gujarat
- Ghughua Fossil Park, Madhya Pradesh
- Salkhan Fossils Park, Uttar Pradesh
- Akal Wood Fossil Park, Rajasthan
- Amkhoi fossil park, West Bengal
- Raiyoli dinosaur fossil park, Gujarat

Do you know?

Narmada human

On December 5, 1982, the geologist Arun Sonakia discovered the only known fossil of a human ancestor from South Asia on the banks of the Narmada, at a place called Hathnora village in Sehore district, nearly 35 kilometres east of Hoshangabad in Madhya Pradesh.

Fossil skull of Narmada human, belongs to the ancestor category of Homo erectus, who inhabited the Earth from 1.8 million to 200,000 years ago and preceded Homo sapiens.

Activity 1 :

Recreation of Fossil Moulds and Fossil Casts

Expected duration : Two, thirty minute sessions on separate days.

Instructions :

1) Place some clay at the bottom of a small container. This clay represents the bottom of the ocean.
2) Press a shell or bone into the clay. This is a hard part of organism that was buried in the clay.
3) Remove the shell or bone, and observe the imprint in the clay. This imprint is a mould of the shell/ bone.
4) In a second container, prepare some plaster of paris by adding water and mixing until it is creamy.
5) Pour the Plaster of Paris into the mould that has been created.

6) Next day, gently tap and remove the fossil cast.

7) Examine the fossil specimens from the first investigation. Identify the fossils as moulds, casts, or other.

Activity 2 :

Simulation of process of petrification :

Expected duration: Thirty minutes session for initial set up, several days for observations and thirty minutes session for conclusion and discussion.

We will model a process whereby the remains of a buried organism or part of an organism are replaced by minerals.

1) Cut two pieces of white sponge into a bone shape. One piece will be used to simulate fossil formation and the other will be used for comparison.

2) Fill a cup with hot water. Prepare a saturated solution of Epsom salts ($MgSO_4$) and add a few drops of food colouring.

3) Pour the solution into a pan.

4) Immerse one bone shaped sponge into the pan and observe the movement of water through the holes of the sponge.

5) Leave the pan untouched for several days until the sponge is dry.

6) Examine the dry sponge.

STRATIGRAPHY

It is a branch of geology that deals with the study of stratified and sedimentary rocks with reference to their description, identification, content, correlation and extent, both horizontal and vertical. 'Stratum' means a layer and 'graphy' means description. Therefore, stratigraphy is a descriptive study of layered or stratified (generally sedimentary) rocks.

The basic idea of stratigraphy is to arrange the rock units in chronological sequence, so that continuous history of the Earth can emerge. This is essential because rocks of different ages are found at different places.

Principles of stratigraphy :

Stratigraphy is based upon three fundamental principles :

1) **Principle of Uniformitarianism :** The concept of uniformitarianism was given by a Scottish geologist, James Hutton (1726-1799). In its simplest form, it states that the processes which have acted in the past, are essentially the same as those in operation on the Earth today. It can be summarized in the statement 'present holds the key to the past'. By actual observation, we can see that layering and variation of grain size seen in the sediments, on the banks of the modern stream, are the result of fluctuations in the velocity of the stream. Hence, we can summarize that the same phenomenon was responsible for the layering in ancient fluvial sediments. Likewise, we know that the ripple marks observed on beaches is a product of wave action. It is, therefore, logical to conclude that ripple marks present in sedimentary rocks were formed by the same process.

Do you know?

James Hutton FRSE (Edinburgh 1797)

was a Scottish physician, geologist, naturalist, chemical manufacturer and experimental agriculturalist. His work helped to establish the basis of modern geology. His theories of geology and geologic time, also called deep time, came to be included in theories which were called plutonism and uniformitarianism.

2) **Order of Superposition :** In 1669 Danish physician Steno on the basis of observation along the walls of the Arno Valley in Italy suggested the concept of Order of Superposition. He pointed out that in any series of sedimentary layers, lying in a normal disposition; the rocks at the bottom of a sequence are older than the rocks at the top of the sequence. However, where the rocks are over folded and thrusted or faulted, it is first necessary to determine whether the rocks are in their normal position or if are overturned.

3) **Faunal Succession :** The British surveyor, William Smith (1769-1839), is regarded as the father of modern stratigraphy and was the first to recognize the fact, that fossils could be used to correlate and date the strata in which they were found. During the course of his work, he noticed that the same assemblage of fossils always occurred in the same rock layers. Fossil species in layers above and below these layers were distinctly different. The fossils occurred in the same order in widely separated localities. This discovery of William Smith led to the establishment of the 'Law of Faunal Succession'.

Stratigraphic Correlation : Correlation is a method of finding equivalence in geological age or stratigraphic position between two rock units that are widely separated. Correlation may be local, regional, intra or inter basinal, short range or long range.

Methods of Stratigraphic correlation :

There are two methods of Stratigraphic correlation i) Lithological correlation and ii) Palaeontological correlation. It can be achieved by a) Physical/ lateral continuity and b) presence of marker horizon or key beds.

Most simple way of correlating strata on local scale is by ascertaining, if there is a physical continuity of strata. If one can walk physically from one locality to another on the same rock type, then correlation is established by the principle of continuity of strata (fig.3.8).

i) Lithological correlation :

If succession of lithological units is similar at different localities then there is every possibility that corresponding rock units are of the same age and can be correlated (fig. 3.9).

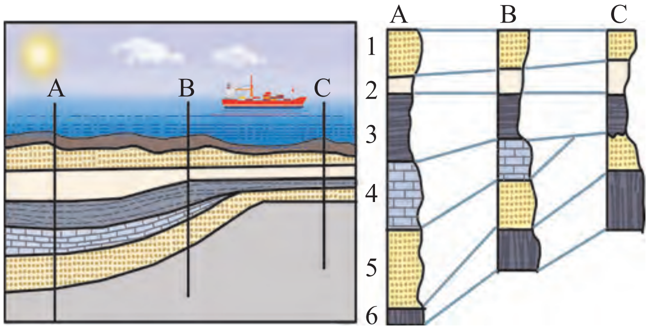


Fig. 3.9 : Correlation based on lithological succession

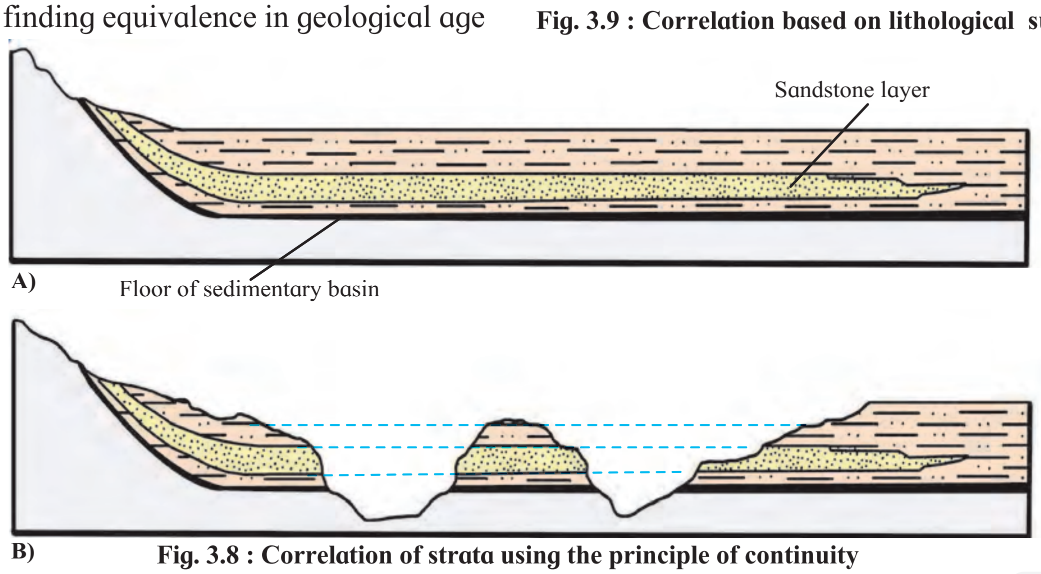


Fig. 3.8 : Correlation of strata using the principle of continuity

In the lower part the lithological succession is similar and the beds of shale and sandstone can be correlated in section A , B and C. It may be noted that, there is a slight variation in the thickness of these beds, at different localities. As we move upwards the limestone bed is missing in section c but correlated in Section A and B. If in a particular exposure only a small part of the succession is seen, then there can be difficulty in correlation.When the horizons pinch or die out, the presence of a Marker Horizon or Key Horizon is extremely useful. This bed is relatively thin but persistent bed having distinctive lithological or structural characters, which permit its identification without any difficulty.

From the above discussion, it is evident that lithological characters are useful only to limited extent. In areas where there is repetition of beds of identical composition and where marker horizons are missing, other methods like Palaeontological correlation are more useful.

ii) Palaeontological correlation :

It is entirely based on fossils or fossil assemblages. Organisms evolve with age and it is possible to differentiate between beds having the same lithology but with fossils of different age (fig. 3.10). Moreover a given species is likely to be present at widely separated localities during a particular period. This enables palaeontological correlation on a regional scale.

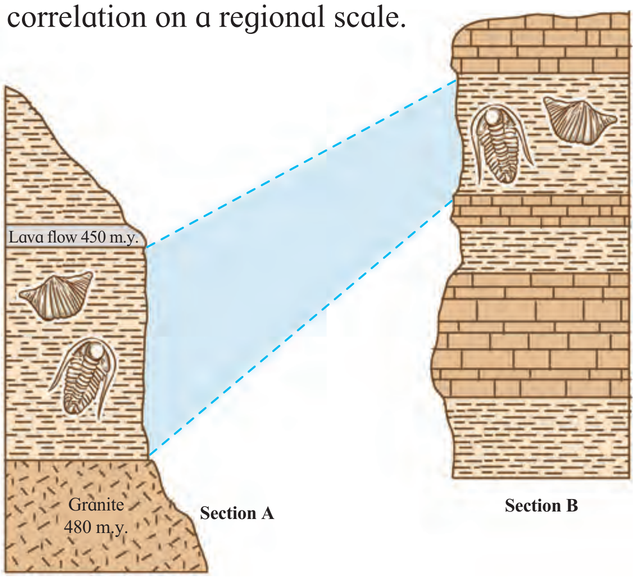


Fig. 3.10 : Palaeontological Correlation

Do you know?

Nicolas Steno (1638, 1686)

A scientist and a pioneer in both anatomy and geology. Steno was trained in the classical texts on science. However, by 1659 he seriously questioned accepted knowledge of the natural world. Importantly he questioned explanations for tear production, the idea that fossils grew in the ground and explanations of rock formation. His investigations and his subsequent conclusions on fossils and rock formation have led scholars to consider him one of the founders of modern stratigraphy and modern geology.

Standard Geological Time Scale :

Age of the Earth is about 4600 million years. This enormous geological time is divided into different durations. The successive sequential arrangement of geological time units for global reference is called as Standard Geological Time Scale (fig. 3.11). It is based on the following criteria. The periods of non-deposition (and consequently of erosion) are called as unconformities, that are related to widespread tectonic activities. The regional unconformities provide the natural boundaries for subdivisions of geological time into different units. Fossils are also of great importance in recognition of particular space of geological time. Radiometric age analysis of older rocks formed before biogenesis is also useful in this respect. The Geological Time Scale is also based on principles of stratigraphy that are discussed earlier.

The time units are Eons, Eras, Periods and Epochs. The largest time unit is known as Eon. It is successively divided into Eras, Periods and Epochs.

Most commonly two Eons Precambrian and Phanerozoic are recognized. The former indicates the time during which life was either absent, obscure or very primitive and the latter suggests the time when evolved life was in existence.

Precambrian Era is further sub divided into Hadean, Archean and Proterozoic.

The second Eon Phanerozoic is subdivided into three Eras viz. Palaeozoic Era containing ancient life, Mesozoic of middle life and Cenozoic contains modern/recent life. The life (animals/plants) of these eras (organic evolution) is shown in (fig. 3.11).

The Palaeozoic Era is further subdivided into (from older to younger) six Periods viz. Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian. Carboniferous is again subdivided into Missisippian and Pennsylvanian.

Mesozoic Era is further subdivided into three Periods, viz. Triassic, Jurassic and Cretaceous.

Cenozoic Era is subdivided into three Periods, viz. Paleogene, Neogene and Quaternary. Palaeogene Period consists of Palaeocene, Eocene, and Oligocene Epochs and Neogene Period consists of Miocene and Pliocene Epochs. Quaternary Period is subdivided into Pleistocene and Holocene Epochs.

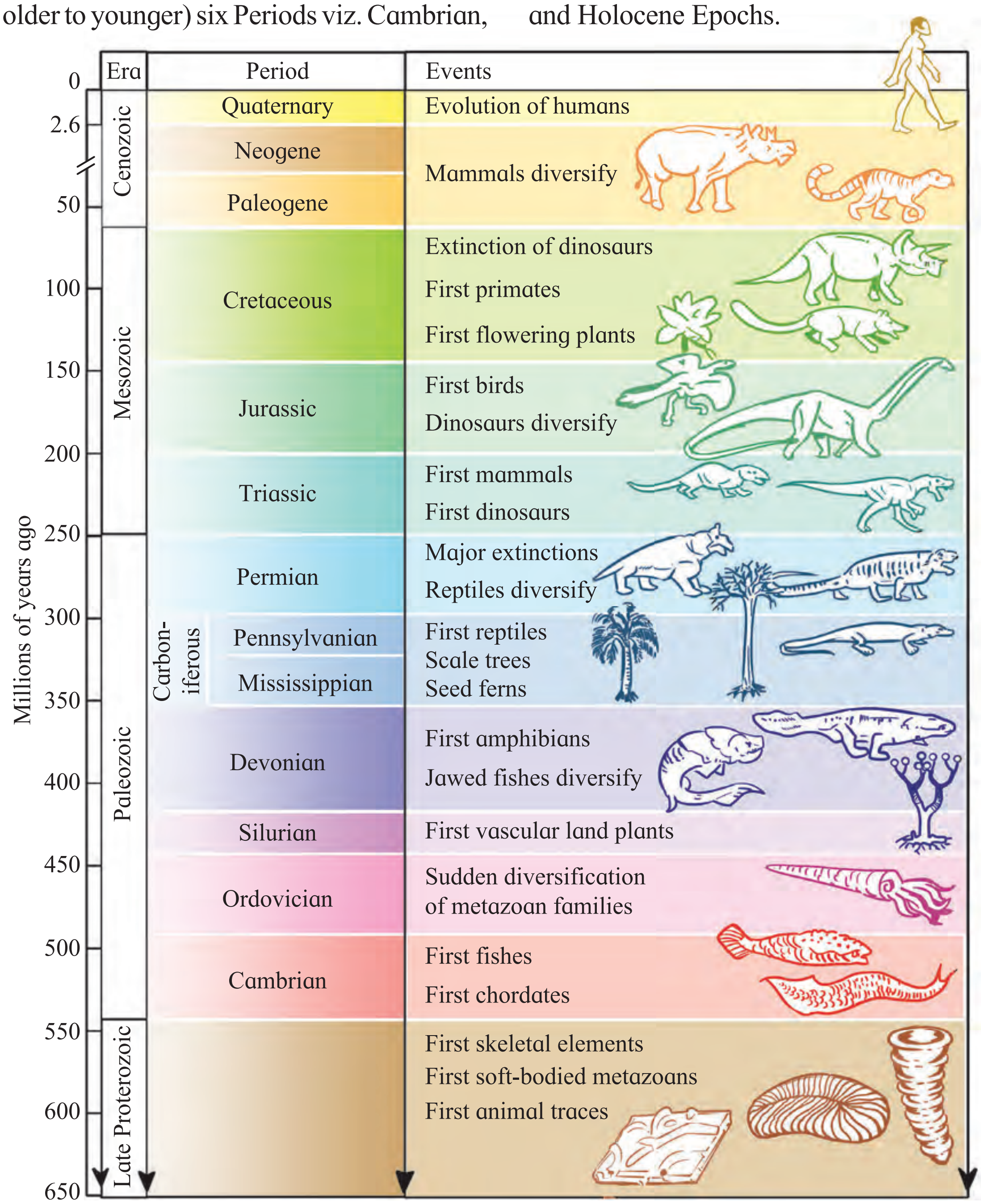


Fig 3.11 : Geologic time scale, 650 million years ago to the present

Do you know? Major Events in Geological Past do you know

Era	Period	Geological Events	Life (Animals-Plants)
Cenozoic	Quaternary	Early period known for ice age formation of Laterites	Ape like man appeared in Pleistocene, Aves, Fish, Important Age of man. Dicot-Monocot dominated.
	Paleogene and Neogene	Most of the Continents and oceans occupied their present positions, India collided with Asia, Alpine-Himalayan orogeny, Himalaya-Alps formed, Red Sea opened.	Age of mammals placental. marsupials, elephants, horses, pigs, dear, cows, primates, flowering plants dominated.
Mesozoic	Cretaceous	Few phases of marine transgression General elevation of land, fragments of Gondwanaland and Laurasia separated Andes and Rockys mountains formed.	Great extinction of ammonites, dinosaurs. Abundance of plants, extinction of cycades plants Mammals evolved.
	Jurassic	Fragmentation of Gondwanaland and Laurasia started, Atlantic ocean formed, Continental drift continued.	Age of dinosaurs Flying reptiles first bird Archaeopterix. True mammals appeared Gymnosperms dominated.
	Triassic	Pangea broke into Gondwanaland and Laurasia, Period of marine regression and salinity crisis	General recession in marine fauna Early dinosaurs came into existence Egg laying mammals, primitive flowering plants Angiosperms appeared.
Paleozoic	Permian	Siberia joined Laurassia-Gondwana, Formation of Pangaea, Ancient Atlantic closed.	Reptiles diversified, brachiopod declined, trilobites extinct. New land plants appeared
	Carboniferous	Gondwana was on South pole and covered by ice sheets, Gondwana collided with Laurassia, Hercynian orogeny began, Appalachian mountains formed.	Early reptiles evolved from amphibians. Amphibians were important. Luxuriant growth of bearing (gymnosperms) Spermatophytic plants Major Coal seams formed.
	Devonian	Formation of Laurassia, Mountain building activities on peak, Caledonian mountains formed, Old Red Sandstaones of Europe formed.	Golden age of fish. Arrival of amphibians. Vascular seedless pteridophytic plants abundant Graptolites become extinct.
	Silurian	Caledonian orogeny. Baltica-Laurentia collided, Formation of Caledonian mountains began, Siberia drifted to North.	Graptolites important, many trilobites declined in number Jawless fish appeared. First land Appeared.
	Ordovician	Main continents converged-diverged, Gondwana moved towards South pole, Baltica to South and Siberia to North	Bush like graptolites are index fossils. Cambrian invertebrates continued Probably by the end of Ordovician, first land plants appeared
	Cambrian	Six to Seven continents lying 60º N and 60º S, Present Antarctica was on Equator, there existed Panthalassic and echinoides, lapetus oceans. They were shallow	All major groups of invertebrate protozoans, mollusca, trilobites, graptolites, sponges, corals, brachiopods, bryozoans present Trilobites are index fossils. Calcareous blue-green Algae present.
Proterozoic		Ancient supercontinent Rodinia split and fragmented, fragments reunited to form another supercontinent Pannotia, Panthalassic ocean present. A chunk of Pannotia tore into fragments. Era began with tectonic zonation with formation of geosynclinal and platformal types of basins. Atmosphere-Hydrosphere purified.	Ediacara fauna of Australia is important Unicelluar life thrived. Stromatolites (biosedimentary structures) important. Burrows of soft bodied worms and termites.
Archean		Older shield areas formed. Extensive volcanism and plutonism. Highest degree metamorphism. Earth attained present shape. Ancient continents and oceans formed. Differentiation of Earth into crust, mantle and core. Accretion of Earth complete.	Probably no life.

Do you know?

William Smith (1769 –1839) was an English geologist, credited with creating the first detailed, nationwide geological map of U.K. It was only late in his life that Smith received recognition for his accomplishments, and became known as the "Father of English Geology".

Brief outline of stratigraphy of Peninsular India :

Lithostratigraphy is one of the elements of stratigraphy. It deals with organization of strata into sequential successive rock units arranged in a chronological order, entirely based on lithological characters. It has its own lithostratigraphic units, like; Supergroup, Group, Formation, Member and Bed. Many comparable mutually related rock layers form a Bed. Numerous Beds constitute a Member, several such Members give rise to Formation. Formation is the fundamental unit recognizable and mapable in the field and can be distinguished locally in a small area. Many such formations make still larger units, covering larger area called Group. An association of similar mutually related Groups constitutes a Supergroup that spreads over a very larger time span of the order of an Era.

Study of the Indian lithostratigraphic units with reference to their origin, distribution, content, age relationship and correlation is known as Indian stratigraphy. Important lithostratigraphic units of peninsula India, according to their age and correlation are depicted in table 3.1.

The important lithostratigraphic units of Peninsular India are described, in brief, with reference to their distribution, age, lithological characters, fossils and economic importance.

Table 3.1 Major Lithostratigraphic units of Peninsular India.

Era	Period	Litho. Unit
Cenozoic	Quaternary	Laterite-Bauxite
	Tertiary	Tertiary of Assam, Gujarat, Rajasthan, Maharashtra and East Coast.
Mesozoic	Cretaceous	Deccan Basalts.
	Jurassic	Upper Gondwana
	Triassic	Midde Gondwana
Paleozoic	Permian	Lower Gondwana
	Carboniferous	
	Devonian	
	Silurian	
	Ordovician	
	Cambrian	
Precambrian – Proterozoic		Vindhyan Supergroup
		Cuddapah Supergroup
Precambrian – Archean		Dharwar Supergroup
		Peninsular Gneisses
Precambrian		Basement complex of South India-Karnataka-Sargur Schist complex.

Do you know?

Sir Thomas Henry Holland KCSI KCIE FRS FRSE (22 November 1868 – 15 May 1947) was a British geologist who worked in India with the Geological Survey of India, serving as its director from 1903 to 1910. He later worked as an educational administrator at Edinburgh University.

Dharwar Supergroup :

Dharwar Supergroup is named after Dharwar district of Karnataka, where it is best exposed. The term Dharwar system was coined by R. Bruce Foote in1888.

Distribution : They occur in Dharwar-Mysore region. Older Dharwars are developed in Bababudan Hills in Chikmagular region. Younger Dharwars are observed at Chitradurga and Ranibenur regions.

Age : Archean.

Lithology : It is divided into three divisions as lower, middle and upper Dharwars. The Lower Dharwar contains rhyolites, schists and gneisses. The Middle Dharwar comprises of the granite porphyries, basic and ultrabasic intrusive igneous rocks, volcanic products and banded ironstones. The Upper Dharwar contains cherts, ferruginous silts, clay, conglomerates and quartzites.

Fossils : No evidence of life.

Economic importance : They are known to contain largest iron ore and manganese deposits. The associated granitic rocks supply best quality of granites for decorative purpose as well as building material. Gold and chromite deposits are also believed to belong to Dharwars. The other minerals include copper, lead, zinc, mica, asbestos and kyanite.

Cuddapah Supergroup :

Cuddapah Supergroup has been named after the Cuddapah district of Andhra Pradesh, where it is best exposed in the form of crescent- shaped outcrop, covering about 42,000 Sq km. area. These rocks are separated from the underlying Archean rocks by the Eparchean unconformity.

Distribution : The Cuddapah Basin of Andhra Pradesh has an east-west width of about 140 km. from Tadpatri to Nellore and is over 300 km. north-south in length from Ongole to Tirupati Nagari Hills. The Cuddapah rocks are largely undisturbed except along the eastern margin, where they are folded and faulted. The thickness of the Cuddapahs is about 6100 m.

Age : Lower Proterozoic.

Lithology : The Cuddapah Supergroup consists of quartzites, limestones, sandstones and slates without any fossils.

Fossils : These rocks are mostly non- fossiliferous

Economic importance : Economic resources of the Cuddapah system include limestone, iron, manganese, copper, cobalt, nickel, barites, asbestos, steatite, diamonds and other minerals.

Vindhyan Supergroup :

Vindhyan Supergroup of India is one of the largest and thickest sedimentary successions of the world. Vindhyan Supergroup has been named after great Vindhyan Mountain in Central India, where these rocks are well exposed. It can be separated into Lower and Upper divisions on the basis of an unconformity marked at various places.

Distribution : These rocks cover an area of about 1,00,000 sq. km. in Central India and are well exposed in the Son valley.

Age : Upper Proterozoic.

Lithology : This group consists of sedimentary rocks such as sandstones, shales and limestones with thickness often over 4000 m. to 6000 m.

Fossils : In the evolution of Peninsular India, for the first time some structures indicative of primitive organisms have been reported.

Economic importance : Shales from the Vindhyan Supergroup contain workable pyrite mineralization. All types of limestone, sandstone and shale are used as building materials. Huge limestone deposits supply basic raw material to cement industries. Most of the Indian diamonds are obtained from Vindhyan Supergroup. They are recovered either from Kimberlite pipes (volcanic necks) or from the diamond bearing conglomerate horizons. Excellent quality of glass sand is obtained from the weathered sandstone found in Vindhyans.

Gondwana Supergroup :

Gondwana rocks are named after the Gond tribe in Madhya Pradesh where these rocks are best exposed. Subsequent to the deposition of the

Vindhyan, there was a break in sedimentation in Peninsular India, till Carboniferous times. It was followed by the deposition, of thick sequence of fluviatile sediments constituting Gondwana sediments.

Distribution : Gondwana rocks mostly occur in the states of Madhya Pradesh, W. Bengal, Chattisgarh, Odisha, Jharkhand, Telangana and Maharashtra. Isolated outcrops occur in Gujarat and Rajasthan. Gondwana Supergroup is today exposed in linear tracts largely corresponding to the valleys of the river Narmada, Damodar, Mahanadi and Godavari.

Age : Permo-Carboniferous to Jurassic.

Lithology : They consist of alternation of sandstones, green sandstones, gritty sandstones, shales, limestones and coal.

Fossils : Plant fossils such as glossopteris, gangamopteris, conifers, cycades, and animal fossils such as crustaceans, fish, insects, reptiles, dinosaur (bones and eggs), coproliths and amphibians are found.

Economic importance : Gondwanas contain thick coal seams which contribute practically all of India's coal output. Gondwana Supergroup is well known for its good steam and gas quality of coal. Beds of oxides of iron ore products have been worked out for blast furnace. Clay for terracotta, pottery. Sandstone is extensively used as building material.

Deccan Volcanic Province (DVP) :

Deccan Volcanic Province cover an area of over 500,000 sq. km. in western India, with flat-topped hills, hence also known as plateau basalts. They also show step-like terrace form and consist of sub- horizontal flows.

Distribution : They occur almost in all parts of Maharashtra and extend to cover parts of adjacent states of Gujarat, Madhya Pradesh, Telangana and Karnataka. Maximum thickness of Deccan Basalts, (> 3500 m), is towards west. They thin out towards east.

Age : Cretaceous- Eocene.

Lithology : The volcanic rock type generally called as basalt is a fine grained, dark grey to porphyritic rock with vesicular to amygdaloidal structures. They contain a rich assemblage of secondary minerals, like; quartz and zeolites. Acidic and intermediate differentiates occur along the west coast of India. In the lower part, the basalt flows are sometimes separated by fluvial sedimentary beds, called the intertrappeans. The intertrappean beds show fresh water lacustrine deposit. Best examples of such sandwiched intertrappeans are in Malabar hills of Mumbai.

Fossils : Fossils of turtle, frogs, molluscs and some plant remains are reported from the intertrappean beds.

Economic importance : Compact basalt is extensively used for building constructions. Old temples, forts and buildings are built with basalt. Deccan basalts host amazing zeolites and silica bearing minerals (amethyst, quartz, chalcedony, agates) as secondary minerals in the cavities within the deccan basalts. A thin capping of bauxite is used as an ore of aluminium. Along the coastal Konkan area of Maharashtra, the laterite blocks are used as building material.

Cenozoic rocks :

In Peninsular India, Cenozoic sedimentary rocks of marine origin are found in Rajasthan, along the onshore and offshore regions of Gujarat and offshore regions of Maharashtra. These rocks are also developed along the east coast in Krishna-Godavari and Cauvery basins. These are important because they form reservoir rocks for oil and natural gas.

Distribution : These rocks occur in Rajasthan, Maharashtra, Andhra Pradesh, Tamil Nadu and Gujarat

Age : Eocene to Pliocene.

Lithology : Majority of the rocks are conglomerates, sandstones, limestones and shales.

Fossils : foraminifera and ostracoda.

Economic importance : Some of the Tertiary rocks contain huge lignite (Neyvelli) deposits, Oil and gas reserves and hydrocarbons (Bombay High, Cambay, K-G Basin).

Do you know?

Birbal Sahni FRS (14 November 1891 – 10 April 1949) was an Indian palaeobotanist who studied the fossils of the Indian subcontinent, was also a geologist who took an interest in archaeology. He founded the Birbal Sahni Institute of Palaeobotany in Lucknow, India. His greatest contributions lie in the study of fossil plants of India. Apart from writing numerous papers on these topics he also served as the President, National Academy of Sciences, India (1937-39 and 1943-44)and as an Honorary President of the International Botanical Congress, Stockholm in 1950.

Summary :

Palaeontology is the scientific and systematic study of fossils. It includes classification of organisms and study interactions with each other and their environments. There are different modes of preservation of organisms depending upon the presence or absence of hard parts, conditions of preservations and depositional environments. Fossils are useful in finding geological ages and correlation of the strata. . Stratigraphy works as a basic source of all geological information, about probable sites of oil and gas, coal reserves, metals (ore) and non-metallic deposits etc. Stratigraphy acts as an agent of identifying geological events. It unites the global information of rocks.

EXERCISE

Q. 1. Fill in the blanks :

1) Cenozoic era is age of ....
(Fishes, Trilobites, Reptiles, Mammals)

2) The principle of uniformitarianism was given by ....
(James Hutton, Steno, William Smith, Wadia)

3) Any evidence of ancient life before .... epoch is considered.
(Holocene, Pliocene, Miocene, Eocene)

4) The branch of geology dealing with study of trace fossils is known as ....
(Paleobotany, Paleoichnology, Palynology, Paleozoology)

5) Insect preserved in amber is an example of ....
(Imprint, Petrification, Entire organism preserved, Carbonization)

6) Paleozoic Era is subdivided into .... periods.
(4, 5, 6, 7)

7) The largest time unit is known as ....
(Eon, Era, Epoch, Period)

8) The Dharwar Supergroup of rocks have ....
(Evidence of life, Evidence of no life, Fishes, Trilobite, Mammals, Reptiles)

Q. 2. True or False :

1) In petrification only soft parts of an organism are preserved

2) Index fossils are useful in correlation.

3) The age of trilobite is Devonian.

4) Age of deccan basalts is Carboniferous.

5) The principle of faunal succession was given by William Smith.

6) Track and trails are the examples of body fossils/ Trace fossils.

7) The study of growth rings in a tree trunk is known as Ichnology.

8) A method of finding equivalence in geological age or stratigraphic position between two rock units is known as correlation.

9) Dharwar Supergroup rocks do not have any evidence of life.

10) The rocks of Vindhyan Supergroup are Upper Proterozoic in age.

11) The rocks of Gondwana Supergroup are of Permo-Carboniferous to Jurrassic age.

12) Gondwana Super group is well known for good quality of coal, plant fossils, reptiles and other fossils.

Q. 3 Choose the correct alternative :

1) The process of carbonisation takes place in case of …
   a) Plants
   b) Animals
   c) Both Plants and Animals
   d) All of the above

2) The diamond bearing beds are found in …
   i) Sandstones of Vindhyans
   ii) Conglomerates of Vindhyans
   iii) Limestones of Vindhyans
   iv) Shales of Vindhyans

Q. 4 Match the following :

i)

	A	B
a)	Devonian	i) Dinosaurs
b)	Cenozoic	ii) Mammals
c)	Jurassic	iii) Fish
d)	Cambrian	iv) Trilobites

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

ii)

	A	B
a)	Dharwars	i) Coal
b)	Cuddapah	ii) Gold
c)	Gondwana	iii) Limestone
d)	Deccan Trap	iv) Basalt

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

Q. 5 Write short notes on :

1) Uniformitarianism
2) Lithological Correlation
3) Carbonisation
4) Economic importance of Gondwana rocks
5) Branches of Paleontology
6) Imprints

Q. 6 Answer in brief :

1) Uses of fossils in organic evolution
2) Tertiary rocks of India
3) Economics of Deccan Volcanic Province
4) Stratigraphy of India

Q. 7 Answer in detail :

1) Differentiate between Imprint and Trace fossil.
2) Describe the uses of fossils.
3) Discuss the various methods of correlation.
4) Describe in detail different modes of preservation of fossils.
5) Describe Dharwar Super Group.
6) Describe Conditions necessary for fossilisation
7) Describe the Geological Time Scale
8) Describe Lithology of Vindhyan Super Group

4 Structural Geology

Introduction :

Rocks constituting the Earth`s crust have varying mechanical properties that get modified with increase in pressure and temperature as we go deeper within the Earth. The rocks are subjected to stress due to tectonic forces which cause their deformation. The driving force for tectonic activity is derived from convection within the upper mantle and the heat released from the core of the Earth. Deformation of rocks results into different structural features such as folds, faults, joints etc. The study of these structural features constitutes structural geology.

Stress and Strain :

Stress is the pressure applied to rocks and is expressed as force per unit area (F/A)

Rocks can be subjected to different kinds of stresses, such as:

a) **Lithostatic stress :** Rocks beneath the Earth's surface experience equal pressure exerted on them from all directions because of the weight of the overlying rocks. It is like the hydrostatic stress (water pressure) that a person feels pressing all around their body when diving deep into the water (fig. 4.1).

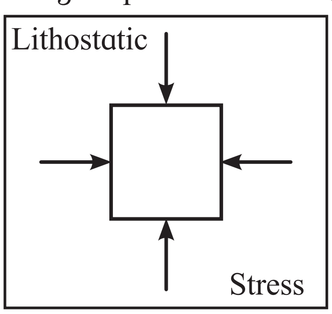


Fig. 4.1 : Depiction of lithostatic stress

b) **Directional stress :** In many cases, rocks may experience an additional, unequal stress due to tectonic forces. Three basic types of differential stresses are : (fig. 4.2)

(i) Tensional stress (stretching/ extension)

(ii) Compressional stress (squeezing)

(iii) Shearing stress

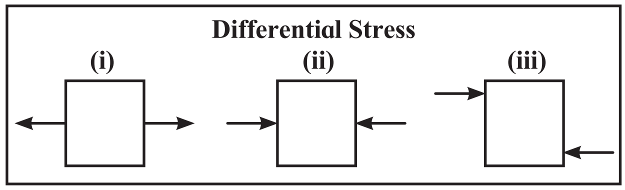


Fig. 4.2 : Types of directional stresses

Strain :

Strain is the deformation of rocks in response to stress.

Types of Deformation :

Four basic types of deformation are described as follows :

1) **Elastic deformation :** For small directional stresses, less than the yield strength, rock deforms like a spring as described by Hooke’s Law. It changes shape by a very small amount in response to the stress, but the deformation is not permanent. If the stress is be released, the rock returns to its original shape (fig. 4.3).

2) **Plastic deformation :** Rocks undergo plastic deformation and flow when the differential stress applied is stronger than their yield strength. This occurs in the lower continental crust and in the mantle (fig. 4.3).

3) **Brittle deformation :** Near the Earth's surface, rock behaves in its familiar brittle fashion. If the differential stress applied is greater than the rock's yield strength, the rock breaks, i.e. it fractures or fails with the development of weak zone/ plane (fig. 4.4).

4) **Ductile deformation :** At depths greater than 10 kms, the enormous lithostatic stress makes it nearly impossible to produce a fracture or crack, as the high temperature makes the rock softer, less brittle and more malleable (fig. 4.4).

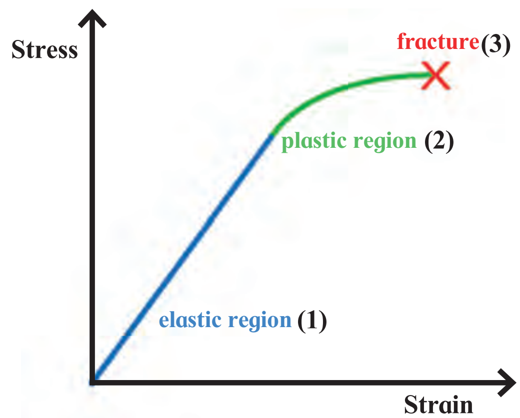


Fig. 4.3 Fig exhibiting stress strain relationship in rocks : With increasing stress, the rocks undergo: 1. elastic deformation 2. plastic deformation and 3. fracture

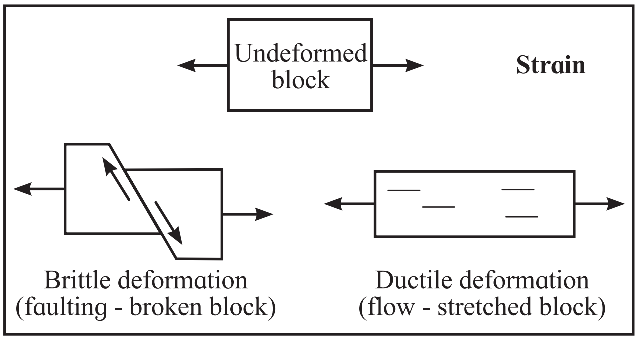


Fig. 4.4 : Brittle and ductile deformation

Measuring the attitude of beds :

The simplest form of deformation that is exhibited in any region, is tilting of initially horizontal sedimentary beds. The amount of tilting may vary within wide limits. The position of the bed on the ground surface is expressed as its attitude. This attitude of the beds can be quantified by their Strike and Dip.

The study of structural Geology requires measurement and documentation of the geometric features. The most common tool to measure strike and dip of an inclined bed is the compass or Brunton and/ or Clinometer compass.

Strike and Dip of Beds :

Any geological formation exposed on the surface is called an outcrop. Outcrops help geologists in examining and measuring the structural characteristics of rock beds and describing their orientation or position in space. Strike and dip refer to the orientation or attitude of a geologic feature. (fig. 4.5)

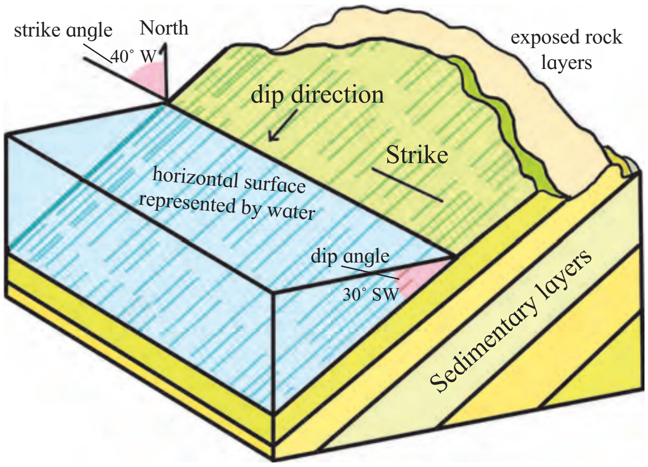


Fig. 4.5 : Attitude of beds

Strike refers to the direction of a horizontal line on any inclined plane such as a bed, fault plane, or any other planar feature. The strike direction is the direction of the line of intersection of that feature with a horizontal plane.

Dip literally means slope or inclination.

In structural geology, dip is expressed both as a direction and its amount or angle.

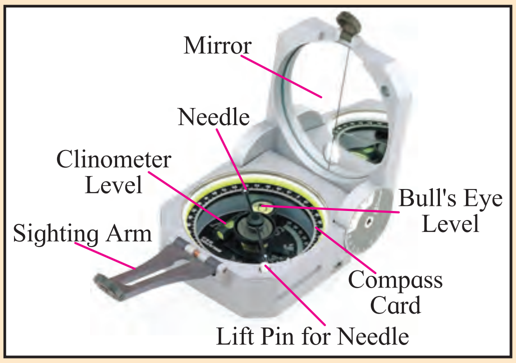
Dip direction is the direction along which maximum inclination of the bedding plane occurs. It is measured in a direction which is 90° to the strike direction. This is called the true dip.

The amount of dip or angle of dip gives the steepest angle of descent of a tilted bed or feature relative to a horizontal plane. This is given in degrees (0°-90°) and the direction in which the bed is dipping.

Do you know?

A Brunton compass, properly known as the Brunton Pocket Transit, is a precision compass made by Brunton, Inc. of Riverton, Wyoming. The Pocket Transit may be adjusted for declination angle according to one's location on the Earth. It is used to get directional degree measurements (azimuth) through use of the Earth's magnetic field. Holding the compass at waist-height, the user looks down into the mirror and lines up the target, needle, and guide line that is on the mirror. Once all three are lined up and the compass is level, the reading for that azimuth can be made. Arguably the most frequent use for the Brunton in the field is the calculation of the strike and dip of geological features (faults, contacts, foliation, sedimentary strata, etc.). Strike is measured by leveling (with the bull's eye level) the compass along the plane being measured. Dip is taken by laying the side of the compass perpendicular to the strike measurement and rotating horizontal level until the bubble is stable and the reading has been made. If field conditions allow, additional features of the compass allow users to measure such geological attributes from a distance.

As with most traditional compasses, directional measurements are made in reference to the Earth's magnetic field. Thus, measurements are sensitive to magnetic interference. For example, if the user is near an outcrop that contains magnetite or some other iron-bearing material, compass readings can be affected anywhere from several inches from the outcrop to tens of yards away (depending on the strength of the magnetic field). Since they are measured with a rotating level, dip measurements are unaffected by magnetic interference.



Apparent Dip and True Dip :

The dip angle and amount measured in a direction other than perpendicular the strike direction is called apparent dip. True dip is always greater than apparent dip. The apparent dip of the inclined bed will vary according to the direction in which it is measured, being zero parallel to strike and increasing in other directions till it is equal to the true dip when the direction of measurement is perpendicular to the strike. Table 4.1 describes the relationship between the orientation of the bed in relation to strike and dip.

Table 4.1 : Orientation of the bed in relation to strike and dip

Orientation of bed	Strike Direction	Dip Direction	Dip Amount (Angle)
Horizontal	Absent	Absent	Zero
Vertical	Present	Absent	90°
Inclined	Present	Present	>0° and <90°

Folds, faults, joints and unconformities :

Structural deformation or defects are represented by folds, faults, joints etc.

These are internal features exhibited by rocks as a resulting due to tectonic disturbances.

Folds :

When a set of layers are subjected to compressive forces, they bend upward or downward. Such bends in rocks are called folds. These bends or curves are a result of permanent deformation due to tectonic forces. Folds may occur singly, isolated or as extensive fold trains of different sizes. A set of folds distributed on a regional scale constitutes a fold belt, a common feature in orogenic zones.

Parts or Elements of a fold :

Different parts of a fold can be described as follows :

Axial plane : An imaginary plane that divides the fold as symmetrically as possible.

Axis or Hinge : It is an imaginary line along which the bedding plane has suffered maximum bending or curvature .It may or may not coincide with the axial plane.

Crest : The convex or the up-arched part of the fold.

Trough : The concave or the down-arched part of the fold.

Limbs or Flanks : The sides of a fold. In a series of folds, it is the part between the crest of one fold and the trough of the adjacent fold.

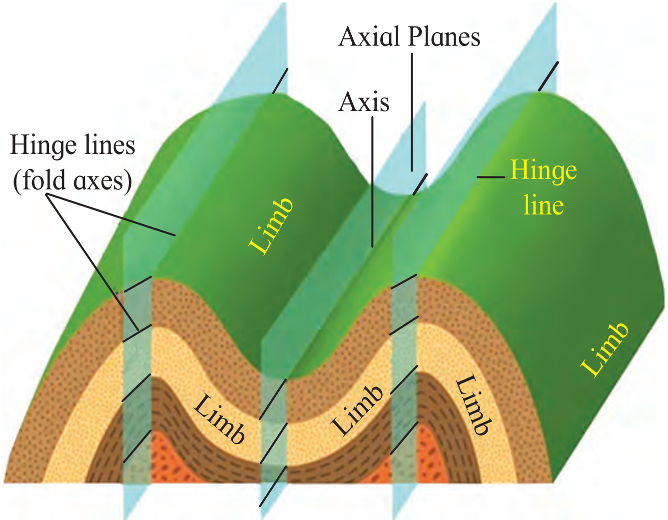


Fig. 4.6 : parts/ elements of a fold

Types of Folds :

1) **Anticline :** The name is derived from Greek term meaning 'opposite inclined'. Shape of this fold is convex upwards. The limbs of the anticline dip away from each other with reference to its axial plane. In such a fold, the older beds occur towards the core or centre of curvature (fig. 4.6).

2) **Syncline :** The name is derived from the Greek term meaning 'together inclined'. Syncline is opposite of anticline. Shape of the fold is convex downwards. The limbs of the syncline dip towards each other with reference to its axial plane. In this fold, the younger beds occur towards the core or centre of curvature (fig. 4.6).

3) **Symmetrical Folds :** The axial plane is vertical and divides the fold into two equal halves in such a way that one half is the mirror image of the other. In such folds, the two limbs dip by the same angle on either side of the axial plane. The compressive forces acting on the beds from either side are equal (fig. 4.7).

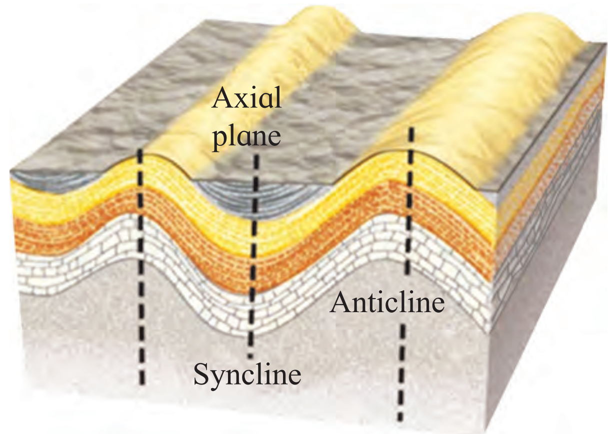


Fig. 4.7 : Symmetrical folds (anticline and syncline)

Symmetrical Folds are of two types :

Symmetrical Anticline : The axial plane is vertical and the two limbs dip away from each other by the same angle.

Symmetrical Syncline : The axial plane is vertical and the two limbs dip towards each other by the same angle.

4) **Asymmetrical Folds :** The axial plane is inclined. In such folds, the two limbs dip at different angles on either side of the axial plane. The unequal angles of dip imply that the forces acting on the beds from the two sides were unequal (fig. 4.8).

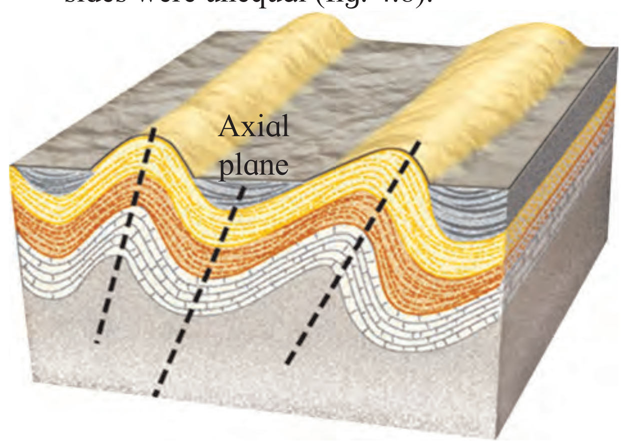


Fig. 4.8: Asymmetrical folds (anticline and syncline)

Asymmetrical folds may be two types:

Asymmetrical Anticline : The axial plane is inclined and the two limbs dip away from each other by different angles.

Asymmetrical Syncline : The axial plane is inclined and the two limbs dip towards each other by different angles.

Significance of Folds :

1) **Mountain building :** Folds result in the most stable features like mountains. Folds can give rise to valleys, hills and long mountains ranges. The great, lofty mountains like the Himalayas in India are fold mountains.

2) **Groundwater occurrence :** In terms of ground water occurrence, synclines sometimes furnish favourable conditions to tap enormous quantities of ground water. Thus, some artesian springs and wells, which are good sources of groundwater owe their origin to synclinal structures.

3) **Oil and Gas deposits :** Occurrence of important oil and gas deposits of the world are associated with anticlinal folds which serve as good structural traps of these valuable and strategic deposits (fig. 4.9).

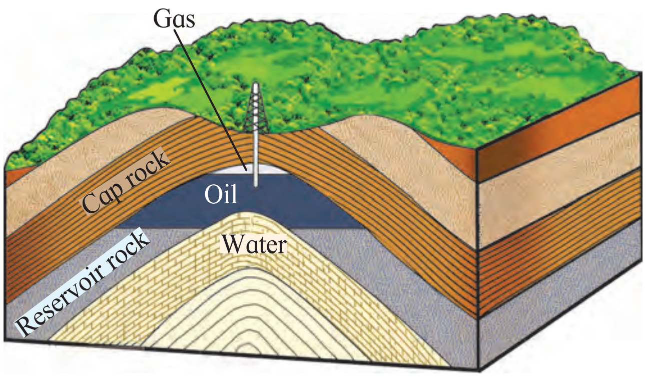


Fig. 4.9 : Anticlinal trap

Do you know?

Mumbai High Field

Bombay High (now Mumbai High) is an offshore oilfield located in the Arabian Sea, approximately 160 km west of the Mumbai coast. Discovered in 1974, by the Russian and Indian oil exploration team from seismic exploration vessel Academic Arkhangelsky while mapping the Gulf of Khambhat between 1964 and 1967. The field started production in 1976 and is operated by Oil and Natural Gas Corporation (ONGC).

Every oil resource rock requires Structural traps which are mainly salt domes, coral reefs, fault traps and fold traps. In case of Bombay High, the structure is a north-northwest to south-southeast trending doubly plunging Anticline with a faulted east limb, 65 km long and 23 km wide and is the most probable reason for calling it 'Bombay High'.

The oil field consists of two blocks named Mumbai High North (MHN) and Mumbai High South (MHS). The blocks were divided based on shale barrier assisting in independent exploitation of reserves at the north and south fields of Mumbai High.

The discovery of Bombay High with subsequent other discoveries of oil and gas fields in western offshore changed the oil scenario of India.

Faults :

Fault is a planar fracture in a volume of rock across which there has been significant displacement along the fracture as a result of Earth movements. (fig. 4.10). Energy release associated with rapid movement on active faults is the main cause of earthquakes.

Fig. 4.10 : Displacement along a fault

Parts or Elements of a Fault :

The different parts of a fault are:

1) **Fault Plane :** This is the plane along which the adjacent blocks are relatively displaced. In other words, this is the fractured surface on either side of which the rocks have moved past one another (FFF) (fig. 4.11). Its intersection with the horizontal plane gives the strike of the fault (ss). The direction (d) along which the fault plane has the maximum slope is its true dip amount.(θ)

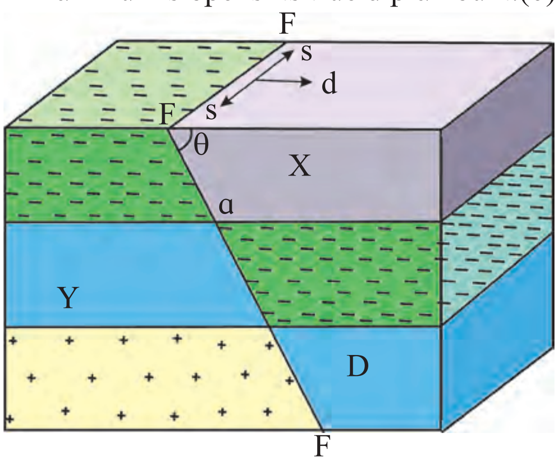


Fig. 4.11 : Parts of a Fault

2) **Foot wall and Hanging wall :** In an inclined fault, the faulted block which lies below the fault plane is called the footwall (Y) and the other block which rests above the fault plane is called hanging wall (X) (fig. 4.12).

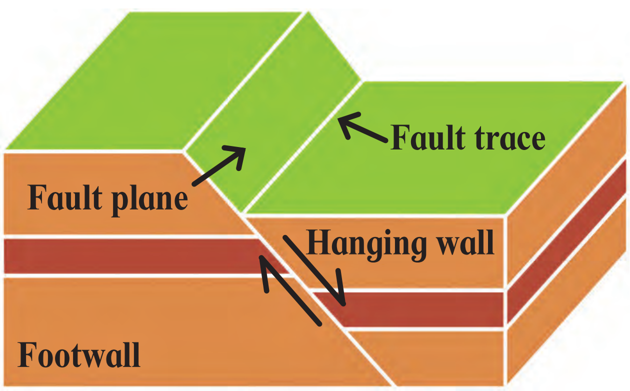
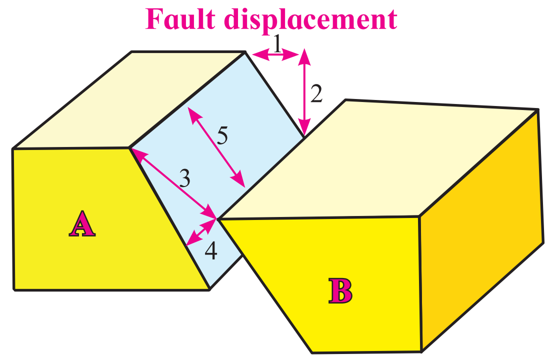


Fig.4.12 : Foot wall and hanging wall

Measurement of movement along fault plane :

1) **Slip :** The displacement that occurs during faulting is called the slip. The total displacement is known as the net slip. This may be along the strike (strike slip) or the dip direction (dip slip) or along both (fig. 4.13).

2) **Heave and Throw :** The horizontal component of displacement is called 'heave' and the vertical component of displacement is called 'throw' of the fault (fig. 4.13).



1-Heave 2-Throw 3-Slip 4-Strike slip 5-Dip slip

Fig. 4.13 : Components of displacement along a fault

Types of Faults :

Faults are classified on the basis of relative movement of footwall and hanging wall.

1) **Normal Faults :** In a Normal fault or Gravity fault, hanging wall is displaced down with reference to the footwall. These terms are very appropriate because the hanging wall is normally expected to move down along the slope of the fault plane, under the influence of gravity. Normal faults have dips greater than 45°. Lengthening and extension of the crust occurs in normal faults. They result from strong tensional forces (fig. 4.14).

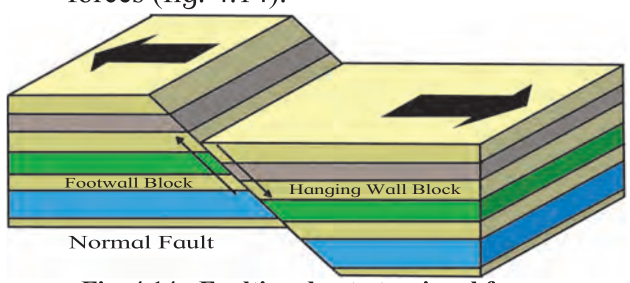


Fig. 4.14 : Faulting due to tensional forces

2) **Reverse Faults :** Hanging wall block moves up relative to the footwall. Reverse faults have dips greater than 45°. Shortening of the crust occurs in case of reverse faults. They result from strong compressional forces (fig. 4.15).

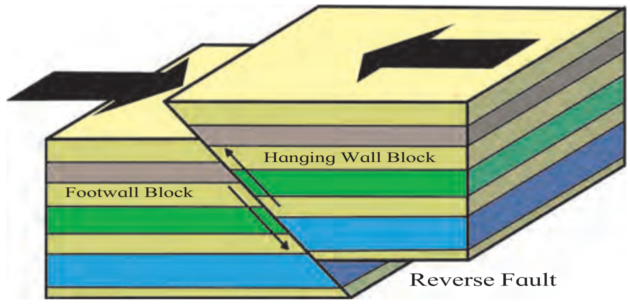


Fig. 4.15 : Faulting due to compressional forces

Thrust Faults :

A special case of reverse faults is the thrust Fault. Thrust faults are characterised by low dip angles (less than 45°) (fig. 4.16).

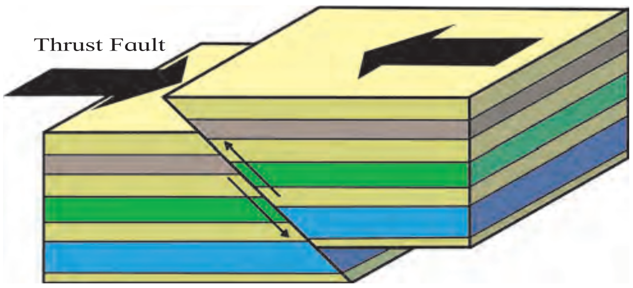


Fig. 4.16 : Thrust fault

3) **Strike Slip Faults :** In this type of fault, the blocks slide past each other along the direction of strike. This fault is also called lateral fault, trans-current fault, wrench fault or tear fault (fig. 4.17).

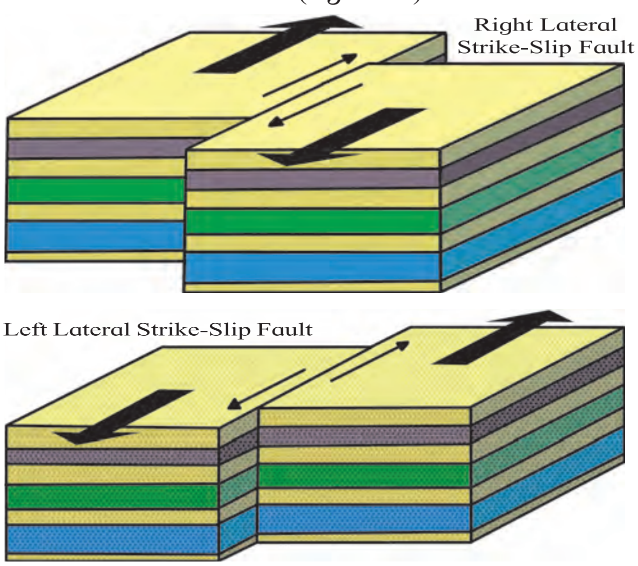


Fig. 4.17 : Strike slip fault

4) **Step Faults :** When a set of parallel normal faults occur at regular intervals, they give a step-like appearance and are called step faults (fig. 4.18).

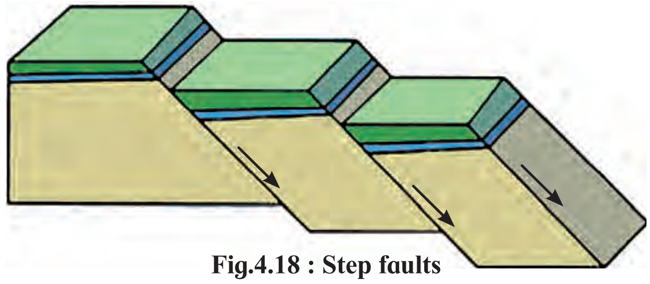


Fig.4.18 : Step faults

5) **Horst and Graben :** When normal faults with mutually diverging or converging fault planes occur, then a few wedge-shaped blocks called 'horsts' are displaced upwards and other blocks called 'grabens' are displaced downwards (fig. 4.19).

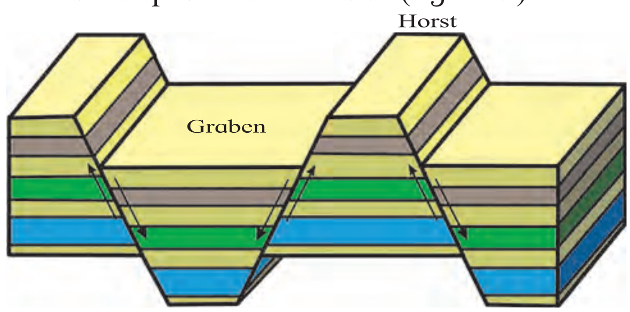


Fig. 4.19 : Horst and Graben

Horst and Graben of large magnitudes result in the formation of block mountains and rift valleys respectively.

Significance of Faults :

Faults are important due to their various disastrous as well as useful effects.

These can be briefly given as follows :

(i) Faults cause considerable damage to rocks and are therefore real hazards in mining and engineering works.

(ii) Fault breccia and fault gouge (pulverized rocks) have low strength and are poor foundation materials.

(iii) Earthquakes and landslides are likely to be triggered by faults.

(iv) It is necessary to have knowledge of the faults as they are conducive to earthquakes. This helps in proper designing of large civil structures for e.g. dams tunnels etc. to prevent them from damage.

(v) Many fault zones are most suitable sites for mineralization of gold, silver, copper etc.

(vi) Faults may create lakes, swamps, marshy zones, hot water springs etc. These hot water springs are good sources of geothermal energy.

(vii) Some fault zones form potential oil traps.

Joints :

Joints are fractures found in all types of rocks. They are cracks or openings along which there is no displacement parallel to the joint plane. The presence of joints divides the rocks into a number of parts or blocks. Though joints may be described as mere cracks in rocks, they differ mutually. Joints, like cleavages of minerals, occur oriented in a definite direction and as sets (fig. 4.20).

Fig. 4.20 : Geological outcrop showing joints

Types of Joints :

1) **Strike Joints :** Joint is parallel to the strike of adjacent beds (fig. 4.21).

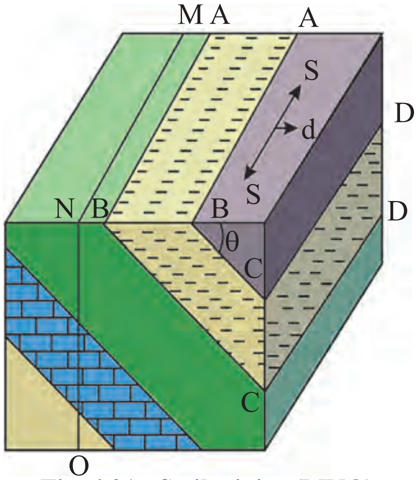


Fig. 4.21 : Strike joint (MNO)

2) **Dip Joints :** Joint is parallel to the dip direction of adjacent beds (fig. 4.22).

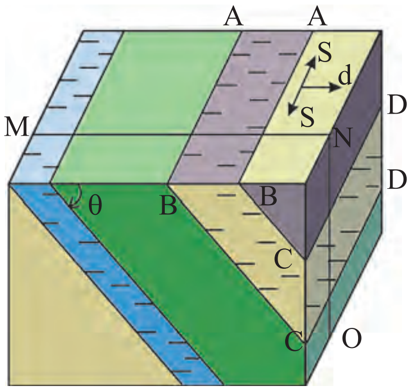


Fig. 4.22 : Dip joint (MNO)

3) **Diagonal Joints :** Joint is oblique to the strike and dip direction of the adjacent beds (fig. 4.23)

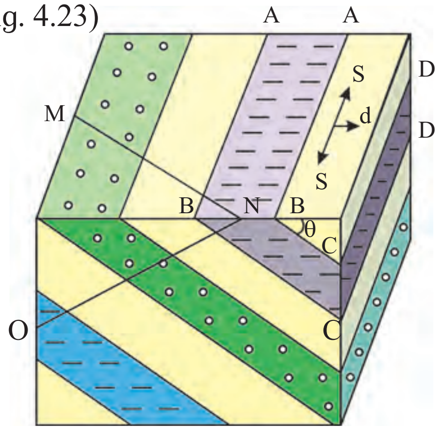


Fig 4.23 : Oblique joint(MNO)

4) **Bedding Joints :** Joint is parallel to the bedding plane (fig. 4.24).

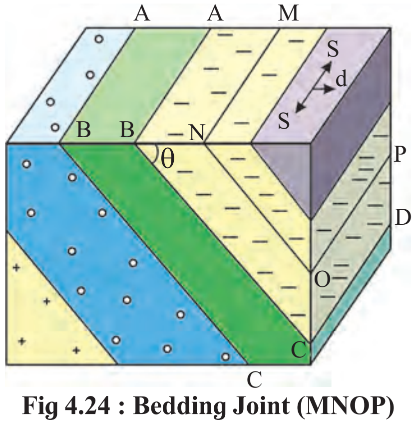


Fig 4.24 : Bedding Joint (MNOP)

5) **Columnar Joints :** Columnar joints are sets of intersecting closely spaced fractures. They occur in many types of igneous rocks and form as the rock cools and contracts. Columnar joints can occur in cooling lava flows as well as in some shallow intrusions (fig. 4.25).

These columns can vary from few

centimetres to few metres in diameter, and can be several hundred metres in height. They are typically parallel and straight, but can also be curved and vary in dimension. The number of sides of the individual columns can vary from 3 to 8.

Most commonly, columnar joints are observed in basalts. Figure explains the genesis or mode of formation of columnar joints.

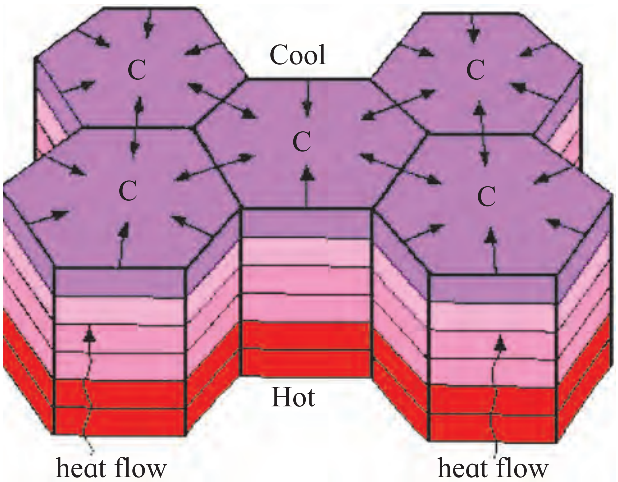


Fig. 4.25 : Columnar joints

When lava cools it contracts, giving rise to the formation of cracks or fractures. If contraction occurs at centres which are equally spaced, then polygonal fracture pattern develops. If the cooling centres are not evenly spaced, then other geometries of fractures, such as 5-sided or 7-sided columns may occur. e.g., columnar joints in basalts of Naldurga Fort, Osmanabad, Panhala Fort, Kolhapur, Gilbert Hill, Mumbai, St. Mary's island in Arabian sea off the coast of Malpe in Udupi, Karnataka, India (fig. 4.26).

Fig. 4.26 : Columnar joints at St. Mary's island Malpe in Udupi, Karnataka, India

Columnar joints are not restricted to basalt. This structure can also form in other types of rocks that undergo cooling and contraction e.g columns in rhyolite at Utan in Thane district.

Significance of Joints :

From the civil engineering point of view, joints are important because they split the rocks into a number of blocks, which in turn reduce the competence of rock mass, increase their porosity and permeability and make them susceptible to quick decay and weathering.

Occurrence of joints increases the ground water potential in any place. The area affected by joints can be easily improved by suitable methods such as cement grouting or plugging.

Unconformities :

Unconformities are a product of diastorphism and involve tectonic activity in the form of upliftment and subsidence of landmass. When sediments are deposited continuously, without any major break, they are said to be conformable. All the beds belonging to a conformable set possess the same strike, dip direction and dip amount. On the other hand, if a major break occurs in sedimentation between two sets of conformable beds, it is termed as an unconformity. Thus, an unconformity is a contact between two rock units that are unconformable with each other. An unconformity, typically, is a buried erosional surface that represents a break in the geologic record. An expected age of layer or layers of rocks is/are missing due to erosion and some period in geologic time is not represented. This is known as a hiatus.

Types of Unconformities :

Different types of unconformities can be recognised as follows :

1) **Angular Unconformity :** When the younger beds and the older set of strata are not mutually parallel, then the unconformity is called an angular unconformity. In such a case, beds of one set occur with a greater tilt or folding (fig. 4.27 and fig. 4.28).

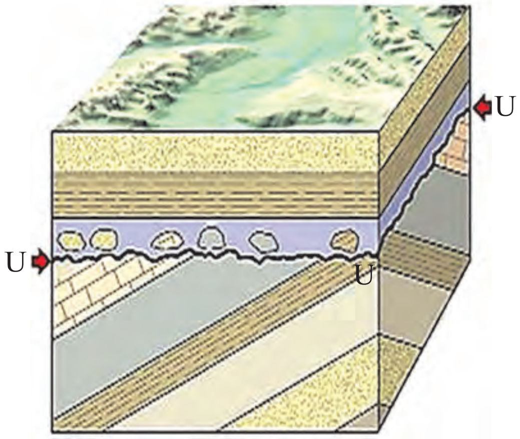


Fig. 4.27 : Angular unconformity

Fig. 4.28 : Field example of angular unconformity

Hutton's angular unconformity at Siccar Point where 345-million-year-old Devonian Old Red Sandstone overlies 425-million-year-old Silurian greywacke.

2) **Disconformity :** Disconformities are usually erosional contacts that separate parallel bedding planes of the upper and lower rock units. Since disconformities are hard to recognize in a layered sedimentary rock sequence, they are often discovered when the fossils in the upper and lower rock units are studied.

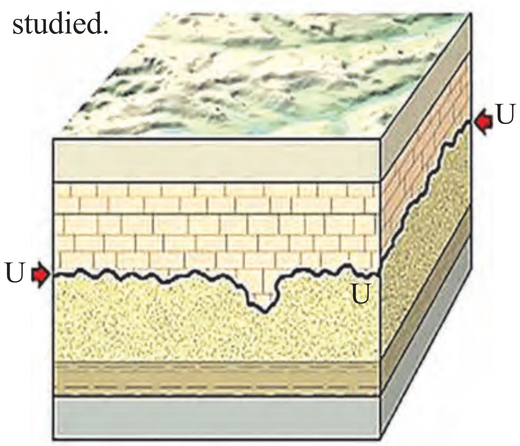


Fig. 4.29 : Disconformity

Fig. 4.30 : Field example of Disconformity

Disconformity between sedimentary rocks in California, with conglomerate deposited upon an erosion surface on the underlying rocks.

A gap in the fossil record indicates a gap in deposition. Disconformities are usually a result of erosion, but can occasionally represent periods of non –deposition (fig. 4.29 and fig. 4.30).

3) **Nonconformity :** When the underlying older formation is represented by igneous or metamorphic rocks and the overlying younger formation is made up of sedimentary rocks, the unconformity is called non-conformity. A nonconformity suggests that a period of long-term uplift, weathering and erosion occurred to expose the older, deeper rock at the surface before it is finally buried by the younger rocks above it. A nonconformity is the old erosional surface on the underlying rock (fig. 4.31 and fig. 4.32).

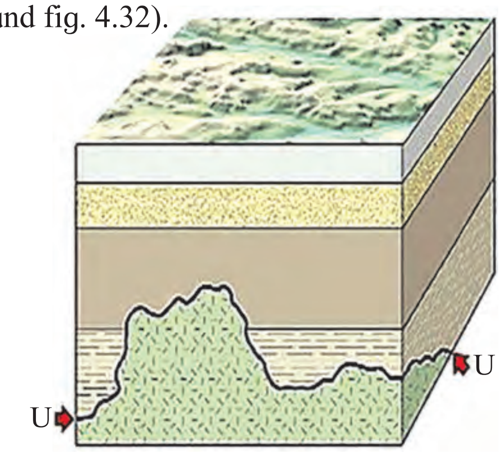


Fig. 4.31: Nonconformity

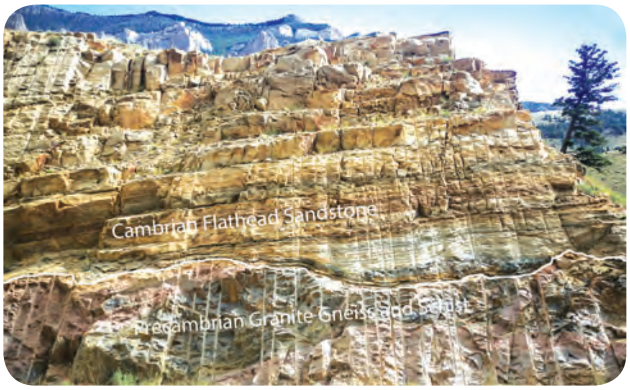


Fig. 4.32 : Nonconformity at yellow stone highway Wyoming

Significance of unconformities :

1) An unconformity represents a gap, break or interval in deposition of beds and forms a record of a gap in time.
2) Recognition of unconformities is useful for subdividing stratigraphic units, determining the timing of tectonic activity, correlating certain stratigraphic boundaries, interpreting sea-level changes etc.
3) In certain situations, an unconformity produces oil traps and aquifers.
4) Unconformities help in visualizing and in reconstructing palaeogeography of a region.
5) Unconformities are favourable sites for mineralization (e.g., uranium, aluminium, phosphates and gold).
6) It is an important structure that affects site conditions for engineering works. It generally forms a weak zone.

Application of Structural Geology :

- In Engineering geology and geotechnology : Problems such as construction of bridges, dams, power plants, highways, airports and issues related to building foundations.
- In Environmental geology : Problems such as land use, planning, earthquake hazard, volcanic hazard, distribution of groundwater.
- In Petroleum and mining geology : Understanding geometric techniques, projection of faults, geologic contacts, trends of regional processes that control the concentration of minerals and hydrocarbons.

Summary :

This chapter deals with the study and interpretation of different structural features like folds, faults, joints, unconformities, etc. found within rocks which constitute the Earth's crust. It helps to interpret their mode and mechanism of formation. This study is used as a framework to analyze and understand global, regional and local scale features. It is of prime importance in the fields of Economic Geology, both, Petroleum Geology and Mining Geology and has varied applications in Geotechnical Investigations and Engineering Geology. Environmental geologists and Hydro geologists apply this knowledge in the selection of suitable geological sites.

EXERCISE

Q. 1. Select and write the correct answer :

1) The direction of a line formed due to intersection of an inclined bed with the horizontal plane is called……..

   a) Strike b) dip c) hade d) heave

2) An imaginary plane that divides the fold into two equal halves is known as……..

   a) Axis b) Axial plane
   c) Fault plane d) Crest

3) An anticline is a fold that is……..

   a) Convex upwards and has its youngest bed at the core
   b) Convex downwards and has its youngest bed at the core
   c) Convex downwards and has its oldest bed at the core
   d) Convex upwards and has its oldest bed at the core

4) In an asymmetrical syncline, the two limbs……..
   a) Dip towards each other by the same angle
   b) Dip away from each other by the same angle
   c) Dip towards each other by different angles
   d) Dip away from each other by different angles

5) A fracture along which there has been no slipping or displacement of rocks is called a …
   a) Joint   b) Unconformity
   c) Fault   d) Fold

6) A type of fault in which the hanging wall block has been displaced upwards with respect to the footwall block is called ……
   a) Graben   b) Normal fault.
   c) Horst   d) Reverse fault

7) An unconformity in which the older bed is made up of igneous or metamorphic rocks is called……….
   a) Conformity   b) Nonconformity
   c) Angular unconformity
   d) Disconformity

Q. 2. Match the following :

1) a) throw — i) hanging wall displaced upwards
   b) Normal fault — ii) Horizontal displacement.
   c) Heave — iii) Footwall displaced upwards.
   d) Reverse fault — iv) Vertical displacement

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

2) a) anticline — i) limbs dip by equal angle
   b) Asymmetrical fold — ii) Convex downwards
   c) Syncline — iii) Convex upward
   d) Symmetrical — iv) Limbs dip by unequal angles

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

3) a) Angular unconformity — i) surface of erosion or non deposition.
   b) Nonconformity — ii) older series parallel to younger series.
   c) Unconformity — iii) older series not parallel to younger series.
   d) Disconformity — iv) older bed made up of plutonic igneous rocks.

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

Q. 2. Answer the following :

1) How will you explain the terms strike and dip of beds?
2) Differentiate between true dip and apparent dip of a bed.
3) Which are the different parts of a fold? Describe with a neatly labelled diagram.
4) Explain the characteristics of an anticline/ syncline with a neatly labelled diagrams.
5) Which are the different types of folds? Describe with neatly labelled diagrams.
6) Describe the different parts of fault with neatly labelled diagram.
7) Differentiate between Normal and Reverse faults?
8) Which are the different types of joints?

Q. 4. Answer in detail :

1) Differentiate between Symmetrical fold and an Asymmetrical fold?
2) Explain the different types of faults with neatly labelled diagrams.
3) What are columnar joints? How are they formed?
4) What is an unconformity? Discuss its process of formation.
5) Differentiate between a Disconformity and Nonconformity?

5 Economic Minerals and Rocks

Introduction :

The branch of Geology that deals with the economically important minerals is known as Economic Geology. Economic Geology studies the exploration, exploitation and origin of the mineral deposits. Economic mineral deposits are geologic bodies that may be worked for one or more minerals or metals. Many geological processes result in the concentration of minerals and elements that are exploited as natural resources. Minerals are the most important natural resources that dictate the industrial and economic development of a country. There is an ever-increasing global demand for these resources due to improved standards of living, industrialization and the growth of population.

The occurrence of economic minerals is therefore restricted to particular geological process and hence the geographic location. Some igneous processes give rise to the ore deposits containing base metals (Cu-Pb-Zn) whereas the coal and petroleum are formed through sedimentary processes. Diamonds are generally restricted to a rock called Kimberlite and chromite is found in a rock called peridotite. It is therefore necessary to understand the mode of origin of the rocks and explore their mineralogy to find whether the rock contains any economic mineral of exploitable value or not.

There are serious implications of the availability of these resources to development of any civilization. In modern times, the industrial revolution has heavily depended on the availability of natural mineral resources.

Terminology used in economic geology :

An ore is a natural concentration of one or more minerals, i.e. rock from which one or more metals can be extracted economically. i.e. the value of the metal obtained must be more than the cost of mining, transportation and processing. Ores of important metals such as iron aluminium, gold, platinum, copper etc. are part of economic and industrial growth of the country. Ore is explored through systematic knowledge of economic and mining geology.

Ore comprises of ore minerals, gangue minerals, and country rock. Earlier the metal bearing deposits were considered as ores however, more recently, nonmetallic minerals of commercial importance are also considered ore minerals.

Gangue comprises of minerals which are associated with the ore. Gangue minerals are commercially insignificant in a particular period of time, possibly becoming ore minerals at a later date. They are commonly silicates, carbonates, or fluorides, and rarely sulfides.

Tenor is the metal content of the ore. It is generally expressed as a percentage and in case of precious metals, it is expressed in parts per million (ppm). Tenor depends on the price of the metal. Higher the price of the metal, the lower the metallic content necessary and vice- versa. The minimum acceptable cut-off grade of the metal content in an ore depends on various factors like nature and size of the deposit, its location in terms of distance and transportation, metal price and the cost of its extraction.

Do you know?

Several government agenies such as GSI, MECL and Mining companies in India carry out geological exploration. The license, records and the economic values of these minerals are maintained by the government agencies like Indian Bureau of Mines and State Departments of Geology and mining. Minerals that contains elements or metals used in national security and defense industries are Strategic Minerals, and they are mined and exploited by the agencies like AMD and IRE. These regulatory organizations manage the industrial supply and use of these metals in India.

The natural resources of economic values can be classified into fuel, non-fuel, metallic and non-metallic. The resources of particular industrial interests and metallic mineral (ores) are shown in table 1. Metallic minerals (ores) occur in combination with other elements which must be separated. Iron, copper, gold, silver, lead, tin, zinc, aluminum, platinum etc. are metallic minerals whereas, clay, limestone, sand, salt, sulphur, phosphate etc. are non-metallic minerals. The non-metallic minerals can be used in their raw form. Non metallic minerals occur in abundance and are available on a local level for local consumption. Thus while metals are international commodities most of the non-metals rarely enter into world trades (there are exceptions such as diamonds).

Economic minerals metallic, non-metallic and mineral or fossil fuel

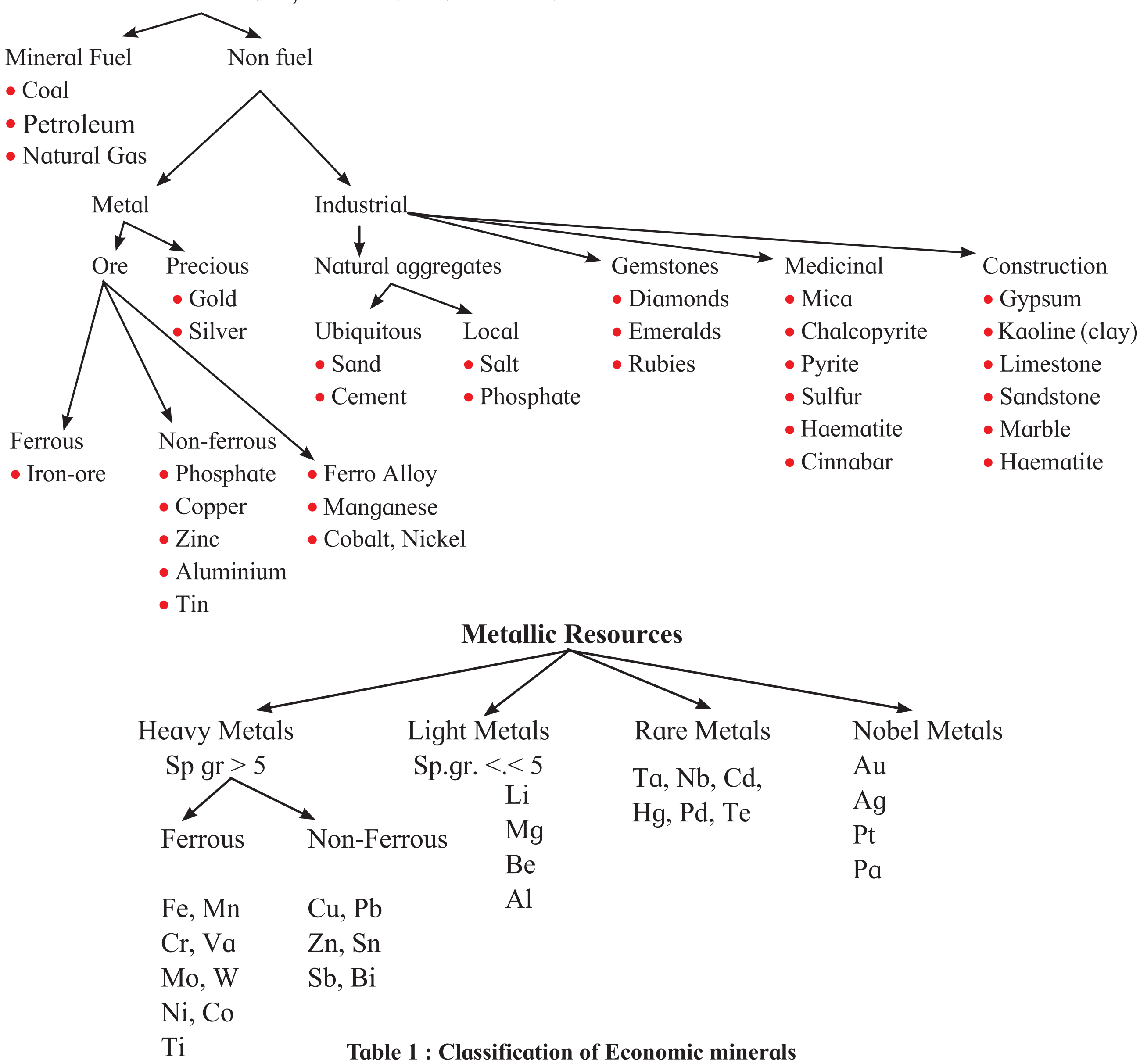


Table 1 : Classification of Economic minerals

Mineral deposits in India :

The mineral resources of our country are vast and varied. The minerals that are found abundantly, are exported and those in which India is deficient, are imported.

Some of the important minerals are described with respect to their chemical composition, physical properties, occurrence and State wise distribution in India.

Ore Minerals:

Iron ores :

The word iron itself comes from 'iren' in Anglo-Saxon. Iron is the fourth most abundant element {5.00%} in the Earth's crust by weight.Iron ore is most often found in the forms of hematite and magnetite.

i) Haematite :

Originally named about by Theophrastus from the Greek word 'Haematitislithos' for 'blood stone' in 300/325 BCE. It is possibly the first mineral ever named ending with a '-ite'suffix. Translated in 79 AD Pliny the Elder to haematites, or 'bloodlike' in allusion to the vivid red colour of the powder. It is known as Gairika in Ayurveda. (fig. 5.1)

Fig. 5.1 : Haematite

Chemical Composition : Fe_2O_3

Colour : Steel grey, iron black

Lustre : Submetallic.

Streak : Cherry red.

Form : Reniform, compact microcrystalline or scaly aggregates and sometimes botryoidal.

Cleavage : Absent.

Fracture : Uneven.

Hardness: 5.5 to 6.5.

Specific Gravity : 4.9 to 5.3

Uses : Used as an ore of iron, as a gem stone and in preparation of Ayurvedic medicines.

Occurrence : In metamorphic rocks like Banded Haematite Quartzite (BHQ).

ii) Magnetite :

Originally called loadstone, is a variety of magnetite i.e. natural magnet (fig. 5.2). Named in 1854 by Wilhelm Karl Von Hai dinger after the locality Magnesia, Greece.

Fig. 5.2 : Magnetite

Chemical Composition : Fe_3O_4

Colour : Iron black.

Lustre : Metallic to submetallic.

Streak : Black.

Form : Massive, granular

Cleavage : Absent.

Fracture : Uneven.

Hardness : 5.5 to 6.5.

Specific Gravity : 5.18.

Uses : Magnetite is used as an iron ore, abrasive, fertilisers, pigment in paint and as an aggregate in high density concrete.

Occurrence : As primary constituent in igneous and metamorphic rocks (banded magnetite quartzite) or as a sedimentary deposit.

Geographic Distribution in India :

Iron ores occurs on a large scale in India. Large deposits of haematite are found in Chhattisgarh, Goa, Jharkhand, Karnataka, Maharashtra and Odisha. Most of these ores are embedded in Banded Haematite Quartzite

(BHQ). The ore deposits consist of alternating bands of haematite and recrystallized Quartz. In Maharashtra, the iron ore deposits occur mainly in Chandrapur, Ratnagiri and Bhandara Districts.

Manganese ores :

Manganese is found as a free element in nature. It is often found in combination as a large variety of minerals. The name of manganese may have come either from the Latin word 'magnes' meaning magnet, or from black magnesium oxide 'magnesia-nigra'. It is the 12th most abundant element in the Earth's crust.

India is the world's fifth largest producer of manganese ore with iron. Polymetallic nodules also called manganese nodules, are rock concretions found on the sea bottom. Manganese is chiefly obtained from ore minerals like Pyrolusite and Psilomelane.

i) Pyrolusite :

The name pyrolusite is derived from Greek word 'pyro' means fire and 'louein' means to wash (fig. 5.3). It was used to remove brown and green tints in making of glass.

Fig. 5.3 : Pyrolusite

Chemical Composition : MnO_2 (Manganese oxide).

Colour : Black, Iron grey or dark steel grey.

Lustre : Metallic, dull, Earthy.

Streak : Black, iron black or dark steel grey.

Form : Botryoidal, reniform, massive.

Cleavage : Absent.

Fracture : Brittle, uneven, Earthy.

Hardness : 6 to 6.5

Specific Gravity : 4.4 - 5

Uses : Important ore of manganese.

Occurrence : Large deposits formed in a bog, lacustrine or shallow water environments.

ii) Psilomelane :

The name Psilomelane is derived from Greek word 'psilos' meaning smooth or bald and 'melas' meaning black in allusion to form and colour (fig. 5.4).

Fig. 5.4 : Psilomelane

Chemical Composition : $MnO_2.H_2O$ (Hydrated oxide of manganese).

Colour : Iron black to steel grey, brownish black.

Lustre : Sub- metallic.

Streak : Brownish black

Form : Massive, botryoidal, reniform, stalactitic.

Cleavage : Absent.

Fracture : Uneven.

Hardness : 5 to 6.

Specific Gravity : 3.7 to 4.7.

Uses : Important ore of manganese.

Occurrence : As a secondary mineral formed by the weathering of other manganese bearing minerals, and also as large deposits formed in lacustrine or shallow water environments.

Geographic Distribution in India :

Manganese ores are mostly found in Maharashtra and Madhya Pradesh which together produce more than half of India's manganese.

Copper ores :

Copper gets its name from Latin word 'cuprum' meaning from the island of Cyprus. Copper ranks as the third most consumed industrial metal in the world after iron and aluminium.

Copper was probably the first metal used by human. It is a soft but tough metal, very ductile and malleable and therefore is used in electrical industry and utensils. Copper is used in various alloys like brass (Cu+Zn), bronze (Cu+Sn+Al), and Electrum (Au+Cu+Ag).

The important ores of Copper are Chalcopyrite, Malachite, Cuprite and Native copper.

i) Chalcopyrite :

Name-named in 1725 by Johann Friedrich Henckel from the Greek word 'chalkos' meaning copper and 'pyrites' means strike. Also called Maxika in Ayurveda (fig. 5.5)

Fig. 5.5 : Chalcopyrite

Chemical Composition : $CuFeS_2$.

Colour : Brass yellow.

Lustre : Metallic.

Streak : Greenish black.

Form : Massive.

Cleavage : Poor or indistinct.

Fracture : Uneven, conchoidal.

Hardness : 3.5 to 4.

Specific Gravity : 4.1 to 4.3.

Uses : Important ore of copper.

Occurrence : It mainly occurs as hydrothermal vein deposit.

ii) Malachite :

Named after the Greek 'mallows' in allusion to the green colour of the leaves. Referred to as Sasyaka in Ayurveda.

Chemical composition : $Cu_2 (CO_3) (OH)_2$

Colour : Bright green

Streak : Pale green

Lustre : Adamantine, vitreous, silky, dull.

Form : Acicular, fibrous, botryoidal, granular

Cleavage : Perfect

Fracture : Conchoidal, uneven

Hardness : 3.5 to 4

Specific gravity : 3.6 to 4

Geographic Distribution in India :

Copper ore is chiefly found in Andhra Pradesh, Jharkhand, Jammu and Kashmir, Kerala, Rajasthan and West Bengal.

Lead ore :

Native lead was probably first discovered in The Langban dist. in the nineteenth century.

The Latin name is also source of the English word 'Plumbing' and 'Plumber' due to the historic use of lead in water pipes. Some researchers have argued that Roman's wide spread use of lead for water pipes and eating utensils have in part contributed to their civilization decline.

Lead is commonly found to be occurring with zinc as polymeric Sulphides (ZnS). The important ore of Lead is Galena (PbS).

i) Galena :

Galena—Named by Pliny the Elder in 77-79 AD. from the Greek word 'galena' meaning 'lead ore' (fig. 5.6).

Fig. 5.6 : Galena

Chemical Composition : PbS

Colour : Lead grey.

Lustre : Metallic.

Streak : Black, lead grey.

Form : Massive, octahedral or cubic crystals, granular.

Cleavage : Three sets, perfect

Fracture : Uneven, sub conchoidal.

Hardness : 2.5.

Specific Gravity : 7.4 to 7.6.

Uses : Used to extract lead. It is mainly used in lead acid batteries.

Occurrence : It is found in structurally disturbed metamorphic terrains and also as hydrothermal deposits. It occurs in pegmatites and limestones and many a times associated with zinc ores.

Geographic distribution in India :

Chhattisgarh, Gujarat, Himachal Pradesh, Rajasthan,Tamil Nadu, Uttar Pradesh and Uttarakhand.

Zinc Ore :

The name Zinc comes from it's Latin name 'Zincum'. Sphalerite is an important ore mineral.

Uses : The important ore mineral is Sphalerite.

i) Sphalerite :

Named in 1847 by Ernst Friedrich Glockerfron the Greek word 'sphaleros' means 'treacherous rock' in allusion to the ease with which dark variety was mistaken for galena,but yielded no lead.

Sphalerite also known as blend or zinc blend, is the major ore of zinc.

Chemical Composition : ZnS.

Colour : Yellow, light to dark brown, black, red brown, colourless, light blue, green.

Streak : Pale yellow to brown.

Lustre : Admantine, resinous.

Form : Massive, granular, crystalline.

Cleavage : Perfect.

Fracture : Conchoidal.

Hardness : 3.5 to 4.

Specific Gravity : 3.9 to 4.1.

Uses : Important ore of Zinc.

Occurrence : It is found in metamorphic, igneous and sedimentary rocks.

Geographic Distribution in India :

Andhra Pradesh, Gujarat, Jharkhand, Karnataka, Madhya Pradesh, Odisha and Rajasthan.

Aluminium ore :

The name aluminium is derived from Latin word 'alumen' means älum. It is the third most abundant element in the Earth's crust. Aluminium is most widely used after iron.

The chief ore of aluminium is Bauxite (fig. 5.7). The term 'Bauxite' is used for a rock made of aluminium oxides and is named after Les Beaux in France, where it was first located. It is mixture of hydrated aluminium oxide minerals like gibbsite, diaspore and bohemite. Large amount of high- grade Bauxite is found in India (around 2500 million tons.)

i) Bauxite :

Fig. 5.7 : Bauxite

Chemical Composition : $Al_2O_3.2H_2O$.

Colour : Yellowish, off-white, pinkish, reddish brown.

Lustre : Dull, Earthy.

Streak : Whitish,yellowish

Form : Pisolitic, Amorphous.

Cleavage : Absent.

Fracture : Uneven.

Hardness : 2.5 to 6.5

Specific Gravity : 2.3 to 3.5.

Uses : Used as an ore of aluminium and in the abrasive, refractory.

Occurrence : It occurs as residual sedimentary deposit, formed as a result of weathering of rocks, under tropical conditions in alternate dry and humid climates. Bauxite occurs as capping on the parent rock.

Geographic Distribution in India :

Andhra Pradesh, Chhattisgarh, Goa, Gujarat, Jharkhand, Madhya Pradesh, Maharashtra, Odisha.

Radioactive minerals :

Radioactive minerals contain natural radioactive elements in excess. The most abundant radioactive mineral is :

i) Monazite :

The name monazite is derived from the Greek word 'monazeis' means to be alone in allusion to it's isolated crystals.

Chemical composition : (Ce, La, Nd, Th) (PO_4. SiO_4)

Colour : Reddish brown to brown, shades of green to brown, yellowish brown.

Streak : White

Lustre : Resinous, waxy, vitreous.

Form : Crystalline, granular.

Cleavage : Good to poor.

Fracture : Uneven, conchoidal

Hardness : 5 to 5.5

Specific gravity : 4.6 to 5.4

Uses : Important source of thorium and rare Earths.

Occurrence : In the beach sand. Usually occurs in Igneous (granite, pegmatite) and metamorphic (schist and gneiss) rocks. Monazite grains are resistant to weathering and become concentrated in soils and sediments derived from the primary source. They may also be mined for their rare Earth and thorium content.

Geographic Distribution in India :

Rajasthan, Bihar, Karnataka, Odisha, Andhra Pradesh, Tamil Nadu and Kerala.

Industrial Minerals:

These are non-metalliferous and are used, with or without processing in various industries, for purposes other than extraction of metal. Various industries like petroleum, cement, abrasive, ceramic, refractory and medicine, use these minerals as a major chunk of their raw materials. It includes even those minerals that are used in metallurgical industry as fluxes, e.g. muscovite, asbestos etc.

Conventional Resources :

Conventional petroleum resources are oil and gas deposits that can be extracted using traditional drilling methods.

I) Coal and Petroleum/ Fuel Industry :

Coal and petroleum are considered conventional sources of energy. Coals are oxygenated hydrocarbons. Combustion of coal releases tremendous amount of heat. Therefore, it is used as fuel in thermal power plants and in the cement industry.

Coal is a black, stratified rock made up of hydrocarbons. Coal has basically originated from the decomposition of the vegetable matter. Grade or rank of coal depends on the degree of decomposition. Therefore, it does not possess a fixed chemical composition.

Peat, Lignite, Bituminous Coal and Anthracite are 4 varieties of coal. These varieties are indicative of the maturity of the Coal. During the conversion of Peat to Anthracite, there is general darkening in the colour, compactness, hardness, loss of moisture and volatiles along with an increase of carbon content. Thus, Anthracite is supposed to be the best variety of Coal.

Geographic Distribution in India :

Coal deposits in Maharashtra belong to Gondwana group occurring in Nagpur and

Chandrapur districts. At the following coal fields: i) Kamptee coal fields, ii) Umrer coal fields, iii) Bokhara coal fields, iv) Wardha valley coal fields and v) Ghugus-Sasti- Rajura coal fileds.

Petroleum :

The word Petroleum is derived from the greek word 'Petra' meaning rock and 'Oleum' meaning oil. It is not a mineral in the geological sense. It has an organic origin and is a mixture of liquid hydrocarbons of complex composition. Petroleum accumulations are commonly associated with gas such as methane, propane, butane etc. which is called natural gas.

Petroleum is derived from the decomposition and distillation of organic matter, contained in sediments of shallow water, marine origin. It is found to be occurring in the pores and cracks of sedimentary rocks.

The petroleum extracted from the Earth is called as 'crude oil', then it is processed in refineries to separate its constituent 'fractions', each with distinctive properties and uses. Petrol, kerosene, diesel, lubricating oil, paraffin wax and asphalt are some of the products.

Geographic Distribution in India :

Assam, Gujarat, Rajasthan and Off-shore regions

Unconventional Resources :

Unconventional petroleum resources are oil and gas deposits that are much more difficult to extract, and require unconventional specialized techniques and tools. For example Coal Bed Methane (CBM), Shale Gas and Gas Hydrates.

Coal Bed Methane (CBM) : It is an unconventional source of natural gas, predominantly methane (CH_4) generated during coal formation and stored or adsorbed in coal seams. It generally does not contain hydrogen sulphide (H_2S). It is considered to be more eco-friendly than other sources.

As India has the fifth largest proven coal reserves in the world, it therefore holds significant prospects for exploration and exploitation of CBM. The Gondwana sediments of eastern India host the bulk of India's coal reserves and all the CBM producing blocks (Jharkhand, West Bengal and Madhya Pradesh).

Shale Gas : The term 'Shale Gas' refers to natural gas that is trapped underground in shale deposits. Shale is a fine grained, very porous rock. These pores are not well connected, which makes extracting the trapped natural gas difficult.

Gas Hydrates : The term 'Gas Hydrates' refers to gas molecules that are encased in ice. These are naturally occurring structures that can be found in permafrost sediments in the Arctic or buried in sediments deep under water.

Hydrocarbon is an organic compound composed exclusively of hydrogen and carbon atoms. Hydrocarbon molecules naturally occur and are found in crude oil, natural gas, coal, gas hydrates and other important sources of energy. Burning hydrocarbons in the presence of sufficient oxygen produces carbon di oxide, water and heat because of which they are desirable as fuels.

Hydrocarbons form naturally from plant and animal remains that are compressed through temperature and pressure over millions of years. Crude oil, tar, bitumen are all liquid forms of petroleum hydrocarbons, while Propane, butane and methane are gaseous hydrocarbons.

II) Cement Industry :

A mixture of limestone and gypsum ground to powder and mixed with water hardens rapidly into stony consistency is called cement. Cement industry utilizes Limestone as the chief raw materials followed by gypsum, bauxite and clay minerals.

Gypsum :

Name Gypsum has originated from the greek word 'Gypsos' meaning plaster. Mineral gypsum found in abundance near Paris is called Plaster of Paris. Gypsum is added to raw materials of Portland cement, because it regulates the setting or hardening time i.e. it prevents the cement from hardening too quickly.

Chemical composition : $CaSO_4.2H_2O$.

Colour : White.

Lustre : Vitreous, pearly, silky.

Streak : White.

Form : Laminated, fibrous, massive.

Cleavage : Perfect 2 sets.

Fracture : Hackly, even

Hardness : 2

Specific Gravity : 2.3

Occurrence : In sedimentary rocks as evaporites.

Geographic Distribution in India :

Jammu and Kashmir, Rajasthan, Tamil Nadu, Uttarakhand.

Limestone :

Limestone is bulk raw material used in cement industry. For making cement, a naturally clayey Limestone or clay and limestone mixed in correct proportion is burnt. The resultant mass is powdered and mixed with water. A chemical reaction takes place and hardens into dense compact mass. All limestone deposits may not be suitable for the manufacture of cement. The specifications for cement grade are:(a) MgO not more than 2.5%, (b) CaO not less than 42%, (c) SiO_2 not more than 14% and (d) P_2O_5 not more than 1%. Some limestones fulfill these conditions.

Geographic Distribution in India :

Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Odisha.

Do you know?

The manufacturing of cement requires large amounts of energy. This increases the emission of greenhouse gases in the atmosphere. Hence, substitute materials, such as fly ash and slag, are being used in place of cement.

- Fly ash is a by-product produced in thermal power plants.
- Slag is a by-product produced in iron and steel plants.
- Fly ash and slag, along with other mineral mixtures, are used to substitute cement for making concrete used in construction activities.

III) Abrasive Industry :

An abrasive is a substance which is used for cutting, polishing, grinding and sharpening another substance.

Abrasives are categorized into two types :

i) Natural Abrasives - these include hard and tough minerals. The common abrasives are Diamond, Corundum, Quartz and Garnet.

ii) Artificial Abrasives.

Diamond :

Diamond is named after the greek word 'adamas' meaning invincible because of its hardness. Diamond being the hardest mineral, is used as an abrasive.

Chemical composition : Pure Carbon.

Colour : White, colourless, sometimes yellow, red or green.

Lustre : Adamantine.

Streak : Not obtained on the porcelain plate.

Form : Cubic crystals with curved surfaces.

Cleavage : One set.

Fracture : Conchoidal.

Hardness : 10.

Specific Gravity : 3.52.

Geographic Distribution in India :

Andhra Pradesh and Madhya Pradesh

Corundum :

Named after a Sanskrit word 'kuruvind' which means ruby. Corundum is next to Diamond in hardness and being cheaper than diamond can also be used in polishing or grinding rough surfaces.

Chemical composition : Al_2O_3.

Colour : Yellow, brown, red, blue

Lustre : Vitreous, sometimes dull on crystal faces.

Streak : Not obtained on the porcelain plate.

Form : Columnar, massive.

Cleavage : Absent.

Fracture : Conchoidal to uneven.

Hardness : 9.

Specific Gravity : 3.9 - 4.1

Geographic Distribution in India :

Andhra Pradesh, Jharkhand, Karnataka and Tamil Nadu

Quartz :

Quartz 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. 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 had the property of splitting into thin, sharp splinters when struck by another hard object.

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 $SiO_2.nH_2O$. Varieties of cryptocrystalline silica are mixtures of cryptocrystalline silica (chalcedony) and hydrous silica (opal).

Fig. 5.8 : Opal

Crystalline Silica :

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 : Approx 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.

Geographic Distribution in India :

W.Bengal, Maharashtra, Jharkhand, Rajasthan, Karnataka, Andhra Pradesh, Uttar Pradesh.

Garnet :

Named from 'granatum' (a pomegranate) for its resemblance to seed of this fruit. It is used as an abrasive and gemstone.

Fig. 5.9 : Garnet

Chemical composition : $X_3Y_2Si_3O_{12}$, where

X= Ca^{2}+, Mg, Fe,

Mn etc., (divalent ions) Y= Al^{3}+, Fe, Cr and Ti (trivalent ions).

Complex silicates of Ca, Mg, Fe, Mn.

Colour : Red, brown, yellow.

Lustre : Vitreous.

Streak : Not determined.

Form : Crystallized, massive (Rhomb dodecahedron).

Fracture : Uneven-Subconchoidal.

Cleavage : Absent.

Hardness : 7.0 - 7.5.

Specific gravity : 3.4.

Occurrence : In metamorphic rocks.

Geographic Distribution in India :

Rajasthan, Jharkhand, Karnataka, Andhra Pradesh.

IV) Ceramic Industry :

Crockery, glazed tiles, sanitary ware, insulators are ceramic products. Ceramic material is also used in electrical, electronic and automobile industries.

Kaolin :

Named as per an ancient chinese type locality 'kaoling (Gaolong)': meaning high ridge.

Chemical Composition : $Al_2(Si_2O_5)OH_4$

Colour : white to cream, pale yellow

Lustre : waxy, pearly, dull, Earthy

Streak : white

Form : massive

Cleavage : perfect

Fracture : uneven, conchoidal to sub-conchoidal

Hardness : 2 to 2.5

Specific Gravity : 2.63

Occurrence : occurs in sedimentary rocks

Geographic Distribution in India :

Gujarat, Kerala, Rajasthan, West Bengal, Jharkhand, Andhra Pradesh, Karnataka, Maharashtra and Madhya Pradesh.

Feldspars :

Feldspar is one of the most abundant minerals 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).

Feldspars are used in the ceramic industry due to their glazed lustre property. They 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., moonstone (orthoclase), sunstone (labradorite) and amazonite (microcline).

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

Chemical composition : It is expressed as $X(Al\,SiO)_4O_8$,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-alkalifeldspars**

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.5.10).

Fig. 5.10 : Orthoclase

Fig. 5.11 : Microcline

ii) Calc-alkali feldspars - Plagioclase series of feldspars or lime soda feldspars, e.g. plagioclase (fig. 5.11) and labradorite (fig. 5.12).

Fig. 5.12 : Plagioclase

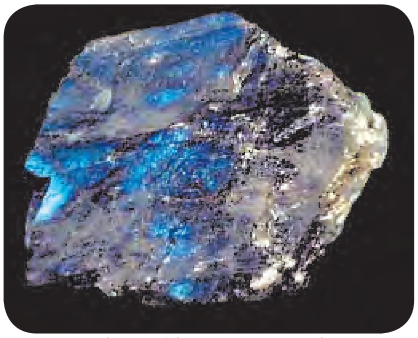


Fig. 5.13 : Labradorite

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) ⇆ Anorthite(An).

Physical properties of feldspar group :

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

Streak : White or pale shade of body colour.

Lustre : Vitreous to sub vitreous

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 at least 25% feldspar) and metamorphic rocks (e.g., gneiss).

Use of ceramics :

In recent times, ceramics and glass fibres are replacing iron, steel, copper, aluminium, etc. etc. The following is a brief account of the use of ceramics and glass fibres.

In the construction industry, the use of ceramics in place of cement is increasing. Ceramics are used as insulators, semiconductors and magnets. Mobile phones, computers, television and a number of other electronic products make use of ceramics. The use of ceramics reduces polluting emissions. Ceramic catalytic converters in vehicles help to convert poisonous hydrocarbons and carbon monoxide into harmless carbon dioxide and water. Nowadays, the telecommunication industry uses optical fibres in place of copper wires. Optical fibres increase the speed and volume of transmission. The demand for copper has come down because of the increasing use of this technology. Therefore, the negative impact of copper mining has also decreased.

Do you know?

Lightweight reusable ceramic tiles are used in NASA's space shuttles. These tiles make a thermal barrier that protects the astronauts and the shuttle's aluminium frame from extreme external temperatures (approximately 1600°C) when the shuttle re-enters the Earth's atmosphere on its way back.

V) Refractory Industry:

Refractories are those minerals and mineral products, which can withstand high temperatures of preferably above 1500°C, without softening and fusion.

Refractories are used for lining furnaces, in the manufacture of crucibles for melting metals, wherever resistance to high temperature and corrosion is required. A good refractory should satisfy the following conditions :

a) It should have a very high melting point.

b) It should not crack or soften at high temperatures.

c) It should resist chemical action and physical wear and tear.

d) It should not react chemically with the substance being fused init.

The refractories are classified into three categories :

1) Acidic : Fire clay and Kaolin, Kyanite and Sillimanite.

2) Basic : Bauxite, Magnesite and Corundum.

3) Neutral : Zircon, Chromite and Graphite.

Raw Materials : The raw materials for the refractory industries are Fire Clay, Kyanite, Bauxite and Zircon.

Kyanite :

Derived from greek word 'Kyanos' meaning blue.

Industrial properties : When Kyanite is heated to a temperature of 1545°C, it changes into Mullite ($3Al_2O_3.2SiO_2$). It is stable at high temperatures of above 1800°C and possesses good mechanical strength, low coefficient of expansion and high electrical resistance. Hence, Kyanite is used as raw material in refractory industry.

Chemical composition : Al_2SiO_5.

Colour : Blue, green, bluish grey.

Lustre : Pearly

Streak : White

Form : Bladed

Cleavage : Two sets

Fracture : Uneven

Hardness : 4 - 7

Specific Gravity : 3.58 to 3.65

Geographic Distribution in India :

Jharkhand and Maharashtra

Bauxite :

(For physical properties refer to page no. 66)

Industrial properties : Bauxite is the chief source of Alumina. It is very hard, resists high temperature and is poor conductor of heat and electricity. Hence, Bauxite is added to clay in the manufacture of high alumina bricks, that are used to line furnaces to withstand high temperatures upto 1800ºC.

Zircon :

Industrial properties : Due to their resistance to corrosion , high thermal shake stability and low ability to generate defects in glass it is widely used in refractories and glass furnaces, refractory coatings, ceramic dentures and other dental procedures.

Chemical Composition : $ZrSiO_4$

Colour : Usually yellow, brown or red, colourless, blue and green

Lustre : Vitreous to adamantine, sometimes oily

Streak : colourless

Form : tabular, prismatic crystals, massive

Cleavage : imperfect

Fracture : uneven

Hardness : 7.5

Specific Gravity : 4.6 – 4.7

Uses : Ore of zirconium metal, ore of zirconium dioxide, whitening agents, gemstone, radiometric dating.

Occurrence : Occurs in igneous (pegmatite), metamorphic and sedimentary rocks.

Geographic Distribution in India :

Andhra Pradesh, Tamil Nadu, Kerala, Odisha.

VI) Medicine Industry :

Medicinal minerals : Use of minerals in ayurvedic system of medicine is known since about 2500 years and this branch of ayurvedic pharmacology is called 'Rasashastra'. It is a science and art of manufacturing drugs from minerals and native metals, for the preparation of ayurvedic medicines the minerals have to go through very definitive refining procedures or 'samskaras' before they can be incorporated into medicine. Some of the samskaras are shodhana, marana.

A systematic and scientific treatment of mineral medicines has been presented by Vagbhata in the 14th century.

Do you know?

Vagbhata's 'Rasaratna Samuchchaya' gives systematic and easy presentation of minerals. Vaghbata has classified minerals employed in medicine into Maharasas, Uparasas, Sadharanaras.

Minerals of Rasashastra are classified, generaly based essentially on their degree of utility in preparation of mineral recipes.

But the basis of such classification is not well documented. Whether the frequent employment of such items has qualified these materials or their importance in Rasashastra in order to qualify them to be classified as Maharasas is not clear.

It has not been possible to understand the basis of Vagbhata's classification of Uparasas. However, the suffix 'Upa' would suggest that these substances are not so important as the Maharasas.

However, the basis of classification is wanting as in the case of other rasas.
Sadharanrasas may mean that these items may be used sparingly in Ayurveda medicine.

Some of the important minerals in **maharasas** are —

Mica (Abhraka), Chalcopyrite (Maxika), Pyrite (Vimala) and Malachite (Sasyaka).

Some of the important minerals in Uparasas are — Sulfur (Gandhaka) and Haematite (Gairika).

One of the important minerals in sadharanarasas is— Cinnabar (Hingula).

A) Maharasas :

There are four Maharasas Mica, Chalcopyrite, Pyrite and Malachite.

Mica :

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.

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.

Mica is populary called 'abhraka' in ayurveda. It is grouped into different varieties based on its changes during heating, namely such as Pinaka, Naga, Manduka and Vajra.

Abhraka which separates into packed layers by the contact of fire is called 'pinaka'.

Abhraka which gives out hissing sound when heated is called 'naga'.

Abhraka which produces sound of frog and jumps on heating is called 'manduka'.

Abhraka which will not change when heated is called 'vajra'. The vajra is the best employed in medicinal preparation.

Muscovite : Hydrated silicate of Aluminium and Potassium with Fluorine and is silvery white in colour. Name Muscovite originated from 'Muscovy glass' because it came from Muscovy province of Russia (fig. 5.14).

In Ayurveda muscovite is termed as 'shewta abhraka' due to its white colour.

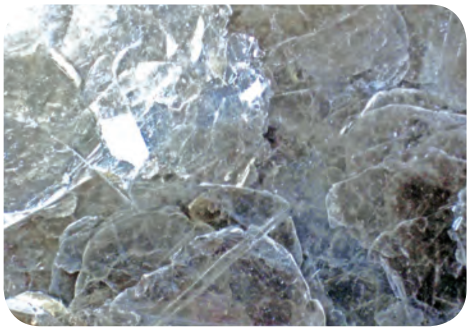


Fig. 5.14 Muscovite

Biotite : Hydrated silicate of Mg, Fe, Al, and K with F, black to brown in colour (fig. 5.15).
In ayurveda biotite is termed as 'krishna abhraka' due to its black colour.

Fig. 5.15 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. Mica is used as medicine for treating diseases like anemia, bronchial asthma, low blood pressure, pleurisy, tuberculosis and coronary cardiac failure. It is also a heart tonic.

Geographic Distribution in India :

Andhra Pradesh, Jharkhand and Rajasthan.

B) Uparasas

Sulfur :

The name sulfur is derived either from the Sanskrit word 'sulvari' or the Latin word 'sulfurium'. In ayurveda, it is termed as 'gandhaka'.

Sulfur is used to make sulfuric acid, fungicide, in skin medicine, in vulcanization of rubber, gun powder, matches, fire works. Sulfur base concretes, cements and wall coatings are used where resistance to chemical attack is important.

Chemical composition : S_8

Colour : Yellow, Beownish or greenish yellow, orange, white.

Streak : Colourless

Lustre : Resinous, greasy

Form : Tabular, massive, reniform, spheriodal

Cleavage : Imperfect

Fracture : Uneven, conchoidal

Hardness : 1.5 to 2.5

Specific gravity : 2.0 to 2.1

Geographic Distribution in India :

Bihar, Rajasthan and Ladakh

C) Sadharanarasas

Cinnabar :

Name- From Persian 'zinjifrah', original meaning lost (dragon's blood). Referred to as Hingula in Ayurveda.

It is an important ore of mercury. Used in ayurvedic medicine, pigment and jewellery and ornaments.

Chemical composition : HgS

Colour : Tint or shade of red, cochineal red, brownish red.

Streak : Red-brown to scarlet.

Lustre : Metallic, adamantine to dull.

Form : Crystals-rhombohedral, massive, granular.

Cleavage : Perfect.

Fracture : Uneven, subconchoidal.

Hatdness : 2 - 2.5

Specific gravity : 8.17 to 8.20

Geographic Distribution in India :

Rajasthan and Gujarat

Mineral /rock based industries :

The Industrial Policy initiatives were

undertaken by the Government of India in 1991, to meet the International Standards and compete in the world market. For the sake of efficiency and economy of production, it is important that the location of industry should be suitably selected. Various factors affect the choice of particular locations for individual industries. The major factors that govern the criteria for the selection for localization of establishing industry are as follows :

1) **Raw Materials :** The total cost of the raw material includes, the amount spent on its transportation to the factory. Those materials that lose considerable weight during manufacture are known as 'weight-losing materials', while those which retain weight are known as 'pure materials'. In order to avoid loss during transportation, the industries are generally located near the market. The 'weight- losing' materials may be immediately processed, if they are located close to the industries. For example in case of cement industry, most of the manufacturing units are located near the limestone deposits. Limestone being the important raw material used in the manufacture of cement. Similarly, iron and steel industries are located near the iron ore and coal deposits.

2) **Market :** Some industries need to be located near the markets. Industries manufacturing fragile products like glass, ceramics or pottery need to be established near the market, in order to avoid the loss during transportation due to damage or breakage.

3) **Skilled Labour :** A manufacturing industry requires skilled, sufficient and efficient labour. Industries are attracted to regions where cheap and capable labour is available. For example, glass industries are located near Agra.

4) **Site and Service :** The physical, geographical and geological conditions are very important, since the ground has to be sufficiently stable for supporting the foundation of the factory.

5) **Capital :** Effective and competitive production requires quality production in minimum time. Advanced technology and skilled labour required, are available at high costs, thus, sufficient capital is required.

6) **Government Policy :** Before establishing an industry, the Industrial policy and provisions, plus renewal etc. need to be considered.

Summary :

The prosperity of any nation is measured on the availability of natural resources within its geographical boundaries. Wars are fought till this day to acquire lands rich in mineral resources. Minerals which are industrially important directly contribute to the GDP of a nation which are in turn decides the living standards of the citizens of that country. The exploration and judicious exploitation of economic or industrially important mineral resources is intrinsically the job of a geologist.

India is a land blessed with a range of mineral resources and has substantial reserves of yet to be exploited materials. We are among the world leaders in having reserves of coal, iron ore, aluminum ore and clay minerals. India also has the largest deposit of monazite sands, which is a source of thorium for nuclear power generation. There are many other minerals which are available in India, though not in huge amounts, but important from a national security and hence of strategic importance, like petroleum, and we explore and exploits that too. Minerals also play an important role in the formulations of medicines used in Ayurveda.

EXERCISE

Q. 1 Choose the correct alternative :

1) Tenor of ore is ………………..
   a) natural concentration of one or more minerals
   b) metal content of an ore
   c) deposit from which metal can be extracted profitably
   d) vein of metal

2) a) Iron ore minerals are Pyrolusite and Psilomelane
   b) Iron ore minerals are Pyrolusite and Magnetite
   c) Iron ore minerals are Pyrolusite and Haematite
   d) Iron ore minerals are Magnetite and Haematite

3) a) Sphalerite — i) $Al_2O_3.2H_2O$
   b) Chalcopyrite — ii) Pbs
   c) Galena — iii) ZnS
   d) Bauxite — iv) $CuFeS_2$

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

   a) Diamond — i) Cement industry
   b) Limestone — ii) Ceramic industry
   c) Kyanite — iii) Abrasive industry
   d) Feldspars — iv) Refractory industry

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

Q. 2 Answer the following questions :

1) What is an ore mineral? Give an example.
2) Name the 2 manganese ore minerals giving their chemical composition.
3) Write the chemical composition of mineral malachite.
4) What is a radioactive mineral? Give an example.

Q. 3 Answer the following questions :

1) What is the role of mineral gypsum in the cement industry? Add a note on its geographical distribution in India.
2) Give the physical properties of corundum.
3) Give the uses of feldspars and its distribution in India.
4) List the physical properties of mineral zircon?

Q.4 Answer the following questions :

1) Name the ore minerals of lead, zinc and aluminium, listing their physical properties, occurrence and use.
2) Describe in detail radioactive mineral monazite
3) Describe the unconventional source of petroleum?
4) Describe sulphur/cinnabar as minerals used in medicine

Q. 5 Answer the following questions :

1) Explain Iron/ manganese ore minerals in detail.
2) Describe copper ore minerals in detail.
3) Give a brief account of the fuel industry.
4) Describe in detail, the raw materials used in the cement industry.
5) List and describe the physical properties of any two abrasive minerals and give their distribution in India.

6 Hydrogeology

Introduction :

Hydrogeology, is a branch of geology dealing with the study of groundwater, its occurrence and movement. It is therefore often referred to as groundwater hydrology, geohydrology or hydrogeology.

Groundwater is extremely important for the existence of humans, as it is the major source of drinking water. It is also an important source for the agricultural and industrial sector all around the globe. About 50% of water required for drinking as well as domestic, agricultural and industrial purposes comes from groundwater. Groundwater is an integral part of hydrological cycle and its availability depends on the rainfall and recharge conditions. Although industrialization and urban growth have started contaminating groundwater, it is still considered a dependable source of potable water.

Groundwater makes up about only 1% of the total water on the Earth. It occurs beneath the Earth's surface, but is usually restricted to depths less than about 750 meters. This water occurs in the pore spaces and fractures of rocks and sediments. It originates as rainfall or snow, and then moves down the soil into the groundwater system, and eventually makes its way back to the surface in the form of springs or streams.

Sources of Groundwater :

a) **Meteoric Water :** The main source of groundwater, which originates in the atmosphere and is received in the form of rain or snow. The downward entry of the water into the soils and rock surface is called infiltration. The flow of water through soil and porous or fractured rocks is known as percolation. Groundwater can also be derived directly from atmospheric moisture by condensation of water vapour from air circulating through the pores and interstices. This is also known as 'condensational water' and is known to replenish the water table in arid and semi-arid areas.

b) **Connate Water :** It is another important source of groundwater that is contained in pores and cavities of sedimentary rocks. It is entrapped in the interstices of sedimentary rocks at the time of deposition. Generally it is highly mineralized and salty and does not mix readily with meteoric groundwater.

c) **Magmatic Water :** Hot magma contains considerable amount of gases and water vapours. The water vapours on condensation are converted into groundwater called magmatic water. It is also called juvenile water. Such water is considered to have been generated in the interior of the Earth.

Vertical distribution of Groundwater :

Water occurs underground in two zones separated by water table. The level beneath which all the pore spaces in the rocks are filled with water is known as water table (fig. 6.1). The zone extending from the water table to an impermeable layer is called saturated zone, wherein all voids are completely filled with water. In this zone, water is held at a pressure greater than the atmospheric pressure, and hence it moves in a direction based on the continuous hydraulic situation. The zone between the ground surface and the top of capillary fringe is called unsaturated zone (zone of aeration) which consists of voids (pores or interstices) partially filled with water and partially with air. Water is held at a pressure less than the atmospheric pressure in the unsaturated zone. Zone between bottom of the unsaturated zone and top of the water table is called capillary zone, wherein most voids are filled with water but the water is held at a pressure less than the atmospheric pressure.

The unsaturated zone can be further sub-divided into 'soil-water zone' and 'intermediate zone' (fig. 6.1). This zone between the ground surface and the top of water table is known as the vadose zone and is part of the unsaturated zone and capillary zone (also known as 'capillary fringe'). Water present in the vadose zone is called vadose water, and is held at a pressure less than the atmospheric pressure. The term vadose zone is technically more appropriate than the conventional term of unsaturated zone because portions of the vadose zone may actually be saturated, even though the pressure of water is below the atmospheric pressure.

Broadly speaking, the water stored in the zone of saturation is called as groundwater. However, not all underground water is groundwater, rather only free water or gravitational water (the water that moves freely under the force of gravity into wells) constitutes the groundwater. Therefore, a practical explanation of groundwater as given by Bouwer in 1978 is: "Groundwater is that portion of the water beneath the Earth's surface, which can be collected through wells, tunnels, or drainage galleries, or which flows naturally to the Earth's surface via seeps or springs".

Inter-granular spaces vary widely in terms of size. Minute voids between the component particles of clay, shale and slate may feature on one end, while large spaces between the pebbles of well-sorted and unconsolidated valley gravel may feature on the other end of the spectrum. Massive spaces are those that occur between large blocks of rocks such as fractures, joints and bedding planes sometimes enlarged by the process of solution.

Capillary interstices or spaces are those that are small enough to hold surface tension forces (fig. 6.1). They can be further classified into two types; namely super capillary and sub-capillary. The former is large and may sometimes be as large as a limestone cave. The latter is very small and water is held in them mainly by molecular forces.

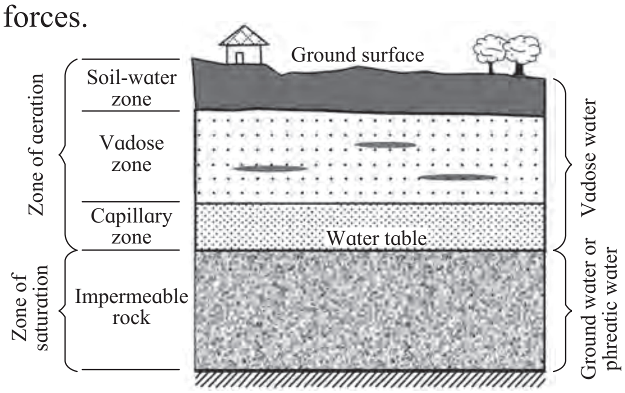


Fig. 6.1 : Vertical distribution of groundwater

Hydrological properties of rocks :

a) Porosity :

Porosity of a rock is its property to possess open spaces or interstices (fig. 6.2. a) like voids, fractures, cracks, joints, crevices etc. Porosity is the ratio of the volume of void space to the total volume of the rock or Earth material. It is the voids or openings of the rock or soil and is sometimes expressed as a percentage. Effective porosity is the void volume that contributes to water movement and is roughly equivalent to specific yield. Specific yield is the ratio of volume of the water that a saturated rock as soil will yield by gravity to the total volume of the rock or soil. It is usually expressed in percentage. Porosity is an indication of the amount of water in the subsurface, but does not equate to the volume that can be released from storage.

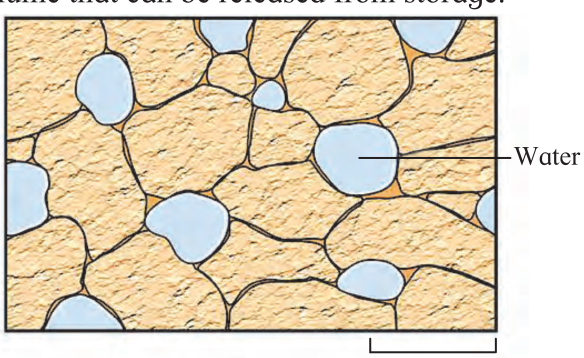
(a)


Fig. 6.2 : a) Porasity

When the pores are formed during the formation of rocks, like pore spaces produced by the process of sedimentation, it is called as primary porosity (e.g. porosity in sandstone). When the pores or fractures are formed due to external Earth processes, after the formation of the rocks it is called as secondary porosity (e.g. vesicles in basalts).

b) Permeability :

The capacity of water bearing formation to transmit water is called permeability (fig. 6.2. b). Thus it is the ease with which a fluid can pass through a porous medium. It is the volume of fluid discharged from a unit area of an aquifer under unit hydraulic gradient in unit time.

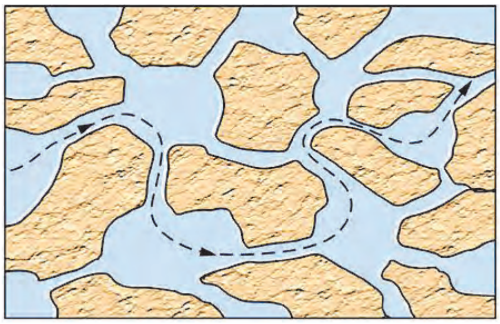


Fig. 6.2 : b) Permeability

Aquifers :

An aquifer is a rock formation of porous material. It has considerable porosity and permeability with sufficient volume to yield appreciable quantities of water.

Characteristics of Aquifers :

An aquiclude, is a rock formation which is porous enough to hold sufficient quantity of water, but does not allow an easy and quick flow through it (e.g. clay). An aquifuge is an impermeable rock formation through which there is no possibility of storage or movement of water (e.g. compact granite). An aquitard is a rock formation which permits the flow of water but does not yield sufficient quantity of water when compared to an aquifer (e.g. sandy clay). Aquifers can be classified into four kinds :

a) **Unconfined Aquifer :** An aquifer which has an impermeable layer at its base is called an unconfined aquifer (fig. 6.3). It is necessarily exposed to the atmosphere and its upper portion is partly saturated with water. The upper surface of saturation is called water table which is under atmospheric pressure. Therefore this aquifer is also called phreatic aquifer.

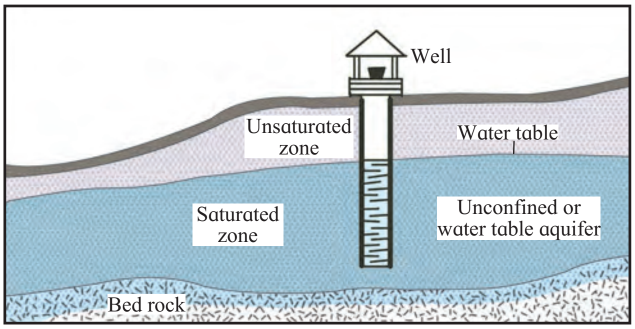


Fig. 6.3 : Unconfined Aquifer

b) **Perched Aquifer :** It is a special case of an unconfined aquifer. This type of aquifer occurs when an impermeable or relatively impermeable layer of limited area in the form of a lens is located in the water bearing unconfined aquifer. As shown in following (fig. 6.4) the water storage created above the lens is perched aquifer and its top layer is called perched water table.

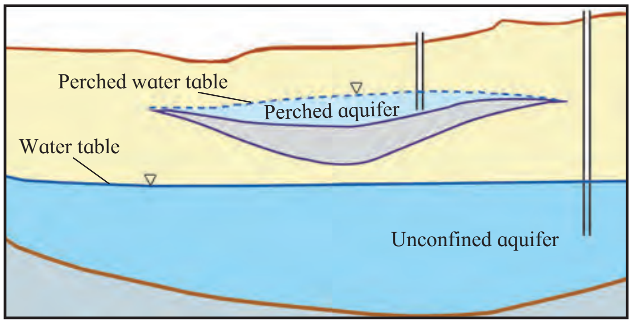


Fig. 6.4 : Perched Aquifer

c) **Confined Aquifer :** It is also called an artesian aquifer. It is overlain as well as underlain by confining layers. The water within the aquifer is therefore, held under pressure greater than atmospheric pressure. A well intersecting such an aquifer will yield water without pumping. The imaginary level up to which the water will rise is called piezometric surface (fig. 6.5).

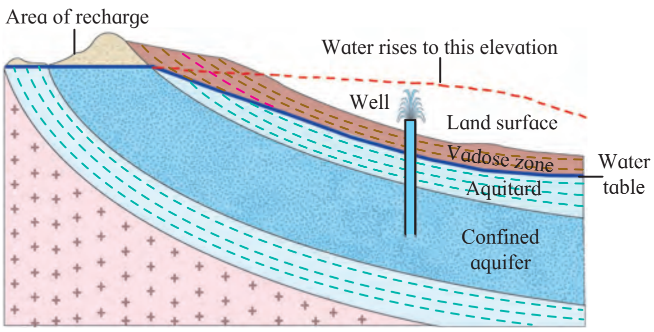


Fig. 6.5 : Confined Aquifer

d) Leaky Aquifer : An aquifer which is overlain or underlain by semi-pervious layer through which leakage of water takes place is called as leaky aquifer.

Do you know?

Artesian is a term originally applied to boreholes in Artois in France from which a constant supply of water was obtained because groundwater spontaneously discharged from them. It is suspected that the term was then applied to confined aquifers into which a number of artesian boreholes had been sunk. The term artesian aquifer is probably a misnomer and the term confined aquifer should rather be used.

Conservation and Management of Groundwater :

Water conservation includes all the policies, strategies and activities to sustainably manage the natural resources of fresh water, to meet the current and future human demand. Water conservation is the practice of using water efficiently to reduce unnecessary water usage. It is important because fresh clean water is a limited resource.

Groundwater management should include objectives of renewability (replenishment, recharge) of the resources, practical exploitation and rational consumption. Rainwater harvesting is one easy and affordable method of groundwater replenishment and recharge.

Methods of Rainwater Harvesting :

Broadly there are two ways of harvesting rainwater.

A) Rooftop Rainwater Harvesting : It is the technique through which rainwater is collected from the roof of the house or building. The collected water can either be stored in a tank or diverted to artificial recharge system. This method is less expensive and very effective in augmenting the groundwater level of the area. The augmented resource can be harvested at the time of need.

Methods of Roof Top Rain Water harvesting:

i) Recharge pit : A recharge pit is the most popular method for artificially recharging of aquifers. This technique is favourable for recharging shallow aquifers and where permeable strata permits infiltration of water. The pitcan be of any shape and size but generally it is 1 to 2m wide and 2 to 3 m deep. The excavated recharge pit is backfilled with boulders of 5-20 cm size at bottom, gravels of 5-10 mm size in between and coarse sand of 1.5-2 mm size at the top (fig. 6.6).

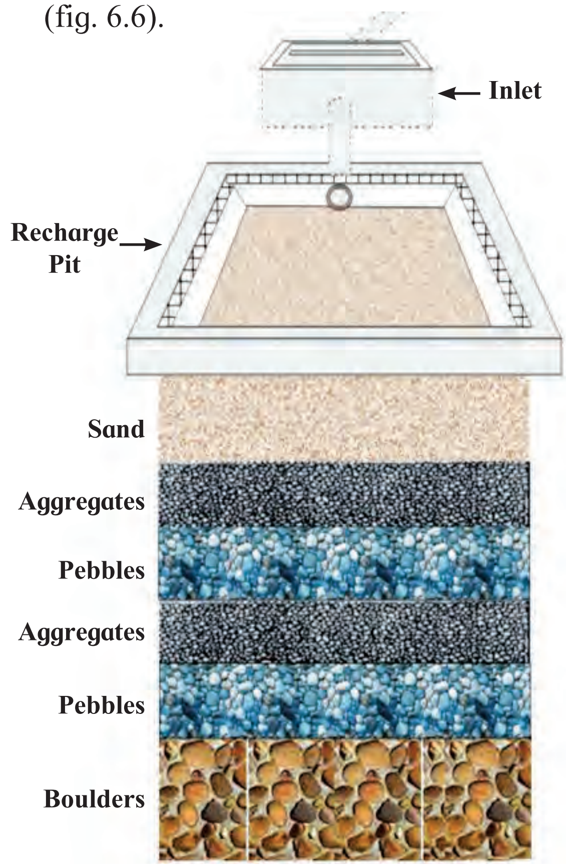


Fig. 6.6 : Recharge pit

A mesh must be provided on the top of the pit to prevent the solid material from entering it. Another mesh should be provided between the sand and gravel layer to avoid the sand from escaping towards the bottom. Periodically the sand layer must be cleaned for maintaining the rate of recharge.

ii) Recharge trench : A recharge trench is excavated on the ground for harvesting runoff water. this may vary in size depending upon the amount of runoff water. Generally it is 0.5 to 1 m wide, 1 to 1.5 m deep and 10 to 20 m long. It is then filled with boulders of 5 - 20 cm size at the bottom, gravels of 5 - 10 mm size in between and coarse sand of 1.5 – 2 mm size at the top. A bore well can be provided inside the trench to enhance the percolation of water (fig. 6.7).

Solid material must be prevented from entering the pit. This can be done by using a mesh on the top. Another mesh should be placed in between the sand and gravel layer in order to prevent the sand from escaping towards the bottom. Rate of recharge can be maintained by periodically cleaning the sand layer. First one or two showers are diverted from entering the recharge pit.

ii) Recharge Tube wells : This recharge method is applicable to existing tube wells which tap less amount of water. Roof water is collected with the help of PVC pipes

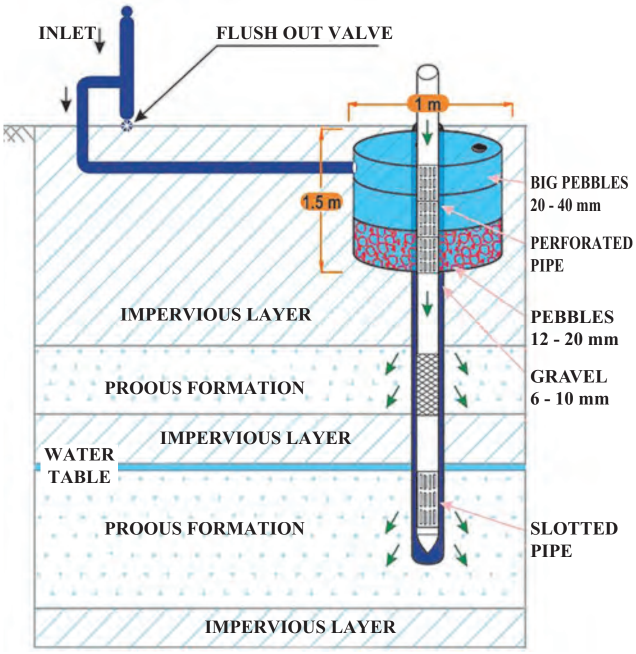
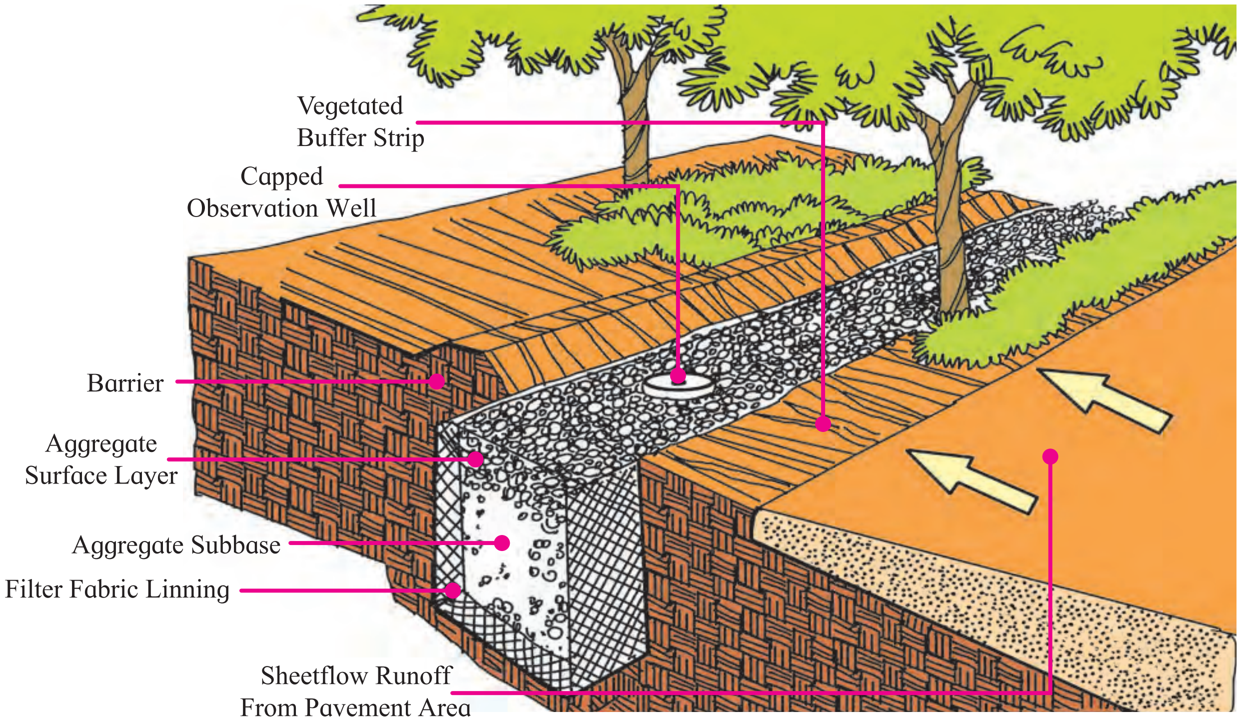


Fig. 6.8 : Recharge Tube Well



Credit and Source: https://www.buildinggreen.com/feature/stormwater-management-environmentally-sound-approaches

Fig. 6.7 : Recharge Trench

Diameter of the filter may vary depending on the roof area. The filter is divided into three chambers. First chamber is filled with gravel of 6 – 10 mm size, middle chamber with pebbles of 12 – 20 mm size and last chamber with bigger pebbles of 20 – 40 mm size (fig. 6.8).

B) Surface runoff harvesting : Surface runoff water harvesting is the collection, accumulation, treatment or purification, and storing of storm water for its eventual reuse. It can also include other catchment areas from manmade surfaces, such as roads, or other urban environments such as parks, gardens and playing fields. Surface runoff (also known as overland flow) is the flow of water that occurs when excess storm water, meltwater, or other sources flow over the Earth's surface. This can occur when the soil is saturated to full capacity, and additional precipitation is greater than the soil absorption capacity. Surface runoff often occurs because impervious areas (such as roofs and pavement) do not allow water to soak into the ground. It is the primary agent of soil erosion by water. The land area producing runoff that drains to a common point is called a drainage basin.

Surface runoff in urban areas is a primary cause of urban flooding, which can result in property damage and street flooding. In urban areas rainwater flows away as surface runoff. This runoff may be used for recharging aquifers by adopting appropriate methods.

Methods of Surface Rain Water Harvesting :

i) Gully Plug : They are built across small gullies. They are built with stones and soil. Gully plugs lowers the speed of water flow, prevents soil erosion and keeps soil moisture. It passes water through it but stops soil flowing through it (fig. 6.9).

Fig. 6.9 : Gully plug

ii) Contour Bund : It is constructed on land with moderate slopes. A line of stones is placed along the contour. This helps in reducing the runoff. The spacing between two contour bunds depend on the slope of the area. Contour bund also reduces soil erosion (fig. 6.10).

Fig. 6.10 : Stone contour bunding

iii) Check Dam : They are constructed across small streams having gentle slope. The purpose is to retain water upstream. Series of such check dams can be constructed to have recharge on regional scale (fig. 6.11).

Fig. 6.11 : Loose rock check dam

iv) Gabion Structure : This structure is a mesh of steel wires filled with rocks and anchored to the stream bank. This is constructed on small streams with width less than 10 m. The height of such structure is less than a meter (fig. 6.12).

Fig. 6.12 : Gabion dam on stream

v) Percolation Tank : Percolation tanks is a shallow tank which allows the excess waters to flow freely. The subsurface rock strata in the submergence area should be permeable to allow percolation with minimum evaporation losses. These are earthen dams and pitching with stones for the upstream wall reduces the damage of the tank wall (fig. 6.13). The purpose of the percolation tanks is to conserve the surface runoff and recharge the aquifers.

Fig.6.13 : Percolation tank

iv) Dugwell Recharge : The runoff water in the existing and abandoned dug wells is discharged through pipes. To avoid the sediments or silt from entering the dug wells, a desilting chamber or filter chamber is provided before the water discharge point. The desilting chamber or filter chamber is filled with pebbles, gravels and coarse sand. These chambers are periodically cleaned to maintain the efficiency (fig. 6.14).

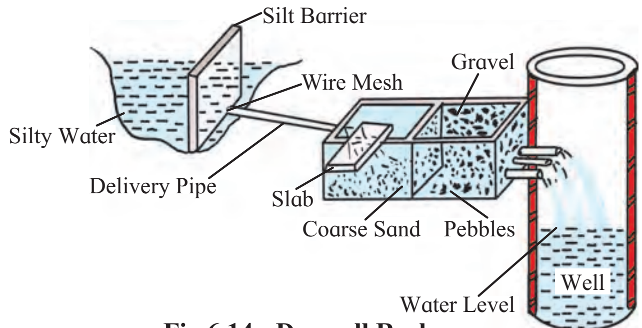


Fig.6.14 : Dugwell Recharge

Activity :

Calculating the quantity of water available from rooftop rainwater harvesting.

The quantity of the Rain water harvested (Q) can be calculated using the following formula :

Q = A X C X P

A = Area in Sq. meter

C = Is the Runoff Coefficient (decide the runoff coefficient according to the type of Roof from the Table 1)

P = Mean annual Rainfall in mm

Table 1. Runoff Coefficient for various types of catchments.

Sr. No.	Type of Catchment	Runoff Coefficient
	Roof Catchment	
1	Galvanised Iron Sheet	0.90
2	Asbestos Sheet	0.80
3	Tiled Roof	0.75
4	Concrete Roof	0.70
5	Organic (Thatched Roof	0.20
	Ground Surface Coverings	
6	Concrete, Asphalt	0.6 – 0.8
7	Brick Pavement	0.5 – 0.6
8	Hard Flat ground without Vegetation	0.25 – 0.75
9	Hard Flat ground with Vegetation	0.15 – 0.60

Example :

For a building with a concrete roof of size 10 m X 12 m (120 sq. meter) in a city with average annual rainfall of 900 mm, the quantity of rainwater that can be harvested in a year is

Q = 120 sq. meter X 900 mm X 0.70 = 75600 litres/year

Watershed management :

Watershed management is the study of the relevant characteristics of a watershed aimed at the sustainable distribution of its resources. It involves the processes of creating and implementing plans, programs, and projects to sustain and enhance watershed functions that affect the plant, animal, and human communities.

Watershed is a geo-hydrological unit draining to a common point by a system of natural drains. It is an area of land and water bound by a drainage divide within which the surface runoff collects and flows out of the watershed through a single outlet into a larger river or lake.

A) Types of Watershed :

Watersheds is classified depending upon the size, drainage, shape and land use pattern.

- Macro watershed (> 50,000 Hectare)
- Sub-watershed (10,000 to 50,000 Hectare)
- Milli-watershed (1000 to10000 Hectare)
- Micro watershed (100 to 1000 Hectare)
- Mini watershed (1-100 Hectare)

B) Objectives of watershed management :

The different objectives of watershed management programmes are :

1) Enhance the groundwater recharge, wherever applicable.
2) Check soil erosion and reduce the effect of sediment loss in the watershed.
3) Control excessive runoff and degradation thereby conserving soil and water.
4) Manage and utilize runoff water for useful purposes.
5) Conserve and improve watershed land for more efficient and sustained production.
6) Rehabilitate the deteriorating lands.
7) Moderate floods in downstream areas.
8) Increase infiltration of rainwater.

Do you know?

Water Audit

A water audit is an accounting procedure that monitors where and how much water enters and leaves a water system. This allows the assessment of current usage, provides data needed to reduce water and revenue losses, and allows forecasts of future water needs. The principal purpose of a water audit is to accurately determine the amount of un-accounted water in a water system, which includes water loss through leakages, etc.

Conducting a Household Water Audit :

A household water audit is an assessment of how much water is used and how much water can be saved in a household. Conducting a water audit involves calculating water use for different activities and identifying simple ways for saving water in a household.

Benefits of conducting a Water Audit :

Conducting a water audit can help you protect your water supply and the community's aquifer. Conducting a water audit will make you aware of how you use your water and help to identify ways you can minimize water use by implementing certain conservation measures. It is possible to cut your water usage by as much as 20 to 40 percent by implementing simple conservation measures and without drastically modifying your lifestyle.

Summary :

A basic knowledge of hydrogeology is essential for the geologist or civil engineer engaged in the development, utilization and management of water resources. It helps assessing the quantity of water available for domestic consumption, industrial usage, agriculture, hydro-electricity generation and other developmental works. Knowledge of hydrogeology is also required for the design of large and small water storage/ percolation structures such as dams and weirs.

In a world that today consumes more water than what is sustainable, the role of water conservation and management assumes utmost importance.

A watershed, affects the people in every sphere of life. The sustained productivity of food, fuel, forage, fibre, fruit and water by the management of vital resources of water, soil and vegetation and phenomena like floods and droughts are determined by the nature of watershed functioning.

EXERCISE

Q. 1. Choose the correct alternative :

1) Hydrogeology is often referred to as groundwater hydrology, geohydrology or hydrogeology
   a) groundwater hydrology, geohydrology or hydraulics
   b) groundwater hydrology, geohydrology or hydrogeology
   c) underground water hydraulics, groundwater hydrology or geohydrology
   d) groundwater hydraulics, geohydrology or hydrogeology

2) .... is the main source of groundwater, which originates in the atmosphere and is received in the form of rain or snow.
   a) Volcanic water b) Magmatic water
   c) Meteoric water d) Artesian water

3) The zone between the ground surface and the top of capillary fringe is called
   a) saturated zone b) zone of aeration
   c) supersaturated zone d) 'o' zone

4) Porosity is the ratio of the
   a) volume of solid soil to the total volume of the rock forming the soil material.
   b) volume of void space to the total volume of the soil or organic material in the aquifer.
   c) volume of void space to the total volume of the rock or Earth material.
   d) volume of solid space to the total density of the rock or Earth material.

5) The capacity of water bearing formation to transmit water is called
   a) Porosity b) Hydraulic constant
   c) Permeability d) Aquaclude

6) An unconfined aquifer is also called a
   a) Phreatic aquifer b) Artesian aquifer
   c) Compact aquifer d) Perched aquifer

7) Is not a method of rooftop rainwater harvesting
   a) Recharge pit b) Recharge trench
   c) Recharge tubewell d) Recharge gabion

8) They are constructed across small streams having gentle slope, for surface rain water harvesting:
   a) Gabions b) Contour trenches
   c) Percolation trenches d) Check dams

9) Gully plug
   a) Allows the passage of water through it but stops soil flowing through it.
   b) Allows the passage of soil through it but stops water flowing through it
   c) Allows the passage of soil through it but stops silt passing through it
   d) Stops the passage of water through it but allows to flow soil through it

10) A roof top rain water recharge pit is filled from bottom to top in this sequence:

a) 40 mm gravel, 20mm pebbles, Coarse sand

b) Coarse Sand, 20mm pebbles, 40mm gravel

c) 20mm pebbles, 40mm gravel, 60mm large cobbles

d) Fine sand, 40mm pebbles, 60mm large gravel

Q. 2. Very Short Answers :

1) Explain the term 'Aquifer'

2) Define the term 'Aquitard'

3) What constitutes an 'Aquifuge'

4) Explain the term 'Aquiclude'

Q. 3. Short Answers :

1) What is meteoric water?

2) What are the characteristics of a good aquifer?

3) What are the characteristics of the vadose zone?

Q. 4. Short Answers :

1) Explain the terms Porosity and Permeability.

2) 'Generally, a sandstone is more porous than basalt'- Explain.

3) 'A porous rock is not always a good aquifer' – Explain.

Q. 5. Long Answers :

1) Explain with illustrations the various methods of roof-top rainwater harvesting.

2) What is a 'Watershed'? What are the objectives of watershed management?

3) Why is watershed management the need of the hour? Explain in context to the present day drought scenario in central Maharashtra.

4) What is the need of surface runoff harvesting? Why is it important to implement it in our rural areas?

5) What are the rainwater harvesting methods you would recommend in an urban area where most of the land area is under built-up land.

7 Geohazards

Indtroduction :

In Chapter I, we learned about dynamic processes of the Earth. All layers of the Earth (internal, surface and atmospheric) are continuously under the process of evolution, equilibration and interaction. Amongst these, the surface layer is of greatest concern to humans, especially when these natural processes act as hazards or geo-hazards. Geohazards are geological and environmental conditions that may lead to widespread damage or risk to life and infrastructure based on some long-term or short-term natural processes. Some of the most significant geohazards include: landslides, debris flows, snow/rock avalanche, volcanoes, earthquakes, tsunami, cloud burst and flash floods, glacial lake outbursts and coastal erosion. Amongst these, earthquakes, volcanoes and landslides make the most common geological phenomena or happenings over the years as great disasters.

EARTHQUAKE

The 1755 Lisabon earthquake in Portugal that killed 32000 people was the benchmark for concerted efforts on earthquakes giving birth to the branch of seismology (seismos means 'earthquake' in Greek). Afterwards, some of the deadliest earthquakes like Shaanxi (China) in 1956 with a death toll of 8,30,000 and Tang-shan (China) in 1976 killing 7,00,000 lives encouraged funding, research and detailed studies in Seismology. The devastating earthquakes that shook India includes Assam (1897), Kangra (1905), Nepal-Bihar (1934), Assam (1950), Koyna (1967), Killari (1993), Kutch (2001) and Nepal (2015). Earthquakes are the indicators of the dynamic and unstable nature of the Earth's interior apart from the expressions of plate interactions. On an average, more than a million earthquakes of varying intensities occur annually, resulting over 10,000 deaths all over the world. A detailed knowledge of the earthquakes is therefore required to understand these major geohazard activities.

Seismology deals with the behaviour of the seismic waves produced by earthquakes. The waves transfer energy (and not matter) from one place to another by vibration of particles. By anology, these waves are similar to the waves (/ripples) produced when a stone is dropped into a pond of calm water (fig. 7.1). Waves travel in all directions and their amplitude decrease with distance of travel from the point (/focus).

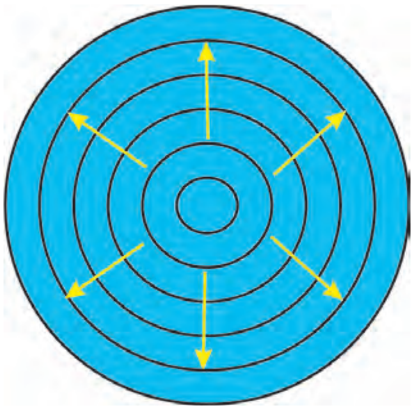


Fig. 7.1 : Visualization of ripples to understand the propogation of seismic waves due to an earthquake

Mainly two types of particle motion (oscillation) occur in this instance. When the particles oscillate perpendicular to the direction of propagation such waves are termed as transverse waves and when the oscillations are parallel to the propagation those are called longitudinal waves. An earthquake produces similar kind of waves in the Earth's crust with the transverse waves known as secondary or S waves and the longitudinal waves are primary or P waves.

Origin of the Earthquakes :

Earthquakes are explained by plate tectonics and the elastic rebound theory. The elastic rebound theory was proposed by H.F. Reid of Johns Hopkins University in 1906. It says that the constant motion of rocks along one side of a fault boundary causes the rocks on the opposite side to bend (fig. 7.2). The bending leads to a build-up of elastic energy which is created when a rock is deformed elastically, like a stretched rubber band. Rocks can also be deformed non-elastically, as a combination of the two. Frictional forces holding the rocks together are overcome and the rocks break at the weakest point along the fault plane, known as the focus of the earthquake (fig. 7.2). The deformed rock experiences slippage and then snaps back to its original position. The energy released by this slippage causes earthquake vibrations.

The energy released by the earthquake travels through the Earth in the form of waves classified as primary (P), secondary (S) and surface waves (L and R). The sudden breaking also called rupture usually results when the tectonic forces develop the strain beyond the limit of their strength (the elastic limit). When the shear (/frictional) forces are steadily increased between the two blocks of rocks separated by an existing fault, initially there is no movement. Finally, when the strain exceeds the strength of the fault, it results in rupture that extends rapidly along the fault plane. This allows the blocks on either side of it to return into less strained state. The energy that had been accumulating over time in the strained volume of rock is then suddenly released.

Science of seismology deals with the fundamental concepts of origin of the earthquake and its tectonic relationship, behaviour of rocks under different stress conditions, locating the earthquake, measuring the energy released by an earthquake, earthquake prediction and recurrence, building of earthquake resistant structures and long term behavior of faults.

Terminology used in Seismology :

The subject of seismology uses a universal terminology to describe the phenomenon. Following are the most common terms frequently used to explain the earthquakes.

i) **Focus :** It is a point within the Earth along the fault plane where the earthquake originates.

ii) **Epicentre :** This is the point on the Earth's surface, which is vertically above the focus.

iii) **Isoseismal lines :** Imaginary lines joining points on the Earth's surface, which have the same earthquake intensity.

iv) **Focal depth :** Vertical distance between focus and epicentre of an earthquake is called as focal depth or depth of focus.

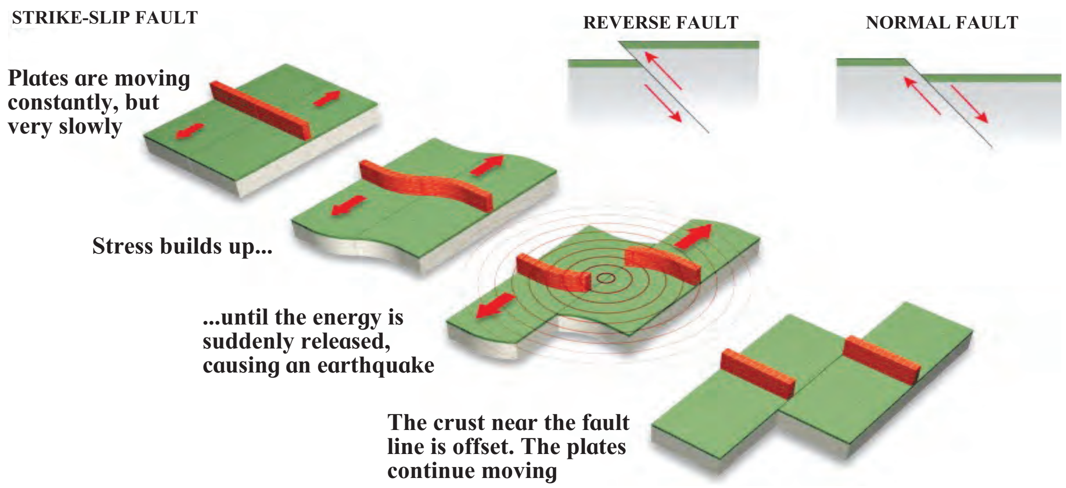


Fig. 7.2 : Diagrammatic representation of elastic rebound theory proposed by H. H. Reid to explain the origin of the earthquake

Depending upon the depth of focus three types of earthquakes are recognized :

a) **Shallow focus earthquakes :** Depth of focii within ~60 kms from the surface. These earthquakes are large in number and more disastrous.

b) **Intermediate focus earthquakes :** Depth of focii is between ~60 - 300 kms.

c) **Deep focus earthquakes :** Focal depth is more than 300 kms and upto 700 kms. These are recorded on a global scale and are less disastrous.

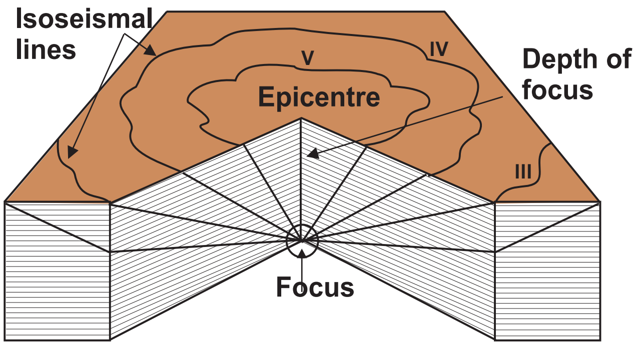


Fig. 7.3 : Focus, Epicentre and Isoseismal lines

Seismogram :

The seismogram is the record that consists of various types of zig-zag lines, that are intermittently recorded in between almost straight lines. The zig-zag lines represent the seismic waves generated by the earthquake, while straight lines are characteristic of the quiet time span, when there is no seismicity (fig. 7.4).

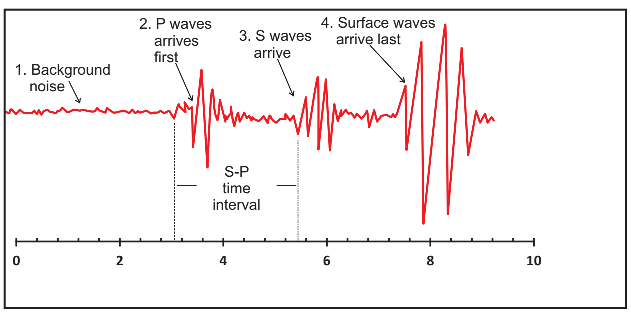


Fig. 7.4 : A typical seismogram

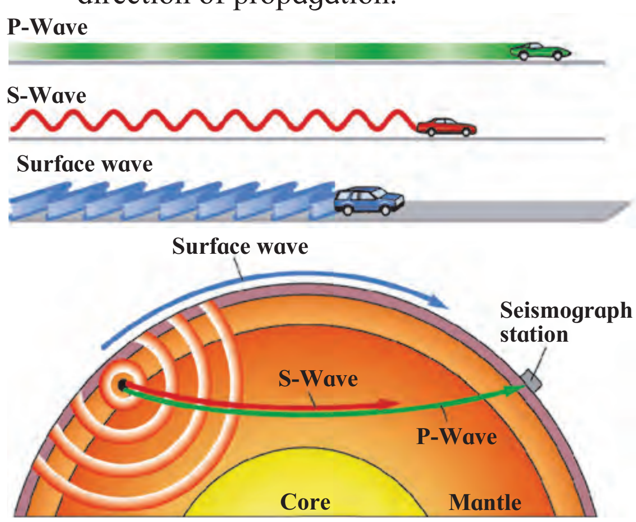
Seismic Waves :

The energy released by an earthquake can be traced in the form of seismic waves. Seismic waves travel through various layers of the Earth to reach a detector instrument.

Seismic waves are of two types (fig. 7.5), i.e., body waves and surface waves. The body waves are further divided into :

1) P waves also called compressional/ longitudinal/primary waves are the first to generate and travel fastest at velocities between 1.5 and 8 km/sec in the Earth's crust.

2) S waves also called shear/ translational/ secondary waves travel at 60% to 70% of the velocity of P waves. This can be reasoned as P waves shake the ground in the direction of propagation, while S waves shake perpendicularly or transverse to the direction of propagation.



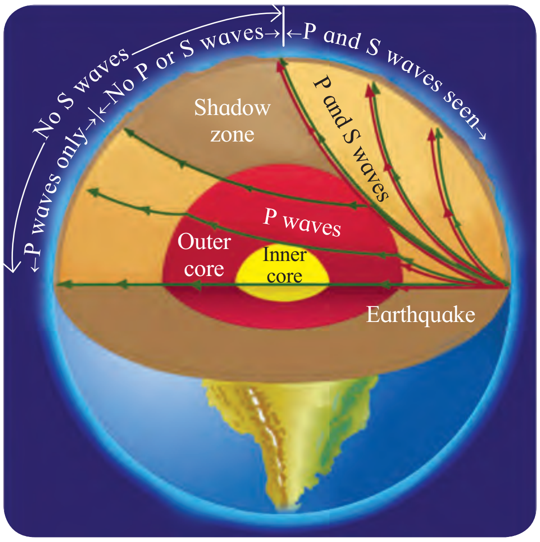
(**Source:**https://prezi.com/ctor9n6ebotf/lesson-11-cat-events/)

Fig. 7.5 : Types of seismic waves and their relative velocities

The second type of waves called surface waves travel along the surface of the Earth are divided into L waves and R waves. The L waves moves ground from side to side like a snake moves whereas the R waves roll the ground apparently up and down. The surface waves are most damaging to property and infrastructure.

Although wave speeds vary by a factor of ten or more in the Earth, the ratio between the average speeds of a P wave and of its following S wave (Vp/Vs) is quite constant. This fact enables to simply time the delay between the arrival of the P wave and the arrival of the S wave. This helps to get a quick and reasonably accurate estimate of the distance of the earthquake from the observation station (fig. 7.6).

For a quick examination the seismologists multiply the S minus P (S-P) time, by a factor of 8 km/s to get the approximate distance of an earthquake epicentre from the earthquake.



(Source:https://multimediascienceleahaviscounte.weebly.com/seismic-waves.html).

Fig 7.6 : Distribution pattern of the body waves from the focus resulting from the reflection/refraction of the waves due to internal structure of the Earth

Do you know?

How Secret Nuclear Tests are detected by seismology?

Nuclear explosion generates similar kind of energy to that of an earthquake. Seismologist sitting in distant countries can differentiate an explosion from an earthquake by looking at the ratio of P to S wave velocities. Earthquakes generate weak P waves and strong S waves. Explosions, on the other hand, generate strong P waves and weak S waves. A powerful explosions have higher P:S ratio than earthquakes. Further, the earthquakes will be detected very deep compared to nuclear explosion. The duration of the wave and its frequency is also characteristic of the explosion and earthquakes.

Both types of surface wave are slower than P- and S waves and so are rarely used for measuring travel-times, but they are important to understand the geohazards due to greater damages on the surface caused by them. Surface waves are generated by most seismic sources and often have the largest amplitude responsible for damage on the surface.

Earthquakes as geohazards :

1) **In developed or urbanised areas :** During an earthquake, the land surface mechanically responds to the waves. It results in partial to complete damage or collapse of buildings, walls, bridges, dams and other man-made structures. It often destroys power supply, water, oil and gas pipe lines. Railway lines and fences get twisted and the roads may crack open or get displaced. Loss of life may result from the collapse of structures or from fire caused due to leakage of gas, friction, electric current and other inflammable objects.

   Fire was a major cause of damage in the 1906 San Francisco earthquake and in the Kobe earthquake in Japan in 1995. It is therefore essential to evaluate every building as measure to damage and safety in the event of an earthquake. Earthquake resistant structures and buildings sustain the damage to a large extent.

Fig. 7.7: Effects of an earthquake in urbanized area example from 2015 Nepal earthquake (source: https://www.preventionweb.net/news/view/51350)

2) **Morphological changes :** Rivers and streams may change their course and cause floods or blocking. Groundwater circulation gets disturbed. The water from

lakes and wells may drain off through cracks and fractures. New lakes may come into existence. Old springs may dry out and new ones may arise elsewhere.

3) **Damage in coastal areas :** Loose sediments on the continental shelf may slide down to the sea floor. Some coastal land may get submerged, while new land may emerge from the sea.

4) **Tsunamis :** These are huge sea waves that strike the coastal regions, resulting from a strong submarine earthquake. The waves generated by these shocks reach coastal areas with very large amplitudes and cause inundation of land. Tsunamis are generated when a mass of water is abruptly displaced by movement of the sea floor, often by an earthquake, volcanic eruptions and landslides. The tsunami waves travel across the deep oceans with a wavelength of perhaps 100 km and an amplitude of about a meter. When the waves reach the shallow water near a coast they 'break' and surf landwards. Tsunamis may reach a height of 30 m or more, and historical evidences are found carrying ships to improbable places and devastating towns. Though the waves travel at ~800 km/hr, they still take several hours to cross an ocean.

5) **Damage in mountainous regions :** Landslides and avalanches may be set off and where glaciers enter the sea, they may break off to form icebergs.

Locating an Earthquake :

When an earthquake occurs the most urgent information needed is about location of earthquake i.e. the epicentre. Since the earthquake is a sudden phenomenon, the immediate information about its location is vital to any rescue agency. The location of earthquake can be immediately established by finding the epicenter, by using triangulation method. The recorded data from a minimum of three stations can be shared to find the radius of an imaginary circle drawn around each station. The intersection of at least three such circles would enable to know the location of an earthquake (fig. 7.8).

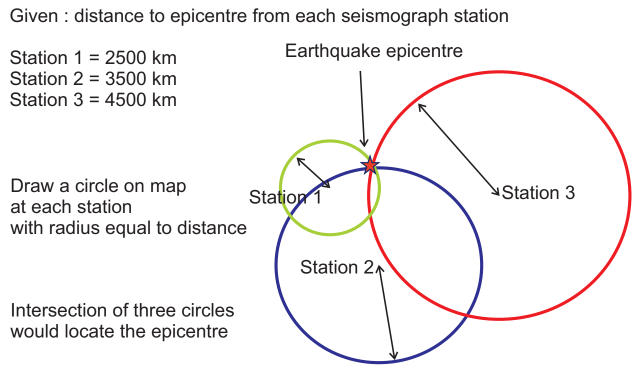


Fig. 7.8 : Triangulation method of locating epicentre of an Earthquake

The traces of an earthquake recorded at number of seismic stations in the form of arrival time of P and S waves are converted into distance. As S-waves travel more slowly than P-waves, the more distant the earthquake from the receiver, greater is the time lag between arrivals of S after the P waves. By matching this delay to standard P and S travel-time curves, the distance of the earthquake from a given station can be located (fig. 7.9).

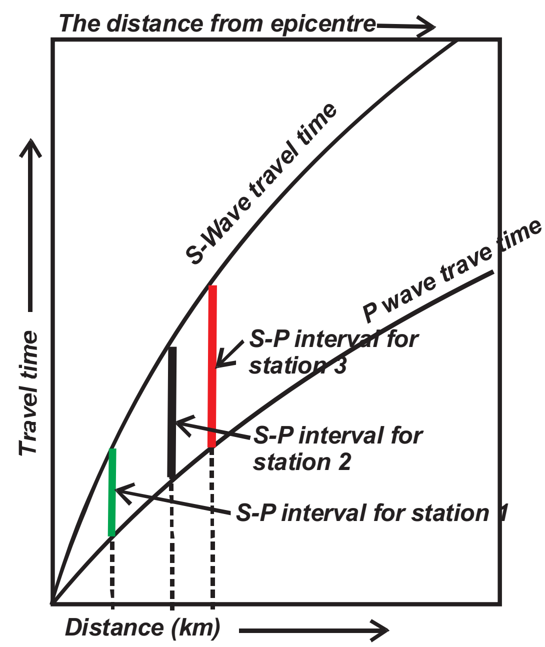


Fig. 7.9 : The concept of using standard travel-time graph to calculate the distance from station to epicentre using P-S time lag

Table. 1: Modified Mercalli Intensity Scale

Zone	Intensity	Abbreviated Description of Effects
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Feeble	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Slight	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Moderate	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Reasonably strong	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Destructive	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Ruinous	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Disastrous	Some well-built wooden structures destroyed; most masonary and frame structures destroyed with foundations. Rails bent.
XI	Very disastrous	Few, if any (masonary) structures remain standing. Bridges destroyed. Rails bent greatly.
XII	Catastrophic	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Earthquake Intensity : An earthquake is expressed by its intensity and magnitude. Intensity is the severity of damage by an earthquake at a given locality or region. Size of an earthquake is proportionate to the effects at the locality or of the disturbance at the source. The scale most commonly used to measure the intensity is Modified Mercalli (MM) Scale of 1931, with twelve categories, I to XII (See table 1). It allows the intensity at each locality to be estimated after the earthquake, by observing and defining the damages with the recording done immediately after the earthquake.

Earthquake Magnitude :

The most widely used Richter scale measures the total amount of energy released by an earthquake as magnitude of the earthquake. In this scale, the amplitude of the largest wave produced by an earthquake is corrected for distance and assigned a value on an open-ended logarithmic scale (fig. 7.10). One order increase in magnitude of Richter scale corresponds to tenfold increase in amplitude.

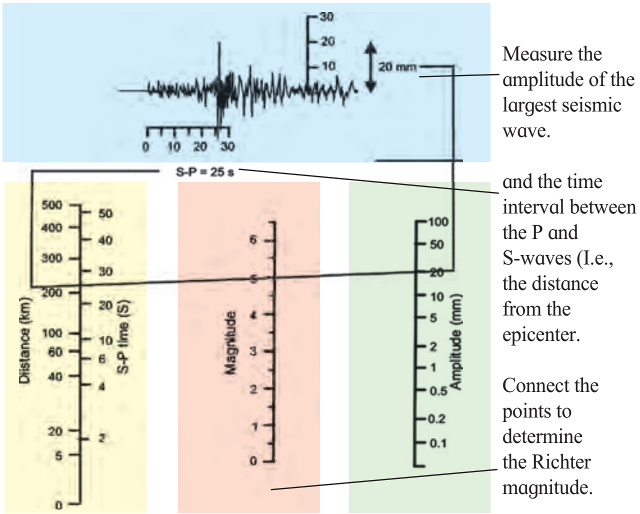


Fig. 7.10 : Description and example of Richter Scale for assigning the magnitude of an earthquake (Source: http://earthquakes.bgs.ac.uk/education/eq_guide/eq_booklet_measuring_size_eqs.htm)

Earthquake belts :

A survey of the Earth's seismic activity over the years reveals that majority of earthquakes are restricted to narrow and elongated zones on the Earth's surface, which are called earthquake belts. These belts are;

1) Circum-Pacific belt
2) Mediterranean-Asiatic belt
3) Mid-oceanic ridge belt

Fig. 7.11, defines the plate boundaries along with the earthquake belts.

1) **Circum-Pacific belt :** This belt runs along the margin of Pacific ocean and passes through Japan, Philippines, Chile, New Guinea, New Zealand, Alaska and the west coasts of North and South America. The San Andreas fault in United States falls under this belt. Almost 70% of the deep focus earthquakes occur in this belt.

2) **Trans-Mediterranean belt :** This belt runs between Gibraltar and south-east Asia. It passes through the Mediterranean Sea, Iran, Himalayas and Myanmar. About 21% of the past deep focus earthquakes have occurred in this belt.

3) **Mid-Oceanic Ridge belt :** This belt passes through most of the ocean floors of the Earth.

Global seismic centres in 1975-99
earthquakes of magnitude 5.5 and greater

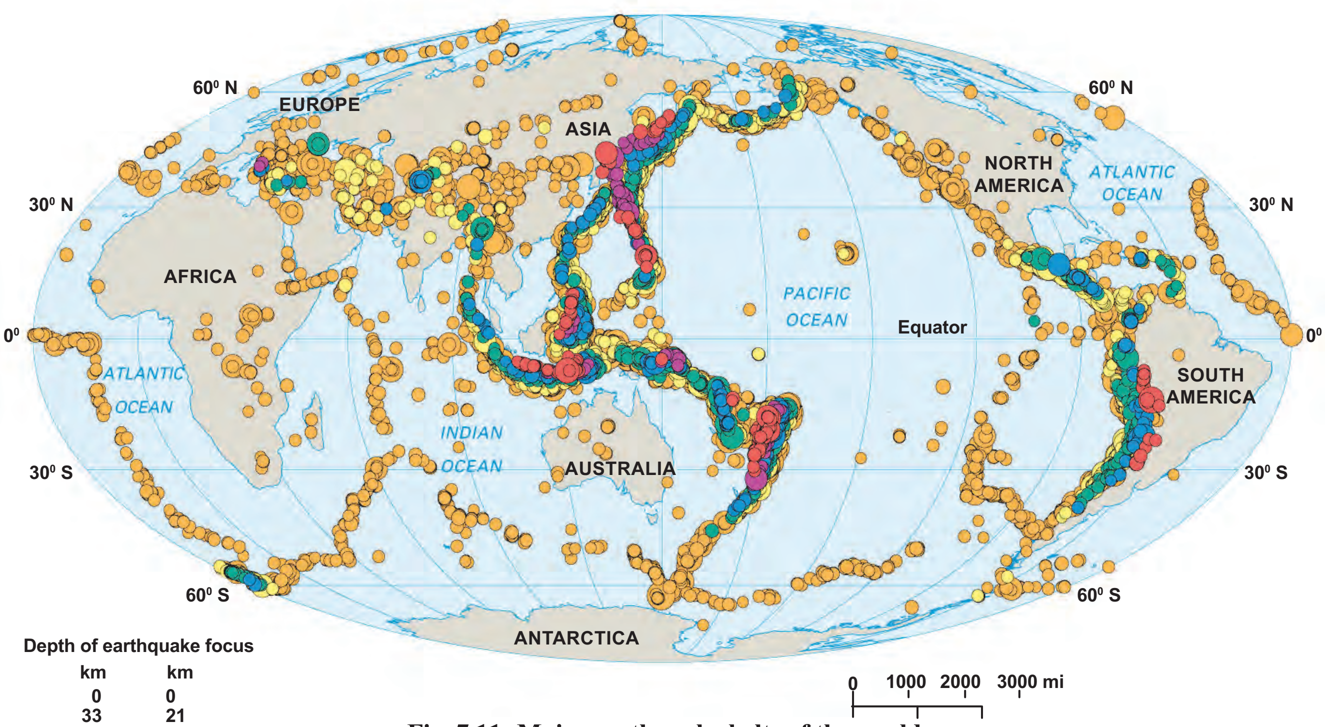


Fig. 7.11: Major earthquake belts of the world

Prediction and mitigation of the earthquake :

Earthquakes are caused by tectonic forces that are beyond our control. Precise prediction of the size, location and time of an earthquake is essential. Despite of all the developments in earthquake science and technology, till date there is no reliable method for such accurate prediction. However, a number of possible precursors warn us of an impending earthquake. These include changes in seismicity; variation in electrical and other properties of ground; variation in the water level in wells and its radon content. Efforts are needed to reduce the severity of damage due to an earthquake and is called the mitigation of the earthquakes adopting precautionary measures. Earthquake prone areas have been identified from.

a) Detailed geology (seismo tectonics),

b) Study of geomorphology (active tectonics),

c) Paleo seismicity signatures and historical records.

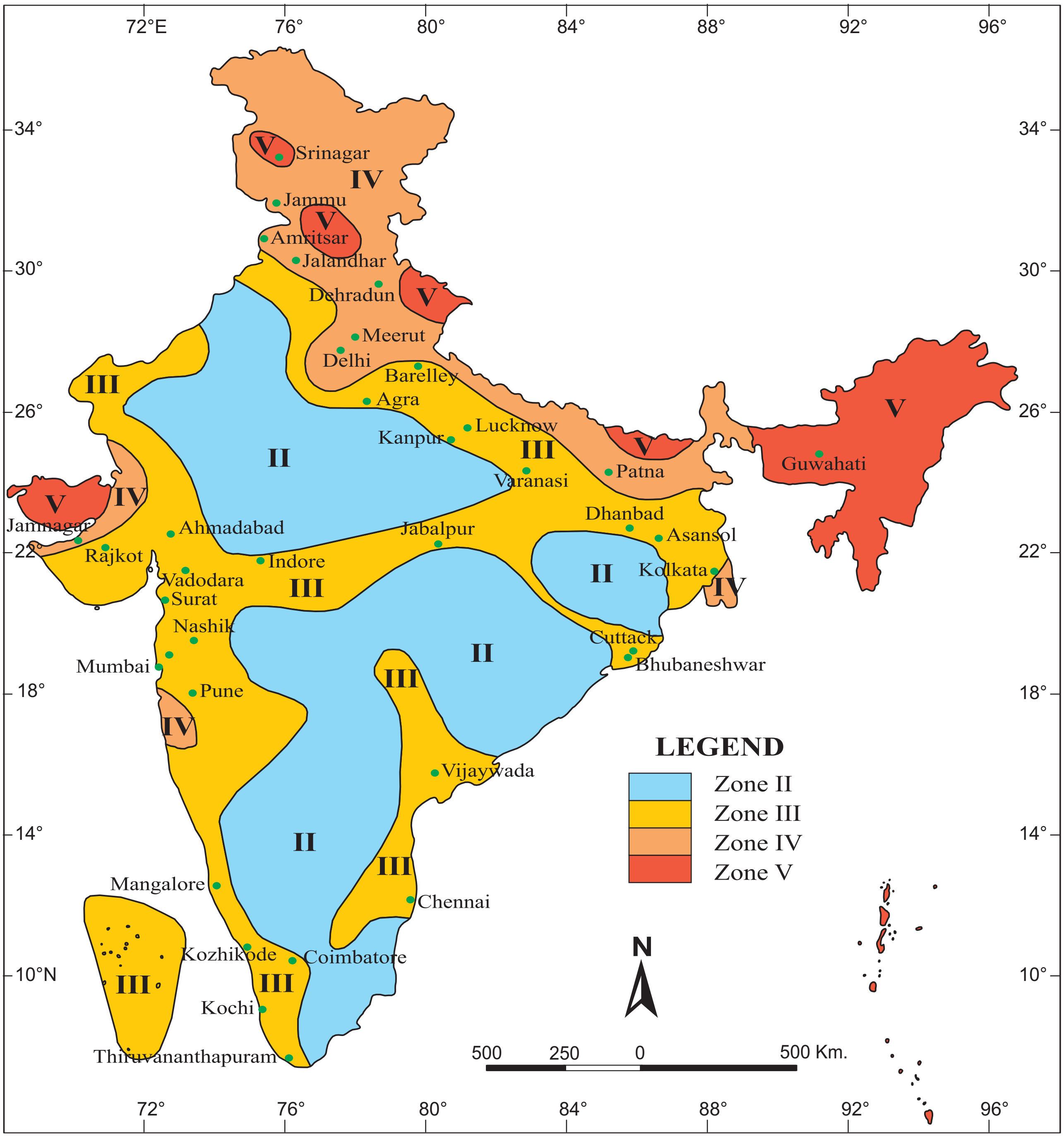


Fig. 7.12 : Seismic Hazard Zonation map of India

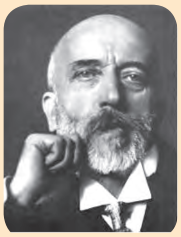
(Source : National Institute of Disaster Management: https://nidm.gov.in/safety_earthquake.asp)

Such information is used to develop hazard zonation maps and draw appropriate building codes to reduce the damage. Currently a hazard zonation map of India is available for such activity

Seismic Hazard Zonation :

The government agencies and research institutes classified the country into different zones based on the intensity of damage or frequency of earthquake occurrences. Such zonation provides guidelines and regulations to adopt norms for design of buildings in these zones (fig. 7.12).

Do you know?



Mohorovicic discontinuity, usually referred to as the Moho. It is the boundary between Earth's crust and the mantle. Named after pioneering Croatian seismologist Andrija Mohorovicic, Moho separates both oceanic crust and continental crust from underlying mantle. It defines the lithosphere – asthenosphere boundary. Mohorovicic discontinuity was first identified in 1909 by Mohorovicic, when he observed that seismograms from shallow-focus earthquakes had two sets of P- waves and S-waves, one that followed a direct path near Earth's surface and the other refracted by a high velocity medium.

Mohorovicic discontinuity is 5 to 10 km below the ocean floor and 20 to 90 km beneath typical continents, with an average depth of 35 km.

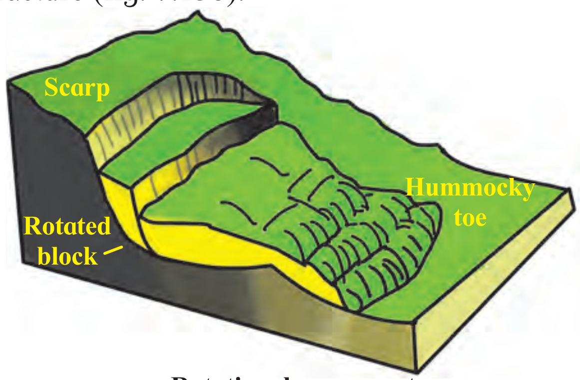
LANDSLIDES

Landslide is a naturally occurring phenomenon. As a geologist, one must know the processes, make predictions, and assess the risk of this threat in order to acclimatize to the potential hazards.

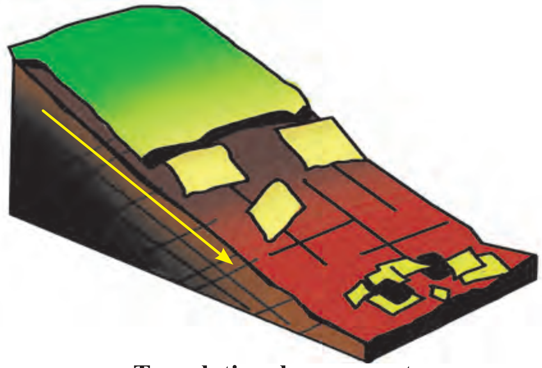
The downslope movement of rock debris/ regolith (loose unconsolidated mixture of soil and rock particles that cover the Earth's Surface) and soil in response to gravitational stresses is referred to as Land slide/ Slope failure or mass wasting. Three major types of mass wasting are classified by the type of downslope movement; they are falls, slides and flows.

Types of Landslides :

Earth materials may fail and move or deform in several ways. Rotational slumps involve sliding along a curved slip plain producing slump blocks (fig. 7.13a). Translational sliding is downslope movement of Earth materials along a planar slip plane such as a bedding plane or fracture (fig. 7.13b).



Rotational movement



Translational movement

Fig. 7.13 a, b: Types of movements due to landslides

Landslides are commonly complex combination of sliding and flowage. Such complex landslides may form when water-saturated Earth materials flow from the lower part of the slope, undermining the upper part and causing slumping of blocks of Earth materials. Important variables in classifying downslope movements are the type of movement (slide, fall, flow, slump, or complex movement), slope material type, amount of water present and rate of movement. In general, the movement is considered rapid if it can be discerned with the naked eye; otherwise, it is classified as slow (fig. 7.14 a-l). Actual rates vary from a slow creep of a few millimeters or centimeters per year to very rapid, at 1.5 m (5 ft) per day, to extremely rapid, at 30 m (98 ft) or more per second.

Impact of Geological structures on landslides:

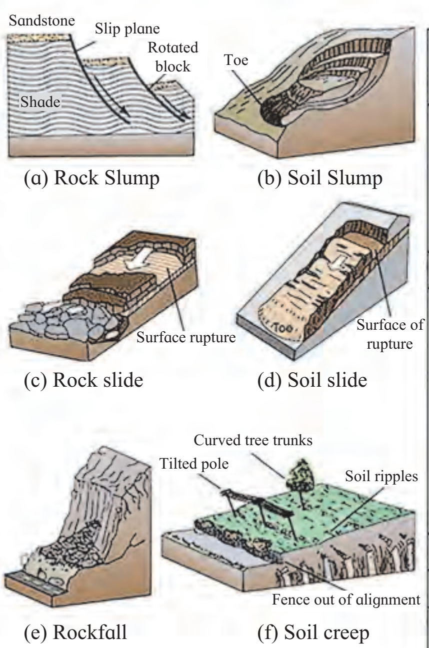
Geology is a critical component in the study of landslides. Specific factors related to the cause of a landslide that can be identified and attributed to geology are low strength rock or soil, faults, joints, bedding planes, etc.

- **Bedding Planes :** This is the plane of least cohesion in the layered rock masses. Bedding plane may be horizontal, inclined or even vertical. Horizontal beds tend to be most stable as compared to the inclined ones.
- **Schistosity and foliation :** They behave as planes of weakness. Failure is most common when they are inclined towards the free slope.
- **Joints :** Very few rocks are free from joints. Joints occur in sets, thereby reducing the strength. While studying the joints, their inclination must be carefully studied. A set of joints inclined towards the free side of the slope reduces the stability of the slope. Joints may be more vulnerable to failure when lubricated with water.

Monitoring and prevention of landslides :

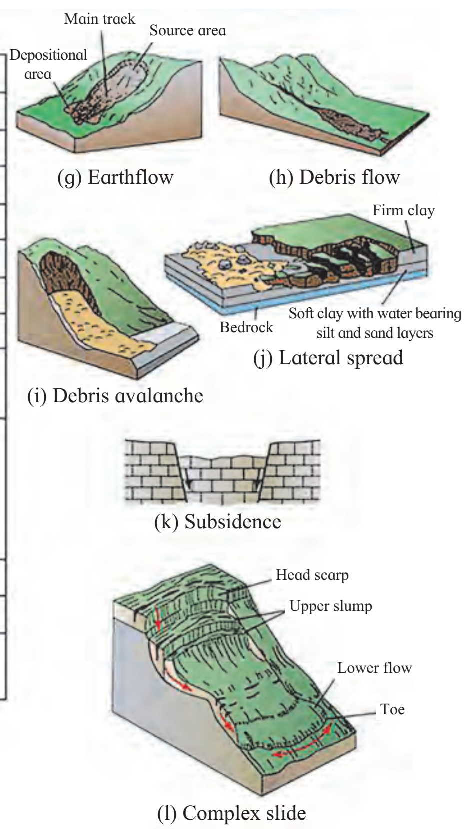
The effect of human use on the magnitude and frequency of landslides varies from nearly insignificant to very significant. In cases where human use has increased the number and severity of landslides, we need to learn how to recognize, control, and minimize their occurrence wherever possible.

Identifying areas with high potential for landslides is the first step in developing a plan to avoid landslide hazards. Slide tendency can be recognized by examining both geologic conditions in the field and aerial photographs to identify previous slides. This information can



(a) Rock Slump (b) Soil Slump (c) Rock slide (d) Soil slide (e) Rockfall (f) Soil creep

Type of Movement	Materials	
	Rock	Soil
Landslides with variable water content and rate of movement	Rotational	
	Slump(a)	Slump(b)
	Translational	
	Rock slide(c)	Soil slide (slip)(d)
Falls	Rock fall(e)	Soil fall
Flows: Slow	Rock creep	Soil creep(f)
	Unconsolidated rock and soil (saturated)	
	Earth flow(g)	
Rapid	Debris flow / mud flow(h)	
Very rapid	Debris avalanche(i)	
Lateral spread	Rock(j)	Soil
Subsidence	Rock(k)	Soil
Complex	Combination of slides, slumps, and flows(l)	



(g) Earthflow (h) Debris flow (i) Debris avalanche (j) Lateral spread (k) Subsidence (l) Complex slide

Fig 7.14 (a-l): Types of landslides

then be used to evaluate the risk and produce slope stability maps.

Preventing large, natural landslides is difficult, but common sense and good engineering practices can help to minimize the hazard. Common engineering techniques for landslide prevention include provisions for surface and subsurface drainage, removal of unstable slope materials, construction of retaining walls or other supporting structures, or combination of these.

The amount of water infiltrating a slope can be controlled by covering the slope with an impermeable layer such as soil-cement, asphalt, or even plastic. Groundwater may be inhibited from entering a slope by constructing subsurface drains. Cut-and-fill can be practiced where the material from the upper part of a slope is removed and placed near the base. The overall gradient is thus reduced. However, this method is not practical on very steep slopes. As an alternative, the slope may be cut into a series of benches or steps. The benches are designed with surface drains to divert runoff. The benches reduce the overall slope of the land and are good collection sites for falling rock and small slides. Slope Supports, retaining walls constructed from concrete, stone-filled wire baskets, bolting, or piles (long concrete, steel, or wooden beams driven into the ground are some of the methods for prevention of landslides).

VOLCANOES

The word volcano comes from the little island of Vulcano in the Mediterranean Sea, off Sicily. A volcano is simply a vent at the surface of the Earth through which lava and other volcanic materials are ejected from the Earth`s interior. Lava is the term used for magma that has reached the surface because of a volcanic eruption. Magma is the molten material below the Earth's surface.

Types of Volcanoes :

There are three primary types of volcanoes: i) Shield ii) Composite and iii) Dome.

i) **Shield volcano :** They are the largest of the three types, are gently sloping and built almost entirely of low viscosity basaltic lava flows (fig. 7.15). The eruptions are generally non-explosive due to the low silica content. Shield volcanoes are typified by those on the Hawaiian and Galapagos Islands and on Iceland. Numerous small shield volcanoes are typical throughout the eastern Snake River Plain in Idaho, USA. Examples include the Wapi lava field and Hells Half Acre U.S.A.

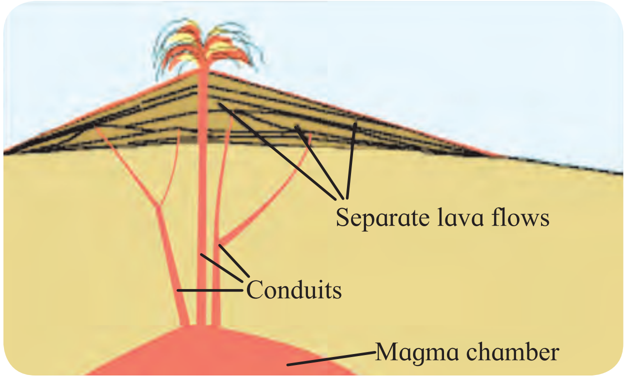


Fig 7.15 : Shield volcano in cross section

ii) **Composite volcanoes :** They are also called as strato-volcanoes and are the most beautiful and most deadly of the volcano types (fig. 7.16). They are steep-sided, symmetrical cones built up by eruptions of intermediate viscosity andesitic lava and explosive tephra, giving rise to crude stratification and hence the name. Examples of composite volcanoes, are Mount Shasta in California, Mount St. Helens and Mount Rainier in Washington state, and Mount Fuji in Japan.

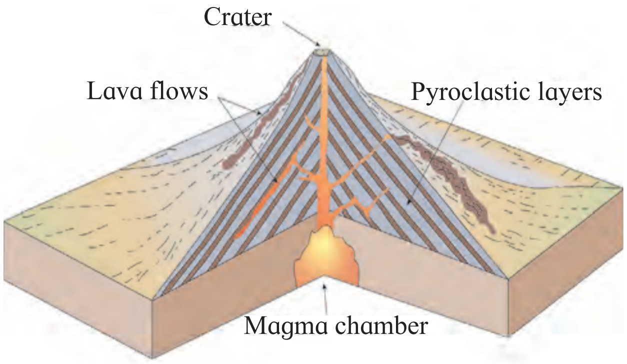


Fig 7.16 : Cross-section of a composite volcano

iii) Volcanic Domes : These comprise the third primary type of volcano. They are formed by highly viscous rhyolitic magma (approximately 70% silica) (fig. 7.17). Volcanic domes are typically small. Some are subject to explosive blowouts during dome building processes. Domes commonly occur adjacent to or within craters of composite volcanoes. Other domes begin as shallow laccolithic intrusions that grow and expand beyond subsurface confinement.

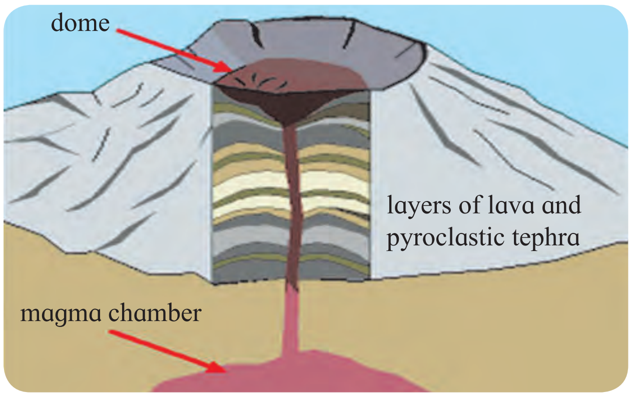


Fig 7.17 : Cross-section of a volcanic dome

Volcanic hazards :

The effects of volcanoes are studied as they cause a lot of human concern. Lava flows, ash-flows, lateral blasts, ash-falls, gases, lahars/mudflows, floods, fires, and tsunamis are the various types of volcanic hazards (fig. 7.18) that disrupt normal human activities.

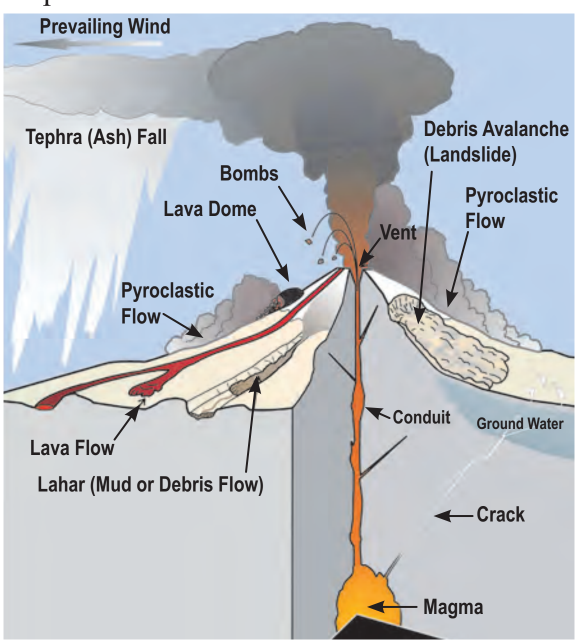


Fig 7.18 : Visualization of volcanic hazards

Volcanic hazard refers to any potentially dangerous volcanic process. It may lead to potential loss or damage. It may negatively impact the productive capacity/ sustainability of a population.

Many eruptions are explosive in nature. They produce fragmental rocks from erupting lava and the surrounding country rock. Some eruptions are highly explosive and produce fine volcanic ash that rises many kilometers into the atmosphere. Explosive activity also causes widespread ash fall, pyroclastic flows, debris avalanches, landslides, pyroclastic surges and lahars.

Types of volcanic hazards :

i) **Lava flows :** These are less dangerous to human life than to property, traffic and communication. Highly viscous lava generally does not advance far but commonly piles up above an active vent as a Lava dome. Such domes collapse repeatedly and generate hot block and ash flows, hot surges and blasts.

ii) **Ash Falls :** A volcanic eruption generally does not directly endanger life, although the collapse of roof and houses under the ash load are most common.

iii) **Pyroclastic flows :** Low density surges that are frequently associated with blasts are extremely hazardous types of volcanic eruptions. Pyroclastic flows are a mixture of volcanic gases and ash are generated during many volcanic eruptions.

iv) **Volcanic Debris/ Avalanches :** They are commonly generated by sliding of larger portions of volcanic cones. These avalanches are highly mobile and may bury large tracts of land and block streams to form lakes that can drain catastrophically and generate lahars and floods.

v) **Lahars (volcanic mud and debris flow) :** These are common major volcanic hazard to life and property. Lahars proceed very quickly and possess great destructive power. They develop either as a direct consequence of a volcanic eruption, or as a secondary event resulting due to heavy rainfall or sometimes as an after effect of eruption.

Effects of Volcanic hazards :

Damage to human life, social structure and property may not always be induced only by direct effects of volcanic eruption. Some of the most dangerous secondary phenomena are tsunamis, contaminated ashes or long-lasting aerosol clouds that can orbit the Earth for years after large volcanic eruption (e.g., Toba volcano). Aerosol clouds are composed of condensed volcanic gases, mainly sulphuric acid. The emission of large quantities of SO_2 and also possibly halogens into the stratosphere may lead to a temperature decrease on the Earth's surface by increasing the global albedo.

Prediction of Volcanic activity :

Prediction of a volcanic eruption is extremely important to provide early evacuation of densely populated regions. Prediction based on statistics of previous eruptions is too vague for specific and short term prediction of an eruption. A forecast is a general announcement that a volcano will probably erupt in the near future. A prediction is a relatively precise statement that describes the future volcanic event, its time and type of eruption.

Volcanic eruptions are often announced years, months, days or hours in advance. The relatively slow ascent of viscous magma to the upper crust generates a surface expansion that can be measured with modern geodetic instruments.

Prevention and mitigation of volcanic hazard :

In order to reduce the after effects of a volcanic hazard, a series of measures must be taken before, during and after a volcanic eruption. Preparation of hazard maps help to determine whether a volcano is potentially hazardous and to assess the risk. Monitoring of volcanoes by satellite must be increased in order to detect possible changes. Public must be informed and educated using brochures, placards, lectures, advertisements on the television etc.

A volcanic eruption cannot be potentially controlled by man. However limited possibilities to control its effects such as barriers against lava flows, cooling lava flow with sea water, channeling small lahars by artificial dams and artificially draining the lahar crater lakes can be practiced.

Summary :

Amongst the natural hazards, earthquakes are the most disastrous, as these cannot be predicted by time and exact location. Earthquake release an enormous energy, and their prevention is impossible. However the risk of damage to property and life can be reduced by acquiring detailed knowledge on seismology and adopting methods such as construction of earthquake resistant structures.

The landslides present one of the most common relatively small scale disasters. The damage due to landslides can be reduced by mapping of the landslide prone area and retrofitting the causes for landslide occurrence. For this purpose the fundamental knowledge on the origin, occurrence and types of landslide is essential.

The volcanoes are the disasters with well-known occurrences of active volcanoes in the given region. The volcanic eruption cause primary as well as secondary disasters. Primary disasters are associated with direct contact of volcanic material to property or life causing loss. Proper study of the given volcano and correct monitoring can produce warning of a volcanic activity with sufficient time of evacuation.

EXERCISE

Q. 1. Fill In the blanks :

1) Downslope movement of rock debris in response to gravitational stresses is called ....
   a) faulting b) slip
   c) thrusting d) landslide

2) Debris avalanche is a ....
   a) Very rapid to extremely rapid debris flow
   b) Slow to extremely slow debris flow
   c) Very rapid to slow debris flow
   d) Very rapid to extremely rapid rock fall

3) Landslides are a complex combination of …..... and …...........
   a) Sliding and slippage
   b) Thrusting and flowage
   c) Sliding and flowage
   d) Slipping and flowage

4) Water contributes to …........... when sediment pores are partially filled with water.
   a) Gravitational forces
   b) Resisting forces
   c) Driving forces
   d) Centrifugal forces

5) ....….. are the most beautiful but deadliest volcanoes
   a) Composite b) Shield
   c) Fissure d) Dome

6) ………. slumps involve sliding along a curved slip plain producing slump blocks
   a) Translational b) motional
   c) rotational d) gravitational

7) For a quick estimation of the distance of an earthquake epicentre from the seismic station, seismologists use a multiplication factor of ………. to the S minus P (S-P) time.

8) The most common scale to measure the intensity of an earthquake is ……….

9) Globally the earthquake occurrence belt coincides with ……….

10) In Richter scale the ………. of the largest wave produced by an earthquake is corrected for distance and assigned a value on an open-ended logarithmic scale.

Q. 2. Choose the correct alternative :

1) The Geohazards can originate
   a) Only from the surface processes,
   b) Surface to atmospheric interaction,
   c) Only from the interior of the Earth,
   d) All of the above

2) The seismic waves can be correlated with the analogy of ripples in pond for
   a) Their travel away from the source
   b) Their velocities inside the Earth
   c) Distribution of body and surface waves
   d) Origin of fault

3) The elastic rebound theory of H H Reid explains
   a) The origin of earthquake
   b) The origin of body waves
   c) The distribution of earthquakes
   d) Rheology of material

4) The contours of imaginary lines on maps joining points of the same earthquake intensity are called.
   a) Isoquake lines b) Isoseismal lines
   c) Isotropic lines d) Richter lines

5) The record of zig-zag lines representing the seismic waves generated by an earthquake is called:
   a) Seismograph b) Seismogram
   c) Seismic train d) Velocity graph

6) Shield volcanoes are:
   i) largest of the three types,
   ii) gently sloping
   iii) highly viscous basaltic lava flows
   iv) eruptions are generally non-explosive
   a) all statements are true
   b) statements i, ii and iv are true
   c) statements ii, iii and iv are true
   d) statements i, iii and iv are true

Q. 3. Short answers :

1) Why do earthquakes not occur deeper than 700 km.

2) Velocities of P waves are greater than S waves. Explain.

3) Why are surface waves more damaging as geohazards than the body waves.

4) In how many seismic zones is India divided and which area of the country is the most susceptible to seismic hazards?
5) What are the major types of mass movements?
6) Discuss the role of joints on occurrence of landslides.
7) What is the difference between intensity and magnitude of earthquake?
8) What is the standard method to find the distance between an earthquake and the recording station?
9) How can volcanic hazards be mitigated?
10) Discuss the importance of monitoring and prevention of landslides.

Q. 4. Long answers

1) Explain the role of geology in occurrence of a landslide.
2) Compare amongst the three major geohazards (Earthquake, Volcano and landslides) for their scale, predictability and mitigation.
3) Describe why the earthquakes cannot be predicted precisely.
4) Describe the different types of seismic waves and how they are produced.
5) Which conditions of volcano are the most significant in prevention of hazards?
6) Discuss the effects of landslides during planning and execution of developmental projects in a region.
7) Which type of volcanic hazard generally does not directly endanger life

Practical exercise
Locating the epicenter of an Earthquake

The different types of seismic waves travel at different speeds. P-waves travel faster relative to S-waves, and the surface waves are still slower. These different travel times of seismic waves after an earthquake occur is the basis of locating the epicenters of earthquakes (refer figures 7.5, 7.6, 7.8 and 7.9).

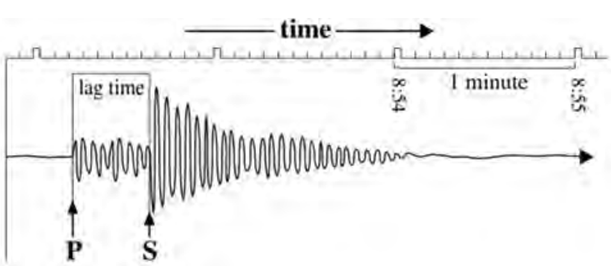


Figure: Seiemogram showing the first arrival times for the P-waves and S-waves. The lag time is the interval between P- and S- wave arrivals.

This exercise is to learn the key concept of seismic wave travel time and to understand how seismograms are used to find the distance to an earthquake epicenter. Imagine that car A and car B depart together at same starting point and same time. However the car A travels at a speed of 100 km per hour (kph), and the car B travels at 85 kph. An observer anywhere along the cars' route can calculate exactly how far they had traveled simply by measuring the arrival time difference between the cars at given location. Now consider that the car A passes a given spot at 2:30 pm, and car B passes the same spot at 2:45 pm, then find the distance between that spot and the cars' point of departure.

We know that the distance travelled (d) is the product of rate (r) and time (t):

$d = r * t$ ....(1.1)

Because the distance travelled is the same for both cars, the following must be true:

$d = rA * tA = rB * tB$.................... (1.2)

Given the speed of the two cars (rA and rB) and that car B passed the spot 15 minutes after car A (tB = tA + 0.25 hrs), Equation 1.2 becomes:

$100\ km/hr * tA = 85\ km/hr * (tA + 0.25\ hrs)$............ (1.3)

Simplifying and solving for

$tA = 1.42\ hr$..........(1.4)

Combining Equations 1.4 and 1.2:

$d = rA * tA$..................... (1.5)

$d = 100\ km/hr * 1.42\ hr$.................... (1.6)

$d = 142\ km$................ (1.7)

Explanations : In case of the earthquake data, a seismogram at given station is used to find the time lag as shown in the figure. Then this time (lag) for P and S wave is plotted along the Y- axis of a tabulation diagram like Figure 7.9 and on X- axis the distance from the epicenter is obtained. Such data from minimum three stations is required to get the epicenter as shown in figure 7.8. In practice however, the seismologists plot the data from more number of stations to reduce the error and get the exact location of the epicenter of an earthquake.

8 Remote Sensing and GIS

Introduction :

The term Remote Sensing envisages : "The process of measurement or acquisition of information of some property of some object or phenomenon by a recording device that is not in physical or intimate contact with the object under study"

So, as per this definition, processes like medical imaging (CT Scan, MRI, Sonography), seismic imaging etc would also be included under the ambit of remote sensing. But, for the sake of brevity, the term Remote Sensing is almost restrictively used for the process of image (data) acquisition by orbiting satellites and photography of the Earth by cameras on aircraft and drones.

Historical account of remote sensing :

As a spin-off from the surveillance technology effectively used by defense establishments around the world since man hoisted a camera on a hot-air balloon in year 1858 for photographing terra firma, remote sensing has come a long way. Among the very first 'civilian' efforts mandated exclusively for 'Earth Observation' (EO) is the LandSat 1, formerly the 'Earth Resources Technology Satellite 1' (ERTS 1) which proudly takes its place in any museum of technology. The data from this satellite and its younger and better siblings, is since the early 1970' regarded as the longest span of consistently acquired visual record of our planetary surface. Efforts of a similar kind are also being successfully carried out by the IRS (Indian Remote Sensing Satellites) series, albeit since the early 1988. Till today, the ISRO has launched a host of remote sensing satellites and we have 13 fully functional remote sensing satellites in orbit as of date. This also includes the RISAT- 1 a radar satellite.

Do you know?

- Who coined the term remote sensing?

The term 'remote sensing', first used in the United States in the 1950s by Ms. Evelyn Pruitt of the U.S. Office of Naval Research, is now commonly used to describe the science—and art—of identifying, observing, and measuring an object without coming into direct contact with it.

Ms. Evelyn Pruitt (1908 – 1969)

Do you know?

Indian Remote Sensing Satellites launched by ISRO and their status. Source: NRSC/ISRO

Sr. No.	Satellite	Date of Launch	Launch Vehicle	Status
1	IRS-1A	17 March 1988	Vostok, USSR	Mission Completed
2	IRS-1B	29 August 1991	Vostok, USSR	Mission Completed
3	IRS-P1 (also IE)	20 September 1993	PSLV-D1	Crashed, due to launch failure of PSLV
4	IRS-P2	15 October 1994	PSLV-D2	Mission Completed
5	IRS-1C	28 December 1995	Molniya, Russia	Mission Completed
6	IRS-P3	21 March 1996	PSLV-D3	Mission Completed
7	IRS 1D	29 September 1997	PSLV-C1	Mission Completed

Sr. No.	Satellite	Date of Launch	Launch Vehicle	Status
8	IRS-P4 (Oceansat-1)	27 May 1999	PSLV-C2	Mission Completed
9	Technology Experiment Satellite (TES)	22 October 2001	PSLV-C3	Mission Completed
10	IRS P6 (Resourcesat-1)	17 October 2003	PSLV-C5	In Service
11	IRS P5 (Cartosat 1)	5 May 2005	PSLV-C6	In Service
12	IRS P7 (Cartosat 2)	10 January 2007	PSLV-C7	In Service
13	Cartosat 2A	28 April 2008	PSLV-C9	In Service
14	IMS 1	28 April 2008	PSLV-C9	In Service
15	Oceansat-2	23 September 2009	PSLV-C14	In Service
16	Cartosat-2B	12 July 2010	PSLV-C15	In Service
17	Resourcesat-2	20 April 2011	PSLV-C16	In Service
18	Megha-Tropiques	12 October 2011	PSLV-C18	In Service
19	RISAT-1	26 April 2012	PSLV-C19	In Service
20	SARAL	25 Feb 2013	PSLV-C20	In Service
21	RESOURCESAT-2A	07 Dec 2016	PSLV-C36	In Service
22	Cartosat-2D	15 Feb 2017	PSLV-C37	In Service
23	Cartosat-2E	23 June 2017	PSLV-C38	In Service
24	Cartosat-2F	12 Jan 2018	PSLV-C40	In Service

- **RESOURCESAT-3 is a planned** Satellite to carry Atmospheric Correction Sensor (ACS) and is stated to be launched in 2021. This satellite is also important from the point of mineral exploration.

Process of remote sensing :

Fig. 8.1 illustrates the generalized processes and elements involved in Earth observation through remote sensing satellites or platforms like aircraft with digital imaging systems. Two basic processes involved are data acquisition and data analysis.

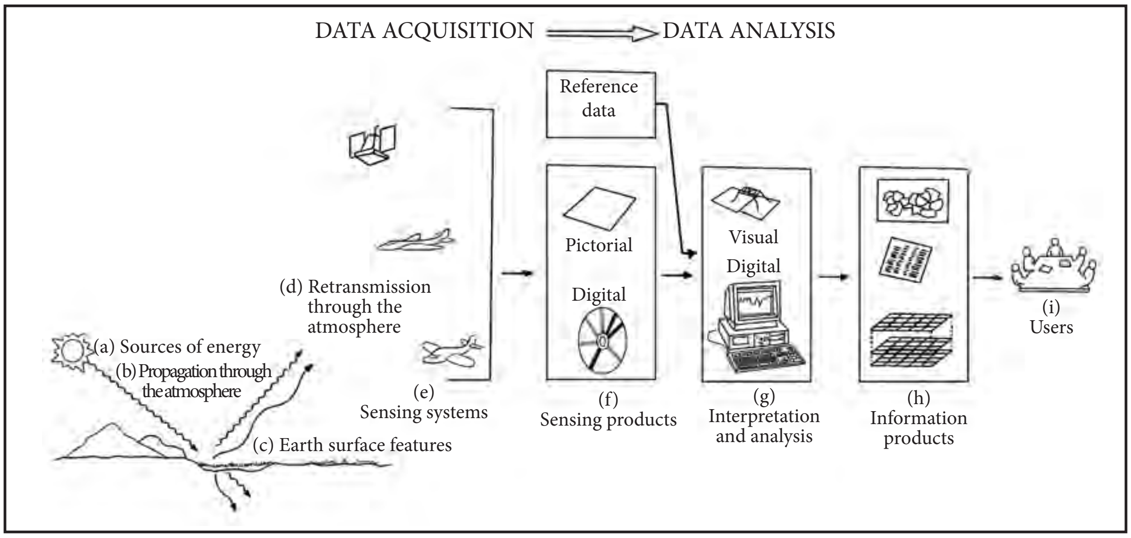


Fig. 8.1 : The process of remote sensing

i) The elements of the data acquisition process are :

a) Energy sources :

b) Propogation or transmission of energy (sunlight) through the atmosphere

c) Energy interactions with Earth's surface

d) Retransmission of the reflected energy through the atmosphere

e) Spaceborne (satellites) or airborne (drones, aircraft) sensors

f) Generation of sensor data in digital or picture form

ii) The data analysis process includes

a) Studying the pictorial data, visually or digital data using computers. Reference data in the form of ground truth or 'spectral signature files' is used to create output images/information which is thematic eg. geology, landuse, vegetation cover etc.

b) This information is then compiled, generally in the form of maps or datatables, which can also be used as an input in GIS.

Classification and Types of remote sensing :

The most common source of illumination of the Earth's surface is sunlight. Most of our remote sensing satellites that orbit around the Earth, have sensors that are designed to record the reflected sunlight from the Earth's surface, and hence cannot collect image data during night. Such a mode of remote sensing is called – 'passive' remote sensing (fig. 8.2). The example is, a simple camera without a flash.

Satellites like India's RISAT are different, and they carry a source of electro – magnetic energy in form of RADAR. Such satellites are also capable of imaging during night, though the images so obtained do not contain information about the sunlight being reflected from the Earth's surface, and are used primarily for preparing contour maps. This mode of remote sensing is known as 'active' remote sensing (fig. 8.3). Here a simple example is the same camera as stated above, but now equipped with a flash for illumination.

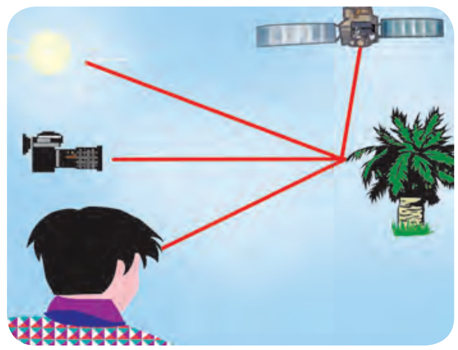


Fig. 8.2 : Passive Remote sensing – Sun is the primary source of illumination. Carried out by remote sensing satellites which record data in the visible and near infra-red wavelengths. e.g. IRS and Cartosat series of satellites launched by ISRO.

Do you know?

Dr. Pisharoth Rama Pisharoty (10 February 1909 – 24 September 2002) was an Indian physicist and meteorologist, and is considered to be the father of remote sensing in India. Dr. Pisharoty became the Director of Colaba and Alibag Magnetic Observatories in 1959 and Founder Director of the Indian Institute of Tropical Meteorology, Pune in 1962. In 1967 he retired as Director of the Institute of Tropical Meteorology and joined the Physical Research Laboratory, Ahmedabad as a senior professor at the invitation of Vikram Sarabhai. He was entrusted with the job of introducing remote sensing technology to India. His pioneering experiment of detection of coconut wilt-root disease using Soviet aircraft and US equipment was considered to be the first success in remote sensing in India.

Dr. Pisharoty served as the Director, Remote Sensing and Satellite Meteorology, at ISRO Space Applications Centre, Ahmedabad during 1972-75. He also served as the Vice-President of the International Association of Meteorology and Atmospheric Sciences, and as a member of Joint Organising Committee for Global Atmospheric Research Programme from 1969 to 1977.

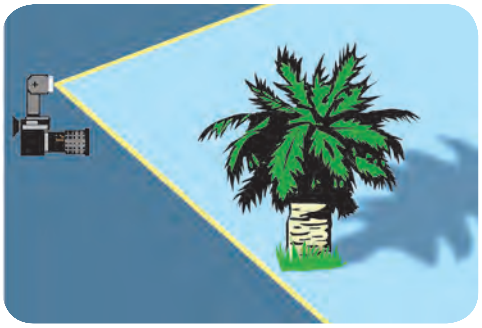


Fig. 8.3 : Active Remote Sensing – External source of Electro Magnetic Energy (EME). Carried out by remote sensing satellites which carry a RADAR. e.g. RISAT I launched by ISRO.

The most popular and commonly used data from remote sensing satellites is usually the one collected in the visible wavelength of light (detected by human eye) and in the near infra-red as well as thermal infra-red wavelengths as depicted (fig. 8.4). The visible and thermal range data is recorded by sensors called multi spectral scanners. The multispectral scanner (MSS) onboard our IRS series of satellites is called LISS (Linear Imaging Self Scanning).

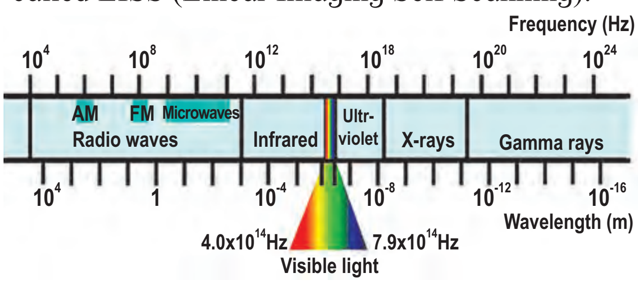


Fig. 8.4 : Wavelengths of Electromagnetic Spectrum (EMS) used in remote sensing

Sources of remote sensing data :

Data from our remote sensing satellites is available from the National Remote Sensing Centre in Hyderabad. Data is made available as printed imageries and also in digital format. Most of the data collected by our satellites in the past decade has been made available by ISRO for free. We can download digital data from the BHUVAN portal.
(https://bhuvan-app1.nrsc.gov.in/thematic/thematic/index.php)

Orbit of remote sensing satellites :

Almost all remote sensing satellites are placed in a Low Earth Orbit (LEO) which range from 300 kms to 700 kms above the Earths surface. The need for repetitive coverage necesseciates that these satellites be secured in a 'sun synchronous polar orbit' (fig. 8.5). This orbit allows for repetitive coverage of the Earth's surface, where the local equatorial crossing time of the polar orbit is adjusted to be between 10:30 and 11:00 hrs. This aids in obtaining imagery with the optimum illumination from the sun and also the slight shadow from topographic features, which aids in visual interpretation.

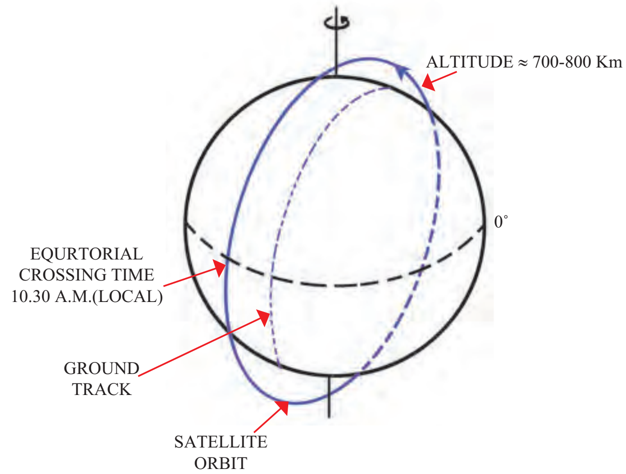


Fig. 8.5 : Orbit of a remote sensing satellite

Sometimes, for special missions, remote sensing satellites are also launched in a LEO which is oblique equatorial orbit. e.g. Razaksat - the Malaysian remote sensing satellite, which exclusively scans a narrow region on either side of the equator, allowing quick repetitive coverage of Malaysia.

Do you know?

Communication satellites are placed in Geo Stationary Orbit (GEO) which is about 36000 to 41000 km above Earth's Surface. India`s INSAT series of satellites are communication satellite which also transmit television signals.

Resolution of satellite data:

The term 'resolution' of a satellite imagery, generally refers to – spatial resolution – or what is very simply understood as the size of the smallest object on the Earth's surface that can be distinctly identified. Our early satellites like the IRS 1A had sensors (digital cameras) which scanned the Earth at a ground resolution of 72.5 m and today we have our Cartosat 2F which has sensors that can scan the Earth at a resolution of less than 1m. The (fig. 8.6) depicts sample imagery taken from our IRS satellites, demonstrating the impact of higher resolution on the interpretability of the features seen in the images.

Satellite Imagery :

Remote sensing satellites record data in digital form and the data is collected in discrete wavelengths. The distinct range of wavelengths are called 'bands'. The IRS satellites collect data in multiple bands depending on the mission requirements. e.g. the IRS P6 LISS 3 sensor collects data in four bands –

Band 2: 0.52-0.59 μm, (green)

Band 3: 0.62-0.68 μm, (red)

Band 4: 0.77-0.86 μm, (NIR)

Band 5: 1.55-1.70 μm, (SWIR)

Band 1 (blue) has been discontinued in many of the IRS satellites because of its limited use and the lack of clarity due to its sensitivity to water vapour in the atmosphere.

Types of Satellite imagery data :

Pan Chromatic : This is an imagery with a single band image, but the data usually has a very high ground resolution. e.g. PAN sensor of Cartosat 2E - is capable of taking panchromatic (black and white) images in a selected portion of the visible and near-infrared spectrum (0.50–0.85 μm) at a resolution of 65 cm.

Colour Composites : A colour imagery requires data in multiple bands, so that one primary colour can be assigned to each of the bands. As we have three primary colours (blue, green and red), at any one instance, we use just three bands to create colour composites. There are two types of colour composites – true colour composite (TCC) and false colour composite (FCC)

True Colour Composite (TCC) : A true colour composite is created by assigning the same colour to a band as the colour of the wavelength range of that band. This creates an image which appears identical to the colours of the Earth`s surface that we can see when viewed from an aircraft. The images we see in Google Earth or Google Maps are examples of TCC. (fig. 8.7)

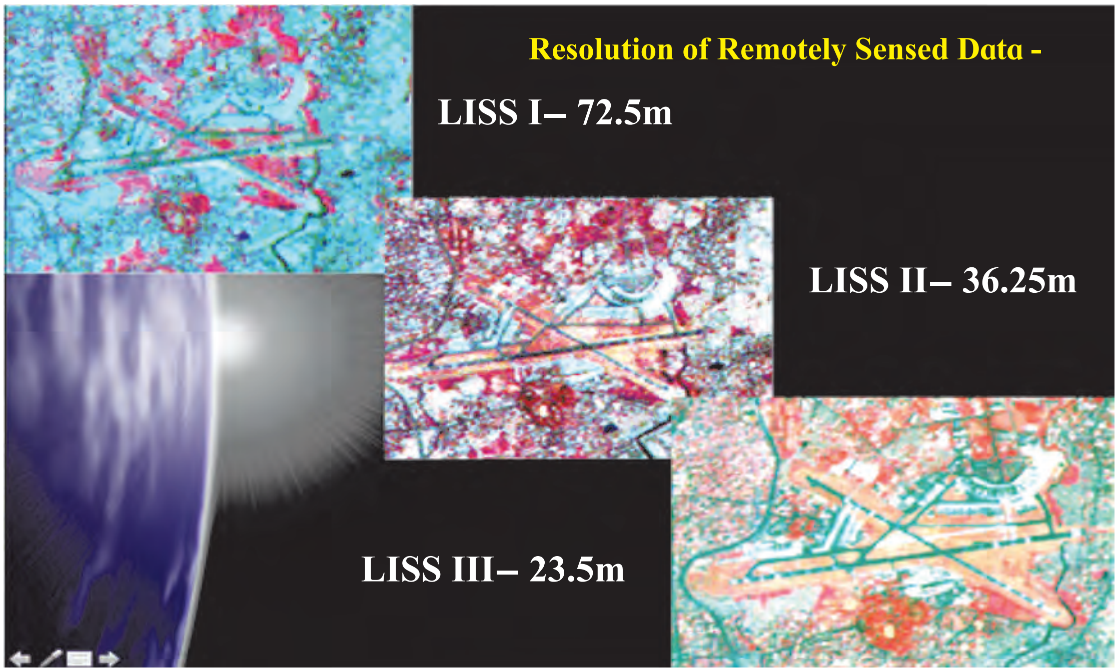


Fig. 8.6 : Sample imagery taken from our IRS satellites

Fig. 8.7 : A True Colour Composite (TCC)

False Colour Composite (FCC) : A false colour composite is created by assigning any of the three primary colours to any of the selected bands in a way where the assigned colour does not match the colour of the wavelength range of that band.

A special type of FCC is a Standard FCC where the green band, red band and near Infra-red bands are assigned blue, green and red colours respectively. This results in all the areas with green vegetation is present, to appear in shades of red. (fig. 8.8) Standard FCC is very useful in demarcating forested areas, crop land, grass land or high bio-mass cover areas on the Earth's surface.

Elements of Image Interpretation :

Visual Interpretation of Satellite Imagery is accomplished using the following criteria (aided by shadow and texture)

- **Shape :** It refers to the general form, configuration or outline of individual objects e.g. roads, airports etc. the shadow cast by tall objects or Earth`s relief (hills, valleys etc) also aids in understanding the shape, thereby helping in interpretation (fig. 8.9.)

Fig. 8.9 : Image interpretation - Shape

- **Size :** The size of an object is one of the most useful clue to its identity, e.g. settlements, reservoirs. It is scale dependent. Fig 8.10 is a FCC depicting a stream network with vegetation (red). If the scale is unknown,

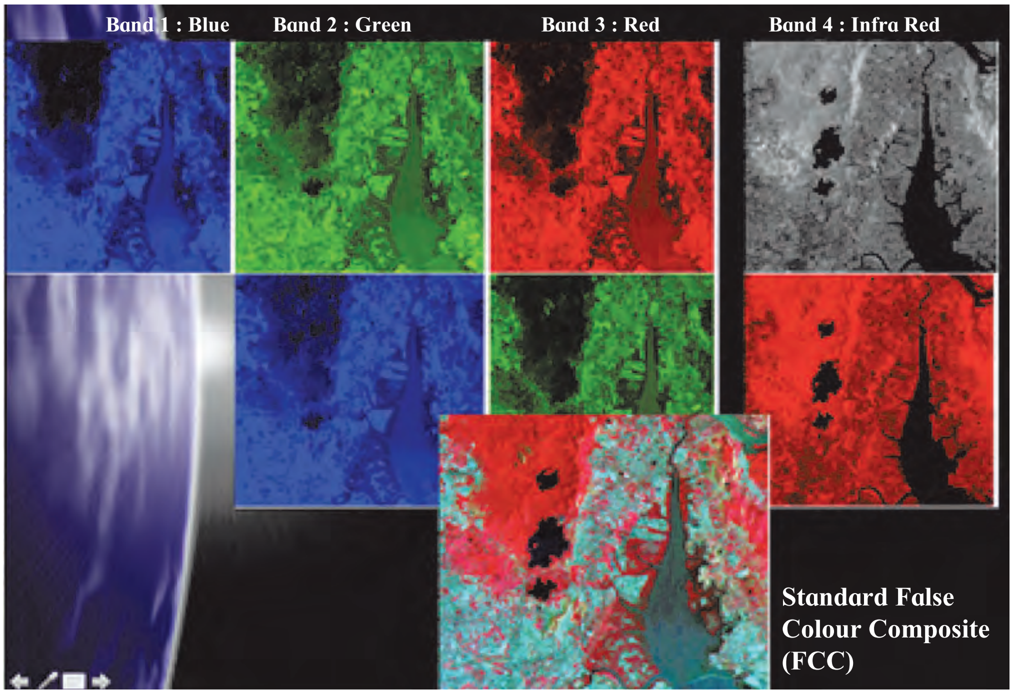


Fig. 8.8 : Resolution of remotely sensed satellite data- sample images from our IRS

the size of the objects in the image cannot be judged and could be misinterpreted as a photo taken under the microscope depicting blood vessels in the human body.

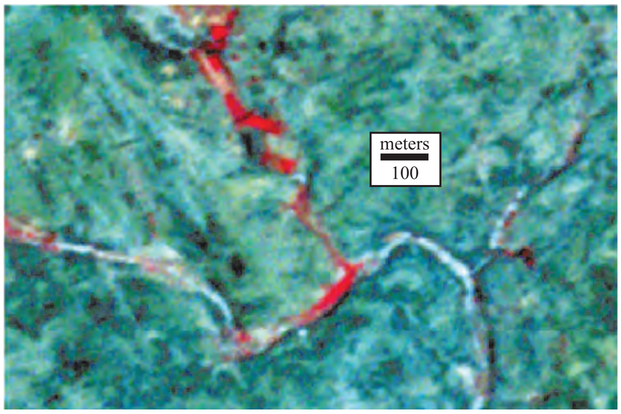


Fig. 8.10 : Image interpretation - Size

- **Pattern :** It relates to spatial arrangement of objects, e.g., uplands, lowlands, deltas, drainage pattern etc (fig. 8.11).

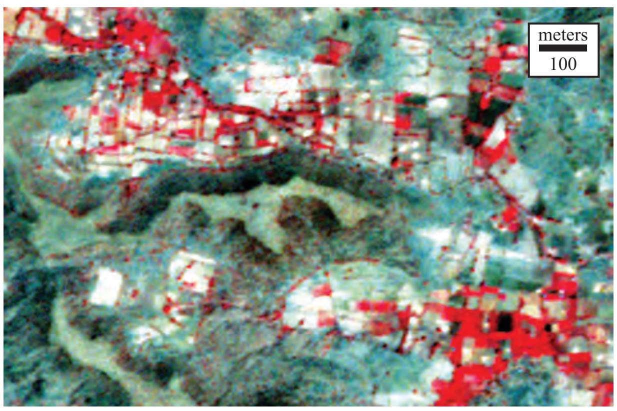


Fig. 8.11 : Image interpretation -

- **Tone :** It is the relative lightness of colour of objects in imageries, e.g., various shades of red for different types of vegetation in FCC (fig. 8.12).

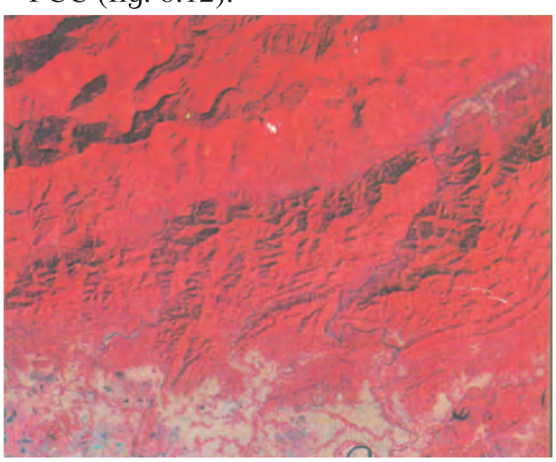


Fig. 8.12 : Image interpretation - Tone

- **Association :** Refers to the occurrence of certain features in relation to others. eg., Sand dunes are associated with deserts, mangroves with coastal regions and buildings associated with urban areas etc (fig. 8.13).

Fig. 8.13 : Image interpretation - Association

Aerial Photographs :

Photographs of the Earth`s surface using cameras (film or digital) are called as aerial photographs. Today such photographs can be obtained by drones (UAV: Unmanned Aerial Vehicles) equipped with digital cameras. Such photographs are generally acquired with low flying drones and hence bring out details of the Earth's surface features in very high resolution e.g. (fig. 8.14).

Fig. 8.14 : Aerial photo captured by drone

GIS – an Introduction :

A Geographic Information System (GIS) is today, necessarily a computer based system or environment, that can manage, analyse, and display geographic data or spatial data.

Geographic or Geo-spatial data is represented by a series of geographic datasets that contain information of spatial objects with respect to their location and all other descriptive attributes. The GIS has to necessarily be able to create and link such datasets with visual interfaces in form of maps or various thematic layers.

So a GIS has to be able to allow us to:

- View
- Query
- Interpret
- Visualize
- Understand and
- Geographic/ geo-spatial data on a computer.

A GIS combines a set of intelligent maps and other views that show features and feature relationships on the Earth's surface data and apply analytic rules to create a model that helps to answer questions.

The satellite imageries obtained from remote sensing satellites are very effectively used for creation and updating of the various thematic layers that are used in any GIS.

Do you know?

Dr Roger F. Tomlinson, (17 November 1933 – 7 February 2014) was an English geographer and the primary originator of modern computerised GIS, and has been acknowledged as the 'Father of GIS'.

It was during his tenure in the 1960s with Ottawa-based aerial survey company Spartan Air Services that Dr. Tomlinson conceptualized combining land use mapping with emerging computer technology. This pioneering work led him to initiate, plan and direct the development of the Canada Geographic Information System, the first computerised GIS in the world.

From the 1970s until his death, Dr. Tomlinson worked in geographic consulting and research for a variety of private sector, government, and non-profit organisations, largely through his Ottawa-based company, Tomlinson Associates Ltd., which has branches of consulting geographers in Canada, the United States, and Australia.

He was Chairman of the International Geographical Union GIS Commission for 12 years. He pioneered the concepts of worldwide geographical data availability as Chairman of the IGU Global Database Planning Project in 1988. He was also a president of the Canadian Association of Geographers.

What can a GIS do?

Today, a GIS has to be able to answer six wise questions – Where, When, Who, What, Why and How, and hence finds applications in all domains. It does so based on the ability of any GIS to organize geographic / geo-spatial data into a series of thematic layers with linked tables. Since geographic datasets in a GIS are georeferenced (have Latitude and Longitude or some grid reference), they have real world locations and overlay one another (fig. 8.15).

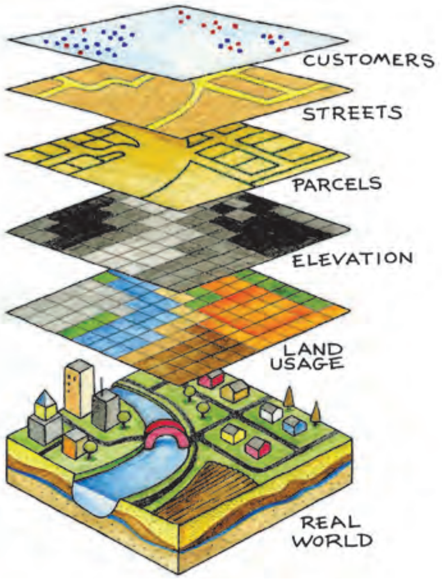
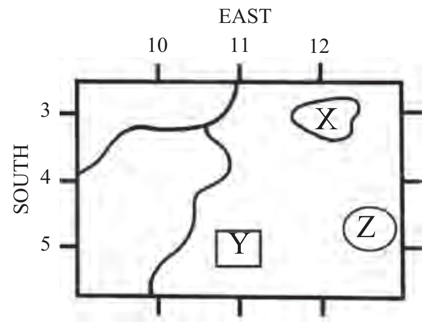


Fig. 8.15 : The concept of thematic georeferenced thematic layers in a GIS. (credit – Saylor Academy)

GIS generic question – Location :

GIS GENERIC QUESTION : LOCATION



Where is Feature X?
ANSWER : X = 3˚ SOUTH, 12˚ EAST

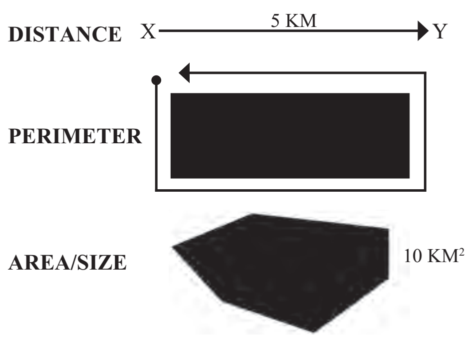
What exist at a specific location?
Ex : What is at 5˚ South, 11˚ East?
ANSWER : Y

GIS generic question – Measurement :

A GIS has to be able to answer queries related to distance between features, length of perimeter, area of a feature etc.

GIS GENERIC QUESTION : AERIAL RELATIONSHIP

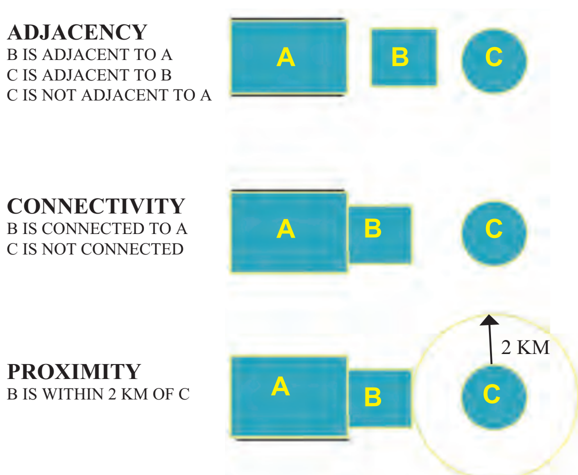
MEASUREMENT



GIS generic question – Neighbourhood analysis :

Queries based on the adjacency, connectivity and proximity should necessarily be answered.

NEIGHBOURHOOD ANALYSIS



Activity 1 :

Assume that your school/college is the polling centre for elections. Using a printout of the satellite imagery of your school and its surroundings, on a transparency sheet –

1) Mark the 100m buffer distance from the various gates of your school, on every road that leads to your school.
2) Prepare an overlay map that will show all the houses that will get effected due to this 100m rule, where no cars / vehicles would be allowed during the day of elections.

GIS generic query from Attributes database :

In a GIS, every feature in a map is necessarily tagged or linked along with its location to an attributes table or database. We can query the details of specific properties of the features seen in the map. e.g. for a specific geological formation depicted with a specific colour on a GIS enabled geological map, we should be able to query from the database – the rock type, its age, its engineering properties, its mineralogy etc.

GIS GENERIC QUESTION:
ATTRIBUTES

PROPERTY NUMBER	AREA (Ma)	OWNER	TAX CODE	SOIL QUALITY
1	1000,000	THOMAS	B	HIGH
2	50,100	BHARATI	A	MEDIUM
3	90,900	BHARATI	B	MEDIUM
4	40,800	ABHIJIT	A	LOW
5	30,200	ABHIJIT	A	LOW
6	120,200	SALMA	B	HIGH

WHO?

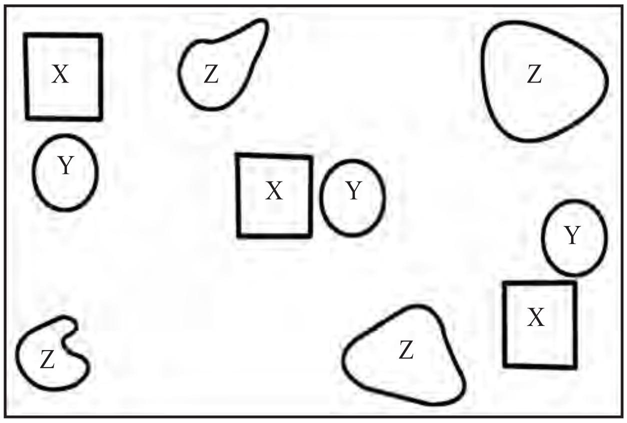
A) Attribute description
E.g. What are the attributes of property 2 ? (Record)

B) Where do certain conditions exist? (Field)
E.g. Who owns High Soil Quality properties?
Answer : Thomas and Salma

GIS generic questions - Patterns and Relationships :

As all features on a GIS enabled map would have linked attribites that would quantify the shape, location, areas etc of various features, it is necessary that a GIS be able to answer queries related to spatial correlation. Such queries are of immense use when geologists are working on mineral exploration. As specific minerals occur in certain geological structures or at specific locations in geological structures, queries related to patterns and mutual relationships help a geologist in mineral occurrence targeting.

GIS GENERIC QUESTION: PATTERNS and RELATIONSHIPS

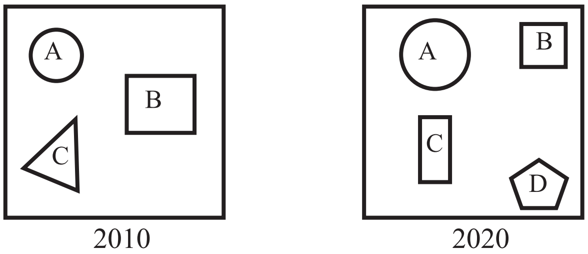


1) Does feature X occur in a pattern?
   Yes. in a line from NW to SE.
2) Is there a relationship between X and Y?
   Yes. Y is always close to X.
3) What other spatial or functional patterns exist?
   Feature Z is always near a border and increases size from West to East.

GIS generic query – Trend analysis :

Apart from geological investigations, GIS is very effectively used for a wide range of analysis. Studying and predicting the growth or change in development of towns and cities is one such area. A GIS can effectively answer queries related to changes in shape, size and locations of features that have been assigned attributes in the linked database.

GIS GENERIC QUESTION : <u>TRENDS</u>



1) How did items A,B,C change from 2010 to 2020?
   A : Increased size
   B : Decreased size, moved
   C : Changed shape
2) What has changed since 2010?
   Change in size of A and B
   Change in location of B
   Change in shape of C
   Addition of D

Activity 2 :

Frame a query or question using – 'where, when, who, what, why, will, which, can and how' as one or more of the words, and list out the various data sets and maps you would need to answer your query. Prepare a brief note on how you will attempt to solve your query using a GIS.

e.g. of a query: 'Will our storm evacuation plan be successful?'

Applications of remote sensing and GIS :

1) Disaster Management and Mitigation (DMM) :

As 'natural disasters' know no bounds - more so the manmade boundaries, the need for global coordination of observing and geographic information systems to address the entire cycle of DMM is necessary. Remote sensing conventionally supplied the post disaster visuals, used very effectively for pre and post assessment. Every state has a State Disaster Management Authority, and at regional level there is a very good understanding of Earth observation technology and a good policy framework. As natural disasters do not confirm to manmade boundaries, all the states and also global nations are committed and cooperate by providing the information and analysis derived from the analysis of various Earth Observation Systems. Such real time data from the sky and space is supplemented by direct linkages with live data from global earthquake monitoring, ocean wave height monitoring, volcanic eruption event prediction, precipitation, snow, and wind speed monitoring - leading to effective early warning system. When appended with geospatial databases which contain census and other social parameters, the rescue and mitigation workers on the ground take effective decisions and appropriate rescue infrastructure is optimally utilized.

2) Natural resources exploration :

The exploration of Oil and Gas, their extraction and production, electricity generation, transport and distribution, form merely a part of the activities of the energy sector. It encompasses not only non-renewable resources, but also renewable resources such as solar, wind, biomass, and hydropower. The energy industry is heavily dependent on EO data. e.g., weather data can form useful estimates for electricity supply and demand. Satellites are important in the exploration, extraction, and transport the world's oil and gas reserves, several of which are located in remote and hostile territory. EOS data can be used to build global resource maps for planning renewable energy projects.

More recently, renewable energy systems have benefitted from the contribution of EO data in not only their optimization, but also in their integration with traditional energy supply systems. While renewable energy sources such as solar, wind, or wave power are environmentally a safer option than fossil fuels, they are highly susceptible to environmental changes. Their availability depends largely on the prevailing weather conditions at their localities. Data on cloud cover and solar irradiance, along with wind speeds and directions, combined with environmental parameters such as land elevation and land cover models are vital elements in planning for the location and operation of renewable energy installations. An example of EOS data in this field is the Surface Meteorology and Solar Energy (SSE) dataset, funded by NASA, a compilation of temperature, wind, and solar radiation data derived from satellite observations and model analysis. Such datasets estimate variability on timescales ranging from seasonal, to several years.

3) Water :

The slowly but sure depleting reserve of the worlds fresh water reserves has been proved by ground observations as well as EO satellite data for gravity measurements. The fact that the Amazon river basin also contains the world's largest single groundwater repository was also confirmed by such observations. On a regional and local scale, watershed and rainwater conservation practices have been drawing heavily on observations from EO satellites for fine tuning the water conservation practices which depend on terrain conditions apart from the climatic zones.

The Asian Water Cycle Initiative (AWCI) utilises apart from meteorological datasets, EO data also for watershed characterisation and prioritisation. At a micro-watershed level, EO data is being effectively used for monitoring and documenting change in groundwater conditions which manifest as a change in vegetation and soil moisture. In Maharashtra, organisations like AQUADAM and Watershed Organisation Trust (WOTR), have incorporated remote sensing data in a GIS This is so because, water resources management is a people and community centric activity where remote sensing data becomes just one data input. It is an excellent tool for benchmarking. But it needs effective integration with GPS along with inputs from local community. Any application developed for 'water' management also needs to have a 'peoples component'. So apart from mapping and change detection, remote sensing data, especially the visualisations generated from such data are today being very effectively used to bring about an awareness among the participants about their prevalent environment. The modeling done for forecasting water demands and resources depletion, is similarly communicated through the rich visualisation modules available in GIS. Such visual medium for educating and opinion building among the impacted communities around the world, plays an important role in water conservation, and convincing impacted communities about the importance of appropriate exploration and sustainable exploitation strategies.

Activity 3 :

Using a printout of the satellite imagery from Google Earth (at known scale) depicting your school/college, prepare individual maps on a transparency sheet as listed below.

a) The school campus.

b) All roads leading to your school/college from the neighborhood.

c) Location of the houses of all your classmates in the school/college vicinity.

Using these three layers, and the measured distances along the roads, arrive at the best location for meeting your friends after school/college such that – all your friends can reach their home from this spot in the same amount of time. Discuss the method followed by you with your classmates.

Activity 4 :

Discuss and Debate :

Is Google Maps a GIS? List your reasons.

Is Google Earth a GIS? List your reasons.

Summary :

Remote sensing has evolved into a fine tuned data collection method over the last century – since the advent of the camera and the aircraft. Satellite remote sensing has effectively added the advantage of repetitive coverage which comes in handy when collecting data on dynamic and temporally varying themes such as water, agricultural fields, and infrastructure development and so on. Multi layered remote sensing carried through drones, aircraft and satellites allows for easy collection of data over a variety of scales and resolutions. Today, data collected through these Earth observation systems, is being effectively used for near real time update to spatial data within GIS.

The power of spatial analysis along with excellent visual creations done through GIS has become ubiquitous and is accepted if not expected in all walks and processes of day to day human functioning. The excellent monitoring of the global pandemic caused due to the Covid – 19, its fallout, spread, containment and control have been made possible through the perfect dovetailing of data from multiple - agencies, countries, formats and scales made available on global data platforms. The study and understanding of how GIS systems work and their capabilities is today an essential part of every Earth-science student's curriculum.

Plate 1 : Satellite imagery - geologically faulted area. (source - Google Earth)

Plate 2 : Satellite imagery - geologically folded area. (source - Google Earth)

Plate 3 : Satellite imagery - rock outcrops showing joints. (source - Google Earth)

Plate 4 : Satellite imagery - Intrusive rocks - dykes. (source - Google Earth)

EXERCISE

Q. 1. Fill in the blanks with correct choice from the list :

1) The term remote sensing was first used in …………… year.
   a) 1949 b) 1959 c) 1988 d) 1996

2) The term remote sensing was coined by ………… Of the U.S. office of Naval Research
   a) Kalpana Chawla b)Valentina Tereshkova
   c) Evelyn Pruitt d) Edelyn Bishop

3) The first civilian Remote sensing satellite launched by the U.S.A was ……………
   a) IRS-1A b) SPOT
   c) RAZAKSAT d) ERTS1

4) The U.S. remote sensing satellite ERTS 1 was later renamed ……………
   a) USRS-1 b) USA SAT-1
   c) LANDSAT-1 d) LSAT-1

5) The first Indian Remote sensing satellite was called ………………
   a) Rohini-1 b) PSLV-1
   c) Bhaskara d) IRS-1A

6) The IRS 1A was launched in the year ………………
   a) 1950 b) 1978 c) 1988 d) 1998

7) The RISAT-1 is India's first ……………. Satellite.
   a) Remote Sensing b) Risk assessment
   c) Radar d)Resource mapping

8) Most remote sensing satellites cannot collect image data during ………………
   a) an earthquake b) a tsunami
   c) night d) winter

9) The abbreviation GIS stands for ……………
   a) Geological Information System
   b) Geographical Information System
   c) Geomorphological Information System
   d) Geophysical Information System

10) A GIS has the ability to organise geographic data into a series of …………… layers.
   a) coloured b) imagery
   c) thematic d) GPS

11) ……………….. is not an example of Remote sensing.
   a) Drone flying b) CT scan
   c) Sonography d) Satellite imaging

12) Vegetation in a standard FCC appears
   a) Green b) Blue
   c) Infra-red d) red

13) ………….... is not an example of active remote sensing
   a) MRI b) Seismic imaging
   c) RADAR d) Drone photography

14) ………….. is not an example of passive remote sensing
   a) LIDAR b) Drone photography
   c) Satellite imaging
   d) Digital camera without a flash

15) ………….. is not a Indian remote sensing satellite
   a) In SAT-1A b) Resource Sat-2
   c) Carto Sat-2F d) IRS-1C

16) Today a remote sensing satellite cannot detect
   a) Oil spills on ocean surface
   b) Open cast coal mines
   c) Underground oil reserves
   d) People sitting on a sandy beach

17) A remote sensing satellite is never in
   a) Sun synchronous equatorial orbit
   b) Geo stationary HEO
   c) Sun synchronous polar orbit
   d) LEO obliged equatorial orbit

Q. 2. Choose the correct sequence :

1) i) Sensing system – Interpretation and Analysis – Users information products – Sensing products.
ii) Users – Sensing products – Information products – Interpretation and analysis – Sensing systems
iii) Sensing systems –Sensing products – Interpretation and Analysis – Information products – User

iv) Sensing systems – Information products – Sensing products – Interpretation and Analysis – Users

2) i) Sources of energy – Sensing systems – Propagation through the atmosphere – Retransmission through the atmosphere – Earth surface features.

ii) Earth surface features – Sources of energy – Sensing systems – Propagation through the atmosphere –Retransmission through the atmosphere.

iii) Sources of energy – Propagation through the atmosphere – Earth surface features – Retransmission through the atmosphere – Sensing systems.

iv) Sources of energy – Earth surface features propagation through the atmosphere – Retransmission through the atmosphere – Sensing systems.

Q. 3. Very short answer :

1) List the two types of Remote sensing.
2) The most commonly used data from Remote sensing satellites is?
3) Remote sensing satellites are usually placed in what kind of orbit?
4) In which form do remote sensing satellites record data?
5) What are 'bands in remote sensing satellite data?
6) What is Pan chromatic imagery?
7) List the types of colour composites available as satellite imagery.

Q. 4. Short answer :

1) What kind of questions should a GIS be able to answer?
2) What does a GIS allow us to do?
3) List the five dements by which interpretation of satellite imagery is accomplished.
4) Explain the term 'resolution' of a satellite imagery.
5) What is the official source of remote sensing satellite data in India?
6) What is the special type of orbit that remote sensing satellites are placed in? Why?
7) Explain with an example how a GIS can query from attributes database.
8) Explain the various elements of image interpretation.
9) Explain how colour composite satellite imageries are prepared.

Q. 6. Long answer :

1) Explain with an example how a GIS can query and answer questions about 'Patterns and relationships'.
2) Explain with an example how a GIS can answer questions an 'trends'
3) With a neat diagram explain the entire sequence in the 'process of remote sensing'.
4) Explain with a diagram the logic behind the creation of a 'False colour composite' satellite image. Why is vegetation depicted in 'red' tone on a standard FCC ?
5) Can Google Earth be considered a GIS? Explain your reasons.
6) Explain how remote sensing and GIS can be effectively used in any one of the listed applications.
   a) Disaster management and mitigation
   b) Natural resources exploration
   c) Water

PRACTICALS

Practical No	Name of the Exercise
1	Study of Physical Properties of Minerals. (Colour, streak, lustre, form, fracture, cleavage, hardness, specific gravity)
2	Study of Ore Minerals
3	Study of Industrial Minerals
4	Study of Textures and Structures of Igneous Rocks
5	Study of Textures and Structures of Sedimentary Rocks
6	Study of Textures and Structures of Metamorphic Rocks
7	Study of Horizontal series of Geological Map
8	Study of Inclined series of Geological Map
9	Study of Seismic Zones of India
10	Identification of Geological Features from Satellite/Aerial photos
11	Calculation of the groundwater available for recharge
12	Calculation of Epicentre
13	Field work/ viva voce
14	Certified Journal

General Instructions for Teachers :

1) Mineral specimens which show required Physical properties should be used.
2) Rock specimens should clearly show the textures, structures and engineering properties clearly.
3) For section drawing use Geological map no.1 to map no. 9 from this textbook.
4) Use the outline map of India for marking seismic zones of India.
5) Use Landsat image or Aerial photograph for identification of geological features.
6) Use given data for location of Epicentre.
7) Use given data for calculation of availability of water for groundwater recharge.
8) Teachers should strictly follow the rules for educational visit, given by concerned authorities.

General instructions for Students :

1) Make the best use of time available for performing experiments.
2) Bring geometrical instruments, colour pencils and journals.
3) Handle the specimen carefully. Do not mark or write on specimens.
4) Draw neatly labelled diagrams wherever necessary in the journal.
5) Use Geological maps from this textbook for drawing sections.

Practical No.1

Study of Physical properties of Minerals.

Practical No.2

Study of Ore minerals.

(Hematite, Magnetite, Pyrite, Pyrolusite, Psilomelane, Chalcopyrite,Malachite, Galena, Sphalerite, Bauxite)

(Refer to Chapter no.5)

Practical No.3

Study of Industrial Minerals.

(Coal, Gypsum, Kaolinite, Feldspar, Quartz, Garnet, Corundum, Kyanite, Zircon, Diamond, Muscovite, Biotite, Sulphur and Cinnabar)

(Refer to Chapter no. 5)

Practical No.4

Study of Texture and Structures of Igneous Rocks.

(Phaneric, Porphyritic, Vesicular, Amygdaloidal, Ropy and Pillow)

(Refer to Chapter no. 2)

Practical No.5

Study of Textures and Structures of Sedimentary Rocks.

(Clastic, Lamination, Stratification, Cross bedding, Graded bedding, Ripple marks)

(Refer to Chapter no. 2)

Practical No.6

Study of Structures of Metamorphic Rocks.

(Schistose, Granulose, Gneissose)

(Refer to Chapter no. 2)

Practical No.7 and 8

Study of Geological Maps and section drawing.

(Use Map no. 1 to 9 from this textbook)

Practical No.9

Study of Seismic Zones of India.

(Refer to Chapter no. 7)

Practical No.10

Identification of Geological features from Satellite image/Aerial Photograph.

(Refer to Chapter no. 8 - Plates 1, 2, 3 and 4)

Practical No.11

Calculate the water available for Groundwater Recharge.

(Refer to Chapter no. 6)

Practical No.12

Calculate Epicentre

(Refer to Chapter no. 7)

Practical Question paper pattern

Marks = 30 **Time = 3 Hrs.**

Q. 1. A) Identify and describe ore minerals from table no. 1 to table no. 3. **- 3 Marks**

B) Identify and describe industrial minerals from table no. 4 to table no. 7. **- 4 Marks**

Q. 2. Identify rock specimens from table no. 8 to table no. 11 and describe their colour, texture, Structures and classification.

- 4 Marks

Q. 3. Draw the Geological section of given map and describe topography, history and order of superposition.

a) Inclined series - 1 map **- 7 Marks**

b) Horizontal series - 1 map
(only description) **- 2 Marks**

Q. 5. Name the sites/zones in given outline map of India.

a) Seismic zones **- 1 Mark**

Q. 6. Calculate the

a) Epicentre **- 1 Mark**

b) Ground water availabile for recharge

- 1 Mark

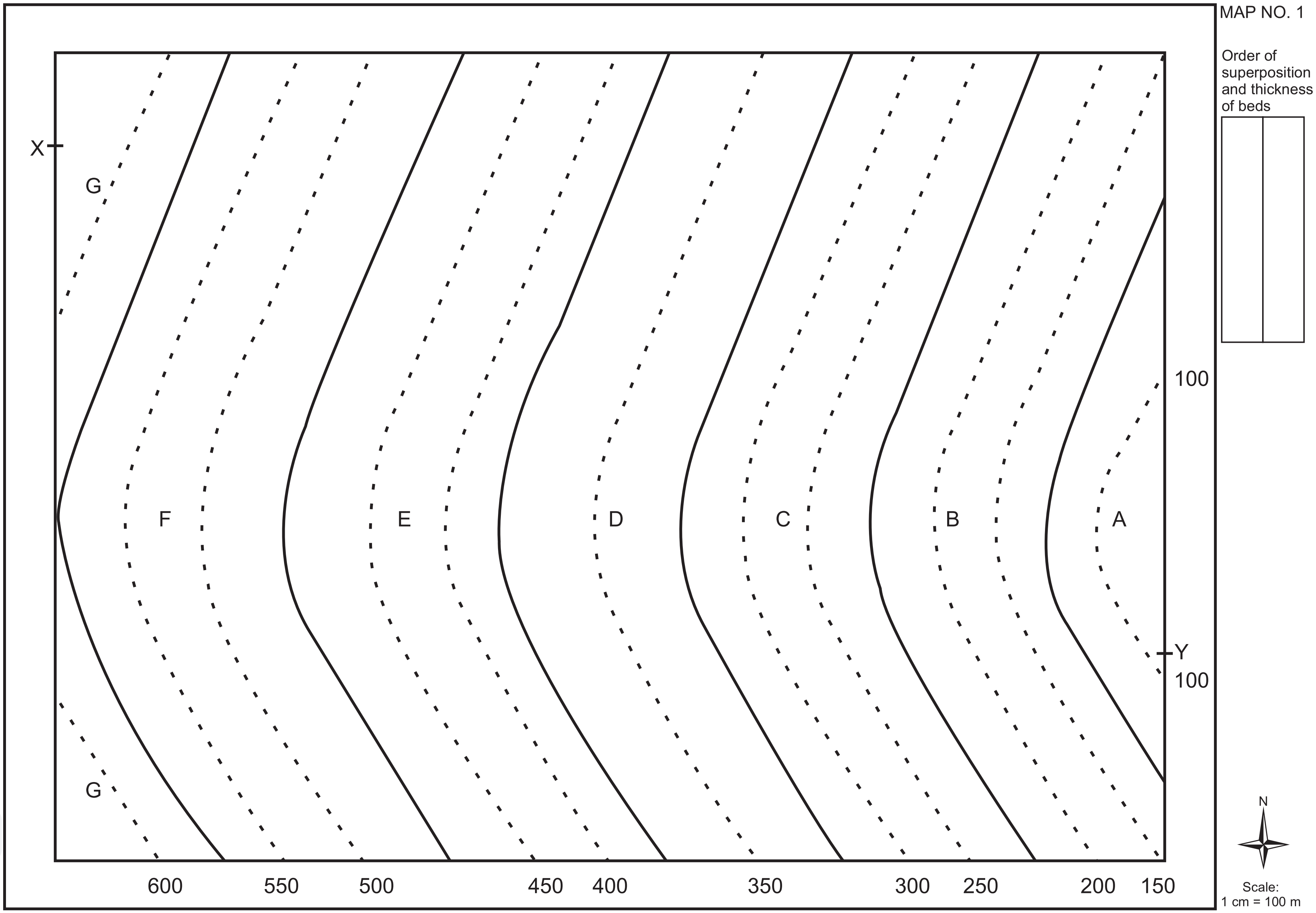
Q. 7. Identify and name features from given satellite image. **- 1 Mark**

Q. 8. Field work/project and Viva voce.

- 4 Marks

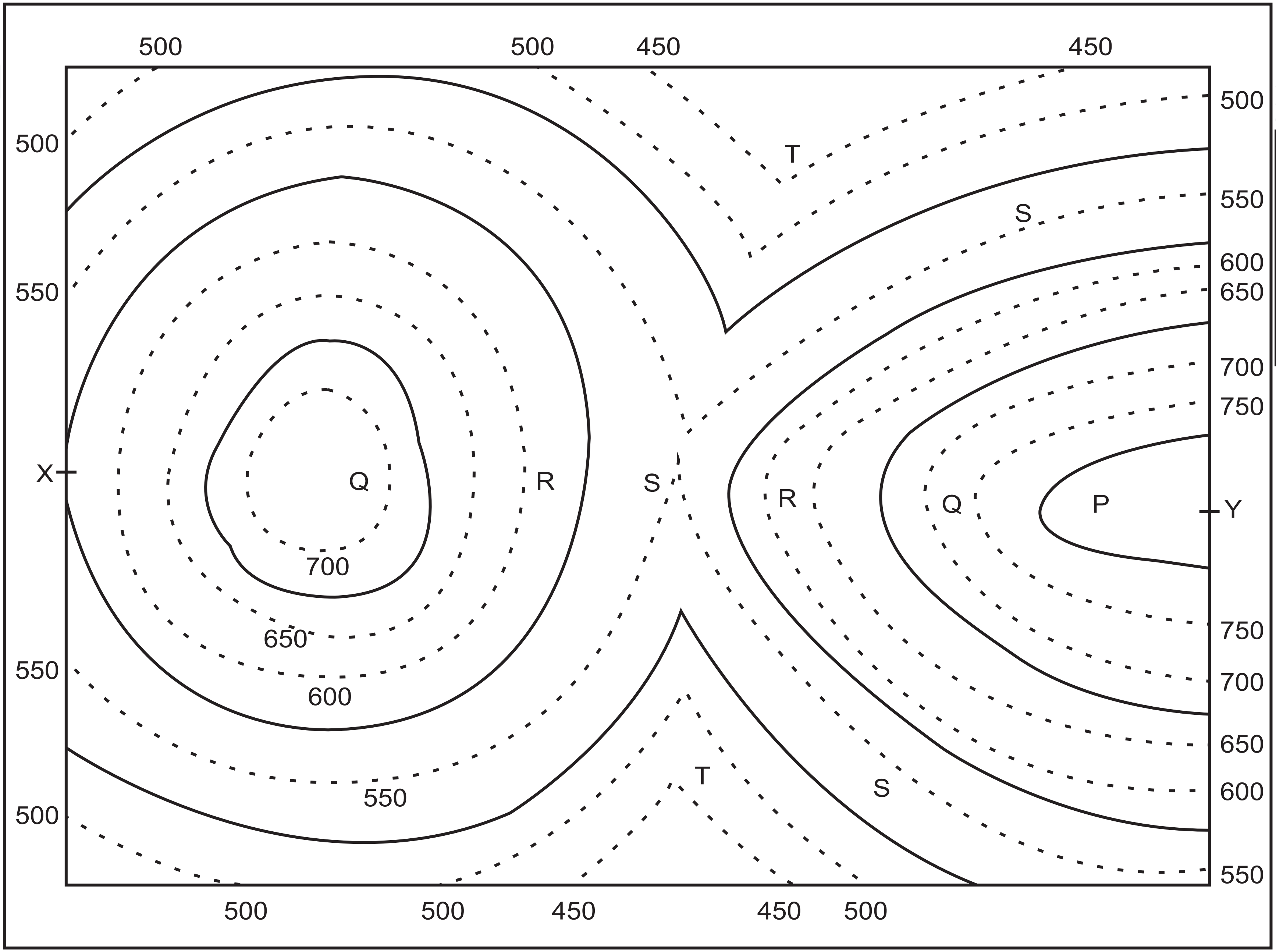
Q. 9. Certified journals.

- 2 Marks


MAP NO. 1
Order of superposition and thickness of beds
X
Y
G
F
E
D
C
B
A
G
100
100
600
550
500
450
400
350
300
250
200
150
N
Scale:
1 cm = 100 m

MAP NO. 2

Order of superposition and thickness of beds



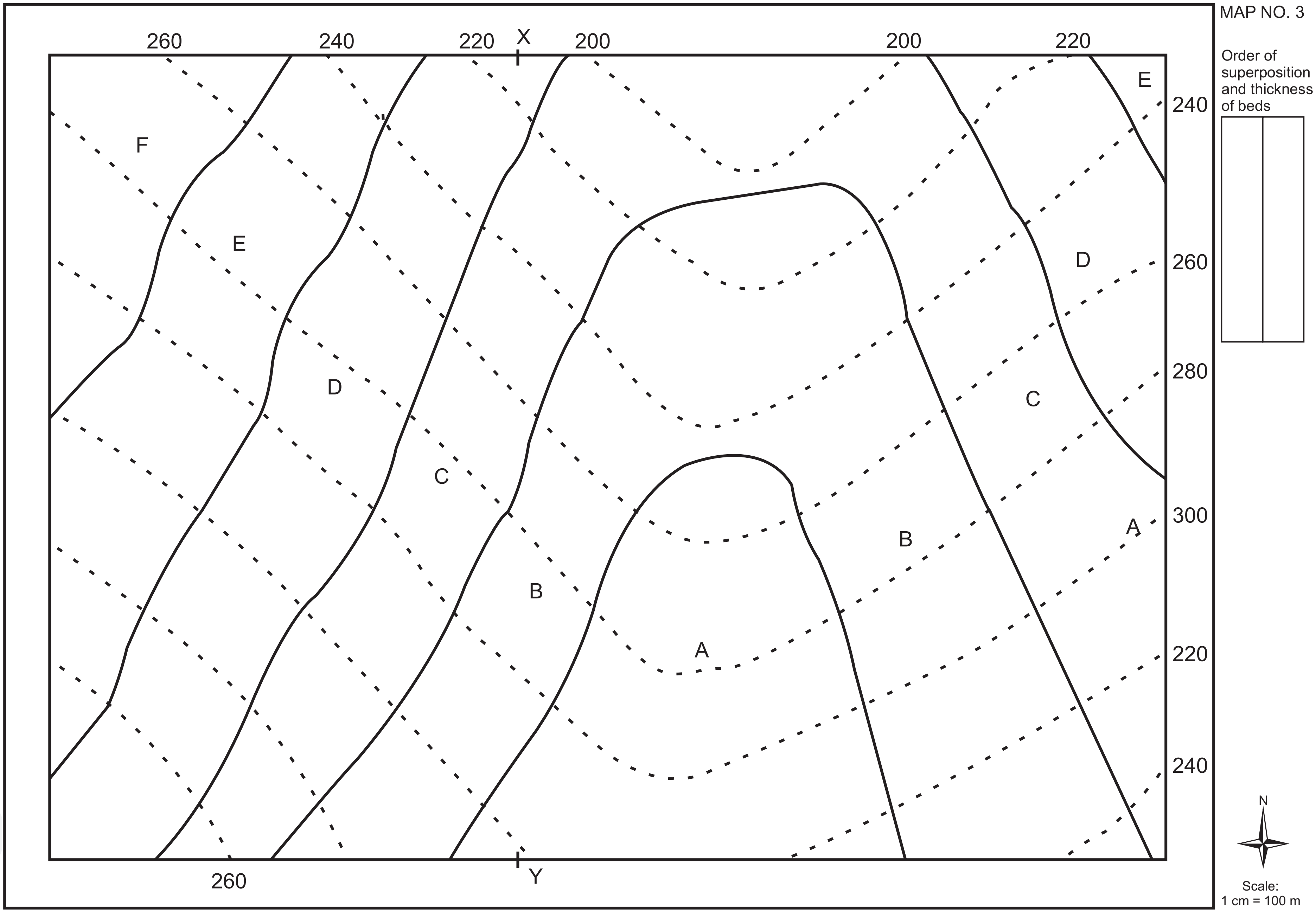
N

Scale:
1 cm = 100 m
CI = 50 m

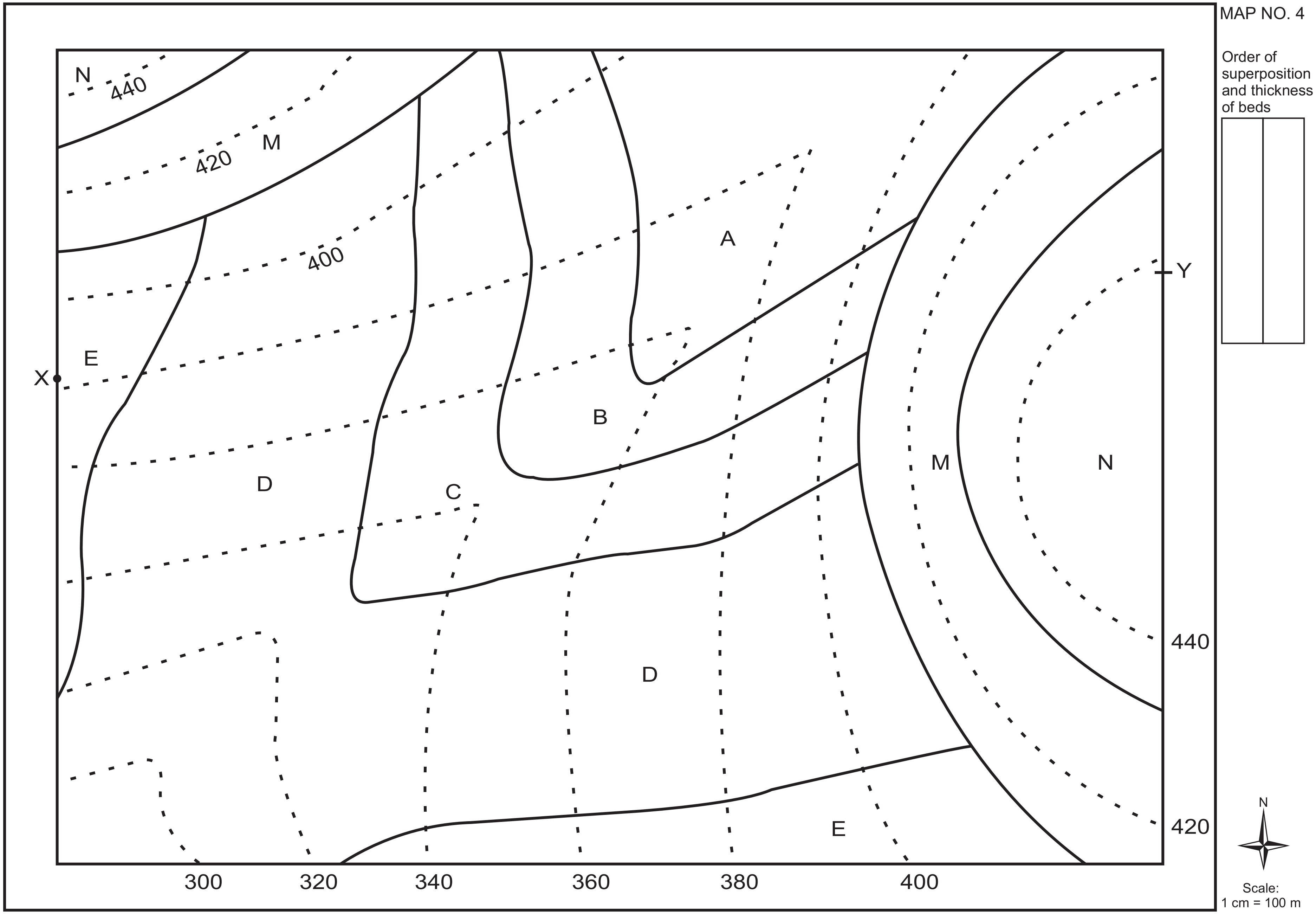
1. Describe the topography
2. Draw topography along X-Y

MAP NO. 3

Order of superposition and thickness of beds	

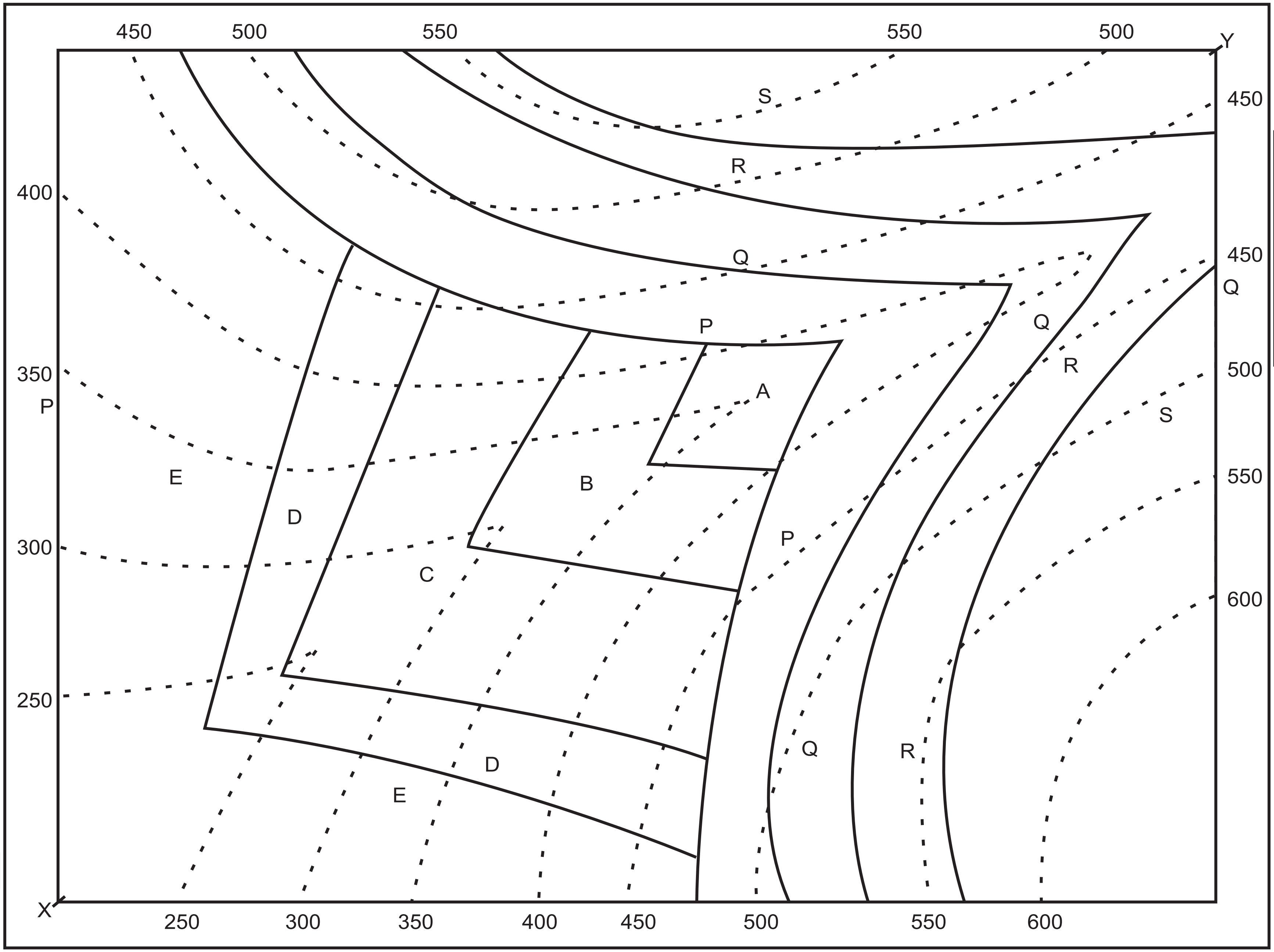


MAP NO. 4



Order of superposition and thickness of beds

MAP NO. 5

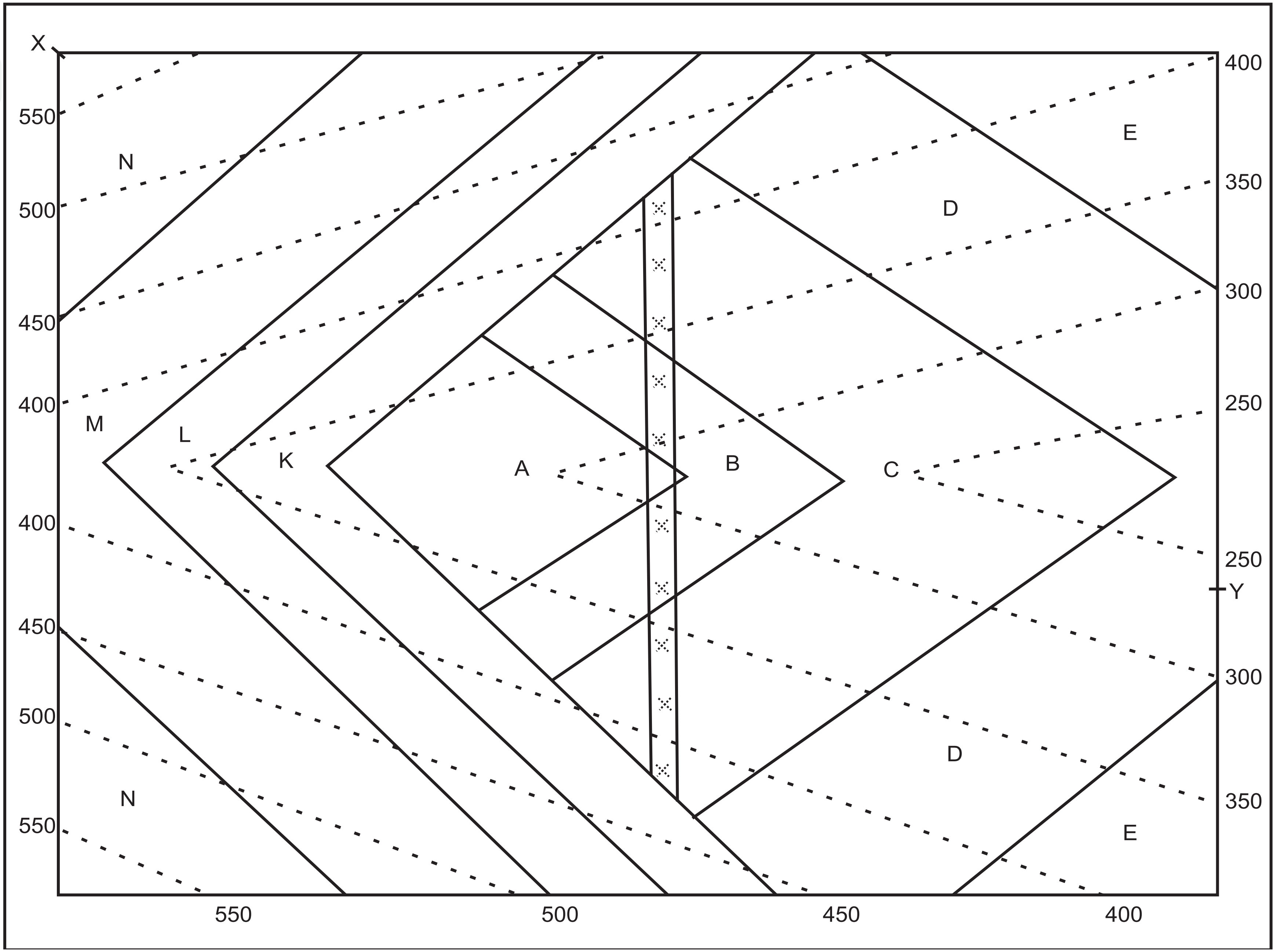


Order of superposition and thickness of beds

N

Scale:
1 cm = 100 m

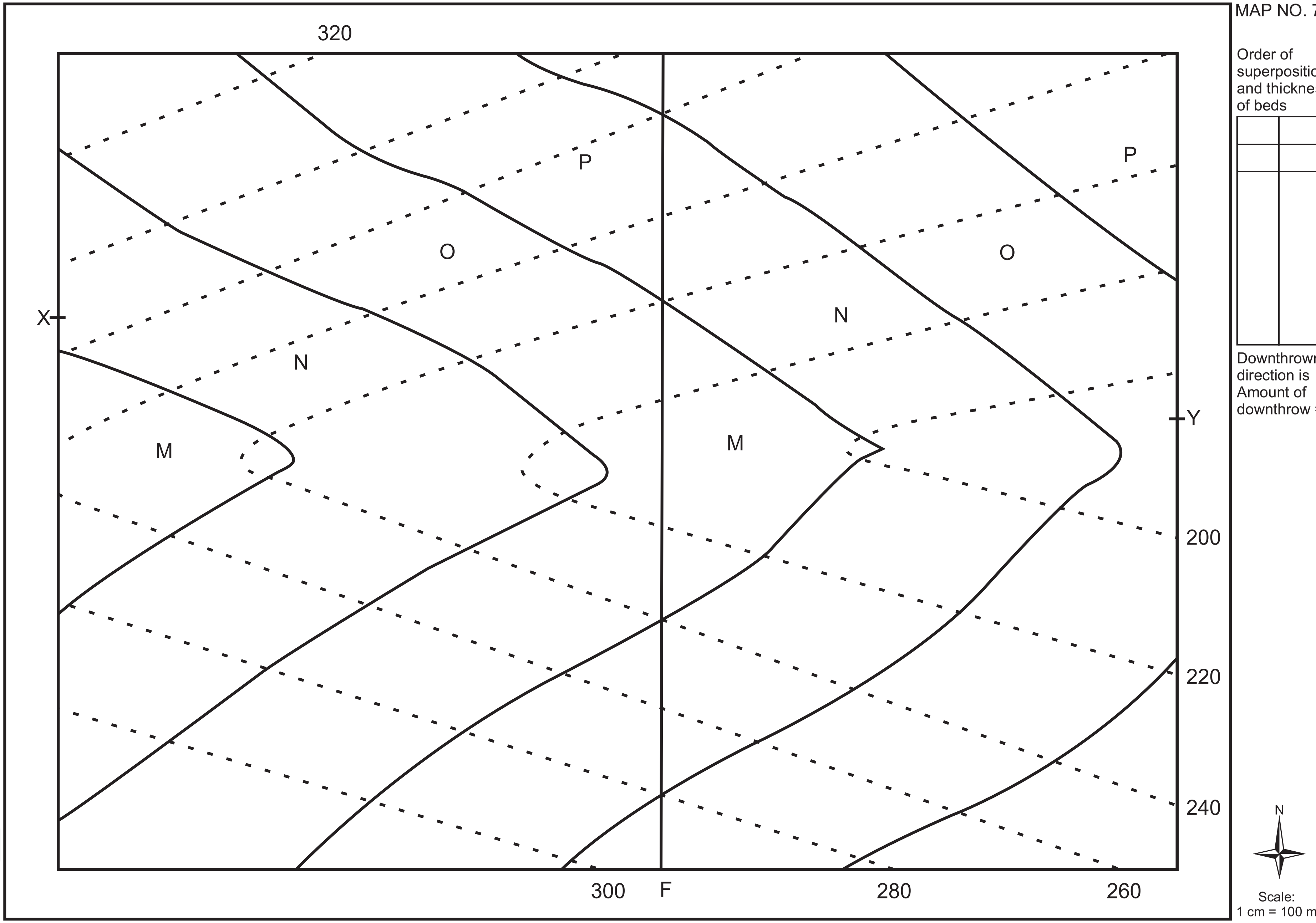
MAP NO. 6



Order of superposition and thickness of beds

Scale:
1 cm = 100 m

MAP NO. 7



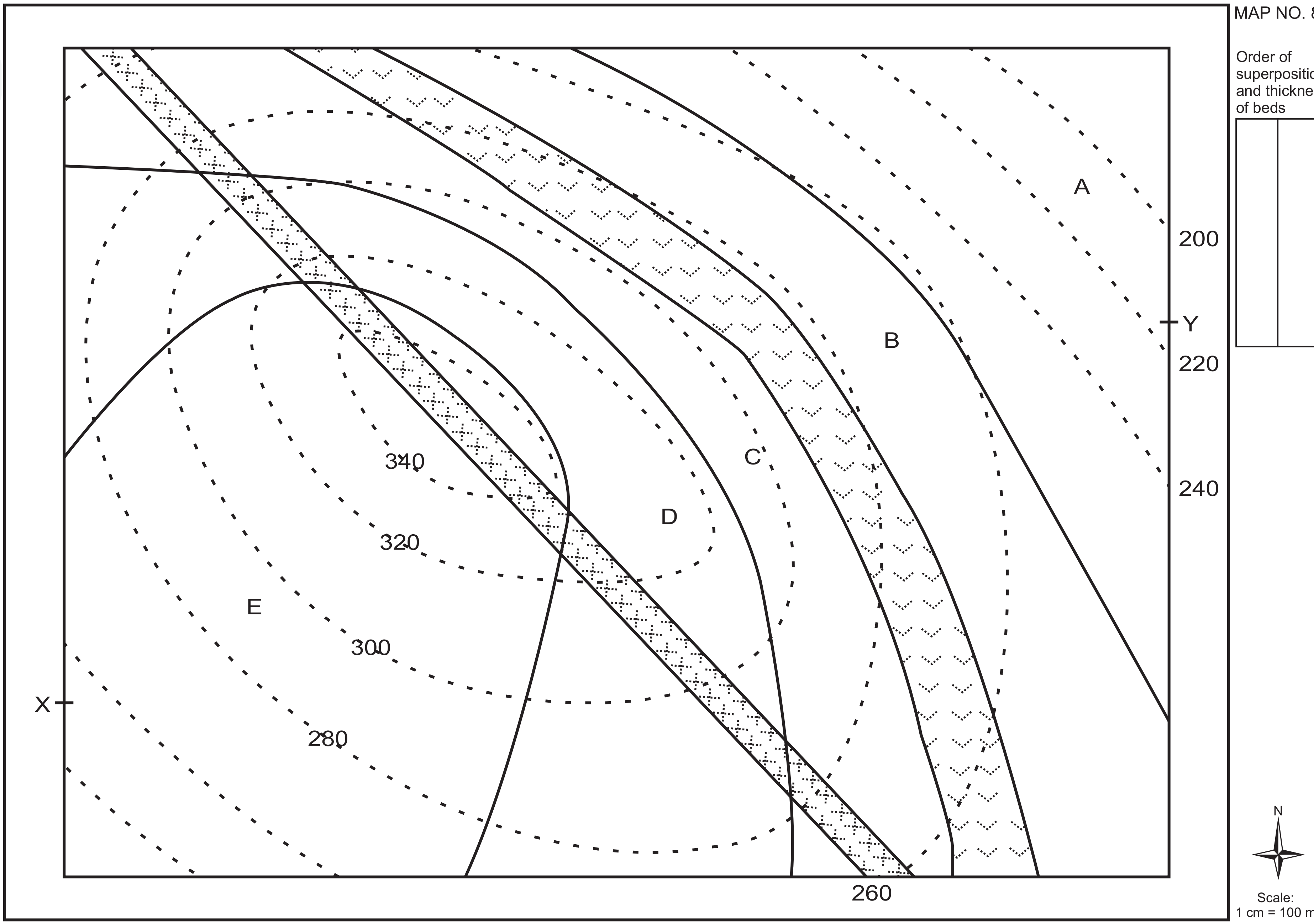
Order of superposition and thickness of beds

Downthrown direction is

Amount of downthrow =

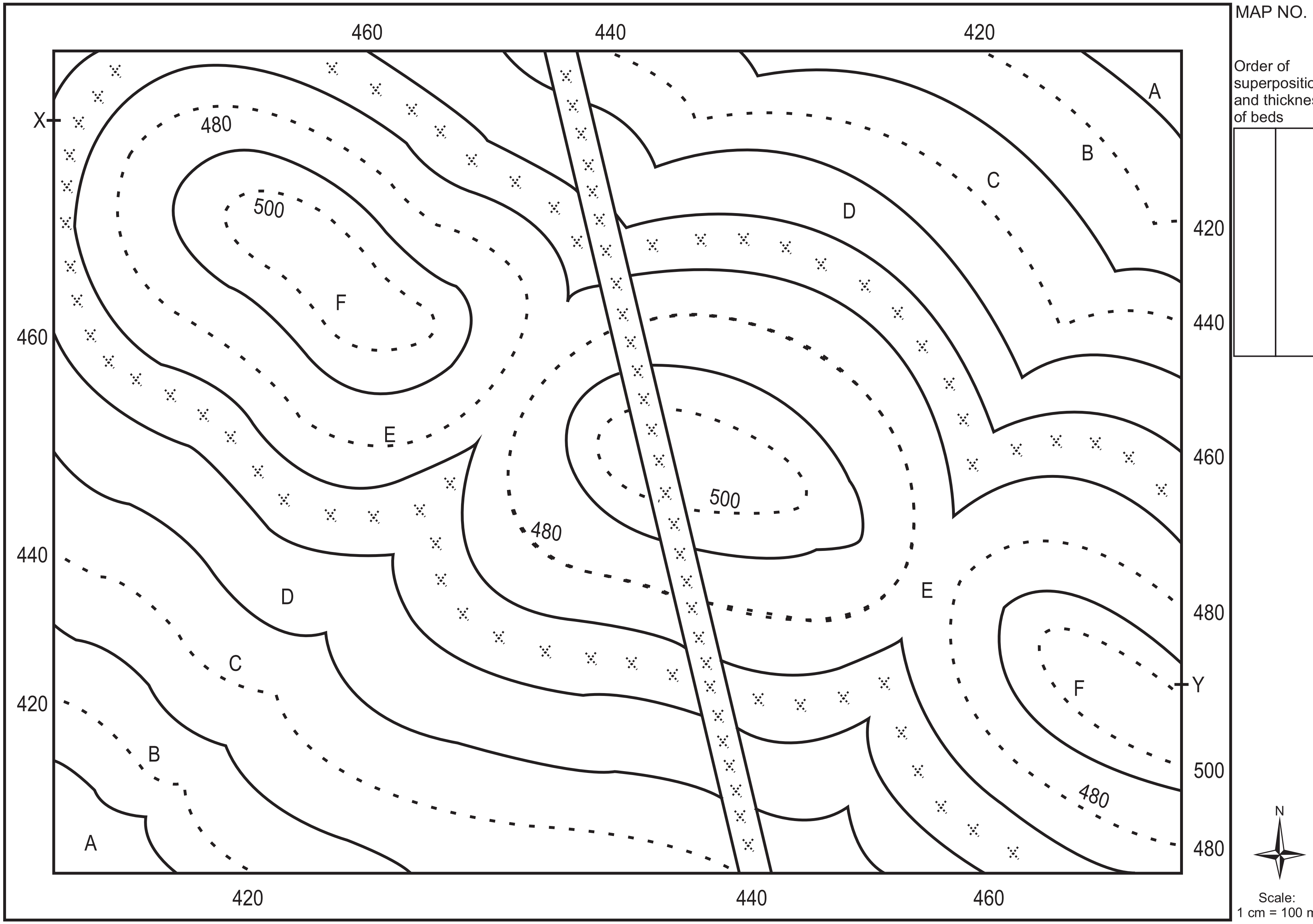
MAP NO. 8

Order of superposition and thickness of beds



MAP NO. 9

Order of superposition and thickness of beds

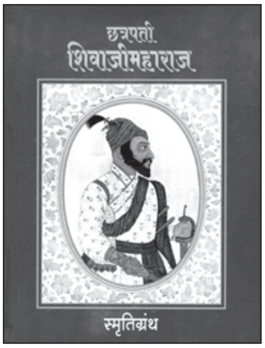


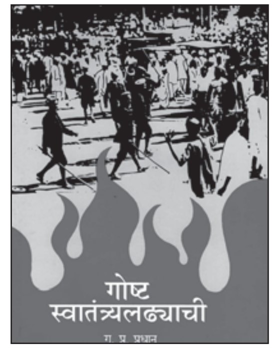
GLOSSARY

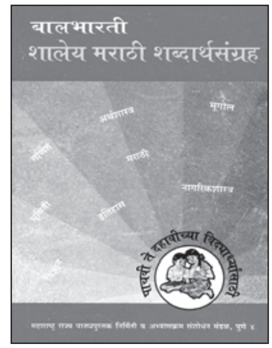
- **Advection :** The transfer of heat or matter by the flow of a fluid, especially horizontally in the atmosphere or the sea.
- **Albedo :** Is a measure of how much light that hits a surface is reflected without being absorbed.
- **Andesitic lava :** A high viscosity lava with high silica content.
- **Apparent polar wandering :** Is the perceived movement of the Earth's paleo-magnetic poles relative to a continent while regarding the continent being studied as fixed in position. ... In reality, the relative polar movement can be either real polar wander or continental drift (or a combination of both).
- **Arenites :** clastic rock with sand grain size between 0.0625 mm (0.00246 in) and 2 mm (0.08 in) and contain less than 15% matrix.
- **Argillite :** is a fine-grained sedimentary rock composed predominantly of hardened clay particles. They contain variable amounts of silt-sized particles.
- **Diatomites :** Naturally occurring fossilized remains of diatoms. Diatoms are single-celled aquatic algae.
- **Differentiation :** Is a complex process whereby a single melt can produce a wide variety of different igneous rocks.
- **Directed pressure :** Is non-uniform, i.e. it is not equal in all directions. It is caused by tectonic forces. Such forces cause the development of major structures such as folds and faults, as well as acting as metamorphic agent.
- **Emplaced :** Inclusion of igneous rock in older rocks, or the development of an ore body in older rocks.
- **Geodetic :** The scientific study of the size and shape of the Earth, its field of ztides.
- **Ichnofossils :** are an expression of the alteration of all textural and structural features in sedimentary rocks by living organisms. Often the organism that produced these structures leave no skeletal remains and hence the products of their activities are known as "trace" fossils.
- **Lahar :** a destructive mudflow on the slopes of a volcano.
- **Nebula :** A nebula is a giant cloud of dust and gas in space.
- **Phyllite :** Is a type of foliated metamorphic rock created from slate that is further metamorphosed so that very fine grained white mica achieves a preferred orientation.
- **Primordial :** Existing in or persisting from the beginning
- **Pyroclastic :** Is a fast-moving current of hot gas and volcanic matter that moves away from a volcano.
- **Radiolarian ooze :** A deep-sea ooze in which at least 30 per cent of the sediment consists of the siliceous radiolarian tests.
- **Rudites :** is a general name used for a sedimentary rock that are composed of rounded or angular detrital grains, i.e. granules, pebbles, cobbles, and boulders, which are coarser than sand in size.
- **Specific yield :** is defined as the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table.
- **Strategic deposits :**
- **Structural traps :** is a type of geological trap that forms as a result of changes in the structure of the subsurface, due to tectonic, gravitational and compactional processes.
- **Tephra :** rock fragments and particles ejected by a volcanic eruption.
- **Yield strength :** the stress at which a specific amount of plastic deformation is produced.

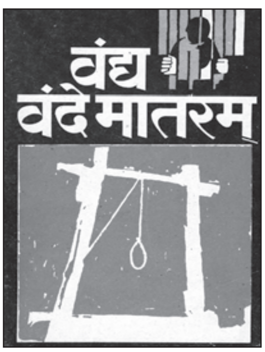
BIBLIOGRAPHY

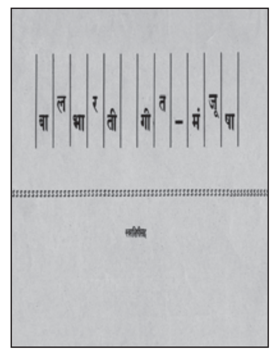
- https//spaceplace.nasa.govauroraen
- http//thebritishgeographer.weebly.complate-tectonic-theory.html
- http//Spurcehttppublish.illinois.edualfredwegenerevidence
- https//www.geolsoc.org.ukPlate-Tectonics
- https//earthref.orgdrupalcontentmagnetic-anomaly
- https//www.nps.govsubjectsgeologyplate-tectonics-evidence-of-plate-motions.htm
- http//ac2emsjcarmona
- https//geology.comarticleseast-africa-rift.shtml
- https//www.chegg.comhomework-helpuse-figure-1-illustrates
- https//www.britannica.comsciencetransform-fault
- https//www.nps.govsubjectsgeology

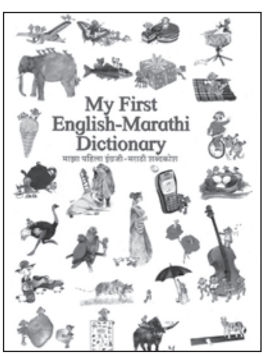












- पाठ्यपुस्तक मंडळाची वैशिष्ट्यपूर्ण पाठ्येत्तर प्रकाशने.
- नामवंत लेखक, कवी, विचारवंत यांच्या साहित्याचा समावेश.
- शालेय स्तरावर पूरक वाचनासाठी उपयुक्त.

पुस्तक मागणीसाठी www.ebalbharati.in, www.balbharati.in संकेत स्थळावर भेट द्या.

साहित्य पाठ्यपुस्तक मंडळाच्या विभागीय भांडारांमध्ये विक्रीसाठी उपलब्ध आहे.

ebalbharati

विभागीय भांडारे संपर्क क्रमांक : पुणे - ☎ २५६५९४६५, कोल्हापूर- ☎ २४६८५७६, मुंबई (गोरेगाव) - ☎ २८७७१८४२, पनवेल - ☎ २७४६२६४६५, नाशिक - ☎ २३९१५११, औरंगाबाद - ☎ २३३२१७१, नागपूर - ☎ २५४७७१६/२५२३०७८, लातूर - ☎ २२०९३०, अमरावती - ☎ २५३०९६५

Maharashtra State Bureau of Textbook Production and Curriculum Research, Pune

भूशास्त्र इयत्ता बारावी (इंग्रजी माध्यम)

₹ 98.00