Contents

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

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

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Chapter - 1 Introduction to Geology

Highlights :

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

Introduction :

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

1.1 Definition, importance and branches of geology :

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

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

1.2 Origin of the Universe and formation of the Earth :

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

Table : 1.1 Geological time scale

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

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

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

Table : 1.2

Branches of geology

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

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

Do you know?

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

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

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

Do you know?

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

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

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

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

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

Do you know?

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

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

Do you know?

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

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

Do you know?

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

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

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

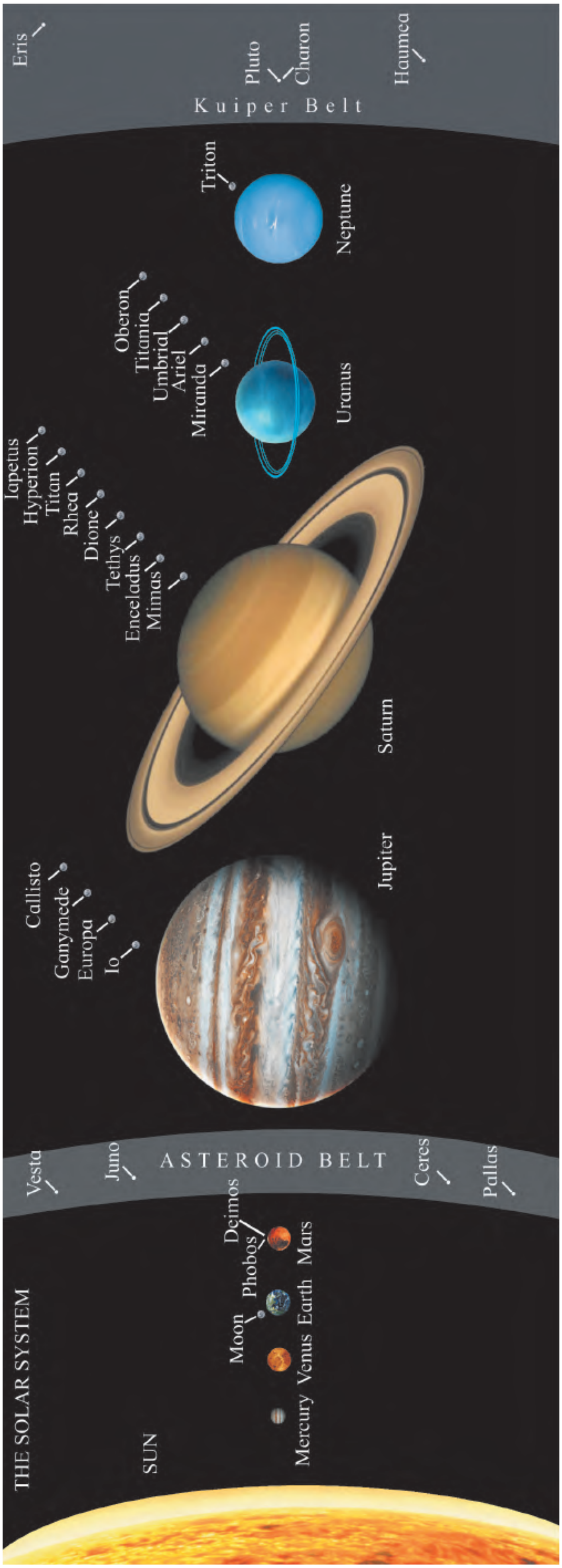


Fig. 1.1 : Details of our solar system

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

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

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

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

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

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

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

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

Do you know?

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

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

Depiction of Habitable Zone

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

1.3 Earth's surface : The Crust

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

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

Oceanic crust : Major features

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

Do you know?

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

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

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

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

Do you know?

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

Continental crust : Major features

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

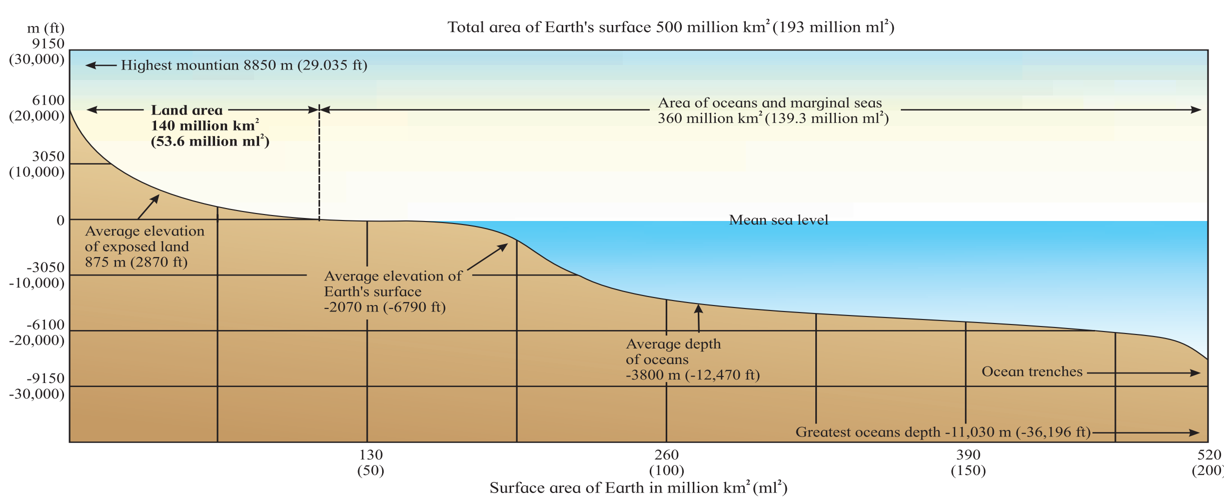


Fig. 1.2 : Hypsometric curve showing bimodal distribution of continents and ocean basins

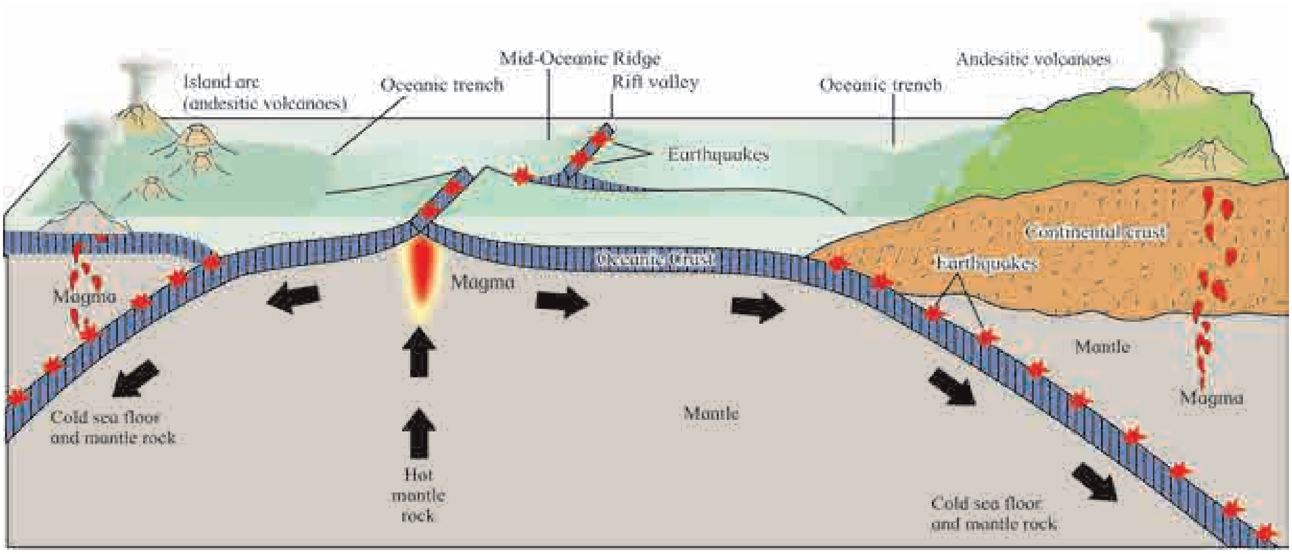


Fig. 1.3 : Important components of the oceanic and continental crust

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

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

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

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

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

1.4 Scope of geology :

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

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

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

Eminent Indian geologists :

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

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

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

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

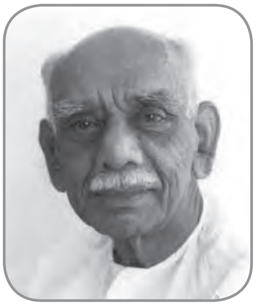
Prof W. D. West (1901-1994)

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

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

B. P. Radhakrishna (1918-2012)

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



Activity :

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

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

Summary :

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

Do you know? **Universe time scale**

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

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

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

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

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

EXERCISE

Q. 1. Fill In the blanks :

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

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

Q. 2. Choose the correct alternative :

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

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

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

Q. 3. Arrange the following in correct order :

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

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

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

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

Q. 5. Find the odd one out :

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

Q. 6. Answer in brief :

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

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

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

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

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

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