

Higher Secondary Course

GEOLOGY

XI



**Government of Kerala
Department of General Education**

Prepared by
State Council of Educational Research and Training (SCERT) Kerala
2026

THE NATIONAL ANTHEM

Jana-gana-mana adhinayaka, jaya he
Bharatha-bhagya-vidhata
Punjab-Sindh-Gujarat-Maratha
Dravida-Utkala-Banga
Vindhya-Himachala-Yamuna-Ganga
Uchchala-Jaladhi-taranga
Tava subha name jage,
Tava subha asisa mage,
Gahe tava jaya gatha.
Jana-gana-mangala-dayaka jaya he
Bharatha-bhagya-vidhata
Jaya he, jaya he, jaya he,
Jaya jaya jaya, jaya he!

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.

GEOLOGY



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Foreword

Dear learners,

The State Council of Educational Research and Training (SCERT Kerala) is pleased to present the revised version of the Higher Secondary Geology text book for Class XI. This revision has been undertaken to align the content with the recent scientific advancements, emerging concerns in earth science studies and the evolving educational needs of learners in the present era.

Geology, as a core branch of Earth Science, plays a vital role in helping learners understand the dynamic nature of our planet. In an era marked by environmental challenges, climate change, natural hazards, and increasing demand for natural resources, the study of Geology has become more relevant than ever. Education in Earth Science enables students to develop a scientific outlook toward the processes that shape the Earth and influence the life on it.

This revised textbook emphasizes conceptual clarity, activity-based learning, and real-world applications, encouraging learners to observe, inquire, analyze, and relate geological processes to their immediate surroundings. I am confident that this textbook will serve as an effective tool for both teachers and students in making the teaching-learning process engaging and meaningful.

This book is the outcome of the dedicated efforts of experienced higher secondary teachers and subject experts who worked together to update the content in accordance with contemporary scientific developments and curricular reforms. I appreciate the sincere efforts of the text book development committee, reviewers, and all those who contributed to bringing out this revised version.

I wish the teachers and students every success in their academic endeavours in Geology.

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Icons used in this textbook for convenience



Check your progress



Know More



Do it Yourself

THE CONSTITUTION OF INDIA

PREAMBLE

WE, THE PEOPLE OF INDIA, having solemnly resolved to constitute India into a ¹**[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 ²[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.**

1. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Sovereign Democratic Republic" (w.e.f. 3.1.1977)
2. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Unity of the Nation" (w.e.f. 3.1.1977)

1 GEOLOGY AS A DISCIPLINE

1.1 Introduction

The Earth where we live, the only known planet in the Solar System that supports life, is a complex, dynamic and ever-changing body. The study of Earth's mountains and sandy beaches, violent volcanic eruptions and earthquakes, mineral extraction and resource management all fall within the field of Earth Science. This branch of science deals with many curious, fascinating and practical questions about our planet. What is the age and size of our planet? What is its relation with other members of the Solar System? When did life originate here, and how has it evolved through billions of years? Will there be Ice Ages in the future? Can we locate places from where groundwater, minerals, coal and oil can be extracted? Earth Science tries to provide answers to such important questions.

It is not easy to answer such questions, as our planet is a dynamic one with a very elaborate and complicated history.

During its long existence, the Earth has been changing. Sometimes the changes are rapid and violent due to events like storms, landslides, volcanic eruptions whereas many other changes take place very slowly like formation of mountains. Scales of size and space also vary greatly among the phenomena studied in Earth Science. The study of Earth Science can help people not only gain access to Earth's resources, but also help people to use them wisely without causing damage to the surroundings. It will also help predict the potential natural disasters, and save life and property.

Earth Science is essentially a field science where the study is based mainly on observations in the field. However, a significant portion of geological study is conducted in the laboratory (involving a large spectrum of scientific equipment as listed in Appendix I), where samples of various earth materials are characterized that give insights into many basic processes. The creation of complex computer models helps in the simulation of our planet's complicated systems like climate dynamics. Earth scientists require basic understanding of the principles and application of branches of science such as physics, chemistry and biology. Geology, Geophysics, Meteorology (Atmospheric Science), Oceanography and Astronomy are the major sub-domains of **Earth System Science**.



*Fig. 1.1
A view of the Earth from the Moon
(Apollo 11 Mission)*

1.2 Geology and its Branches

The word 'Geology' is derived from ancient Greek word 'gaia' meaning 'earth or land' and 'logos' meaning 'study'. This multi-disciplinary subject deals with the study of the Earth, its chemical, physical and biological aspects. It examines the Earth's origin/ evolution, structure and composition, and changes that have occurred over time. Geology covers everything from the study of rocks and minerals to phenomena like earthquakes, volcanoes and the formation of mountains, and all the features we see on the surface of the planet as well as its interior. Geologists use this knowledge to understand the Earth's past, study natural hazards,

locate natural resources, and know the interaction between humans and the environment. Geologists typically study Earth's rocks, sediments, soils, groundwater, fossils and other natural resources. Increasing population, longer life span and better quality of life have increased the demand for more natural resources and their judicious use making geology more relevant.

Do you Know!!!



The term 'Geology' was used technically by Genevan naturalist Jean-Andre Deluc in 1778 and H.B.de Saussure was the early user of the term in 1779. It evolved in the late 18th century to describe the study of the Earth.

The field of geology has several well-defined branches. Some of the important branches include Physical Geology, Geomorphology, Mineralogy, Crystallography, Petrology, Palaeontology, Stratigraphy, Structural Geology, Geochemistry, Economic Geology, Exploration Geology, Engineering Geology, Hydrogeology and Environmental Geology.

Physical Geology

Physical Geology studies the various processes operating on and below the surface of the earth and their products. These processes include weathering, erosion, landslides, earthquakes, volcanism and plate tectonics. Many other branches of Geology can be regarded as sub-topics of Physical Geology. Physical Geology is sometimes referred to as General Geology, meaning a broad scientific study of the Earth.

Geomorphology

Geomorphology specifically deals with the description and origin of landforms and the processes that change them. This includes the origin and evolution of mountains, deserts, valleys, plateaus, plains and other features of the Earth's surface.

Mineralogy

Mineralogy is the study of minerals, the main constituents of rocks. A mineral is an inorganic solid substance of natural origin, with known chemical composition and specific internal atomic structure. Mineralogy deals with chemical composition, physical and optical properties, classification, origin and occurrence of minerals.

Crystallography

Crystallography deals with the study of crystals, including its internal atomic arrangement and external form. When formed under ideal temperature, pressure and chemical environment, minerals grow as well-formed crystals. Crystallography is basic to mineralogy as most of the minerals are crystalline in nature.

Petrology

Petrology is the branch of geology dealing with the study of rocks, the major constituent of the lithosphere. The study of rocks constitutes their mineral contents, chemical composition, classification and origin. Three types of rocks are the igneous rocks, the metamorphic rocks and the sedimentary rocks. Thus, we have subdivisions, namely Igneous Petrology, Metamorphic Petrology and Sedimentary Petrology.

Palaeontology

Paleontology is the scientific study of the life of the geological past, mainly through the study of fossils. Fossils are the preserved remains or traces of plants and animals. Fossils help us to study the age of rocks, and provide evidence for the evolution and extinction of organisms.

Stratigraphy

The term stratigraphy is derived from the Latin word 'stratum' meaning 'layer'. This branch of geology, dealing with sequence of rocks, their age relationship and distribution in space and time, help to understand the geological history of the Earth.

Structural Geology

Structural Geology deals with the primary and secondary (deformational) structures in rocks. It mainly deals with the deformation of rocks, the forces responsible for this and the effect of deformation. Essentially it studies the common structures in rocks such as folds, faults and joints, and help understand the tectonic history of a region. Geological structures are crucial in

the localization of mineral resources and this discipline is thus significant in their exploration.

Geochemistry

Geochemistry deals with the chemistry of the earth materials, and includes processes that control the distribution of elements and isotopes in rocks, soil and water.

Economic Geology

Economic Geology is concerned with the processes of formation/accumulation, exploration and distribution of earth materials (called deposits) that can be used for economic and industrial purposes. These materials include ores of precious and base metals, non-metallic minerals, coal, petroleum, natural gas and building stones.

Engineering Geology

Engineering Geology is an applied branch of geology where geological knowledge is provided in civil engineering projects, especially in construction of dams, tunnels, roads and buildings.

Hydrogeology

Hydrogeology is the study of groundwater i.e., water stored in fractures and other openings in soil and rocks below the Earth's surface. This branch studies the occurrence, movement, prospecting, quality and management of groundwater.

Environmental Geology

Environmental geology deals with the interaction between man and geological environment. It studies the interaction of geological processes and human activities. These studies help to manage natural hazards, to understand the pollution of the air, water, soil and its effects on life on earth.

There are several other branches and sub-branches of Geology, in addition to the main branches described above. These include Applied Geology, Exploration Geology, Mining Geology, Petroleum Geology, Glaciology, Polar Science, Geological Remote Sensing, Isotope Geology, Geochronology, Marine Geology, Planetary Geology, Pedology, Geoarchaeology, Medical Geology and Forensic Geology.



Check your progress

Name the branches of geology concerned with the study of the following: rocks, groundwater, fossils and landforms.

1.3 Geology and Human Society

Geology has played a crucial role in shaping human civilization. From providing essential resources to settlement patterns, geology influences many aspects of human life. Geologists of the day are involved in extracting natural resources, providing guidance for proper planning and land use management, disaster management, environmental protection and conservation, climate studies and sustainable development.

One of the most visible connections between geology and society lies in the management of natural resources. Modern society is increasingly dependent on natural resources. Minerals, fossil fuels and groundwater are all products of geological processes that (coal, petroleum and natural gas) sustain modern economies. Geologists are involved in exploring and extracting such resources.

The extraction and consumption of natural resources have an impact on our environment. Efficient extraction and responsible use of natural resources require geological insight to minimize environmental damage and ensure sustainability. Thus, geologists help in the conservation of the depleting non-renewable resources and help manage renewable resources, such as solar or wind energy.

Geological information helps in the proper land-use planning and safe construction of buildings. Before building highways, tunnels or dams, engineers rely on geological surveys to assess the ground stability and material suitability. Poor understanding of geological conditions can lead to structural failures, costly repairs or environmental degradation. Thus, collaboration between geologists, engineers and urban planners is essential for safe and sustainable development.

Geologists also study natural hazards like landslides, earthquakes, tsunamis, floods, volcanic eruptions and sea-level rise that are potentially dangerous to human life or property. Proper understanding of geological aspects of these hazards helps in planning and executing disaster management measures efficiently.

Today, humanity faces growing environmental challenges. Geology contributes to climate studies. The analysis of rocks, sediments, and ice cores by geologists helps in reconstructing the Earth's past climate and in understanding long-term changes.

In conclusion, Geology is much more than the study of rocks, minerals and fossils; it is one of the foundations upon which societies are built. Geologists help mankind make informed decisions

about resource management, disaster mitigation and environmental conservation. Hence, the role of Geology in shaping a sustainable planet for the future is more crucial than ever.

1.4 Recent Developments in Geology

The development of geology as a branch of study can be traced back to 17th century. A combination of field studies with instruments and advanced laboratory investigations has given rise to certain modern branches in geology that have evolved in the last century.

Planetary Geology (Planetary Science)

Planetary Science deals with study of planets, moons, asteroids, comets and other bodies in the Solar System, and even beyond it. It is an applied field where principles of geology, astronomy, physics, chemistry and atmospheric science are used to understand their origin and evolution.

Geological Oceanography (Marine Geology)

Geological Oceanography deals with the study of topography, structure and geological processes that shape the sea bed and coastal regions. It examines marine sediments, rocks of the ocean floor, submarine landforms, tectonic movements and geological resources of the ocean floors. Most of the geological resources of the land have been identified and quantified. Since the land resources are depleting, we have to focus upon the oceans, which cover more than two-thirds of the Earth's surface, and contain valuable mineral resources.

Computational Geology (Mathematical Geology)

Computational Geology uses mathematical modeling and computational analysis to study the geological processes, analyze complex data and solve geoscience problems. It applies computational methods to understand the phenomena that are not directly observable, such as those happening deep within the Earth, and is used in fields like geophysics, environmental science and resource exploration. Understanding of mathematical and statistical modeling techniques is fundamental to this field.

Medical Geology

Medical Geology refers to the study of interactions between geological materials and processes, and their effects on human, animal and plant health. It looks at how rocks, minerals, soils, water and geological hazards influence the health, nutrition, and well-being of the society. For e.g., deficiency or excess content of elements such as iodine, selenium, fluorine and arsenic in food or drinking water can lead to severe health issues. These elements enter the food chain from geological sources,

especially the groundwater. Evaluating impact of dust, volcanic gases, airborne minerals and soil composition on health also comes under medical geology.

Forensic Geology

The idea of using earth materials in forensic investigations began informally in the late 19th century. Forensic geology is the application of earth materials such as soil, minerals, rocks and sediments to legal investigations. Geological data on these materials may indicate their source area and may provide certain supporting evidence in the investigations of crimes.

1.5 Major Geological Organizations in India and Kerala

There are a number of organizations and institutions in our country, directly or indirectly related to geological studies (Table 1.1)

Table 1.1 Major geological organizations in In India and Kerala

Organization	Year of Establishment	Headquarters	Major Activity
Geological Survey of India (GSI)	1851	Kolkata, West Bengal	Geological mapping, mineral resource assessment, creation and updating of national geoscientific information.
Oil and Natural Gas Corporation (ONGC)	1956	Dehradun, Uttarakhand	Exploration and production of petroleum (crude oil) and natural gas.
Central Ground Water Board (CGWB)	1970	Faridabad, Haryana	Groundwater exploration, evaluation, monitoring and management.
Atomic Minerals Directorate for Exploration and Research (AMD)	1949	Hyderabad, Telangana	Exploration of atomic minerals, especially minerals containing Uranium and Thorium used for nuclear energy.
National Remote Sensing Centre (NRSC)	1963	Hyderabad, Telangana	Satellite data reception, processing and remote-sensing applications.
Indian Space Research Organization (ISRO)	1969	Bengaluru, Karnataka	Space research, satellites and launch vehicles.

National Centre for Earth Science Studies (NCESS)	1978	Thiruvananthapuram, Kerala	Earth science research and environmental studies.
Centre for Water Resources Development and Management (CWRDM)	1978	Kozhikode, Kerala	Water resources research and watershed management.
Department of Mining and Geology (Kerala)	1946	Thiruvananthapuram, Kerala	Mineral exploration and implementation of mining regulation.
Groundwater Department (Kerala)	1978	Thiruvananthapuram, Kerala	Groundwater investigation, monitoring and recharge programmes.
Kerala State Land Use Department	1975	Thiruvananthapuram, Kerala	Land use planning and resource management.



Check your progress

1. Mention the areas in which Earth scientists contribute to human welfare.
2. Name two geological organizations operating in Kerala.
3. Identify some emerging fields associated with geology and Earth science.

Summary

Geology is the scientific study of the Earth—its origin, materials, structure, processes, and history. It is mainly a field science, supported by laboratory analysis and computer modelling. The subject includes many branches such as Mineralogy, Petrology, Paleontology, Stratigraphy, Structural Geology, Hydrogeology, Economic Geology, Environmental Geology, and others.

Geology plays a vital role in human society by locating natural resources like minerals, fossil fuels, and groundwater; guiding construction and land-use planning; managing natural hazards; and supporting environmental protection. Some of the modern branches in this discipline include Planetary Geology, Marine Geology, Computational Geology, Medical Geology, and Forensic Geology. A number of geological organizations function in India, conducting research, extending services, and contributing to mapping, resource exploration, groundwater management, remote sensing, and environmental studies.

2

EARTH'S PLACE IN THE UNIVERSE

2.1 Introduction

In the vast expanse of the Cosmos, the Earth is a tiny blue dot, as seen in the 1990 photograph taken by NASA's Voyager I from a distance of 6 million Km. Yet, despite its small size, our planet is home to an astonishing array of life forms, from the smallest virus to the complex organisms like humans.

The Earth occupies a unique position in this vast universe. From the intricate position of celestial bodies in our solar system to the majestic sweep of galaxies there is only a small habitable zone in which the Earth, the only living planet is placed. This chapter will take you on a journey, exploring the Earth's position within the Solar System and the universe as a whole. Here, we learn about the evolution of the universe, the Solar System and the Earth itself. You will be introduced to fundamental scientific ideas that help explain the forces shaping Earth and its environment. Through simple explanations and illustrations, this chapter aims to kindle curiosity about the world we live in and the universe beyond.

2.2 Origin of the Universe: Big Bang Theory

The universe includes all matter, energy, space and time. Understanding how the universe began and how it is changing is one of the most puzzling questions in science.

Scientists believe that the universe began about 13.8 billion years ago with a huge event called the **Big Bang**. According to this theory, all the matter and energy in the universe were once squeezed into a point so tiny that it had no size. This extremely small and dense point is called the **Big Bang singularity**. The temperature and pressure inside the singularity were unimaginably high. Suddenly, this singularity expanded explosively (Fig. 2.1). This event was not an explosion in space, instead it was an explosion of space itself. Space and time both began at this moment.

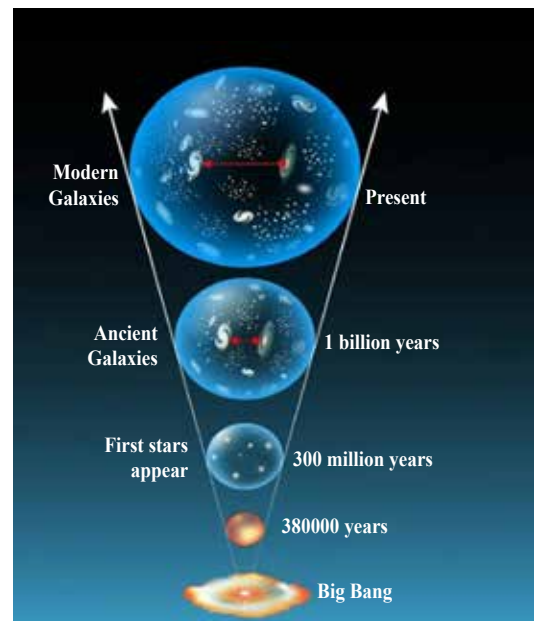


Fig. 2.1
Expanding Universe

Right after the Big Bang, the Universe was unimaginably hot, with temperatures near the **Planck Temperature**. As it expanded, it cooled down. In the first few seconds, tiny particles like protons, neutrons and electrons were formed. A few minutes later, the nuclei of simple atoms like hydrogen and helium appeared. It took about 380,000 years for the Universe to cool enough for these nuclei to capture electrons and form the first complete atoms. These hydrogen and helium atoms are still the most abundant elements in the Universe.

Matter in the early Universe was not evenly spread out. Some regions were slightly denser. Gravity pulled these dense regions together to form protogalaxies and the first stars. Stars act like nuclear furnaces. Inside them, lighter elements join to form heavier ones like carbon, oxygen, silicon and iron. When massive stars explode as supernovae, they scatter these elements into space, helping form new stars, planets and even life.

In the 1920s, **Edwin Hubble** discovered that galaxies are moving away from us and that galaxies which are farther away move at faster speeds. This observation is called Hubble's Law. It shows that the Universe is expanding. Hubble used a phenomenon called **redshift** to prove this. Redshift happens when the light from an object moving away from us shifts toward the red end of the spectrum. It is explained by the **Doppler Effect**, the same effect that changes the pitch of a moving siren.



Do it Yourself

Materials

- A balloon
- A marker pen

Procedure

1. Draw several small dots on the surface of the balloon. Each dot represents a galaxy.
2. Slowly blow air into the balloon.
3. Watch what happens to the distance between the dots as the balloon expands.

Observations

As the balloon gets bigger, the dots (galaxies) move away from each other even though the dots themselves do not expand. This simple model helps you imagine how the Universe expands and space stretches, carrying galaxies with it!

You might wonder, what is the fate of the universe? The universe is still expanding today, but what will happen in the future? One of the popular concepts, the universe may continue expanding endlessly. Galaxies will keep moving farther apart, and the universe will become colder and emptier over time. This might lead to a hypothetical scenario where all energy in the universe is evenly distributed, leading to a cold, dark and lifeless state called as **Cold Death**. Some scientists believe that the expansion will eventually slow down and stop. Then, gravity may begin pulling everything back together. The universe would contract until all matter is squeezed into another singularity. This collapse is called the **Big Crunch**. Some theories even suggest that after the Big Crunch, another Big Bang may occur, leading to a new universe. This idea describes an oscillating universe that expands and contracts repeatedly.

2.3 Origin of the Solar System

The Solar System is a group of celestial objects bound together by the gravitational pull of the Sun. It includes the Sun at the centre, eight planets and their moons, as well as smaller bodies such as asteroids, comets, dwarf planets and meteoroids. All these objects orbit the Sun in well-defined paths. The Solar System, including our planet Earth was formed about 4.6 billion years ago. Understanding how our Solar System formed has been a major scientific question for centuries. Over time, scientists have proposed different models based on observations and evidences. These models can be broadly grouped into Evolutionary Hypotheses and Catastrophic Hypotheses.

Do you Know!!!

The Earth is approximately 4.6 billion years old. The term 'geologic time' refers to the entire duration from the formation of the Earth to the present day. The Geological time scale relates events in the Earth's history to time. Geological time scale is provided in Appendix II.

2.3.1 Evolutionary Hypotheses

Evolutionary hypotheses suggest that the Sun and planets formed gradually from pre-existing matter. They describe a slow, natural process of change over millions of years. Among these models, the most influential and widely accepted one is the Nebular Hypothesis, which provides a clear explanation for the orderly arrangement of the planets in our Solar System.

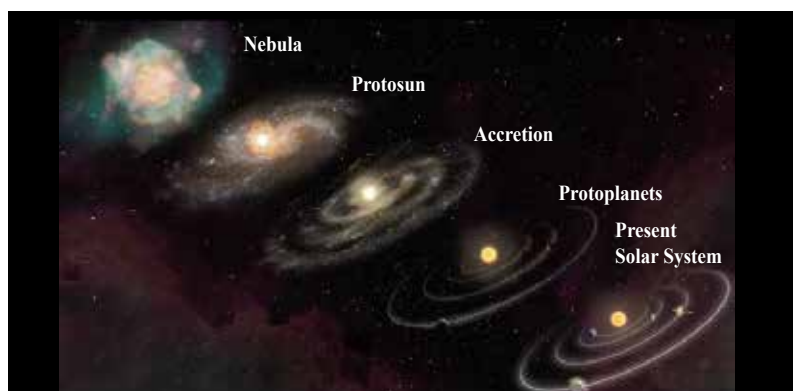


Fig. 2.2
Nebular Hypothesis

disc) (Fig. 2.2). As the disc spun faster, small clumps of matter began to stick together. Through a process called accretion, they formed increasingly larger rocky bodies. Such large bodies grew into protoplanets. Protoplanets are early, developing planetary bodies that form when smaller particles collide and merge; they are large enough to have their own gravity but have not yet reached the full size or stability of true planets, some of these protoplanets by further accretion later became the planets we see today. As the process continued, the remaining central mass of the nebula became

the Sun, while some leftover fragments formed asteroids and other small celestial bodies. The Nebular Hypothesis explains why planets orbit in nearly the same plane and direction.

Modern observations strongly support this hypothesis. Telescopes like the Hubble Space Telescope and advanced radio observatories have captured images of young stars surrounded by protoplanetary discs, showing real-time examples of planet formation similar to what the Nebular Hypothesis describes. These findings provide solid evidence that the origin of our Solar System followed the same natural, evolutionary process seen throughout the Universe.

2.3.2 Catastrophic Hypotheses

Catastrophic hypotheses suggest that the Solar System did not form gradually, but



Know More

Other evolutionary hypotheses:

1. Planetesimal Hypothesis / Dust Cloud Aggregation Theory: Planets formed in a protoplanetary disk where dust grains stuck together by electrostatic forces and grew into larger aggregates. These aggregates evolved into solid planetesimals, which collided and accreted under gravity to form protoplanets and eventually planets.

2. Disk Instability Model: This model proposes that the massive protoplanetary disk became gravitationally unstable and fragmented into dense gaseous clumps. These clumps rapidly collapsed to form gas giant planets, bypassing slow core formation.

instead originated from a sudden, violent event involving the Sun and another passing star. One of the popular catastrophic hypotheses is the tidal hypothesis.

The Tidal Hypothesis

The Tidal Hypothesis, proposed by the British Astronomer Sir James Jeans (1917) and further developed with Harold Jeffreys, suggest that a massive star once passed very close to the young Sun. The gravitational pull of this passing star created enormous tidal bulges on the Sun's surface, similar to how the Moon causes tides on Earth, but on a far more dramatic scale (Fig. 2.3).

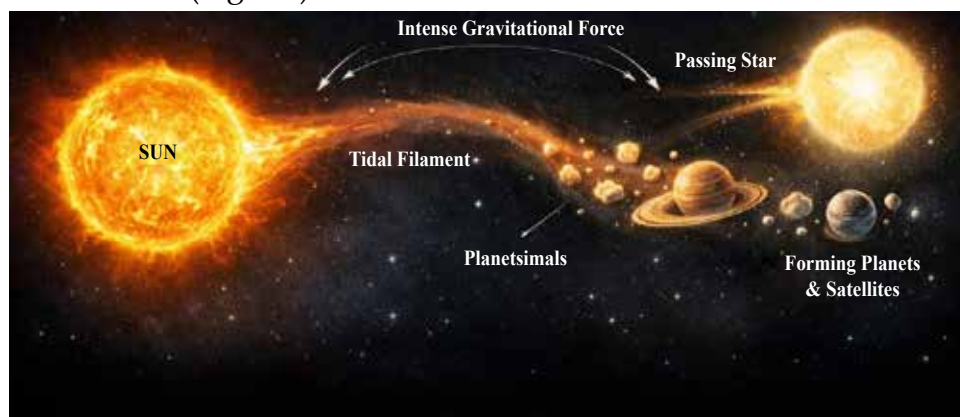


Fig. 2.3
Tidal Hypothesis

These powerful tidal forces pulled out large masses of hot gas from the Sun. As these gaseous streams stretched into space, they eventually broke into several smaller pieces. Over time, these pieces cooled, condensed and solidified, forming the building blocks of the planets. According to the Tidal Hypothesis, the planets were therefore formed from material originally pulled out of the Sun itself. The hypothesis also explains why the planets revolve around the Sun in roughly the same direction and plane. Since all the planetary material was drawn out from the Sun during the same tidal event, the planets inherited similar orbital characteristics.



Know More

Although the Tidal Hypothesis provided an explanation for the origin of our Solar System, it has limitations. Later evidences showed that close encounters between stars are extremely rare, making such a tidal event highly unlikely. In addition, the cooling and condensation of such hot material into solid planets is difficult to reconcile with modern science. For these reasons, the Tidal Hypothesis is not widely accepted today. However, it remains historically important because it highlighted the role of gravity, tidal forces and catastrophic events in shaping celestial systems, and it encouraged scientists to explore various possibilities for the origin of planets.



Check your progress

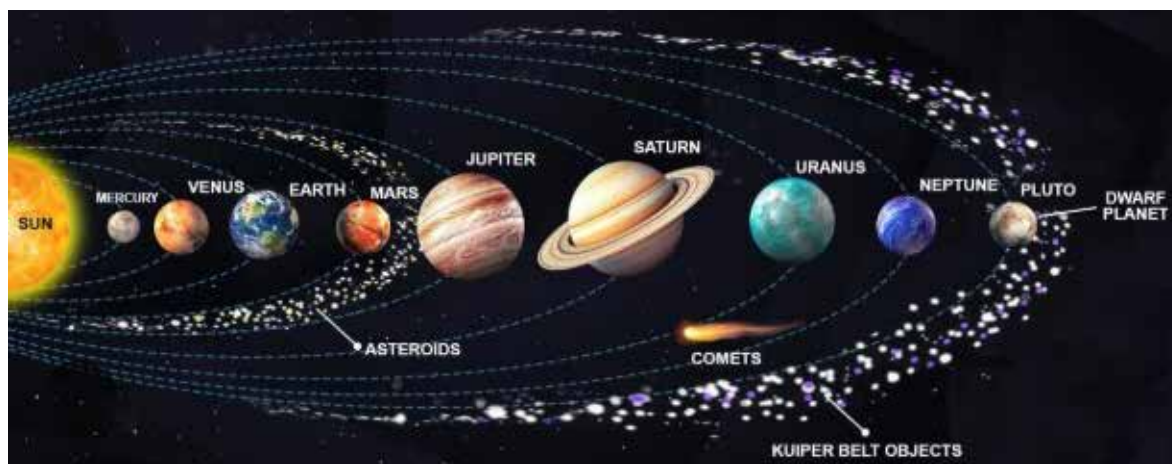
1. According to the Nebular Hypothesis, how did the Sun and planets form?
2. What are protoplanets?

2.4 Constituents of the Solar System

2.4.1 The Sun

The Sun is at the centre of our Solar System. Unlike planets, it has no solid surface; instead, it is composed entirely of extremely hot, glowing gases known as plasma. With a radius of about 696,000 km, roughly 110 times that of the Earth, the Sun is so large that nearly one million Earths could fit inside it. Its mass is enormous as well, about 330,000 times the mass of our planet, making up almost 99.9 percent of the total mass of the entire solar system.

The Sun is made up of hydrogen (nearly 75%) and helium (nearly 25%). A small fraction contains heavier elements such as oxygen, carbon, silicon and iron. Although this fraction is tiny, it is still thousands of times greater than the mass of the Earth. The Sun's gases are held together by gravity, creating extremely high pressure and temperature at its centre. Temperatures at the core reach nearly 15 million degree Celsius. Here, **nuclear fusion** occurs, combining hydrogen nuclei to form helium, releasing enormous amounts of energy. This energy travels outward and eventually reaches the Sun's surface, where the temperature is around 5,700 °C.



*Fig. 2.4
Components of the Solar System (Not to scale)*

Because the Sun is not a solid body, different parts rotate at different speeds. Its equatorial regions complete one rotation in about 25 Earth days, while the polar regions take roughly 36 days. The outer atmosphere of the Sun, called the corona, extends millions of kilometers into space and can be seen during a total solar eclipse as a faint, pearly glow.

2.4.2 Planets (Terrestrial, Jovian and Dwarf)

The solar system consists of eight planets. They are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune (Fig. 2.4). Based on their size, structure and distance from the Sun, planets are grouped into three main categories: terrestrial planets, jovian planets and dwarf planets.

a. Terrestrial Planets

The terrestrial planets are the first four planets closest to the Sun: Mercury, Venus, Earth and Mars (Table 2.1). These planets have solid, rocky surfaces and relatively smaller sizes. They are also called inner planets because they lie inside the main asteroid belt. Their surfaces contain mountains, craters and valleys, and some of them have thin atmospheres. The Earth is the only terrestrial planet known to support life due to its suitable temperature range and presence of water and oxygen.

b. Jovian Planets

Beyond the asteroid belt lie the jovian planets, also known as the outer planets. These include Jupiter, Saturn, Uranus and Neptune. Unlike the terrestrial planets, they do not have solid surfaces. Instead, they are made mostly of gases and ices, with thick atmospheres and deep layers of swirling clouds. Jupiter and Saturn are referred to as gas giants because they are mainly composed of hydrogen and helium. Uranus and Neptune are known as ice giants due to the larger amounts of icy substances such as water, methane and ammonia in their composition. These planets are much larger than the terrestrial planets and have many moons and ring systems.

c. Dwarf Planets

In addition to these two groups, the solar system also contains dwarf planets. These are smaller, spherical celestial bodies that orbit the



Know More

Although the Sun is only one star among billions in the Milky Way galaxy (the galaxy in which our Solar System forms a part), it is vital for life on Earth. The energy it emits drives Earth's weather and climate, powers the water cycle and influences winds and ocean currents. Sunlight supports photosynthesis, the process by which plants make food, forming the base of nearly all food chains. Without the Sun's steady supply of energy, the Earth would be cold and lifeless.

Sun. Some well-known dwarf planets are Pluto, Ceres, Makemake, Haumea and Eris. Ceres is the only dwarf planet located in the inner solar system, within the asteroid belt between Mars and Jupiter, while the others are found in the outer regions, mostly in the Kuiper Belt.

2.4.3 Moon (Satellites)

Satellites are celestial bodies that revolve around the planets in definite orbits. Our Earth has one satellite i.e., the Moon. Mercury and Venus have no satellites, while the gas giants like Jupiter and Saturn possess dozens of moons. Natural satellites may be rocky or icy in nature and are believed to have formed along with their parent planet, been captured later from nearby space or formed as a result of giant impacts. These moons play an important role in understanding the formation, evolution and dynamics of the Solar System.

Table 2.1 Characteristics of planets

Sl. no	Planet	Average Distance from Sun (million km)	Number of Moons (satellites)	Average Temperature (°C)	Orbital Period in days (one revolution)
1	Mercury	57.9	0	167	88
2	Venus	108	0	464	225
3	Earth	149.6	1	15	365.25
4	Mars	227.9	2	-65	687
5	Jupiter	778.3	95	-110	4,333
6	Saturn	1,427	146	-140	10,767
7	Uranus	2,870	27	-195	30,687
8	Neptune	4,497	14	-200	60,225

2.4.4 Asteroids

Asteroids are small rocky bodies that orbit the Sun, mostly found in a region called the asteroid belt located between Mars and Jupiter. They are considered remnants from the early formation of the Solar System. Asteroids vary greatly in size, from small pebbles to objects that are hundreds of kilometers wide. Unlike planets, they do not have atmospheres or a regular spherical shape; many have irregular surfaces marked by craters from collisions.

2.4.5 Meteoroid and Meteorites

Have you ever noticed a sudden flash of light moving quickly across the night sky and disappear? Most probably it is a meteor. Meteoroids are small rocky fragments from space that enter the Earth's atmosphere at very high speed. As these fragments travel at speed up to 40 km per second in the atmosphere, they create intense friction, which produces heat and causes them to glow brightly. This usually happens at heights of about 80 to 110 km above the Earth's surface. Most of the meteoroids burn up completely before reaching the ground. However, some rock fragments are large enough not to burn completely within the atmosphere. These partially burnt meteoroids that fall on the Earth's surface are called meteorites.



Do you Know!!!

Rheasilvia in the Vesta asteroid is the highest mountain in the Solar System



Know More

Meteor Shower and Significance of Meteorites

Sometimes, many meteors appear in the sky one after the other. This is known as meteor shower. Meteor showers often occur when the Earth passes through the trail of debris left behind by comets. These beautiful natural displays can be seen on certain nights and are eagerly observed by sky watchers around the world.

Meteorites have great scientific importance. They are the only objects that come to us directly from outer space. Their study provides valuable information about the age of the planets and the history of the solar system. They also help in understanding the chemical composition of the early solar system and how it evolved over billions of years. Impact of meteorites on planetary surface creates bowl-shaped depressions called craters (e.g. Lonar Crater in Maharashtra). Large impact events have resulted in mass extinction.

2.4.6 Comets

Comets are smaller celestial bodies made of dust, ice and gases that orbit the Sun. The orbits of comets are highly elliptical and elongated. The solid center of a comet is known as its nucleus. It is made of frozen gases, dust and rock, and is usually quite small-only a few kilometers across (Fig. 2.5). When a comet is far from the Sun, such as in the Kuiper Belt or Oort Cloud, it remains frozen. As the comet moves closer to the Sun, its frozen material begins to warm up. The ice slowly turns into gas, and sometimes this gas escapes forcefully, carrying



Fig. 2.5
Comets

**Do you Know!!!**

Halley's Comet is named after the English astronomer Edmond Halley (1656–1742). This comet takes 75-76 years to orbit the sun. It last appeared in the inner solar system in 1986.

small dust particles within it. These materials form a glowing cloud around the nucleus, known as the **coma (tail)**, making the comet appear bright and fuzzy in the sky.

**Know More**

Comets are mostly found in the outer parts of the Solar System. Some of them are located in a region beyond Neptune called the Kuiper Belt. These comets are known as short-period comets because they take less than 200 years to complete one orbit around the Sun. Other comets come from a distant, round region called the Oort Cloud, which is much farther away from the Sun, about 50 times farther than the Kuiper Belt. These are called long-period comets, and they take a very long time to travel around the Sun. Some long-period comets may take more than 250,000 years to finish one single orbit.

**Check your progress**

Match the following celestial bodies with their correct characteristics.

A	B
a) Asteroids	i) Highly elliptical orbits, icy composition
b) Meteors	ii) Rocky remnants mainly between Mars and Jupiter
c) Comets	iii) Burn up in the Earth's atmosphere
d) Meteorites	iv) Reach the Earth's surface

Summary

This chapter explains Earth's position in the Universe. It introduces the origin and evolution of the Universe through the Big Bang Hypothesis, the expansion of the Universe and possible future outcomes such as the Big Crunch and Cold Death. The chapter also describes the origin of the Solar System, highlighting evolutionary and catastrophic hypotheses, and outlines the structure and characteristics of the Sun.

It further discusses the classification of planets into terrestrial, jovian, and dwarf planets, along with natural satellites. The chapter also introduces smaller celestial bodies such as asteroids, meteors, meteorites and comets.

3

THE EARTH

3.1 Introduction

The Earth is a dynamic and ever-evolving planet composed outwardly of land, water, air, and living organisms that function together as a unified system. Is the planet homogeneous internally? Rather than being a uniform solid sphere, the Earth consists of several distinct layers, each with unique physical and chemical properties. This chapter explores the dimensions of the Earth, its internal structure, and provides an overall understanding of how the Earth system operates.

Earth System Science examines the Earth as an integrated whole, comprising the solid lithosphere, the gaseous atmosphere, the liquid hydrosphere, frozen water in the cryosphere, and the biosphere. These components constantly interact with one another through physical, chemical, and biological processes. This chapter further explains the major components of the Earth system and the interactions within them, helping us understand the nature of our planet and how it functions and supports life.

3.2 Dimensions of the Earth

People often think of Earth as a perfect sphere, but scientific measurements show that it is only almost spherical. In reality, the Earth is slightly flattened at the poles and slightly bulged at the equator.

The distance from the centre of the Earth to its surface is not the same everywhere. If we measure from the centre to the Equator, the distance is about 6,378 km. But the distance from the centre to the North or South Pole is slightly shorter, around 6,357 km. This means that the Earth is a little wider at the Equator than from pole to pole. The diameter across the Equator is about 12,756 km, while the diameter from one pole to the other is about 12,714 km. The equatorial bulge of the planet is due to its spinning motion or rotation. The difference between equatorial and polar diameter is around 42 km, which results in an oblate spheroid (ellipsoid) shape

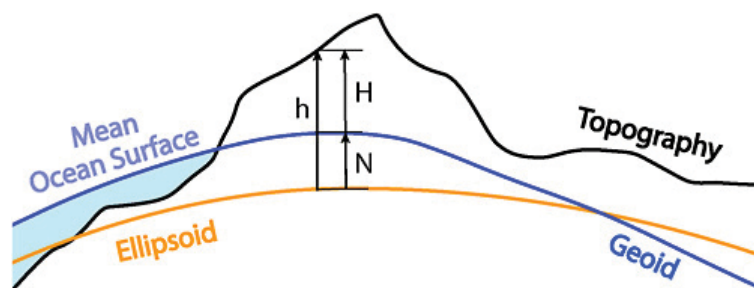


Fig. 3.1
The concept of geoid
h (geometric/ellipsoidal height)
H (orthorhombic height)
N (geoidal height)

The diameter across the Equator is about 12,756 km, while the diameter from one pole to the other is about 12,714 km. The equatorial bulge of the planet is due to its spinning motion or rotation. The difference between equatorial and polar diameter is around 42 km, which results in an oblate spheroid (ellipsoid) shape

for the Earth. While the spheroid is a smooth, idealized shape, Earth's actual surface includes sea level, mountains, valleys and plains. To represent Earth's real shape more faithfully, scientists use the concept of the **geoid** (Fig. 3.1). It is the true shape of the Earth. Geoid is a modelled equipotential gravity surface, more or less corresponding with the mean sea-level. The force of gravity acts perpendicular to the geoid everywhere.

3.3 Internal Structure of the Earth

Have you ever wondered what lies deep beneath your feet? Although we walk only on the surface, the Earth is made up of several layers, each with unique properties. Since humans cannot directly reach deep inside the Earth, scientists study earthquake (seismic) waves, volcanic material and other geological evidences to understand its internal structure.

The idea about the internal structure of the Earth has been obtained mainly through the study of earthquake waves. During earthquakes, three different types of waves are generated namely, Primary (P waves), Secondary (S waves) and Surface waves. Among them, the P and S waves mainly travel through the earth. The P and S wave velocities change with depth, and each change can be related to a change in density and state of materials.

Each region of changing seismic wave velocity demarcates a Zone of Discontinuity. A Discontinuity is a boundary demarcating two layers inside the earth, which are geochemically or mineralogically distinct. Here a sudden change in earthquake wave velocity and direction takes place. Thus, the Earth's

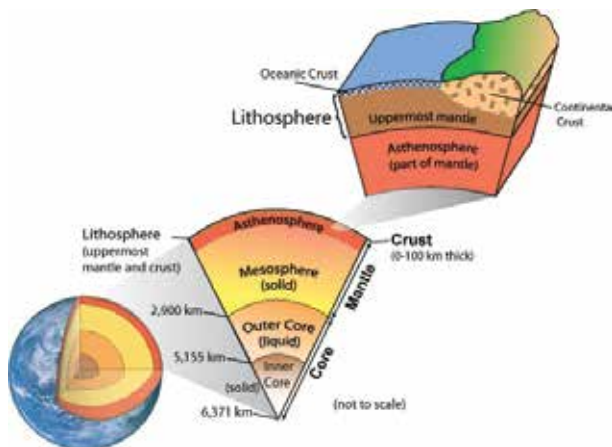


Fig. 3.2
Internal layers of the earth

internal structure is grossly understood as made up of three layers called Crust, Mantle and Core (Fig. 3.2).

3.3.1 Crust

The outermost of these layers is the crust, a relatively thin but significant shell forming the solid surface of the planet. Although it represents only a small fraction of Earth's total volume, the crust supports all life, and contains the continents, oceans, landforms and natural resources we depend on. The crust is composed of different types of rocks. However, its thickness is not uniform everywhere.

Beneath the oceans, it is generally very thin, about 5 to 10 km whereas beneath continents it becomes much thicker, and varies widely with an average of 35 km. In regions with massive mountain systems, such as the Himalayas, the crust may extend from 55 to 70 km. The lower boundary of the crust, where a noticeable change in the velocity of earthquake waves is observed, is known as the **Mohorovicic Discontinuity**, or simply Moho. This boundary marks the transition from the crust to the underlying mantle. From seismic research, geologists have learned that the crust is not uniform in composition.

There is drastic difference between the continental crust and the oceanic crust, the latter being denser and thinner. Further, the oceanic crust is geologically much younger and less complex.

The concept of Sial and Sima

Early models of the crust involved a denser lower crust and a lighter upper crust along continental regions and that the lower crust is akin to oceanic crust. The sial, the upper part of the continental crust, is composed of rocks rich in silica and aluminium, and hence, the name. This layer consists of a mixture of igneous, sedimentary and metamorphic rocks, with an overall granitic composition. The density of sial averages around 2.75 g/cm³, making it lighter than the layer beneath it. Beneath the sial lies the sima, rich in silica and magnesium, and this chemical composition gives it the name. It is denser than the sial, with a density of 2.8 to 3.3 g/cm³, and typically of basaltic composition. It is comparable to oceanic crust in terms of bulk composition and density. Seismic waves travel faster through the sima than through the sial, supporting the conclusion that sima rocks are heavier and more compact. The boundary between the sial and sima is marked by a seismic discontinuity called the **Conrad Discontinuity**, typically located at a depth of about 15-20 km below the continental surface.



Know More

The bulk of Earth's crust is made of rocks (>95 %); essentially **igneous** and **metamorphic** rocks, and a small amount of **sedimentary** rocks (restricted to near surface). Rocks to a large extent are composed of **minerals**. Most of the rock-forming minerals are complex **silicates** like **feldspar**. **Ore minerals**, though very small in occurrence, are significant part of the crust. Other constituents of the crust include soil, partly weathered rock, sediments, coal, fossils, other organic remains and fluid constituents including water, petroleum and natural gas.

Approximate chemical composition of crust: O (47%), Si (28%), Al (8%), Fe (5%), Mg (4%), Ca (2%), K (2%), Na (2%) and Others (2%).

Examples of common igneous rocks:
Granite, Basalt, Dolerite

Common metamorphic rocks: Gneiss, Granulite, Schist, Marble

Common sedimentary rocks: Shale, Sandstone, Clay, Limestone.

3.3.2 Mantle

Beneath the crust lies the Earth's second major layer, the mantle. It forms the thick middle portion of the planet and extends from the base of the crust (marked by the Mohorovicic Discontinuity) to a depth of about 2,900 km. Because of its greater thickness, the mantle accounts for the largest share of Earth's interior representing roughly 83% of its total volume and about 68% mass. This makes it the most dominant layer in terms of size and influence on geological activity. Mantle is much denser than the crust.

In terms of chemical makeup, the mantle differs much from the crust. While the crust contains relatively more aluminum and lighter elements, the mantle is rich in iron and magnesium bearing minerals like olivine and pyroxene, which are capable of withstanding the intense heat and pressure conditions found at depth.

The mantle is not uniform throughout its entire depth. As seismic waves pass through it, they behave differently at various depths, indicating changes in its composition and physical state. The bottom boundary of the mantle, where it meets the core, is known as the **Gutenberg-Wiechert Discontinuity**. Here, a sharp change in the behavior of seismic waves is observed.

Lithosphere and Asthenosphere

The outermost mechanical layer of the Earth is called the lithosphere. It includes the entire crust and the uppermost solid portion of the mantle. Together, these layers are cool and rigid compared to the deeper interior. On an average, the lithosphere extends to a depth of about 100 km, though its thickness varies depending on whether it lies beneath continents or oceans. Under continental regions it is generally thicker, while under ocean basins it may be thinner. The lithosphere is not a single unbroken shell. Instead, it is divided into several large and small pieces called tectonic plates, which are involved in many dynamic processes (*See Chapter 5 for details of Plate Tectonics*).

Beneath the lithosphere lies the asthenosphere, which is the major source for magma. It is a distinct mechanical layer of the upper mantle that plays a key role in the movement of tectonic plates. It extends from about 100 to over 350 km below the Earth's surface. Its boundaries are gradual rather than sharply defined. Unlike the strong and rigid lithosphere above it, the asthenosphere is partially molten and highly ductile. Temperatures in this region are high enough to soften the solid mantle rocks. Seismic studies show that

earthquake waves travel more slowly through the asthenosphere supporting its partially molten character.

Do you Know!!!

There is a recently discovered crucial layer (of around 250 km thickness) at the bottom of the mantle called the D"-layer lying just above the core-mantle boundary. Modern studies reveal that this is the most enigmatic of the internal layers of the Earth along which the core-mantle interaction takes place and is highly complex in nature. Studying the D"-layer is important for understanding the thermal and chemical evolution of the Earth, the Earth's magnetic field, mantle dynamics and energy transition.

3.3.3 Core

The inner most part of the Earth is the core, which begins where the mantle ends, roughly 2,900 km beneath the surface. It continues all the way to the very centre of the Earth. The core has a radius of about 3,500 km. It contributes up to 17% of the Earth's total volume, and nearly 34% of the planet's total mass. The core is made of metallic elements such as iron and nickel. Hence, core becomes the densest among the earth's layers. Temperatures are estimated to reach values approaching those found on the surface of the Sun, close to 6,000°C. Pressure also increases

dramatically toward the center. Core is divided into two layers- the outer and inner. The outer core is a layer of hot, molten metal. It is mostly made of liquid iron and nickel. The temperatures here range from about 4,000°C to 6,000°C. Because the pressure in the outer core is lower than in the inner core, the metals remain in a liquid state. The movement of this liquid metal creates Earth's magnetic field, which protects the planet from harmful solar radiation. The inner core is made up of solid iron and nickel. The temperatures here can reach up to 6,000°C. Despite these extreme temperatures, the inner core remains solid because the pressure is incredibly high. The boundary that separates the liquid outer core from the solid inner core is called the **Lehmann Discontinuity**.



Know More

Future of the core-A chilling twist!

Over millions of years, the Earth's core will gradually cool. As this happens, the solid inner core may continue to grow, while the liquid outer core will shrink. If the outer core eventually becomes completely solid, Earth's magnetic field could collapse. Without this protective shield, solar radiation would bombard the planet. Hence, the Earth could become geologically inactive, much like Mars today.



Check your progress

1. What is the difference between continental crust and oceanic crust?
2. Distinguish between outer core and inner core?
3. Arrange the following layers of the earth from the surface to the centre.
 - a. Inner core, b. Mantle, c. Crust, d. Outer core

3.4 The Earth System: Geosphere and Biosphere

The Earth is not just a collection of rocks, oceans and air. It is a large, connected system where many natural processes work together. Scientists call this the Earth System, and it includes several major components that interact with each other continuously. This mainly includes the geosphere and biosphere. The geosphere has four important components, namely lithosphere, atmosphere, hydrosphere and cryosphere. Each sphere has its own important role, but none of them can function independently. Energy from the Sun and heat from inside the Earth move through these spheres, driving processes such as weathering, erosion, plant growth, rock cycle, hydrologic cycle, climate change, and even plate tectonics.

Understanding these relationships is important as many environmental changes occur when the balance between Earth's systems is disturbed. By studying how the geosphere and biosphere work together, we get a better idea of how our planet functions and how life continues to thrive on it.

3.4.1 Divisions of Geosphere

a. Lithosphere

The lithosphere is an important part of the geosphere. It forms the rigid, outermost solid layer of the Earth. It includes the crust and the uppermost mantle, and acts as the surface foundation of continents and ocean basins. As the upper solid portion of the geosphere, the lithosphere is where major geological processes such as plate movement, volcanic activity, mountain formation and earthquakes occur. The slow but continuous movement of tectonic plates within the lithosphere, has shaped the Earth's landscapes over millions of years and continues to influence natural hazards and surface environments today.

b. Hydrosphere

The hydrosphere includes all of the Earth's water in liquid, solid and gaseous forms. It covers more than 75% of the planet's surface. It forms a discontinuous layer because water is stored in many separate places such as oceans, rivers, lakes, groundwater, glaciers, wetlands and the atmosphere. If all the water on Earth were spread evenly, it would form a layer about 3 km thick. The largest part of the hydrosphere is the oceans and seas, which make up about 97% of all Earth's water (saline water) and play a key role in regulating global temperatures by storing and distributing heat. Glaciers and ice caps contain most of the remaining freshwater. Only a small portion exists as groundwater, rivers and lakes. Yet this small amount is vital for plants, animals and humans.

The hydrologic (water) cycle (explained in a later paragraph) keeps water constantly moving between oceans, land and the atmosphere. This continuous cycling of water is essential because it distributes heat, shapes the landscape and provides fresh water necessary for ecosystems and life on the Earth.

c. Atmosphere

Have you ever wondered why life can exist on Earth but not on most other planets? One major reason is the atmosphere, a protective blanket of gases, surrounding our planet. This layer does much more than simply exist around Earth; it plays an active role in supporting life. It protects us from harmful solar radiation, traps heat to maintain a suitable temperature, and enables weather, climate and the availability of breathable air. The atmosphere is dynamic and the concentration of gases changes slightly over time due to natural causes and human activities. Without this dynamic and life-supporting atmospheric system, Earth would be cold, barren and lifeless much like the Moon.

Composition of the Atmosphere

The atmosphere consists of several gases (Fig. 3.3), with the top four making up 99.998% of all gases. Among these, nitrogen is the most abundant gas. It plays an important role by reducing the concentration of oxygen, preventing things from burning too quickly on the Earth's surface. Nitrogen is also essential for living organisms as they need it to build proteins. Oxygen is the second most common gas and is vital for life. Argon, the third abundant gas in the atmosphere has many uses in daily life. Carbon dioxide, though

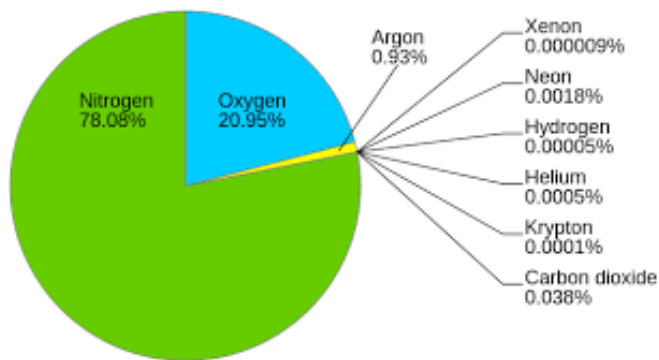


Fig. 3.3
Composition of the atmosphere

present in a small percentage, is extremely important as plants use it during photosynthesis and it helps keep the Earth warm by trapping heat. Apart from this, the atmosphere also contains minor amounts of water vapor.

Layers of the Atmosphere

The different layers of the atmosphere (Fig. 3.4) are described below.

Troposphere

The troposphere is the lowest layer of the Earth's atmosphere. It extends from the Earth's surface up to an average of 10 km. But its thickness changes depending on location. It is around 18–20 km near the equator and as low as about 6–7 km near the poles. This layer contains most of the air in the atmosphere, about 90% of the total mass and almost all the water vapor. Because of this, all weather events, such as clouds, rain, storms and snow happen in the troposphere. The temperature in the troposphere decreases with height. This drop in temperature is called the **lapse rate**. On an average, the air cools by about 6.5°C for every kilometer you go upward. The top boundary of the troposphere is called the **tropopause**, which separates it from the next atmospheric layer, the stratosphere. The tropopause acts like a lid and prevents most weather clouds and water vapour from rising into higher layers.

Stratosphere

The stratosphere is the second major layer of the atmosphere, located above the troposphere and extending up to 50 km above the Earth's surface. It contains around 19% of the atmospheric gases, but holds very little water vapor compared to the troposphere. A unique feature of the stratosphere is that the temperature increases with height. This warming occurs because the **ozone layer**, found within this layer, absorbs harmful ultraviolet (UV) radiation from the Sun. When UV light breaks oxygen molecules (O_2) into individual atoms (O), which combine with O_2 molecules to form ozone (O_3). The highest concentration of ozone occurs at roughly 25 km above the Earth. Temperature in this layer range from about

-60°C near the bottom to about -15°C near the top. The warmer temperature and very dry air make the stratosphere extremely stable and mostly cloud-free. The **stratopause** is the boundary between the stratosphere and the mesosphere, located at around 50 km above the Earth's surface. It marks the warmest portion in the upper stratosphere, where temperature stops increasing and begins to decrease again in the layer above.

Mesosphere

The mesosphere is the third atmospheric layer and lies above the stratosphere. It extends from about 50 km to around 85 km above the Earth's surface. The air in this layer is extremely thin. Although gases such as oxygen still exist, their amount decreases greatly with height. Unlike the stratosphere, the temperature in the mesosphere gets colder as altitude increases. This happens because there are fewer gas molecules at higher levels to absorb heat and solar radiation. Temperatures in this region can drop to around -100°C, making the mesosphere one of the coldest parts of the atmosphere. One of the most interesting features of the mesosphere is the burning of most meteors as they enter the Earth's atmosphere. The gases here, although thin, are still dense enough to create friction, causing meteors to heat up and leave bright trails known as **shooting stars**. At the top of the mesosphere lies the **mesopause**, the boundary separating it from the next atmospheric layer above.

Thermosphere

The thermosphere is the fourth major layer of the Earth's atmosphere and lies above the mesosphere. It begins at about 85–100 km above the surface and can extend up to 600–1000 km. Even though the air here is extremely thin, the thermosphere experiences very high temperature. This is because it absorbs strong radiation from the Sun, including X-rays and UV rays. During periods of high solar activity, temperature in this layer can reach 500°C or more. But it would not feel hot to us because the air is too thin to transfer heat. Most of the thermosphere is considered to be part of outer space because its air density is



Know More

Aurora Magic

Auroras (Fig. 3.4) are natural display of light like brilliant ribbons of green, pink and purple, dancing across the polar skies. They happen when charged particles from the Sun zoom toward the Earth and collide with gases in the upper atmosphere, almost like cosmic fireworks. The colors even depend on which gas is hit: oxygen glows green or red, while nitrogen puts on a blue or violet show. In the north, they are called Aurora Borealis, and in the south, Aurora Australis.

very low. This is the region where the **International Space Station (ISS)** and many satellites orbit the Earth. The gases in this layer include nitrogen (N_2), oxygen (O_2), and single oxygen atoms formed by the breakup of oxygen molecules under intense solar radiation. The boundary between thermosphere and exosphere is known as **thermopause**. The altitude of thermopause fluctuates depending on solar activities and other factors like the time of day.

Within the thermosphere lies the **ionosphere**, a region filled with electrically charged particles called ions. These ions are formed when solar radiation knocks electrons away from atoms in the upper atmosphere. The ionosphere does not have a fixed boundary. The ionosphere is extremely important for radio communication. Radio waves sent from the ground can bounce (reflect off) ionized layers in the ionosphere and return to Earth, allowing long-distance communication without satellites. The ionosphere is also where auroras (the Northern and Southern Lights) form. Charged particles from the Sun collide with gases here, causing spectacular glowing colors in the sky.

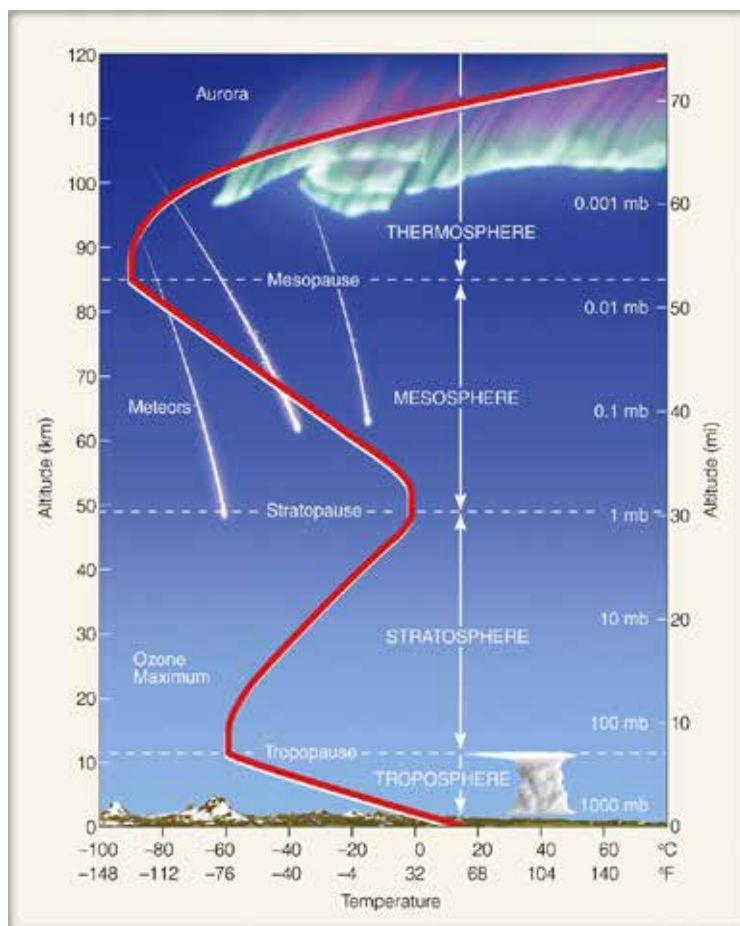


Fig. 3.4
Layers of the atmosphere

Exosphere

The exosphere is the outermost layer of the Earth's atmosphere and marks the transition into outer space. Although the Earth's gravity still holds gases here, they are extremely thin and widely spaced. This layer is mainly made of very light gases such as hydrogen and helium, with small amounts of oxygen and carbon dioxide. Because the air here is so thin, particles can travel long distances, sometimes several kilometers, before colliding with other particles. Since the exosphere has very few particles, it cannot refract radio waves. The temperatures can vary widely, from extremely cold at night and more than 1000°C during the day. Its low density and minimal friction make it an ideal location for satellites to orbit smoothly without experiencing much drag. The exosphere is also the Earth's first protective boundary, interacting directly with solar wind, cosmic rays and charged particles from the Sun. Although it is the most distant atmospheric layer, it plays a key role in shielding our planet and linking the atmosphere with interplanetary space.

d. Cryosphere

This term originates from the Greek word 'Kryos', meaning frost or ice cold. The cryosphere includes all the places on the Earth where water is frozen. These frozen areas are found mostly in the coldest parts of the world, such as the Arctic, Antarctica and high mountain ranges. Frozen water can also appear seasonally in many places. Even tiny ice crystals in clouds are part of the cryosphere. The cryosphere is important because it helps control the Earth's temperature. Ice and snow reflect a lot of sunlight back into space, helping keep the planet cool, almost like Earth's natural air-conditioning system. When the cryosphere grows or melts, it affects sea level, weather, ocean currents and life on Earth.



Know More

Cryosphere and Global warming

*The cryosphere is one of the first parts of the Earth to show the effects of global warming because frozen water melts quickly when temperatures rise. Glaciers, sea ice and permafrost are shrinking faster than ever recorded, and some of this ice has been frozen since the **Last Ice Age**. Thawing permafrost also releases greenhouse gases like carbon dioxide and methane, adding to climate change. Although the cryosphere looks frozen and still, it is actually one of the Earth's most active warning signs of a rapidly warming climate.*

If all the frozen water in the cryosphere melts, the sea level may rise by 70 m!



Check your progress

1. Explain the formation and importance of the ozone layer.
2. Explain the significance of ionosphere.

Interaction within the Geosphere

The components of the geosphere have unique features. Their interactions drive various processes of the planet. For example, the atmosphere and the hydrosphere interact when the Sun heats ocean water, causing evaporation and cloud formation. This later returns as rain or snow. Similarly, the lithosphere interacts with the hydrosphere and the atmosphere through processes like weathering and erosion. The cryosphere along with the atmosphere also plays a role by reflecting sunlight and keeping the Earth cool. Additionally, the melting of ice adds freshwater to the oceans and influences weather and climate. Together, the atmosphere, hydrosphere, lithosphere and cryosphere form a connected system that makes Earth a dynamic, ever-changing and life-supporting planet.

Hydrologic Cycle

The hydrologic cycle, also called the water cycle, is the continuous circulation of water through the land, oceans, atmosphere and living organisms by the processes like evaporation, transpiration, condensation, precipitation, infiltration and runoff, through solid, liquid and gaseous states (Fig. 3.5). This cycling ensures that water is always moving, changing form and redistributing energy across the planet.

To start with, water reaches the surface of the earth through precipitation (rainfall and snow fall). Once precipitation reaches the surface, some of the water soaks into the ground through infiltration. This infiltrated water moves deeper underground to form groundwater. Over time, this groundwater moves slowly toward rivers and lakes through subsurface flow. The rest of the precipitation flows across the land surface as run off. Once water reaches oceans, lakes, soils and vegetation, it begins the return journey to the atmosphere. Water from exposed surfaces changes to vapor through evaporation. Living plants also release water vapor through transpiration. As moist air rises and cools, water vapor undergoes condensation, forming clouds. When droplets grow large enough, precipitation begins again, continuing the cycle.

The hydrologic cycle is essential because it regulates climate, shapes landscapes, distributes freshwater and supports life across

the planet, making it one of the Earth's most important natural systems. Just like the water cycle, another important cyclic process in the geosphere is the rock cycle, which explains how rocks change from one form to another over time. You will learn more about it later.

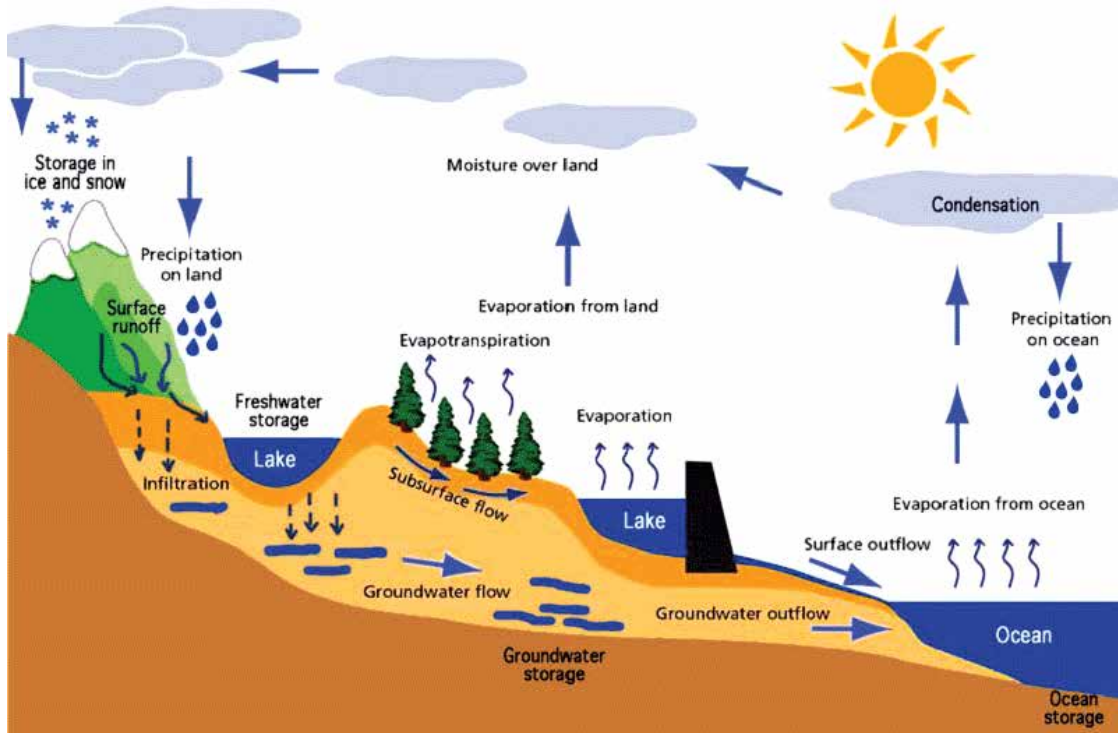


Fig. 3.5
Hydrologic cycle

3.4.2 Biosphere

The biosphere includes all living organisms on the Earth such as plants, animals, microorganisms and humans as well as the environments they interact with. The biosphere depends on the components of geosphere for survival. It needs air from the atmosphere, water from the hydrosphere and soil from the lithosphere. In some regions it even relies on frozen environments (cryosphere).



Do you Know!!!

The driving forces for the hydrologic cycle are solar energy and gravity.



Do it Yourself

Interaction among the lithosphere (rock), hydrosphere (water) and atmosphere (air).

Materials Required:

Two transparent glass jars or beakers, water (distilled or clean tap water), small pieces of limestone/marble or chalk (CaCO_3), straw (or a way to blow air gently), pH paper, labels or marker.

Procedure:

1. Fill both jars with equal amounts of water. Label them A and B.
2. Add equal-sized pieces of limestone/marble/chalk to both jars.
3. Leave Jar A undisturbed (normal water + limestone). In Jar B, gently blow air through a straw into the water for 2–3 minutes to add carbon dioxide (CO_2).
4. Test the pH of water in both jars using pH paper.
5. Leave both jars for 24–48 hours.
6. Observe any visible changes in the limestone pieces and test the water again if possible.

Observation

In Jar B, carbon dioxide (CO_2) from the atmosphere dissolves in the water of the hydrosphere when air is blown through it, lowering the pH and making the water slightly acidic. This acidic water reacts with limestone of the lithosphere, causing gradual dissolution. As a result, the limestone piece in Jar B becomes smaller, and calcium ions dissolve into the water, increasing its mineral content. Jar A shows little or no noticeable change. This activity demonstrates the interaction among the atmosphere, hydrosphere and lithosphere.

Summary

This chapter explains the Earth, describing its shape, difference in equatorial and polar radii, and the concepts of spheroid and geoid. The internal structure of the Earth is explained in detail, covering the crust, mantle, and core, and defining major seismic discontinuities.

Finally, the chapter introduces the Earth system, focusing on the geosphere and of its subdivisions. It explains in brief the lithosphere, the composition and layers of the atmosphere, the hydrosphere and hydrologic (water) cycle. The chapter also highlights the interactions among the components of the geosphere in sustaining life and regulating climate. Overall, the chapter drives home the idea that the Earth is a dynamic, inter-connected system within the vast Universe.

4

EARTH PROCESSES

4.1 Introduction

Nothing about our planet is static. Our home, the Earth, is a dynamic planet and is undergoing continuous change. The changes affect the solid, liquid and gaseous components of the Earth. The Earth functions as a system in which there is constant interaction among its components-the lithosphere, hydrosphere, atmosphere, cryosphere and biosphere. The constant interaction and exchange of energy and matter is crucial for maintaining the conditions suitable for life on the Earth. The changes can be small or large, and occur at different rates, ranging from very slow processes (e.g., formation of soil from rocks, mountain building) to very rapid events (e.g., earthquakes, volcanic eruptions).

Earth processes or **Geological processes** are brought about by external or internal forces. Thus, they can be divided basically into exogenic (external) and endogenic (internal) processes. Exogenic processes operate at or near the surface and include weathering, mass wasting, erosion, sediment transportation (together called denudation) and deposition (Fig. 4.1). Endogenic processes originate from within the Earth and include tectonic activity, earthquake, magmatism and metamorphism. Tectonic activity

involves subsurface movements due to natural forces within the lithosphere, resulting in the deformation of rock layers, land uplift, rifting, mountain building and a variety of associated processes (See Chapter 5 for a detailed account of tectonics). We focus on some of the exogenic processes in this chapter as the rest of the exogenic as well as the endogenic processes are dealt with in later chapters of

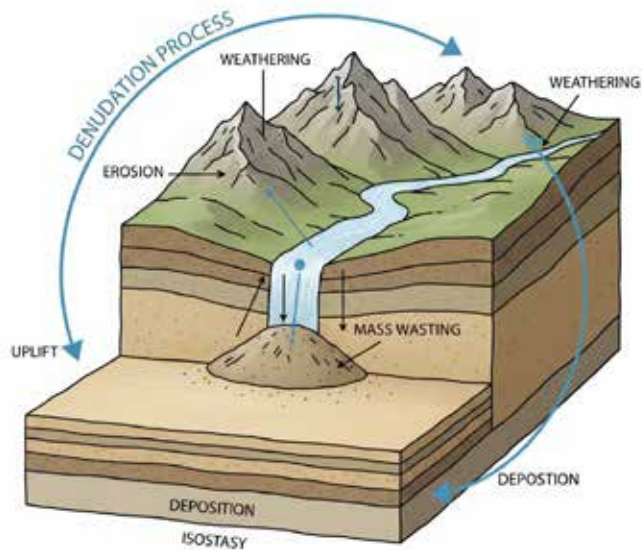


Fig. 4.1
Different denudational processes on the Earth

this book and in Class XII Geology textbook.

4.2 Exogenic (External) Processes

Exogenic processes are driven by solar energy, gravity, water, wind and ice, all interacting within the geosphere to continuously reshape landscapes, build landforms and cause occasional hazards. These processes are further broadly classified in to two types: (i) Degradation (denudation) and (ii) Aggradation (deposition). The process of degradation is the general lowering of the earth's surface by the combined action of weathering and erosion. Aggradation is the process of raising the level of the land surface through the accumulation of sediments by deposition. Gradation is the process whereby higher areas are worn down and depressions or low-lying areas are filled up leading to the formation of a featureless landform or even plain. Thus, degradation and aggradation are complementary in nature.



Do you Know!!!

The major driving force behind all exogenic processes on Earth is solar.

Degradation is the geologic process by means of which various parts of the surface of the earth are worn away and its general level is lowered. The process of degradation consists of sub processes, namely weathering, mass wasting and erosion. The processes derive their energy

from the Sun and atmosphere. Of course, tectonic processes do influence the exogenic processes like mass wasting and erosion in many ways. A related broader term **Denudation** (means 'to uncover') is defined as the combined processes of weathering, mass wasting, erosion and transportation, and thereby the wearing down and leveling of the Earth's surface. Aggradation is a geological process where the land surface is built-up due to the accumulation or deposition of eroded materials or sediments. The removal of the eroded materials, their transportation and deposition are done by water, wind, glacier, waves and currents; and thus, they can be called the **geological agents**, all of them do geological action or geological work in their own peculiar ways. Thus, we have **fluvial, aeolian, glacial and coastal** processes. Gravity also plays a prominent role in moving materials downslope (mass wasting).

The process of Weathering, Mass Wasting, Erosion and Deposition are described in the following sections.

4.3 Weathering

Bedrock refers to the solid crystalline rock that makes up the Earth's outer crust. Weathering is a process that makes bedrock fragile and breaks it down into smaller particles, and the top portion of the bedrock gets converted to regolith and soil. It is a process of disintegration and decomposition of rocks in situ. As it is a static process, the weathered material simply accumulates where it forms. The breakdown of rocks is by mechanical (physical), chemical and biological processes. Weathering prepares the materials for mass wasting and erosion.

The pressure, temperature and chemical conditions inside the earth are different from that in the surficial environment. Weathering is the response of rocks when exposed to the surface to become more stable in the new environment. The rate of weathering depends on the composition of the rock and their response to varying surface environments. Weathering is a prerequisite for the formation of soils. Under some conditions, weathering can lead to the formation of economic deposits such as bauxite, an ore of aluminium.

Weathering processes are not restricted to natural materials alone. The response of any material to its environment at the earth's surface should be considered as a weathering process. Man-made structures exposed at the earth's surface also show signs of weathering. Loosening of mortar in brick walls, peeling-off of paints and rusting of iron and steel materials are some of the familiar examples of the process of weathering. Weathering of the Taj Mahal where the smooth white marble surface is turned yellowish or brownish and rough is spoiling the beauty of the monument.

Three types of weathering processes are

- i. Physical Weathering
- ii. Chemical Weathering
- iii. Biological Weathering

The type of weathering, to a great extent, is decided by climate. For example, physical weathering dominates in arid conditions and chemical, in humid. In many situations, physical, chemical and biological processes act in combination.



Know More

The thickness of regolith may reach tens of meters as in the midlands of North Kerala or hundreds of meters as in Australia.

4.3.1 Physical (Mechanical) Weathering

Physical weathering is the process of breaking down of bedrock into smaller pieces. The usual factors involved in this type of weathering are pressure, temperature, freezing/thawing cycle of water, plant/animal activity and evaporation. This leads to fragmentation and breakdown of rock masses into small blocks and pieces. Physical weathering involves no change in the chemistry of the material involved. This weathering prepares the surface of materials for easier chemical weathering and erosion. When a large block of rock is broken into smaller pieces, additional surface area is created for easier chemical weathering. The different types of physical weathering are described below.

a. Weathering due to Pressure Release

Bedrock buried deep within the earth is under high pressure and temperature. When uplift and erosion bring bedrock to the surface, its temperature drops slowly, while its pressure drops immediately. The sudden drop in pressure and variation in temperature causes the rock to rapidly expand and crack; this is called **Unloading** or pressure expansion and the rock breaks along 'sheeting joints' as stored pressure is released. This expansion leads to the development of almost horizontal fractures that are parallel



Fig. 4.2
Exfoliation

to the ground surface, which is frequently noticed in quarries. Over a period of time, the outer layers of the rock break away in sheets by the process of **Exfoliation** (Fig. 4.2). Exfoliation is the process by which layers peel away from the outer surface of the exposed rock. The process of unloading in rocks like granite to 'exfoliate' or break into sheets that are parallel to the earth's surface. It is also known as sheeting. Rocks which are subjected to such a process, assume a characteristic dome shape.

b. Insolation Weathering

The physical breakdown of rocks by their expansion and contraction due to diurnal (taking place daily) temperature changes is termed insolation weathering. The surface of rocks expands more than the

interior of the rocks as rocks are poor conductors of heat. The repeated heating by day and cooling by night cause the outer layers of the rock to expand and contract alternately, while its interior remains unaffected. The resulting differential expansion and contraction ends up in rupture of rocks leading to insolation weathering. The type of minerals and rate of expansion of grains are important factors influencing this type of weathering. Insolation is significant in arid regions where there is considerable difference between day and night temperatures (Fig. 4.3).

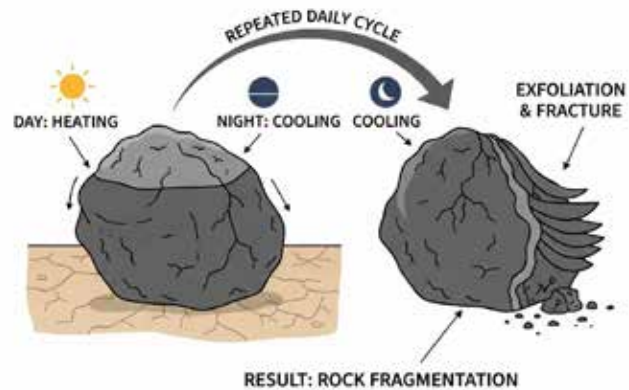


Fig. 4.3
Insolation weathering

c. Frost Wedging (Ice Wedging)

This type of weathering uses the power of expanding ice to break apart rocks. Water enters various cracks, voids and crevices in rocks. As the water freezes, it expands (by about 10%) with great force, exploiting any weaknesses. When ice melts, the liquid water moves further into the widened spaces. Repeated cycles of freezing and thawing thus push the rocks apart and split (Fig 4.4). The cycles can occur daily when fluctuations of temperature, between day and night, leads to freezing. It is confined to regions in higher latitudes and altitudes.

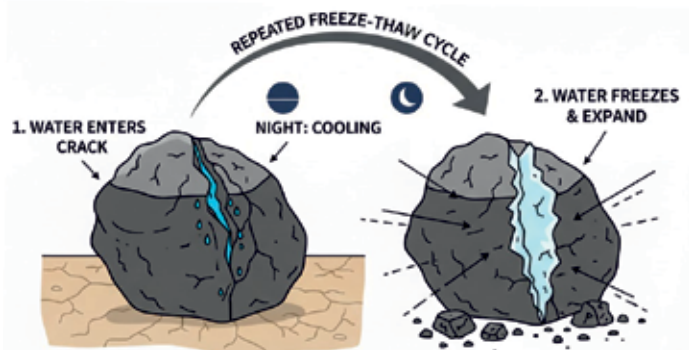


Fig. 4.4
Frost wedging

4.3.2 Chemical Weathering

It is the dominant weathering process in warm, humid environments. It takes place when water, oxygen, and other reactants chemically decompose the mineral components of bedrock and turn them into water-soluble ions. These ions are then transported by water. Chemical weathering takes place due to the loss of stability of certain minerals when they are exposed to surface temperature, pressure and fluids. For example, feldspar (the most abundant mineral

on the crust of the Earth) is decomposed to clay minerals. Water, which contains dissolved carbon dioxide from the atmosphere, is the most important agent of chemical weathering. Higher surface temperatures increase the rate of chemical weathering. Chemical and mechanical weathering work hand-in-hand through a fundamental concept called surface area-to-volume ratio. Chemical weathering initially affects rock surfaces only, as water and reactants cannot penetrate the solid rock. Mechanical weathering penetrates the bedrock, breaking large rocks into smaller pieces and creating new

rock surfaces. This exposes more surface area for chemical weathering. In other words, higher surface area-to-volume ratios produce higher rates of overall chemical weathering. Chemical weathering plays a key role in soil formation by creating clay minerals and soluble nutrients. There



Do you Know!!!

Water is the key factor in chemical weathering

are many processes that can chemically alter and weather rocks. Some of the more important types of chemical weathering like dissolution, oxidation, hydrolysis, hydration and carbonation are briefly discussed below.



Fig. 4.5
Dissolution by chemical weathering

a. Dissolution

Water is a universal solvent and many minerals get dissolved in it. Solution is commonly the first stage in chemical weathering and it removes the most readily soluble minerals. Minerals like halite (NaCl) dissolve in water. Limestones and marble, made up of the mineral calcite (CaCO_3), are insoluble in pure water but in the presence of dissolved CO_2 are soluble when the water attains a pH of <7 . Here, calcium carbonate is replaced by calcium

bicarbonate, which is soluble in water. The process depends on pH of water. SiO_2 is more soluble at pH >9 , while Al_2O_3 is soluble in water having pH <4 and >9 (Fig. 4.5).

b. Oxidation

In this type of weathering, oxidation takes place when oxygen dissolved in water reacts with the minerals in the rocks. Oxygen, dissolved in water, combines with atoms of metallic elements in

minerals. Any mineral containing iron can be oxidized. It is oxidation that causes rust in metallic iron. The red or brown colour, commonly seen in the weathered zones of rocks and soils, is due to oxidation. Oxidation reaction in rock transforms iron-bearing minerals (such as biotite and pyrite) into a weak rusty brown mixture of various iron oxide and iron hydroxide minerals. Three commonly found minerals produced by iron-oxidation reactions are red or grey haematite, brown goethite and yellow limonite. When the newly formed minerals in the bedrock are resistant to further weathering, iron concretions may form (Fig. 4.6).



Fig. 4.6
Oxidation by chemical weathering

c. Hydrolysis

In this process, water reacts chemically with minerals and breaks them down to form secondary minerals. The H^+ and OH^- ions of water react with the ions of the mineral. In hydrolysis, water is a reactant and not merely a solvent. E.g. feldspars in granite, under hydrolysis, form clay minerals.



Orthoclase Water Kaolinite Silicic acid

Hydrolysis takes place when acidic water reacts with rock-forming minerals like feldspars to produce clay (and salts, which are removed through solution). Quartz, being stable, resists hydrolysis. Hence, quartz and clay are two of the most common minerals in weathered rocks and sediments. This process also involves volume expansion.

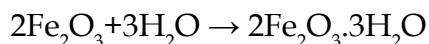
d. Hydration

The process of hydration is related to the addition of water to the crystal lattice of the mineral. The process helps breaking down rocks by increasing their volume through water absorption. Hydration of the common iron oxide mineral haematite leads to the formation of another hydrated iron oxide mineral called limonite that is much lighter. E.g., Iron oxide absorb water and turn to hydrated iron oxide



Know More

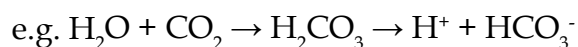
When fossil fuels such as coal and petroleum are burnt, CO_2 and SO_2 escape into the atmosphere and increase their concentration to an abnormal level. During rainfall these gases dissolve in the rainwater, and may cause 'acid rain'.



Haematite (sp.gr 5.26-5.3) Limonite (sp.gr. 2.7 -4.3)

e. Carbonation

The chemical weathering caused by naturally formed carbonic acid is termed carbonation. Rain water is normally slightly acidic due to the presence of carbonic acid. In addition, as the rainwater infiltrates through the soil, it acquires more amounts of carbon dioxide that is released by decaying organic matter of the upper horizons of the soil. Carbonic acid that acts as weak acid after reacting with carbonate rocks like limestone forms calcium bicarbonate which is easily soluble in water.



Water with higher levels of carbonic acid, natural or man-made, dissolves rocks at a higher rate. In regions where extensive limestones occur, carbonation by groundwater gives rise to underground caves and sink holes.



Fig. 4.7
Spherical weathering or onion skin weathering

f. Spheroidal Weathering

Spheroidal weathering is a type of chemical weathering that affects jointed bedrocks. The corners of joint blocks in the rocks weather faster than their edges and faces while the interior remains with relatively fresh core. The resulting blocks of rocks form roughly spherical boulders with highly decayed concentric layers. Successive outer layers peel off from the boulder, like layers of an onion. Thus, it is also called **onion skin weathering** or spheroidal weathering (Fig. 4.7). Typical examples of rocks, showing this type of weathering, are jointed granite and basalt.

4.3.3 Biological Weathering

Biological weathering takes place due to the life activities of organisms. It includes both the processes of disintegration and decomposition, often in combination. Tree roots can grow into fractures in a rock and pry open the rock apart, causing mechanical fracturing. This is called root wedging (Fig. 4.8). The organic processes

involve biological dissolution of rocks from bacterial activity and humic acids. The changes occur by the growth of roots in the rocks on which they grow. The prolonged activities over a long period of time can destroy significant amount of rock. Burrowing animals too can aid in weathering and erosion. Biological weathering plays a vital role in soil formation by breaking down parent material into finer particles and mixing it up with organic matter.

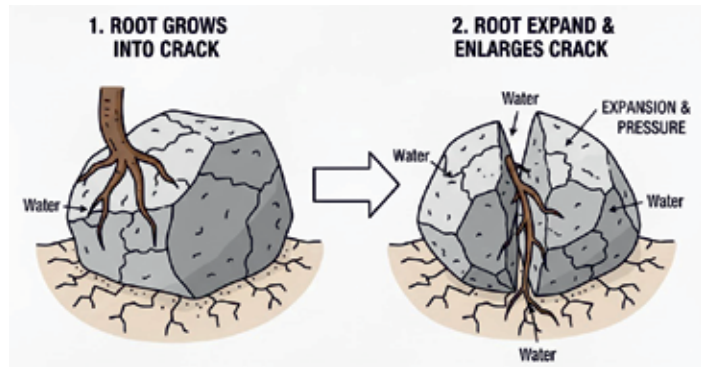


Fig. 4.8
Root wedging

4.4 Products of Weathering: Regolith and Soil

4.4.1 Regolith

Weathering results in the disintegration and decomposition of rocks and produce a mantle of rock fragments of varied sizes and composition from underlying bedrock. Regolith is the layer of unconsolidated and heterogeneous material that covers bedrock. The constituents of regolith range in size from large boulders to clay-sized particles.

4.4.2 Soil

Life on our planet is made possible by the abundance of air (with oxygen and nitrogen in the right proportion), water and soil. Soil is a combination of air, water, minerals and organic matter (called humus) that forms at the transition between the biosphere and geosphere. Geologically, soil is the unconsolidated layer of material at the Earth's surface that results from the physical, chemical and biological weathering of bedrock. The study of soil comes under the science 'pedology'. Soils can be broadly grouped into two types:

- i. **Residual soils:** Those derived from underlying bedrock and remains at the place of their formation. This soil will have same composition as that of the underlying bedrock.
- ii. **Transported soils:** Those derived from the rock materials, which were transported from elsewhere. Hence, their composition can be different from the underlying bedrock.

4.5 Factors Influencing Soil Formation

The nature of the soil in a region is determined primarily by five components:

- i. Mineralogy of parent material
- ii. Topography
- iii. Weathering
- iv. Climate
- v. Organisms that inhabit the parent material/soil
- vi. Time

For example, soil tends to erode more rapidly on steep slopes. Hence, the soil layers in these areas may be thinner than in flood plains, where it tends to accumulate. The quantity and chemistry of organic matter of soil determine how much and what varieties of life it can sustain. Temperature and precipitation, two major weathering agents, are dependent on climate. Fungi and bacteria contribute organic matter and the ability of soil to sustain life.

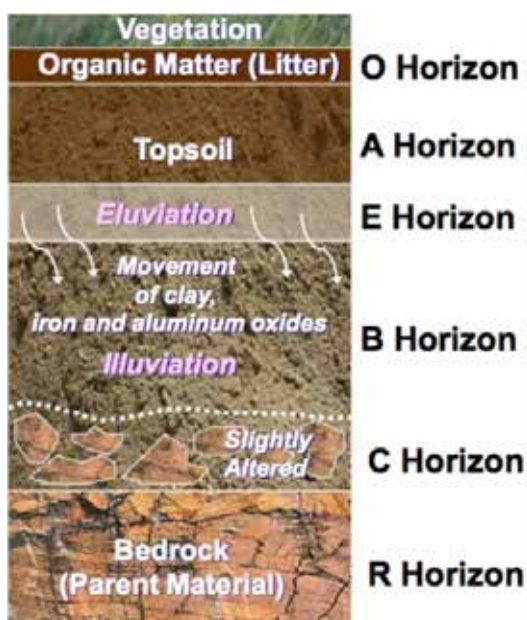


Fig. 4.9
A typical soil profile

4.6 Soil Profile and Soil Horizons

In well-formed soils, there is a discernible arrangement of distinct layers called soil horizons. These soil horizons can be seen in road cuts, railway cuttings, river cuttings etc. The vertical section of soil horizons is known as soil profile. Each soil horizon reflects climate, topography, and other soil-development factors, as well as its organic material and mineral composition. The horizons are assigned with names, designated by alphabets. A simplified soil profile that uses commonly designated names is shown in Fig. 4.9.

O-Horizon

The topmost horizon is a thin layer of predominantly organic material, such as leaves, twigs, and other plant parts that are actively decaying into humus. In areas of severe erosion this horizon may be absent.

A-Horizon

The next layer below (dark in colour), called topsoil, consists of humus mixed with mineral grains of sand/silt/clay. Some mineral constituents from the A-horizon are dissolved and removed when precipitation soaks down through it.

B-Horizon

Also called subsoil (reddish or yellowish), this layer consists essentially of secondary minerals mixed with small amount of humus, derived from the upper layer. The subsoil is where rock is chemically weathered. The amount of organic material and the degree of weathering decreases with depth. The process of removal of soil materials through solution or by other means from soil horizons by percolating water is technically called leaching. Some constituents, removed from the A-horizon through leaching, accumulate within B horizon and the term E-horizon is given for this layer.

C-Horizon

The C-horizon is located below the B-horizon. It consists of partially weathered bedrock and thereby indicates that the weathering and soil forming processes have not effectively reached that depth. Here, bedrock fragments are physically broken, but not chemically altered. This layer does not contain organic material.

R-Horizon

This final layer consists of totally unweathered, parent bedrock and fragments. The term D-horizon is also given for this unweathered parent rock layer.

Weathering and soil formation are extremely slow processes. It is important to note that it takes several hundreds of years for the development of a mature soil profile with A, B and C horizons. As soils are valuable natural resources we have to initiate methods of soil conservation for a sustainable future. In modern days, we find high rate of soil loss through human activities like agriculture, deforestation and urbanization.

4.7 Slope Processes

A slope is an inclined surface of any part of the earth's surface. Some slopes are steep, others are gentle. Landscapes are composed of a mosaic of slopes, varying in areal extent and in degree of inclination. The geometric form of a slope depends on the various geologic processes acting on it. In cross section, a slope may be

concave, convex or straight. Most slopes on the surface of the Earth are covered with regolith and soils. Human activities can upset the balance and result in the loss of soil, trigger landslides and severe erosion. Therefore, we should be aware of the basics of geologic processes that are active along natural slopes. Under natural conditions, gravity and agents like running water, wind and glaciers tend to move sediments, rocks and soil down the slope. The movement of material downslope by gravity is generally called mass wasting and the movement of earth materials by agents (running water, wind and glaciers) is called erosion. Mass wasting and erosion are described briefly in the following sections.

4.8 Mass Wasting

Mass wasting is the downward movement of loose rock, soil or debris on slopes due to the influence of gravity. There is no direct involvement of transporting agents like water, wind or ice in the movement of materials. Still, we can see that water plays a key role in some forms of mass wasting. Here, water contributes to reduce the strength and compactness of rock materials. Water also plays a pivotal role by adding weight and acting as lubricant, making the slope more unstable and triggering movement. Mass wasting represents an important process that prepares the earth materials for erosion.

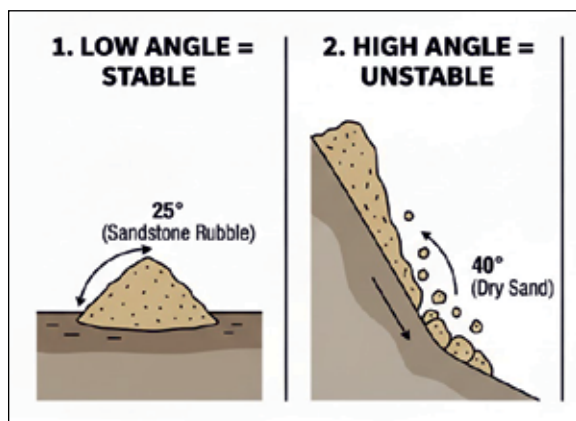


Fig. 4.10
Angle of repose

Mass wasting occurs when a slope fails i.e., when a slope is too steep and unstable for existing materials and conditions. Slope stability is ultimately determined by two principal factors: the slope angle and the strength of the underlying material. The steepest angle at which rock and soil material is stable and will not move downslope is called the **angle of repose** (Fig. 4.10). The angle of repose describes the natural angle at which a granular material, such as sand or gravel, will rest without slipping. It is therefore, the maximum slope angle

that unconsolidated materials can maintain. The angle of repose is measured from the horizontal. Know-how of this property for different materials plays an important part in the cutting of slope and building of embankments.

4.8.1 Classification of Mass Wasting

There are different ways of classifying mass wasting. However, it is not easy to precisely separate the bases of classification because one type often merges into another. Generally, they are classified based on the nature of movement (fall, slide, or flow), type of material involved (rock, debris, or soil) and speed of movement. The nature of movement involved are shown in Fig. 4.11 and discussed in the following section.

a. Fall

Falls are abrupt rock movements that detach from steep slopes or cliffs. Rocks separate along existing natural breaks such as joints or bedding planes. Movement occurs as free-falling, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering and water.

b. Slide

Slides often are rapid movements along a plane of distinct weakness between the overlying slide material and the more stable underlying material.

c. Flow

In flows, particles or earth materials move around and mix while undergoing movements and behave partly as a viscous fluid. Rather than moving downslope as a coherent mass, as in the case of a slump or fall, the material flows downhill as a chaotic mixture. In flows no discontinuities exist and the velocity gradient of the flowing mass gradually diminishes onward.

d. Slump

A slump occurs when a mass of soil or rock moves downward along a curved surface. Thus, the surface of failure is spoon-shaped. The top part often tilts backwards, and a curved scar (scarp) is left behind. Slumps are caused by excess moisture, undercutting of slopes, or earthquakes.

Based on the type of material involved and the type of movement, mass wasting processes can be classified into different categories and are mentioned in table 4.1.

Table 4.1 Different types of landslides classified based on type of material and movement.

Type of material	Type of movement	Type of landslide
Rock	Fall	Rock fall
	Slide	Rock slide
Debris	Fall	Debris fall
	Slide	Debris slide
	Flow	Debris flow
Earth/Soil	Fall	Earth fall
	Slide	Earth slide
	Flow	Earth flow

Some of the other important types of mass wasting, taking into consideration, various aspects of movement, velocity and materials involved, are also known. A few of these are mentioned briefly.

a. Creep

Creep is the slowest form of mass movements. The process of creep along slopes cannot be monitored in a short interval of time and is undetectable by the human eye. Though slow, it causes noticeable effects such as tilted fences, bent trees and leaning poles.

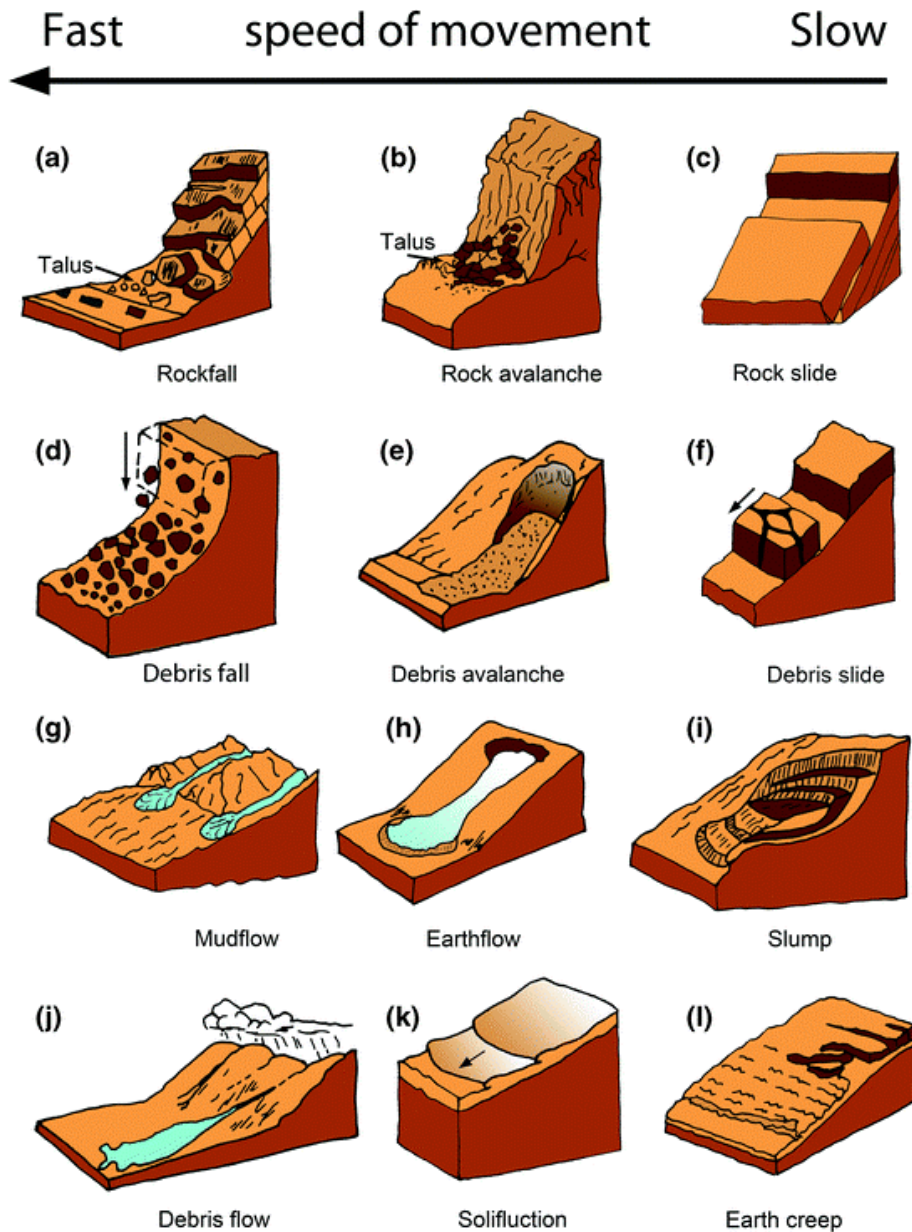
b. Mudflow

A mudflow is a fast-moving mixture of water and fine sediments like clay and silt, resembling wet cement. Unlike debris flows, mudflows are dominated by fine materials. They can travel long distances along stream channels and cause serious destruction.

c. Avalanche

The term avalanche refers to a form of mass movement where the downward moving mass of material comprises mostly of snow and ice (often referred as snow avalanche). Avalanches can be triggered by slight disturbances at the toe of mountains or when the overburden of snow and ice increases in weight and the angle

of repose is exceeded. Avalanches can be really destructive as they devastate all forms of plant and animal life along their flow path. This type of mass movement is common along mountain slopes, especially in cold countries and at high altitudes covered with snow.



*Fig. 4.11
Various types of mass wasting*



Know More

Landslides in Kerala

The state of Kerala is bordered on the eastern side by the mighty Western Ghats. Districts like Idukki, Pathanamthitta and Wayanad are largely mountainous. During the monsoon seasons many parts of these districts experience frequent landslides, which cause immense damage to life and property. The most common type of landslide is debris flow, called 'Urul Pottal' in Malayalam. In this type of mass wasting, rapid and sudden movement of highly water saturated overburden takes place. Apart from the factors like slope, unconsolidated soil and rainfall, human activities like construction of roads, buildings, deforestation and unscientific cultivation of crops play important roles in causing landslide. One such worst disaster took place in Wayanad in 2024. On 30th of July, 2024, a major landslide devastated the villages of Punjirimattom, Mundakkai, Chooralmala and Vellarimala in Meppadi Panchayat, Vythiri taluk in Wayanad district, killing 266 people and 32 are missing. This landslide is due to a combination of rock slide, and debris flow.

4.9 Erosion

Erosion is a degradational process. It is the removal of surficial earth materials by geological agents like running water, wind, glaciers and sometimes groundwater. (See Chapter 8 for fluvial erosion, Chapter 7 for erosion by groundwater and Chapter 10 for Coastal erosion). Erosion is a dynamic process and includes the removal of weathered materials away from their place of existence. Gravity plays an important role in this process. Continuous erosion leads to lowering of land surface.

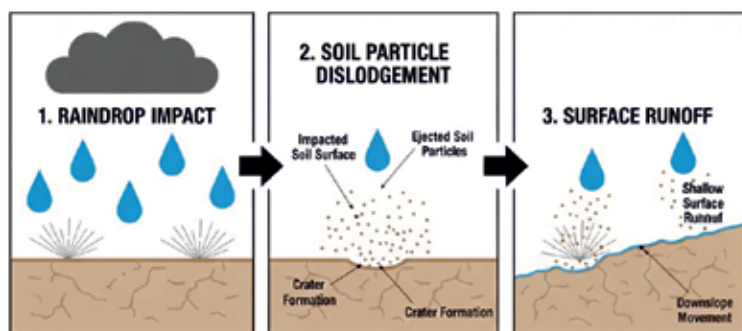


Fig. 4.12
Splash erosion

There are different types of erosion. During rainfall, rain drops fall on loose sand particles on the ground hurling them away. This process is called **splash erosion** – the detachment of soil particles by the impact of rain drops (Fig. 4.12). Stream erosion is important in sculpturing

a major part of the land surface and gives rise to features like valleys, canyons and gorges. In sloping terrain, running water removes surface materials by **sheet erosion**, which is the removal of thin layers of soil by sheet of running water in overland flow on

non-vegetated land surfaces. Surface runoff begins when the rainfall intensity exceeds the infiltration capacity of the soil or other earth materials (Fig. 4.13). Due to the continuous movement of rain water, rills are formed. The presence of surface irregularities transforms sheet flow into small channels called rills. **Rills** are formed by minute streams of water cutting separate flow channels. They join together to form slightly larger channels called **gullies**. Erosion produced by water flowing along the gullies is called **gully erosion** (Fig. 4.14). Gullies occupy relatively small area, but they have major localized erosional effects.

A variety of human activities cause or aggravate erosion and pose a major environmental threat. Erosion results in the loss of fertile soil of agricultural lands. Similarly, valuable minerals and construction materials can be eroded due to intense human activity like mining, construction of highways, tunnels and dams.

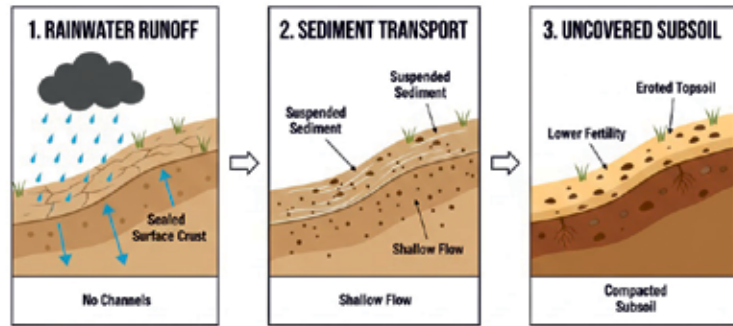


Fig. 4.13
Sheet erosion

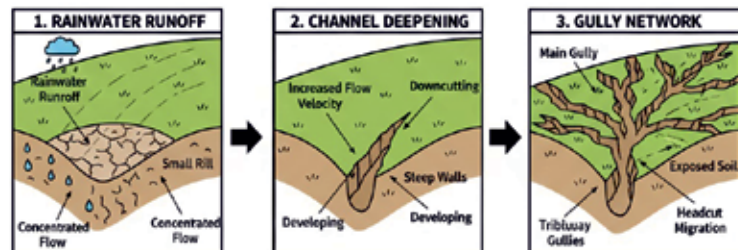


Fig. 4.14
Gully erosion



Check your progress

1. Select the correct answer for each from the bracket (Creep, Subsidence, landslide, Avalanche)
 - a. Wide variety of processes that result in the downward movement of earth materials along slopes
 - b. Slowest types of mass movement
 - c. Sudden mass movement seen in mountain area comprises mostly of snow and ice
 - d. Direct sinking or lowering of a mass of earth material below the surrounding ground level

2. Identify the process in Column A and complete the table

A - Process	B - Type
Falling by forward rotation of rock	
Slowest form of mass movement	
Direct sinking down of earth material	

3. Select the odd one out Splash erosion, Gully erosion, Sheet erosion, Colluviation

4. What is the major force that causes mass wasting?

4.10 Deposition

Deposition is one of the important exogenic processes that is responsible for shaping the land surface. Deposition refers to the process by which sediments, particles and organic material are transported and settle in a new location, often in water bodies such as rivers, lakes or oceans or even in the air. Over time, layers of sediment build-up and can eventually harden into solid sedimentary rock. The transported materials will not travel continuously for ever; it will come to rest temporarily in different places or permanently settle in some locations. It occurs when the forces that transport sediments, obtained by agents of erosion such as water, wind or



Do you Know!!!

Earth's internal heat sources and the gravitational force are the main factors of internal earth process

glacier, and mass wasting, lose their energy and can no longer carry the materials. As a result, the materials settle at a specific location. The factors influencing deposition include the energy of the transporting medium.

4.11 Internal Earth Process

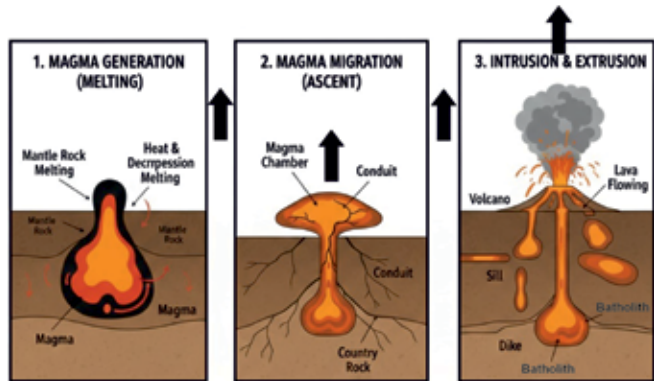
The processes which are driven from below the surface of the Earth are called endogenic processes. Most important among them are the tectonic processes, magmatism, metamorphism, earthquakes and uplift (both tectonic and non-tectonic).

4.11.1 Tectonic Processes

Stress within the Earth causes deformation like the formation of mountains, oceans, continental margins and rifts. The evidences of such actions are preserved in rocks of all ages. More details on tectonic processes are given in Chapter 5.

4.11.2 Magmatism (Magmatic activity or Igneous activity)

Magmatism is a key endogenic process. The molten rock material inside the earth, called magma, comes out to the surface during volcanic eruptions and is called **lava**. Magmatism originates from within the Earth, involving the generation, movement, and solidification of magma either deep underground or on the surface to form igneous rocks (Fig. 4.15). Driven by Earth's



*Fig. 4.15
Magmatism*

internal heat, magma forms from rock melting, then rises up, creating new crustal material and landscapes through volcanic eruptions or intrusive formations. Thus, the processes of origin, ascent, emplacement (intrusion or extrusion) and solidification of magma is termed magmatism. Magmatism is fundamental to creating new crust, recycling Earth's materials, and driving tectonic activity, making it a primary force shaping the planet from within. Formation of ore deposits are also associated with magmatism. One of the classic examples of large-scale volcanic eruption is the Deccan Traps.

4.11.3 Metamorphism

Metamorphism is an internal process of transformation of pre-existing rocks into new types by the action of heat, pressure, and chemically active migrating fluids. It involves mineralogical change and re-arrangement of minerals in solid state condition below the surface. Metamorphism too can cause formation of certain ore/mineral resources.

4.11.4 Earthquakes

Earthquakes normally form due to rupturing of rock segments, usually due to tectonism. This causes sudden release of energy in the lithosphere and generates seismic waves. The study of seismic waves is quite useful in understanding the interior of the Earth. As an offshoot of studying

seismic waves, geophysicists developed seismic prospecting or exploration used to find out mineral/hydrocarbon/groundwater resources.

4.11.5 Uplift

Land uplift is the natural process where the Earth's surface rises vertically, regional or local, that take place at several regions of the Earth. Most of them are due to tectonic processes (like those associated with rifting or mountain building) while other causes of uplift include magmatism and isostatic or flexural rebound. Uplift give rise to plateaus and domal hills, and may alter the geomorphology and drainage of a region. Reverse of the processes i.e., sagging and formation of depressions or basins of certain regions are caused due to internal dynamics.



Do it Yourself

Activity type	Exercise
Degradation (Erosion)	Observe erosion (splash, sheet, gully) patterns on a hill slope during or after rainfall. See how weathering and rain water degrade the land surface.
Aggradation (Deposition)	Take a tray filled with a mixture of soil and small stones. Slightly tilt the tray and gently pour water from one side. Observe how materials move downslope and accumulate (deposit) at the base.

Summary

The earth processes are basically divided into exogenic and endogenic processes. One of the prominent exogenic processes is weathering, which involves physical, chemical and/or biological processes. The end product of weathering is soil. Other important exogenic process is mass wasting, a geologic term describing all downhill rock and soil movement due to gravity. Mass wasting occurs when a slope is too steep to remain stable with existing material and conditions. Rapid forms of mass wasting involve huge amount of earth materials causing damage to life and property are considered as one kind of natural hazard, especially in mountainous terrains affected by heavy rain fall/ snow fall, earthquakes and volcanic eruptions. The processes of erosion, transportation and deposition finally take away the material to new destination. The important endogenic processes are tectonism, magmatism, metamorphism, earthquake and uplift, which are dealt in more details in the subsequent chapters.

5 PLATE TECTONICS

5.1 Introduction

From the earlier chapters, we got an idea about the Earth and its layered internal structure. Outwardly, our planet appears to be quite lively with several processes in the hydrosphere, atmosphere and biosphere, and also the interactions among them. What about the lithosphere? It appears very stable and sturdy. However, in reality it is not so. On the surface of the Earth, we have geological processes like weathering, erosion, sediment transportation and deposition all of which shape the landforms. Similarly, powerful internal processes such as volcanism, metamorphism, earthquakes and rock deformation caused by stress, operate deep within the Earth, continuously reshaping its interior and influencing the Earth's surface. We have to understand that these internal processes are due to the internal dynamics of the Earth. This internal dynamics is studied as **Plate Tectonics**, a great unifying theory that evolved after 1960 and which revolutionized the science of Geology. If you study plate tectonics in detail, you will understand that it contributes more to the uniqueness of the planet. Furthermore, plate tectonics is the fundamental mechanism for overall dynamics on the surface and near surface of the Earth as well.

During the early period of development of the science of Geology (i.e., 18th, 19th and early part of the 20th centuries), a vast amount of geological knowledge from all over the world were acquired. Though there was excellent understanding of the crustal materials, their genesis and their significance in assessing earth resources, there was no consensus on the origin of certain major global features like

- i. Distribution of mountain belts, the highly deformed nature of the rocks and the presence of thick pile of marine sediments in them
- ii. Seismic zones, their locations, recurring activity
- iii. Different types of continental margins
- iv. Localization of past and modern volcanoes
- v. Origin and evolution of oceans.

Several hypotheses like the Continental Drift hypothesis, Isostasy models, Expanding Earth hypothesis, Contracting Earth hypothesis, and Geosynclinal model for orogeny are among the once popular geological explanations for major earth processes. But none of these postulates stood the test of time as most of them

were speculations and lacked sufficient scientific proof. Another reason was that the geological science was mostly qualitative at that time and specific tools (like radiometric dating and geophysical techniques) had not been developed during those days.

In this chapter, we will very briefly review the Continental Drift hypothesis and developments in Geology later to 1960, which led to the emergence of the unified theory of plate tectonics.



Fig. 5.1
Alfred Wegener

5.2 Continental Drift Hypothesis

According to the Continental Drift hypothesis, there were large-scale, very slow horizontal movements of the continents in the past few hundreds of millions of years, changing their positions relative to one another, and to the poles of the Earth. In 1912 Alfred Wegener (1880-1930), a German meteorologist (Fig. 5.1) elaborated this hypothesis after keenly studying several global maps and the geological data available till then. Details about his ideas became popular with the publication of his classic book '*Origin of Continents and Oceans*'.

Before Wegener, several people had studied the global distribution of continents. They had observed that the continents are not randomly distributed. Wegener also noticed that the continents are not distributed in a haphazard way. Instead, there was geometrical fit of opposite sides of the continents. For example, the continents of Africa and South America look like pieces of a jigsaw puzzle. In addition, he noticed the similarity of specific fossils and rock formations in different continents separated by vast oceans. This made him assume that all the continents of the Earth were once joined together as a single landmass-he named this single vast continent as **Pangaea** (means 'all lands'). The Pangaea was surrounded by a single ocean - which Wegener called **Panthalassa**. He believed that Pangaea was intact till Mesozoic Era (250 million years ago); later on, with time, the continents drifted apart into their present positions.

In support of his hypothesis, Wegener put forward a number of evidences. No doubt Wegener was a genius. Even though so many others had thought about the continents being together in the past, he was the one to comprehensively put these ideas in the form of a hypothesis with many convincing evidences from different areas of science like different branches of geology, geography, meteorology and oceanography.

5.2.1 Evidences for Continental Drift

Some of the evidences for continental drift are the jigsaw fit of the continents, geological evidences like lithological similarities, palaeo-climatic evidences and distribution of similar fossils. Each one of these pieces of evidence is briefly discussed in the following paragraphs.

a. Fit of Continental Margins

The most remarkable fit of the continents, especially the coastlines of South America and Africa, is often cited as important evidence (Fig. 5.2). Edward Bullard, a geophysicist, in 1964 showed precise fit when matching the continental shelf at the 1,000-fathom (approximately 1800 m water depth) contour line.

b. Geological Evidences

The rock formations and structures on either side of the oceans show close similarities, indicating that they were once part of a continuous land. For example, very old rock belts of Precambrian age formed more than 2000 million years ago on the coast of Brazil (South American continent) perfectly match with those found in Western Africa (in between lies the Atlantic Ocean). The Appalachian Mountains of North America are geologically similar to the Caledonian Mountains in Scotland and Scandinavia (Fig. 5.3), showing that they were once part of the same mountain range (in between is the Atlantic Ocean).

c. Palaeo-climatic Evidences

Ancient climates (palaeo-climates) in locations where they could not have formed under the present conditions provides strong evidences. Glacial deposits in the form of tillites are noticed in India, Africa, Australia and Antarctica. The presence of tillites shows that these continents were once together and were located near the Pole undergoing continental glaciation. The matching glacial striations across the southern continents (Fig. 5.4) also provide strong geological evidences that these landmasses were once united before drifting apart later. Similarly, coal formations (which form in



Fig. 5.2
Fitting continents across the Atlantic Ocean similar to a jigsaw puzzle



Fig. 5.3
Termination of mountain belts (shaded dark)



Fig. 5.4
*Directions of glacial striations of
Permo-Carboniferous time in southern continents*

ancient tropical swamps) in Antarctica, tell us that the continent must have been once located in the equatorial climatic zone.

d. Distribution of Fossils

Identical plant and animal fossils have been found on continents, which are now separated by thousands of kilometres of ocean. Fossils of *Mesosaurus* (small aquatic reptile) have been found only in South Africa and eastern South America (Brazil). These animals could not have crossed the vast Atlantic Ocean, suggesting that the two continents were once together. Similarly, *Lystrosaurus* (land reptile) fossils have been discovered in Africa, India and Antarctica, supporting the idea of continental drift. *Glossopteris* (fern fossil), found in the coal formations of India, South Africa, Australia and Antarctica, indicate that these continents were once joined together. These tropical plants in Antarctica also point to its position previously closer to the equator (Fig. 5.5).

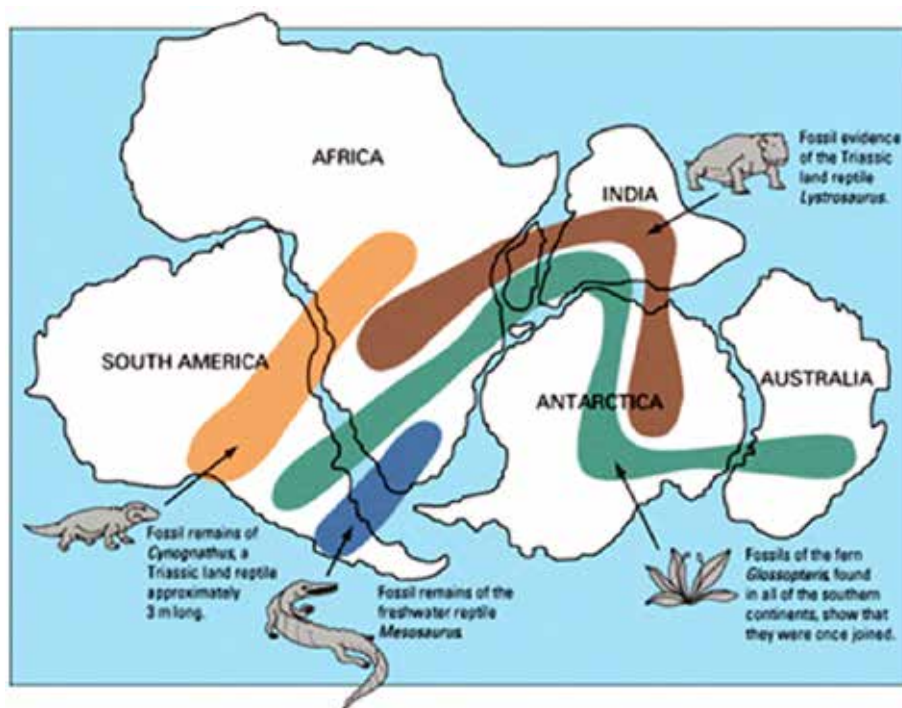


Fig. 5.5
*Geographic distribution pattern of fossils in
southern continents*

5.2.2 What Happened to Continental Drift Hypothesis?

Wegener believed that throughout most of the geologic time there was only one supercontinent (Pangaea) and opined that it started to break apart during Mesozoic Era (Fig. 5. 6) and the broken parts began to move away from one another resulting in the formation of oceans and great mountain ranges like the Himalayas. Wegener tried to explain the formation of mountains as due to the movement of continents. The edge of the continents experienced resistance and their compression and upward folding gave rise to vast mountain ranges. Thus, mountain ranges were formed near the leading edges of the drifting continents. This idea was totally different from the 'Contraction theory', which was popular during that time.

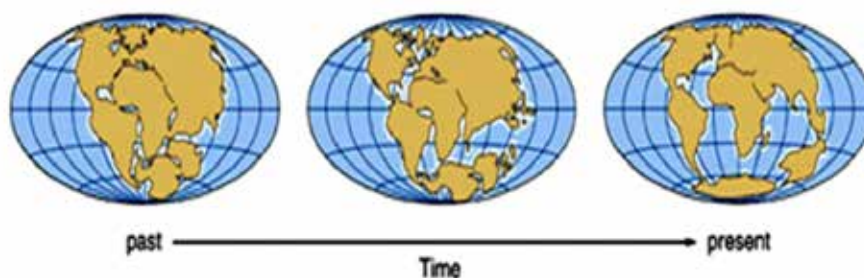


Fig. 5.6
The concept of Drifting of continents with time

Wegener suggested that the mechanism for continental drift was a centrifugal force towards the Equator. He believed that the Pangaea originated near the South Pole. The centrifugal force of the planet resulting from rotation caused the break up and drifting of continents towards the Equator. This was rejected by scientists as the actual forces due to the rotation of the Earth were found to be far insufficient to move continents.

The major objection against Wegener's continental drift hypothesis was its inability to suggest a mechanism for the movement of the continents extensively.

Wegener's proposal that the continents slid over or plowed through the ocean floor was not at all convincing. Thus, the continental drift hypothesis failed to get universal acceptance by the scientific community. Moreover, most of the evidences given by Wegener in support



Know More

Contracting Earth hypothesis

Contracting Earth hypothesis was proposed by geologists like J.D. Dana and Harold Jeffreys. It states that the Earth's surface features, like mountains and ocean basins, were formed as the planet cooled and contracted from a molten state, causing the crust to wrinkle and fold. This theory suggests that the cooling and shrinking of the Earth's interior caused the cooler outer crust to crumple, similar to how an apple wrinkles. However, it was found that all the great mountain ranges did not form at the same time.



Know More

Expanding Earth hypothesis

In 1889 and 1909 Roberto Mantovani published this hypothesis of Earth expansion as an alternative to continental drift. This is a discredited hypothesis that claims the Earth was once smaller and has grown over time, causing continents to drift apart as new space was created. Proponents of this hypothesis have suggested various mechanisms for expansion, like mass accretion on a smaller Earth or a decrease in the gravitational constant. The peak of the popularity of the hypothesis was the publication of a comprehensive book 'The Expanding Earth' by S.W. Carey in 1976. Scientists in general were sceptical about the hypothesis as it was against the concepts of planetary motion and gravitational history. The hypothesis is widely rejected, as it lacked a viable physical mechanism and the later emergence of the theory of plate tectonics with overwhelming evidence in support of the latter. All the evidences earlier put forward in support of this were better explained as outcome of plate tectonics.

of his hypothesis were obtained from the Southern Hemisphere. Most prominent geologists of those times lived in the Northern Hemisphere. They ignored all his other arguments, interestingly many of which, in later years, turned out to be mostly correct.

Continental drift hypothesis was largely abandoned by the late 1920s, as its supporters could not suggest a suitable driving mechanism for the movement of continents. However, there were some later supporters like Alex Du Toit of South Africa and Arthur Holmes, the famous Scottish geologist, who tried to revive the continental drift hypothesis. Du Toit (1937) suggested that instead of one Pangaea there were two ancient super continents, namely Gondwanaland in the Southern Hemisphere and Laurasia in the Northern Hemisphere. The **Gondwanaland** was made up of the Indian peninsula, Australia, Antarctica, Africa, the island of Madagascar and South America. **Laurasia**, on the other hand, consisted of North America, Greenland, Europe and most of Asia. This modification was suggested based essentially on the similar ages for glacial deposits in the regions of Gondwanaland and the presence of coal deposits in the landmasses of Laurasia.

Arthur Holmes (1928) tried to explain the forces behind the movement of

continents. He postulated that the thermal convection within the mantle was the force that moved continents (Fig. 5.7). When a liquid is heated from below, its density decreases with the temperature's

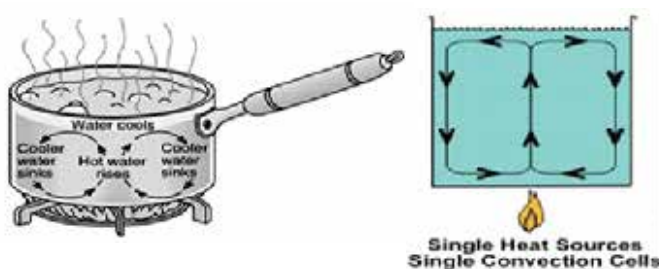


Fig. 5.7
Idea of thermal convection currents

upward increase until a critical temperature gradient is formed resulting in convection currents. When there is increase in temperature in the mantle, thermal circulation currents (Fig. 5.8) form and rise to the base of the continent and get cooled and the mantle sinks again. Arthur Holmes suggested that convection currents associated with a number of convection cells formed in the mantle could have given sufficient energy to move continents.

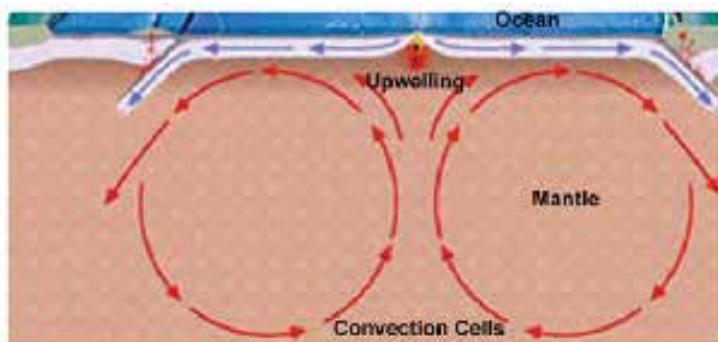


Fig. 5.8

The proposed thermal convection currents in the mantle



Check your progress

1. What do similar fossils found in different continents suggest?
2. What do coal beds located in Antarctica now indicate?
3. Why did scientists reject the Continental Drift Hypothesis of Alfred Wegener even though he had put up a number of strong evidences in support of his ideas?

In the next few paragraphs, we will see the drastic developments in geology after 1950, which paved the way for the emergence of Plate Tectonics as a more convincing alternative to the Continental Drift. The basic difference between the two theories is that according to the Plate Tectonics, the lithospheric plates are in motion (in the place of drifting continents), which could explain all the evidences earlier put forward in favour of Continental Drift. Furthermore, it explains the evolution of oceans and the major oceanic features as well.



Do it Yourself

Take a printout of a world map showing the continents. Carefully cut out South America and Africa and try to fit their continental margins together like pieces of a jigsaw puzzle. You will notice that the east coast of South America closely matches with the west coast of Africa, suggesting that these continents were once joined together. Next, add cut-outs of India, Antarctica, and Australia to Africa to observe how these landmasses fit together to form the ancient southern supercontinent, as envisaged by Alfred Wegener.

5.3 Scientific Developments in the 1950s and 1960s, and the Advent of Plate Tectonics

The topography of the ocean floors had not been well studied prior to the 1950s. Detailed mapping of the ocean floors that began in the 1950s revealed details of many features like mid-oceanic ridges (which show geomagnetic anomalies), rift valleys, flat mountains, oceanic trenches and deep abyssal plains. These data gave a better understanding of the vast ocean floors. With the evidence from these new findings, Harry Hess and Robert Deitz published their works in the 1960s on mantle convection currents. At this time, Arthur Holmes' idea of thermal convection received attention again from geologists and geophysicists.

Though the Mid-Atlantic ridge was discovered in 1872, it was later, during the ocean floor mapping of the 1950's only, the presence of a world-wide submarine ridge system running for a length of about 80000 km with geomagnetic anomalies (Fig. 5.9) came to be known. The Deep-Sea Drilling Project, which began in 1968, also started adding valuable information on the nature of ocean floors.

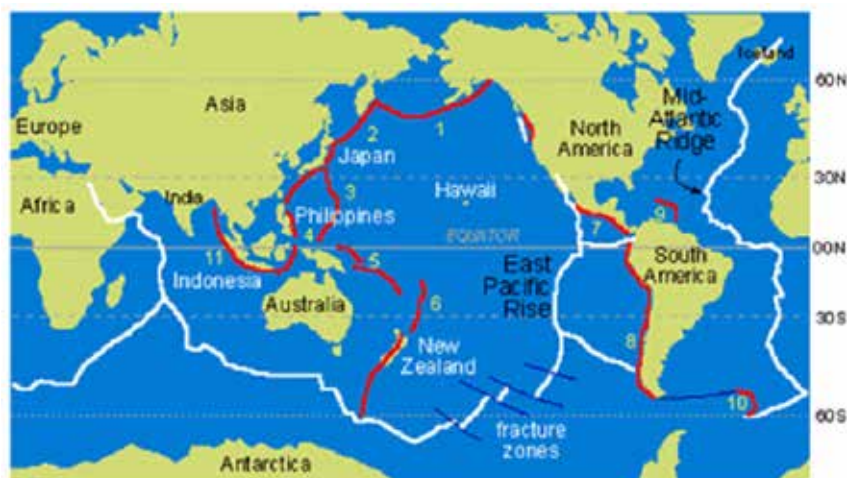


Fig. 5.9
*Distribution of ocean ridges (white)
and trenches (red)*

The presence of geomagnetic anomalies and young ocean floors, and absence of ocean sediments at the axial portion – all associated with mid ocean ridges - and new explanations for the driving mechanism in the drifting of continents, resulted in the formation of a great theory called Plate tectonics. Brief descriptions of ideas like palaeomagnetism, polar wandering and sea floor spreading that contributed to the theory of Plate Tectonics are given in the following paragraphs.

5.3.1 Palaeomagnetism

The concept of palaeomagnetism was first introduced by French physicist Bernard Brunhes in 1906. He wanted to explore how volcanic rocks captured the earth's magnetic field at the time of cooling. Palaeomagnetism is the study of the earth's magnetic field preserved in old rocks.

Rocks containing tiny crystals of iron minerals, like magnetite, act as fossil compasses. The grains of magnetite acquire permanent magnetization when they crystallize in igneous rocks. These iron-bearing minerals preserve the orientation of the Earth's magnetic field at that time when igneous rocks are cooled below a specific temperature called Curie point (about 580°C for magnetite). Consequently, the direction of their magnetization will be the same as the direction of the Earth's magnetic field at the time and place of crystallization. Thus, one will be able to know the position of the magnetic pole of the Earth at that time (Fig. 5.10). The later movement of these rocks can be found out by the orientation of the current magnetic field compared to the rock's palaeomagnetism. The longitude and latitude of the rock's place of formation is given by the declination and dip of the palaeomagnetic measurements.

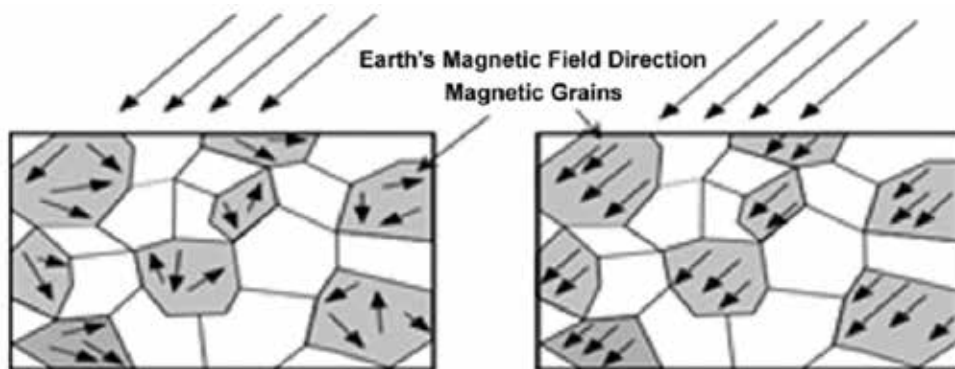


Fig. 5.10
Direction of earth's magnetic field in relation to magnetic grains before and after reaching curie temperature (580°C)

Was the Earth's magnetic field repeatedly reversed during the geologic past?

Mapping of magnetic properties of the rocks of the ocean floors revealed the presence of alternating, parallel and symmetric stripes of normal and reversed polarity in rocks, on either side of the mid ocean ridges (Fig. 5.11). Palaeomagnetic studies showed that reversals of the Earth's magnetic field (N becomes S and vice-versa) have occurred, every few hundred thousand years, during the geologic past. With the help of radiometric dating and correlating

the reversals throughout the world, scientists could establish the magnetic time scale.

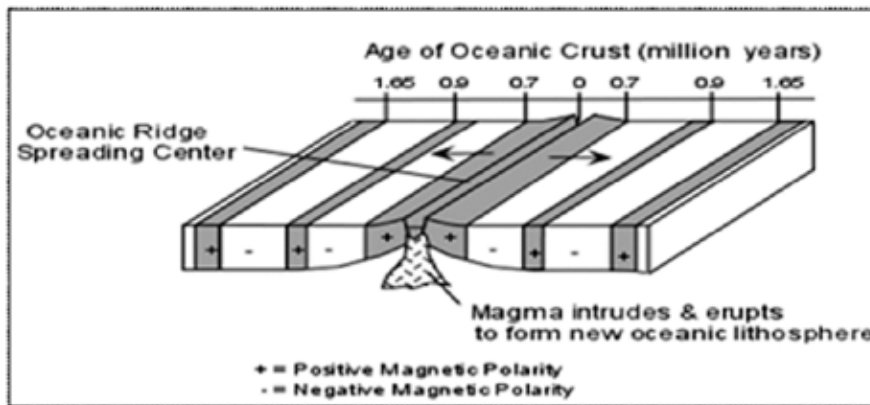


Fig. 5.11

Parallel and symmetric stripes of normal and reversed polarity rocks, on either side of the oceanic ridges

At the mid ocean ridges, new crustal rock formed from mantle material is magnetized in the direction of the magnetic field of the time of eruption. As the new rocks move away from the ridge, they carry with them a record of the magnetic direction corresponding to the time of their solidification. When the magnetic polarity reverses, the new rock formed at the ridge is magnetized in the opposite direction, and as it moves away, it too carries a record of the direction, opposite to the direction of the previously formed strip of oceanic crust. Thus, alternating regions of normal and reversed magnetic directions symmetrically disposed on either side of the ridge are formed. Such a pattern is seen with the oceanic ridges. It provides strong evidence for the main mechanism of sea floor spreading, and thus, explains the apparent drifting of continents.

Polar wandering curves

As palaeomagnetists sampled and measured older rocks of varying geological ages, they found that the North magnetic pole was far from the modern pole and seemed to change through time. They proposed the "Polar wander hypothesis" assuming that magnetic pole was at different locations at different geologic past and constructed polar wandering curves. Later it was realized that the "polar wander curves" were only apparent polar wander curves (APWC) because it was the continents that moved, not the magnetic poles. So, when you draw the polar wander curves for two different continents, like Europe and North America, they matched, once you removed the continents back to their pre-drift locations (Fig.5.12 a & b). APWCs are currently used widely by paleomagnetists for reconstructing positions of continents in the geologic past.

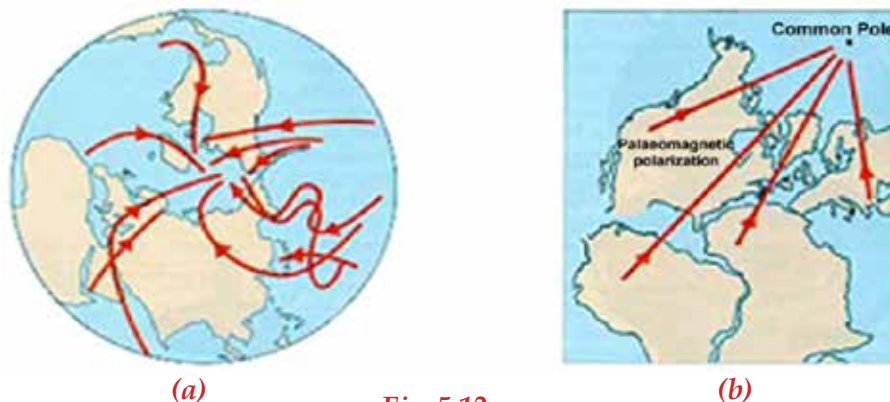


Fig. 5.12

Palaeomagnetic poles

(a) Apparent polar wandering curves showing multiple poles

(b) Polar position after reconciling pre-drift positions of continents (common pole)

5.3.2 Sea Floor Spreading

Sea Floor Spreading Theory gave a very strong impetus for the emergence of the Plate Tectonics theory. Moreover, research in the areas of sonar mapping, magnetometer surveys and palaeomagnetic studies along with the development of this theory led to a better understanding of the dynamic nature of our planet. The Sea Floor Spreading Theory was proposed by Robert Dietz as well as by Professor Harry H. Hess, independently, during 1961-62.

Immediately after the proposal came up the strong and startling supporting evidence of palaeomagnetic records of the ocean floor by Lawrence W. Morley, Frederic J. Vine and Drummond H. Mathews (Vine- Mathews-Morley hypothesis, 1963), which provided a way to calculate spreading rate by dating palaeomagnetic stripes.

The Theory of Sea Floor Spreading postulated that the ocean floors are spreading and moving away from the mid ocean ridges; ocean crust is continuously created along the axial portion of the mid ocean ridges and destroyed at deep sea trenches (Fig. 5.13 a & b). Both these are thought to be driven by thermal convection cells in the mantle. The Sea Floor Spreading theory helped to explain the topographic features of the ocean floor, the magnetic records (the pattern of alternating stripes of normal and reversed polarity of rocks on either side of the mid ocean ridges), and increasing age of the oceanic crust with increasing distance from the ridge. Seafloor spreading concept is supported by the presence of earthquakes and volcanic activity along the mid-ocean ridges, and the newly discovered great rift systems therein.

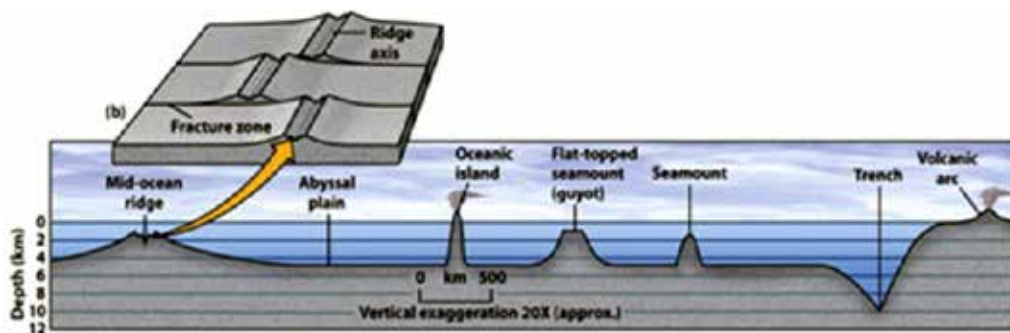


Fig. 5.13 (a)
*Topography of ocean floor showing oceanic ridges
(where oceanic crust is continuously created)*

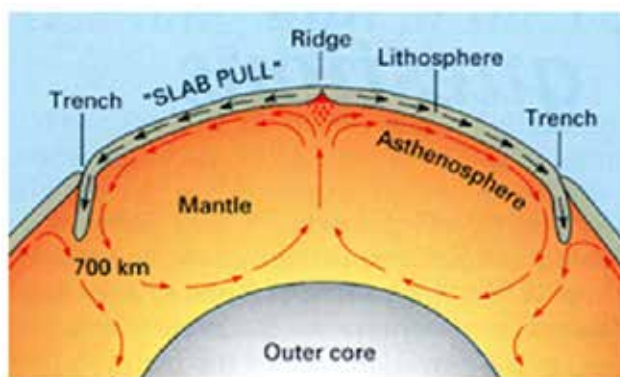


Fig. 5.13 (b)
Trenches (where oceanic crust is destroyed)

The rates of sea-floor spreading vary from about 2.5 cm/yr in the North Atlantic to more than 18 cm/yr in some parts of the Pacific oceanic ridge. This rate is measured by the amount of new oceanic crust added to each side of a mid-ocean ridge annually and can be estimated by measuring the age of the oceanic crust and its distance from the ridge.

Sea floor spreading provided a mechanism for separation of continents, revival of the old

continental drift hypothesis and the synthesis for the evidences from continental drift. The sea floor spreading and palaeomagnetic records paved the way for the New Global Tectonics (as it was termed earlier) or the Plate Tectonics Theory. Thus, Sea Floor Spreading Theory is a forerunner to the Plate tectonics theory. Plate Tectonics explains not only sea floor spreading, but other processes like rifting, collision and subduction, and gives a holistic picture of evolution of oceans, continents, mountains, rifts and continental margins, and thus, the whole internal dynamics of the Earth.

5.4 Plate Tectonics

Tectonics deals with the study of deformation in the Earth and the forces which produce deformation. The theory of plate tectonics is based on a broad fusion of geologic and geophysical data. By the late 1960s, the synthesis of the evidences from continental drift, sea floor spreading and palaeomagnetic records gave rise to the Plate Tectonics Theory. The theory is now almost universally accepted, and its adoption represents a true scientific revolution. The Plate

Tectonics Theory envisages that the Earth's outer rigid shell (lithosphere) is broken into a number of plates, which move over the semi-fluid asthenosphere. These plates, are in constant motion relative to each other. The rate of plate motion is a few centimetres per year but varies widely.

According to Plate Tectonics, the outer rigid layer of the Earth (the lithosphere which has a mean thickness of 100-125 km, and is made up of the crust and uppermost solid layer of mantle) is divided into about a dozen larger plates and several smaller plates. Thus, a tectonic plate is also called lithospheric plate (from the Greek lithos, meaning 'rock').

5.4.1 Lithospheric Plates

A lithospheric plate (tectonic plate) is a massive, irregularly shaped slab of solid rock, composed of the crust and a portion of the upper mantle. Plate size can vary greatly, from a few hundred to thousands of km across (the Pacific and North American Plates are among the largest).

Plate thickness also varies greatly, ranging from less than 15 km for young oceanic lithosphere to about 200 km or more for ancient continental lithosphere (e.g., the interior parts of North and South America). Oceanic plates (50-100 km) are thinner than the continental plates (up to 200 km) and even thinner at the ocean ridges (Fig. 5.14).

Some plates, like the Pacific Plate are almost entirely oceanic (i.e., oceanic crust and underlying mantle up to the semi-fluid layer called asthenosphere).

5.4.2 Plate Motion and Plate Boundaries

The plates meet in various ways along their edges, called the 'plate boundaries'. The plate boundaries are loci of severe geologic activities like earthquakes, volcanoes and mountain building. The places where three tectonic plates meet are called triple junctions (e.g., the point in

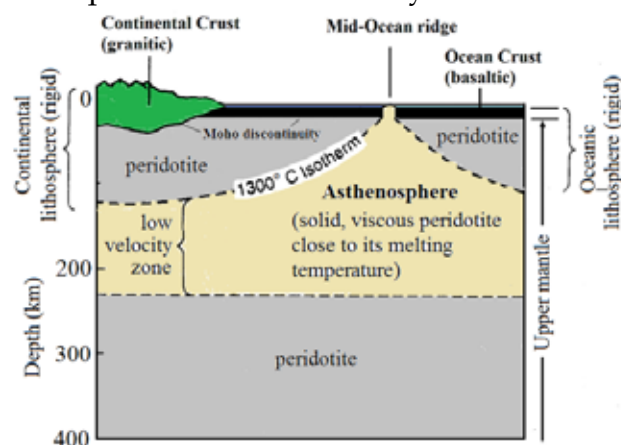


Fig. 5.14
Lithospheric plates (continental and oceanic) above the asthenosphere

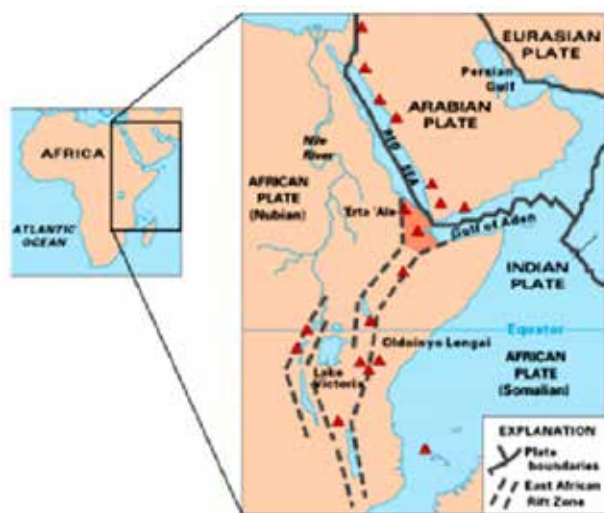


Fig. 5.15
Afar region triple junction
 (Afar: darker shading, Volcanoes: red triangles)

the Afar region of Northern Ethiopia). Most of the triple junctions are in the oceans (Fig. 5.15).

In the given world map of tectonic plates (Fig. 5.16), you can note that boundaries of most of the plates run across the oceans as well as across the continents. The boundary of the Indian Plate runs across the Indian Ocean (Arabian Sea and Bay of Bengal), and also through the Mountain belt of Himalayas.

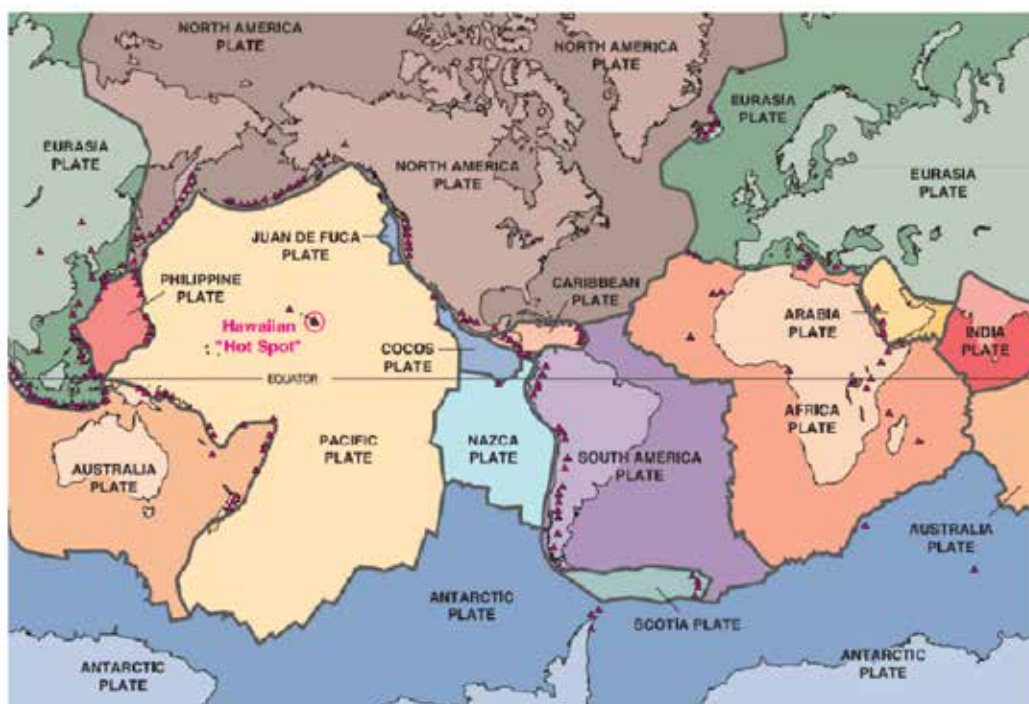


Fig. 5.16
World map of tectonic (lithospheric) plates

The mechanism by which tectonic plates move is still a subject of investigation among Earth scientists. Mantle convection was long thought to be responsible for the movement of tectonic plates. This mechanism is now not favoured as convection cells in the mantle sufficiently large enough to drive plates could not be found by geophysical studies.

5.4.3 Types of Plate Boundaries

Three types of plate boundaries/margins are mainly noticed: (i) divergent, (ii) convergent and (iii) shear or transform. Fig. 5.17 illustrates these three types of plate boundaries and their nature of movement, and are briefly described in the following paragraphs.

a. Divergent Boundaries/Constructive Boundaries

At a divergent plate boundary, the plates move apart. As tectonic plates move apart, the release of pressure (without a significant drop in temperature) causes partial melting of the underlying mantle rocks (Fig. 5.17 a, 5.18). This molten material, magma, is buoyant. It moves up and cools close to the surface to form new crust. As new crust is formed along the divergent boundaries they otherwise are known as constructive boundaries/margins.

In oceans, divergent boundaries coincide with the mid oceanic ridge system. The North American and Eurasian Plates are moving away from each other along the line of the Mid Atlantic Ridge. In continents, divergent plate boundaries coincide with rift valleys (e.g., the East African Rifts, the Rhine Valley in Europe). Active rifts may develop into new oceans by continued divergence.

b. Convergent Boundaries /Destructive Boundaries

Convergent plate margins are those margins where two plates move towards one another. Convergent margins are zones of plate destruction, and hence, also called as destructive margins. Huge mountain chains and explosive volcanoes are typical of these margins. Depending on the nature of adjacent plates, three types of convergent boundaries are possible where: (i) oceanic plate and oceanic plate meet, (ii) oceanic plate-continental plate meet and (iii) continental plate-continental plate meet.

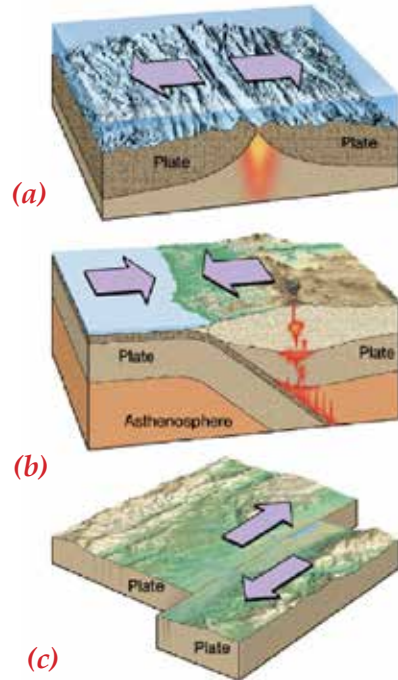


Fig. 5.17
Three types of plate boundaries and their nature of movement (a) divergent, (b) convergent and (c) shear or transform

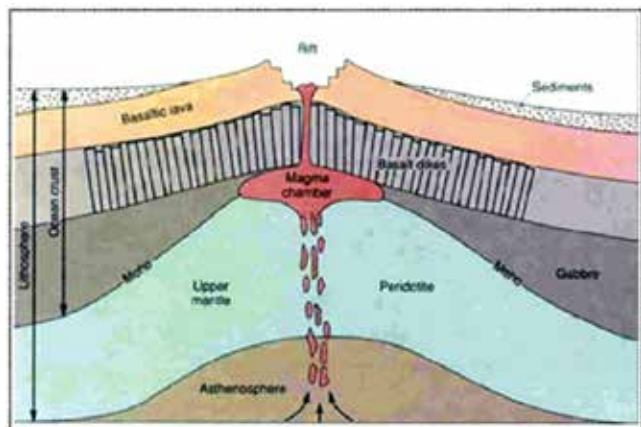


Fig. 5.18
Axial rift of Mid Ocean Ridges

At an oceanic plate–oceanic plate convergence, the older and denser oceanic plate descends into the mantle beneath the younger oceanic plate by a process called **subduction**, leading to the formation of deep-sea trenches and volcanic island arcs.

Do you Know!!!

As per recent scientific reports, the African continent is slowly splitting into two, with the eastern part, the Somali Plate, pulling away from the Nubian Plate along the East African Rift System (EARS).



Know More

The East African Rift System (EARS)

The EARS is a 4800 km long, Y-shaped rift system extending from the Afar Triple Junction in the north to Mozambique in the south. This slow geological process, occurring at a rate of roughly 5–9 mm/ year, is creating a rift valley. This rift valley that may ultimately lead to the formation of a new ocean basin in about 10–25 million years. The rift, which started forming millions of years ago, is an ongoing process, resulting in earthquakes, volcanic activity, and surface fissures. The rift could eventually separate East Africa, including parts of Ethiopia, Kenya, Somalia, and Mozambique, from the rest of the continent, forming a new, smaller landmass and a new ocean. The separation is extremely slow (fingernail-growth speed), and it will not dramatically change the continent in our lifetime. However, it is a significant long-term tectonic event. The visible, huge linear cracks often seen in the media, such as in Kenya, are often accelerated by erosion and heavy rainfall acting upon this underground, tectonic process.

At an oceanic plate–continental plate convergence, the oceanic plate descends into the mantle below the adjacent plate by subduction. The descending plate dips at an average angle of 45°, forms an ocean trench called the subduction zone (Fig. 5.17 b).

Along the regions of convergence of two continental plates, collision takes place resulting in the formation of fold mountain belts like the Himalayas by folding and uplift. Collision happens when an intervening oceanic plate portion is consumed by subduction, and the disappearance of the intervening ocean.

c. Shear Boundaries (Transform / Conservative Boundaries)

Transform boundaries occur when two plates slide past or grind past each other with only limited convergence or divergence, ideally with little or no vertical movement as transform faults, and without production or destruction of crustal material. Therefore, these are also known as conservative margins (Fig. 5.17 c). Most of the transform faults join two segments of a mid-oceanic ridge. Examples of Transform fault include the San Andreas fault (USA) and the Alpine fault of New Zealand. They also cause frequent earthquakes.



Check your progress

1. Match the following

A	B
Andes Mountains	Transform fault
Mid-Atlantic Ridge	Oceanic–continental convergence
San Andreas Fault	Divergent boundary
Himalayas	Continental–continental convergence



Do it Yourself

Draw a world map and mark a) Mid-Atlantic Ridge, b) The Himalayas c) Japanese islands d) Indonesian islands e) Appalachian mountains and then identify the type of plate boundary at each location.



Know More

Relevance of Plate tectonics

The plate boundaries are loci of intense geologic activity - earthquakes, volcanoes, metamorphism and mountain building. The interior of plates is generally free from seismic activities. Let us find its influence of plate tectonics on the evolution of basins, magmatism, seismicity, metamorphism and ore genesis.

a. Evolution of basins: A basin can be defined as a large, low-lying area of the Earth's surface where sediments accumulate due to subsidence and deposition. The entire history of many basins, from its formation to its eventual filling and deformation or uplift (called basin evolution) is due to plate tectonic processes. The tectonic setting – divergent, convergent, or transform – controls the main processes such as lithospheric stretching in rift zones and tectonic loading in convergent regions, and thereby determines a basin's geometry, subsidence and preservation potential.

b. Magmatism: Tectonic setting influences magma generation, composition and eruptive style. At divergent boundaries, basaltic magma is produced, which erupts at oceanic ridges to form new oceanic crust. In convergent boundaries, the subducting plate heats up, releasing water, which lowers the melting point of the overlying mantle, leading to partial melting. Magma of intermediate composition rises, and can either erupt at the surface or solidify underground to form large intrusive bodies.

Most of the Earth's volcanic activity is located along or adjacent to plate boundaries. However, there are some important exceptions in which this activity occurs within plates. Geophysicists Tuzo Wilson and Jason Morgan explained them as the result of **hotspots**. Hotspots are believed to be the surface expression of giant plumes of heat, termed **mantle plumes**, that ascend from deep within the mantle, some 2,900 km below the surface. These plumes are thought to be stationary relative to the lithospheric plates that move over them. A volcano builds upon the surface of a plate directly above

the plume. As the plate moves on, the volcano is separated from its underlying magma source and becomes extinct. Extinct volcanoes are eroded as they cool, subside and submerge below the surface of the sea to form sea mounts.

c. Seismicity: Earthquakes are primarily caused by the movement of tectonic plates. When these plates move, stress builds up. During the movement, the edges of the plates can get stuck due to friction. An earthquake occurs when this stress overcomes the friction, undergo rupturing or faulting of the crust, causing a sudden release of energy in the form of seismic waves. Thus, most earthquakes (about 80%) occur along plate boundaries. The type and intensity of seismicity depend on the type of plate boundary. In convergent plate boundaries, at subduction zones (oceanic plate under continental or another oceanic plate), the most powerful and deepest earthquakes are noticed (e.g. Circum-Pacific Belt). Regions where two continental plates collide also produce powerful earthquakes; here the crust is compressed, folded and uplifted (e.g. the Himalayas). In divergent plate boundaries, shallow and less powerful earthquakes are noticed (e.g. Mid Atlantic Ridge) whereas in transform plate boundaries, shallow and often powerful earthquakes are observed (e.g. Earthquakes associated with the San Andreas Fault in California, USA). Some less frequent earthquakes can occur within the interior of plates, often along pre-existing weaknesses or ancient fault lines (e.g. Gujarat, Maharashtra regions).

d. Metamorphism: Metamorphism is defined as the geological process where existing rocks change into new types of rock due to change in temperature, pressure or chemical reactions, mostly in solid state. During the movement of plates high-temperature and high-pressure environments necessary for rocks to change are created. Thus, due to heat and pressure variations along plate boundaries, and intraplate regions a variety of metamorphic rocks are formed.

e. Ore Genesis: The movement and interaction of tectonic plates control the geological processes that concentrate minerals. Deep crustal faults and shears along collision zones are pathways for ore forming fluids. At divergent boundaries, rising magma brings metals to the surface, while subduction at convergent boundaries causes fluids to melt the overlying mantle, generating metal-rich magmas and forming ore deposits along volcanic arcs. Coal deposits originate mostly along rift basins. Oil and gas accumulation takes place in basins along passive continental margins, rifting or foreland settings with favourable sedimentation and thermal history.

Summary

The theory of Plate Tectonics that developed during 1950s and 1960s has revolutionized the entire Earth Science. The main aspect of the theory is that the rigid outer shell of the Earth, lithosphere, is broken into large laterally moving slabs, called plates, driving geological processes like mountain building, seismicity, volcanism, rifting and origin of ocean basins. Prior to the Plate Tectonics theory, the Continental Drift hypothesis was the most popular fore-runner of the theory. The strongest evidence for Plate Tectonics is provided by the magnetic data from the ocean floor.

6

MOUNTAINS

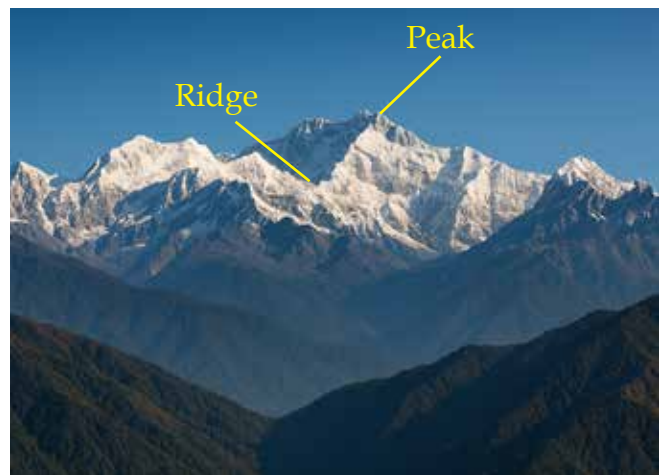
6.1 Introduction

Mountains constitute the most visible positive relief features (Positive relief feature means landform rising above the surrounding land). Do you know that approximately 24% of the land area of the Earth is occupied by mountains?

Mountains have greatly influenced human civilizations. They have acted as great natural barriers in controlling climate, influencing culture and providing natural resources. India itself is well protected by the >2000 km long mighty Himalayan mountain ranges in every sense. Similarly the Western Ghats influence the climate of Kerala and Tamilnadu. Before going into the details of mountains and their origin, we have to understand certain terminologies related to mountains. These terms are briefly explained below:

A **hill** is a landform with a rounded top and gentle slopes, typically lower in elevation than a mountain. A **mountain** is a larger, steeper landform with a more prominent summit. The difference between a hill and a mountain is relative. The minimum height for a mountain is generally considered to be 300 m above its surrounding area. However, an isolated hill, even if they are taller, are referred to as hill (eg. Chamundi Hill, which is >800 m above the surrounding land). Besides, along a mountainous region or mountain belt, you can encounter several hills or mounts (e.g., Nilgiri Hills, Anamudi Hills).

A **mountain peak** is a more or less cone-shaped mountain mass, i.e., it is a tall mountain with a pointed or narrow top. A **mountain ridge** is a long, narrow, elevated landform with sloping sides, forming a continuous crest or chain of peaks separating higher ground from lower areas on either side. A **mountain range** is a series or chain of mountains, and sometimes hills, that are connected and formed by similar geological processes (Fig. 6.1). It is a relatively elongated, narrow mountain mass. A **mountain system** or mountain belt is



*Fig. 6.1
Mountain range showing peak and ridge*

a group of mountain ranges with similarity in form, structure and alignment that have arisen from similar processes. A **cordillera** is made of several inter-related mountain chains.

6.2 Mountain Building Processes

Mountains are products of dynamic interplay between endogenic and exogenic processes. The endogenic processes are primarily responsible for the origin and uplift of a mountain, while exogenic processes cause their later morphological sculpturing and final degradation over time.

Five prime endogenic processes of mountain genesis include:

- i. Compressional stress-related deformation (essentially folding and thrusting) and uplift along colliding or subducting plate margins
- ii. Block faulting and uplift giving rise to horsts or block uplift
- iii. Large-scale regional uplift caused by a variety of internal factors bringing about domes, plateaus or elevated continental margins
- iv. Piling up of volcanic products around areas of repeated volcanism
- v. Rifting and other deep crustal faulting accompanied by uplift giving rise to steep scarps.

Sometimes two or more processes may work hand in hand. All these processes take very long-time span (millions of years), depending on the thermo-tectonic factors. During these long periods, the endogenic processes will also play an important role in shaping the mountains. Though denudation normally degrades or destructs a mountain, at times, it can increase the ruggedness or steepness (e.g., formation of steep plateau edges or escarpments). Each mountain has an evolutionary history, tracing of which is an interesting task in geological research. Thus, we can identify the different types of mountains.



Check your progress

Choose the most appropriate one from the options given.

1. Mountains are the result of _____ (Exogenic processes only, endogenic processes only, exogenic and endogenic processes, dynamic processes only).
2. A _____ is made of several inter-related mountain chains. (Mountain ridge, cordillera, mountain peak, hill).

6.3 Types of Mountains

The different types of mountains are briefly described below.

6.3.1 Fold Mountains

These are the most complex mountains formed along continent-continent collision zones. The world's largest mountain ranges are fold mountains (Fig. 6.2). Studying fold mountains helps geologists understand tectonic activities and the Earth's dynamic evolution.



Fig. 6.2
Folded Himalayas in Nepal

When two tectonic plates collide, a mountain chain is formed as a result of folding and faulting of rocks. Fold mountains are formed mainly by the compressional forces acting on the Earth's crust, especially at convergent plate boundaries. The Great Himalayan Mountains are formed in this manner. The major processes involved in the formation of fold mountains are:

- i. Deposition of sediments in large elongated ocean basins
- ii. Plate convergence
- iii. Compression and folding of rock layers
- iv. Uplift of folded layers
- v. Erosion and shaping of the folded structures.

The Great Andes Mountains of South America originated by the subduction of Nazca and Antarctic Ocean plates under the South American continental plate. Along this convergent plate margin, the denser oceanic plate slides



Know More

Orogeny

The word orogeny is derived from the Ancient Greek words *óros*- 'mountain' and *genesis*- 'origin'. The American geologist G. K. Gilbert used the term in 1890 to mean the process of mountain-building. Before the advent of Plate Tectonics theory, the most accepted theory was the geosynclinal theory of orogeny. A 'geosyncline', a large linear basin wherein thick piles of sediments accumulated which later subjected to lateral compression to form a fold mountain belt. Mountain chains formed in this way are called orogens.

Geologists identified several cycles of orogeny throughout the geological past. The four more recent orogenies are Caledonian orogeny (Late Silurian to Early Devonian), Hercynian orogeny (Upper Carboniferous to Permian), Alpine orogeny (started in Late Mesozoic) and Himalayan orogeny (Cenozoic). Now with the establishment of Plate tectonics theory, the process of formation of long mountain chains are explained as a result of collision and deformation of tectonic plates. This process takes place at convergent plate margins when plate motion compresses the margin.

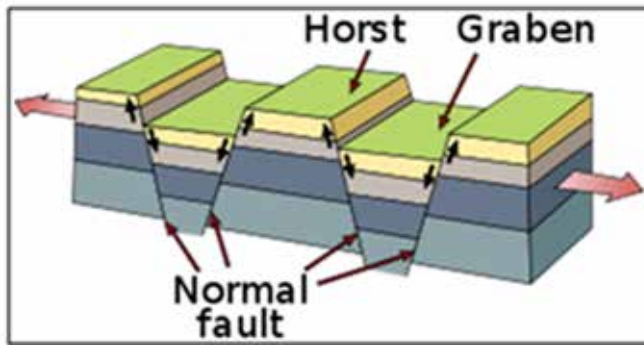


Fig. 6.3
Fault Block Mountain



Fig. 6.4
Dome Mountain



Fig. 6.5
Volcanic Mountain (Mt. Fuji)

beneath the continental crust, resulting in folding, faulting, uplift and magmatic activity.

6.3.2 Fault Block Mountains

Where tectonic plates are thinning and separating, groups of normal faults form.

Mountain ranges can form when these faulted blocks are lifted relative to the surrounding rock. Initiation of rift is mostly accompanied with large scale regional land uplift.

Blocks that are elevated compared to adjacent blocks can form a fault-block mountain. **Horsts** are fault blocks raised higher and **Grabens** are blocks that are lowered (Fig. 6.3). Vindhya and Satpura Ranges in central India and East African Rift Valley are examples.

6.3.3 Dome Mountains and Plateaus

Large scale regional uplift caused by a variety of internal factors like extensive magmatic activity can give rise to domes, plateaus and elevated continental margins (Fig. 6.4). E.g., Black Hills, South Dakota, USA and Colorado Plateau, USA (this includes the Grand Canyon, a well-known example of broad tectonic uplift followed by significant river erosion).

6.3.4 Volcanic Mountains

These mountains have been built-up by the accumulation of igneous materials around the vents of volcanoes (Fig. 6.5). In many cases, these mountains are made up of alternate layers of lava and fragmentary materials. Barren island in the Bay of Bengal, Mt. Vesuvius (Italy), Mt. Etna (Italy) and Mt. Fuji (Japan) are examples. Several volcanic mountains occur in oceanic areas (e.g., Hawaii and Reunion Islands).



Know More

Mountain building and Plate tectonics

The largest mountain ranges form over millions of years as tectonic plates collide, or as one tectonic plate over-rides another plate. Faulting and folding and uplift on large-scale build mountains. Mountain building along plate margins is described briefly in the following sections:

Mountain building along convergent margins

A. Continental-continental plate collision: When two continental plates collide, a mountain chain is formed as a result of folding and faulting of rocks. The Himalayas, lofty landlocked mountain ranges, are an example of a mountain chain formed in this manner. The collision also raised the plateau to the north of the Himalayas. The Eastern Ghats originated essentially during Proterozoic as a collision belt, which later got thoroughly modified by rifting and denudation.

B. Oceanic-continental plate collision: The Great Andes Mountains (which is a more than 8000 km long mountain chain characterised by an average height of 4000 m along the western margin of South American continent) originated by the subduction of Nazca and Antarctic Ocean plates under the South American continental plate. Along this convergent plate margin, the denser oceanic plate slides beneath the continental crust, resulting in the folding, faulting, uplift and volcanic activity. (as the oceanic plate subducts, it melts partially causing generation of magma and volcanic activity). These processes were going on for millions of years and is still continuing and so is the growth of the Andes.

C. Oceanic-oceanic plate collision: Volcanic island arcs are mountain chains made of volcanoes that form along subduction zones where two oceanic plate margins meet. The Kuril Islands is an example. The Kuril-Kamchatka Trench marks a subduction zone where the Pacific Plate is being subducted beneath the Okhotsk Plate.

Mountain building along divergent margins

Where plates are thinning and separating, groups of normal faults form.. Mountain ranges can form when these faulted blocks tilt backward or are lifted relative to the surrounding rock. Initiation of rift is mostly accompanied with large scale - regional land uplift. Blocks that are elevated compared to adjacent blocks can form a fault-block mountain (Horsts are fault blocks raised higher and Graben are blocks that fall lower). E.g., 1. Vindhya and Satpura Ranges in central India are suspected to be the horsts on either side of the Narmada River, flowing in a graben, 2. East African Rift Valley bordered by horsts which form mountains, 3. Fault block mountains formed in eastern North America.

Mid-ocean ridges which are as prominent as large mountain chains (but under water or submarine) are also products of rifting and magmatism along divergent margins.

Intra-plate Mountain Chains: Geologic features found away from plate boundaries are called as intra-plate features. Intra-plate chains of volcanic mountains such as the Hawaiian-Emperor seamount chain are formed by hotspots. A chain of volcanoes is formed in this manner.



Fig. 6.6
Residual mountain



Fig. 6.7
Western Ghats Escarpment

6.3.5 Residual or Relict Mountains

These types are essentially formed by differential erosion. In the extensive plateaus or highlands, geological agents cause large scale erosion. The highlands consisting of softer rocks are eroded, whereas those made of harder rocks are preserved. Thus, the harder rocks form elevated landmasses called relict mountains or residual mountains or erosional mountains (Fig.6.6). Aravalli Range (India) and Mt. Monadnock (USA) are examples.

6.3.6 Escarpments

Escarpments are long steep slopes or cliffs separating two areas of different elevations, formed by rifting/faulting/uplift/folding and modified by denudation. These are also regarded as mountains. The Western Ghats (Sahyadri mountains), which has a mean elevation of 1200 m, evolved by rifting, passive margin uplift and denudation, is a typical example (Fig. 6.7). The largest escarpment of the world is the Southern Great Escarpment of Africa.

Do you Know!!!

Mountain ranges are not confined to the planet Earth; they are seen in other terrestrial planets and natural satellites. The Olympus Mons on the Mars is 22-26 km high, i.e., three times the height of Mt Everest !



Check your progress

Identify the processes involved in the formation of the following mountains.

- a) The Himalayas
- b) Mount Etna
- c) The Western Ghats

6.4 Mountain Ranges of India

In India one can see representatives of most of the mountain types. Table 6.1 provide details of some of the important mountain ranges of India.

Table 6.1 Major mountain ranges of India

Sl. no	Name of Mountain Range/ Chain	Location Countries/Indian States	Highest Peak (Name and Height in m.)	Remarks
1	The Himalayas	Nepal, China, Pakistan, Bhutan, India & Afghanistan	Mount Everest- 8,848.86 m	The youngest mountain range in India
2	The Aravallis	Delhi, Haryana, Rajasthan, Gujarat	Guru Shikar, Mount Abu, Rajasthan - 1722 m	Oldest Mountain Range in India
3	The Vindhyas	Gujarat, Rajasthan, Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Bihar	Sadbhavana Shikar, Damoh District, (Madhya Pradesh)- 752 m	Runs through central India
4	The Satpuras	Madhya Pradesh, Gujarat, Maharashtra, Chhattisgarh	Dhupgarh, Pachmarhi, Madhya Pradesh- 1350 m	Natural barrier between northern and southern India
5	The Eastern Ghats	Odisha, Andhra Pradesh, Telangana, Tamil Nadu & Karnataka	Jindhagada Peak, Araku Valley, Andhra Pradesh, 1690 m	Run parallel to the east coast of India
6	The Western Ghats	Kerala, Tamil Nadu, Karnataka, Goa, Maharashtra & Gujarat	Anamudi, Idukki district, Kerala - 2,695 m	Run parallel to the west coast of India

6.5 Influence of Mountains on the Earth System

Mountains greatly influence the climate, the availability of water, soil formation, biodiversity and human civilizations.

Climate: Mountains influence wind and precipitation patterns, which results in diverse climates and ecosystems on either side of mountain ranges. They help regulate wind and weather patterns on a global scale.

Water: Mountains are the source of about 60% of the world's freshwater that supply rivers to downstream populations.

Soil formation: Geologically, the mountains are regions for large-scale sediment source, where erosion and mass wasting are

rampant. For example, the huge accumulation of sediments along the Indo-Gangetic Plains, the Sundarbans Delta and the Bengal Fan are essentially derived from the Himalayas. The fertile soils in mountain regions are crucial for agriculture.

Biodiversity: Mountains are home to nearly half of the world's biodiversity, making them critical ecosystems for a vast number of animal and plant species. The varying elevations, climates and isolation of mountain ranges give rise to distinct habitats for unique flora and fauna.

Cultural and spiritual significance: Just like rivers, mountains are home to ancient human civilizations and are spiritually important for many cultures.



Do it Yourself

Thermocol (polystyrene) mountain models can be created by stacking, carving, and texturing sheets to build realistic, lightweight landscapes. The techniques include layering foam for height, using hot wire cutters or sharp paper cutting knives for shaping, and covering with plaster of Paris or acrylic-painted tissue paper for rocky textures.

Key techniques for creating thermocol mountains:

- **Layering and Shaping:** Cut thermocol sheets into irregular, stacked shapes to create elevation, using glue to secure them.
- **Carving:** Use a hot wire cutter or sharp paper cutting knives to carve mountain profiles.
- **Texturing:** Cover the foam with a mixture of cement/sand (1:1 ratio) or plaster of paris, tissue paper, and adhesive to create a rugged, rock-like surface.
- **Painting:** Apply acrylic paint for detailing.
- **Adding Details:** Enhance the model with waterfalls made from hot glue, artificial greenery, and mini trees.

Summary

A mountain is a larger, steeper landform with a more prominent summit. Though endogenic processes are primarily responsible for the origin of mountains, exogenic processes modify them over time. We can identify different categories of mountains on the basis of their origin - fold mountains, fault block mountains, plateaus/domes, escarpments, volcanic mountains and residual/relict mountains. Tectonic movements and mountain building are closely associated. Mountains greatly influence Earth System and human civilizations.

7

GROUNDWATER

7.1 Introduction

Water is a vital natural resource essential for human survival. Without water, life on earth would not be possible. Water plays a pivotal role in shaping the planet's geological processes. Because of its essential nature, human settlements have historically developed near water bodies such as rivers and lakes. However, the availability of fresh water on earth is very limited. Nearly 97% of the total global water exists as salt water in oceans and seas, while only about 3% is available as fresh water. Major portions of this fresh water is locked- up in glaciers and ice caps, leaving only a very small fraction available as easily accessible surface water (rivers, lakes and ponds) and ground water.

7.2 Groundwater

The phrase 'subsurface water' can be used for all the water present below the earth's surface. However, the term 'groundwater' is used to describe that portion of subsurface water, which is present in the underground, filling the pores, cracks and cavities in rocks and other earth material. Groundwater makes up about 1% of the water on the Earth. It is an important resource for potable water, irrigation and industry.

It is worthwhile now to remember the statement by a renowned water scientist David Keith Todd "the largest source of fresh water lies under the Earth's surface."

Hydrogeology is that branch of geology, which deals with all the aspects of ground - water such as origin, occurrence, movement and distribution. Hitherto uncovered aspects of underground water, like its conservation, artificial recharge in to the underground basin and its management also are now included under hydrogeology.

7.3 Sources of Groundwater

The important genetic types or sources from which water is accumulated in the underground are the following:

7.3.1 Meteoric Water

It is the water which is derived from precipitation i.e., snow and rain. Meteoric water originates in the atmosphere by evaporation from surface water bodies, falls as rain or snow or other minor forms of precipitation, and part of it becomes groundwater by the process of infiltration.

7.3.2 Juvenile Water

Juvenile water is also known as magmatic water as it originates in the earth's interior and associates with the magmatic activities below the crust. Magmatic water rises from great depth accompanying magma intrusion. With the cooling of magma, part of its contents, i.e., gases and vapour separate out from it. The water vapours get condensed into hot water and gradually move upward from the area of high temperature and pressure to that of low temperature and pressure and becomes juvenile water or virgin water.

7.3.3 Connate Water

It is the water which gets trapped in the rock (sedimentary rock), at the time of its formation. Because rock containing connate water is typically formed from ocean sediments, it is normally saline. Connate water contains many mineral components in the form of ions in solution.

Other minor sources of groundwater are metamorphic water, condensation water and cosmic water.

7.4 Rock Properties that Control the Occurrence and Movement of Groundwater

Groundwater is not uniformly distributed throughout the earth's crust. There are large areas of the world where groundwater cannot be obtained in sufficient quantities even though a number of deep bore holes and wells have been sunk. The reason for this is justified by several factors, the most important being the extent to which the rocks are porous. That is, if there are only a few small voids, then the amount of water contained in a given volume of rock will be limited. We can make quantitative comparisons between different rocks in terms of porosity.

7.4.1 Porosity

Groundwater resides in the void spaces of rock, sediment or soil. Porosity is the ratio of the volume of the voids in the rock to the total volume of the rock. Usually, this ratio is expressed as a percentage of void or pore spaces present in a rock formation. Thus,

the porosity is expressed as '20%' or '30%' meaning that the voids occupy, respectively twenty or thirty percent of the rock volume.

Well-rounded coarse-grained sediments usually have higher porosity than fine-grained sediments because the grains do not fit together well (Fig. 7.1). Poorly sorted sediments i.e., sediments with uneven size, usually have lower porosity because the fine-grained fragments tend to fill in the open space between the coarser ones (Fig. 7.2). Poor sorting reduces porosity due to filling of open space by finer grains.

In igneous and metamorphic rocks, porosity is usually low because the minerals tend to be intergrown, leaving little free space (Fig. 7.3). Highly fractured igneous and metamorphic rocks, however, could have high porosity.

7.4.2 Permeability

Permeability is the ability of a rock to transmit water through it. It is a measure of the degree to which the pore spaces are interconnected.

Low porosity usually results in low permeability, but high porosity does not mean that the permeability too is high. It is possible to have a highly porous rock with little or no interconnections between pores (e.g. clay)

Conversely, a rock that has no voids except for one or two open cracks will have a low porosity, but water will be able to pass easily through the cracks, because the permeability will be high. (e.g. fractured crystalline rocks).

Sandstone, gravel and sand are good examples for permeable formations.

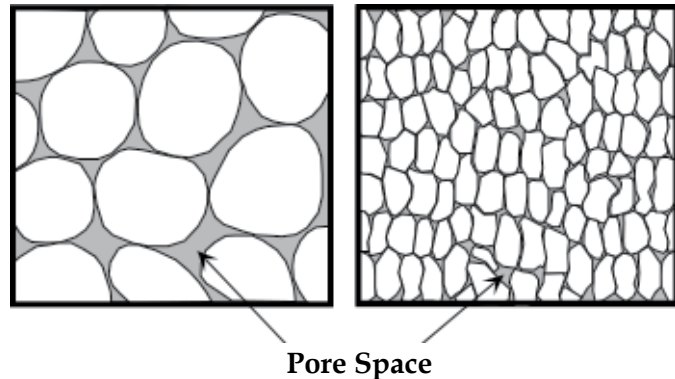


Fig. 7.1
Coarse-grained sediments with higher porosity than fine-grained sediments

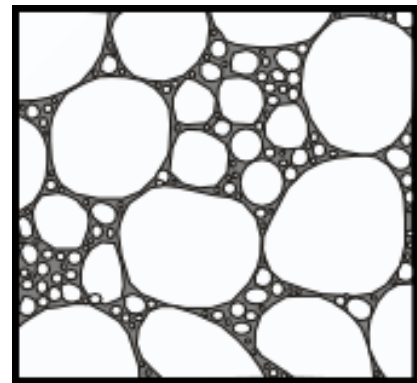


Fig. 7.2
Poorly sorted sediments with low porosity

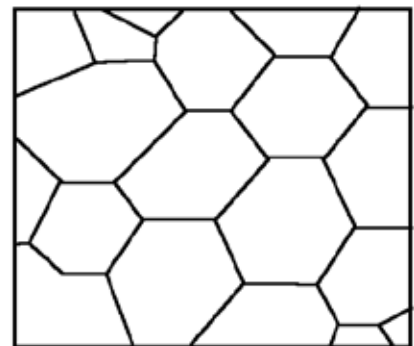


Fig. 7.3
Intergrown mineral grains resulting in lack of porosity

7.5 Zonal Distribution of Groundwater

In most places of the earth, if you dig a well, the well will first pass through a zone where the inter-granular pore spaces are partly filled with water and partly filled with air. Then, on further deepening, it will pass through a zone where all the pore spaces are fully filled with water.

On the basis of the distribution of groundwater, there will be two well-defined zones in most places of the Earth.

7.5.1 Zone of Aeration or Unsaturated Zone

It is a zone where the pore spaces in rocks are partly filled with water and partly with air. It is also termed as **vadose zone**. This zone extends from the ground surface to the upper surface of the zone of saturation. Within the zone of aeration, the movement of water is vertically downwards.

7.5.2 Zone of Saturation

It is the zone where all the pore spaces in rocks are fully filled with water. The water in this zone is termed as **groundwater** and will be under hydrostatic pressure. In this zone the net movement of water will be in a lateral direction.

The upper surface of the zone of saturation is called the **water table** (Fig. 7.4 a). It represents the top most level of zone of saturation. It is otherwise termed the phreatic surface as the groundwater pore pressure equals the atmospheric pressure along it. In general, one can see the water table as the surface of water in an open well. The depth of water table from the ground surface in an area is influenced by several factors. Most important among these factors are the topography, lithology and amount of rainfall or other forms of precipitations. It generally follows the outline of the topography and continuously adjusts itself with water moving from higher to the lower level.

The level of the water table in a locality over an extensive region is not stationary. It fluctuates up and down with addition or removal of water. Generally, during rainy season the level of the water table will move up while in summer seasons and drought conditions it will move down.

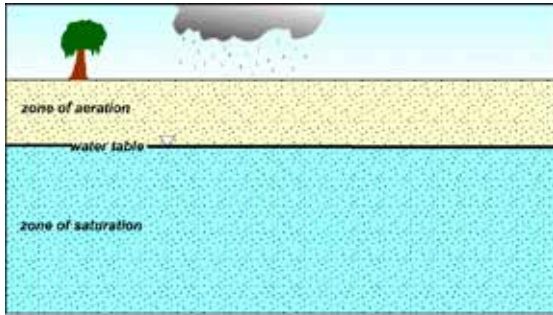


Fig. 7.4a
Zonal distribution of ground water

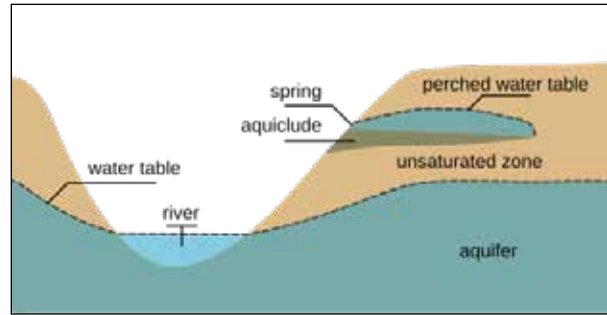


Fig. 7.4b
Perched water table

Sometimes, a layer of more or less impermeable material such as clay or silt occurs above the water table. Infiltrating water is held up by this layer, forming a saturated lens of limited extent above the main saturated zone. The upper level of groundwater present in such case is known as a **perched water table** (Fig 7.4b). A perched water is a local and temporary accumulation of groundwater that occurs above the main water table, resting on an impermeable layer.

7.6 Water-Bearing Formations

It is necessary to know the nature of rocks and other geologic features of a place to have an idea of their water-bearing capacity and to assess the groundwater potential there. Rock types show wide variations in their capacities to store and yield water. Based on their capability to receive, hold and transmit water, geologic formations can be classified into aquifer, aquiclude, aquitard and aquifuge.

7.6.1 Aquifer

Water-bearing geological formations are known as aquifers. An aquifer is a rock unit that holds and transmits water freely through it. Aquifers are saturated geological formations below the earth's surface, which provide water to wells and springs. Unconsolidated sedimentary formations are excellent aquifers. Moreover, fractured metamorphic and igneous rocks also form good aquifers. Porous sandstone, gravel bed, highly fractured crystalline rocks, limestone with solution cavities are examples of good aquifers.

7.6.2 Aquitard

An aquitard is a water-saturated geological formation (such as silt, clay or shale) with low permeability, which restricts groundwater flow and does not provide water freely to wells or springs (e.g., sandy clay).

7.6.3 Aquiclude

An aquiclude is an impermeable but porous geological formation that is incapable of transmitting good amount of water (e.g., clay).

7.6.4 Aquifuge

Aquifuge represents relatively impermeable rocks that can neither store nor transmit water. Examples include crystalline rocks without any fracture, limestone without any solution cavities or fractures and highly cemented sandstone.



Check your progress

1. Say whether the given statements are true or false:

- a. Water table is the lower surface of the Zone of Saturation
- b. Aquicludes are highly porous and permeable formations

2. Name the following.

- a. The groundwater zone which is fully saturated with water.
- b. The upper surface of the saturated zone of groundwater.
- c. The rock formation that allows water to pass through easily.
- d. The process by which rainwater enters the ground.

3. Which type of rocks act as good aquifers?

7.7 Unconfined and Confined Aquifers

Unconfined aquifers are found where the rock is open at the ground surface and water is directly recharged. This is the common form of aquifer. These aquifers receive water from rainfall and melting snow and are not overlain by impermeable rocks. In an unconfined aquifer, the groundwater is under atmospheric pressure.

Confined aquifers are aquifers that are sandwiched by impermeable materials above and below. These **confining beds** (impermeable layers) prevent or slow down the movement of groundwater. Confining cover can cause groundwater in the aquifer to be under pressure. When the confining layer is punctured, such as by a borehole drilled through it, there is release of pressure and groundwater will rise through this borehole and reaches the surface and overflows. Such a well is known as an **artesian well** (Fig. 7.5). The water in artesian wells rise and reach the surface naturally without any external pumping.

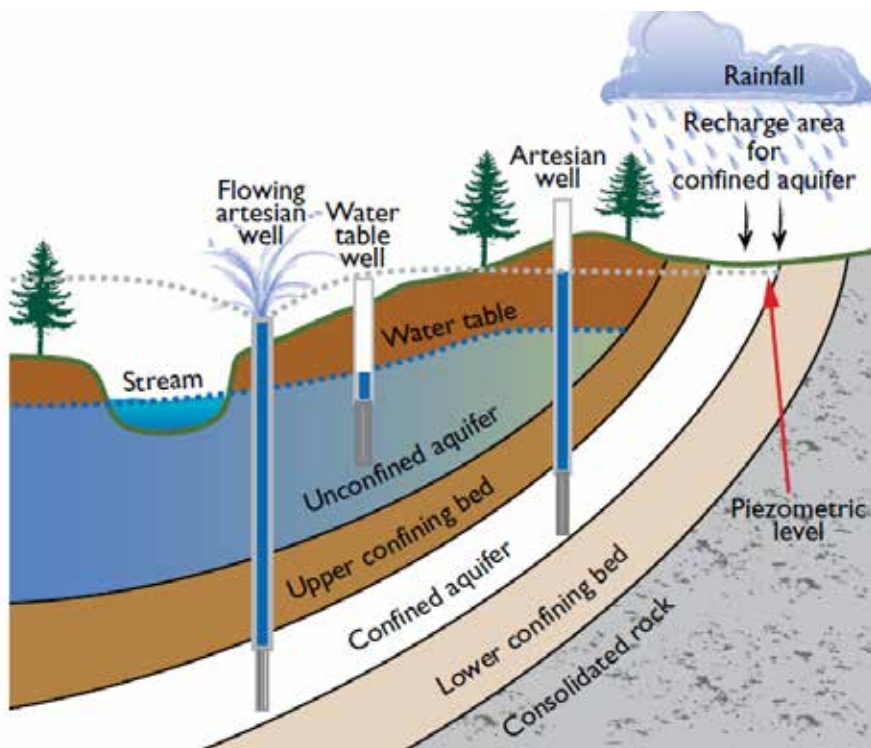


Fig. 7.5
*Confined aquifer, piezometric surface,
artesian well and flowing well*



Do it Yourself

Materials Needed:

Two transparent containers/ bottles (with holes at the bottom), sand, clay soil, water, tray or bowl

Procedure:

1. Fill one container with **sand** and the other with **clay**.
2. Place both containers on a tray.
3. Pour the same amount of water slowly into each container.
4. Observe the rate at which water passes through both the containers.

Observations

Water passes quickly through sand, but passes slowly in clay. Permeable materials like sand allow **infiltration & groundwater recharge**, while impermeable materials like clay restrict the movement of groundwater.

Do you Know!!!

Piezometric surface is the term used for the upper level of water in a confined aquifer and is similar to the water table in an unconfined aquifer (Fig. 7.5)

7.8 Water Wells

A water well is an opening made in to the subsurface of the earth for the purpose of getting groundwater. Wells come in different shapes and sizes, depending on the type of the aquifer formation, the depth of the water occurrence and how much

water is to be drawn or pumped out. Wells can be classified on the basis of the type of construction and type of aquifers.

7.8.1 Dug Wells

Dug wells are made by digging in to the ground, removal of the soil and rock cover till the opening is sufficiently deep to give an appreciable supply of groundwater.

7.8.2 Bore Wells

Bore wells are constructed by drilling a hole into the aquifer using a suitable drilling machine. It is best suited to be constructed in places where the groundwater occurs at depth in aquifers formed by fractured crystalline rocks.

7.8.3 Tube Wells

Tube wells are similar to bore wells in construction that they are also opened by drilling a hole into the aquifer. However, a considerable section of the top portion of the well is provided with a perforated tube or pipe, so that water alone from the aquifer can enter the well, and loose sediments are prevented from falling into it. Tube wells are commonly constructed in sandy aquifers.

7.8.4 Filter Point Well

A filter point well is a type of shallow well, often used in sandy soils that incorporate a screened, perforated section called the filter point at the bottom. The filter point is provided to draw water efficiently from the aquifer while preventing excessive sand and sediment from entering the well. It is a common, cost-effective way to access groundwater, especially in areas with shallow water tables. Filter point wells are used for getting drinking water and for dewatering construction sites.

7.8.5 Horizontal Wells

These are made by construction of a gently sloping underground tunnel that taps groundwater from higher elevations and carry it to the surface by gravity without pumping. The upper end of the tunnel will be below the water table and the lower end will

be at the ground surface, usually ending in to an irrigation canal. Horizontal wells are also known as **Qanats** (Fig. 7.6). There will be closely spaced vertical openings (shafts), which provide access to the tunnel.

Suranga (also *Surangam* or *thurangam*) (English: Tunnel well) is a tunnel dug through a laterite hillock from the periphery of which water and moisture seeps out (Fig. 7.7). This is a traditional water management system used to provide a reliable supply of water for human settlements and irrigation in the Kasaragod district of Kerala and Dakshin Kannada district of Karnataka.

7.9 Groundwater Recharge and Discharge

The process of entry of water into and out of a groundwater system is known as recharge and discharge, respectively. Recharge adds water to the groundwater system there by increases water level, whereas, discharge lowers the water level. Groundwater recharge is vital for replenishing water supplies, and is influenced by geology, land use and human use.

7.9.1 Recharge of Groundwater

Recharge is the entry of water into the aquifer to become part of the groundwater. Water is mainly added by precipitation. However, wet-lands, rivers, lakes and other surface water bodies too naturally recharge ground water. Water from the above sources first infiltrates the ground surface and then travels downward (Fig. 7.8). This infiltration and percolation are controlled by the permeability of the soil and rocks through which the water moves down in to the aquifer.

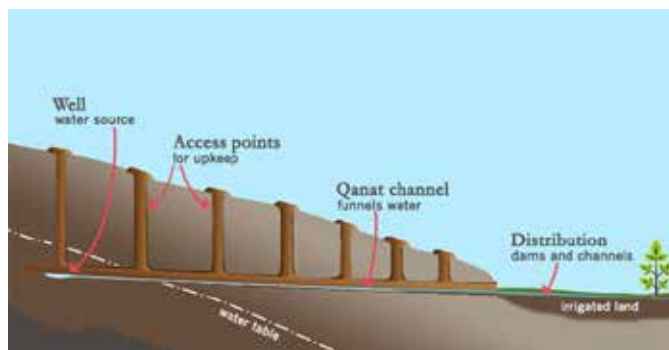


Fig. 7.6
Horizontal well or Qanat



Fig. 7.7
Suranga

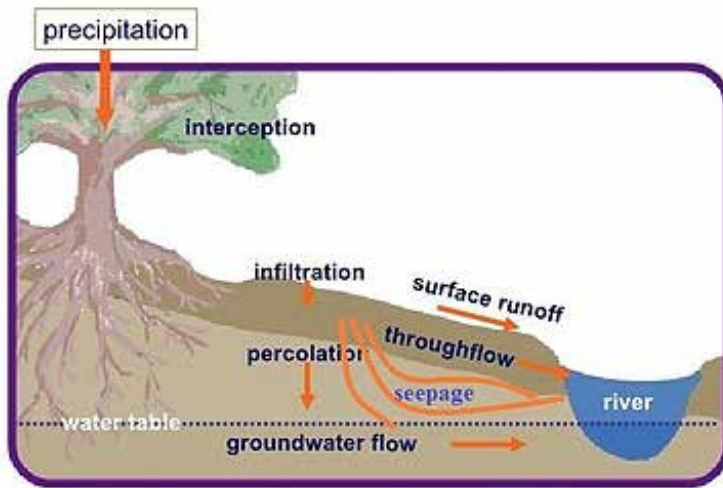


Fig. 7.8

Infiltration and percolation processes

When the recharge happens naturally, without deliberately allowing surface water to the underground, it is called natural recharge. Artificial recharge refers to the deliberate methods adopted by humans to enhance groundwater replenishment. It constitutes any man-made scheme or facility that replenishes depleted aquifers.

7.9.2 Methods of Artificial Recharge

A variety of methods have been developed to recharge groundwater artificially.

a. Basin Method

Water may be recharged by releasing it into basins formed by the construction of dikes or levees or by excavation (Fig. 7.9).

b. Stream-Channel Method

Recharge of water artificially can be achieved in this method by improving the stream channel through widening, leveling or ditching to enhance infiltration (Fig. 7.10).



Fig 7.9
Basin method



Fig 7.10
Stream channel method

c. Check Dams

This is another method in which recharge of the groundwater is achieved by construction of check dams which recharges

groundwater by slowing down seasonal stream flow, promoting deeper infiltration into aquifers (Fig. 7.11). Locally available cheap materials like tree trunks, branches, soil and rocks can be used for the construction.



Fig. 7.11

Recharging of ground water by constructing check dams.

d. Ditch and Furrow Method

In the ditch-and-furrow method, water is distributed through shallow, flat-bottomed, closely-spaced ditches or furrows to provide maximum contact between water and soil for effective recharge (Fig. 7.12). Surface water spread over a large, flat area for recharging ground water.



Fig. 7.12

Ditch and furrow method of groundwater recharge.

e. Pit Method

A pit excavated into a permeable formation serves as an ideal facility for groundwater recharge (Fig. 7.13). Abandoned excavations such as gravel pits can also be used for recharge.



Fig 7. 13

Recharging of groundwater through pits

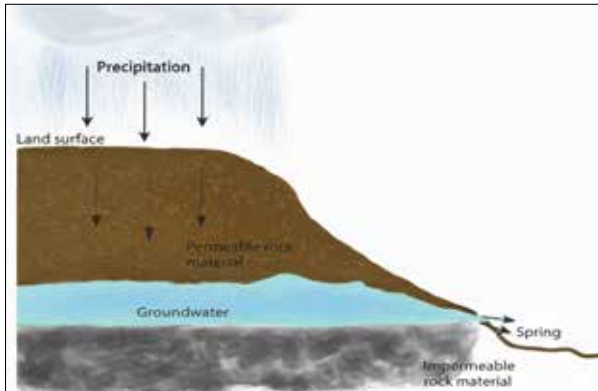


Fig. 7.14
Springs



Fig. 7.15
Hot spring in Yellowstone National Park, U.S.A



Fig. 7.16
Old Faithful Geyser in Yellowstone National Park, U.S.A.

7.10 Springs

Springs are locations or points on the ground surface, where water from beneath the ground emerges on to the surface. It is a natural discharge of groundwater to the land surface. Such flows are controlled by either gravity or hydraulic pressure (artesian) (Fig. 7.14).

Hot springs and Geysers

A **hot spring** is a spring that is produced when geothermally heated groundwater emerges from the Earth's crust. The source of heat for thermal springs come from volcanic activity, radioactivity or from natural thermal gradients- the increase in temperature of rocks with depth (Fig. 7.15).

In India, hot springs are primarily concentrated in the Himalayan regions (Ladakh, Himachal Pradesh, Uttarakhand, Sikkim) and also found in states like West Bengal, Odisha, Bihar, Assam and Maharashtra.

A **geyser** is a hot spring that erupts periodically. It is a rare geothermal feature found in volcanic regions. Groundwater trapped in underground cavities is heated by magma or hot rocks. When the water becomes very hot, it quickly turns into steam, creating high pressure. This pressure forces hot water and steam suddenly out of the ground up to hundreds of feet into the air. Such eruptions may occur at regular intervals of time. The best example of a geyser is the Old Faithful Geyser of Yellowstone National Park of USA (Fig. 7.16).



Check your progress

1. Mention some of the human activities that lead to the depletion of groundwater.
2. What is the difference between a well and a spring?
3. Under what condition does an artesian well flow naturally?

7.11 Geological Work of Groundwater

Groundwater is a very powerful natural agent responsible not only for modifying the existing features but also for creating geological features on and below the surface of the Earth. Geological work of groundwater is studied under three processes such as erosion, transportation and deposition.

7.11.1 Erosional Features

Erosion by groundwater is caused by chemical action. Mechanical process of erosion is insignificant in the case of groundwater. Groundwater becomes an active agent of dissolution of many sedimentary rocks such as those containing carbonates (limestone, and marble), sulphates (gypsum) and chlorides (rocksalt) with which it comes into contact.

When groundwater moves through such soluble rocks, it tends to dissolve the materials where it comes into contact with the rocks. Groundwater enlarges the fractures and other types of channel ways through which it passes, giving rise to chambers of varying size. Groundwater transports the dissolved materials derived from the rocks in solution and deposits them in favourable places under suitable conditions. It has been observed that the dissolution of limestone by water depends on its temperature, chemical composition, and above all, its dissolved carbon dioxide content.

A variety of landforms are produced by the erosion, transportation and deposition work by groundwater. The most common features associated with the geological work of groundwater are briefly described below.

a. Sinkholes

Cylindrical or funnel-shaped depressions or large cavities found on land surface in limestone regions, are called sink holes (Fig 7.17a & b). Groundwater resides within carbonate rocks beneath the Earth's

surface and gradually dissolves limestone over time, carving out underground cavities or chambers.

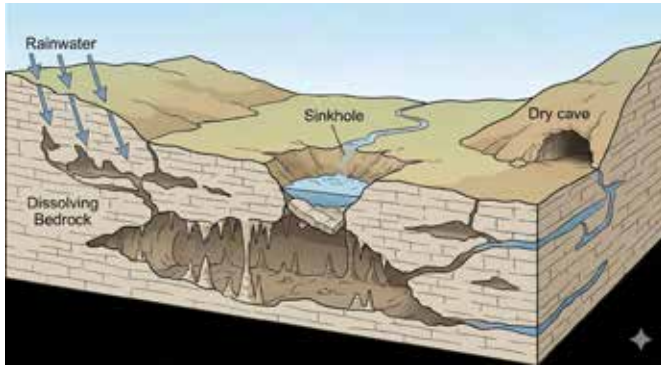


Fig. 7.17a
Formation of sinkholes and caves



Fig. 7.17b
Sinkholes: Heavenly pit in China

Do you Know!!!

The biggest sinkhole in the world is Xiaozhai Heavenly Pit in China which has a depth of 662m and width of 626m. Krem Liat Prah happens to be one of the largest caves in India, and is located in the Jaintia Hills, Meghalaya - this cave is 34 km long and forms part of 150 such caves.

b. Caves and Caverns

The caverns are large, interconnected subsurface cavities found in areas of carbonate rocks, especially limestone terrains. When these cavities have openings to the ground, they are called caves (Figs. 7.17a & 7.18).



Fig. 7.18
Cave: Krem Liat Prah

Do you Know!!!

Belum caves in Andhra Pradesh is the second largest and the longest caves in the plains of Indian subcontinent, known for its stalactite and stalagmite formations. The cave is formed by the constant flow of groundwater.



7.11.2 Depositional Features

a. Stalactites and Stalagmites

When water table drops below the level of a limestone cave or cavern, the cavity becomes an open space filled with air. The places where percolating groundwater, containing dissolved calcium carbonate, emerges from ceiling (roof) of the cave, it evaporates, the calcium carbonate precipitates from water, producing deposits of varying shapes. The deposits, which grow downward from the ceiling/roof of the caves, are called **stalactites**.

Whereas the groundwater enriched with calcium carbonate dripping down over the floor of the cave, from the terminal point of stalactite, when evaporated, result in the deposition of calcium carbonate on the floor of the cave. Gradually these deposits of calcium carbonate grow upward. The upward pointing/massive cones are called **stalagmites**.

If the process of stalactite-stalagmite formation continues long enough, stalagmite merges with stalactite to produce vertical columns or pillars (Fig 7.19).

b. Karst Topography

Irregular topography found in limestone regions characterized by features like sinkholes, caves, caverns and underground streams is termed Karst topography. In Karst region, where surface streams intersect cracks (joints) or sinkholes that link to caverns, the water cascades downward into the subsurface and vanishes. Such

Do you Know!!!

The longest cave in the world is Mammoth Cave in Kentucky, USA (686 km).

Houchins (in 1799) was the first person who entered the Mammoth Cave. Stephen Bishop (1821-1857) was an American cave explorer who was the first person to explore the Mammoth Cave.



Fig. 7.19
Stalactites and stalagmites

Know More

The word karst comes from the Kras (Karst) Plateau in Slovenia and Italy. Geologists studied this limestone region in the 19th century and found many special landforms – sinkholes, caves and disappearing rivers – created by groundwater dissolving the rock. The term was established by Jovan Cvijić, a Serbian geographer (1893–1918), who is often called the father of karst geomorphology.

Because these features were typical of the Kras region, scientists began using the word karst for similar landscapes all over the world. The Karst Plateau has the following dimensions- Length 60 km, Width 15 – 20 km, Area - 440 km², Elevation 250 – 600 m above MSL

disappearing streams may flow through passages underground and later emerge from a cave entrance.

7.12 Groundwater Exploration

Groundwater exploration is the process of finding out where groundwater exists, how much of it is available and whether it is good for use. We cannot see groundwater directly as it is hidden below the surface. Hydrogeologists therefore collect clues from the landscape, rocks, soils, plants and instruments to identify the location of wells and borewells. To locate groundwater, proper observations, measurements and tests based on hydrogeology, geophysics and remote sensing are used. The results are reliable, repeatable and help avoid drilling in the wrong place.



Know More

Botanical Indicators of Groundwater

Certain plants naturally grow well where the water table is shallow or soil moisture is high. These are called botanical indicators of groundwater.

Tamarind (*Tamarindus indica*): Often found thriving where sub-surface moisture is good, even in dry seasons.

Neem (*Azadirachta indica*): If a neem tree stays unusually green during summer, it may indicate higher soil moisture below.

Banyan (*Ficus benghalensis*): The extensive root system prefers spots where groundwater is closer to the surface.

Pipal (*Ficus religiosa*): Common along old river channels and moist depressions – areas that often have shallow groundwater.

Acacia (*Acacia nilotica*): Grows well in areas with moisture-retaining soils such as floodplains.

Date Palm (*Phoenix dactylifera*): Found along oases and coastal belts indicating brackish but available groundwater.

Eucalyptus: Frequently planted because its roots seek out moisture, but its presence often corresponds to shallow water levels (though it can lower water tables, if overused).

7.12.1 Methods of Groundwater Exploration

a. Geological Studies

Studying topography, rock types, fractures, faults and identifying aquifers (water-bearing formations).

b. Geophysical Surveys

These methods send signals (electrical or electromagnetic) into the ground to understand underground layers. The most common method is Electrical Resistivity Survey (ERS), based on the principle that wet zones conduct electricity better.

c. Remote Sensing & GIS

Satellite images to identify the linear cracks, fractures, valleys and recharge zones.

7.13 Hydrogeological Field Tests

Water quality tests help us understand whether water is safe for drinking, irrigation or domestic use. Three common parameters measured are pH, hardness and salinity.

a. pH

pH tells us whether water is acidic, neutral or alkaline. The pH scale ranges from 0 to 14, with 7 corresponding to neutral. Drinking water should have pH between 6.5 and 8.5. Very low pH (acidic) of water can corrode pipes whereas very high pH (alkaline) affects water taste and soap lather.

b. Hardness

Hardness comes from calcium (Ca^{2+}) and magnesium (Mg^{2+}) minerals dissolved in water. Hard water forms less lather with soap and may cause white scaling in pipes- this is not harmful to health, but can reduce the efficiency of detergents. Water can be soft (<75 mg/L) and hard (75 - 150 mg/L) based on hardness.

c. Salinity

Salinity measures the amount of dissolved salts, mainly sodium chloride. It is important in coastal areas, where seawater intrusion can increase salinity. High salinity affects taste, agricultural soils and human health.



Do it Yourself

Conduct a short field-based study to understand the **sources, recharge methods, and conservation of groundwater** in your area.

Guidelines:

1. Identify the main sources of groundwater (such as dug wells, tube wells, bore wells and springs if any).
2. Observe and record seasonal changes in water levels.
3. Identify natural and artificial recharge methods (ponds, tanks, rainwater harvesting, soak pits).
4. Find out one major problem related to groundwater including pollution, hardness in your locality.
5. Suggest two practical measures to improve groundwater quality and recharge.
6. Consolidate your findings along with suggestions for improvement and record in your activity log.



Check your progress

1. Mention the various features commonly seen in karst topography.
2. Distinguish between stalactites and stalagmites.
3. List the ions which cause hardness to well water.
4. What are the effects of increase in salinity of groundwater?

Summary

Groundwater forms an important component of the hydrosphere. In fact, the quantity of groundwater in the hydrosphere is much more than that in the rivers and lakes. Groundwater is trapped in many geological materials. Water-bearing formations called aquifers are of different types. Groundwater is extracted through different types of wells for consumption use.

Groundwater is also an important geological agent carrying out erosion, transportation and deposition, resulting in the formation of different types of landforms. The exploration and quality measurement of groundwater is important for the present water-starved world.

8

STREAMS

8.1 Introduction

In your High school classes you have studied human civilization. All the major ancient civilizations flourished around the banks of major rivers such as the Mesopotamian Civilization along the River Tigris and Euphrates, the Egyptian Civilization along the River Nile, and the Harappan Civilization along the River Indus and so on. This is because in addition of supplying fresh water, rivers provide essential resources for agriculture, transportation, and other human activities. Thus, rivers form an integral part of human civilizations.

Large rivers as well as smaller streams of different sizes are seen all over the land area. Streams can be defined as a body of water, flowing continuously over the surface, down the slope along a natural channel. They usually start their journey from steep mountains and flow out across a gentle plain into a sea or a body of standing water (such as a lake) or another stream or into a dry depression as in an arid region. The point at which a stream joins another stream is called **confluence**. Usually stream implies size - rivers are large, streams smaller, and brooks even smaller. But geologically speaking stream is a body of running water from small brooks to a huge river. Streams may vary in width from a few centimetres to several tens of kilometres. The processes and landforms created by the action of flowing water are called **fluvial**, means 'of or relating to a river or stream' ('fluvius' in Latin means river).

Do you Know!!!

Even Mars once had a well-developed fluvial system. Billions of years ago, Mars had a dynamic fluvial system with rivers, lakes, and even deltas. Strong evidence for these ancient rivers is in the form of inverted channels (ridges made of riverbed material), sedimentary rocks, and other landforms that provide a timeline of Mars' watery past.



8.2 Importance of Streams

Streams are geologically important for the following reasons:

- i. Running water - in the form of streams - is the most important agent that plays a significant role in shaping the major portion of the Earth's landscape through erosion, transportation, and deposition of sediments.

- ii. Stream flow not only accounts for 85-90% of total sediment transport to the ocean basins but also carry dissolved ions into the oceans, and thus, make the sea water salty.
- iii. They form an important part of the water cycle as they carry most of the water that goes from the land to the sea.
- iv. When stream channels overflow, flooding often occurs downstream - one of the common natural disasters.

And of course, streams are a major source of water and transportation for the world's human population, and thus, have great environmental and economic significances.

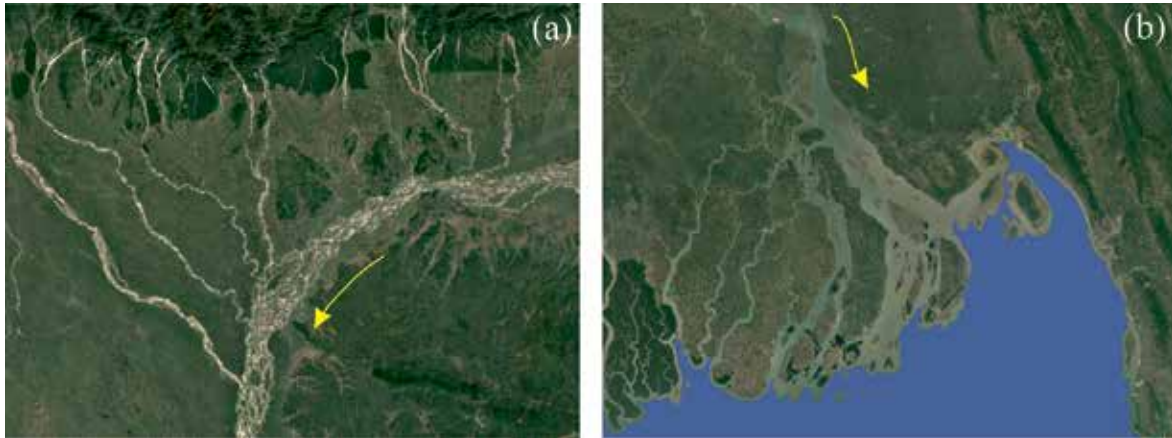
8.3 Sources of Water

Streams are supplied with water from various natural and artificial sources. The main source is rainwater and snowmelt, where a part of it flows over the land surface into stream channels. In cold mountainous regions, snowmelt (glacier) feed streams during summer. Both the water from rain and snowmelt form the runoff component of the hydrologic cycle. The other sources are groundwater seepage, lakes and tanks and human sources. From these sources, water stored underground, seeps into the stream channel through springs and porous rocks, maintaining the flow even during dry seasons. In the case of human made or human-induced sources, streams receive water from dams, irrigation channels, or urban runoff.

8.4 Parts of a Stream, Tributary and Distributary Streams

The parts of a stream include the **source**, **course**, and **mouth**. The point where the stream begins, usually in hills or mountains, is called the source or head whereas the path or channel through which the stream flows is its course, and the point where the stream joins ocean/sea or lake is called the mouth. The portion of stream located nearer to its source is usually called its **higher reaches** while that which is closer to its mouth is called the **lower reaches**.

A smaller stream joining and discharging its water to another larger stream is called **tributary stream** of the larger stream (Fig. 8.1a). On the contrary, a smaller stream which branches off from another larger stream is called a **distributary stream** of the larger stream (Fig. 8.1b).



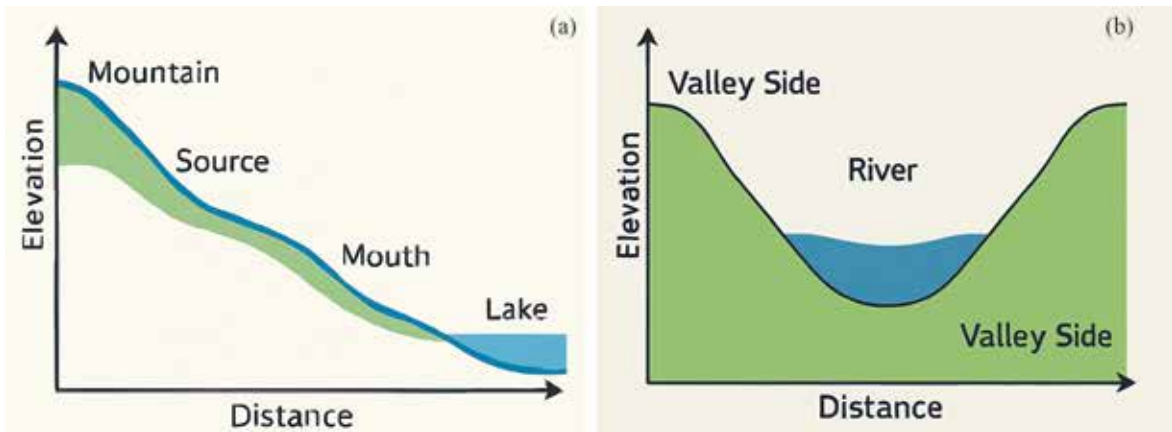
(a) Tributaries joining the trunk river

Fig. 8.1

(b) Distributaries arising from the trunk river

8.5 Stream Profiles/River Profiles

A river profile shows the shape of a river and its valley, primarily as a long profile (side view from source to mouth) (Fig. 8.2a) or a cross profile (cut across the valley showing its width/depth) (Fig. 8.2b). Stream profile illustrates changes in gradient, speed, and erosional power across the river's three stages: the steep, vertical erosion of the upper course (youthful); the gentler, lateral erosion and meanders of the middle course (mature); and the flat, depositional nature of the lower course (old age). These profiles can be created in the field or from topographic sheets or from digital elevation model (DEM).



(a) Longitudinal River Profile

Fig. 8.2

(b) Cross Profile

8.6 Types of Stream Flow

Water flows either as overland or rill flow. When overland flow is not confined to a valley, rills are bounded by channel. Overland flow is the initial, unchanneled movement of water, which then

erodes small channels, or rills, to become rill flow. Rill flow is faster and more erosive than overland flow because the water is confined to a smaller channel.

Additionally, fluids in motion display two distinct modes of flow depending upon flow velocity, fluid viscosity, and the roughness of the bed over which the flow takes place. These two modes are **laminar flow and turbulent flow**. Laminar flow is smooth, orderly fluid movement in parallel layers (laminae) with little or no mixing. Laminar flow typically occurs at low fluid velocities and over smooth channel beds. It is characteristic of high-viscosity materials such as glacial ice, or very slow-moving water. Turbulent flow occurs when the velocity increases or the viscosity of the fluid decreases. Here the fluid moves as a series of constantly changing and deforming masses with significant transport of fluid perpendicular to the mean direction of flow.



Check your progress

Say whether the following statements are true or false

1. Streams always end in oceans only.
2. Most natural water flow on Earth is turbulent.
3. Laminar flow consists of smooth, parallel layers of water.
4. Arrange the following in order from upstream to downstream:
 - a. Course
 - b. Mouth
 - c. Source

Correct order: _____

8.7 Classification of Streams

Several classifications are available for streams based on the nature of stream course, status of stream channel, relation between stream water and groundwater, seasonality, topography and underlying geology. Some of them are described briefly.

8.7.1 Based on the Nature of the Stream Course

a. Straight

Streams with a single thread that is straight and have a direct path and typically occur in steep terrain or areas with resistant bedrock or underlying lithological or structural controls. The

primary difference lies in their formation processes, associated landforms, and the underlying topography (Fig. 8.3a). e.g. Bavali and Achankovil rivers.

b. Meandering

Streams with a single thread, but the channels are sinuous, S-shaped curves and are common in flat areas (Fig. 8.3b). e.g. Bharathapuzha river course west of shornur.

c. Braided

These streams form a network of multiple, interconnected channels that split and merge, separated by islands or bars of deposited sediment; they migrate frequently (Fig. 8.3 c). e.g. Cauvery delta.



Fig. 8.3

(a) Straight stream

(b) Meandering stream

(c) Braided stream

8.7.2 Based on Status of Stream Channel

The main stream is called the trunk stream. The other smaller streams joining and discharging its water to the trunk stream are called its tributaries. But near the mouth, both the trunk and tributaries branch-off forming distributaries.

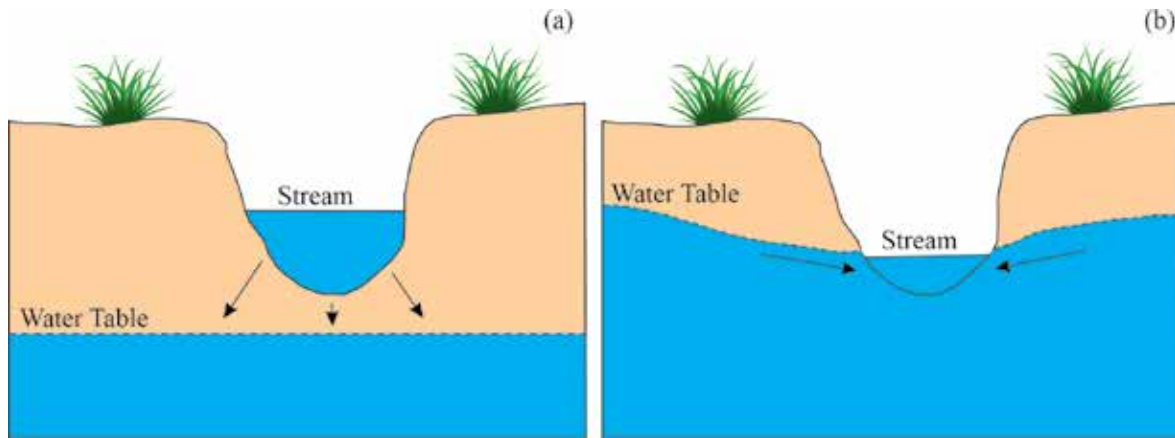
8.7.3 Based on the Relation between Stream Water and Groundwater

a. Influent Stream

A stream that contributes water to groundwater is influent stream. Here the stream flows above the water table (Fig. 8.4a).

b. Effluent Stream

A stream that gains water from groundwater is called effluent stream. This means that the effluent stream flows below the water table (Fig. 8.4b).



a. Influent stream **Fig 8.4** *b. Effluent stream*

8.7.4 Based on Seasonality

a. Perennial Stream/River

It flows continuously throughout the year as it has a constant source of water such as melting snow, springs, or rainfall. Examples include rivers originating from the Himalayas or those fed by springs. Their flow does not typically cease during dry seasons.

b. Seasonal Stream/River

A seasonal river flows only during certain seasons, usually coinciding with periods of heavy rainfall such as the monsoon. During dry seasons, its channel may dry up partially or completely. Examples include many of the small rivers of Kerala and most of the rivers in Tamil Nadu.

c. Ephemeral Stream/River

Such a stream flows only immediately after a precipitation event and remains dry for the rest of the year. It is common in arid or semi-arid regions and does not have a permanent water source (e.g. Luni River in Rajasthan).

Do you Know!!!

The Himalayan rivers have maximum hydroelectric power projects compared to the Peninsular rivers as the Himalayan streams are perennial in nature.

8.8 Fluvial Cycle

The fluvial cycle is a geomorphological model describing how a river shapes the landscape over time through a sequence of stages marked by varying relative dominance of erosion, transportation, and deposition. The model divides the life of a river into three primary stages: youth, mature, and old, each characterized by distinct landforms, energy levels, and landscape features.

8.8.1 Youthful Stage

In this early stage, rivers have steep gradients and high energy, leading to active vertical erosion cutting down into the rock beneath. Such valleys are typically deep, narrow, and V-shaped. Common features associated with such valleys include gorges, canyons, waterfalls, and rapids.

8.8.2 Mature Stage

In the mature stage the gradient of the river is reduced. Lateral (sideways) erosion becomes dominant; there is widening of valleys and development of broader floodplains. The river increases its volume by collecting water from tributaries. The river meanders more prominently, and features such as meander bends and slip-off slopes become common. Vertical erosion decreases compared to the youthful stage. Features like meanders, oxbow lakes, and floodplains form as erosion and deposition go hand in hand.

8.8.3 Old Stage

Rivers flow calmly through broad, flat valleys, and their velocity is much reduced and deposition far exceeds erosion. The landscape is generally low-lying, close to the sea level. The river meanders freely over extensive floodplains, and depositional features like oxbow lakes, levees, estuaries and deltas at the river mouth become common.

8.9 Drainage Basin and Drainage Divide

A drainage basin is the land area where all surface water run-off collects and drains toward a common outlet, such as a river mouth, lake, or ocean. In short, the entire area drained by a stream and its tributaries is called drainage basin. Drainage basin can range in size from a few sq. km (for small streams) to extremely large areas (such as Ganga and Brahmaputra river basins in India). Drainage basin is also called as watershed, catchment area, or river basin. Sub-basins for tributaries can be identified for large basins for study purpose. A ridge or strip of high ground, dividing one drainage basin from



Know More

Rejuvenation

It refers to the renewed erosive activity of a river, i.e., change of river from its old age to mature or from mature to youth. The process occurs during sudden fall in sea level or during orogeny, in both cases the gradient of stream increases.

River Piracy

River piracy, also known as stream capture, is a geomorphological phenomenon where a river or stream is diverted from its original course, and its flow is captured by a neighbouring river system.

Misfit River

The captured river, which now carries significantly less water than its large valley.

adjacent one, is termed as a drainage divide (Fig. 8.5). Drainage basin studies help in sustainable land use and management, estimation of groundwater resources, and evaluation of pollution of surface and sub-surface water resources.

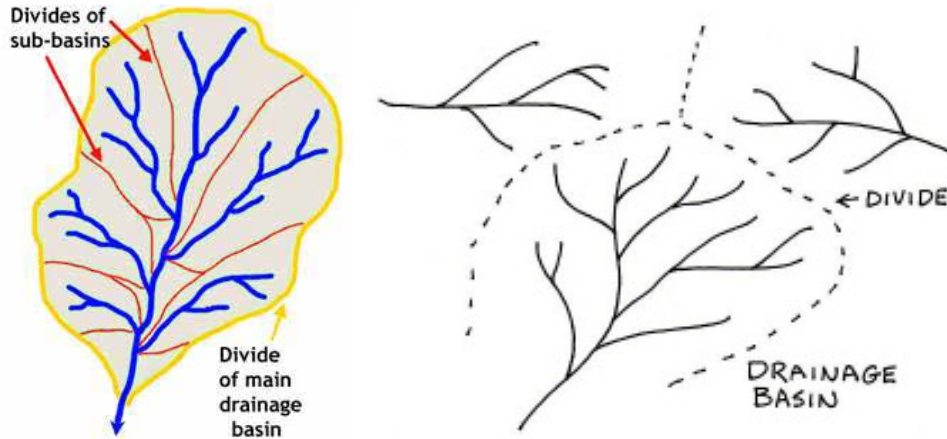


Fig 8.5
Schematic diagram of a drainage basin

8.10 Stream Ordering

Stream ordering is a way of classifying streams according to their size and position within a drainage basin. In order to study the drainage density of a given area, the streams are classified in the first, second, third, and higher orders. Stream orders help to rank and identify relative sizes of channels in a drainage basin. Smaller stream order numbers indicate smaller, headwater streams that are typically found in the upper reaches. Higher order streams are given larger numbers and are found in the lower reaches. Stream networks can be analysed using two methods-Strahler method and Shreve Magnitude method.

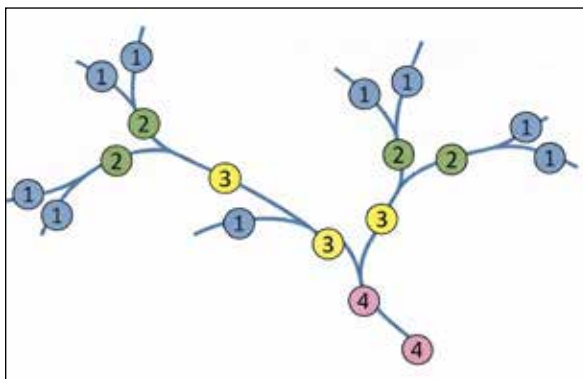


Fig. 8.6
Strahler's method of stream ordering

8.10.1 Strahler Method

The Strahler method is the most popular one. In this method, the smallest channels, usually found in hilly or mountainous areas where runoff collects and also that lack tributaries, are called first-order streams (Fig. 8.6). Depending on the groundwater water condition, the first order streams may be ephemeral, intermittent or perennial. When two of these first order streams meet, they form a second-order stream,

and so on, as the network grows larger and more complex. However, if streams of different orders merge, then there is no change in the stream order i.e. if a first-order joins a third-order, the stream remains third-order.

8.11 Drainage Patterns

Drainage pattern is the geometrical form of the drainage system and describes the spatial relationship of streams in an area. A number of factors affect the pattern including slope, lithology, structures in the rocks, tectonism, climate, and vegetation. Some of the important types of drainage patterns are shown in Fig. 8.7 and listed in Table 8.1.

Table 8.1 Different types of drainage patterns with description and examples

Drainage pattern	Description	Examples
Dendritic	It resembles the branching of a tree and is the most common drainage pattern on Earth. Uniform lithology is the most ideal condition for its development (Fig. 8.6 a).	One of the most dominant patterns seen in the Himalayas (Ganga river basin), Mississippi river basin of USA and Amazon river basin in South America.
Trellis	This has a grid-like river system where primary tributaries flow parallel to each other. This drainage pattern develops based on the inclination of regional terrain as well as geological structures in that area (Fig. 8.6 b).	Shiwalik, outer Himalayas. Eastern Ghat folded belt, Odisha. Alps foreland regions, Europe. Andean fold belt valleys, South America
Rectangular	It is developed in regions where rock joints and faults form rectangular patterns. Tributaries join their master streams almost at right angles. Similar to trellis pattern but is not based on rock bed inclinations or have closely spaced tributaries (Fig. 8.6 c).	Upper Chambal river basin and Son river tributaries in India. Zambezi tributaries, Africa. Rhine massif sections, Europe

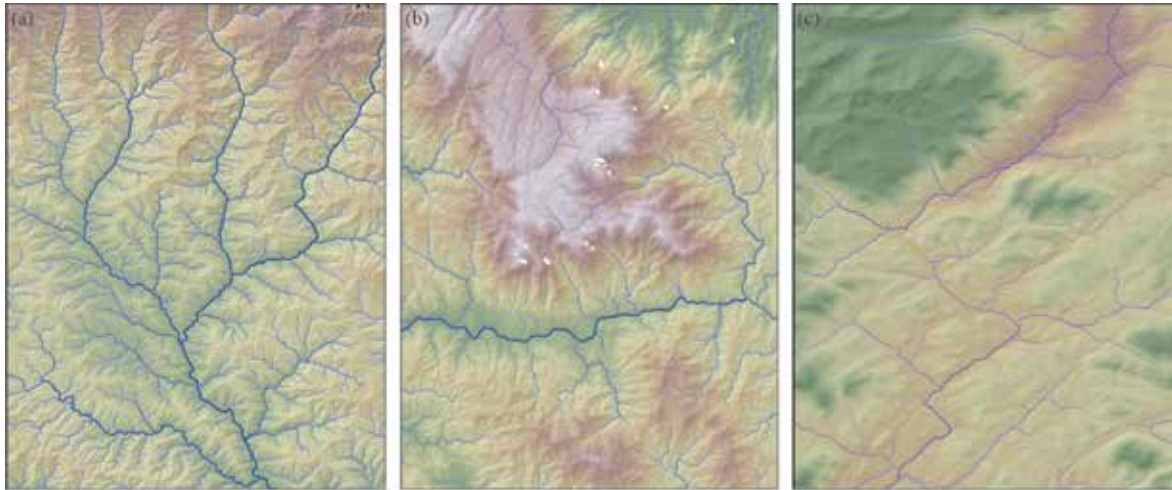


Fig. 8.7
Drainage patterns

(a) Dendritic

(b) Trellis

(c) Rectangular

8.12 Geological Action of Streams

As mentioned at the beginning of this chapter, landforms created by streams, and running water in general, have helped in shaping our earth more than any other process. Now let us see how streams modify the land surface by the geological processes of erosion, transportation and deposition.

The term fluvial denudation is applied for the combined action of channel erosion (erosion caused by flowing water along channels), overland flow (erosion by sheet flow or overland flow), mass wasting (erosion by gravity) and weathering resulting in the modification of land surfaces.

8.12.1 Fluvial Erosion

The process of fluvial erosion includes a complex group of processes like channel erosion, overland flow, splash erosion, mass wasting and weathering. Stream erosion is the progressive removal of rock materials from the floor and sides of a stream channel. The process of erosion by stream involves both mechanical and chemical actions. Mechanical erosion involves corrasion or abrasion, hydraulic action, and attrition. Chemical erosion involves corrosion or solution. These stream erosional processes are described briefly.

a. Hydraulic Action

Hydraulic action is a geological process where the force of moving water erodes sediments and rocks by exerting pressure on cracks and cavities, leading to their eventual breakup which results in

significant changes in landforms. This erosive process is especially important in shaping riverbanks and coastal cliffs. Poorly consolidated bedrocks and uncemented materials on the banks are prone to hydraulic action. The important factors that influence the effectiveness of hydraulic action are water volume, velocity, and the lithologic composition of the riverbed. The process can lead to the formation of potholes on rocky river beds.

b. Abrasion /Corrasion

It is the mechanical wearing away of river bed and banks by the impact and friction of the sand, pebbles and boulders carried by the flowing water. This process acts like sandpaper, constantly scouring and smoothing the channel over time. Abrasion involves the wearing, grinding, or rubbing or bumping action of the rocks of the channel floor and channel sides (It is similar to smoothening of walls by a painter using sand paper). Through this process even the hardest rocks in stream beds are smoothened.



*Fig. 8.8
Potholes*

Smooth potholes of varying sizes are often observed along rocky channel floors (Fig. 8.8). This erosive process is mainly responsible for the ability of the streams to deepen their channels and in creating **gorges** and **canyons**.

c. Attrition

It is a type of stream erosion in which rocks and pebbles carried by the river collide with one another, causing them to break into smaller, smoother, and rounder fragments. Attrition takes place during the transportation and results in reduction of the size of the sediment over time. The resulting smooth pebbles are particularly abundant in the lower reaches of a river.

The velocity and pressure of the stream water flow, the hardness, size, and shape of the rocks being transported and the distance travelled by the transported sediments are the key factors which affect the attrition process.

d. Corrosion/ Solution

The chemical or solvent action of water on soluble rocks like limestone in the river course results in the wearing down of surface of the bedrocks is called corrosion/solution. Stream water is slightly acidic due to the presence of dissolved carbon dioxide; the weak carbonic acid thus produced, effectively dissolves rocks like limestone, chalk, gypsum and rock salt. Remember that corrasion, another type of stream erosion, is totally different as it is the physical scraping and grinding caused by the moving sediment load of the river.

8.12.2 Fluvial Erosional Landforms

Now let us move towards features associated with stream erosion; some of these are described briefly below.

River valley/Canyon/Gorge

A river valley is a low topographic zone that is created by stream erosion (Valleys can as well be created by tectonic activity, in which case the valley existed before the river. However, the vast majority of valleys are formed by stream erosion). It is an elongated low area often running between hills or ridges and typically containing a stream running from one end to the other. Typically, small valleys containing streams feed into still larger valleys. River valleys have a V-shaped profile. Most stream valleys take a very long time for their formation. The width and depth of river valleys depends upon the stage of erosion and geology of the area.



Fig. 8.9
Gandikota in Andhra Pradesh

Gorges are deep V-shaped narrow valleys whereas a **canyon** (from Spanish *cañón*) is an extended form of a gorge. Thus canyon is a deep cleft between escarpments or cliffs. Canyons are much more common in arid areas than in humid areas because physical weathering has a more localized effect in arid zones. Canyon walls are often formed of resistant sandstones or granite. The Grand Canyon of Colorado, USA is an example of a canyon. Gandikota, often called the 'Grand Canyon of India', is located in the Kadapa district of Andhra Pradesh (Fig. 8.9).

Waterfalls

Waterfall is a vertical drop of a massive volume of water from a great height. The force of the falling water creates a plunge pool at the base, and the constant erosion of the softer rock causes the waterfall to gradually move upstream. Rapids are fast flowing, turbulent sections of river where water rushes over a steep slope, rocks or uneven river bed. A cascade is a waterfall that descends over a series of rock steps. Minor falls occur due to interruption in the cycle of erosion. Normally, waterfalls are formed due to the erosion of rocks of variable rock strength (differential erosion). Jog Falls in Karnataka and Athirappally Falls (Fig. 8.10) in Kerala are very famous falls.



Fig. 8.10
Athirappilly Falls

Do you Know!!!

Knickpoint in a stream is a sharp, abrupt change in the river's slope, often appearing as a waterfall or rapids, caused by factors like tectonic uplift, sea-level drop, or changes in rock hardness. It rejuvenates the river, causing it to cut down and migrate upstream, leaving behind terraces. These features indicate a change in the river's profile, representing a river adjusting to new erosional conditions.

River terraces

River terraces are narrow flat surfaces on the side of the valley, which are remnants of earlier flood plains. Terraces are usually formed when the river rejuvenates causing severe incision and occupies a narrow channel instead of the earlier wider channel. Except the currently occupied narrow channel, the rest of the wider channel forms the terraces. Sometimes there can be several generations of terraces with each terrace representing a geological activity (Fig. 8.11).



Fig. 8.11
River terraces

Potholes

Potholes are common circular or near circular depressions that are eroded into the hard rock of a stream-bed by abrasion. Potholes (Fig. 8.8) form when eddies in the water trap abrasive hard materials like sand, gravel, and pebbles, which then grind and drill into the rock. Lithological and structural aspects of bedrock, availability



Fig 8.12
Meandering and oxbow lakes

of hard grinding stones and velocity of water flow influence pothole formation.

Meanders and Oxbow lakes

Meanders are the bends seen in sinuous rivers. They form as water erodes the outer bank (cut bank) and deposits sediment on the inner bank (point bar). Thus, one side of the meander will have concave slope where severe erosion occurs and the other side has a convex slope, receiving deposition of stream sediments. The continuous process of erosion on the outer bank and deposition on the inner bank causes the meander to become more exaggerated and to migrate sideways across the floodplain. Eventually, a meander loop can be cut off by a flood, forming a crescent-shaped oxbow lake (Fig. 8.12). Meanders are usually formed during middle or old stage of a stream. Hence it is a common characteristic of rivers flowing through flatter floodplains.



1. Assertion (A): Streams play an important role in shaping the landscape.

Reason (R): They erode, transport, and deposit sediments.

- a) A and R are true; R explains A
- b) A and R are true; R does not explain A
- c) A true; R false
- d) A false; R true

2. Assertion (A): Meanders develop due to lateral erosion and deposition in a river.

Reason (R): Velocity of water is greater on the outer bank than on the inner bank of a bend.

- a) A and R are true; R explains A
- b) A and R are true; R does not explain A
- c) A true; R false
- d) A false; R true

3. In which stage (youthful/mature/old) is the river in the middle part of the given map? Name the landform seen near the mouth where the river meets the sea.



8.12.2 Transportation

Transportational work of streams involves moving products of weathering and eroded materials from upstream to downstream; the moved materials are called **load**. The amount of load transported past a point during a specified time interval in a stream will be proportional to the velocity and the gradient of the stream. In general, three types of loads are noticed. They are a) **Bed load**, b) **Suspended load** and c) **Dissolved load**. Brief descriptions of the loads and their mode of transportation are explained briefly in the following paragraphs:

a. Bed Load

Bed load is that part of a stream's load transported along its bottom or bed of its channel. The amount and type of bed load increases directly with the velocity of the stream. The mechanical erosive power of a stream and the intensity of modification of stream channel depend on the nature and amount of bed load. The transportation of the bed load is either by **traction**, a process of movement of load along the river bed by rolling or sliding - or by **saltation** - lifting of sediment by eddies and dropping them downstream by a small distance.

b. Suspended Load

The suspended load of a stream, is the portion of its sediment uplifted by the stream's flow in the process of sediment transportation.

This type of load consists of fine sand, silt and clay that are light enough to be transported in the stream water in a state of **suspension**. The presence of suspended particles gives the water a muddy or cloudy appearance. Rapid flowing and more turbulent rivers can carry more suspended load. When there is a reduction in the velocity of a stream suspended load will partly/fully settle down. Most streams carry the major part of their load in suspension which is very much visible during floods.

c. Dissolved Load

The portion of the load carried by a stream as ions in **solution** is termed its dissolved load. This load comes primarily from the corrosion of soluble minerals, such as those found in limestone and chalk, which constitutes the stream channels. The amount of dissolved load depends on the climate and the geologic setting of the region. Some of the dissolved load may get precipitated through evaporation on its course. However, most of the dissolved load reaches the oceans or seas, the ultimate destination of a stream.

8.12.3 Deposition by Streams

It is a geological process where a stream drops eroded sediment, like sand, silt, and gravel, due to the decrease in its velocity and energy. This happens when the carrying capacity of the stream is exceeded, and results in the formation of different types of landforms like meanders, levees, floodplains, sand bars and deltas. The coarser fragments i.e. gravel will get deposited first, followed by sand, silt and clay. The factors which influence stream deposition are: i) Loss of energy due to a decrease in channel gradient and stream velocity, and/or an increase in load, ii) stream entering a larger body of water like ocean or lake, iii) spreading of water during floods, iv) meandering of stream where the river flows slowly on the inside bend of a meander, and v) reduction in discharge of water due to seasonal change.

Some of the major fluvial depositional landforms of streams are mentioned in the following sections.

a. Alluvial Fan and Cone

This is formed at the base of the foothills by the accumulation of materials due to sudden drop in channel gradient. It is semi-circular (with decreasing sediment thickness towards the periphery) and is formed when a stream flowing from a high gradient enters a gentle hill or mountain slope. This fluvial deposit is made up of coarse detrital sediments. The sediments spread out forming a fan shape and hence the name (Fig. 8.12 a).

b. Natural Levee

Natural levees are formed due to deposition of sediments during flood periods, especially on the banks of the river. This unchanneled flow reduces the velocity significantly, and some of the suspended sediment settles down. The coarsest material deposits first, i.e. closest to the channel, followed by finer particles. They form high embankments on either side of a river (Fig. 8.12 b).

c. Floodplains

Floodplains are created by the overflowing of river during heavy rains, spilling its finer grained deposits onto its banks and beyond. It is a flat surface, formed due to extensive sediment deposition. The base of a floodplain can be a gently sloping surface. During high floods, a floodplain may be completely covered with water. Active floodplain is the river bed made of fluvial deposits. Inactive floodplains are those that are not frequently flooded but have the possibility of flooding in extreme events (Fig. 8.12 c).

d. Sand Bars

Stream deposits may take the form of a bar, a ridge of sediment, usually sand and gravel, deposited in the middle or along the banks of a stream. Bars are formed by deposition when a stream's discharge or velocity decreases. Point bar is one which forms on the inside bend of the meander where deposition takes place (Fig. 8.12 d).

e. Deltas

The triangular depositional feature at the mouth of a river where it enters a sea or lake is called a Delta. As the river enters the sea/lake, it slows down and its sediment carrying capacity decreases. This leads to the river dumping its sediments in the sea/lake forming a huge fan of alluvial deposits. The name is derived from the Greek letter delta, because of its usual triangular shape. Deltas are in different shapes. They are mainly classified based on their shapes (arcuate, cuspate and bird-foot), or the dominant process which form them (wave-dominated, tide-dominated, and Gilbert deltas) (Fig. 8.12 e). Some of the major river deltas of the world include the Ganges-Brahmaputra Delta (known as Sundarbans Delta, the world's largest), Nile Delta, Mississippi Delta, Amazon Delta, and Indus River Delta. These deltas are significant for their size, ecological importance, and the rich agricultural land they provide.



Fig. 8.12
Fluvial Depositional Features



Do it Yourself

Materials: A plastic paint roller tray (or aluminum roasting pan), sand, water, small plastic cup with a hole poked at the bottom, and blocks/books to create a slope.

Procedure:

1. Place the tray at a slight incline by propping up one end.
2. Fill the tray with wet, packed sand, smoothing the surface or pre-carving a shallow, straight channel.
3. Slowly and steadily pour water from the cup (with the hole) onto the high end of the sand.

Observation: Students observe how the water carves a channel, watch for meanders to form, and identify where sand is picked up (erosion) versus where it is dropped off (deposition).



Check your progress

Can you detail the step-by-step process of how a meander loop forms and migrates over a flood plain?

Stage 1:

Stage 2:

Stage 3:

Stage 4:

Show it diagrammatically

8.13 Major Rivers of Kerala

The state of Kerala is endowed with a dense network of 44 rivers (a few are detailed in Table 8.2) of which 41 are westward-flowing towards the Arabian Sea, while the remaining three (Kabini, Bhavani, and Pambar rivers) drain eastwards towards the Bay of Bengal. The rivers of Kerala are relatively small in length, width, and discharge. They originate in the Western Ghats and travel only a short distance to the sea, and hence, they flow rapidly through steep and hilly terrains. All these rivers are monsoon-fed, and about half of them are reduced to narrow streams or dry up completely during the summer months. However, the major rivers such as the Periyar (the longest river in Kerala), Bharathapuzha, Pamba, and Chaliyar remain perennial and play a significant role in shaping the landscape and supporting the environment of Kerala. These rivers exhibit distinct fluvial characteristics controlled by the region's geology, topography, and heavy monsoonal rainfall.

Table 8.2 Major rivers of Kerala and their morphometric parameters

No.	River	Length (Km)	Stream Order	Basin Area (km ²)	Drains into
1	Periyar	244	8	5216	Arabian Sea
2	Bharathapuzha	209	7	5988	Arabian Sea
3	Pamba	176	5	2235	Vembanad Lake
4	Chaliyar	169	7	2933	Arabian Sea
5	Chalakyudy	145.5	7	1704	Arabian Sea
6	Achankovil	128	7	1484	Pamba
7	Kallada	120	7	1654	Ashtamudi Lake
8	Vamanapuram	88	6	687	Anchuthengu lake
9	Valapattanam	110	5	1321	Arabian Sea
10	Manimala	91.73	6	803	Pamba

The rivers of Kerala characterized by steep gradients and swift flow, lack delta formation and primarily follow a dendritic drainage pattern, though trellis, sub-parallel, and radial patterns also occur.

Rivers of Kerala form the backbone of the state's water-resource system. They provide drinking water to urban and rural populations, support irrigation for crops such as paddy and coconut, and sustain major hydroelectric projects, especially where they descend steeply from the Western Ghats. River systems recharge groundwater aquifers, maintain wetlands and backwaters including the Vembanad and Ashtamudi, and help regulate floods by distributing excess monsoon runoff. However, unsustainable extraction of river sand, bank erosion, and ecological degradation pose significant threats. Proper management is essential to protect river channels, preserve sediment balance, maintain aquatic habitats, and ensure long-term water security.



Know More

Economic-Geological Aspects of the Rivers of Kerala

The rivers of Kerala form an essential part of the state's economic and geological framework. Originating from the Western Ghats and flowing westward into the Arabian Sea, they transport significant quantities of sand, gravel, silt, and alluvium, which contribute to construction materials, agriculture, placer mineral deposits, and overall water-resource management. These rivers also shape the geomorphology of Kerala through continuous erosion, transport, and deposition processes.

The rivers carry abundant sand, a crucial construction material used widely across the state. Derived from the erosion of crystalline highlands, this river sand supports masonry, plastering, and infrastructure development. Alluvial deposits are extensive along Kerala's major river valleys, forming fertile floodplains ideal for agriculture. The coastal plain includes the Periyar Formation, a representative fluvial unit, while the Achankovil floodplain contains sandy silt and clay widely used for country brick manufacturing.

The rivers of Kerala also host valuable placers and secondary mineral deposits. In the Nilambur valley, alluvial gold occurs within soils, gravels, and river sands, particularly in the Pandipuzha-Chaliyarpuzha and Punnapuzha-Karakodupuzha-Maradipuzha zones. Investigations estimate that 8.5 million cubic metres of gravel may contain nearly 1972.5 kilograms of gold. Chrysoberyl, derived from weathered pegmatites and high-grade metamorphic rocks, is recovered from lateritised gravel beds and palaeochannels along the Karamana, Killiar, Vamanapuram, and Kulathupuzha rivers. Clay deposits, used in the tile and brick industries, occur across many riverbanks. In the Malappuram region, the Chaliyar, Kadalundi, and Ponnani rivers host significant tile clay deposits, while the Achankovil floodplain supports brick clay extraction. Scheelite, the principal tungsten mineral, occurs in the Attappady valley, and grains of scheelite are found in heavy mineral samples from the Siruvani river and its tributaries. Heavy mineral sands enriched in ilmenite, rutile, garnet, monazite, and zircon are concentrated along the coastal tract south of the Valapattanam river, reflecting long-term sediment transport and coastal reworking).

Summary

Streams are a central component of the Earth's hydrologic cycle, primarily serving to transport water from higher elevations to the sea. In this chapter brief description of classification of streams based on various parameters is provided along with the geological action of streams. The geological work of a stream is divided into three main processes: erosion, transportation, and deposition. As water flows, it carves the landscape by erosion. The eroded material, moved by a stream known as its load, is deposited downslope forming alluvial fans, deltas and other features. Ultimately, the continuous fluvial processes reshape the Earth's land surface, lowering mountains and widening valleys over millions of years.

9

WIND AND GLACIERS

9.1 Introduction

Wind acts as an important geological agent in shaping the Earth's surface, especially in arid and semi-arid environments where vegetation is limited and unconsolidated sediments are widespread. The geological activity of wind, referred to as aeolian processes, involves erosion, transport, and deposition of sediments. These processes are responsible for the formation of characteristic landforms. The study of aeolian processes offer valuable insights into desert geomorphology, paleoenvironments and climate change.

Glaciers are dynamic geological agents that play a major role in shaping the Earth's surface, particularly in high-latitude and high-altitude regions. Glaciers are formed from the long-term accumulation and compaction of snow into ice. Glaciers move slowly under the influence of gravity and exert a powerful influence on the landscapes they occupy. The geological work carried out by glaciers is collectively known as glacial processes, which include erosion, transportation and deposition of rock materials. Overall, glacial processes are fundamental in sculpting mountainous and polar landscapes, redistributing sediments, and influencing sea level and climate. The study of glacial geology offers important insights into Earth's climatic history, landscape evolution and ongoing climate change.

9.2 Wind

Moving air masses are known as winds. Wind is influenced by seasonal variations that cause an uneven distribution of solar heat over the Earth's surface. The circulation of air due to these variations gives rise to wind. Wind is capable of creating both aggradational and degradational landforms on the surface of the earth.

Wind is an effective geological agent capable of eroding, transporting and depositing the surface materials in arid and semi-arid regions and along some sea shores, which are regions unprotected by vegetation. Geological action of wind is known as aeolian action and the landforms formed by the action of wind are called aeolian landforms.

9.3 Geological Action of Wind

The geological action of wind, as in the case of other geological agents, such as running water and glaciers, consists primarily of erosion, transportation and

deposition of rock materials on the surface of the earth. During these processes, a variety of landforms are produced.

9.3.1 Wind Erosion

We are all familiar with the blowing away of dust particles by wind wherever loose rock materials are found exposed and unprotected by a cover of some sort of vegetation. Strong winds blowing over ground covered with loose materials, such as dry soils or in the deserts, are capable of transporting enormous amounts of loose rock materials (sand, silt and clay particles) from one place to another.

The erosional processes associated with wind action or aeolian erosion consists of **deflation, abrasion and attrition**. Let us learn more about these aeolian processes.

a. Deflation

The process of removal of clay, silt and sand particles from the land surface by wind is called **deflation** (Fig. 9.1). When the surface sediment consists predominantly of fine particles, the erosion of these particles by wind can lower the land surface substantially. Deflation is the main process of erosion in desert regions.

b. Abrasion

The process of mechanical wearing down of rock surfaces by the grinding or sand blasting actions of wind-borne particles is termed aeolian **abrasion** (Fig. 9.1). In general, during the times of desert winds, the rock particles, forming the tools for abrasion are found concentrated mostly within 50 cm above the desert surface. Similar to the action of a sand paper, the frequently blowing winds that are armed with sand grains bring about wear and tear of the exposed desert rocks.

c. Attrition

In wind action, the sand grains and other rock particles lifted up from the ground from different places are transported to considerable distances from their source regions. During such journeys, because of turbulence within the moving mass of air, the particles do not move in straight and parallel paths. Instead, the grains carried by winds continuously collide with one another and rub each other during their transit. Such repeated collisions of grains cause their continuous wear and tear. This process is called **attrition** (Fig. 9.1). Apart from bringing about a reduction in size of the particles, the process of attrition removes irregularities of the surfaces of grains and ultimately makes them smooth and nearly spherical in shapes.

9.3.2 Aeolian Transportation

The modes of transportation of rock particles in wind action are

(a) suspension (b) saltation and (c) traction.

a. Suspension

The silt and clay sized particles are carried in suspension, above the ground surface. The suspended grains travel thousands of kilometres and reach to great altitudes. The force of the wind lifts clay and silt particles of lighter density from the ground and carries high up to upper layers. This is called suspension. Normally, fine particles, once taken in suspension and raised up, are not allowed to immediately settle down onto the ground, because the intensity of air turbulence rapidly increases with altitude (Fig. 9.2).

b. Saltation

This process involves the lifting of heavier and coarser sediments such as sand grains, pebbles and gravels for short distances and up to small heights above the ground during periods of high wind velocity. The movement occurs close to the Earth's surface. The particles that are picked up often fall back and then are lifted again, repeating this cycle throughout transportation (Fig. 9.2).

c. Traction (creep)

The heavier particles and rock fragments are transported by dragging and rolling along the ground and it is known as traction or creep (Fig. 9.2).

9.3.3 Aeolian Erosional Landforms

The common and important landforms associated with wind erosion are briefly described below:

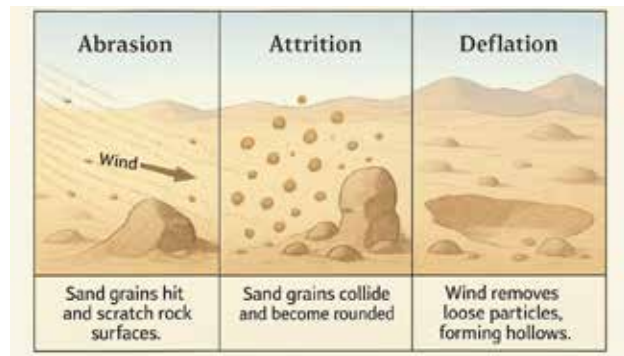


Fig. 9.1
Erosion by wind

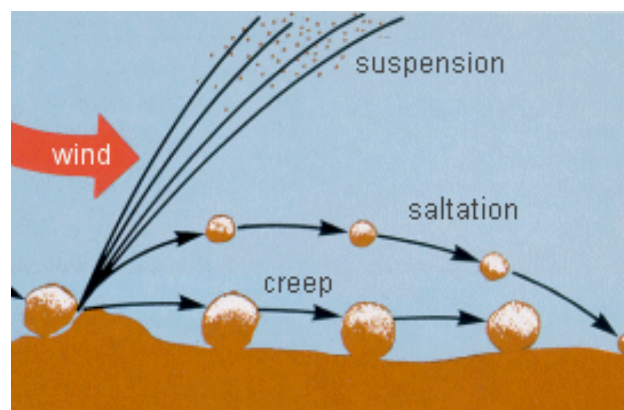


Fig. 9.2
Aeolian transportation

a. Deflation Hollows

Continuous deflation ultimately lowers the ground surface of the desert and creates topographic depressions of varied dimensions. Relatively smaller depressions thus formed are called deflation hollows (Fig. 9.3) while the larger ones are known as deflation basins. Blowouts are the smallest type of deflation basins scooped out in soft unconsolidated deposits. The deflation basins range from a few meters to several kilometers in diameter. Once the bottom of the deflation basin encounters the local water table, an oasis is formed. Desert oases form where the water table comes close enough to the surface that the roots of the plants can reach it (Fig. 9.4).



Fig. 9.3
Deflation hollows



Fig. 9.4
Oasis

Do you Know!!!

The Al-Ahsa Oasis in Saudi Arabia is the largest oasis in the world. It is a vast geocultural landscape recognized by UNESCO, featuring over 2.5 million palm trees, lush gardens, springs, canals, and numerous historical sites, making it the world's largest palm oasis.



Fig. 9.5
A mushroom rock

b. Mushroom Rocks

The term **mushroom rocks** are applied to isolated rocks in which their basal portions have been partially undercut by the abrasion carried out by windblown sands (Fig. 9.5). They are also known as pedestal rocks. Mushroom rocks remotely resemble mushrooms and are characterized by slender supporting rock stems.

c. Ventifacts

Ventifacts are wind-faceted rock fragments that have several curved or almost flat surfaces that meet at sharp ridges, stones of any size that have been abraded, shaped or faceted by wind-blown sediment. The term '**ventifact**' is derived from the Latin word meaning 'wind-made' (Fig. 9.6).



Fig. 9.6
A Ventifact

d. Desert Pavement

Desert surfaces that are covered only with angular, interlocking fragments of pebbles, gravel or boulders are called desert pavements. Desert pavements are products of deflation in regions composed of a heterogeneous mixture of loose rock materials with varied sizes and shapes. The finer rock particles are selectively removed during the course of time, leaving behind the larger ones (Fig. 9.7).

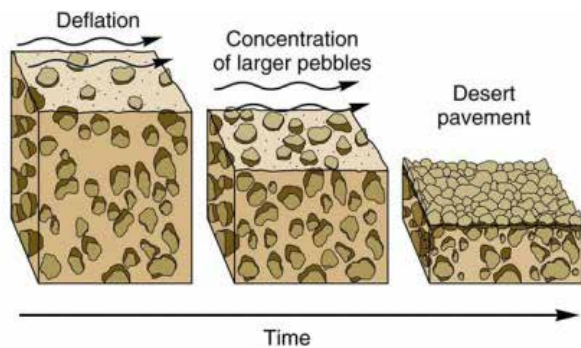


Fig. 9.7
Formation of desert pavements

9.3.4 Aeolian Depositional Landforms

When wind velocity decreases to the point where it can no longer transport particles, it begins to deposit them. This often happens when topographic barriers—such as hills, rocks or vegetation—slow the wind on their downwind side. As the wind slows, suspended sediment is released and settles out. Over time, this deposition gives rise to various aeolian landforms, which occur at different spatial scales. The important types of wind deposits are **loess** and sand **dunes**.

a. Loess

Loess is a wind-deposited sediment composed mainly of silt-sized particles, with a small proportion of clay (Fig. 9.8). Loess deposits may



Fig. 9.8
Loess deposits



Fig. 9.9
Sand dunes

range in thickness from just a few centimetres to several tens (and in some places, even hundreds) of meters. Extensive loess covers large parts of the world notably in China (especially the Loess Plateau), Europe and North America.

b. Sand Dune

Sand dunes are conical or asymmetrical mounds or ridges of sand deposits created by the action of wind. Sand dunes form when there is (i) a ready supply of sand, (ii) a steady wind and (iii) some kind of obstacle such as vegetation, rocks or fences or even a pre-existing sand heap to trap some of the wind-blown sand. Sand dunes form when

moving air slows down on the downwind side of any of those obstacles mentioned above. The sand grains drop out and form a tiny mound that grows into a dune in due course of time (Fig. 9.9).

A typical dune is characterized with a gentle ($5\text{--}15^\circ$) windward face or up-wind face and a steep (usually up to 30°) leeward face or down-wind face. The latter face is also known as the slip face. The size of the dune ranges from low knolls to huge hills of more than 100 m high.

Dunes are not permanent landforms, they migrate by erosion of sand by saltation on the gentle upwind slope, and deposition and sliding on the slip face. Coastal sand dunes are common in different parts of the world. These are natural structures which protect the coastal environment by absorbing energy from wind, tide and wave action.

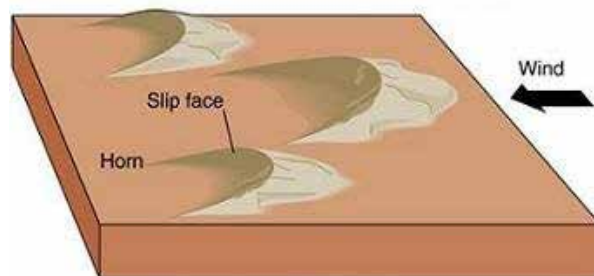
Do you Know!!!

The Badain Jaran Desert in China hosts some of the largest sand dunes in the world and represents one of the most remarkable natural phenomena on the planet.

Dunes are classified into four main types: barchans, longitudinal, transverse and parabolic dunes. Their size, shape, and arrangement depend on the interaction of several factors, including sand supply, the direction and velocity of the prevailing wind and the extent of vegetation cover.

i. Barchans

Barchans are crescent-shaped dunes, with the horns of the crescent pointing downwind. They commonly form in desert regions where there is a hard, flat surface, a constant wind direction and a relatively limited sand supply. These dunes lack vegetation, are highly mobile and have steep slip-faces on their downwind sides (Fig. 9.10 a). Barchans grow to heights as great as 30 m and widths up to 350 m.



*Fig. 9.10 a
Barchans*

ii. Longitudinal Dunes

Longitudinal dunes are long, straight, ridge-shaped dunes parallel with the wind direction. They form in desert areas where the sand supply is moderate and winds usually blow from the same general direction (Fig. 9.10 b).



*Fig. 9.10 b
Longitudinal dunes*

iii. Transverse Dunes

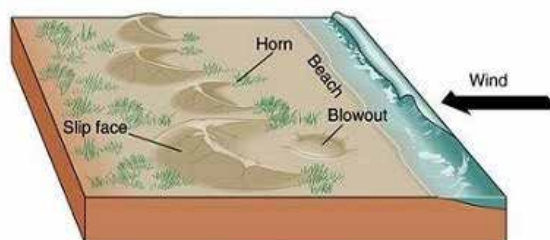
Transverse dunes are dunes forming wave-like ridges transverse (at right angles) to wind direction (Fig. 9.10 c). These dunes form where sediment supply is abundant and the wind blows in constant direction. If the supply of sand increases, then, the barchan dunes merge into transverse dunes.



*Fig. 9.10 c
Transverse dunes*

iv. Parabolic Dunes

Parabolic dunes (also called U-shaped dunes) have their open end pointing upwind, which is the opposite of barchans. The steep slip-face is located on the convex side of the dune (Fig. 9.10 d). These dunes typically form where there is abundant vegetation, plentiful supply of sand and a fairly constant wind direction.



*Fig. 9.10 d
Parabolic dunes*



Do it Yourself

You can simulate and study the geological activity of wind and the formation of sand dunes at home using simple materials. This activity allows you to observe the processes of erosion, transportation, and deposition.

Materials

A large, flat container (such as a shoebox lid or shallow tray), fine-grained sand, a hair dryer or a straw to blow air, pebbles, pieces of dried moss or lichen (to represent vegetation), safety glasses or goggles

Procedure

1. Spread a thin layer of fine sand across the container.
2. Place small obstacles (pebbles, rocks, moss, or lichen) on the sand surface to simulate natural features such as rocks and vegetation.
3. Put on safety glasses or goggles to protect your eyes from the blowing sand.
4. Use the hair dryer or gently blow through a straw to create 'wind' across the sand surface.
5. Observe how the sand moves. Notice to where sand is removed (erosion), how it is carried by the wind (transportation), and where it settles to form small dunes (deposition).

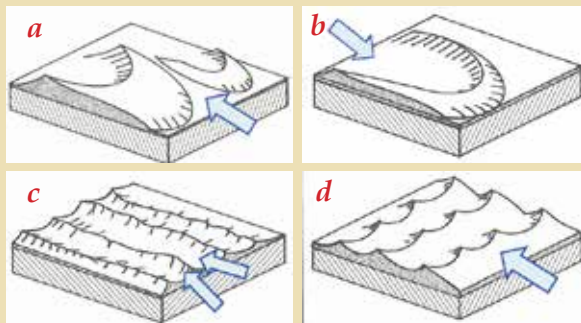
Observation

As air moves across the surface, it lifts (erodes) and transports sand grains. When the wind slows down, often behind obstacles, the sand is deposited, gradually forming small dune-like shapes.



Check your progress

1. Which locations on the Earth are prone to the formation of aeolian landforms?
2. Do the direction of wind, sand supply, and vegetation influence sand dunes?
3. Can you identify the types of dunes shown in the given figures?
4. How do an oasis and a desert pavement form?



9.4 Glaciers

You know that some places on the Earth are so cold that water of those regions exists in solid form i.e., ice or snow. Scientists group these frozen parts of our planet together under the term **cryosphere**. Glaciers form an important component of the cryosphere. Today, about 11% of the Earth's land area is covered by ice. **Glaciology** is the branch of geology that deals with the study of glaciers.

A glacier is a large, long-lasting mass of ice, formed on land by the compaction and recrystallization of snow. It shows evidence of present or past motion. The solid masses of ice capable of movement, under the influence of gravity considered as glaciers.

Widespread occurrence of glaciers on Earth during a particular period of time in geological past is termed **Glacial Period or Ice Age**. There are numerous geological records that indicate the occurrences of several ice ages during the history of the Earth. The concept of '**Snowball Earth**' describes the coldest global climate imaginable – a planet covered by glacial ice from pole to pole. Scientists believe that our planet was covered by ice from pole to pole, at least twice, for long periods, in the geological past.

9.5 Formation of Glacial Ice

The glaciers are formed from snow. Snow is precipitation made up of ice crystals. The detailed formation of glacial ice is described below.

Snow crystals form in nature when cold temperatures and high humidity levels combine in the atmosphere. As long as air temperature remains below the freezing point, snow crystals will rain down to the ground. It exhibits feathery hexagonal habit and possesses high porosity and will contain mostly air (up to 90%) by volume.

The snow layer originally composed of delicate hexagonal snow crystals, gradually changes to an aggregate of spherical grains (Fig. 9.11). This process also leads to a reduction in porosity. This intermediate stage in the transformation of snow to glacial ice is known as '**firn**' or '**névé**'.

Firn is partially compacted névé, a type of snow that has been left over from past seasons

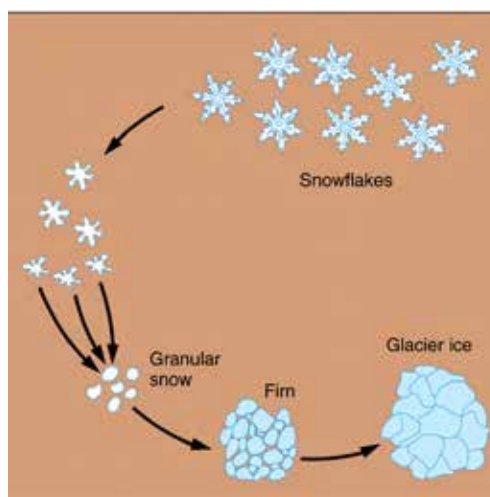


Fig. 9.11
Formation of glacial ice

and has been recrystallized into a substance denser than névé. It is ice that is at an intermediate stage between snow and glacial ice. Further compaction, as a result of melting of individual grains and accompanying recrystallization, transforms névé or firn to glacial



Know More

Glacial Terminology

Zone of accumulation: Snow falls in the zone of accumulation, usually in the part of the glacier with the highest elevation beyond the snowline and adds to the glacier's mass. As the snow slowly accumulates and is transformed to glacial ice, the glacier increases in thickness, forcing down-slope movement.

Zone of ablation: Further down, the glacier is in the ablation zone, where most of the melting and evaporation occur.

Ablation can be defined as the collective processes that remove snow, ice or water from a glacier or snow field. Loss by ablation involves melting, evaporation, sublimation, calving (glacier calving or iceberg calving) or erosive removal of snow by wind (deflation).

A **snowline** is a boundary marking where snow cover meets snow-free ground, which varies by altitude, latitude, climate and slope. Snowline refers to the level of a glacier covered region above which snow is permanently found throughout the year. It marks the base of the permanent ice cover on the mountains. Snowfield refers to the area situated at a level above the snowline.

Sublimation is the transition of a substance directly from the solid to the gaseous phase without passing through an intermediate liquid phase.

Calving is the breaking off of chunks of ice at the edge of a glacier where it meets a sea or a large body of standing water. It involves a sudden release and breaking away of a mass of ice from the terminus of a glacier.

Icebergs are the floating masses of glacial ice that have broken or calved from the seaward end of either a glacier or an ice shelf.

ice.

9.6 Distribution of Glaciers

Glaciers are found chiefly in

- i. The Polar and sub-Polar regions
- ii. At mountainous zones of very high elevations, such as the Himalayan Mountains or Alps Mountains.

Glaciers are found in widely scattered mountainous regions of North America, South America, Europe, Asia, Africa and Australia. In India only the Himalayas, 'the abode of snow', has many glaciers

distributed throughout its higher elevations. One of the largest occurrences of snow or ice outside the Polar Regions occurs in the Himalayan ranges. It is estimated that 33,200 km² of the Himalayan region is covered with ice (18%). The glaciers of the Himalayan Mountains are the major sources of fresh water and all the rivers of northern India are nourished by the melt waters of the Himalayas.

9.7 Types of Glaciers

Basically, three types of glaciers can be recognized in nature, namely,

- i. Mountain glaciers or Alpine glaciers,
- ii. Continental glaciers or ice sheets,
- iii. Ice shelves.

9.7.1 Mountain Glaciers (Alpine Glaciers)

Glaciers that form in high mountains, known as mountain glaciers, are generally small and are confined to distinct valleys. They are also known as Alpine glaciers because these are found confined to the high mountain ranges such as the Alps. Maximum widths of mountain glaciers may be a few hundred meters and thicknesses a few tens of meters. Most of you are probably aware of the fact that the Himalayan Mountains of our country gets its name from its association with glacial ice and snow at its peaks and valleys.

9.7.2 Continental Glaciers (Ice Sheets)

Continental glaciers form in high latitudes and are generally much larger and thicker than



Know More

Movement of Glaciers

Glaciers move to lower elevations under the force of gravity by two different processes:

1. Internal Flow: *This results from deformation of the ice crystal structure - the crystals slide over each other like deck of cards. This type of movement is the only type that occurs in polar/continental glaciers, but it also occurs in temperate glaciers.*

2. Basal sliding: *Meltwater at the base of glacier reduces friction by lubricating the surface and allowing the glacier to slide across its bed. Polar glaciers are usually frozen to their bed, and thus, too cold for this mechanism to occur.*

The upper portions of glaciers are brittle, whereas the lower portion deforms by internal flow, and the upper portions may fracture to form large cracks called crevasses.

Movement of continental glaciers is not unidirectional (as in valley glaciers), but radial and outward from their zones of accumulations. The direction of the movement of continental glaciers is different from that of the mountain glaciers. These do not usually move downhill with respect to the land beneath them, but rather from areas of thicker to thinner margins. In many cases, this is actually uphill with respect to the ground! The thicker zones correspond to the zone of accumulation and their thinner zones to the zone of ablation.

Alpine glaciers are not confined to specific valleys. These are the largest types of glaciers found on the earth. Some of these attain continental dimensions. Ice sheets or continental glaciers occur in Greenland and Antarctica, and these two comprise about 95 percent of total glacial ice on the Earth.

Continental glaciers may cover several million square kilometers and may reach many kilometers thick. These glaciers bury even mountain ranges of the region where they occur. Mountain peaks that project out prominently above the general surface of a continental glacier are called **nunataks**.

9.7.3 Ice Shelves

Extensive sheets of glacial ice found floating on water forming a seaward continuation of a land glacier is called an ice shelf. Some of these extend hundreds of kilometers away from the land and reach thicknesses exceeding one kilometer.



Do you Know!!!

The world's largest glacier is the Lambert Glacier in Antarctica, measuring approximately 100 km in width, 400 km in length, and up to 2.5 km in depth. It exceeds the size of Kerala!



Check your progress

Fill in the blanks.

1. Glaciers move under the influence of _____
2. The intermediate stage in the transformation of snow to glacial ice is known as _____
3. Which is the largest type of glaciers found on earth?
4. _____ is the mechanical removal of pieces of rock from bed rock surfaces that are in contact with moving glacier.

9.8 Geological Work of Glaciers

Like all other geological agents, glaciers also act as agents of erosion of land surface, transporting the eroded materials and finally depositing the materials in various locations. During these processes they give rise to a variety of unique landforms, characteristic of glacial action. They create new landforms as well as modify the pre-existing ones.

9.8.1 Glacial Erosion

Erosive work by glaciers is accomplished chiefly through the processes of glacial plucking and abrasion.

a. Glacial Plucking

Glacial plucking is the mechanical removal of pieces of rock, or particle detachment from bed rock surfaces that are in contact with moving glacier. In this process, basal ice freezes in cracks of underlying rocks. As the main body of the glacial ice moves, rock fragments are pulled off from the parent rock and plucked out. The basal portion of glaciers will be carrying enormous quantities of glacially plucked, mostly angular rock fragments, of varied sizes and shapes. These act as tools for the process of abrasion.

b. Glacial Abrasion

Glacial abrasion is the process of mechanical scraping of a rock surface by friction between rocks and moving particles during their transport by glacier. Rock fragments, from varied sources that are incorporated within a glacier, will be distributed throughout the mass of a glacier. Those at the basal portion and its flanks act as tools for the process of abrasion of rocks with which it will come into contact. As a result of abrasion, various sorts of grooves and striations are formed in the rocks of the glaciated regions. These are described below.

Glacial grooves are linear depressions, centimeters to kilometers in length, produced by the removal of rock material by the abrasive action of a glacier. The less prominent **glacial striations** (Fig. 9.12) are scratches cut into bedrock by glacial abrasion.



Fig. 9.12
Glacial striations

Chatter marks are small, curved (crescent-shaped) or wedge-shaped fractures that generally range from one to five centimeters, formed by the pressure and impact of boulders moved along by irregular rolling or sliding around on hard, brittle rocks (such as granite) of glaciated regions (Fig. 9.13). These resemble chatter of a carpenter's chisel slipping along the surface of a piece of wood, and hence the



Fig. 9.13
Chatter marks

name. Chatter marks are commonly arranged in nested series, with the orientation of the fractures at right angles to the direction of ice movement.

9.8.2 Landforms Formed by Glacial Erosion

Now let us learn some of the common landforms created by the process of glacial erosion.

a. Cirques

Cirques are often the starting point of a mountain glacier or Alpine glacier. This is known also under the name '**corrie**'. A cirque may be defined as a semicircular or half bowl-shaped depression present at the valley head in a glaciated mountain. They are arm-chair like depressions (Fig. 9.14 a, b). Cirques are invariably bounded on three sides by steep walls. Generally, they range in diameter from a few meters to a few kilometers.

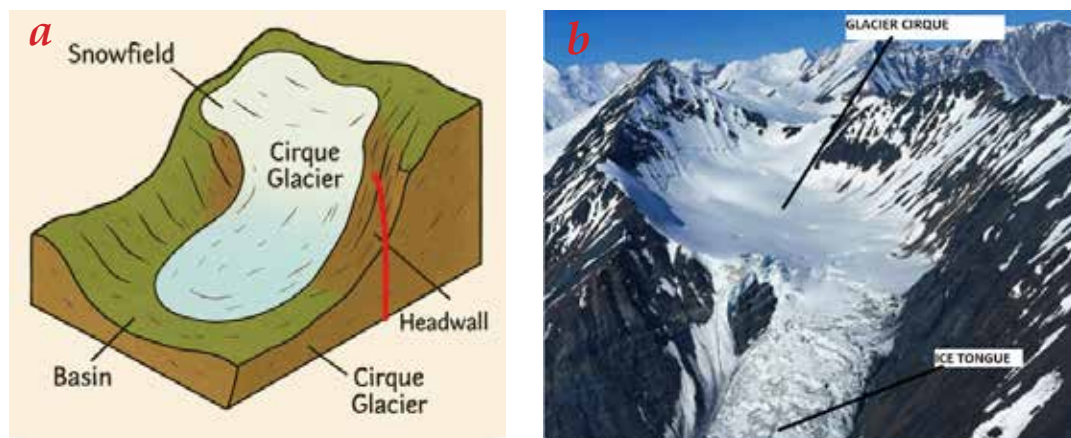


Fig. 9.14
Glacier Cirque



Fig. 9.15
Tarn

Cirques result from a combination of frost wedging, glacial plucking and abrasion. After the disappearance of glaciers, the depression of cirques will be sometimes occupied by a small circular lake. Such lakes are called **tarns** (Fig. 9.15).

b. Arete

An **arête** is a knife-edge like ridge, formed when two neighboring cirques (corries) erode back-to-back and meet (Fig. 9.16). As each glacier erodes either

side of the ridge, the edge becomes steeper and the ridge becomes narrower.

c. Horn or Pyramidal Peak

Horns are mountain peaks or pinnacles, progressively thinned by glacial erosion from three or more glacial cirques. These are also known as pyramidal peaks (Fig. 9.16) and are formed in mountainous areas where three or more cirques (Corries) and arêtes meet and where the valley glaciers carved away the peak of a mountain, creating a sharply pointed summit. Matter horn in Alps is the best known example.

d. Col

Glacial erosion of two cirques, located on both sides of a mountain results in a mountain pass, is known as a col (Fig. 9.16). The term is exclusively used in the description of topography of glaciated regions. Cols, like gaps, offer convenient and short communication routes or passage ways permitting movement of men and animals across mountain chains.

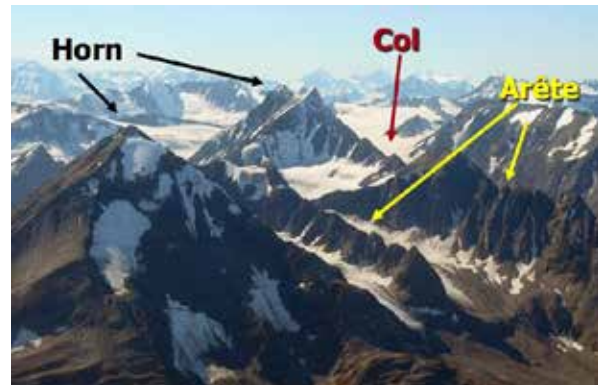


Fig. 9.16
Horn, Col and Arête

e. Glacial Valley (Glacial Trough)

A glacial trough is a mountain valley reshaped or modified by glacial action into a valley with a flat floor and steep sides.

Glaciers (valley glaciers) that occupy valleys of mountainous regions modify these, in due course of time, into valleys with a U-shaped transverse section (cross section) (Fig. 9.17). Such glacial valleys or glacial troughs have broad bottoms and steeper sides, in contrast to the ordinary stream valleys of the region. The diagrammatic representation of the developmental stages of a glacial valley or glacial trough from a stream valley is shown in the Fig. 9.18.



Fig. 9.17
Glacial valley (glacial trough)

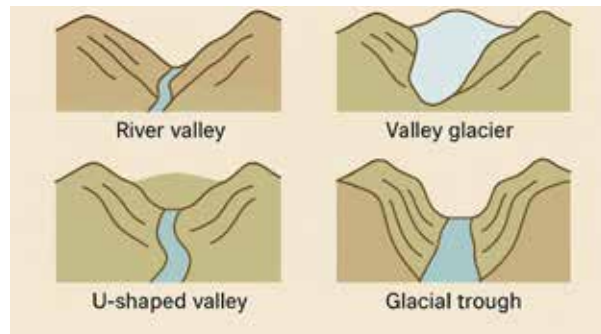


Fig. 9.18
Development of glacial valley



Fig. 9.19
Hanging valley

f. Hanging Valley

Hanging valleys form where glaciers or former valleys intersect at different elevations. When a smaller tributary glacier joins a larger main glacier, it lacks the erosive power to cut its valley floor down to the same depth as the main valley. After the ice melts, the tributary valleys hang above the main valley floor, and such valleys are called Hanging Valleys (Fig. 9.19). Waterfalls occur where the hanging valley meets the main valley.



Check your progress

1. Which is a glacial trough?
2. Which erosive mechanism is involved in the formation of glacial grooves?
3. Which erosional feature is formed by the joining of two cirques?

9.8.3 Glacial Transport

There are various sources that supply rock materials to a glacier. In addition to the materials eroded by glaciers (through the processes of glacial plucking and glacial abrasion), various other sources also supply materials to the total load carried by a glacier. In the case of mountain glaciers, the dominant share of the load carried by a glacier is supplied by the valley walls on either side of the glaciers.

Unlike a stream, a glacier is capable of carrying rock materials not only along its bottom or basal portion, but also on its surface and within its entire body. The general term **moraine** is applied for the rock material in transit and this term is also used to describe the rock materials ultimately deposited by a glacier.

9.8.4 Glacial Deposition

Glaciers carry enormous quantities of heterogeneous materials and when they melt, these materials get deposited. Glacial deposits are characteristically unsorted. Unlike streams, no sorting is observable in the case of glacial deposition. The process results in the dumping of a heterogeneous and jumbled mass of rock fragments, ranging in

size from finest clay particles, silt, pebbles, cobbles and boulders, derived by various means.

9.8.5 Glacial Drift

The term glacial drift is used as a general term for all materials transported and deposited directly by or from the glacial ice, or by water running off from the terminus of a glacier undergoing melting (melt-water streams). There are two categories of glacial drifts, namely:

(a) Till or unstratified drift and (b) Fluvio-glacial or stratified drift.

a. Till

The unsorted and unlayered rock debris carried or deposited by a glacier is called till.

b. Fluvio-glacial Drift

All those accumulations of glacial origin where meltwaters have played a prominent part in their deposition are called fluvio-glacial, glacio-fluvial or stratified drifts. As they are transported by meltwater streams, these deposits frequently exhibit the typical characteristics of alluvial deposits. However, these are often less sorted in terms of their particle size.

9.8.6 Landforms of Glacial Deposition

Glacial deposits form a variety of characteristic landforms in regions from where both mountain glaciers and continental glaciers have retreated during the recent past. These are briefly described below.

a. Morainic Landforms

Moraines are accumulations of rock debris (till) deposited by glaciers along their sides, at their base or at their ends. There are different types of moraines.

- i. **Ground Moraine:** A gently rolling ground surface underlain by till deposited beneath a glacier and usually bordered by terminal moraines (described below) is called ground moraine.
- ii. **Terminal Moraine or End Moraine:** A ridge formed by the accumulation of glacial deposits, deposited at the farthest point reached by an advancing glacier.
- iii. **Recessional Moraine:** A ridge like deposit of glacial till, composed of unsorted, unconsolidated debris, that forms transversely across a valley during a temporary standstill or slight re-advance of a retreating glacier.



Know More

Types of moraines

Based on their location in relation to the body of the glacier the following categories of moraines are recognized:

1. Superglacial moraine (morainic materials occurring on the surface or top of a valley glacier)
2. Englacial moraine (those occurring within a glacier)
3. Subglacial moraine (morainic materials carried and moving along the basal portion of a glacier).

Superglacial moraines are further classified in to the following types:

a. Lateral moraines

These are thin or thick streaks or ridges of rock debris that generally extend all along the sides of a glacier or where the ice meets the valley walls.

b. Medial moraines

Where two mountain glaciers converge or when two tributary glaciers merge, their lateral moraines unite to form a dark band of rock fragments traceable along the medial portion of the resulting glacier. These are known as medial moraines.

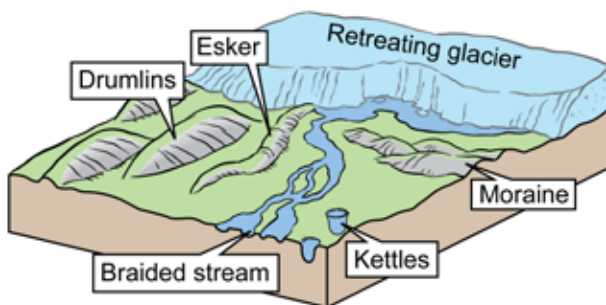
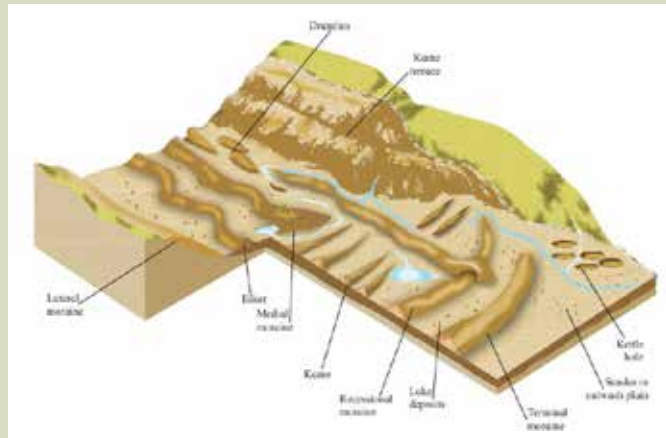


Fig 9. 20
Drumlins

b. Drumlins

A drumlin is a smooth, glacially streamlined hill that is elongate in the direction of ice movement and composed of till and, in many cases, even the bedrock (Fig. 9.20). These glacially deposited landforms may stretch over several kilometers.

They are typically groups, clusters or swarms and produce drumlin fields and the associated topography is sometimes described as **basket of eggs topography**.

c. Esker

The term 'esker' is given for a sinuously curving, narrow ridge of stratified glacial sediments deposited by meltwater streams formed in water filled tunnels beneath, above and within the ice (Fig. 9.21). Eskers are one of several types of landforms associated with deglaciation. Eskers are most common in areas of continental glaciation. The most extensive esker formations in the world are found in Canada where some of these are up to 800 km long, but most of these are not continuous ridges. Due to their long winding shape, many roads are built on top of eskers.



*Fig. 9. 21
Eskers*

d. Erratics

Huge rock boulders carried and transported within a glacier and deposited several kilometers away from their source as the glacier melts are called erratics (Fig 9.21). An erratic is an ice-transported piece of rock that has not been derived from underlying bedrock, for example, a volcanic erratic boulder located over a region of sedimentary rocks. Erratic rock boulders vary in size from small boulders to boulders of enormous size.



*Fig. 9.22
Erratics*

9.9 Glaciation and Ice Ages

Glaciation is the modification of the land surface by the action of glaciers. The geological periods during which large scale glaciations have occurred are called **Ice Ages**. At the peak of glaciations, about 25 to 32% of the earth's land surface was glaciated (in contrast to the present 10%). Pleistocene glaciations were the last ice ages that the earth had experienced. In the Pleistocene epoch, many parts of the northern Europe and northern parts of North America were covered by glaciers.

Glaciation has occurred so recently in North America and Europe that weathering, mass wasting and stream erosion have not had enough time to significantly alter the landscape. Thus, the evidences of glacial erosion and deposition are still present on different parts of the earth's surface.



Check your progress

1. Match the following

A	B
Peak formed by meeting of cirques	Erratic
Unsorted glacial debris	Horn
Large boulder carried by glacier	Moraines

2. Name the following

1. A half bowl-shaped depression found at the head of a glaciated valley.
2. Lakes formed after the disappearance of cirque glaciers

Summary

A moving mass of air is called wind, which serves as an important geological agent. Its action is especially significant in arid regions lacking vegetation and in coastal plains. Wind shapes the landscape, producing landforms that are distinct from those formed by other geological agents. Erosional features formed by wind include mushroom rocks (pedestal rocks), deflation basins, deflation hollows, blowouts and ventifacts. Common aeolian depositional landforms are sand dunes and loess. Sand dunes occur in various forms, including barchans, longitudinal dunes, transverse dunes and parabolic dunes.

A moving mass of ice is called a glacier. Glacial action is most significant in polar regions and high-altitude areas. Glaciers act as powerful agents of erosion, shaping the land as they move. They also transport the eroded materials and eventually deposit them, forming a variety of glacial landforms. Over geological time, the Earth has undergone several glaciation periods that have shaped its surface.

10 OCEANS

10.1 Introduction

Since the dawn of human history, the oceans have stirred our imagination. These vast blue bodies of water have offered food to nourish civilizations, paths for explorers to cross unknown horizons and pathways for trade that connected cultures and ideas. Through the ages, oceans have been life's cradle, mankind's pantry and humanity's wonder.

Oceans support an enormous variety of plant and animal life, providing food, habitat and breeding grounds for countless species. Additionally, billions of people around the world depend on oceans for food, transportation, trade and employment.

We often imagine the Earth in terms of its land, but in reality, oceans cover more than two-thirds of the Earth's surface, making them the largest habitat on our planet. Oceans hold the majority of the Earth's water, accounting for 97% of all surface water in the hydrosphere. All of this water is not distributed equally over the Earth; 61% of the Northern Hemisphere and 81% of the Southern Hemisphere are covered by oceans. Majority of the Earth's landmass – around 68% of the total – is located north of the Equator. Hence, the Northern Hemisphere is called **Land Hemisphere**. On the other hand, the Southern Hemisphere is named **Water Hemisphere**. Let us explore the vast oceans that cover our planet, mainly focusing on its geological aspects. Marine Geology, also known as Geological Oceanography, deals with geological aspects of oceans, essentially aimed at exploring and exploiting marine resources.

10.2 Marine and Coastal Water Bodies

Oceans are the vast, connected bodies of saltwater. Oceans together form a single, continuous body of water known as the World Ocean. It is traditionally divided into five major oceans (Fig. 10.1). These five major oceans are the Pacific, the Atlantic, the Indian, the Southern, and the Arctic oceans. Among these, the Pacific Ocean is the largest and the deepest.

Sea is a smaller part of an ocean that is partly enclosed by land. Most of them are marginal portions of oceans. For example, the Arabian Sea and the Andaman Sea are parts of the Indian Ocean. Certain seas are fully landlocked. The Caspian Sea and Aral Sea are examples of seas that are not connected to ocean. Geomorphologically,

the Caspian Sea may be classed as a lake, but its size, salinity and historical connection to ancient oceans make it to be treated as sea. Similarly, the Dead Sea, known for its hypersalinity, is also a lake. The term sea is sometimes referred to the entire oceans as in the Law of the Sea. Anything related to the sea or ocean, especially its water, life and processes is described as **marine**.



Fig. 10.1
World ocean

Any indentation in a shoreline, a recess or inlet in the shore of a sea (or lake) is called an embayment. A bay is a recessed, coastal body of water that directly connects to a larger main body of water, such as an ocean, a lake, or another bay. The Bay of Bengal, a part of the Indian Ocean, is the largest bay in the world. A large bay, but more enclosed with is usually narrower mouth to open ocean called a gulf. It can be considered as a relatively large portion of ocean or sea, partly enclosed by land. Examples of gulfs include the Gulf of Kutch, the Gulf of Cambay and the Gulf of Mannar.

An **estuary** or river mouth is a partially enclosed coastal body of brackish water, which forms a transition zone between river and marine environments.

Oceans play a vital role in regulating climate by controlling temperature, humidity and influencing patterns of rainfall. Oceans continuously shape and reshape landforms through action of waves, tides and currents. Therefore, oceans play crucial role in the Earth's ecological balance, human livelihood and the overall functioning of life on our planet.



Do it Yourself

Examine the five major oceans illustrated in Figure 10.1 and mark the important seas associated with each ocean on a world map.

10.3 Composition of Sea Water

Sea water is a complex mixture of water and several dissolved salts. Salinity refers to the total amount of dissolved salts present in seawater. The salts and ions dissolved in seawater determine its salinity, which is expressed as grams of salt per 1000 gram of sea water. On an average, seawater contains about 35 grams of salts per kilogram of water, which is expressed as 35 parts per thousand (35 ‰ or 35 ppt).

Have you ever thought what makes seawater salty and which are the salts present in it? Examine the diagram showing salinity composition (Fig. 10.2). Calculate what percentage of the dissolved salts are contributed by sodium (Na^+) and chloride (Cl^-) together. What does this reveal about the dominant salt in seawater? If heavy rainfall occurs over an ocean region, how would the composition of salts shown in the table be affected? Give the findings in your activity log.



Know More

A **coastal lagoon** is a shallow, brackish body of water that is separated from the ocean by a natural barrier like sand bar, spit or reef. It is partially enclosed by land and connected to the sea having tidal influence. Chilika Lake in Odisha, the largest brackish water coastal lagoon in India, is an example.

Backwater is the water that is 'backed up' or held back by an obstruction like an opposing current, or tide, resulting in a part of a river or lake with very little or no current. The Backwaters in Kerala are formed by a network of lakes, canals and lagoons which are fed by rivers but separated from the open sea by a sand bar or barrier.

Nearshore wetlands are transitional ecosystems where land and water meet along certain coastlines. They are influenced by waves and tides.

Mangroves are a specific type of coastal wetland dominated by salt-tolerant trees.

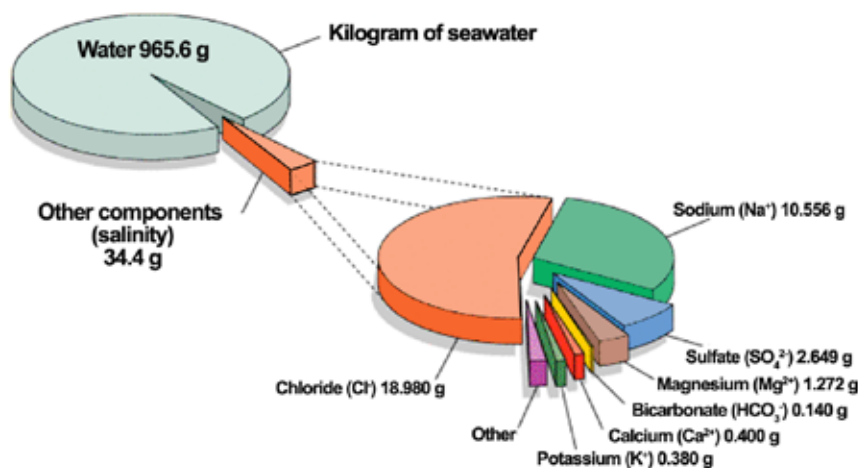


Fig. 10.2
Major constituents of sea water

You have realized that most of these ions are chloride and sodium, the components of common salt (NaCl), which together account for over 85% of the dissolved salts, giving seawater its characteristic salty taste. Other important ions include sulphate (SO_4^{2-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^+) and bicarbonate (HCO_3^-).

All the salts and ions dissolved in seawater contribute to its overall salinity. It can vary significantly from one region to another. Since proportions of major ions remain fairly constant, these regional differences are primarily due to variations in water input and addition or removal of ions. Freshwater input comes from rainfall, river discharge and melting of ice, while freshwater removal occurs through evaporation and ice formation. When seawater freezes, most of the salts are left behind, making the remaining water more salty.

Do you Know!!!

Equatorial regions, although hot and experiencing strong evaporation, often have slightly lower surface salinity because of frequent heavy rainfall that dilutes seawater.

The highest salinity is typically found in subtropical, warm regions where evaporation is high and precipitation is low, such as the Mediterranean Sea and the Red Sea (around 40 ppt). Conversely, polar regions have low surface

salinity due to minimal evaporation and addition of melt water. For example, the Baltic Sea has a low surface salinity of about 10 ppt, because it is largely enclosed and receives abundant river input.

One of the saltiest large bodies of water in the Earth is the Dead Sea, located between Israel and Jordan, with a salinity of about 330 ppt, caused by extreme evaporation in a hot, dry climate.

Do it Yourself

Materials and requirements

Three transparent glasses/beakers, water, salt, spoon, marker or labels (A, B, C), a sunny place or warm area.

Procedure

1. Take three transparent glasses and label them as:

A – Normal sea water

B – Fresh water inflow

C – Evaporation

2. Pour the same amount of water into all three glasses.
3. Add one teaspoon of salt to each glass, stir well until the salt dissolves completely and taste the saltiness of water.
4. Keep Glass A (normal sea water) aside without making any change.
5. Add some extra plain water into Glass B (fresh water inflow) and stir gently.
6. Place glass C (evaporation) in sunlight for a few days or boil up to half of the original volume to allow evaporation.
7. Taste the water and observe the changes in salinity in each glass and record your observations.

Observations

In Glass A, which was kept unchanged, no noticeable change in saltiness was observed. When extra fresh water was added in Glass B, the saltiness of the water decreased. When the water was allowed to evaporate (Glass C), the saltiness increased.

10.4 Topography of the Ocean Floor

We are familiar with mountains, plains and valleys that shape the continents, but what about the ocean floor? If we could drain all water from oceans, what kind of landscape would appear? Now we will have a look at the topography of the ocean floor.

The ocean floor is neither flat nor of uniform elevation; instead, it is a dynamic and complex surface that includes diverse geological features such as mountains, valleys, plains and trenches. Beneath the vast water body lies a world that is still largely to be explored. Although these features are hidden under water, modern techniques such as sonar mapping and satellite altimetry have revealed the varied topography of the ocean floor. Broadly, the ocean floor is divided into two major parts: continental margin and deep-ocean floor.

10.4.1 Continental Margin

If you were to walk from the shore straight into the ocean, what characteristic changes would you experience as you move to the deeper parts of the ocean floor? Analyse the given diagram (Fig. 10.3). The diagram shows major parts of a continental margin, with three main zones that mark the boundary between the continents and oceans. Instead of ending sharply at the shoreline, the continents gradually slope down under the sea, exhibiting

marginal features such as continental shelf, continental slope and continental rise. Continental margins are the region of transition from land to the deep sea.

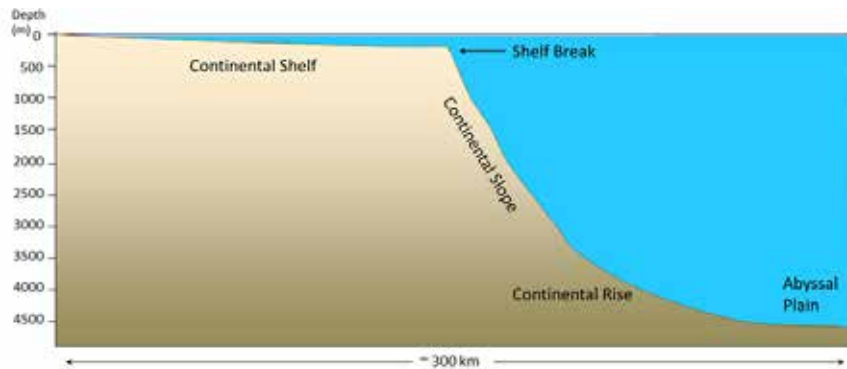


Fig. 10.3
Schematic diagram of continental margin

a. Continental Shelf

Continental shelf is the gently sloping, submerged edge of continents. It begins from the shoreline and extends into the sea until the point where the slope becomes steep. On an average, it is about 150–200 m deep and extends around 70 km from the coast. Some shelves are much wider, such as the Siberian Shelf in the Arctic, which stretches about 1,500 km. Some of the narrowest continental shelves (10 – 15 km) are found along the Pacific coast of South America.

Sunlight penetrating shallow parts of the shelf allow rich growth of plankton and other marine life. This makes the continental shelf one of the most productive fishing grounds in the world. Moreover, it contains valuable resources such as oil, natural gas, and minerals. Most continental shelves are located within the territorial waters and Exclusive Economic Zones (EEZs) of coastal nations. Territorial waters extend 12 nautical miles (22.2 km) from the shore, while EEZs extend out to 200 nautical miles (370.4 km) from the coast. Within these zones, every country has sovereign rights to explore, exploit, conserve and manage natural resources, both living and non-living, found on and beneath the continental shelf. The United Nations Convention on the Law of the Sea (UNCLOS) is the primary international agreement governing the use and protection of the oceans, including continental shelves.

b. Continental Slope

Beyond the shelf lies continental slope. This is a much steeper section of the sea floor, descending from the edge of the continental shelf to

the deep ocean basin at an average angle of 2° to 5° . The slope generally extends from a depth of 200 m to nearly 3,000 m. Submarine canyons, mostly carved by ancient rivers, are common features on the slope. These canyons act as natural channels through which sediments from the land are carried to the deep ocean floor.

c. Continental Rise

Continental rise is a gently sloping area at the base of the continental slope, formed by the accumulation of sediments that have been transported down the slope. It is made up of thick sequences of continental material that accumulate between the continental slope and the abyssal plain. Continental rises form mainly due to mass movements, deep ocean currents and vertical settling of the sediments.

The continental shelf, slope and rise together make up the continental margin. Beyond the continental margin lies the vast deep-ocean basin, which covers majority of the ocean floor.

10.4.2 Features of the Deep Ocean Floor

Let us now examine the features of the deep ocean floor. Beyond the continental margins, the ocean floor shows a variety of landforms such as abyssal plains, ridges, trenches and seamounts (Fig. 10.4).



Know More

Continental shelf of India's coast

As width of the continental shelf varies widely around the world, it also varies greatly along India's coast. India's continental shelf covers a large area of the surrounding seas, forming part of its territorial waters and supporting rich marine resources. Along the western coast of India, the shelf is generally wider, reaching its maximum width of 345 km, off the coasts of Daman, and gradually narrowing southwards towards Kerala. In contrast, along the eastern coast (Bay of Bengal), the shelf is generally narrower but becomes wider near major river deltas such as the Ganga-Brahmaputra, Mahanadi, Godavari, Krishna and Cauvery, where large amounts of sediments are deposited. Off Kerala's coast, the shelf width is relatively narrow, about 65 km. The shelf break usually occurs at a depth of about 140 m, and these variations in shelf width influence coastal processes, marine biodiversity and fishing potential.

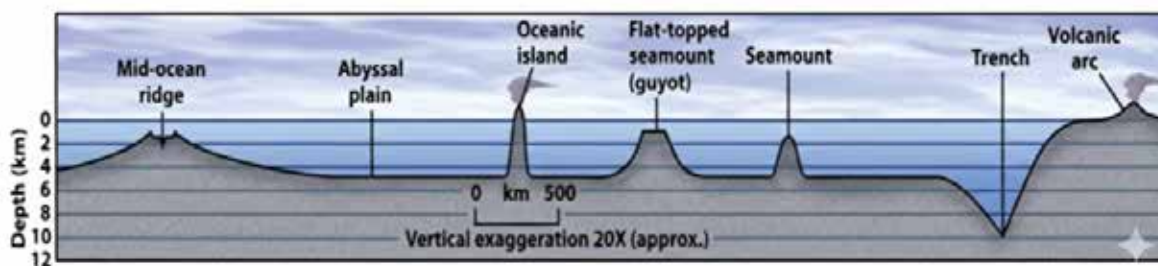


Fig. 10.4
Major topographic features of the ocean floor

a. Abyssal Plains

The abyssal plains are the flattest and deepest region on the Earth, extending from the base of the continental slope at depths of 3,000 to 6,000 m below sea level. They are covered by fine sediments brought by river, wind and ocean currents, which gradually accumulated over millions of years. They are interrupted occasionally by deep sea features such as ridges, trenches and seamounts. Though sunlight never reaches such great depths, these plains are not lifeless. Specially adapted organisms live here in the cold, dark environment. These plains cover about 70% of the ocean floor forming the largest habitat on earth.

b. Mid-Oceanic Ridges

Mid-ocean ridge (MOR) , also called oceanic ridge, is a long chain of submarine mountains that stretches for about 80,000 km through all the oceans. It is the largest mountain system on the Earth, even though most of it lies hidden beneath the sea. It typically has a depth of about 2,600 m and rises about 2,000 m above the deepest portion of an ocean basin.

If you want to scale the tallest mountain on Earth from its base to its peak, you would have to dive down almost 6 km under the surface of the Pacific Ocean to the sea floor to climb Mauna Kea on the Big Island of Hawaii. Although this peak reaches only 4,207 m above sea level, the mountain extends another about 6,000 m below the surface — a total height of about 10,210 m from base to summit. Remember that Mt. Everest has an elevation of only 8,849.9 m above sea level.

The Mid-Atlantic Ridge is the most studied oceanic ridge that runs roughly north-south through the centre of the Atlantic Ocean. It continues into the Indian Ocean as the Mid-Indian Ridge, forming part of the global oceanic ridge system. All the ridges together form one continuous global oceanic ridge system. The Mid-Indian Ridge System is a network of ridges, including the Mid-Indian Ridge, Carlsberg Ridge, and the Southwest and Southeast Indian Ridges. This ridge system extends across the basin of Indian Ocean.

The MOR mark divergent plate boundaries along which new ocean floor is created. Magma from the mantle rises along the axis of the ridge. This magma then cools and creates new oceanic crusts pushing the seafloor on either side to spread.

It must be remembered that there are certain ocean ridges that are tectonically and magmatically inactive. They are called aseismic ridges (e.g., The Ninety East Ridge in the Pacific ocean)

c. Oceanic Trenches

Oceanic trenches are long, narrow and steep-sided depressions that form along the margin of ocean basins, usually near continental edges or island arcs. These are the deepest parts of the ocean floor and are among the most striking topographic features of the deep ocean basins. They are typically 50 to 100 km wide and 3 to 4 km below the level of the surrounding oceanic floor, but can be thousands of kilometers long.

Trenches typically occur where one tectonic plate is subducted beneath another, marking convergent plate boundaries. A trench marks the position at which the subducting slab begins to descend beneath another lithospheric slab. There are about 50,000 km of oceanic trenches worldwide. Many trenches reach depths of more than 10 km, with some extending up to 200 km wide and over 2,400 km long. The Mariana Trench in the western Pacific Ocean and the Puerto Rico Trench in the North Atlantic are well-known examples. The main trenches in the Indian Ocean include the Java Trench (Sunda Trench), which is the deepest, the Diamantina Trench, the Chagos Trench and Mauritius Trench.

d. Seamounts and Guyots

Seamounts are conical submarine volcanic mountains that rise from ocean floor but do not reach sea surface. Seamounts are typically formed from extinct volcanoes that rise abruptly and have wide ranging heights from 100 to 4,000 m. They are not islands or cliff-rocks. The peaks of sea mounts are often found hundreds to thousands of meters below the surface.

Over geological time, the oceanic crust on which a seamount sits may subside, causing the seamount to sink deeper below the surface. If the top of the seamount is eroded flat by wave action before subsidence, it becomes a flat-topped seamount, known as a guyot or table mount. Guyots provide evidence of ancient volcanic islands that once stood above sea level before slowly sinking into the depths of the ocean. Now, analyse the given diagram and (Fig. 10.5) and find out the fundamental difference in appearance between volcanic island, seamount and guyot.

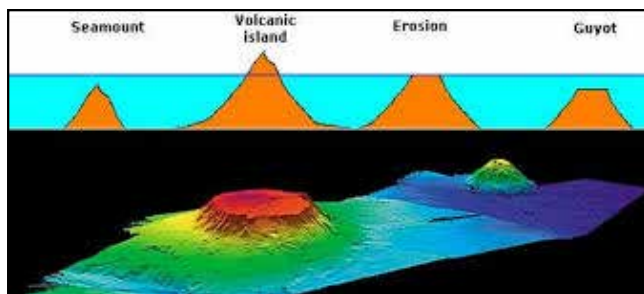


Fig. 10.5
Volcanic island, sea mount and guyot



Know More

Origin and significance of seamounts

Seamounts may originate in different tectonic settings. They form at (1) mid-ocean ridges (divergent boundaries), (2) ocean-ocean subduction zones (convergent boundaries) and (3) intra-plate hotspots. Over time, as tectonic plates move over a stationary hotspot, older seamounts can drift away from their magma source and new ones form above the hot spot, creating chain of volcanic islands and seamounts – such as the Hawaiian–Emperor chain in the Pacific Ocean. When a seamount grows large enough to reach above ocean surface, it forms a volcanic island.

What is the significance of seamounts? More than 14,500 seamounts have been identified, which cover a total area of nearly 9 million sq. km. Thus these are one of the most common marine ecosystems in the world. Seamounts are a possible future source of economically important metals. Their large numbers, non-availability of exact locations and large areal coverage have sometimes resulted in naval vessels accidentally colliding with uncharted seamounts. The collapse of flanks of sea mounts can lead to submarine landslides which in turn can trigger tsunamis.

e. Island Arcs

These are elongated chains of active volcanoes with severe seismic activity found along convergent plate boundaries where one oceanic plate is forced beneath another along subduction zone. The volcanoes are arranged in a curved, arc-like chain following the curvature of the subduction zone, and hence, the name. As descending plate sinks into the mantle, it melts due to high temperature and pressure. The resulting magma rises through overlying plate and reaches ocean floor, forming a line of volcanoes that appear as islands. A deep ocean trench is typically located on the oceanic side of the island arc, marking the line where subduction is occurring. These zones are characterized by frequent earthquakes due to immense force and movement of tectonic plates.

Well-known island arcs include Andaman-Nicobar Islands, Sunda Islands (Indonesia), Japanese Islands, the Philippines and the Aleutian Islands (between Alaska and Russia).

f. Submarine Canyons

A submarine canyon is a steep-sided valley cut into the seabed of the continental slope, sometimes extending well onto the continental shelf. These have nearly vertical walls. Many canyons have been noticed at depths greater than 2 km below sea level. Some may extend

seawards across continental shelves for hundreds of kilometres before reaching the abyssal plain.

There are an estimated 9,477 submarine canyons on the Earth, covering about 11% of the continental slope. Some well-known submarine canyons include Amazon Canyon, Congo Canyon, Hudson Canyon, Ganges Canyon and Indus Canyon. Just as land canyons serve as channels for the flow of water, submarine canyons serve as channels for the flow of **turbidity currents** across the seafloor.

In conclusion, the topography of the ocean floor is highly diverse, ranging from the shallow continental shelves to the deep abyssal plains. The study of the ocean floor helps us understand plate tectonics, marine ecosystems and the distribution of natural resources beneath the sea surface.



Know More

Turbidity currents

Turbidity currents are flows of dense, sediment - laden waters that are supplied by rivers or generated on the seabed by storms, submarine landslides, earthquakes and other disturbances. Turbidity currents travel downslope at great speed, eroding the continental slope and finally depositing sediment onto the abyssal plain.

10.5 Ocean Sediments

It is important to know about the ocean sediments as they are economically important in a world where terrestrial resources are fast depleting. Ocean sediments are derived through processes like weathering of pre-existing rocks on land (lithogenous), biological activity (biogenous), chemical precipitation from dissolved materials in seawater (hydrogenous) and falling of meteorite dust (cosmogenous).

Marine sediments are a crucial source of valuable resources like petroleum and natural gas (>30% of global oil is sourced offshore), gas hydrates (ice-like crystalline compounds of water and methane found in deep-ocean sediments under high pressure and low temperature, mineral resources like sand and gravel used for construction, polymetallic manganese nodules (rich in manganese, iron, and valuable metals such as copper, cobalt, and nickel), evaporative salts (halite - common salt & gypsum), precious metals and minerals like diamonds, tin, titanium, platinum, and gold.



Know More

Distribution of marine sediments

The distribution of marine sediments varies with location and type. The thickest marine deposits are near continental margins and the thinnest layers are at mid-ocean ridges. Coarse sediments accumulate near margins due to strong currents, while fine sediments settle in deeper, low-energy areas like abyssal plains. Biogenous sediments (from diatoms and foraminifera) are concentrated in high-productivity regions. The location of volcanic ash and cosmogenous dust depends on where they fall and the ocean currents in the region.

The Indus Fan: It is one of the most significant depositional features of the offshore Indus basin. It is the second largest fan system in the world. The Indus fan was deposited in an unconfined setting on the continental slope, rise and basin floor, covering much of the Arabian Sea. The entire fan extends over an area of 110,000 square km with greater than 9 km thick sediment cover accumulating near the bottom most part.

The Bengal Fan: It completely covers the floor of the Bay of Bengal, being about 3,000 km long, 1,430 km wide with a maximum thickness of 16.5 km. The fan is the result of the uplift and erosion of the Himalayas and the Tibetan Plateau produced by the collision between the Indian Plate and the Eurasian Plate. Most of the sediment is supplied by the Ganges and Brahmaputra rivers. Turbidity currents have transported the sediment through a series of submarine canyons, some of which are more than 2,414 km in length, to be deposited in the Bay of Bengal. The oldest sediments recovered from the Bengal fan are from Early Miocene age suggesting its origin to Himalayan orogeny.



Check your progress

1. Choose the correct answer from those given in brackets

(Continental Shelf, Abyssal Plain, Oceanic Trench, Mid-Oceanic Ridge)

- Deepest parts of the ocean floor, often found near subduction zones.
- Vast, flat, deep area of the ocean floor.
- Shallow, gently sloping submerged edge of the continent.
- Underwater mountain range where tectonic plates are pulling apart.

2. State whether the given statements are true or false.

- The continental shelf is the shallowest part of the ocean basin.
- Abyssal plains are steep, featureless areas of the deep ocean floor.
- Guyots are flat-topped seamounts.
- Ocean trenches are the deepest parts of the ocean.
- Island arcs are submerged volcanic mountains.



Do it Yourself

Materials Needed: World map (printed or atlas), Pencil/ sketch pens.

Procedure

1. Take a world map and locate the Indian Ocean.
2. Collect necessary data to identify and label areas where the continental shelf is wide, such as the Bay of Bengal in the map.
3. Identify and label areas where the continental shelf is narrow, such as along the western coast of Sri Lanka.
4. On the same world map, locate and label the following.
 - A. The Mid-Atlantic Ridge (running north-south through the centre of the Atlantic Ocean)
 - B. The Mariana Trench (in the western Pacific Ocean near the Philippines and east of Japan),
 - C. The island arcs of Japan and Indonesia.

Use different colours or symbols to clearly distinguish shelves, ridges, trenches and island arcs.

10.6 Coastal Processes and Landforms

We have learnt from previous topics that the ocean floor has mountains, plains and trenches. Now, let us come closer to the shore and explore the landforms that develop where waves continuously shape the land.

10.6.1 Coastal Erosion

Coastal landforms are the diverse and dynamic features formed along the shoreline by the combined action of waves, tides and currents. The shoreline offers a direct and accessible view of ocean processes, allowing us to observe how waves continuously shape and transform the land.

The coast is a constantly changing zone where the land meets the sea, and waves play a dominant role in shaping its landscape. To understand how coastal landforms develop, we must examine how waves originate and act upon the coast.

Ocean waves are rhythmic rises and falls of the sea surface produced mostly by the action of wind. When the wind blows across the water, it transfers energy to the surface, forming small ripples that gradually develop into waves.

Each wave consists of a **crest**, the highest point above the still-water level, and a **trough**, the lowest point below it. The **wave height** is

the vertical distance between the crest and the trough, while the **wavelength** is the horizontal distance between two successive crests or troughs. Waves travel in a circular motion, carrying energy forward without transporting water itself. Do you know what happens when waves move toward the shore and reach shallow water?

As waves move from deep water toward the shore, they begin to 'touch the bottom' when the water depth becomes equal to half of their wavelength. At this point, the lower part of the wave starts to slow down due to friction with the sea floor, while the upper part continues moving at the same speed. This uneven motion makes the wave grow steeper and higher. As it reaches even shallower water, the wave becomes unstable and eventually breaks. When the wave breaks, its stored energy is released onto the shoreline. These breaking waves play a major role in shaping coastal landforms by eroding rock, transporting sediments and depositing materials along the coast.

Depending on their strength, frequency and direction, waves can either erode, transport or deposit sediments along the coast. The interaction between wave energy and the nature of coastal rocks or sediments gives rise to a variety of erosional and depositional features.

Along many coastlines, the land does not form a smooth, straight line. Instead, some parts of the land extend out into the sea like narrow projections. These projecting, rocky parts of the coast, called headlands, are usually made of harder rock, so they stand out into the sea, while the softer rock around them gets eroded faster. Because headlands face the open sea, they receive the full force of strong waves. This makes them active zones of coastal erosion, where powerful waves carve out various erosional landforms such as coastal cliffs, sea caves, sea arches and sea stacks.

10.6.2 Erosional Landforms of the Coast

a. Coastal Cliffs

One of the most striking erosional landforms along the coast is the coastal cliff. Coastal cliffs or sea cliffs are steep rock face along the coast formed by wave erosion at the base of the headland. It develops when strong waves repeatedly hit the rocky shoreline. The relentless force of the waves through hydraulic action (pressure of water against the rocks), abrasion (grinding by rock fragments carried by

waves) and solution (chemical action of seawater) gradually erodes and cuts into the base of the rock. Over time, the weakened rock above collapses, leaving behind a vertical, or near vertical, rock exposure at the shoreline (Fig. 10.6).

b. Sea Caves

Sea caves are formed by the erosional action of waves along rocky coastlines (Fig 10.7). When waves hit a weak or less resistant part of a rocky headland repeatedly, they slowly carve out a hollow space. The force of the waves, along with sand and pebbles carried by them, acts like sandpaper and enlarges the opening. Over time, the crack becomes bigger and deeper, eventually forming a hollow space inside the rock. This hollow opening formed by wave erosion is called a sea cave.

c. Sea Arches

When waves continuously erode a sea cave or a narrow part of a rocky headland, they gradually cut deeper into the rock. If the erosion happens from both sides, the waves eventually break through the rock, creating an opening that looks like a natural bridge. This arch-shaped structure is called a sea arch (Fig. 10.7).

d. Sea Stacks

When waves continue to erode a sea arch, the top of the arch gradually becomes weak. Eventually, the roof of the arch collapses due to constant wave action. After the arch falls, a tall, isolated pillar of rock known as a sea stack remains standing in the sea. Now study Fig. 10.7, which shows coastal landforms and analyse how continuous wave action changes a headland into a sea cave, then a sea arch, and finally a sea stack.



Fig. 10.6
Coastal cliffs

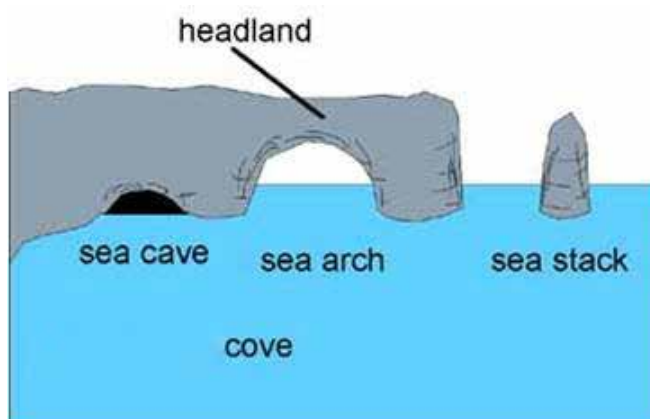


Fig. 10.7
Wave-cut landforms

10.6.3 Coastal Deposition

Waves not only shape coastlines by eroding rocks and cliffs, but they also deposit the sediments they carry. As the waves wash up the beach (swash) at an angle and then flow straight back down due to gravity (backwash), the water moves sediment along the beach. This process is called longshore drift. Analyse the Fig. 10.8



Fig. 10.8
Formation of longshore currents



Know More

Tides and tidal action

Tides are the periodic rise and fall of sea level caused mainly by the gravitational attraction of the Moon and, to a lesser extent, the Sun. This vertical movement of seawater produces alternating high tides and low tides along coastlines and varies from place to place depending on the shape of the coastline, the depth of the sea and the position of the Moon and the Sun. The horizontal movement of water associated with this rise and fall is known as tidal action, which includes the landward-moving flood tide and the seaward-moving ebb tide. Tidal action plays a significant role in coastal processes by eroding shorelines, transporting sediments and depositing materials in sheltered areas such as bays, estuaries and lagoons. Through these processes, tides and tidal action help in shaping coastal landforms like mudflats, sand bars and estuaries, and also help in flushing and maintaining the ecological balance of coastal environments.

and note that the waves are approaching the shore at an angle, generating a longshore current that transports sand along the beach. Longshore current moves a tremendous amount of sediment along coasts and is responsible for creating a variety of depositional features.

Waves and tides are two major movements of ocean water that strongly influence coastal environments. You have already learnt that waves are the rhythmic movements of ocean water, mainly produced by the action of wind blowing over the sea surface. Tides, on the other hand, are the regular rise and fall of sea level caused by the gravitational pull of the Moon and the Sun. Together, waves and tides control the distribution of sediments along the shore and play a vital role in the formation and modification of coastal landforms such as beaches, spits and bars.



Know More

Ocean Currents

In addition to waves and tides, another important movement of ocean water is ocean currents. Unlike waves, which mainly transfer energy, ocean currents involve the continuous movement of large masses of water from one region to another. These currents operate on a global scale and influence climate, marine ecosystems, and coastal environments. Ocean currents are broadly classified into two: surface currents and deep-ocean currents.

a. Surface Currents

Surface currents are wind-driven movements of water occurring in the upper layers of the ocean (generally up to about 400 m depth). They are influenced by global wind systems, the Earth's rotation (Coriolis Effect), and the shape and position of continents and ocean basins. Some of the important surface currents include the Gulf Stream (a warm current), the California Current (a cold current) and the Kuroshio Current. Surface currents significantly influence regional climates.

*Surface currents form large circular systems known as ocean **gyres**. Some of the major gyres are the North Atlantic gyre, South Atlantic gyre, North Pacific gyre, South Pacific gyre and Indian Ocean gyre. Gyres rotate clockwise in the Northern Hemisphere and counter-clockwise in the Southern Hemisphere.*

b. Deep Ocean Currents

Deep ocean currents are driven not by wind but by differences in water density, which depend on factors such as temperature (colder water is denser) and salinity (saltier water is denser). This circulation is known as thermohaline circulation (thermo = temperature; haline = salinity). Cold, dense water sinks in high-latitude regions and flows slowly through deep ocean basins. This movement forms a global-scale circulation system often described as the Global Ocean Conveyor Belt, which may take nearly 1000 years to complete one cycle. Surface and deep currents are interconnected and together regulate the distribution of heat and nutrients across the oceans.

*In certain regions, deep cold water rises to the surface. This process is called **upwelling**. Upwelling brings nutrient-rich water to the surface, supporting plankton growth. It creates some of the world's richest fishing grounds, such as those off the coasts of Peru and California. Seasonal coastal upwelling also occurs along the south-west coast of India, contributing nutrient-rich waters and enhancing marine productivity during this period.*

Ocean currents interact closely with the atmosphere and influence global climate patterns. They redistribute heat from the equator toward the poles and help maintain Earth's energy balance. Changes in ocean circulation can affect rainfall patterns, monsoons, marine biodiversity, and even global climate change.

10.6.4 Depositional Landforms of the Coast

a. Beaches

Beaches are gently sloping depositional landforms made up of sand, gravel or shingle that accumulate along the coast. They are formed and are continually reshaped by longshore drift acting as natural bars, absorbing wave energy and reducing coastal erosion.

When you picture a beach, you're thinking of a beautiful place where land meets the sea. This entire area is called the coastal zone, and it is much more than just the sand where you stand. The coastal zone consists of several distinct parts (Fig. 10.9), defined by how frequently ocean water covers them.

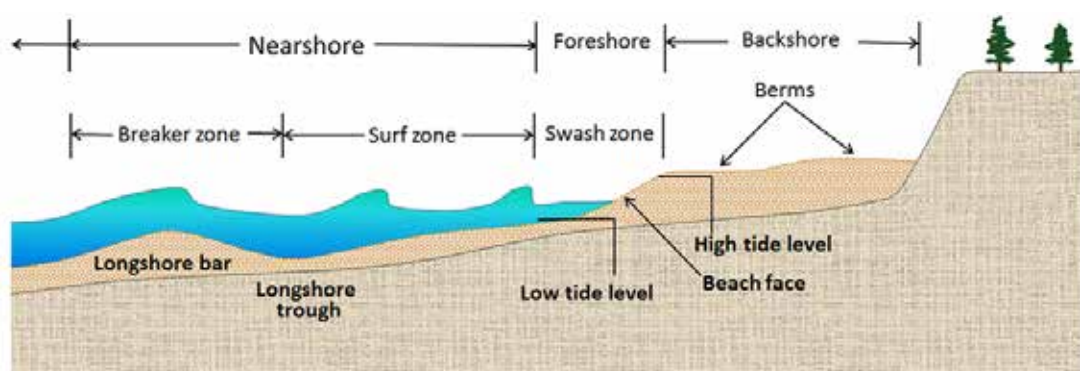


Fig. 10.9
Zonal classification of shoreline



Know More

Zonal classification of shoreline

Starting from the land and moving outward toward the sea, the coastal region is divided into four main zones. Let's explore these zones, moving from the land towards the open sea.

- **The Back shore:** This is the area above the high-tide line. This is often where you find permanent dunes or vegetation.
- **The Foreshore:** This is the most active part of the beach, located between the high tide and low tide lines. It's an ever-changing environment because it is submerged during high tide and then exposed during low tide.
- **The Nearshore:** This zone extends from the low tide line out into the sea. It's where the waves start to feel the bottom, and begin to interact with the sea floor. This region includes the surf zone, where the waves break.
- **The Offshore Zone:** The offshore zone represents the depths beyond the nearshore region. In this zone, waves travel freely without breaking.

b. Spits and Bars

Spits and bars are significant coastal landforms created primarily by the process of longshore drift. A **spit** is a narrow, elongated ridge of sand or gravel that projects from the land out into the sea or across the mouth of a bay or river.

What happens when the longshore current carrying sand down the coast encounters a bay mouth? When the coastline suddenly bends or turns inward at a bay or a river mouth, the longshore current, carrying sediment, often continues to move straight out instead of following the sharp curve of the land, depositing the material in the form of a ridge. Thus, spits develop where the coastline bends or turns inward (such as at a bay or estuary).

A **bar** (often called a **bay-mouth bar**) is a depositional feature closely similar to a spit (Fig. 10.10). A bar forms when a spit continues to grow across the mouth of a bay and eventually closes the bay mouth. A bar is a spit that connects two ends of a bay.

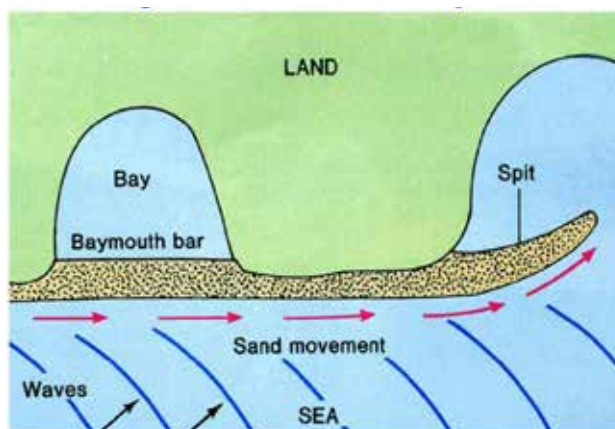


Fig. 10.10
Spit and Bar formation



Do it Yourself

Materials Needed

Atlas or world map of India, internet access/Google Earth maps/online maps/coastal photographs/field visit provisions) and pen/pencils.

Procedure

1. Visit a nearby beach or use ICT tools such as Google Earth, online maps or digital photographs to explore coastal tourist and picnic places along the Indian Coast (e.g., Kovalam, Marina Beach, Gokarna, Varkala, Goa beaches).
2. Observe the coastal features visible at these places, such as beaches, cliffs, spits, bars, lagoons, estuaries, mudflats or sand dunes.
3. Observe or infer the type of wave action present (strong waves, gentle waves, breaking waves and longshore currents).
4. Relate each landform to the action of waves — whether it is mainly formed by erosion, transportation or deposition.
5. Record your observations neatly in the activity log.



Check your progress

Identify the landform described by each of the given statements.

- i. A long, narrow ridge of sand projecting from the coast into the water, often across a bay mouth.
- ii. A sediment ridge that completely closes off a bay, creating a lagoon behind it.
- iii. A steep rock face formed by powerful waves continuously eroding the coastline.
- iv. A landform created when an arch collapses, leaving only an isolated vertical column of rock.

10.7 Sea Level Fluctuations

We have already learned that the coastline is shaped by waves and tides, but what if the level of the sea is not steady? Now we turn our discussion to Sea level fluctuations – the rise and fall of the average height of the ocean surface over time.

The term sea level generally refers to the mean sea level (MSL), which is the average height of the ocean surface relative to the land. It is usually defined as the midpoint between the mean low tide and mean high tide at a particular location. Mean sea level serves as a standard reference point for measuring elevations and depths on Earth. Sea level is not uniform across the globe. It varies from place to place due to differences in the gravitational pull of the Earth, variations in water density, atmospheric pressure and local oceanographic conditions. Sea level also changes over time - daily, seasonally and over geological periods-influenced by both natural processes and human activities.

Over the Earth's history, sea levels have risen and fallen many times. These changes, known as sea level fluctuations, occur because of several major geological factors. The main causes of sea level fluctuations include tectonic movements, melting or formation of ice sheets, thermal expansion of seawater due to warming, and human-induced climate change.

10.7.1 Causes of Sea Level Fluctuations

Sea level fluctuations are caused by both natural and human-related factors. Earth's crustal movements, such as uplift and subsidence, change the shape and depth of ocean basins, leading to local and global sea level changes. Uplift causes a fall in relative sea level,

while subsidence leads to a rise. Tectonic processes can deepen ocean basins, lowering sea level, or make them shallower through uplift and sediment accumulation, raising sea level.

The formation of ice on land (glaciers, ice sheets) removes water from oceans, lowering sea level; conversely, the melting of this land-based ice adds freshwater to the ocean, causing sea level rise, with Greenland and Antarctic ice sheets being the primary contributors. Thermal expansion (water expanding as it warms) also significantly raises sea levels along with meltwater input, driven by rising global temperatures.

10.7.2. Impacts of Sea Level Fluctuations

The impacts of sea level fluctuations are widespread and significant. Rising sea levels cause coastal erosion, washing away of beaches and altering coastal landforms. The loss of coastal habitats, such as mangroves, wetlands, and coral reefs, affects biodiversity and weakens natural protection against storms. Flooding of low-lying areas can submerge settlements, farmlands and infrastructure, threatening human lives and livelihoods. As sea level rises, seawater can move inland and intrude into rivers, lakes and underground aquifers. This process, known as saltwater intrusion, contaminates freshwater sources and soil, reducing agricultural productivity and affecting the availability of clean water in coastal areas.

Rising sea levels pose serious challenges to human communities living along the coasts, causing displacement, economic loss and increased vulnerability to storms and cyclones. These changes seriously affect people living in low-lying coastal regions.

10.8 Coral Reefs

Let us now explore one of the spectacular underwater landforms created by millions of tiny organisms working together- the coral reefs. Coral reefs (Fig. 10.11) are limestone structures formed by the accumulation of calcium carbonate skeletons secreted by some tiny marine organisms called coral polyps.



*Fig. 10.11
Coral reefs*

Corals need warm, clear, sunlit water to survive. So coral reefs often grow in shallow tropical seas with clear water, free from much silt or clay. The algae living inside coral tissues use sunlight to make food through photosynthesis, which helps the corals grow. Because of this need for light, new corals often grow on top of the hard skeletons of older corals, forming large reef structures over time.

10.8.1 Types of coral reefs

Based on how corals grow in relation to the shoreline, coral reefs are broadly grouped into three distinct types as given in Fig. 10.12.

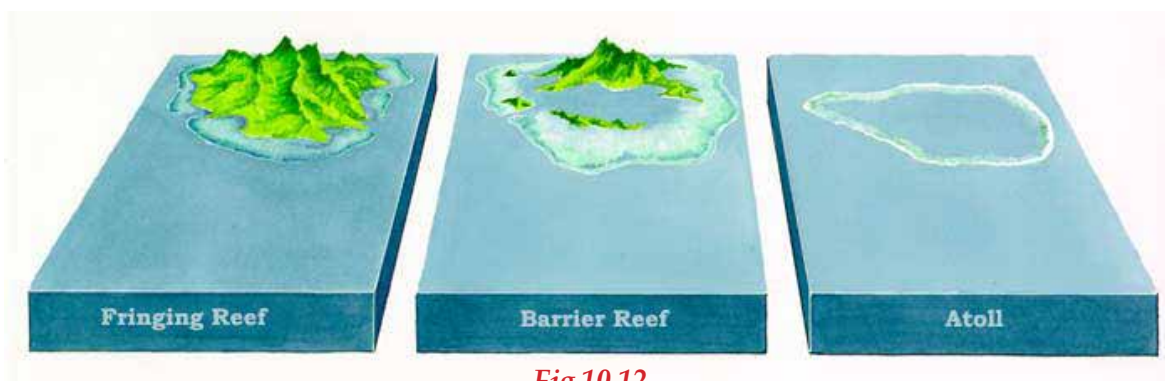


Fig 10.12
Types of coral reefs

a. Fringing Reefs

Fringing reefs grow close to the shore and are separated from the land by shallow water. E.g., Reefs along the Andaman and Nicobar Islands (India).

b. Barrier Reefs

These run parallel to the coast but are separated from it by a lagoon, such as the Great Barrier Reef of Australia.

c. Atolls

Atolls are ring-shaped coral reefs that surround a lagoon, often forming a circle of small islands. E.g., The Lakshadweep Islands of India.

10.8.2 Importance of Coral Reefs

Coral reefs are among the most biologically diverse and productive ecosystems on the Earth. Although they occupy less than 1% of the ocean floor, they support nearly 25% of all marine species. Coral reefs provide shelter, breeding grounds, and feeding areas for thousands of marine organisms such as fish, molluscs, sea turtles and algae. Reefs contribute to the recycling of nutrients such as

carbon, nitrogen and calcium, which are essential for marine food webs and ocean productivity.

Coral reefs act as natural barriers that absorb the energy of waves, protecting shorelines from erosion, storms and tsunamis. Their scenic beauty and rich biodiversity attract millions of tourists, contributing significantly to the economies of tropical coastal nations and islands.

Coral reefs play a vital role in maintaining marine environmental balance. They are highly sensitive to changes in temperature, water quality, salinity and acidity. Reefs require warm, clear, shallow and saline waters with stable conditions for their growth and survival. Any disturbance in these factors, such as global warming, ocean acidification or pollution, can lead to destruction of coral habitats. Thus, coral reefs are vital for scientific studies related to marine ecosystems, environmental change and biodiversity evolution.



Check your progress

1. Rising sea levels have many consequences on coastal areas. List two positive and two negative impacts that you expect. Use examples to support your ideas.

Negative Impacts

- Saltwater intrusion into freshwater sources
-

Positive Impacts

- Expansion of coastal wetlands and mangroves
-

2. Match the column A with B

Column A (Process)

Longshore drift
Subduction
Sediment deposition
Divergence

Column B (Landform)

Mudflat
Mid-ocean ridge
Spit
Trench

3. What environmental conditions are necessary for the growth of coral reefs?
4. Why are coral reefs important for marine biodiversity?

10.9 Kerala Coast

The Kerala Coast is one of the most diverse and dynamic coastal regions of India. It extends for about 590 km, forming a mixed type of coast that includes a variety of landforms such as lateritic cliffs, rocky headlands, long sandy beaches, estuaries, lagoons, spits and bars.

One of the most distinctive features of the Kerala coast is its extensive backwater system (kayals) - a network of lakes and lagoons running parallel to the coast. The Vembanad Lake, the largest of these, extends about 80 km between Munambam and Alappuzha, with widths varying from a few hundred metres to 14.5 km approximately. These backwaters support inland navigation, fishing, agriculture and tourism, and host a unique estuarine ecosystem. The Ashtamudi Kayal and Cochin-Vembanad Estuarine System are among the most significant backwaters in India.

Another remarkable feature of the Kerala coast is the occurrence of mudbanks, locally known as *chakaras* (*chaakaras*), which form close to the shore. A *chakara*/mud bank is a distinctive natural phenomenon observed along the coast, particularly near Alappuzha, Kollam and Kochi. It appears mainly during the south-west monsoon season and act as safe fishing grounds during the monsoon season even when the surrounding sea remains rough and turbulent. Chakaras play a vital role in Kerala's fishing economy, as the muddy waters are rich in nutrients and plankton, which attract large numbers of fish and provide abundant fishing opportunities.

The process involved in the appearance of *chakara* is coastal upwelling, whereby surface water moves away due to special waves/currents/wind making space for nutrient-rich water laden with fine sediments from deeper regions to come up at favourable locations. Organisms including fish will gather along such areas and the sea will be calm or free of waves as the water is muddy. Thus, fishermen can easily identify this bonanza and make their fortune. There are several locations in the world where coastal upwelling occurs due to special oceanographic and climatic conditions.

Historically, the Kerala coast supported extensive mangrove forests, but today only a small portion remains, mainly around Valapattanam

and Puthuvype near Kochi. These mangrove ecosystems are crucial for protecting the shoreline, conserving biodiversity and sustaining fish productivity.



Fig 10.13
Mangroves in Kerala



Do it Yourself

Materials Needed

Computer with Internet access, Google Earth or any online map application, Outline map of Kerala coast (printed or drawn), Colour pencils/sketch pens

Procedure

1. Open Google Earth or an online map and locate the Kerala Coast along the Arabian Sea.
2. Trace the major backwater systems and estuaries, such as Vembanad Kayal and Ashtamudi Lake.
3. Observe how these backwaters and estuaries are connected to the Arabian Sea through narrow inlets or openings.
4. Transfer these features onto your outline map by marking and labelling the backwaters, estuaries and their sea connections.
5. Identify and mark the locations of two important mangrove forests along the Kerala coast, such as Kadalundi mangrove (Malappuram-Kozhikode), Puthuvypin/Chellanam mangroves (Ernakulam)
6. Use different colours or symbols to distinguish backwaters, estuaries, mangroves and the open sea.
7. Record your observations in your activity log.



Check your progress

1. Match the cause and effect puzzle

Cause	Effect
Warm clear shallow water	Mudflat formation
Heavy river sediment	Spit/bar
Gentle tidal action	Coral reef growth
Longshore drift	Prevents coral formation

2. What are the distinctive features of the Kerala coast?

Summary

Oceans are vast, interconnected bodies of saltwater. Oceans play an essential role in regulating global climate, supporting marine life, providing resources and enabling transportation. Ocean water is characterized mainly by its salinity (salt content), which varies from place to place depending on factors such as evaporation, freshwater inflow and temperature. The ocean floor is not flat but contains a variety of landforms. Starting from the coast, the sea bottom begins with the shallow continental shelf, followed by the steep continental slope and then reaches the deep, flat abyssal plain. Major features of the deep ocean include mid-oceanic ridges (underwater mountain ranges formed by plate movement), trenches (the deepest parts of the ocean) and underwater volcanic mountains such as seamounts and flat-topped guyots. Along coastlines, the continual action of waves shapes landforms like coastal cliffs, sea arches and sea stacks, and depositional features such as beaches, spits and bars.

Coastal environments constantly change due to sea level fluctuations, influenced by global factors like melting or formation of ice sheets and local land movements. These changes can lead to coastal flooding, erosion and habitat alteration. Coral reefs such as fringing reefs, barrier reefs and atolls form rich and diverse marine ecosystems, and act as natural barriers that protect coastlines. Regional features like mud banks (Chakara) and the backwaters (kayals) along the Kerala Coast further show how coastal environments can vary from place to place.

Appendix I: Geological Tools and Field Gadgets

This appendix lists the common tools and field gadgets used in Geology along with their specific purposes and applications in field investigations.

Sl. No.	Name of Tool	Purpose
1	Topographic sheets and Geological maps	Provide spatial context for field navigation, locating geological boundaries, structures, landforms, and planning traverses; serve as a fundamental reference for geological interpretation and mapping.
2	Global Navigation Satellite System (GPS)	Used to determine precise geographic coordinates, navigate to sampling sites, record outcrop locations, and georeferencing field data.
3	Compass (Brunton/ Clinometer)	Measures strike and dip of bedding, foliation, joints, and faults for structural mapping and tectonic interpretation.
4	Field book / Notebook	Records field observations, sketches, coordinates, interpretations, and contextual details for permanent documentation.
5	Measuring tape	Enables accurate stratigraphic measurements, section logging, spacing analysis, and scaling of sketches and outcrop logs.
6	Magnifying lens (Hand lens)	Allows close examination of mineral grains, textures, and rock structures for mineral and rock identification (10x–20x magnification).
7	Streak plate	Used to identify minerals by observing the colour of their powdered streak.
8	Magnet	Helps determine the magnetic properties of minerals and rocks.
9	Mohs Hardness Scale	Used to identify minerals based on their scratch resistance and relative hardness.

10	Hammer and chisel	Geological hammer and chisel are used for breaking rocks, collecting samples, and exposing fresh rock surfaces. The hammer is suited for splitting hard rocks, while the chisel allows precise and controlled extraction of minerals or fossils from delicate or layered rocks.
11	Unmanned Aerial Vehicle	Equipped with optical, thermal, hyperspectral cameras, and LiDAR to map terrain, study minerals, water, and generate detailed topographic data, even in inaccessible areas.
12	Ground Penetrating Radar	Uses high-frequency electromagnetic waves to image subsurface structures; detects sedimentary layers, buried channels, faults, water tables, and supports archaeological mapping.
13	Borehole Camera	Captures visual footage inside wells and boreholes; identifies fractures, cavities, lithological changes, and assists in groundwater and engineering assessments.
14	Micro-Electro-Mechanical Systems (MEMS)	Small accelerometers that measure ground motion with high accuracy; immune to tilt/orientation errors and used in engineering geophysics, hydrocarbon exploration, and seismic monitoring.
15	Soil Moisture Probe	Measure volumetric water content in soils; useful for landslide risk assessment, agriculture, and infiltration studies with real-time, repeatable data.
16	Sediment Corer	Extracts undisturbed sediment cores from lakes, wetlands, or soils; preserves layering and organic content for paleoenvironmental, climate, and stratigraphic studies.

17	Altimeter and Rangefinder	Altimeter measures elevation relative to a reference level; rangefinder measures distance to a target using laser pulses. Both are used in surveying, forestry, engineering, and field mapping
18	Terrestrial Laser Scanner	Captures high-resolution 3D point clouds of outcrops, landforms, or structures using laser pulses; provides mm-scale accuracy for mapping and analysis.
19	Water level meter	Measures groundwater levels in wells and piezometers; essential for aquifer monitoring, recharge studies, and hydrology.
20	pH and EC meter	pH meter measures acidity/alkalinity; EC meter measures dissolved ions in soils and water, assessing salinity or contamination.
21	Geophysical instruments	Includes electrical resistivity, gravimetric, seismic, magnetic, and induced polarization methods to investigate subsurface conditions, density contrasts, and resource potential.
22	Petrological Microscope	Used to examine rock and mineral thin sections under polarized light to identify minerals, textures, microstructures, and mineral relationships.
23	Geographic Information System (GIS)	Used for capturing, storing, analysing, managing, and visualizing spatial data from satellite imagery, field observations, and other geospatial sources.
24	Mirror Stereoscope	Enables three-dimensional viewing of aerial photographs to interpret geomorphology, structural features, and drainage patterns for photogeological analysis.
25	Sieve Shaker	Separates sediment grains into different size fractions to obtain quantitative grain-size distribution for depositional and sedimentological studies.

26	Shear Test Apparatus	Determines the shear strength and deformation characteristics of soils under controlled conditions, commonly used in soil mechanics and geotechnical studies.
27	X-ray Diffractometer (XRD)	Identifies crystalline mineral phases by analysing X-ray diffraction patterns and comparing them with standard reference databases.
28	Scanning Electron Microscope (SEM)	Produces high-magnification images of mineral surfaces to study texture, morphology, and micro-scale features, and can provide chemical information.
29	Laser Raman spectroscope	Identifies minerals based on vibrational spectra and is especially useful for detecting high-pressure mineral polymorphs related to impact events.
30	Electron Probe Micro Analyser (EPMA)	Determines the elemental composition of small solid volumes using characteristic X-ray emission in a non-destructive manner.
31	X-ray Fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	XRF measures major oxides and trace elements, while ICP-MS measures rare earth, and platinum-group elements at very low concentrations for geochemical analysis.
32	Advanced remote sensing techniques (Hyperspectral & Microwave)	Used for mineral and lithological mapping, planetary surface studies, and hazard assessment; hyperspectral enables mineral identification, while microwave penetrates clouds for all-weather monitoring.
33	Mass spectrometry (for age determination)	Determines the age of geological materials by measuring parent-daughter isotopic ratios using radiometric dating methods (e.g., U-Pb, Ar-Ar), providing high-precision age data even from very small samples through techniques such as AMS.

34	GIS tablets	Enable real-time digital field mapping and data entry using applications like FieldMove or ArcGIS Field Maps, improving efficiency, positional accuracy, and integration of field data.
35	3D printing	Converts digital geological and geophysical data into physical models, allowing three-dimensional visualization of complex subsurface structures, pore networks, and planetary landscapes.
36	Robotic rovers	Mobile robotic platforms equipped with cameras, sensors, and robotic arms for autonomous or remote exploration, data collection, rock and soil analysis, and environmental mapping on planetary surfaces and terrestrial terrains.
37	Cloud-based and AI-based GIS platforms	Provide centralized storage, real-time collaboration, and advanced spatial analysis of large geological datasets using cloud computing and AI/ML algorithms for automated feature extraction, prospectivity mapping, and environmental monitoring.

Appendix II: The Geological Time Scale

The Geological Time Scale is a chronological framework that represents Earth's history from its formation to the present. This vast span of time is divided into major and minor units such as eons, eras, periods, and epochs. The time scale relates important geological and biological events in Earth's history to specific intervals of time, helping scientists understand the sequence of changes that have occurred on the planet.

EON	ERA	PERIOD		EPOCH	AGE (m.y. ago)
Phanerozoic	Cenozoic	Quaternary		Holocene	0.01
				Pleistocene	1.6
		Tertiary	Neogene	Pliocene	5.3
				Miocene	23.7
			Paleogene	Oligocene	36.6
				Eocene	57.8
				Paleocene	66.4
				Mesozoic	Cretaceous
	Early				
	Jurassic	Late	208		
		Middle			
	Triassic	Early	245		
		Late			
		Middle			
		Early			
	Paleozoic	Permian		Late	245
				Early	286
		Carboniferous	Pennsylvanian	Late	320
			Mississippian	Early	360
		Devonian		Late	408
				Middle	
				Early	
		Silurian		Late	438
				Early	
		Ordovician		Late	505
				Middle	
				Early	
		Cambrian		Late	570
				Middle	
	Early				
Precambrian	Proterozoic	Late		900	
		Middle		1600	
		Early		2500	
	Archean	Late		3000	
		Middle		3400	
		Early		3800?	
pre-Archean					4550

Appendix III: Practical Works

1. Determination of pH of Water

This involves the determination of the pH of water samples to identify whether the water is acidic, neutral, or alkaline.

Objective

Learner will be able to measure the pH of water using simple laboratory methods and determine whether the water is acidic, neutral, or alkaline.

Procedure

A small quantity of the water sample is taken in a clean container, and pH paper or a pH meter is used to measure its pH value. The colour change of the pH paper is compared with the standard chart to obtain the pH reading. Reading in pH meter gives the value.

The observed pH value is then interpreted to assess the quality of water. Water with pH less than 7 is acidic, equal to 7 is neutral, and greater than 7 is alkaline.

2. Field-Based activity on Groundwater in the Local Area

Learners examine the major sources of groundwater in the local area, estimate the depth of the water table at locations with different topographic elevations, observe seasonal fluctuations, and identify both natural and artificial groundwater recharge methods.

Objectives

Learners investigate the sources, storage, and seasonal variation of groundwater, analyse the influence of topography on water table depth, identify recharge methods, and suggest practical measures for groundwater conservation.

Procedure

The activity shall be conducted in two selected locations that differ in topography, such as a coastal and midland area or a plain and hilly region. Students should first identify the main sources of groundwater in these areas, including dug wells, bore wells and tube wells, and record their approximate depth of water level. The depth to the water level in selected wells should be measured using a rope with a weight or a measuring tape, and the depth of each well should also be noted. The water table levels at the two locations (two selected topographic regions) should then be compared, and the relationship between topography and groundwater levels shall be observed and analysed.

Seasonal observations must be carried out at least three times a year, preferably during the pre-monsoon, monsoon, and post-monsoon periods, to record changes

in water levels. The measured depths shall be compared to understand seasonal fluctuations and the influence of rainfall and groundwater recharge.

The study should also include the identification of natural recharge sources such as ponds, lakes, rivers, and open fields, as well as artificial recharge methods like rainwater harvesting systems, soak pits, recharge wells, and percolation tanks. Observations should be recorded, and the collected data should be summarized and consolidated in the practical record book.

3. Construction of Long Profile of a River Using a Topographic Map

Learners construct the long profiles of a river with the help of a topographic map (toposheet).

Objective

Learner will be able to interpret changes in slope and valley in the upper, middle, and lower courses of a river.

Procedure

In the construction of long profile, the portion of a river course from its source to mouth is traced on the toposheet. The elevations at points where contour lines intersect the river are noted. These elevation values are plotted against distance on graph paper to obtain a long profile, which shows how the river gradient gradually decreases downstream.

4. Determination of Stream Order

Learners determine the stream order of a drainage basin from a topographic map and study the hierarchy of streams using toposheets.

Objective

Learners analyse the hierarchy of streams and the relationship among stream order, basin size, and runoff characteristics.

Procedure

Learners identify and classify streams in a drainage basin using a topographic map. The network of streams is examined, and stream order is assigned following the system proposed by Strahler. The smallest streams with no tributaries are marked as first-order streams. When two streams of the same order join, the order increases by one, while the joining of streams of different orders retains the higher order. The size of streams is analysed and represented diagrammatically in the practical log book.

5. Identification of drainage patterns

Aim: To identify major drainage patterns from a given topographic map or drainage map.

Procedure

Learners take the given topographic or drainage map and clearly locate the river basin. Trace the main river with a pencil to make its course distinct, and mark all the tributaries joining it. Observe the overall shape of the river network and note whether it appears tree-like, rectangular, or arranged in parallel lines. Learners compare the features with standard drainage patterns such as dendritic, rectangular, and trellis, and identify the pattern present.

The dendritic drainage pattern resembles the branches of a tree. The rectangular drainage pattern is characterized by streams that follow straight courses with sharp right-angle bends. Tributaries meet the main stream at nearly 90°. The trellis drainage pattern shows a main river flowing through a valley with short, parallel tributaries joining it at right angles.

5. Field Visit to Study Earth Processes and Geomorphological Features

Learners observe Earth surface processes, the work of different geological agents, and related landforms directly in natural settings through a field visit.

Objective

To provide learners with real-time, direct experience of Earth surface processes and landforms through field observation.

Procedure

A short (one-day) visit is conducted to nearby places to observe Earth processes, the geological work of various geomorphic agents, and related landforms directly in the field. During the visit, learners examine different geomorphological features and identify the processes responsible for their formation. Earth processes such as weathering, erosion, transportation, and deposition, as well as fluvial and coastal landforms and evidence of mass movements can be observed.

Learners prepare sketches of the landforms observed and collect photographs or videos for documentation. A field diary is maintained to record details such as the subject of study, date and time of visit, location, features observed, and active geomorphic processes. Learners discuss their observations with peers and teachers to clarify doubts.

After the visit, groups review the collected information and present their findings in class. Each learner prepares a field report describing the features observed, processes involved and reflections on the field trip experience. The report is then submitted for evaluation.

GLOSSARY

A Horizon: The upper soil layer/ topsoil (in a typical soil profile) rich in minerals and humus, supporting most plant roots and biological activity.

Ablation: The process by which a glacier loses ice through melting, sublimation, or breaking off of ice blocks (calving).

Ablation Zone: The lower part of a glacier where ice loss exceeds snowfall gain, causing net reduction in glacier mass.

Abrasion: Wearing away of rock surfaces by friction from sediments carried by water, wind, or ice.

Accretion: Gradual growth of planets by the sticking together of smaller particles.

Accumulation Zone: Upper glacier region where snowfall adds into glacial mass.

Aeolian: Relating to erosion, transportation, or deposition of sediments by wind.

Aggradation: Build-up or raising of land surface due to deposition of sediments.

Alluvial: Pertaining to material deposited by running water, especially rivers.

Alluvial Fan: Fan-shaped deposit formed where a stream loses energy at the base of a hill or mountain.

Alluvium: Loose sand, silt, clay, and gravel deposited by rivers and streams.

Alpine Glacier: Glacier confined within mountain valleys, flowing downslope under gravity.

Angle of Repose: Maximum slope angle at which loose material remains stable without sliding.

Annular Drainage: Ring-like drainage pattern formed around structural domes or basins.

Aquiclude: Porous rock that can store water but does not allow it to flow through.

Aquifer: Permeable rock formation that can store and transmit groundwater in usable amounts.

Aquifuge: Rock body that neither stores nor transmits groundwater.

Aquitard: Layer of low permeability that slows down groundwater movement between aquifers.

Arete: Sharp, narrow ridge formed between two glacial cirques by erosion.

Artificial Recharge: Human-made methods used to increase groundwater storage in aquifers.

Artesian Condition: Situation where groundwater in a confined aquifer is under pressure.

Artesian Well: Well that taps a confined aquifer and allows water to rise naturally.

Asteroid: Small rocky body orbiting the Sun, mostly found between Mars and Jupiter.

Asthenosphere: Weak, plastic-like upper mantle layer that allows tectonic plates to move.

Attrition: Rounding and size reduction of particles due to repeated collisions during transport.

Avalanche: Rapid movement of snow, ice, and debris down a mountain slope.

B Horizon: Subsoil layer in a typical soil profile where minerals leached from above accumulate.

Back Shore: Beach area above high-tide line, usually dry except during storms.

Backwater (Kayal): Lagoon-like water body running parallel to coast, separated by barriers.

Barrier Reef: Coral reef lying parallel to shore but separated by a lagoon.

Bar: A ridge of sediment deposited in a river or along a coast.

Base Level: Lowest limit to which a river can erode, usually sea level.

Basal Sliding: Glacier movement by sliding over bedrock, aided by meltwater lubrication.

Basin: Depressed area where sediments accumulate over time.

Basket of Egg Topography: A landscape characterised by many small, rounded hills called drumlins, formed by glacial deposition, giving the area the appearance of a basket filled with eggs.

Bay: Broad inlet of sea partly enclosed by land.

Bay-Mouth Bar: A sandbar that forms across the mouth of a bay, partially or completely enclosing it.

Beach: Gently sloping coastal deposit of sand, gravel, or pebbles shaped by waves.

Bed Load: The portion of a stream's sediment load that moves by rolling or sliding along the bottom.

Bedrock: Solid, unweathered rock beneath soil and loose deposits.

Big Bang: The scientific theory that the universe began from an extremely hot and dense state and has been expanding ever since.

Big Crunch: A hypothetical cosmological event in which the universe's expansion reverses and collapses inward.

Biosphere: Global zone of life including all organisms and their environments.

Blowout: Small hollow formed by wind removing loose sand.

Bore Well: Deep, narrow well drilled mechanically to access groundwater.

Boulder: Large, rounded rock fragment transported by natural agents.

Braided Stream: River with many interlacing channels separated by sand bars.

Brook: Very small natural stream of flowing water.

Calving: Breaking of large ice blocks from a glacier front to form icebergs.

Canyon: Deep, narrow valley carved mainly by river erosion.

Carbonation: Chemical weathering where carbonic acid reacts with rocks like limestone.

Catchment Area: Total area from which rainfall drains into a river system.

Channel Erosion: Removal of material from stream bed and banks by flowing water.

Chemical Weathering: Breakdown of rocks through chemical reactions altering minerals.

Cliff (Coastal): Steep rock face formed by continuous wave erosion.

Cold Death: A theory that the universe will eventually reach a state of maximum entropy with no usable energy remaining.

Col: Mountain pass formed by erosion between two cirques.

Coma (of a comet): The cloud of gas and dust that forms around a comet's nucleus when it gets close to the Sun and its ice begins to vaporise.

Comets: Smaller celestial bodies made of dust, ice, and gases that orbit the Sun.

Confluence: Place where two rivers or streams meet.

Confined Aquifer: An aquifer trapped between impermeable layers.

Confining Beds: Impermeable rock or sediment layers that restrict groundwater movement.

Conrad Discontinuity: The boundary within the Earth's continental crust that separates the upper crust (sial) from the lower crust (sima).

Continental Drift: Idea that continents were once joined and later drifted apart.

Continental Glacier: Massive ice sheet covering large land areas like Antarctica.

Continental Margin: Transition zone from continental crust to deep ocean basin.

Continental Shelf: Shallow submerged extension of a continent.

Continental Slope: Steep descent from shelf edge to ocean depths.

Convection Currents: Circular mantle movements driven by heat differences.

Coral Reef: Limestone structure built by colonies of coral polyps.

Cordillera: A large, continuous chain of mountain ranges.

Corrasion: Mechanical erosion by sediments carried in water or wind.

Corrie (Cirque): A bowl-shaped or armchair-shaped depression on a mountainside formed at the head of a glacier by glacial action.

Creep: Extremely slow downslope movement of earth material under the influence of gravity.

Crust: Thin outer solid layer of the Earth.

Cryosphere: All frozen water parts of Earth including glaciers and ice sheets.

Debris Fall: Quick falling of loose soil and rock fragments from steep slopes, usually after heavy rain.

Debris Flow: A rapid flow of water, soil, rocks, and organic material that can be highly destructive.

Debris Slide: Fast movement of loose soil and rock down a slope as a mass.

Deflation: Removal of loose fine particles like sand and dust from the ground by wind action.

Deflation Basin: Large depression formed when wind continuously removes surface materials.

Delta: Landform created at a river's mouth by deposition of sediments as flow slows.

- Dendritic Drainage:** Tree-like stream pattern developed on uniform rock structures.
- Denudation:** Overall wearing down of land by weathering, erosion, and mass wasting.
- Deposition:** Settling of sediments when transporting agents lose energy.
- Desert Pavement:** Surface layer of closely packed stones left after fine materials are blown away.
- Discharge:** Volume of water passing a point in a stream per unit time.
- Distributaries:** Streams that branch off and flow away from the main river channel.
- Dissolution:** Chemical weathering process where minerals dissolve in water.
- Dissolved Load:** Minerals and salts dissolved in stream water and carried along with it.
- Doppler Effect:** Change in wave frequency caused by the movement of a source toward or away from an observer.
- Drainage Basin:** Entire land area drained by a river and its tributaries.
- Drumlin:** Smooth, elongated hill formed from glacial till shaped by moving ice.
- Dune:** Hill or ridge of sand deposited and shaped by wind.
- Earth Flow:** Slow to moderate flow of water-saturated soil down a slope, forming a tongue-shaped mass.
- Earth Processes (Geological Processes):** Natural processes, including tectonic movements, volcanism, weathering, erosion, and deposition, that operate within and upon the Earth.
- Earth System Science:** The interdisciplinary study of Earth's atmosphere, hydrosphere, lithosphere, biosphere, and their interactions.
- Erosion:** Removal and transportation of weathered materials by natural agents.
- Esker:** Long winding ridge of sand and gravel deposited by glacial meltwater streams.
- Estuary:** Coastal area where river water mixes with seawater under tidal influence.
- Evaporation:** Process by which liquid water changes into water vapour.
- Exfoliation (Onion-Skin Weathering):** A mechanical weathering process in which outer rock layers peel off in sheets due to pressure release or temperature changes.

Firn (Neve): Partly compacted snow that is gradually changing into glacial ice.

Folding: Bending of rock layers due to compressional tectonic forces.

Floodplain: Flat valley floor built by repeated river flooding and sediment deposition.

Fluvial: Relating to rivers/streams and the processes associated with them.

Frost Wedging: Breaking of rocks when water in cracks freezes, expands, and exerts pressure.

Geoid: The irregular, equipotential surface representing mean sea level used as a reference for measuring elevations.

Geological Agents: Natural forces such as water, wind, ice, and gravity that cause erosion and deposition.

Geological Processes (Earth Processes): Natural processes, including tectonic movements, volcanism, weathering, erosion, and deposition, that operate within and upon the Earth.

Geology: Science that studies Earth's materials, structure, history, and processes.

Geomorphology: Study of landforms and the processes that shape them.

Geosphere: Solid portion of Earth including crust, mantle, and core.

Geyser: A hot spring that intermittently erupts water and steam due to underground heat.

Glacial: Relating to glaciers or processes caused by ice, such as erosion, deposition, and movement of ice.

Glacial Drift: All sediments that are transported and deposited by glaciers.

Glacial Till (Till): Unsorted and unstratified sediment deposited directly by glacial ice.

Glacier: A large mass of ice formed from compacted snow that slowly flows over land under its own weight.

Glaciology: The branch of science that studies glaciers, ice sheets, and other forms of ice on the Earth.

Gondwanaland: Hypothetical southern supercontinent that included present-day Africa, South America, Antarctica, Australia, and India.

Gorges: Deep, narrow valleys with steep sides formed mainly by stream erosion.

Graben: A depressed block of land bordered by parallel faults.

Groundwater: Water stored beneath Earth's surface in pore spaces and fractures within rocks.

Gulf: A large, deep inlet of the sea almost surrounded by land.

Gullies: Large channels formed by concentrated water flow during erosion.

Gully Erosion: Severe erosion that creates large channels or gullies in soil.

Horizon (A): The upper soil layer/ topsoil (in a typical soil profile) rich in minerals and humus, supporting most plant roots and biological activity.

Higher Reaches: The upper course of a river near its source where gradients are steep.

Hill: A naturally raised area of land lower and less steep than a mountain.

Horst: An uplifted block of land bordered by faults.

Hot Springs: Springs where heated groundwater emerges at the surface.

Hydrology (Hydrogeology): Study of groundwater.

Ice Age (Glacial Period): A long period of time when Earth's climate is much colder, and large areas are covered with ice sheets and glaciers.

Igneous Rock: Rock formed from cooled and solidified magma or lava.

Infiltration: Movement of surface water downward into soil.

International Space Station (ISS): An artificial satellite orbiting Earth that serves as a platform for scientific research and experiments.

Ionosphere: A layer of the upper atmosphere ionized by solar radiation that affects radio communication.

Island Arc: Curved chain of volcanoes formed above a subduction zone.

Isostasy: The equilibrium condition of Earth's crust floating on the denser mantle.

Laminar Flow: Smooth, orderly fluid motion in parallel layers.

Land Hemisphere: The hemisphere of Earth with the greatest concentration of land.

Lapse Rate: The rate at which air temperature decreases with increasing altitude.

Laurasia: Hypothetical ancient northern supercontinent that included present-day North America, Europe, and Asia (except India).

- Lava:** Molten rock that reaches Earth's surface during a volcanic eruption.
- Lehmann Discontinuity:** The boundary between Earth's outer core and inner core.
- Levee:** Natural raised embankment formed by flood sediment deposition.
- Lithosphere:** Rigid outer shell of Earth including crust and uppermost mantle.
- Load:** The total amount of sediments/material carried by a stream, including dissolved, suspended, and bed load.
- Loess:** Wind-blown fine sand deposit.
- Lower Reaches:** The final course of a river near its mouth where gradients are gentle.
- Mantle:** Thick layer beneath crust composed of hot, semi-solid rock.
- Marine:** Relating to the sea or ocean.
- Mass Wasting:** Down slope movement of soil and rock due to gravity.
- Meander:** Curved bend in a river channel.
- Mesopause:** The boundary between the mesosphere and thermosphere.
- Meteor:** Flash of light produced when a meteoroid burns in the atmosphere.
- Mid-Ocean Ridge:** Underwater mountain chain formed at divergent plate boundaries.
- Mineral:** Naturally occurring inorganic solid with definite chemical composition and structure.
- Mohorovicic Discontinuity (Moho):** The boundary between Earth's crust and mantle.
- Moraine:** An accumulation of rock debris (till) transported and deposited by a glacier.
- Mountain Peak:** The highest point of a mountain.
- Mountain Range:** A chain of connected mountains.
- Mountain Ridge:** A long, narrow elevated landform with a crest and steep slopes on both sides, often connecting peaks within a mountain range.
- Mountain System:** A group of mountain ranges formed by related geological processes.
- Mud flow:** A fast flow of water mixed with fine soil and mud, often occurring after intense rainfall.

- Nebula:** Cloud of gas and dust in space where planets and stars may form.
- Neve (Firn):** Partly compacted snow that is gradually changing into glacial ice.
- Nuclear Fusion:** The process in which two light atomic nuclei join together to form a heavier nucleus, releasing a large amount of energy.
- Nunatak:** Mountain peak protruding above an ice sheet or glacier.
- Oasis:** A fertile spot in desert.
- Ocean Basin:** Large depression on Earth's surface filled with ocean water.
- Oceanic Trench:** Deep, narrow depression formed at subduction zones.
- Onion-Skin Weathering (Exfoliation):** A mechanical weathering process in which outer rock layers peel off in sheets due to pressure release or temperature changes.
- Oxbow Lake:** Crescent-shaped lake formed when a river meander is cut off.
- Panthalassa:** The ancient hypothetical global ocean that surrounded the supercontinent Pangaea.
- Pangaea:** The ancient hypothetical supercontinent that existed during the late Paleozoic era.
- Pedology:** The scientific study of soils, their formation, and classification.
- Perched Water Table:** A localized zone of groundwater above the main water table caused by an impermeable layer.
- Permeability:** Ability of a rock to transmit water through connected pores.
- Petrology:** Study of rocks.
- Phreatic Water:** Groundwater located below the water table in the saturated zone in shallow unconfined aquifers.
- Planck Temperature:** The highest theoretically possible temperature, approximately 1.4×10^{32} Kelvin.
- Plate Tectonics:** The scientific theory that Earth's lithosphere is broken into a number of plates that move and interact with each other, causing earthquakes, volcanoes, and mountain formation.
- Qanats:** Ancient underground horizontal wells/channels constructed to discharge groundwater to the surface.
- Recharge:** Addition of water to the groundwater system, replenishing subsurface water.

Red Shift: The shift of light toward the red end of the electromagnetic spectrum when light comes from an object moving away from an observer.

Regolith: Layer of loose weathered material covering bedrock.

Ridge: A long, narrow elevated landform.

Rift Valley: Valley formed by stretching and faulting of Earth's crust.

Rockfall: Sudden dropping of rocks from steep slopes or cliffs, often caused by weathering or earthquakes.

Rockslide: Rapid sliding of a large block of bedrock along a flat or sloping surface.

Runoff: Water flowing over land into streams after rainfall.

Rills: Small channels formed by running water during early stages of stream flow.

Saltation: The movement of sediment particles by bouncing along the stream bed.

Sandstone: Sedimentary rock made of compacted sand grains.

Sea Stack: Isolated pillar of rock left after coastal erosion.

Sedimentary Rock: Rock formed from deposited and compacted sediments.

Seamount: Underwater volcanic mountain not reaching the surface.

Sheet Erosion: The uniform removal of a thin layer of soil by surface runoff.

Shelf Break: Boundary where continental shelf ends and slope begins.

Shooting Stars (Meteors): Streaks of light produced when meteoroids burn up in Earth's upper atmosphere.

Sial: The upper layer of the Earth's continental crust, mainly composed of silica and aluminium.

Sima: The lower layer of the Earth's crust (and oceanic crust), mainly composed of silica and magnesium.

Singularity: A point of infinite density and temperature thought to have existed at the beginning of the universe.

Slip Face: Steep leeward slope of a sand dune where sand slides down.

Slump: Downward movement of soil or rock along a curved surface.

Snowball Earth: A theory suggesting that the Earth was once almost completely covered with ice from the poles to the equator.

Snowline: Elevation above which snow remains throughout the year.

Soil Creep: Very slow downhill movement of soil.

Soil Horizon: Distinct soil layer with specific characteristics in a typical soil profile.

Soil Profile: Vertical section showing different soil horizons.

Solution: The process by which minerals dissolve in water and are transported in dissolved form.

Spit: Narrow ridge of sand extending from the coast into the sea formed by longshore drift.

Splash Erosion: The displacement of soil particles caused by the impact of raindrops.

Spring: Natural outlet where groundwater flows to the surface.

Stratigraphy: Study of rock layers, their sequence, and age.

Stratopause: The boundary between the stratosphere and mesosphere.

Subduction: Process where one tectonic plate sinks beneath another into the asthenosphere/mantle.

Suspended Load: Fine sediment particles (like silt and clay) carried within stream water in suspension.

Suspension: The transport of fine particles within moving water without settling.

Suranga: A traditional horizontal tunnel dug into laterite hills to collect groundwater in north Kerala.

Talus: A pile of rock fragments accumulated at the base of a steep slope due to repeated rockfalls.

Tarn: A small mountain lake formed in a cirque after the glacier has melted.

Terminal Moraine: Ridge of debris marking the furthest advance of a glacier.

Terrace: Step-like flat surface along a valley side, representing former floodplain levels.

Thermopause: The boundary between the thermosphere and exosphere.

Tides: Periodic rise and fall of sea level caused by gravitational pull of Moon and Sun.

Traction: Movement of large particles by rolling or sliding along the ground or stream bed.

Transform Fault: Geologic feature that occurs along fracture zones at mid-oceanic ridges, where tectonic plates interact.

Transverse Dune: Sand dune ridge formed at right angles to wind direction.

Tributaries: Smaller streams that flow into a larger stream.

Tropopause: The boundary between the troposphere and stratosphere.

Turbidity Currents: Underwater flows of sediment-laden water driven by gravity.

Turbulent Flow: Chaotic, irregular motion of water characterized by eddies and mixing.

U-Shaped Valley: Broad valley with steep sides formed by glacial erosion.

Unconfined Aquifer: An aquifer with no confining layer above it and is under atmospheric pressure.

Unloading: The release of pressure on overlying rocks due to erosion, causing expansion and fracturing.

Upwelling: Upward movement of deep, nutrient-rich ocean water to the surface.

Vadose Water (Zone of Aeration): Water present in the unsaturated zone above the water table.

Valley: Low area between hills or mountains often containing a stream.

Ventifact: Rock shaped, polished, or faceted by wind-blown sand.

Water Hemisphere: The hemisphere of Earth with the greatest concentration of water.

Water Table: The upper surface of the zone of saturation of groundwater.

Wave Length: The horizontal distance between successive crests of a wave.

Weathering: Breakdown of rocks in place by physical, chemical, or biological processes.

Well: Artificial hole dug or drilled to obtain groundwater.

Zone of Aeration (Vadose Zone): Subsurface zone above the water table where pores contain both air and water.

Zone of Saturation: Subsurface layer below the water table in which all the pores and fractures of soil or rock are completely filled with water.

FOR FURTHER READING

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