M.A. GEOGRAPHY
SEMESTER I (CBCS)

GEOGRAPHY PAPER - 101
PRINCIPLES OF GEOGRAPHY

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PRINCIPLES OF GEOMORPHOLOGY

After going through this chapter you will be able to understand the following features

Unit Structure

1.1. OBJECTIVES

By the end of this unit, you will be able to -

A. To understand the processes that shape the landforms
B. To understand evolution of geomorphological concepts over the time period
C. To understand evolution of planet earth and concept of geological time scale
D. To understand development of geomorphic thought

1.2. INTRODUCTION

Geomorphology is the study of landforms and landform evolution. The topic traditionally has been studied both qualitatively, which is the description of landforms, and quantitatively, which is process-based and describes forces acting on Earth's surface to produce landforms and landform change. Over the period of time content, nature and scope of the subject got radically change.

1.3. SUBJECT DISCUSSION

Geomorphology is the study of landforms, their formation processes, form and sediments at the surface of the Earth. Study includes looking at landscapes to work out how the earth surface processes, such as air, water and ice, can mould the landscape. It also studies past land forms of the specific areas.

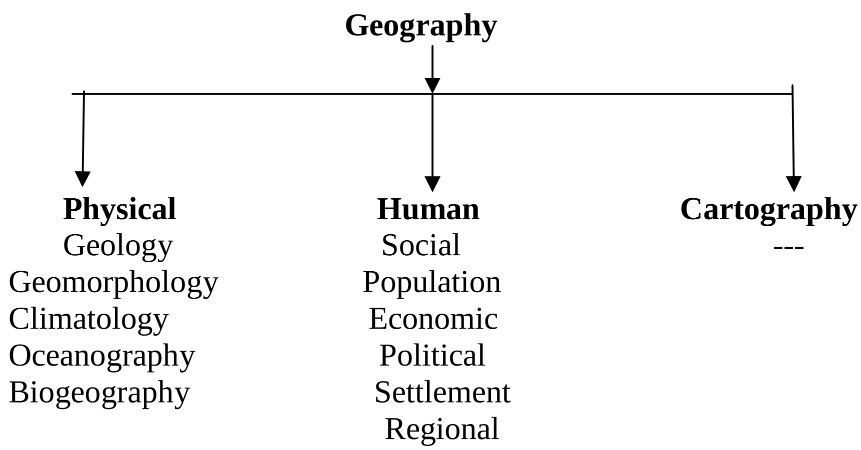
1.4. NATURE, SCOPE AND CONTENT OF GEOMORPHOLOGY

1.4.1. EARLY BEGINNING OF GEOGRAPHY:

Geography is a Greek Word here ‘Geo’ means Earth and ‘Graphy’ means Description. Geography is a science to study lands, features, inhabitants, and phenomena of the Earth. The first person to use the word "geography" was Eratosthenes. Eratosthenes (276–194 BC) - Calculated-circumference of the Earth, tilt of the Earth's axis, distance sun and Earth Geography has been called "the world discipline" and "the bridge between the human and the physical science". Geography is divided into three main branches as physical geography, human geography and cartography.

1.4.2 BRANCHES OF GEOGRAPHY:

At present subject geography divided in to three major branches as:



1. Physical Geography: Physical geography is that branch of natural science which deals with the study of processes and patterns in the natural environment like the atmosphere, hydrosphere, biosphere, and geosphere, as opposed to the cultural or built environment, the domain of human geography. Within the body of physical geography, the Earth is often split into several spheres, the main spheres being the atmosphere, biosphere, geosphere, hydrosphere, lithosphere and pedosphere. Research in physical geography is often interdisciplinary and uses the systems approach.

2.Human Geography: Human geography is the branch of the social sciences that deals with the study of man-environment relationships. It is the study of the world, its peoples, and their communities and cultures, by emphasizing their relations of and across space and place. Human geography is further subdivided in to branches as – social geography, population geography, political geography, economic geography, settlement geography, regional geography etc.

3. Cartography: A map is defined as – representation of three dimensions of earth on two dimensions paper with help of projection, scale and signs and symbols. Cartography is the study and practice of making maps. Combining science, aesthetics, and technique, cartography builds on the premise that reality can be modelled in ways that communicate spatial information effectively.

1.4.3. GEOMORPHOLOGY A BRANCH OF PHYSICAL GEOGRAPHY:

Geomorphology is a diverse discipline. Although the basic geomorphological principles can be applied to all environments, geomorphologists tend to specialise in one or two areas, such aeolian (desert) geomorphology, glacial and periglacial geomorphology, volcanic and tectonic geomorphology, and even planetary geomorphology. Most research is multi-disciplinary, combining the knowledge and perspectives from two contrasting disciplines, combining with subjects as diverse as ecology, geology, civil engineering, hydrology and soil science.

1. Definition- Geomorphology is a Greek Word. 'Geo' – means Earth. 'Morphe' –means form and 'logos'- means discourse. Geomorphology may be defined as – 'the scientific study of surface features of the earth involving, their origin and development and nature and mechanism of geomorphological process which evolves the landforms'. In short we can say that Geomorphology is scientific study of earth's landforms.

As per A. N. Strahler, -"Geomorphology is a systematic study of landforms and their origin." **According to Small** "Geomorphology is a science of landform study is concerned with the study of the form of the earth." **Arthur L. Bloom defined Geomorphology as** "Scientific study of landscapes and the processes that shape them."

1.4.4 Nature of Geomorphology:

Earth's surface is modified by a combination of surface processes that sculpt landscapes, and geologic processes that cause tectonic uplift and subsidence, and shape the coastal geography. Surface processes comprise the action of streams, wind, glaciers, waves, volcanoes, earthquakes and living things on the surface of the earth. It is accompanied by the chemical reactions that form soils and alter material properties, the stability and rate of change of topography under the force of gravity, and other factors, such as human alteration of the landscape. Many of these factors are strongly mediated by climate. Geologic processes include the uplift of mountain ranges, the growth of volcanoes, isostatic changes in land surface elevation and the formation of deep sedimentary basins where the surface of the earth drops and is filled with material eroded from other parts of the landscape. The Earth's surface and its topography therefore are an intersection of climatic, hydrologic, and biologic action with geologic processes.

The broad-scale topographies of the Earth illustrate this intersection of surface and subsurface action. Mountain belts are uplifted due to geologic processes such as folding. Denudation of these high uplifted regions produces sediment that is transported and deposited elsewhere within the landscape or off the coast. Individual landforms evolve in response to the balance of uplift or deposition and subtractive processes. Often, these processes directly affect each other: ice sheets, water, and sediment are all loads that change topography through flexural isostasy. Topography can modify the local climate, for example through orographic precipitation, which in turn modifies the topography by changing the hydrologic regime in which it evolves. Many geomorphologists are particularly interested in the potential for feedbacks between climate and tectonics, mediated by geomorphic processes.

In addition to these broad-scale questions, geomorphologists address issues that are more specific or more local. Glacial geomorphologists investigate glacial deposits such as moraines, eskers, and proglacial lakes, as well as glacial erosional features, to build chronologies of both small glaciers and large ice sheets and understand their motions and effects upon the landscape. Fluvial geomorphologists focus on rivers, how they transport sediment, migrate across the landscape, cut into bedrock, respond to environmental and tectonic changes, and interact with humans. Soils geomorphologists investigate soil profiles and chemistry to learn about the history of a particular landscape and understand how climate, biota, and rock interact. Other geomorphologists study how hill slopes form and change. Still others investigate the relationships between ecology and geomorphology. Because geomorphology is defined to comprise everything related to the surface of the Earth and its modification, it is a broad field with many facets.

Practical applications of geomorphology include hazard assessment such as landslide prediction and mitigation, river control and stream restoration, and coastal protection. Planetary geomorphology studies landforms on other terrestrial planets such as Mars and others. Indications of effects of wind, fluvial, glacial, mass wasting, meteor impact, tectonics and volcanic processes are studied. This effort not only helps better understand the geologic and atmospheric history of those planets but also extends geomorphological study of the Earth. Planetary geomorphologists often use Earth analogues to aid in their study of surfaces of other planets.

1.4.5 Scope of Geomorphology:

Geomorphology studies the origin and structure of the interior of the earth. It also studies the landform building forces of the earth. These forces are of two types' **endogenic** and **exogenic** forces. The endogenic forces origins from interior of the earth and they are of two types'**slow**endogenic forces and **fast**endogenic forces. Exogenic forces are originating from atmosphere some of them are fluvial, marine, glacial, aeolian and weathering and mass movements. Geomorphology also studies past and present distribution of continents and oceans as well as the landforms. Theories such as continental drift theory, plate tectonic theory, isostacy, cycle of erosion. Geosyncline theory etc.are some of the important theories in geomorphology. Climatic geomorphology was developed in France and Germany based on basic tenet that "each climatic type produces its own characteristic assemblage of landforms". As per geomorphology landforms are classified in two three orders:

i. First order landforms – Continents and Oceans
ii. Second order landforms –

- **Continents** - Mountain, Plateaus ad Plains
- **Oceans –** Continental shelf, Continental slope, Ocean Plains/ abyssal plains and trenches/deeps

iii. Third order landforms: At present only details of continents are available. For example on mountain there are erosional landforms as peak, cliff, valley, george, waterfall, rapid etc. On plain one can see landform such as floodplain, meanders, levees, deltas etc.

First order and second order landforms are products of endogenic forces and third order landforms are products of exogenic forces. Processes that are caused by forces from within the Earth are **endogenous** processes. By contrast, **exogenous** processes come from forces on or above the Earth's surface.

Geomorphology is the field concerned with understanding the surface of the earth and the processes by which it is shaped, both at the present as well as in the past. Geomorphology as a field has several sub-fields that deal with the specific landforms of various environments Some of the important sub branches of geomorphology are -e.g. desert geomorphology, coastal geomorphology, tropical geomorphology, fluvial geomorphology, applied geomorphology etc. Geomorphology seeks to understand landform history and dynamics, and predict future changes through a combination of field observation, physical experiment, and numerical modeling.

1.4.6.Evolution of the subject geomorphology:

i. Ancient geomorphology: The study of landforms and the evolution of the earth's surface can be dated back to scholars of Classical Greece. **Herodotus** (484 – 425 BC) argued from observations of soils that the Nile delta was actively growing into the Mediterranean Sea, and he estimated its age. **Aristotle**(384–322 BC) speculated that due to sediment transport into the sea, eventually those seas would fill while the land will be lowered. He claimed that this would mean that land and water would eventually swap places, whereupon the process would begin again in an endless cycle. **Strabo- (**54BC -25 AD) mentioned about variation in size of delta according to nature of rocks of the river catchment region.

The first theory of geomorphology was arguably devised by the polymath Chinese scientist and statesman ShenKuo (1031–1095 AD). This was based on his observation of marine fossil shells in a geological stratum of a mountain hundreds of miles from the Pacific Ocean. He inferred that the land was reshaped and formed by soil erosion of the mountains and by deposition of silt, after observing strange natural erosions of the Taihang Mountains and the Yandang Mountain near Wenzhou. Furthermore, he promoted the theory of gradual climate change over centuries of time once ancient petrified bamboos were found to be preserved underground in the dry, northern climate zone of Yanzhou, which is now modern day Yan'an, Shaanxi province.

ii. Early modern geomorphology: The term geomorphology seems to have been first used by Laumann in an 1858 work written in German. Keith Tinkler has suggested that the word came into general use in English, German and French after John Wesley Powell and W. J. McGee used it during the International Geological Conference of 1891. Book by John Edward Marr 'The Scientific Study of Scenery' is considered as first book related to land form studies.

An early popular geomorphic model was the geographical cycle or cycle of erosion model of broad-scale landscape evolution developed by William Morris Davis between 1884 and 1899. It was an elaboration of the uniformitarianism theory that had first been proposed by James Hutton (1726–1797). With regard to valley forms, for example, uniformitarianism posited a sequence in which a river runs through a flat terrain, gradually carving an increasingly deep valley, until the side valleys eventually erode, flattening the terrain again, though at a lower elevation. It was thought that tectonic uplift could then start the cycle over. In the decades following Davis's development of this idea, many of those studying geomorphology sought to fit their findings into this framework, known today as "Davisian". Davis's ideas are of historical importance, but have been largely superseded today, mainly due to their lack of predictive power and qualitative nature.

In the 1920s, Walther Penck developed an alternative model to Davis's. Penck thought that landform evolution was better described as an alternation between ongoing processes of uplift and denudation, as opposed to Davis's model of a single uplift followed by decay. He also emphasised that in many landscapes slope evolution occurs by backwearing of rocks, not by Davisian-style surface lowering, and his science tended to emphasise surface process over understanding in detail the surface history of a given locality. Penck was German, and during his lifetime his ideas were at times rejected vigorously by the English-speaking geomorphology community. His early death, Davis' dislike for his work, and his at-times-confusing writing style likely all contributed to this rejection.

Both Davis and Penck were trying to place the study of the evolution of the Earth's surface on a more generalized, globally relevant footing than it had been previously. In the early 19th century, authors – especially in Europe – had tended to attribute the form of landscapes to local climate, and in particular to the specific effects of glaciation and periglacial processes. In contrast, both Davis and Penck were seeking to emphasize the importance of evolution of landscapes through time and the generality of the Earth's surface processes across different landscapes under different conditions.

During the early 1900s, the study of regional-scale geomorphology was termed "physiography". Physiography later was considered to be a contraction of "physical" and "geography", and therefore synonymous with physical geography, and the concept became embroiled in controversy surrounding the appropriate concerns of that discipline. Some geomorphologists held to a geological basis for physiography and emphasized a concept of physiographic regions while a conflicting trend among geographers was to equate physiography with "pure morphology," separated from its geological heritage. In the period following World War II, the emergence of process, climatic, and quantitative studies led to a preference by many earth scientists for the term "geomorphology" in order to suggest an analytical approach to landscapes rather than a descriptive one.

iii. Quantitative geomorphology: Part of the Great Escarpment in the Drakensberg, southern Africa. This landscape, with its high altitude plateau being incised into by the steep slopes of the escarpment, was cited by Davis as a classic example of his cycle of erosion.

Geomorphology was started to be put on a solid quantitative footing in the middle of the 20th century. Following the early work of Grove Karl Gilbert around the turn of the 20th century, a group of natural scientists, geologists and hydraulic engineers including Ralph Alger Bagnold, Hans-Albert Einstein, Frank Ahnert, John Hack, Luna Leopold, A. Shields, Thomas Maddock, Arthur Strahler, Stanley Schumm, and Ronald Shreve began to research the form of landscape elements such as rivers and hillslopes by taking systematic, direct, quantitative measurements of aspects of them and investigating the scaling of these measurements.[14][citation needed] These methods began to allow prediction of the past and future behavior of landscapes from present observations, and were later to develop into the modern trend of a highly quantitative approach to geomorphic problems. Quantitative geomorphology can involve fluid dynamics and solid mechanics, geomorphometry, laboratory studies, field measurements, theoretical work, and full landscape evolution modeling. These approaches are used to understand weathering and the formation of soils, sediment transport, landscape change, and the interactions between climate, tectonics, erosion, and deposition.

iv. Contemporary geomorphology: Today, the field of geomorphology encompasses a very wide range of different approaches and interests. Modern researchers aim to draw out quantitative "laws" that govern Earth surface processes, but equally, recognize the uniqueness of each landscape and environment in which these processes operate. Particularly important realizations in contemporary geomorphology include:

1) That not all landscapes can be considered as either "stable" or "perturbed", where this perturbed state is a temporary displacement away from some ideal target form. Instead, dynamic changes of the landscape are now seen as an essential part of their nature.

2) That many geomorphic systems are best understood in terms of the stochasticity of the processes occurring in them, that is, the probability distributions of event magnitudes and return times. This in turn has indicated the importance of chaotic determinism to landscapes, and that landscape properties are best considered statistically. The same processes in the same landscapes do not always lead to the same end results.

v. Processes in Geomorphology:

The earth and atmospheric process are responsible for shaping land forms on the surface of the earth. The process relevant to subject matter of geomorphology generally fall into following types;

i. Weathering and erosion

ii. The transportation of weathered or eroded material

iii. Deposition of transported material

Some of the prominent processes are as following:

The surface processes responsible for most topographic features includes streams, wind, waves, mass wasting, glaciers, ground water, tectonic activities etc. Other exotic geomorphic processes includes freeze-thaw processes, salt-mediated action, changes to the seabed caused by marine currents, seepage of fluids through the seafloor or extra-terrestrial impacts etc.

i. Fluvial processes: The Rivers are considered as global agents of erosion as they are active in all the topographic landscapes. The water, as it flows over the channel bed, is able to mobilize sediment and transport it downstream as load. Rivers are also capable of eroding into rock and creating new sediment, both from their own beds and also by coupling to the surrounding hill slopes. As rivers flow across the landscape, they generally increase in size, merging with other rivers. The network of rivers thus formed is a drainage system.

ii. Aeolian processes: These processes are pertain to the activity of the winds. Winds may erode, transport, and deposit materials, and are effective agents in regions with sparse vegetation and a large supply of fine, unconsolidated sediments. Aeolian processes are important in arid environments such as deserts.

iii. Glacial process: Glaciers are the rivers of ice and very common process in high mountains and Polar Regions. The gradual movement of ice down a valley causes abrasion and plucking of the underlying rock. The debris transported by the glacier, when the glacier recedes, is termed a moraine. Glacial erosion is responsible for U-shaped valleys, as opposed to the V-shaped valleys of fluvial origin.

iv. Hillslope processes: Soil, regolith, and rock move downslope under the force of gravity via creep, slides, flows, topples, and falls. Such mass wasting occurs on both terrestrial and submarine slopes, and has been observed on earth and other planets. Ongoing hillslope processes can change the topology of the hillslope surface, which in turn can change the rates of those processes. Hillslopes that steepen up to certain critical thresholds are capable of shedding extremely large volumes of material very quickly, making hillslope processes an extremely important element of landscapes in tectonically active areas.

v. Tectonic processes: Tectonic effects on geomorphology can range from scales of millions of years to minutes or less. The effects of tectonics on landscape are heavily dependent on the nature of the underlying bedrock fabric that more or less controls what kind of local morphology tectonics can shape. Earthquakes can, in terms of minutes, submerge large areas of land creating new wetlands. Isostatic rebound can account for significant changes over hundreds to thousands of years, and allows erosion of a mountain belt to promote further erosion as mass is removed from the chain and the belt uplifts. Long-term plate tectonic dynamics give rise to orogenic belts, large mountain chains with typical lifetimes of many tens of millions of years, which form focal points for high rates of fluvial and hillslope processes and thus long-term sediment production.

vi. Marine processes: Marine processes are those associated with the action of waves, marine currents and seepage of fluids through the seafloor. Mass wasting and submarine landsliding are also important processes for some aspects of marine geomorphology. Because ocean basins are the ultimate sinks for a large fraction of terrestrial sediments, depositional processes and their related forms are particularly important as elements of marine geomorphology.

1.5 GEOLOGICAL EVOLUTION OF EARTH AND GEOLOGICAL TIME SCALE

1.5.1 A. ORIGIN OF THE EARTH:

Scientists and philosophers have propounded from time to time their concepts, hypotheses and theories to unravel the mystery and to solve the riddle of the problems of the origin and evolution of our solar system in general and of the earth in particular but none of these could be accepted by majority of the scientific community.

Though there is no common consensus among the scientists about the origin of our solar system but it can be safely argued that all planets of our solar system are believed to have been formed by the same process. It means that all the concepts, hypotheses and theories propounded for the origin of the solar system are also applicable for the origin of the earth.

i. Hot origin concepts: According to the school of ‘hot origin’, our solar system was believed to have been formed from the matter which as either initiallyhot or was heated up in the process of the origin of the earth.

ii. Cold origin concepts: On the other hand, according to the school of ‘cold origin’ our solar system was formed of the matter which was either initially cold or always remained cold.After the formation the earth might have been heated up due to the presence of radioactive elements or only the interior of the earth might have been heated up due to intense pressure exerted by the super incumbent load of the upper layers.

1. Origin of the earth - nebular hypothesis: The nebular hypothesis is the most widely accepted model to explain the formation of the Solar System. It suggests the Solar System is formed from gas and dust orbiting the Sun. The theory was developed by Immanuel Kant initially in 1755 and then modified in 1796 by Pierre Laplace.

According to the nebular theory, stars form in massive and dense clouds of molecular hydrogen giant molecular clouds (GMC). These clouds are gravitationally unstable, and matter coalesces within them to smaller denser clumps, which then rotate, collapse, and form stars. Star formation is a complex process, which always produces a gaseous proto planetary disk around the young star. This may give birth to planets in certain circumstances. Thus the formation of planetary systems is thought to be a natural result of star formation. A Sun-like star usually takes approximately 1 million years to form, with the proto planetary disk evolving into a planetary system over the next 10–100 million years. If the disk is massive enough, the runaway accretions begin, resulting in the rapid—100,000 to 300,000 years—formation of Moon- to Mars-sized planetary embryos. Near the star, the planetary embryos go through a stage of violent mergers, producing a few terrestrial planets. The last stage takes approximately 100 million to a billion years. Super-Earths and other closely orbiting planets are thought to have either formed in situ or ex situ, that is, to have migrated inward from their initial locations.

2. Tidal hypothesis: This hypothesis was given by James Jeans and Harold Jeffreys, explained the origin of the solar system as a result of a close encounter between the Sun and a second star. After as a detailed mathematical analysis, Jeans concluded in 1916 that the tidal interaction between the Sun and a passing star would raise tides on the Sun resulting in the loss of a single cigar-shaped filament of hot gas. This hot gas would then condense directly into the planets. The central section of the "cigar" would give rise to the largest planets – Jupiter and Saturn – while the tapering ends would provide the substance for the smaller worlds.

3. Binary start Hypothesis: The "Binary" hypothesis was put forth by Russell (1937) who believed in the existence of many stars as pairs in the universe.Our solar system was born from one of these star pairs which consisted of the sun and another smaller star known as the companion star.A huge-sized third star came into the region of this paired stars and caused tidal explosion in the companion star which was completely disrupted, When the third star came close to the companion star some parts of the companion star, were carried away along with the third star which eventually receded away. The rest fell into the sun's gravitational control, these parts retained by the sun revolved round it and gradually cooled down to form the planets.

4. Stages in Evolution of the Earth: C.Chamberlin (1905) has attempted to describe and explain the evolution of different components of the earth. e.g. continents and ocean basins, folds and faults, volcanoes and earthquakes, mountains and plains, heat of the interior of the earth and its structure and the origin and evolution of its atmosphere through specific periods or stages.

First stage– 'the period of planetesimal accession' or 'the period of acquisition of the present shape and size by the earth'.**Second stage**– "the period of dominant volcanism" or 'the period of the evolution of the earth's interior and the evolution of continents and ocean basins'.**Third stage**– 'the actual geological period' or 'the period of the formation of the folds and faults, mountains and plateaux etc.

These stages of the evolution of the earth are separated from each other only for the sake of convenience; otherwise these are so interlinked with each other that it is quite difficult to differentiate one stage from the other.
The planet earth initially was a barren, rocky and hot object with a thin atmosphere of hydrogen and helium. This is far from the present day picture of the earth. Hence, there must have been some events–processes,

which may have caused this change from rocky, barren and hot earth to a beautiful planet with ample amount of water and conducive atmosphere favouring the existence of life.

Between the 4,600 million years and the present, led to the evolution of life on the surface of the planet. The earth was mostly in a volatile state during its primordial stage. Due to gradual increase in density the temperature inside has increased. As a result, the material inside started getting separated depending on their densities. This allowed heavier materials (like iron) to sink towards the centre of the earth and the lighter ones to move towards the surface. With passage of time it cooled further and solidified and condensed into a smaller size. This later led to the development of the outer surface in the form of a crust. During the formation of the moon, due to the giant impact, the earth was further heated up. It is through the process of differentiation that the earth forming material got separated into different layers. Starting from the surface to the central parts, we have layers like the crust, mantle, outer core and inner core. From the crust to the core, the density of the material increases.

1.5.2. B. GEOLOGICAL TIME SCALE:

The **geological history of Earth** follows the major events in Earth's past based on the geologic time scale, a system of chronological measurement based on the study of the planet's rock layers. Earth formed about 4.6 billion years ago by accretion from the solar nebula, a disk-shaped mass of dust and gas left over from the formation of the Sun, which also created the rest of the solar system https://en.wikipedia.org/wiki/Solar_System.

Earth was initially molten due to extreme volcanism and frequent collisions with other bodies. Eventually, the outer layer of the planet cooled to form a solid crust when water began accumulating in the atmosphere. The Moon formed soon afterwards, possibly as a result of the impact of a planetoid with the Earth. Outgassing and volcanic activity produced the primordial atmosphere. Condensing water vapor, augmented by ice delivered from comets, produced the oceans.

As the surface continually reshaped itself over hundreds of millions of years, continents formed and broke apart. They migrated across the surface, occasionally combining to form a supercontinent. Roughly 750 million years ago, the earliest-known supercontinent Rodinia, began to break apart. The continents later recombined to form Pannotia, 600 to 540 million years ago, then finally Pangaea, which broke apart200 million years ago.

The present pattern of ice ages began about 40 million years ago, then intensified at the end of the Pliocene. The Polar Regions have since undergone repeated cycles of glaciation and thaw, repeating every 40,000–100,000 years. The last glacial period of the current ice age ended about 10,000 years ago.

A. Precambrian : The Precambrian includes approximately 90% of geologic time. It extends from 4.6 billion years ago to the beginning of the Cambrian Period (about 541 Ma).

1. Hadean Eon: During Hadean time (4.6–4 Ga), the Solar System was forming, probably within a large cloud of gas and dust around the sun, called an accretion disc from which Earth formed 4,500 million years ago. The Hadean Eon is not formally recognized, but it essentially marks the era before we have adequate record of significant solid rocks. The oldest dated zircons date from about 4,400 million years ago.

2. Archean Eon: The Earth of the early Archean (4,000 to 2,500 million years ago) may have had a different tectonic style. During this time, the Earth's crust cooled enough that rocks and continental plates began to form. Some scientists think because the Earth was hotter, that plate tectonic activity was more vigorous than it is today, resulting in a much greater rate of recycling of crustal material. This may have prevented cratonisation and continent formation until the mantle cooled and convection slowed down. Others argue that the sub-continental lithospheric mantle is too buoyant to subduct and that the lack of Archean rocks is a function of erosion and subsequent tectonic events.

3. Proterozoic Eon: The geologic record of the Proterozoic (2,500 to 541 million years ago) is more complete than that for the preceding Archean. In contrast to the deep-water deposits of the Archean, the Proterozoic features many strata that were laid down in extensive shallow epicontinental seas; furthermore, many of these rocks are less metamorphosed than Archean-age ones, and plenty are unaltered. Study of these rocks show that the eon featured massive, rapid continental accretion (unique to the Proterozoic), supercontinent cycles, and wholly modern orogenic activity. Roughly 750 million years ago, the earliest-known supercontinent Rodinia, began to break apart. The continents later recombined to form Pannotia, 600–540 Ma.

4.The Phanerozoic Eon: is the current eon in the geologic timescale. It covers roughly 541 million years. During this period continents drifted about, eventually collected into a single landmass known as Pangea and then split up into the current continental landmasses.The Phanerozoic is divided into three eras — the Paleozoic, the Mesozoic and the Cenozoic.

A: PALEOZOIC ERA:

The Paleozoic spanned from roughly 541 to 252 million years ago (Ma) and is subdivided into six geologic periods; from oldest to youngest they are the **Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian**. Geologically, the Paleozoic starts shortly after the breakup of a supercontinent called Pannotia and at the end of a global ice age. Throughout the early Paleozoic, the Earth's landmass was broken up into a substantial number of relatively small continents. Toward the end of the era the continents gathered together into a supercontinent called Pangaea, which included most of the Earth's land area.

a. Cambrian Period: The Cambrian is a major division of the geologic timescale that begins about 541.0 ± 1.0 Ma. The waters of the Cambrian period appear to have been widespread and shallow. Continental drift rates may have been anomalously high. Laurentia, Baltica and Siberia remained independent continents following the break-up of the supercontinent of Pannotia. Gondwana started to drift toward the South Pole. Panthalassa covered most of the southern hemisphere, and minor oceans included the Proto-Tethys Ocean, Iapetus Ocean and Khanty Ocean.

b. Ordovician Period: The Ordovician Period started at time about 485.4 ± 1.9 Ma. During the Ordovician the southern continents were collected into a single continent called Gondwana. Gondwana started the period in the equatorial latitudes and, as the period progressed, drifted toward the South Pole. Early in the Ordovician the continents Laurentia, Siberia and Baltica were still independent continents (since the break-up of the supercontinent Pannotia earlier), but Baltica began to move toward Laurentia later in the period, causing the Iapetus Ocean to shrink between them. Also, Avalonia broke free from Gondwana and began to head north toward Laurentia.

C.Silurian Period: The Silurian is a major division of the geologic timescale that started about 443.8 ± 1.5 Ma. During the Silurian, Gondwana continued a slow southward drift to high southern latitudes, but there is evidence that the Silurian ice caps were less extensive than those of the late Ordovician glaciation. The melting of ice caps and glaciers contributed to a rise in sea levels, recognizable from the fact that Silurian sediments overlie eroded Ordovician sediments, forming an unconformity. Other cratons and continent fragments drifted together near the equator, starting the formation of a second supercontinent known as Euramerica. The vast ocean of Panthalassa covered most of the northern hemisphere. Other minor oceans include Proto-Tethys, Paleo-Tethys, Rheic Ocean, a seaway of Iapetus Ocean (now in between Avalonia and Laurentia), and newly formed Ural Ocean.

d. Devonian Period: The Devonian spanned roughly from 419 to 359 Ma. The period was a time of great tectonic activity, as Laurasia and Gondwana drew closer together. The continent Euramerica (or Laurussia) was created in the early Devonian by the collision of Laurentia and Baltica, which rotated into the natural dry zone along the Tropic of Capricorn. In these near-deserts, the Old Red Sandstone sedimentary beds formed, made red by the oxidized iron (hematite) characteristic of drought conditions. Near the equator Pangaea began to consolidate from the plates containing North America and Europe, further raising the northern Appalachian Mountains and forming the Caledonian Mountains in Great Britain and Scandinavia. The southern continents remained tied together in the supercontinent of Gondwana.

e. Carboniferous Period: This period extends from about 358.9 ± 0.4 to about 298.9 ± 0.15 Ma. A global drop in sea level at the end of the Devonian reversed early in the Carboniferous; this created the widespread epicontinental seas and carbonate deposition of the Mississippian. There was also a drop in south polar temperatures; southern Gondwana was glaciated throughout the period, though it is uncertain if the ice sheets were a holdover from the Devonian or not. These conditions apparently had little effect in the deep tropics, where lush coal swamps flourished within 30 degrees of the northernmost glaciers.

The Carboniferous was a time of active mountain building, Hercynian orogeny in Europe, and the Alleghenian orogeny in North America; it also extended the newly uplifted Appalachians southwestward as the Ouachita Mountains

f. Permian Period: The Permian extends from about 298.9 ± 0.15 to 252.17 ± 0.06 Ma. During the Permian all the Earth's major land masses, except portions of East Asia, were collected into a single supercontinent known as Pangaea. Pangaea straddled the equator and extended toward the poles, with a corresponding effect on ocean currents in the single great ocean (Panthalassa, the universal sea), and the Paleo-Tethys Ocean, a large ocean that was between Asia and Gondwana. The Cimmeria continent rifted away from Gondwana and drifted north to Laurasia, causing the Paleo-Tethys to shrink. A new ocean was growing on its southern end, the Tethys Ocean, an ocean that would dominate much of the Mesozoic Era. Large continental landmasses create climates with extreme variations of heat and cold ("continental climate") and monsoon conditions with highly seasonal rainfall patterns. Deserts seem to have been widespread on Pangaea.

B. MESOZOIC ERA:

The **Mesozoic** extended roughly from 252 to 66 million years ago. After the vigorous convergent plate mountain-building of the late Paleozoic, Mesozoic tectonic deformation was comparatively mild. Nevertheless, the era featured the dramatic rifting of the supercontinent Pangaea. Pangaea gradually split into a northern continent, Laurasia, and a southern continent, Gondwana.

a. Triassic Period: This Period extends from about 252.17 ± 0.06 to 201.3 ± 0.2 Ma.

The remainder was the world-ocean known as Panthalassa ("all the sea"). All the deep-ocean sediments laid down during the Triassic have disappeared through subduction of oceanic plates; thus, very little is known of the Triassic open ocean. The supercontinent Pangaea was rifting during the Triassic—especially late in the period—but had not yet separated. The first non-marine sediments in the rift that marks the initial break-up of Pangea—which separated New Jersey from Morocco—are of

Late Triassic age; in the U.S., these thick sediments comprise the Newark Super group. Because of the limited shoreline of one super-continental mass, Triassic marine deposits are globally relatively rare; despite their prominence in Western Europe, where the Triassic was first studied. In North America, for example, marine deposits are limited to a few exposures in the west. Thus Triassic stratigraphy is mostly based on organisms living in lagoons and hyper saline environments, such as *Estheria* crustaceans and terrestrial vertebrates.

b. Jurassic Period: This Period extends from about 201.3 ± 0.2 to 145.0 Ma.[2] During the early Jurassic, the supercontinent Pangaea broke up into the northern supercontinent Laurasia and the southern supercontinent Gondwana. The Tethys Sea closed, and the Neotethys basin appeared. Climates were warm, with no evidence of glaciation. As in the Triassic, there was apparently no land near either pole, and no extensive ice caps existed. The Jurassic geological record is good in western Europe, where extensive marine sequences indicate a time when much of the continent was submerged under shallow tropical seas; famous locales include the Jurassic Coast World Heritage Site and the renowned late Important Jurassic exposures are also found in Russia, India, South America, Japan, Australasia and the United Kingdom.

c. Cretaceous Period:

The **Cretaceous** Period extends from circa 145 million years ago to 66 million years ago.[2]

During the Cretaceous, the late Paleozoic-early Mesozoic supercontinent of Pangaea completed its breakup into present day continents, although their positions were substantially different at the time. As the Atlantic Ocean widened, the convergent-margin orogenies that had begun during the Jurassic continued in the North American Cordillera, as the Nevadan orogeny was followed by the Sevier and Laramideorogenies. Though Gondwana was still intact in the beginning of the Cretaceous, Gondwana itself broke up as South America, Antarctica and Australia rifted away from Africa (though India and Madagascar remained attached to each other); thus, the South Atlantic and Indian Oceans were newly formed. Such active rifting lifted great undersea mountain chains along the welts, raising eustatic sea levels worldwide.

To the north of Africa the Tethys Sea continued to narrow. Broad shallow seas advanced across central North America (the Western Interior Seaway) and Europe, then receded late in the period, leaving thick marine deposits sandwiched between coal beds. At the peak of the Cretaceous transgression, one-third of Earth's present land area was submerged.[24] The Cretaceous is justly famous for its chalk; indeed, more chalk formed in the Cretaceous than in any other period in the Phanerozoic. Mid-ocean ridge activity—or rather, the circulation of seawater through the enlarged ridges—enriched the oceans in calcium;

this made the oceans more saturated, as well as increased the bioavailability of the element for calcareous nano plankton. These widespread carbonates and other sedimentary deposits make the Cretaceous rock record especially fine. Famous formations from North America include the rich marine fossils of Kansas's Smoky Hill Chalk Member and the terrestrial fauna of the late Cretaceous Hell Creek Formation. Other important Cretaceous exposures occur in Europe and China. In the area that is now India, massive lava beds called the Deccan Traps were laid down in the very late Cretaceous and early Paleocene.

C. CENOZOIC ERA:

The **Cenozoic** Era covers the 66 million years since the Cretaceous–Paleogene extinction event up to and including the present day. By the end of the Mesozoicera, the continents had rifted into nearly their present form. Laurasia became North America and Eurasia, while Gondwana split into South America, Africa, Australia, Antarctica and the Indian subcontinent, which collided with the Asian plate. This impact gave rise to the Himalayas. The Tethys Sea, which had separated the northern continents from Africa and India, began to close up, forming the Mediterranean Sea.

a. Paleogene Period ; Period is a unit of geologic time that began 66 and ended 23.03 Ma[2] and comprises the first part of the Cenozoic Era. This period consists of the Paleocene, Eocene and Oligocene Epochs.

1. Paleocene Epoch: The **Paleocene**, lasted from 66 million years ago to 56 million years ago.

In many ways, the Paleocene continued processes that had begun during the late Cretaceous Period. During the Paleocene, the continents continued to drift toward their present positions. Supercontinent Laurasia had not yet separated into three continents. Europe and Greenland were still connected. North America and Asia were still intermittently joined by a land bridge, while Greenland and North America were beginning to separate.[27] The Laramide orogeny of the late Cretaceous continued to uplift the Rocky Mountains in the American west, which ended in the succeeding epoch. South and North America remained separated by equatorial seas (they joined during the Neogene); the components of the former southern supercontinent Gondwana continued to split apart, with Africa, South America, Antarctica and Australia pulling away from each other. Africa was heading north toward Europe, slowly closing the Tethys Ocean, and India began its migration to Asia that would lead to a tectonic collision and the formation of the Himalayas.

2. Eocene Epoch: During the **Eocene** (56 million years ago - 33.9 million years ago),[2] the continents continued to drift toward their present positions. At the beginning of the period, Australia and Antarctica remained connected, and warm equatorial currents mixed with colder

Antarctic waters, distributing the heat around the world and keeping global temperatures high. But when Australia split from the southern continent around 45 Ma, the warm equatorial currents were deflected away from Antarctica, and an isolated cold water channel developed between the two continents. The Antarctic region cooled down, and the ocean surrounding Antarctica began to freeze, sending cold water and ice floes north, reinforcing the cooling. The present pattern of ice ages began about 40 million years ago.

The northern supercontinent of Laurasia began to break up, as Europe, Greenland and North America drifted apart. In western North America, mountain building started in the Eocene, and huge lakes formed in the high flat basins among uplifts. In Europe, the Tethys Sea finally vanished, while the uplift of the Alps isolated its final remnant, the Mediterranean, and created another shallow sea with island archipelagos to the north. Though the North Atlantic was opening, a land connection appears to have remained between North America and Europe since the faunas of the two regions are very similar. India continued its journey away from Africa and began its collision with Asia, creating the Himalayan orogeny.

3. Oligocene Epoch: The **Oligocene** Epoch extends from about 34 million years ago to 23 million years ago. During the Oligocene the continents continued to drift toward their present positions.

Antarctica continued to become more isolated and finally developed a permanent ice cap. Mountain building in western North America continued, and the Alpsstarted to rise in Europe as the African plate continued to push north into the Eurasian plate, isolating the remnants of Tethys Sea. A brief marine incursion marks the early Oligocene in Europe. There appears to have been a land bridge in the early Oligocene between North America and Europe since the faunas of the two regions are very similar. During the Oligocene, South America was finally detached from Antarctica and drifted north toward North America. It also allowed the Antarctic Circumpolar Current to flow, rapidly cooling the continent.

b. Neogene Period: Neogene Period is a unit of geologic time starting 23.03 Ma.[2] and ends at 2.588 Mya. The Neogene Period follows the Paleogene Period. The Neogene consists of the Miocene and Pliocene and is followed by the Quaternary Period.

1. Miocene Epoch: This epoch extends from about 23.03 to 5.333 Ma. During the Miocene continents continued to drift toward their present positions. Of the modern geologic features, only the land bridge between South America and North America was absent, the subduction zone along the Pacific Ocean margin of South America caused the rise of the Andes and the southward extension of the Meso-American peninsula. India continued to collide with Asia. The Tethys

Seaway continued to shrink and then disappeared as Africa collided with Eurasia in the Turkish-Arabian region between 19 and 12 Ma (ICS 2004). Subsequent uplift of mountains in the western Mediterranean region and a global fall in sea levels combined to cause a temporary drying up of the Mediterranean Sea resulting in the Messinian salinity crisis near the end of the Miocene.

2. Pliocene Epoch: Pliocene extends from 5.333 million years ago to 2.588 million years ago. During the Pliocene continents continued to drift toward their present positions, moving from positions possibly as far as 250 kilometres from their present locations to positions only 70 km from their current locations.

South America became linked to North America through the Isthmus of Panama during the Pliocene, bringing a nearly complete end to South America's distinctive marsupial faunas. The formation of the Isthmus had major consequences on global temperatures, since warm equatorial ocean currents were cut off and an Atlantic cooling cycle began, with cold Arctic and Antarctic waters dropping temperatures in the now-isolated Atlantic Ocean. Africa's collision with Europe formed the Mediterranean Sea, cutting off the remnants of the Tethys Ocean. Sea level changes exposed the land-bridge between Alaska and Asia. Near the end of the Pliocene, about 2.58 million years ago (the start of the Quaternary Period), the current ice age began. The Polar Regions have since undergone repeated cycles of glaciation and thaw, repeating every 40,000–100,000 years.

c. Quaternary Period:

1. Pleistocene Epoch: The **Pleistocene** extends from 2.588 million years ago to 11,700 years before present. The modern continents were essentially at their present positions during the Pleistocene, the plates upon which they sit probably having moved no more than 100 kilometres relative to each other since the beginning of the period.

2. Holocene Epoch: The **Holocene** Epoch began approximately 11,700 calendar years before present https://en.wikipedia.org/wiki/Geological_history_of_Earth - cite_note-ICS2015-2 and continues to the present. During the Holocene, continental motions have been less than a kilometer.

The last glacial period of the current ice age ended about 10,000 years ago.[28] Ice melt caused world sea levels to rise about 35 meters in the early part of the Holocene. In addition, many areas above about 40 degrees north latitude had been depressed by the weight of the Pleistocene glaciers and rose as much as 180 metres over the late Pleistocene and Holocene, and are still rising today. The sea level rise and temporary land depression allowed temporary marine incursions into areas that are now far from the sea. Holocene marine fossils are known from Vermont, Quebec, Ontario and Michigan. Other than higher latitude temporary marine incursions associated with glacial depression, Holocene fossils are found primarily in lakebed, floodplain and cave deposits. Holocene marine deposits along low-latitude coastlines are rare because the rise in sea levels during the period exceeds any likely upthrusting of non-glacial origin. Post-glacial rebound in Scandinavia resulted in the emergence of coastal areas around the Baltic Sea, including much of Finland. The region continues to rise, still causing weak earthquakes across Northern Europe. The equivalent event in North America was the rebound of Hudson Bay, as it shrank from its larger, immediate post-glacial Tyrrell Sea phase, to near its present boundaries.

1.6. DEVELOPMENT OF GEOMORPHIC THOUGHT

1.6.1 EARLY MODERN GEOMORPHOLOGY:

The term geomorphology seems to have been first used by **Laumann**in an 1858 work written in German. Keith Tinkler has suggested that the word came into general use in English, German and French after **J. W. Powell** and **W. J. McGee** used it during the International Geological Conference of 1891. John Edward Marr in his 'The Scientific Study of Scenery' considered his book as, 'an Introductory Treatise on Geomorphology, a subject which has sprung from the union of Geology and Geography'.

An early popular geomorphic model was the **cycle of erosion** model of broad-scale landscape evolution developed by William Morris Davis between 1884 and 1899. It was an elaboration of the **uniformitarianism theory** that had first been proposed by **James Hutton** (1726–1797). With regard to valley forms, for example, **uniformitarianism** posited a sequence in which a river runs through a flat terrain, gradually carving an increasingly deep valley, until the side valleys eventually erode, flattening the terrain again, though at a lower elevation. It was thought that tectonic uplift could then start the cycle over. Davis's ideas are of historical importance, but have been largely superseded today, mainly due to their lack of predictive power and qualitative nature.

In the 1920s, **Walther Penck** developed an alternative model to Davis's. Penck thought that landform evolution was better described as an **alternation between ongoing processes of uplift and denudation,** as opposed to Davis's model of a single uplift followed by decay. He also emphasized that in many landscapes **slope evolution** occurs by back wearing of rocks, not by Davisian-style surface lowering, and his science tended to emphasise surface process over understanding in detail the surface history of a given locality. Penck was German, and during his lifetime his ideas were at times rejected vigorously by the English-speaking geomorphology community.

In the early **19th century**, authors – especially in Europe – had tended to attribute the form of landscapes to local climate, and in particular to the specific effects of glaciation and periglacial processes. In contrast, both Davis and Penck were seeking to emphasize the importance of evolution of landscapes through time and the generality of the Earth's surface processes across different landscapes under different conditions.

During the **early 1900s**, the study of regional-scale geomorphology was termed "physiography". Physiography later was considered to be a contraction of "physical" and "geography", and therefore synonymous with physical geography, and the concept became embroiled in controversy surrounding the appropriate concerns of that discipline. Some geomorphologists held to a geological basis for physiography and emphasized a concept of physiographic regions while a conflicting trend among geographers was to equate physiography with "pure morphology," separated from its geological heritage. In the period following World War II, the emergence of process, climatic, and quantitative studies led to a preference by many earth scientists for the term "geomorphology" in order to suggest an analytical approach to landscapes rather than a descriptive one.

1.6.2. QUANTITATIVE GEOMORPHOLOGY:

Geomorphology was started to be put on a solid quantitative footing in the middle of the 20th century. Following the early work of **Grove Karl Gilbert** around the turn of the 20^{th} century, a group of natural scientists, geologists and hydraulic engineers including Ralph Alger Bagnold, Hans-Albert Einstein, Frank Ahnert, John Hack, Luna Leopold, Arthur Strahler, and Ronald Shreve began to research the form of landscape elements such as rivers and hill slopes by taking systematic, direct, quantitative measurements of aspects of them and investigating the scaling of these measurements. These methods began to allow prediction of the past and future behavior of landscapes from present observations, and were later to develop into the modern trend of a highly quantitative approach to geomorphic problems. Quantitative geomorphology can involve fluid dynamics and solid mechanics, geomorphometry, laboratory studies, field measurements, theoretical work, and full landscape evolution modeling. These approaches are used to understand weathering and the formation of soils, sediment transport, landscape change, and the interactions between climate, tectonics, erosion, and deposition.

1.6.3. CONTEMPORARY GEOMORPHOLOGY:

Today, the field of geomorphology encompasses a very wide range of different approaches and interests. Modern researchers aim to draw out quantitative "laws" that govern Earth surface processes, but equally, recognize the uniqueness of each landscape and environment in which these processes operate. Particularly important realizations in contemporary geomorphology include:

1) That not all landscapes can be considered as either "stable" or "perturbed", where this perturbed state is a temporary displacement away from some ideal target form.

2) That many geomorphic systems are best understood in terms of the sarcastically of the processes occurring in them, that is, the probability distributions of event magnitudes and return times.

Geologists haven't always agreed about the history of our planet. They have debated between **catastrophism and uniformitarianism** over the last few hundred years! Learn about the two main theories of geologic evolution and how scientists came to resolve the dispute.

1. Catastrophism: Catastrophism is the theory that the Earth has been affected in the past by sudden, short-lived, violent events, possibly worldwide in scope. This was in contrast to uniformitarianism, in which slow incremental changes, such as erosion, created all the Earth's geological features. **Uniformitarianism held that the present is the key to the past**, and that all things continued as they were from the indefinite past. Since the early disputes, a more inclusive and integrated view of geologic events has developed, in which the scientific consensus accepts that there were some catastrophic events in the geologic past, but these were explicable as extreme examples of natural processes which can occur.

Catastrophism held that geological epochs had ended with violent and sudden natural catastrophes such as great floods and the rapid formation of major mountain chains. Plants and animals living in the parts of the world where such events occurred were killed off, being replaced abruptly by the new forms whose fossils defined the geological strata.

Catastrophism concept was first popularized by the early 19^{th}-century French scientist **Georges Cuvier,** who proposed that new life forms had moved in from other areas after local floods, and avoided religious or metaphysical speculation in his scientific writings. At that time in history, European scientists had a habit of interweaving their studies of the Bible with their studies of natural science. When it came to Earth's history, they looked to the biblical story of the great flood to help them understand the geologic events of the past.

Cuvier was also making observations that puzzled him about the **fossil record**. He saw a lot of mysterious gaps; that is, certain species would show up for long periods of geologic time and then suddenly disappear. Combined with his impressions of the violent natural disasters recounted in the Bible, Cuvier's observations made him believe that most of Earth's history was characterized by geologic catastrophe. This idea emerged and spread among scientists as the theory of **catastrophism**.

Cuvier and other scientists believed that most major features of the land we see today were established a very long time ago by very dramatic events. These events would not at all resemble the small-scale natural disasters we experience in our time. The drama was over, immortalized in religious texts, never again to be seen on such a humongous scale.

2. Uniformitarianism:

In 1785, a geologist and physicist named **James Hutton** proposed another idea. He thought that most of the features on the surface of the Earth were formed by slow, ongoing geologic processes, not by sudden catastrophic events. Hutton didn't believe that there was anything happening long ago that wasn't still happening on Earth today. In other words**, 'the present is the key to the past.'** The erosion of landforms, the deposition of sediments, the drifting of continents and the eruption of volcanoes - all of these were happening long ago, on roughly the same scale and at roughly the same rate as they are today.

Hutton's idea was a major turning point in the field of geology. He called it **uniformitarianism**: the theory that Earth's features are mostly accounted for by gradual, small-scale processes that occurred over long periods of time. Also called **gradualism**, the theory of uniformitarianism was fleshed out and popularized by another geologist, **Charles Lyell**.

In the 1830s, Lyell published **Principles of Geology**, which explained the finer details of uniformitarianism. The book became a keystone text for geologists and also influenced the evolutionary theories of Charles Darwin. But although Charles Lyell published the actual book, it is still James Hutton who gets the credit for being '**The Father of Modern Geology**.' Hutton's principle of uniformitarianism gave geology a real boost that helped it grow into the highly-detailed, functional discipline that it is today.

Principles of Geology was published right around the time when Western science was trying to unravel itself from biblical and other religious associations. Scientists didn't feel like they had to account for the great flood anymore. Instead, they stuck to the things they could see: mountains eroding, volcanoes erupting, rivers shifting their courses.

3.Neo-catastrophism -The view or theory, similar in some respects to the earlier ideas of catastrophism, that geological features and the evolution and extinction of living organisms have been influenced to a great extent by sudden and powerful natural events occurring at intervals, rather than having been mainly the result of slow continuous processes; a modified form of catastrophism. In the latter part of the twentieth century a new school of thought emerged in geology that has been dubbed **'neo-catastrophism'** as opposed to the gradualism of Lyell and Darwin.

N.S. Shatskij (1937) has introduced the term neocatastrophism to describe certain trends in contemporary geology.

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Activity: Identify land forms those are around your place of residence, work or at the place which you have recently visited. Classify them as per the criteria’s such as erosional landforms, deposition landforms, agent of erosion or agent of deposition formed it.

❖❖❖❖

2

INTERIOR OF THE EARTH

Unit Structure:

2.0 OBJECTIVES:

By the end of the module, the learner will be able to -

- Explain the changing nature of the interior of the earth.
- Explain the formation of the continents and oceans.
- Explain the formation of the mountains and the processes of Mountain Buildings.

2.1 INTRODUCTION:

Three centuries ago, the English scientist Isaac Newton calculated, from his studies of planets and the force of gravity, that the average density of the Earth is twice that of surface rocks and therefore that the Earth's interior must be composed of much denser material. Our knowledge of what's inside the Earth has improved immensely since Newton's time, but his estimate of the density remains essentially unchanged. Our current information comes from studies of the paths and characteristics of earthquake waves traveling through the Earth, as well as from laboratory experiments on surface minerals and rocks at high pressure and temperature. Other important data on the Earth's interior come from geological observation of surface rocks and studies of the Earth's motions in the Solar System, its gravity and magnetic fields, and the flow of heat from inside the Earth.

2.2 INTERIOR OF THE EARTH:

The planet Earth is made up of three main shells: the very thin, brittle crust, the mantle, and the core; the mantle and core are each divided into two parts. All parts are drawn to scale on the cover of this publication, and a table at the end lists the thicknesses of the parts. Although the core and mantle are about equal in thickness, the core forms only 15 percent of the Earth's volume, whereas the mantle occupies 84 percent. The crust makes up the remaining 1 percent. Our knowledge of the layering and chemical composition of the Earth is steadily being improved by earth scientists doing laboratory experiments on rocks at high pressure and analyzing earthquake records on computers.

A. The Crust

Because the crust is accessible to us, its geology has been extensively studied, and therefore much more information is known about its structure and composition than about the structure and composition of the mantle and core. Within the crust, intricate patterns are created when rocks are redistributed and deposited in layers through the geologic processes of eruption and intrusion of lava, erosion, and consolidation of rock particles, and solidification and recrystallization of porous rock.

By the large-scale process of plate tectonics, about twelve plates, which contain combinations of continents and ocean basins, have moved around on the Earth's surface through much of geologic time. The edges of the plates are marked by concentrations of earthquakes and volcanoes. Collisions of plates can produce mountains like the Himalayas, the tallest range in the world. The plates include the crust and part of the upper mantle, and they move over a hot, yielding upper mantle zone at very slow rates of a few centimetres per year, slower than the rate at which fingernails grow. The crust is much thinner under the oceans than under continents (see figure above).

The boundary between the crust and mantle is called the Mohorovicic discontinuity (or Moho); it is named in honour of the man who discovered it, the Croatian scientist Andrija Mohorovicic. No one has ever seen this boundary, but it can be detected by a sharp increase downward in the speed of earthquake waves there. The explanation for the increase at the Moho is presumed to be a change in rock types. Drill holes to penetrate the Moho have been proposed, and a Soviet hole on the Kola Peninsula has been drilled to a depth of 12 kilometres, but drilling expense increases enormously with depth, and Moho penetration is not likely very soon.

B. The Mantle

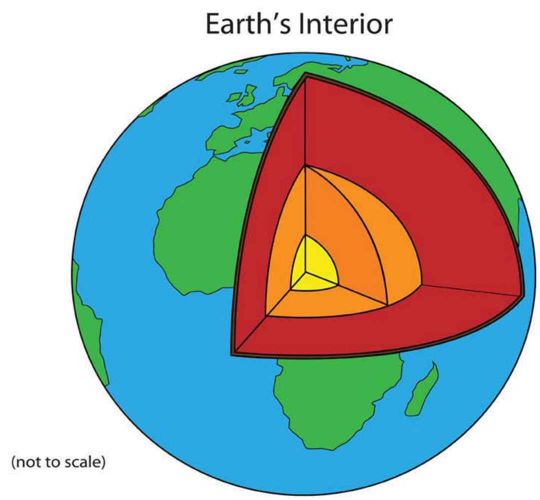
Our knowledge of the upper mantle, including the tectonic plates, is derived from analyses of earthquake waves (see figure for paths); heat flow, magnetic, and gravity studies; and laboratory experiments on rocks and minerals. Between 100 and 200 kilometers below the Earth's surface, the temperature of the rock is near the melting point; molten rock erupted by some volcanoes originates in this region of the mantle. This zone of extremely yielding rock has a slightly lower velocity of earthquake waves and is presumed to be the layer on which the tectonic plates ride. Below this low-velocity zone is a transition zone in the upper mantle; it contains two discontinuities caused by changes from less dense to more dense minerals. The chemical composition and crystal forms of these minerals have been identified by laboratory experiments at high pressure and temperature. The lower mantle, below the transition zone, is made up of relatively simple iron and magnesium silicate minerals, which change gradually with depth to very dense forms. Going from mantle to core, there is a marked decrease (about 30 percent) in earthquake wave velocity and a marked increase (about 30 percent) in density.

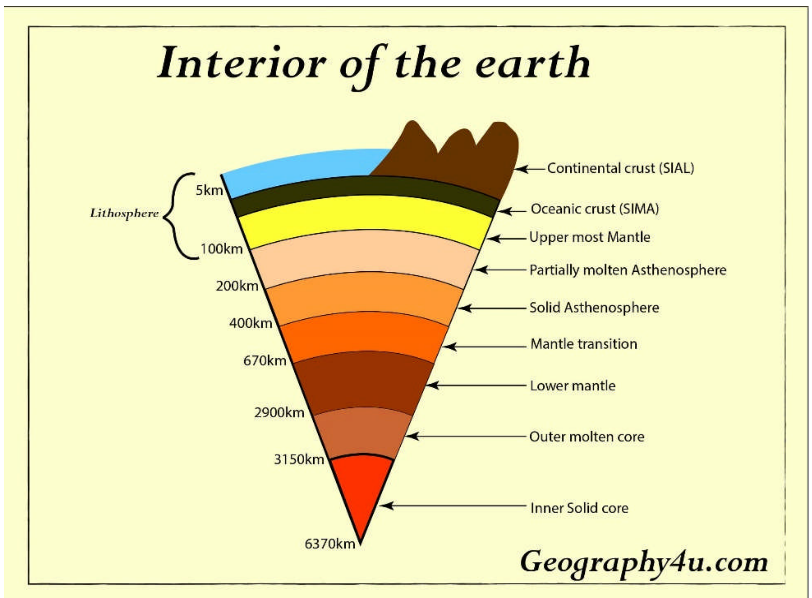
C. The Core

The core was the first internal structural element to be identified. It was discovered in 1906 by R.D. Oldham, from his study of earthquake records, and it helped to explain Newton's calculation of the Earth's density. The outer core is presumed to be liquid because it does not transmit shear (S) waves and because the velocity of compressional (P) waves that pass through it is sharply reduced. The inner core is considered to be solid because of the behavior of P and S waves passing through it.

Cross-section of the whole Earth, showing the complexity of paths of earthquake waves. The paths curve because the different rock types found at different depths change the speed at which the waves travel. Solid lines marked P are compressional waves; dashed lines marked S are shear waves. S waves do not travel through the core but may be converted to compressional waves (marked K) on entering the core (PKP, SKS). Waves may be reflected at the surface (PP, PPP, SS).

Data from earthquake waves, rotations and inertia of the whole Earth, magnetic-field dynamo theory, and laboratory experiments on melting and alloying of iron all contribute to the identification of the composition of the inner and outer core. The core is presumed to be composed principally of iron, with about 10 percent alloy of oxygen or sulfur or nickel, or perhaps some combination of these three elements.





2.3 THE THEORY OF CONTINENTAL DRIFT

Continental drift was a theory that explained how continents shift position on Earth's surface. Outlined in 1912 by Alfred Wegener, a geophysicist, and meteorologist, continental drift also explained why look-alike animal and plant fossils, and similar rock formations, are found on different continents.

Wegener thought all the continents were once joined together in an "Urkontinent" before breaking up and drifting to their current positions. But geologists soundly denounced Wegener's theory of continental drift after he published the details in a 1915 book called "The Origin of Continents and Oceans." Part of the opposition was because Wegener didn't have a good model to explain how the continents moved apart.

Though most of Wegener's observations about fossils and rocks were correct, he was outlandishly wrong on a couple of key points. For instance, Wegener thought the continents might have plowed through the ocean crust like icebreakers smashing through the ice.

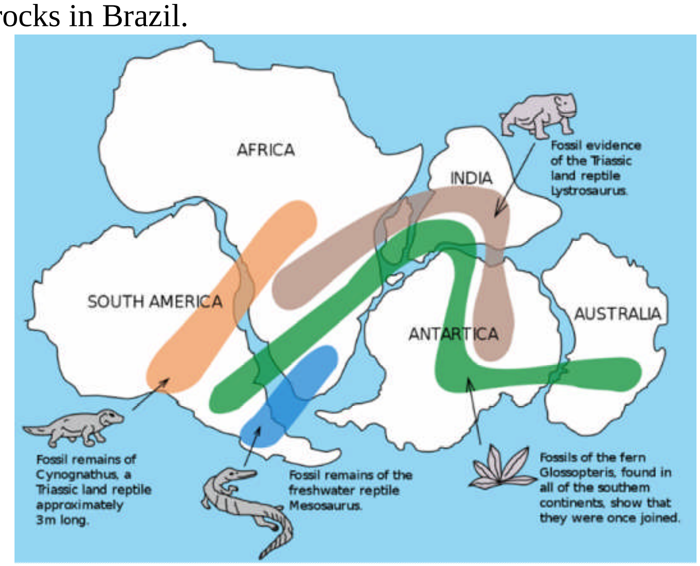
"There's an irony that the key objection to continent drift was that there is no mechanism, and plate tectonics was accepted without a mechanism," to move the continents, said Henry Frankel, an emeritus professor at the University of Missouri-Kansas City and author of the four-volume "The Continental Drift Controversy" (Cambridge University Press, 2012).

Although Wegener's "continental drift" theory was discarded, it did introduce the idea of moving continents to geoscience. And decades later, scientists would confirm some of Wegener's ideas, such as the past existence of a supercontinent joining all the world's landmasses as one. Pangaea was a supercontinent that formed roughly 200 to 250 million years ago, according to the U.S. Geological Survey (USGS), and was responsible for the fossil and rock clues that led Wegener to his theory.

Evidence for continental drift

A map of the continents inspired Wegener's quest to explain Earth's geologic history. Trained as a meteorologist, he was intrigued by the interlocking fit of Africa's and South America's shorelines. Wegener then assembled an impressive amount of evidence to show that Earth's continents were once connected in a single supercontinent.

Wegener knew that fossil plants and animals such as mesosaurs, a freshwater reptile found only in South America and Africa during the Permian period, could be found on many continents. He also matched up rocks on either side of the Atlantic Ocean like puzzle pieces. For example, the Appalachian Mountains (United States) and Caledonian Mountains (Scotland) fit together, as do the Karroo strata in South Africa and Santa Catarina rocks in Brazil.



Plates moving together created the highest mountains in the world, the Himalayans, and the mountains are still growing due to the plates pushing together, even now, according to National Geographic.

2.4 GEOSYNCLINAL THEORY OF KOBER

The objective of Geosynclinal Orogen Theory:

Famous German geologist Kober has presented a detailed and systematic description of the surface features of the earth in his book 'Der Bau der Erde'. His main objective was to establish the relationship between ancient rigid masses or tablelands and more mobile zones or geosynclines, which he called orogen.

Kober not only attempted to explain the origin of the mountains based on his geosynclinal theory but he also attempted to elaborate the various aspects of mountain building e.g., formation of mountains, their geological history, and evolution and development.

He considered the old rigid masses as the foundation stones of the present continents. According to him, present continents have grown out of rigid masses. He defined the process of mountain building or orogenesis as that process which links rigid masse with geosynclines. In other words, mountains are formed from the geosynclines due to the impacts of rigid masses.

Kober's geosynclinal theory is based on the forces of contraction produced by the cooling of the earth. He believes in the contraction history of the earth. According to J.A. Steers (1932) **"Kober is a constructionist, contraction providing the motive force for the compressive stress".**

In other words, the force of contraction generated due to cooling of the earth causes horizontal movements of the rigid masses or forelands which squeeze, buckle and fold the sediments into mountain ranges.

The base of the Geosynclinal Orogen Theory:

According to Kober, there were mobile zones of water in the places of present-day mountains. He called mobile zones of water geosynclines or orogen (the place of mountain building). These mobile zones of geosynclines were surrounded by rigid masses which were termed by Kober as kratogen.

The old rigid masses included Canadian Shield, Baltic Shield or Russian Massif, Siberian Shield, Chinese Massif, Peninsular India, African Shield, Brazilian Mass, Australian, and Antarctic rigid masses. According to Kober mid-Pacific geosyncline separated the north and south forelands which were, later on, foundered to form the Pacific Ocean.

Eight morphotectonic units can be identified based on the description of the surface features of the earth during the Mesozoic era as presented by Kober e.g.:

(i) Africa together with some parts of the Atlantic and Indian Oceans,
(ii) Indian Australian landmass,
(iii) Eurasia,
(iv) North Pacific continents,
(v) South Pacific continents, and
(vi) South America and Antarctica etc.

Kober has identified 6 major periods of mountain building. Three mountain-building periods, about which very little is known, are reported to have occurred during the pre-Cambrian period. The Paleozoic era saw two major mountain building periods-the Caledonian orogenesis was completed by the end of the Silurian period and the Variscan orogeny culminated in the Permo-Carboniferous period. The last (6th) orogenic activity known as Alpine orogeny was completed during the Tertiary epoch.

Kober has opined those mountains are formed out of geosynclines. According to Kober geosynclines, the places of mountain formation (known as orogen) are long and wide water areas characterized by sedimentation and subsidence. According to J.A. Steers (1932) 'Kober's views (on geosynclines and orogenesis) are, then, a combination of the old geosynclinal hypothesis of Hall and Dana, which was developed later by Haug, and his views on orogenesis.

Mechanism of the Geosynclinal Orogen Theory:

According to Kober, the whole process of mountain building passes through three closely linked stages of lithogenesis, orogenesis, and Gliptogenesis. The first stage is related to the creation of geosynclines due to the force of contraction caused by the cooling of the earth. This preparatory stage of mountain building is called lithogenesis. The geosynclines are long and wide mobile zones of water which are bordered by rigid masses, which have been named by Kober as forelands, or Kratogen.

These upstanding landmasses or forelands are subjected to continuous erosion by fluvial processes and eroded materials are deposited in the geosynclines. This process of sediment deposition is called sedimentation. The ever-increasing weight of sediments due to gradual sedimentation exerts enormous pressure on the beds of geosynclines, with the result the beds of geosynclines are subjected to gradual subsidence.

This process is known as the process of subsidence. These twin processes of sedimentation and resultant subsidence result in the deposition of the enormous volume of sediments and attainment of the great thickness of sediments in the geosynclines.

The second stage is related to mountain building and is called the stage of orogenesis. Both the forelands start to move towards each other because of horizontal movements caused by the force of contraction resulting from the cooling of the earth. The compressive forces generated by the movement of forelands together cause contraction, squeezing, and ultimately folding of geosynclinal sediments to form mountain ranges. The parallel ranges formed on either side of the geosyncline have been termed by Kober as randketten (marginal ranges) (figs. 11.6 and 11.7).

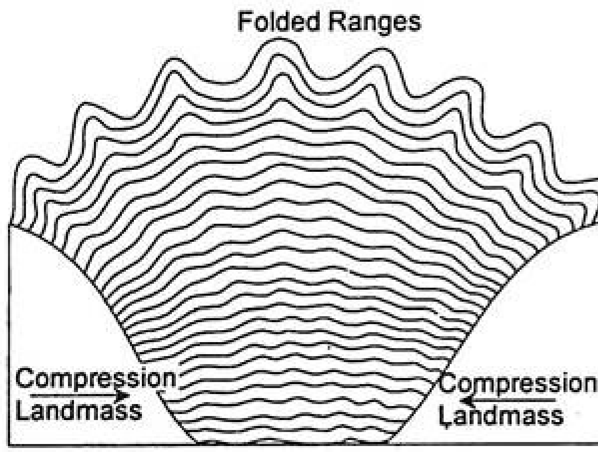


Fig. 11.6: Folding of marginal sediments into marginal ranges and formation of median mass when the compressive forces are moderate.

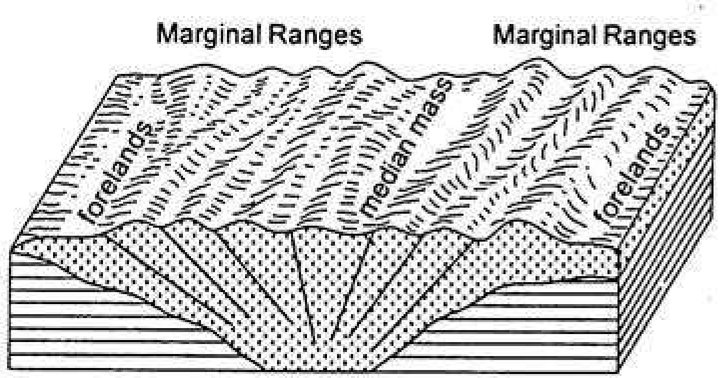


Fig. 11.7: Illustration of Kober's geosynclinal theory of mountain building through a block diagram.

According to Kober folding of entire sediments of the geosyncline or part thereof depends upon the intensity of compressive forces. If the compressive forces are normal and of the moderate-intensity, only the marginal sediments of the geosyncline are folded to form two marginal randketten (marginal ranges) and the middle portion of the geosyncline remains unaffected by folding activity (thus remains unfolded).

This unfolded middle portion is called Zwischengebirge (be- twixt-mountains) or median mass (figs. 11.6 and 11.7).

Alternatively, if the compressive forces are acute, the whole of geosynclinal sediments are compressed, squeezed, buckled and ultimately folded (fig. 11.5) and both the forelands are closeted. This process introduces complexity in the mountain because acute compression results in the formation of recumbent folds and nappes.

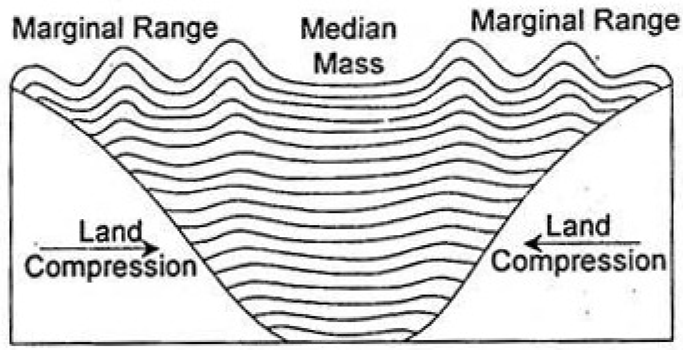


Fig. 11.5: The stage of orogenesis: squeezing and folding of geosynclinal sediments due to compressive forces; the whole of geosyndinal sediments are folded when the compressive forces coming from the sides of geosyncline is enormous and acute.

Kober has attempted to explain the forms and structures of folded mountains based on his typical median mass. 'Really, Kober's typical "orogen" (geosynclines) well explains the origin of mountains. 'The idea of the median mass of Kober fully explains the process of mountain building'. According to Kober the Alpine Mountain chains of Europe can well be explained based on median masses.

According to him, Tethys geosyncline was bordered by European landmass in the north and by African rigid mass in the south. The sediments of Tethys geosyncline were compressed and folded due to movements of European landmass (foreland) and African rigid mass (foreland) together in the form of the Alpine Mountain system. According to Kober, the Alpine Mountain chains were formed because of compressive forces coming from two sides (north and south).

Betic Cordillera, Pyrenees, Provence ranges, Alps proper, Carpathians, Balkan Mountains, and Caucasus mountains were formed due to northward movement of African foreland (fig. 11.8). On the other hand, Atlas Mountain (north-west Africa), Apennines, Dinarides, Hellenides, and Taurides were formed due to the southward movement of the European landmass (fig. 11.8).

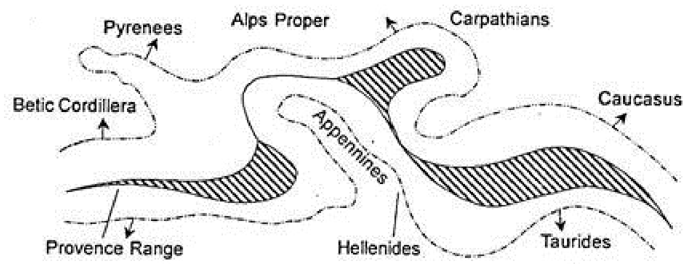


Fig. 11.8: The directions of folding in Alpine mountains of Europe. Arrows indicate directions (based on Kober).

The median masses located in the Alpine mountain system very well explain the mechanism of mountain building. It is apparent from fig. 11.8 that the direction of folding in the Carpathians and Dinaric Alps (Dinarides) is north and south respectively, which means that Hungarian median mass is located between two mountain ranges having opposite directions of folding.

The Mediterranean Sea is an example of median mass between Pyrenees-Provence Ranges in the north and Atlas Mountains and their eastern extension in the south. Corsica and Sardinia are remnants of this median mass. The Anatolian plateau between Pantic and Taurus ranges is another example of median mass. Similarly, further eastward, the Iranian plateau is a median mass between Zagros and Elburz mountains.

Alpine mountains further extend into Asia where mountain ranges follow latitudinal direction e.g., west-east orientation but the latitudinal pattern is broken in the north-eastern hill region of India where mountain ranges take the southerly trend in the form of Burmese hills.

Asiatic Alpine ranges begin from Asia Minor and run up to Sunda Island in the East Indies. Kober has also explained the orientation of thrust or compression of Asiatic folded mountains based on his foreland theory. Asiatic folded mountains including the Himalayas were formed due to compression and folding of sediments of Tethys geosyncline caused by the movement of Angaraland and Gondwana forelands together (fig. 11.9). Two marginal ranges (randketten) were formed on either side of the geosyncline and unfolded middle portion remained as median mass.

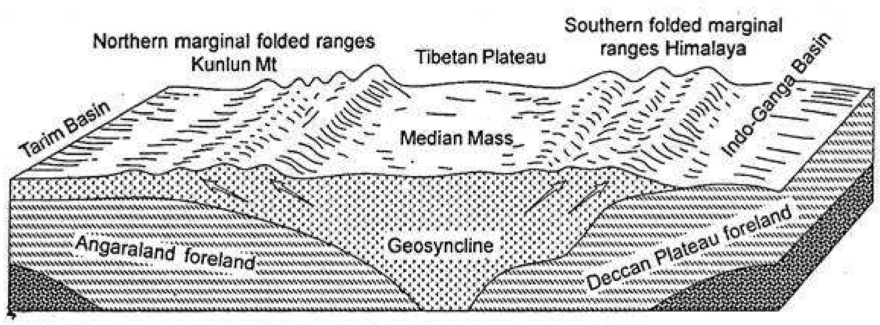


Fig. 11.9 : Illustration of Kober's median mass through Tibetan plateau between Kunlun and Himalaya.

According to Kober Asiatic Alpine folded mountains can be grouped into two categories based on the orientation of folds:

(i) The ranges, which were formed by the northward compression, include Caucasus, Pantic and Taurus (of Turkey), Kunlun, Yannan and Annan ranges, and

(ii) The ranges, which were formed by the southward compression, include Zagros and Elburz of Iran, Oman ranges, Himalayas, Burmese ranges, etc. Tibetan plateau is a fine example of median mass between Kunlun- Tien-Shan and the Himalayas.

The median mass may be of various forms e.g.:

(i) In the form of the plateau (examples, Tibetan plateau between Kunlun and Himalaya. Iranian plateau between Zagros and Elburz, an Anatolian plateau between Pantic and Taurus, Basin Range between Wasatch ranges and Sierra Nevada in the USA);

(ii) In the form of plain (example, Hungarian plain between the Carpathians and Dinaric Alps), and

(iii) In the form of seas (examples, the Mediterranean Sea between African Atlas mountains and European Alpine mountains, the Caribbean Sea between the mountain ranges of middle America and West Indies).

The third stage of mountain building is characterized by the gradual rise of mountains and their denudation by fluvial and other processes. Continuous denudation results in a gradual lowering of the height of mountains.

Evaluation of the Geosynclinal Orogen Theory:

Though Kober's geosynclinal theory satisfactorily explains a few aspects of mountain building the theory suffers from certain weaknesses and lacunae:

(1) The force of contraction, as envisaged by Kober, is not sufficient to cause mountain building. Very extensive and gigantic mountains like the Alps, the Himalayas, the Rockies, and the Andes cannot be formed by the force of contraction generated by the cooling of the earth.

(2) According to Suess only one side of the geosyncline moves whereas the other side remains stable. The moving side has been termed by Suess as backland whereas the stable side has been called foreland. According to Suess, the Himalayas were formed due to the southward movement of Angaraland.

The Gondwanaland remained stationary. This observation of Suess gained much favor previously but after the postulation of plate tectonic theory his views have become meaningless and the concept of Kober, that both the forelands move together, has been validated because ample pieces of evidence of paleomagnetism and seafloor spreading have shown that both Asiatic and Indian plates are moving towards each other.

(3) Kober's theory somehow explains the west-east extending mountains but north-south extending mountains (Rockies and Andes) cannot be explained based on this theory. Despite a few inherent limitations and weaknesses, Kober is given credit for advancing the idea of the formation of mountains from geosynclinal sediments because geosyncline found a berth in almost all the subsequent theories even in plate tectonic theory.

2.5 THERMAL CONVECTION CURRENT THEORY OF HOLMES

Objectives of the Thermal Convection Current Theory:

Arthur Holmes postulated his thermal convection current theory in the year 1928-29 to explain the intricate problems of the origin of major relief features of the earth's surface. Holmes' major objectives were not confined to search the mechanism of mountain building based on the sound scientific background but were also directed towards finding scientific explanation for the origin of the continents and ocean basins in terms of continental drift as he was opposed to the concept of permanency of the continents and ocean basins as envisaged by the advocates of thermal contraction of the earth.

Wooldridge and Morgan have aptly remarked. 'The only unifying theory which shows a hopeful sign of reconciling certain of the divergent hypotheses of mountain building and continental drift is that due to Holmes'.

The driving force of mountain building implied by Arthur Holmes is provided by thermal convection currents originating deep within the earth. The main source of the origin of convective currents is excessive heat in the substratum wherein disintegration of radioactive elements generates heat regularly. The whole theory depends exclusively on the mechanism of thermal convective currents.

The base of the Thermal Convection Current Theory:

According to Holmes, the earth consists of 3 zones or layers e.g.:

(i) Upper layer of granodiorite (10 to 12 km),
(ii) Intermediate layer (20 to 25 km) of amphibolite, and
(iii) Lower layer of eclogite.

He has further grouped these three layers into two zones e.g.:

(i) Crust consisting of upper and middle or intermediate layers and crystalline upper part of the lower layer, and
(ii) Substratum representing molten part of the lower layer.
(iii) Crust and substratum are composed of sial and sima respectively. Generally, sial is absent in the oceanic areas.

The origin of thermal convective currents within the earth depends on the presence of radioactive elements in the rocks. The disintegration of radioactive elements generates heat which causes convective currents. According to Holmes, there is maximum concentration of radioactive elements in the crust but temperature is not so high because there is gradual loss of heat through conduction and radiation from the upper surface at the rate of 60 calories per square centimeter per year.

'This is approximately equal to the radioactive energy produced by a layer 14 km thick of granite, 16.5 km of granodiorite, 52 km of plateau basalt or gabbro, and 60 km of peridotite'.

According to Holmes the loss of heat from the earth's surface is compensated by the heat produced by a crustal shell of 60 km thickness. Thus, there is no accumulation of additional heat in the earth's crust despite the maximum concentration of radioactive elements. On the other hand, though there is a very low concentration of radioactive elements in the substratum the gradual accumulation of heat produced by the radioactive elements causes convective currents.

The convective currents depend on two factors e.g.:

(i) Thickness of the crust near the equator and the poles, and

(ii) Uneven distribution of radioactive elements in the crust.

Ascending convective currents originate under the crust near the equator because of the greater thickness of crust whereas descending convection currents are originated under the polar crust because of their shallow depth.

The rising convective currents originating from below the continental crust are more powerful than the convective currents originating from below the oceanic crust because of the greater concentration of radioactive elements in the continental crust.

Mechanism of the Thermal Convection Current Theory:

Convective currents, thus, are generated at some places in the substratum. Because of the difference of temperature gradient from the equator (greater) towards the poles (low) rising convective currents are formed under the equatorial crust while downward-moving (descending) convective currents are generated under the polar crust.

The convective currents originating under the continental crust are more powerful than the convective currents originating under the oceanic crust. It may be pointed out that the Currents originating under the equatorial crust move towards the poles i.e. towards north and south and thus the crusts are carried away with the convective currents.

There are two situations of rising convective currents when they reach the lower limit of the crustal masses:

(i) The crustal mass, where two rising convective currents diverge in opposite directions, is stretched and thinned due to tensional forces and ultimately the crust is ruptured and broken into two blocks which are carried away by lateral divergent convective currents and the opening between two blocks becomes seas. Thus, divergent convective currents cause continental drifts,

(ii) Where two lateral convective currents originating under the continental and oceanic crusts converge (fig. 11.11), compressive force is generated which causes subsidence in the crustal zones giving birth to geosynclines and closing of the sea.

It is apparent that divergent convective currents move the crustal blocks away in opposite directions and thus create seas and oceans while convergent convective currents bring crustal blocks together and thus form mountains.

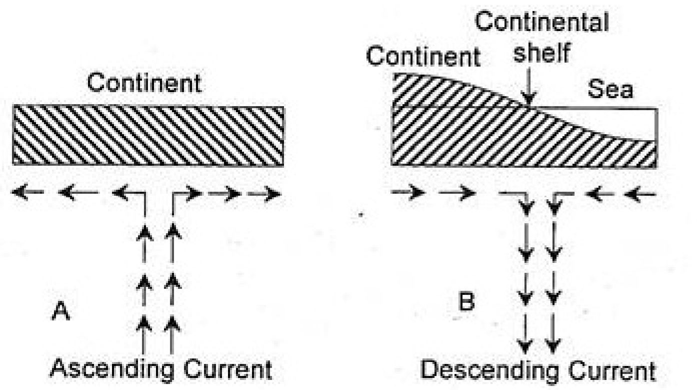


Fig. 11.11 : Illustration of rising and descending convective currents under the crust. A- Divergent convective currents cause opening of the landmass and creation of oceans. B-convergent convective currents cause closing of land masses and oceans and create mountains.

The convective currents are divided into two groups based on their locational aspect e.g.:

(i) Convective currents of rising columns, and

(ii) Convective currents of falling columns.

The rising convective currents after reaching the lower limit of the crust diverge in opposite directions.

This outward or divergent movement introduces tensional force due to which the crust is stretched, thinned, and ultimately broken and the broken crustal blocks are moved apart. The wide-open area between two drifting crustal blocks in opposite directions is filled with water and thus an ocean is formed. According to Holmes the equatorial crust was stretched and ruptured due to divergence of rising convective currents which carried the ruptured crustal blocks towards the north and south and the Tethys Sea was formed.

This phase is called 'opening of Tethys' Again two sets of convergent or downward moving (descending) currents brought Laurasia and Godwnaland together and thus Tethys was compressed and folded into Alpine mountains. This phase is called the 'closing of Tethys'.

'The convective mechanism is not a steady process but a periodic one, which waxes and wanes and then begins again with a different arrangement of center'. It means that the convective currents originate at several centers which are not permanent. Geosynclines are formed due to subsidence of crustal blocks mainly continental shelves due to compressive force generated by convergent convective currents moving laterally together under continental and oceanic crusts.

In other words, when the continental and oceanic crusts move together and converge under the continental shelves, they descend downward and thus cause immense compression due to which the crust is subjected to subsidence to form geosyncline. The convective currents of rising columns under continental and oceanic crusts bring materials in the geosynclines which are always located above the descending convective currents of the falling column.

Continuous compression and sedimentation cause gradual subsidence of geosynclines. Holmes has described a cyclic pattern of thermal convective currents which includes the origin of convective currents, formation of geosynclines, sedimentation and orogenesis, and the further rise in the mountains. According to Holmes, the cyclic pattern of convective currents and related mountain buildings pass through three phases or stages (fig. 11.12).

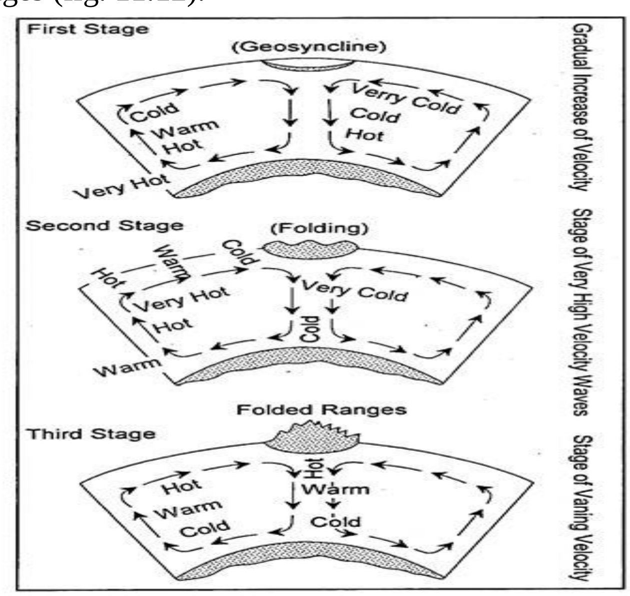


Fig. 11.12 : Illustration of successive stages of thermal convective currents under the crust and mountain building.

The first stage is of the longest duration during which convective currents are originated in the substratum. The rising convective currents of two centers converge under the continental shelves and thus form geosynclines due to compression coming from the convergence of two sets of lateral currents. Geonsynclines are subjected to continuous sedimentation and subsidence. As the sediments are pressed downward into geosynclines, these go further downward and are intensely heated and metamorphosed.

Metamorphism of sediments causes a rise in their density which further causes downward movement of the metamorphosed materials. Thus, the falling column of downward moving convective currents is the column of increasing density. Amphibolites are metamorphosed into eclogites. A portion of heat is spent during the process of metamorphism and hence the heat does not accumulate to a greater extent.

The first stage, characterized by high-velocity convective currents, is the preparatory stage of mountain building which is marked by the creation of geosynclines, sedimentation, and subsidence of materials partly caused by compression resulting from the convergence of convective currents and partly by an increase in the density of materials due to metamorphism.

The second stage is marked by a phenomenal increase in the velocity of convective currents but this stage is relative of short duration. The main cause for the phenomenal increase in the velocity of convective currents is the downward movement of cold materials in the falling column and upward movement (rise) of hot materials in the rising column of convective currents.

Increased pressure due to metamorphism of geomaterials in the falling column of descending currents increases the velocity of downward moving convective currents. The high velocity convergent convective currents buckle geosynclinal sediments and thus initiate the process of mountain building (fig. 11.12). This stage, thus, is called the stage of orogenesis.

The third stage is characterized by the waning phase of thermal convective currents due to incoming hot materials in the falling column and upward movement (rise) of colder materials in the rising column. Gradually, the rising column becomes a cold column i.e., cold materials are accumulated at the center of the origin of rising (upward moving) convective currents due to which these currents cease to operate and the whole mechanism of convective currents comes to an end.

The termination of the mechanism of collective currents yields several results e.g.:

(i) The materials of the falling column start rising because of a decrease in the pressure at the top of the falling column due to the end of deposition of materials. This mechanism causes further rise in the mountains,

(ii) The depressed and subsided heavier materials in the falling column of descending convective currents start rising due to a decrease in the weight and pressure at the top of the falling column,

(iii) Eclogite, which was depressed downward, gets melted due to immense heat and thus it expands.

This expansion in the volume of molten eclogite causes a further rise in the mountains. This stage is known as the stage of gliptogenesis. It is, thus, apparent that the thermal convective currents of Holmes explain all the three stages of mountain building e.g., lithogenesis, orogenesis, and gliptogenesis.

Griggs through his experiments has validated the mechanism of convective currents and consequent mountain building.

Evaluation of the Thermal Convection Current Theory:

Commenting on Holmes' thermal convective current theory J.A. Steers (1932) has remarked, 'the theory is interesting, but it depends upon such factors about which little is known. It may be pointed out that this comment of Steers about 80 years ago is not valid today as there are ample convincing scientific evidences that validate the mechanism of convective currents originating from within the mantle. Even much-appreciated plate tectonic theory is based on thermal convective currents.

The theory was criticized, at the time of its postulation in 1928-29, on the following grounds:

(1) Convective currents theory, no doubt, is a leading theory in a new direction but the whole of the theory depends on such factors about which very little is known. Rising and falling columns are doubtful phenomena and therefore doubtful stage can never be taken for the explanation of natural phenomena.

(2) The whole mechanism of convective currents depends on the heat generated by radioactive elements in the substratum (now mantle) but several scientists have raised doubt about the availability of the required amount of heat generated by radioactive elements. If heat, thus, is insufficient, convective currents may not be generated and, therefore, the whole mechanism and working of the theory would not be possible. It may be further pointed out that the rising currents pass on their heat into the crust through conduction. This process also causes loss of heat which may weaken the currents.

(3) The horizontal flow of thermal convective currents under the continental and oceanic crusts is also a doubtful phenomenon because of the lack of required amount heat to drive these currents. If horizontal flow of convergent movement of convective currents is not possible, then the falling column would not exist and hence mountain cannot be formed.

(4) The metamorphism of amphibolites into eclogites and resultant downward movement of relatively denser eclogites is also a doubtful phenomenon. Even we accept the metamorphism of amphibolites into eclogites but the resultant increase in density from 3.0 to 3.4 would not be enough to depress and sink eclogites in the falling column. If the desired sinking of eclogites is not possible, there would not be proper accommodation of materials brought by the horizontal convergent convective currents into the falling column.

If this is so, the whole falling column would be filled with eclogites and the next stage of the mechanism of the convective currents would not work. It is, thus, argued that the theory does not make proper provision for the accommodation of additional materials.

(5) According to this theory convective currents are originated at few centers only under the continental and oceanic crusts but the question arises, why are not they originated at all places? If this so happens, the horizontal movement of these currents would not be possible.

The whole of the continents would be divided into several blocks as the rising convection currents originating from numerous centers would break the crusts and would give birth to volcanic eruptions of various sorts. This observation has been now validated based on plate tectonics as rising convective currents diverge under the mid-oceanic ridges and thus the plate is ruptured and two plates move in opposite directions due to divergent convective currents and fissure flows of lavas occur along the mid-oceanic ridges representing the rupture zone.

It may be concluded that the idea of thermal convective currents conceived by A. Holmes about 80 years ago (in 1928-29) proved its worth in the 1960s when the scientists were looking forward to searching for such a force that can explain the movement of plates. Now, the process of mountain building can be very satisfactorily explained based on convective currents though not in the way as conceived by A. Holmes in 1928-29 but on the lines of plate tectonics.

2.6 SUMMARY

In this module, we have discussed the interior of the earth, continental drift theory of wegner, geosyncline theory of Kober and Convectional Current Theory of Holmes. The students might have understood the formation of continents and oceans and the process of Mountain buildings.

2.7 CHECK YOUR PROGRESS/ EXERCISE

2.7.1 True or False

2.7.1.1 Temperature increases with the depth in the interior of the earth.

2.7.1.2 The main aim of the Wegner’s continental drift theory was to explain climatic changes.

2.7.1.3 The crust records the maximum density.

2.7.1.4 Holmes postulated the plate tectonic theory.

2.7.1.5 The term Kratogen is used by Vidal De La Blache.

2.7.2 Fill in the blanks

2.7.2.1 The planet Earth is made up of …………….main shells.

2.7.2.2 The mantle and core are each divided into…………….. parts.

2.7.2.3 Continental drift was a theory that explained how ………………….. shift position on Earth's surface.

2.7.2.4 Kober has identified ………………… major periods of mountain building.

2.7.3 Multiple Choice Questions

2.7.3.1 The boundary between the …………… and mantle is called the Mohorovicic discontinuity. (crust, mantle, lower mantle, core)

2.7.3.2 Between ……………….. and 200 kilometers below the Earth's surface, the temperature of the rock is near the melting point. (100, 0, 50, 1000)

2.7.3.3 The core was the first internal structural element to be identified. It was discovered in ………………….. by R.D. Oldham. (1906, 1910, 1920, 1940).

2.7.3.4 According to…………., the whole process of mountain building passes through three closely linked stages of lithogenesis, orogenesis, and Gliptogenesis. (Kober, Penck, Holmes, David)

2.7.4 Answer the following questions

2.7.4.1 Explain the changing nature of the interior of the earth.

2.7.4.2 Explain the continental drift theory.

2.7.4.3 Critical evaluate the continental drift theory of Wegner.

2.7.4.4

2.8 ANSWERS TO THE SELF-LEARNING QUESTIONS

2.8.1 True or False

2.8.1.1 True

2.8.1.2 True

2.8.1.3 False

2.8.1.4 False

2.8.1.5 False

2.8.2 Fill in the Blanks

2.8.2.1 Three

2.8.2.2 Two

2.8.2.3 Continents

2.8.2.4 Six

2.8.3 MCQ

2.8.3.1 Crust

2.8.3.2 100

2.8.3.3 1906

2.8.3.4 Kober

2.9 TECHNICAL WORDS AND THEIR MEANING

2.9.1 Albedo: On average 35% of the incoming solar radiation is reflected and it is called albedo.

2.9.2 Lag of Temperature: There is no coincidence between the time of maximum and minimum amount of insolation received from the sun and maximum and minimum temperatures of the air. This is called the lag of temperatures.

2.9.3 Inversion of temperature: Sometimes due to certain reasons the temperature in the troposphere increases with increasing elevation, this is called the inversion of temperature. The inversion of temperature is also called a negative lapse rate.

2.10 TASK

Measure the temperature of the air in your locality through Google Weather App and try to convert it

2.11 WORK CITED AND THE SOURCES FOR FURTHER STUDY

a) Anhert, F., (1996), 'Introduction to Geomorphology', Arnold, London, Sydney, Aukland

b) 2. Bloom, A. L. (2002), 'Geomorphology: A Systematic Analysis of Late Cenozoic Landforms', Pearson Education Pvt. Ltd., and Singapore.

c) 3. Christopherson, R.W. (1994), 'Geosystems : An Introduction to Physical Geography', Macmillan College publishing Company, New York.

d) 4. Dayal, P. (1990), 'A Textbook of Geomorphology', Shukla Book Depot, Patna.

e) 5. Engeln, O. D. Von (1944), 'Geomorphology', The Macmillan Company, New York.

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3

PRINCIPLES OF GEOMORPHOLOGY

Unit Structure:

3.0 OBJECTIVES

Surface of the Earth is modified by the erosional and depositional work carried out by the various agencies of erosion as River, Glacier, Wind, Sea waves and Underground water.

In this unit we will try to understand various Geomorphic processes related to these agencies and landforms developed by them. The main objectives are as follows.

- To understand and study various Geomorphic processes related to flowing water (Fluvial) -River.
- To study various landforms of erosion developed by the work of River.
- To study various landforms of deposition developed by the work of River.
- To understand and study various Geomorphic processes related to Glacier.
- To study various landforms of erosion developed by the work of Glacier.
- To study various landforms of deposition developed by the work of Glacier.

- To understand and study various Geomorphic processes related to Underground water.
- To study various landforms of erosion developed by the work of Underground water,
- To study various landforms of deposition developed by the work of Underground water.
- To understand and study various Geomorphic processes related to Wind.
- To study various landforms of erosion developed by the work of Wind.
- To study various landforms of deposition developed by the work of Wind.
- To understand and study various Geomorphic processes related to Sea waves.
- To study various landforms of erosion developed by the work of Sea waves.
- To study various landforms of deposition developed by the work of Sea waves.

3.1 FLUVIAL GEOMORPHIC SYSTEM : PROCESSES AND RESULTING LANDFORMS

We know about the hydrological cycle. Water of rainfall flows in the direction of slope as streams. These streams join together to form river. River or the work of running water is most widespread and important exogenic process.

(Exogenic process operate on the surface of the earth e.g. work of river, glacier, sea, waves, wind etc.)

Various processes involved in erosion process by the river are termed as Fluvial process.

(Fluvius is the Latin word, which means river)

The landforms developed by the action of river are of two types - (1) Erosional and (2) depositional. These are known as fluvial landforms.

FLUVIAL PROCESSES:

Water cycle or Hydrological cycle is operated by the Insolation (solar radiation) & the Gravitational pull of the Earth.

River is one of the important external agency of erosion. River water provides kinetic energy or force for the process of erosion but actual work of erosion is done by the pieces of rocks or material transported by the river. This material is known by different names as follows.

Size in m.m. (diameter)	**Knows as**	**Velocity of river (m/sec) required to carry this material**
2 - 4 mm	Granules	1. 0.6
4 - 64 mm	Pebbles	2. 1.6
64 - 256 mm	Cobbles	3. 3.2
> 256 mm	Boulders	4. 11.7

These different sizes of weathered pieces of rock-angular or rounded act as powerful tools of erosion.

Various factors affect erosive capacity of the river.

1) **Volume of water** - large size rivers are able to erode more than the small size rivers.
2) **Velocity** - i.e. the speed of river water. It depends on the slope or river channel gradient. If the slope is gentle, velocity is less and it is more when the slope is steep. Normally rivers originate from hilly areas at higher altitude. This region has many steep slopes & so velocity of river is more in this region.

It is found out that the erosive capacity of river is proportional to the square of the velocity.

$$\text{Erosional Capacity } \alpha \text{ (velocity of the stream)}^2$$

It means when velocity is doubled the erosional capacity of river increases four times.

Velocity of the river is more in upper course, i.e. in hilly areas & so erosive capacity of river is maximum in this zone. So most of the major landforms of erosion formed by the action of river / stream are found here.

3) Nature of rocks : Geological structures & lithological (Rock) characteristics also influence erosive action & formation of fluvial landforms.

FLUVIAL PROCESSES:

Fluvial processes which are involved in the erosional work of rivers can be classified in two groups as follows.

a) Chemical erosion processes
   1) Solution or corrosion
   2) Carbonation

b) Mechanical erosion processes
   1) Abrasion or corrosion
   2) Attrition
   3) Hydraulic action

A) Chemical erosion processes:

1) Solution or Corrosion:

River water flows over the surface composed of different types of rocks. Rocks are composed of various minerals. Some of the minerals like common salt are most soluble in water.

2) Carbonation:

Rain water comes in contact with the carbon dioxide in the atmosphere. It is easily dissolved in it and so weak carbonic acid (H_2CO_3) is formed. This acid becomes part of river water and reacts with the carbonate rocks like limestone.

$$C_aCO_3 + H_2O + CO_2 \rightarrow C_a\left(HCO_3\right)_2$$

↓	↓	↓
Calcium carbonate	*Carbonic acid*	*Calcium bicarbonate*

Calcium bicarbonate is easily soluble in river water, so the process of carbonation is also termed as solution (fig.1). According to the estimate of Murray about 5 billion tons of minerals are removed every year in the form of solution by the rivers all over the world.

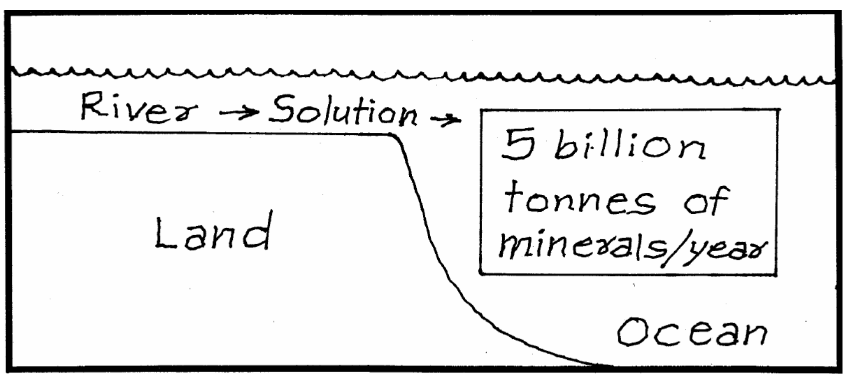

Fig. 1

b) Mechanical erosion process:

1) Abrasion or Corrosion:

Mechanical disintegration of rocks in the river is termed as Abrasion or corrosion.(fig.2)

River contains different sizes of rock pieces. Rock pieces formed after mechanical disintegration have sharp edges. Force or kinetic energy is provided to these sharp pieces of rock by the strong force of high velocity river water. Collision of these rock fragments with the rocks on the bed & sides of the river channel by rubbing, scraping, bumping and crushing leads to the further disintegration of bed rock or of fragments.

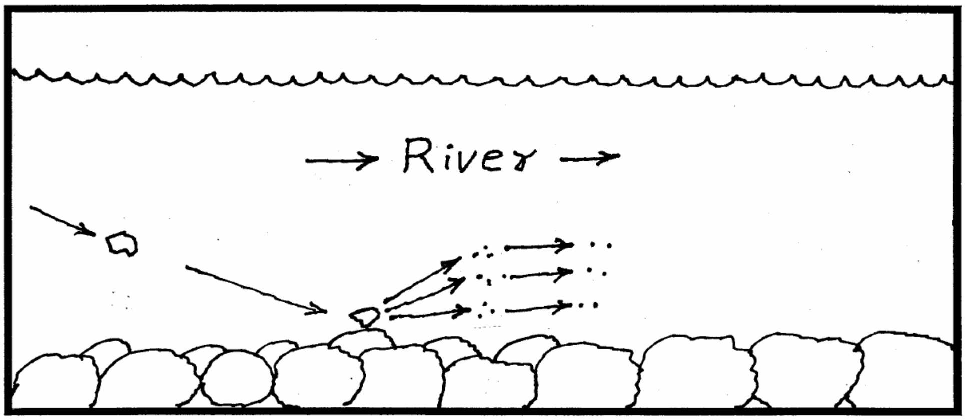

Fig. 2

2) Attrition:

Rock fragments are carried by the forceful flow of river water. These fragments of rock collide with each other and disintegrate is termed as attrition **Fig. 3**

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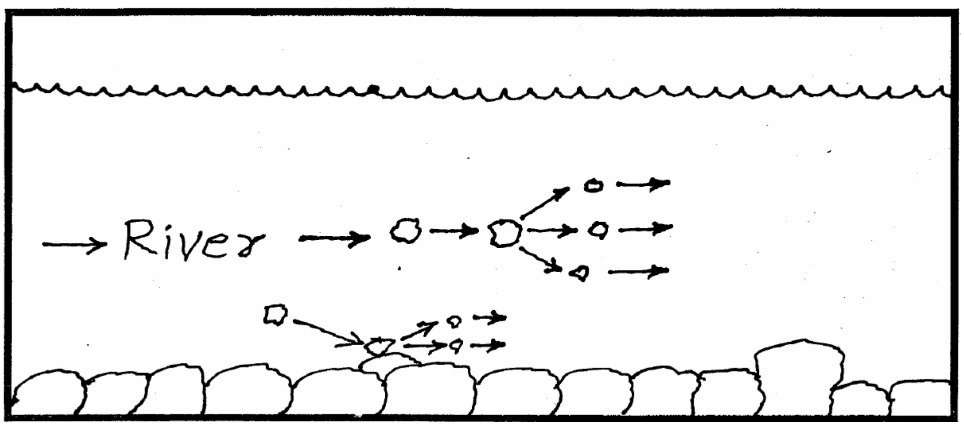


Fig. 3

3) Hydraulic action:

Mechanical loosening, lifting and removal of material by river water are the part of hydraulic action.

Bubbles of air are formed in the strong flow of river water. These bubbles burst and produce shock waves which shatter the adjoining area of river bed. Liberated particles are carried away by the river water. This is called the process of cavitations, which increases the rate of erosion. This process also plays an important role in the formation of pot holes and plunge pools below waterfalls.

TRANSPORTATION BY THE RIVER:

Weathered, eroded material carried by the river is of different types & sizes. Hence it is transported by different methods. Major methods are as follows:

1) Solution
2) Suspension
3) Saltation
4) Traction

1) Solution: Minerals and Chemicals either solid or gaseous, are dissolved in river water and carried by the river in the form of solution e.g. Limestone or soluble salts.

2) Suspension - very small size particles of disintegrated rocks or minerals are practically very light due to their microscopic size. These are carried in suspension to longer distance by the strong force or river water. These particles are deposited when the velocity of river is reduced.

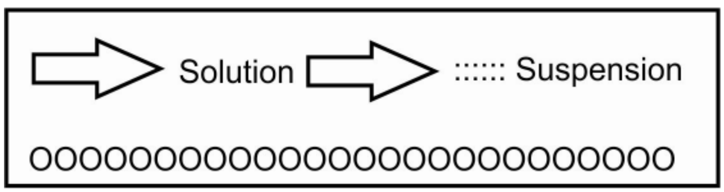


Fig. 4

3) Saltation

This process of transportation is found at the bed or river channel. Medium size pebbles are uplifted by the strong force of river water, but are dropped at some distance due to the force of gravity.

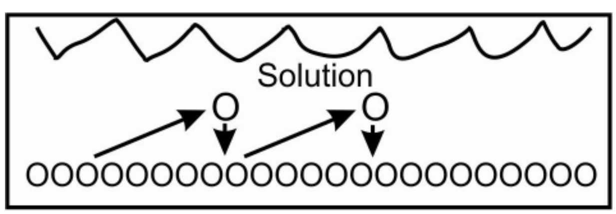


Fig. 5

4) Traction:

Large size boulders are pushed by the strong force of river water. This rolling action of large pebbles or boulders on best of river is termed as traction.

Various factors as climate and lithology - structure and relief of the river basin affect type & amount of weathered material transported by the river.

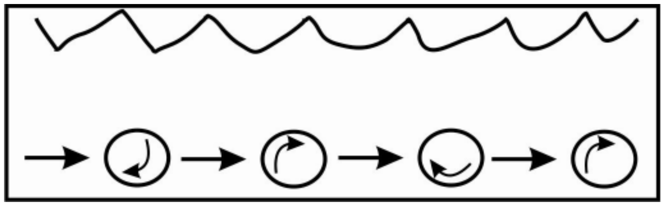


Fig. 6

BASE LEVEL OF EROSION AND GRADED PROFILES:

River water flows in the direction of slope. Rivers originate in hilly areas of high altitude or other places which are at higher elevation than the sea level and most of the rivers join sea.

Sea level is considered as base level of erosion for river. Profile of river valley from its source to mouth (sea level) is termed as long profile or Longitudinal.

Profile: The ideal longitudinal profile has concave shape, which is steeper near source of the river, while it is very gentle or almost flat near to the mouth.

Every river tries to achieve this perfect curve by eroding and depositing transported material on or near its channel.

Every river has certain capacity to carry weathered, eroded material, which is called as load.

The load carrying capacity of river depends on the volume and velocity of river water. Capacity of river increases with increases in volume and velocity river water.

River is termed as graded river when the actual amount of load (weathered material carried by the river) in river is equal to its carrying capacity. In such situation river neither erodes nor does it deposit material.

When river contains less amount of load than its carrying capacity it is termed as degraded river. This river obtains more load or weathered material through the process of erosion.

On the other hand if the material in the river or its load is more than its carrying capacity, it deposits excess load. This river is known as a graded river.

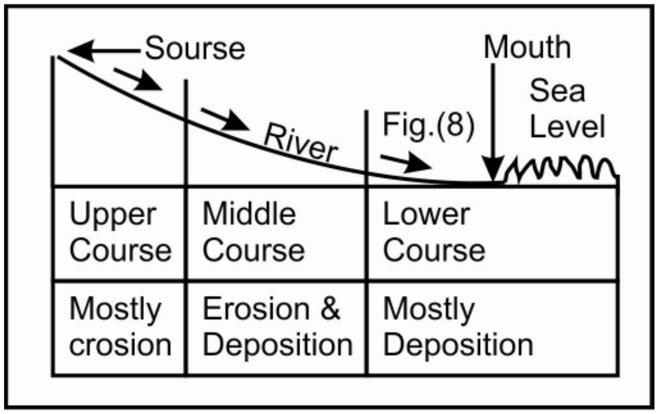


Fig. 7

Longitudinal profile of river:

The upliftment or subsidence of land surface or climate change can affect sea level and thus can modify longitudinal profile of river.

The course or river is divided into three zones as 1) Upper course 2) Middle course and 3) Lower course.

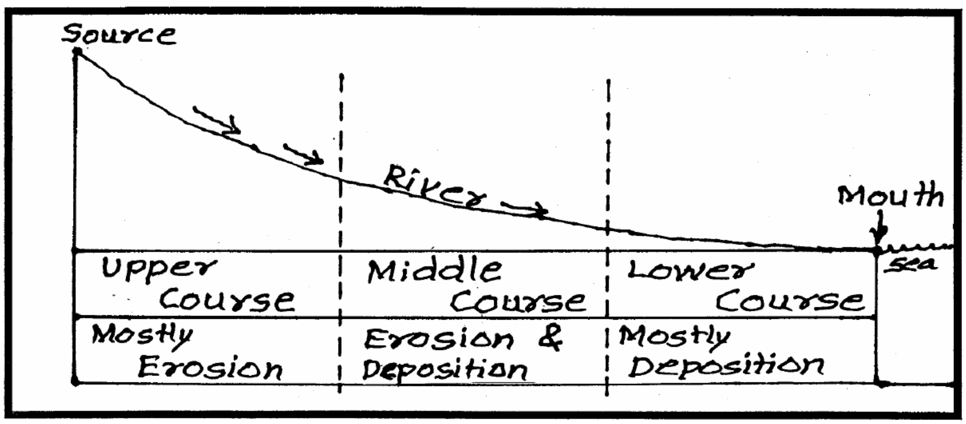


Fig. 8

Slopes are steeper in the upper course & so velocity & erosive capacity of river is more.

On the other hand slopes are very gentle in the lower course & so velocity is less. Carrying capacity of river is reduced very much & so river is unable to carry load, which is deposited on or near river bed.

FLUVIAL LANDFORMS:

Major landforms developed by the erosional or depositional work or river (fluvial landforms) are as follows -

1) 'V' Shaped Valley :

River water flows in the direction of slope & it carry material from the valley floor along with it. Hence in the initial stage vertical downcutting of valley is important. After certain period valley becomes wide due to later erosion and so the shape of river valley - i.e. cross profile of river appears like letter 'V' of the English alphabet.

Mass wasting of the material from the river banks in the downward direction also contribute to the development of 'V' shaped valley.

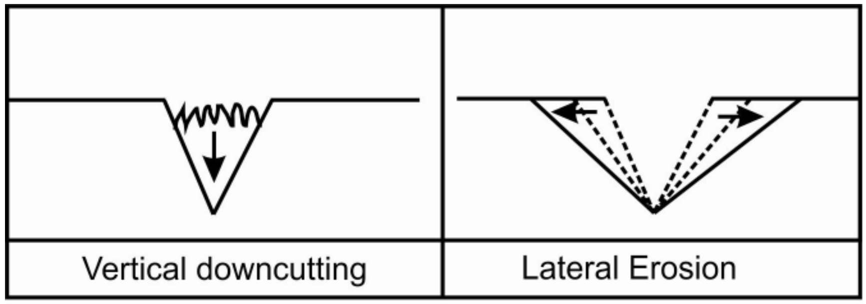


Fig. 9

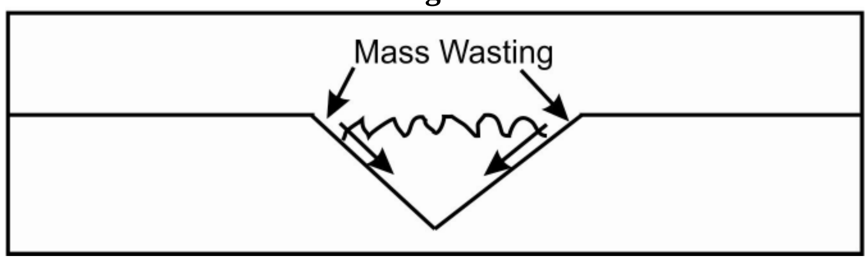


Fig. 10

2) Gorge:

It is the river valley which is more narrow and deep than the normal 'V' shaped valley is termed as Gorge or canyon. e.g. Grand Canyon at Colorado river is 1.6 km deep and 480 kms long.

In the semi arid area the amount of rainfall is less hence the mass wasting of river bank is very less vertical erosion is much more prominent than the latered erosion. So the sides of the Gorge become very steep. Gorge also develops in the area of hard and resistant rock.

Steep walls of Gorge develop due to vertical down cutting by the fluvial processes.

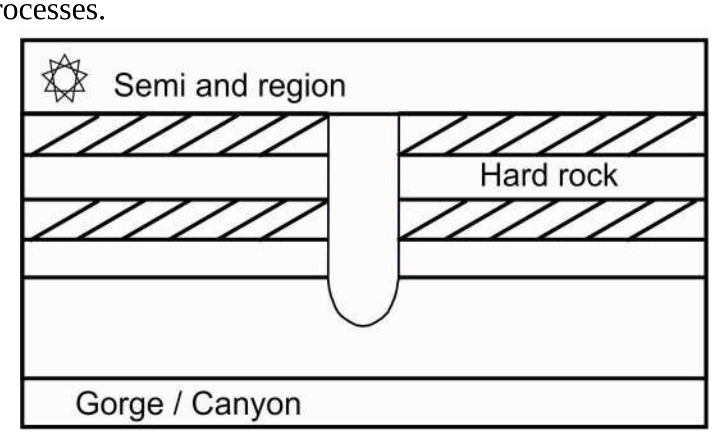


Fig. 11

3) Pot holes:

Potholes develop on the bed of river having solid hard rock foundation slight initial depression is enlarged in large circular depression or pot hole by the grinding action of sand and pebbles.

These tools of erosion swirl round in the hole by the strong in the hole by the strong force of rapidly moving river water having high velocity. Hence large size pot holes are formed on the river bed.

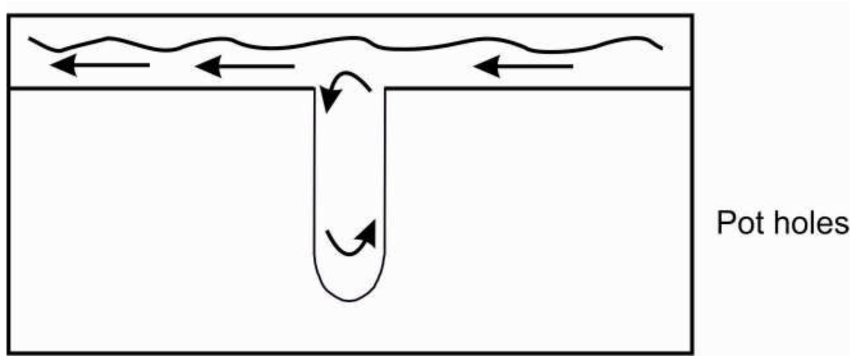


Fig. 12

4) Rapids:

Rapid means fast and so rapids are formed where the velocity or speed of river water increases.

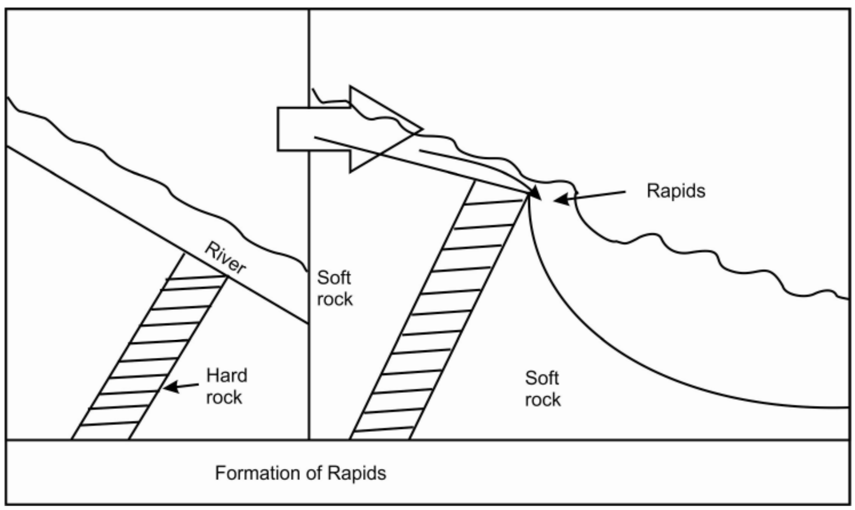


Fig. 13

Sometimes hard rock formations are found on the bed of river. Portion of the soft rock is eroded by the erosive action of river. Hence flow of water of river becomes rapid at the hard rock formation due to steep slope.

Rapid are generally found of the upper course of the river.

5) Water fall:

Rapids and water falls mostly develop due to hard rock formation. Height of the waterfall is much greater than the height of the rapids. Both rapids and waterfalls are found in the upper course of the region having hilly region & steep slopes.

When river water falls from great height it is called as waterfall its this water falls from great height along with stones of different sizes, they hit the bottom floor of waterfall, with great speed. Hence a large depression is formed at the base of waterfall. Water accumulates in it is termed as plunge pool.

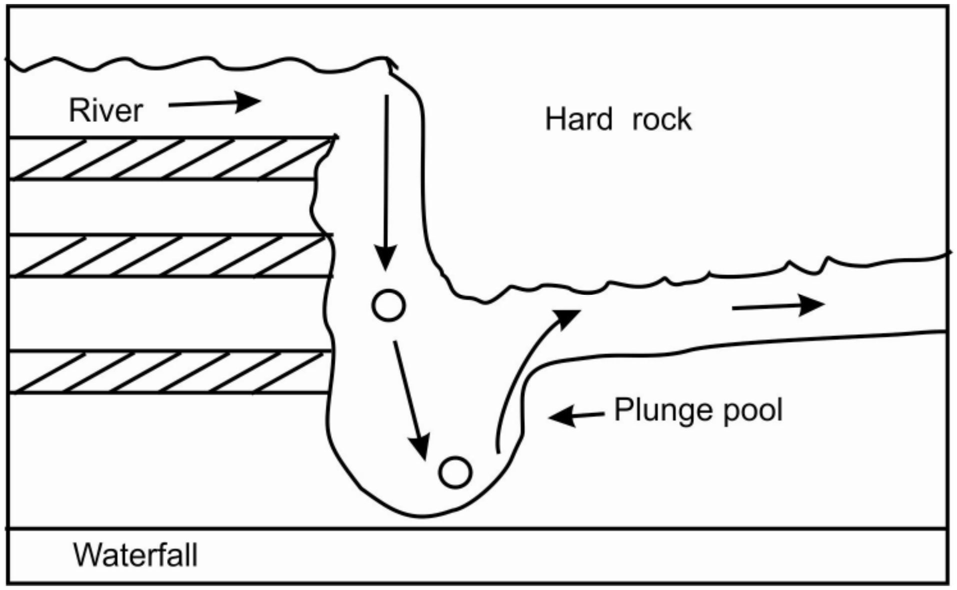


Fig. 14

Waterfalls develop in many different landform formations.

1) Hard, resistant rock formation:

Hard resistant rock is eroded much less than the soft rock, which is eroded at rapid rate forming very steep fall (waterfall) in the course of river.

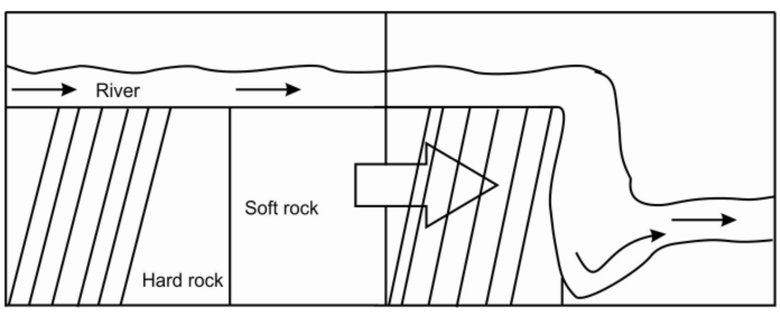


Fig. 15

e.g. Kaieteur Falls in Guyana (250m) and Niagara falls in U.S.A. (50 m)

2) Faulting -

Levels of river bed change due to the process of faulting. Hence water fall develops at the location of fault.

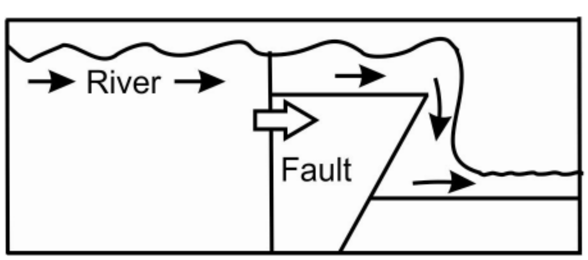


Fig. 16

e.g. Victoria falls on river Zambesi in Africa

3) Plateau -

Plateau is situated at higher elevations than the surrounding region. Waterfall develops when the river originated on the plateau falls down at the edge of a plateau.

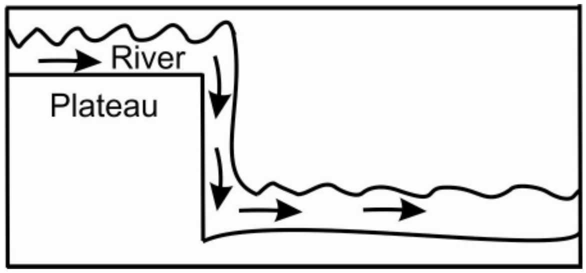


Fig. 17

e.g. Livingstone falls (270 m) on river Congo in Africa.

4) Hanging Valley -

Hanging valley is formed at greater elevation than the main 'U' shaped valley of the glacier. When glacier melts, waterfall is formed at the hanging valley.

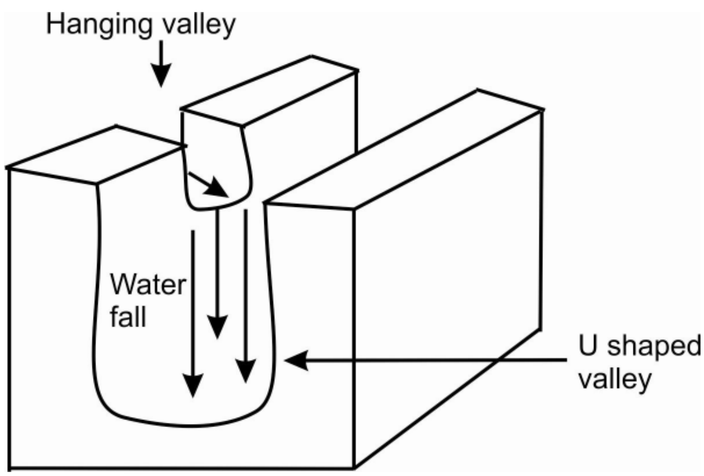


Fig. 18

e.g. Yosemite falls (780 m) of California in U.S.A.

5) Knick point:

Due to upliftment of land or fall in sea level, river is rejuvenated and starts erosion. Hence knick points develop at the breaks in channel gradient or sudden drops of elevation in the longitudinal profile of the rivers. Waterfall develop at such knick points.

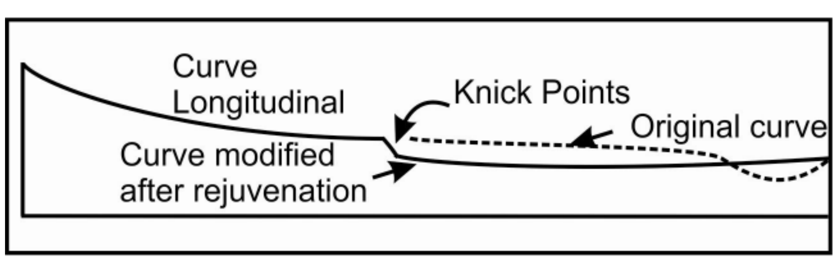


Fig. 19

e.g. Dhunwadhar falls on Narmada river (M.P.) Hundru falls on Subarnaekha river near Ranchi.

6) Interlocking spurs -

These are found in upper course and at the beginning of the middle course, in the hilly region.

Rain water flows in the direction of slope & is accumulated in the river valley. River has to cross many obstructions in the form of mountain ranges & hills. River water flows through the gap between these ranges & so we find that the spurs of the mountains appear interlocked.

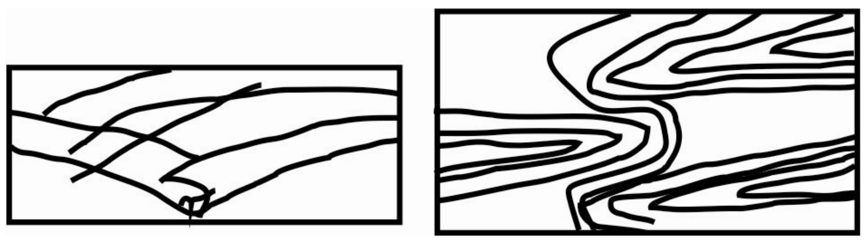


Fig. 20

7) Alluvial cone & Alluvial fans -

These depositional landform features develop at the junction of upper and middle course.

Upper course has steep slopes due to hilly nature of the region hence the velocity of river water and its carrying capacity is also more. River can carry more load in this upper course. The slope of land at the beginning of the middle course is relatively gentle & so speed or velocity of the river is reduced. Hence the carrying capacity of the river is also reduced. Hence river deposits the excess load at the junction of upper and middle course in the form of alluvial cone or alluvial fan. Alluvial fan has greater spread of alluvial deposition than the alluvial cone. Alluvial fans mostly develop during rainy season when the sometimes the neighboring alluvial fans may merge together to form extensive alluvial plain in the foot hill or piedmont zone. It is termed as piedmont alluvial plain.

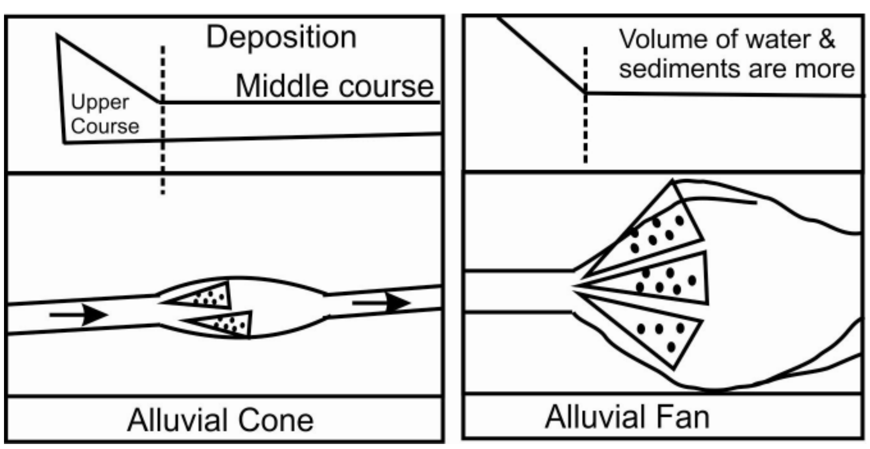


Fig. 21

8) Meanders -

In the middle and lower course of the river slope of the region is gentle and amount of water in the river is also more hence any small elevated portion of land or any obstruction is responsible for diverting flow of the river, forcing the river to swing in loops, which are termed as Meanders (This term is derived from the Meadderez river in Asia Minor, which has developed such loops.)

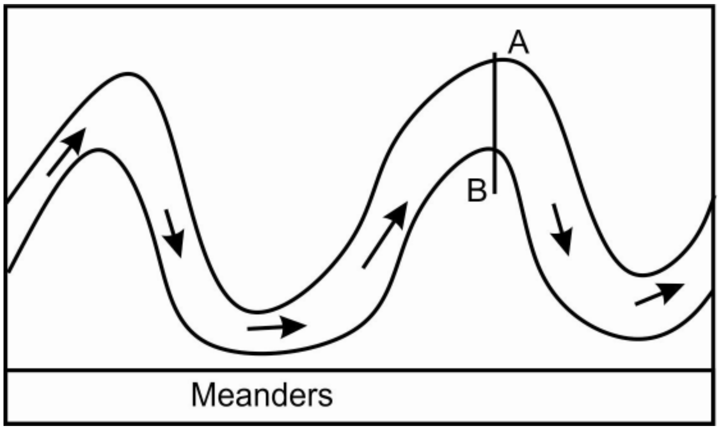


Fig. 22

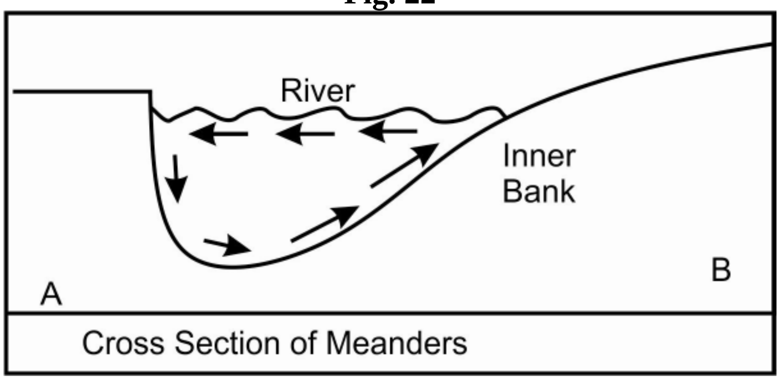


Fig. 23

The river water hits bank 'A' (outer flow) and erodes it. Hence this bank has steep slope like cliff & so it is termed as River Cliff. On the other hand eroded material is either carried away by the river or deposited at river bank 'B' (Inner bank).

Hence concave slope develops at the outer bank (A) and convex slope develops at the inner bank (B).

9) Ox -Bow Lake -

Ox-bow lakes are associated with the meanders. When meandering of river becomes extreme, the outer banks are progressively eroded by the erosive action of the meandering river. These ultimately two outer banks join together & so river water prefers straight channel instead of meandering channel. This often happens when the river is in flood. This C shaped or Ox - bow shape portion of the meander is cut off from the main river due to deposition of alluvium. As water remains accumulated in this Ox-bow shaped portion it is termed as Ox-bow Lake.

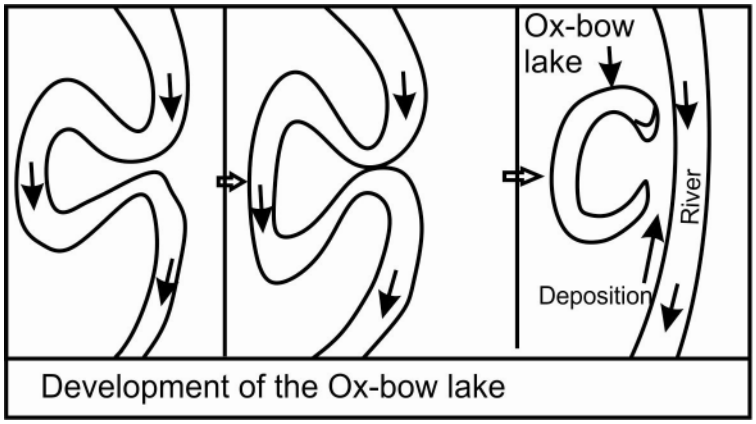


Fig. 24

Ox-bow lakes are also known as Bayous cut-off Bilabong or Mortlake.

10) Flood Plain -

These develop in the lower course of the river. At the time of flood river water spreads over the adjoining areas sediments brought by the river are deposited on the adjoining plain area, forming flood plain. Flood plains are very fertile & useful for agricultural production.

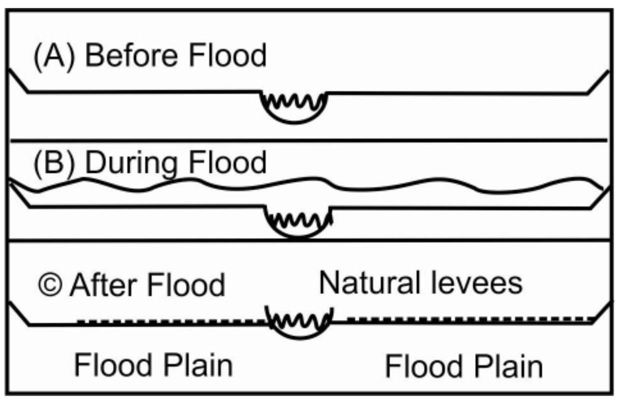


Fig. 25

11) Natural Levees:

During the normal course the sediments are also deposited on the banks of the river. Hence the height of the banks increases which is termed as Natural levees. During flood additional sediments are deposited on the natural levees.

At the time of flood level of water in the river increases but this water is not able to spread in the adjoining area of flood plain due to the obstruction of natural levees. Sometimes artificial embankments are erected on the natural levees for extra protection from floods.

When these embankments or natural levees break due to excessive pressure of flood water, it spreads over extensive area of flood plain at rapid rate, due to gentle slope of the surrounding area. Thousands of people are killed and heavy loss of property occurs during this type of flash floods. e.g. In 1852 million people died in China due to such type of flood of river Hwang-Ho. Hence this river is known as sorrow of China. Similar floods also occur in the plains of Mississippi, Po, Yangtze Kiang and Ganga rivers.

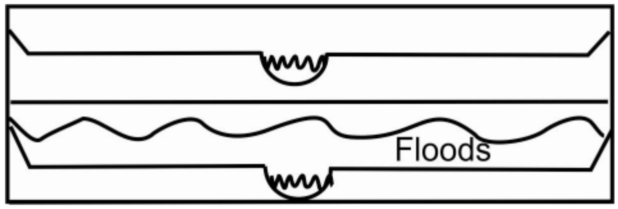


Fig. 26

12) Alluvial Terraces:

Fall in the sea level or upliftment of land area is responsible for rejuvenation process of the river. Change in the base level of erosion (sea level) leads to river gain extra energy for erosion. Alluvial terraces are formed due to erosion of flood plain area. Step like terraces are developed on either side of the river.

Alluvial terraces are also known as River terraces. These are classified as (a) Paired terraces and (b) Unpaired terraces.

a) Paired terraces:

River terraces on both side and banks of the river are at the same level. This type of paired terraces develops due to rapid rate of vertical erosion by the river.

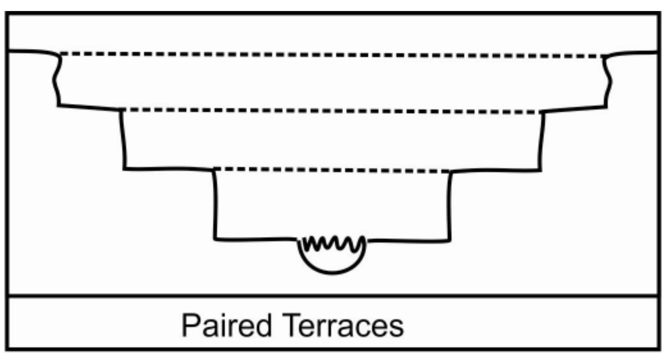


Fig. 27

b) Unpaired terraces:

These are formed when vertical down cutting by the river is associated with the lateral erosion, meandering river in the stage of rejuvenation develop unpaired terraces. These are not at same level.

13) Delta -

River joins sea. Sea level is known as the base level of erosion for the river. Sediments brought by the river are deposited near to the mouth or river. This deposition of sediments is triangle shape like Greek letter Delta, hence it is termed as Delta. This term was first used by the Herodotous (485 - 125 BC) for the delta of river Nile.

The size of delta depends on the rock characteristics, rate of erosion, amount of rainfall, vegetation cover etc.

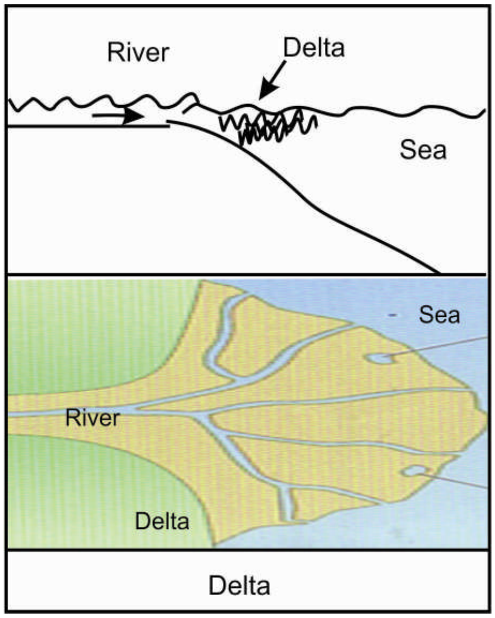


Fig. 28

Types of Delta:

Normally delta has triangle shape but on the basis of different type of shapes deltas are classified as follows :

1) Arcuate delta (Fan shaped)
2) Bird foot delta
3) Estuarine delta
4) Cuspate delta

1) Arcuate delta (Fan shaped) :

The fan shaped delta is termed as Arcuate delta e.g. Delta of river Nile, Ganga, Rhine, Po, Hwang - Ho Volga, Leena, Irrawaddy, Mekong are of this type. Mahanadi, Godawari.

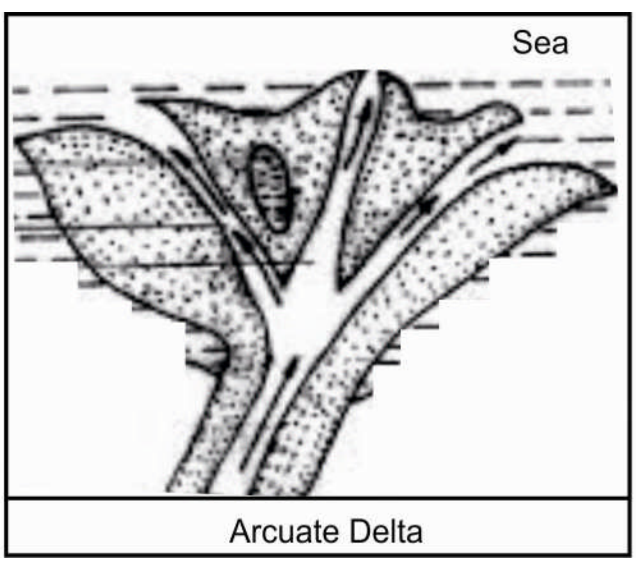


Fig. 29

Arcuate deltas often form in semi-arid climate. These are composed of coarser materials like garrets, sand & silt.

2) Bird foot delta:

Shape of this delta is like foot of bird and so it is termed as bird foot delta. As this delta resembles the fingers of human hand and so it is also known as finger delta.

Rivers with high velocity carry finer suspended particles of sediments to greater distance in the Ocean / Sea. These finer sediments settle down on either side of the stream channels. e.g. Delta of Mississippi river is of this type.

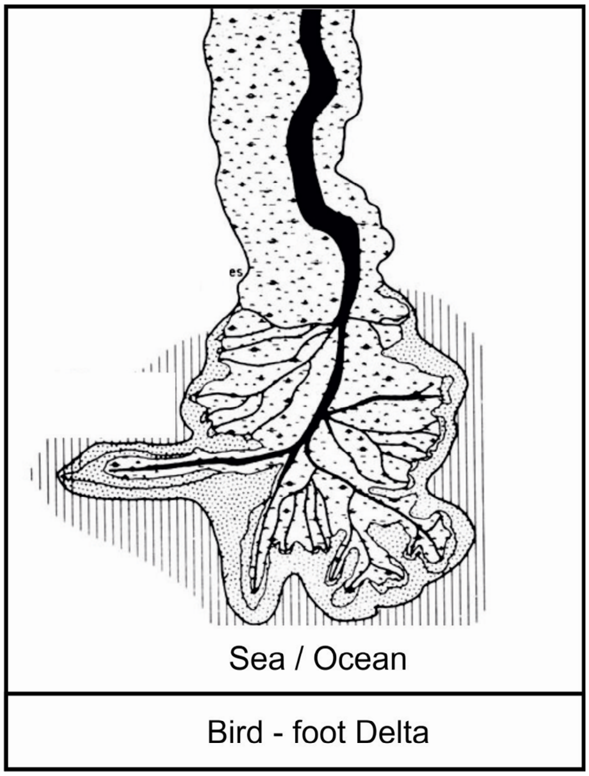


Fig. 30

3) Estuarine delta:

This delta is narrow as compared to other types of delta. There is very little scope for deposition as the sediments brought by the river are carried away by Ocean water currents & wave. Still if river is able to deposit sediments at its submerged mouth, narrow, long delta is formed, which is known as the estuarine delta.

4) Cuspate delta:

It is also known as tooth-shaped delta due to its shape. It is symmetrical as the sediments are deposited evenly in concave shape on either side of the river mouth.

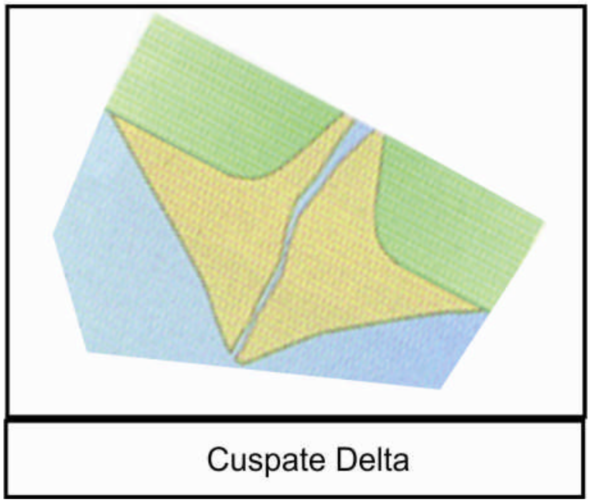


Fig. 31

e.g. Delta of river Tiber at the Italian coast in Europe.

3.2 GLACIAL GEOMORPHIC SYSTEM: GEOMORPHIC PROCESS AND FEATURES

About 30,000 years ago during the Ice Ages much of the temperate latitudes were covered by the continental ice sheets. Today only two major ice caps are found near north & south poles - i.e. at Greenland and Antarctica.

Glacial geomorphic processes and landforms are found in many parts of the world which are above the snow line. Areas above snow line are covered by ice. Height of snow line is more near to equator e.g. Mt. Kilimanjaro (5,200 m.) This height of snow line decreases as we move from equator towards the pole. e.g. Alps in Europe (2700 m.)

Snow falls on the slopes of the mountains. This becomes hard and compact - which is known as Neve (in France) and firm (in Germany). Neve slides in the downward direction due to the force of gravity. It can be considered as beginning of the flow of the glacier.

The rate of movement of glacier is rapid in the middle but less at the sides & at bottom due to friction with sides & bottom of valley of the glacier.

Several glaciers may converge at the foot hill part of the mountain ranges. So an extensive mass of ice is formed which is known as piedmont glacier. e.g. Malaspina glacier of Alaska, which covers area of about 4000 sq.km.

GLACIAL GEOMORPHIC PROCESS:

Glacier is one of the external agencies of erosion. Various erosional landform features are developed by the action of glacier in the highland areas and depositional landform features are formed on the lowlands. Glacier plays a combined role of erosion, transportation and deposition throughout its course. The major processes of erosion by the glacier are as follows:

1) Plucking:

Melt water enters into the cracks or joints of the rocks, beneth the glacier. it freezes & so expands. Hence the joint becomes wide and that piece of rock becomes loose. This loosed rock is attached to the lower side of the glacier due to freezing of water. It is plucked from the parent rock and moves along with the glacier. This angular piece of rock acts as a cutting tool in the process of glacial erosion.

2) Abrasion:

It is a very significant process of erosion by the glacier. Rock pieces embedded in the glacier, which are mostly angular, act as powerful cutting tools in the process of abrasion. Glacier is a solid mass of ice and the weight of ice in the glacier give extra pressure to the angular rock pieces embedded at the bottom part of the glacier. Hence abrasion becomes very effective process. (A glacier 300 m. thick can exert pressure of about 300 tonnes per sq.m.

3) Scratching or striation:

Scratches develop on the floor of the glacier due to angular fragments of rock, which move on this surface along with the glacier.

The rate of glacial erosion is determined by several factors as

1) Weight of the glacier
2) Gradient of the slope
3) Velocity or speed of the glacier
4) Temperature
5) Geological structure

EROSIONAL LANDFORMS DEVELOPED BY GLACIER:

1) 'U' shaped valley:

Glacier contains compact ice, which exerts pressure on the bottom part of the valley of glacier. As glacier moves in the direction of slope, angular pieces of rock embedded in the glacier wear away the sides and floor of the valley. So the shape of valley becomes like English alphabet 'U'. Hence the valley of the main glacier is termed as 'U' shaped valley.

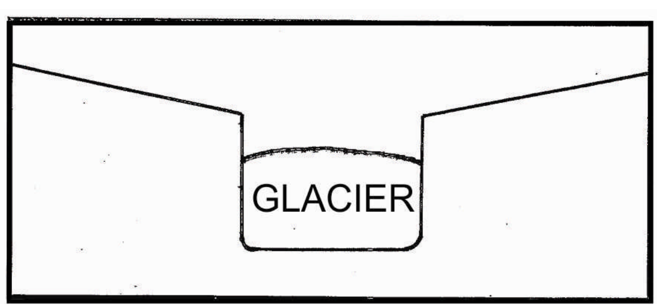


Fig. 1 'U' Shaped Valley

2) Hanging Valley:

Main glacier contains greater quantity of ice, hence it exerts more pressure on the valley floor. Due to more erosion the valley of main glacier - 'U' shaped valley is deeper.

On the other hand tributary glacier being smaller contains less amount of ice. So the erosive capacity of tributary glacier is much less than the capacity of main glacier. Hence the depth of tributary glacier is much less than the depth of main U shaped valley. After melting of ice in the glacier, valley of the tributary glacier appear at higher elevation as it is hanging near the valley of main glacier. Hence valley of the tributary glacier is termed as 'Hanging' valley.

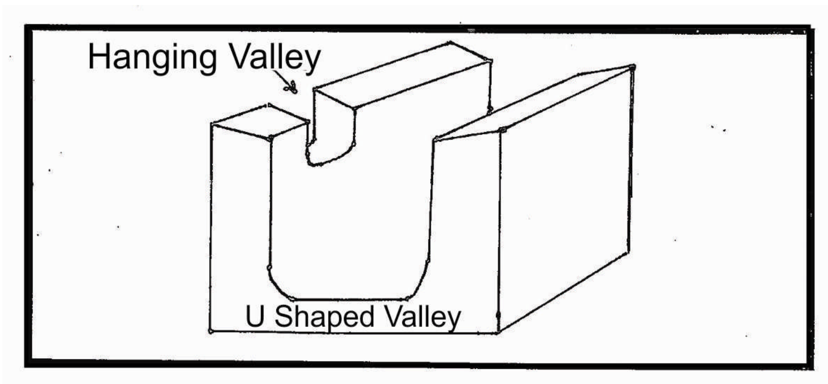


Fig. 2 Hanging Valley

3) Truncated spurs:

River contains water and so river can take a turn at the obstruction by the spur in its course. So we observe this landform as 'Interlocking spurs'.

Glacier contains ice which is hard and compact; hence when glacier moves through the spurs of mountain ranges, end portion of spur is eroded by the glacial erosion. These eroded spurs are termed as truncated spurs.

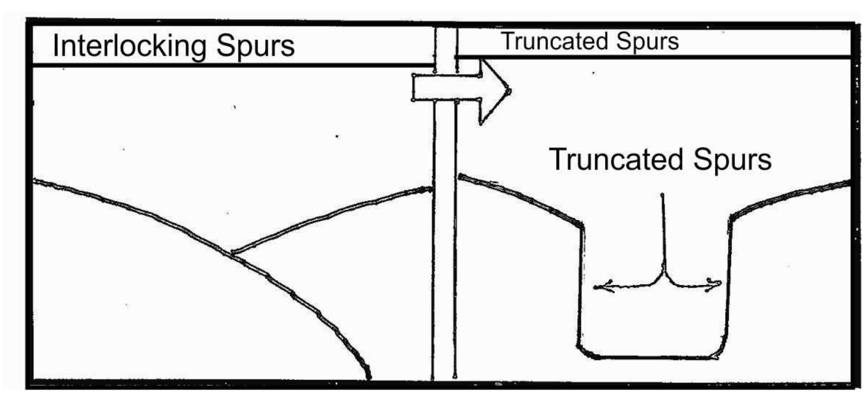


Fig. 3

4) Cirque:

Glaciers move from mountains in the direction of slope. The processes like plucking, abrasion along with frost shattering help to create steep horse-shoe shaped basin along the sides of mountain. It is termed as cirque in France, Corrie in Scotland, CWM in wales. Other names are Kar, botu, etc.

This huge armchair shaped depression has steep headwall and steep sidewalls. There is rocky ridge at the exit of the cirque. The normal ratio between the length and height of the cirque is 3:1. Area covered by cirque may be many square kilometres.

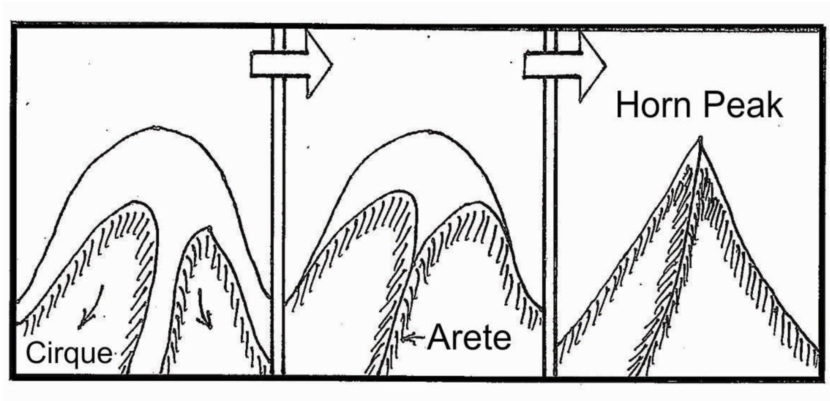


Fig. 4

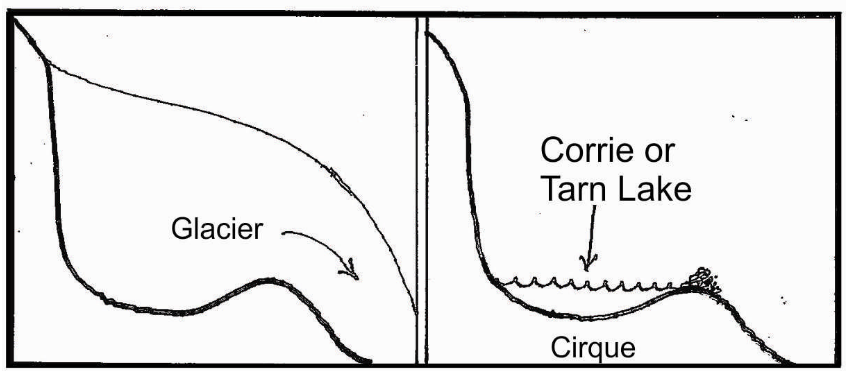


Fig. 5

5) Corrie Lake or Tarn:

After melting of glacier or ice, melt water is collected in the depression of cirque. It is termed as Corrie Lake or Tarn. (Ref Fig. 5)

6) Arête:

Arête is a French term used to indicate knife edged ridges formed between two adjacent cirques. Initial area of cirque is enlarged due to various erosional processes. Ultimately borders of adjoining cirques meet together to form Arête. (Ref Fig. 4)

7) Horn peak:

Cirques developed along all sides of the mountain enlarge due to various erosion processes and ultimately sharp angular horn shaped peak is formed at the mountain top. It is also termed as pyramidal peak. e.g. The Matterhorn of Switzerland. (Ref Fig. 4)

8) Crag and Tail:

Crag is a hard rock in the path of a glacier. Tis rock resist erosion by the glacier as it is hard. The side of this rock, from which glacier comes is steep. Hence this block of hard rock protects weathered, eroded material accumulated on other side (Leeward side) of crag. This deposited weathered material is termed as tail, which has gentle slope

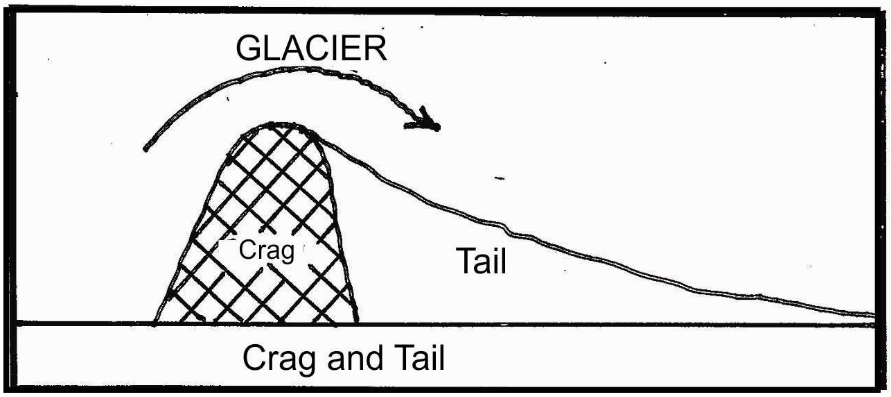


Fig. 6

Volcanic plug mostly develop as crag.

9) Roches Moutonnees :

Roches Moutonnee is the French term used for the sheep skin wig common in France in the past. Hence this name is given to the rock structure, developed by the erosional process of glacier and which resembled to the sheep skin wig.

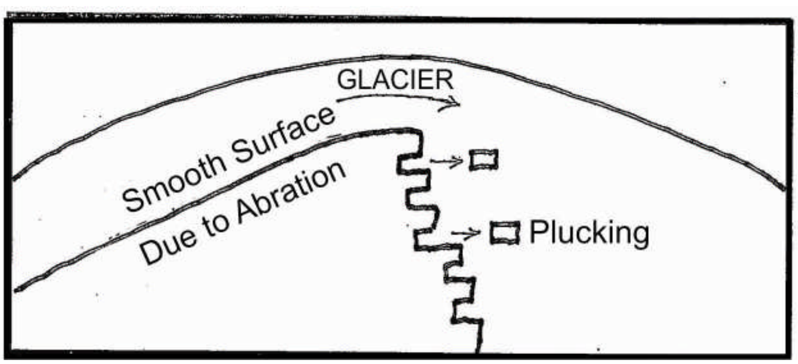


Fig. 7 Roche Moutonnee

The upstream side of Roche Moutonnee has gentle slope & surface is smooth due to abrasion process done by the glacier & angular pieces of rock embedded in it.

Action of plucking blocks of rocks from jointed rock formation takes place at the leeward side. Hence this side is steep and has uneven surface.

Roche Moutonnees are found in swarms in both lowland and highland glaciated regions.

10) Glacial Stairways:

These step like structures are found in the glacial valleys. These appear like benches separated by nearly vertical cliffs. The distance between two vertical cliffs may vary from 30 to 300 m.

These can form due to faulting or hard / soft or jointed rock formations. Blocks of jointed rock could have removed by the glacial erosion to form glacial stairways.

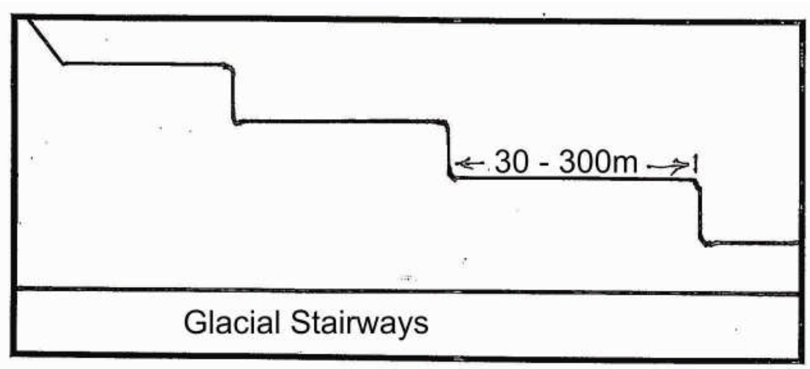


Fig. 8

11) Fiords:

The mouth of the glacier, where it enters into the sea is termed as fiord. It is a long deep, steep sided inlet at the coast whose depth is below sea level due to glacial erosion - icebergs. Fiords generally have a threshold or rock towards sea side end, which can be the site of deposition of terminal moraine.

Fiords mainly found along the coast of the countries in the temperate belt e.g. Norway, Greenland, Alaska, British Columbia, Chile and New Zealand.

DEPOSITIONAL LANDFORMS DEVELOPED BY THE GLACIER:

1) Lateral moraine:

Weathered, eroded material or load carried by the glacier is termed as moraine (in the case of river it is termed as sediments).

Moraines are identified by different names as per their location with respect to the glacier.

Lateral moraines are found along the sides of the glacier. Weathered, eroded pieces of rock fall at the sides of glacier from the steep wall of the glacier valley.

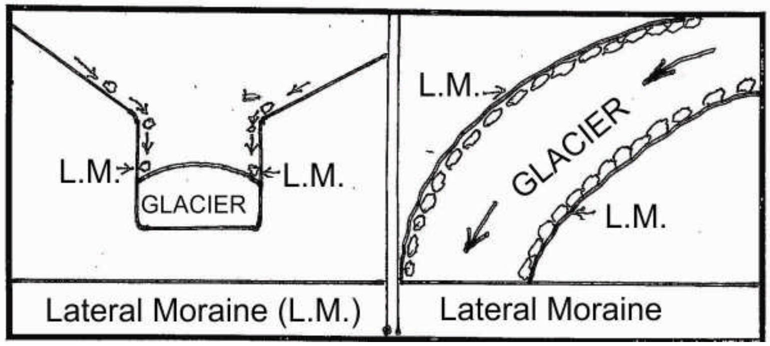


Fig. 9

Lateral moraine may consists of a mixture of sand, silt, dirt, small boulders etc.

3) Medial moraine:

It is also known as Median Moraine. As the name indicates this type of moraines are found at the middle portion of the glacier. Medial moraines are formed when two glaciers join together. In such situation lateral moraines of two glaciers merge together to develop medial moraine.

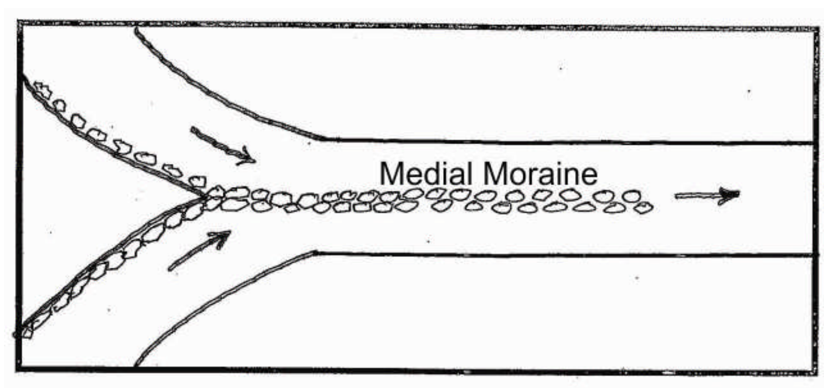


Fig. 10

4) Terminal Moraine:

Moraine at the end or terminal part of glacier is termed as terminal moraine. It appears as linear ridge of debris brought by the glacier, whose inner slope (towards glacier) is steep than the outer slope. Terminal moraine may have drumlins, kettles etc. along with large angular boulders.

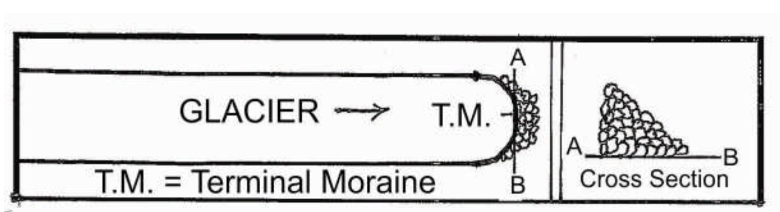


Fig. 11

5) Ground Moraine:

These are at the ground portion of the glacier (bottom part) and are visible after melting or retreat of the glacier. It has a thick sheet of glacial till on the undulating surface of low relief, with small depressions and scattered boulders.

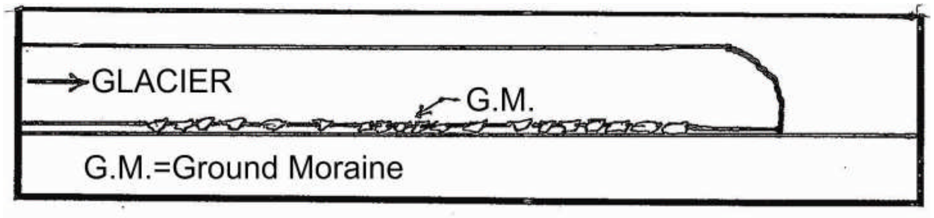


Fig. 12

6) Englacial Moraine:

The pieces of weathered, eroded material which is trapped in the glacier & moves along with it is termed as Englacial Moraine. This weathered material can enter into the glacier either from top surface or from bottom.

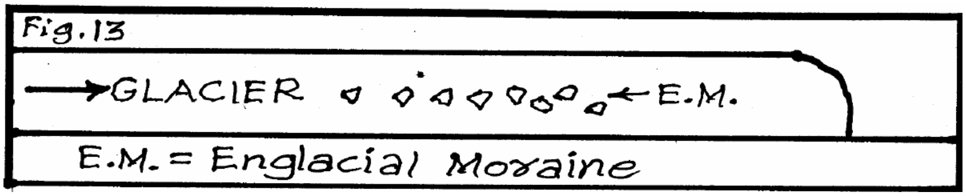


Fig. 13

7) Sub-glacial Moraine:

These are the angular fragmented, weathered pieces of rock embedded in the bottom part of the glacier, which carry out the work of abrasion as glacier mores forward.

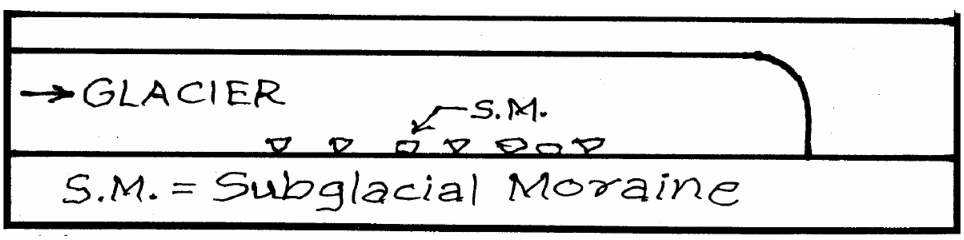


Fig. 14

8) Recessional Moraine:

It is the deposition of the terminal moraines in several succeeding deposits as melting of ice in the glacier may occur in stages & so a series of recessional moraines are formed.

9) Drumlins:

These are small hills composed of boulder clay, deposited by the glacier. Drumlin is an Irish term for this oval elongated hill. It looks like 'whale-back'. Height of the Drumlin varies from few metres to about 120 m. and the length of about one or two kms.

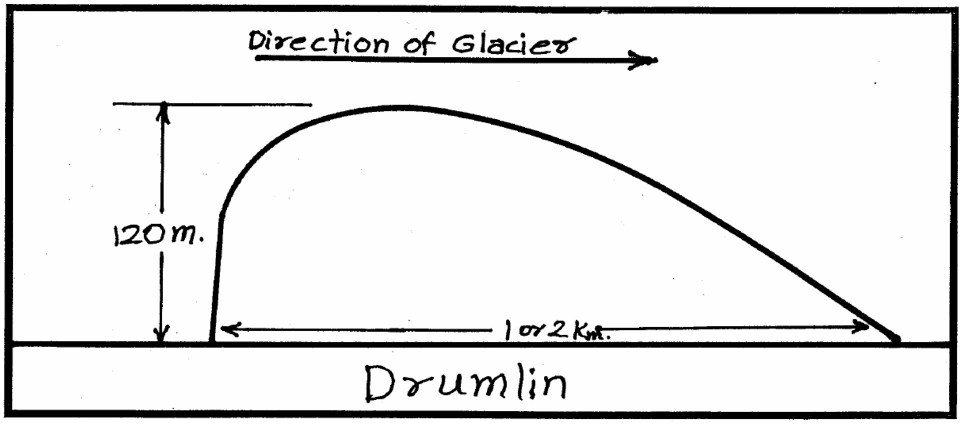


Fig. 15

Upstream side of Drumlin is steeper than the leeward side. An area covered by oval shaped, elongated drumlins is termed as the 'basket of eggs' topography. Drumlins are found in Finland, Ireland and the glaciated plain around the Great Lakes in N. America.

10) Eskers:

These are long, narrow ridges, which are about 60 m. in height and many kilometres long. Eskers are composed of sand and gravel. We find more eskers in the Scandinavian countries.

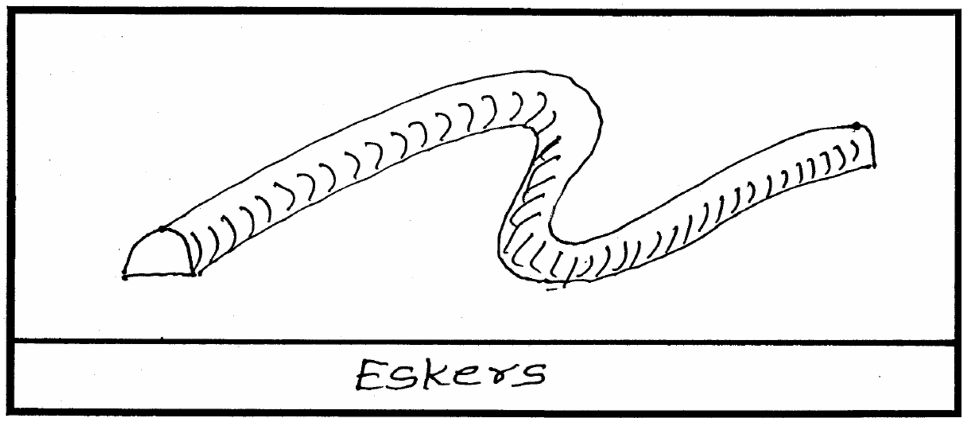


Fig. 16

11) Kame:

There are small rounded alluvial cones composed of sand and gravel.

12) Erratics:

Glaciers originate in the area of high altitude. They move in the direction of slope and most of them join sea at Fiord. Glaciers carry different type of rocks and weathered pieces of rock. Erratic is a huge boulder rock transported by the glacier and deposited at the lowlands. The mineral composition of erratic rock is different from the other rocks found in that region and hence it is termed as Erratic.

These erratics are very useful in tracing the source and direction of glacier.

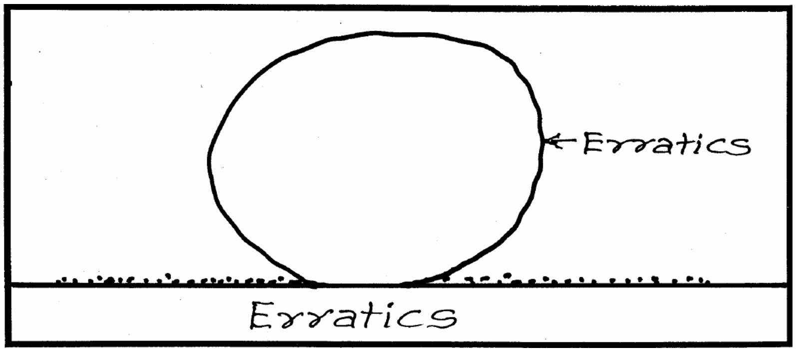


Fig. 17

12) Outwash plains:

It is composed of fluvio - glacial deposits. Streams of water carry deposited material from the terminal moraines and redeposit this material in a variety of forms as small hills, undulating plains etc.

3.3 KARST LANDSCAPE DEVELOPMENT AND PROCESSES

KARST LANDSCAPE:

Various erosional and depositional landform features developed by the work of underground water are the part of Karst landscape.

This type of landform features were first identified at the limestone region (Karst region) in Yugoslavia on the Adriatic coast. Hence the name Karst Landscape is given to this type of landscape.

Ideal conditions essential for the development of Karst Landscape:

Following conditions are essential for the development of Karst landscape.

1) Limestone rocks should be on or near to the surface of earth:

If the limestone rocks are at great depth, underground water - weak carbonic acid - cannot reach up to these rocks for the development of landscape. Hence the limestone rocks should be at the surface.

2) Presence of cracks and joints:

Rainwater converted into carbonic acid can percolate more in the limestone region if it has more cracks and joints. The erosion process & development of erosional landscape will be rapid.

3) Rock should not be very porous:

If the rock is very porous, surface water can percolate through it at very rapid rate and hence it will not get chance for erosion & development of landforms.

4) Location of the limestone beds with reference to water table / aquifer in that region:

Limestone beds should be situated above water table or aquifer for effective erosion and development of Karst landscape.

5) Impermeable base layer:

Underground water percolates through the limestone rock layers, and erodes them to develop various landform features. This process becomes more effective if there is impermeable base layer of rock. It is also termed as impermeable Base Layer.

6) Humid Region:

The process of erosion and the development of Karst landscape depend upon the availability of water - especially rain water and hence Karst landscapes have mostly developed in the humid regions of temperate & tropical zones. Desert region or arid zones are not suitable due to lack of sufficient water.

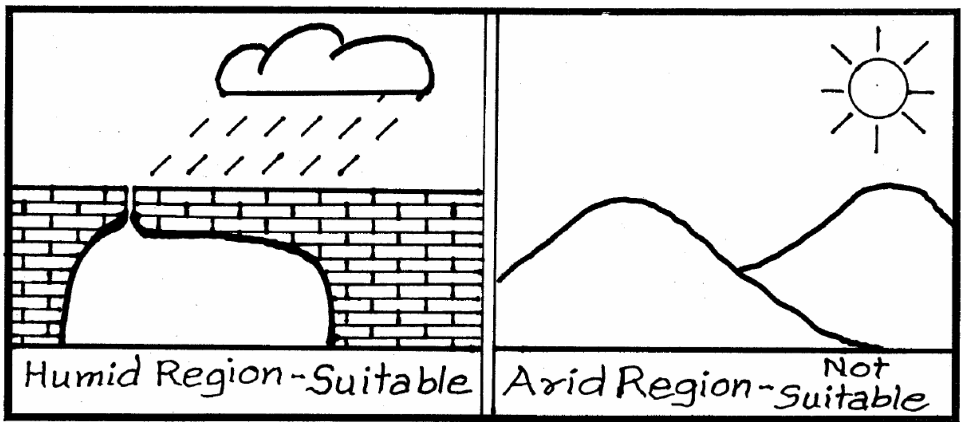


Fig. 1

Process involved in the development of Karst Landscape:

The only major process of erosion involved in the development of Karst Landscape is chemical action or Corrosion, solution.

Atmospheric Carbon dioxide is able to dissolve in the raindrops as they come towards earth's surface. So the raindrop is converted into weak carbonic acid. Rain water falls on the ground and flows in the direction of slope.

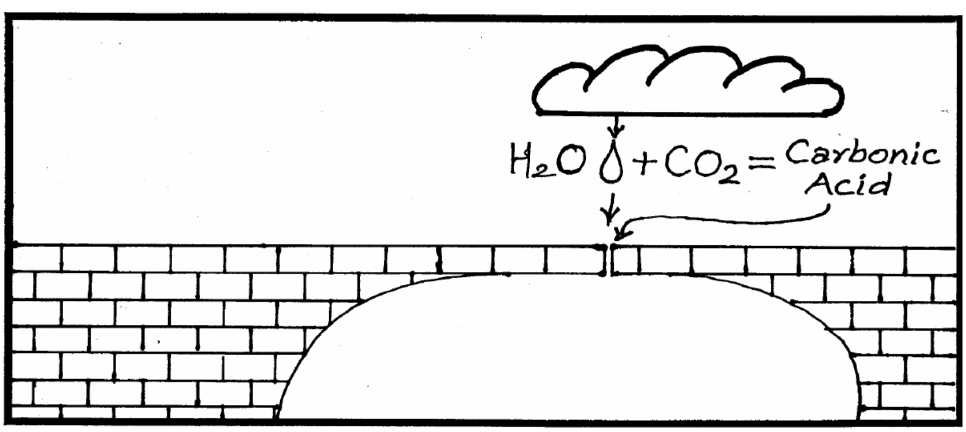


Fig. 2

At this stage it absorbs additional carbon di-oxide produced by various organisms like bacteria in the soil. This enhances the erosive capacity of weak carbonic acid.

Limestone, which is composed of calcium carbonate reacts with weak carbonic acid (H_2CO_3) (formed due to the combination of rainwater and carbon dioxide) and is converted into calcium bicarbonate ($(CaCHCO_3)_2$) which is soluble in water

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca\left(HCO_3\right)_2.$$

Various other factors also affect the process of erosion, in Karst region. Major factors are as follows:

1) Temperature
2) Chemical composition of Carbonate rocks.
3) Partial pressure of atmospheric CO_2
4) Joints in the rock
5) Rate of flow and nature of groundwater
6) Route of flow of water
7) Contact time of the chemical reaction

KARST - EROSIONAL LANDFORMS:

1) Limestone pavement:

Limestone is a well jointed sedimentary rock. Rainwater converted into carbonic acid enters into the joints & cracks & erodes them. hence they are enlarged & so the landscape which is developed is termed as limestone pavement.

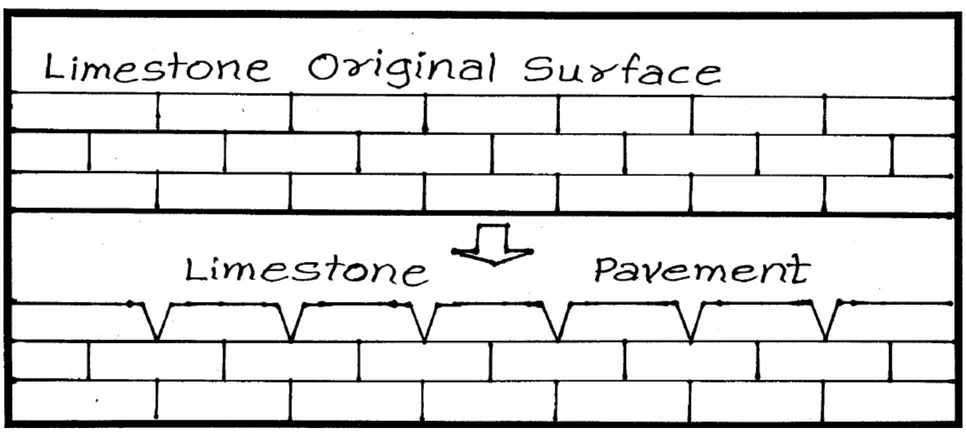


Fig. 3

2) Clints:

These are the rectangular blocks of the limestone pavement. These are known as Karren in Germany & Lapies in France.

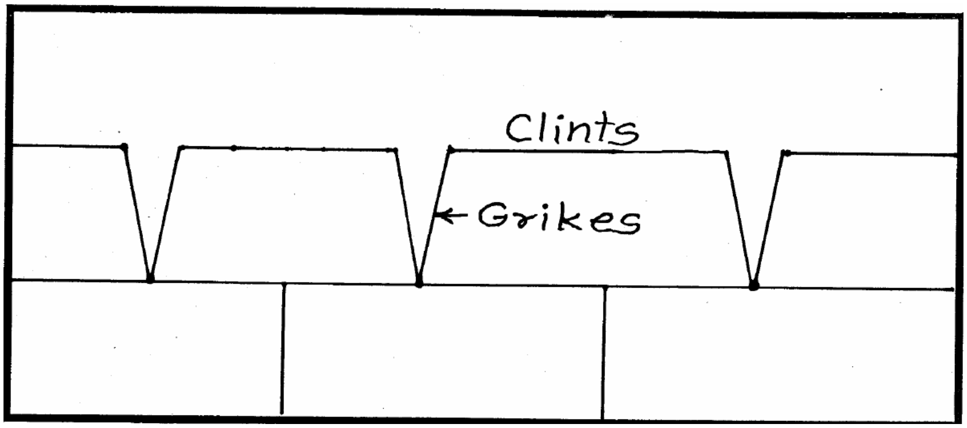


Fig. 4

3) Grikes:

The joints of the limestone pavement, widened due to chemical weathering and erosion are termed as Grikes

4) Sink Hole:

These are the small holes developed in the depressions of Limestone pavement or limestone surface, especially at the junction where joints in different directions meet. Rain water converted into carbonic acid moves along the joints in the direction of slope. When these minute streams coming from different direction meet at the joints, water remains stagnant at that point for a longer period of time. So the chemical weathering at this point is more & sink hole is developed. Sink hole connects underground cave with the upper surface. Rainwater / carbonic acid enters into the cave through sink hole. These are known as Avens in France.

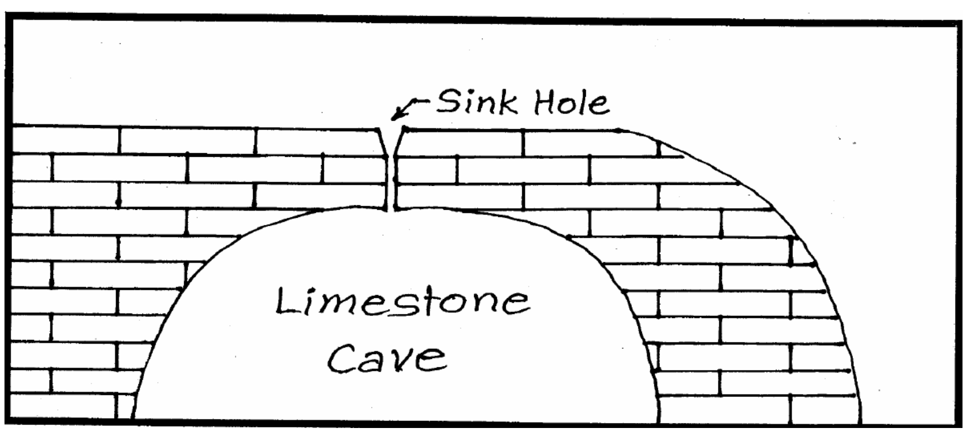


Fig. 5

5) Doline:

Sink holes are further enlarged due to chemical action or merging of adjoining sink holes. This enlarged hole is known as 'Doline'.

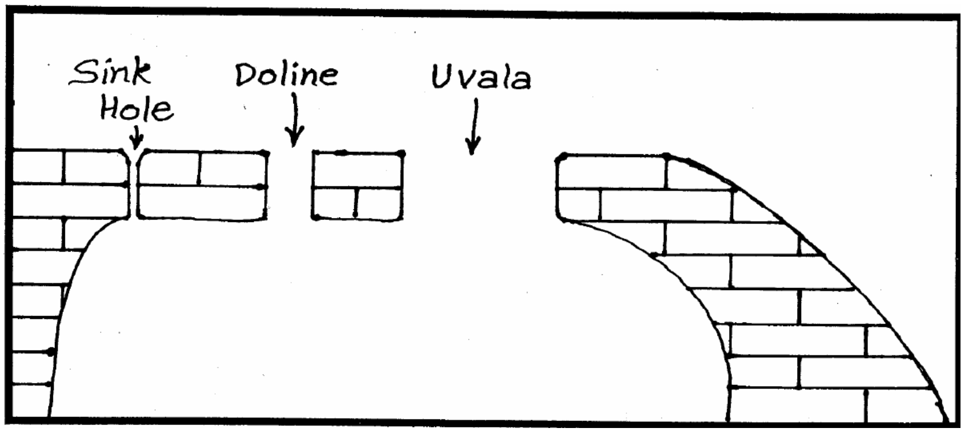


Fig. 6

6) Uvala:

'Uvala' is large depression formed on the limestone surface by the coalescence of adjoining dolines.

7) Polje:

'Polje' is huge depression formed in the limestone region due to collapse of roof of underground cave.

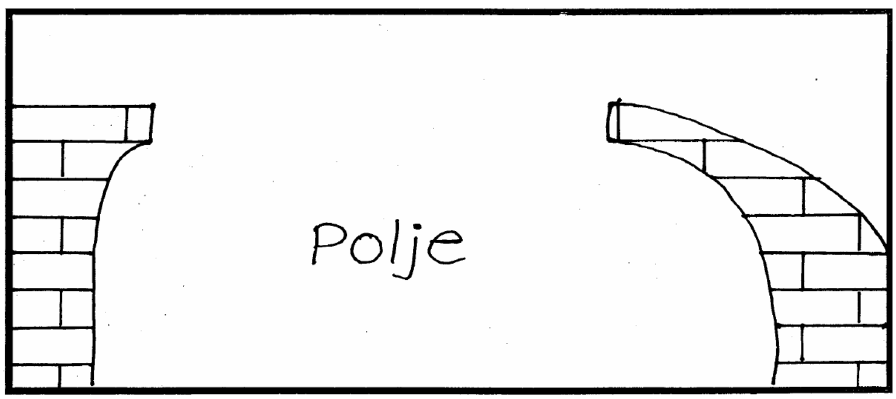


Fig. 7

8) Swallow hole:

Stream or a small river flowing on the surface of the limestone region disappears underground at swallow hole. It is also known as Swallet. In France it is known as embut.

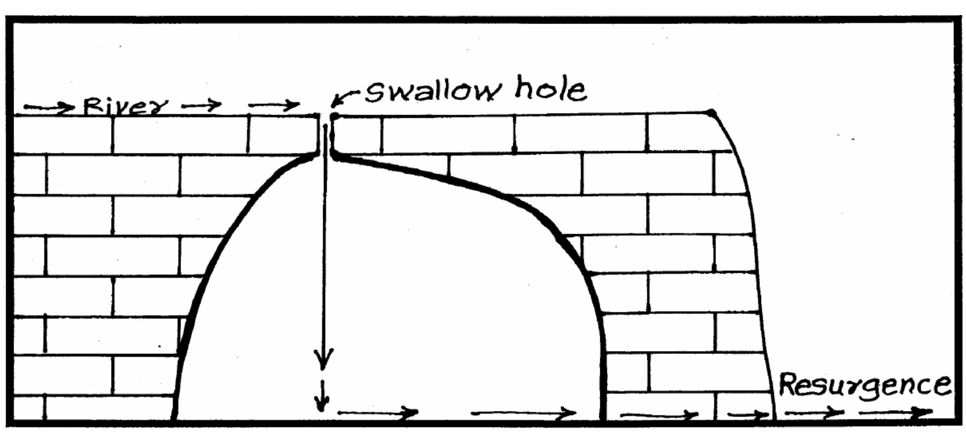


Fig. 8

9) Caverns (Caves):

Underground caves formed in the limestone region are termed as Caverns or Caves. These are formed as the limestone is dissolved by the weak carbonic acid which percolates down through sink holes, doline, etc.

These caves are irregular in size and shape. The Hollock cave (85 km. long) is the longest cave in the world. Mammoth cave in Kentucky region of USA is 72 km. long.

10) Terra Rosa:

Carbonic acid in rainwater dissolves upper part of the sedimentary rocks. As this water percolates through sink hole, particles of red clay soil remain deposited on the surface. The colour of these particles is similar to the laeritic soil and hence it is termed as Terra Rossa.

These are mostly found on the flat surface & may have thickness of few metres.

11) Karst Window:

Sinkholes and Dolines are found at the surface level above the underground cave. When upper surface of the cave collapses due to excessive erosion, the gap which is formed is termed as Karst Window. It is very useful for the geomorphologists and geological researchers to observe various landform features below the surface & sub-surface drainage.

12) Sinking creek:

If the sink holes are more in number and close together, located in a line, surface water percolates through these sink holes. This feature is termed as 'sinking creek'.

13) Blind valley:

The flow of surface stream terminates at swallow hole & the valley looks dry valley. It is known as 'Blind valley'. It is not possible sometimes to know the direction in which the water flows.

14) Ponors:

It is a deep shaft like hole / pipe in the limestone region, which helps to bring surface water into the interior part of this region. It is termed as Aven in France.

15) Natural Bridge :

When the underground cave in the limestone region collapses and small upper part is not destroyed, it is termed as 'Natural Bridge'.

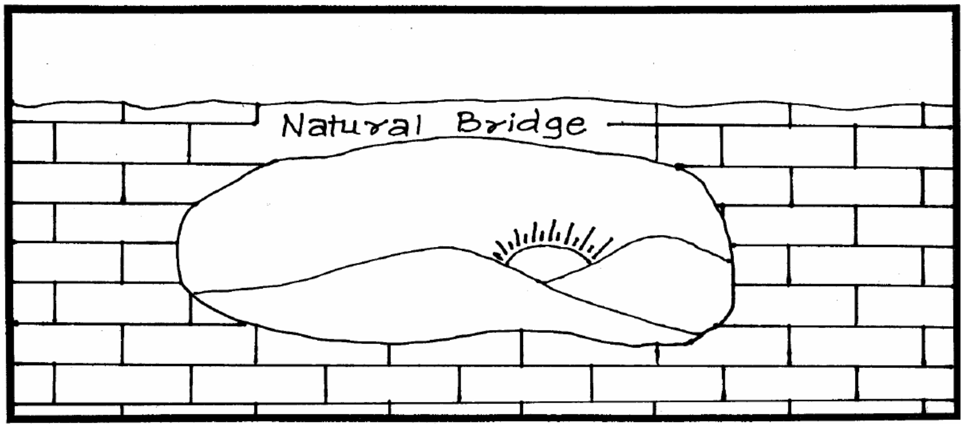


Fig. 9

16) Pocket Valley:

Due to chemical erosion many depressions are formed, which have vertical sides and plain floors. These become wide & broad due to further chemical erosion. These are termed as pocket valleys.

In pocket valleys water table is at higher level & this water can sometimes comes out in the form of spring. (In the blind valley water disappears into underground channels.

17) Dry Hanging valley:

Rivers in the limestone region do not have much water as water percolates into underground area through sink holes. Hence these rivers appear dry and are known as Dry valleys or Bournes.

Due to lack of water in these tributary rivers, their erosional capacity is less than the erosion done by the main river, (which is eroded more.) So the valleys of the tributary rivers appear hanging over the valley of the main river. Hence these are termed as dry hanging valleys. Many hanging valleys of this type are found near Karst region at Adriatic coast.

18) Hums:

If there is a impermeable rock layer below limestone rock layers, rainwater percolated through limestone is accumulated over the impermeable rock layer. This acidic water dissolves most of the limestone present on the floor. The portion of unaffected limestone on the impermeable rock layer is termed as Hums Monad - knocks in the limestone region are also known as ‘Hums’.

KARST - DEPOSITIONAL LANDFORMS:

1) Stalactite:

Carbonic acid is formed when the atmospheric carbon dioxide dissolved in the rain drops. This carbonic acid flows over the limestone region and limestone - is dissolved in it.

This water percolates through sink hole and enters into underground cave. If the flow of incoming water is less, the drops of water are attacked to ceiling of the cave. Water evaporates and calcium bicarbonate (which is dissolved form) is deposited at the roof (ceiling) of the cave.

This process is repeated many times & so the length of calcium bicarbonate piller extends from roof towards floor of the cave. It is termed as stalactite.

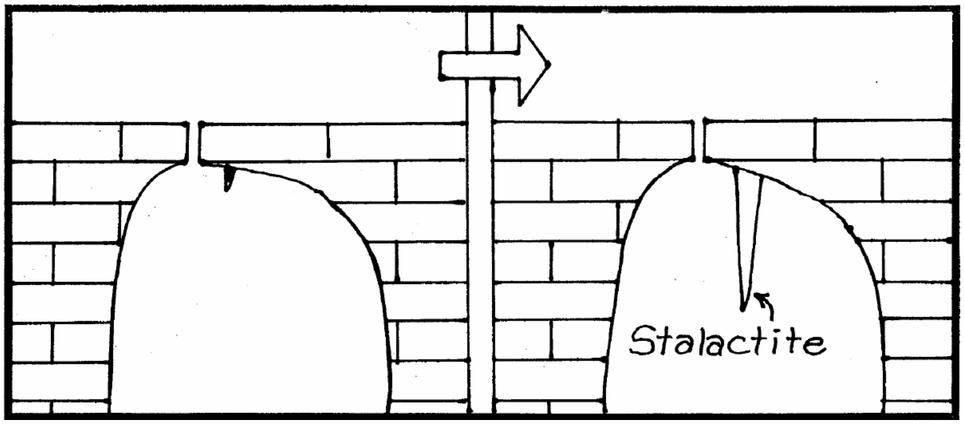


Fig. 10

2) Stalagmite:

The process of formation of stalagmite is similar to the process of formation of stalagmite. Only difference is that the stalagmite extends from roof of the cave in downward direction, while the stalagmite is formed on the floor of the limestone cave and extends in the upward direction.

At the time of formation of stalactite, if the rate of incoming water droplets is more, extra droplets fall on the floor of limestone cave, below stalactite. Water is evaporated and the deposition of calcium bicarbonate increases in the upward direction from the floor. This is termed as stalagmite.

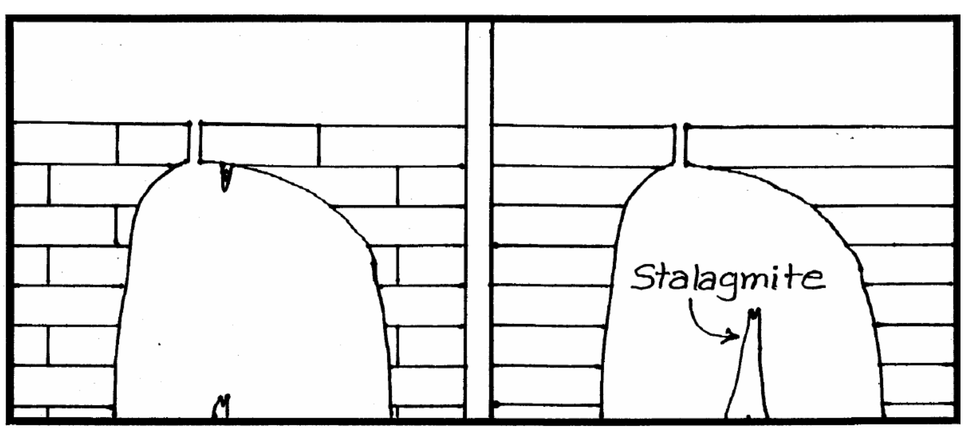


Fig. 11

3) Limestone Pillar:

Stalactite extends from roof to floor of cave and stalagmite extends in the opposite direction - i.e. from floor to ceiling of the cave. These two landforms join together to develop Limestone Pillar. These are also known as cavern pillars.

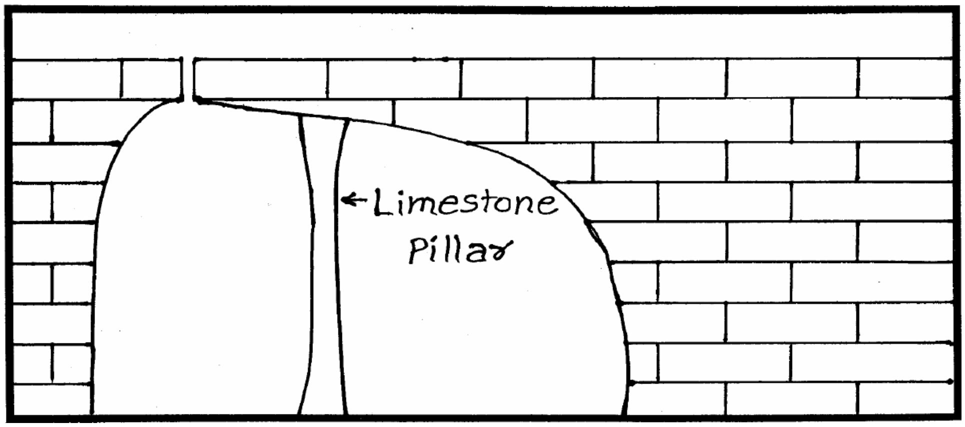


Fig. 12

4) Drip curtain:

Sometimes water percolating from the fracture in the roof of the limestone cave may form a thin vertical sheet of rock, which is termed as Drip curtain.

3.4 AEOLIAN GEOMORPHIC SYSTEM: PROCESSES AND LANDFORMS

'Aeolian' means related to wind. Landforms developed by the erosion & deposition done by the wind are termed as Aeolian landforms.

Action of wind is more pronounced in arid and semi-arid regions of the world. It is also significant along the sandy coasts and at glaciated plains.

Arid and semi-arid areas are identified on the basis of rainfall.

a) Arid areas = Rainfall less than 25 cm.
b) Semi and areas - Rainfall 25 to 50 cm.

Aeolian landforms are mostly found in the deserts. Some of the major desert areas are as follows:

i) Sahara (N. Africa)
ii) Rub-al-Khali (Arabian Desert)
iii) Nubian Desert (Sudan)
iv) Gobi (Mongolia)
v) Atacama (S. America)

vi) Patagonia (S. America)

vii) Arizona (N. America)

viii) Thar (Asia - India)

ix) Takla Makan (China)

x) Great Sandy Desert (Australia)

xi) Great Victoria Desert (Australia)

About 20% of the land in the world is covered by the deserts.

Most of the deserts are found in between the Parallels of latitudes of 15^0 to 30^0, North and South of the equator. These are known as the 'Trade wind deserts' as they are in the zone of trade winds.

These deserts are mostly situated along the western margins of the continents, where Trade winds are off-shore. The cold Ocean currents in this region produce 'desiccating effect.' So that moisture is not easily condensed into precipitation.

The high pressure belt produces descending air currents & so this is just reverse process needed for precipitation. (i.e. ascending air currents, upliftment of moisture, condensation, cloud formation etc.)

e.g. Sahara, Arabian, Iranian, Thar, Kalahari, Atacama Namib, Great Australian Desert etc.

Deserts in the Arid, semi-and regions are classified into five types:

1) **Rocky deserts** - or Hamada. e.g. Hamada el Homra in Libya.
2) **Stony deserts** or Reg.
3) **Sandy deserts** or Erg.

e.g. Rub-al-Khali is the largest (Arabian Peninsula), Sandy Desert (Erg) in the world.

4) Badlands -

Area badly eroded into gullies & ravines, due to occasional rainstorms in and region. e.g. Painted desert of Arizona.

5) Mountain deserts -

The mountains & plateau at higher elevations are dissected due to erosion, weathering (frost shattering etc.). e.g. Ahaggar mountain in Sahara desert.

AEOLIAN / WIND - EROSIONAL PROCESSES:

Various processes are involved in shaping Aeolian landforms. Major processes are as follows:

1) Weathering - Chemical:

The amount of rainfall is very less in the arid region, but when rain water percolates into the cracks and joints of the rock, rainwater reacts with some minerals.

2) Weathering - Mechanical:

a) Exfoliation:

Deserts have extreme temperature range. Temperature during day time is very high but during night time is very low. The outer portion of rock is heated more than the inner part. Hence outer surface of rock expands more and is separated from the inner part. Outer part peels off in successive thin layers like onion.

This process of mechanical weathering is termed as 'Exfoliation'.

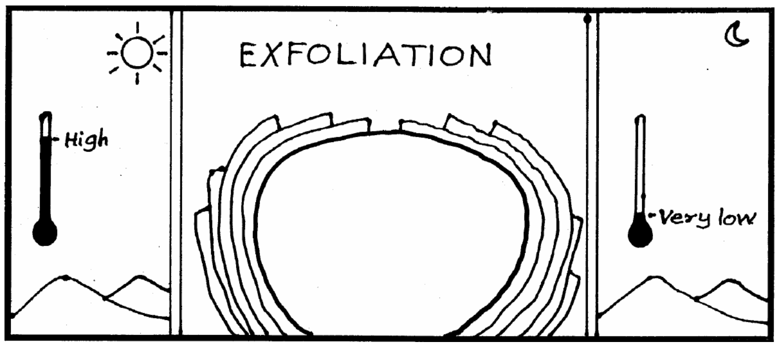


Fig. 1

b) Frost Shattering:

Water enters into the cracks & joints during day time. This water is converted into ice due to extreme low temperature during night time. Ice requires about 10% more space than water & so the formation of ice in the crack exerts pressure on the walls of the rock ultimately the fragments of rock are separated from the main rock. This process is termed as frost shattering. The sharp angular fragments of rock produced in this process act as powerful effective tools of erosion in Aeolian processes.

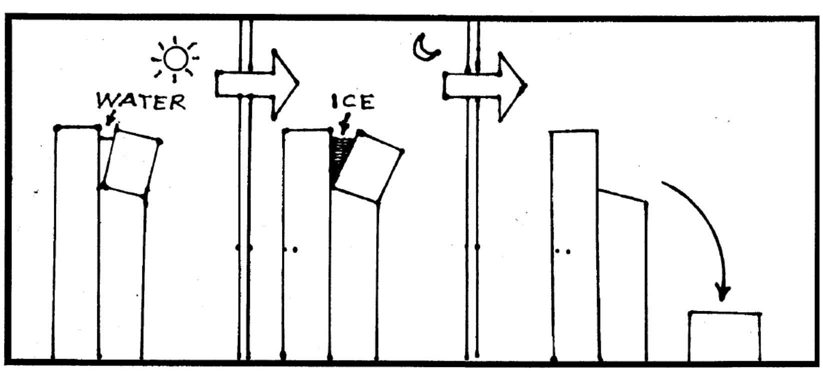


Fig. 2

3) Abrasion or Corrosion:

Wind carries fragmented pieces of rock, sand etc. Due to the force of wind these sharp pieces or particles of sand brush against rock, and thus rock is eroded. This process of wearing away of the rock by friction, rubbing grinding and scraping is termed as Abrasion or Corrosion.

Rock surfaces are scratched, polished and worn away due to abrasion.

Many landform features are developed due to abrasion. The effect of abrasion is more up to 2 m. from the ground.

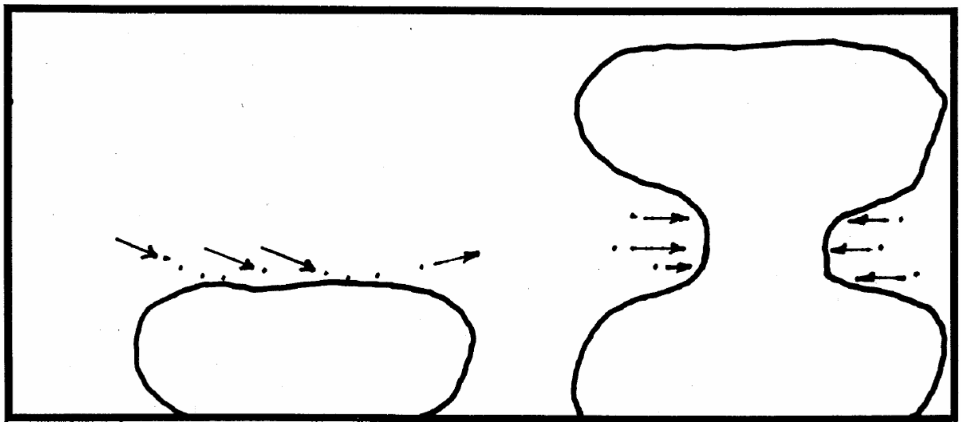


Fig. 3

4) Attrition:

Pieces of rocks collide against each other or against base rock. These pieces break in this process and thus reduce in size. Ultimately rounded grains of rock are formed, which are termed as millet seed sand. This process is termed as attrition.

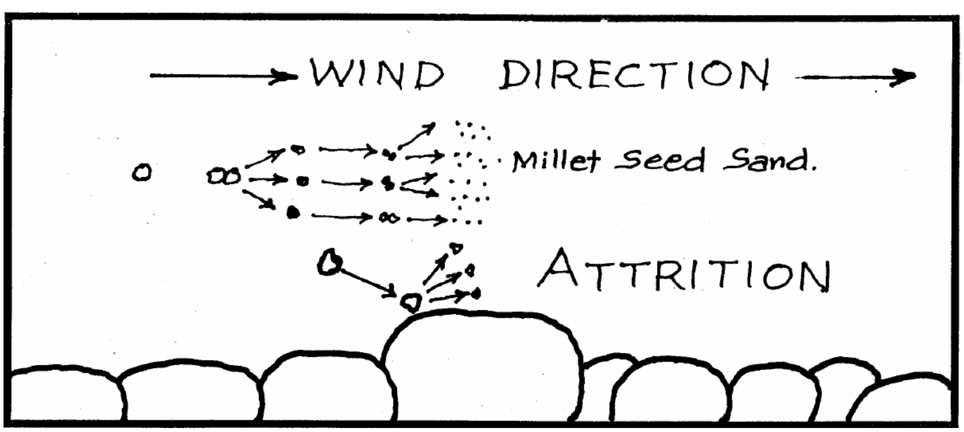


Fig. 4

5) Deflation:

Find dust / sand particles are removed from one place due to the process of deflation. Wind can carry dry sand, silt or clay particles.

Large size depression is formed in the desert due to deflation which is known as deflation hollows or blow-outs.

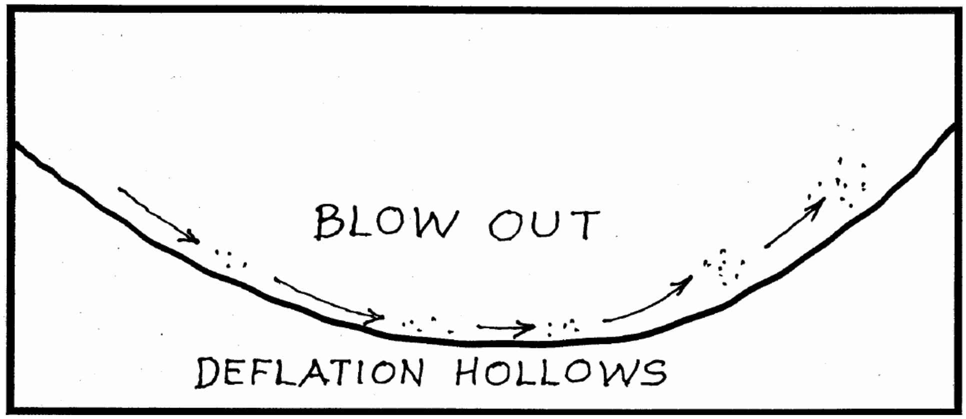


Fig. 5

Aeolian / wind - Transportation processes:

Suspension, saltation and creep or traction.

Finer sand, silt or clay particles are carried over longer distance by strong wind. This process is known as suspension.

Medium size boulders are uplifted by the strong force of wind and carried away at short distance. When force of wind becomes weak this boulder falls on the Earth due to the gravitational force. This process is known as saltation.

Large size boulders are rolled at the surface by the process of creep or traction.

Dust storms called Haboobs in Arabia - Egypt, Saudi Arabia & Yemen carry small particles over very long distance.

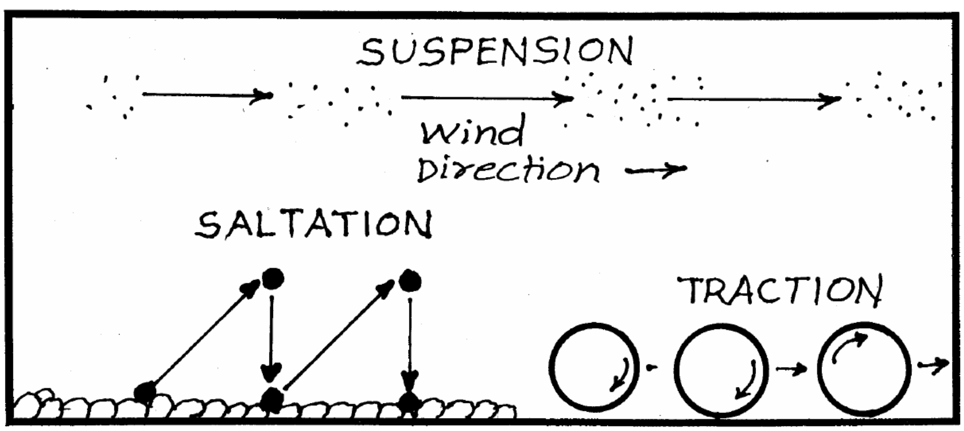


Fig. 6

Aeolian / wind Landforms of Erosion:

1) Deflation Hollows:

Wind is able to lift sand and small particles of rock and thus can create small or large depressions called as deflation basins or deflation hollows.

Faulting in desert area may lower part of land forming depression, which is enlarged by the deflection of sand by strong wind.

Deflation of sand by wind continues up to the water-table in that region. (wet particles are difficult to lift). Oases or swamps develop where the deflation hollows meet underground water table.

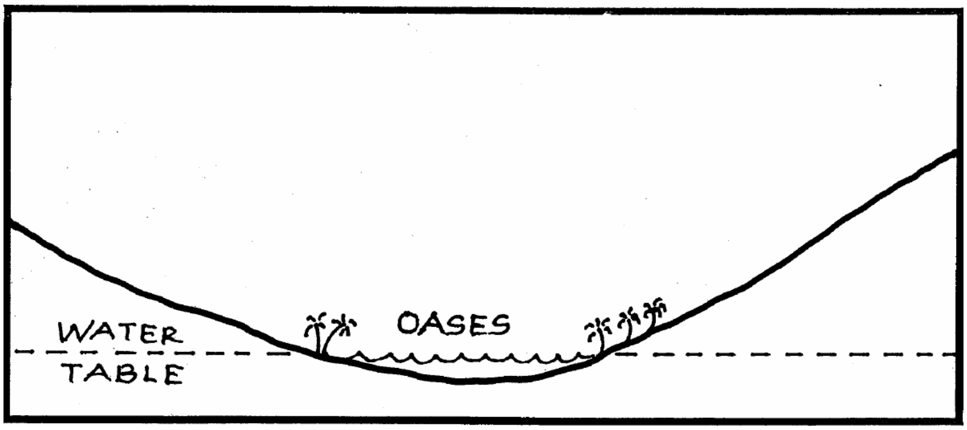


Fig. 7

Faiyum depression in Egypt is about 40 m. below sea level.

Natural vegetation in western part of U.S.A. was removed for the purpose of cultivation.

Trees act as a natural barrier for the strong wind. When trees were removed, there was no obstruction to the strong wind. Hence all fertile upper layer of soil was removed during dust storms. So the potential productive area was converted into what is known as the Great Dust Bowl.

2) Rock Pedestals:

Hard rock formations resist erosion done by the wind, hence such huge blocks of rock undercut more near bottom due to action of wind are termed as Rock Pedestals.

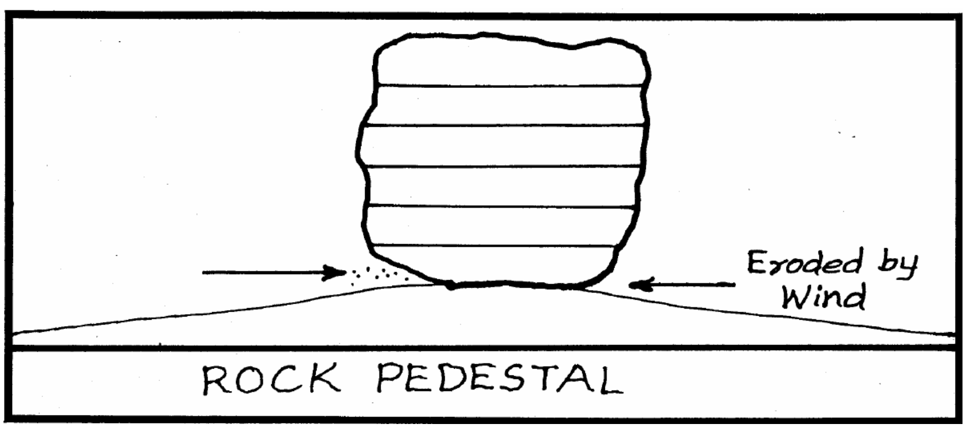


Fig. 8

3) Mushroom Rock:

These are similar to rock pedestals but due to excessive erosion it appears as Mushroom.

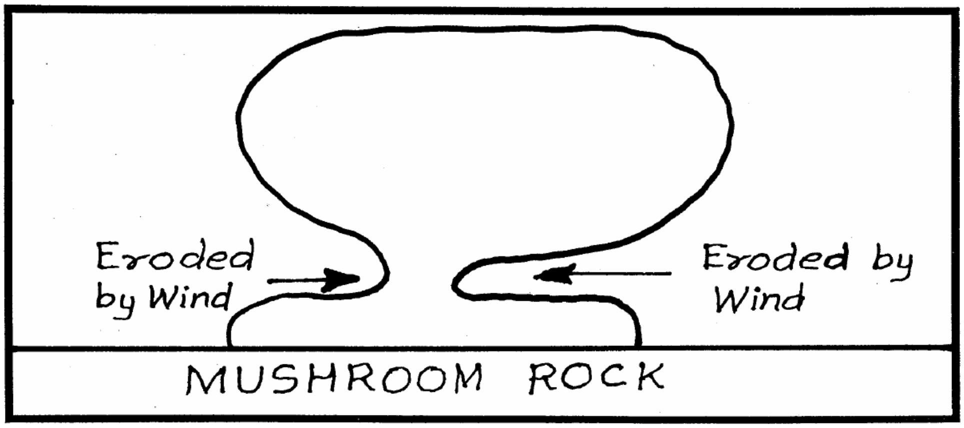


Fig. 9

It is also known as 'Gour'.

4) Yardang:

When alternate layers of hard and soft rocks are in vertical direction, soft rocks are eroded at much rapid rate than the hard rocks. Steep sided hard rock formations appear over hanging over excavated bands of soft rocks.

These are termed as 'Yardangs'. It is a Turkish word. 'Yar' means ridge. The biggest Yardang in the world is in the Iran. (About 150 meter high & 300 meter long). These are also found in Taklamakan Desert (China) and the Atacama Desert (Chile)

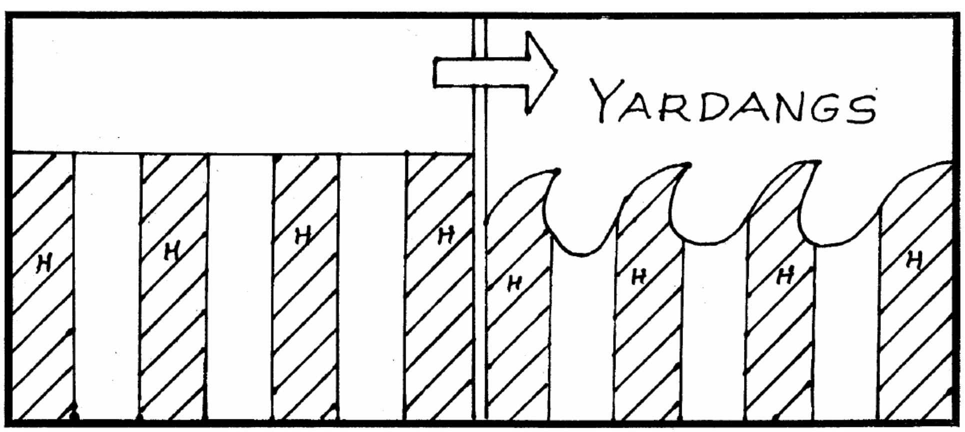


Fig. 10

5) Zeugen:

In this case the hard and soft rock formations are in horizontal direction. Soft rock formations are eroded at much rapid rate than the hard rock formations.

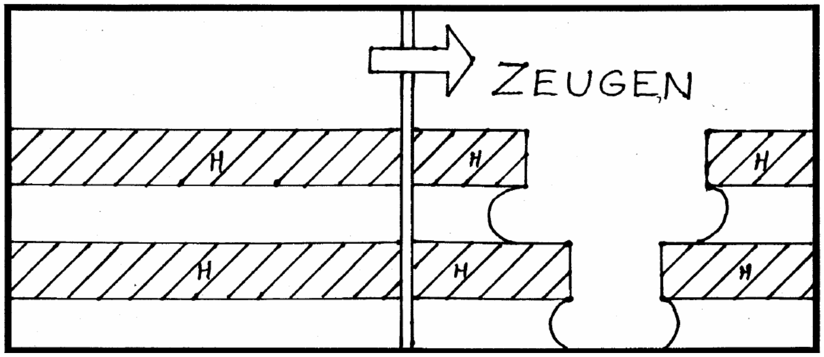


Fig. 11

6) Mesa & Buttes:

'Mesa' means 'table' in Spanish language. Hence the flat table like landform in the arid-semi-arid region is termed as Mesa. Hard and soft layers of rock are in the horizontal direction. Hard resistant rock protects under lying layers of rocks from being eroded away. Due to erosion of Mesa over a longer period of time it is converted in isolated flat topped hill, smaller than Mesa, is termed as Buttes. Generally deep gorges or canyons are found between them.

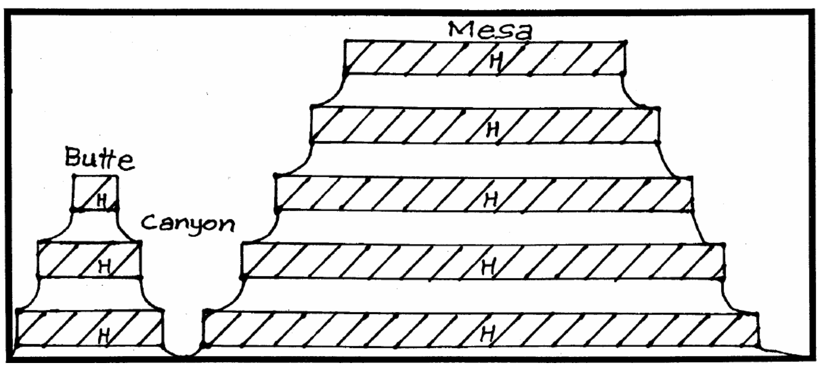


Fig. 12

7) Inselberg:

'Inselberg' is a German term used for individual isolated mountain or Island Mountain. Inselberg are composed of hard rocks like Granite or gneiss. It is assumed that these are probably the relics of an original plateau which is almost entirely eroded away. These are found in W. Australia, Kalahari Desert and N. Nigeria.

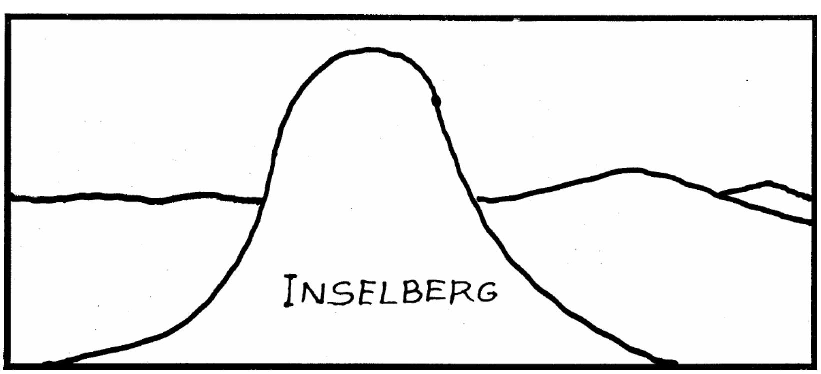


Fig. 13

8) Ventifacts:

The pebbles faceted by sand-blasting due to erosion by wind are termed as 'Ventifacts'. When the direction of wind changes another facet is developed. These facets are flat with sharp edges. Different names are given to rock having many facets.

a) Ventifacts: About 8 facets.
b) Dreikanter: 3 facets
c) Zweikanter: 2 facets

These wind - faceted pebbles develop desert pavement.

9) Demoiselles:

Earth pillars are found in the desert areas. These are pillars of earth or sand having pebble on the top.

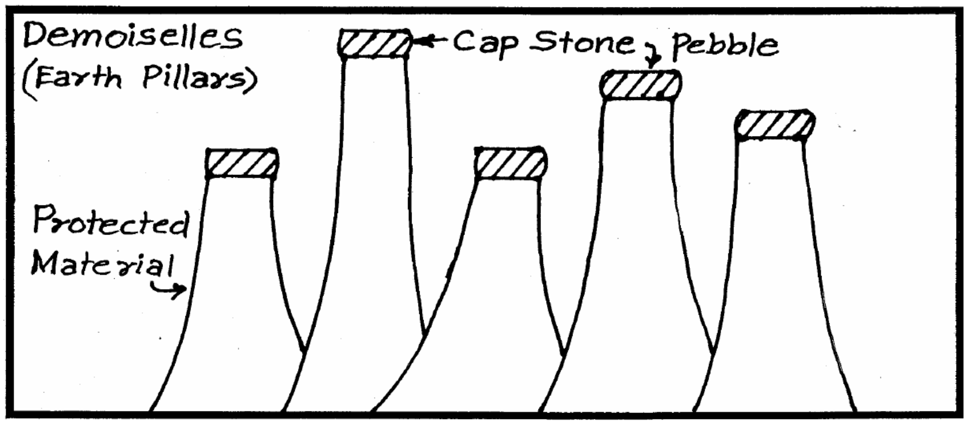


Fig. 14

Hence material below is protected by the pebble.

Earth pillars are known as Demoiselles.

10) Stone Lattice:

Rocks in the desert area may have different type of compositions. Hence the portion of rock which is weak is exposed more to the erosion by wind and so is eroded more as compared to more resistant portion of rock. Hence the surface of rock becomes uneven which is termed as stone Lattice.

11) Wind bridges and Windows:

Due to continuous erosion by the wind sometimes hole develops in the rock, from which we can look through. It is termed as wind windows.

When these wind windows are further enlarged much more due to erosion by the wind, this landform is termed as wind bridges.

12) Bowls & Caves:

Erosion by wind and chemical weathering are responsible for the formation of Bowls and caves.

Sandstone contains calcium carbonate, which is dissolved in carbonic acid formed by the combination of atmospheric carbon dioxide with water. It acts as binding cement for the sand particles of the sand stone. When it is dissolved, sand particles are separated & are carried away by wind.

The circular shaped depressions with symmetrical overhanging sides are termed as Bowls.

They are also known as animal traps.

Bowls are found in the deserts of Sudan, Egypt, Turkmenistan etc.

The process of formation of cave is similar. Large size caves are found in massive sandstones.

13) Desert Pavement:

Winds carry finer particles leaving behind larger pebbles. Hence this landform feature is termed as desert pavement.

With the extended exposure to the erosion by wind, these are more polished.

As desert pavement protects underlying sand particles, it obstructs the process of deflation by the wind.

AEOLIAN / WIND LANDFORMS OF DEPOSITION:

1) Dunes:

In the desert areas dunes of sand are formed due to deposition of the sand, carried away by the wind. They have interesting shapes and hence are known by different names. e.g. Star dune, sword dune, hairpin dune, pyramidal dune, parabolic dune etc. Study of dunes is very important for geomorphologists & Geologists. Dunes can be fixed or live. Fixed dunes are those which are not mobile, formed and fixed at a particular place by the growth of vegetation or different types of land uses on it. On the other hand live or active dunes constantly change their location and or shape according to their modifying factor wind.

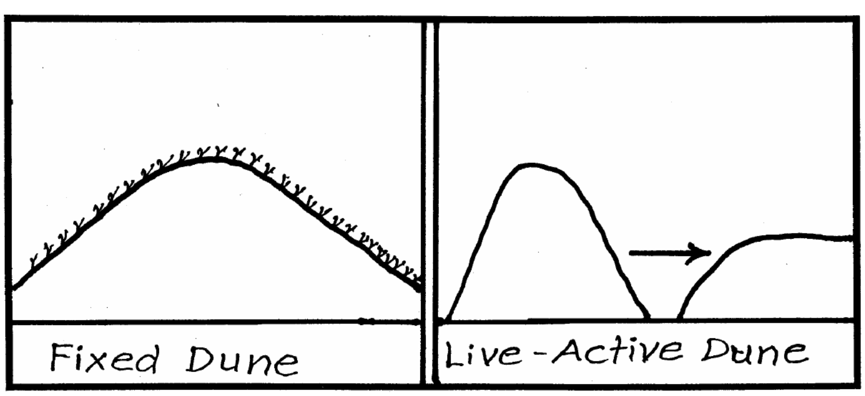


Fig. 15

Erg deserts are known as sea of sand and hence various types of live or active dunes are found here.

2) Barchan:

It is a crescent or curved moon shaped sand dune. These are also known as Barchans or Transverse dunes. The height of these dunes varies from one m. to about 50 m.

When there is any type of obstruction in the form of a heap of rock or a patch of vegetation / grass, sand carried by the wind is obstructed and deposited. Hence the obstacle is covered by the sand. As these process continues for a longer period of time, ultimately Barchan develops.

The windward side of Barchan is convex and has gentle slope, on the other hand the leeward side is steep and concave.

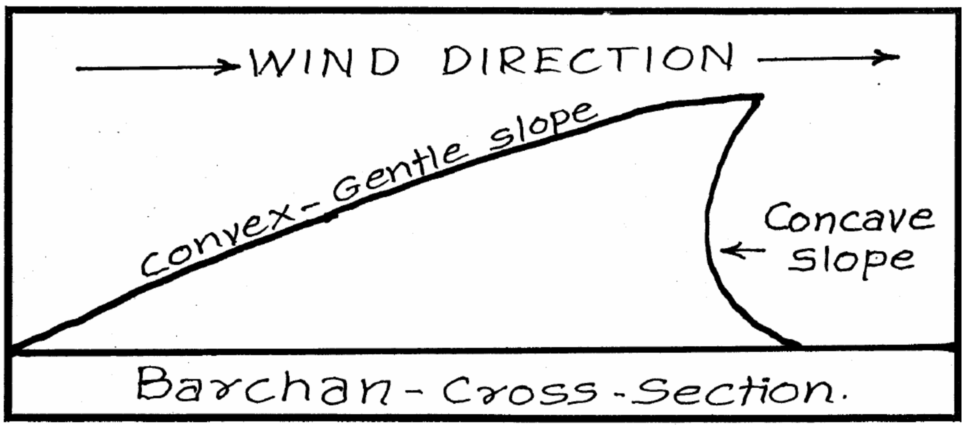


Fig. 16

The two horns give crescent shape to this dune. These horns thin out and become lower in the direction of wind.

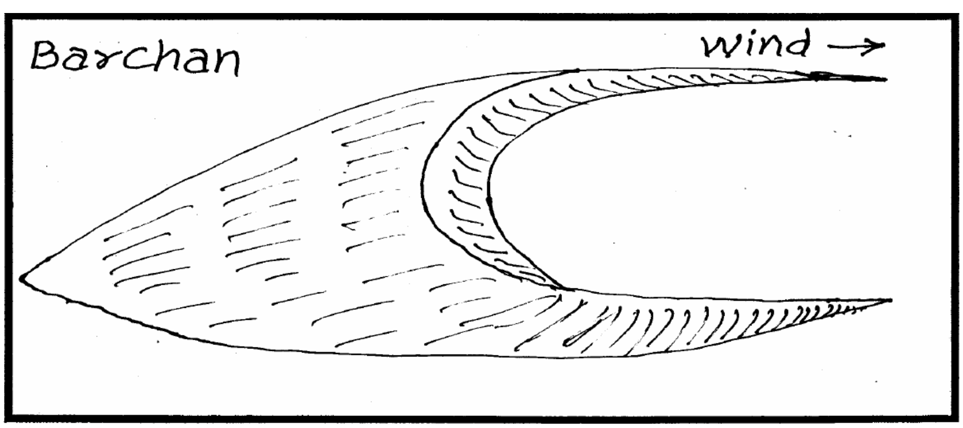


Fig. 17

As there is continuous accumulation of sand near crest, brought by the wind, the excess sand slips down to leeward side. Hence in the due course of time sand dune move forward. The rate of advancement may vary from 8 to 30 m per year. These shifting dunes may encroach on an

Oasis burying houses & vegetation in that area. So grass and different types of trees are planted to stop the advancement of sand dunes and their encroachment on fertile land.

Erg or sandy deserts are very difficult to cross due to these shifting sand dunes.

2) Seifs or Longitudinal Dunes:

These are long narrow ridges of sand often extend over hundred kilometers, parallel to each other in the direction of wind. Height is about 50 - 60 meter.

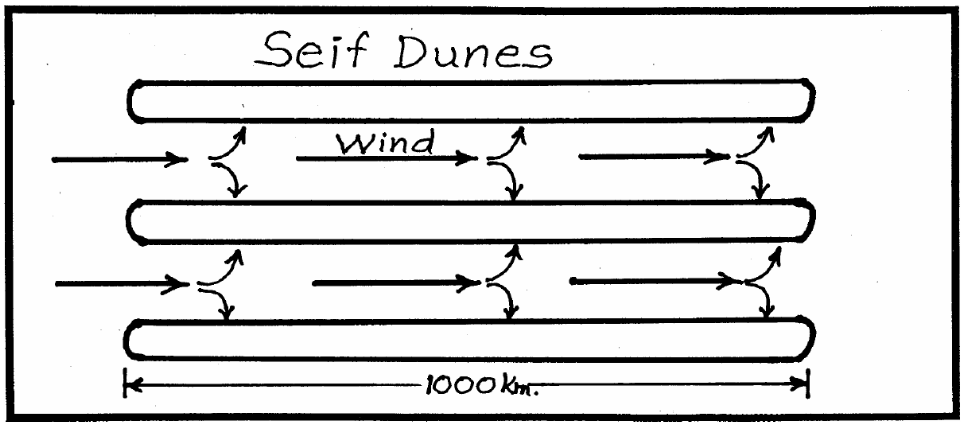


Fig. 18

Strong winds blowing parallel to these dunes help to keep passage clear. Weak eddies are developed & they help to spread sand brought by the wind to the dunes.

So the prevailing wind helps to increase length of the seif dune. Cross wind help to increase height & width of these dunes.

These are mostly found in Sahara, Thar, Qattara Deserts and Australian desert.

'Seif' in Arabic is Sword, which is used to describe these long knife edged ridges of sand-seif dunes.

4) Ripple Marks:

These are very small scale depositional features of sand found in the desert. These are like ripple marks formed on beach sand by sea waves. These ripple marks can be transverse or longitudinal w.r.t. direction of wind.

5) Star dunes:

These are huge star shaped or pyramidal shaped sand dunes with three or more arms extending outwards to form star shape.

These arms develop due to changing wind directions & deposition of sand in those directions.

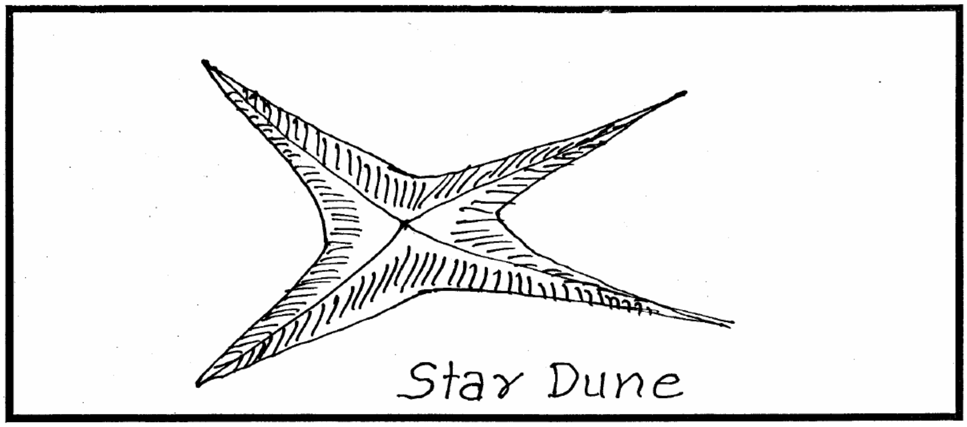


Fig. 19

6) Reversing dunes:

These are asymmetrical ridges of sand found between transverse dune and star dunes. Shape of these dunes changes according to the direction of wind.

7) Whaleback dunes:

These are found in Egypt. These are huge flat topped sand ridges having length of about 150 kms, width 3 to 4 kms. & height is about 50 m. These extend in the direction of existing wind.

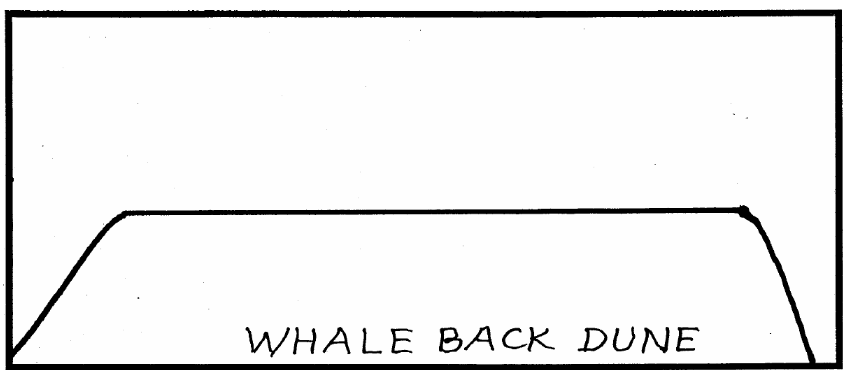


Fig. 20

8) Loess:

The wind - blown deposit of fine dust and silt is termed as Loess. Loess is generally yellowish in colour. Weathered material in hot deserts is one of the major sources of Loess. It may consist of particles of Calcite, Quartz, and Feldspar etc.

Loess is transported over a longer distance, away from its source by the wind.

Outwash region of glacier has very fine powder as deposit, which is transported by the wind as Loess.

Loess are found in China, N. European plains & Asia. Yellow colour of Hwang H_0 and Hwang Hai is due to the deposition of loess.

AEOLIAN -WIND:

LANDFORMS RELATED TO ACTION OF WATER IN DESERT:

1) Dry Delta - Alluvial cone or Alluvial fan:

Alluvial cone and alluvial fans are formed at the foot hill regions, due change in slope steep to gentle & so the material carried by flash flood is deposited. As the region is arid, flash flood occur rarely. Water is quickly evaporated or percolated down & so alluvial fans & cones in the desert area are termed as Dry Delta.

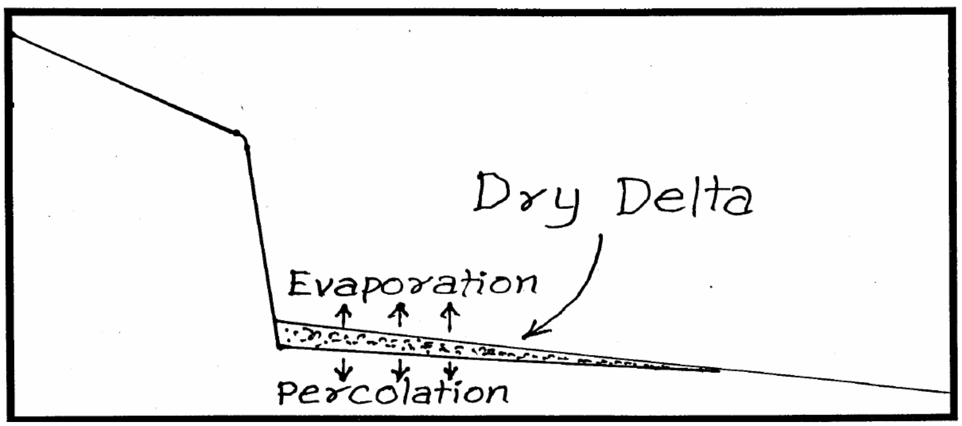


Fig. 21

2) Wadis:

These are the dry channels or valleys of streams of water. They have water occasionally at the time of cloud bursts.

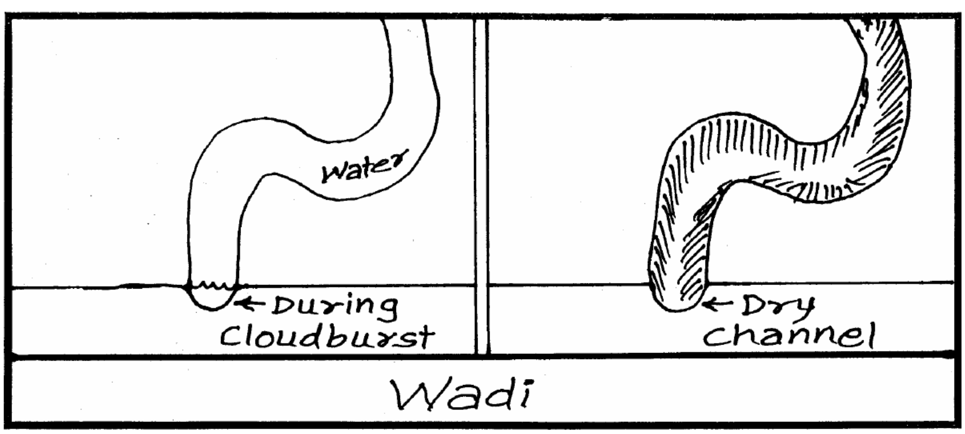


Fig. 22

3) Exotic Streams:

These are streams in the desert which get their supply of water from melting of snow from distant mountains.

4) Chebka:

Gorges with steep walls, in the desert areas are termed as chebka in Algeria.

5) Temporary lakes:

If the water collected in depressions is not totally evaporated, it forms lake. These are known as Temporary lakes. These lakes are called playas, Salinas or Salars due to higher percentage of salts in it.

6) Bajada:

Intermittent streams deposit alluvium, which is termed as 'Bajada'. It is a depositional plain.

7) Pediment:

An erosional plain formed at the base of surrounding steep slopes of the mountains is termed as Pediment.

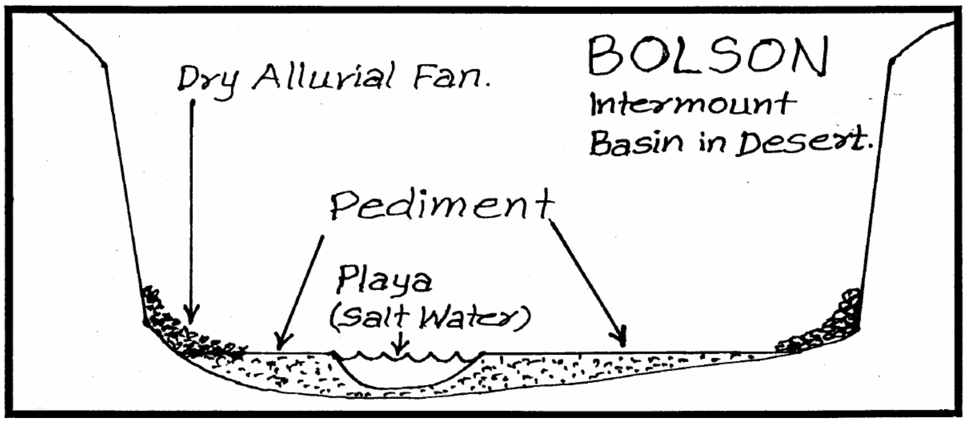


Fig. 23

8) Bolson:

An intermontane basin in the desert consists of Playas, Bajadas and Pediments.

9) Badland:

These are mostly formed in the semi-arid areas, where entire landscape is dissected by ravines, gullies and sharp - edged ridge. e.g. Chambal ravines (M.P.).

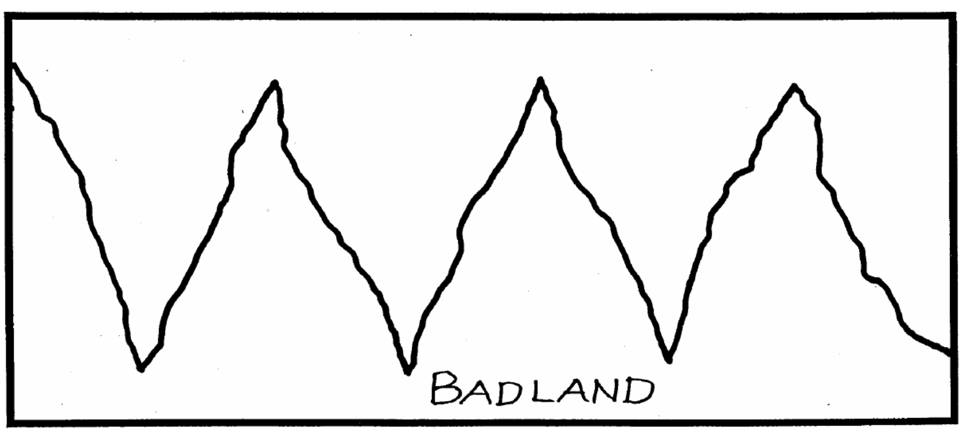


Fig. 24

Due to extreme erosion this land becomes useless for any type of land-use & hence it is termed as 'Badland'.

3.5 COASTAL GEOMORPHIC PROCESSES AND LANDFORMS

COASTAL GEOMORPHIC PROCESSES:

1) Corrosion:

Coarse sand, pebbles sharp fragments of weathered rock act as tools of erosion. Necessary force required for erosion by these tools is provided by the sea waves. Corrosion or Abrasion is an important coastal geomorphic process. Waves with the tools of erosion attack on coastal area, cliffs etc. & erode them. Ocean currents & tides help to remove eroded material.

2) Attrition:

In this processes pieces of rocks collide together & break or tools of erosion - pebbles - attack on other landform like cliff. Either pebble is broken or it breaks small portion of cliff.

3) Hydraulic Action:

It is the action of water on the rock, which helps in the process of erosion.

When wave attacks coast with great force / pressure, water enter into the cracks & joints of the rocks. Air which is inside joints & cracks is compressed and exerts pressure on the sides of rock. When wave retreats, the compressed air expands with explosion continuous repetition of this process is responsible for enlarging and weakening joints & cracks. Ultimately block of rock is removed from the parent rock. (The average pressure of normal wave on the coast is about 3000 kg. per sq.m. During storms it is about 30,000 kg per sq.m. Hence we find more destruction of coastal areas during storms).

4) Solution or Corrosion:

Atmospheric CO_2 is dissolved in sea water to convert it into Carbonic acid. Such waves are responsible to dissolve limestone or calcium Carbonate. Hence the limestone coasts are eroded more by this process.

COASTAL GEOMORPHIC LANDFORMS OF EROSION:

1) Head land and Bay:

If the coastal rocks are hard and soft, the softer rocks (sand & clay are eroded more than the hard rocks (Granite). Hence inlets, bays or coves develop at the soft rock formation.

Hard rock formations are not eroded much and hence such rock formation remain projected into sea as Headland, Cape or promontory.

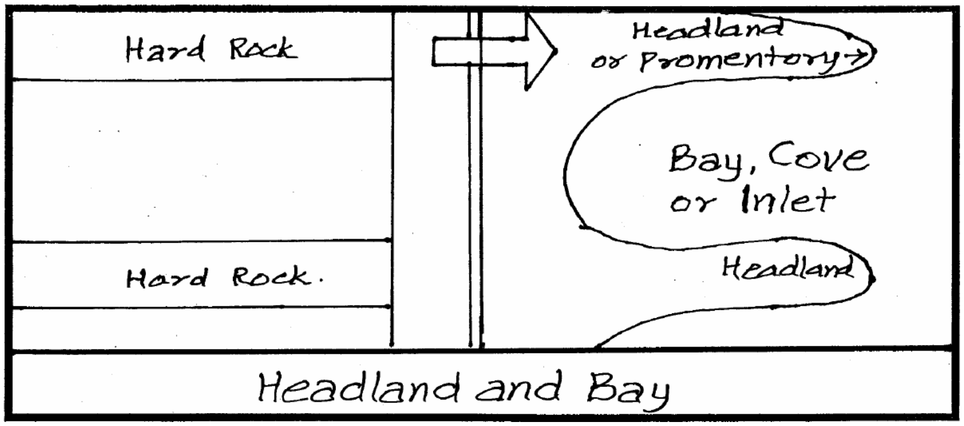


Fig. 1

2) Sea Cave:

Waves with great force and tools of erosion attack base of cliff or headland. Weal portion of the rock is eroded more and weathered material is removed by the wave. Small depression develops at that place. More erosion & enlargement of this area leads to the development of caves.

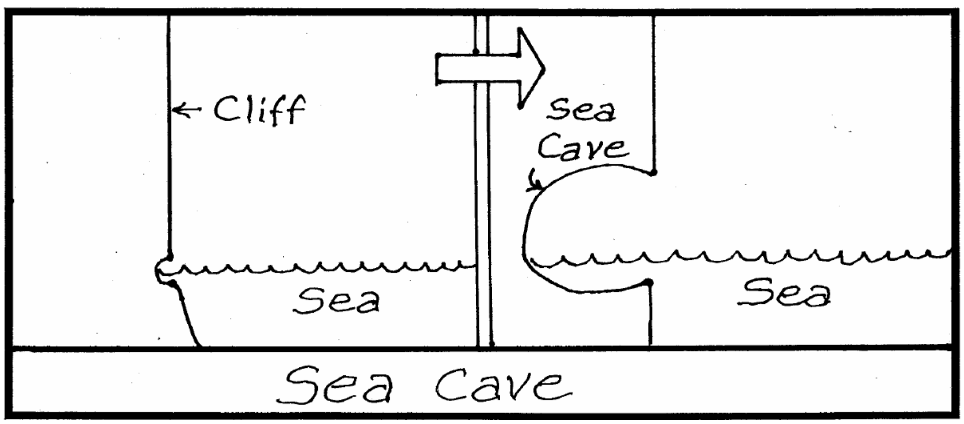


Fig. 2

3) Sea Arch:

Sea caves developed on either side of headland merge together due to excessive erosion. Hence Sea Arch is formed.

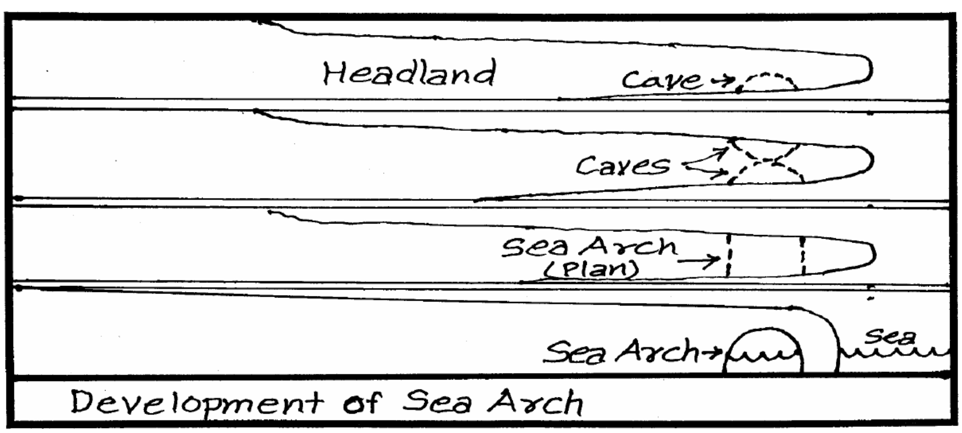


Fig. 3

4) Sea Stack:

When roof of a Sea Arch gets collapsed due to wave erosion then seaward portion of a headland is separated from the main headland. This isolated portion of rock which is above sea level is termed as Sea Stack.

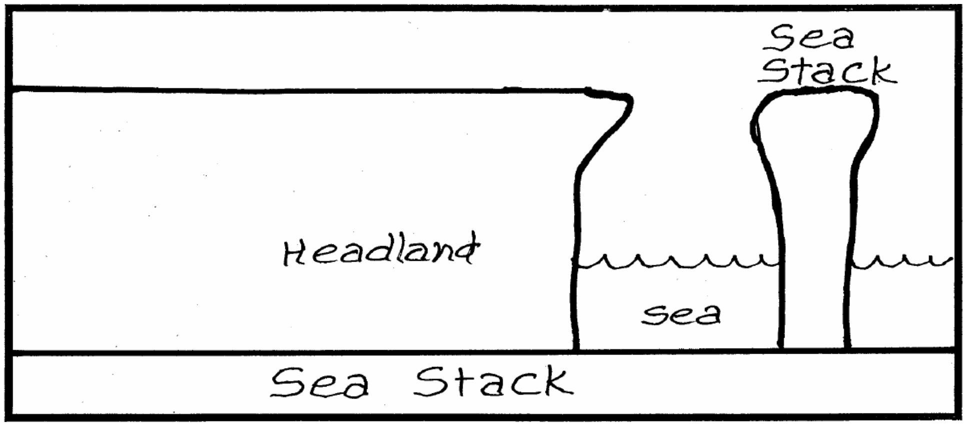


Fig. 4

5) Sea Stump:

When sea stack is reduced in height due to erosion, it is known as Sea Stump. It is just at the sea level.

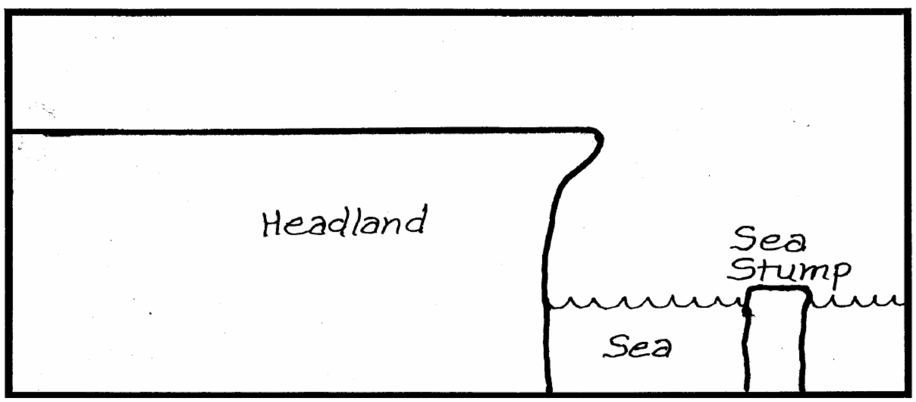


Fig. 5

6) Sea Cliff:

Very steep rock face near to coast forms Sea Cliff.

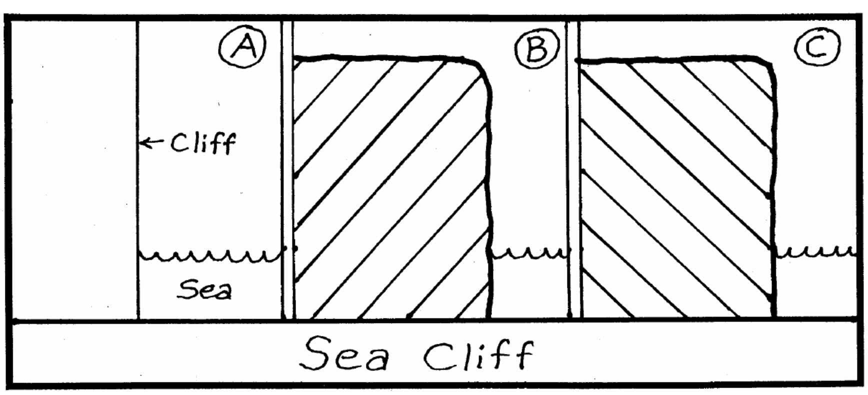


Fig. 6

The sea cliff is eroded by the action of sea waves. The rate of erosion depends on the composition of rock geological structure, joints and their orientation. e.g. in the adjoining diagram orientation of joints is towards land in (B) & hence erosion will be slower but in (C) orientation of joints is towards sea & so it will be eroded at faster rate.

7) Sea Notch:

Small elongated notch is developed at the base of cliff, at the sea level by erosion. it is termed as 'Sea Notch'.

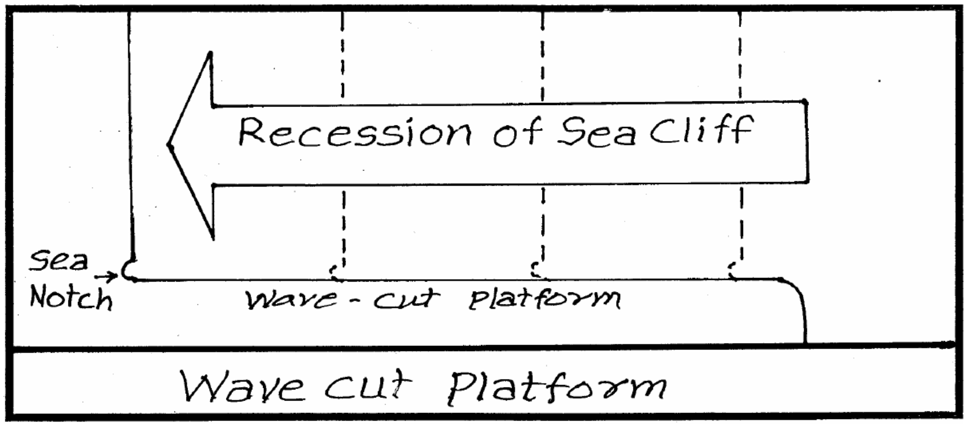


Fig. 7

8) Wave Cut Platform:

Due to the recession of Sea cliff by erosion, flat platform of rock is formed at sea level, which is exposed at the time of low tide is termed as wave-cut platform.

9) Gloup:

It is a curved hole / shaft formed inside cave. The other end of it opens at the surface of rock. It is known as Gloup. It develops due to erosion by sea waves. When wave strikes against the cave, sea water enters into 'Gloup' and comes out through hole at the surface of the rock. It is termed as blow hole.

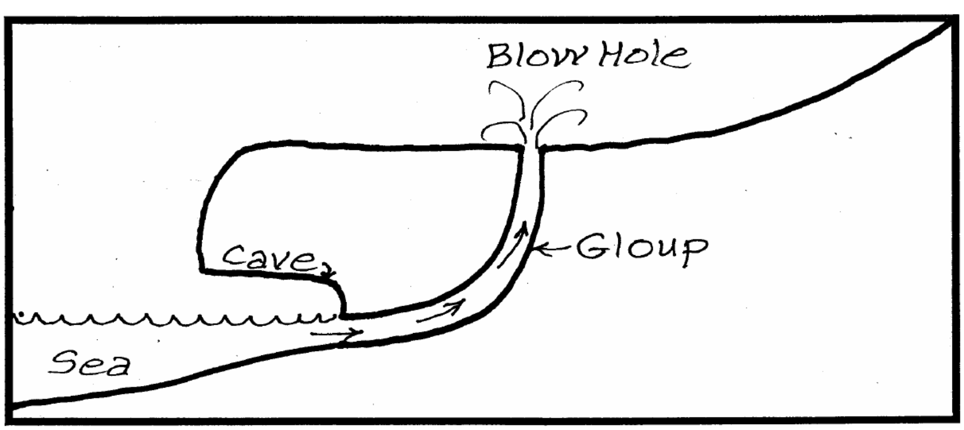


Fig. 8

10) Geo:

Excessive erosion of Gloup and collapse of roof of the cave leads to the development of landform - termed as 'Geo'. It is long narrow inlet (about 30 m.)

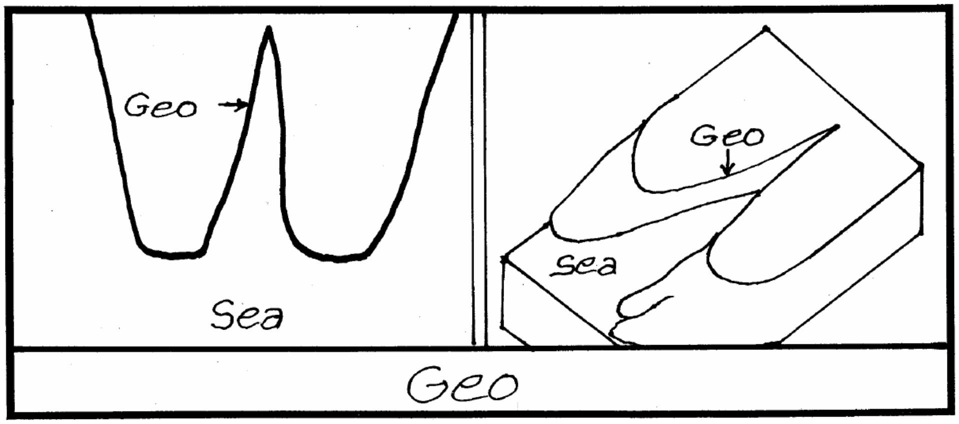


Fig. 9

TRANSPORTATION BY SEA WAVES:

Long shore drift:

As the name indicates sand and weathered material is shifted along the shore by the waves.

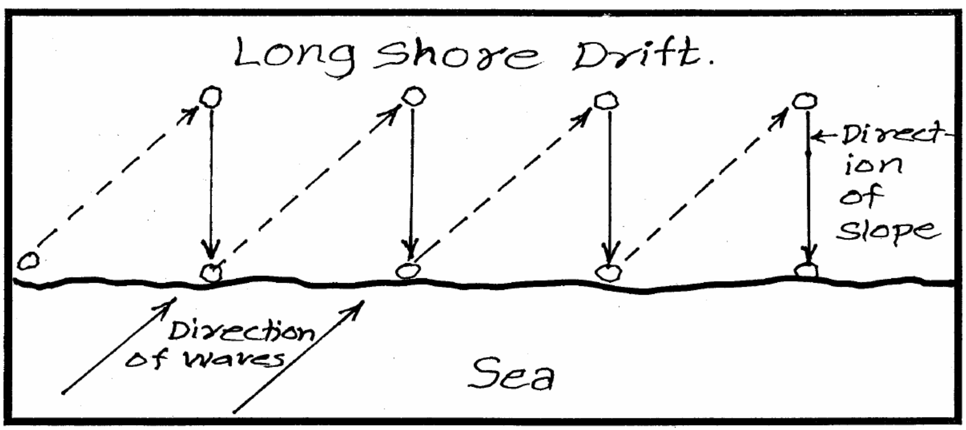


Fig. 10

If the wave approaching to sea shore is in oblique direction, it drifts weathered material in the same oblique direction with it (swash). At the time of backwash the sea water in the wave returns to the sea in the direction of slope. This is a continuous process & so material is drifted from one place to another along the shore. Hence it is known as the 'Long Shore Drift'.

COASTAL GEOMORPHIC LANDFORMS OF DEPOSITION:

1) Beach:

Sea waves attack land and erode rock converting them into gravel & sand. These are deposited along the shore to form beach. Coarser material like boulders is deposited on the upper side of the beach and finer material like sand & gavel is deposited near sea, by the backwash of the waves. Beach is formed along the shore between the levels of high and low tides. Storm beach is formed during storm and it is situated above the level of high spring tide. It is a temporary beach.

Beaches are classified as

a) Boulder beach - (7100 mm in diameter)
b) Shingle beach - (2 - 100 mm in diameter)
c) Sand beach - (0.5 - 2 mm in diameter)

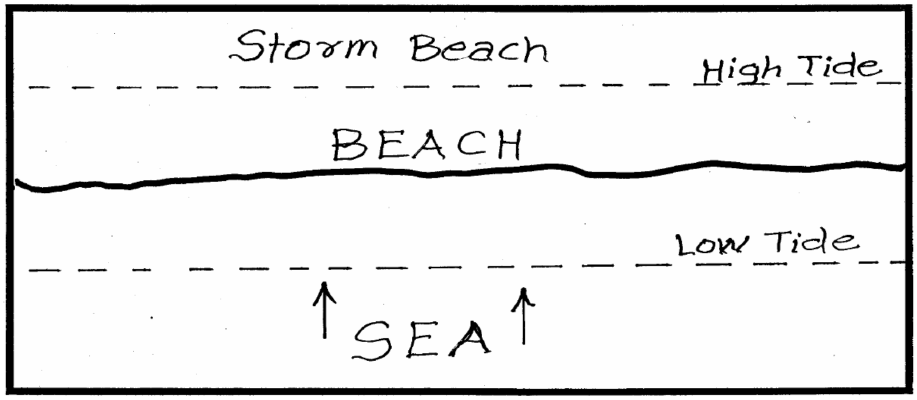


Fig. 11

2) Bay mouth Bar:

If the deposition of sediments brought by the sea waves, in the form of long ridge or embankment, is at the open and of bay, it is termed as Bay Mouth Bar.

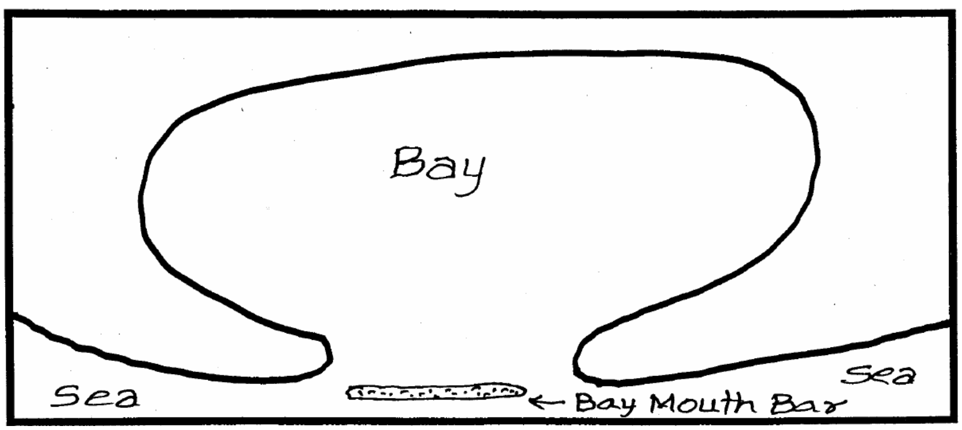


Fig. 12

3) River mouth bar:

An elongated embankment or ridge of sediments brought by the sea waves in front of the mouth of the river is termed as river mouth bar.

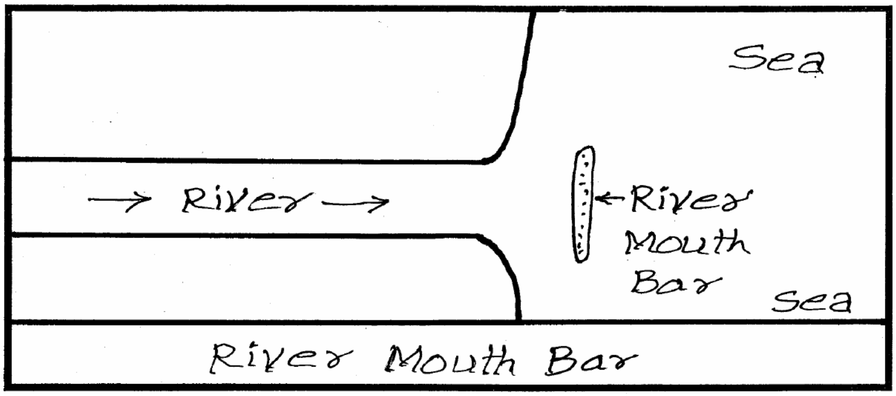


Fig. 13

4) Offshore bar:

An elongated deposition of sediments brought by sea waves in front of shore / coast is termed as offshore bar, which is located at some distance from the shore in the sea.

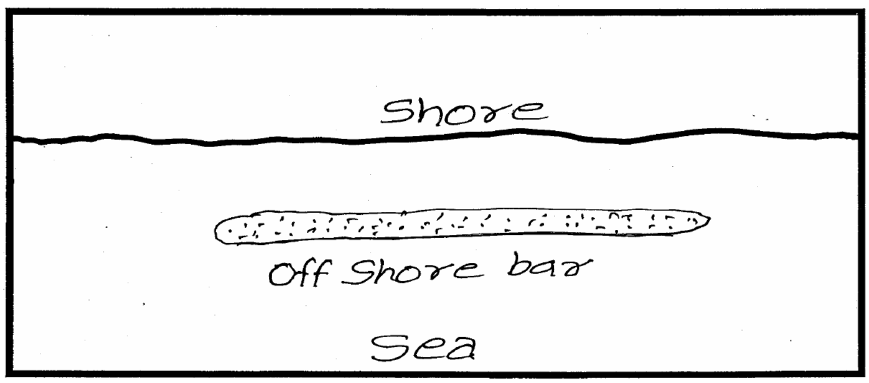


Fig. 14

These are also known as long-shore bar.

5) Tombolo:

It is a deposition of sand or material deposited by the sea waves in the form of sand bar connecting island with the mainland.

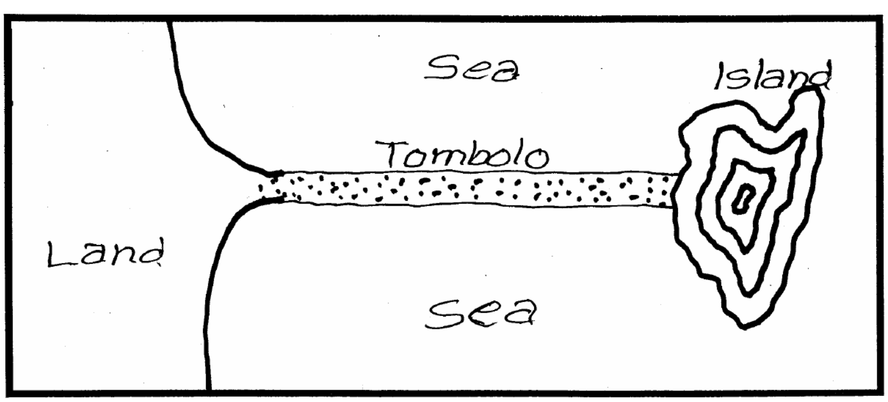


Fig. 15

6) Spit:

It is a sand bar formed by the deposition of sand & gravel by the sea waves. This bar which is attached to the mainland is termed as 'Spit'. It extends towards sea.

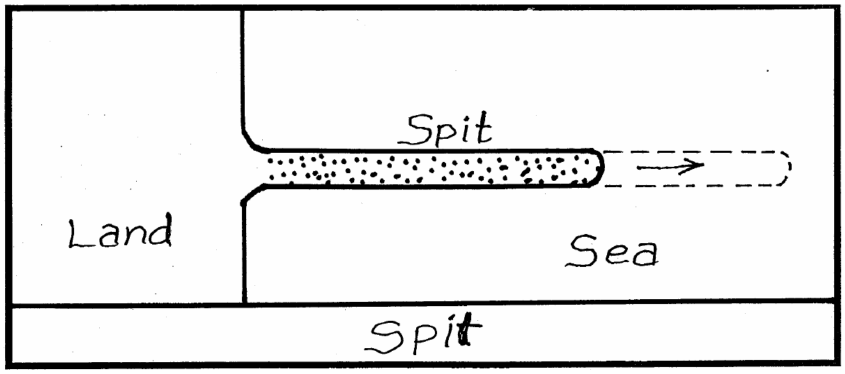


Fig. 16

e.g. 1) Spit at the mouth of Chilka Lake is about 50 km. long.
2) Spit at Rameshwaram projects into the sea from the coast of Tamil Nadu.

7) Curved spit or Hook:

During storms the high energy strong sea waves modify shape of spits by bending them towards the coast. Hence the straight spit becomes curved. It is also termed as Hooked Spit or Hook.

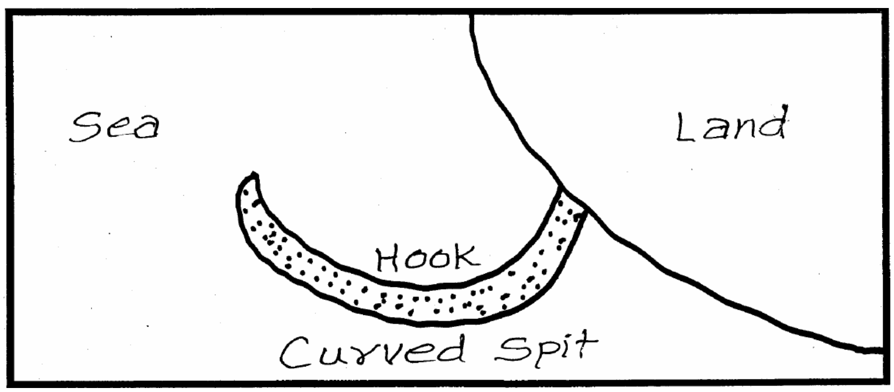


Fig. 17

8) Recurved spit:

Curved spit having more number of hooks is termed as Recurved spit or Compound hook.

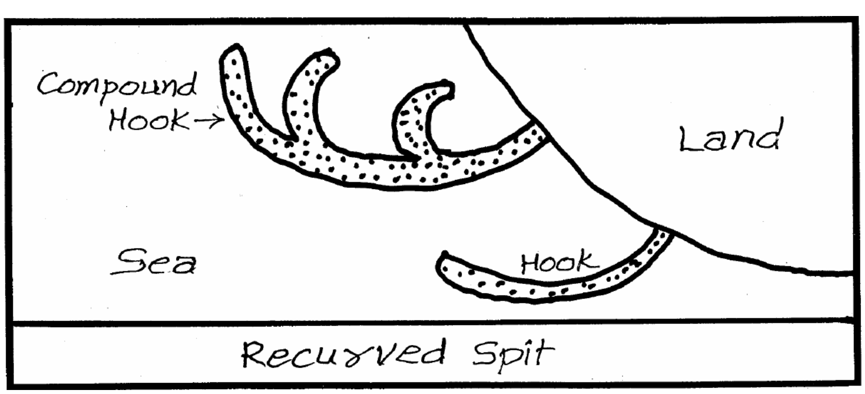


Fig. 18

9) Loop:

'Loop' is a deposition in the form of curved spit whose curved end comes closer to land enclosing part of sea within.

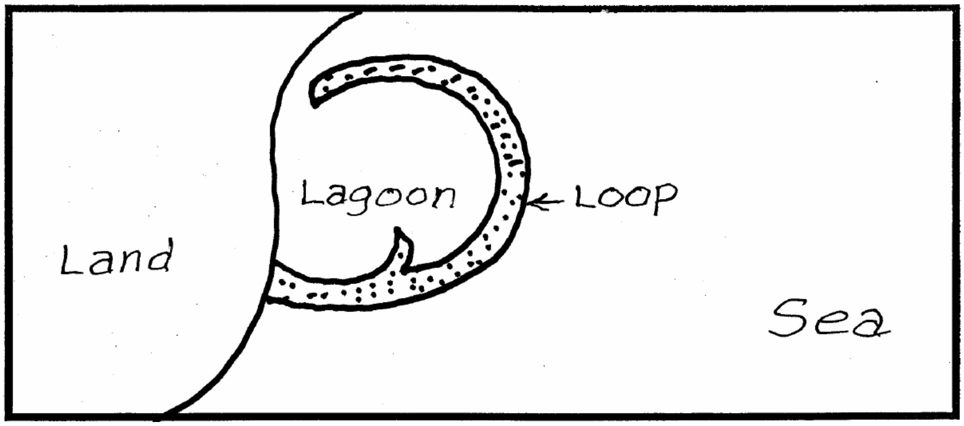


Fig. 19

10) Lagoon:

These are formed when the bays or part of sea water is completely enclosed by the sand bars. e.g. Chilka and Pulicat lakes in India.

Along the Baltic coast of Germany long sand bars called Nehrungs completely enclose large part of sea to form lagoons which are termed as Haffs.

11) Mud flats:

Fine silt is deposited by sea waves during tides in bays & estuaries. Alluvium brought by the river is added to this deposition, which forms a platform of mud called as Mud flats. Such mud flats are converted into mangrove swamps after the growth of coastal vegetation.

12) Barrier islands:

These are long offshore islands developed due to deposition of material brought by the river. These are separated by the mainland by Lagoon.

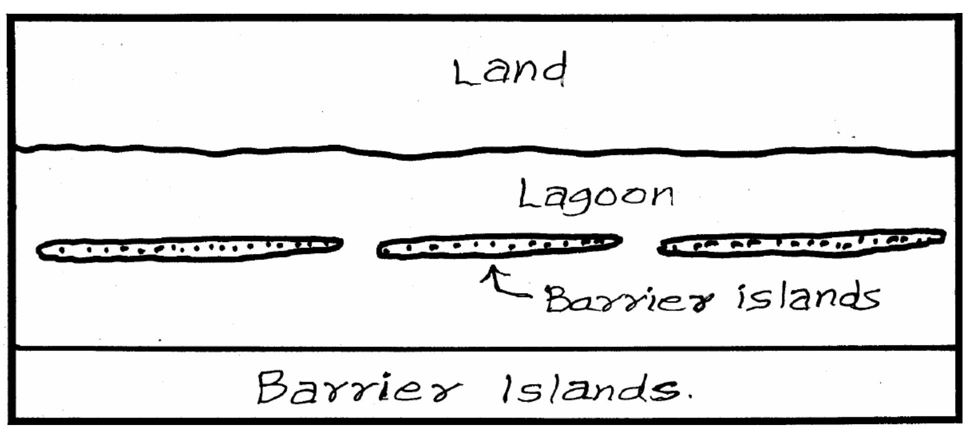


Fig. 20

13) Coastal wetlands:

These are marshy flat lands developed in coastal areas of humid tropics. Mangrooves growth is very extensive in this area. e.g. Sundarbans in West Bengal.

14) Sabkha:

These are the deposits in coastal area of dry tropical zones. These are flat but barren. These are also known as salt flats. These are found in Egypt, UAE and Mexico.

TYPES OF COAST:

Coasts can be classified in different ways.

A) Classification by W.K. Hamblin :

1) Primary Coasts:

These are the coasts developed by non-marine processes of erosion & deposition. e.g. Glacier or river.

2) Secondary Coasts:

These are produced by the sea waves i.e. marine erosion & deposition.

B) Davis (1902) divided coasts into

1) Emergent coast &
2) Submergent coast

1) COASTLINES OF EMERGENCE:

a) Uplifted lowland coast:

This coast is smooth, with gentle slope & it develops due to the upliftment of the continental shelf. Lagoons mud flats & salt marshes are found on these coasts. e.g. W. Finland, E. Sweden S.E. USA.

b) Emergent upland coast:

The entire coastal region is raised upward due to faulting and earth movements. A raised beach is found along this coast. e.g. Western Coast of Maharashtra. W.Arabian Coast.

2) SUBMERGENT COASTS:

Coastlines of Submergence.

1) Ria coast:

After the ice age large amount of water was added to sea due to melting of snow.

In an upland area where mountain ranges are perpendicular to sea (transverse or discordant) the lower parts of the valleys is submerged. Hence long narrow inlets are formed which are separated by narrow headlands.

These are very useful as ports. e.g. Coasts of S.W. Spain, N.W. France fishing ports & naval base at Plymouth are examples of Ria type of coast.

2) Dalmation Coast:

In this type of coast mountain ranges are parallel to the coast. As this type of formation was found at Dalmatia in Yugoslavia it is termed as Dalmatian coast. There is a chain of islands parallel to the coast - i.e. top portion of submerged hill ranges, with narrow inlets e.g. west coast of North & South America.

3) Fiord Coast:

These are confined to the higher latitudes of temperate region where glaciers join sea. Fiords are submerged ‘U’ shaped glacial trough. They have straight vertical, steep walls. e.g. Norway, Alaska, S. Chile.

❖❖❖❖

4

AIR MASSES, FRONT AND CYCLONE

After going through this chapter you will be able to understand the following features:

Unit Structure:

4.1 Objectives
4.2 Introduction
4.3 Landscape Evolution
4.4 Factors Controlling Landform Development
4.5 Cycle of Landform Evolution
4.6 Davisian Theory of Erosion Cycle
4.7 Penck's Morphological System
4.8 Slope
4.9 Type of slopes
4.10 Factors Influencing Slope Origin and Development
4.11 Models and Theories of Slope Development
4.12 Slope Decline theory by Davis (1899)
4.13 Penck's Theory of Slope Replacement (1924)
4.14 Hill Slope Cycle Theory By L C King (1948)
4.15 Wood's Theory of Slope Evolution
4.16 Nine Unit Model
4.17 Slope and Human Activities
4.18 Some geomorphic processes intensely related to slope
4.19 Summary
4.20 Check your Progress / Exercise
4.21 Answers to the Self-learning Questions
4.22 Technical words and their meaning
4.23 Task
4.24 References for further study

4.1. OBJECTIVES

After this unit, students will be able to

- Define and locate different types of landforms and landscapes on earth surface.
- Explain the factors and processes of landscape evolution.
- Critically evaluate the theories of landscape evolution.
- Describe the concept of slope, development process and factors.

- Examine the theories of slope development.
- Recognize the relation of slope with human activities and geomorphic processes.

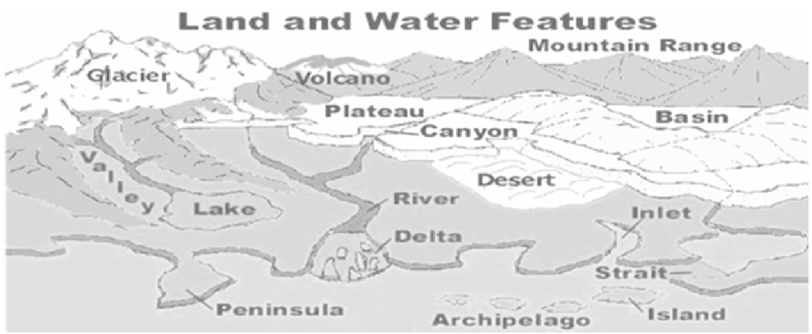
4.2 INTRODUCTION

Earth is a planet where surface of lithosphere occupied by land and oceans as a primary features. Landform evolution is an important process of earth and atmospheric sciences and involves dynamic interaction among and between different physical processes and environmental factors such as underlying rock structures, tectonics movements, climatic factors and climatic changes as well as human activities. The agents of erosion and the tectonic forces are responsible for the development of secondary and tertiary landforms on the surface of earth. The tectonic forces are relatively uniform than the dynamic erosional agents. Thus, it is the erosional and depositional agents are mainly responsible for the dynamic nature of landforms on the earth. A landform is a feature on the Earth's surface that is part of the terrain. Mountains, hills, plateaus, and plains are the four major types of landforms. Minor landforms include buttes, canyons, valleys, and basins. The slope or gradient describes both the direction and the steepness. Slope is calculated by finding the ratio of the "vertical change" to the "horizontal change" between two distinct areas on the earth surface. A slope is the rise or fall of the land surface. A slope is easy to identify in mountainous area. Evolution of landforms are depend on the denudation chronology. The surface landforms determined by the slope. Development of land form and slope is happen simultaneously due to weathering, erosion and deposition which is caused by different agents operated forces on the earth surface. Earth surface is dynamic in terms of landform formation and distribution along with changes over a period of time.

4.3 LANDSCAPE EVOLUTION

Typical structures which are small to medium tracts or parcels of the earth’s surface are called landforms. Several related group of landforms together creates landscapes. For example Many hills together forms a mountain ranges like Himalayan Mountain is a togetherness of upper, middle and lower Himalayan ranges. Each landform has its precise physical shape, size and materials as a result of the action of certain geomorphic processes by different agent over a geological period of time. Every landform has a beginning, maturity and decline. Landforms once formed may change in their shape, size and nature slowly or at a greater speed due to continue actions and reactions of geomorphic processes such as due to changes in climatic conditions, vertical or horizontal movements of landmasses and the intensity of processes change leading to modifications in the present landforms and initiation of new landforms.

Evolution of landforms and landscapes implies stages of transformation of either a part on the earth’s surface from one type of landform into another or many landforms. That means, each and every landform has a history of development and changes through geologic time. A landmass passes through stages of development somewhat comparable to the stages of life that is youth, maturity and old age. For example the distinct landforms formed by action of river water at upper, middle and lower course. Landscapes are created by Exogenic and Endogenic processes. A landscape is the visible landforms on the earth surface integrated with man-made features. The physical processes and laws that are operating today had operated throughout geological time with different intensity and affected landform development. Hutton first postulated the ‘principle of uniformitarianism’ in 1785. It was again followed by Playfair in 1802 and exposed latter by Lyell. Hutton gave the concept of ‘present is the key to the past’. Geologic structure is a dominant factor in the evolution of landform.



Source : https://sites.google.com/a/uni.edu/the-landforms-of-the-united-states-geography-webquest/task

According to W M Davis major controlling factors in the development of landforms are structure, process and stage. The term structure is applicable as a rock characteristic both physical as well as chemical and folds, faults and the landform carved and differ in their physical and chemical attributes. The large degree of the earth’s surface possesses relief features due to the differences of processes involved in landform evolution. The main reason is that the rocks are very in their lithology and structure, which cause different degree of resistance. In addition, altitude, moisture, temperature, topography, slope, vegetation cover etc. are also affect the landform evolution. Geomorphic process leave its footprint on landforms and each process develop unique landforms. These forces are Endogenic and Exogenic in nature and develops assemblage of landforms for examples – flood plain, meanders, deltas are formed due to the depositional work of fluvial work by the streams. As the different erosional agents work upon the earth surface there is formation of landforms in sequence. Davis explained it in three stages that is youth, maturity and old in the series of landform development by the river work. Now a day it is proved that there might not followed staged of normal cycle of erosion and landform development. Complexity of landform evolution is more common than simplicity. It is very difficult to find the landforms originated by a single geomorphic process and thus

Horberg in 1952 categorized landforms in five categories (simple, compound, monocyclic, multicyclic and resurrected). Earth's topography is older than tertiary and not generally older than Pleistocene. Historical approach also applied to understand the present day topography and landforms.

4.4 FACTORS CONTROLLING LANDFORM DEVELOPMENT

The following are the controlling factors of landform development-

- Rock structure and composition
- Terrain structures and Slope
- Geological structures
- Climatic agents
- Endogenic forces
- Exogenetic agents
- Biological activities
- Human activities

Rock structure and composition: Landforms development depends the size and shape of rocks and composition such as texture, hardness or softness, chemical composition etc. that is rock may be made of grains or fine particles. Some rocks are hard such as Quartz which are resistant to erosion and weathering process for prolonged time. Some rocks are soft such as limestone which are low in resistance against weathering and erosion. As a result it leads to fast depletion of original landforms and form a new landform progressively.

Terrain structures and Slope: Relief is the difference between the highest and lowest elevation of an area. The steep slope support for mass wasting at greater speed compare to plains. Steep relief is prone to erosion such as vertical erosion by river water at bed is very high. Landform development is faster in the Himalayan region than in the Ganges plains. Steep relief means more gravitation force which leads to the mass movement of materials such as creep and landslides.

Geological Structures: Particular rocks are resistant to one and non-resistant to other weathering agents which result the different rates weathering, erosion and deposition that give the rise to different landforms. The geomorphic processes are all those physical and chemical changes which effect a modification of the earth's surficial form.

Climatic factors: Temperature, rainfall, humidity, air pressure and winds are the important factors of climate which involves in landform development. High humidity enhances the process the chemical and biological weathering. High and heavy rainfall and greater winds speed enhance erosional activities in High Mountain and desert areas respectively. High diurnal range temperature variation leads rock to expands and contract and result in to rocks to disintegrate. The process and intensity of landform development vary in the different climatic regions and also vary within the similar climatic region due to variations in the climatic factors.

Exogenic forces: A geomorphic agent or agency is any natural medium which is capable of securing and transporting materials existing on earth's surface. For example-Running water both concentrated and interconnected run off, ground water, glaciers, wind and movements within bodies of standing waters including waves, current tides, tsunami are some of the geomorphic agencies. Most of the geomorphic agencies originate within the earth's atmosphere and are directed by the force of gravity. Gravity is not a geomorphic agent because it cannot secure and carry away materials. All the agencies mentioned above originate outside the earth's crust and for that reason have been termed exogenetic by Penck. The earth's surface continues affects by external forces. From time to time external forces cause weathering, erosion and mass movement changes the structure of landforms and change it to other types of landforms. Due to the external forces by different agents mountains changes to hills and at last it converted to plateaus and plains.

Endogenic forces: Some geomorphic processes originate within the earth's crust and are thus designated as endogenetic. In this category we can keep vulcanism and diastrophism which are responsible for the formation of secondary landforms on the earth surface such as mountains, plateaus, valleys etc.

Biological and Human Activities: The presence of forest increases the process of chemical weathering as they release the acid and humidity to rocks at the same time roots of trees breaks the rocks in to particles. In opposition to it trees slow down the action of temperature and rainfall on the rocks. Thus the absence of vegetation increases the erosion process which leads to the fast depletion of elevated landforms or flattening the upper part the landform. Human activities like agriculture, dam construction, roads and rail building, brick making, urban expansion etc. affect the landform development. Pollution of land, water and air does have direct or indirect impact on landform development.

4.5 CYCLE OF LANDFORM EVOLUTION

The concept of cycle was first postulated in 1785 by Scottish Geologist James Hutton. He propounded the concept of 'Cyclic Nature of Earth History'. Later the concept of 'cyclic nature of earth history' was transformed into concept of 'uniformitarianism'. Davis presented his concept of ‘Cycle of Erosion’ which was concerned with evolution of landforms in humid temperate areas, but later it was applied to all geomorphic processes like arid cycle, marine cycle, glacial cycle etc. Penck accepted the basic concept of cycle of erosion but rejected Davisian model of geomorphic cycle and postulated his own cycle of erosion.

Crickmay also suggested modifications in Davis' model. Later on Strahler rejected the concept of time dependent theories of development of landforms and presented their own time independent theories of development of landforms. Many other models were developed in later years which were modifications of Davis model.

The task of endogenetic forces is to create irregularities on the surface of the Earth by volcanism, mountain building etc. As soon as these end forms are exposed on the surface, the various processes of weathering start working on them. In due course of time, the weathered products are transported by various agents and get deposited in other areas cause modification of surface landforms. The process of erosion goes on and the final result is the lowering of the elevation of the exposed surface up to the sea level or base level. Erosion cannot occur beyond the base level. This obviously takes long time. The landform is stable to allow the erosion processes to go on again however, if the landform has been reduced to such a level. It usually happens that there is continued emergence of endogenetic forces and when the new landform has been created. The entire process gets renewed again. The whole period during which erosion processes erode the new surface to sea level is one cycle and since erosion plays an important part in it thus it is called 'the cycle of erosion'.

The cycle concept is basically an ideological framework because of the complexities in the intensities of endogenetic and exogenetic force in time and space and explains the sequential development of landforms.

4.6 DAVISIAN THEORY OF EROSION CYCLE

The most popular theory of landform development was given by American Geomorphologist W M Davis. His concept of geographical cycle (cycle of erosion) provided an indigenous genetic classification and systematic description of landforms. According to Davis, geographical cycle is a period of time during which an uplifted land surface undergoes its transformation by the process of land from development ending into low featureless plain or peneplain. His theory was the representation of a multiple theories and models presented by him during the 1880s and 1890s. He postulated the model of complete cycle of river (stream) life in his essay on the Rivers and Valleys of Pennsylvania (1889). Geographical Cycle (1899), Slope Evolution etc. focusing the concept of progressive development of erosional and depositional river valleys. Through this cycle, he described the sequential development of landforms over a period of geologic time. The basic aim of Davisian model was to provide the basis for a systematic description and classification of landforms. He stated that an orderly sequence of landforms is developed over a period of time under the uniform or external environmental conditions such as temperature and rainfall.

According to Davis, three factors play an important role in origin and development of landforms of a particular region. These factors are:-

(a) **Structure:** Lithological and structural characteristics of rocks includes types, faults, joints, , hardness, permeability etc.

(b) **Process:** It includes all the agents of denudation - weathering and erosion like works of water, wind, sea waves etc.

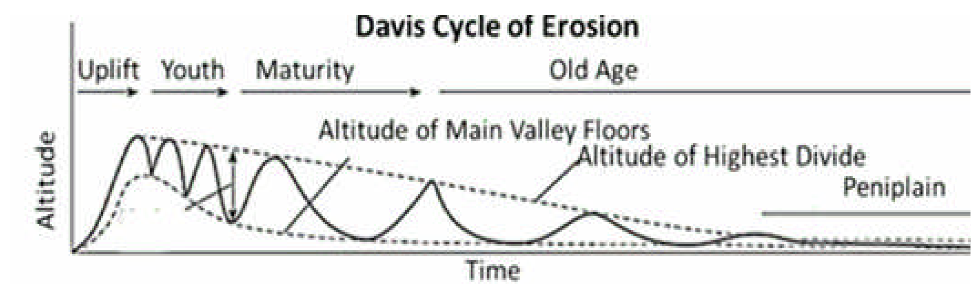
(c) **Time:** Time was used both in temporal sense and as a process, which leads to progression and development of landforms.

Assumptions

1. Landforms are evolved and developed as a result of interactions of endogenetic movements and exogenetic forces.
2. There is a short period of rapid upliftment during which the landform is tectonically stable.
3. Initial uplift of landform is main source of potential energy.
4. During the uplift there is no erosion which starts once the initial landform has uplifted.
5. Fluvial erosion erodes the river valleys rapidly and graded condition is achieved.
6. Erosion cannot occur below the base level or which is the lowest limit of erosion.
7. Landform has a uniform and homogeneous lithological characteristics.
8. The development of landforms is sequential over geologic time period.

Stages

Davis cycle of erosion explains three stages of landform development. The cycle of erosion begins with the upliftment of landmass. There is a rapid rate of upliftment of landmass which is homogeneous structure. This phase of upliftment is not included in the cycle of erosion. These stages are sequential and each stage possesses distinct landforms. These stages are the youthful, mature and old stages.

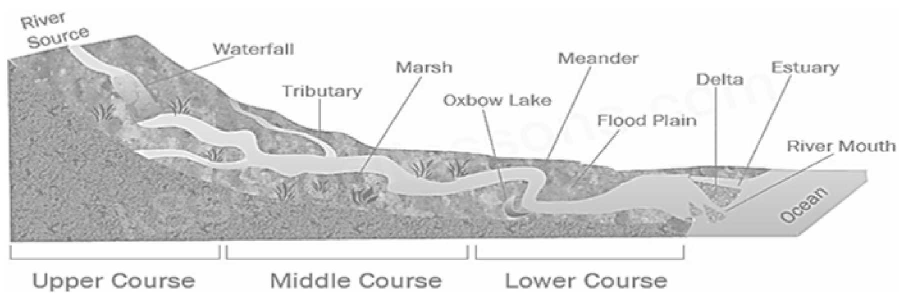


Source : https://www.examrace.com/Study-Material/Geography/Geomorphology/Slope-Evolution-YouTube-Lecture-Handouts.html

a) Youthful Stage: In this stage, potential energy is high and river is busy in vertical erosion which increases the depth of river valleys rather than lateral erosion. This process is also called valley deepening. Valley deepening is also aided by pothole drilling, waterfall formation. Small streams are active in headword erosion to the source of river or stream due to which, length of the stream increases. The youthful stage is characterised by rapid rate of vertical erosion and valley deepening because the channel gradient is very steep, the velocity and kinetic energy of the river flow, increased the eroding and transporting capacity of the rivers. Increased transporting capacity of the river carries big boulders of high caliber which is responsible in valley deepening through vertical erosion. This stage is characterised by V shaped valleys, water falls, rapid cataracts, potholes etc.

b) Maturity Stage: As the landform enters the mature stage, vertical erosion slows down and lateral erosion becomes important. During this stage, mountain tips are eroded cause reduction of height however, valleys are lowered slowly. Vertical erosion is reduced significantly and lateral erosion changes the V shaped valleys to wide U shaped valley responsible for valley widening. The marked reduction in altitude of the water divide leads to reduction in the potential energy of the river flow. A graded profile is formed as most of the stream are reduced and graded to the base level of erosion. Meanders, U shaped valleys etc. are common landforms mature stage.

c) Old Stage: This stage is totally characterized by no valley deepening but lateral erosion in initial stage and valley widening dominates. Extensive floodplains are developed in river valleys. At end stage valleys become almost flat or broad and gentle sloping valleys and residual hills known as Monadnocks. This entire landscape known as a peneplain, which is a uniform terrain.



Source : https://www.youtube.com/watch?v=1R65cuWagFs

Criticisms

1) Davis did not rely on detailed study of the mechanism and nature of the present day processes. 2) He has given less attention to structure of rocks as an important controlling factor and thereby not proved his own statement that landforms are a function of structure, process and stage.

3) He neglected biological processes completely.

4) The assumption of initial rapid uplift and erosion proceeding only after complete and under prolonged tectonic stability is simplistic but not possible all the time.

5) Davis has neglected depositional processes as a factor in landform formation.

6) Environmental changes may cause interrupted cycles giving rise to partial cycles.

7) The cycle of erosion has a descriptive simplicity and is a gross useful only at elementary level. 8) His approach of assuming a homogeneous landform throughout the cycle is very simple and not possible.

Significance of the Theory

As a concept of the cycle of erosion that Davis had given does not found wide acceptance among Geomorphologist nor used as the basis of geomorphological research. Even rarely find the use of the term youthful, mature and old to describe landscapes.

There are mainly two reasons for this

i) Later studies basically concerned themselves with elaborating the mechanism of the process of erosion where Davisian concepts finds no place.

ii)

iii) Many regional studies have shown the complexity of the past in evolution of landforms and usually formed under the influence of a series of partial cycles with in climatic or anthropogenic interventions.

iv)

Essentially, the cycle concept is a long term view of landscape and it stresses on:

1. Profile and plans of rivers
2. Development of drainage system
3. Development of slope forms
4. Effect of rock type on different stages.
5. Importance of climatic accidents in controlling complexity of denudational forces.
6. One of the most attractive features of Davis cycle is its simplicity.

4.7 PENCK'S MORPHOLOGICAL SYSTEM

German scientist Walther Penck who did not accepted Davis model of Geographical Cycle and presented his own model of 'Morphological System' for the description of landscape development.

According to him landforms of a given region are related to tectonic activity of the particular region. Landforms are thus a result of the ratio between endogenetic forces and denudational exogenetic forces. His theory of landforms developments is time independent. Penck used the term 'phase' to present a new model.

Basic Postulates

a) Upliftment starts on a featureless plain dotted with residual hard rocks, similar to peneplain of Davies and Penck called it as Primarumf.

b) Upliftment is very long time process.

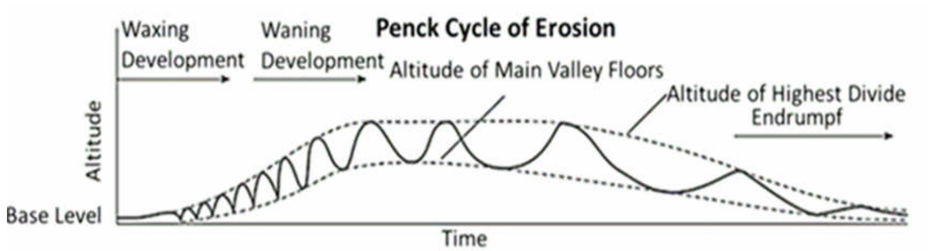
c) Endogenetic and exogenetic works together and thus, upliftment and erosion goes side by side.

d) Landforms are the expression of ratio of effect by both endogenetic and exogenetic forces.

e) Landform development takes place in Phases rather than Stages.

f) End product of landform development process is called Endrum.

On the basis of his assumption that landform is an expression of rate of upliftment to the rate of erosion where he described three phases as follows:



Source : https://www.examrace.com/Study-Material/Geography/Geomorphology/Slope-Evolution-YouTube-Lecture-Handouts.html

Phase 1 : It is the phase of waxing - accelerated rate of landform development. In this phase, initially the land surface rises slowly but after sometime, upliftment is accelerated because of this upliftment, flow velocity and kinetic energy of the stream increases and it results in increased rate of valley deepening. Both the water divide and valley floor of the river is increasing in altitude because the rate of upliftment always exceeds the rate of erosion. In this phase V shaped valleys are formed by vertical erosion.

Phase 2 : This phase describes constant development of landforms. It is further divided into three sub-phases.

Phase 2.A : There is upliftment in initial stage but rate of upliftment is still less than rate of erosion. Height of water divide and valley floor increases but at a slower rate. There is uniform rate of valley deepening and lowering of water divide. The valley sides are characterised by straight slopes.

Phase 2.B : Relief neither increases nor decreases as rate of upliftment is equal to rate of erosion.

Phase 2.C: Upliftment of land reduces completely and relief start declining due to continued erosion and result in to declining the altitude of water divide and valley floor. It characterised by constant development of landforms and parallel retreat of river valleys responsible for vertical steep valleys.

Phase 3 : This is the waning phase of development in which landscapes are dominated by lateral erosion and valley widening and reduction in rate of valley deepening. Water divide is continuously eroded and lowered in altitude. Gravity slope and wash slope are formed.

Criticisms

Johnson Criticized that Penck's conception of slope profiles are convex, plane, or concave according to the circumstances of the uplifting action one of the errors. Allaoua Saadi claimed that Davis' ideas are more applicable near active margins where tectonics are "cataclysmic" and Penck's ideas fit better in passive margins and continental platforms.

4.8 SLOPE

slope is an inclined surface, the gradient which is determined by the amount of its inclination from the horizontal and the distance between its crest and its foot. Slope is expressed in percentage or degrees which corresponds to the amount of rise (vertical distance) divided by the run (horizontal equivalent). Since degree of slope is equal to the tangent of the fraction rise/run, it can be calculated as the arctangent of rise / run expressed as a gradient also. Slope is a measure of change in elevation. A slope is the rise or fall of the land surface. The curved inclined surface that bounds landforms is known as slope (Chiristophereson, 1995). The degree of inclination from the horizontal of an element of ground surface is known as slope. (Strahler, 1996). It is important for the farmer to identify the slopes on the land for furrow irrigation. Driving car from the foot of a hill towards the top is called a rising slope or upslope and declining slope of downslope for vice a versa. Steep Slope represented with contour lines close to each other on a topographical map and gentle slope by contour line far away from each other. The elements of are crest, cliff, talus and pediment. All these elements differ due to the difference in structure, process and time of slope formation.

Crest : Convex slope and soil creep
Cliff : Steepest, escarpment, free face, no deposition, parallel regression
Talus : Debris slope, scree, constant and deposition of courser material
Pediment : Concave, deposition of fine material

4.9 TYPE OF SLOPES

1) **Convex slope or Waxing slope** - rounded like the exterior of a circle, i.e. goes from less steep to more steep. Convex Slope gets progressively steeper downhill. Convexity in a slope may be determined by structure such as on exfoliation domes associated with limestone in humid environment.

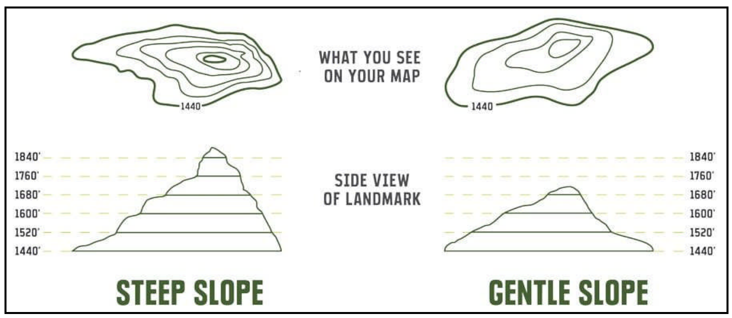
2) **Concave slope or Waning slope** - a terrain feature that is rounded inward like the inside of a bowl, i.e. goes from more steep to less steep. Concave Slope is a slope which declines in steepness with movement downwards and it is also known as a waxing slope. Most often, the concave slope occurs at the base where it is known as a basement concavity.

3) **Free face –** Free from regolith i.e. weathered material and most probably look like as a escarpment.

4) **Rectilinear slope or constant slope –** midslope and not too step or too gentle which is also called straight slope or medium slope. It is land located at the middle of a slope profile or at the base of the free face is a slope with a uniform angle that did not alter as the slope developed through time. Many constant slopes only have a very thin cover of rock waste.

5) **Composite slope –** Large hilly terrain forms many composites of slopes together depend on the time period of denudation and environment.

6) **Gentle slope and Steep slope** - A gentle slope represented with contour lines spread far apart from each other in both up and down slope and steep slope represented with contour lines close to each other on a topographical map. Steep slope areas are not suitable for transport development as well as agriculture.



7) **Tectonic slope –** These are formed through indigenous forces that result in the folding, warping and faulting of rock masses or layers. Anticlines and synclines, are formed when layers of rock are folded and horsts (Block Mountains) as well as graben (rift valleys) are formed when blocks of land rise or fall in relation to each other when faulting occurs which may be symmetrical or asymmetrical.
8) **Erosional slope –** formed due to erosion by agents of denudation such as wind, water and wave. Erosional slopes are gentle or steep depend on the environment and also affected by the structure and process operated on it over a period of time.
9) **Depositional slope** - Deposits of weathered and eroded material build up to form inclined surfaces, mounds and hills when an agents of erosion (e.g. wind, water, wave or ice) which has lost its energy of movement leave behind its load at a low lying or flat plains an forms alluvial fans, alluvial cones, deltas and sand dunes, sand bars etc.

4.10 FACTORS INFLUENCING SLOPE ORIGIN AND DEVELOPMENT:

Simple correlation between slope form and process rarely exist. The factors controlling the type and rate of processes are always related to the slope form. For instance, one can say the relationship between climate and slope form. It should be always thought that the control operates through the processes. Some of the factors which control hill slope processes are:-

a) Lithology and structure of rocks - compactness
b) Climatic conditions – temperature and rainfall
c) Slopes and relief
d) Process of denudation working on it – weathering, erosion, deposition
e) Vegetation cover and it's types
f) Human interventions

a) Lithology and Structure

Many observations and studies recommend that the geological control on slope formation but as rocks and structures act in combination with other factors influences the complex landscapes. Rock type influences the slope angle both directly and through its control on the nature of surface deposits. Resistant hard rocks normally responsible for steeper slope than those on weak rocks.

b) Climate

Since climatic parameters such as temperature and rainfall are bound to influence the rates of weathering, erosion and surface run-off processes, then it is said that climate is bound to influence slope form. Some Geomorphologist forcibly argued that slope develop similarly in all climates.

c) Slopes, Relief and the Drainage Basin

The amount of available relief (the difference between the highest and lowest points in the landscape) and the degree of dissection, are both bound to affect slope form. Slope angles tend to be greatest in areas of high relief and where dissection is rapid compare to stable and low-relief areas. Slopes are usually less steep and more concave-convex in profile in plateau or plain areas. The connection lies in the activity of the valley streams. It is impossible to consider slopes and streams as completely separate entities as they are parts of the same open system of drainage.

d) Process of denudation : Denudation is the name for the processes of erosion, leaching, stripping, and reducing the mainland due to removal of material from higher to lower slope areas like valleys, river valleys, lakes and seas with a permanent filling of low lands the eroded and transported material from high slope to lower slope. The process of slope modification is taken place due to erosional of depositional action of wind, water waves and glaciers etc.

e) **Vegetation cover**: The relationship is a complex combination of the type of soil, the rainfall regime, the plant species present, the slope aspect, and the steepness of the slope. Slope stability and vegetation cover are interrelated which promote and hinder the stability of the slope. There are different ways vegetation influences slope stability directly or indirectly like wind diversion, the removal of water, vegetation cover and mechanical reinforcement of roots.

f) **Human interventions**: Different developmental projects hinder the slope elements. In the past century human intervention has caused remarkable changes in hilly and mountain landscapes. Human activities principally modified the natural drainage patterns, the original slope profile and cut forest for farming. It has been found that land use changes are directly associated to landscape morphology and one of the main factor influencing landslide occurrence and slope modification.

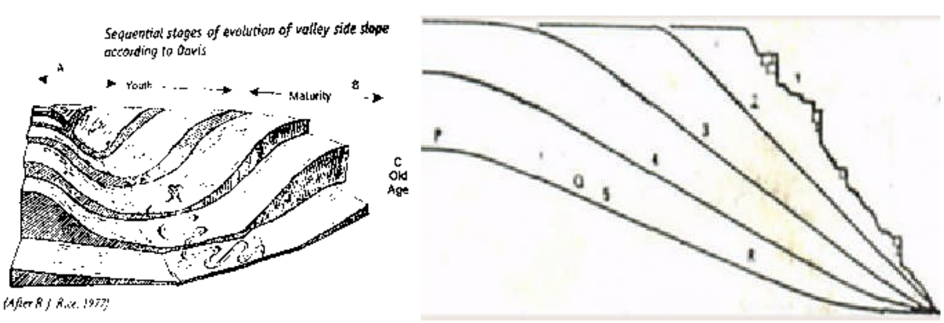
4.11 MODELS AND THEORIES OF SLOPE DEVELOPMENT:

The origin and development of slopes can be studied in three ways that is theoretically, experimentally and empirically. The theories of development of slopes must explain as to whether the slope undergoes parallel retreat or there is progressive decline in slope angles. There are two distinct schools on the development of land forms. All the theories and models of slope development are broadly grouped in to:

1) **Slope Decline**: the steepest part of a slope gradually declines and concave-convex landform is developed.
2) **Slope Replacement**: maximum angle of slope decreases from below through replacement of slopes by the gentler slopes. A concave profile is formed by slope replacement.
3) **Parallel Retreat:** in parallel retreat, maximum angle remains constant, length of concavity increases and the angle at any (vertically constant) point on concavity decreases.

4.12 Slope Decline theory by Davis (1899)

According to Davis, "there is progressive decline in slope angle and sequential change in the slope form, from youth (convex slope) through mature (uniform slope) to old (concave slope) stage."
Stage -1 elimination of the free faces
Stage -2 regolith maintains a constant thickness
Stage 3 and 4 : length of the straight segment increased
Stage 5 - length of straight segment diminishes.



Source : https://slidetodoc.com/drainage-basin-system-ii-the-slope-subsystem-a/

Steep convex slope evolves during youth stage due to own cutting which results in valley deepening (V shaped valley). In this stage, slope angle is increased. During mature stage, lateral erosion dominates and water divides are eroded. This reduces the slope angle and slopes becomes relatively uniform. In the old stage, there is further lateral erosion and weathered debris is transported downslope. Slope becomes concave.

Davisian model of slope evolution includes three aspects

(i) **Rounded Convexity of Hills tops** - summit rounded convexity results from the action of soil creep in humid climates.

(ii) **Graded Waste sheets** - when the transporting capacity of transporting agents equals the required energy to transport the material a layer of waste sheet of debris on slope profile is formed, which is known as graded waste sheet.

(iii) **Graded Valley Sides –** as the cycle of erosion progresses with time, gradient of valley side slopes decreases and valley side becomes flatten with declining slope angle.

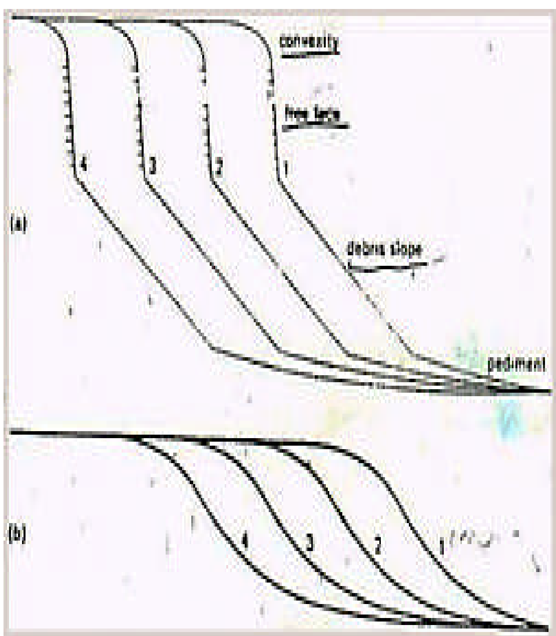
4.13 PENCK'S THEORY OF SLOPE REPLACEMENT (1924)

For explaining the evolution of hill slope, Penck selected a steep landform of homogeneous structure and composition. According to him a surface layer of rock of a definite thickness is loosened and removed in a unit of time. The loosened particles crumble and fall down due to steepness in the gradient. The slope except the lowest segment undergoes parallel retreat due to uniform weathering and instant removal of weathered material from slopes.

Parallel retreat of slope segments, except the lowest segment, results in development of a concave slope profile. If parallel retreat is occurring on both sides, down wasting occurs and there is lowering of altitude and it results in slope decline. Based on his model we can determine morphological analysis. Slope replacement means original steep slopes being replaced by lower angle slopes, which extends upwards from the base at a constant angle. Hill slope is depends on rate of vertical erosion. Denudation exposes bare rock slope surface. Retreat of slope depends on gradient of hill slope. Retreat of slope occurs in parallel manner. Flattening of slope always takes place from below to upwards. A free face slope is slowly buried by a scree which accumulates at the base of cliff. Slope angle and lengths remain uniform as the slope retreats parallel to itself. Hill slopes are essentially free of sediment. Parallel retreat occurs where underlying strata are protected by a resistant cap rock such as a layer of sandstone. Parallel retreat is responsible for the formation of flat-topped buttes, mesas, and pinnacles such landforms are observed in Colorado Plateau.

4.14 HILL SLOPE CYCLE THEORY BY L C KING (1948)

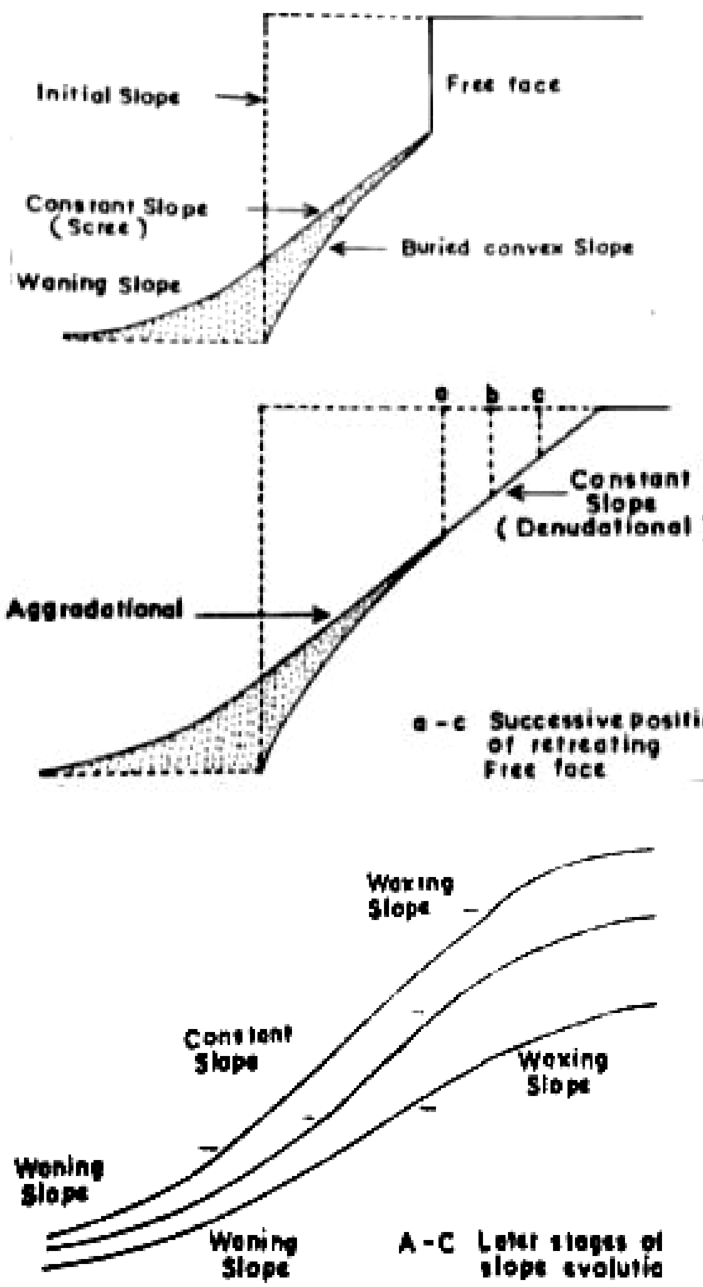
King carefully observed the South African landscape understood that temperate climate areas are not best suitable for landscape development because most of the topographic features have been modified by Pleistocene glaciation period. According to him, sub-tropical semi-humid regions are most suitable for evolution of high graded landscapes. His model is qualitative and based on observation of inselbergs in Africa. He explained that in the initial stage of hill slope development, the escarp face experiences parallel retreat due to back wasting. This parallel retreat controls the evolution of entire hill slope. According to him, debris slope just below the scarp or free face does not extend upslope thus it is not capable of destroying the free face. There is a balance between supply of debris from upslope and removal of debris from downslope. The gradual parallel retreat results in formation of concave pediments at the base of hill slope. As the parallel retreat continues for long time, length of free face decreases and ultimately sediments extend up to hill crest and an extensive erosion surface with a concave slope get formed. This concave sloped surface is a pediplain, which is a unification of various pediments from upslope to downslope. This concept is based on modifications made in views of Penck and Wood. He included concepts of river cycle, hill slope cycle and landscape cycle. Pediplain formation is result of two process that are scarp retreat and pedimentation. The gradual parallel retreat of free face and debris slope results in formation of pediment at the base of hill slope.



Source : https://slidetodoc.com/drainage-basin-system-ii-the-slope-subsystem-a/

4.15 WOOD'S THEORY OF SLOPE EVOLUTION

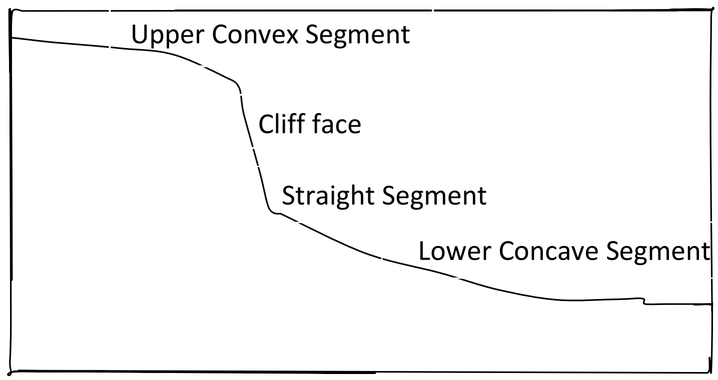
A Wood selected a cliff slope formed either due to tectonic Faulting or erosion. The free face of the landform is subjected to weathering, which causes its retreat through backwashing. The weathered debris is transported downslope and accumulates at the base. The accumulation of debris extends towards upslope and free face is continuously buried under debris cover. The height of free face decreases and lower segment of free face becomes constant slope. The regular backwashing results in constant extension of constant slope but no debris can rest on this extended slope, which is known as Denudational Constant Slope. This denudational slope is also called slope of derivation.



Source : https://www.youtube.com/watch?v=icSxi_aUMqI

As mechanism of retreat continues, this extended slope ultimately reaches the divide summit and process of retreat is finally completed. The disappearance of free face results in rounding of water divides and development of summit convexity with time, lower segment becomes concave and a convex-rectilinear-concave slope is formed. Ultimately the rectilinear slope disappears and convex-concave slope is formed.

a) The waxing slope is the curve over edge of the horizontal surface of the hilltop. It is also called the convex slope or upper wash slope.



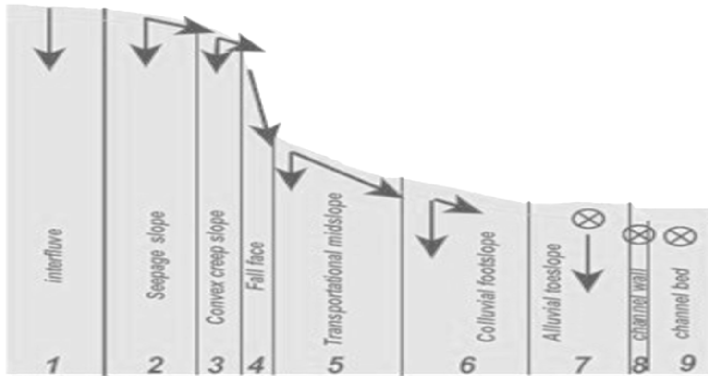
b) The free face is a steep slope or part of a slope formed of bare rock.

c) The constant slope is a slope with a uniform angle that did not alter as the slope developed through time. Many constant slopes only have a very thin cover of rock waste. It usually extends upward to the rock cut slope of the free face

d) Waning slope stretches to the valley floor with lower angle and is characterized with fine materials. It is also known as pediment, valley floor basement or lower wash slope.

4.16 NINE UNIT MODEL

It was proposed by Dalrymple in 1968 and is a more complex model which relates slope form to the processes of slope formation. The main processes in operation are weathering, through flow and mass movements.



Source : http://www.haldiagovtcollege.org.in/wp-content/uploads/2017/12/Types-of-Slopes.pdf

1. Interfluve: divide area characterized by largely vertical subsurface water and soil movement
2. Seepage slope : gently dipping portion dominated by downward percolation
3. Convex creep slope: upper convex area characterized by creep and terrace formation
4. Fall face : cliff face characterized by rapid detachment of material or bedrock exposure
5. Transportational midslope : active region characterized by mass movement, terrace formation, slope wash and subsurface water action
6. Colluvial foot slope : Material is further transported down slope by creep, slope wash and subsurface flow
7. Alluvial toe slope : region of alluvial deposition
8. Channel wall : removal by corrosion, slumping, fall etc.
9. Channel bed: down stream transport of material

4.17 SLOPE AND HUMAN ACTIVITIES

Settlement: People build houses on gentle slopes rather than steep slope. When space is limited or for the view that their home will have on sun facing slope.

Agriculture: Steep slopes are not suitable for crops and irrigation. It is used for used for forestry or certain crops suitable to grow on slope land like tea and coffee. Contour ploughing and terracing is practiced on steep slope land.

Recreation: Hiking and trekking adventure tourism supports steep slope areas.

Barriers and defense: Mountain passes were used for transport development rather steep slope hills. Many forts were constructed for defense purpose on top of hills with steep slope.

4.18 SOME GEOMORPHIC PROCESSES INTENSELY RELATED TO SLOPE

Mass Wasting: When material moves down slopes under the influence of gravity.

Soil Creep: When soil moves down slope due to expansion and contraction as a result of temperature changes.

Solifluction: When soil slides down the slope on frozen ground beneath it.

Earth flow: When clay that moves down slope in large mass.

Mud flow: When channels of mud flow downhill slope fast.

Rock falls: When individual rocks break off and fall down the side of slope.

Landslides: When large part of rocks breaks, loose and slides down the slope

4.19 SUMMARY

Earth is full of dynamic group of landforms. Landscapes are created by Exogenic and Endogenic processes acting along the interface between the lithosphere and the atmosphere and hydrosphere where various landscapes with multiple landforms is the result of weathering and erosion upon the highly heterogeneous lithospheric surface. Landscapes are dynamic, acutely sensitive to change over a period of time by the multiple factors and evolved through a succession of stages from youth to maturity to old relief. The progression of an erosion cycles are responsible for series of landform evolution but also interrupted by tectonic or environmental changes. Landforms are bounded by slopes, so their evolution is best understood through study of slopes and the complex of factors controlling slope character and development. Slope is referred as an angle with any part of the earth's surface along the horizontal datum which includes slope inclination, slope angle and slope gradient. Slopes attain a different forms and recede parallel to themselves or gentler over a period of time. The convex, linear, concave and complex profiles of many slopes reflects an interplay between weathering, erosion, transportation and depositional work by different agents (Exogenic forces) as well as endogenic forces. Landscapes and slopes are usually formed by unique process at different places which are studied by different scientist with different angles propounding the scientific principles for its evolution and development. Nature has unique landscapes for billions of years and mankind can learn about landscape from natural examples in the field.

4.20 CHECK YOUR PROGRESS / EXERCISE

A) Mention True or False.

Sr. No.	Statement	Answer
1	One of the mountain range in Europe is Rockies.	………..
2	The waxing slope is the curve over edge of the horizontal surface of the hilltop.	………..
3	Steep convex slope evolves during youth stage which results in valley deepening.	………..
4	The theory of landform development was given by Darwin.	………..
5	Hutton first postulated the 'principle of uniformitarianism' in 1785.	………..

B) Fill in the blanks.

1 One of the mountain range in South America is……….
2 Slope Decline Theory was propounded by…….
3 End product of landform development process is called ………by Penk.
4 River is busy in vertical erosion rather lateral which increases the depth of river valleys in……..stage described in Erosion Cycle.
5 Hill Slope Cycle Theory was propounded by………… (1948)

C) Match the columns

Sr. No.	Column A	Sr. No	Column B
1	James Hutton	a	Theory of Slope Replacement
2	Penck	b	Nine Unit Model of Slope Development
3	Dalrymple	c	Hill Slope Cycle Theory
4	L C King	d	Cycle of Erosion
5	W M Davis	e	Cyclic Nature of Earth History

D) Choose the correct option for the following statements.

Sr. No.	Statement	Answer
1	One of the mountain range located in Asia. a) Rockies b) Himalaya c) Andes d) Alps	………..
2	According to Cycle of Erosion, the extensive valley widening takes place in which stage? a) Old b) Maturity c) Pre-maturity d) Young	………..
3	When large part of rocks breaks, loose and slides down the slope? a) Mudflow b) Earthflow c) Solifluction d) Landslide	………..
4	A Wood selected which type of ……….slope formed either due to tectonic faulting. a) Plain b) Gentle c) Cliff d) Concave	………..
5	Which slope is also known as pediment, valley floor	………..

basement or lower wash slope?
a) Steep b) Convex c) Cliff d) Waning

E) Answer the following questions.
1) Explain the Process of landscape evolution.
2) Critically evaluate the 'Cycle of Erosion' given by W M Davis.
3) Describe the Penk's Theory of Slope Replacement with the help of diagram.
4) Give an account slope decline stages given in theory of Davis.
5) Examine the effect of land slope on human activities.

4.21 ANSWERS TO THE SELF-LEARNING QUESTIONS

A) 1) False 2) True 3) True 4) False 5) True

B) 1) Andes 2) W. M Davis 3) Endrum 4) Youth 5) L C King

C) 1) e 2) a 3) b 4) c 5) d

D) 1) b 2) a 3) d 4) c 5) d

E) For answers refer the content given the unit.

4.22 TECHNICAL WORDS AND THEIR MEANING

Landform - are features that forms the relief / terrain on the earth surface.

Landscape - is the group of visible features of an area on land either natural or manmade.

Geographic cycle - cycle is an idealized model that explains the development of relief in landscapes.

Erosion - is the geological process in which earthen materials are worn away and transported by natural forces.

Pediplain - a pediplain is an extensive plain formed by the pediments.

Peneplain - a peneplain is a low-relief plain formed by erosion.

Slope - is the rise or fall of the land surface.

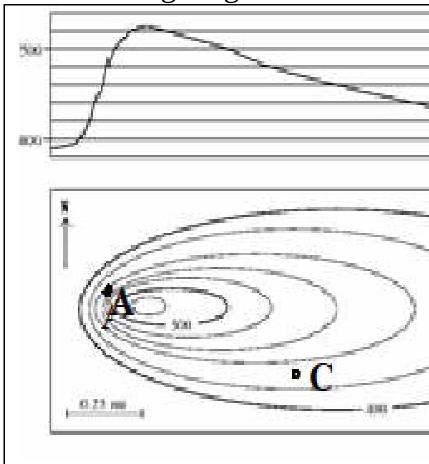
Concave slope - a terrain feature that is bended inward.

Convex slope - a terrain feature that is curved out to the exterior.

4.23 TASK

a) Refer, read and identify different landforms in physical maps given in the atlases and mark the following features in the outline map.
   i) Use World outline map to mark and label the following features. (Rockies Mountain, Sahara Desert, Madagascar Island, Angel Waterfall, Amazon delta, Carter Lake, Pampas plain,)
   ii) Use India outline map to mark and label the following features. (Sahyadri Mountain, Thar Desert, Andaman Island, Jog Waterfall, Chhota Nagpur Plateau, Sundarban, Sāmbhar Lake, Godavari delta, Ganga river plain)

b) Identify the type and characteristics of slope at place A, B and C in the following diagram.

 Height in ft.	A : ……………………………….. 1)………………………………………… ………………………….. 2)………………………………………… ………………………….. B : ……………………………….. 1)………………………………………… ………………………….. 2)………………………………………… ………………………….. C : ……………………………….. 1)………………………………………… ………………………….. 2)………………………………………… …………………………..

4.24 REFERENCES FOR FURTHER STUDY

1) Anderson S. A. : Geomorphology
2) Goudie A. S. : Encyclopedia of Geomorphology
3) Huggett H. J. : Fundamental of Geomorphology
4) Kale V. S. : Landscapes and Landforms in India
5) Naqi M : Encyclopedia of Geomorphology
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7) Singh Savindra : Geomorphology
8) Siddhartha K : The Earth’s Dynamic Surface
9) Sparks, B.W. : An Introduction to Geomorphology
10) Strahler A. : Physical Geography: Science and System of the Human Environment
11) Thornberry W.D. : Principles of Geomorphology

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